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Foreword

This report has been prepared on behalf of the Associate Committee on Geodesy and Geophysics, National Research Council of Canada, by C.M. Carmichael, Chairman of the Geomagnetism Subcommittee, and T.R. Hartz, Chairman of the Aeronomy Subcommittee. It briefly reviews studies in geomagnetism and aeronomy by Canadian institutions for the period 1967 through 1970, and the bibliography lists published reports under appropriate headings. More complete résumés of work during this period may be found in the Canadian Geophysical Bulletin, vols. 20, 21, 22, 23, published by the National Research Council of Canada.

Avant-propos

Le présent rapport a été préparé pour le Comité mixte de géodésie et de géophysique du Conseil national de recherches du Canada, par MM. C.M. Carmichael, président du sous-comité de géomagnétisme, et T.R. Hartz, président du sous-comité de l'aéronomie. Les auteurs passent en revue brièvement les études sur le géomagnétisme et l'aéronomie menées par des institutions canadiennes entre 1967 et 1970. La bibliographie donne la liste des rapports publiés sous des rubriques appropriées. On trouvera des résumés plus complets des travaux réalisés au cours de cette période dans le *Canadian Geophysical Bulletin,* vol. 20, 21, 22, 23, publié par le Conseil national de recherches du Canada.

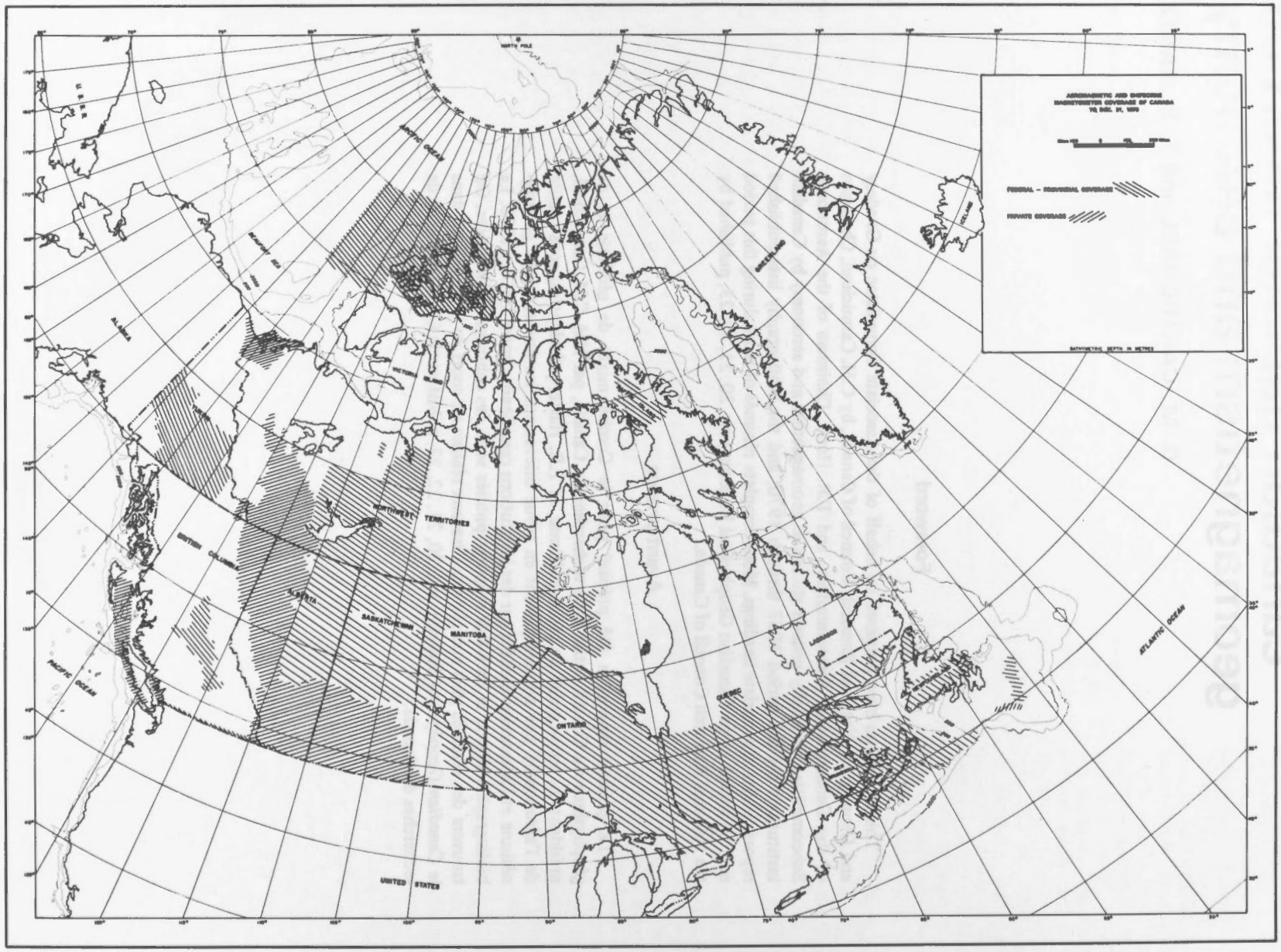

Figure 1. Detailed total-intensity surveys completed by December 31, 1970, including low-level aeromagnetic and shipborne coverage by government agencies and private industry.

Part I — Geomagnetism

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1. Magnetic surveys

(a) Instruments. The development of geomagnetic instruments continued at the Earth Physics Branch (formerly the Dominion Observatory), the Geological Survey of Canada, the Defence Research Establishment Pacific (formerly the Pacific Naval Laboratories), the National Aeronautical Establishment, the University of Alberta, and the Bedford Institute of Oceanography. Significant improvements were made in the performance of fluxgate and Overhauser effect magnetometers, and the design of air-cored and high-permeability cored induction coils. Much attention was given to digital recording and data processing equipment, both for survey vehicles and for fixed stations. The development of a magnetometer capable of recording on the sea floor is in progress.

(b) Surveys. As part of a continuing study of secular change, the Earth Physics Branch observed at 95 of its repeat stations, and established six new stations. Recording instruments were operated at each station for several days.

High-level three-component airborne surveys covered the Canadian Arctic Archipelago, Northern Greenland and the Arctic Ocean up to the north pole, as well as British Columbia and an area of 1,500,000 square miles of the northeast Pacific Ocean.

Surveys of total intensity by ship have included the continental shelf on Canada's east coast, a detailed survey of the mid-Atlantic ridge at 45°N, and the path followed by the *Hudson* on its 'Around the Americas' expedition, with detailed work in the Queen Charlotte Islands region and the Beaufort Sea.

