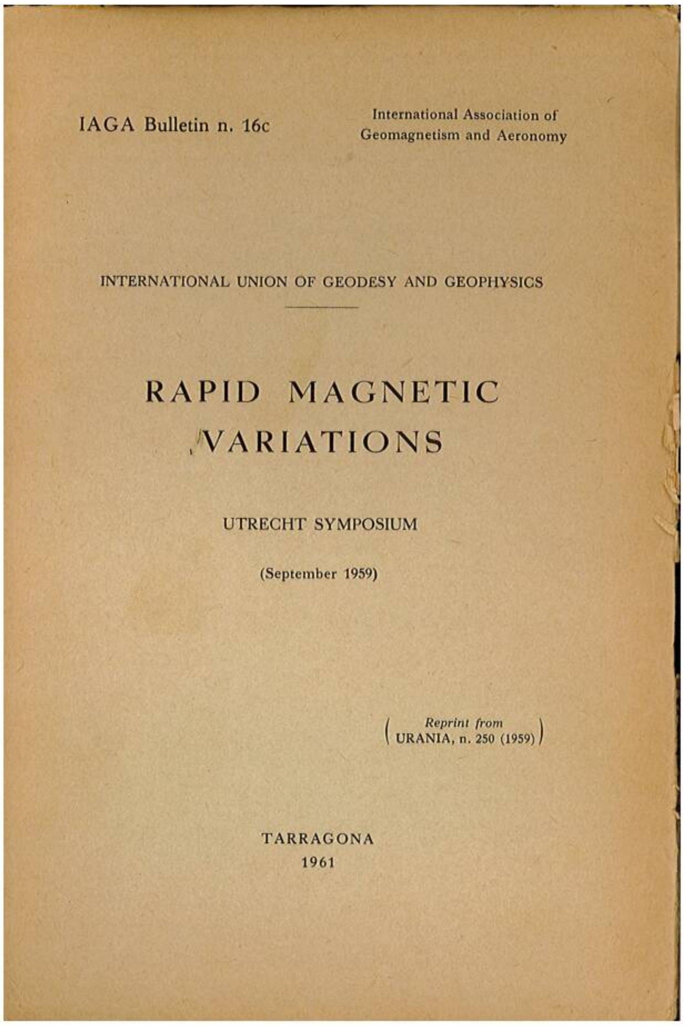

IAGA Bulletin n. 16c

International Association of
Geomagnetism and Aeronomy

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

RAPID MAGNETIC VARIATIONS

UTRECHT SYMPOSIUM

(September 1959)

(*Reprint from*
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U. G. G. I
INTERNATIONAL ASSOCIATION
OF GEOMAGNETISM AND AERONOMY

SYMPOSIUM
ON
RAPID MAGNETIC VARIATIONS

UTRECHT 1-4 SEPT. 1959

EDITED BY

J. O. CARDÚS S. J. AND T. R. KAISER

TARRAGONA
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I.A.G.A. SYMPOSIUM
ON RAPID MAGNETIC VARIATIONS

Utrecht, 1-4 September 1959

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PREFACE

An increasing interest in the problem of geomagnetic rapid pulsations has characterized the work of geomagneticians in recent years. New theories on magnetohydrodynamics have appeared and have been applied to study the movements of the cosmic plasma which may be the cause of the magnetic phenomena. On the other hand the increasing number of magnetic and earth-current observatories established for the International Geophysical Year have made available most valuable observational data which have been collected by Committee N. 10 of the International Association of Geomagnetism and Aeronomy (IAGA).

A meeting of Committee N. 10, held at Copenhagen from the 9th to the 11th of April 1957, discussed the data which should be collected by the observatories and following a recommendation from the Special Committee for the International Geophysical Year (CSAGI) at Barcelona (1956) and ratified at Moscow (1958) it was decided to hold a symposium on Rapid Variations in Geomagnetism and Earth-Currents early after the Geophysical Year; this symposium should combine theory and observation and its organization was entrusted to the Chairman of Committee N. 10, Fr. A. Romañá, who was assisted in his task by Prof. J. Veldkamp, Chairman of the FAGS Permanent Service on Geomagnetic Indices, Dr. E. Selzer from the Chambon-la-Forêt Observatory and Fr. J. O. Cardús, Secretary of the IAGA.

It was decided that the symposium would take place at De Bilt or at Utrecht at the beginning of September 1959. The offer of the De Bilt Observatory to take care of the external organization of it was gratefully accepted and the symposium was held from the 1st to the 4th of September of 1959, in the Utrecht University. Financial support was given by the IAGA (2.500$) and by ICSU (2.000$) from UNESCO funds. As stated every support was given by the De Bilt Observatory and many facilities were provided by the Utrecht University.

Together with the letter announcing the symposium a preliminary list of subjects of special interest in the field of rapid variations was sent by the organizing committee and a notice was published in the IUGG Chronicle (December 1958). Many suggestions have been received and incorporated in the program and a list of interested persons to be invited was arranged by the Committee.

The following persons were present at the meetings:

Prof. Dr. G. ANGENHEISTER, Geophysikal. Observatorium der Universität München, Richard-Wagnerstr. 10, München 2. *Germany.*

Prof. Dr. J. BARTELS, Direktor Geophysikalisches Institut, Herzbergerlandstrasse 180, (20b) Göttingen. *Germany.*

Prof. Dr. R. BOCK, Fregestrasse 70, Berlin-Friedenau. *Germany.*

Dr. J. BOUSKA, Geofysikalni Ustav CSAV, Praha XIII - Sporilov, Bocni II. *Czechoslovakia.*

R. Fr. J. O. CARDÚS, S. J., Observatorio del Ebro, Tortosa. *Spain* (Secretary).

Prof. S. CHAPMAN, High Altitude Observatory, Boulder, Colorado. *U.S.A.*

Miss A. B. COOK, Division of Geomagnetism, Dominion Observatory, Ottawa. *Canada.*

Prof. J. COULOMB, Directeur, Conseil National Recherche Scientifique, 13 Quai Anatole-France, Paris (7e). *France.*

Ir. A. H. DE VOOGT, Piet Heinstraat 62A, The Hague. *Netherlands.*

Dr. J. DOOLEY, Bureau of Mineral Resources, Geology and Geophysics, 203 Collins Street, Melbourne. *Australia.*

Dr. J. W. DUNGEY, 6 Whitley Road, Benton, Newcastle upon Tyne 12. *Great Britain.*

Dr. F. ELEMAN, Kungl. Sjöfartsstyrelsen, Stokholm 100. *Sweden.*

Prof. G. FANSELAU, Geomagnetisches Institut, Telegrafenberg, Potsdam, DDR. *Germany.*

Prof. V. C. A. FERRARO, 226 Ballards Lane, North Finchley, London N. 12. *Great Britain.*

Dr. N. FUKUSHIMA, Geophysical Institute, Tokyo University, Tokyo. *Japan.*

Miss G. E. GJELLESTAD, Magnetic Bureau, Nygaardsgaten 114, Bergen. *Norway.*

Mr. P. GOUIN, University College, P. O. Box 399, Addis Ababa. *Ethiopia.*

Prof. G. GRENET, Directeur de l'Institut de Météorologie et de Physique du Globe, B.P. 1296, Alger. *Algeria.*

Mr. A. K. HARRIS, U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. Y. *U.S.A.*

Miss V.R.S. HUTTON, Department of Physics, University College of Ghana, Achimota, Ghana. *West-Africa.*

Prof. J. A. JACOBS, Department of Physics, University of British Columbia, Vancouver 8, British Columbia. *Canada.*

Dr. Y. KATO, Geophysical Institute, Faculty of Science, Tôhoku University, Sendai. *Japan.*

Dr. L. KOENIGSFELD, Rue Etat Tiers 17, Liège. *Belgium.*

Dr. A. KORSCHUNOW, Geophysical. Observatorium der Universität München, Richard-Wagnerstrasse 10, München 2. *Germany.*

Dr. V. LAURSEN, Meteorologisk Institut, Charlottenlund. *Denmark.*

Dr. E. MAPLE, Airforce Cambridge Research Center, L. G. Hanscom Field, Bedford, Massachusetts. *U.S.A.*

Dr. J. H. NELSON, U.S. Coast and Geodetic Survey, Washington 25, D. C. *U.S.A.*

Dr. J. OLSEN, Det Danske Meteorologiske Institut, Copenhagen. *Denmark.*

R. Fr. A. ROMAÑÁ, S. J., Observatorio del Ebro, Tortosa, *Spain* (Chairman).

Mr. R. SCHLICH, Institut de Physique du Globe, 191 rue Saint-Jacques, Paris (5e.) *France.*

Dr. E. SELZER, Chef du Service Magnètique, Institut de Physique du Globe, 191 rue Saint-Jacques, Paris (5e.) *France* (Secretary).

Dr. M. SIEBERT, Geophysikalisches Institut, Herzbergerlandstrasse 180, (20b) Göttingen. *Germany.*

Dr. M. SUGIURA, Geophysical Institute, University of Alaska, College, Alaska. *U.S.A.*

Dr. J. UNTIEDT, Geophysikalisches Institut, Herzbergerlandstrasse 180, (20b) Göttingen. *Germany.*

Dr. VAN SABBEN, Royal Netherlands Meteorological Institute, De Bilt. *Netherlands.*

Prof. Dr. J. VELDKAMP, Royal Netherlands Meteorological Institute, De Bilt. *Netherlands.*

The provisional agenda of the Symposium was arranged as follows:

Tuesday, September 1st, 1959

9.30 a.m.	Opening remarks by A. Romañá.

Geomagnetic pulsations

9.45	Introductory lecture on theories of pulsations by J. Coulomb.
10.45	Presentation of results by groups of observatories (Russian, Japanese, French, American, Netherlands, German, etc.)
12.30	End of the session.
14.30	Continuation of the presentation of results and general discussion on pulsations (theory, observations).
17.30	End of the session.

Wednesday, September 2nd.

Earth-current pulsations

9.30 h	Introductory lecture by A. H. De Voogt.
10.00	Pulsations in high latitudes. USSR Results. Other results. Discussion.

ssc + si

14.30 h	Introductory lecture by S. Chapman. Discussion.

Thursday, September 3rd.

Solar-flare effects

9.30 h	Introductory lecture by J. Veldkamp. Discussion.
11.30	*Discussion on Work of IAGA Committee N. 10.* a. Monthly reports and checking-lists. b. Atlas of Rapid Variations. c. Suggestions for observatories. d. Varia.
12.30	End of the session.
14.30 h	Continuation of the morning session.
17.30	End of the session.

Friday, September 4th.

Atlas on Rapid Variations

9.30 h	Beginning of the session.
12.30	End of the session.

On the evening of the 2nd of September the symposium participants were invited to the Meteorological Institute at De Bilt where they could see the instruments and the research work done in geophysics.

It was the idea of the organizers to allow round-table discussion as much as possible and to restrict the number of papers to be read by the authors to a minimum; a result was that many papers prepared by the authors were produced in an informal way following the discussion of the different items of the agenda, and that in some cases the order of presentation was not the most logical one. Nevertheless, any lack of logical order was easily compensated by the lively discussions and by the presentation of slides showing the more interesting examples of the phenomena under discussion. In preparing this volume we have tried to present the papers in a logical order, rather than in order of presentation at the meetings. Discussions, when they could be recorded, have been appended to each paper.

Too little is still known of the theoretical processes which cause many of the rapid variations in the geomagnetic field and earth-currents, but we are sure that the confrontation of the theoretical studies with the observational results, as achieved in this symposium, will help towards a better understanding of the laws regulating these rapid variations.

The Association and its Committee N. 10 express their gratitude to the University of Utrecht, to the Meteorological Service at De Bilt, and specially to Prof. Veldkamp and his staff for all the facilities provided during the Symposium and its preparation. Our thanks go also to the IUGG and to UNESCO for their financial help.

J. O. CARDÚS, S. I.

Observatorio del Ebro, Tortosa.

OPENING ADDRESS

by A. ROMAÑÁ

Messieurs:

C'est pour moi un grand honneur de pouvoir ouvrir cette séance en vous adressant de tout coeur la plus sincère salutation de bienvenue. Je pense que pour nous tous c'est une satisfaction de nous trouver réunis pour ce symposium avec ceux qui s'intéressent aux mêmes problèmes auxquels nous avons voué notre activité; mais pour ce qui me regarde personnellement je dois avouer que votre présence ici me fait espérer et à juste titre un avancement considérable dans la connaissance des phénomènes rapides, dont l'étude a été spécialement confiée par l'AIGA au Comité dans lequel j'ai le plaisir de collaborer avec plusieurs d'entre vous. Ne craignez pas que j'abuse de votre patience avec un long discours d'ouverture; je ne me reconnais pas d'autorité pour le prononcer devant les spécialistes que vous êtes et tout particulièrement devant les maîtres si universellement connus qui ont voulu nous honorer avec leur présence. Puisque en ma qualité de Président du Comité 10 j'ai été désigné par notre Association pour diriger ce symposium, je vous demande le permission de faire un petit nombre de remarques préliminaires pour mieux en assurer le succès.

Comme vous le savez, ce symposium est en quelque sorte le complément et la seconde partie de celui tenu à Copenhague peu avant le commencement de l'Année Géophysique. L'un et l'autre ont été demandés dans une résolution du Groupe de Travail de Géomagnétisme à l'Assemblée plénière du CSAGI à Barcelone en Septembre 1956. Grâce à l'obligeance du Comité Exécutif de l'AIGA et à l'aide financière de l'UNESCO le premier symposium a pu être célébré à Copenhague les premiers jours d'Avril 1957. Nous y avons été une vingtaine, dont la plupart j'ai le plaisir de constater qu'ils se trouvent de nouveau parmi nous; et le résultat a été une précision bien plus grande dans la définition et la divisíon des types des phénomènes rapides étudiés par le Comité 10 de même qu'une meilleure organisation de leur observation et la publication de l'Atlas Provisoire des Variations Rapides dans le but de rendre plus aisée la tâche des Observatoires. Il était tout à fait naturel d'envisager un second symposium avec des horizons plus larges, destiné à mieux connaître les premiers résultats de l'application des résolutions de Copenhague à l'observation de ces phénomènes pendant l'AGI, les discuter à la lumière des théories actuellement en vogue pour expliquer leur production, et faciliter de la sorte une revision de la valeur de ces théories, en vue de la confirmation que les phénomènes observés leur apportent ou par contre des difficultés qu'ils puissent leur créer. Voici donc l'objet de notre réunion. Comme l'a remarqué très justement Mr. Bartels au moment d'entreprendre son organisation, en traitant dans les mêmes séances des questions théoriques et des problèmes d'observation nous entendons contribuer à éviter que théoriciens et observateurs parlent, pour ainsi dire, deux langages divers, et que chaque groupe aille de son côté de sorte qu'il se crée un hyatus entre leurs travaux et points de vue. C'est donc dans cet esprit que nous nous proposons de recourir à la théorie autant qu'elle peut être utile pour mieux exploiter les observations, vérifier leurs méthodes et les orienter dans l'avenir; et que de l'autre côté nous voulons utiliser les observations autant qu'elles peuvent servir d'orientation et de sujet d'expérimentation des différentes écoles théoriques. Nous souhaitons et nous espérons que cette prise de contact entre théoriciens et observateurs se revèle féconde pour améliorer et ajuster leurs méthodes de travail; de cette façon les heureux résultats du symposium de Copenhague pourront encore une fois être égalés et largement dépassés à ce symposium d'Utrecht.

Et maintenant quelques mots sur la méthode de travail prévue. D'après tous, le succès du symposium de Copenhague a été dû à ce qu'il n'a pas consisté en une série de communications suivies de discussions plus ou moins vivantes, mais qu'il a été un véritable symposium, c'est-à-dire, une conversation en table ronde sur une série de sujets intéressant non seulement les présents, mais aussi l'ensemble des observatires géomagnétiques, qui avaient été préalablement consultés. Nous aurions voulu donner la même forme au symposium actuel; mais la chose ne semblait pas tout à fait faisable du fait que le nombre des participants était pratiquement double de celui des réunis à Copenhague. C'est pour cela que, pour en garder l'esprit sans risquer pourtant de glisser dans le désordre, nous avons adopté la forme intermédiaire suivante. Les phénomènes rapides pouvant être divisés en trois groupes principaux, pulsations, storm-sudden-commencements et sudden-impulses et finalement solar-flare-effects, sur chacun d'eux l'on fera en premier lieu une lecture de mise au point, en passant surtout en revue les théories formulées pour en expliquer la production, laquelle devra servir comme de marc pour l'encadrement de la discussion qui suivra. Après cette introduction les représentants des divers groupes d'observatoires qui ont fait des observations pendant l'AGI seront invités à exposer leurs résultats; après quoi l'on pourra passer à la discussion générale. Dans le cours de celle-ci c'est le moment d'exposer chacun ses propres idées et ses expériences personnelles, s'appuyant, s'il le veut, sur ses études et ses publications, présentant des propositions et des suggestions pour l'avenir, etc. La publication du symposium devant comprendre non seulement les lectures d'introduction, mais aussi toutes ces interventions avec les documents que l'on aura apporté pour confirmer les exposés verbaux, il est évident que la tâche de tout prendre par écrit, réservée aux secrétaires tous seuls, serait évidemment trop lourde; c'est pour cela que tous les participants aux discussions sont priés dès maintenant de bien vouloir rédiger de résumés de leurs interventions et les faire arriver aux secrétaires ou à la présidence pour leur inclusion dans les comptes rendus des séances.

Quant à la distribution du temps nous avons dû modifier légèrement celle prévue dans la lettre d'invitation. Vous avez déjà remarqué sans doute l'absence de nos collègues soviétiques. Nous la regrettons d'autant plus que nous étions convaincus qu'ils se trouveraient parmi nous et nous attendions avec beaucoup d'intérêt leurs apportations scientifiques, non seulement à cause de leur grande qualité personnelle en tant que scientifiques et chercheurs de première ligne, mais aussi parce que leurs observatoires couvrent une extension immense, surtout dans l'Asie et les régions polaires et ils sont d'importance capitale pour l'étude de l'allure de certains phénomènes à échelle universelle. Heureusement ils ont eu la gentillesse de nous faire parvenir un certain nombre de communications avec leurs données et les points de vue qu'ils voulaient nous exprimer et Mr de Voogt et le Père Cardús ont eu l'obligeance de se prêter à nous en rendre compte en leur nom. D'autre part c'était Mme Troïtskaja que nous avions prié de bien vouloir nous faire la lecture d'introduction sur les aspects particuliers des pulsations étudiées du point de vue des courants telluriques; cette tâche lui revenait presque de droit comme organisatrice du réseau d'observatoires de courants telluriques le plus étendu du monde; le vide créé par son absence sera ausi aimablement rempli par Mr de Voogt, chef des observatoires de courants telluriques des PTT des Pays Bas, dont les stations de Noord Oost Polder, Paramaribo et Hollandia sont aussi stratégiquement distribuées par tout le globe. Mais comme ces substitutions donneront lieu à une réduction du temps prévu pour ces matières, il a semblé opportun d'entrer déjà dès l'après-midi du deuxième jour dans l'étude des *ssc* et des *si* et dans celle des *sfe* dans la matinée du troisième; de cette façon, s'il y avait des questions concernant d'autres types de variations rapides, tels que les baies ou les *pg*, on aurait le loisir de s'en occuper. En tout cas l'on envisage de consacrer l'après-midi du troisième jour et la matinée du quatrième à l'examen direct des travaux du Comité 10 et à la préparation de l'Atlas définitif des Variations Rapides avec des exemples réels, tirés autant que possible des données de l'Année Géophysique. L'expérience a montré qu'un certain nombre de retouches dans la méthode de travail du Comité est indispensable pour assurer davantage l'efficacité de sa labeur et alléger le travail de dépouillement et contrôle demandé aux observatoires. Je veux profiter cette opportunité pour signaler encore une fois la collaboration vraiment splendide de la presque totalité de ceux-ci et les en remercier de tout coeur; certes il y a toujours quelques vides et parfois il y a des données qui n'arrivent pas au moment voulu et avec la clarté souhaitable; mais ces petites lacunes sont l'apanage inévitable de toute activité humaine et leur mince volume rend encore plus éclatant le mérite de l'effort de ceux qui se distinguent par la régularité de leurs envois et la scrupulosité de leurs dépouillements. D'ailleurs c'est l'essentiel que les données arrivent, même si parfois elles sont en retard; le Comité est toujours prêt à les recevoir et à les encadrer dans l'ensemble dans la mesure du possible et je peux vous assurer qu'il le fait volontiers et continuera à le faire dans l'avenir.

Et cela dit, je ne retiens plus longtemps votre attention. Avant pourtant d'entrer dans l'ordre du jour je crois interpréter vos sentiments en remerciant l'Université d'Utrecht pour l'accueil si cordial qu'elle nous a amenagé dans son enceinte; l'Institut Royal Météorologique des Pays Bas qui a voulu prendre le haut patronage de cette réunion; et surtout le Prof. Veldkamp qui a bien voulu s'occuper de tous les détails d'organisation avec cette gentillesse et ce dynamisme que nous connaissons tous si bien. Je tiens aussi à remercier tous ceux qui sont venus de si loin, et au prix parfois de lourds sacrifices, pour prendre part à nos travaux et nous enrichir de leurs apportations. Enfin il ne me reste qu'à souhaiter que la série d'exposés et de discussions qui vont suivre puisse être une contribution de premier ordre à cet avancement de la Science Géomagnétique que l'on s'est efforcé de promouvoir avec tant de dépenses et de sacrifices pendant l'Année Géophysique Internationale.

Observatorio del Ebro,
Tortosa.

PART I

GEOMAGNETIC PULSATIONS

LES THEORIES DES PULSATIONS

par J. COULOMB

1. INTRODUCTION.

Exceptons la plus ancienne théorie des pulsations, celle de *Störmer*, qui les attribue à des nuages de particules électrisées se déplaçant sur des orbites fermées et qui néglige, comme toutes les théories de *Störmer*, les interactions du champ et des diverses particules. Toutes les autres explications font appel à l'oscillation de parties ionisées de l'atmosphère terrestre.

Un gaz ionisé peut être soumis d'une part à des oscillations de plasma, dans lesquelles les forces de rappel sont électrostatiques, d'autre part à des ondes électromagnétiques et hydromagnétiques, avec entre elles des formes de transition. (Il peut également s'y propager des paquets d'électrons comme dans les tubes à modulation de vitesse.) De toutes ces possibilités, la seule qui ait valu d'être explorée, parce que sa fréquence est assez basse, c'est la formation d'ondes hydromagnétiques.

Dans un premier genre de théories, les oscillations hydromagnétiques affecteraient, comme l'a envisagé *Lehnert*, une portion limitée de l'ionosphère aurorale. Elles exciteraient, d'une façon que j'ai essayé d'étudier, des oscillations électromagnétiques dans la cavité résonante constituée par l'espace compris entre le sol et l'ionosphère. La décroissance d'amplitude à partir de la source est extrêmement rapide et ne pourrait convenir qu'à des pulsations géantes.

L'ionosphère oscille mal parce que l'amortissement dû aux chocs est beaucoup trop grand. On est donc conduit à placer le plus loin possible la région d'oscillation. La région F2 équatoriale offre quelques caractéristiques favorables. Mais la cause des pulsations a surtout été recherchée, à la suite de *Dungey*, dans les portions extrêmes de l'atmosphère terrestre. Ce genre d'explications est le plus prometteur, sans qu'on connaisse encore suffisamment ces régions pour pouvoir obtenir des vérifications quantitatives. Le mode d'oscillation le plus facile à étudier (toroïdal) est peu favorable parce qu'il implique des variations de période avec la latitude géomagnétique.

2. PULSATIONS ATTRIBUABLES À LA ZONE AURORALE.

A priori, deux catégories de pulsations: les pulsations géantes *(pg)* et les trains de pulsations *(pt)*, pourraient être attribuées à des phénomènes liés aux aurores polaires, qui se propageraient électromagnétiquement des zones aurorales vers les basses latitudes.

Une propagation électromagnétique dont la vitesse est de l'ordre de celle de la lumière met en jeu des longueurs d'onde beaucoup plus grandes que le rayon terrestre et son étude pose nécessairement le problème de la diffraction par la Terre. Il est impossible de se contenter de traiter un problème plan.

Propagation des oscillations

On peut examiner cette question de propagation sans préciser la nature des phénomènes, en supposant seulement que la source de rayonnement (périodique ou périodique amorti) est peu étendue et que le phénomène de propagation a une symétrie de révolution autour du rayon terrestre passant par la source (1). Une objection évidente est que la structure de l'ionosphère est bien plus compliquée, en particulier que l'ionisation est grande le long de la zone aurorale elle-même. Mais on veut se borner au schéma le plus simple.

Le principe du calcul est le même que pour la diffraction des ondes radioélectriques autour de la Terre, mais les périodes très différentes conduisent à des approximations très différentes aussi. Deux solutions satisfont aux équations de Maxwell: la solution «électrique», telle que le champ électrique soit contenu dans le plan méridien (poloïdal), tandis que le champ magnétique est dirigé suivant le parallèle (toroïdal); et la solution «magnétique» où les propriétés des deux champs sont inversées. La solution à prendre dépend du phénomène primaire et des conditions aux limites. Dans les *pg* la composante magnétique EW semble la plus importante, ce qui les rapprocherait de la solution électrique. Pour les *pt*, c'est la composante NS (certains graphiques de *Kato* indiquent une polarisation plus ou moins nette vers la zone aurorale nocturne); elles se rapprocheraient donc de la solution magnétique. Cependant les résultats de *Scholte* et *Veldkamp*, relatifs à des latitudes peu élevées, sont complexes et il semble bien que le sous-sol joue un rôle prépondérant.

L'espace soumis au calcul comprend quatre milieux concentriques homogènes:

— Le sol de conductivité σ_s,
— L'atmosphère non conductrice,
— L'ionosphère proche, de conductivité σ_i (on néglige l'effet du champ magnétique),
— Les parties extérieures de l'ionosphère, de conductivité σ_e.

Dans les calculs on fait $\sigma_s = \infty$, $\sigma_c = \infty$ (naturellement la structure de l'ionosphère et du globe terrestre devraient intervenir dans une théorie moins grossière). Pour la conductivité superficielle, on adopte $4\pi\sigma_s = 10^{10}$, intermédiaire entre les valeurs correspondant aux trajets continentaux et maritimes. Pour l'ionosphère, si on prend $5.10^7 < 4\pi\sigma_i < 5.10^8$, la profondeur de pénétration $c/\sqrt{2\pi\sigma_i\omega}$ est de l'ordre de 200 km. pour une période $2\pi/\omega$ de l'ordre de 90 secondes, donc supérieure à l'épaisseur (80 km.) de la couche E. Mais il paraît impossible que la région F soit intéressée elle aussi, car on devrait alors prendre $4\pi\sigma_i = 4.10^{10}$ par exemple, et la profondeur de pénétration ne serait plus que de quelques kilomètres.

Avec ce schéma, le calcul montre qu'il ne peut y avoir d'oscillations propres stationnaires.

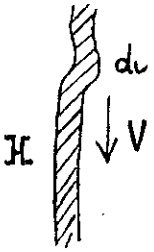
Peut-il y avoir des oscillations forcées, engendrées dans les régions aurorales par une cause périodique? Pour le voir, on assimile les champs que produiraient une telle cause dans un vide illimité à ceux d'un dipôle vertical, électrique ou magnétique situé un peu en-dessous de l'ionosphère. On trouve que pour un dipôle magnétique les oscillations diminueraient d'amplitudes suivant une loi en $\cos \frac{1}{2}\theta / \sin^2 \frac{1}{2}\theta$, θ étant la distance angulaire à la source. Cette diminution est beaucoup trop rapide pour expliquer les *pt*, qui s'observent encore de part et d'autre de l'équateur.

Pour un dipôle électrique, la variation est en $\operatorname{cotg} \frac{1}{2}\theta$, et s'accorde assez bien avec celle des *pg*. Comme l'a remarqué *Grenet*, on pourrait étayer cette interprétation en mesurant leur champ électrique.

Excitation des oscillations.

Des oscillations hydromagnétiques, pouvant jouer plus ou moins bien le rôle des sources précédentes, ont eté envisagées par *Kato* et *Watanabe* (2) et par *Lehnert* (3). Le champ magnétique étant voisin de la verticale dans les régions polaires, ils le considèrent comme absolument vertical; les ondes qu'ils étudient correspondent à un déplacement horizontal, lequel coupe perpendiculairement les lignes de force. (Ceci est d'ailleurs en conflit avec une observation ancienne faite par *Harang* à Tromsö avec un sondeur ionosphérique puissant (4) au cours de laquelle il semble avoir mis en évidence une oscillation *verticale* de l'ionosphère au moment d'une pulsation; cependant d'autres interprétations sont possibles.) La gravité n'intervient évidemment pas. D'autre part on peut linéariser les équations, négliger l'effet Hall, la dissipation par viscosité, le courant de déplacement.

Le cas le plus simple est celui des ondes transversales de *Alfvén*, qui sont bien connues mais dont nous pouvons rappeler très brièvement l'origine: Si la conductivité électrique est très élevée, le champ magnétique est attaché à la matière, gelé comme on dit parfois, puisque leur déplacement relatif engendrerait des courant énormes qui freineraient le mouvement. Suivant l'image de *Alfvén*, tout se passe alors somme si les tubes de force vibraient transversalement comme des cordes élastiques en contenant toujours la même quantité de matière et comme si cette vibration se propageait verticalement à la vitesse V_A. L'énergie potentielle du champ magnétique H contenue dans un élément de volume dv étant $H^2 dv/8\pi$ on peut retrouver la vitesse des ondes de *Alfvén* en égalant cette énergie potentielle à l'énergie cinétique $\frac{1}{2} \rho V_A{}^2 dv$.



La formule obtenue

$$V_A = H / \sqrt{4 \pi \rho}$$

néglige les collisions, autrement dit la pression du gaz. Elle n'est strictement valable que pour un gaz complètement ionisé, ce qui n'est pas le cas de l'ionosphère.

La question a été examinée par *Dungey* (5) dès 1954. Si l'on regarde l'ionosphère comme le mélange d'un gaz complètement ionisé avec un gaz neutre, l'oscillation correspondante des particules chargées se communiquera au gaz neutre de façon plus ou moins efficace suivant la fréquence des chocs entre molécules neutres et ions positifs (les électrons comptent peu par suite de leur faible masse). *Dungey* montre que dans l'ionosphère le nombre de chocs par minute reste faible devant le nombre de molécules neutres. Donc celles-ci oscillent peu avec les particules chargées et ne modifient pas beaucoup la vitesse calculée avec la densité du seul gaz ionisé; leur effet principal est d'amortir les ondes. Cependant l'amortissement et la vitesse dépendent de la période; il y a donc dispersion.

Dans leurs premiers travaux (2) (les autres étant au contraire inspirés de ceux de *Dungey*), *Kato* et *Watanabe* admettent que certaines pulsations pourraient être engendrées par des ondes hydromagnétiques se propageant de haut en bas dans l'ionosphère et se réfléchissant sur sa base de façon à produire des ondes stationnaires. Dans l'atmosphère, où la conductivité est faible, apparaîtraient des ondes électromagnétiques de même fréquence. *Kato* et *Watanabe* obtiennent cette fréquence en assimilant l'ionosphère à une couche d'épaisseur D, et en écrivant le retour en phase $2D/V_A = nT$, où n est un nombre entier. Si on applique ce raisonnement à l'ionosphère aurorale, les pulsations géantes devraient comporter une vibration fondamentale et des harmoniques, ce qui semble difficile à soutenir par l'observation. D'autre part la formule précédente suppose constante la vitesse V_A des ondes de *Alfvén* laquelle, dans l'ionosphère, dépend beaucoup de l'altitude et, comme nous venons de le voir, dépend un peu de la période. Par dessus tout il n'est pas question de l'amortissement.

L'article de *Lehnert* est beaucoup plus poussé. Si on assimile l'ionosphère à un conducteur *compressible*, et si la densité est assez grande, l'intensité du champ magnétique augmente par compression. La pression magnétique agit comme la pression d'un gaz et permet la propagation horizontale d'ondes analogues aux ondes sonores, en plus de celle des ondes de *Alfvén*. Ces ondes sont longitudinales, du moins en ce qui concerne la vibration, le vecteur électrique restant transversal comme dans les ondes de *Alfvén*.

Si la densité est trop faible, le courant de Hall produit par l'un des types d'ondes influe sur le deuxième et ils ne sont plus indépendants.

Les deux types sont amortis; pour les ondes progressives l'amplitude comporte un facteur exp $(-Z/Z_0)$. Des ondes stationnaires peu amorties dans le temps existent seulement pour les longueurs d'onde λ de l'ordre de $2\pi Z_0$. Voici, à partir de données convenables et pour des périodes de 60 à 300 sec., les résultats numériques de *Lehnert* correspondant aux couches E et F2 (il a également fait les calculs pour D et F1) :

RÉGIONS	E	F 2
Epaisseur moyenne en km	50	200
Ondes longitudinales		
Vitesse de phase en m/s	311	2×10^4
Longueur d'onde λ en km	20 à 100	1200 à 6000
Distance d'amortissement Z_0 en km	9,6 à 240	300 à 7200
$2\pi Z_0/\lambda$	3 à 15	1,6 à 7,5
Ondes transversales		
Vitesse de phase en m/s	58	2×10^4
Longueur d'onde λ en km	3,5 à 20	1200 à 6000
Distance d'amortissement Z_0 en km	$2{,}3 \times 10^{-3}$ à $5{,}8 \times 10^{-3}$	300 à 7200
$2\pi Z_0/\lambda$	4×10^{-3} à 18×10^{-3}	1,6 à 7,5

Lehnert admet l'existence d'ondes longitudinales dans E et d'ondes des deux types dans F2, bien qu'elles correspondent à des rapports $2\pi Z_0/\lambda$ assez différents de 1 et par conséquent à des amortissements un peu trop grands dans des conditions atmosphériques normales.

Pour l'onde longitudinale, la plus grande valeur de λ imaginable serait, dit *Lehnert,* égale à 4 fois la largeur de la zone aurorale, soit 4000 km; on aurait alors des ondes stationnaires perpendiculaires à la zone, et des courants induits le long d'elle. Pour l'onde transversale, *Lehnert* suggère comme *Kato* la production d'une onde stationnaire par réflexion multiple sur les «surfaces» d'une couche ionosphérique. On devra avoir $\lambda \leqq 4D$, D étant l'épaisseur de la couche; le courant sera encore horizontal.

Sauf vers 300 sec, les périodes des *pg* sont compatibles avec l'un ou l'autre cas.

Les résultats de *Lehnert* ont été critiqués par *Pickelner* (6). Comme nous l'avons vu, la densité à introduire dans la formule de *Alfvén* est voisine de celle des particules chargées. Or *Lehnert* admet que la formule reste valable avec la densité totale si l'intervalle moyen entre deux collisions des ions avec les particules neutres est inférieur à la période des pulsations géantes (60 à 300 secondes). Cet intervalle est, en secondes:

	5×10^{-6}	5×10^{-4}	1	300
dans	D	E	F1	F2

La condition n'est donc pas remplie dans F2. De plus, elle n'est pas suffisante pour que l'ensemble du gaz oscille avec les ions. Il faut encore que l'ionisation soit élevée, beaucoup plus que dans l'ionosphère normale. *Lehnert* réplique qu'elle peut être élevée dans la zone aurorale au moment d'une pulsation géante. C'est dans cet état incomplet qu'il laisse la théorie.

3. EVENTUALITÉ D'UNE PROPAGATION ÉQUATORIALE.

Pour expliquer les débuts brusques de tempêtes magnétiques *(ssc), Dessler* (7) fait une suggestion qui serait peut-être utilisable pour une théorie des pulsations: Il envisage l'arrivée, dans l'atmosphère terrestre, de gaz solaire ionisé. Celui-ci serait poussé verticalement vers la Terre dans les régions équatoriales où la pression magnétique $H^2/8\pi$ est minimum. Selon *Dessler* son arrivée engendrerait, par compression semble-t-il, une onde hydromagnétique longitudinale à propagation horizontale, perpendiculairement au méridien magnétique. Dessler prend pour vitesse de l'onde la vitesse $V_A = H/\sqrt{4\pi\rho}$ de l'onde de *Alfvén,* où ρ est la densité des particules chargées. En fait, si la conductivité est infinie, et si l'onde est longitudinale, sa vitesse est donnée par $V^2 = V_A{}^2 + V_S{}^2$, V_S étant la vitesse des ondes sonores en l'absence de champ (8); les deux vitesses sont pratiquement les mêmes dans le domaine qui nous occupe. Voici leur variation avec l'altitude, calculée par *Dessler* en supposant au champ magnétique équatorial superficiel la valeur de 0,3 gauss:

Altitude en km	Nombre de particules chargées par cm³	Poids moléculaire	V en km/s
32000	10^3	1,0	95
6000	10^3	1,0	2800
1200	10^3	1,0	12400
1050	10^3	1,0	13300
900	$1,3 \times 10^3$	5,0	5500
750	3×10^3	18,0	2000
600	3×10^3	18,7	670
400	10^3	18,7	126
300	10^3	18,7	132
200	5×10^3	21,6	180

Verticalement, V passerait donc par un minimum dans F2; en même temps V serait plus faible à l'équateur qu'aux points situés à la même altitude. *Dessler* en conclut à la formation d'un canal équatorial où les ondes hydromagnétiques se propageraient à la vitesse minimum de 130 km/sec. et mettraient donc 5 minutes à faire le tour de le Terre, causant d'après lui les *ssc* sur leur passage.

Il n'est pas douteux qu'un minimum de vitesse focalise les ondes, puisque des rayons inclinés sur l'axe du canal sont réfractés vers lui. Mais la propagation doit se faire avec dispersion: si on représente le déplacement initial par une intégrale de Fourier, les composantes de grande longueur d'onde intéresseront des régions éloignées de l'axe du canal, et il est à prévoir qu'elles se propageront plus vite. Il faut donc s'attendre à ce qu'un déplacement brusque soit remplacé par un mouvement comportant au début des ondes de grande période et de très faible amplitude, la période décroissant et l'amplitude augmentant jusqu'à une fin brusque propagée à la vitesse minimum. On sait que l'on observe au contraire après le *ssc* des pulsations d'amplitude décroissante; le mécanisme de Dessler ne paraît donc pas expliquer convenablement les débuts brusques. Une vérification soignée de *Gerard* (9) n'a d'ailleurs montré aucune trace de propagation équatoriale.

Le canal de *Dessler* pourrait peut-être, au contraire, propager des oscillations observables sous forme de pulsations. Certes il n'est pas question d'observer l'onde ayant pour longueur le tour de la Terre, mais le tableau ci-dessus montre que V est sensiblement constant entre 300 et 400 km. Une onde ayant une longueur de l'ordre de 100 km, donc une période de l'ordre de la seconde, se propagerait en restant assez pure. Les ondes beaucoup plus courtes seraient diffusées par les accidents d'ionisation. On aurait là une explication pour les pulsations de période inférieure à la seconde observées par *Mme Troïtzkaïa* et par *Selzer* au cours des tempêtes magnétiques; à une condition toutefois, c'est que la conductivité du canal soit très élevée, au moins temporairement. L'existence d'un électrojet équatorial laisse de ce côté quelque espoir.

4. THÉORIE DE STÖRMER.

Störmer (10), ayant obtenu par le calcul un certain nombre de trajectoires périodiques pour une particule chargée se déplaçant dans le champ du dipôle géomagnétique et trouvé des périodes de l'ordre de grandeur de celles des pulsations, imagine que l'une de ces trajectoires soit parcourue par un nuage de particules semblables, assez dense pour que le champ magnétique produit soit mesurable au sol.

Le raisonnement sur particule unique, dont on sait qu'il conduit parfois à des paradoxes, peut être admis pour des descriptions qualitatives dans les régions où le libre parcours est très grand, et permet de poser certains problèmes intéressants. Par exemple, une partie des trajectoires trouvées s'approchent alternativement des zones aurorales Nord et Sud, tandis que d'autres trajectoires s'attardent au voisinage de l'une des deux zones; on se demandera donc s'il y a correspondance entre pulsations arctiques et antarctiques.

Quantitativement, la coïncidence d'ordre de grandeur entre les périodes est un argument assez maigre, car elle s'obtient en fait difficilment. Examinons le cas le plus simple, où la particule chargée décrit un cercle de rayon R dans le plan équatorial géomagnétique. Si e est la charge de la particule, m sa masse, v sa vitesse, H le champ magnétique, la force evH exercée par celui-ci équilibre la force centrifuge mv^2/R, d'où la relation bien connue:

$$HR = mv/e$$

D'autre part $H = M/R^3$, M étant le moment magnétique terrestre, donc:

$$R = (Me/mv)^{1/2}$$

Les rayons ainsi déterminés sont ceux que *Störmer* introduit comme unités de longueurs et il en a donné des tables, notamment la Table I, p. 294, de son livre «The Polar Aurora», d'où est tirée la suivante, à ceci près qu'on a corrigé une erreur évidente et ajouté la valeur de la période

$$T = 2\pi R/v$$

HR	R en km	Pour des électrons			Pour des protons		
		v en km/sec	Energie en ev	T en sec	v en km/sec	Energie en ev	T en sec
10^4	$9{,}0\times10^5$	$3{,}0\times10^5$	$2{,}5\times10^6$	19	$9{,}6\times10^2$	$4{,}8\times10^3$	6×10^3
10^5	$2{,}9\times10^5$	$3{,}0\times10^5$	$3{,}0\times10^7$	6	$9{,}6\times10^3$	$4{,}8\times10^5$	2×10^2
10^6	$9{,}0\times10^4$	$3{,}0\times10^5$	$3{,}0\times10^8$	2	$9{,}1\times10^4$	$4{,}8\times10^7$	6

Si l'on veut que R ne dépasse pas quelques dizaines de rayons terrestres, on est obligé de recourir à des particules de haute énergie, et la période devient faible. Si au contraire on augmente R, le courant électrique que transportent les particules doit avoir une intensité énorme (pour obtenir une perturbation de l'ordre du γ au centre d'une spire de 9×10^4 km de rayon il faut déjà $1{,}4\times10^5$ ampères).

Il semble donc qu'il y ait peu à tirer des trajectoires périodiques de *Störmer* pour l'interprétation directe des pulsations. Elles pourraient toutefois éclairer la genèse des zones de *Van Allen,* dont nous dirons quelques mots tout à l'heure, parce qu'il s'agit là de particules de très grande vitesse. Il y a moins encore à attendre de la théorie principale de *Störmer* sur les trajectoires de corpuscules chargés provenant du Soleil. Même dans le gaz interplanétaire le densité est encore assez grande pour que les interactions entre particules ne soit pas négligeables; d'autre part le champ de dipôle y est, comme nous allons le voir, fortement altéré.

5. OSCILLATIONS DE L'EXOSPHÈRE.

C'est *Dungey* (11) qui a attribué le premier les pulsations à des oscillations de l'atmosphère lointaine. Ses idées forment encore la base de tous les travaux publiés. Nous nous écarterons donc peu de son exposé, bien qu'il remonte à 1954. Il y a intérêt à lire aussi celui, plus récent, de *Tamao.*

L'exosphère selon Dungey.

La frange extrême de l'atmosphère a une structure très différente de celle d'un gaz ordinaire. *Dungey* s'est attaché très longuement à la préciser. C'est la région où les gaz de l'atmosphère commencent à s'en échapper. Les conditions statistiques y sont évidemment complexes. Le libre parcours des particules neutres, que *Dungey* considère d'abord, est non seulement très grand, mais dépend de la nature des orbites de particules. Il est maximum pour des particules montant verticalement, puisqu'elles rencontrent des densités de plus en plus faibles. La distribution des vitesses est également anisotrope puisqu'il y a très peu de particules redescendant après un choc et ayant une vitesse supérieure à la vitesse d'expulsion. Cependant, si on néglige ces quelques particules, on peut admettre que l'exosphère est grossièrement en équilibre isotherme, et *Dungey* lui assigne une température de l'ordre de 1500° K. Cette distribution peut être maintenue si l'atmosphère tourne en bloc avec la Terre.

A vrai dire ce sont les particules chargées qui comptent. Elles tire-bouchonnent autour du champ terrestre ce qui, sauf aux pôles, les empêche de s'évader. Inversement le champ empêche le gaz interplanétaire de pénétrer dans l'exosphère. La distribution des vitesses des particules chargées formant chacun des constituants de l'exosphère peut elle aussi être considérée comme isotherme, au sein d'un milieu dépourvu de courant. Le plus important des constituants à cette altitudes, ce sont certainement les protons, et de beaucoup. Pour une température de 1500° K, *Dungey* trouve que leur densité ρ doit avoir une variation de la forme.

$$\rho = \rho_0 \exp (2{,}5/R),$$

où R est la distance au centre de la Terre, le rayon terrestre étant pris pour unité. Le nombre des protons aux limites de l'atmosphère (et aussi celui des électrons) doit être d'environ 400/cm^3 d'après la théorie des siffleurs de *Storey*, ce qui donne, pour ρ_0, de 30 à 1200 protons/cm^3.

A l'extérieur de l'atmosphère se trouve le gaz interplanétaire. D'après les observations de la lumière zodiacale dues à *Siedentopf* (1953) il contiendrait environ 600 électrons par cm^3. *Dungey* admet qu'il n'y règne aucun champ magnétique important.

Ce gaz interplanétaire est en mouvement relatif par rapport à la Terre avec des vitesses qui correspondent surtout à la vitesse orbitale. Les circonstances (Terre plongée dans un flux corpusculaire) sont analogues à celles qui servent d'hypothèse de départ à la théorie des tempêtes magnétiques de *Chapman* et *Ferraro*. Le résultat est bien connu: il doit se former une cavité entourant la Terre, dans laquelle le champ magnétique est confiné (le gaz interplanétaire agissant comme un conducteur parfait et les courants induits à sa surface annulant le champ magnétique dans le conducteur). Mais il y a une différence évidente entre le point de vue de *Chapman* et *Ferraro* et celui de *Dungey*, c'est que ce dernier attribue à la cavité le caractère permanent d'une limite de l'atmosphère.

En écrivant l'équilibre de la pression magnétique avec la pression du gaz, *Dungey* obtient la valeur de 9 rayons terrestres pour le rayon de la cavité. Les recherches des géomagnéticiens sur l'anneau de courant responsable du champ de post-perturbation, courant qu'on pourrait assimiler aux courants à la surface de la cavité, conduisent à des rayons plus faibles, 3 ½ rayons terrestres par exemple dans un article de *Chapman* (1952). A 9 rayons terrestres, la vitesse de rotation atteint 4 km/sec et *Dungey* la néglige devant la vitesse orbitale (20 km/sec).

Cette façon de faire n'a pas toujours été acceptée. Ainsi *Tamao* (12) et *Maeda* ont attribué aux courants produits par la seule rotation une torsion du champ géomagnétique qui expliquerait l'écart découvert par *Simpson et al.* entre l'observation des rayons cosmiques et l'effet théorique d'un champ de dipôle. *Tamao* (13) justifie par une hypothèse hardie le fait qu'il ne considère pas la vitesse orbitale: le gaz interplanétaire tournerait avec le Soleil, comme le prouverait la forme de la lumière zodiacale.

Les calculs de *Dungey* sont faits avec 1500° K pour température à la limite de l'atmosphère. Avec 10 000° K, admis par *Tamao* (13) ou par *Obayashi* (14), le rayon limite passe seulement de 9 à 10 rayons terrestres. Les conditions très particulières de la nappe de courants formant la couche limite ont été étudiées par *Tamao* (13) qui lui trouve une épaisseur de l'ordre de 170 mètres seulement. Cette couche limite forme barrière magnétique pour les particules thermiques, mais non pas, bien entendu, pour les particules de grande énergie.

Avant d'examiner les conséquences que *Dungey* a tirées du schéma précédent il serait bon de considérer les progrès faits récemment dans l'étude de la très haute atmosphère. L'auteur du présent rapport est peu qualifié pour traiter cette question et s'excuse de lui consacrer seulement quelques mots: La connaissance des densités dans l'exosphère semble avoir peu progressé, et en ce qui concerne la densité du gaz interplanétaire la plupart des estimations restent de l'ordre de grandeur de 1000 ions et électrons par cm^3. Mais l'hypothèse d'une atmosphère isotherme paraît en contradiction avec les idées actuelles. Des calculs de *Chapman*, supposant le gaz interplanétaire émis en régime stationnaire par la couronne solaire, indiquent qu'il aurait encore une température de l'ordre de 200 000° K à la distance de l'orbite terrestre. Elle s'abaisserait à 30 000° K au niveau où les particules neutres commencent à être présentes, tandis que la température vers 80 km est inférieure à 200° K.

La présence des zones de radiation de *Van Allen* a certainement un lien important avec notre problème, mais ce lien est complexe car les particules mises en évidence ont, surtout pour la zone interne, une très grande énergie et ne contribuent guère à l'ionisation présente. La zone externe entre 3 et 4 rayons terrestres est certainement la plus intéressante pour nous (elle serait composée d'électrons d'énergie relativement petite; d'après des informations de presse la fusée lunaire soviétique aurait observé en la traversant un minimum puis un maximum du champ magnétique, en sorte que cette zone serait le siège de courants électriques importants). On peut espérer connaître un jour le spectre d'énergie des particules chargées dans les diverses régions de l'exosphère, ce qui permettra de fonder vraiment les calculs du genre de ceux de *Dungey;* mais nous n'en sommes pas là.

Oscillations toroïdales.

Plutôt que de considérer immédiatement la suite du travail de *Dungey,* il est plus intuitif de procéder comme l'a fait *Obayashi* (14) dans un article plus récent.

On part de la formule $V = H/\sqrt{4\pi\rho}$ donnant la vitesse des ondes de *Alfvén* (comme nous l'avons signalé elle doit être modifiée pour tenir compte des collisions; mais celles-ci sont très rares dans l'exosphère et les difficultés rencontrées dans le cas de l'ionosphère ne se présentent pas ici). Une onde de *Alfvén* se propageant le long d'une ligne de force du dipôle terrestre se réfléchit alternativement aux deux points où cette ligne s'enracine sur la surface de la Terre, et l'ensemble de ses réflexions produit une onde stationnaire dont la période est:

$$T = \int_{-\lambda_0}^{+\lambda_0} \frac{1}{V_A} \frac{ds}{d\lambda} \, d\lambda$$

s étant l'arc, λ la latitude géomagnétique, $\pm \lambda_0$ celle des points d'enracinement.

La même onde stationnaire se produit sur toutes les lignes de force qui se déduisent de la précédente par rotation autour de l'axe géomagnétique, et qui forment dans l'ensemble une surface de révolution. En un point quelconque de cette surface, en particulier sur ses parallèles d'enracinement, la vibration est perpendiculaire au méridien géomagnétique. Les surfaces engendrées par rotation d'une autre ligne de force vibrent de même, indépendamment (cette indépendance n'a lieu, en toute rigueur, que si on néglige la viscosité), avec une période différente.

Remarquons que l'orientation de la vibration ainsi définie ne correspond guère aux observations des *pt,* qui sont plutôt polarisées en direction méridienne; elle conviendrait moins mal aux pulsations continues *pc,* assez bien aux *pg.* D'autre par les *pc* et les *pt* s'observent parfaitement dans les régions équatoriales, alors qu'une ligne de force coupant la Terre aux latitudes géomagnétiques ± 10° ne dépasse nulle part l'altitude de 200 km et reste donc dans des régions où les vibrations, s'il s'en produisait, seraient fortement amorties.

Revenons à la formule donnant la période. Elle amène à calculer l'intégrale $\int \rho^{\frac{1}{2}}(H)^{-1}ds$, qu'il est instructif de comparer à l'intégrale $\int \rho^{\frac{1}{2}}(H)^{-\frac{1}{2}}ds$, fournie directement par la "dispersion" des siffleurs. *Obayashi* n'utilise d'ailleurs pas les résultats de *Storey,* mais admet, par référence à *Dungey,* que l'exosphère est composée essentiellement d'hydrogène ionisé en équilibre isotherme et lui emprunte la formule $\rho = \rho_0 \exp(\alpha/R)$ donnant la densité. Il compare alors les courbes calculées donnant $\tau\rho_0^{-\frac{1}{2}}$ en fonction de λ avec les courbes résultant de quelques enregistrements de pulsations (des *pt* semble-t-il) en provenance de diverses stations. Ces enregistrements le conduisent à admettre que la période moyenne croît avec la latitude géomagnétique (cette période passerait de 40 secondes pour 40° à 120 secondes pour 60° et à 220 secondes pour 67°, ce qui, même pour les *pt*, est au moins surprenant). *Obayashi* trouve que l'accord avec la courbe calculée est satisfaisant si la densité ionique pour R infini est $3{,}75/\text{cm}^3$ ce qui correspond à une densité de l'ordre de $10^3/\text{cm}^3$ à quelques rayons terrestres; mais si, d'autre part, on prend $\alpha = 15$, très différent de la valeur $\alpha = 2{,}5$ préconisée par *Dungey*, *Obayashi* tente d'en déduire la température correspondante de l'atmosphère extérieure et trouve seulement 250° K, ce qu'il reconnaît lui-même être beaucoup trop faible.

Théorie générale des oscillations de l'exosphère.

Revenons à l'article fondamental de *Dungey* (11). Il écrit l'équation générale linéarisée des ondes de *Alfvén* dans un champ magnétique non uniforme. Mais il lui paraît impossible de définir la frontière extérieure et les conditions qui doivent y être satisfaites (à la frontière inférieure, pour des périodes de l'ordre de la minute, l'ionosphère est mince devant la longueur d'onde, mais avec le sol elle forme un bon réflecteur et peut être assimilée à un réflecteur parfait).

Dungey se borne ensuite au cas où le champ magnétique présente une symétrie axiale et considère les vibrations dépendant de l'azimut φ et du temps t par l'intermédiaire de facteurs $\substack{\cos \\ \sin}(m\varphi - \omega t)$. Les résultats sont simples pour les vibrations symétriques $m = 0$, car il se produit alors une décomposition des équations, et le mouvement peut être considéré comme la superposition de modes appartenant à deux types différents: un type électrique (champ électrique poloïdal, champ magnétique toroïdal, déplacement toroïdal) et un type magnétique (champ électrique toroïdal, champ magnétique poloïdal, déplacement poloïdal). Le premier correspond aux oscillations de torsion dont nous venons de donner la description intuitive suivant *Obayashi*. Dans ce type d'oscillation on n'a pas besoin, dit *Dungey*, de condition à la frontière extérieure pour calculer les fréquences; mais cela revient bien entendu à prendre pour fontière extérieure une des surfaces vibrantes.

Comme plus tard *Obayashi*, *Dungey* trouve des valeurs de la période qui croissent avec la latitude géomagnétique, mais ses valeurs sont encore beaucoup moins acceptables, surtout, semble-t-il parce qu'il introduit comme approximation, à un moment de ses calculs, une valeur de la densité ionique constante avec l'altitude. Pour $\rho = 10^{-21}$ gr/cm³ par exemple, il trouve approximativement $T = 0{,}6 \sec^8 \lambda$, d'où:

pour $\lambda =$	45°	55°	65°	70°
$T =$	10 sec,	54 sec,	11 min,	55 min.

D'autre part, pour un champ de 1 γ, les déplacement en km serait $10 \sec^5 \lambda$ donc 56 km pour $\lambda = 45°$, et deviendrait infini au pôle. La linéarisation n'a plus alors grand sens.

Si, au lieu d'oscillations axiales, on envisageait des modes supérieurs en $\genfrac{}{}{0pt}{}{\cos}{\sin}(m\varphi - \omega t)$ avec m entier, on aurait bien entendu des périodes moindres. *Dungey* suggère qu'on pourrait ainsi expliquer les *pg*.

La question a été reprise par *Kato* et *Watanabe* (15) qui considèrent les *pg* comme présentant des périodes privilégiées sousmultiples d'une période fondamentale et les comparent à la loi asymptotique $T_n \sim T/n$ valable pour les modes supérieurs des oscillations axiales. Si on suppose que l'exosphère contient 1000 protons par cm³ les valeurs de T correspondant aux latitudes géomagnétiques

	45°,	55°,	65°,	70°,
sont en secondes	9,	47,	538,	2929,

ce qui est inadmissible. Comme *Dungey*, les auteurs attribuent cet échec à l'hypothèse de la symétrie axiale, contraire au caractère local des *pg* (il faudrait en effet rechercher des solutions d'extension limitée, ce qui nécessiterait l'introduction des valeurs de m non entières; mais ce n'est pas la seule difficulté!).

Oscillations poloïdales.

Prenons maintenant, parmi les oscillations axiales de *Dungey*, le type magnétique à déplacement poloïdal. La perturbation s'étend alors à toute l'atmosphère et sa période dépend étroitement des régions à champ faible. On ne peut la calculer sans connaître les conditions à la limite extérieure de la cavité. *Dungey* pense néanmoins que la période fondamentale est du même ordre que celle qui correspond, pour le type électrique, à la ligne de force touchant la cavité; c'est à dire qu'elle est de l'ordre de l'heure. Elle ne nous intéresse donc pas directement. Evidemment les *pt* pourraient correspondre à des modes supérieurs, mais devraient alors présenter des lignes nodales que l'on n'a jamais observées.

Kato et *Akasofu* (16) ont essayé de tirer parti du type magnétique en adoptant une hypothèse pour les conditions à la frontière extérieure, conditions que *Dungey* ne s'était pas cru autorisé à préciser. Dans leurs calculs, ils supposent comme d'habitude la conductivité infinie et la viscosité nulle, quitte à estimer ensuite ces deux causes d'amortissement;

ils constatent comme d'autres qu'on peut négliger l'effet Hall et les effets mécaniques (gravitation, force de Coriolis) devant les effets électrodynamiques. Ils choisissent alors un modèle comportant, autour d'une Terre parfaitement réfléchissante, une atmosphère non conductrice, puis une atmosphère ionisée (qui réunit l'ionosphère et l'atmosphère supérieure), confinée par un espace interplanétaire non conducteur, ce qui est physiquement assez étrange. On trouve alors une équation aux périodes pour chaque degré n des fonctions de Legendre qui entrent dans la solution (degré fixant le nombre des parallèles nodaux). Le fait que le système, comme tous ceux de dimensions finies, présente seulement des périodes discrètes ne semble pas un obstacle majeur, car on peut concevoir des fluctuations dans la structure donnant aux périodes leur diversité réelle.

Les auteurs résolvent numériquement l'équation pour $n = 1$. Ils supposent que l'atmosphère conductrice comporte $8{,}3 \times 10^5$ ions O^+ par cm^3 à sa base, 470 ions H^+ par cm^3 à 5,5 rayons terrestres. Un tel choix est compatible avec une valeur constante (200 km/sec) pour la vitesse des ondes de *Alfvén* dans toute l'épaisseur, hypothèse qui simplifie beaucoup les calculs.

Voici par exemple quelques valeurs des périodes pour deux valeurs du rapport β entre les rayons des deux frontières de l'atmosphère ionisée:

$\beta = 6$ . . . 378 sec, 182 sec, 118 sec, 87 sec, 69 sec . . .
$\beta = 10$ . . . 604 sec, 334 sec, 200 sec, 154 sec, 125 sec . . .

La variation, par rapport à la latitude géomagnétique, du champ magnétique méridien dépend en première approximation d'un facteur $\cos \lambda$ ce qui n'est pas incompatible avec le comportement des *pt* (ou même des *pc)*.

Les auteurs étudient ensuite la dissipation d'énergie par freinage magnétique, par effet Joule, et par viscosité. Cette dernière cause d'amortissement est pratiquement la seule à considérer en dehors de l'ionosphère. Voici les temps d'amortissement trouvés pour diverses périodes dans un cas qui sert d'exemple:

Période	10 sec,	20 sec,	100 sec,	300 sec.
Temps d'amortissement .	5,1 sec,	20,3 sec,	508 sec,	4580 sec.

Les *pt* de courte période devraient être beaucoup plus amorties que celles de longue période, ce qui n'a guère été observé. Quant aux *pc*, pour lesquelles on ne peut parler d'amortissement, elles ne semblent pas pouvoir être ainsi expliquées.

Les oscillations de type magnétique ont également été considérées par *Kato* et *Watanabe* (17) avec des hypothèses différentes: Une difficulté intrinsèque du problème des oscillations, qu'elles soient de l'un ou l'autre type, c'est que les lignes de force ne ressemblent guère à des cercles méridiens, si ce n'est dans les régions équatoriales. Mais *Kato* et *Watanabe* s'affranchissent de cette difficulté en remplaçant l'expression de H^2 par une fonction de la distance seule. De plus ils supposent constante la densité ionique. Ils trouvent des solutions analogues à celles de l'équation des ondes, contenant des produits de fonctions de Bessel par des fonctions de Legendre; ces fonctions de Legendre seraient de degré 1 parce que le sens des pulsations en France et à Madagascar a été trouvé le même par *Schlumberger* et *Kunetz*. *Kato* et *Watanabe* admettent alors qu'une surface limite sphérique sépare l'exosphère d'un vide extérieur (cependant, paradoxalement, le rayon R_0 de la surface ne s'accroît pas). On trouve des périodes discrètes d'expression asymptotique $T_n \sim T_0/n$, où T_0 est proportionnel à $R_0{}^4$ et atteint quelques centaines de secondes losque R_0 croît jusqu'à 8 rayons terrestres par exemple. *Kato* et *Watanabe* pensent pouvoir interpréter les *pc* comme des battements entre deux de ces oscillations.

Excitation des oscillations

La façon dont les oscillations propres de l'ionosphère seraient excitées par les agents extérieurs semble bien difficile à comprendre, surtout pour les oscillations toroïdales qui ont été les plus étudiées.

Obayashi, après *Dungey*, attribue leur mise en route à l'arrivée de corpuscules solaires. Les faisceaux corpusculaires s'arrêteraient lorsque leur énergie cinétique serait annihilée par l'énergie du champ magnétique, autrement dit lorsque leur vitesse serait celle de *Alfvén*. Pour 10 particules par cm^2 de faisceau, cela conduit à une distance de 7 rayons terrestres. La ligne de force correspondante s'enracine vers $\lambda = 67{,}5^\circ$. Si l'on suppose que les corpuscules atteignent la frontière dans les régions équatoriales, c'est cette ligne de force qui sera excitée au maximum. L'amplitude des pulsations devrait donc décroître de part et d'autre. Cela ne correspond en rien aux observations des *pt*. Cela rappelle davantage le comportement des *pg*, qui semblent disparaître à l'intérieur de la zone aurorale et dont l'amplitude décroît rapidement vers l'extérieur; malheureusement on n'a jamais signalé de variation dans la période des *pg* avec la latitude géomagnétique.

Tamao (13) envisage la possibilité d'excitation des oscillations par un accroissement brusque de la radiation solaire *(sfe)*; les crochets magnétiques ne sont pourtant pas accompagnés de pulsations. Au terme de longs calculs, il trouve lui aussi un maximum d'intensité, vers 75° géomagnétiques, dont il ne précise pas la valeur absolue.

Dungey (11) étudie la façon dont certaines ondes lentes seraient engendrées à la surface de la cavité atmosphérique par le flux interplanétaire, comme les vagues sont engendrées par le vent. Les fluctuations du champ magnétique que produiraient ces ondes à la surface de la Terre sont seulement de l'ordre du γ. *Dungey* y voit une parenté avec certaines perturbations mobiles observées pour la couche F et peut-être, ce qui nous intéresse ici, avec l'agent excitateur de certaines pulsations. L'idée serait à creuser pour la raison suivante: un point resté obscur dans la théorie des pulsations, ce sont les groupes d'ondes qui constituent les *pc* régulières, et la simultanéité de ces groupes aux divers lieux. La présence de groupes dans un phénomène physique est caractéristique d'un spectre étroit, et résulte en général du passage par un système filtrant tel qu' une propagation avec dispersion. Pour les *pc* une propagation de haut en bas par ondes plus ou moins concentriques à la Terre (poloïdale par exemple), avec filtration quelque part sur le trajet, assurerait la simultanéité des groupes.

