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

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Award Numbers: N00014-13-1-0435; N00014-13-1-0434; N00014-13-1-0446
http://www.apl.washington.edu/project/project.php?id=arctic_sea_state

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

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **Wave-Ice and Air-Ice-Ocean Interaction During the Chukchi Sea Ice Edge Advance**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Texas San Antonio,San Antonio,TX,78249**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- 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 38-day cruise on the R/V Sikuliaq in Sept-Oct 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**
Ocean gliders	Ahead of ice edge	Upper ocean (0-200m)	T, S, O2, bio-optics, currents	During cruise	CU-B UAF
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
Acrobat Towed Vehicle; 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 (UpTempo buoys); profiling CTD casts; Acrobat Towed Vehicle	~1 year (buoys) and During cruise	CU-B UAF UW
Airborne expendable Ice Buoy (AXIB)	Ahead, at and inside ice edge	Surface meteorology	T, SLP	~1 year	CU-B UW
Unmanned Airborne Vehicle (UAV)	Ice edge vicinity	Surface characterization, ice concentration, floe size distribution	Airborne digital photography	During Cruise	WHOI
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: Winsor-UAF; Steele&Rigor-UW; Perovich-CRREL)

WORK COMPLETED

(Ackley,Maksym,Stammerjohn) The field program part of the science plan strategy was written 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. Commitments for deployment of additional buoys were reaffirmed from U of Washington and CRREL.Mike Steele and Ignatius Rigor (UW) plan to have us deploy UpTempo Buoys (Steele) and AXIB or SVP buoys (Rigor) which will augment the DRI, as well as satisfy their program objectives. Don Perovich (CRREL) has also committed 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 which is being designed for vessel mounting on the Sikuliaq DRI 2015 cruise. The procurements have been initiated for the Riegl Lidar, Snow Radar (Kansas Univ), Geonics EM 31 and FLIR Infrared Camera to be used in this new system(see Table of Instrumentation above). A 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 thickess from the surface. Analyses were conducted of previous Lidar data from sea ice for surface roughness and drag coefficients and of prior deployment results from Ice Mass Balance buoys (see Publications List). These analyses have provided the basis for planning the data requirements for the DRI instrumentation during the field program. Ice edge traverse cruise modules have been designated and design of the ice edge transects using the new suite of instrumentation has been initiated.

(Maksym) Build of the SeaBed-100 AUV has been completed and is in preparation for trials at WHOI beginning in October. Visits to the Sikuliaq in July and August at WHOI, options for deployment and recovery were explored. A Seatronics ROV has been acquired and tested at WHOI. This ROV has been equipped with a Norbit WBMS broadband multibeam sonar, a Nortek 500 kHz AD2CP, and a hyperspectral radiometer. A Seabird Fastcat-49 CTD will also be added. This ROV will complement the AUV for potential under ice mapping within the pack and for investigation of ice growth processes at the advancing ice edge. Based on experience during deployment of autonomous buoys, two possibilities for the IMB/GPS buoy array are being evaluated – SAMS IMBs as deployed for the MIZ DRI, with improved GPS, or a new WHOI designed IMB. The latter has the capacity for inclusion of additional sensors such as acoustic snow depth sensors and upper ocean conductivity sensors. DJI Phantom quadcopters for aerial monitoring of ice conditions have been tested.

(Stammerjohn) Discussion with Peter Winsor, U of Alaska, resulted in plans for his contributions of instrumentation, two gliders and the Acrobat towed vehicle, to be used in the Sikuliaq 2015 cruise, significant additions (at minimal cost) to the regional study of ocean heat and sea state during the cruise. Work was initiated on creating and refining analytical tools for processing/analyzing hydrographic data from the multiple platforms that will be deployed during the 2015 cruise.

RESULTS

Most activities were focussed on planning, procurements of equipment and 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 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 this year provides some guidance for next year's cruise, as some of the buoys have begun to freeze back in again. How the freeze-up advances and any effect of waves on this advance will help guide buoy deployments in October 2015 on the SeaState 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 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. et al. (6 others), accepted, Surface Flooding of Antarctic summer sea ice, Annals of Glaciology (publication 2015)

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

Weissling, B. and S.F. Ackley (accepted) Spectral Analysis of Amundsen Sea Pack Ice Roughness and Estimates of Air-Ice Drag Coefficient, Annals of Glaciology (publication 2015)

Williams, G*., T. Maksym*, J. Wilkinson*, C. Kunz, P. Kimball, H. Singh, Thick and deformed Antarctic sea ice mapped with autonomous underwater vehicles, submitted *to Nature Geoscience*(in revision). * these authors contributed equally to this work.

Maksym, T., H. Singh, C. Bassett, A. Lavery, L Freitag, F. Sonnichsen, J. Wilkinson (2014), Oil spill detection and mapping under Arctic sea ice using autonomous underwater vehicles, *Bureau of Safety and Environmental Enforcement*, 99 pp. http://www.bsee.gov/Research-and-Training/Oil-Spill-Response-Research/Projects/Project1000/