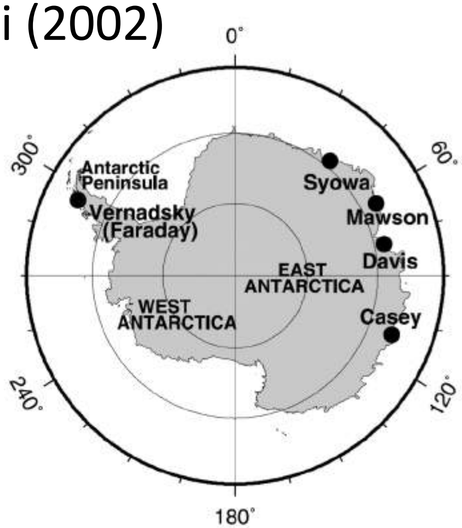
Causal mechanisms of sea level and ocean heat content changes over the Antarctic continental shelf analyzed with ECCO V4

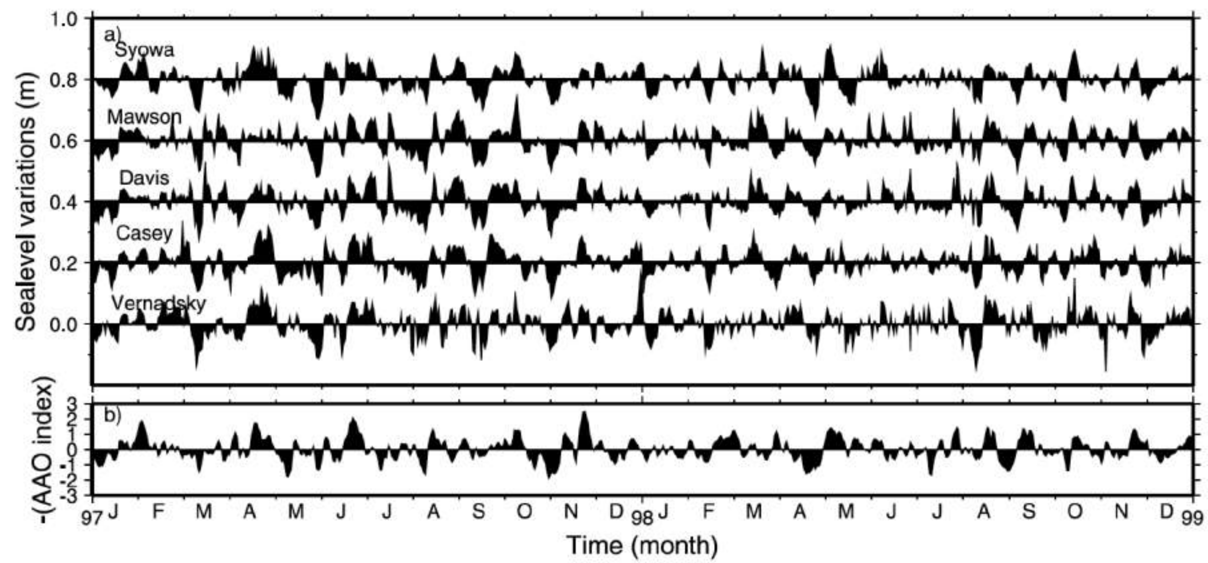
Ichiro Fukumori, Ou Wang, and Ian Fenty

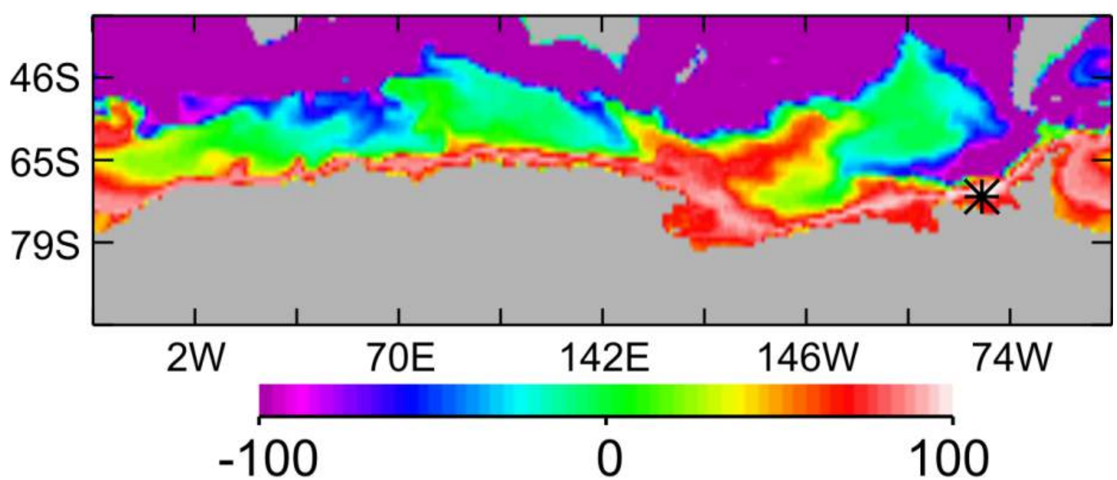
(JPL)

"Southern Mode" Hughes et al. (2014)

Aoki (2002)







Coherence (% explained variance) of ocean bottom pressure (OBP) at asterisk with those elsewhere in ECCO V4r3;

