Wave-Ice and Air-Ice-Ocean Interaction During the Chukchi Sea Ice Edge Advance

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LONG-TERM GOALS

Ocean Heat: In the new Arctic summer ice regime, with extended open water periods in areas previously covered with sea ice, ocean heat, received during these summer ice-free periods, may be either confined to the surface mixed layer or enter deeper ocean waters. Our goal is to determine the amount and disposition of ocean heat received and determine whether it is exhausted during fall freeze-up and affects only initial ice growth or, remains in the ocean and has residual effects on ice growth during winter and spring.

Sea State Regime: Large expanses of ice-free water in the Chukchi Sea in the late summer have potentially changed the impact of fall storms by creating wave fields in the vicinity of the advancing ice edge. A goal is to determine if larger amounts of frazil ice and increased turbulence levels in the water column result, leading to significant increases in pancake ice formation and higher incorporation of sediment into pack ice in the continental shelf regions.

OBJECTIVES

- Conduct a complete (the first) wave-ice interaction field experiment that adequately documents the relationship of a growing pancake ice cover with a time and space varying measured wave fields
- Document the state of sea ice advance, i.e., rate of advance, sea ice properties and thickness evolution, and compare rates relative to presence/absence of waves and on changing heat/freshwater content
- Document the state of ocean-atmosphere-ice interactions before and during the autumn sea ice advance to assess seasonal changes in ocean heat/freshwater content and effects on ice-ocean interactions post ice formation
- Provide the necessary data to allow ocean-atmosphere-ice interactions and pancake ice growth at the advancing ice edge, including waves, to be correctly parameterized in the next generations of ice-ocean coupled models and wave prediction models

- Provide the necessary data to improve and refine remote sensing algorithms that aspire to describe sea ice morphology (signatures of brash, pancake ice and young congelation ice) during sea ice advance.

APPROACH

The principal field activity of the SeaState DRI will be a 42-day cruise on the R/V Sikuliaq in Oct-Nov 2015. Within the full suite of ice-wave and ocean- ice-atmosphere interaction studies that will be needed in this work, we propose a comprehensive, multiplatform suite of measurements that will characterize the ice cover and upper ocean, and importantly, their co-evolution over spatial scales that can capture their horizontal (i.e., north-south) variability during the ice edge advance. The Table lists the instrumentation and parameters that will be measured using the ship platform and buoys deployed during the cruise to achieve our main objectives.

Instrument	Location	Physical Component	Measurements	Duration	Lead
Autonomous underwater vehicle (AUV)	Under ice, up to 50km transects	Ice thickness, floe-size distribution, waves, upper ocean properties	ADCP, CTD, camera,multibeam sonar	During cruise	WHOI
uCTD and CTD casts; Upper Ocean Buoys	Ahead, at and inside ice edge; Stations and Underway	Upper Layer Properties of Polar Ocean (2-300 m)	Discrete T; S at one level; profiling CTD casts;	~1 year (buoys) and During cruise	CU-B UW
Airborne expendable Ice Buoy (AXIB)	Ahead, at and inside ice edge	Surface meteorology	T, SLP	~1 year	CU-B UW
Unmanned Airborne Vehicles (UAV)	Ice edge vicinity	Surface characterization, ice concentration, floe size distribution	Airborne digital photography	During Cruise	WHOI UTas
Electromagnetic Induction (EMI)	Underway in sea ice	Snow/sea ice thickness	Conductance estimated thickness	During cruise	UTSA
Marine Lidar	Underway in sea ice	Surface Topography	Range and Elevation	During cruise	UTSA
Stereo digital camera	Underway in sea ice	Sea ice concentration, type and floe distribution	Digital (stereo) photography	During cruise	UTSA
FMCW Snow Radar	Underway in sea ice	Snow Depth and Surface and Snow-Ice Interface Roughness	Line track of snow depth from returned radar pulses	During cruise	UTSA
Infrared Camera	Underway in sea ice	Surface Temperatures of snow, ice and water	Images from FLIR infrared digital imager	During cruise	UTSA
Ice Mass Balance (IMB) buoys	Inside ice edge w/ >50cm thickness	Ice mass balance	T in snow-ice-ocean, T, SLP at surface	~1 year	WHOI CRREL

(SeaState DRI Investigator by Institution Team: Ackley-UTSA; Maksym-WHOI;Stammerjohn CU-B)
(Guest Investigator(s) by Institution Team: Perovich-CRREL;Williams=UTas;Rigor and Rainville-UW)

WORK COMPLETED

(Ackley,Maksym,Stammerjohn) The field program part of the science plan strategy was written and updated including preparation of figures, the instrumentation tables and deployment schematic diagram, cruise track map, and summary table of processes to be investigated, including all other DRI investigations as well as the Ocean Heat and Ice-Wave interaction studies under this set of grants. Don Perovich (CRREL) committed and shipped one CRREL Ice Mass Balance Buoy, which together with buoys from WHOI (see below) will increase our probability of monitoring ocean heat flux throughout the winter period from initial ice growth to spring-summer decay.

