CISESS ANNUAL REPORT ON RESEARCH FOR THE

JASON PROGRAM

April 1, 2020 to March 31, 2021

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CISESS: ALTIMETRY OF THE ARCTIC OCEAN AND SUBPOLAR SEAS: INVESTIGATING CHANGES IN CIRCULATION AND DYNAMIC TOPOGRAPHY

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RESEARCH TOPIC: Climate Research, Data Assimilation, and Modeling

NOAA LEAD: Eric Leuliette

TASK STAFF: Kyle Duncan

TASK CODE: SFSF_AAOS_19 Yr 2

HIGHLIGHT: This year, CISESS Scientists Sinead Farrell and Kyle Duncan assessed the prevalence of winter storms in the Bering Sea for an 18-year period between 2003-2020. Ocean remote sensing data was obtained from the Radar Altimeter Database System (RADS). They found an increasing trend in storminess in the Bering Sea during the study period. The two, independent, altimeter time series show strong agreement, however the percentage of winter storms in the Envisat time series is twice that of the Jason time series. The reason for this doubling in the slope of the trend is currently unknown.

BACKGROUND

Although sea surface topography is an important parameter in the global ocean climate system, our knowledge is limited in the Arctic Ocean and subpolar seas, due to the constant presence of sea ice. As a result of the permanent ice cover, knowledge of the mean sea surface and bathymetric features of the Arctic Ocean is limited, as is detailed knowledge of geostrophic circulation, and its seasonal and interannual variability. Knowledge of sea surface height (SSH) is critical for deriving sea ice freeboard, and hence ice thickness from satellite altimeter data, where freeboard is defined as the difference between sea ice elevation and the local SSH. Beyond this, measuring SSH in the polar oceans provides a means of conducting a number of geodetic and oceanographic investigations such as monitoring variability in dynamic ocean topography and geostrophic circulation, changes in significant wave height, and the impacts of increasing storms on the marginal ice zone.

Satellite altimeters have been profiling the Arctic Ocean and subpolar seas since 1992 via the radar altimeter carried on-board the European Space Agency's (ESA) ERS-1 satellite. Between 1992 and 2012, ERS-1, -2 and Envisat measured polar ocean topography to a latitudinal limit of 81.5^{o}N. Since then, more recent altimeter missions, such as NASA's ICESat and ESA's CryoSat-2, have afforded us the chance to extend coverage pole ward, to 86^{o}N and 88^{o}N, respectfully. Near complete coverage, to 88^{o}N, is maintained by NASA's ICESat-2 mission, which was launched in 2018. Under this task we analyze CryoSat-2, ICESat-2 and Sentinel-3 altimeter data in the Arctic Ocean, as well as Jason-2 and SARAL/AltiKa measurements in the ice-free areas south of the marginal ice zone. We assess satellite-derived sea level anomaly, significant wave height, and dynamic ocean topography estimates, to investigate inter-annual variability and quantify trends over the past two decades. The research supports the NOAA/NASA Ocean Surface Topography Science Team (OSTST).

ACCOMPLISHMENTS

We collated all available daily radar altimeter measurements over a 21-year period spanning 2000-2020 to characterize the seasonal cycle, decadal trends, and inter-annual variability in sea state in the Bering Sea, south of the Bering Strait between Alaska and Russia. The goal of the study is to understand if the Bering Sea become stormier, as Arctic sea ice has retreated in recent years. Significant wave height (SWH) derived from the slope of the leading edge of radar altimeter waveforms was assessed in winter (November – April), for the period 2000 to 2020. The results are presented in Figure 1 and Figure 2 below.

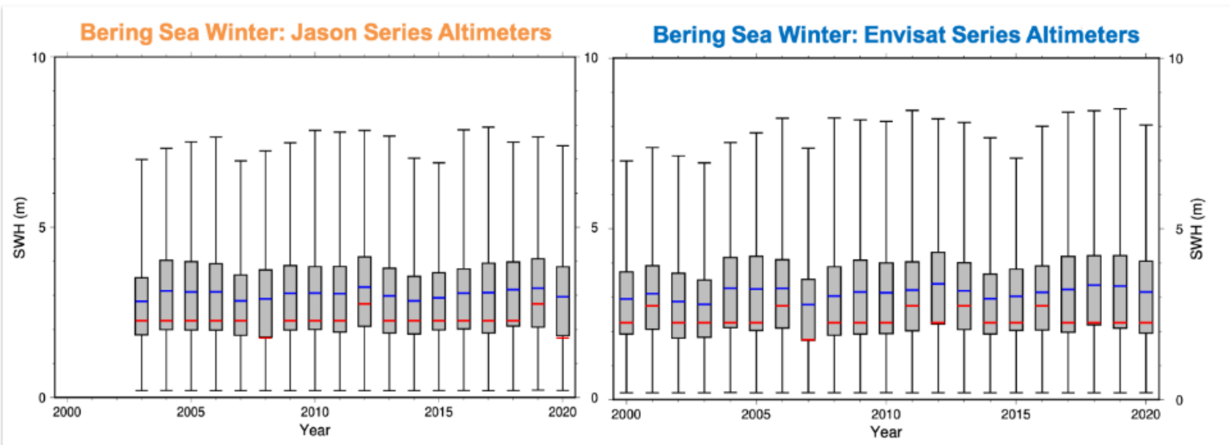

Figure 1: Significant wave height (SWH) in the Bering Sea, spanning 2000-2020. (Left) SWH observations from the Jason Series Altimeters (Jason-1, -2, -3) are compared with (right) measurements from the Envisat Series Altimeters (ERS-2, Envisat, CryoSat-2, SARAL/AltiKa, Sentinel-3A, -3B). Data accessed through the Radar Altimeter Database System (RADS): http://rads.tudelft.nl/rads/rads.shtml.

