ARCTIC UPPER OCEAN STUDIES

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LONG TERM GOALS

The goal of the project is to understand the turbulent transfer of momentum, heat, salt, and other scalar contaminants in naturally occurring boundary layers of the ocean, and to apply this knowledge to understanding air-ice-ocean interaction in polar regions.

OBJECTIVES

Objectives of the project include (i) gathering and analyzing turbulence data from the boundary layer under sea ice; (ii) developing techniques, including both new instrumentation and analysis methods, for determining turbulent fluxes in the boundary layer; (iii) combining measurements and theory (including numerical modeling) for concise descriptions of turbulent boundary layer scales; and (iv) using the results to develop parameterizations of important boundary layer processes for large scale numerical models of the sea ice/upper ocean system.

APPROACH

Sea ice provides a superb platform for studying the upper ocean without the complicating effect of surface waves. A long series of experiments utilizing instrument clusters on inverted masts suspended from drifting ice have provided unique documentation of turbulent fluxes in a rotational ocean boundary layer, including the first direct (covariance) measurements of both turbulent heat and salinity flux. By gathering observations over a wide range of surface stress forcing from quiescent to full gale, with surface buoyancy flux ranging from moderate freezing (destabilizing) to rapid melting (stabilizing), important constraints have been placed on theoretical descriptions of the boundary layer. The data have been used to develop relatively simple conceptual models for eddy exchange which have been incorporated into numerical models with application ranging from modeling strong heat flux in the Weddell Sea to sediment transport in the Kara Sea.

ACCOMPLISHMENTS

Accomplishments in FY 97 include:

- Extension of the *inertial dissipation method*, which estimates momentum flux (Reynolds stress) and scalar fluxes from spectral density levels in the inertial subrange of turbulence spectra, to conditions in which free convection governs turbulent kinetic energy production. Data from the Arctic Lead Experiment were used to illustrate and confirm the method, as described by McPhee [1997a].
- Developed a *Local Turbulence Closure* (LTC) numerical boundary layer model used for both interpretation of existing turbulence data, and for prognostic modeling evolution of the temperature/salinity structure in the upper ocean. The model was used in conjunction with flux measurements to derive exchange coefficients for ocean-to-ice heat flux in the

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Weddell Sea, as reported in McPhee ate al. [1997]. It was also compared with second-moment closure (Mellor-Yamada level 2 $^1/_2$) for the Liege Colloquium "Marine Turbulence Revisited," as reported by McPhee [1997b].

- Assembled a new turbulence mast system designed around a Sea-Bird Electronics 911+ CTD system with Falmouth Scientific and SonTek 3-axis current meters. The system was tested in Puget Sound in August and will be deployed for the horizontal variability study during the Surface Heat Budget of the Arctic (SHEBA) field project.
- Analyzed boundary layer data from under fast ice in Barrow Strait near Resolute Bay NWT, where flow was tidal.
- Served as *rapporteur* for the session on Polar Oceans of the AMS Workshop on Polar Processes in Global Climate. A multi-author manuscript is in preparation.

SCIENTIFIC/TECHNICAL RESULTS

A major thrust of my research is looking for parameterizations of boundary layer exchange processes that conform with the body of observational data gathered under High Latitude sponsorship, and that are efficient enough to be of use for numerical modelers interested in global aspects of air-sea interaction. An example from McPhee [1997b] demonstrates this pursuit. I constructed an idealized scenario with sea ice overlying an ocean with a deep mixed layer and a substantial heat reservoir in the thermocline/pycnocline below the mixed layer. I then specified a constant conductive heat flux through the ice cover and forced the system with ice motion corresponding to two intense storms spaced 10 days apart. I modeled the one-dimensional response of the ocean in two ways. The first used Mellor-Yamada second-moment closure to solve a coupled set of 6 conservation equations (u, v, T, S, q^2, q^2l) where q^2 is twice the turbulent kinetic energy per unit mass and l is the master length scale. A 1-h timestep was used as the model became unstable for longer timesteps. The second model uses LTC based on my similarity theory for turbulence scales [McPhee, 1994]. Since closure is local, it carries prognostic conservation equations for temperature and salinity only, and allows a timestep of more than 6 h with little degradation in response. The model scenario includes periods of both stabilizing buoyancy flux as ice melts in response to heat mixed from below the mixed layer during storms, and destabilizing buoyancy flux as it freezes between storms. Although differences between the two models in their predictions of the temperature, salinity, and flux fields were not large, mean surface heat flux differed by only a few percent over the 20-day simulation. Tthere were times during the simulations when substantial disparities in eddy viscosity existed, as demonstrated in Fig. 1. Between storms, M-Y 2 $^1/_2$ maintains a much larger eddy diffusivity (upper panels) than LTC, with more complete mixing [McPhee, 1997b], mainly because the master M-Y 2 $^1/_2$ length scale (lower right panel) remains large. The LTC mixing length (λ) and l are not directly comparable unless stratification is weak, in which case they should be of the same order. As suggested in the manuscript, this provides a way of discriminating between upper ocean models using existing data. Our experience from LEADEX and the Antarctic Zone Flux Experiment suggests that the smaller mixing length is appropriate.

