# An Extreme Oceanic & Atmospheric Event in the South Pacific & Western Antarctica Associated With the 2009-10 El Niño

*Tong Lee*, Carmen Böning, Will Hobbs, Josh Willis, Daria Halkides, Ichiro Fukumori, Ed Armstrong, Akiko Hayashi, Tim Liu, Bill Patzert, Ou Wang*

*NASA Jet Propulsion Laboratory, California Institute of Technology*

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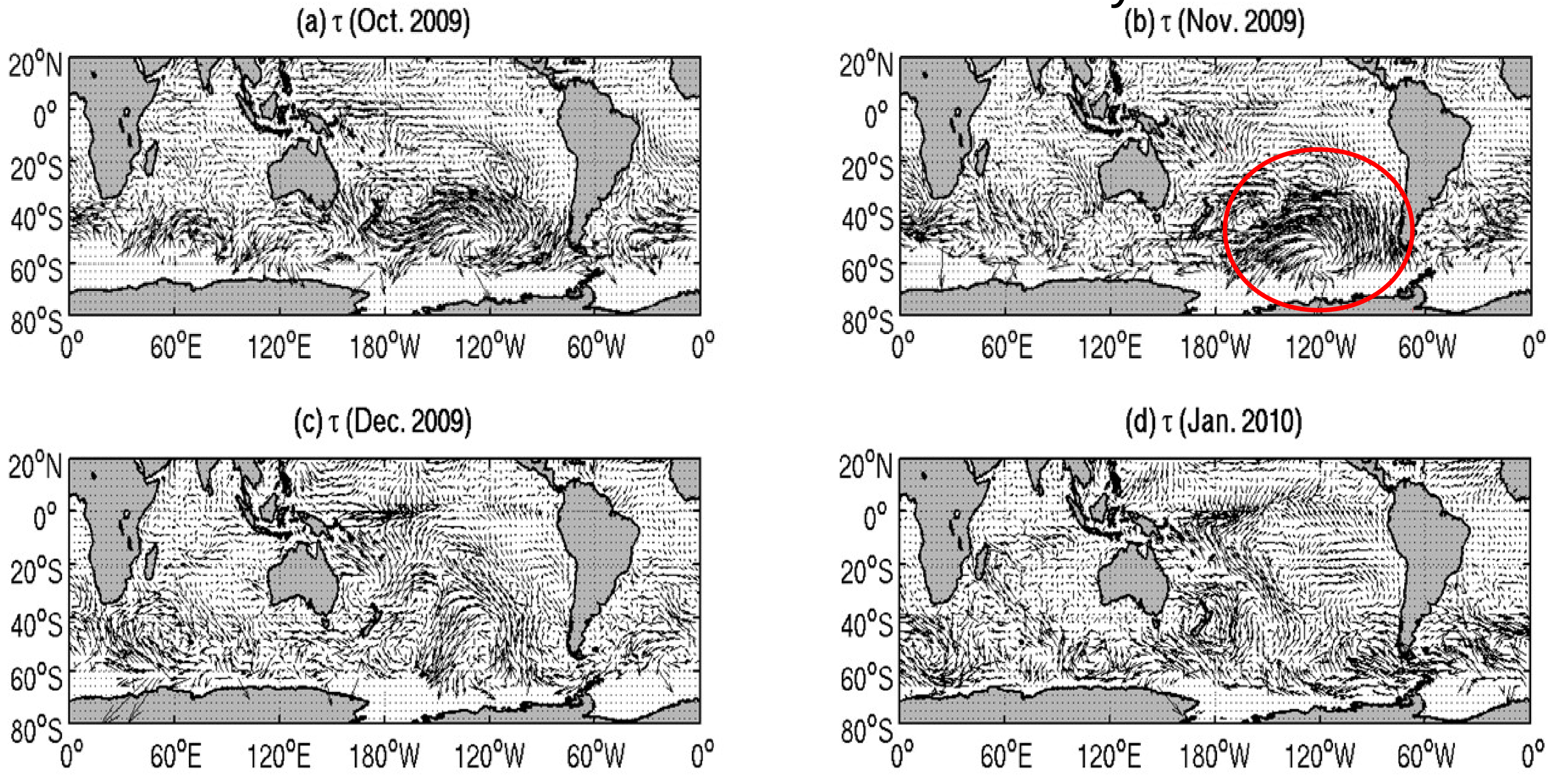
# Outline

- Extreme oceanic & atmos. conditions in the S. Pac. & western Antarctica during El Nino 2009-10 revealed by satellite and in-situ data.
- Heat budget analysis for based on observations and ECCO ocean state estimation product.
- Vorticity balance analysis using ASCAT & GRACE data.
- Contrasting the effects of central-Pacific and eastern-Pacific El Nino.

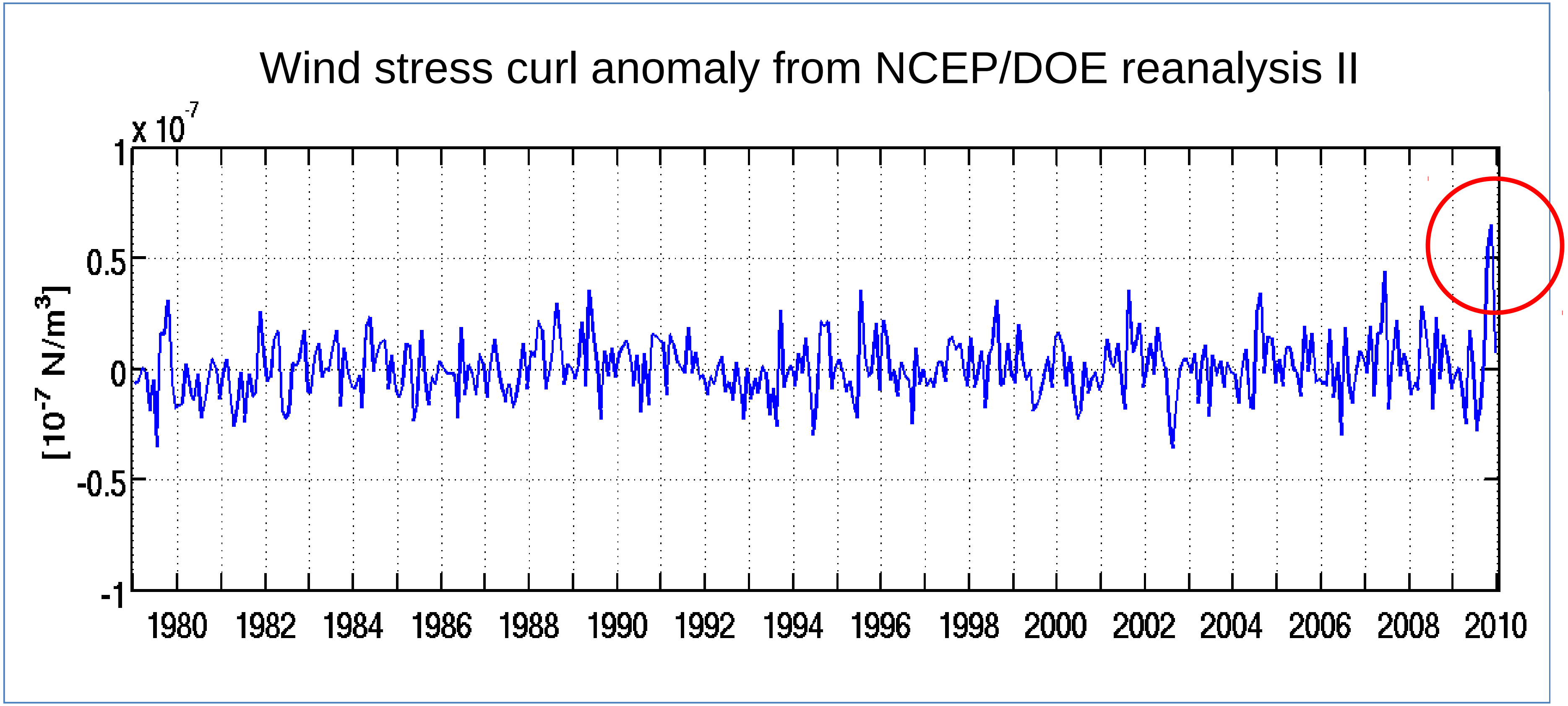
# A huge, persistent anticyclone in the South Pacific during 2009-10 El Niño

