Mean structure, long-term change and eddy motions in the Southern Ocean: A perspective from altimetry, Argo and state estimation

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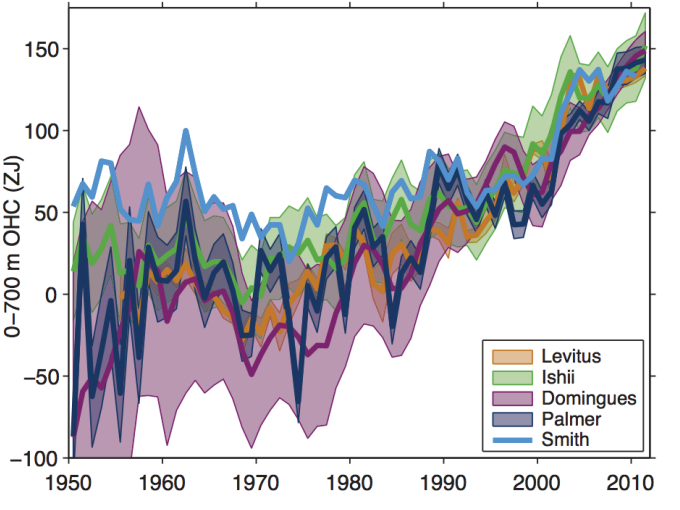
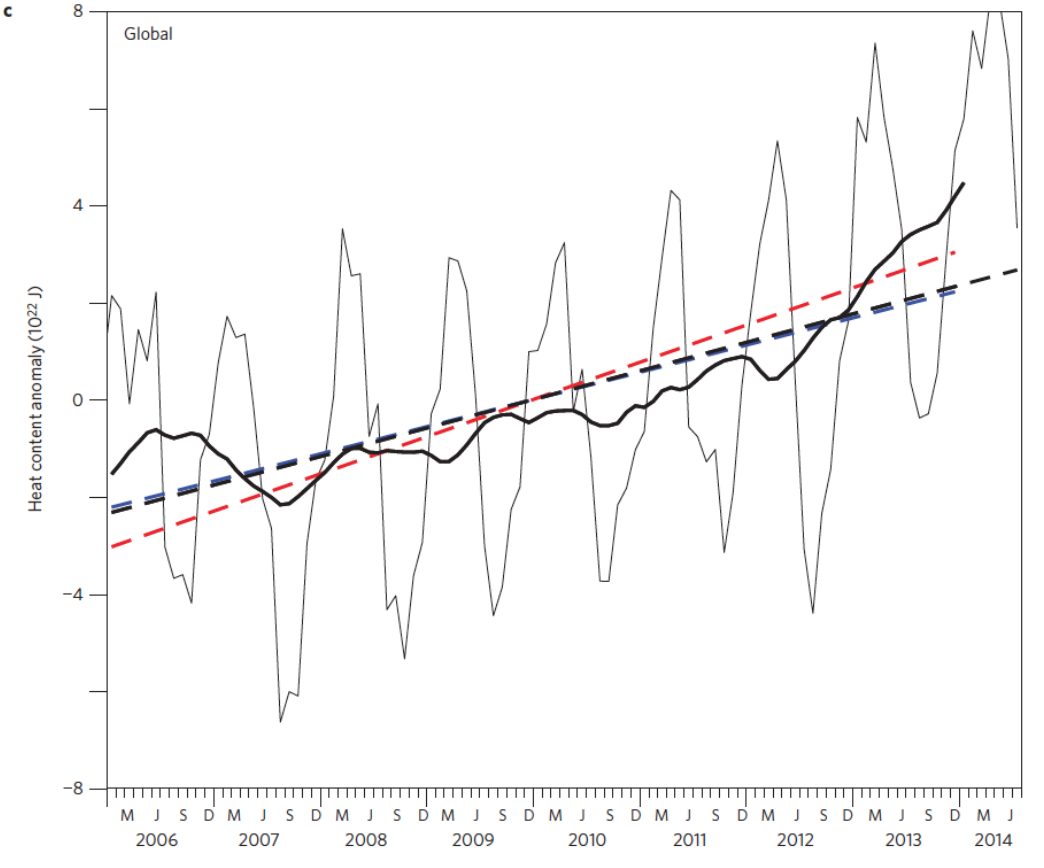


