J6.3 Comparison of Turbulent Statistics and Spectra at Two Heights over a Semi-Arid Grassland Surface

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1. INTRODUCTION

Understanding the turbulent exchange of mass and energy from a surface remains essential to appropriate characterization and quantification of the components of surface energy balance. This is particularly true for arid and semi-arid regions that often contain surfaces that are highly heterogeneous, exhibit significant topographical features; abrupt changes in vegetation cover (Fig. 1) and contain large spatial and temporal gradients in the water and energy balance components.

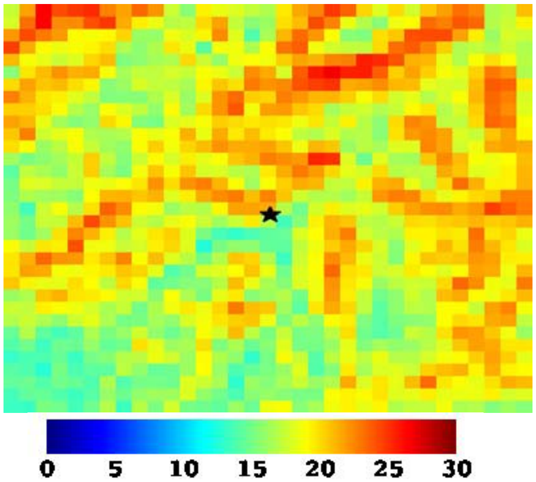

Figure 1. Landsat image (1 x 1 km) of vegetation density (relative units) of the Kendall site on July 29, 2004. The location of the 10 m tower is indicated in the center of the image and North is at the top of the image. The pixels are 40 m on a side.

Collectively all of the above can result in the physical turbulent exchange processes at the surface to significantly deviate from fundamental assumptions associated with eddy covariance measurements of energy and mass.

2. SITE DESCRIPTION

The Walnut Gulch watershed is a research station for the U.S. Department of Agriculture, and is representative of approximately 60 million hectares of brush and grass covered rangeland found throughout the semiarid southwestern United States. The site is semi-arid, with a hot summer and a dry winter. During the summer precipitation in this region is spatially and temporally variable resulting from localized monsoon convective events that provide two thirds of the annual rainfall with the remaining precipitation occurring during the winter period in the form of frontal systems. A micrometeorological tower was deployed at Kendall, a sub-basin within the Walnut Gulch watershed. Primarily C4 grasses with mean canopy heights that range between 0.4-0.7 m characterize the site. The soils are generally gravelly sandy loam with slopes that range from 4-9 %.

Instrumentation-eddy covariance

Two eddy covariance (EC) systems were deployed in a vertical configuration at 2 and 10 m above a grass / shrub surface on a 10 m tower. Eddy covariance instrumentation at the two heights included Campbell Scientific Inc.

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(CSI) CSAT3 3-D sonic anemometers and LiCOR-7500 H_2O/CO_2 sensors. Additional surface energy balance and ancillary meteorological instrumentation included a Kipp & Zonen CNR-1, 4-component net radiometer mounted 4 m above ground level (AGL), Radiation Energy Balance Systems (REBS) soil heat flux plates (0.06 m below the soil surface), a Vaisala HMP-45 temperature/humidity sensor (4 m AGL) and an Apogee radiometric temperature sensor (4 m AGL). **[Trade and company names do not imply endorsement by USDA]**. Sampling frequency for the EC instruments was 10 Hz where all of the high frequency time series data were preserved. Surface energy balance and ancillary instrumentation were sampled at 0.1 Hz and stored as 30-minute averages.

3. DATA

The time series data were collected as binary on a CR 5000 (Campbell Scientific Inc.) and stored on 512 MB PCMCIA cards. Preliminary post-processing included conversion from binary to ASCII, and appropriate scan-offset corrections to appropriately align velocity components (*u, v* and *w*) and sonic temperature (T_s) data (3-D anemometer) with water vapor and carbon dioxide concentrations (LI7500) and then saved as 24-hour blocks of 10 Hz data. Individual 1-hour sections of the 24-hour blocks were selected for further spectral analysis. The high frequency data were conditioned following standard procedures in micrometeorology for turbulence analysis (Kaimal and Finnigan, 1994). These included linear trend removal (where appropriate), and multiplying the series by a Hamming window (‘tapering’). Power and co-spectra analysis were calculated using the complex Fast Fourier Transform (FFT) for the *u, v*, and *w* components of velocity and scalar values of T, q and CO_2 concentrations. Additional analysis included tests for non-stationary (trend) conditions following Foken and Wichura, 1996.

