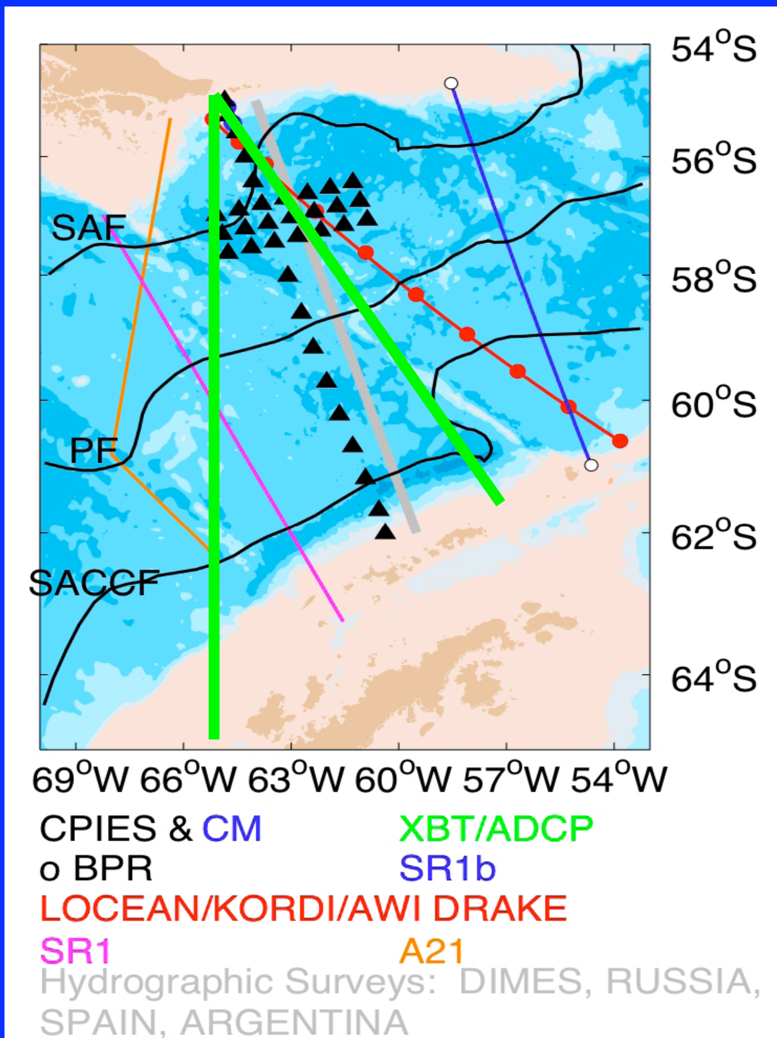
Pacific-Atlantic Interocean Exchanges: Drake Passage Programs



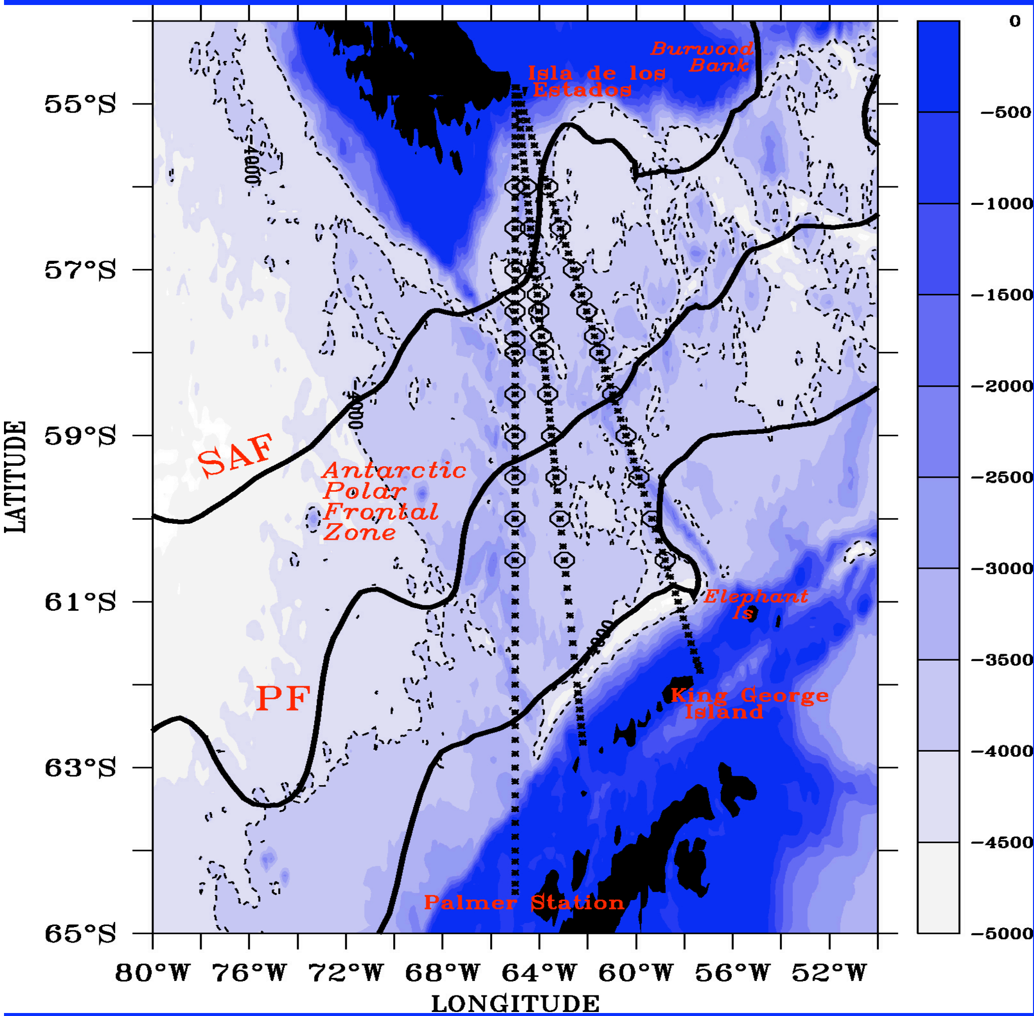
Outline:

1. Focus on sustained shipboard observations on L.M. Gould
   - seasonal property variability
   - eddy variability
   - long-term property trends

   and links to climate variability

2. Transport variability
   - proxy estimates
   - C-Drake program

Drake Passage Near-Surface Time Series



Year-round R/V L.M. Gould underway observations (~20 xings/year;~2 days):-

- High-resolution XBT:

70 XBTs; 6-8 transects/year

88 T transects (1996->)

- XCTDs (2000->)
- ADCP: ~200 V transects

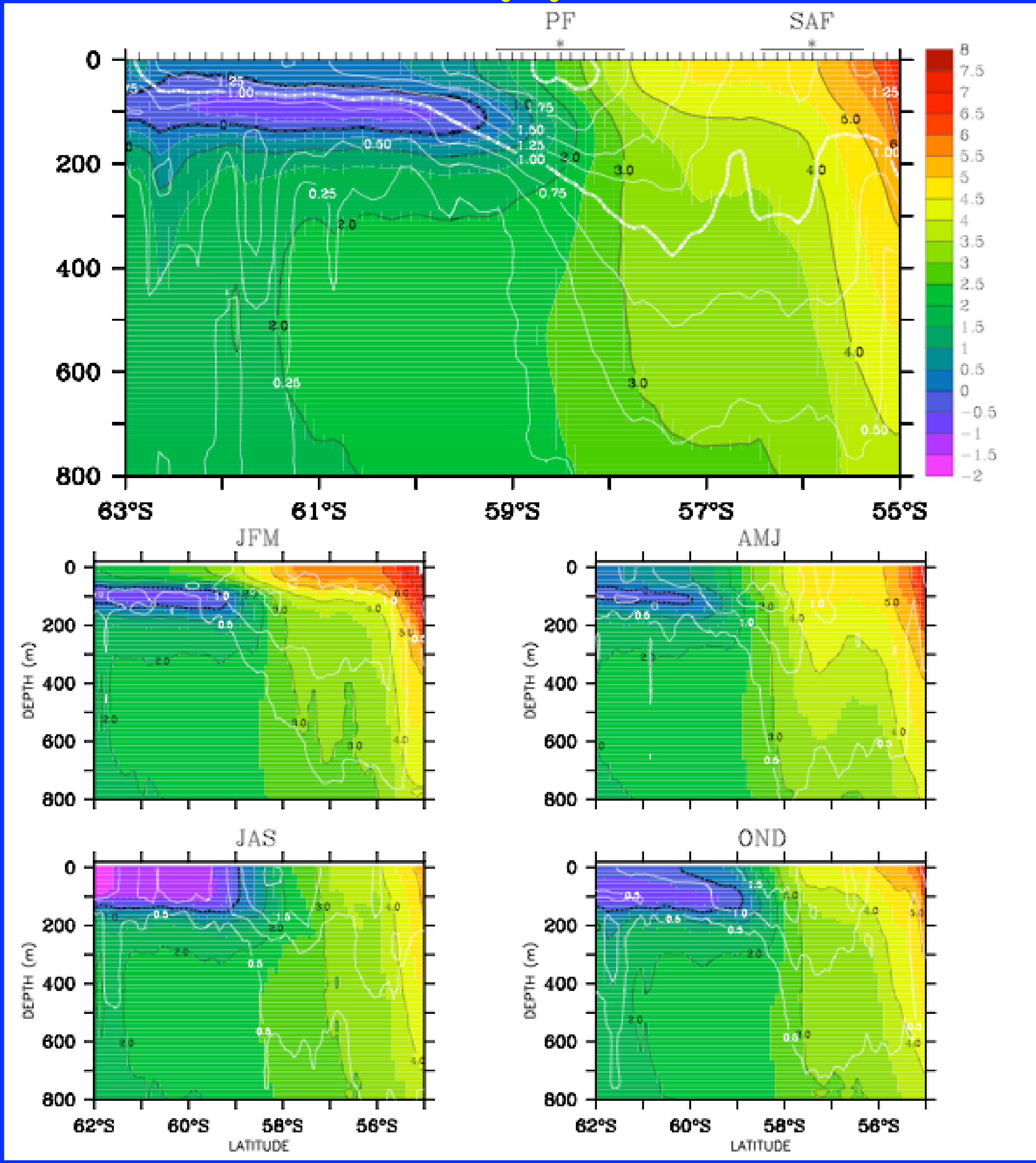
(~300 m 1999-2004;

~1000 m 2004->)

- pCO_2 & TCO_2: (2002->)
- IMET (full suite) & TSG

Long-term time series of simultaneous measurements of V, T, S, air-sea heat and gas fluxes -> characterize spatial and temporal variability of near-surface processes in ACC.

