SOME INITIAL RESULTS OF 50 MHz METEOR RADAR OBSERVATION AT SYOWA STATION

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Abstract: A 50 MHz doppler radar installed at Syowa Station, Antarctica, in 1982 acts as a meteor radar, when an operator assigns a meteor mode operation to the radar. This paper describes some initial results obtained from the meteor echo data covering the period 29 December 1982–15 January 1983. The altitude distribution and hourly occurrence probability of echoes and also the mean zonal and meridional wind components derived from doppler velocities of meteor trails are nearly consistent with the results obtained at mid- and high-latitudes in the opposite hemisphere. Evidence showing that neutral winds may be partly modified by electric fields, Joule heating or Lorentz force appearing under geomagnetically disturbed condition is also presented.

1. Introduction

Neutral atmospheric winds at meteor heights at southern high-latitudes, especially in Antarctica, are not well understood partly because wind measurements there have been extremely less (ELFORD and MURRAY, 1960; ILJICHEV *et al.*, 1974) than at northern high-latitudes (HOOK, 1970; NASTROM *et al.*, 1982 and references therein; CARTER and BALSLEY, 1982; BALSLEY, 1983; AVERY *et al.*, 1983). To fill this gap and also to study how the Antarctic middle atmosphere between 80 and 100 km differs from or is similar to that at other latitudes, a 50 MHz meteor radar was installed at Syowa Station (69°00′S, 39°35′E geographic; 70.0°S, 80.2°E geomagnetic) in 1982 as one of the ground-based study programs in Antarctica for the Middle Atmosphere Program (MAP, 1982–1985) (IGARASHI *et al.*, 1982; OGAWA *et al.*, 1983). The radar was successfully operated, though not necessarily on a continuous base, for 40 and 80 days in 1982 and 1983, respectively.

In this paper, the occurrence probability and altitude distribution of meteor echoes and the mean wind profiles are presented using data obtained during 29 December 1982–15 January 1983. Our results are nearly consistent with those in the opposite hemisphere. Also presented is evidence showing that neutral winds may be partly modified under disturbed condition.

2. Equipment

The Syowa Station VHF radar is a pulse doppler radar which transmits a frequency of 50 MHz with a nominal peak power of 15 kW (IGARASHI *et al.*, 1982). The radar can detect aurorally-associated echoes appearing often in the disturbed *E*-region and also meteor echoes. This radar has three operation modes (spectrum, double-pulse and meteor mode), one of which an operator can select depending on the objectives of study. The spectrum and double-pulse modes are used to measure the intensity, doppler velocity spectrum and mean doppler velocity of auroral radar echoes, thereby to investigate both motions of 3-m irregularities and characteristics of plasma turbulence in the *E*-region. From the meteor mode, neutral wind motions in the 80–100 km altitudes can be studied using meteor trails. Some results obtained at an early stage of the experiment have been presented by OGAWA *et al.* (1983) and IGARASHI *et al.* (1985).

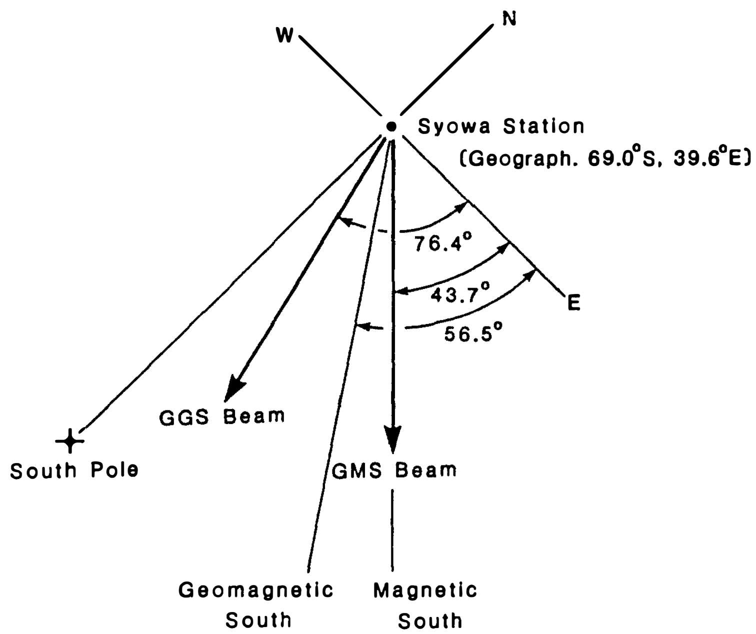

Fig. 1. Two antenna beam directions (GGS and GMS) used for meteor radar observation.