Explained variance of *a* by *b*

$$= 1. - \frac{\mathrm{var}(a-b)}{\mathrm{var}(a)}$$

Cause of the "Southern Mode"

Identify the forcing responsible for the "Southern Mode" by adjoint gradient decomposition;

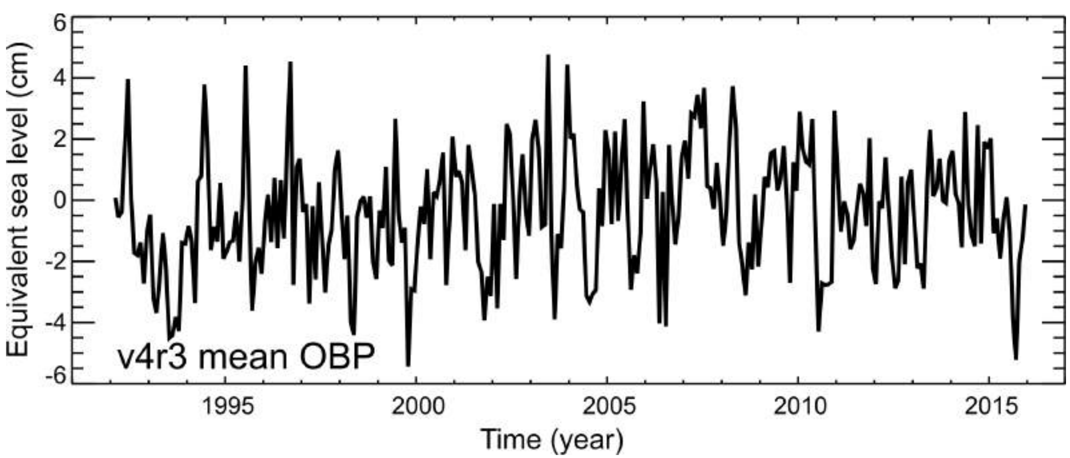
$$J(t) \approx \sum_{i}\sum_{\mathbf{x}}\sum_{\Delta t} \frac{\partial J}{\partial \phi_i(\mathbf{x},\Delta t)} \delta\phi_i(\mathbf{x}, t-\Delta t)$$