XBTs: Upper Ocean Temperature



Eddy-resolving sampling and near synoptic

Mean (colors) and standard deviation (white) temperature from 88 sections (1996-2010)

Closely spaced profiles needed to resolve PF (within ~3 XBTs/~20 km)

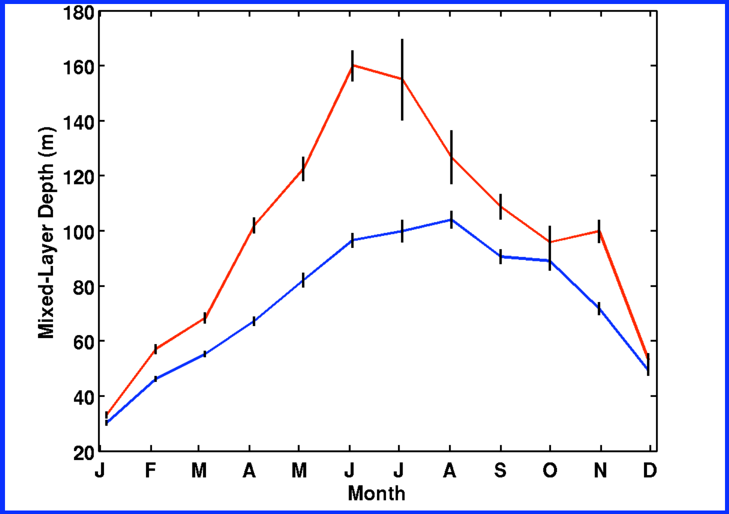
PF clearly separates Antarctic water masses (AASW/WW; uCDW) from Subantarctic water (SASW; SAMW)

www-hrx.ucsd.edu

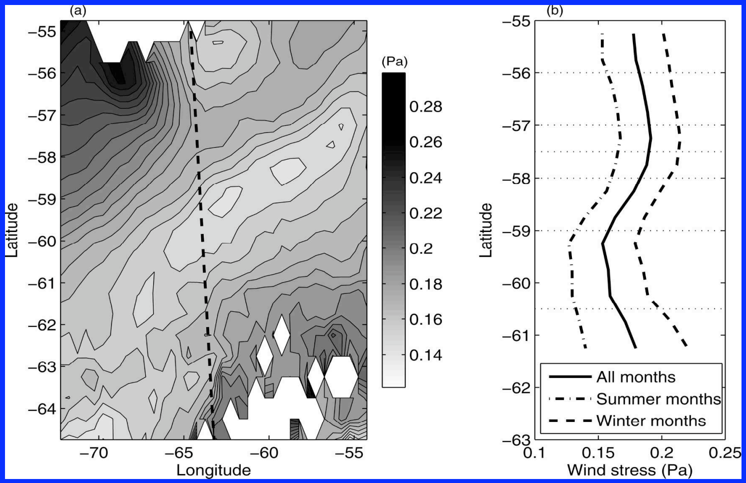
Mixed Layer Depth Variability

- Different MLD seasonal cycle found north and south of the Polar Front
- Higher MLD variability north of PF
- seasonal change in *mean* wind stress uniform across passage, but *variance* stronger in winter north of Polar Front

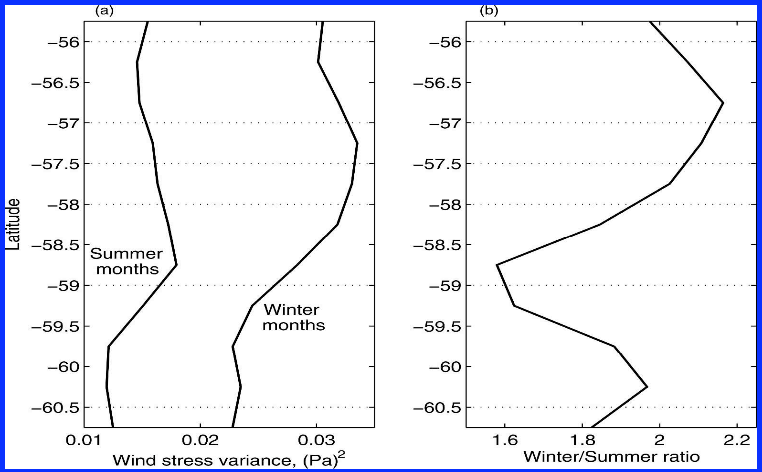
MLD



Mean Wind Stress

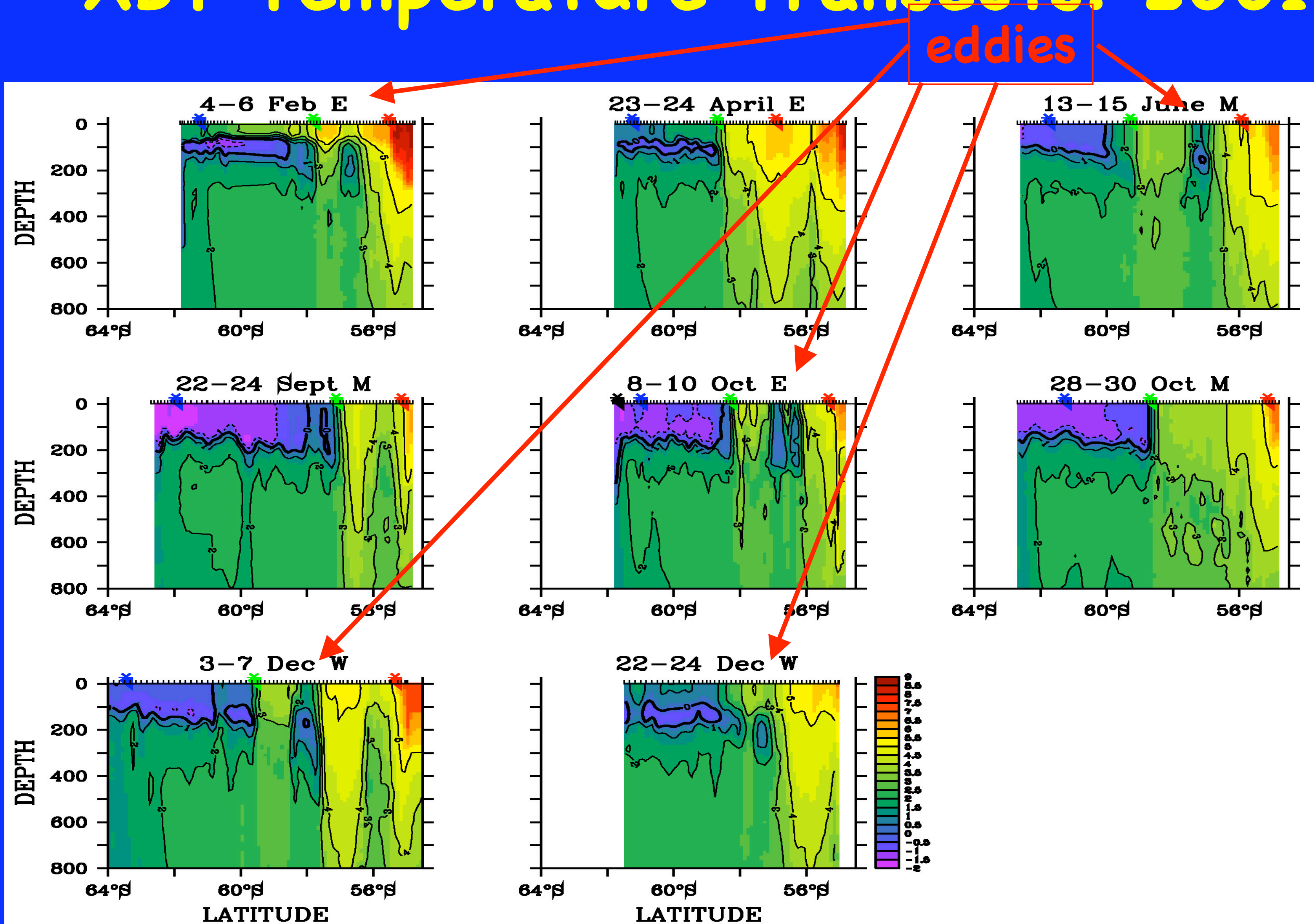


Wind Stress Variance



Stephenson, Sprintall and Gille, *in prep*, 2010.

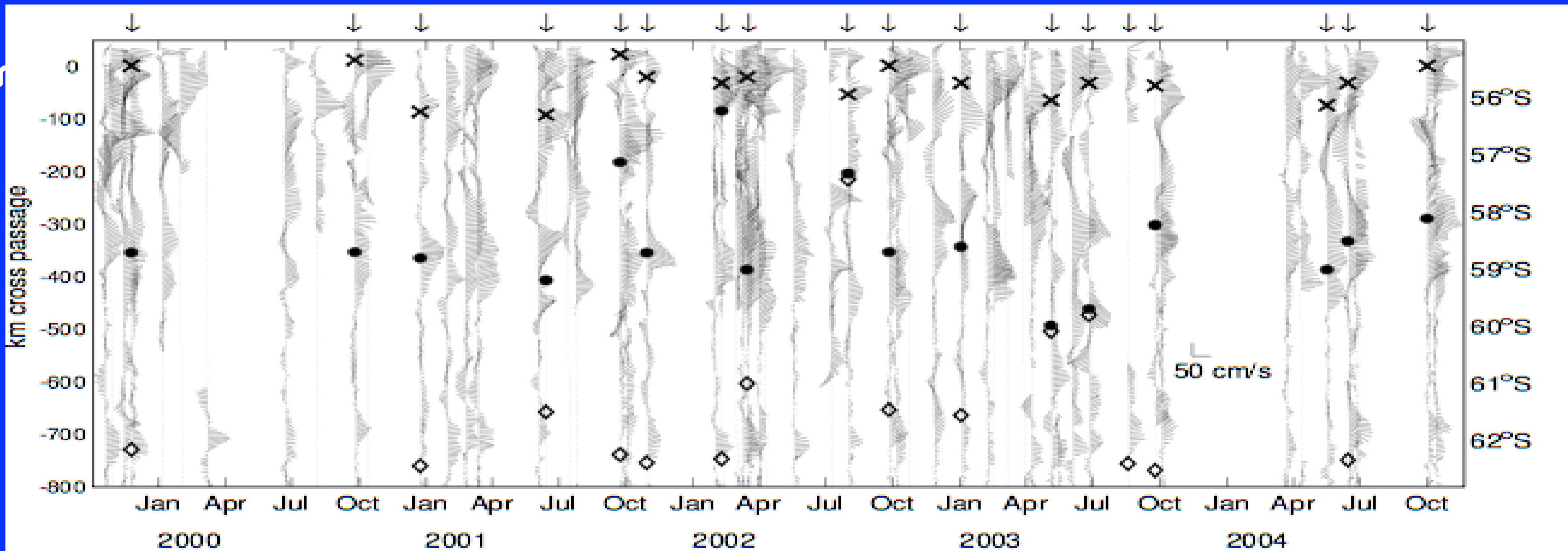
XBT Temperature Transects: 2001



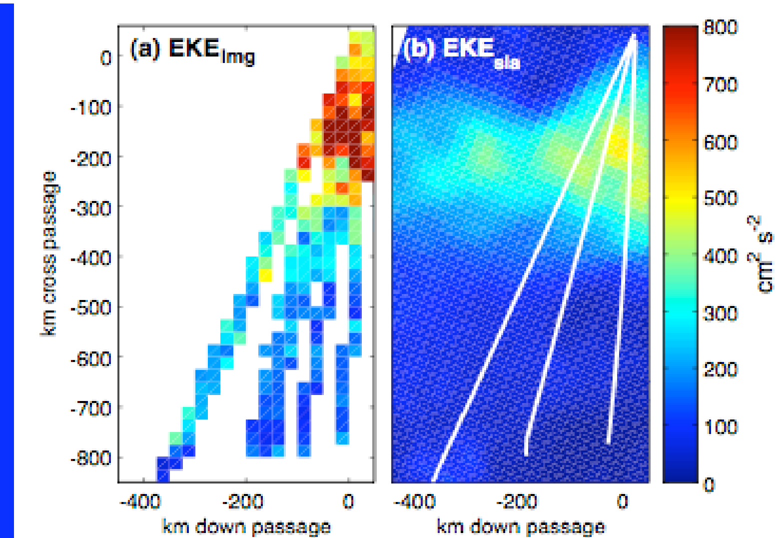
Sprintall, *J. Mar. Res.*, *61*, 2003.

