Boundary Layer Coherent Structures (MBL ARI)

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LONG-TERM GOALS

It is well known that a substantial portion of the air/sea fluxes of heat, moisture, and momentum is accomplished via intermittent processes (Khalsa and Greenhut 1985), processes that are poorly understood at the present time. Recently, Mahrt (1989) and Sikora and Young (1993) have demonstrated that coherent structures in the marine boundary layer (MBL) are responsible for this flux intermittency. These coherent structure types include such secondary circulations as two-dimensional rolls (cloud streets), three-dimensional convective cells (thermals), and shear-driven eddies (billows) (Brown 1980). These features occur in different atmospheric boundary layer thermal stratification and shear regimes; some are forced primarily by thermodynamic, and others by dynamic, mechanisms.

Our ultimate goal is to determine the mechanisms underlying the intermittency in air/sea fluxes produced by these coherent structure types. As summarized below, we are using a variety of complementary statistical/mathematical approaches to objectively identify the spatial and temporal characteristics of these structures. Our primary data sources include both the high resolution output produced by the Penn State version of Moeng's Large-Eddy Simulation (LES) code (e.g. Schumann and Moeng 1991) and observations from the MBL ARI experiments performed in 1995 off the California coast.

OBJECTIVES

Our final scientific objective of the project was to complete analysis of the 1995 MBL ARI field program datasets using our own specialized implementations of these statistical/mathematical approaches (Rinker 1995; Rinker *et al*. 1995; Rinker and Young 1996; Winstead *et al*. 1995; Rohrbach 1996; Suciu 1996; Rogers 1997; Rogers *et al*. 1997; Shirer *et al*. 1997, 1998; Rishel 1998; Mason 1999). To identify the spatial and temporal behavior of the coherent structures, we use obliquely rotated principal component analysis (PCA). To capture the contribution of each coherent structure type to intermittency, we use both the capacity dimension (Takens 1981; Henderson and Wells 1988) and the multiscale line-length algorithm of Higuchi (1988); we provide a thorough review of how we use these chaos quantities in the MBL book chapter by Shirer *et al*. (1998).

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APPROACH

PCA has been shown to be capable of distinguishing and quantitatively describing multivariate structures within the atmosphere (e.g., Richman 1986; Preisendorfer 1988; Alexander *et al*. 1993). To identify the individual coherent structure types, we use both the spectral coherence of pairs of temporal PC score series as well as their chaotic behavior. Nonperiodic, temporal variation is chaotic if the details of a particular time series can not be simulated beyond a few cycles with virtually identical initial conditions, a situation typical of most atmospheric flows. Our hypothesis is that each coherent structure type has its own identifiable chaotic behavior as revealed by how the fractal dimension estimates vary as a function of scale. As we summarize below, we have tested this hypothesis extensively using several quantitative measures of chaos behavior and datasets drawn from LES and marine surface layer observations.

WORK COMPLETED

Our analysis required that we both test existing approaches and develop new methods to assess the chaotic properties of the coherent structures provided by the PCA. We tested the Higuchi multiscale algorithm (Higuchi, 1988; Winstead 1995), and we developed two new algorithms to calculate estimates of the fractal dimension. The first of the new algorithms estimates the correlation dimension and is discussed in a paper by Shirer *et al*. (1997). The second estimates the capacity dimension; the algorithm is developed in an MS thesis by Suciu (1996) and summarized in a book chapter by Shirer *et al*. (1998). Our procedure for identifying coherent structures was first tested using LES data by MS students Donald Rinker, Joseph Rohrbach, Nathaniel Winstead and Laurentia Suciu. Our approach was next extended by MS students Aric Rogers, Jeremy Rishel and Richard Mason to analysis of the measurements taken in 1995 MBL off the coast of California. These coherent structure results have been published in numerous articles and conference papers as summarized in the next section.

RESULTS

Using both standard and newly developed PCA algorithms, we studied several LES datasets to see which principal components (PCs), or coherent structure types, are largely independent of the large-scale forcing and which vary sensitively with it (Rinker 1995; Rinker *et al.* 1995; Rinker and Young 1995; Winstead 1995; Winstead *et al.* 1995; Rohrbach, 1996; Suciu 1996; Shirer *et al*. 1998). These results identified, for each forcing regime, the primary physical processes and coherent structure types associated with air-sea flux intermittency. Significantly, our applications of the PCA algorithms to idealized data tests demonstrated that the method is able to distinguish multiple coherent structure types under several realistic conditions. These tests provided proof that PCA can yield valid results without having an *a priori* conceptual model, as required of previous (conditional sampling) methods.

In the second half of the project, we acquired the 1995 RP FLIP MBL ARI dataset and calibration codes from Dr. Jim Edson of WHOI and Drs. Carl Friehe and Tihomir Hristov of UC-Irvine. Graduate students Aric Rogers and Jeremy Rishel completed calibration of these data, which included incorporating the new cup anemometer calibration algorithm of Hristov and Friehe (1998) into the WHOI calibration code. Rogers (1997) and Rogers *et al.* (1997) described a case study of the convective atmospheric surface layer using these data and the coherent structures identification algorithm described above. Rishel (1998) extended the work of Rogers (1997) and showed that Rogers' single case study results are robust. Mason (1999) will complete the series of RP FLIP case studies by analyzing the flux contributions of each coherent structure type observed in the experiment.

These results are summarized in a chapter (Shirer *et al.* 1998) of a book edited by Gary Geernaert that summarizes the entire MBL project.

IMPACT/APPLICATIONS

The observational and modeling studies performed in this study will lead to improved understanding of the flux intermittency commonly observed in the MBL. This will help advance our overall understanding of processes that affect the state of the sea surface.

TRANSITIONS

Improved understanding of air/sea flux intermittency will lead to improved means for interpreting sea surface roughness patterns on SAR imagery. This improvement will become possible as we obtain an increased understanding, via this ARI project, of the vertical momentum transports by the various coherent structure types. Collaborative work with Don Thompson and Robert Beal of JHUAPL that was funded by ONR at the same time of this ARI project took advantage of this approach to derive from SAR imagery quantitative estimates of boundary layer depth, surface wind speed and direction, and air-sea fluxes.

RELATED PROJECTS

Drs. Jim Edson and Carl Friehe have suggested that another deployment of RP FLIP is necessary to sample the near-surface regions of the atmospheric and oceanic boundary layers much better than was possible during the MBL ARI. The goals of such an experiment would be to understand the processes in the wavy boundary layer much better through the study of the interactions among ocean waves, surface layer oceanic and atmospheric eddies, and mixed-layer atmospheric eddies. In our analysis of the 1995 RP FLIP data, we identified a coherent structure type associated with the interaction between the near-surface wind flow and the ocean waves, but there were not enough observations close to the surface for us to resolve the structure very well (Shirer *et al.* 1998). With observations of the type suggested by Edson and Friehe, our objective algorithm would be able to provide one means for quantifying the flux intermittency of the coherent structure types in the wavy boundary layer.

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