Verisk | Atmospheric and Environmental Research

Inferring subsurface density changes in ice-covered oceans from ICESat-2 and GRACE Follow-On observations

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Motivation

- Ice-covered oceans difficult to observe with in situ instruments, particularly if one needs broad spatial and temporal coverage of subsurface properties like temperature and salinity
- Leveraging availability of ICESat-2 (**IS2**) and other satellite data to improve knowledge of subsurface density changes in ice-covered regions

In this talk…

- Examine sea surface height (**SSH**) estimates from IS2, and ocean bottom pressure (**OBP**) estimates from the GRACE Follow-On mission, in comparison with similar fields from model-based solutions from the project for Estimating the Circulation and Climate of the Ocean (**ECCO**)
- Assess subsurface density anomalies derived from differencing SSH and OBP fields (**steric height = SSH minus OBP**)
- Derive approximate errors of IS2 SSH fields and implications for the joint use of SSH and OBP data for constraining subsurface density fields

Data Sets

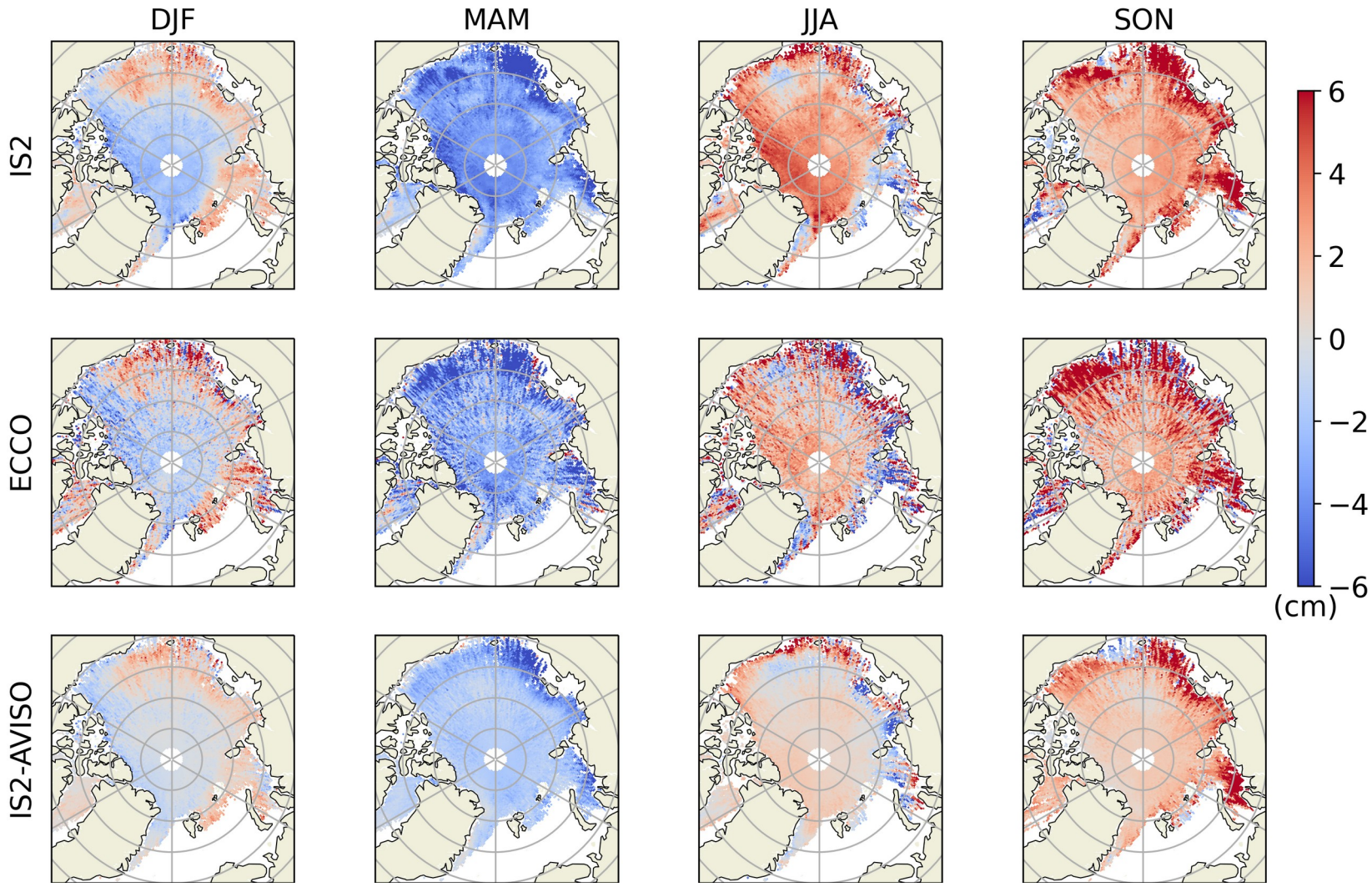
- **SSH:** IS2 (ATL21 product)
  - Provided on 25 km polar stereographic grid
  - Monthly averages over both northern and southern high latitudes
  - Covering ~5 years (11/2018 – 11/2023)
  - Corrected for inverted barometer, mean sea surface removed
- **SSH:** AVISO (multi-mission product, no IS2 data; Auger et al. 2022; Prandi et al. 2021)
  - Same 25 km polar stereographic grid as IS2
  - Corrections and coverage similar to IS2 but only through end of 2021
- **OBP:** GRACE Follow-On (converted to equivalent water thickness)
  - JPL mascon solutions (product JPL RL06.1_v3)
  - 3-degree, equal area caps, interpolated to ATL21 grid
  - Global mean mass signals removed

