

# Small-scale and short-term variability of ocean surface winds: Applications to objective analyses and ocean modeling

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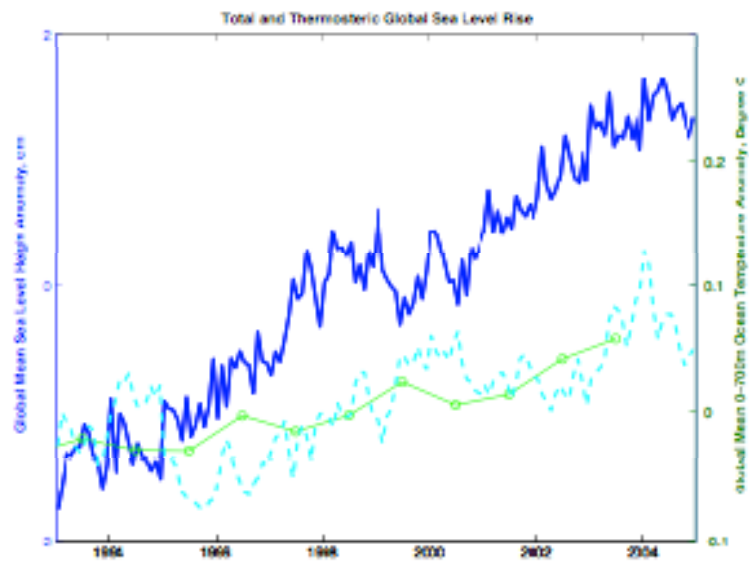
H.-P.Huang (ASU)



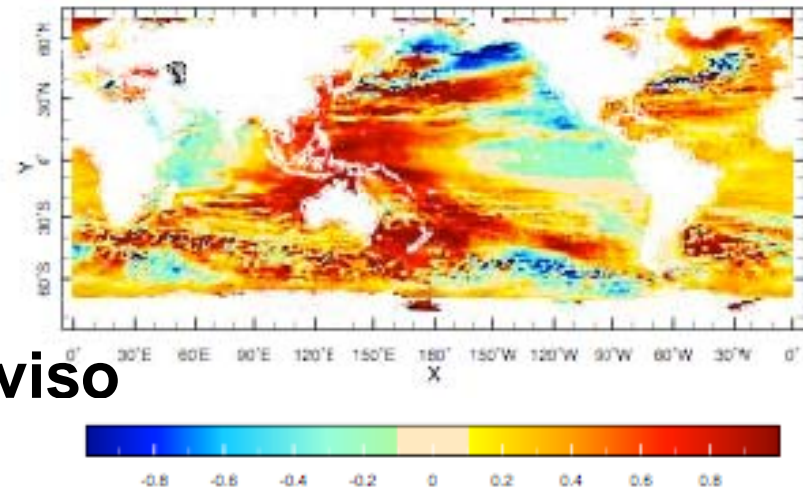
# **Importance of high-quality continuous wind products:**

- 1. Major influence of wind forcing on the patterns of decadal-bidecadal sea level trends**

# Global vs Regional Sea Level Rise

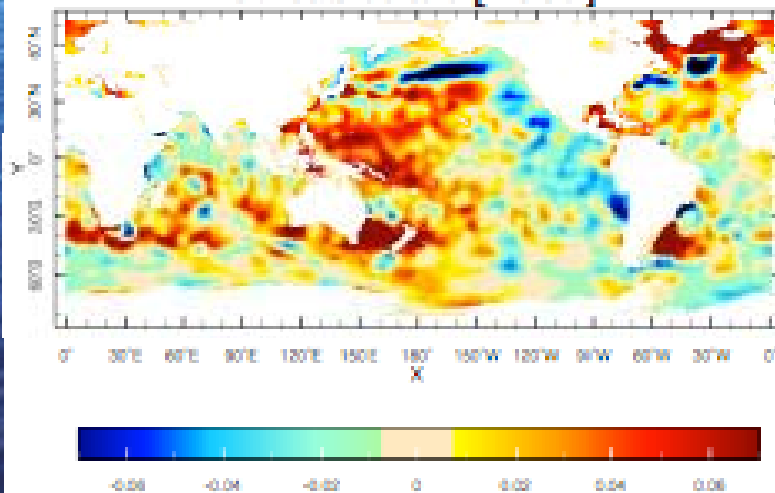


Linear trend in surface heights: 1993-2003, cm/yr

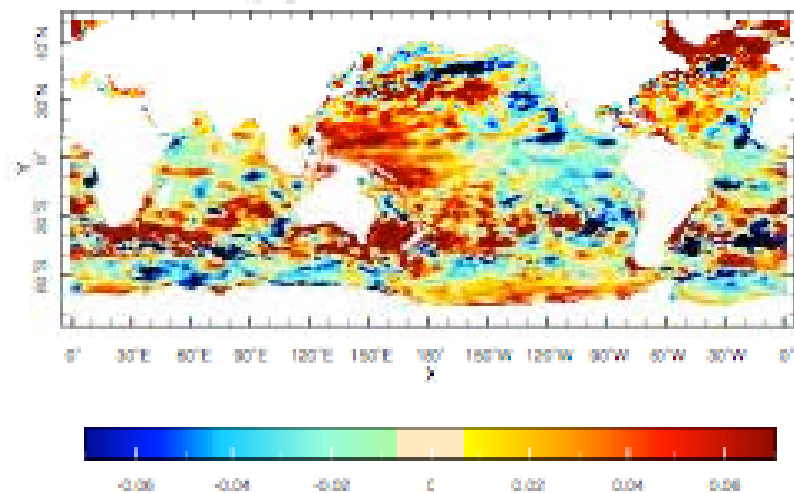


Linear trend in mean temperature of the ocean top 700m, °C/yr

Levitus et al. [2005]



SODA

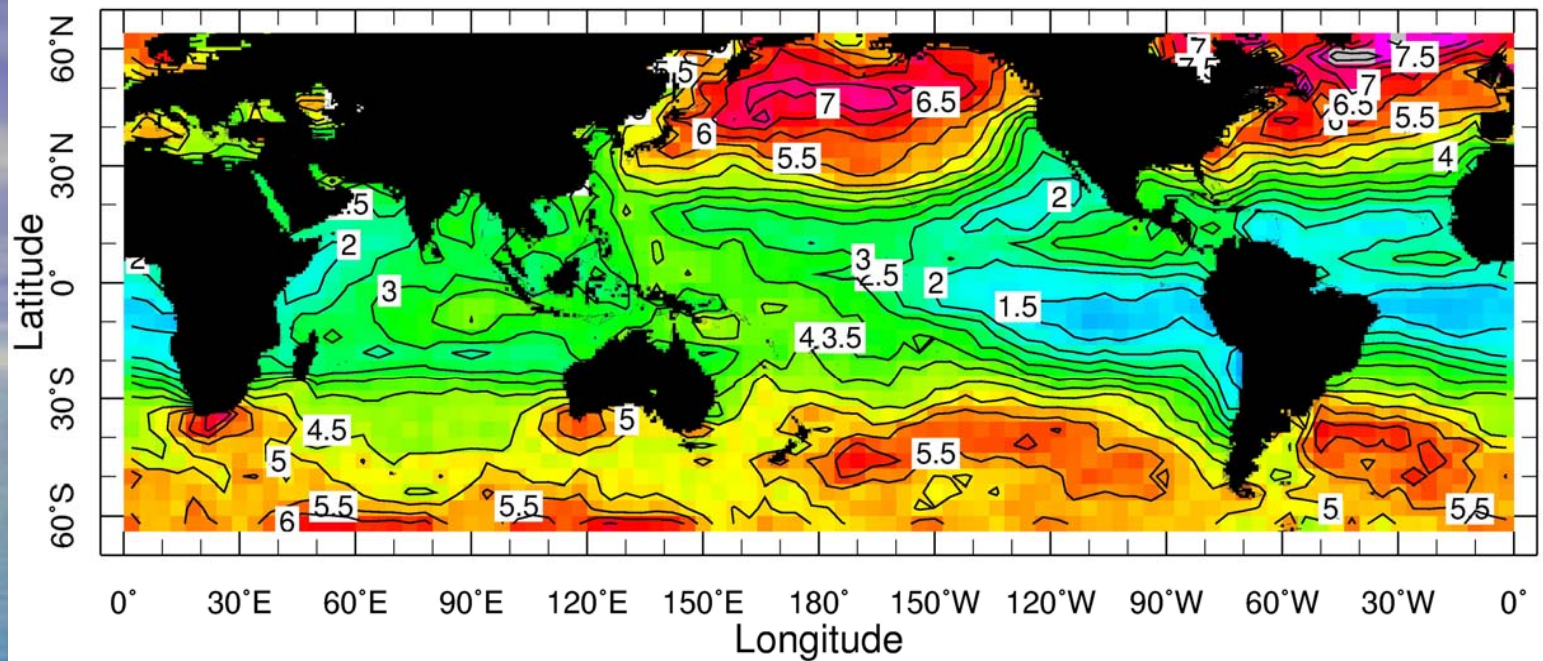




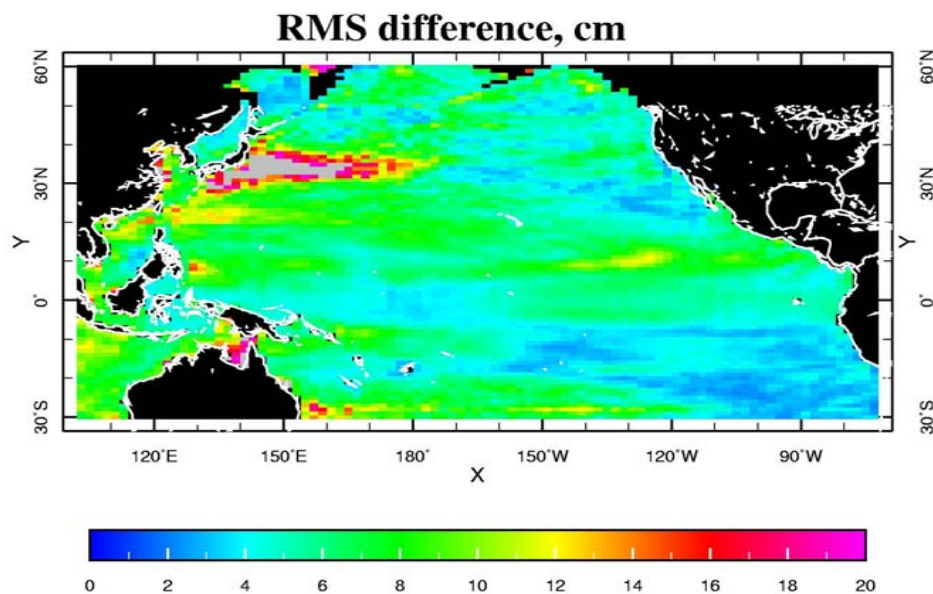
**Importance of high-quality  
continuous wind products:**

**2. Ocean model responses to  
errors in winds**

Zonal wind  
Variability  
Inside  
4degx4deg  
x1mon bins  
(NSCAT)

