New estimate of the time-varying Arctic Ocean bottom pressure using GRACE: Validation and interpretation

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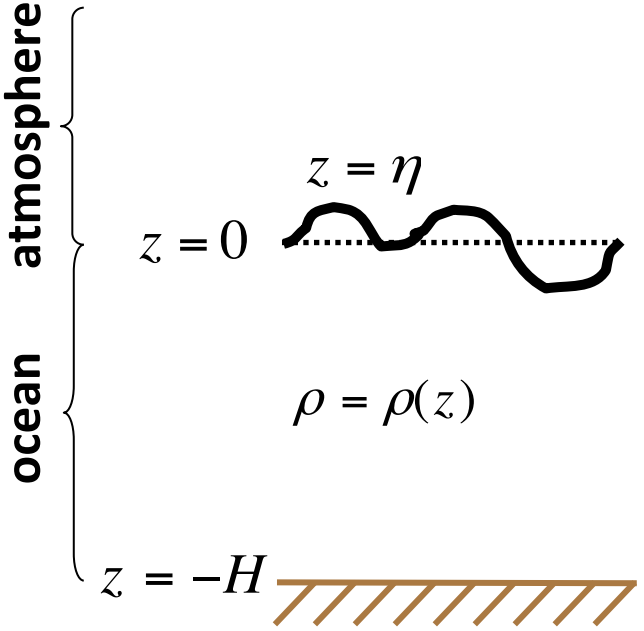
Ocean bottom pressure (OBP)

$$P_b(t) = g\int_{-H}^{\eta} \rho(z,t)dz + P_a'(t) = \underbrace{g\int_{-H}^{0} \rho(z,t)dz}_{\text{baroclinic}} + \underbrace{\rho_o g\eta'(t)}_{\text{barotropic}}$$

[*Gill*, 1982]



Ocean mass sources and re-distribution:
- Runoff and net P-E into ocean
- Ocean mass fluxes from Atlantic and Pacific
- Tides
- Wind-driven transport

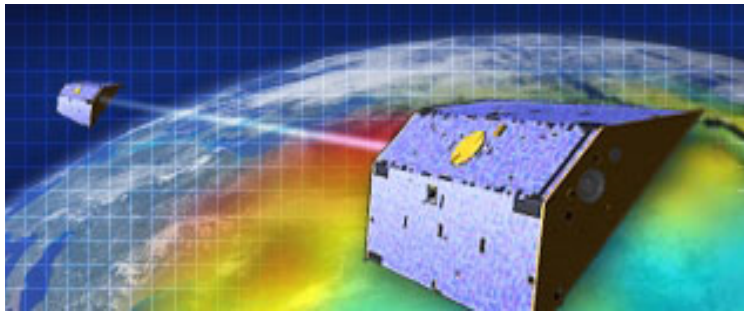
Direct effects on:
- Sea level change
- Steric pressure change
- Heat and freshwater budget

→ Ocean circulation

Observations

GRACE

U. of Texas, Center for Space Research CSR-Release 4.
Processed by D. Chambers [*Chambers*, 2006] and J. Bonin.



Gravity Recovery and Climate Experiment, http://grace.jpl.nasa.gov/

Processing includes:

- De-aliasing of high-frequency OBP into monthly solutions using OMCT.
- Post-glacial rebound [*Paulson,* 2007].
- Land-contamination minimized.
- **Filters:**
  - -De-striping algorithm [*Wahr*, 2002]
  - -Gaussian smoother (500km half width)

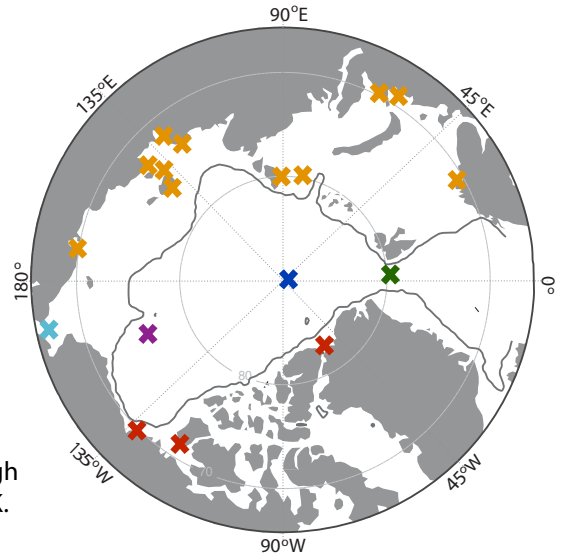
Monthly solutions of OBP anomalies in units of cm of water equivalent

18 tide/pressure gauges

Processing includes:

- Tides removed from the pressure and tide gauges with available high frequency data.
- Sea level data from TG were IB-corrected to yield OBP, using NCEP/NCAR reanalysis.
- Data averaged monthly.

- BPR, North Pole (NPEO)
- BPR, Beaufort Sea (BGEP)
- BPR, Bering Strait (RUSALCA)
- TG, Fisheries and Oceans, Canada
- PIES, Fram Strait (AWI)
- TG, Russian (AARI), available through PSMSL from the Nat. Oc. Centre, UK.



Objective

1. **Demonstrate the capability of GRACE to accurately observe variations and re-distribution of Arctic Ocean mass associated with large scale atmospheric circulation (monthly and longer time-scales).**

2. **Demonstrate the utility of GRACE OBP to validate AOMIP models.**

Ocean models

PIOMAS (UW)

Pan-Arctic Ice Ocean Modeling Assimilation System

[*Zhang and Rothrock,* 2003]

- Baroclinic, 30 vertical levels
- Resolution ~20 km
- Forced with NCEP/NCAR

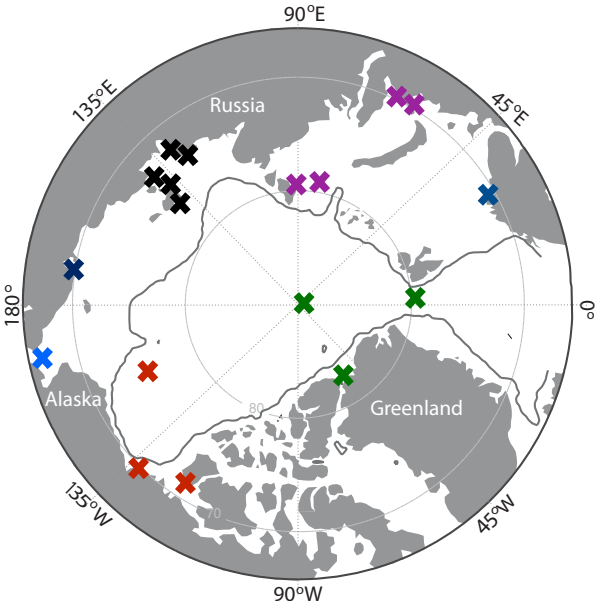
ECCO2 (JPL)