Malheureusement on voit mal comment échapper aux objections que soulève l'amortissement de telles ondes avant même qu'elles atteignent l'ionosphère.

De plus les effets considérables de latitude liés au mécanisme même de leur excitation ne paraissent pas devoir bien s'accorder avec l'ensemble des faits observés.

Dans tous ces problèmes on peut concevoir que les phénomènes extérieurs apportent au système résonant lui-même des perturbations importantes, qui expliqueraient peut-être les changements de régime observés dans les *pc*, notamment par *Kunetz* dans les *pc* telluriques.

Effet d'écran de l'ionosphère.

Un caractère commun à toutes les théories résumées dans cette cinquième partie, c'est qu'elles négligent l'ionosphère. Si, avec *Dungey*, on se représente l'atmosphère comme la superposition d'un gaz complètement ionisé et d'un gaz neutre, le fait que la proportion du premier soit grande ou petite, joint au fait que la période des oscillations soit courte ou longue, décident de la présence ou de l'absence d'oscillations hydromagnétiques. Celles-ci sont possibles dans l'exosphère. Si elles se propagent vers le bas, elles se transforment dans l'ionosphère en oscillations électromagnétiques. Le passage, qui est complexe (notamment par suite de l'existence des rayons ordinaire et extraordinaire), a été étudié notamment par *Akasofu* (18), mais il y reste beaucoup d'inconnu.

Watanabe (19) termine sa discussion par un calcul simplifié à l'extrême, purement électromagnétique, mais dont le résultat vaut néanmoins d'être mentionné. Il suppose que l'ionosphère est un écran métallique mince, à distance négligeable de la surface terrestre supposée plane. (Dans la deuxième partie nous avons indiqué l'insuffisance des modèles plans pour étudier une propagation horizontale; mais il s'agit ici d'atténuation verticale. L'effet d'écran de l'ionosphère pour les ondes électromagnétiques a d'ailleurs été étudié sur des modèles sphériques par de nombreux auteurs.) Le champ magnétique est supposé vertical, la conductivité du sol indépendante de la profondeur. *Watanabe* trouve alors que le champ magnétique superficiel avance en phase de $\pi/4$ sur le champ à la surface extérieure de l'ionosphère, et qu'il est réduit en amplitude proportionnellement à $(K\sigma T)^{-\frac{1}{2}}$, où T est la période, K la conductivité intégrée de l'ionosphère, σ la conductivité du sol. Le facteur de réduction peut être inférieur à 1, en sorte que le champ soit renforcé (en fait, pour $T = 10$ sec et pour une résistivité du sol de 1000 ohms-mètres, le rapport des champs magnétiques au-dessus et au-dessous de l'ionosphère passe de 0,3 à 3 lorsque K passe de 10^{13} à 10^{14} u. e. s. Cette dernière valeur paraît forte; l'effet d'écran serait donc peu important). Le modèle est tellement simplifié que *Watanabe* en retient seulement la grande variabilité des résultats pour des variations de la conductivité ionosphérique qui ne sont pas énormes.

Tout ceci n'aide d'ailleurs pas à comprendre la raison pour laquelle les *pc*, si elles sont attribuables à des oscillations de l'exosphère sont renforcées pendant le jour malgré l'accroissement de conductivité de l'ionosphère.

Centre National de la Recherche Scientifique.
Paris.

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Soit *n* l'indice de réfraction et *c* la vitesse de la lumière; posons $n = qc$; si ω est la pulsation, $\frac{1}{q\,\omega}$ a les dimensions d'une longueur. Dans le cas d'une propagation longitudinale les formules ci-dessus donnent aisément:

$$q^2 = \frac{4\,\pi}{\omega}\,(-\,j\,\sigma_1 \pm \sigma_2)$$

le signe + correspondant au rayon extraordinaire et le signe — au rayon ordinaire.

Pour une propagation transverselle on a:

$$q^2 = \frac{4\,\pi}{\omega}\,j\,\sigma_0 \qquad \text{pour le rayon ordinaire}$$

$$q^2 = \frac{4\,\pi}{\omega}\,j\,\sigma_3 \qquad \text{pour le rayon extraordinaire}$$

En propagation longitudinale, ces formules donnent des résultats de même ordre de grandeur que ceux obtenus par Dungey par une autre voie. En propagation longitudinale, les deux propagations correspondent à une polarisation circulaire et l'absorption est beaucoup plus faible pour le rayon extraordinaire. En propagation transversale, les ondes sont polarisées linéairement. L'influence de cette conductibilité est telle que les perturbations ayant une période plus grande que la minute peuvent traverser facilement l'ionosphère. Pour les perturbations de période inférieure à la minute, le rayon extraordinaire en propagation longitudinale étant le moins absorbé peut cependant être transmis sans trop d'amortissement. Il faut remarquer que, du fait de la très grande valeur de l'indice de réfraction, des perturbations ne peuvent être observées au sol que par suite de l'indice de réfraction très élevé de la terre qui provoque une réflexion des ondes. Le champ magnétique observé dépend alors à la fois des propriétés de l'ionosphère et des propriétés du sol.

DEUX HYPOTHESES POUR EXPLIQUER LE CARACTERE UNIVERSEL DES PULSATIONS MAGNETIQUES DITES PT

par G. GRENET

Les trains de pulsations (pt) se retrouvent en des lieux très éloignés avec une étrange ressemblance. En particulier, dans la majorité des cas, elles débutent par un accroissement de la composante horizontale, composante qui est en général prédominante. Cet aspect universel de ces pulsations est difficile à expliquer au moyen des théories habituelles. C'est pourquoi il me semble utile de montrer comment le phénomène classique de l'induction unipolaire permet de rendre compte qualitativement de l'aspect universel des pt.

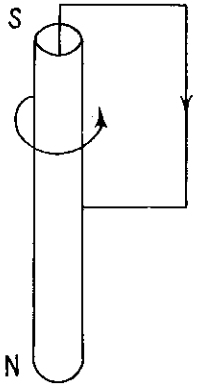

Fig. 1

Rappelons, tout d'abord, qu'un conducteur fixe relié à un aimant tournant, comme il est indiqué dans la fig. 1, est le siège d'un courant électrique qui se reférme dans l'aimant. Ce phénomène classique s'appelle induction unipolaire.

(12) *T. Tamao,* Sc. Rep. Tôhoku Univ., 5th Series, Vol. 9 pp. 1-21, 1957. Cet article est aujourd'hui considéré comme incorrect par son auteur (voir l'article suivant).

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DISCUSSION

Dungey: It is believed that well out in the outer atmosphere the positive ions are predominantly H^+, while in the F-layer they are predominantly O^+. Thus the graph of electron density against height will flatten out rather suddenly at the transition and this has been found by a Russian rocket at about 2.000 Km. The maximum Alfvén velocity occurs above this, because it involves the ion mass density, and so Dessler's graph requires modification. This is important for Prof. Kato's new theory, because the height of reflection is increased by at least a factor of two, and the period of oscillations is increased by a similar factor. It may be that we should think in terms of shock waves as well as free oscillations, but Kato's new theory seems very promising.

Coulomb: I think that in the theories we have to take into account normal modes as well as resonance.

Ferraro: Is there any observed influence of latitude?

Coulomb: If you limited the study to 1.000 or 2.000 Km, there is no influence of latitude.

Kato: For the toroidal propagation in the inner atmosphere there is an influence of latitude.

Selzer: A propos du *canal équatorial de Dessler,* il ne parait pas entraîner obligatoirement, comme l'indiquait Mr Coulomb, que les ondes longues accompagnant par exemple un *ssc* arrivent plus tôt que les autres —et en particulier que le décrochement brusque— en un lieu donné. En effet, s'il est bien exact, comme l'a montré Mr. Coulomb, qu'elles bénéficient, en empruntant les bords du canal, d'une vitesse plus grande que celle des ondes plus courtes cheminant plus près de l'axe, par contre leur trajet géométrique est plus long. C'est en fait la longueur du *chemin optique* qui doit compter. Or, on peut se rendre compte qu'en l'absence de renseignements suffisants sur la loi de variation de la vitesse quand on s'écarte de l'axe, les probabilités pourqu'il en résulte une augmentation ou une diminution de la longueur de ce *chemin optique* sont égales. Ceci résulte de ce qu'il est toujours possible d'imaginer une loi de distribution des vitesses pour laquelle tout le canal fonctionnerait comme un système stigmatique, c'est-à-dire, pour laquelle le trajet axial serait *stationnaire* au sens du principe de Fermat. En imaginant alors des lois de distribution qui s'écarteraient symétriquement dans les deux sens opposés de celle assurant le stigmatisme, on trouverait ainsi pour les trajets s'écartant du trajet axial, soit une diminution, soit une augmentation de la longueur du *chemin optique*. Le deuxième de ces cas ne serait donc pas contraire aux résultats expérimentaux et l'objection que l'on pouvait faire, de ce point de vue, au rôle que pourrait jouer le *canal de Dessler*, ne nous parait pas à retenir.

Grenet: Dans son exposé J. Coulomb fait état des résultats obtenus par Watanabe sur l'influence de l'ionosphère sur la propagation des ondes électromagnétiques à la fréquence des pulsations magnétiques. Mais ces résultats ont été obtenus sans tenir compte de l'épaisseur de l'ionosphère. J'ai montré antérieurement que cette épaisseur était souvent supérieure à celle du skin effect, calculé sans tenir compte du champ magnétique:

$$e = \frac{1}{\sqrt{2 \pi \mu \sigma \omega}}$$

Il est facile de préciser davantage les propriétés de l'ionosphére aux très basses fréquences en tenant compte du champ magnétique terrestre. Si on appelle

σ_0 la conductibilité dans la direction du champ magnétique
σ_1 la conductibilité perpendiculairement au champ magnétique
σ_2 la conductibilité à Hall

$$\sigma_3 = \sigma_1 + \frac{\sigma_2^2}{\sigma_1}$$

En négligeant le courant de déplacement, ce qui est légitime pour ces très basses fréquences, on peut écrire:

$$\mathrm{rot}\, H = 4 \pi i \qquad \mathrm{rot}\, E = - \frac{\partial H}{\partial \sigma}$$

$$I_x = E_x \sigma_0$$

$$I_z = E_z \sigma_1 + E_y \sigma_2$$

$$I_y = E_y \sigma_2 - E_z \sigma_1$$

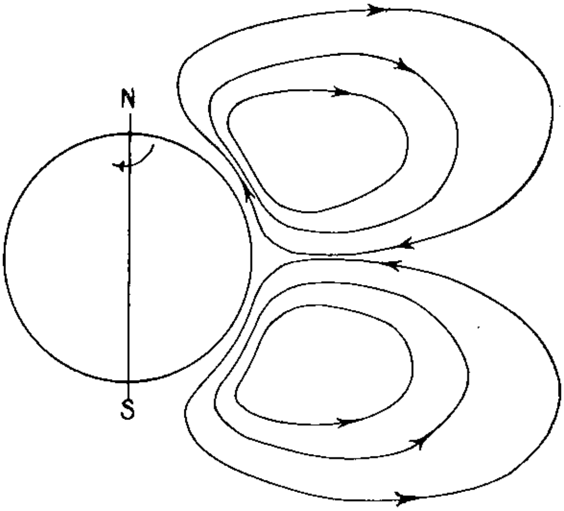

Fig. 2

Dans le cas de la terre, si on suppose un conducteur fixe reliant un pôle à l'Equateur, ce conducteur est le siège d'un courant induit allant du pôle vers l'Equateur et correspondant à une différence de potentiel de 50.000 volts aisément calculable. Admettons que l'ionosphère participe à la rotation de la Terre et qu'à partir d'une distance R du centre de la Terre (Rayon R_0), l'exosphère ne participe pas à cette rotation. L'ensemble Terre-ionosphère doit être assimilé à l'aimant tournant et l'exosphère au conducteur fixe de l'expérience classique.

Bien entendu, il faut admettre une variation continue de la vitesse de rotation et peut-être un certain entraînement de l'exosphère. Mais ceci ne change rien qualitativement au phénomène d'induction unipolaire. Les courants produits vont avoir tendance à circuler suivant les lignes de force du champ magnétique terrestre, ce qui doit donner lieu, en première approximation, à des courants circulant dans les plans méridiens suivant le schéma de la fig. 2. Ces courants sont limités par un volume toroïdal et ne produisent à l'exterieur aucun champ magnétique. Mais les courants se referment par l'ionosphère où le champ magnétique terrestre produit un effet Hall. De ce fait, il faut ajouter aux courants méridiens des courants qui suivent des parallèles et produisent dans les deux hémisphères une augmentation de la composante horizontale du champ magnétique terrestre.

Une augmentation de l'ionisation de l'exosphère en produisant une augmentation du courant de Hall, amènerait une augmentation de l'amplitude de la composante horizontale sur tout le globe. D'autre part, ces courants étant dus à une même cause, cela permet d'expliquer l'étrange similitude constatée dans les *pt* en des régions du globe très éloignées les unes des autres.

Bien entendu, il serait désirable de mieux connaître les propriétés de l'exosphère, afin de pouvoir évaluer quantitativement l'importance de ces courants qui pourraient concourir au ralentissement de la vitesse de rotation de la Terre.

* * *

La seconde hypothèse est la suivante: Considérons qu'à 200 Km par exemple on puisse considérer que l'ionosphère est une couche sphérique infiniment conductrice ayant une épaisseur plus grande que la hauteur d'échelle. La masse de cette couche est de l'ordre de grandeur de la masse totale de l'atmosphère au dessus de sa surface inférieure. Supposons que cette couche sphérique ait un rayon variable avec une pulsation ω. L'énergie du champ magnétique $\iiint \frac{\beta \varkappa}{8 \pi} dv$ tant entre l'ionosphère et la terre qu'au dessus de l'ionosphère va varier avec la pulsation ω. A chaque altitude il y aura résonance pour une pulsation donnée fonction de l'altitude. A la période de résonance il suffit naturellement d'une énergie très faible pour provoquer des oscillations. En choisissant convenablement la hauteur on trouve aisément comme périodes de résonance celles observées pour les pulsations.

Il faut remarquer que les hypothèses exposées par d'autres auteurs expliquent mal le caractère universel des pulsations. Mais par contre je reconnais bien volontiers que les hypothèses que je présente, si elles sont compatibles avec le caractère universel des pulsations, sont peu satisfaisantes pour expliquer que leur amplitude à un instant donné soit très différente suivant le lieu d'observation.

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SOME LAWS IN THE BEHAVIOUR OF THE VERTICAL COMPONENT OF THE SHORT-PERIOD OSCILLATIONS OF THE GEOMAGNETIC FIELD WITH A STEADY REGIME (PC) ACCORDING TO THE IGY DATA

by O. V. Bolshakova, K. Yu. Zybin
and N. F. Maltseva

(*Abstract*)

The present work is based on the data obtained by the geophysical stations of the Institute of the Physics of the Earth (USSR Academy of Sciences), built and put into operation at the beginning of the IGY, viz. Lovozero (67° 58' N, 35° 05' E), Borok (58° 02' N, 38° 58' E) and Petropavlovsk-on-Kamchatka (53° 06' N, 158° 38' E). As initial data taken are 24-hour photographic records of the fluxmetric induction installations recording the *Z*-component of the geomagnetic field's short-period oscillations with the time scale speed of 90 mm per hour. The period of observations which were processed embraces the first half of the IGY, including the epochs of the autumn equinox and of the winter solstice (August 1957-January 1958).

The behaviour of oscillations with periods from 10 sec. to 4 min. has been studied, the oscillations being divided into groups of: 10, 20, 30, 40, 50, 60, 70, 80, 90 sec. and 2, 3, 4 min. The tables compiled for each group of oscillations comprised: *a*) the time of occurrence of oscillations, *b*) hours with oscillations present, *c*) amplitudes of oscillations of a corresponding group.

The oscillations included in the table passed a kind of steady regime, i. e. at the periods from 10 to 50 sec. correspond to the Pc type (according to the classification given by the IAGA Committee N. 10), and at the periods from 1 to 4 min. were typical of the field of short-period oscillations for no less than 2 successive hours.

The type of steadiness of oscillations is noted to be different for different stations. Thus at Lovozero it is characterized by frequent changes of regimes and by the occurrence of stable long-period oscillations; at Borok—by the occurrence of relatively stable oscillations with periods from 60 to 90 sec; at Petropavlovsk—by a large duration of the stable regimes.

The pictures of the frequency spectra of the fields of the short-period oscillations within the range of periods from 10 to 90 sec. have been obtained for the three stations both for each month of observations and, on the average, for half a year.

It is established that the appearance of short-period oscillations of different periods is not equally probable even from the mean monthly data. The most typical oscillations prevalent over others by the number of hours present on the records are those with the periods 20-30 and 60 sec. The oscillations with the period 50 sec for all the stations prove to be the least typical. The oscillations with the period of 40 sec can be treated as the intermediate.

The frequency spectra of the stations Lovozero and Petropavlovsk (mean half-year data) almost completely correspond to each other while at Borok the oscillations of each period are only half as frequent and the second maximum, which at other stations occurs for oscillations with period 60 sec, is not clearly expressed.

The season variation of the number of cases with oscillations having periods 20 and 30 sec is, in general, similar at all the three stations, whereas that of the oscillations with periods from 60 to 90 sec is different for all the three stations, being especially distinct at Borok.

The daily variations of the number of cases of the occurrence of oscillations are different for different periods: the daily variation amplitude changes, the time of extrema shifts and their number varies with period. Though the data of only three stations cannot easily lead to confident conclusions concerning the local time of the occurrence of phenomena over the world, one can, nevertheless, note that oscillations with periods 20-30 sec are excited at all the three stations by local time while those with period 40 sec at the middle-latitude stations—by world time. The occurrence of oscillations with periods 60-90 sec at the middle-latitude stations is controlled by local time. In Lovozero, the oscillations have reverse daily variations by local time in comparison to Borok and Petropavlovsk. The occurrence of oscillations with the period of 50 sec at all the stations is equally probable around the clock.

The daily variation of the mean maximum amplitude of oscillations is equal for oscillations of all periods. The extrema of the daily variations are observed at the same time. The daily variation amplitudes of oscillations with different periods are different but even for oscillations with the period 50 sec the presence of the daily variation of the mean maximum amplitude is not doubtful. The daily variations of the mean maximum amplitude for all periods of oscillations at the middle-latitude stations coincide in local time, the maximum amplitude falling on 11 hours local time. The maximum of the amplitudes at Lovozero is shifted to earlier hours in comparison to Borok and Petropavlovsk.

The excitation of oscillations whith different periods is assumed to be related to different physical processes which is reflected in the difference between the times of the extrema of the daily variations of the number of cases of occurrence as well as in the fact that some oscillations are controlled by world time and others by local time.

On the other hand the daily variation of the mean maximum amplitude in local time permits us to think that the change of the amplitude of the short-period oscillations is connected with the solar wave radiation.

It is pointed out that the group of oscillations with periods 60-90 sec at Borok behaves as oscillations marked by the index Pc. The conclusion was drawn from the daily variation of the number of occurrence cases, from the unusual (for oscillations of these periods) steadiness of the regime; from the distinct manifestation of pulsating regimes (beating oscillations); and from a relatively distinct dependence of the number of occurrence cases on the season.

In view of the fact that at stations with different co-ordinates the amplitudes of the geomagnetic field's oscillations differs very much, «activity Pc», was introduced to reveal the general laws. The measure of Pc activity is chosen on similar lines to the international geomagnetic characteristics of activity: grades 0, 1 and 2 estimated the amplitude of oscillations with periods from 10 to 50 sec for each hour. The amplitude ranges for each grade were chosen experimentally for each period respectively. Each hour of 24 was estimated by a certain grade corresponding to the maximum amplitude of that group of oscillations which yielded the maximum grade.

The Pc activity has a daily variation whith distinct extrema at all the tree stations, Pc maximum falling on noon hours irrespectively on the longitude of the station. The time of the Pc activity maximum shifts with latitude: at Lovozero the maximum arrives at 08 hours, at Borok—at 10 and at Petropavlovsk—at 14 hours local time.

There is a clear lowering of the level and an earlier arrival of extrema of Pc activity during winter solstice as compared to autumn equinox.

It was found that the same estimates of the amplitude activity for the oscillations with periods over 1 minute were not expedient owing to some technological peculiarities of the recorders.

The Pc activity and the «disturbances» of the regime are being compared. Disturbances are meant both as a group of oscillations with a higher amplitude on a steady background and a period equal to that of the background (PcA type) and as a group of oscillations with a higher amplitude and a period different from that of the background of oscillations. In the first case, a rise of the activity of oscillations of a steady regime takes place, in the second—oscillations with a new period are superimposed on a steady regime.

The disturbances are observed to have a regular daily variation with several maxima. It can be stated that all the three stations have a general maximum falling on 21-22 hours world time, the maximum being especially well expressed at Lovozero. Apart from this maximum, another one is outlined at Borok and Petropavlovsk, at noon hours local time.

The maximum of Pc activity coincides with the maximum of the number of cases of occurrence of disturbances with periods from 10 to 50 sec for the stations Borok and Petropavlovsk. At Lovozero this coincidence is broken because of the presence of a special group of disturbances with periods less than 1 minute and occurring at night hours. Such disturbances accompany aurorae and are typical only of high-latitude stations.

In conclusion the acknowledgement is expressed of the contributions made by Dr. G. N. Petrova, head of the work, and workers having participated in the observations and processing of the data.

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SOME OBSERVATIONAL RESULTS OF THE VARIATION OF THE HORIZONTAL COMPONENT VECTOR OF THE GEOMAGNETIC FIELD

by A. G. KALASHNIKOV and K. YU. ZYBIN

(*Abstract*)

Some regularities of horizontal component vector of variation of geomagnetic field.

The full vector of the geomagnetic field's short-period oscillations is observed at the geophysical station Borok of the Institute of the Physics of the Earth (Academy of Sciences of the USSR) (58° 02' N, 38° 58' E) by means of an installation which synchronously records the variations of components H_x, H_y and Z of the geomagnetic field. Z is a component recorded by means of a horizontal ring loop buried in ground. Components H_x and H_y are recorded by means of vertical loops placed on the walls of a magnetic pavilion in mutually perpendicular planes. The fluxmeters linked with the loops record components Z, H_x and H_y with scale value $1{,}4.10^{-2}$, 0,53 and 0,502 γ/mm respectively. The recording of the variations of the three components is run on a tape 200 mm wide with the speed 90 mm/per hour. Owing to the complex picture of the behaviour of the variation vector in space, the behaviour of the variation vector of only the horizontal component of the geomagnetic field will be considered (further referred to as «the vector»). To construct diagrams of the behaviour of the variation vector, the amplitudes of H_x and H_y records were computed from an arbitrary zero line at the same moments of time. The diagrams showed the relative positions of the vector end point at a given moment of time which were determined by the vector sum of the component amplitudes.

1. In all cases, the vector end point moves along a more or less complex, largely ellipsoidal, sometimes almost circular and seldom sways along one direction. In the greater part of cases the curve has a stretched form with a distinct direction of the large axis. In 346 cases the large axis is directed from the northwest to the southeast,

in 35 — northsouthwards, in 8 — westwards and only in 42 cases from 456 the curve is isometric.

The number of cases of the appearance of this or that azimuth (the data are in magnetic co-ordinates) of the large axis is different. The azimuth has a distinctly prevalent direction. The mean value of the western azimuth is equal to 38° 3. The eastern azimuth is encountered only in 8 per cent of the cases and seems to be casual (fig. 1). The number of cases of the appearance of the western azimuth has a daily variation, its maximum falling on noon world time (fig. 2-a).

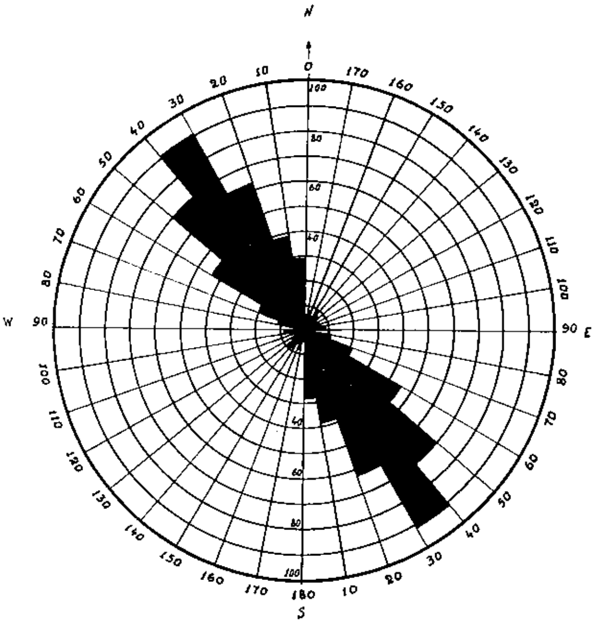

Fig. 1. — The distribution of the azimuths of large axes of figures circumscribed by the end of the variation vector.

The appearance of figures of an isometrical form as well as of those directed northsouthwards and westeastwards is the most frequent in the morning (04 hours) and in the evening (20-21 hours). The maxima of such a diagram are located symmetrically of the daytime maximum of the daily variation of the number of cases when the western azimuth is present (fig. 2-b).

Mean hourly values of the western azimuths of the large axis have a distinct daily variation. At 04-05 hours the azimuth reaches its maximum values, at 15-16 hours — the minimum changing from 59° 3' to 23° 3' (fig. 2-c). The daily variation of the azimuth of the prevalent direction of the variation vector of the geomagnetic field's horizontal component well coincides with that of the azimuth of the prevalent direction of the earth-current vector variation computed by O. M. Barsukov by quite a peculiar method (fig. 2-d). The variation vector of the geomagnetic field's horizontal component is directed perpendicularly to the earth-current variation vector during 24 hours despite the clearly expressed daily variation of the prevalent direction of both vectors.

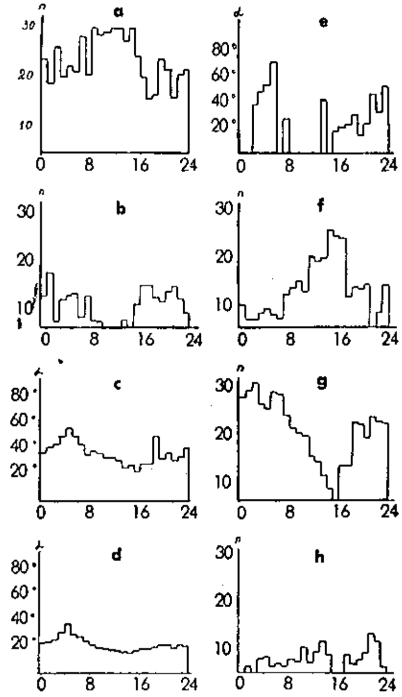

Fig. 2

a) The daily variation of the number of cases with the appearance of the western azimuth.
b) The daily variation of the number of cases of figures with isometrical forms.
c) The daily variation of mean hourly values of the prevalent azimuth (the azimuth is computed from the magnetic meridian).
d) The daily variation of the mean hourly values of the prevalent azimuth of the earth-current variation vector according to data obtained by O. M. Barsukov (the azimuth is computed from the geographical parallel).
e) The daily variation of the mean hourly values of the eastern azimuth.
f) The daily variation of the number of cases when the vector rotates clockwise.
g) The daily variation of the number of cases when the vector rotates counter-clockwise.
h) The daily variation of the number of cases when the vector moves without rotation.

Mean hourly values of the eastern azimuths of the major axis display no daily variation which is another proof of a casual character of the eastern azimuth for the behaviour of the vector at Borok (fig. 2-e).

2. The prevalent direction of the vector rotation runs counter clockwise. In 258 cases from 456 the vector rotates counter clockwise, in 146 cases — clockwise and only in 52 cases it sways along one direction with alternating and complex deviations which cannot be regarded as rotative.

The clockwise rotation of the vector is, chiefly, observed at afternoon hours with maximum number of occurrence cases at 14-15 hours (fig. 2-f).

The vector rotation counter clockwise is most frequent at morning hours with maximum number of occurrence cases at 04 hours (fig. 2-g). The vector motions without rotation happen seldom and their distribution within 24 hours is casual (fig. 2-h).

3. In view of the fact that the variation vector periodically changes its direction while rotating, the directions of vectors of the Earth's magnetic and electric fields in respect to each other should be checked up at each given moment of time. The form of the curve circumscribed by the end of the earth-current variation vector is analogous to that circumscribed by the variation vector end of the geomagnetic field's horizontal component within the accuracy of error for observations and graphical schemes. The direction of the vector rotation coincides for each given case.

The directions of changes in the Earth's magnetic and electric vectors are almost perpendicular for each interval of time. On the whole, one vector diagram is turned in respect to another by 90° and the directions of large axes of figures formed by the ends of the variation vectors of the Earth's electric and magnetic fields form, on the average, a direct angle. The perpendicularity is retained approximately for any period of times as well as for any oscillations in the Earth's electromagnetic field at Borok. Potential deviations from the perpendicularity can come as the result of the effect exerted by horizontal anisotropy of the station underlying rocks.

The coefficient of the analogy between the vector diagrams or the ratio of the amplitudes of variations of the Earth's electric and magnetic fields do not remain constant. An attempt is made to establish the dependence of the ratio of the oscillation amplitudes in the Earth's magnetic and electric fields on the period of oscillations. The ratio of amplitudes E/H was considered for oscillations simultaneously appearing both on the earth-current records and on those of the magnetic field. The magnetic field's variations were measured in gammas, those of earth currents—in millivolts per kilometre.

The ratio of the amplitudes E/H sharply decreases within the range of periods from 10 to 40 sec from 0,7 to 0,4 and then remains nearly constant slightly decreasing within the range of periods from 50 sec to 2 min.

4. The chosen characteristics for the behaviour of the variation vector of the Earth's magnetic and electric fields (the form of the curve circumscribed by the variation vector end, azimuth of the curve large axis and the rotation direction of the variation vector) sufficiently fully characterize the vector behaviour in time and space. The ratios of the directions and amplitudes of the Earth's magnetic and electric fields are closely connected.

The cause of the occurrence of the above oscillations can lie in the electrical vortices developing in vertical planes at an altitude of 100 km and above. The vortices form the magnetic field's force lines almost parallel to the Earth's surface and displaying considerable values of the horizontal components as against the vertical one. The direction of the rotation of vortices and projection of their axis on to the Earth's surface change with the time of the day. Amplitude and phase relations between the variation vectors of the Earth's electric and magnetic fields are determined by geological peculiarities of the region of the station.

VARIATIONS OF THE SMALL-PERIOD REGIONAL ELECTROMAGNETIC FIELD[1]

by A. G. KALASHNIKOV and E. N. MOKHOVA

(*Abstract*)

To study the electromagnetic field's oscillations, simultaneously occurring over a vast territory, the results of the registration of the magnetic field's vertical component H_z obtained on fluxmetric installations and of the earth-current field's horizontal components E_x and E_y recorded at the stations Borok (B), Lovozero (L), Petropavlovsk-on-Kamchatka (P) and Dusheti (D) have been used. As to the long-period oscillations the data of the American Stations have been utilized.

The oscillations in the form of impulses trains and microbays were distinguished on magnetograms ant tellurograms by their similar form and simultaneity of occurrence.

Determinations were made of: the period, amplitude, the time of the occurrence of oscillations on the records of H_z, E_x and E_y, of the ratio $\frac{H_z}{E}$ for each station, the ratio of the amplitudes for different stations. It was established that:

$$H_{ZB} < H_{ZD} < H_{ZP} < H_{ZL};\ E_B < E_P < E_L;$$

$$\left(\frac{H_z}{E}\right)_B < \left(\frac{H_Z}{E}\right)_{L,\,P};$$

$$\text{where } E = \sqrt{E_x^2 + E_y^2}$$

The latitudinal dependence cannot account for the obtained distribution of the amplitudes. The ratio of the amplitudes is supposed to depend on geological conditions in the vicinity of the stations, on the presence of stable heterogeneities in the ionosphere and upper atmosphere, on shore electric currents at sea. There are some assumptions on the probable mechanism of occurrence of simultaneous oscillations in the Earth's electromagnetic field.

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(1) Published in IZV. Ac. Sci. USSR (Gecphys. ser.). N.° 1, 1960.

H_{ZB}, Vertical component of the magnetic field in Borok,
($\varphi = 58^\circ 02'$ N, $\lambda = 38^\circ 58'$ E)

H_{ZD}, Vertical component of the magnetic field in Dusheti.
($\varphi = 41^\circ 43'$ N, $\lambda = 44^\circ 49'$ E)

H_{ZP}, Vertical component of the magnetic field in Petropavlovsk,
($\varphi = 52^\circ 59'$ N, $\lambda = 158^\circ 39'$ E)

H_{ZL}, Vertical component of the magnetic field in Petropavlosk and Lovozero consequently.

E_B. E_P E_L — the gradient of the electric field (Earth currents) at the stations Borok, Petropavlovsk and Lovozero.

SHORT-PERIOD OSCILLATIONS OF THE GEOMAGNETIC FIELD

by V. I. AFANASIEVA

(Abstract)

Before the beginning of the IGY, taking into account the next application of IGY materials we made some investigations of short-period oscillations of the geomagnetic field. We used magnetograms, on which one hour corresponded to 20 mm and 1-4 gammas corresponded to one millimetre of ordinate and also normal tellurograms. Table I enumerates the data used.

TABLE I

Abbreviated	Observatory	Geomagnetic		Years	Material
		Lat.	Long.		
Lov	Lovozero	63.1	126.1	1953	tellurograms
Lo	Lovo	58.1	105.8	1957	magnetograms
Ln	Leningrad	56.0	117.0	1938	»
Sr	Srednikan	53.2	210.5	1938	»
				1954	»
Ka	Kazan	49.3	130.4	1954	»
Sha	Shatsk	48.7	123.7	1954	tellurograms
Sv	Sverdlovsk	48.5	140.7	1954	magnetograms
Nz	Niznedevitsk	46.9	119.6	1938	»
Od	Odessa	43.8	110.9	1952	»
Vl	Vladivostok	32.9	198.0	1938	»
Tsh	Tashkent	32.4	143.8	1954	»

The magnetograms of four observatories: Leningrad, Niznedevitsk, Srednikan, Vladivostok were the sources. These observatories are sufficiently apart in pairs from one another in longitude and have different latitudes. All the rest relate to oscillations with the periods from 30 to 240 seconds and with amplitudes not less than 1 gamma. We distinguish oscillations lasting longer than an hour (Pc) and shor-

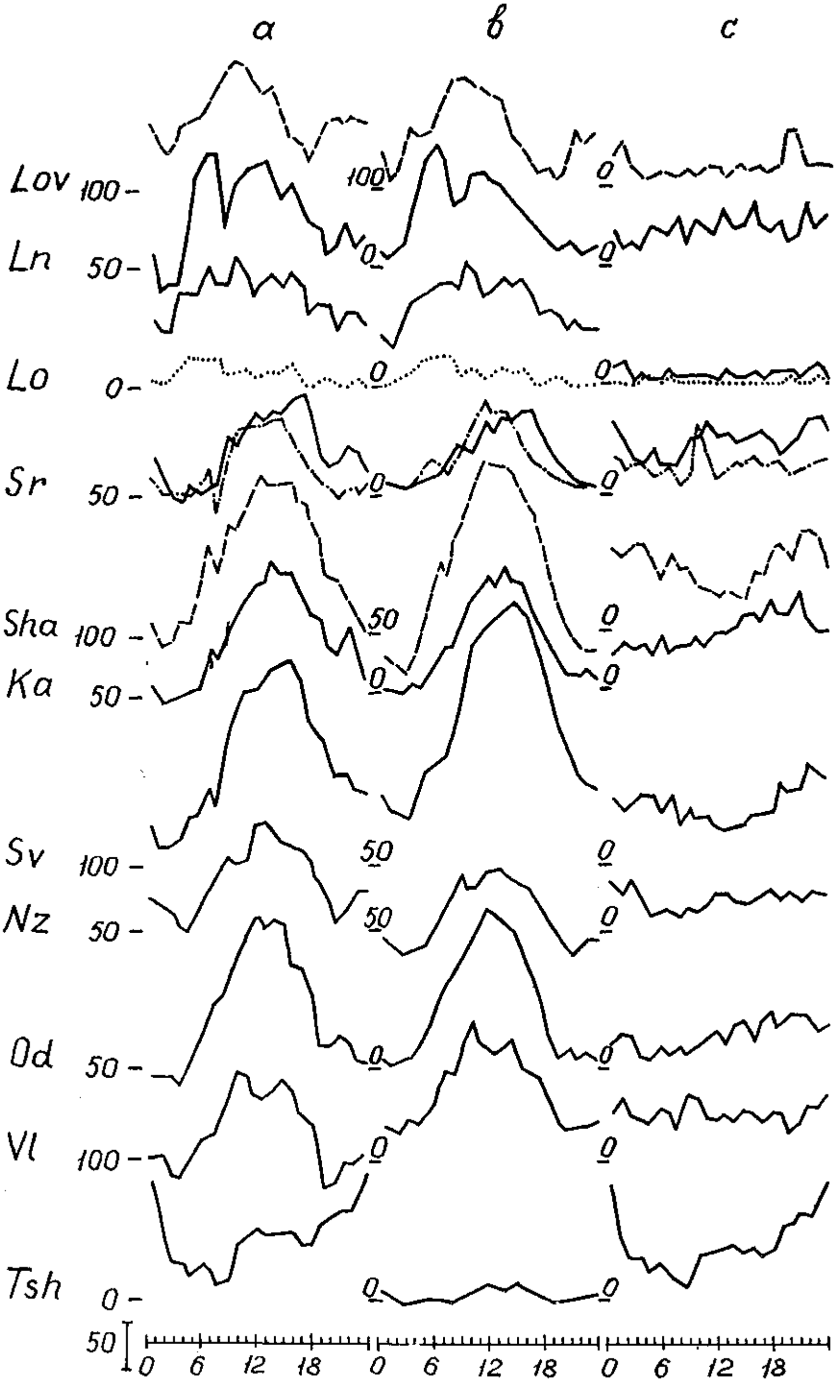

Fig. 1. — Daily distribution of pulsations of different time-duration. a) P = Pc + Pt, b) Pc, c) Pt. The figures near the lines mark the number of cases; beyond this number distribution of P is expressed by a curve, which is typical for P-distribution during the day (see marks at the Table I).

ter than an hour (Pt). All the data used cover about 180 000 hours at different observatories.

Daily distribution of Pc - S (Pc). S (Pc) is controlled by local time. In the middle latitudes the maximum appears at 11ʰ-14ʰ (fig. 1). For more northern (by geomagnetic latitudes) observatories there is a second maximum at 5ʰ - 7ʰ. The form of S (Pc) does not depend on seasons.

At night, Pc as a rule, are absent. In winter an interval without Pc is longer than in summer, but it is not in proportion with latitude (fig. 1). As a rule, the form of S (Pc) does not depend on degree of magnetic activity; with the increase of activity maximum S (Pc) displaces from afternoon towards earlier hours (before noon) (fig. 2).

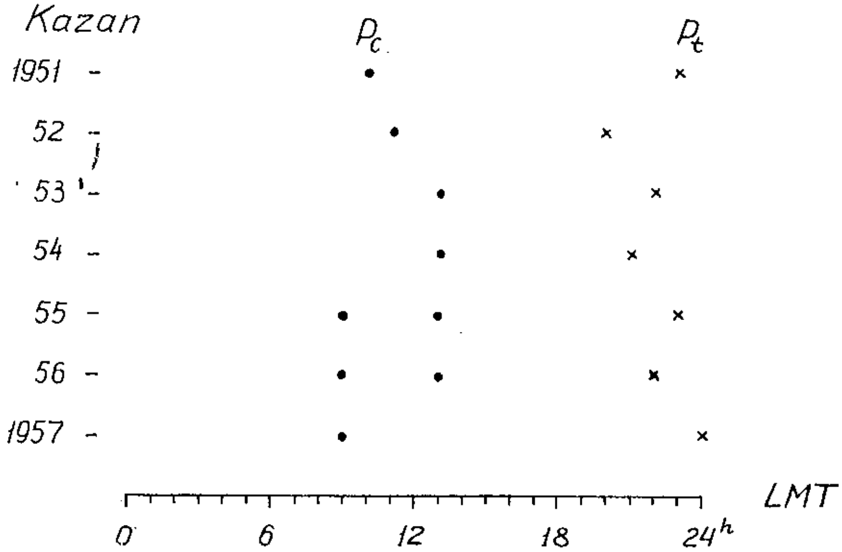

Fig. 2. — Kazan. Displacement of Pc and Pt maximums during the day depending on solar activity.

Daily distribution of Pt - S (Pt). 1) The maximum of S (Pt) takes place at middle latitudes at 20ʰ - 24ʰ of local time. For more northern (by geomagnetic latitudes) observatories there is no distinct maximum. S (Pt) does not depend on seasons either on the level of magnetic activity. The number of the hours of maximum of Pt increases towards the south. The number of Pt is greater in winter than in summer. With growth of activity during a cycle, the maximum S (Pt) displaces from 20ʰ to midnight (fig. 2).

Comparison of S (Pc) with S (Pt). At a given hour Pc occurs for almost 80-90 % of all the days, Pt occurs only for about 30 %.

Dependence of Pc on seasons. There is no distinct similarity between distribution of Pc and magnetic activity.

Very continuous Pc. Out of the class of Pc there are Pc with duration 5^h - 20^h running. At night-hours their amplitudes decrease. The most of the Pc were observed in the year of decreasing activity during the cycle (1952).

Comparison with ionospheric data. The correlation between S (Pc) and daily variation f_0 F2 - S (f_0 F2) was studied. The correlation coefficient for Sverdlovsk was found to be 0,74-0,97. The similarity of the form S (Pc) of Leningrad with S (f_0 F2) of Tiksy was found, and such similarity of S (Pc) with S (f_0 F2) was absent in Leningrad.

The Earth currents data. Daily distribution of pulsations (P) in Earth currents S (Pc) in Shatzk is similar to S (Pc) at observatories of middle latitude. S($P_{e.c.}$) at Lovozero for Earth currents has only the morning maximum. Hence, the noon maximum for Pc towards the north from Leningrad becomes less than the morning one.

Leningrad and Srednikan. The morning maximum S (Pc) at Leningrad corresponds by the time of occurence, to that of Pt in Srednikan. Hence, with the growth of geomagnetic latitude the stability of oscillations is increased.

The interpretation of results. Undoubtedly, short-period oscillations are a manifestation of electromagnetic oscillations of the external atmosphere of the Earth. It is evident that there are some regions where ionization is great enough to produce P on the Earth's surface. There are at least three such regions. One of them is located on the sunlit part of the Earth above low latitudes. It is the course of noon-maximum. The second region above high latitudes in the morning. The third is located above subarctical latitudes at night. Ionization of the first region is of wave origin, ionization of the other two is of corpuscular origin. The first exists constantly, while the other two only at the periods of influence of corpuscular streams on the Earth.

If the stream embraces the Earth, it gives rise to Pt. If the Earth crosses the remainders of former streams within interplanetary space, it gives rise to Pc. Using Kato's and Akasofu's formulas, the author comes to the conclusion (1), that in order to explain Pc with an amplitude of 5 γ one should admit that in interplanetary space matter keeps the rate, relative to the Earth, of the order of 300 km per sec. So Pc is due to the influence of «slow» streams or clouds on sunlit regions of higher ionization, and Pt due to the influence of more energetic corpuscular streams on two high latitudinal regions of ionization, caused by the same streams and swung by them.

Above Leningrad in the ionosphere part is screened so much that S (Pc) of Leningrad is identical with S (f_0 F2) of Tisky, where there is not such a strong screen of Pc.

As in general statistics contribute mainly Pc, but not Pt, and Pc arise from matter almost constantly existing near the Earth surface, it becomes clear that S (Pc) does not depend on magnetic activity (this fact was mentioned above). If one believes that P is created by two streams, one which meets the Earth exactly and another which is «passing by» near the Earth surface, then from Kato's and Akasofu's theory one may assume that as the author showed, P with the periods 1 min. to 2 min. will be prevailing in number. In reality out of 241 cases with periods from 30 sec. to 240 sec. only 11 cases had shorter periods than 1 min. and in 47 cases longer than 2 min.

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ON THE PROBLEM OF THE DIURNAL DISTRIBUTION OF IRREGULAR MAGNETIC DISTURBANCES IN HIGH LATITUDES

by A. P. NIKOLSKY

(*Abstract*)

It is characteristic of recent years that a great number of scientists-geophysicists who study phenomena caused by corpuscular impinging on the upper atmosphere, try to explain the observed facts in terms of Störmer's theory. In particular, Kato and Watanabe (1) apply to this theory when studying short period geomagnetic disturbances.

Kato and Watanabe mention one of the consequences of Störmer's theory, that four zones A, B, C, D, on the Earth's surface should exist where greater activity of the phenomena, caused by corpuscular impinging should be observed.

The authors show that two types of geomagnetic short period pulsations seem to be excited by solar corpuscles. These particles impinge on the B and C Störmer's regions at 20-21^h and 08-09^h local time, respectively. We have studied the problem: what define the moment of appearance of irregular magnetic disturbances (active period). Since some regularities of short period pulsations of geomagnetic field, as shown by Kato and Watanabe, may be understood from Störmer's theory, we believe that the results obtained may be of interest for geophysicists dealing with the problem of short period geomagnetic pulsations.

If we consider the curve of the diurnal distribution of magnetic activity (according to the hourly characteristics) separately for the days of severe storms and for other days, well pronounced displacements are obvious for morning maximum to later hours and night maximum to earlier hours on the days with severe storms (Fig. 1).

Assuming that average speed increases in the solar corpuscular streams, responsible for severe storms in comparison with streams which cause weak storms, it was natural to suggest that this reason may be connected with the time displacements of the activity maxima.

Our recent studies (2, 3, 4, 5) based on data obtained from a greater number of stations enabled us to make some new conclusions on the nature of magnetic disturbances in high latitudes.

It is shown that the isochrons of morning maximum of magnetic disturbances have the form of spirals coming out of the pole of uniform magnetization and unrolling clockwise.

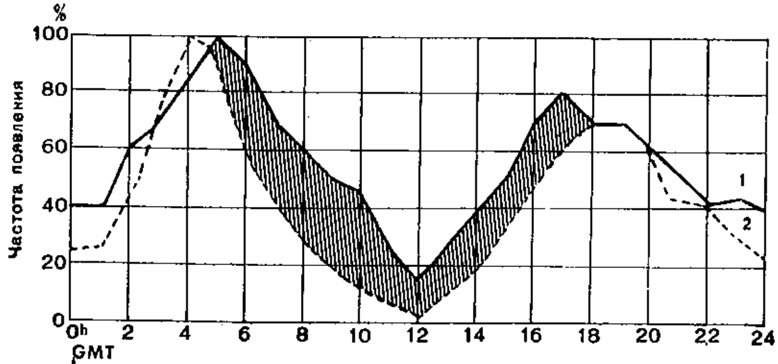

Fig. 1. — Distribution of magnetic activity indices > 10 during 24 hours in Tikhaya Bay: 1 - on the days with severe storms. 2 - on other days.

As a consequence from Störmer's theory (6) we may assume that on the precipitation spiral there are regions, where proton trajectories concentrate.

These regions are centering on 15. 20. 02. 08 h local geomagnetic time; we called these regions: A, B, C, D respectively. From the direct observations of the morning maximum of magnetic disturbances we had the possibility to draw spirals in the longitudinal direction on the limited extent having the order of 180°. As a result of Störmer's theory we may assume that for existing conditions on the Earth the actual precipitation spiral of protons in the Arctic covers all the 360° that is 24 hours.

We may assume that the night maximum of magnetic disturbances will represent the total effect of Störmer's B and C zones falling on 20 and 02 h respectively. If it is so it means that both morning and night magnetic disturbances are due to protons impinging on the upper atmosphere.

From Störmer's theory follows that angular distance of spiral from the pole depends on the velocity of the corpuscles, in particular.

On an average, as the velocity of protons in the stream increases, the whole spiral will descend to the south-east-south. It means that 6h-7h (UT) spiral passes through Tikhaya Bay. Under average conditions this spiral passes further north-west of Tikhaya Bay and 4th spiral typical of average conditions will pass Tikhaya Bay.

Is it possible to explain shifting of night maximum to the earlier hours on the days with severe storms considering that night maximum is due to protons and lies on the precipitation spiral of protons. It may be shown that such shifting is due to changing of the value of γ (integration constant in the solving of Störmer's equation), to the larger negative value till $\gamma = -1$, these variations of γ are themselves the consequence of velocity increasing (fig. 2), (7, 8).

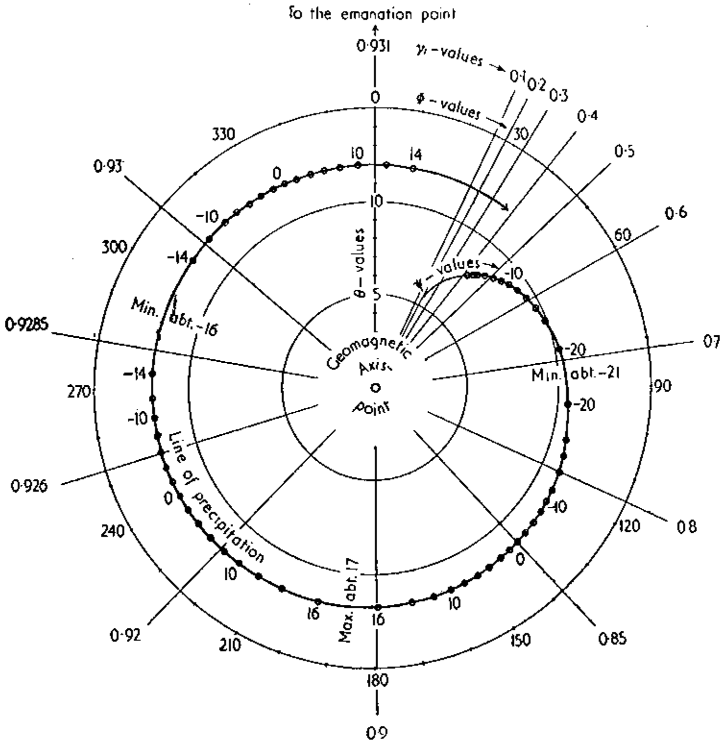

Fig. 2. — Line of precipitation of positive corpuscles in the Arctic (according to Störmer).

Thus, variation of proton velocity in the stream approaching the Earth will influence the moment of their impinging on the Earth's atmosphere in two ways. First, the spiral of proton precipitation deviates to the southeast with the increase of proton velocity in the stream which result in the shifting of the morning maximum to later hours.

Secondly, with the increasing of the negative value of γ the increase of the protons velocity will result in proton deviation to the west, that is in the earlier appearance of magnetic disturbances.

Theoretically, both of the effects of the proton velocity variation will appear simultaneously, which of them will be larger depends on the position of the station.

Numerous observations on the aurorae show that the southern limit of the magnetic storms ascends further to the south and the time of their appearance shifts to earlier hours on the days of severe magnetic storms and strong aurorae. These facts may be explained in the same way as in the case with diurnal variation of magnetic activity.

Thus, it may be considered that both morning and night disturbances in high latitudes seem to be the result of proton impinging.

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RAPID ELECTRIC AND MAGNETIC VARIATIONS OF THE EARTH AND THEIR LAWS AS OBSERVED IN ASHKHABAD

by V. G. DUBROVSKY

(*Abstract*)

The present paper gives the results of studying some laws in the occurrence of rapid electric and magnetic variations of the Earth as observed in Ashkhabad during the International Geophysical Year.

The records of earth currents for the period from January 1956 to December 1958 and magnetograms from April to December 1958 obtained by the geophysical station «Ashkhabad» of the Institute of Physics and Geophysics, Academy of Sciences of Turkmenian SSR, located 21 km to the west of Ashkhabad were here used as primary data.

The geographical and geomagnetic coordinates are:

$\varphi = 37^\circ\, 57'$; $\lambda = 58^\circ\, 06'\, 30''$; $\Phi = 30^\circ\, 20'\, 23''$; $\Lambda = 133^\circ\, 04'\, 20''$ (1)

The earth-current installation has two receiving pairs of electrodes with base lengths of 0,37 km each oriented in the geographical directions N-S and E-W and linked with the recording equipment by underground lines. The records are made at a speed of 90 mm/hr and 30 mm/min.

The recording of geomagnetic variations is carried out at a speed of 90 mm/hr by an improved magnetograph with a high-speed recorder.

The classification of short-period oscillations adopted by the Committee N.10 of IAGA has been assumed as a basis of methods for processing observation data.

The processing involved investigation of daily laws and season variations if data available proved to be sufficient; distribution in periods, presence of accompanying phenomena, relation to other geophysical phenomena, for instance to the geomagnetic activity and phenomena in the ionosphere. Owing to the lack of data from other stations, the whole of the data processing was perfomed in world time.

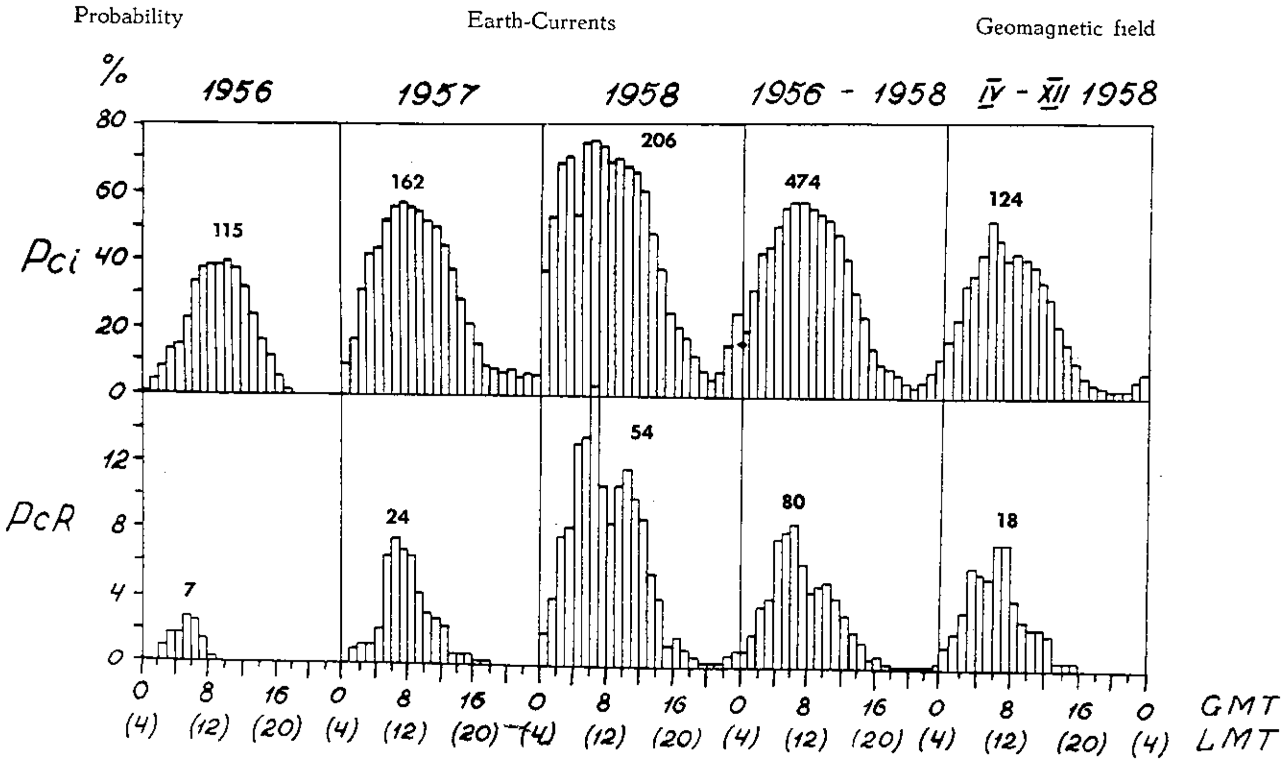
Probability
Earth-Currents
Geomagnetic field
%
1956
1957
1958
1956 - 1958
IV - XII 1958
80
60
40
20
0
Pci
115
162
206
474
124
12
8
4
0
PcR
7
24
54
80
18
0
8
16
GMT
(4)
(12)
(20)
LMT

Fig. 1

1. *Short-Period Oscillations of Earth Currents and of the Geomagnetic Field of the type Pc, PcR and Pt.*

The daily distribution of the probability of occurrence of short-period oscillations of the earth currents and the geomagnetic field of the type of Pc and PcR is shown in fig. 1. As the graphs show, the laws of daily variations plotted separately for 1956, 1957 and 1958 are similar.

The increase of maximum values of occurrence of earth-current short-period oscillations between 1956 and 1958 seems to be explained by a rise of solar activity in these years. The daily distribution of Pc oscillations is characterized by the greatest probability of occurrence at noon hours, the maximum (55 per cent) at local midday (8 hours GMT) and minimum (4 %) at midnight (20 hours GMT).

The daily variation of PcR (oscillations of a regular form) has the same form with a slight probability of occurrence (8.5 per cent) during the maximum. The daily distribution of the same types of the geomagnetic field's oscillations is quite identical to the daily variation of the Earth's current oscillations.

The consideration of the dependence of the occurrence probability of short-period oscillations of the earth currents on the season evidences that, first, the qualitative character of Pc and PcR daily variations does not change with the season; second, the maximum value of the occurrence of these pulsations is the greatest in summer time and the least—in winter.

To determine the probable dependence of the frequency of continuous oscillations Pc and PcR on the level of activity of the geomagnetic field we have considered the daily distribution of their occurrence for two levels of geomagnetic activity, viz, for quiet magnetic days (the characteristics of days is 0.0 under a five-grade scale) and for magnetic disturbed days (the characteristics of the days is: 1.0, 1.5 and 2.0). The data show that the maximum probability of Pc oscillations is 10 per cent higher on magnetic disturbed days than on quiet days. However, owing to the difficulty of identifying short-period oscillations on the background of highly disturbed records, a greater probability of their occurrence can be expected than it follows from the graphs.

The frequency spectrum of the distribution of short-period oscillations shows that most periods of Pc fall in the range from 20 to 25 sec whereas PcR oscillations have periods mainly in the range from 15 to 20 sec.

The laws of the daily variations of short-period oscillations with an unstable regime of the type Pt are represented in fig. 2. Hence it follows that oscillations of this type usually occur at night hours, being practically absent on the records at noon hours. The maximum probabi-

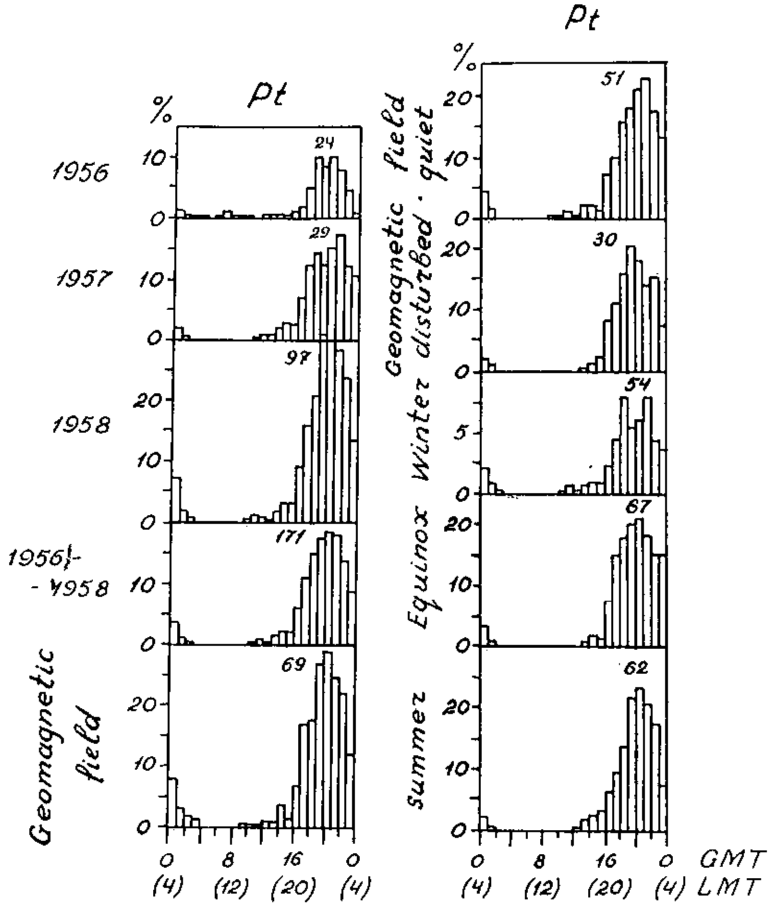

Fig. 2

lity of their occurrence (18 per cent) falls on local midnight (20 hours GMT). The daily variations of this type of oscillations plotted separately for 1956, 1957 and 1958 are similar, the maximum probability of the occurrence of Pc and PcR oscillations falling on 1958.

The dependence of the occurrence probability of trains of oscillations (fig. 2) on season is also analogous to steady-type oscillations, viz. the probability of their occurrence reaches its maximum in summer time and minimum — in winter.

Thus the results we have obtained in general well agree with data available, though some peculiarities can be noticed. For instance, the maximum probability of occurrence of continuous-type oscillations and train-type oscillations falls on local midday and local midnight respectively which can be indicative of the law of exciting short-period oscillations at local time. Then, the occurrence probability of continuous oscillations as well as of trains of oscillations is the greatest in summer time and the least in winter which does not agree with the results obtained by some authors.

2. *Rapid Variations of the Type «PP», «b» and «SSC».*

Among other types of rapid variations of the Earth's electromagnetic field, it is necessary to note some peculiar short-period oscillations, the type of pulsations, marked as «PP», which are characterized by a small period (1-3 sec) regular sinusoidal form and pulsating nature.

From July 1957 to March 1959 the Ashkhabad station recorded PP oscillations in 68 cases, 50 of them being observed during the Earth's magnetic and electric storms. The latter shows that these oscillations are one of the components of a complex microstructure of disturbances of the earth-current field. As is seen from table I where the distribution of the number of cases recording «PP» and their dependence on the period of oscillations are shown, the prevailing number of the oscillations recorded have periods from 1.0 to 2.0 sec.

TABLE I

Period in sec.	Number of cases	Period in sec.	Number of cases
0.5-1.0	7	2.6-3.0	0
1.1-1.5	14	3.1-3.5	1
1.6-2.0	25	2.6-4.0	1
2.1-2.5	4	4.1-4.5	0

The daily distribution of PP oscillations is characterized by the greatest frequency of their occurrence at night hours with maximum at about midnight, local time.

The direct comparison of cases of occurrence of bay disturbances and PP variations indicates that only in 3 cases from 42 bay disturbances pulsating oscillations were observed. At the same time in 27 cases train oscillations were recorded.

Thus it is evident that PP oscillations are not linked with bay disturbances of the Earth's electric field, the latter being more closely correlated with train oscillations.

The amplitudes of the pulsating short-period oscillations recorded in Ashkhabad usually have values from 0.3 to 0.6 millivolts/km. However, in many cases, e.g. on September 4, 13, 29, 1957, February 11, June 6, and September 4, 1958 the pulsating oscillations had amplitudes over 1-5 millivolt/km. In each case the oscillations were observed on the background of the Earth's high magnetic and electric disturbances, as a rule, with a sudden commencement. Apart from it, in all the cases of the same time the Ashkhabad station took instrumental records of aurorae, the times of the beginning maximum and end of these gigantic pulsations being well correlated.

