Mean and Variability of Air-Sea Heat Fluxes in the Indian Ocean

Lisan Yu
Woods Hole Oceanographic Institution

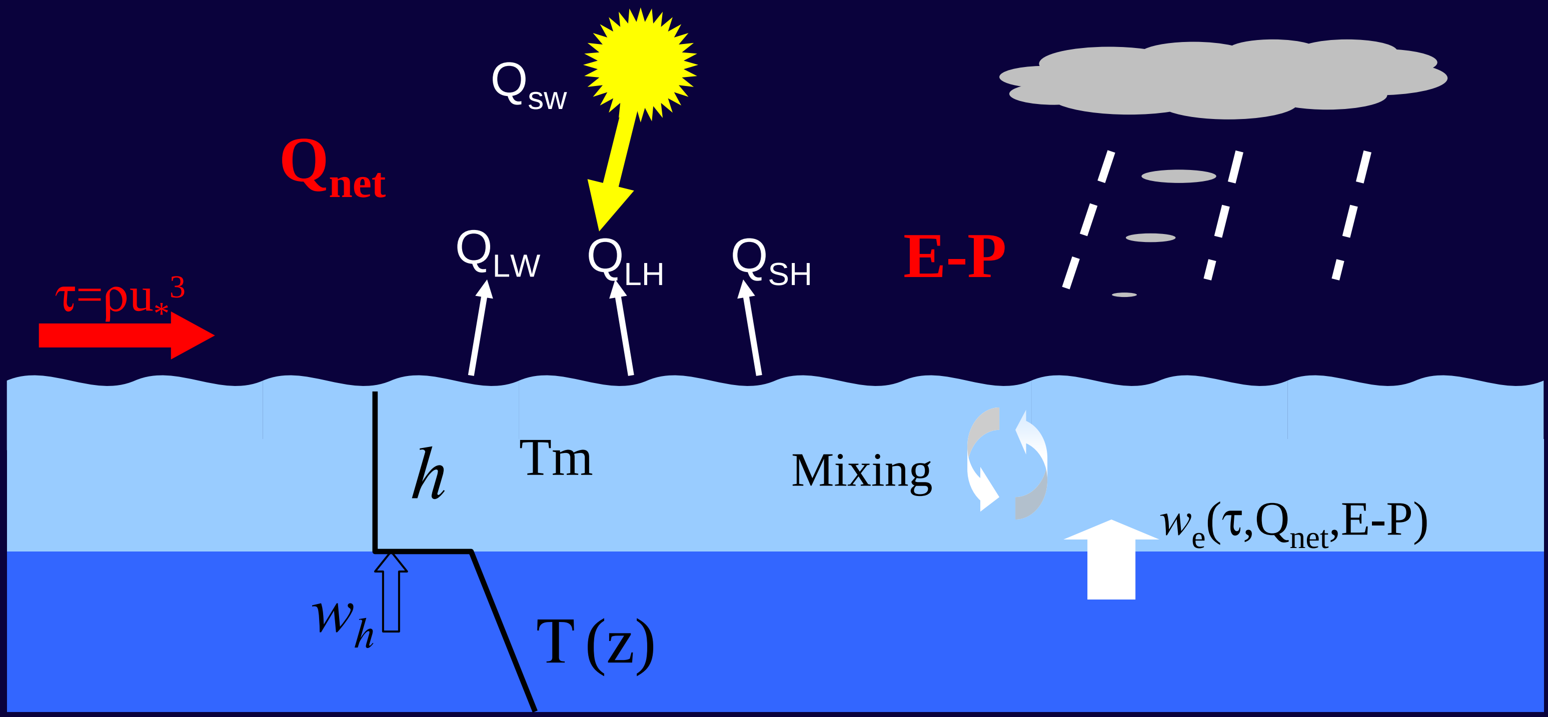
Major topics:

1. Estimating the IO air-sea heat fluxes
   – what are the most challenging issues?

2. Mean and variability of currently available heat flux products
   – seasonal
   – interannual
   – decadal

“Indian Ocean Climate Symposium” Hobart Australia. March 2005.
Sponsored by the World Climate Research Program’s CLIVAR project and the Intergovernmental Oceanographic Commission’s Global Ocean Observing System.

Importance of air-sea heat exchanges



- Net surface heat flux: $Q_{net} = Q_{LH} + Q_{SH} + Q_{LW} + Q_{SW}$
- The time rate of change of upper ocean temperature is balanced by Q_{net}, the divergence of heat transport, and diffusion.

$$\frac{\partial}{\partial t}\int_{-h}^{0} T_m dz = \frac{Q_{net}}{\rho c_p} - \nabla \cdot \int_{-h}^{0} \mathrm{u} T_m dz + \kappa \nabla^2 T_m$$

- The time rate of change in mixed layer depth (h),

$$\frac{\partial h}{\partial t} = w_e - w_h = C_1 u_*^3 - C_2 B(Q_{net}, E-P)h - w_h$$

Global datasets

- Southampton Oceanographic Centre (SOC Climatology): COADS climatological monthly based on the 1982-1997 period

- NCEP/NCAR reanalysis (NCEP1): fixed model/analysis system
six hourly, 1.875º-grid, 1948 – present

- NCEP/DOE reanalysis (NCEP2): fixed platform
six hourly, 1.875º-grid, 1979 – present

(NCEP2 is an update of NCEP1. It corrects some known errors in NCEP1 and upgrades parameterization schemes for shortwave radiation, cloud, and soil moisture)

- ECMWF operational analysis (ECMWF): model/analysis platform changes
six hourly, 1.125º-grid, 1979 – present

- ECMWF Re-Analysis 40 (ERA-40): fixed platform
six hourly, 1.125º-grid,1957 – 2002

➢ OAFlux (Objectively Analyzed air-sea heat Fluxes) Project: blended product
planned activity: daily, 1º-grid, mid 1950's – present
currently available: daily, 1º-grid, 1988-2003

OAFlux (Objectively Analyzed Air-sea Heat Fluxes) For the Global Oceans

– in collaboration with Bob Weller and Xiangze Jin

- What is the project about?

to develop daily Q_{LH}, Q_{SH}, Q_{LW}, Q_{SW} fields for the global oceans for the past 50 years.

- Principle of the development:

to use weighted objective analysis to combine data from satellite retrievals, COADS ship reports, and atmospheric reanalysis outputs.

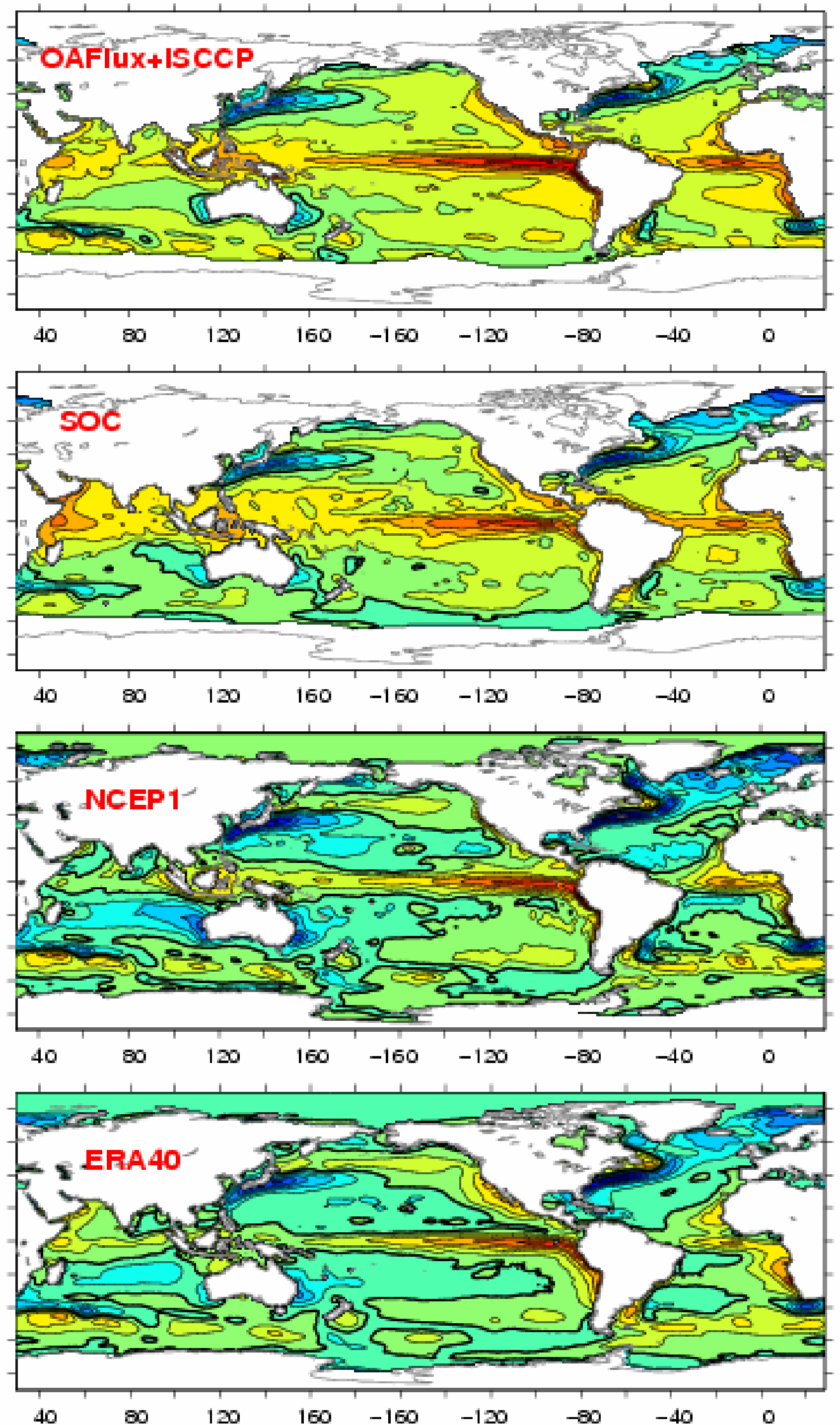
- Type of product:

a blended flux product with daily and 1-degree grid resolution

References regarding the methodology and validation of the OAFlux analysis:

Yu, L., R. A. Weller, and B. Sun, 2004a: Improving latent and sensible heat flux estimates for the Atlantic Ocean (1988-1999) by a synthesis approach. J. Clim. 17, 373-393.

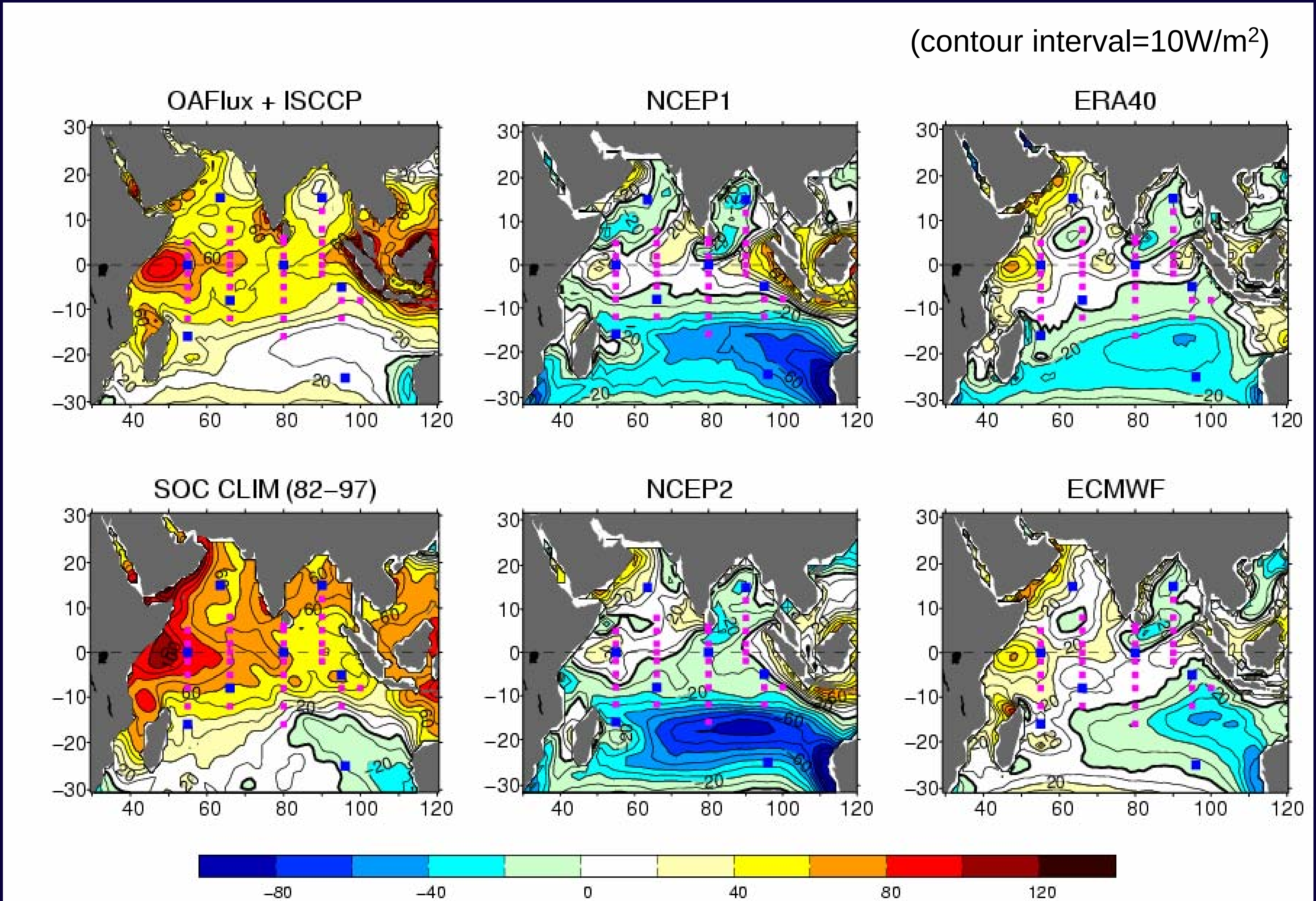
Yu, L., R. A. Weller, and B. Sun, 2004b: Mean and variability of the WHOI daily latent and sensible heat fluxes at in situ flux measurement sites in the Atlantic Ocean. J. Clim., 17, 2096-2118.



