TEMPERATURE VARIATIONS SEEN BY HIGH RESOLUTION RADIOSONDES AS SIGNS OF TURBULENCE, COMPARISON WITH ESRAD

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ABSTRACT

Temperature variations seen by radiosondes can be an important source of information about the turbulence in the atmosphere. By using slow-ascent rate Meteolabor radiosondes with very fast temperature sensor response and high sampling rate, the vertical resolution of temperature measurements can be significantly increased and aid us in testing if the fluctuations due to turbulence can be detected in the temperature variations. The interpretation of the small-scale variations seen by the sonde as signatures of the turbulence is supported by a comparison with measurements from the ESRAD 52 MHz radar. The radar detects layers with higher levels of turbulence (short correlation times - τ) at the same heights as the sonde sees enhancement in the amplitude of the temperature variations in a layer. Using Thorpe's method, overturning areas can be identified and aid in estimating the vertical extent of some mixing events [3]. In comparison with radar data, Thorpe length derived from high resolution sounding measurements can provide finer vertical resolution of mixing events in the atmosphere. However it detects overturning areas without regards for age or their turbulent activity (except in regions of convective instability). It complements turbulence data measured by VHF radar which measures active turbulence.

1. INTRODUCTION

In the polar regions with an otherwise statically stable troposphere, turbulence plays an important role as a potential source of vertical mixing of atmospheric constituents [1]. For example, it contributes to stratosphere-troposphere exchange in these areas. However, the importance of turbulence in these processes still needs to be quantified. For example this might help us to explain the seasonal variation of tropospheric ozone in the polar regions.

Strong turbulence, especially the kind not associated with characteristic cloud formations, known also as Clear Air Turbulence (CAT), can present a significant danger for aircraft. In aviation weather forecasting the identification of potentially dangerous CAT areas is an important task. It is realized with the help of Numerical Weather Prediction (NWP) models and by meteorologists identifying these areas from synoptic analysis and available remote sensing sources on the basis of current understanding of CAT and empirical rules (for example moderate CAT can be found in areas where horizontal wind shear is greater than 10 m/s per degree of latitude or where vertical wind shear is greater than 3 m/s per 300 meters of height, CAT turbulence is often also associated with jet stream areas). As CAT is a rather small scale and short lived meteorological phenomenon, it is often not good resolved by current operational NWP models.

Better understanding of turbulence and more convenient methods of its detection can aid to increased aviation safety as well as to better understanding of stratosphere-troposphere exchange processes in polar or tropical regions where the use and possibilities of other means of turbulence detection (like MST radars) are rather scarce.

We have concentrated on a method originally used in oceanography to identify turbulent areas, which was already applied to detect and identify turbulent areas in the tropical troposphere [2], and the comparison of the data gained with this method with observations by ESRAD (ESrange RADar).

2. INSTRUMENTS AND MEASSUREMENTS

The vertical profile of temperature, relative humidity, ozone current and wind direction and speed was measured by a Meteolabor SRS-C34 ozone sonde with an ECC ozone sensor. It was launched at the ESRAD site on 27th September 2010. This sonde was equipped with a high-response temperature sensor with a response time less than 0.5 second acquiring in average 2 to 3 measurements per second. To improve the vertical resolution of the sonde further, the amount of helium gas needed for the balloon for the sonde to ascend at a rate between 1.5 – 3 m/s was calculated. With the combination of fast response time of the sensor and slow ascent rate of the sonde we gained a vertical resolution for temperature measurements of 0.75 m. With this resolution we could look at the turbulence on scales down to 3 m, which makes it possible to compare these results directly with the turbulence data measured by ESRAD radar which covers the same length scales.

ESRAD is an interferometric VHF wind-profiling radar, located in northern Sweden at ESRANGE (67.9°N,

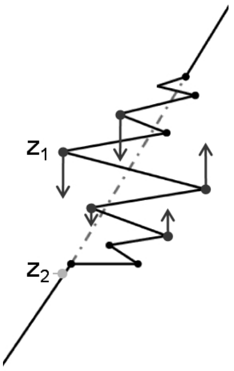

Figure 1. Schematic representation of reordering in Thorpe's method.

21.1°E). It operates at 52 MHz frequency. The measurements used for comparison were 1 hour mean profiles of signal to noise ratio, horizontal and vertical wind measurements and correlation time (τ) determined by the full correlation technique.

3. METHOD AND DATA ANALYSIS

Thorpe's method is used in oceanography for empirical estimation on the length scale of turbulent overturning from analysis of vertical density profiles. It is a useful visual aid to define the vertical extent of some mixing events [3].

