6.6 TURBULENCE IN THE STABLE NEAR-SURFACE ATMOSPHERE IN THE COMPLEX TERRAIN OF OWENS VALLEY, CA DURING T-REX

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1. BACKGROUND

The study of the stably stratified near-surface atmosphere has been marked by an inability to objectively quantify the characteristics of intermittent turbulence and therefore an inability to establish an objective and broadly useful methodology for representing (e.g. parameterizing) the impact of such turbulence on realistic numerical models of the atmosphere (Coulter 1990, Nappo 1991, Katul et al. 1994, McNider et al. 1995, Mahrt 1998, Derbyshire 1999, Acevedo and Fitzjarrald 2001, Poulos and Burns 2003). A number of field projects have now taken detailed observations of the statically stable atmosphere over surfaces of differing physiographic characteristics (e.g. Poulos et al. 2001), and promise the possibility of unifying individually applicable results to a more broadly applicable physical understanding (Sun et al. 2002).

During the Terrain-induced Rotors Experiment (held 1 Mar – 30 Apr 2006 near Independence, CA) three densely instrumented tall towers were deployed in a complex terrain valley to study, in part, fluxes and transports in the near-surface stable atmosphere. These towers were 30 m in height and located such that cross- and along-valley differences in stable near-surface atmospheric behavior could be intercompared and the representativeness of any individual tower assessed (Figure 1). The Central and the South tower (Figure 1b) were located within the flood plain of the Owens River – near flat terrain with local undulations of ~ 0.5°. The West tower (Figure 1c) was located along a east facing alluvial slope of 3.2°, and was within 1.0 km of the foothills of the steep slopes of the Sierra to the west.

Each tower was outfitted with 6 (20Hz) sonic anemometers that were equally spaced at 5 m intervals, three heights of slow-response temperature and relative humidity sensors, 2 krypton hygrometers, along with additional equipment. One site was further instrumented with 3 NCAR OTIHS (Poulos et al. 2006). Each OTIHS is comprised of a sonic anemometer with an embedded, automatically reorienting 3-d hot-film anemometer set to sample at 2000Hz. The OTIHSs were placed at 0.8, 1.4 and 2.4 m above the local displacement height of approximately 0.6 m

Figure 1. a) The locations of the three 30 m towers in the Owens Valley (encircled), b) the West tower and c) the south tower (central tower is not shown).

(1.4, 2.0 and 3.0 m above ground) and although are an important component of this work will not be discussed further in this preprint because data processing is not yet complete.

In this study we utilize observations from these three tower sites and numerical simulations using the ARPS model to evaluate turbulence in the near-surface stable ($Ri_B > 0$) atmosphere. The towers are evaluated for composite (5 minute averages of not fully quality controlled data) near-surface stable atmospheric evolution in relatively undisturbed lower tropospheric conditions in the valley bottom and along the relatively uniform alluvial slope to the west of the town of Independence, CA. This work will be combined with other analyses to ascertain the relative frequency of globally intermittent turbulence (Kunkel and Walters 1982, Mahrt 1999, Poulos and Burns 2003).

In addition, evidence of persistent mesoscale features in the Owens Valley are shown from 350 m horizontal resolution ARPS simulations. These mesoscale phenomena are presented as plausible sources of recurring instances of significant near-surface constituent and momentum transport. The tall-tower observations are used, in part, to evaluate the ARPS simulations and in combination with aircraft data in companion papers (Schmidli and Poulos 2006a, b , Daniels et al. 2006 and Mobbs et al. 2006).

2. DATA ANALYSES

We have chosen three synoptically relatively calm, near clear to clear sky nighttime (01-13Z) periods for study, 1) 30 Mar (EOP-2), 2) 19 Apr (EOP-3) and 3) 20 Apr 2006. We will refer to these periods as 1, 2 and 3, respectively. As shown in Figure 2, each tower was subject to statically stable conditions between 5 m and 30 m agl throughout the period of interest at all three towers for the 5 minute interval data shown.

