atio-Temporal Surface Vector Wind Retrieval Error Mod

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Motivation:

In addition to accurate estimates of the surface vector wind (SVW), scatterometer observations, and scatterometer datasets include precise information regarding uncertainties in the SVW retrievals, as functions of space, time and environmental conditions (e.g. rain).

We exploit the uncertainty information in the Ku2011 retrievals to develop a space-time error process model for SVW retrievals. This is a necessary development on a path toward global ensemble SVW from a Bayesian Hierarchical Model (BHM), based on multi-platform data stage inputs.

tio-Temporal Error Model Parameterizations

Let $\mathbf{Z}_t$ be an $m_t \times 1$ vector of scatterometer wind component obs at time t
Let $\mathbf{Y}_t$ be an associated $n \times 1$ vector of the “true” wind component from a prediction grid at time *t*

Then a Gaussian spatial error model is:

$$\mathbf{Z}_t = \mathbf{H}_t \mathbf{Y}_t + \epsilon_t, \quad \epsilon_t \sim Gau(0, \mathbf{K}_t \boldsymbol{\Sigma}_{e,t} \mathbf{K}_t')$$

where $\mathbf{H}_t$ is an $m_t \times n$ matrix that maps obs to the prediction grid,
$\boldsymbol{\Sigma}_{e,t}$ is an $m \times m$ spatial error covariance matrix, and
$\mathbf{K}_t$ is an $m_t \times m$ incidence matrix for mapping errors to prediction locations

Parameterization 1: Diagonal variance matrix

Let $\hat{\mathbf{s}}_j, j = 1, \ldots, 12$ be *m*-dimensional scatterometer error estimates for month *j*, then $\hat{\boldsymbol{\Sigma}}_{e,t}$ is a diagonal variance matrix approximation to the full covariance

$$\hat{\boldsymbol{\Sigma}}_{e,t} = \sigma_\epsilon^2 \ \mathrm{diag}(\hat{\mathbf{s}})$$

where σ_ϵ^2 is a (monthly) variance inflation parameter

io-temporal Error Model parameterizations (cont'd)

Parameterization 2: EOFs of error variance

- Remove temporal mean variance for each *x,y*
- Find $\mathbf{\Phi}$ the *m* x *p* matrix of spatial structure functions then

$$\hat{\hat{\mathbf{\Sigma}}}_{e,t} = \mathrm{diag}(\,\mu\mathbf{1} + \sum_{k=1}^{p} \phi_k \nu_k\,)$$

where the ν_k are the p principal component time series associated with p EOFs

Plan

Error estimates from monthly SOS QuikSCAT Ku2011 wind speed vs. Windsat Cl
Monthly Maps for weak ENSO warm event (WE) and neutral years
EOFs and PCs for WE and neutral time series (i.e. as in parameterization 2)
Prototype global wind BHM with spatio-temporal error model
regional (tropical Pacific), parameterization 1

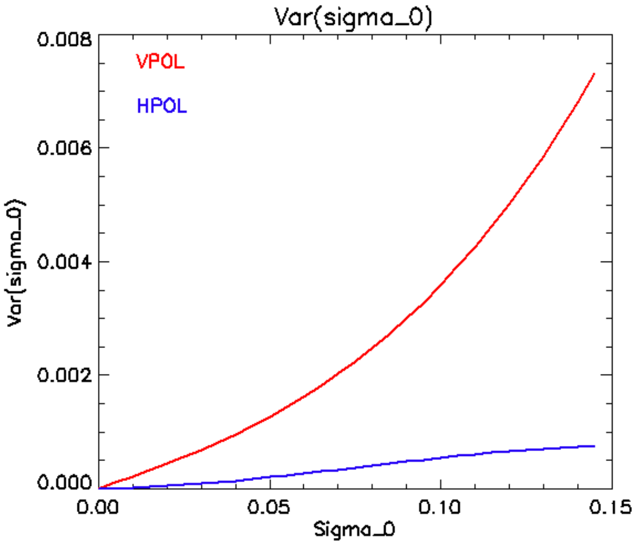
SOS: Sum of Squared Differences

For each cell, with i=1,N observations

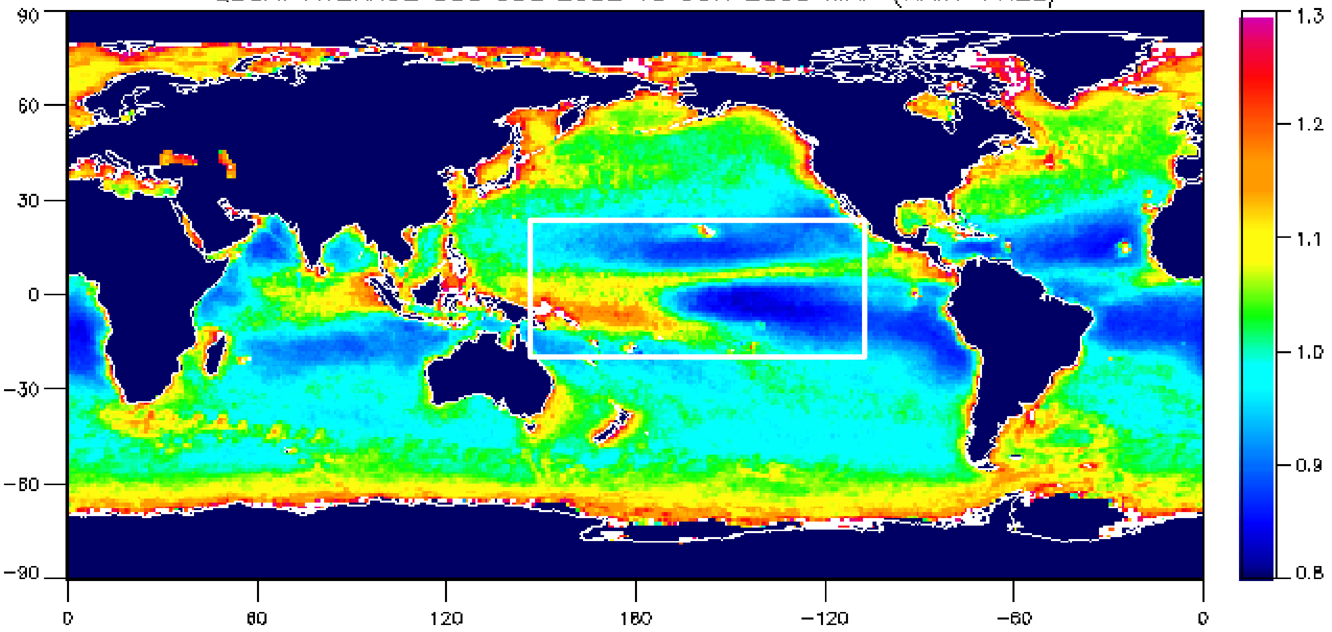
$$SOS = \frac{1}{N}\sum_{i=1}^{N}\frac{(\sigma_{obs}-\sigma_{model})_i^2}{var(\sigma_{obs})}$$

$$var(\sigma_{obs}) = a*(b + c\sigma_{obs} + d\sigma_{obs}^2 + e\sigma_{obs}^3)$$

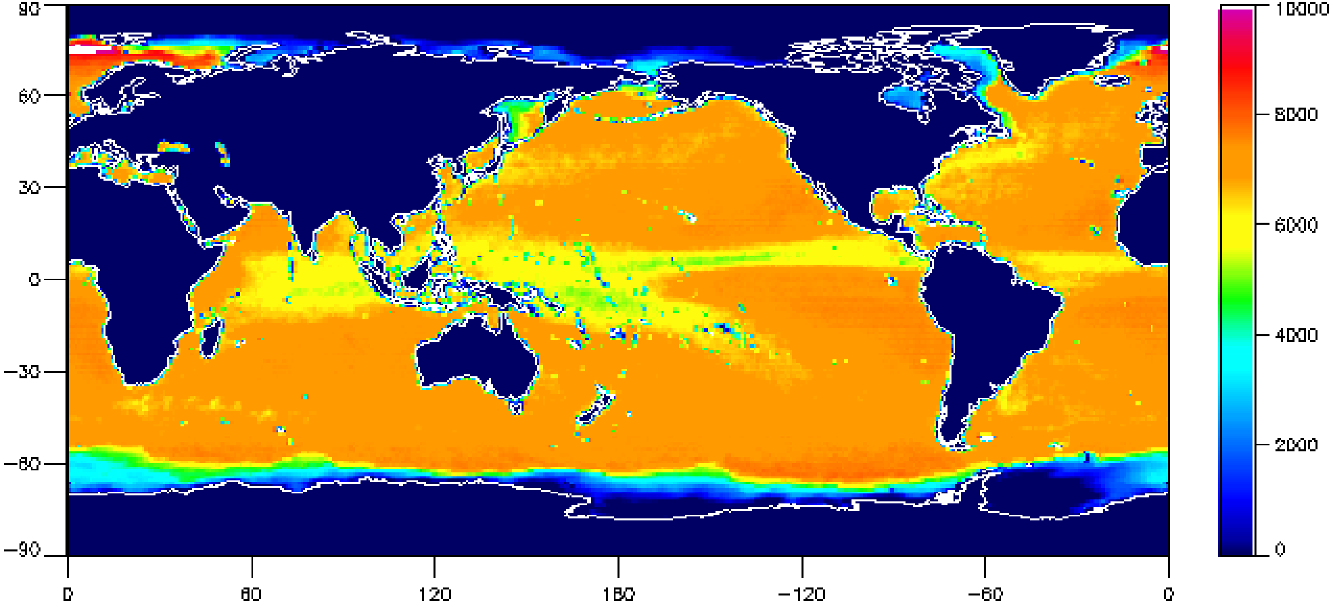
Where var(σ*obs*) represents the measurement noise



Average SOS in a weak ENSO Warm Event Year (2002-2003)