Thorpe's method is based on monotonic rearrangement of density (or potential temperature) profile. The new monotonic profile does not contain any inversions. In fig. 1 we show a schematic representation of this reordering. The points with given potential temperature are moved from their original height z_1 to a height z_2 which represents the height of the point in the rearranged profile. These heights can be determined for each point of the vertical profile and their difference gives a characteristic called Thorpe displacement:

$$d = | z_1 - z_2 | \qquad (1).$$

Thorpe length L_T is then given as root mean square of Thorpe displacement:

$$L_T = \langle d^2 \rangle^{1/2} \qquad (2),$$

where $\langle\ \rangle$ denotes appropriate averaging process [2]. In our case averaging over 3.5 m bins was done and a10 point running mean was applied to the data to reduce noise. All overturns smaller than 1.1 times the vertical resolution of the sonde were discarded to eliminate spurious overturns as described and applied by Clayton and Kantha [4] or Alappattu, and Kunhikrishnan [2].

On the left side of fig. 2 we show the temperature and relative humidity profile measured by sonde on 27th September 2010. From this, the profile of potential temperature was derived and then the Thorpe displacements (fig. 2 right side) were calculated. In the Thorpe displacement we can observe several overturning areas around 2, 5.5, 7 and 8.6 km. Areas with small Thorpe displacement can be seen to correspond with the inversions in the temperature profile around 3.8 and 4.2 km. As potential temperature is a conservative characteristic of an airmass, changes in Thorpe displacement can be also linked with changes of airmasses in the vertical profile.

To gain more information about the character of the turbulent areas, Richardson number was also calculated from the sonde data. Thorpe length and Richardson number are shown in fig. 3. They exhibit internal integrity in our sonde data as the overturning areas shown by Thorpe length can be identified in the profile of Richardson number as well.

Hourly means of ESRAD measured turbulence (represented as 1/τ) and signal to noise ratio (SNR) are shown in fig. 3. The black lines in the plots represent the ascent of the sonde with time. While comparing the results from our sonde measurements with ESRAD measurements we have to keep in mind that the compared entities are based on measurement of different properties. While Thorpe length is detecting overturning areas from the spatial variation in potential temperature, ESRAD is detecting turbulence based on the change in vertical movements of air parcels.

In fig.3 we can see that several overturning areas can be linked with turbulence observed by ESRAD. At heights 2.0-2.8 km we can see weak turbulence in the radar data and Thorpe length up to 80 m at the same heights. Overturning at heights between 8 and 9 km is in agreement with the radar data too. The radar data

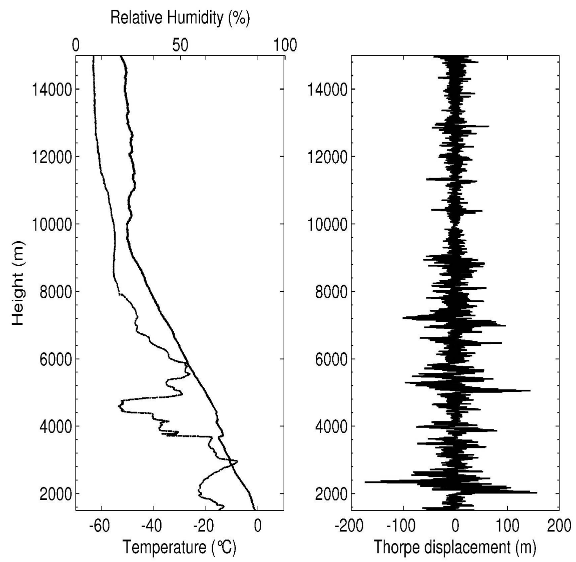

Figure 2. Temperature and relative humidity profile (left), Thorpe displacement (right)