As shown in Fig. 1, the radar has two antenna beams, one toward magnetic south (GMS beam) and the other toward approximately geographic south (GGS beam) with a crossing angle of about 33°. This configuration enables us to determine a two-dimensional wind motion. Each beam is formed by using three 14-element coaxial collinear antennas and has a beamwidth of approximately 4° in the horizontal plane and of approximately 30° in the vertical plane.

The minicomputer annexed to the radar controls real-time data processing of meteor echoes. If the receiver detects a meteor echo according to the selection criteria (1) that the echo width in range is shorter than or comparable to the transmitting pulse width (typically 100 μs) and (2) that the echo power is beyond a threshold strength, a "flag" signal is sent from the receiver to the computer. Then, the computer begins to determine the echo range with a time resolution of 1 μs and to sample every 200 μs the doppler signal and echo intensity at the echoing range (R). The line-of-sight velocity (V_d) of echo trail is calculated from the output of the doppler signal detection circuit having an offset frequency of 40 Hz (covering V_d between -120 and 180 m/s without aliasing) by using the so-called zero-crossing method. The echo amplitude decay time gives the ambipolar diffusion coefficient (D) from which the echo height (H) is determined (McKINLEY, 1961). The digitized doppler signals and echo intensities at 500 sampling-points are stored on magnetic tapes together with V_d, D, H and R for later analysis. After the computer completes these procedures, the radar returns to the watch mode for detecting next meteor echo.

3. Results and Discussions

About 40 day observations in total were made from February 1982 to January 1983. In this paper, some results obtained through a continuous operation for the summer period 29 December 1982–15 January 1983 are presented. Note that ΣK_p's were between 6+ and 39 during the period. In the auroral region, meteor echo may be contaminated with radio aurora echo when both echoes appear simultaneously. In such a case, the computer may regard radio aurora echo as a meteor echo in spite of the meteor detection criteria (see Section 2) imposed on the receiver. In order to remove these unwanted data, the time profile of each echo stored on magnetic tapes was reexamined. As a result, only the underdense echoes decaying exponentially with time were selected for analysis.

3.1. Basic characteristics

Altitude distribution of the number of echoes (about 2600 echoes in total) is presented in Fig. 2. The echo altitudes range from 70 to 110 km. Most of echoes come from the 80–100 km altitudes and there is a maximum occurrence around 90 km. AVERY *et al.* (1983) have shown from the 50 MHz MST radar observation at Poker Flat, Alaska (65°22′N) that the meteor echo rate attains a maximum at 92 km. The

