



# Comparative Analysis of Upper Ocean Heat Content Variability from an Ensemble of Operational Ocean Reanalyses

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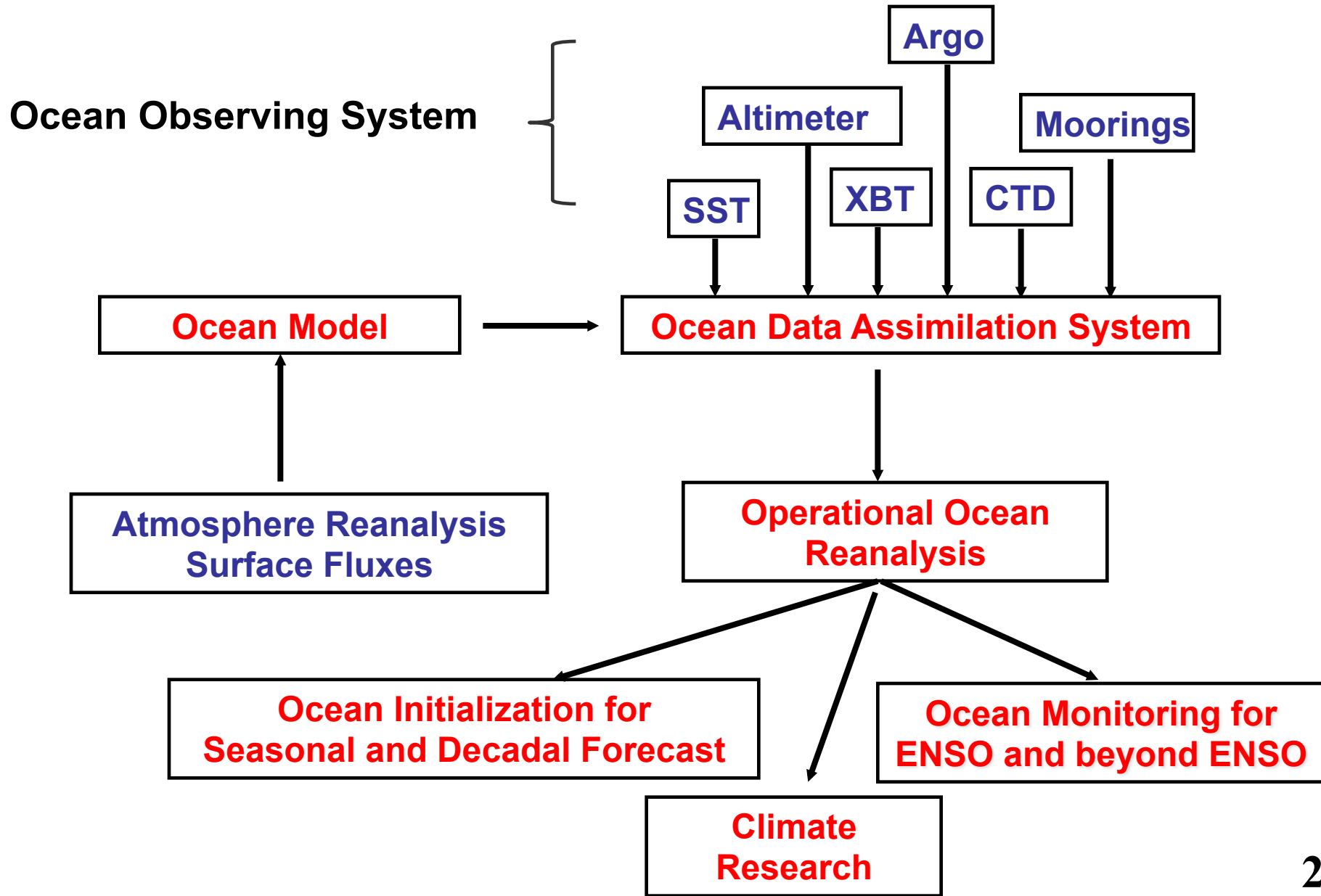
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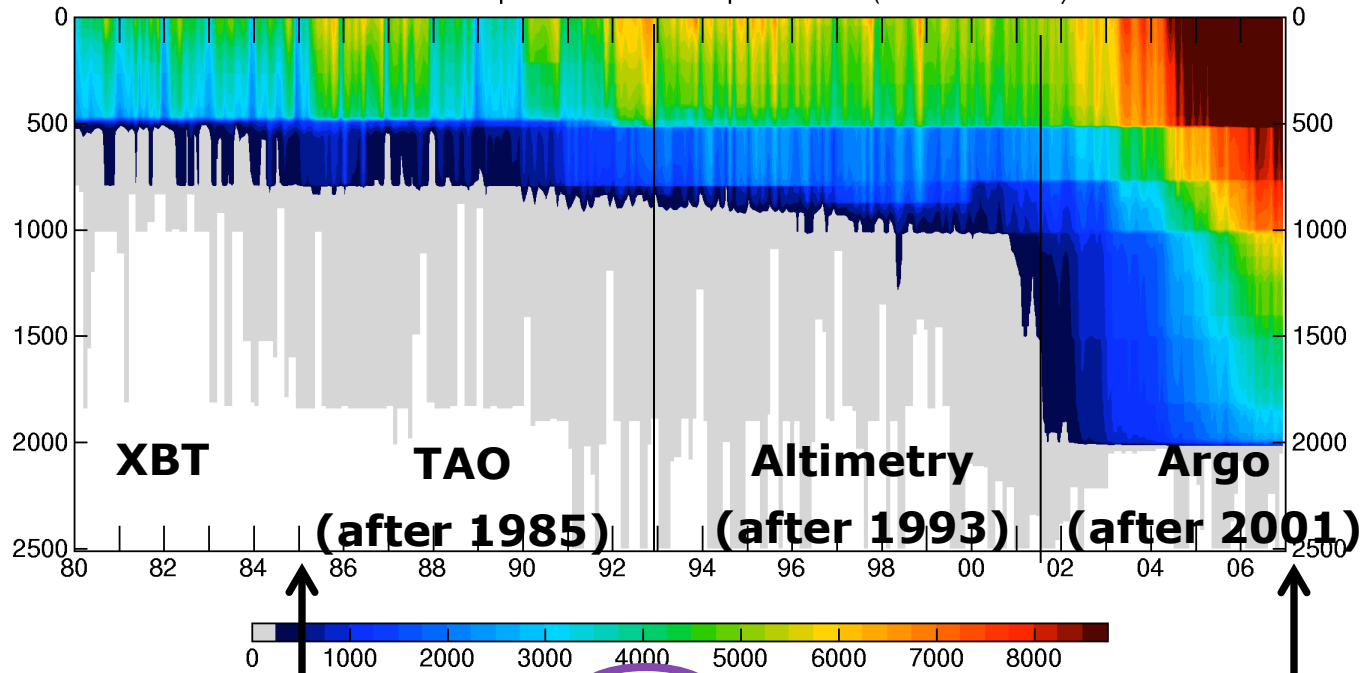
# (Operational) Ocean Reanalysis



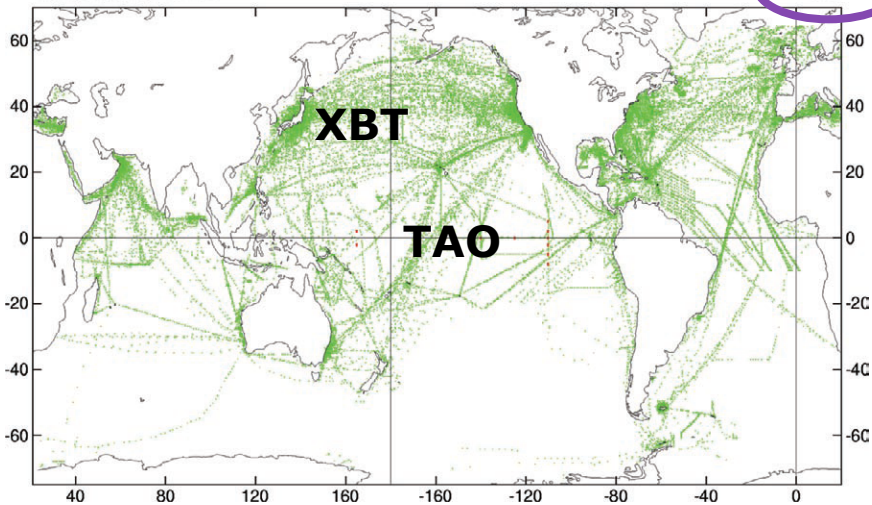
# Ocean Observations

from Saha et al. (2010)

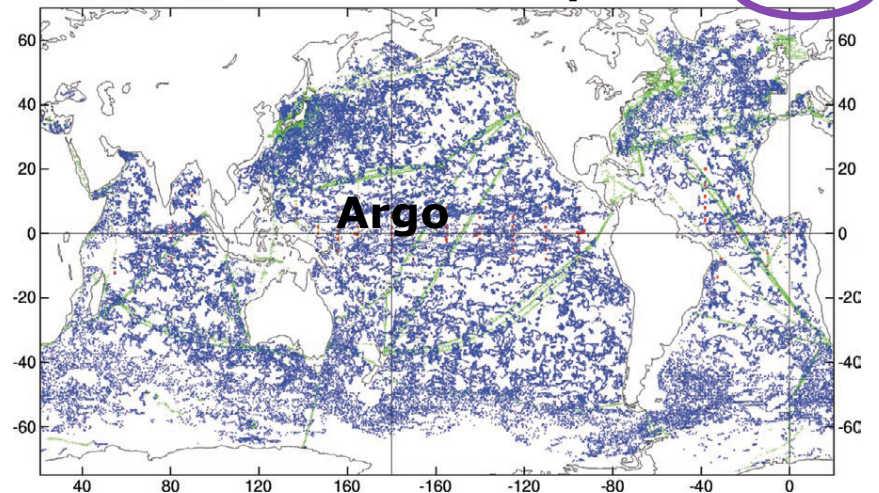
Number of Temperature Profiles per Month (1980-Present)



Temperature Profiles



Temperature Profiles



## **Uncertainties in Ocean Reanalysis**

- **Uncertainties in surface fluxes**
- **Biases in ocean models**
- **Deficiencies in data assimilation schemes**
- **Changes in ocean observing systems**

## **Intercomparison of Ocean Reanalysis**

- **Carton and Santorelli (2008): Decadal variability of ocean heat content**
- **Lee et al. (2009): ): CLIVAR-GSOP intercomparison activities**
- **Stammer et al. (2010): OceanObs'09 Community White Paper**
- **Zhu et al. (2012): Tropical Atlantic variability**

## **Ocean Reanalysis for Ocean Monitoring**

- **Xue et al. (2010): OceanObs'09 Community White Paper**

# Operational Ocean Reanalyses

Name	Method & Forcings	In Situ Data	Altimetry Data	Resolution	Period	Vintage	Reference
<b>EN3.v2a</b>	Analysis Correction Scheme	No XBT corrections	No	1°x 1°, 42 Levels Monthly Temp.	1950-present	2009	Ingleby and Huddleston (2007)
<b>NODC</b>	Objective Analysis	No XBT corrections	No	1°x 1°, 16 Levels, 0 to 700m Seasonal Temp.	1955-present	2010	Levitus et al. (2009)
<b>GODAS</b>	3D-VAR	No XBT corrections	NO (Yes in real time)	1°x 1° (1/3° near Eq), 40 Levels Pentad, Monthly	1979-present	2003	Behringer and Xue (2004)
<b>ECMWF (S3)</b>	OI	No XBT corrections	Yes	1°x1° (1/3° near Eq), 29 Levels Daily, Monthly	1959-present	2007	Balmaseda et al. (2008)
<b>JMA</b>	3D-VAR	No XBT corrections	Yes	1°x1° (1/3° near Eq), 50 Levels Pentad, Monthly	1979-present	2009	Usui et al. (2006)
<b>CFSR</b>	3D-VAR Partially coupled	No XBT corrections	No (Yes in real time)	1/2°x 1/2° (1/4° near Eq), 40 Levels Daily, Pentad, Monthly	1979-present	2010	Xue et al. (2011)
<b>GFDL</b>	EnKF Fully coupled	XBT corrections	Yes	1°x 1° (1/3° near Eq), 50 Levels Daily, Pentad, Monthly	1970-present	2010	Zhang et al. (2009)
<b>GMAO</b>	EnOI Partially coupled	XBT corrections	No	1/2°x 1/2° (1/4° near Eq), 40 Levels Daily, Monthly	1980-present	2011	Rienecker et al. (2011)
<b>MERCATOR (PSY2G2)</b>	KF-SEEK	No XBT corrections	Yes	2°x 2° (1/2° near Eq), 31 Levels Daily, Pentad, Monthly	1979-present	2007	Drévillon et al. (2008)
<b>BOM (PEODAS)</b>	EnKF	No XBT corrections	No	2°x 1.5° (1/2° near Eq.), 25 Levels Daily, Monthly	1980-present	2009	Yin et al. (2010)

# Upper 300m Ocean Heat Content Analysis

- **How well is the mean upper 300m ocean heat content (HC300) analyzed by operational ocean reanalysis (ORA)?**
- **How well is the interannual variability, multi-decadal and long term variability of HC300 analyzed by ORAs?**
- **What are the impacts of changes of ocean observing systems on the spread of HC300 analyses?**
- **What are the prospects for **operational HC300 climate indices** derived from an ensemble of operational ORAs?**

Xue, Y., M. A., Balmaseda, T. Boyer, N. Ferry, S. Good, I. Ishikawa, A. Kumar, M. Rienecker, T. Rosati, Y. Yin, 2011: A comparative analysis of upper ocean heat content variability from an ensemble of operational ocean reanalyses. *J. Climate* (in press).

