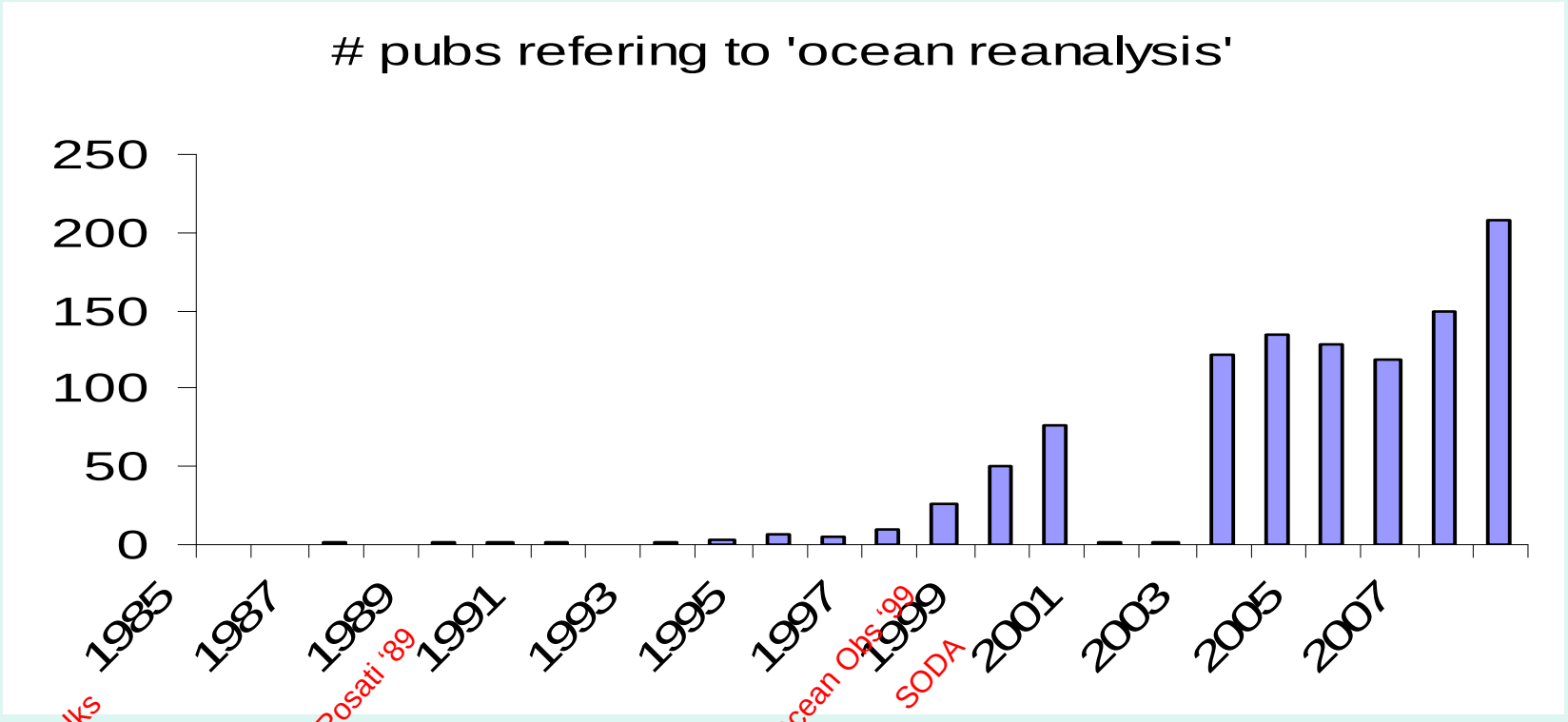
Ocean Reanalyses: Prospects for Climate Studies

James A. Carton *(University of Maryland)*

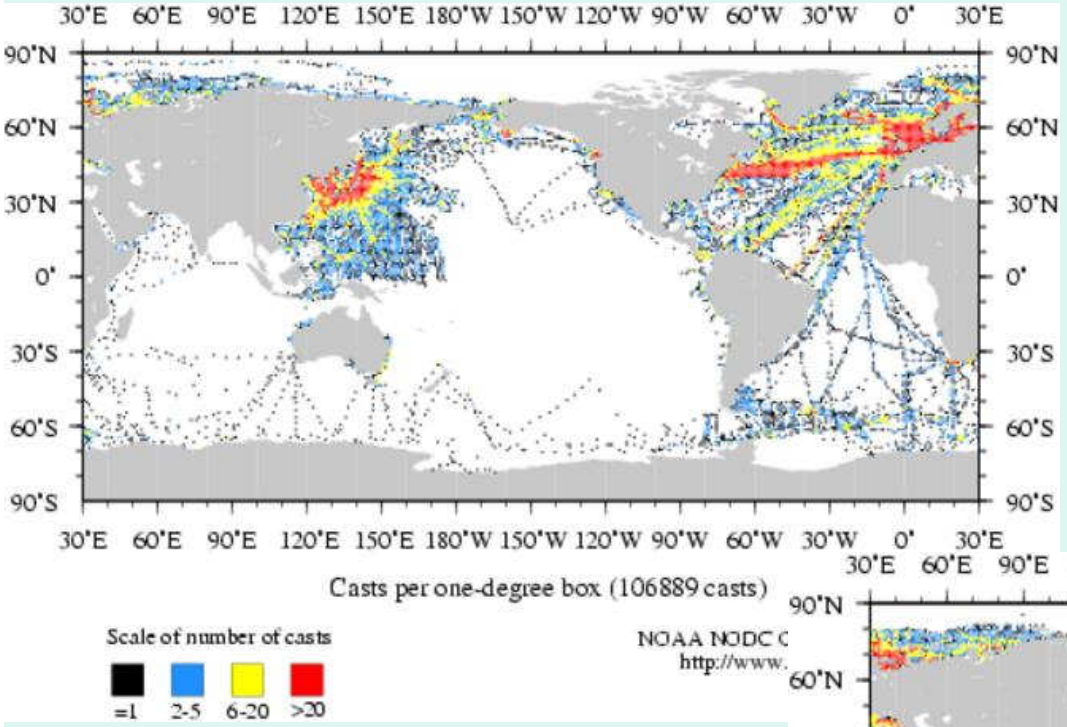
Thanks: Gennady Chepurin, Anthony Santorelli, *You-Soon Chang*



Some motivating questions

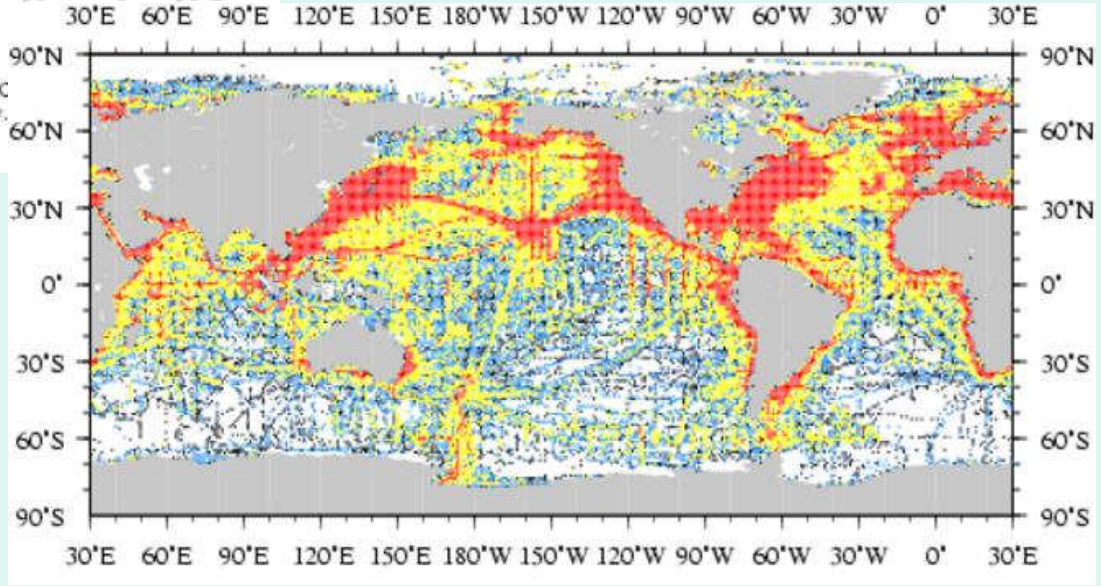
- What climate signals can we detect?
  - Where and when?
  - How large?
  - What level of diagnostic analysis is possible?
- How biased are the results?
  - Are the signals we see real?
- How do we evaluate the error (and bias) in our analyses?
- What comes next?

