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## **Small scale turbulence and instabilities observed simultaneously by radiosondes and the MU radar.**

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**Abstract.** A Japanese-French field campaign devoted to study small-scale turbulence and instabilities in the lower atmosphere was conducted in September 2011 for three weeks at Shigaraki MU observatory (34.85N, 136.15E; Japan). The VHF MU radar was operated in range imaging mode (e.g. Luce et al., 2001) for turbulence observations at high temporal ( 24 s) and high range (typically 30 m) resolutions. In addition, 59 balloons instrumented with RS92SGP Vaisala radiosondes were successfully launched during the campaign when the radar was operated. Wilson et al. (2011, 2012) showed that turbulence can be detected from raw vertical profiles of temperature measured from standard radiosoundings through the detection of overturns using the so-called Thorpe analysis (Thorpe, 1977). In the present work, we shall present some comparison results between radiosonde and MU radar data.

### **1 Introduction**

Soon after their conceptions, ST (Stratosphere-Troposphere) VHF radars have been used simultaneously with instrumented balloons for measuring atmospheric parameters. Intercomparisons improved our knowledge on the radar backscattering mechanisms at VHF which, in turn, provided some information on atmospheric dynamics and structures at various scales. A variety of methods was then developed for retrieving small-scale turbulence parameters from ST radars. However, the dominant sources and characteristics of the turbulent events detected by ST radars in the troposphere are still poorly documented partly due to the lack of temporal and range resolutions of these instruments (typically a few minutes and 150 m, respectively). Recently, the MU radar has been upgraded for being operated in range imaging mode (called Frequency domain radar Interferometry Imaging -FII-), allowing a range resolution of several ten meters and a time resolution of several ten seconds (e.g., Luce et al., 2001, 2006).

A Japanese-French field campaign devoted to the study of turbulence and instabilities in the free atmosphere with the MU radar in FII mode was carried out for three weeks in September 2011 at the Shigaraki MU Observatory (Japan). During this campaign, 59 radiosondes (Vaisala RS92SGP) were launched at the radar site. Turbulent events were detected from temperature/humidity profiles collected from radiosondes by applying the methods described by Wilson et al. (2011, 2012).

The dataset collected in September 2011 helped us to characterize the turbulent events detected by the MU radar and the background atmospheric conditions in which they occurred. We shall present some results of this campaign including direct

comparisons between observables collected simultaneously by radiosondes and MU radar.

## **2 Dataset**

The 59 RS92SGP Vaisala radiosondes were launched every three hours mainly during night periods. The measurements consist of pressure, temperature, relative humidity (and horizontal wind) at a vertical sampling of 1 Hz (i.e. 3-5 m), the balloons being under-inflated. The MU radar is a flexible and fast beam-steering Doppler pulsed radar operating at 46.5 MHz (6.45-m radar wavelength, 3.5-MHz bandwidth and 1-MW peak output power) (e.g., Fukao et al., 1990). The radar beamwidth is 3.6°. The FII technique consists in transmitting several closely-spaced frequencies switched pulse to pulse.

The collected data at the various frequencies are processed using the adaptive Capon processing method (Luce et al., 2001). The radar was operated with five equally spaced frequencies from 46.0 MHz to 47.0 MHz (i.e., with a frequency spacing of 0.25 MHz). Range sampling was performed from 1.32 km up to 20.37 km ASL with a step of 5 m (the initial range resolution was 150 m). The radar antenna beam was steered into three directions (one vertical and two oblique directions at 10° off zenith toward North, East) so that winds could be estimated and echo powers between directions could be compared. The number of coherent integrations was set equal to 32 and one profile was acquired every 24.5 s at a time sampling of 6.14 s.