Eddies in Drake Passage

V_{150m}



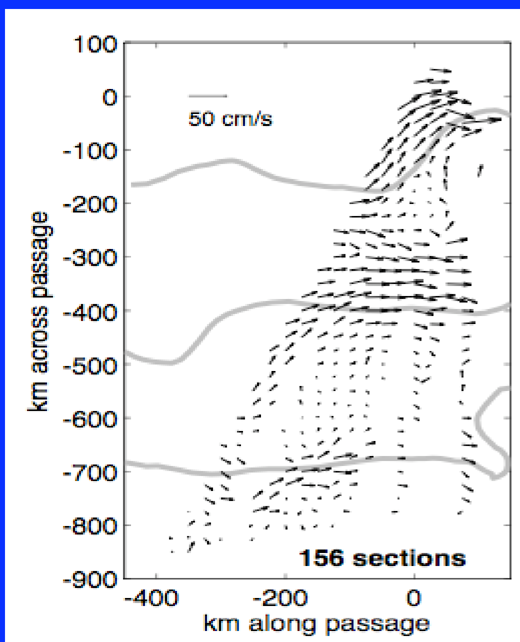
- multiple frontal jets vary in amplitude, direction and width
- variability dominated by eddies
- high EKE between SAF and PF



Lenn, Chereskin, Sprintall, and Firing., *J. Mar. Res.*, *65*, 2007.

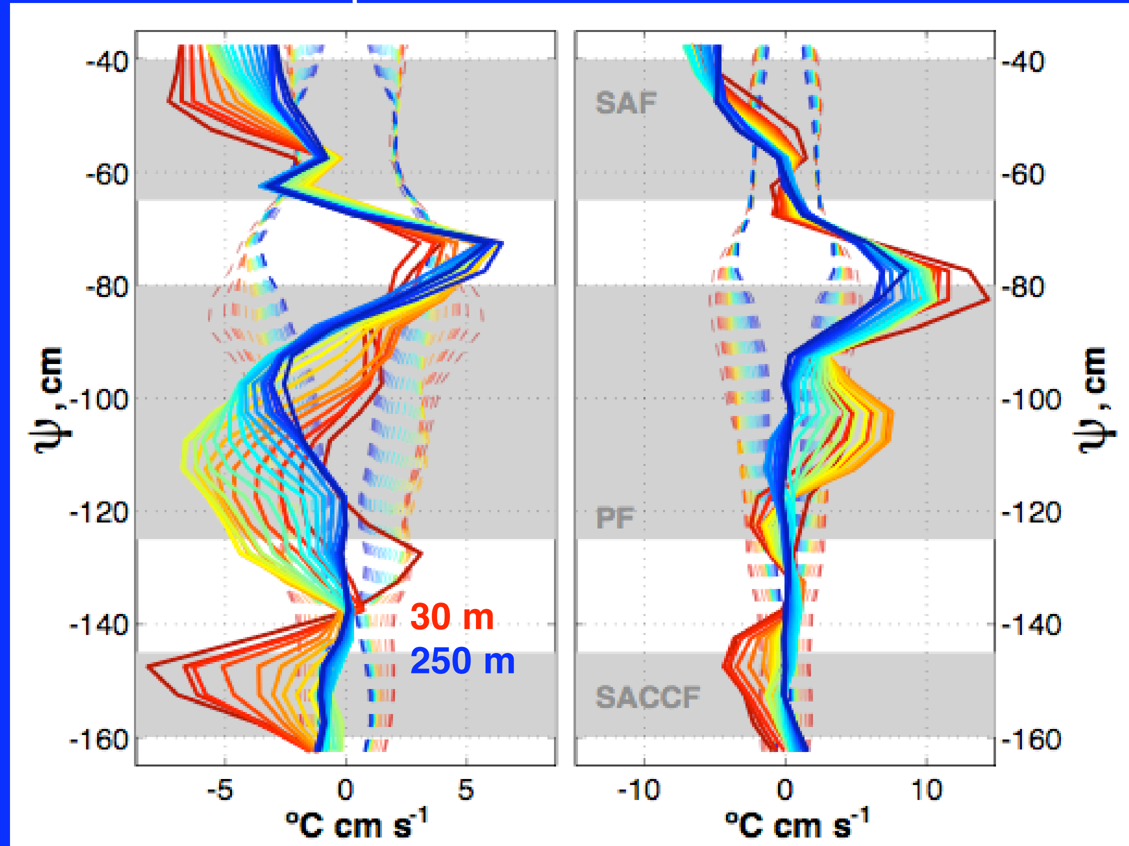
Eddy Heat Fluxes

- <v′T′> = <v(t)-<v>><T(t)-<T>> are small - need a good mean!
- mean ADCP V to map ACC streamlines; project V into stream co-ordinates and average fluxes along streamlines.
- 38 concurrent ADCP/XBT sections



<v′T′>
equatorward ->

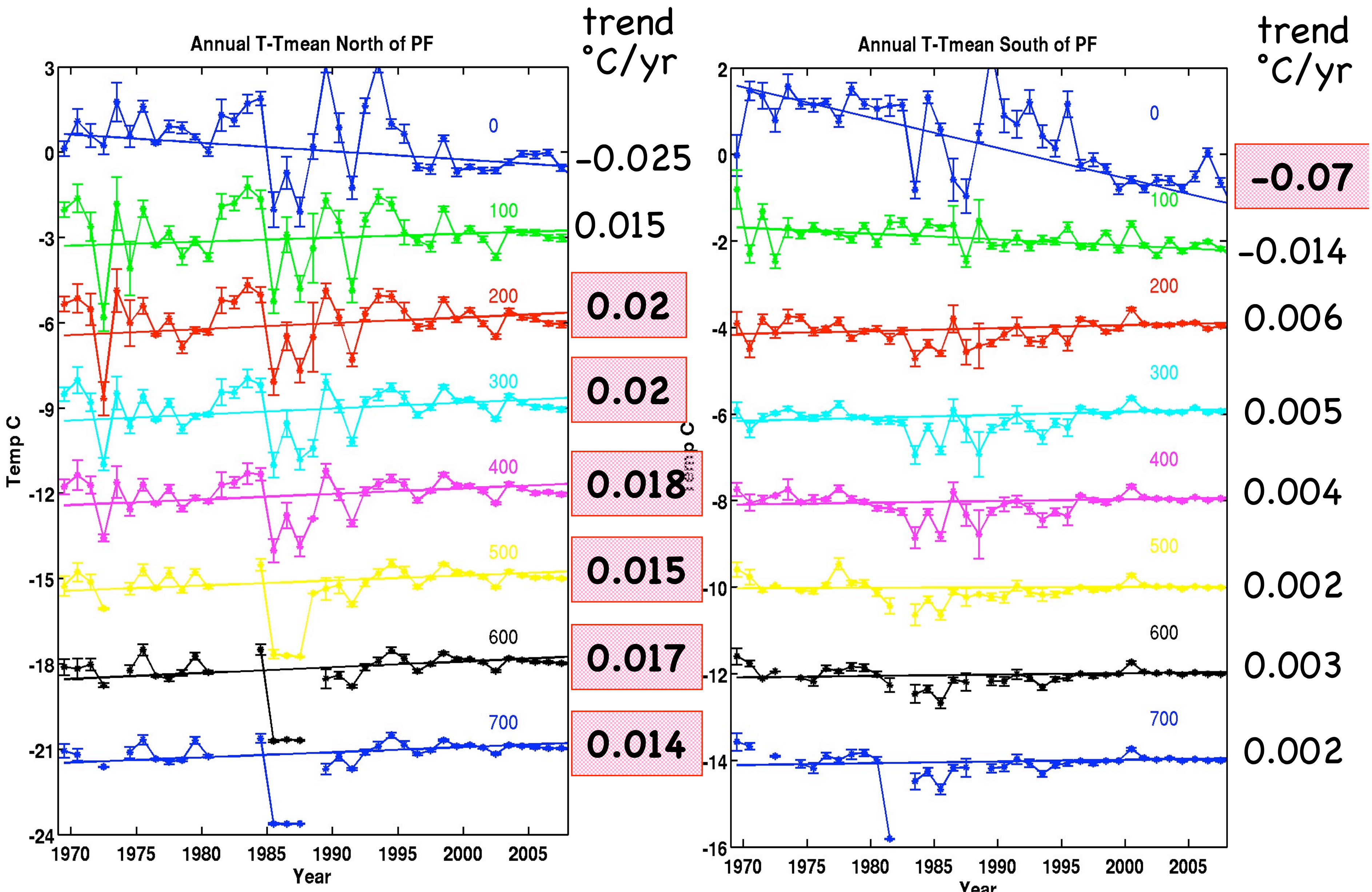
<u′T′>
downstream->



(Noisy!) eddy heat fluxes are polewards and downstream (where significant), typically near the mean front positions

Lenn, Chereskin, Sprintall, and McClean, *JPO*, submitted, 2010

Long-term Trends: Temperature



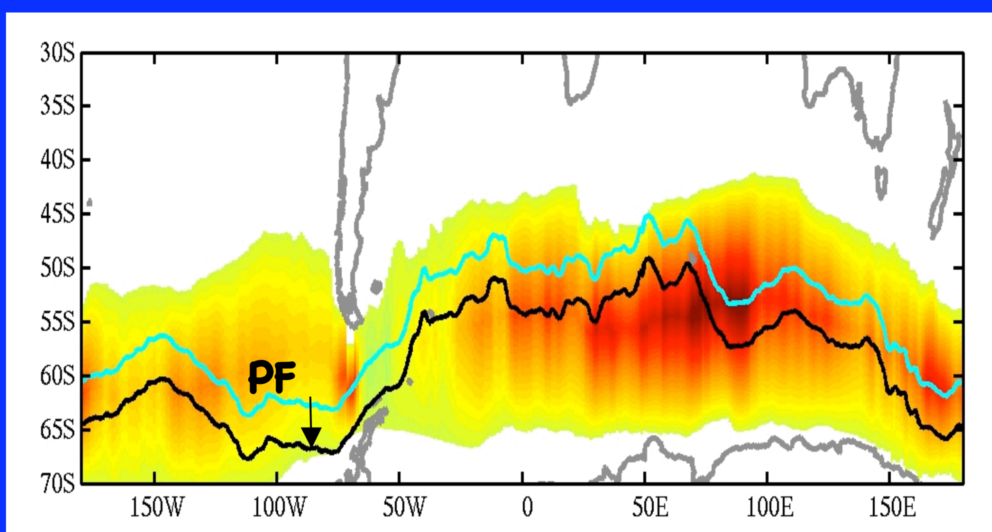
Trends consistent with Southern Ocean studies (e.g. Gille, 2003; 2008; Boning et al, 2008)

