ARKTALAS Hoavva Science Workshop Report

Deliverable D150

UNIS, Longyearbyen, Spitsbergen
Tuesday 26 April - Friday 29 April 2022

Arktalas Hoavva core project team visiting SvalSat station in Longyearbyen (Photo by Marjo)
(The Arktalas Hoavva project is funded by ESA under the contract 4000127401/19/NL/LF)

Arktalas Project attendants: Bertrand Chapron, Mathilde Cancet, Fabrice Collard, Craig Donlon, Igor Esau, Anton Korosov, Johnny A. Johannessen and Lasse H. Pettersson.

On-site participants: Jøran Moen (UNIS), Frank Nilsen (UNIS), Shridhar Jawak (SIOS),

On-line participants: Diego Fernandez (ESA-ESRIN), Thomas Lavergne (MET), Einar Olason (NERSC)

ARKTALAS HOAVVA PROJECT

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Table of Content:

Introduction

During the last 3 decades there has been a dramatic decline in Arctic sea ice extent, age and volume. This decline is assumed to be connected to global warming and the corresponding regional Arctic Amplification response triggering multidisciplinary coupled atmosphere, ocean and sea-ice interactive processes and mutual feedback. However, although we have gained good qualitative understanding of these processes and feedback mechanisms we still lack proper quantitative insight. This is predominantly due to the limitation of the existing observing system to routinely collect collocated and multidisciplinary measurements across the broad range of spatial and temporal scales. To advance the knowledge gap it is therefore necessary to design and implement a systematic multi-modal data-driven analysis framework whereby one benefit from the synergy of satellite sensor measurements complemented with improved in-situ measurement capabilities and tools including models, data assimilation and artificial intelligence. This was highlighted during the Arktalas Hoavva science workshop at UNIS in Longyearbyen from 26-29 April 2022.

The main goal of the workshop was to *Use satellite measurements in synergy with in-situ data and modelling tools to characterize and quantify the processes driving changes in the Artic sea ice and Arctic Ocean.* This was in particular tailored to the following major interlinked and cross-disciplinary Arctic Scientific Challenges (ASC):

- *ASC-1: Characterize Arctic Amplification and its impact*
- *ASC-2: Characterize the impact of more persistent and larger area of open water on sea ice dynamics*
- *ASC-3: Understand, characterize and predict the impact of extreme event storms in sea-ice formation*
- *ASC-4: Understand, characterize and predict the Arctic ocean spin-up*

In so doing the status of the published and submitted scientific papers to international peer review journals (see list below) under this Arktalas Hoavva project were presented and assessed in respect to achievements and findings relevant to the four ASC.

Paper 1: Response of Total and Eddy Kinetic Energy to the recent spin up of the Beaufort Gyre *(Relevant ASC-4)*. Published in *Journal of Oceanography* in 2019 by H. Regan, C. Lique, C. Talandier and G. Meneghello. https://doi.org/10.1175/JPO-D-19-0234.1

Paper 2: Observational evidences of eddy-sea ice interactions in the pack-ice and in the MIZ *(Relevance to ASC-2)*. Published in *Geophysical Research Letter* in 2020 by A. Cassianides, Camille Lique, and Anton Korosov. https://doi.org/10.1029/2020GL092066

Paper 3: Wind-wave attenuation under sea ice in the Arctic: a review of remote sensing capabilities (*Relevant to ASC-2)* submitted to *Journal of Geophys. Res.-Ocean* by Fabrice Collard, Louis Marie, Frederic Nouguier, Marcel Kleinherenbrink, Frithjof Ehlers, and Fabrice Ardhuin

Paper 4: Modelling the Arctic wave-affected marginal ice zone, comparison with ICESat-2 observations *(Relevant to ASC-2)*. Submitted to *Philosophical Transactions A* by G. Boutin, T. Williams, C. Horvat and L. Brodeau

Paper 5: Driving mechanisms of an extreme winter sea-ice breakup event in the Beaufort Sea *(Relevance to ASC-3)*. Submitted to *Geophys. Res. Letter* by Jonathan W. Rheinlænder, Richard Davy, Einar Olason, Pierre Rampal, Clemens Spensberger, Timothy D. Williams, Anton Korosov, Thomas Spengler

Paper 6: The Arctic amplification and its impact: Attribution through remote-sensing data *(Relevance ASC-1)*. To be submitted by Igor Esau, Johnny A. Johannesen, Lasse H. Pettersson, Aleksander Chernokulsky, Oleg Sizov et al., To be submitted to tbd-journal in 2022

Paper 7: Impact of sea-ice friction on tidal modelling in the Arctic Ocean *(Relevance ASC-1)* To be submitted to tbd by M. Cancet et al., 2022

