Coupled Ocean-Atmosphere Modeling of the Coastal Zone

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LONG-TERM GOAL

The long-range goal of this project is to improve our ability to understand and predict environmental conditions in the coastal zone.

OBJECTIVES

The primary scientific objectives of the proposed research are to use a coupled atmosphere--ocean model to investigate and quantify the interaction between the oceanic and atmospheric boundary layers and its effect on environmental conditions in the coastal zone. The main focus will be on boundary layer interactions under coastal upwelling conditions, in which cold, upwelled ocean surface water induces the development of stable internal boundary layers in the atmosphere and thereby reduces low-level winds and surface stress.

APPROACH

The approach used in this project is to combine numerical model results with in-situ and remote-sensing observations to understand and quantify physical processes in the coastal, coupled atmosphere-ocean and test their representation in mesoscale atmospheric models.

WORK COMPLETED

Work has continued on testing a coupled version of the COAMPS and ROMS models. Results from an idealized coastal upwelling scenario have been reported in a paper submitted to Journal of Physical Oceanography (Perlin et al., 2006). Further model development has continued on generalizing the coupled model for domains with differing grid sizes. Extension of the model to more realistic coastal domains has begun with an initial case representing a coastal point or cape feature.

RESULTS

We continued our efforts to investigate the effects of ocean-atmosphere coupling in a simple two-dimensional coastal wind-driven upwelling scenario. The geometry, topography, and initial and boundary conditions were chosen to be representative of summertime coastal conditions off the Oregon coast, as the simulations were motivated in part by recent observations of the coastal ocean and

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lower atmosphere along the Oregon coast. Results of the coupled simulation show a strong influence of air-sea coupling on the atmospheric boundary layer and surface wind stress on mesoscale forecast timescales.

Within 20 km off the coast, wind stress was reduced to half of its offshore value in the 72-hour coupled ocean-atmosphere simulation (Figure 1). This change in stress due to air-sea coupling is substantially larger than that predicted by some previous studies, such as of Enriquez and Friehe (1995). The major reason for this difference is that, in the coupled model, the atmospheric boundary layer structure is fundamentally altered by air-sea fluxes over the cold upwelled water, through the development of a stable internal boundary layer. The increased stability of the entire boundary layer, and weaker turbulence in the internal boundary layer, in the coupled simulation are consistent with previous observational studies and with large-eddy simulations performed as part of the CBLAST experiment. In contrast, previous studies predicting weaker coupling have focused on the stability dependence of drag coefficients, with a fixed near-surface wind.

For these 72-hr simulations, comparisons of coupled and uncoupled model results showed that the coupling caused measurable differences in the ocean upwelling circulation within 20 km off the coast. Between 3 and 15 km from the coast, offshore Ekman transport increased more rapidly with offshore distance, and vertical velocities at the base of the surface layer were stronger for the coupled case (Figure 2). The coupled case also generated a thinner near shore surface layer with gradual seaward deepening. Overall, adjustment of surface Ekman divergence to the coastal boundary occurred over a slightly greater offshore distance in the coupled case than in the uncoupled case. Because of the wind reduction in the coupled case, vertical mixing in the upwelling zone was weaker, resulting in a shallower surface mixed layer. This delayed the merging of the surface and bottom boundary layers over the inner shelf and allowed further inshore propagation of the bottom upwelling front. Within 2 km off the coast, local cross-shore transport estimates were slightly greater and SST slightly cooler for the coupled case. Weaker near shore wind stresses in the coupled case also resulted in consistently smaller alongshore transport in the oceanic surface layer.

This work examined very simple cases with idealized conditions for the purpose of understanding the basic importance of two-way ocean-atmosphere coupling in the coastal zone, and was intended to lay a foundation for applying the coupled models to the study of a variety of air-sea interaction problems. In general, the ocean inner shelf, loosely defined as the region in which surface and bottom boundary layer interact, remains poorly understood and difficult to observe and model. The results described here indicate that air-sea interaction on short temporal and horizontal scales may play a central role in controlling essential elements of inner-shelf circulation. Planned extensions of this research include the simulation of three-dimensional flows with coastal land topography and bathymetry similar to the coastal regions along Oregon and California. Other possible future extensions include the addition of fresh water sources, such as the Columbia River plume as well as simulations focusing more generally on the effects of variable stratification in the coastal ocean, and investigation of the role of air-sea interaction in low-level coastal stratus formation in the atmosphere.

