FRACTAL CONCEPTS AND THE ANALYSIS OF ATMOSPHERIC PROCESSES

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LONG-TERM GOALS

Data collected during field projects or the outputs from elaborate numerical simulations are often not analyzed to their fullest extent. Although, field data sets that are as complete as we would like are still quite rare, the results from numerical modeling now cover large ranges of scale with considerable spatial detail. The hardware and data are now available to support the development and application of new tools for analyzing the details of fluid flows. Such improvements in analysis methods will provide the means for obtaining greater insight into the nature of fluid flow, which in turn will improve the modeling and prediction of environmental parameters that affect the Navy's operations. The goal of our research is to improve our understanding of atmospheric processes and the simulations of them through the application of analytical approaches derived from methods associated with multiresolution feature and wavelet analyses. We seek a clear understanding of the spatial and temporal characteristics of atmospheric motions that have many scales and are intermittent. Second, we build tools to analyze these motions, in the field and in simulations of atmospheric motions. Finally, we seek to determine the causes of key features of the motions.

OBJECTIVES

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Our first objective is to identify and obtain existing data that are suitable for studying spatial distributions of atmospheric properties [including aerosols and plume materials], to develop multiresolution feature analysis methods and the computer algorithms and codes necessary to apply them, to apply the analysis methods to atmospheric observations, to interpret the results of the analyses to identify and characterize important physical processes, and to communicate the results of the analyses and interpretations. Our second objective is to identify useful wavelets for analysis of the dynamics of stratified flows which are related to the atmosphere, and then to analyze several different laboratory and simulated flows with these wavelets. The knowledge gained here can then be applied to the analysis of atmospheric flows, to identify features of such flows that are not elucidated by conventional methods.

APPROACH

Multiresolution feature analysis (MFA), as originally proposed for estimating the fractal dimension of two-dimensional scalar-fields, is used. MFA applies specified correlation filters to a data field (such as a greyscale image) at different resolutions and examines the scaling of the intensities of the spectral peaks in the filter outputs at the different scales. These scaling properties can be related to different types of fractal dimension. One attractive aspect of MFA is that it gives the analyst flexibility to choose physically significant features for filtering. Our work extends the technique from two-dimensional scalar fields to three-dimensional vector fields.

We use the wavelet as an analysis tool to study the evolution of the mixing and production terms in stratified turbulent flow as a function of the strength of the stable stratification. In this work, we employ the 10-point Daubechies orthogonal wavelet and the fast wavelet transform algorithm.

WORK COMPLETED

We have developed and applied some unique methodologies for the analysis of fluid flow under our current Grant. They include a multiresolution feature analysis (MFA) methodology that is suitable for use with three-dimensional vector fields (Ludwig and Street, 1995). Since the original development and application of this technique, we have modified the computer codes to be more easily used on different data sets, and have undertaken some preliminary studies of relatively fine scale LES results for flow over an undulating surface. We are in the process of adapting and evaluating methods for estimating values for missing data, and for transferring data on irregularly spaced grids to regular Cartesian grids, because observational data frequently suffer from gaps in coverage and numerical model outputs are often obtained on highly irregular grids.

We completed our development and application of wavelet analysis techniques (Piccirillo et al., 1997a, b) to a lengthy, high resolution time series observations of temperature, and the fluctuating streamwise and vertical velocity components in uniform mean-shear, stably-stratified turbulence (Piccirillo, 1993; Piccirillo and Van Atta, 1996).

RESULTS

The work of Piccirillo et al. (1997a&b) provided new physical insights into the behavior of turbulence in stratified flows that will be invaluable in future interpretations of DNS results, laboratory data and field observations. As a result of these studies of five data sets with different gradient Richardson numbers, we have an analysis tool that gives information in both time and frequency. Already, we have confirmed that the mixing in stratified turbulence is driven by a small number of powerful mixing events, as hypothesized by Piccirillo and Van Atta (1996).

IMPACT FOR APPLICATIONS

Our work with wavelets has revealed clear physical insight to the behavior of turbulence in stratified flows. This has the potential to change the interpretation of both laboratory and field data, as well the modeling of turbulence in numerical simulations.

TRANSITIONS

None

RELATED PROJECTS

We work closely with some of the active modelers in our Laboratory (Calhoun, 1996; Calhoun and Street, 1997, Cederwall and Street, 1997) in the interpretation of the results that they are getting. This work links to several ongoing projects on stratified flows and to our continuing work on large eddy simulation. Sponsors include DOE, ONR and NSF.

REFERENCES

Calhoun, R. J., 1996: "Turbulent Flow over Sinusoidal Topography," presented at the 1996 Fall Meeting of Amer. Geophys. Union, Paper A71A-12, San Francisco, Dec. 15-19, 1996

Calhoun, R. J. and R. L. Street, 1997: "A Comparison of Turbulent Flow over Two- and Three-Dimensional Sinusoidal Topographies", 12th Symp. Bound. Layers and Turbulence, Vancouver, B. C., July 27-Aug 1, Amer. Meteorol. Soc., Boston, pp 215-216.

Cederwall, R. T., and R. L. Street, 1997: "Use of a Dynamic Subgrid-Scale Model for Large-Eddy Simulation of the Planetary Boundary Layer,", 12th Symp. Bound. Layers and Turbulence, Vancouver, B. C., July 27-Aug 1, Amer. Meteorol. Soc., Boston, pp 215-216.

Ludwig, F. L., and R. L. Street, 1995: "Modification of Multiresolution Feature Analysis for Application to Three-dimensional Atmospheric Wind Fields," *J. Atmos. Sci*, *52*, 139.

Piccirillo, P., 1993: “An experimental study of the evolution of turbulence in a uniformly sheared thermally stratified flow,” Ph.D. Thesis, University of California, San Diego.

Piccirillo, P. and C.W. Van Atta., 1996: “The evolution of a uniformly sheared thermally stratified turbulent flow,” *J. Fluid Mechanics*, in press.

Piccirillo, P., R. L. Street, and J. R. Koseff, 1997a: "Using Wavelets to Study Mixing in Stably Stratified Turbulent Flow", *12th Symp. Bound. Layers and Turbulence*, Vancouver, B. C., July 27-Aug 1, Amer. Meteorol. Soc., Boston, pp 249-250.

Piccirillo, P., R. L. Street, and J. R. Koseff, 1997b: " Wavelet Analysis of Uniform Mean-Shear Stably-Stratified Flow", submitted to *Phys. of Fluids*.