Global Upper Ocean Heat and Freshwater Contents and Climate Variability

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24rd Conference on Climate Variability and Change
American Meteorological Society
23-27 January 2012

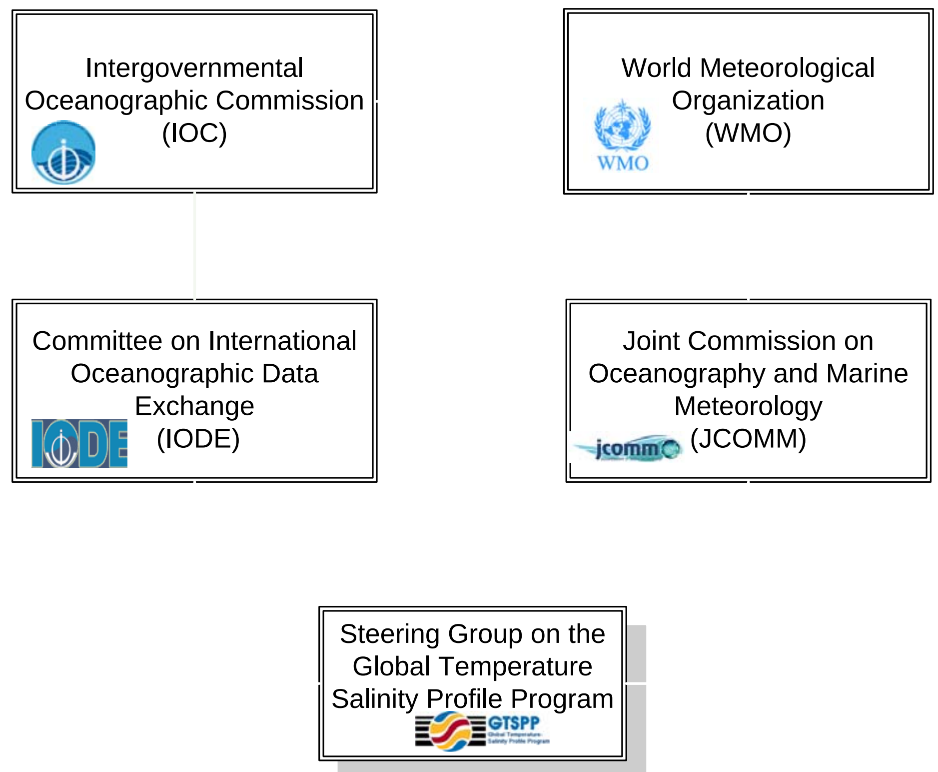
Outline

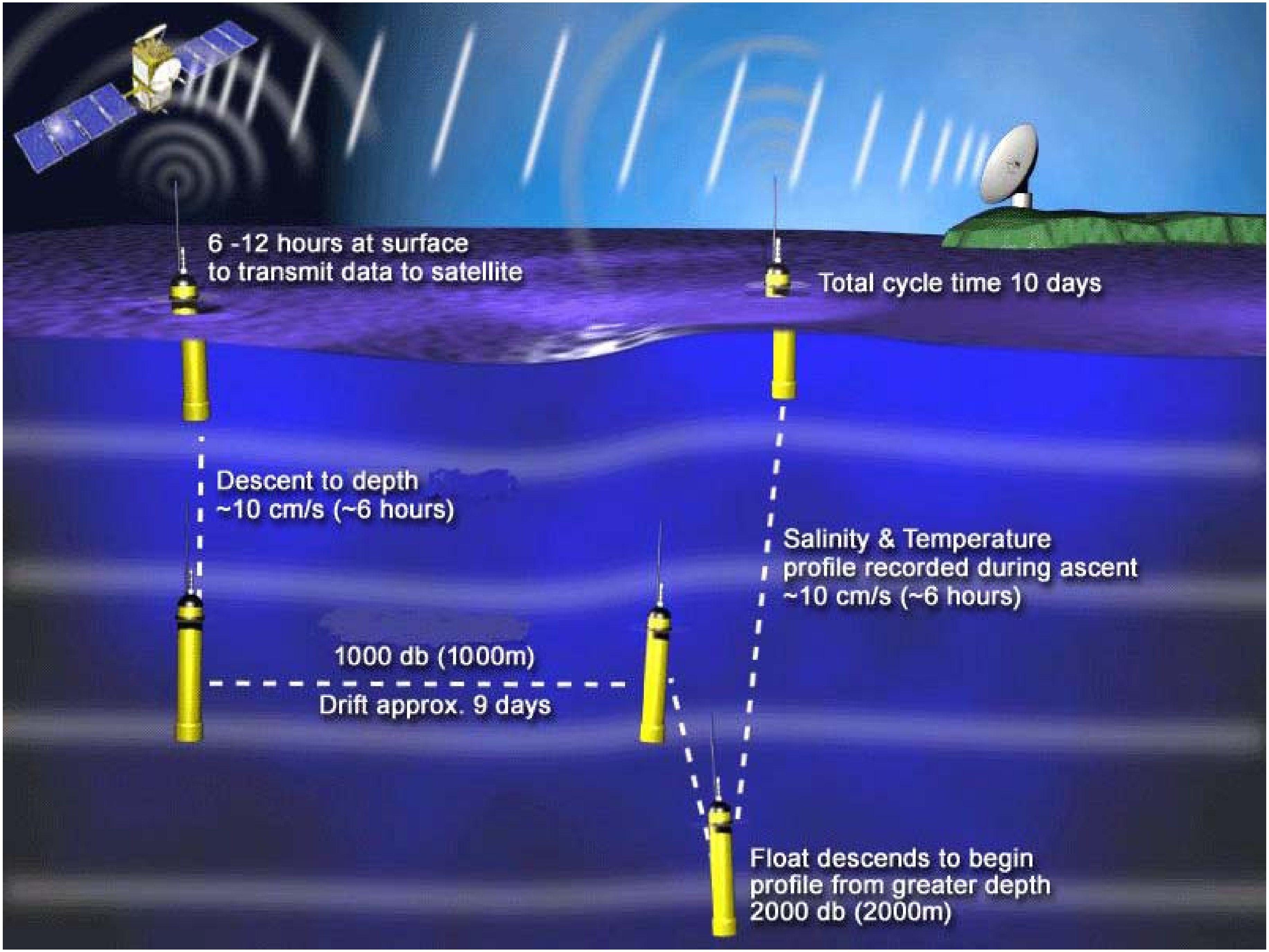
- (1) New Discoveries in Short-term Climate Variability
- (2) Data Analysis: (T, S) Profiles → Synoptic Gridded Data with Monthly Increment
- (3) Synoptic Upper Ocean (0-300 m) Heat Content
- (4) Global Tripole → Canonical El Nino, El Nino Modoki, Indian Ocean Dipole, …

