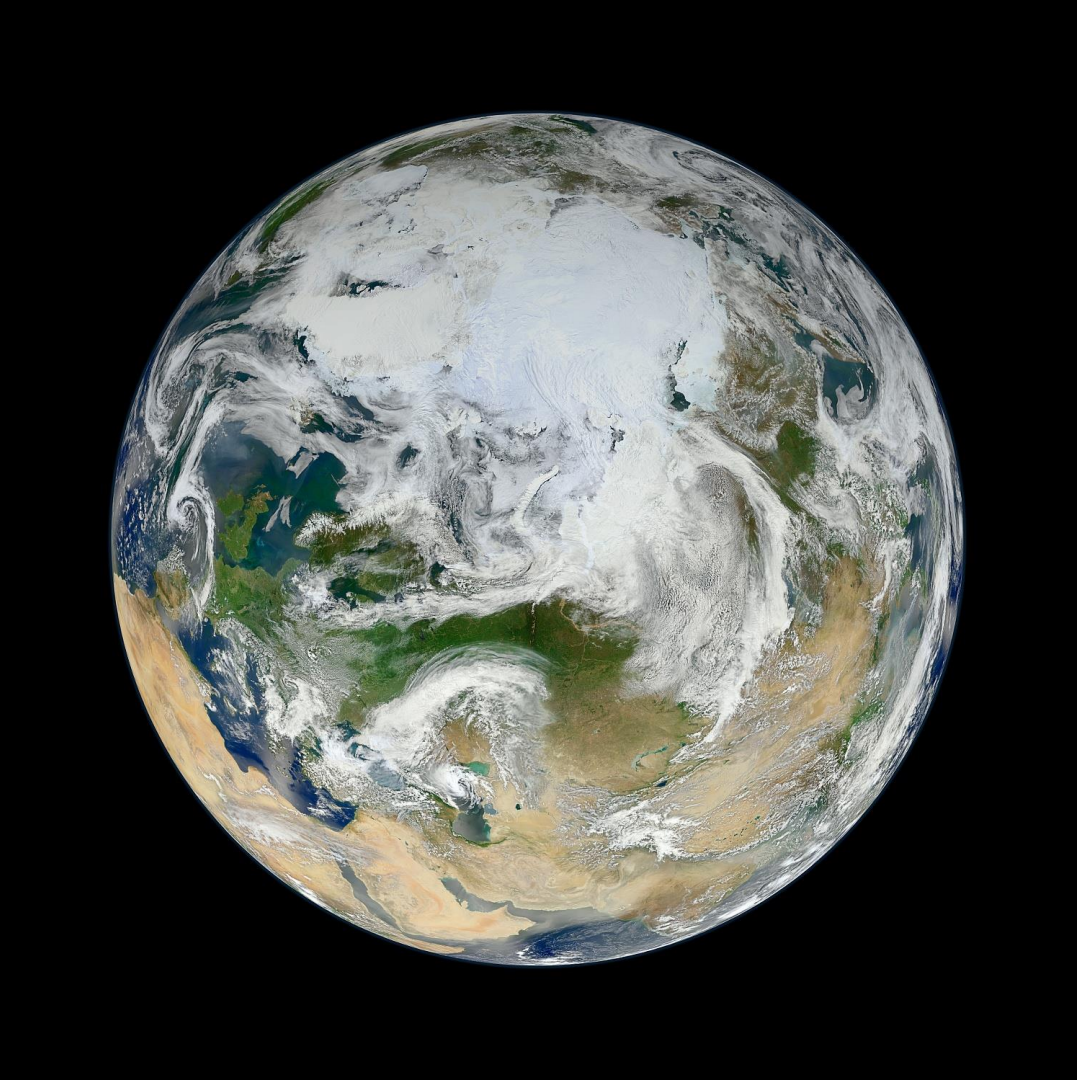

Satellite-derived sea level in the ice-covered polar oceans

Tom Armitage[1], Ron Kwok[1], Sheldon Bacon[2], Andrew Thompson[3], Alek Petty[4]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
[2]National Oceanography Centre, Southampton, UK
[3]Environmental Science and Engineering, California Institute of Technology, Pasadena, CA, USA
[4]Cryospheric Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA

Jet Propulsion Laboratory
California Institute of Technology

1. Why study sea level of the polar oceans?

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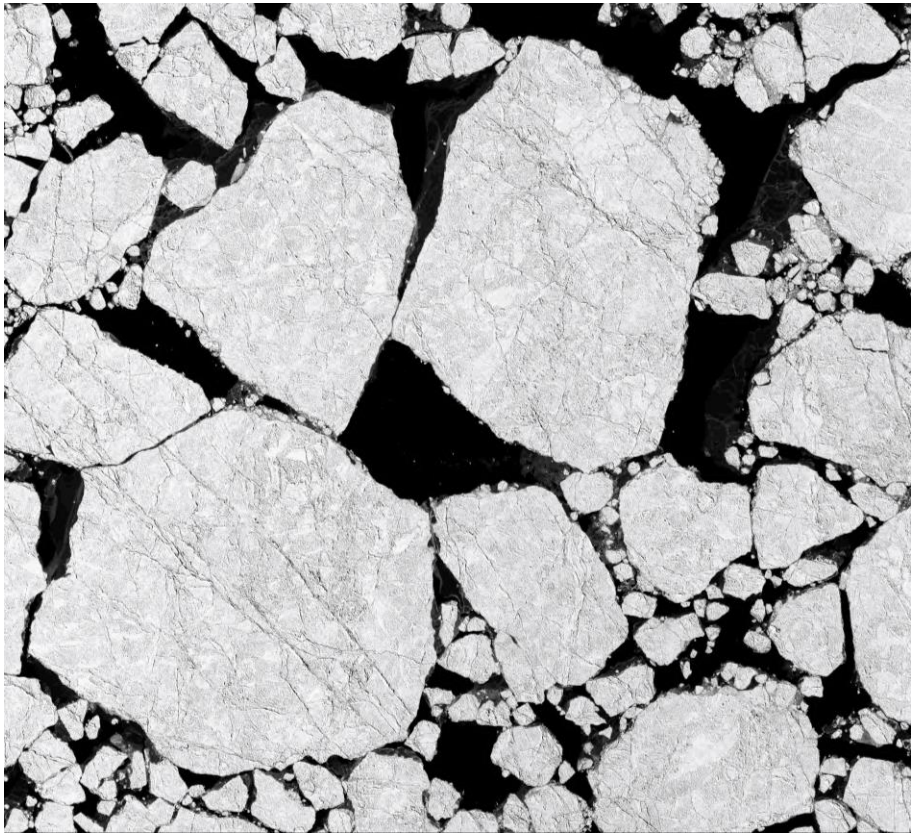
- The polar oceans are small but essential for understanding climate change
- Arctic region is experiencing rapid climate change
  - Arctic sea ice loss
  - ‘Arctic amplification’
- Southern Ocean is a climatically important region
  - water mass modification, surface fluxes, sea ice formation, glacial input
  - Driving Antarctic ice sheet melt



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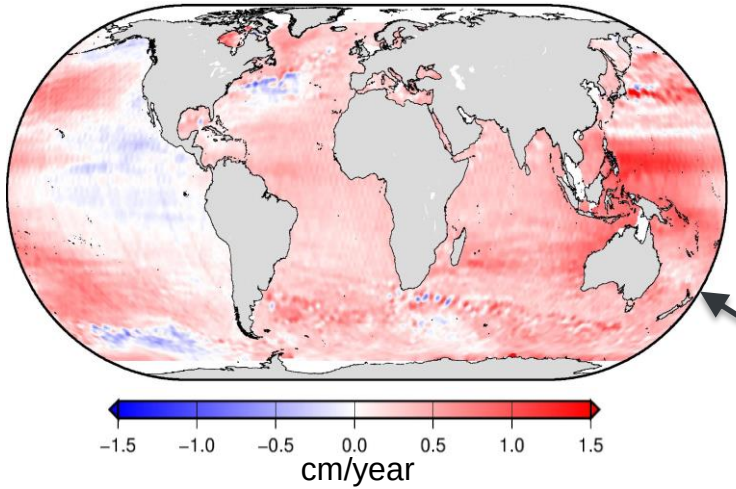
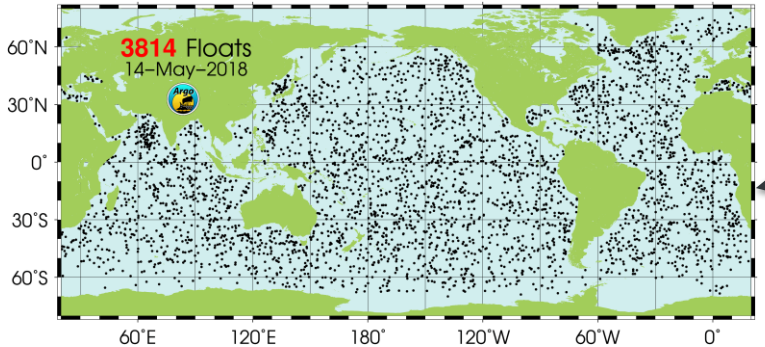




- Sea level an important indicator of global climate change
  - Reflects a host of processes and acts as a ‘bulk’ measure of ocean column properties
- **But**: it is poorly measured in the polar oceans due to
  - Conventional altimetry does not cover the polar oceans or fails due to sea ice
  - *In situ* data (tide gauges, ARGO, etc.) more difficult due to harsh conditions/expense