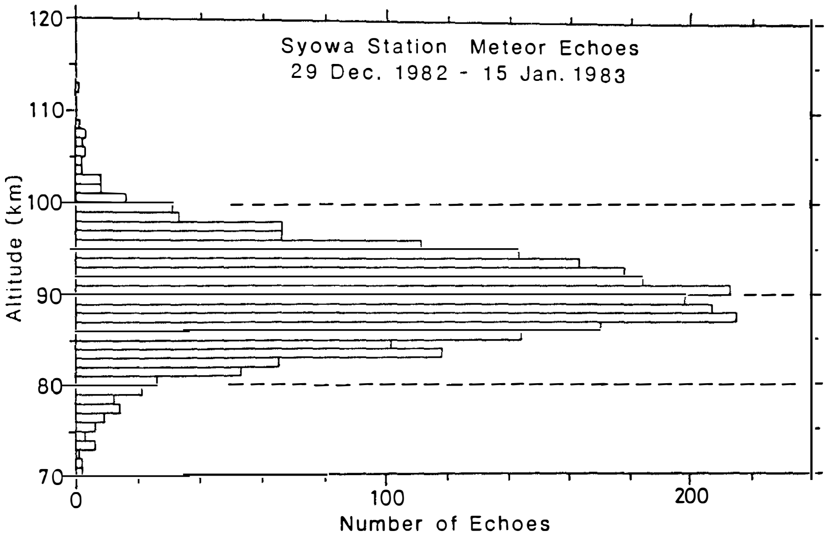

Fig. 2. Altitude distribution of the number of meteor echoes for the period 29 December 1982–15 January 1983.

difference of 2 km in altitude may be attributed to the air density model adopted by us (McKinley, 1961) and/or to the altitude resolution of 2.2 km for the Poker Flat radar. On the other hand, the Kyoto meteor radar (34°51'N) operated at 31.57 MHz shows a maximum echo rate at 94 km (Aso *et al.*, 1980) which is higher by 4 km than our case. This difference is explained by that a meteor radar transmitting lower frequency can detect echoes at higher altitudes (Greenhow and Hall, 1960; McKinley, 1961).

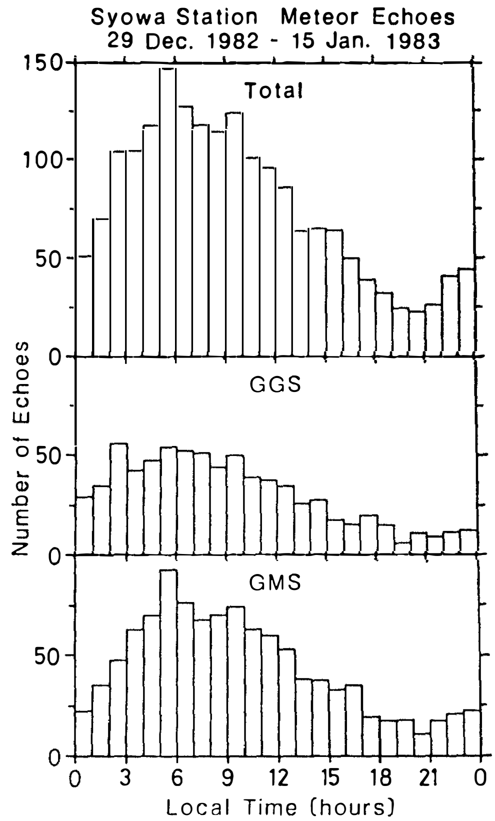

Fig. 3. Hourly distributions of the number of meteor echoes for GGS beam (middle panel) and GMS beam (bottom panel) for the period 29 December 1982–15 January 1983. Total distribution is shown in the top panel.

Hourly distributions of the number of echoes for the GGS beam (middle panel) and GMS beam (bottom panel) together with the total distribution (top panel) are shown in Fig. 3. Each distribution has a maximum hourly rate around 0600 LT and a minimum around 2100 LT, a result which is nearly consistent with those by Aso *et al.* (1980) and Avery *et al.* (1983). Radio aurora activity usually becomes higher for hours during, say, 1800–0600 LT, so that the hour of the minimum occurrence may be somewhat artificial and may shift toward earlier hour because meteor echoes contaminated with radio aurora echoes are excluded in our analysis.

Figure 4 displays the slant range distributions of the number of echoes obtained from the data set for the period 8–15 January 1983. On the whole, the number of echoes decreases monotonically with range, a plausible result indicating that received power decreases with range. The minimum slant range of about 110 km stems from the antenna pattern and the maximum range of about 600 km can be attributed partly to the antenna pattern and partly to the transmitting power of 15 kW. For the antenna

