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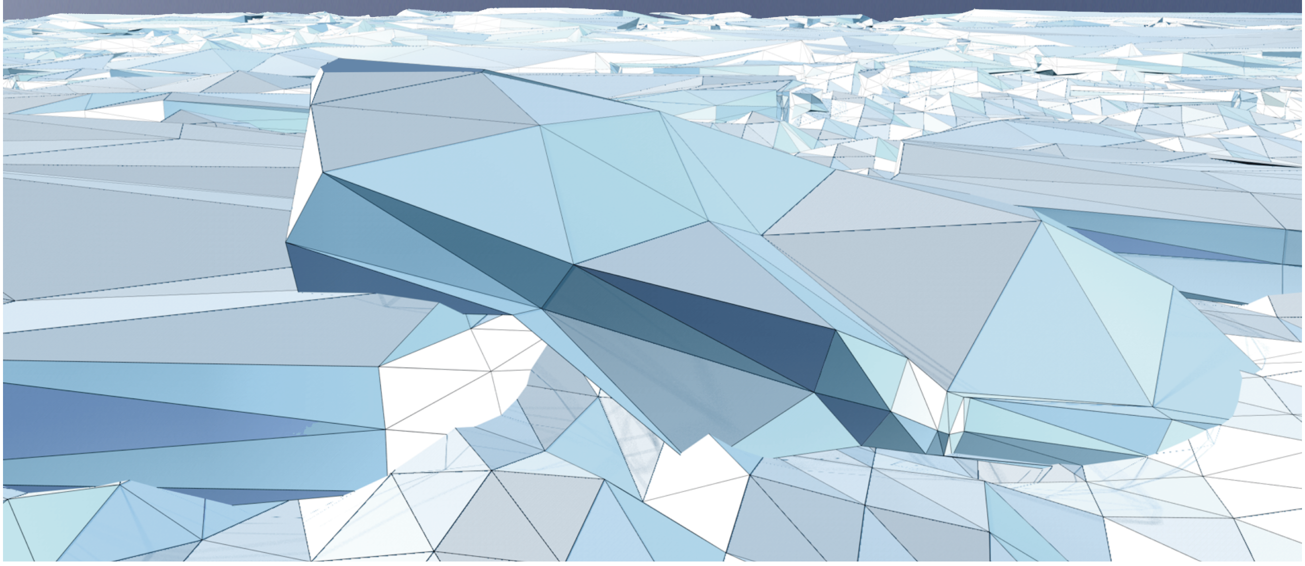
Advanced prediction in polar regions and beyond

POLICY BRIEF

STRATEGIC PLACEMENT OF IN-SITU SAMPLING SITES TO MONITOR ARCTIC SEA ICE

Monitoring changes in sea ice is important, as it provides clear messages about climate variability and change in polar regions. However, the resources that can be allocated to the deployment of new observing platforms are limited. In this context, a rational strategy for the development of cost-effective observing systems is desirable, if not required. In line with this need, this APPLICATE policy brief suggests six well-placed sampling locations for in-situ sampling of sea ice, which can help better understand the interannual variability of the total Arctic sea ice volume, while minimising the required costs.



SEA ICE OBSERVING SYSTEM

Many processes occurring in polar regions are poorly represented in weather and climate models because they are still not sufficiently understood. The demand for environmental information in these regions is growing, sparked by the development of a plethora of human activities. To respond to this demand, initiatives like the Polar Prediction Project's Year of Polar Prediction[1] (YOPP) and the MOSAiC International Drift Expedition[2] are working to improve weather and climate models and to increase the availability of polar observations through national and international coordination.

The current polar observing network consists of a mixture of elements that can be broadly categorised as in-situ and remote sensing observations.

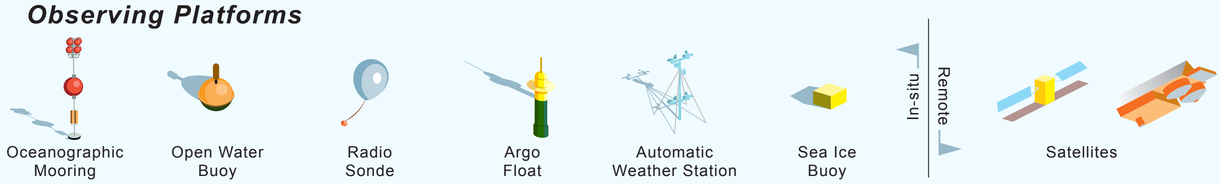
[1] https://www.polarprediction.net/

[2] https://mosaic-expedition.org/

Marta Terrado, Dragana Bojovic, Leandro Ponsoni, François Massonnet, Irina Sandu, Sara Pasqualetto & Thomas Jung. Strategic placement of in-situ sampling sites to monitor Arctic sea ice. APPLICATE Policy Brief, 2021

