

Numerical Studies Pertaining to Airflow on the West Coast of the U.S Fy98 Annual Report

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LONG-TERM GOAL:

An understanding of the origin and nature of the sudden transition in the local weather from clear skies to dense stratus clouds that often occurs during the spring and summer along the west coast of the U.S.

SCIENTIFIC OBJECTIVE:

To develop a correct fluid-dynamical understanding of the coastal flows that bring about such sudden transitions.

APPROACH:

Our working hypothesis is that the basic fluid-dynamics problem is one of a reservoir of relatively dense air (the marine layer), bounded by an insurmountable wall on one side (the coastal mountains of the U.S. west coast), under the influence of the Earth's rotation. Our approach is to use a hierarchy of models of increasing complexity; in the case at hand, the two-dimensional (long-shore and cross-shore variation allowed) shallow-water equations (SWE) on an f-plane provide the minimal model. Primitive-equation models with simplified initial and boundary conditions provide the next step in our attempt to relate observational results to simple theoretical models.

WORK COMPLETED:

Our development of the theory and conceptual models for the most common CTD events is complete, and the results will appear in Skamarock et al. (1998). The theory highlights the critical role the earth's rotation plays in allowing the large-scale offshore flow to push out to sea the marine layer and climatological northerly coastal jet, in producing onshore flow south of the localized lee trough, and in

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trapping the northward-propagating disturbance that is generated as a result of the onshore flow being blocked by the coastal mountains.

The results described above were obtained for straight coastlines. The U.S. West coast is characterized by significant bends, such as the California bight. We have nearly completed work on the effects of coastline curvature on the generation and propagation of the CTD. As a result of this work we can now see that the formation of the flow phenomenon known as the Catalina Eddy is a subclass of the phenomena described in our theory for CTDs.

NCAR postdoctoral fellow R. Pandya, working with the PIs, has solved the two-layer linearized shallow water equations for the case where the lower layer is bounded by the step (i.e. the coastal mountains) and the upper layer covers the step (i.e. the free atmosphere) in an attempt to understand more clearly the CTD response in terms of Kelvin waves and/or topographic Rossby waves. These solutions also help clarify the physical interpretation of solutions found by R. Samelson for continuously stratified flow with a step.

SCIENTIFIC RESULTS:

Background:

The analyses of the results of the 1994 field program conducted under this ARI shows how changes on the synoptic scale lead to the small-scale coastally trapped disturbance [CTDs; see Ralph et al. 1996 (R96)]. Consistent with the climatology (Bond et al. 1996), R96 find the following: On the synoptic scale, the chain of events leading to a CTD begins with a ridging at 850 mb in the U.S. Pacific Northwest; concomitant with this ridging is an offshore-directed wind at the same level, but focussed in central California (south of the ridge). R96 found that as the synoptic-scale wind turns offshore at 850 mb, the climatological northerly winds in the marine boundary layer also shift to an offshore direction south of Cape Mendocino, and that a mesoscale low-pressure feature develops at the coast and out to sea roughly between Monterey and Los Angeles. The mesoscale analysis of R96 suggests that the westward-shifted, southward-flowing marine boundary layer eventually turns cyclonically around the coastal mesoscale low-pressure feature, and therefore toward the coast near southern California; they hypothesize that the stable marine boundary layer then piles up at the coastal mountains, and the CTD is initiated. R96 present further evidence that the CTD observed on 10 June 1994 is consistent with a Kelvin wave, except that there is a more complex vertical structure than that of the (essentially) one-layer shallow water equations.

The basic conceptual model for the CTD derived from our model, theory and observation is summarized in Fig. 1.

