# Numerical Simulation of Coastal Trapped Disturbances along the U.S. West Coast

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## LONG TERM GOALS

The long-term goal of this research is to better understand and explain the initiation, propagation and demise of trapped atmospheric disturbances in the coastal marine boundary layer, particularly those which have been observed to occur along the US West Coast. In particular we wish to obtain a better understanding of how topographic variability along the west coast of North America influences the evolution, propagation, and decay of Coastal Trapped Disturbances (CTDs). Emphasis is placed on examining the termination of events which observations to date suggest may occur in the vicinity of bends, such as Cape Mendocino and Cape Blanco. A secondary objective is to determine whether a reduced gravity model (applied to these events in previous work) is a good approximation of the coastal atmosphere during CTD events. It is anticipated that this improved understanding will lead to enhanced forecasting of CTDs and their impact.

## OBJECTIVES

Our proposed research has the objective of determining firstly, what forces CTD generation, secondly, what the fundamental dynamics responsible for CTD generation are, thirdly, how topographic variability along the U.S. west coast influences CTD propagation and demise, fourthly, the sensitivity of CTD propagation and evolution to variability in surface heating and frictional gradients, and lastly, whether a reduced-gravity approximation of the atmospheric stratification and wind distributions is a reasonable assumption. These objectives build on those originally proposed and take into account some of the important theoretical and observational findings made during the previous few years by various members of the ARI.

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## APPROACH

The major tool being used to address the above objectives is the Colorado State University Regional Atmospheric Modeling System (RAMS), a 3D mesoscale numerical model which will continue to be used in two modes, namely idealized and realistic simulations. Idealized simulations with simplified topography and initial conditions are most easily interpreted, can be compared most directly with analytic models, and can be used for parameter sensitivity tests. They are limited however because the CTD simulated must be specifically inserted into the model. This is problematic given that there does not appear to be a canonical CTD structure: they have been described as both single and combined manifestations of trapped gravity currents, Kelvin waves, and as down-gradient acceleration due solely to synoptic pressure forcing (e.g. Dorman, 1985, 1987; Mass and Albright, 1987).

Secondly, realistic simulations of observed events with realistic topography, and with observed horizontally and temporally variable initial and boundary conditions are being used. These simulations provide information on forcing mechanisms, internal dynamics and propagation characteristics of observed CTD events. A careful force balance analysis of model results after Jackson and Steyn (1994) tells us about CTD initiation and propagation characteristics for a specific event. We are presently simulating the May 1985 event whose characteristics, based upon sparse observations, have been documented in the literature (Mass and Albright, 1987).

## WORK COMPLETED

A number of 2- and 3D RAMS simulations have been performed with idealized configurations to investigate the sensitivity of an idealized coastal trapped disturbance to changes in background synoptic conditions and topography. The background synoptic changes have included: wind speed, stratification (inversion height strength and depth), initiation mechanism (low-level cooling), sea-surface temperature, and sea breeze strength. The topographic changes have involved: coastal mountain gaps (valleys) of various magnitudes, coastal mountains of varying slope and the presence of bends in the mountains and coastal islands (Fu, Reason, and Jackson, 1997; Reason and Jackson, 1999 in progress).

A RAMS configuration with three nested grids, realistic topography and nudged towards NCEP analyses at the boundaries of the coarsest grid has been used to simulate an observed CTD event. The particular event chosen was that of May 15-17 1985 observed (Mass and Albright, 1987) along the Northern California and Pacific North West coast, since this was an event whose dynamics was relatively straightforward to interpret and which lead to relatively intense and abrupt weather changes in the coastal zone. The first paper from this study (Guan, Jackson and Reason, 1998) validated the simulation against available observational data, and concluded that RAMS can be successfully applied to further understanding of these events. The second part of the study (Jackson, Reason and Guan, 1998) has analyzed detailed diagnostics from the simulation with the aim of isolating the fundamental processes important in the initiation, propagation and demise of this event.

