UpTempO buoys for Understanding and Prediction

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MAJOR GOALS

Our long-term goal is to better understand the evolution of 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).

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.

ACCOMPLISHED

Over 2019-2022, we deployed a number of UpTempO buoys made for us by Pacific Gyre Company in Oceanside, CA: Three in 2019, none in 2020 (owing to the COVID-19 pandemic), five in 2021, and twelve in 2022. We also deployed one WARM (Warming and Irradiance Measuring) buoy. These were all deployed in the Beaufort Sea north of Alaska. We also deployed two thermistor string buoys in the Eurasian Basin via the MOSAiC project, which were made for us by Marlin-Yug. Some of these buoys used relatively inexpensive 1-wire digital thermistors, although the equivalent conductivity/salinity sensor is not yet available. Some used inductive modem technology, which is more expensive but provides higher accuracy temperature and salinity observations. We have been using T/C (temperature/conductivity) cells made Soundnine (a spin-off of Seabird Electronics), which are less expensive and smaller than Seabird's. These generally work well, although we've found that their lifetimes are often less than Seabird sensors.

Our project expanded during this funding cycle in two directions. First, we have a new interest in conductivity/salinity measurement, owing to increasing research on Arctic sea surface salinity (SSS) as measured by NASA's SMAP and the ESA's SMOS satellites. These satellite programs are very much interested in "ground truthing" in the ocean, and our buoys are a key resource in this regard. This expands our strong collaboration with sea surface temperature (SST) satellite validation and algorithm improvement. Second, in addition to our usual buoys with sensor strings to observe the upper euphotic zone, we have also been deploying buoys with short or even no sensor strings. The idea is to focus on surface observations for satellite validation and air-sea-ice interaction studies. This is becoming

increasingly important as sea ice retreats more each year. The advantage of these buoys is that the cost is lower relative to a full sensor-string buoy, and thus more can be deployed for synoptic coverage.

Upper Arctic Ocean warming research:

1) A review paper on SST satellite and in situ observations was published (***Minnett et al., 2019***), with a special section devoted to Arctic surface warming and SST.

2) A paper was published on using buoy data to improve NOAA's very popular OISST global, gridded SST product in ice-covered waters (***Banzon et al., 2020***).

3) A paper was published on the validation of global gridded SST data sets in the Chukchi and Beaufort Seas (***Vazquez et al., 2021***).

4) A paper was published on the partition of anthropogenic vs internal climate variability forcings responsible for recent upper ocean warming in the Arctic (***Li et al., 2021***).

5) A paper was published on the value of in situ ocean surface observations (including SST) for regional weather forecasting in the Beaufort Sea (***Zhang et al., 2022)***.

6) A paper was published on increasing upward heat fluxes from the ocean to sea ice in the Beaufort Sea, forced by enhanced seasonal ice growth (***Zhong et al., 2022***).

7) A paper was published on what causes the maximum SST observed in the Arctic each summer. For now, it's the timing of sea ice retreat, but in the future it will be the cloud state (***Sledd et al., 2023***).

8) A paper was published on using SST data to improve gridded sea ice concentration products near the ice edge (***Castro et al., 2023)***.

9) A paper is in preparation on how heat in the northward-flowing Atlantic Water influences the sea ice edge north of Svalbard (***Steele et al., 2023***).

Salinity and freshwater research:

1) A paper was published on validation of a suite of satellite SSS products using in Arctic situ observations (***Fournier et al., 2019***).

2) A paper was published linking freshwater release from the Beaufort Gyre to salinity change in the Labrador Sea (***Zhang et al., 2021***).

3) A paper was published on an improved algorithm to extend SMAP satellite SSS closer to the ice edge (***Tang et al., 2021***).

4) A paper was published on the validation of SMAP satellite SSS observations using in situ observations in the Bering, Chukchi, and Beaufort Seas (***Vazquez-Cuervo et al., 2021***).

5) A paper was published on the role of the Russian Arctic shelves in pan-Arctic surface salinity and vertically integrated freshwater interannual changes (***Hall et al., 2023***).

TRAINING
None.