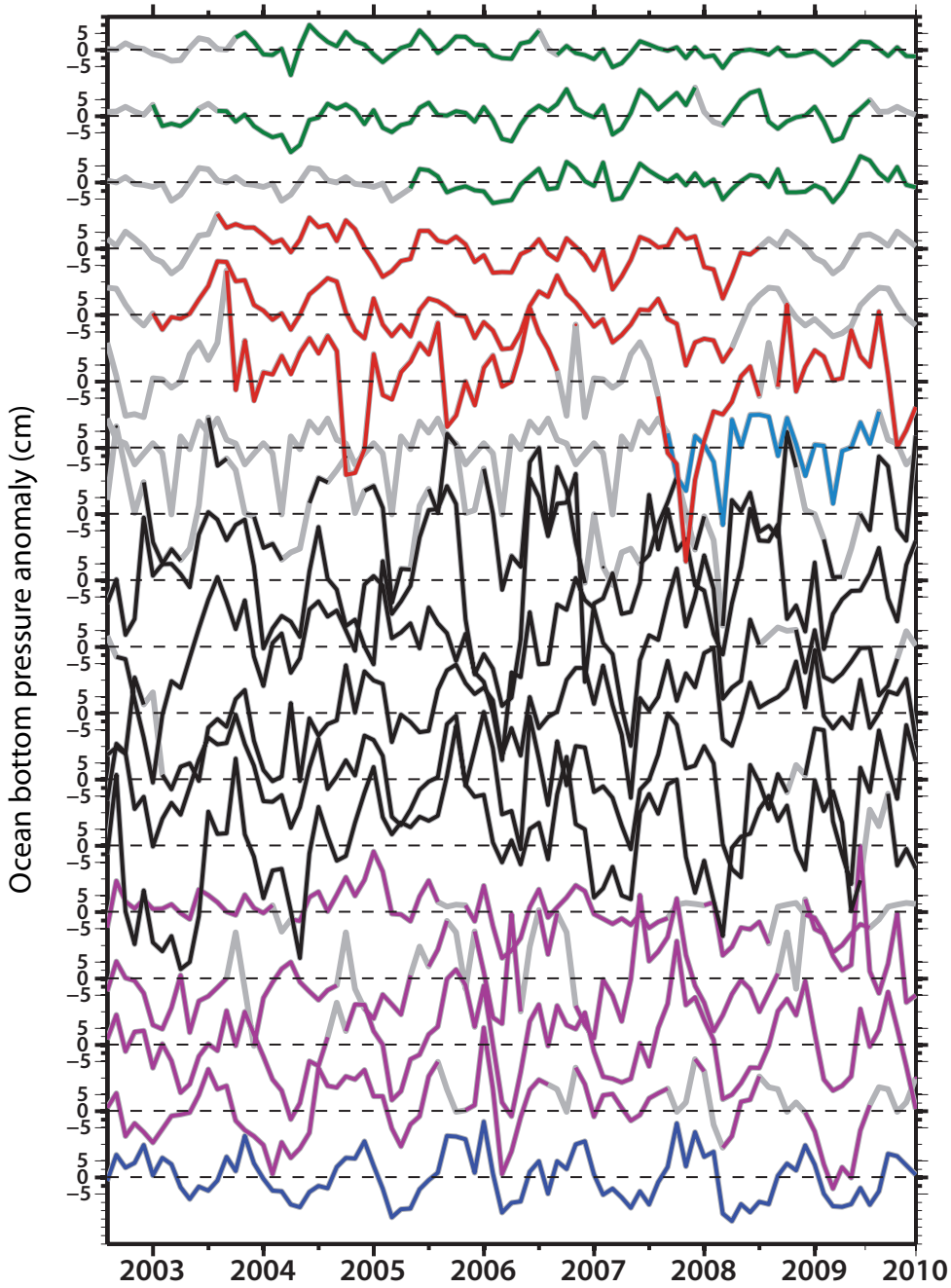
Estimating the Circulation and Climate of the Ocean, Phase II Project

[*Nguyen, et al.,* 2011]

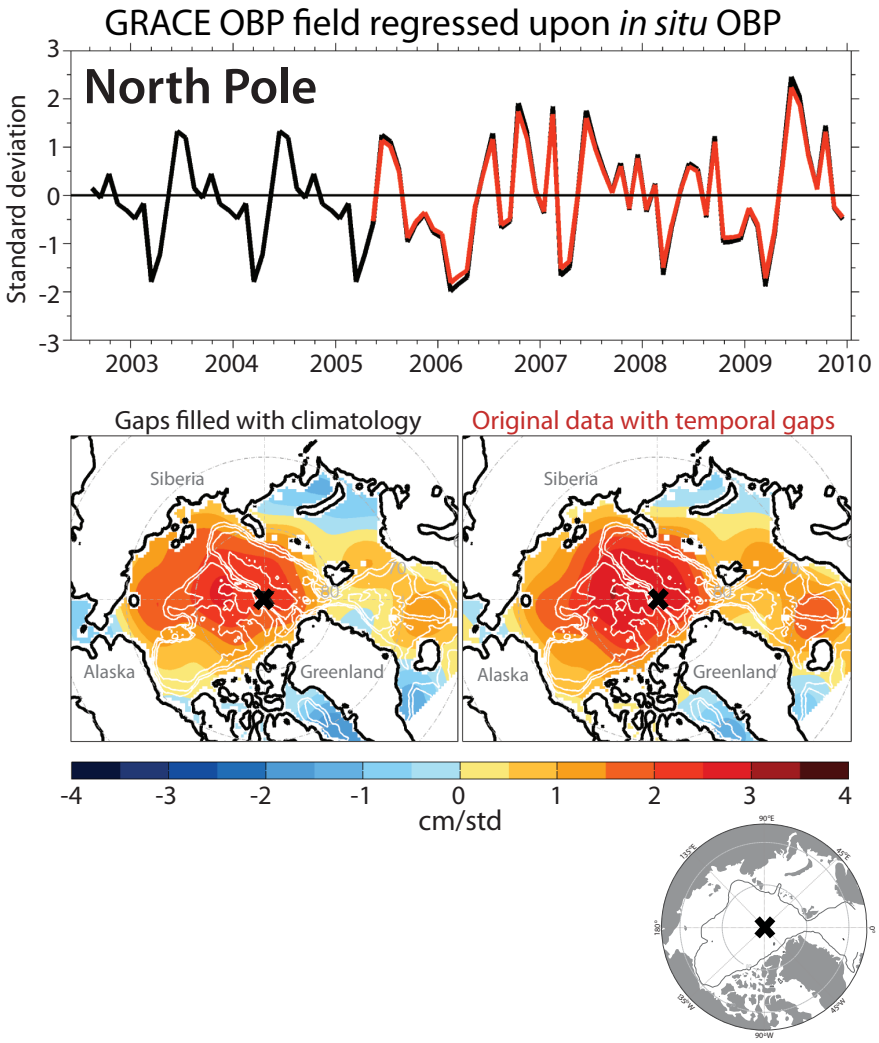
- Baroclinic, 50 vertical levels
- Resolution ~18 km
- Forced with JRA-25