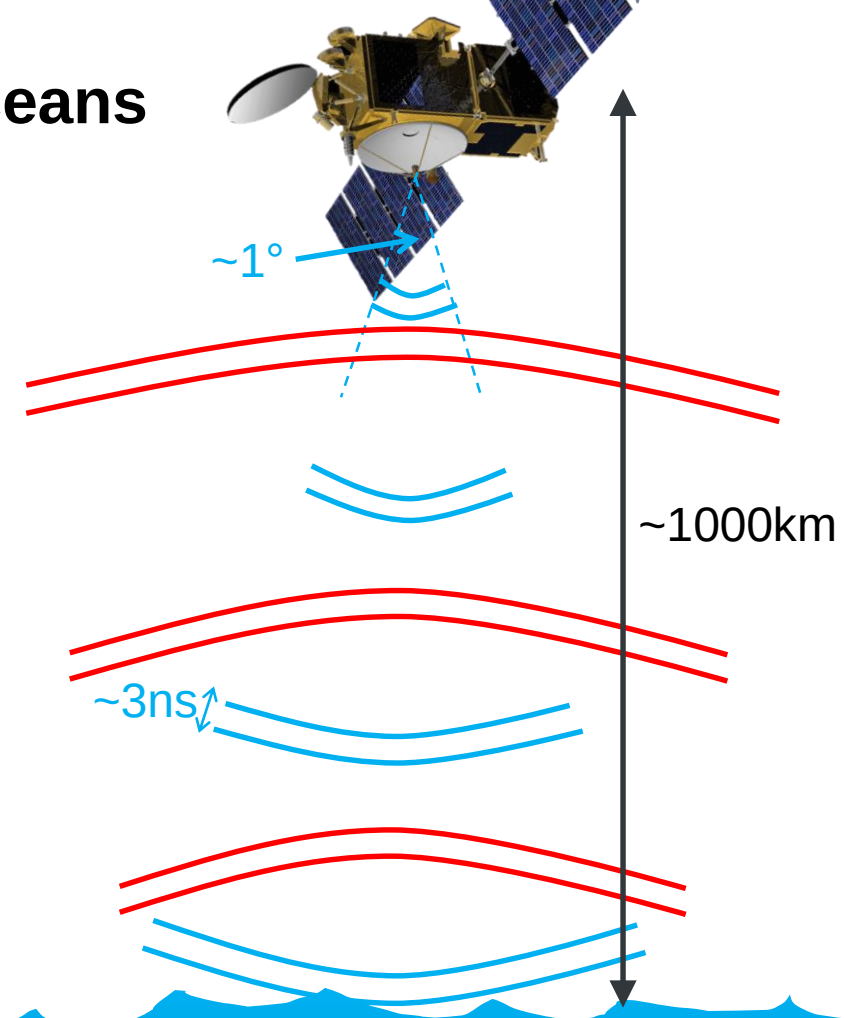
2. Radar altimetry in the polar oceans

2. Radar altimetry in the polar oceans

Conventional altimetry

- Satellite orbiting at ~1000km
- Emit radar pulses to surface
- Receive the reflected pulses and estimate the two-way travel time, convert to range
- Combine this with:
  - Satellite altitude
  - Geophysical corrections

→ Get sea surface height



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  - Homogeneously rough
  - Known decorrelation scales

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  - Deformation features (e.g., ridging)

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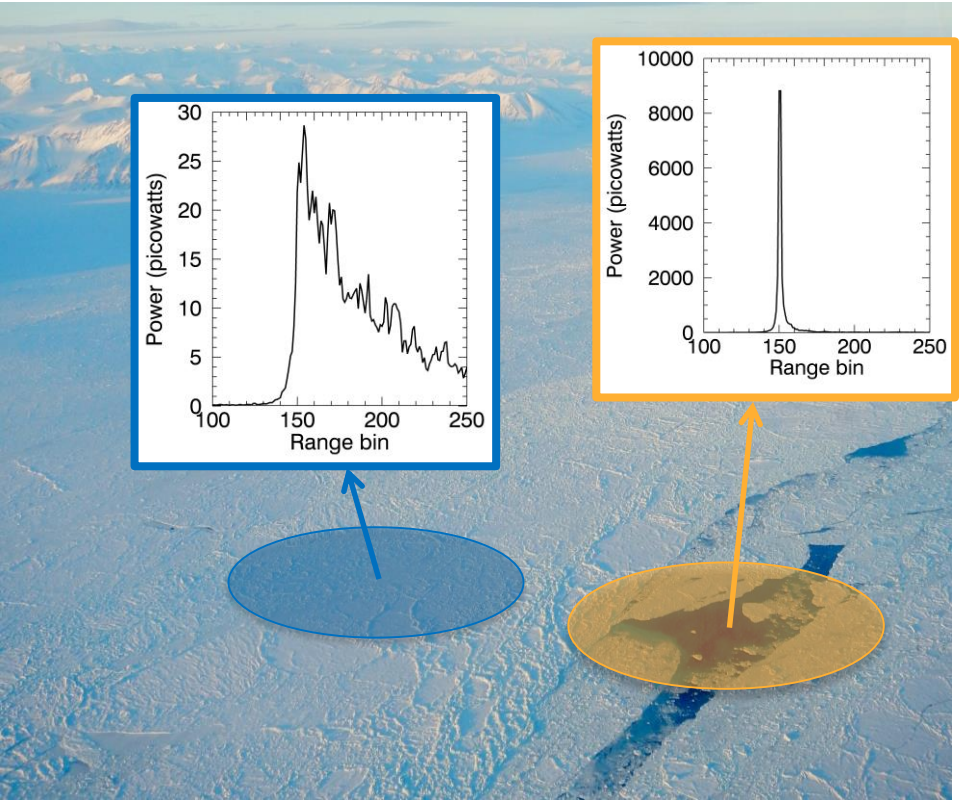

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  - Homogeneously rough
  - Known decorrelation scales
- Sea ice scattering is highly *inhomogeneous*
  - Leads (cracks) appear very bright (specular; mirror-like)
  - Deformation features (e.g., ridging)
- Different scattering properties allows to distinguish between surface types

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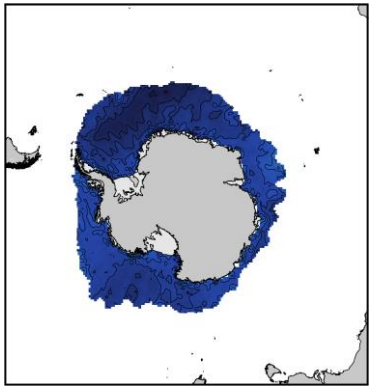

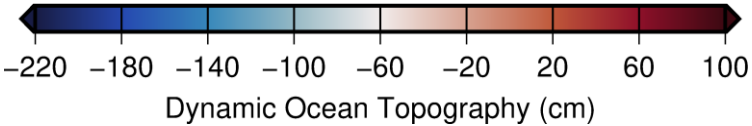

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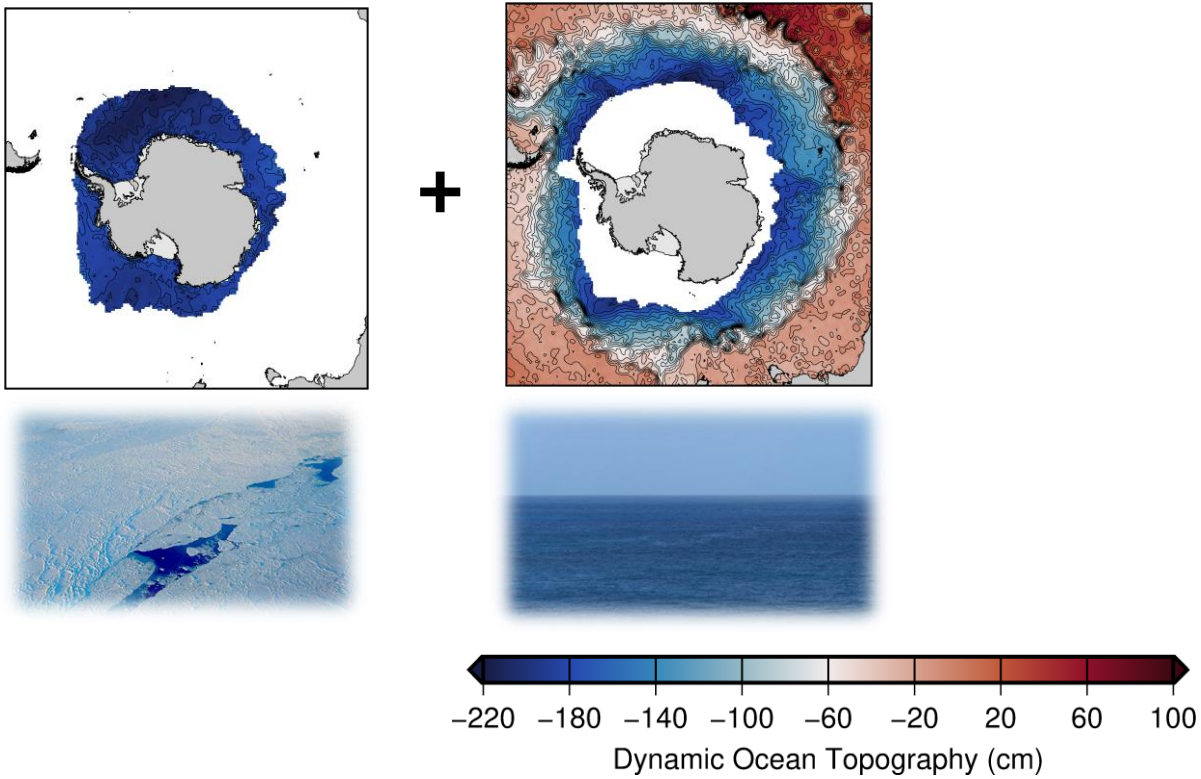