It can be assumed then that great amplitudes of pulsations in the southern regions are directly connected with the propagation of aurorae to low latitudes. From July 1957 to March 1958 the Ashkhabad station recorded 77 cases of rapid variations of the type SSC and SSC*. As a rule, these observations are observed simultaneously on the records of earth currents and the geomangetic field, a peculiar feature of variations of the type of sudden commencements is the presence of accompanying short-period oscillations of earth currents observed in 79 cases of SSC rapid variations recorded in Ashkhabad. In 59 cases of earth-current records the accompanying oscillations predominantly had periods from 6 to 15 sec.

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RESULTATS D'ENSEMBLE DES STATIONS FRANÇAISES

par EDOUARD SELZER

Stations et Equipement

Rappelons que nous avons disposé de cinq stations principales: Chambon-la-Forêt (doublé au début de l'A.G.I. par Garchy), Bangui, Kerguelen et les deux stations de Terre Adélie, représentant donc dans l'ordre: une station de latitude moyenne Nord, une station équatoriale, une station antarctique subaurorale, et deux stations antarctiques interaurorales, l'une côtière (Dumont d'Urville), l'autre continentale (Charcot).

Ces stations ont toutes été équipées de façon homogène en variomètres rapides *barres-fluxmètres,* déjà décrits (Annals of the I.G.Y., V. 4, parts 4-7, 1957, p. 287-301), les inscriptions étant soit photographiques soit à encre par suiveurs de spots.

Les enregistrements ont porté sur les trois composantes H, D et Z, les deux premières étant remplacées par X et Y, suivant des axes géographiques, en Terre Adélie.

Les sensibilités maximales, de l'ordre de 15 à 20 mm par gamma pour les trois premières stations, étaient environ trois fois plus faibles en Terre Adélie. Les enregistrements telluriques rapides associés (cf. ibid.), ont complété les traces magnétiques aux mêmes premières stations. A Dumont d'Urville un enregistrement tellurique rapide du type V. A. Troitskaya a été mis en service après la relève de Janvier 1958 et a donné toute satisfaction.

Toutes les stations disposaient également de variomètres normaux (réduits à une balance de Z enregistreuse à Charcot).

Précisons aussi qu'à Chambon les variomètres semirapides Gibault, en service continu depuis 1952 pour l'enregistrement des pulsations, ont permis de combler bien des lacunes.

Conduite et dépouillements des enregistrements

Au début de l'A.G.I.. seules les stations de Chambon-Garchy et de Dumont d'Urville assuraient des enregistrements quasi permanents à des vitesses de déroulement comprises entre 5 et 10 mm/minute. Les autres stations opéraient par ponctions suivant les horaires mondiaux, à des vitesses de l'ordre de 25 mm/min.

Les défauts évidents —malgré quelques avantages— de cette méthode par ponctions, nous ont conduits à généraliser par la suite, dans toute la mesure du possible, les enregistrements continus à 5 ou 10 mm/min.

L'étude détaillée de la grande quantité de documents ainsi ramenés à Paris pose des problèmes de méthodologie encore non complètement résolus. Mais dans ses grandes lignes la solution adoptée sépare les dépouillements systématiques, ou les études particulières, assurés station par station par les anciens observateurs eux-mêmes, des études synoptiques plus générales. Il va sans dire que les premières préparent les deuxièmes qui seront les seules dont je vais tâcher maintenant de vous donner un aperçu, en m'excusant à l'avance si, à ce stade encore provisoire du travail, mes conclusions vous paraissent trop personnelles.

Nous le ferons en prenant, comme référence de nos anciennes connaissances, celles qui avaient été à l'origine de la mise sur pied de l'Atlas provisoire, lors du Colloque de Copenhague d'Avril 1957.

Faits ou Problèmes en cause

Ce seront principalement les suivants:

a) L'extension des pc vers les courtes périodes et les pc nocturnes.

b) Les micro-pc d'orages (ou «micro-pulsations» tout court, si on ne veut pas les assimiler à des pc) et la génération des pc par les orages.

c) Le rôle joué par les phénomènes statistiques dans le double contrôle des pc par les heures universelles et locales.

d) L'agitation J (c'est-à-dire l'agitation de jour, au sens du P. Mayaud) des régions intra-aurorales et sa relation avec le problème des pg des régions subaurorales, et des «petites agitations du matin» des régions de plus faibles latitudes.

e) Les diagrammes vectoriels des pc et des pt soumis, le cas échéant, aux influences perturbatrices considérables des mers.

Examinons-les dans cet ordre.

* * *

A Chambon et à Bangui, parfois aux Kerguelen, avec incertitude en Terre Adélie, des pulsations régulières de trois à dix secondes, le plus souvent d'environ 6 secondes, apparaissent souvent, peu avant le minuit local, même par temps magnétique calme, sur les enregistrements. Elles laissent place aux *pc normaux* (de périodes supérieures à dix secondes) aux heures locales habituelles de lever de celles-ci.

* * *

Les orages des 4 Septembre 1957. 8 Juillet et 4 Septembre 1958 (ainsi que, depuis la fin de l'Année Géophysique, celui du 15 Juillet 1959), ont donné lieu à des phases aigües de micro-pulsations de périodes comprises entre 0.6 et 3 secondes, qui ont atteint exceptionnellement près d'un gamma en amplitude des variations du champ magnétique, et plusieurs millivolts par km pour celles du champ tellurique. Ces phases aigües, qui ne durent chacune, en général, qu'une vingtaine de minutes, véritables orages de micro-pulsations se manifestant à l'intérieur de l'orage général, paraissent coïncider avec des décrochements abrupts du champ général rappelant ce que jadis nous avions étudié, mais à partir seulement d'enregistrements normaux, sous le nom «d'oscillations semi-locales-instables» ou «d'Oslis» (cf. E. Selzer, Manifestations semi-locales instables du Magnétisme Terrestre, Annales de Géophysique, Tome 8, fascicule 3, Juillet-Septembre 1952, pp. 275-285). En fait nous n'avons pas eu encore l'occasion d'étudier en enregistrements barres-fluxmètres de vitesses suffisantes (au moins 25 mm/min.), des «Osli» aussi caractéristiques que ceux de 1950 qui avaient été l'objet de l'article cité ci-dessus; nous ne pouvons donc nous prononcer présentement sur le caractère micropulsatoire de tels «Osli». D'un autre côte, n'ayant pu enregistrer sans lacunes les micropulsations d'orages qui étaient susceptibles d'apparaître à nos différentes stations —ceci à cause des difficultés expérimentales de leur mise en évidence— nous n'avons pas encore de certitude sur le caractère semi-local que nous leur supposons aussi. De même nous ne pouvons encore affirmer qu'elles soient moins fréquentes à l'intérieur des zones aurorales, bien que les pulsations de cet ordre de périodes n'apparaissent que rarement sur les enregistrements de Terre Adélie. Un effort particulier va être fait dans ce sens pour la prochaine relève. L'étude à l'échelle mondiale de ces orages de micro-pulsations parait en tout cas un sujet majeur et peut-être pourra-t-elle être entreprise dès maintenant grâce à notre collaboration internationale.

Un autre phénomène, lui plus commun, relatif aux orages, est celui des pc, apparament normaux, mais issus de l'orage, ou renforcés par lui. Ce phénomène pourra jouer un rôle important dans l'examen théorique *du* ou *des* domaines où peuvent prendre naissance les pc.

* * *

Dans la vieille, et amicale, «querelle» sur la double influence des heures mondiales et locales sur les heures de lever et de coucher des pc il ne me semble pas que le phénomène statistique lié à la structure discontinue des régimes successifs de pc aient été jusqu' ici pris suffisamment en considération.

En interprétant sous ce jour les pc observés journellement à Chambon, à Bangui et aux Kerguelen, stations étalées sur cinq heures de longitude, je pense pouvoir expliquer au moins partiellement le paradoxe qui est à l'origine de cette «querelle». J'ai trouvé, par exemple, qu'il y avait, pour tout jour donné quelconque, une certaine probabilité P, de l'ordre de 90 %, pour que Chambon et Bangui qui diffèrent d'un peu plus d'une heure en longitude relèvent exactement la même heure T. U. pour le lever de leurs pc.

Entre Chambon et Kerguelen une telle probabilité n'est pas nulle, mais beaucoup plus faible, de l'ordre de 5 à 10 %.

D'une façon plus précise, on peut dire qu'une telle probabilité P est liée par une relation:

$$F_1\ (P,\ \Delta\theta,\ A,\ B) = 0 \qquad (1)$$

à l'écart $\Delta\theta$ de longitudes horaries entre les deux stations comparées, et à leurs seuils respectifs A et B de détection des pc.

La forme de la fonction F_1 dépend elle même de celle de la fonction de modulation «Jour-Nuit» des pc au sol et des paramètres précisant la distribution aléatoire dans le temps T.U. des régimes de pc primaires.

Substituant dans la relation (1) la valeur $P = 1/2$ on détermine ainsi l'écart probable $\Delta\theta_p$ conditionnant la coïncidence des heures de lever aux deux stations.

Une fonction en général différente de F_1, soit F_2, des mêmes variables (déterminant pour $P = \frac{1}{2}$ une valeur différente pour le $\Delta\theta_p$ correspondant) peut être d'une façon analogue définie pour les heures de coucher. F_2 diffère de F_1, dans la mesure où la fonction de modulation Jour-Nuit n'est pas symétrique.

Nous ne pouvons ici entrer dans le détail de l'étude des relations entre cette fonction de modulation Jour-Nuit et les fonctions F. Notons que les paramètres qui ont trait à la distribution aléatoire des régimes des pc primaires interviennent aussi.

De même nous passerons sans plus sur la discussion qui serait nécessaire au sujet d'une définition pratique des seuils A et B.

Remarquons seulement que tout progrès expérimental sur la détermination de F devrait permettre d'améliorer notre connaissance de ce phénomène de modulation «Jour-Nuit» qui reste encore totalement inexpliqué. C'est en ce sens que l'on pourrait axer de nouvelles méthodes de dépouillement statistique des pc.

Une méthode complémentaire des précédentes pourrait être basée sur l'étude de la distribution aléatoire, jour par jour, des heures de lever et de coucher des pc, relevées à chaque observatoire déterminé. A

Chambon, les $\Delta 0$ horaires probables correspondants sont de l'ordre de une à deux heures pour les levers et de deux à trois heures pour les couchers. Nous nous proposons d'en faire une étude systématique.

Je terminerai cette question en soulignant l'unité que le point de vue précédent apporte à la manifestation de l'ensemble des phénomènes magnétiques: ssc, pt, et pc. Tous sont mondiaux mais subissent des modulations de formes et d'amplitudes qui pour les pc vont en général jusqu'à l'extinction complète durant certaines heures locales. Inversement il n'est pas interdit de penser que si on étendait les statistiques de ssc en y incorporant des ssc trop petits pour qu'ils puissent dépasser à toute heure locale les seuils d'enregistrement, ces statistiques accuseraient une influence de l'heure locale sur la densité des ssc enregistrés. Cette question se trouve donc régie par les doubles influences contraires, d'une part des *amplitudes minima* adoptées conventionnellement pour la définition du phénomène, d'autre part des *sensibilités* des montages utilisés pour leur détection. Ces points de vue ne sont pas nouveaux et ont entre autres été exprimés très clairement par J. W. Dungey; si je les ai rappelés c'est pour montrer comment ils pouvaient être étendus aux pc. Remarquons de plus qu'une grande augmentation de sensibilité peut, paradoxalement, suffire parfois à mettre d'accord les deux influences rappelées ci-dessus, dans la mesure où elle permet la découverte d'une classe nouvelle indiscutable du phénomène étudié.

* * *

Lors de son hivernage en Terre Adélie en 1951-52, le P Mayaud a insisté sur le rôle énorme que jouait en zone intra-aurorale, ce qu'il a appelé «l'agitation J» (agitation de Jour) («Terre Adélie». 1951-1952- Magnétisme Terrestre — Fascicule II. Activité magnétique dans les régions polaires. Expéditions Polaires Françaises — Paris, 1955).

Cette agitation J est de beaucoup l'agitation dominante apparaissant journellement sur les enregistrements normaux. durant l'été austral. Sur les enregistrements barres-fluxmètres elle se manifeste sous la forme de grandes oscillations irrégulières, de quelques minutes de durées (pseudo-périodes), la bande passante du montage n'ayant pu que modérer partiellement ses effets, ce qui rend parfois difficile sa séparation d'avec les pc, sans que l'on ait pu clairement décider si les deux phénomènes étaient ou non liés.

Le P. Mayaud a voulu examiner ce que devenait cette agitation J aux latitudes plus modérées, mais sa méthode statistique basée sur les caractères K ne pouvait évidemment lui donner des résultats corrects que tant que les niveaux moyens de ce type d'agitation restaient assez élevés. Or ce n'est plus le cas aux Kerguelen ni, a fortiori, à Chambon ou à Bangui où cependant il existe une agitation de jour, appelée depuis longtemps à Chambon «petite agitation du matin» ayant une individualité morphologique indubitable. Mais la manifestation la plus remarquable de cette forme d'agitation se produit aux Kerguelen où, beaucoup plus régulière (question d'amplitude moyenne mise à part) à la fois qu'en Terre-Adélie et qu'à Chambon, elle prend par continuité en certaines occasions la forme classique des pulsations géantes, pg. D'où le nom de «micro-pulsations géantes» que nous lui avons donné sous sa forme journalière habituelle.

Par extrapolation nous pouvons nous demander dans quelle mesure la «petite agitation du matin» des latitudes modérées (visible encore à l'équateur), ne serait pas les restes de l'agitation J des zones intra-aurorales ou subaurorales.

Quoi qu'il en soit, bien que se superposant plus ou moins partiellement aux pc dont elle semble suivre le rythme diurne, surtout le matin, cette «agitation de jour» mérite —à toutes les latitudes— une étude séparée.

* * *

Diagrammes vectoriels de pc et de pt

Ceux des pc, très délicats à mener à bien, et nécessitant des vitesses d'enregistrement d'au moins 20 mm/min, sont en cours d'étude. Disons seulement qu'il nous paraît inutile, si l'on s'intéresse essentiellement au phénomène primaire, de retenir les diagrammes de stations côtières telles que Kerguelen ou Dumont d'Urville. Par exemple à cette dernière station, et contrairement à ce que l'on observa à Charcot, les pulsations apparaissent avec une amplitude deux à trois fois plus grande sur Z que sur X ou Y et les pulsations sur X doivent être très affectées par la direction privilégiée Est-Ouest des pulsations telluriques. Je rappelle à ce sujet d'autres anomalies classiques telles que celles qui se manifestent le long des côtes du Portugal (à Coimbra) ou d'Afrique du Sud (Hermanus).

En ce qui concerne les pt, la question est plus facile et la réponse claire, avec, bien entendu les mêmes suspicions nécessaires envers les stations côtières.

La polarisation Sud-Nord des pt devient de plus en plus précise au fur et à mesure que l'on s'éloigne des zones aurorales. Elle est la plus parfaite à Bangui, comme on pourra en juguer par quelques uns des graphiques obtenus pour cette station.

L'origine aurorale des pt trouve ici une nouvelle confirmation.

* * *

Nous n'avons guère insisté, au cours de cet exposé, sur les vérifications que les confrontations d'enregistrements auxquelles nous avons procédé nous ont permis de faire relativement aux corrélations qui existent, phénomènes locaux mis à part, entre les phénomènes affectant les deux hémisphères Nord et Sud, malgré les influences parfois considérables des latitudes et des longitudes.

Une telle corrélation est en effet maintenant à ranger parmi la petite liste des faits définitivement acquis, à condition toutefois de ne pas trop vouloir examiner le détail de ce qui se passe à *l'intérieur* des zones aurorales. Citons le fait que parfois des «si», minuscules à Chambon, ont pu être retrouvés avec certitude sur les enregistrements de Charcot. D'autres plus importants n'ont pas pu l'être. Disons aussi qu'à Chambon on retrouve nettement, bien que moins beaux en général, les pt des Kerguelen, mais non, comme il se doit, les pg.

Dans un autre ordre d'idées signalons aussi que des mesures en cours sur les instants d'apparition à Chambon, Bangui, Kerguelen et Terre-Adélie, des ssc les plus nets (mesures aussi précises que possible, en général à quelques secondes près), n'ont jamais encore mis en évidence de divergences —non expliquées expérimentalement— supérieures à quinze secondes. (Nous avions éliminé, il va sans dire, les cas pour lesquels l'interprétation de ce que l'on pouvait choisir comme début prêtait à discussion).

J'espère que de telles mesures pourront être comparées à celles de nombreuses autres stations.

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Paris

ANNEXE

au rapport sur les résultats des stations françaises pour l'étude des variations magnétiques et telluriques rapides, durant l'A.G.I.

Stations		*Coordonnées géographiques*	*Coordonnées magnétiques*
Chambon-la-Forêt		48° 01' Nord	50°, 4 Nord
		2° 16' E. G.	83°, 9 Est
Bangui		4° 26' Nord	4°, 8 Nord
		18° 34' E.G.	88°, 5 Est
Kerguelen (Port aux Français).		49° 21' Sud	56°, 5 Sud
		70° 12' E.G.	127°, 0 Est
Terre Adélie	Dumont d'Urville.	66° 40' Sud	75°, 6 Sud
		140° 01' E.G.	231°, 0 Est
	Charcot	69° 30' Sud	78°, 3 Sud
		139° 02' E.G.	234°, 5 Est
et pour mémoire:			
Tamanrasset		22° 47' Nord	26°, 0 Nord
		5° 32' E.G.	81°, 5 Est

(L'équipement de cette station ne constituant pas un ensemble homogène avec celui des autres stations ci-dessus, le dépouillement de ses résultats a été, pour l'instant, conduit de façon indépendante.)

DISCUSSION

Schlich: In Terre Adélie we had micropulsations not only during the storms, but also in quiet periods.

Selzer: With periods of about 2 seconds and amplitudes of 1 gamma?

Schlich: Yes; the amplitude in Terre Adélie is of 1,6 γ. May be there are two sorts of micropulsations.

Selzer shows two types of micropulsations in the records of the magnetic storms of the 4th September 1957 and 9th July 1958.

Bartels: Do you not think, Prof. Dungey, that this sort of micropulsations may be due to modes?

Dungey: I think that we must take into account Kato's theory.

Coulomb: I agree.

Maple: At what time do they appear, these very short-period pulsations?

Selzer: 5 to 7 in the afternoon.

Bartels: What was the greatest amplitude at 1 to 8 seconds period?

Selzer: 1,2 γ.

Schlich: In Terre Adélie the maximum was 1,6 γ and the mean value was 0,6 γ.

Coulomb: Dr Selzer has made reference to the influence of atmospherics; this agrees completely with the theory.

VARIATIONS RAPIDES DU CHAMP MAGNETIQUE TERRESTRE A LA STATION CHARCOT EN TERRE ADELIE

par R. SCHLICH

Les variations rapides du champ magnétique terrestre ont été enregistrées à la Station Charcot en Terre Adélie (coordonnées géographiques: 69° 22' 5 Sud et 139° 01' Est) à l'aide du système barre-fluxmètre (1). Les enregistrements ont eté effectués d'une façon intermittente, suivant les indications du Comité Spécial N.° 10 de l'A.I.G.A. (2) pour les observatoires ne fonctionnant pas d'une manière continue.

Il est très difficile, à partir d'enregistrements réalisés par ponctions, de donner des résultats statistiques; malgré tout, le dépouillement des observations réalisées pendant la période allant du 15 Juillet 1957 au 28 Janvier 1958, conduit aux conclusions suivantes:

Les pc (pulsations présentant une certaine continuité, d'une période comprise entre 10 et 40 secondes, et durant plusieurs heures) apparaissent avec des périodes comprises généralement entre 15 et 35 secondes; très rarement, la période peut atteindre 45 secondes. L'amplitude sur les composantes horizontales dépasse parfois 10 gammas.

Si l'on porte sur un graphique les heures et les dates auxquelles apparaissent les pc, on obtient leur distribution dans le temps; ce schéma est naturellement très affecté par le choix des intervalles d'enregistrements: sur le graphique, les zones hâchurées correspondent aux périodes pour lesquelles il n'existe pas d'observations.

Les pc sont d'autant plus nombreuses et leur qualité est d'autant meilleure que l'intervalle considéré pour un mois déterminé est plus proche du midi local (environ 2 heures T. U.); autour du minuit local, nous n'avons jamais de pc. Le 4 Septembre 1957, à 14h40m T.U., les pc signalées sont des pc d'orage, donc pas significatives pour notre étude. Les pc seraient liées à l'heure locale; il est impossible de donner une heure de maximum; il faut se contenter d'affirmer que celle-ci est voisine du midi local.

Le graphique met en évidence, d'une façon nette, une importante variation saisonnière pour les pc; les phénomènes vont en s'amplifiant


1 Août
1 Sept.
1 Oct.
1 Nov.
1 Déc.
1 Janv.
0 h
Mid. local
3
6
9
12
Minuit local
15
18
21
24 H.
p.c.A
p.c.B
p.c.C

quand on s'approche de l'été austral. La comparaison du mois d'Août et du mois de Janvier, pour l'intervalle 01 h. T.U., confirme ce résultat.

Certaines pc se manifestent avec beaucoup de regularité. Nous avons été amenés à étudier leur diagramme polaire; les résultats ne sont pas très concluants: sur une centaine de cas bien définis, à peine une dizaine d'exemples paraissent simples. L'allongement des diagrammes est très variable d'un exemple à l'autre et souvent même quelconque. Le sens de rotation du vecteur perturbation dans un plan horizontal, n'est que rarement bien défini.

Les pt (trains de pulsations de durée individuelle ne dépassant pas 10 à 20 minutes en général, mais pouvant se relayer pendant plus d'une heure) se manifestent difficilement et n'apparaissent jamais d'une façon très nette; la vitesse d'enregistrement 25 mm/min., déjà rapide, ne facilite pas leur mise en évidence. Par ailleurs, les enregistrements de nuit sont relativement plus rares que ceux de jour; or, les principaux exemples proviennent d'observations nocturnes. Enfin, l'agitation matinale très importante masque peut-être ce phénomène.

Les diagrammes polaires, pour les quelques exemples de pt, sont plus simples que ceux relatifs aux pc; malheureusement, les cas où les pt se dessinent nettement, son trop rares pour permettre une étude systématique.

Les micropulsations (pulsations de périodes inférieures à 10 secondes) semblent se produire indifféremment à toutes les heures, avec une prédominance lors des mois d'Août et de Septembre. Leurs périodes privilégiées varient entre 3 et 6 secondes; l'amplitude est comprise entre 0,05 et 0,4 gamma; exceptionnellement, le 13 Septembre 1957, l'amplitude atteint 1,6 gamma et la période descend jusqu'à 2 secondes.

L'intérêt essentiel de ces enregistrements réside sans doute dans leur comparaison avec les documents provenant du plus grand nombre possible d'observatoires; ce travail reste à faire. D'une façon générale, il apparaît qu'un enregistrement discontinu est fortement à déconseiller et qu'il est préférable, plutôt que d'enregistrer par ponctions horaires journalières, de réaliser des enregistrements de durée au moins égale à 24 heures, quitte d'espacer les journées d'observation, la vitesse d'enregistrement pouvant être réduite à 12 mm/min.

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INVESTIGATIONS ON THE GEOMAGNETIC RAPID PULSATIONS

by Yoshio Kato

(Abstract)

Introduction

As it is well known geomagnetic pulsations —the rapid variations of the geomagnetic field— become more and more important in Geophysics as shown by recent theoretical investigations of the outer atmosphere of the earth.

During the recent International Geophysical Year, these geomagnetic pulsations were observed at many observatories in the world by using the rapid run high sensitivity magnetometer or the induction magnetometer.

Therefore the nature of the geomagnetic pulsation becomes more and more clear and furthermore the knowledge obtained by artificial satellites is very useful for the theoretical study of the outer atmosphere and for the study of geomagnetic pulsations.

Now we shall again review the observational and theoretical knowledge on geomagnetic pulsations obtained in recent few years and we want to discuss the nature of geomagnetic pulsations.

The author presented the paper «Investigations of Geomagnetic Pulsations» at the International Symposium on Rapid Geomagnetic Variations held at Utrecht on 1-4 September 1959.

This is the summary of this paper; the full paper is published in «The Science Report of the Tôhoku University», Series 5, Geophysics, Vol. 11, 1959.

1. *On the Geomagnetic Pulsation pt.*

The pt pulsation is the most remarkable pulsation and it is well known that these pulsations are usually observed in the early part of a bay disturbance, and the pt pulsation is a damped type oscillation of period from 60 to 100 sec.

But usually the short period pulsation whose period is 20 sec. is overlapped simultaneously with the pt pulsation of rather long period.

The shorter period oscillation has rather similar period to the pc pulsation.

As the author pointed already the pt pulsation occurs sometimes simultaneously in Japan and Tamanrasset, Algeria, and the oscillation starts with dH/dt > 0 in both stations which are situated on the opposite side of the globe.

The pt pulsations occur mostly in the night time and most frequently near 23 h. of local time.

2. *On the Geomagnetic Pulsation pc.*

It is clear that on the record of induction magnetograph the very regular and continuing pulsation occurs in the daytime; in particular the pc pulsation is more active one or two days after the magnetic disturbance. The pc pulsation occurs sometimes accompanying the beat type oscillation.

It is clear that the pc pulsation having period between 10 and 30 sec. occurs in the day time and maximum frequency of occurrence occurs on about between 8 h. to 10 h.

3-1. *Outeratmosphere and Geomagnetic Pulsation*

Recently according to investigations of zodiacal light and whistler phenomena it becomes clear that the interplanetary space between the sun and the earth is not a vacuum, but filled with ionized gas whose density is much greater than previously believed.

Because there is relative motion between the interplanetary ionized gas and the earth with a velocity comparable to the orbital velocity of the earth which is 30 km/sec., the magnetic cavity, wherein the earth's magnetic field is confined, is produced through Chapman-Ferraro process. This cavity is named the outer atmosphere or exosphere and its radius is 9 earth's radii.

On the other hand we must also consider the outer atmosphere or exosphere in which the earth's magnetic field must be confined in this cavity in order to avoid the rotational instablity of a conducting sphere with a magnetic field as well as to avoid the decay of rotational motion of a conducting rigid sphere which is surrounded by highly conducting fluid under the magnetic field. According to T. Tamao the radius of this cavity is about 10 earth's radii.

Anyhow we must consider the existence of the outer atmosphere in which the earth's magnetic field is confined.

Recently Dungey (1954) discussed the geomagnetic pulsation which would be caused by the hydromagnetic oscillation of the outer atmosphere. The general equations of hydromagnetic oscillation of the outer atmosphere are presented by Dungey, but are too difficult to be solved analytically. However the axisymmetric case can be treated easily, where the coupling between the poloidal and toroidal oscillation is weakened.

The equation of poloidal oscillation is given by

$$\left(4 \pi a^2 \rho H^{-2} \frac{\partial^2}{\partial t^2} - \frac{1}{R^2} \sin \theta \frac{\partial}{\partial \theta} \sin^{-1} \theta \frac{\partial}{\partial \theta} - \frac{\partial^2}{\partial R^2}\right) (R \sin \theta E \Phi) = 0$$

and that of the toroidal one by

$$\left\{ 4 \pi a^2 \rho \frac{\partial^2}{\partial t^2} - (R \sin \theta)^{-2} [(\overrightarrow{H} \cdot \nabla)(R \sin \theta^2)(\overrightarrow{H} \cdot \nabla)] \right\} \left(\frac{U \Phi}{R \sin \theta} \right) = 0$$

In this case we use spherical polar coordinates, R, θ and Φ, where R is the distance of any representative point from the origin measured in units of earth's radius a, which is the radius of the inner boundary of the outer atmosphere assumed to be a spherical surface concentric to the earth.

The density ρ of the outer atmosphere is assumed to be constant, 600 protons/cm^3 as obtained from the observation of the zodiacal light.

In the toroidal oscillation, the magnetic field is directed to the east-west direction, and the eigen-periods form a nearly harmonic spectrum:

$$T_1 = 3.0 \times 10^{10} \sqrt{\gamma} \sec^8 \lambda_o \sin \lambda_o \int_o^1 (1 - \sin^2 \lambda_o x^2)^3 dx$$

It is clear that T_1 depends on the latitude of observing station λ_0 very sensitively and will become too small to be detected in the lower latitudes. Thus, it can be observed only in the auroral zone.

It is the author's opinion that the pg pulsation—so called giant pulsation—is caused by the hydromagnetic oscillation of the outer atmosphere of this toroidal type. The magnetic field of the giant pulsation is directed nearly in the east-west direction.

Under some approximations we can solve the differential equation of poloidal type oscillations and if we assume that the shape of the outer boundary of the outer atmosphere is a spherical surface concentric with the earth, of which the radius is R_1 times the earth's radius, we can obtain fundamental period of the poloidal oscillation

$$T_1 \simeq \frac{1}{2\varepsilon} \frac{a R_1^4}{V_o}$$

where a is the radius of the earth and εV_0 is the Alfvén wave velocity at the outer boundary in the equatorial plane when $\varepsilon = 1$ or in the poleward direction when $\varepsilon = 2$.

It is clear that the fundamental period of poloidal oscillation depends on the dimension of the outer atmosphere but not on the latitude of the observing station.

It is the author's opinion that pt and pc pulsations are causued by the hydromagnetic oscillation of the outer atmosphere of poloidal type since the geomagnetic pulsation pt or pc is observed simultaneously over considerably wide regions.

The above equation teaches us that

a) the fundamental period depends on R_1 very sensitively:

b) it depends on ρ through the factor $\sqrt{\rho}$, because $V_0=H/\sqrt{4\pi\rho}$.

We can calculate the relation between the fundamental period T_1 and the radius of the outer atmosphere R_1, if we assume the number density of the outer atmosphere. Fig. 1 shows the relation, when the number density of the outer atmosphere is assumed to be 600 protons/cm³. As the figure shows the period T_1 is about 100 sec. when the radius of the outer atmosphere is about 6 times the earth's radius.

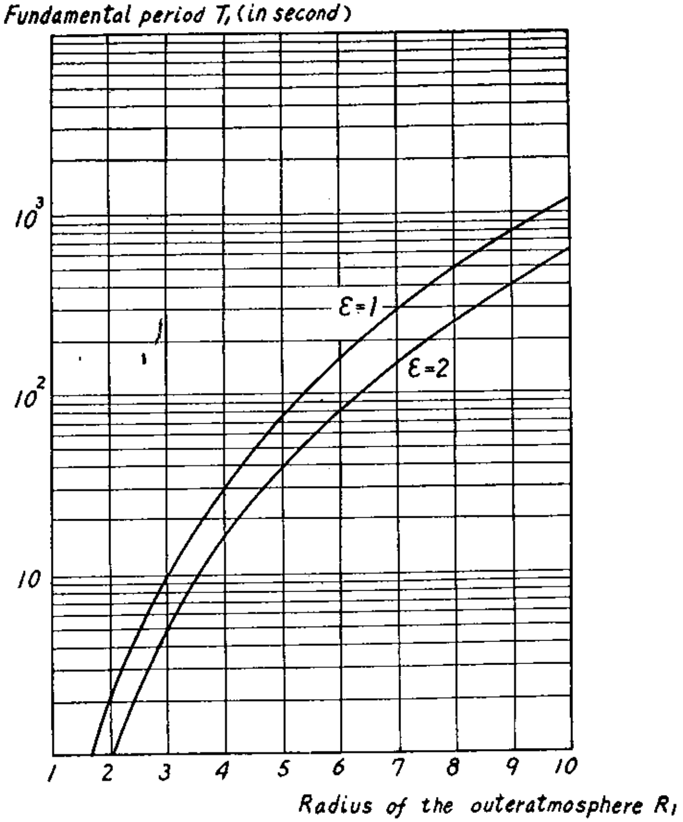

Fig. 1. — Relation between the fundamental period T_1 and the radius of the outeratmosphere R_1, when the number density of the outeratmosphere is assumed to be 600 protons/cc.

In section 1, the author presented the statistical result of the observed period of pt pulsation and it is about 100 sec.

As already stated the pt pulsation appears at the time of bay disturbance or magnetic storm.

Therefore it is the author's opinion that the pt pulsation is caused by hydromagnetic oscillations of poloidal type in the outer atmosphere whose radius is about 6 times earth's radius and is contracted by the kinectic pressure of the incoming corpuscular stream.

On the other hand, the period of pc pulsation is about 20 sec. and we cannot consider that the period of pc pulsation is the fundamental or harmonic period of the outer atmospheric oscillation because the period is very short.

On the cause of pc pulsation, the author considers the other mechanism as discussed in the following section.

3-2. *Possibility of the Excitation of Standing Oscillations in the Lower Boundary of the Outer Atmosphere*

Recently Dessler stated that the Alfvén wave velocity is maximum at the height of about 1000 km. as shown in Fig. 2. It is noticed that the Alfven velocity becomes about one hundred times larger at the height of 1000 km. If we call this region an inner exosphere we can consider one kind of standing oscillation in this inner exosphere, having the period of oscillation between 10 and 40 sec. for various density distributions.

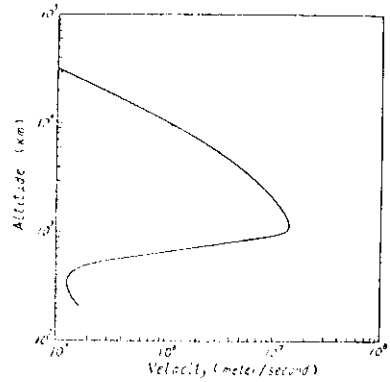

Fig. 2. — Hydromagnetic wave velocity vs altitude (after A. J. DESSLER).

As the author already pointed, pc pulsation is considered as the hydromagnetic standing oscillation in this inner exosphere. In section 2 we clarified that the statistical result of observed pc pulsations shows the continuous train of pulsations.

Mutual action between the incoming corpuscular beam and the hydromagnetic wave may reflect at the boundary of maximum Alfvén velocity whose height is 1000 km and consequently the standing oscillation may be excited in this region.

The pc pulsation and the short period pulsation which is superposed on the pt pulsation is considered as the hydromagnetic oscillation in this inner exosphere, while pt pulsation is caused by the hydromagnetic oscillation of the outer atmosphere itself.

Conclusion

The statistical results of geomagnetic rapid variations obtained at Onagawa Magnetic Observatory are reviewed and the character and the cause of geomagnetic pulsations are discussed.

The following are the results obtained by the investigation:

1) pg pulsation is caused by the toroidal type hydromagnetic oscillation of the outer atmosphere which can be observed only in the auroral zone.

2) pt and pc pulsations are caused by the poloidal type hydromagnetic oscillation of outer atmosphere.

3) The period of pt pulsation is the fundamental period of the oscillation of the outer atmosphere whose radius is about 6 earth's radii, contracted by the corpuscular stream which impinges on the auroral zone intermittently.

4) pc pulsation is the standing oscillation in lower boundary (or inner exosphere) of outer atmosphere excited by the corpuscular beams of lower energy which impinge on rather higher latitudes of the day hemisphere.

In conclusion the author expresses his hearty thanks to his colleagues in his laboratory for their kind help.

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RECORDS OF PULSATIONS IN GÖTTINGEN

by G. ANGENHEISTER

Since 1952 the pulsations of the geomagnetic field have been recorded by an induction magnetograph of the Grenet-type in Göttingen (Germany). The time-scale was at first 4 mm per minute, later 6 mm per minute. The smallest amplitude of the magnetic field (level) S recorded and the scale values depend on the period.

In order to get a continuous series of an index for pulsation activity we have analysed records of Göttingen from 1952 to 1958 and we continue this series. We used the H-component only. A complete harmonic analysis for every hour and day needs too much time. Therefore we have replaced the analysis by eyeinspection. In this case it is convenient to use the intervals of periods (octaves) given in the following table: T: 7,5-15 sec.; 15-30 sec.; 30-60 sec.; 60-120 sec.; 120-240 sec.; 240-480 sec. There are two reasons for this classification: *i*) On the registration-sheet every minute is marked by a small black line. Therefore it is easy to distinguish to which interval the pulsation-effect concerned belongs. *ii*) Only large intervals enable the analysis by eye. According to our experience the octave-bands (relation of periods equal 2) are the smallest ranges, which give satisfactory results. But from the physical point of view there are serious objections against this choice of period-intervals: It is very improbable that the given classification, which has a consequent formal character, agrees with the natural division of periods caused by different physical sources of pulsations. Especially the most frequent interval T = 20-40 sec. (pt) is split by the given formal classification of periods. (Perhaps another classification with an overlapping of periods is better: T:1,875-5 sec.; 3,75-10 sec.; 7,5-20 sec.; 15-40 sec.; 30-90 sec.; 60-180 sec.; 120-360 sec.) But for the sake of simplicity —especially for the person who made the analysis by eye- – we favoured the above mentioned classification of periods.

As a measure of pulsation activity we introduced an index: Pz (called: Pulsationszahl) defined by: $Pz = n\bar{a}/N$. n is the number of periods in one hour belonging to one octave interval and $\bar{a}$ is the mean amplitude of the same interval in the same hour. We have prepared tables which contain n, ā, Pz for every hour from 1952 to 1958 (in handwriting). Three months are missing.

The index Pz is a good measure for the pt. The daily variation curves of Pz (mean of all days, quiet and disturbed) show the maximum of the short periods (7,5-15 sec.) early in the morning. With increasing period the maximum changes to noon (30-60 sec.) and to the afternoon (120-240 sec.). During the night Pz is small but does not vanish due to the fairly frequent occurence of pt.

THE MORPHOLOGY
OF GEOMAGNETIC MICROPULSATIONS PC (1)

by J. A. Jacobs and K. Sinno

Abstract

An analysis of the occurrence frequency of geomagnetic micro-pulsations Pc has been carried out using data obtained during the IGY from a world-wide network of stations. From the characteristiscs of the diurnal occurrence frequency and their latitudinal and longitudinal dependence, the following points are concluded:

1) The occurrence frequency of Pc's shows a maximum in the auroral zones. Also the hour of maximum occurrence appears earlier at auroral zone stations.

2) The occurrence frequency of Pc's depends not only on local time, but also in part on universal time. The time of maximum occurrence of Pc's is about 23 hours GMT in the northern hemisphere. In the southern hemisphere the GMT factor has opposite phase to that in the northern hemisphere. When the GMT factor is a maximum in the north (or south) hemisphere, the north (or south) geomagnetic pole is about 18 hours LMT. The GMT dependence derived in this investigation shows about 6 hours difference compared with Troitskaya's conclusion which was based on data from several stations in the USSR.

1. *Introduction*

In recent years the study of the Earth's outer atmosphere has received an added stimulus by the discovery of the existence of remarkably dense ionized particles, and by «whistler atmospherics». The use of artificial satellites has also increased enormously the possibility of making direct observations.

Dungey (1), Kato and Watanabe (2), and Obayashi and Jacobs (3) have investigated theoretically the possibility that geomagnetic micro-pulsations are caused by hydromagnetic oscillations of the Earth's outher atmosphere. However, not enough is known about the morphology of these micro-pulsations to make more precise theoretical inter-

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pretations. Several investigations have been made of micro-pulsations as observed at a single station (4), but almost nothing is known about their world wide morphology. However, Troitskaya (5) has investigated the GMT dependence of Pc's and Pt's using data from several Soviet stations. Such a GMT dependence has not been further investigated, in spite of the fact that her conclusions have been criticized by many investigators. For these reasons we have analysed the occurrence frequency of Pc's using data obtained during the International Geophysical Year from a world-wide network of stations. This analysis has led to a number of conclusions.

2. *Sources of the Data*

For the present investigation, data from rapid run magnetograms for the period from October 1957 to June 1958 from ten American geomagnetic observatories were used. The location of these stations is given in Table I.

TABLE 1

Station	Abbreviation	Lat. Geographic	Long. Geographic	Lat. Geomagnetic	Long. Geomagnetic
Point Barrow .	PB	N 71° 18'	W 156° 46'	N 68°.6	E 241°.0
College . . .	Co	N 64° 51'	W 147° 50'	N 64°.7	E 256°.5
Big Delta . .	BD	N 64° 09'	W 145° 51'	N 64°.4	E 259°.0
Healy	Hy	N 63° 51'	W 149° 00'	N 63°.6	E 256°.5
Sitka	Si	N 57° 03'	W 135° 20'	N 60°.0	E 275°.4
Fredericksburg .	Fr	N 38° 12'	W 77° 22'	N 49°.6	E 349°.9
Tucson . . .	Tu	N 32° 14'	W 110° 57'	N 40°.4	E 312°.1
Honolulu . . .	Ho	N 21° 18'	W 158° 08'	N 21°.0	E 266°.4
Guam	Gu	N 13° 27'	E 144° 45'	N 3°.9	E 212°.8
Koror	Kr	N 07° 16'	E 134° 32'	S 3°.3	E 203°.5

Further data was obtained for Decembre 1957 from three antartic stations viz,

Station	Abbreviation	Lat. Geographic	Long. Geographic	Lat. Geomagnetic	Long. Geomagnetic
Byrd Station . .		S 79° 59'	W 120° 01'	S 70°.6	E 336°.0
Little America .	LA	S 78° 18'	W 162° 10'	S 74°.0	E 312°.0
Wilkes	Wk	S 66° 15'	E 110° 31'	S 77°.8	E 179°.0

All the data (three components) was photographically recorded by high sensitivity ordinary magnetograms with a recording speed of 4 millimeters per minute.

Additional data, for the same period (October 1957 to June 1958) was taken from the publications (6) of the International Union of

Geodesy and Geophysics. The location oh these stations is given in Table 2.

TABLE 2

Station	Abbreviation	Geographic Lat.	Geographic Long.	Geomagnetic Lat.	Geomagnetic Long.
Lerwick . . .	Le	N 60° 08'	E 01° 11'	N 62°.5	E 88°.6
Hartland . . .	Ha	N 51° 00'	W 04° 29'	N 54°.6	E 79°.0
Toledo	Tl	N 39° 53'	W 04° 03'	N 43°.9	E 74°.7
Memambetsu .	Mb	N 43° 55'	E 144° 12'	N 34°.1	E 208°.3
Kakioka . . .	Ka	N 36° 14'	E 140° 11'	N 26°.0	E 206°.0
Tamanrasset. .	Ta	N 22° 48'	E 05° 31'	N 25°.4	E 79°.6
Quetta . . .	Qu	N 30° 11'	E 66° 57'	N 21°.6	E 139°.7
Apia.	Ap	S 13° 48'	W 171° 46'	S 16°.0	E 260°.2
Hermanus. . .	Hr	S 34° 24'	E 19° 13'	S 33°.3	E 80°.3
Watheroo . .	Wa	S 30° 19'	E 115° 53'	S 41°.7	E 185°.8

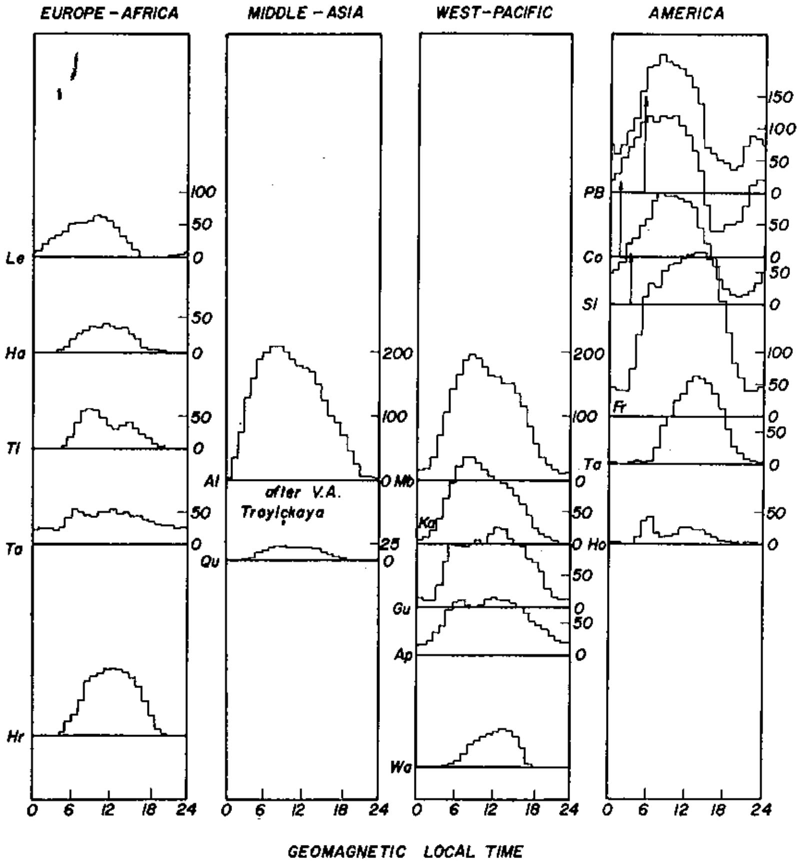

Fig. 1

3. *Occurrence Frequency of Pc's at different Latitudes and Longitudes*

By counting the number of hours during which Pc's were observed during the nine months (October 1957 - June 1958) Fig. 1 was obtained which shows the occurrence frequency of Pc's at different places in the world. The stations are grouped into four classes according to their geographic location.

It is rather meaningless to compare the occurrence frequency between different stations, because the sensitivity of the recording equipment varies and because the data is read by different persons. However it is possible to analyse the form of the diurnal variation. In the case of the American geomagnetic data, however, it is possible to compare the results from the different stations since the sensitivities of the records at each station are known and since the occurrence of all Pc's was read by one of the authors (K. Sinno).

For the sake of comparison, Fig. 1 also shows the occurrence frequency at Alma Ata as determined by Troitskaya.

3. 1. *Latitudinal Characteristics of Pc's*

The number of hours during which continuous wave trains were recorded with periods in the range from about 10 seconds to 1 minute were counted, regardless of the amplitudes. The total number of hours of Pc's during the nine months at each of the American observatories are shown in Fig. 2. The points marked + represent data uncorrected

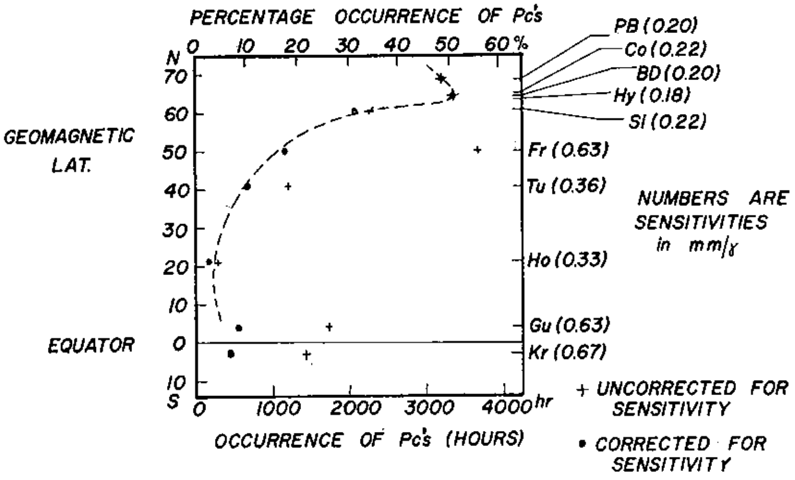

Fig. 2

for sensitivity. After allowing for the different sensitivities (referring everything to 0.2 mm/γ as standard) the points marked · are obtained. The curve through these points shows a pronounced maximum occurrence in the auroral zone. The significance of the slight second maximum at the equator is very doubtful.

The correction for the different sensitivities was made from Fig. 3 which was based on the accumulative distribution function derived from data obtained during February 1958 at Fredericksburg (the station with the most sensitive recording equipment). The accumulative distribution is well approximated by the curve Na = const., where N is the number of hours of Pc's with amplitudes greater than a. On the other hand, the minimum observable amplitude, a_{min}, is controlled by the sensitivity S, i.e.

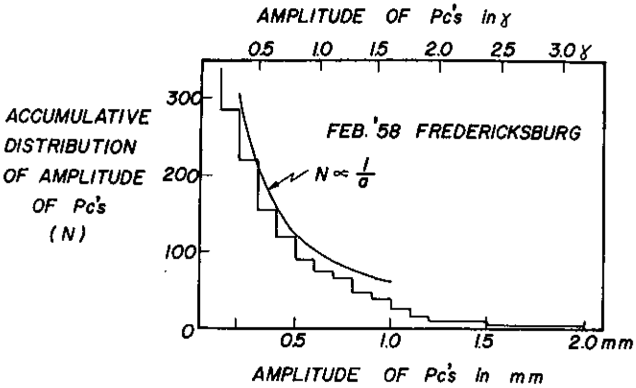

Fig. 3

$$a_{min} \propto \frac{1}{S}$$

Thus the total occurrence, N_{tot}, is proportional to the sensitivity S, and it is easy to correct the occurrence frequencies for different sensitivities.

From Fig. 1 two characteristics are evident. Firstly, the diurnal peak in the occurrence frequency is earliest in the auroral zone gradually tending towards the afternoon at lower latitudes. This characteristic is particularly apparent in the records from Europe and North America. Secondly, in the Western Pacific region, there are two maxima, one pre-noon and one post-noon which predominate in the North- and South- hemispheres, respectively. The limited amount of data from the antarctic observatories confirms this last characteristic. At the antartic station, Wilkes, which is located south of the West Pacific region, the maximum occurrence of Pc's is about 15 hours local geomagnetic time in December 1957.

3. 2. *Longitudinal Characteristics of Pc's*

If the occurrence frequency of Pc's in different regions in about the same geomagnetic latitude is compared, it is found that the maximum occurrence appears earlier at middle and East Asian stations than at American and European stations. For example, the maximum occurrence at Memambetsu in Japan, is about five hours before that at Tucson in North America (geomagnetic local time). This suggests that the occurrence frequency of Pc's depends only on universal time, as has been stated by Troitskaya who based her results on the data from several Soviet stations.

There are not sufficient observatories to separate statistically that part of the variation which depends on LMT, as has been done for geomagnetic (7) and ionospheric disturbances (8). However, three observatories, Toledo (74°.7 E), Memambetsu (208°.3 E) and Tucson (312°.1 E) in approximately the same latitude are located at about equal distances in geomagnetic longitude apart. The separation in longitude of the former two stations is rather large, viz. 133°.6. However, the fact that the shape of the diurnal Pc occurrence frequency at Alma Ata (150°.5 E) is not so different lends support to the fact that the occurrence frequency of Pc's at places 120° apart may not be too different.

Using data from these three observatories, equioccurrence frequency patterns of Pc's are shown in the upper half of Fig. 4, where geomagnetic longitude is plotted against universal time. A certain difficulty arises since the data from Toledo and Memambetsu were taken from published numerical figures, i.e. the actual records were not available. The sensitivities of the recording equipment are unknown and the records were read by different individuals. However, as explained below, the ratios of the sensitivities from Toledo, Memambetsu and Tucson were taken as 1.4:0.7:1.0.

Suppose the occurrence frequency of Pc's at three equidistant observatories around a circle of latitude may be expressed in the form

$$\begin{array}{l} \alpha' \ A(\tau - \lambda') \ B(\tau) \\ \alpha'' \ A(\tau - \lambda'') \ B(\tau) \\ \alpha''' \ A(\tau - \lambda''') \ B(\tau) \end{array} \qquad (1)$$

where α', α'', α''', are factors depending on the sensitivity at the three observatories, the functions $A(\tau - \lambda')$, $A(\tau - \lambda'')$, $A(\tau - \lambda''')$ being GMT factors and $B(\tau)$ an LMT factor. τ is local geomagnetic time and λ geomagnetic longitude, so that $(\tau - \lambda)$ represents «geomagnetic universal time». If the function A be expressed as a Fourier series and any differences in α be allowed for, the average of the expressions (1) may be written $\alpha A_0 B(\tau)$, neglecting third and higher order terms. This average is purely a local time factor typical of the 40° N latitude zone of these three stations, and is plotted in Fig. 5. It shows an almost perfect symmetrical distribution around noon (local time).

The GMT factor $A(\tau-\lambda)/A_0$ may then be obtained for each station by dividing the expressions (1) by the local time factor $\alpha A_0 B(\tau)$. Its variation is shown in the lower half of Fig. 4. Only day light time values around noon at the three observatories are shown since the values at night show more erratic behaviour owing to the comparative lack of occurrences. Originally when this curve was drawn with uncorrected values of α it appeared as three discontinuous sections, one for each station. These could be made into a smooth connected curve by using sensitivity factors for Toledo, Memambetsu and Tucson in the ratio 1.4:0.7:1.0. Such ratios also appear reasonable from an

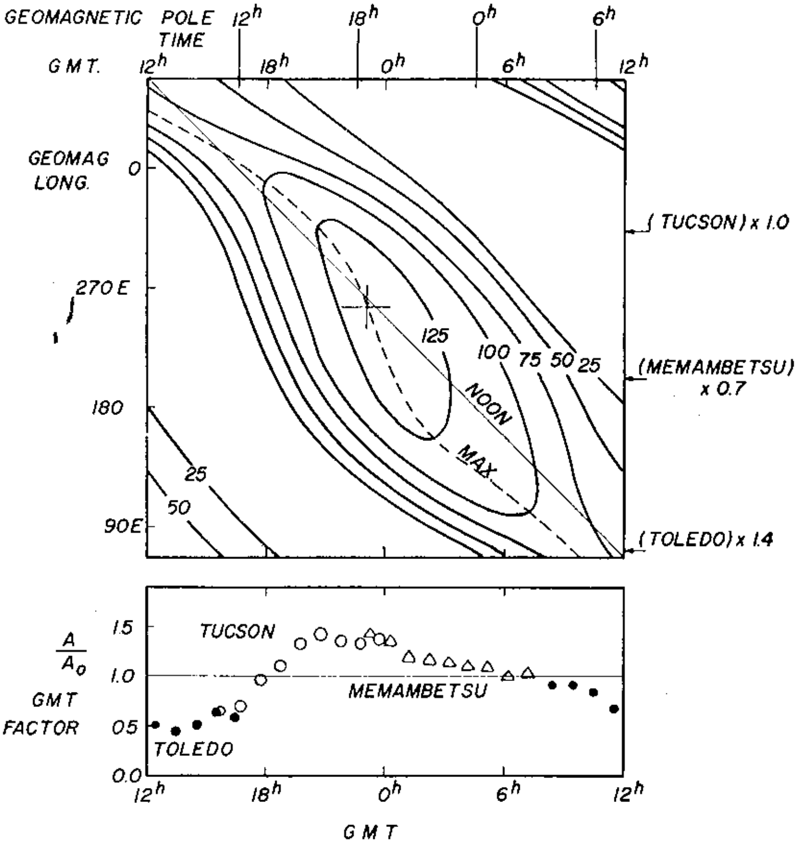

Fig. 4

inspection of the relative frequency of occurrence at the three stations. The maximum value of the GMT factor occurs at about 23 hours GMT. The place where Pc's are most frequent, taking into account both the GMT and the LMT factors, is located in the centre of the Pacific Ocean, and is marked by a cross in Fig. 4. The small bump in the curve at about 6 hours GMT, may be the effect of another GMT factor in the southern hemisphere which may be antiphased to that in the north, as described at the end of Section 3.1.

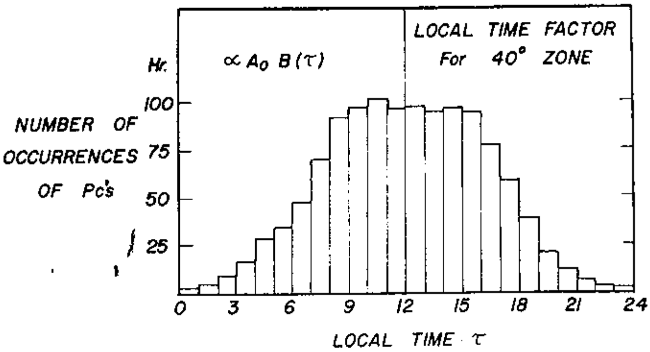

Fig. 5

4. *Discussions of the Results*

It is clear that the occurrence frequency of Pc's depends not only on local time but also on universal time, the GMT factor being connected with the inclination of the geomagnetic to the geographic axis. This investigation shows that the location of the exciting origin of Pc's is on the morning side in the auroral zone. This fact has been already anticipated by Kato and Watanabe (9) on theoretical grounds. Also the morning side in both auroral zones is always excited to some extent, the excitation intensity depending on GMT. The local time of the most excited point appears later in the afternoon as the latitude decreases.

The GMT factor is a maximum at 23 hours GMT in the northern hemisphere, i.e. when the north geomagnetic pole is about 18 hours LMT. The GMT factor in the southern hemisphere is also a maximum when the southern geomagnetic pole is about 18 hours LMT. It is worth noting that this GMT dependence differs by about 6 hours from Troitskaya's conclusion.

Micropulsations Pt are now being investigated. Although the investigation is in its early stages, it appears that Pt's have a rather regular diurnal occurrence frequency with respect both to longitude and latitude.

Data used in this study have been supplied from the geomagnetic stations of the U.S.A. and the IGY World Data Center A, Coast and Geodetic Survey, and the International Union of Geodesy and Geophysics. The authors wish to acknowledge the above source of data.

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* * *

The paper, entitled «The Morphology of Geomagnetic Micro-pulsations Pc», has ben distributed and I will therefore not discuss it in detail. There are, however, a few changes in the results, since I have since analysed data for an additional three months period, the whole period being now the twelve months October 1957 to September 1958.

I find that the occurrence frequency of pc's increases continually as the auroral zones are approached from lower latitudes, and that the hour of the diurnal occurrence appears earlier at high latitude stations. The time of maximum occurrence of pc's is about 21 hours GMT in the northern hemisphere. I still find that the occurrence frequency of pc's depends not only on local time, but also in part on universal time. The universal time factor affects the modulation of the diurnal occurrence by about 50 per 100. The modulation is quite large, the maximum value being about thee times the minimum. The place where pc's are most frequent, taking in account both the universal and the local time factors, is located on the west coast of North America.

Most of the above results are based on American data. This was because the sensitivities of all the instruments were known and because the actual quick-run magnetograms were available so that they all could be examined by one person and hence any personal bias in reading the data avoided. In this connection I would like to make two requests and ask one question concerning the IUGG-IAGA magnetic disturbance reports.

1. It is possible two describe the type of instrument and give their sensitivities for all reporting stations.
2. Would it be possible to include data on pc's and pt's from American stations — or alternatively, could there be a similar publication giving information from quick-run magnetograms in the U.S.
3. Why do reports of pt's from quick-run magnetograms and ordinary manetograms not always agree. One would at least expect that reports from the same stations using different instruments would agree in the case of very pronounced pt's.

I would also like to call attention to my paper entitled «Geographical variations in geomagnetic micropulsations» (J. Geophys. Res. 64, 581, 1959). Here the ratio of the amplitudes at two stations approximately 25 miles apart was plotted as a function of the period. Station 1 was by the sea and station 2 about 12 miles in land. It was found that $x_2 > x_1$ for periods of less than about 2 minutes. The increase was about 25 % at periods of the order of one minute and 50 % at periods of the order of 30 seconds. There was a marked increase in the ratio x_2/x_1 for periods of less than 15 seconds. The variation in gamma was much less and did not exceed 20 % at any period. The ratio z_2/z_1 was always less than unity. Even at periods of the order of ten minutes, the ratio is only 0,8. For periods of the order of 20 seconds, $z_2/z_1 < 0{,}3$ and at shorter periods this ratio decreases even more rapidly.

It is highly probable that these results are due to the fact that station 1 was by the sea and confirms the remarks made earlier by Dr E. Selzer on the effect of the sea.

The question of geographical variations is being investigated in more detail this summer by the Pacific Naval Laboratory, Esquimalb, British Columbia, the University of British Columbia and the University of Alleuta. A base station will be set up and a mobile field station at 100 meters, 1 Km, 5 Km... 100 Km... first along the geomagnetic meridian and then at right angles to the meridian. When any directional variation has been investigated, 3 or 4 stations will record simultaneously in an endeavour to see what effect, if any, local terrain has on the results. The experiments are been carried out in the plains of Alleuta far removed from the sea in a region of fairly uniform geological structure.

Finally I would like to call your attention to a short note in «Nature» (183, 381, 1959) concerning the effect of magnetic activity on geomagnetic micropulsations. A plot of z/k_p against period is almost linear. The graphs of both x/k_p and y/k_p, however, consist of parts of two straight lines, the change of slope occurring at a period of about 2 minutes. It has been since noticed that a plot of H/k_p against period is also linear, the departure from this linear relation being thus solely due to changes in the declination.

DISCUSSION

Cardús: I am not quite happy about the suggestion (on 3.2) that the occurrence of pc's depends only on universal time. If we plot the hours of maximum occurrence of pc's in local time taken from fig. 1 against geomagnetic longitude we can see that these hours arrange themselves into two practically horizontal lines suggesting perhaps the presence of two hours of maximum but with a clear dependence on local time. A similar result is obtained by T. Yoshimatsu on his paper «On the frequency of geomagnetic pulsations pc» (Journal of Geomag. and Geoelect. 10, 208-213, 1959). The same result was obtained by us independently with the data from 19 observatories received at Committee No 10. The presence of the possible double maximum may be like the double maximum found by us with the psc's data (Misceláneas del Observatorio del Ebro n.º 18) although in the pc's both maxima are further apart that in the psc's.

Selzer: How did you get the hour of maximum?

Cardús: When a pc was reported for instance from 7h 30m to 13h 15m I counted a pc for each hour between 7-8 and 13-14; this gave me an hour of maximum occurrence for each observatory.

Selzer: I am afraid that the method is not valid because in fact pc's are not absolutely continuous.

Cardús: May be, but I think that when an observatory reports pc's from 7h 30m to 13h 15m there is no interval greater than an hour without pc's; if there was such an interval, pc's should be reported as two different ones.

Selzer: I think that the hour of the beginning of pc is more relevant.

Cardús: We may look into that; and it will be shorter than our method. I would like to point out that the method we used is the same as that of Prof. Jacobs. Am I right?

Jacobs: Yes, you are.

Königsfeld presented a thesis done under his guidance with a study of the pc registered at Manhay.

Cardús: The result about the hour of maximum occurrence of pc are in good agreement with the results which I could deduce with the monthly data you send to Committee No. 10.

SUR LA VARIATION DIURNE DE LA FREQUENCE D'ARRIVEE DES PULSATIONS CONTINUES

par L. KOENIGSFELD et P. VILLERS

En prévision de l'année géophysique, un enregistreur à marche rapide (300 mm/heure, système «barre fluxmètre» de Selzer) a été installé à l'Observatoire Magnétique de Manhay —Université de Liège— dans un nouveau bâtiment approprié.

L'enregistreur à marche rapide La Cour a également fonctionné d'une façon continue.

Les pulsations continues (pc) ont été repérées heure par heure et placées à la façon de Prof. Kato en notant la qualité, la période et l'amplitude; le travail s'est limité entre septembre 1957 et novembre 1958, les observations ont été divisées de 3 en 3 mois, car sur un seul mois le nombre de pc est souvent trop faible.

En ordonnée (fig. 1) on a placé le nombre d'heures pendant lesquelles étaient apparues des pc, quelles que soient leurs qualités, amplitudes ou périodes.

En abscisse sont placées les 24 heures de la journée.