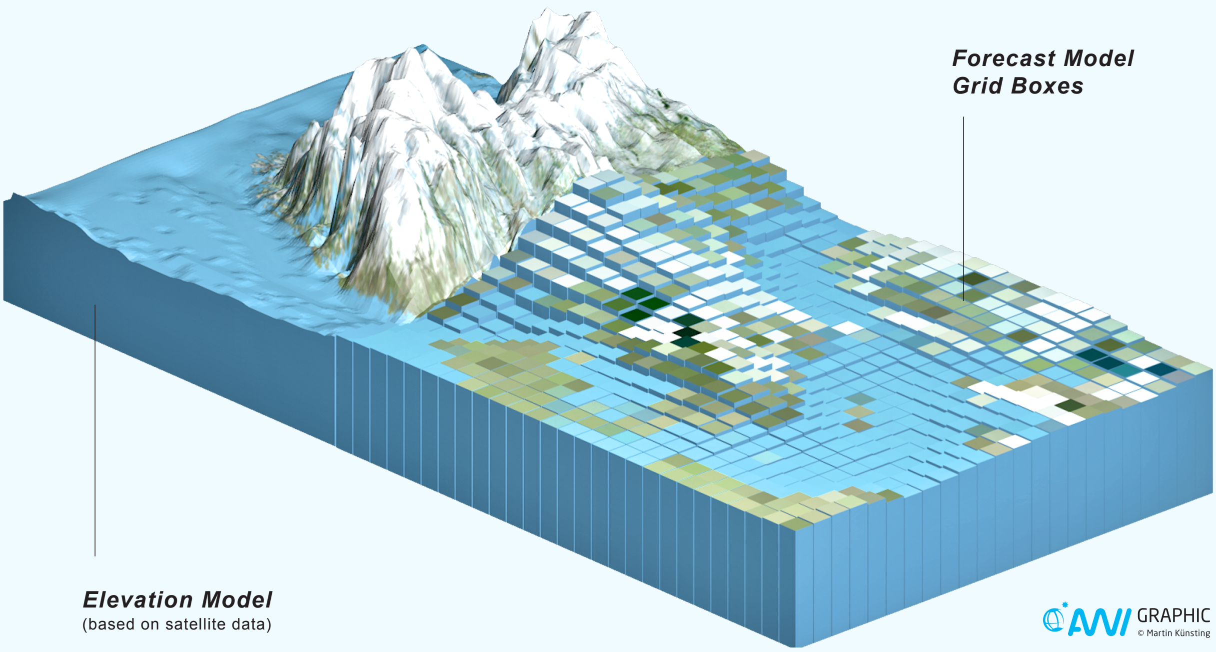
In-situ observations

For decades, in-situ observations have been collected from automatic weather stations, drifting buoys, moorings, oceanographic vessels, radiosonde launches, aircraft-borne instruments, and submarines, among others. These observations are particularly valuable to study the atmosphere-ocean-sea ice system. In situ observations are not free of errors, and are not uniformly distributed in time and space. Due to the high costs and inherent difficulties for reaching such a harsh and remote environment, a reduced number of in-situ campaigns are carried out in the polar regions.