Southern Mode OBP at time t → $J(t)$

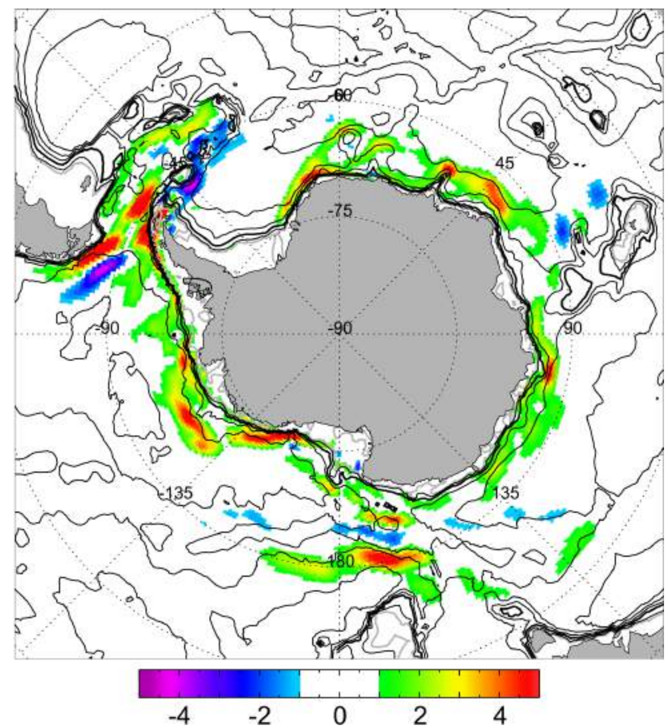
forcing i at location **x** & time *t-Δt* → $\delta\phi_i(\mathbf{x}, t-\Delta t)$

adjoint gradient → $\frac{\partial J}{\partial \phi_i(\mathbf{x},\Delta t)}$

Along-bathymetry winds explain most of the mode's variation.



Location of winds responsible for the variation (% explained variance per km^2×10^5)



Cause of the "Southern Mode"

Identify the forcing responsible for the "Southern Mode" by adjoint gradient decomposition;