DISSEMINATION

How Atlantic heat makes Arctic sea ice retreat, Tor Eldevik[1], Ingrid Husøy Onarheim[1], Lars Henrik Smedsrud[1], Michael Steele[2], Paul Anthony Dodd[3], Morven Muilwijk[1] and Marius Årthun, AGU Oc. Sci Mtg, San Diego, CA, Feb, 2020.

Impact of the Beaufort Gyre freshwater release on deepwater formation in the North Atlantic, Jiaxu Zhang[1], Wilbert Weijer[1], Wei Cheng[2], Michael Steele[3] and Tarun Verma[4], AGU Oc. Sci Mtg, San Diego, CA, Feb, 2020.

Arctic Saildrone field campaign: measurements of sea surface salinity and temperature for validation of satellite retrievals, Chelle L Gentemann[1], Peter J Minnett[2], Michael Steele[3], Jorge Vazquez[4], Wenquing Tang[5], Jacob Hoyer[6], Sotirios Skarpalezos[6], Chidong Zhang[7], Dongxiao Zhang[8] and Richard Jenkins[9], AGU Oc. Sci Mtg, San Diego, CA, Feb, 2020.

Evaluation and Intercomparison of SMOS, Aquarius and SMAP Sea Surface Salinity Products in the Arctic Ocean, Severine Fournier, Tong Lee, Wenqing Tang, Michael Steele, and Estrella Olmedo, AGU Oc. Sci Mtg, San Diego, CA, Feb, 2020.

Seasonal Ice Zone Reconnaissance Surveys for Aircraft-Based Eulerian and Lagrangian Sampling of a Changing Arctic, Michael Steele, James Morison, John Guthrie, Axel Schweiger, Zheng Li, Ignatius Rigor, AGU Winter Mtg., New Orleans, LA, Dec, 2021.

Does the Subsurface Arctic Know What's Happening at the Surface? Michael Steele, Aspen Global Change Institute, Aspen, CO, May, 2022.

The SIZRS project and related ocean surface research, Michael Steele, Pacific Arctic Group meeting, Tromso, Norway, March, 2022.

Recent upper Arctic Ocean warming expedited by summertime atmospheric processes, Michael Steele, CLIVAR Workshop on Observing, Modeling, and Understanding the Circulation of the Arctic Ocean and Sub-Arctic Seas Workshop, Seattle, WA, July, 2022.

Recent upper Arctic Ocean warming expedited by summertime atmospheric processes, Michael Steele, Group for High Resolution SST (GHRSST) meeting, Barcelona, Spain, July, 2022.

Does the Subsurface Arctic Know What's Happening at the Surface? Michael Steele, Gordon Research Conference, Ventura, CA, March, 2023.

Papers: See Products section

PLANS
Nothing to report

HONORS & AWARDS
Nothing to report

TECH TRANSFER
Nothing to report

PARTICIPANTS
PI: M. Steele (6 man-months)

STUDENTS
None

PRODUCTS

Steele, M., T. Eldevik, I. H. Onarheim, L. H. Smedsrud, P. A. Dodd, M. Muilwijk, and M. Årthun, How Atlantic heat makes Arctic sea ice retreat, *Geophys. Res. Lett., in prep,* **2023.**

Castro, S.L., G.A. Wick, S. Eastwood, M. Steele, and R.T. Tonboe, Examining the consistency of sea surface temperature and sea ice concentration in Arctic satellite products, *Remote Sensing, 15,* https://doi.org/10.3390/rs15112908, **2023**.

Sledd, A., T.S. L'Ecuyer, J.E. Kay, & M. Steele, Clouds increasingly influence Arctic sea surface temperatures as CO_2 rises. *Geophys. Res. Lett.*, https://doi.org/10.1029/2023GL102850, **2023**.

Hall, S. B., B. Subrahmanyam, & M. Steele, The role of the Russian Shelf in seasonal and interannual variability of Arctic sea surface salinity and freshwater content. *J. Geophys. Res.*, https://doi.org/10.1029/2022JC019247, **2023**.