## **3 Balloon data processing method**

The Thorpe method consists in comparing a measured potential temperature profile conserved during reversible dry or moist adiabatic motions to the sorted profile  $\theta^s$ , used as a reference profile. Small scale turbulence is expected to induce local overturns within the  $\theta$  profile. Identification of the turbulent layers is based on the identification of the overturns by subtracting the observed and sorted profiles (Figure 1). Such a method has been used mostly in oceanic studies, and more recently in an atmospheric context (Luce et al., 2002; Gavrilov et al., 2005, Nath et al, 2010, Alapatu et al., 2010, Kantha and Hocking, 2011). Wilson et al. (2010, 2011) proposed an objective method based on both an optimal filtering and on a statistical test making possible to reject artificial overturns produced by noise.

Water vapour saturation may significantly reduce the stability of the atmospheric stratification. The impact on turbulence detection in clouds from in situ measurements was recently considered by Wilson et al. (2012). According to the state of the air parcels probed by the sensors, dry (i.e. subsaturated) or saturated, the dry and moist (saturated) adiabatic lapse rates were estimated by using the derivations given by , e.g., Durran and Klemp (1982). Composite potential temperature profiles were calculated by a numerical integration of the vertical profiles of dry or saturated lapse rates (Wilson et al., 2012). The saturated (i.e. cloudy) layers were detected from the radiosonde measurements of relative humidity by applying an empirical multi-thresholds' method described by Zhang et al. (2010).

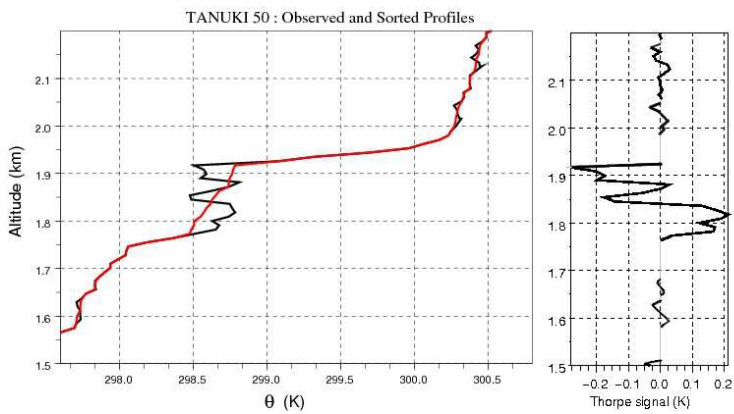


Fig.1 Exemple of detection of an overturn based on the Thorpe sorting

#### 4 A case study

Before 21 September 2011, summer anticyclonic conditions were met over Japan. Just after the passage of typhoon Roke over Japan (September 21st), the tropospheric jet-stream, initially running at higher latitudes, drifted southward. Autumnal weather conditions started from 22 September with negative temperature anomaly at tropospheric heights and the passage of an upper level frontal zone over Japan. We observed the passage of this front by both MUR and radiosondes. A very intense turbulent layer was detected by MUR during the night of September 25–26, corresponding to the passage of the upper level front ( below the dashed line drawn in Figure 2a showing the location of the frontal zone). Echo intensities were similar in the three beam directions, indicating pure isotropic scattering in this layer (not shown). This turbulent event was probed by three radiosondes (51, 52 and 53) as shown by Figure 2a.