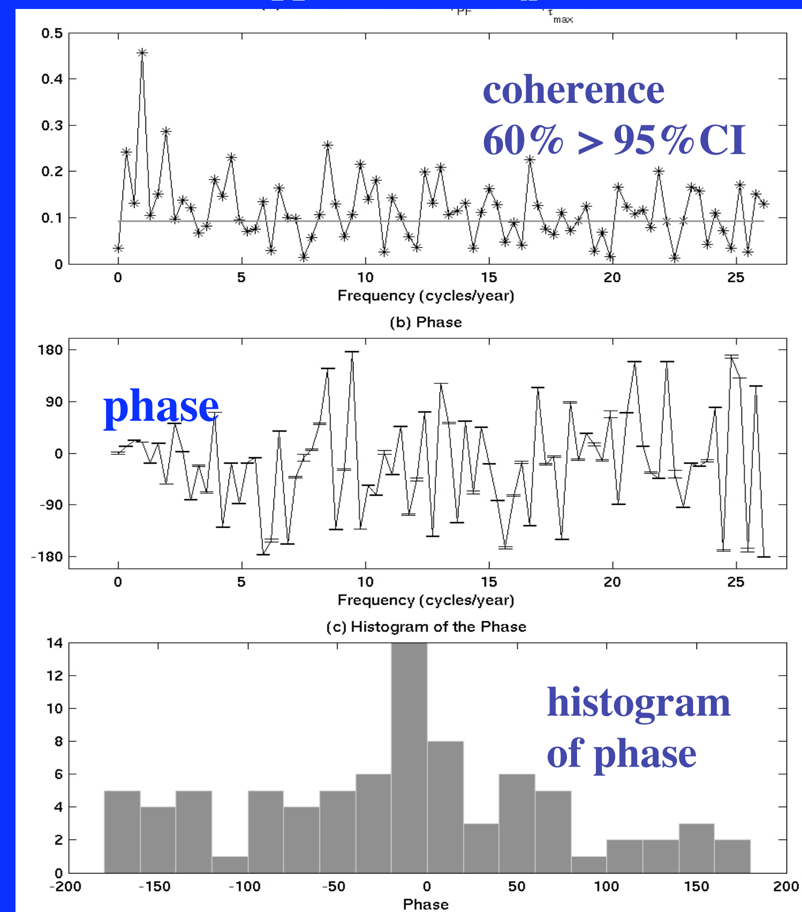
What drives long-term trends?

Increasing positive trend in Southern Annular Mode (SAM) associated with stronger winds that have shifted poleward.

$(\partial\varphi_{PF}/\partial t \sim \partial\varphi(\tau_x)/\partial t)$

Meridional displacement of band of maximum wind stress significantly coherent (and leads) the meridional displacement of a 3-yr time series of Polar Front from AMSR-E SST



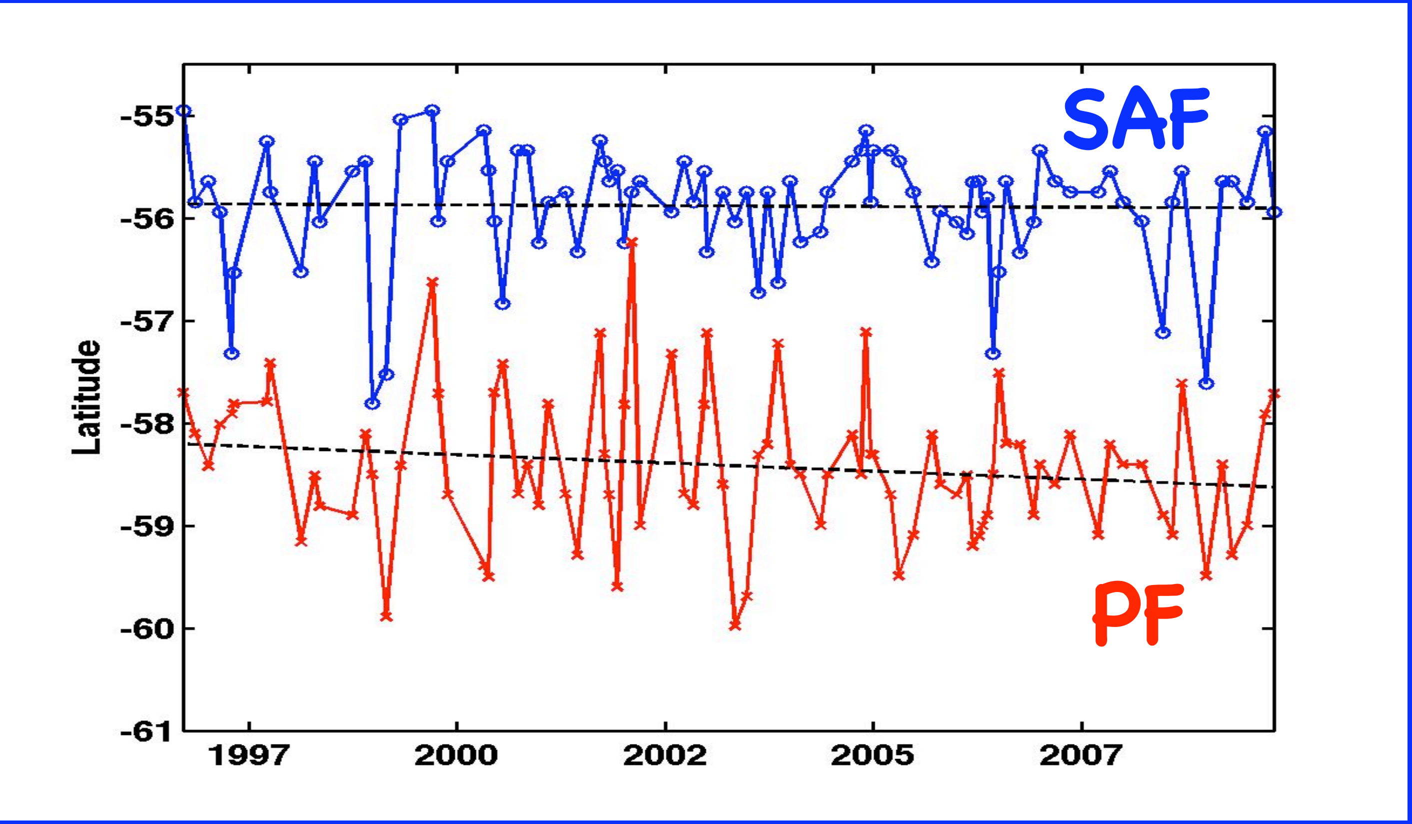


Dong, Sprintall and Gille, *JPO,* (2006)

Poleward Shift in the DP Polar Front?

HR-XBT Fronts: 1996-2009

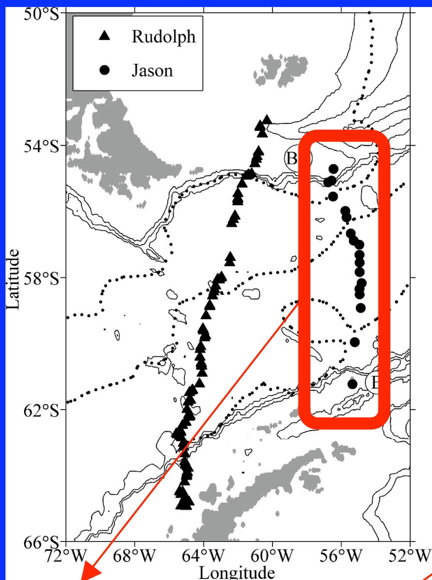
(well resolved spatial sampling, 6-8 transects/year)



Poleward PF Trend:
~47 km since 1996

"Indirect" Transport Estimates

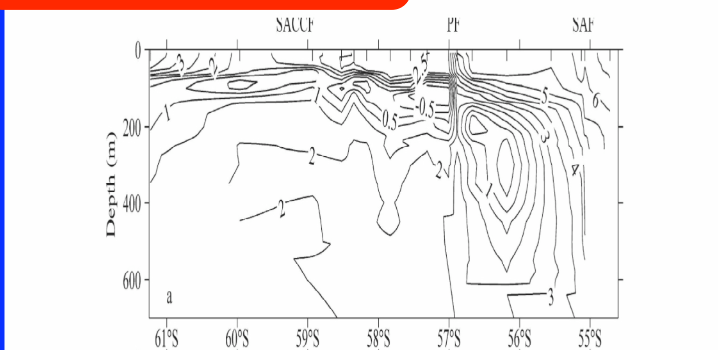
Seal Tracks with CTD measurements (SEaOS)



- Use full-depth hydrographic sections to derive empirical relationship between upper ocean T and a baroclinic transport structure (stream) function (e.g. Sprintall, 2003; Sokolov et al., 2004; Boehme et al., 2008)
- Relationship of T and/or Q with altimetry

Cumulative Transport from Rudolph & Jason derived through empirical $Q_{2500}(T_z)$

T-z from Jason



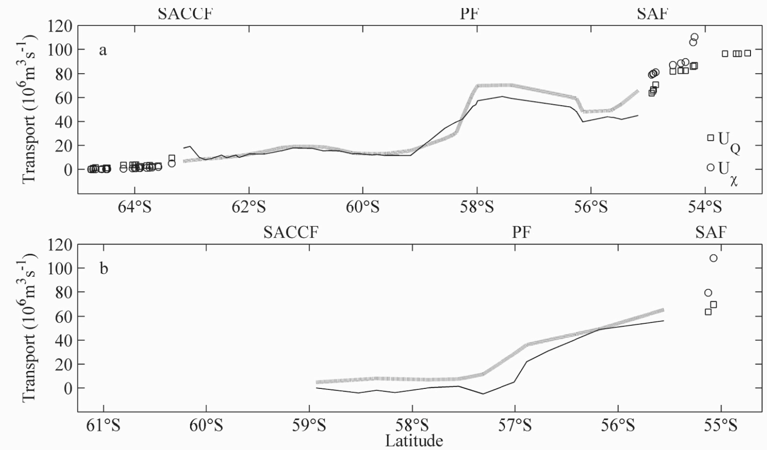


Fig. 6. Cumulative transport (10^6 m^3 s^{-1}) above 2,500 m depth derived from mass transport function $Q_{2,500}$, U_Q (solid line) and the baroclinic transport stream function $\chi_{2,500}$, U_χ (dotted line) for the Drake Passage transects of (a) Rudolph in June 2004 and (b) Jason in April 2005. The data are integrated from south to north, starting at the first profile with a water depth of more than 2,500 m. Data from positions with water depths of more than 2,500 m are lines, whereas others are marked with a circle and square. Front locations are marked on the upper axis. SACCF, southern ACC Front; PF, Polar Front; and SAF, Subantarctic Front.

