NOTES AND CORRESPONDENCE

Short-Period Fluctuation of the Lower Tropospheric Winds Observed by MU-Radar

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1. Introduction

The MU (Middle and Upper Atmosphere) radar was constructed at Shigaraki (34.85°N, 136.10°E) southeast of Kyoto for the Middle Atmosphere Project (MAP) (Kato *et al.*, 1984). This radar is operated as a national cooperative facility by the Radio Atmospheric Science Center (RASC), Kyoto University. It is a new-generation MST (Mesosphere-Stratosphere-Troposphere) radar, which is an active phased-array system composed of 475 Yagi antennas, and the operating frequency is 46.5 MHz.

As this radar is originally designed for upper atmosphere studies, various observational research works relating to the breaking of the internal gravity waves in the upper atmosphere have been conducted (Fukao *et al.*, 1986; Hirota and Niki, 1986; Yamanaka *et al.* 1988). On the other hand, its potential ability for examining meso-scale phenomena and cloud physics have been well acknowledged, because we can make nearly continuous wind observations in the lower atmosphere (Gage and Balsley, 1978; Larse and Rottger, 1982). During the build-up period, several preliminary observations for tropospheric phenomena have been conducted and interesting results were obtained. (Fukao *et al.*, 1985; Fukao and Yamanaka, 1988).

They especially found that the falling velocity of snow flakes and rain drops can be observed together with the vertical velocity of the atmosphere because the operating frequency is 46.5 MHz and the intensity of echoes of rain or snowflakes are of the same order as that of atmosphere (Fukao, *et al.*, 1984; Wakasugi *et al.*, 1985). By using this information they estimated the cloud size distribution (Wakasugi *et al.*, 1987).

However, the potential ability of the MU radar for the mesoscale meteorology has not yet fully been investigated. Frequently, meso-scale (meso- α and meso- β) disturbances are observed in the Baiu sea-

son, and it is an interesting problem to investigate their structure and dynamics. The kinematical and thermodynamical budget studies of the meso-scale disturbances have been extensively conducted by many researchers (Akiyama, 1979; Ninomiya and Akiyama, 1971, 1972, 1973; Yoshizumi, 1977a, b; Ninomiya and Yamazaki, 1979). However, these studies were due to the conventional twice (or four times for the special observing period) daily upper-air observations and the structures were mainly investigated by composite technique. On the contrary, the study for the meso- β scale disturbances has been conducted by using GMS satellite and radar imaginary and surface observation networks, because those are the only data which can describe the meso- β scale disturbances. However, as there are few observations of temperature, humidity and motion fields for the meso- β disturbances, only the morphological study has been conducted. In order to investigate the dynamics for the meso- β scale the finer resolution of observation of temperature, humidity and motion field is indispensable. As a first step to achieve this purpose wind observation with MU radar has been conducted between 4-9, July, 1986. During this observation period, a significant short-time scale fluctuation of the motion field is observed, and is presented in this note.

2. Observations

[A] Observational methods

In the MU radar, wind speed is estimated from a Doppler-shifted frequency. Therefore, to estimate the three components of wind fields, more than three independent observations are necessary. For wind observation, five beams are used; the zenith angle, θ , of one beam is 0°, and the others are 10°. Four beams are directed toward east, south, west, and north, respectively. Here, V_E , V_W , V_N , V_S denote the wind velocities in the beam direction estimated from the Doppler shift frequency and $\theta = 10^\circ$ (Fukao *et al.*, 1988). The radial velocities are represented as

Fig. 1. 1-minute time-averaged horizontal winds in the lower troposphere observed by the MU-radar between 1300 JST, 5, July, 1986. Inconsistent winds result from the failure of fitting due to noise.

follows;

$$V_E(V_W) = w \cos \theta \pm u \sin \theta, \quad (1)$$

$$V_N(V_S) = w \cos \theta \pm v \sin \theta. \quad (2)$$

V_E and V_N corresponds to +, and V_W and V_S to -. If we assume that wind fields are uniform within beam ranges, u and v are estimated as;

$$u = \frac{V_E - V_W}{2 \sin \theta} \quad (3)$$

$$v = \frac{V_N - V_S}{2 \sin \theta} \quad (4)$$

That is, it represents the horizontally averaged wind field over $2h \times \tan \theta$ (h is the height). The accuracy of wind measurement by MST radar was investigated by comparing it to the rawinsonde observation (Farley *et al.*, 1978). Fukao *et al.* (1982) conducted comparative study of wind measurements by MST radar with Rawinsonde over 26 days at Arecibo and found the standard deviation of the difference of two measurements was 3.3 ms^{-1} in the upper troposphere. The accuracy for wind estimates

by the MU radar was also confirmed by comparing those with the wind measurements of the operational RW/RS (Rawin/Radio Sonde) station located nearby the MU-radar (Shionomisaki).