ASCAT vector wind anomaly



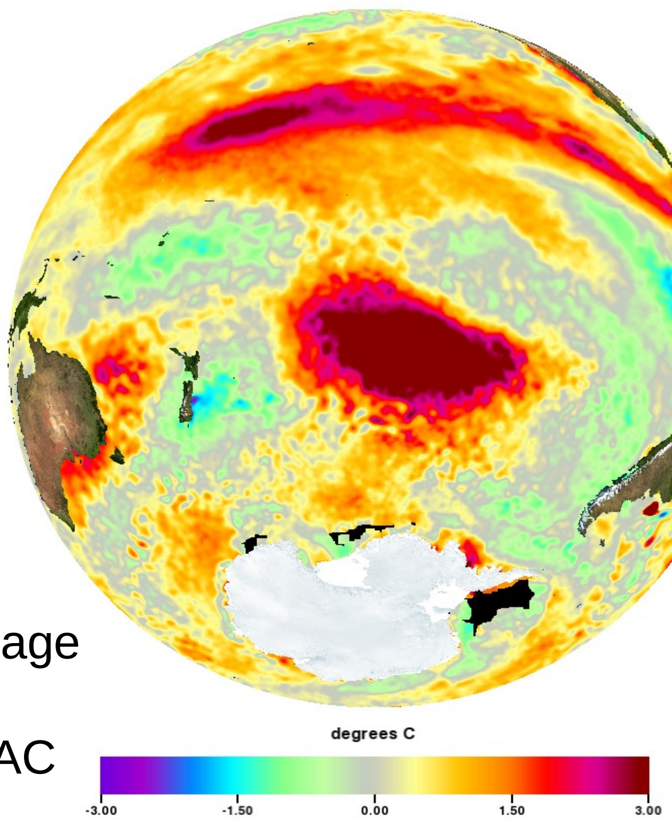

More persistent than blocking events typically associated with the Southern Annular Mode

# Unprecedented strength of the anticyclone



# Corresponding extreme anomalies in many variables (all can be explained by wind changes)

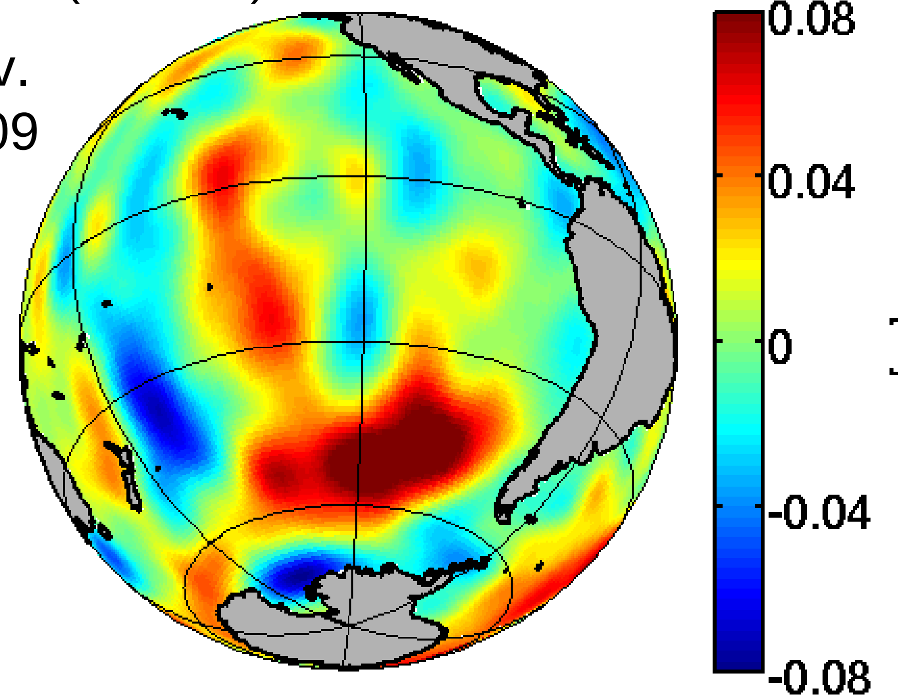
SST (Reynolds' 1°/4 GHRSST)




SST Image credit: PO.DAAC

Ocean Bottom Pressure (OBP) (GRACE)