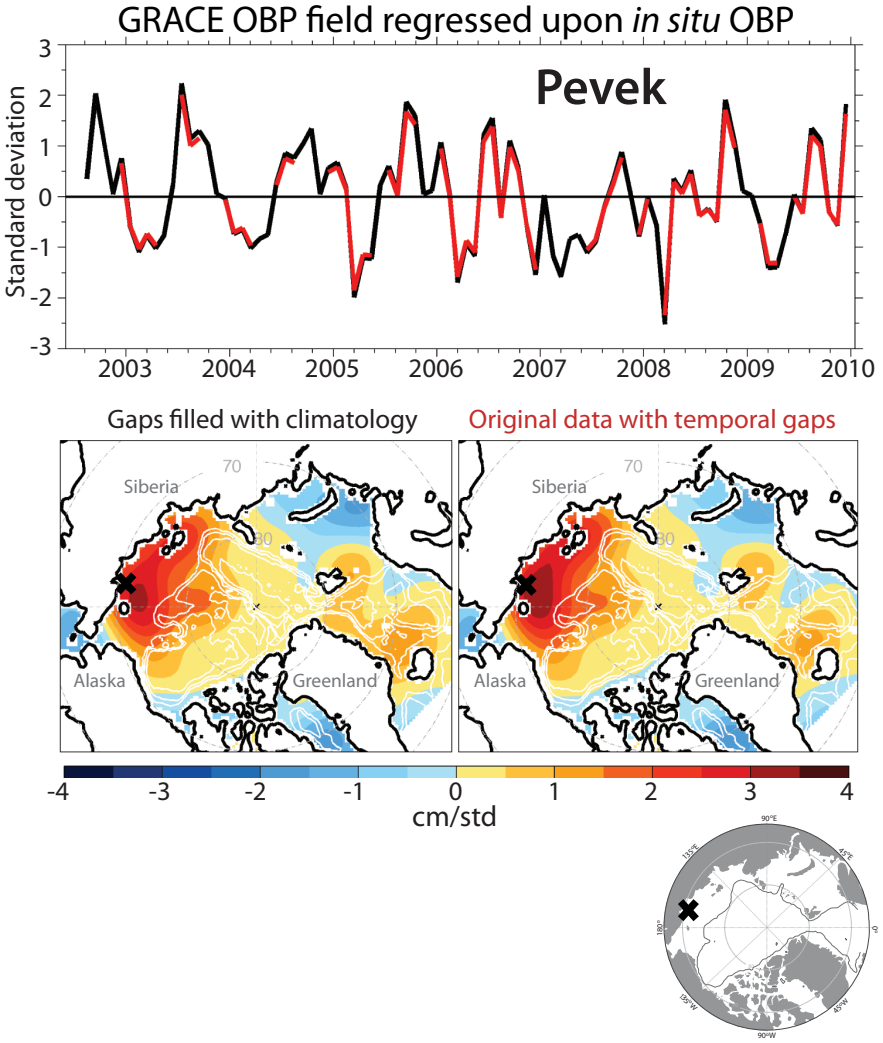
In situ OBP from pressure and tide gauges





Effects of filling temporal gaps on GRACE OBP

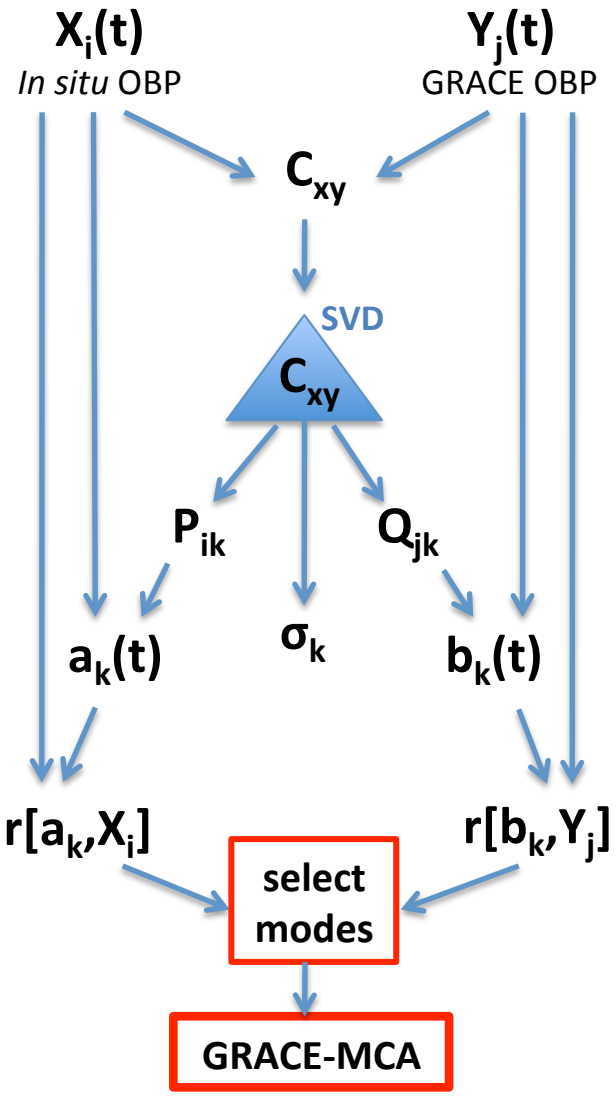




Filling gaps of *in situ* data (using *in situ* climatology) does **not** affect the general structure of the GRACE OBP field.