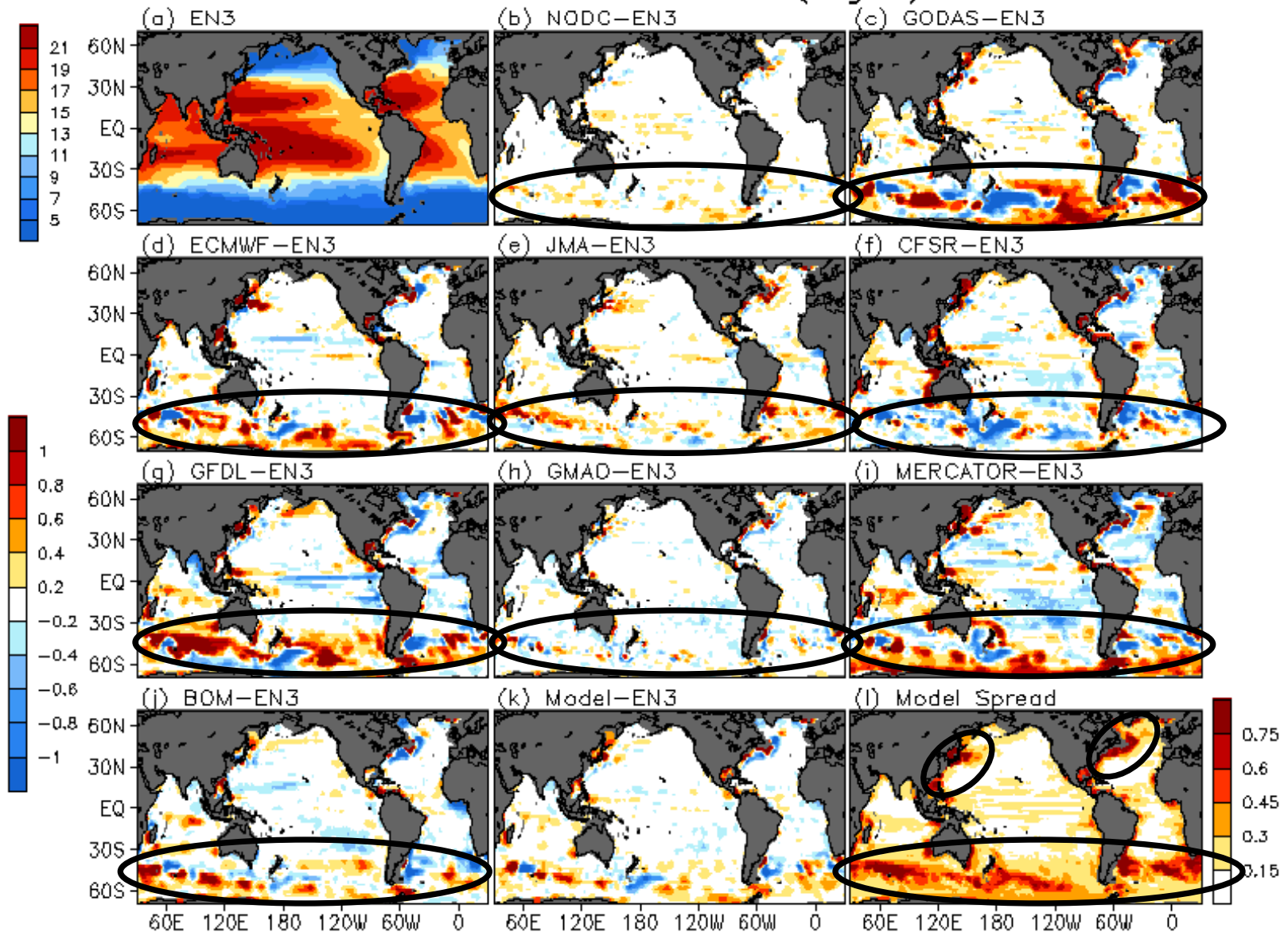
<http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00542.1>

# Outline

- **Model Data**
  - Ten operational ocean reanalyses
  - Upper 300m temperature average
  - Monthly, 1980-2009,  $1^\circ \times 1^\circ$ ,  $70^\circ\text{S}$ - $70^\circ\text{N}$
- **Total HC300**
  - Annual climatology in 1984-2009
  - Ensemble spread vs observation counts
  - Basin mean HC300 time series
- **Anomalous HC300**
  - Standard deviation
  - Anomaly correlation
  - Signal to noise ratio
  - Co-variability with SST
  - HC300 climate indices

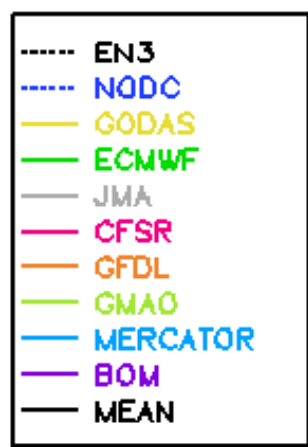
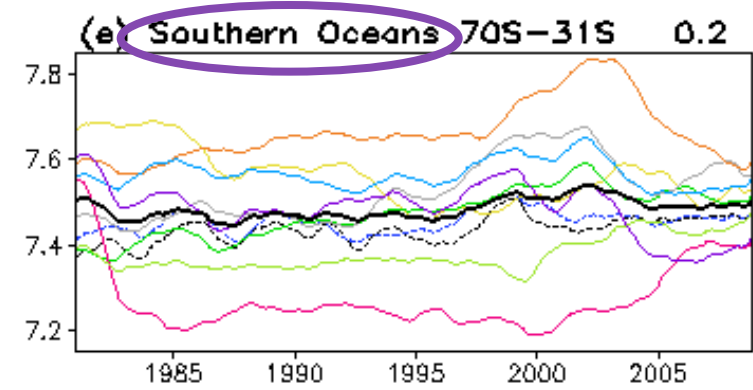
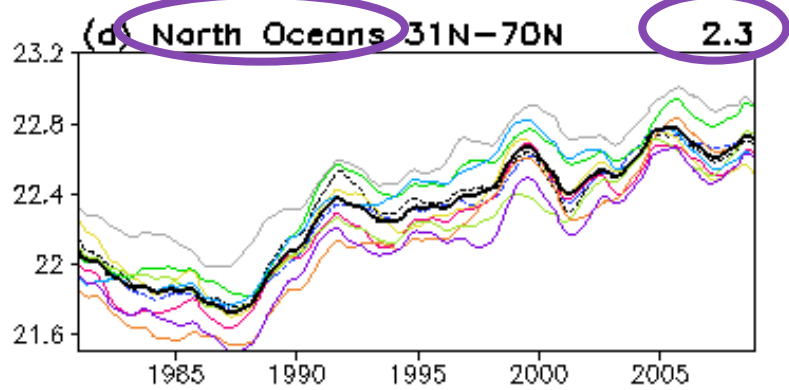
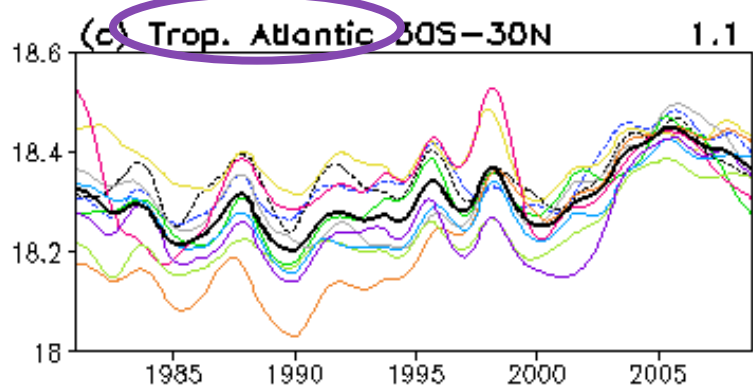
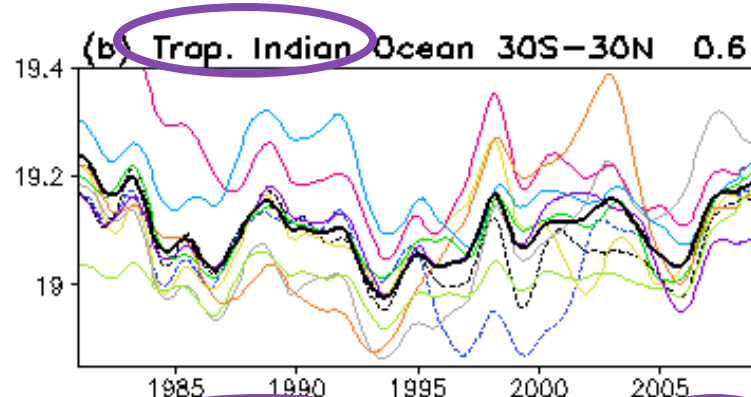
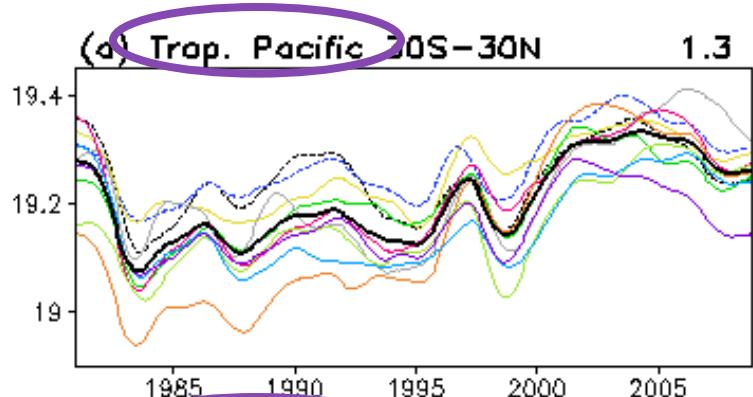
# Mean Ocean Heat Content

Mean HC300 in 1985–2009 (degree)



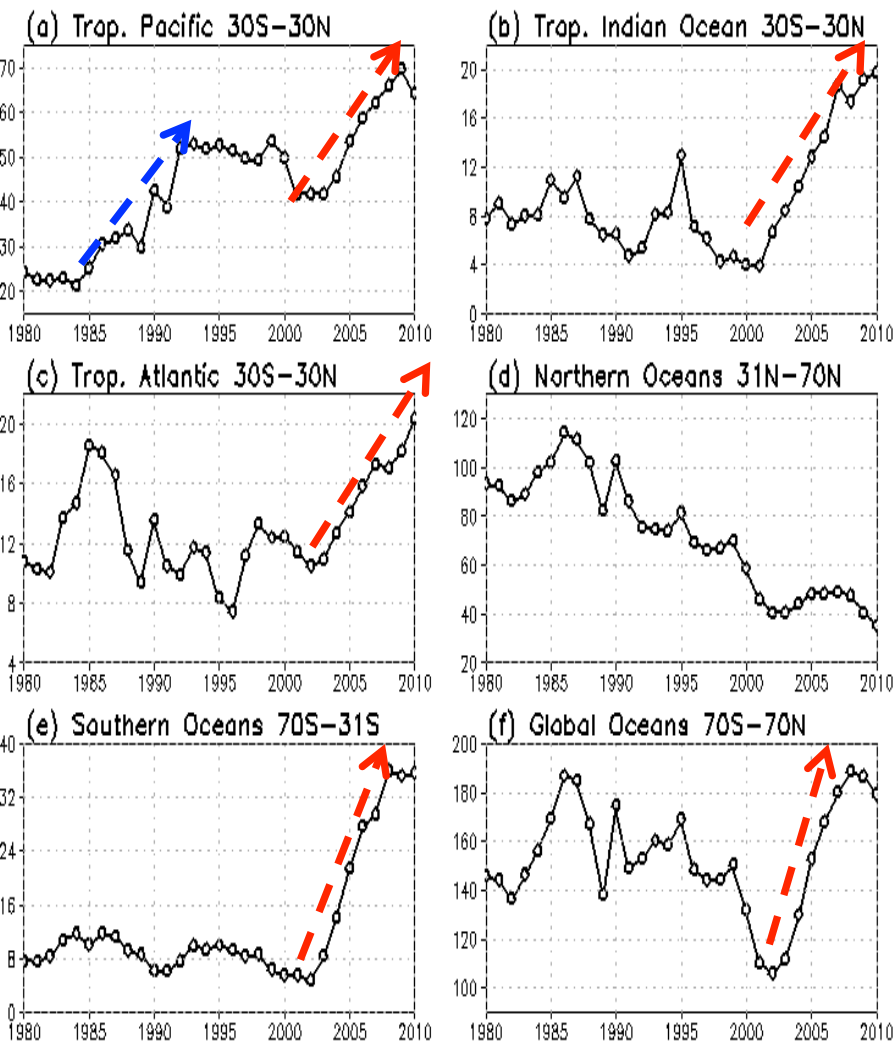


# Average Ocean Heat Content in Each Ocean Basin

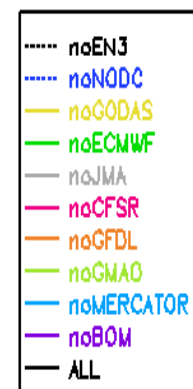
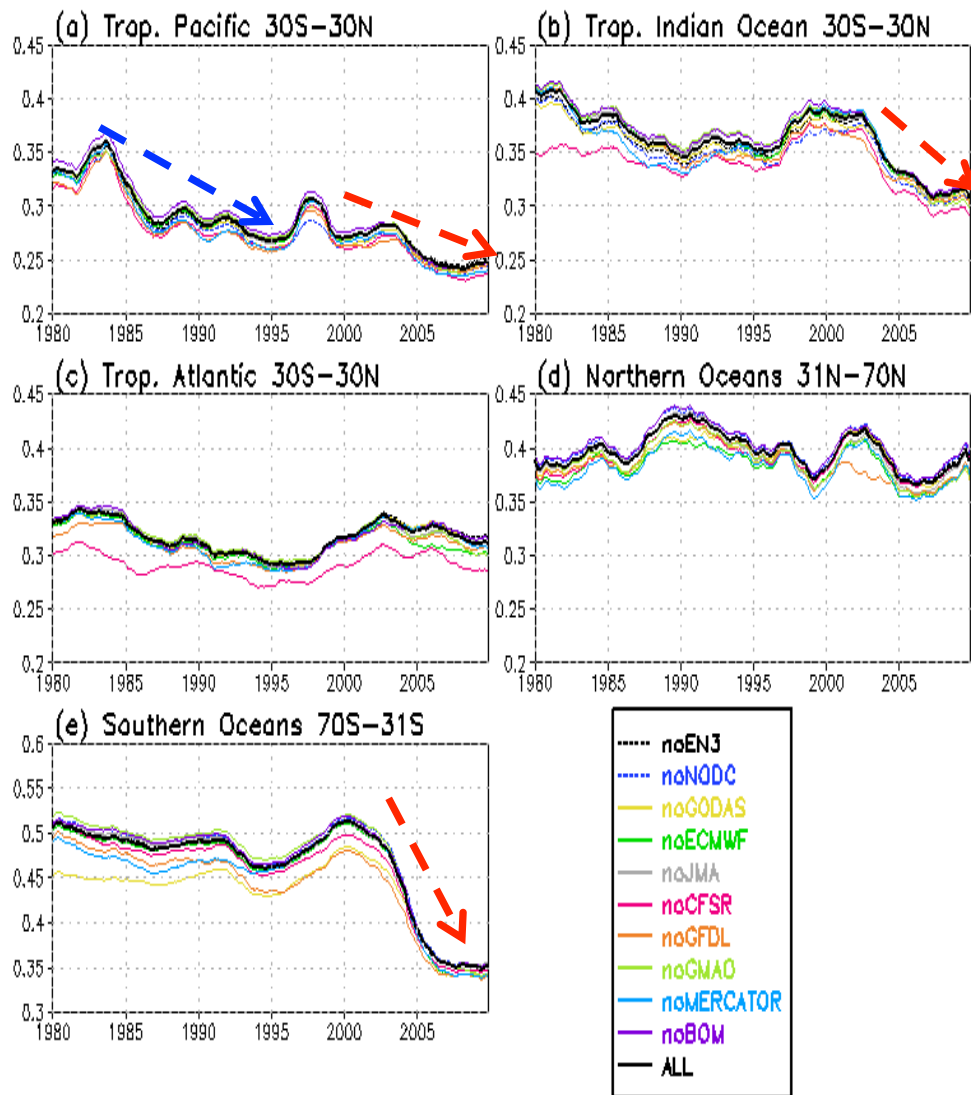