Du graphique de la fig. 1 nous pouvons tirer quelques conclusions importantes:

1) La variation diurne est nettement marquée pour toutes les périodes;

2) le maximum des pc apparaît particulièrement important dans la période de juin, juillet, août;

3) le maximum est nettement déterminé dans les 5 courbes;

4) l'heure de ce maximum qui est placé à 8 et 9 h. pour les mois de juin, juillet et août, se déplace à 10 h. pour les 3 mois précédant et suivant cette période;

5) le nombre des pc a été inférieur en 57 qu'en 58 pour la même période de septembre, octobre et novembre, mais le maximum a lieu à la même heure.

6) pour les mois de décembre, janvier et février, le maximum se déplace encore et recule à 13 h.; ce qui semble montrer nettement sa variation avec l'heure du lever du soleil.

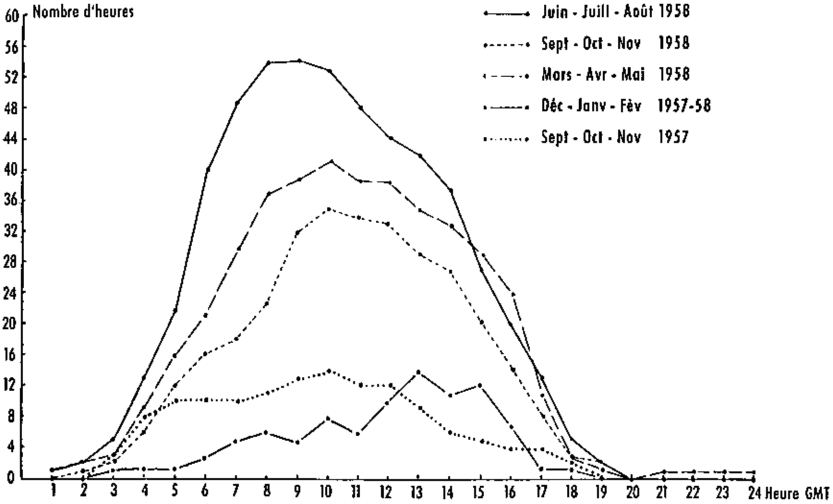


Fig. 1. — Station de Manhay. Variation diurne de la fréquence d'arrivée des pc.

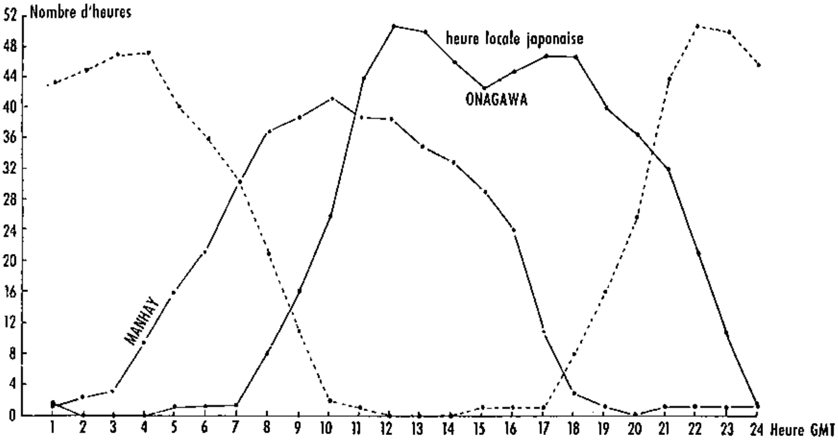


Fig. 2. — Station d'Onagawa. Variation diurne de la fréquence d'arrivée des pc. (mars - avril - mai 1958).

Nous avons repris les seules données similaires que nous possédions alors au sujet des pc: ce sont les «Monthly Reports of the Onagawa Magnetic Observatory» Géophysical Institute, Tôhoku University, Japan.

La fig. 2 donne la variation diurne des pc pour les mois de mars, avril, mai 58, calculée de la même façon que précédemment pour Manhay.

Le graphique établi tout d'abord en GMT, a été rapporté en heure locale japonaise. On remarquera que la variation diurne des pc a la même allure que celle trouvée à Manhay et rapportée sur le graphique avec le maximum de 10 h. que nous retrouvons à 12 h.

Cependant si l'allure générale du nombre d'heures de pc concorde assez bien pour ces deux stations très éloignées, elles ne correspondent plus si on les compare séparément.

C'est ainsi que nous relevons par exemple pendant le mois de novembre, seulement 6 trains de pulsations à Manhay pour une quarantaine à Onagawa et d'autre part, les 6 trains que nous trouvons ne sont pas renseignés à Onagawa.

Par contre si nous examinons les renseignements que nous avons avec ceux de De Bilt, nous retrouvons pratiquement les mêmes heures et tout particulièrement lorsque nous avons la mention AR.

Nous citerons en particulier les cas des 24 et 25 septembre 1957 où nous avons obtenu des pulsations exceptionnellement régulières et de grande amplitude et qui sont complètement confirmées à De Bilt.

Il en résulterait que les pc seraient des phénomènes locaux et en particulier simultanés dans les environs d'un même méridien.

ETUDE DE LA REPARTITION DES TRAINS DE PULSATIONS (PT) ENREGISTREES A TAMANRASSET DU 1er AVRIL 1958 AU 31 MARS 1959 SUIVANT LA POLARISATION DE LEUR DEBUT

par MICHEL BECCARIA

A Tamanrasset on enregistre les variations rapides du champ magnétique terrestre à l'aide de variomètres électromagnétiques qui permettent de déceler les pt d'une manière satisfaisante.

Sensibilité des appareils: 0,035 γ/s par mm pour $\frac{dH}{dt}$

0,024 γ/s par mm pour $\frac{dD}{dt}$

Vitesse de déroulement: 6 mm/min.

Nous nous sommes proposés de les dénombrer pendant 12 mois consécutifs —1er Avril 1958 - 31 Mars 1959— et de les classer ensuite suivant la polarisation de leur début.

Sur les enregistrements $\frac{dH}{dt}$ nous avons ainsi relevé un total de 240 pt dont nous avons étudié le début suivant les deux composantes.

Nous avons éliminé 16 perturbations sur les 240 comptées, parce que leur début était incertain pour 8 d'entre elles et négatif (vers le Sud magnétique) pour les 8 autres.

Les 224 pt restants, débutant vers le Nord magnétique, ont été répartis en 3 catégories caractérisées par le sens de leur début sur $\frac{dD}{dt}$:

a) début vers l'Ouest magnétique: 122

b) début vers l'Est magnétique: 52

c) début incertain ou n'apparaissant pas sur l'enregistrement: 50

De cette classification il ressort que la majorité des pt présente une polarisation de début Nord-Ouest magnétique pour les mois considérés.

Les tableaux 1, 2, 3 indiquent la répartition horaire mensuelle de ces trois catégorias *(a, b, c)* de pt.

TABLEAU 1

Répartition horaire mensuelle des pt débutant vers le Nord-Ouest magnétique

HEURES	Avril	Mai	Juin	Juillet	Août	Sepbre.	Octobre	Novembre	Décembre	Janvier	Février	Mars	TOTAUX
0	4	2	1	1	1	2			1			1	13
1		1		1	1			1	1	2		1	8
2				1		1	1						3
3				1								1	2
4				1									1
5				1									1
6													
7										1			1
8					1								1
9													
10													
11								1					1
12											2		2
13													
14		1				2					1		4
15													
16													
17				1			1	2		1	2		7
18	1		1				1			2	1		6
19							2			1	1		4
20		2				1	3		4	1		2	13
21	2	2	1		1	2	2		2	1			13
22	3	4	1		5	5	2	1	2		1	1	25
23	2	1	1	3		1	1		1	3	3	1	17
	12	13	5	10	9	14	13	5	11	12	11	7	122

TABLEAU 2

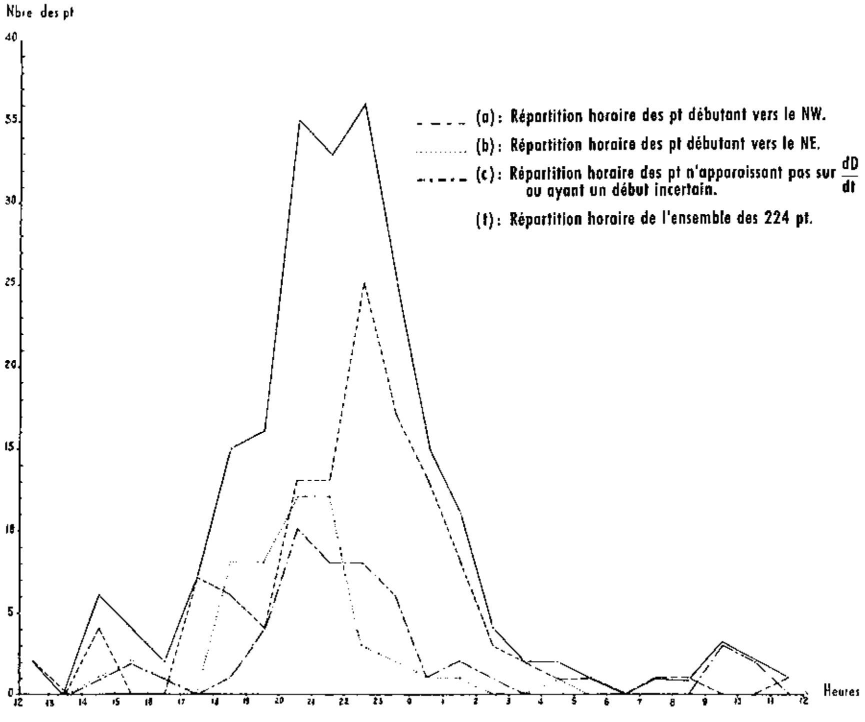
Répartition horaire mensuelle des pt débutant vers le Nord-Est magnétique

HEURES	Avril	Mai	Juin	Juillet	Août	Sepbre.	Octobre	Novembre	Décembre	Janvier	Février	Mars	TOTAUX
0			1										1
1												1	1
2													
3													
4								1					1
5													
6													
7													
8													
9													
10													
11													
12													
13													
14		1											1
15			1						1				2
16				1									1
17													
18	1		1							4	2		8
19	1				1		2	1		1	1	1	8
20	2			1		1	1	3	1			3	12
21	1	1	3	1			2			2	1	1	12
22		1				1			1				3
23				1								1	2
	5	3	6	4	1	2	5	5	3	7	4	7	52

TABLEAU 3

Répartition horaire mensuelle des pt n'apparaissant pas sur $\frac{dD}{dt}$ ou ayant un début incertain

HEURES	Avril	Mai	Juin	Juillet	Août	Sepbre.	Octobre	Novembre	Décembre	Janvier	Février	Mars	TOTAUX
0		1											1
1	1			1									2
2												1	1
3													
4													
5													
6													
7													
8													
9		1							2				3
10						1						1	2
11													
12													
13													
14									1				1
15										1	1		2
16										1			1
17													
18										1			1
19		1				1	1				1		4
20	3					2	2			2	1		10
21	3	2							1	1	1		8
22	1	2	1	2				1				1	8
23	1				1			1	2		1		6
	9	7	1	3	1	4	3	2	6	6	5	3	50



Les courbes *(a, b, c)* de répartition horaire sont construites sur un même graphique en portant les totaux horaires des pt de chacune des 3 catégories en fonction de l'heure, (vu le grand nombre de perturbations nocturnes on est conduit à prendre 0^h T.U. comme centre des abscisses).

La quatrième courbe (*t*) montre la répartition horaire de l'ensemble des 224 pt envisagés.

Les courbes présentent des maxima, mais à des heures différentes:

a) vers 22^h T.U.

b) et *c)* vers 20^h T.U.

Ces deux maxima apparaissent aussi sur la courbe (*t*).

On peut en conclure seulement que le nombre de pt débutant vers le Nord est maximum entre 20^h et 22^h T.U.

GIANT PULSATIONS IN THE SOVIET ARCTIC FOR THE PERIOD 1935-1956

by G. Korobkova, N. Nikitina,
E. Zubareva, and V. Troitskaya

(Abstract)

Pg were investigated using standard magnetograms with the time scale 20 mm/h obtained for different periods in the years 1934-1956 at the Soviet Arctic observatories, viz., Dixon Is. (Lat. 73° 33' N; Long. 80° 34' E); Wellen Is. (Lat. 66° 10' N; Long 190° 10' E); Matochkin Schar (Lat. 73° 50' N; Long. 56° 30' E); Tixie Bay (Lat. 71° 35' N; Long 128° 55' E); Cheliuskin (Lat. 77° 43' N; Long. 104° 17' E); Tikhaya Bay (Lat. 80° 37' N; Long. 58° 03' E).

The greatest number of pg were registered at the stations Dixon and Wellen. The analysis of pg on periods showed that in most cases their periods were 60 sec and 90 sec. These periods were revealed also for other stations. It is of interest to note that the greatest part of period spectrum for the station Dixon may be considered as a series of harmonics with the least period equal to 60 sec. Some other periods (except 60 and 90 sec) are characteristic for the station Wellen (namely the small period of 45 sec.). For some stations are characteristic periods of 75 sec. and 135 sec.

These data give evidence in favour of the existence of one or two fundamental periods of pg (1,2). Depending on local conditions we probably observe at the stations different harmonics of these two fundamental periods.

The amplitudes of investigated pg fall in the range from several to several tens of gamma. They amount usually to the greatest values in the horizontal component.

The diurnal distribution of pg in local time show, that pg occur mainly in the first half of the day. The maximum of occurrence falls on 5-11 hr. local time for Dixon. A supplementary plot for pg of the type A (regular) and B (irregular) was built for the station Wellen. This curve showed the maximum of pg-A occurrence falls on the

morning hours and of the pg-B on hours about noon. This explains the difference between the distribution of pg on Dixon (where mainly regular pulsations were taken in account) and the distributions of pg on Wellen. From the pg distribution in GMT, one can draw the conclusion that the pg have the tendency to occur in the time interval 20-8 GMT.

Seasonal variations in occurrence of pg for Dixon (a) reveal a clear rise of pg occurrence in equinoxes. This fact is in full agreement with the results obtained in Scandinavia (3, 4, 5, 6). The curve for Wellen is less expressive. (One has to keep in mind, however, that in course of the statistical processing of the data of this station in the category of pg were included pulsations with small periods).

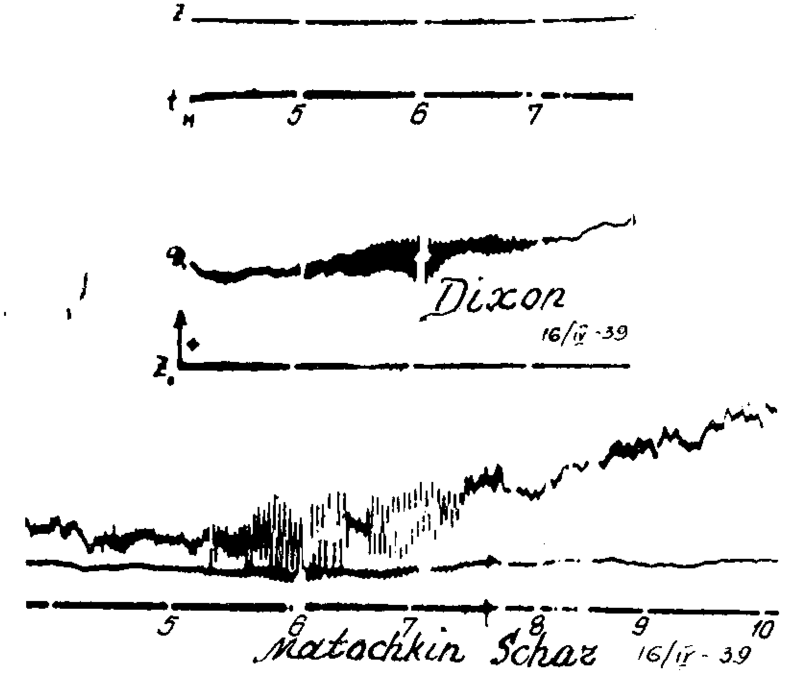


Fig. 1. — Example of Giant Pulsation registered simultaneously at stations Dixon and Matochkin Schar on April 16, 1939.

As regards the geographical distribution of pg the comparison of all observed cases showed that under existing parameters of equipment, pg are observed simultaneously on several stations only in rare cases. Nevertheless, some cases of pg were registered simultaneously in Dixon and Wellen, i.e. in the longitudinal interval of about 110°. It is quite possible, that for the investigation of the pg geographical distribution a special adjusting and coordinating of the parameters of records at different stations is necessary.

It is of interest to note, that pg are frequently observed at different stations on adjacent days, approximately at the same time of the day. Sometimes pg occur during the same day at different hours on different stations. In this case, pg frequently occur at first at the station which is located closer to the East and then at the station which is situated nearer to the West (see also ref. 7).

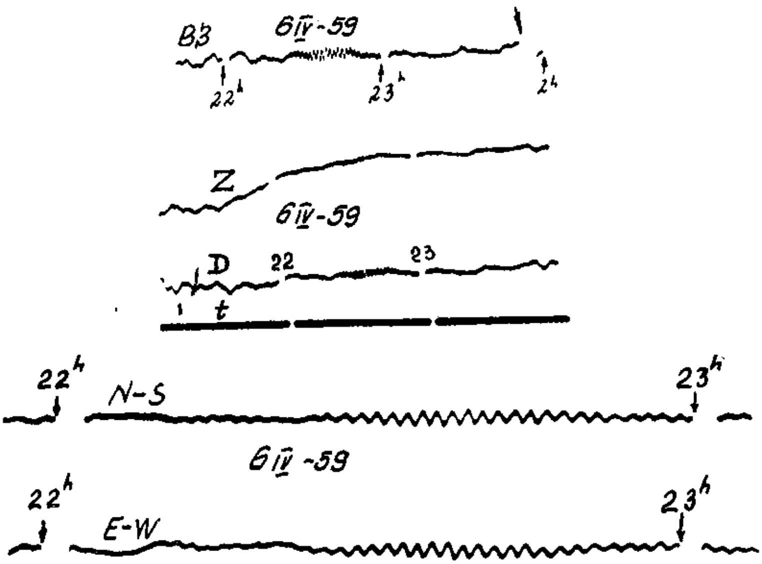


Fig. 2. — An interesting case of GP registered on magnetic and Earth current records (time scale 90 mm/hour and 20 mm/hour) in Tixie Bay.

* * *

An interesting result of the investigation is the fact that the propagation of pg is restricted not only to the South from the Aurora zone but also to the North of it. During 20 years of registration not one case of typical pg was noticed in Tikhaya Bay (Lat. 80° 37' N; Long. 58° 03' E). Besides, not one typical pg was registered at the stations North Pole 6 and North Pole 7 during the period 1957-1958 and the first three months of 1959.

All the examined cases of pg confirm us in the conclusion that pg belong to the Earth's electro-magnetic field disturbances typical for the aurora zone and diminishing quickly to the South and to the North from this zone.

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A GIANT GEOMAGNETIC PULSATION

by J. VELDKAMP

Abstract

A giant geomagnetic pulsation, which occurred on July 17th, 1958, was recorded by many European observatories between 50° and 60° geomagnetic latitude. The movements (with periods of about 100 sec) are coherent in only a small part of the area in which they were recorded. The greatest amplitudes (25γ) are found in a strip following the circles of geomagnetic latitude. Comparisons are made with theories of Obayashi and Jacobs and Scholte.

On July 17th, 1958, a remarkable vibration of the geomagnetic field was recorded at many magnetic stations in Western Europe. The vibration was almost harmonic, with a period of somewhat more than 100 sec; it lasted for more than one hour, at some stations even for more than three hours. Although pulsations of the geomagnetic field are very common phenomena, vibrations with periods and amplitudes as large as those recorded on July 17th, 1957, are rare. These vibrations have been described by Rolf (1931), by Harang (1932, 1936, 1939) and by Sucksdorff (1939) as giant pulsations *(gp)*. Harang found that during the giant pulsation the perturbing vector moves in an elliptical orbit. The g.p. are confined to the auroral zones and they can after him be ascribed either to periodic vertical movements in the ionosphere, or to a periodic intrusion of an ionizing agency in the ionosphere. Kato and Watanabe (1956) suggest that for a certain station a nearly harmonic spectrum of periods is observed. Whitham and Loomer (1958) found that the g.p.'s appear only in an extent considerably less than 2000 to 3000 km. They think that magnetohydrodynamic waves in the upper part of the ionosphere can best explain the regular oscillations, as was suggested by Lehnert (1956).

The g.p. of July 17th, 1958 offered an excellent opportunity for studying the properties of this disturbance, as the number of magnetic observatories which recorded this phenomenon was exceptionally large. In figure 1 part of the quick-run magnetogram from the Netherlands Magnetic Observatory Witteveen is reproduced. The g.p. started at 0915 hours and ended at 1245 hours; the greatest movements occurred

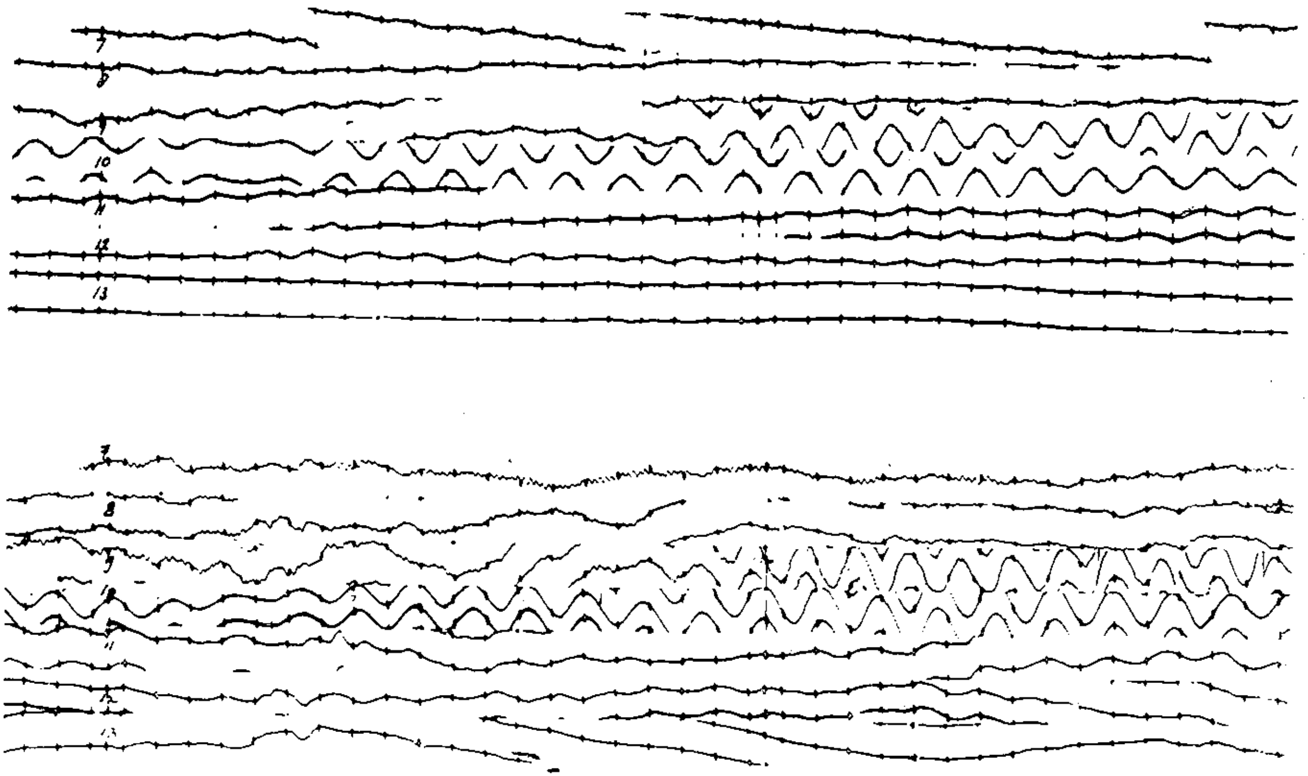

Fig. 1. — Part of the La Cour quick-run magnetogram of July 17, 1958, recorded at the magnetic observatory Witteveen (above; declination; below; horizontal intensity). The dots in the record are minute-marks. The maximum double amplitude of the pulsation is 12 γ for D and 10 γ for H.

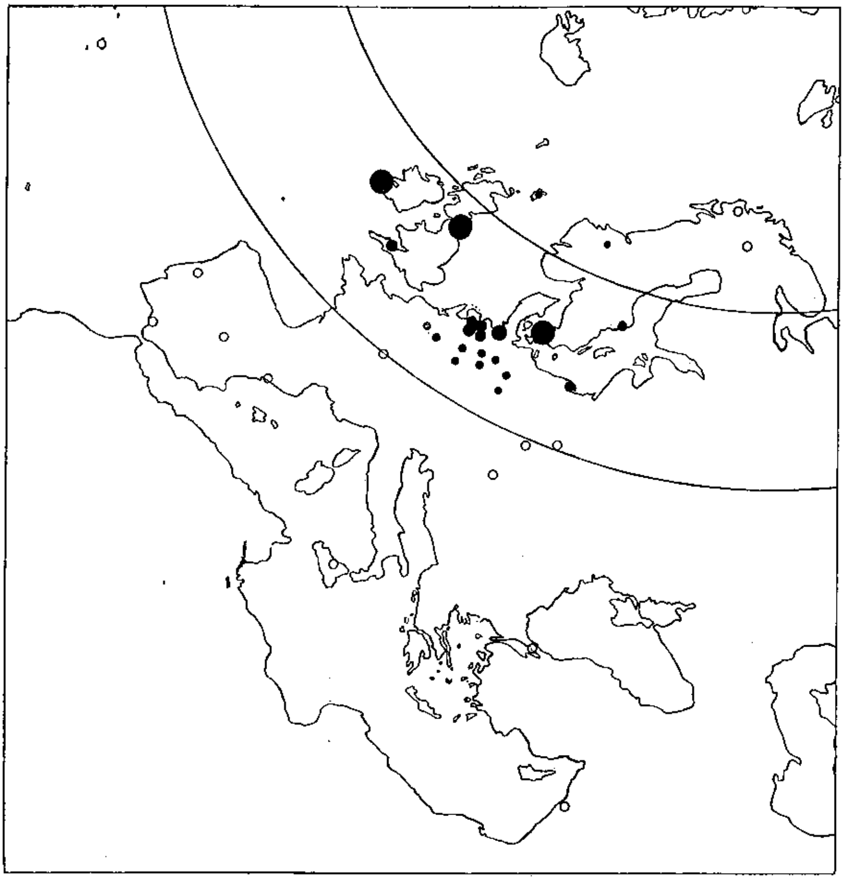

Fig. 2. — Stations in which the giant pulsation of July 17, 1958, was recorded (open circles). The size of the dots is a measure for the amplitude of the g.p. The great circles are drawn at geomagnetic latitudes of 50° and 60°. For the names of the stations see Table I.

between 0915 hours and 1045 hours. The perturbing vector moved anticlockwise in an elliptical horizontal path. The maximum amplitude was about 12 γ. The period was about 95 sec in the beginning; after 0930 hours the period increased to 105 sec and remained constant during a remarkably long time. The greatest axis of the ellipse was in the direction WNW to ESE; the ratio between the two axes was about 1:2. When comparing the geomagnetic pulsations H with the corresponding geoelectric pulsations E recorded at the same station Witteveen, we find a phase difference of 17° between corresponding maxima and minima, and an amplitude ratio E/H of 0.4 mV/γ km. These values fit rather well to the E/H curve valid for Witteveen (Scholte and Veldkamp, 1954).

Figure 2 shows the geographical distribution of the geomagnetic stations in which the g.p. of July 17th, 1958, was recorded. Thery are all situated in Europe, except for one station in America (Fredericksburg). The dots represent stations in which the pulsation was recorded; open circles are stations in which no g.p. was registered. The greatest amplitudes (about 25 γ) were measured in the stations Valentia (Ireland), Eskdalemuir (Scotland) and Rude Skov (Denmark). Roughly speaking, the pulsation occurred in a strip which follows the circles of geomagnetic latitude, far below the auroral zone.

Table 1 gives a summary of the maximum (double) amplitudes recorded; stations with a quick-run recorder have been marked by an asterisk. The time indicated is the total time during which the g.p. was recorded.

TABLE I

Station	Coordinates		Time U. T.	Amplitude		
				H	D	Z
Dombas	62°04′	9°07′	9,15 – 10,00	1 γ	1 γ	0 γ
Lerwick*)	60 08	358 49	9,10 – 10,20	2	6	0
Lovö*)	59 21	17 50	9,10 – 11,45	8	6	6
Rude Skov	55 51	12 27	9,15 – 12,20	10	25	5
Eskdalemuir*)	55 19	356 48	9,15 – 12,30	20	25	6
Hel	54 36	18 48	9,15 – 10,45	3	2	
Wingst*)	53 45	9 04	9,15 – 12.30	12	13	0
Lathen	52 52	7 19	9,15 – 10,45	9	9	2
Witteveen*)	52 49	6 40	9,15 – 12,45	10	12	0
Vorwald	52 37	6 47	9,15 – 10,45	5	8	0
Westerholfe	52 33	7 50	9,15 – 10,45	5	4	1
Fallersleben	52 25	10 44	9,15 – 10,45	3	4	3
Elze	52 07	9 45	9,15 – 10,45	3	4	0
Niemegk*)	52 04	12 40	9,20 – 10,40	2	2	1
Valentia*)	51 56	349 45	9,10 – 12,20	10	20	25
Göttingen	51 33	9 58	9,15 – 10,45	3	2	1
Collmberg*)	51 19	13 00	9,30 – 10,30	1	1	0
Schalksmühle	51 14	7 32	9,15 – 10,45	1	1	0
Hartland*)	51 00	4 30	9,00 – 11,50	9	7	6
Ehringhausen	50 36	8 24	9,15 – 10,45	1	1	0
Manhay*)	50 18	5 41	9,35 – 10,40	1	1	0
Dourbes*)	50 06	4 23	9,15 – 10,50	1	2	0
Chambon la Forêt*)	48 01	2 16	9,30 – 10,45	1		
Fredericksburg*)	38 12	282 38	9,45 – 11,40	1	2	1

The giant pulsation occurred in the beginning of a period of moderate disturbance; the Kp figures for the first half of the day were 4o, 5—, 4o and 3+. No real magnetic storm developed although the disturbed period was the recurrence of previous periods of storminess in the months of May and June. In the beginning of the day almost continuously lasting pulsations (p.c.) with periods of about 12 sec and amplitudes of a few γ were recorded. They disappeared at 0930 hours with a sudden impulse (s.i.); after that the great periods and amplitudes of the g.p. began.

When comparing the records of different stations, a remarkable phenomenon is observed. Whereas the maxima and minima of the pulsations occur at practically the same time for near stations, the correlation is completely lost for stations with distances greater than 500 km. The period of the vibrations is the same for all stations, but phase differences between the movements at different stations are found which vary over a large angle during the pulsation. The times of beginning and ending of the g.p. are also different for various stations. The ratio of the axes of the elliptical movement varies between 1.0 and 2.0 from one station to another. For most stations the movement of the perturbing vector is anticlockwise, except for Lovö (Sweden), and Fredericksburg (USA), where the movement is clockwise. It is obvious that the direct cause of the g.p. cannot be the same in stations far apart.

Coulomb (1957) has tried to explain the pulsations by ascribing them to an electric dipole (or a vertical current) in the polar region. This would imply east-west geomagnetic variations. However, the movements observed during the g.p. of July 17th, 1958, were elliptical and for some stations even almost circular. Moreover the movements were not simultaneous in stations far apart.

After the theory of Obayashi and Jacobs (1958) the geomagnetic pulsations are caused by hydromagnetic (or magneto-ionic) oscillations in the exosphere. The g.p. might indeed be ascribed to magneto-ionic oscillations along the lines of force of the geomagnetic field. The period observed (105 sec) fits very well to the period (100 sec) found by these authors for a geomagnetic latitude of 57°. The phenomenon of the whistling atmospherics has proved (Storey, 1953) that the so-called whistlers are generally propagated through tubes of somewhat enhanced ionization; hereby the whistler can only be recorded in a limited area. The fact that the giant pulsation is coherent over only a small part of the area in which it was recorded, makes it difficult to suppose a tube or sheet of enhanced ionization in which the whole movement of the g.p. takes place.

Scholte (1959) has shown that a disturbance in an ionized medium can be propagated through a homogeneous magnetic field along the lines of force without loss of energy in directions perpendicular to the field. We may suppose that this also holds for the dipole field of the earth. This means that a disturbance somewhere in the exosphere caused by an outburst on the sun, will be propagated along the lines of force while retaining its original dimensions.

So we might conclude that the area over which the g.p. of July 17, 1958, was recorded, is an indication of the size of the area in which the exosphere was disturbed at the generation of the g.p. The loss of coherence of the vibrations over a rather small distance, and the shift of starting and ending times might be caused by the occurrences in the source of the disturbance; probably not the whole area was disturbed at the same moment.

The proof of the supposition of longitudinal propagation of the magneto-ionic disturbance might be delivered by the records of stations situated at the southern end of the lines of force. However, records of such stations have not come to my attention.

ACKNOWLEDGEMENT

Magnetograms were thankfully received from the following observatories; Tromsö, Dombas, Lerwick, Eskdalemuir, Lovö, Abisko, Kiruna, Rude Skov, Hel, Belsk, Raciborz, Wingst, Vorwald, Schalksmühle, Göttingen, Lathen, Westerholte, Fallersleben, Elze, Ehringhausen, Witteveen, Niemegk, Valentia, Collmberg, Hartland, Manhay, Dourbes, Chambon-la-Forêt, Churchill, College, Baker Lake, Resolute Bay, Meanook, Agincourt, Yellow Knife, Sitka, Victoria, Fredericksburg, Ebro, Toledo, Coimbra, San Miguel, Ksara, Istanbul Kandilli, San Fernando, M'Bour, Bangui, Tamanrasset, Luanda, Elisabethville, Tucson, San Juan, Honolulu, Tananarive, Manila, Quetta, Kuyper, Huancayo, Hermanus, Pilar, Watheroo, Sodankylä and Mauritius.

Royal Netherlands Meteorological Institute,
De Bilt.

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DISCUSSION

Nelson: Why are pg's not observed inside the auroral zone?

Selzer: As a matter of fact, they have not been observed.

Coulomb: On the other hand, pg's have been observed very near the equator at Tamanrasset.

Selzer: In Kerguelen pg's follow pt's and not in Chambon-la-Forêt.

Olsen: On the Godhavn records (geomagnetic latitude 80°) no pg has been found since the establishment of the observatory in 1926.

Veldkamp: This confirms Mrs. Troitskaya's statement.

Selzer: This may be due to the fact that magnetic activity is very high and that pg's are obscured by it.

Olsen: At Godhavn there are very quiet periods just in the hours when pg could be expected.

Selzer: Could there be any influence from the sea on the pg's of the 17th of July, as the figure shown by Prof. Veldkamp may suggest?

Veldkamp: No.

G. Gjellestad: At Tromsö we observed no pg's on the 17th of July and we have the sea quite near.

Veldkamp: How can we explain the loss of coherence between records of pg's of stations further apart than a few hundreds kilometres? Must we think on bundles of lines of force which are vibrating more or less independently?

Ferraro: Yes; you are right.

Dungey: Were there pulsations with different periods?

Selzer: They are two phenomena.

Coulomb: I am not quite sure.

Dungey: Different periods are more difficult to explain than different phases.

Olsen: Was the period the same?

Veldkamp: Yes and a change occurs simultaneously in all latitudes.

Grenet: Perhaps it may help to explain the loss of coherence the fact observed in a comparison made by J. L. Bureau of pt's registered at Tamanrasset and at M'Bour. Although in general the same phenomenon was observed in both stations, sometimes the whole pulsation is registered in one station and only a part of it in the other. It seems to be a universal phenomenon which may be more or less clear in different stations.

Selzer: Perhaps we should see the total vector.

Romañá: Similar things occur with other phenomena than pulsations, for instance, with bays where it is necessary to study the total or horizontal vector if we wish to have a clear idea.

Chapman: Is this the pg observed at the lowest latitude?

Veldkamp: No; I think there were pg's observed at lower places.

Coulomb: Surely; there were pg's observed at Tamanrasset.

Bartels: Talking of giant pulsations having a few gammas amplitude, it is perhaps the time to recall the enormous world-wide pg of 100 gammas or more at the end of the storm of 1942 March 1. Dr. La Cour proposed then to make a special study of this outstanding event, when regular periods of about 10 minutes occurred for more than one hour. I suggest that this case should be taken up in the Atlas of Rapid Variations.

Romañá: This is a very valuable suggestion.

Harris: I should like to ask: what is the definition for giant pulsations?

Bartels: They are big in amplitude and period.

Harris: This sounds rather vague.

Romañá: Unfortunately it is; in the symposium of Copenhagen we did not give a definition for pg's because we could not find an appropriate one; and now in the monthly lists of rapid variations sent to Committee N. 10 we have too many reports of pg's coming from equatorial regions.

PART II

EARTH-CURRENTS PULSATIONS

ENREGISTREMENT DIRECT DES VECTEURS DE COURANT TELLURIQUE

par A. H. DE VOOGT

L'administration néerlandaise des PTT a installé des stations d'enregistrement de courants telluriques à Hollandia dans la Nouvelle-Guinée néerlandaise, à Paramaribo au Surinam et à deux endroits dans les Pays-Bas, à savoir à la station-radio Kootwijk et à Espel, village situé dans le Noordoostpolder.

L'Institut Royal Météorologique des Pays-Bas à De Bilt possède des stations magnétiques à Hollandia, Paramaribo et à Witteveen dans les Pays-Bas, de sorte qu'il se présente une occasion unique pour comparer des mesures magnétiques et telluriques.

A l'exception de Hollandia, toutes les stations sont munies d'une base Nord-Sud et Est-Ouest, donnant la possibilité d'obtenir des mesures vectorielles. A Hollandia, une base Nord-Sud additionelle est en préparation.

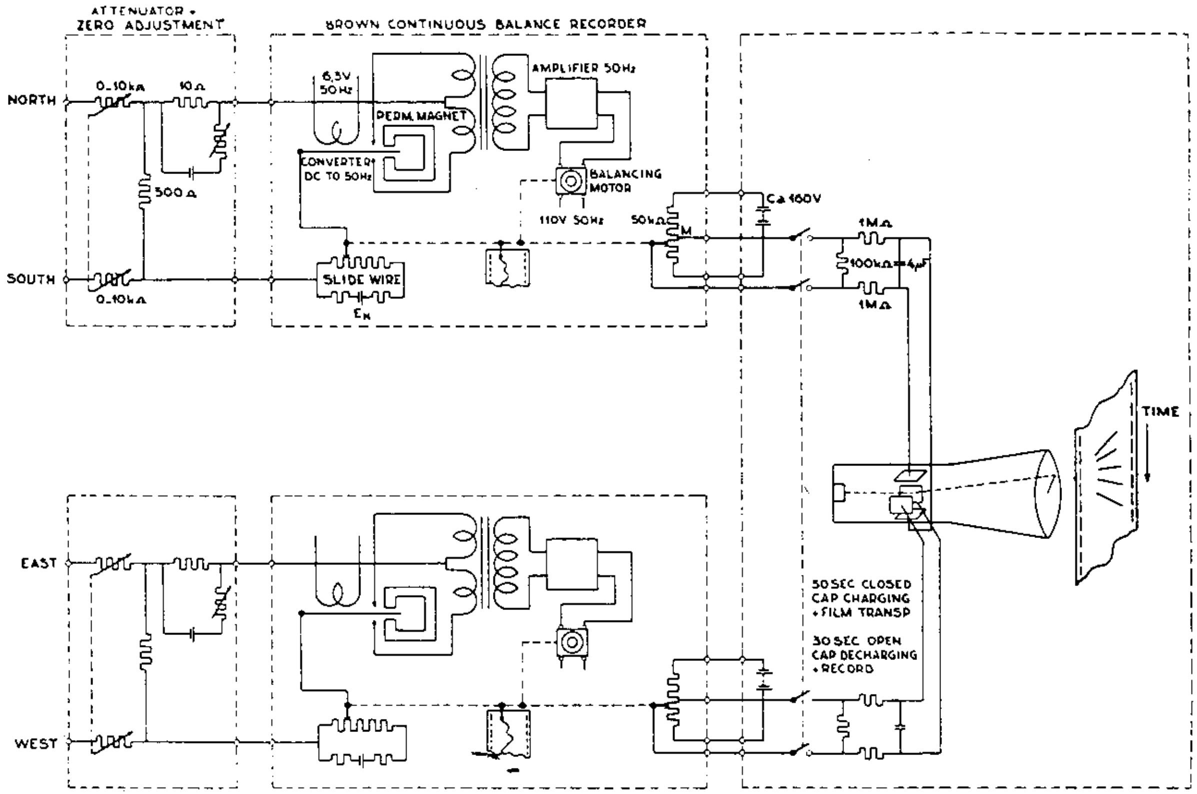
On emploie des circuits dans les câbles téléphoniques souterrains en les terminant avec des câbles isolés au plastique, lesquels relient les circuits aux prises de terre ou à des combinaisons de plusieurs prises de terre. (Voir le «Journal of Atmospheric and Terrestrial Physics», Vol. 5, pages 108-110, 1954).

En général, les bases ont une longueur de 4 km, à l'exception de Kootwijk où la base Est-Ouest est de 49 km et la base Nord-Sud est de 110 km.

Les stations à bases N-S et E-O peuvent déterminer la position du vecteur de la différence de potentiel tellurique. Pour effectuer cette détermination, il faut analyser les diagrammes N-S et E-O, ou bien on fait usage de dispositifs automatiques photo-électriques.

La première méthode est très compliquée; les méthodes automatiques photo-électriques donnent des résultats immédiats, quoique la sensibilité et la précision soient inférieures.

Je veux donner quelques détails des méthodes automatiques photo-électriques. A Kootwijk on emploie un dispositif avec deux galvano-



EARTH POTENTIAL VECTOR RECORDER AT N.O. POLDER

Fig 1

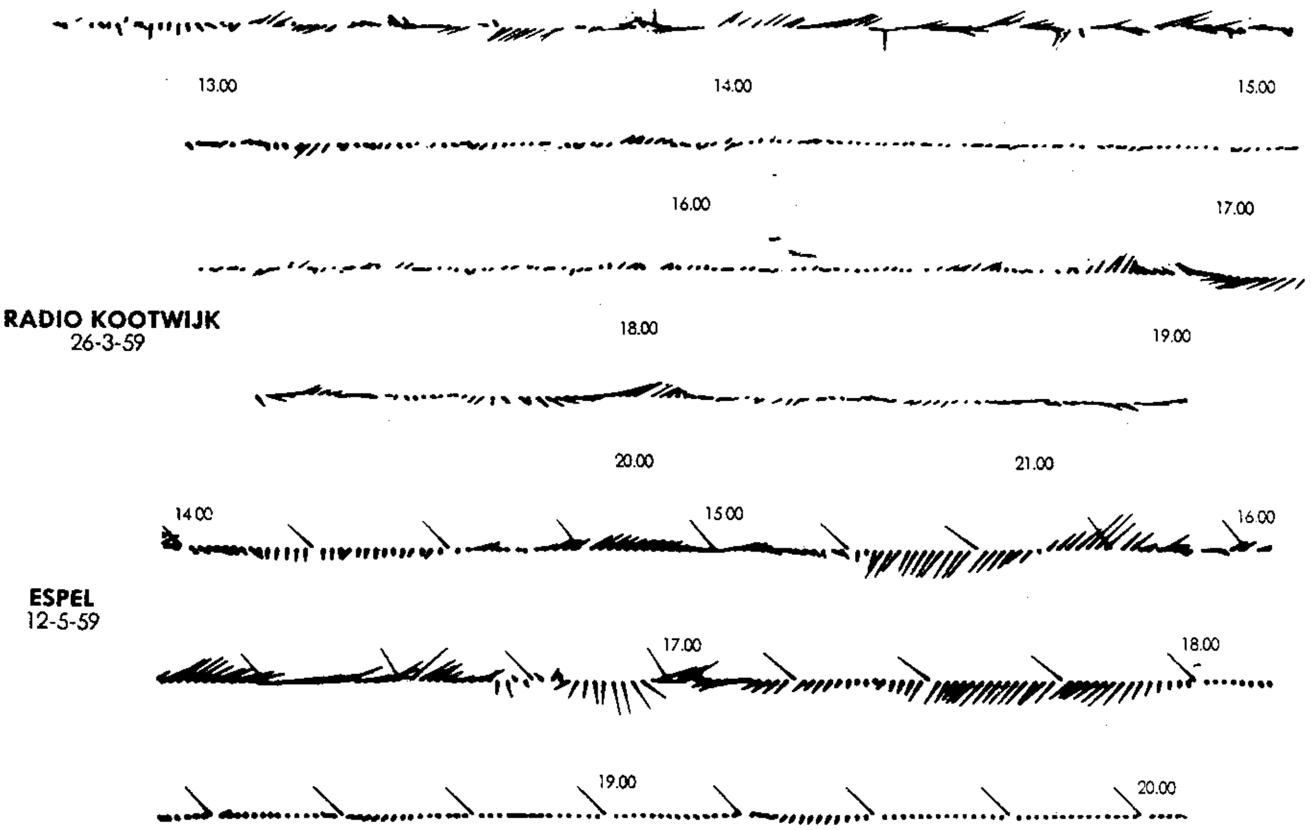

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Fig. 2

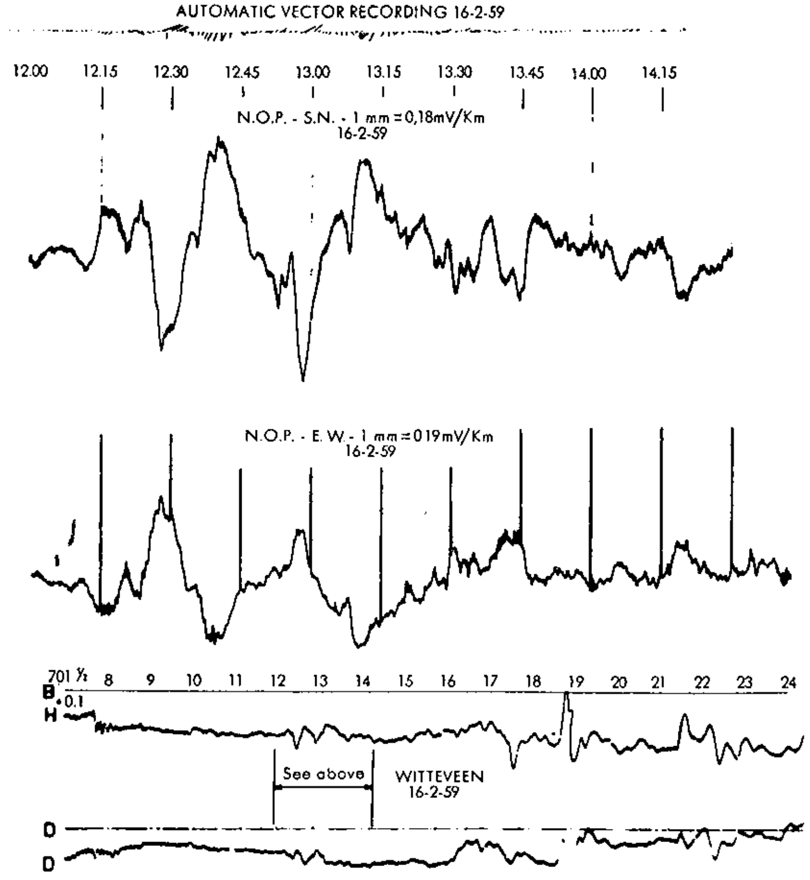


Fig. 8

mètres à miroir et un systeme de miroirs et de lentilles, de telle façon qu'un faisceau lumineux suit le mouvement du galvanomètre N-S, en donnant une déflexion N-S au spot, en même temps que le galvanomètre E-O lui donne un mouvement E-O. Les circuits N-S et E-O sont reliés pendant 30 secondes à un réseau de résistances et de condensateurs et ensuite isolés pendant le temps que les condensateurs se déchargent lentement (± secondes).

En conséquence, le spot retourne à la position zéro tout en décrivant sur le papier photographique le vecteur désiré. Le vecteur apparaît ainsi toutes les minutes.

A Espel (Noordoostpolder) on a installé un dispositif mécano-électrique. Je vais expliquer le principe en deux mots:

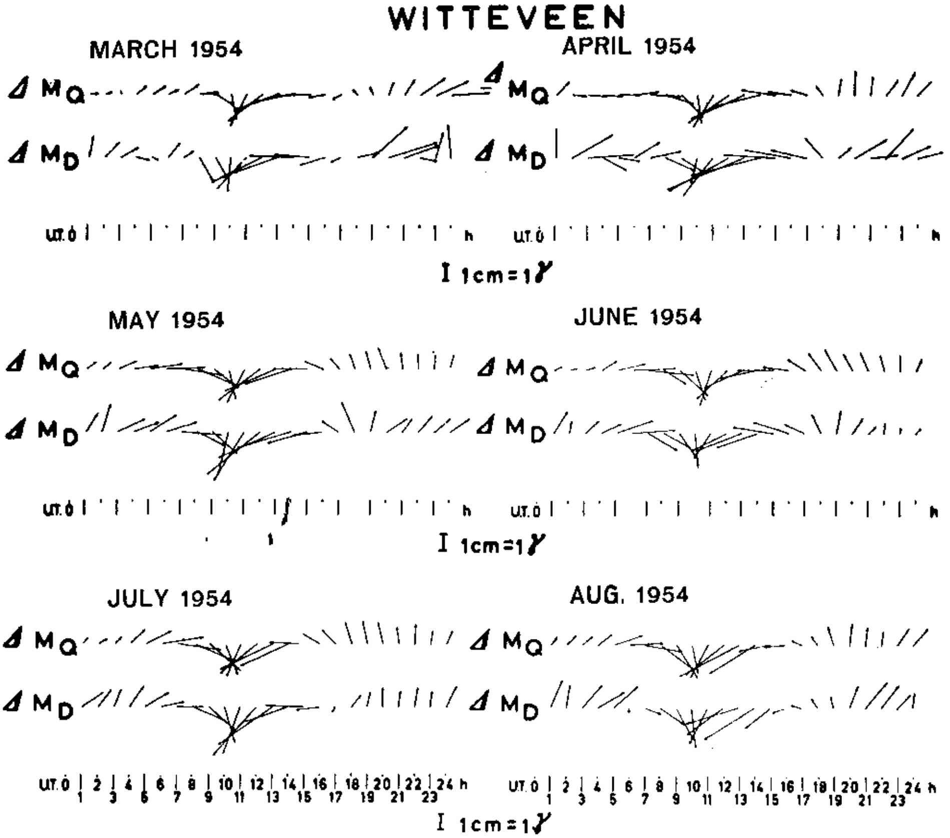


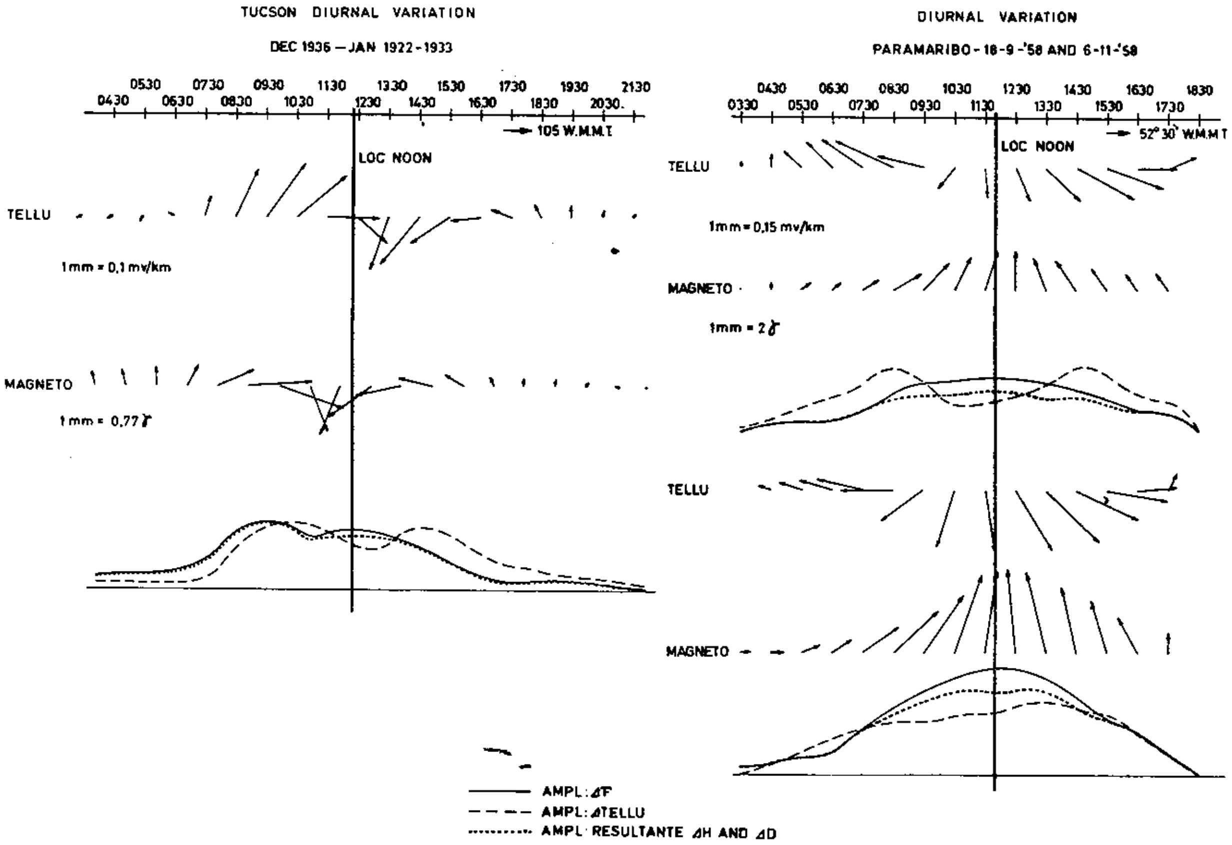
Fig. 4

On emploie les «Brown-continuous-balance recorders». (Fig. 1.)

Dans ces appareils, un potenciomètre est réglé par un petit moteur jusqu'à ce qu'il arrive dans la position où le potentiel tellurique est compensé. Cette position fixe en même temps la position de l'aiguille indicatrice laquelle décrit la courbe d'enregistrement sur le papier.

Pour le nouveau dispositif nous avons accouplé avec le potentiomètre original de l'enregistreur Brown un second potentiomètre auquel une tension électrique assez considérable est appliquée afin de lui donner une déflexion suffisante au spot d'un tube à rayons cathodiques avec écran.

De cette façon, une paire de plaques du tube donne une déflexion pour la potentiel N-S et l'autre pour le potentiel E-O.


TUCSON DIURNAL VARIATION
DEC 1936 — JAN 1922-1933
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0530
0630
0730
0830
0930
1030
1130
1230
1330
1430
1530
1630
1730
1830
1930
2030.
2130
→ 105 W.M.M.T
LOC NOON
TELLU
1mm = 0,1 mv/km
MAGNETO
1 mm = 0,77 γ
DIURNAL VARIATION
PARAMARIBO - 18-9-'58 AND 6-11-'58
0330
0430
0530
0630
0730
0830
0930
1030
1130
1230
1330
1430
1530
1630
1730
1830
→ 52° 30' W.M.M.T
LOC NOON
TELLU
1mm = 0,15 mv/km
MAGNETO
1mm = 2 γ
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MAGNETO
AMPL: ΔF
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AMPL· RESULTANTE ΔH AND ΔD

Fig. 5

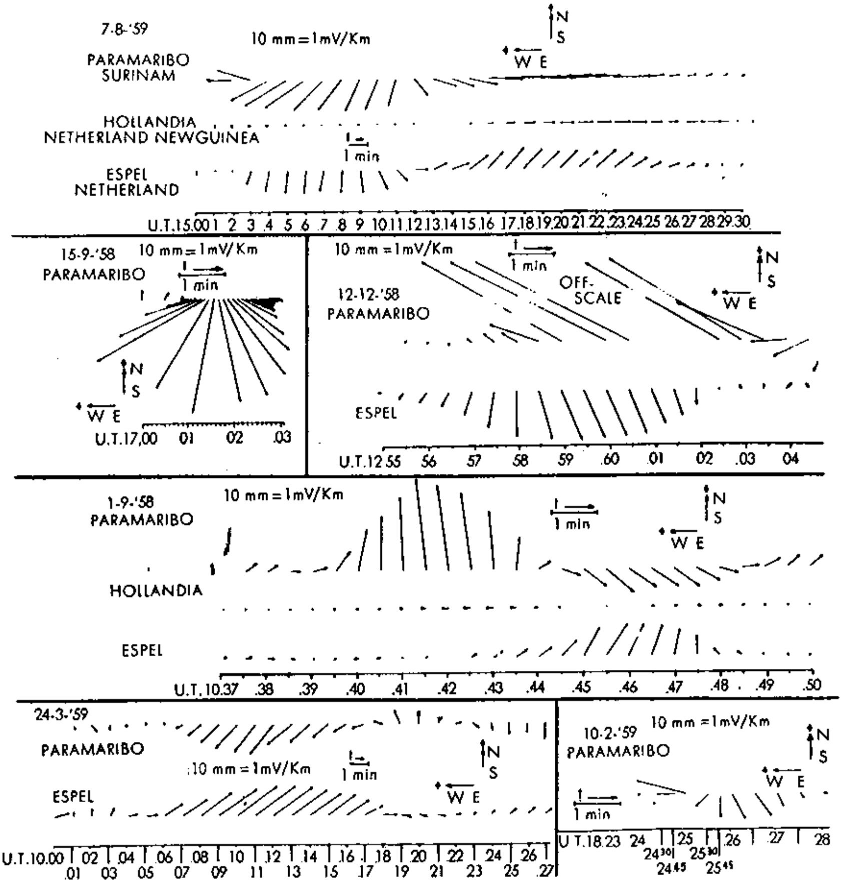


Fig. 6

La décharge du réseau de condensateurs et de résistances, toutes les 30 secondes, cause une trace sur l'écran cathodique, laquelle est photographiée automatiquement.

La fig. 2 montre quelques résultats; les traits obliques, qu'on aperçoit toutes les 15 minutes, donnent les marques de temps et en même temps un étalonnage.

Leur longueur représente 26 mV/km. La rotation du vecteur pendant une perturbation baie se montre nettement.

Dans la fig. 3 on a ajouté les enregistrements normaux. En les examinant on s'apercevra qu'aucune indication positive n'est donnée pour trouver le caractère de la perturbation. On ne sait pas si le vecteur a une rotation ou bien s'il ne prend que des positions «random».

tandis qu'au contraire l'enregistrement vectoriel fait une distinction nette.

A l'heure actuelle l'enregistrement direct vectoriel n'est pas suffisamment sensible pour montrer la variation diurne.

A Paramaribo l'enregistreur Brown fournit cette variation, mais pas encore au moyen du dispositif automatique. Celu-ci sera aménagé au cours de cette année. Nous avons dépouillé les diagrammes suivant la méthode classique analytique pour trouver les vecteurs.

A mon avis, il est important de connaître chaque jour l'intensité de la variation magnétique et tellurique diurne, parce qu'on pourrait en tirer à terme court une indication de l'activité solaire.

La variation magnétique diurne de Witteveen, une station de «De Bilt» (fig. 4), est représentée sous forme de vecteurs successifs pour toutes les heures. Les données sont tirées du «Year Book of De Bilt». On voit que le vecteur tourne en concordance avec le système des courants électriques dans la haute atmosphère.

La fig. 5 représente la variation diurne tellurique et magnétique à Paramaribo et à Tucson. En comparant ces diagrammes, il faut faire remarquer que

1.º les échelles ne sont pas les mêmes;

2.º Paramaribo donne les valeurs pour un seul jour, tandis que les diagrammes de Tucson sont basés sur des moyennes mensuelles pendant un cycle solaire. Pourtant on voit le caractère différent typique de la saison et on peut constater que ni à Paramaribo ni à Tucson il existe un angle de phase déterminé entre les vecteurs magnétiques et telluriques.

Nous avons aussi fait l'analyse des diagrammes pour un nombre de «solar flare effects»; l'enregistrement automatique et vectoriel n'était pas encore disponible à ce but, mais il le sera à l'avenir.

La fig. 6 donne des exemples typiques pour trois stations:
Hollandia, Paramaribo et Espel (Noordoostpolder).

Il est évident que, pendant l'intervalle relativement court du s.f., les vecteurs font des rotations considérables.

DISCUSSION

Bartels: Dr Untiedt has obtained at Göttingen vectograms of the magnetic variations which we can compare with the work of Mr de Voogt.

GEOMAGNETIC HORIZONTAL VECTOGRAPH

By J. Untiedt

At Göttingen we have established a selfrecording geomagnetic horizontal vectograph during the IGY (1957 July - 1958 August). Fig. 1 shows the principle of the apparatus. (See also «Zeitschrift für

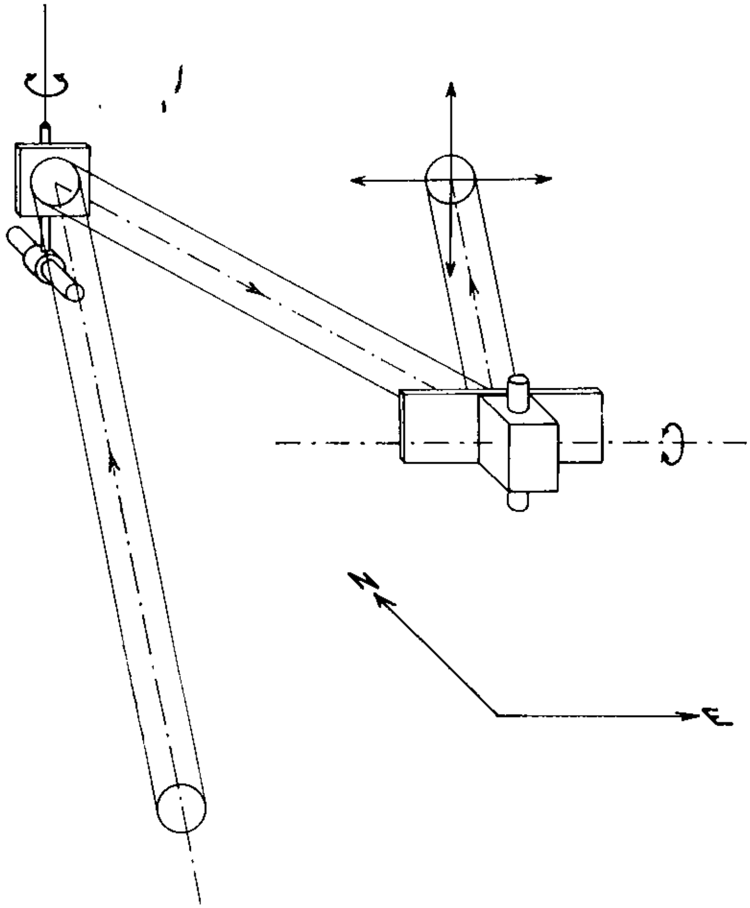


Fig 1

Geophysik» 24, 125-133, 1958). At first we intended to examine «Sangster's phenomenon» (Proc. Roy. Soc. London A, 84, 85-92, 1910; Chapman and Bartels «Geomagnetism» Oxford 1940, 314-317). However, when we learnt from the records that the geomagnetic variations showed partly a linear polarization we turned our attention to this unexpected phenomenon. From the detailed investigation by Schmucker we know that the effect has nothing to do with the anomalous behaviour of the geomagnetic variations due to the anomaly of underground conductivity in northern Germany.