State Estimates

- State estimates from the project for Estimating the Circulation and Climate of the Ocean (ECCO; www.ecco-group.org)
  - Global setup of ocean-sea ice general circulation model, optimized to fit most available data within estimated uncertainties
  - Use version 4 release 5, extends over 1/1992--2/2024
  - Coarse resolution (nominally 1 degree)
  - Covers full IS2 period but mostly not constrained by data after 2019, moreover no IS2 data used
  - ECCO SSH and OBP monthly fields interpolated to ATL21 grids

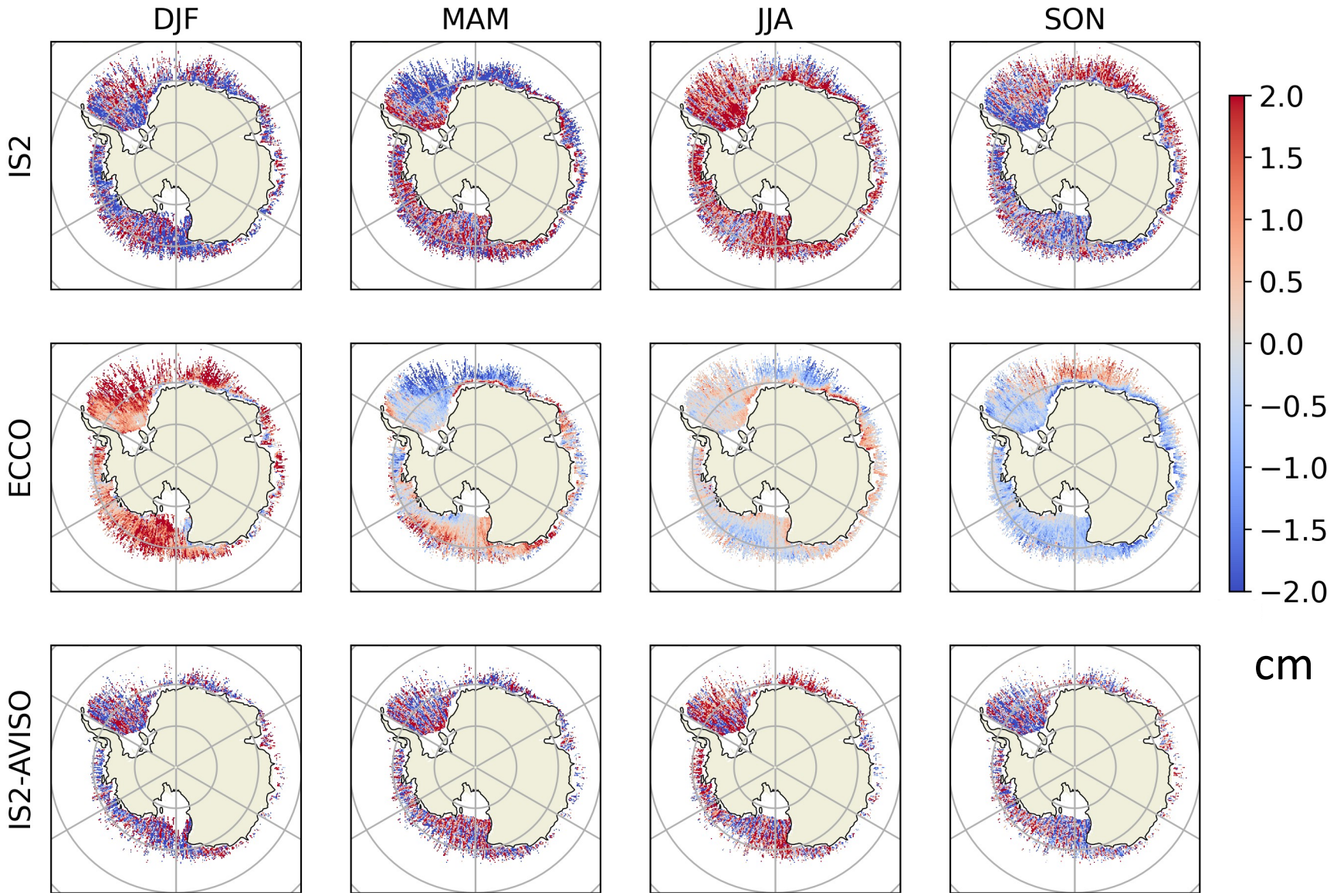
Mean Seasonal Cycle (SSH, Arctic)