4. PRELIMINARY RESULTS

We begin our analysis by simply observing the raw time series for the components of wind velocity and scalar quantities. This approach allows for a qualitative sense of turbulent features in terms of structure and distribution. Figures 2 and 3 are examples of the instantaneous u (10 Hz) velocity component on July 29 2004, (1130-1200 hrs) at the 2 and 10 m heights. Mean wind speeds for this period were 4.8 and 5.6 m s^{-1} for the 2 and 10 m heights respectively. Radiometric surface temperature averaged 43 ºC indicating increasingly convective conditions as the day progressed.

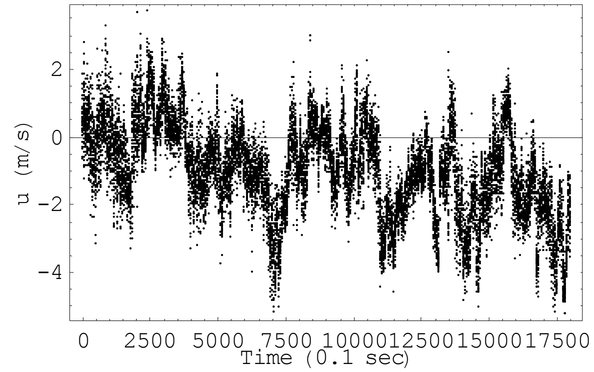

Figure 2. Time series of instantaneous stream wise velocity component (*u*) for the 2 m EC at the Kendall tower on July 29, 2004 from 1130-1200 hours.

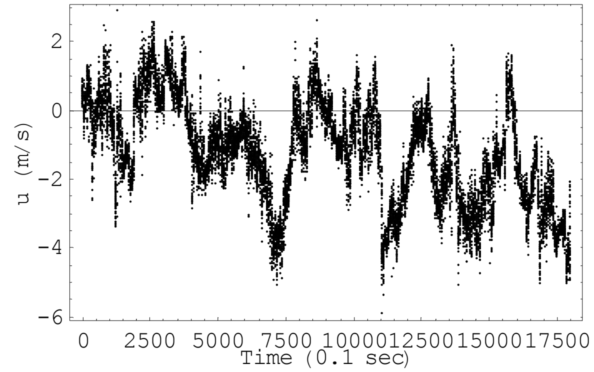

Figure 3. Time series of the instantaneous stream wise velocity component (*u*) for the 10 m EC at the Kendall tower on July 29, 2004 from 1130-1200 hours.

Variability in instantaneous magnitudes of *u* ranged approximately from 0-4 m s^{-1} at 2 m and from 0-6 m s^{-1} at the 10 m height. Stream wise turbulent structures were evident and correlated at both heights but with more distinct features (ramps and peaks) at 10 m relative to the 2 m. The standard deviation for instantaneous *u* was approximately 10% greater at 10 m relative to 2 m (1.47 and 1.34 m s^{-1} respectively). A similar pattern was also observed for the water vapor concentrations (*q*) (Figs. 4 and 5).

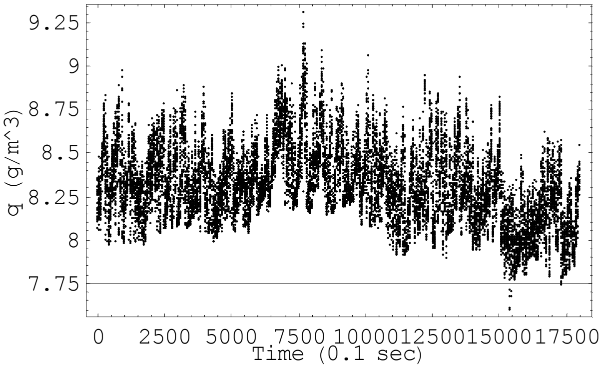

Figure 4. Time series of the instantaneous water vapor concentrations (*q*) for the 2 m EC at the Kendall tower on July 29, 2004 from 1130-1200 hours.