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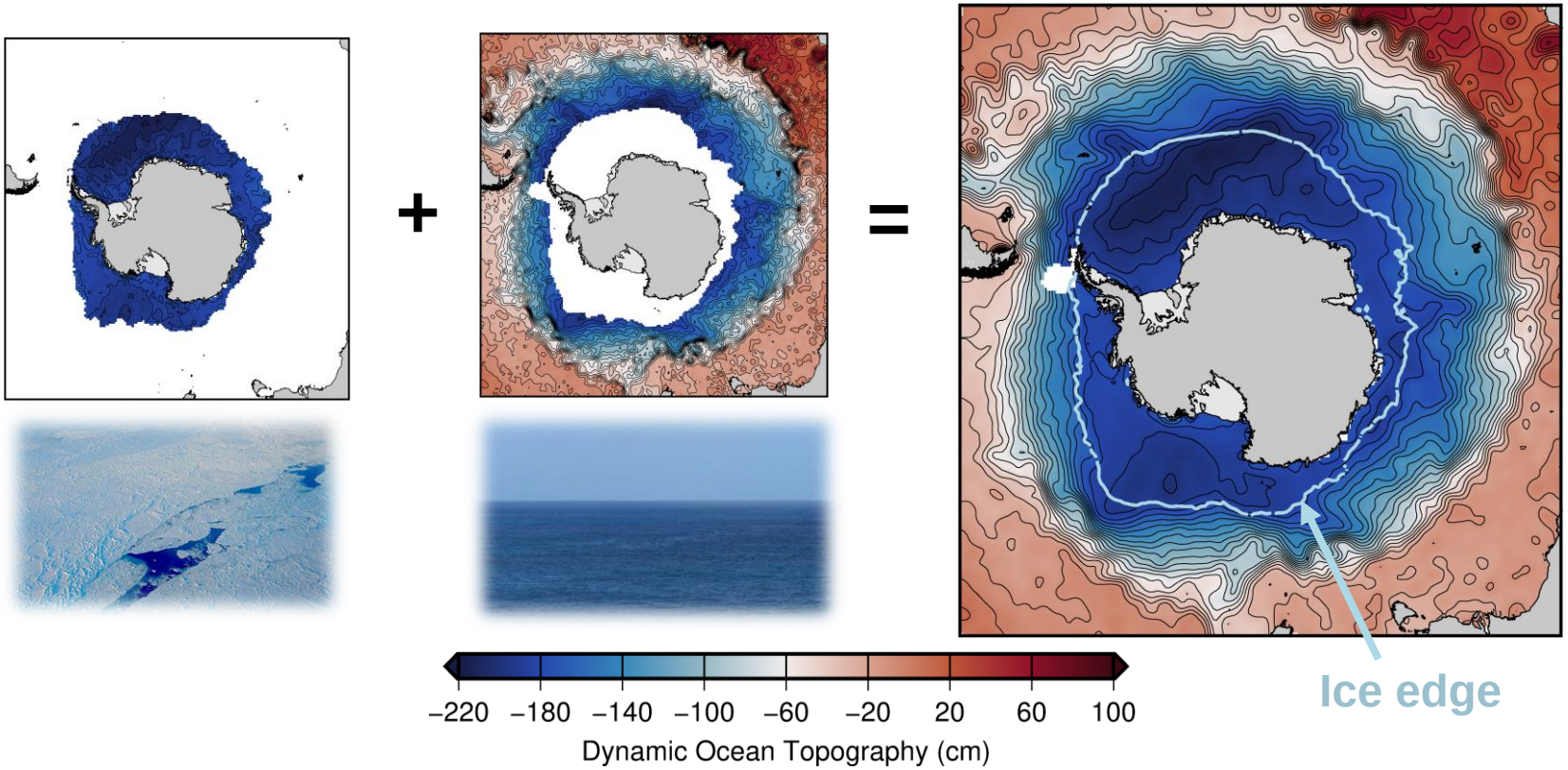

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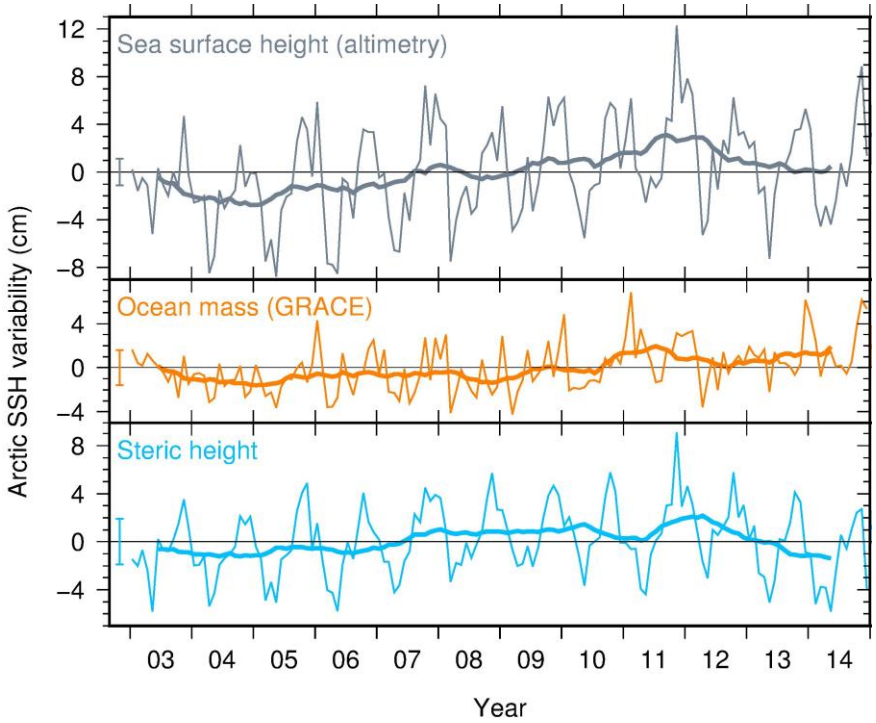

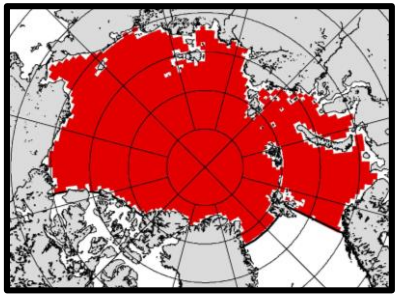

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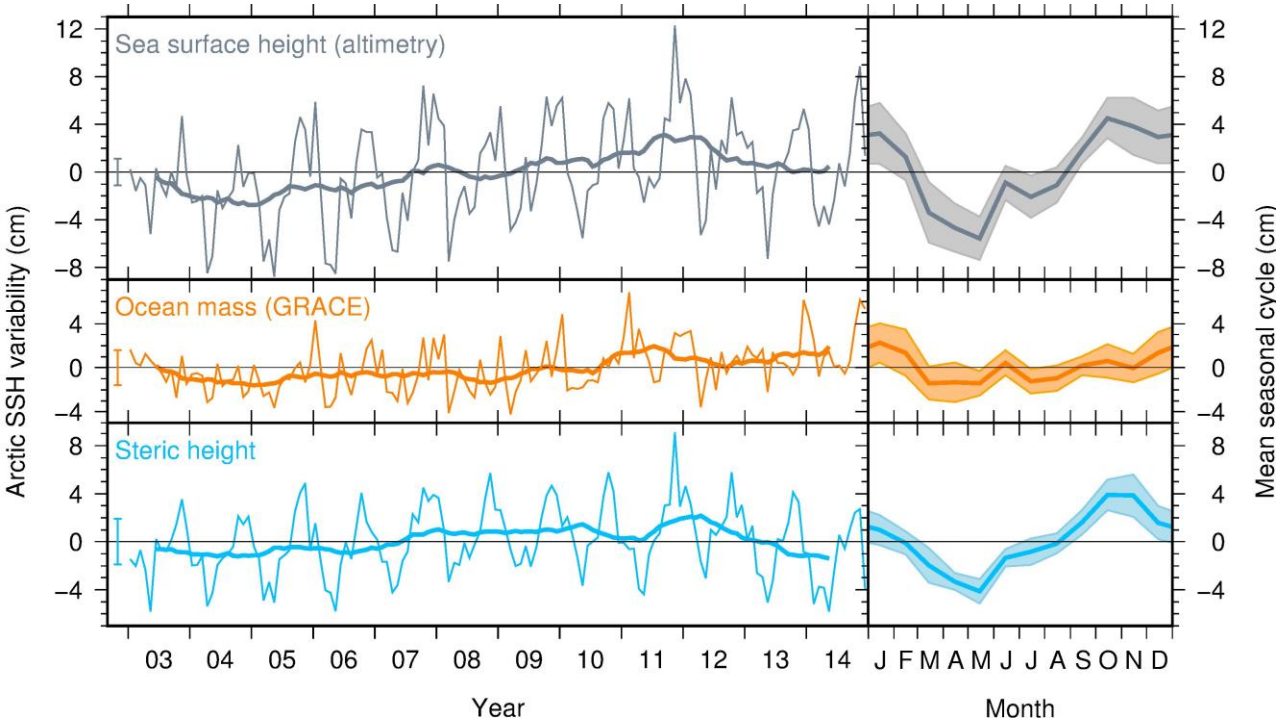

