1 Observed Results of "Alaska Project" — Developed Instrument Performance —

Comprehensive Arctic Atmosphere Observing System and Observed Results for "System Performance Demonstration"

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The "middle atmosphere", defined as the atmospheric layer at altitudes from approximately 10 to 100 km, has been stressed as a region important in global environment and climate change studies; importance is also stressed on the Arctic region where the global warming is predicted to appear most predominantly. The "Alaska Project", an international joint research project with National Institute of Information and Communications Technology (NICT) and Geophysical Institute of University of Alaska Fairbanks, developed radio/optical technology and instruments which are effective for global environment and related atmospheric/space science studies. Project overview and results are shown the article.

Keywords
Global Environment, Arctic region, Middle atmosphere, Upper atmosphere, International cooperative research

1 Introduction

The effects of global environmental changes are enhanced in the regions around the North and South Poles, as seen in the phenomena of ozone holes and global warming. The problems like ozone holes for example, highlights the extent to which the conditions in the atmosphere of the distant, upper skies are key to understanding global environmental issues. The atmosphere at altitudes of 10 to 100 km from the ground is referred to as the "middle atmosphere", and the ozone layer is present within this region, which is also considered to be particularly sensitive to the effects of global warming.

Much remains to be resolved with respect to individual mechanisms associated with environmental changes. However, if we are to understand the global environment and related processes as part of a comprehensive system, data must be acquired in a multi-faceted and comprehensive manner. If we take the ozone hole as an example, the mechanism for the generation of strong air flow circulating around a pole (referred to as the "polar vortex") involves various factors such as low temperatures inside the vortex, the presence of chlorine and bromine compounds inside the vortex, fine particles in the atmosphere (aerosols) that act as catalysts in the dissociation of chemical compounds, and others. Comprehensive observation data on the middle atmosphere of the polar regions and the surrounding areas is eagerly anticipated, with a view to the elucidation of these mechanisms.

The middle atmosphere is closely related to the state of the global environment, and it is believed that the middle atmosphere is also a region sensitive to changes in the global environment at low altitudes. Furthermore, although debate is ongoing, it has long been held that changes in solar activity have a considerable impact on the middle atmosphere and influence the global environmental and climate. These environmental changes tend to appear intensified in the polar regions. Moreover, the proximity of the North Pole to densely populated and industrially active Eurasian and North American continents has raised questions on the role of human activity in environmental changes such as global climate changes and Arctic ozone holes.

A number of observations and research projects have been undertaken by world-class research institutions and groups in the Arctic regions, focusing on the importance of the polar middle atmosphere. In Northern Europe, Greenland, and Canada, projects are underway under the auspices of various European and US research groups. International efforts to promote such studies in Alaska, however, initially lagged behind these earlier initiatives. In any study of the state of the environment and the atmosphere, it is important to identify and understand regional characteristics and longitudinal differences. The participation of the National Institute of Information and Communications Technology (NICT; formerly Communications Research Laboratory) of Japan in these studies has thus received positive response from the international scientific community and from other research groups. As our group's accumulated observation data began to reach a critical mass, studies became possible involving comparison of different observation points and comprehensive analysis, in the process facilitating the establishment of a community capable of undertaking joint multilateral studies.

As stated above, the polar regions are portals for a large influx of energy from outer space, through auroras and cosmic radiation; there has been much controversy over the effect of these processes on the atmospheric environment, although academic discussions are still in progress. The Alaska Project is one of few that have approached this pioneering yet little-studied issue in a straightforward manner. In the past, the international scientific community did not consider the effects of solar activity or the space environment on terrestrial atmosphere to be worth studying, and some scientists had even openly stated their doubts as to the existence of such effects.

However, from our current vantage point 10 years since the start of the project, studies of the middle and upper atmosphere in this context have now been firmly progressing in international academic projects established by large and international academic bodies and groups. Debate continues on the degree of the effects of phenomena in these regions on global environment change, but these effects are now included in general scientific evaluations of global environmental changes, along with the effects of carbon dioxide.

In the course of these discussions on the association between the terrestrial atmosphere, solar activity, and the space environment, we have attempted to bring together various researchers in the fields of atmospheric and space science. This collaboration represents another of the innovative elements of the Alaska Project. As noted above, even while questions had been raised regarding the effects of solar activity and the space environment on the terrestrial atmosphere, there had been virtually no communication or collaboration between specialized groups in the atmospheric and space sciences. The Alaska Project promoted precisely this sort of collaboration through a variety of means, from discussions among individual researchers to participation in various academic meetings in both fields, with a view to making the most of the potential applications of each field.