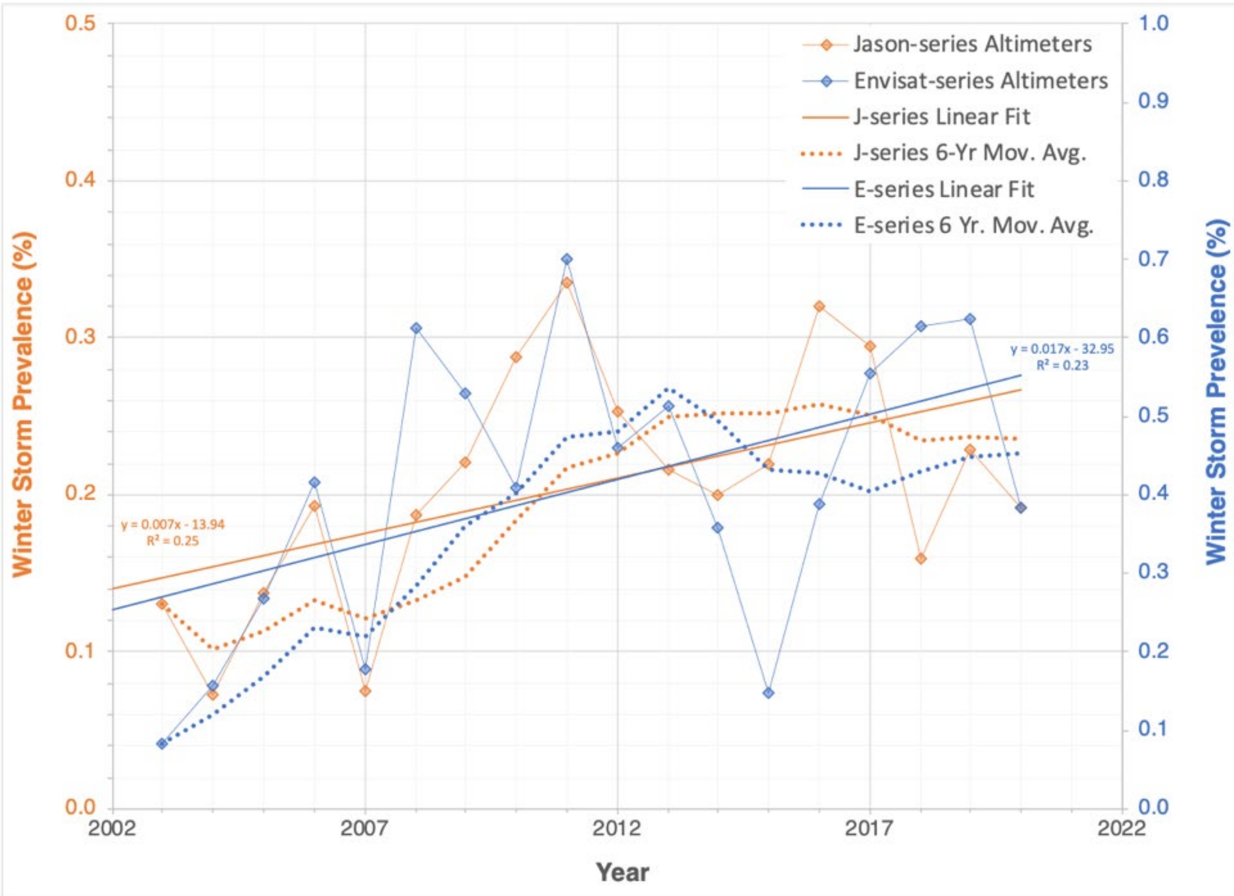

Figure 2: Increasing winter storminess in the Bering Sea 2003-2018.

We found that winter SWH in the Bering Sea is dominated by interannual variability, and the time series of results is consistent between the Envisat and Jason altimeters (Figure 1). Mean (modal) SWH was 3.03 m (2.25 m) according to the Jason altimeters, and 3.12 m (2.25 m) according to the Envisat altimeters. The data suggest that SWH > 7.5 m only 1% of the time. Seas were roughest in 2006, 2011 and 2017 and calmest in 2000, 2003, 2007 and 2015. We also assessed the prevalence of extremely stormy winter seas which are defined as those with a World Meteorological Organization (WMO) sea state code of 8 and 9 (i.e., SWH > 9 m). We defined winter storm prevalence is defined as the number of SWH measurements > 9m per winter per satellite as a percentage of the total number of SWH observations per winter per satellite. SWH from the Jason Series Altimeters (Jason-1, -2, -3, orange diamonds) are compared with measurements from the Envisat Series Altimeters (ERS-2, Envisat, CryoSat-2, AltiKa, Sentinel-3A/B, blue diamonds) in Figure 2. We found that the Bering Sea has seen increasing storminess during the 20-year study period (Figure 2, linear regressions, solid blue and orange lines). The two, independent, altimeter time series (Jason-series and Envisat-series) show strong agreement, especially when a 6-year moving average is fit to the data (Figure 2, dotted blue and orange lines). The percentage of winter storms in the Envisat time series is however twice that of the Jason time series and the reason for this doubling in the slope of the trend is currently unknown.