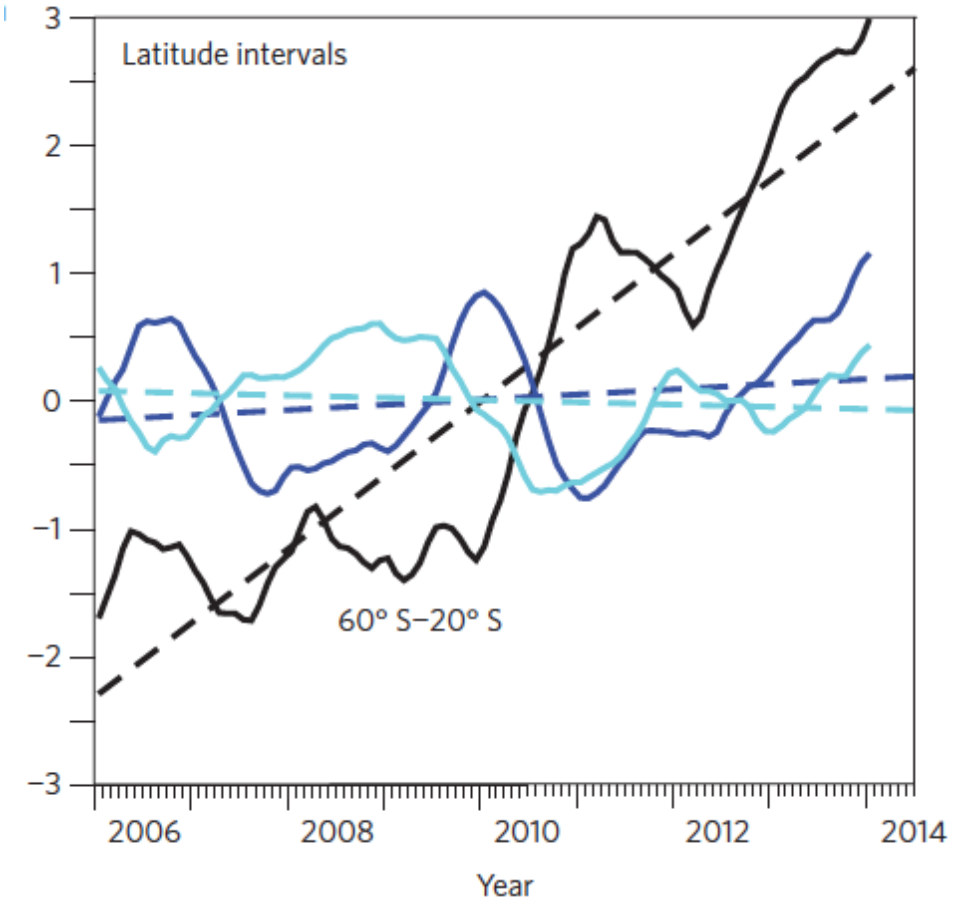
IPCC AR5, Ch. 3
http://www.ipcc.ch/report/ar5/wg1/
1 ZJ = 10^{21} J

Ocean heat content trends since the start of Argo



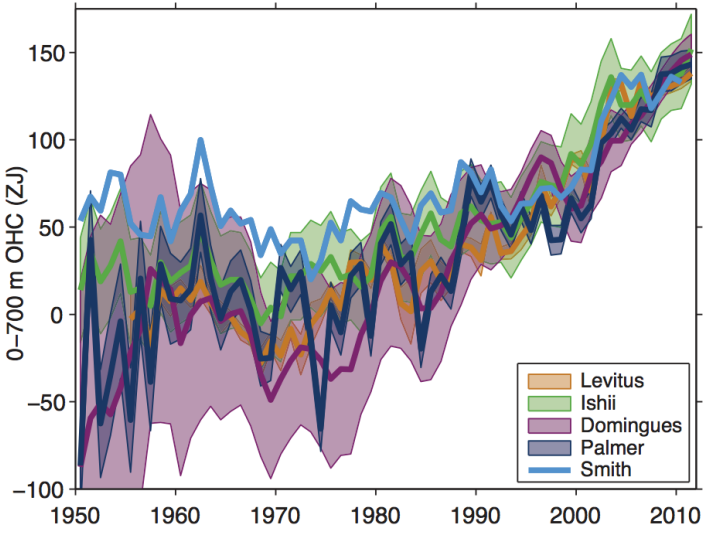
Roemmich et al, Nature Climate Change, 2015