Profile Obs Coverage

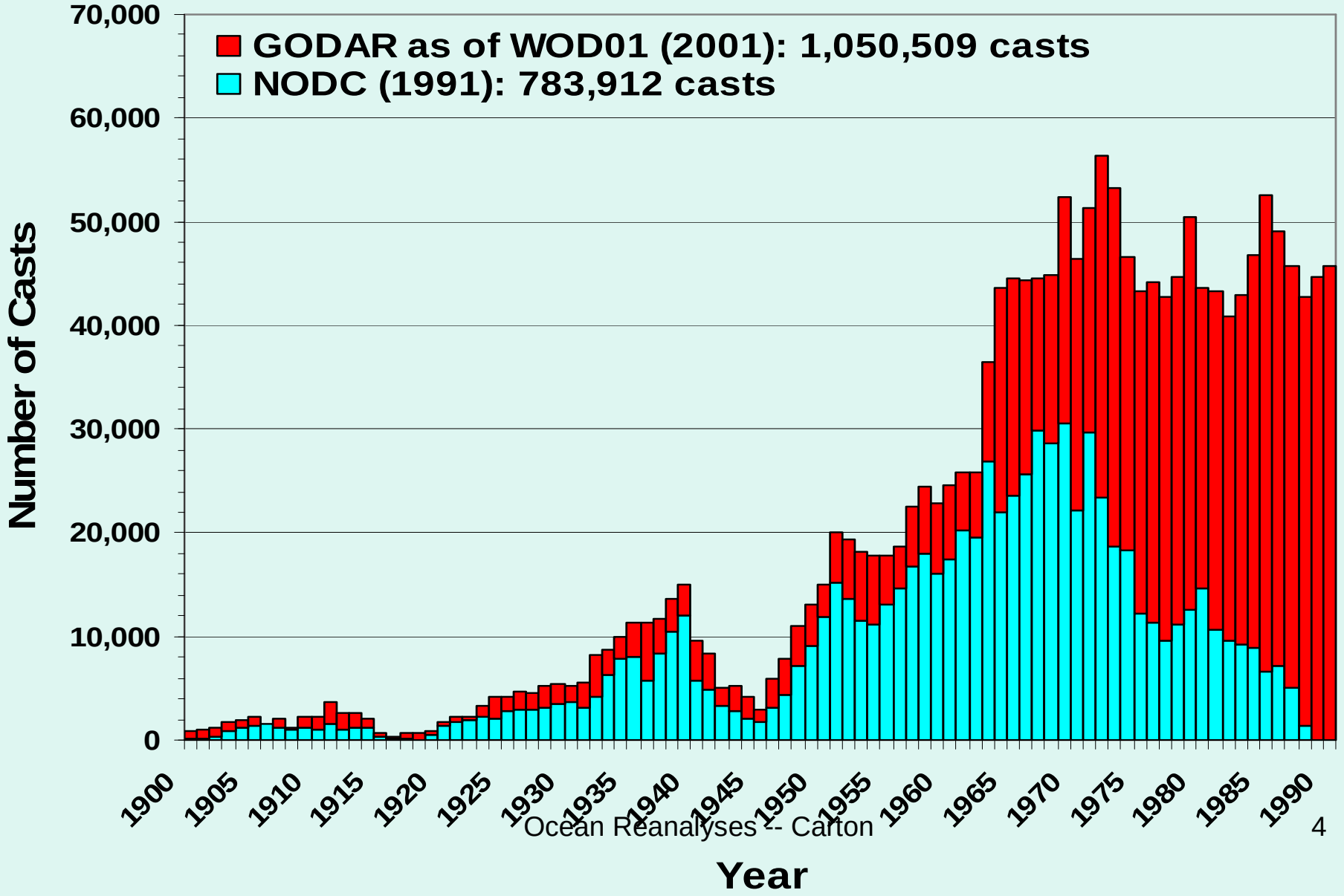


1930-1939

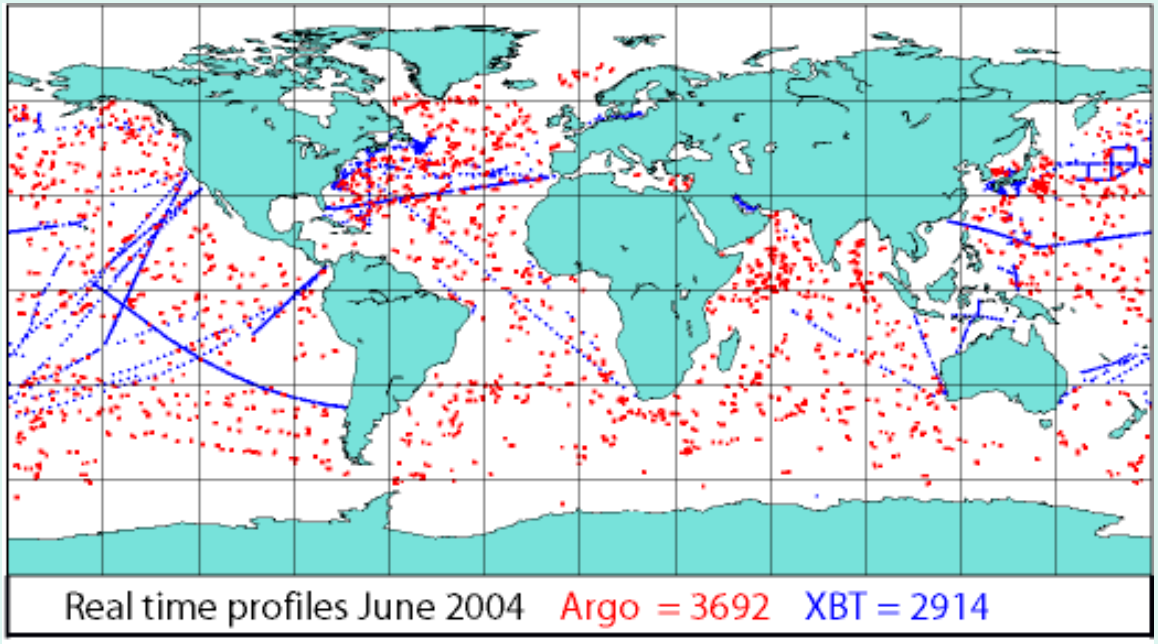
1960-1969

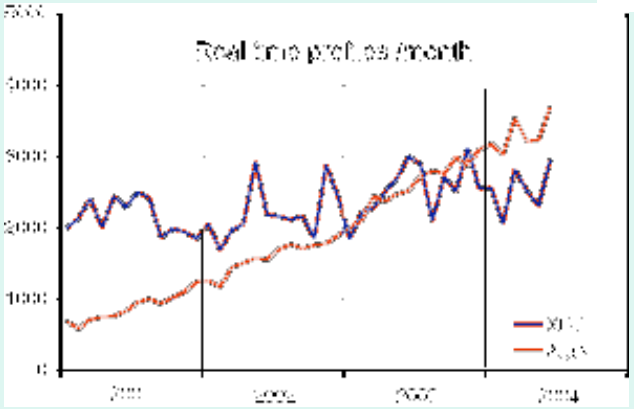


OSD cast data with time at NODC (picture from NODC)



Growth of ARGO since 2003



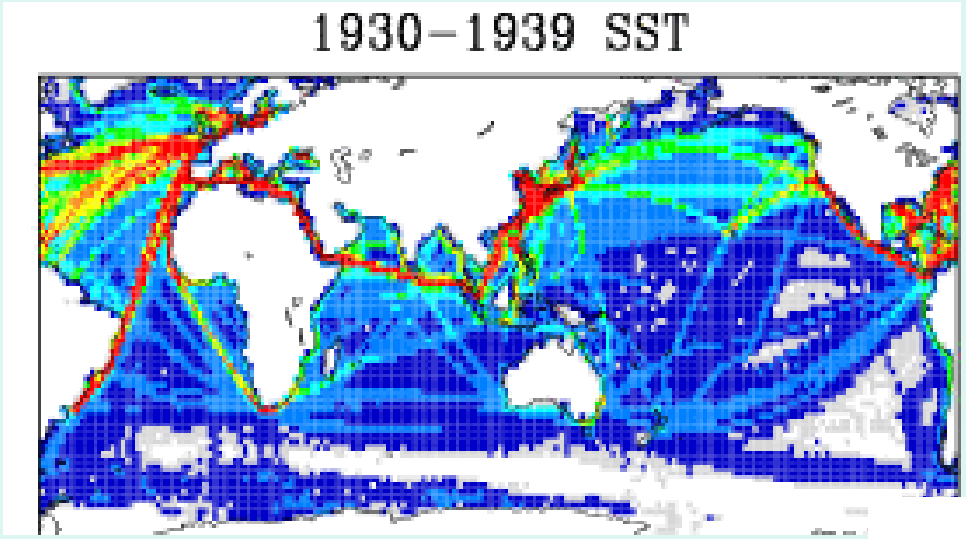


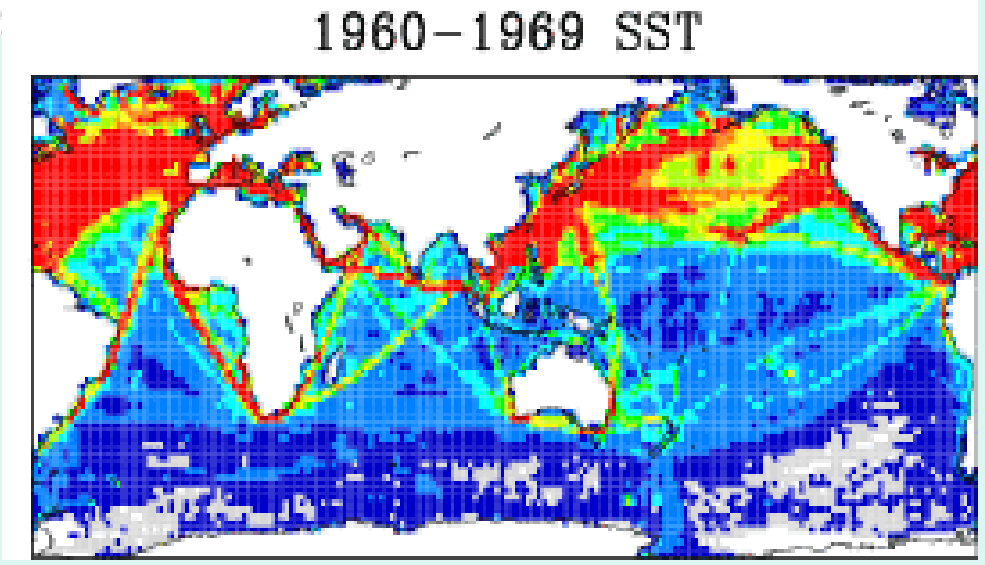
Time →

(pictures from ARGO website and S. Wilson)

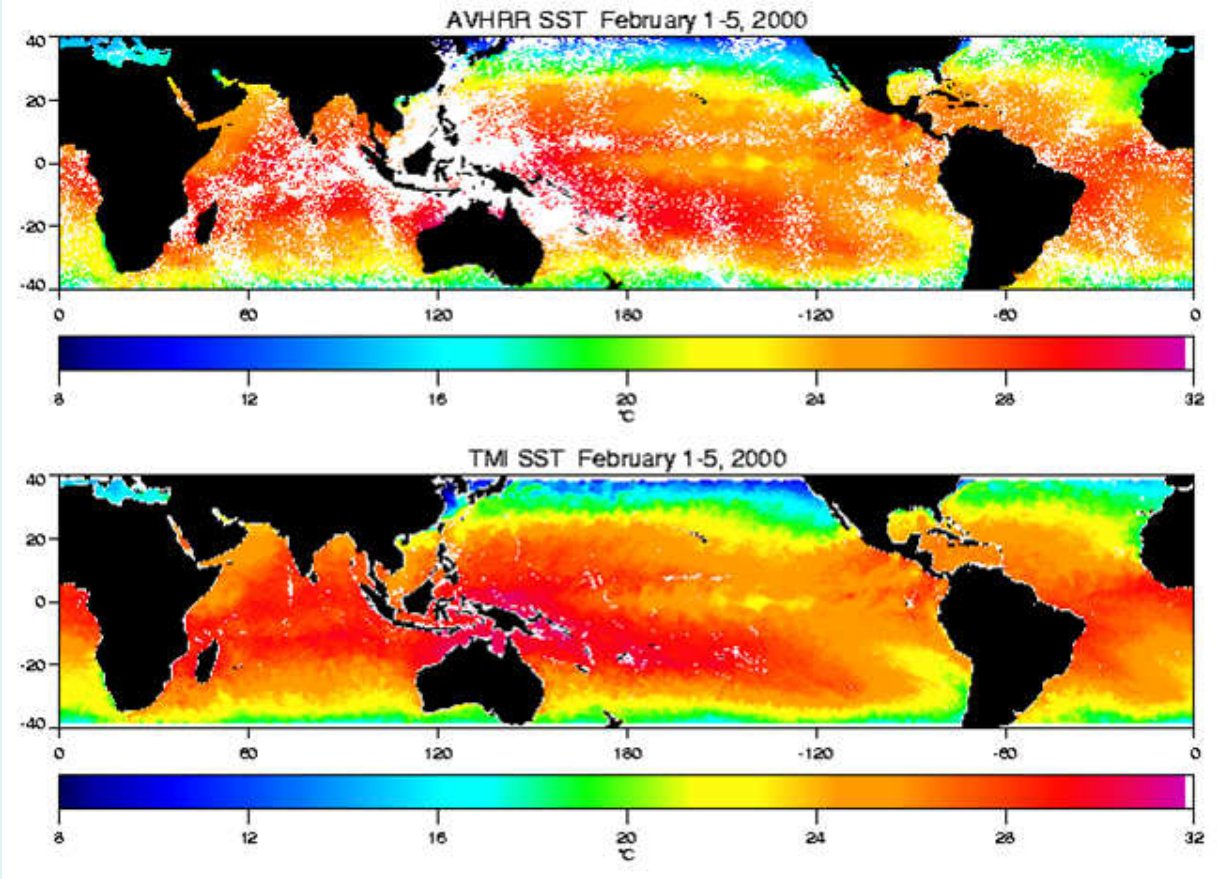
In-situ SST observation coverage

SST obs





Remotely sensed SST since 1981

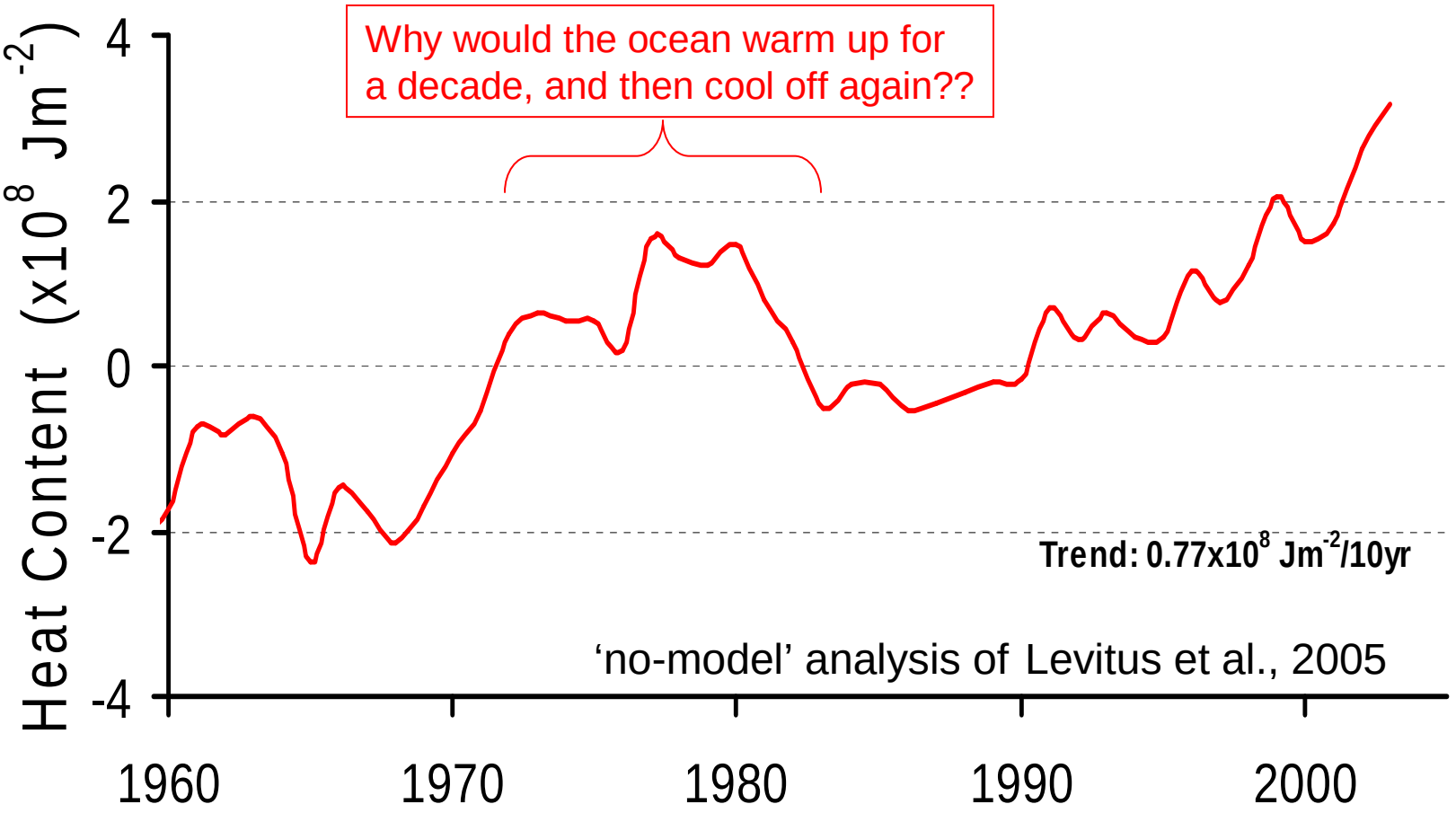


Source: John Maurer, UC Boulder http://cires.colorado.edu/~maurerj/class/SST_presentation.htm

Most of this talk will focus on the time period 1960-2001 corresponding to ERA40. At the end I will consider the full 20th century.