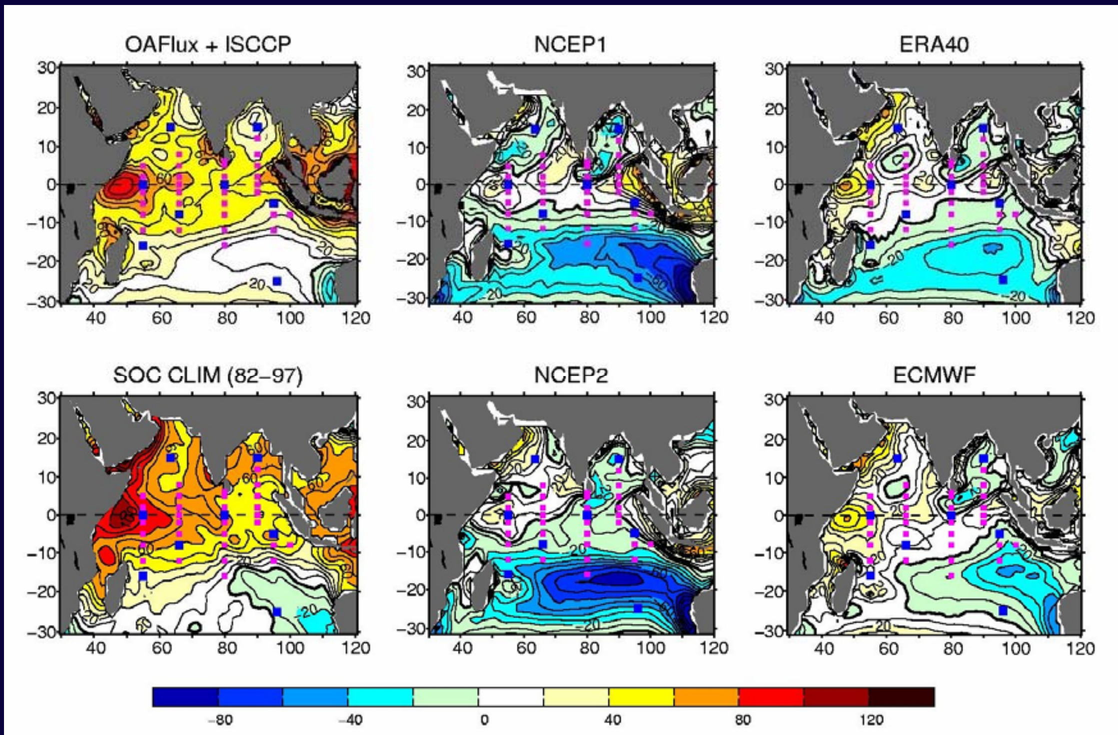
Global Surface Heat Flux

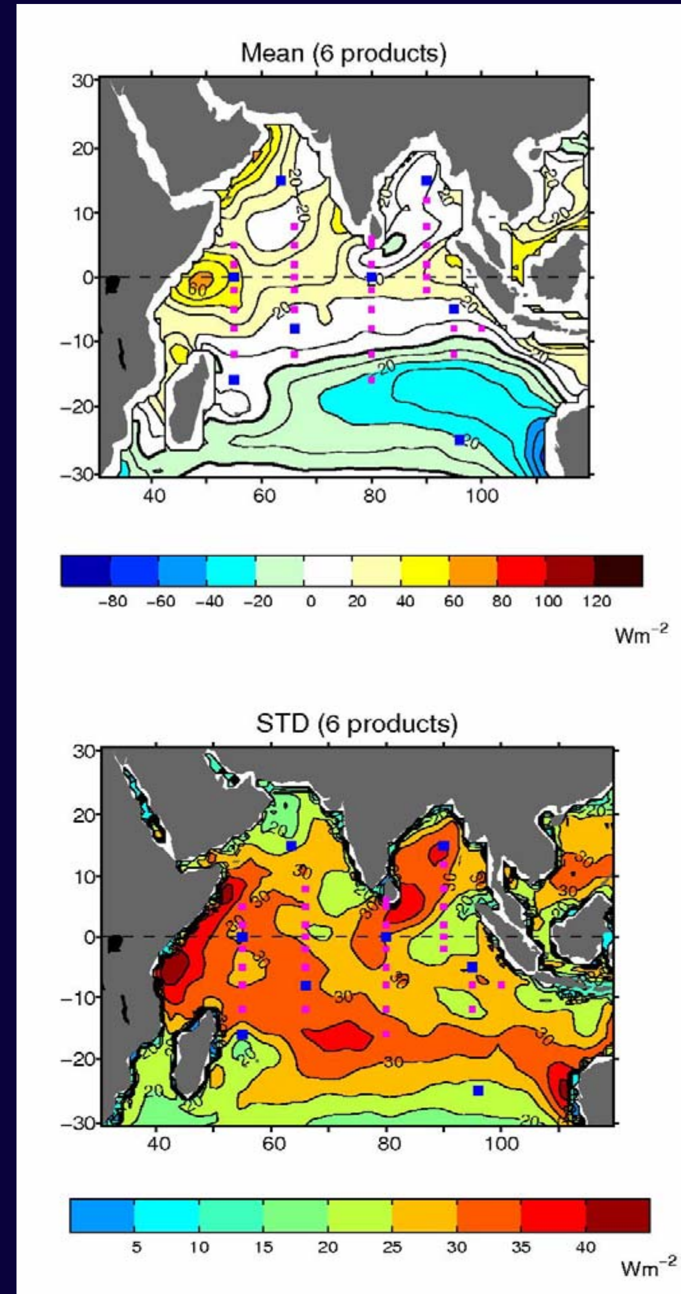
Mean Q_{net} (1988-2000)

Mean net surface heat flux (1988-2000)



Differences between the 6 products



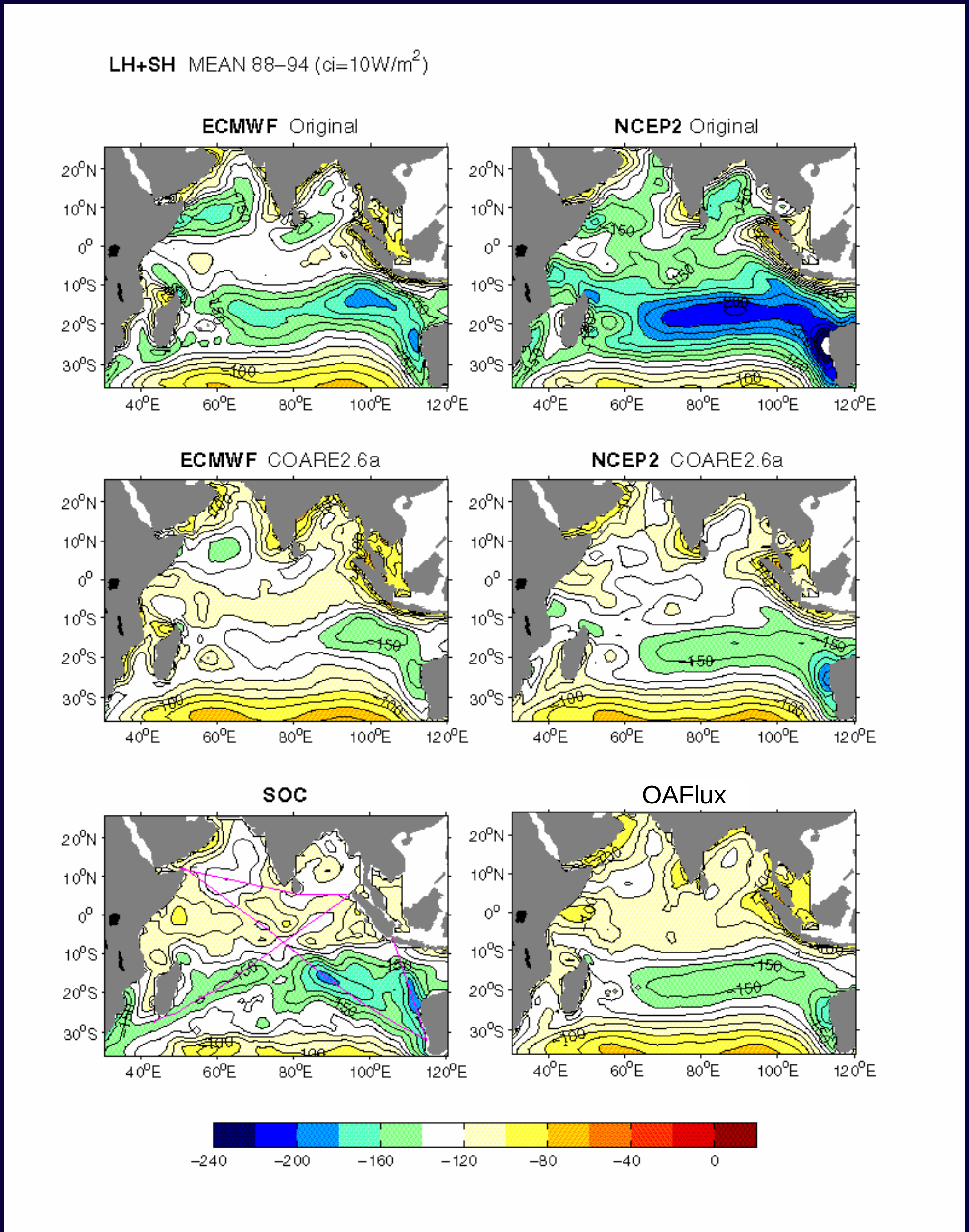


Why is it difficult to get the flux right?

- algorithm
- data

Which one is most problematic?

Impact of the flux algorithm on flux estimation



Latent and sensible fluxes

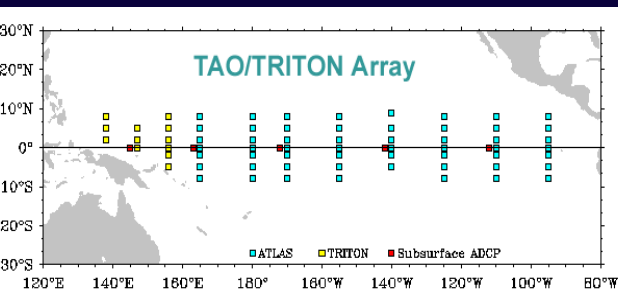
$$Q_{LH} = \rho\, L_e\, c_e\, U\, (q_a - q_s)$$

$$Q_{SH} = \rho\, c_p\, c_h\, U\, (T_a - T_s)$$

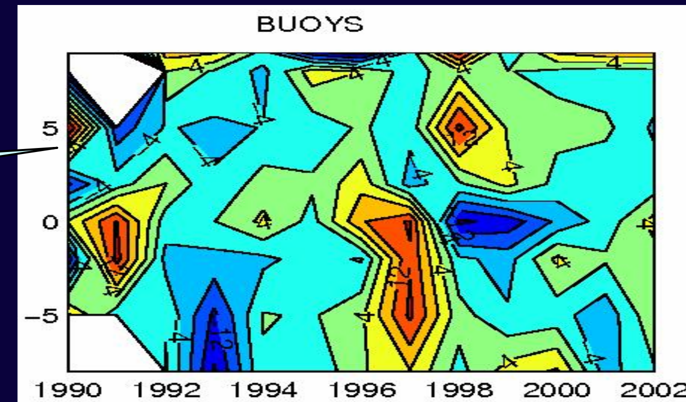
Problems in model humidity

Yu-1

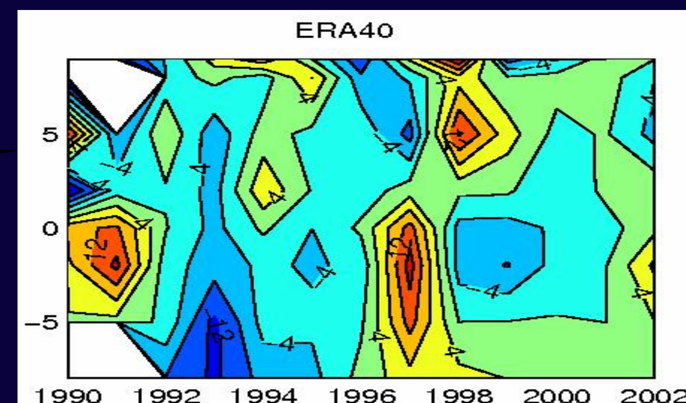
Year-to-year variations of zonally averaged latent heat flux from TAO buoys and ERA40



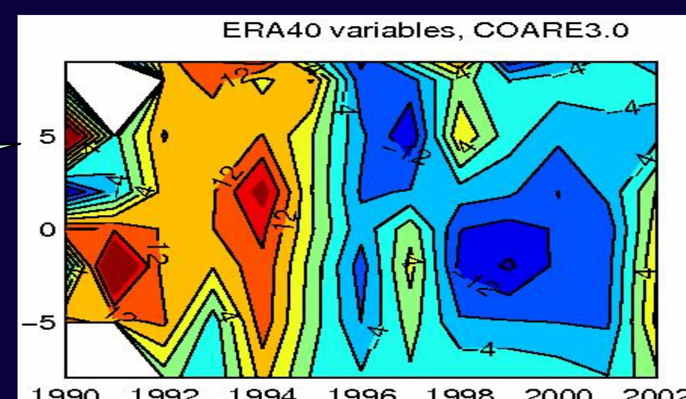
Buoy Q_{LH}



ERA40 Q_{LH}



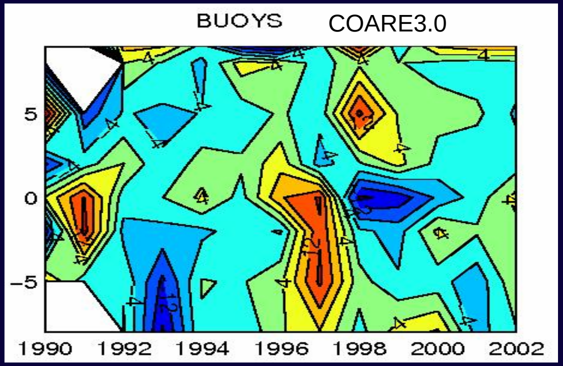
ERA40 variables COARE algorithm

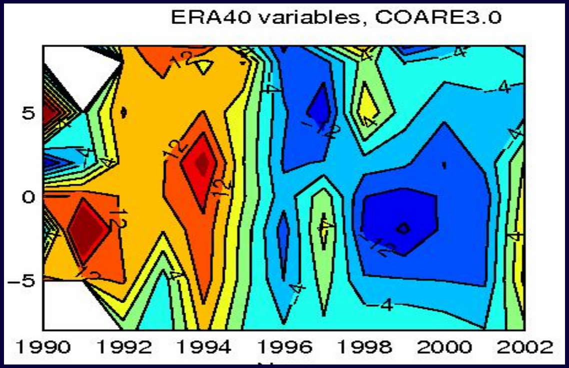


Positive (negative) flux anomalies indicate more (less) latent heat loss from the ocean.