The goal of the present project was to conduct R&D on a range of observation technologies for the atmospheric environment, mainly in the middle atmosphere, with a special focus on observation technologies for specific atmospheric parameters and fundamental system technologies. Interdisciplinary studies involving engineering and the atmospheric/space sciences were pursued to establish instruments and technologies and to verify their effectiveness. Below, we will introduce some of the achievements of the Alaska Project, which ended in March 2003.

2 Development of environmental measurement technologies

In the present project, a joint undertaking with the University of Alaska, Fairbanks, comprehensive measurement technologies for the atmospheric environment were developed through the application of radio and optical technologies. The developed instruments were used to collect scientific data on the phenomena associated with the atmospheric environment and environmental changes in measurement experiments conducted in the arctic region around Alaska, in order to assess the usefulness of the developed comprehensive atmospheric environmental measurement technologies. By contributing to the clarification of arctic atmospheric environmental changes and the associated processes, we had hoped to determine the scientific usefulness of the developed instruments and technologies.

NICT has a long history of studies of the practical application of radio and optical technologies, from its days as the former Radio Research Laboratory and the former Communications Research Laboratory (CRL), and we are internationally competitive in the development of multi-faceted observation technologies with respect to the above atmospheric environmental changes, particularly in R&D and application technologies for the comprehensive observation of numerous atmospheric parameters and fundamental system technologies.

The target of development in the Alaska Project was the establishment of a comprehensive measurement system capable of enduring the harsh and variable conditions anticipated in surveys in the arctic environment. It was clear from the start that a comprehensive understanding of the characteristics of the middle atmosphere in the polar regions, the targets of observation must cover a wide range of parameters, such as atmospheric dynamics (winds, temperature, etc.), chemical composition (ozone and other trace chemical compounds in the atmosphere), and plasma processes and related aurora (Fig. 1). Since it was not feasible to measure all of the above characteristics with a single sensor, we aimed at developing a comprehensive measurement system consisting of nine types of individually operated ground-based remote sensors. Observations of the various targets are divided among the sensors, which ultimately work effectively as a whole through the integration and sharing of the measured data.

In practice, in order to extract new envi-

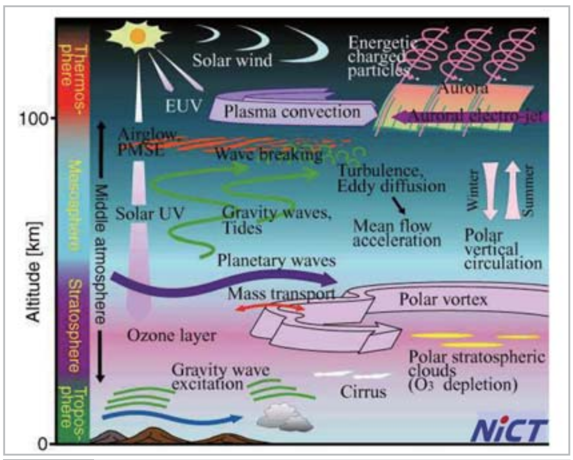

Fig. 1 Various natural phenomena in the polar middle atmosphere

ronmental information through integrating observation data of individual sensors having significantly different characteristics — e.g., different resolutions and data-processing methods — the engineering characteristics of the individual sensors and the measured atmospheric environmental characteristics must be taken into consideration in the design of the data-processing method and method of analysis in data interpretation. In the latter part of the project when the sensors began producing data, while validation tests were performed on individual sensors, the focus of the project shifted to the fine tuning of the observation system and the development of a software system for sophisticated observed data processing based on knowledge in atmospheric science (and less technique and instrument development work), and these efforts have resulted in advanced research results. The developed sensors are shown in Table 1 and Fig. 2.

3 Developed technologies, observation instruments, and validation studies

In the Alaska Project, technologies were developed for validation, comparison, and integration of the observation results provided by each of the observation sensors developed. This development took place first through validations of individual sensors, then by integrating multiple measured variables for a single sensor, and then by integrating measured variables for multiple sensors. The observation results accumulated in the process produced impressive results in our atmospheric