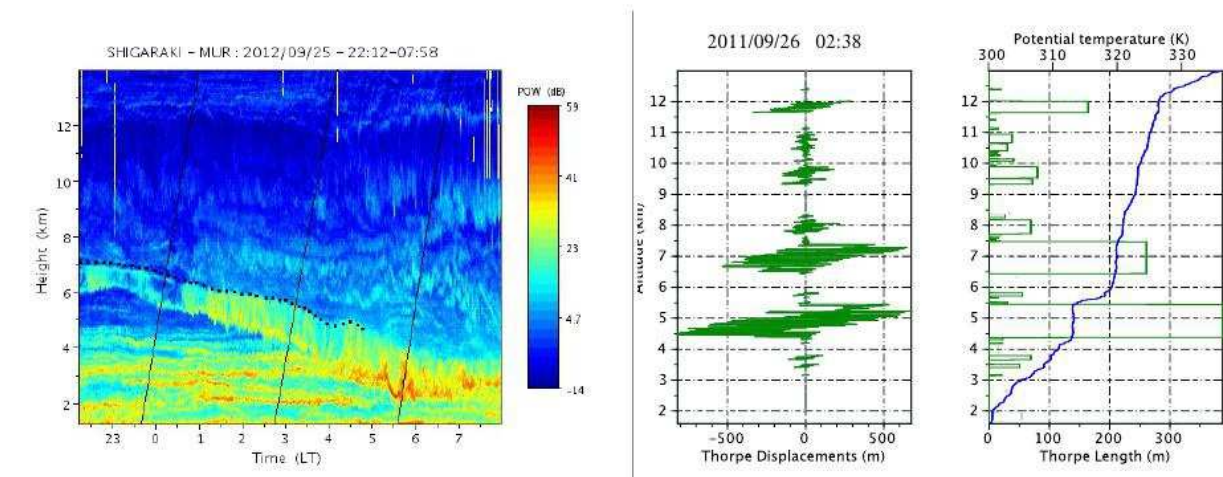


Figure 2 (a) Time-height cross-section of echo power from MU radar measurements in FII mode and at vertical incidence. The dashed line shows the height of the front and the continuous lines show the altitude versus time of the three balloons launched during this event. (b) The turbulent layers detected from the radiosounding 52. (Left) Thorpe displacements (Right) Thorpe lengths and potential temperature (blue line). The intense layer seen by the MU radar is within the height range 4.5-5.5 km.

Figure 2b shows the locations of the turbulent layers for balloon flight 52, the Thorpe displacements and Thorpe lengths. A 1-km deep turbulent layer was observed around

the altitude of 5 km underneath the frontal zone, consistent with the radar observations in Figure 2a. The concurrent observations from MU radar and balloons makes thus possible to estimate the energetics of this turbulent event. Turbulent kinetic energy (TKE), estimated from the vertical velocity variance measured by the MU radar, reaches 3.5 J/kg in average. Turbulent potential energy (TPE) inferred from the Thorpe length and Brunt-Väisälä frequency calculated from balloon data, is 0.7 J/kg within the layer. The corresponding dissipation rates of kinetic energy,  $\varepsilon_k$ , and potential energy,  $\varepsilon_p$ , are very large:  $\varepsilon_k \sim 30$  mW/kg,  $\varepsilon_p \sim 9$  mW/kg. From these dissipation rates and the background stability of the stratification within the turbulent layer, a sensible heat flux  $\rho c_p K_\theta d\theta/dz \approx 130$  W/m<sup>2</sup> is obtained.

## 5 Conclusions

The data collected in September 2011 were obtained during various meteorological conditions. In the present work, we focused on an intense turbulent event associated with a frontal zone. The turbulence layer was generated at a cloud base and extended well below the frontal zone. As already reported by Luce et al. (2010), turbulence was very likely produced by a convective instability due to evaporative cooling near the cloud base. In the present case, the data from four consecutive balloon flights confirmed the presence of a statically unstable layer ( $N^2 < 0$ ) giving extra-credence to this interpretation. In addition, the presence of a turbulent layer of depth similar to the radar echo layer thickness ( $\sim 1.0$  km) was confirmed from the in situ profile by applying detection method of turbulence described by Wilson et al. (2010). Such a mechanism of turbulence generation is an alternative to dynamic shear instabilities, commonly proposed in the literature. The energetics associated with this event could be estimated using the standard approaches and extreme values of TKE, energy dissipation rates and heat flux were obtained. These results indicate that such turbulent events may have a strong impact on its environment. Further studies will be performed from this dataset and will aim at evaluating the agreement between the radar and balloon data and identifying the mechanisms of generation of turbulence in various weather conditions.

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