We presented our OSTST Report for the four-year period 2016-2020 at the 2020 Ocean Surface Topography Science Team Meeting in October 2020. Our reporting summarized the major accomplishments of the team in recent years. These included an analysis of the existing, state-of-the-art mean sea surface (MSS) models for the Arctic Ocean. Our study (Skourup et al., 2017) demonstrated that the inclusion of CryoSat-2 radar altimeter measurements of sea surface height (SSH) has improved the mapping of the Arctic Ocean MSS. MSS models that incorporate CryoSat-2 SSH show improved definition of features of the marine gravity field, and coverage of the field extends north to 88°N. Although widely used in previous studies, the EGM2008 geoid is not recommended for use in the retrieval of Arctic sea ice freeboard from satellite altimeter data, since the use of this geoid results in large freeboard errors across the central Arctic Ocean.

As part of this task, we also continue to provide mission support and scientific guidance for two polar altimeter missions: ICESat-2 (Magruder et al., 2020) and CRISTAL (Kern et al., 2020). Long term, uninterrupted observations of the polar oceans are of the utmost importance for climate and sea-level related scientific studies. The first two years of sea ice retrievals from ICESat-2 demonstrate its capability to track the evolution of the ice cover throughout the year, and detailed satellite altimeter measurements of the summer melt season have been obtained for the first time (Farrell et al., 2020). ICESat-2 sea ice freeboard and thickness results are fully consistent with complementary results from CryoSat-2 (Perovich et al., 2020). ICESat-2 mission data products are now publicly available from the National Snow and Ice Data Center (NSIDC). CryoSat-2 and ICESat-2 measurements of the cryosphere are providing scientific results that are vital in the preparation and design of future polar altimetry missions such as the Copernicus polaR Ice and Snow Topography Altimeter Mission (CRISTAL). The CRISTAL mission is currently in Phase B2 of development and the contract for the mission was recently signed (September 2020). CRISTAL will carry a dual-band radar altimeter with the goal of measuring variability in sea ice and land ice thickness, thus extending the CryoSat-2 and ICESat-2 time series. CRISTAL is planned for launch in 2027. There exists however a significant concern that a 2027, or later, launch timeframe may result in a gap in observational capabilities of the polar regions due to the expected lifetimes of the two current altimeters (CryoSat-2 and ICESat-2).

PLANNED WORK

The following tasks are planned for the upcoming year:

- Continue mission support for the ICESat-2, CRISTAL, Sentinel-6, and OSTST Science Teams.
- Continue assessments of CryoSat-2 and ICESat-2, to investigate ice/leads and ocean surface topography measurements in the Arctic Ocean and surrounding seas.
- Monitor sea surface topography in the Arctic Ocean and subpolar seas using suite of available radar and laser altimeter data, to quantify mean dynamic topography and geostrophic circulation, on monthly and inter-annual time-scales.
- Evaluate the increase in storminess identified in the 20-year radar altimeter data set using NCEP reanalysis data to understand the impact of atmospheric forcing.
- Calibrate and validate ICESat-2 ocean height and significant wave height measurements through detailed comparisons with the suite of radar altimeter data available through RADS.

PUBLICATIONS

1. Rösel, A., **Farrell, S. L.**, Nandan, V., Richter-Menge, J., Spreen, G., Divine, D. V., Gallet, J.-C., and Gerland, S. (2021). Implications of surface flooding on airborne thickness measurements of snow on sea ice, *The Cryosphere Discuss.,* https://doi.org/10.5194/tc-2020-168, accepted.

2. International Altimetry Team [includes **S.L. Farrell**) (2021). Altimetry for the future: Building on 25 years of progress. Advances in Space Research, in press.

3. Perovich, D., W. Meier, M. Tschudi, S. Hendricks, A. A. Petty, D. Divine, **S. Farrell**, S. Gerland, C. Haas, L. Kaleschke, O. Pavlova, R. Ricker, X. Tian-Kunze, M. Webster, and K. Wood (2020). *Sea Ice. Arctic Report Card 2020*, R. L. Thoman, J. Richter-Menge, and M. L. Druckenmiller, Eds., https://arctic.noaa.gov/Report-Card/Report-Card-2020 https://doi.org/10.25923/vtdn-2198

4. **Farrell, S. L., Duncan, K., Buckley, E. M**., Richter-Menge, J., & Li, R. (2020). Mapping Sea Ice Surface Topography in High Fidelity with ICESat-2. *Geophysical Research Letters*, **47**, e2020GL090708. https://doi.org/10.1029/2020GL090708

