GENERALIZED ANALYSIS OF OROGRAPHICALLY MODIFIED WINDS AND PRECIPITATION OBSERVED BY AIRBORNE DOPPLER RADAR DURING PHASES I & II OF COAST

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LONG TERM GOALS

Accurate short-range forecasts (~0-48 h lead) of significant mesoscale weather disturbances, especially high winds and heavy precipitation, that can accompany landfalling cool-season frontal systems and intervening periods of steadier flow impinging upon steep coastal terrain.

OBJECTIVES

The purpose of this research is to obtain a quantitative, dynamically-based understanding of the airflow and precipitation patterns associated with both oceanic frontal systems and steady onshore flows as they encounter steep coastal terrain. While the capability of mesoscale numerical forecast models to address this problem has not yet been fully tested, such models offer great potential for capitalizing upon this improved understanding if critical processes are identified and appropriate model physics/parameterizations are put into place. Emphasis is thus placed upon analysis of specialized observations from multiple storm events to identify repeatable mesoscale kinematic and related precipitation patterns and subsequently relate their occurrence to features of the evolving large-scale and variations in underlying coastal orography. Through cooperation with other ONR-supported PIs, these analyses are used to validate, test and improve mesoscale models. Of particular interest are those processes leading to development of high winds, restricted ceiling/visibility and heavy precipitation over coastal waters, as well as modulation of airflow and precipitation over the adjacent sloped

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terrain. Data obtained through observational efforts are also evaluated critically to focus hypotheses and improve observational strategies applied in subsequent field programs.

APPROACH

To be readily comparable to output from state-of-the-art mesoscale research models, observations of landfalling storms and associated flow perturbations near steep terrain should be four dimensional and address disparate parameters such as wind velocity and precipitation intensity. A further challenge is that these observations be optimally timed and located so as to envelop relatively limited yet dynamically critical periods/regions in which rapidly varying flow and stability interact strongly with underlying orography. An important platform that can be used to meet this challenge is NOAA's Lockheed WP-3D Orion "hurricane hunter" research aircraft, and in particular its tail-mounted scanning Doppler radar. As outlined in our prior Annual Reports, the NOAA P-3 aircraft was brought to bear on this problem under of ONR's Coastal Meteorology ARI during "COAST" (Coastal Observations And Simulations with Topography), whose field phase encompassed six research flights conducted during Nov-Dec 1993 and an additional eight flights more closely tied to the coastline in Nov-Dec 1995. Convolution of baroclinically- and orographically-induced flow disturbances renders identification of their underlying dynamics difficult, but we will endeavor to surmount this difficulty in two distinct ways: (1) through comprehensive analysis of a select number cases using a combination of Doppler radar and flight level observations and application of a fully non-hydrostatic mesoscale model in a diagnostic sense (i.e., to relate these observations to key thermodynamic/microphysical quantities not adequately specified through in situ or remote sensing), and (2) through a less detailed yet more sweeping analysis of multiple cases predicated upon development of a common analysis/display format that relates observed flow/precipitation features to key attributes of the large-scale baroclinic structure and underlying terrain. In so doing, we seek to identify and understand processes that lead to the initiation, propagation and decay of mesoscale zones of enhanced winds and precipitation adjacent to and over steep coastal terrain.

WORK COMPLETED

In our previous report, we described analysis of a unique dataset collected on 8 December 1993 during COAST IOP3, which tracked a convectively intense occluding frontal system from a point nearly 400 km offshore to the early stages of its landfall and associated orographic modification (which included changes in pre-frontal wind profiles qualitatively consistent with those predicted by theory) on the southern Oregon coast. During the past year, an article summarizing these results (Braun et al. 1997) was submitted to Monthly Weather Review, underwent minor revision, and was accepted for publication.