# Impacts of Changes of Ocean Observing Systems

## Data Count



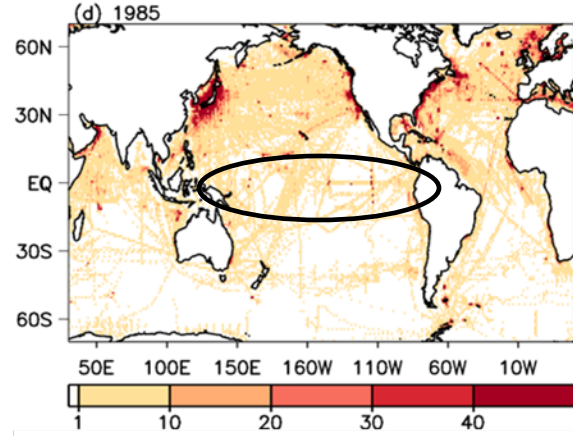
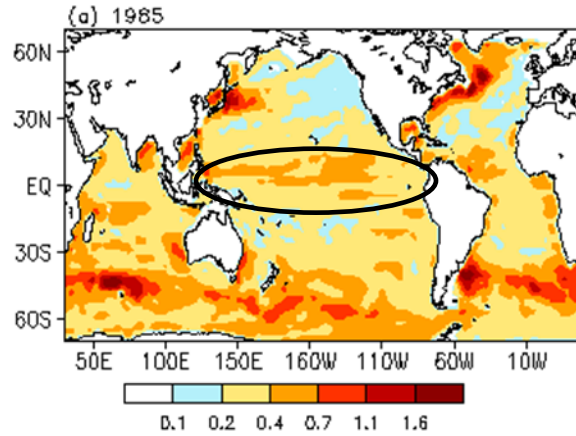
## Ensemble Spread



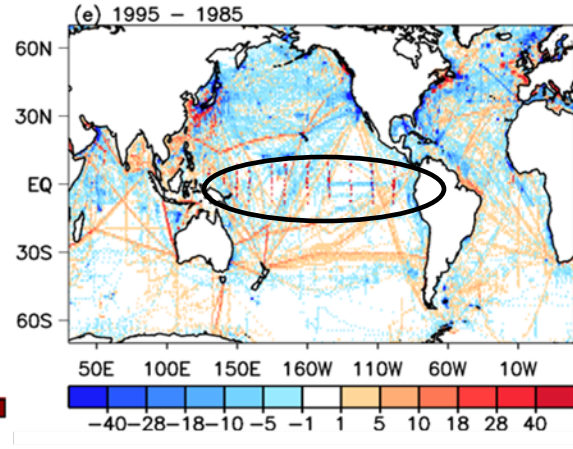
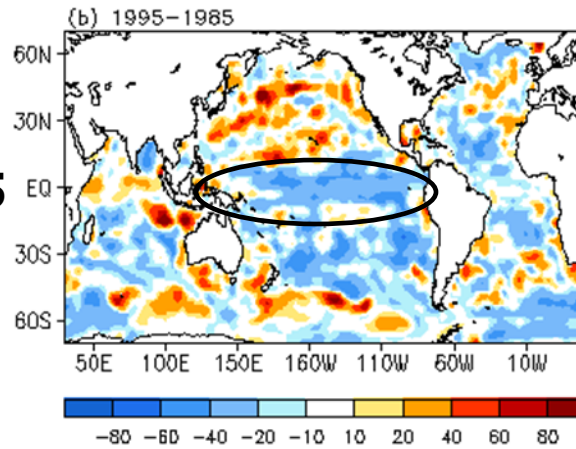
# Ensemble Spread

# Data Count

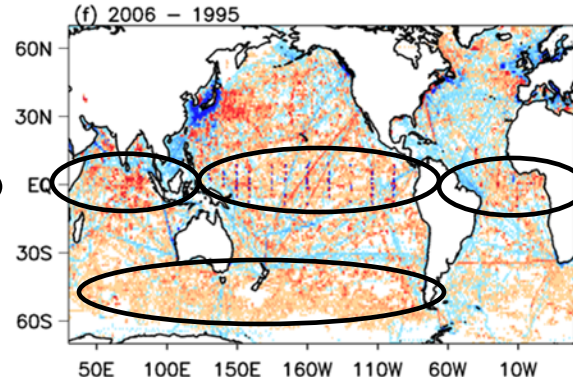
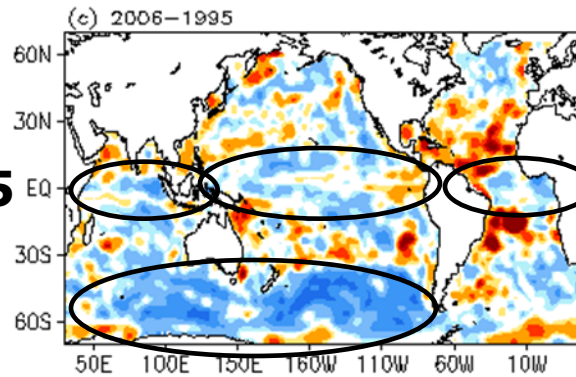
1985