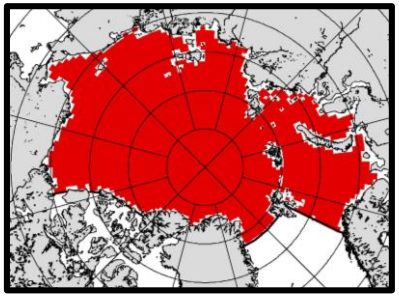

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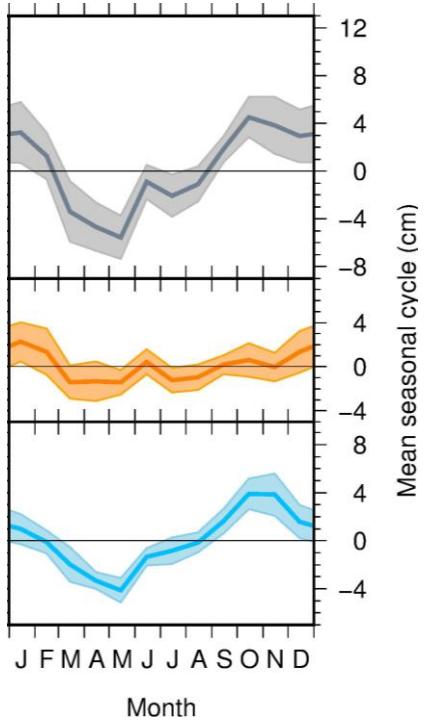
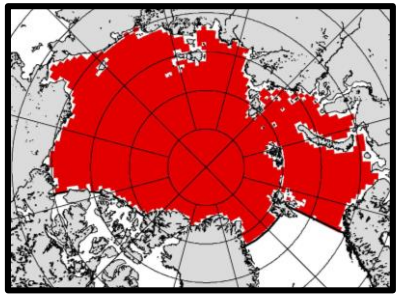
3. Freshwater fluxes dominate Arctic sea level variability

- Seasonal cycle of steric height dominates SSH variability (39% of total variability)
  - ➢ Summertime freshwater input from rivers, P-E, sea ice melt, Bering Strait inflow
  - ➢ Wintertime freshwater reduction from sea ice formation, Fram Strait export





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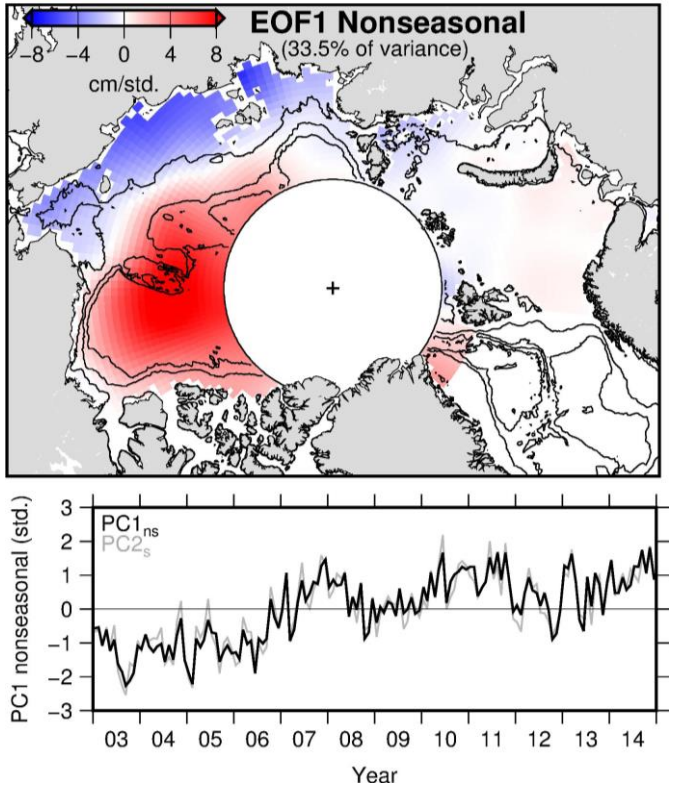
3. Freshwater fluxes dominate Arctic sea level variability

- Non-seasonal SSH variability is dominated by regional changes in freshwater storage
  - Beaufort Gyre freshwater accumulation signal accounts for 1/3 of non-seasonal variability
  - Concurrent reductions in freshwater on Siberian shelf seas



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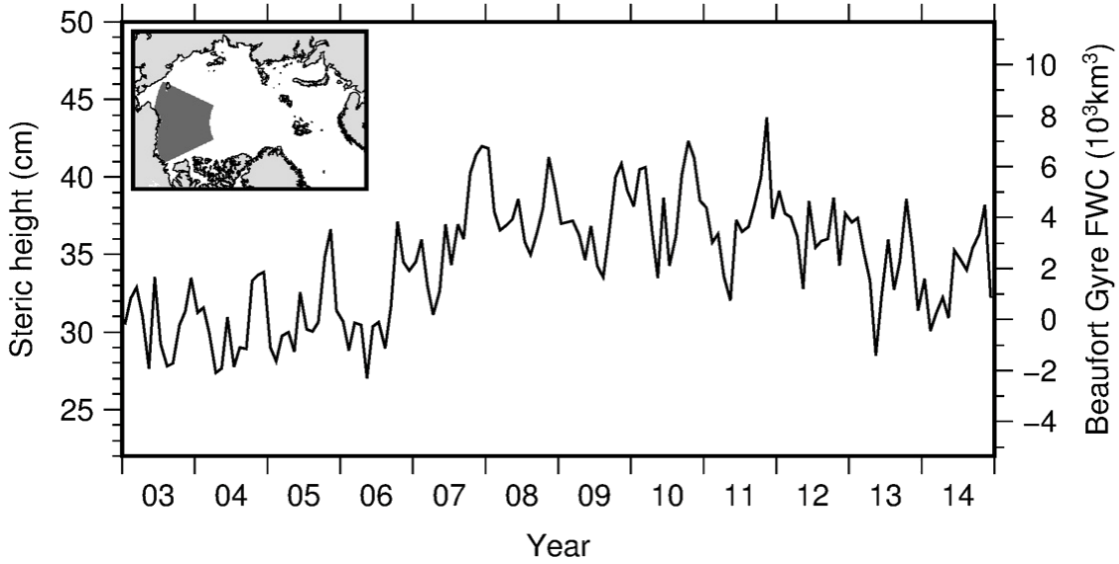
3. Freshwater fluxes dominate Arctic sea level variability

- Can use steric height to estimate FW accumulation in BG
  - +4,600 km^3 in 2010 relative to 2003-06; dominated by increase in 2007-08



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4. Currents sped up and the Beaufort Gyre wandered NW

