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# Turbulence Spectra of the FIRE Stratocumulus-topped Boundary Layers

by

G. S. Young, J. J. Nucciarone and B. A. Albrecht

## Abstract

There are at least four physical phenomena which contribute to the FIRE boundary layer turbulence spectra: boundary layer spanning eddies resulting from buoyant and mechanical production of turbulence kinetic energy (the microscale subrange); inertial subrange turbulence which cascades this energy to smaller scales; quasi-two-dimensional mesoscale variations; and gravity waves. The relative contributions of these four phenomena to the spectra depend on the altitude of observation and the variable involved (vertical velocity, temperature and moisture spectra are discussed). The physical origins of these variations in relative contribution will be discussed below. As expected from theory (Kaimal et. al., 1976), mixed layer scaling of the spectra (ie. nondimensionalizing wavelength by $Z_i$ and spectral density by $Z_i$ and the dissipation rates) is successful for the microscale subrange and inertial subrange but not for the mesoscale subrange.

The most striking feature of the normalized vertical velocity spectra shown in figure 1 is the lack of any significant mesoscale contribution. The spectral peak results from buoyant and mechanical production on scales similar to the boundary layer depth. The decrease in spectral density at larger scales results from the suppression of vertical velocity perturbations with large horizontal scales by the shallowness of the atmosphere. The spectral density also decreases towards smaller scales following the well known inertial subrange slope.

There is significant variation in the shape of the normalized spectra with height. However, the spectra assume similar forms within each of three height ranges: 0.1-0.4 $Z_i$, 0.4-0.9 $Z_i$, 0.9-1.0 $Z_i$. The mid mixed layer spectra, 0.4-0.9 $Z_i$, closely resemble those observed in the overland convective boundary layer (Young, 1987). The spectra for the lower mixed layer, 0.1-0.4 $Z_i$ are similar but have a lower spectral peak than those for the mid mixed layer or those for similar height ranges in the overland CBL. This difference in spectral form may be related to the greater contribution of mechanical production relative to buoyant production for this height range of the FIRE boundary layers. The FIRE turbulence kinetic energy dissipation profiles fall into two classes which support this hypothesis. Some of these dissipation profiles are nearly constant with height, suggesting that buoyant production is the dominant energy source while, others of them decrease linearly with height, suggesting that mechanical production resulting from surface stress is an important energy source. This form of mechanical production makes much less of a contribution to the turbulence spectra at higher levels in the FIRE boundary layers and is entirely absent in purely convective boundary layers. The peaks of the upper mixed layer spectra, 0.9-1.0 $Z_i$, are shifted to a significantly smaller scale than those at lower levels because of the eddy size limitation imposed by the adjacent capping inversion. This effect is physically similar to that observed in the surface layer. There is also a secondary peak in the upper mixed layer vertical velocity spectra at wavelengths much greater than $Z_i$ which may be associated with gravity waves in the capping inversion. Thus, considerable insight into

the dynamical processes at work in the boundary layer and capping inversion can be diagnosed from the observed variations of the FIRE vertical velocity spectra with height.

The temperature spectra shown in figure 2 have a somewhat different form than the vertical velocity spectra because they do exhibit a strong mesoscale contribution. The mesoscale subrange is separated from the microscale peak by a shallow spectral gap ranging up to a decade in width. The microscale peak and the inertial subrange are well normalized by mixed layer scaling while the mesoscale subrange is not. The temperature spectra in the mid and lower mixed layer are similar without any indication of the change in shape observed with the vertical velocity spectra. It is possible that because the stratification is weak the mechanical mixing does not affect the shape of the temperature spectra as much as it does the shape of the vertical velocity spectra. Any gravity wave contribution to the temperature spectra in the upper mixed layer is indistinguishable from the mesoscale contribution. The differences between the temperature and vertical velocity spectra highlight the relative importance of mesoscale and microscale contributions to the variance of these two quantities.