Table 1 *Individual sensors developed and constructed in the Alaska Project*

Instrument	Observed item	Observation altitude	Observation mode
Millimeter-wave radiometer	Atmospheric trace gases	Stratosphere, lower mesosphere (20–70 km)	Vertical profile, daytime & nighttime
FTIR spectrometer	Atmospheric trace gases	Troposphere, lower stratosphere (10–30 km)	Vertical profile, daytime
Multi-wavelength lidar	Aerosols, cloud particles	Upper troposphere, lower stratosphere (5–40 km)	Vertical profile, nighttime
Rayleigh-Doppler lidar	Wind direction, wind speed, and temperature	Stratosphere, lower mesosphere (30–80 km)	Vertical profile, nighttime
Partial reflection radar	Wind direction, and wind speed	Upper mesosphere, lower thermosphere (60–100 km)	Vertical profile, daytime & nighttime
Fabry-Perot Interferometers	Horizontal and vertical wind speed and neutral atmosphere temperature at airglow altitudes	Upper mesosphere, lower thermosphere (85, 95, and 250 km during quiet periods, and 85, 120, and 250 km during auroral disturbances)	Horizontal distribution, nighttime (during new moon)
Imaging riometer	Cosmic noise absorption (CNA) by lower ionosphere	Lower thermosphere (80–90 km)	Horizontal distribution, daytime & nighttime
SuperDARN HF radar	Wind direction and speed	Lower thermosphere (up to 80–110 km)	Vertical profile, daytime & nighttime
	Ionospheric electric fields	Middle thermosphere (up to 250 km)	Horizontal distribution, daytime & nighttime
Airglow imager	Luminous intensity of airglow layer, atmospheric wave imaging	Upper mesosphere, lower thermosphere (85, 95, and 250 km during quiet periods, and 85, 120, and 250 km during auroral disturbances)	Horizontal distribution, nighttime (during new moon)

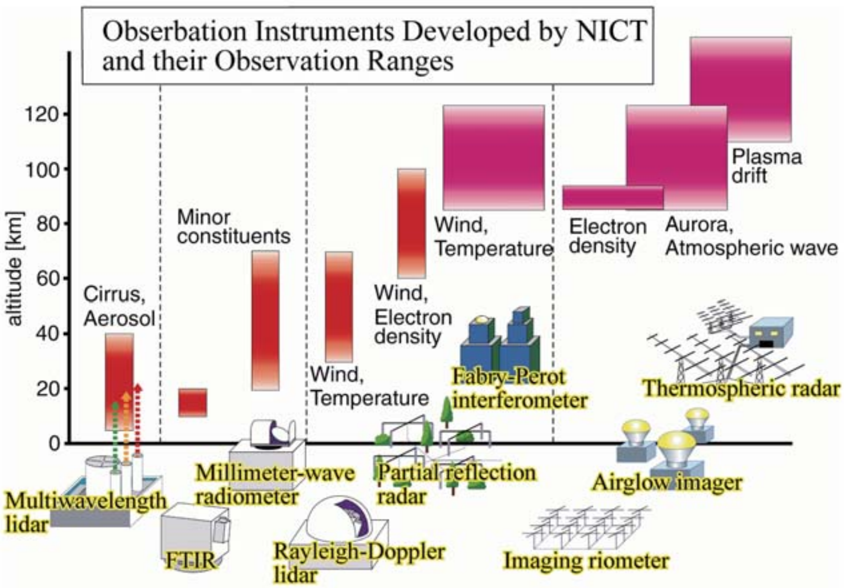

Fig.2 *Sensor groups constituting the comprehensive arctic measurement system*

and environmental studies, including progress in the understanding and sometimes new findings of atmospheric/ space sciences. Some example results are described below.

- Measurement-based validation of wind velocity and chemical substance transport

Wind velocity data at high altitudes over Alaska is important for understanding atmospheric processes and climate-change phenomena. The top panel of Fig. 3 presents east-west wind velocity data observed with a partial reflection radar; data from the ground to an altitude of approx. 50 km publicized by the UK MetOffice is complemented by our data for higher altitudes. The bottom panel in Fig. 3 shows the Arctic Oscillation index (AO index), which is considered to be a measure of climate changes in the Arctic region (Baldwin and Dunkerton, 2001). In the regions indicated in blue, AO index values are positive, in which the cold air tends to be contained over the Arctic region, resulting in warmer winters in the mid latitudes, while areas of red — corresponding to negative AO index values — tend to permit the cold air to flow out to the surrounding mid-latitude regions, resulting in colder winters. In the top panel of Fig. 3, this climate variation, which affects the entire Arctic region, is observed as large variation in wind velocity reversal over an altitude of 95 km down to the ground. These results indicate the extent to which the global environment is subject to complex mechanisms involving layers as distant as 100 km vertically from one another.

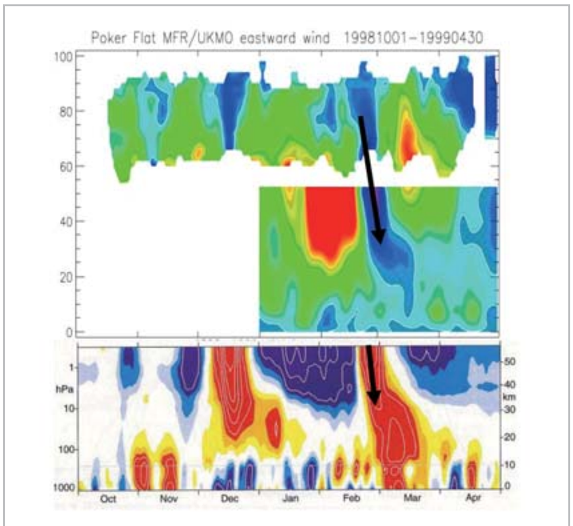

Fig.3 Zonal (east-west) wind velocities from the ground to an altitude of 100 km (top) and the Arctic Oscillation index (bottom), a measure of climate change in the Arctic region (Baldwin and Dunkerton, Science, 2001) for the period of Oct. 1998 to April 1999