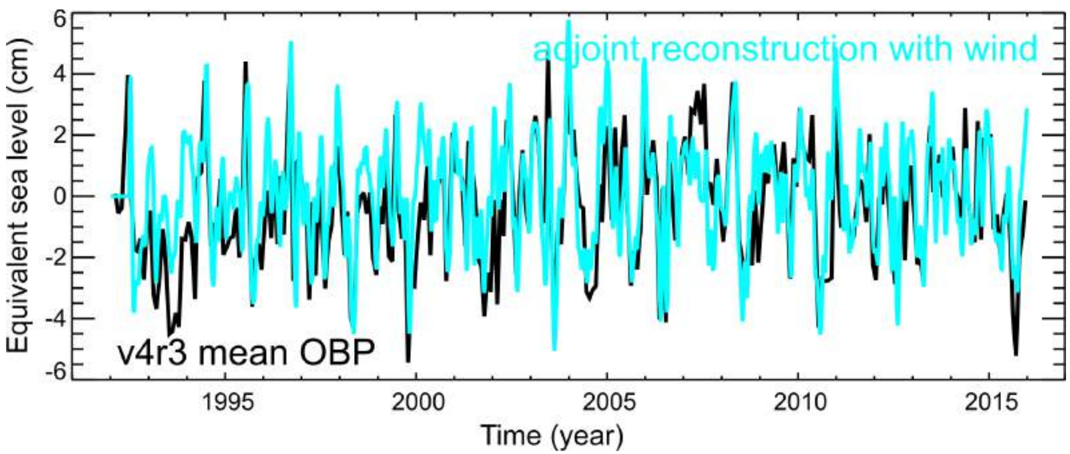
Southern Mode OBP at time t →

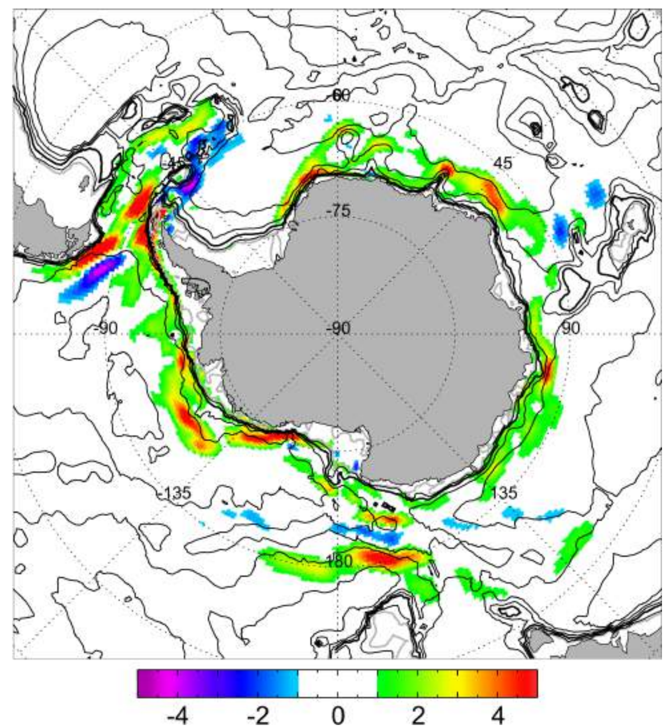
$$J(t) \approx \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial \phi_i(\mathbf{x}, \Delta t)} \delta\phi_i(\mathbf{x}, t-\Delta t)$$

forcing i at location **x** & time *t-Δt*

adjoint gradient

Along-bathymetry winds explain most of the mode's variation.

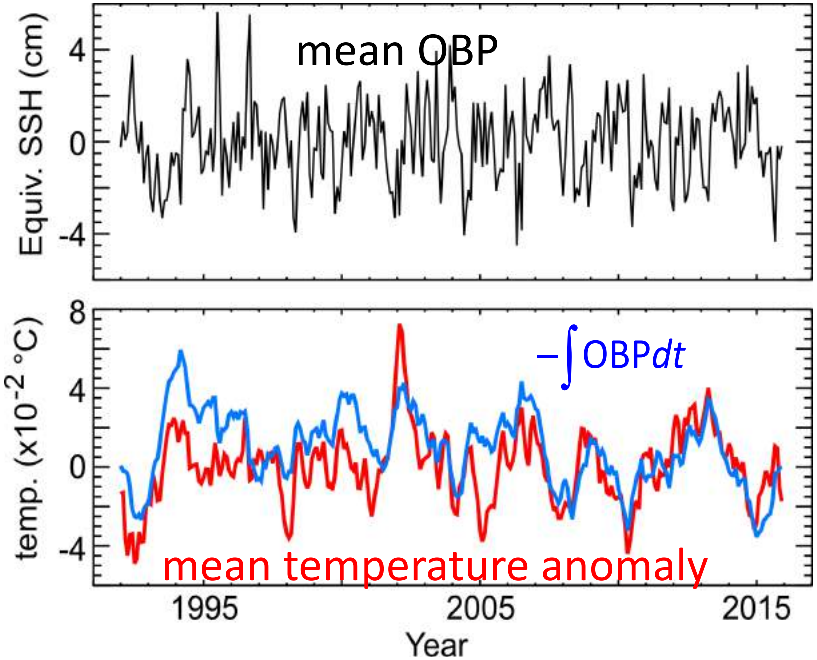




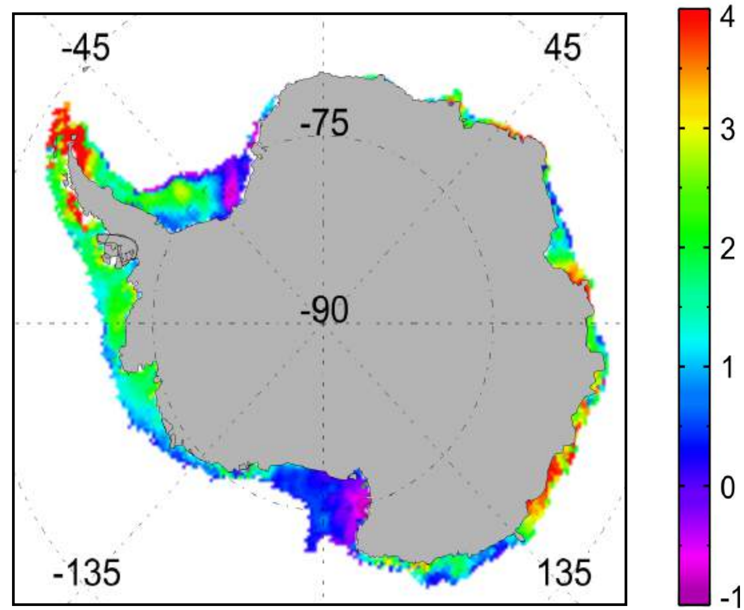
Location of winds responsible for the variation (% explained variance per $km^2 \times 10^5$)