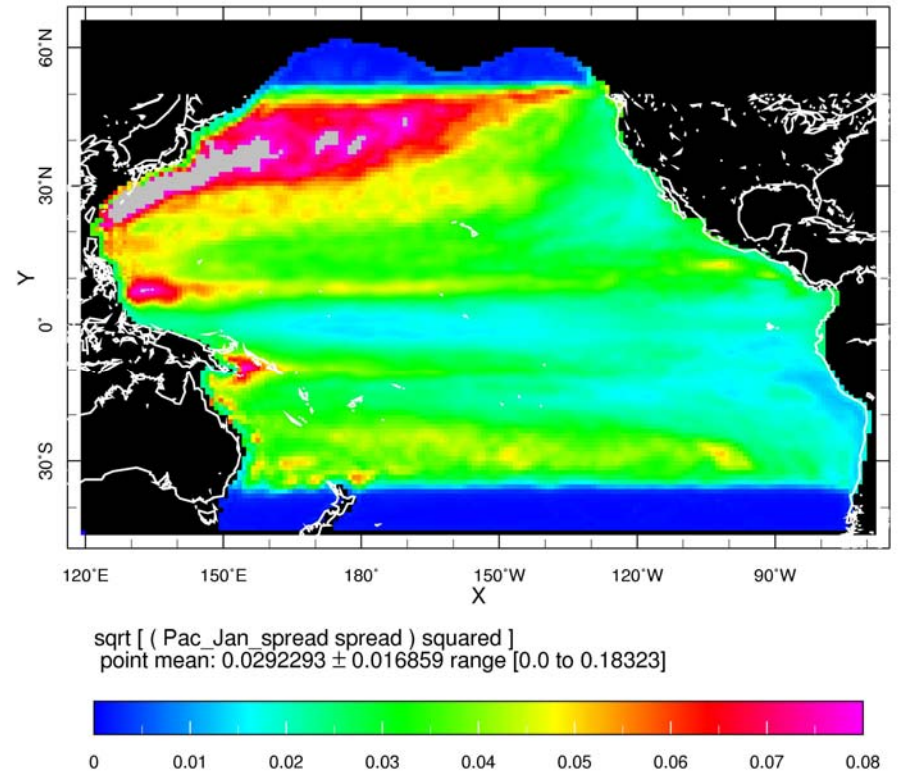


## Comparison of sea level height deviation

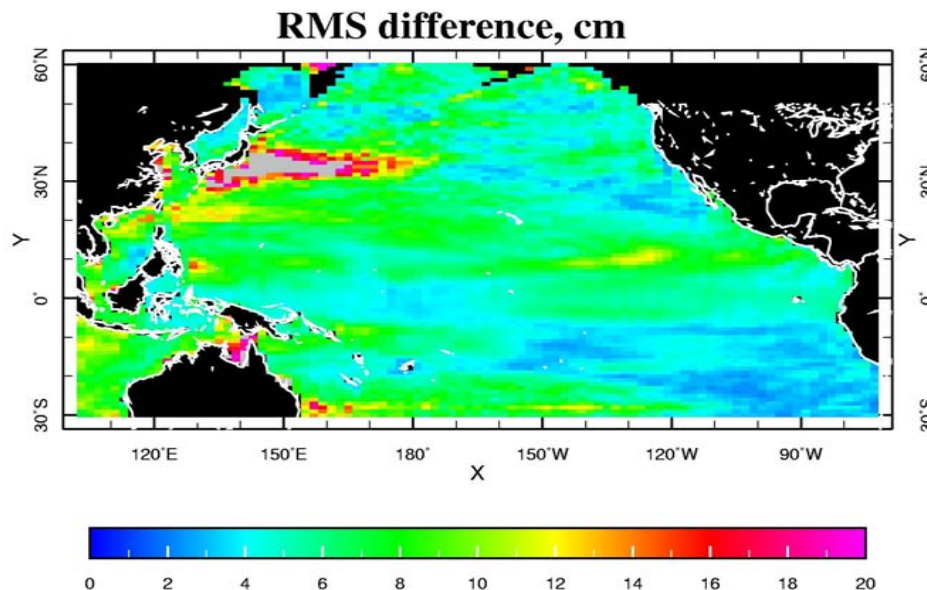


RMS SSH [Npac-DUACS],  
Curchitser et al. 2005

SSH response to perturbations from AMIP fluxes (GMAO Poseydon ocean model, Borovikov et al. 2005)



Comparison of sea level height deviation

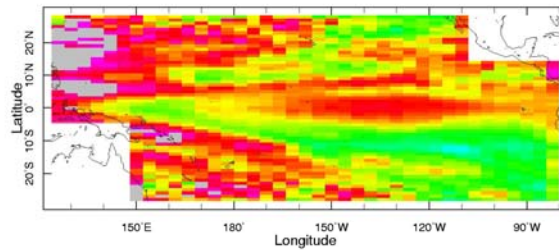


RMS SSH [Npac-DUACS],  
Curchitser et al. 2005

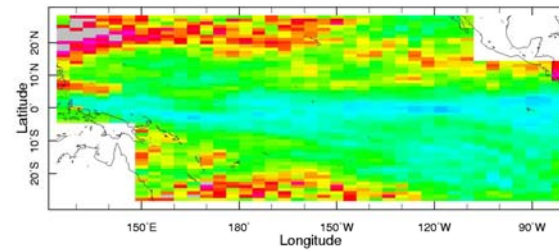
Sea level height anomaly:  $\text{RMS}[\text{Topex} - \text{models}]$ , cm

### Linear model

No assimilation

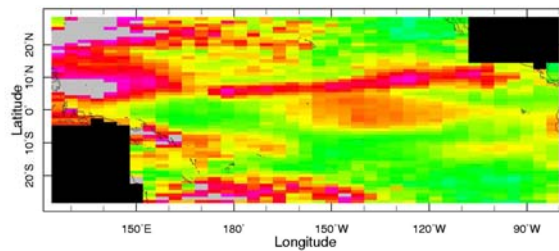


Altimetry assimilated

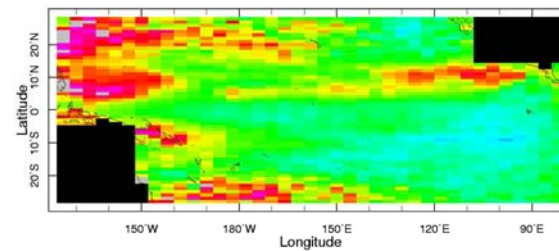


### ECCO-1

No assimilation

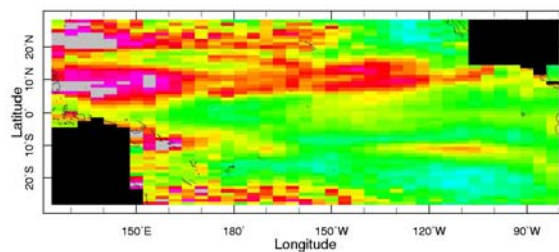


Everything assimilated

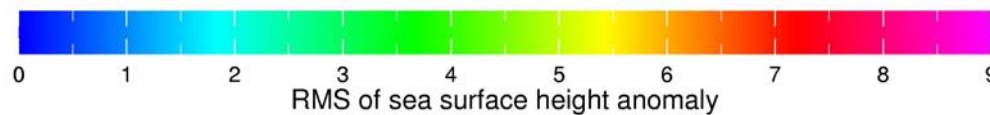
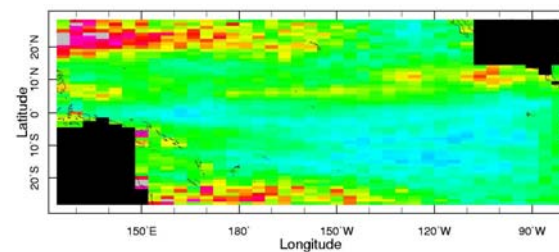


### ECCO-2

No assimilation



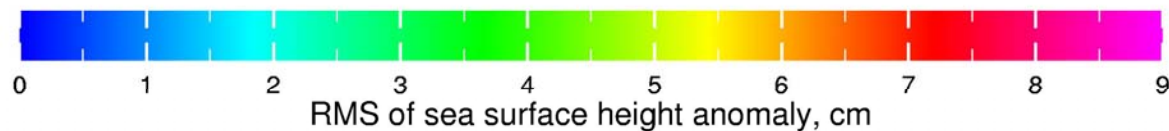
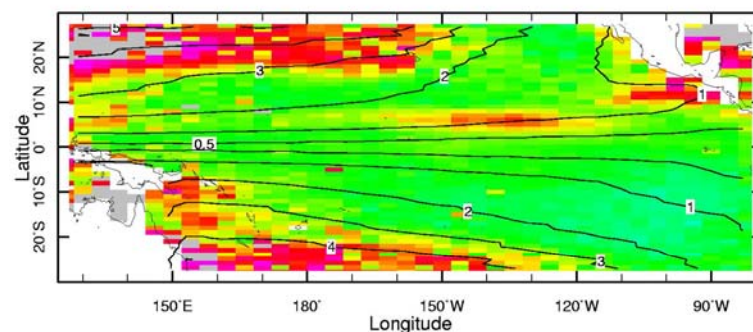
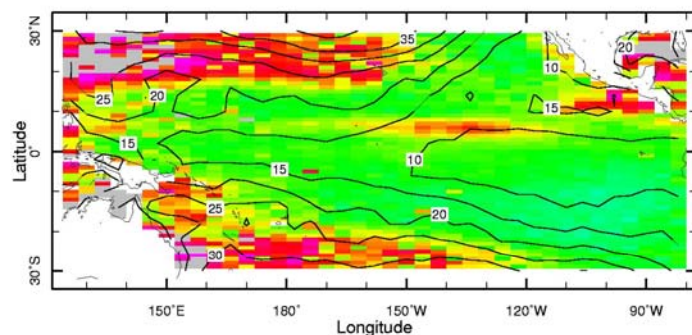
Topex assimilated



# Small-scale variability in wind and sea level height

(a) SSV of zonal pseudostress

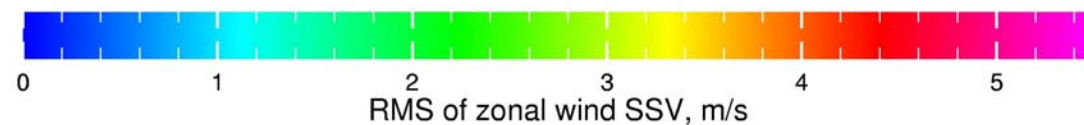
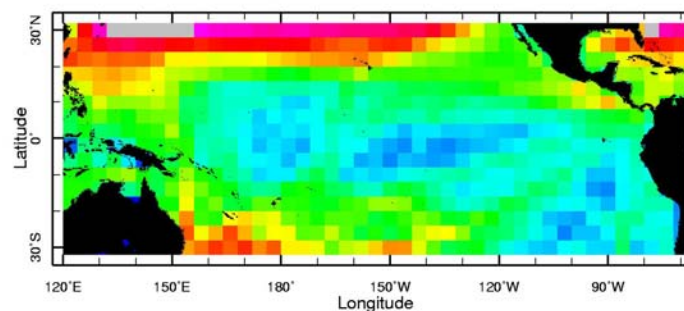
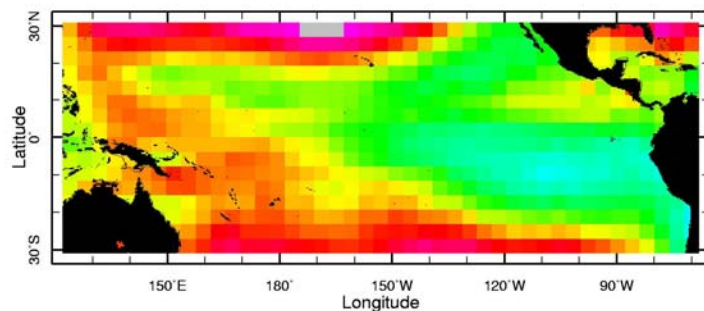
(b) Simulated sea level height SSV



