Investigation of turbulence during the passage of a frontal system as estimated using Doppler lidar during COPS

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Introduction

The Convective and Orographically-induced Precipitation Study (C.O.P.S.) field trial was conducted in the Black Forest region of Germany during the summer of 2007. Its aim was to advance the quality of forecasts of orographically-induced precipitation using extensive observations and modelling (COPS, 2007).

As part of this study, the Salford University UFAM Doppler Lidar, Radiometer and AWS were deployed in the COPS region, at the Achern site (Supersite R) (Figure 1). All instruments were set to run continuously from the 13th June to the 16th August 2007.

Doppler lidar, radiometer and AWS based at Supersite R, ★ Achern (see map for location).

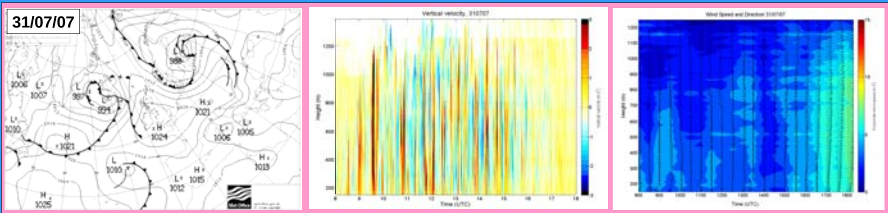
Doppler lidar can measure wind velocity and relative backscatter co-efficient. For reference, the Hornisgrinde is in the background

Figure 1 – The COPS Study area and Supersite R

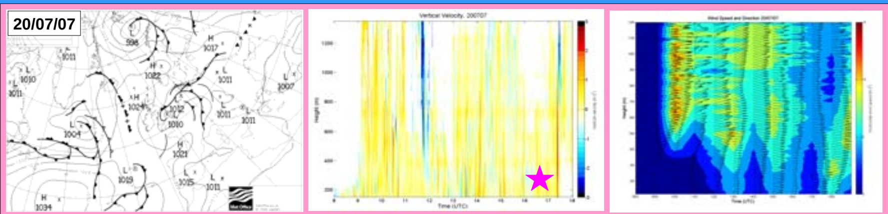
Frontal Turbulence

Very little is known about the nature of turbulence in the transition zone of a synoptic-scale front, especially at the dissipative scales (Piper and Lundquist, 2004). Lacking this knowledge, accurate models of turbulent mixing following the frontal passage are compromised. Chamecki and Dias (2004) and others have pointed out that to understand the dynamics of turbulent flows it is essential to know the energy dissipation rate. There is a close link between the properties of clouds and the properties of the tke budget (Collier and Davies, *in press*). Using data from Doppler lidar and AWS, energy dissipation is investigated during a frontal passage and some conclusions have been suggested.

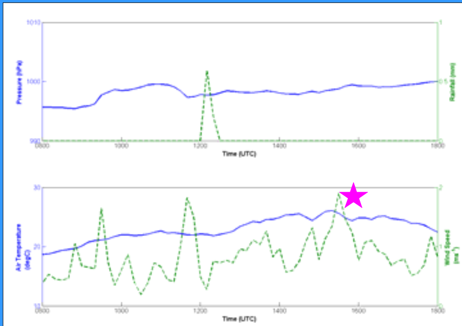
Case Studies (20/07/07 and 31/07/07)



310707 – High pressure system, no rain, near-clear sky with a well mixed boundary layer. Light winds from the south-west increasing later.



20/07/07 – Fronts passing throughout the day, sporadic clouds and rain at noon. Gust front observed at around 1700 UTC.



Data from the AWS shows a double feature between 0930 and 1200 UTC on 200707, with 2 peaks in wind speed. These peaks coincide with a rise and fall in atmospheric pressure. It is considered that these features indicate the passage of a front. It is considered that the 3rd peak in wind speed later on is related to a gust front as marked by a pink star and highlighted in the eddy dissipation rate timeseries on 200707.