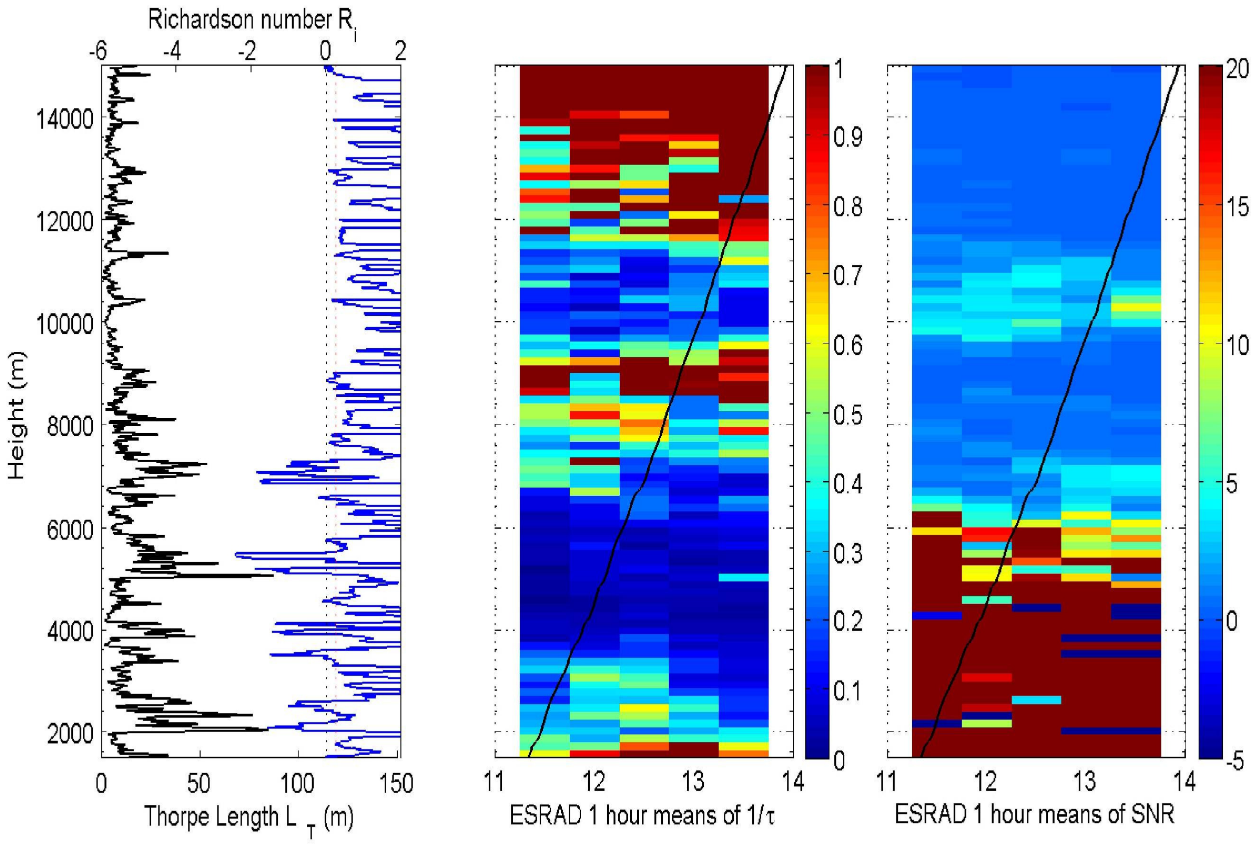

Figure 3. Thorpe length and Richardson number derived from sonde data (left), hourly means of ESRAD 1/correlation time – τ (middle) and hourly means of ESRAD signal to noise ratio (right).

indicates a turbulently active area just below the tropopause (the increase in SNR data at about 10 km marks the tropopause). The tropopause height observed by the radar is in good agreement with the tropopause observed in the temperature profile. Turbulence seen by the radar at these heights is recognized in the Thorpe length, although having characteristic scale length of only around 30 m. Small positive Richardson numbers would indicate that turbulence is here caused mainly by wind shear, which is in agreement with changes in wind speed and direction measured by both ESRAD and the sonde at these heights. Overturning in the height around 7.2 km, with Thorpe length around 50 m, can be also weakly linked with the radar data. As there is turbulence observed in the previous hourly mean in these heights, the discrepancy can be caused either by spatial displacement of the sonde or it is a sign of remnants of previous turbulence in a layer where the overturning is still visible in the temperature measurements.

However, in the Thorpe length or Richardson number inferred from sonde data we also see overturning or turbulent areas that are not visible in the turbulence measurement of ESRAD. Most noticeable is the area between 5 and 6 km. In the sonde data it has a layered structure. Some of these layers were identified as neutrally stratified. ESRAD does not observe any active turbulence at these heights suggesting that the variations in the temperature profile are a result of earlier overturning.

4. CONCLUSIONS

Thorpe length can be used as simple method for detection of overturning areas in the free atmosphere from a vertical profile measured by sondes. As it detects these areas without regard for the activity or age of turbulence further characteristics and analysis is needed for better interpretation (e.g. identification of well mixed and neutrally stratified layers). As suggested by Clayson and Kantha in [4], concurrent or close observation in time and space could help to overcome some problems and given the statistical nature of turbulence, they could create a proper ensemble average to obtain a clear picture of turbulent processes. However, taking into accounts the cost of sondes and problematic logistic, this could become costly [4].

As we show here, turbulence characteristics derived from sonde data can provide a useful compliment to radar measurements and help us to gain more detailed information with finer vertical resolution of individual layers. We believe that collocating sonde measurements with VHF wind profilers can lead to better understanding of turbulence and radar measurements as well. In this study we have concentrated on the comparison of sonde-deduced turbulence with radar data mainly in the upper troposphere in the polar region. With data gained by slow-ascent and high-response sondes, the resolution would also be satisfactory for studying overturning in the stratosphere, where the local stability is high and the scales of overturning are smaller.

Further investigation of possibilities for quantifying turbulent areas under and in the tropopause region can help us to better determine the role of turbulence in troposphere-stratosphere exchange processes which still represent a not quantified and not well understood area of global air circulation, not just in polar regions but also in the tropics as shown in [2].

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