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Climate observations of sea-ice motion

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Introduction

Sea ice is frozen sea water that insulates the atmosphere from the ocean in the polar regions. Pushed by winds and ocean currents, sea ice is always on the move.

Sea ice motion reacts to the changing polar environment, be it the changes of the sea ice itself (e.g. thinner sea ice tends to move faster) or of its driving forces (stronger winds push sea ice farther).

Observing techniques

The main techniques to observe polar sea-ice motion over the last 40 years are from on-ice drifters, satellite remote sensing, and using geophysical models.

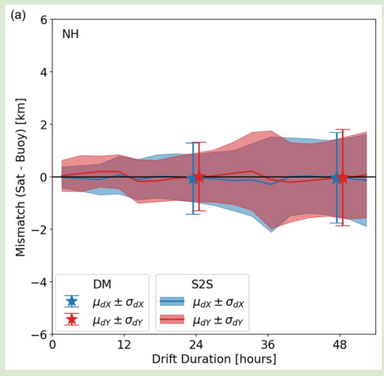
The optimal use of these sources of data to obtain global, calibrated, error characterized climate data records of sea-ice motion is still an open area of research. Here we focus on three topics - related to Metrology - on which the community should work further.

Challenge #1: Naming, definition, and units of measurements

The term “sea-ice motion” describes the general concept, but it can be measured and reported in different ways, e.g. u/v components of a vector, x/y components on a grid, speed and direction, trajectory with position records (buoys), and can even include rotation… There are thus many names and units attached to this concept. “Velocity” can be ambigious (vector or scalar?).

Most observing systems (e.g. buoys, satellites image tracking) do not measure velocities (unit $m.s^{-1}$) but rather a (net Lagrangian) displacement (unit m) over a duration (unit s). To report this with unit $m.s^{-1}$ can be misleading as:

- It is different from a (Eulerian) model velocity.
- Motion and its RMSEs do not scale with duration (fig).



Right: Evolution of the RMSE of a satellite-derived product (AMSR2) to buoy vectors (y axis) with the duration of the drift (x-axis). The RMSE does not grow 1-to-1 with duration, which could be implied by using a unit of $m.s^{-1}$. From Lavergne et al. (2021).

Challenge #2: Uncertainty propagation and validation

There are no established methods to propagate uncertainties for satellite-based sea-ice motion products. This might be because sea-ice motion vectors are not computed using a mathematical formula, but via a computer procedure (e.g. Maximum Cross-Correlation).

As a result, statistics (bias, RMSE, etc…) from validation against in-situ drifters are the de-facto standard to sea-ice motion vector uncertainty characterization. This has many drawbacks, including the unknown contribution of representativeness error (point- vs area-estimate), the lack of in-situ drifters (esp. Antarctic) and does not result in per-vector uncertainties.

Since sea-ice motion vectors are 2D quantities, uncertainties are in the form of a 2x2 matrix (2 variances, 1 co-variance).

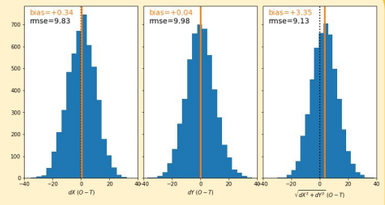
Motion vectors (retrieved daily) are sometimes aggregated into longer trajectories (e.g. as an input to sea-ice age). We do not know how to characterize the uncertainty of these trajectories (in general, we lack knowledge of space/time correlation lengths).

Challenge #3: Trend Analysis and Pseudo-biases

Most observing systems natively measure vector components (not speed & direction). This poses a challenge when transforming components into speed, ahead of computing climate trends.

Indeed, the non-linear transform creates artificial biases (aka pseudo-biases) that can interfere with the true climate signal (Stoffelen, 1998, Appendix B).

What are alternative (linear) metrics to report trends?



Above: Illustration of pseudo-biases in speed. Although both dX (left) and dY (middle) are un-biased observations (O) of the true (T) components, the computed speed (right) is biased.

Click here for an investigation of the impact of pseudo-biases on trend analysis.

Stoffelen, A. (1998), Towards the true near-surface wind speed: Error modeling and calibration using triple collocation, JGR

Recommendations:

- **Adopt “sea-ice motion” as a general term, be cautious with ambiguous terminology (e.g. velocity vs speed).**
- **Be cautious with units: observations are displacements (unit m) over a duration (unit s), it is misleading to report them as velocities (unit $m.s^{-1}$).**
- **Develop reliable uncertainty propagation for sea-ice motion vectors, including the space/time correlation lengths.**
- **Be cautious with non-linear transforms (e.g. to sea-ice speed) as they will introduce pseudo-biases. Develop alternative metrics (not sea-ice speed) to characterize trends.**