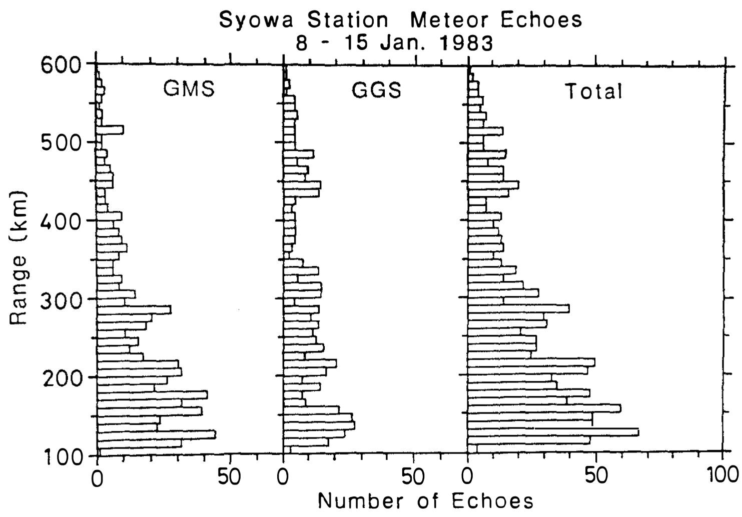

Fig. 4. Slant range distributions of the number of meteor echoes along GMS beam (left panel) and GGS beam (middle panel) for the period 8–15 January 1983. Total distribution is shown in the right panel.

configuration shown in Fig. 1, the slant ranges of radio aurora echoes should be limited roughly between 220 and 450 km, outside of which the echo power originating from the field-aligned *E*-region irregularities is heavily reduced because the radar wave intersects the geomagnetic lines of force with a large off-perpendicularity beyond $90\pm4°$ (OGAWA *et al.*, 1983). If radio aurora echoes would be mixed up in the distributions shown in Fig. 4, a maximum might appear at range somewhere between 220 and 450 km. Figure 4 indicates that our selection scheme of meteor echo data is satisfactory.

3.2. *Variability of wind motions*

At auroral-zone latitudes, the effect of electric field on neutral wind motion cannot be neglected, especially under highly geomagnetically disturbed condition (HOOK, 1970; BALSLEY *et al.*, 1982; REID, 1983). Examples showing that this effect may be important are demonstrated in Fig. 5 where hourly-average doppler velocity vectors averaged over 85 to 95 km in altitude are shown in geographic coordinates; two left figures (30 December 1982 and 1 January 1983) for disturbed day (ΣK_p=24− and 20, respectively, and $2- \lesssim K_p \lesssim 4-$) and two right figures (6 and 7 January 1983) for quiet day (ΣK_p=6+ and 8, respectively, and maximum K_p=2−). At a glance, for disturbed days the wind velocities exceeding 100 m/s can be observed at some hours but for quiet days they are always below 100 m/s.

Other examples are presented in Fig. 6. A geomagnetic storm started at 1545 UT (1845 LT) on 9 January 1983 and on the next day ΣK_p was 39 (K_p=7+, 8+, 7, 5, 3+, 3−, 2+, 3 in UT) which means highly disturbed conditions for hours from the local midnight to the noon. Contrary to the expectation, the wind velocities at these hours were not high ($\lesssim$50 m/s). Higher velocities ($\gtrsim$50 m/s) appeared rather at hours from 1700 LT on January 10 to 0200 LT on January 11 under magnetically unsettled conditions ($2+ \lesssim K_p \lesssim 3+$).

