Danish Arctic Ionosphere Research

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HISTORICAL BACKGROUND

The Danish Meteorological Institute celebrated its centennial on 1 April this year and on the same date the Ionosphere Laboratory, a division under the Meteorological Institute, observed its tenth anniversary, although its history goes back almost twenty years.

The idea of establishing an Ionosphere Laboratory was first conceived by the active and foresighted Professor P. O. Pedersen who in his book entitled "The Propagation of Radio Waves Along the Surface of the Earth and in the Atmosphere" (1927) presented the theory of the physical properties of the ionosphere based upon a knowledge of the propagation of radio waves at different frequencies.

During the Second Polar Year 1932-33 Pedersen wanted to build an ionosphere station in Godhavn (see Fig. 1) but it was not until 1951 that his wish was fulfilled by his assistant and later successor, Professor Jørgen Rybner. The year before, the U.S. Department of Commerce's National Bureau of Standards had established an ionosphere station at the American military base in southern Greenland and in 1957 when the U.S. Armed Forces left what is now called Narssarssuaq, Professor Rybner also undertook the responsibility for this station in his capacity as the Chairman of the Danish National Committee of the International Radio Union (URSI).

It was realized that operation of the Greenlandic stations would only be feasible if there were an active group in Copenhagen to analyze the ionosphere data obtained and to train the station personnel before leaving for Greenland. To fill this need Professor Rybner founded a laboratory at the Technical University based upon support from local URSI funds. At the same time rapid technological development made possible measurements in the ionosphere with instruments launched with rockets or from satellites. Using the resources at the new laboratory, Professor Rybner in 1961 accepted a Norwegian proposal for a joint campaign with rocket launchings from Andøya in Lofoten, Norway, in cooperation with the National Aeronautics and Space Administration (NASA). This project formed the basis later for a Greenlandic ionosphere rocket program.

Because of this and other developments in connection with Denmark's "space research" program it was deemed desirable to change the laboratory supported under the Danish URSI Committee to an official laboratory under the Technical University of Denmark. Thanks to Professor Rybner's efforts, on 1 April 1962 the Ionosphere Laboratory was established at the University, where it is still

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Frontispiece: *Stratosphere balloon. See "Danish Arctic Ionosphere Research" p. 258.*

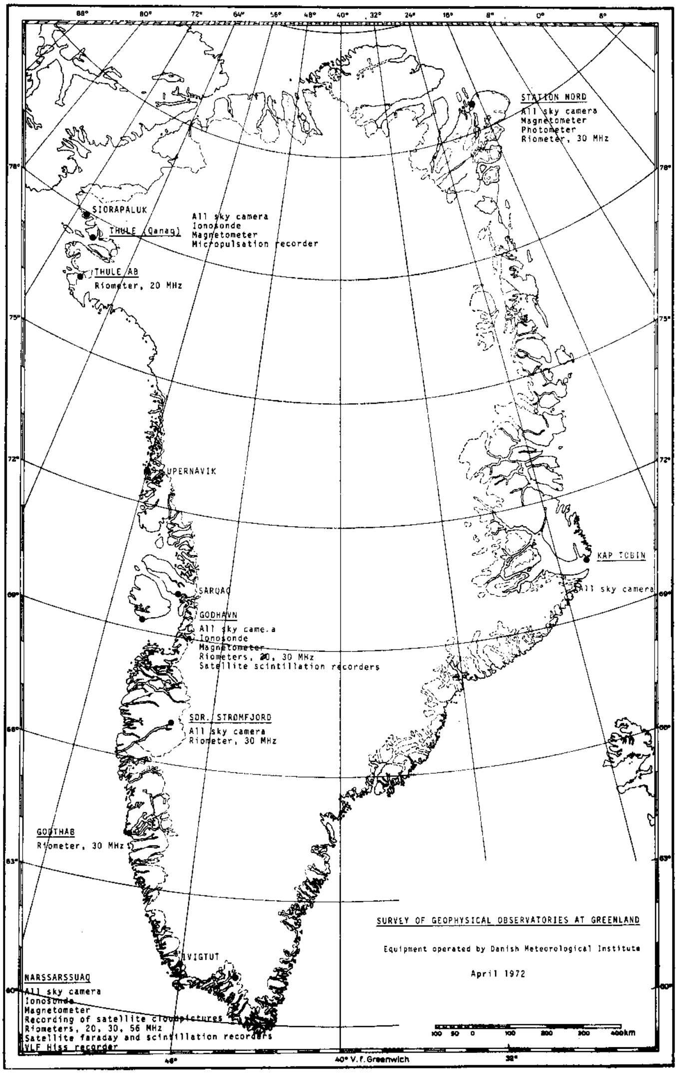

FIG. 1. Map showing Greenlandic observatories.

