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Coupling of Waves, Turbulence and Thermodynamics Across the Marginal Ice Zone

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LONG TERM GOALS

Long term goals are to observe and model processes controlling ice retreat in the marginal ice zone (MIZ), the narrow strip between open ocean and the ice pack where the seasonal retreat of the main ice pack takes place. It is a highly variable sea ice environment, usually comprised of many individual floes of variable shape and size and made of mixed ice types, from young forming ice to fragmented multiyear ice. The presence of sea ice significantly affects the transport of energy and momentum between the atmosphere and ocean. Deformation of sea ice absorbs atmospheric surface stress acting on the ocean surface and resulting surface features affect aerodynamic drag. Ice cover prevents the local formation of surface gravity waves and attenuates and scatters waves that propagate from the open ocean. As a result, wave motions and wave-driven flows, such as Langmuir circulations, are greatly diminished below pack ice. The albedo of sea ice is large compared to open water, and most of the incoming solar radiation incident on sea ice is reflected back to the atmosphere. The thermal conductivity of sea ice is small, so sensible energy transport between ocean and atmosphere is limited in the presence of sea ice. Specialized Autonomous Ocean Flux Buoys have been developed to study wave effects, thermodynamic responses and turbulent coupling across the coupled ocean – ice – atmosphere system in the context of the larger MIZ DRI program.

OBJECTIVES

Key upper-ocean processes that contribute to strong coupling and feedbacks within the MIZ ocean-ice system that will be studied in this project are: (1) propagation and attenuation of ocean surface waves, (2) absorption and storage of incoming solar radiation and subsequent lateral transport and (3) vertical mixing within and at the base of the ocean mixed layer.

Surface-wave induced deformations are responsible for fracturing the ice cover and reducing the size of floes across the MIZ. Small broken-up ice floes are more mobile than large, compacted floes of the pack interior. This mobility is a significant characteristic of the MIZ. Floes at the seaward edge of the MIZ are vulnerable to being swept out to the open ocean. Small floes within the MIZ readily respond to divergent oceanic or atmospheric forcing compared to the ice pack, decreasing ice concentration inside the MIZ during divergent forcing events.

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During the summer heating season, solar radiation locally absorbed by the upper ocean is available for bottom and lateral melting of the ice cover. Relative motion of the MIZ edge toward the open ocean promotes melting by bringing water elevated above the freezing point into contact with the base and edges of MIZ floes. These lateral inhomogeneities produce complicated vertical in the surface mixed layer, necessitating high vertical resolution thermal structure observations near the ocean-ice interface (e.g. Stanton et al 2012.)

The rate at which heat is transported from the ocean to sea ice is set by turbulence levels in the surface mixed layer, which controls both the ocean-to-ice heat flux and the entrainment heat flux across the base of the surface mixed layer. The ocean-to-ice heat flux is reasonably well parameterized in the horizontally homogeneous conditions of the interior ice pack. In the MIZ, however, strong lateral temperature gradients, intense solar heating, and temperatures elevated well above the freezing point significantly complicate the vertical heat transport processes.

Below pack ice, entrainment rates of heat contained in the upper pycnocline into the surface mixed layer are typically low (Toole et al., 2010; Shaw et al., 2009). Recent increased stratification from upper ocean freshening in the Western Arctic has further inhibited entrainment fluxes (Toole et al., 2010). In the MIZ, however, the presence of wave-driven circulations such as Langmuir cells and the reduced absorption of wind stress by the mobile ice cover may produce mixed layer turbulence that is energetic enough to overcome the stable stratification and entrain heat into the mixed layer that can contribute to ice melting.

The classic feedback mechanism operating in ocean-ice systems is the ocean-ice-albedo feedback, which is primarily thermodynamic in nature. In the MIZ, ocean-ice-albedo feedback is augmented by ocean wave and turbulence dynamics. Surface-wave-initiated divergent openings increase solar radiation absorbed by the surface ocean, acting as triggers for ocean-ice-albedo feedback and accelerated melting of the ice cover.

The thinning, weakening, and retreat of the ice cover during the summer melting season also feeds back to waves and turbulence. The penetration of wave energy into the ice pack sets the initial lateral scale of the MIZ. During summer, it is likely that wave motions penetrate further into the ice pack, creating a wider MIZ. As more open water is created during the summer melt season, the larger fetch allows more energetic waves to be generated. These two effects create secondary positive feedbacks.

APPROACH

Two enhanced Autonomous Ocean Flux Buoys will be deployed in concert with the MIZ DRI instrument array in the Beaufort Sea in spring 2013. The AOFBs measure the vertical fluxes of heat, salt and momentum near the top of the ocean mixed layer to determine entrainment fluxes and summer time solar heating fluxes over annual time scales. These buoys are designed and fabricated by the Ocean Turbulence Group at the Naval Postgraduate School (see <http://www.oc.nps.navy.mil/~stanton/fluxbuoy>). The buoys have two main components: a surface housing that sits on the ice and an instrument frame that hangs from the housing, by a series of torsionally-rigid poles, into the Ice-Ocean Boundary Layer. The surface housing contains processing electronics, Global Positioning System (GPS) electronics, an Iridium satellite modem, GPS and Iridium antennae, and batteries. These two buoys are being enhanced with a high precision Inertial Motion Unit

to measure wave induced motion of the ice flow, and shortwave solar radiative fluxes, and bulk meteorological variables. The ocean instrument frame is outfitted with a downward looking 300 kHz Acoustic Doppler Current Profiler (ADCP, RDI Workhorse) and a custom-built 'flux package'. An acoustic travel-time current meter ACM 3D current meter, with 1 mm s^{-1} rms noise level), an inductive conductivity cell ($\pm 0.002\text{ mS cm}^{-1}$), and a fast-response thermistor ($\pm 1\text{ mC}$) comprise the flux package sensor suite. These fast-response instruments are collocated within a 0.001 m^3 sample volume, and directly measure the turbulent fluxes of momentum, heat, and salt over approximately 40-minute long Reynolds averaging periods using the eddy-correlation technique. The flux package sensors are installed approximately 4m below the ice. A 16-element thermistor string measures finescale thermal structure between the flux package and the ice. After field installation, AOFBs maintain twice-daily, two-way communications with a computer running at NPS. During each data transfer, sampling parameters may be updated.

Entrainment fluxes across the base of the mixed layer will be studied at the logistics base camp using a 6m long instrumented frame equipped with two ADCP's, two ocean flux packages and a fast thermistor string. The frame will be positioned across the mixed layer base using a servo controlled winch to measure mixed layer structure and resulting heat fluxes in response to wind-forced movement of the ice floe. It is hoped that these observations will span pack ice to early MIZ conditions.

WORK COMPLETED

Construction of the two AOFBs is nearly completed, and mechanical modifications to mount the meteorological sensors are underway. Computer code upgrades to sample and control the IMU and met package are in progress, and we plan test deployments in the Beaufort Sea during 2013.

RESULTS

This startup year has focused on experiment design, contributing to the authorship the MIZ DRI Science plan, and construction of the buoy components.

IMPACTS/APPLICATIONS

Improved understanding of the complex feedbacks and determining dominant forcing mechanisms in the seasonal MIZ will contribute to predictability of ice cover in the Central Arctic. Many of the mechanisms being studied in this project are not currently considered in regional coupled models of the Arctic Ocean.

RELATED PROJECTS

This project is a component of the larger collaborative MIZ DRI observational and modeling program, strong ties to the other ocean, wave and ice projects.

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