## Small-scale variability in zonal wind $\sigma_{4^{\circ} \times 4^{\circ} \times 1 \text{ month}}$

(a) NSCAT

(b) COADS

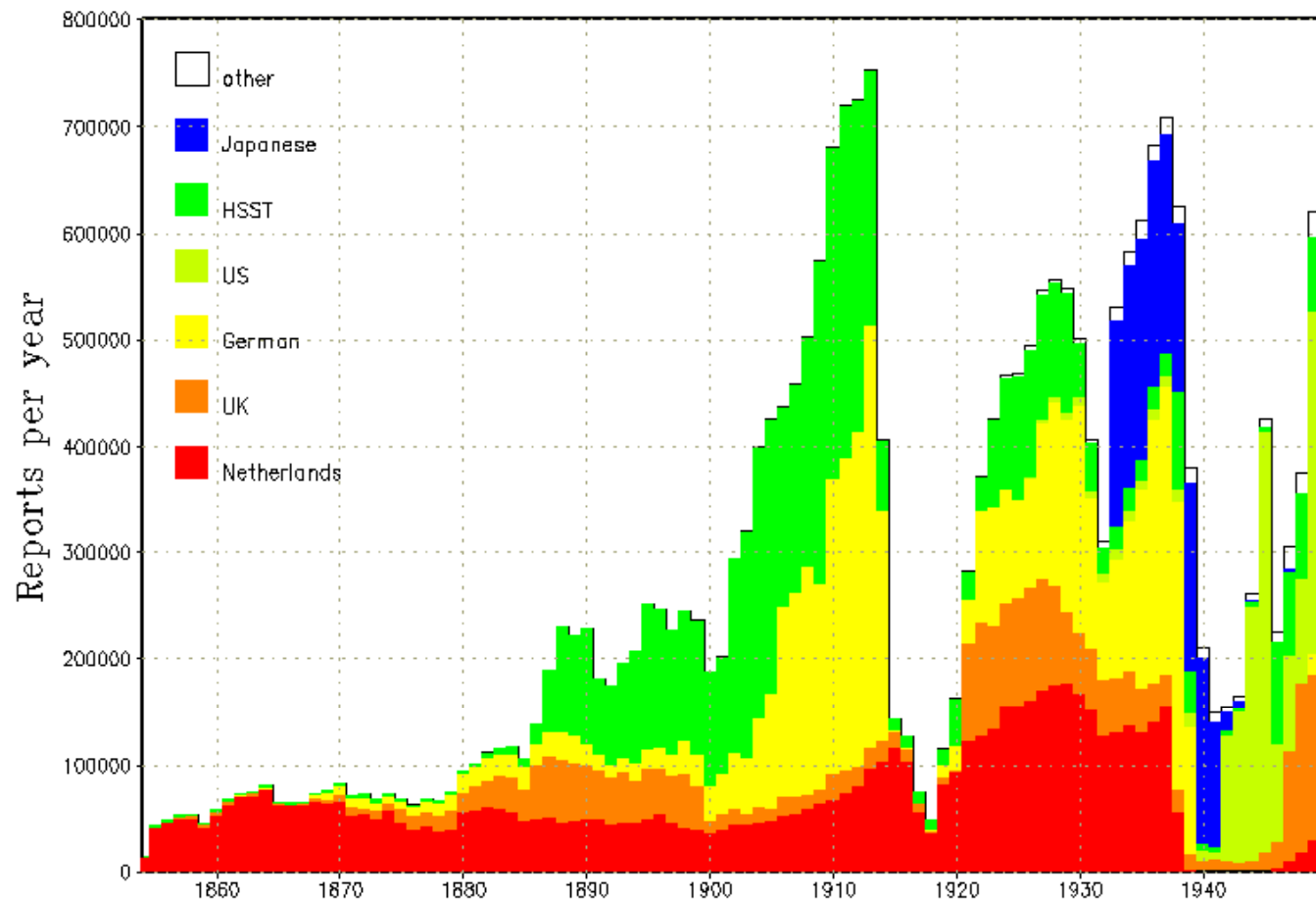




**Importance of high-quality  
continuous wind products:**

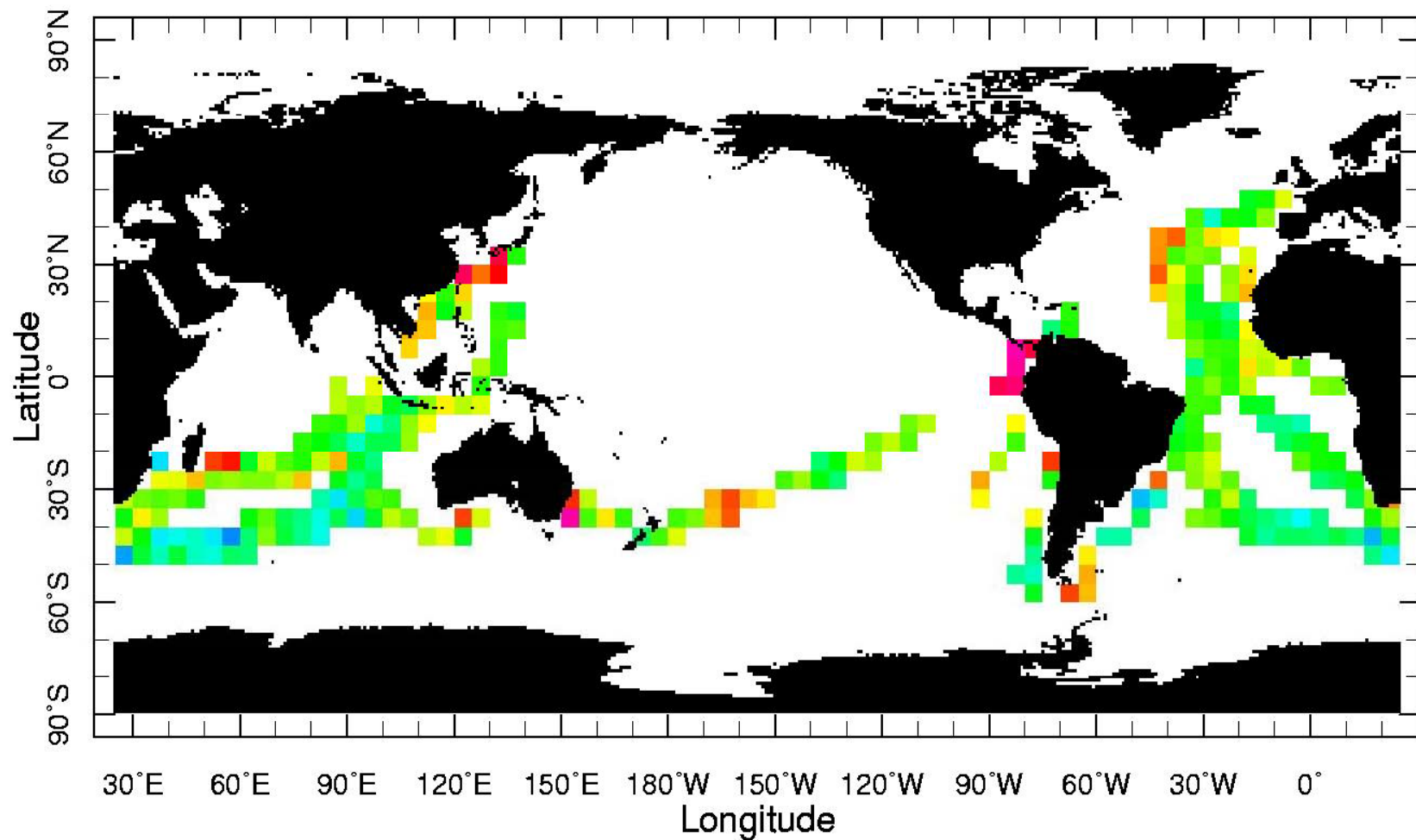
**3. Learning relationships to  
constrain reconstructions of  
wind fields in pre-satellite era**

# Number of observations in ICOADS



<http://icoads.noaa.gov/>

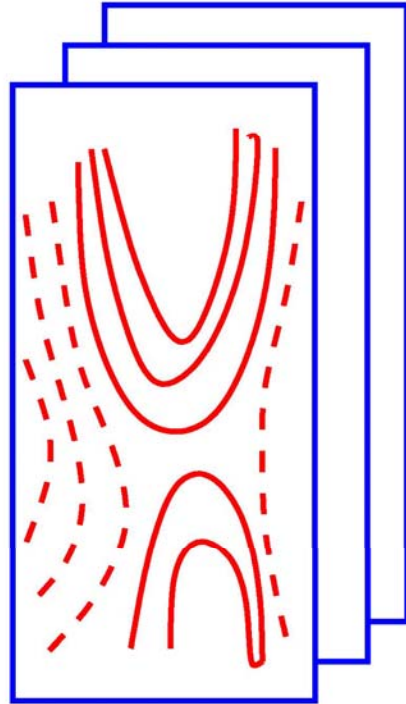
# Dec 1868: Available observations



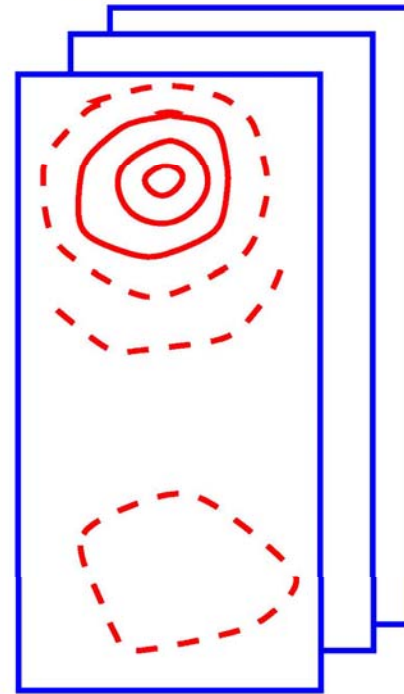
Dec 1868

# APPROXIMATING COVARIANCE

$$C = E \Lambda E^T + E' \Lambda' E'^T$$



Reduced Space  
Optimal Analysis



Kriging,  
Traditional OI

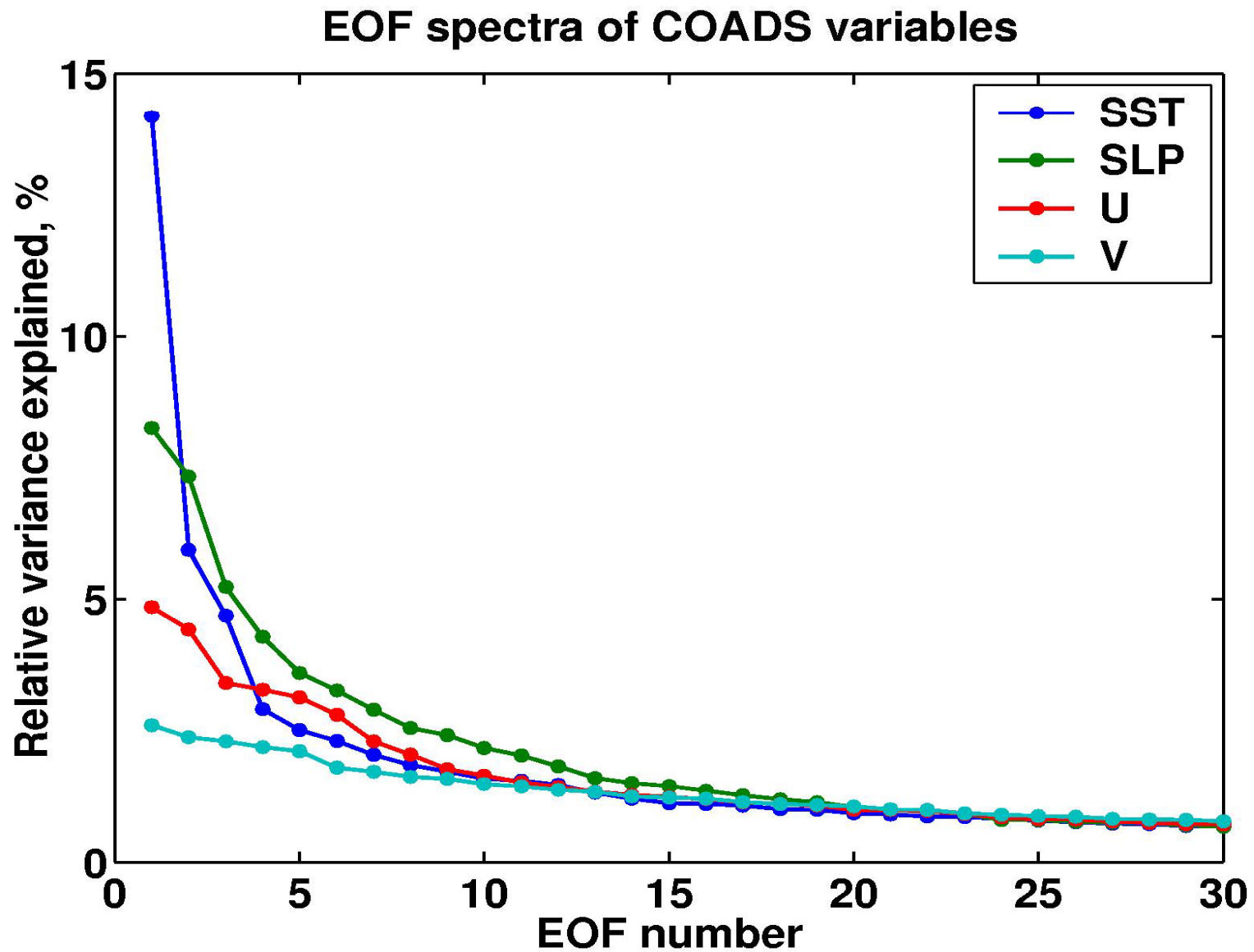


Figure 1: Eigenvalue spectra of climate variables from COADS, 1950-2000

# EOFs of zonal wind anomaly

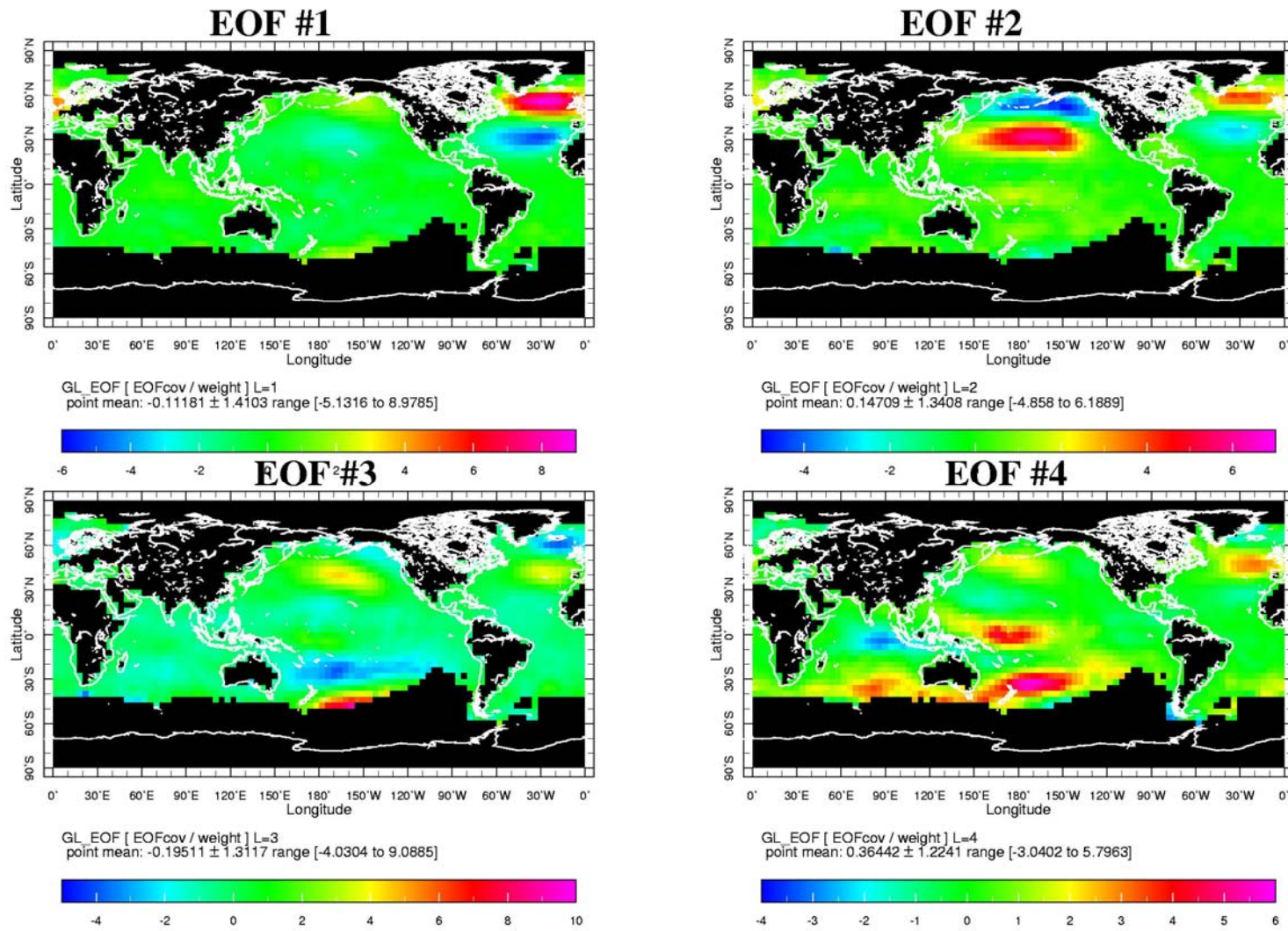
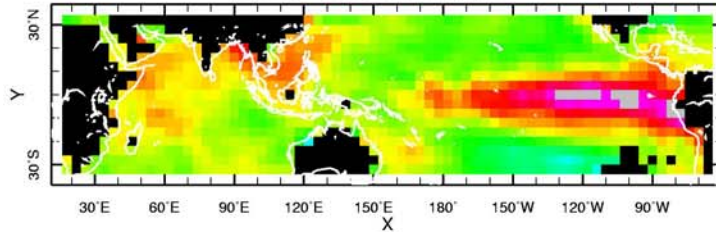


