4-2 Imaging Riometer Database Developed in Cooperation with the University of Alaska

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To study the effects of the high-energy electron precipitations to the polar middle-atmosphere, "The CNA-auroral luminosity comparison database" is compiled in cooperation with the Geophysical Institute of the University of Alaska from the cosmic noise absorption (CNA) data obtained by the CRL's 256-element imaging riometer at Pokar Flat, Alaska and the auroral image data observed at the same place by the all-sky camera of the University of Alaska. The outside researchers can use this database with the convenient color contour plots by WWW through the Alaska data network system "SALMON".

Keywords
256-element imaging riometer, High-energy electrons, Auroral luminosity, Cosmic noise absorption, Polar middle-atmosphere

1 Introduction

As a part of a collaborative project with the Geophysical Institute, University of Alaska Fairbanks (GI/UAF), the Communications Research Laboratory (CRL) has developed a 256-element imaging riometer, together with the National Institute of Polar Research and the Solar-Terrestrial Environment Laboratory of Nagoya University. The riometer was installed at the UAF Poker Flat Research Range (geographic coordinates 65.1˚N, 147.5˚W; geomagnetic coordinates 65.4˚N, 100.2˚W) and began observation in October 1995. Observation was interrupted in August 1999 when lightning struck the facility, after 3 years and 10 months of successful observation prior to the incident.

Presently, the goals of the riometer observation are to obtain data for resolving the spatial distribution of cosmic-noise absorption (CNA) and to perform a comparative analysis with auroral morphology. To this end, a CNA/auroral-luminosity comparative database is being compiled to enable comparison with the auroral image data observed by the all-sky camera of UAF at the same temporal and spatial resolutions.

In recent years, determining the causes of, and planning countermeasures against, global environmental deterioration (such as global warming and ozone depletion) have become important international goals. To achieve these goals, it is essential to gain a sufficient understanding of the basic causal relationship between solar activity and global changes. In the polar regions, precipitation of high-energy electrons and protons in the atmosphere accompany solar activity, directly affecting the middle atmospheric regions through heating and generation of winds. Therefore, the polar regions represent important sites of observation for the study of global changes caused by solar activity. Fig.1 shows the schematic relationship between the energy of precipitating electrons and the vertical ionization rate profile for an identical energy flux in the polar regions. The numbers in the figure represent the energy of the precipitating electrons (keV). Electrons with energies of up to several keV reach altitudes above 100 km, and release energy through ionization of the atmosphere and auroral luminosity[1]. Electrons with higher energies (of several tens of keV) reach the upper middle atmosphere at altitudes below 100 km, causing ionization and heating of this region; these electrons may even have various effects on the lower layers of the atmosphere, with significant effects on the global environment. The increase in the density of electrons in this energy range at altitudes below 100 km results in the absorption of the cosmic-noise influx (cosmic-noise absorption, or "CNA"), so observation of the CNA will reveal the precipitation status of high-energy electrons on the order of several tens of keV[2]. The CRL's 256-element imaging riometer features the highest spatial resolution in the horizontal plane for CNA observation, and was developed with the purpose of performing observations at unprecedentedly high spatial resolutions.

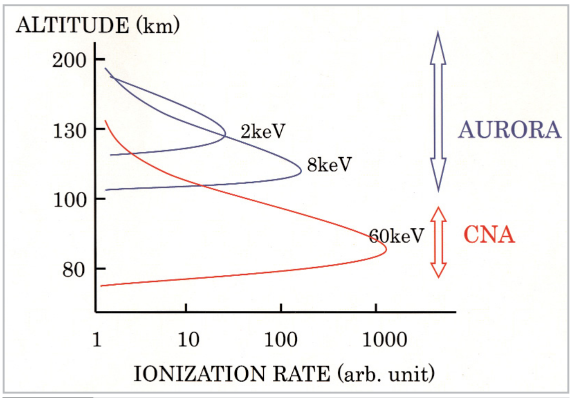

Fig. 1 *Energy of precipitating electrons and the vertical profile of ionization rates in the polar regions*

