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UpTempO buoys for Understanding and Prediction

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LONG-TERM GOALS

Our long-term goal is to better understand the evolution heat content in the upper Arctic Ocean within the Seasonal Ice Zone (**SIZ**), both seasonally during summer warming and fall cooling, and interannually as sea ice retreats and the warming season lengthens. The effort is a contribution to the multi-investigator ONR-sponsored **SIZRS** project (SIZ Reconnaissance Surveys).

OBJECTIVES

Our main objectives are to:

(1) Develop the capability to observe upper ocean warming and cooling using air-deployed ocean drifting buoys.

(2) Better understand the time and space scales of summer warming in the SIZ.

(3) Investigate the relationships between sea ice retreat and upper ocean warming.

APPROACH

Our approach is two-fold:

<u>SIZRS UpTempO buoy deployments</u>: We are working with the Pacific Gyre (**PG**) buoy company (Oceanside, CA) to re-start an air-drop buoy capability that had grown dormant over the past several years. This program was initiated by Professor Peter Niiler at Scripps (UCSD) to drop 200 m long thermistor string buoys ahead of hurricanes in the Gulf of Mexico via Air Force C130 planes, the so-called "hurricane hunters." In recent years, a surplus of buoys developed which coincided with a lack of technological updating. Thus our approach is to work with PG to develop a state-of-the-art air-drop buoy for polar applications. At the same time, we have been working with the US Coast Guard (**CG**) to obtain approval to deploy these buoys from the Alaskan CG C130 planes based out of Kodiak, Alaska as part of the SIZRS program.

Scientific analysis of multi-sensor ocean and ice observations: We are working with existing arctic buoy data as well as model output and satellite and in situ data on sea ice and upper ocean temperatures to better understand the time and space scales of upper ocean heating and cooling and how these relate to sea ice retreat and advance. The idea here is to develop a measure of where and when we actually need to deploy buoys for climate applications, and how these needs might vary with ice conditions.

WORK COMPLETED

I. Buoy deployments:

(a) *Buoy air deployment*. PG built two thermistor string buoys for deployment in summer 2012 as part of SIZRS (**Figure 1**). Each buoy consists of a 16" spherical surface hull with electronics, GPS, alkaline batteries for 1.5 years of operation, Iridium antenna, sea level pressure sensor, and sea surface temperature sensor at 0.12 m depth nominal. Hanging down from the hull is a 60 m long string of 12 thermistors at the following nominal depths (in meters below sea level): 2.5, 5, 7.5, 10, 15, 20, 25, 30, 35, 40, 50, 60. There are also two ocean pressure sensors at 20 m and 60 m nominal to detect "swing" in the cable owing to current shear (typically forced by surface stress). For SIZRS air-deployment, the buoys are specially packaged in a custom box with spooling designed for self-deployment in the ocean.

The CG approval process for buoy deployment was not completed until early summer, 2013, so we stored the buoys in Kodiak over winter 2012/2013. On August 13, 2013 our first SIZRS UpTempO buoy was deployed by the Alaskan CG at 72°N, 150°W (**Figure 2**). The deployment was a success, and another aircraft pass by the location was performed to drop AxCTD (air-deployable expendable CTD) and AxCP (air-deployable expendable current profiler), the former especially useful for intercalibration of buoy and profiler temperature data.

Initially, the buoy sits rather high on the water surface, until it becomes wet enough to dissolve the salt blocks that hold the straps and box together (~6 hours for this particular deployment). At this point the buoy enters the ocean and begins operation when its magnetic switch is activated by a salt-dissolving fastener. Position, sea level pressure, sea surface temperature, and engineering information then begins transmission via Iridium satellite every ten minutes, which we then re-set via the PG data web interface to hourly sampling. Within the hour, the buoy string's terminal weight pulls the ocean sensor string down to nominal depth (60 m) and ocean data (temperature, pressure) begin transmission.

We held the second PG buoy for deployment in September, but unfortunately this flight was cancelled. Owing to the relatively cool and icy 2013 summer in the Beaufort Sea, the ocean did not warm up much and thus we plan to hold our second buoy for deployment in 2014. We will also order 3 additional buoys for air-deployment in 2014.

