Coupled Ocean-Atmosphere Interaction And The Development Of The Marine Atmospheric Boundary Layer - Aasert

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LONG TERM GOALS

The goal of this research is to provide support to graduate students to provide training and research opportunities leading to an understanding of the processes that control the structure of the marine atmosphere and its interaction with the ocean.

SCIENTIFIC OBJECTIVES

Two themes are investigated here: the marine boundary layer, and cloud radiative properties.

The marine boundary layer objectives are to understand the processes that control the exchange of heat and moisture between the ocean and the atmosphere; to understand the physical processes that control the formation, development and decay of stratocumulus clouds and fog in the marine boundary layer; and to understand the structure of the coastal marine layer.

The radiative objectives are to improve the parameterization of clouds in general circulation models, emphasizing the characteristics of fair-weather cumulus over the open ocean.

APPROACH

Three students are supported under this award. One student is focusing on a numerical model of clouds, another is using data collected during Coastal Waves '96 to investigate the structure of the coastal marine boundary layer, and one has completed a preliminary study of California fog.

WORK COMPLETED

Coastal Waves

Ms. Kathleen Edwards has written and submitted a multi-authored paper to the Journal of Atmospheric Sciences, "Topograpically-induced structure in the marine atmospheric boundary layer," which presents aircraft, buoy, and remotely sensed observations and model results for the 7 June flight of Coastal Waves 96.

Ms. Edwards presented results from her analysis of the Coastal Waves 96 data set at several conferences.

In January 1999, she gave a talk entitled "Scaled Vertical Profiles of the Marine Atmospheric Boundary Layer during Coastal Waves 96" at the American Meteorological Society's Thirteenth Conference on Boundary Layers and Turbulence. This work showed that the 377 aircraft profiles of

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wind speed and virtual potential temperature could be satisfactorily reduced to dimensionless, similar profiles with the choice of appropriate height, speed, and temperature scales. This was not expected, given the range of conditions observed throughout the month-long project. It confirms that the marine atmospheric boundary layer is typically slightly stably stratified beneath a strongly stably stratified inversion layer, and that the wind profile is jet-like with a peak near the inversion base. Interestingly, the scaling improved with the choice of different height scaled for the speed and temperature profiles.

An analysis of the differences in height scales used to produce the dimensionless speed and temperature profiles was presented at the Fifth California Islands Symposium hosted by the Minerals Management Service. It was found that under stable conditions in the surface layer, it was more likely that the same height scale could be used to reduce the speed and virtual potential temperature profiles. When the surface layer was near neutral or unstable, it was more likely that the scales differed. As well, the presence of cloud at the top of the boundary layer made it more likely that the height scales of the speed and temperature profiles differ. This was attributed to the ability of clouds to decouple the layer from the surface, and to enhance layering within the boundary layer.

Work in progress includes revision of a paper, “Vertical structure of the marine atmospheric boundary layer during Coastal Waves 96”, and the production of a third paper, “Topographical modification of the marine atmospheric boundary layer during June 1996”. Both papers analyze the aircraft, surface station, and synoptic data collected during Coastal Waves 96. The third paper will include results of a shallow-water model and seeks to expand on a result found in the paper described above: that the extent of the supercritical region off California typically exceeds the Rossby radius in summer, a feature presented in remotely-sensed maps of surface wind speed.

Cloud Radiation

Ms. Dana Lane has investigated the sensitivity of cloud-radiation codes to changes in vertical resolution. The tests were performed using a single-column model (SCM), which can be envisioned as one column of a General Circulation Model (GCM) containing all of the same model physics. The number of vertical layers in the atmosphere was uniformly increased from 16, a typical GCM resolution, to 60. The output domain-averaged model variables of cloud fraction, downwelling shortwave radiation at the surface, outgoing longwave radiation at the top of the atmosphere, and the layer convective mass flux and detrainment rate were analyzed and compared when possible to observed values.

The radiative-transfer band model uses a stochastic approach, developed in nuclear engineering, to distribute clouds in a clear sky and determine the domain-averaged radiative field. As the model calculates the absorption, scattering and transmission of radiation according to the statistical properties of the cloud field, a detailed description of an observed cloud field is input into the stochastic model on an hourly basis. The output is validated against observations from a network of radiometers that covers an area comparable to the model’s horizontal domain. In addition the performance of the stochastic model is compared to that of a plane-parallel radiation model which is part of most current GCMs.

Fog

Ms. Jessica Lundquist is a new Ph.D. student with a primary interest in understanding the processes that control the formation and evolution of marine fog. She has completed a preliminary assessment of California fog using data collected during Coastal Waves 1996 and provided a summary of past work. This is published in an internal SIO report.

RESULTS

Coastal Waves

Ms. Edwards has shown that the thinning and acceleration of the marine atmospheric boundary layer corresponds to a supercritical expansion fan. Local clearing in the marine stratocumulus occurred within the expansion fan, where the layer thins beneath the lifting condensation level. Layer-averaged maps of the layer height, speed, and Froude number show that the flow is transcritical; i.e., subcritical upstream flow became supercritical as it passed around Cape Mendocino. These features are reproduced with a transcritical shallow-water model which simplifies the coastline into an infinitely high coastal wall with several bends. The model indicates a hydraulic jump at a downstream bend, which corresponds to an increase in the layer depth viewed by the the aircraft's lidar. The model shows that when the Cape Mendocino topography protrudes into the upstream flow, it exerts an upstream influence on the oncoming flow, namely a thickening and slowing within a Rossby radius of the coast. For all simulations, the along- and across-shore extent of the supercritical region downstream of the cape exceeds the Rossby radius.

This work implies that the thinning and accelerating of flow around coastal promontories observed during Coastal Waves 96 behaves as a shallow layer of fluid which, when supercritical, supports expansion fans. During summer months, the marine atmospheric boundary layer is topped by an inversion and is characterized by strong along-coast winds. Under these conditions, similar behaviour of the flow at capes to those analyzed here may be likely.

Cloud Radiation

Ms. Lane has shown that the Single column model is very sensitive to changes in the vertical resolution scheme in each of the three time periods analyzed, especially in the variables involved in the model convection. The stochastic model appears promising in its ability to represent the radiative effect of broken cloud fields. A parameterization will be developed that will allow correction of the plane-parallel code in GCMs to account for the diffuse fraction of the net radiation.

Fog

Ms. Lundquist examined the meteorological data from thirteen coastal surface stations, seven radar profilers, five cooperative observing stations, 700 hPa synoptic charts, and GOES 9 visible satellite images for months of June to October 1996. She has demonstrated the synoptic conditions that prevail during most California marine fog episodes and the frequency of occurrence. This information will be used to plan future studies that will focus on the microphysics of the fog and the mesoscale conditions, which control the small scale variability of these events.

IMPACTS

Ms. Edwards has demonstrated the ability of a simple shallow water model to describe topographically constrained flow.

Ms. Lane has demonstrated that increasing the typical vertical resolution of GCM models is required to resolve small scale convective clouds, typical of open ocean conditions, adequately. These ideas are contributing to development of new community models of the large scale general circulation of the atmosphere.

TRANSITIONS

Ms. Edwards' work is contributing to a new effort to use similar models to explore the structure of the coastal boundary at the Naval Research Laboratory, Monterey.

RELATED PROJECTS

This project is related to ongoing coastal work by Clive Dorman and Clinton Winant, an NSF project that supported the coastal California field work, and ONR award N00014-97-1-0554 that supports studies of the littoral atmosphere.

PUBLICATIONS

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