housed although it is now administered and financed by the Meteorological Institute.

Recordings of naturally generated electromagnetic noise at very low frequencies (VLF recordings), and studies had been made at Godhavn and Narssarssuaq for some years when, in 1964, a "VLF-station" was established at the Danish site Thule, approximately 80 miles north of Thule Air Base. Financial support was given by the U.S. National Science Foundation (NSF) and locally by the U.S. Army Research Support Group (USARSG). When in 1966 the American scientific camp situated approximately 16 miles east of Thule AB was closed down, the U.S. ionosphere station there was transferred to the Danish station at Thule; an ionosonde was made available from the U.S.A. and a building of 150 sq.m. was moved from the camp to the station by helicopter! The U.S. National Science

Foundation supported the operation for the following three years until the Danish Government took over financial responsibility.

Between 1966 and 1968 the Ionosphere Laboratory was reorganized involving among other administrative changes the establishment of an independent Danish Space Research Institute for work with balloons, rockets and satellites. Today, ten years after it was officially established with a staff of four, the Laboratory with a staff of twenty, is continuing its ionospheric research based largely upon the operations of the Greenlandic observatories at Godhavn, Narssarssuaq, and Thule. Although it is administered and financed by the Danish Meteorological Institute, it is still located at the Technical University north of Copenhagen, and maintains close cooperation with other laboratories at the University in teaching and providing guidance to graduate students.

THE RESEARCH

In the auroral zone as well as in the polar cap region the ionospheric condition is complex, and our Greenlandic stations cover the area from the geomagnetic pole near Thule to Narssarssuaq in the northern part of the auroral zone.

Ground-Based Measurements

Today the three ionosphere stations are part of the three geophysical observatories, operated by the Danish Meteorological Institute at Narssarssuaq, Godhavn and Thule. At these observatories a series of long-range as well as special recordings of important ionospheric parameters are conducted.

Vertical Soundings

The most important ionospheric recordings at the Greenlandic stations are the vertical soundings which utilize the radio wave reflecting properties of the ionosphere to give information about the plasma frequency, which is related to the electron density, versus time delay which is related to the virtual height. The equipment used, an ionosonde, is a pulsed radar in which the transmitting frequency is varied over a frequency range from 0.25 to 20 MHz.

The echo of the vertically-directed part of the transmitted signals is usually recorded on an oscilloscope and then again on a 35 mm. film. The record, an ionogram, is usually taken automatically every 15 minutes day and night.

The ionograms are scaled at each station every day, and the many characteristics which are digitized from the ionograms are presented in a graphic format called an f-plot, covering a 24-hour period. Based upon the f-plot and the hourly values a daily telegram is sent to radio propagation forecast centres at Colorado Springs and at Boulder, Colorado, U.S.A.

At the forecast centres the Greenlandic data among others are used as the basis for forecasting for HF radio communication. Ionosphere data from Narssarssuaq and Godhavn covering a 15-year period are presented by Olesen and Taagholt (1968). These data show the well-known feature that although the photo-ionization in the F-region should be rather limited during the polar night, fairly high electron densities are seen during the winter months.

In the arctic region periods with high absorption of radio waves occur frequently. Such "black out" periods result from unstable conditions in the outer part of the magnetosphere resulting in enhanced ultraviolet X-ray or charged particle radiation responsible for ionization, and the absorption is caused by the unusually high electron density in the lower D-region at altitudes of from 60 to 90 km. with the result that the electrons responding to the electromagnetic waves collide with and transfer energy to the ionized particles.

During black out no reflections at all are observed by the ionosonde owing to the high absorption; this means that no information can be gathered about the electron density profile or the level of absorption at a time when the information would be of most interest.

