SAR-Related Stress Variability in the Marine Atmospheric Boundary Layer (MABL)

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By stressing the sea surface, the marine atmospheric boundary layer (MABL) wind field can alter the sea surface wave field and so can produce discernable signatures on SAR images of the ocean (e.g. Visecky and Stewart, 1982). Among the resulting signatures, the quasi-linear and cellular microscale patterns still require adequate explanation. The ubiquitous MABL two- and three-dimensional convective circulations provide promising candidates for the forcing phenomena producing these signatures. These microscale circulations have horizontal wavelengths on the order of one to ten times the boundary layer depth, or approximately one to ten km, and temporal scales on the order of one to ten hours. Thus, they produce stress variations on the spatial and temporal scales of the quasi-linear and cellular SAR signatures.

Long Term Goals:

Our ultimate goal is to develop methods of diagnosing both the form of MABL convection and its effect on the sea surface stress variability patterns given only the values of the large-scale meteorological and oceanographic parameters. As briefly summarized below, we are making good progress on this problem in several interacting, complementary ways, which range from data analysis to model development.

Near Term Objectives:

Our most immediate goal is to determine how effective the two- and three-dimensional convective circulations are in producing microscale patterns of sea surface stress variability that can be directly linked to the quasi-linear and cellular SAR signatures. Two primary objectives must be met for us to achieve these goals. First, the surface layer structure within the MABL must be related to the sea surface stress patterns for each of the three microscale atmospheric boundary layer convective forms: the two-dimensional mixed-layer rolls, the three-dimensional mixed-layer thermals, and the surface-layer plumes. Second, the environmental conditions that are necessary and sufficient for the formation of each of these forms of convection must be identified.

Approach:

The first objective is being achieved by using both conditional sampling and composite analysis of atmospheric surface layer observations to describe the occurrence, structure and sea surface stress patterns for each of the three forms of microscale MABL convection; this work provides the MS thesis topic for Todd Sikora. Aircraft data from marine stratocumulus-topped boundary layers that were observed during Project FIRE (First ISSCP (International Satellite Cloud Climatology Program) Regional Experiment) are being used for the first stage of the data analysis. Subsequent stages will use data from the two cruises of the Hi- Resolution ARI. The ship-based sensors that are used in these cruises will permit measurements closer to the sea surface than are possible with instrumented fixed-wing aircraft such as those used during Project FIRE. Conditional sampling of the boundary layer data has been used to identify the updrafts and downdrafts, while composite analysis is being used to summarize the spatial variations within each updraft and downdraft to produce the average structure of each. Particular attention has been given to the filtering and thresholding methods so that the obtained updraft/downdraft boundaries reflect the scales of the microscale eddies of interest. Current work focuses on normalizing and compositing the observations from a large number of events into a comprehensive description of the surface stress pattern induced by boundary-layer-spanning eddies.

Dave Ledvina is testing an alternative approach using principal component analysis to distinguish the modes of surface stress variation. This analysis technique is being developed using data from a deployment of the Penn State sensor suite aboard the RV Wecoma and will be applied to the Penn State shipboard data from the High- Resolution ARI cruises as they become available.

The second objective is being achieved via the development and study of a new, intermediate-order, spectral model of three-dimensional MABL convection; this modeling project is being performed by Ms. Julie Schramm. The boundary conditions for this model are based on boundary layer similarity theory and so are sufficiently general that the surface stress can be nonzero. The model results will be compared with those given by the Fall 1991 pilot HI-Resolution field experiment that was conducted off the coast of North Carolina.

In order to meet both objectives, we need to be sure that the model results are related to the measured ones, and we believe that such measures of the chaotic structure as the correlation and capacity dimensions are good candidates for quantifying this relationship. Both Dr. Harry Henderson and MS student Christian Fosmire are continuing to develop methods for diagnosing the structure of chaotic flows via the calculation of attractor dimensions and other related chaos quantities. Atmospheric boundary layer data measured in marine environments are being analyzed for their chaotic attractor and predictability behavior. In addition, idealized dynamical systems are being studied to determine the best way to analyze time series for the diagnosis of the chaotic structure.

