# Surface energy budget estimations based on satellite radiation, turbulence and precipitation measurements

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# Outline

- Introduction: sfc energy for climate
  - climate heat balance
  - interact with water cycle
  - previous results: blended data & assessment
- Energy balance: TOA, sfc, atm.
  - radiation & turbulence ↔ precipitation
  - land surface fluxes
  - global and regional annual means
  - energy & water balance
- Summary

# Introduction

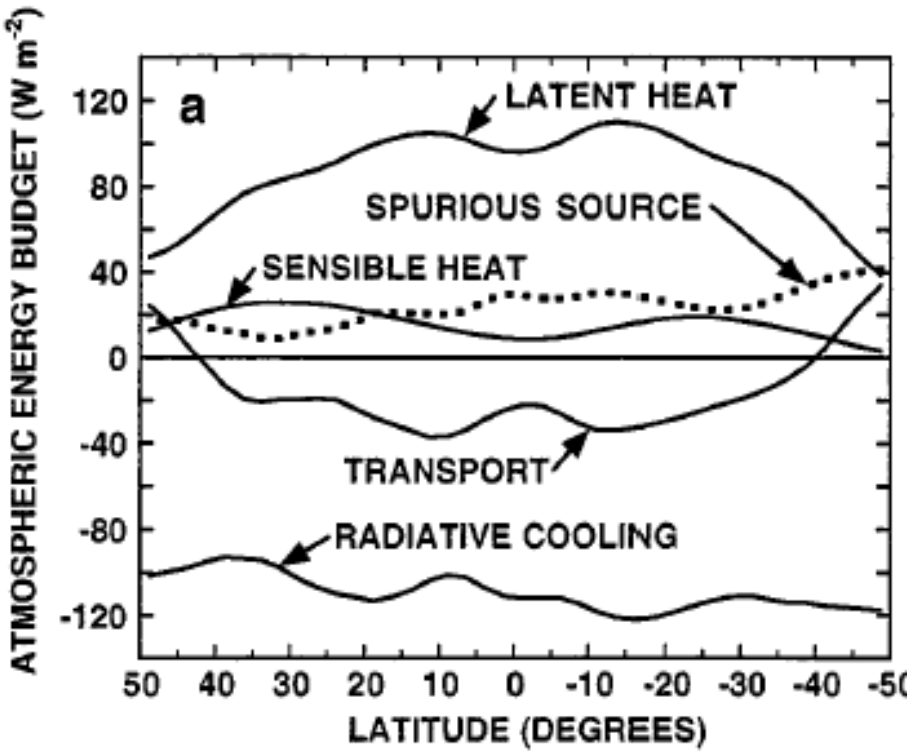
- Energy balance: a fundamental process:
  related directly to climate sensitivity*
- Entwined with water cycles – latent heat
- Reanalyses: potentially large errors;
  obtain: heat transports, global/large scale balances, interannual variability
- Observations: radiation & oceanic turbulent heat fluxes, rain latent heat
  lack: turbulent fluxes: land/cold regions