Detailed low-level airborne surveys of total intensity were carried out under the federal-provincial government plan, and by many private companies. Figure 1 shows the area of Canada covered to date by detailed total intensity surveys, including surveys by ship.

(c) Magnetic charts. During the period over 2,000 aeromagnetic maps were published on a routine basis and in addition anomaly and other charts were published for special areas. These include: anomaly charts of the Scandinavia, Greenland, Iceland region, a Z residual chart of the eastern Pacific Ocean and British Columbia, a magnetic map of Canada with the regional gradient removed, a Natural Resources chart of the magnetic data over the continental shelf and an Isogonic Chart of Canada 1970, showing lines of equal declination and its rate of change.

(d) Interpretation. The classical methods of depth-to-basement determination from isolated magnetic anomalies are still widely used, especially in ocean areas, but the period under review saw the development of several new techniques of interpretation. Downward continuation, digital filtering, and power spectra techniques have been applied by the Geological Survey of Canada and the Universities of Alberta, Dalhousie, Manitoba, and Toronto. Modelling of structures with self-adjusting computer programs has become a practical tool for interpretation at the Bedford Institute of Oceanography and the above institutions. Considerable success in correlating aeromagnetic maps with the properties of exposed rocks has been achieved by the University of Manitoba and the Geological Survey of Canada. In situ measurements of susceptibility are made, and oriented core specimens are taken for laboratory analysis.

Interest in magnetic information as an aid to understanding crustal structure on a broad scale was greatly stimulated by the publication of a magnetic anomaly map of Canada, compiled by the Geological Survey of Canada by combining 3,400 detailed total intensity map sheets. It shows striking correlations between broad-scale magnetic features which are not apparent on the original map sheets, and the boundaries between adjacent geological provinces.

2. Magnetic observatories

On April 1, 1965 the observatory at Agincourt was closed because of steadily increasing industrial interference, thus ending 70 years of records from that location, and the continuous record from the Toronto region which began in 1840. Agincourt observatory is replaced by Ottawa observatory. The observatories in St. John's, Newfoundland and Ottawa began operation in June 1968. The other eight observatories operated continuously during 1967-70: Alert, Baker Lake, Churchill, Great Whale River, Meanook, Mould Bay, Resolute Bay and Victoria. Microfilms of the magnetograms from these observatories are deposited in World Data Centres on a monthly basis, with provisional baselines and scale values. K indices and hourly ranges are reported to the appropriate commissions of IAGA. Automatic magnetic observatories are in operation at St. John's, Ottawa, Meanook and Victoria.

As part of a co-operative program with NASA, four unattended magnetic recording stations were set up in 1969 in the vicinity of the point conjugate to the synchronous satellite ATS-5 and have been kept operational since then. Three component fluxgate magnetometers with analogue records have been used at these stations.

The mu-metal cored coil magnetometers built by the Defence Research Establishment Pacific have been operated unattended over several week periods at Ralston in southern Alberta since June 1969.

The Bedford Institute of Oceanography has operated a station recording total intensity since July 1967. Monthly data reports are published, including 10-minute and hourly mean values as well as reproductions of the magnetograms. In addition several temporary stations were located by Bedford Institute during 1967-70 along the east coast of Canada for monitoring diurnal variations in this area.

The observatory operated by University of Alberta at Leduc, Alberta has been in operation since 1967. The data from the observatory, mainly high frequency magnetic and telluric variations, have been used for magnetotelluric studies.

During the summer months, the University of Alberta has operated eight magnetic recording stations, located on a geomagnetic meridian passing through Edmonton and extending from magnetic latitude 58.7°N to 77.0°N. The outputs of three-component fluxgate magnetometers are recorded on digital tape every two seconds, for studies of polar substorms and pulsations.

3. Magnetotellurics and electromagnetic induction

Experimental and theoretical studies of magnetotellurics and electromagnetic induction in the earth have been conducted by the Earth Physics Branch, the Bedford Institute of Oceanography, and the Universities of Alberta, British Columbia, Dalhousie, McGill, Memorial, Toronto, and Victoria. Areas in which experiments have been conducted include the British Columbia coast, the Rocky Mountains and southern Alberta, the Canadian Arctic Islands, the eastern continental shelf, Iceland, and Newfoundland.

The University of Alberta, in co-operation with the University of Texas, has operated an array of over 40 three-component magnetometers for several seasons across the Rocky Mountain Front, from the U.S.-Mexican border to the Trans-Canada Highway. Local conductivity anomalies as well as the broad-scale conductivity changes associated with the Rocky Mountain and Wasach Fronts have been investigated. The variation field of polar substorms have been separated by surface integral methods into parts of external and internal origin. Magnetotelluric surveys of buried rift-valley structures in southern Alberta have been completed, and the observations fitted with theoretical two-dimensional models.

The coast induction effect has been studied intensively at the Bedford Institute of Oceanography, using data from eastern Canada and from India. Equipment for magnetotelluric recording on the sea floor is being developed.

In a co-operative program, the University of British Columbia and the Earth Physics Branch have continued the mapping of conductivity anomalies in British Columbia and have published several quantitative interpretations. The Earth Physics Branch has extended its observations and interpretations of crustal induction in the Canadian Arctic. In co-operation with Cambridge University, a survey of geomagnetic variations in the British Isles has been completed.

The University of Toronto completed the analysis of its observations made in Iceland, and carried out magnetotelluric measurements across the Superior-Churchill boundary in northern Manitoba. Model studies of the distortion of a uniform electric current field by conductive bodies were completed, and applied to the Alert anomaly.

At the University of Victoria, a scaled laboratory model has been used to study the electromagnetic variations over an inhomogeneous conductor in the fields of overhead line currents, sheet currents, and vertical or horizontal magnetic dipoles. Theoretical investigations, in addition to the above models, include the development of a general theory of induction in a many-layered earth, and the computation of the magnetic fields induced by internal ocean wave movements.

4. Paleomagnetism and rock magnetism

There has been a healthy growth in Canada's activities in paleomagnetic and rock magnetic research. New laboratories have been set up at the University of Alberta and Dalhousie University. The research groups at the Earth Physics Branch and at Memorial University have moved into new quarters specifically designed for geomagnetic research. As of 1970 research groups or individuals engaged in rock magnetism and paleomagnetism are located at the Earth Physics Branch, the Geological Survey of Canada, and the following universities: Alberta, Dalhousie, Laval, Manitoba, Memorial, Toronto, and Western Ontario.