Period 1 is notable for its relatively low value of mean ΔT which is roughly 1^oC lower than that of period 2 which is again about 1^oC lower than period 3. These differences can be traced generally to the intensity of larger-scale atmospheric forcing of valley winds before and during these cases. Period 1 and period 2,

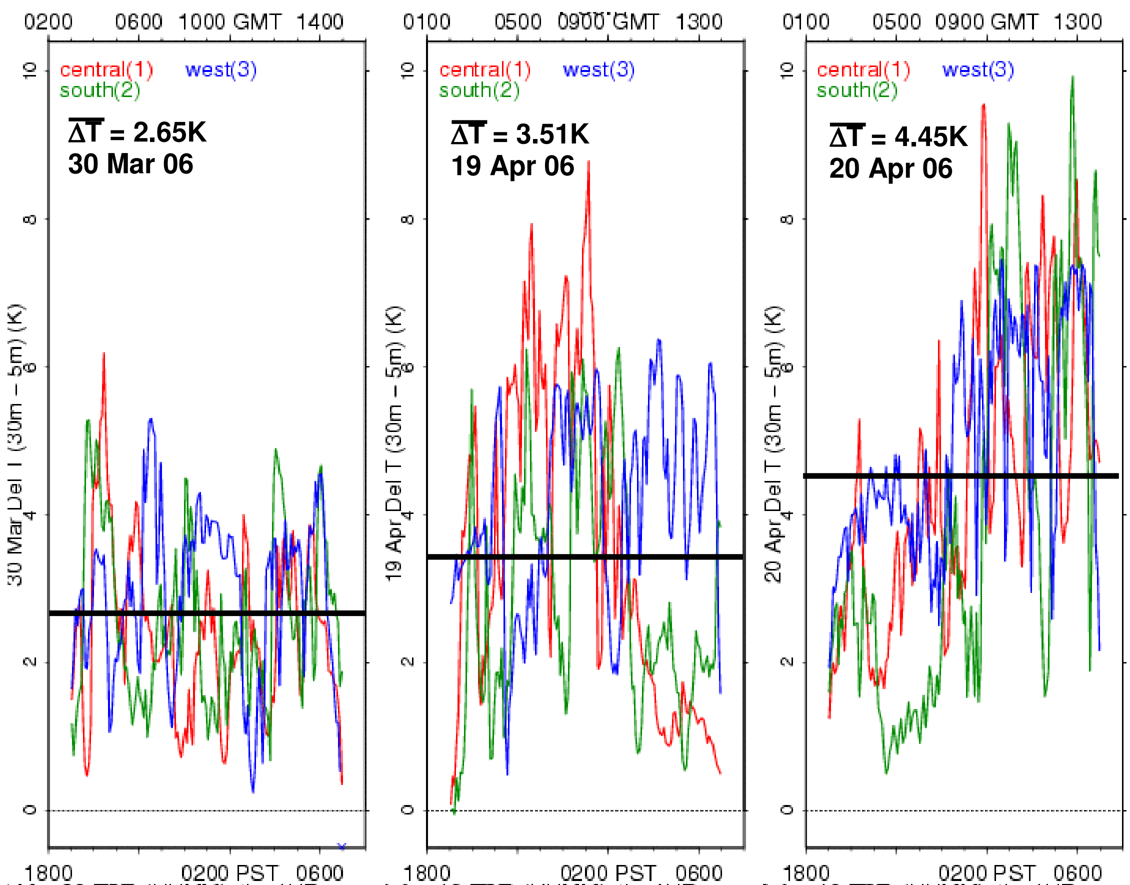

Figure 2. Overnight ΔT (30 m less 5 m) for the three nights of interest for the three Owens Valley towers (central – red, south – green, west – blue). The mean value for all towers combined is shown with a black line.

having somewhat lower magnitude ΔT were, subject to noted northerly synoptic forcing, occasional inopportune cloudiness and/or a **less well-defined canonical** valley wind structure. Period 3 was marked by a well-defined valley wind structure (upvalley daytime and a transition to down-valley northerlies before again turning southerly), clear skies and weak synoptic forcing.