Effects of the “Southern Mode”

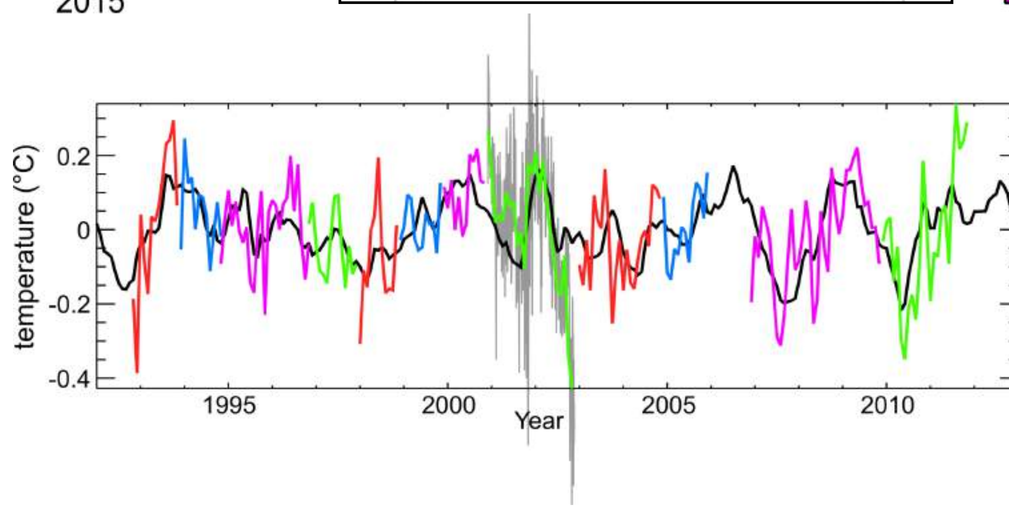
Time-integrated OBP is correlated with inter-annual mean T on the shelf



% explained variance of shelf-mean T anomaly (per $m^3 \times 10^{13}$)



V4r3 has skill resolving observed T (OBP gauge at “Drake Passage South”)



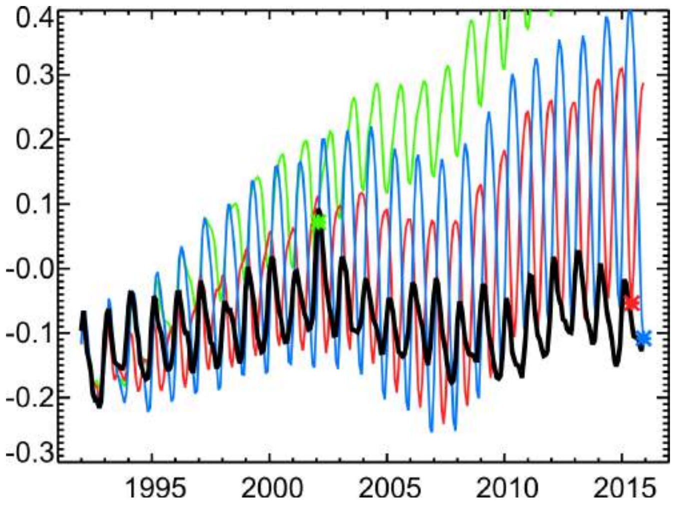
Analyzing Cause of Antarctic T variations

Adjoint gradients of T are often non-stationary due to changes in ocean circulation, which must be accounted for when conducting gradient reconstructions.

$$J(t) \approx \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial \phi_i(\mathbf{x}, t-\Delta t)} \delta\phi_i(\mathbf{x}, t-\Delta t)$$