The paleomagnetic efforts of these groups have been directed toward obtaining paleodirectional data, and to a lesser extent, paleointensity data from a variety of Precambrian and Phanerozoic formations exposed in Canada. A number of these groups however, are studying material collected in other countries and have studied dredge and core material from the ocean basins with specific emphasis on mid-Atlantic Ridge material from 45°North. Two of the laboratories have also done work on lunar samples obtained in the Apollo program.

The rock magnetic investigations of these groups have involved optical and electron microscopy of the magnetic grains in some of the units which have been studied paleomagnetically. Other workers are studying the magnetic properties of pyrrhotite, single domain magnetites, pseudo single domain grains and super-paramagnetism in fine-particle hematite.

Paleomagnetic measurements made at the University of Alberta on samples from northern Labrador and a comparison with six other rock units between Labrador and Colorado suggest that the earth's field was essentially dipolar and that no large relative movements have occurred within a large part of North America in the last 1400 m.y. The high coercivity of the Michikamau anorthosite is attributed to single domain needles of magnetite.

The Earth Physics Branch concluded from measurements on samples from Canada that a significant polar drift may have occurred between the Upper Mississippian and Lower Permian,

and that two geomagnetic reversals took place in the Upper Mississippian. Secondary magnetization of red beds during diagenesis was studied. An investigation of the magnetic properties of dredge and core samples from the mid-Atlantic Ridge was completed, and an explanation advanced for the spectacular remanence anomaly associated with the Median Valley. Samples collected in Vancouver Island indicate that it was not part of the continent in the early Mesozoic.

Results obtained by the Geological Survey of Canada from samples in Labrador indicate that the North American Jurassic pole position differs significantly from its Cretaceous and Triassic equivalents. Thellier's double heating technique was applied to about 100 specimens representative of basic igneous rocks across the country. This study gave an estimate of the intensity of the earth's field in the Geological past and yielded unique support for the dipole hypothesis. Magnetization measurements on samples from the Sudbury Irruptive have been published and paleointensity work is in progress. The thermomagnetic properties of banded manganiferous sediments from the mid-Atlantic Ridge have been studied. A fundamental study on synthetic pyrrhotites is under way to establish the magnetic phase relations.

A remanent magnetic study in the central and southern sectors of the Labrador Trough has been conducted at the Université Laval. The rocks are mainly iron formations of Proterozoic age belonging to the Churchill Province.

The University of Manitoba has studied the magnetic properties of samples from the Kenora area, Ontario and southeastern Manitoba to determine the nature of the magnetization associated with the regional magnetic anomaly system.

The random field demagnetization of rocks has been investigated at Memorial University. Results suggest that conversion to a steady-field method is feasible under certain restraints. Measurements on Ordovician and Cambrian rocks from Newfoundland and Labrador have been compared with results from samples in Ireland and Britain. Similar studies on Tertiary rocks in Greenland, Iceland and Baffin Island are in progress.

Measurements have been made at the University of Toronto of time effects and of magnetization and demagnetization curves for isothermal, anhysteretic and thermo remanences. A good fit to the isothermal results can be obtained if particle interactions are treated by a Preisach model. Research on the thermomagnetic properties of materials containing dispersions of very fine ferromagnetic grains has shown that the Néel theory, modified to include the effects of grain interactions can quantitatively explain nearly all experiments. An almost continuous record of the magnetic directions for a period of about .2 m.y. has been obtained from portions of the Eocene Green River Shale. In addition to the expected secular variation, there is a strong suggestion that significant transients up to 90° occur in the earth's field with a duration of a few thousand years. Lunar samples from Apollo 11 and 12 were intensively studied. Many of the iron-bearing minerals have been identified and the results suggest that a weak field of a few thousand gammas was present on the moon 3.6 x 10^9 years ago.

An outline of the paleomagnetic field intensity from 2.5 x 10^9 yrs to the present has been obtained mainly from stable basalt lavas at the University of Western Ontario. The field in the Precambrian had an intensity equal to or greater than the present value; in the early Paleozoic it is quite weak, then increased during the Mesozoic and Tertiary to present values. Paleomagnetic results from samples dredged from the mid-Atlantic Ridge indicate that the magnetic anomalies are due to a thin veneer of fine-grained basalt only a few hundred metres thick and that the remainder of the oceanic crust is relatively coarse grained, differentiated and only weakly magnetic. Studies of the middle Keweenawan in the Lake Superior region show only one reversal of magnetic polarity. The sensitivity of the conglomerate test as used in paleomagnetic studies has been statistically analyzed.

5. Geomagnetic disturbances and pulsations

Studies of geomagnetic disturbances and micropulsations have been conducted at the Universities of Alberta, British Columbia, and McGill, and at the Defence Research Establishment Pacific and the Earth Physics Branch.

The University of Alberta made detailed studies of the development and morphology of polar magnetic substorms, and of the polarization of micropulsations, using data from the array of eight special recording stations described in Section 2 above. Investigations continued of conjugate point phenomena, the propagation of VLF signals and micropulsations, and changes in the magnetic field in the magnetotail. Computer programs were developed to model current systems from observed electron densities and electric fields.

The University of British Columbia, in co-operation with other groups, has investigated natural electromagnetic noise in the sub-audible frequency range. Detailed studies of the conjugate stations Byrd and Great Whale River have revealed differences in the Pc4 and Pc5 generation mechanisms. Investigations of hydromagnetic emissions continued. The testing of a high voltage dc transmission line with ground return, connecting Vancouver Island with the mainland, was used to make a large-scale resistivity survey.

Experimental and theoretical work on the magnetic noise produced by ocean waves was carried out by the Defence Research Establishment Pacific. Micropulsations recorded at ground stations in southern Alberta and Resolute, NWT are being compared with results from an airborne caesium magnetometer survey.

The Earth Physics Branch studied the correlation of magnetic variations recorded at Byrd in the Antarctic and at five stations in an east-west line in the region conjugate to Byrd. An analysis was published of the effect of the solar cycle on diurnal and seasonal patterns of irregular magnetic activity at four high-latitude magnetic observatories. A detailed study of the intense polar substorm of 5/12/68 was based on

magnetograms from 26 auroral and polar cap observatories. Micropulsations in the Pc3, 4 range recorded simultaneously at Ottawa, Meanook, Baker Lake and Resolute Bay have been analyzed for diurnal and latitudinal variation in occurrence, amplitude, and period. Special recordings in connection with the solar eclipse of March 7, 1970, revealed a pronounced decrease in the relative amplitude of magnetic fluctuations at the location of totality, compared with stations 200 km distant.

Correlations between the vertical telluric currents recorded at Mont St-Hilaire and Thetford Mines, both in Quebec, have been studied at McGill University.