Boehme et al., Limn. Ocean., (2008)

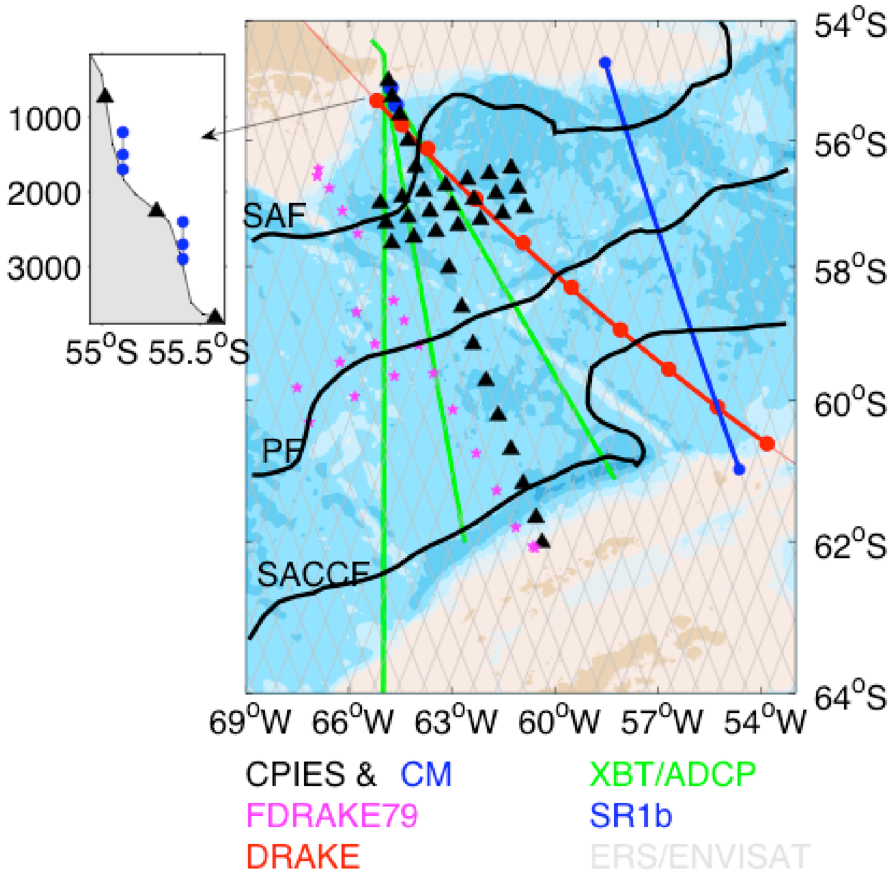
Future Plans for Drake Passage Sampling: Application to SAMOC

- 14 years of upper ocean T measurements (OPP renewal) and ~10 years of XCTDs (T-S-z), ADCP (V), air-sea flux measurements
- Some ongoing/planned studies of relevance to SAMOC:-

- length and time scales of turbulent heat fluxes from met measurements and cf recent NWP products (e.g. small-scale fluxes and SO water mass formation; fronts)
- MLD variability related to heat and momentum fluxes
- inventory of AASW and SAMW from XBT and SOSE model & relationship to large-scale climate modes e.g.SAM
- determining proxy transport variability
- combine upper ocean South Atlantic regional data sets through upper ocean heat budget using AX22 Drake Passage transect with AX18 and AX25 (upper ocean heat transport); Argo, SEaOS and historical data (heat storage); NWP products (air-sea heat exchange)

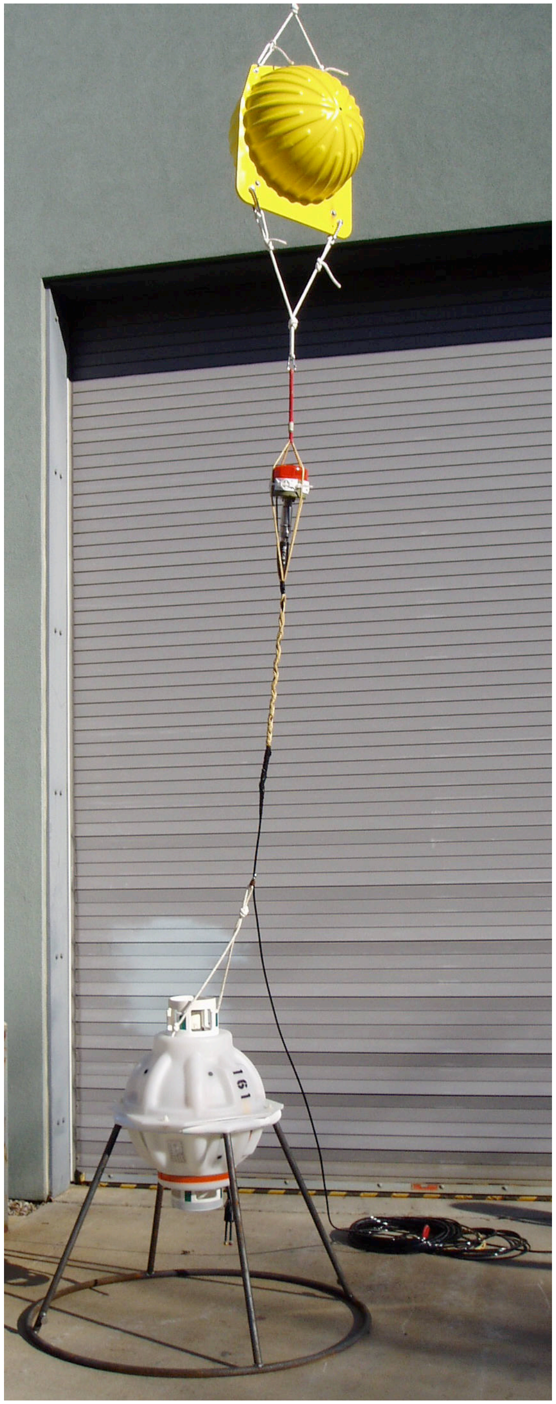
cDrake: Dynamics and Transport of the ACC in Drake Passage

T. Chereskin, K. Donohue, R. Watts



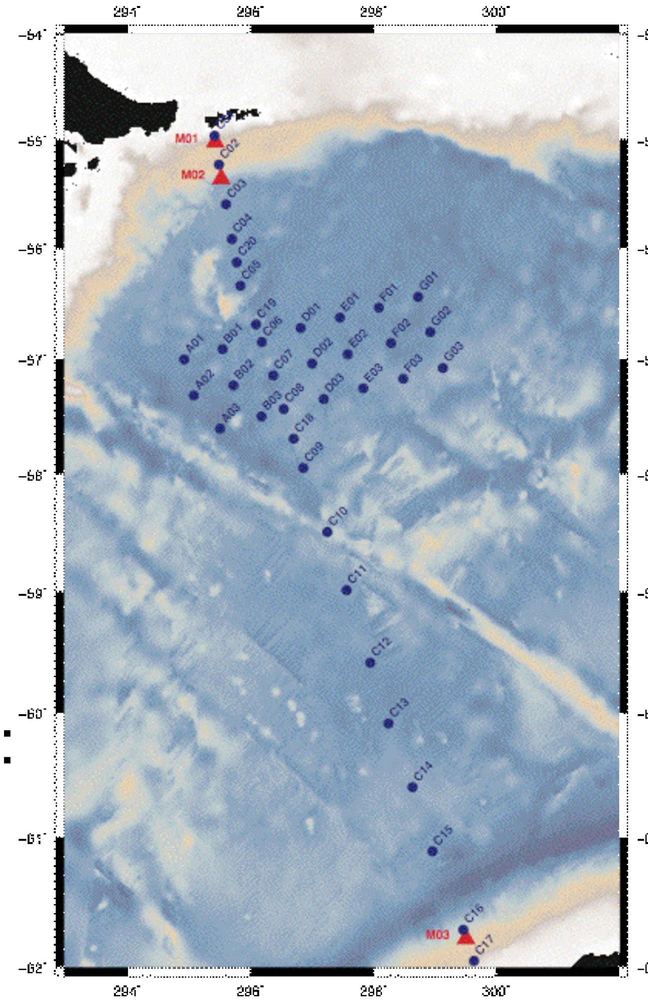
cDrake Objectives

- Determine the time-varying ACC transport
- Describe the mesoscale eddy field
- Guide future monitoring
- Assess model skill



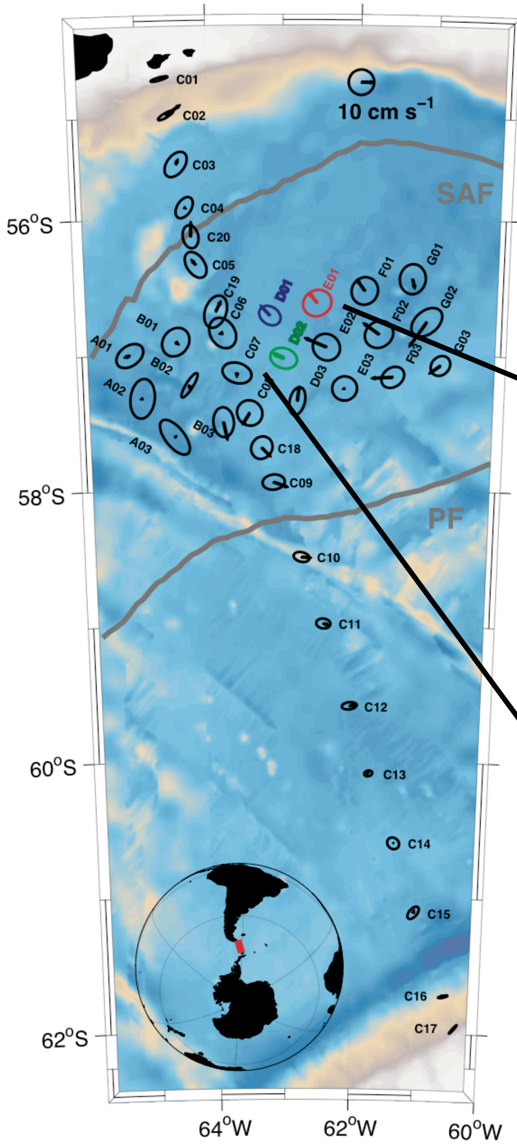
cDrake Array

- Transport line: 22 CPIES
- Local dynamics array: 21 CPIES
- 4-year deployment: 2007-2011
- Annual data return via acoustic telemetry



cDrake status

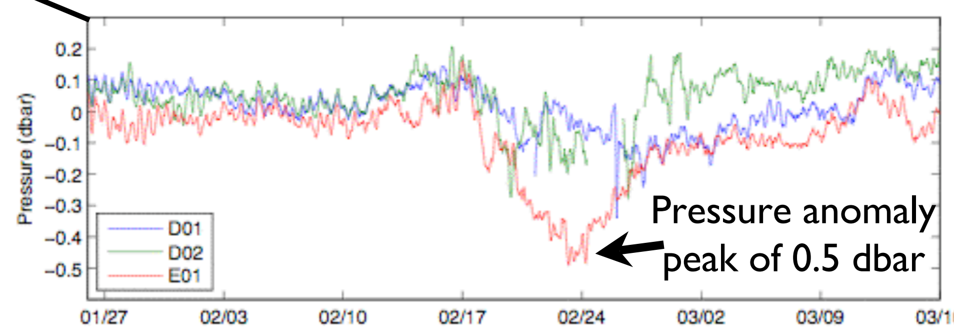
- Two years of daily-averaged data recovered from all 38 sites as of Dec 2009.
- Preliminary results confirm transport line and local dynamics array are well-situated for our goals.
- One first-look paper is published (GRL, Nov 2009) and several others are in preparation.
- Third year of daily-averaged data will be recovered during N. B. Palmer cruise, scheduled for Oct-Nov 2010 (NBP10-04).