5. Andersen, J. K., Andreassen, L. M., Baker, E. H., Ballinger, T. J., Berner, L. T., Bernhard, G. H., Bhatt, U. S., Bjerke, J. W., Box, J. E., Britt, L., Brown, R., Burgess, D., Cappelen, J., Christiansen, H. H., Decharme, B., Derksen, C., Drozdov, D. S., Epstein, H. E., Farquharson, L. M., **Farrell, S. L.**, Fausto, R. S., Fettweis, X., Fioletov, V. E., Forbes, B. C., Frost, G. V., Gerland, S., Goetz, S. J., Grooß, J., Hanna, E., Hanssen-Bauer, I., Hendricks, S., Ialongo, I., Isaksen, K., Johnsen, B., Kaleschke, L., Kholodov, A. L., Kim, S., Kohler, J., Labe, Z., Ladd, C., Lakkala, K., Lara, M. J., Loomis, B., Luks, B., Luojus, K., Macander, M. J., Malkova, G. V., Mankoff, K. D., Manney, G. L., Marsh, J. M., Meier, W., Moon, T. A., Mote, T., Mudryk, L., Mueter, F. J., Müller, R., Nyland, K. E., O'Neel, S., Overland, J. E., Perovich, D., Phoenix, G. K., Raynolds, M. K., Reijmer, C. H., Ricker, R., Romanovsky, V. E., Schuur, E. A. G., Sharp, M., Shiklomanov, N. I., Smeets, C. J. P. P., Smith, S. L., Streletskiy, D. A., Tedesco, M., Thoman, R. L., Thorson, J. T., Tian-Kunze, X., Timmermans, M., Tømmervik, H., Tschudi, M., van As, D., van de Wal, R. S. W., Walker, D. A., Walsh, J. E., Wang, M., Webster, M., Winton, Ø., Wolken, G. J., Wood, K., Wouters, B., & Zador, S. (2020). The Arctic, *Bulletin of the American Meteorological Society*, 101(8), S239-S286. https://doi.org/10.1175/BAMS-D-20-0086.1

6. **Duncan, K., S. L. Farrell**, J. Hutchings, J. Richter-Menge (2020). Late Winter Observations of Sea Ice Pressure Ridge Sail Height*. IEEE Geoscience and Remote Sensing Letters*, https://doi.org/10.1109/LGRS.2020.3004724

7. Kern, M., R. Cullen, B. Berruti, J. Bouffard, T. Casal, M. R. Drinkwater, A. Gabriele, A. Lecuyot, M. Ludwig, R. Midthassel, I. Navas Traver, T. Parrinello, G. Ressler, E. Andersson, C. Martin Puig, O. Andersen, A. Bartsch, **S. L. Farrell**, S. Fleury, S. Gascoin, A. Guillot, A. Humbert, E. Rinne, A. Shepherd, M. R. van den Broeke, J. Yackel, (2020), The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) high-priority candidate mission, *The Cryosphere*, **14**, 2235–2251, https://doi.org/10.5194/tc-14-2235-2020

8. **Buckley, E. M., Farrell, S. L., Duncan**, K., Connor, L. N., Kuhn, J. M., & Dominguez, R. T. (2020). Classification of sea ice summer melt features in high-resolution IceBridge imagery*. J. Geophys. Res*., **125**, e2019JC015738. https://doi.org/10.1029/2019JC015738

9. Magruder, L., T. Neumann, H. Fricker, **S. L. Farrell**, K. Brunt, A. Gardner, D. Hancock, K. Harbeck, M. Jasinski, R. Kwok, N. Kurtz, J. Lee, T. Markus, J. Morison, A. Neuenschwander, S. Palm, S. Popescu, B. Smith and Y. Yang (2019), New Earth orbiter provides a sharper look at a changing planet, *EOS,* 100*,* https://doi.org/10.1029/2019EO133233

PRODUCTS

NOAA POLARWATCH PRODUCTS

PolarWatch (https://polarwatch.noaa.gov/) increases access to physical and biological ocean remote sensing data to diverse end-users across disciplines within NOAA, in support of broad applications in Arctic and Southern Ocean science.

NOAA / NESDIS / STAR LABORATORY FOR SATELLITE ALTIMETRY (LSA) POLAR OCEAN DATA SYSTEM (PODS) ARCTIC SEA ICE DATA PRODUCTS:

Daily, near-real-time, and science-quality remote sensing products characterizing Arctic sea ice.

https://www.star.nesdis.noaa.gov/sod/lsa/SeaIce/DataProducts/products_SeaIce.php

ftp://ftp.star.nesdis.noaa.gov/pub/socd/lsa/SeaIceProducts/Airborne/

PRESENTATIONS

1. **Farrell, S. L., K. Duncan, E. M. Buckley**, J. Richter-Menge, R. Li (2020), Exploring High-resolution Observations of Arctic Sea Ice with ICESat-2, [C034-02] presented at *2020 AGU Fall Meeting* (virtual), 1-17 Dec. 2020

2. **Duncan, K**. and **S. L. Farrell** (2020), High-Resolution Sea Ice Topography from ICESat-2, presented at *2020 AGU Fall Meeting*, 1-17 Dec. https://doi.org/10.1002/essoar.10505000.1

3. **Farrell, S. L**. (2021), NASA ICESat-2 Status Update, *Copernicus Polar Ice and Snow Topographic Mission Advisory Group (MAG) Meeting* #12 (virtual), 12 April 2021

4. **Farrell, S. L.** (2021), NASA IceBridge Observations in Support of Tri-band Altimetry, *DUAL-CRYO Workshop on Dual-Band Altimetry of the Cryosphere*, 13-14 January 2021 (virtual).