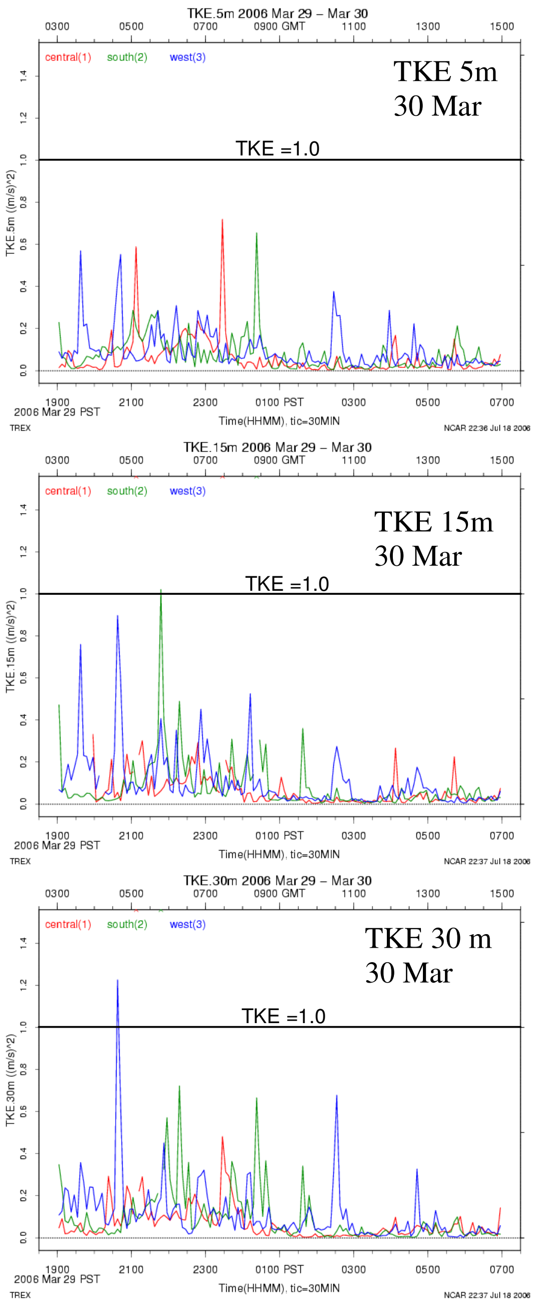

Figure 3 shows the evolution of TKE overnight for 3 heights during period 1 and also for one height during nights 2 and 3. Clear evidence of regularly occurring enhanced TKE is found at all heights and for all three nights. The magnitude of these turbulence events is