Figure 2: Leading EOF patterns of zonal wind anomalies from COADS, 1950-2000

# El Niño of 1877-1878 in analyzed anomalies

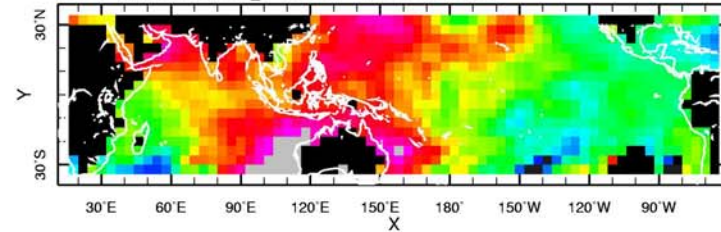
**SST, °C: Dec 1877**



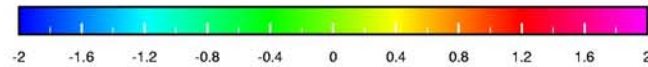
RSA\_COADS\_sstFP95 OS sstca T=Dec 1877  
point mean:  $0.45326 \pm 0.81865$  range [-1.7467 to 3.7493]



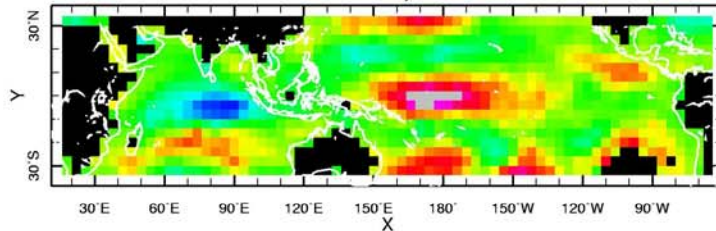
**SLP, mb: Sep 1877-Jan 1878**



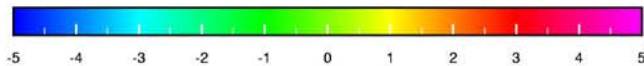
RSA\_COADS\_slp OI mslpa T=Nov 1877  
point mean:  $0.26096 \pm 0.97148$  range [-3.1618 to 5.633]



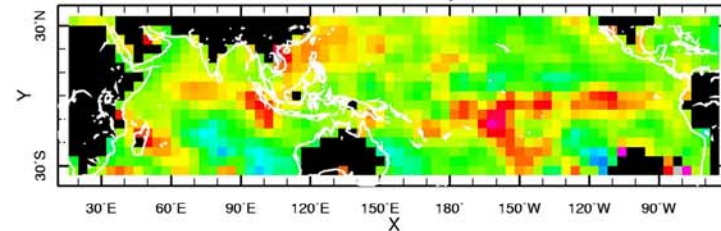
**Zonal wind, m/s: Nov 1877**



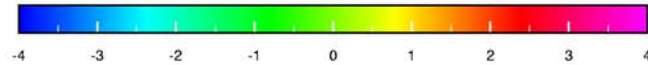
RSA\_COADS\_uwnd OI uwnda T=Nov 1877  
point mean:  $0.0229419 \pm 1.4972$  range [-4.8119 to 5.9475]  
Reduced space (80 EOFs) analysis of COADS uwnd data



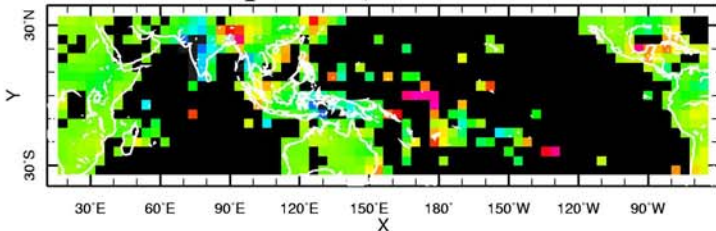
**Meridional wind, m/s: Nov 1877**



RSA\_COADS\_vwnd OI vwnda T=Nov 1877  
point mean:  $0.20265 \pm 0.96678$  range [-3.1376 to 4.5608]



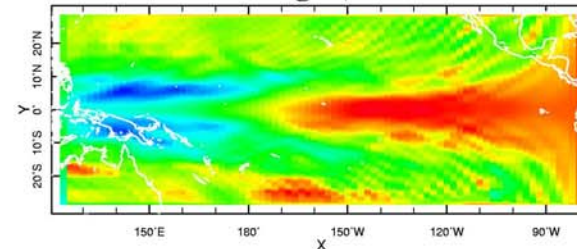
**Precipitation, mm: Jul 1877**



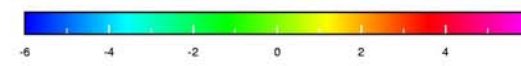
RSA\_GHCN\_prpc\_anoml\_cgrid OI prcpa T=Jul 1877  
point mean:  $-9.2232 \pm 53.891$  range [-320.72 to 200.16]



**Sea surface height, cm: Dec 1877**



sl\_OI Sea\_Level Z=0 T=Dec 1877  
point mean:  $0.00201655 \pm 1.9395$  range [-5.8358 to 3.8843]



# Independent ENSO Indices

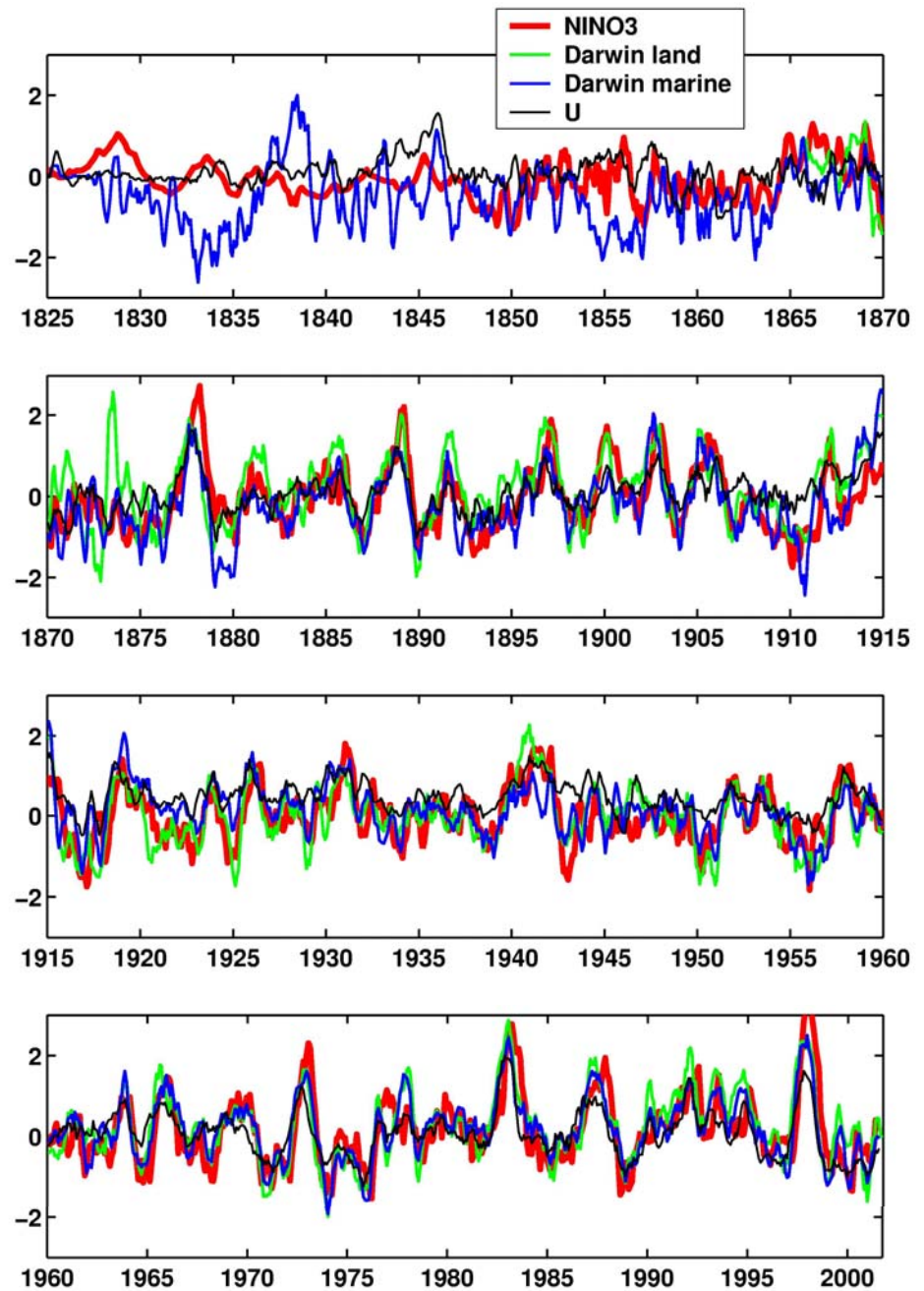
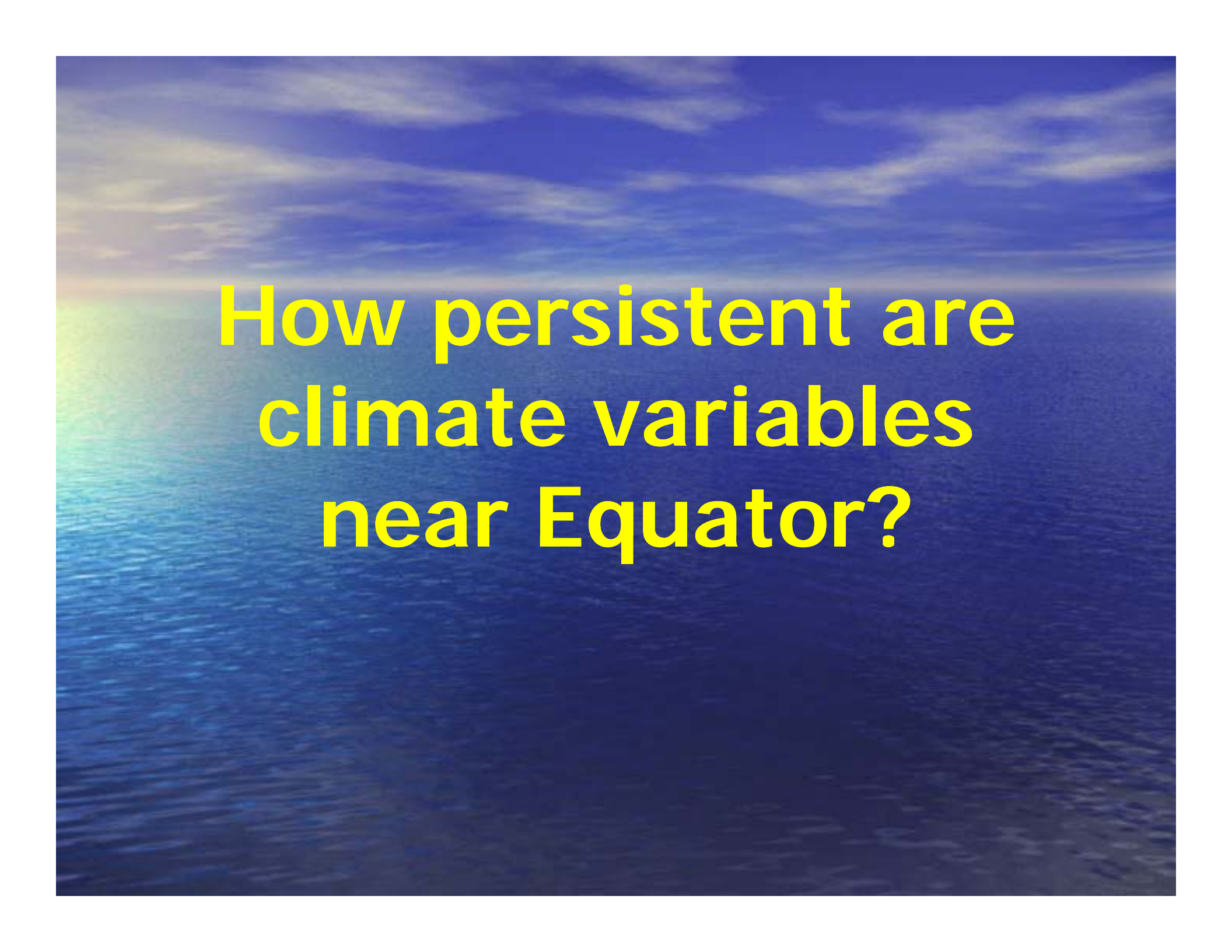