Evolution of a Coastally-Trapped Disturbance

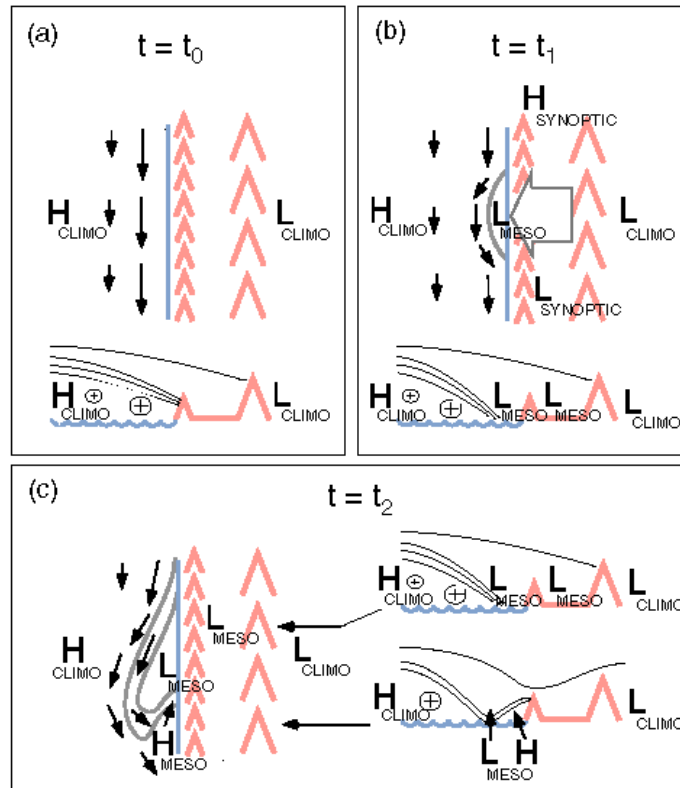


Figure 1: Summary of coastally trapped disturbance evolution.

The observed climatological flow is represented as in Fig. 1a: There is northerly flow in the sloping marine boundary layer along a straight coast with steep mountains. The synoptic-scale perturbation to the climatological flow is represented in Fig. 1b with the development of anomalous high pressure to the north and low pressure to south. The geostrophic easterly wind implied by the synoptic pressure perturbation produces warming at the coast through advecting the sloping marine layer seaward, and through adiabatic compression of air flowing downslope. This warming produces a coastal mesoscale low pressure signal. In Fig 1c, the displaced northerly flow attempts to come into geostrophic balance with the low pressure associated with the depressed marine layer; when this flow turns eastward and encounters the coastal range, the marine layer piles up there and triggers a Kelvin-type wave that propagates northward toward, and eventually through, the center of the originally depressed marine layer.

Catalina eddies, a cyclonic circulation in the southern California bight region that appears occasionally from late spring to early fall, can sometimes be a prelude to a CTD that propagates far to the north of the bight, but most times does not lead to a CTD event. The climatology of the Catalina eddy events is similar to that of a CTD, except that for CTD events the synoptic scale offshore flow is more easterly, whereas the Catalina eddy events the flow is northerly onto the bight. Three-dimensional model simulations using an idealized coastal topography that includes the bight and the climatological northerly marine layer jet that does not extend into the bight region, show that Catalina eddies are generated when forced with an imposed northerly offshore flow in the bight region, and a easterly offshore flow.