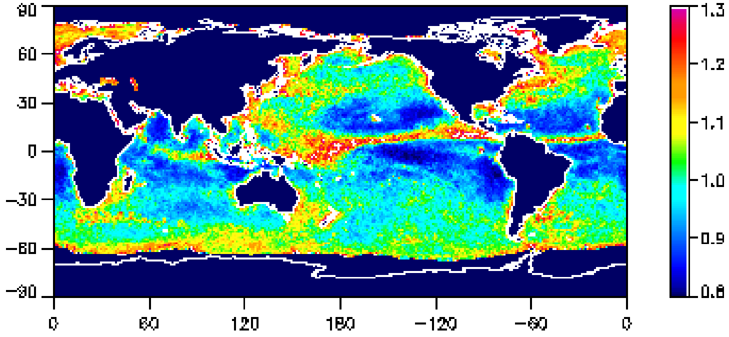
QSCAT AVERAGE SOS JUL 2002 TO JUN 2003 MAP (RAIN–FREE)



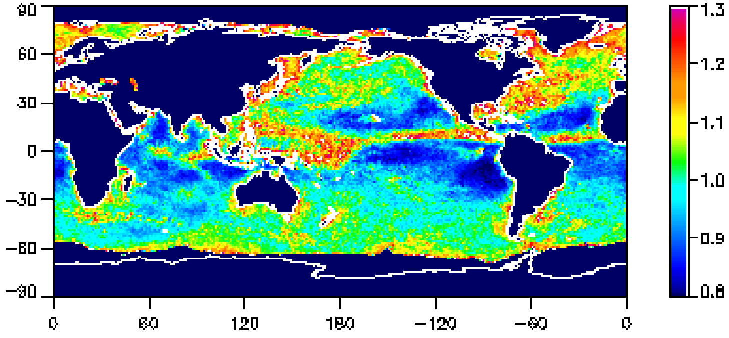
QSCAT # RETRIEVALS IN SELECTED YEAR (RAIN_FREE)

thly Average SOS: July 2002 – June 2003

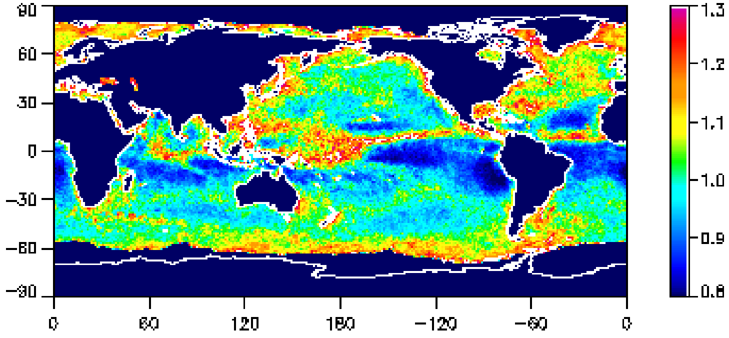
QSCAT AVERAGE SOS JUL 2002 (RAIN–FREE)



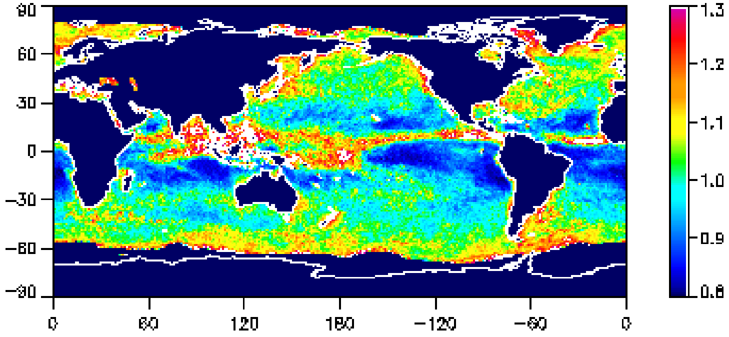
QSCAT AVERAGE SOS AUG 2002 (RAIN–FREE)



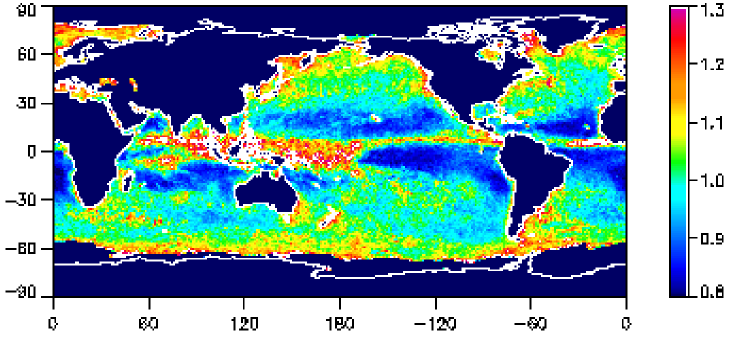
QSCAT AVERAGE SOS SEP 2002 (RAIN–FREE)



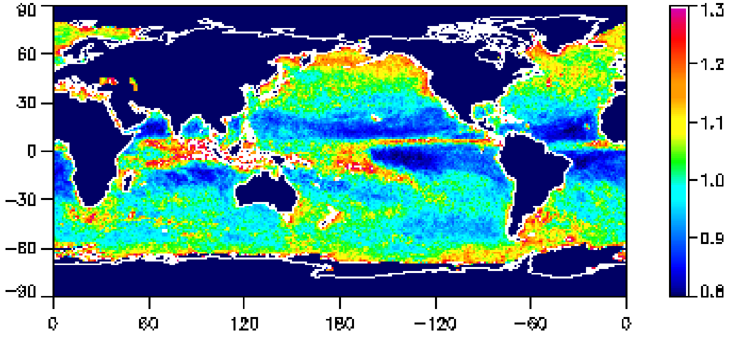
QSCAT AVERAGE SOS OCT 2002 (RAIN–FREE)



QSCAT AVERAGE SOS NOV 2002 (RAIN–FREE)

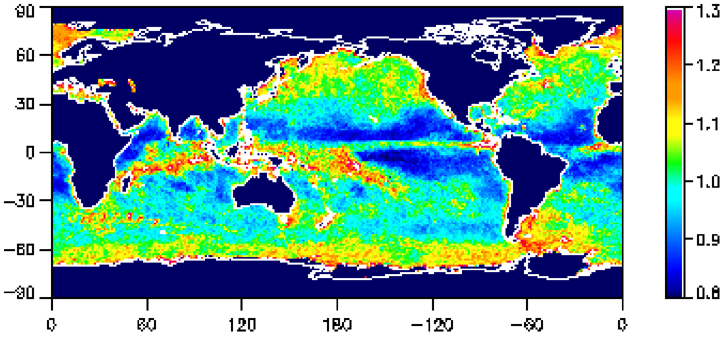


QSCAT AVERAGE SOS DEC 2002 (RAIN–FREE)

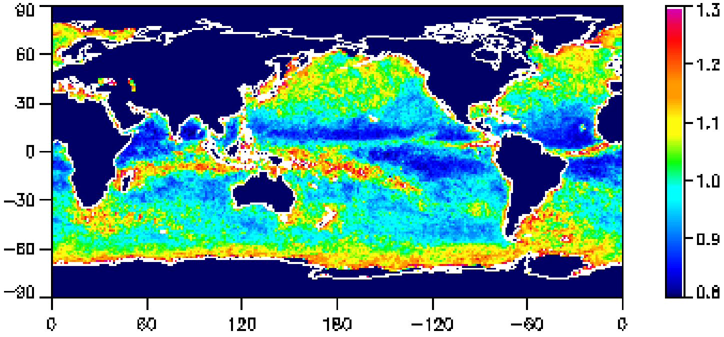


thly Average SOS: July 2002 – June 2003

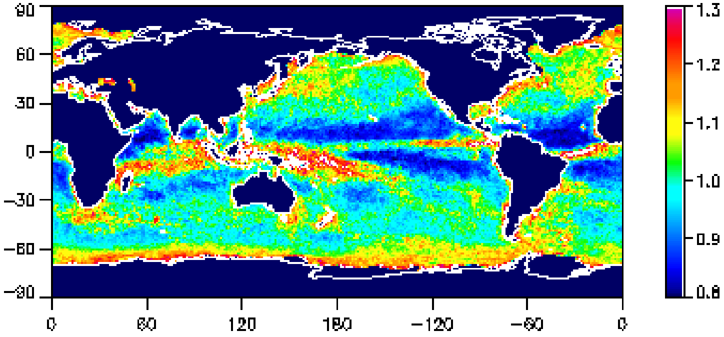
QSCAT AVERAGE SOS JAN 2003 (RAIN–FREE)



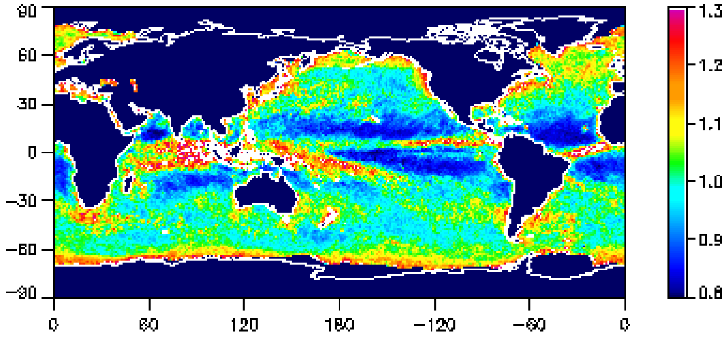
QSCAT AVERAGE SOS FEB 2003 (RAIN–FREE)



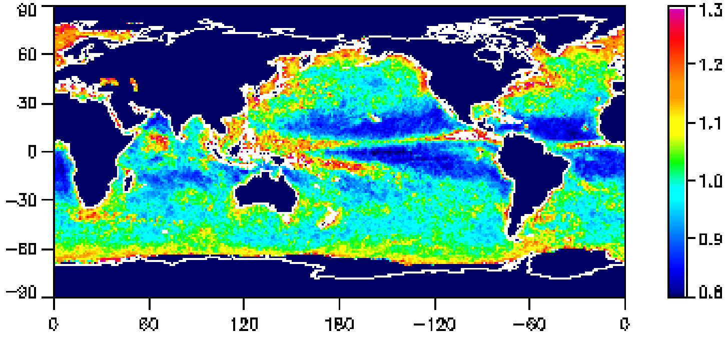
QSCAT AVERAGE SOS MAR 2003 (RAIN–FREE)