I'll begin by looking at ocean heat content, essentially the vertical integral of temperature. Then I'll look at water masses.

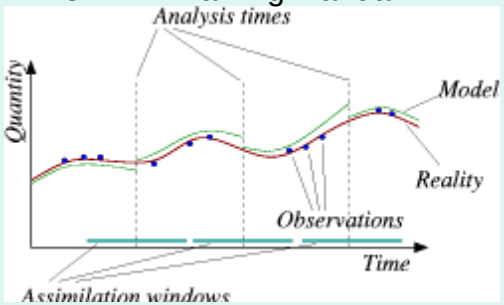
Problem of time-dependent bias in the profile data



Assimilation/synthesis methodologies

- Sequential filters

ECMWF Training manual



$$\frac{\partial \vec{U}}{\partial t} + f\hat{k}x\vec{U} + \vec{U}\cdot\nabla\vec{U} = -\frac{\nabla p}{\rho} + stress + friction$$

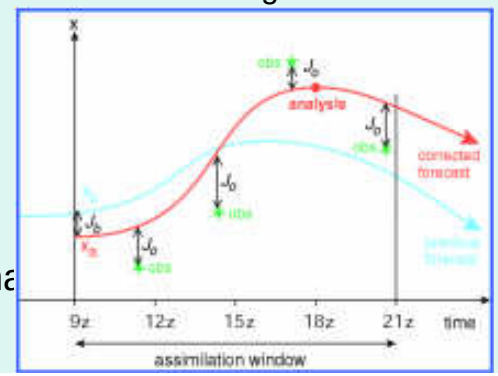
$$J(x) = (x - x^b)^T B^{-1}(x - x^b) + (Hx - x^o)^T R^{-1}(Hx - x^o)$$

$$x^b : background; \quad x^o : \quad observations$$

- Smoothers

J=J[X(t)]

ECMWF Training manual

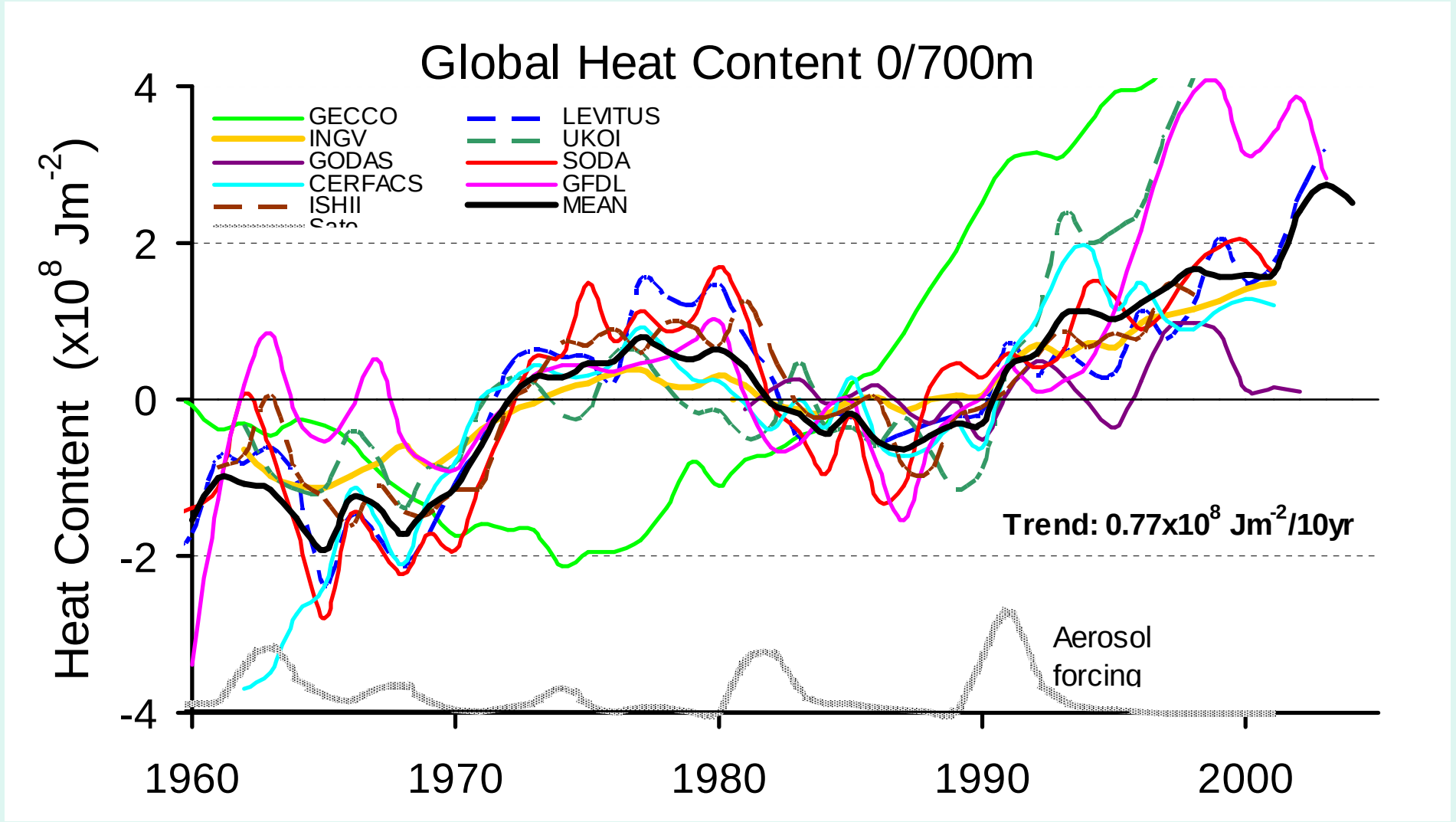


'physically consistent'

Eight examples

Analysis	Time Span	Analysis procedure
CERFACS *Davey* (2005)	1962-2001	Sequential
ECMWF	1962-2001	sequential
GECCO *Köhl et al. (2006)*	1950-1999	4DVar
GFDL 1,2 *Sun et al. (2007)*	1955-1999 1980-2005	Sequential, Coupled Sequential
GODAS *Behringer* (2005)	1979-2005	Sequential
INGV *Davey* (2005)	1962-2001	Sequential
ISHII *Ishii et al. (2006)*	1945-2005	Objective analysis
LEVITUS *Levitus et al.* (2005)	1955-2003	Objective analysis
SODA *Carton and Giese* (2007)	1958-2005	Sequential
UK-OI	1962-2001	Objective Analysis
UK-FOAM *Bell. (2000), Bell et al. (2004)*	1962-1998	Sequential

Global heat content



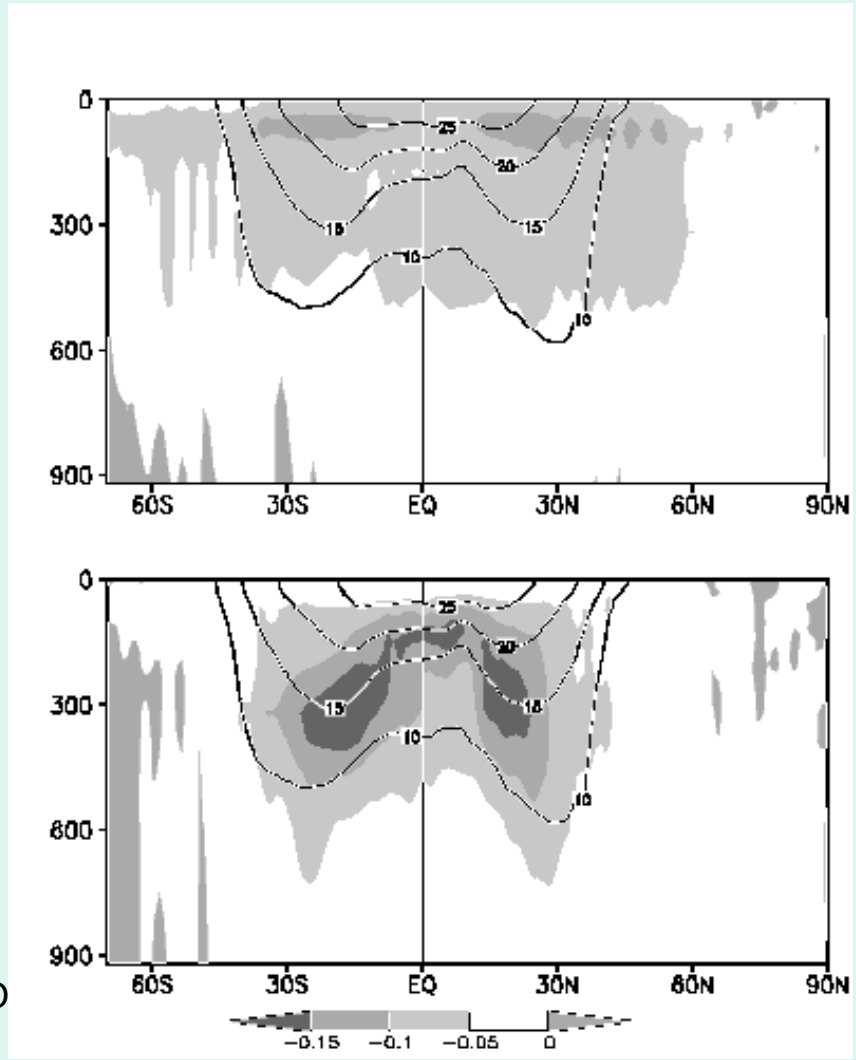
Bathythemograph fall rate corrections

XBT

(from Sippican)

