4.1 EDDY CORRELATION FLUX MEASUREMENTS IN AN ALPINE VALLEY UNDER DIFFERENT MESOSCALE CIRCULATIONS

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1. INTRODUCTION

In the search for a general description of the boundary-layer in highly complex terrain, the associated turbulent fluxes and the interaction of the boundary-layer with local winds, an intensive field experiment was conducted in an Alpine valley.

The MAP-Riviera project's observational phase, which lasted from August to October 1999, produced a highly detailed picture of the thermal, dynamical and turbulent structure of the atmosphere within and above the Riviera valley (Rotach et al. 2000). Near-surface eddy covariance data were continuously collected in a cross-section of the valley using several micrometeorological towers.

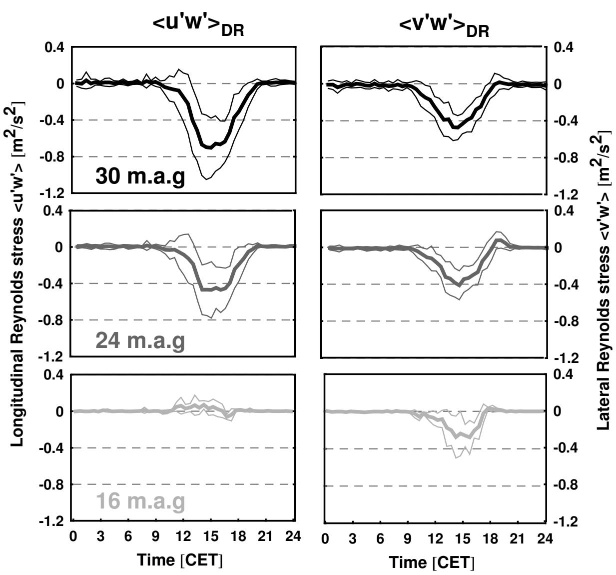

Fig. 1: Mean diurnal cycles of longitudinal and lateral stress for three levels at the west-facing slope site in the Riviera Valley. Averages over 15 VWS, based on 30-min data processed using the Double Rotation (DR) method. Thin lines indicate one standard deviation from the mean.

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Andretta et al. (2000) presented results from the investigation of the near-surface boundary layer associated with a well-developed valley and slope wind system (VWS).

They showed that the interaction between slope and valley winds locally produces strong directional wind shear. This latter emerges from a turning of the mean flow direction from the 'slope wind direction' near the surface to the 'valley wind direction' more distant from the surface. The diurnal cycle of the longitudinal Reynolds stress, <u'w'> was observed to be similar to that measured over flat terrain (Fig.1), but they found uncommonly large values of lateral Reynolds stress in the afternoon hours. The lateral stress, <v'w'> reaches the same absolute magnitude as the along-wind component and was related to directional shear. It was further pointed out that lateral shear stress has to be included in the definition of a suitable local scaling velocity.

In their analysis Andretta et al. (2000) used the conventional micrometeorological post-processing scheme based on a double coordinate rotation (DR). Thus, the question arises whether the above results are crucially dependent on this post-processing scheme. In other words, is it possible that the significant lateral stresses are an unwanted 'effect' of the DR method due to errors in the vertical alignment of the sonics? The latter stress could also be increased by the effect of the inherent sampling uncertainty in the determination of the mean vertical wind speed in combination with the DR method. To address these questions we decided to re-compute the turbulent Reynolds stresses using an alternative technique, the Planar Fit method presented in Wilczak et al. (1999).

2. SITE DESCRIPTION

The Riviera Valley is a typical alpine valley located in the southern part of Switzerland. It is U-shaped, with an average ridge height of 2000m. The valley floor, oriented from SE to NW, is 15km long and 1.5-2km wide. The micrometeorological data discussed in this paper come from a tower situated on the west-facing slope about 500 meters above the valley floor (see Fig. 1, site E_SF in Matzinger et al. 2002 - this conference, paper 3.4). At this location the slope angle is approximately 30-35 deg. The slope is mostly covered with chestnut and beech trees. The surrounding forest forms a rather homogeneous fetch for several hundred meters in all directions. The fetch can roughly be divided into three sectors with characteristic mean tree height and type: from NWW to NEE there are mainly beech trees of about 12m height, from NEE to S the chestnut trees with a mean height of about 20m, and from S to NWW (where the up-slope wind is coming from) the mean height varies from 12 to 20m with a mixed forest.

