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# OBSERVATIONS OF THE LOWER ATMOSPHERE OVER THE EQUATORIAL WESTERN-PACIFIC WITH A SHIP-BORNE LOWER TROPOSPHERE RADAR

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## 1. Introduction

Wind profilers are a powerful tool to obtain vertical profiles of three components of wind velocities and are widely used for not atmospheric researches but also operations for weather prediction [Ishihara and Goda, 2000]. However observation data over the sea are still insufficient. We have developed a wind profiler for lower tropospheric observations over the sea (Ship-Borne Lower Troposphere Radar: SB-LTR), based on the L-band (1357.5 MHz) lower troposphere radar [Hashiguchi *et al.*, 2004], which we previously developed. The SB-LTR was installed to the oceanographic research vessel MIRAI (Figure 1) of JAMSTEC, Japan for test observations in March, 2004 (MR04-01) and in December, 2004-January, 2005 (MR04-08) and provided wind profile data over the equatorial western-Pacific.

Figure 1. Overview of the oceanographic research vessel MIRAI of JAMSTEC, Japan.

## 2. SB-LTR System

The SB-LTR system consists of five parts, which are a phased array antenna, an active module unit, a transmitter/receiver unit, a data acquisition unit, and a signal processing unit. An electromagnetic coupling coaxial dipole (ECCD) antenna is used as the antenna element [Miyashita *et al.*, 1999]. The physical arrangement of the antenna is 24 rows and 24 columns of elements, each of which is sub-divided into 2 sub-elements. A total of 96 sub-elements are used.

The active module is connected to four sub-elements through distributors in such a way that a module controls two sub-elements each for one row and one column. The antenna can be divided into four sub-antennas. It is possible to operate the

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*Corresponding author address*: Hiroyuki Hashiguchi, Research Institute for Sustainable Humanosphere (RISH), Kyoto University, Gokasho, Uji, Kyoto 611-0011, JAPAN; E-mail: hasiguti@rish.kyoto-u.ac.jp radar using one sub-antenna (whose size is 2 m x 2 m) for utilization in a relatively small installation space. In MR04-01, one sub-antenna was used. It is possible to vary the beam direction by electronically steering the zenith angle within 45 degrees. A peak output power of 2 kW is obtained by 24 active transmitting modules.

The overview and specifications of the SB-LTR are shown in Figure 2 and Table 1, respectively. 2 m x 2 m antenna and 4 m x 4 m antenna were used in MR04-01 and MR04-08, respectively. All equipment except for the antenna was stored in a container to avoid salt damage. A GPS navigational sensor (Furuno SC-60) and a three-axis angular sensor (MicroStrain 3DM) were deployed to provide necessary adjustments to wind profiles. A clutter fence was used around the antenna to reduce sea clutter echoes.

Table 1. Principal specifications of SB-LTR.

| | |
|---|---|
| Operational frequency | 1357.5 MHz |
| Power | 2 kW (peak),<br>428 W (average) |
| Antenna | 2 m x 2 m (MR04-01)<br>4 m x 4 m (MR04-08) |
| Beam width | 8 deg. (MR04-01)<br>4 deg. (MR04-08) |
| Beam angle | 0-45 deg. of zenith |
| Pulse length | 0.67, 1.0, 1.33 us |
| IPP | 25, 50, 100 us |
| Pulse compression | Spano's optimized code |

Figure 2. Overviews of SB-LTR. (Upper: MR04-01, middle: MR04-08, lower: in-house).

## 3. Observations and signal processing

During the observation, antenna beams were steered to vertical and 4 oblique directions with the zenith angle of 10 degrees. One cycle for 5 directions took about 1 s. Sub-pulse length was 1 us, which corresponds to the range resolution of 150 m. Since 8-bit pulse compression coding with the IPP of 50 us was used, average output power was about 854 W. Time series complex data after conducting pulse-decoding and 128 coherent integrations were stored every 3.2 ms. The data such as roll, pitch, direction, speed, latitude, longitude of the ship simultaneously obtained were also stored for off-line analysis. FFT, incoherent integrations, parameter estimation were performed in off-line mode. In incoherent integration process, when pitch and/or roll in each time exceeds $2\sigma$ (where $\sigma$ is standard deviation), power spectra in that time are not integrated. Spectral parameters (echo power, Doppler shift, and spectral width) are estimated using Gaussian fitting method. For a zenith beam, we omitted data when the average of roll or pitch exceeds 1 degree to avoid the contamination of horizontal wind.

Horizontal wind velocity estimated with above method is relative velocity to ship. Using the direction of ship head $\theta_h$ (where 0 is northward and 90 is eastward), the velocity vector of ship $\mathbf{v}_s = (u_s, v_s)$, and the vertical profile of wind velocity vector relative to ship $\mathbf{v}_o(h) = (u_o(h), v_o(h))$, we can obtain wind profiles in stationary system $\mathbf{v}(h) = (u(h), v(h))$ by

$$\mathbf{v}(h) = \mathbf{R}\mathbf{v}_o(h) - \mathbf{v}_s,$$

where $\mathbf{R}$ is the following rotation matrix:

$$\mathbf{R} = \begin{pmatrix} \cos\theta_h & -\sin\theta_h \\ \sin\theta_h & \cos\theta_h \end{pmatrix}$$

## 4. Observation Results

Figure 3 shows time-height cross-section of zonal and meridional winds observed with SB-LTR in MR04-08. Westerly wind was changed to easterly wind around December 24. During this period, a few MJO passed over, but the precipitation was not observed so frequently. In spite of relatively dry condition above 2 km (not shown), we could obtain wind profiles up to about 5 km.