The moisture spectra shown in figure 3 are dominated by their mesoscale contribution to an even greater extent than are the temperature spectra. The mesoscale contribution to the moisture spectra is so strong that except in the lowest layer, 0.1-0.3 $Z_i$, no microscale peak can be distinguished. In the mid and upper mixed layer the mesoscale spectra merges more or less smoothly into the inertial subrange spectra. In the lower mixed layer, on the other hand, there is a separate microscale peak separated from the mesoscale by a shallow spectral gap a decade wide. Further investigation involving dissipation rates for temperature and moisture variance will help explain the differences in relative contribution of mesoscale and microscale processes to the FIRE boundary layer. The relative contribution of these two scales may have a significant impact on other aspects of the marine atmospheric boundary layer including the cloud size distribution and the horizontal scales of variation in the radiative budget.

## References

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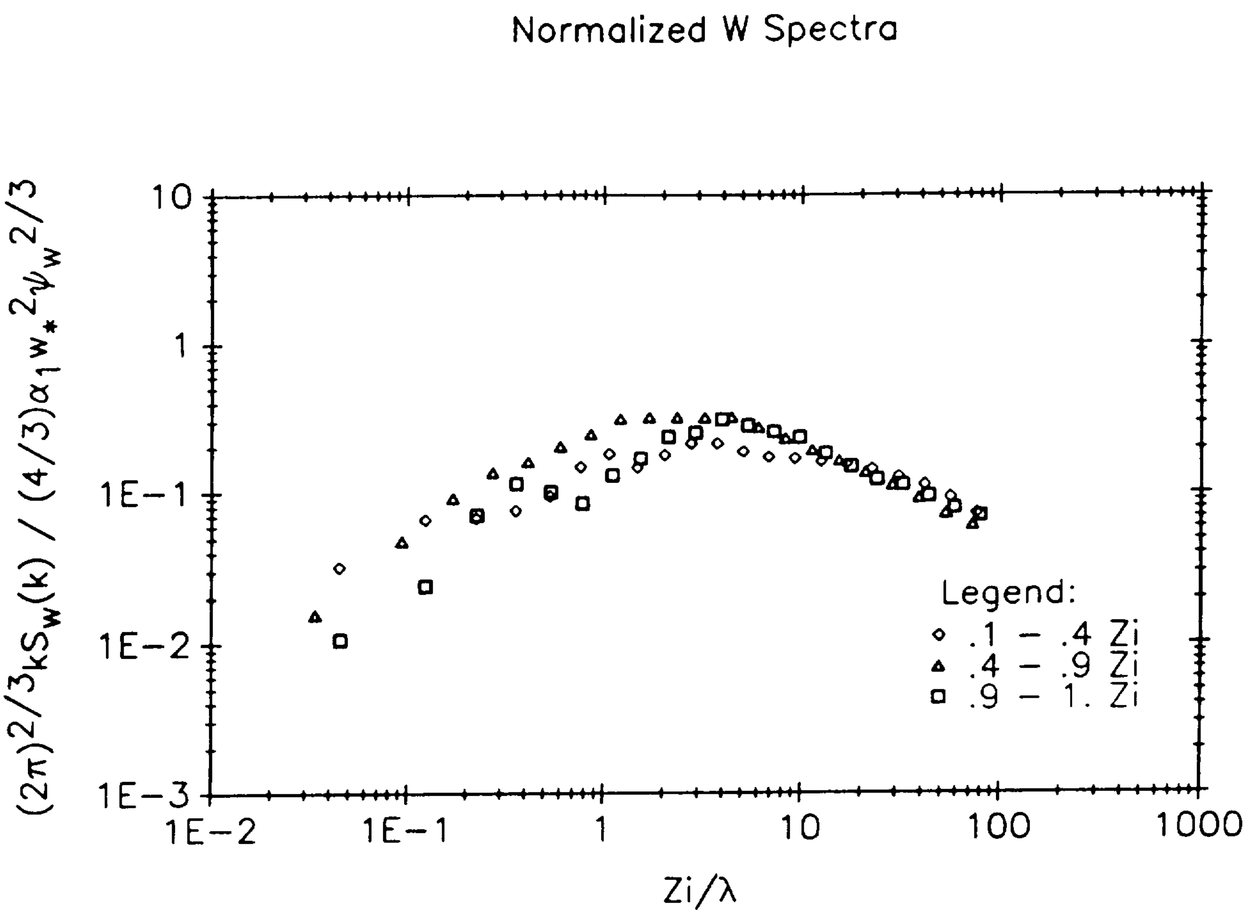