(1) How different are the COARE3.0 and ERA40 flux algorithms? ??

(2) Which EAR40 variable is most different from TAO? Some Experiments

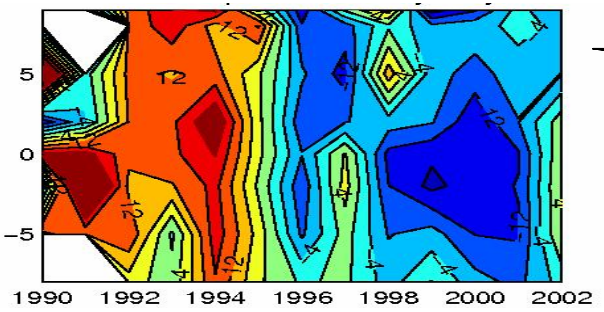




Latent heat flux:

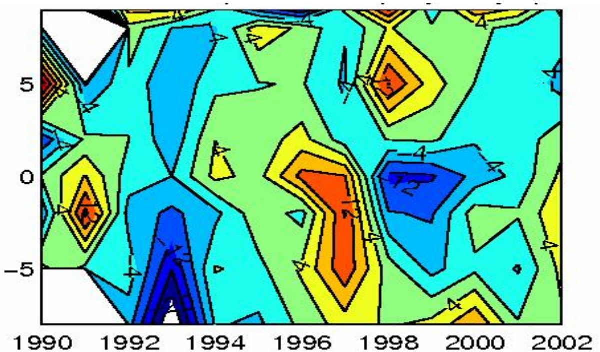
$$Q_{LH} = \rho L_e c_e U (q_s - q_a)$$

Replace ERA *U* with Buoy *U*



Exp#1:
Does ERA40 have correct U estimates?

Replace ERA q_a with Buoy q_a

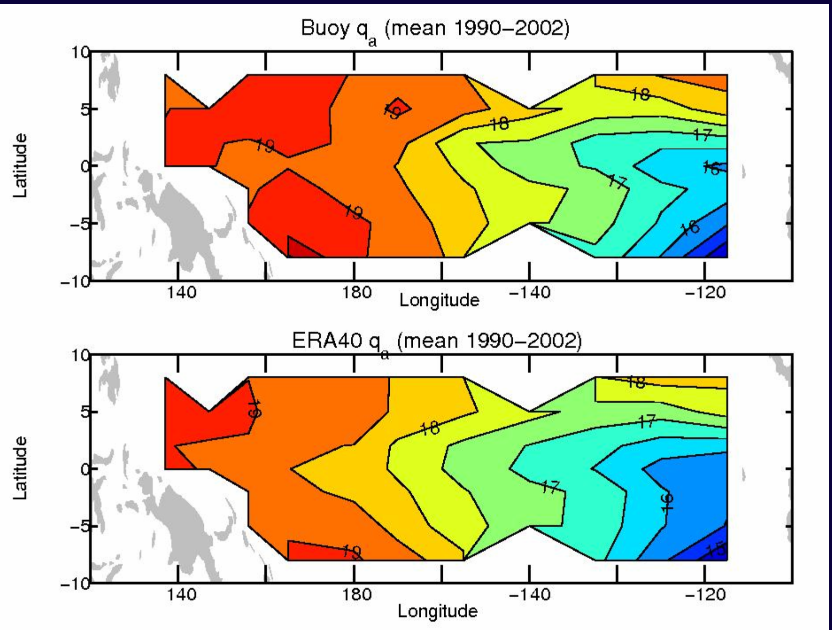


Exp#2:
Does ERA40 have correct q_a estimates?
NO!!!

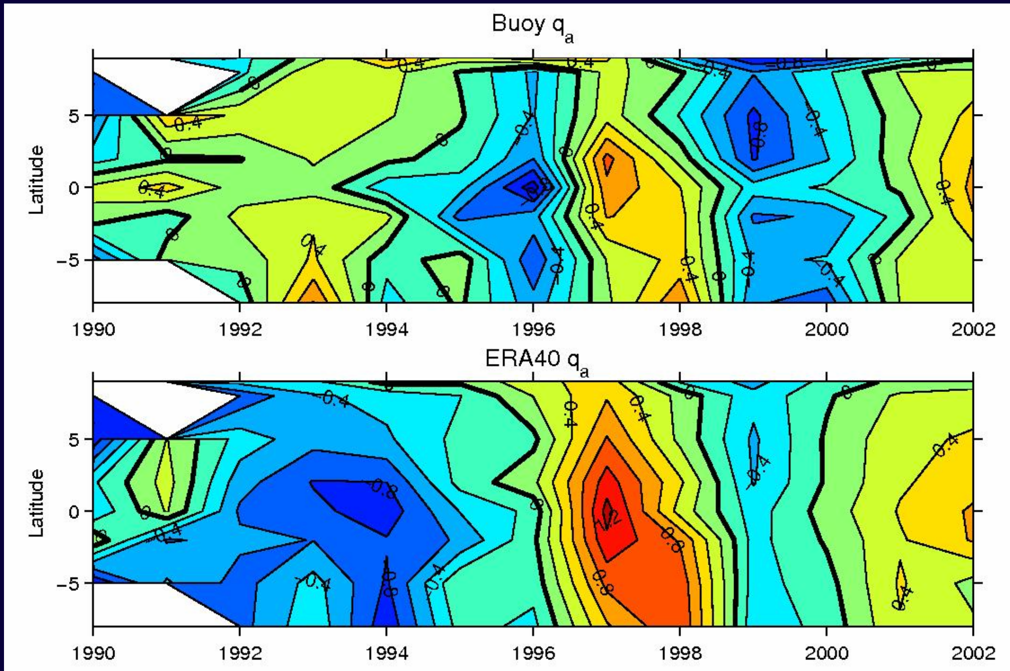
Errors in ERA40 near-surface humidity field

• Which one is incorrect, mean pattern or variability?

Mean q_a pattern
Buoy versus ERA40



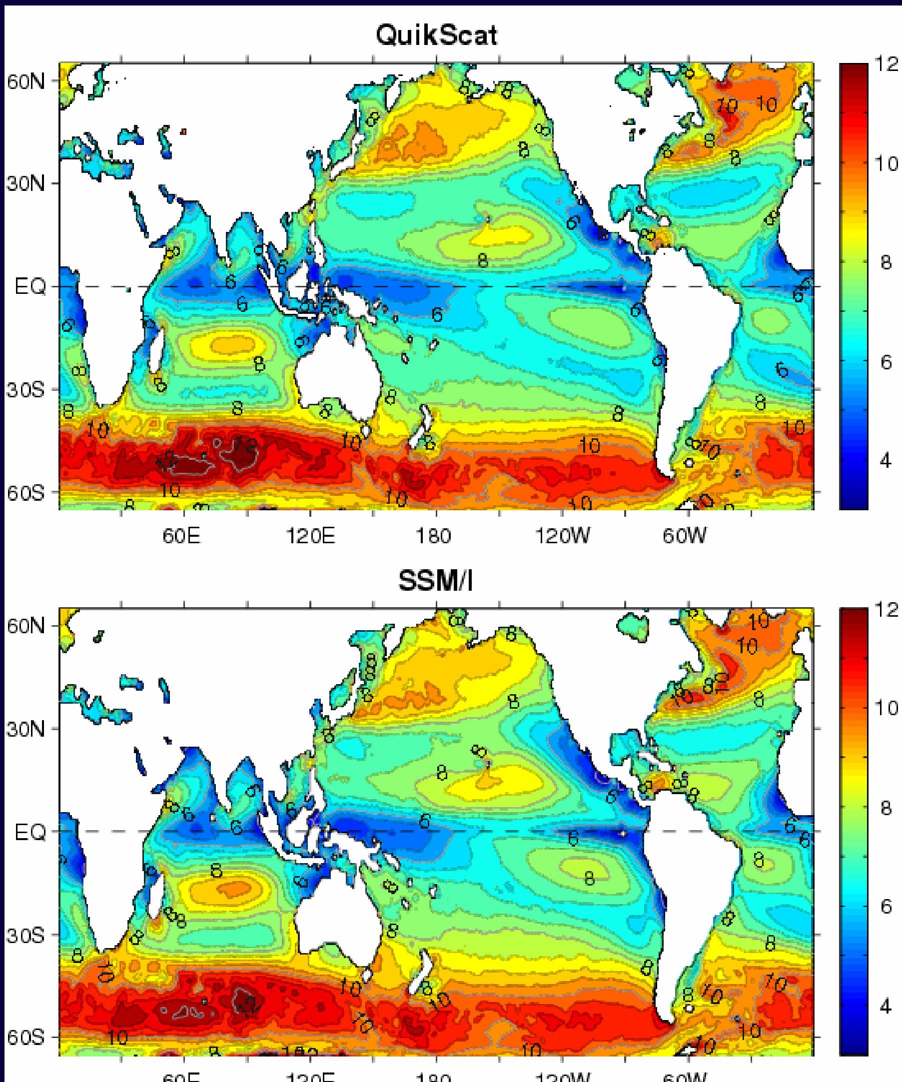
Year-to-Year Variations of zonal averages with mean removed
Buoy versus ERA40

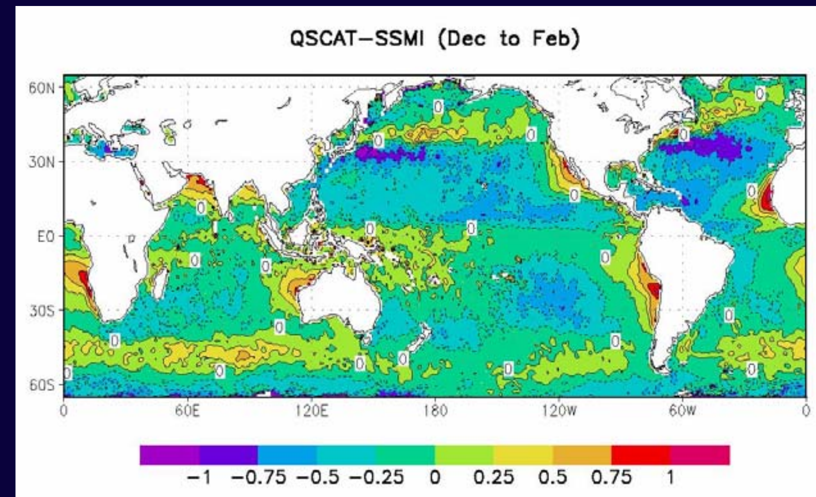


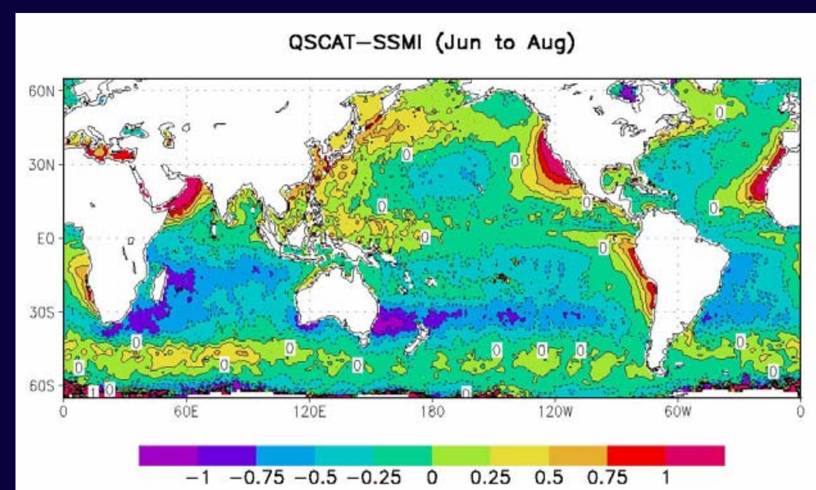
Positive (negative) q_a anomalies: wet (dry) q_a bias

Problems in satellite wind speed

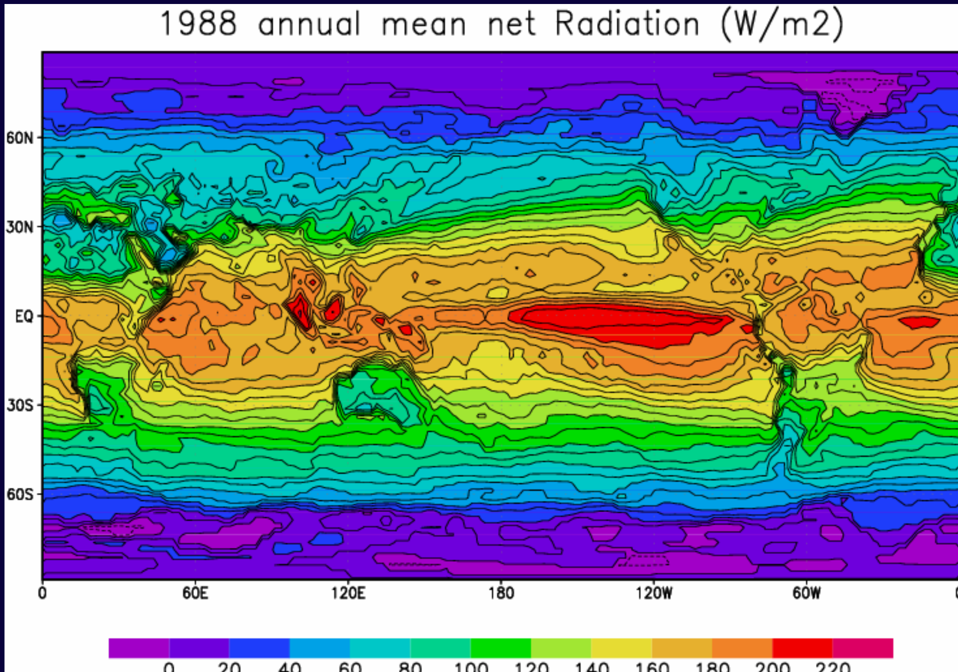
Mean Wind Speed (2000-2004)



