The WHOI Daily Flux Product and its Comparison with in situ Flux Measurements and the SOC Climatology

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The WHOI Daily Flux Analysis for the Atlantic Ocean

- **Latent and sensible fluxes:**
  - A synthesized product that is made from combining satellite observations (AVHRR, SSMI), the ECMWF operational forecast outputs, and the NCEP reanalysis outputs.
  - Covering the basin from 65°S to 65°N on 1°×1° grid.
  - Presently available for the period from 1988 to 1999 with daily resolution.

- **Longwave and shortwave radiations:**
  - Under development using satellite observations.
  - Daily resolution, 1°×1° grid.

Methodology used in developing the WHOI flux analysis

The WHOI flux analysis results from the use of

the best possible basic variable estimates

through synthesizing satellite and ECMWF and NCEP2 model outputs.

the best possible flux bulk algorithm

by applying the state-of-the-art COARE algorithm (Bradley et al., 2000; Fairall et al., 2003)

Why can the synthesis approach improve estimates of basic variables?

- **The objective of the synthesis is to obtain an optimal analysis field that is as close as possible to the true state in a rms sense.**

  i.e, the synthesis cancels out the errors in input data and produces an optimal estimate that has the minimum error variance.

- **The methodology governing the synthesis is based on the Gauss – Markov theorem.**

  It states that the linear least squares estimator is the most efficient estimator and the solution has the minimum variance, when data are combined in a linear fashion.

- **The application of the theory involves finding a minimum of the objective function**,

  $$J = J_{ECMWF} + J_{NCEP2} + J_{satellite,} + \textit{a priori} \text{ constraints}$$

  where $J_{obs} = (X_{obs} - X_{ana})^T W (X_{obs} - X_{ana})$. X denotes a variable.

- A conjugate-gradient method is used iteratively to find a minimum of the objective function J.

How is the WHOI flux analysis compared with existing products?

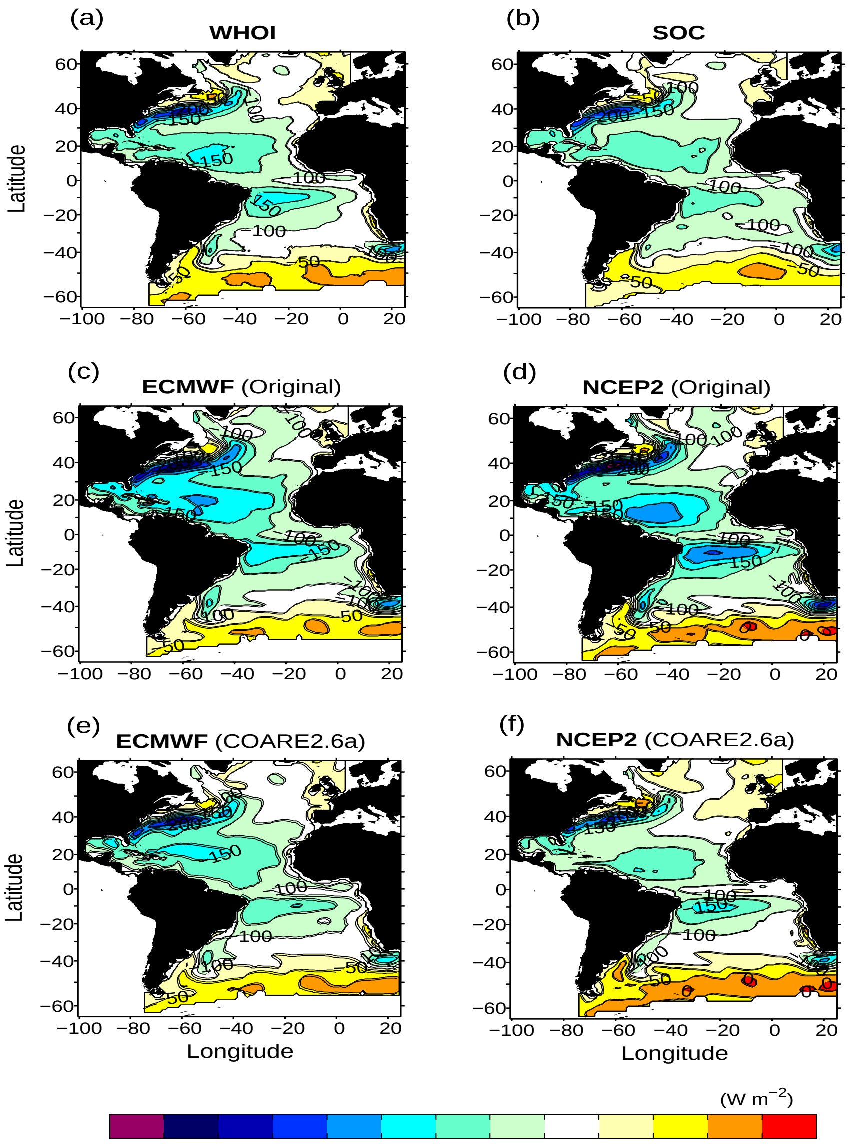
- **The WHOI fluxes versus the SOC fluxes**
  - Data sources are different.
  - Temporal resolutions are different.
  - Methodologies are different.

