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13. ABSTRACT (*Maximum 200 words*)

A high density of surface and upper air observations, including aircraft observations, were accumulated during the STORM-FEST field campaign in the central United States (1 February-13 March 1992). These data were analyzed to identify significant internal gravity wave and turbulent activity that occurred in association with low-level frontal passages through the boundary layer. The principal analysis method was local decomposition using wavelets as basis functions. These functions provided information on both scale and translation of coherent events, and were well-suited for frontal and boundary layer analyses. Dissipation of kinetic energy in frontal zones was determined using data obtained during STORM-FEST. This information was used to interpret some of the physical processes in low-level frontal zones, but specific models of the observed events were not constructed.

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STORM-FEST 1992: Waves and turbulence in frontal zones.
Final technical report: 1 January 1992 - 31 December 1993.

1. Research objectives

A principal goal of the U.S. Weather Research Program STORM-FEST experiment is to investigate the structure and evolution of fronts and associated mesoscale phenomena. The goals of this investigation were to:

i) participate in the STORM-FEST field program carried out in the midwest Great Plains region, 1 February - 13 March 1992,

ii) analyze data collected during this field phase, particularly high frequency - large wavenumber data that revealed evidence of turbulence and waves in frontal zones,

iii) analyze the kinetic energy dissipation within frontal zones and compare these value with pre- and post-frontal dissipation, particularly in the planetary boundary layer,

iv) provide models for the initiation of waves and turbulence within frontal zones.

A comprehensive presentation of the goals, operations and preliminary results of the STORM-FEST experiment may be found in:

-STORM 1 Experiment Design (chapter 7), 1991,
-STORM-FEST Operations Summary and Data Inventory, 1993.

These documents may be obtained from the U.S. Weather Research Program Office, National Center for Atmospheric Research, Foothills Laboratory; P.O. Box 3000, Boulder, CO 80303.

2. Boundary-layer observations

The focus was to meet the stated goals by concentration on processes occurring in the boundary layer before, during, and after frontal passages. This effort requires the acquisition of data on spatial scales of meters to tens of kilometers, and on temporal scales of seconds to tens of minutes. The Principal Investigator, in conjunction with investigators at the University of Colorado, National Center for Atmospheric Research (NCAR and the Wave Propagation Laboratory of the National Oceanographic and Atmospheric Administration (NOAA), participated in the establishment of a dedicated boundary - layer array of instruments that collected data during the six-week observational period of STORM-FEST. This array, situated in northeastern Kansas, consisted of several surface mesonet stations (NCAR PAM II), radiosonde observations (CLASS), surface heat and momentum fluxes (NCAR ASTER), wind and temperature profiles (NOAA/WPL/LASS and RASS), and dual-Doppler radar coverage to provide wind circulations.

This network was supplemented by data acquisition from the NCAR King Air aircraft during frontal passages over, and close to, the boundary-layer array.

There were three or possibly four frontal passages through the boundary layer array, accompanied by aircraft penetrations, that can be used to examine the boundary-layer response.

3. Research

STORM-FEST frontal research was carried out by the P.I., W. Blumen, Research Associate, N. Gamage, and Graduate Research Assistant, V. Ostdiek who is supported by an AASERT grant that is, in effect, a supplement to the Air Force grant: his Ph.D. research is closely tied to the parent award. All three participated on site at the STORM-FEST Operations Center at Richards-Gebaur Air Force Base, south of Kansas City, during the six week field program. The approximately twelve month period following this observational phase was devoted to the acquisition of data as it was released from the various field facilities of both the NCAR and NOAA laboratories. These data were primarily 20Hz data from the NCAR King Air low-level traverses of frontal events and all data from the boundary-layer array situated in northeastern Kansas. Data were also acquisitioned from the various surface sites and their relative accuracy determined by examination of collocated instruments. Upper air soundings (particularly during Intensive Observing Periods, IOPs) and profiler observations from the NOAA Demonstration Network completed the observational data base for current and future research.

The NCAR King Air low-level 20Hz data taken by traverses through the relatively intense front of 9 March 1992 were used with NOAA Boulder Atmospheric Observatory tower observations of two cold fronts to provide a limited catalogue of cold front events. These events have been analyzed by Gamage and Blumen (1993a) to depict the relative value of wavelet, Fourier and empirical orthogonal function (EOF) decompositions in the analysis of local structures comprising the cold front and its concomitant turbulent patches and wave motions. It was demonstrated that the wavelet transform offers a space-scale decomposition that overcomes some of the inadequacies of both the Fourier and EOF transforms.