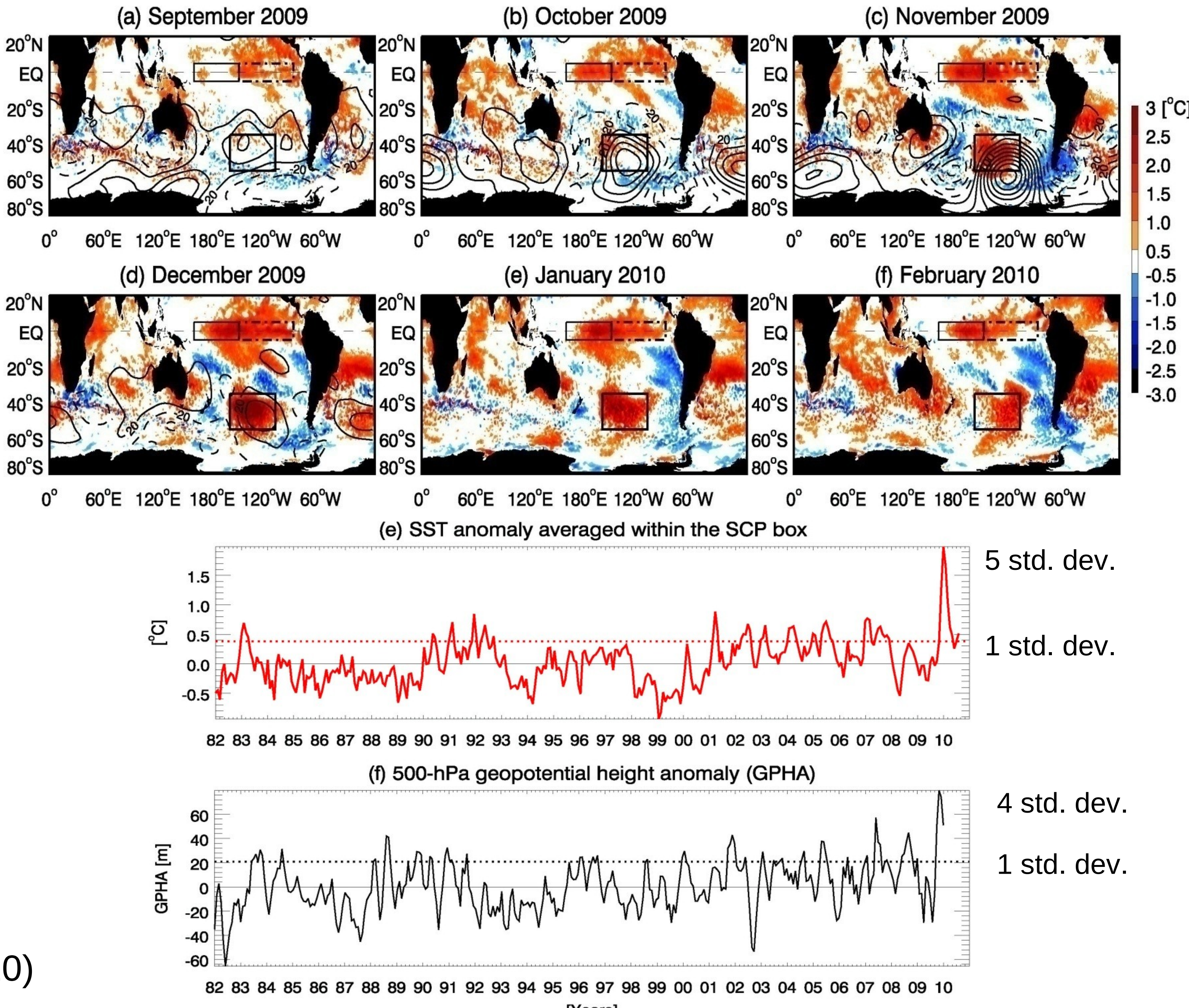
Nov. 2009



# Anomalies of SST & atmos. pressure associated with the anticyclone

Colors: SSTA

Contours: 500-hPa geopotential height anomaly




5 std. dev.

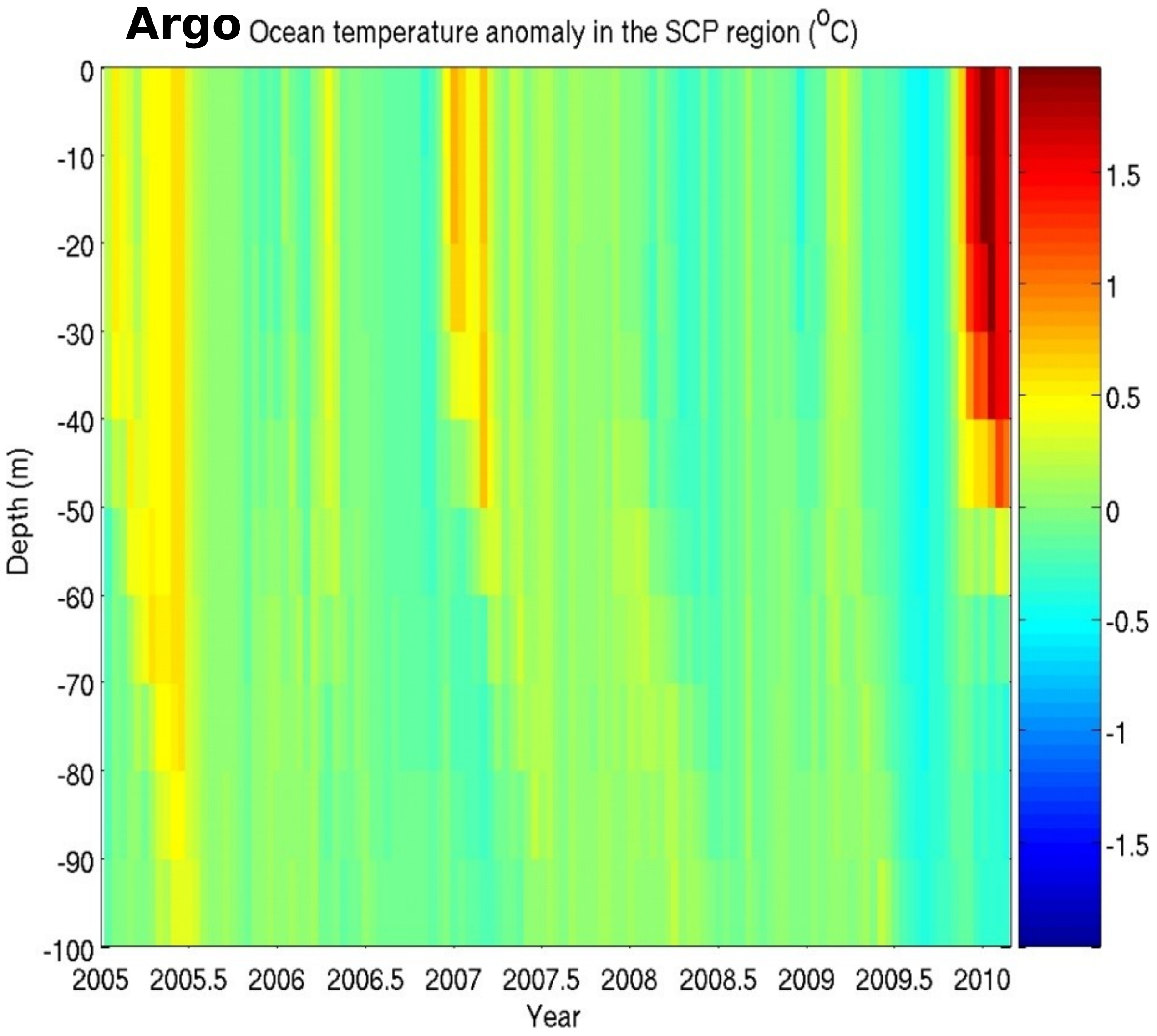
1 std. dev.

4 std. dev.

1 std. dev.

Lee et al. (2010)