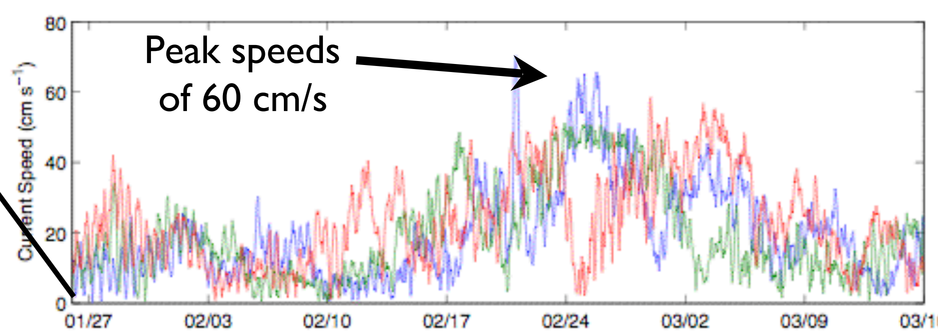


cDrake bottom currents & pressures:

•Mean currents > 10 cm/s at 15 sites in northern Drake Passage

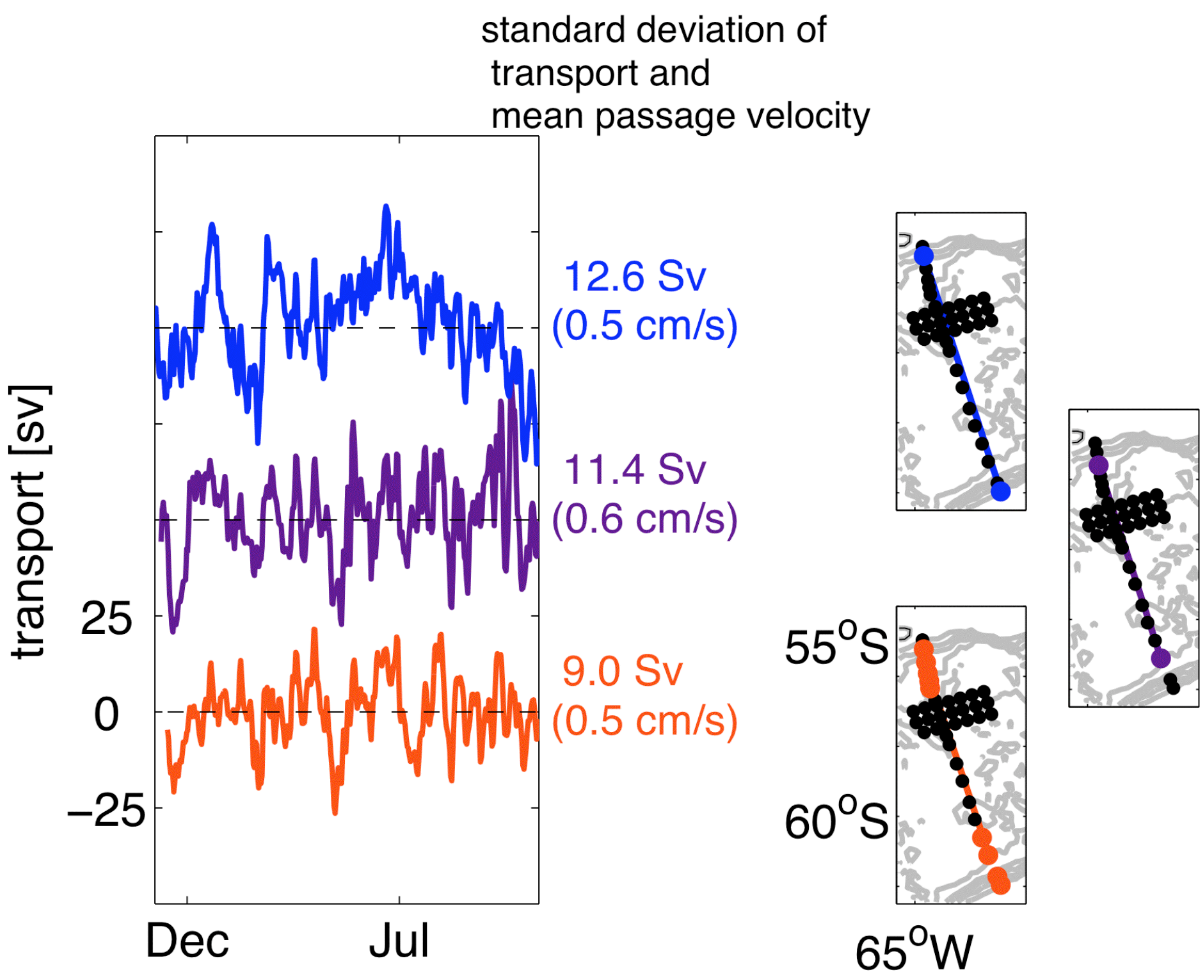
•Observed deep cyclogenesis associated with frontal meanders





Chereskin et al., GRL 2009

cDrake barotropic transport variability



- `BEST' ESTIMATES VARY
- SENSITIVE TO ENDPOINT CHOICE
- REQUIRES TEMPORALLY AND SPATIALLY RESOLVED MEASUREMENTS

cDrake future outlook

- After November 2010, we will have a 3 year dataset.
- Analyze 3 years of observations to test hypotheses regarding monitoring ACC transport.
- Assimilate CPIES data into the Southern Ocean State Estimate (SOSE, w/ collaborator Matt Mazloff).
- Evaluate temporal aliasing in transport estimates from other measurements (e.g. altimetry, repeat hydrography, XBT, ADCP).
- Design a reduced array for future monitoring of Drake Passage to continuously (daily) measure the baroclinic and absolute transport in total and partitioned amongst the major components (SAF, PF, and SACCF).

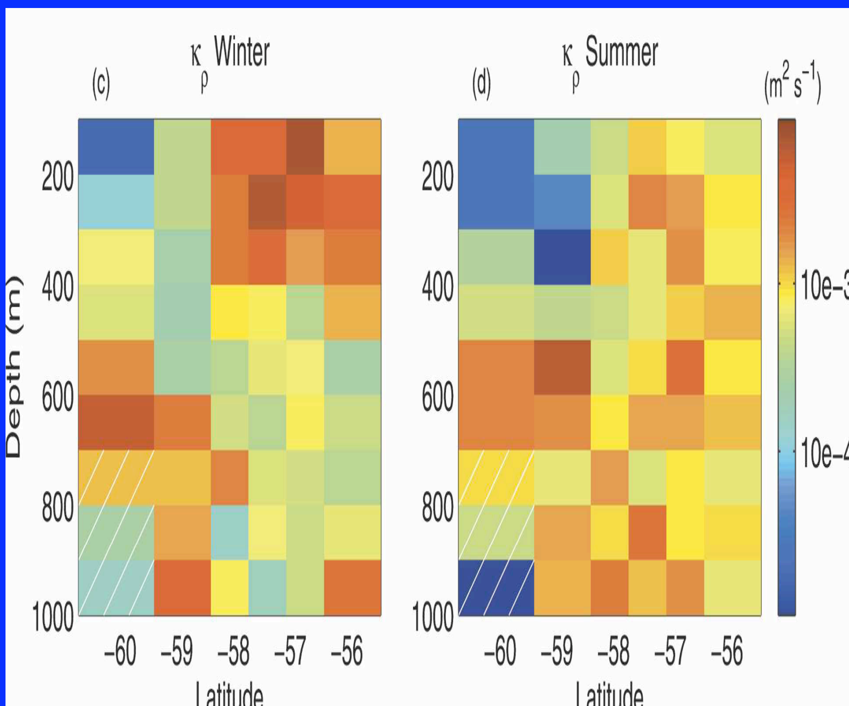
Summary and statement of intent

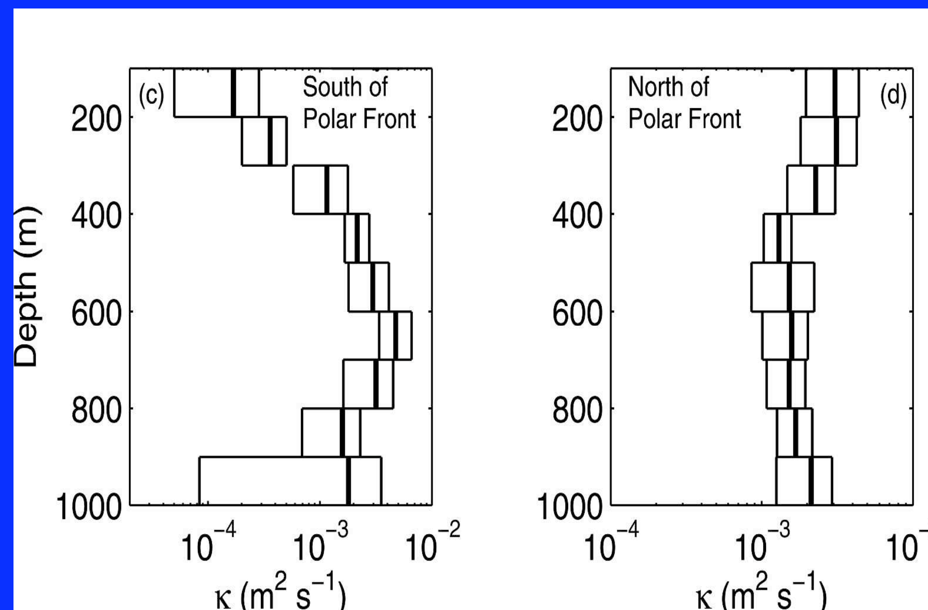
- We plan to propose an optimized array for long-term monitoring of the ACC transport through Drake Passage, contributing to SAMOC and SOOS.
- We plan to seek support from NSF OPP. Our goal is to have an optimized transport array in place by 2013.
- We seek collaborations with SAMOC investigators, specifically to combine regional data sets (possibly through SOSE?) and utilize/evaluate numerical simulations.