The 30m high tower is a guyed telescopic mast, with ultrasonic anemometers (sonics) type R2A (Gill Instruments LTD) at three levels (16, 24, 30m, nominal heights). For a description of the whole campaign setup see the MAP-Riviera Meta Data Report (http://www.iac.ethz.ch/research/map_riviera).

3. MESOSCALE CIRCULATION

Valley and slope wind systems (VWS) are thermally driven circulations that frequently form in areas of complex terrain. Their diurnal wind and temperature structure evolution is well known. Fifteen days between 21.8.1999 and 16.10.1999 with a well-developed VWS were selected from the entire data set. In addition to calm winds above the valley atmosphere and clear skies, the determining factors for the choice of these days are given by the strong day/night oscillations of the surface pressure gradient along the valley and the associated up-valley/down-valley wind pattern (Andretta et al 2001). During the entire field phase, 20% of the total days were VWS days.

4. POST-PROCESSING OF SONIC DATA

In their work Andretta et al. (2000) used a standard Double Rotation (DR) method. A recursive filter of 300s was applied to the raw time series, to remove the low frequency part of the signal. Wind components are then aligned with the mean streamlines such that <v>=0 and <w>=0. The averaging period was set to 30min. No third rotation to force <v'w'>=0 was applied, because over complex terrain the flow lines cannot be expected to be two-dimensional and axially symmetric.

For an unbiased estimate of the longitudinal and the lateral stresses, a generally accepted analysis suggests that knowing perfectly the terrain inclination the sonic anemometers should be leveled with an accuracy of 0.1 degree. The telescopic mast, due to the anchoring technique (guyed), does not allow us to know the vertical alignment of our instruments with that kind of precision.

Furthermore, as in most cases, the sonic anemometers were not equipped with an inclinometer. Note that even with inclinometer available, one would still need to exactly know the tilt of the underlying topography. The inclination of a complex structured slope depends on the observation scale we use and thus cannot be known a priori with the required accuracy.

There is also an interpretation problem inherent of the DR method that arises immediately when we are interested in vertical profiles of the fluxes: the flux vectors are usually not parallel. The angle between them is the same as the difference of the vertical inclination angels of the averaged flow lines. Thus in Fig.1 we are actually comparing components of three stress vectors, expressed as projections on the axis of three very different cartesian coordinate systems.

The definition of a reference system with the best characteristics for analysis of vectorial profiles was therefore our next goal. Following the paper of Wilczak et al. 1999 (W99), we tried to apply the Planar Fit (PF) method to our data taken over a steep valley slope. The PF method was successfully used to derive correct stress estimates with slightly tilted instruments. It has the advantage of minimizing the run-to-run stress errors due to the sampling uncertainty of the mean vertical velocity.

In a first step the PF technique defines a plane parallel to the local terrain slope, or better, to the more often-observed mean flow lines crossing our sampling point. Our definition of the rotation angles of the PF technique exactly follows W99: □ is the pitch angle about the original y-axis, □ is the roll angle measured about the intermediate x-axis, and finally □ is the rotation about the new z-axis.

Using 10 weeks of continuously recorded turbulence data, 15-min averages of the three wind components (u, v and w) where computed and then every two consecutive runs were again averaged to reduce errors due to main flow instationarity. A linear regression analysis performed on 8496 runs leads to a set of fixed Eulerian angles □=8.604, □=-21.124 and a bias in the vertical velocity c=-0.056. The fixed (□, □) angles were then used to obtain all the mean wind vector and stress tensors in a coordinate system which has its z-axis perpendicular to the mean streamlines. Like in the DR method the azimuthal rotation is then applied to force <v>=0 for each 30min interval.