**Fig. 1** Average vertical velocity spectra for the lower, middle and upper FIRE mixed layer. The spectra have been nondimensionalized using mixed layer scaling following Young (1987). Both axes are logarithmic.

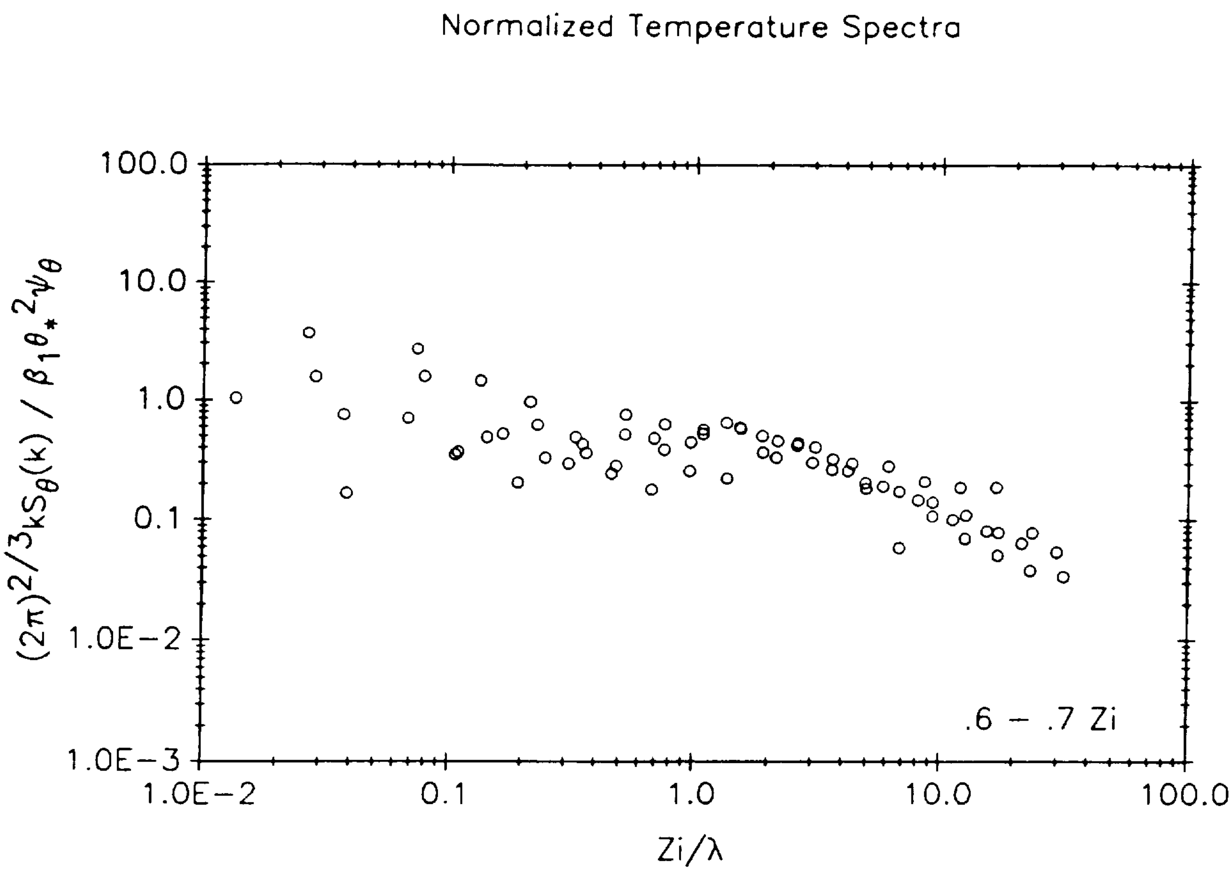


**Fig. 2** Sample temperature spectra from FIRE flight legs in the mid mixed layer. The spectra have been nondimensionalized using mixed layer scaling following Young (1987). Both axes are logarithmic.

