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Towards improved freeboard estimates using ICESat-2 data and models

Rui M Ponte[1], Mengnan Zhao[1],

Ian Fenty[2], Ichiro Fukumori[2], Ou Wang[2]

[1]AER   [2] JPL/NASA

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Motivation

Overall goal

- Characterize the evolution of the sea ice-ocean state over recent years observed by ICESat-2 (IS2) and understand the physical mechanisms responsible for such evolution

In this talk…

- Examine spatiotemporal characteristics of freeboard variability using available IS2 data and compare to that produced by model-based state estimates of the sea ice-ocean coupled system

- Assess uncertainties of freeboard estimates and evaluate possible benefits of using IS2 data for constraining sea ice-ocean state estimates on monthly to interannual time scales

Data and State Estimates

- IS2 freeboard estimates (ATL20 product)
  - Provided on 25 km polar stereographic grid
  - Total freeboard (ice + snow)
  - Monthly averages over both northern and southern high latitudes
  - Covering ~5 years (11/2018 – 12/2023)

- State estimates from the project for Estimating the Circulation and Climate of the Ocean (ECCO; www.ecco-group.org)
  - Use version 4 release 5, extends to 2/2024
  - Covers full IS2 period but mostly not constrained by data after 2019, moreover no IS2 data used
  - Separate ice and snow thickness converted to total freeboard
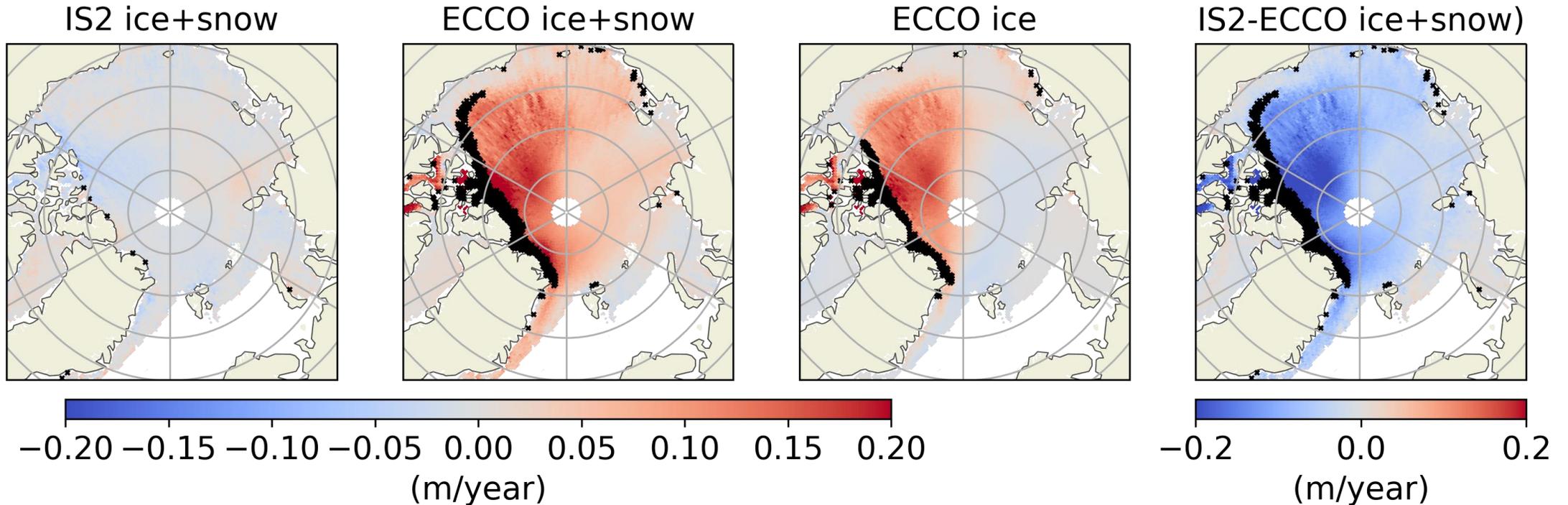 - ECCO monthly fields interpolated to ATL20 grids