- Similar spatial patterns and signs but sizable magnitude differences between IS2 and ECCO
- Differences between IS2 and AVISO comparable in magnitude to the seasonal anomalies
- Differences on both large and grid scales

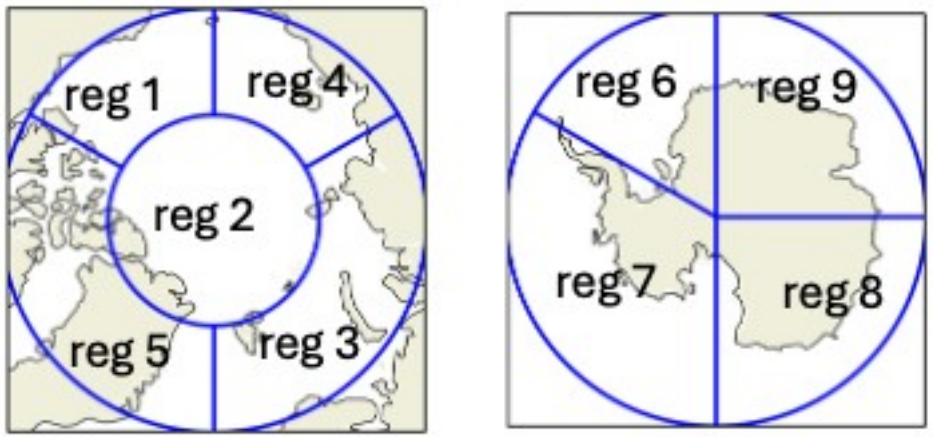


Mean Seasonal Cycle (SSH, Antarctic)