(Ackley) A DURIP proposal was funded this past year and funding ($510K) received for an innovative Sea Ice Measurement System designed for vessel mounting on the Sikuliaq DRI 2015 cruise. The procurements were completed and equipment shipped for the Riegl Lidar, Snow Radar (Kansas Univ), Geonics EM 31 and Infrared Camera to be used in this new system(see Table of Instrumentation above). A second tour of the Sikuliaq with the Science Operations Coordinator identified the placement for mounting the Lidar and Cameras on the deck over the bridge, and the use of the port side crane for slinging the EMI and Snow Radar for underway measurements. Part of the DURIP monies were designated for instrumentation to be used in any surface sea ice investigations on the cruise, a GSSI multi-frequency EMI for hand-held use on ice, and a GSSI Ground Penetrating Radar for snow depth and ice thickness from the surface. Ice edge traverse cruise modules were designated and design of the ice edge transects using the new suite of instrumentation has been initiated. Ice observation software (ASSIST) was received and installed on a laptop to be used on the cruise. Coordination was made with the National Ice Center to receive daily reports of the shipboard ice observations for use in preparing ice charts. Coordination with Nick Hughes at the Norwegian Met Office has resulted in regular retrievals of Sentinel 1 Radar imagery starting Sept 2015 and will continue through the cruise period.

(Maksym) After testing of robotic platforms at WHOI, the suite of platforms for the cruise was modified. We have elected not to bring a glider given the potential risk of loss and subsequent impact to the overall program. The impact to the program is minor as the measurements originally planned for the glider will be covered by the uCTD transects (see below). The Jaguar AUV platform was chosen for the cruise as this is a proven platform, and it was decided that the ice conditions during ice advance will be challenging and a high-risk for a new platform (Seabed-100) that has not been tested in ice. The ROV and all sensors were tested extensively at WHOI. This platform will complement the AUV by performing rapid, short under ice measuremements at times when there isn't the opportunity for a full AUV deployment. The build of the autonomous buoy suite has been completed. We will bring four types of IMB: 1) three SAMS IMBs (as originally planned), 2) one IMB equipped with a higher precision temperature chain and webcam from BAS/Bruncin, 3) two WHOI-built IMBs also equipped with acoustic snow depth sensors and CTDs, and 4) one CRREL Seasonal Sea Ice Zone IMB. In addition, an additional buoy with an 80m temperature chain for monitoring the upper ocean evolution has been built at WHOI to replace the loss of one of the UpTempo buoys from the program. SVP and AXIB buoys provided by Ignatious Rigor of APL will provide meteorological measurements to complement the IMB suite. Guy Williams (UTas) will participate in the cruise as part of the AUV team. He will also serve as our primary UAV pilot as he has obtained various certifications and recently operated UAVs from the RV Nathaniel B. Palmer in Antarctica. He will bring several platforms for aerial photography, including DJI multi-rotors, and small fixed wing aircraft, as well as a helikite for use in high-wind conditions.

(Stammerjohn) A significant addition was made to the Sea State field program through separate funding to Luc Rainville of APL, who will provide an underway temperature and salinity profiling system (uCTD) that we will deploy from the Sikuliaq during underway transits or while holding stations in the pack ice. This addition greatly enhances the study of feedbacks between the upper ocean and ice formation by allowing us to collect high-resolution observations of temperature and salinity ahead, near, and inside the advancing ice edge (at minimal cost to the program and with least impact on ship time). Coincident with surface flux and wave measurements, the uCTD will be used to characterize the conditions of the upper ocean to provide estimates of ocean heat content and will allow us to study the evolution of fresh water lenses that isolate the ice edge from thermal forcing, thus affecting ice formation. In addition, one Marlin-Yugg Ocean Heat Buoy (aka 'UpTempO' buoy) with a 25-30 m temperature chain provided by Mike Steele of APL will be deployed in the vicinity of the APL AWAC mooring on the outer continenal shelf in ~100 m water depth. This drifing buoy will monitor the thermal evolution of the shallower upper ocean and will complement the WHOI ocean heat buoy, which will be deployed in deeper waters off the continental shelf. In the form of satellite-based regional sea ice analyses, contributions were made to the Sea State overview paper led by Jim Thomson (to be submitted to *Ocean Modelling*) showing variability and trends over 1979 to 2014 in the timing of the autumn ice-edge advance in the Chukchi and Beaufort Seas. results were then related to variability in storm and wave activity and changes in ice type and set the historical context for the Sea State field observations. Work also continued on creating and refining analytical tools for processing/analyzing hydrographic data from the multiple platforms that will be deployed during the 2015 cruise. Related analyses on atmoshere-ice interactions and the identification of freshwater sources and distributions based on stable oxygen isotope data were also completed (see publications); these published results will provide background and methodology for anticipated studies resulting from the Sea State project.