Time Means (Arctic)
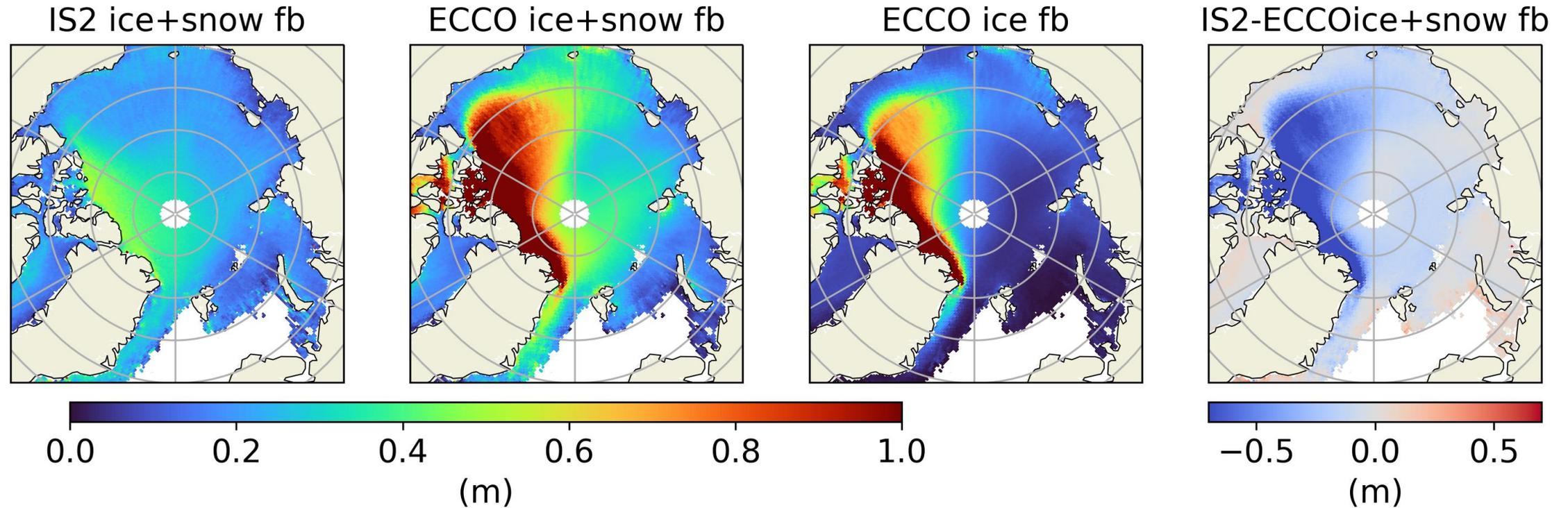
- Large differences in mean freeboard between IS2 and ECCO in the western Arctic
- Most differences seem related to much thicker ice freeboard in ECCO
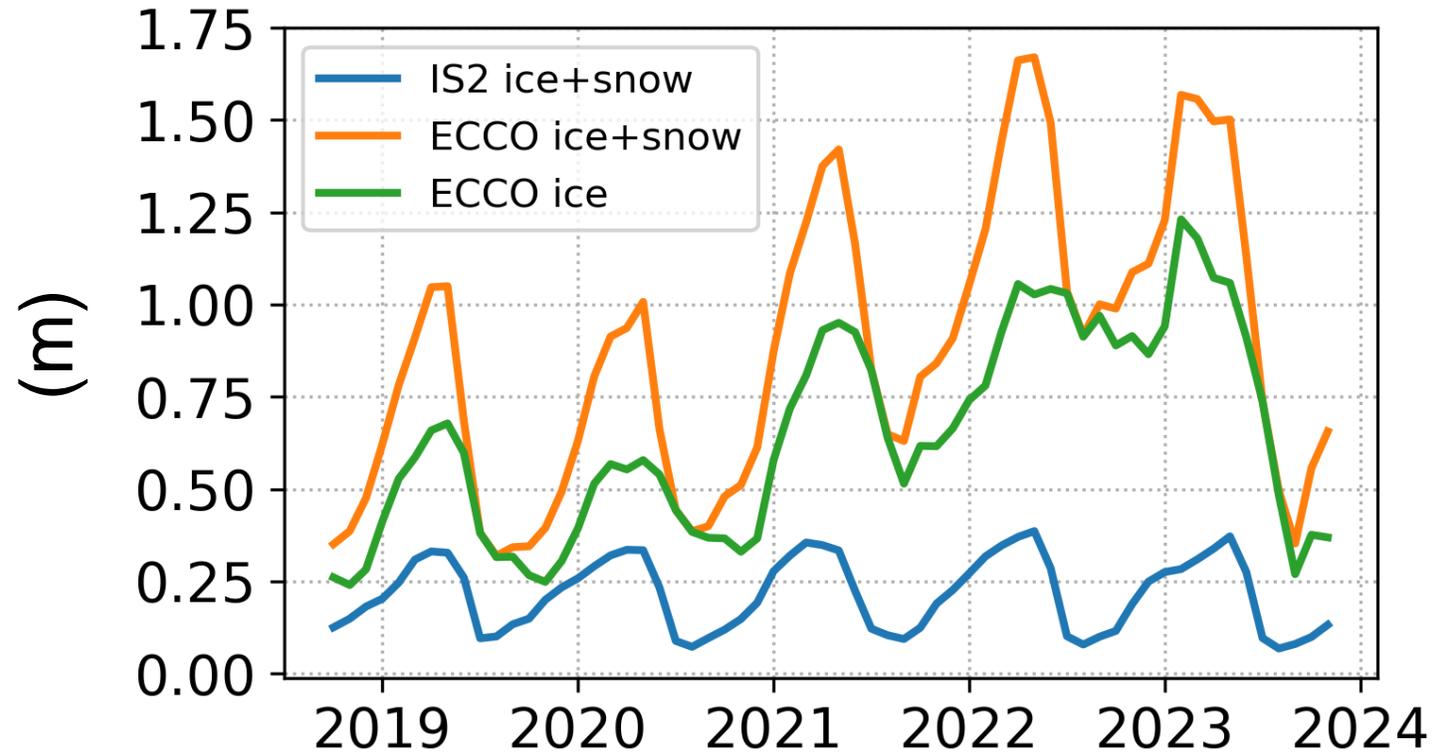
5-Year Trends (Arctic)