6. Theoretical studies of the main field

The following studies of the main magnetic field and electromagnetic coupling in planetary interiors were carried out, at the beginning of the period under review, at the Universities of Waterloo and Western Ontario, and later, at Memorial University and the University of British Columbia.

A simplified model of electromagnetic core-mantle interaction, neglecting magnetic diffusion, predicts extremely weak damping of the Chandler wobble, in agreement with an earlier detailed study. It also shows that the accompanying core motion may be strongly damped electromagnetically.

A laboratory model of thermal convection under a central force was operated successfully. The central force is provided by an intense alternating electric field gradient acting on the dielectric fluid. With cylindrical geometry, the behaviour is similar to that of a Benard fluid layer wrapped around a cylinder. A model with spherical geometry and rotation is under construction.

Geomagnetic coupling of the earth's core-mantle system appears able to explain the observed rate of change of obliquity arising from the lunisolar precessional torque, but the simple model also predicts a nontidal deceleration of axial rotation much greater than is observed.

The electrical properties of Jupiter's interior have been inferred from changes in the rotation of the Great Red Spot, on the assumption of electromagnetic coupling between a molecular hydrogen mantle and a liquid metallic hydrogen core.

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Part II — Aeronomy

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1. Airglow

Investigations of the airglow are being carried out in Canada with increased vigour, the number of stations where these studies are being made having increased during the past four years. Impetus for these studies has been provided by the increased availability of rockets and satellites; however, ground-based observations continue to make an important contribution. Much inspiration for both aurora and airglow studies resulted from the Summer Advanced Study Institute "Aurora and Airglow", which was organized by Dr. B.M. McCormac, and held at Queen's University in Kingston, Ontario, in 1970.

Ground-based measurements at the University of Saskatchewan have revealed the pre-dawn enhancement of 6300 Å emissions were successfully made on April 23, 1970 at Fort Churchill.

The twilight decay of the (0-1) band of the infra-red atmospheric system of O_2 $[^1\Delta_g - {}^3\Sigma_g^-]$ at 1.58μ has been observed using a Fabry-Perot interferometer. This band has also been observed in the dayglow, the brightness in the zenith at local noon being about 600 kilorayleighs. Height profiles for $[O_2(^1\Delta_g)]$ have been calculated.

Rocket measurements at Churchill of $[O_2(^1\Delta_g)]$ at 1.27μ have revealed a large maximum near 50 km, and also the existence of another layer at 85 km.

1.27μ emissions were measured during day and night using a grating spectrometer and also a filter wheel radiometer fitted with a PbS detector. The exponential time constant for

evening decay declined from 50 minutes in January to 31 minutes in May over New Mexico.

Measurements of the relative intensities of the (0-0) and (0-1) bands of O_2 at 1.27μ and 1.58μ gave a value of 46 photon units.

The rate of the reaction:

$$O_2(^1\Delta_g) + O_3 \rightarrow 2O_2 + O$$

has been measured and the rate constant obtained was $4.5 \times 10^{-11} \exp[-5620/KT]$ $cm^3 sec^{-1}$ molecule $^{-1}$ with energy units in cal/mole.

Measurements of the deactivation of $O_2(^1\Delta_g)$ by oxygen, nitrogen, argon, water vapour, and carbon dioxide show that oxygen is the only significant quencher of $O_2(^1\Delta_g)$. There appears to be a $T^{\frac{1}{2}}$ temperature dependence.

Recent work on the ozone-oxygen photochemical system at 2537 Å has shown that $O_2(^1\Delta_g)$ is produced entirely by photolysis and the $O_2(^1\Sigma_g^+)$ entirely by energy transfer from $O(^1D)$. Measurements of the relative intensities of these two species suggest that the efficiency of $O_2(^1\Sigma_g^+)$ production from the quenching of $O(^1D)$ is high (at least 75 per cent).

The rate of the reaction of $O(^1D)$ with O_2 was found to be 1.4 times faster than the corresponding reaction with nitrogen. These results indicate that about 25 – 30 per cent of the $O(^1D)$ atoms formed by solar photodissociation of ozone will produce $O_2(^1\Sigma_g^+)$ in the atmosphere.

A laboratory source has been used to study the band structure of the O_2 atmospheric system. With this source a spectrum of the (0-0) band at 1.27μ has been obtained at a resolution of 2 Å.

Ground-based observations of the (4-1) and (5-2) bands of OH in the nightglow have been made with a spectrometer having an (S-1) response, and working at 6 Å spectral resolution. A temperature structure in the hydroxyl emitting region has been shown to exist at all seasons with a variation which is in phase with the atmospheric temperature in the same region.

Using a balloon-borne grating spectrometer to monitor the (1-0) band at 2.8μ a diurnal variation of intensity of OH emission was observed over a 24-hour period (extending over two days). A pronounced drop in intensity occurred at sunrise, followed by a slow recovery during the morning to roughly the night-time value.

Some rocket flights have shown that OH emission in the evening twilight apparently exists down to altitudes of 55 km. It can therefore be suggested that the collisional quenching of the vibrationally excited OH molecules is relatively slow. Balloon data also support this conclusion.

Ground-based twilight lithium observations made with a birefringent photometer have shown that unusual enhancements of the red emission occur infrequently throughout the year, the zenith intensity reaching values of about 150 rayleighs during these times. The times of the enhancements do not seem to be correlated with the times of release of lithium vapour into the atmosphere by rockets so that lithium may be deposited into the atmosphere from a natural source. The height of maximum density of the lithium layer appears to be between 90 and 95 km.

A study of the seasonal variation of the height of the twilight sodium layer has suggested an evening-morning effect in which the morning heights appear to be lower than the evening heights, the difference amounting to about 5 km near the times of the equinoxes and 1 km or less near the times of the solstices. The same effect has been noted for twilight lithium. The scale height of free atomic sodium above the layer maximum seems to have a value between 3 and 4 km. Comparisons between twilight sodium abundances at Saskatoon and Victoria, with stratospheric temperatures at several Canadian stations show a high correlation with Arctic stratospheric warmings for Saskatoon sodium but a low correlation with Victoria sodium suggesting that Victoria lies outside the Arctic circulation regime at 90 km.

The identity of the potassium emission in the twilight airglow has been definitely established by using a potassium vapour cell to show that the emission could be completely absorbed.

Studies of He emission at 1.083μ, using a 12 cm spatially scanned Fabry-Perot interferometer have shown that different twilight decays occur during magnetically active, magnetically quiet, and auroral conditions.

An analysis of spectra of the night airglow in the spectral region between 3 and 8 microns has been carried out.

Curves of growth for the R branches of the ν_3 carbon dioxide band at 4.26μ, and the ν_3 methane band at 3.31μ found in solar spectra were prepared from the best known absorption line parameters.