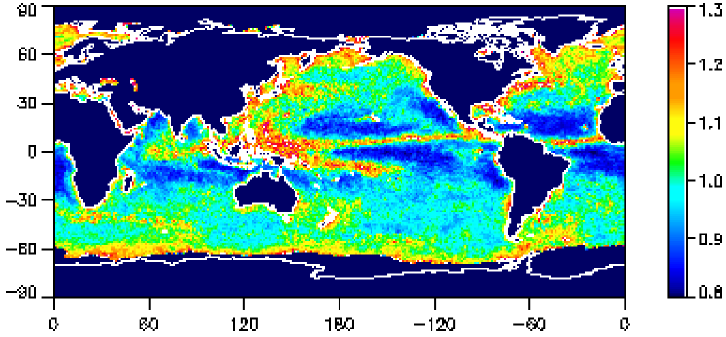
QSCAT AVERAGE SOS APR 2003 (RAIN–FREE)



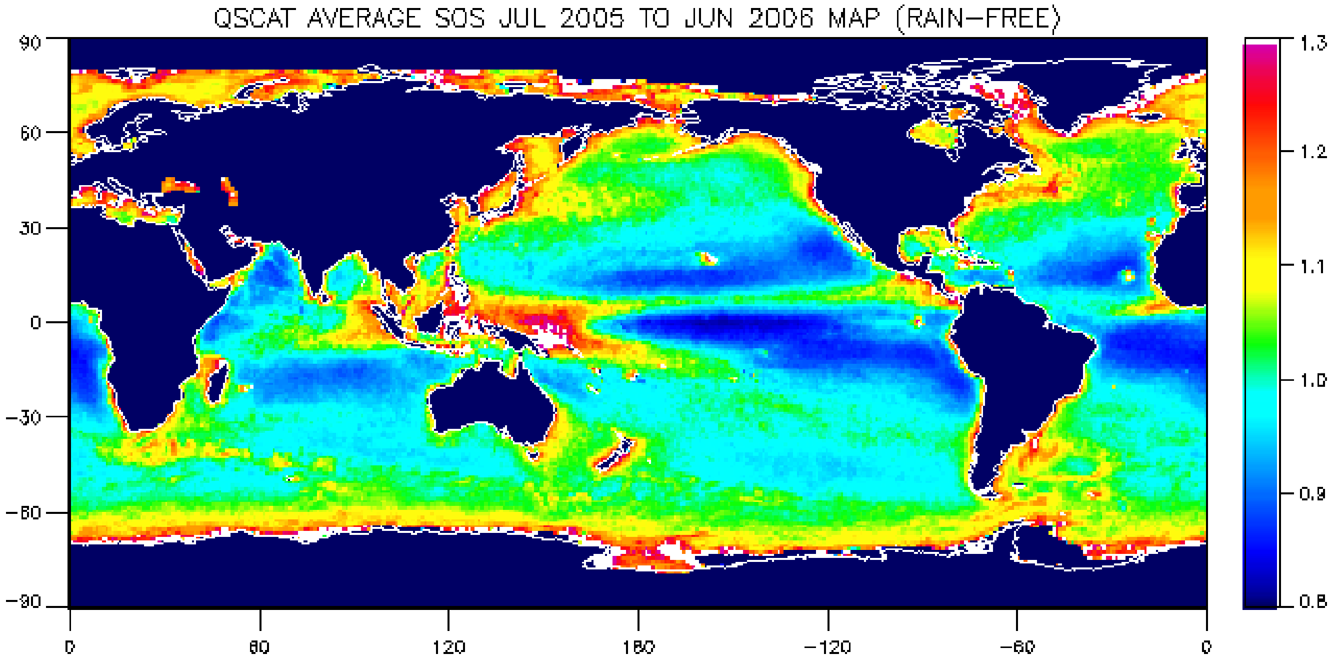
QSCAT AVERAGE SOS MAY 2003 (RAIN–FREE)

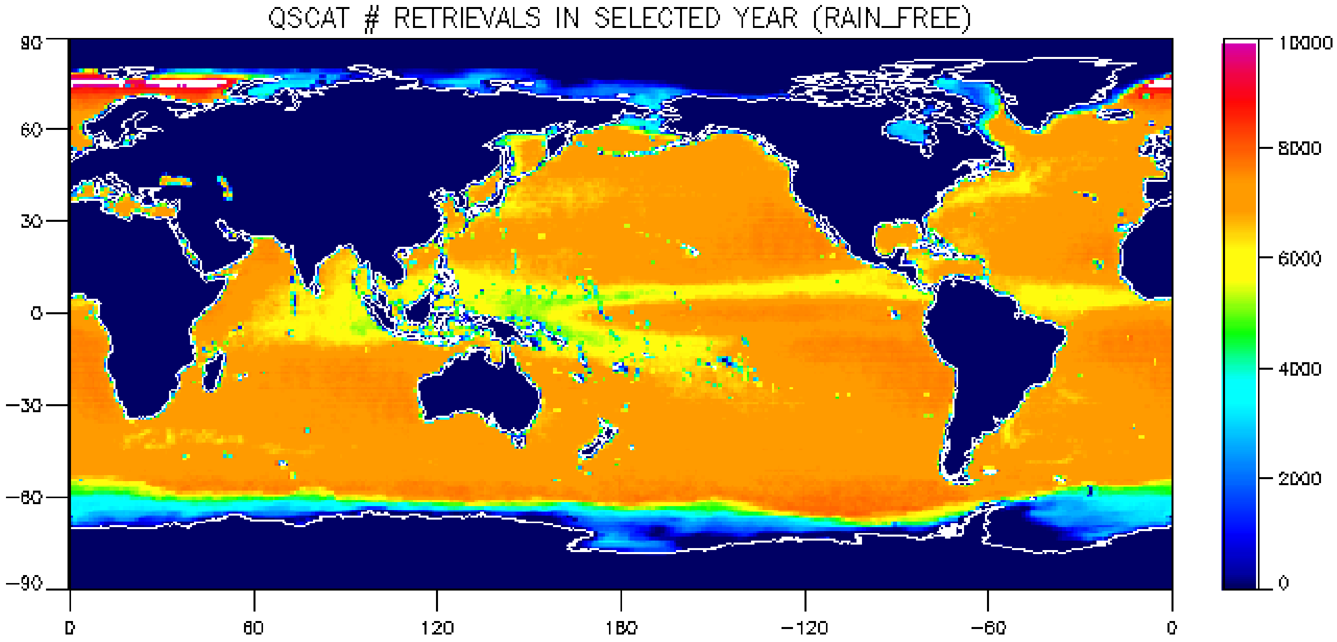


QSCAT AVERAGE SOS JUN 2003 (RAIN–FREE)

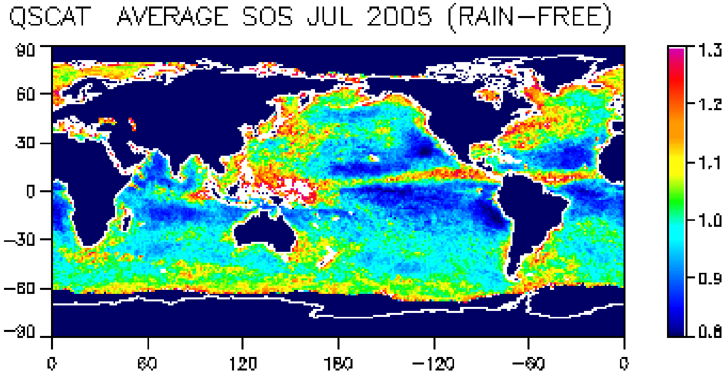


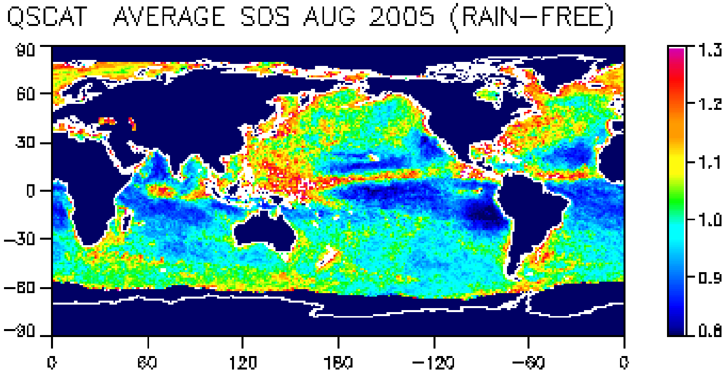
l Average SOS in an ENSO Neutral Year (2005-2006)

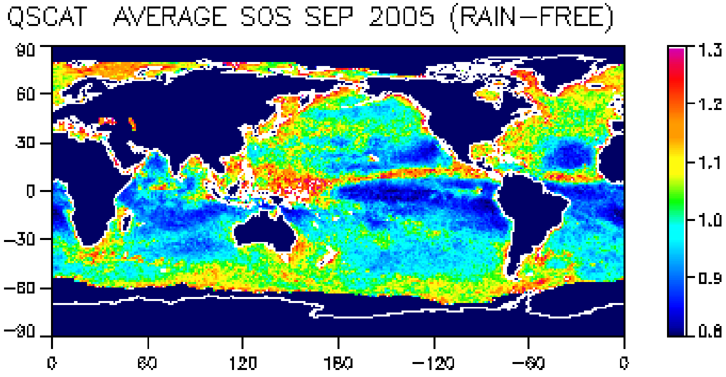

QSCAT AVERAGE SOS JUL 2005 TO JUN 2006 MAP (RAIN-FREE)

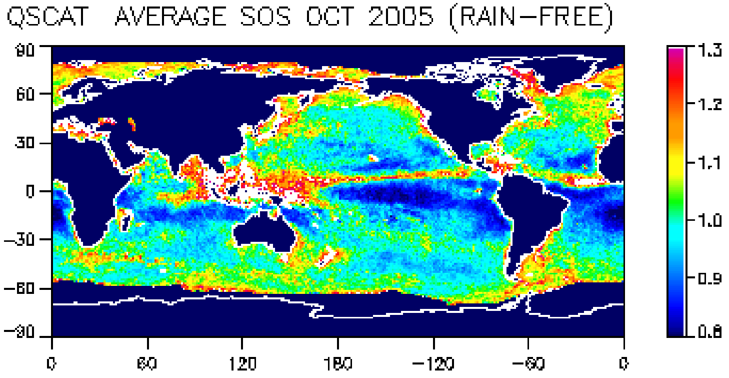

QSCAT # RETRIEVALS IN SELECTED YEAR (RAIN_FREE)