Remote sensing observations

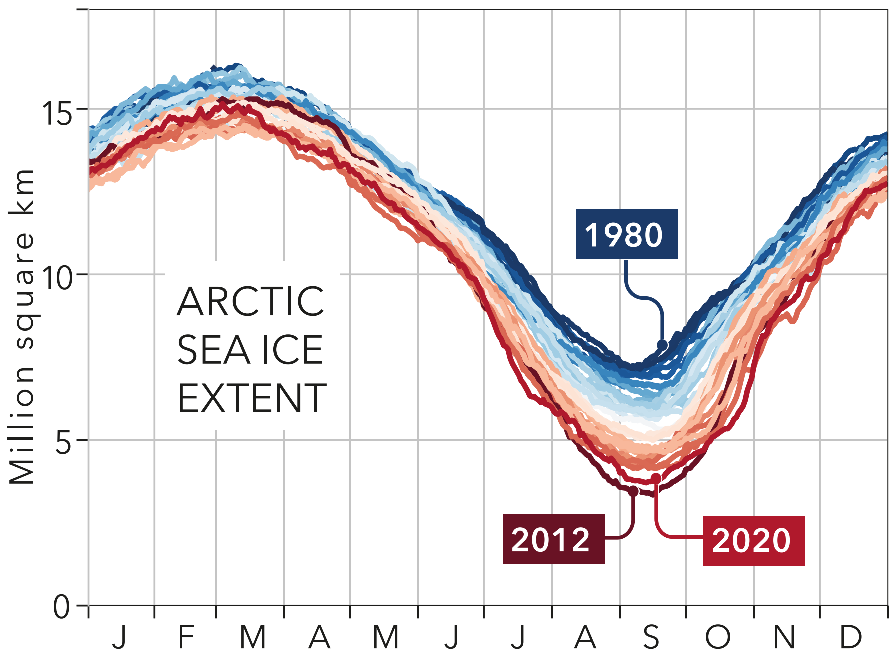
The advent of satellite information, first from passive infrared microwave measurements on-board satellites (since the late 1970s) and then from active backscatter, laser and radar altimetry measurements (since the 1990s), has been a leap forward in the study of polar regions, particularly by providing near real-time monitoring of sea ice concentration and thickness. While raw measurements can be accurate as long as instruments are well-calibrated, the products derived from remote sensing can have significant errors. This is because satellites do not directly measure physical variables like sea ice concentration or thickness. Instead, they rely on indirect measurements (e.g. emitted radiance by a surface, distance travelled by an electromagnetic signal), which are then converted into environmental variables (e.g. sea ice concentration or thickness) using appropriate transformation algorithms. In addition, satellites do not always provide year-round data (e.g. summer measurements of sea ice thickness are less reliable because of liquid water formed from the melting of snow and ice) and, due to their defined orbit, a small area around the North Pole is never sensed.



It has generally been accepted that observations support the development of climate models. They are used to design model parameterisations, for model initialisation, and to evaluate numerical simulations. In turn, climate models have been used to fill the observational gap and answer questions that available observations cannot address, being an asset to test real-world hypotheses. Climate models can thus guide the development of observational networks by indicating the type, location, frequency, and timing of measurements that would be most useful for addressing climate-related questions in polar regions (Massonnet, 2019).

ARCTIC SEA ICE

The Arctic is a hotspot of global climate change, witnessing warming rates that exceed the global average at least by a factor of two. The extent of Arctic sea ice has undergone a marked decline over the past four decades, with the most pronounced reductions occurring in summer and autumn. Today's sea ice covers smaller areas and is thinner, younger and more prone to drifting than the historical multi-year, several-metre-thick ice pack.



Arctic Sea Ice Extent

from 1979 to 2020 estimated from passive microwave satellite observations. Colouring is done according to the value of the minimum sea ice extent for each year. Source: François Massonnet, using data from the National Snow and Ice Data Center Sea Ice Index.

The continuous melting of Arctic sea ice has significant impacts on regional and global scales. Regionally, native communities have experienced disturbances in subsistence activities like fishing, gathering and hunting. Other issues with important implications for Arctic countries are the opening of new sea routes, the development of the tourism industry, and mineral resource extraction. On a global scale, sea ice depletion can potentially impact the weather at low and mid-latitudes by means of both oceanographic and atmospheric teleconnections, including the higher occurrence of extreme events. Since sea ice loss is projected to continue throughout the twenty-first century, the interest of the scientific and the policy communities in sea ice variability and predictability has increased exponentially.

The sea ice volume is informative because it accounts approximately for the total mass of sea ice. However, in-situ and/or satellite-based estimates of sea ice area and thickness, which are necessary to estimate the global sea ice volume, are still sparse. On top of that, the presence of snow on sea ice, for which no reliable estimates of depth are available, complicates the retrieval of sea ice thickness information and makes global volume estimates even more uncertain.

OPTIMAL SEA ICE SAMPLING

The monitoring of sea ice characteristics (e.g. area and thickness) in the Arctic is subject to financial and logistic constraints. These constraints call for a prioritisation of the location, time of the year, and type of instrument to be deployed. For instance, the cost of placing a single buoy on sea ice can range between 2000–8000€, depending on the system used (e.g. deployed on-site, thrown from an aircraft), while the deployment of an oceanographic mooring underneath the sea ice can be even more expensive. The deployment of Instruments becomes even more challenging considering that sea ice is a drifting material.

Optimal locations

Results from the APPLICATE project indicate that an observational system only based on four optimally selected locations can provide information to reproduce and/or predict more than 70% of the interannual pan-Arctic variability of sea ice volume.

The first identified optimal location is placed at the transition Chukchi Sea–central Arctic–Beaufort Sea. The second, third, and fourth best locations are placed near the North Pole, at the transition central Arctic–Laptev Sea, and offshore of the Canadian Archipelago (see figure on page 5).