As stated previously, auroral luminosity is generated mainly by precipitation of electrons of up to several keV, while CNA is generated by electrons of several tens of keV. Therefore, by comparing the two sets of observation data, we can expect to obtain a variety of data concerning the energies of precipitating electrons and their temporal and spatial variations over a wide energy range, in addition to information on the interactions between the precipitating electrons and the atmosphere. From past observations of optical aurora, regions of high-energy electron precipitation are known to have spatial structures on a variety of scales. By using CNA data obtained with the 256-element imaging riometer at Poker Flat, it is now possible to perform comparisons between CNA and auroral luminosity at an unprecedentedly high spatial resolution of approximately 11 km (at an altitude 90 km) in the horizontal plane in the zenith direction. At present, a database comparing CNA and auroral-luminosity is being prepared as a basic reference for comparative morphological studies. This database represents the combination of our CNA image data and the UAF's auroral-luminosity data (obtained with the all-sky camera at Poker Flat during the same period) at equivalent spatial and temporal resolutions. This comparative database, containing large-volumes of numerical data, will be stored as a data file within the CRL firewall. Currently, an automatic processing and display system for the Alaskan data is being developed (the "SALMON" system[3]) to provide easy access to visual data by outside researchers via the worldwide web.

In Section 2, the specifications will be given for the 256-element imaging riometer for CNA observation and the all-sky camera for auroral luminosity observation, which will obtain the basic data for the comparative database. In Section 3, we will describe the creation process and contents of the comparative database, and display format of SALMON.

2 Observation instrumentation

2.1 The 256-Element Imaging Riometer

A riometer is an instrument that measures the cosmic noise absorption (CNA) based on electron density in the upper portion of the middle atmosphere[4]; this instrument has long been used to monitor increases in electron density due to auroral-particle precipitation in the polar region. These conventional riometers conducted wide field observation using a single receiving antenna. However, in the late 1980s, Rosenberg et al. developed the Imaging Riometer for Ionospheric Study (IRIS)[5], an instrument for conducting 2-D observations of CNA distribution, by combining a 64-element array antenna and a Butler Matrix[6]. The CRL has essentially adopted the IRIS method and improved the spatial resolution by a factor of two, and through development of new technologies (in the electronic circuitry of the receiving system, for example) it has succeeded in producing the world's first 256-element imaging riometer.

This system consists of a 256-element array antenna (designed to receive cosmic noise), the Butler Matrix (for phasing of the received signal), 16 receivers, and a computer system for system controls and data acquisition. The selected operating frequency for cosmic noise observation is 38.2 MHz within the protected frequency band for astronomical observation (37.75 - 38.25 MHz), which is sufficiently higher than the critical frequency of the ionospheric plasma and features little artificial radio noise.

The 256-element array antenna has 256 half-wavelength crossed dipole antennas arrange in a square 16×16 array with sides aligned parallel to the geomagnetic east-west and north-south directions. To prevent grating lobes, the antenna intervals are set at half-wavelength (3.92 m), and so the total antenna geometry is 61.6×61.6 m^2.

The output signals from the 256 antennas carrying information on the intensity of cosmic radiation are passed through a pre-amplifier with a gain of approximately 10 dB and sent to the 256 input terminals of the Butler Matrix. The Butler Matrix employs a combination of a hybrid coupler and a phase shifter to perform real-time phasing of input signals from each antenna to form an output signal with 6 °wide pencil-beam patterns in 256 directions. Adjacent beams have angular intervals of approximately 7 °. Since a total of 48 beams at the four corners do not properly form beams as construed by this study, we restricted observation to 208 beams within approximately 70 °of the zenith. Fig.2 is a plot of the elevation and azimuth angles of the beam directions. The asterisk in the figure indicates the direction of the magnetic zenith. The beams cover a square approximately 400×400 km on the 90-km altitude plane, and the beam intervals near the zenith are approximately 11 km.

