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9.10A THE MU RADAR NOW PARTLY IN OPERATION

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ABSTRACT

The MU radar (middle- and upper-atmosphere radar) of RASC (Radio Atmospheric Science Center, Kyoto University) is now partly in operation, although the facility will be completed in 1985. The active array system of the radar makes it possible to steer the radar beam as fast as in each interpulse period. We expect various sophisticated experiments by the system. A preliminary observation was successful to elucidate atmospheric motions during Typhoon No. 5 which approached the radar site in August, 1983.

INTRODUCTION

The MU radar (middle- and upper-atmosphere radar) has been under construction since 1981 at Shigaraki (35°N, 136°E) northeast of Kyoto. Whilst the total system will be completed in 1985, the system is now, on a reduced scale, in operation for observations of the troposphere and lower stratosphere. In the present paper we shall first outline the MU radar system, which was improved from that originally designed in 1980 (FUKAO et al., 1980), and, later, present some results so far obtained.

SYSTEM OUTLINE

The MU radar under construction is a pulse-modulated monostatic Doppler radar with active antenna array working on the frequency of 46.5 MHz. The basic idea of the system design was discussed by FUKAO et al. (1980) and has remained very similar even after some later improvements; the bandwidth is now given as 1.65 MHz which allows us to have the 1 μs-wide pulse equivalent with 150 m height resolution. The basic parameters are listed in Table 1 where some parameters are changed from those on the original design in 1980. The block diagram of the system under construction is illustrated in Figure 1, where the number of the subgroup of antennas is now 25, increased from 15 in the original 1980 design. Figure 2 shows a recent photo of the MU radar system. The radar site is in hilly national forests and fairly well protected against radio noise interference.

The radar antenna system consists of 475 antennas of 3-subelement crossed Yagi arrayed in a circular area with diameter of, approximately, 100 m (Figure 2). The array is divided into 25 subgroups. Each subgroup consists of 19 elements which are on equilateral triangular grids in each hexagon. Exception is for the 6 subgroups, distributed along the circular periphery, for precise correction or the desirable antenna pattern. This basic triangular distribution with an antenna at each apex of the regular triangle of its side 0.7 long, where λ is the radar wavelength, is found to prevent grating lobes from appearing in the antenna beam steering not exceeding 40° from the zenith. Thus, under such beam steering, the side lobe level for elevation angle less than 20° is suppressed smaller than -40 dB to the main lobe. The circular array has an effective area of 8330 m^2 producing the main beam of 3.6° in width. When the radar beam is directed vertically, the sidelobe is symmetric about the main lobe, the first sidelobe being as low as -18 dB to the main lobe. The crossed Yagi can produce two linear (mutually orthogonal) polarizations and also

TABLE 1. Basic Parameters of the MU Radar

Location:	Shigaraki, Shiga, Japan (34.85°N, 135.10°E)
Frequency:	46.5 MHz
Antenna configuration:	circular array of 475 crossed Yagi antennas
Aperture:	8330 m^2 (103 m in diameter)
Beam width:	3.6°
Polarizations:	linear or circular
Beam directions:	0-30° zenith angle
Transmitter:	
Power amplifier:	475 solid-state amplifiers
Peak power:	1 MW
Average power:	50 kW (duty ratio 5%)
Bandwidth:	1.65 MHz max (pulse length: 1-512 μs variable)
Receiver:	
Bandwidth:	1.65 MHz Maximum
Dynamic range:	70 dB
IF:	5 MHz
A/D converter:	12 bit x 4 channels