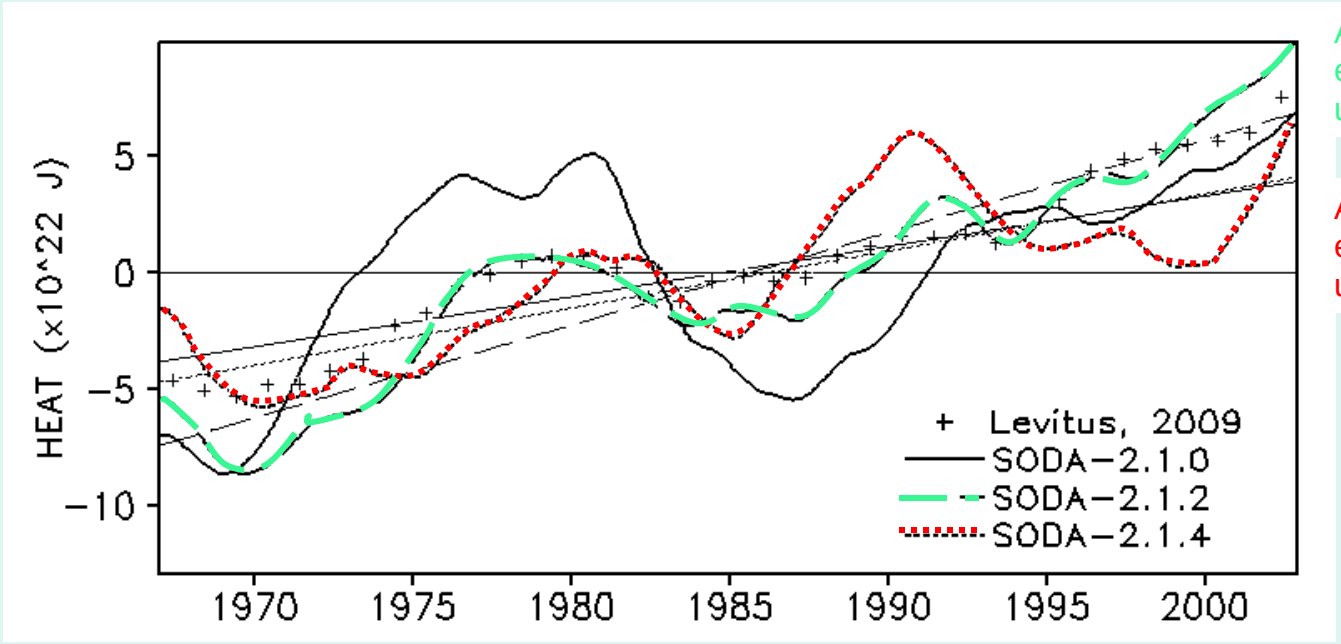
L09

W08



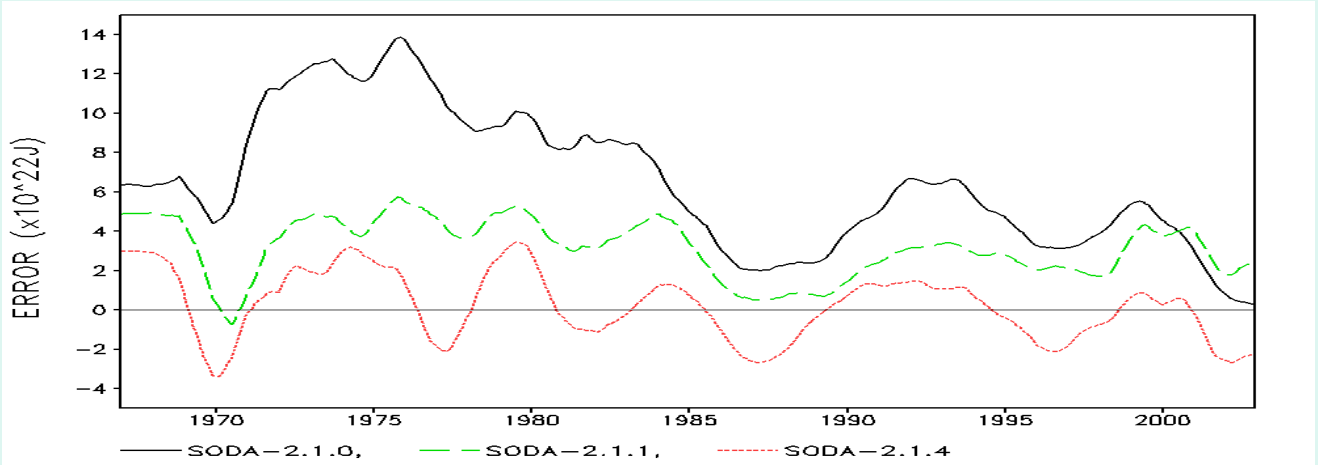
O

Global heat content after obs correction

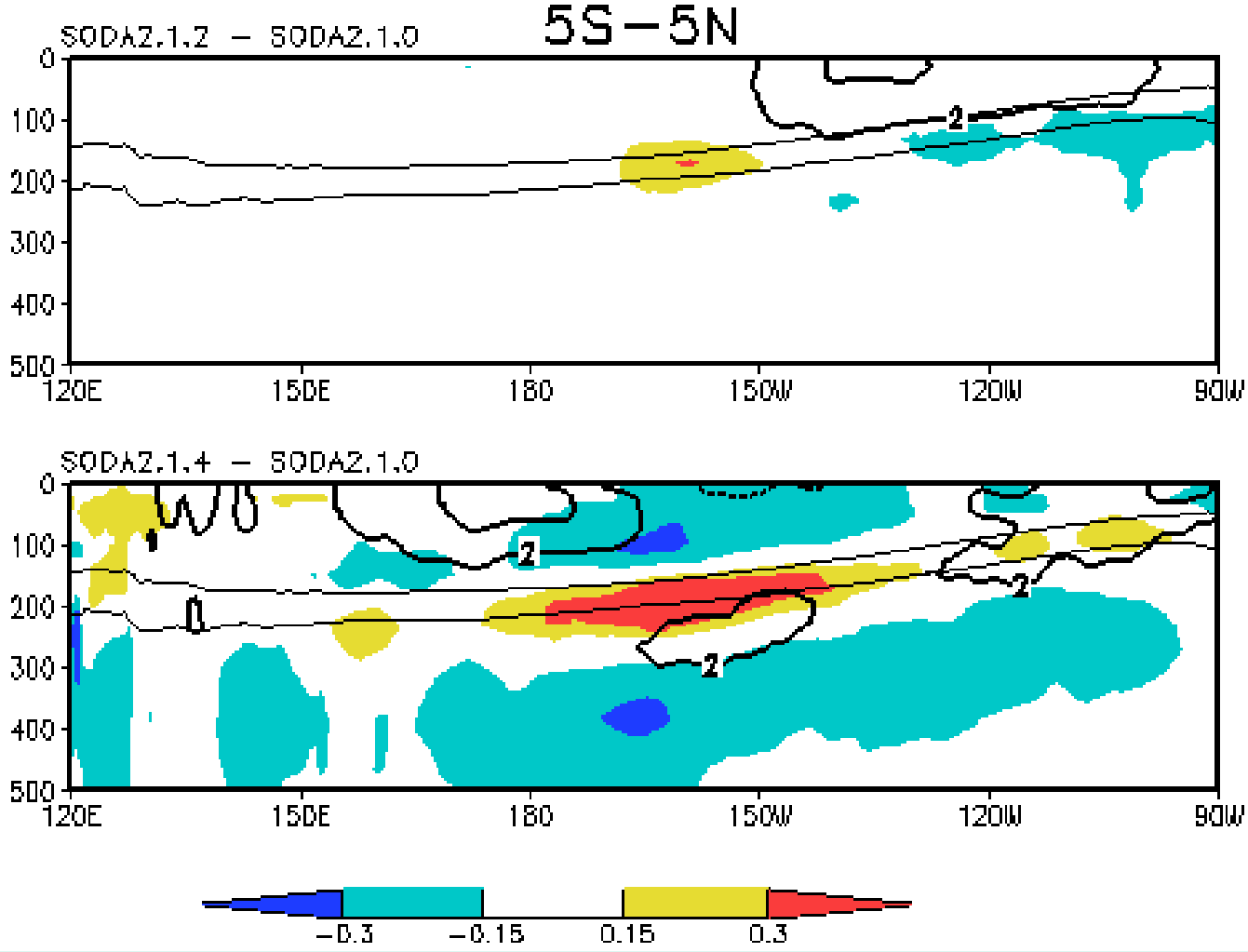


Assim experiment using L09

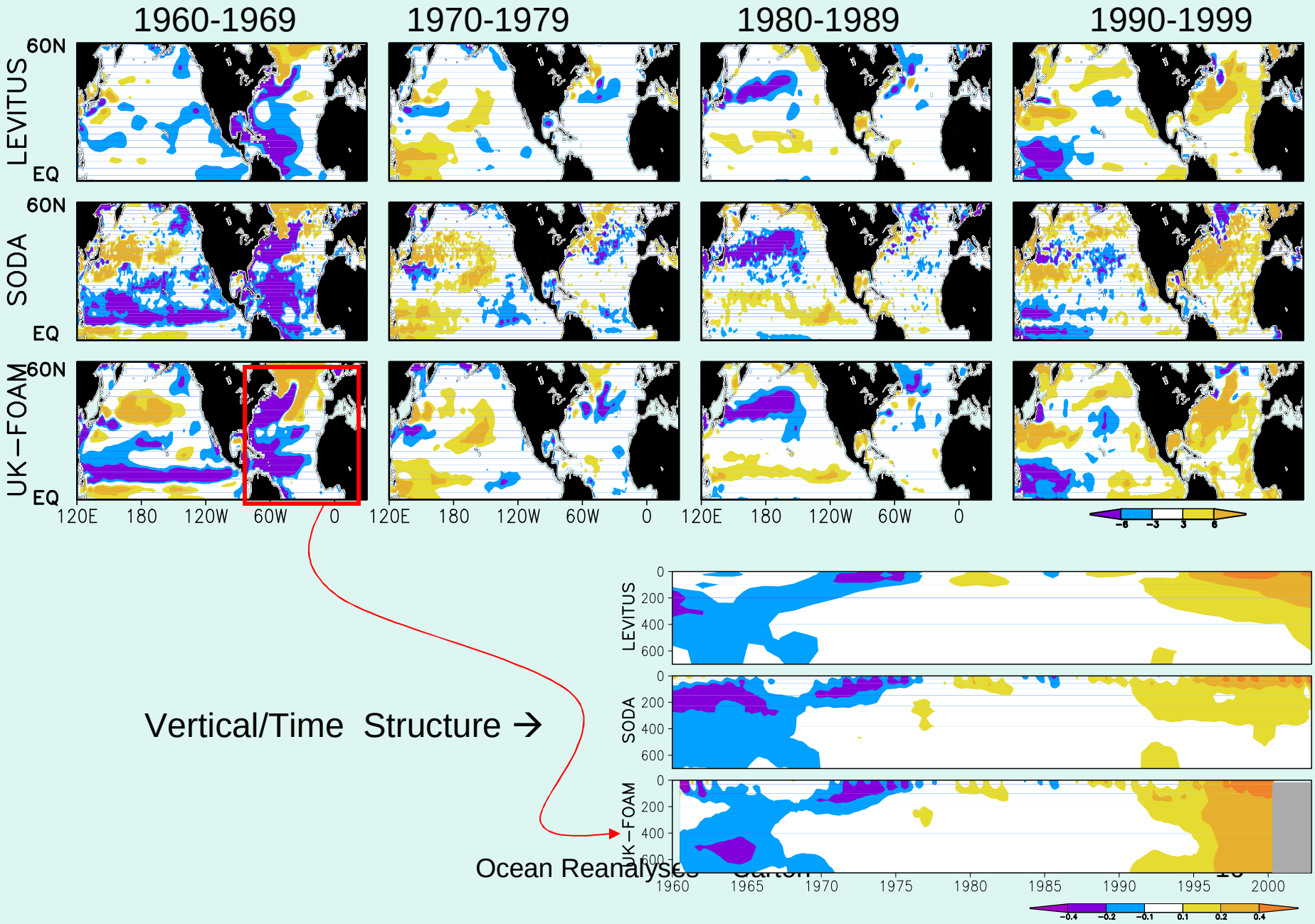
Assim experiment using W08

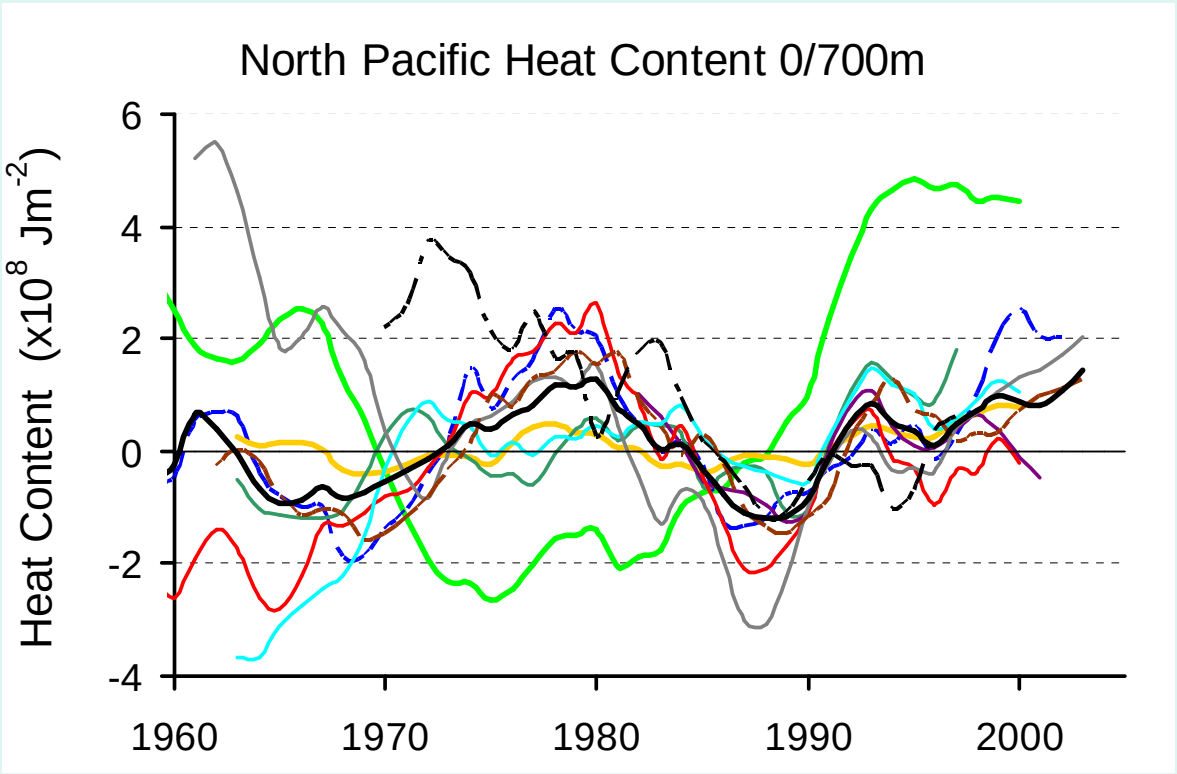


Impact of bias correction on mean tropical circulation

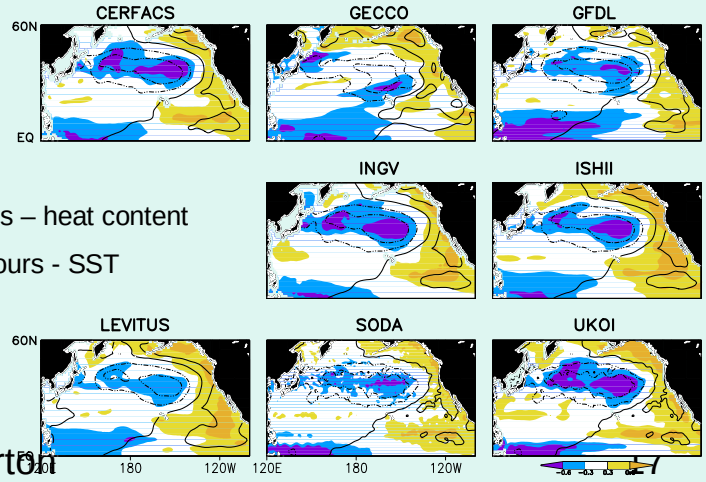


Heat Content by decade





Correlation with Pacific Decadal Oscillation



Colors – heat content

Contours - SST

Much of the decadal variability is correlated with PDO

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Decadal N. Pacific density variations