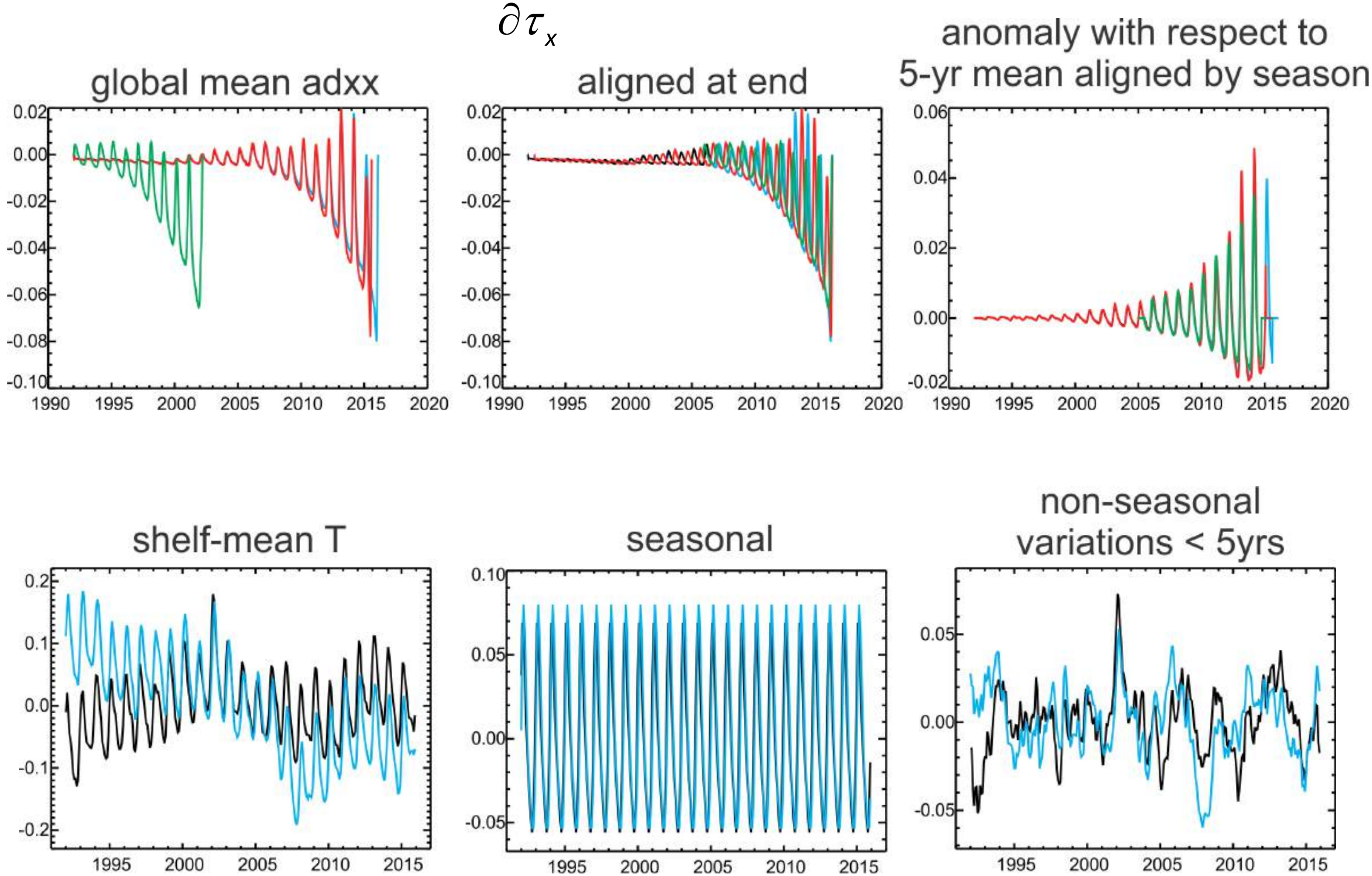
$$\approx \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial \phi_i(\mathbf{x}, \Delta t)} \delta\phi_i(\mathbf{x}, t-\Delta t)$$

Reconstruction assuming stationarity using gradients with respect to mean T of 02/2002, 01/2015 and 12/2015.



