Impact of assimilating sea-ice thickness on the ECMWF system – DANTEX/CRISTAL

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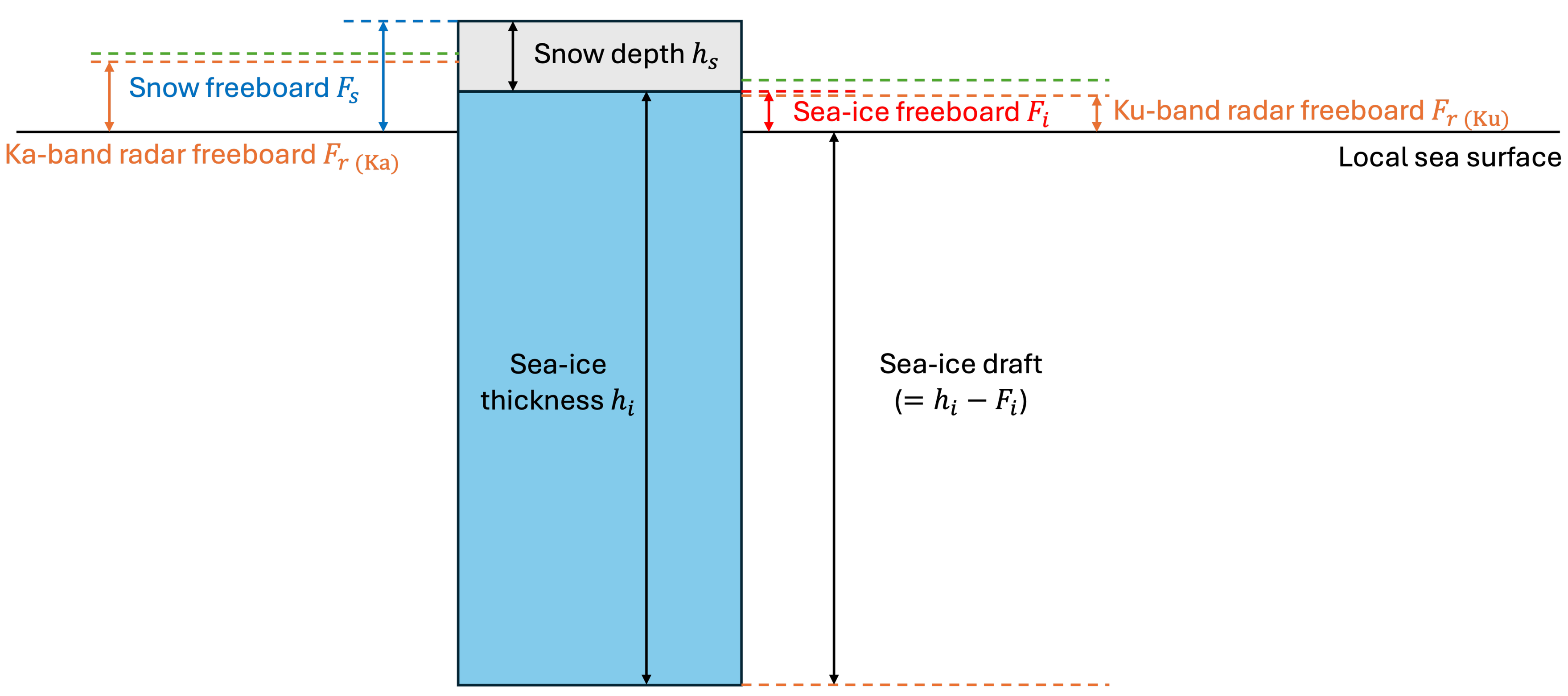
Background