Cosmic Noise Absorption Measurements

By means of sensitive calibrated radio receiver the intensity of the incident cosmic electromagnetic noise received by a vertical antenna at a single frequency

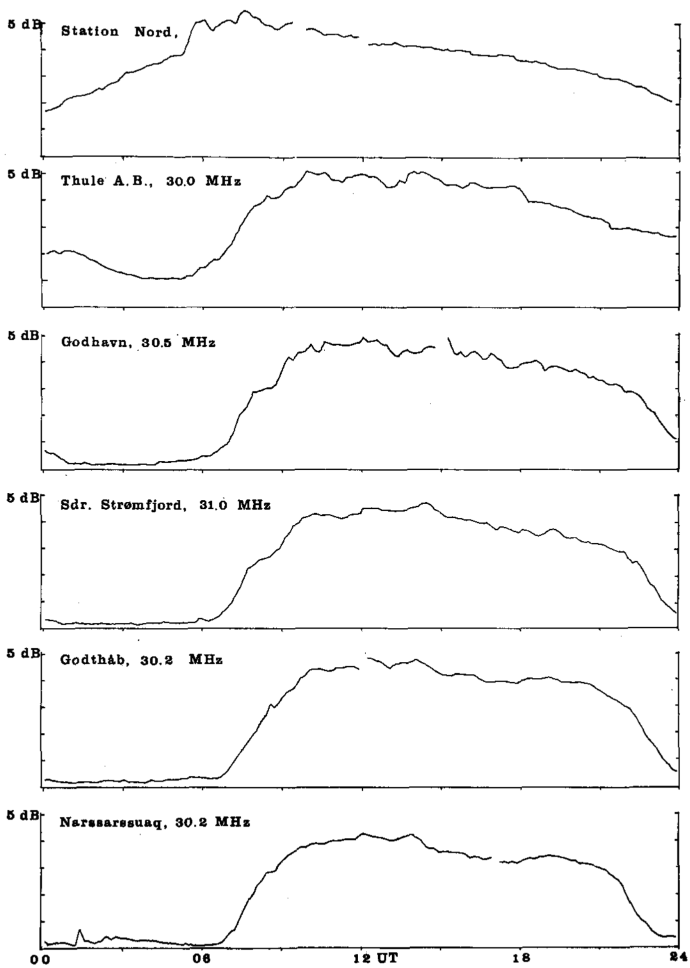

FIG. 2. Cosmic noise absorption from PCA event 2 September 1971.

can be recorded. The measured cosmic noise is a "white" noise generated by a great number of random-distributed radio galaxies. The source intensity is a function of sidereal time only, and the recorded intensity would thus repeat itself each sidereal day if the ionospheric attenuation was absent. Actual recordings below the undisturbed level (the "Quiet Day Curve") are indication of ionospheric radio wave absorption (Fig. 2).

With a riometer (Relative Ionospheric Opacity Meter), absorption is recorded at a single frequency. As described by Peter Stauning (1970a), a group at the Ionosphere Laboratory under his leadership has designed a quite new riometer system: Ionlab Riometer Model II.

During recent years the Ionosphere Laboratory has built up a chain of riometer stations as shown in Fig. 1. Spangslev and Christensen (1971) have shown that the absorption at Greenland has no clear diurnal variation, and that the resulting occurrence of absorption events is a complicated function of time of day and year combined with more random absorption caused by different radiation, which produces an appreciable change of the lower part of the electron density profile.

In a series of reports (Stauning 1971a,b, 1972; Taagholt 1971; Neble Jensen and Taagholt 1972), riometer data of polar ionospheric absorption are presented. During the summer of 1972 the Ionosphere Laboratory set up 3 new riometers on the Greenlandic east coast, under the management of Stauning, in order to obtain an optimum background for the goal: to investigate the dynamical behaviour of high latitude absorption events particularly the expansion and drift of auroral latitude substorms into the auroral oval and solar cap regions. Fig. 3 shows massplots of riometer recordings from a transauroral observatory (Godhavn) and an auroral observatory (Narssarssuaq) showing the strong variations in auroral absorption.