Paper 8: Changes in the Arctic Ocean: Knowledge gaps and Impact of future satellite missions Satellite missions for the Arctic Ocean *(Relevant to all ASCs)*. To be submitted to *Journal of Remote Sensing* by S. Lucas, J.A. Johannessen, M. Cancet, L.H. Pettersson, I. Esau, J. Rheinlaender, F. Ardhuin, B. Chapron, A. Korosov, F. Collard, S. Herlédan, E. Olason, C. Donlon

Arktalas Scientific Papers: Summary of key achievement and findings

In this session the focus was on the key findings and achievements from papers not yet published (e.g. recently submitted or to be submitted). The presentations stimulated constructive discussions around a range of issues such as:

- Have we advanced the understanding of the four ASC?
- What are the strength and weaknesses of the existing and approved satellite observing system?
- Can we design a roadmap for further advances in Arctic Science based on Arktalas results and findings blended with existing and new approved missions, in-situ data and model fields?

Paper 3: Wind-wave attenuation under sea ice in the Arctic: a review of remote sensing capabilities (*Relevant to ASC-2)* submitted to *Journal of Geophys. Res.-Ocean* by Fabrice Collard, Louis Marie, Frederic Nouguier, Marcel Kleinherenbrink, Frithjof Ehlers and Fabrice Ardhuin.

Fabrice Collard highlighted the new findings addressed in the paper based on innovative use of satellite sensor synergy. Wind-generated waves strongly interact with sea ice and impact air-sea exchanges, operations in sea ice covered regions and marine life. Unfortunately, the dissipation of wave energy is not well quantified and its possible effect on upper ocean mixing and ice drift are still mysterious. As the Arctic ocean is opening up and wave energy increases, the limited amount of in-situ observations is a clear limitation to our scientific understanding. Both radar and optical remote sensing has revealed the frequent presence of waves under the ice, and could be used more systematically to investigate wave-ice interactions. Here we show that, in cloud-free conditions, Sentinel-2 images exhibit brightness modulations in ice-covered water, consistent with the presence of waves measured a few hours later by the ICESat-2 laser altimeter (see Figure 1). We also show that a full-focus SAR processing of Sentinel-3 radar altimeter data reveals the presence of waves under the ice and their wavelengths, within minutes of Sentinel-2 imagery. The SWIM instrument on CFOSAT is another source of quantitative evidence for the direction and wavelengths of waves under the ice, when ice conditions are spatially homogeneous. In the presence of sea ice, a quantitative wave height measurement method is not yet available for all-weather near-nadir radar instruments such as altimeters and SWIM. However, their systematic co-location with optical instruments on Sentinel-2 and ICESat-2, which are less frequently able to observe waves in sea ice due to presence of clouds, may provide the empirical transfer functions needed to interpret and calibrate the radar data, greatly expanding the available data on wave-ice interactions. In turn, these observations can provide useful observation for understanding the interactions of waves and sea ice.