Approximating the Adjoint's Time-dependence

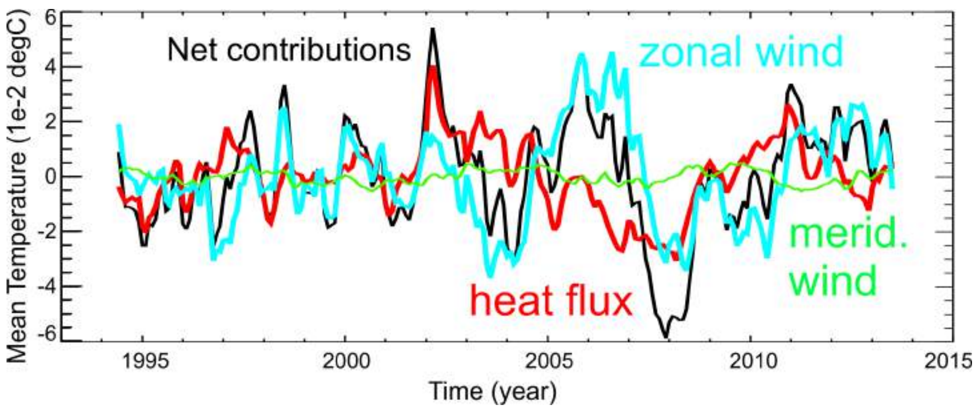
The adjoint of T can be approximated by a stationary one by separating its time-scales; e.g., $\frac{\partial J}{\partial \tau_x}$ of 02/2002, 01/2015 and 12/2015 *J.*



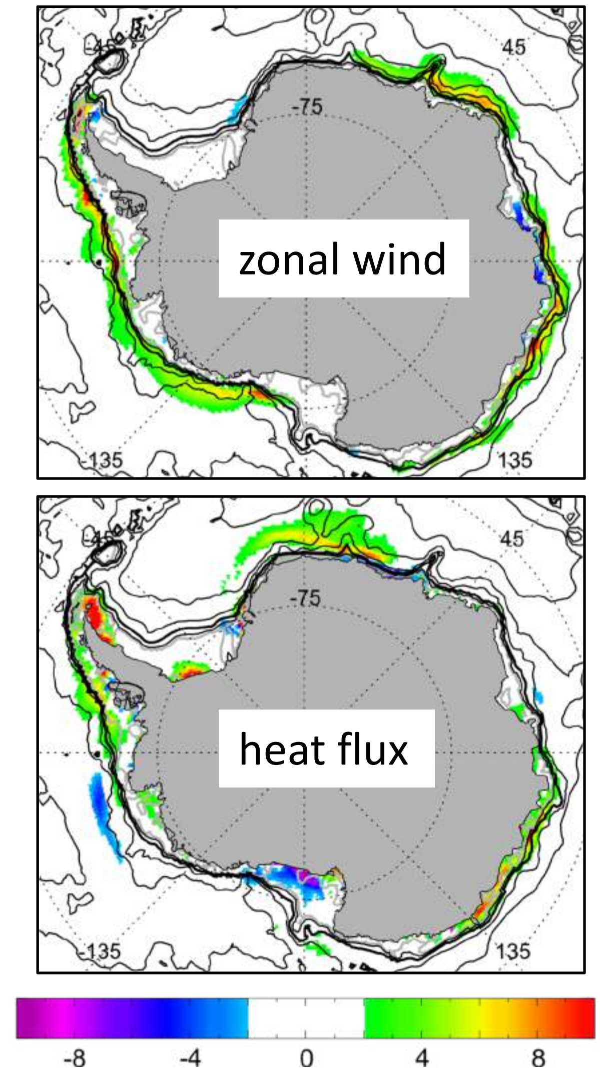
Cause of Interannual Antarctic T variations

$$J(t) \approx \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial \phi_i(\mathbf{x},\Delta t)} \delta\phi_i(\mathbf{x}, t-\Delta t)$$

Zonal wind (55%) and heat flux (29%) contribute equally to temperature variations.