MCA, maximum covariance analysis

[*Bretherton et al.*, 1992]



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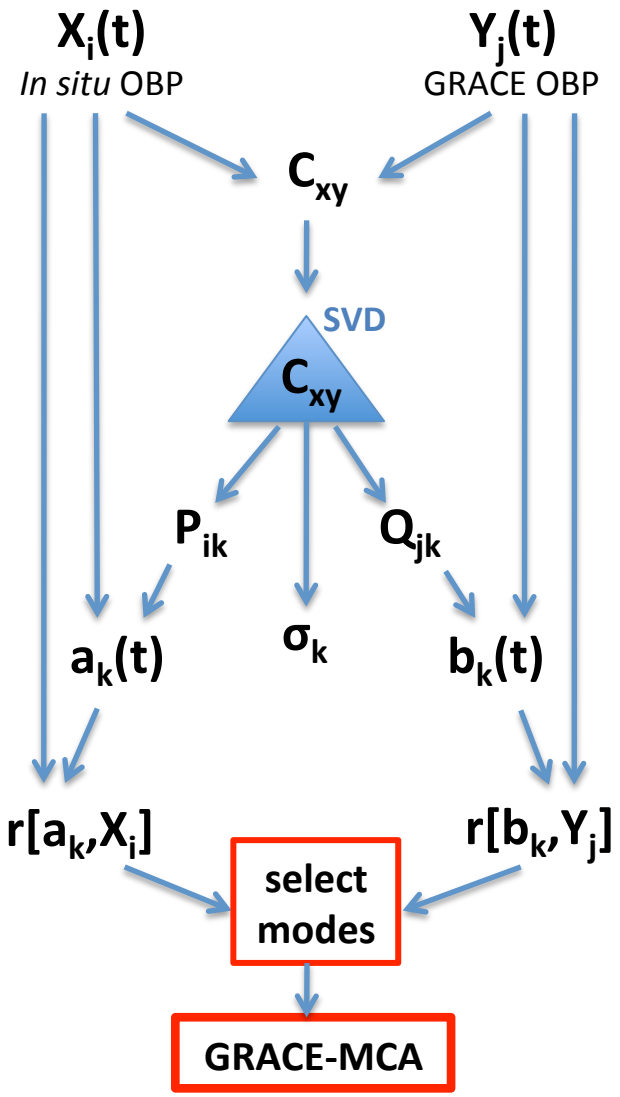
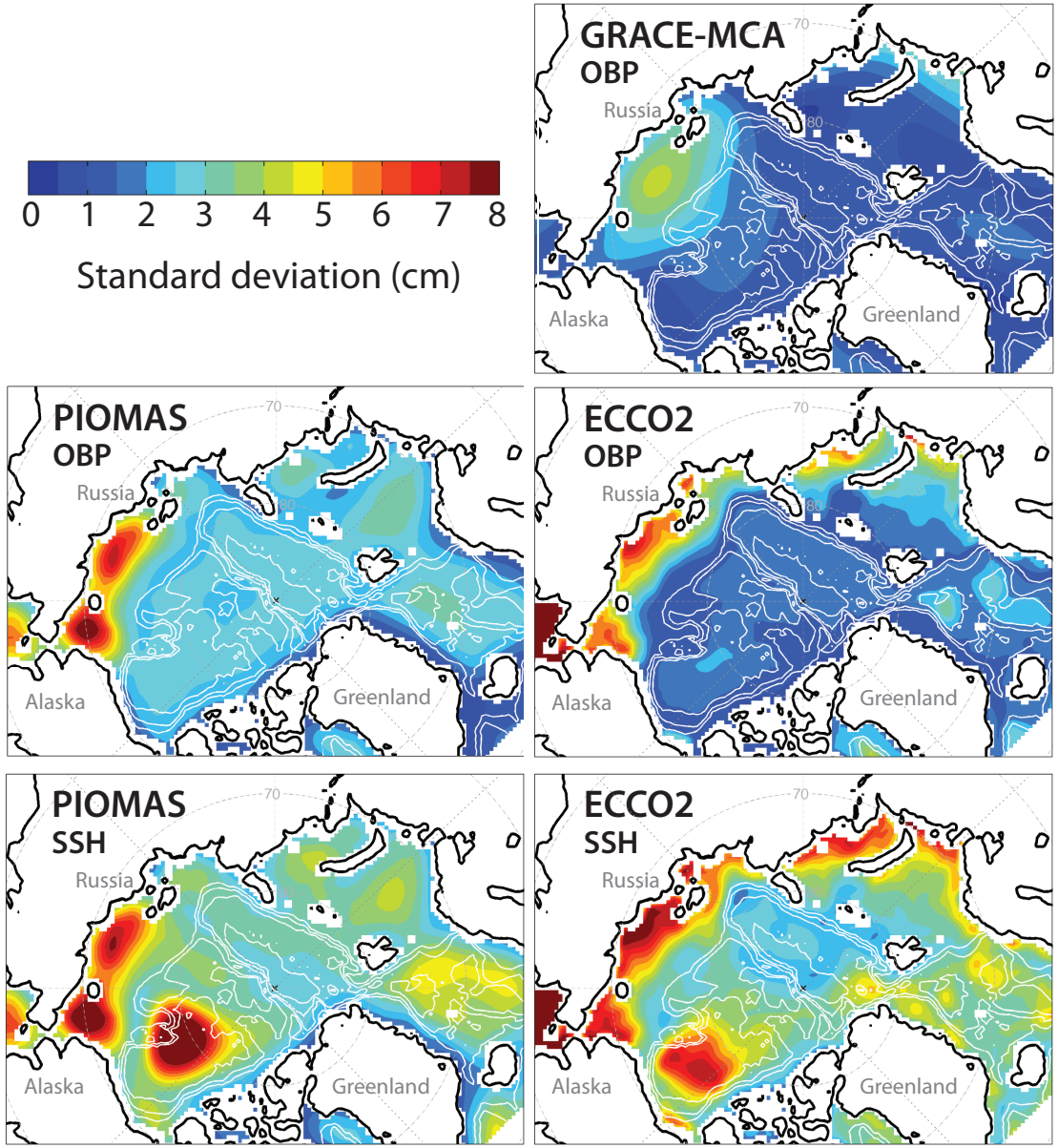
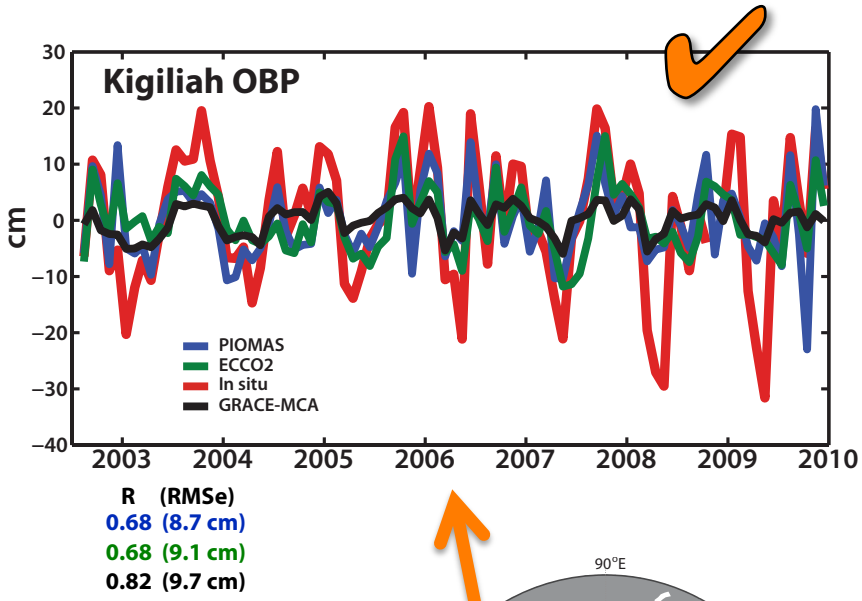
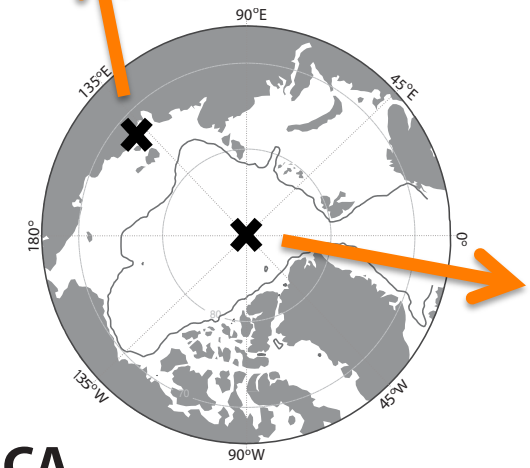