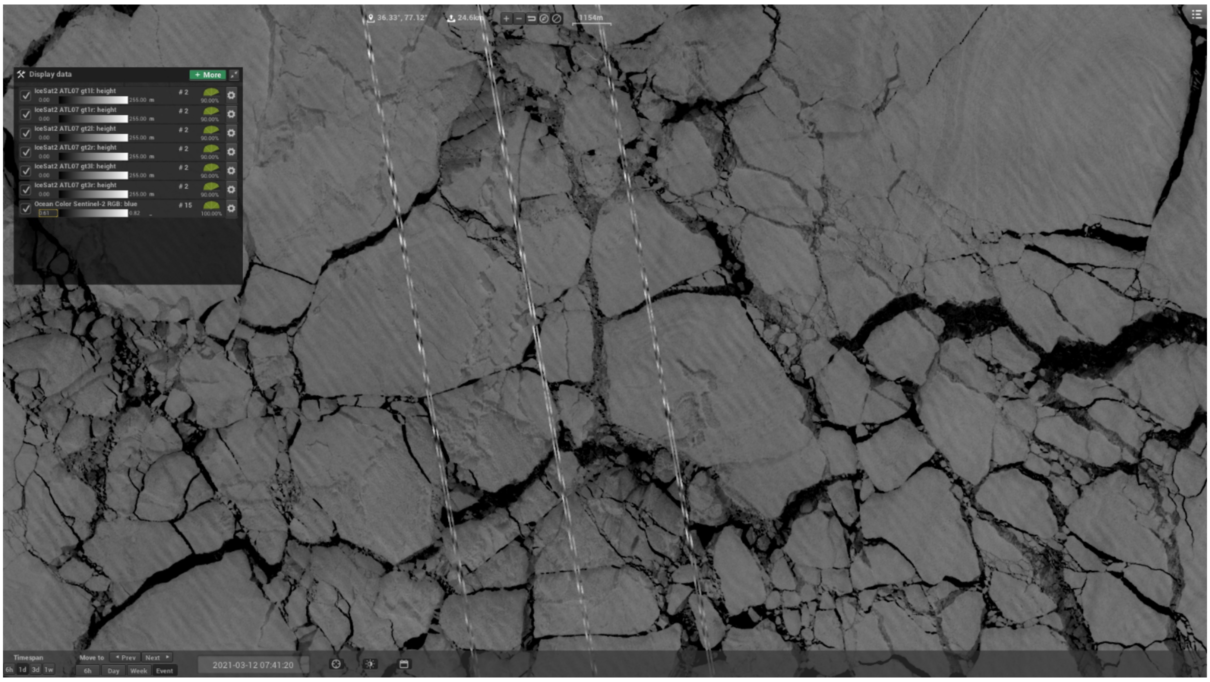

Figure 1. *Colocated Sentinel-2 (11:08 UTC) and IceSAT-2 (18:34 and 07 :41 UTC) in the sea ice covered Arctic Ocean on 12 March 2021.*

Paper 4: Modelling the Arctic wave-affected marginal ice zone, comparison with ICESat-2 observations *(Relevant to ASC-2).* Submitted to *Philosophical Transactions A* by G. Boutin, T. Williams, C. Horvat and L. Brodeau.

On behalf of the authors, **Anton Korosov** presented the interesting findings in this paper that has evaluated the marginal ice zone (MIZ) extent in a coupled wave-ice 25-km resolution model, compared to pan-Arctic wave-affected sea ice regions derived from ICESat-2 altimetry over the period December 2018 - May 2020. Using a definition of the MIZ based on the monthly maximum of the wave height, a metrics is suggested to evaluate the model simulation taking into account the sparse coverage of ICESat-2 (due to presence of clouds). The simulation produces MIZ extent comparable to observations, especially in winter. Sea ice drift velocity differences are also assessed due to inclusion of the effect of sea ice damage by passing storms (see Figure 2). A sensitivity study highlights the need for strong wave attenuation in thick, compact ice, but weaker attenuation in summer or during sea ice formation, as the model underestimates the MIZ extent in autumn and summer. This underestimation may be due to limited wave growth in partially sea ice covered regions or due to the absence of other processes affecting floe size. Investigation of impact due to other definitions of the MIZ based on floe size and sea ice concentration, as well as the potential wave-induced fragmentation on ice dynamics, were found to have minor contribution at the climate scales.

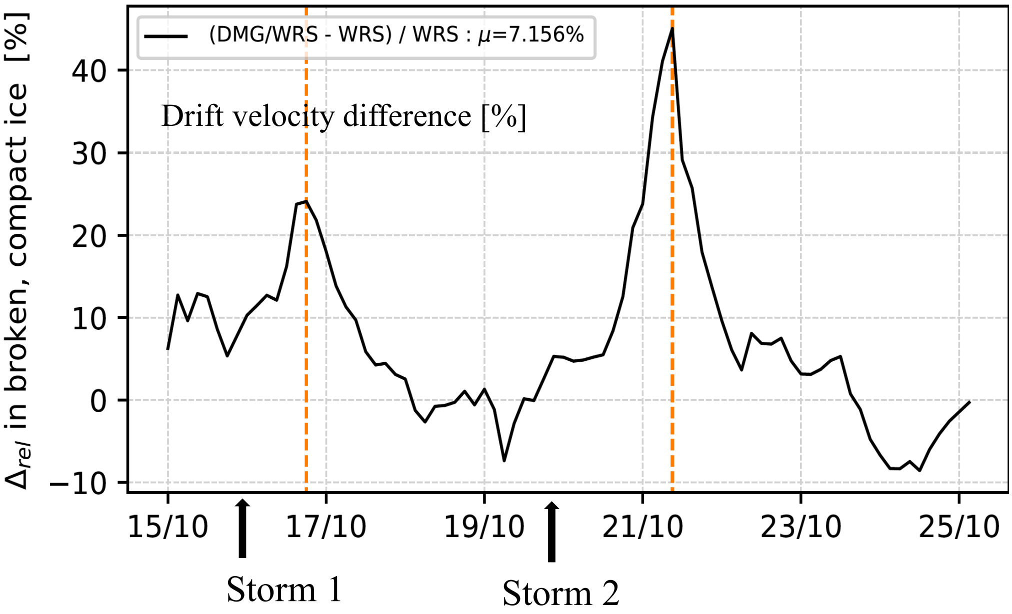

Figure 2. *Simulation of impact on sea ice dynamics. Fragmentation increases the mobility of compact and broken sea ice after passage of extreme events. DMG relates to coupled simulation with damage/fragmentation link; WRS relates to coupled simulation without damage/fragmentation link (G. Boutin et al, unpublished 2022).*

Paper 5: Driving mechanisms of an extreme winter sea-ice breakup event in the Beaufort Sea *(Relevance to ASC-3)*. Submitted to *Geophys. Res. Letter* by Jonathan W. Rheinlænder, Richard Davy, Einar Olason, Pierre Rampal, Clemens Spensberger, Timothy D. Williams, Anton Korosov and Thomas Spengler.