The third and fourth parts of this study (Tory, Reason and Jackson, 1999; and Jackson, Reason and Tory, 1999; both in progress) are focussing on assessing the influence of topography and surface properties on CTD evolution and decay. In order to do this, mountain heights, the presence or absence of mountains and islands, gap widths, sea surface temperature, surface fluxes, etc., are being adjusted and the CTD response quantified.

## RESULTS

Idealized simulation results of gravity current-like CTD suggest that they are quite sensitive to the size and intensity of the initiating cold pool. Large cold pools with large amounts of cooling of a scale which allows geostrophic adjustment to take place, result in CTD which decay more rapidly than those initiated with smaller cooling areas. If the cooling amount or area is too small however, the supply of cold air becomes the limiting factor and the CTD will also decay more rapidly. Sea surface temperature values similar to those of the cold pool seem to enhance propagation speed and are associated with idealized CTD which exhibit sharp surface transitions. When coastal mountains are less steep, onshore flow is not blocked as effectively and the CTD response is weaker. The simulations reveal that CTD weaken and their across-shore scale is reduced, when they propagate past gaps in the coastal mountains. Wider, deeper gaps cause more attenuation. Idealized simulations with a near-shore island reveal that there is a trapped response on both the mainland coastal mountains and on the island (Fu, Reason and Jackson, 1997; Fu, 1998).

Analysis of the initiation stage of the realistic simulation of the May 15-18, 1985 event suggested that synoptically driven offshore flow ahead of the CTD and deceleration of onshore flow of relatively cool, marine air by the coastal mountains in the Southern California Bight were important for initiation. The time scales and force balances diagnosed in the numerical simulation were consistent with theory presented in Reason and Steyn (1992) and Reason (1994). The along-shore propagation of the event was essentially that of a coastally trapped gravity current in semigeostrophic balance, again consistent with the theory and with the observations of Mass and Albright (1987). Demise of the event near the northern tip of Vancouver Island occurred once favorable synoptic forcing no longer existed; however, the detailed force balances involved were complex and varied at different locations on the coast with advective and diffusive contributions significant (Jackson, Reason, and Guan, 1998).

A tool to quantitatively assess the intensity of a CTD and allow comparison between simulations, has been developed. This tool, an example of which is shown in Fig. 1, is a latitude vs. time contour plot of the meridional potential temperature gradient in a coast-parallel transect near the surface. It is a useful way of characterizing CTD intensity and propagation characteristics: the zone of maximum meridional potential temperature gradient marks the CTD leading edge; the slope of this leading edge position is the propagation speed; the CTD intensity is related to its potential temperature gradient and propagation speed. The event depicted in Fig. 1 initiates around hour 30, rapidly propagates north until hour 40 when it appears to reform and move more slowly north until hour 72 when it begins to decay.

## IMPACT

The realistic simulations represent some of the very few attempts to model the initiation, propagation and demise of an actual event. It has now been demonstrated that a 3D mesoscale numerical model can be used to study in detail the evolution of particular events, providing that the data used to initialize the model and as lateral boundary conditions are of sufficiently good resolution. The NCEP analyses appear to satisfy this requirement, at least for strong CTD events where synoptic forcing rather than internal boundary layer dynamics dominates. These results provide guidance for future modeling efforts by the community as well as further understanding of CTD in general.

**RELATED PROJECTS**

Between August 1994 and August 1995, one of us (Jackson) has been PI in an observational program designed to detect CTD along the Beaufort Sea coastline between Barrow Alaska and the MacKenzie River. Four pressure and temperature measuring devices were deployed between Prudhoe Bay and Shingle Point to supplement the existing meteorological network. It was reasoned that the combination of a large coastal mountain barrier and strong Coriolis forcing in the presence of stable stratification should result in trapped disturbances in this region. Kubu and Jackson (1998) found several likely CTD, and one event which very closely resembles a non-linear Kelvin Wave ridge. Jackson has continuing funding from the Canadian Natural Science and Engineering Research Council and Atmospheric Environment Service, part of which supports modeling and analysis of CTD along the British Columbia Coast.