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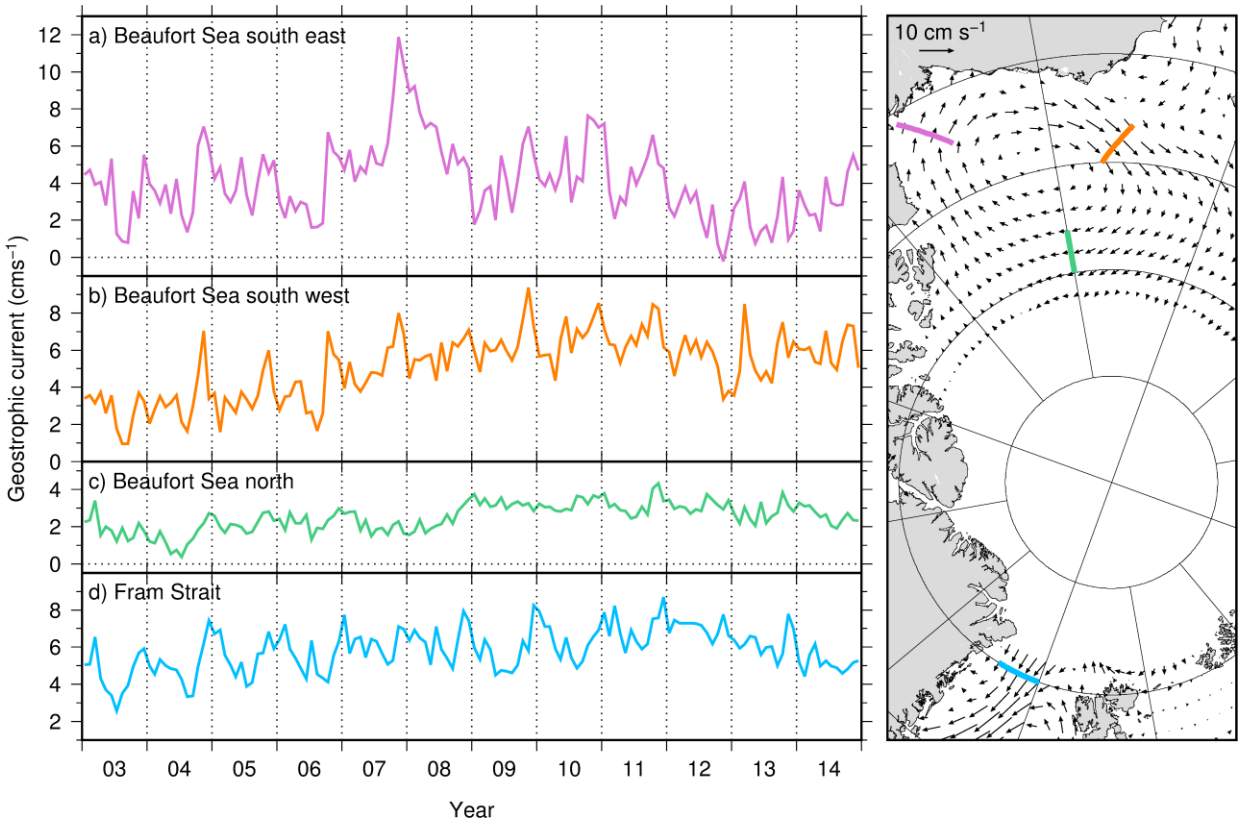
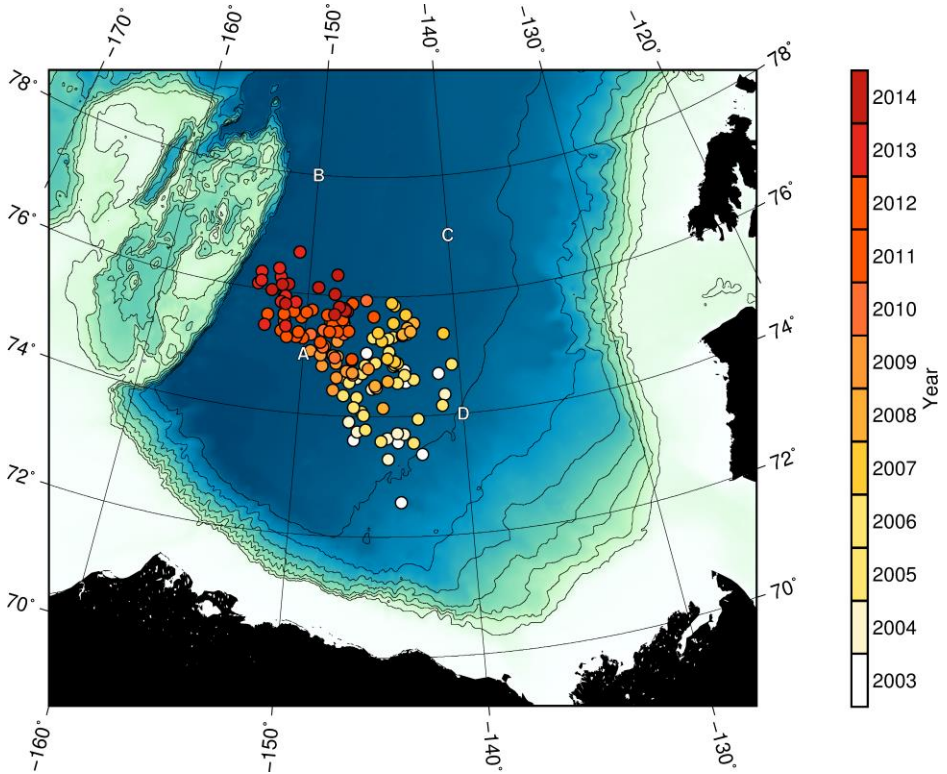
- Sea level changes associated with changing surface geostrophic circulation
- Anomalous circulation in the BG region in 2007
- Coincides with significant FW accumulation



Armitage et al. (2017), “Arctic Ocean surface geostrophic circulation 2003-2014”, *The Cryosphere*, 11.

4. Currents sped up and the Beaufort Gyre wandered NW

- Beaufort Gyre shifted position by ~300km
- Gyre center close to Chukchi plateau by end of time period
- Implications for gyre interactions/dissipation with bathymetry



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5. The Antarctic Slope Current shows strong seasonal variability

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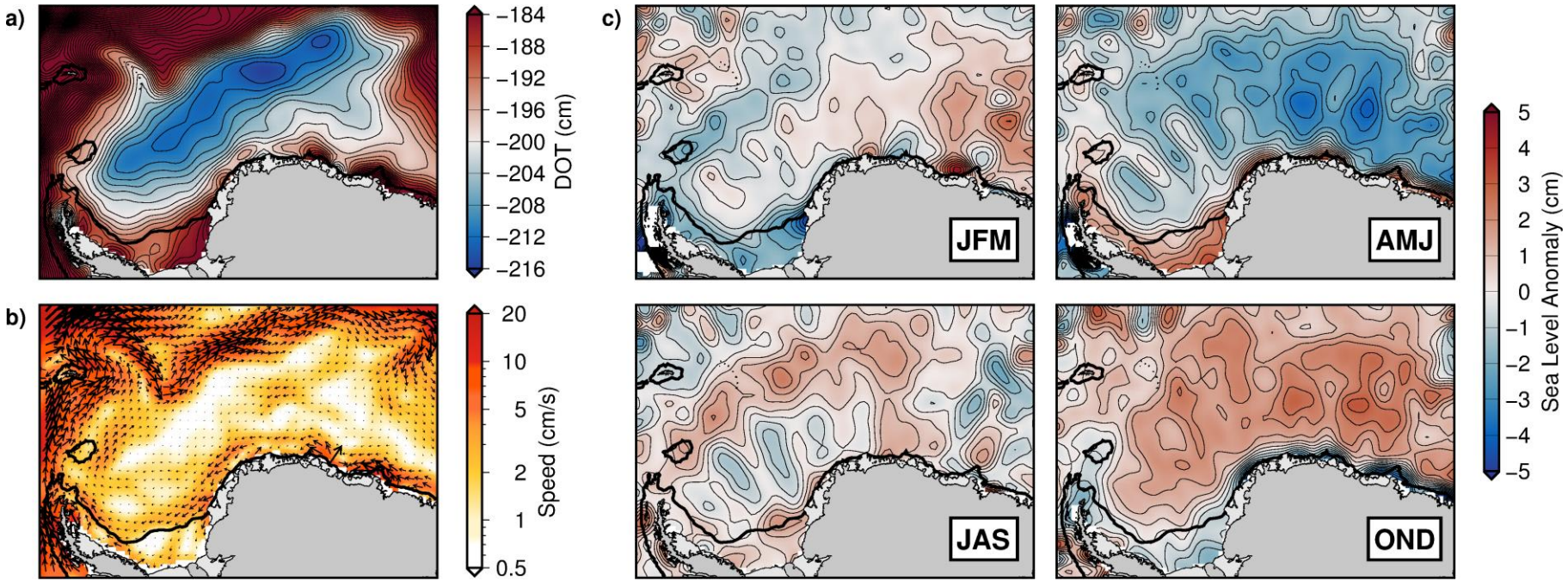

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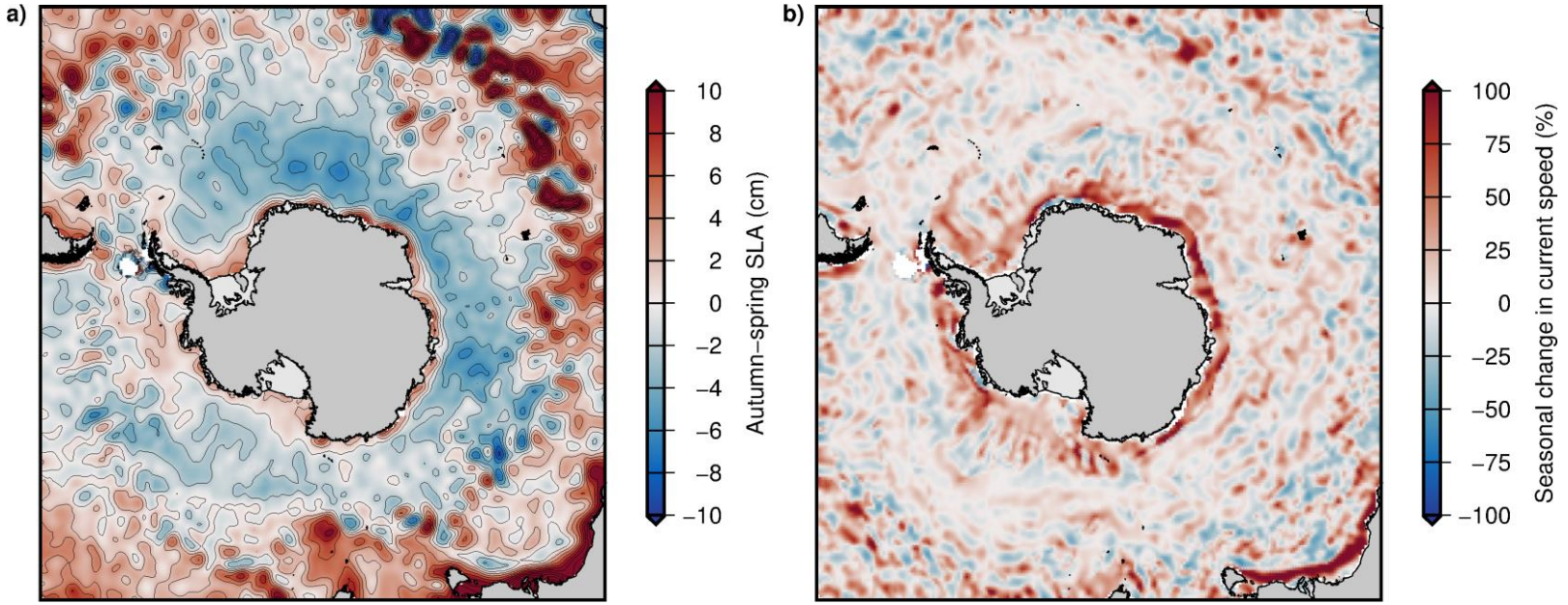

- Opposing seasonal anomalies between shelf and deeper basins
- ASC up to twice as fast in Autumn, weakest in winter and spring

Armitage et al. (2018), “Dynamic topography and sea level anomalies of the Southern Ocean: Variability and teleconnections”, *JGR-Oceans*, 123.