Recent Tasks Completed:

The computer program to locate updraft/downdraft boundaries has been run on the entire FIRE data set (ten flights of the NCAR Electra). The combined composite/conditional sampling analysis program has also been run on the entire data set. Procedures for normalizing and combining the results from multiple events to build a coherent description of the surface stress pattern associated with boundary-layer-spanning eddies have been developed and are in use. Figure 1 shows an example of this stage of the analysis. In this figure, the updraft region of each eddy has been divided into three bins (upwind, center, and downwind) and the surface momentum flux computed for each. A consistent pattern is apparent in four of the five drafts shown here: the downward flux is greatest in the center of the updraft and asymmetrically distributed around the center.

The computer program to perform principal component analysis of the surface stress variability has been developed and is being tested.

The eigenvalue/eigenfunction problem specifying the basis functions for the velocity and temperature expansions of the nonlinear boundary layer model have been specified and the model development is well under way. Four vertical modes are included and appear to be sufficient for adequate resolution of the height dependence of the mesoscale momentum and thermal fluxes.

A new algorithm for calculating the correlation dimension has been developed and tested using time series from idealized dynamical systems (Wells et al., 1992). The resulting tests have revealed that standard model reconstruction techniques may need to be modified for analysis of observations. This algorithm will be applied to observations of the planetary boundary layer during both a land/sea breeze event and a mountain/valley breeze event to best characterize their chaotic structures. In addition, this algorithm will provide the basis for the model/observation comparison using data from the Fall 1991 HI-Resolution field experiment.

For debugging purposes, the improved dimension algorithm of Wells et al. (1992) has been applied to various atmospheric and oceanic acoustical time series. The improved algorithm has been employed along with other techniques to study the nonlinear predictive aspects of these time series. With these techniques, periodic components are easily recognized in the data; thus, such analyses will provide good means for ensuring that the ship motion has been successfully removed from data measured during the HI-Resolution cruises.

Results:

A manuscript, Wells et al. (1992), summarizing the new correlation dimension algorithm is being written for an expected submission to *Physica D* in the spring of 1992. Not only does this algorithm produce a more accurate estimate of the value of the correlation dimension, but it also produces error estimates for this value. In Figure 2, we show a comparison of the dimension estimates d for the Lorenz attractor given by the usual method (thin line) and the new method (thick line). The usual method gives very noisy results that become even more noisy as the data is examined more finely. In contrast, the new method produces an increasingly more robust result with greater resolution. This algorithm is being thoroughly tested and refined with time series generated by both simple dynamical systems and observations of the atmosphere and ocean. This algorithm will be applied to the results from both the intermediate-order model and observations of kilometer-scale convective circulations over the ocean.

Three non-referred conference papers (Thomson and Henderson, 1991a,b; Thomson *et al.*, 1991) summarizing some of our approaches for analyzing atmospheric and oceanic data have been written. Data from a variety of sensors have been analyzed using both standard and chaos quantities, including the correlation and capacity dimensions and the Lyapunov exponents.

Accomplishments:

A graduate student (Todd Sikora) has been taught the composite analysis technique, and we have supervised him through the systems analysis stage, the programming stage and most of the analysis stage of the project. A research associate (Dave Ledvina) has developed software that uses principal component analysis to relate surface stress variability to variability in other atmospheric and oceanographic variables. A research associate (Julie Schramm) has solved the eigenvalue/eigenfunction problem for the intermediate-order spectral model basis function specification. Another graduate student (Christian Fosmire) has finished testing the new correlation dimension algorithm (Wells et al. 1992) in several idealized dynamical systems. A postdoctoral associate, Harry Henderson, has calculated the chaotic dimensions and Lyapunov exponents of several geophysical time series. He has also compared the new integral technique of Wells et al. (1992) with standard techniques. H. Henderson presented a talk at the First Experimental Chaos Conference, Arlington, VA, in which he summarized recent work that was performed under the direction of D. W. Thomson. Two additional papers that were coauthored by H. Henderson were presented by D. W. Thomson in Boulder, CO, and in Turkey. In February, 1991 two of us (H. Shirer and G. Young) participated in the third HI-Resolution ARI Workshop for planning the Fall 1991 pilot field experiment and later produced a contribution to the science plan for this experiment. Two of us (G. Young and T. Sikora) also participated in the August, 1991 HI-Resolution ARI Workshop at Penn State that refined these plans and edited the operations plan. T. Sikora supported the HI-Resolution Operations Center during the cruise with daily weather forecasts. G. Young and a graduate student deployed the Penn State sensor suite aboard the USNS Bartlett for the first HI-Resolution ARI cruise off Cape Hatteras in September. Measurements of surface fluxes of momentum (stress), heat, moisture, shortwave radiation, and longwave radiation were made throughout each cruise day. Moreover, continuous observations of precipitation, temperature and humidity were made. These results are being analyzed for the priority days specified during the October HI-Resolution ARI workshop attended by G. Young.