Atmospheric carbon dioxide and methane concentrations in the lower stratosphere derived from recorded solar spectra indicate near uniform mixing over latitudes from 10°N to 75°N.

2. Atmospheric dynamics

The principal centres for studies in atmospheric dynamics include the Universities of Toronto, McGill, Saskatchewan, Victoria and Western Ontario and the Meteorological Branch, Department of the Environment, Toronto.

Theoretical and analytical studies of wave motions including atmospheric tides and shorter period gravity waves have been performed at the Physics Department of the University of Toronto; and in particular, sources of gravity waves, their propagation through realistic atmospheres and their influence upon the momentum and energy balance of the mesosphere and thermosphere have been studied. At the Department of Meteorology, McGill University, model calculations and analytical studies of the propagation of planetary scale waves to heights above 30 km have been performed. The atmospheric dynamics group in the Physics Department, University of Saskatchewan, is investigating coupling between the stratosphere and ionosphere on a seasonal time scale, using radio waves at Saskatoon and meteorological rockets at Cold Lake (Alberta) as probes. The influence of planetary, tidal and gravity waves are involved. Model calculations and analytical

studies of dynamical effects upon radio wave reflection processes and ionization changes have been made. The Institute of Space and Atmospheric Studies, University of Saskatchewan and the University of Victoria are conducting co-operative studies of seasonal variations in the twilight sodium emissions, and in particular, are making correlation studies with stratospheric temperatures. The Centre for Radio Science, Western Ontario is making meteor wind measurements.

The Meteorological Branch, Toronto, is conducting theoretical and experimental studies of the interaction between the dynamics and photochemistry of the mesosphere and lower thermosphere. A network for observations of noctilucent clouds has been established. Studies are also made of the effect of density and temperature variations ($\simeq 30-100$ km) upon aerospace vehicles.

3. Aurora

3.1 Optical studies of the aurora

Ground based optical studies of the aurora are being conducted by the Universities of Calgary, Saskatchewan, and York and by the National Research Council of Canada. Auroral research of a continuing nature at Churchill ceased in 1970 with the transfer of the scientific staff to Ottawa. A number of field operations have been carried out there, however, and at such locations as Thompson, Gillam, Resolute Bay and Cold Lake to obtain specific auroral measurements associated with balloon, rocket or satellite measurements or for studies of particular auroral phenomena.

Auroral photometers have been operated at the near conjugate stations of Great Whale and Byrd in a National Research Council of Canada project beginning in 1967 and automatic photometers are being installed there. Photoelectric measurements of the auroral spectrum between 1 and 2μ are being made at Calgary and a high speed image intensifier TV system has been developed and used for investigating pulsating aurora.

A chain of patrol spectrograph stations covering the latitude range 55-78° N magnetic has been used to investigate proton and electron precipitation. The spectra show that the region of proton precipitation lies a few degrees equatorward of the electron oval of precipitation before midnight, crossing to the poleward side after 0100 hours. A study of the observed H_β intensity relative to the N_2^+ 4709 Å band has also been made yielding values of less than 0.2 for normal aurora and up to about 3.0 for proton aurora. Spectrometric measurements of Type B red aurora have been carried out and show the intensity of O_2^+ system enhanced by a factor of 2-3 relative to the N_2 1PG, although subsequent independent measurements do not confirm this.

3.2 Radio studies of the aurora

A number of centres have been actively investigating auroral phenomena by radio techniques. Auroral radars have been operated continuously by the National Research Council of Canada at Ottawa, Thompson, Churchill and Great Whale for the study and detailed examination of radio aurora. A bistatic VHF radio system operated in eastern Canada by the University of Western Ontario for the past decade has been used for a study of the rate of occurrence of radio aurora and its diurnal and seasonal characteristics. It has been established that there are two or more fundamentally different types of radio aurora, with ion-acoustic waves generated by the auroral electrojet being responsible for the observed signal amplitudes in the morning hours.

Auroral backscatter recordings from a 42 MHz transmitter were made by the University of Saskatchewan to measure the fading rates and to determine the relation between the scatter bursts and pulsating electron influx.

A study of auroral absorption events in relation to visual aurora and satellite particle measurements has been carried out by the Communications Research Centre using data from a chain of riometer stations in the latitude range 67° – 76° invariant.

3.3 Rocket, balloon and satellite studies

Rockets launched from the Churchill Rocket Range have been used increasingly in auroral studies. The National Research Council of Canada has been a major participant in this area while the Universities of Calgary, Montreal, Saskatchewan, York and Western Ontario have also participated actively.

The general characteristics of particle precipitation during various types and phases of ionospheric disturbances have been determined. Electron energy spectra and angular distributions have been measured in a variety of auroral protons and α-particles yielding evidence for a direct solar wind origin of auroral ions. Extensive measurements of plasma densities and temperature in visual aurora have been obtained.

Balloon borne detectors have been employed to investigate the association between auroral X-rays and particular types of aurora.

The latest ISIS satellite launched in March 1971 includes two auroral photometer experiments measuring 6300 Å and 3914/5577 Å emissions respectively, in addition to the energetic particle experiments of the type included in the ISIS-A and Alouette satellites. Rocket borne photometers too have been used to obtain measurements of the intensity and luminosity profiles of a number of auroral emissions in both the visible and ultraviolet regions. H_β luminosity profile measurements have been used to deduce the nature of the incoming proton spectrum.

4. Cosmic rays and particle physics

Cosmic ray and energetic particle measurements have continued at ground stations and in rockets and satellites. The National Research Council of Canada maintains stations at Ottawa, Resolute and at Churchill (jointly with the University of Texas at Dallas, Texas). The Atomic Energy of Canada Limited maintains a station at Deep River, Ontario and jointly with the National Research Council of Canada is responsible for the stations at Alert and Inuvik in the Arctic Islands and at

Goose Bay, Labrador. The University of Calgary maintains the Sulphur Mountain Station (near Banff, Alberta) and a station at Calgary and the University of Victoria maintains a station at Victoria. The University of Manitoba, Winnipeg has a number of meson telescopes, each telescope consisting of two large ($\sim$ 1.5m) scintillation counters, separated by a distance of several metres.

Most of these stations have a counter or scintillation telescope in addition to the neutron monitor. With the exception of Ottawa, the neutron monitors register rates of the order of a million counts per hour. Data from these stations are distributed to the World Data Centre on a routine basis and exchanged with various groups. The monthly Solar Geophysical Data put out by ESSA Research Laboratories (presently re-named NOAA), US Department of Commerce publishes the data from Churchill, Deep River, Alert, and Calgary and Sulphur Mountain (as of January 1, 1971).