Method: Using the Thorpe scales (L_T) estimated from XCTD density:- $$L_T \cong \sqrt{\langle d'^2 \rangle}$$

We can obtain the turbulent dissipation of an overturn (Ozmidov, 1965):- $$\varepsilon i = 0.64 L_{Ti}^2 \langle N \rangle_i^3$$

which can be converted to a diapycnal diffusivity (κ_ρ) (Osborn, 1980):- $$\kappa_\rho = \Gamma \varepsilon N^{-2}$$





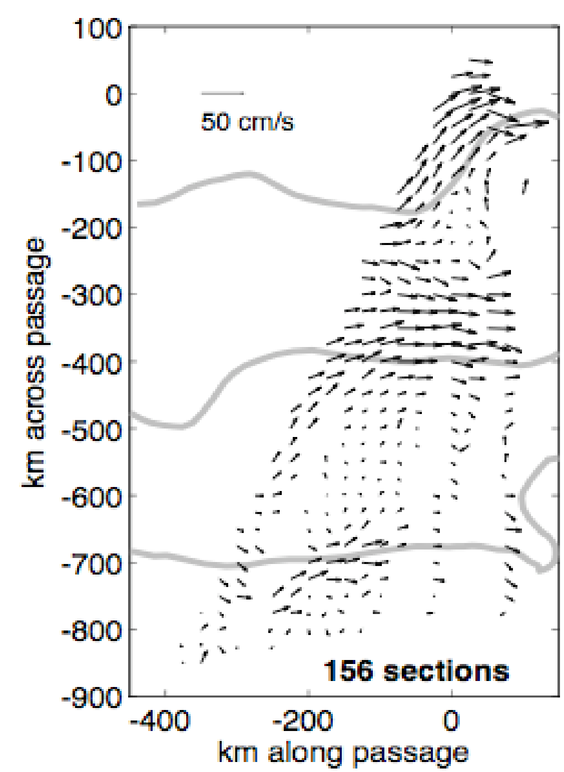
Distinctly different patterns are found North (wind stress variance; internal waves; eddies) and South (double diffusive convection; weak stratification) of the Polar Front and in winter and summer (wind stress variance)

ACC Zonal Momentum Balance

$$\underbrace{\frac{\partial}{\partial y}\langle u'v'\rangle} - \underbrace{f\,\frac{\partial}{\partial z}\,\frac{\langle v'T'\rangle}{\langle \theta \rangle_z}} = \underbrace{\frac{1}{\rho_o}\,\frac{\partial \tau}{\partial z}}$$

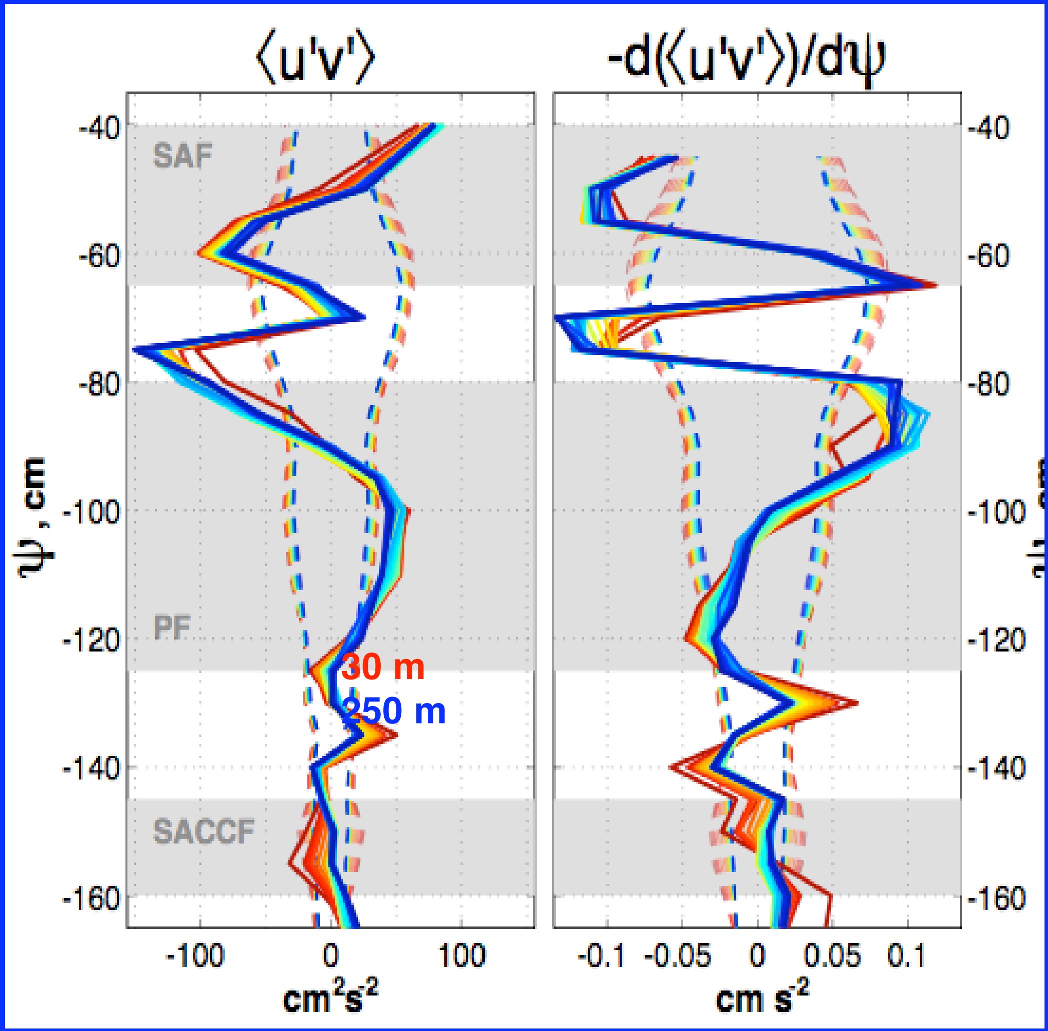
Ekman momentum flux divergence | Interfacial form stress divergence | stress divergence

- interfacial form stress links the downward transfer of momentum input from surface winds to meridional eddy heat flux <v'T'>.
- lateral divergence in the eddy momentum flux <u'v'> acts to accelerate the mean flow.
- eddy fluxes (Reynold's stresses) are small - need a good mean!
- use mean ADCP V to map ACC streamlines; project V into stream coords and average eddy momentum and heat fluxes along streamlines.



Lenn, Chereskin, Sprintall, and McClean, *subm. JPO,* 2010.

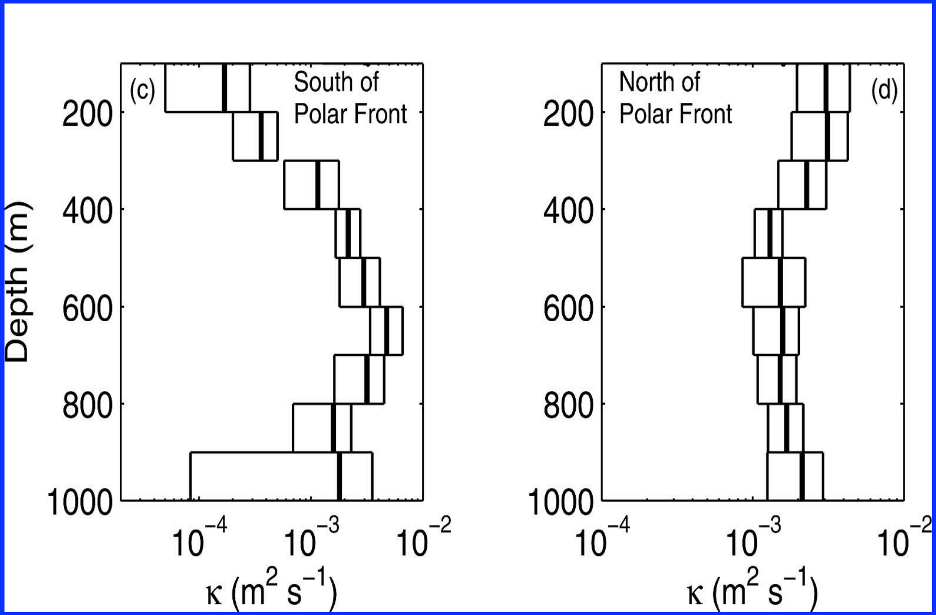
Eddy Momentum Fluxes



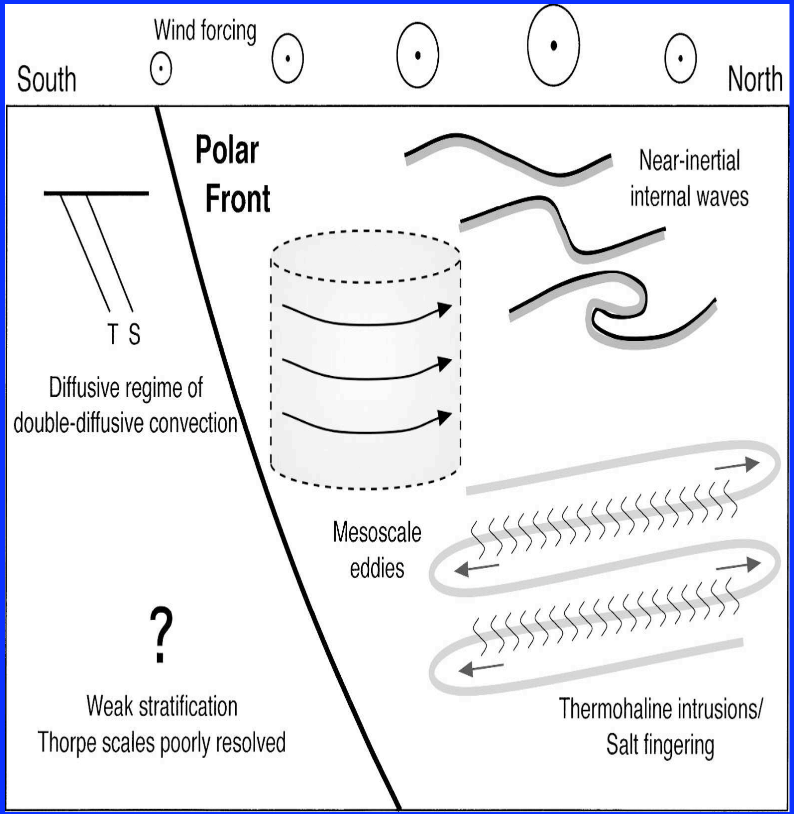
eddy momentum fluxes accelerate the mean flow consistent with the mean front convergences and divergences

Lenn, Chereskin, Sprintall, and McClean, JPO, subm., 2010.

