Comparison of weather-balloon observations of in-cloud and clear-air turbulence with model predictions

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Introduction

Turbulence costs the airline industry millions of dollars each year and injures many passengers. There are still difficulties in the numerical prediction of turbulence, especially clear-air turbulence (CAT), which is particularly damaging because planes cannot detect it in advance. The aim of this work is to confront atmospheric CAT theories with turbulence measurements made using adapted RS92 radiosondes, which carry motion detectors based on magnetometer devices sensing the Earth's magnetic field. The radiosondes also carry solar radiation sensors, allowing in-cloud turbulence and CAT to be distinguished. The Richardson number and Thorpe lengths scale can also be deduced from the ascent profile, allowing for a combination of measurements to be made.

Sensor package

The sensor package consists of a magnetometer sensor aligned along the vertical axis and a solar radiation sensor mounted at the top. The magnetometer sensor measures the Earth's magnetic field, which, as it is stable, allows the motion of the balloon to be measured. The solar radiation sensor allows the sensor package to detect whether it is in cloud. The data from both sensors is sent through the PANDORA system (Harrison et al. 2012) connected to a standard Vaisala RS92 radiosonde via the ozone port, for inclusion with other meteorological data (Pressure, Temperature and Humidity, "PTU") and telemetry to the ground station (Fig 2).

Fig 1. RS92 radiosonde flown beneath a 200g balloon (University of Reading)

Fig 2. Instrumentation setup: PANDORA box containing magnetometer sensor and solar radiation sensor (left) attached to RS92 radiosonde (right)

Data processing

Thirty radiosondes including the magnetometer and radiometer sensor package were launched between October 2012 and April 2013 from the University of Reading's Atmospheric Observatory. PTU, GPS and sensor package data were sent back at 1 second resolution. The data from the magnetometer sensor had the standard deviation taken over an 8 second period, to give Magnetic Variance Units (MVUs). The data were then de-trended to remove the temperature effects on the magnetometer sensor. This provides a high vertical resolution method for detecting turbulence. The magnetometer sensor has been calibrated against boundary layer LIDAR at the Chilbolton observatory (Harrison et al. 2009). Additionally, quantiles of the data based on the probability of turbulence being experienced anywhere in the free atmosphere are used to estimate MVU threshold values, to indicate turbulence.

Length scales of a Thorpe analysis were calculated from the raw PTU data, to estimate the size of turbulent eddies induced by inversions in the potential temperature profile (Clayson & Kantha 2008). Positions of the Thorpe length scales can then be compared in regions of increased MVU.

The ERA-Interim reanalysis data set was then used to calculate a variety of CAT turbulence diagnostics that feature in many turbulence forecasts. These are compared with MVU measurements to test if the diagnostics were successfully able to detect turbulence.

Conclusions

From the initial results of these flights it can be demonstrated that the magnetometer sensor can effectively detect turbulence. In the case study the sensor detected CAT near the jet region and turbulence caused by near-cloud radiative cooling near cloud tops as identified by the solar radiation sensor. Results from the magnetometer sensor can therefore be used in the validation of CAT diagnostics.

Case Study: 24 January 2013

Ascent

At the cloud edge (height ~2 km), shown by an increase in solar radiation and a drop in RH (Fig 3b-c), there is a sharp increase in MVU (Fig 3e) implying near-cloud radiative cooling regions at the cloud top, causing turbulence. Thorpe length scales also indicate overturns at this height (Fig 3f).

Turbulence is detected at 5 km at the jet boundary, indicated both in MVU and the Thorpe length. Near the jet core at 8 km, there is another turbulent region. This time, however, the Thorpe length is much smaller. It is important to note that at 4 km, despite a larger length scale calculated, there seems to be a smaller MVU detected than for other instances. The balloon ascended to 18 km but began to lose telemetry at 14 km.