The Division of Physics at the National Research Council of Canada, Ottawa, has recently completed a study of the daily variation of cosmic ray intensity and its relation to the interplanetary magnetic field. The Atomic Energy of Canada Limited has made an extensive cosmic ray latitude survey, which has resulted in a number of publications.

Studies of the low energy part of the particle spectrum including the particles trapped in the magnetosphere and Cosmic Ray studies have been conducted using data from some of the US satellites like Mariners 2, 4, 5, Explorers 33 and 35, and Imp-Ogo series, in collaboration with the US institutions. The cosmic ray gradient in the interplanetary space for protons and alphas, ($E > 50$ MeV) is negative, that is, it increases in going towards the sun. This indicates the solar contribution at low energies and also shows that it is not possible to determine the gradient of galactic cosmic rays even at the time of solar minimum. Study of a number of Solar Cosmic ray events during 1968-1969 is in progress. This is collaborative work between the University of Iowa and the University of Calgary. The data from Explorer 33 and 35 and the neutron monitor data from Calgary and Sulphur Mountain are used. Of particular interest is the low energy alphas and protons ($\sim$ 1 MeV/nucleon) and nuclei of $Z > 2$. The variability of the ratios of these from event to event are being studied with reference to propagation effects.

Nuclear emulsions are also flown on high altitude balloons by the University of Calgary to study primary cosmic rays, particularly in identification of solar neutrons. An excess of 2.2×10^{-2} neutrons/cm^2 sec in the energy range 20-160 MeV was observed from the direction of the sun. Balloon borne counter telescopes are also used by Calgary to study the energy spectra of different charge components of the primary cosmic radiation at different levels of solar activity to study solar controlled modulation processes. Apparatus for the measurement of energy spectrum of primary cosmic ray electrons using balloons at high geomagnetic latitudes is under construction at Calgary. Radio emissions from air showers have been investigated by the University of Calgary at the site of the Dominion Radio-Astrophysical Observatory at Penticton, British Columbia. Of particular interest are the production mechanisms and lateral dependence of the intensity of the radio signal as a function of frequency and its dependence on primary energy.

The time variation of the total detected cosmic radiation as well as that of the cosmic rays of different energies as inferred from the multiplicities of neutrons evaporated from the lead, are studied at the University of Victoria. The University of Manitoba is interested in the study of primaries of energy > 100 GeV. Apart from studies of daily variation, solar as well as sidereal, they are also interested in detecting the elusive quarks, if any are around. A watch is kept, for this purpose, over one of the telescopes.

5. The ionosphere

Studies of the ionosphere are carried on at a number of institutions on Canada. The Defence Research Telecommunications Establishment (DRTE), which has been the primary centre of such studies, was transferred in 1969 to the newly-created Department of Communications and is now called the Communications Research Centre (CRC). Ionospheric research is also done at the National Research Council of Canada, the Universities of Saskatchewan, Western Ontario, British Columbia, and Laurentian, and at RCA Ltd. in Montreal.

The Department of Transport has had responsibility for the standard vertical incidence ionosonde operation and data reduction. In 1969, these functions were transferred to the new Department of Communications.

5.1 Ionospheric sounding

Alouette-I, Alouette-II, and ISIS-I topside sounders continue to operate. A variety of studies are carried out with the data, both in Canada and internationally since the data are available through the World Data Centres. Particular attention has been given in Canada to high latitude effects. Investigations include the high latitude trough, F-region disturbances, and the equatorial anomaly. New analysis techniques have been developed to permit derivation of extremely low electron densities from the topside sounder data.

The third satellite, ISIS-I, was launched on 30 January, 1969 and is operating successfully. Six of the 10 experiments are Canadian. The addition of an onboard tape recorder to this satellite permits the acquisition of data on a much greater geographical scale.

ISIS-II was launched successfully on 31 March, 1971.

Partial reflection sounders for the D-region using 2.66 MHz transmitters have been in operation at Ottawa, Churchill, and Resolute. More recently, a second frequency of 6.275 MHz has been added. These sounders permit daily monitoring of the electron density profiles from 60 to 90 km in quiet conditions and 50 to 80 km in disturbed conditions. The technique provides a very sensitive indicator of solar disturbances.

Partial reflection observations at Saskatoon are directed toward the dynamics of the high atmosphere. Investigations include the effects of magnetic activity, particle precipitation,

motions, and the detailed examination of the partial reflection mechanism.

5.2 Transmission of radio waves through the ionosphere

Radio wave absorption data are obtained from a number of riometer stations. In addition, forward scattered signals from meteor trails are employed for absorption measurement and for ionospheric wind and diffusion studies. Beacon transmitters on a number of satellites are analyzed for Faraday rotation, differential absorption, and antenna phase scintillations, to yield data on ionospheric densities, horizontal structure, absorption, and travelling waves. Similarly, beacon transmitters have been ejected from rockets at Churchill to measure auroral ionization and absorption at E-region heights.

5.3 Direct measurements of the ionosphere

In the interval 1967-70, 45 rockets were flown from Churchill by which direct ionospheric measurements were made using Langmuir probes and retarding potential analyzers. These measurements were made in auroral and in quiet ionospheric conditions, and have yeilded high resolution values of electron density, electron temperature, and ionization macro- and micro-structure. Other experiments have measured soft electron fluxes and the fluxes of high energy ionizing particles. Spin stabilized ejected probes have been released from rockets to measure the electric and magnetic fields in the ionosphere.

In addition to Churchill launches, six rocket experiments have been flow from Resolute, in the region of the north magnetic pole, to obtain electron densities by Langmuir probe and radio propagation techniques.

5.4 Radio wave scatter measurements

VHF auroral radars have been operated on a continuous basis for auroral backscatter studies at Ottawa, Thompson, Churchill, and Great Whale. VHF continuous wave bistatic experiments between Ottawa and London, Ontario, have also been used for similar purposes. Positive evidence has been obtained of scatter from ion acoustic waves in aurora, and other mechanisms appear to be present also. The polarization and fading characteristics of backscatter have been examined in detail from Saskatoon. Measurements of radio aurora at UHF were made at the Prince Albert Radar Laboratory, but this installation was closed in 1967.

Incoherent scatter measurements were made at Prince Albert, and more recently Arecibo radar data has been used to obtain ionospheric composition and temperatures.

5.5 Radio noise

Broad-band VLF and swept-frequency LF and HF receivers in the Alouette and ISIS satellites are used to study various noise emissions. Latitudinal and diurnal analyses of 200 KHz whistler-mode signals have shown a correlation with parts of the auroral oval and with the energetic electron fluxes detected on the satellite. Radio noise measurements on rockets launched from Churchill have been made in conjunction with energetic particle detectors. The antennas used for these experiments show interesting impedance variations and amplitude and harmonic modulation of the noise signals which are dependent on the $V \times B$ potential generated.

