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MF RADAR OBSERVATIONS OF ANTARCTIC MESOSPHERE AND LOWER THERMOSPHERE

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Abstract: The observations of middle atmosphere have been conducted mainly in mid-latitudes so far, although global scale observations are required for the study of the middle atmosphere. We are planning to construct an MF radar observatory at Syowa Station, Antarctica (69°S, 39°E) in 1999. The MF radar observations of horizontal neutral wind velocity (60–100 km) are characterized by its high time-height resolutions of 2 min–4 km and the continuous operation throughout a day, which enables us to observe various atmospheric phenomena over wide frequency range from gravity waves to planetary waves. Further, we discuss the importance of combined observations with other measurement techniques like Na lidar, FPI, all-sky imager and HF radar, and also international cooperative studies through global atmospheric radar networks.

1. Introduction

When we discuss the environmental changes of the Earth's atmosphere, a global point of view is essentially important. This is obvious from the fact, for example, that artificial chlorine compounds produced mainly in mid-latitudes through human activity, are transported to high latitudes by the atmospheric motion, 'the general circulation', and affect polar atmosphere. It is now believed that the general circulation in the middle atmosphere (about 10 to 100 km altitude) plays a crucial role for the global-scale transport of energy and minor constituents (*e.g.*, ANDREWS *et al.*, 1987). It is noteworthy that various theoretical and observational studies have shown that dynamical processes such as atmospheric waves propagating from lower altitudes play an important role to maintain the general circulation. In the upper middle atmosphere (upper mesosphere to lower thermosphere), breaking of gravity waves is believed to even reverse zonal mean winds (*e.g.*, LINDZEN, 1981; MATSUNO, 1982; VINCENT and REID, 1983; TSUDA *et al.*, 1990).

The observations of the middle atmosphere, however, have been rather limited in mid-latitudes so far, and not sufficient in the polar regions, especially in Antarctica. It is important to note that the upper middle atmosphere in the polar regions is affected by the atmosphere above as well as below unlike the low and mid latitudes where effects from below are thought to dominate. In polar regions, the middle atmosphere and thermosphere are directly coupled through magnetic field lines to the magnetosphere and the solar wind. In particular, high latitude magnetic field lines provide routes for solar wind particles to reach the middle atmosphere, where they interact with the neutral gas (RÖTTGER, 1991). The influence of geomagnetic activity on neutral winds in the upper middle atmosphere has been reported by several authors (*e.g.*, PRICE and JACKA, 1991; PRICE *et al.*, 1991).

In order to study the dynamics of the upper middle atmosphere in Antarctica, we are planning to construct an MF radar observatory at Syowa Station in 1999. The MF radar is a powerful instrument to observe horizontal wind velocities in the upper middle atmosphere. We describe the MF radar observation techniques in Section 2. Further, we discuss the combined observations with other measurement techniques and cooperative study through global atmospheric radar network in Section 3.

2. MF Radar Observations

We are planning to use an MF radar produced by Atmospheric Radar System Pty. Ltd. (ATRAD), Adelaide, Australia. Even under the severe weather condition in Antarctica, the radar should be easily operated, reliable, and transportable. The MF radar is well designed to meet these requirements. It consists of two small racks, one for the transmitter, and the other for radar controller and receivers. One IBM-PC compatible computer is employed for on-line data processing and data storage (VINCENT and LESICAR, 1991). The reliability of the radar system is shown from the fact that the almost identical MF radar installed on Christmas Island in the Pacific has been operated without any major trouble since 1990 (REID, 1996).

Table 1 shows the planned basic parameters of Syowa MF radar. It is a monostatic pulse radar, which operates at a radio frequency of approximately 2 MHz. The antenna configuration is designed to meet the MF radar specifications, and the outlook is illustrated in Fig. 1. The radar employs spaced antenna technique (*e.g.*, VINCENT, 1984). The radar consists of four cross dipole antennas located at the three corners of equilateral triangle with a spacing of about 200 m and at the

Table 1. Basic parameters of MF radar.

Type	Coherent pulse radar
Peak transmitting power	50 kW
Duty ratio	0.4% (maximum)
Operating frequency	around 2 MHz
Pulse width	15–50 μs (30 μs typical)
Pulse repetition frequency	80 Hz typical
Half power bandwidth	30 kHz typical
Antennas	4 cross dipoles
Radar controller	IBP-PC (compatible)

