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

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LONG-TERM GOALS

Detailed process studies of the MIZ are necessary to build accurate Arctic region ice-ocean-atmosphere numerical models. Streove et al. (2007) provide an example of the challenges of modeling the Arctic ice-ocean-atmosphere system - current global circulation models under predict the observed trend of declining sea ice area over the last decade. A potential explanation for this under-prediction is that models are missing important feedbacks within the ocean-ice system, particularly in late summer low ice concentration conditions. Results from the proposed research will contribute to improving the upper ocean and sea ice physics contained in regional and global circulation models.

OBJECTIVES

1. Identify enhanced ice albedo feedbacks associated with rapidly increasing open water areas in the marginal ice zone.

Within the MIZ, the ocean-ice-albedo feedback mechanism is coupled to upper mixed layer heating and melting cycles when open water fraction rises above a few %. In addition wave induced deformation and fracturing that results from the presence of surface wave orbital motions and non-linear sub-harmonics resulting from interaction with the MIZ. We are interested in exploring, over the course of a summer heating season, the relationships between open water fraction, ocean surface warming, wave action, and ice melt rates in the MIZ.

2. Identify forcing mechanisms and quantify vertical mixing rates within the ocean surface layer across the marginal ice zone.

It is expected that mixing rates in open water areas of the Arctic are larger than in ice-covered areas due to presence of surface waves and the direct transmission wind stress to the upper ocean. Do enhanced vertical mixing rates and ocean / ice heat fluxes occur as melt ponds and basal melting form shallow seasonal mixed layers in late summer?

3. Identify changes in in the atmospheric boundary layer and oceanic surface boundary layer in response to local ice-floe changes as the MIZ evolves.

As the mean thickness and strength of the winter ice pack changes with increased summer ice retreat (with less multi-year ice and thinner seasonal first year ice), the character of the floes and ice ridges are expected to also change. The resulting changes in both the atmospheric boundary layer and oceanic boundary layer hydraulic roughness (expressed as a drag coefficient) need to be measured and modeled for use in regional coupled ocean/ice/atmosphere models.

APPROACH

Enhanced Autonomous Ocean Flux Buoys

Autonomous ocean flux buoys (AOFB) developed at NPS 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 (Stanton et al, 2012, Shaw et al, 2008, 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 IOBL. The surface housing contains processing electronics, Global Positioning System (GPS) electronics, an Iridium satellite modem, GPS and Iridium antennae, and batteries. The 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 0.5mm s^{-1} rms noise level), an inductive conductivity cell ($\pm$ 0.002 mS cm^{-1}), a platinum resistance thermometer, and a fast-response thermistor (0.1 mK resolution) comprise the flux package sensor suite. These low noise, fast-response instruments are collocated within a 0.001m^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 techniques. A 16-element thermistor string measures finescale thermal structure between the 4m below the ice flux package and the ice. A mechanically profiled micro CTD sensor was added to measure temperature and salinity gradients between the flux package depth and the ice/water interface under summer solar heating conditions. The previous AOFB design was enhanced for the MIZ study with a bulk meteorology package, a shortwave incident radiation sensor, and a 3D acoustic anemometer providing atmospheric boundary layer stress and heat flux estimates.

WORK COMPLETED

Three of these instrument systems with different sensor combinations were deployed in the MIZ instrument clusters 2, and 3 in the Eastern Beaufort Sea in March 2014, and cluster 5 in August 2014 during the Araon cruise (Figure 1). During the 6 day MIZ component of the Araon ice breaker cruise, a 6m long instrumented frame was positioned every hour to span the base of the surface mixing layer to directly measure entrainment fluxes occurring in response to current shear across the density interface (Figure 2) .

RESULTS

A timeline summary of data reported from the three AOFB systems deployed in the center of clusters 2, 3 and 5 (Figure 3). AOFB33 deployed in the center of cluster 2 encountered MIZ conditions around yearday 200 with significant changes in buoy tilt and wave induced motion lasting another 30 days before the buoy was consumed by an ice ridge event. The large open water areas surrounding the ice floe supporting this set of instruments was seen in the 1m resolution visible satellite imagery.

a. b.

Figure 1 a. An AOFB flux package being deployed through the ice access hole. The 3D velocimeter, temperature sensor and conductivity sensor are at the bottom of the package, with the downward-looking ADCP current profiler at the top.

Figure 1 b. The deployed AOFB with the meteorology sensor tree with bulk met, shortwave radiometer, 3D turbulent boundary layer sensor, GPS antenna and iridium antenna left to right.

a.

b.

Figure 2 a. The portable used to deploy the entrainment frame at the cluster 5 site, supported by the Araon ice breaker.

Figure 2 b. The 6m long instrument frame equipped with upper and lower flux packages, a 20cm bin ADCP downward looking current profiler and a 16 element precision thermistor string. The frame was positioned every hour in the water column to span the base of the ocean mixing layer.