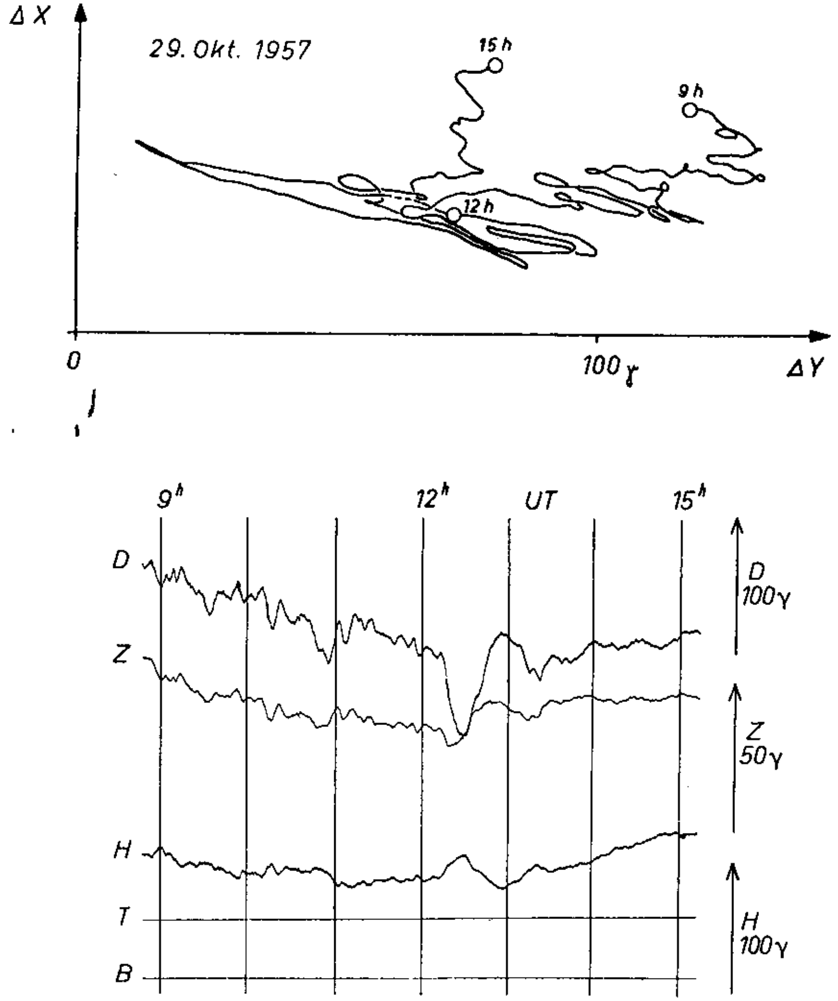


Fig 2

Three selected examples showing especially clear «linear deflections of the geomagnetic horizontal vector» may illustrate this type of variations (fig. 2-4. Above, the horizontal vectograms drawn from the original records; below, the corresponding Göttingen standard magnetograms).

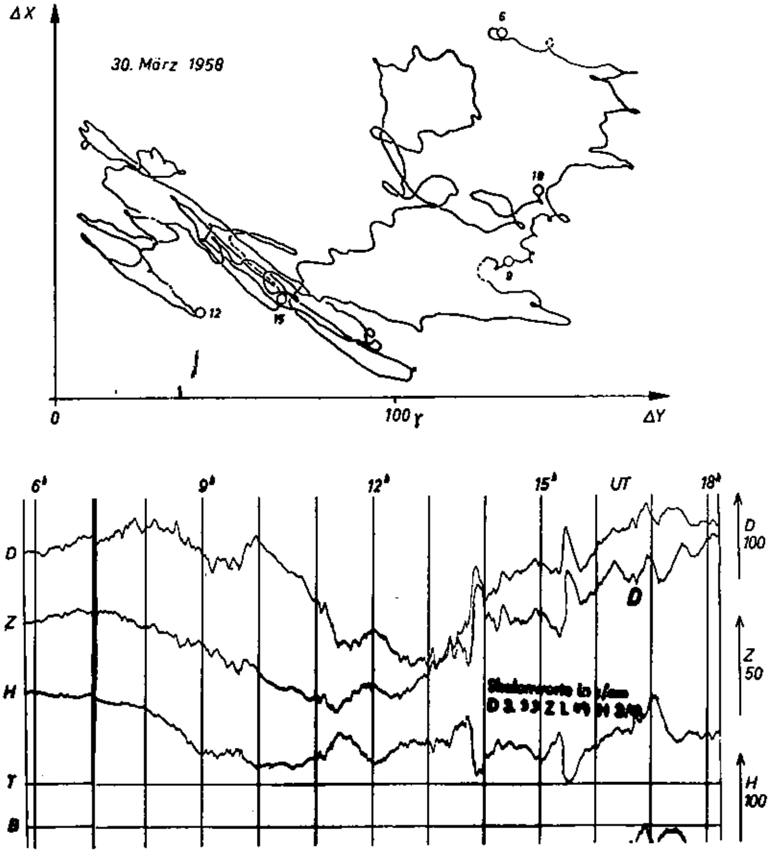


Fig. 3

The polarization appears in the day-time about 4 and 18h UT (approximately LMT for Göttingen). It controlls nearly all variations with periods between, say, 10 and 60 minutes and amplitudes larger than 20 γ if storm-time intervals are excluded.

Fig. 5 shows frequency-distributions of the direction-angles. The angles are counted anti-clockwise from the east direction, modulo 180°. The data have been arranged with respect to months and eights of the day (E_2: 3-6 h UT. E_3: 6-9 h UT...). Obviously the angle of polarization is approximately the same for each eighth of the day and each month, but there seem to be systematic daily and annual variations. During the day the angle turns clockwise, and between 9 and 18 h UT it is larger in winter than in summer, whereas there are no seasonal variations in E_2 and E_3 (in winter the deflections have approximately W-E-direction, in summer after 9h NW-SE-direction). For E_4, E_5 and E_6 the systematic annual variations of the mean angles are rather well represented by sinecurves (fig. 6. Empty circles: Mean values. Full circles: Median values).

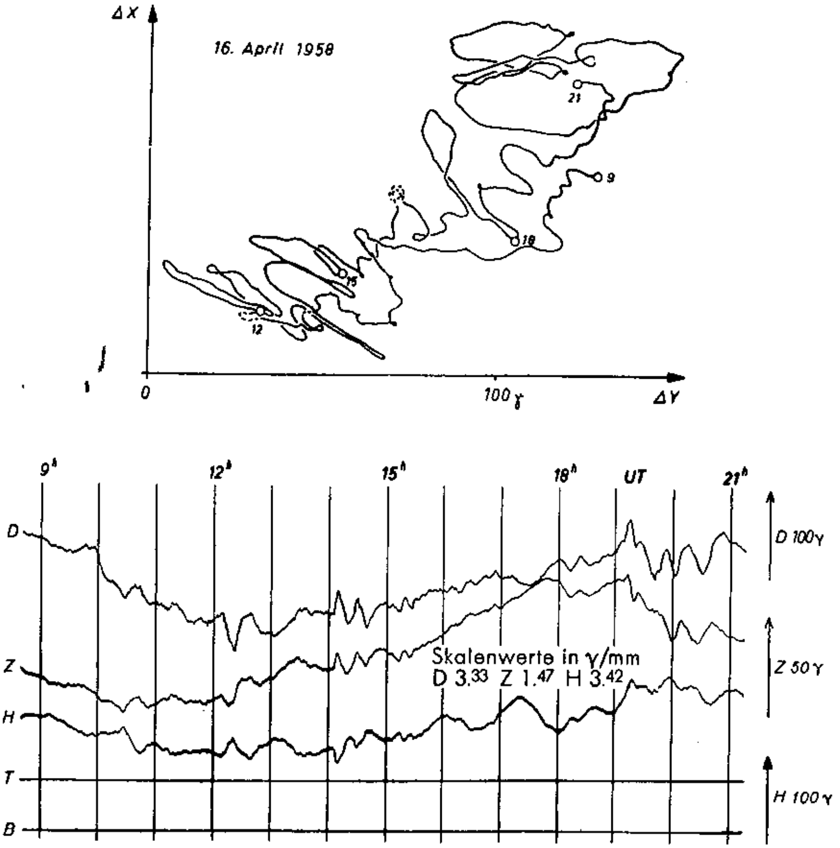
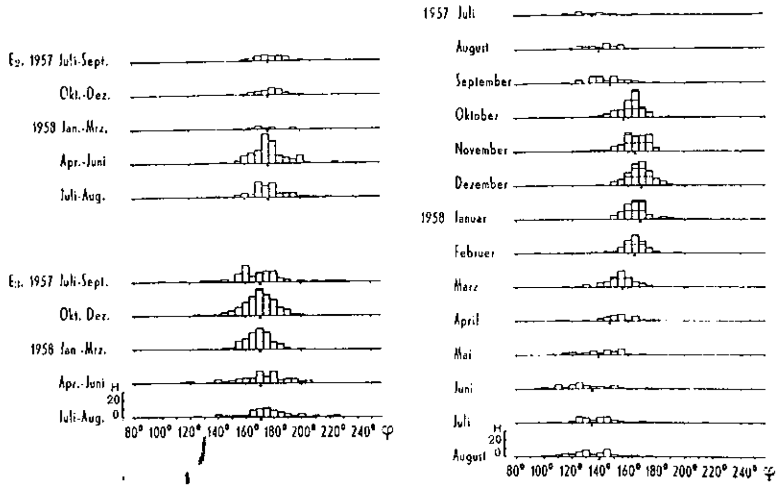


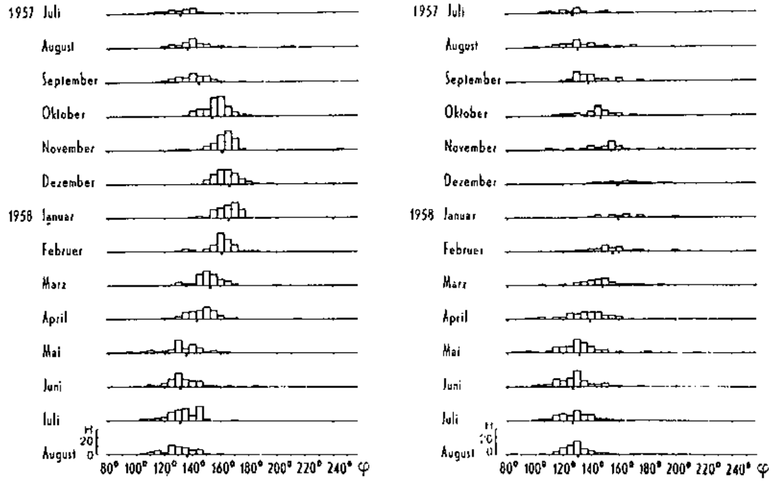
Fig. 4

These linear deflections of the geomagnetic horizontal vector have not immediately to do with pulsations. The investigation, however,



$3-9^h$ UT

$9-12^h$ UT



$12-15^h$ UT

$15-18^h$ UT

Fig. 5

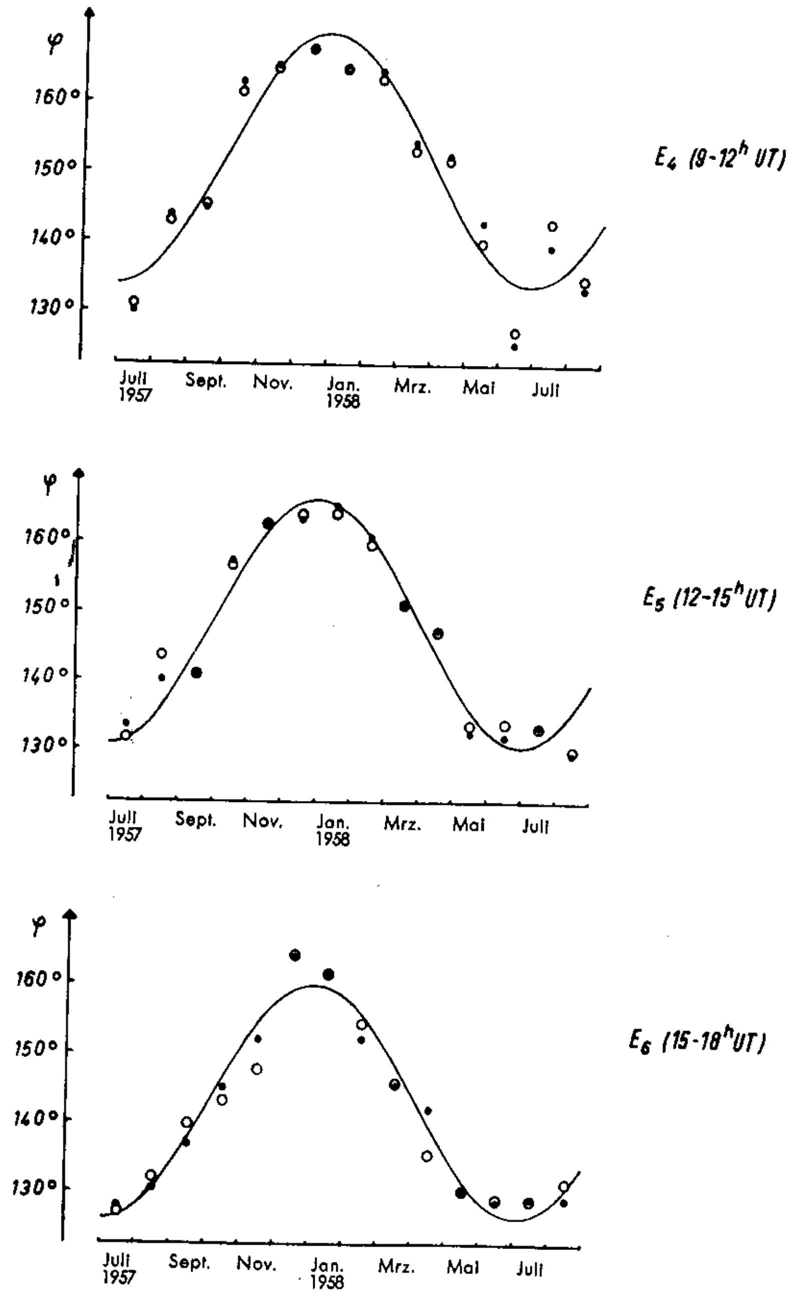

φ
160°
150°
140°
130°
Juli 1957
Sept.
Nov.
Jan. 1958
Mrz.
Mai
Juli
E₄ (9-12ʰ UT)
φ
160°
150°
140°
130°
Juli 1957
Sept.
Nov.
Jan. 1958
Mrz.
Mai
Juli
E₅ (12-15ʰ UT)
φ
160°
150°
140°
130°
Juli 1957
Sept.
Nov.
Jan. 1958
Mrz.
Mai
Juli
E₆ (15-18ʰ UT)

Fig. 6

was confined to periods higher than, say, 5 min. This confinement was probably more due to the apparatus than to the phenomenon itself. So it may be that a corresponding predominant direction will be found also for pulsations with longer periods (see the report by Kalashnikov and Zybin presented to this meeting).

DISCUSSION

Chapman: This vectors show a rotation. Did you find a sense in the rotation of the loops?

Untiedt: Yes; before night the sense is anticlockwise; but we did not study this point in particular.

Chapman: Have you found any discrepancy with the Greenwich results?

Untiedt: There is no discrepancy; and the vector at Chambon-la-Forêt turns in the same way.

De Voogt: How does the vector vary?

Untiedt: In one day it turns clockwise.

Coulomb: What was the sense of rotation in the giant pulsations of the 17th of July 1958?

Veldkamp: The sense was counterclockwise.

Cardús: Have you related the sense of rotation with the rotation of the vector of geomagnetic bays?

Untiedt: Yes, but only in a general way.

Bartels: All that means that the ionosphere changes in intensity.

Coulomb: But it could also shift.

Bartels: Yes, you are right.

Schlich: We have studied the vector-diagrams of polar stations for about 150 cases: for pc there is no sense of rotation; for pt there is a small rotation, but we need more cases before we get final results.

Selzer: At Charcot Dr Lebeau tried to make magnetograms, but the work was discontinued because the traces were too confused.

PULSATIONS OF BEATING TYPE (T~1-4 SEC) «PEARLS», IN THE ELECTROMAGNETIC FIELD OF THE EARTH

by V. A. TROITSKAYA

(*Abstract*)

A new characteristic type of short periodic oscillations of the Earth's electromagnetic field was discovered on a wide network of stations (1). The installations used for 24-hour running rapid registration are described in (2).

These oscillations, bearing the features of a beating type pulsations were named pearls for the beauty of forms of a series of these oscillations. The pearls may occur as separate bursts lasting 1-2 minutes or as a series of oscillations lasting several tens of minutes with a very steady period of oscillations inside the series.

A tendency of repeating approximately at the same hours in the course of two adjacent days is characteristic of this type of pulsations. In such cases the periods of pulsations may change. The pearls have a very narrow spectral distribution from several portions of a second to 4-5 seconds.

Pearls with periods greater than 4 sec are very rare. They occur mainly at the beginning of intervals of pulsations diminishing to periods (IPDP) (2) in the course of magnetic storms. In those cases separate bursts of pulsations of beating type with periods 5-10 sec may take place. The amplitude of pearls falls within the range of 0.01 to 0.1 mV/km for the middle latitude Earth currents stations on quiet days. On disturbed days the amplitude of pearls rises in the middle latitude to several millivolt per kilometre. In polar regions the amplitude of these pulsations has the order of several and several tens of millivolt per kilometre. The estimation of the amplitude of these pulsations in the magnetic field give values of the order from several thousandth's to several hundredth's of gamma (for Z). The results of pearl investigations show, that these pulsations may occur simultaneously in the Arctic, in the Antartic and in a vast longitudinal interval in the middle latitudes (more than 120°). The pearls on the other hand belong to the

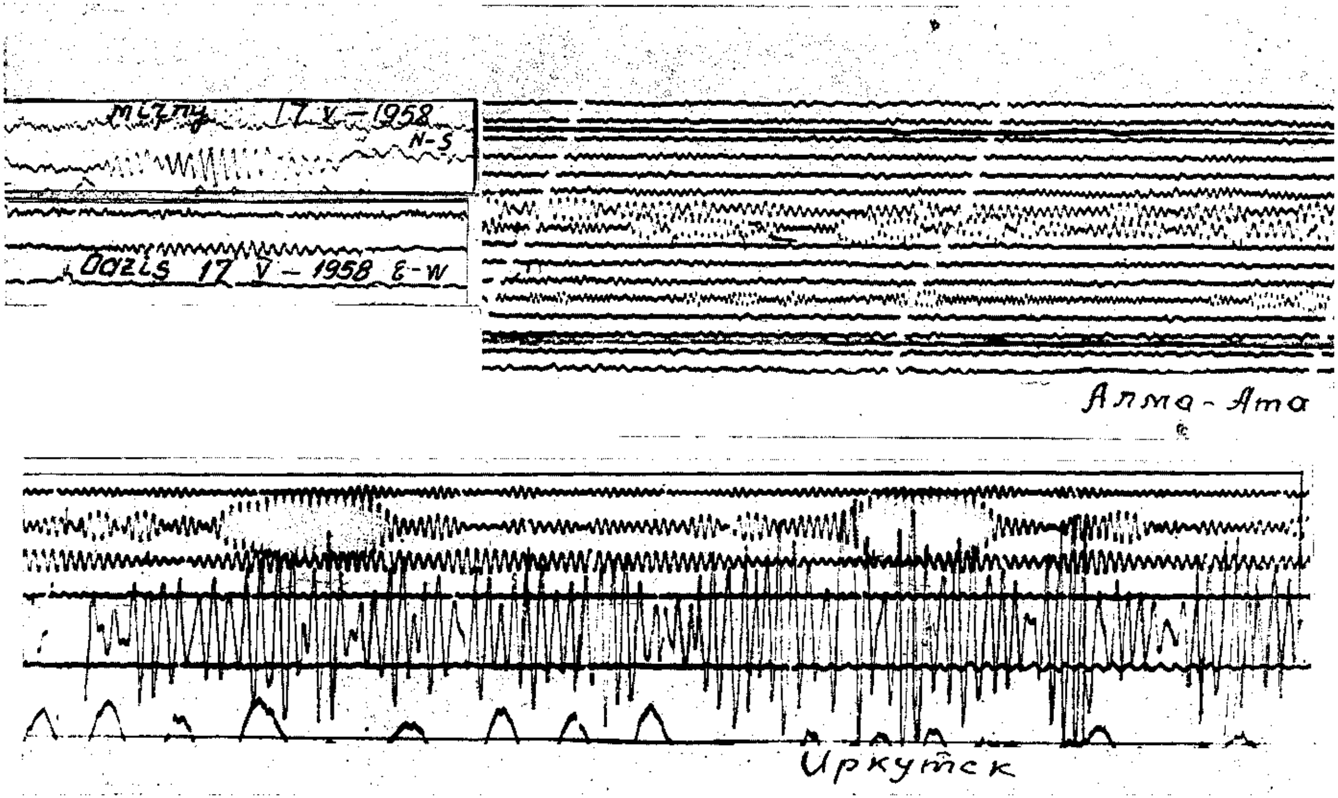


Fig. 1. — Examples of the beating type pulsations-pearls:
a) Typical burst of pearls, 17-V-1958.
b) A series of pearls.
c) Pearls during a magnetic storm (Irkutsk).

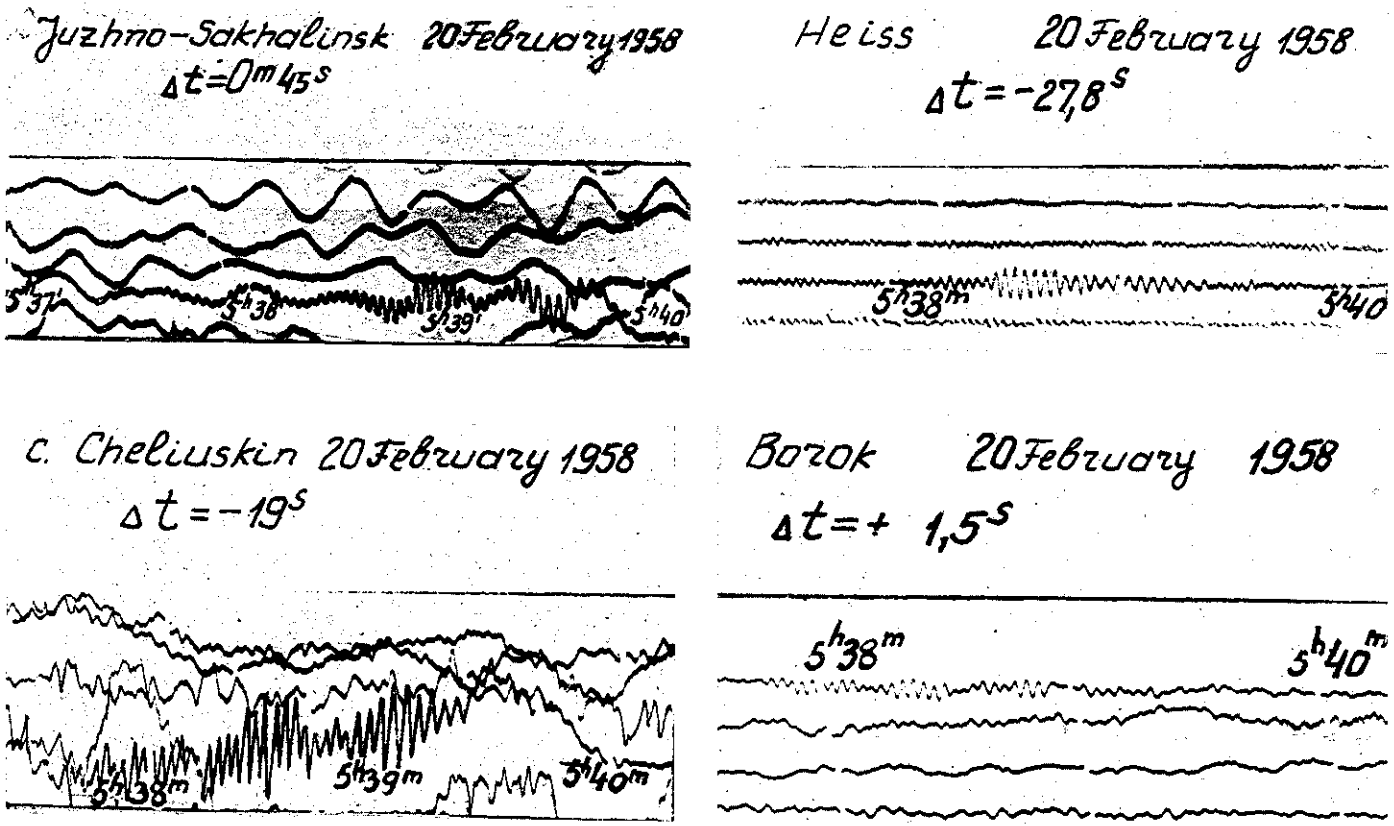


Fig. 2. — Burst of pearls registered simultaneously at different stations.

characteristic elements of great magnetic storms microstructure in respect of pulsations. They compose for instance the characteristic intervals of pulsations diminishing by period (the IPDP) revealed for the greatest magnetic storms (3). A direct correlation with the development of intensive high atmosphere disturbances was discovered for these «stormy» pearls. In some cases coincidence of pearls occurrence with bursts of X-rays in the atmosphere (~30 Km) was noted. The investigation of their geographical distribution lead to the conclusion that their excitation may be controlled both by local and universal time. It seems that they originate in the outer atmosphere beyond the ionosphere. The first results show that the regimen of pearls excitation in the Arctic and in the middle latitudes is somewhat different. In the Arctic short separate bursts of oscillations prevail. and in the middle latitudes continuous series of pearls are often observed. Pearls of greater periods (~4 sec) are more characteristic for the Arctic, than for the middle latitudes. The diurnal distribution shows, that pearls are recorded mainly during the evening, night and morning hours of local time.

The latitudinal difference in the diurnal distribution of pearls may be due to the above-mentioned difference in types of pearls registered in polar regions and in the middle latitudes (bursts and series of pearls).

The diurnal distribution of pearls in polar regions has several maxima.

Considering seasonal changes of pearls it is necessary to distinguish cases of pearls arising during magnetic storms and belonging to intervals of pulsations diminishing by periods (IPDP) (1) from pearls occurring during quiet and moderately disturbed days.

It is clear that the first ones, i.e. pearls recorded during magnetic storms or days following the storm (this feature is characteristic of pearls) will reveal seasonal changes similar to seasonal changes of magnetic storms with maxima falling on equinoxes. Seasonal changes of pearls occurring during quiet days will be investigated on the basis of more extended experimental material.

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DISCUSSION

Bartels: The name of pearls has been used by V. Troitskaya as a good expression for a quite typical phenomenon. I must confess that I used the expression of a string of pearls for something different, namely, the appearance of a photographic magnetogram during an overhead aurora, when pulsations are superposed on the general course of an auroral bay disturbance (Gerland Beiträge zur Geophysik, 55, 193-203. 1939).

Selzer: When registering with free magnets we must be sure that pearls in the records are not due to the free oscillations of the undamped magnet.

Olsen: In the records of the 2nd Polar Year we have many cases of pearls in the Arctic Regions where undamped recording magnets were used; but at least in some cases these pearls correspond to the oscillation period of the magnet itself.

De Voogt: Telluric measurements have to do with electric currents and electric instruments. Now in electric circuits there is a distinct difference between *pulses* and oscillation. Pulses are changes in current or potential with an abrupt change and no definite frequency at any moment; oscillations have more or less constant amplitudes and a constant definite frequency. Combination of oscillations of different frequencies and amplitudes gives very often current-curves or potential-difference-curves which resemble (are quite like) series of pulses. In Paramaribo we therefore indicate pt's often as long series of oscillations of different frequencies, one or the other now and then dying out. Pearls may be regular «beats» of oscillations of a frequency of 0.25 Hertz (4 per second) and 0.26 Hertz giving 100 sec. for the total length of the pearl.

ON CHARACTERISTIC INTERVALS OF PULSATIONS DIMINISHING BY PERIODS (IPDP) IN THE ELECTROMAGNETIC FIELD OF THE EARTH AND THEIR CONNECTION WITH PHENOMENA IN THE HIGH ATMOSPHERE

by V. A. TROITSKAYA, and M. V. MELNIKOVA

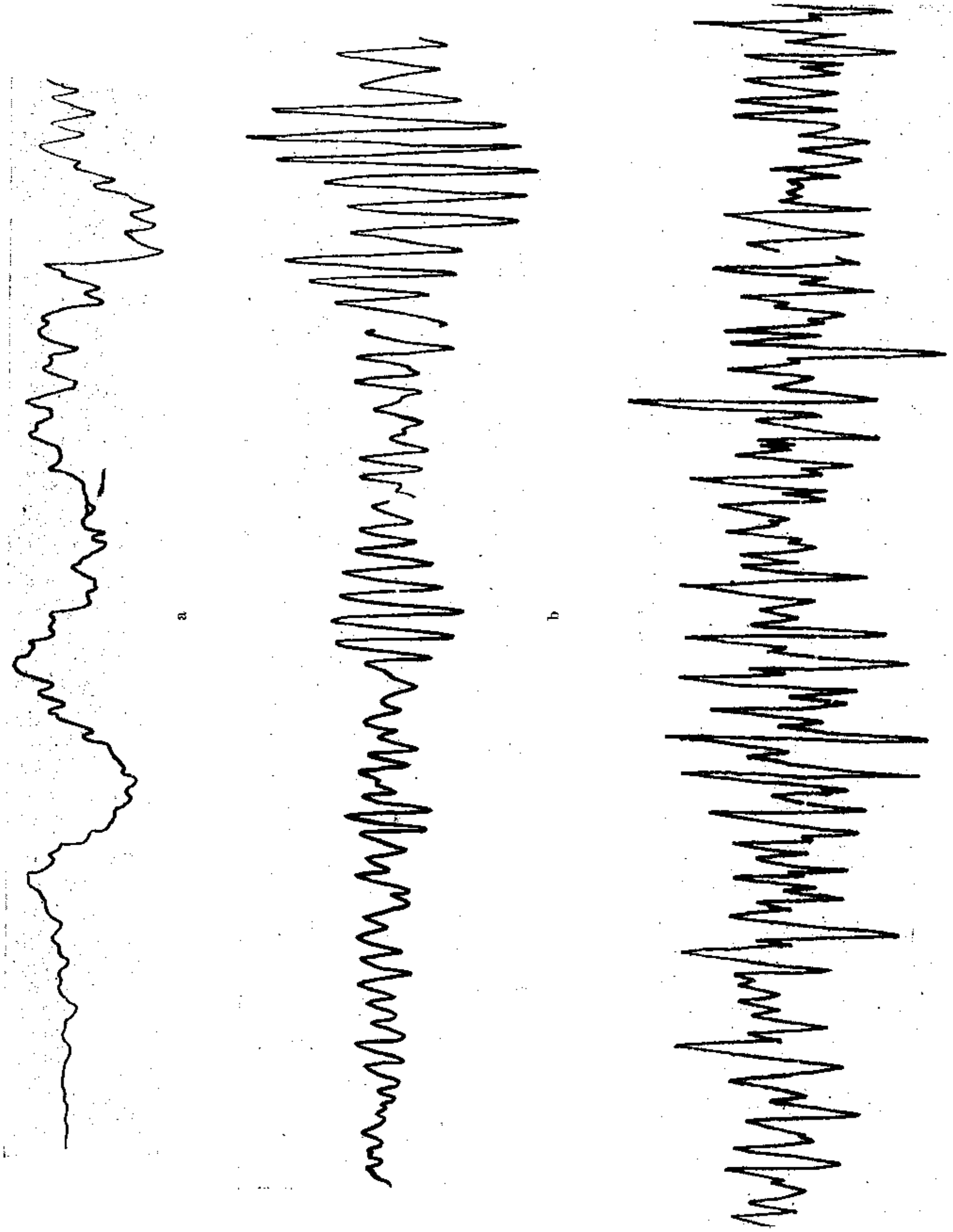
(*Abstract*)

Investigation of quick 24 hours running records (1/2 mm per sec) of Earth currents showed that characteristic intervals of pulsations diminishing by periods (~from 10-8 to 1 sec) systematically occur in the course of great magnetic storms (1, 2). The beginning of these IPDP coincides with the appearance of aurora displays in low latitudes and with the beginning of periods of great disturbances in ionosphere, namely sharp falls of critical frequencies of the layer F_2, absorption or diffusion (3).

The experimental materials studied up to date showed that IPDP represent the specific variations of the Earth's electromagnetic field which are directly connected with the development of great disturbances in the high atmosphere.

Thus the IPDP can be used as the morphological criteria for the determination of periods inside magnetic storms when the disturbances in the high atmosphere are most intensive. On the other hand, the characteristics of pulsations in the IPDP, the laws of their excitation on local and universal time and the peculiarities of latitudinal distributions of IPDP give new parameters, which can be used in investigations of magnetic storms, high atmosphere phenomena and processes of interaction of solar corpuscular streams with the belts of charged particles surrounding the Earth.

The IPDP were discovered in the course of analysis of magnetic storms microstructure in respect of pulsations (4). Twenty-four hours quick run records (1/2 mm per sec) for the period of the IGY from 17 Earth current stations were used in this investigation. Two of these stations are located in the Antarctic, five in the Arctic and ten in the middle latitudes. Fig. 1 (a, b, c, d, e, f, g) shows characteristic series of pulsations which form the IPDP - the elements of IPDP.


a
b

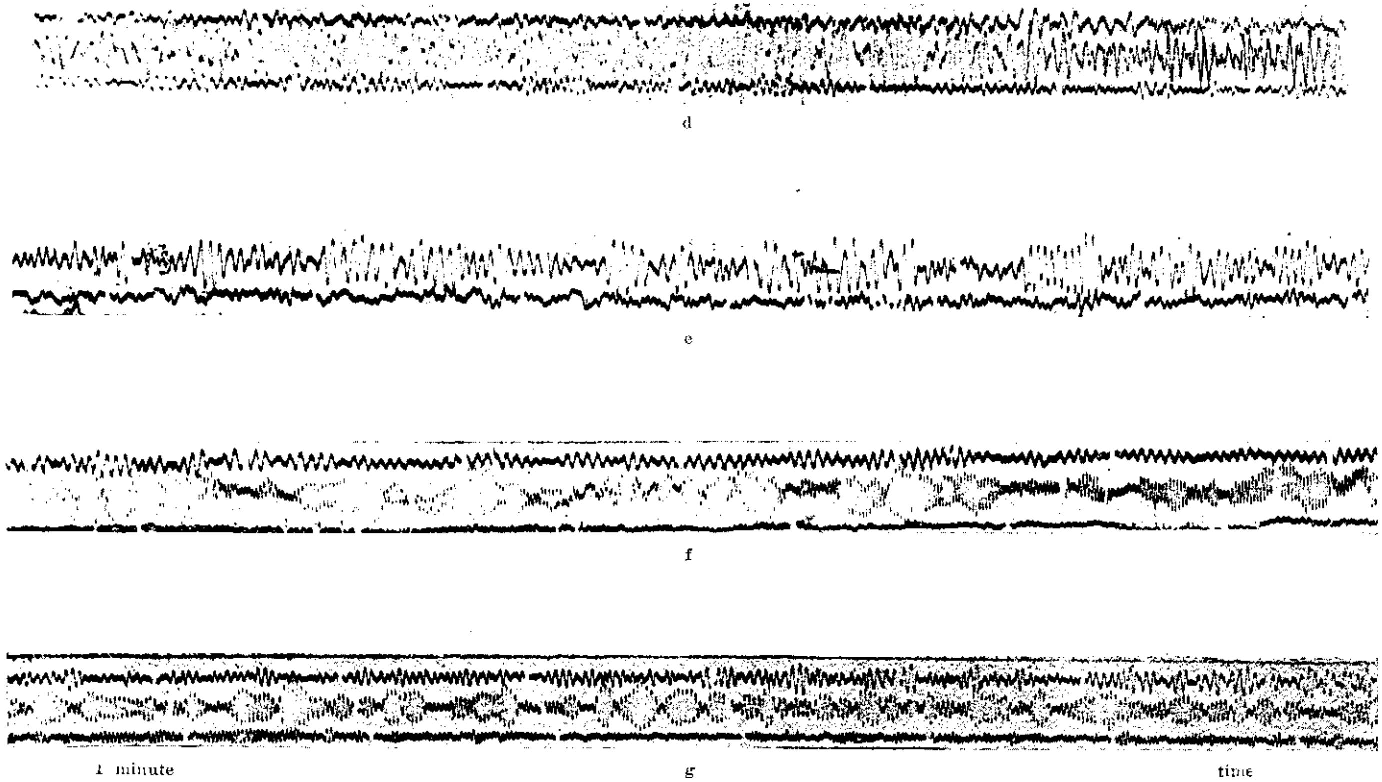


Fig. 1. Characteristic pulsations for IPDP — different elements of IPDP. The sequence of the elements is given in the usual order of IPDP developments.

The IPDP begins with some irregular movements of line of record (fig. 1-a). Several bursts of relatively regular oscillations with periods 6-10 sec are superposed on this irregular movement (fig. 1-b), then series of regular oscillations with smaller periods are observed (1-c, d, e, f, g). The most characteristic element of IPDP are oscillations with periods 2-4 sec. That is, oscillations of these periods may be observed without damping during several tens of minutes. Amplitude modulation sometimes expressed as beating of oscillations is characteristic for all pulsations comprising the IPDP.

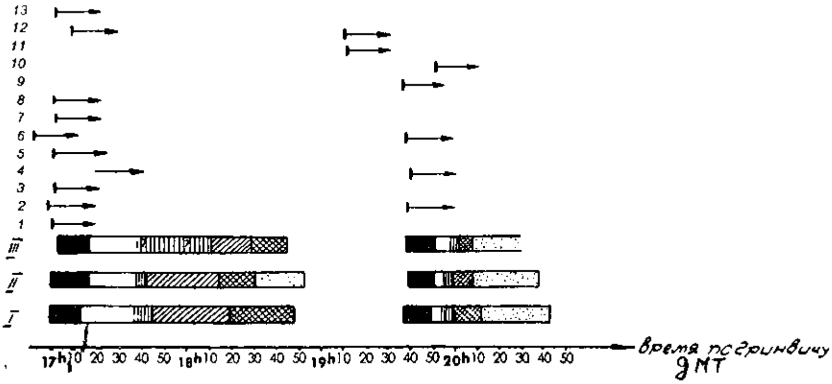


Fig. 2. Scheme of IPDP development for the magnetic storm of 29th September 1957. The schemes are given for the stations I – Alushta ($\varphi = 44°41'N$, $\lambda = 34°25'E$), II – Alma-Ata ($\varphi = 34°16'N$, $\lambda = 77°22'E$) and III – Irkutsk ($\varphi = 52°28'N$, $\lambda = 104°02'E$) together with the results of visual observations of the Aurora at this date.

The arrows show the moments of beginning of aurora displays in different geographic points.

The numbers mean following geographic locations:

1.	Several stations located in Ukraine.		
2.	Poltava	φ=49°36'N	λ=34°38'E
3.	Rostov	φ=47°30'N	λ=41°30'E
4.	Vilnus	φ=55° N	λ=25° E
5.	Pavlodar	φ=52°17'N	λ=76°57'E
6.	Odessa	φ=46°47'N	λ=30°53'E
7.	Buzuluk		
8.	Stavropol	φ=45° N	λ=42° E
9.	Riga	φ=56°58'N	λ=24°04'E
10.	Simferopol	φ=44°50'N	λ=34°04'E
11.	Smolensk	φ=55° N	λ=32° E
12.	Alma-Ata	φ=43°15'N	λ=76°55'E

From one to four IPDP were observed up to date in the course of magnetic storms. The duration of individual IPDP is usually not longer than one hour. The IPDP's can follow one another with intervals from tens of minutes to 2-3 hours. All great storms that occurred during the IGY contained the IPDP's. For instance, the magnetic storm of the 29th Sept. 1957 comprised two intensive IPDP.

The duration of the first IPDP (1 hour 45 min.) in this case was approximately two times longer than the duration of the second one (about 1 hour). The beginning of the first IPDP was registered at 17 hr. GMT and of the second one at 19 hr. 38 min. The schemes of these intervals are shown for three stations on fig. 2. Both IPDP were registered more or less distinctly at all Soviet Earth current stations. As the first results show, the IPDP, which possibly occur simultaneously on the whole Earth, can be distinctly developed and registered on the surface including ~ 6-8 hour belts, where it is evening, night or early morning hours. Most expressive they are in the middle latitudes. The fact, that the beginnings of IPDP's fall mainly in the time interval 16.30 to 18.00 GMT, is hardly accidental. These hours coincide with the hours of noon on meridians of geomagnetic and magnetic poles.

The moments of the beginnings of the IPDP may be regarded as the moments of the deepest penetration of solar corpuscular streams into the Earth's atmosphere.

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EXCITATION LAWS OF SHORT-PERIOD OSCILLATIONS IN MIDDLE LATITUDES

by M. V. Okhotsimskaya, Yu. B. Rastruhin,
I. I. Rokityansky and R. V. Shepetnev

(*Abstract*)

The study of the short-period oscillations of the earth-current field, carried out during the IGY period by the middle latitude stations of the Institute of the Physics of the Earth of the USSR Academy of Sciences, enabled them to reveal a series of general laws governing the excitation of the short-period oscillations in the middle latitudes of the USSR.

The conditions (the stations are situated in Borok $\varphi = 58^\circ\, 02'$ N, $\lambda = 38^\circ\, 58'$ E; Alma-Ata $\varphi = 43^\circ\, 16'$ N, $\lambda = 77^\circ\, 22'$ E; Alushta $\varphi = 44^\circ\, 41'$ N, $\lambda = 34^\circ\, 25'$ E; Petropavlovsk-on-Kamchatka $\varphi = 53^\circ\, 06'$ N, $\lambda = 158^\circ\, 38'$ E) permit us to state that the laws discovered may be valid for middle latitudes in general.

The short-period oscillations under consideration were of two types: of a steady regime (Pc) and pulsation trains (Pt).

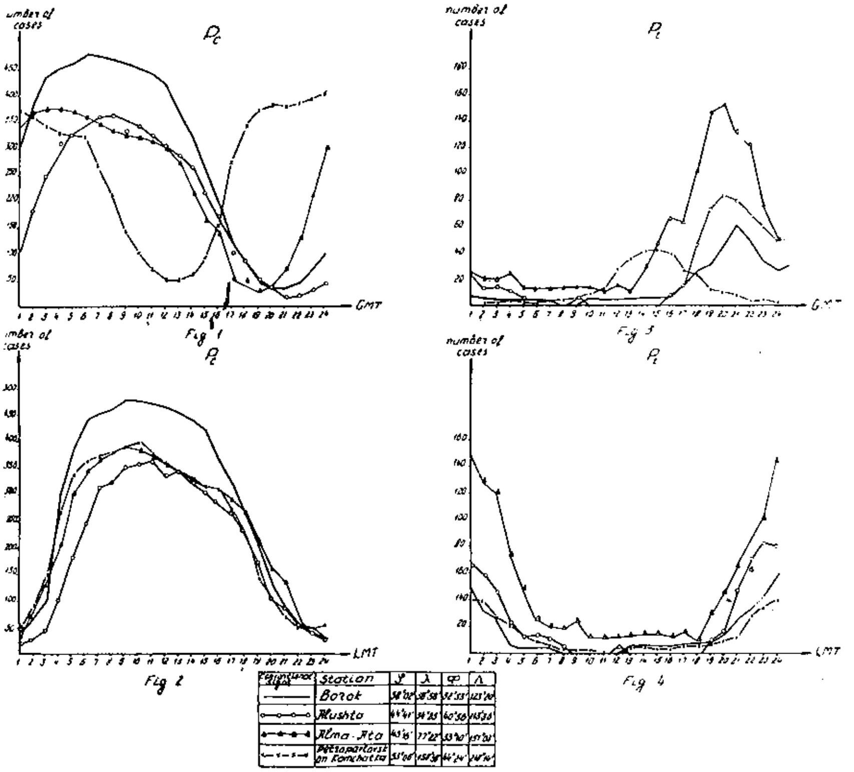
The study of the frequency spectrum of the short-period oscillations shows that the prevalent periods of Pc are those of 15-30 sec (80 per cent of the total number of cases observed) and Pt from 50 to 90 sec. (60 per cent).

The analysis of the daily variations of the occurrence of Pc and Pt (figs. 1-4) clearly shows that the time of maximum or minimum of this or that regime of the short-period oscillations viewed from the aspect of world time depends on the longitude of the observation points. Therefore the main control of the daily variations of the oscillations, both Pc and Pt, depends on local time.

The form of the Pc daily variation for all the stations is not symmetrical. The left branches of the daily variation curves are steeper than the right ones, the angles of slope of the right and left branches relatings as 1 to 1.5.

In a general case the excitation law of Pc is presented in the following form: The number of Pc increases by 3-4 hours, local time, forming a wide midday maximum 8-10 hours later. The decrease goes on more gradually, the minimum being reached in 14 hours after the time of maximum.

In contrast to Pc, the Pt daily variation reaches its maximum at local midnight and its minimum — at local midday.

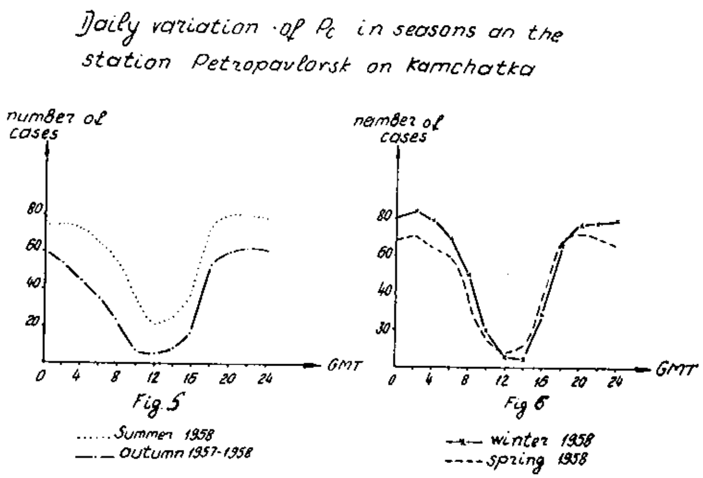


A summary distribution of Pc and Pt in periods at the stations Alma-Ata, Borok, Alushta, Petropavlovsk-on-Kamchatka july 1957 - December 1958

Figs. 1-4. — Diurnal distribution of pc and pt in universal and local time.

The seasonal changes of Pc daily variations is observed (figs. 5-6). The summer curve has a narrow night minimum. The winter curve has a wide night maximum. The curves for spring and autumn are intermediate. These data testify the connection between the short-period oscillations (Pc) and solar wave radiation.

The Pt seasonal variation has not been clearly determined, obviously due to insufficient statistic data.



Figs. 5-6. — Seasonal variation in the diurnal distribution of pc, at the station Petropavlovsk-on-Kamchatka.

The values of the most probable amplitude gradients for Pc vary within fractions of units and whole units of millivolts per kilometre and for Pt — first dozens of millivolts per km. A tendency of the rise of the amplitude gradient at shore stations is observed.

In addition, preliminary studies are made of the prevalent direction of earth currents by disturbances of the type of sudden commencements (SSC) and bays (b). The earth-current directions are different at different stations, the shore stations showing a tendency towards the direction perpendicular to the shore.

It is noted that alongside the undoubted dependence of the excitation of short-period oscillations on local time there are cases controlled by world time which requires additional investigations.

SUR QUELQUES REGULARITES DU CHAMP PERTURBE DES COURANTS TELLURIQUES

par V. V. KEBULADZE

(*Résumé*)

Dans l'article on pourra voir certaines régularités en activité électrotellurique, résultat de l'interprétation statistique des tellurogrammes continus diurnes pour la période 1948-1958 (1,2) à la station Dusheti ($\varphi=42^{\circ}\ 05'$ N, $\lambda=44^{\circ}\ 42'$ E).

On y examine les types des variations électrotelluriques suivants:

A. Tempêtes et perturbations de longue durée.

B. Perturbations à courte période du régime stable (Pc) et trains des pulsations (Pt).

A. Sous tempêtes et perturbations de longue durée nous sous-entendons toutes les perturbations électrotelluriques durant de 3-4 h. jusqu'à plusieurs jours. On y fait entrer des perturbations fortes, modérées et faibles avec le début progressif et brusque à l'exception des baies et des impulsions évoluées indépendamment. Ces tempêtes et perturbations sont bien et facilement découvertes sur les inscriptions lentes avec déroulement 20 et 90 mm/h.

Pour la découverte des régularités en activité électrotellurique nous avons dressé des tableaux par mois, par saisons et par années des caractéristiques de toutes les heures à 3 degrés ainsi que le catalogue des tempêtes et des perturbations électrotelluriques fixées à station Dusheti pour la période 1948-1958 (2, 3, 4, 5). Selon ces caractéristiques le champ était envisagé: comme calme lorsque pour la période envisagée les amplitudes des variations de l'une ou des deux composantes EW et NS étaient moins grandes que 5 mV/km; comme modéré - lorsque les amplitudes des variations variaient à la limite de 5-15 mV/km; et comme perturbé fortement - lorsqu' elles dépassaient 15 mV/km.

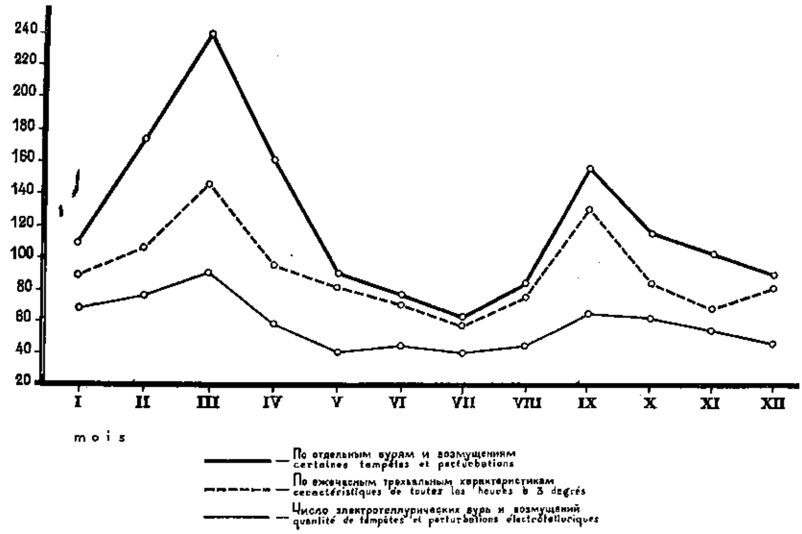
Ces tableaux ont permis d'étudier pour la période de 11 ans les variationes diurnes, saisonnières et annuelles des heures perturbées ainsi qu'apprécier l'activité de chaque journée.

Le catalogue que nous avons fait contient 708 tempêtes et perturbations desquelles 146 sont fortes, 179 modérées et 383 faibles. Le choix et l'étude de ces perturbations et tempêtes étaient effectués sur la composante latitudinale puisque elle est plus perturbée à la station Dusheti que celle méridienne.

Au cours du travail sur l'établissement de ces caractéristiques et du catalogue nous avons éliminé toutes les perturbations dues aux phénomènes d'orage et à d'autres facteurs locaux.

L'interprétation statistique des matériaux utilisés pour ces caractéristiques et le catalogue nous ont permis d'établir les régularités suivantes:

Среднегодовой ход электротеллурических возмущений за 1948–1958 г.г.
Marche moyenne annuelle des perturbations électrotelluriques pour la période 1948-1958



— По отдельным бурям и возмущениям
certaines tempêtes et perturbations

— По ежечасным трехбальным характеристикам
caractéristiques de toutes les heures à 3 degrés

— Число электротеллурических бурь и возмущений
quantité de tempêtes et perturbations électrotelluriques

Fig. 1

1. Une certaine regularité se fait voir en distribution des débuts, des fins et des périodes actives des perturbations électrotelluriques; la plus grande quantité de perturbations commence à l'intervalle de temps de 4 à 18 h. avec maximum entre 13 et 14 h. d'après le temps mondial. Le temps entre 5 et 7 h. est caractérisé également par un grand nombre de débuts tandis qu'entre 18 et 4 h. ils sont observés assez rarement. L'intervalle de temps entre 2 et 5 h. est caractérisé par une activité minimum, ensuite elle augmente peu à peu et atteint le maximum entre 17-19 h. La plus grande quantité de perturbations et de tempêtes électrotelluriques se terminent entre 21 et 23 h. (5).

2. La variation diurne de la fréquence des heures perturbées est assez nettement découverte à l'aide des caractéristiques de toutes les

heures à 3 degrés. La deuxième moitié de la journée est caractérisée par une activité plus élevée que celle de la première. La quantité maximum d'heures perturbées est entre 18 et 21 h. et celle minimum entre 4 et 6 h. d'après le temps mondial. Les courbes de celle-ci obtenues pour les différentes années et la courbe moyenne annuelle pour 11 ans sont bien conciliées entre elles (2, 4, 5).

3. Les données du catalogue et des caractéristiques de toutes les heures à 3 degrés montrent que la fréquence de l'apparition des perturbations électrotelluriques est soumise à la variation annuelle. La plus grande quantité de tempêtes et de perturbations de longue durée d'année en année coïncide avec les mois d'équinoxe et la moindre avec les mois de solstice (fig. 1). On a établi que les mois de juin et de juillet sont caractérisés par une activité minimum.

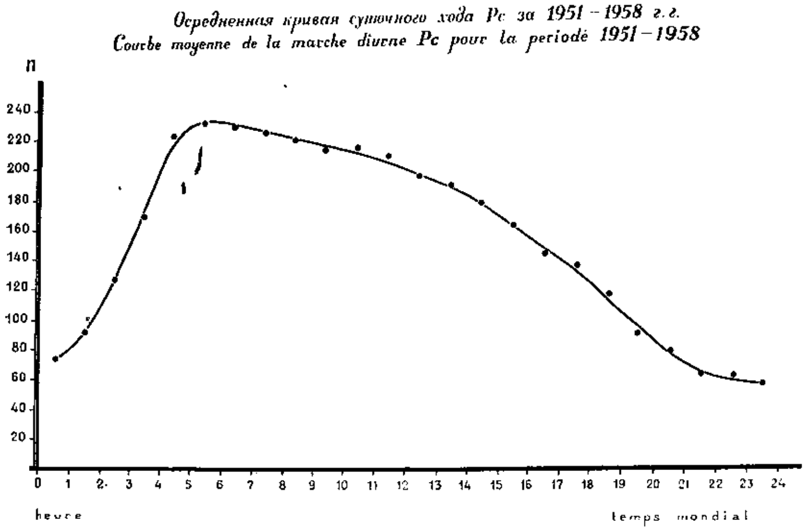


Fig 2

4. Selon nos données (5) l'activité maximum du champ électrotellurique a été notée en 1951, 1952 et 1956 tandis que celle minimum en 1954 et 1955, ce qui correspond complètement à la durée du dernier cycle de l'activité solaire.

5. Malgré un caractère conventionnel de l'appréciation de l'activité du champ tellurique à l'aide des caractéristiques mentionnées on peut dire qu'en ayant le matériel suffisant ces caractéristiques permettent bien de découvrir des régularités du champ électrotellurique. Les courbes de la variation annuelle de l'activité du champ électrotellurique (fig. 1) dressées selon les données du catalogue (ligne pointillée) et

selon les caractéristiques des toutes les heures (ligne continue) sont bien conciliées.

B. L'étude des perturbations à courte période du régime stable (Pc) et des trains des pulsations (Pt) est devenue possible depuis 1951 après l'augmentation de la sensibilité d'enregistrement (jusqu'à 0,1-0,15 mV/mm) et celle de la vitesse du déroulement de 20 mm/h à 40 et 80 mm/h. Le dépouillement des inscriptions de la station électrotellurique Dusheti pour la période 1951-1958 a été fait en vue d'étudier les variations diurnes, saisonnières et annuelles de Pc et Pt. Les limites du changement des périodes et des amplitudes de ces pulsations ont été également définies d'après les enregistrements rapides (30 mm par min.) 1957-1958 (2).

Осредненная кривая суточного хода Pt за 1951 - 1958 г.г.
Courbe moyenne de la marche diurne Pt pour la période 1951-1958

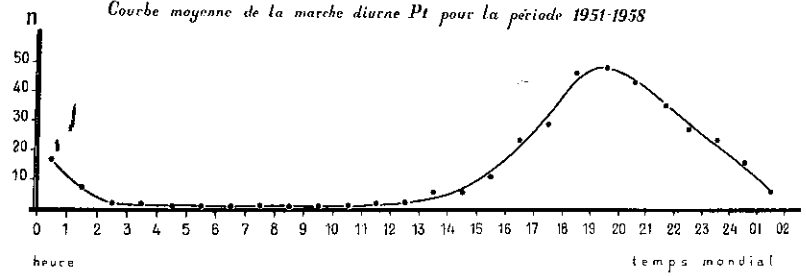


Fig. 3

Les régularités suivantes obtenues à l'aide du dépouillement statistique des tellurogrammes pour la période 1951-1958 ont été établies:

1. Les amplitudes des pulsations à courte période du régime stable varient à la station Dusheti d'une dixième à quelques unités de mV/km et leurs périodes de quelques secondes à 30-40 sec. Les pulsations à période de 15-25 sec. sont inscrites le plus souvent. Les amplitude maxima des trains des pulsations atteignent 10 mV/km, leur période 60-80 sec. (2).

2. Les pulsations Pc ont une variation diurne bien exprimée. La plus grande quantité d'heures avec pulsations stables d'année en année a été fixée à Dusheti d'après le temps mondial (fig. 2) de 4 à 18-19 h. Les courbes moyennes saisonnières de la variation diurne Pc montrent qu'aux mois d'hiver la quantité d'heures avec les plus grandes valeurs de pulsations stables diminue tandis qu'aux mois d'été elles croissent ce qui permet de supposer qu'il y a une certaine liaison entre ces pulsations et la radiation solaire directe (2, 4, 5).

3. La courbe moyenne annuelle de la variation diurne des trains des pulsations pour la période 1951-1958 (fig. 3) fait voir qu'ils sont presque toujours absents entre 2 et 14 h. d'après le temps mondial.

La fréquence de l'apparition de Pt augmente brusquement à partir de 15-16 h., atteint le maximum entre 18-21 h. et ensuite se réduit. Une telle régularité des trains des pulsations dans la marche diurne est toujours la même d'année en année (2, 4, 5).

La plus grande quantité de trains des pulsations coïncide avec le développement maximum de l'activité du champ électrotellurique.

La variation annuelle des pulsations Pt est peu exprimée. Pour la période 1951-1958 selon les données moyennes une certaine augmentation de la quantité de trains des pulsations aux mois de mars et avril est notée.

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SOME RESULTS OF PC AND PT INVESTIGATIONS IN IRKUTSK

(For the period 1957-1959)

by P. A. VINOGRADOV

1. Observations of the Earth currents in the region of Irkutsk are conducted on two stations: Baiandai ($\varphi = 53°04'N$; $\lambda = 105°32'E$) and Uzur ($\varphi = 53°19'N$; $\lambda = 107°44'E$).

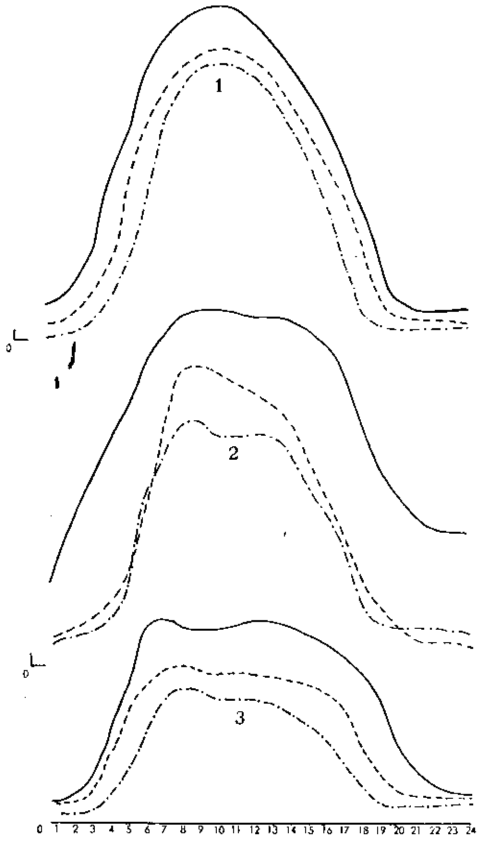
2. Diurnal variation of Pc - S (pc) in Baiandai has a shape of a simple wave (Fig. 1-1) with a maximum before noon (10-11^h LMT) and a minimum in the night hours (23-01^h LMT). A characteristic feature of S (pc) form for all seasons is its assymetry around noon. Both the degree of S (pc) assymetry and its form change very little from season to season, but in the summer months the degree of assymetry is a little less. The number of hours with Pc at maximum is the greatest in summer (95.5 % and 94.2 % for 1958 and 1959). The winter numbers are 75.2 % and 63.5 % consequently. The maxima S (pc) at equinoxes are less, than in summer by 10 %. (The frequency of Pc occurrence was determined for each hour in % to all hours of observations for a month, a year, a season). The duration of interval favourable for Pc occurrence widens from winter to summer. For the first year Pc were observed in winter mainly in the interval 5-18^h LMT and in summer in the interval 2-20^h LMT. A characteristic feature of diurnal distribution of intensive Pc (pc A) is their total absence during the night (exceptions were noted in summer 1959) and their most frequent occurrence around local noon.

The time intervals of Pc A occurrence depend on seasons and change from year to year. For instance, in winter 1958, Pc A were observed mainly in the interval 8-15^h (LMT), and in summer mainly in the interval 5-17^h (LMT). In 1959, in summer Pc A were noted in the interval from 2^h to 20^h LMT.

The maximum of Pc A frequency occurrence falls on the hours 8-11^h LMT.

Comparing S (pc A) and S (pc B) we noticed, that the intensity of Pc rise more quickly in summer than in winter (from night to day).

The diurnal distribution of weak Pc (with amplitude less than 0.18 mV/km) in Uzur has a shape of a simple wave with a maximum in night hours (21-24^h LMT) and a minimum before noon (8-11^h LMT). This fact is important because it shows, that the form of S (pc)



I

Fig. I - I. Distribution of Pc in LMT (Baiandai) 1. — September 1957 - August 1958. 2.— September 1958 - August 1959. 3. — Pc with amplitudes from 1.6 mV/km to 5.4 mV/km ——— summer; - - - - - winter; -·-·-·- equinoxes.

depends on the sensitivity of equipment. Indeed comparing the records of our two stations Uzur and Baiandai we found that Pc occurred much more frequently in night hours at Uzur[1]. At the same time the frequency of Pc occurrence at noon was almost the same at both sta-

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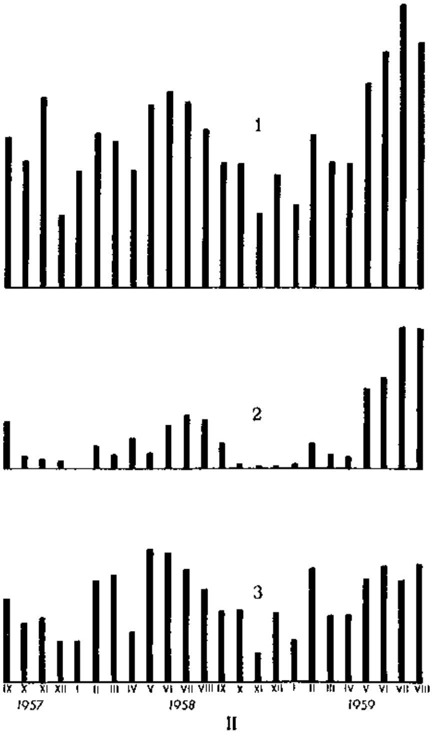
[1] The sensitivity of records in Uzur was 0.11 mV/km/mm and in Baiandai 0,54 mV/km/mm.

tions. That is the reason of obtained more homogeneous distribution of Pc on all hours in Uzur.