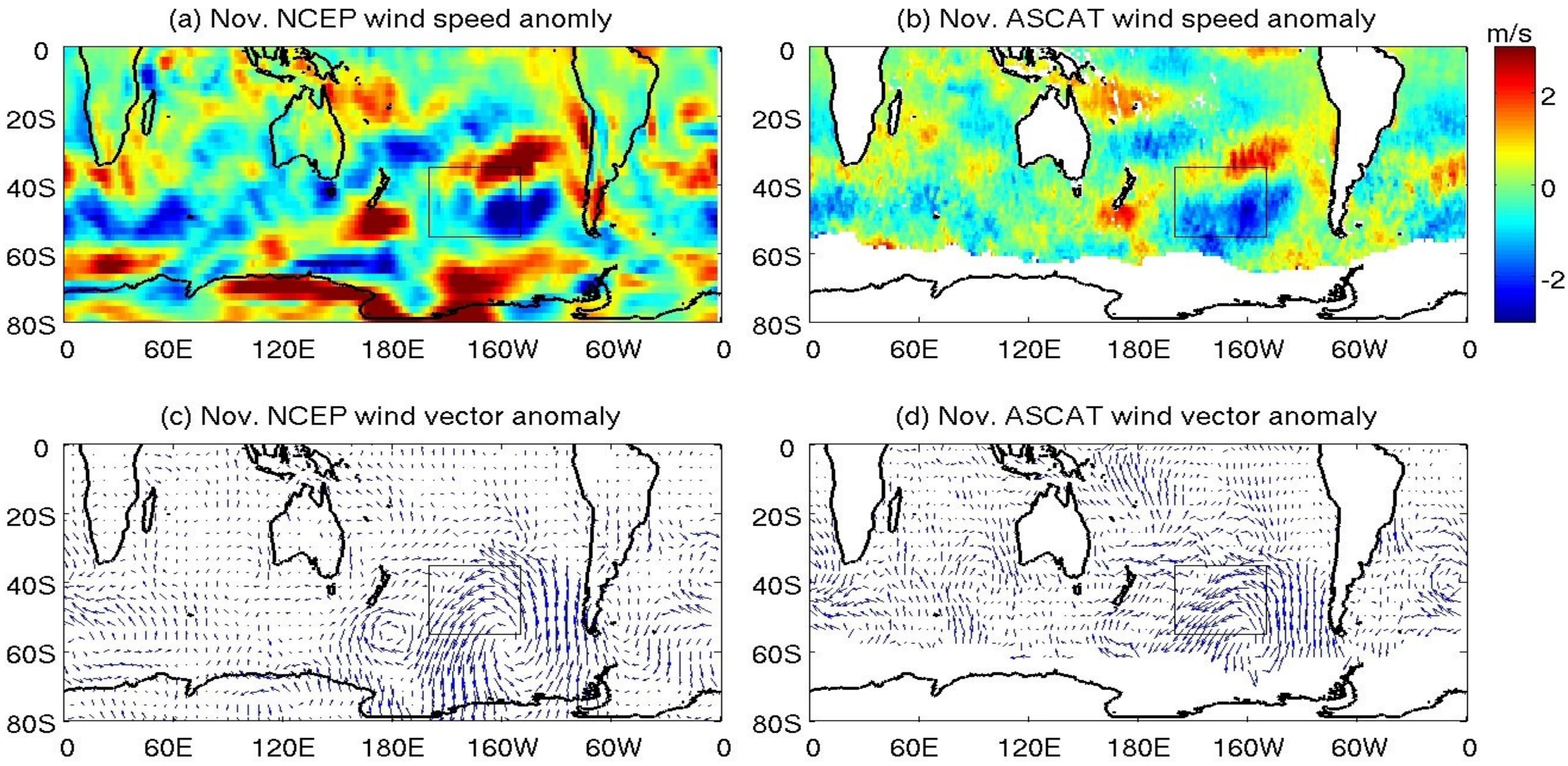
# Vertical structure of the warming in the South Pacific: confined to top 50 m (Austral spring-summer mixed-layer depth)




Lee et al. (2010)

# Anomalous wind speed & direction associated with the anticyclone caused the oceanic warming: observational analysis suggest comparable roles of ocean & atmos. processes

- Weaker wind reduced evaporative heat loss
- Easterly anomaly of wind suppressed northward intrusion of cold waters




Lee et al. (2010)

# Mixed-layer temperature (MLT) balance

- Mixed-layer depth (MLD) defined as ($\sigma(z) = \sigma_o + 0.125\ kg \cdot m^{-3}$ )
- Calculate MLT budget integrated over MLD [ ]

**"Ocean Processes"**

Net Tendency

Surface Fluxes

Horizontal advection

Horizontal mixing (small)

Subsurface Processes

$$\frac{\partial T}{\partial t} = \frac{1}{\rho C_p}\frac{\partial Q}{\partial z} - \left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) + \left(\frac{\partial}{\partial x}\left(\kappa_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\kappa_y \frac{\partial T}{\partial y}\right)\right) + subsurface$$

$$subsurface = -\frac{1}{h}\Delta T\frac{\partial h}{\partial t} - \left(w\frac{\partial T}{\partial z}\right) - \frac{1}{h}\kappa\frac{\partial T}{\partial z}\Big|_{-h}$$

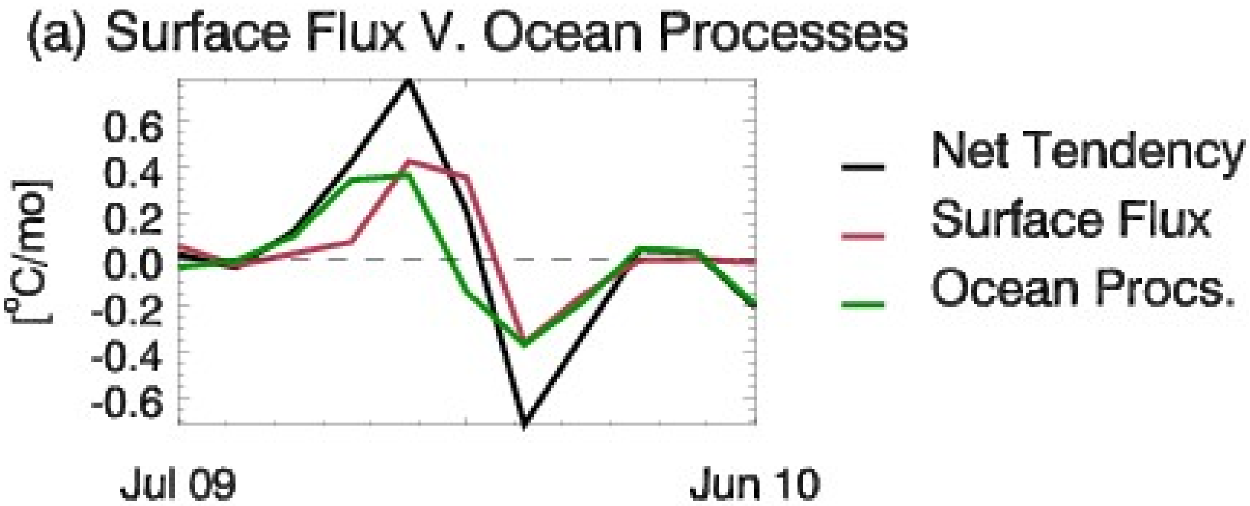
Vertical Mixing

Entrainment-Detrainment (ML base motion)