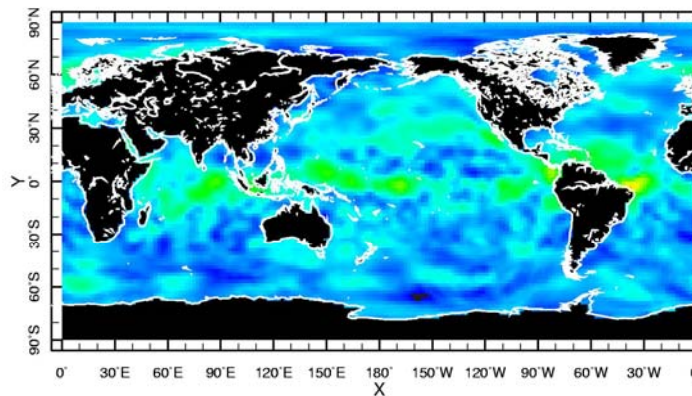
Figure 3: Intercomparison of ENSO indices: NINO3, °C, by *Kaplan et al.* [1998]; Darwin station SLP, mb, [*Allan et al.*, 1991; *Können et al.*, 1998]; Darwin area SLP estimate from ship-based RSOI, mb, [*Kaplan et al.*, 2000]; and Central Equatorial Pacific zonal wind anomaly ( $5^{\circ}\text{N}$ - $5^{\circ}\text{S}$ ,  $160^{\circ}\text{E}$ - $120^{\circ}\text{W}$ ), 5m/s [*Kaplan et al.*, 2001]. Pressure and wind data are 5 month running means.



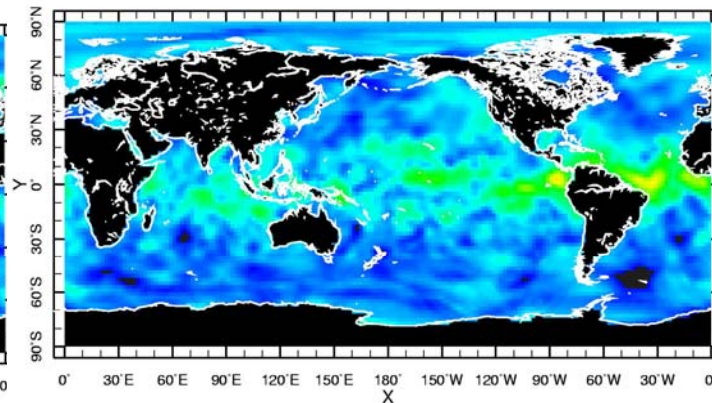
**How persistent are  
climate variables  
near Equator?**

# Persistence: Anomaly autocorrelations with 1 month lag

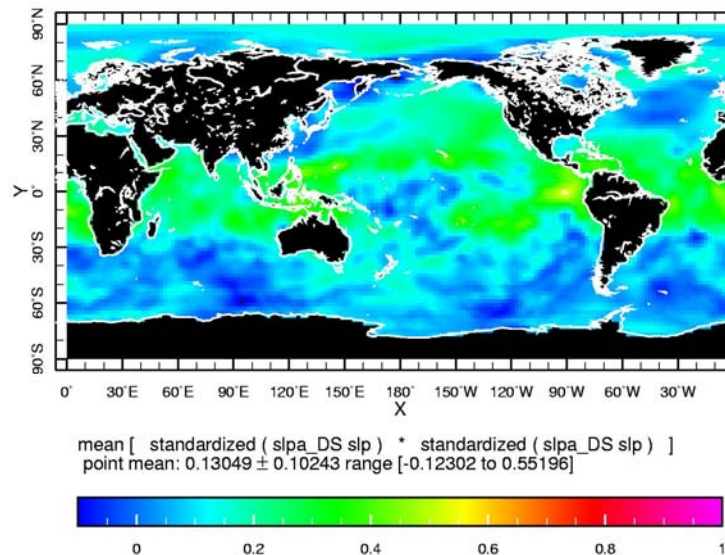
Da Silva U



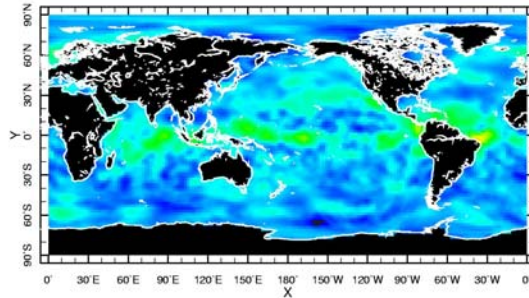
Da Silva V



Da Silva SLP



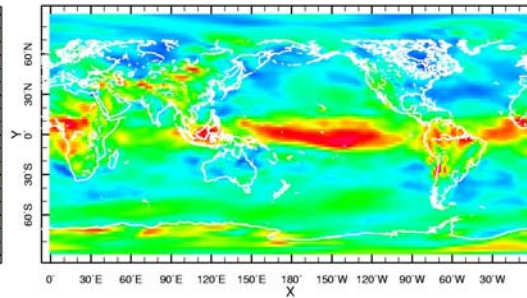
Da Silva U



mean [ standardized (11dsua u) \* standardized (11dsua u) ]  
point mean: 0.0801182 ± 0.0758377 range [-0.14909 to 0.58812]



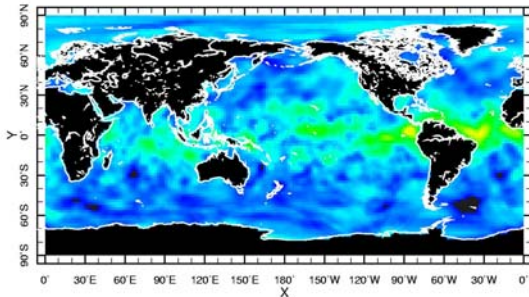
Reanalysis U



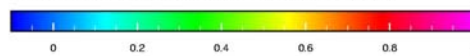
mean [ standardized (ua\_RA u) \* standardized (ua\_RA u) ] Z=10  
point mean: 0.24699 ± 0.17392 range [-0.0738043 to 0.89465]



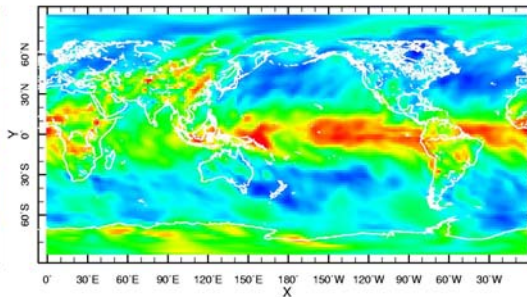
Da Silva V



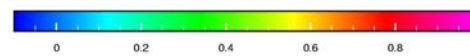
mean [ standardized (va\_DS v3) \* standardized (va\_DS v3) ]  
point mean: 0.0665146 ± 0.0883734 range [-0.18889 to 0.57847]



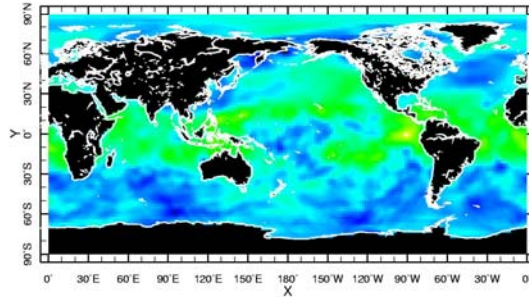
Reanalysis V



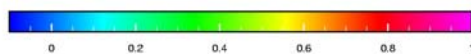
mean [ standardized (va\_RA v) \* standardized (va\_RA v) ] Z=10  
point mean: 0.22861 ± 0.18595 range [-0.10558 to 0.81411]



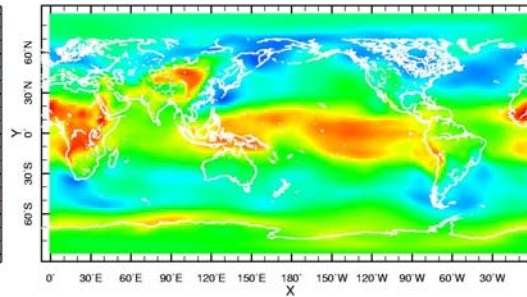
Da Silva SLP



mean [ standardized (slpa\_DS slp) \* standardized (slpa\_DS slp) ]  
point mean: 0.13049 ± 0.10243 range [-0.12302 to 0.55196]



RA SLP



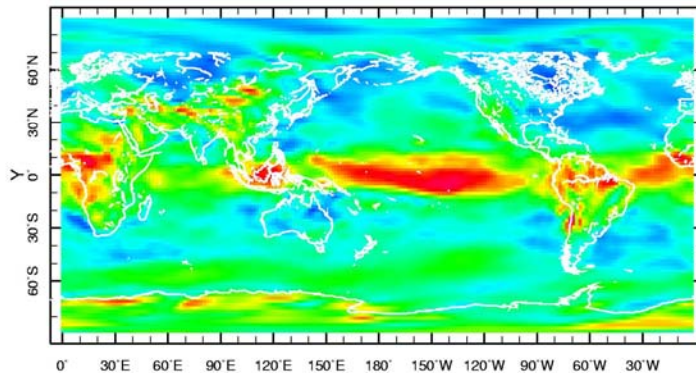
mean [ standardized (pressure\_RA pressure) \* standardized (pressure\_RA pressure) ]  
point mean: 0.30659 ± 0.17881 range [-0.0274382 to 0.78673]  
standardized [ pressure\_RA pressure ]  
Averaged over T2[1949, 2002]  
Averaged over T1[Feb 1949, Dec 2002]



Persistence:  
Anomaly  
autocorrelations  
with  
1 month lag

# Verification from the satellite data

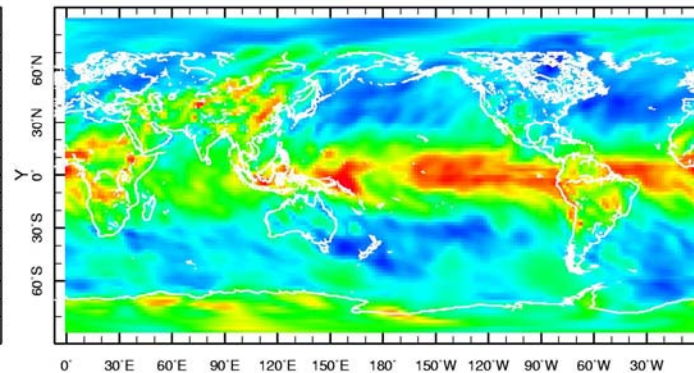
## Reanalysis U



mean [ standardized ( ua\_RA u ) \* standardized ( ua\_RA u ) ] Z=10  
point mean:  $0.24699 \pm 0.17392$  range [-0.0738043 to 0.89465]



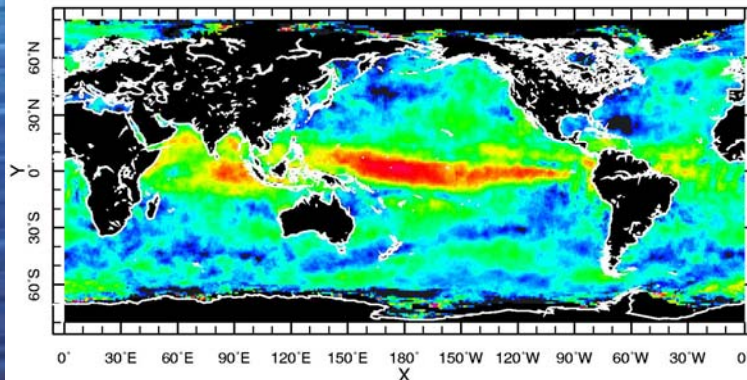
## Reanalysis V



mean [ standardized ( va\_RA v ) \* standardized ( va\_RA v ) ] Z=10  
point mean:  $0.22861 \pm 0.18595$  range [-0.10558 to 0.81411]



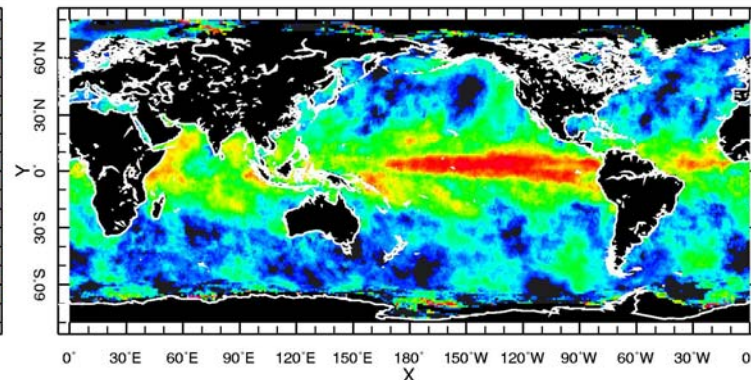
## ERS U



mean [ standardized ( ers12\_ua u ) \* standardized ( ers12\_ua u ) ]  
point mean:  $0.18349 \pm 0.21465$  range [-2.4082 to 3.2552]