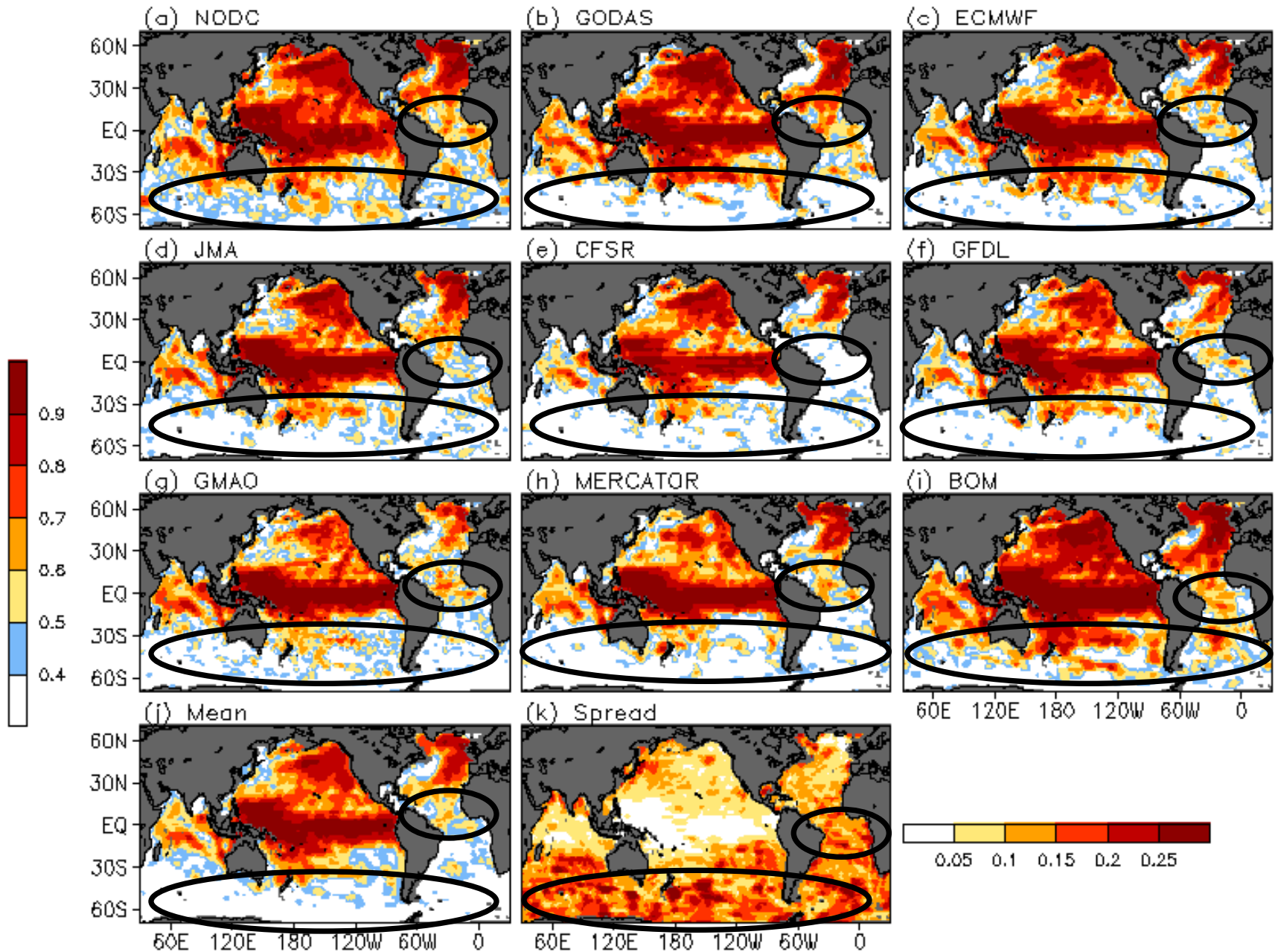
1995 minus 1985



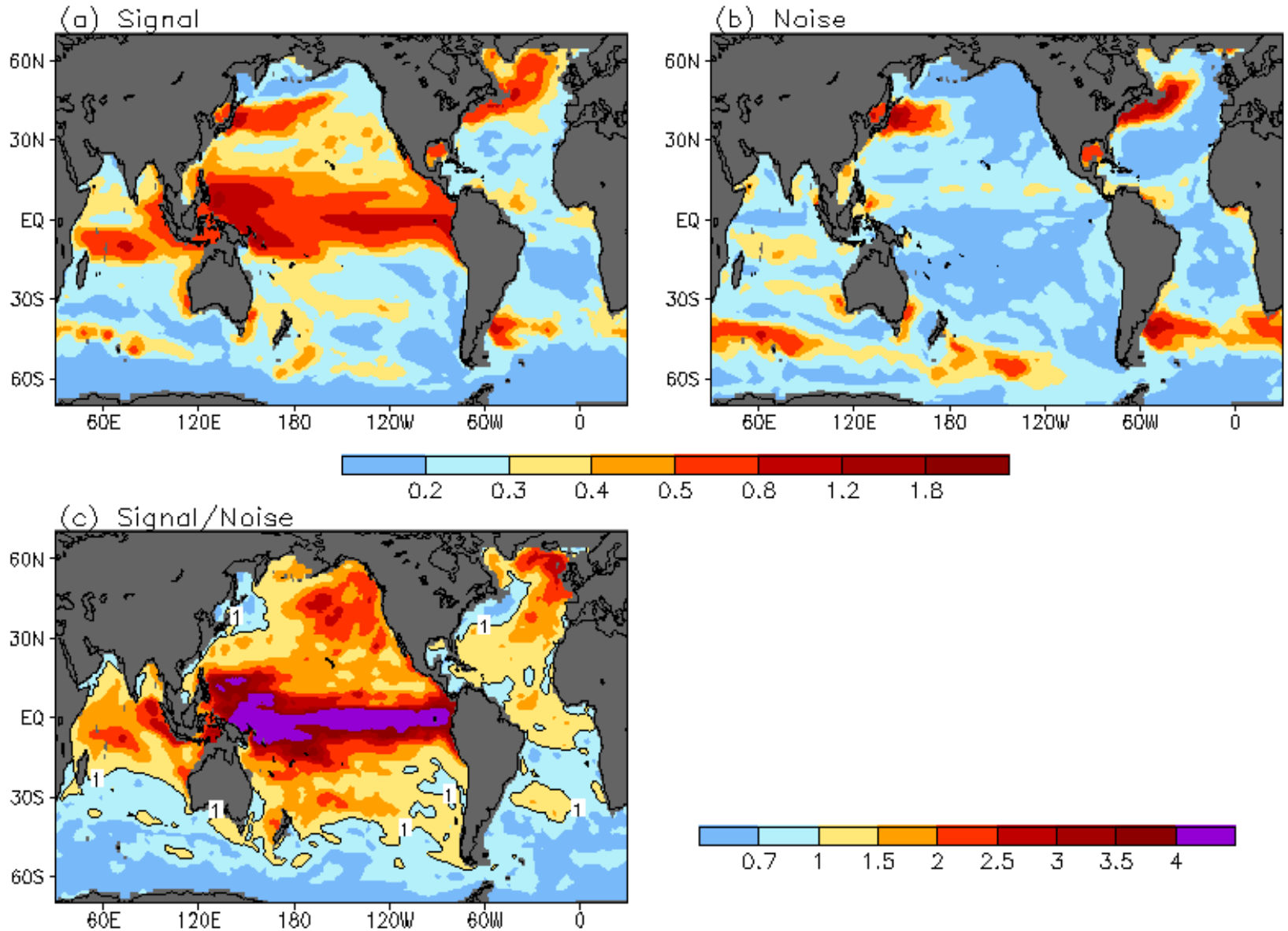
2006 minus 1995



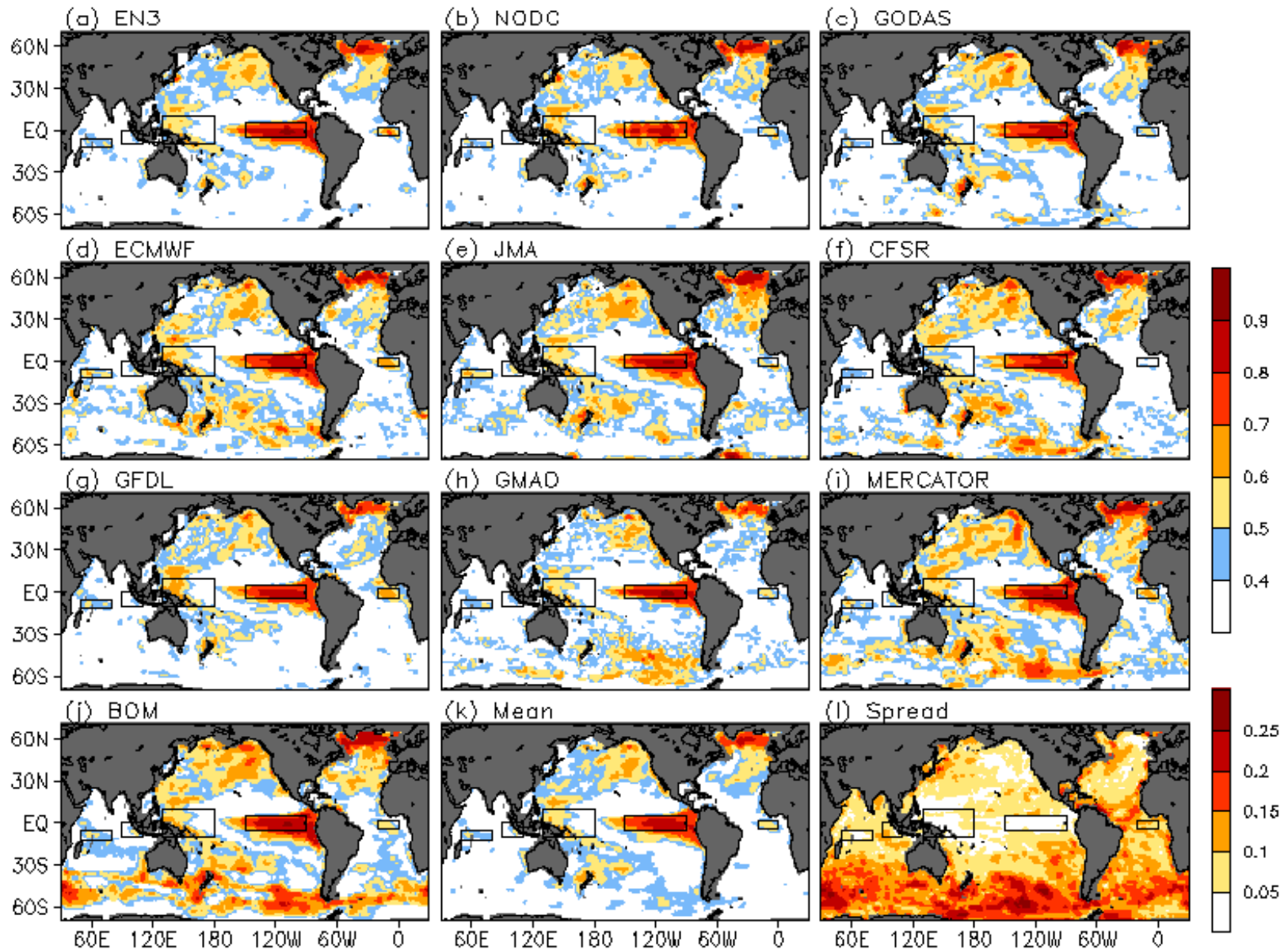
# Anomaly Correlation with EN3



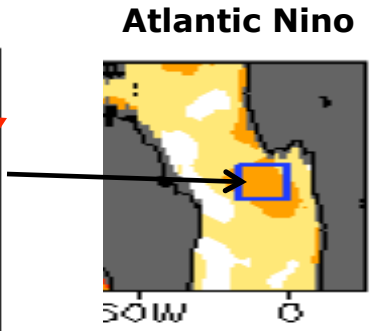
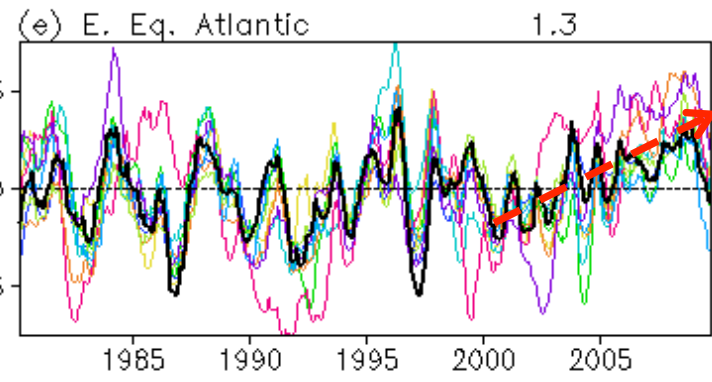
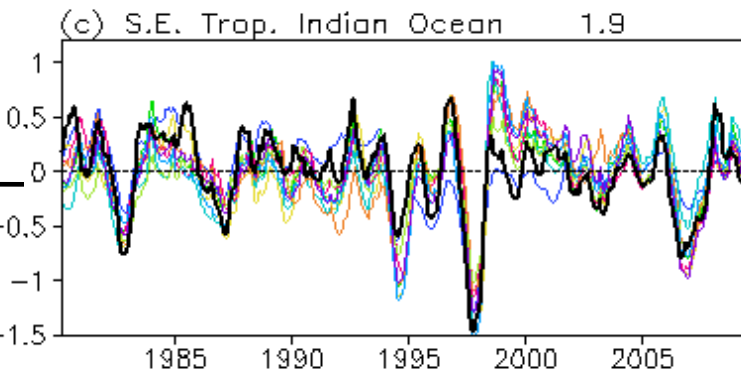
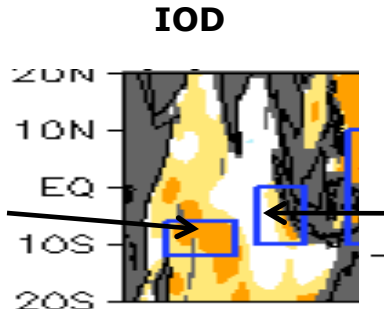
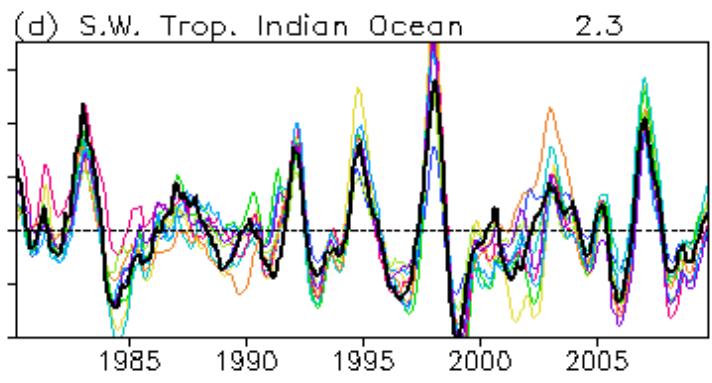
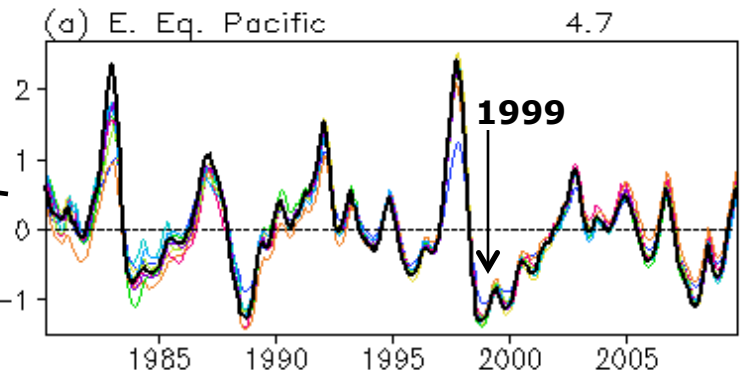
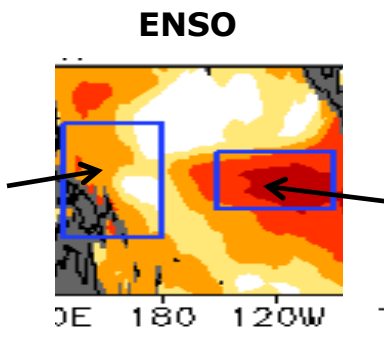
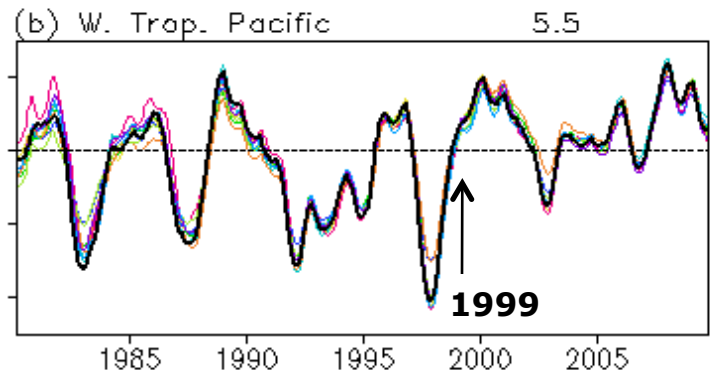
# Signal to Noise Ratio



# Anomaly Correlation between HC300 and OI SST



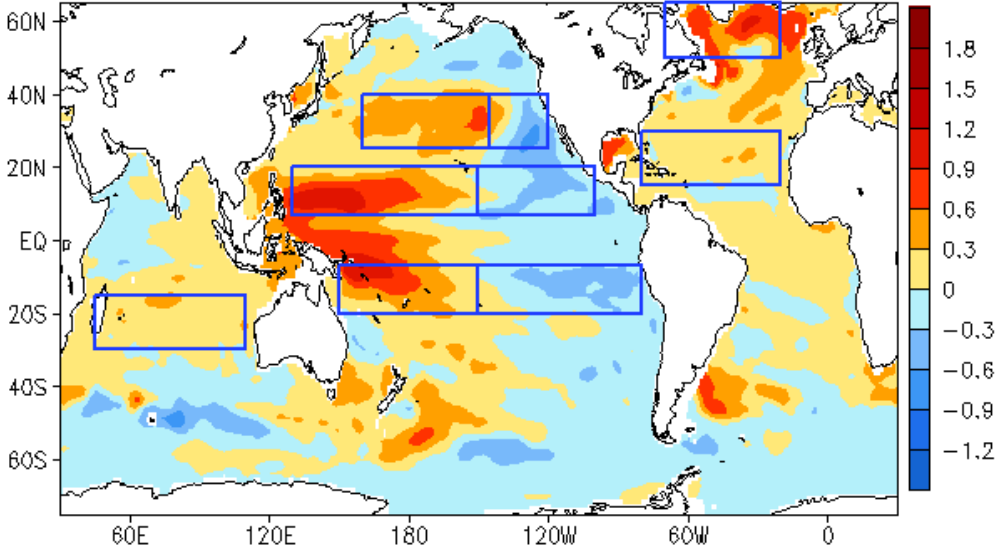
# HC300 Indices for ENSO, IOD and Atlantic Nino