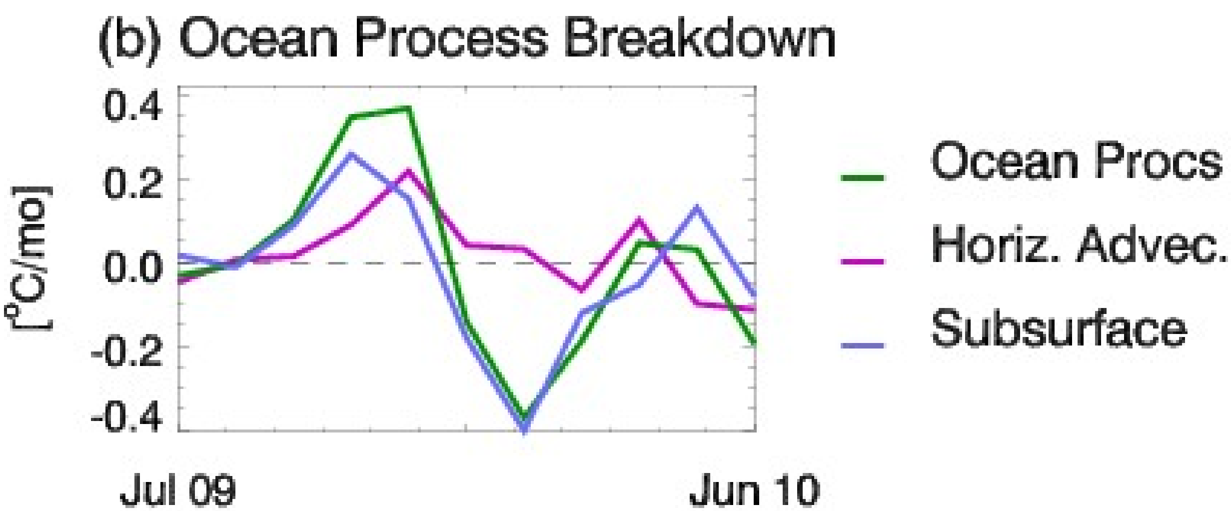
Vertical Advection

# Analysis of mixed-layer heat budget based on ECCO-JPL ocean state estimation product

Comparable roles of surface heat flux & ocean dynamics

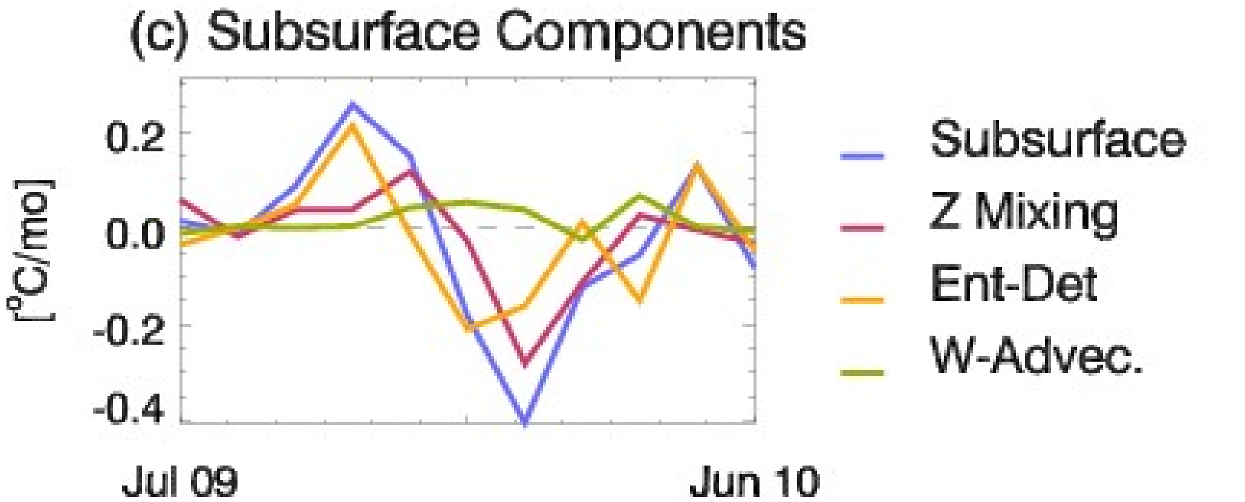



Comparable roles horizontal advection & vertical/subsurface processes

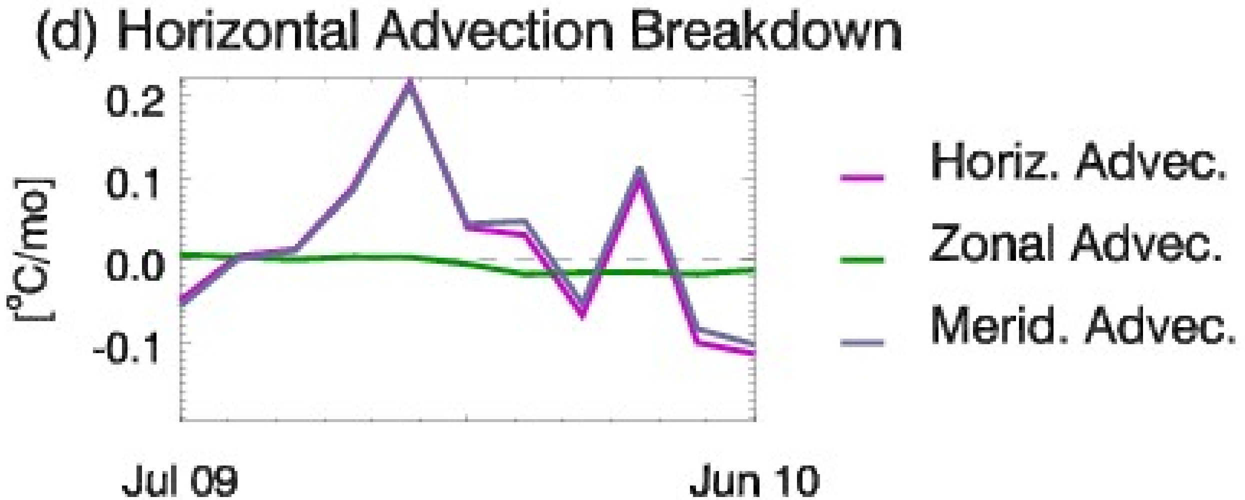


# Detailed breakdown subsurface & horizontal processes

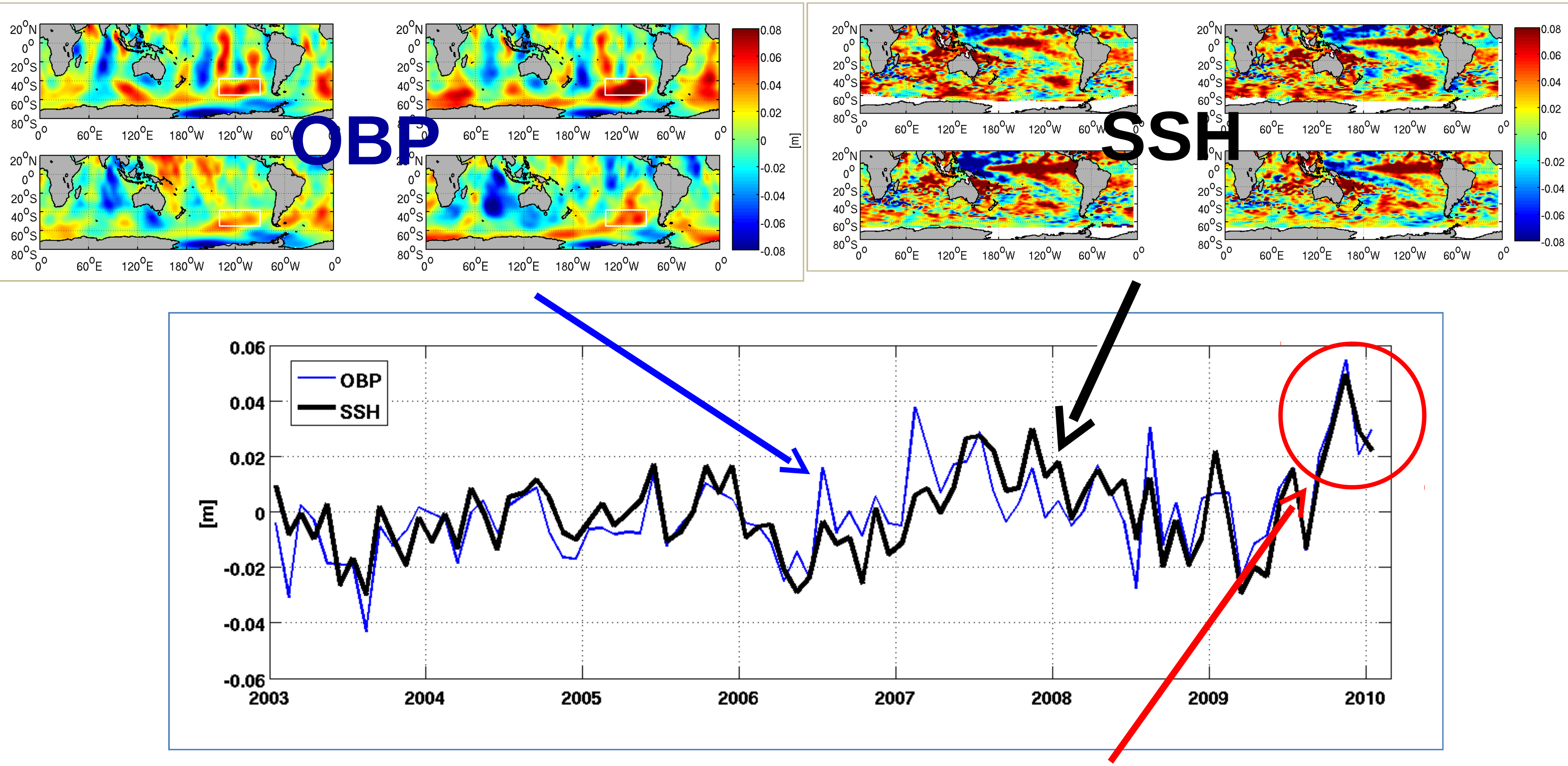
Entrainment-detrainment dominates vertical processes




Meridional advection dominates horizontal processes