Depth of sigma 25.5 surface (*Miller and Schneider, 2000*)

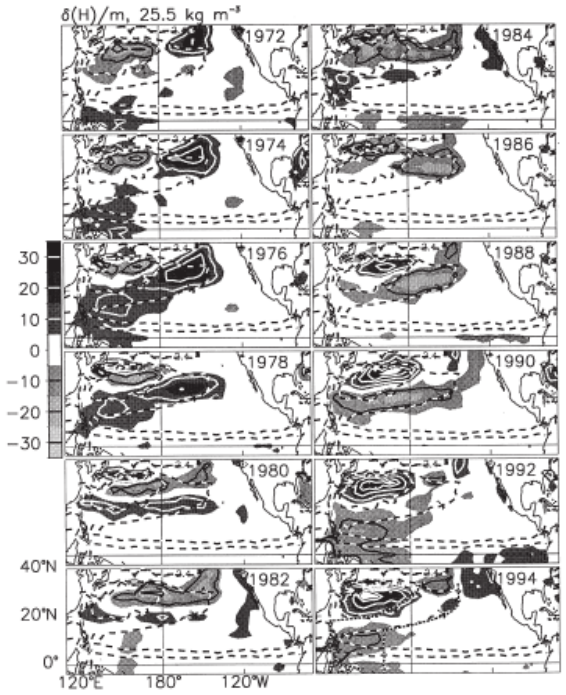
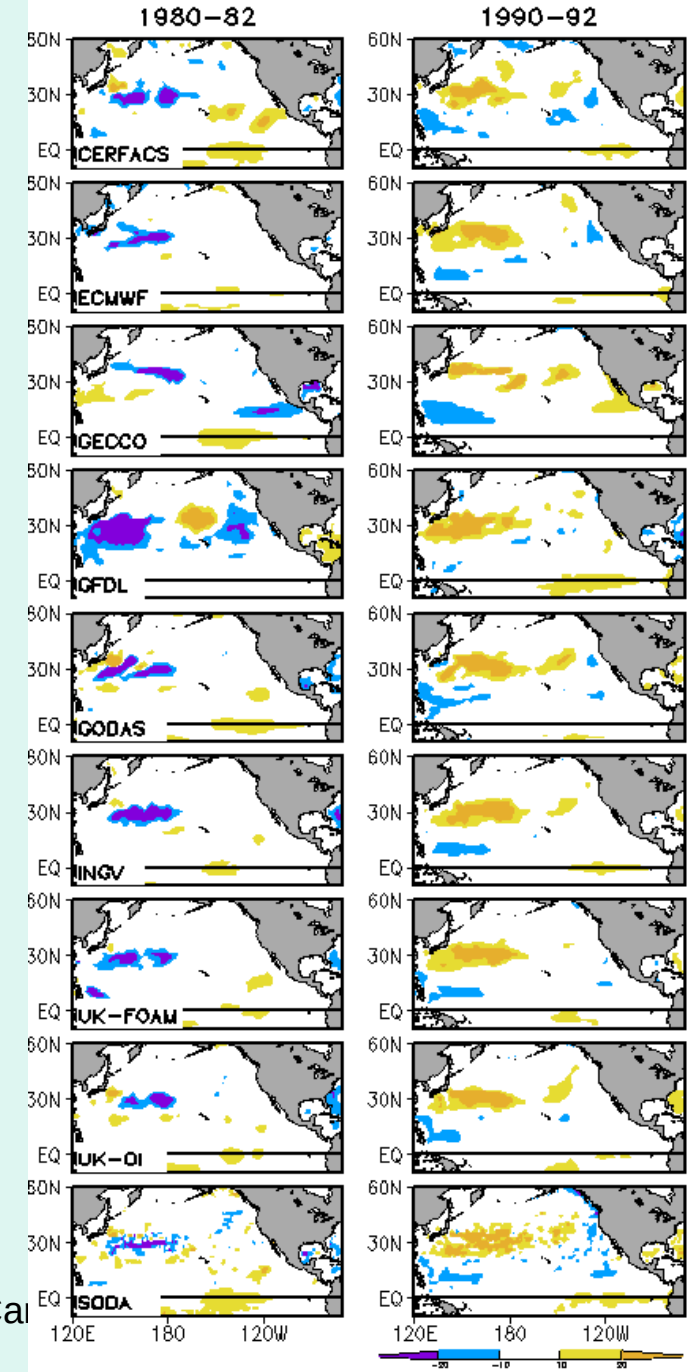
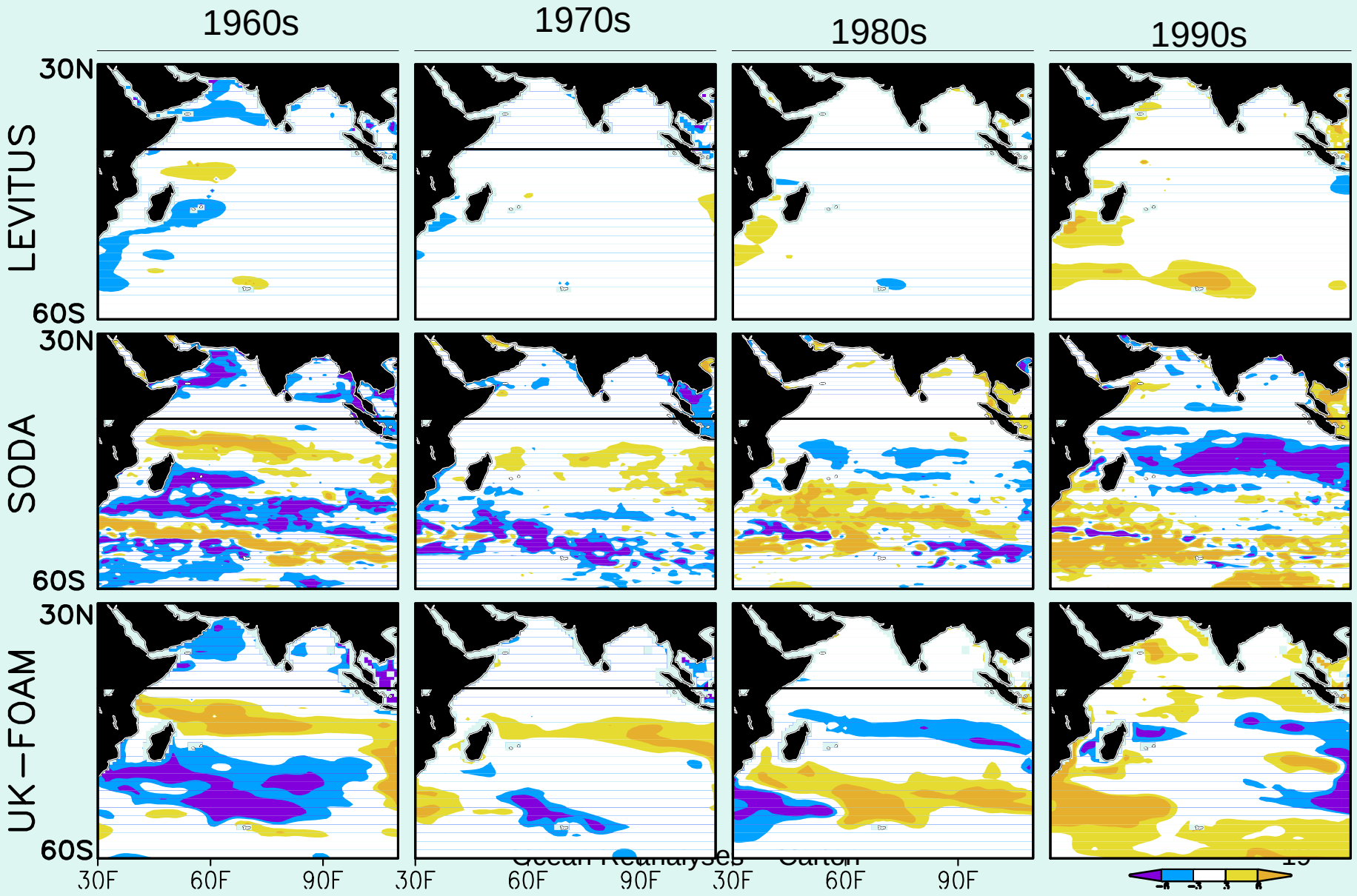


Fig. 4. Decadal anomalies in the North Pacific of the observed depth of the 25.5 kg m^{-3} isopycnal surface for years 1972 to 1994. Isopycnal depth was estimated from the White (1995) XBT data and the mean distribution of salinity (see Schneider et al., 1999b). Annual average anomalies were smoothed with a 1–2–3–2–1 filter over a 5-year interval. Dark shaded areas mark positive anomalies larger than 5 m (warm conditions) and light grey shading indicate negative anomalies larger then −5 m (cold conditions). Contour interval is 10 m, with the grey scale changing at ±5, 15 and 25 m. Overlaid as dashed lines are the 2.4×10^{-10} and 4.5×10^{-10} m^{-1} s^{-1} isolines of the potential vorticity obtained from the mean difference of depths of the 25.3 and 25.7 kg/m^3 isopycnals. The dotted lines in the lower right hand panel denote the region of zonal average used to produce Fig. 5. The anomalies follow the isolines of potential vorticity poleward of 14°N in this corridor.



ean Reanalyses -- Ca

Heat Content by Decade: Indian Sector

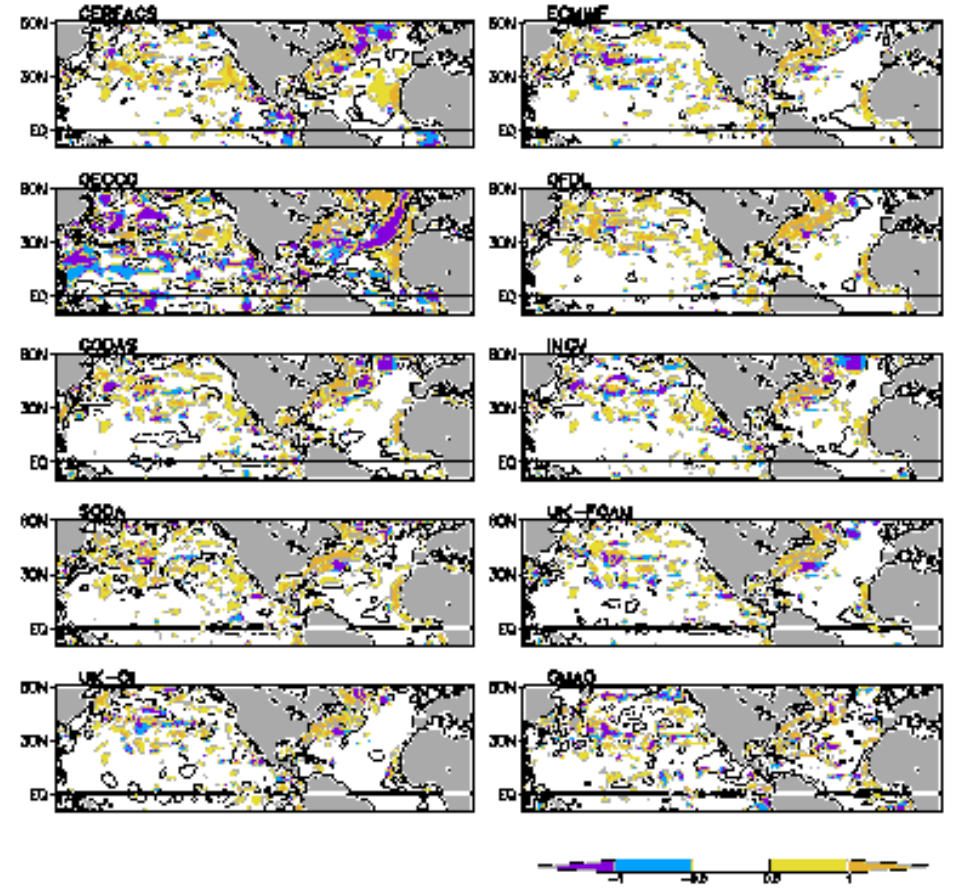


Quick Look at Upper Ocean Water Masses

Examples of the upper ocean response to freshwater events:

- HOT
- Bermuda
- Great Salinity Anomalies

SST_{Anal}-SST_{OBS} during winter



Slowdown of the meridional overturning circulation in the upper Pacific Ocean

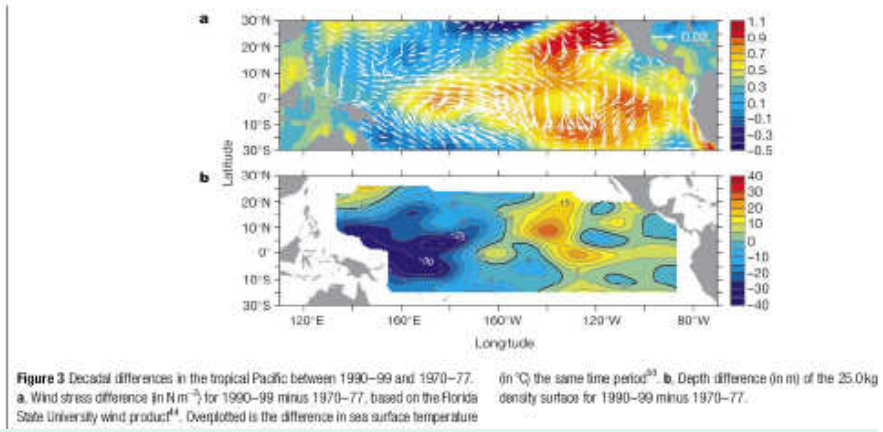
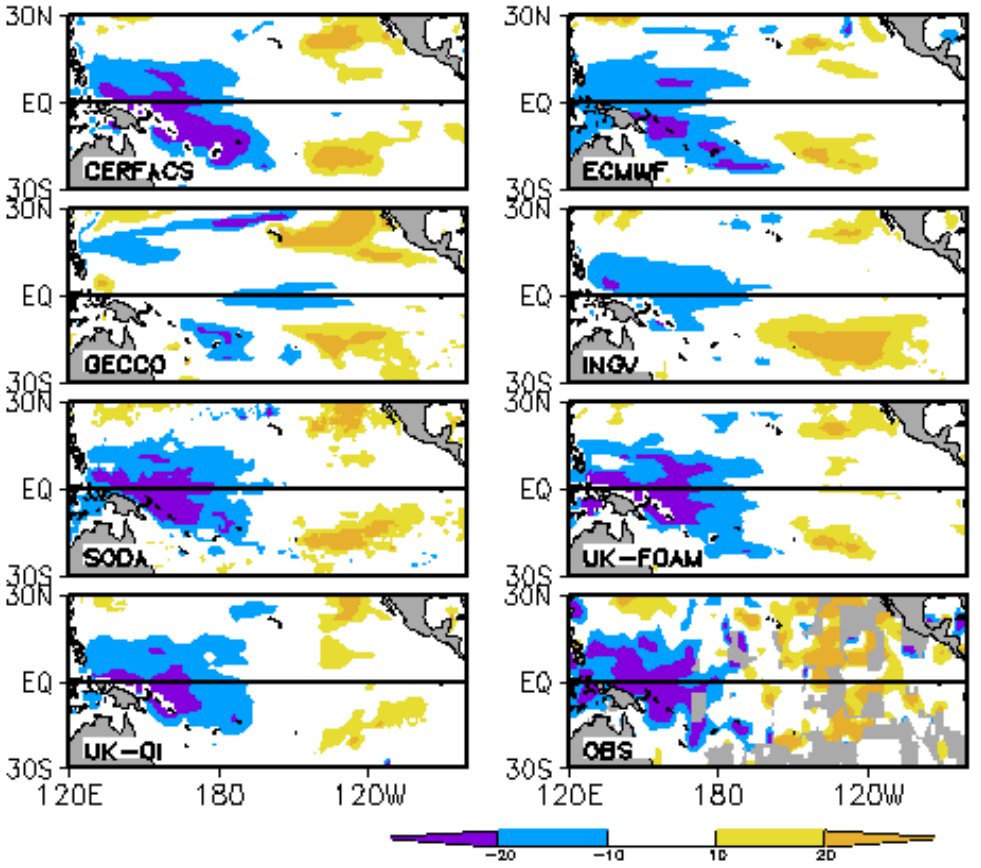


Figure 3 Decadal differences in the tropical Pacific between 1990–99 and 1970–77. **a**, Wind stress difference (in N m^{-2}) for 1990–99 minus 1970–77, based on the Florida State University wind product[44]. Overplotted is the difference in sea surface temperature (in °C) the same time period[33]. **b**, Depth difference (in m) of the 25.0kg density surface for 1990–99 minus 1970–77.

McPhaden and Zhang (2002)

Change in depth (meters) of the 24.5σ surface averaged 1990-1999 minus 1970-1977



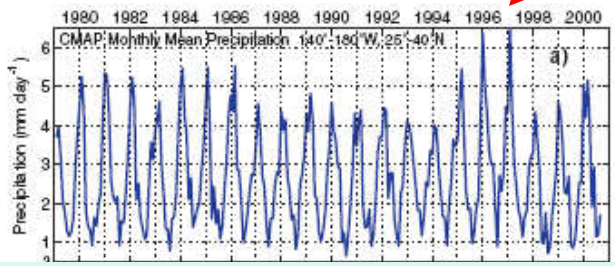
Response of the North Pacific to Heavy precipitation (’95-’97)

Hawaii Ocean Time series

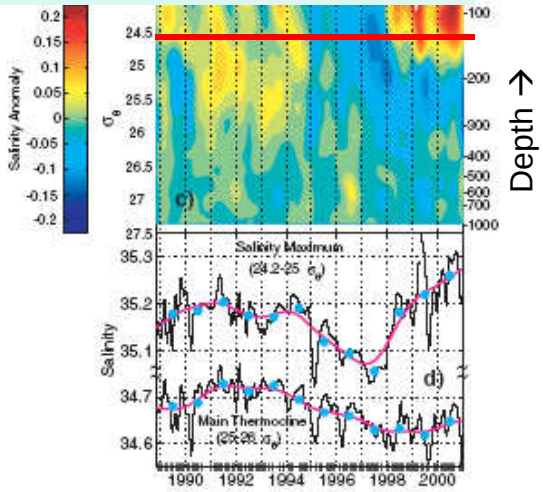
Heavy rainfall

Lukas (2001)

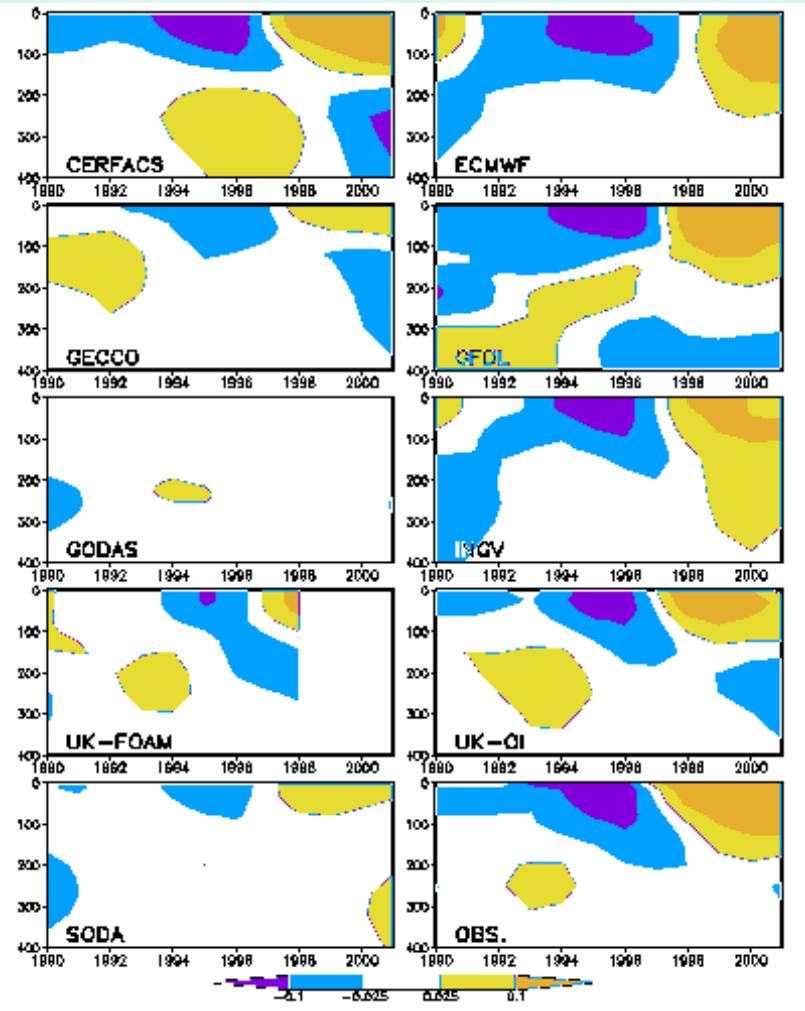
Precip



Salinity



Salinity Anomalies at HOT showing penetration of near-surface freshwater



PV variability at Bermuda

Joyce and Robbins (1996)

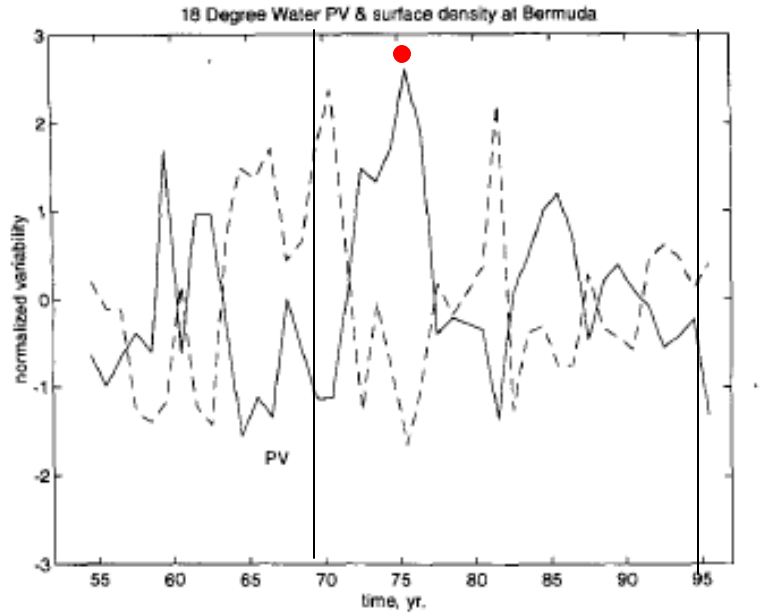
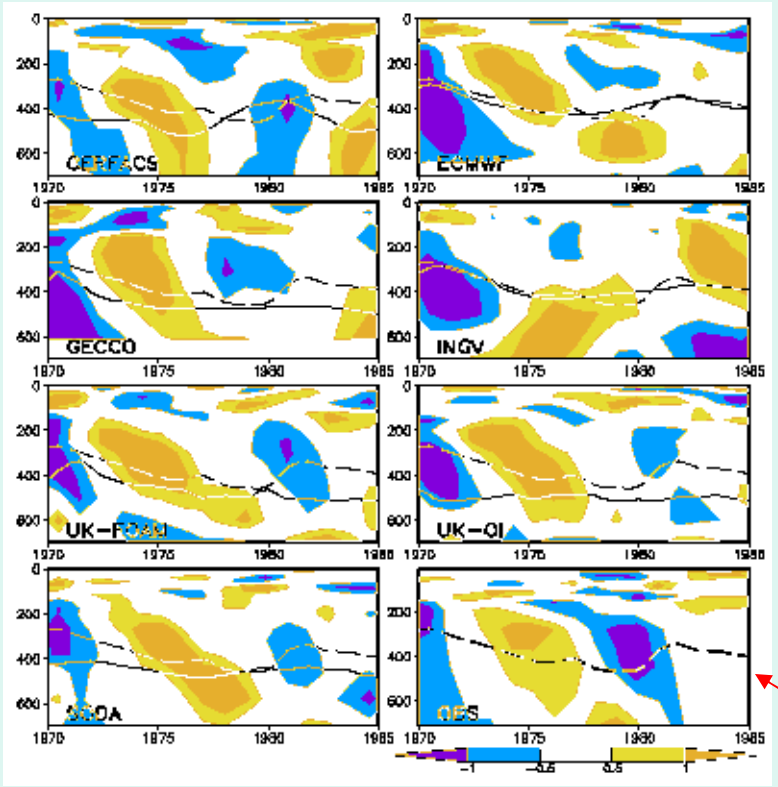