5. **Farrell, S. L**. (2020), NASA ICESat-2 Mission Update, *Copernicus Polar Ice and Snow Topographic Mission Advisory Group (MAG) Meeting* #11 (virtual), 3 November 2020

6. **Farrell, S. L**., L. Connor, C. Jackson, **K. Duncan**, J. Kuhn, A. Egido, D. Yi, E. Leuliette, **E. Buckley** (2020), Satellite and Airborne Products for Arctic Sea Ice, *NOAA CMMB Coastal Ocean Modeling Seminar*, NOAA National Ocean Service, 3 November 2020. [*Invited*]

7. **Farrell, S. L., K. Duncan**, J. M. Kuhn (2020), Altimetry of the Arctic Ocean and Subpolar Seas: Ocean Surface Topography Science Team Report 2016-2020, *2020 Ocean Surface Topography Science Team Meeting* (virtual), 19-23 October 2020.

https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST_2020.Farrell.Report.pdf

8. **Farrell, S. L., K. Duncan, E. Buckley**, J. M. Kuhn (2020), Monitoring Arctic Sea Ice with CryoSat-2 and ICESat-2, *2020 Ocean Surface Topography Science Team Meeting* (virtual), 19-23 October 2020. https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST_2020.Farrell.Cryosphere.pdf

9. **Farrell, S. L., K. Duncan, E. M. Buckley** (2020), Exploring Recent Changes in the Arctic with Remote Sensing, *Geographical Sciences Departmental Seminar*, University of Maryland, 22 October 2020.

10. **Farrell, S. L.** (2020), Tracking the Decline of Polar Sea Ice – Four Decades of Satellite Observation, *Scripps Institution of Oceanography Polar Science Seminar*, UCSD, CA, 4 June 2020. [*Invited*]

OTHER

SCIENCE TEAMS

- NOAA/NESDIS/STAR/SOCD Ocean Remote Sensing Sea Ice and Polar Dynamics Team (SIPD) CISESS Scientists Dr. Sinéad L. Farrell and Kyle Duncan are members.
- NOAA/NASA Ocean Surface Topography Science Team (OSTST): CISESS Scientist Dr. Sinéad L. Farrell (2017-) and Kyle Duncan (2021-) serve as members.
- ICESat-2 Science Team: CISESS Scientist Dr. Sinéad L. Farrell serves as a member (2012-).
- Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) Mission Advisory Group: CISESS Scientist Dr. Sinéad L. Farrell serves as a member of the Mission Advisory Group (MAG) for the ESA CRISTAL mission (2018-).

COMMUNITY OUTREACH

CISESS Scientists Dr. Sinéad L. Farrell co-chaired the “Science Results IV Splinter Session: Altimetry for Cryosphere and Hydrology” at the *Ocean Surface Topography Science Team Meeting*, 19-23 Oct. 2020.

MENTORING, ADVISING, TEACHING

CISESS Scientist Dr. Sinéad L. Farrell mentored graduate student Ms. **Ellen Buckley** at the Dept. Atmospheric & Oceanic Science, University of Maryland, in collaboration with CISESS.

CISESS: UNH MULTI-SENSOR AIR-SEA INTERACTION STUDIES USING THE SATELLITE ALTIMETER CONSTELLATION WITH ADDITIONAL WORK TO HELP DEVELOP FULLY-FOCUSED SAR ALTIMETRY FOR OCEANOGRAPHIC APPLICATIONS

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RESEARCH TOPIC: Climate Research, Data Assimilation, and Modeling

TASK STAFF: Hui Feng

TASK CODE: DVDV_NASA_19 Yr 2

HIGHLIGHT: Scientists at the University of New Hampshire conducted a new evaluation of fully-focused Synthetic Aperture Radar (FF-SAR) data using new Sentinel-3 FF-SAR altimeter data for the Nova Scotia and Gulf of Maine region. The results, presented in a publication in preparation, indicate that the FF-SAR approach is able to lower range noise and provide more data for the 10 km closest to the US and Maritime Canada coastlines.

BACKGROUND

As part of extensive past research in wind, wave, and sea state bias (SSB) correction measurements using satellite altimetry, our group at UNH brings significant data tools to bear for this study sea state, surface radar backscatter and SSB models for the delay Doppler altimeters of Cryo-Sat and Sentinel 3. We have previously helped to develop and formalize non-parametric methods for operational empirical sea state bias solutions and their validation for pulse-limited altimetry (Tran et al., 2010; Feng et al, 2010). This includes three-input SSB correction models that include use of ancillary global ocean wave model data shown to clearly improve performance and that can only be produced using sea level anomaly averaging approaches rather than crossovers or collinear methods employed so far for standard 2D-input models.

ACCOMPLISHMENTS

A new evaluation of fully-focused Synthetic Aperture Radar (FF-SAR) data application is detailed in Feng et al. (in preparation) and using new Sentinel-3 FF-SAR altimeter data for the Nova Scotia and Gulf of Maine region (data provided by NOAA scientist Alejandro Egido). The results are quite promising and indicate that the FF-SAR approach is able to both lower range noise and provide more data for the 10 km closest to the US and Maritime Canada coastlines. These improved data then allow us to resolve coastal currents and their time variability that have previously not been possible without SAR altimetry. The specific focus is on the Scotian Shelf and Gulf of Maine coastal currents.