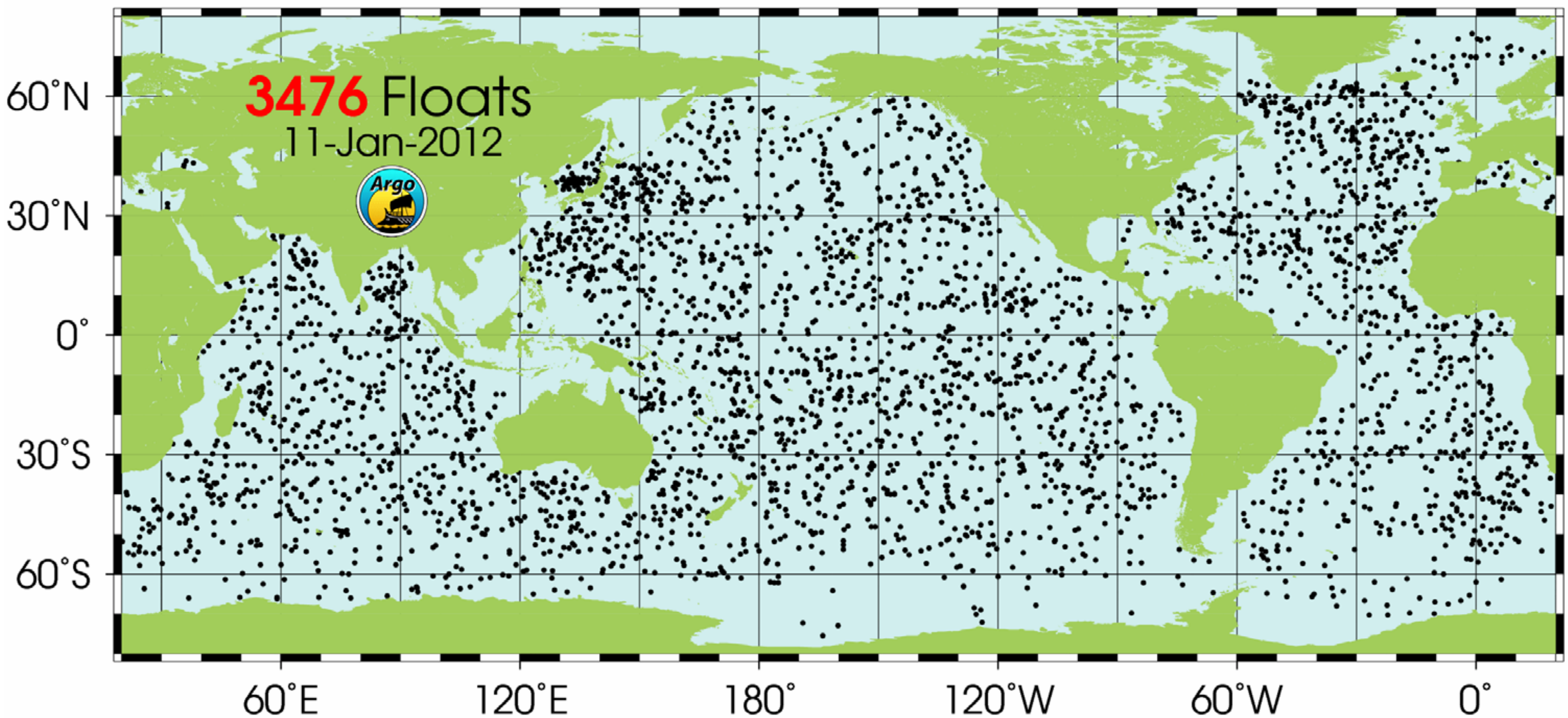
GTSPP

GTSPP = Global Temperature Salinity Profile Program

- GTSPP is a joint WMO-IOC program designed to provide improved access to the highest resolution, highest quality data as quickly as possible.
- GTSPP began as an official IODE pilot project in 1989.
- It went into operation in November 1990.




6 -12 hours at surface
to transmit data to satellite
Total cycle time 10 days
Descent to depth
~10 cm/s (~6 hours)
Salinity & Temperature
profile recorded during ascent
~10 cm/s (~6 hours)
1000 db (1000m)
Drift approx. 9 days
Float descends to begin
profile from greater depth
2000 db (2000m)


3476 Floats
11-Jan-2012
Argo
60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°

OSD
Spectral Representation

$$c(\mathbf{x}, z_k, t) = A_0(z_k, t) + \sum_{m=1}^{M} A_m(z_k, t)\ \Psi_m(\mathbf{x}, z_k),$$

Spatial Variability is represented by the basis functions

→ Vertical structure is preserved

Basis Functions (Closed Basin)

$$\triangle\Psi_k = -\lambda_k\Psi_k, \quad \Psi_k|_\Gamma = 0, \qquad k = 1, ..., \infty$$

$$\triangle\Phi_m = -\mu_m\Phi_m, \quad \frac{\partial\Phi_m}{\partial n}|_\Gamma = 0, \qquad m = 1, ..., \infty.$$