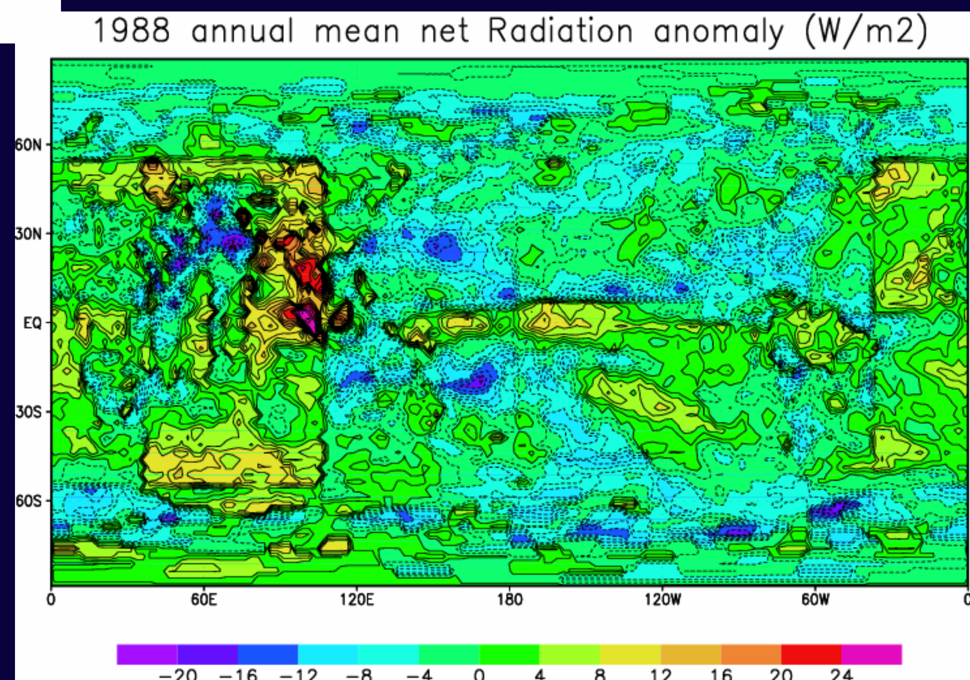




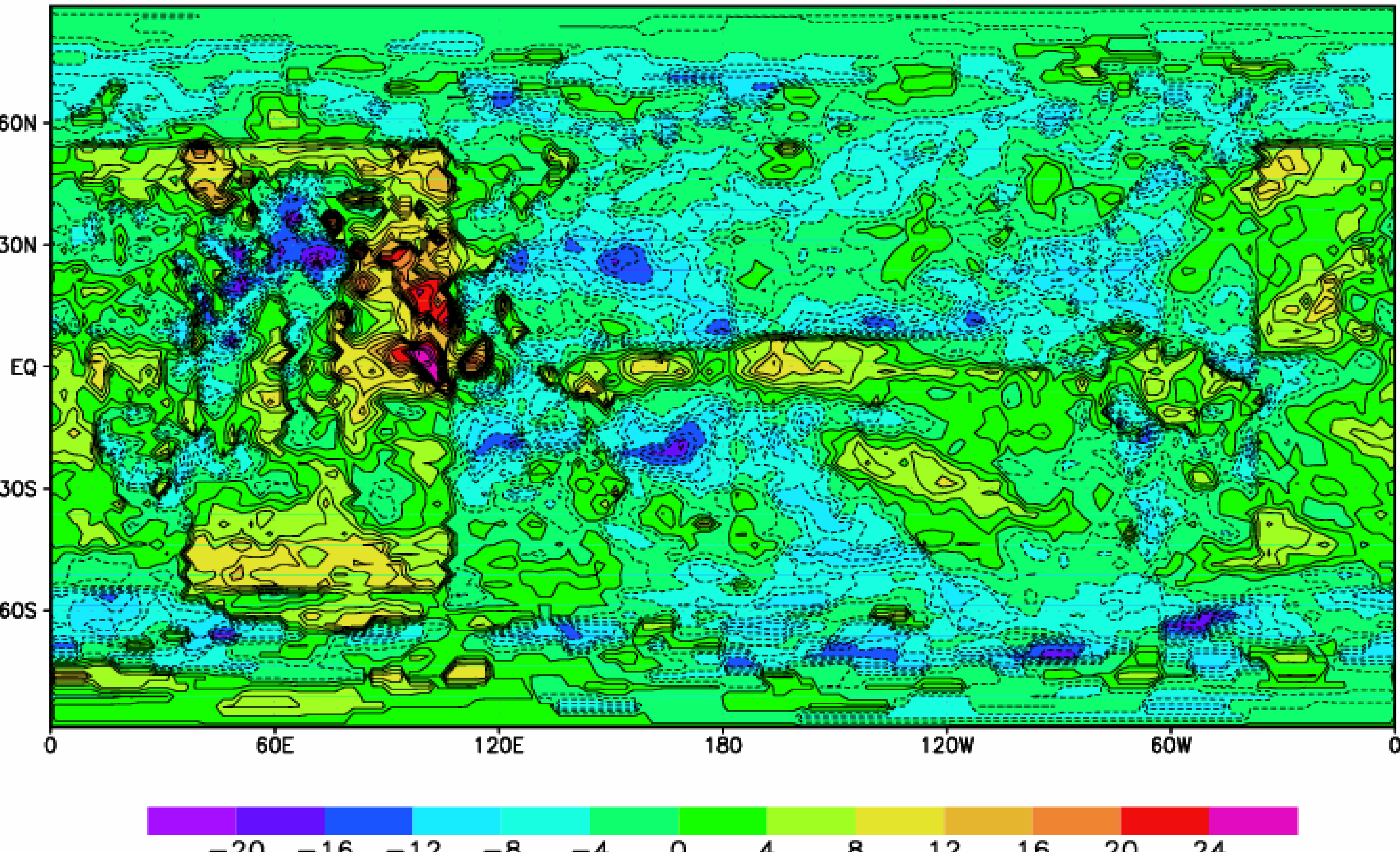
Problems in satellite radiation product



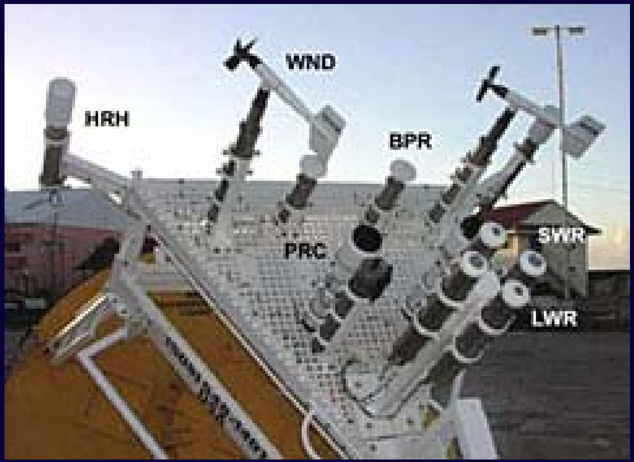
ISCCP radiation:
Global, 2.5-grid, 3 hourly



1988 annual mean net Radiation anomaly (W/m2)



Flux buoy measurements
WHOI Upper Ocean Processes Group – Bob Weller



What are measured by flux buoy?

- Air and sea temperatures
- Relative humidity
- Barometric pressure
- Wind speed and direction
- Incoming shortwave radiation
- Incoming longwave radiation
- Precipitation

How are the buoy surface heat fluxes derived?

- **Latent and sensible fluxes:**

  $Q_{LH} = \rho L_e c_e U (q_s - q_a)$

  $Q_{SH} = \rho c_p c_h U (T_s - T_a)$

  COARE bulk flux algorithm 3.0.

- **Net shortwave radiation:**

  $Q_{SW} = SW\downarrow - \alpha (SW\downarrow)$

  α: the surface albedo based on Payne(1972) formulation

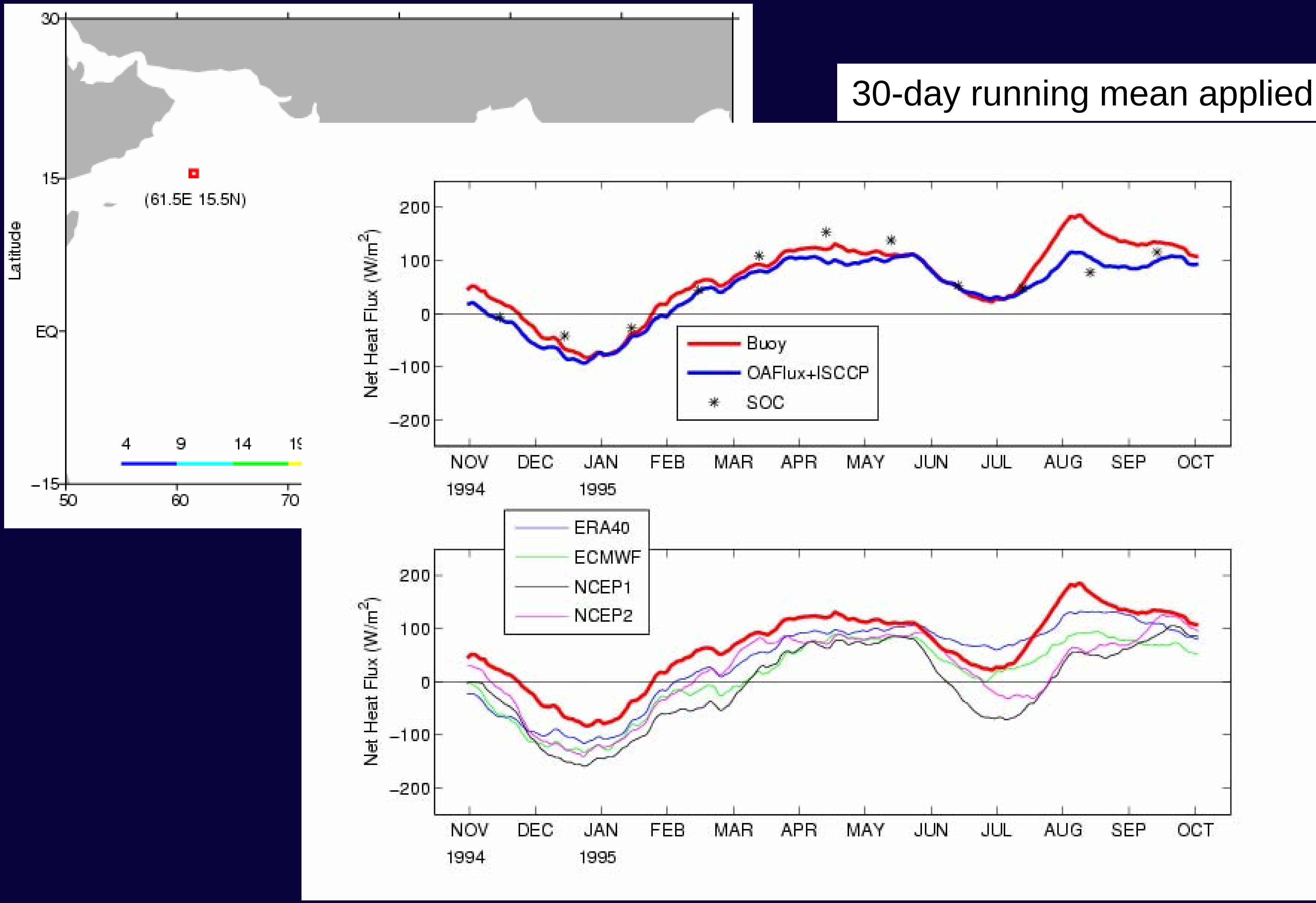
- **Net longwave radiation:**

  $Q_{LW} = LW\downarrow - (\varepsilon \sigma T_s^4 + (1 - \varepsilon) LW\downarrow)$

  σ: the Stefan – Boltzmann constant

Validation with in situ measurements – Arabian Sea Buoy

30-day running mean applied



Comparison with Buoy

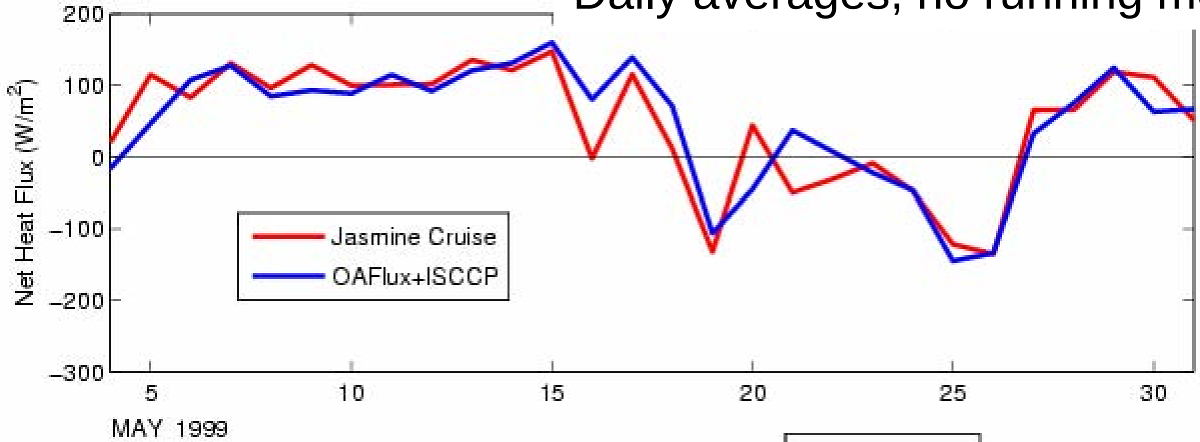
NET Heat FLux

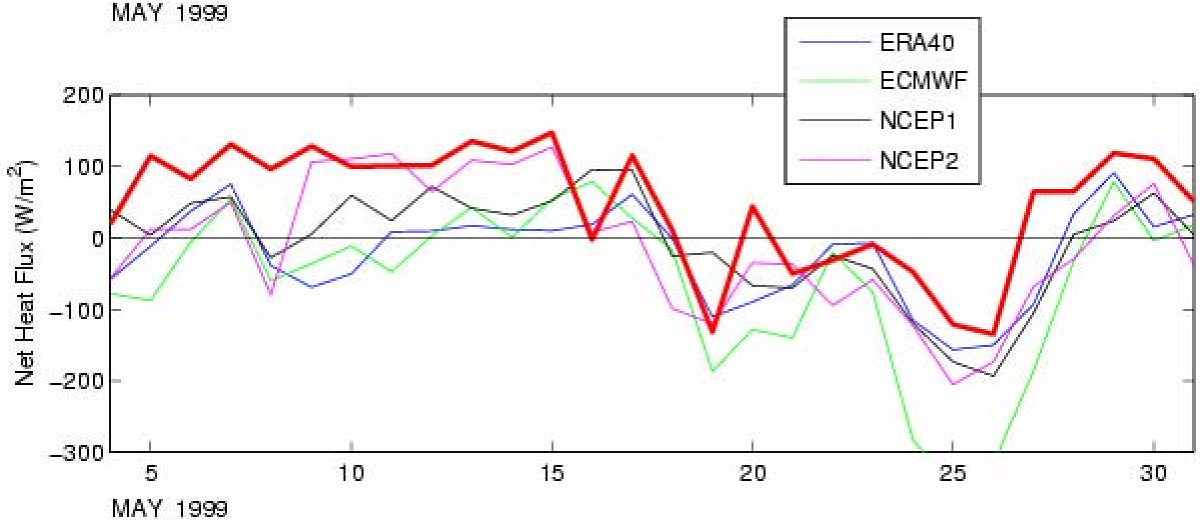
	Buoy	ERA40	ECMWF	NCEP1	NCEP2	OAFlux+ISCCP
ave	64.8	38.1	12.7	-4.9	20.6	48.3
dif	----	-26.7	-52.1	-69.7	-44.2	-16.5
rms	----	55.4	75.3	89.3	73.3	38.8
cor	----	0.84	0.80	0.82	0.79	0.91