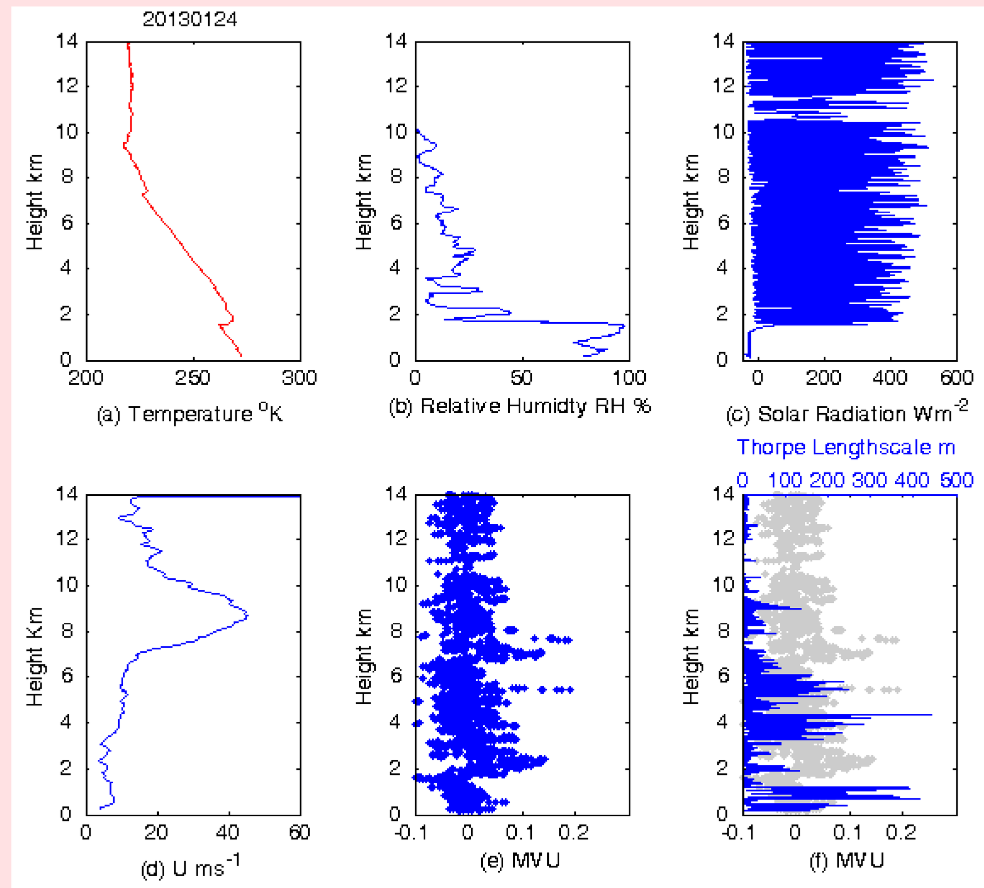

Fig 3. (a) temperature, K (b) relative humidity, % (c) solar radiation, W m^{-2} (d) wind speed, m s^{-1} (e) MVU (f) calculated Thorpe length scale, m (blue) over-plotted on MVU (grey) at 1100 on 24/01/2013.

Comparison with turbulence diagnostics

Turbulence diagnostics for the time of launch were calculated from ERA-Interim data. The six shown in Fig 4 are six of the more common turbulence diagnostics used by aviation forecasters. Here, the eddy dissipation rate (Fig 4c) is calculated from the Brown index. Ellrod's turbulence index (Fig 3d) forecasts moderate turbulence but only for one of the instances. The product of flow deformation with temperature gradient (Fig 4e) provides the best forecast for the turbulence encountered. Sharman (2006) states that this quantity is one of the best turbulence forecasting diagnostics.