Catalina Eddy Simulation

θ (c.i. = 1 K), vectors at $z = 200$ m MSL
day 1.5 day 2.5

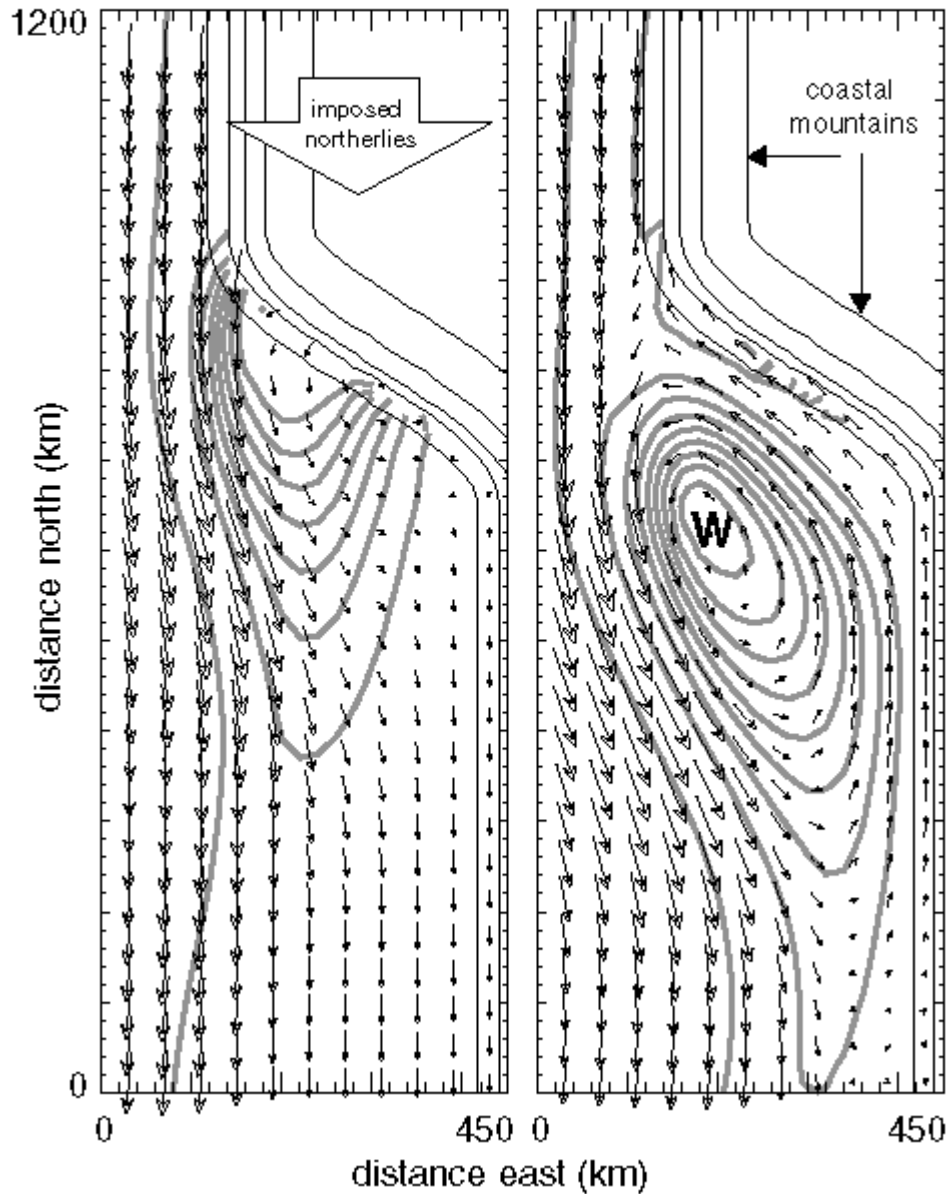


Figure 2: Idealized simulation of a Catalina eddy.

For the imposed northerly offshore flow, a CTD-like disturbance is produced, but it does not propagate around the northern point of the bight because it is blocked by the strong northerly marine-layer jet; the jet is not displaced by the imposed offshore flow. In the case of easterly offshore flow, the CTD propagates around the bend far to the north of the bight because the imposed flow displaces the marine layer jet. Thus the dynamics producing CTDs and Catalina eddies are essentially the same, with the

strength, direction and location of the offshore flow relative to the bight determining whether or not a long-lived CTD is produced from the evolving Catalina eddy circulation.

IMPACT/APPLICATION:

1. We have solidified our theoretical/conceptual of the CTD through application of those ideas to the Catalina eddy,
2. The appreciation that both Kelvin waves and topographic-Rossby waves play a role in the evolution of the CTD motivated a theoretical study by using the two-layer shallow water in which the lower layer is blocked by the step and the upper layer covers the step.

TRANSITIONS:

RELATED PROJECTS:

1. R. Samelson (WHOI) has investigated the effects of continuous stratification on a variety of linear Kelvin-wave models of CTDs.
2. M. Rapp (NOAA) and co-workers are working on analysis of the field data which motivated the design of our numerical experiments.

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Skamarock, W. C., R. Rotunno, J. B. Klemp, 1998: Models of coastally trapped disturbances. To appear in The Journal of The Atmospheric Sciences.