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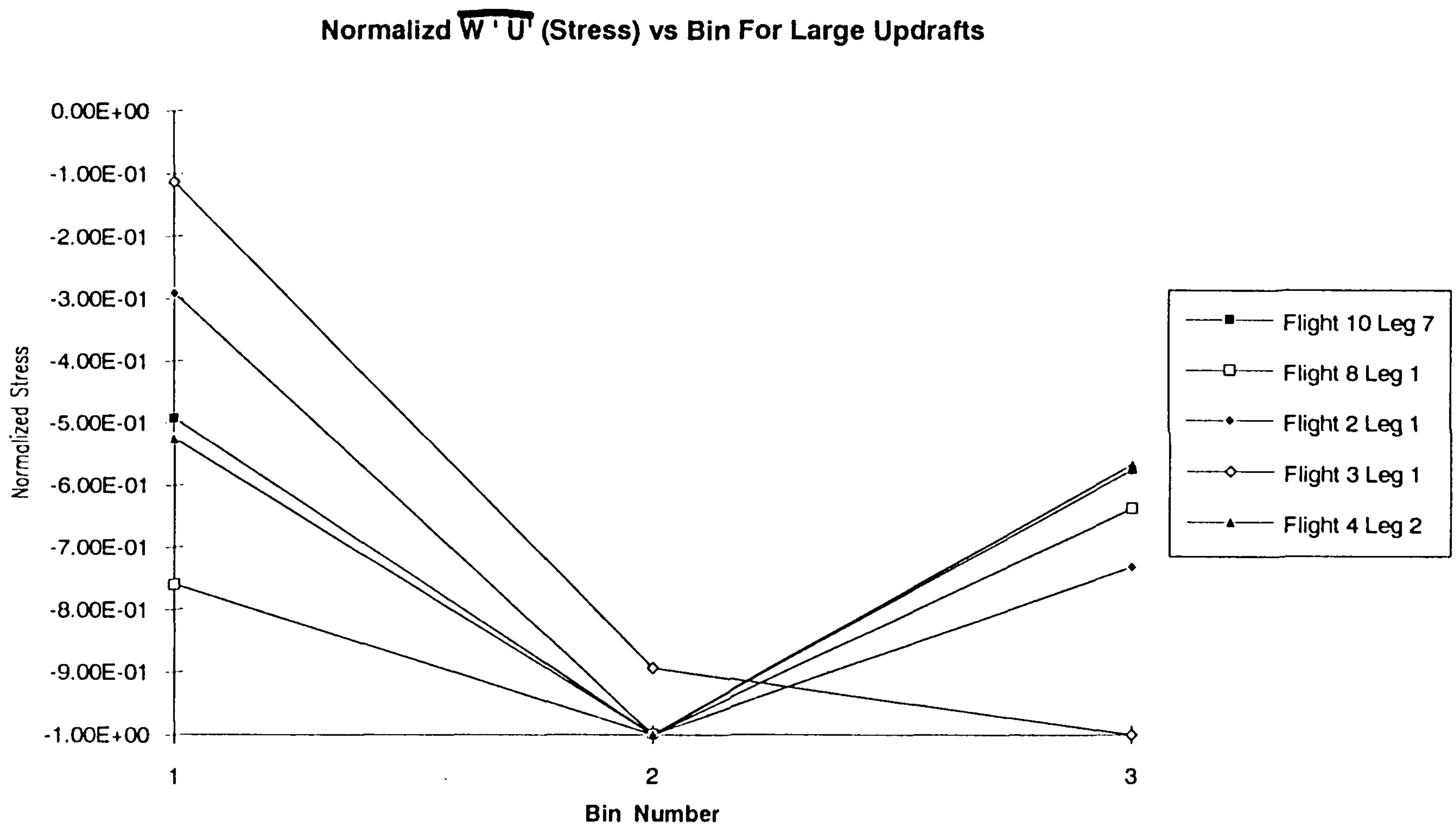
Normalizd W ' U' (Stress) vs Bin For Large Updrafts
0.00E+00
-1.00E-01
-2.00E-01
-3.00E-01
-4.00E-01
-5.00E-01
-6.00E-01
-7.00E-01
-8.00E-01
-9.00E-01
-1.00E+00
Normalized Stress
1
2
3
Bin Number
Flight 10 Leg 7
Flight 8 Leg 1
Flight 2 Leg 1
Flight 3 Leg 1
Flight 4 Leg 2