The comparison is not to validate but to identify the differences and similarities between the two fairly independent products

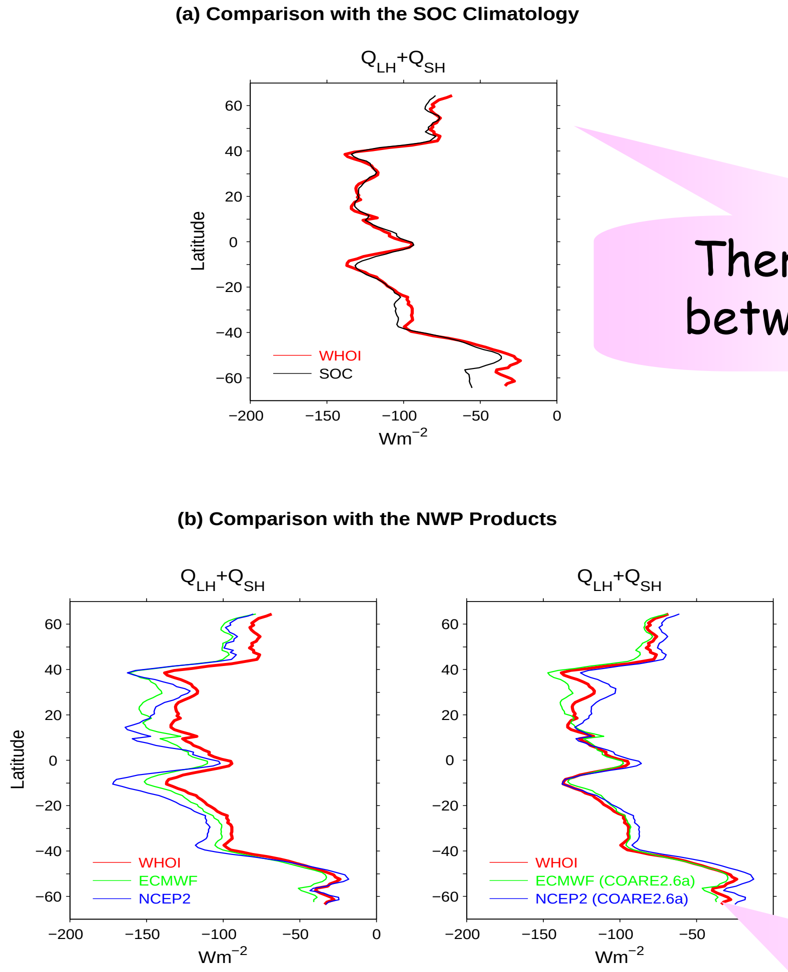
- **The WHOI fluxes versus the ECMWF and NCEP2 fluxes**
  - The basic variables from the two models are input data in the WHOI synthesis.
  - Flux algorithms are different.

The comparison is not to validate but to identify the differences and the causes of the differences.

Comparison of mean field structures



Comparison of zonally averaged mean fluxes

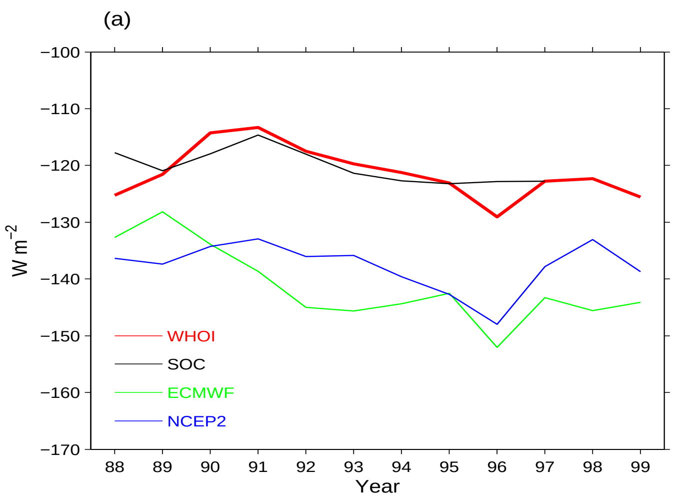


There is a GOOD agreement between the WHOI and SOC fluxes

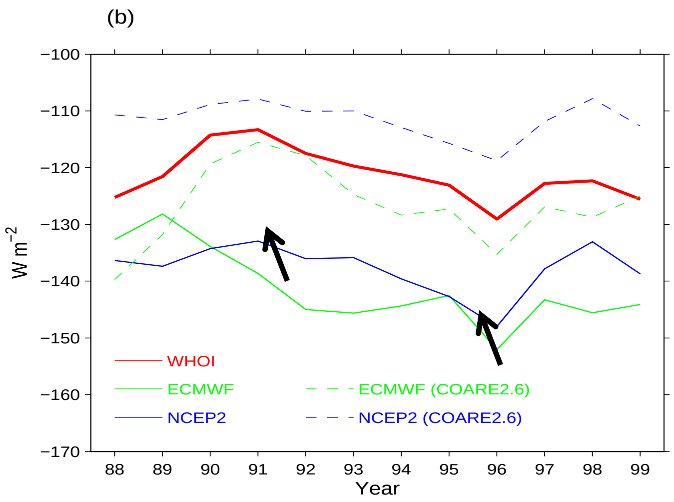
The revised ECMWF and NCEP2 fluxes do not replicate the WHOI fluxes