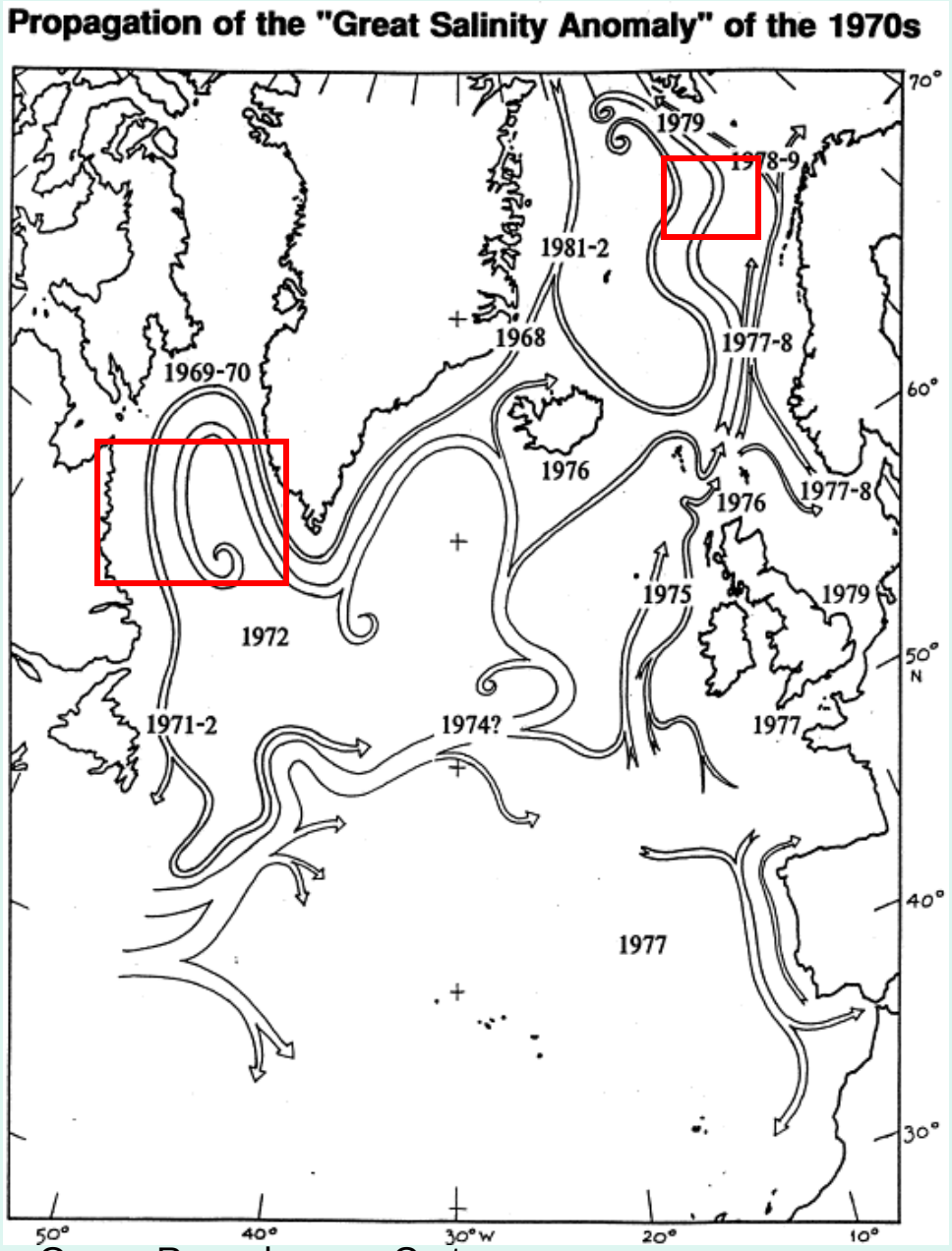
FIG. 5. Time series of the potential vorticity of the 18°C Water and surface-layer potential density at Bermuda. The PV of the 18°C Water was calculated using a least squares fit to the potential density between 200 and 400 dbar, inclusive. We have plotted the normalized variables (with means subtracted and scaled by the respective standard deviations) in order to show the long-term changes in each: PV as a solid line and surface layer potential density as a dashed line. For reference, the (PV, ρ_θ) means (7.03, 25.901) and standard deviations (1.81, 0.075) are provided in units of 10^{-11} (m s)$^{-1}$ and kg m^{-3}. The correlation coefficient between the two series is −0.75.

Normalized PV from the Analyses



eanalyses -- Carton

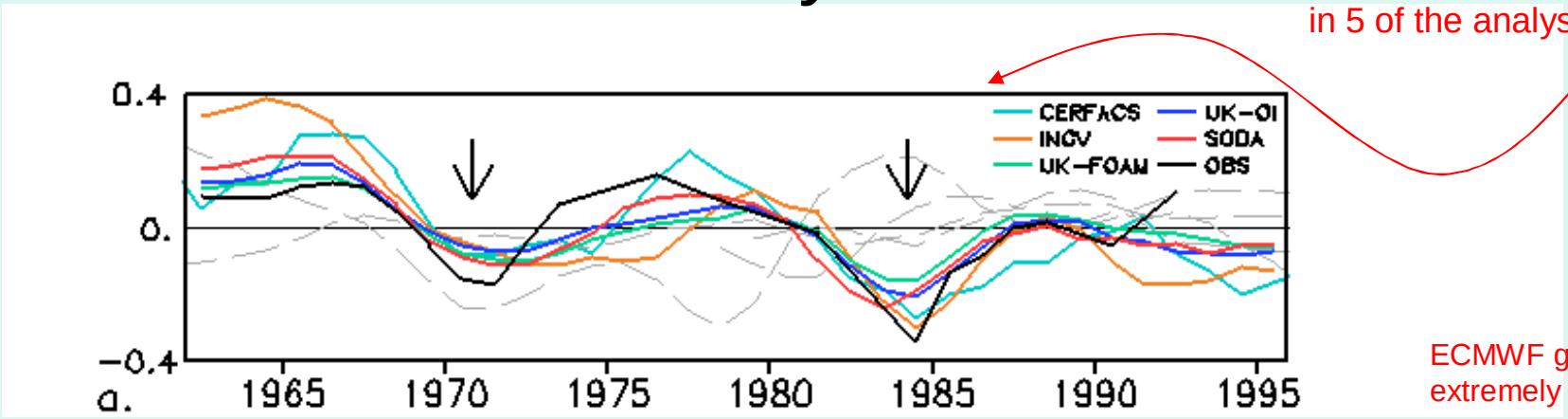
Our analysis of OBS



Dickson et al (1988) revised: Ellett and Blindheim (1992, Fig. 6)

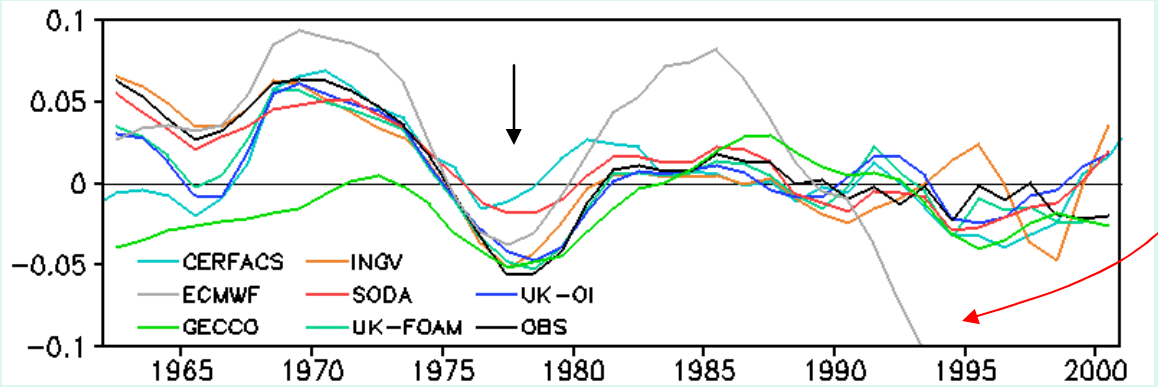
Great Salinity Anomalies

Lab Sea GSAs appear in 5 of the analyses



ECMWF gets extremely fresh

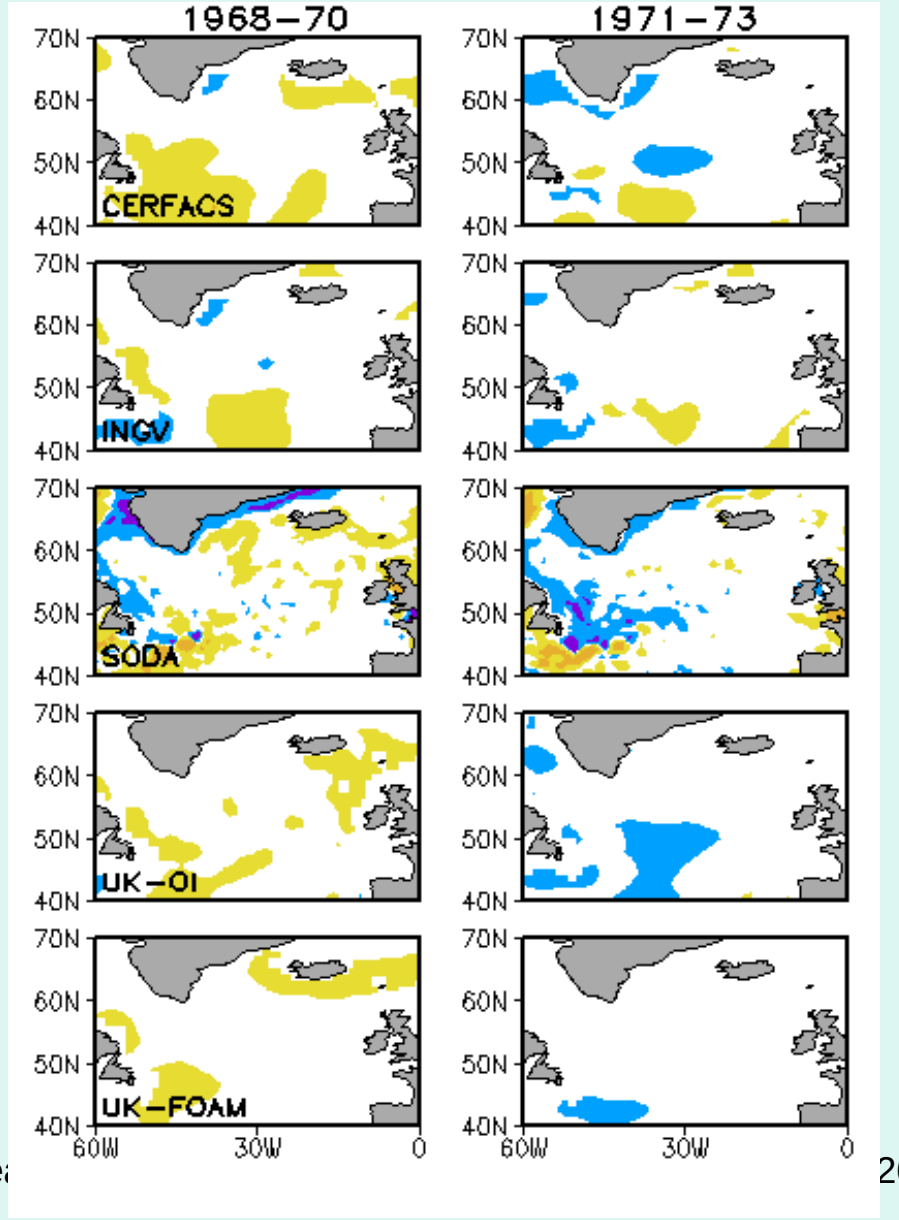
0/250m Salinity changes within the southern Labrador Sea (53oW-59oW, 50oN-56oN).



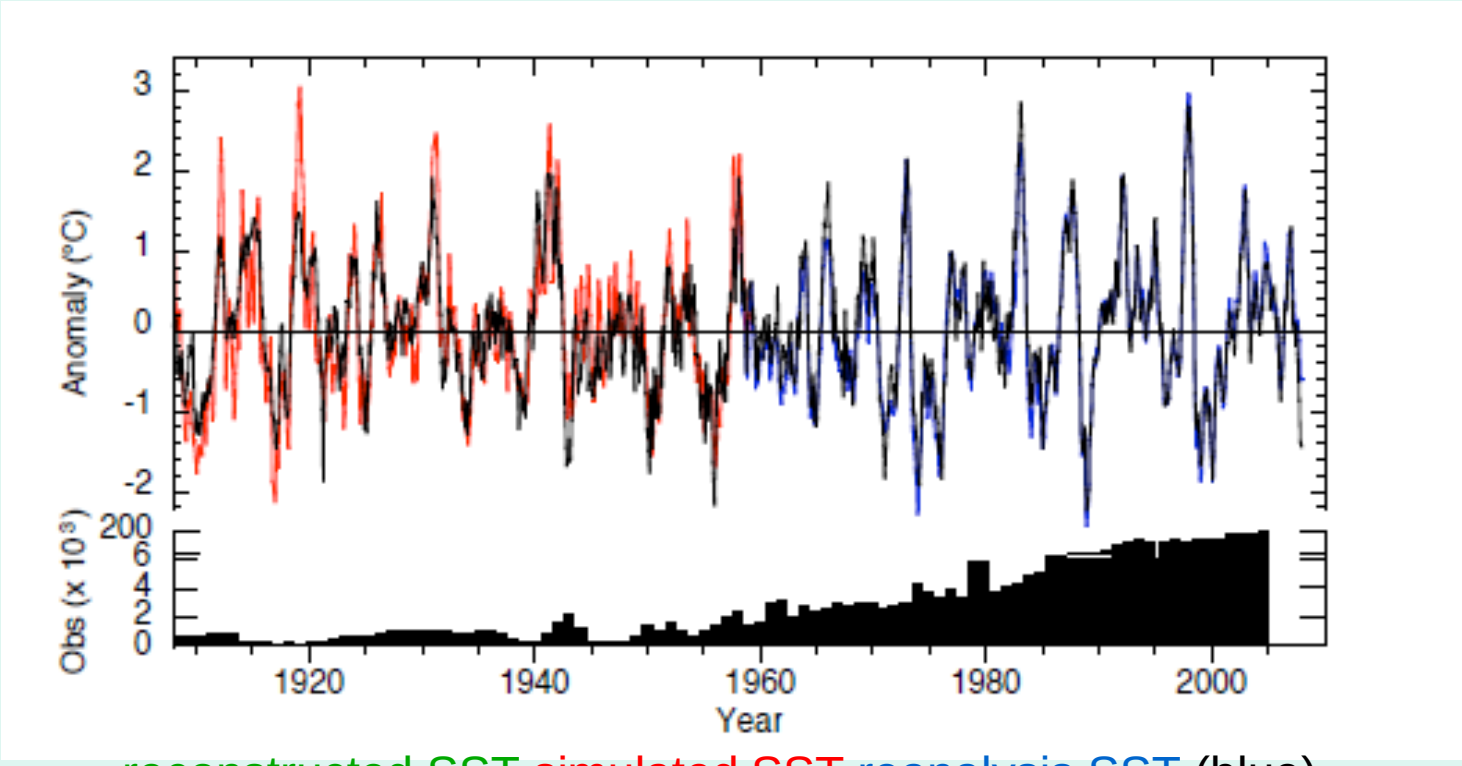
Annually averaged upper ocean salinity (0-500m) in the Norwegian Basin (0-5oE, 63oN-69oN) for the seven analyses spanning the time period. ECMWF becomes quite fresh after 1990.