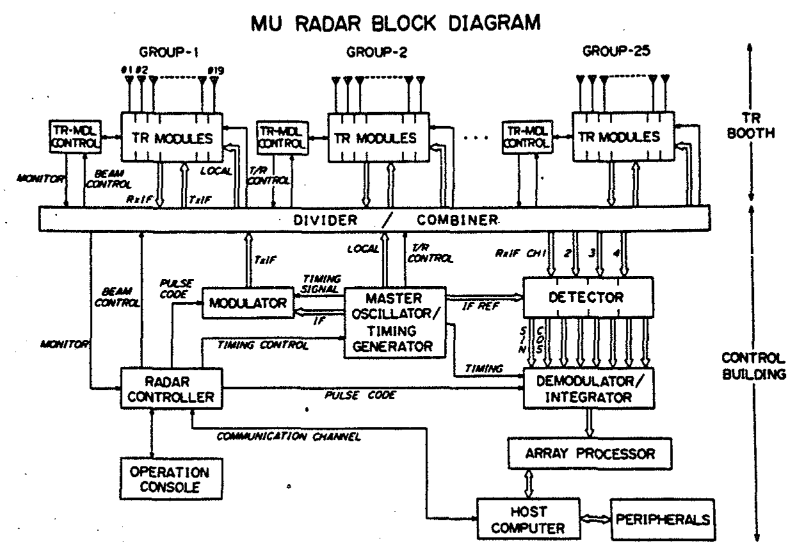


Figure 1. Block diagram of the MU radar system. The radar controller (HP 9835) basically controls all parts of the system, both in the observation rooms and the booths. Computer (Vax 11/750) is used for data analysis (as calculating various spectral moments) and data taking, and for controlling an array processor (MAP 300) which works for calculation of FFT and ACF, and incoherent integration: TR module control is done by 25 microprocessors; the received signal can be processed in four channels, each for sine and cosine detection; the basic signal generator uses a rubidium vapor frequency standard.

Figure 2. Bird's-eye view of the MU radar system. The antenna circular area is marked by white paint line, along and just outside of which the six booths are distributed; each subgroup of the antenna corresponds to each hexagon or each peripheral region as marked by white paint, solid or broken lines, the solid line showing the territorial boundary of each booth; the booth and the antenna element being connected by coaxial cables extended along the surface; the antenna level is lower by 15 m than the surrounding bank on which the iron net fence of 10 m high is built, mainly for avoiding the ground clutter due to the sidelobe radiation in low elevation angle; the two-storied building on the left on the bank is the control building, next door is the guest house; the white circle just beyond the fence on the right is a heliport.

left-handed and right-handed polarizations.

A remarkable feature of the MU radar system is that each antenna element is activated by its own solid-state power amplifier, its peak output power being 2.4 kW. Since the total number of the antenna is 475, the total peak output power becomes approximately 1 MW allowing for antenna loss. Each antenna has also its own receiver preamplifier. Both of the power amplifiers and preamplifiers are mounted on transmitter-receiver (TR) modules. Each of the six booths near the antenna accommodates the modules of four subgroups i.e. (19 x 4) modules except for one booth which accommodates the modules of five subgroups i.e. (19 x 5) modules. Conversion of the 5-MHz IF frequency to and from 46.5 MHz for transmission and reception, respectively, takes place in the modules, thereby simplifying the signal transfer between the booth and the control building which is on the bank overlooking the antenna.

The main advantage of this active array system is that the phase of signal transmitted from each antenna required for beam steering is electronically controlled at low power level. The beam can be tilted to as many locations as 1657 within 30° from the zenith for each interpulse period i.e., as short as

400 ms. Thus, it would contribute to observing the fast varying dynamic behavior of the atmosphere, e.g., gravity waves with fairly short periods.

Each independently operative antenna subgroup is expected to realize various sophisticated observations as that of the close-spaced antenna method (e.g. BRIGGS, 1980) which detects propagation of the interference pattern among the signals received at each antenna. Further technical details of the MU radar are shown elsewhere (SATO, 1980). They remain the same in many respects to the 1980 original design.