Comparison of year-to-year variations

averaged over the region [0, 45°N]



- The WHOI fluxes agree well with the SOC fluxes.
- The WHOI fluxes are about 20Wm^{-2} weaker than the ECMWF and NCEP2 fluxes

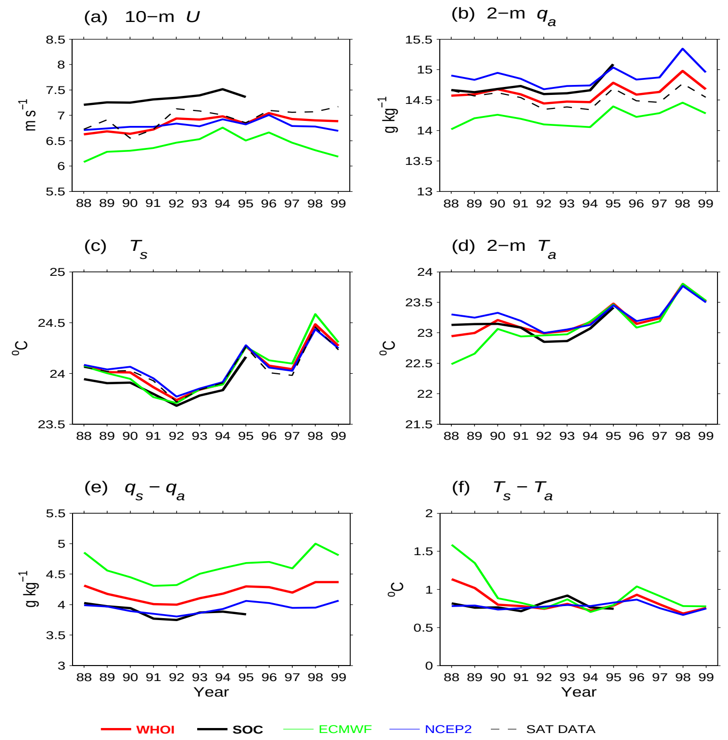


- There is a large difference between different algorithms.
- Differences in the WHOI and revised NWP fluxes are due to the differences in basic variables

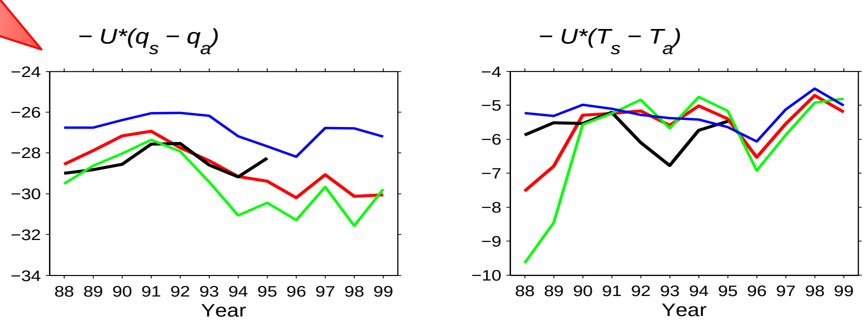
Comparison of basic variables

- The comparison between the WHOI and SOC variables is not as good as fluxes.

- Differences exist between the WHOI and NWP variables.



Effects of error compensation



How much improvement has been made in the WHOI fluxes?

Validation using in situ measurements

What are measured by the WHOI flux buoys?

- Air and sea temperatures
- Relative humidity
- Barometric pressure
- Wind speed and direction
- Incoming shortwave radiation
- Incoming longwave radiation
- Precipitation
- Measurements are recorded every minute

How are the buoy surface heat fluxes derived?

- **Latent and sensible fluxes:**

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

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

The COARE bulk flux algorithm2.6a is used.