(b) *Buoy ship deployment:* In early 2014 we were still not sure that we would obtain air-dropping approval in this year. To hedge our bets, we used SIZRS funding to order three buoys for ship deployment in summer 2014. The buoys were ordered from the MetOcean buoy company in Bedford, NS, Canada, using a model that had been successfully ship-deployed in 2012. These buoys will be deployed by the Canadian icebreaker Amundsen in early October, 2013 in the southeastern Beaufort Sea.

II. Scientific analysis of ocean and ice observations:

(a) *SST analysis*: As a first step in our analysis of sea surface temperature (**SST**) patterns in the Arctic Ocean, we have collected gridded fields from three sources: (i) the "Reynolds" a.k.a. OIv.2 NOAA product, (ii) the high resolution MUR product available from JPL's PODAAC = Physical Oceanography Distributed Active Archive Center, and (iii) output from our colleague Dr. Jinlun Zhang's coupled ice-ocean arctic model "**PIOMAS**" = Parallel Ice Ocean Modeling and Assimilation System. Using these fields, we have started to investigate spatial and temporal patterns of correlation and their relationship with sea ice retreat.

(b) *Sea ice analysis*: We expect that the amplitude and patterns of upper ocean heating responds to the time history of sea ice retreat in each summer. As such, we have collected a variety of gridded sea ice fields for analysis: (i) NSIDC's passive microwave "near-real time" ice concentration product, (ii) NSIDC's higher resolution **MASIE** = Multisensor Arctic Sea Ice Extent product, and (iii) output from the PIOMAS model. Using these fields, we have begun to investigate the spatial and temporal patterns of sea ice retreat, with a special focus on the past 6 years (2007-2012).

RESULTS

I. Initial analysis of buoy data:

Analysis of the single 2013 SIZRS UpTempO air-deployed buoy data is just getting started. **Figure 3** shows good but not exact agreement between buoy observations and the widely used "Reynolds" SST field. A major goal of the overall UpTempO buoy program is to improve these fields by increasing the quantity and quality of in situ observations. The figure also indicates that initially, surface temperature was cooler than the isothermal mixed layer just below, probably owing to the presence of a recently formed fresh, stable melt layer. Observing and understanding such differences are vital in the interpretation of satellite data for large-scale, mixed layer temperature mapping.

II. Analysis of gridded SST fields:

Figure 4 shows preliminary analysis of correlation in Reynolds SST fields. The upper two panels show r^2 correlation for a point over the Chukchi Borderland (left) and in the Chukchi Sea (right) over the month of September. The analysis indicates longer correlation length scales for the more southern location, where warming starts earlier and warm Pacific Water flows. Zonal correlation in the northern location may be related to the position of the maximum ice edge retreat. The lower two panels show how correlation length scale can vary interannually. Comparison of Reynolds with MUR and PIOMAS SST fields indicates that Reynolds may underestimate the length scales of SST variability, by as much as 100 km relative to these other sources.

III. Patterns of sea ice retreat:

We are interested in the relationship between ice retreat and ocean warming. In the course of this investigation, we have discovered a previously unnoted behavior of sea ice retreat that occurs to varying extent every summer over the past six years, 2007-2012. **Figure 5** shows an example from summer 2011, where in panel (a) we have plotted the number of days that the ocean was "open" (i.e., ice concentration < 0.15, a common definition) by September 1. Not surprisingly, the field is somewhat zonal, indicating earliest opening in the south. In panel (b) we have then plotted the magnitude of the two-dimensional gradient of this field. Such gradient maps are common in SST analysis, but this is the first time (to our knowledge) that such a map has been made for sea ice fields. The result is fascinating. Low values indicate areas where the ice retreated quickly, while high gradients indicate places where the ice edge "loitered" in place for a number of days. In panel (c) we focus on a meridional section along 125°E in the Laptev Sea. The ice opens earliest to the north of a coastal fast ice area that takes a while to melt, creating a high gradient area in panel b (red color). Subsequent retreat of the mobile sea ice pack happens in spurts between ice edge "loitering" periods marked by arrows in panel (c). Preliminary analysis of wind data from reanalysis fields indicates high correlation. That is, retreat-favorable south/southeast winds rapidly push the ice edge northward, while unfavorable winds from other quadrants tend to stall the ice retreat or in fact push ice back southward into warm water, where it melts. A manuscript on this material is in preparation (*Steele, M., W. Ermold, I. Rigor, J. Zhang, Episodic sea ice retreat in the Arctic Ocean, in prep. for submission to GRL, 2013*).