3. The frequency of Pc occurrence rise with the degree of geomagnetic field activity. The mean Pc occurrence on days with a magnetic characteristic 0 is 27.4 %. For days with characteristic 2, the mean Pc occurrence is 62.8 %. Together with the rise of the degree of geomagnetic activity widens the duration of interval favourable for Pc occurrence. No change of S (pc) assymetry was observed for different degrees of geomagnetic activity. For instance the ratio of number of hours in the first half of 24 hours to the number of hours in their second half was the same for the days with characteristics «0» and «2» and was equal 1.4. The distribution of Pc on periods shows that on disturbed days most frequently occur Pc with periods 10-16 sec, and on quiet days Pc with periods 20-30 sec are observed.



II

Fig. I - II. Seasonal distribution of Pc. 1. — All cases. 2. — Pc with amplitudes > 5.4 mV/km. 3. — Pc with amplitudes from 1.6 mV/km to 5.4 mV/km.

4. The diurnal variation of Pc mean hourly amplitudes has also a shape of a simple wave with a maximum around noon (11-12^h LMT) and a minimum around midnight. A close correlation exists between

the diurnal variation of Pc and the diurnal variation of mean hourly amplitudes of Pc.

5. Characteristic for Pc is a noticeable rise of number of hours with Pc from winter to summer (Fig. I-II). For instance the smallest number of hours with Pc was observed in 1958 in November (20 %). The greatest number of hours with Pc for the same year was noticed in June (54.6 %). Similar rise to number of hours from winter to summer was observed in 1959. (In January 22.4 %; in June 77.5 %.) A significant rise of Pc intensity from winter to summer was noticed. The mean amplitude of Pc in winter is equal 0.29 mV/km in Uzur). In summer it rises up to 1.09 mV/km. In winter Pc of the category A (amplitude >5.4 mV/km) constitute 2.6 % from all cases of Pc. In summer their number rises to 29.2 %.

The comparison of yearly changes of Pc mean monthly amplitudes with seasonal curves of Pc occurrence shows a close correlation with these distribution — they have the shape of a simple wave with a maximum in July and a minimum in December.

6. S (pt) has a shape of a simple wave with a maximum around midnight and a minimum at local noon. Sometimes, pulsations with the same periods as Pt are observed in the evening and night hours, but these pulsations do not show the characteristic for Pt damping. The diurnal and seasonal distribution of such pulsations coincide with the distribution of Pt. This is the reason to think that the origin of Pt and of the above-mentioned pulsations is the same. The most intensive Pt are observed during the night. The diurnal distributions of Pt and of their mean amplitudes are similar.

For 12 months, the number of days with Pt was equal 38 % and the number of hours with Pt about 3 % from all hours of observations. For the same period the number of days with Pc was 93.7 % and the number of hours with Pc 71.1 %.

7. The frequency of Pt occurrence depends on the degree of magnetic activity. But, most frequently they are observed not during the days of maximal magnetic activity (2.0 and 2.5) but during the days of mean activity (1.0 and 1.5). The mean amplitude of Pt is somewhat greater in winter than in summer.

8. The distributions of Pc and Pt on GMT and LMT are shown on Fig. I-III. They were built using the data of Com. N.° 10 IAGA. The comparison of S (pc) for the three eastern stations (Memambetsu, Kanoi and Irkutsk) shows that the distributions do not show any significant differences both in local and in universal time. The comparison of the S (pc) for the western stations also gives no conclusive evidence in favour of either universal or local control of S (pc). The comparison of S (pc) for all 6 stations shows undoubtedly the predominance of local time control for Pc.

The analysis of Pc distribution in universal time shows that, the moments of S (pc) minima for the eastern stations do not greatly differ from the moments of S (pc) maxima for the western stations. Taking into account the above-mentioned similarity between Pc occurrence and their intensity distribution one can think that at each given

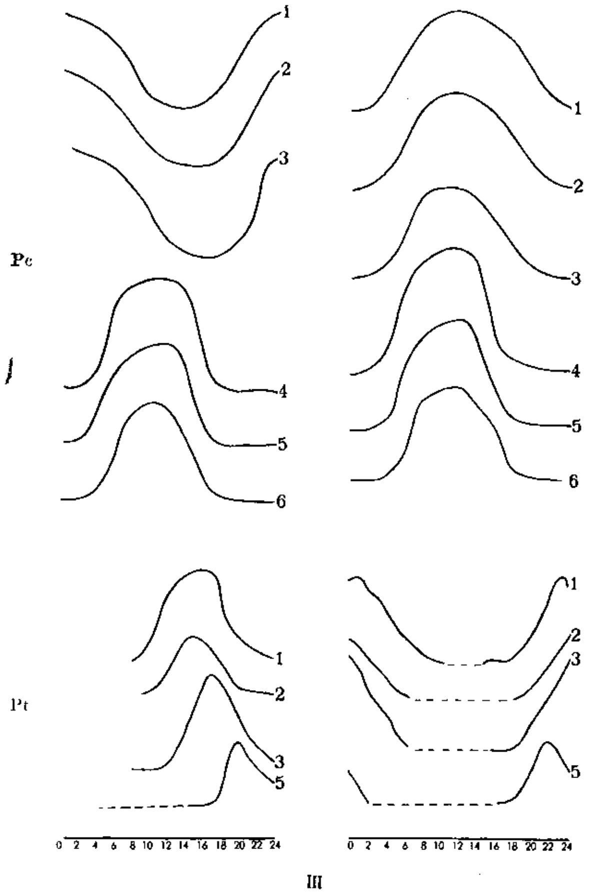


Fig. I - III. Diurnal distribution of Pc and Pt at differents stations: 1. — Memambetsu; 2. — Kanoi; 3. — Irkutsk; 4. — Hartland; 5. — Budkov; 6. — Valentia.

moment of time the most intensive Pc are observed at the day-side of the Globe and the weak Pc at its night-side. During the days of Pc intensive development they may be observed on the whole Globe (as the duration of Pc, excitation depends on their intensity). An interesting feature of S (pt) for the eastern stations is the coincidence of the S (pt) maximum with the moment of S (pc) minimum.

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CONTINUOUS PULSATIONS (PC) AND PULSATION TRAINS (PT) IN THE ARCTIC AND IN THE ANTARCTIC

by V. TROITSKAYA

(Abstract)

Observations of short periodic pulsations with periods within the range of ~ 10-100 sec were conducted before the IGY mainly in middle and low latitudes. The classification of these pulsations into two groups — «pc» and «pt» was based mainly on data received at the middle latitudes stations. It was hoped that simultaneous and technically coordinated observations in the Artic and in the Antarctic would give new features of these pulsations.

The materials of the following stations for the period 1957-1958 were used in the investigation. (Heiss, Lat: 80° 37′ N, Long: 58° 02′ E; Piramida/Barentsburg, Lat: 78° 38′ N, Long: 16° 23′ E; Chelyuskin, Lat: 77° 43′ N, Long: 104° 17′ E; Tixie, Lat: 71° 34′ N; Long: 128° 54′ E: Lovozero, Lat: 67° 58′ N; Long: 35° 05′ E). The most complete series of observations for the first year of the IGY were received at the stations Lovozero and Chelyuskin. Therefore the results described below will be based mainly on data received at these two stations. Observations of Earth currents in the Antarctic were conducted during the IGY period at two stations — Mirny (Lat: 66° 33′ S, Long: 93° 00′ E) and Oasis (Lat: 66°16′ S, Long: 100° 43′ E). The records of both these stations were processed for the first 6 months of the IGY (July-Dec. 1957). For the period January-July 1958 were processed the records of Oasis. Data of Mirny for 1958 were processed only partially. In studying the laws of simultaneous occurrence of pulsations in both polar regions and in the middle latitudes, records of some middle latitude stations were used. (Mainly Alushta, Lat: 44° 41′ N, Long: 34° 25′ E; and Petropavlovsk on Kamchatka, Lat: 53° 06′ N, Long: 158° 38′ E).

The results were obtained in the course of processing Earth currents records with time scale 90 mm per hour. In some cases quick run records (30 mm per minute) were used. The description and technical characteristics are given in (1, 2).

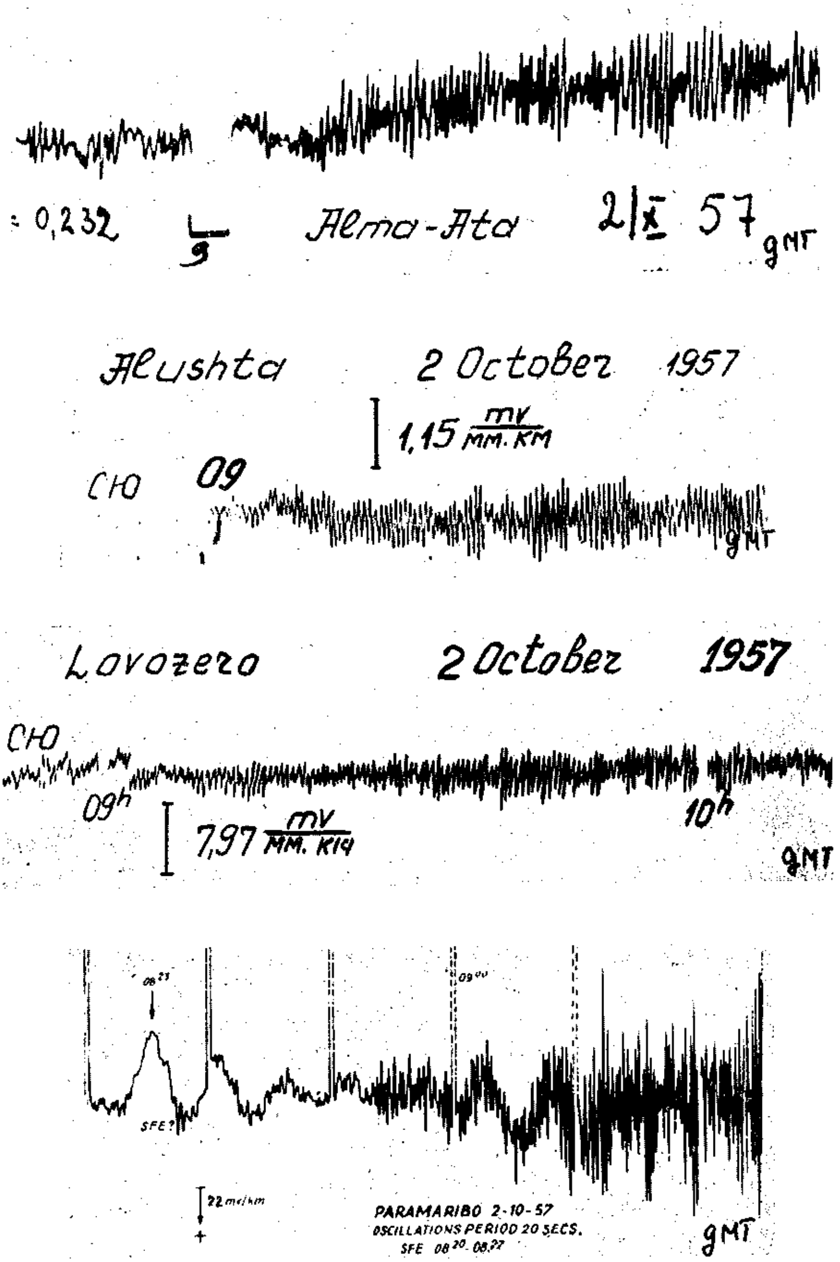


Fig. 1. — Pc registered simultaneously at very distant stations.

Of great interest was to find out in polar regions the peculiarities of pulsations typical for the middle latitudes and to trace pulsations occurring simultaneously in the Arctic and in the Antarctic and to investigate the laws of excitation of such pulsations. For the theory of «pc» and «pt» it was important to know these laws of their excitation in the Northern and in the Southern hemispheres. to establish their spectral distribution, etc.

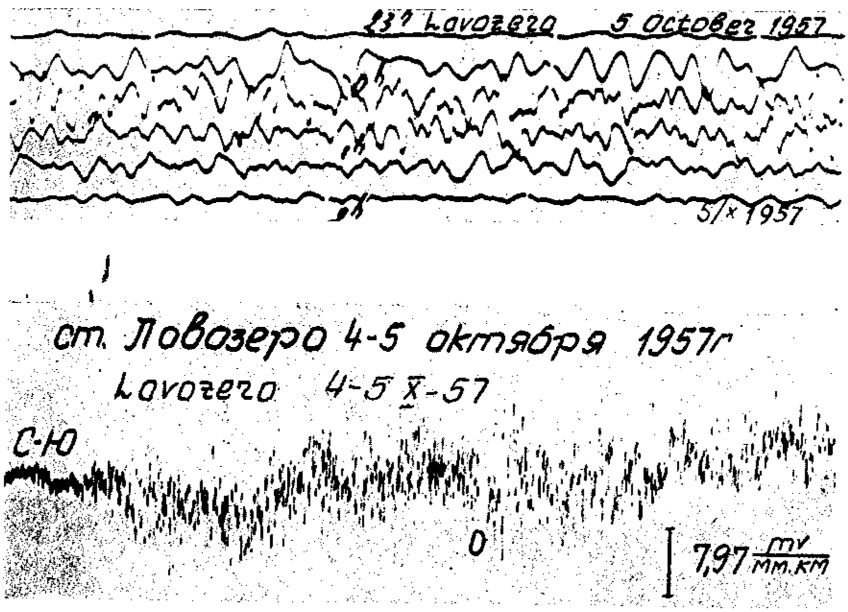


Fig. 2. — Example of pulsations characteristic for the Polar regions — pc^{v}

The results obtained up to date allow us to draw the following preliminary conclusions:

1. Continuous regular pulsations (pc) with periods 20-30 sec are characteristic both for the middle latitudes and for the polar regions.

2. Pulsation trains (pt) having a very typical form in middle latitudes, present in polar regions either one of the elements of a polar disturbance or an indistinct separate disturbance. In both cases the typical features of middle-latitudes pulsation trains are lost. In this connection arises the question whether it is reasonable to consider them as a typical form of pulsations in polar regions.

3. The classification of continuous pulsations in polar regions has to be widened. It seems reasonable up to date to determine three types of continuous pulsations for polar regions:

a) Short periodic continuous pulsations with periods falling mainly within the range of 5-15 sec (pc^{v}). Contrary to regular pc with periods 20-30 sec these pulsations (pc^{v}) quickly fade away with latitude. Diurnal variation of pc^{v} is quite different from the diurnal variation of regular pc; its maximum is located around local midnight. For this type of pulsations was traced a very close correlation with aurora. Their seasonal maxima fall on equinoxes.

b) Irregular continuous pulsations with periods falling mainly within the range 50-90 sec — pc^{o}. These pulsations are usually traced in middle latitudes, but they are most typical and intensive in polar regions. Their diurnal variation is similar to the diurnal variation of regular pc, but with somewhat less distinct maxima. Perhaps it can be said that pc^{o} compose the basic background in polar regions and that other oscillations are superimposed on this background. The seasonal variation of these pulsations (pc^{o}) differs from the seasonal variation of regular pc. Their maximum falls on equinoxes.

c) Regular continuous pulsations with periods falling mainly within the range of 20-30 sec (pc). These pulsations are typical for the middle latitudes, for the Arctic and for the Antarctic. The diurnal variation of pc in the polar regions is similar to the diurnal variations obtained for these pulsations in the middle latitudes.

4. One of the most interesting results of investigation was the discovery of a polar night effect for regular continuous pulsations (pc) in the Antarctic and the Arctic. The effect of polar night consists in the sharp fall of number of hours with continuous pulsations in the middle of the polar night.

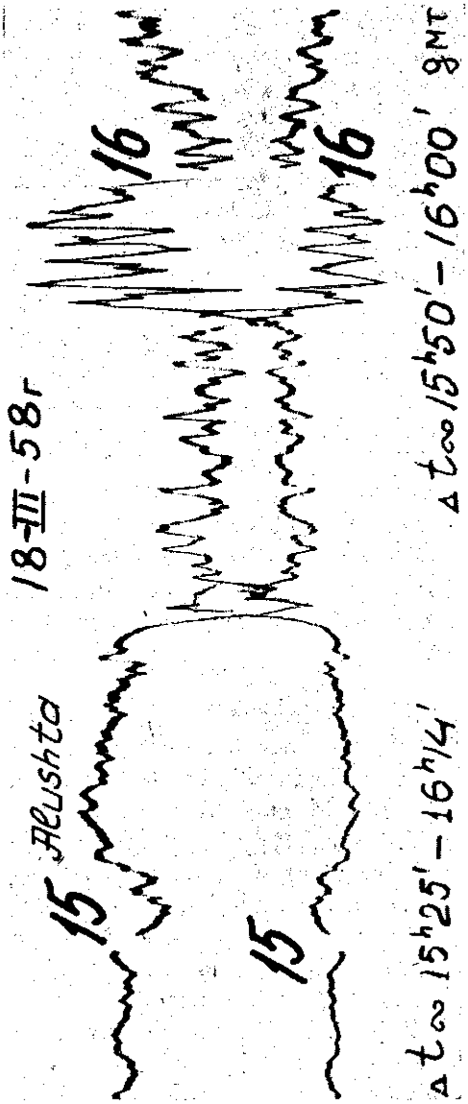
5. A consequence of the polar night effect is the dependence of geographical distribution of regular pc on the season. It seems that the most favourable conditions for the world wide propagation of pc coincide with equinox months.

6. The study of geographical distribution of pc and pt reveal many cases of simultaneous excitation of both types of pulsations in the Northern and Southern hemispheres. The pulsations were often observed not only in this vast latitudinal interval but also in a very great (more than 1/3 of Earth's perimeter) longitudinal interval. For these days was introduced the conception of *transparent* days.

7. No definite connections between pt regularly observed in middle latitudes and typical polar disturbances were established up to date. The middle latitudes pt may coincide with polar disturbances, may be traced as pt everywhere (it is worth noting that in these cases the least characteristic pt are found just in polar regions) and sometimes the pt are observed only in the middle latitudes and the records in polar regions can be in these cases almost quiet.

8. The diurnal variation of pt in the Arctic and in the Antarctic is


C. Cheliuskin
18-III-58
Δt ≈ 15h45' - 16h40'
15h
16h
gMT


18-III-58г
Alushta
15
16
15
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Δt ≈ 15h25' - 16h14'
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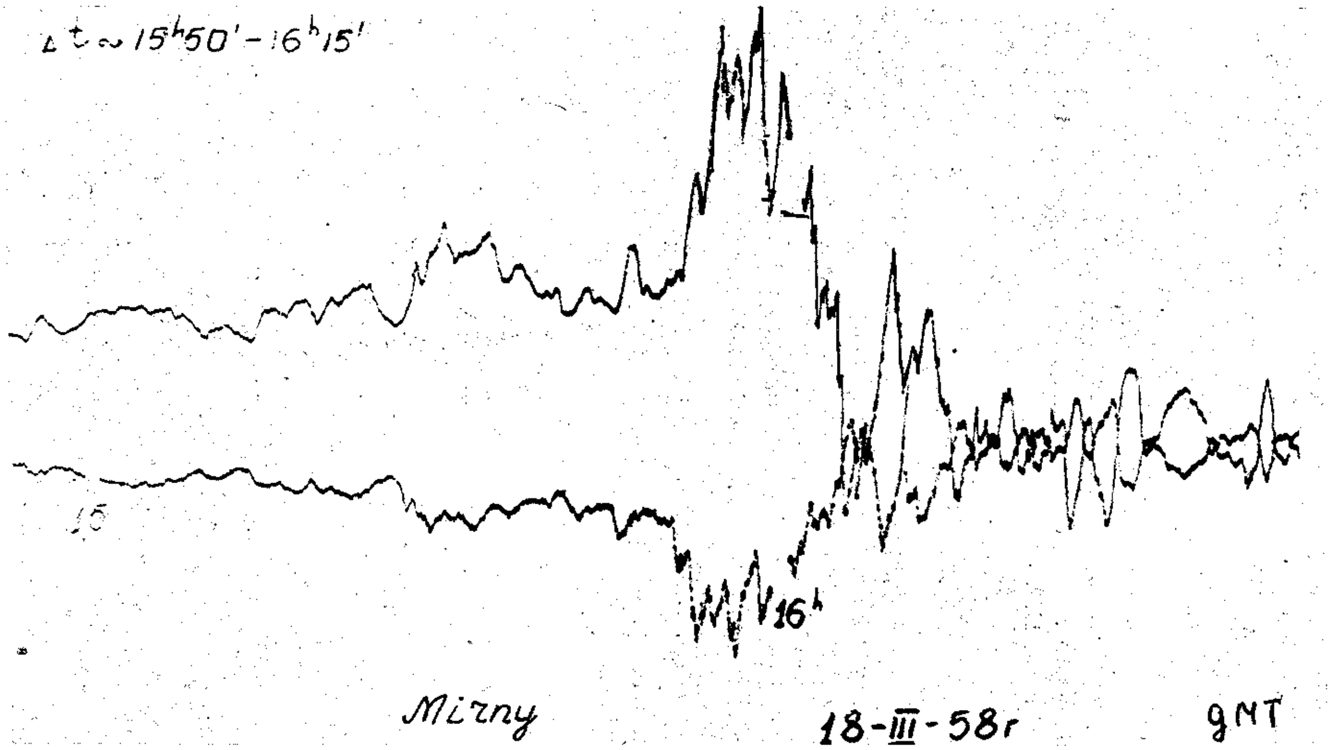

Fig. 3. — Illustration of one of the regularities of excitation of pt in the Arctic, the Antarctic and in the middle latitudes.

similar and has the same features which were obtained for diurnal variations of pt in the middle latitudes.

9. The amplitudes of pt and pc in the Arctic and in the Antarctic are very great and have the order of tens and hundreds of millivolt per kilometre.

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DISCUSSION

Olsen: It is very important to use data for equinox periods when results are to be compared over the whole globe, especially in the Arctic and the Antarctic. North of the auroral zone the corpuscle-stream from the sun hits the ionosphere about noon, that is at a time when the ionosphere is ionized by the sun rays and this combination give rise to extraordinary phenomena as shown by research on the Godhavn results.

Romañá: There is also the discrepancy between spring and autumn equinox, but naturally the results are more uniform than in summer and winter.

EARTH-CURRENT REGISTRATION IN NORTH-WEST-GERMANY

by R. Bock

R. Bock (Berlin-Friedenau) reported on registrations of earth-current which were carried through in North-West-Germany on the occasion of the International Geophysical Year.

Contrary to earlier observations and registrations which have been restricted to two directions it was attempted to arrange registrations of more than two lines. Finally eight simultaneous registrations were established.

The German Ministry of Federal Post agreed to place cable wires at disposal. Investigations in some districts of the Federal Republic had shown that in the amplifier office of Apen — a village between the cities Oldenbourg and Leer — the disturbances and troubles provoked by induction or vagabondizing currents are insignificant with respect to the natural potential differences.

As an example: the reproduction of some disturbed hours (1958, June 6/7) was given, so that the fact, that the majority of bays (or such) harmonize with other ones, but that some bays run towards one another, was recognizable.

The committee was asked for advice how to represent and publish the large gathered material.

Berlin-Friedenau.

DISCUSSION

Cardús: Do you get the same vectogram when you combine the results of different lines?

Bock: No.

Nelson: They must be different due to the difference in the ground conductivity.

COURANTS TELLURIQUES DUS AUX ORAGES TROPICAUX ET ENREGISTRES A TAMANRASSET

par G. Grenet

On observe à Tamanrasset des courants telluriques de périodes voisines de la seconde dont l'amplitude a une variation diurne analogue à celle des orages équatoriaux africains: augmentation vers 11 h T.U., maximum l'après-midi et diminution vers 20 h ou plus tard dans la nuit. La variation annuelle présente également un maximum caractéristique en été, alors que les orages équatoriaux sont le plus proche de Tamanrasset.

L'amplitude du maximum journalier est sensiblement trois fois plus forte en Juillet-Août (1 $\mathrm{mV.km^{-1}}$) qu'en Décembre et Janvier (0,3 $\mathrm{mV.km^{-1}}$) tandis que la distance des foyers orageux à Tamanrasset varie approximativement dans le rapport inverse.

On sait que la charge négative de la terre est maintenue grâce aux charges électriques transportées, lors des orages, de la terre vers l'ionosphère. Si on décompose ces courants en un courant continu et des courants alternatifs sinusoïdaux, ils vont se propager à partir de la zone orageuse à une profondeur et à une hauteur déterminées par leur fréquence.

Soit θ la distance angulaire du foyer orageux à la station d'observation, ρ la résistivité du sol supposée uniforme, ω la pulsation. On peut calculer le champ magnétique horizontal H, le champ tellurique e et le champ électrique vertical E produit par le courant d'intensité I, qui sont respectivement en u.e.m.c.g.s.:

$$H = \frac{I}{R} \operatorname{cotg} \frac{\theta}{2}$$

$$e = \frac{I}{R} \operatorname{cotg} \frac{\theta}{2} \sqrt{\frac{\omega \rho}{4 \pi}}$$

$$E = \frac{I c^2}{\omega R^2}$$

c étant la vitesse de la lumière et R le rayon de la terre. (1)

Bien entendu ces formules ne sont valables que pour les fréquences assez faibles pour que le champ magnétique soit tel que l'on puisse négliger le champ de l'onde électromagnétique.

H a été calculé en supposant les conductibilités du sol et de l'ionosphère infinies et la fréquence du courant assez basse pour que le champ de l'onde électromagnétique puisse être négligé.

Mais le champ tellurique e serait nul si la conductibilité du sol était infinie ce qui peut sembler en contradiction avec ce qui précède. Toutefois les ordres de grandeur sont tels que les approximations faites sont légitimes.

La valeur du champ électrique E est valable sur toute la terre sauf au voisinage de la pertubation.

Ce qui entre en ligne de compte ce n'est pas le courant I comme je l'ai écrit pour simplifier, mais la quantité $\frac{Il}{h}$, l étant la longueur du courant vertical I et h la hauteur de l'ionosphère. C'est dire que les décharges des nuages vers le sol ont infiniment moins d'importance pour le champ à très basse fréquence que les décharges des nuages vers l'ionosphère.

Le champ électrique a été observé par Large et Wormell (2) pour des fréquences de 5 - 10 et 20 cycles par seconde et pour des fréquences plus élevées. Pour les fréquences élevées la variation diurne est due à la propagation. Au contraire pour les très basses fréquences la variation diurne est semblable à celle des orages tropicaux. En appliquant aux valeurs de E trouvées par Large et Wormell la formule $E = \frac{Ic^2}{\omega R^2}$ on trouve pour le courant I les valeurs suivantes:

20 cycles	21 ampères,
10 cycles	18 ampères,
5 cycles	14 ampères

Ces ordres de grandeurs sont très acceptables puisque le courant continu moyen de charge de la terre est de l'ordre de 1.800 ampères.

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(1) Cette formule est identique à celle trouvée par des voies plus mathématiques par J. COULOMB dans son travail "Sur une origine aurorale possible de certaines pulsations géomagnétiques". Ann. de Géophysique t. 13, pp. 91-102, 1957.

(2) LARGE et WORMELL, Recent advances in atmospheric electricity, Pergamon Press 1959, pp. 603-617.

DISCUSSION

Koenigsfeld: Perhaps it would be more convenient to make the comparison with the direct current (electric field) than with the Wormell field.

Maple: We are recording at frequencies of 1 c/s to 50 c/s the lightening and the energy between cloud and earth is greater than between cloud and ionosphere.

Grenet: The electric field at a distance of 100 Km depends on the current flowing into the ionosphere.

Maple: We know the frequency spectrum of the discharge between cloud and ground and not between cloud and ionosphere.

Grenet: For the current between cloud and ionosphere the discharge is greater for the same intensity.

Coulomb: I should like the reasons for saying that the intensity between cloud and earth is greater than between cloud and ionosphere.

Selzer: At Chambon-la-Forêt we observe in the earth-current records pulsations of a period of 0,6 sec and during storms these pulsations turn out into pulses due to lightening. The same effect, although with less sensitivity, can be seen in magnetism.

Nelson: This can be due, may be, to two different sources of the 50 c/s industrial current which produce interferences and that in the case of a storm appear more clearly because of the change of the soil conductivity due to the rain, etc.

Coulomb: In France all the net is unified.

Selzer: Kalashnikov studied the influence of meteorites in magnetism. We could not find any traces of it in our records; the only effect we could find was due to lightening. In America they have critizised the individual results and are surprised at a possible correlation with the time times of meteorites fall. The cause of this correlation may be that meteorites produce a ionisation of the air.

Dungey: Was the correlation immediate or delayed?

Selzer: Kalashnikov says that it was a little delayed.

Dungey: As meteorites produce a ionizised trail, they may offer a new way to cloud discharges.

Jacobs: Up to what period did you observe the pulsations?

Grenet: Up to 1 sec, but the limit is due to my equipement.

Maple: The energy of lightening extends to periods lower than 1 sec, but then its effect may be masked by normal magnetic activity.

Selzer: Why?

Maple: On account of their relative energy.

Jacobs: Do you think that there is a low limit in the periods?

Coulomb: I think that we have to stop at 1/50 s due to effects of the industrial currents.

Selzer: The lowest limit is due to the electric or magnetic method of recording, but if we could go still further into periods overlaping with radio studies, it would be a wonderful study.

A REPORT ON RESEARCH IN PULSATIONS OF THE ELECTROMAGNETIC FIELD OF THE EARTH

by J. Bouska

Before the beginning of the International Geophysical Year the Geophysical Institute of the Czechoslovak Academy of Sciences had already made plans for a research in quick variations of the electromagnetic field of the Earth as part of the Czechoslovak program of the IGY. Our attention turned principally to regular short periodic variations of the field - to pulsations. A research in quick variations on a full scale is also perspectively planned.

Theoretical research must, of course, be based on large numbers of observational data: hence, a geomagnetic and earth currents observatory was founded in 1957 in Budkov near Prachatice ($\varphi = 49° 04' N$, $\lambda = 14° 01' E$).

The geomagnetic section is equiped with several apparati of different types. First of all there is the Danish instrument La Cour recording ΔD, ΔH, ΔZ with a recording speed of 6 mm/min., and the following scale values: $\varepsilon_D = 1{,}5'$ per mm, $\varepsilon_H = 2{,}6$ gamma per mm, $\varepsilon_Z = 3{,}2$ gamma per mm. The apparatus has been recording since January 1st 1958. An electronic fluxgate apparatus MKR-3 produced in Czechoslovakia is also situated here, recording ΔY, ΔY, ΔZ with recording speeds of 1 mm per sec., 0,5 mm per sec., and 6 mm per min. and scale values $\varepsilon_X = \varepsilon_Z = 0{,}5$ to 0,8 gamma per mm. $\varepsilon_Y = 1$ gamma per mm. Recording material used is normal 35 mm Cine film. The apparatus has been recording since January 1st 1958. There are also two induction loop Z variometers recording dZ/dt. The IZV-1 has the following parameters: radius of the horizontal circular loop $r = 8$ m, number of windings $n = 42$, resistance $R = 25$ Ohms; the loop is layed underground at an average depth of 80 cm. The recording galvanometer used is a Kipp & Zonen, Zernike type Zb A 14 with a selfoscillation period of $T_0 = 3{,}5$ secs, internal resistance 35 Ohms and sensitivity $\varepsilon = 3.10^{-9}$ A per mm per m. This galvanometer has been recently substituted by another Kipp & Zonen galvanometer of the Kb A 53 type with the following parameters: $T_0 = 4$ secs, $R_i = 50$ Ohms and $\varepsilon = 4.10^{-9}$ A per mm per m. The scale value of this instrument is 10^{-2} gamma per sec

SOME NOTES ON THE INTERPRETATION OF RAPID FLUCTUATIONS IN EARTH CURRENTS OBSERVED IN HIGH LATITUDES

by M. SUGIURA

(Abstract)

Earth-current records have been made in the College area by Heuler since July 1955; similar but not quite continuous records have been taken at Point Barrow. Rapid fluctuations in earth-currents are found to be an excellent indicator of the upper atmospheric disturbance, and are used as such by the auroral and radio workers at the Geophysical Institute. However little study has been made of these rapid earth-currents variations in high latitudes.

Electromagnetic induction is shown to be adequate in magnitude to account for rapid fluctuations in the electric field as measured by earth currents in high latitudes. A cylindrical current of infinite length, producing a magnetic field of order one gamma/sec at a distance of 100 km from the current, is associated with an electric field of order of a few hundred millivolts/km at the same distance.

A general method is given to treat electromagnetic induction problems in a system consisting of an inducing magnetic field and a semi-infinite uniform conductor. The method is applied to the cases when the inducing field is due to (i) an infinite linear current, and to (ii) a magnetic dipole. Considering the earth to be a semi-infinite conductor, the electric field is estimated at the earth's surface with the above two models for the inducing source. The results show that electric fields of order 10^{-2} to 1 volt/km are necessarily associated with periodically changing magnetic fields of order 100 to 10 gamma or less with period of one second to several minutes.

A remark is made that a frequently used method of estimating the induced electric field by considering a vertical loop and by calculating the magnetic flux change within the loop is likely to be erroneous, since the electric field is mainly horizontal. (Geophysical Rep. n.º 5.)

Geophysical Institute, Alaska.

per mm, and it has been recording since January 1st 1959. The second induction loop variometer IZV-2 has a circular loop with a radius of $r=50$ m, 50 windings and a resistance of $R=46$ Ohms. The loop is also placed under the surface. The recording galvanometer Kipp & Zonen of the Moll A 1 type has the following parameters: $T_0=1.5$ secs, $R_i=80$ Ohms, $\varepsilon=1.10^{-8}$ A per mm per m. The scale value of the instrument is of the order of 2.10^{-3} gamma per sec per mm. It has been recording since August 11th 1959. The series of induction loop variometers will be completed by instruments for recording the horizontal components. It is also proposed that the observatory be equipped with a three component fluxmetric apparatus of the Kalashnikov type.

The earth currents section is situated 2 km to the North of the geomagnetic observatory. The observatory is spread over an area of about 1 square km in a region without any remarkable departures from the local natural electric field. The base of the region is formed by a crystallic gneissic layer.

Recordings are made on two systems each containing two crosswise lines placed in the direction of the geographic meridian and the parallel. One system is composed of two lines 1 km in length placed above the surface, the other of two lines 100 m in length placed underground. Connection with the earth is supplied by electrodes in the form of lead plate 3 mm thick and placed 2 m under the surface in a clayish layer.

Three kinds of recording instruments are used with the following recording speeds: 90 mm per hour (recording begun on September 1st 1957), 22 mm per hour (recording begun on May 1st 1958) and 30 mm per min (recording begun February 1st 1958). The circuits of the slower recorders, i.e. 90 and 22 mm per hour, are connected parallelly to the long lines, the 30 mm per min recorder to the 100 m lines.

In the 90 mm per hour recorder two galvanometers of Czechoslovak production of the NS - 10 type are used; their sensitivity is of the order of $\varepsilon\sim10^{-9}$ A per mm per m, self-oscillation period $T_0\sim4$ to 6 secs and internal resistance $R_i\sim1000$ Ohms. The damping with both the galvanometers is roughly 0,7. Serial resistances in circuits of both the components were chosen for ranges of 50, 100, 250 and 500 mV. The galvanometer circuits have a built-in arrangement for switching the ranges by means of photomultipliers and a system of sensitive relays.

In the circuits of the 22 mm per hour recorder galvanometers with $\varepsilon\sim10^{-8}$ A per mm per m, $T_0\sim1{,}5$ to 2 secs and $R_i\sim45$ to 500 Ohms were used. The scale values of both the slower recorders are determined by calibration impulses brought into the recording circuits from a special calibration unit. The scale values of the 90 mm per hour recordings are in the range of 0,5 to 1,8 mV/km per mm, for the 22 mm per hour recordings in the range of 2,6 to 5,6 mV/km per mm.

The galvanometers connected to the 30 mm per min recording circuits (made in the German Democratic Republic type 5a) have $\varepsilon \sim 10^{-9}$ A per mm per m, $T_0 \sim 1$ sec and $R_i = 1000$ Ohms. A condenser with a capacity of 80 μF for the NS component and 60 μF for the EW component as well as a main disturbances filter are connected into the circuits of both the components in series with the galvanometers. The scale values of the recordings for oscillations of different periods were determined from frequency characteristics obtained by a very low frequency generator.

With the help of apparati of principally different types we get reliable recordings for our research in quick variations. In analyzing them we keep to the general classification contained in the «Rapport du Comité No 10» agreed upon at the XIth General Assembly of the UGGI in Toronto in 1957. We have taken up research of pc, pt, pg, bp, bps. As far as special phenomena are concerned, sudden commencements of storms ssc and ssc*, sudden impulses si and crochets sfe were evaluated. In earth currents research, we specially noticed pulsations of the pearl type pp and to special pulsations ps. We recommend that on magnetograms special notice be paid to isolated groups of pulsations with a period of about 45 secs, whose initial small amplitudes grow larger to diminish again, while the whole phenomenen lasts about 6 mins.

So far we have not been able to work out a more detailed classification, which we feel is very necessary. In order to be able to work out such a classification, it is necessary to organize a systematic research of a much larger number of records.

The main theme of our research lies with the characteristics of the various phases of the geomagnetic storms. A separate research is conducted into pulsation activity at the time of crochets (sfe), in between crochets and ssc, at the time of ssc or at the time of beginning of storms with no ssc, characteristics of the main phase of the storms and their ends. Up to now we have been lead to recognize the following: Crochets are not accompanied by pulsations. Before, during and after chromospheric flares, which are the cause of crochets, no distinguished pulsations can be found on magnetograms. Pulsations therefore, disappear before a storm and reappear about ten mins after its beginning. This delay has so far been considered as undoubtful. From observations made up to now, it seems that the intensity of pulsations rises after that for some time, even may be two days, should the storm last so long. This traditional point of view does not coincide with reality. Directly after the ssc we have observed pulsations with periods of 8 to 10 secs, e.g. during the storm of May 11th 1959. We have not so far taken up in earnest the studying of the main phase of geomagnetic storms, but we have observed some unusually regular pulsations of about 3,5 min. At the end of the storm on the other hand, we have recorded pulsations with periods bigger than 1 min. and amplitudes of about 7 gammas in the H component. Our research is so far in the state of qualitative and quantitative analysis. We expect partial results during 1960 (1).

Short periodic variations of the pc and pt type recorded at the Budkov earth currents observatory during the IGY, have some similar as well as different properties with pulsations of the same type recorded in the USSR by V. A. Troitskaya and V. V. Kebuladze. They are similar in charcteristic form, range of periods, time of occurrence during the day and in some cases in the graphic design of the diurnal variation of occurrence. The basic difference with both types of pulsations shows itself in the displacement of the maximum as well as the total decomposition in the graph of the diurnal variation of the pc and pt pulsations received from our and Soviet observations. These differences and coincidences which have appeared in comparing the diurnal variation of bays and pt pulsations, lead to a conclusion that the occurrence of pulsations of both types depends on local time. In observing the course of average critical frequency for ionospheric layers F_1 and F_2 in comparison with the course of the maximum of the diurnal variation of pc pulsations, we may say that the occurrence of pc pulsations can be influenced by direct solar radiation in the ionosphere (3).

We have also undertaken the correlation of pulsations of the electromagnetic field and solar activity. A correlation between the observations of pc and pt pulsations and geomagnetic as well as solar activity was found, in which case both types of pulsations differ from each other from this point of view according to the character of the solar situation at the center of the Sun's disk. The solar situation described by flare activity tends more to the pc pulsations; if, on the other hand, the situation is characterized by presence of filaments outside the region of facular fields, it tends to the pt type of pulsations.

Furthermore we have studied pulsations which accompany bay disturbances. We are also interested in the research on the outer atmosphere by means of geomagnetic pulsations and whistlers in cooperation with our inonospheric department (4).

The regional conference of the IGC, which took place in February of this year in Moscow recommended that a symposium on some problems of quick variations should be held in Prague Czechoslovakia. Through lack of time as well as the fact that most of the countries of the region have not as yet taken up quick variations seriously, only an international meeting was held at the Geophysical Institute of the Czechoslovak Academy of Sciences on the 23rd and 24th June 1959, which was attended by the vicepresident of IAGA prof. A. G. Kalashnikov and Dr. H. Schmidt of the GDR as guest. Resolutions concluded at this meeting were sent to the Regional Secretary and to the Institute of Physics of the Earth Ac. Sci. USSR in Moscow with which we are cooperating in the problem of quick variations of the electromagnetic field of the Earth. We presume that we will be able to organize a symposium in Czechoslovakia with a very much larger attendance later.

LITERATURE

Papers presented at the international meeting on short periodic variations of the electromagnetic field of the Earth held in Prague, Czechoslovakia, on the 23rd and 24th June 1959:

1. Bouska J.: Research in geomagnetic pulsations in Czechoslovakia during the IGY and IGC.
2. Pecová J.: Results obtained from observations of earth currents at the earth currents observatory of Budkov during the IGY.
3. Halenka J., Pecová J.: A contribution to the problem of correlating pulsations of the Earth's electromagnetic field to solar activity.
4. Mrázek J.: Czechoslovakian observations of whistlers in the IGY.

DIURNAL VARIATION OF PC IN GHANA

by Miss V. R. S. Hutton

It may be of interest to make brief reference to the result of an investigation into the diurnal variation of the occurrence frequency of pc in Ghana, W. Africa, at an observatory situated near the equatorial electrojet and about 6 miles from the S. Atlantic Ocean. The present analysis has made use of earth current records.

There are three maxima on this curve, at 6, 11 and 19 hours, but it is difficult at this stage to be sure that the minimum which occurs at 8 hours is significant, as at this time of the day, the mean value of the potential difference is changing very rapidly and it is difficult to detect short period fluctuations.

The day - time curve then bears fairly close resemblance to others which have been shown at this symposium, but the occurrence of a marked night-time maximum at 19h presents a most unexpected result.

It will be interesting to make a similar study of pc in magnetic records in Ghana to find out whether this night-time occurrence of pc

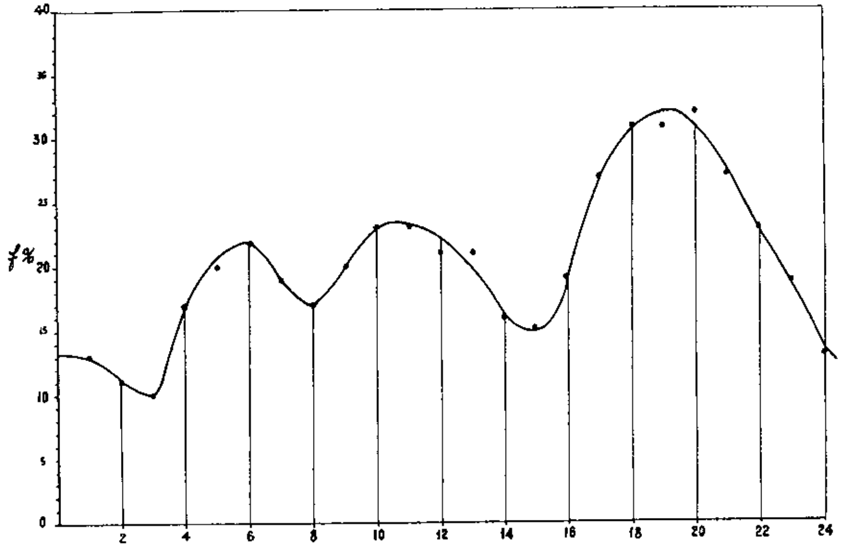

Fig. 1. — Diurnal variation of occurrence of regular pulsations (pc).

is a phenomenon peculiar to earth currents. It will also be worthwhile to compare this result with similar data from stations which are on or near the magnetic equator, but at some distance from the ocean.

DISCUSSION

Cardús: I think that this maximum of pc's during local night hours is most interesting. In the monthly reports sent to Committee 10 of pc's registered at Tamanrasset we see an anomalous feature: in the month of July and August 1957 there is a night maximum, and from September 1957 to February 1958 the maximum occurs at day hours. It is unfortunate that we had no time to study the months of March to December 1958 to see if the night maximum in summer is confirmed.

Grenet: We studied the daily behaviour of pt at Tamanrasset, but until now no study has been made about pc. We shall look into it.

Selzer: In Bangui we have not seen this night maximum. The reason may be that earth-currents are more sensitive than magnetism and register some pc which do not appear in the magnetic records. At Kerguelen pc's are also registered during local night.

PART III

STORM SUDDEN COMMENCEMENTS
SUDDEN IMPULSES
AND
SOLAR FLARE EFFECTS

THE SUDDEN COMMENCEMENT OF GEOMAGNETIC STORMS

by S.-I. Akasofu* and S. Chapman+

Abstract

Many magnetic storms begin suddenly, and simultaneously all over the earth within about a minute. These sudden commencements may be denoted by Sc: according to the sign and order of the sudden changes of horizontal intensity, which may be different at different places, different local types of Sc may be distinguished, and denoted by Sc (+), Sc (—+), Sc (+—), Sc (—), also Sc (++). The known statistical facts as to the daily and yearly variations of frequency and amplitude of Sc's of different types are summarized: and similarly for Si's, the sudden impulses shown sometimes by the magnetographs, that are not followed by any easily recognizable storm. The study of the simultaneous Sc's over different regions leads to conventional current diagrams for the external, primary, Sc field. This can be analyzed into two parts, one part being of type Sc (+), the other corresponding to a current system that is strongest in polar regions, and is probably generated there. The combination of the two parts, in different proportions at different places, explains the production of different local types of Sc.

The available theoretical explanations of the Sc are discussed. The Sc (+) part of the field is attributed to field changes produced by the sudden retardation of a stream of ionized solar gas impinging on the earth's field at a distance of a few earth radii. The polar current system is thought to be energized by the entry of solar particles (or alternatively shock waves) into the polar regions. The Sc (+) field change appears to be transmitted to the earth's surface by hydromagnetic waves.

I. Introduction

The sudden onset of many geomagnetic storms is one of the most striking phenomena of the earth's magnetism. On some magnetograms it resembles what is known to mathematicians as a step function, though of course the change is not instantaneous. But this is not the

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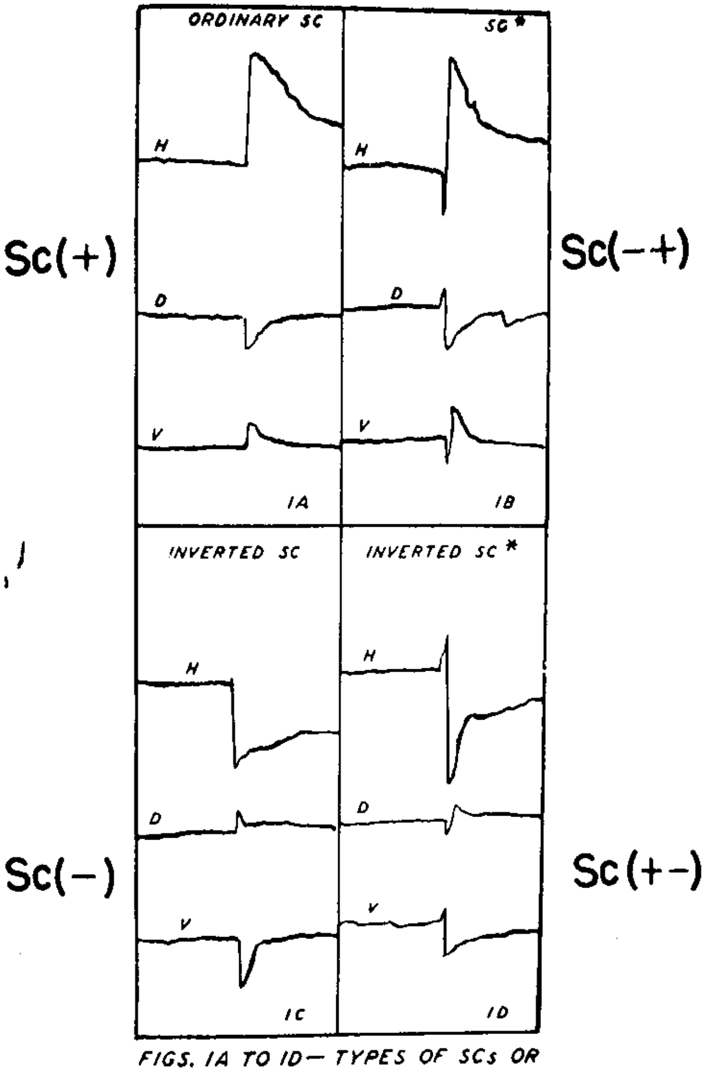

Fig. 1. — Four typical Sc's: Ia,Sc(+); Ib,Sc(—+); Ic,Sc(—); and Id,Sc(+—). (Ferraro, Parkinson and Unthank 1951; Fig. IA)

only kind of sudden commencement. In an important pioneer paper, Ferraro, Parkinson and Unthank (1951) clearly distinguished four main types, indicated by their Fig. 1, here reproduced. The first is the one already mentioned—it is usually an increase in H and a decrease in V. Sometimes the initial changes are of the opposite sign. The other two types show a small initial change in one direction followed by a larger opposite change.

We venture to propose a new notation[1] for the various types of sudden commencement, to replace the current notations (SSC, SSC*, reversed Sc, reversed SSC*—or, as Matsushita (1957) proposed, Sc, —Sc, Sc—); these notations seem to us not sufficiently clear and immediately indicative. Sudden commencements in general we would denote by Sc; the four types shown in Fig. 1 we would denote by Sc (+), Sc (− +), Sc (−), Sc (+ −), indicating the sign of the change (s) in H, and also their order, when there are changes of more than one sign. We may also notice yet another type of Sc, denoted by Sc (+ +), which shows two distinguishable successive increases of H. An Sc for a particular magnetic storm may appear in one form, e.g., Sc (+), in some regions, and elsewhere in other forms, e.g., Sc (− +) or Sc (+ −).

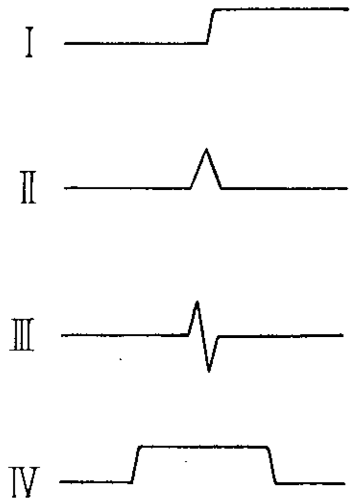

Fig. 2. — Four typical Si's: I, Si(+i)c for *continued;* II, Si(+p) p for *peak;* III, Si(+—o) o for oscillation; and IV, Si(+i) i for *interval.* (Yamaguchi 1958; Fig. 1) See S 1.

It is an essential part of the definition of an Sc that it is followed by increased magnetic activity with storm characteristics, for a sufficiently long period of storminess (IAGA 1957).

Other sudden magnetic changes occur, which in some respects resemble Sc's, but are not followed by magnetic storms, or at least by easily recognizable storms. These are called sudden impulses, and denoted by Si (Ferraro, Parkinson and Unthank 1951). However, Yama-

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[1] This proposal is intended to relate only to discussions of the phenomena, and is not intended to suggest any change in the usages of observatories in their reports to the permanent service.

guchi (1958) showed clearly that, on the average, Si's are followed by a storm time variation Dst, though its range is much less than that in the usual storm. Fig. 2 shows some typical Si's (Yamaguchi 1957; his Fig. 1). The notation for Sc cannot be immediately extended to such Si changes; the symbols suggested are Si (+c), where c signifies a continued change: Si (+p) and Si (+−o), where p and o signify a peak or oscillatory movement returning to the same value; and Si (+i) where i signifies that the change lasts for a certain interval and then the original value of H is restored.

It may be mentioned that Sc's of type Sc (+ −), mentioned as new by Matsushita (1957), were already noted by Van Bemmelen in 1908 (cf. Chapman and Bartels 1940, p. 297).

In low latitudes the usual type is Sc (+). For example, Chakrabarty (1951), who examined about 800 sudden changes at Alibag (9.5° N gm. lat.), found none of type Sc (− +), and not more than 28 of Sc (—). He appears not to have distinguished between Sc and Si, so that his results apply to Sc + Si.

The dual type of Sc becomes more frequent in higher latitudes. Matsushita (1957) examined 44 Sc's at six observatories in geomagnetic latitudes ranging from 21° N to 68° N gm. lat.; the distribution of their types in the higher latitudes was as follows:

Type of Sc	Sc (+)	Sc (− +)	Sc (+ −)
Number	9	21	14

Watson and McIntosh (1950) found that among 340 Sc's observed at Lerwick (62.5° N gm. lat.) only 65 were Sc (+) and 162 were Sc (− +).

2. Studies of Sc and Si at individual observatories.

As with other types of transient geomagnetic variation, the sudden changes —Sc and Si— should be studied in various ways at individual observatories with records over a sufficiently long period. Several workers, following Moos (1910) for Bombay (9.5° N gm. lat.), have examined the daily variation of frequency of sudden magnetic changes. The earlier studies did not distinguish between Sc and Si. A forenoon minimum and afternoon maximum of frequency were found by Rodés (1932) from 218 cases (1905-31) at Ebro (43.8° N gm. lat.), by McNish (1933) from 151 cases (1919-30) at Watheroo (41.7° S gm. lat.), and by Newton (1948) from 681 cases (1874-1944) at Greenwich (54.2° N gm. lat.); see also Fig. 3 (broken curve), Ferraro, Parkinson and Unthank (1951) first analyzed the Sc and Si data separately, from the following six observatories, for the period 1926-46, common to all six.

	gm. lat		*gm. lat*
Cheltenham	50° N	Honolulu	21° N
Tucson	40° N	Huancayo	1° S
San Juan	30° N	Watheroo	42° S

No sudden change was included unless it was shown by at least one station in two elements. Their data included 141 Sc's and 381 Si's. As Chakrabarty found at Alibag, Sc (−) did not appear in the San Juan records, and only 13 cases in all were found (8 at Watheroo, 2 at Honolulu, 1 each at the other three stations). They found a slight tendency for Sc's to be most frequent at about 13^h local time, and least frequent at about 5^h; but the daily variation of frequency was small; relative to the mean frequency taken as unity, the daily variation was expressed thus:

$$1 - 0.007 \cos(\theta - 63^\circ) + 0.002 \cos 2(\theta - 7^\circ),$$

where $\theta = 15\ (t + 1/2)$.

The Si's, on the other hand, showed a more marked daily variation, expressed thus, in the mean for the six stations:

$$1 + 0.008 \cos(\theta + 43.1^\circ) + 0.17 \cos 2(\theta - 34^\circ)$$

The probable errors for the two amplitudes are 0.04, so that, at most, only the semidiurnal variation can be considered reliable. As Si's are more numerous than Sc's, this variation will appear in combined statistics for Sc and Si taken together. Nevertheless this variation is only small, relative to the mean. The difference between the daily variations of Sc and Si may indicate another real distinction between these two kinds of sudden change. But the reliability of statistical conclusions on the daily (and seasonal) variation of frequencies of Si's is rendered doubtful because Si's can be clearly recognized only during quiet periods. Hence it is necessary to consider how the daily (and seasonal) variation of frequencies of Si's might influence the conclusions regarding Si's.

Ferraro, Parkinson and Unthank also examined the daily frequency variation for Sc (− +) and Si (− +) at five of their stations (Honolulu being excluded because it had too few cases). They found that for the higher geomagnetic latitudes (30° to 50°), both Sc (− +) and Si (− +) are most frequent from noon to 19^h; this was confirmed by Nagata (1952).

Ferraro and Parkinson (1950) found also that the ratio of the number of Sc (− +) to the total number of Sc is about the same as the corresponding ratio for Si. A more remarkable result was that these ratios both showed a marked dependence on geomagnetic longitude.

This conclusion, as Jackson (1950) suggested, is not yet certainly established. The question calls for further examination at other observatories.

The *yearly* frequency variation of Sc and Si has been examined for Greenwich by Newton (1948) for both types together, and for the separate types at Honolulu by Ferraro *et al* (1951). The Honolulu Sc's show marked equinoctial maxima of frequency (like those for magnetic storms in general). The Si's show no marked yearly variation either of frequency or average amplitude, and this agrees with the Sc+Si results (doubtless mainly Si) for Greenwich. But many Si's may go unrecognized, more particularly during disturbed equinoctial periods.

The combined Sc + Si frequency for each of the six stations considered by Ferraro *et al.* (1951) shows a clear variation with the sunspot cycle.

There is need for further studies of this kind for other observatories with long series of records—and also studies of the inter-relation of Sc's and Si's with other phenomena, ionospheric, auroral, etc., such as those by Matsushita (1957) and by Thomas and Robbins (1958), who considered the ionospheric disturbances associated with Si.

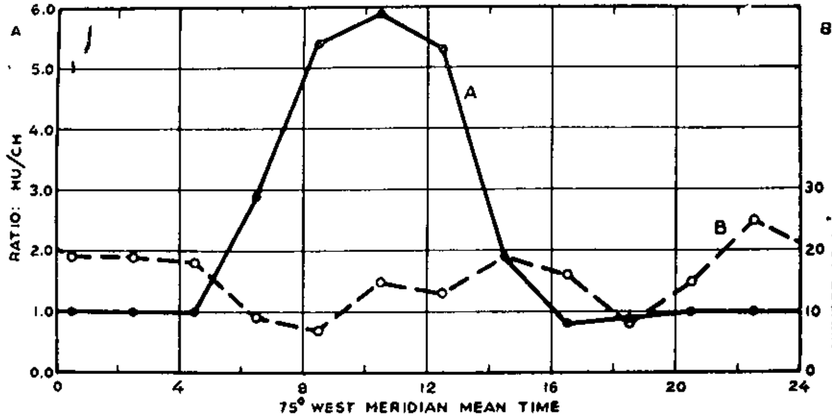

Fig. 3. — Enhancement of the Sc in H under the equatorial electrojet. The full curve indicates the daily variation of the ratio of the amplitude of Sc's at Huancayo to the amplitude of the corresponding Sc's at Cheltenham, for 183 Sc's, 1922-46. This shows the daytime enhancement of the Sc in H at Huancayo. The broken line gives the daily variation of the frequency of these Sc's, relative to local time (which is approximately the same at the two stations). (Sugiura 1953; Fig. 1).

In addition to studies of the *frequency* of the sudden changes, important results have been obtained as regards their *amplitude*. At Huancayo, almost on the magnetic equator, the Sc amplitude shows a marked daily variation (Fig. 3, Sugiura (1953); his Fig. 1), which is reminiscent of the abnormal enhancement of Sq (H) at this station;

see Ferraro, Parkinson and Unthank (1951), Sugiura (1953), Forbush and Vestine (1955). The latter paper also showed that the initial storm phase (and not only the Sc) is enhanced at Huancayo, though the Dst and DS variations appear not to be enhanced (Chapman 1951). Ferraro (1954) found that the other five stations (see above) considered by him and his colleagues in 1951 did not show the Sc daytime enhancement; in fact there seemed to be a weak daily minimum of amplitude at about 8^h local time. Jackson (1952, p. 163) concluded that the structure of the Ss at this hour is radically different from Sc (+), and is not *merely* [1] Sc (+ —); also that the form is not what one might expect from a simple process of ionospheric screening, which would have the effect of slowing down the rate of change; and that the initial quick stroke, as well as the oscillations found to be associated with these «8^h» Sc's, may be a secondary effect which has its origin in currents which are set up in the ionosphere at the time.

3. MORPHOLOGICAL STUDIES

For a proper understanding of the sudden changes Sc and Si, another —morphological—type of study is even more necessary than the studies at individual observatories. A morphological study is one concerned with the determination and representation of the magnetic field vector over the earth's surface as a function of both time and position. This involves all three magnetic elements. The effectiveness of morphological studies depends on the number and world distribution of the observatories that record the kind of phenomenon under consideration. The more locally differentiated is its distribution, the closer must be the network of observatories.

The general morphology of magnetic storms has been studied by Moos (1910), Chapman (1919, 1935), Vestine *et al.* (1947), Sugiura and Chapman (1959) and others. The average variations are generally determined in two parts, denoted by Dst and DS. The additional D field, present during a storm, is a function of storm time —reckoned from the storm commencement— and of position. In each element, at each instant of storm time, Dst denotes the mean value of the storm field round a parallel of geomagnetic latitudes; thus Dst is a function of t and geomagnetic latitude. It represents the part of the field that is symmetrical around the geomagnetic axis. The difference between the whole field D, and its part Dst, is denoted by DS; it is a function of t, of geomagnetic latitude, and of geomagnetic local time (or geomagnetic longitude relative to the geomagnetic midnight meridian at that instant of storm time). The parts Dst and DS have been determined

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[1] Our italics.

for the average of many magnetic storms of similar intensity, for groups of storms of different intensity, at different seasons. The material used was the hourly values of the magnetic elements published by the magnetic observatories.

Such values cannot suffice for the study of the morphology of sudden brief changes such as Sc and Si; it is necessary to refer directly to the magnetograms. Nevertheless, on this shorter time scale, it is convenient to divide up the Sc or Si field into the two parts Dst and DS. In order to be sure that these two parts are accurately determined, for the same instants in different parts of the earth, it is clear that the timing of the records at each observatory used must be accurate to a small fraction of the duration of these sudden changes.

4. SIMULTANEITY AND TIME ACCURACY.

If everywhere over the earth an Sc or Si were simple, namely a sudden increase in H (and decrease in V), the first important question that would arise is «how nearly simultaneous is it over the earth?». In other cases, when the sudden change is not simple, morphological study requires a knowledge of the vector distribution of its field over the earth at a succession of instants, accurately timed. The accuracy of time estimation depends partly on the time scale of the record and its absolute synchronization, and partly on the actual rate of the magnetic change. Early studies by Adams (1892) and Ellis (1892) showed that Sc's may be simultaneous over the earth to within a few minutes. Bauer (1910) studied this question of simultaneity, and inferred that the Sc has a time of propagation round the earth of order 3 or 4 minutes. His results were critically discussed by Chree (1910), Angenheister (1913) and Chapman (1918). They concluded that the observations did not provide a safe basis for the determination of propagation speeds; instead they indicated the relative inaccuracy of the records. Chapman suggested that the time differences of the Sc between different stations might depend on simple geometrical considerations involving the aspect of the earth as viewed from the sun. He envisaged the envelopment of the earth in a stream issuing radially from the rotating sun. This suggested a possible minimum range of the times of Sc at different places, of order 30 seconds, the time being earliest near the sunset meridian and latest near the dawn meridian. The data were not accurate enough to confirm or overthrow this simple conception.

Gerard (1959) has recently made a more accurate study of the times of Sc (+) and Sc (− +). He found that the time differences, in either case, range only up to a few seconds, and concluded that the sun controls the hemisphere in which the Sc first appears. However, his time differences seem to be of the order of the timing accuracy, so that there is need to check his conclusions as to the time distribution relative to the aspect of the earth seen from the sun, using still more accurate data. The IGY saw a general improvement in timing and recording techniques, and many stations provided quick-run magnetograms. But a timing accuracy of 1 or 2 seconds is desirable. Campbell (1959) used methods giving this accuracy. It would be valuable for this purpose to have Sc records from Huancayo and from other low-latitude stations, Pacific and African, Indian and Australian, with open time scales, and synchronized by registration of WWV signals.