- **Net shortwave radiation:**

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

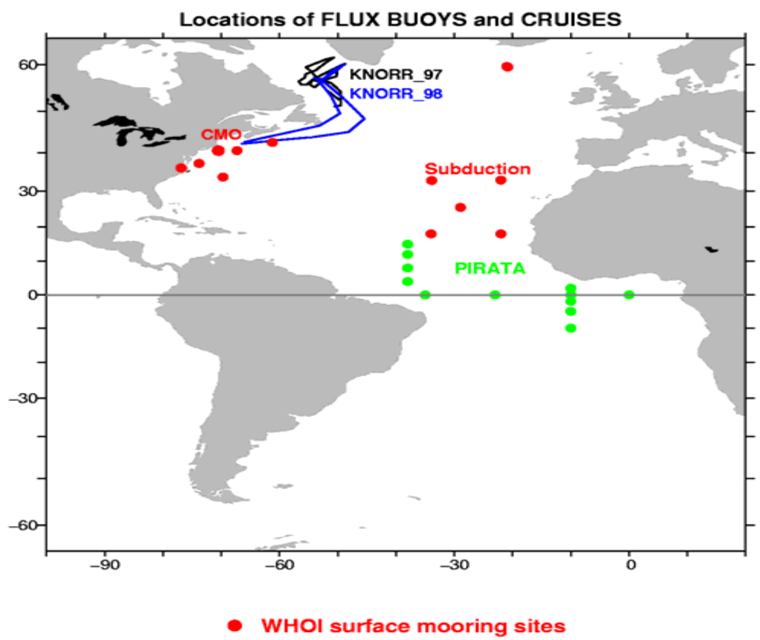
α: the surface albedo based on Payne(1972) formulation

- **Net longwave radiation:**

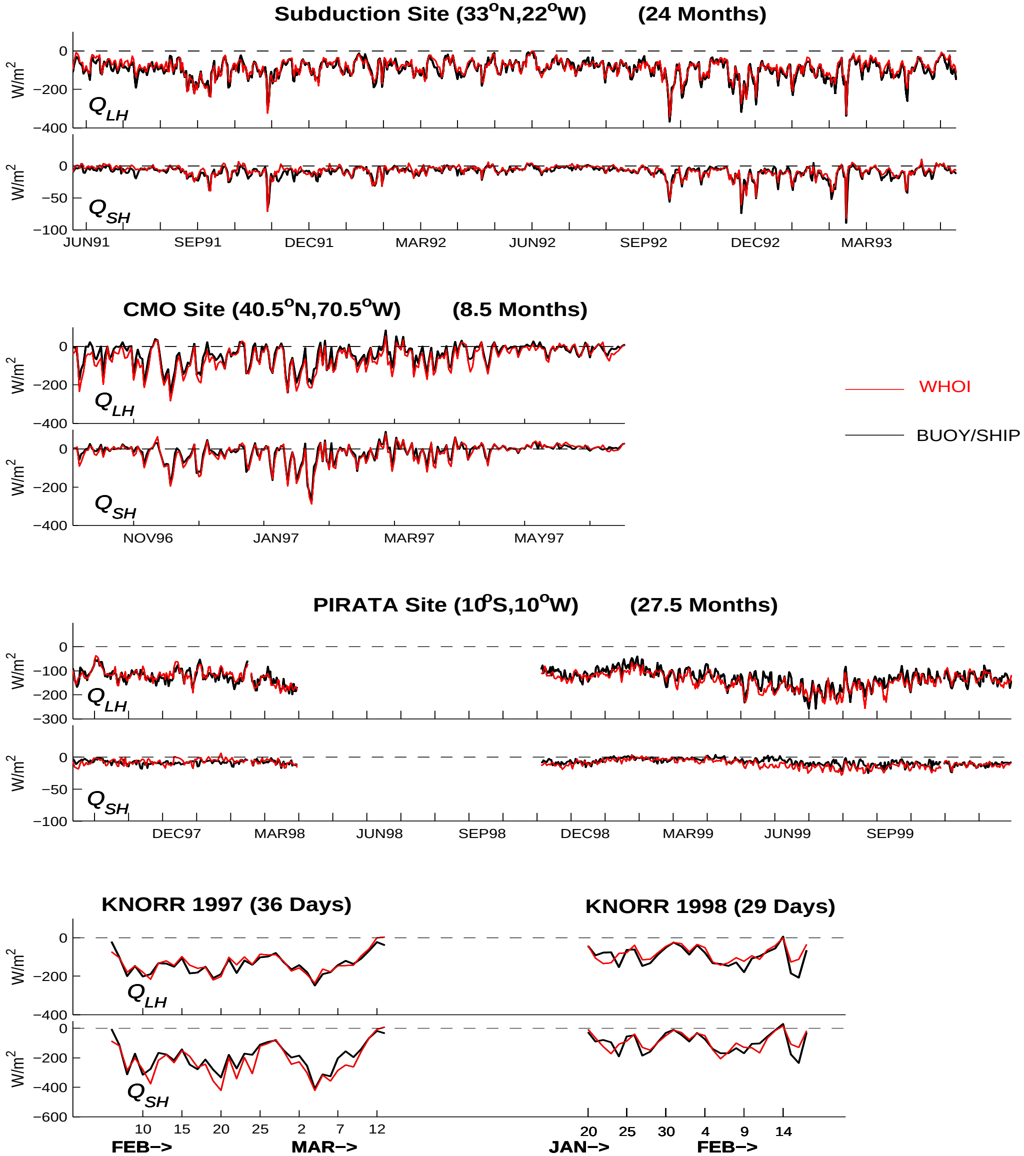
$$Q_{LW} = LW\downarrow + (\varepsilon \sigma T_s^4 - (1 - \varepsilon) LW\downarrow)$$