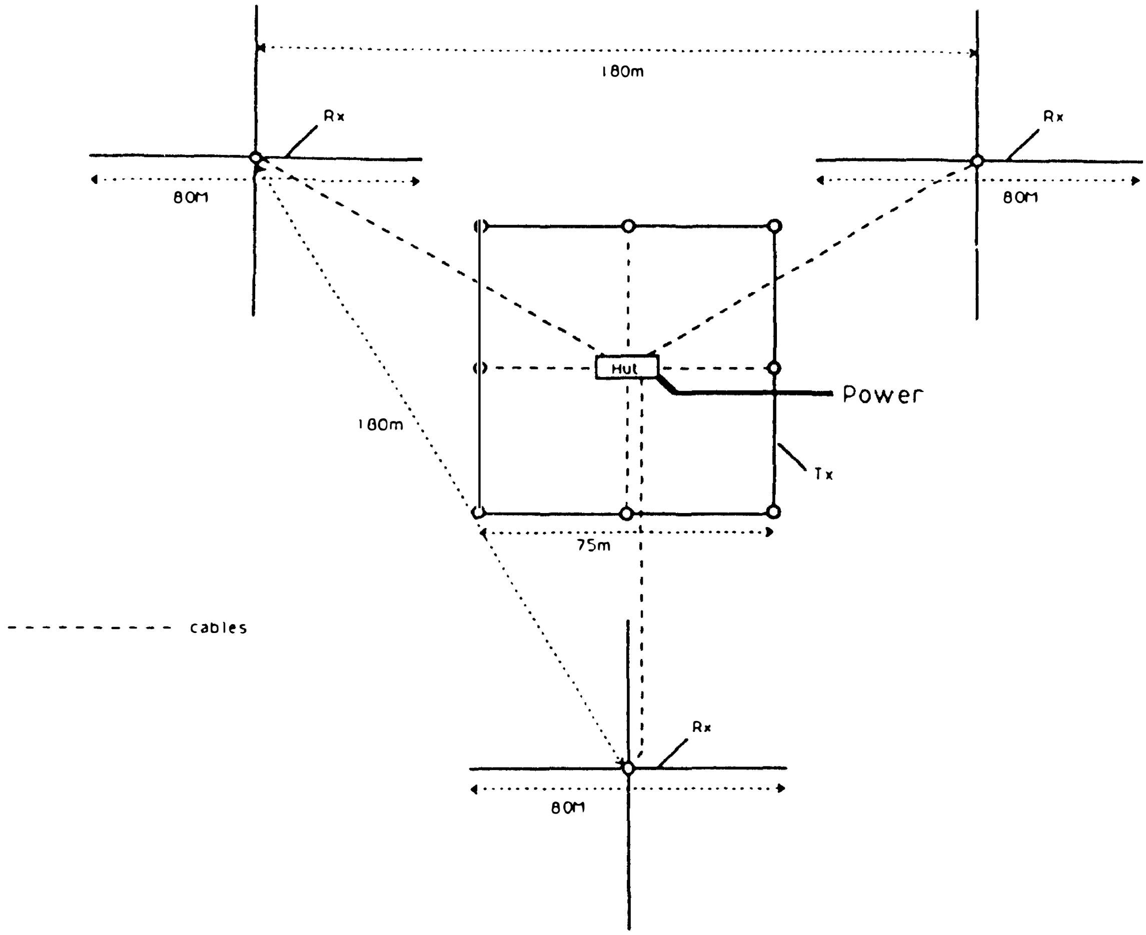

Fig. 1. A typical example of MF radar antenna configuration. Three cross dipoles are for reception (Rx). Square-shaped array antenna is for transmission (Tx). Transmitters, receivers and data processing PC are installed in the small hut (Hut). Radio frequency is assumed to be 2 MHz in the diagram. Note that four dipole anttenas are planned to be installed for Syowa MF radar system, where the four antennas are used for both transmission and reception. Electricity (power) is supplied from the main site of Syowa Station.

center of the triangle. RF output of 50 kW is divided into 4 antennas, and transmitted vertically. The transmitted radio wave is backscattered in the 60–100 km height region by the vertical gradient of refractive index due to electron density gradient, and then received with the four antennas. Normally, full correlation analysis is applied to the spaced antenna technique of MF radar observations (BRIGGS, 1984). It uses the antennas to sample the ground diffraction pattern produced by the backscattering irregularities, and cross correlation techniques are used to determine its velocity of motion. Further, the analysis takes account of random changes in the pattern, and also any anisotropy of the pattern, so that the horizontal component of wind field is derived at a particular height in a single region directly above the radar (REID, 1996).

Taking account of possible radio interference with existing communicating facilities and radars, 'Kai-no-hama Beach' on the west edge of East Ongul Island is considered as the candidate of the radar site. Stored data on the hard disk of PC is transferred to the main site of Syowa Station via local area network (LAN).