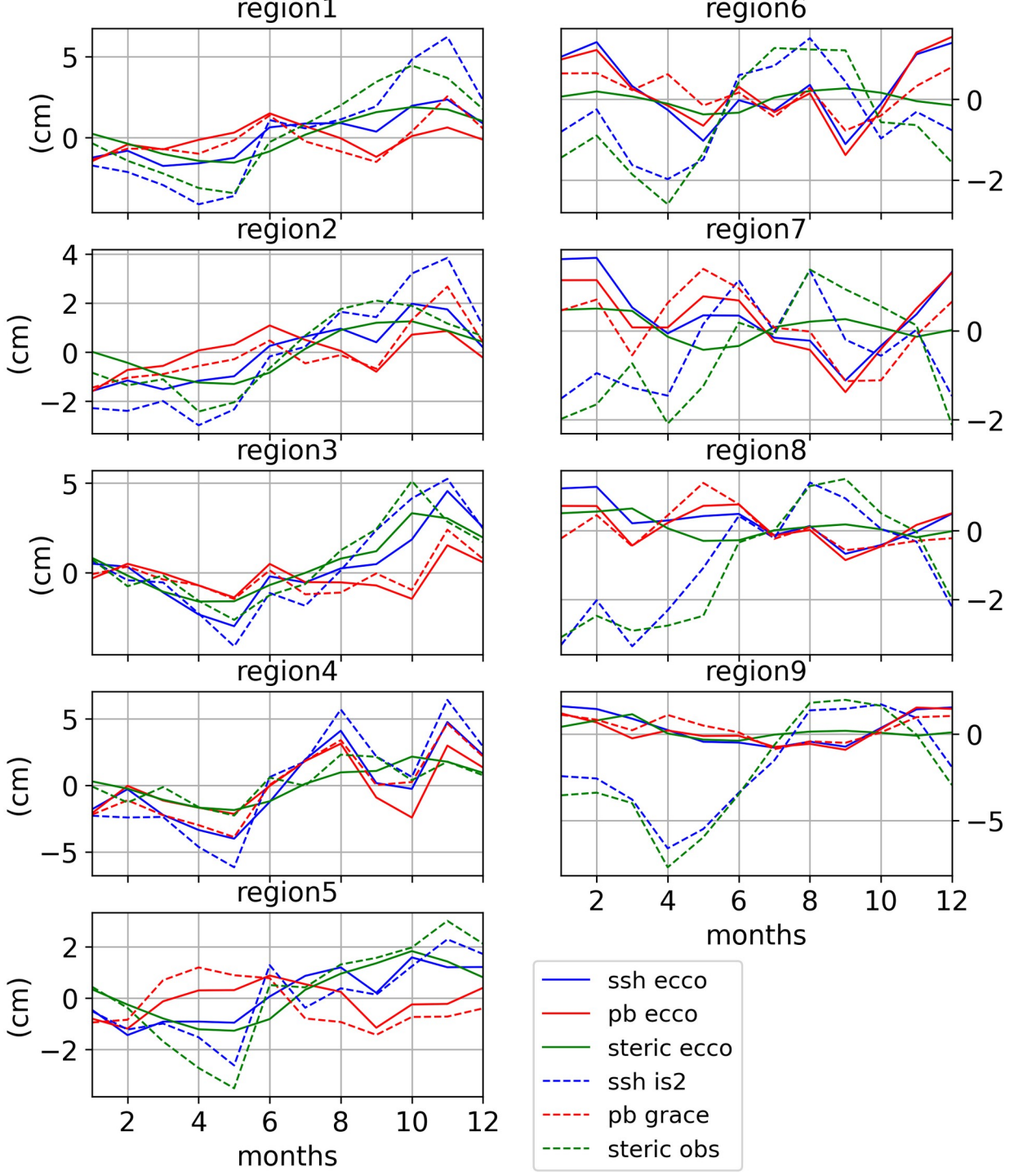
- Larger differences in spatial patterns and signs than seen in the Arctic
- Differences between IS2 and AVISO relatively large



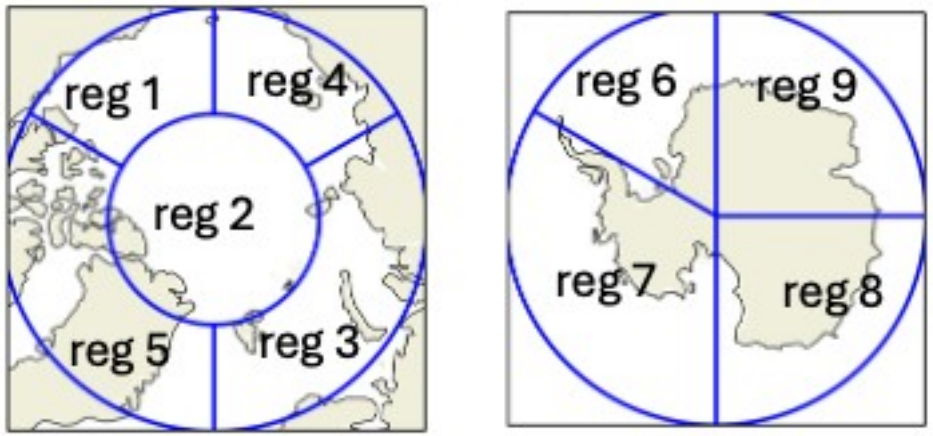
Mean Seasonal Cycle
(Regional Time Series)