One observation takes one minute, and each observation has been conducted every 2 minutes. Raw-data estimated by using (3) and (4) are displayed in Fig.1. Just looking at this figure, we can easily understand that most of the 1-minute observation of the horizontal wind in the troposphere between 2 km and 10 km are quite reasonable and reliable, because they are completely consistent each other on the vertical and time axes. Surprisingly, the synoptic-scale motion is dominant in the free atmosphere and short-time scale fluctuations are hard to define, although there exists some noise. The reason for this may be due to the fact that the meso- α scale disturbance is moderate and the intensive convective system is not located near the MU-radar. In other words, this MU observation is not enough to describe this meso- α disturbance. To obtain conclusive results about the structure of the meso-scale disturbance, more frequent observations will be nec-

Fig. 2. (top) Sea-level pressure field and (bottom) 700mb geopotential height field on 2100 JST, 5, July.

essary.

[B] Synoptic situations

The synoptic situation during this observation period is shown in Fig. 2. A medium-scale disturbance which was generated over the East-China Sea was propagating north-northeastward along the Honshu island in the Japan Sea and located to the north of the MU-radar on 21 JST, 5, July, 1986 (see, Fig. 2 (top)). The synoptic-scale trough associated with this disturbance is noted at 700mb (Fig. 2 (bottom)). It should be noted that no fine structure can be analyzed by using conventional wind data.

[C] Results

In Fig. 3, the 10-minute precipitation at the MU-radar site at 5, July 1986 is displayed. It is noted

that medium-scale disturbance passed over the MU-radar site between 1100 JST and 1900 JST. Furthermore, an 1 hour time-scale fluctuation is noted in the precipitation field in the medium-scale disturbance. The intensity of the rainfall is moderate (maximum is ~ 10 mm/hour), and we have to say that the results obtained in this observation is for a weak meso-scale disturbance. In general, we can not say that the assumption of uniform wind field in (1) and (2) holds good in the severe convective system. However, as the rainfall rate is moderate in this case, this assumption may be correct.

The horizontal wind observation (u and v) with the MU-radar for this disturbance is displayed in Fig. 4, (top and bottom) respectively. In this case, time scales shorter than 20 minutes are filtered out. The westerly wind fluctuation is found between 1100 and 1700 JST in the middle of the troposphere (~ 4.6 km). On the other hand, around 1400 JST, the north-south wind changed its sign, and the north wind was blowing for 3 hours in the middle of the troposphere. If we assume that this change is due to the passage of a trough or ridge system, this is corresponding to the passage of the trough. From the viewpoint of the time scale, these wind fluctuations relate to the precipitation between 1100 and 1900 JST.

Beside this, remarkable high frequency fluctuations are found in the wind fields between 1100 and 1700 JST.

For example, the westerly becomes strong and the southerly becomes weak around 1230 JST and then the westerly becomes weak and the southerly becomes strong around 1300 JST. This coherent fluctuation in the wind fields is found between 1000 JST and 1700 JST. It is clearly understood that the short-time scale fluctuation is superimposed on the slower time-scale fluctuation. It is dominant in the lower troposphere from 3.0 km to 5.5 km. To show this, a time-filtering technique is applied for the wind field at 4.2 km (Fig. 5). Its period is estimated to be about 1 hour. It is in good accordance with the time scale of the fluctuation found in the precipitation field. Then, this wind fluctuation is considered to be related to the convective system. It is noteworthy that a fluctuation on the time scale of hours is found in the motion field in the middle and lower layer of the atmosphere.

Fig. 6 shows a digitized and objectively composited radar echo observed by Japan Meteorological Agency (JMA) between 1100 and 1600 JST. The ensemble of echoes located to the west of the MU-radar at 1100 JST gradually moved eastward and passed over the MU-radar at 1600 JST. This movement of echoes corresponds to the movement of the meso- α scale disturbance. In this, an intense echo cell is generated to the west of the MU-radar (1309 JST), moves toward east-northeastward (1400 JST)

Fig. 3. 10 min precipitation amount observed at the MU-radar between 0500 JST, 5, July and 0200 JST, 6, July. Unit is mm. Figures below a horizontal axis denote a local time.

and decays at 1600 JST. This echo cell is considered to correspond to the short-time scale fluctuation in the motion field and the precipitation. As a major echo cell passed by the MU-radar at 1400 JST, the wind data of the MU-radar around 1400 JST (1300 JST-1500 JST) was converted into the horizontal wind distribution by applying the space-time transformation. The wind field at 4.5 km is shown with the composited radar echo in Fig. 7. Propagation direction and phase velocity was determined by the movement of the echo cell. Fig. 4 infers that the trough is trapped lower than 5.5 km and the trough axis is vertically declined toward eastward. It should be noted that this small scale and short-time scale fluctuation can be detected only by the fine time resolution observation.