IMPACT/APPLICATIONS

UpTempO buoys are designed to better observed the warming of the upper ocean that occurs in response to sea ice retreat. Air-deployable SIZRS UpTempO buoys fill a crucial, unique niche in the over-all program, by providing placement opportunities when icebreakers don't operate and in locations where they may not travel owing to weather or ice conditions. Data from SIZRS buoys are available on the global GTS network for weather forecasting and other purposes. We plan to use SIZRS buoys in combination with other buoys to better understand the time/space scales of variability in upper ocean heat content, in part to create more objective deployment plans for the long-term.

RELATED PROJECTS

We are working with J. Zhang and A. Schweiger as part of ONR's Marginal Ice Zone DRI to improve sea ice – ocean modeling for the Arctic Ocean, with a focus on the MIZ of the Beaufort and Chukchi Seas. UpTempO buoys have been deployed in open water, in the MIZ, and in the main ice pack, and thus provide valuable validation data for the model. Our work described above on the nature of ice retreat is also using output from the model to better understand the physics of this phenomenon.

The SIZRS UpTempO buoy project is part of the over-all SIZRS project, where a group of scientists are working together to better understand the air-sea-ice coupling of the SIZ. The various components of the project are described in a separate progress report by J. Morison.

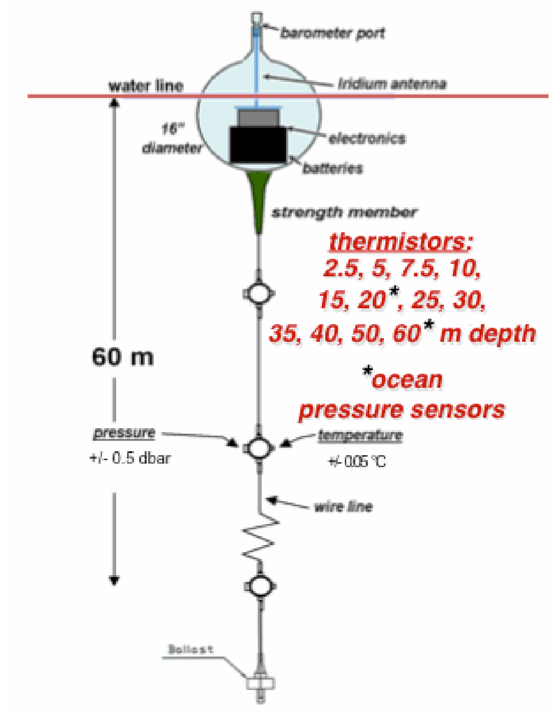

Figure 1. SIZRS air-deployable UpTempO buoy schematic.