The radar is characterized by its high time-height resolutions of 2 min–4 km. Recent observational studies revealed that gravity waves with wave periods shorter than 1 hr play a crucial role in driving the general circulation and determining the thermal state of the middle atmosphere (*e.g.,* FRITTS and VINCENT, 1987). Considering that the shortest period of gravity wave is about 5 min, Brunt-Väisälä period, the time resolution of 2 min is good enough for studying gravity wave activity. Further, atmospheric radars operating at MF and lower HF are the only instruments capable of providing measurements in the 60–100 km height region with reasonable temporal and spatial resolution (REID, 1996). Although in the low to middle latitudes the observations of the region below 80 km are limited in the day time, relatively high electron density in the polar region, which is maintained by the precipitation of auroral particles, often enables us to measure the height region below 80 km throughout a day even during polar night (*e.g.,* VINCENT, 1994). Further, a pulse coding technique is planned to be introduced to Syowa MF radar. It increases the signal to noise ratio of the received signal and facilitate the observation of the lower altitudes.

In addition to horizontal wind velocity, the radar can provide information on radio scattering layers, like the aspect sensitivity of mesospheric scatterers, which further gives us a clue to investigate turbulence activity in the region (LESICAR *et al.,* 1994). Electron density observations can be conducted as well. Conspicuous enhancements of electron density in upper stratosphere and lower mesosphere, which are thought to be due to high energy particles, have been reported using an MF radar at Scott Base in Antarctica (VON BIEL, 1992).

Note that some problems of MF radar techniques have been discussed so far. HINES *et al.* (1993) reported that wind velocity observed with an MF radar is not correct above 80 km in comparison with other measurement techniques. At least, part of the discrepancy of HINES *et al.* (1993) is thought to be due to their Imaging Doppler Interferometer technique employed for the MF radar observations, which is inferior to FCA, and can cause some bias in measured winds (REID, 1996). Another major source affecting wind measurements is the saturation of the receivers, which occurs in upper observation height due to high electron density and causes underestimation of measured winds (REID, 1996; IGARASHI *et al.,* 1996). To minimize this problem at Syowa Station, we are planning to interleave two gain levels every few minutes, which are adjusted to the receiving signal from the lower and higher altitudes, respectively, and use only unsaturated data for further analysis (REID, private communication 1996).

It is also noteworthy that the contamination of vertical wind component to the horizontal wind velocity is discussed (*e.g.,* NAKAMURA *et al.,* 1993). Although this effect is negligible for wind fluctuations with relatively long wave period, we have to be careful when analysing short period fluctuations, especially, those with wave periods close to Brunt-Väisälä frequency.

3. Combined Observations with Various Techniques, and Global Radar Network

MF radar observations have been adopted to study atmospheric dynamics in the upper middle atmosphere since 1960s. The behavior of mean winds and various atmospheric waves like gravity waves, atmospheric tides and planetary waves has been investigated (*e.g.*, VINCENT, 1984). In addition to MF radar, various measurement techniques have been also developed and provided a lot of useful information about atmospheric phenomena (*e.g.*, ANDREWS *et al.*, 1987). Since each of these techniques can present different physical quantities with one another, the simultaneous operation of multiple observation techniques gives us more physical parameters. This is desirable not simply because the number of physical parameters increase, but new crucial physical quantities like momentum fluxes can be also estimated by combining observed parameters.

At Syowa Station, observations using Na lidar, Fabry Perot Interferometer (FPI) and all-sky imager are also under contemplation. Na lidar observations can provide profiles of Na density in 80–110 km height region (GARDNER *et al.*, 1989). Further, using two narrowband filters with different center frequencies, we can observe absolute atmospheric temperature and atmospheric density (SHE *et al.*, 1990). Although the information on temperature and density itself is quite important for atmospheric dynamics, by conducting simultaneous observations with the MF radar, we can investigate wave structure more precisely using theoretical relations between wind velocity and temperature fluctuations caused by waves, and also obtain vertical momentum flux of waves, which is a quite important parameter to study the interaction between mean winds and waves. Further, very fine vertical structures of waves can be studied by utilizing the much better height resolution of Na lidar ($\sim$100 m) than the MF radar (4 km). While the MF radar and the Na lidar observe vertical profiles of atmospheric parameters, all-sky imager and FPI provide 2-dimensional information of atmospheric parameters in the horizontal plane within several hundred km in diameter. Both are passive observation techniques, utilising atmospheric airglow emissions like OH (centered at $\sim$87 km) and OI ($\sim$96 km). The all-sky imager measures the intensity of the emissions, which often shows a striped pattern and is believed to be caused by atmospheric wave activity (*e.g.*, TAYLOR *et al.*, 1995). FPI employs narrowband filters and measures Doppler frequency shift and broadening of particular emission lines. The obtained images are further used to deduce wind velocity and atmospheric temperature (*e.g.*, SWENSON *et al.*, 1990). These airglow techniques can directly observe horizontal structure of waves, which are only estimated with the aid of some theories in the case of the MF radar and Na lidar observations. Therefore, these radar and optical measurements are complementary with each other, and combined observations of them are expected to give us useful data set for better understandings of polar middle atmosphere.