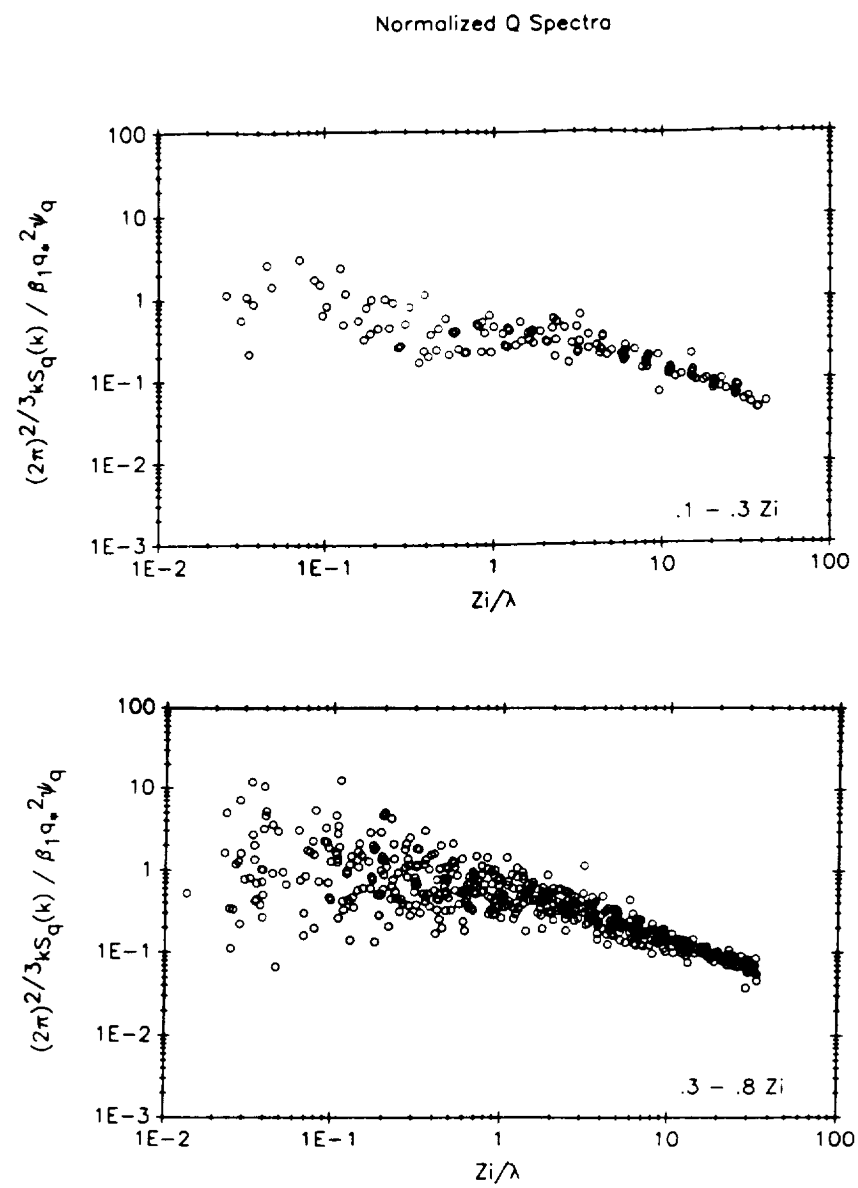


Fig. 3 Sample moisture spectra from FIRE flight legs in the lower and middle mixed layer. The spectra have been nondimensionalized using mixed layer scaling following Young (1987). Both axes are logarithmic.