Warming concentrated in Southern Ocean



10^{22} J, Roemmich et al, Nature Climate Change, 2015

Outline



IPCC AR5, Ch. 3
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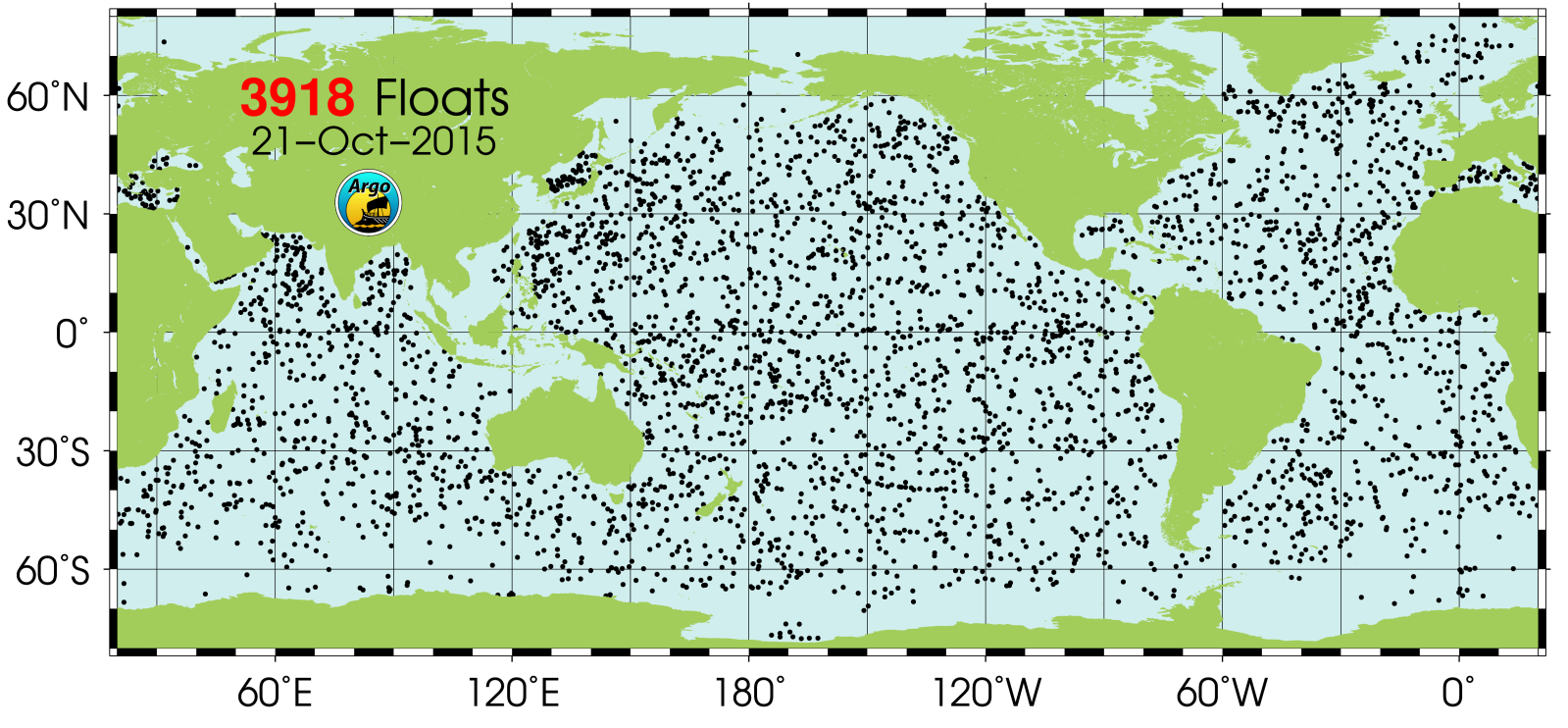
1 ZJ = 10^{21} J

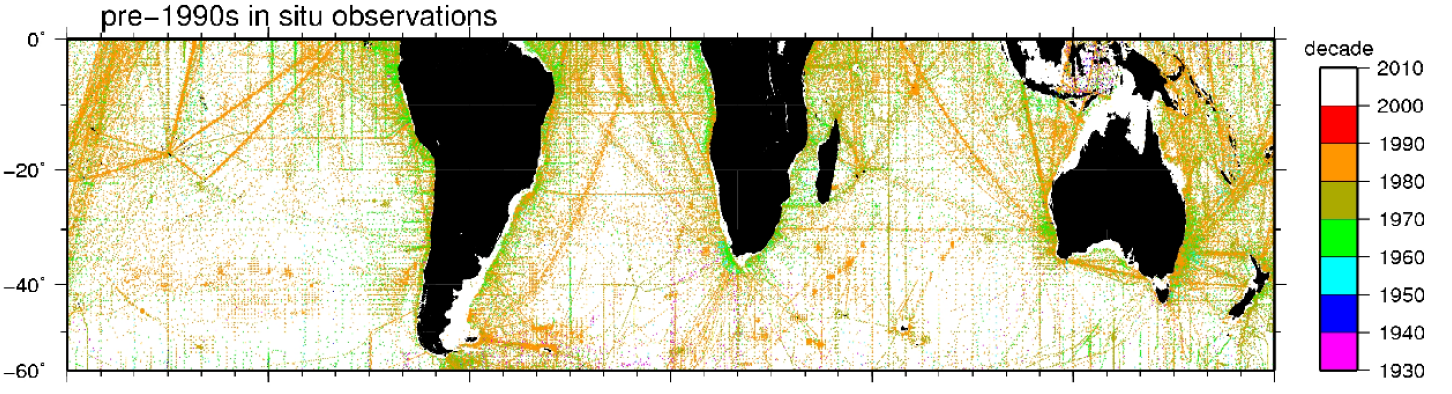
- Can we use eddy variability from altimetry to refine our estimates of ocean warming?
- What does altimetry tell us about the role of eddies in heat advection of the ACC?

Since 2004, Argo has provided dense data coverage



Floats reporting data in last 30 days: http://www.argo.ucsd.edu/

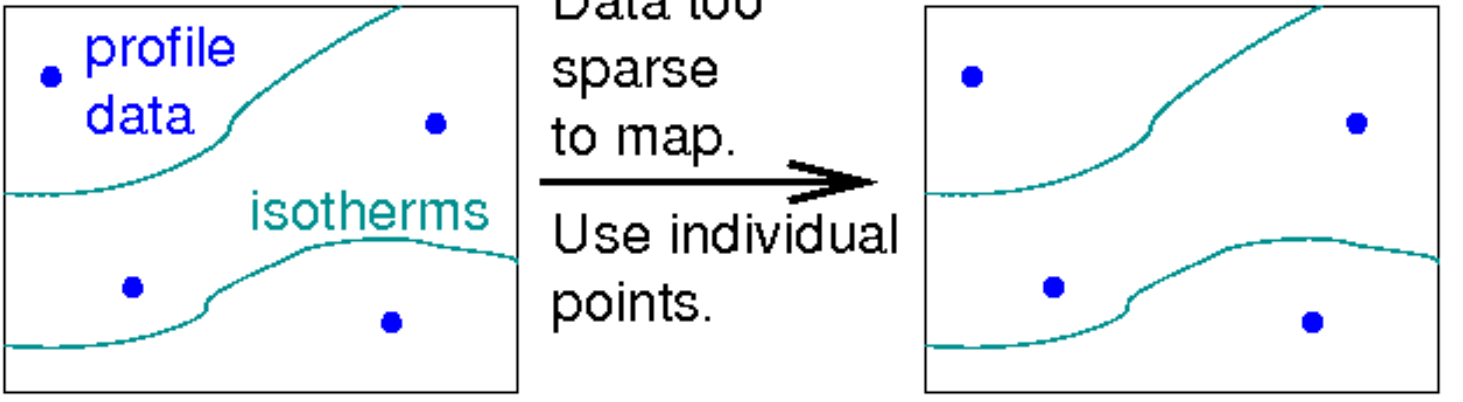
Sparse historic data: Too gappy to map easily