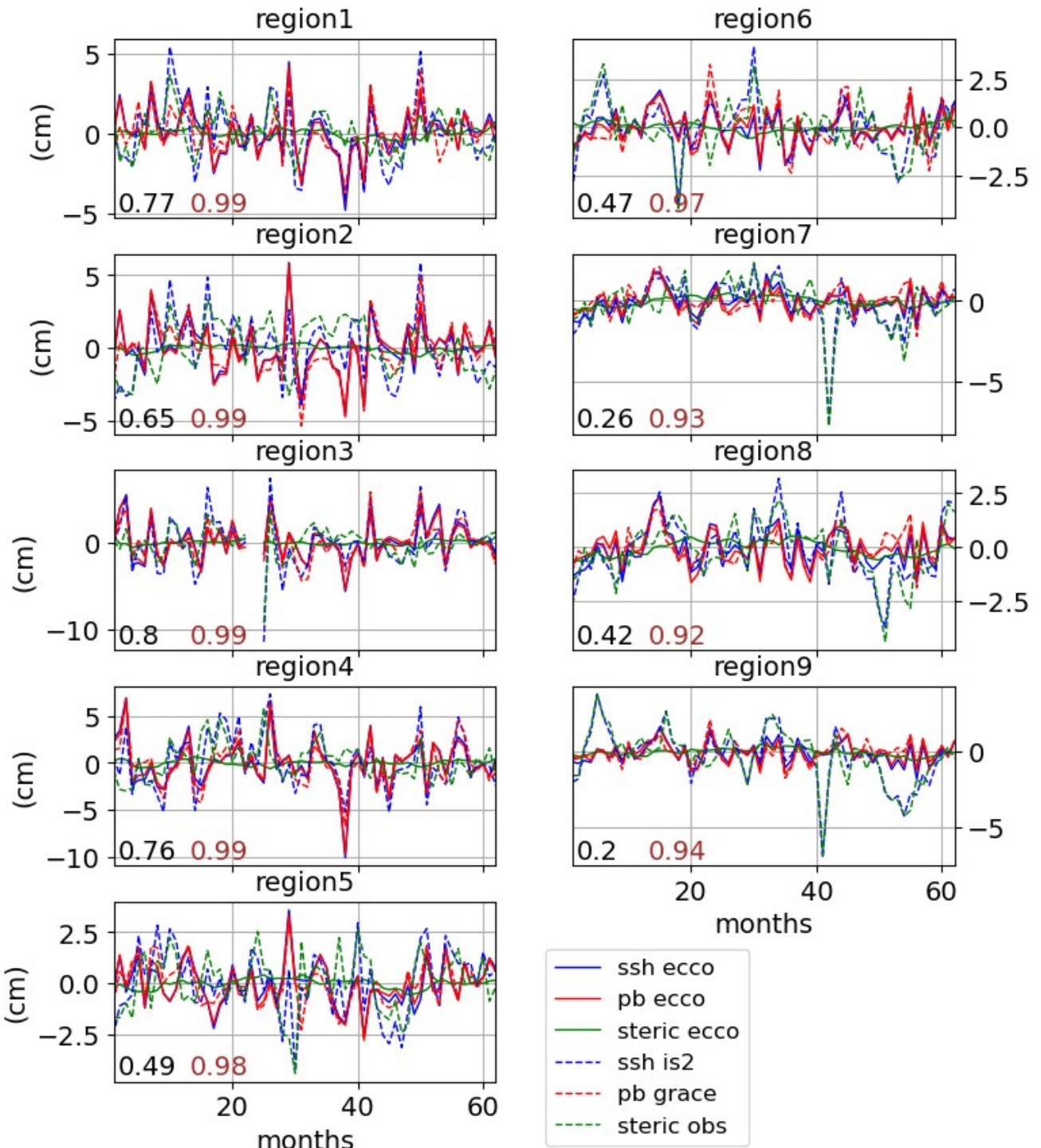
- IS2 SSH seasonal cycle somewhat larger than ECCO in the Arctic
- IS2 and ECCO SSH with very different behavior in the Antarctic
- GRACE and ECCO OBP more similar in both hemispheres
- Differences in inferred steric height (SSH minus OBP) stem mostly from SSH



Non-Seasonal Residuals



- IS2 SSH variability somewhat larger and different from that of ECCO in the Antarctic
- IS2 SSH better correlated with GRACE OBP in the Arctic than in the Antarctic
- Large differences in inferred steric height are mostly due to SSH



Non-Seasonal Residuals (Correlations)

	SSH (IS2, ECCO)	OBP (GRACE, ECCO)
region 1	0.56	0.84
region 2	0.47	0.9
region 3	0.72	0.89
region 4	0.66	0.91
region 5	0.35	0.86
region 6	0.45	0.87
region 7	0.49	0.82
region 8	0.69	0.87
region 9	0.49	0.86

- GRACE and ECCO OBP very well correlated
- IS2 and ECCO SSH correlations significant but generally weaker (particularly in Antarctic regions)