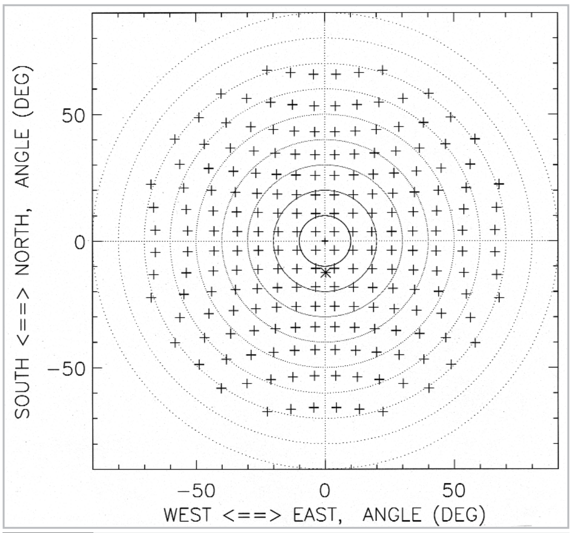

Fig.2 *Polar-coordinate distributions of beam directions for the 256-element imaging riometer*

Of the 16×16 output signals from the Butler Matrix, signals for 16 beams in one row in the N-S direction are input to 16 receivers, and after amplitude detection, they are then sent to the computer, where they are stored as 12-bit digital data via A/D conversion. These rows of beams in the N-S direction are successively switched from east to west using the beam-switching signal supplied to the Butler Matrix by the computer. The switching signals can be selected from among four frequencies: 1/16 s, 1/8 s, 1/4 s, and 1/2 s. In the case of the fastest 1/16 s signal, a single screen of 2-D distribution data of the intensity of cosmic radiation is obtained every second. Observation is normally conducted in this fastest mode.

The receiver has a built-in automatic gain control (AGC) function, and in response to commands from the computer, the "observation mode" periodically switches to the "calibration mode," which inputs noise temperature signals on eight levels, and to the "AGC mode," which adjusts the receiver amplification by inputting a constant noise temperature signal. The time constant of the receiver can be set at 10, 20, 40, or 80 ms, and the received frequency bandwidth can be set at 10, 30, 100, or 200 kHz on the computer.

This observation data is monitored in real time at the CRL via a computer network, rendering it possible to monitor the operational status of the system and to keep track of the current status of the phenomenon being observed.

To determine the CNA (in dB) from observation data, the data for a certain time period—normally about 1 month—is used to first determine the quiet—day curve (QDC) of the received radio wave intensity for each beam during this period. The decibel value of the ratio of QDC to the observed radio wave intensities [or 10 log (QDC/radio wave intensity)] is then calculated.

The above represents an outline of the system. For more details, see reference[7].

2.2 All-Sky Camera

The all-sky camera used for auroral observation at GI/UAF is equipped with a fish-eye lens with a 180° field of view and a high-sensitivity silicon-intensifier target (SIT) camera. The SIT camera has panchromatic sensitivity with a maximum near the oxygen atom's green line (557.7 nm—one of the characteristic auroral luminosity emissions) without a filter. Gamma corrections are made to its I/O characteristics to enhance the dynamic range of measurement. However, calibrations are not made for absolute luminance.

Observations are made at Poker Flat every year from September to May, and the observation data is recorded on videotape and also as 8-bit digital JPEG data files of one frame (341×243 pixels) per minute. At the UAF, a "Table of the Elevation and Azimuth Angles for Each Pixel" was created using multiple stars for each observation period for compilation of the CNA/auroral-luminosity comparative database. This table will enable precise polar coordinate determination of the observed auroral images.

3 A Comparative Database of the CNA and All-Sky Auroral Luminosity

3.1 Contents of the Comparative Database

The comparative database will be used to perform comparative analysis of the 2-D image data of CNA and auroral luminosity to study the temporal and spatial variations of high-energy electron precipitation in the polar regions accompanying solar activity and the effects of this precipitation on the polar atmosphere.

The polar atmosphere is subject to highly variable conditions both spatially and over time, and to understand these conditions, it is important to analyze individual phenomena as well as to perform statistical analyses of the phenomena over a period of time. Since optical auroral observation is affected by meteorological conditions, long-term observation data is required to ensure the validity of observation data. Therefore, out of the total period of continuous observation by the 256-element imaging riometer at Poker Flat, Alaska, the present CNA/auroral-luminosity comparative database will cover the period from January 1996 to May 1999; for this period of time, auroral data is available for observations using the all-sky camera at Poker Flat.