Anton Korosov highlighted the achievements presented in this paper. The thick multi-year sea ice that once covered large parts of the Arctic is increasingly being replaced by thinner and weaker first-year ice, making it more vulnerable to breakup by storms. The neXtSIM sea-ice model is used to investigate the driving mechanisms behind a large breakup event in the Beaufort Sea during winter 2013 (see Figure 3). The simulations are the first to successfully reproduce the timing, location, and propagation of sea-ice leads associated with storm-induced breakup and highlight the importance of the accuracy of the atmospheric forcing, sea-ice rheology, and changes in sea-ice thickness. The breakup is found to result in enhanced export of multi-year ice from the Beaufort Sea. Overall, this lead to a relatively thinner and weaker ice cover that potentially preconditions earlier breakup in spring and accelerates sea-ice loss. Finally, the results indicate that large breakup events will become more frequent as Arctic sea ice continues to thin.

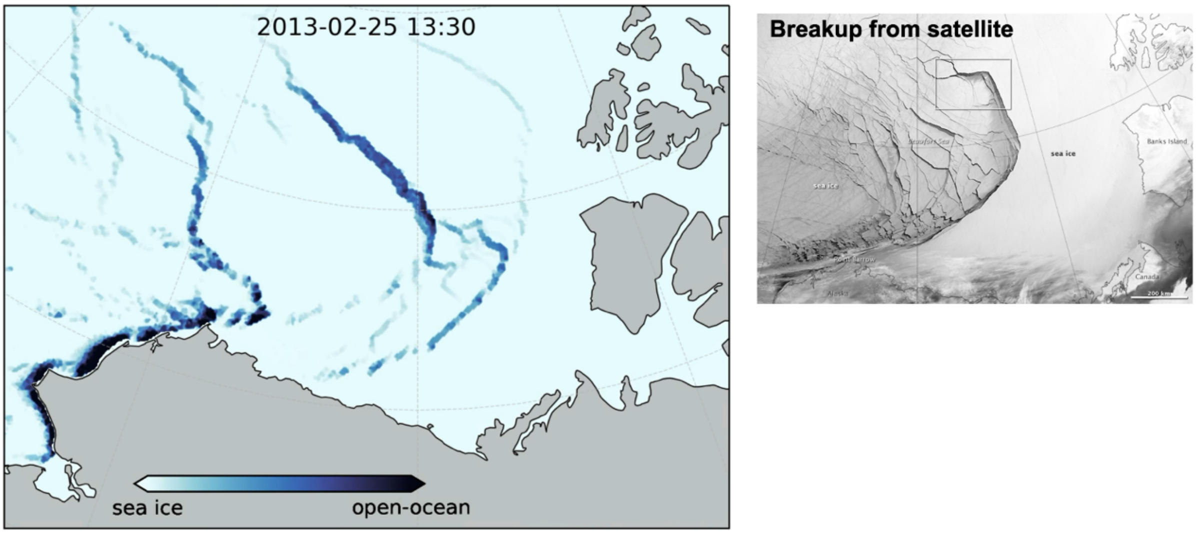

Figure 3. *(right) The February 2013 breakup event in the Beaufort Sea; (left) Simulation of the break-up using the neXtSIM sea ice model developed at the Nansen Center (J.W. Rheinlænder et al, unpublished 2022).*

Paper 6: The Arctic amplification and its impact: Attribution through remote-sensing data *(Relevance ASC-1).* To be submitted to tbd-journal by Igor Esau, Johnny A. Johannesen, Lasse H. Pettersson, Aleksander Chernokulsky, Oleg Sizov et al., To be submitted 2022.

Igor Esau presented new findings addressed in this paper. Satellites witness temperature raise, sea ice loss, decline of snow season, and enhancement of phytoplankton and vegetation productivity. The Arctic warming leads the temperature increase compared to other global region by a significant margin. This climate phenomenon is known as the Arctic Amplification. Since 1990s, the Arctic temperature change has been 2.5 – 3.5 times larger than that over the Northern Hemisphere. The Amplification does not develop as a monotonic process (see Figure 4). The remote sensing data have captured the rapid and massive transition from multiyear to seasonal sea ice as well as from tundra to tall shrubs and forest. Moreover, satellite observations have provided the key data for distinction between the contribution from the surface albedo feedback and the sea ice insulation and heat accumulation feedbacks, thus, being critical for shifting the physical paradigm of this climate phenomenon. In this paper the important and diverse aspects the Amplification that have been captured by satellite observations are further examined with regards to impact of clouds and long wave radiances and suggests that the atmospheric boundary layer stratification and snow/sea ice surface melting plays a significant role. The findings and results complement physical understanding established by countless modeling studies. However, additional efforts are needed to improve cross-satellite calibrations, retrieval algorithms and to reduce uncertainties. In addition, as the Amplification is set to continue in the 21st century, a new generation of satellite-born instruments (e.g. EarthCare) are in high demand.