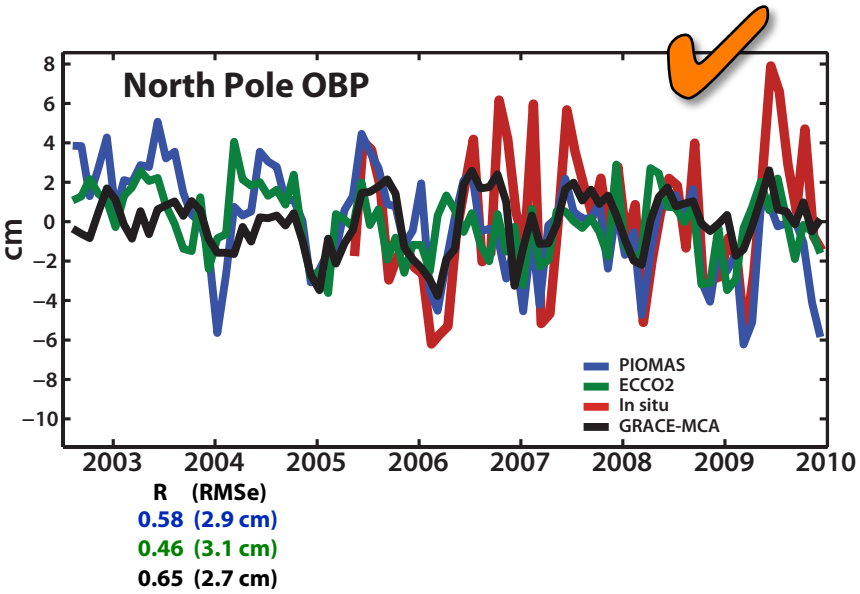
GRACE and models monthly variability



GRACE-MCA and model validation with *in situ* OBP

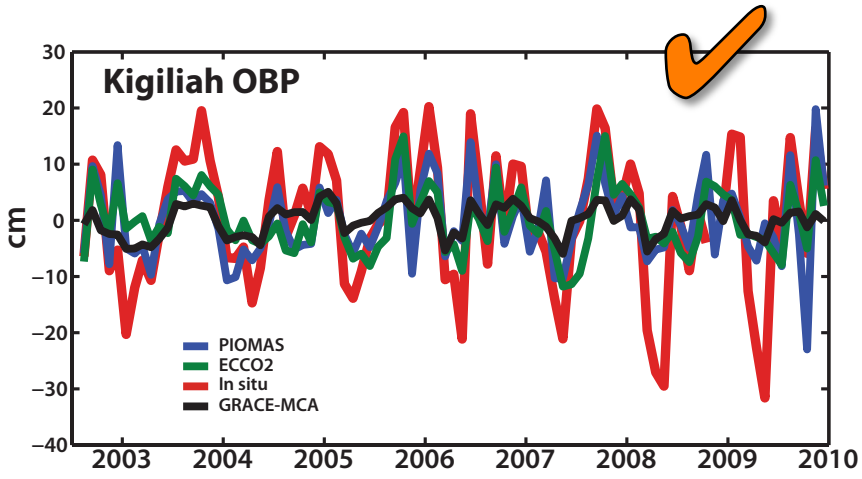




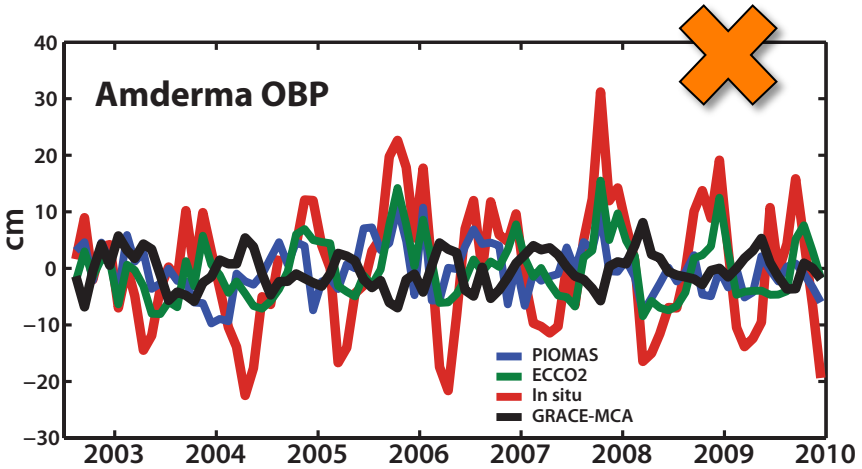


PIOMAS
ECCO2
In situ
GRACE-MCA

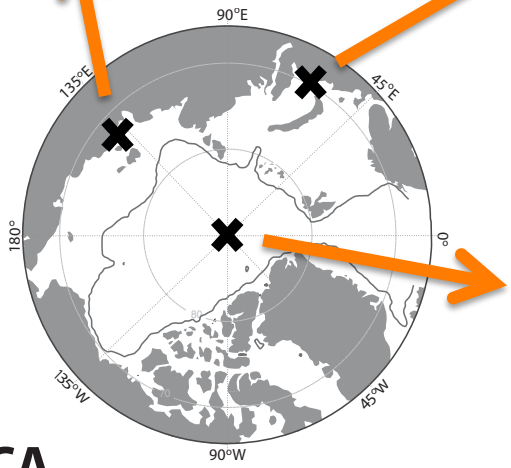
GRACE-MCA and model validation with *in situ* OBP