During late 1996, the previous post-doctoral worker on this project (Dr. Ming-Jen Yang) accepted a permanent position with the Research and Development Center of Taiwan's Central Weather Bureau. Although Dr. Yang continues to contribute to COAST research under the present proposal (at no additional cost to ONR), this necessitated identifying a replacement for Dr. Yang. After conducting telephone interviews with four prospective candidates, during October 1996 the PIs formally interviewed and ultimately hired Dr. Cheng-Ku Yu, who received his Ph.D. from National Taiwan University in 1996. Dr. Yu's Ph.D. dissertation dealt with analysis of airborne Doppler radar data collected by the NOAA P-3 aircraft (the same platform employed during both phases I & II of COAST) to investigate organized convective systems occurring in association with orographically-modified flows over the rugged island of Taiwan. Skills in processing, analyzing and interpreting P-3 Doppler radar data are confined to researchers at a handful of institutions world-wide, and as such the PIs feel fortunate to have successfully hired Dr. Yu to pursue research under the auspices of COAST.

A somewhat more generic yet valuable effort to which the PIs made significant contributions was an overview article on COAST (Bond et al. 1997). This article not only will serve to draw attention to ONR-supported research on cool-season coastal weather phenomena, but will be an extremely useful reference for COAST researchers desiring to refer to yet not repeat details related to the observational platforms and sampling strategies employed during COAST I & II.

Progress continues on the COAST-II IOP8 study. Dr. Yu is leading the observational component of that investigation, which is the subject of Yu et al. (1998). Through a combination of multiple flow realizations provided by systematic airborne dual-Doppler sampling in the coastal zone and analysis of high temporal resolution (6-min) wind data from the ETL profiler at Crescent City, a clearer picture is emerging of the timing and offshore extent of pre-frontal coastal wind maximum and it's role in modulating mesoscale frontogenesis as the large-scale baroclinic zone encountered the coastal terrain. These detailed four-dimensional depictions of flow and precipitation structure are being used to evaluate structures emerging from an MM5 simulation of this event being conducted by Dr. Yang (former postdoc on this project) in conjunction with Brian Colle at the University of Washington. That work is summarized in Yang et al. (1998). Another source of model validation is the use of both cooperative observer raingage network data and archived WSR-88D reflectivity volume scans from the National Weather Service Doppler radar on Cape Mendocino. Additionally, sensitivity tests have been conducted with the MM5 in which the effects of near-coastal terrain and latent heat release were selectively eliminated from the simulation. In collaboration with ONR-supported PI Cliff Mass and Dr. Brian Colle at the University of Washington, analysis of 17 airborne Doppler volumes collected during COAST IOP5 (11 December 1993) has been completed. In tandem with an MM5 simulation of this case, these data illustrate the intricate aspects of a cold front encountering and sweeping around the Olympic barrier and subsequent development of a Convergence Zone-like feature over Puget Sound. Results of these complementary approaches to this problem are summarized in a manuscript by Colle et al., which is on the verge of being submitted to Monthly Weather Review.

In keeping with our stated goal of achieving a "generalized" description of coastally-modified flow and precipitation features, work is either now complete or in progress on processing available radar data for nine out of 14 P-3 missions during COAST I & II (IOP's 2-5, 8, and 10-13; refer to proposal for a table highlighting the foci of these missions). Work is underway to develop a common display format to summarize the salient structural and statistical characteristics of these data so as to reliably identify repeatable flow and precipitation structures, their relationship to features of the underlying terrain such as distance from the coastline/crest and relationship to local terrain slope, and to the extent possible their relationship on boundary conditions such as the stability and baroclinic character of the large-scale flow. A priority list and timetable for processing of Doppler radar data collected during several other IOPs have been developed.