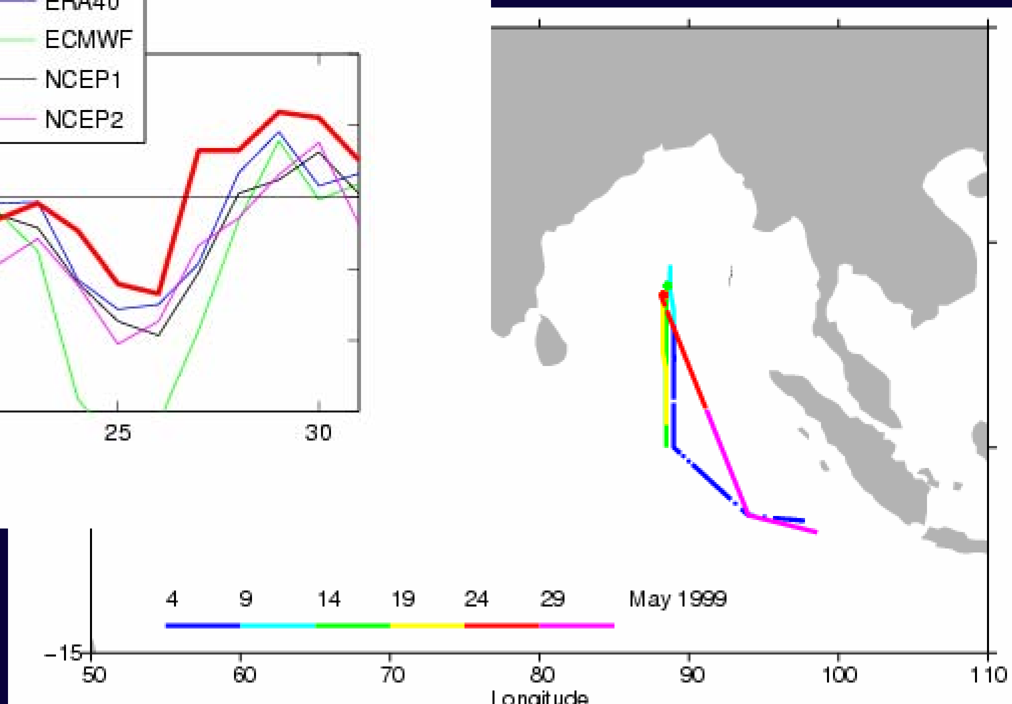
based on daily mean data from 1994.10 to 1995.10

Validation with in situ measurements – JASMINE cruise

Daily averages, no running mean







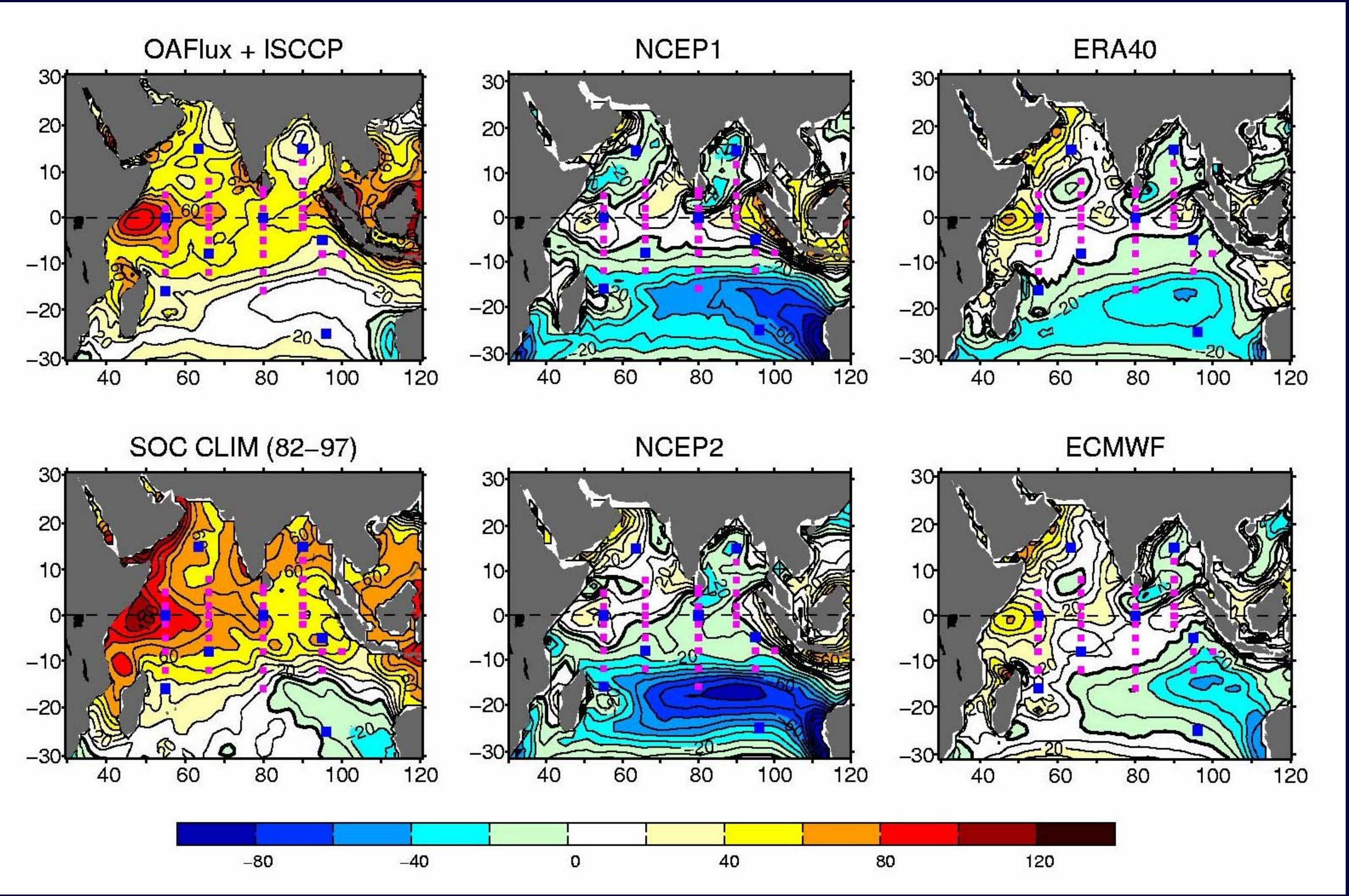
Comparison with JASMINE ship data

NET Heat FLux

	Buoy	ERA40	ECMWF	NCEP1	NCEP2	OAFlux+ISCCP
ave	47.5	-21.6	-61.0	-5.4	-9.6	48.0
dif	----	-69.1	-108.5	-52.9	-57.1	0.5
rms	----	91.3	130.9	80.0	74.2	38.7
cor	----	0.70	0.76	0.71	0.86	0.89

based on daily mean data

Mean Net Heat Flux



Assessing the role of surface heat fluxes in seasonal-to-interannual variations of SST

$$dSST = dt\, Q_{net}/\rho c_p h$$

(1) How much can the surface heat fluxes explain the seasonal-to-interannual evolution of SST?

(2) How different are different heat flux products in describing the SST seasonal-to-interannual variability?

In calculating the correlation <dSST, Qnet>,

dt: one month

dSST: $\overline{SST}$(the last 5 days of the month) - $\overline{SST}$(the first 5 days of the month)

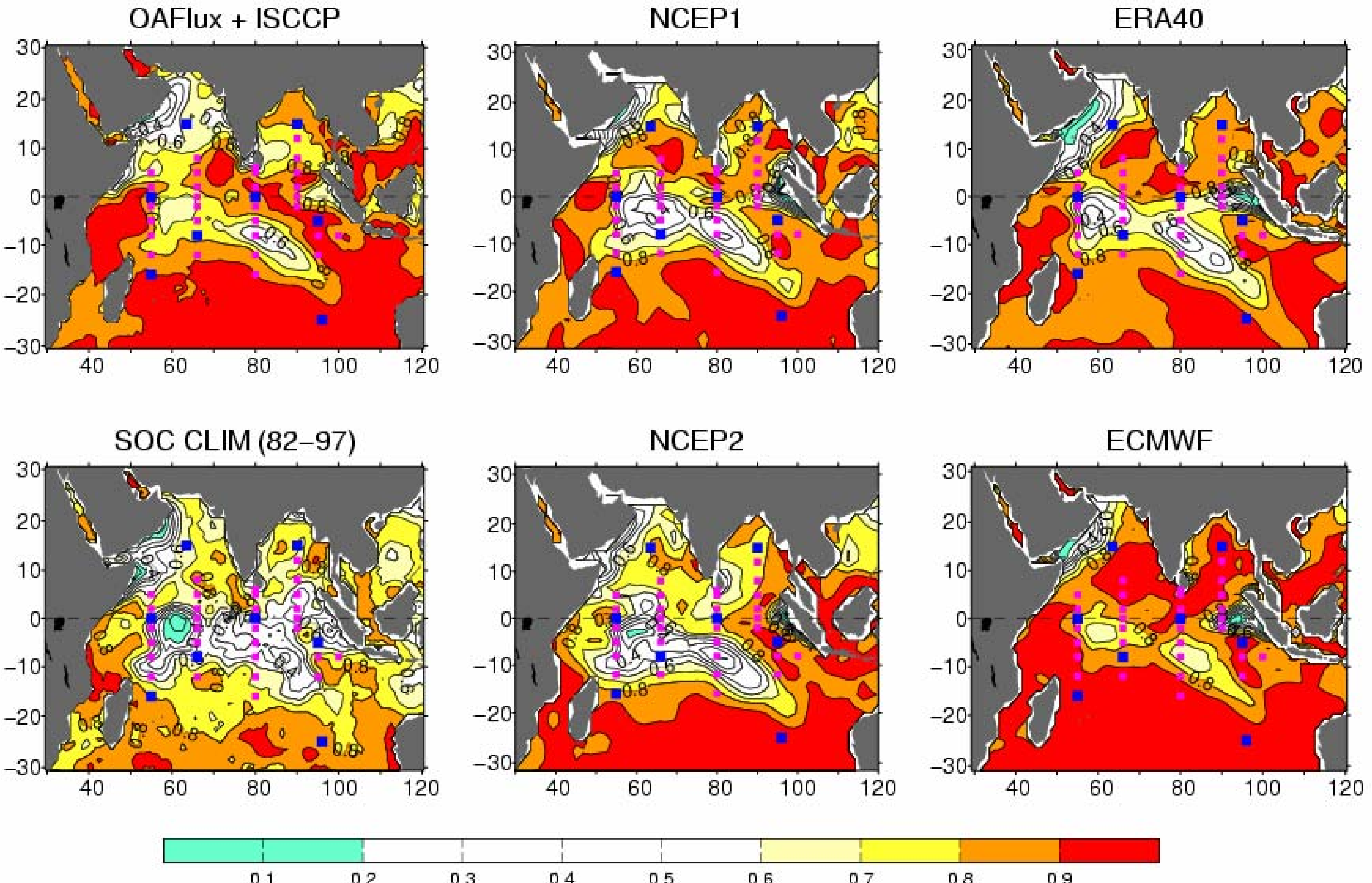
Q_{net}: monthly average

seasonal variability: annual mean removed

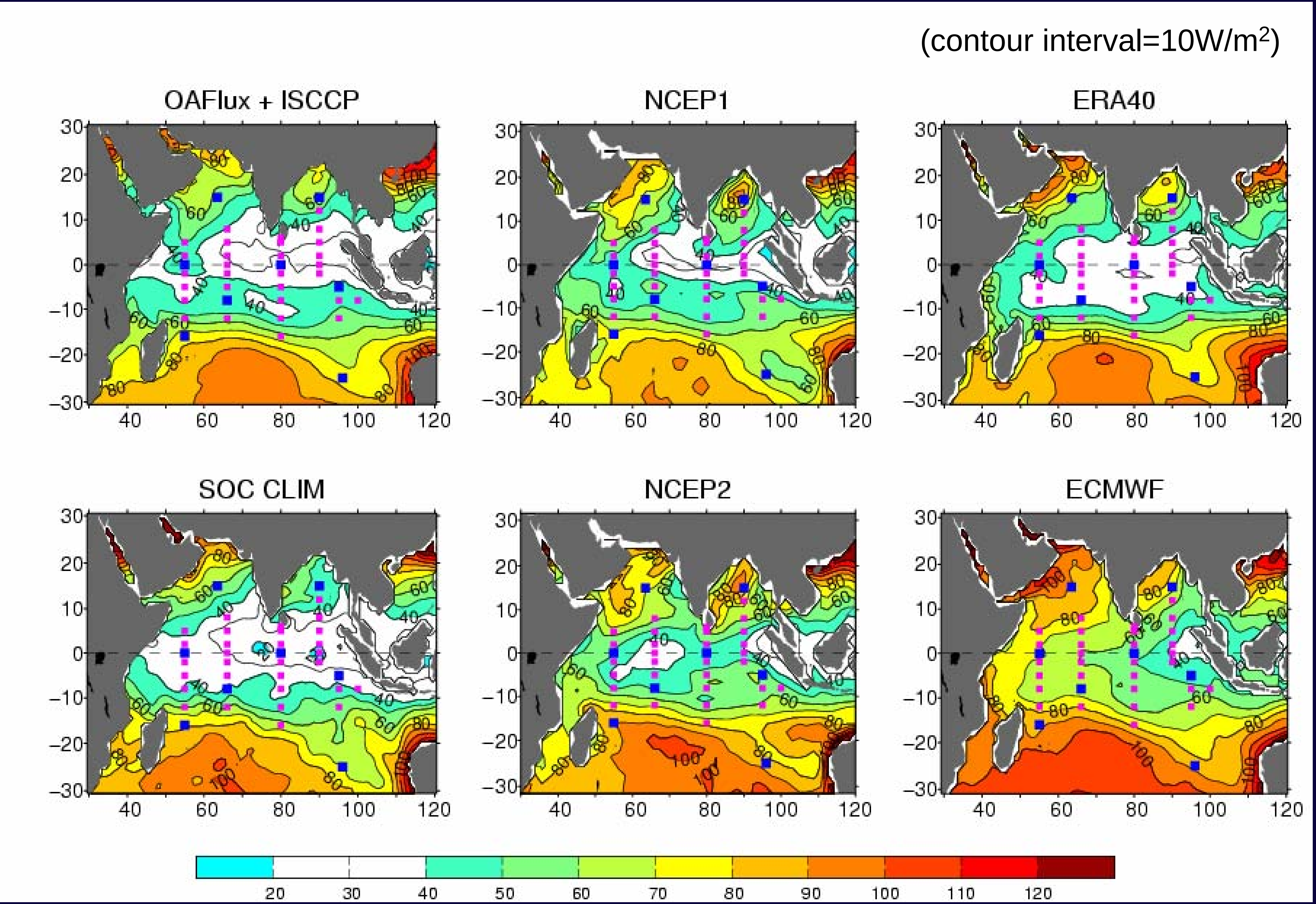
interannual variability: mean seasonal cycle removed