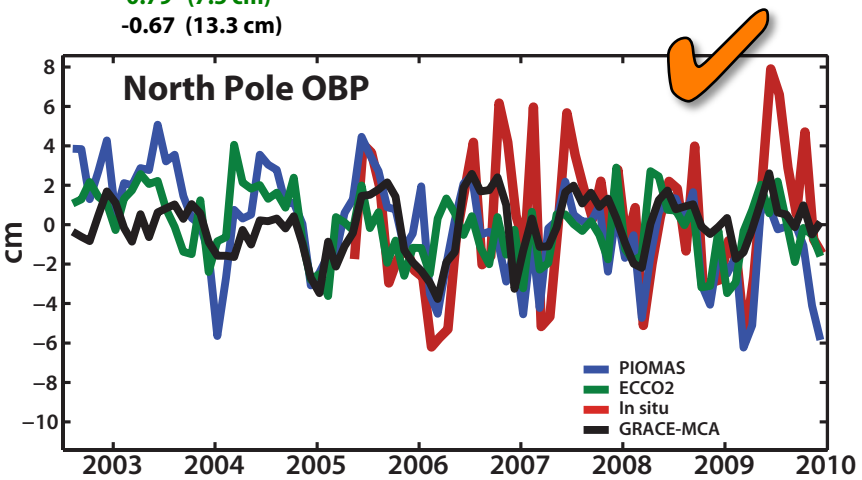


R (RMSe)
0.68 (8.7 cm)
0.68 (9.1 cm)
0.82 (9.7 cm)



R (RMSe)
0.46 (9.7 cm)
0.79 (7.5 cm)
-0.67 (13.3 cm)





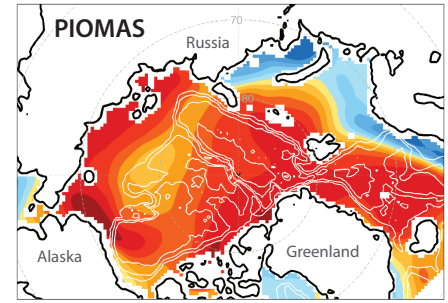
R (RMSe)
0.58 (2.9 cm)
0.46 (3.1 cm)
0.65 (2.7 cm)

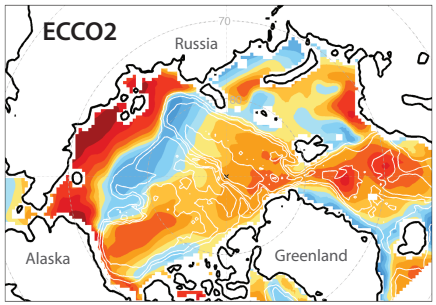
PIOMAS
ECCO2
In situ
GRACE-MCA

GRACE-MCA and models OBP inter-comparison

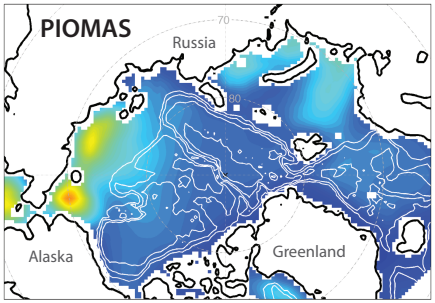
All timescales

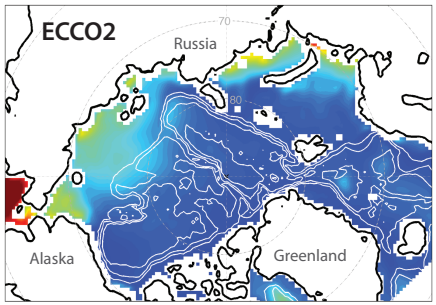
Correlation coefficient

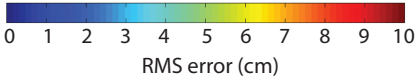




RMS difference





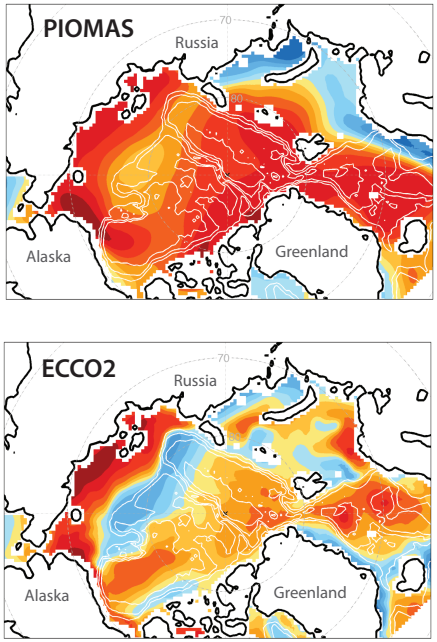


R > 0.23 are above the 95% conf. level

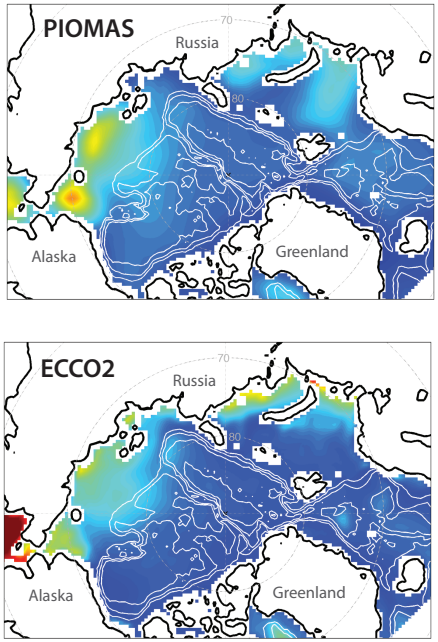
GRACE-MCA and models OBP inter-comparison