6. The Ross/Weddell Gyres strongly influenced by wind

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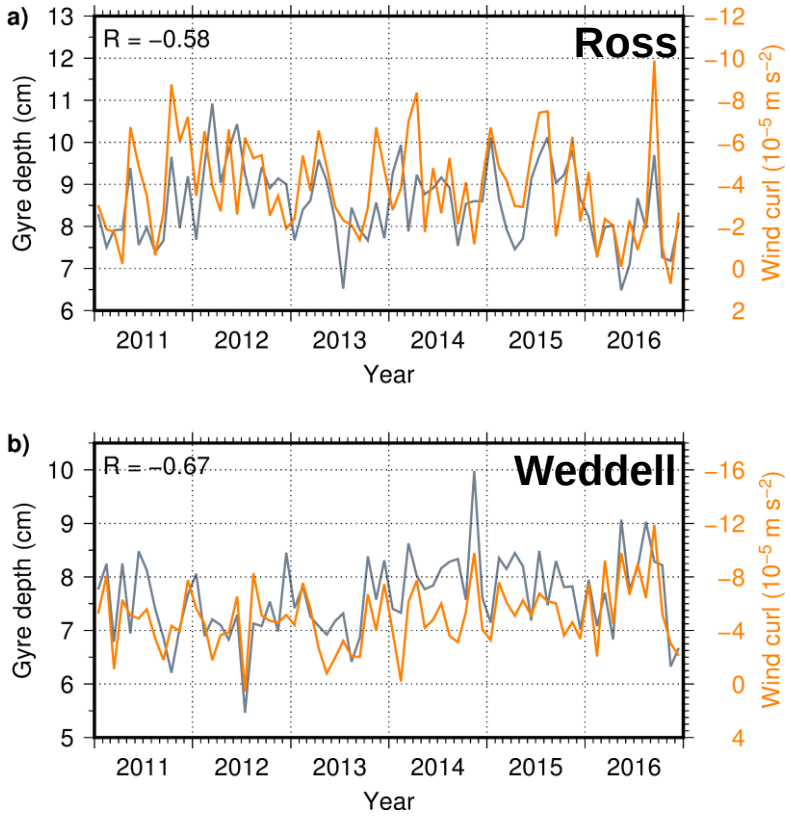
6. The Ross/Weddell Gyres strongly influenced by wind

- Gyre circulation strength is well correlated with (nonseasonal) wind curl
  - In turn weakly correlated with SAM



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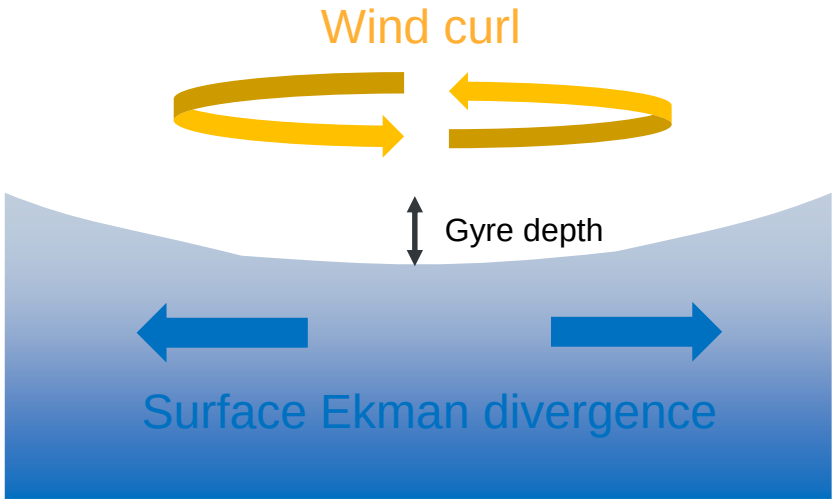

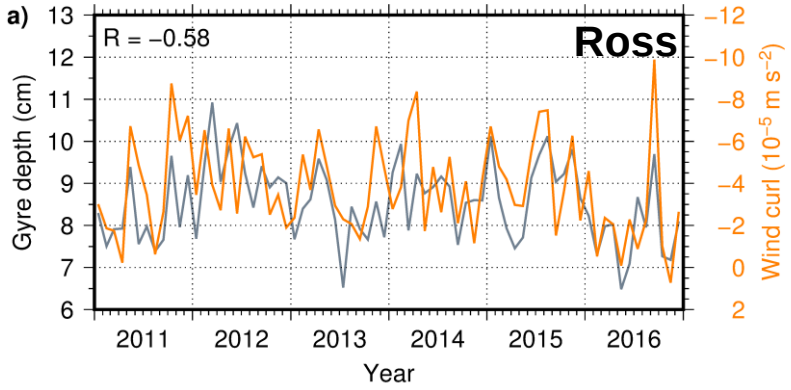

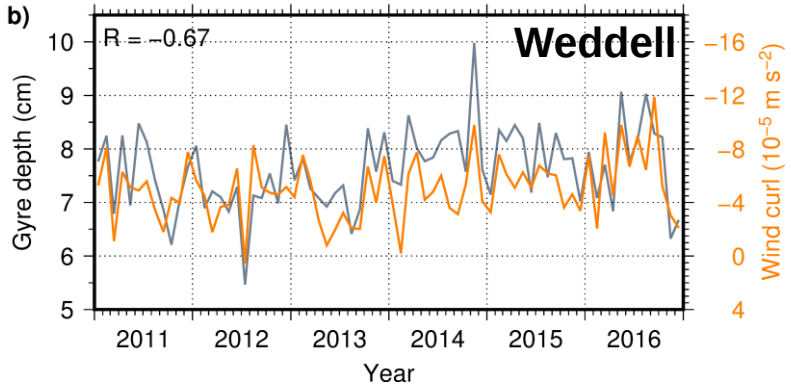

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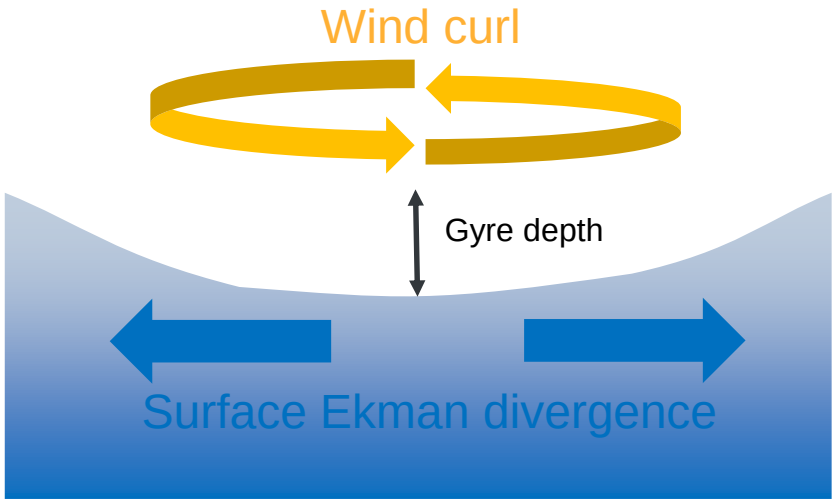