Whistler and VLF Emissions

Since 1957 the Ionosphere Laboratory has been involved in VLF observations at the island Saltholm near Copenhagen and at various sites in Greenland, mainly at Godhavn, Narssarssuaq and Thule, but also for shorter periods at Ivigtut, Godthåb, Sarqaq, Upernavik, Siorapaluk and Station Nord. The equipment used is a 100 $m.^2$ untuned loop antenna oriented for minimum man made noise connected to a transistorized preamplifier, placed thermally insulated on the antenna mast. The VLF emission in the frequency range from 500 to 30,000 Hz is recorded on a tape recorder.

Naturally-generated VLF emissions not associated with lightning discharges have been recorded, together with the whistlers, among this "dawn chorus" with rising tones, which sound like a chorus of birds. Ungstrup and Jackerott (1963) have shown that the features of the chorus observed at Greenland are different from those at middle latitudes, and introduced the term "polar chorus" for this type of emission at frequencies below 1,500 Hz.

Observations of wide-band noise of the hiss type in the frequency range 4-9 KHz have been presented by Stockflet Jørgensen (1966) who describes the morphology of the VLF hiss zones and their correlation with particle precipitation events.

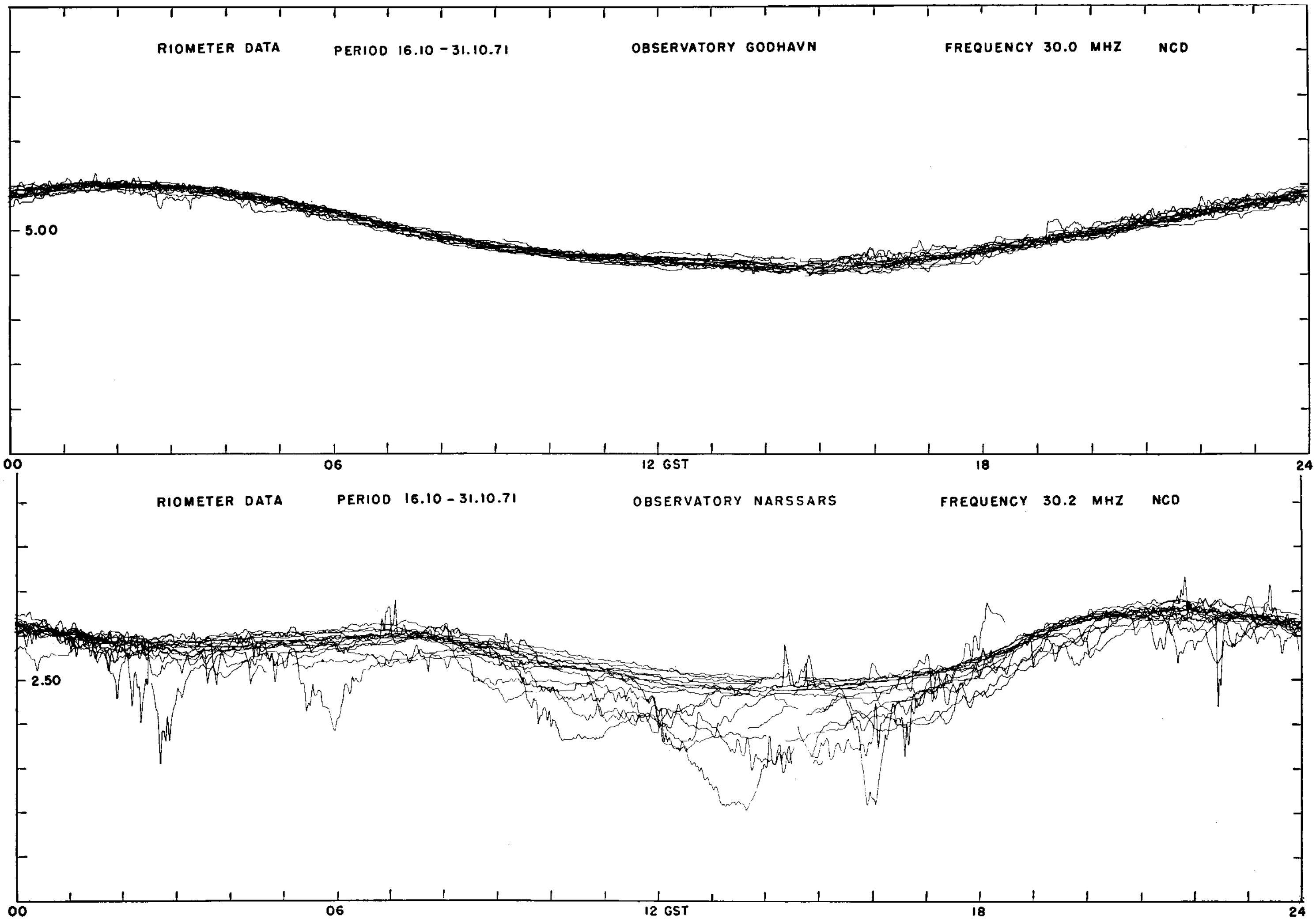

FIG. 3. Massplots of riometer recordings from a transauroral station (Godhavn), and an auroral station (Narssarssuaq) showing the strong variations in auroral absorption.

Auroral Electrojet Activity

Various types of geophysical disturbances such as geomagnetic storm and substorm activities are known to be accompanied by enhanced electric fields in the polar and auroral ionosphere.

Stauning (1970b,c,d,e) in a series of reports from the Ionosphere Laboratory presented his calculations of the auroral electrojet activity. The projects are part of a study of geophysical data to be correlated with measurements performed from different satellites, especially the European satellites ESRO I A and ESRO I B.

The auroral electrojet is a current system which develops at a height of approximately 100 km. in the polar ionosphere during various geophysical disturbances associated with solar activity. These ionospheric currents are detectable at ground level due to the induced geomagnetic disturbances — magnetic bays.

To derive a measure for auroral electrojet activity geomagnetic data are collected from a net of observatories located at different longitudes in the auroral and polar regions.