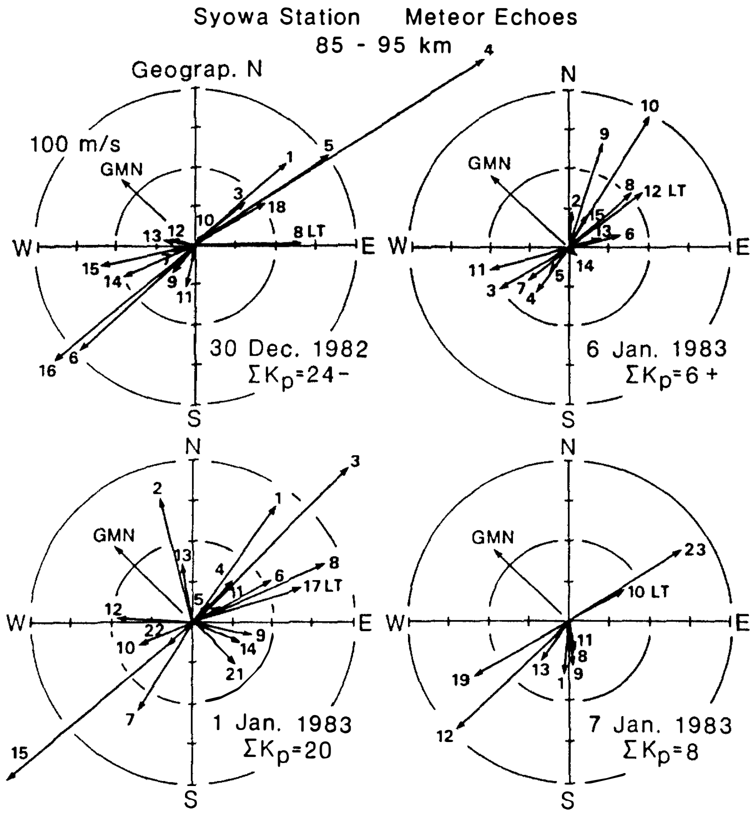

Fig. 5. Hourly-average doppler velocity vectors in geographic coordinates averaged over altitude 85–95 km (geomagnetically disturbed condition for two figures in the left side and quiet condition for two figures in the right side). GMN means geomagnetic north direction.

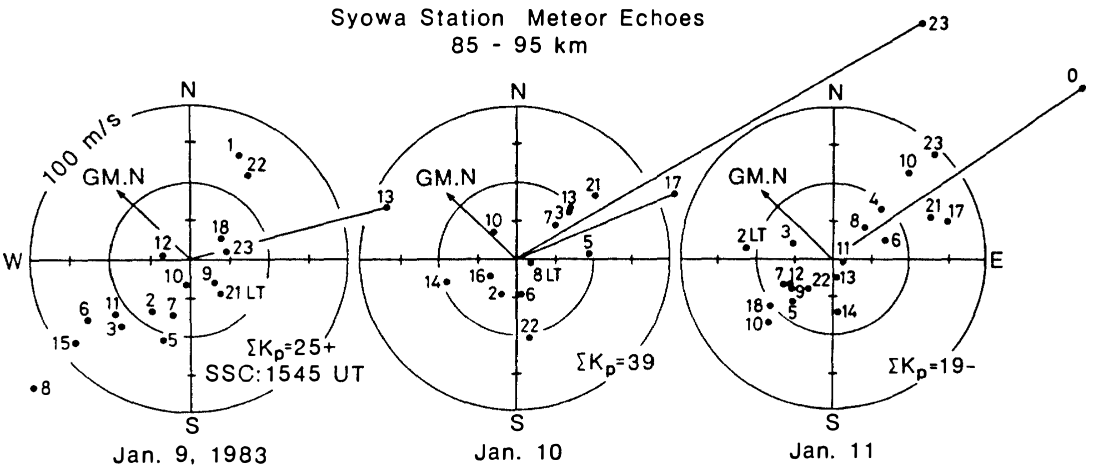

Fig. 6. Hourly-average doppler velocity vectors in geographic coordinates averaged over 85–95 km for the period 9–11 January 1983. Geomagnetic storm started at 1545 UT (1845 LT) on January 9. GMN means geomagnetic north direction.

The above examples under disturbed conditions indicate that the wind motions may not necessarily be affected by electric fields associated with geomagnetic activity. When electric field is large, movement of plasma column produced by meteor may be deviated from neutral wind (REID, 1983). Apart from the electric field effect, neutral wind velocities may fluctuate due to either Lorentz force or Joule heating enhanced during disturbed condition (BALSLEY *et al.*, 1982). More studies seem necessary for clarifying these subjects.