Note that radio meteor echo observations are also useful techniques to study horizontal wind velocity and atmospheric temperature in the upper middle atmosphere (*e.g.*, TSUTSUMI *et al.*, 1994). Although the time resolution of meteor observations is not as good as the observations mentioned above, continuous operation regardless of weather condition is possible. Especially in summer months, when it is hard to conduct observations with optical techniques, the interaction between mean winds and gravity waves are thought to be very active (VINCENT, 1994), and temperature information would be very useful to study this mechanism.

VHF radar and HF radar observations have been conducted routinely in Syowa Station for studying dynamics in *E*-region and *F*-region (IGARASHI *et al.*, 1995). The simultaneous operation with the MF radar covers height regions from mesosphere to *F*-region, and is expected to provide useful information to investigate coupling processes between neutral and ionized atmosphere.

We are looking forward to an international cooperative study through global radar network as well. In Antarctica, several MF radars are now in operation, or under a plan, as seen in Fig. 2. When the MF radar observatory at Syowa Station is constructed, those radars distributed around the south pole will be very useful means to study horizontal structures of planetary scale waves, mean winds and also latitudinal differences of gravity wave activity in Antarctica. The study of hemispheric differences is also an important subject. For example, the difference of occurrence of Polar Mesospheric Summer Echoes (PMSE) and Polar Mesospheric Clouds (PMC) between the southern and northern hemispheres is thought to be due

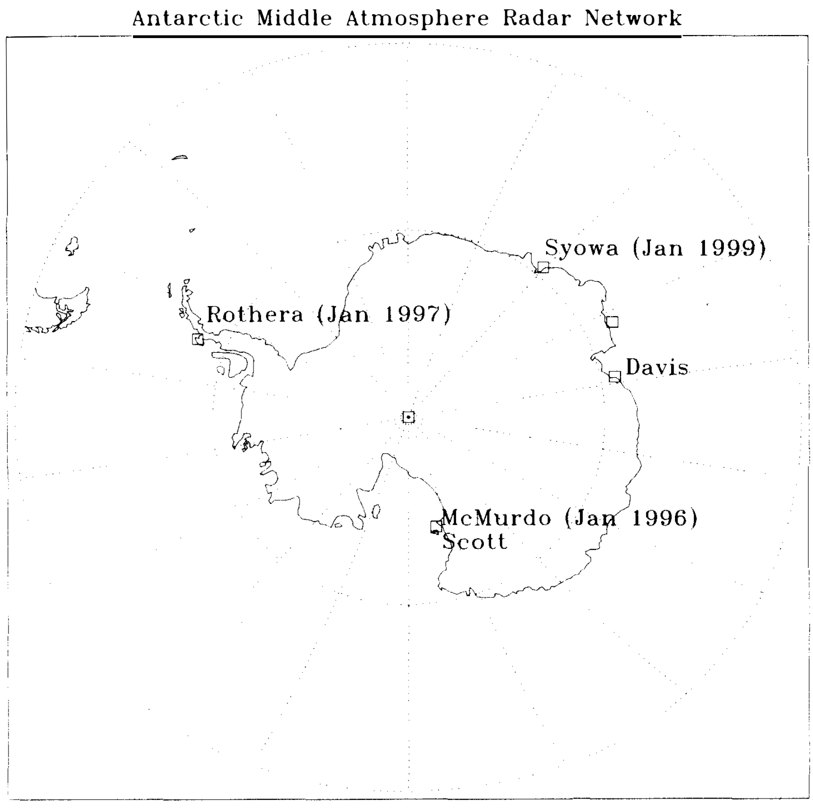

Fig. 2. Locations of MF radar observatories in operation or under contemplation in Antarctica.

to different temperature structures, mean circulation patterns and gravity wave activity between them (BALSLEY *et al.*, 1995; VINCENT, 1994). Quantitative analysis of these differences is required.

4. Conclusions

In the present paper we described our future plan of MF radar observations at Syowa Station, in Antarctica. The MF radar is a powerful measurement technique in the upper middle atmosphere. It is a very reliable and easily operated system, and a stable continuous operation in long term can be conducted even in the severe weather condition in Antarctica. Moreover, the combined operation with existing and planned instruments at Syowa Station would provide us with invaluable information on atmospheric phenomena in vertically and horizontally wide spatial area. International cooperative study through radar network in Antarctica and also global radar network would contribute to the better understandings of our atmosphere.

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