The magnetic perturbations due to ionospheric currents found by the different observations are combined in an auroral electrojet activity index, at present derived every 5 minutes during selected periods.

The Polar Ionization

Through the study of the ionosphere during the polar night, when no electromagnetic radiation from the sun can be a source of ionization, new knowledge about the particle radiation can be gathered.

In cooperation with the Norwegian Defence Research Establishment the Ionosphere Laboratory has conducted a study of physical conditions in the polar F-region. As a part of this project photometer recordings at Thule have been made at 6,300 Å for gathering information about time variation in the flux of electrons. Olesen *et al.* (1971a) concluded that the high latitude region of low energy electron precipitation expands in northward and southward directions during geomagnetically disturbed conditions.

For studies of irregularities and time variations in the polar F-layer the Ionosphere Laboratory has made recordings at Godhavn of scintillations of radio signals from satellite beacon transmitters.

A new system for measuring parameters such as power spectra and accurate scintillation indices has been discussed in a report by Spangslev (1972). The possible connections between the occurrence of regular deep fading and certain ionospheric conditions as measured by ionosondes are being investigated.

Geomagnetic Micropulsation Studies

In connection with action on the earth's magnetosphere by the solar wind and during creation of the earth's magnetic tail region, micropulsation in the geomagnetic field is generated. As described by J. K. Olesen *et al.* (1970) this pulsation has since 1966 been recorded at Thule in joint cooperation between American, Russian and Danish groups with the same electronic equipment used at the Danish Thule station and the U.S.S.R.-operated station Vostok in Antarctica which is the geomagnetic conjugate station to Thule.

The study of these recordings of the very fast variations in the magnetic field is of great value for understanding the geometry and dynamics in the magnetosphere.

The Polar Slant E Condition

Based upon the ionograms the occurrence of different types of sporadic layers has been studied. Olesen and Rybner (1958) presented their first observations of slant E_s disturbances at Godhavn seen in relation to magnetic disturbances. Olesen (1971b,c) illustrated various aspects of what he calls the polar slant E condition, SEC, which is used to identify a special disturbed state existing in the ionosphere, when high current flow in the ionospheric E-region is seen as a laguna phenomenon on the ionograms.