Optimal SSH Estimates

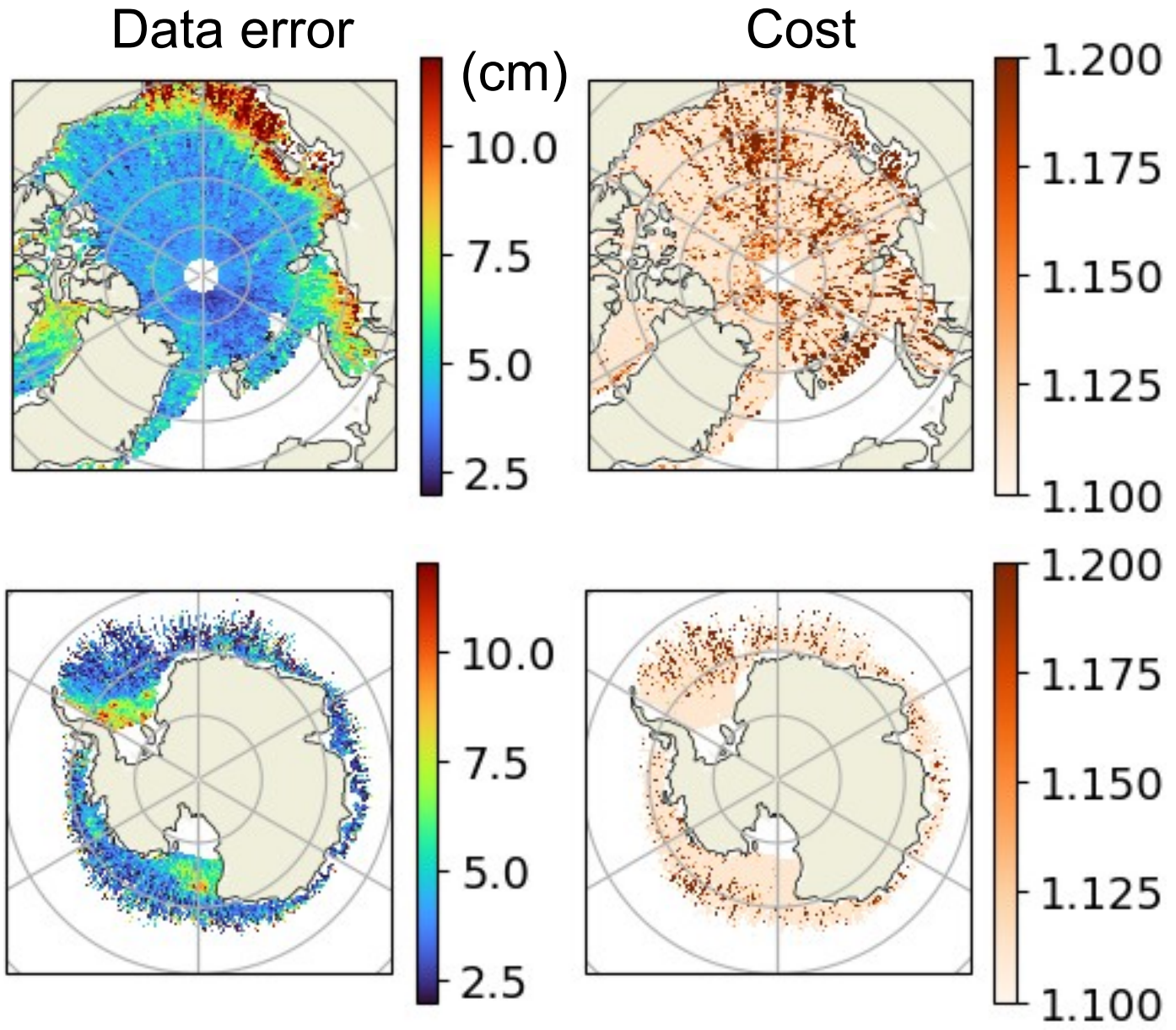
- Use IS2 data as a constraint in the ECCO optimization to bring SSH estimates closer to the data within respective data uncertainties
- Together with constraints on OBP, should lead to improved estimates of steric height/subsurface density changes
- Optimization involves minimization of a “cost function” defined in general terms as

J ~ (model minus data)**2 / 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 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 SSH 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 removed
- Rather weak constraints due to relatively large uncertainty in SSH data for both Arctic and Antarctic