Figure 4 presents the carbon monoxide (CO) concentrations in the stratosphere and mesosphere, measured for the first time anywhere from spectral analysis of ground-based Fourier Transform Infrared Spectrometer (FTIR) by Kasai et al. (*Adv. Space Res.*, 2005). It can be seen from this figure that the CO values in the high altitudes are higher in winter and lower in summer. It is known that this reduction of CO in the summertime is mainly due to photodissociation by summer sunlight. Observations carried out in Alaska in collaboration of NICT, Australian, and European groups (Jones et al., Strato-Mesospheric CO measured by a ground-based Fourier Transform Spectrometer over Poker Flat, Alaska; comparisons with Odin/ SMR and a 2-D model., *accepted by J. Geophys. Res.*, 2007) have revealed that the concentration of CO in the transient state from the winter to summer is controlled by the large-scale air circulation involving the entire Arctic region as discussed above. According to Jones et al., the variations in CO concentrations measured by infrared spectroscopy may be explained by the

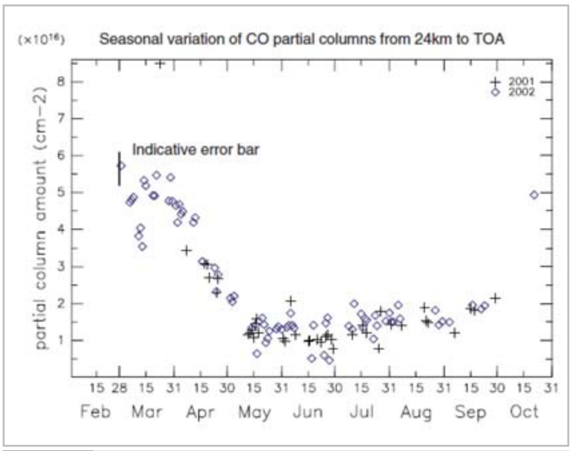

Fig.4 Amounts of mesospheric CO (carbon monoxide) and mesospheric wind velocity (FTIR and MF radar) (Kasai et al., Adv. Space Res., 2005)

intra-annual variations in the air currents measured by the partial reflection radar, and these results indicate that such instruments provide effective tools for the understanding of chemical transport processes at high altitudes.

This circulation of air currents in the middle atmosphere is believed to play an important role in small-scale transversal waves in the air (specifically known as “atmospheric gravity waves”). These atmospheric waves are generated in the lower atmosphere and transport momentum and energy of the lower layers to higher altitudes, thereby maintaining global-scale circulation due to changes in the balance of momentum.

Figures 5 and 6 show the results of atmospheric gravity wave observations by an all-sky imager installed in Alaska. The manner in which natural luminous phenomena (airglows) are affected by atmospheric gravity waves may be photographed using the imager, which is a high-sensitivity camera. Several pulsating lines may be seen in the CCD image in Fig. 5, corresponding to phenomenon caused by atmospheric gravity waves. The uppermost panel in Fig. 6 shows time-series values along the North-South line (meridian) passing through the zenith (the center of the circular image in Fig. 5), and the line-shape structures clearly propagate in the N-S direction. The second panel in Fig. 6 shows the aurora-free regions in the photographed aurora divided using numerical filters into various wave components having various horizontal wavelengths. The results show that the middle atmosphere is constantly flooded with atmospheric gravity waves, displaying a variety of wave parameters. Using such imaging data, it becomes possible to determine the direction and speed of propagation of such striations (atmospheric gravity waves), and through estimation of the momentum transport of such phenomena, it is expected to be possible in the future to clarify the effects of and relationships between momentum variations in the atmosphere and climate change and global-scale circulations.

Atmospheric gravity waves also affect the

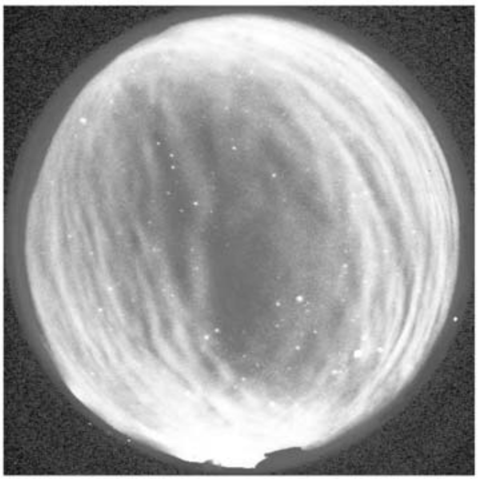

Fig.5 Imaging of the horizontal structure of atmospheric gravity waves in regions of aurora generation