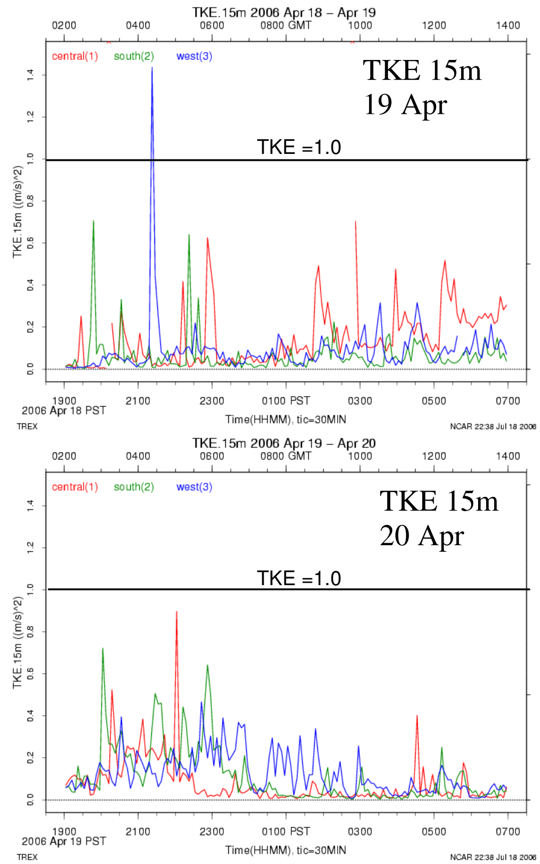

Figure 3. Overnight TKE for 30 Mar 2006 at a) 5m, b) 15 m, c) 30 m and for 19 Apr at d) 15 m and 20 Apr at e) 15 m for the central (red), south (green) and west (blue) towers.

smaller both during the latter portions of the night in all 5 figures, but the overall magnitudes of these sporadic enhancements of TKE are significant (the TKE = 1.0 line is shown for clarity on all panels). Evidence from wind profiler data and ARPS simulations (Figures 4 and 5) indicate that shear-induced turbulent exchange may have been created by the evolving mesoscale features in the Owens Valley. These sources include, semi-permanent deep valley vortices generated by tributary katabatic flows, local terrain and down valley flows (Figure 4) and shear between down and upvalley flows (Figure 5). Wave activity generated by flow over the Sierra and other local terrain maxima may have also been a source since there was significant synoptic cross-valley flow during periods 1 and 2.

The gradient and bulk Richardson number and z/L have been used as measures of atmospheric stability in numerical parameterizations of atmospheric exchange (Poulos and Burns 2003, Arya 1972, Woods 1969) We show Ri_b evolution for all three nights in Figure 6. Here we note a very distinct