# Ocean Bottom Pressure (OBP) signal from GRACE) & sea surface height (SSH) signal from JASON-1



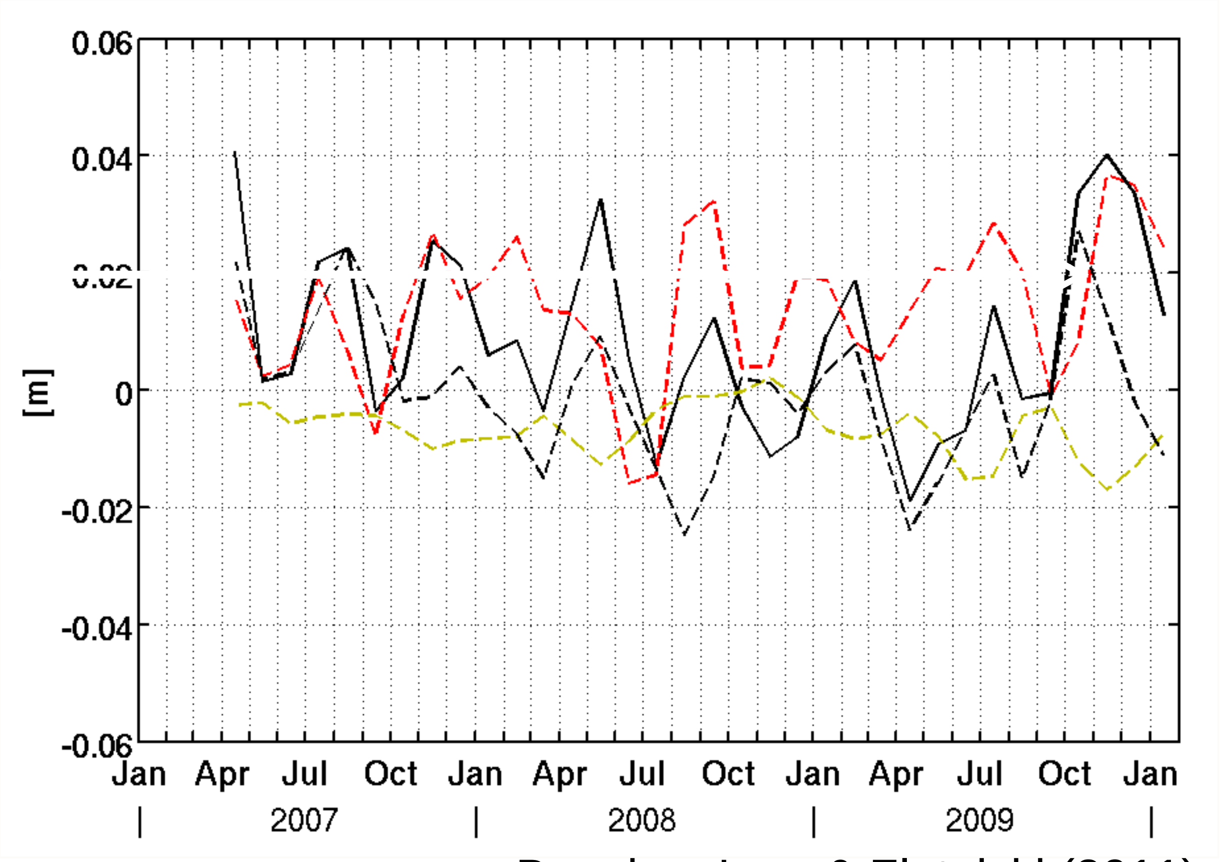

Agreement indicates mass convergence is the primary cause for the SSH increase.

Boening, Lee, & Zlotnicki (2011)

# Re-enforcement of wind forcing and topographic effect caused the OBP anomaly as observed by GRACE

$$\beta \frac{\partial \eta}{\partial x} + \frac{f}{H}\left(\frac{\partial \eta}{\partial x}\frac{\partial H}{\partial y} - \frac{\partial \eta}{\partial y}\frac{\partial H}{\partial x}\right) + \nabla \cdot \left(\frac{rg}{fH}\nabla \eta\right) = \frac{f}{\rho g}\nabla \times \frac{\tau}{H}$$