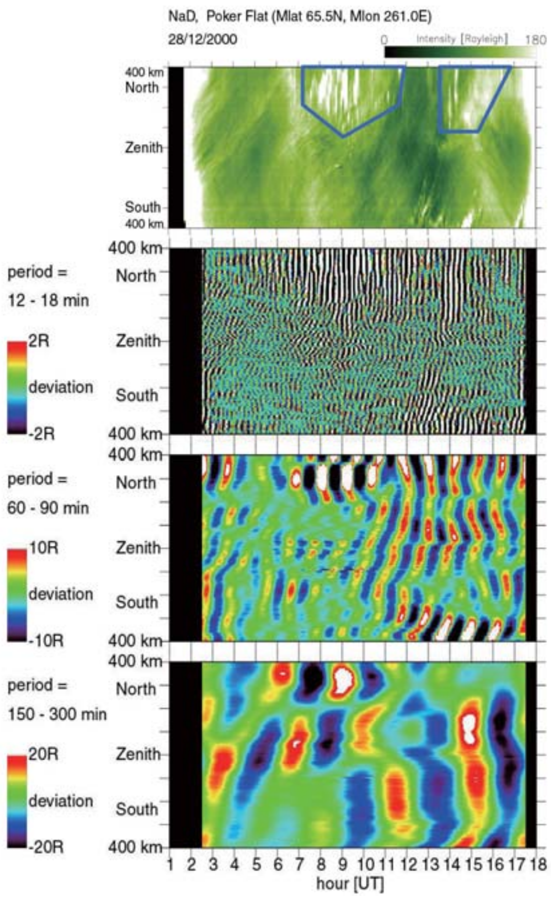

Fig.6 Observation of horizontal structure of atmospheric gravity waves in regions of aurora generation

ambient air in various ways by causing fluctuations of winds and temperature in the middle atmosphere. Figure 7 shows the fluctuating components of wind velocity and electron density observed by the partial reflection radar. In the upper part of the middle atmosphere (mesosphere), ion-chemical processes may cause significant variation of electron density. Moreover, the electron density variations observed in the observation results may be explained quantitatively by a simple ion-chemistry model and cannot be explained without ion-chemistry in a model of the lower ionosphere. The observation results in Alaska have shown the possibility, for the first time, that atmospheric gravity waves — presented as sinusoidal wave structures in the figure — do not only change the wind velocity fields but also affect the ion chemical processes through the atmospheric fluctuations. These results may in the future contribute to the understanding of the dynamical-chemical coupling processes, as well as understanding of the chemical processes in the upper parts of the middle atmosphere.

Further, it is possible to apply the developed observation system for investigation of aurora characteristics by integrating data obtained by multiple sensors. The aurora is a phenomenon in which the atmosphere in the high altitudes becomes luminous when high-energy radiation trapped by the terrestrial magnetic field is drawn into these regions, just as a neon sign lights up when an electric current is passed through the thin neon gas. It is said that an electric current on the order of 10,000 A passes through the upper skies even during a single aurora event. The influx of this large amount of energy causes the terrestrial atmosphere to become ionized and may result in certain chemical reactions taking place in this region; accordingly, auroras are accompanied by a significant increase in nitrogen oxide, which is the same gas as that discharged in automobile emissions.

In Figure 8, the energy of the aurora that triggers such changes in atmospheric environment is mapped as a two-dimensional image. This is the result of a combination of the 2-D mapping of radio signals obtained by the imaging riometer in Poker Flat, Alaska, which receives galactic radio signals (cosmic noise) in the VHF band, with the processing of images obtained by the all-sky imager. This 2-D information allows us to obtain detailed information that was previously unavailable, such as the sites within the aurora curtain structure at which high-energy particles enter the atmosphere, as well as the magnitude and manner of influx.

The continuous measurement of aurora has also led to the discovery of unexpected natural phenomenon. Figure 9 is the same figure introduced in *Nature* — an image of an aurora event that remained "stationary" over the ground for several tens of minutes. Since the relative position of the Earth and the Sun is an important determining factor in the generation of aurora, it is unusual for the same or similar features of aurora to be observed for a long period of time in the same sky over one location on the Earth. This means that the aurora is rotating with the Earth's rotation within the Earth-Sun coordinate system. Fig. 9 shows this unusual auroral event, in which the aurora is rotating approximately in tandem with the Earth, thus appearing to be nearly stationary when observed from the ground. This rare aurora has provided some useful information for space environment studies, such as the characteristics of the energetic particles