5. MORPHOLOGICAL REPRESENTATION BY CURRENT SYSTEMS IN CONCENTRIC SPHERICAL SHEETS.

The transient magnetic changes at the earth's surface can be analyzed into parts that originate respectively above and below the surface. In all cases the major part is of external origin, and the part of internal origin is reasonably explained as due to electromagnetic induction by the primary external part. Hence the main interest centers on this external part.

From a knowledge of the distribution of this external changing field over the earth, as a function of time and position, its magnetic potential can be determined. From this it is possible to determine a current system, flowing in a spherical sheet concentric with the earth, that *could* produce the said field. But this may or may not be the current system that *does* produce the field; and even if the system does flow in a concentric layer, the surface magnetic data cannot determine the radius of the current sheet. In any case, however, such a current representation is valuable and interesting, because it provides a convenient graphical scalar synopsis of the field morphology.

In the case of the external storm field D, *average* current systems for the middle belt of the earth have been determined that represent its parts Dst and DS, and the combined total field, throughout the average storm. Worldwide or partial current systems associated with a number of individual magnetic storms have also been given, by McNish and Johnston (1939) and Vestine (1940), and also for bays (Fukushima 1953).

The D field at its sudden commencement has been likewise examined by several writers. Nagata (1952) and Nagata and Abe (1955) studied Sc's of the type Sc (— +). Further and more comprehensive studies were made by Oguti (1956) and Obayashi and Jacobs (1957). Fig. 4 gives an *average* representation (Obayashi and Jacobs 1957; their Fig. 4) of the Dst, Ds and total current systems for an Sc. The Dst part of the current of the Sc field is eastward, opposite to that for the main storm phase in which H is below normal. The DS currents

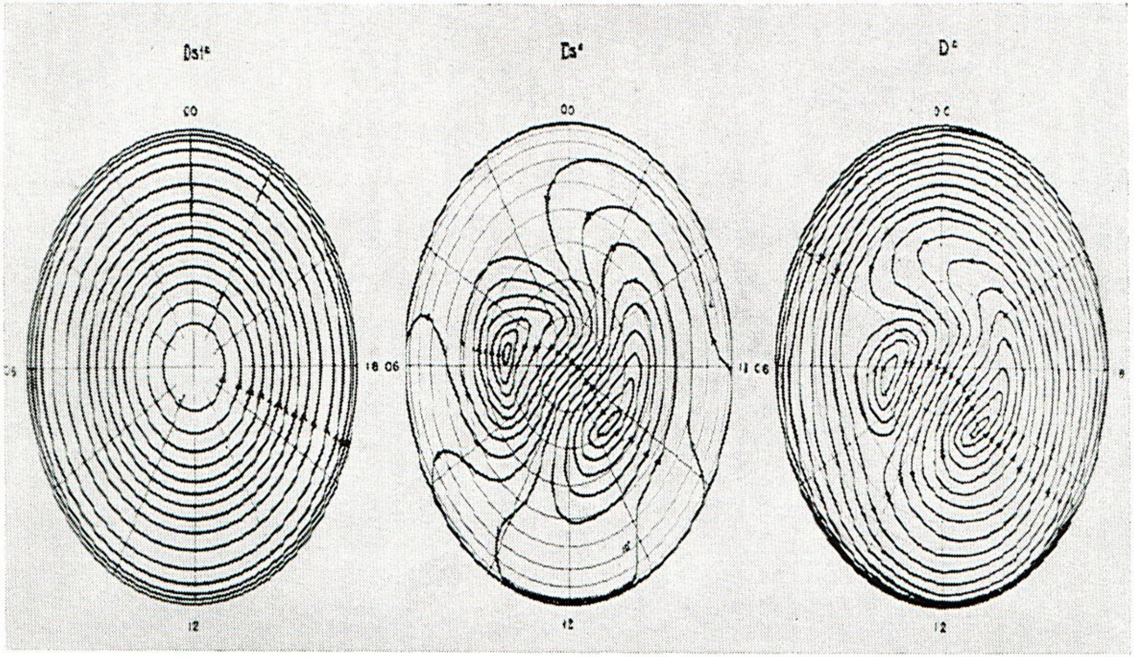

Fig. 4 —Average equivalent current-systems of Sc Dst, Sc DS and of the combined Sc(Dst+DS) fields for sudden commencements. The local time is indicated on the periphery; the sun is in the direction of the downward vertical. (Obayashi and Jacobs 1957; Fig. 4)

for the Sc field are similar in some respects to those observed during the initial and main storm phases; that is to say, the current system shows a nearly parallel flow over the polar cap centered on the geomagnetic pole, with lateral eastward and westward return flow. But the DS currents of the Sc field differ from those of the main storm phase in that they may show no auroral zone electrojets—that is to say, there may be no marked concentration of eastward and westward current along the auroral zone, especially at the initial time of Sc (− +). (Such a concentration may, however, be shown if there was local magnetic activity in polar regions before the Sc.) Nor does the Sc, DS current system show the additional current loops *outside* the auroral zone that appear during the main storm phase. The orientation of the DS field around the geomagnetic axis may fluctuate during the main course of a storm, with little change in its general form, but much less rapidly than during the Sc.

Fig. 5 (Obayashi and Jacobs 1957; their Fig. 8) shows current diagrams for the earlier (−) and main (+) epochs of an Sc that occurred on 1949 October 13 at 20^h 12^m. At the earlier instant the Dst part seems to be inconspicuous. The current system is almost wholly of Sc DS type, and is practically confined to higher latitudes; then follows the main Sc movement, which shows an eastward Dst current in low latitudes and a DS current system in higher latitudes; this is nearly oppositely directed to that shown for the earlier Sc epoch. Some large current arrows in this diagram suggest that already there is a concentration of current along the auroral zone, though the current lines, as drawn, do not show this. In this case the Sc appeared to be an Sc (+) in lower latitudes, and an Sc (− +) in higher latitudes. Oguti (1956) independently found similar changes; he stated that the DS part of the current system may rapidly rotate clockwise, during an Sc which in high latitudes appears as an Sc (− +). Fig. 6 (Oguti 1956; his Fig. 4) shows his idealized current systems for the first and main epochs of an Sc.

The DS part of the Sc field, most intense in high latitudes, and changing in orientation (at least in some cases) during the Sc, accounts for the greater complexity of Sc's in higher latitudes than in low (where in general the simpler Dst part is paramount).

There is need for further studies of this type based on the extensive IGY data. Future studies of post-IGY data would be aided if gaps were filled in the network of stations that operate rapid recorders—for example, at San Juan, Toolangi and Muntinlupa.

Vestine (1940) first gave current diagrams for successive epochs of several magnetic storms (from data obtained during the second International Polar Year). His diagrams referred to hourly means of the disturbance field. Hence his diagrams for the *initial phase* of two

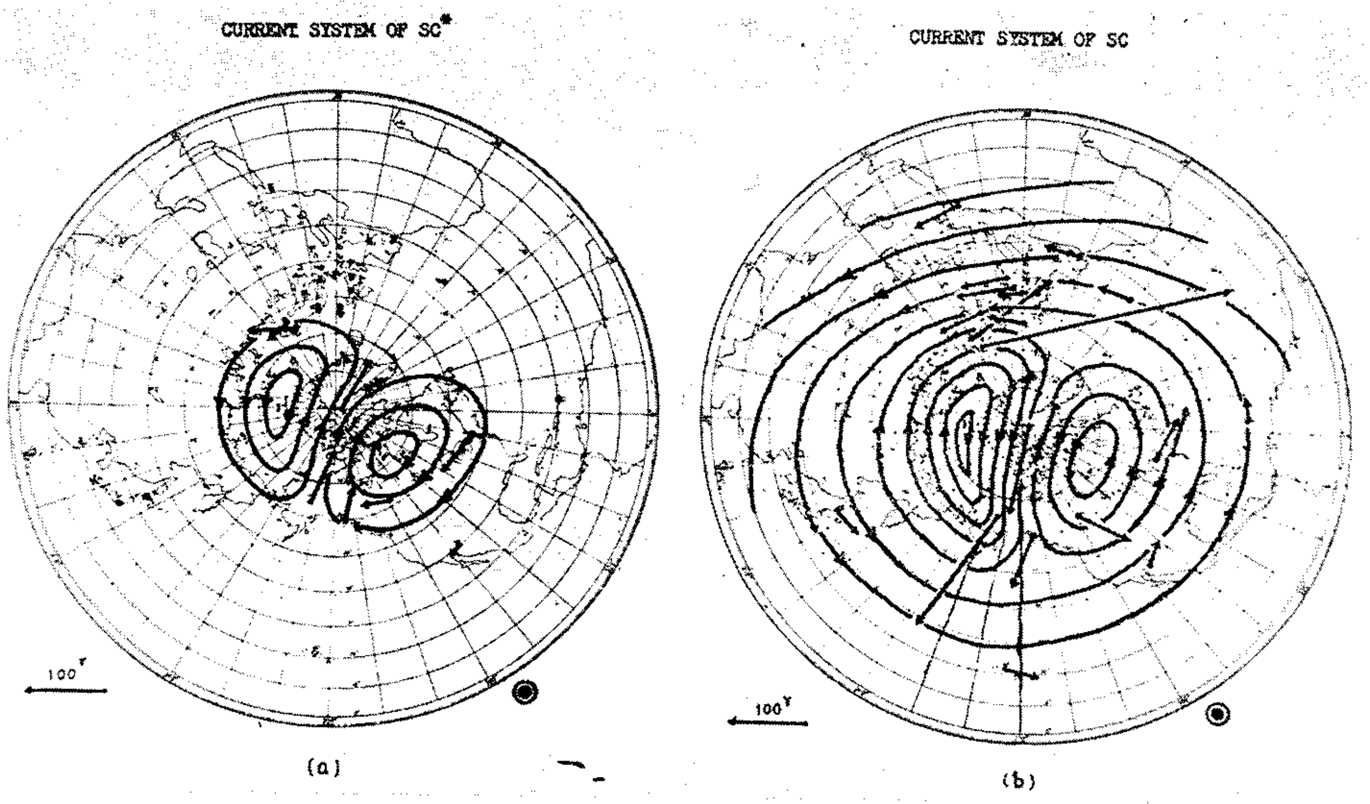

Fig. 5. — Equivalent current systems of Sc(— +) at 20h 12m UT, October 13, 1949. The left hand diagram refers to the epoch of initial decrease of H at many stations; the right hand diagram refers to the epoch of increased H; the time difference between the two diagrams is less than three minutes. (Obayashi and Jacobs 1957; Fig. 8)

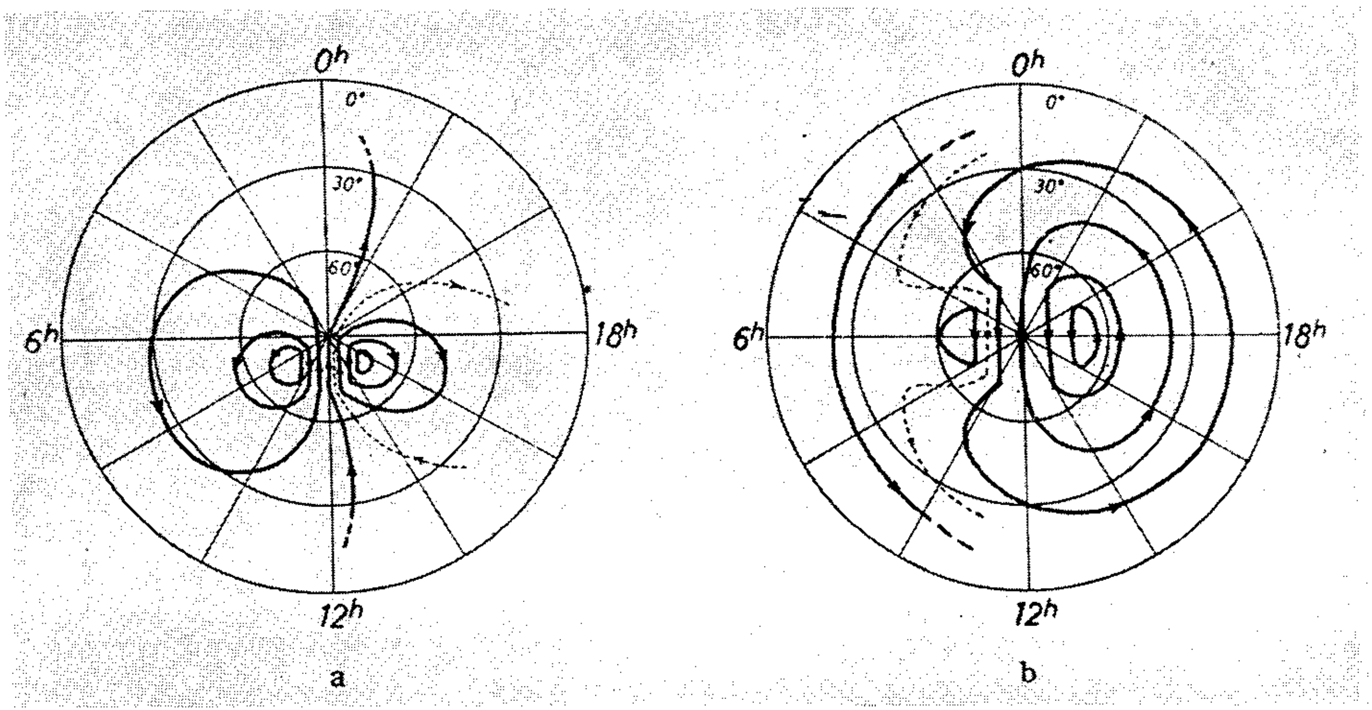

Fig. 6. — Idealized equivalent current systems for Sc(—+). (Oguti 1956; Fig. 4)

magnetic storms (1932, October 14, and 1933, April 30), though highly interesting, do not refer to the brief Sc field of these storms.

6. THE TRUE FORM AND LOCATION OF THE Sc CURRENTS.

As stated in S 5, the current systems illustrated for the Sc field and the field of the later phases of a magnetic storm are convenient representations of the field morphology, but do not necessarily represent the true form and location of the external currents. The polar part of these current systems is, however, generally believed to be located in the atmosphere at auroral levels (that is, in the lower ionosphere). There the atmosphere is known to be strongly ionized during most of the initial and main phases of magnetic disturbances, especially along the auroral zones. The strongest currents in high latitudes flow along these zones, partly eastward, partly westward. The polar currents consist mainly of DS but may also include a substantial Dst current.

In lower latitudes, except near the magnetic equator (as at Huancayo), Dst is the major part. The small difference of current intensity between the day and night hemispheres —despite the great difference in the ionization of the atmosphere over the two regions— is one main reason for the view, held by a number of workers, that these Dst currents flow mainly outside the ionosphere (as this term is usually understood). The Huancayo daytime enhancement of Sc (H) indicates, however, a notable current flow along the daytime equatorial electrojet which is part of the Sq current system. This enhanced Sc electrojet current must find its return flow to north and south, and will show as an apparent enhancement of the Sq current system—such as has been tentatively noted by Obayashi and Jacobs (1957, p. 596).

Rocket and satellite observations can help to solve some of the uncertainties as to the form and location of the external electric current systems during magnetic storms, both for Sc's and for the later phases. By magnetic recording along its path, a rocket or satellite can show when it traverses regions of electric current flow. Naturally it may be expected that the results will mainly refer to the main phases of storms, rather than to Sc's, on account of the short duration of Sc's.

Further light on the nature of the external storm current systems, especially of Sc's, may be sought also from theories of magnetic storm production.

7. THEORY OF THE Sc OF GEOMAGNETIC STORMS.

The first fairly plausible theory of the sudden commencement of a magnetic storm was given in 1931 by Chapman and Ferraro. It was part of an attempt to infer the course of events, supposing that the sun ejects a stream of neutral ionized gas towards the earth. This hypothesis was suggested by Lindemann (1919), to overcome Schuster's objection (1911) to earlier theories, like those of Birkeland (1913) and Stormer (cf. 1955), which assumed a solar stream of charged particles all of the same sign.

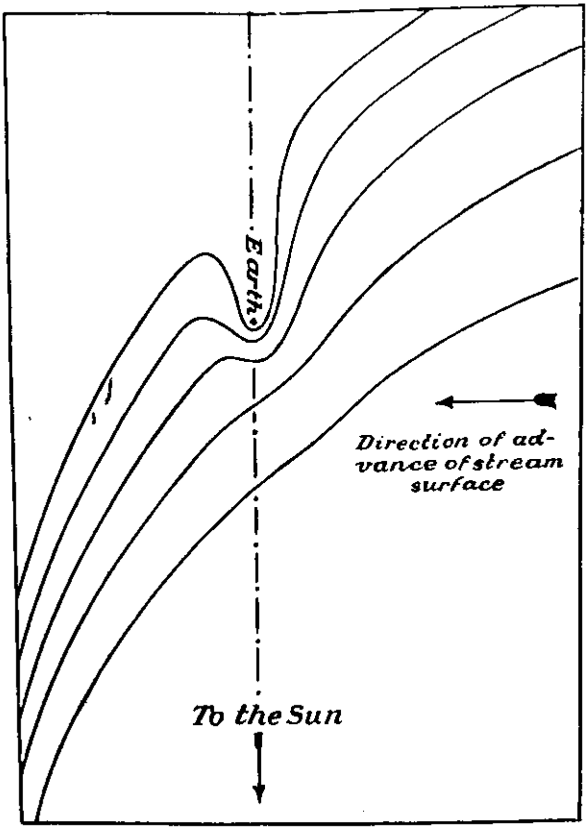

Fig. 7. — Idealized geometry of the advancing front surface of the corpuscular stream. (Chapman and Bartels 1940; p. 856: from ref. 27, Fig. 2)

Chapman and Ferraro tacitly treated the solar stream as uniform in density and speed, and traversing empty space between the sun and the earth. They inferred that the stream would be retarded by the geomagnetic field, which would produce a hollow in the stream. At first they treated the stream as having initially a plane front perpendicular to the velocity of the gas, and parallel to the geomagnetic axis. They inferred that an electric current system would be induced in a thin front layer of the stream. This system would increase the geomagnetic field intensity within the hollow. But to north and south of the geomagnetic equatorial plane there would be focal points round which the electric current would flow. Everywhere except at these points the geomagnetic force on the currents would retard the stream surface; but the gas could flow freely through the focal points. It was guessed that «horns» of gas would extend from these focal areas,

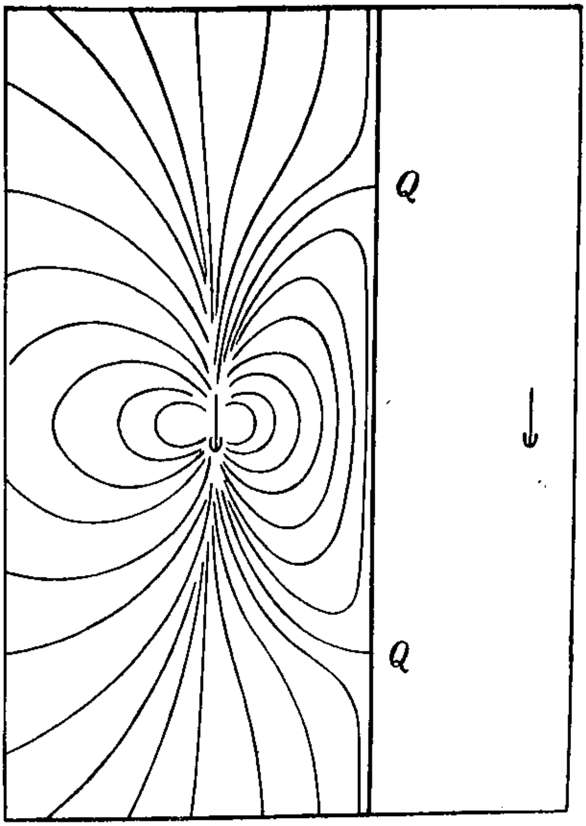

Fig. 8 — Diagramatic sketch of the combined field of the geomagnetic dipole and of the electric currents induced in the plane surface layers of the advancing ionized stream. (Chapman and Bartels 1940; p. 861: from ref. 27, Fig. 4)

perhaps approximately along geomagnetic lines of force, and flow into the earth's atmosphere somewhere in the auroral zone.

The shape of the hollow, and the detailed course of events, could not be calculated because of the complexity of the problem. But illustrative idealized problems were solved (note especially Chapman and Ferraro 1940 and Ferraro 1952), that seemed to indicate some probable features of the actual geomagnetic storm commencement.

The determining characteristic of the stream was found to be its energy density E just before the stream became affected by the geomagnetic field. This is the initial kinetic energy of the gas per unit volume—the gas being composed of protons and electrons in equal number. Let Za denote the distance from the earth's center O to the point C of closest approach of the stream towards the earth; here a denotes the earth's radius. The point C (the «vertex» of the hollow) (Fig. 7, Chapman and Bartels, p. 856) will lie on the line joining the sun S to the earth's center O. It was found that approximately

$$Z = \left[\frac{H_0^2}{8\pi E}\right]^{1/6}, \qquad (1)$$

where H_0 denotes the earth's equatorial surface magnetic intensity (0.3 gauss). This is a consequence of the simple approximate relation $E = H^2/8\pi$, where H denotes the geomagnetic field at C. Thus Z varies inversely as the one-sixth power of E, so that a great range of E, for example in a ratio of 3^6 or 729, corresponds only to a threefold range of Z. The corresponding magnetic disturbance at the earth's center O may be inferred from the approximate Chapman-Ferraro conception of an image dipole for the field of the electric currents induced in the stream front (Fig. 8, Chapman and Bartels, p. 861); it is northward, and of amount

$$H_0/8\,Z^3 \quad \text{or} \quad (\pi\, E/32)^{1/2},$$

varying as $E^{1/2}$.

Thus, for a sudden commencement of moderate magnitude, in which the external part of the initial increase (only slightly more than half the total increase) is 10γ, Z would be approximately 7.2. For twice this initial increase, Z would be approximately 5.7, and for a very intense Sc, showing an initial increase of 420γ[1], of which 225γ was of external origin, Z would be approximately 2.56. Such considerations given by Chapman and Ferraro indicated the scale of the hollow space and of the electric current distribution round the earth, during the earliest stage of storms of different intensities, from mild to very great. This scale was far smaller than that previously envisaged, in Störmer's theory.

Our subject here being the sudden commencement of geomagnetic storms, it is not necessary for us to consider the subsequent course of events according to this theory. Actually Chapman and Ferraro were unable to infer this course, and made only tentative suggestions

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[1] This was the value at Hermanus Observatory (33.3° S gm. lat.) at the second Sc on February 11, 1958, at $01^h59^m30^s$ UT; this followed the first Sc that day after 34 minutes. The associated flare was observed on February 9 at 21^h08^m UT. The travel time was 28^h52^m and the corresponding speed was 1.46×10^8 cm/sec. The above formulae give $Z = 2.56$, $E = 1.3 \times 10^{-5}$ erg/cc, and for the number density of the stream protons or electrons, about 750/cc.

as to how the main storm phase could be produced by the growth of a westward ring current, of radius a few times that of the earth.

In their theory of the initial impact of the solar stream upon the geomagnetic field, it was clearly shown how abruptly the stream front was stopped at the distance Za where Z depends on the energy density E of the stream. Owing to the nature of the relation (1), a hundredfold increase in E would diminish Z by less than half, and the initial Sc would vary tenfold. Moreover, the change of the field near the earth would be very rapid, increasing to its full amount from a tenth of this value in a time less than two minutes. This estimate assumes a stream speed of 1000 km/sec, which is of the order indicated by the travel time from the sun (in cases where the initiation of the stream can be associated with an identifiable solar event, such as a flare or radio burst). The undisturbed number density of the stream, just outside the geomagnetic influence, is then of order 28/cc for $Z = 5$.

The particles at the front of the stream, near the line OS, would be turned back, those further from OS would be deflected sideways. Near the vertex C of the hollow, the initial kinetic energy of the protons and electrons would be much reduced (the balance of their energy going into the disturbed magnetic field). Their remaining energy would be much greater for the electrons than for the protons. Other particles coming on from behind would pass through the earlier particles flowing backwards, before their motion also was reflected or deflected. The main change of the motion would be concentrated in a thin front layer of the stream, whose density would be increased. This thin layer might be called a *shock* front, but this term is perhaps better not used, because it could be taken to imply a closer analogy with shock waves in ballistics than is actually the case (cf. Parker 1959).

The treatment of the stream as being of uniform density and speed is of course an idealization, permissible in a first attack on such a problem. In actual solar streams there will be non-uniformities of density, a spread of forward speeds, and irregularities in the form of the front «surface». During the travel from the sun the speeds will to some extent sort themselves out (if the stream carries away no magnetic field from the sun). Thus the faster particles arrive first, with a reduced spread of speeds. A small spread would only slightly affect the abruptness of the stream stoppage and of the resulting sudden storm commencement (see also S 9).

In their discussion of the sudden commencement, Chapman and Ferraro mainly considered the disturbance of the geomagnetic field by the surface electric currents at the front of the stream when the front is at a distance of a few earth radii from the earth's center O. These may be called the corpuscular flux (or CF) currents. These would produce a disturbance of rather simple form, of plain Sc (+) type. But their theory suggested also some inflow of the stream gas into auroral latitudes along the «horns». They did not discuss the magnetic effects of this inflow. But during the main phase of a storm the inflow is supposed to produce the polar electric current system DS in the ionosphere, mainly at high latitudes. This formation of the DS current system is far from being fully understood at present, though some workers favor a dynamo theory of its origin. It is still one of the main problems why aurora is so largely a nighttime phenomenon, and also why such a strong current as DS can flow in the auroral ionosphere. But it is natural to suppose that some kind of inflow and some form of DS current system begin from the onset of the storm. Thus the corpuscular flux electric current, at a distance Za may be responsible for the main (Dst) part of the Sc field in low latitudes, and the polar currents and their field may be due to the incoming gas flow—as already indicated by Obayashi and Jacobs (1957, pp. 596, 600). Chapman (1952) indicated that the two parts of the storm field develop almost simultaneously, but vary somewhat differently with storm-time (Fig. 9, Chapman 1952; his Fig. 2).

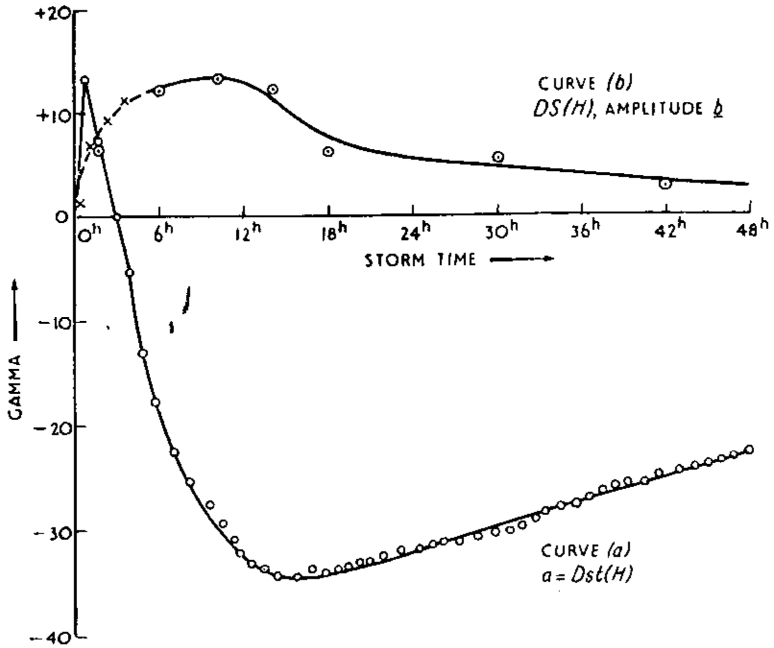

Fig. 9. — Average development of Dst (H) and DS (H) in low and middle latitudes during the course of magnetic storms. (Chapman 1952; Fig. 2)

(a) *Alfvén's electric field theory*

The Chapman-Ferraro conception of a storm Sc, extended by the inclusion of the polar DS currents, was described in S 7 as fairly plausible. Although this is not the occasion to enter upon a discussion of the larger and much disputed field of magnetic storm theory in general, some mention is needed of other theories of the *sudden commencement.*

Alfvén, during the period 1939 to date, has developed an alternative theory of magnetic storms and auroras. In attempted mathematical development it vies with the Chapman-Ferraro theory, and its author and his colleagues have also offered interesting experiments in support of the theory. The author has answered criticisms raised against the theory, and in turn has criticized the Chapman-Ferraro theory, forcefully though appreciatively. His essential criticism is that the hypothesis on which the Chapman-Ferraro theory is built ignores a fundamental feature of the stream or cloud of solar gas, namely that it carried with it, from the sun, an internal magnetic field. He cites independent evidence for the presence of such a field—namely, the cosmic ray changes associated with some magnetic storms. However, he agrees that «there are many storms, in connection with which no decrease» (of cosmic rays) «as large as 1 % was observed. This may indicate that the breadth of the beam is smaller than 10^{13} cm, that the field is smaller than 1γ, or that the field is irregular». Thus it may be that not all solar streams do carry any significant magnetic field, and that the Chapman-Ferraro initial hypothesis may be valid, at least in some limiting cases. Moreover, it should be possible to trace a continuous transformation from the conclusions drawn from the Chapman-Ferraro theory to those drawn from the Alfvén theory, as the internal magnetic field of the solar stream increases from zero to 1γ—at least so far as these conclusions are valid. This is suggested as an interesting and perhaps profitable undertaking for magnetic storm theorists.

In the earlier development of his theory, Alfvén gave no explanation of the initial storm phase (Alfven, 1955, p. 51). He first offered an explanation in the paper just cited. He concluded that owing to the inertia of the solar stream an outer eastward ring current with a radius about 30a will be formed; also he associated this current with the production of an inner auroral zone in geomagnetic co-latitude 5° to 10°. He rightly stressed the importance of auroral and magnetic observations in this region. The evidence of the IGY all-sky auroral camera films, as to the evidence of such an inner auroral zone, will be of great interest. His theoretical inferences as to the first phase of a magnetic storm, however, do not parallel the observed facts. Fig. 10 shows his calculated curve (Alfvén 1955; his Fig. 7) for the time variation of the amount of electric current flowing across the geomagnetic meridian through the sun; eastward current is reckoned positive. As he remarked (p. 60) «the duration of the initial phase» (during which the current is eastward) «is according to Fig. 7 of the order of 10 minutes. This is less than one tenth of the observational value, which is a few hours». Apart from this marked discrepancy, the diagram gives no indication of a *sudden* onset, that is, of a considerable Sc increase of H. Thus the Alfvén theory appears unsuccessful in the aspect of magnetic storms here particularly considered.

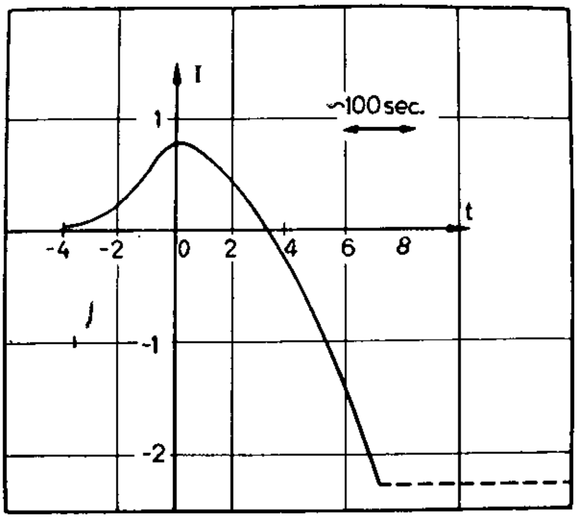

Fig. 10. — Alfvén's Ss. The circular eastward current (+ current) produces the initial phase with no Sc. Note that the duration of field increase is very short compared with the actual, initial phase. (Alfvén 1955; Fig. 7)

(b) Singer's theory of magnetic storm Sc's.

Since 1956 Singer has been a valued active contributor to the discussion of aeronomic and geomagnetic storm phenomena (1957, 1959). The following quotations are taken from his papers. «The initial injection of solar corpuscular radiation consists mainly of protons and electrons with velocities of 2×10^8 cm/sec. These 20 kev protons form a third and rather transient (~ 1 day) radiation belt at 4-8 earth radii; they account for most of the effects observed during magnetic storms. Their initial diamagnetic effects produce the Sc (— +).» «Their increase of upper atmospheric ionization accounts for the Sc currents... We can therefore calculate the complete development of a magnetic storm as a function of time...» «The Sc itself may be due to the incidence of such protons into the ionosphere, there causing additional ionization which increases conductivity and allows existing dynamo EMFs to drive a larger current through the ionosphere.»[1] Singer does not attach essential importance to any magnetic and electric field in the solar stream.

His earlier account of the origin of a magnetic storm (1957, p. 178) started with an interplanetary shock wave. «This suggestion was advanced by Gold (1955, p. 103) to explain the high degree of collimation in time of the worldwide Sc, even after a long travel time from the sun. This, of course, accounts for the sharp face of the approaching gas in the Chapman-Ferraro theory, but does not yet explain the origin of the Sc.»

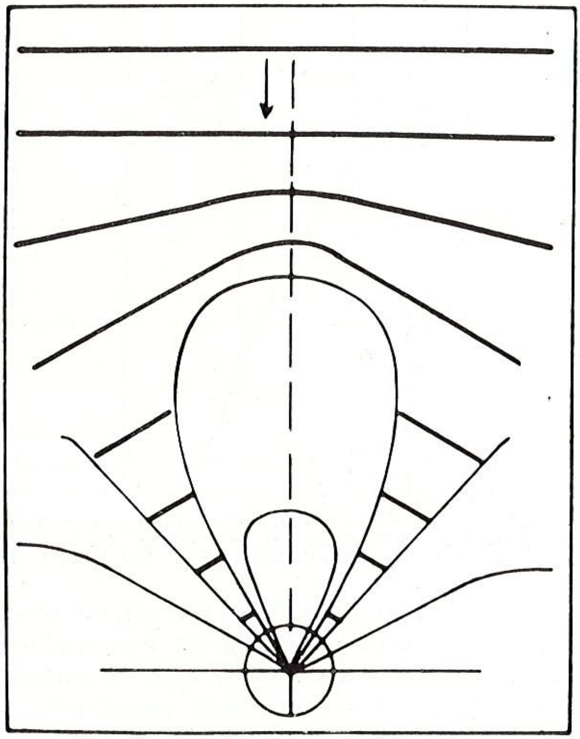

Fig. 11. — The suggested propagation of shock waves into the outer atmosphere. Positions of the shock front at successive intervals are indicated. (Singer 1957; Fig. 4)

In S 7 we have given some comments on shock waves in relation to magnetic storms; this is further discussed in S 9.

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[1] These quotations are taken from a paper (not yet published) entitled "Properties of the upper atmosphere deduced from the radiation belt".

«We now consider what happens when the shock wave impinges on the earth's dipole field. The gas enveloped by the shock, likewise therefore the field B in the equatorial plane, is compressd... This process should occur some earth radii out, well above the ionosphere. This process of course is equivalent to the retardation and stopping of the beam in the Chapman-Ferraro model...» (Singer, 1956, p. 180).

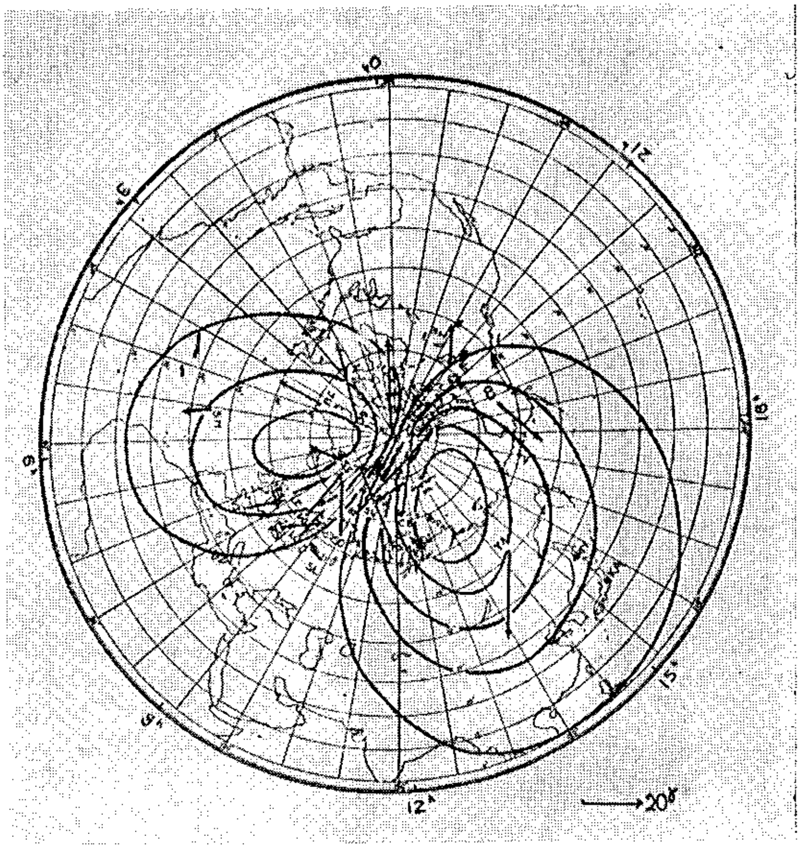

Fig. 12. — Equivalent current system for the first epoch of Sc(—+) at 06ʰ 25ᵐ UT, May 29, 1933. (Nagata and Abe 1955; Fig. 3)

But his discussion proposes the addition of new concepts to our picture of what happens above and below the equatorial plane. The shock wave finds its way into the auroral zone (Fig. 11, Singer 1957; his Fig. 4), being confined by lines of geomagnetic force, as by the walls of a shock tube, and also twisted in longitude with some charge separation. By convergence the speed of the shock front is increased from 2×10^8 cm/sec to 10^9, «in other words, high enough to produce auroral effects, ionization, and motions of the auroral ionosphere». (Ibid, p. 180.) The charge separation is supposed to produce EMFs that drive the Sc current system.

One criticism of Singer's work is that the effects are not yet adequately calculated in his Appendix 3 (1957) or otherwise. The calculations are difficult, and success demands time and effort; but meanwhile judgement on the conclusions may remain in suspense. Until he explains more fully his mechanism for the production of Sc (− +), it is also hardly possible to judge whether it accords with the equivalent current diagrams, e. g., those obtained by Nagata and Abe (1955; their Fig. 3), here reproduced as Fig. 12.

(c) The Parker, Dessler and Piddington theories.

Attracted by the fascinating and challenging problems presented by geomagnetic storms and the aurora, Parker (1956, 1958a), Dessler (1958, a, b), Dessler and Parker (1959), Piddington (1958, 1959) and Francis *et al.* (1959) have independently produced a remarkable series of papers on these subjects. They are notable for the boldness and range of the new ideas imported into a field of theory where, as Elsasser (1957, p. 17) remarked, stagnation seemed to prevail for a decade or so. While in many respects they go much beyond the stage reached by Chapman and Ferraro, in others, and particularly as regards the Sc here discussed, they seem to agree with, or at least to incorporate and supplement, the Chapman-Ferraro theory of Sc, despite important differences of expression.

The extension of the Sc theory by these authors relates especially to the question of the transmission of the field effects at the front of the solar stream, retarded by the geomagnetic field, to the earth's surface. This problem is discussed in S 10.

9. TRANSMISSION OF THE DISTURBANCES FROM THE SUN TO THE REGION JUST OUTSIDE THE GEOMAGNETIC FIELD.

During the decade that included the studies of geomagnetic storm theory by Chapman and Ferraro (1931-1940), it was natural to ignore the presence of any interplanetary gas. This became actively studied later, from observations of the zodiacal light (Siedentopf *et al.* 1953) and of the outer solar corona (Blackwell 1955, 1956; Hewish 1955, 1958, and others). This led to varied speculations (Biermann 1957, Chapman 1957, 1959).

Here our special concern is with the influence of the interplanetary gas on the transmission to the earth of solar influences connected with eruptions and solar flares. Three main possibilities have been considered:

(1) A blast wave travels from the sun, without mass transport.
(2) Ejected solar matter collides with the interplanetary gas, and pushes it forward.
(3) Ejected solar matter interpenetrates the interplanetary gas.

All these three possibilities have been discussed, in many cases using the terms *shock wave* or *shock front*. But there are important differences between them.

(1) The first case was discussed by Gold (1955) in 1953, and later by Jennison (1955). At a symposium on gas dynamics, Gold remarked that for a geomagnetic Sc to be produced by a solar stream that is unimpeded until it nears the earth, the stream must have a quite unreasonably small velocity dispersion. «Even the purely thermal velocity dispersion would cause a time of build-up of more than one half hour... A much more reasonable interpretation of the phenomenon would be the arrival of a highly supersonic shock wave with the characteristic sharp wave front.»

(2) The second case was discussed by Singer (1957) and Akasofu (1957), who supposed that a shock wave might develop at the front of the solar stream, and that both the stream and the shock front would advance toward the earth, with slightly different speeds.

(3) Parker (1959) has considered the case of interpenetration, and has discussed the stream front and the plasma oscillations that will occur. In these oscillations there is a continual interchange between relative kinetic energy and electrostatic potential energy. Interaction with the oscillating electric field may almost fully preserve the initial velocity distribution of the stream protons, Maxwellian or otherwise, without direct collisions. The «relaxation time» will be of the same order of magnitude as the ion plasma oscillation (for the number density of 100/cc, it is less than 10^{-4} sec. cf. Parker 1959). The range of the relative oscillations of ions of different speeds will be of order 10 to 20 meters.

The generally accepted view is that solar matter not only reaches the outer region of the geomagnetic field, but also enters the earth's ionosphere in auroral regions. The protons observed by Vegard (1939, 1940), Gartlein (1950), and Meinel (1950) are usually interpreted as being of solar origin, though it has not been absolutely demonstrated that they must come from the sun.

The blast wave and collision wave hypotheses (1, 2) are rendered unlikely by reason of the large mean free paths in the stream and in the interplanetary gas. As regards Gold's objection based on velocity dispersion, particles of different speeds will, as already remarked (S 7), to some extent sort themselves out during the travel of the solar matter to the earth. Moreover, there is solar evidence that the ejected matter includes two distinct emissions, in which the dispersion of the particles that produce storms may be small (Wild, 1955, p. 661; 1957, p. 321). They come from type II bursts; the other type, III, may produce solar cosmic rays but no magnetic disturbance.

Opinions differ as to whether, as Biermann (1957) suggested, there is a continual though non-uniform ejection (the «solar wind») from all over the sun (Parker, 1958b). Instead the emission may be mainly in the form of clouds ejected from flare regions, and continued though perhaps intermittent streams from M regions (Babcock and Babcock 1955). Biermann's conception might imply that there is no static or nearly static interplanetary gas. The alternative conception would allow that there may be. But if such a nearly static gas exists, its temperature and density are as yet not well enough known to allow certain deductions as to the interaction between it and the ejected solar gas. Further information from satellite and cosmic ray studies is very desirable.

As regards a magnetic field in the solar gas, several writers (Alfvén 1956, Parker 1958b) have suggested that the stream or wind stretches out magnetic lines of force anchored in the sun, so that the gas flow is along or nearly along the lines of force. This would seem to imply that the electric field associated with the stream motion is absent or small.

10. TRANSMISSION OF MAGNETIC CHANGES FROM THE SOLAR STREAM FRONT TO THE EARTH'S SURFACE.

The Chapman-Ferraro studies of magnetic storms indicated that a solar stream would cause important field changes at a distance of a few earth radii from the earth's center. At that time it was natural to regard the space where these phenomena occur as being empty. Hence those authors took no account of any residual gas in the region of the stream retardation and of the growth of the supposed ring-current. They regarded the field changes as being propagated with the speed of light *in vacuo* towards the earth's surface, until the ionosphere was reached. There electric currents would be induced that would partly shield the earth's surface from the primary field changes. The non-uniform ionization and electric conductivity of the ionosphere would somewhat modify the form of the field transmitted to the earth's surface (Ashour and Price 1948; Sugiura 1950).

In 1954, Storey's theory of whistlers gave the first strong evidence of the presence of ionized gas out to distances of a few earth radii. Later it become recognized that the earth's outer atmosphere will consist mainly of atomic hydrogen, and that this will extend out to at least a few earth radii. Associated speculations were developed, about the temperature of the interplanetary gas and the possible ionization of the upper layers of this atomic hydrogen (Chapman 1957, 1959). At about the same time the problem of geomagnetic storms and auroras attracted active attention from many young workers in America, Europe, Japan, and Russia.

One result of this enhanced interest was a controversy over the transmission of the outer geomagnetic storm field changes to the lower ionosphere and the earth's surface. Parker (1956), who has contributed greatly to our understanding of many difficult problems in this field, argued that the ionized gas intervening between the earth and the region where field changes are generated would shield the earth from the Dst decrease of the horizontal field—the transmission requiring months or even years. Hines (1957) and Hines and Storey (1958) gave counter arguments, in favor of rapid transmission through the outer ionized atmosphere, by hydromagnetic waves. This view is now adopted also by Dessler and Parker (1959) and by Piddington (1959). Estimates of the speed of such waves over most of the path range abound 1000 km/sec, so that passage over a distance of, say, 5 earth radii, or about 30,000 km, would require a time of order 1/2 minute, and a little longer (about 10 seconds) to reach the dark side of the earth (Green *et al.* 1959; Francis *et al.* 1959); these times are less than those earlier estimated by Dessler (1958a). The inferred time difference of transmission to different parts of the earth would thus appear to be of order 10 seconds. However, the transmission of hydromagnetic waves through a non-uniform partly ionized gas can be complex, and as regards Sc the results are not yet clear.

Dessler and Parker (1959) and Piddington (1959) both conclude that during an Sc the field-changes produced by the retardation of the solar stream are transmitted downwards by hydromagnetic waves to the ionosphere. They refer to the suggestion by Forbush and Vestine (1955) «that important sources of the field of geomagnetic storms were located in the atmosphere» (by atmosphere they mean the region below about 1000 km.). Dessler and Parker (1959) conclude that «the surface magnetic observations may be interpreted as ionospheric current systems». Piddington (1959) concludes that «the currents directly responsible for *all* geomagnetic disturbances must flow below about 1000 km.» He gives a simplified picture of the atmosphere as consisting mainly of two regions (with a transitional layer betwen them):

(1) Up to a few hundred km the medium behaves as a rigid conductor and dispersive medium for waves of all periods between 1 and 10^4 seconds;

(2) Above 1000 km magnetic disturbances travel as hydromagnetic waves in the plasma (ions and electrons) alone. Losses in this region are small, but transmission is likely to be complicated by refraction, partial reflection and (for the extraordinary wave) by anisotropy.

Our own view is that currents of the type that produce the Sc (+) continue to flow during the early hours of a storm, that is, as long as the stream is impinging on the earth's field and being reflected back or pushed sideways so as to travel on beyond the earth. Temporary initial hydromagnetic wave effects may occur in the ionosphere, involving some transient current flow in the E layer; but the main Dst effect in the first phase comes from currents at the inner surface of the stream. These currents probably continue to flow during at least part of the development of the main phase. During this period the observed Dst magnetic changes are a superposition of effects due to currents at the inner stream surface and ring currents in the Van Allen belt.

At present the details of these processes remain obscure, and affect important questions relating to the distribution of electric currents and energy in the space round the earth.

11. THE SUDDEN COMMENCEMENT Ds CURRENTS.

The conception of a storm Sc attained as the result of observational and theoretical studies may perhaps be described as follows. The Sc field at the earth's surface is partly formed by the initial retardation of a solar cloud or stream at a distance of a few earth radii; this field change is transmitted in some way from that region, through the outer atmosphere and the ionosphere, to the earth's surface. This part of the Sc field includes much of the Dst part, or Sc (+), in the lower latitudes. Another major part of the Sc field, comprising most of the DS part, is due to a current system generated in our atmosphere, mainly in polar latitudes; but these currents also extend over a large part of the earth. They are supposed to be produced by solar particles or possibly by shock waves from the solar stream, which enter the auroral ionosphere.

It is not known how this entry into the polar region generates this second electric current system. Dynamo action has been proposed as an explanation, by Wulf (1945, 1953), Vestine (1954) and Obayashi and Jacobs (1957). But by detailed analysis of the current system and the probable dynamo-induced emf's, Maeda (1957, 1959) concluded that dynamo action was inadequate. Other evidence adverse to the conclusion that dynamo is the main cause is provided by the rapidity of change of the DS currents during an Sc, as reported by Oguti (1956). It seems scarcely possible that the winds responsible for dynamo emf's could change, over a wide area, during the brief interval occupied by an Sc (less than three minutes), so rapidly as to reverse the current system, or rotate it through a large angle. Hence some more direct source of emf, related to the changing intensity and location of influx into the auroral ionosphere, seems to be needed. Martyn (1951) suggested that during the main phase of a storm an emf is transmitted along the geomagnetic lines of force from the ring current; if the ring is symmetrical this might explain the polar Dst and (because of non-uniform conductivity) part of the DS currents during the main phase; but we are here concerned only with the Sc, not the main phase.

The emf's supposed to be generated in the polar regions impel electric current flow over a large part of the earth. It may be that during the day hours at Huancayo some of this current system flows preferentially along the narrow electrojet belt of high electrical conductivity that lies above the magnetic equator. This effect, suggested by Forbursh and Vestine (1955, p. 315) and Piddington (1959, S 6), may provide an explanation of the large daytime enhancement of the Sc at Huancayo. We hope elsewhere to examine this possible explanation in more detail. Its plausibility will depend, however, on the results of detailed accurate analyses of the Sc field over the earth. Such analyses, especially using the fairly abundant IGY data for Sc's, are much needed, as well as further theoretical studies, in order to increase our understanding of the sudden commencements of magnetic storms. Similar analyses of the field of Si's are likewise needed.

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DISCUSSION

Bartels: We must give our thanks to Prof. Chapman for this comprehensive paper on the storm sudden commencements. I should like to ask him to accept the notation of *ssc* proposed by the Committee No 10 instead of *sc*.

Chapman: I have no objection to it. I only did not know that the Committee had proposed such a notation.

Ferraro: It seems unlikely that a ring current with a radius of 30 earth radii will be formed in the manner envisaged by Alfvén in his 1955 paper in «Tellus». For at this distance the intensity of the earth's magnetic field is of the order of one tenth of a gauss and so about one hundred times smaller than the magnetic field (of the order of 10γ) which this ring current is supposed to produce at the earth. That means that the field of the ring current would *reverse* the earth's magnetic field at the place where this is supposed to form the ring current. The objection is the same as Chapman and Ferraro raised against Störmer's theory of the formation of the ring current. In Störmer's theory the ring current is situated at distances greater than 100 earth radii and if it were to produce at the earth's surface a field comparable with the decrease observed during the main phase it would reverse the earth's field in the vicinity of the ring by several orders of magnitude. These objections seem fatal to both Alfvén's and Störmer's formulation of the ring-current.

Chapman: You are right.

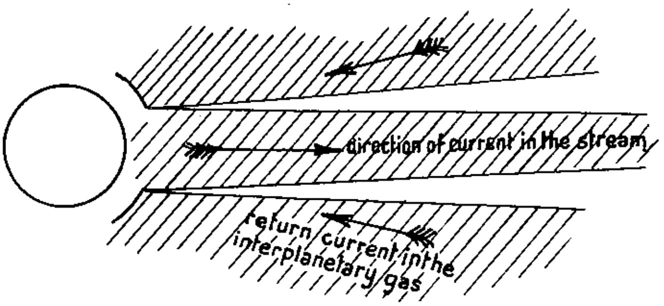
Ferraro: Several authors have suggested that a shock wave will develop at the front surface of a solar corpuscular stream during its passage through the interplanetary gas. This seems unlikely; the mean free path l of an ion moving with a velocity of v cm per sec in an ionized gas of number density n is of the order of

$$l = \frac{m^2 v^4}{\pi n e^2 f} \text{ cm},$$

where e and m denote the *electronic* charge and mass and f is a factor of order 20. Taking $v = 10^8$ cm per sec, which is the usual estimate of the velocity of a solar corpuscular stream emitted from the Sun, and $n = 500$ particles per cc., we find $l = 10^{13}$ cm which is very large compared with the dimensions of the earth and comparable with the radius of the earth's orbit. Hence, we can hardly speak of a shock wave in this connection since its thickness, of the order of a free path, would be of the same order of magnitude as the radius of the earth's orbit.

It has not yet been demonstrated whether a shock wave will be formed when a *rare* ionized gas moves through a magnetic field in a direction perpendicular to it. But in any case should a magnetic field exist in interplanetary space, it is likely to be highly tangled and that if there is a preferred direction this is likely to be radial. In this case no shock wave will arise.

Because the mean free path of an ion for a speed of the order of 1.000 Km per sec or more is comparable with the radius of the earth's orbit, the solar stream is able to pass almost unimpeded through the interplanetary gas up to the distance of the earth. However, as was suggested by Bennett and Hulburt, an electric current may be engendered in the stream during its passage from the Sun to the earth. For in an ionized stream emitted from the Sun in which the ions and electrons have nearly the same speed, the lighter electrons are scattered out of the stream during their passage through the stationnary interplanetary gas and to neutralise the resultant positive charge left on the stream, their place is taken by slower moving electrons drawn from the interplanetary gas. In this way a current will develop in the stream. But its growth will be limited by the effect of self-induction and the limiting current is smaller than the estimate given by Bennett and Hulburt. Its maximum value, moreover, may not be attained by the time the stream reaches the earth; this maximum is of the order of 1,000 amperes and thus too small to be of interest for theories of magnetic storm, though it might be of some interest in auroral theory.



Finally, one interesting feature also noted by Bennett is that as the stream passes out of the solar atmosphere it will tend to pinch itself into a narrower beam, though not at all rapidly, whilst the surrounding gas will expand to have a region almost void of gas between the stream and interplanetary gas. The latter carries the return current.

Dungey: The shock wave could be reflected on the earth, a perfect conductor, and arrive at the ionosphere and cancel the direct shock wave.

Coulomb: The conductivity of the Earth may change the sign of the shock wave and therefore enhance the effect on the ionosphere.

Chapman: The comment will be good for the ssc, but not for the main phase of the storm; it does not show any daily variation as it will happen it the ionosphere were the location of the currents; we put these currents on a higher level.

Dooley: It seems that a weakness in the shock-wave theories of sudden commencements lies in the relation to event on the sun. The emission of the shock-wave from the sun must coincide with some event on the sun. If we imagine a fairly narrow beam resulting from this, then the event on the sun must occur in a very limited area of the sun's visible disk, in order that the beam will strike the earth. If this were so, a sudden commencement would be a rather rare event. On the other hand, if events which may occur over a large proportion of the sun's visible disk can produce an ssc on the earth, then this implies a wave or front spread over a very wide solid angle, and the energy of the shock in the vicinity of the earth would be diminished accordingly.

Bartels: Sudden commencements are believed to be always caused by fronts of streams of solar gas ejected from the sun during solar eruptions (solar flares). If the cloud passes the earth's orbit without hitting the earth inmmediately, it may be that, with the 27-day rotation of the sun, the following parts of the gas stream may overtake the Earth later. This causes a storm without an ssc. It is well known that the 27-day recurrences in geomagnetic activity consists mainly of smaller activity without ssc, although, of course, ssc due to solar eruptions occurring 1 or 2 days earlier may happen simultaneously. I have called a stream of solar gas nascent, if it caused one ssc, and mature if it sweeps across the earth, due to the solar rotation, long after its front has passed the earth's orbit (Terr. Magn. 1940).

Coulomb: As it was shown by Prof. Thellier magnetic storms without an ssc are more likely to recurr than those with ssc.

Cardús: Nevertheless the best recurrences of the IGY are of storms with ssc as can be seen in the K diagrams prepared by Prof. Bartels.

Selzer: An important point in the study of the ssc is the time of them and to see if there is some differences between these times at different observatories. Between Chambon-la-Forêt and Kerguelen the difference was never greater than 15 sec. I should like to propose therefore the following resolution in order to improve the study or the ssc: «Les Observatoires dont les modes d'enregistrement permettent de préciser les instant d'apparition des ssc avec des précisions nettement meilleures que la minute, sont invités à dresser des listes des ssc les plus nets qu'ils ont enregistrés au cours de l'AGI, en faisant mention, non seulement de l'instant d'apparition donné avec l'ultime précision possible, compte tenu de la rapidité du début, mais aussi *pour chaque cas* de l'ordre de grandeur des erreurs qui affectent cette précision, ceci à tître d'indication pour organiser des études ultérieures».

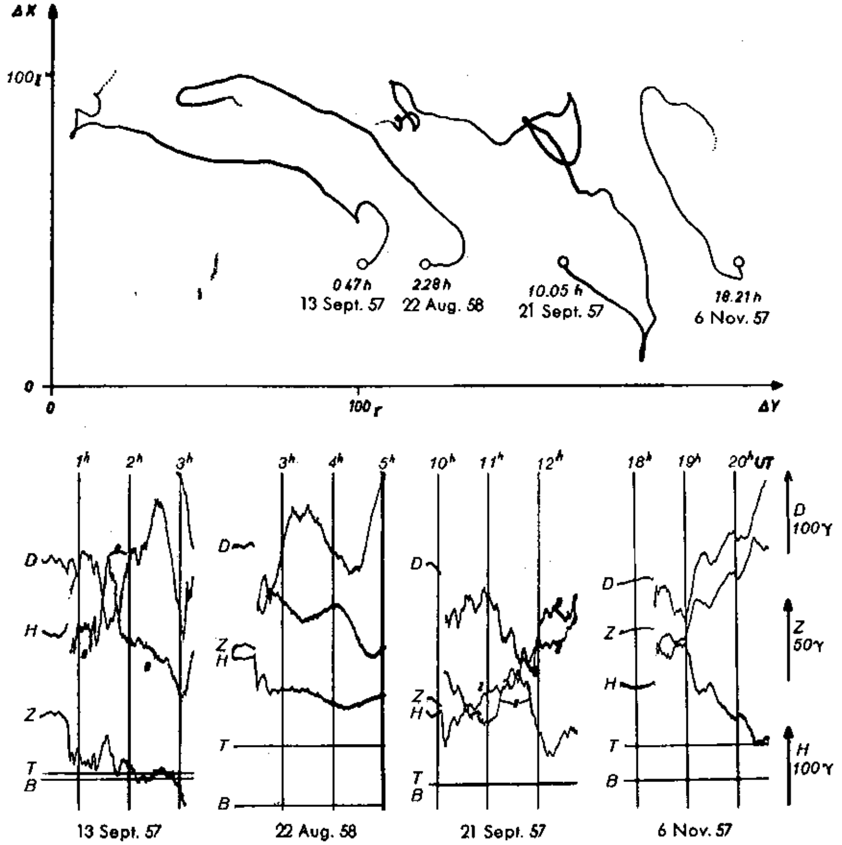
Cardús: I should like very much to get times as accurate as possible, but I should like to point out that the data arriving in the monthly lists to Committe N. 10 show very great discrepancies; for instance in the ssc of the 21 July 1958, a very good case reported by 67 observatories, the times of arrival were $16^{h}\ 34^{m}$: 1 observatory; 35^{m}: 4; 36^{m}: 32; 37^{m}: 20; 38^{m}: 7; 39^{m}: 0; 40^{m}: 3; as you see there was a difference of 6 minutes between the first and the last time indicated; and this is not an exception: the mean time-dispersion for the 9 more clear cases reported in the quarterly lists of 1958 is 8 minutes.

Nelson: Sometimes it is rather difficult to put a beginning; some times I wonder if it would be not better to fix a point, say, 1/5 of the whole stroke.

Cardús: I am afraid that this will only confuse the observers a little more.

Selzer: Gérard compared the times of the ssc, as I said before, and all were well into the 15 seconds except when there was ssc in one station and ssc* in the other. If we take allways the first movement (whether this is the principal or the reversed one) then all the times are accurate.

Untiedt: During the IGY we have directly obtained at Göttingen some ssc horizontal vectograms. The figure shows four typical cases together with the standard magnetograms. Perhaps they indicate that there is a continuous transition from ssc to ssc.* The case of August 22, 1958, shows that a sudden commencement which is an ssc in X may be an ssc* in Y. We could distinguish ssc from ssc* looking only into the H component.



Chapman: It is very expensive to have instruments which can give the accuracy of a second; perhaps a solution would be to use magnetic tape.

Harris: We use this system, but it is also very expensive.

Selzer: When we look carefully into the ssc recorded in the rapid-run instruments, we see that the structure of the sudden commencements is more complicated than only ssc and ssc*. I think that we should ask for some more information.

Cardús: I should again call the attention to the fact that the signs of the ssc reported to Committee 10 are rather discouraging. I have tried to get an idea of the electric currents which produced the ssc from the signs given in the monthly lists and the result was absolutely negative; observatories very near one from another give contradictory signs. I think therefore that before asking for supplementary information we must try to get more accuracy in the data now recommended.

Selzer: Perhaps it would be better to classify ssc into ssc with pulsations and ssc without pulsations, than into ssc and ssc*. The difficulty is that this classification would be possible only for observatories with rapid-run instruments.

OBSERVATIONS OF SSC BY MEANS OF VERY LARGE HORIZONTAL LOOPS

by A. K. HARRIS

The experimental, large horizontal loop installed by the U.S. Army Signal Research and Development Laboratory in a low-interference region of Arizona USA was described. It consisted of two turns of wire, on the ground, enclosing 26 square miles. It was possible to detect variations of the order of 10^{-4} gamma at 1 cycle per second.

An ssc recorded on 17 August 1958 (06.22 UT) by a second, slightly smaller loop in New Jersey, was shown (figure herewith).

A second ssc (24 August 1958, 01.40 UT) was recorded at both stations, about 2.000 miles apart, apparently starting about 2 seconds earlier in New Jersey. Remarkable similarities occurred in the two records, between 20 and 35 minutes after this ssc (figure herewith). A cross-correlation curve for this 15-minute interval was shown, in which the correlation coefficient was plotted against the time of one record relative to the other. A maximum occurred with a time shift approximately equivalent to the time difference observed at the ssc itself.

The detection of signals, believed to be propagated hydromagnetically, from the high-altitude Argus detonations, was mentioned. The figure appearing in the current issue of the Journal of Geophysical Research (Vol 64, No 8, page 930) in an article by P. Newman, was shown.

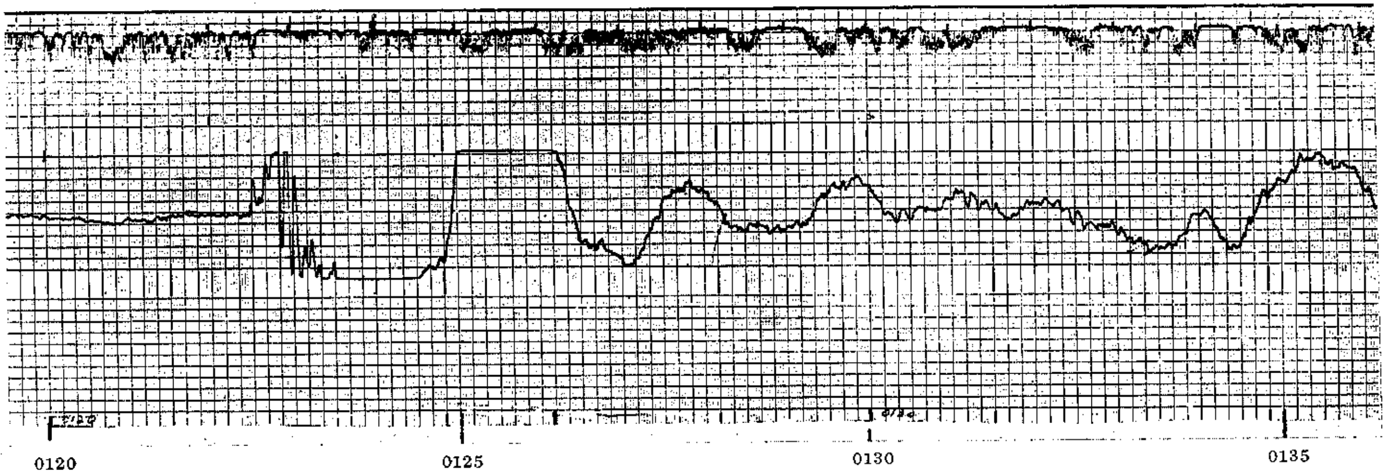
(The material presented was essentially similar to an article prepared for publication now being submitted to the Journal of Geophysical Research.)