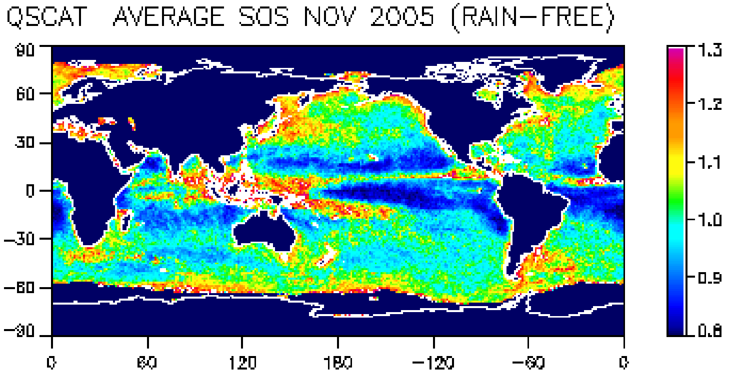
thly Average SOS: July 2005 – June 2006

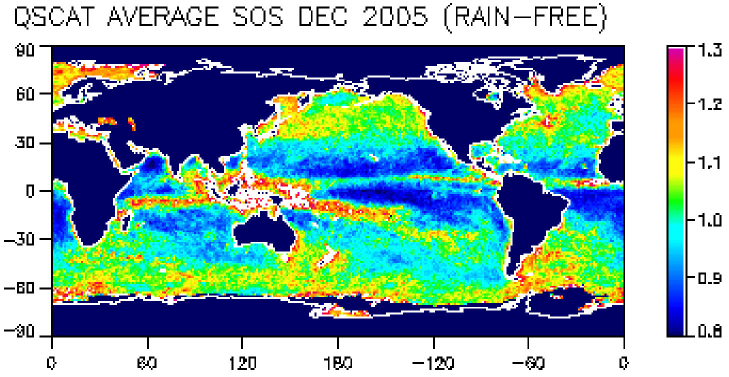

QSCAT AVERAGE SOS JUL 2005 (RAIN–FREE)


QSCAT AVERAGE SOS AUG 2005 (RAIN–FREE)


QSCAT AVERAGE SOS SEP 2005 (RAIN–FREE)

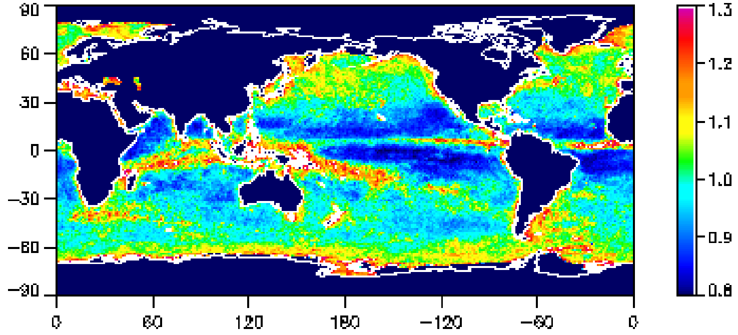

QSCAT AVERAGE SOS OCT 2005 (RAIN–FREE)


QSCAT AVERAGE SOS NOV 2005 (RAIN–FREE)

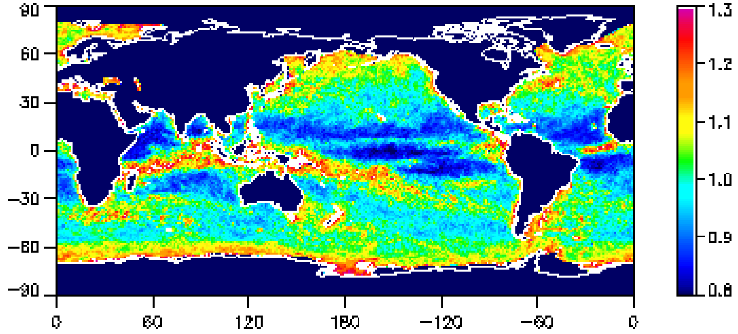

QSCAT AVERAGE SOS DEC 2005 (RAIN–FREE)

thly Average SOS: July 2005 – June 2006

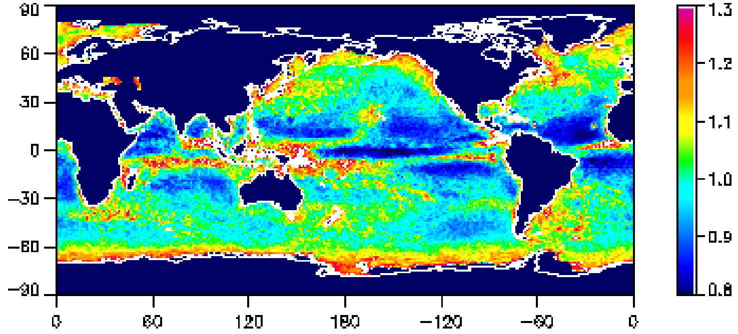
QSCAT AVERAGE SOS JAN 2006 (RAIN—FREE)



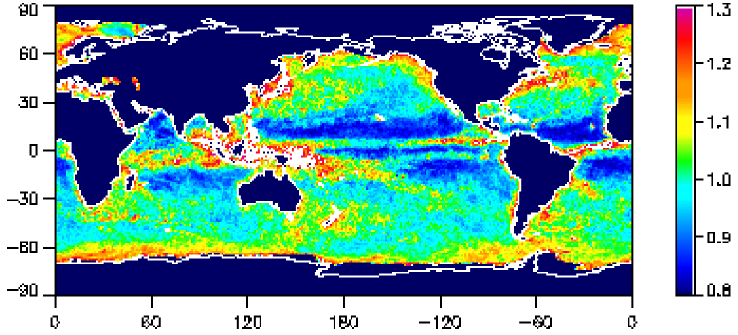
QSCAT AVERAGE SOS FEB 2006 (RAIN—FREE)



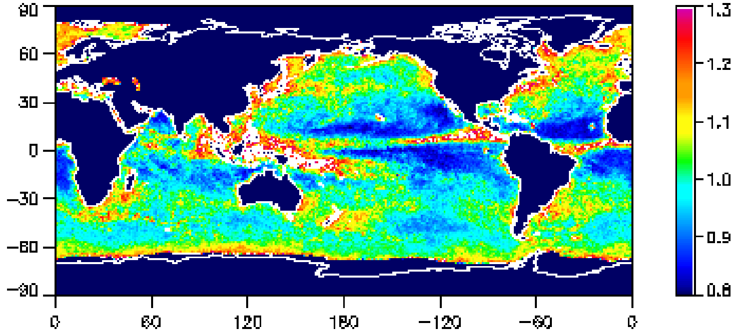
QSCAT AVERAGE SOS MAR 2006 (RAIN—FREE)



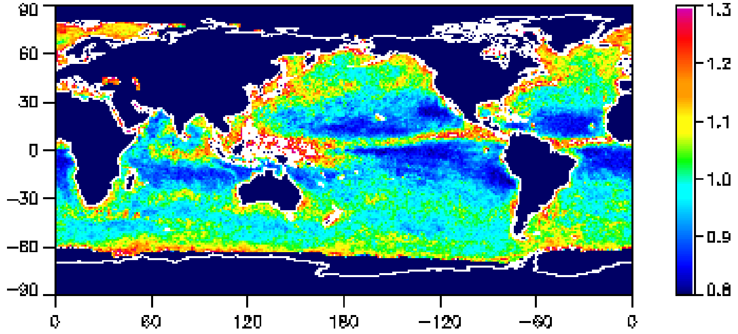
QSCAT AVERAGE SOS APR 2006 (RAIN—FREE)



QSCAT AVERAGE SOS MAY 2006 (RAIN—FREE)



QSCAT AVERAGE SOS JUN 2006 (RAIN—FREE)



Error EOF and PC Calculation

Monthly diagonal variance matrix from vectorization of SOS maps

Remove temporal mean at each x,y

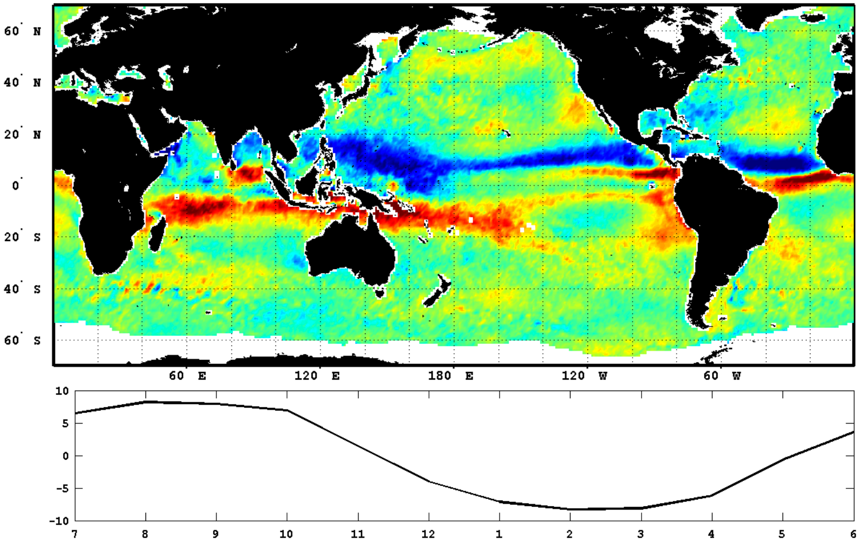
Singular value decomposition (lose 1 d.o.f. by removing mean)
  - yields 11 EOFs and associated PCs for 12 month dataset

Compare ENSO warm event year with ENSO neutral year
  - ENSO cold event year (2007-2008) roughly the same as neutral (not shown