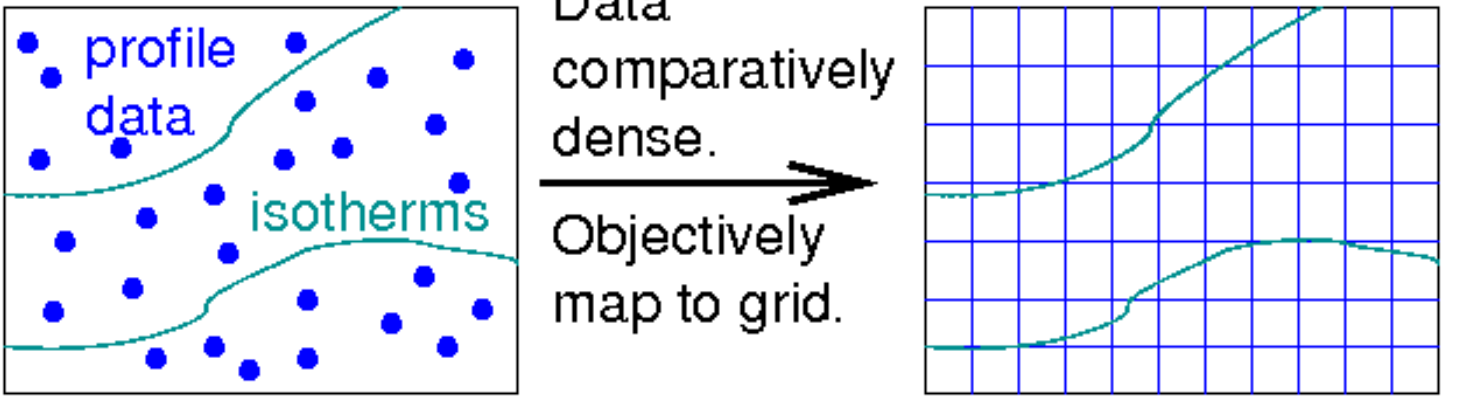
(Gille, J. Climate, 2008)

How do we assess change in T or S?

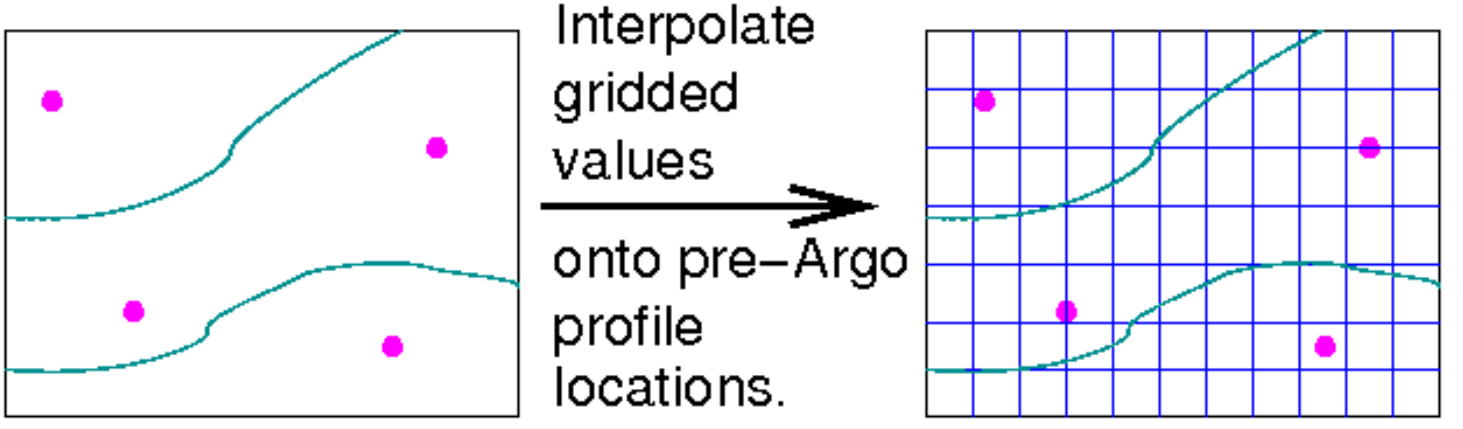
Historic data:



Since 2004:

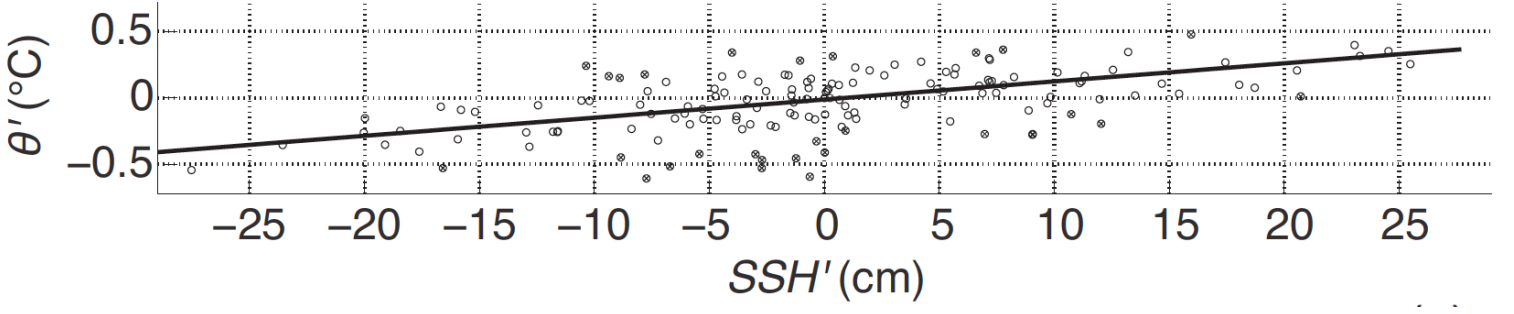


How do we assess change in T or S?



- Compute $T_{mapped} - T_{profile}$.
- Largest uncertainties in historic profile data....
- But best prospects for minimizing uncertainty are by improving Argo-based maps.
- For historic data and modern data, eddy variability poses large source of uncertainty.
- Can we use eddy variability from altimetry to reduce uncertainty in modern reference maps? (See Willis and Fu, 2008)

Eddy variability from altimetry correlations with sub-surface temperature anomalies

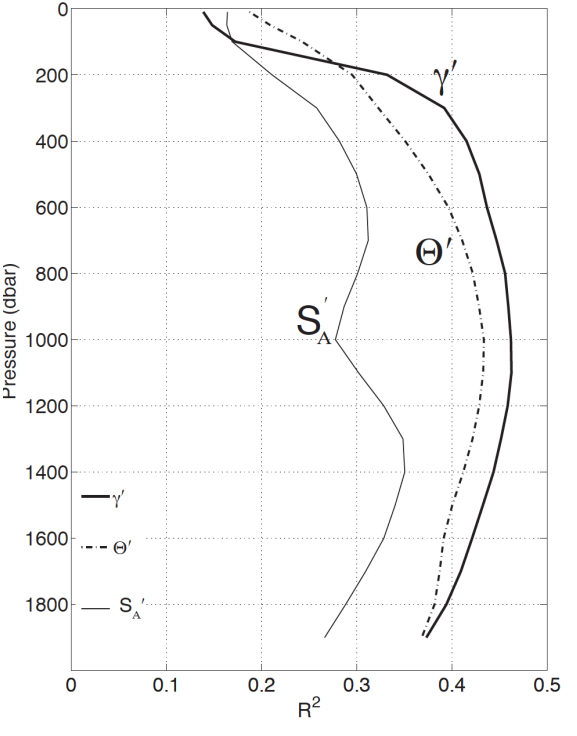


Zajaczkovski and Gille, submitted, 2015

- Correlation at 400 dbars, in southwest Atlantic (55°S, 45°W).
- Eddies are the biggest non-seasonal process.
- Regressions have similar structure for neutral density and salinity.

Southern-Ocean-averaged correlation coefficients (R^2) as a function of depth

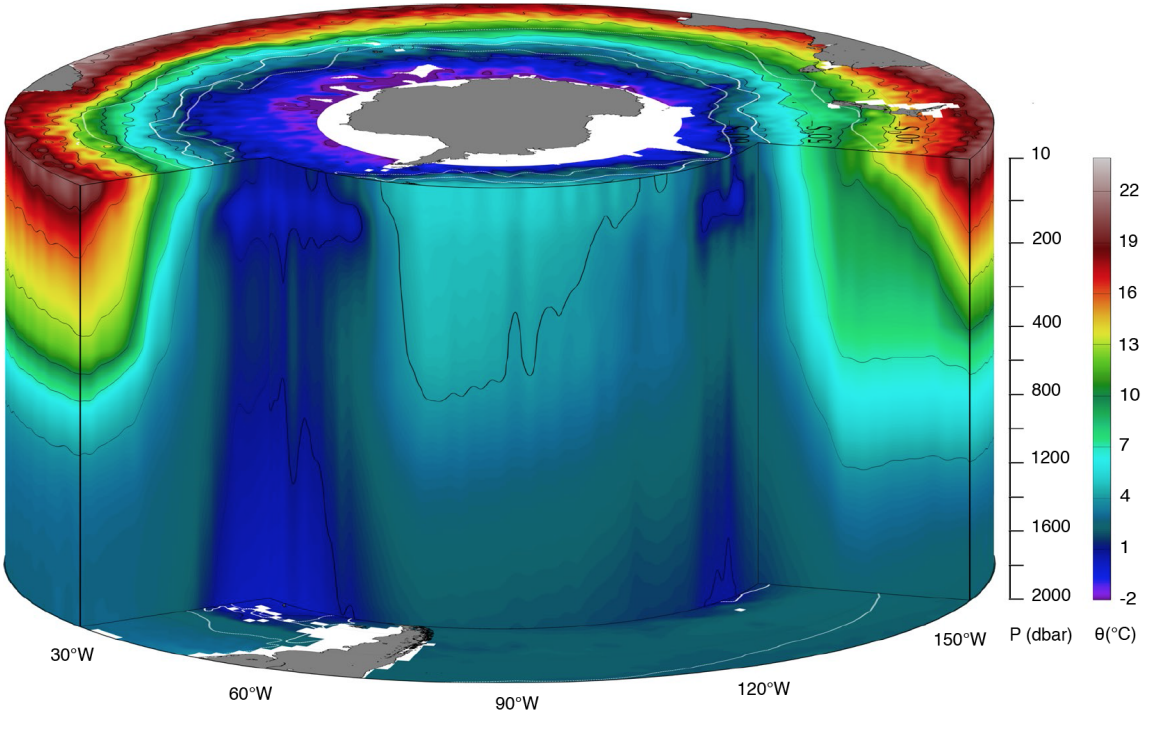
- SSH more correlated with sub-surface anomalies than mixed-layer anomalies
- Largest correlation coefficients between 800 and 1200 dbars
- Consistent with deep-reaching eddy variability in Southern Ocean.
- Implication: Can use altimetry to reduce impact of eddy anomalies throughout water column.