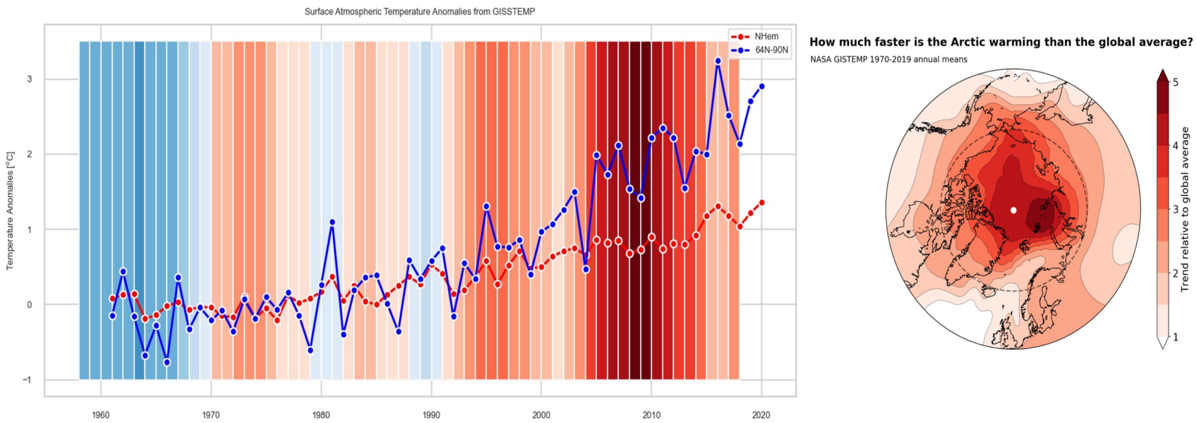

Figure 4. *Emergence of the apparent Arctic Amplification shown through the annual temperature anomalies in high latitudes (64N-90N, blue line) and the Northern Hemisphere (NHem, red line). The color strips show divergence rate of temperature anomalies averaged within 7-years moving window. Red – high divergence rate, blue – negative divergence (convergence) rate. Dataset: GISTEMP. (Esau et al, unpublished 2022.*

Paper 7: Impact of sea-ice friction on tidal modelling in the Arctic Ocean *(Relevance ASC-1)*
To be submitted to tbd by M. Cancet et al., 2022.

The aim of this study presented by Mathilde Cancet is to analyze the interaction between the tides and the sea ice cover in the high latitude seas and Arctic Ocean using simulations with a hydrodynamic model, with particular focus on the sensitivity and impact of the parameterization of the friction invoked by the presence of fast ice and floating sea ice. Limited availability of tide gauges is a challenge for validation, as is uncertainties in access to high-resolution and accurate shallow water bathymetry data along the shelves and in straits and channels in the high latitude seas and Arctic Ocean. Moreover, the range of sea ice ages (thickness), extent and concentration are also factors that will influence the friction parameterization and therefore impose a challenge associated with seasonal tidal modelling of these sea ice covered seas and ocean. The decline in sea ice extent observed over the last 3 decades will therefore also potentially have a significant impact on long-term tidal modelling, both regional as well as global.

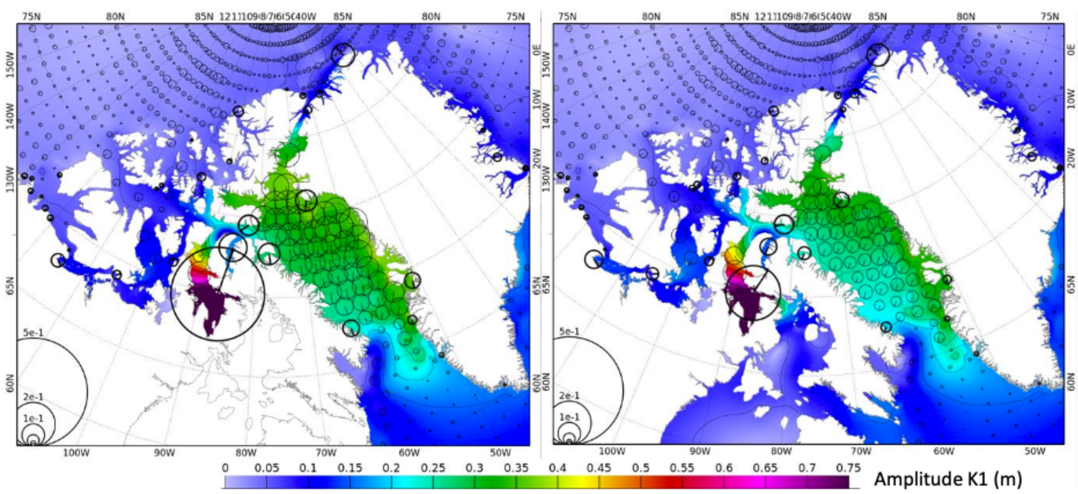

Figure 5. *Illustration of model configuration. Integration of the Hudson Bay in the model extent has given major positive impact on the solution, especially on the diurnal waves (K1), notably a reduction of the K1 error by 20% relative to CryoSat-2 altimetry data and 30% relative to Arctic tide gauges (Cancet et al, unpublished 2022).*