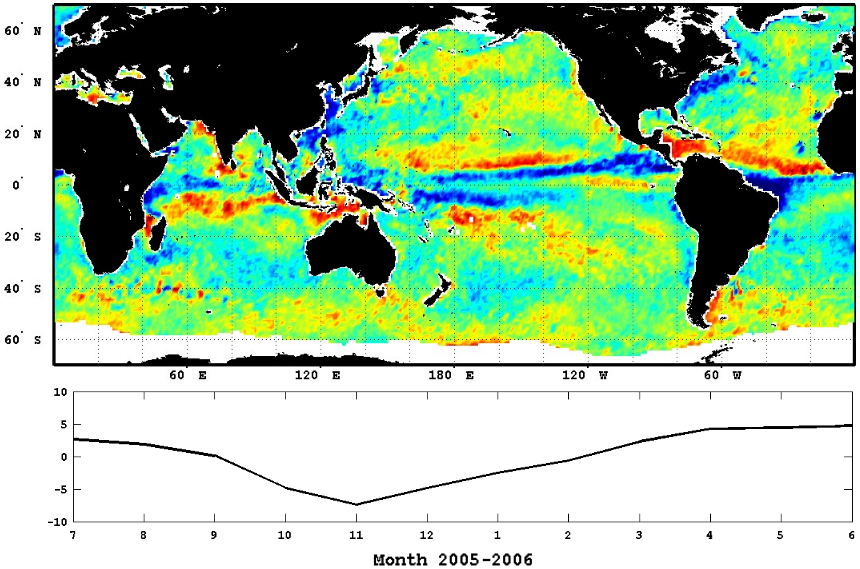
F and PC Comparison: Leading Modes ENSO WE and

Neutral Year

EOF:1 2005-2006 Per Cent Variance: 0.33755

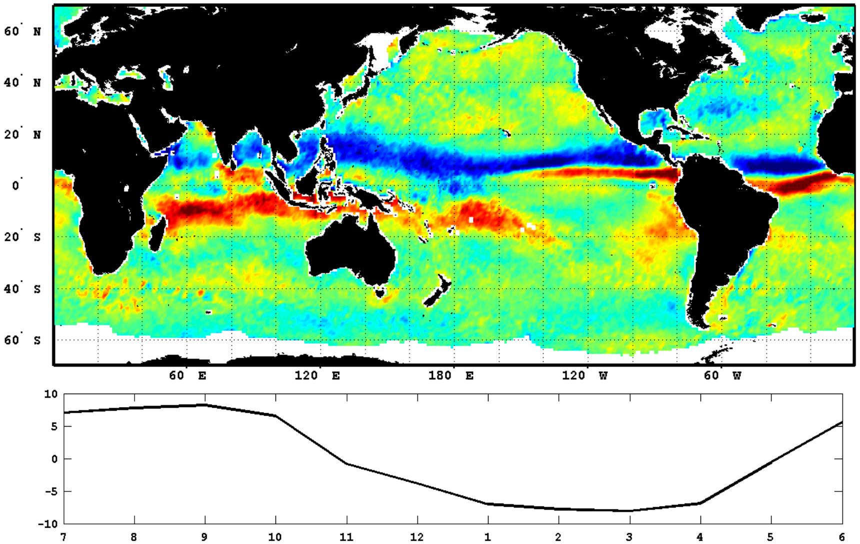


EOF:2 2005-2006 Per Cent Variance: 0.13074

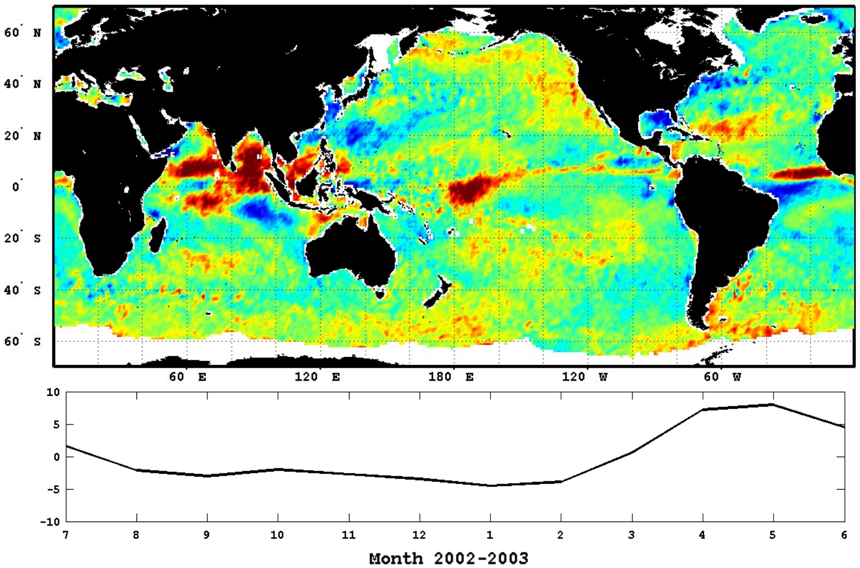


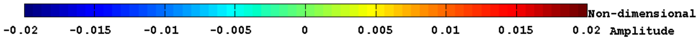
Warm Event Year

EOF:1 2002-2003 Per Cent Variance: 0.32926



EOF:2 2002-2003 Per Cent Variance: 0.14302



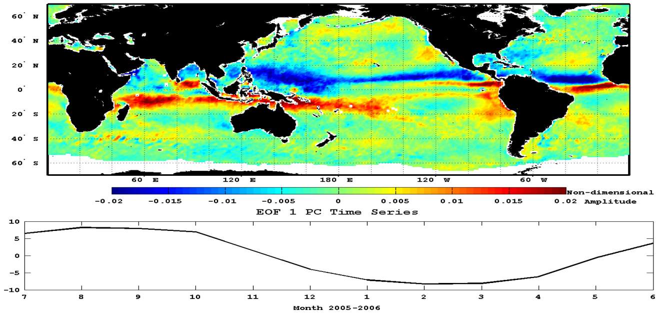


Spatial Structure Functions:

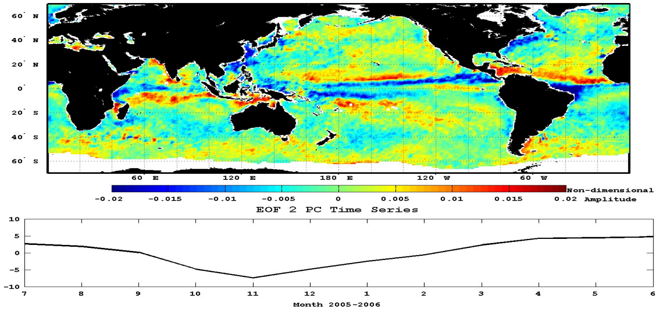
Modes 1-4

2005-2006 (neutral)

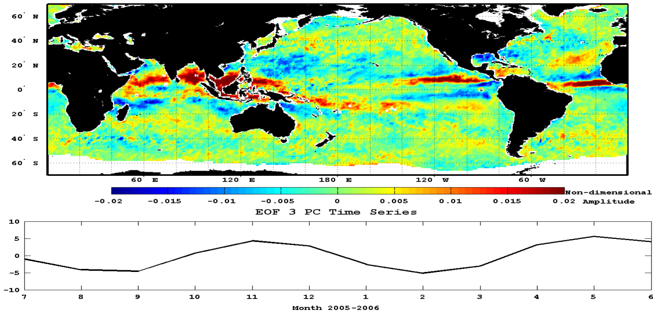
EOF:1 2005-2006 Per Cent Variance: 0.33755



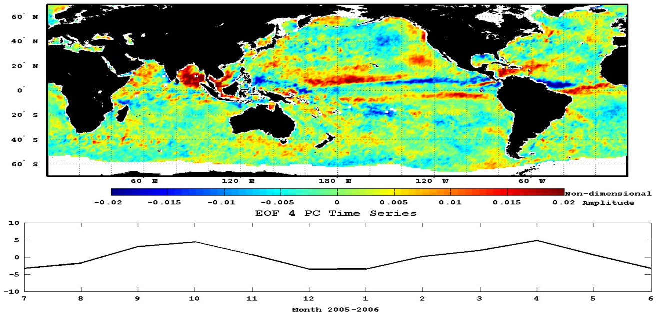
EOF:2 2005-2006 Per Cent Variance: 0.13074



EOF:3 2005-2006 Per Cent Variance: 0.11771

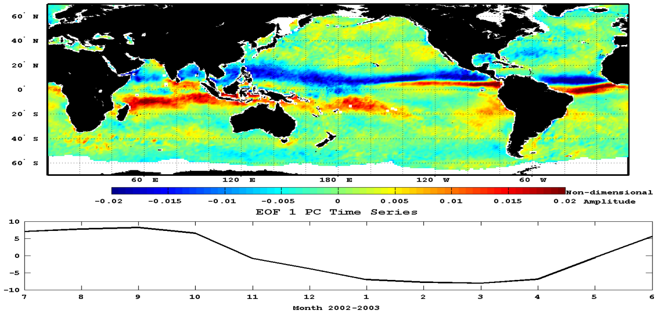


EOF:4 2005-2006 Per Cent Variance: 0.075166

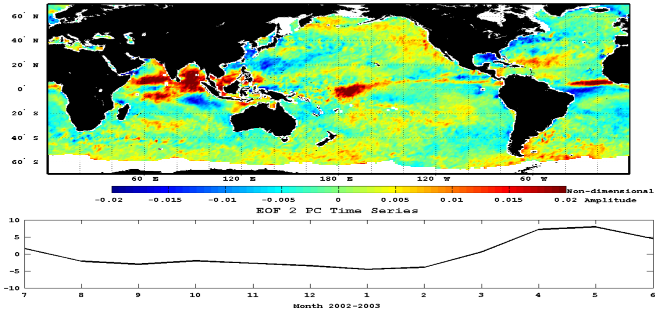


2002-2003 (warm event)

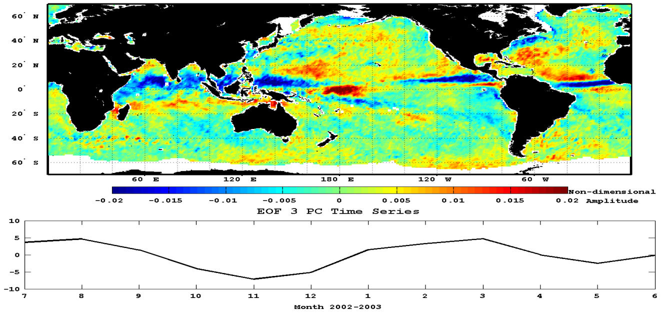
EOF:1 2002-2003 Per Cent Variance: 0.32926