Correlation <dSST, Q_{net}> Seasonal variability

(contour interval=0.1)

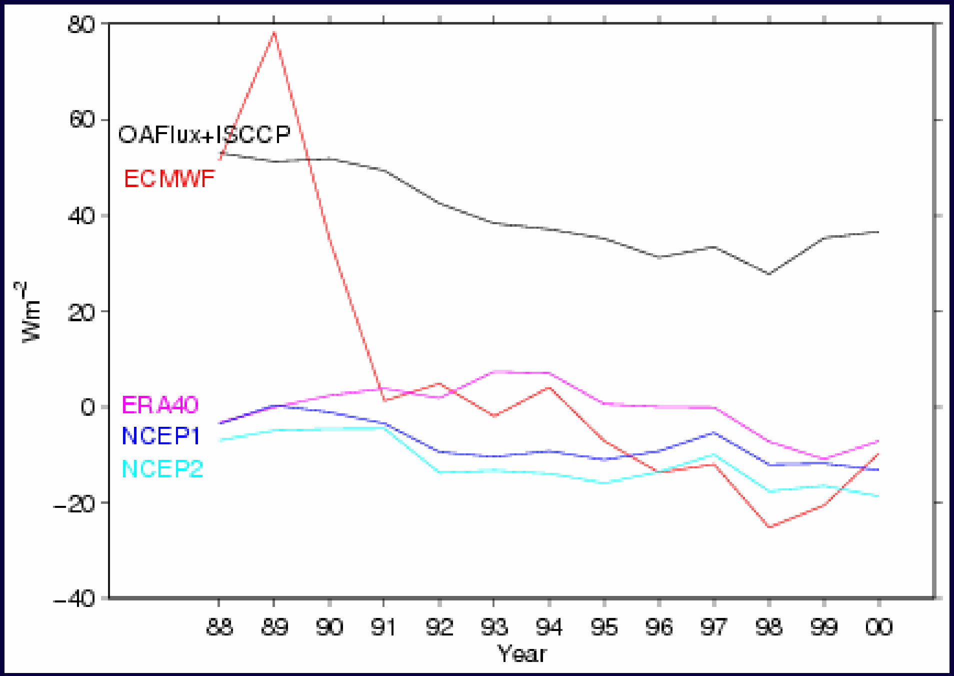


STD of Net Surface Heat Flux (1988-2000)

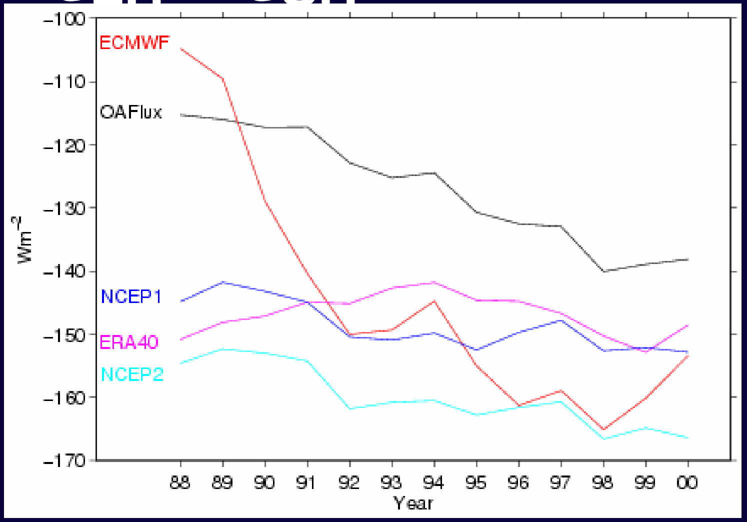


Effects of changing model platforms on ECMWF fluxes

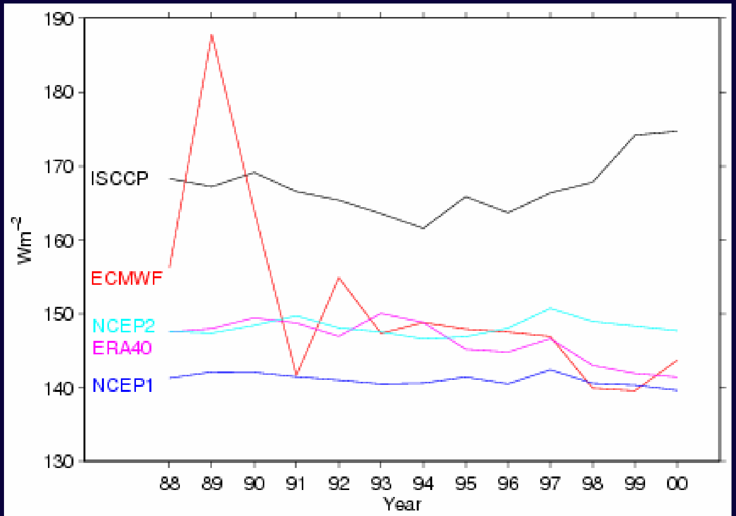
Q_{net}



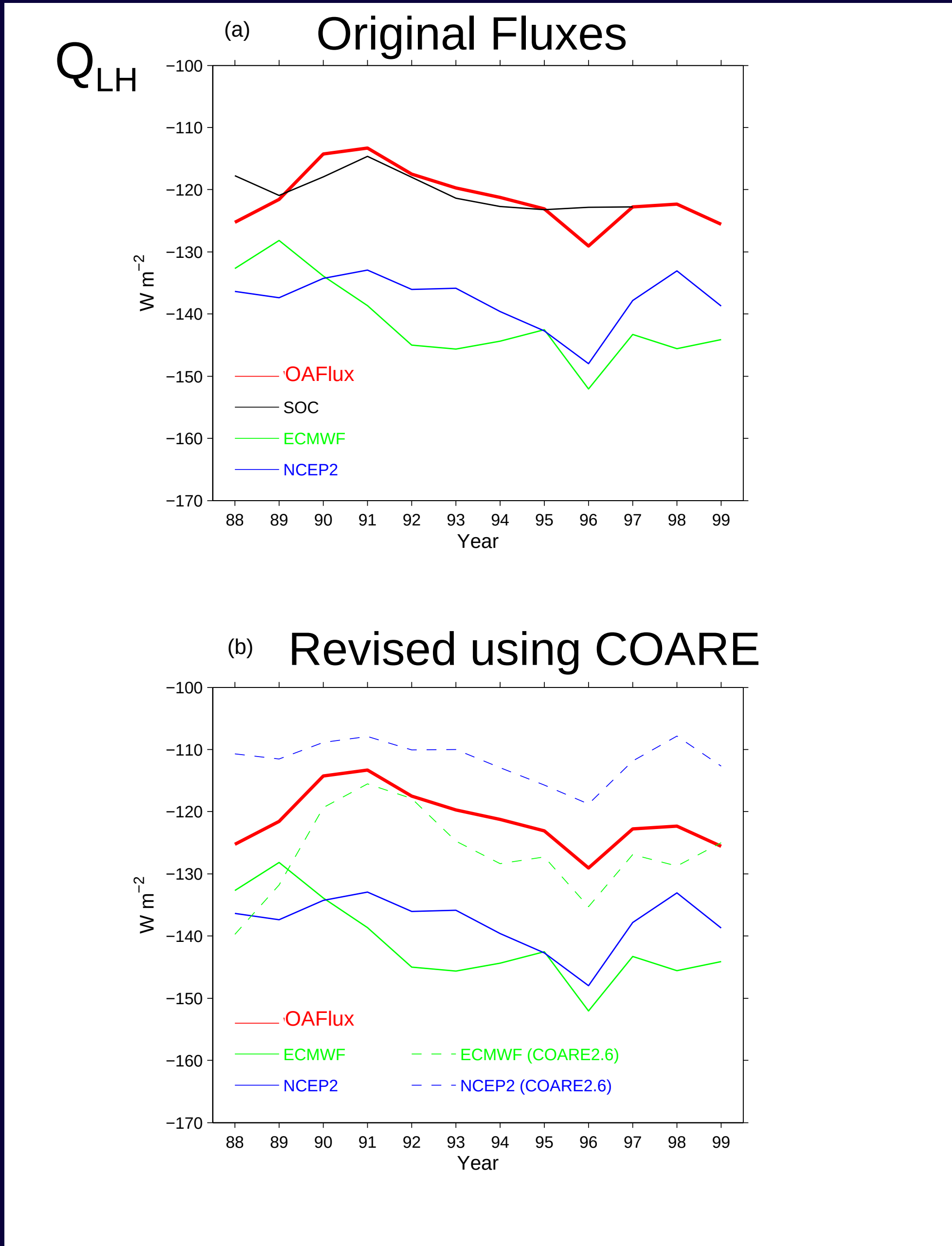
$Q_{LH}+Q_{SH}$



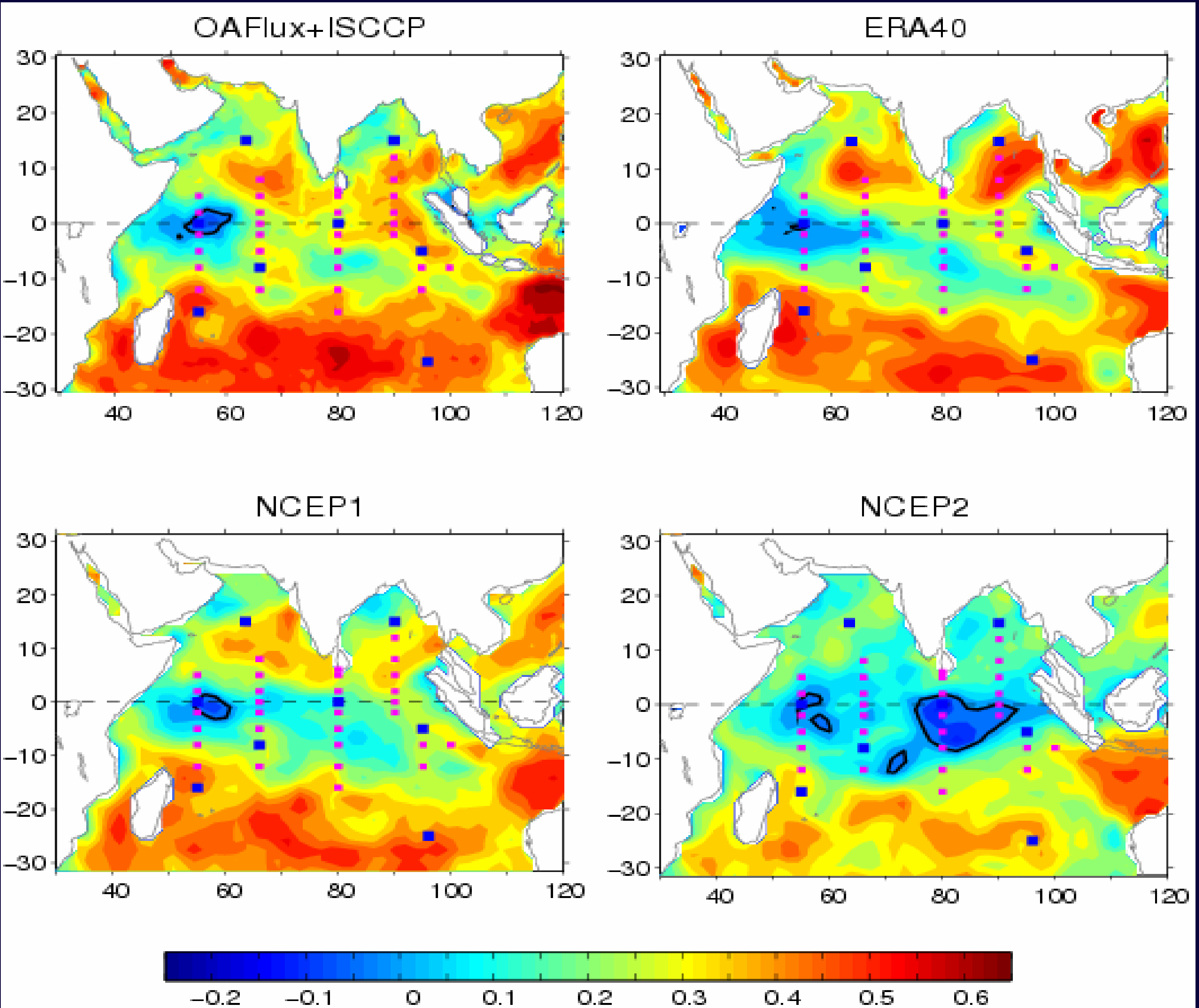
$Q_{LW}+Q_{SW}$



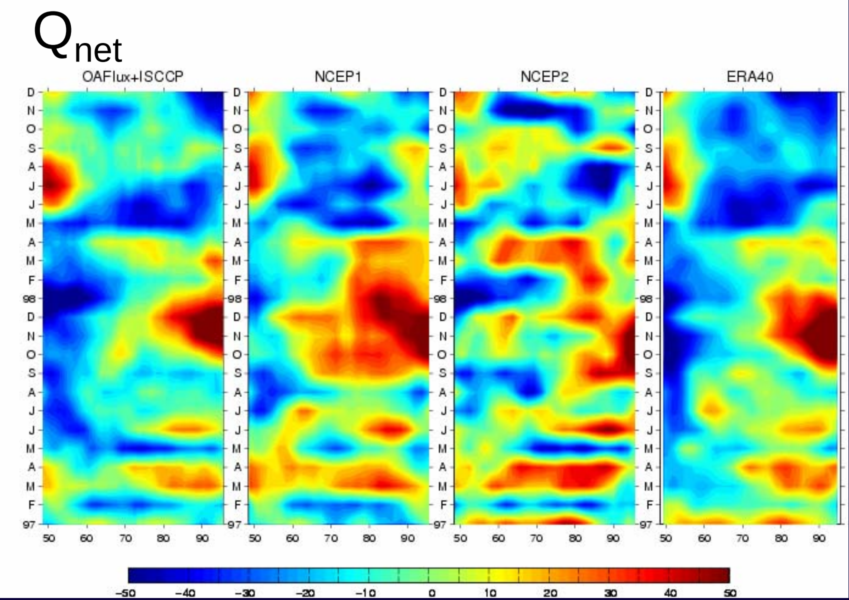
Atlantic Ocean: average over the region [0, 45°N]