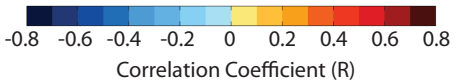
All timescales

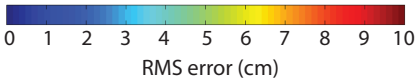
Correlation coefficient



RMS difference







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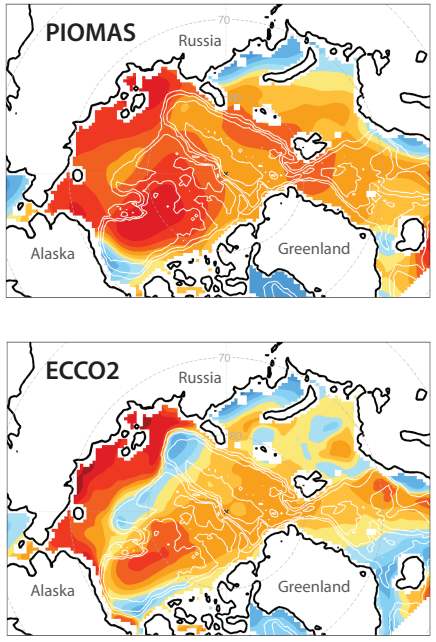
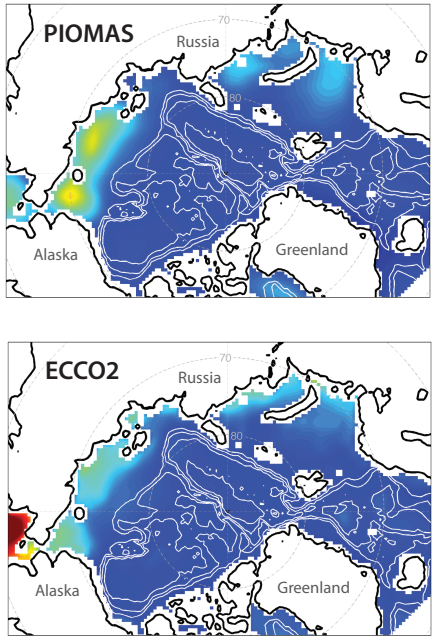
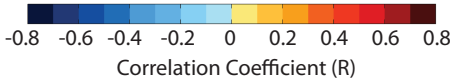
Annual cycle and trend removed

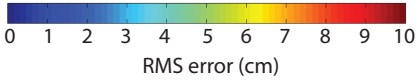
Correlation coefficient



RMS difference







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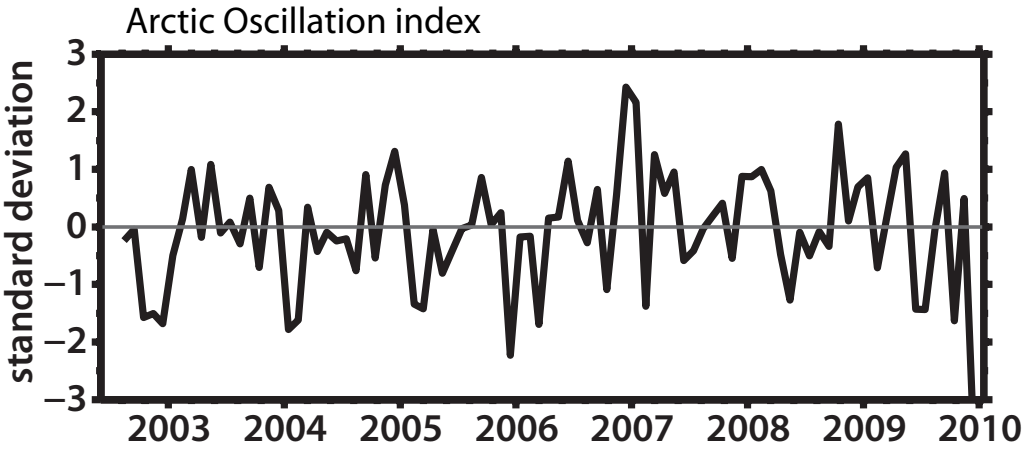
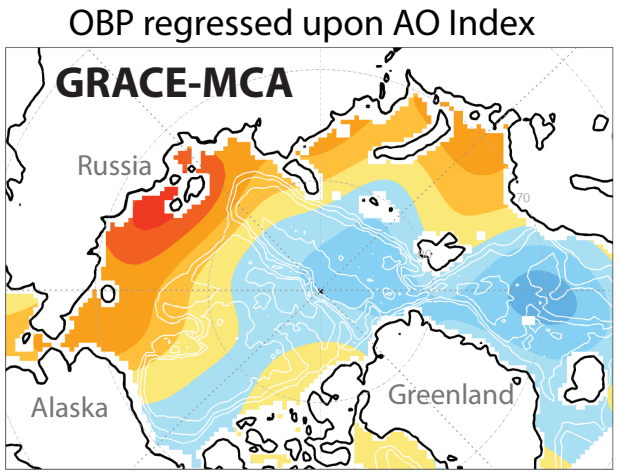
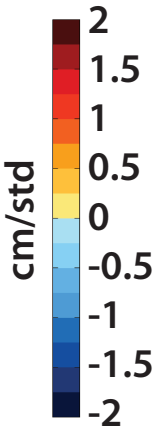
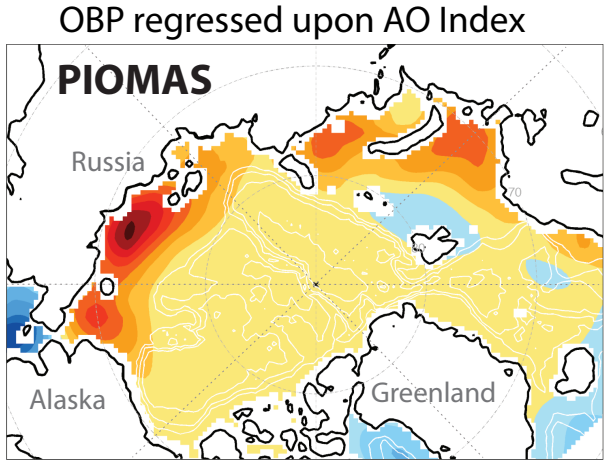
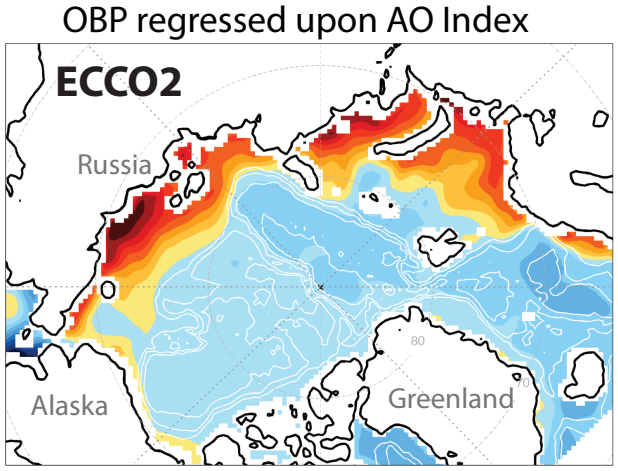
Ocean dynamics, example 1: OBP and the AO