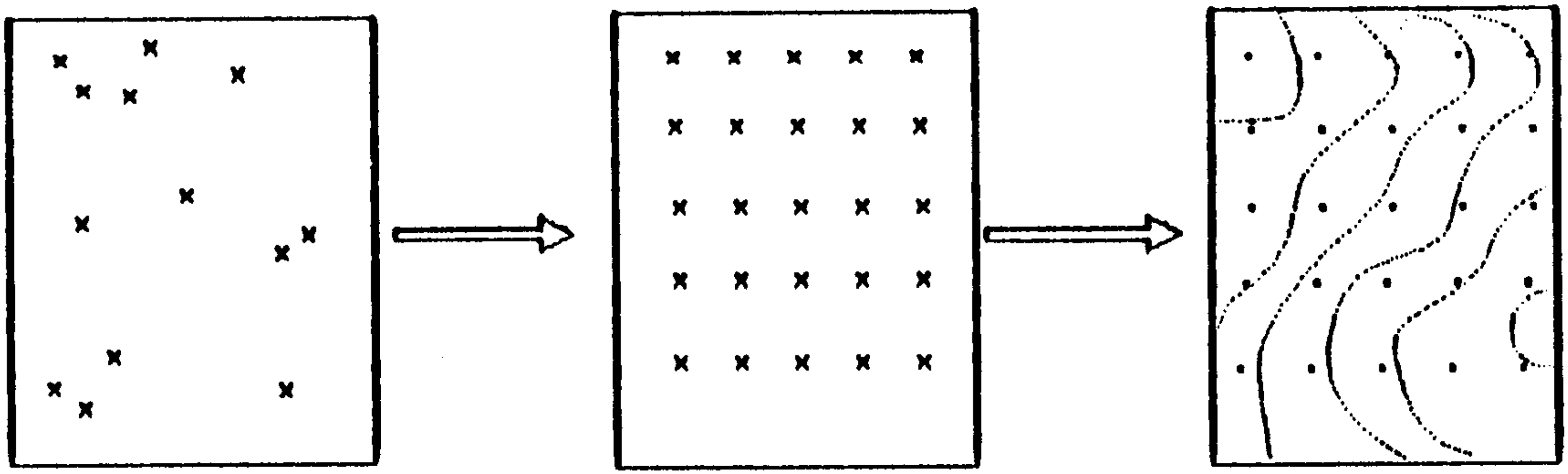
Data Analysis

Global Temperature and Salinity Profile Program (GTSPP)

↓ Optimal Spectral Decomposition (OSD)

Monthly Varying gridded (T,S) fields

GTSPP Data Analysis



Generalized Fourier Series Expansion

→Optimal Spectral Decomposition

→Monthly Varying 3D (T, S) Fields

Upper Ocean Heat Content

$$\mathrm{HC} = \int_{-h}^{0} \rho c T dz$$

Globally Integrated HC $\rightarrow \mathrm{GHC}(t) = \iint_{\Omega} HC(x, y, t)dxdy$

$$HC = HC_{\mathrm{mean}} + HC_{\mathrm{seasonal}} + HC_{\mathrm{anomaly}}$$

EOF Analysis → HC_{anomaly}

→Global Ocean Thermal Triple Modes

Inter-annual Variability

Chu (2011, Ocean Dynamics)

Freshwater Content (0 to –*h*)

$$\text{FWC} = \int_{-h}^{0} \left[1 - \frac{S(z)}{S_{ref}} \right] dz, \quad S_{ref} = 34.8 \text{ ppt}$$

Small *FWC*(*x*, *y*, *t*) → *high salinity (less fresh)*

Large *FWC*(*x*, *y*, *t*) → *low salinity (more fresh)*

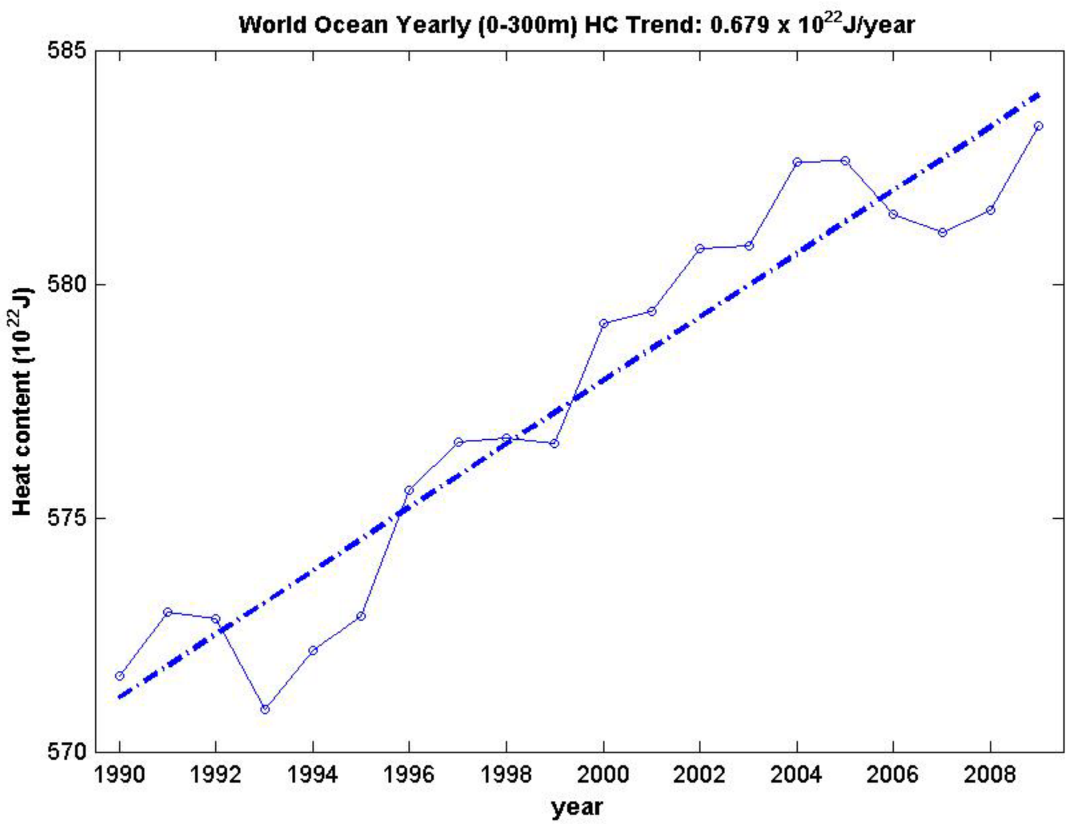
Analysis of Freshwater Content

Globally Integrated FWC $\rightarrow$ $\mathrm{GWFC}(t) = \iint_{\Omega} WFC(x, y, t)\,dxdy$