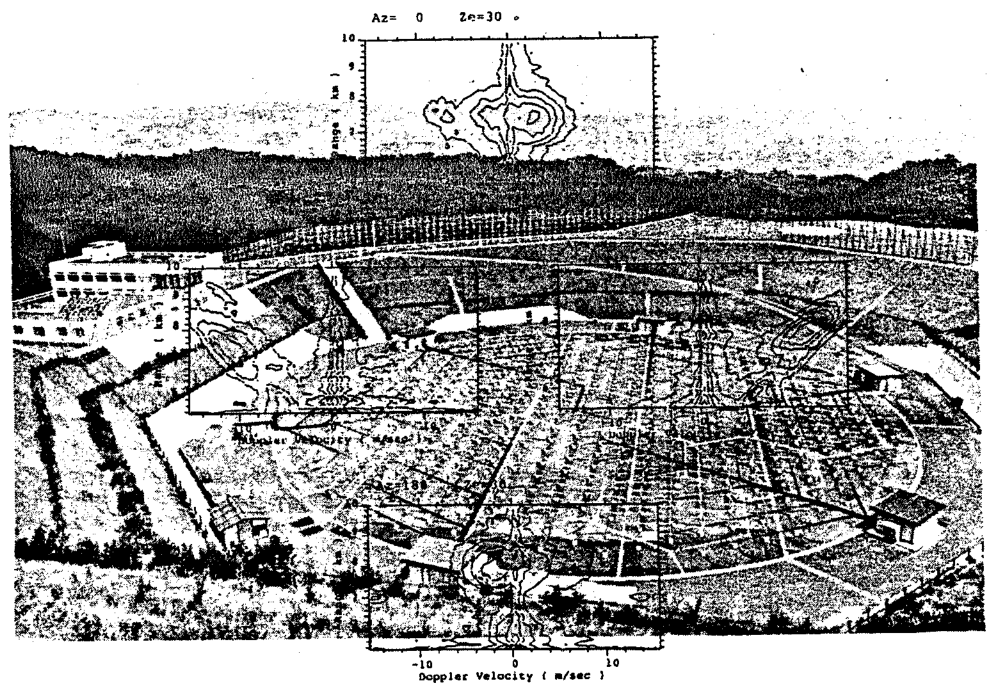
The system, now in operation, is on a reduced scale as having 3 subgroups (57 antennas) which are transmitting, approximately, the 120 kW pulse in the 10°-wide beam. This system is, however, complete in other parts as in controlling, modulation, demodulation and signal-processing, all of which are installed in the control building (Figure 1). We have already confirmed various operations ot the present system to be in good shape. Figure 3 illustrates an observation in which the beam was steered azimuthally, keeping it in a constant zenith angle of 30° (VAD method (velocity azimuth display); BALSLEY and FARLEY, 1976). The beam was steered in every interpulse period. The result shows the well-behaved system (Figure 3(b)).

OBSERVATION OF THE TROPOSPHERE AND THE LOWER STRATOSPHERE DURING TYPHOON NO. 5 IN 1983

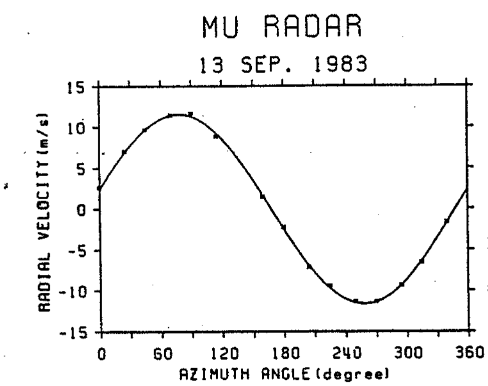
Since April, 1983, we have attempted to measure the wind velocity between 4 and 15 km in height on many occasions using the three subgroups which are now complete. Observation is limited only for periods with no construction work for additional parts of the antenna system.

Figure 4 gives observations in August, 1983 when typhoon No. 5 approached Japan as shown in Figure 5. The observation was done using the complementary code of 16 bits of the 1 μs subpulse, the pulse repetition frequency of 2.5 kHz; after 128-times coherent integration of the orthogonally detected signal, 128-point FFT was carried out and averaging was done on every ten of the result. Since the sampled levels were 64 in number between 4 km and 15 km from the ground, this implies an observation at each level approximately in every one minute. Note that in Figure 4 further averaging is done for approximately 30 minutes. The antenna beam was tilted by 30° from the zenith towards the east, so one can get zonal velocity by doubling the line-of-sight velocity, positive for the leaving and negative for the approaching given in Figure 4. Note that since the averaged vertical velocity is much smaller than the horizontal the positive and negative values correspond to eastward wind (westerly) and westward wind (easterly), respectively. It is clear that the wind observed by the MU radar is consistent with that observed by the conventional radiosonde at Wajima and Shionomisaki considering the location of the typhoon; the distance between Shionomisaki and Shigaraki is about 150 km and that between Shigaraki and Wajima 250 km. The wind velocity distribution with height was obtained from the spectral peak at each altitude and the distribution changed with the typhoon location relative to Shigaraki, as is expected. Figure 4(a), (b) and (c) give such features where one can readily find the wind field to have returned normal i.e., a westerly when the typhoon left. The overall wind distribution varying with time is shown in Figure 6.