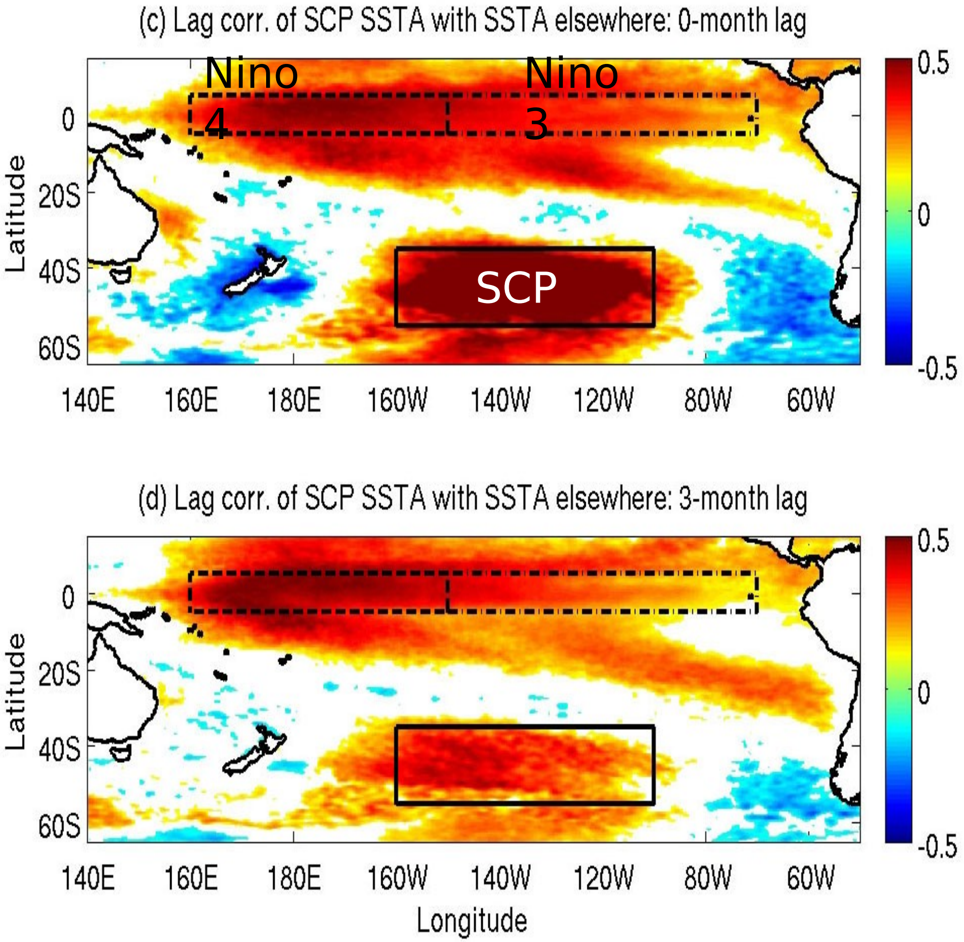
- Overall: topographic effect important
- Late '09 event: **wind forcing** re-enforce topographic effect, counteracted by friction.

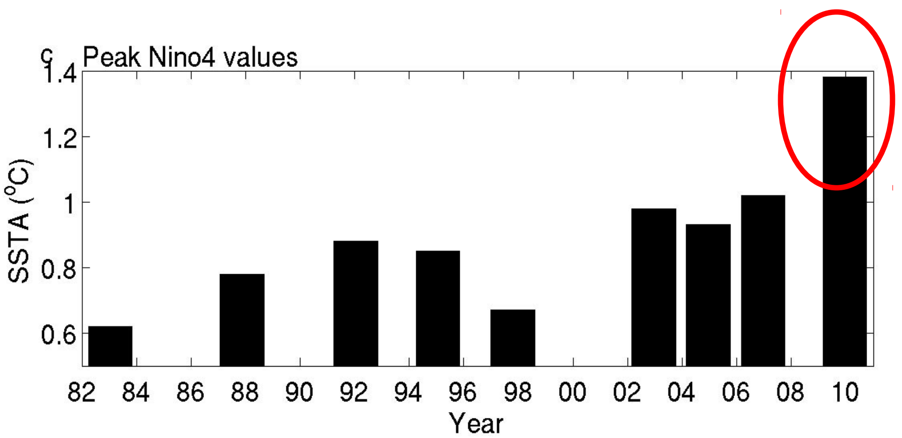



Boening, Lee, & Zlotnicki (2011)

# The extreme event in the South Pacific (and western Antarctica) was attributed to the 2009-10 El Nino

- SCP SSTA best correlated with Nino4 SSTA (up to a few months of lags).
- Nino4 SSTA for the 2009-10 El Nino is a record high.