RESULTS

Observations collected on 1 December 1995 during COAST IOP-8 indicate that frontal intensity (as evinced by local development of density-current like structure, depth of the post-frontal airmass, and associated banded precipitation structures). Evidence of sharply-defined frontal structures on 1 December was confined between Cape Blanco, Oregon (on the north) and Cape Mendocino, California (on the south), and were thus confined to the region adjacent to the most steeply rising coastal terrain. In addition to a control simulation of this event, which has served to point out the strong dependence of the simulation on model initialization (in this case necessitating an extended period of four-dimensional data assimilation to produce a satisfactory integration), experiments in which the effects of coastal terrain and latent heating were selectively removed (NOCOAST and NOLH, respectively) have served to quantify key physical processes. In particular, the presence of the coastal ranges (as distinct from the major inland barrier constituted by the Sierras) was found to be critical to the development of a zone of enhanced precipitation in accord with observations, yet to have almost negligible effect on the modulation of mesoscale frontogenesis in association with the advancing baroclinic zone. Processing and initial examination of data from several other noteworthy missions has begun (including the 12 December 1995 windstorm during IOPs 12-13) and a nicely documented warm-frontal landfall on Vancouver Island (IOP 10), but in accord to the timetable laid out in the proposal, definitive statements re: the presence/absence of repeatable "generalized" structures must await Year 2 of this effort.

TRANSITIONS

Results of our research have been viewed with great interest by several individuals/agencies within the operational community. These include Dr. James Doyle at NRL-Monterey, who has examined selected dual-Doppler results in conjunction with evaluation of output from the Navy's COAMPS model, and the Storm Prediction Center of the National Weather Service (collocated with the headquarters of NOAA/NSSL, with whom the PI is affiliated), whose personnel are particularly interested in an evaluation of the strengths and limitations of coastally deployed WSR-88D Doppler radars to nowcast high wind and coastal flooding/erosion events. Moreover, flight and analysis experience gained during COAST I & II has played a key role in planning by NOAA/ETL for a P-3 experiment in Jan-Feb 1997. CALJET plans to examine the landfall of low-level jets and their role in producing flooding events along the northern and central California coast.

RELATED PROJECTS

Two key projects in which the PIs are providing leadership in planning for scientific planning and focused field data collection include CALJET (described above) and MAP, the Mesoscale Alpine Programme whose field phase is slated for late summer/autumn 1999 on the southern flank of the Swiss Alps and will in part address the interaction of moist stratified flows and deep convection to yield extreme precipitation events over mountainous terrain adjacent to the Mediterranean Sea.

PUBLICATIONS

Formal:

Bond, N.A., C.F. Mass, B.F. Smull, R.A. Houze, Jr., M.-J. Yang, B.A. Colle, S.A. Braun, M.A. Shapiro, B.R. Colman, P.J. Neiman, J.E. Overland, W.D. Neff and J.D. Doyle, 1997: The Coastal Observation and Simulation with Topography (COAST) experiment. Bull. Amer. Meteor. Soc., 78, (In Press, September issue).

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Colle, B.F., C.F. Mass and B.F. Smull, 1997: An observational and numerical study of a cold front interacting with the Olympic mountains during COAST IOP5. Mon Wea. Rev. (To be submitted, November 1997).

Informal:

Colle, B.A., C.F. Mass and B.F. Smull, 1998: An observational and numerical study of a cold front interacting with the Olympic mountains during COAST IOP5. (Accepted for presentation at AMS 16th Conf. on Weather Analysis & Forecasting, Phoenix, Jan. 1998.)

Yang, M.-J., B.A. Colle, B.F. Smull, R.A. Houze, Jr., and C.-K. Yu, 1998: Interaction of a Pacific cold front with the coastal mountains of the western U.S. (Accepted for presentation at AMS 16th Conf. on Weather Analysis & Forecasting, Phoenix, Jan. 1998.)

Yu, C.-K., B.F. Smull and R.A. Houze, Jr., 1998: Airborne Doppler radar observations of a coastal jet associated with a landfalling Pacific cold front during COAST-95. (Accepted for presentation at AMS Conf. on Coastal & Oceanic Prediction and Processes, Phoenix, Jan. 1998.)