Paper 8: Changes in the Arctic Ocean: Knowledge gaps and Impact of future satellite missions for the Arctic Ocean *(Relevant to all ASCs)*. To be submitted to *Journal of Remote Sensing* by S. Lucas, J. A. Johannessen, M. Cancet, L. H. Pettersson, I. Esau, J. Rheinlaender, F. Ardhuin, B. Chapron, A. Korosov, F. Collard, S. Herlédan, E. Olason and C. Donlon.

Mathilde Cancet presented the status of this synthesis paper. Polar orbiting satellite observations are of fundamental importance to answer the main Arctic Ocean scientific challenges, as they provide information on bio-geo-physical parameters with a denser spatial and temporal coverage than in-situ instruments in such remote, harsh and inaccessible environment. However, they are limited by several challenges, such as the very-high latitude lack of coverage near the North Pole (Polar gap), the polar night and frequent cloud cover or haze over the ocean and sea ice, that prevents the use of optical satellite instruments in many situations, and the limited availability of external validation data. The spatial coverage and repeat cycles of the remote sensors may also have limitations to properly identify and resolve the dominant spatial and temporal scales of atmospheric, ocean, cryosphere and land variability in the region. In this paper, the state-of-the-art regarding the use of satellite observations to contribute to the understanding of the main polar environment and climate scientific challenges targeted within the Arktalas Hoavva project is investigated. The limitations to a wider use of existing polar orbiting satellite data as well as the observational gaps of the current and near future approved satellite missions are addressed (see Figure 5). Finally, the expected capability of the future satellite missions to answer today's scientific challenges in the Arctic Ocean are assessed.