The CRL computer will retrieve the digital JPEG data files of the all-sky auroral observation data from the UAF via network, and a comparative database will be created by combining these files with the imaging riometer data accumulated at CRL through the process described in Section 3.2.

The obtained database will be stored as a numerical data file within the firewall of the CRL, and will not be available for use by outside researchers. However, through the use of "SALMON," the automatic processing and display system for Alaskan observation data, the database will be available for outside use in two types of simple-to-use visual formats.

3.2 Creation Process of the Comparative Database

As stated in Section 2, the CNA observation that will form the basis of the comparative database is to be conducted at time intervals of one second and a spatial resolution (beam interval) of approximately 7°. The digital files produced by auroral observation feature a time interval of 1 minute and a spatial resolution (pixel interval)of less than 1°. The comparative database will be compiled by extracting observation data taken at the same time from the two observations (albeit with different temporal and spatial resolutions), and by recompiling the extracted data to create a 2-D image data set for CNA and auroral luminosity featuring the same coverage and spatial resolution for both types of data. Therefore, the time interval of the comparative database will be that of the per-minute auroral observation, and the CNA will be calculated by selecting the comparative CNA data from the imaging riometer data (taken at one-second intervals) coinciding with the auroral data within one second. The coverage and the spatial resolution (Fig.2) will be based on the spatial resolution of the beam of the imaging riometer. The auroral data for comparison will first be converted back to the actual auroral luminance observed through the spectral response function of the camera by removing the effect of gamma correction for the SIT camera. The resulting 341×243 pixel digital data will be converted into an auroral image reconstructed as an auroral luminance distribution over the 208 beam directions of the image riometer, using the "Table of the Elevation and Azimuth Angles for Each Pixel" as a reference.

The "CNA per-minute file" and the "Reconstructed auroral luminosity image file" data created in this manner will be combined to form "The CNA/auroral-luminosity comparative database" with a time resolution of one minute (coinciding with the auroral observation time), a spatial resolution of 7°(equivalent to the beam interval of the imaging riometer), and a coverage of approximately 70° from the zenith (equivalent to the coverage of the imaging riometer).

3.3 Display Format of the Comparative Database for SALMON

The following two types of color contour plots, representing the numerical data of the CNA/auroral-luminosity comparative database, are available at the SALMON website.

(1) Time-Trend Representation

These are color contour plots of temporal variations of CNA and of the reconstructed auroral luminosity (for 16 beam directions for an east-west row and a north-south row passing through the zenith) at UT1:00-18:00. Fig.3 shows an example of a sample plot. The four panels in the figure, from top to bottom, are plots of the E-W distribution of auroral luminosity, the E-W distribution of CNA, the N-S distribution of auroral luminosity, and the N-S distribution of CNA. When the temporal variations of the phenomena are gradual, theory predicts that the square root of the auroral luminosity and the CNA will change proportionally, and so the plotted intensity of auroral luminosity is shown by the square root of auroral luminosity[8]. The plots for CNA use the data from the "CNA per-minute file" of the comparative database for the period during auroral observation, and for all other periods, the plots show the CNA calculated from continuous observation data (i.e., for every minute). Visual comparisons of data are facilitated by these color contour plots that range over 17 hours; these plots show the variations in the intensities of auroral luminosity and CNA in the E-W and N-S directions for the observation date specified by the viewer via keyboard. This method of representation proves effective when searching for certain phenomena or when attempting to understand overall trends in spatial distribution and temporal variations.

(2) Representation of the 2-D Image

These are color contour plots of the JPEG image of all-sky auroral luminosity, the auroral image reconstructed from this JPEG image, and the corresponding CNA image. Fig.4 presents examples of these plots, from left to right.