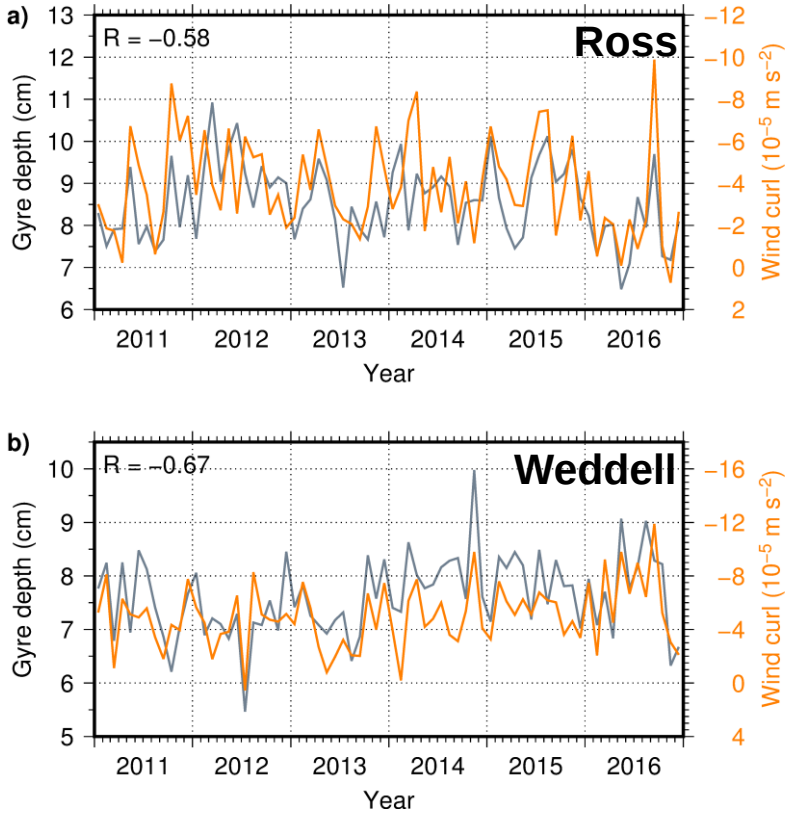

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7. Climate variability significantly affects polar sea level

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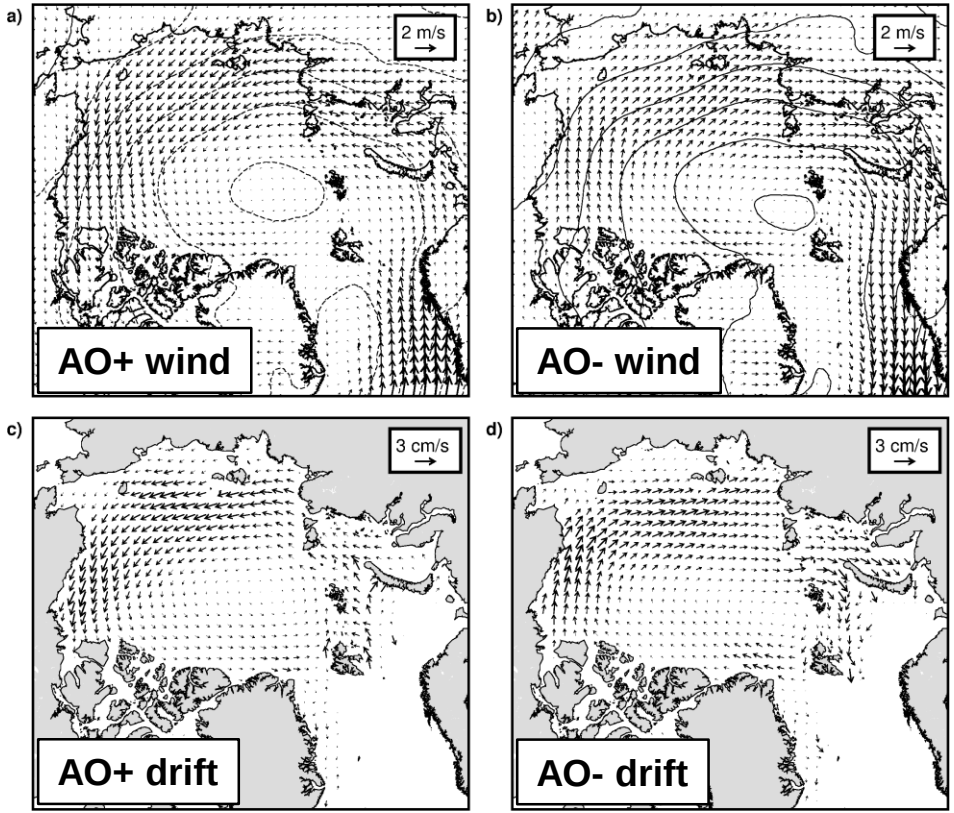
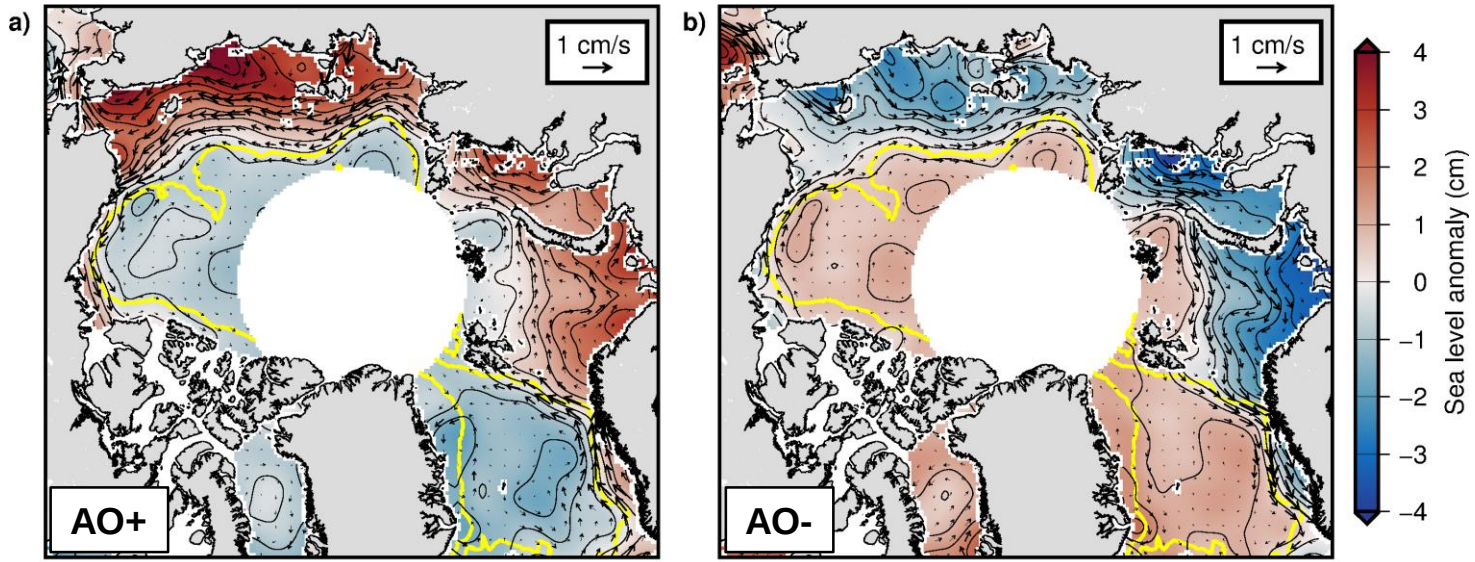
- Arctic Oscillation (AO) is leading mode of extratropical northern hemisphere atmospheric variability
- Pressure anomalies drive (anti)cyclonic wind anomalies
  - Drives ice drift anomalies in response



Armitage et al. (2018), "Arctic sea level and surface circulation response to the Arctic Oscillation", *GRL*, accepted.

7. Climate variability significantly affects polar sea level

- Opposing sea level response between shelves/deep basin
- Sets up along-shelf geostrophic current anomalies



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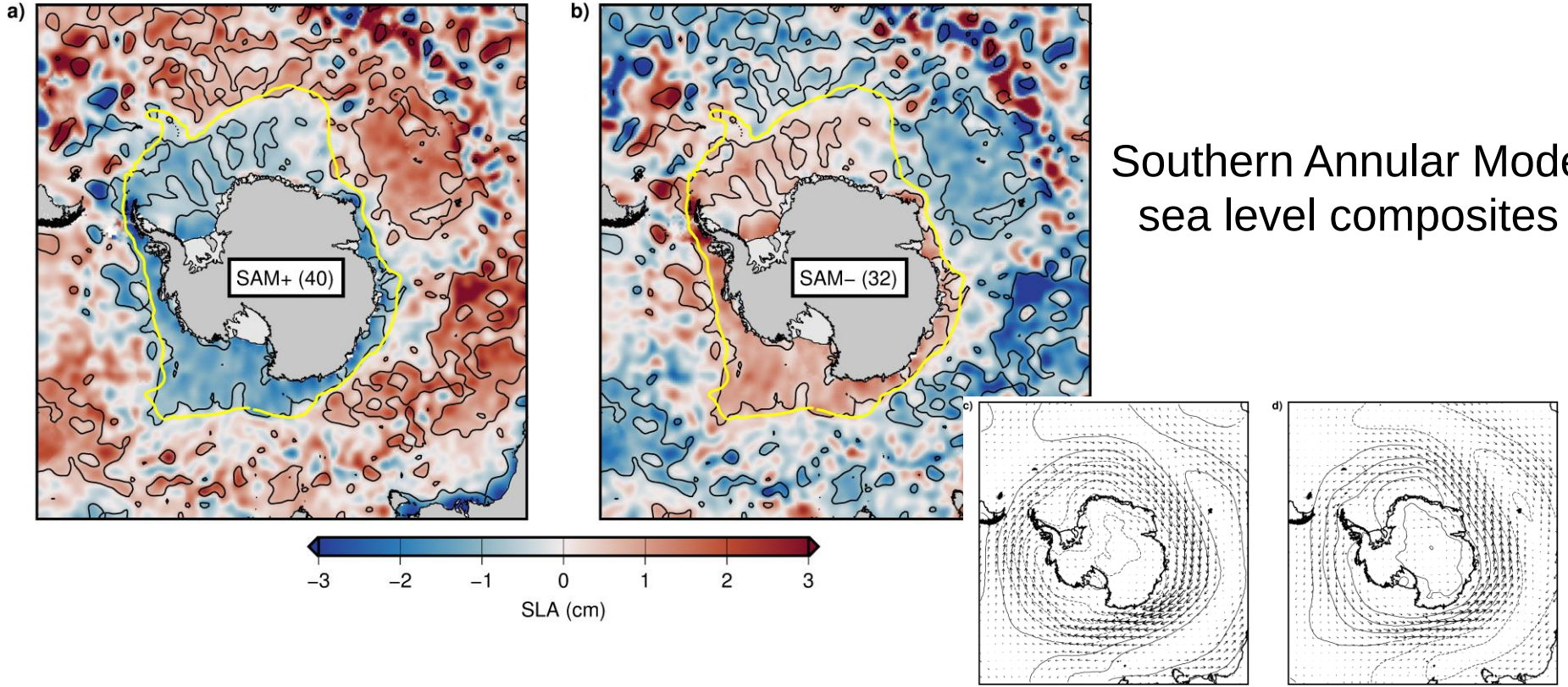

Southern Annular Mode sea level composites

Armitage et al. (2018), "Dynamic topography and sea level anomalies of the Southern Ocean: Variability and teleconnections", *JGR-Oceans*, 123.