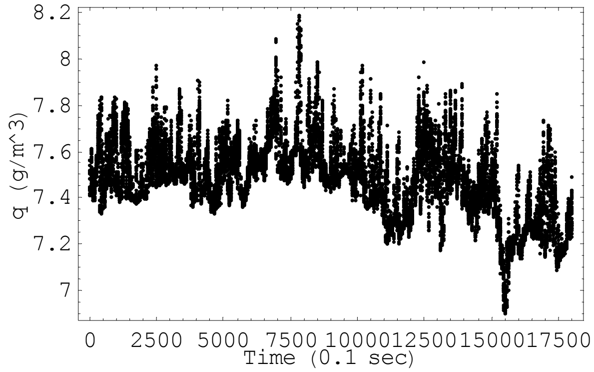

Figure 5. Time series of the instantaneous water vapor concentrations (*q*) for the 10 m EC at the Kendall tower on July 29, 2004 from 1130-1200 hours.

In figures 4 and 5 the instantaneous *q* time series trace appear to be correlated at both heights, that is to say ramps and peaks are nearly coincident but again as in the case for instantaneous *u*, ramps and peaks appear to be more distinct at the 10 m relative to the 2 m height. The mean instantaneous *q* concentrations at 2 and 10 m differed by approximately 10 % (8.31 and 7.48 g m^{-3}, respectively) while the standard deviations differed by 25 % (0.22 and 0.16 g m^{-3} respectively). The difference is likely due to the proximity of the EC systems to the actual surface, i.e. closer to the water vapor source. Additionally at both heights a trend can be readily observed where a decrease in water concentration in the surface layer begins to occur toward the end of the measurement period indicating a weakening source term in response to increasing temperatures and radiation and a limited water source. The similarity in the instantaneous velocity and scalar quantities (this included *v, w* and T not shown here) for this day and time caused us to wonder if it could also be expected to be observed in the cospectra for the covariance's. An example of the cospectra for latent heat (w' q') at 2 and 10 m for the same day and time is shown in figure 6.

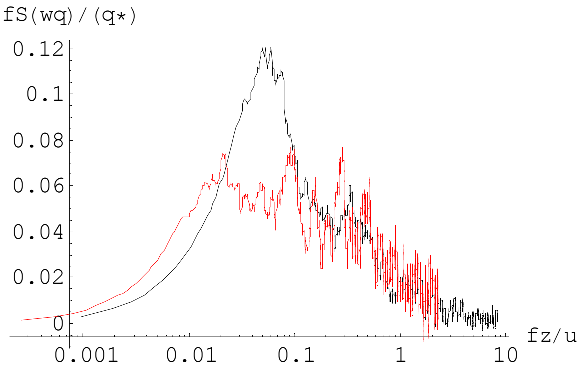

Figure 6. Cospectra for w' q' at 2 (red) and 10 (black) m heights at the Kendall tower on July 29, 2004 from 1130-1200 hours.

For the conditions during this day and time, differences in the magnitude of the cospectra density values as well as the distribution across the frequency range were evident and significant. The peak contribution at the 2 m height was distributed over a broader range of frequencies (Fig, 6) relative to the 10 m height and also occurred as multiple distinct peaks. Considerable variability in the higher frequency range was also evident at the 2 m than at 10 m. The magnitude of the cospectra density values at 2 m was nearly half compared to the 10 m height. This was not expected if the two EC systems were measuring the same region. Even in conditions when the time series at each height are qualitatively similar, the covariance spectra may take a markedly different form. Not only is the shape of the two spectra different, but the area under the curves (the total flux) also differs by approximately 12 %. We believe the unusual nature is due to the highly variable surface (see Fig. 1) which contains regions which may be very dry or relatively moist.

5. SUMMARY COMMENTS

Preliminary results suggest that the time series of atmospheric parameters and their cospectra can vary significantly between days and heights, particularly in arid and semi-arid regions that are highly heterogeneous in both land cover and topography. A number of factors can contribute to the spatial variation in turbulence energy exchange and thus the observed differences. We believe that a proper analysis of eddy covariance data must include a close inspection of the raw and processed data, to include the power and covariance spectra. While anomalies in the spectra may not always indicate problems with the data, they are an indicator. At the time of this writing more analysis are being conducted with the time series and flux average data, some more results will be presented at the conference.

6. REFERENCES

Finnigan, J. 1999. A comment on the paper by Lee (1998): “On micrometeorological observations of surface-air exchange over tall vegetation”. Agric. & Forest Meteorol., 97:55-64.

Foken, T. and Wichura, B., 1996. Tools for quality assessment of surface-based flux measurements. Agric. & Forest Meteorol., 78:83-105.