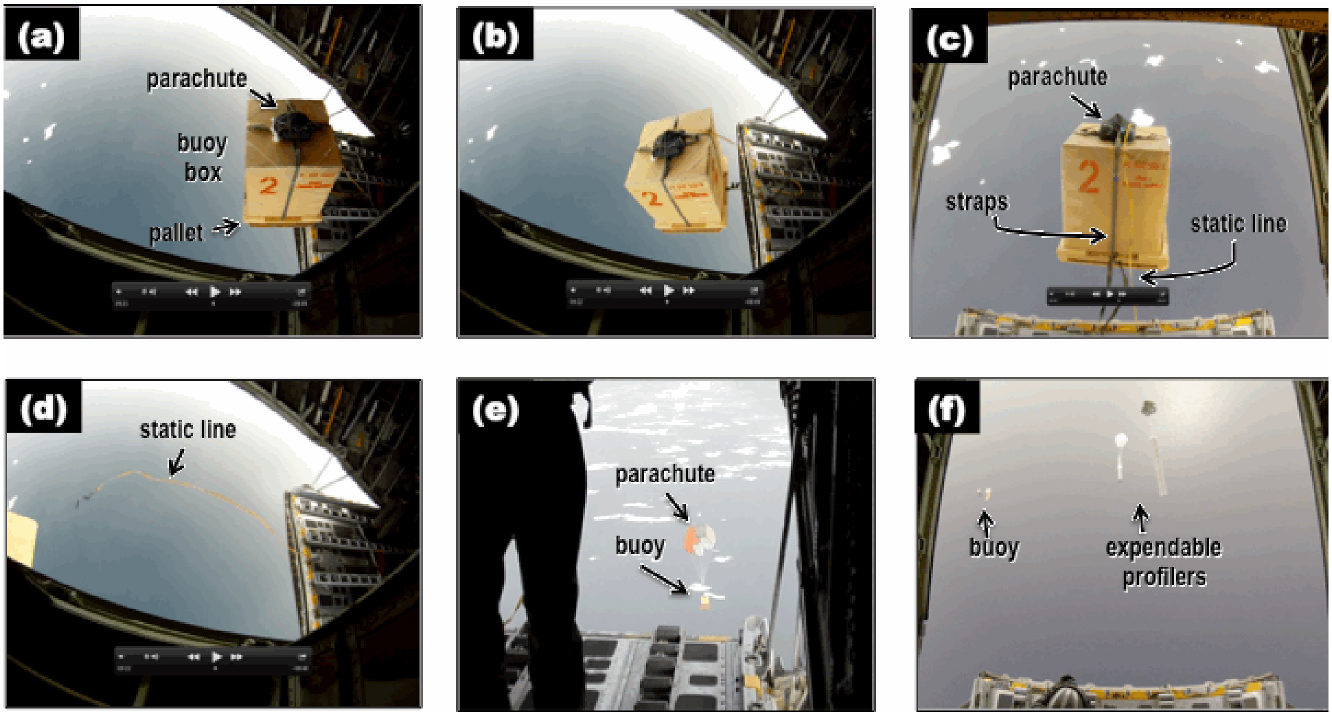

Figure 2. Deployment via C130 aircraft of the first SIZRS UpTempO buoy, August 13, 2013 by the Alaskan Coast Guard (CG) at 72N, 150W. (a) The buoy is packaged in a cardboard box strapped to a wooden pallet (below) and a parachute (above). CG personnel push the buoy out the aircraft's back door along rollers (a, b, c) when over the target drop location at an altitude of 200-500 feet. A static line releases the parachute (c, d, e). (f) Another pass is then performed for co-located deployment of expendable profilers (AxCTD, AxCP). Images from video shot by Dr. I. Rigor, PSC/APL/UW.