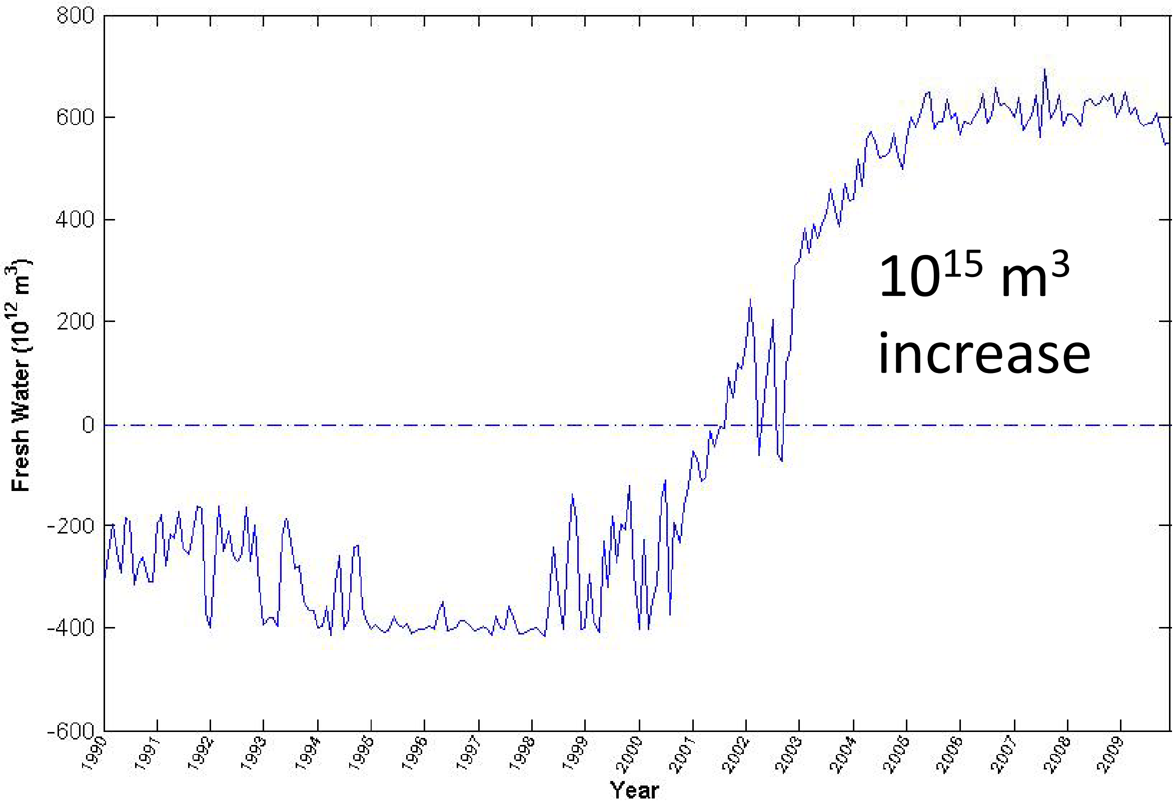
$$FWC(x, y, t) = FWC_{\mathrm{mean}} + FWC_{\mathrm{seasonal}} + FWC_{\mathrm{anomaly}}$$