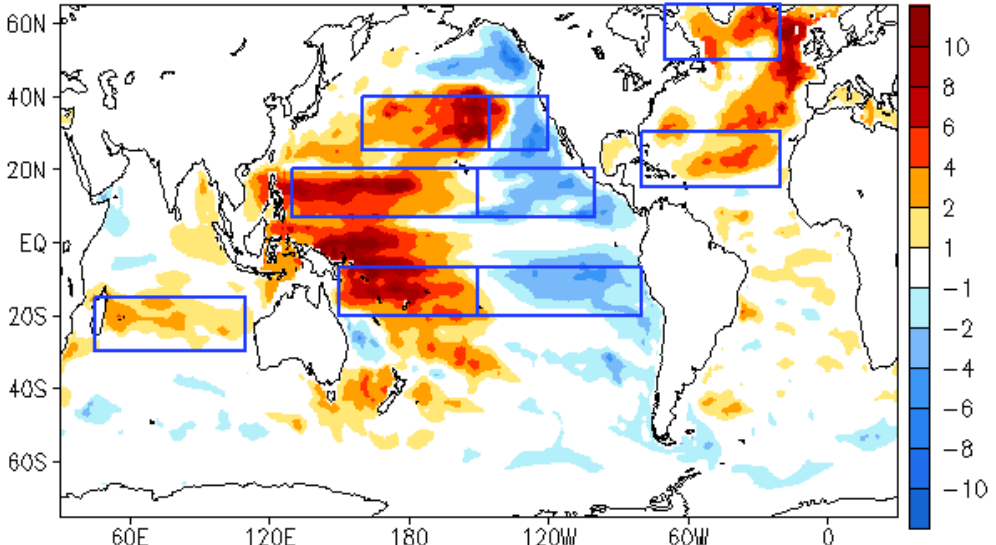
- EN3
- NODC
- GODAS
- ECMWF
- JMA
- CFSR
- GFDL
- GMAO
- MERCATOR
- BOM

# Linear Trend in 1993-2009

(a) Mean

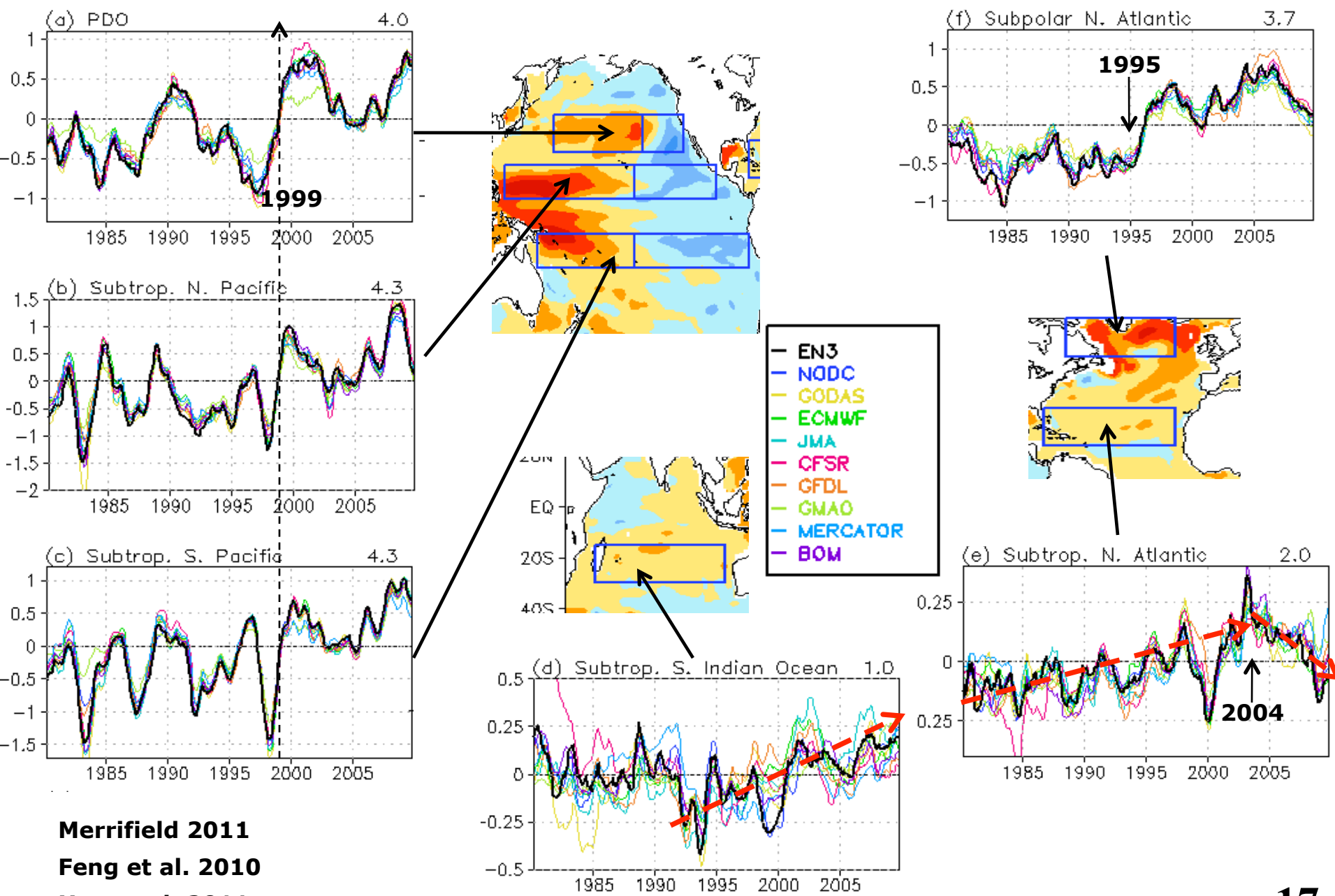


(b) Mean/Spread





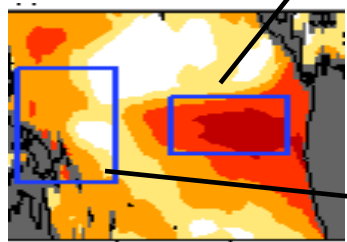
# HC300 Indices for Multi-decadal Variability



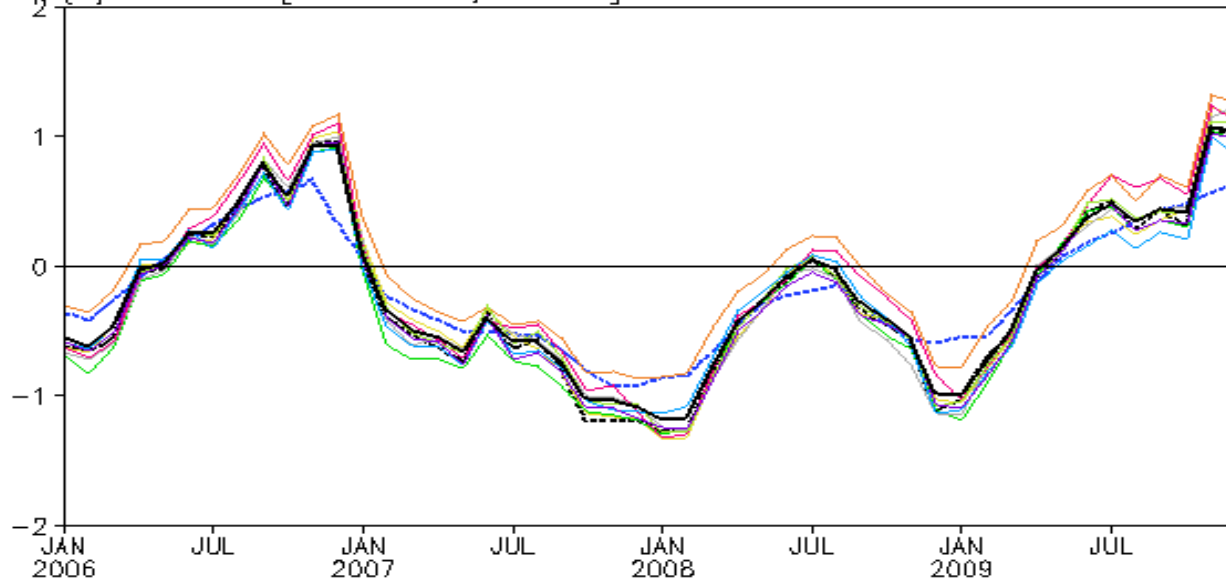
Merrifield 2011  
 Feng et al. 2010  
 Han et al. 2011

**GSOP-GODAE  
OceanView  
Calls for Near  
Real-Time  
HC300 Indices**

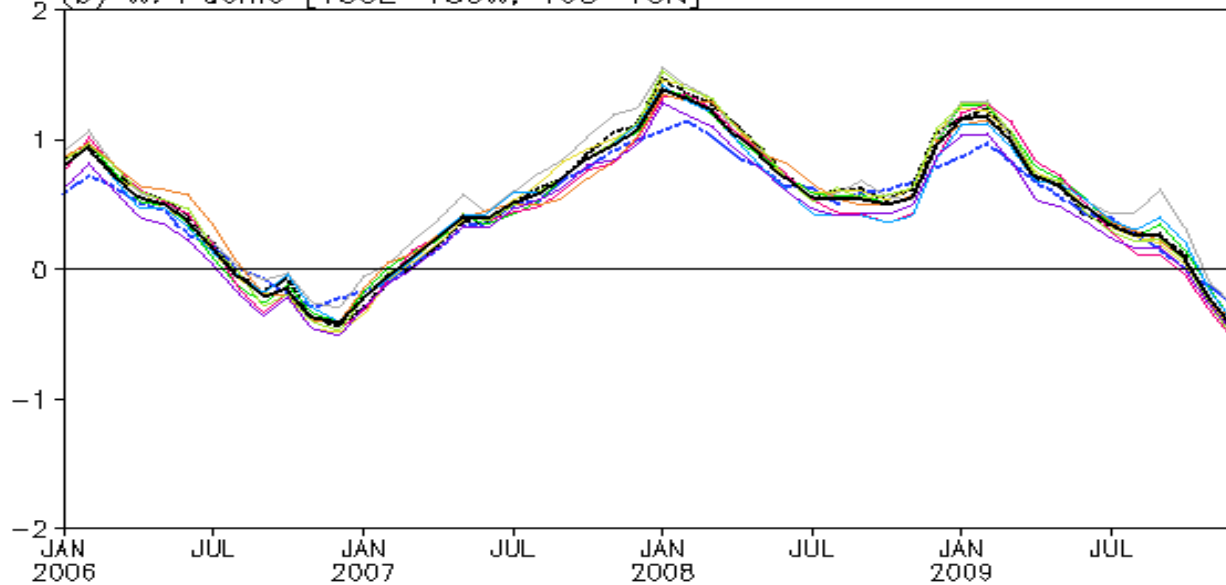
**ENSO**



(a) E.Pacific [150W-90W, 5S-5N]

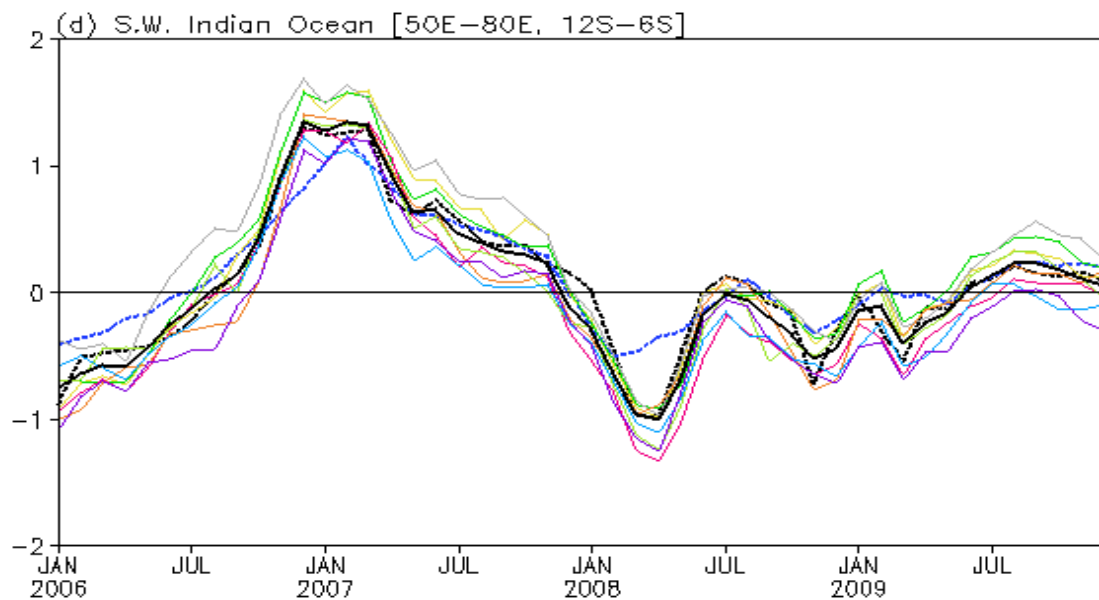
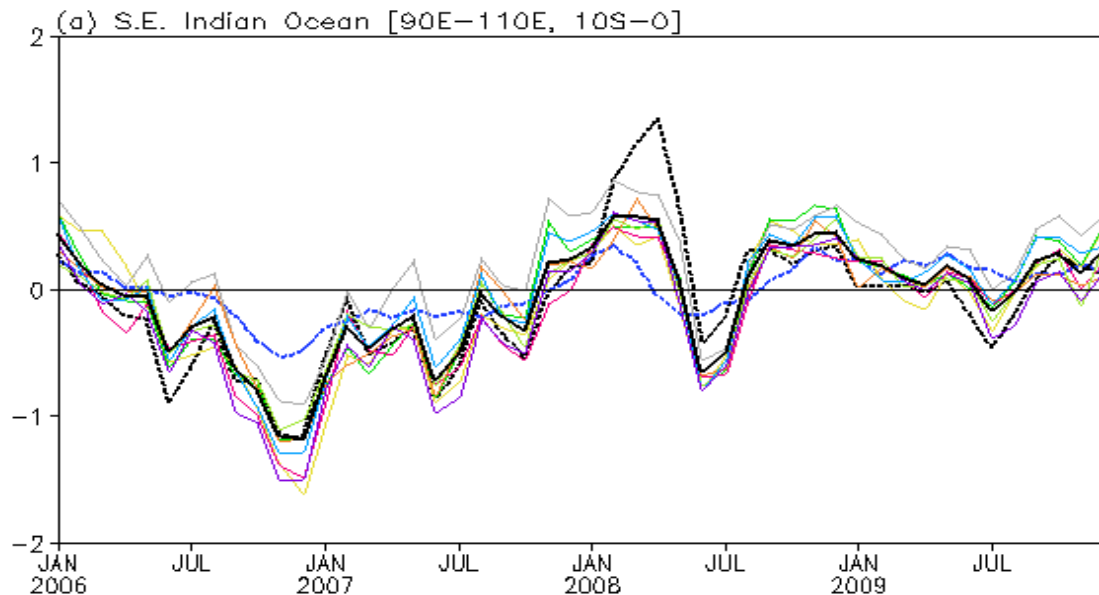
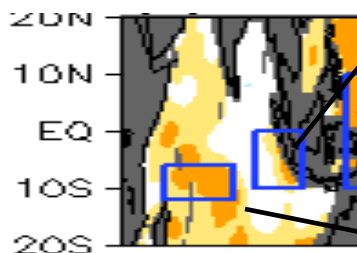


(b) W. Pacific [130E-180W, 10S-10N]