Figure 3 shows a mapping of S3A altimeter-derived ocean surface currents near the southwestern Scotian Shelf and entrance area to the Gulf of Maine. On the bottom left are three different data processing approaches used to derive the data and their respective derived currents. The results indicate that the SAR-processed altimeter data products (fully-focused (FF-SAR) and unfocused (UF-SAR)) both outperform the traditional low-resolution mode altimeter data.

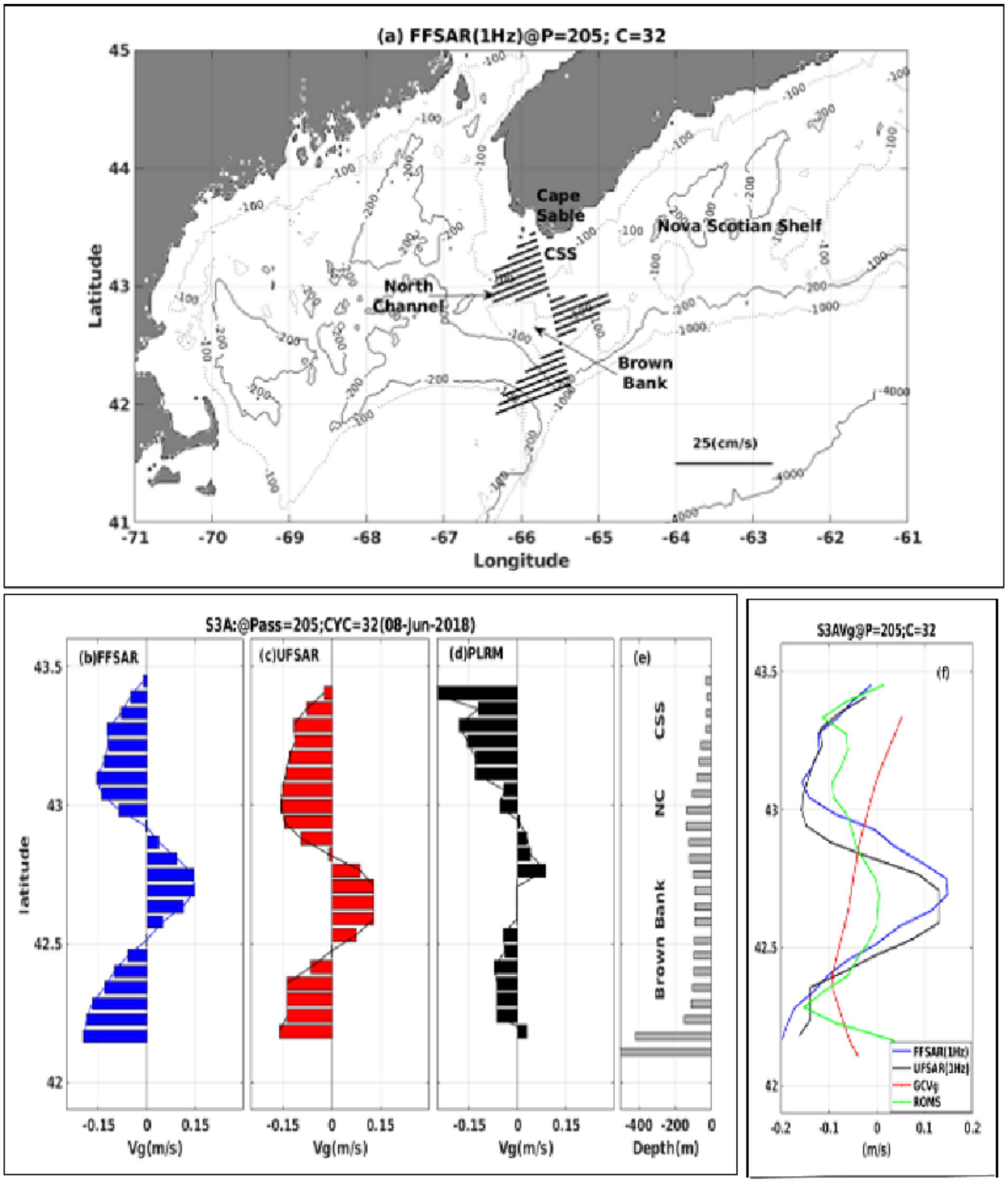

Figure 3: Mapping of of S3A altimeter-derived ocean surface currents near the southwestern Scotian Shelf and entrance area to the Gulf of Maine. Bottom left are three different data processing approaches used to derive the data and their respective derived currents. The results indicate that the SAR-processed altimeter data products (fully-focused (FF-SAR) and unfocused (UF-SAR) both outperform the traditional low resolution mode altimeter data.

PLANNED WORK

This was the final year for this project.

PUBLICATIONS

1. **Feng, H.**, **D. Vandemark**, and A. Egido, Exploring the potential of Sentinel-3 SAR altimetry for enhanced detection of coastal currents along the Northwest Atlantic shelf, in preparation.
2. Tran N., **D. Vandemark**, E. D. Zaron, G. Dibarboure, and N. Picot, 2019: Assessing the effects of sea-state related errors on the precision of high-rate Jason-3 altimeter sea level data. *Advances in Space Research*. https://doi.org/10.1016/j.asr.2019.11.034
3. **Vandemark, D.**, **H. Feng**, J. Tournadre, N. Tran and B. Chapron, Multi-Sensor Air-Sea Interaction Studies using the Satellite Altimeter Constellation, NASA Ocean Surface Topography Science Team Meeting, Virtual, Oct. 2021.
4. Jayasinghe A., S. Elliott, and **D. Vandemark**, Biomacromolecular Role in High-Return Ocean Altimetric Blooms, Atmosphere, submitted.