Summarizing…

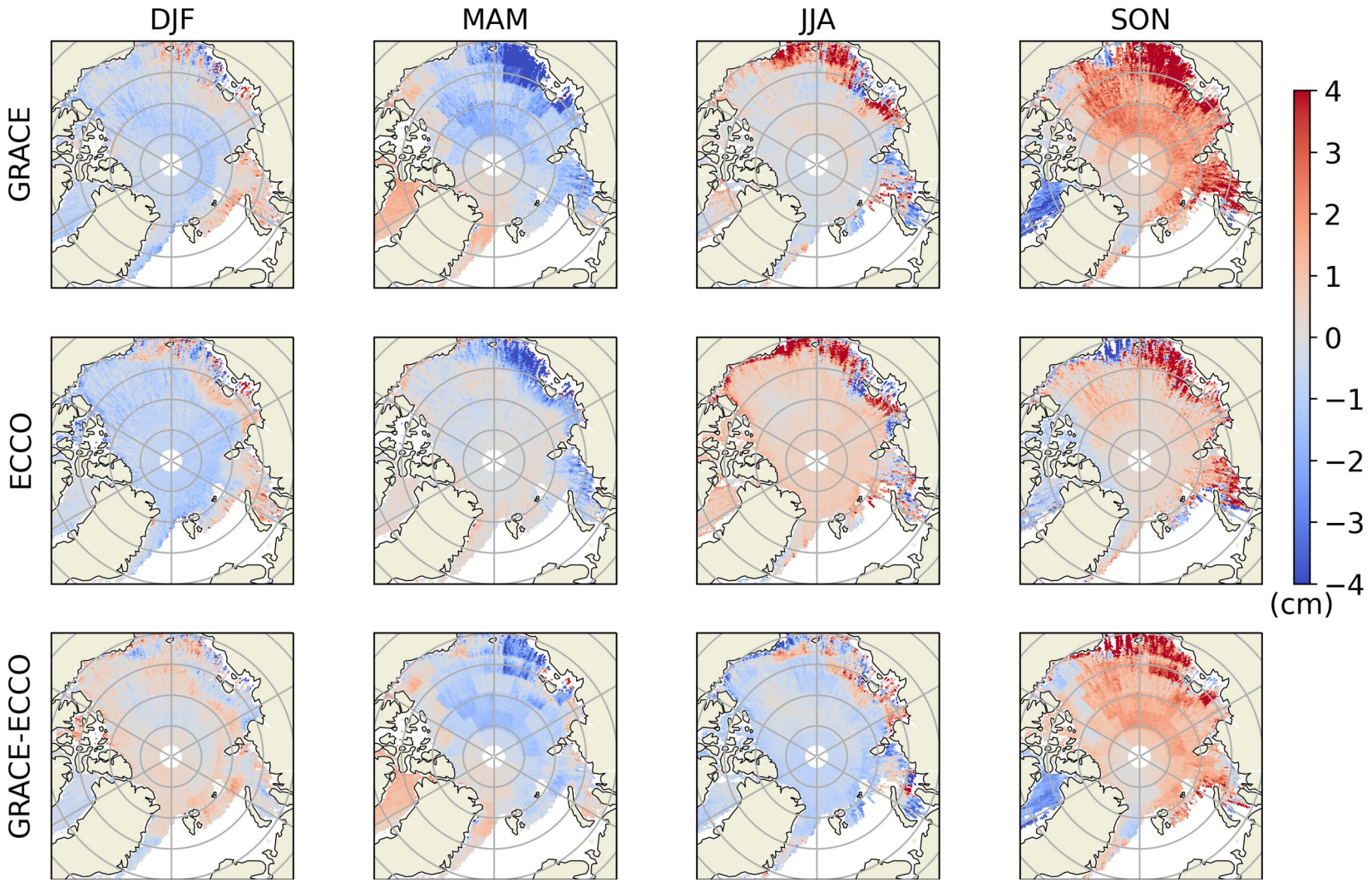
- Modest agreement between IS2 and ECCO estimates of SSH for the Arctic, for both the mean seasonal cycle and non-seasonal residual variability, but relatively large SSH differences for the Antarctic
- GRACE and ECCO estimates of OBP variability in good agreement
- Steric height inferred from the IS2 and GRACE observations likely to have large uncertainty, particularly related to the SSH component
- Estimates of SSH data uncertainty comparable to differences between IS2 and ECCO SSH values (on non-seasonal time scales and on the grid scale)
- Use of IS2 SSH data to constrain ECCO solutions likely to have more impact on the optimization if averaged over time and space (e.g., mean seasonal cycle) to smooth out noise

Next Steps

- Extend analyses to other SSH fields (e.g., AVISO, CryoSat-2) with longer data spans
- Assess uncertainties of seasonal cycle
- Explore understanding of data and model differences