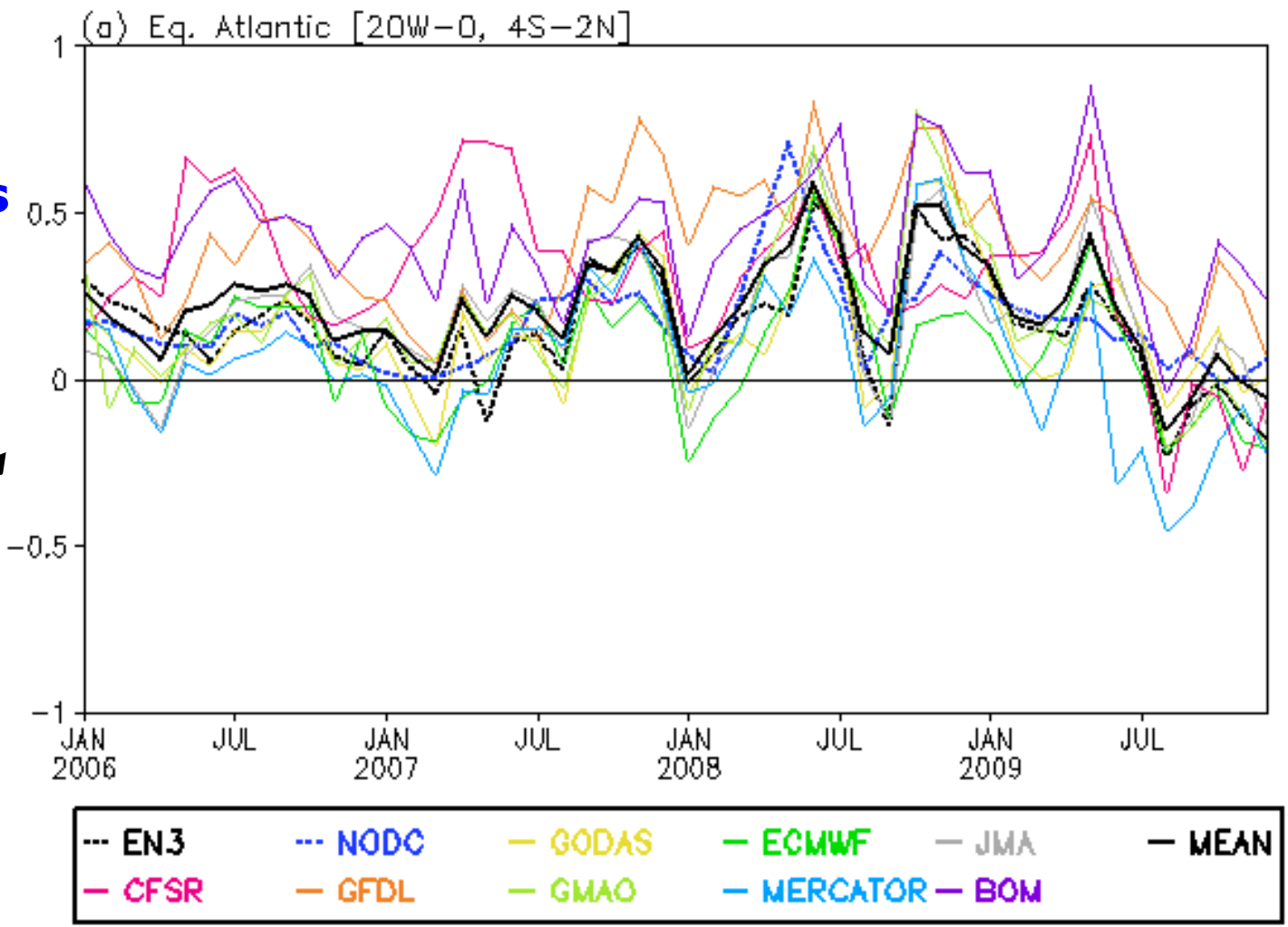
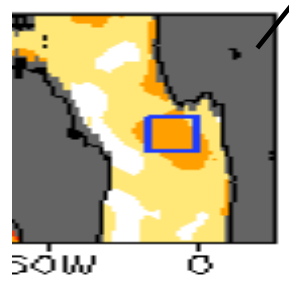
**GSOP-GODAE  
OceanView  
Calls for Near  
Real-Time  
HC300 Indices**

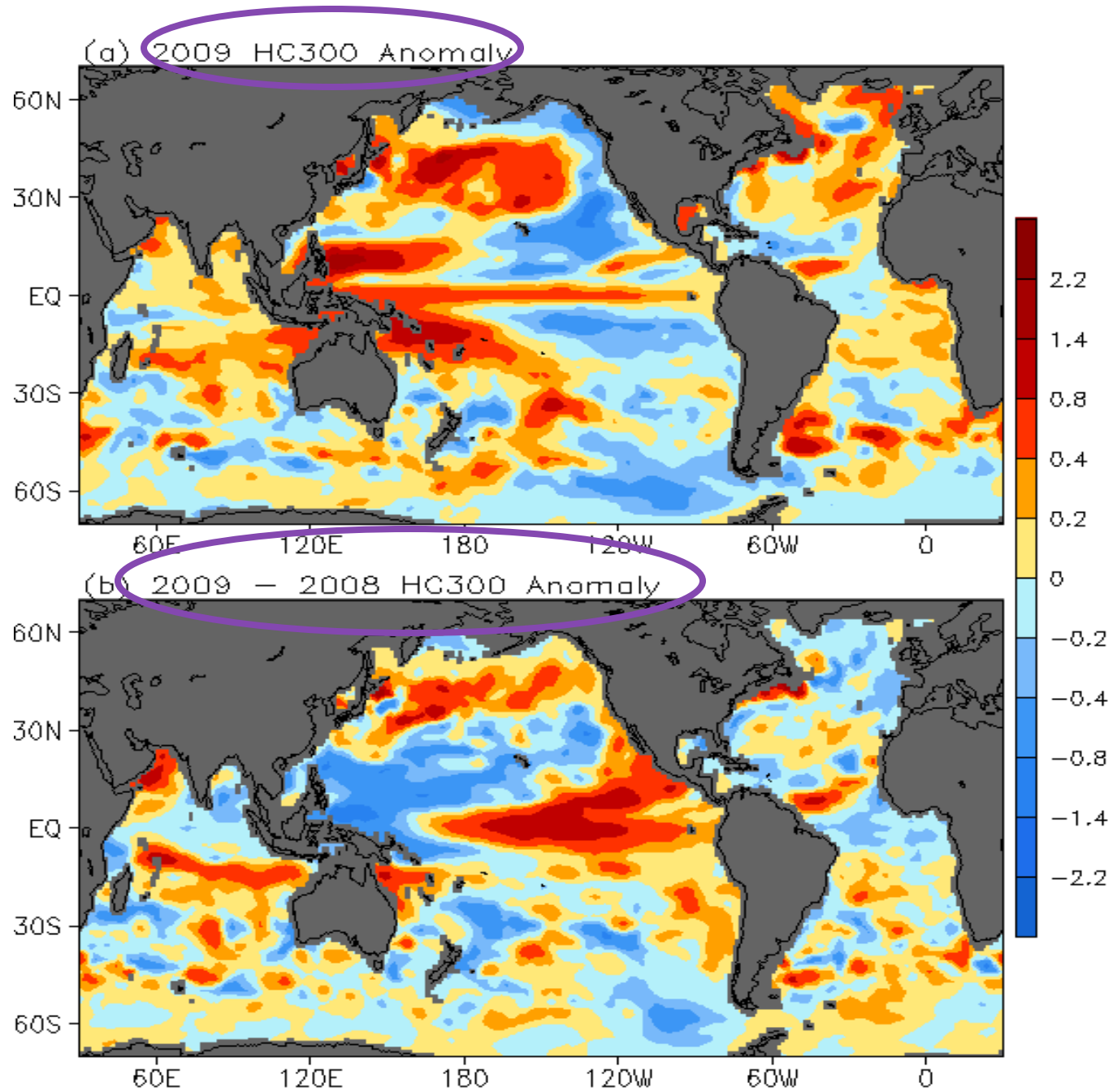
**IOD**



**GSOP-GODAE  
OceanView  
Calls for Near  
Real-Time  
HC300 Indices**

**Atlantic Nino**

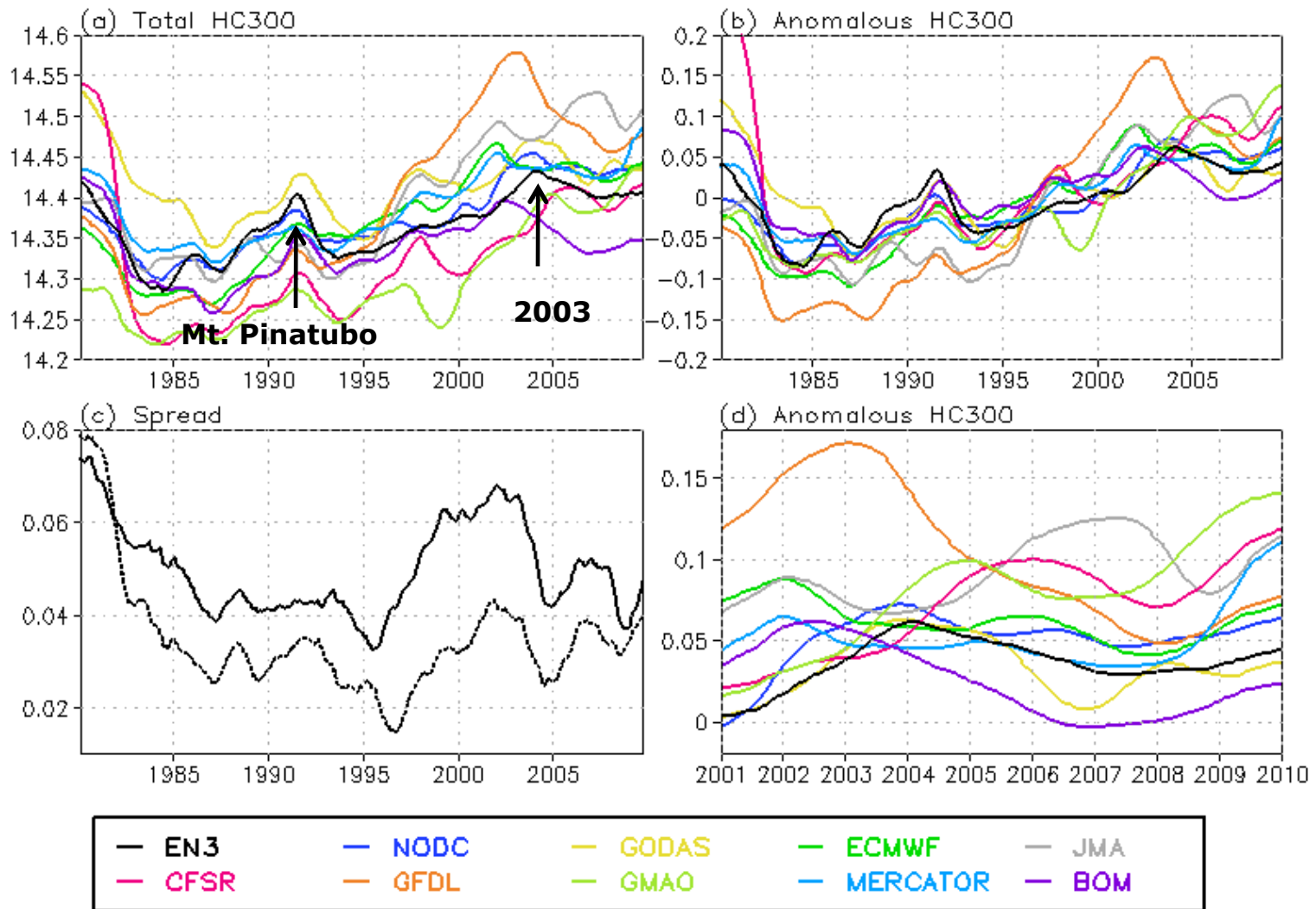




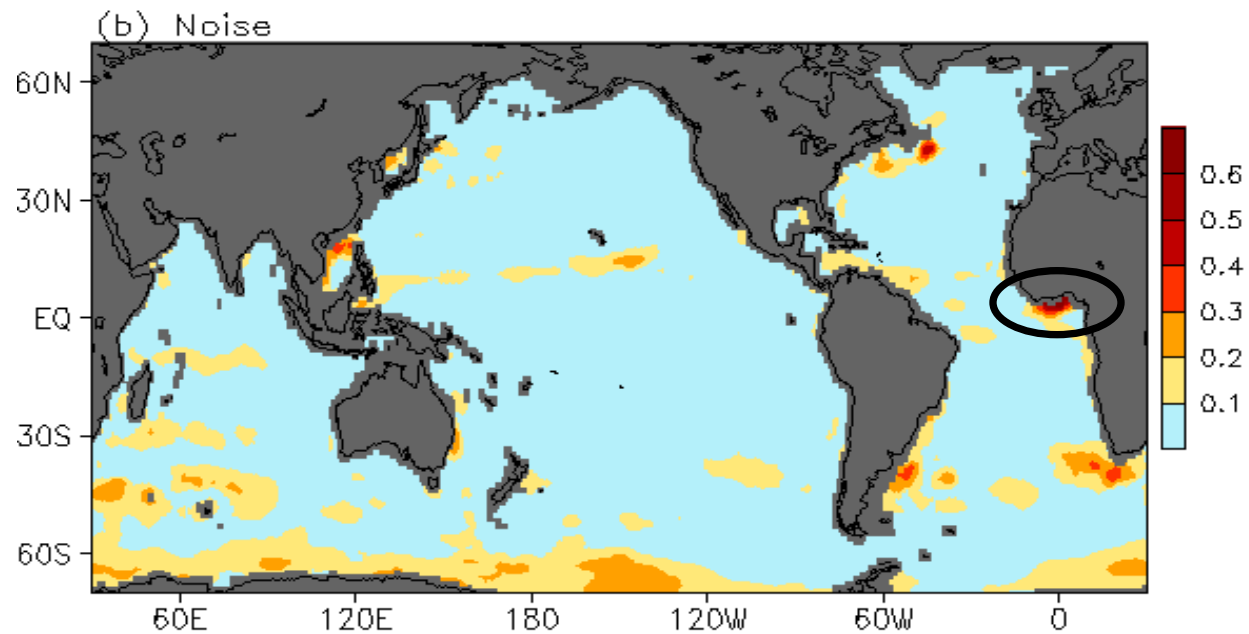
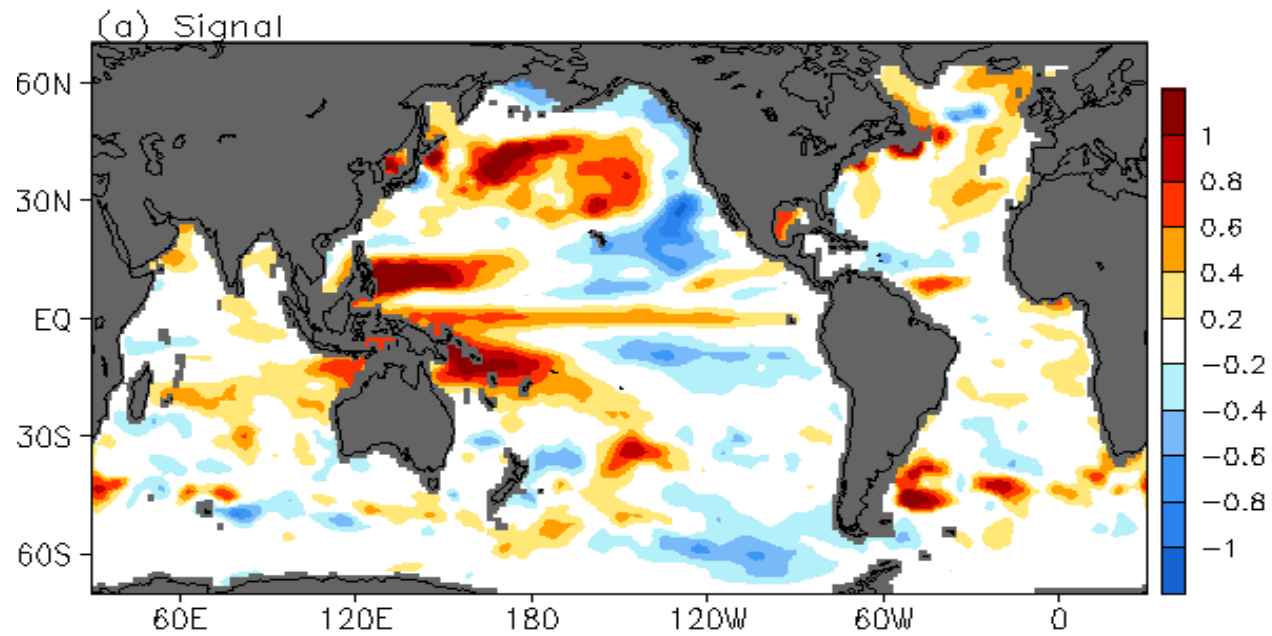
# Summary