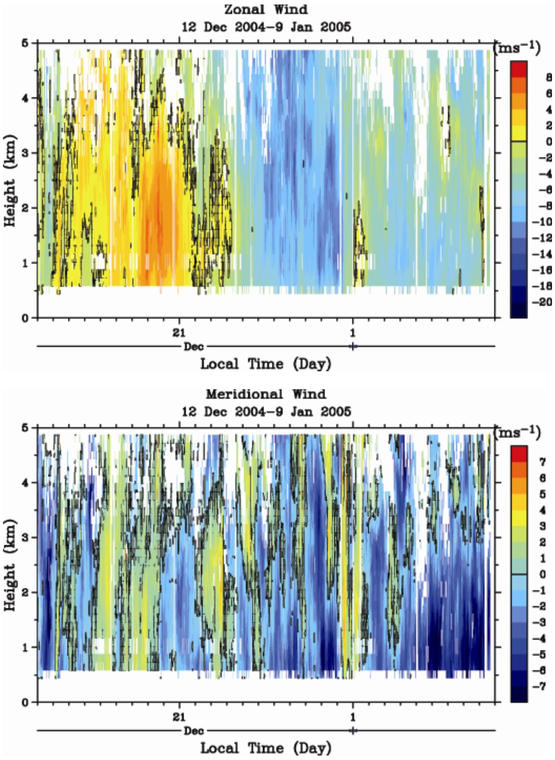

Figure 3. Time-height cross-section of zonal (upper) and meridional (lower) winds observed with SB-LTR during December 12, 2004-January 9, 2005.

Figure 4 shows IR images obtained with GOES-9 on December 28. Cloud system with 100 km scale was passed over 'Mirai' at 03 LT and stayed in the south side. Other larger cloud system was passed the north side. Figure 5 shows time-height cross section of three components of wind profiles on December 28, 2004. Downward velocity larger than 0.7 m/s is due to precipitation echoes. Updraft is maintained for several hours during 7-11 LT which precedes rainband. North-easterly wind is observed in lower height, which blows toward cloud cluster existing in the south-side. Temporal variations of horizontal wind are small.

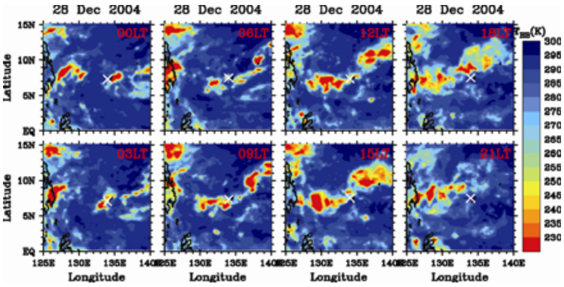

Figure 4. GOES-9 IR images on December 28, 2004.

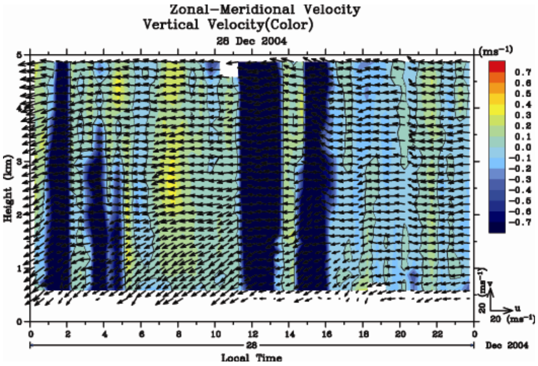

Figure 5. Time-height cross-section of vertical velocity (contour) and horizontal winds (vector) on December 28, 2004.

## 5. Summary

SB-LTR boarded on ‘Mirai’ could continuously observe wind profiles. Wind profiles could be obtained up to about 5 km, although the atmospheric condition was relatively dry. Updraft was maintained for several hours, which precedes westward propagating rainband. Pitch and roll of ‘Mirai’ are very small. To use merchant ships in future, we may need to develop full active phased array system which can control beam directions to compensate ship’s pitch and roll.

## References

Hashiguchi, H., S. Fukao, Y. Moritani, T. Wakayama, and S. Watanabe, A lower troposphere radar, 2004: 1.3-GHz active phased-array type wind profiler with RASS, *J. Meteor. Soc. Japan*, **82**, 915—931.

Ishihara, M. and H. Goda, 2000: Operational 1.3 GHz-wind profiler network of Japan Meteorological Agency, Proceedings of the Ninth International Workshop on Technical and Scientific Aspects of MST Radar, Toulouse, March 13-18, 2000, 538-540.

Miyashita, H., H. Ohmine, K. Nishizawa, S. Makino, and S. Urasaki, 1999: Electromagnetically coupled coaxial dipole array antenna, *IEEE Trans. Antennas Propagat.*, **47**, 1716-1726.