Both observational data and theoretical model calculations suggested that kinetic energy dissipation is significantly larger in magnitude within a cold frontal-zone than in the pre-or post-frontal environment. An observational study of this phenomenon was carried out by Gamage and Blumen (1993 b). Data were obtained from three separate frontal missions carried out by the NCAR King Air on 9 March 1992: early morning, early afternoon, and late afternoon- early evening flights. The early morning data were also supplemented by high frequency (20 samples per second) data obtained from the NCAR Atmospheric-Surface Turbulence Exchange Research Facility (ASTER). The frequency cut-off of the flight data corresponds to a 4m horizontal spatial resolution over an 82 km cross frontal flight traverse. The ASTER data are converted to a spatial resolution of 0.5m. Approximately three decades of data ranging from 10m to 10^3 m, are contained within the inertial subrange of turbulence theory, where the wavenumber k follows a $k^{-5/3}$ spectral decay. A least square fit of the data to a $k^{-5/3}$ slope is established with an error estimate of ± 10 percent. The relative enhancement of dissipation between the pre-frontal boundary layer and the frontal zone is determined for each cross-frontal flight segment, and frontal passage past the ASTER facility. The relative enhancements when the pre-frontal data are normalized by the minimum pre-frontal dissipation value are also determined, and both results are presented in tabular form. The transects show a relative enhancement of approximately two to ten in the horizontal kinetic energy dissipation, while relatively little increase is noted in the vertical kinetic energy dissipation. The kinetic energy dissipation can, however, be one to two orders of magnitude larger than the minimum dissipation in the pre-frontal boundary layer, which occurs in the early morning when the boundary layer is relatively stable. The specific mechanism for enhanced dissipation within the frontal zone has not been delineated. Future work planned for spring 1995 will address this problem (see section 4).

Hagelberg and Gamage (1993) have examined observed intermittency in turbulence transport and dissipation using conditional sampling schemes and with the use of global statistics. In this paper intermittent coherent structures and associated transport properties are studied using a local wavelet transform and filtering schemes based on it. Partitioning of the observed signal into coherent structures and the residual using the wavelet based filtering scheme proposed here results in the ability to define and intermittency index, and to study the effect of imtermittency on the global statistics associated with such events. Superior localization is achieved via the use of non-orthogonal decomposition.

Although not available during STORM-FEST, atmospheric boundary layers have been observed with both ground based and aircraft based Lidar equipment. Such data usually provide visual data of the evolution of the atmospheric boundary layer (ABL). In a study by Davis, Hagelberg and Gamage (1993) a wavelet based edge detection scheme is used to detect the location of the ABL top and any coherent structures within the ABL. Data from many experiments are used to develop measures such as the skewness of the ABL top and link them to the general characteristics of the underlying ABL. Using a two dimensional transform characteristic, scales of plumes and other features are extracted providing useful information that, until now, has been unavailable from Lidar data.

4. Work in progress

STORM-FEST research has not been completed.

V. Ostdiek is constructing a spatial and temporal depiction of a relatively weak cold front that passed through the boundary-layer array and then become stationary in central Kansas and Missouri on 21 February 1992. The analyses of this event, as well as other weak frontal cases, will be used to evaluate the relative significance of various horizontal gradient terms in the nonlinear Boussinesq system of equations. These are the terms usually neglected in theoretical boundary-layer models, but should be relatively significant when frontal gradients are present. The completion of the analysis of the 21 February case and at least one other is expected to continue. The AASERT award supports Mr. Ostdiek's work until 31 May 1995.

Gamage and Blumen are completing work on the analysis of the boundary layer during frontal events and nonevents during STORM-FEST. The data are being examined by a wavelet analysis. The purpose is to extract the significant features in the boundary layer, for which wavelet analysis is an ideal tool, that characterize frontal passages, and distinguish this situation from an undisturbed boundary layer.

Plans are also being formulated to place hot wire anemometers on ASTER towers to measure the atmosphere at 25,000 samples per second. This type of measurement provides data in the dissipative range of turbulence. The goal will be an evaluation of dissipation estimates made by the inertial subrange hypothesis, and to delineate features in both frontal zones and in the boundary layer that will lead to models of the waves, coherent eddies and the turbulence observed.

5. Publications

Gamage, N. and W. Blumen, 1993a: Comparative analysis of low-level cold fronts: Wavelet, Fourier, and empirical orthogonal function decompositions. Monthly Weather Review, 121, 2867-2878.

Gamage N. and W. Blumen, 1993b: Dissipation in a frontal zone observed during the STORM-FEST field experiment. Journal of the Atmospheric Sciences, under review.

Hagelberg, C. and N. Gamage, 1993: Structure preserving wavelet decomposition's of intermittent turbulence. Boundary Layer Meteorology, in press.

Hagelberg, C. and N. Gamage 1993: Application of structure preserving decompositions to intermittent turbulence: a case study. Wavelet Transforms in Geophysics, E Foufoula-Georgiou and P Kumar, eds., Vol IX, in Weavelet Analysis and its Applications, C Chui, series editor. Academic Press, under review.

Davis, K., C. Hagelberg and N. Gamage, 1993: An objective method for determining atmospheric structure from airborne lidar observations. Wavelet Transforms in Geophysics, E Foufoula-Georgiou and P Kumar, eds., Vol IX, in Weavelet Analysis and its Applications, C Chui, series editor. Academic Press, under review.

Planned for submission after 31 December 1993.

Gamage, N. and W. Blumen, 1993: Wavelet analysis of the boundary layer during STORM-FEST. Monthly Weather Review. To be submitted.

6. Personal supported

William Blumen, principal investigator
Nimal Gamage, research associate

7. Conference presentation

Wavelet analysis of low-level cold fronts. American Geophysical Union conference. Baltimore, MD, 24-28 May 1993.