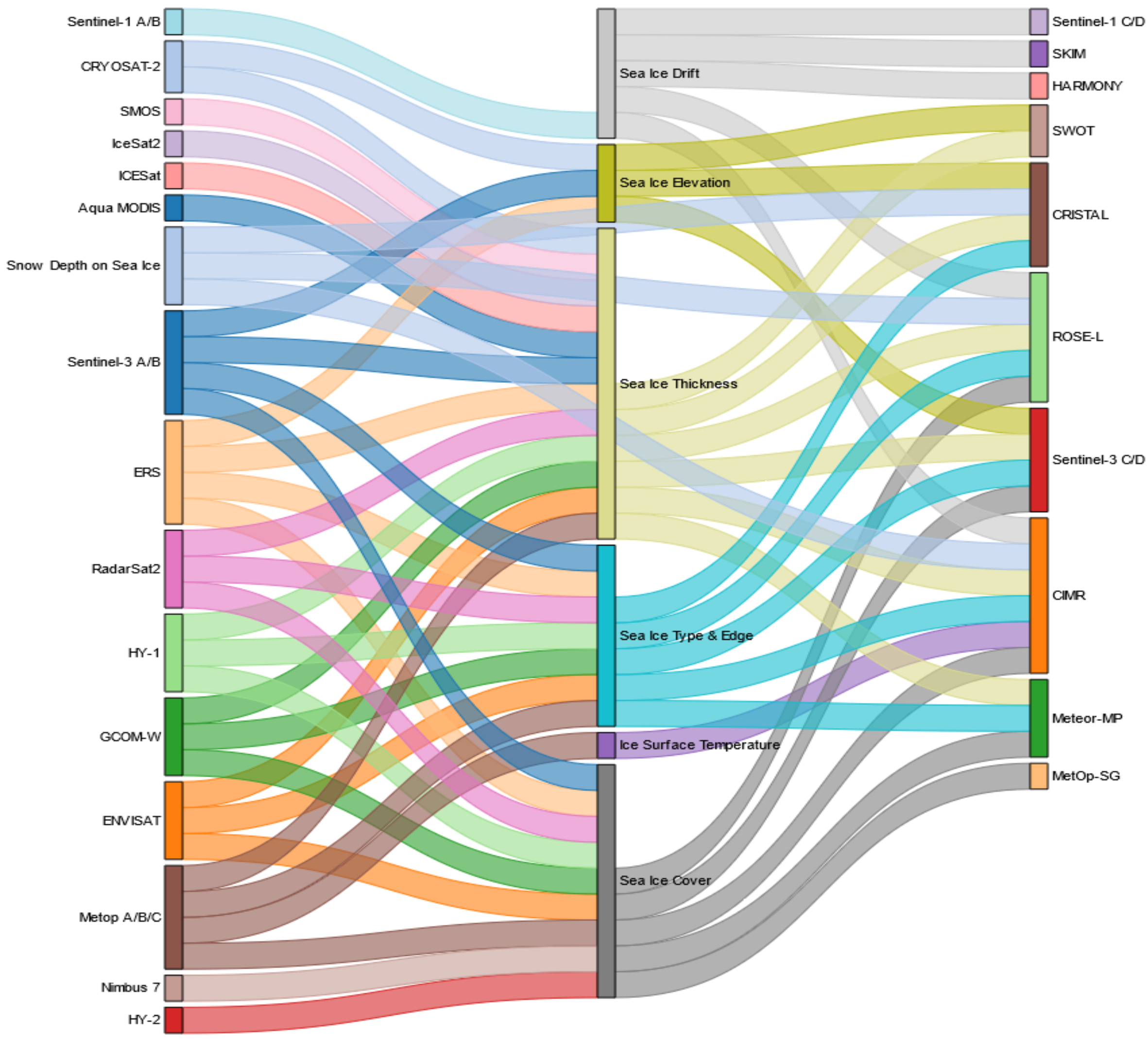

Figure 5. *Synthesis of the sea ice related geophysical parameters retrieval capacities by satellite missions. On the left are listed past and present (currently flying) missions. On the center are exposed the geophysical parameters related to sea ice. Future planned missions are listed on the right. It does not include project or proposed missions. This Sankey diagram indicates the measurement of a parameter by a satellite with a link between the two. (Cancet et al, unpublished 2022).*

Status of Arktalas Hoavva Scientific Roadmap

The Arktalas Scientific Roadmap (SR – project deliverable D-160) aims to summarize and assess the project findings and results including new knowledge, tool development and lessons learned into a SWOT (Strengths, Weaknesses, Opportunities and Threats) analyses. The SWOT analyses will be referenced to the Arctic Scientific Challenges highlighted at the onset of the Arktalas Project, notably:

- *Characterize Arctic Amplification and its impact (ASC-1)*
- *Characterize the impact of more persistent and larger area open water on sea ice dynamics (ASC-2)*
- *Understand, characterize and predict the impact of extreme event storms in sea-ice formation (ASC-3)*
- *Understand, characterize and predict the Arctic ocean spin-up (ASC-4)*

Moreover, these regional challenges are also expected to be highly relevant in a global context, notably due to teleconnections and feedback from changes in the Arctic on weather and climate at lower latitudes including the water cycle, energy cycle and carbon cycle.

The ultimate goal is to design and implement a roadmap for further advances in Arctic Science. This shall be based on a systematic multi-modal data-driven analysis framework whereby one benefit from the synergy of satellite sensor measurements complemented with improved in-situ measurement capabilities and tools including models, data assimilation and artificial intelligence.

Strengths

The unique potential to merge multi-sensor satellite-based observations (from visible to L-band) operating at different resolution to strengthen the temporal sampling and advance the development of spatial-temporal monitoring of the Arctic region.

Ability to routinely explore and identify mesoscale upper ocean eddy circulation signatures derived from the high resolution Sentinel-1 SAR sea ice structure and pattern, drift and vorticity (reference to Arktalas paper by Cassianides, A., Lique, C., and Korosov, 2021). The implication of such findings (see also https://www.nature.com/articles/s41467-022-29663-0) is highly important for parameterization of ocean-sea ice-atmosphere heat fluxes in climate models.

Sea ice rheology inversion using an advanced Lagrangian model (such as neXtSIM operated by NERSC, reference paper by Rheinlænder et al., 2022) to match observations, and to allow for calibration of data-driven methodologies to downscale estimates from medium and low resolution observations (for instance L-band SMOS, ASCAT on Metop and future CIMR). This effort enters precursor demonstrations of model-driven strategies to illustrate possible Digital Twin capabilities and usage.

Weaknesses

Deficiencies and limitations in the in-situ observing system impact the ability to: (i) advance process understanding; (ii) conduct proper calibration and validation; and (iii) carry out model validation. Regarding the first point examples include (not exclusive) tidal-driven dynamics under variable sea ice conditions, air-sea fluxes (momentum, heat, gas), interaction of the satellite-based electromagnetic waves with snow covered sea ice surfaces.

Lack of multi-purpose in-situ reference sites for satellite calibration, validation, and long-term monitoring. To optimize the use of satellite synergy, multi-disciplinary in-situ measurements are necessary to advance process understanding and provide (fiducial) information to strengthen development of retrieval algorithms. In order to agree and implement the necessary in-situ (possibly including drone measurements) reference sites, the choice of locations will be highly important (e.g. discussion with Rector at UNIS).

Opportunities

The point of contact with UNIS opens up a very interesting opportunity to establish a in-situ reference site in Svalbard. Further discussion is in the planning.