## ERS V

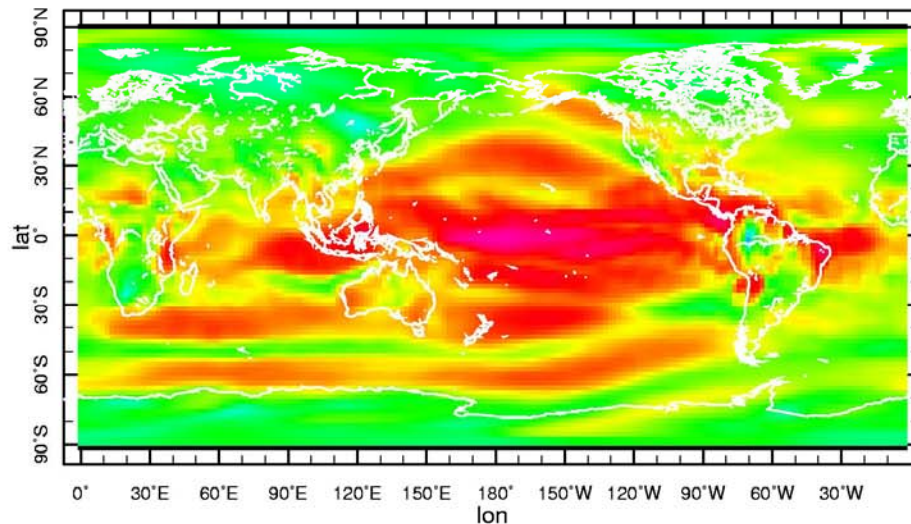


mean [ standardized ( ers12\_va v ) \* standardized ( ers12\_va v ) ]  
point mean:  $0.16236 \pm 0.24263$  range [-2.4018 to 2.5866]

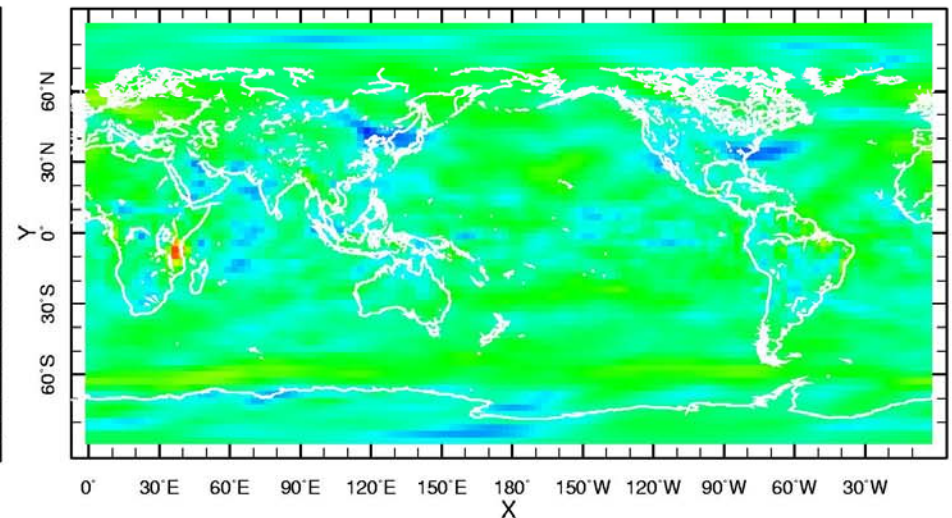
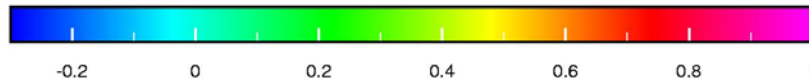


# Persistence in AMIP experiments: zonal wind anomaly

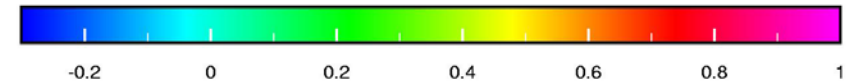
**CCM3 runs with boundary conditions of  
Full SST**

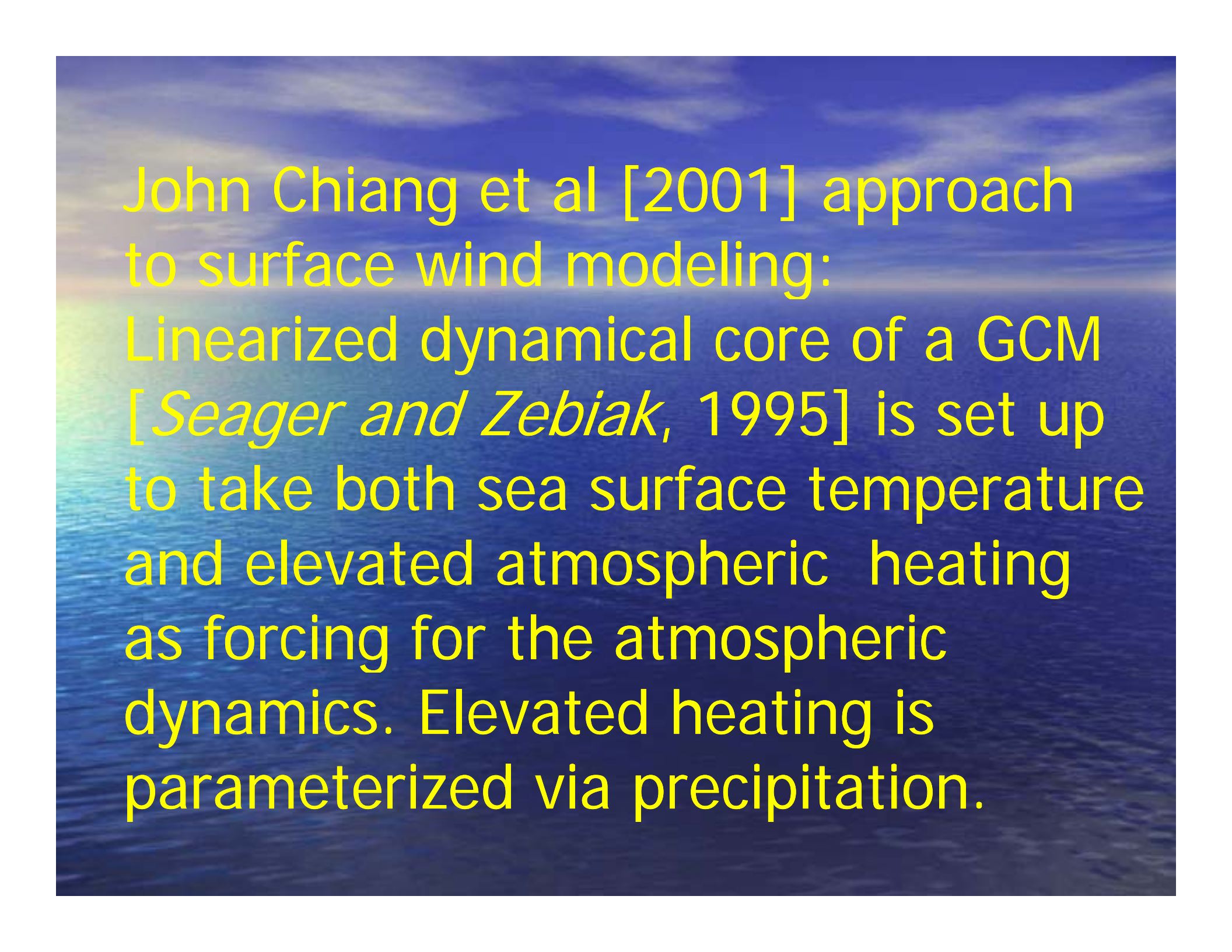


mean [ standardized ( ua U ) \* standardized ( ua U ) ] lev=992.528  
point mean:  $0.41535 \pm 0.18511$  range [-0.11828 to 0.91104]



mean [ standardized ( ua u ) \* standardized ( ua u ) ]  
point mean:  $0.0923794 \pm 0.0857176$  range [-0.25793 to 0.6717]



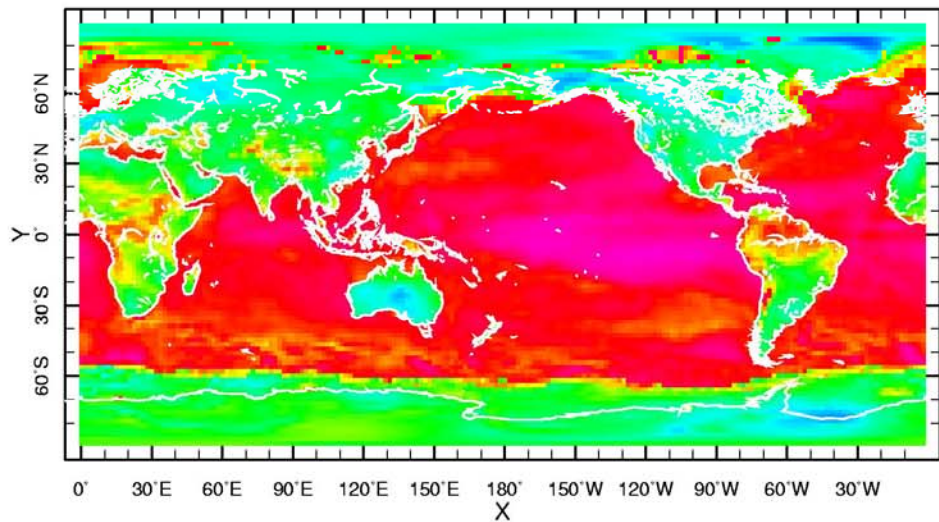


John Chiang et al [2001] approach to surface wind modeling:  
Linearized dynamical core of a GCM [*Seager and Zebiak, 1995*] is set up to take both sea surface temperature and elevated atmospheric heating as forcing for the atmospheric dynamics. Elevated heating is parameterized via precipitation.

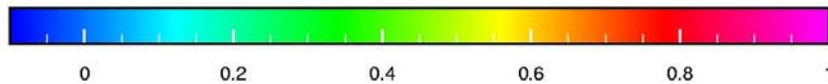
# Persistence of the actual forcing

## Lag-1 autocorrelations

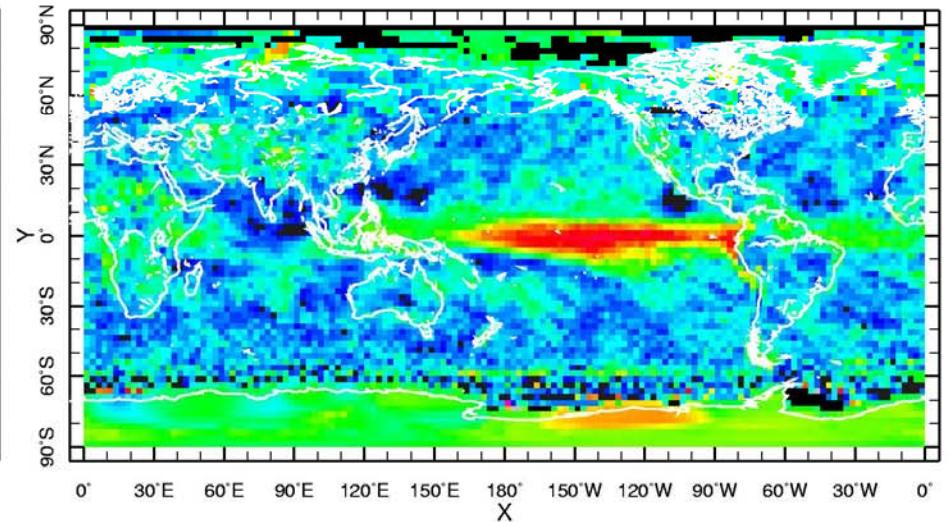
### Surface temperature



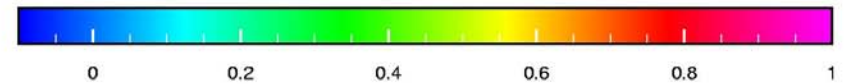
mean [ standardized ( tempa\_RA temp ) \* standardized ( tempa\_RA temp ) ]  
point mean:  $0.55176 \pm 0.27342$  range [-0.0231465 to 0.95874]