DISCUSSION

Nelson: Such a great loop with a great sensitivity may register microseisms.

Harris: It has a response period of about 6 sec, and the great loop will smooth the microseismic influence.

Coulomb: Some microseisms have a period of 6 sec.



Full Scale: $\pm$ 25 mV

Fig. 1. — Sudden Commencement, New Jersey, 17 August 1958, 0122 EST.

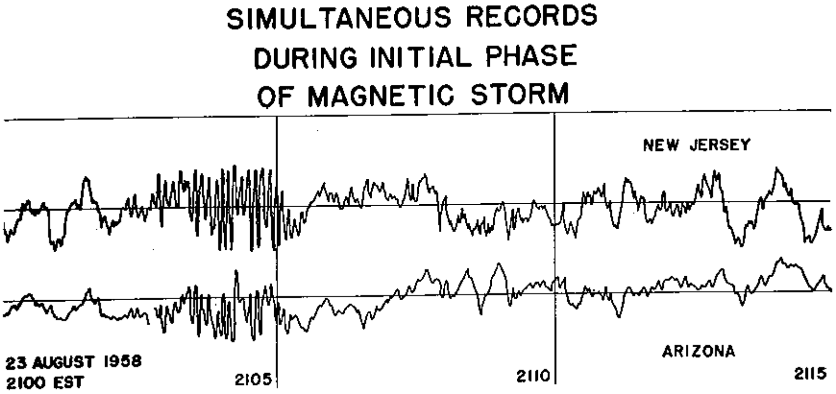


Fig. 2

Harris: We shall look into this possibility.

Grenet: Il n'y a pas à s'étonner que ce boucle de grande dimension soit insensible à l'agitation microséismique, la sensibilité à l'agitation microséismique étant proportionnelle à la longueur du fil utilisé, alors que la sensibilité en volt aux variations du champ magnétique terrestre est proportionnelle au produit de cette longueur par les dimensions linéaires. Le rapport

$$\frac{\text{sensibilité aux variations magnétiques}}{\text{sensibilité à l'agitation microséismique}}$$

varie donc en sens inverse des dimensions linéaires de la boucle. Il est donc normal qu'il soit faible pour les grandes boucles.

Selzer: As for the ssc of the 24th of August 1958, we have found the same pattern at Chambon-la-Forêt and also the pulsations.

Schlich shows the records of this ssc obtained at Charcot.

Selzer: The times at Chambon-la-Forêt and in America agree to the minute, but we disagree with Charcot in one minute.

Chapman: What was the local time?

Selzer: It was about 7 hours at night in America and practically at midnight (1 hour) in Chambon-la-Forêt.

ON THE CURRENT SYSTEM OF SOLAR FLARE EFFECTS

by J. VELDKAMP and D. VAN SABBEN

ABSTRACT

The electric current system responsible for the great solar flare effect (s.f.e.) of March 23rd, 1958, is compared with the currents of the normal daily variation of the geomagnetic field. Whereas the standard Sq currents are symmetric with respect to the geographic equator, the currents of the s.f.e. as well as the current of the normal daily variation at the thime of the s.f.e. are controlled by the magnetic equator. The same result is found by a re-examination of selected s.f.e.'s published in the IATME Bulletins No. 12f and 12h. It is shown that the s.f.e. currents must flow in a region where the disappearance of electrons follows an attachment law. The decrease of the s.f.e. leads to a loss coefficient $\beta = 5 \times 10^{-4}$ sec^{-1}, which compares with the known value for the D layer.

Solar flares are generally accompanied by several forms of sudden ionospheric disturbances (s.i.d.), viz. short wave fade outs (s.w.f.), sudden cosmic noise absorption (s.c.a.), sudden phase anomalies of very long radio waves (s.p.a.), sudden anomalies of field strength of very long radio waves (s.f.a.), sudden enhancements of long-wave atmospherics (s.e.a.), and last but not least by typical disturbances of the geomagnetic field (s.f.e. or crochet). The first group of ionospheric disturbances (s.w.f., s.c.a., s.p.a., s.f.a., s.e.a.) is due to the increased ionization and lowering of the D-layer. The s.f.e. must be caused by an increased conductivity in the ionosphere; it is generally supposed that the electric currents responsible for this geomagnetic disturbance also flow in the lower ionosphere, e.g. in the D-layer.

Several examples of s.f.e.'s have been studied by McNish (1937) and by Veldkamp (1951, 1952 and 1954); they compared the current vectors responsible for these disturbances with the electric current vectors of the normal daily variation.

On March 23rd, 1958, a very strong solar flare was observed on the sun; the accompanying s.f.e. was about 5 times greater than usual.

Therefore it offered an excellent opportunity to study the properties of this remarkable magnetic disturbance.

The position of the flare on the sun was 14°S 77°E, the importance was 3+. It commenced at 9h50m, maxima were observed at 10h05m, 10h10m, 10h16m and 10h18m; it ended at 14h20m.

The ionospheric recorder at De Bilt showed a very strong s.w.f., beginning at 9h50m. From 10h05m to 10h45m there was a complete fade-out of all normal ionospheric echoes; after that the F2-echo gradually reappeared. However, it lasted till about 14h before the panoramic soundings behaved normally again.

The receiving station NERA of the Netherlands PTT recorded a great outburst in solar radio noise on 200 Mc/sec, 545 Mc/sec and 2980 Mc/sec, beginning between 10h00 and 10h05m. Dellinger effects in the field strength of transmitters at Paramaribo and Karachi were recorded at NERA from 9h52m on.

The magnetic disturbance (s.f.e.) began at 9h52m, but at 10h01m a further big sudden increase occurred. The greatest deviation of the magnetic trace was recorded by many stations at 10h15m.

The magnetic record of this unusual great flare was somewhat spoiled by a polar disturbance which casually started at 10h15m with a sudden commencement in the stations Si and Co in Northern America, and at the same time in the Antartic stations Mw and MI(1). The magnetograms of the European stations showed a little unrest, following the s.f.e. Stations in Central America and in the Pacific recorded a bay disturbance, beginning at 10h15m, with a maximum at 11h. No or almost no disturbance was recorded in the equatorial belt. As in most stations this polar disturbance became visible after the maximum of the s.f.e., accurate readings of the s.f.e. were quite well possible, except for the records of the northern stations Tr, Ai and So. Here the s.f.e., if present, was obscured by the polar storm.

Fig. 1 shows the s.f.e. as recorded by the stations Wi, Hr and AA. The disturbance vector was calculated by measuring the maximum deviations of the horizontal intensity H and the declination D with respect to the interpolated undisturbed traces.

Fig. 2 shows the horizontal electric currents in the ionosphere (heavy arrows with single head), necessary to produce the horizontal components of the s.f.e. during its greatest development, as well as the currents for the normal daily variation at the same time (light arrows with double head).

The components of the daily variation were measured taking the

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(1) The magnetic observatories are indicated by the two-letter symbol introduced in the IATME (IAGA) Bulletins No. 12.

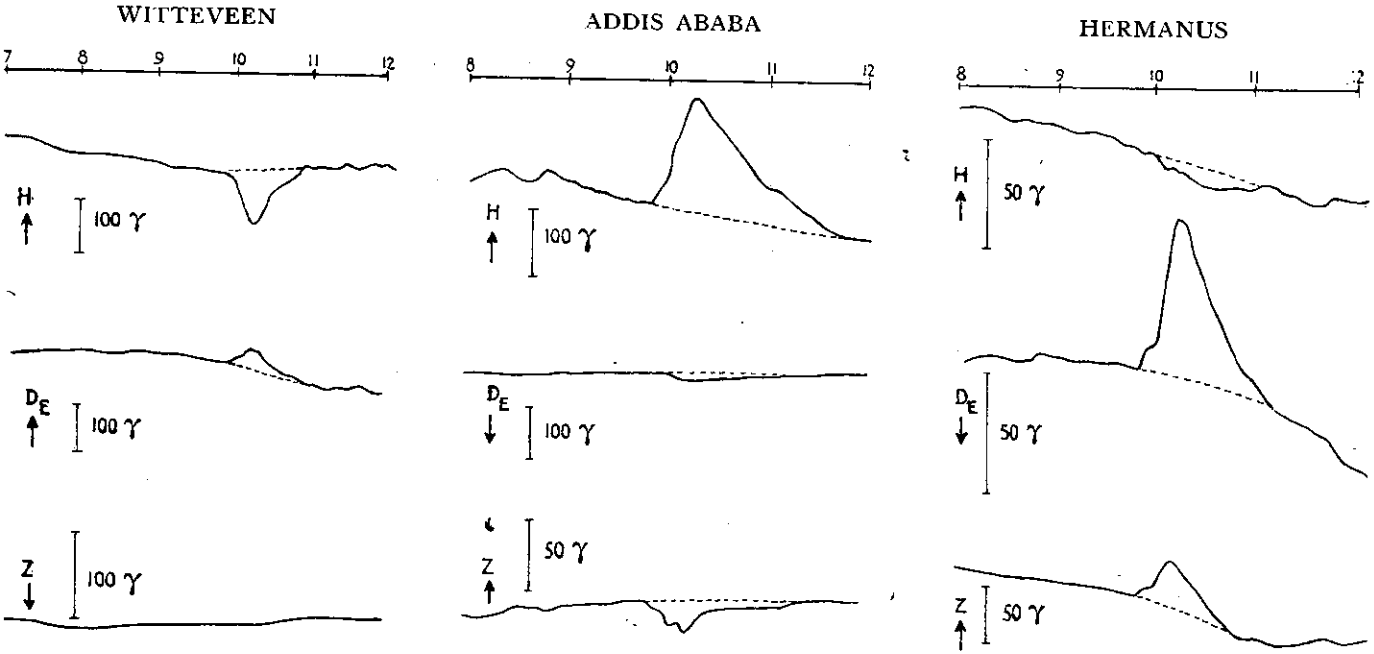

Fig. 1. — Magnetograms from the stations Wi, AA and Hr, showing the s.f.e. of March 23rd, 1958. The arrows indicate the directions of increasing horizontal intensity H, easterly declination D and vertical intensity Z.

values during the night hours (22h to 02h local time) as base values; no measurements were made for those stations where the night hours showed too much disturbance. Scales of γ and A/km are indicated at the bottom of the figure; the relation between the current density in A/km and the magnetic disturbance in γ is:

$$i = 0{,}6 \frac{H}{0{,}2\pi} \tag{1}$$

where the factor 0.6 accounts for the induced currents in the earth (Chapman and Bartels, 1940). In order to avoid overcrowding the figure, some stations were taken together, e.g. ME shows the mean value of the s.f.e. in the stations Wn, Wi, Ni, Cm, Db, Ma, Pr, Fu, Ti and Hb. A heavy black dot means that no s.f.e. was recorded.

Roughly speaking, the electric currents responsible for the s.f.e. were twice as strong as the currents of the daily variation.

The solid lines in fig. 2 show the current pattern of the s.f.e., drawn according to the disturbance vectors. The broken lines are currents of the standard Sq-system for the equinoxes (Chapman and Bartels, 1940). The star is the subsolar point, the hatched strips indicate the limitation of the day-light hemisphere.

It is quite clear that the current pattern of the s.f.e. is almost symmetric with respect to the magnetic equator (the partly broken line). Consequently, the greatest disturbance (160 γ) was recorded by the station AA which lies nearly on the magnetic equator and under the equatorial electrojet (Onwumechilli, 1959; Gouin, 1959). The currents of the daily variation at the time of the s.f.e. are in better accordance with the Sq-pattern for the equinoxes; it is, however, clear that in the vicinity of the equator the currents of the normal daily variation are also influenced by the magnetic equator, and that the centres of the current systems lie easterly from the centres of the standard Sq-pattern, especially in the southern hemisphere. The great vortices of the s.f.e. are accompanied by smaller ones; however, they cannot be drawn accurately for lack of observations.

Compared with Chapman's Sq-system, the current pattern of the s.f.e. is compressed in a north-south direction, especially in the northern hemisphere. This is apparently due to the fact that the magnetic equator is here north of the geographic equator.

Moreover there is practically no difference in longitude between the centres of the s.f.e. system and the subsolar point, so that the Sq system is about one hour in advance to the s.f.e. pattern.

As for stations lying on the night-side of the earth, no s.f.e. was recorded at Fr, Tu, Te, SJ, Fq, Ka, As, Ss, Mm, Kr, Gu, Hn, PM, MI, Mw and Am. The stations Hu and To recorded a small deviation, which may have been caused by the s.f.e. or by the following polar disturbance. Tw, lying in the twilight zone, recorded a small crochet. The s.f.e. was practically confined to the day-light hemisphere.

Formerly it was thought (McNish, 1937) that the s.f.e. was caused by an enhanced ionization in the Sq-region, so that the disturbance vectors of the s.f.e. should have the same direction as the vectors of the normal daily variation. However, the vectors of the solar flare effect and the daily variation generally do not coincide, as is shown by the selected examples in the IATME Bulletins No. 12e, 12f and 12h (Bartels and Veldkamp, 1951, 1952 and 1954).

Grafe (1958) has drawn attention to the fact that the occurrence of the s.f.e.'s shows maxima during the equinoxes, just as other magnetic disturbances of corpuscular character. His conclusion is that the current system of the s.f.e. is not an enhanced Sq-system; probably the currents responsible for the s.f.e. flow at a different height to the Sq-currents. Volland and Taubenheim (1958) are of the same opinión. As there appears to be a close correlation between the s.f.e., the s.i.d. and a temporary enhancement of the E-ionization, these authors think that the s.f.e. current system must flow partly in the D-layer and partly in the E-layer, and therefore below the Sq-currents which they suppose to flow above the E-region.

The exploration of the ionosphere by means of rockets (Singer, 1954; Cahill and Van Allen, 1958) has proved the existence of electric currents flowing in the ionosphere. Supposing an unbounded horizontal sheet current, the change in the geomagnetic field strength in going through the sheet would be twice the geomagnetic variation measured at the earth's surface. It was found that under normal circumstances no appreciable current flows in the D-layer, that a deviation from the inverse cube-law as a function of the altitude was present from 95 to 110 km above the earth, and that a second deviation began at 117 km. The anomaly in passing through the E-layer was less than one-half of the expected value. Therefore the Sq-currents must flow partly in the lower part of the E-layer and partly at a somewhat greater height. Whereas the normal D-layer is formed by Ly α radiation, which gives a maximum ionization at the height of about 80 km, hard X-rays with wave-lengths to 1 or 2 A are necessary in order to get ionization at levels as low as 65 km. Indeed, rocket measurements obtained during solar flares gave positive evidence of an intense coronal X-ray emission, penetrating below 80 km (Chubb et al. 1957). This temporary X-radiation accounts for the intense ionization in the D-layer which causes the s.i.d. phenomena.

Appleton and Piggott (1954) have argued that the Sq-currents must flow in the E-layer, whereas the absorbing layer must be identical with the D-layer. These conclusions are based on the measurements of the recombination coefficient α from the diurnal variation of the electron density N and from the variation of the absorption on normal days and during s.i.d.'s. It is supposed that the electron density is controlled by the equation:

$$\frac{dN}{dt} = q(t) - \alpha N^2 \qquad (2)$$

and it is found that $\alpha N = 4.10^{-4}$ sec^{-1} in the D-layer whereas $\alpha N = 12.10^{-4}$ sec^{-1} in the E layer. Moreover they found that in both layers the dissipation of electrons follows the recombination law (αN^2) and not the attachment law (βN).

Mitra and Jones (1954) calculated the following values of α: $\alpha = 10^{-5}$ cm^3 sec^{-1} for 65 km height, $\alpha = 10^{-7}$ cm^3 sec^{-1} for h = 90 km and $\alpha = 5.10^{-8}$ cm^3 sec^{-1} for h = 110 km. They find that the recombination curve may be explained by attachment and formation of negative ions below 80 km and by dissociative recombination above 90 km.

Ratcliffe (1956) confirms the recombination law in the E-and F1-layers. In the F2-region the disappearance of electrons is according to βN but here the dissipation by vertical drift introduces considerable uncertainty.

Some new information can be obtained by the investigation of the decrease of the s.f.e. under consideration. Supposing that at some time t = 0 after the maximum of the s.f.e. no new extra ionization is formed in the region where the s.f.e. currents flow, and that electrons disappear by recombination as well as by attachment, the decrease of the electron density with time t is given by

$$\frac{d(N+x)}{dt} = q(t) - \alpha(N+x)^2 - \beta(N+x) \qquad (3)$$

where N is the normal electron density and x the extra ionization due to the s.f.e.

The solution of (3) is

$$\frac{x}{x_o} = \frac{1}{(\xi_o+1)\,e^{\gamma t} - \xi_o} \qquad (4)$$

where $\xi_0 = \alpha\, x_0/\gamma$ and $\gamma = \beta + 2N\alpha$; x_0 is the excess electron density at the time $t = 0$.

Figure 3 gives some graphs of x/x_o for various values of ξ_o. The decrease is exponential for $\xi_o = 0$, but for values of $\xi_o > 0$ the extra-ionization disappears more slowly at the end.

Now the decrease of the s.f.e. in question is practically exponential, as is shown by the examples of figure 1; this is also the case with many other s.f.e.'s (see e.g. the selected examples in IATME Bulletin no. 12h). This means that

$$\alpha x_o < \beta + 2N\alpha \qquad (5)$$

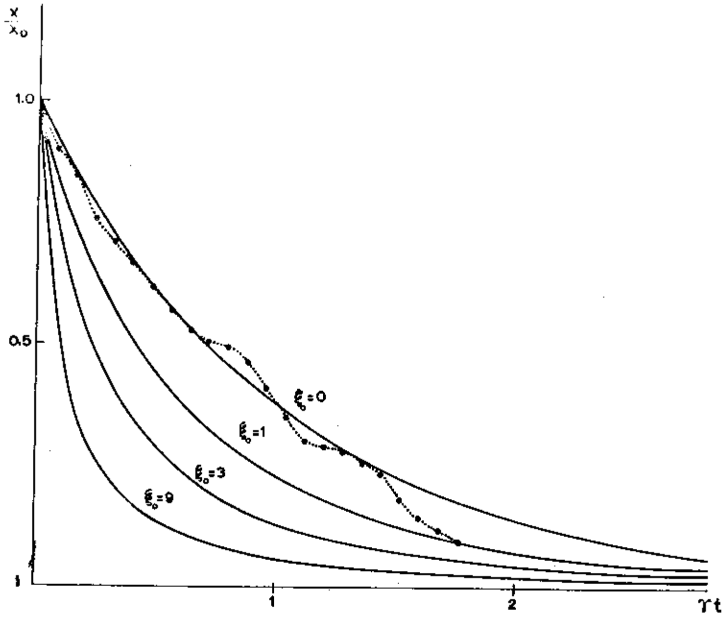

Fig. 3. — Graphs of x/x_0 for some values of ξ_0. The dots indicate the decrease of the s.f.e. at Addis Ababa. The irregularities may be ascribed to the polar disturbance which started during the s.f.e.

The current density in the ionosphere is determined by the conductivity

$$\sigma = \frac{eN\nu}{m\,(\nu^2+\omega^2)} \tag{6}$$

where N is the electron density, ν the collision frequency and ω the gyrofrequency ($\omega = 7.10^6$ sec^{-1}). In the E-layer N is about 2.10^5 cm^{-3} and ν is between 10^4 and 10^5 sec^{-1}; in the normal D-layer N is about 10^3 and ν between 10^3 and 10^8 sec^{-1}.

Taking these values we see that σ is only somewhat smaller in the D-layer than in the E-layer; in the F-region the conductivity is much smaller owing to the low value of the collision frequency, which is here between 10^3 and 10 sec^{-1}. The s.f.e. currents are comparable with the currents of the normal daily variation. If they flow in the D-region where normally the current density is small, it follows that $x_0 \gg N$, so that from (5) $\beta > \alpha x_0$ and therefore $\beta \gg \alpha N$, which means that the s.f.e. currents must flow in a region where the disappearance of electrons is analogous to an attachment process. This might also point to the F2-region but it is improbable that here the ionization is enhanced to such a degree as required by the s.f.e. currents.

The following values were found for the half-value time t_1: 20 m (Lo), 15 m (Le), 12 m (Wi), 25 m (TI), 20 m (He), 30 m (Ta), 30 m (AA), 20 m (Qu), 35 m (Ba), 20 m (Mr), 20 m (Hr). There seems to be an increase for t_1 from higher latitudes towards the equator.

Taking $t_1 = 25$ m as a mean value, we obtain $\beta = 5 \times 10^{-4}$ sec^{-1}. This value compares with the value for α N for the D-layer found by Appleton and Piggott.

ACKNOWLEDGEMENTS

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The Directors of these observatories are thanked for the readiness with which they supplied us with the necessary data to complete this study. Without their help and kind cooperation this investigation would not have been possible.

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DISCUSSION (1)

Bartels: Dr. Veldkamp, as Director of our Permanent Service of Geomagnetic Indices, has to cope with so much material, that we may congratulate him on having found this precious representative case of an sfe in it. But before I could accept this thesis, that the currents flow above the E-layer, I should make two remarks concerning his two arguments.

His first argument is that the sfe, just like the F-layer, is controlled by the geomagnetic equator, whereas S_q he states, is controlled by the geographic equator. But this does no longer hold, since the records of magnetic observatories on the magnetic equator, such as Huancayo or Addis Ababa, have demonstrated that S_q likewise is controlled by the magnetic equator.

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(1) The paper presented at the symposium by Prof. Veldkamp was slightly different from the one submitted for publication. A very good part of the discussion refers to the first paper. If we publish here the discussion in full is only because we believe that it claryfies many points on the sfe theories.

His second argument, based on the quick exponential decay of the sfe, which he uses to calculate a recombination coefficient, assumes that the excess solar radiation has ceased at the time when the maximal geomagnetic sfe is attained. But can it not be that the excess solar radiation itself decays only slowly and persists partially after the maximal geomagnetic sfe?

Chapman: I would like to join in congratulating Dr Veldkamp on this valuable and fruitful study of notable sfe's, and at the same time expressing my uncertainty as to his argument in favour of a high level for the sfe electric currents. As regards S_q, the current diagram shown by Dr Veldkamp indicates good agreement with the Chapman-Bartels diagram except near the magnetic equator; there the S_q arrow agrees better with control by the magnetic equator than by the geographic one.

When my S_q analysis was made, the Huancayo Observatory had not been started, and the method of analysis did not include the spherical harmonic terms concerned with the magnetic equator.

As regards the influence of the magnetic equator, this powerfully affects the electrical conductivity in the E-layer, also in the D-layer, even though the distribution of ionization in these layers is not anomalous near that equator, as is the F-layer ionization.

Solar flares emit enhanced Lyman alpha radiation, that ionizes the D-layer, and in the exceptional case studied by Dr Veldkamp may have also materially increased the E-layer ionization. This favours the possibility that the sfe currents flow there; rocket observations during a solar flare may settle this point.

In the D-layer the electrons disappear rapidly by attachment, and in Dr Veldkamp's equation p may approximate to 1 for the D-layer (though radiactive and collisional detachment may prolong the life of the electrons). I think, like Dr Veldkamp, that the decay period (at least the later part) is often, perhaps usually, after the solar flare itself has ceased.

Veldkamp: If S_q is also controlled by the magnetic equator, then my first argument is not valid.

Ferraro: One is impressed by the fact that Dr Veldkamp's value of the coefficient of recombination (for a linear law) obtained from the decay of the sfe is in good agreement with that derived by Ratcliffe et al. from ionospheric studies of the F_2-region. This is certainly not at variance with Veldkamp's suggestion that the sfe currents flow in the F_2-layer. However, the agreement may be fortuitous, since the molecular densities obtained in the F_2-layer may be too low to allow of sufficient conducting power in the F-region to produce the observed magnetic effects by dynamo action.

Dungey: In discussing the decay of sfe, the electron density should be written $N_q + N_f$, where N_q is the value without a flare. Then

$$\frac{dN_q}{dt} = P - \alpha N_q{}^2$$

where P is the production rate, and

$$\frac{d}{dt}(N_q + N_f) = P - \alpha\; N_q + N_f)^2$$

The decay is described approximately by

$$\frac{dN_f}{dt} = -2\,\alpha N_q N_f \qquad (\text{when } N_f \ll 2N_q).$$

I think that for the E-layer, $2\alpha N_q \sim 2\text{hrs}^{-1}$.

Bartels: The sfe is an augmentation of $(S_q + L)$ and one must not forget L. The small current circuits near the lines of sunrise and sunset remind us of L circuits. Since S_q and L flow at different altitudes (the strongest argument for this is the quite different annual variation of S_q and L in Huancayo) it may be that the sfe is, say, $(aS_q + bL)$ with a and b coefficients to be determined from sfe's analysed for many cases with different phases of the moon.

Chapman: The side current circuits shown by Dr Veldkamp's diagram seem to me to be a specially rewarding result of his valuable study. Dr. Bartels suggestion that they may be associated with the lunar daily magnetic variation L seems to me very promising. It will be useful if Dr Veldkamp will examine this suggestion with reference to the position of the moon at the time of this sfe. I would recommend that the position of the moon be examined also with reference to the remarkable sfe observed in the earth currents and mentioned by Dr. Velkamp from records supplied by Dr. de Voogt. Whereas the main S_q circuit lies fairly centrally over the sunlit hemisphere whose ionization is affected by the solar flare, the side current circuits lie near the twilight circle. The earth currents associated with them may well extend further beyond the twilight circle than the ionospheric electric circuits. These ionosphere currents are limited by the decrease of ionization and conductivity in the ionosphere towards and beyond the twilight circle; but the electric conductivity is in no case affected by day or night, it is continuous across the twilight circle. Hence earth currents sfe may more readily extend into the night hemisphere than can the ionospheric currents. Still it is remarkable that they should be so evident as much as four hours beyond the twilight circle. This would be more easily possible four hours after sunset than four hours before sunrise.

Cardús: I think that an interesting feature of Dr. Veldkamp's study is the difference in the center of the S_q and sfe current circuits. In this connection I should like to point out the importance of observatories lying in the line connecting both centers; as a matter of fact we have in the south hemisphere Hr; in it the S_q arrow, although very small, does not follow the general pattern. In these observatories the S_q and sfe arrow should show angles greater than 90°; this fact could perhaps be related to the existence of the reversed sfe.

Veldkamp: In the northern hemisphere L'Aquila was in a similar position but unfortunately no records for this day were available.

Jacobs: Are there many cases of sfe reported to Committee No 10 during local night hours?

Cardús: Yes; but I am afraid that they are not always very reliable. In some cases there may be (as in the case of Dr Veldkamp's study) another perturbation almost at the same time; some observatories may have a real movement in the curves but in other cases we are almost sure that there is some mistake, as happens with an observatory reporting class A (that is to say, a very clear sfe) for almost every sfe included in the checking-list, without distinction between day and night hours.

Romañá: In some cases observatories reported sfe's during the night hours with a special note saying that although it was at night the curves shew a movement like those normally attributed to sfe's.

Grenet: L'argumentation de Mr Veldkamp est basée sur le fait que le vecteur représentant le champ des crochets ne coïncide pas avec le vecteur représentant S_q. Mais puisqu'il s'agit de phénomènes transitoires et que le crochet est bien plus rapide que S_q le skin effect oblige le courant correspondant à circuler à des profondeurs différentes dans le sol et dans l'ionosphère. Bien entendu, je ne prétends pas expliquer ainsi le décalage des vecteurs observé par Mr Veldkamp; je dis simplement que le skin effect est une cause qui peut contribuer à expliquer les observations de Mr Veldkamp.

Nelson: The equinox maximum of sfe's is a real one?

Veldkamp: I have not found it.

Cardús: At Tortosa Fr Bolufer has done a comprehensive study of the sfe's registered at the Ebro Observatory with reference to their diurnal and annual variation, direction and intensity of the vector in the three magnetic components separately and in the horizontal plane and I must say that it is impossible to say that there is an equinoctial maximum. The winter minimum is certain, but for the equinox we got very different results when we put together the sfe cases divided into calendar month and into Bartels's periods to obtain a more uniform and well centered distribution; I think that this discrepancy is due to the fact that we have still too few cases to get good statistical results, but also that we can say now that the equinox maximum does not appear in the Tortosa sfe's.

Dooley: Some peculiar effects have been noted in sfe at Watheroo. A recent strong sfe recorded at surrounding stations produced no effect whatsoever although it was about midday local time. A preliminary investigation of sfe recorded at Watheroo over the past few years has shown that practically no effects have been recorded at about 13.00 local time, although many instances have been reported during morning and afternoon hours. The map of sfe currents shown by Veldkamp shows that the vortex of the current system in the southern hemisphere is about the same latitude as Watheroo, and would nearly overhead if the sfe occurred at about 13.00 local time. This would partly explain the absence of any recorded magnetic effect, but it is believed that local induction effects are also a contributing cause.

Parkinson (Geoph. Jour. Vol. 2 p. 1, 1959) has shown that the magnetic vectors at Watheroo for disturbances of duration about 5 minutes to 1 hour lie in a plane dipping to the west at an angle of about 45°. Thus an east-west current overhead will cause a north-south magnetic effect, which will be nearly horizontal. However if the current is north-south, the east-west magnetic component will be strongly damped by this induction. Thus even if the vortex of the current system is not immediately overhead but is slightly east or west of Watheroo, the neighbouring currents will be north-south, and their effect will be reduced substantially.

This effect is shown further in the fact that the vectors of sfe recorded at Watheroo during the morning or afternoon have strong north-south components and small east-west components. It may be expected that such induction effects (which occur also at many other stations) might in some instances affect the current pattern deduced from the magnetic vector. In particular, referring to the currents system displayed by Dr Veldkamp for 23rd March 1958, it is possible that the loops near the twilight zones may not be real, but may be the result of such effects, particularly as they depend only on the vectors at 4 stations, one of which is Watheroo. Has a similar analysis been made for other occurrences of sfe at different universal times, if the subsidiary loops were present for various times, i.e. with sunrise and sunset at various longitudes, the evidence for their reality would be much stronger, as in each case they would be drawn from the results at different observatories.

Bartels: The reason of this anomaly for Watheroo is that the S_q center is passing overhead.

Veldkamp: Tananarive (Tn) and Mauritius (Mr) have rather different vectors, which may be influenced by local anomalies, but in general I must say that I did not find great difficulties in drawing the lines.

Coulomb: How did you draw the lines?

Veldkamp: By hand; they do not represent values of intensity lines.

GEOMAGNETIC PULSATIONS ACCOMPANYING THE INTENSE SFE'S

by YOSHIO KATO

(*Abstract*)

Very intense solar flares were observed during the International Geophysical Year, and very remarkable micropulsations were also recorded by the induction magnetometer at Onagawa Magnetic Observatory.

Date	Occurrence time (U. T.)	Max. Intensity (E.-W. Comp.)	Period
1957 Sept. 19th	04h 03m	0.15 γ/sec	——
1958 July 29	03 02	0.3	ca 80 sec
1958 Aug. 9	03 48 - 54m	0.3	ca 80
1958 Aug. 16	04 33.5- 45	0.4	ca 80

Usually we cannot detect the micropulsations caused by the solar flare in the record of the induction magnetograph, but at the time of these very intense solar flares we observed very remarkable geomagnetic pulsations, continuing for a few minutes with a period of about 70-100 sec.

The theories of sfe of the geomagnetic field were presented by many authors and the sfe for the geomagnetic field is explained by the sudden increase of conductivity in the ionosphere.

But the cause of above observed geomagnetic pulsation is yet obscure. It is the author's opinion that the hydromagnetic oscillations may be excited in the outer atmosphere by the sudden increase of the solar radiation.

If the intensity of external radiation illuminating a highly conducting gas, which rotates rigidly with magnetic field, increases suddenly and the radiative equilibrium condition is established within a rotating

gas during the very short time, then the torsional oscillation of line of force will be excited through the magnetic restoring force.

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DISCUSSION

Selzer: It is unfortunate that at Chambon-la-Forêt sfe's are generally not clear and that therefore we could not study this point for pulsations and sfe's in our very rapid registrations.

PART IV

DISCUSSION ON WORK OF I.A.G.A. COMMITTEE N. 10

PRACTICAL RESOLUTIONS

THE ATLAS ON RAPID VARIATIONS

DISCUSSION ON WORK
OF I.A.G.A. COMMITTEE N. 10

Before and during the meeting many practical proposals were presented and discussed. Especially the last two sessions were devoted to discuss the work of the I.A.G.A. Committee N. 10 and to prepare the composition of the Atlas on Rapid Variations.

We are trying to summarize the most important items, viz.,

Report of the Chairman of the Committee.

Comments sent by Mrs. Troitskaya.

Comments sent by Prof. Kalashnikov.

Practical resolutions, following the order stablished in this publication: pulsations, storm sudden commencements and bays, general problems.

Atlas on Rapid Variations.

RAPPORT DU PRESIDENT DU COMITE N. 10

Un nombre considérable des magnéticiens n'étant pas familiarisés avec le fonctionnement du Comité pour les Variations Magnétiques et Telluriques Rapides, il semble nécessaire de fournir avant tout quelques renseignements sur le travail qu'il réalise et la façon de l'accomplir.

Tous les Observatoires collaborateurs relèvent mensuellement sur leurs enregistrements les phénomènes dont la liste est donnée plus loin et les envoient au Comité. Pour leur épargner du travail et des frais de poste, ils peuvent faire cet envoi en même temps que celui des indices K et des caractères C à l'Institut Météorologique de De Bilt, lequel a soin de retransmettre les données concernant les Variations Rapides à l'Observatoire de l'Ebre (Tortosa), où le Comité a actuellement son siège. Il va sans dire que les Observatoires peuvent envoyer directement ces données à Tortosa, s'ils le préfèrent.

Avec les données de l'ensemble des Observatoires le Comité prépare la liste des phénomènes à échelle universelle et la fait paraître tous les trois mois sous le tître «Preliminary Report on Sudden Commencements»; la publication est assurée par l'Institut de De Bilt en même temps que celle des «Geomagnetic Planetary Three-hours-range Indices Kp» et les «Preliminary International C-figures (Ci)». Elle est partiellement réproduite aussi, pour ce qui regarde les ssc, si et sfe, par le *Journal of Geophysical Research* dans la Section «Geomagnetic and Solar Data».

Une fois publiées les quatre listes trimestrielles de l'année, le Comité dresse une nouvelle liste avec une grande partie des phénomènes relevés pendant l'année par les Observatoires sur leurs enregistrement à marche normale et la fait parvenir à tous les Observatoires collaborateurs avec la prière d'examiner encore une fois leurs enregistrements et exprimer leur avis définitif sur chacun des phénomènes renseignés (cheking-lists). On a dit «une partie des phénomènes» parce que, pour ne pas encombrer les checking-lists, on en exclue à priori les cas qui n'ont pas été signalés par un nombre minimum d'Observatoires, variable avec les régions; par contre sur les checking-lists trouvent leur place les phénomènes signalés par un nombre suffisant d'Observatoires, mais arrivés trop tard au Comité pour être insérés dans les listes trimestrielles.

Avec les réponses des Observatoires aux checking-lists on prépare les listes définitives des différents types des phénomènes, lesquelles sont publiées tous les ans dans les *I. A. G. A. Bulletin No. 12 (a, b, c...)* «Geomagnetic Data 19... Indices K and C, Rapid Variations». Jusqu'à présent les phénomènes relevés sur les enregistrements à marche rapide n'ont pas été inclus dans les checking-lists ni dans les *I. A. G. A. Bulletins No. 12,* la forme de les publier d'une façon définitive réguliere n'ayant pas encore été décidée.

* * *

Les phénomènes à relever sur les magnétogrammes forment deux groupes différents d'après le type d'enregistrement.

Pour ce qui regarde les enregistreurs à déroulement normal (15-30 mm/h) les phénomènes demandés sont les suivants:

ssc (ssc*)	*storm sudden commencements,* commencements brusques d'orages
si	*sudden impulses,* impulsions brusques
b bs bp bps	*bays, bays with sharp beginning, bays with pulsations, bays with pulsations and sharp beginning,* baies, baies à commencement brusque, baies accompagnées de pulsations, baies à commencement brusque accompagnées de pulsations
pt pg	*pulsations's trains, giant pulsations,* trains de pulsations, pulsations géantes
sfe	*solar flare effects,* crochets dus à une éruption solaire chromosphérique.

Quant aux enregistrements à marche rapide (entre 2 et 6 mm/min), très rapide (entre 6 et 20 mm/min) et ultra-rapide (> 20 mm/min), les phénomènes à relever sont les suivants:

pt	trains de pulsations
pc	pulsations continues
pg	pulsations géantes

Les définitions précises de ces divers types de variations rapides et la forme d'en faire le relevé ont été établies par le Symposium de Copenhague du mois d'avril 1957 et publiées d'abord dans la *Chronique de l'U. G. G. I.* n.° 4, pages 123-140; plus tard dans les *I. A. G. A. Transactions of the Toronto Meeting* (september 3-14, 1957), pages 318-347; et finalement dans les *Annals of the International Geophysical Year,* volume II B, pages 668-709. Dans cette dernière publication on trouve aussi l'Atlas Provisoire (Provisional Atlas on Rapid Variations) lequel comprend les pages 694-709. Il avait été publié antérieurement en oxalyte et distribué à tous les Observatoires collaborateurs.

Pour faciliter le rapport des phénomènes on a dressé et distribué aux Observatoires plusieurs types de formulaires dont on donne ici la réproduction de ceux qui sont actuellement employés.

* * *

Avant la fin du symposium il faut mettre à discussion un certain nombre de questions pratiques relatives au travail du Comité, dans le double but de le rendre plus utile et d'alléger en même temps la tâche des Observatoires. Parmi ces questions quelquesunes ont été soulevées par les Observatoires eux-mêmes dans leurs réponses à la lettre circulaire qu'on leur a adressé pendant la préparation du symposium; d'autres ont été suggérées par la pratique quotidienne du travail du Comité; d'autres finalement ont été proposées par les participants au symposium le long des séances. Il y a des questions concernant des phénomènes particuliers; d'autres plutôt l'ensemble du travail et la publication des résultats. Voici leur résumé d'après l'ordre adopté dans le symposium pour les différents phénomènes.

A. *Pulsations.*

a) Pour ce qui regarde celles-ci les suggestions les plus complètes sont celles de Mme. Troïtskaya et du Prof. Kalashnikov dont on donne plus loin le texte en entier à cause de leur importance. Bien que quelquesunes, surtout parmi les dernières, ont des rapports à d'autres matières concernant par exemple l'ensemble des observations, nous croyons pourtant préférable ne pas les diviser parce qu'elles forment en quelque sorte un corps.

b) Dans un sens semblable aux propositions de Mme. Troïtskaya l'Observatoire de Tolède fait la remarque suivante:

«L'on a considéré jusqu'ici comme pc toute sorte de variations rapides de type vibratoire et de période comprise entre 10 et 40 secondes. Or nous avons trouvé quelques types divers qu'il faudrait peut être dorénavant distinguer: 1.° Un type très clair de vibration à forme sinusoïdale et de période pouvant osciller entre 12 et 20 secondes; il se manifeste surtout dans les enregistrements des Courants Telluriques et mieux encore dans les enregistrements magnétiques obtenus avec la bobine d'induction; l'on peut citer comme exemple parmi les enregistrements du mois de mai 1959 ceux du 4 de 9 h. à 10 h., du 6 de 11 h. à 12 h., du 9 de 8 h. à 9 h. et du 24 de 6 h. à 7 h. 2.° D'autres pulsations se présentant pendant les orages, lesquelles sont aussi certainement à type vibratoire, mais très altéré et irrégulier, comme s'il s'agissait d'une superposition d'impulsions et par conséquent de périodes, très difficiles à déterminer, parfois plus grandes que les périodes normalement admises (par ex., le 5 mai de 10 h. à 11 h.) et d'autres fois plus courtes (comme par ex. le 13 mai de 9 h. à 11 h. en plein orage). 3.° Finalement un certain type de pulsations de période comprise entre 30 et 40 sec. qui se manifeste très clairement dans les enregistrements magnétiques ordinaires, mais qui par contre est totalement absent des enregistrements telluriques et des magnétiques à bobine d'induction.»

c) Une proposition du Prof. Selzer regarde précisement les dispositions à prendre pendant les phases les plus violentes des orages pour assurer l'enregistrement de ces micropulsations qui les accompagnent souvent: «Durant les phases les plus violentes des orages les Observatoires sont invités, contrairement à un usage assez répandu, à utiliser, au moins sur un de leurs dispositifs d'enregistrement et sur une composante, les sensibilités les plus grandes dont ils disposent. Corrélativement la vitesse d'enregistrement devrait être, si possible, augmentée. Ces opérations se feront avantageusement sur un variomètre indépendant. Si pour des raisons de sécurité la sensibilité devait être diminuée, ceci ne devrait pas être fait par simple abandon sans contrepartie, mais échangé contre une plus grande rapidité de réponse, sensibilités et réponses étant en général deux qualités contraires. Par exemple dans le cas d'un enregistrement galvanométrique, au lieu de shunter purement et simplement le galvanomètre, on commutera les connexions sur un galvanomètre moins sensible, mais plus rapide».

d) Une proposition du Prof. Jacobs vise à l'obtention des données des pt et des pc de l'hémisphère occidental: «Would it be possible to include data on pc's and pt's from American stations —or alternatively, could there be a similar publication giving information from quick-run magnetograms in the U. S. A.?»

e) C'est encore le Prof. Jacobs qui se demande: «Why do reports of pt's from quick-run magnetograms and ordinary magnetograms not always agree? One would at least expect that reports from the same stations using different instruments would agree in the case of very pronounced pt's».

f) L'Observatoire de Kakioka fait la recommandation suivante concernant la façon générale de traiter les pulsations: «Improving the method of scaling and selection of rapid changes to be reported to I. A. G. A., especially of pulsations, at each Observatory, as well as at the Bureau of the Committee, seriously considering inequalities due to different sensitivity and different instruments used, method of classification of pulsations A, B and C, depending upon beautifulness of the form, amplitude, period, duration, etc.».

B. *Storm sudden commencements, sudden impulses, bays, etc.*

a) Il faut signaler tout d'abord la suggestion faite par le Professeur Chapman au cours de sa lecture, relative à une classification plus nuancée des ssc et des si, tendant à faire ressortir s'ils ont été accompagnés ou non de petits mouvements préliminaires et en cas affirmatif à spécifier le signe de ces mouvements.

b) Trois propositions venant de l'Observatoire d'Hermanus, du Prof. Selzer et du Prof. Chapman, visent à obtenir une plus grande précision dans l'heure de ces phénomènes. Celle d'Hermanus est accompagnée de l'expression du désir d'une plus grande précision aussi dans l'appréciation de l'intensité et celle du Prof. Chapman est la quatrième des suggestions faites par lui pour améliorer le travail des Observatoires dans cette ligne. Les voici:

1. *Proposition d'Hermanus:*

> «That Observatories equiped with reliable rapid-run variometers be requested to report the starting times of very sharp ssc's, sfe's and bps's, etc. to 0.1 minute or, alternatively, to 0.2 minutes.
>
> »That in order to facilitate comparison with Earth-currents changes the Committee consider the desiderability of indicating the «intensity» of an ssc by the maximum rate of change (irrespective of sign) .during the first five minutes of the ssc —or, alternatively—, by the *mean rate of change* (irrespective of sign) during the first four minutes of the sc.»

2. *Proposition de Mr. Selzer:*

> «Les Observatoires dont les modes d'enregistrement permettent de préciser les instants d'apparition des ssc avec des précisions nettement meilleures que la minute, sont invités à dresser des listes des ssc les plus nets qu'ils ont enregistrés au cours de l'A. G. I., en faisant mention, non seulement de l'instant d'apparition donné avec l'ultime précision possible, compte tenu de la rapidité du débout, mais aussi, *pour chaque cas,* de l'ordre de grandeur des erreurs qui affectent cette précision, ceci à tître d'indication pour organiser des études ultérieures.»

3. *Suggestions du Prof. Chapman:*

> «1. Statistics of si's: daily frequency variation, daily variation of amplitude, seasonal variation; correction or allowance for the incidence of disturbed periods, which may obscure si's so that they may go unrecognized.

»2. si's: extension of the study by Yamaguchi (Mem. Kakioka Magn. Obs. *8* 33-40 1958) of Dst following si's to other observatories.

»3. Further detailed studies of the morphology of ssc's and si's.

»4. Improved timing of ssc's and si's to within a few seconds accuracy.»

C. *Miscellanea.*

a) Une extension des fonctions du Comité est envisagée par l'Observatoire de Kakioka: «Extending the function of the Committee to be able to collect the world-wide data literally, now omitted in their three-month tables data, in the most important regions geomagnetically and the largest area of the world».

b) L'Observatoire de Halley Bay, après une analyse de ses propres données, croit qu'il n'y a pas lieu à changer la classification des phénomènes rapides telle qu'elle a été élaborée par le Comité; mais il pense qu'il serait très utile pour les stations à latitude élevée que l'on donne dans l'Atlas des exemples des divers phénomènes pour les différentes zones magnétiques du Globe, car à Halley Bay les baies enregistrées sont d'ordinaires beaucoup plus raides que celles données dans l'Atlas.

c) Le Prof. Dooley croit que, supposée la difficulté d'étudier à fond l'ensemble des enregistrements, il faudrait bien faire attention à des intervalles tout spécialement choisis. «One is in connection with ultra-quick-run records. Because of the large amount of trace recorded, it is difficult to analyse throughly all the data recorded, particularly at high latitude stations. Presumably through analysis will in the first place be directed towards the periods recommended in Resolution N. 9 of the Copenhagen Conference. However it might be considered wether particular attention should be given towards analysis of particular periods, related to the appearance of special phenomena, e. g. periods near the beginning of bays, sudden commencements, etc.»

d) Toujours dans l'ordre des considérations générales l'expérience de trois années a montré au Comité bien d'autres difficultés pratiques qu'il faut prendre en considération.

1. Et tout d'abord, quoique la plupart des Observatoires envoient leurs données dans les délais prévus, il y en a pourtant qui sont souvent en retard. Or, s'il faut les attendre, la publication des données sera encore plus retardée; et si l'on ne les attend pas, les données publiées risquent d'être trop fragmentaires, quelquesuns de ces Observatoires en retard pouvant être placés dans des endroits très significatifs du point de vue magnétique. C'est ainsi par exemple

qu'à cause des difficultés des communications les Observatoires polaires doivent être comptés la plupart du temps dans ce nombre; or tout le monde voit l'importance de leurs données.

2. D'autre part, pour ce qui regarde les pt et les pc, dans les rapports trimestriels on ne donne jusqu'à présent que l'heure du commencement et de la fin de l'ensemble du phénomène, sans faire référence aux morceaux particuliers plus intéressants de même qu'aux périodes, amplitudes, etc. Or il peut se faire qu'il y ait beaucoup d'intérêt à publier ces caractéristiques que l'on ne donne pas pour le moment; mais d'autre part il n'est pas facile à trouver une méthode de publication de ces données qui soit en même temps suffisamment compréhensive et analytique et qui n'augmente pas trop les dépenses de publication déjà très élevées.

3. Enfin les checking-lists deviennent de plus en plus longues, le nombre des phénomènes rapportés par les Observatoires grandissant tous les jours. C'est tout d'abord une conséquence naturelle de l'heureuse coïncidence de l'Année Géophysique avec un maximum de l'activité solaire; mais il y a encore à compter sur le grand nombre des nouveaux Observatoires et sur le plus grand soin mis pendant l'A. G. I. par les observateurs à dépouiller les courbes. Cette augmentation des données, évidemment bonne en soi, peut pourtant avoir une conséquence fâcheuse, à savoir, que le nombre des phénomènes à insérer dans les checking-lists devenant énorme, les Observatoires peuvent en être découragés et se sentir enclins à ne pas répondre aux checking-lists ou à les expédier d'une façon un peu sommaire. D'autre part les checking-lists, telles qu'on les fait actuellement, rendent des bons services pour confirmer certains phénomènes, par exemple l'universalité d'un ssc ou la réalité d'un sfe; mais par contre pour d'autres phénomènes, par exemple les baies, leur influence peut être nuisible; car nombre d'Observatoires qui n'avaient pas d'abord signalé un phénomène, parce qu'ils ne l'avaient pas remarqué sur leurs courbes, sous l'influence des checking-lists s'efforcent à le découvrir et s'exposent à donner comme des phénomènes avérés n'importe quel mouvement s'ayant présenté à l'heure en question.

Il semble donc qu'il s'impose d'urgence une plus grande élasticité dans la façon de préparer les checking-lists et surtout une réduction substantielle du nombre des phénomènes devant être admis en elles.

COMMENTS SENT BY MRS. TROITSKAYA

I. *Pc*

As it follows from our preliminary results of pc investigations in the Arctic, the Antarctic and the middle latitudes it seems reasonable to introduce three types of pc: 1, T ~ 5 - 15 sec (regular); 2, T ~ 20 - 40 sec, (regular); 3, T ~ 50 - 90 sec (irregular).

The reasons for dividing them into three groups are given in my article concerning pc and pt in the Arctic and the Antarctic.

2. For the investigation of existence of universal time control for pc it is perhaps advisable to introduce the conception of transparent days for pc, and their special investigation. The transparent day means a day, when pc are observed in a very great longitudinal and latitudinal interval (see the article on pc in the Arctic and the Antarctic).

3. A special interests presents the effect of polar night for regular pc (T ~ 20 - 30 sec) in the Arctic and the Antarctic. (This effect consists in sharp fall of a number of hours of pc, during the middle months of polar night.) This fact is to be taken into account in the investigation of geographical distribution of pc.

II. *Pt*

Pt in polar region loose usually their characteristic forms. Our investigations did not give up to date clear direct connections between pt in the middle latitudes and polar disturbances. Sometimes the pt in the middle latitudes are in fact traces of polar disturbances in the Arctic and the Antarctic. There are cases, however, when this connection does not exist.

Perhaps subdivision of pt into subgroups is necessary (referring to the connections with polar disturbances); as a supplementary criteria for their division may be used their microstructure in respect of short-periodic pulsations (T ~ 2 - 5 sec). The examples of records of different pc and pt in the polar regions and in the Antarctic are applied to the corresponding article.

III. *Short periodic pulsations*

1. Of great interest are pc with periods ~ 5 - 15 sec. They are characteristic mainly for the polar regions, and were studied especially at the station Lovozero. Their diurnal distribution is quite different from the diurnal distribution of regular pc (T ~ 20 - 30 sec) and reveal a very close connection with diurnal distribution of aurora at the same station.

2. To my mind of great importance are future coordinated investigations of beating pulsations (pearls) with T ~ 1 - 4 sec (see the articles about pearls and intervals of pulsations diminishing on periods IPDP). These pulsations during magnetic storms are directly connected with phenomena in high atmosphere.

3. In the problem of si and ssc's analysis it is important to my mind to study their microstructure in respect of pulsations (T ~ 6 - 15 sec) (see the reports at Fifth Assembly of CSAGI). New criteria for division of different types of si and ssc may be drawn from such analysis.

General remarks

1. As you will find in the letter of Prof. A. G. Kalashnikov we consider it to be a very important question to think over and to organize in the future (perhaps to nominate at first) a network of stations especially equiped for pulsation studies. (That is, to think over a certain body like permanent service for pulsation studies.) The number of stations, their location (using existing observatories), their equipment, have to be discussed perhaps at the symposium.

2. If the question of pulsations atlas is discussed, I hope that we shall be able to give necessary copies of records.

COMMENTS SENT BY PROF. KALASHNIKOV

1. Numerous observations made during the IGY at the Soviet and other countries' stations lead us to conclusions which I ask you to discuss at the Symposium on Rapid Variations.

2. The existing classification of separate types of rapid variations worked out at the Copenhagen meeting in 1957 is very valuable but too general giving no differentiated conception on some more or less frequently occurring types of oscillations.

It is often observed that the known pc and pt oscillations constitute superimposition of different series of oscillations differing in amplitude and period. A purely qualitative analysis of the record by the types pc and pt, etc. is no longer sufficient to meet our requirements fully as its results contain many subjective elements. An especially subjective process observed among many workers engaged in the processing of data is the distinguishing of the group of pt oscillations.

Therefore it is desirable to elaborate such types of rapid variations which would be based on objective quantitative elements, which are, first of all, period, amplitude and duration of oscillations.

Different combinations of these elements most frequently met on records could help to elaborate such types which are based on quantitative characteristics of variations. These types would provide for a more objective character of the analysis of the records.

3. At the present time the records of rapid variations are being made on separate components of the geomagnetic or geoelectric field (earth currents).

This separation of elements of the single electromagnetic field of the Earth deprives us of the possibility to put the problem on the origin of oscillations and localization of their sources in a more direct way.

It seems that it is necessary to expand in every way synchronous observations of the three components of the geomagnetic field and two components of earth currents to get an idea of the vector character of the rapid-variation field. This is the more necessary as earth-current variations —evidenced by our observations— under a vector analysis much depend on geology of a terrain.

4. The further direction in studying rapid variations should be such an organization when it is possible to solve problems on the localization of their sources. In my opinion, both, the sources of rapid variations and the processes of their excitation, are numerous. This means that the sources of rapid variations can be located as in distant spheres which may cause their occurrence all over the Globe, as in nearby points from the Earth's surface. Some types of rapid variations seem to occur as a result of pulsating processes in the Earth's crust and the mantle.

What is recorded on our tapes is superimposition of different-type rapid variations caused by different sources and different excitation processes. A further progress in these studies can be made by elaborating such methods of observations which would make it possible the solution of problems on the localization of rapid-variation sources. Therefore, the principal method in this respect should be a synchronous observation of the separate elements of the rapid-variation field in different points of the Earth's surface. Such observations are already underway in the USSR. At stations Borok, Lovozero, Petropavlovsk-on-Kamchatka there were built fluxmetric gradient installations which evidence that there are often periods of time when the field of rapid variations becomes non-homogeneous and noticeable differences of the field of the order of tenths of γ exist at a distance of 1 km in latitudinal and longitudinal directions.

It is desirable to have in other points too observations of gradient differences of separate elements of the rapid-variation electromagnetic field, for instance, in points of the Earth's surface more or less distant from each other.

The modern theories on the origin of rapid variations take no account of the numerous sources of rapid variations of the Earth's electromagnetic field; therefore, it is necessary to collect experimental data on the localization of the sources of rapid variations of the Earth's field to further develop and make more accurate the theory of their origin.

5. The formal analysis of the rapid-variation records by separate types —pc, pt, etc.—, elicitation of their dependence on periods and amplitudes, distinguishing of daily and season variations and dependence on geographical distribution are of extremely great importance.

The greater part of the works deals at present with this direction precisely. Attention, however, should be paid to the revealing of different correlations between rapid variations and geophysical and heliophysical phenomena as well as magnetic storms, behaviour of the ionosphere and solar activity. These investigations are also very important for the localization of sources of rapid variations. Besides, with time this will make possible to forecast from the observations of separate types of rapid variations the time of arrival and character of occurrence of different geophysical processes.

6. On behalf of IAGA it should be recommended that a network of stations recording rapid variations with periods from 1 sec. to 5 - 10 min (10 - 12 stations): one station in the Arctic and one in the Antarctic, four or five stations in middle and equatorial latitudes of the southern and northern hemispheres, should be organized more or less evenly all over the Globe. It is desirable that such stations would conduct synchronous records of all the components of the Earth's electromagnetic field by means of apparatus with approximately equal response and frequency characteristics.

In this way, a permanent service of rapid variations would be created which at the present period of fighting cosmic space would be of immense importance, as rapid variations reflect some keen electromagnetic processes occurring in the sphere of the Globe, at different distances from its surface.

PRACTICAL RESOLUTIONS

A. *Pulsations.*

a) The problem of pulsations required a long time to be discussed and it was finally possible to arrive at the following resolutions:

Pulsations will be divided in future in four groups

pp	pearl pulsations
pc	continuous pulsations
pt	train of pulsations
pg	giant pulsations

For pearl pulsations or pulsations with periods of about 1 to 4 sec. see the paper of Mrs. Troitskaya on page 130 and the discussions which is raported on page 134.

Supplementing the decisions taken at the Copenhagen Meeting it has been adopted that the periods and amplitudes to be reported are

for pt : the greatest period and amplitude
for pc : the predominant period and amplitude

For the newly introduced pearl pulsations it has been decided to ask the Russian scientists to present to the Committee a note with practical examples of how to report them; this note will be discussed during the Helsinki General Assembly.

b) A precise definition for giant pulsations was the object of a lively discussion; it was very difficult to find one and finally the following one was tentatively accepted:

«exceptional pulsations of very great period and very regular with a sufficient relative amplitude»,

«pulsations exceptionelles d'une très grande période et très grande régularité avec l'amplitude relative suffisante».

c) The introduction of new types of pulsations and the selection of some observatories for special studies on rapid pulsations was left for some future meeting of the Committee.

d) It was decided to draw the attention of the observatories to the proposal of Prof. Selzer, but it was agreed that no resolution was necessary.

e) To the questions raised by Prof. Jacobs the Committee reafirmed its wish to publish results on rapid pulsations from as many observatories as possible, but that observatories were free to collaborate in the form they thought possible and that no new action should be taken in this direction.

f) The discrepancies in the reporting times of pt's from quick-run magnetograms and from ordinary magnetograms was aknowledged and observatories are asked to reduce it as much as possible.

B. *Storm sudden commencements, bays, etc.*

a) In order to complement the Copenhagen resolutions it was adopted that:

In case some stations particularly in the Arctic and in the Antarctic, wish to give the duration of bays, they should give the total duration of the whole phenomenon taking into account the three components.

b) The clasification of ssc or of si into ssc (or si) with pulsations and ssc (or si) without pulsations was not adopted.

Prof. Chapman proposed in his lecture a classification of ssc much more accurate than the one adopted by Com. n.° 10 which only consider ssc * (storm sudden commencements with one or many reversed movements) and ssc (storm sudden commencements without reversed movement). A lively discussion developed on the advisability of imposing to the observatories the Chapman's notation, but considering that the combination of the * with the signs of the chief movement, as requested in the monthly reports, gives a classification similar to that of Prof. Chapman, it was finally decided to follow the notation used in the work of the Committee, but to recommend the Chapman's notation for scientific investigations and papers dealing with ssc's.

C. *Checking-lists.*

The Chairman of Committee, Fr. Romañá, noted the great difficulty which arises in the compilation of the checking-lists from the fact that there is a great number of observatories and that some observatories send monthly reports with a too great number of cases. If all the phenomena are entered into the checking-lists, these will be too long (f.i. for 1958 the bays reported are over one thousand) and there is the danger that observatories will find a too great burden to go through these lengthy lists to check them. It seems therefore that some selection must be applied in the compilation of the checking-lists.

It was immediately agreed to drop from the lists those phenomena which have been reported only as doubtful (quality C). Prof. Bartels proposal was to make a complete list of all phenomena to be sent to about 10 observatories well distributed in longitude and latitude and to ask them to revise the list and to suggest what should be accepted and what to be rejected; with the indications of these 10 observatories a reduced checking-list could then be stablished and sent to all collaborating observatories. This proposal has a major objection that it will take a great time till the final list can be stablished. It was decided that the problem should be considered again at the Helsinki General Assembly.

THE ATLAS OF RAPID VARIATIONS

It has been a wish of the Committee, following a CSAGI resolution, to produce an Atlas with real examples of the different geomagnetic and Earth Current rapid variations.

In the task of preparing this Atlas the following principles were adopted.

1. Not to be afraid to publish many cases of the same phenomenon. The cloud-atlas is a good example of how useful may be to have different types of the same phenomenon.
2. To ask all observatories to send copies of selected periods of their magnetograms to Comm. N. 10 and that in view of these copies, either the Committee itself or an especially appointed reporter, will select the more significant cases and will prepare the final version of the Atlas.
3. It is very important to provide examples showing how some phenomena change in aspect when observed at different longitudes and latitudes.

The following list of selected periods was adopted:

I. Magnetograms to be reproduced in the Annals of the AGI:

Worldwide storms:

30 June 1957 00h to 1 July 24h
3 August 1957 15h to 4 August 03h
4 September 1957 09h to 5 September 24h
11 February 1958 00h to 12 February 24h
8 July 1958 06h to 9 July 09h
3 September 1958 06h to 5 September 24h

Very quiet intervals:

30 November 1958 00h to 1 December 24h
31 December 1958 18h to 2 January 12h

Solar flare effects:

23 March 1958 06h to 15h
29 July 1958 00h to 06h
16 August 1958 03h to 09h

Giant pulsations:

17 July	1958 06h to 15h

Bays:

13 October	1957 18h to 24h

pt:

14 August	1958 15h to 19h

Sudden impulses:

30 August	1957 15h to 21h
13 July	1958 18h to 14 July 03h
31 October	1958 15h to 24h

All observatories are requested to send to the Committee copies of their ordinary, quick-run and storm magnetograms and tellurigrams.

If some observatories think that better cases can be found they should report them to Committee N. 10.

A supplementary list for polar bays will be prepared by Committee N. 10.

II. For the Atlas the following list was adopted in addition to the list given before:

Storm sudden commencements:

6 August	1957 05h 08m
25 March	1958 15h 40m
24 August	1958 01h 40m
25 September	1958 04h 08m

The Committee was requested to look for some cases of ssc with the storm beginning many hours afterwards and also for some cases of more than one ssc for the same storm.

Sudden impulses:

22 January	1956 19h 40m (from Manhay only).
25 November	1956 13h 30m
21 October	1957 22h 41m (reported in the monthly list as ssc by 30 observatories, and as si by 25 observatories).
15 October	1958 (from polar stations only).

Bays:

12 May	1958 22h 31m
2 October	1958 21h 57m
23 October	1958 19h 12m (from Pacific stations only).

Solar flare effects:

28 August 1957 20h 18m (from American stations only).
29 March 1958 13h 41m

pt:

12 November 1957 10h 10m (from polar stations only).
23 July 1958 23h 34m (from CF only).
23 September 1958 02h 41m
23 September 1958 23h 19m
12 October 1958 20h 17m
23 October 1958 19h 13m

pc:

It was decided to ask the Russian scientists for some examples of the different types proposed by them and to publish them in order of their increasing periods.

It was also recommended to ask Dr. Selzer and Miss Hutton for examples of pc observed during the night hours.

pg:

1 March 1942 14h - 18h
26 November 1957 19h 07m

Earth Currents:

It was agreed to ask: Mrs. Troitskaya and Drs. Bock, De Voogt, Fanselau, Grenet, Kato and Romañá to prepare a list of possible examples to be included in the Atlas, and to leave the final selection to the Committee.

All observatories are requested to send copies of their magnetograms for the periods indicated above; the phenomenon must appear in the center of the reproductions. In order to show what the Committee feels necessary for the reproduction it was decided that for *ssc* and *si* copies must contain about 4 hours for normal magnetograms and half an hour (or at least a quarter of an hour) for rapid-run magnetograms, with the *ssc* or *si* centered in the reproduction. For the other examples: *bays, pulsations* and *sfe* a reasonable period before and after phenomenon must appear in the reproduction.