Emerging of new capabilities to combine satellite observations, including fully-focused altimeter measurements, imaging radar and spectrometer (under cloud free conditions), to better assess wave propagation in the very dynamical marginal ice zone (reference to Arktalas paper by Fabrice Collard, 2022).

From small scale deformation to large scale modulation of atmosphere interactions, with new variations of stability conditions to possibly enhance mixing and fluxes between the ocean-sea ice-atmosphere and eventual leading to the upper (warming) atmosphere (reference to Arktalas paper by Esau et al., 2022).

Develop a high-resolution multi-sensor satellite-based (altimetry, imaging radar, spectrometer) product to advance understanding of the sea ice deformation, dissipation of waves in sea ice, thickness variations, and dynamics. Approach might be based on an extension of the RGPS products first developed for Radarsat application by R. Kwok (2003).

Threats

Arktalas Hoavva Science Workshop Agenda
UNIS, Longyearbyen, Svalbard
26-29 April 2022

Day 1 - 16:00 ***Workshop at UNIS*** (flight delay caused late start)

16:15 -16:30 Welcome and Logistics
16:30 -16:45 Main Goals of the Science Workshop (J.A. Johannessen)
16:45 -17:10 Words from ESA (C. Donlon)
17:10 -17:40 Status overview of the Arktalas project (J.A. Johannessen)
17:40 -18:10 Rearrangement of agenda due to change of visit to SvalSat and availability of on-line participants.

Day 1 – 18:10 ***Adjourn***

18:15 Transport from UNIS and check in at Svalbard Guesthouse
19:30 Joint Dinner at Kroa

Day 2 – 09:00 ***Workshop at UNIS***

08:30 Transport to UNIS
09:00 – 11:00 Status of science papers (~ 45 minutes to 1 hour per paper with questions and comments)

- √ Wind-wave attenuation under sea ice in the Arctic: a review of remote sensing capabilities by Fabrice Collard, Louis Marié Frédéric Nouguier, Marcel Kleinherenbrink, Frithjof Ehlers and Fabrice Ardhuin, submitted to JGR-Oceans.
- √ Evaluation of a coupled wave-sea-ice model against the ICESat-2-derived wave-affected fraction, G. Boutin, T. Williams, C. Horvat and L. Brodeau, submitted to Phil. Trans. Roy. Soc. London A

11:00 - 11:30 ***Break***

11:30- 12:30 Status of science papers (continue)

- √ On the assessment of Arctic storm effects on sea ice dynamics, new sea ice formation and ice-ocean stress (Anton Korosov), submitted to GRL.

12:30 - 13:30 ***Lunch***

13:30- 14:30 Overview of EU-ESA´s polar science cluster projects and future plans (D. Fernandez)
14:30- 16:30 Status of science papers (continue)

- √ Arctic amplification and its impact (I. Esau)
- √ Impact of sea-ice friction on tidal modelling in Arctic Ocean (M. Cancet)

16.30-17:15 Round table discussion on scientific findings and results

Day 2 – 17:15 ***Adjourn***

17:30 Transport to Svalbard Guesthouse
19:30 Joint Dinner at Fønken

Day 3 – 09:00 ***Workshop at UNIS***

08:30 Transport to UNIS

09:00 - 11:30 Presentations from participants from the University Centre at Svalbard (UNIS)

- √ Svalbard Integrated Arctic Earth Observing System (SIOS), Shridhar Jawak, SIOS-Knowledge Center, UNIS
- √ UNIS- A University in the Arctic, Rector Jøran Moen,

√ Trends and variability in the ocean around Svalbard based on in situ data and satellite observations, Frank Nilsen, Professor at UNIS

11:30 – 11:45 Break

11:45- 12:30 First examples of a Digital Twin Arctic, Einar Olason, NERSC (remotely)

12:30 – 13:30 Lunch

13:30 -14:30 CIMR over sea ice, Dr. Thomas Lavergne, MET.no (remotely)

14:30- 15:30 ESA´s future mission observing the Cryosphere**,** Craig Donlon, ESA

15:30 – 16:00 Break

16:00 -16:45 Changes in the Arctic Ocean: Knowledge gaps and Impact of future satellite missions, Status of draft synthesis paper by Mathilde Cancet

16:45 - 17:25 Discussion on Roadmap for future studies, Bertrand Chapron, IFREMER.

Day 3 – 17:25 Adjourn

17:30 Transport to Svalbard Guesthouse

19:30 Joint Dinner at Stasjonen

Day 4 – 09:00 Workshop at UNIS

08:30 Transport to SvalSat

09:00-11:00 Visit at SvalSat. Host: Knut Ødegård, KSAT.

11:00- 11:30 Transport to UNIS

11:30 -12:30 Round table discussion addressing major Arctic scientific challenges, their level of maturity, approaches to remove knowledge gaps, possible design of a Digital Twin Arctic.

12:30 – 13:30 Lunch

Day 4 – 14:00 Adjourn