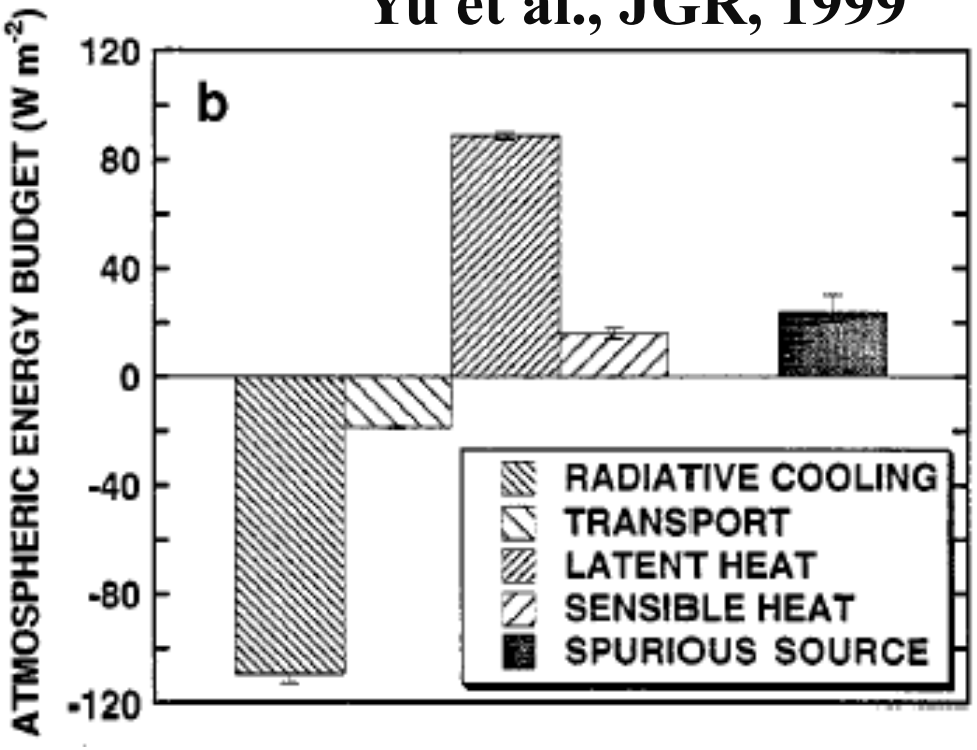
* Lin et al: ACP 2010; JQSRT 2011

# Historical results

- Blended data: satellite radiation, in-situ & assimilation turbulent fluxes ⇨ -20 W/m$^2$ systematic errors ⇨ insufficient SW absorption!

Yu et al., JGR, 1999



# Land heat budget

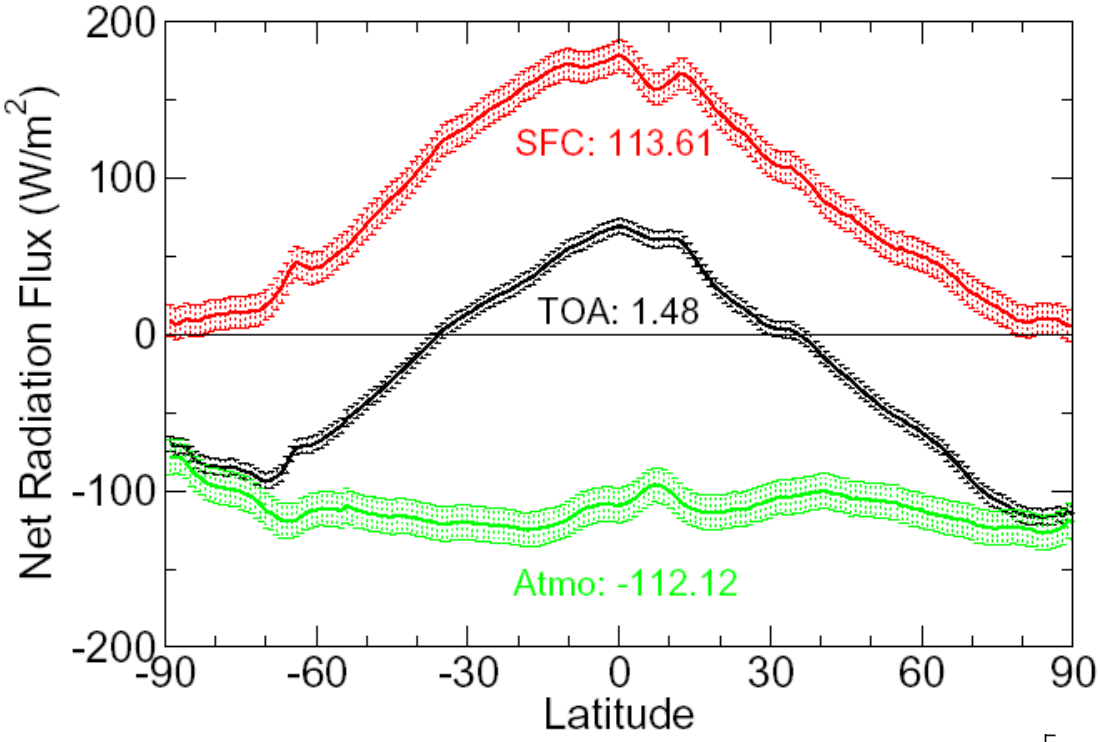
- Land surface fluxes: GLDAS
  heat storage (S), Bowen ratio,
- Observations: sfc net radiation