(black crosses: insignificant trends)

- Mostly negative trends in IS2 contrast with positive trends in ECCO
- Large positive trends in ECCO in the western Arctic mostly associated with growing ice thickness
- Differences in trends in western Arctic consistent with time mean differences
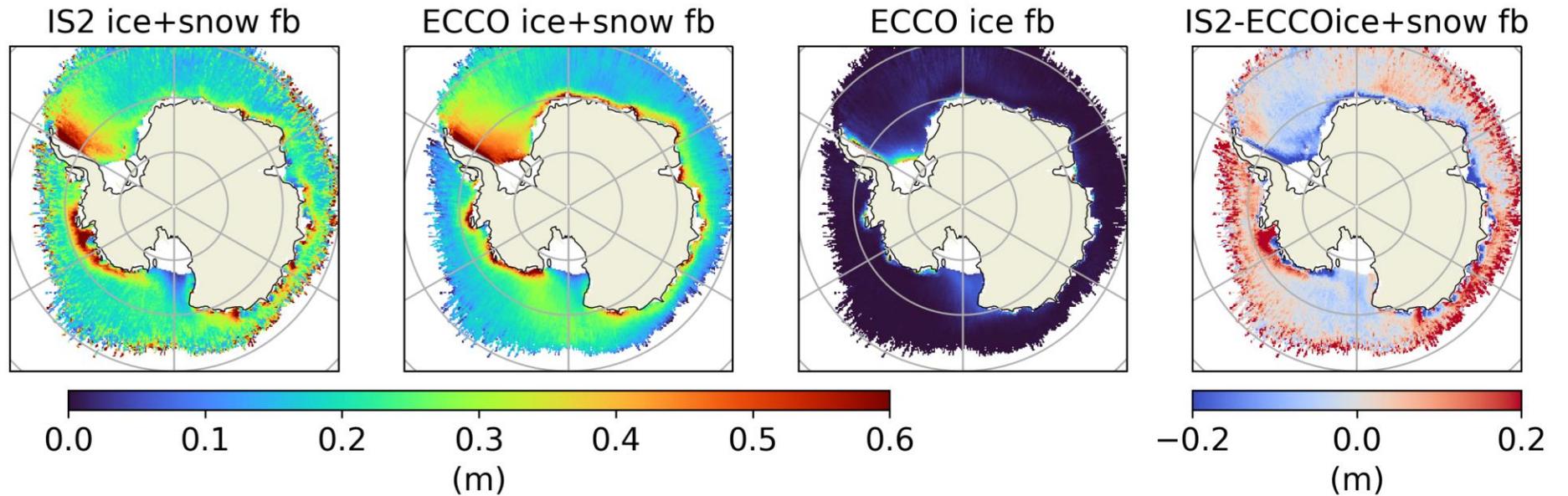
Time series (Beaufort Sea)
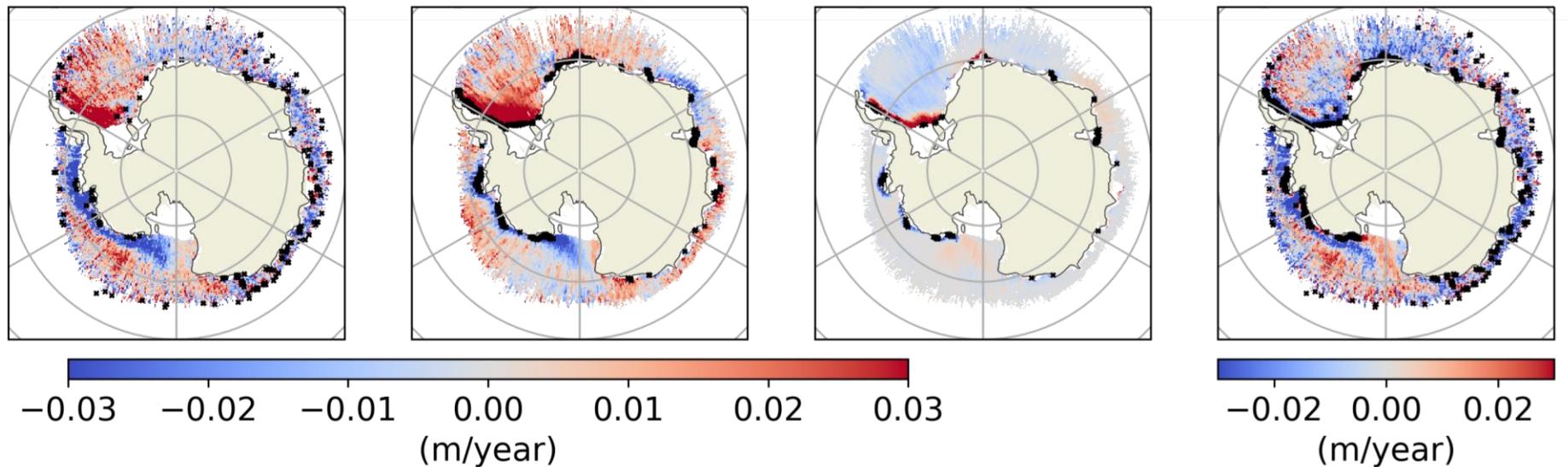

