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. 1] for turbulence observations at high temporal ($\sim$ 25 s) and high range (typically $\sim$ 30 m) resolutions. In addition, 59 balloons instrumented with RS92G Vaisala radiosondes were succesfully launched during the campaign when the radar was operated. Reference [2] 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 [3]. In the present work, we shall present some comparison results between radiosonde and MU radar data.

Key words: Turbulence, Observations, ST radar, radiosoundings.

1. INTRODUCTION

Soon after their conceptions, ST (Stratosphere-Tropopshere) 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 [1; 4]. A Japanese-French field campaign devoted to the study of turbulence and instabilities in the troposphere and the lower stratosphere with the MU radar in FII mode was conducted in September 2011 for three weeks at the Shigaraki MU observatory (Japan). Turbulent events could also be detected from temperature profiles collected from 59 RS92G radiosondes launched at the radar site by applying a Thorpe analysis to the raw data sampled at 1 Hz (corresponding to a vertical resolution of 3-6 m depending on the vertical velocity ascent of the balloons). Turbulent events are expected to produce local superadiabatic lapse rates (overturns) in the potential temperature profiles. An original and objective processing method for selecting real overturns from those produced by instrumental noise in weakly stratified regions was successfully developped [5; 2]. In addition, Brunt-Vaisala frequency and and Richardson number profiles can be estimated in the vicinity or even within the turbulent layers. 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 RS92G Vaisala radiosondes were launched every three hours mainly during night periods. The measurements consist of temperature, pressure, relative humidity (and horizontal wind) at a vertical sampling of 1 Hz (i.e. 3-5 m). Based on these observables, we computed profiles of dry and moist (saturated) adiabatic lapse rates for dry and saturated layers [6]. Potential temperature profiles were estimated by a numerical integration of the vertical profiles of lapse rates. The effect of saturation on

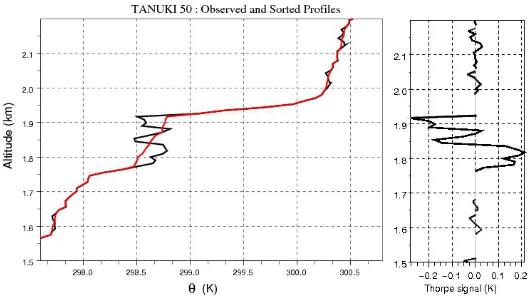

Figure 1. Exemple of detection of an overturn based on the Thorpe sorting. The red curve shows the reference (i.e. sorted) potential temperature profile, the black curve showing the observed profile.

the static stability was thus taken into account.

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) [7, e.g.]. The radar beamwidth is 3.6^o. 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 [1]. 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^o 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 the observed profile $\theta(z)$ to a reference profile $\theta_s(z)$, the reference profile being obtained par sorting the θ profile. Small scale turbulence is expected to induce local overturns within the θ profile. Identification of the turbulent layers is based on the identification of these overturns by performing the difference between the observed and sorted profiles (Figure 1). Such a method has been used mostly in oceanic studies, and more recently in an atmospheric context [8; 9]. It was suggested by [10] to apply the Thorpe detection to standard radiosoundings. However, this method cannot be blindly applied to any radiosounding profile because instrumental noise effects must be carefully considered. [5, 2] proposed an objective and robust method based on both an optimal filtering and on a statistical test ensuring the rejections of artificial overturns produced by noise. This detection method makes it possible to detect turbulent layers or patches typically deeper than $\sim$ 40 m in the troposphere and $\sim$ 15 m in the lower stratosphere.

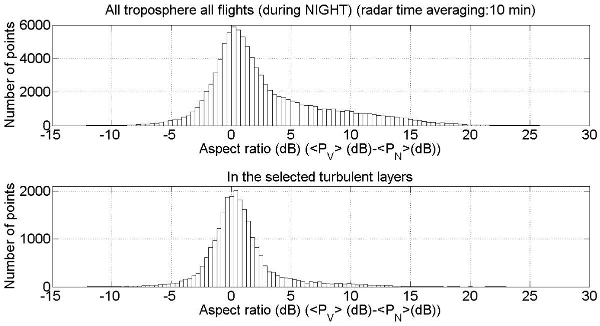

Figure 2. Top: histogram of radar aspect ratios (see text). Bottom: histogram of radar aspect ratios measured in the altitude ranges of the layers selected from radiosondes.

4. STATISTICAL RESULTS

For each selected turbulent layer, the time lag for which the corresponding air mass passed the nearest to the radar has been estimated. We thus constructed a composite profile of the radar echo power corresponding to the balloon flight. The radar aspect ratio is defined as the ratio between radar echo powers measured from the vertical beam to an off-vertical beam. An aspect ratio of unity (i.e. 0 dB) is expected for echoes backscattered from refractive index irregularities produced by isotropic turbulence. The top panel figure 2 shows the histogram of aspect ratios for the overall radar profiles during the balloon flights. The bottom panel shows the corresponding histogram obtained when selecting the altitude ranges of the turbulent layers detected from the radiosondes. In this latter case, the distribution of aspect ratios appears to be almost symmetrical with respect to 0 dB as expected for nearly isotropic turbulence. Such a result strongly supports that nearly isotropic turbulence produced the radar echoes.

Another result (not shown) is a significantly high positive correlation between radar echo power and the refractive index structure constant C_n^2 inferred from the temperature variance within the turbulent layers independently detected by balloons. Also, the dynamics of both quantities is very similar, allowing an indirect calibration of the radar. These first results appear very encouraging.

5. CONCLUSIONS

The data of the September 2011 campaign were collected during various meteorological conditions. In the present work, we focused on statistical comparisons of quantities related to the energy of small scale turbulence observed independently by both the MU radar and radiosondes. We found an overall satisfying agreement between radar and balloon observables, giving thus strong credence in the proposed detection method. Further studies will be performed from this dataset and will aim at identifying the mechanisms of generation of turbulence in various weather conditions.

ACKNOWLEDGMENTS

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