Scaling Stably Stratified Shear Turbulence using Ri

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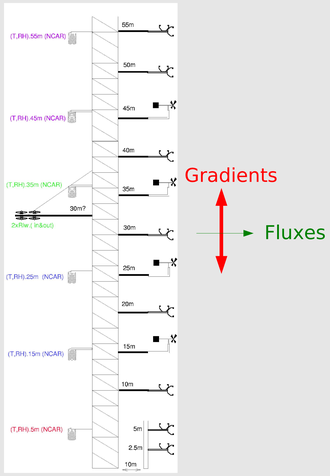


Gradients

Fluxes

Method

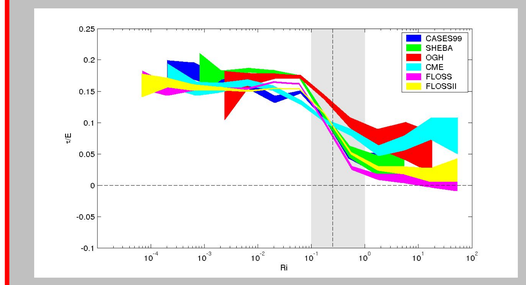
The gradient Richardson number is approximated by the Bulk Richardson. It is calculated from the gradients of mean potential temperature and wind. These date originate from sensors placed above and below the sonic anemometer.

$$Ri = \frac{N^2}{S^2}$$

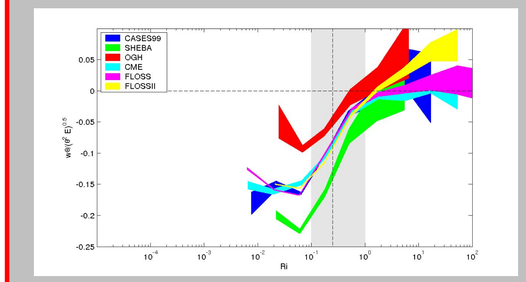
The fluxes and variances are normalised with variance at the level in question. In this way the non-dimensional stress, temperature flux and anisotropy is obtained:

$$\frac{\tau}{E}, \qquad \frac{\overline{w\theta}}{\sqrt{E\overline{\theta^2}}}, \qquad \frac{\sigma_u^2+\sigma_v^2}{\sigma_w^2}.$$

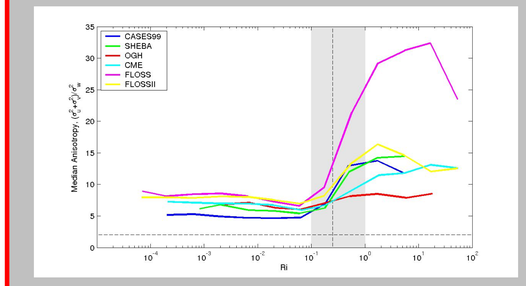
Non-dimensional Stress



Non-dimensional Heat Flux



Anisotropy



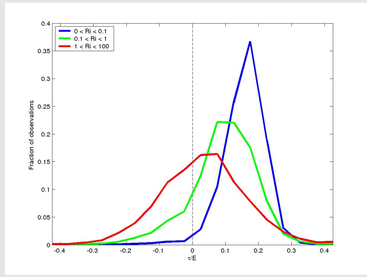
Advantages

The method has the following advantages:

It avoids artificial correlation, which appears whenever a measurement is used more than once. This is for instance the case in local Monin-Obukhov type scaling.

It deals with variables with near-Gaussian error distributions. This was for instance not the case in Nieuwstadt (1984), whom used the inverse of the non-dimensional fluxes.

It allows the study of turbulence at large Ri.



Summary

We have studied turbulence at a large range of bulk Richardson numbers. The observations were made during six campaigns in widely varying physical conditions and a range of different instrumentations and setups. The total amount of active data included in the plots corresponds to 5.5 years.

The main findings are:

1) In the weakly stable regime, Ri<0.1, fluxes scale with variance, such that more variance leads to stronger fluxes.
2) At 0.1<Ri<1 a rapid transition occurs.
3) The strongly stable regime, Ri>1, is very different. Here the momentum flux is found to be finite, while the heat flux appears to go to zero though this is quite uncertain.
4) Atmospheric shear driven turbulence is anisotropic at all stabilities. At strong stability this is even more pronounced.

We suggest that the results presented here are compared with LES as well as 1D turbulence closure models.

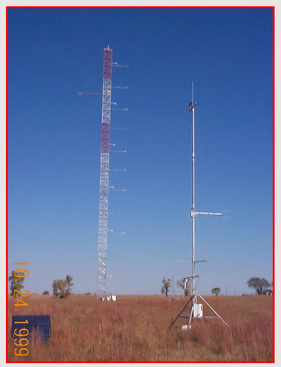
Issues

The results demonstrate several similar features among the six datasets. However, in many cases statistically significant differences occur. For example the neutral limit level of the non-dimensional heat flux and the strong stability level of anisotropy appears to be uncertain.

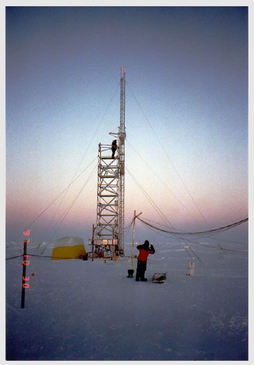
We perceive that the major reasons for differences between datasets and problems associated with the method are:

1) Varying physical environments. It was a deliberate choice to include many different environments in the present study.
2) Differences among the instrumentations and physical layouts of the experiments will naturally affect the results.
3) Different post-processing techniques were used to calculate means and turbulent moments.
4) Horizontal inhomogeneity. In at least one of the experiments more can be done to avoid this.
5) The local gradient method used here does not exclude the possibility of non-local convective instability.

CASES-99



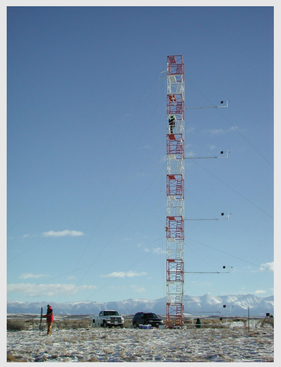
SHEBA



Östergarnsholm (OGH)

CME

FLOSS I / FLOSSII



Thanks to all those people that made great efforts to collect data, and then willingly shared them with us.