PRESENTATIONS

1. Feng and Vandemark, New sea state bias models for the final TOPEX altimeter data processing, provided to *JPL* in Nov. 2020.

OTHER

Mentoring new student at University of Colorado with Steve Nerem, Alexa Putnam, who is working on sea state bias modeling.

CISESS: DEVELOPMENT OF FULLY-FOCUSED SAR ALTIMETRY FOR OCEANOGRAPHIC APPLICATIONS

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RESEARCH TOPIC: Climate Research, Data Assimilation, and Modeling

NOAA LEAD: Alejandro Egido

TASK CODE: EBCB_ICES_20

HIGHLIGHT: The scientific part of this effort focused on extending the existing theory about how higher order spectral moments effect SAR altimetry signals, especially the retrieved geophysical parameters from these, and how more complicated antenna patterns can be introduced into existing SAR altimetry signal models. Next, these model extensions and existing models were coded into a C-library, which is going to be called LSA-Retlib, with a MATLAB and IDL interface.

BACKGROUND

Since its conception, satellite altimetry has been a breakthrough in the field of ocean surface topography, enabling an improved understanding of ocean processes at global scales. From Geos-3 in 1975, until the recently launched Jason-3, most satellite radar altimeters have used the same data processing scheme. Referred to as “conventional” or low-resolution mode (LRM), this technique enables due to incoherent processing the reliable estimation of sea surface height (SSH), surface roughness or significant wave height (SWH), and radar backscatter coefficient that can be related to wind speed.

The European Space Agency (ESA) launched in 2010 the Cryosat-2 mission, the first satellite radar altimeter to incorporate the delay/Doppler (D/D) altimetry concept (Raney, 1998). Initially devoted for Cryosphere observations, the SAR mode capability of the Synthetic Aperture Interferometric Radar Altimeter (SIRAL) altimeter also provides the opportunity of demonstrating significant potential benefits of D/D altimetry for ocean applications (Wingham, et al., 2006). As part of the continuation of the Jason altimeter series, NASA together with its international partners ESA, EUMETSAT, NOAA, and CNES, are developing Jason-CS/Sentinel-6. This mission will be operated in an interleaved mode that will produce simultaneously both SAR and LRM data.

Leveraging on the SAR Altimetry technology, we have developed a novel radar altimeter data processing technique. By accounting for the phase evolution of the scatterers in the scene during their illumination period by the radar, it is possible to perform inter-burst coherent averaging potentially reducing the along-track resolution down to the theoretical limit, corresponding to half the antenna length. We call this fully focused SAR (FF-SAR) altimetry. For the development of the technique, we have used CryoSat-2 SAR Mode data, but this method is equally applicable to similar data from Sentinel-3 or Sentinel-6/Jason-CS. The technique has been validated using transponder data, demonstrating an along-track achievable resolution of 0.5 meters.

ACCOMPLISHMENTS

Last year's work can be divided into two parts. The scientific part, which was focused on extending the existing theory about how higher order spectral moments effect SAR altimetry signals, especially the retrieved geophysical parameters from these, and how more complicated antenna patterns can be introduced into existing SAR altimetry signal models. Secondly, these model extensions and existing models were coded into a C-library, which is going to be called LSA-Retlib, with a MATLAB and IDL interface. In the following more details are given regarding the parts mentioned before.

SCIENTIFIC ACCOMPLISHMENTS

As FF-SAR is due to its high resolution a good candidate for sea-ice retracking - which mainly aims to determines the freeboard but other parameters such as backscattering or elevation variation might be of scientific interest too – an update on the physical signal model needs to be done. The reason behind was the fact that sea-ice elevations do not follow a normal distribution such as ocean surfaces, but something close to an exponentially modified normal distribution. Therefore, it was necessary to characterize the variance and rate of this distribution with respect to the sea-ice elevation variation and to introduce its probability density function to the existing SAR altimetry signal model. These tasks were performed, and the final model is implemented in LSA-Retlib. A publication of this method will follow when the results of real data processing are validated.

Last year it was tried to eliminate discrepancies between SAR altimetry derived second order spectral moments and ocean wave models, such as ECMWF, or buoy observations. One possible error source on the altimetry data processing side was identified to be the approximation of the antenna pattern as a Gaussian. With the help of colleagues from CLS it was accomplished to derive a more general description of the real antenna pattern as a sum of Gaussians. However, it was observed after processing a small test dataset that the antenna pattern did not cause a big enough error on second order spectral moment estimations. However, it is planned to publish the method at some point. At a later point it was tested to use a back-projection algorithm, which is usually used in FF-SAR processing, in an unfocused SAR processing scheme. It could be observed that especially the second order spectral moment estimation at low sea states benefits from this approach and that the overall quality with respect to accuracy of the data improved. However, most discrepancies of second order spectral moments remained. It is planned to publish these findings after the processing of a bigger dataset could be done.