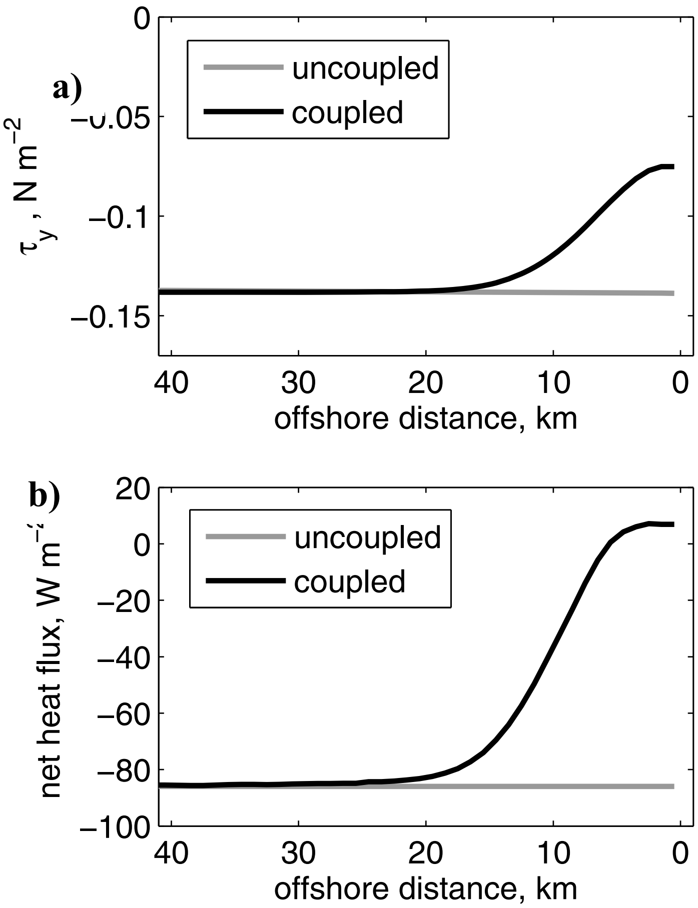

Figure 1 (a-b). Atmospheric surface forcing variables in the end of 72-h run for three simulations: a) surface meridional wind stress from the atmospheric model, b) downward surface net heat flux (positive downward). Note that this model time corresponds to 0400 LST, and therefore solar radiation is zero at that time. Negative net heat fluxes into the ocean correspond to heat loss by the ocean and thus unstable conditions in general.

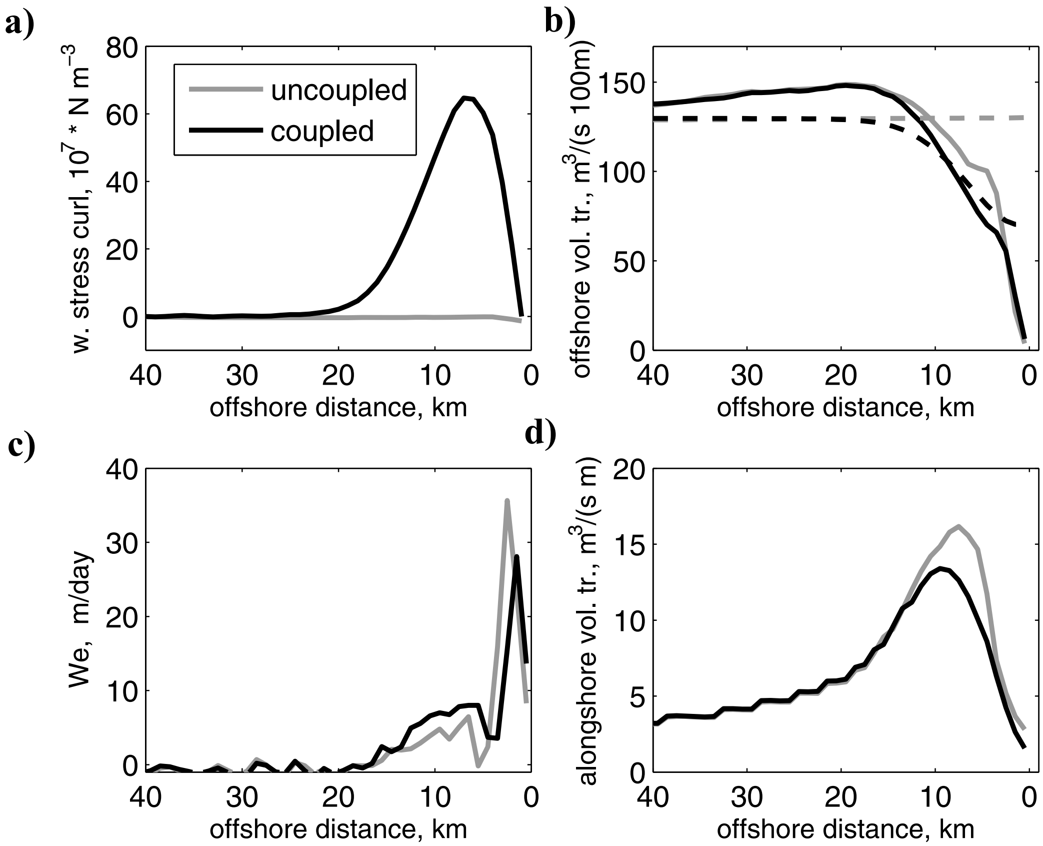

Figure 2. a) Model wind stress curl computed from meridional wind stress shown in Fig. 1a; b) Vertically-integrated offshore volume transport in the ocean surface layer from model results (solid lines), and offshore transport estimated from wind stress forcing (dashed lines); c) Vertical velocity at the base of the surface layer (also see text); d) Vertically-integrated alongshore volume transport in the surface layer.

IMPACT/APPLICATIONS

A new coupled model numerical code has been developed for use in research on ocean-atmosphere coupling. Results indicate that air-sea coupling during coastal upwelling can cause large changes in wind stress and atmospheric boundary layer structure over upwelled water on the mesoscale forecast timescale. Although the atmospheric response is large, changes in the ocean response are more subtle in these short-term simulations Nevertheless, for long-term prediction, the role of coupling could prove to be very important for accurate simulation of the coastal ocean circulation. Additional effects on the lower atmosphere (e.g. stratus/fog formation) can be anticipated and will be accessible to study through simulations conducted with the new coupled model.

TRANSITIONS

The coupled model code has been made available to the general community. For example M. Spall (WHOI, personal communication) is using the model to study open-ocean air-sea coupling in the North Atlantic.

RELATED PROJECTS

Continued interaction with the CBLAST-low project (Skyllingstad) is planned as part of this project. The focus of this work has been on understanding the importance of fronts on the marine boundary layer, and quantifying resolution requirements for accurate mesoscale predictions. Simulations with LES suggest that fronts of order 20 km cause significant changes in the boundary layer structure and should be resolved in mesoscale models. Future experiments are planned to examine how these fronts affect the circulation in the coupled model.

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PUBLICATIONS

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