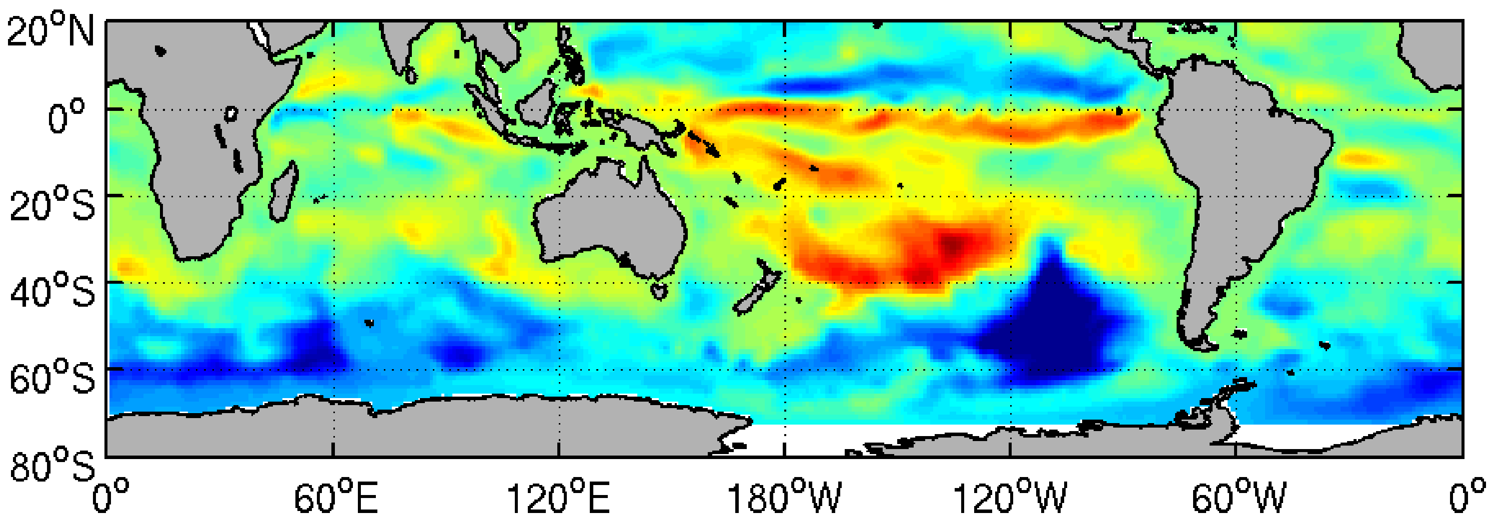


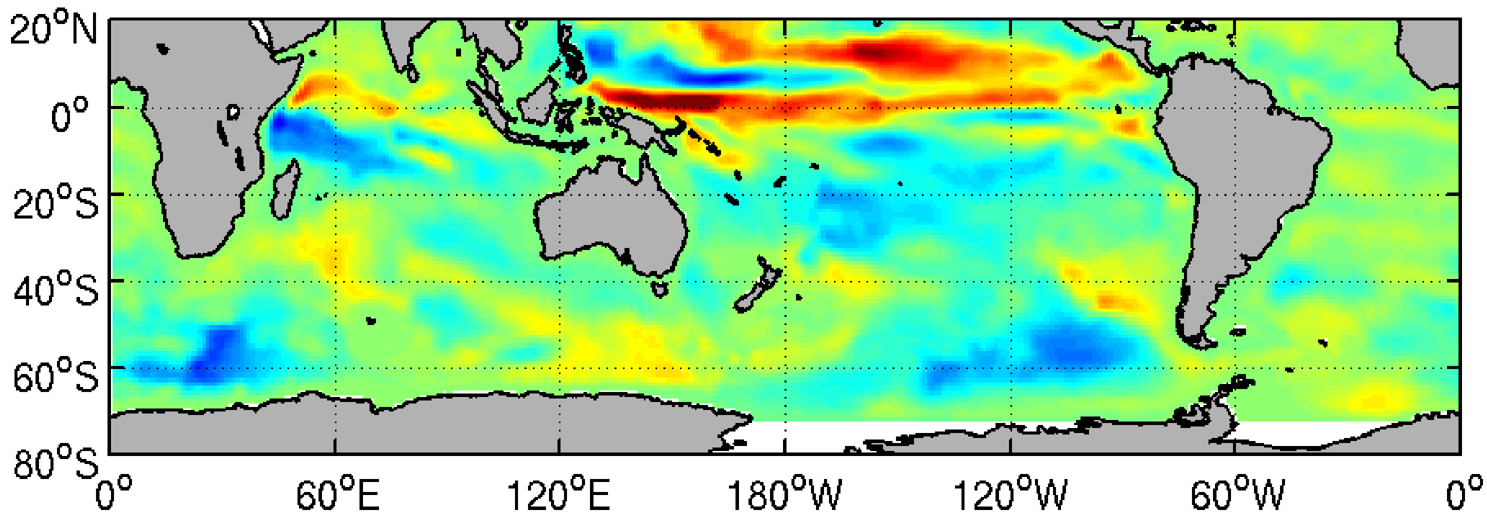

Lee & McPhaden (2010)

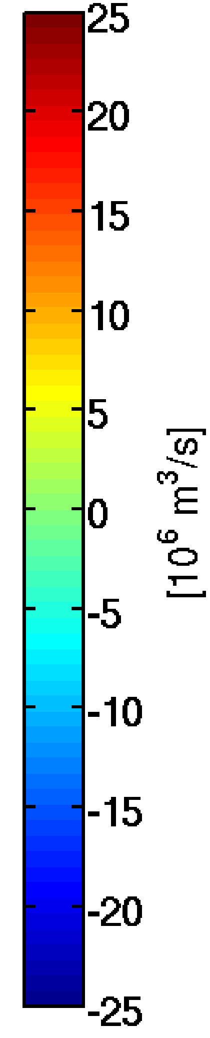
# Effects of El Nino on Southern Ocean circulation: contrasting central- and eastern-Pacific El Nino

Barotropic stream function anomaly in Nov. ‘09 (the strongest CP-El Nino) (ECCO-JPL)

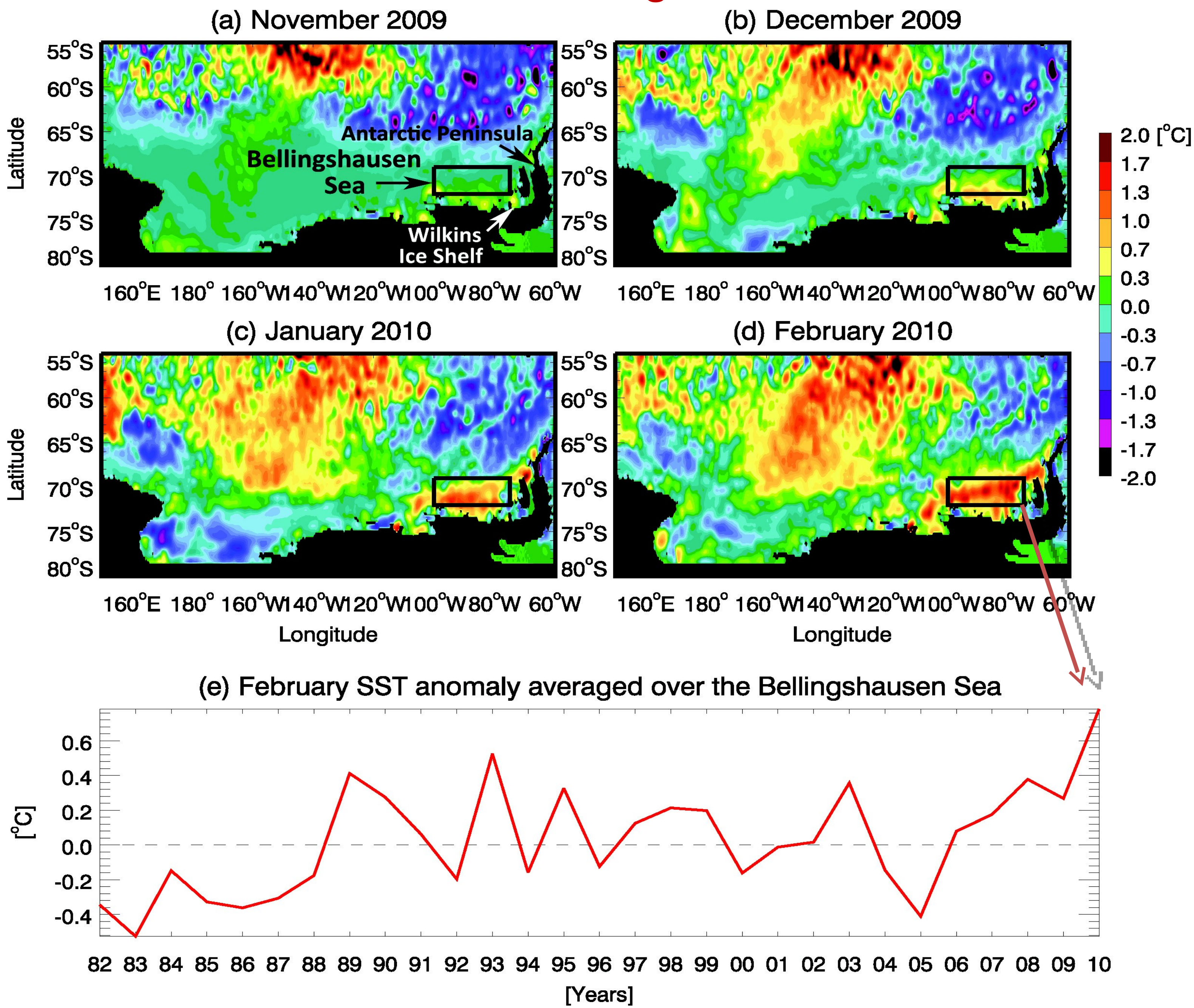



Barotropic stream function anomaly in Nov. ‘97 (the strongest EP-El Nino)



# Record austral-summer warming off the western Antarctica



# Summary

- Satellite and in-situ data revealed extreme oceanic & atmos. conditions in the S. Pac. & western Antarctica during El Nino 2009-10.
- Huge, persistent anticyclone with unprecedented strength.
- Five standard-deviation, record warming in the ocean mixed layer; large signatures in SSH/OBP (altimeter/GRACE).
- Heat budget analysis suggests that anomalous wind speed and wind direction were the cause of the mixed-layer warming.
- Vorticity balance analysis indicates that re-enforcement of wind stress curl by topographic effect can explain the record high anomaly of OBP.
- These anomalies are very different from those associated with the 1997-98 El Nino -> warrant a systematic investigation of the effects of central-Pacific & eastern-Pacific El Nino.