Recently, funding has been received from the Australian Research Council to investigate the characteristics of CTD in southeastern Australia. With lower topography and generally less pronounced stratification in southeastern Australia than in California, conditions are not as favorable for CTD events there. However, there are several documented cases of pronounced coastal weather changes associated with the propagation of a coastally trapped ridge. Other cases appear to be more related to the enhancement in the coastal zone by the topography of the weather associated with the passage of a cold front (Southerly Busters). RAMS has been applied to diagnose the characteristics of the CTD event of Nov 9-11, 1982 (Holland and Leslie, 1986) that brought rapid and severe weather changes along the Australian coast from near Melbourne to Brisbane (Reason, Tory and Jackson, 1998, Tory, Reason and Jackson, 1999 in preparation).

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Guan, S., P.L. Jackson and C.J.C. Reason, 1998: Numerical modeling of a coastal trapped disturbance. Part I: Comparison with observations. *Mon. Wea. Rev.*, **126**, 972-990.

Jackson, P.L., C.J.C. Reason and S. Guan, 1998: Numerical modeling of a coastal trapped disturbance. Part II: Structure and dynamics. *Mon. Wea. Rev. in press.*

Closely related FY 1998 publications:

Kubu, C., and P.L. Jackson, 1998: Evidence of coastally trapped disturbances along the Beaufort Sea coastline. *Preprints, 8^th^ Conference on Mountain Meteorology.* Amer. Meteor. Soc., Flagstaff, August 3-7, pp. 353-356.

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**IN-HOUSE / OUT-OF-HOUSE RATIOS**

All work was performed “out-of-house” – at UNBC and The University of Melbourne.

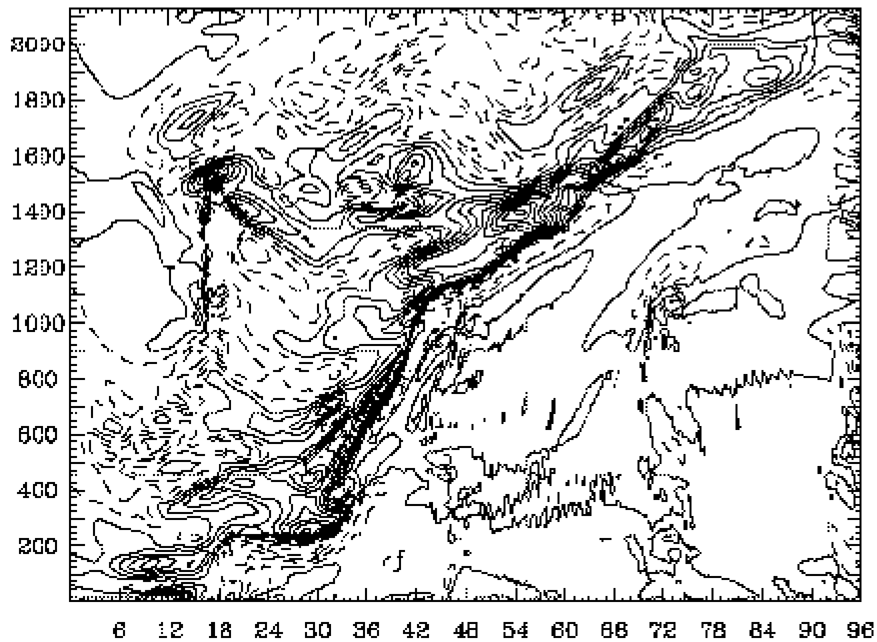


***Figure 1 Meridional potential temperature gradient in an along-coast transect during 96 hours of simulation. The y-axis is km from south to north, the x-axis is time from the start of simulation in hours.***