σ: the Stefan – Boltzmann constant

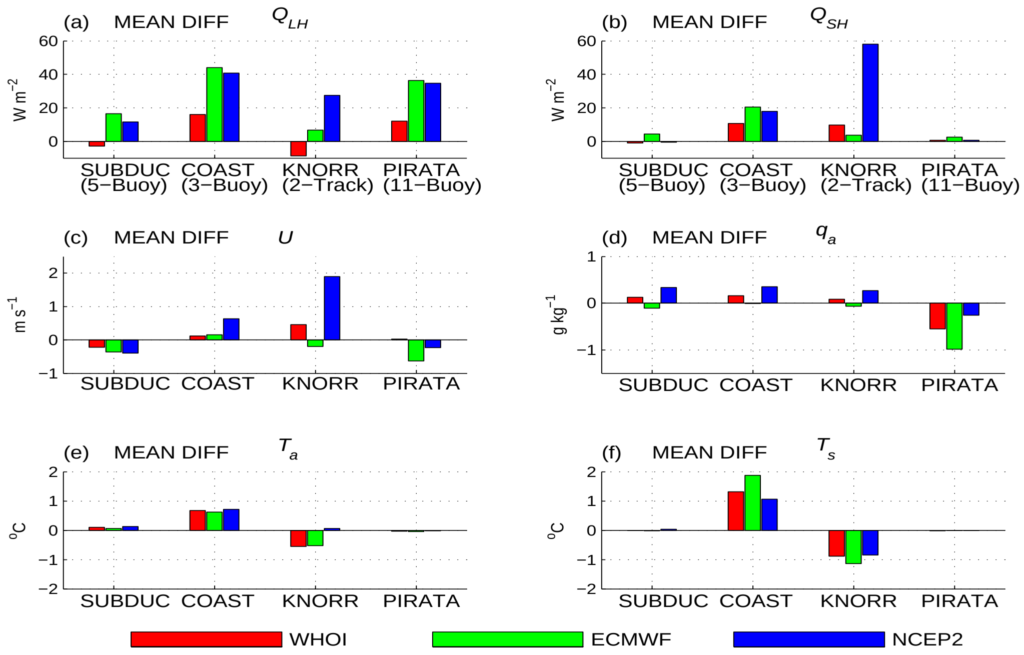
Locations of in situ measurements



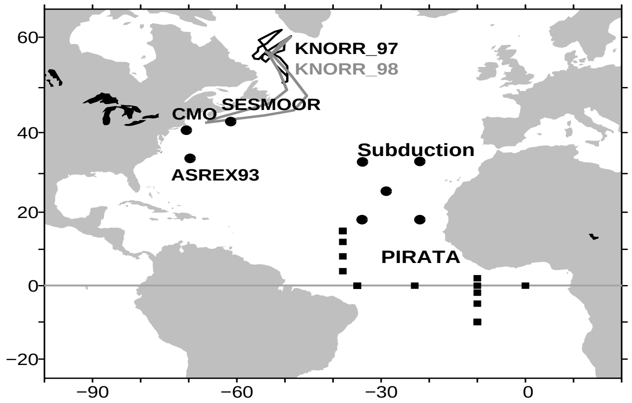
Time series comparison



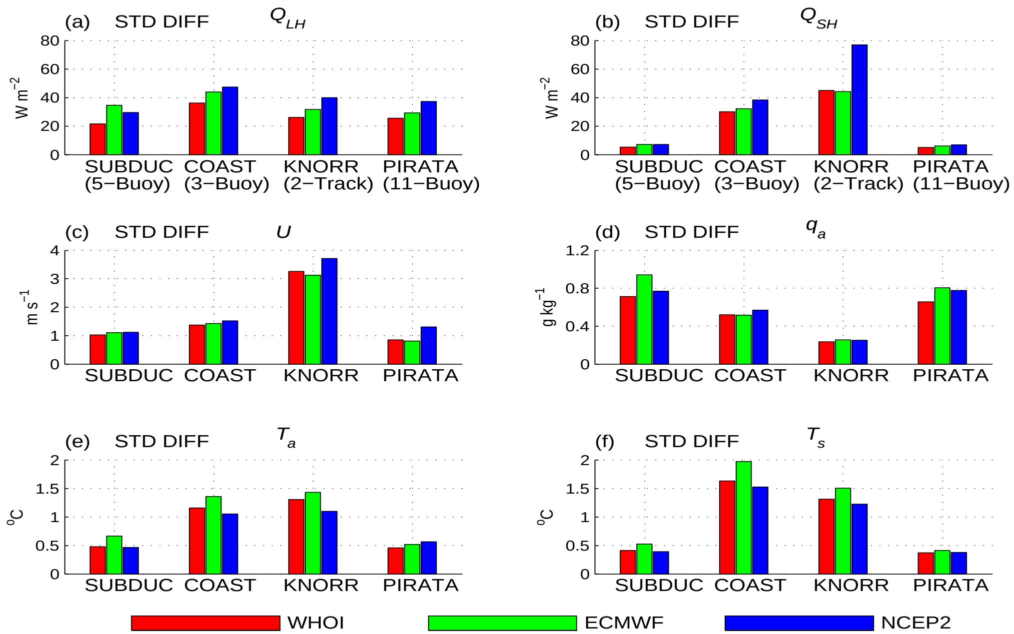
Bar comparison at buoy sites – Mean differences