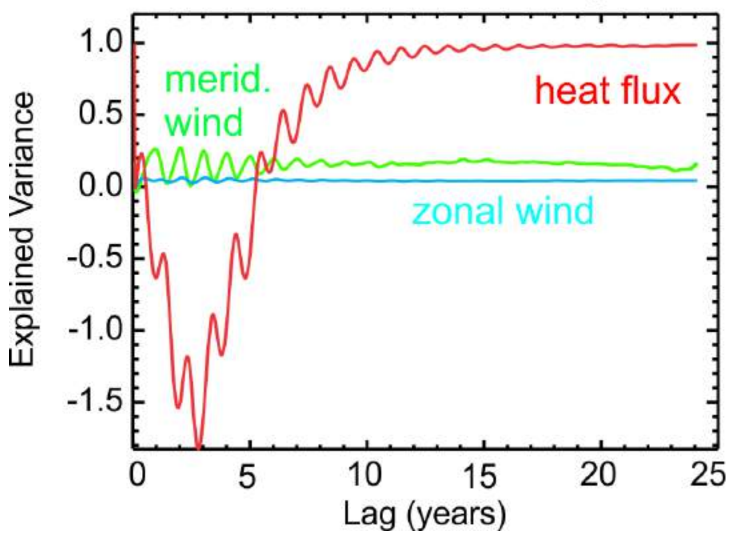
Zonal winds along the slope and heat flux over the shelf are responsible for the variation (% explained variance per $km^2 \times 10^7$)



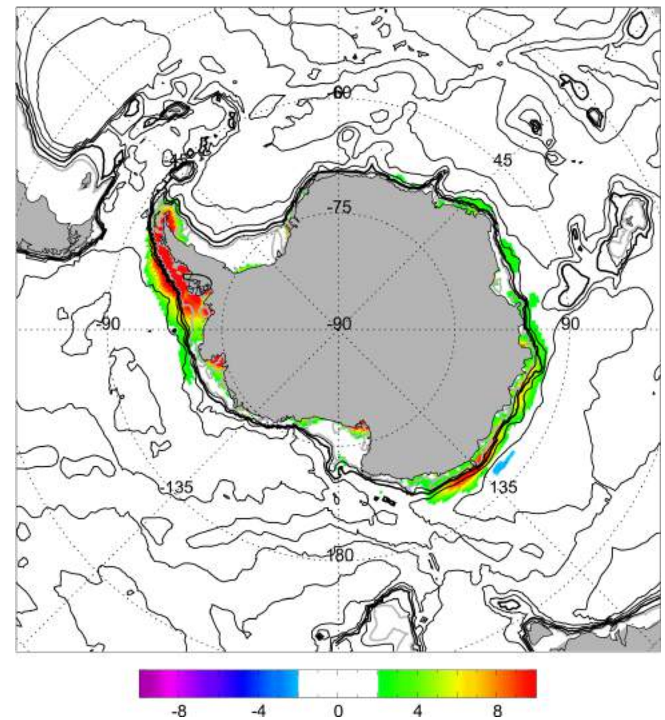
Cause of Annual Cycle in Antarctic T

$$J(t) \approx \sum_{i} \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial \phi_i(\mathbf{x}, \Delta t)} \delta \phi_i(\mathbf{x}, t - \Delta t)$$

Cause as a function of forcing and lag.



Results are in contrast with
Gill and Niiler (1973), who concluded seasonal cycle being solely due to local heat flux with infinite time-scale.



Location of responsible heat flux
(% explained variance per km^2×10^5)

Summary

- The “southern mode” is driven by winds along the Antarctic continental slope,
- The “southern mode” has an associated interannual variation of temperature on the Antarctic continental shelf,
- Temperature’s adjoint can be treated as being stationary by splitting time-scales, thus allowing diagnosis of causal mechanisms using a single adjoint,
- The shelf’s interannual temperature change is driven by surface heat flux on and off the shelf, in addition to winds along the continental slope,
- The shelf’s seasonal temperature change is dependent on surface heat flux on and off the shelf within a 10-year window.