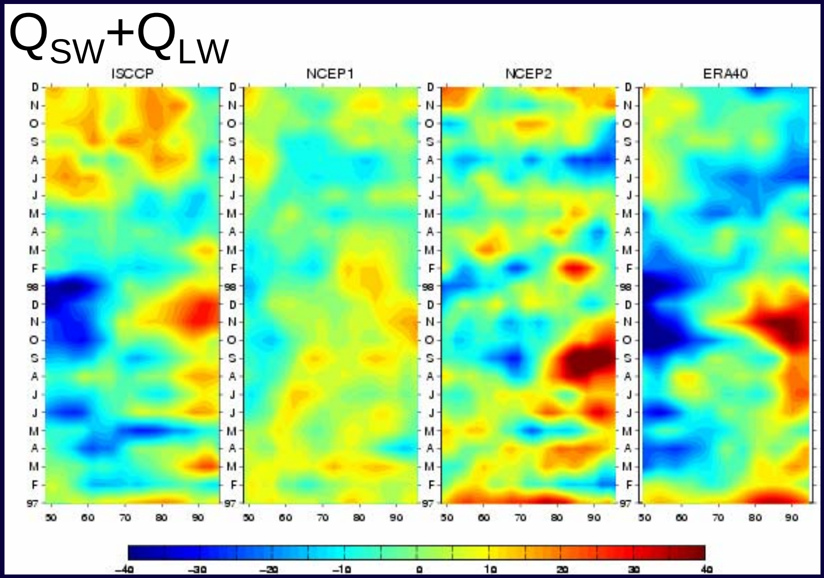


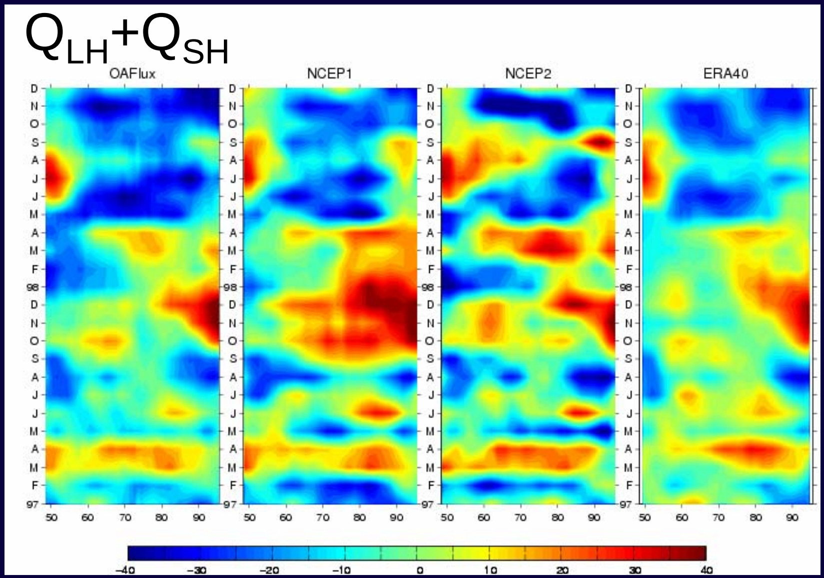
Correlation <dSST, Qnet>   Interannual variability



Changes in Q_{net} during 1997-98 Avg[5°S – 5°N]





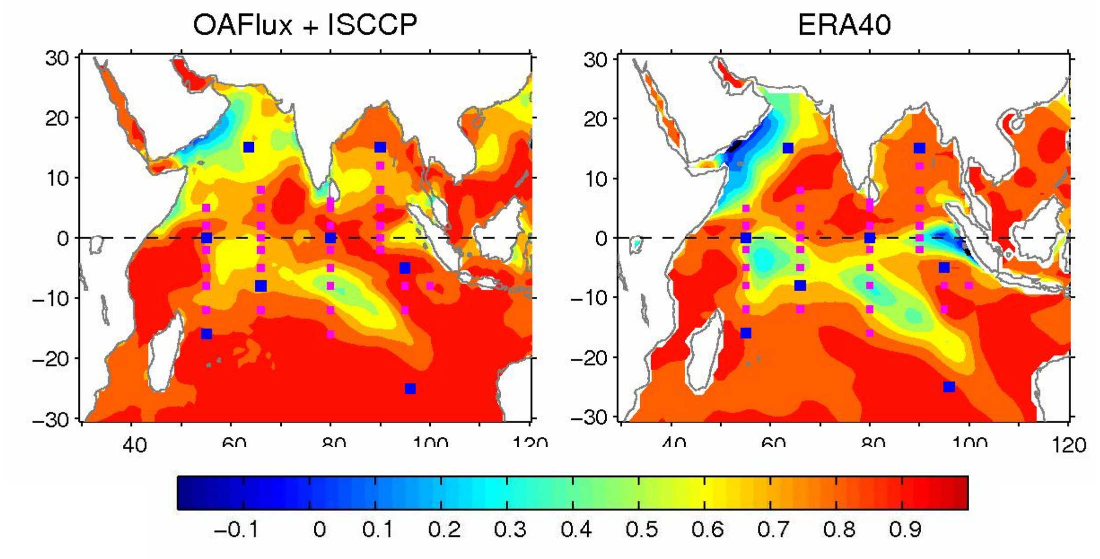


Correlation patterns: seasonal versus interannual

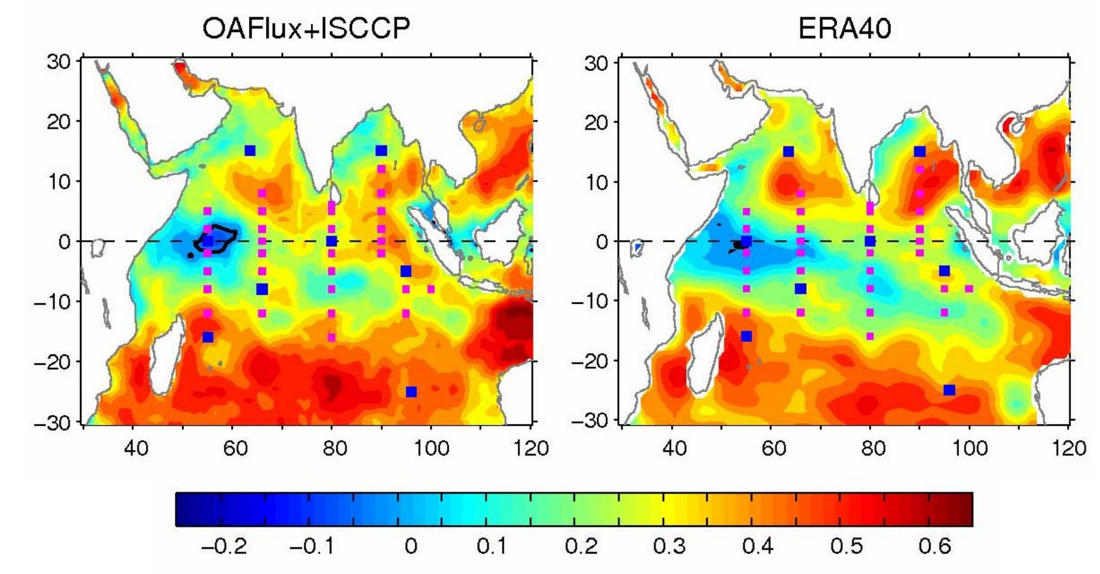
Pattern does not change in:
- Arabian Sea
- Southern IO