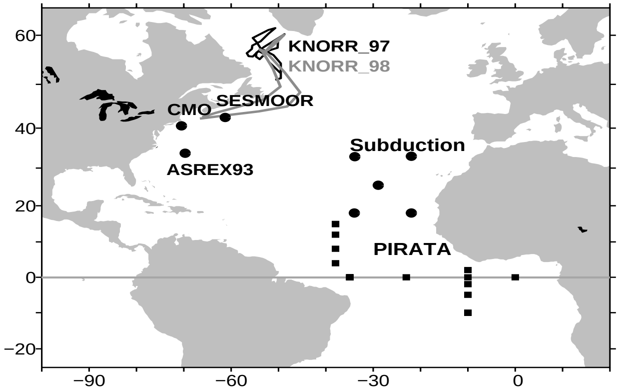
- The warm (cold) bias in Ts and Ta is the major error source for the fluxes at COAST(KNORR).
- The dry bias in qa is the major error source for the fluxes at PIRATA.



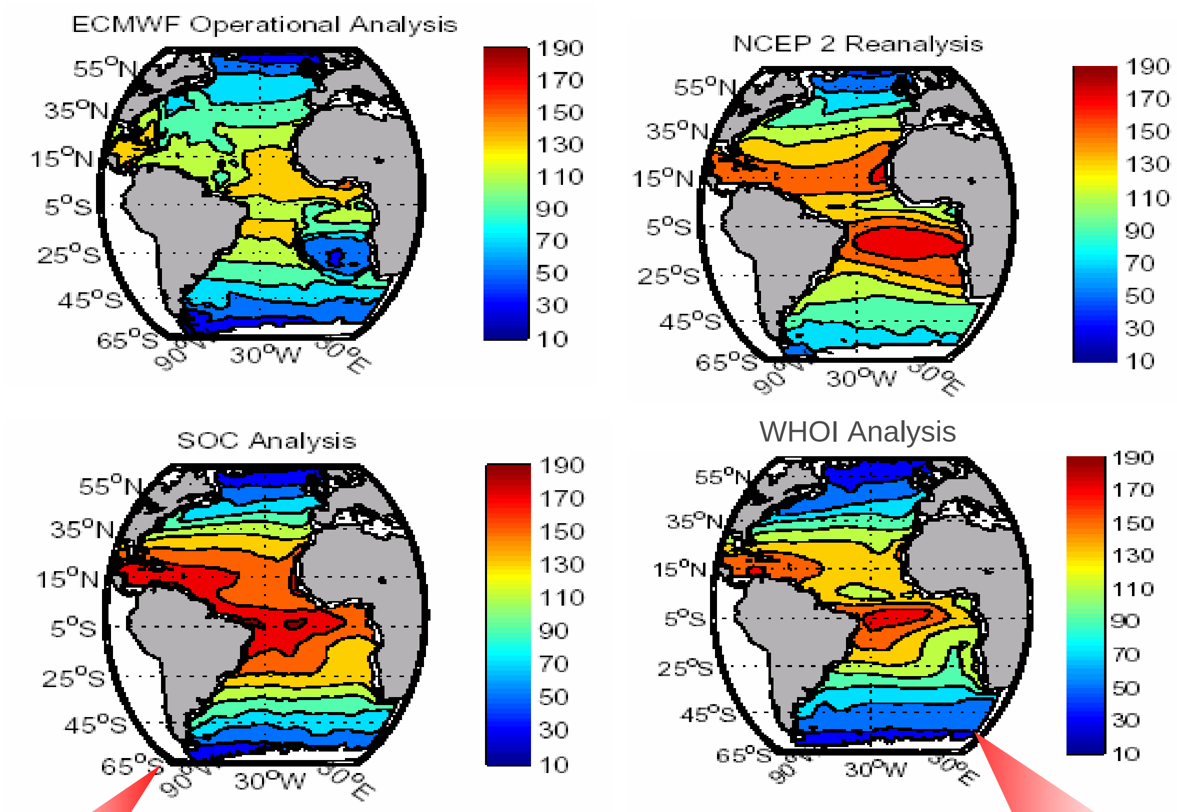
Bar comparison at buoy sites – STD of daily differences



- The WHOI fluxes have the smallest STD at all measurement sites
- The WHOI synthesis improves the STD of U and qa.
- The STD of Ts and Ta from the WHOI synthesis appear to be a compromise between the two NWP values.