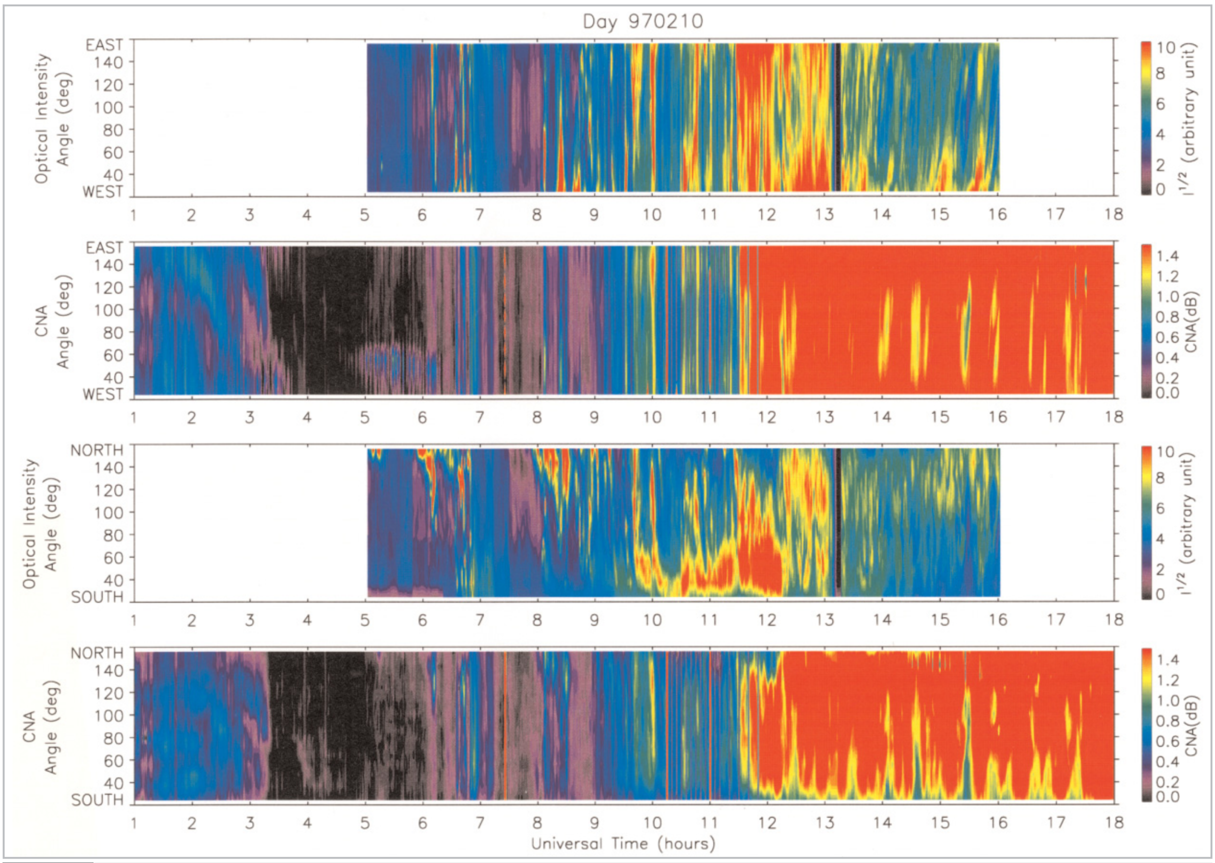

Fig.3 An example of a SALMON time-trend plot from the comparative database

The plots are aligned according to observation time, with plots for more recent data at the bottom. The JPEG images are shown in polar-coordinate plots for a range approximately 90˚ from the zenith. The other two images are polar-coordinate plots for a range 70˚ from the zenith. Here the reconstructed auroral image is shown by the square root of the relative luminance. The viewer will be asked to input via keyboard the observation date (year/month/day), starting time in UT (hour/minute), end time in UT (hour/minute), and the data interval (in minutes) of their choice to display the corresponding data from the comparative database. This method of representation will facilitate visual comparison of the 2-D luminance distribution of auroral luminosity and CNA at the highest spatial resolution currently available.