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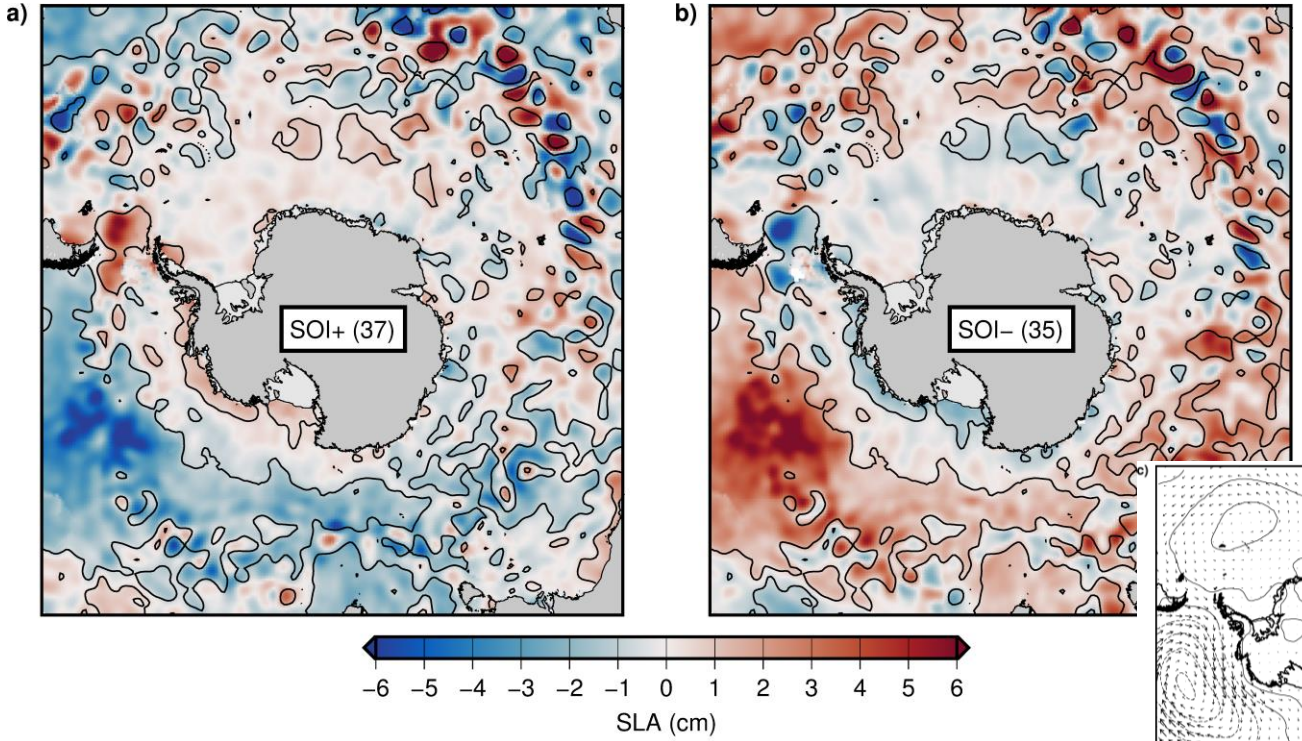
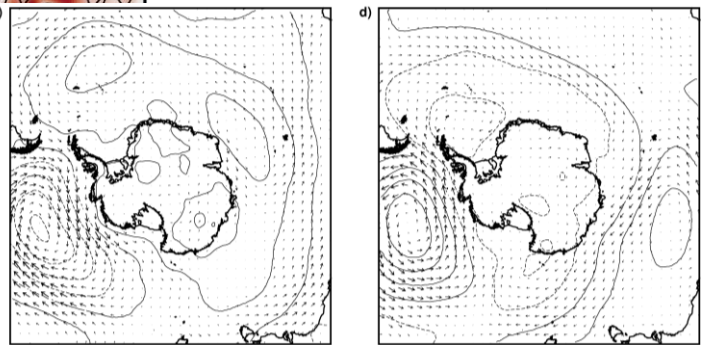


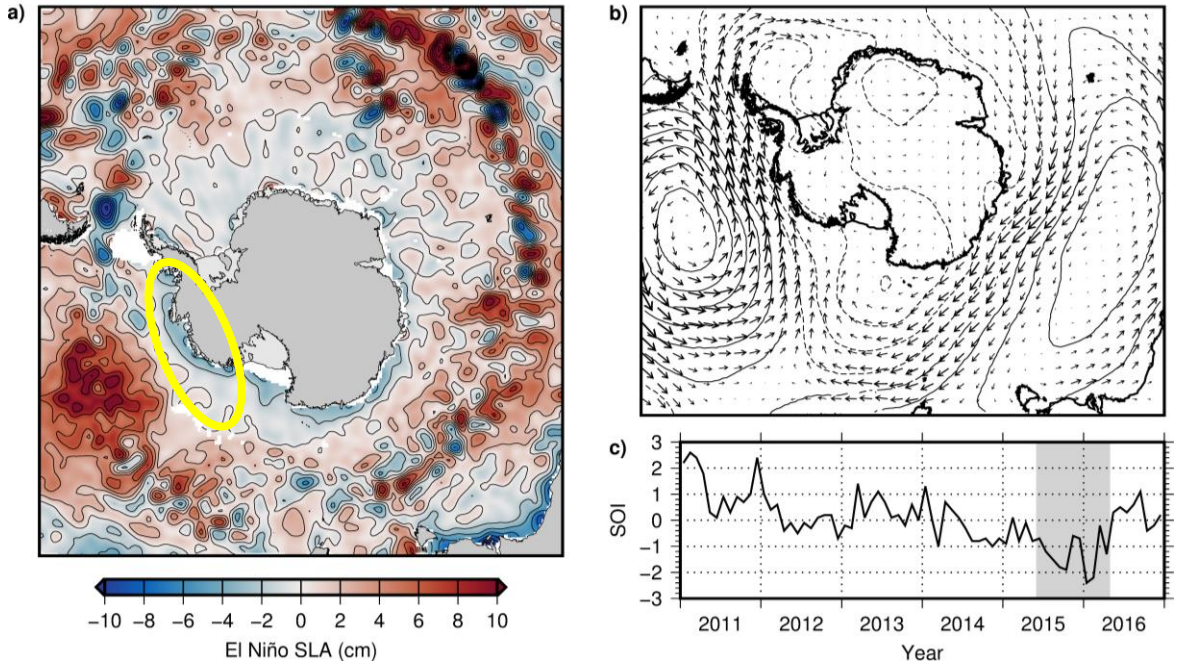


Southern Oscillation sea level composites

Armitage et al. (2018), “Dynamic topography and sea level anomalies of the Southern Ocean: Variability and teleconnections”, *JGR-Oceans*, 123.

7. Climate variability significantly affects polar sea level

- Negative wind-driven coastal sea level anomalies observed off West Antarctica during 2015-16 El Niño event
- What was the sub-surface response?



Armitage et al. (2018), “Dynamic topography and sea level anomalies of the Southern Ocean: Variability and teleconnections”, *JGR-Oceans*, 123.

Summary

Radar altimetry is a great tool for polar oceanography!

1. Freshwater fluxes dominate Arctic sea level variability
   - Seasonal freshwater flux drives large seasonal cycle
   - Decadal freshwater accumulation in the Beaufort gyre
2. Arctic surface geostrophic currents accelerated and the Beaufort Gyre drifted 300km northwest between 2003-2014
3. The Antarctic Slope Current shows strong seasonal variability
4. The Ross/Weddell Gyres are strongly influenced by local wind
5. Atmospheric climate variability (SAM/Southern Oscillation/Arctic Oscillation) drives significant sea level variability

Data:

- Arctic Ocean: http://www.cpom.ucl.ac.uk/dynamic_topography/
- Southern Ocean: https://rkwok.jpl.nasa.gov/cryosat2/

Armitage et al. (2016), “Arctic sea surface height variability and change from satellite radar altimetry and GRACE, 2003-2014”, *JGR-Oceans*, 121.

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@twkarmitage

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