Patterns of Small Scale Mixing



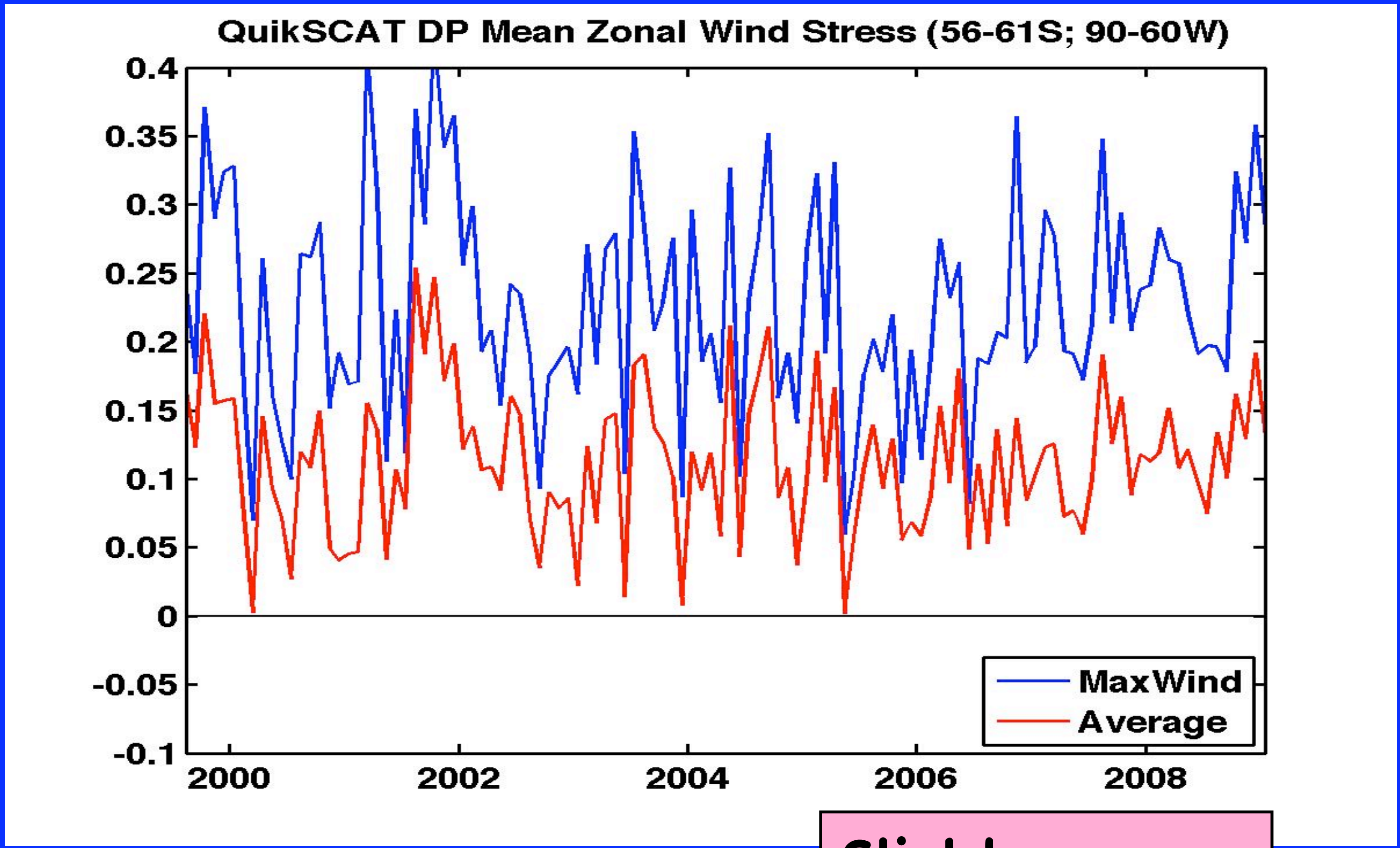
Distinctly different patterns are found north and south of PF



North: thermohaline intrusions, eddies, near-inertial internal waves
South: weakly stratified; double-diff. convection

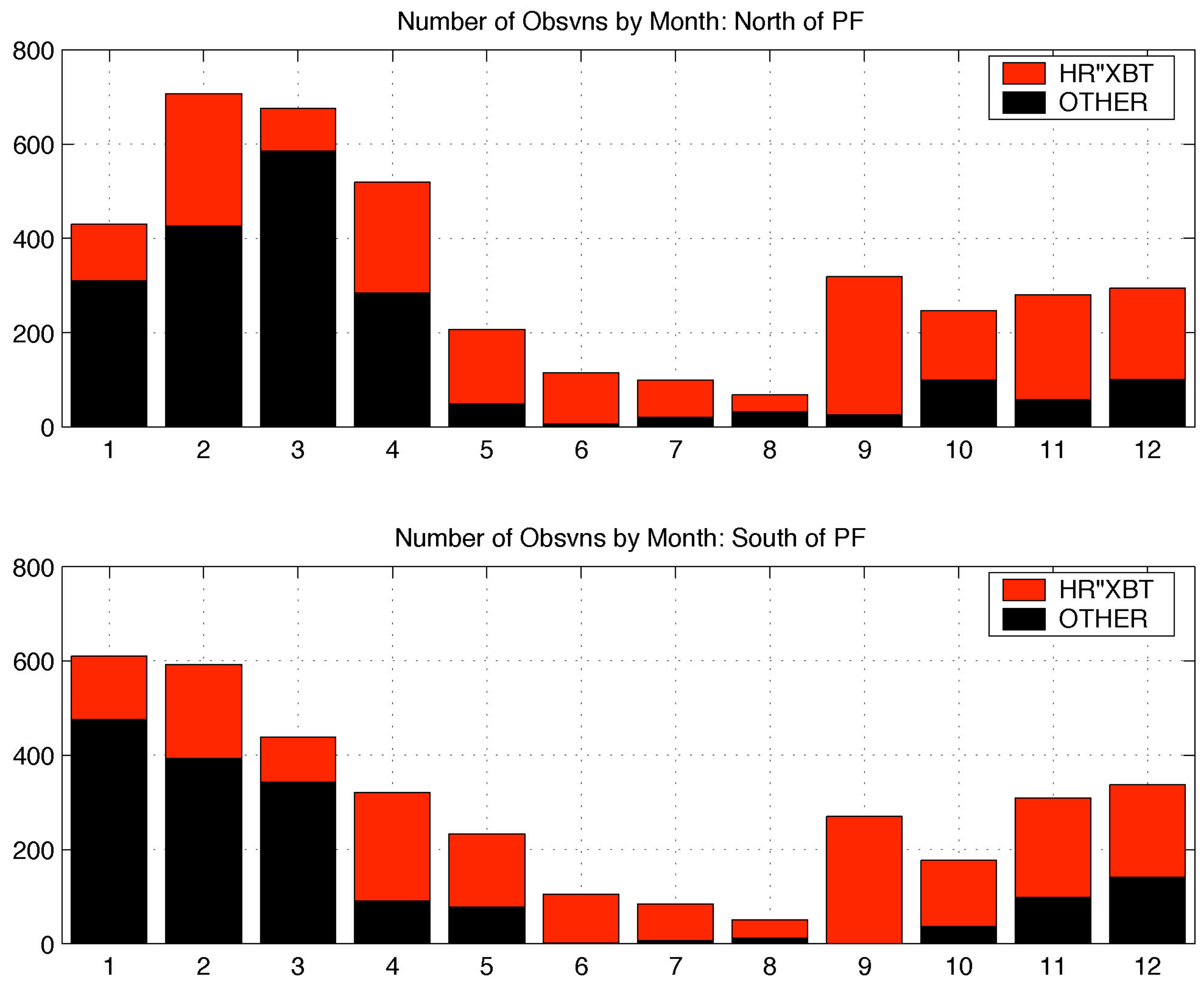
Thompson, Gille, MacKinnon, and Sprintall. *J. Phys. Oceanog.*, 37, 2007.

Wind Stress Increase in the DP?



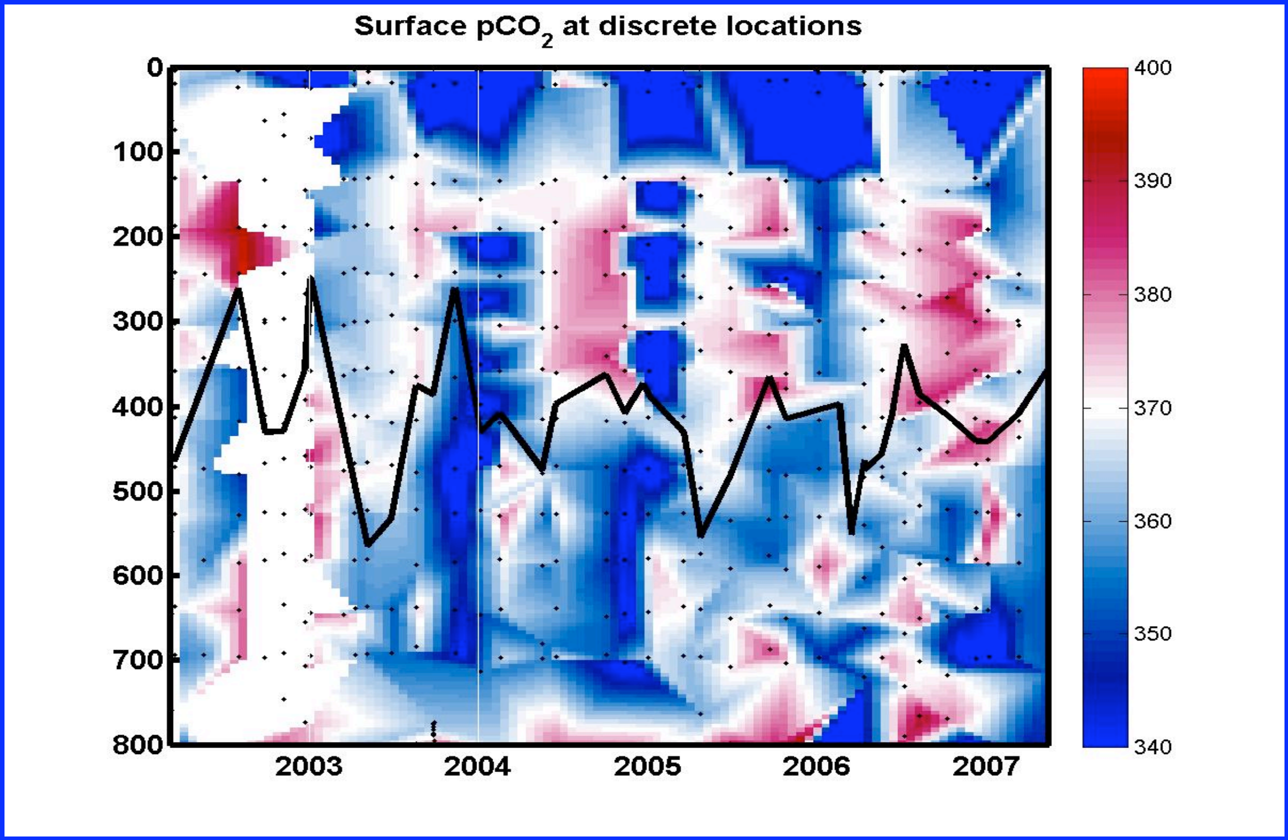
Slight increase since 2005?

Is the Surface Cooling A Function of Data Distribution?



Long-term Trends: Surface pCO_2

Distinctly different patterns in winter and summer; and north and south of PF



North:
high in winter -> cooler T? stronger storms? Increased mixing?

South:
vertical mixing and biological uptake probably important

⇑ pCO2 trend from ⇑ winds (SAM response?)

Sweeney et al.,*in prep*, 2010