Correlation coefficients: sea surface height and Argo

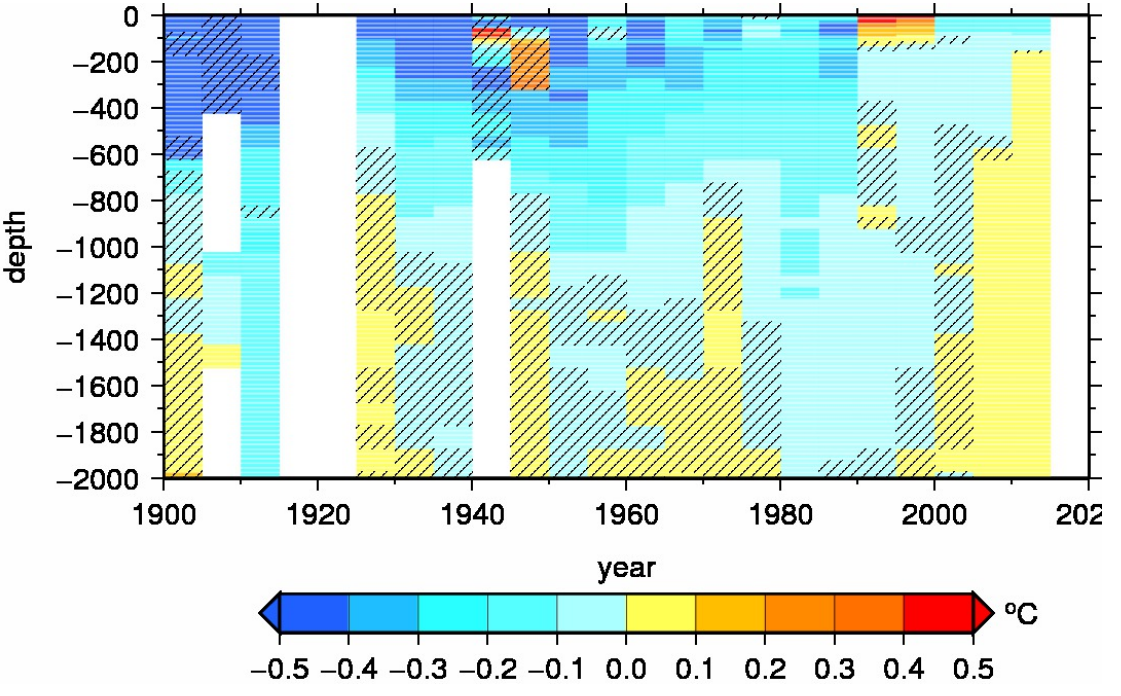
Zajaczkovski and Gille, submitted, 2015

Mapping the ocean from Argo: Time-mean temperature



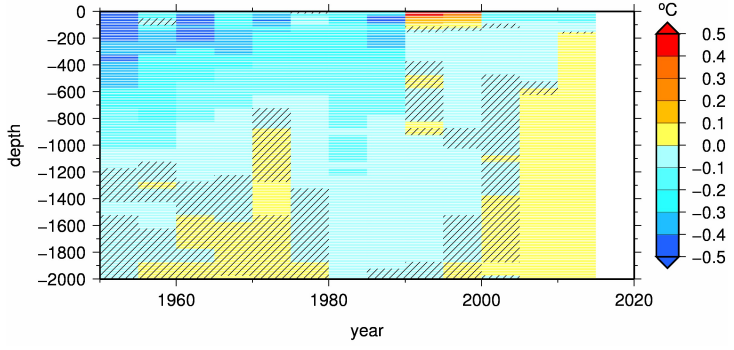
Zajaczkovski and Gille, submitted, 2015

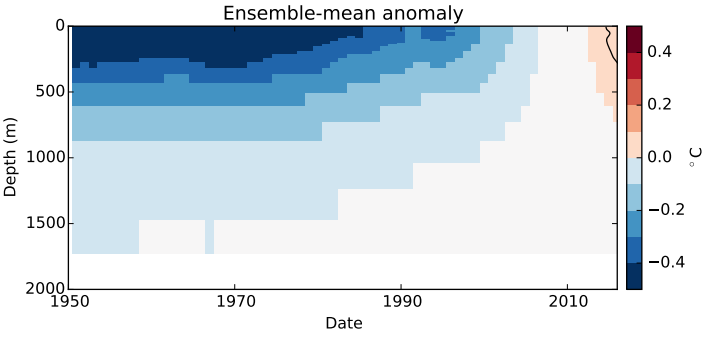
$\langle T_{mapped} - T_{profile} \rangle$: 5-year periods, 40-60° S



- Steady warming over past century.
- Large uncertainties in 1940s due to limited data.
- Apparent warming trend in 1990s mixed layer associated with seasonality.