Freeboard averaged over
75N-80N, 150W-140W

- Large differences in IS2 and ECCO time means related to both larger ECCO initial values and significant trend over the 5 years of record

- Large ECCO trend is mostly related to growth in ice thickness
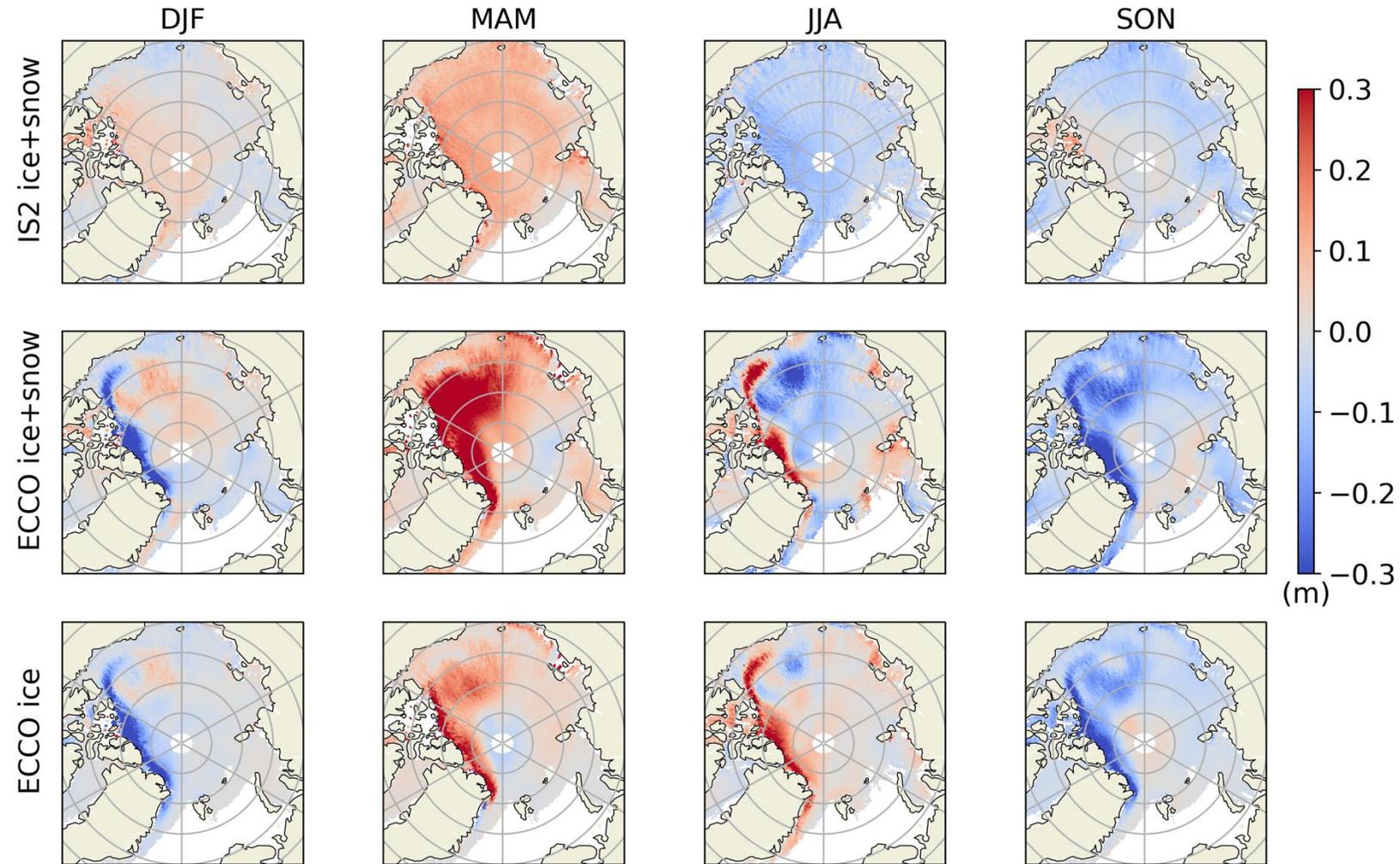
Time Means and Trends (Antarctic)