Apart from these four best observing sites, up to ten additional sites are identified. Adding two additional well-placed locations (fifth and sixth best locations) would reproduce up to 80% of the sea ice volume variability, and adding more locations does not lead to significant improvements. Each of the locations is identified together with its region of influence. The region of influence is the area around the optimal location for which extra measurements are not necessarily required.

The selection of optimal sampling sites is only possible if the spatio-temporal variability of sea ice is well characterised. In this sense, in-situ and remote sensing sources are of limited use. Starting from the assumption that sea ice characteristics used to predict sea ice volume are correlated in space (i.e. the thickness of sea ice over a certain location is similar to the sea ice thickness in neighbouring regions), the pan-Arctic sea ice volume can be monitored and statistically predicted using only a handful of in-situ measurements. Then, by determining the distance over which two measurements of sea ice thickness would become substantially different from each other, the minimal number of sampling sites necessary to estimate temporal changes in the pan-Arctic sea ice volume can be identified.

This policy brief shows a sampling location strategy based on identifying a small number of optimal locations for monitoring sea ice volume variability. The locations have been identified using a multi-model-based approach (Ponsoni et al., 2020). Thus, the variables for predicting sea ice volume can be systematically sampled from these locations using oceanographic moorings and/or buoys. Collecting data at this limited number of locations makes it much more feasible to sustain a long-term programme of operational oceanography from both the logistical and financial point of view.

RANK	LATITUDE	LONGITUDE	SUBREGION
1	79.5° N	158.0° W	Chukchi Sea (CS)
2	88.5° N	040.0° E	Central Arctic (CA)
3	81.5° N	107.0° E	Laptev Sea (LS)
4	82.5° N	109.0° W	Central Arctic (CA)
5	74.5° N	136.0° W	Beaufort Sea (BeS)
6	77.5° N	155.0° E	East Siberian Sea (ESS)
7	78.5° N	154.0° E	Barent Sea (BrS)
8	83.5° N	001.0° W	Central Arctic (CA)
9	72.5° N	176.0° E	East Siberian Sea (ESS)
10	74.5° N	134.0° E	Laptev Sea (LS)

Optimal sampling locations

useful reconstruct and/or predict the variations of pan-Arctic sea ice volume. The numbers indicate the ten best observing locations in respective order. The hatched area around each location (same colour code) represents their respective region of influence. The selection of points respects the hierarchy of the regions of influence in a way that the second point cannot be placed within the region of influence of the first point (shades of red), the third point cannot be placed within the regions of influence of the first and second points (shades of red and purple), and so on.

Key messages

- This policy brief provides recommendations for ongoing and upcoming observational initiatives in terms of optimal sampling locations that better represent the variability of the pan-Arctic sea ice volume. To this end, between four and ten optimal locations are identified.
- This work is a step forward in demonstrating how climate models can be combined with in-situ observations to monitor and predict climate variability at high latitudes. It also shows that climate models can be successfully used to design cost-effective observation systems.
- In case that not all the identified locations can be sampled (for instance, due to logistics, environmental harshness, or strategical sampling), observationalists could still take advantage of the "region of influence" concept to avoid deploying two or more observational platforms that would provide relatively similar information in terms of pan-Arctic sea ice volume variability.

Considerations

While model results provide an average representation of variables (e.g. sea ice thickness) inside a grid cell, real-world observations would be much more heterogeneous than represented by climate models at their current resolution. This heterogeneity may be a source of uncertainties in real observing systems and, therefore, more observations would be required for effectively predicting the sea ice volume.

In addition, the variability of sea ice thickness is not stationary and its persistence decreases as the ice becomes thinner. This means that a different number of stations might be required as the Arctic sea ice shifts toward a seasonally ice-free regime. With the sea ice depletion, in the future some of the suggested optimal sampling locations might be ice-free.

Despite the considerations mentioned, this work is a proof-of-concept that provides objective reasons to prioritise in-situ observational products, which provide crucial information for many stakeholders in the Arctic region and beyond (e.g. space agencies, local communities, business sectors like shipping or tourism, etc.).

Relevant studies

Massonnet, F. (2019) Climate Models as Guidance for the Design of Observing Systems: the Case of Polar Climate and Sea Ice Prediction, Current Climate Change Reports, https://doi.org/10.1007/s40641-019-00151-w

Ponsoni, L., Massonnet, F., Docquier, D., van Achter, G. Fichefet, T. (2020) Statistical predictability of the Arctic sea ice volume anomaly: identifying predictors and optimal sampling locations, The Cryosphere, 14: 2409–2428, https://doi.org/10.5194/tc-14-2409-2020

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