3.3. Average winds

To investigate average wind motion, hourly-average doppler velocities were averaged over 85 to 95 km for the period from 30 December 1982 to 15 January 1983. The results are shown in Fig. 7 where the doppler velocities along the GGS and GMS beams are displayed in the lower panel and those in geographic coordinates in the upper panel. Note again that ΣK_p range from 6+ (quiet) to 39 (highly disturbed). There seem to exist diurnal and semidiurnal components, though harmonic analysis to obtain them is not carried out. The wind vectors are mostly in the northeast quadrant during 2300–0500 and 0900–1200 LT but are in the southwest quadrant during 0600–0800 and 1300–1600 LT. The vectors fluctuate during 1700–2200 LT.

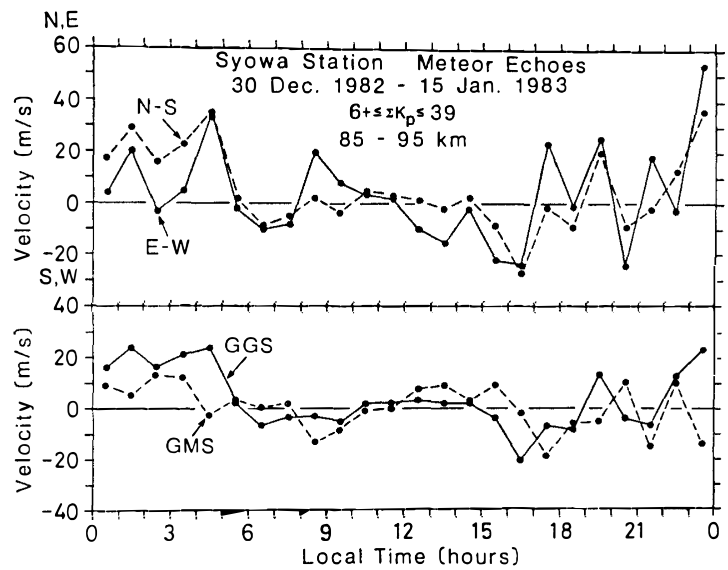

Fig. 7. Hourly-average doppler velocity variations averaged over altitude 85–95 km and over the period 30 December 1982–15 January 1983 along GGS and GMS beams (lower panel, plus sign means motion toward Syowa Station). Velocities are converted into geographic coordinates in the upper panel.

The flow directions during 2300–0500 LT which are magnetically eastwards are consistent with the *E*-region plasma drifts caused by equatorward-directed electric fields after midnight (*e.g.*, OGAWA *et al.*, 1982), indicating that the average neutral winds may be affected partly by the electric field. On the other hand, in the evening the plasma drifts direct geomagnetically westwards due to poleward-directed electric fields, indicating that the neutral wind flows might be geographically southwestwards if they would be affected by the electric field. In our case, clear southwestward flows were not always observed in the evening (1700–2200 LT) but the fluctuation in direction was observed. Our results are not final ones. More future analysis is necessary for judging whether electric field affects neutral wind motion or not. This can be done by comparing average wind motions under disturbed condition with those under quiet condition.

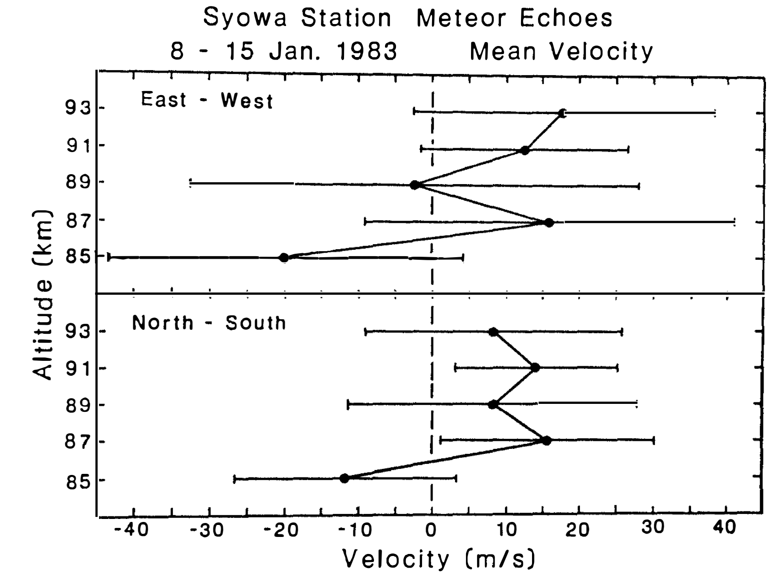

Fig. 8. Altitude profiles of mean zonal (upper panel) and meridional (lower panel) doppler velocities averaged over the period 8–15 January 1983. The horizontal bar indicates standard deviation.