Preliminary Results
Net radiation in the Atlantic Ocean

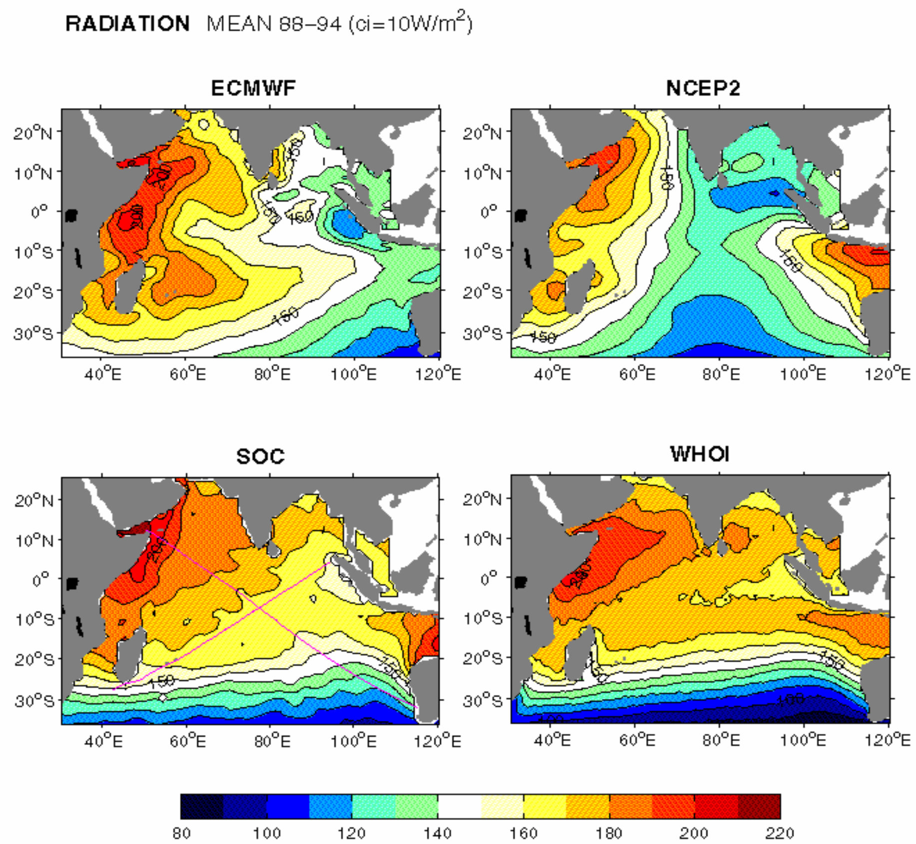


Ship obs

Satellite obs

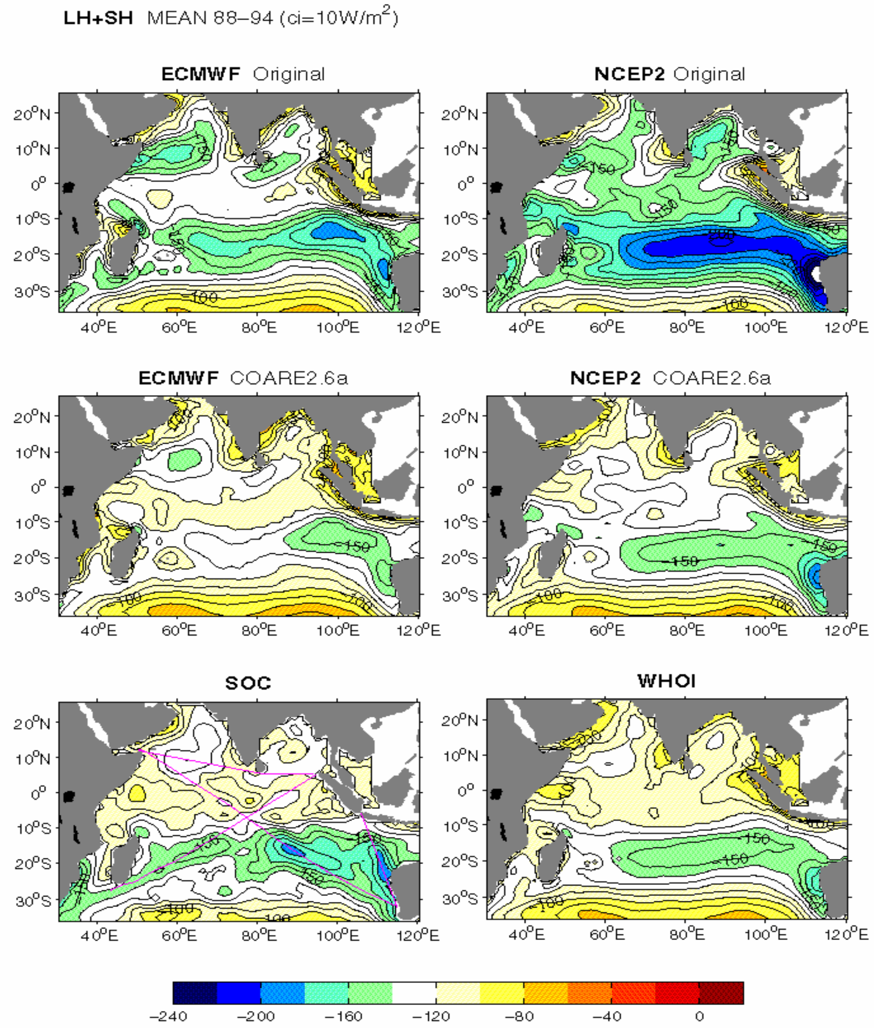
- The net surface radiation heat flux from different products differs in both pattern and magnitude. The differences are particularly large in the tropical region.
- The WHOI product appears to have a pattern similar to SOC, despite the use of different data sources.