EOF Analysis $\rightarrow FWC_{\mathrm{anomaly}}$

$GHC_{300}(t)$ → Increasing from 1990

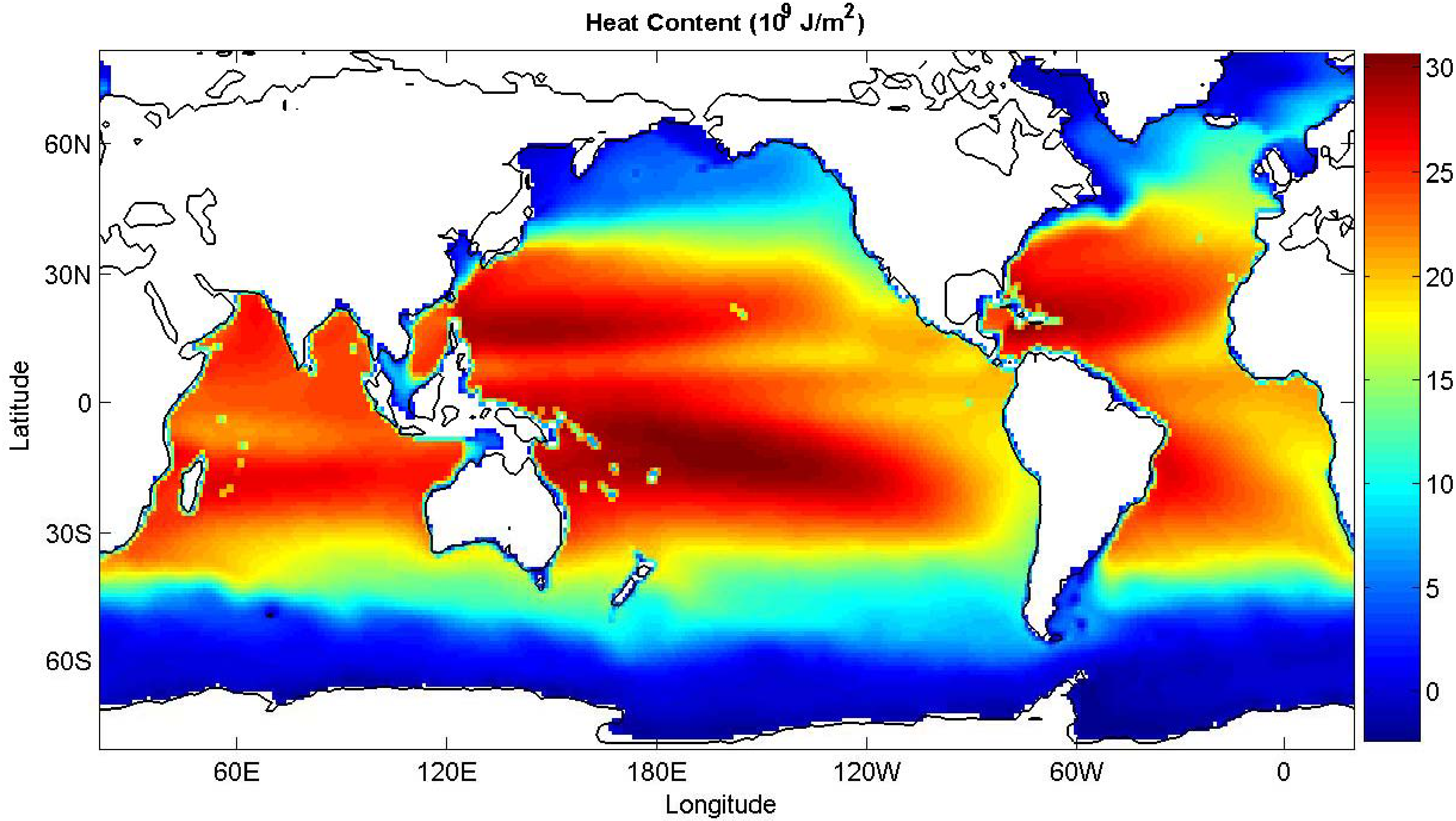


$GFWC_{300}(t) \rightarrow$ increasing from 2000



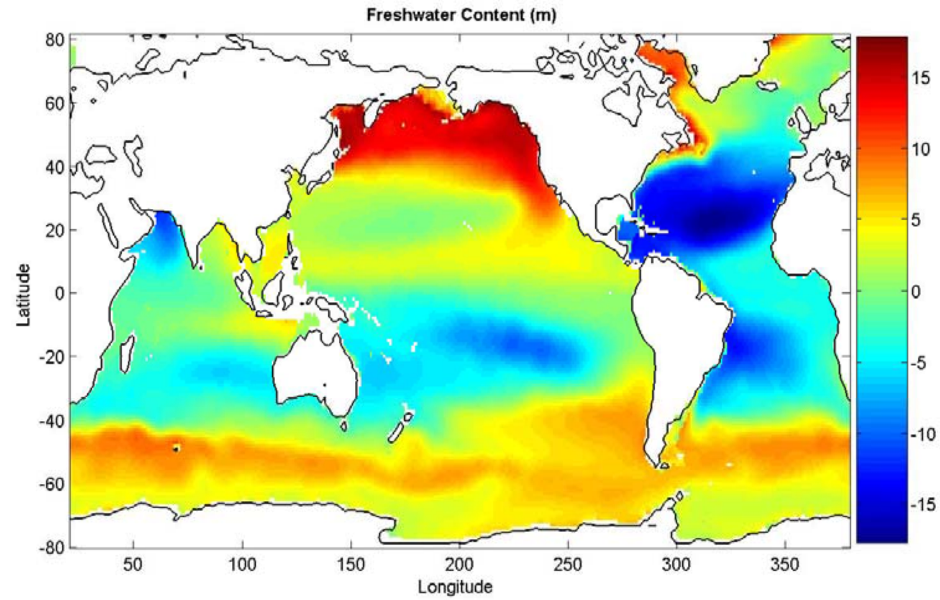
$GFWC_{300}$ increase from around $-4X10^{14}$ m^3 during 1999-2000 to near $6X10^{14}$ m^3 during 2000-2010

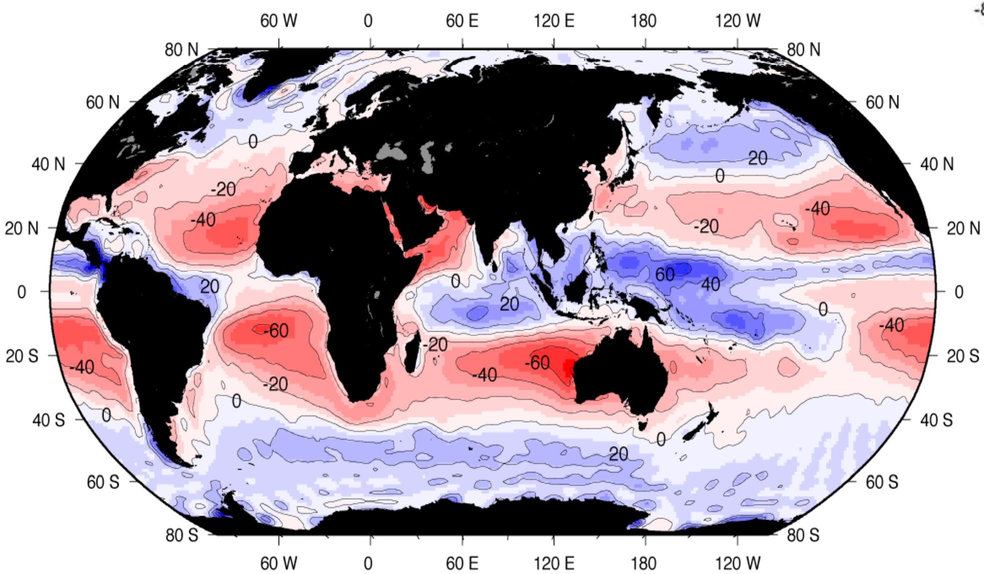
Upper Ocean (0-300 m) Mean Heat Content (J/m^2) (1990-2010)