Quantifying eddy dissipation rate

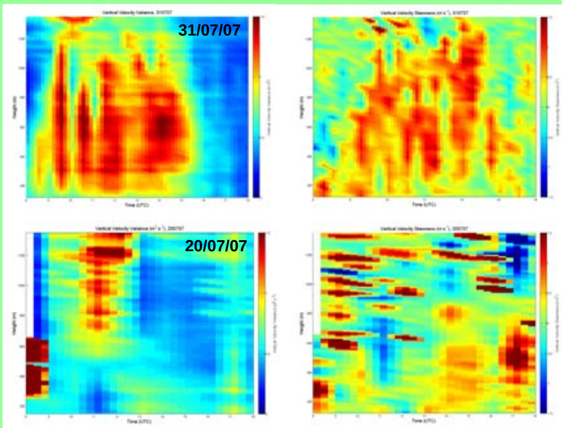
To quantify the turbulence in the front, a method proposed by Champagne et al., (1977) has been followed. Here, Taylors Hypothesis (Stull, 1988) is assumed and is used to calculate the wave number. The $\bar{u}$ is calculated from the lidar data using VAD analysis. The $\bar{u}$ is the average mean wind speed over the height ranges as shown.

The spectrum can be calculated from:

$$nS(n) = 0.68\varepsilon^{2/3}\left(\frac{2\pi n}{\bar{u}}\right)^{-2/3}$$

where S(n) is the spectral energy of frequency n and $\bar{u}$ is the mean wind speed. Here, the inertial subrange is characterized by a -2/3 gradient. Examples are shown below in figures 4 and 5. This method will henceforth be referred to as the temporal spectra method.

Turbulence, Skewness and Eddy Dissipation rate (ε)



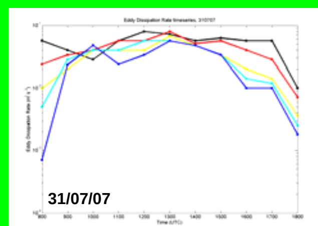


Figure 2

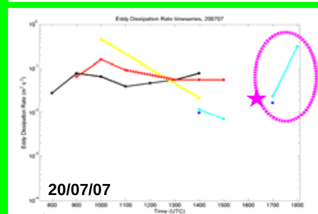


Figure 3

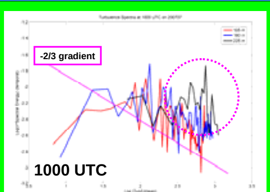


Figure 4

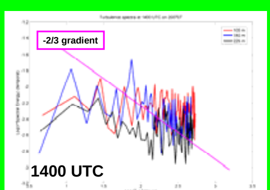


Figure 5

Turbulence, Skewness and Eddy Dissipation rate (ε)

The 310707, is taken as a case study of a near-clear sky, well mixed situation. ε appears to follow a typical diurnal cycle (figure 2) driven by convection at the surface. In comparison ε on the 200707 (figure 3) is not so well behaved. The timeseries of ε on 200707 shows ε increasing with height with the approach of the front (the individual spectra are shown in figure 4 for 1000 UTC). Shortly after this, because of the frontal zone, it was not possible to fit a -2/3 gradient to the data. Spectra after the passage of the front at 1400 UTC show decreasing ε and are shown in figure 5.

Figures of variance and skewness through the day highlight the difference between the near-clear sky and frontal cases. Variance in the near-clear sky case study shows a well defined mixed layer with boundary layer top at approximately 1200m. The turbulence decreases rapidly after 1600 UTC. The skewness is largely positive describing the thermally driven boundary layer.

In the frontal case, on 200707, variance is seen to be maximum in the region of the rainfall and very low subsequent to this. The skewness appears to show turbulence prior to the front at 1200 UTC in the upper layers. The negative regions of skewness indicate cloud driven turbulence. Later at 1700 UTC, surface-driven positive skewness can be seen coinciding with a possible gust front also seen in the AWS wind speed and the lidar vertical velocity and eddy dissipation (shown with a pink star but not investigated here).

Conclusions

- Lidar estimates of ε in the near-clear sky case behave as expected rising and falling with the diurnal cycle.
- ε has been shown with standard met measurements to increase by an order of magnitude during frontal events (Piper and Lundquist, 2004).
- In this work we have shown that lidar estimates of ε are also increased during the passage of a frontal system.
- ε is shown to increase with height in this case possibly due to the structure of the front being modified within the Rhine Valley.

References

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