FIGURE 1

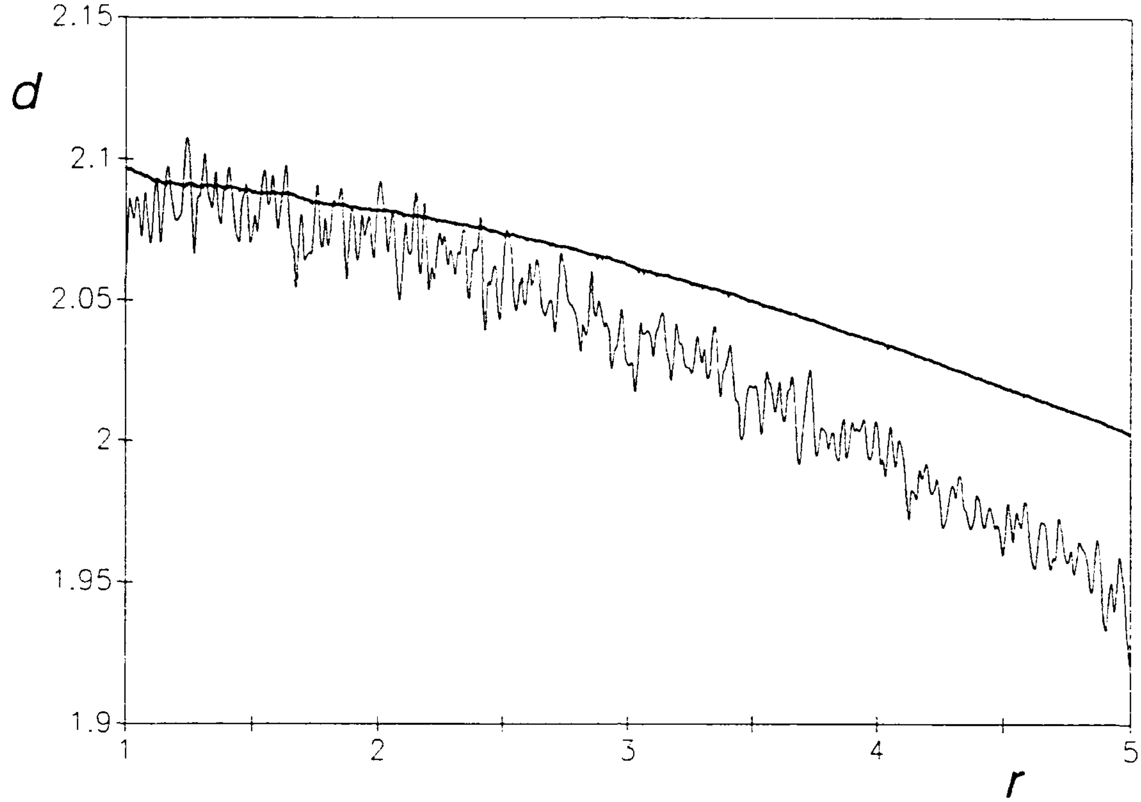

Figure 2. Two estimates of the correlation dimension d for the Lorenz attractor. The usual method of estimating slopes of the ln $C(r)$ versus ln r graph, where $C(r)$ is the correlation integral and r is the distance between two points on the attractor, is given by the thin line, and the new method is given by the thick line. The usually quoted value for d is 2.06, although 2.06 ± 0.05 would appear to provide a better description. (From Wells et al., 1992).

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