Further analysis of the data for typhoon No. 5 has revealed existence of temporal fluctuation of the wind as shown in Figure 7 where the contour map (top) distinguishes between positive and negative velocity regions; the data used are those obtained approximately in every one min and filtered to pick up only shorter period components than 10 min. The period of fluctuation is around several min which corresponds to the Brunt-Vaisala frequency. Figure 7 (b) shows height profiles of wind averaged over 23 min.



a)



b)

Figure 3. VAD observation. (a) Height distribution of Doppler spectrum of line-of-sight velocity is shown as contour map; positive for leaving and negative for approaching. Each beam steering was completed during an interpulse period, i.e., 400 μs for the 16-bit complementary code with the 1 μs-wide sub-pulse; the antenna zenith angle was kept at 30° and the azimuth angle changed, from the north, by 25° or 20° in every other swinging, completing 16 observations in one round; two consecutive rounds are required to finish one observation set for a pair of complementary codes. After coherent integration of 16 sweeps, FFT was done by 128 points. The wind along the radar line-of-sight varies with the azimuth as is expected. The wind remained almost unchanged during the observation period as short as 0.1 s. (b) The line-of-sight (radial) velocity at 6.2 km varying with azimuth; the observed value (small cross) follows well the expected sinusoidal curve (solid curve) giving the wind velocity U (eastward) V (northward) W (upward) as shown.