- **Consistency among ORAs tends to increase with time, particularly in the tropical Pacific, the tropical Indian Ocean and extra-tropical southern oceans, due to constraints from tropical mooring arrays and Argo floats.**
- **HC300 anomalies (HC300a) associated with ENSO are highly consistent among ORAs; HC300a associated with Indian Ocean Dipole (IOD) are moderately consistent, and model-based analyses are superior to in situ-based analyses in the eastern pole of the IOD; HC300a associated with the Atlantic Nino has considerable uncertainties among ORAs, which are comparable to signals.**
- **An ensemble of operational ocean reanalyses provide a tool to monitor **signals** and **uncertainties** in upper ocean heat content in **real time**.**

# Mean HC300 and HC300 Anomaly in 70°S-70°N

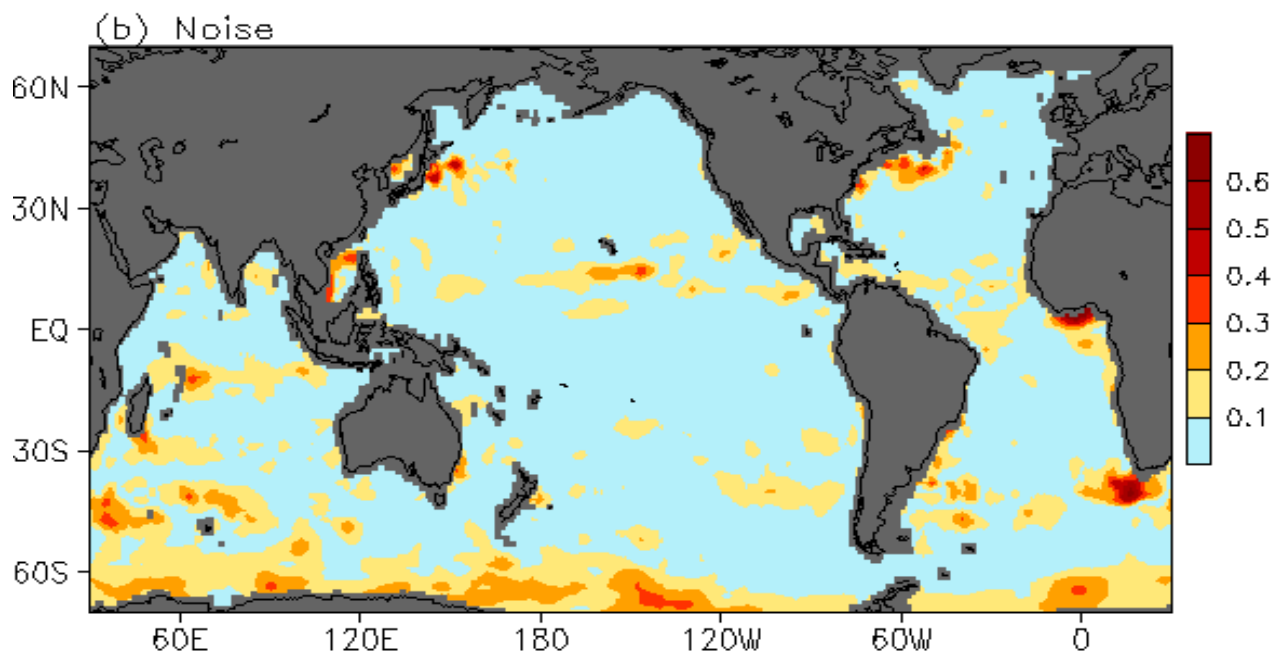
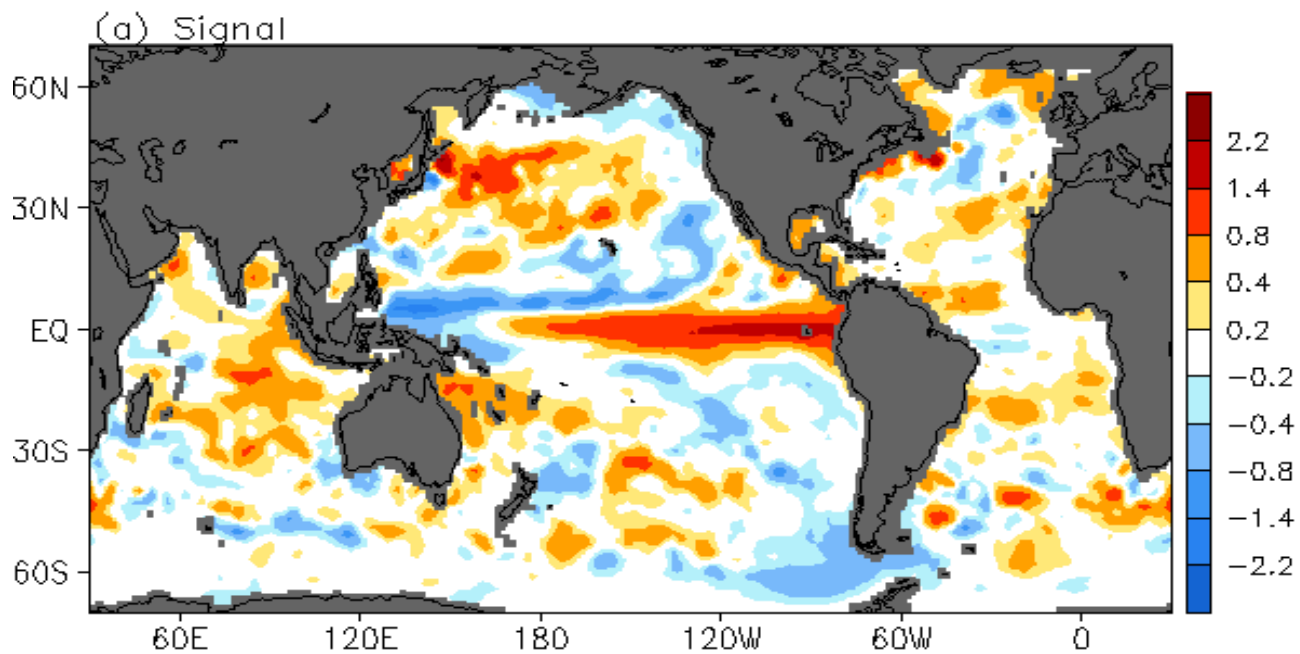


# HC300 Anomaly in 2009 (degree)

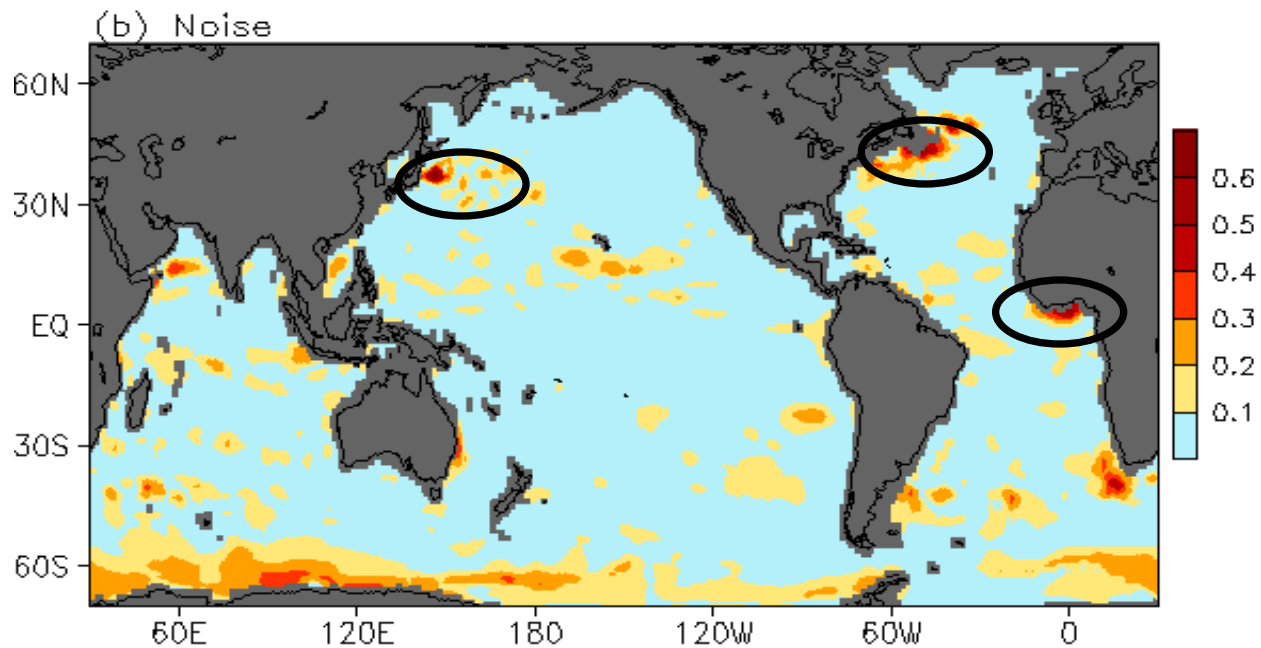
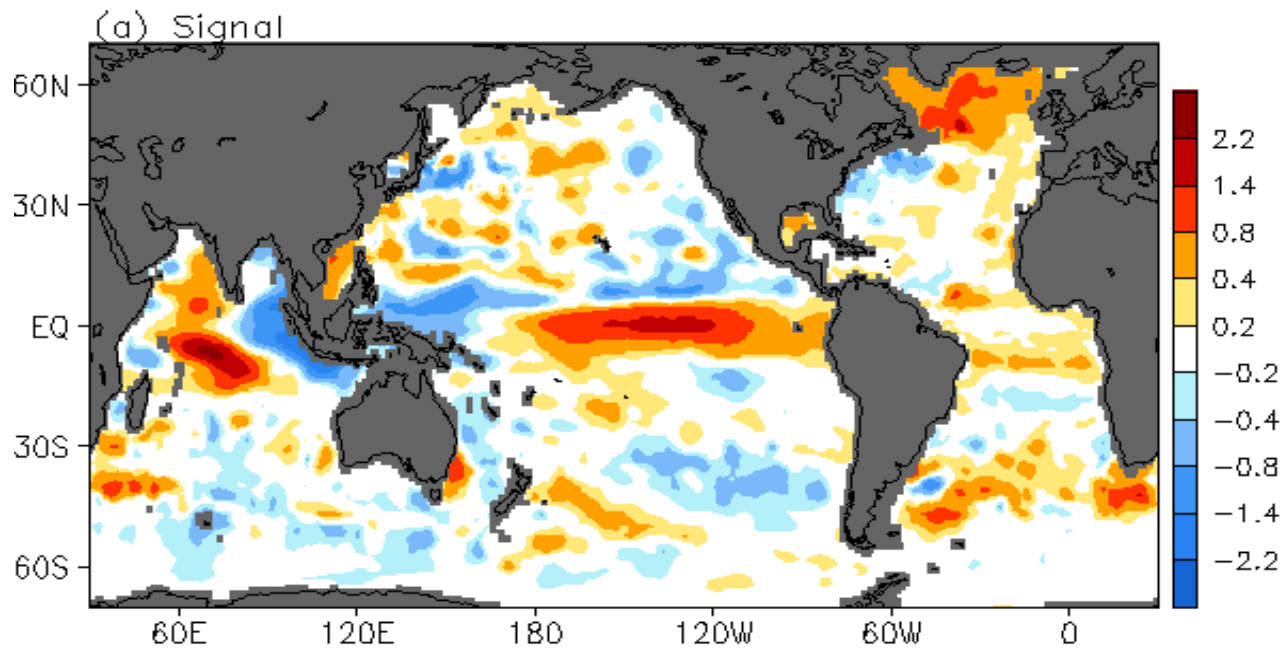