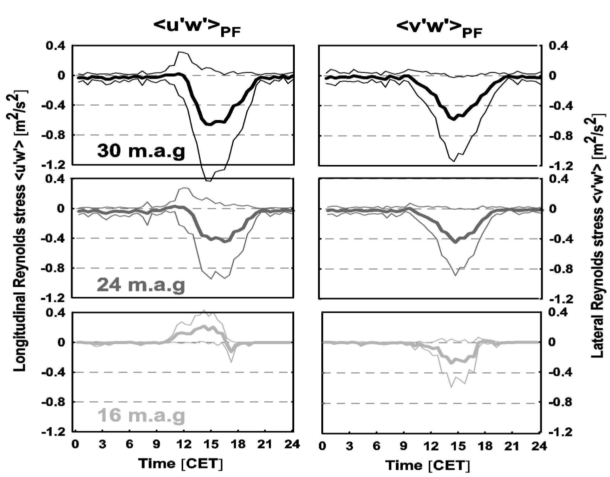

Fig. 2: Mean diurnal cycles of longitudinal and lateral stress for three levels at the west-facing slope site in the Riviera Valley. Averages over the same 15 VWS days as in Fig. 1,based on 30-min data processed using the Planar Fit (PF) method. Thin lines indicate one standard deviation from the mean.

4. RESULTS AND CONCLUSIONS

The longitudinal and the later stresses obtained using exactly the same raw data set, but this time processed using the PF technique are shown in Fig.2 averaged over the 15 VWS days. All components of the stress tensor have now the same vertical axis.

Comparing Figs.1 and 2 we observe that on average, i.e. for the ensemble of the 15 VWS days, similar patterns of both longitudinal and lateral stress components emerge at the slope site. However, the variability around the mean appears to be much larger when applying the PF method instead of DR. This is also evident when comparing individual daily cycles (not shown). In general, we find similar daily cycles from both post-processing methods (Fig.3).

In particular, from both methods significant lateral stress components result, supporting the conclusion of Andretta et al. (2000) that not only shear stress is important for the flow near a slope on a clear day, but also directional shear.

However, when comparing the magnitude of the stress components from the two post processing methods, significant differences are observed. They amount to typically 30-50% for moderate flow and increase (similar to the findings of W99) for smaller absolute values of the stress components. It remains to investigate in more detail which of the post processing methods (DR or PF) yields the more realistic stress estimates.

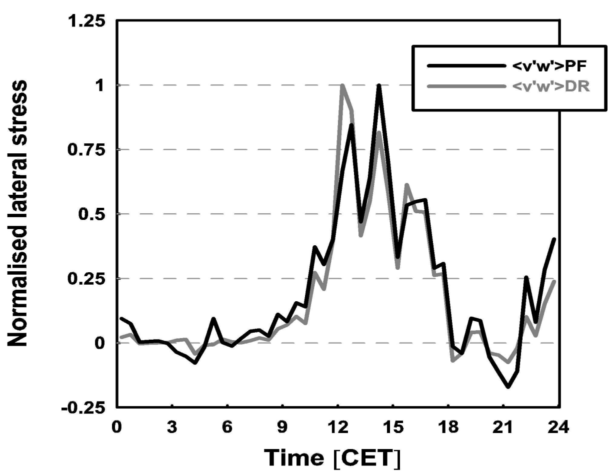

Fig. 3: Diurnal cycle of lateral stress measured 30m.a.g on a steep valley slope in the Riviera Valley. The stresses are normalized with the maximum of that day (negative). The dark line represents data processed using the PF method, the light line those processed using DR.

Therefore, we conclude that the characteristics of the stress components on al steep slope under 'valley wind conditions', namely non-zero lateral stresses due to directional shear, does not seem to be dependent on the post processing method. The magnitude of the retrieved stress components, however, is strongly dependent on whether DR or PF is used. Further research will have to show, based on other independent measures, which of the two is to be preferred.

ACKNOWLEDGEMENTS

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