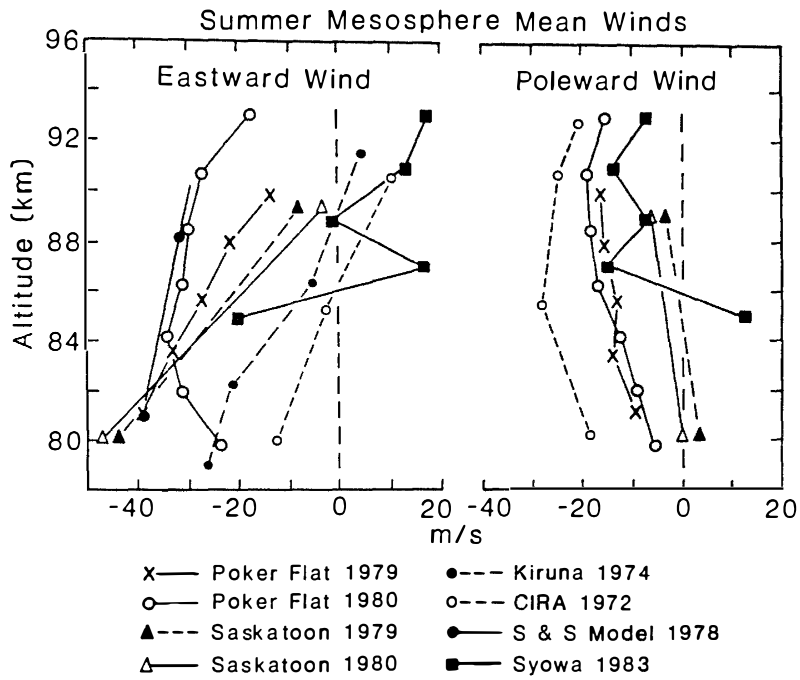

Fig. 9. Comparison of altitude profiles of summer mesospheric mean wind. Syowa Station data are indicated by filled square. Profiles except for Syowa Station were adopted from CARTER *and* BALSLEY *(1982).*

3.4. *Altitude profile of mean wind*

In order to estimate simply an altitude profile of the mean wind, hourly-average doppler velocities were averaged over the period 8–15 January 1983. Figure 8 shows the zonal (upper panel) and meridional (lower panel) mean wind profiles for the altitude range of 85–93 km. Though the standard deviations of data are quiet large, a tendency of the zonal mean winds to change at about 87 km from westward to eastward with increasing altitude can be observed in the upper panel in Fig. 8, and the meridional mean winds at altitudes of 87–93 km are northwards (equatorwards) with velocities between 10 and 15 m/s. The large standard deviations may be partly due to the small number of data points (only 8 days). This will be improved in the future analysis.

Figure 9 compares our results with other profiles obtained at northern high-latitudes and also with theoretical results. See a paper by CARTER and BALSLEY (1982) for the profiles except for Syowa Station. The Syowa Station zonal wind profile, though the data at 87 km is peculiar, seems to be similar to the CIRA 1982 model and and to the Kiruna meteor radar result. On the other hand, the meridional winds except at 85 km are between the profiles from Saskatoon and Poker Flat, confirming that the mean meridional flow in the summer upper mesosphere is equatorwards (NASTROM *et al.*, 1982; CARTER and BALSLEY, 1982).

4. Summary

Some results from the Syowa Station 50 MHz meteor radar operated for the period 29 December 1982–15 January 1983 are summarized as follows:

(1) The meteor echo altitudes range from 70 to 110 km. Most of echoes come from 80 to 100 km and a maximum occurrence appears around 90 km.