Seasonal Means (Arctic)

- Different patterns and magnitudes especially in western Arctic

- Seasonal cycle in ECCO substantially larger

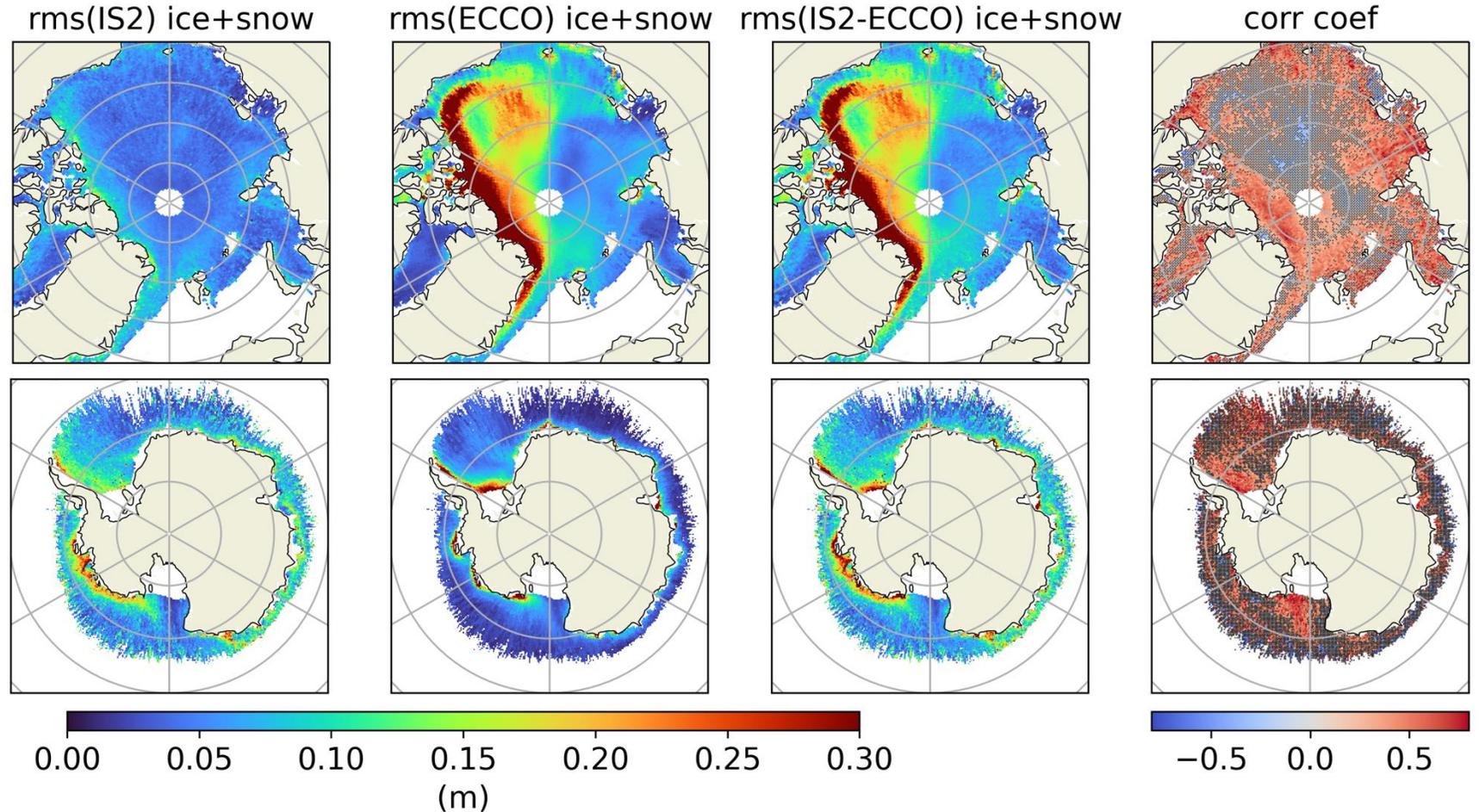- Considerable influence of snow depth in ECCO, particularly for MAM

Seasonal Means (Antarctic)