FWC_{Mean} (0-300 m) ←→ (P – E) Climatology

FWC_{Mean} (0-300 m) from GTSPP (1990-2010) →

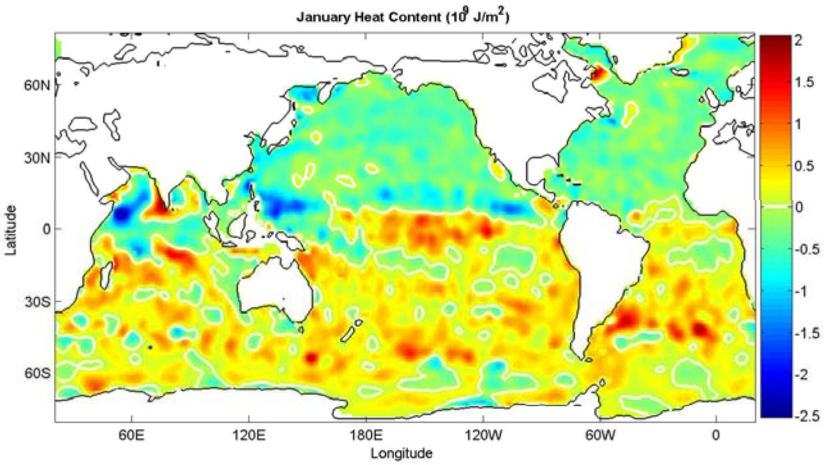




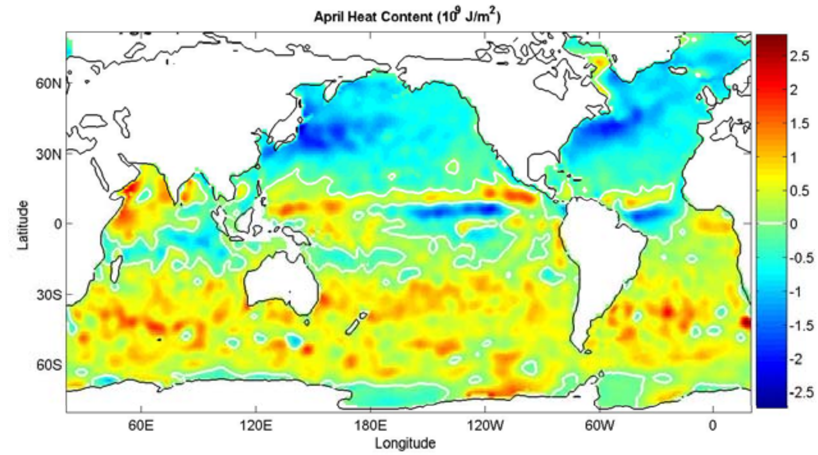
←NCEP Climatology P- E (cm/yr)

Seasonal Variability of Upper Ocean (0-300 m) Heat Content (J/m^2) (1990-2010)