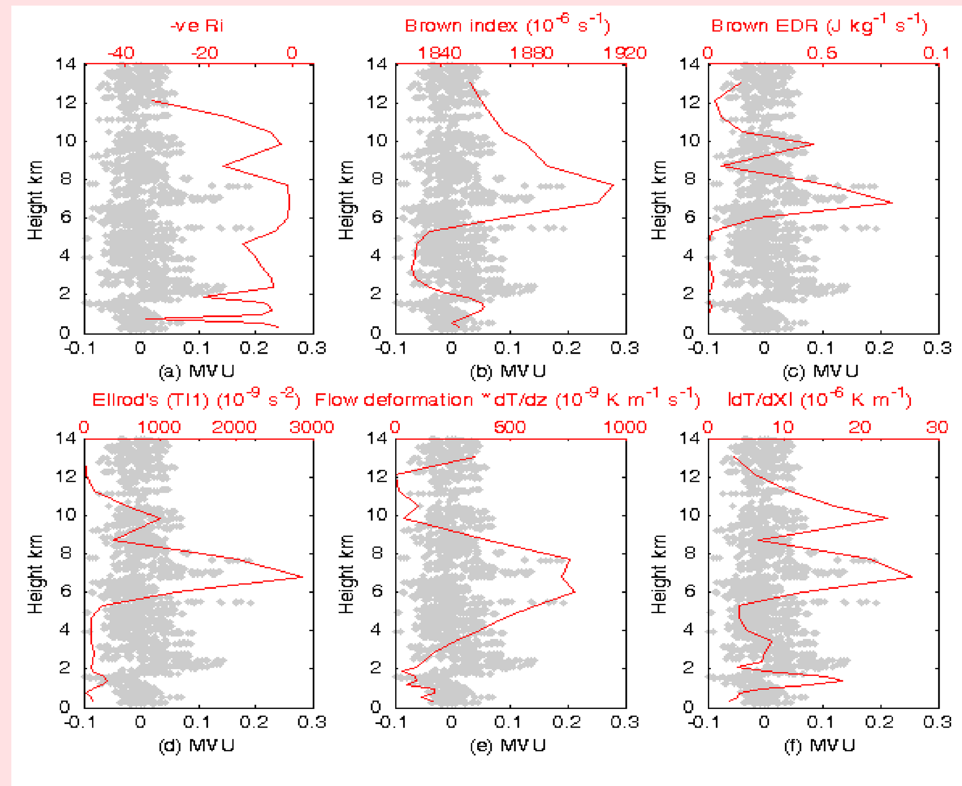

Fig 4. Turbulence diagnostics (red) calculated from ERA-Interim for 12Z on 24/01/2013 over-plotted with MVU (grey): (a) negative Richardson number (b) Brown index, 10^{-6} s^{-1} (c) Brown eddy dissipation rate, 10^{-6} J kg^{-1} s^{-1} (d) Ellrod's T1 index, 10^{-9} s^{-2} (e) flow deformation times vertical temperature gradient, 10^{-9} K m^{-1} s^{-1} (f) horizontal temperature gradient, 10^{-6} K m^{-1}.

The Thorpe method calculated from the PTU data showed similar agreement in some turbulent episodes, but not in others. Further work will test for a relation between the two.

Currently, accelerometers are being developed to fly with the sensor package, to increase the data sent back. In addition, a Point Discharge Current (PDC) sensor is also being developed to identify regions of in-cloud turbulence associated with electrified cloud regions.

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References

1. R.G. Harrison, K.A. Nicoll, A.G. Lomas, 2012, Note: Programmable data acquisition system for research measurements from meteorological radiosondes, *Review of Scientific Instruments,* **83**(3).
2. R.G. Harrison et al, 2009, Comparisons of balloon carried atmospheric motion sensors with Doppler lidar turbulence measurements, *Review of Scientific Instruments,* **80**(2).
3. Sharman et al, 2006, An integrated approach to Mid- and Upper level Turbulence Forecasting, *Weather forecasting,* **21**.
4. C.A. Clayson & L. Kantha, 2008, On Turbulence and Mixing in the free atmosphere inferred from High-Resolution Soundings, *Journal of Atmospheric sciences,* **25**(6)

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