- Sea-ice concentration (SIC) is so far the only type of sea-ice observations monitored and assimilated operationally at ECMWF
- An earlier ECMWF study [1] showed that nudging model sea-ice thickness (SIT) to observational products benefits seasonal forecasts
- To better constrain model SIT, we have started developing new capability to monitor and assimilate another observation type: **freeboard** (height of the portion of sea ice above the local sea surface)
- The assimilation of freeboard observations will provide valuable information on the vertical structure of sea ice and of snow over sea ice
- Together with SIC information, it could result in more accurate estimation of sea-ice volume, with potential benefits in numerical weather prediction (NWP) and climate projections

CRISTAL in the DANTEX project

- DANTEX (Data Assimilation (DA) and Numerical Testing for Copernicus Expansion Missions): an ESA-ECMWF joint project aimed at exploiting data from Copernicus Expansion Missions, including CRISTAL, in NWP
- Objectives for CRISTAL part of DANTEX: develop robust capability to assimilate L2 freeboard data into ECMWF's ocean and sea-ice system in time for CRISTAL's launch (2027 or 2028)
- Technical developments are carried out using test data from existing freeboard-measuring satellites (e.g. **C**ryo**S**at-**2**, **I**CE**S**at-**2**, **S**entinel-**3A**/**B**), which could be assimilated alongside CRISTAL data when the capability for freeboard assimilation becomes operational

The different flavours of freeboard



Sea-ice freeboard: Height of snow-ice interface above the local sea surface

Snow freeboard: Height of air-snow interface above the local sea surface

Radar freeboard (Ku / Ka band) intends to measure the height of the dominant scattering horizon (point of reflection) of the radar signal (in green) above the local sea surface, but the measurement is contaminated by the slower speed of light in snow. The actual measured value is shown in orange, which is always below the dominant scattering horizon. In rare cases (heavy snow over thin ice) the radar freeboard could be negative.

Ku band: 13.5 GHz, penetration factor $f = 0.84 \pm 0.04$

Ka band: 35.75 GHz, penetration factor $f = 0.46 \pm 0.05$

(Penetration factor = Portion of snow depth travelled by the altimeter signal, i.e. between air-snow interface and the dominant scattering horizon. Hence $f = 0$ for snow freeboard and $f = 1$ for sea-ice freeboard. See [2].)

Observation operator

The observation operator is derived from Archimedes' principle:

$$F = \left(1 - \frac{\rho_i}{\rho_w}\right) h_i + \left(1 - f\frac{c}{c_s} - \frac{\rho_s}{\rho_w}\right) h_s$$