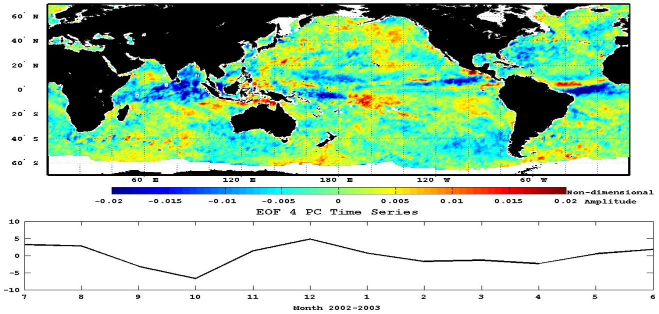
EOF:2 2002-2003 Per Cent Variance: 0.14302

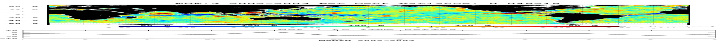


EOF:3 2002-2003 Per Cent Variance: 0.11604



EOF:4 2002-2003 Per Cent Variance: 0.075337





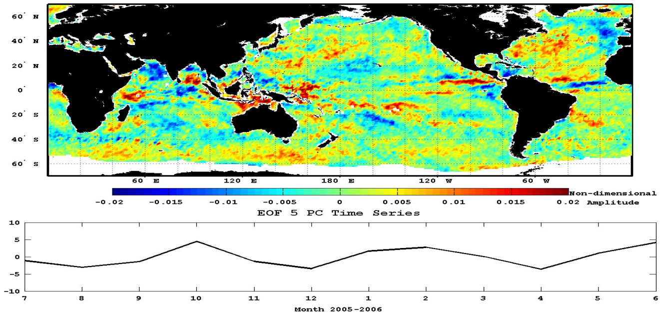
Spatial Structure Functions:

Modes 5-8

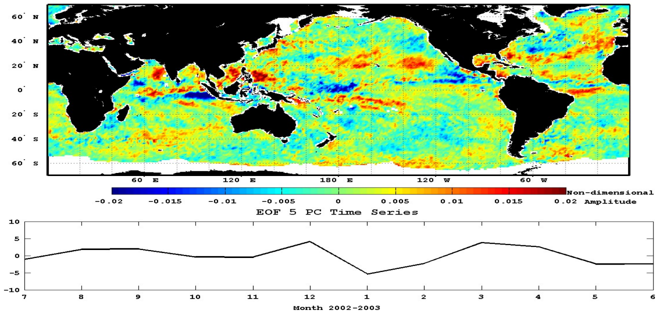
2005-2006 (neutral)

2002-2003 (warm event)

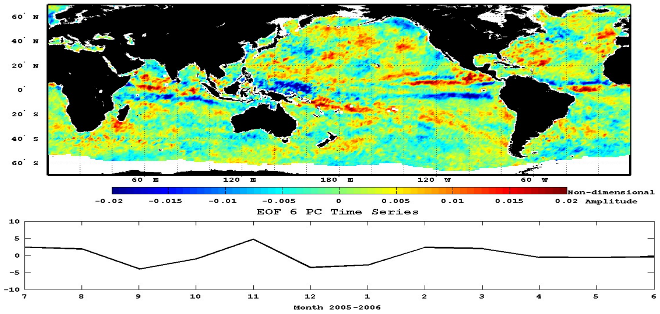
EOF:5 2005-2006 Per Cent Variance: 0.062738



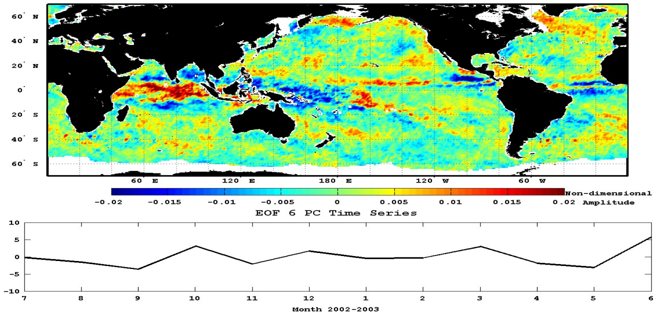
EOF:5 2002-2003 Per Cent Variance: 0.062451



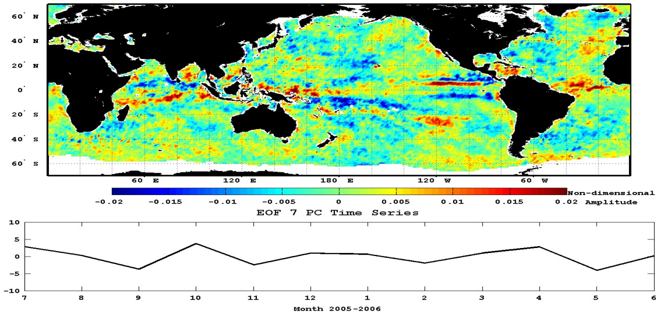
EOF:6 2005-2006 Per Cent Variance: 0.056261



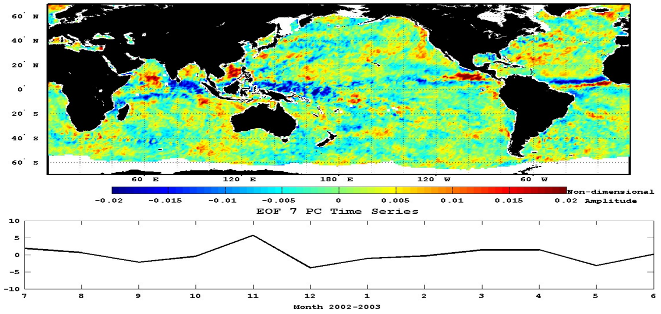
EOF:6 2002-2003 Per Cent Variance: 0.059159



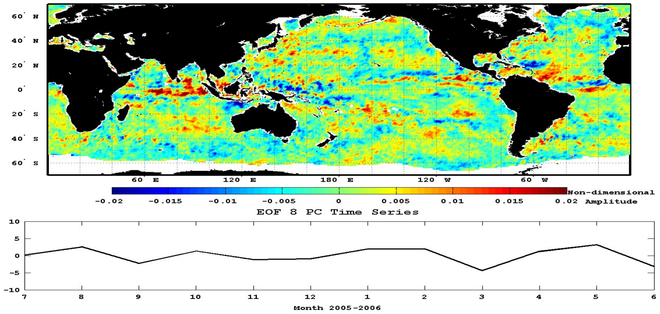
EOF:7 2005-2006 Per Cent Variance: 0.051544



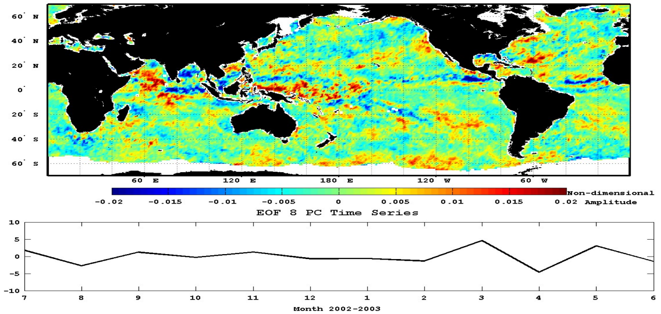
EOF:7 2002-2003 Per Cent Variance: 0.048218

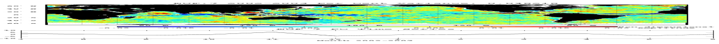


EOF:8 2005-2006 Per Cent Variance: 0.045894



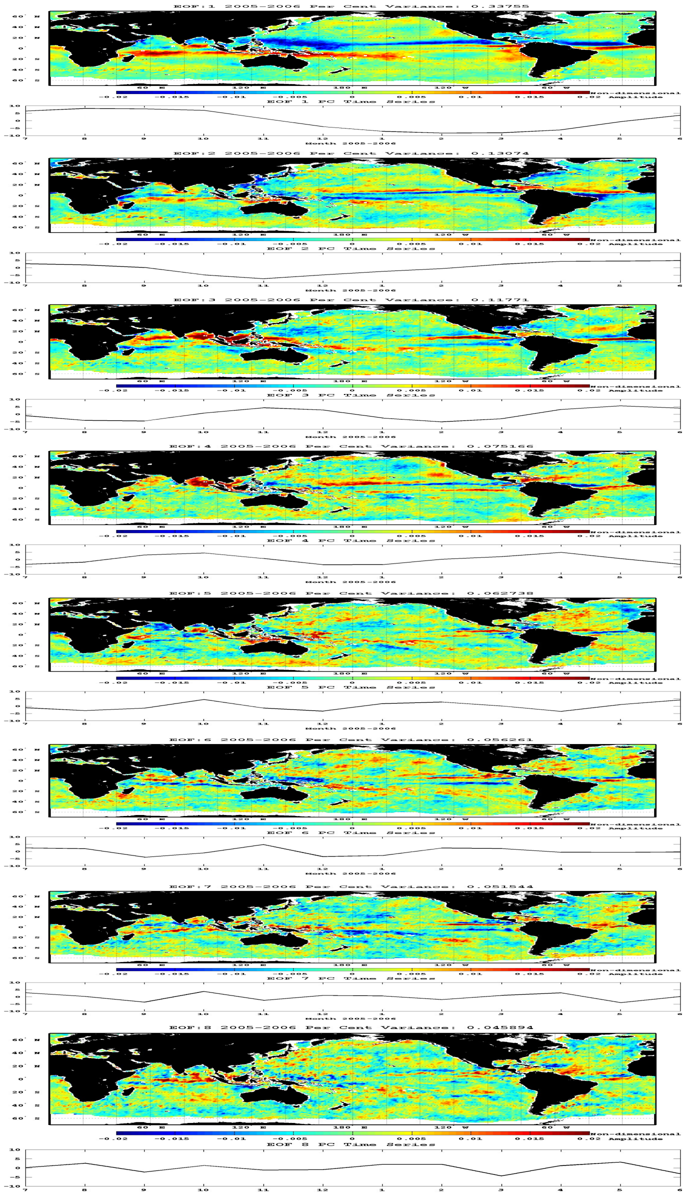
EOF:8 2002-2003 Per Cent Variance: 0.047081





cipal Components: ENSO Neutral and WE years, modes

2005-2006 (neutral)