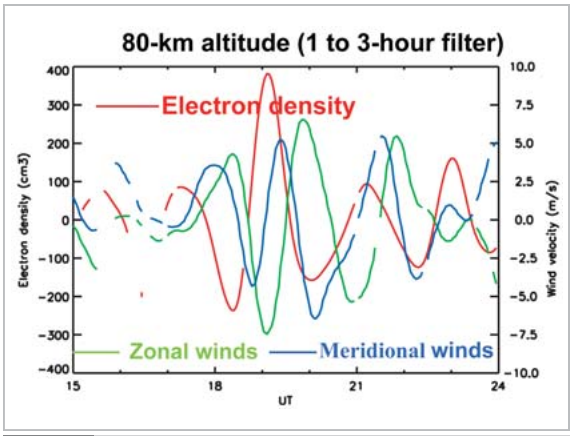

Fig.7 *Observation of an atmospheric gravity wave and ionization process in the mesosphere*

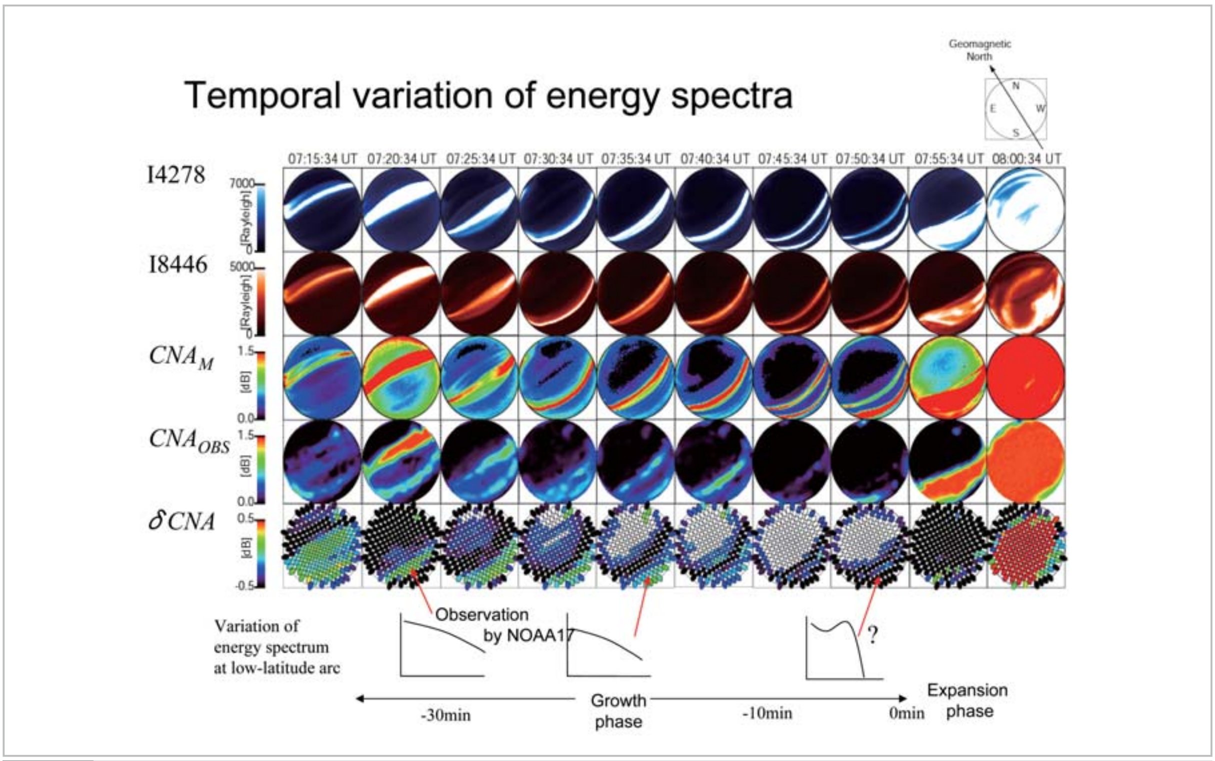

Fig.8 *Temporal variations of the spatial distribution of auroral energy in simultaneous measurements using the imaging riometer and all-sky imager*

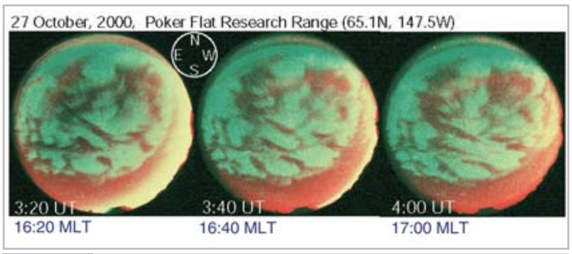

Fig.9 *Stationary aurora (or Quasi-Corotating Aurora) depicted with the all-sky imager (Kubota et al., Geophys. Res. Lett., 2003). The photos are the same as presented in Nature (Newell, Nature, 424, PP. 734-735, 2003)*

trapped by the terrestrial magnetic field and the rotation of these particles together with this magnetic field.