5.6 The 1970 total solar eclipse

Four rockets were flown from East Quoddy, Nova Scotia, in the path of totality of the 1970 solar eclipse on 7 March. The rockets carried Langmuir probe experiments and a 2.66 MHz radio receiver for electron density measurements in the D and E-regions. Lyman-α and X-ray experiments were provided by the R.S.R.S. (Slough) for the determination of the primary ionizing radiation levels. A 2.66 MHz ground-based partial reflection sounder was installed at the launch site to monitor the D-region electron density variations. A control measurement was obtained by the continuous operation of the 2.66 MHz partial reflection sounder at Ottawa where the eclipse was partial.

6. Laboratory studies

A well attended "Symposium on Laboratory Measurements of Aeronomic Interest" was held at York University in September 1968 under IAGA sponsorship.

The measurement of absolute band strengths using the methods of emission and absorption spectroscopy as well as the interferometric hook method has continued, principally at York University. Absolute band strengths are now available for selected band systems of NO, O_2, CO, SO_2 and NO_2. An extensive recalculation of Franck-Condon factors of over 100 important diatomic molecular band systems including all those of aeronomic importance has been made using realistic potential functions derived from experimental wavelengths. Theoretical studies relating to the factors important in the computation of molecular band intensities continues.

A considerable amount of laboratory work has concerned the problems related to the production and removal of the excited singlet states of atomic and molecular oxygen. Rate constants for the collisional deactivation of O_2 ($^1\Delta$) by N_2, O_2, O_3, N_2O, CO_2, H_2O and Ar have been obtained and the temperature dependence of the deactivation by O_2 and O_3 measured. It has been shown that the photolysis of O_3 at 2537 Å yields O_2 ($^1\Delta$) but not O_2 ($^1\Sigma$) whereas energy transfer from $O(^1D)$ leads to $O_2(^1\Sigma)$ but not $O_2(^1\Delta)$. The results show that the quantum efficiency of $O_2(^1\Sigma)$ formation from $O(^1D)$ is greater than 60 per cent and, further, that it is approximately equal to the quantum efficiency of $O_2(^1\Delta)$ formation in the photolysis of ozone. The relative rates of destruction of $O(^1D)$ in O_2, N_2, O_3 and H_2O were measured.

At the R.C.A. Limited Research Laboratories work of aeronomic interest has included theoretical studies on wave-plasma interactions with a major emphasis on the ionosphere, and on antennas; experimental work on electromagnetic wave propagation in plasmas, with the source exterior, and within (antennas) the plasma; and experiments with flowing plasma used for simulation studies.

In the simulation studies the interaction of a flowing plasma with a magnetic dipole to simulate the boundary region

between the earth's magnetosphere and the solar wind produced a boundary width less than, or comparable to, an ion gyro radius. It appears that the large scale features of the boundary can be simulated, but details such as a separate detached shock were not observed. The simulation of spacecraft-environment interactions using a plasma flow provided information that was successfully applied to the Alouette II and ISIS A spacecraft.

The experimental work carried out with electromagnetic waves in plasmas includes the reflection of circularly polarized waves from a plasma, antenna radiation properties at arbitrary angles of incidence, strong field interactions where nonlinear effects become evident, and the radar return from turbulent media.

There has been a continuing effort in the study of antennas in plasmas. A large, uniform, anisotropic plasma has been used to study antenna problems such as impedance, for antennas (short, long and loops) under various plasma conditions. A steady theoretical effort has been maintained on wave-plasma interactions, and on spacecraft-plasma interactions.

7. Magnetospheric disturbances

A number of studies are being carried out on magnetospheric dynamics that are based on a detailed examination of substorm data. While much of this involves magnetic data, energetic particles, aurora and other data are also being studied in close association with substorms and a number of equipment developments have been made to facilitate the gathering of better data.

At the National Research Council of Canada studies have continued of the energetic particle fluxes, based on data from the Alouette and ISIS satellites as well as from several rocket flights. The high latitude flux of electrons and protons in association with substorms has been investigated, in relation to the fluxes in the magnetotail and with regard to acceleration mechanisms. Studies of alpha particles have also been made in order to obtain evidence for a direct entry of solar wind particles. Data have also been studied for direct neutral point entry and neutral point acceleration mechanisms.

The study of ionospheric absorption during substorms has continued at the Communications Research Centre (formerly the Defence Research Telecommunications Establishment) in order to determine the scale and morphology of particle precipitation, and thus the magnetospheric scale of the substorm.

At the Churchill Research Range studies have been made of the auroral electrojet behaviour during substorms using a network of four magnetometers.

At the University of Calgary research is continuing into the characteristics of X-rays, detected with balloon-borne equipment, that are generated during magnetospheric substorm activity, and into their relationship to the aurora and other features of the substorm.

At the University of Alberta digital recording systems have been built for use in recording magnetic data at frequencies up to 0.3 Hz with a sensitivity of $\pm 1\gamma$ over the range $\pm 1000\gamma$. A line of fluxgate magnetometers with such digital recording systems was set up along the geomagnetic meridian from Calgary to Cambridge Bay. The data have been used to study the dependence of P_c micropulsations on latitude, and the results appear consistent with an origin in the Kelvin-Helmholtz instability at the magnetospheric boundary. The data have also been used in a detailed study of magnetic substorms, including such features as the intensification of the southern border of the electrojet, the quasi-periodic bursts of activity at the northern border, multi-current systems, and the broad eastward electrojet in the post-noon sector. In another study using an array of 42 magnetometers, the phase of the D-component was investigated during a substorm and related to the westward travelling surge. A co-operative study with the Royal Institute of Technology, Sweden, has been made on three-dimensional model current systems, and another with the University of Saskatchewan has been undertaken on electric and magnetic field data from a rocket launch into an auroral breakup. Satellite (IMP-1, -2, and -3) magnetometer data have been studied for dynamic effects in the magnetotail during substorms that can be related to distinct phases of the substorm.

Studies have been carried out on the use of hydromagnetic whistlers as a diagnostic tool in the study of the ambient magnetospheric plasma, and densities have been estimated using both cold and warm plasma approximations. Pcl micropulsation characteristics have been studied, and theoretical investigations are underway of wave-particle and wave-wave interactions.

At the University of British Columbia studies are going on of various geomagnetic phenomena. A theoretical investigation of the magnetodynamic approximation for waves in the magnetosphere was carried out, as was an analysis of plasma waves propagating across a steep density gradient. In a collaborative study with the University of California, the relationship between magnetotail field perturbations and Pi micropulsations was studied.