34%

13%

12%

7%

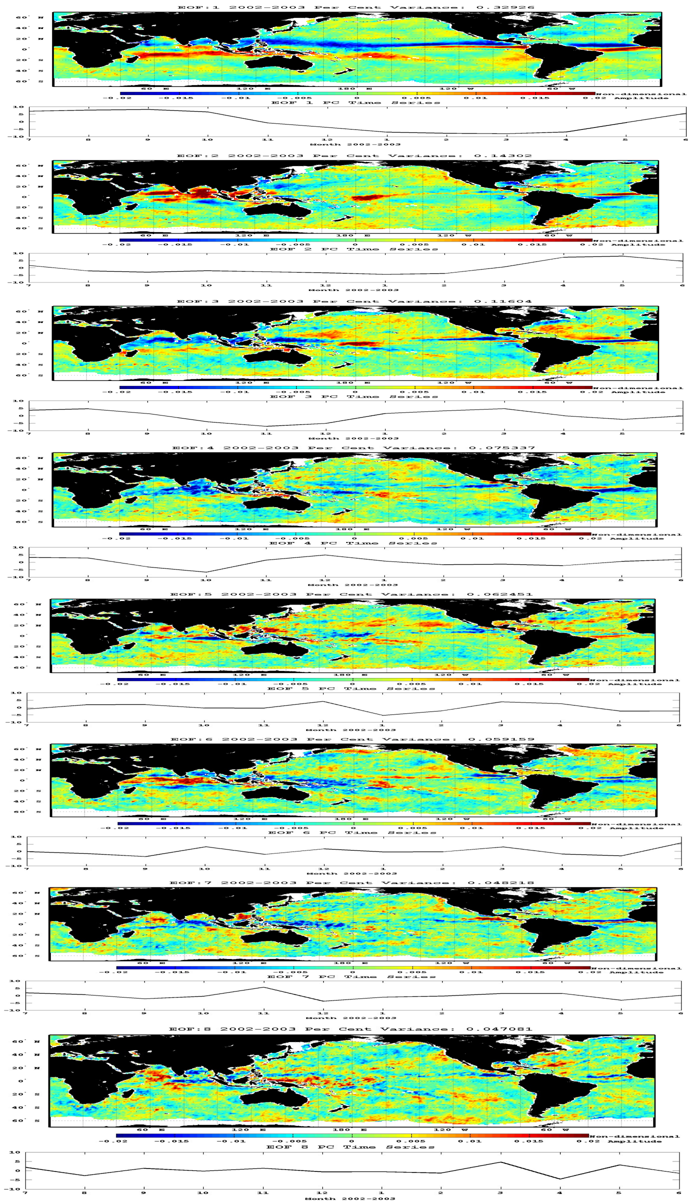
6%

6%

5%

4%

2002-2003 (warm event)



33%

14%

12%

7%

6%

6%

5%

5%

ptype SVW BHM with a Spatial Error Model

Data Stage; $[Y|Z,\theta_d]$

$$\mathbf{Y}_t = \mathbf{K}_t\mathbf{Z}_t + \epsilon_t, \quad \epsilon_t \sim \mathcal{N}(0, \mathbf{K}_t\hat{\mathbf{\Sigma}}_{e,t}\mathbf{K}_t')$$

Process Model Stage; $[Z|\Psi,b,\theta_p]$

$$\mathbf{Z}_t = \mathbf{\Psi}\,\mathbf{b}_t + \gamma_t, \quad \gamma_t \sim \mathcal{N}(0, \tau\mathbf{I})$$

$\mathbf{\Psi}$ are nested wavelet basis functions,
$\mathbf{b}_t$ are monthly amplitude coefficients and
τ is needed to account for small-scale variability

Parameter Distributions; $[\theta_p]$, $[\theta_d]$

$$\mathbf{b}_t \sim \mathcal{N}(0, diag(q))$$

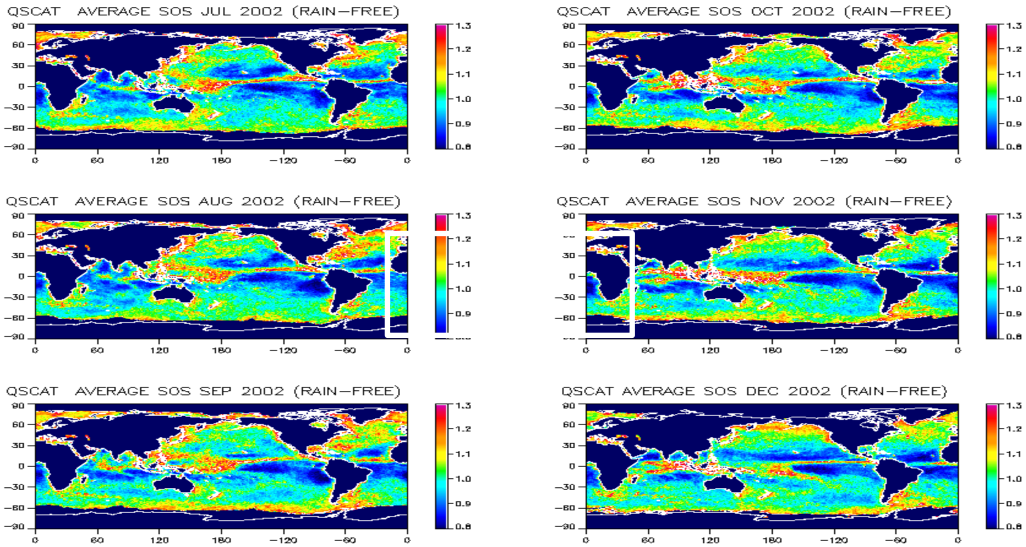
where the vector q is *specified* to reflect
decreasing variance with wavelet scale
(i.e. based on spectra for Sept winds).

recall $\hat{\mathbf{\Sigma}}_{e,t} = \sigma^2_\epsilon\, \mathrm{d}iag\,(\hat{\mathbf{s}}_{\mathbf{9}})$
$\hat{\mathbf{s}}_9$ are diagonal variances for Sept 2002
$\sigma^2_\epsilon \sim \mathcal{IG}(p,r)$

Posterior Distribution; $[Z,\Psi,b,\theta_p,\theta_d|Y]$

BHM with wavelet bases:
Berliner, Wikle, Milliff, (1999); Wikle, Milliff, Nychka, Berliner, (2001);
Milliff, Bonazzi, Wikle, Pinardi, Berliner, (2011)

155°E to 105°W; 25°S to 25°N
392 x 200 at 0.25°
Ku2011 3-day Avg L3 SVW
30d (Sep 2002)



QSCAT AVERAGE SOS JUL 2002 (RAIN–FREE)

QSCAT AVERAGE SOS OCT 2002 (RAIN–FREE)

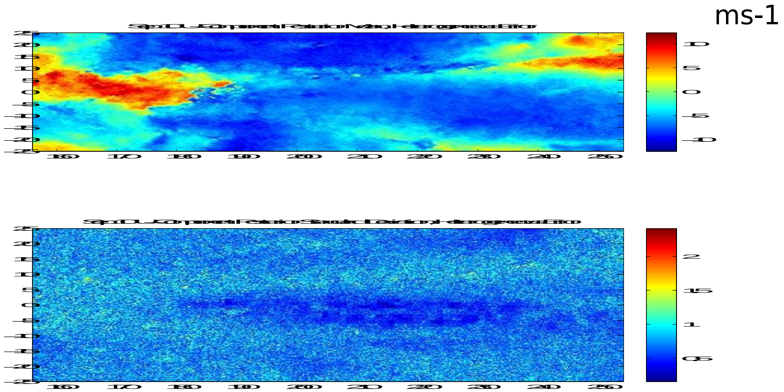
QSCAT AVERAGE SOS AUG 2002 (RAIN–FREE)

QSCAT AVERAGE SOS NOV 2002 (RAIN–FREE)

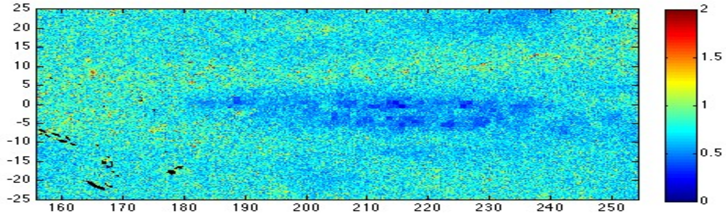
QSCAT AVERAGE SOS SEP 2002 (RAIN–FREE)

QSCAT AVERAGE SOS DEC 2002 (RAIN–FREE)

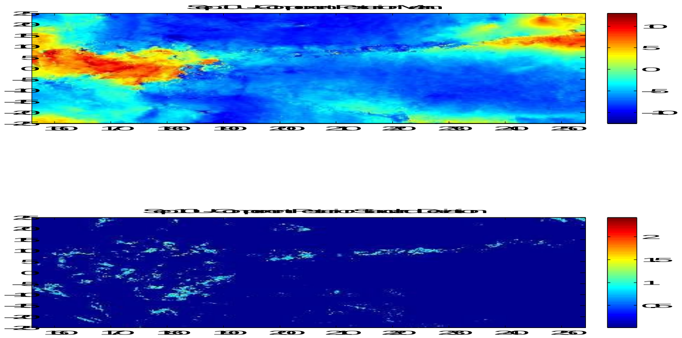
terior Mean Results: 10 Sep 2002



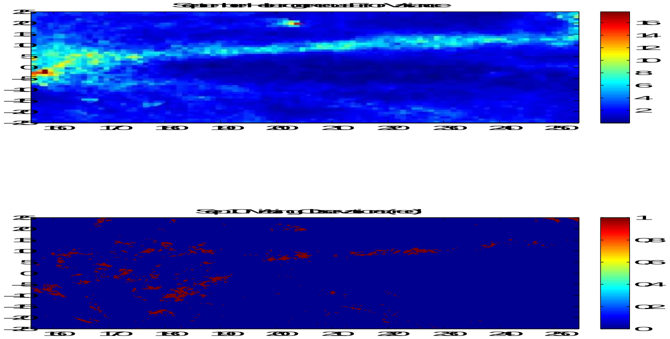
u(x,y)