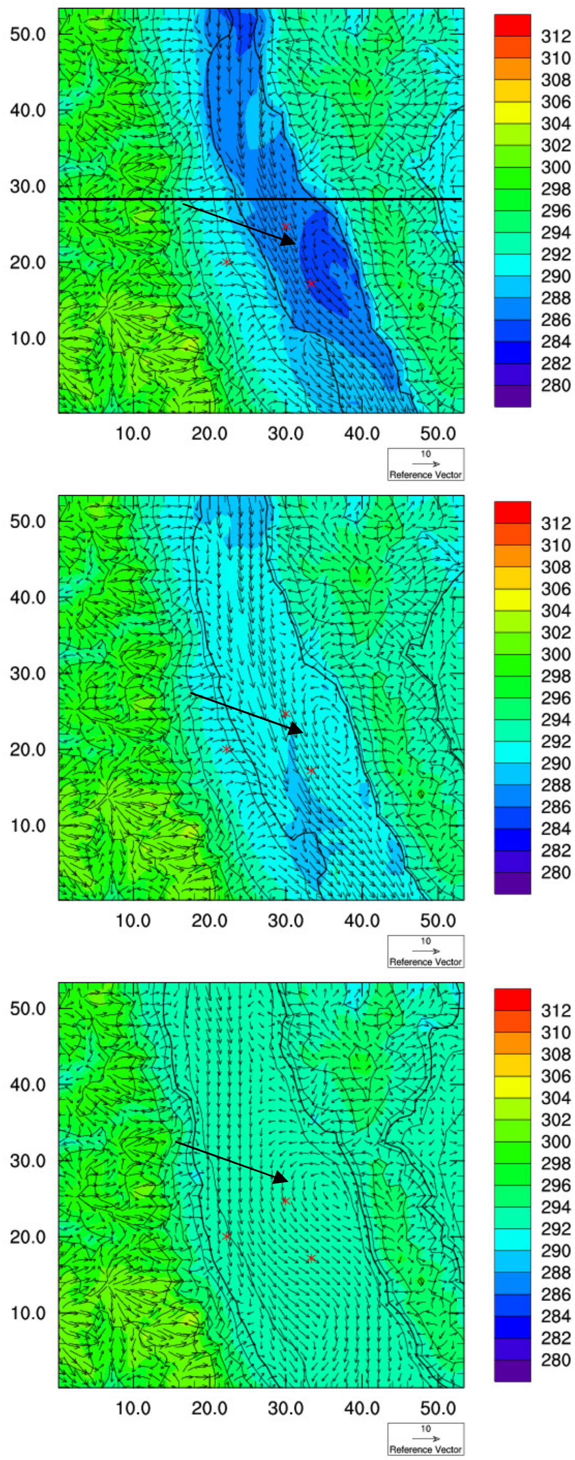

Figure 4. Plan views of ARPS simulation cross-sections at a) 1250 m (black horizontal line shows the cross-section in Figure 5), b) 1400 m and c) 1800 m MSL. Note the semi-permanent circulations (arrows) at 09UTC 30 Mar 2006. The bold black contour indicates the height at which the cross-section intersects topography.

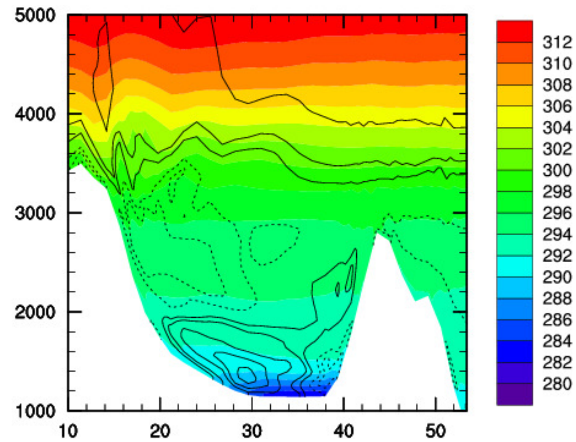

Figure 5. An x-z cross-section of meridional winds that shows layered valley flow structure and the eddy structure shown in Figure 4. The line of the cross-section is shown in Figure 4a, through the location of the West tower at 09UTC 30 Mar 2006.

set of very large values of Ri_b, interspersed with periods of much lower Ri_b. This behaviour is consistent with the sporadic nature of intermittent turbulence found in TKE and by other authors in different environs (e.g. Kunkel and Walters 1982, Nappo 1991). Considering the always positive static stability in Figure 2, the very large values of these 5 minute averages imply long periods of small near surface shear. Indeed, windspeed observations at the tall towers confirm the ebb and flow of shear at each site, the source of which is currently unknown.

Figure 7 shows the resulting exchange of momentum and kinematic heat flux for each tower site for each of the three periods. Significant positive values of heat flux, implying countergradient heat flux, are likely to be caused by random error in this dataset due to the use of 5 minute averaging in a stably stratified near-surface data set (Vickers and Mahrt 2006). Figure 7 shows, consistent with the implications of our analysis of TKE and Ri_b, that significant exchange of quantities occurs at sporadic intervals. Future analysis will use the full 20 Hz data set to identify specific occurrences of exchange and relate them physically to processes in the Owens Valley, such as have been found in wind profiler data and in the ARPS simulations referenced herein.

3. CONCLUSIONS

This work has shown, using TKE, Rib, momentum and heat flux evolution on three different statically stable nights, that intermittent turbulence is a recurring feature of the Owens Valley atmosphere. ARPS simulations were used to illustrate the larger scale mesoscale/valley-scale phenomena that may have contributed to the routine generation of shear and turbulent exchange. This initial analysis suggests that while the turbulent processes found at each tower on each night were likely to be driven by different mesoscale phenomena due to their different geographic location, that the statistics of their intermittent turbulence may have similar characteristics. If confirmed by future more rigorous analysis, this holds promise for the development of a broadly applicable parameterization scheme for intermittent turbulence in the statically stable near-surface atmosphere.