Temperature change: 40-60° S (Observations vs Canadian Earth System Model)

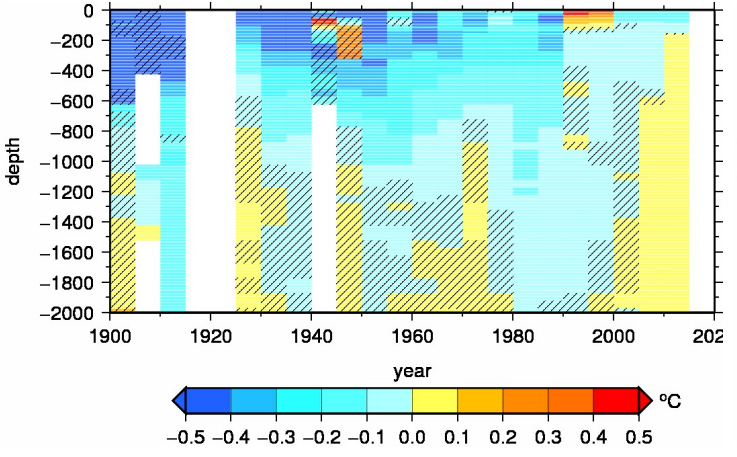




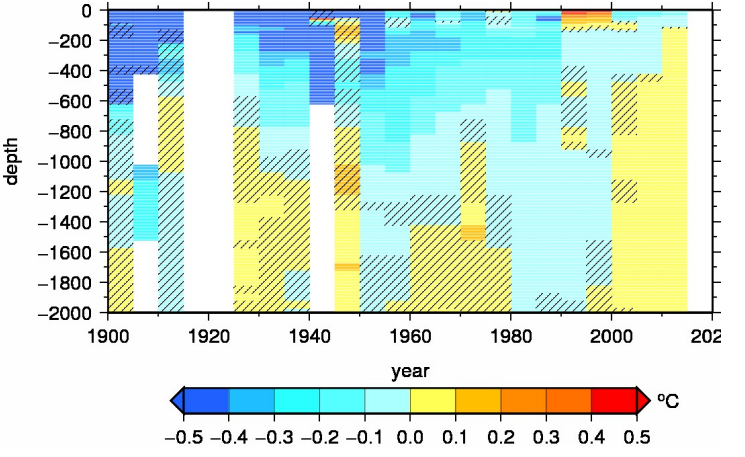
- Model and data show similar warming patterns since 1950.
- Warming surface intensified.
- Warming appears greater in recent years.

model from Swart and Fyfe, in prep, 2015

Does altimetry reduce statistical uncertainties?