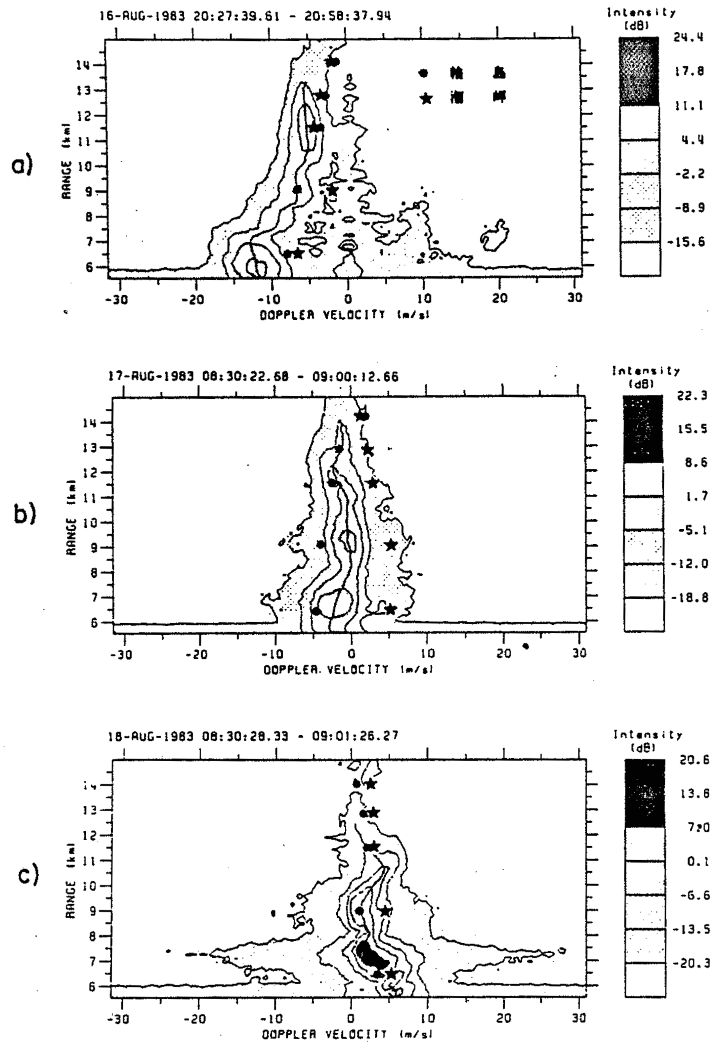


Figure 4. Doppler spectrum of the line-of-sight wind velocity for the 30° tilting from the zenith towards the east. Contour is subject to the dB scale as shown beside the main diagram. The dark asterisk denotes observation at Shionomisaki and the circle at Wajima. Average on 20h28m-20h59m, August 16 in (a), 08h30m-09h00m, August 17 (b), and 08h30m-09h01m, August 18 in (c).

DISCUSSION

The MU radar is now in operation only on a reduced scale. However, as is shown above, we have already been successful in the observation of a typhoon, detecting some of its temporal dynamical behavior varying with altitudes.

Figure 4(a) shows that typhoon No. 5 produced strong westward winds on the left-hand side to the direction of the typhoon course, its intensity attaining as strong as 20 m/s near Shigaraki, distance about 250 km, then decreasing with distance, yet still detectable at Wajima, distance about 520 km; the ob-

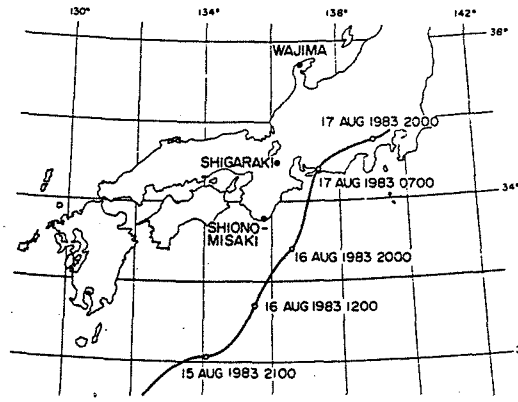


Figure 5. Path of typhoon No. 5. The thick solid line shows the typhoon path. The three dark small circles on the path are the location of the typhoon center on August 15 (21h), 16 (20h) and 17 (20h), respectively. The movement was as slow as 18 km/h.

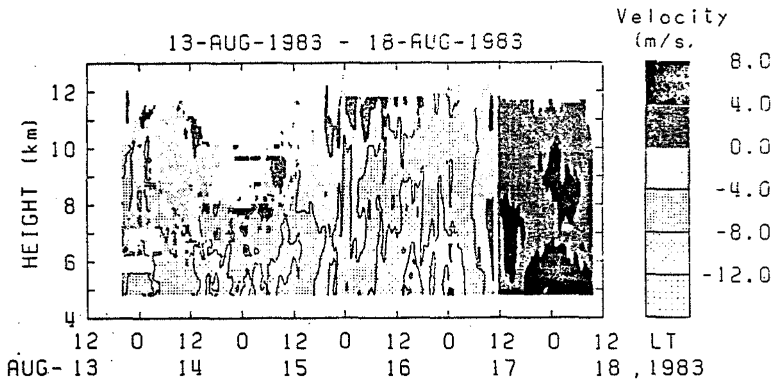


Figure 6. Line-of-sight (tilted towards the east by 30° from the zenith) wind distribution varying with time during typhoon passage. Contour is subject to the m/s shown in the column beside the diagram.

served wind, at this time, at Shionomisaki, was weaker partly because of its location which is more deflected to the west than that of Shigaraki relative to the typhoon. Such effects of the typhoon as reversing the weak westerly usually present, i.e., the eastward wind, were very remarkable at the lowest level observed though the effects became less with altitude. When typhoon No. 5 moved further northeastwards and reached the east side of Shigaraki (Figure 4(b)), the typhoon effect became very weak on the zonal wind as is expected; considering the anticlockwise spiral wind into the typhoon center, the typhoon then should produce mainly southward winds. This is much more remarkable at Shionomisaki (Figure 4(b)) where the typhoon effect had almost disappeared as understood from comparison of the observation there between Figure 4(b) and Figure 4(c). At this time Wajima is most disturbed by the typhoon. However, the general situation is unclear because of no data for meridional winds at all. Nevertheless, a dynamic behavior of typhoon No. 5 seems to be fairly clearly