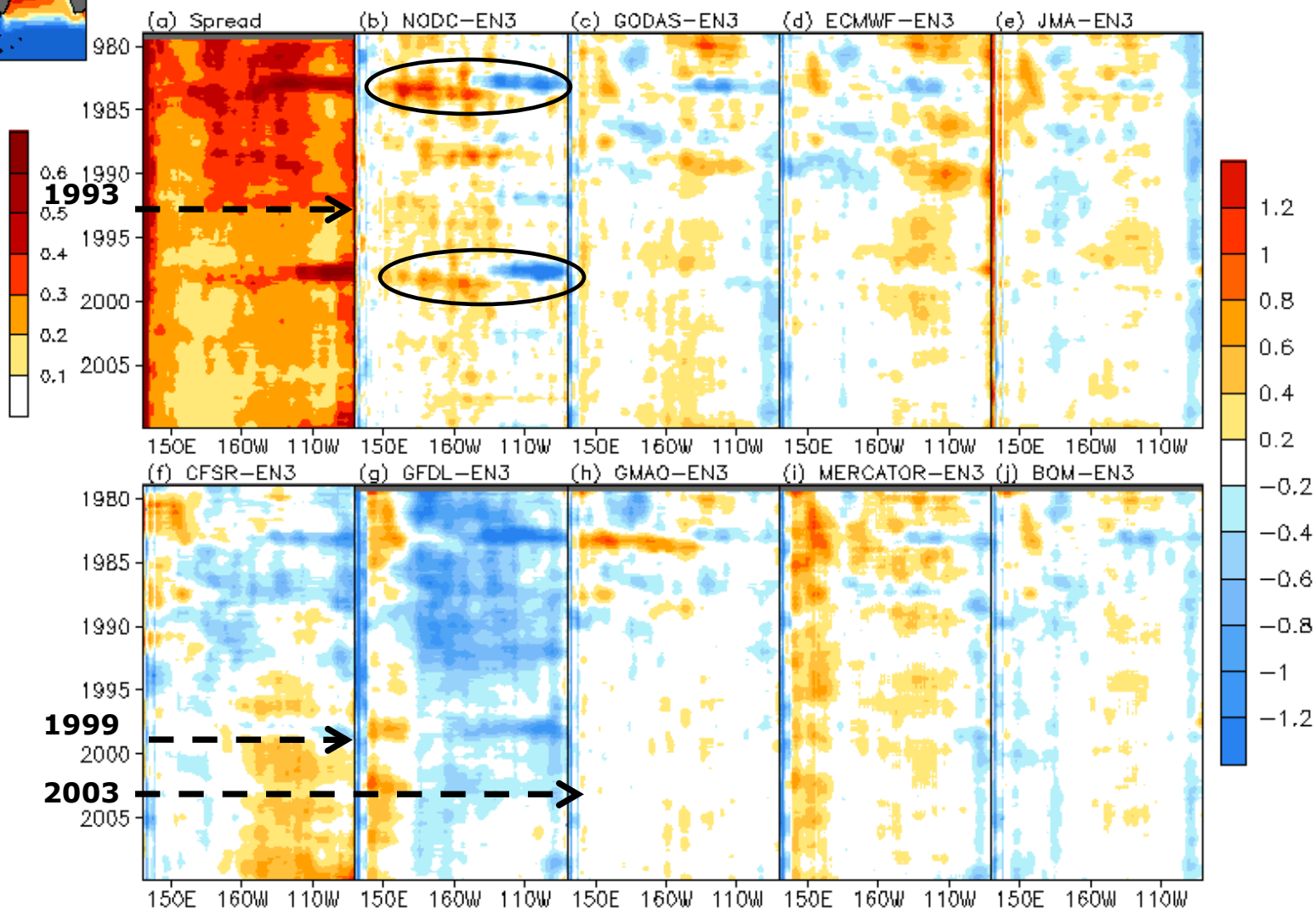
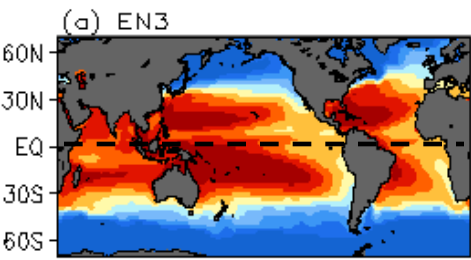
# HC300 Anomaly in Dec 2009 (degree)



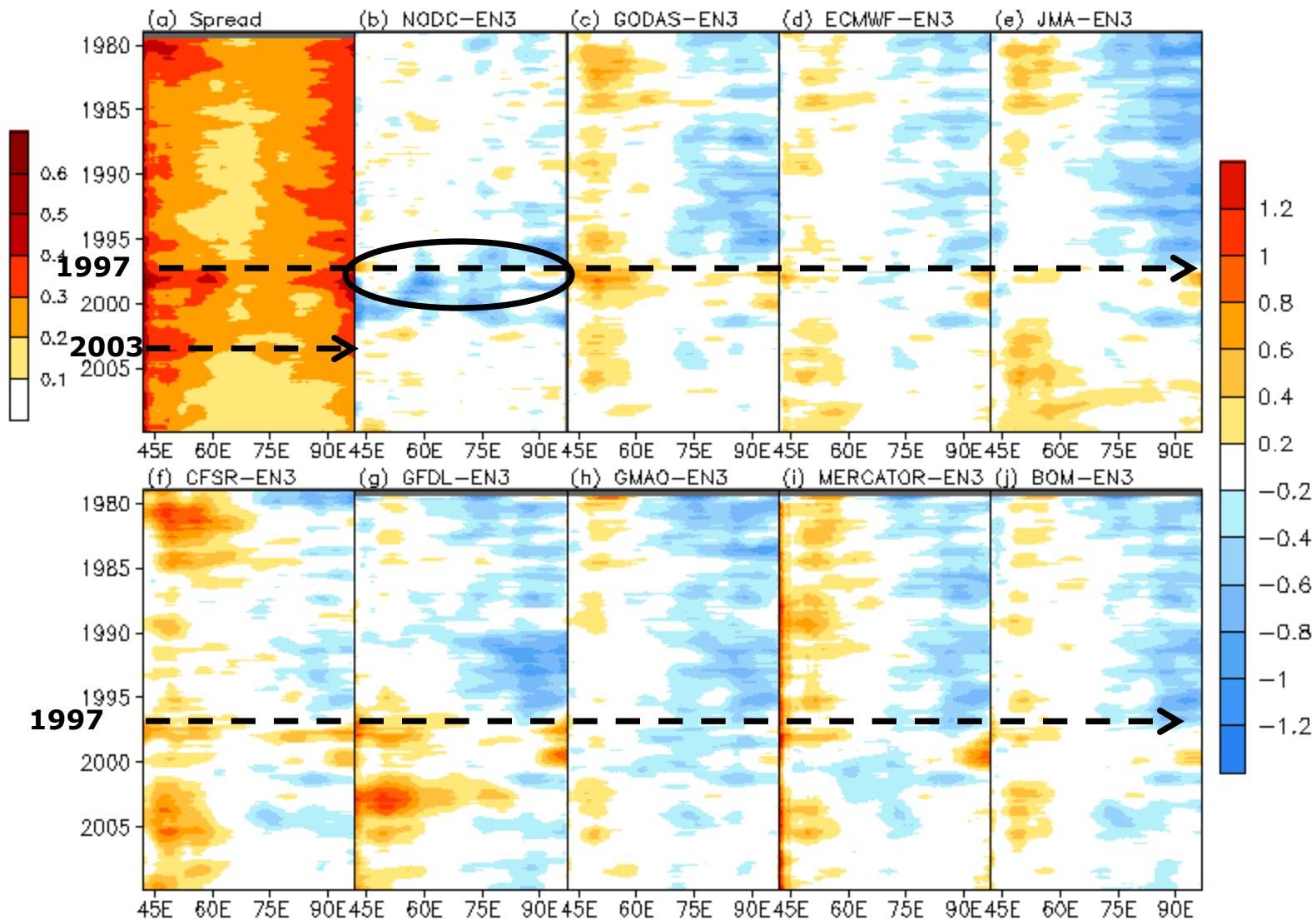
# HC300 Anomaly in Nov 2006 (degree)



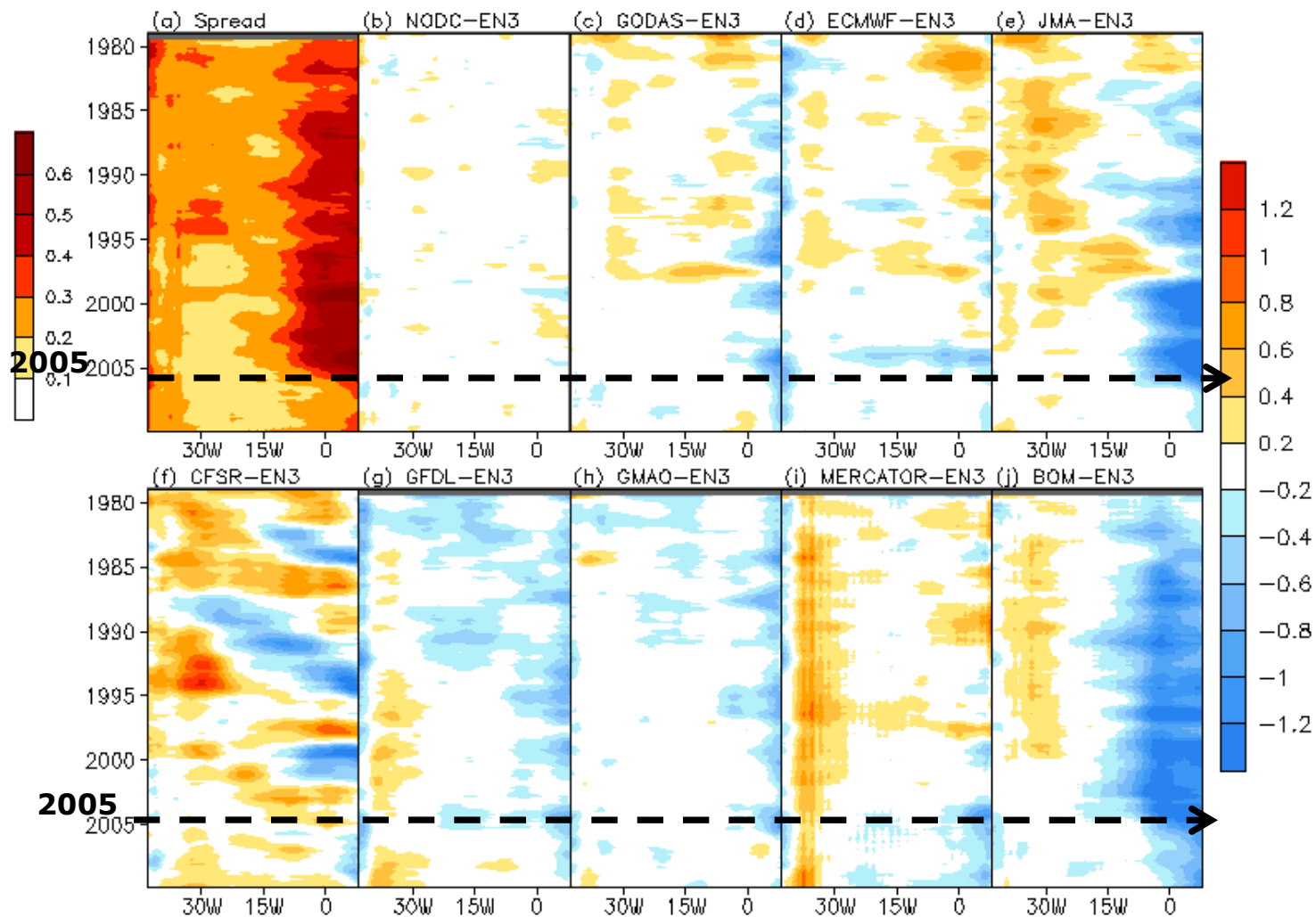
# HC300 in Equatorial Pacific (2°S-2°N)



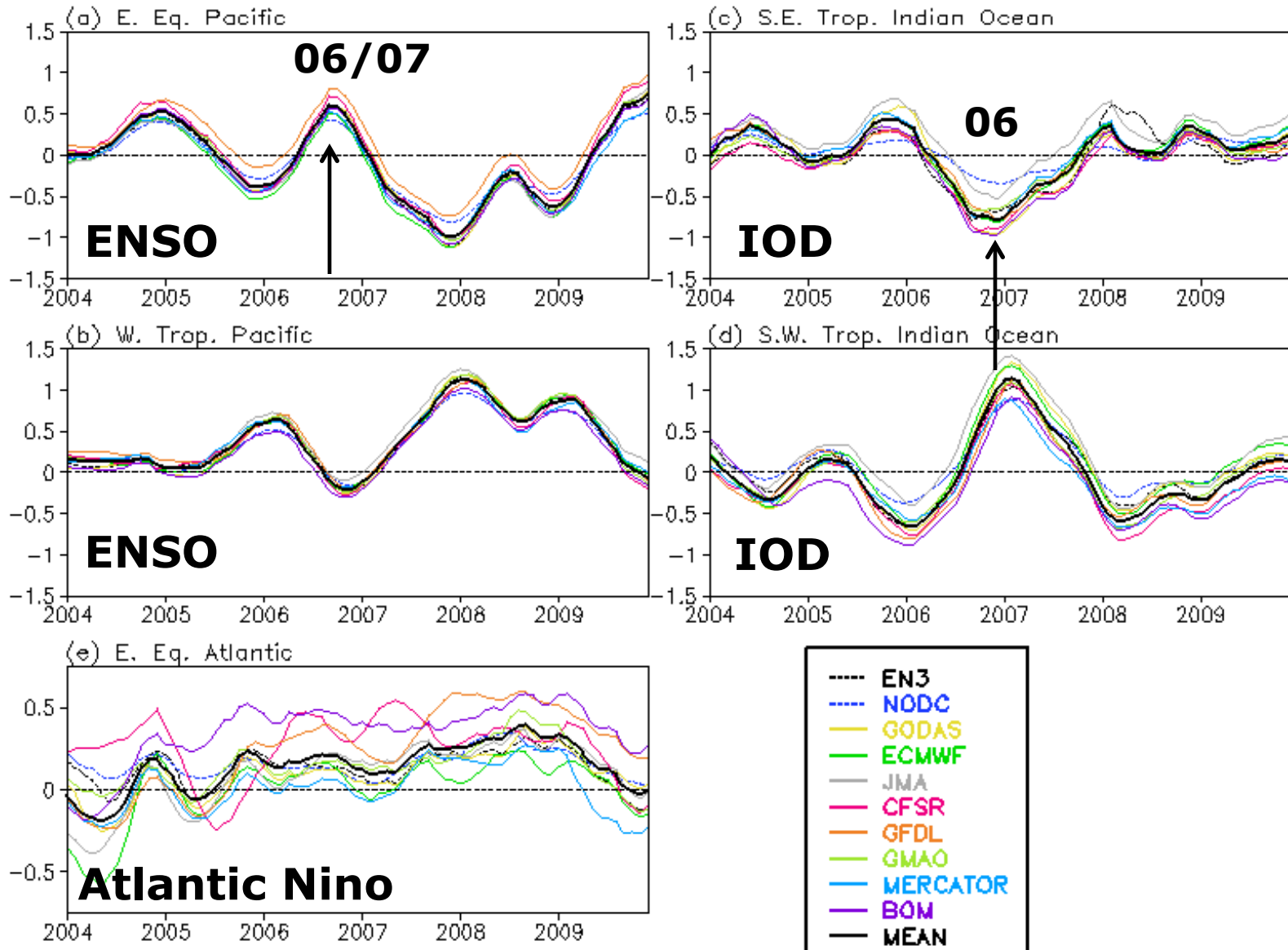
# HC300 in Equatorial Indian Ocean (2°S-2°N)



# HC300 in Equatorial Atlantic (2°S-2°N)



# Prospect for Operational HC300 Indices (need to extend in real time)



# Prospect for Operational HC300 Indices (need to extend in real time)