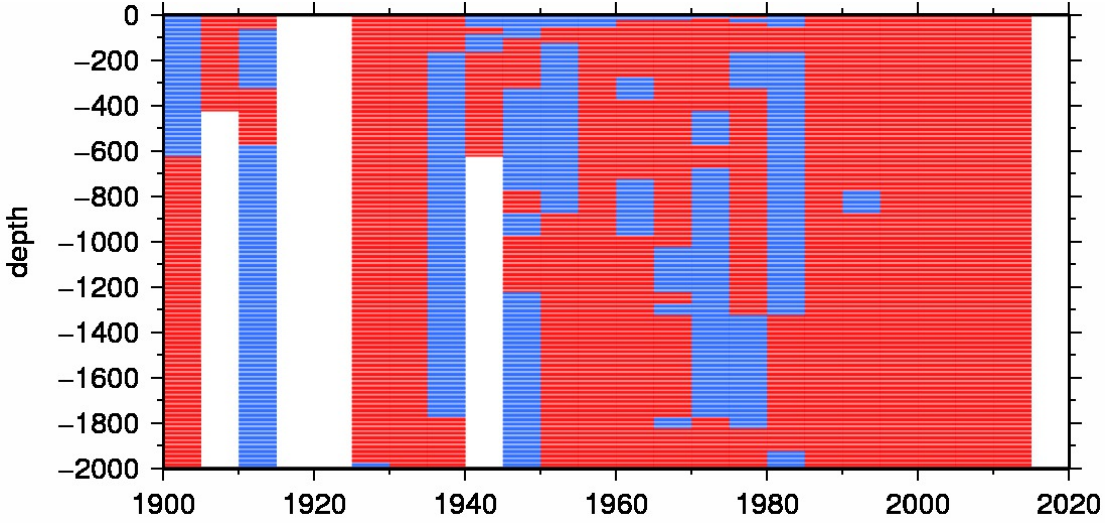
With altimeter-based eddy correction



Argo data alone

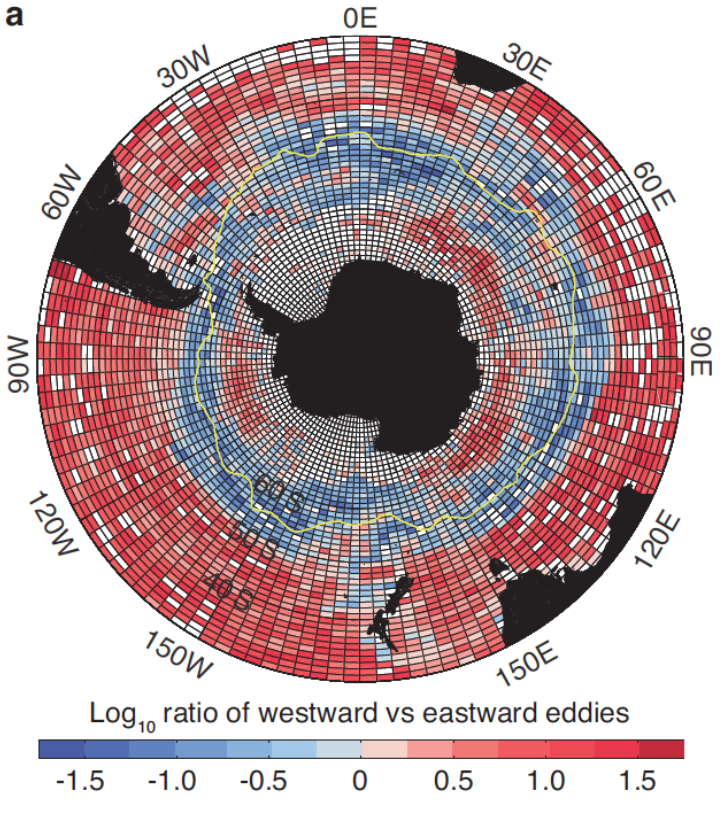
- Differences are largely negligible.
- In undersampled time periods (late 1940s, early 1910s), variance does appear to be reduced using SSH.

Altimeter-corrected mean typically leads to larger statistical uncertainties (counter to hypothesis)



- Smaller uncertainties with altimeter-corrected mean.
- Larger uncertainties with altimeter-corrected mean.
- Possible explanations
  - — Lingering bug in code....
  - — Altimeter correlation coefficients explain add than half variance; net effect of correction is to add noise.

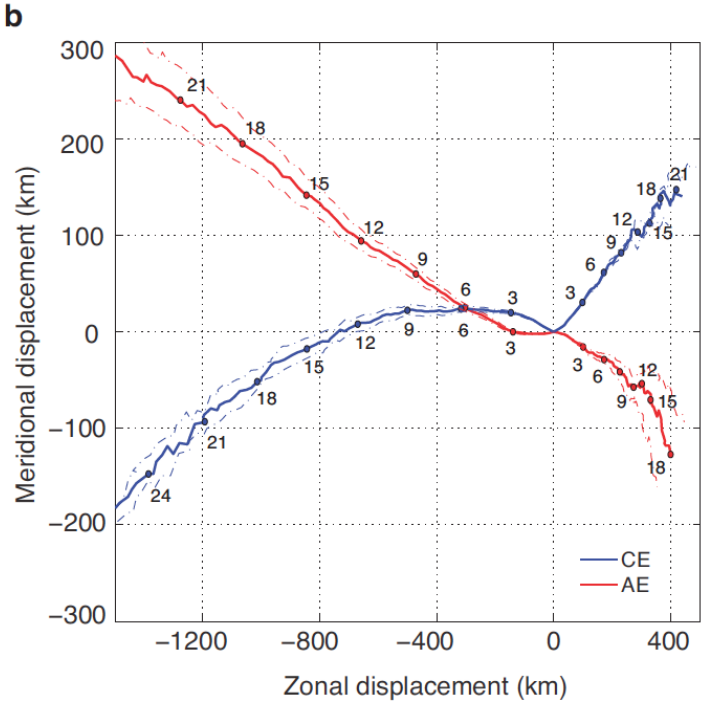
Southern Ocean replete with eddies



- Eddies identified with Chelton et al database.
- Westward propagation outside of Antarctic Circumpolar Current.
- Eastward propagation in Antarctic Circumpolar Current.

Zajaczkovski et al, in prep, 2015

Eddies provide "thermally direct" heat transport in ACC



Zajaczkovski et al, in prep, 2015

- Small numbers indicate time in months.
- Westward propagating eddies: anticyclonic (warm-core) rings move equatorward; cyclonic (cold-core) rings move poleward. Upgradient heat transport.
- Eastward propagating eddies: anticyclonic rings move poleward, and cyclonic rings move equatorward.
- Implies down-gradient cross-ACC heat transport. Small perturbations in eddy energy or temperature can intensify this transport.
- Mechanism: Doppler shift due to eastward propagating eddy moving faster than deep currents.

Summary

- SSH anomalies well correlated with sub-surface anomalies, in principle provide a means to refine reference mean field against which century-scale temperature changes are evaluated, albeit possibly introducing more noise than benefit....
- Southern Ocean warming persistent throughout 20th century.
- Eastward-moving Southern Ocean eddies result in poleward heat transport across the ACC—may help to explain mechanisms governing observed warming in Southern Ocean.