- Patterns/magnitudes more similar than in the Arctic

- Most seasonal variability in ECCO related to snow depth
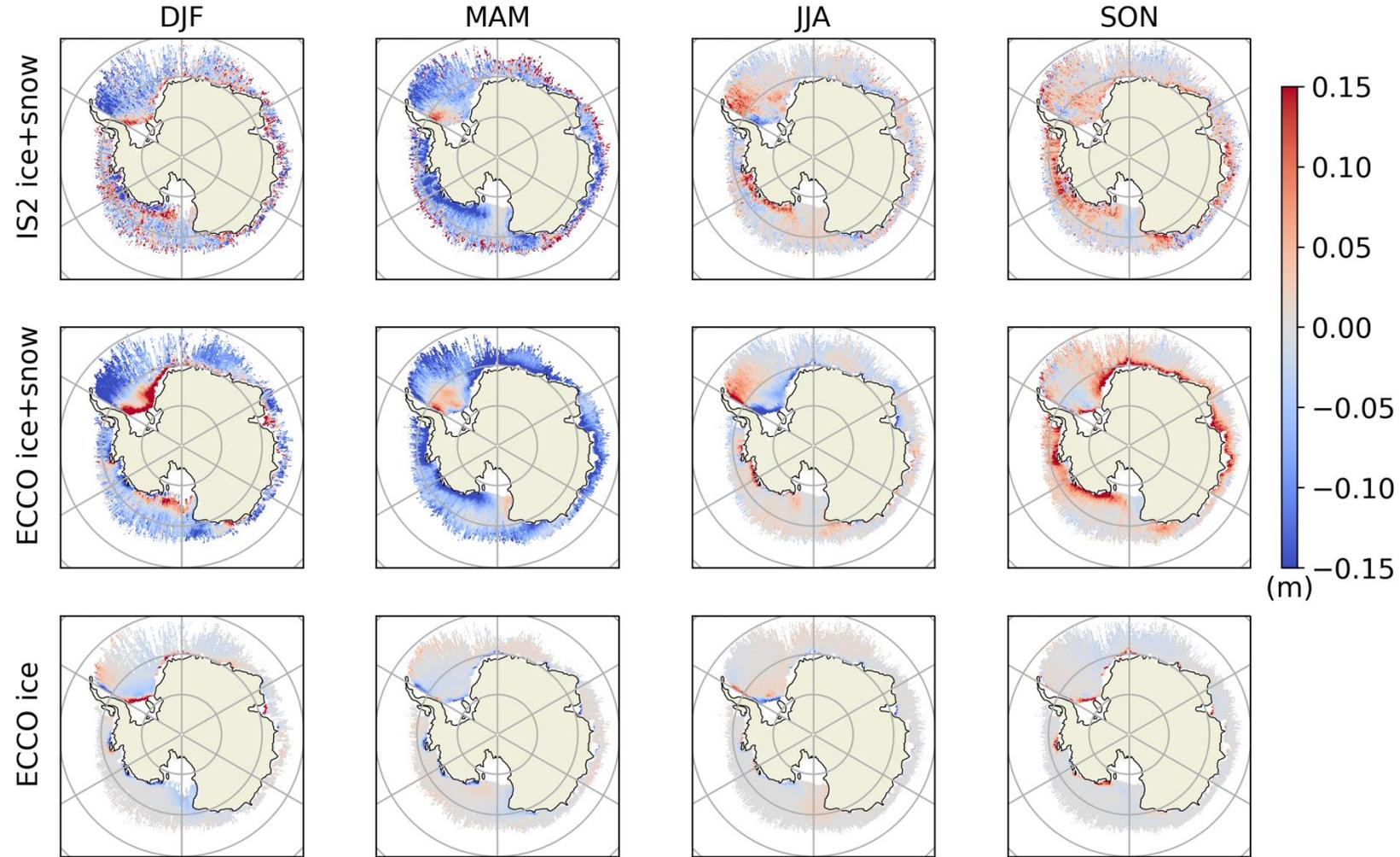
Non-Seasonal Residuals