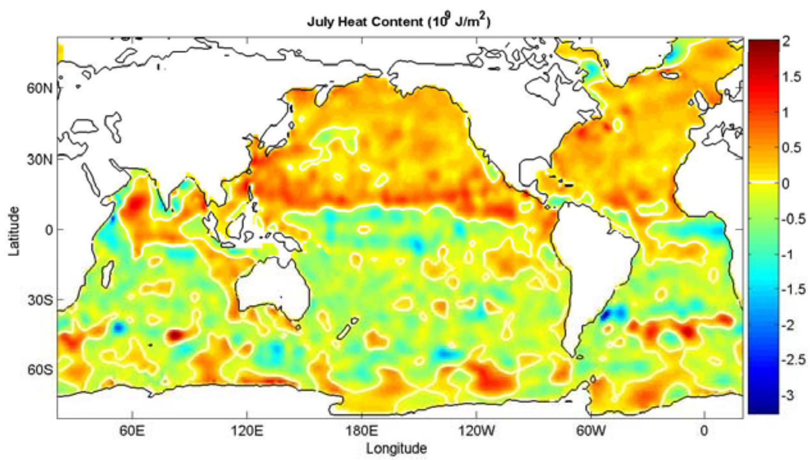
January



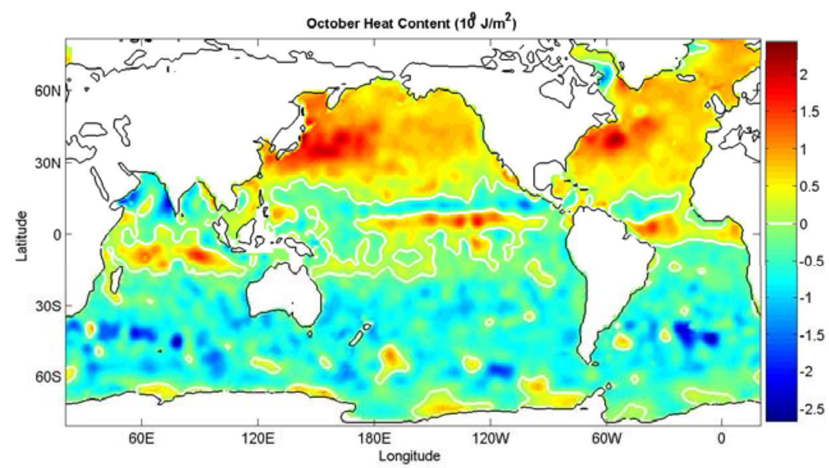
April



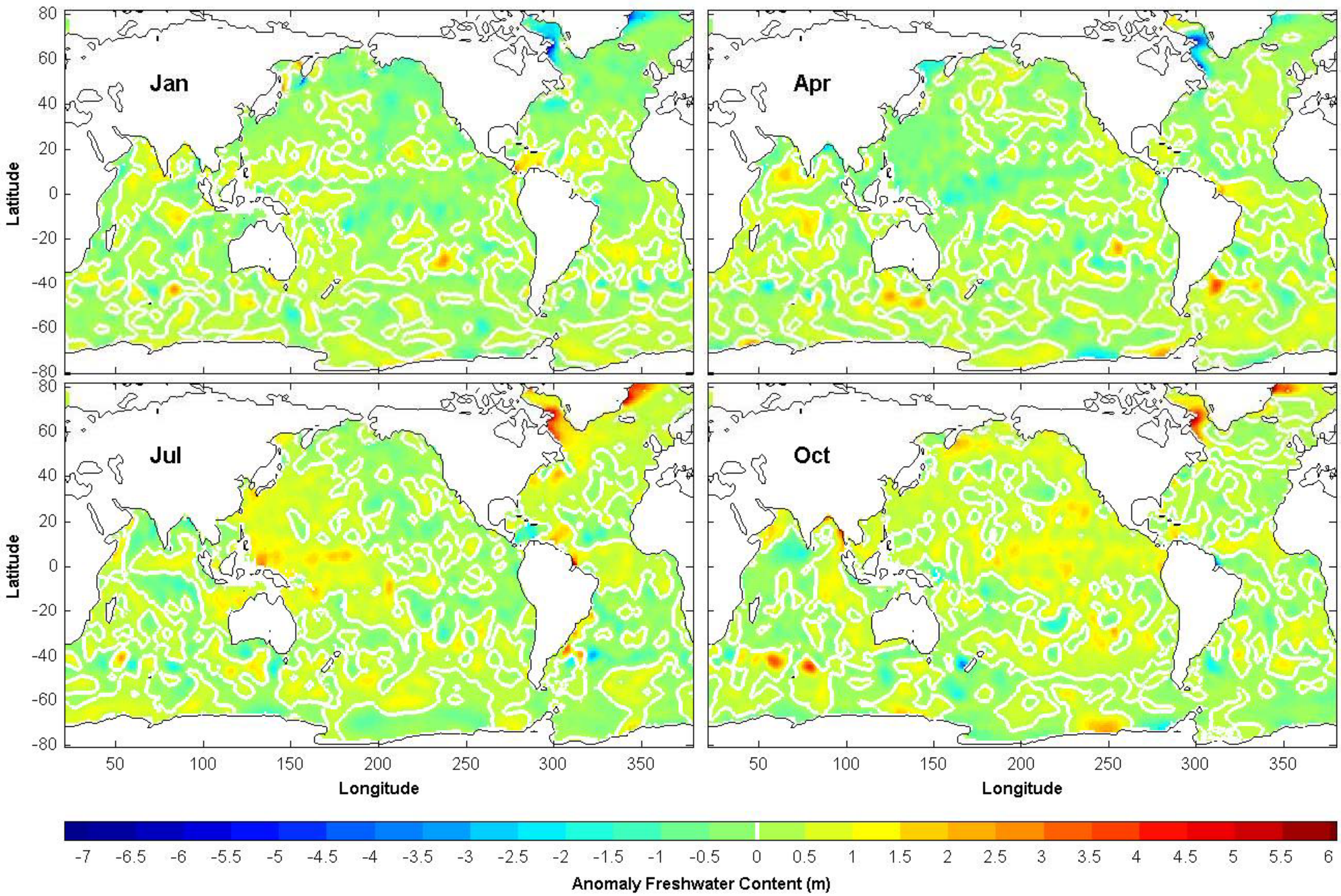
July



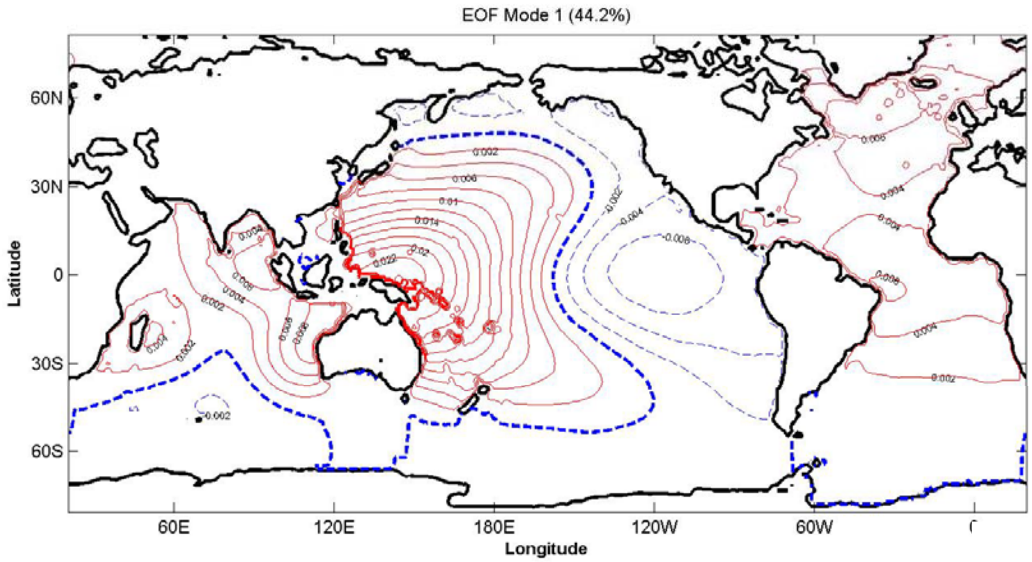
October



FWC$_{seasonal}$ (m) (0-300 m) (1990-2010)



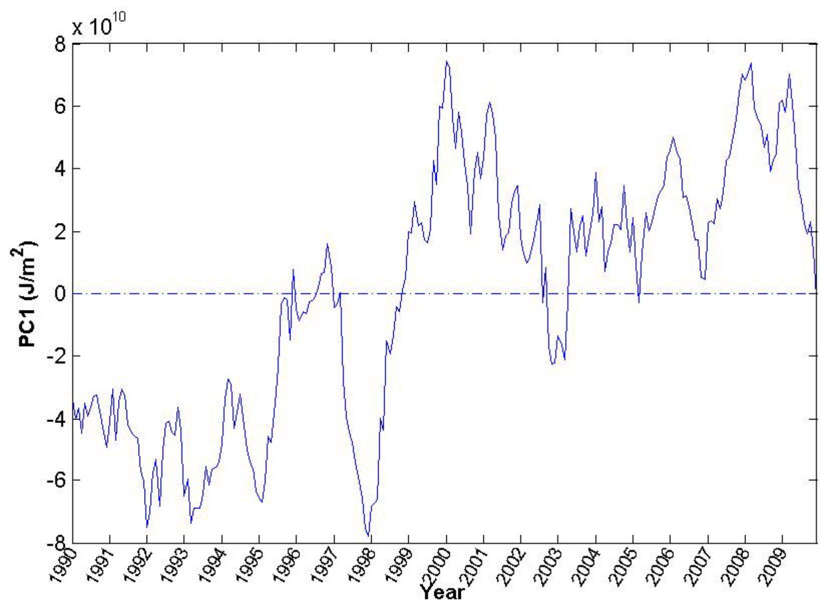
$HC_{anomaly}$ (0-300 m) → Global Thermal Triple (Chu 2011)



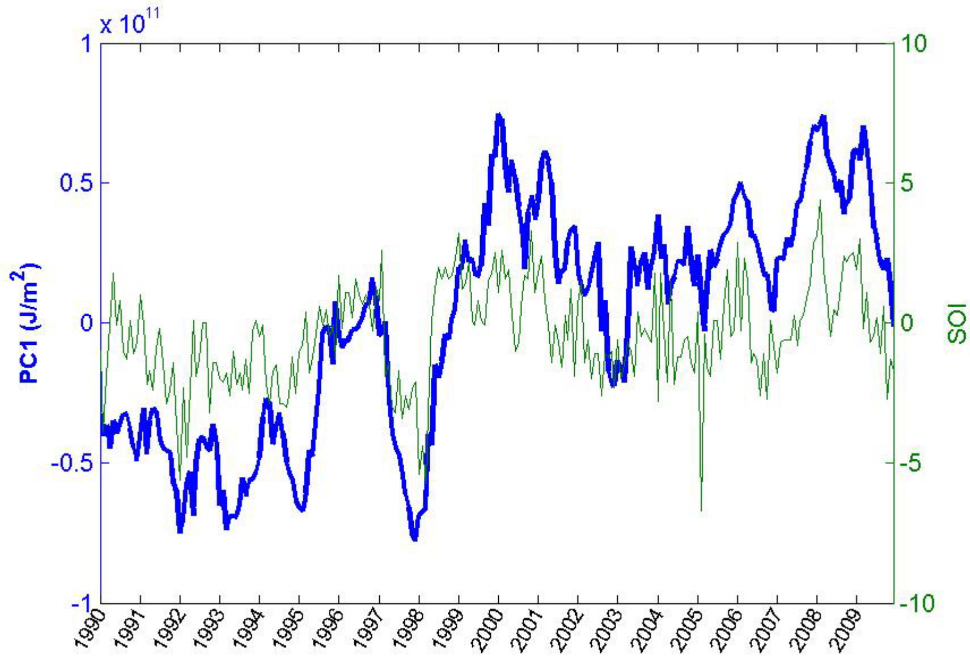
←EOF_1 (44.2%)