We have also succeeded in observing winds in regions of aurora generation with the development of an ultra-high resolution spectroscope known as the Fabry-Perot Interferometer, which allows us to calculate the Doppler shift in auroral light emissions. The scientific usefulness of such measurements may be seen in the resultant verification that the large energy influx associated with auroras cause vertical winds that may reach up to several tens of meters per second in the vicinity and at the altitude of the generated aurora, and further that the motion of the plasma flow (i.e., the ionized atmosphere) within the ionized layer (also known as the ionosphere) causes frictional drag on the terrestrial atmosphere (non-ionized atmosphere, or neutral atmosphere) (Ishii et al, this issue).

It has been postulated that ultrahigh energy protons (H^+) that are occasionally released from the Sun penetrate the terrestrial atmosphere, causing changes in the atmosphere. Figure 10 shows the relationship between the increase in solar proton volume captured by the US GOES satellite and changes in atmospheric wind velocities observed over Alaska. Although the average wind velocity fluctuations was about 10−20 m/s during the three-month period shown in the figure, this change corresponds to a nearly threefold enhancement compared to average seasonal variations under normal conditions. These results indicate the possibility that solar protons have some dynamical or chemical impact on the arctic middle atmosphere. The mechanism of this

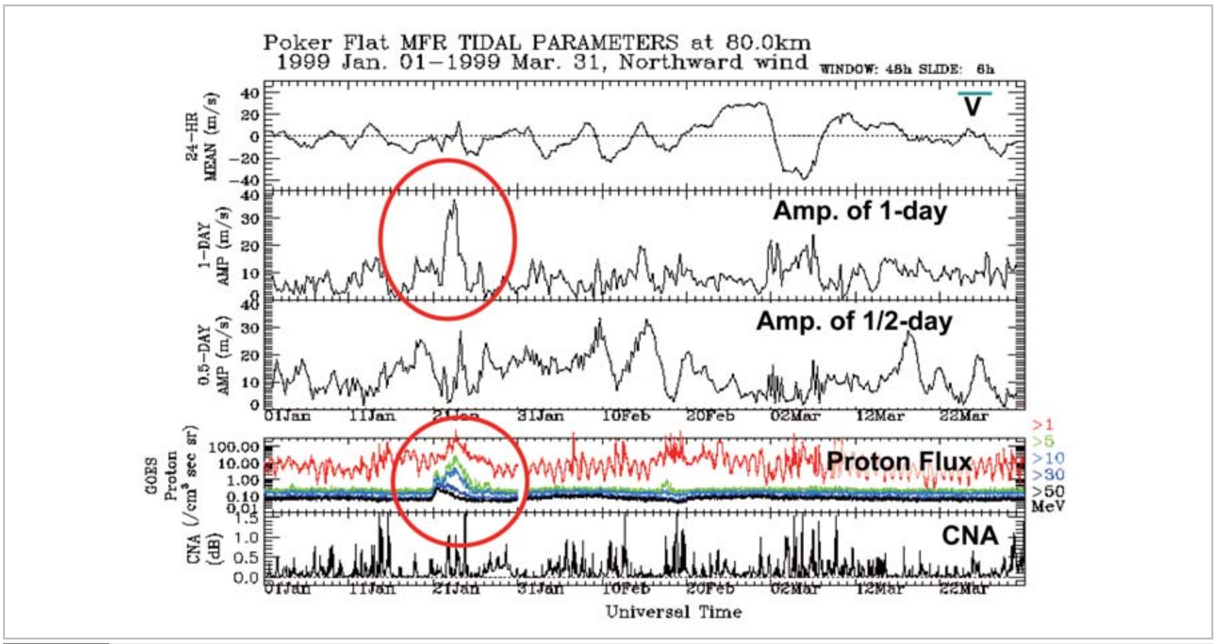

Fig.10 A solar proton event and variations in the middle atmosphere (wind measured by the Alaska partial reflection radar)

impact has yet to be resolved, but we hope that studying the changes in the chemical reactions in the atmosphere induced by solar protons will contribute to an understanding of the interactive processes involved in variations in chemical composition and in dynamic wind velocity.

4 The System for Alaska Middle atmosphere Observation Data Network (SALMON)

The instrument controls and methods of data acquisition introduced so far are presently all carried out by computers, and so the massive volumes of data continuously acquired during experiments are all digitally archived. However, it would be very difficult for this data to be fully exploited if it were to be solely maintained in groups of data files on hard disks. To overcome this problem, we have developed and are operating the “System for Alaska Middle atmosphere Observation Data Network” (SALMON), which performs automatic monitoring the instrument operation and automated browsing of the necessary data (Fig. 11).