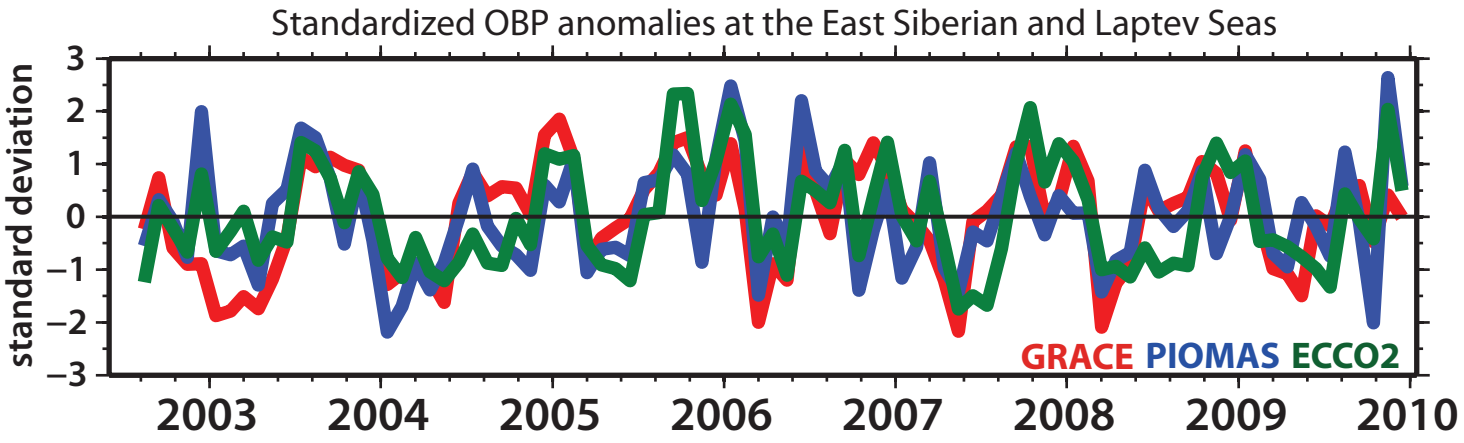




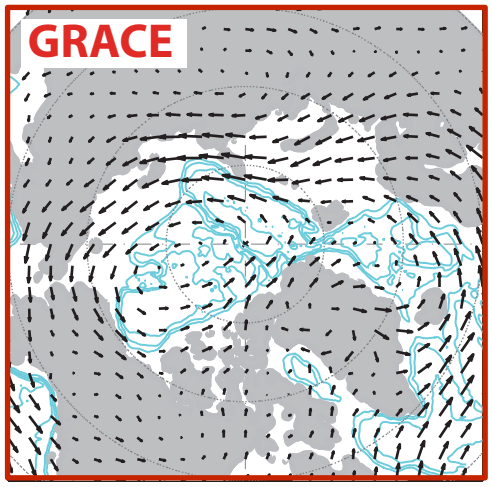


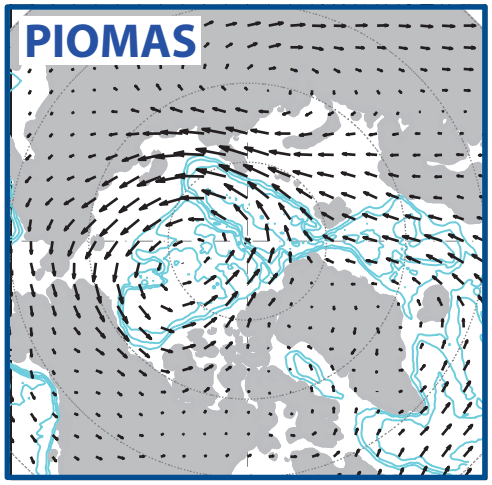


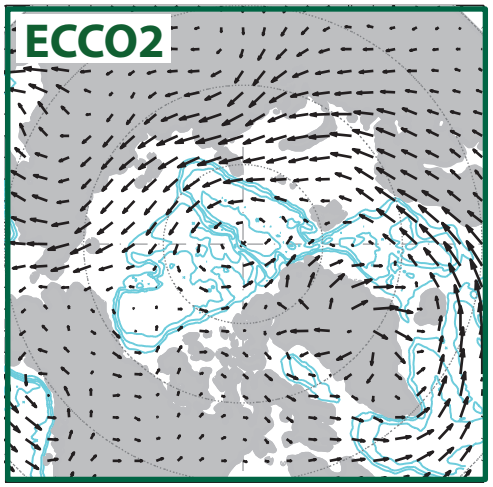
Ocean dynamics, example 2: Wind forcing in the East Siberian and Laptev Seas



NCEP/NCAR wind anomalies (925 hPa) regressed on the standardized OBP anomalies







scale: 3 m/s/std →

Summary

1. **Available Arctic *in situ* OBP has been used to improve and validate GRACE data, as well as validate two models.**

2. **GRACE, PIOMAS and ECCO2 generally show significant correlations with *in situ* data. GRACE fails to capture the *in situ* variations in the Kara Sea.**

3. **All GRACE, PIOMAS and ECCO2 underestimate *in situ* OBP observations in the Arctic shelves, where RMS variability in observed OBP is largest.**

4. **Improved OBP field from GRACE is useful to validate AOMIP models at inter-monthly and longer timescales: Persistent disparity between GRACE and the models (also model to model, *not shown*), is in the East-Siberian shelf break.**

5. **Despite of its coarse spatial resolution, GRACE is useful to identify large scale dynamics of the ocean associated with atmospheric circulation, and these are also well captured by PIOMAS and ECCO2.**

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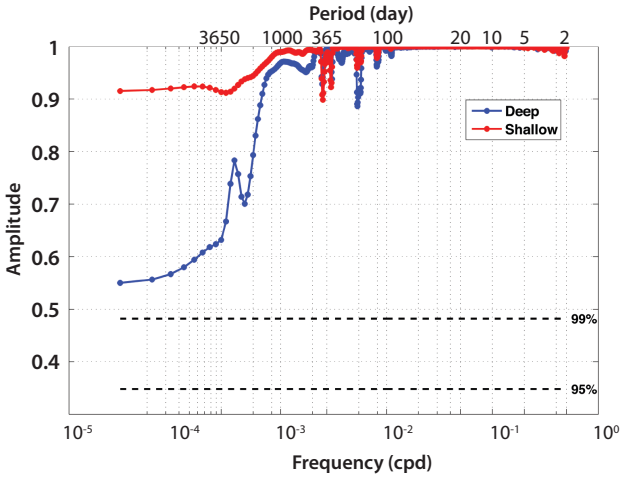
5. **Despite of its coarse spatial resolution, GRACE is useful to identify large scale dynamics of the ocean associated with atmospheric circulation, and these are also well captured by PIOMAS and ECCO2.**

Thank you

Note on inter-annual variations: 2005 to 2008 trend

$$\underbrace{P_b}_{\text{OBP}} = g\int_{-H}^{\eta}\rho(z)dz + P_a = \underbrace{g\int_{-H}^{0}\rho(z)dz}_{\text{StP}} + \underbrace{\rho_o g\eta'}_{\text{SSH}}$$

Squared coherence between OBP and SSH from PIOMAS



- Deep basins of the Arctic adjust baroclinically, and OBP represents only a fraction of SSH (at inter-annual timescales).

- GRACE-MCA inter-annual change in OBP is similar to the modeled OBP (in shallow regions of the shelve) than original GRACE.