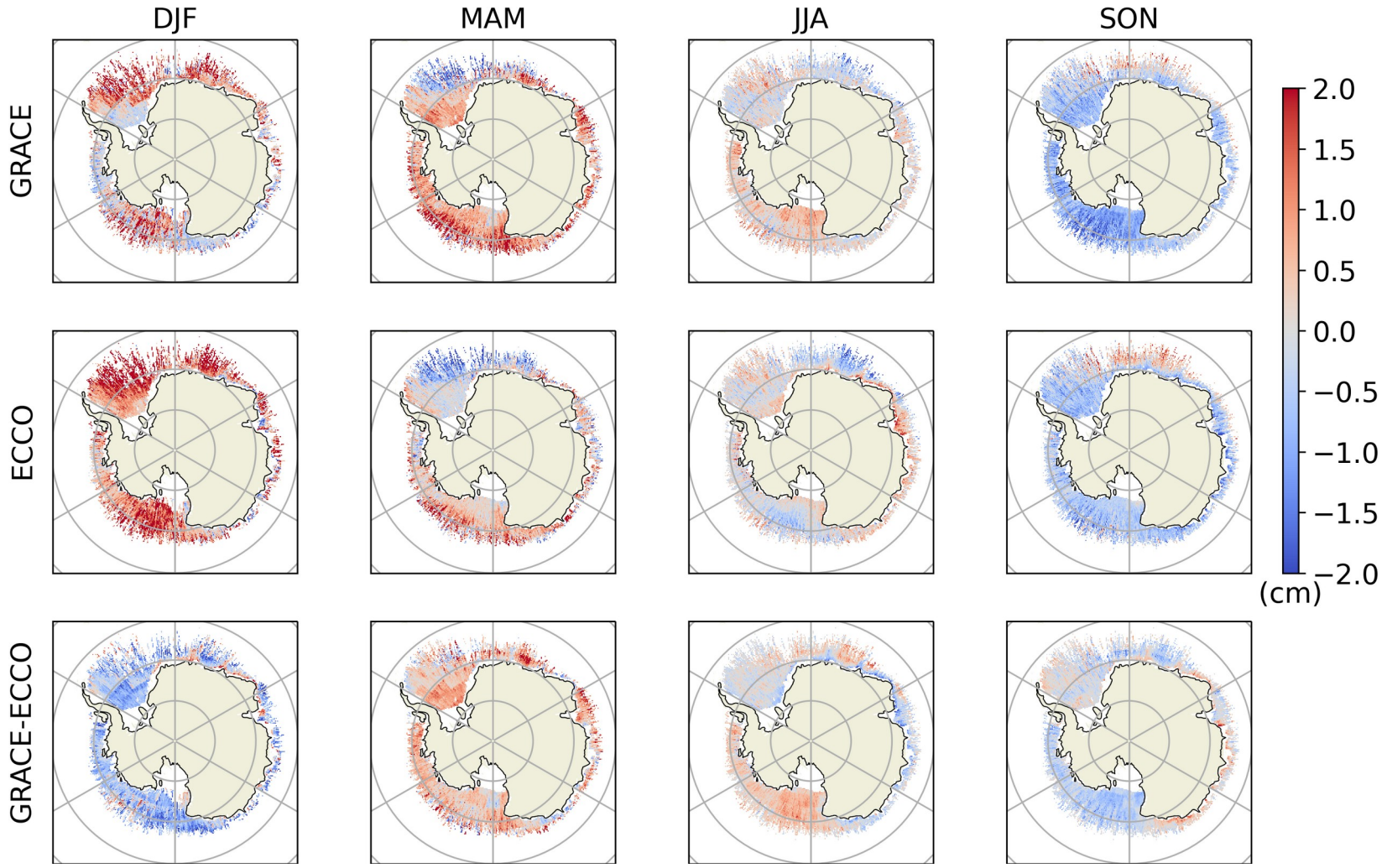
Mean Seasonal Cycle (OBP, Arctic)

- Similar to SSH patterns but relatively weaker anomalies outside of shallow shelf regions
- Suggesting substantial seasonal steric changes
- Large-scale biases between GRACE and ECCO



Mean Seasonal Cycle (OBP, Antarctic)

- Weaker OBP seasonal cycle than in the Arctic (as with SSH)
- Similar patterns in ECCO and GRACE but not for all seasons or regions
- Large-scale differences between GRACE and ECCO, comparable to seasonal magnitudes



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region 5	0.35	0.86	0.43
region 6	0.45	0.87	0.45
region 7	0.49	0.82	0.51
region 8	0.69	0.87	0.64
region 9	0.49	0.86	0.31

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Potential Impact of IS2 SSH Data

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

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