IMPACT FOR SCIENCE

Research into basic questions of how the ocean boundary layer works has wide application ranging from detailed studies of ice/ocean interaction to ocean parameterization in global circulation models. Relevant Naval programs include High Latitude Dynamics (Code

322HL), Ocean Modeling and Prediction Program (322OM), Physical Oceanography Program (Code 322 PO).

TRANSITIONS

SHEBA represents a shift from intensive, highly focused process experiments done in the past to long term monitoring of ocean heat flux as part of the annual cycle of the heat and mass balance of the Arctic ice pack. Intensive observations will also be made during limited periods of the SHEBA experiment.

RELATED PROJECTS

This project is closely related to work being done for the Arctic Nuclear Waste Assessment Project under subcontract to the University of Washington Applied Physics Laboratory. A shallow water version of the similarity mixing length closure has been used to simulate sediment transport and radionuclide concentration in the Kara Sea, both as a standalone one-dimensional model, and as a sediment transport submodel for the Arctic and Antarctic Research Institute Kara Sea ocean model.

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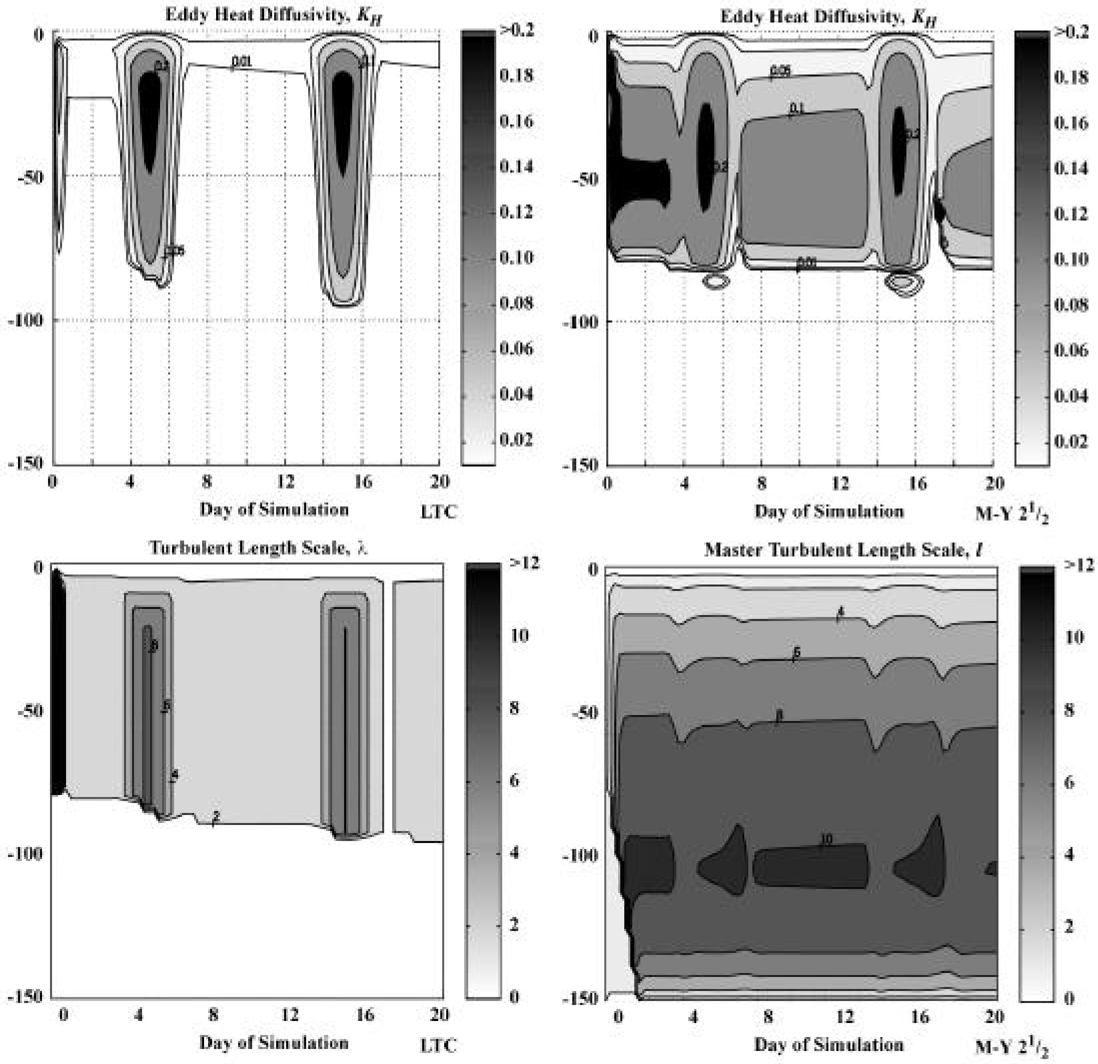

Figure 1. Side-by-side comparison of eddy heat diffusivity (top panels) for simulations of two intense storms, centered at days 5 and 15 using local turbulence closure (LTC) and Mellor-Yamada level $2\ {}^{1}/_{2}$ second moment closure. Between storms MY retains large values of K_h and efficient mixing, whereas the mixing length for LTC (lower left) drops sharply, allowing temperature gradients to develop in the 'mixed layer'. In the MY model, master mixing length, which is solved prognostically, remains large. In the mixing layer above about 80 m, the two scales should be roughly comparable. Existing data suggest the smaller scale is more appropriate.