Zhang, C., A. F. Levine, M. Wang, C. Gentemann, C. W. Mordy, E. D. Cokelet, P. A. Browne, Q. Yang, N. Lawrence-Slavas, C. Meinig, G. Smith, A. Chiodi, D. Zhang, P. Stabeno, W. Wang, H. Ren, K. A. Peterson, S. N. Figueroa, M. Steele, N. P. Barton, and A. Huang, Evaluation of operational forecasts at Alaskan arctic sea surface using in situ observations from saildrones, *Mon. Wea. Rev.,* https://doi.org/10.1175/MWR-D-20-0379.1, **2022**.

Vazquez-Cuervo, J., S. L. Castro, M. Steele, C. Gentemann, J. Gomez-Valdes, and W. Tang, Comparison of GHRSST SST analysis in the Arctic Ocean and Alaskan coastal waters using saildrones, *Remote Sens., 14*, https://doi.org/10.3390/rs14030692, **2022**.

Zhong, W., S. T. Cole, J. Zhang, R. Lei, and M. Steele, Increasing winter ocean-to-ice heat flux in the Beaufort Gyre region, Arctic Ocean over 2006-2018, *Geophys. Res. Lett.,* 49, https://doi.org/10.1029/2021GL096216, **2022**.

Li, Z., Q. Ding, M. Steele, and A. Schweiger, Recent upper Arctic Ocean warming expedited by summertime atmospheric processes. *Nat Commun* **13,** 362, https://doi.org/10.1038/s41467-022-28047-8, **2022**.

Tang, W., S. H. Yueh, A. G. Fore, A. Hayashi and M. Steele, An Empirical Algorithm for Mitigating the Sea Ice Effect in SMAP Radiometer for Sea Surface Salinity Retrieval in the Arctic Seas, *IEEE J. of Selected Topics in Appl. Earth Obs. Remote Sens.*, 14, 11986-11997, doi:10.1109/JSTARS.2021.3127470, **2021**.

Vazquez-Cuervo, J., C. Gentemann, W. Tang, D. Carroll, H. Zhang, D. Menemenlis, J. Gomez-Valdes, M. Bouali, and M. Steele, Using Saildrones to Validate Arctic Sea-Surface Salinity from the SMAP Satellite and from Ocean Models. Remote Sens., 13, https://doi.org/10.3390/rs13050831, **2021**.

Zhang, J., W. Weijer, M. Steele, W. Cheng, T. Verma & M. Veneziani, Labrador Sea freshening linked to Beaufort Gyre freshwater release., *Nat. Commun.,* 12, https://doi.org/10.1038/s41467-021-21470-3, **2021**.

Banzon, V., T.M. Smith, M. Steele, B. Huang, and H. Zhang, Improved Estimation of Proxy Sea Surface Temperature in the Arctic. *J. Atmos. Oceanic Technol.,* **37**, 341–349, https://doi.org/10.1175/JTECH-D-19-0177.1, **2020**.

Fournier, S., T. Lee, W. Tang, M. Steele, and E. Olmedo, Evaluation and Intercomparison of SMOS, Aquarius and SMAP Sea Surface Salinity Products in the Arctic Ocean, *Remote Sens., 11(24), 3043*, https://doi.org/10.3390/rs11243043, **2019**.

Minnett, P. J., A. Alvera-Azcárate, T. M. Chin, G. K. Corlett, C. L. Gentemann, I. Karagali, X. Li, A. Marsouin, S. Marullo, E. Maturi, R. Santoleri, S. Saux Picart, M. Steele, and J. Vazquez-Cuervo, Half a century of satellite remote sensing of sea-surface temperature, *Rem. Sens. Environ., 233, https://doi.org/10.1016/j.rse.2019.111366*, **2019**.

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14. ABSTRACT

This is a renewal proposal for SIZRS-UpTempO, a project designed to better understand the interactions between upper ocean warming and sea ice retreat and advance in the Beaufort and Chukchi Seas of the Arctic Ocean. "SIZRS" refers to Seasonal Ice Zone Reconnaissance Surveys, a multidisciplinary effort to track and understand the changing seasonal sea ice zone (SIZ). Over the coming years, SIZRS will continue to take advantage of the U.S. Coast Guard Arctic Domain Awareness flights to make a suite of air, ice, and ocean observations across the SIZ at monthly intervals through the spring-summer-fall seasons.

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