(2) The number of echoes varies with local time and is highest around 0600 LT and lowest around 2100 LT.

(3) The slant range of echoes is between 110 and 600 km and the number of echoes decreases nearly monotonically with range.

(4) The neutral wind motions derived from the observed doppler velocities of meteor trails may be affected partly by electric fields appearing during geomagnetically disturbed condition. A role of Joule heating or Lorentz force on wind motions may also be important. More analysis is necessary for clarifying these effects. In this connection, coordinated observation of electric field and meteor radar is highly recommended.

(5) The altitude profiles of mean meridional and zonal wind components are nearly consistent with the results obtained in the summer northern high-latitudes in the opposite hemisphere.

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References

ASO, T., TSUDA, T., TAKASHIMA, Y., ITO, R. and KATO, S. (1980): Observation of lower ionospheric wind by the Kyoto meteor radar. J. Geophys. Res., **85**, 177–184.

AVERY, S. K., RIDDLE, A. C. and BALSLEY, B. B. (1983): The Poker Flat, Alaska, MST radar as a meteor radar. Radio Sci., **18**, 1021–1027.

BALSLEY, B. B. (1983): Poker Flat MST radar measurement of winds and wind variability in the mesosphere, stratosphere and troposphere. Radio Sci., **18**, 1011–1020.

BALSLEY, B. B., CARTER, D. A. and ECKLUND, W. L. (1982): On the relationship between auroral electrojet intensity fluctuations and the wind field near the mesopause. Geophys. Res. Lett., **9**, 219–222.

CARTER, D. A. and BALSLEY, B. B. (1982): The summer wind field between 80 and 93 km observed by the MST radar at Poker Flat, Alaska (65°N). J. Atmos. Sci., **39**, 2905–2915.

ELFORD, W. G. and MURRAY, E. L. (1960): Upper atmosphere wind measurements in the Antarctic. Space Research **I**. Amsterdam, North-Holland, 158–163.

GREENHOW, J. S. and HALL, J. E. (1960): The importance of initial trail radius on the apparent height and number distributions of meteor echoes. Mon. Not. R. Astron. Soc., **121**, 183–196.

HOOK, J. L. (1970): Winds at the 75–110 km level at College, Alaska. Planet. Space Sci., **18**, 1623–1638.

IGARASHI, K., OGAWA, T., OSE, M., FUJII, R. and HIRASAWA, T. (1982): A new VHF doppler radar experiment at Syowa Station, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **22**, 258–267.

IGARASHI, K., OGAWA, T., KURATANI, Y., FUJII, R. and SATO, N. (1985): 50 MHz auroral doppler radar observations of Pc 5 geomagnetic pulsations. Mem. Natl Inst. Polar Res., Spec. Issue, **36**, 104–113.

ILJICHEV, Yu. D., LYSENKO, I. A., ORLYANSKY, A. D. and PORTNYAGIN, Yu. I. (1974): Space and time variations of large-scale air motions in the lower thermosphere. J. Atmos. Terr. Phys., **36**, 1841–1849.

MCKINLEY, D. W. R. (1961): Meteor Science and Engineering. New York, McGraw-Hill.

NASTROM, G. G., BALSLEY, B. B. and CARTER, D. A. (1982): Mean meridional winds in the mid- and high-latitude summer mesosphere. Geophys. Res. Lett., **9**, 139–142.

OGAWA, T., BALSLEY, B. B., ECKLUND, W. L., CARTER, D. A. and JOHNSTON, P. E. (1982): Auroral radar observations at Siple Station, Antarctica. J. Atmos. Terr. Phys., **44**, 529–537.

OGAWA, T., IGARASHI, K., OSE, M., KURATANI, Y., FUJII, R. and HIRASAWA, T. (1983): Preliminary results of new 50 MHz doppler radar experiment at Syowa Station. Mem. Natl Inst. Polar Res., Spec. Issue, **26**, 193–201.

REID, G. C. (1983): The influence of electric fields on radar measurement of winds in the upper mesosphere. Radio Sci., **18**, 1028–1034.

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