Stratospheric Balloon Measurements

By means of rockets or satellites only transitory recordings can be made at rather fixed locations. In order to study the time variations in the particle radiation, the Ionosphere Laboratory during 1969 and 1970 launched a series of balloons from Narssarssuaq, equipped with a scintillation crystal for measurement of X-rays and three Geiger Müller counters in a telescope arrangement for recording charged particles (see frontispiece). The balloons were tetrahedron shaped, about 30 m. high with a volume of *c*. 5,000 m.^{3} and had a net weight of *c*. 37 kg. which gave a ceiling at about 7 to 8 mb corresponding to approximately 40 km. for a period of up to 15 hours.

During 1970 a joint program between Max-Planck Institut für Aeronomie, Germany, and the Ionosphere Laboratory was organized by the Solar Particle and Radiation Monitoring Organization (SPARMO). Simultaneous balloon flights were performed from Kiruna in Sweden and Narssarssuaq for measuring auroral X-rays and for investigating the longitudinal extension of the precipitation of electrons with energies $E > 40$ KeV during magnetospheric substorms.

The results presented by Taagholt *et al.* (1972) indicate a local time dependence of the extension of electron precipitation. It extends over distances of at least 3,000 km. in the evening to midnight sector of the auroral zone. Distances of the same order are also covered in the midnight to morning sector. The precipitation is then due to two different magnetosphere processes. In the noon to afternoon sector strong precipitation was observed in Greenland but none in Scandinavia.

High Altitude Meteorological Observations

By means of traditional radiosonde balloons meteorological upper air data are daily collected up to *c*. 30 km. altitude from 6 Danish stations at Greenland and from the USAF Air Weather Service Station at Thule AB.

By means of a meteorological rocketsonde launched to an altitude of *c*. 85 km. high altitude data from about 60 km. and below can be obtained during the payload descent in parachute.

With the permission of the Danish Government meteorological rocket operations were begun from Thule on 15 July 1964. The station at Thule is operated by USAF personnel under the operational guidance of the USAF Environmental Rocket Sounding System (USAFERSS) Manager.

From the initial concept of a meteorological rocket network it was recognized that an arctic station such as Thule AB was an essential part of such a network. Thule is well within the region which is dominated at high levels by the Polar night vortex, and it is obvious that it is an important "anchor" station. In addition to its contributions to the network, Thule's geographic location provides an excellent point to investigate some of the most interesting atmospheric events which occur in the high atmosphere, i.e., rapid stratospheric warning, auroral displays, large and rapid variations in density, etc.

Some of the results obtained by US Air Weather Service can be mentioned. The uniformity of the observations taken over several years establishes a definite pattern and certifies the occurrence of rather large changes in these regions. The transition from westerlies to easterlies during the spring months, continuing through most of the summer, is to be expected; however, the continuance of the strong wind speeds throughout this period at the 56 km. level is an interesting observation which requires further investigation. An additional observation is that there are significant yearly temperature variations at the 35 and 45 km. levels (60 to 70 degrees temperature change), while the temperature changes at the 56 km. level are less extreme.

The October through November portion of the 1968 temperature curve indicates that stratospheric sudden warming did occur. Whether it started then or in November through December is a debatable point. Either case is early when reviewed against a background of stratospheric warmings generally beginning in January or February.

Ionospheric Rocket Experiment

In addition to its normal meteorological rocket launches, the US Air Weather Service has provided support to the Ionosphere Laboratory since 1967. In this support the meteorological rockets are used to launch payloads that have been modified by the Ionosphere Laboratory to include sensors to investigate Polar Cap Absorption events (Fig. 4).

The purpose of the particle experiments launched by Arcas rockets from Thule is the investigation of the time and height variations in intensities and spectra of high energy solar protons in the ionospheric D-region and below.

To obtain a clean sample of solar protons without contamination by auroral particles, the launching site, Thule, near the geomagnetic pole, is extremely well suited.

The proton energy distribution is explored in the range from about 200 KeV to 20 MeV, which is expected to include the major part of particles responsible for PCA-events.

The height profile of the proton flux is investigated at altitudes from below 30 km. to about 80 km. In this region the high energy solar protons come to rest, and here, also, the main part of the radio wave absorption takes place.

In cooperation with the Norwegian Institute for Cosmic Physics a payload carrying a photometer to measure auroral activity on 4278 Angström has been built and it is hoped will be launched during the coming dark season.