This system also represents a computer network application experiment, and more specifically may be viewed as an application study using experimental computer network testbeds. The network is a part of the Asia Pacific Advanced Network [APAN; headquarters at KDDI Corporation, domestic participants: Keio University, the Electrotechnical Laboratory (currently AIST), the Science and Technology Agency (presently the MEXT), MAFF, NICT, etc.], an international coopera-

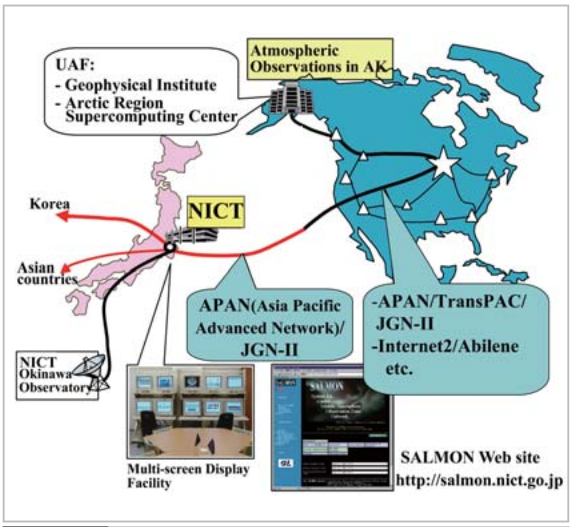

Fig.11 Overview of the network connection for System for Alaska Middle atmosphere Observation Data Network (SALMON)

tive research network. On the US side, the network is connected to networks of “next-generation Internet” research and testbed experiments such as “TransPAC/vBNS” and “Abiline”, enabling long-distance and high-speed transmission connections between experiments. The system is also the outgrowth of an attempt to promote the effective use of data through computer technologies, and provides a structure for online data distribution that may be accessed from outside organizations.

This system allows the data to be accessed readily by domestic and foreign researchers, and has contributed to greater data use on a global scale. The system also carries out automatic data processing and has eliminated the need for manual data processing, an innovation that has led to a number of new research achievements.

The system has enabled a dramatic leap in the number of academic presentations (e.g., papers), and as seen from Fig. 12, the numbers of these papers are increasing by the year. The accumulated number of papers with referee reading topped 116 in Japanese FY 2006.

We have also provided lectures on the polar environment and auroras targeting senior high school science teachers and students, including training courses in handling scientific data over the Internet, as part of the Science Partnership Program and Super Science High School program of MEXT. We have received positive responses to these activities, and we are continually receiving requests for them every year (Fig. 13).

5 Conclusions

The global environment and climate changes noted in the middle atmosphere at altitudes of 10-100 km above ground are highly important, especially in the arctic regions. On the other hand, restrictions on observational techniques for the middle atmosphere have limited our understanding of the mechanisms of such changes and process-

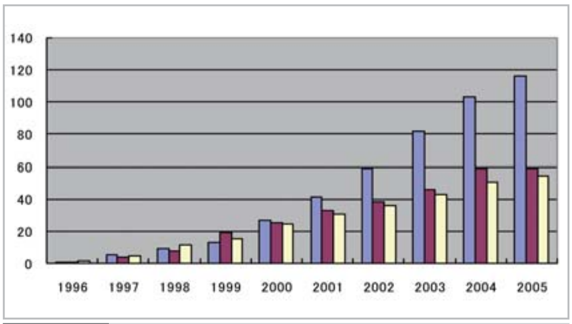

Fig.12 *Numbers of research results presented in association with the Alaska Project*

Blue, red, and white represent accumulated number of papers with peer-reviewed journal papers, unrefereed papers, and conference papers (oral and poster) (the latter indicated in tens of units), respectively.

Fig.13 *Lectures on the Polar environment and auroras carried out as induction courses for science teachers using the Internet, carried out as part of the Science Partnership Program of MEXT. Lectures are given by NICT researchers*

es. The Alaska Project was promoted as an international collaborative undertaking with the University of Alaska, Fairbanks to develop multi-faceted observation technologies that could provide tools for resolving the atmospheric environment in the arctic. In the present paper, we have presented an overview of this project, as well as introduced some of its achievements.

In order to predict the future of the global atmospheric environment, which is essentially a non-linear and complex system, it is crucial that we make progress in our understanding of atmospheric processes, as well as climate predictions, using computer simulations. However, the input from the real world that forms the basis of such simulations is also indispensable, and so measurement technologies for acquiring such information must also be developed. The highly sophisticated remote-sensing technologies now held by NICT will be a valuable asset for the Japan of tomorrow, and we hope that these technologies will continue to be useful to international society overall.

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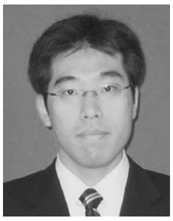

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