### Precipitation [Xie and Arkin]

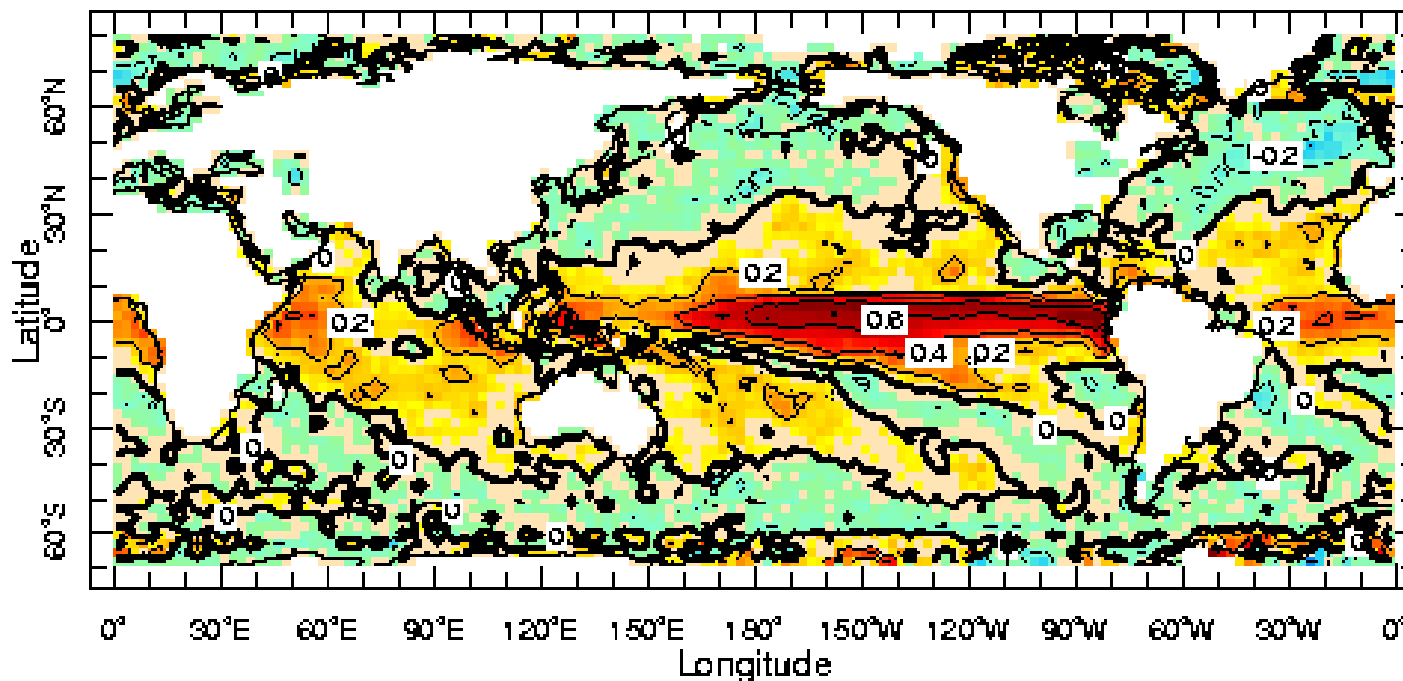
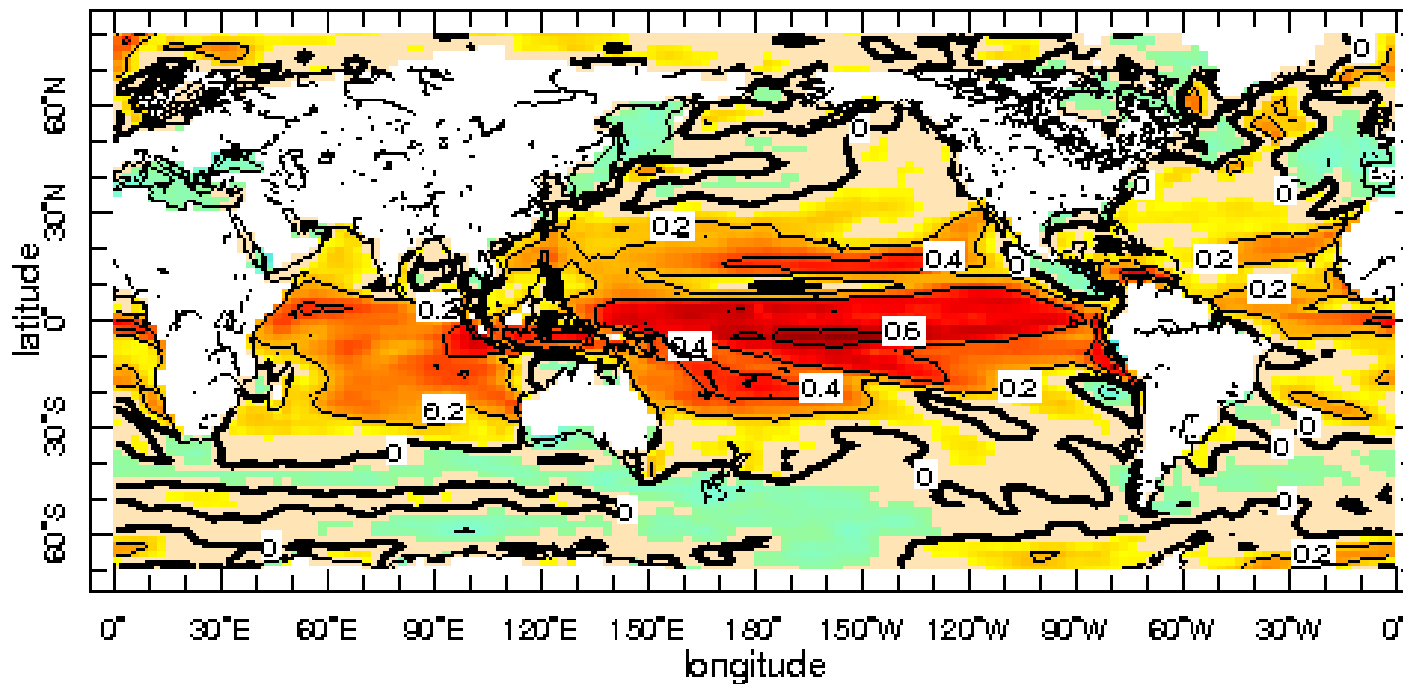


mean [ standardized ( prcpa\_XieArkin prcp\_est ) \* standardized ( prcpa\_XieArki  
point mean:  $0.15705 \pm 0.17386$  range [-0.73877 to 1.1561]



## SST and Precip correlations

GFDL model  
(CM2.1)

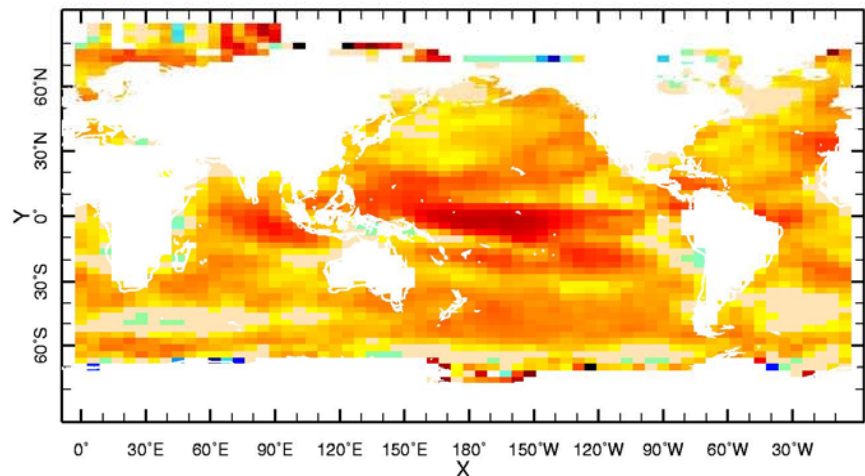


Observations  
(NCEP OI and  
CMAP)

# Simulation skill

Consistency of persistence pattern in ERS (colors) and simulation (contours)

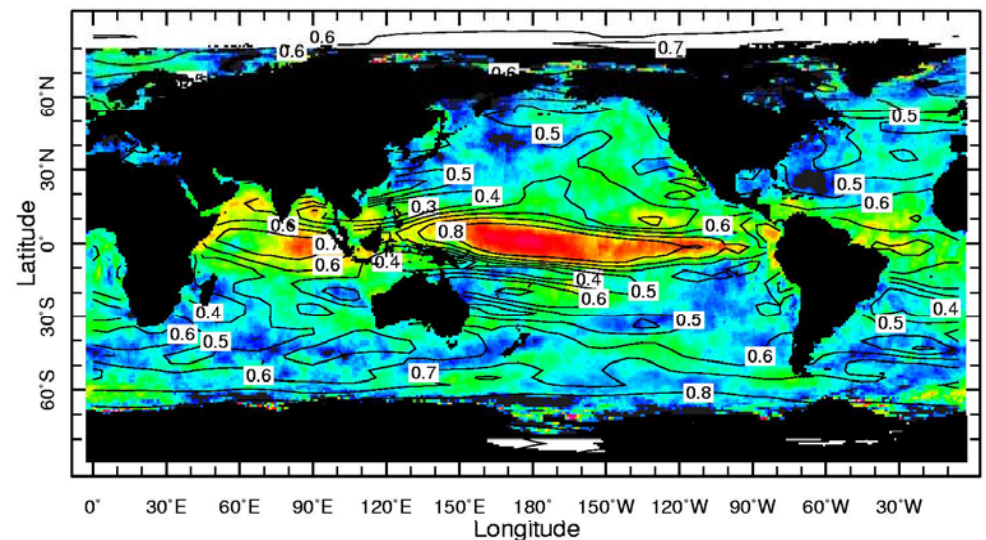
$\text{corr}[\text{model}, \text{ERS}]$

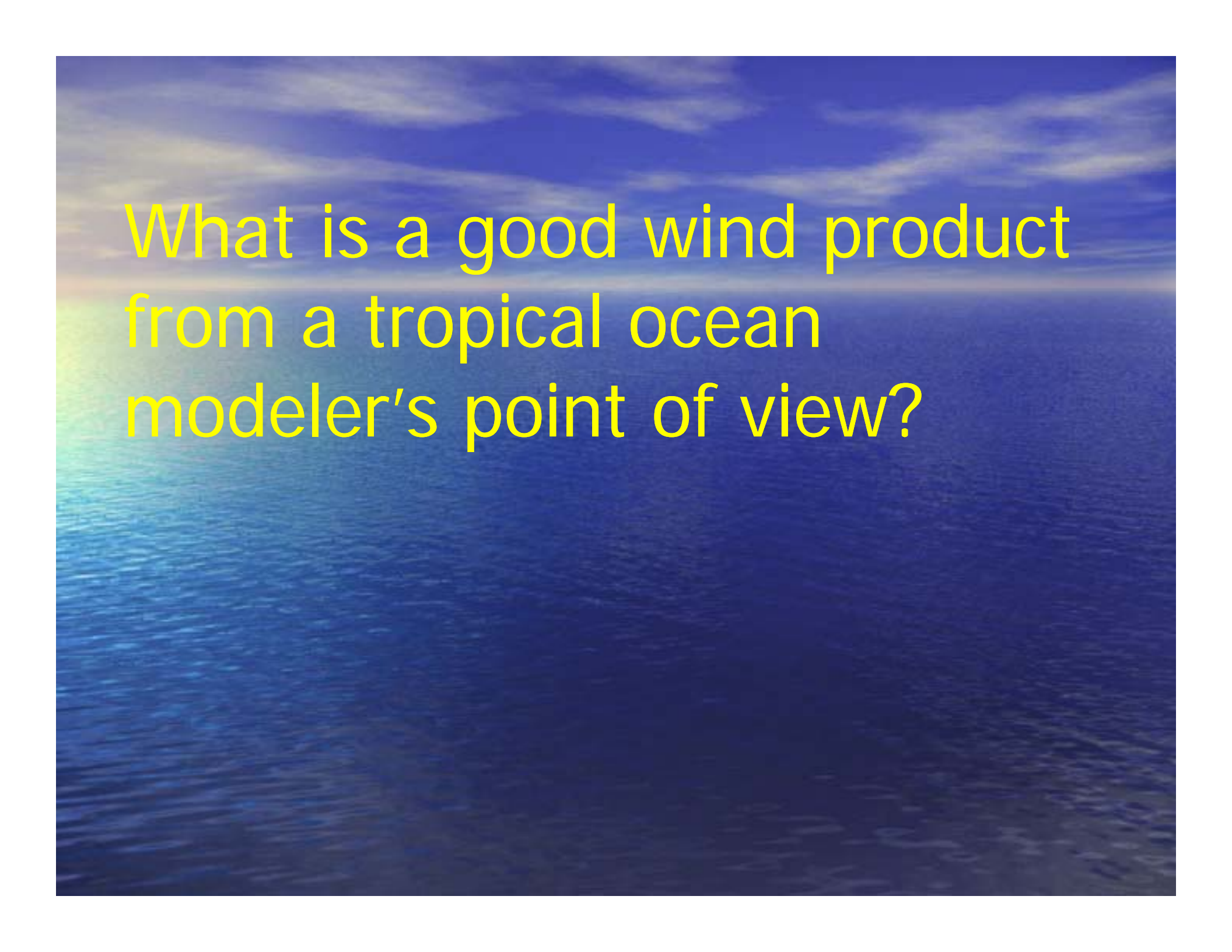


mean standardized  $[(\text{ers12\_ua } u) * (\{ \text{Ua\_obsfor ua} \} + \text{ers12\_ua} \{ u * 0. \} )]$   
point mean:  $0.27816 \pm 0.20503$  range [-1.0 to 1.0]



$\text{corr}[\text{model}(t), \text{model}(t+1)]$



A photograph of a tropical ocean scene. The sky is a deep blue with wispy white clouds. A bright sun is visible on the left side, creating a strong lens flare and reflecting a shimmering path of light across the dark blue water. The text is overlaid in the upper left quadrant.