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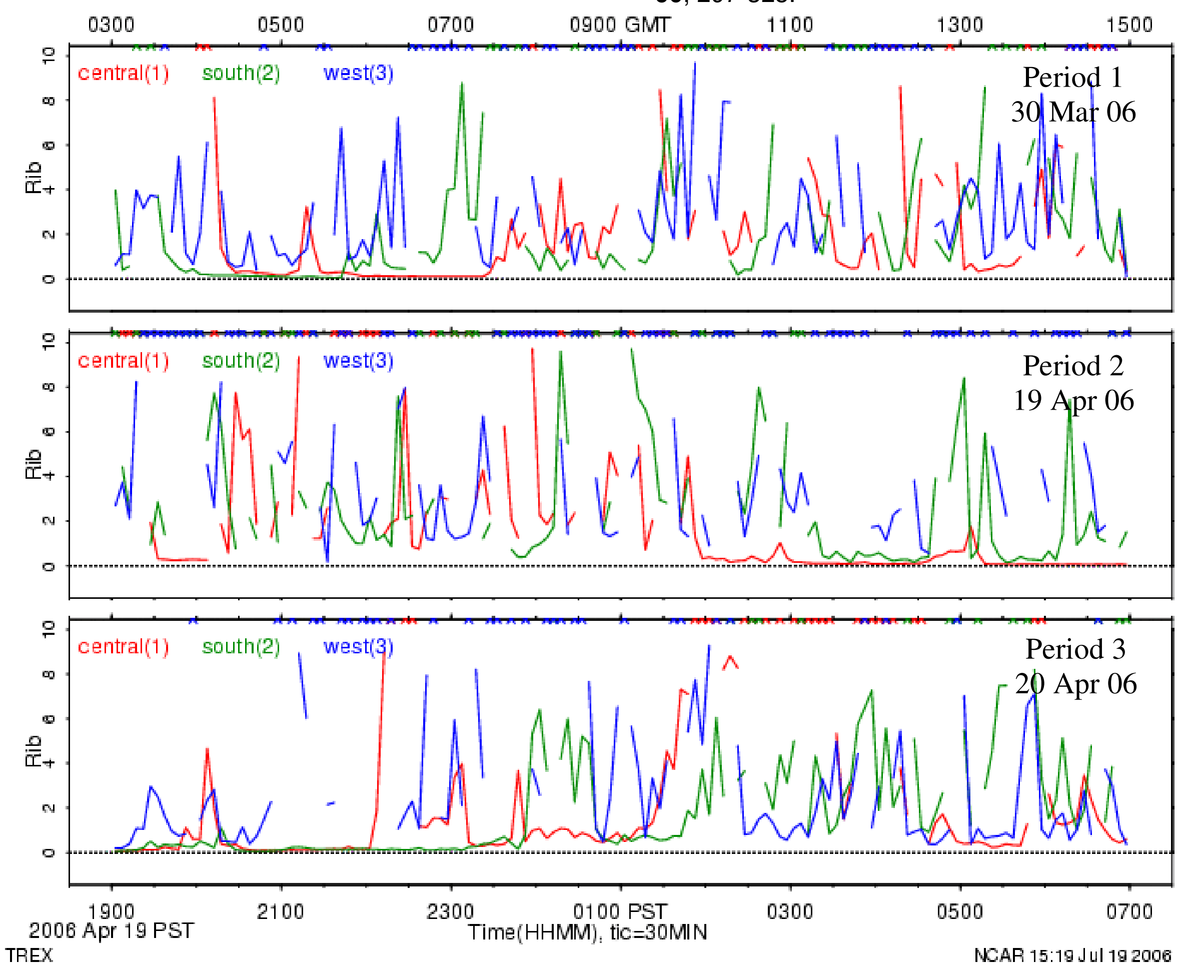

Figure 6. Bulk Richardson number for periods 1-3. Values > 10 are not shown.