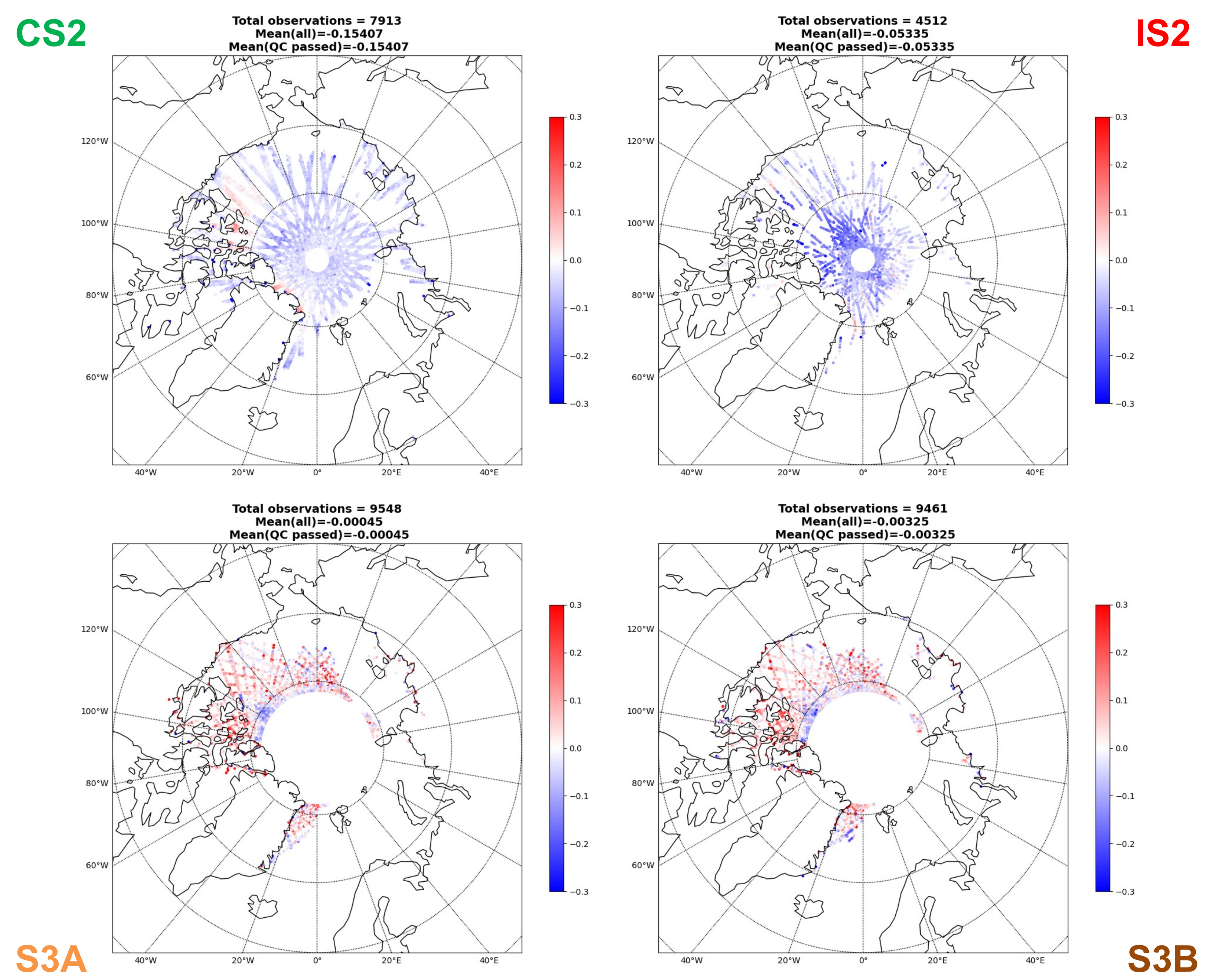
with ρ_i, ρ_s and ρ_w being the density of ice, snow and seawater respectively, and c/c_s being the air-to-snow speed-of-light ratio. F could be the sea-ice, snow or radar freeboard when the appropriate penetration factor is applied.

- Freeboard depends (linearly) on SIT and snow depth, so the assimilation of freeboard data will lead to analysis increments in **both** SIT and snow depth (through the operator's adjoint).
- If we allow ρ_w to be variable, then there will be an increment in seawater density (and hence temperature and salinity) too. The non-linearity of the operator requires careful handling of tangent-linear and adjoint codes.

Monitoring plots

CS2, S3A, S3B: Ku-band radar freeboard

IS2: Snow freeboard



Background departures ("B" minus "O"), in metres, of freeboard superobservations, 20201030 – 20201103

- CS2 and IS2 results demonstrate thin bias in the model
- S3A/B and CS2 are supposed to measure the same quantity but have very different departures (perhaps due to observation biases?)

Next steps

- Make the freeboard monitoring capability more mature and robust, with the aim of operationalising it within 2026.
- Start working on assimilating freeboard observations in NEMOVAR. Decisions to be made include: choice of control variables, background- and observation-error parameters, cross-covariances with other ocean variables, observation perturbation strategies in ensemble DA.
- Assimilation capability hopefully to be operational by 2027 or 2028 in time for CRISTAL's launch.
- Further ahead: extend the freeboard assimilation capability into ECMWF's coupled system and explore potential synergies with CIMR.

References

1. Balan-Sarojini et al. (2021), DOI: 10.5194/tc-15-325-2021
2. Armitage and Ridout (2015), DOI: 10.1002/2015GL064823