3. Consistency with the conventional upper-air observations.

Even though the continuous observation of the wind fields at a single station has a lot of information, we can not estimate the horizontal structure of the wind fields by using them alone. In order to observe the horizontal structure, a horizontal network of observations is indispensable. If we have a network of MU-radars over Japan, it will give us sufficient information about the nature of the meso-scale phenomena. At the present moment there exists only the network of conventional RW/RS observations. However by combining the MU-radar data

with the existing upper-air observations we can obtain additional information.

In this section the consistency of the temporal fluctuation between the conventional upper air observations and the MU-radar is discussed. In Japan, we have four-times-daily wind observations, and by using these data we can investigate small scale disturbances such as a gravity wave (Ninomiya, 1983). In Fig. 8, the filtered data of the MU-radar data to which a 6 hour running mean is applied is shown with the conventional RW/RS data at 5, July, 1986. The 6 hour running mean is corresponding to the time interval of the conventional upper-air observations. The RW/RS observation is an instantaneous observation and consists of a synoptic scale fluctuation and a small-scale fluctuation. Then, the synoptic-scale fluctuation is filtered out by applying the analysis scheme horizontally. MU data produce the data which are suitable for the synoptic scale analysis by applying a time filtering.

The strong southerly flow started blowing in the morning of July, 5. At Yonago the strong southerly at 850 mb is found on 009 JST, 5, July (refer to the arrow in Fig. 7), and at Wajima it is found on 21 JST, 5. These two stations are located to the west/north of the MU radar. At Shionomisaki, which is located to the south of the MU-radar, a strong southerly is not found. At Hamamatsu a weak low level southerly is noted, and at Tateno which is located to the east of the MU-radar, a

Fig. 4. (top) The east-west wind component and (bottom) the north-south wind component observed by the MU. Unit is m/s. Negative region is shaded.

Fig. 5. Time filtered wind data with the periods from 20 minutes to 2 hours at 4.2 km between 1100 JST and 2000 JST. Unit is m/s.

Fig. 6. The digitized radar echo from 1100 JST to 1600 JST, 5, July, 1986. Dotted region is for very weak echo (equivalent rainfall intensity; ≤ 2 mm/hour), shaded region for weak echo (2–4 mm/hour), and dark region (4–8 mm/hour) for moderate echo.

strong low-level southerly is noted on 21 JST, 5, July.

These changes of wind direction in several RW/RS wind stations suggest that the trough extending southward has moved eastward. This trough did not extend to Shionomisaki, because a strong southerly wind was not found there.

A corresponding southerly flow blows around 1300 JST and the wind direction has changed in the middle of atmosphere ($4 - 6$ km) at the MU-radar. A northerly wind blows 4 hours later. In section 2 we assume that the change of wind direction is associated with the passage of a trough system. Its period is estimated to be about 8 hours. This trough also corresponds to the precipitation from 1100 to 1900 JST observed at the MU-radar (see, Fig. 3). Thus, it is concluded that the medium scale trough (meso- α scale) in the middle of the troposphere had passed over the MU-radar around 1400 JST, which is consistent with the RW/RS observation.

In this case we could obtain the information of the meso- α scale from the conventional upper-air observations without the time-continuous data such as the MU-radar. However, this observation suggests the possibility that we can obtain much more information by combining the time-continuous data and the conventional data.

4. Summary

The time-continuous observation of tropospheric wind field by using the MU-radar is a powerful tool for mesoscale meteorology. At least, time-resolution for observation can be increased, although horizontal resolution is limited. Particularly, it can resolve the wind-field in the middle of the troposphere in minutes. Therefore, we can completely describe the temporal behavior of the meso-scale phenomena at a single station.

In order to apply this potential ability to meso-scale phenomena, an observational program was conducted in the Baiu-season from 1 to 7, July, 1986. One meso-scale disturbance passed over the MU-station during this period.

The following results are obtained;

- (1) The wind direction from southerly to northerly occurred at 1342 JST and the northerly lasted for 4 hours in the middle of troposphere (3.5 km $-$ 6 km). This change of wind direction is due to the passage of the trough system which is confirmed by the conventional upper-air observations.
- (2) Significant change of horizontal wind direction on the time scale of hours was observed. Its period is about 1 hour, which is consistent with that in precipitation change. If this change is assumed to be due to the trough /ridge system, it corresponds

Fig. 7. The digitized radar echo from 1100 JST to 1600 JST, 5, July, 1986. Dotted region is for very weak echo (equivalent rainfall intensity; ≤ 2 mm/hour), shaded region for weak echo ($2 - 4$ mm/hour), and dark region ($4 - 8$ mm/hour) for moderate echo.

to the trough, which is trapped under 6 km, and the system was eastward tilted. Collocation study with the radar echoes shows the consistency between the echo and the trough. The above results confirm the usefulness of the wind measurement of the MST radar for the mesoscale phenomena.

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Fig. 8. Time-space transformation of the MU data observed from 1300 to 1500 JST with the moderate radar echoes (thick lines) at 1400 JST for $z = 3.0, 3.7, 4.5, 5.2$ and 6.0 km.

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