- Larger variability in ECCO over most of the western Arctic

- Larger variability in IS2 in the Antarctic

- IS2 and ECCO correlated in extensive regions of the Arctic

- Significant correlation in parts of Ross and Weddell Seas

rms(IS2) ice+snow · rms(ECCO) ice+snow · rms(IS2-ECCO) ice+snow · corr coef

0.00 0.05 0.10 0.15 0.20 0.25 0.30
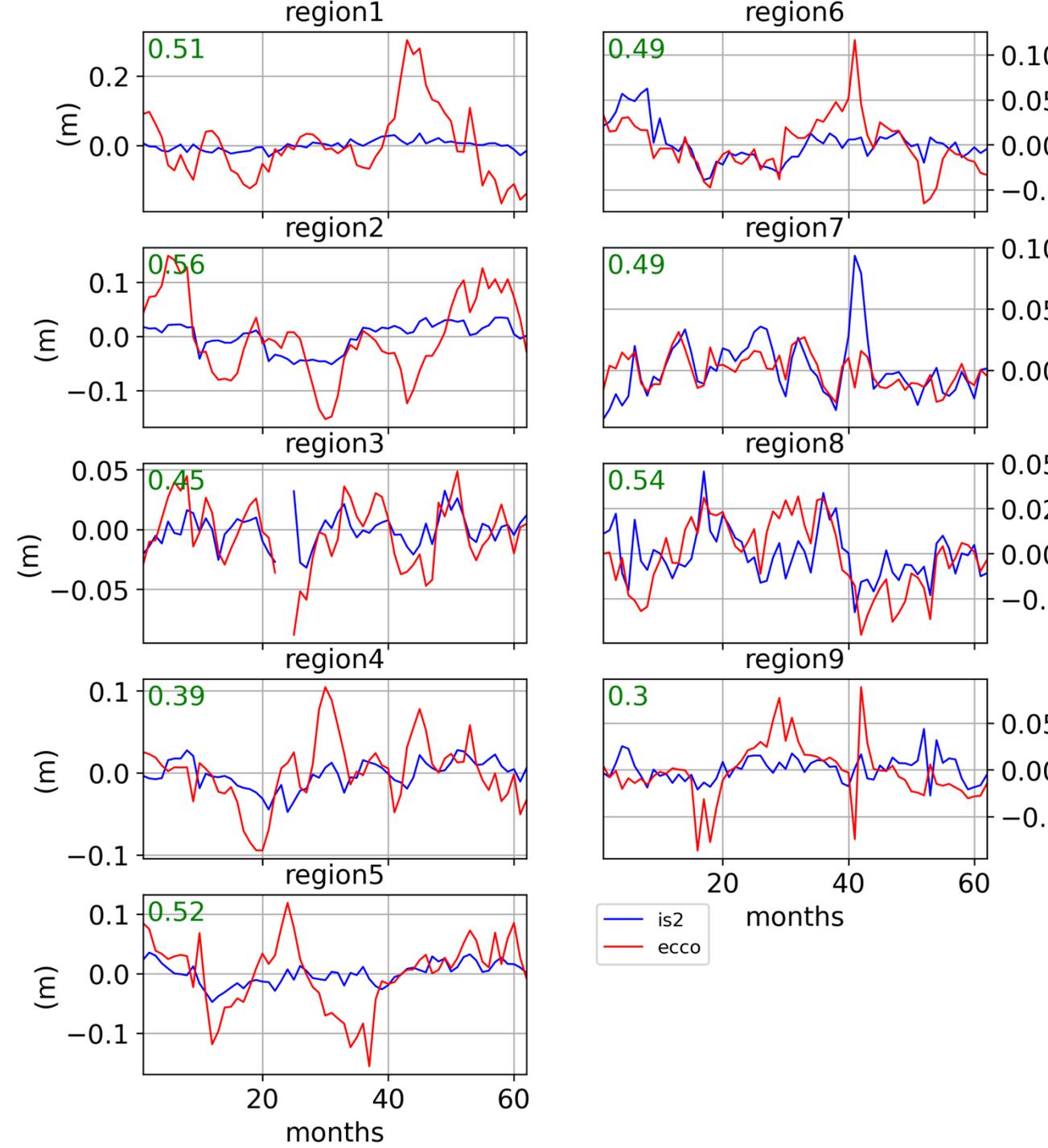(m)

−0.5 0.0 0.5

(gray stippled areas: correlation not significantly different from zero)

Regional Time Series
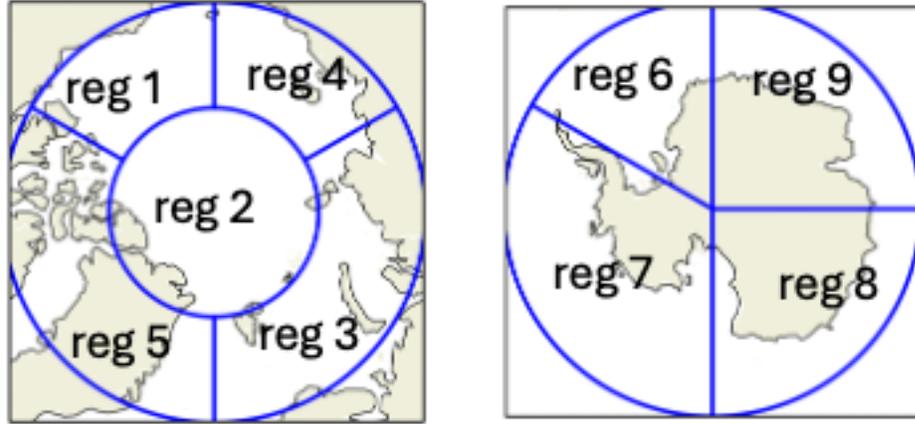
- Larger ECCO variability in the Arctic

- Moderate correlation between IS2 and ECCO when averaged over large areas

Optimal Freeboard Estimates

- Use IS2 data as a constraint in the ECCO optimization to bring freeboard estimates closer to the data within respective data uncertainties

- Optimization involves minimization of a "cost function" defined in general terms as

$$J \sim (\text{model minus data})^{**}2 / \text{data error}^{**}2$$

- Need an estimate of the data error, which in this case includes a representation component (i.e., true variability in the data that cannot be represented by the physical model)

- Initial cost values ~1 indicate model – data differences are at the data noise level and thus imply weak impact of data constraints

- Conversely, cost values > 1 imply errors in initial model estimates that can be mitigated by the data constraints

Potential Impact of IS2 Freeboard Data

- Under assumption of a common signal and uncorrelated errors, data error can be approximately derived from estimates of model/data variances and covariances