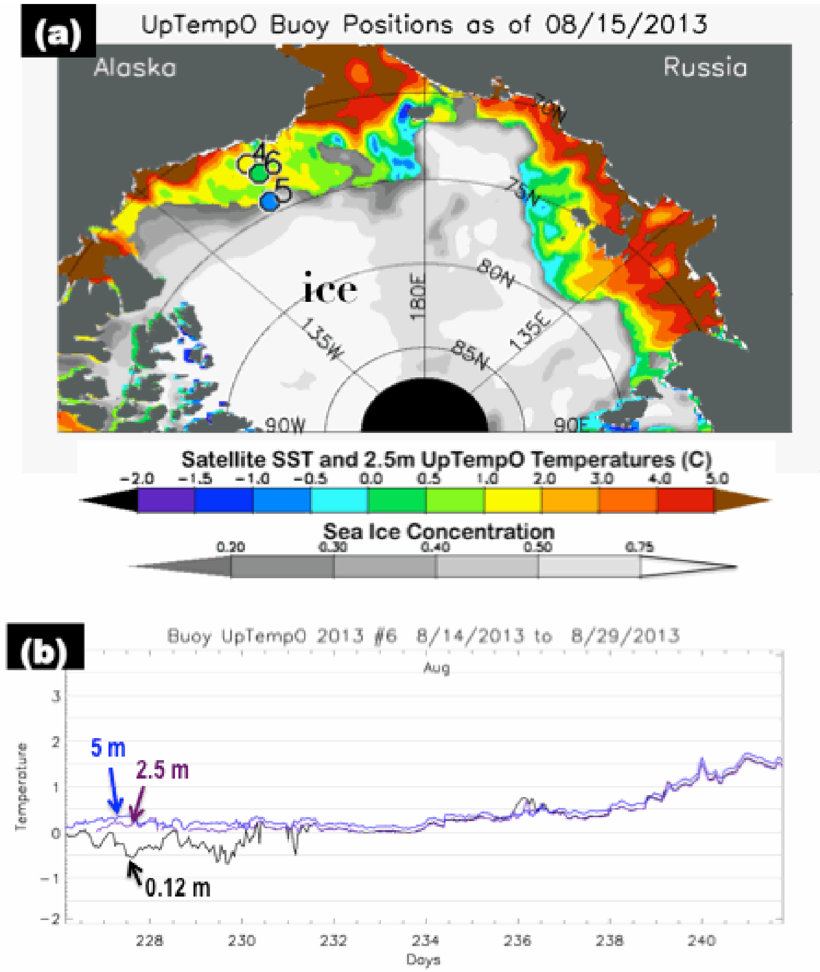

Figure 3. (a) UpTempO buoys deployed as of August 15, 2013. Buoy 4 was deployed with NASA funding via the small research vessel Ukpik; Buoy 5 was deployed with NSF funding via the Canadian icebreaker Louis St. Laurent; Buoy 6 is the SIZRS air-deployed buoy. The colored dots indicate buoy-observed ocean temperature at 2.5 m depth, with the same color scale as the contours from the large-scale gridded "Reynolds" (a.k.a. OIv.2) SST product from NOAA. (b) The uppermost three thermistor time series from the buoy.

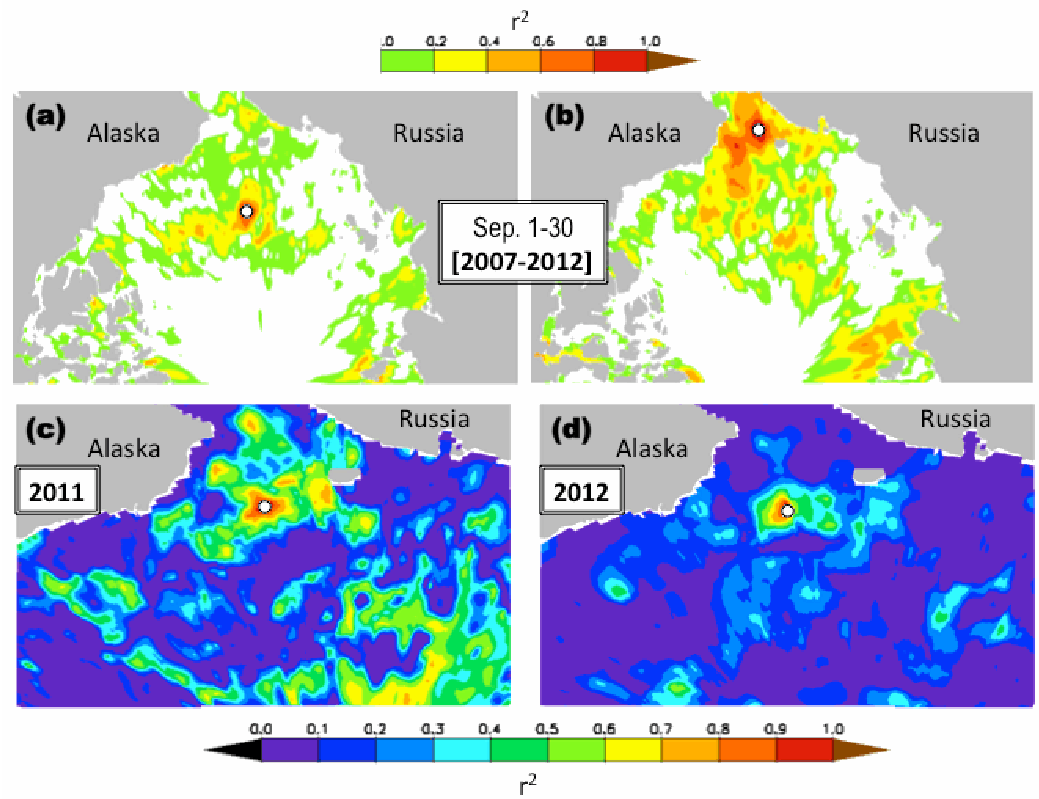

Figure 4. Upper panels: Correlation between the time series of Reynolds SST at a single location (white dot) over the month of September (averaged over 2007-2012) for (a) the Chukchi Borderland and (b) the Chukchi Sea, and all other locations. Lower panels: Same as upper panels, but for two individual years (c) 2011 and (d) 2012 in the northern Chukchi Sea.