Net radiation in the Indian Ocean



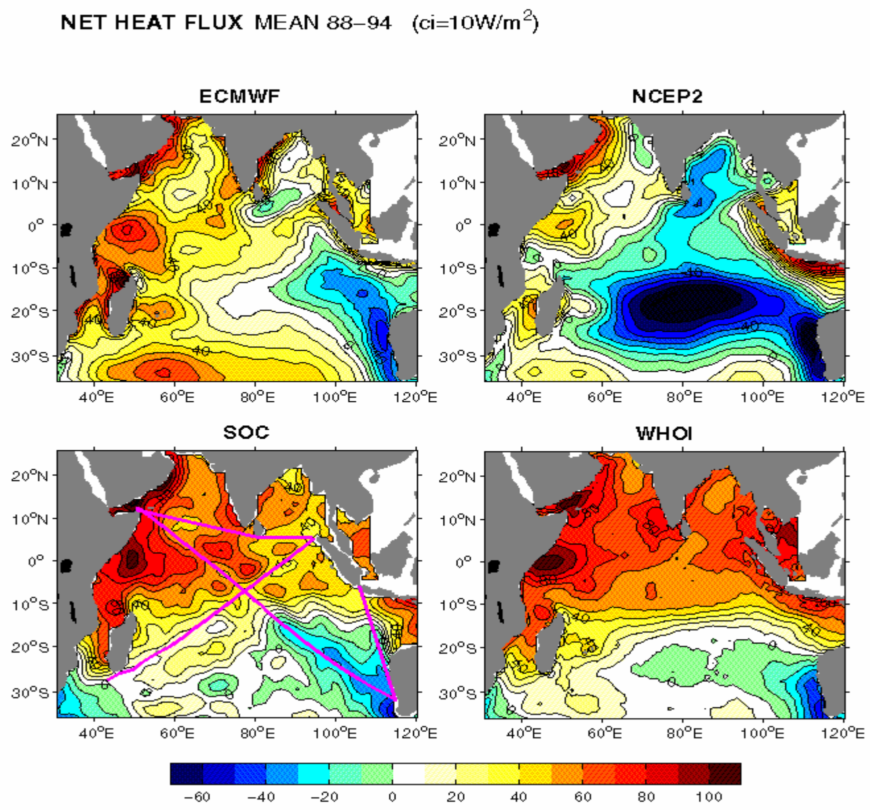
- The tropical Indian Ocean provides another example that the net surface radiation from the NWP models can be very different from the climatology that is based on ship data.
- The WHOI product shows again a pattern similar to SOC.

Turbulent fluxes in the Indian Ocean



- The turbulent fluxes from NWP are also larger in the Indian Ocean. This is caused partially by the NWP flux algorithms.
- Influence of ship tracks can be evident in SOC in regions where sufficient coverage is lacking.

Net heat flux in the Indian Ocean



There are large degrees of uncertainty in different estimates of net surface heat flux in the tropical Indian Ocean.

Summary

- A new daily latent and sensible heat flux product developed from synthesizing the NWP and satellite data sources is available for the Atlantic Ocean (1988-1999). Net longwave and shortwave radiative fluxes are under validation.
- The long-term mean properties of the WHOI flux fields have a good agreement with the SOC climatology, but differences do exist in the estimates of basic variables.
- The validation using in situ measurements shows that the mean and daily variability of the WHOI fluxes are an improvement over the NWP fluxes.
- Mean errors in the WHOI fluxes wrt in situ measurements:

	the tropical Atlantic	the eastern North Atlantic	the western North Atlantic coastal region	the Labrador Sea region
LH	11.9 Wm^{-2} (13%)	2.7 Wm^{-2} (3%)	15.9 Wm^{-2} (20%)	8.7 Wm^{-2} (7%)
SH	0.7 Wm^{-2} (11%)	1.0 Wm^{-2} (13%)	10.5 Wm^{-2} (34%)	9.7 Wm^{-2} (6%)

- The synthesis approach can effectively improve the estimates of flux related variables. It is anticipated that such an approach may become increasingly relied upon in the preparation of future high quality flux products.