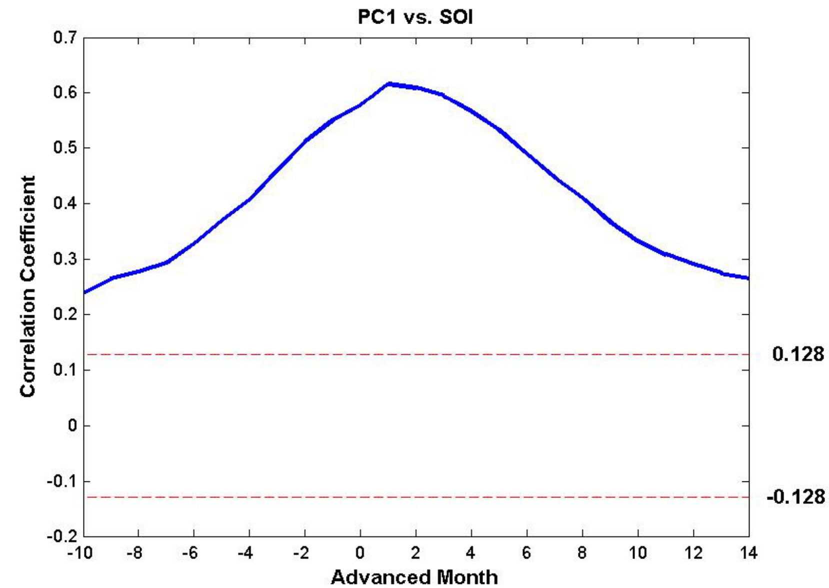
PC_1 →

Interannual Oscillation



Lag Correlation between PC_1 and SOI

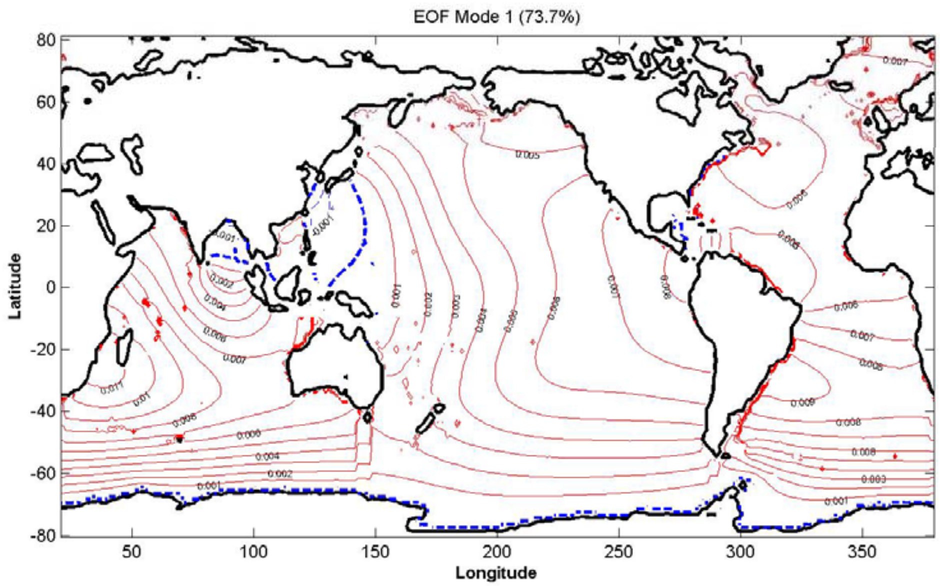




PC_1 advancing SOI

Negative SOI → El Nino

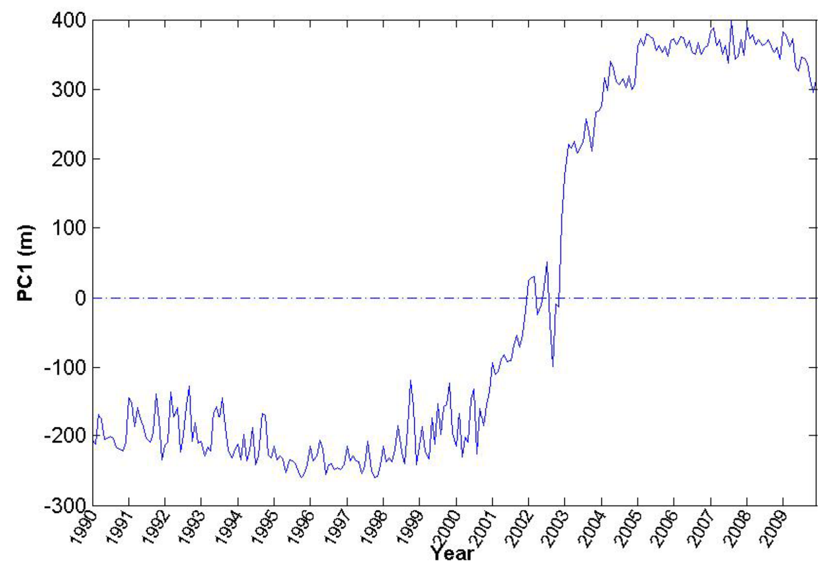
FWC$_{anomaly}$ (0-300 m) → Global Decadal Oscillation



←EOF_1 (73.7%)

Positive almost everywhere

PC_1 →
Negative before 2001
Positive after 2001



Conclusions

- (1) Global datasets for heat content and fresh water content have been established.
- (2) The data shows faster upper ocean warming in the recent two decades (1990-2010).
- (3) Upper ocean heat/fresh water content anomalies provide different global climate change signals:
  - Heat Content Anomaly → Interannual Variability
  - Freshwater Content Anomaly → Global Decadal Oscillation