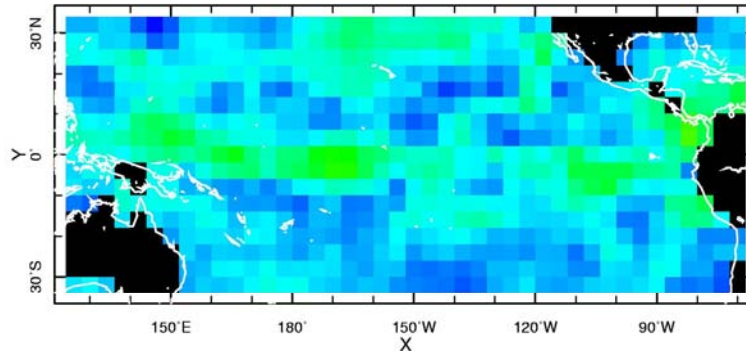
What is a good wind product  
from a tropical ocean  
modeler's point of view?

# Why equatorial persistence is so important?

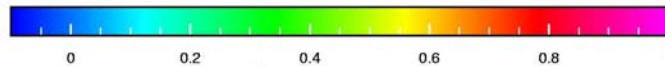
## Anomaly autocorrelations, 1 month lag

Da Silva

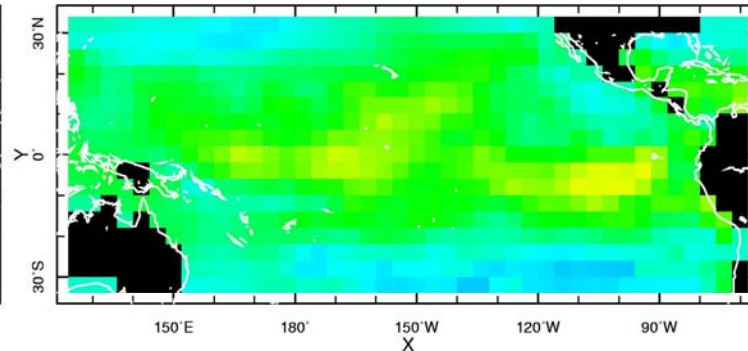
OI



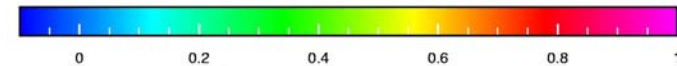
$\tau_x$  lag-1 autocorrelation for Da Silva  
point mean:  $0.11302 \pm 0.0734073$  range [-0.0896335 to 0.40176]  
Time period: 1961-1993



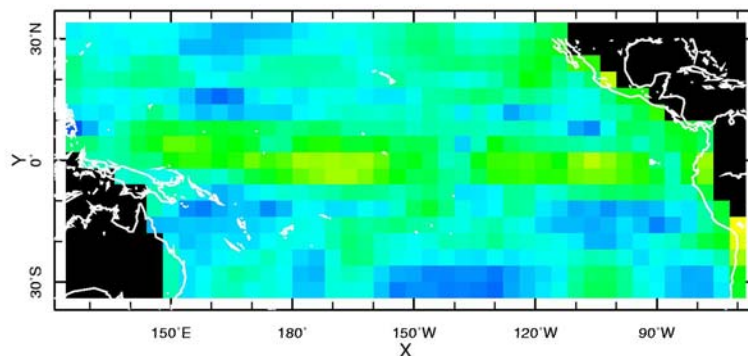
FSU



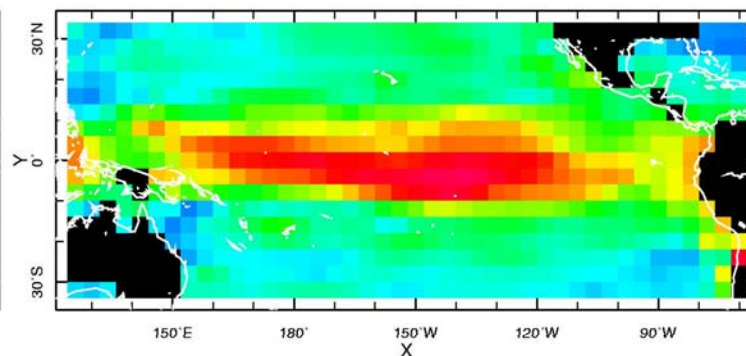
$\tau_x$  lag-1 autocorrelation for our OI  
point mean:  $0.27002 \pm 0.10796$  range [0.0751456 to 0.54349]  
Time period: 1961-1993



Reanalysis



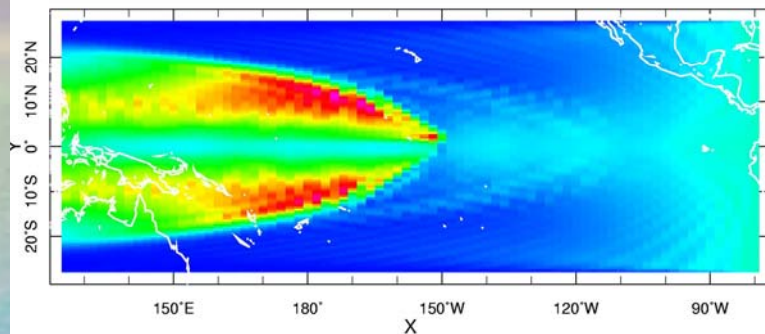
$\tau_x$  lag-1 autocorrelation for FSU  
point mean:  $0.18477 \pm 0.10402$  range [-0.0215749 to 0.55858]  
Time period: 1961-1993



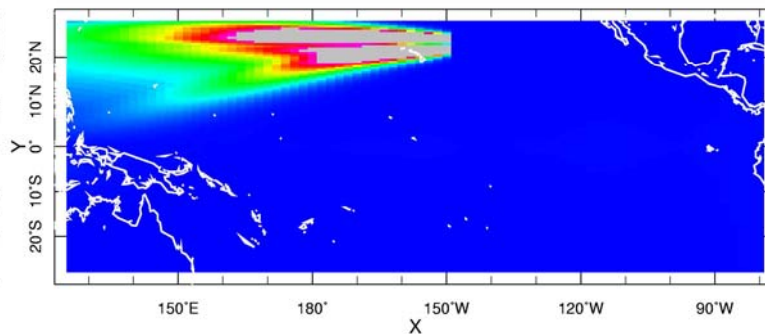
$\tau_x$  lag-1 autocorrelation for RA Z=10  
point mean:  $0.33054 \pm 0.21696$  range [0.00504754 to 0.85654]  
Time period: 1961-1993



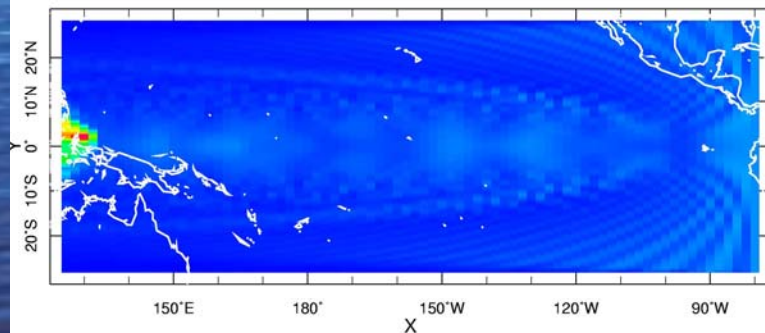
# RMS of sea level response to the wind noise in a single location



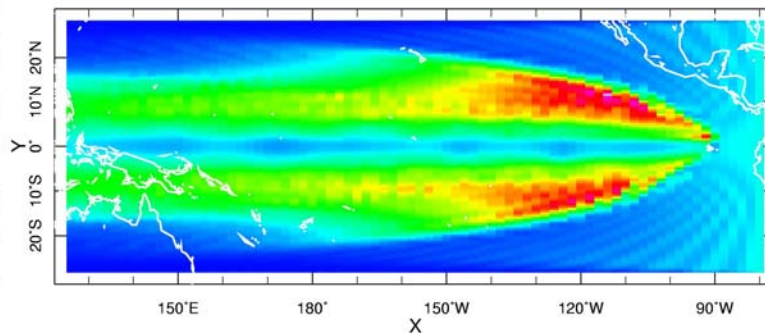
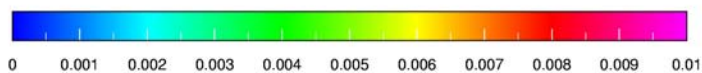
slrmsfull slrms Z=0  
point mean:  $0.00224041 \pm 0.00201079$  range [ $4.05545 \times 10^{-5}$  to  $0.00994284$ ]



slrmsfull slrms Z=0  
point mean:  $0.00103701 \pm 0.00363671$  range [ $2.00303 \times 10^{-7}$  to  $0.047464$ ]



slrmsfull slrms Z=0  
point mean:  $0.000531426 \pm 0.00043452$  range [ $2.35884 \times 10^{-5}$  to  $0.00899953$ ]

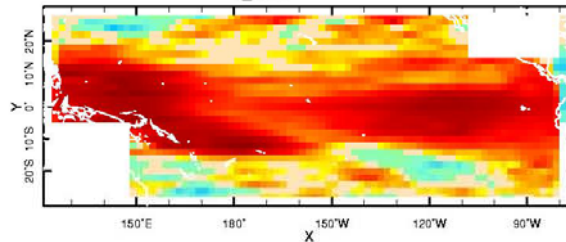


slrmsfull slrms Z=0  
point mean:  $0.00266023 \pm 0.00199111$  range [ $4.56169 \times 10^{-5}$  to  $0.0100805$ ]

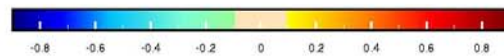


# Correlation with TOPEX altimetry of ocean model sea level height response to wind products

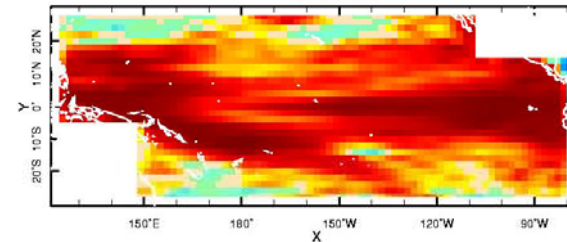
**OI**



OI  
point mean:  $0.34439 \pm 0.32224$  range [-0.52142 to 0.86477]



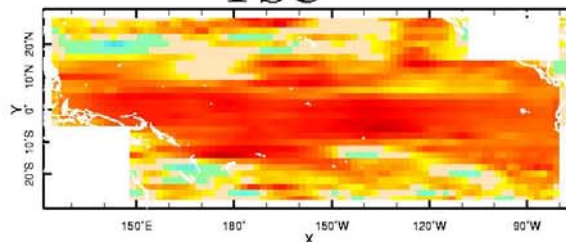
**RA**



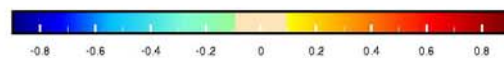
RA  
point mean:  $0.44961 \pm 0.34652$  range [-0.67668 to 0.92057]



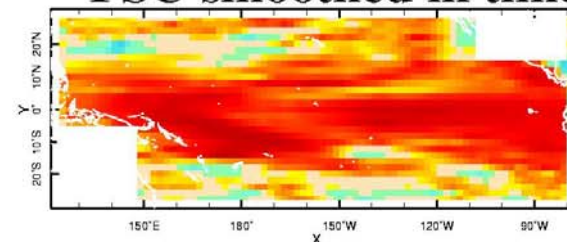
**FSU**



FSU raw  
point mean:  $0.30128 \pm 0.22447$  range [-0.3895 to 0.74195]



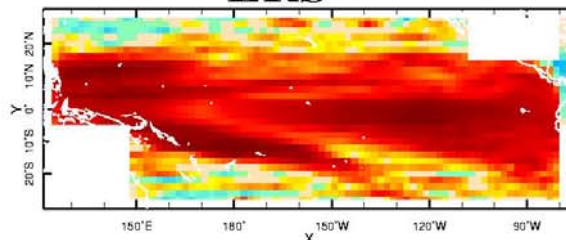
**FSU smoothed in time**



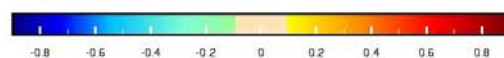
FSU smoothed  
point mean:  $0.34232 \pm 0.27099$  range [-0.42666 to 0.76556]



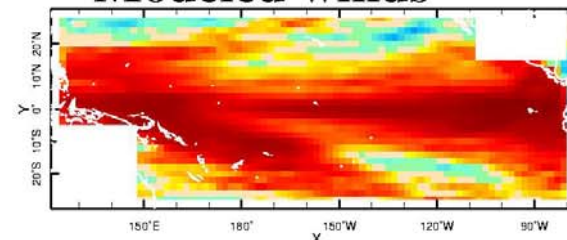
**ERS**



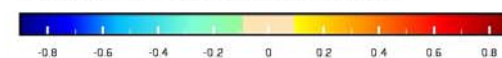
ERS  
point mean:  $0.42227 \pm 0.35051$  range [-0.56178 to 0.90786]



**Modeled winds**



obsfor  
point mean:  $0.38023 \pm 0.35446$  range [-0.58309 to 0.88631]



# Conclusions and Outlook

- Univariate statistical analyses of historical climate data sets are useful but additional constraints are needed.
- Within  $\sim 10$  degree of Equator there is a persistence of surface wind and pressure anomalies.
- It is driven by the persistence in SST and precipitation (via elevated heating).
- It can be used in historical analyses of instrumental data by either fitting AR model to the wind or pressure data or by including temperature and precipitation in the analysis.
- Wind analyses suitable for driving ocean models must be persistent near Equator.