4 Conclusions

Through collaboration with the Geophysical Institute, University of Alaska Fairbanks (GI/UAF), a CNA/auroral-luminosity comparative database is being compiled using CNA observation data collected by CRL's 256-element imaging riometer installed at Poker Flat as well as auroral luminosity observation data taken by the UAF's all-sky camera. The purpose of this database is to permit the study of the effects of high-energy electron precipitation accompanying solar activity in the polar regions on atmospheric conditions, through a comparative morphological analysis of CNA and auroral luminosity. This comparative database will compile observation data from January 1996 to May 1999, using data taken at time intervals of one minute, with a coverage of approximately 70˚ from the zenith and a spatial resolution of approximately 7˚ in the polar-coordinate plots. An automatic processing and display system for Alaskan observation data (SALMON, or "System for the Alaska Middle-atmosphere Observation-data Network") currently being developed will present

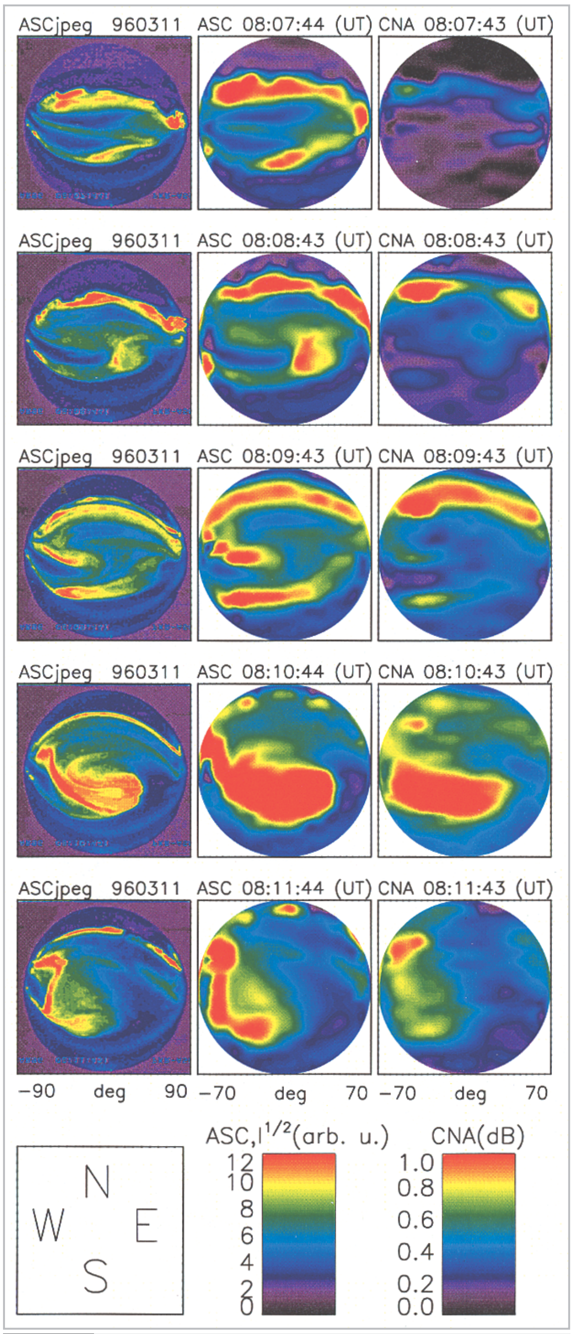

Fig.4 *Examples of the SALMON 2-D image plots from the comparative database*

the data visually, as color contour plots, to offer easy access to the comparative database by outside researchers via the worldwide web.

Since the comparative database uses unfiltered (panchromatic) auroral luminosity images, it is not suitable for detailed spectral analysis of the energy of precipitating electrons. However, it is believed to be useful in (i) conducting efficient searches for target auroral phenomena, (ii) the estimation of temporal and spatial variations of precipitation of high-energy electrons and the hardness of energy in such currently active regions, and (iii) comparisons with other observation data.

During the interruption in the operation of the 256-element imaging riometer in the summer of 1999, some improvements were made in the observation system, such as an upgrade from a DOS-based to a Windows-based computer system. Preparations are underway for the resumption of observations.

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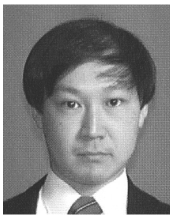

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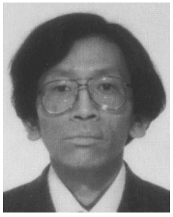

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