Spatial structure of 0/500 salinity’

0/250m Salinity changes within the southern Labrador Sea (53oW-59oW, 50oN-56oN).

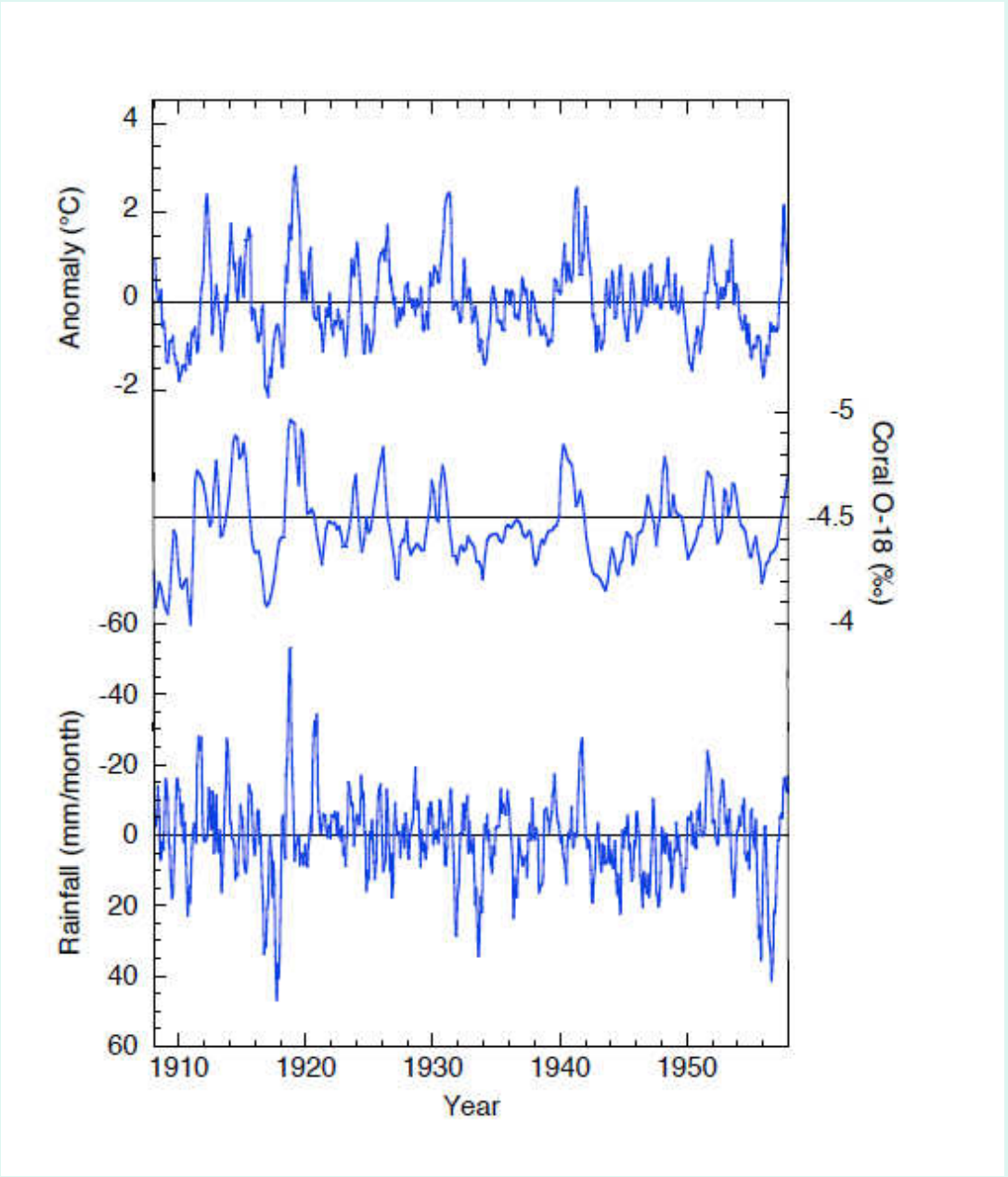


20th Century Reanalysis: ENSO

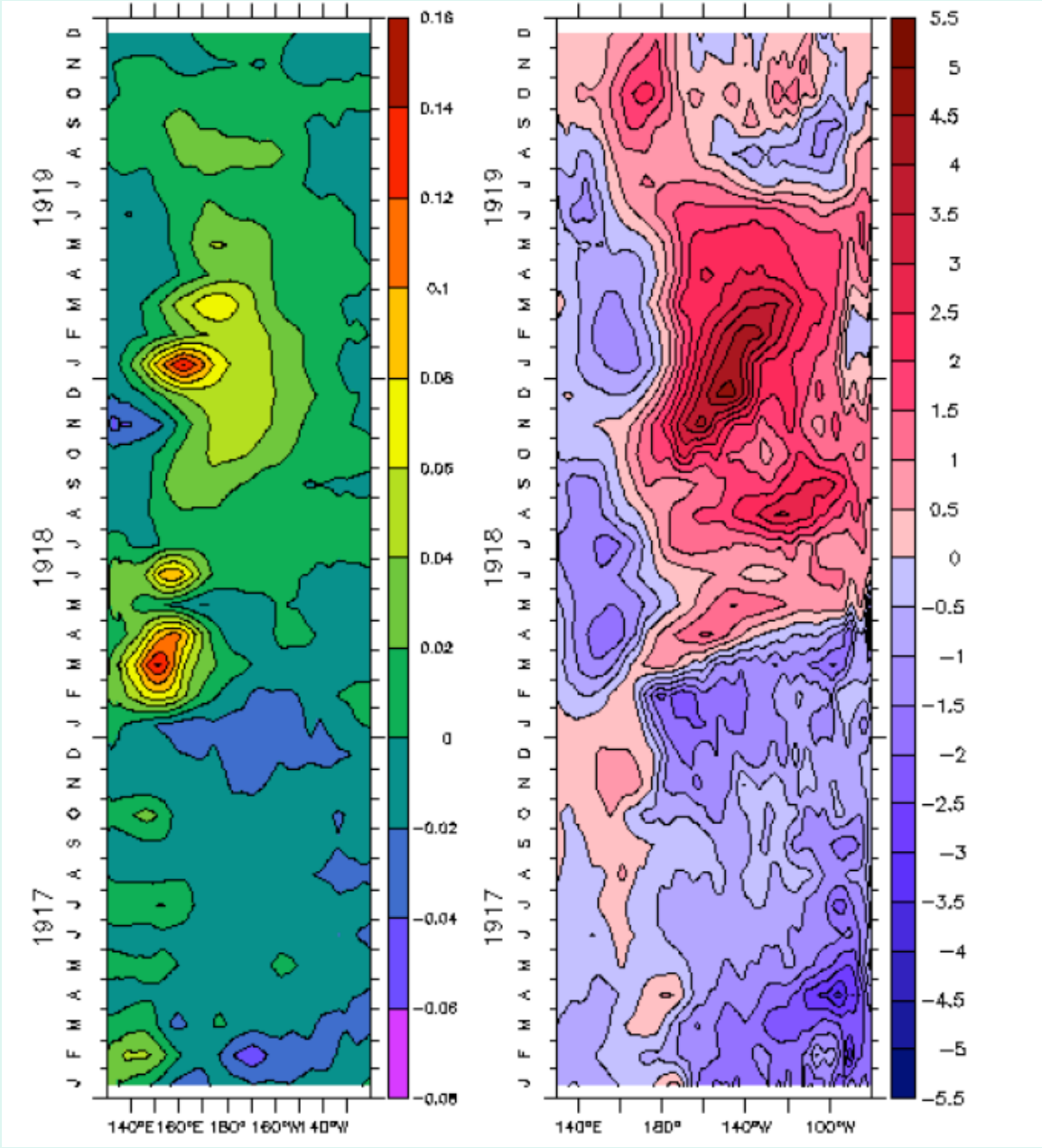


reconstructed SST simulated SST reanalysis SST (blue)

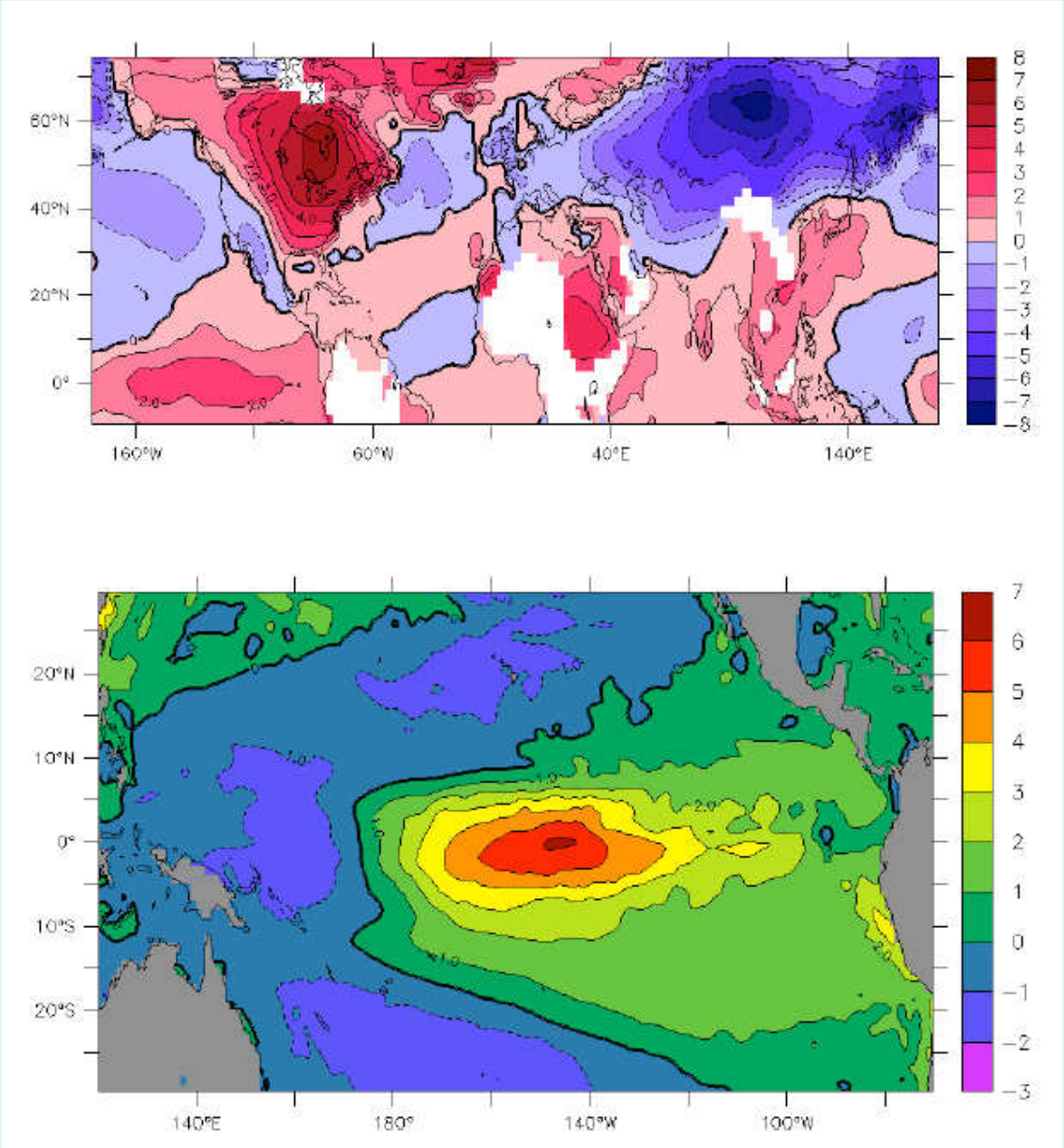
From: *Giese et al. (2009)*



From: *Giese et al. (2009)*



From: *Giese et al. (2009)*



From: *Giese et al. (2009)*

What have we learned?

- **What climate signals can we detect?**
  - See above.
- **How biased are the results?**
  - Observation bias is certainly present, but seems mainly to afflict basin- or global integral quantities. Model bias (including bias in meteorological forcing) does not seem insurmountable. But we still aren't sure just how large it is.
- **Are the signals we see real? Are we learning new things?**
  - Yes. Beginning to. This is a new tool and the community is just getting used to it.
- **How do we evaluate the error (and bias) in our analyses?**
  - Unbiased data sets like ctd/osd are uniquely valuable for this.
- **What next?**
  - Ensemble methods seem like a logical next step.
  - Analyses really should be done in the coupled system.
  - Impact of circulation on ecosystem models.