Pattern changes in:
- Bay of Bengal
- W. equatorial region

Seasonal

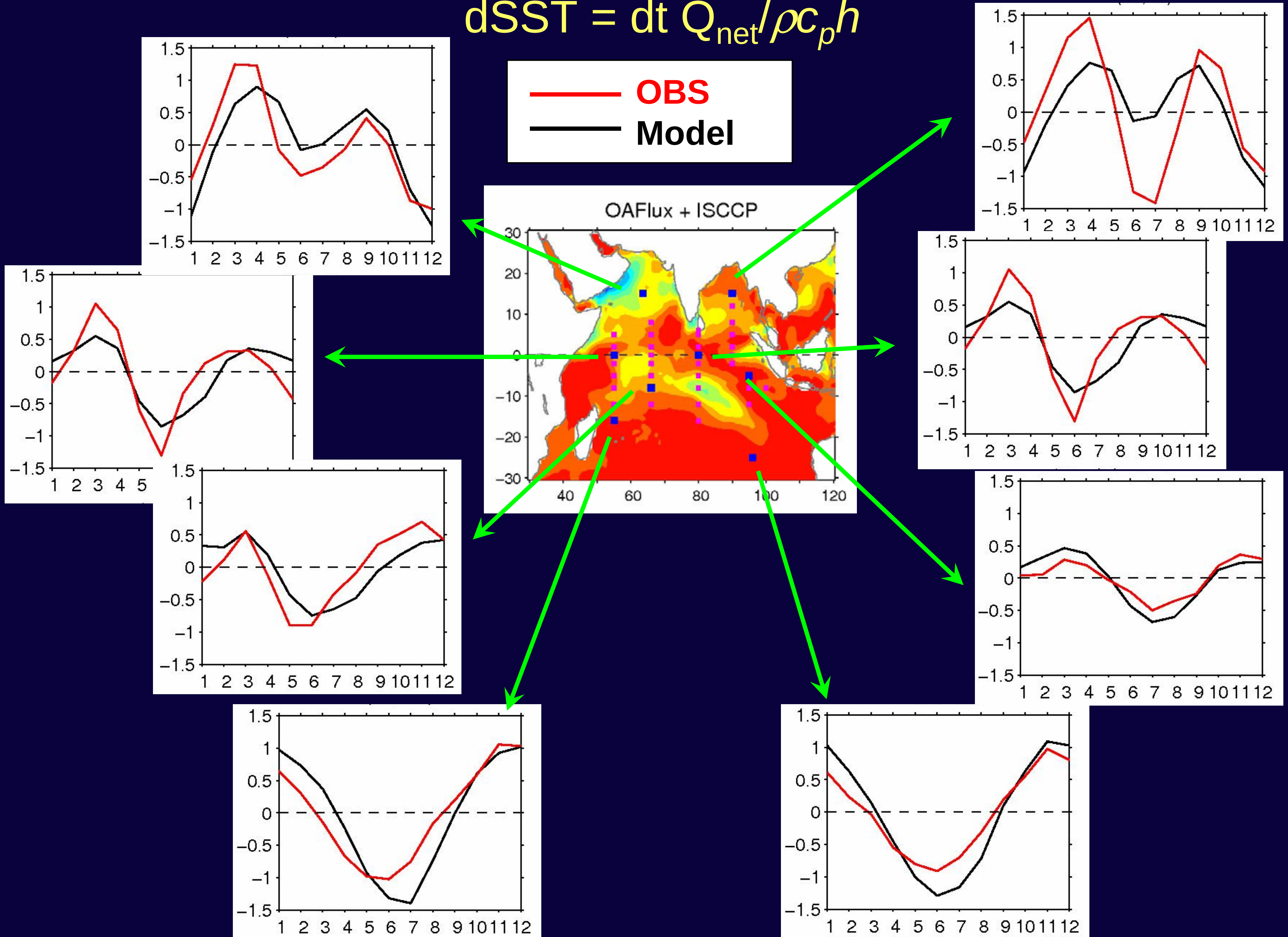


Interannual



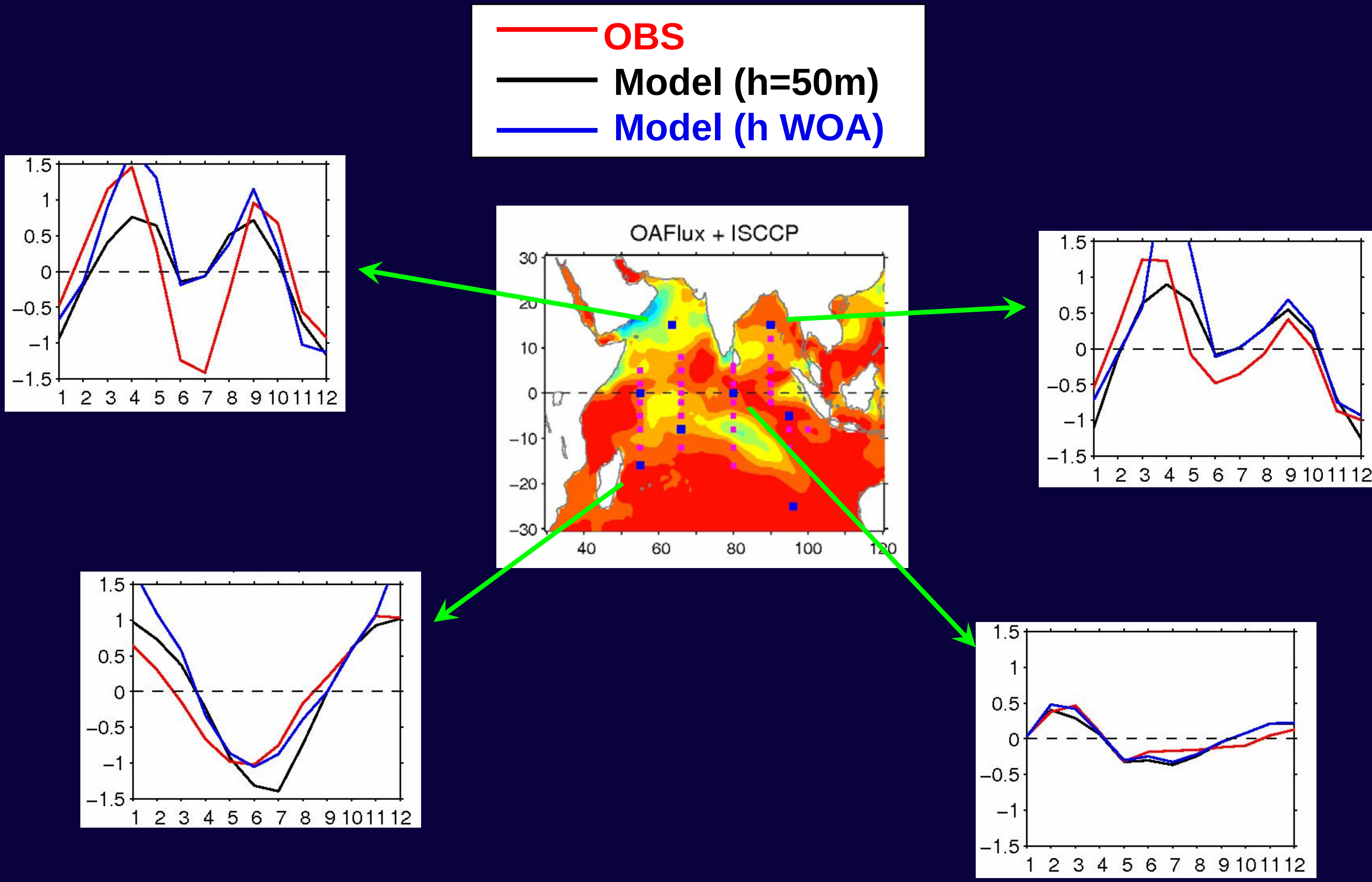
Model prediction of dSST: seasonal cycle

$$dSST = dt\, Q_{net}/\rho c_p h$$



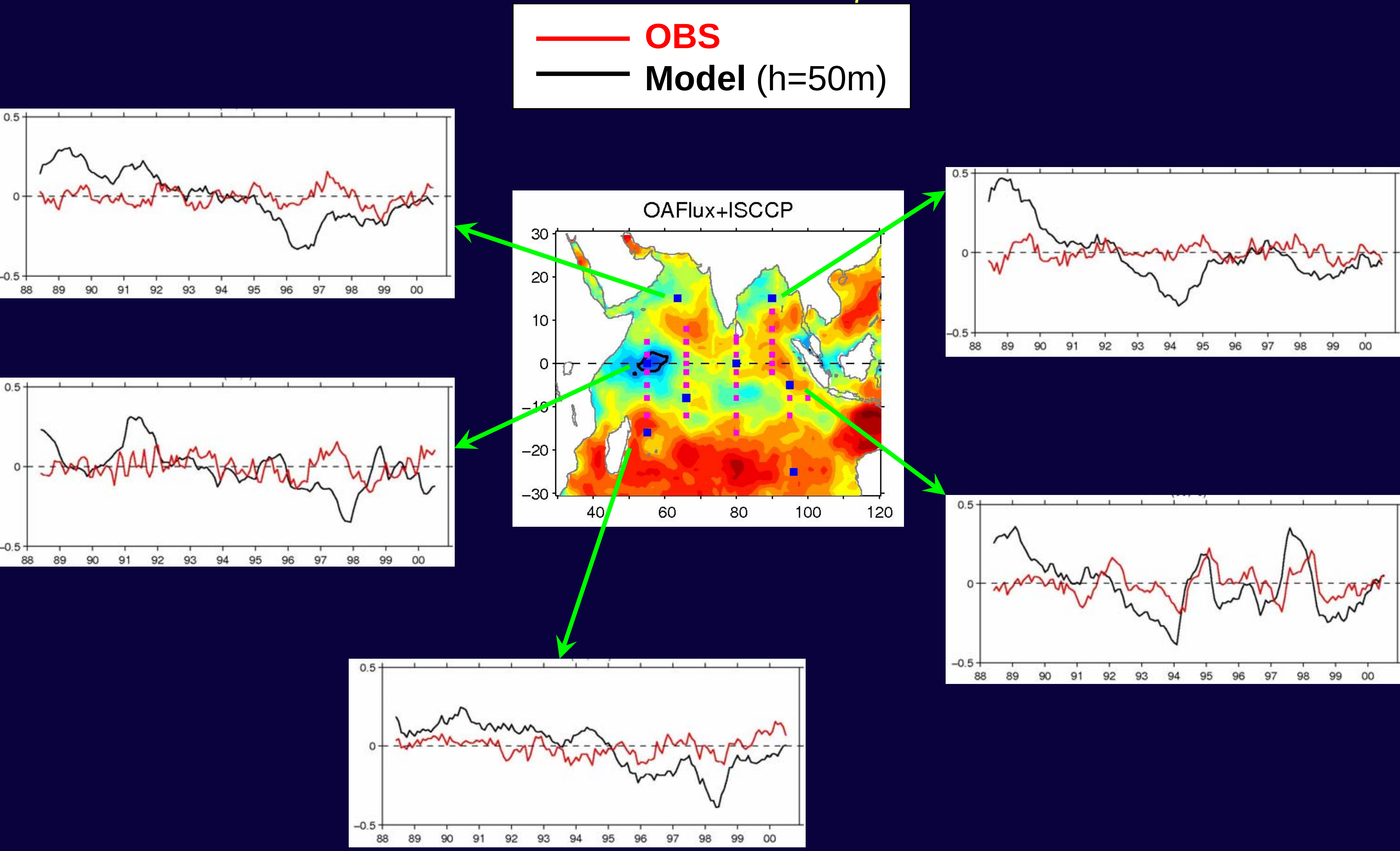
Model prediction of dSST: seasonal cycle

$$dSST = dt\, Q_{net}/\rho c_p h$$



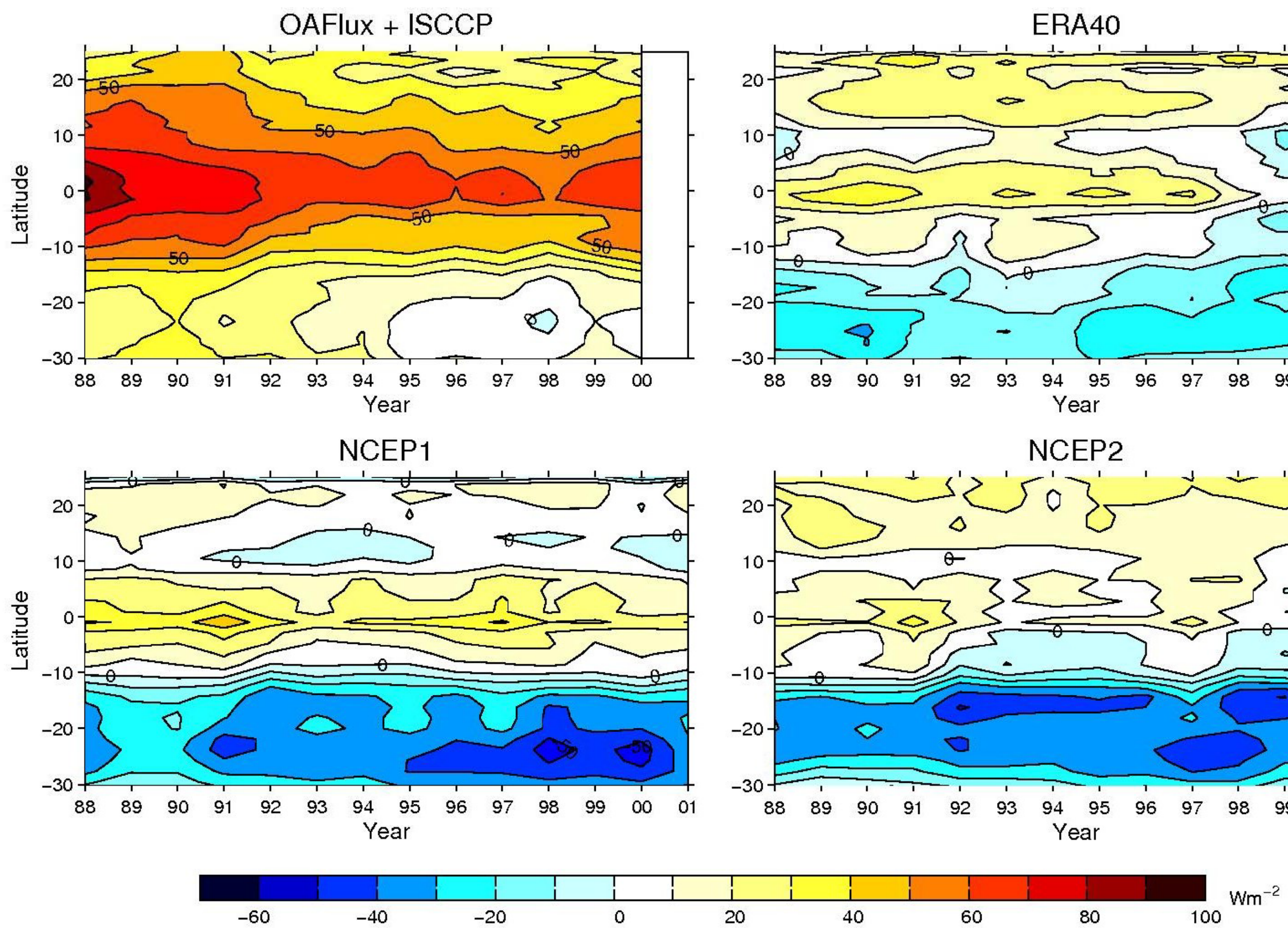
Model prediction of dSST: interannual variability

$$dSST = dt\, Q_{net}/\rho c_p h$$

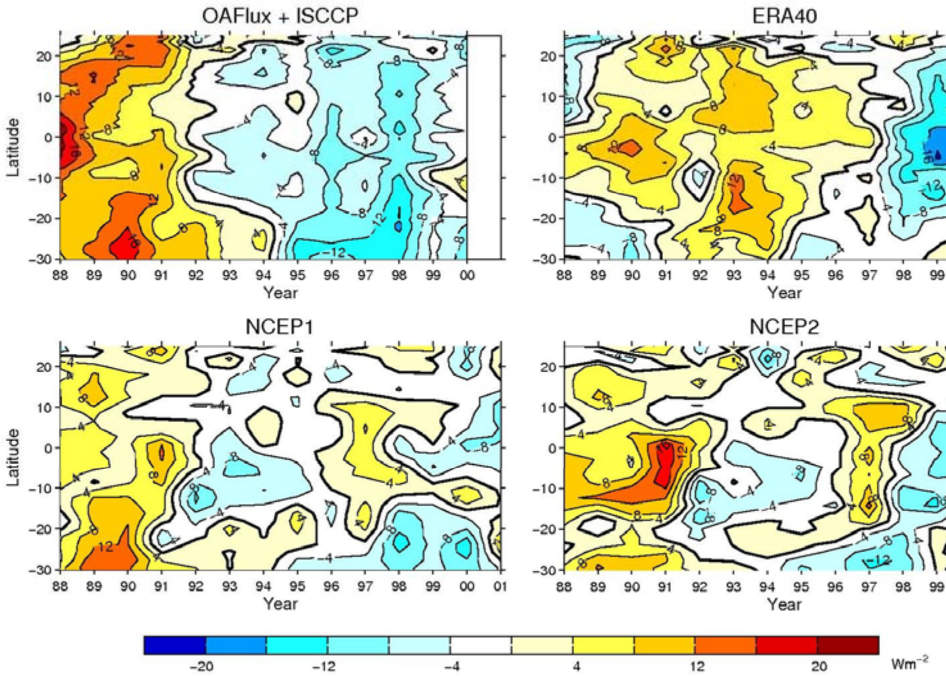


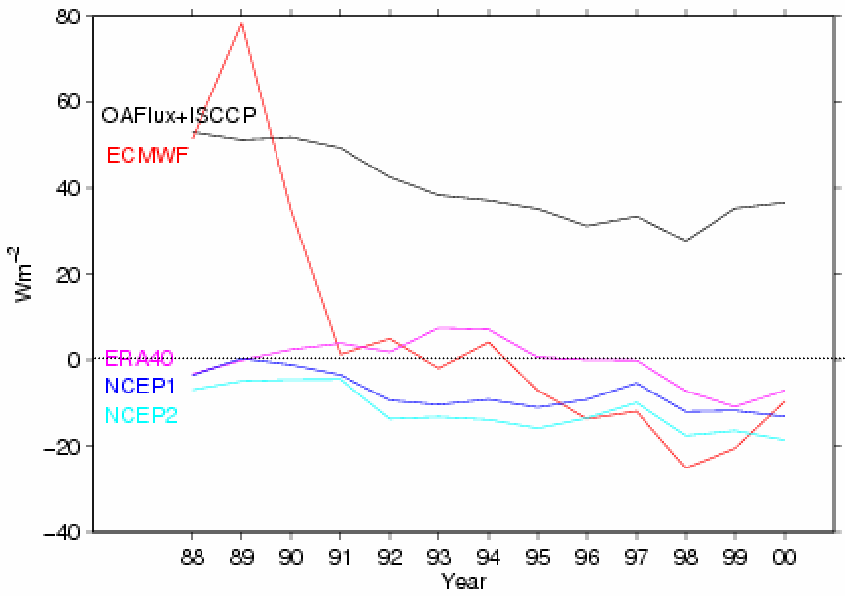
Year-to-year variations in Q_{net}

(contour interval=10Wm^{-2})



Year-to-year variations in zonally averaged Q_{net} if the mean removed





Summary

On improving the flux estimation:

- The most challenge issue in estimating surface heat fluxes is to reduce the bias in every data source.
- Long-term buoy observations are the only means that the biases can be identified and corrected.
- A proper combination of data from different sources can reduce the bias and improve the mean and variability of the fluxes.

On variability of the flux products:

- The NWP reanalysis flux products have a reasonable representation for the variability on seasonal-to-interannual timescales.
- For decadal and longer timescales, there are major differences between the products.