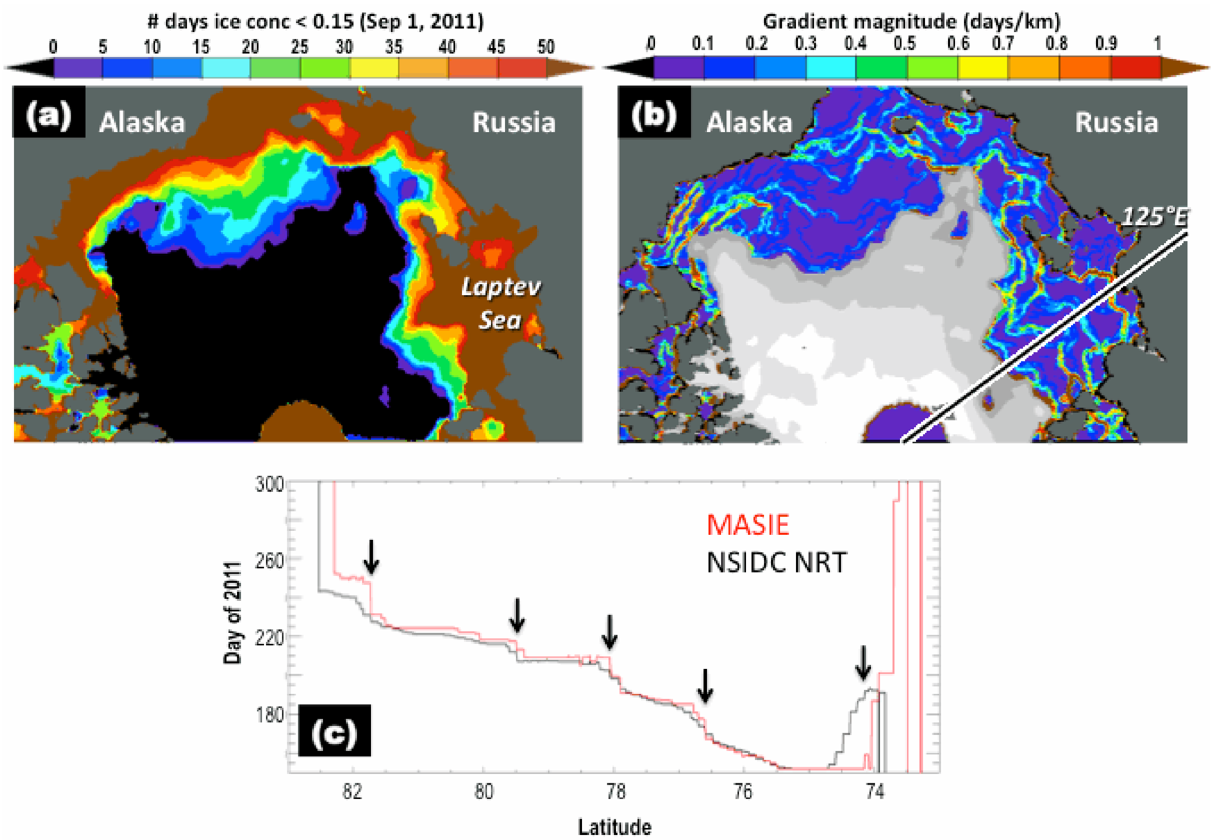

Figure 5. An example of sea ice retreat patterns for summer 2011. Panel (a): Number of days "ice free" (i.e., concentration < 0.15) using NSIDC near-real-time (NRT) passive microwave daily data. Panel (b): The magnitude of the two dimensional spatial gradient of the field in panel (a). Panel (c): Earliest 2011 day of open water (NRT = concentration < 0.15; MASIE = no ice) as a function of latitude along 125°E (see panel b) using MASIE and NSIDC NRT ice fields. Downward black arrows indicate ice edge "loitering" where gradients in open water days (panel b) are high.