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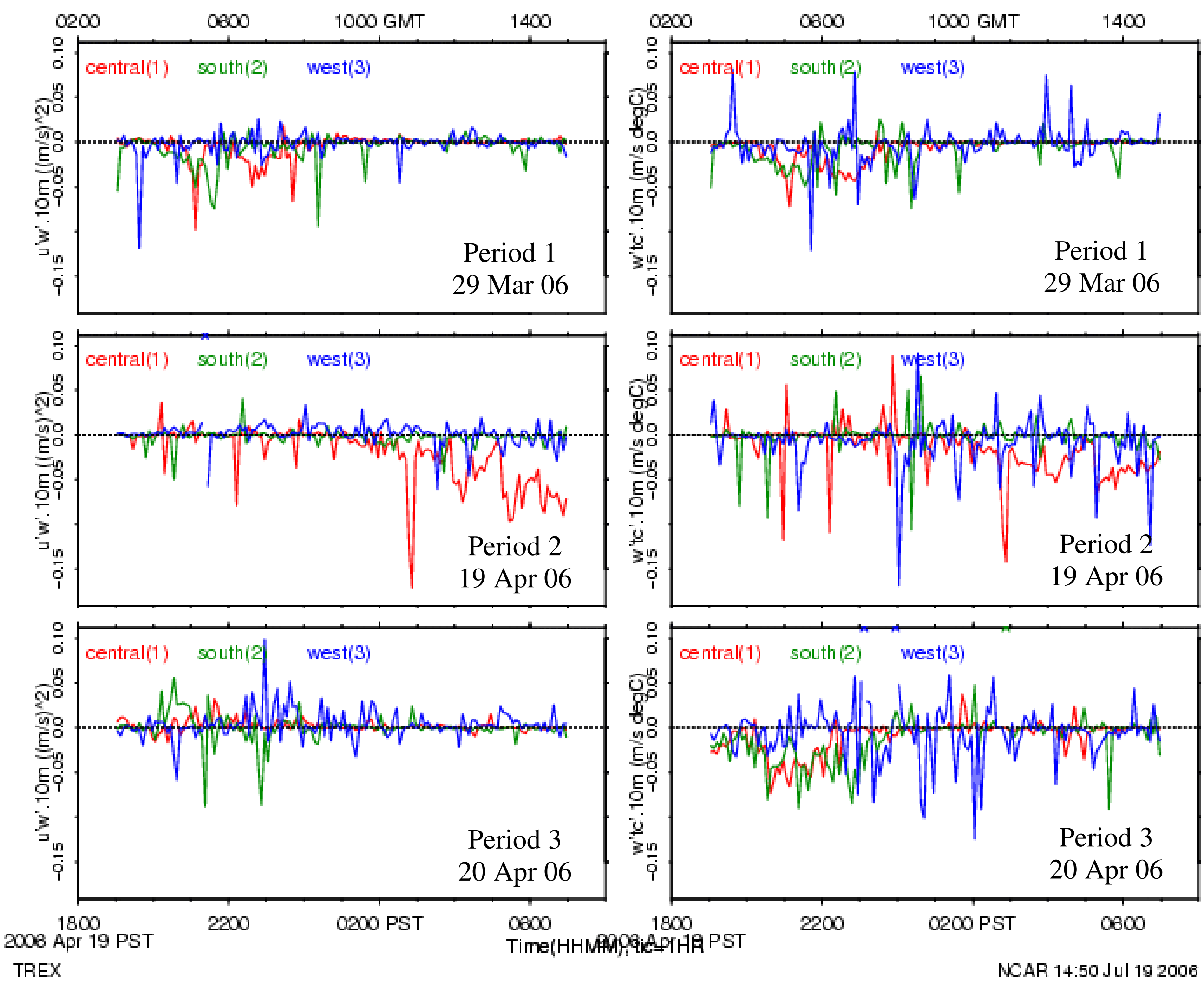

Figure 7. Momentum flux and kinematic heat flux for periods 1-3.

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