- Based on variability with seasonal cycle and trend removed

- Large costs in the western Arctic
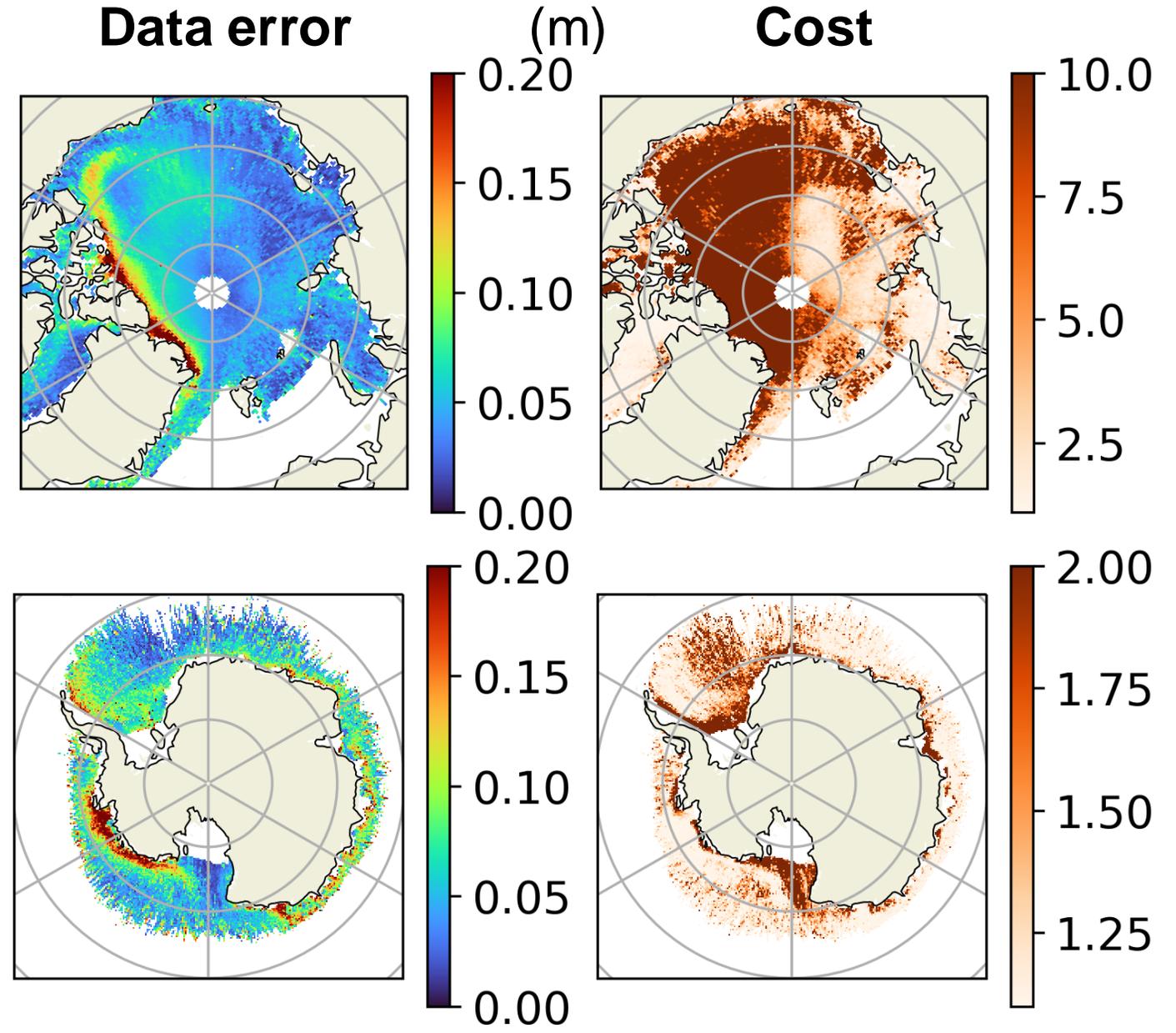
Summarizing…

- Relatively large differences in time mean freeboard between IS2 and ECCO estimates, partly related to positive trend in ECCO values in the Arctic

- Similar differences for mean seasonal cycle and non-seasonal residuals

- Model – data differences in the Arctic larger than in the Antarctic

- Estimates of data uncertainty substantially smaller than present differences between IS2 and ECCO freeboard values, particularly in the Arctic

- Use of IS2 data to constrain ECCO solutions has potential to improve currently available freeboard estimates

Next Steps

- Decide on formulation of IS2 data constraints (separate time mean? mean seasonal cycle?)

- Derive respective data weights for different terms (e.g., use differences between IS2 and Cryosat-2 to assess errors in time mean)

- Use data from other missions like Cryosat-2

- Explore reasons for present model/data differences

- Carry out optimization tests with different formulations and data weights

- Analyze ECCO estimates for improved understanding of sea ice thickness/volume variability and underlying physical mechanisms (atmospheric or ocean forcing, internal ice dynamics)