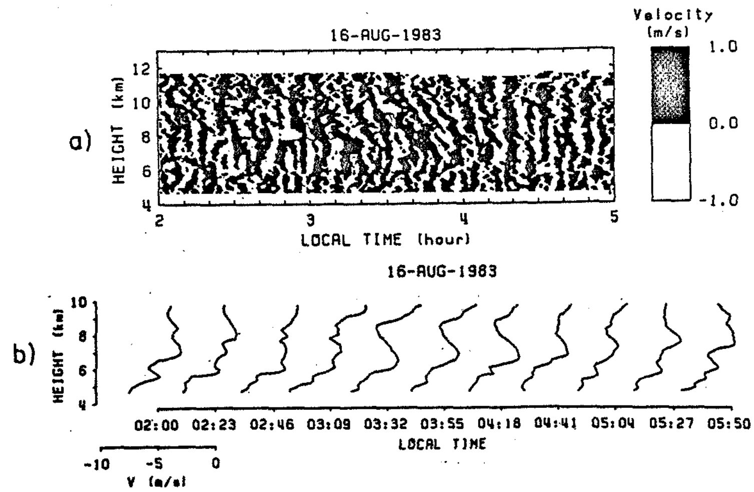


Figure 7. Fluctuating winds in typhoon No. 5. (a) Contour distinguishes between positive and negative velocity regions; averaged values for 1 min are used, removing longer period components than 10 min. (b) Height profiles at various times; averaged values for 23 min are used.

demonstrated by the MU radar as in Figure 4(a-c). The facility would play a role in typhoon monitoring for practical purposes.

Severe weather activity such as typhoons and intense tornadoes has been suspected to be a generator of gravity waves which propagate upwards to the ionosphere, producing small TIDs (traviling ionosphere disturbances) (e.g., TSUTSUI and OGAWA, 1973; HUANG et al., 1978). Some meteorological observations have also been carried out to detect gravity waves with periods long as a few hours in association with severe convective storms (UCCELLINI, 1975). The present observation as in Figure 7 would be novel in that it is a direct wind observation with good time resolution as one minute. The contour pattern in Figure 7(a) recurs with a period of 7 min. The updraft of the typhoon vortex is likely to stimulate the Brunt-Vaisala oscillation overshooting the equilibrium height for the heated air of the updraft (PIERCE and CORONITI, 1966). Looking at Figure 7(b), one can imagine phase progression both upward and downward from a height of 6 km at which the stimulation occurs. Figure 8 illustrates the

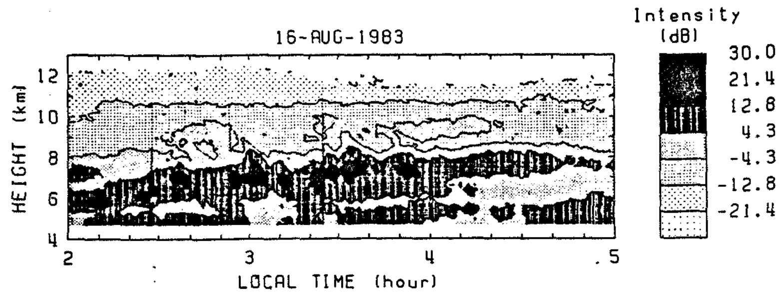


Figure 8. Echo power during typhoon No. 5. The contour corresponds to relative intensity in dB as given by the scale beside the diagram. Intense echo occurs around 7 km height first, descending with time.

signal power during the same period. The power is found intense corresponding to this height suggesting existence of a strongly disturbed situation. Since no data were available for meridional winds, the horizontal wind vector remained unknown. Note that the horizontal wind vector is an important quantity, because it is along the horizontal direction of the gravity-wave propagation. Another drawback of the present observation is the fact that, while the pulse width used in the observation is as short as 1 μs, the beam width of the present small system is as wide as 10°, yielding the height resolution as only 1 km, a resolution which is not enough to decide the phase variation very precisely in Figure 7(b). In atmosphere dynamics it seem important to study three-dimensional wind fluctuation during typhoons under better height-resolution.

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