RESULTS

Most activities were focussed on planning, procurement construction and shipping of equipment and completion of vessel mounting designs and, with the experimental/field nature of this investigation, no specific DRI results are expected until after the field data is obtained in late 2015. Analysis techniques were refined and resulted in the Publications, using previously obtained sea ice data, listed below.

IMPACT/APPLICATIONS

No significant applications as yet.

RELATED PROJECTS

The ONR MIZ DRI provided some guidance for this year's cruise. Within the Sea State DRI(list below), a closely related project is the theory/modeling studies of Hayley Shen. Parameters derived from our Sea Ice Measurement System and ship-based camera, of floe size distributions, ice concentration and ice thickness will be used in her analytical modeling simulations of ice-wave interaction. Peter Guest/Chris Fairall's project will provide atmospheric forcing data to inform analysis of ice formation rates and liberation of ocean heat. Martin Doble/Peter Wadham's and Alison Kohout's deployment of wave buoys will provide information on the dynamic forcing to inform our observations of autumn ice advance.

An Arctic Ice/Ocean Coupled Model with Wave Interactions
Squire, Williams, and Holt
Wave–Ice Interaction in the Marginal Ice Zone: Toward a Wave–Ocean–Ice Coupled Modeling System
Rogers
An Integrative Wave Model in the Marginal Ice Zone Based on a Rheological Parameterization
Shen
Proving and Improving Wave Models in the Arctic Ocean and its MIZ
Wadhams and Doble
Wave Climate and Wave Mixing in the Marginal Ice Zones of Arctic Seas: Observations and Modeling
Babanin
Storm Flux: Heat and Momentum Transfer in the Arctic Air–Sea–Ice System
Thomson
Quantifying the Role of Atmospheric Forcing in Ice Edge Retreat and Advance Including Wind–Wave Coupling
Fairall, Persson, and Guest
Wave–Ice and Air–Ice–Ocean Interaction During the Chukchi Sea Ice Edge Advance
Ackley, Maksym, and Stammerjohn
Radar Remote Sensing of Ice and Sea State and Boundary Layer Physics in the Marginal Ice Zone
Graber
Wave Processes in Arctic Seas Observed from TerraSAR-X
Gemmrich and Lehner

PUBLICATIONS

Thomson, J. et al, Sept 2013, Sea State and Boundary Layer Physics of the Emerging Arctic Ocean: Science Plan, Tech Report, APL-UW-TR1306, Applied Physics Lab, UW, Seattle, 59pp [published] Available at:
http://www.apl.washington.edu/project/project.php?id=arctic_sea_state

Ackley, S.F., E. Murphy and H. Xie (published 2015)), Ocean heat flux under Antarctic sea ice in the Bellingshausen and Amundsen Seas, Annals of Glaciology

Randall-Goodwin, E., M. P. Meredith, A. Jenkins, P. L. Yager, R. M. Sherrell, E. P. Abrahamsen, R. Guerrero, X. Yuan, R. A. Mortlock, K. Gavahan, A.-C. Alderkamp, H. Ducklow, R. Robertson and S. E. Stammerjohn (2015). "Freshwater distributions and water mass structure in the Amundsen Sea Polynya region, Antarctica." Elem Sci Anth 3: 000065: 1-22, doi:10.12952/journal.elementa.000065.

Stammerjohn, S. E., T. Maksym, R. A. Massom, K. E. Lowry, K. R. Arrigo, X. Yuan, M. Raphael, E. Randall-Goodwin, R. M. Sherrell and P. L. Yager (2015). "Seasonal sea ice changes in the Amundsen Sea, Antarctica, over the period of 1979-2014." Elem Sci Anth 3:000055: 1-20, doi:10.12952/journal.elementa.000055.

Thomson et al, (submitted). “Emerging trends in the sea state of the Beaufort and Chukchi Seas.”, Ocean Modelling, xx:xx, doi: 10.xxx/x.

Williams, G†., **T. Maksym†**, J. Wilkinson†, C. Kunz, P. Kimball, H. Singh (2015), Thick and deformed Antarctic sea ice mapped with autonomous underwater vehicles, submitted *to Nature Geoscience*, 8, 61–67, doi:10.1038/ngeo2299. † **-Joint lead authors**.