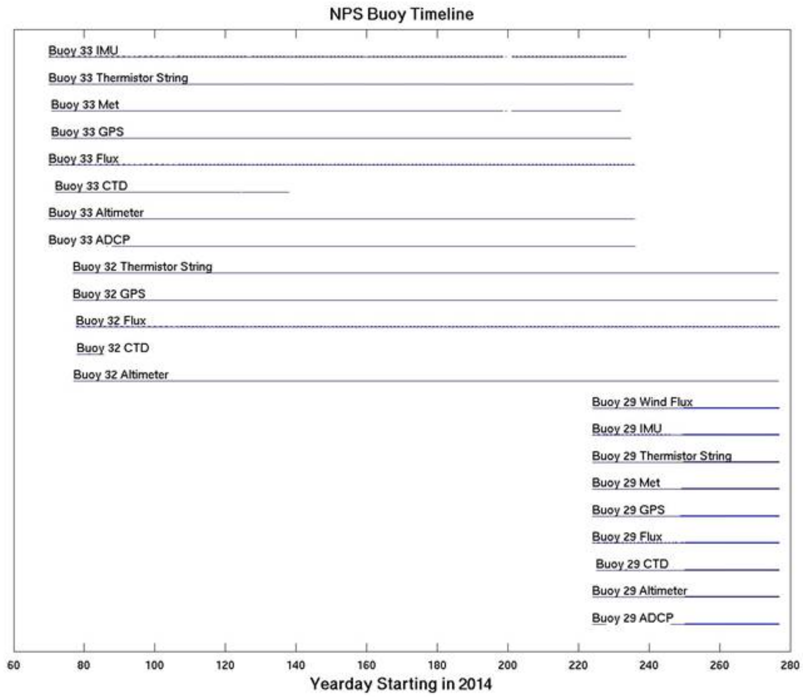

Figure 3. The timeline for data return for the three NPS AOFB instrument systems deployed at the center point of cluster 2 (AOFB 33), cluster 3 (AOFB 32), and the Araon deployed cluster 5 (AOFB 29).

The transition from late winter compact ice to MIZ conditions was captured by both AOFB 33 and 32 (buoys 29 and 32 continues to report), allowing the ocean-ice heat and salt fluxes to be calculated as the local open water fraction increases. Both the high resolution visible and Synthetic Aperture Radar (SAR) images are being used to measure local open water fraction upstream of the buoy trajectories (A. S. Heiles, NPS thesis, Sep. 2014) and the number and area of melt ponds on the local ice floes as the summer progresses. The AOFB shortwave solar sensors allow direct estimates of inbound solar energy to be calculated and compared with observations and a 1D model of upper ocean heat storage and release during low and high wind forcing conditions. Details of these processes are being recovered from the high resolution thermistor strings, profiling near-surface CTD and the adjacent ITP profiles deeper in the water column when available. While Buoy 32 continues to operate and report data, the primary travel-time velocimeter in the flux package developed an intermittent problem in one of the four measurement paths, making flux calculations more challenging for this instrument, and the near-surface profiling CTD failed after only 10 days. Buoy 29, deployed during the Araon cruise continues to report a complete data set except for a 20 day data gap in the ADCP profiler. While this ice floe did not transition into a full marginal ice zone, the data set will provide a useful contrast with strong local melting and wide-spread melt ponds which transitioned into a full freezeup. The 3D acoustic anemometer continues to operate, providing concurrent measurements of surface wind stress and ocean stress water shear stress measured by the AOFB flux package 4m below the ice. While the anemometer is subject to ice-up, a data set is being gathered through the summer to winter transition of the ice surface, allowing representative surface drag coefficients to be estimated, along with stress balance calculations on the transfer of wind stress through the ice to the ocean. Buoy 29 continues to report, and provided an intriguing near-surface CTD profile data set in the late summer of 2015 which is being used in an analysis of the role of shallow fresh layers in enhanced basal melting.

The entrainment frame deployed near the Araon operated over a five day a period that included low to moderate wind forcing. The focus was on tracking the weakly stratified mixed layer base below a warm, fresh surface layer typical of late summer Arctic conditions. Direct measurements of heat and salt vertical turbulent fluxes either side of the density interface are being used to test existing parameterizations of these fluxes over a range of forcing conditions. Local morphology of the ice base surrounding the entrainment mast were made with a high resolution acoustic fan beam scanned profiler and digital camera / laser sheet system resolving features down to 1 cm height with 3 cm horizontal resolution. This entrainment data set is being contrasted with one gathered during early summer data set gathered during ICEX2011 (B. K. Schmidt).

An analysis of surface ponding, meltwater influx and IOBL structure in later summer of 2014 using data primarily from C2 and C3 has been submitted for publication (Gallaher et al 2015). A second paper analyzing epheral mixed layer formation and late season heat trapping in the mixed layer is prepartion.

RELATED PROJECTS

This work is closely aligned with other MIZ projects including the ITP buoys collocated with each AOFB, and other measurments made during the Araon-supported MIZ ice camp. The MIZ filed observations are also closely aligned with the NSF Arctic Observation network (AON) project.

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