Around the end of this time period, a breakthrough was reached by identifying the sea surface slope/velocity correlations as the error source of significantly underestimated second order spectral moments (around 20% error). A very coarse estimation of the theoretical error was identified to be around 22%, depending on wave steepness and the chosen spectra, which matches very well with the observed differences with respect to the ECMWF model. Additionally, weakly nonlinear waves, in the form of a second order Stokes approach, could be introduced in the SAR altimetry signal model, and the solution indicates that the sea state bias, being one of the major remaining sea surface height errors, could be explainable using the developed approach. However, a deeper investigation needs to be done first and the new model needs to be implemented into LSA-Retlib before a real data processing campaign can be started.

PROGRAMMING A C-BASED LIBRARY FOR ALTIMETRY RETRACKING

In many processing campaigns of Radar altimetry data, it is necessary to fit millions of signals and the fitting of each signals takes five to twenty (mostly around six) model evaluations. Therefore, it is important to have these models in a well programmed library. It was decided to have the model implementations be done in C and that a MATLAB and IDL interface shall be possible. This task is mostly finished (only the nonlinear waves model is missing) and first tests showed that the LSA-Retlib is around four to ten times faster than its MATLAB or IDL version.

PLANNED WORK

- All the accomplishments mentioned before were tested for a rather small test dataset. Therefore, they need to be proven within a bigger processing and validation campaign using in-situ data.
- LSA-Retlib still misses the nonlinear waves altimetry signal model. This will be added and then the documentation of the library will be finished.
- While the previous period was used to develop, test, and code new approaches (no publications were made), it is planned to publish all findings, which will result in around four scientific papers.
- Due to COVID all conferences in the previous year were either cancelled or changed to virtual meetings (no official presentations were held); however, this will change in the next time period.

CISESS: AOSC IMPLEMENTATION OF LETKF-BASED DA IN HYCOM OF COUPLED HWRF SYSTEM

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RESEARCH TOPIC: Climate Research, Data Assimilation, and Modeling

NOAA LEAD: Eric Leuliette

TASK STAFF: Timothy Smith, Mike Goodliff, Hsin-Yi Lin, Tse-Chun Chen

TASK CODE: SPSP_ HWRF_19 Yr 2 (no-cost extension)

BACKGROUND

This project supports the development of an ensemble data assimilation (DA) system to initialize the ocean component of the NOAA Hurricane Analysis and Forecast System (HAFS). In past activity, an LETKF ocean data assimilation system was implemented with the HYCOM ocean model at 1/12-degree resolution. It was deemed that maintaining a perpetually running ocean ensemble data assimilation system at this resolution was too computationally costly. As a result, we are now exploring the potential for implementing the same LETKF DA with Artificial Intelligence / Machine Learning (AI/ML) based surrogate models to generate necessary ensemble error statistics at a fraction of the cost.

ACCOMPLISHMENTS

No activities have been charged to this award to date.

PLANNED WORK

- This project will specifically target the potential of initializing the HYCOM component of the HAFS by integrating LETKF with AI/ML methods in the DA cycle.
- In coordination with collaborators working on NOAA hurricane supplemental funded activity, an LETKF-based data assimilation system will be set up to initialize the ocean component of the HAFS.
- The LETKF DA system will leverage Artificial Intelligence / Machine Learning (AI/ML) model emulators that are being developed in outside activity.

CISESS: AOSC OPERATIONAL OCEAN DATA ASSIMILATION TO IMPROVE UPPER OCEAN CURRENT ESTIMATES FOR GLOBAL OCEAN MONITORING, COUPLED CLIMATE FORECASTS, AND COUPLED HURRICANE FORECASTS

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TASK CODE: SPSP_OODA_19 Yr 2 (no-cost extension)

BACKGROUND

Past activity from this project supported the Ph.D. of Dr. Luyu Sun at the University of Maryland, who implemented a Lagrangian Data Assimilation (LaDA) scheme to assimilate near surface drifter positions in an idealized setting (Sun and Penny, 2019). This has led to further support for Sun to study the application of the LaDA method in a realistic application in the Gulf of Mexico (Sun, Penny, and Harrison, 2021; submitted) using observations from the Grand Lagrangian Deployment (GLAD) field campaign, and continued support from the NASA ROSES program for Sun and Penny to investigate the impacts on tropical cyclones. The ongoing activity of this project aims to leverage this previous LaDA work as well as continued developments in methods in artificial intelligence and machine learning (AI/ML) to better utilize ocean surface observations in order to improve surface current estimation in multiple NOAA applications, with a particular focus on coupled hurricane forecasts.

ACCOMPLISHMENTS

No activities have been charged to this award to date.

PLANNED WORK

- This project will specifically target the potential of improving ocean surface currents by integrating LETKF with AI/ML methods in the DA cycle.
- Leverage development of an externally developed LETKF-based data assimilation system to assimilate surface observations with a target to improve surface current estimation at high resolutions (e.g. 1/12-degree horizontal resolution).
- The LETKF DA system will leverage Artificial Intelligence / Machine Learning (AI/ML) model emulators that are being developed in outside activity.

APPENDIX: CISESS PROJECT SLIDES

This report includes a single slide summary of the accomplishments of Sinéad L. Farrell. You can download these slides in PowerPoint from the CISESS DropBox:

https://www.dropbox.com/sh/xqdsha54xm8o3sy/AADQ97aAonX6hVhRDMYo-1-Ba?dl=0