At the Department of Energy, Mines and Resources research into long period micropulsations has been carried out, and Pc3 activity was shown to be strongly correlated with Kp while Pc4 activity was poorly correlated with Kp. A study of the polar electrojet is underway with reference to conditions during substorms.

At Victoria Magnetic Observatory a new micropulsation recording system has been developed using air-core induction coils which produces accurately calibrated data for frequencies up to 10 Hz.

At the University of Saskatchewan rocket released probes have been developed to measure electric and magnetic fields in the ionosphere, and digital recording systems are being built for magnetometer studies.

8. Meteors

The major centres for meteor research are at the National Research Council of Canada, Ottawa, through its Upper Atmosphere Research Section and Springhill Meteor Obser-

vatory, and at London, the Centre for Radio Science of the University of Western Ontario. Research which was formerly carried out at the Dominion Observatory and its field stations is now under the auspices of the National Research Council of Canada.

The continuing program of the spectrographic and radio recording of meteors has been supplemented by photo-electric techniques, particularly through the use of television-type systems and image-intensifier devices. Some cases of individual fireballs were studied and meteoroid orbits examined. The Leonid meteor shower has been studied in some detail since several strong returns have occurred in the past decade. A network of cameras covering 7 x 10^5 square kilometres has been established on the Canadian prairies to patrol the skies for bright meteors. Photographic records will be used to study the influx of these objects and to provide data for rapid recovery of meteorite falls.

The determination of meteoroid mass distribution from radio measurements yielded a discrepancy in results obtained at London by forward-scatter equipment and at Ottawa by back-scatter techniques. Continuous-wave forward-scatter systems have also been used to measure meteor ionization profiles to clarify the ablation and ionization processes in the atmosphere. The effects of upper atmosphere winds on meteor trails have been investigated. Conversely, radar data on meteors have been used to measure winds and to study ionospheric absorption. Concomitant theoretical studies have been carried out.

Various models of micrometeoroid detectors were flown on 17 rockets to determine the flux and distribution of these particles in the upper atmosphere. Two of the payloads, flown during the Geminid meteor shower, included different types of detectors supplied by a number of scientists from other countries.

9. Sun–Earth relations and magnetospheric physics

During late 1969, the University of Alberta, Edmonton and the University of California, Berkeley, had a co-operative study of magnetospheric electric fields; the former provided ground based magnetometer data at a number of launch sites, while the latter were responsible for the balloons equipped with electric field probes.

The University of Alberta is also studying perturbations in the magnetotail associated with polar magnetic substorms. The analysis of magnetic field data from IMP-1 and IMP-2 in the magnetotail suggests a relaxation of sections of magnetotail to a more dipole configuration. There is strong evidence for a magnetotail geometry during substorms which is consistent with magnetic field merging at an X-type neutral point. A joint study of the VELA satellite energetic particle data by University of Alberta and the Los Alamos Scientific Laboratory (University of California) is underway.

A study of the magnetic data from IMP-3 when inside the magnetotail, has shown that there is a thick sheet of magnetic field depression surrounding the neutral sheet and that low frequency magnetodynamic noise appears to propagate preferentially along the magnetic lines of force in the magnetotail.

A study of the relationship between fluctuations in the interplanetary magnetic field and geomagnetic activity has shown that the strength of the geomagnetic activity is a function of the direction of the interplanetary magnetic field in the ecliptic plane; being higher when the interplanetary field is directed away from the sun than when it points towards it.

Hydromagnetic whistlers have been used as a diagnostic tool to determine plasma parameters in the ambient magnetospheric plasma. During a study of the propagation characteristics of ion cyclotron waves in a warm plasma it has been found that the temperature of the plasma is an important variable when the frequency of the hydromagnetic whistler is close to the ion gyro frequency. Plasma densities estimated using the cold plasma approximation are approximately 10-20 per cent lower than those obtained for a warm plasma when the ratio of the thermal velocity of the protons to the Alfven velocity is 0.1.

Theoretical studies at the University of Calgary are concerned with the mechanism and a detailed model of the heating of the outer layers of the sun by shock waves. The study leads to the production of the solar wind in the same formalism. Theoretical work is currently in progress to investigate hydro-magnetic oscillations of the magnetospheric tail to examine possible effects on wave propagation, geomagnetic pulsations, convection and particle precipitation.

The study of Solar Terrestrial Relationships including the problem of the region of modulation of Cosmic Ray variations has led into the quest of solar planetary relationships. The collaborative studies of Calgary and NASA-Goddard Space Flight Center (High Energy Astrophysics Division) have shown solar cycle variation in (a) the intensity of the Great Red Spot of Jupiter and (b) the luminosities of the planets Jupiter, Saturn, Uranus and Neptune. Thus there is direct indication of the observation of solar cycle variation up to 30 AU. The changes in the luminosities are attributed to the EUV from the sun.

The University of Calgary and the Applied Physics Laboratory/Johns Hopkins University, Maryland, USA have completed a study of the differential energy spectra of trapped low energy protons (0.3 to 1.8 Mev) using a year's data of Iowa Satellite Injun V. The study reveals the existence of a quasi-persistent peak in the differential spectrum in the L range 2.0 to 2.6 and the energy range of $\sim$0.38 to 0.72 Mev. The study is also concerned with changes in spectra correlated with geomagnetic activity, and also adds to the general body of evidence favouring diffusion from the solar wind as the primary mechanism for populating the radiation belts.

The Division of Physics, NRC, Ottawa has made use of data from the Alouette II satellite to carry out further studies of the entry of solar particles into the inner part of the earth's magnetosphere. Latitude profiles of solar protons and electrons have been studied and compared with recent cut-off rigidity calculations and with the location of the high latitude boundary of 35 keV outer zone electrons. It has been found

that the latitude knee for solar electrons lies 5° to 8° above the knee for low energy (∿ 1 Mev) solar protons and that the location of the electron knee agrees approximately with the 35 keV outer zone boundary. The measurements indicate that a field model could be chosen to give agreement between trajectory calculations and measured knee latitudes for 100 Mev solar protons and 35 keV solar electrons but that lower energy protons penetrate more deeply into the magnetic field than can be accounted for on the basis of these calculations. In some cases intensity changes, not associated with the knee latitude, occur in the lower energy proton distributions at latitudes which coincide approximately with the calculated cut-offs.

Data processing for the ISIS-I satellite has started and some initial studies have begun. ISIS-II was launched on March 31, 1971.

At York University theoretical studies of the effects of superimposed electric fields on particle precipitation into the magnetosphere have been made.

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