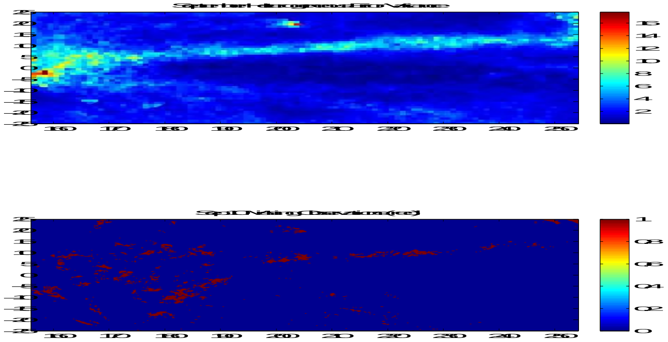


σu(x,



σu





missing data

ummary and Future Plans

- Scatterometer retrievals include valuable uncertainty information for construc spatio-temporal error models
    - useful advances in data assimilation (Kalman gain, denom Cost Functio
    - required for global SVW BHM development (“surface wind ensembles”)

- Parameterization 1: diagonal error variance matrix
- Parameterization 2: diagonal spatial structure functions (EOFs) and PC time se
    - model time dependence of leading modes; e.g. ENSO neutral vs. WE
    - mixture models

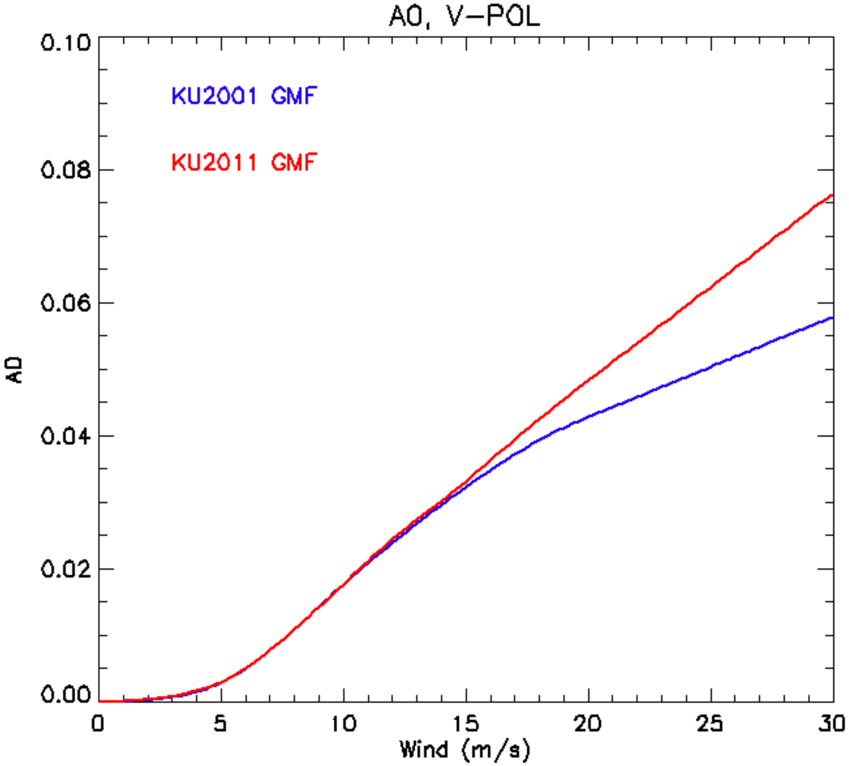
- Prototype regional SVW BHM for Sep 2002
    - spatially varying u std. deviation from posterior distribution (paramete

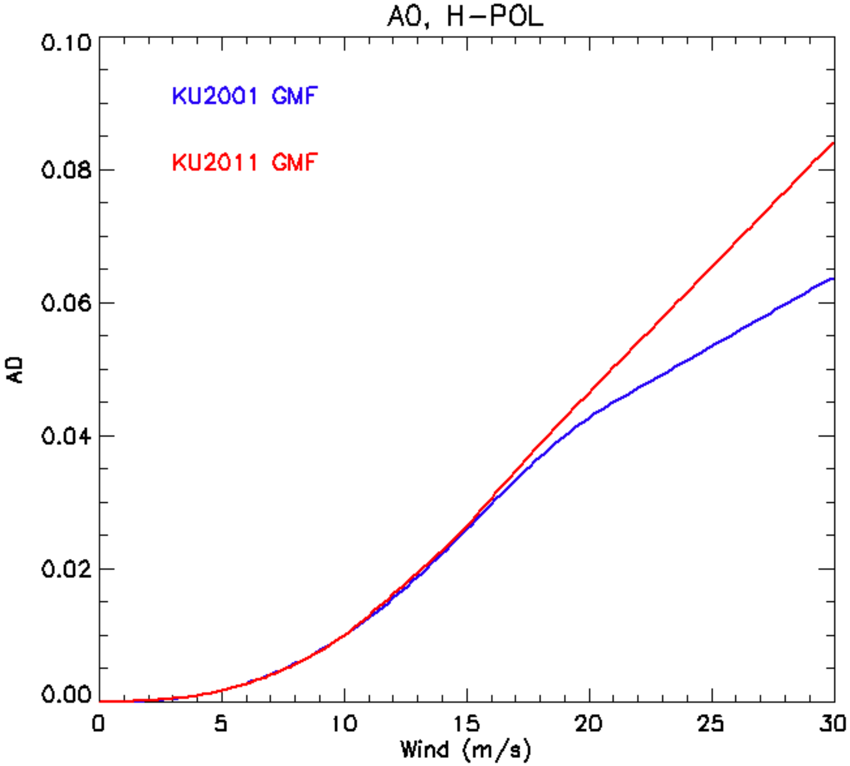
- Basis function process model structure as in spectral parts of GCMs
    - e.g. Hermite polynomials in tropics

- Multiplatform data stage inputs; all with specific spatio-temporal error models
    - enforce k-2 spectral dependence (nested wavelets at small scales)

EXTRAS

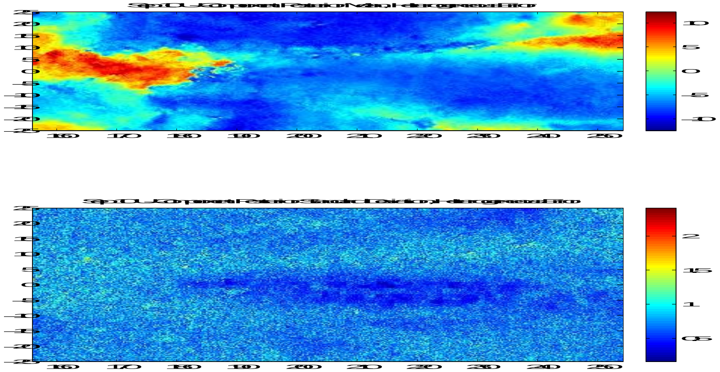
σ0(wind speed, polarization)
A0 as a first approximation for σ0



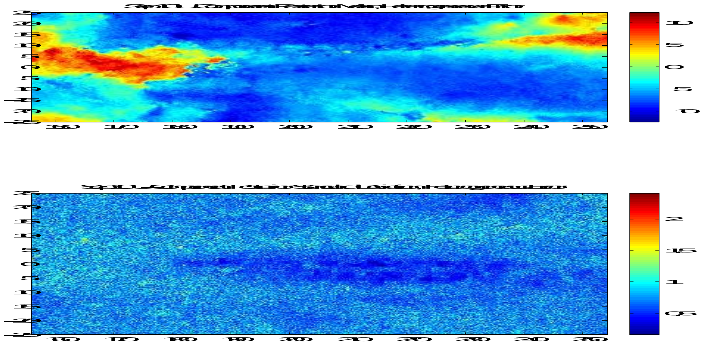


terior Mean Results: 10 Sep 2002

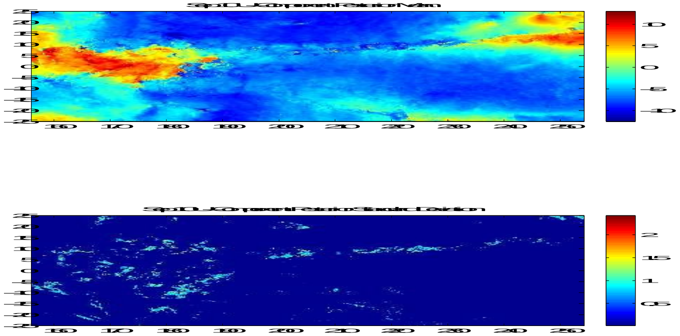
u(x,y)

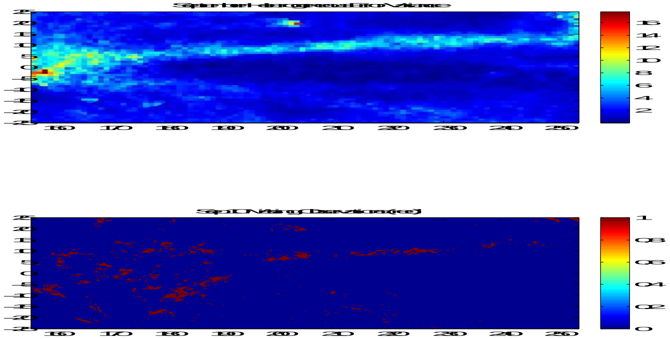


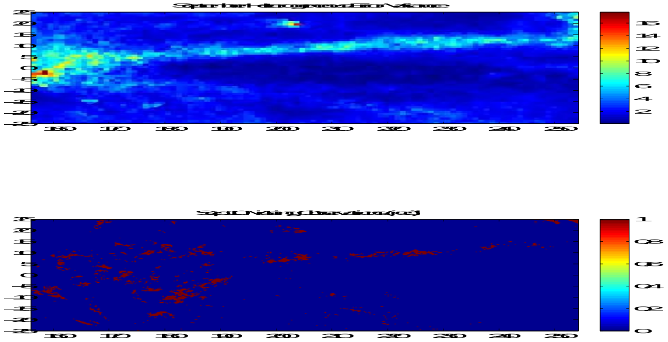
σu(x,y)



σu







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