The experiment constitutes an important part of the integrated study by rocket,

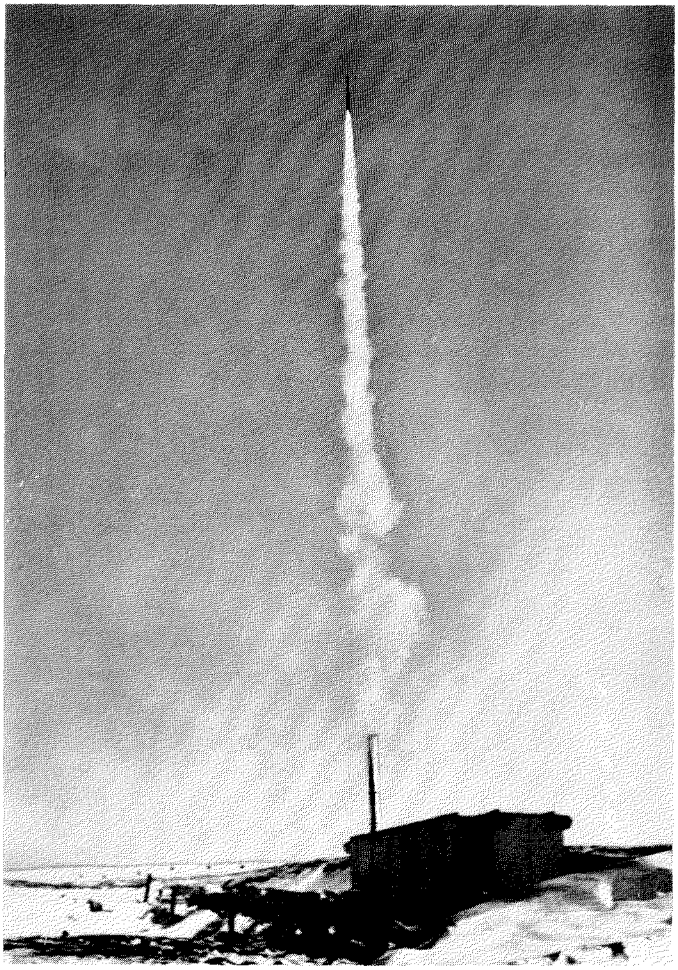

FIG. 4. Rocket launch from Thule AB.

satellite and ground based observations of the particle radiation and of the associated radio wave absorption phenomena during a Polar Cap Absorption event.

In connection with the rocket experiment, data from the polar orbiting satellite are analyzed, and the Ionosphere Laboratory additionally carries out relevant ground based ionospheric observations from a number of stations ranging from the magnetic pole down to and including the auroral zone.

Electric Field Measurements

From Danish rocket facilities at Søndre Strømfjord the Ionosphere Laboratory in cooperation with the other geophysical divisions of the Danish Meteorological Institute has started a study of the electric field in the polar ionosphere based upon barium cloud experiments during quiet geophysical conditions and during substorm conditions with rocket launch.

Assisted by the Danish Armed Forces 2 Nike-Apache were launched during 21 and 23 August 1971 at about 23^{30} local Mean Time (local magnetic midnight). At approximately 200 km. altitude 2 kg. Ba-CuO mixture was released. The barium is subject to photo-ionization by the solar ultraviolet radiation and the initially released barium gas forms visible ionclouds (Fig. 5).

FIG. 5. Barium clouds seen from Søndre Strømfjord.

The artificial clouds released during polar autumn twilight were tracked photographically with Hasselblad camera from the launch site, from Godhavn, and from the radar station Dye 2 on the Greenland ice cap.

During the experiment successful photographs of the drifting ionized clouds and of the more steady neutral clouds were obtained from at least two of the camera stations.

The coloured and black-and-white films have now been analyzed, and the positions of the clouds have been determined by means of the star pictures. Based upon a computer program a calculation of the current system corresponding to the observations is at present being performed.

POSTSCRIPT

Owing to the importance of the polar cap region and to the favourable geographic position of the Danish arctic island Greenland, the Ionosphere Laboratory feels it an obligation to continue investigations there.

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