$$Rnet = LH + SH + S \quad (1)$$

$$B = LH/(LH+SH) \quad (2)$$

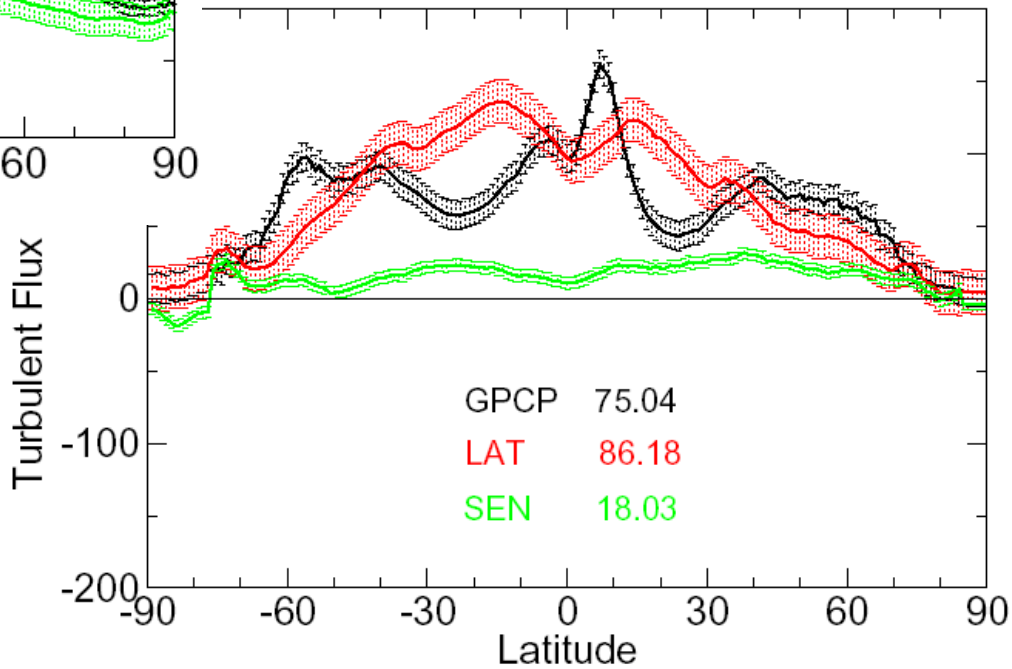
- negligible horizontal heat transport
- forced by surface net radiative fluxes in daily to monthly time scale

# Previous Results
## (annual mean)




Year: 2000

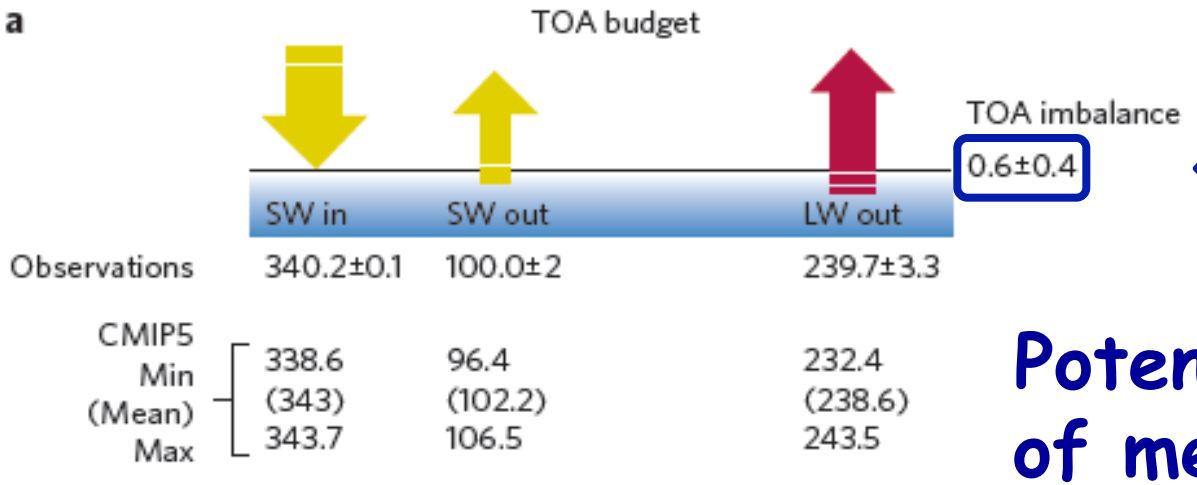
water budget ~11 W/m$^2$
GPCP: no snow and drizzle precipitation



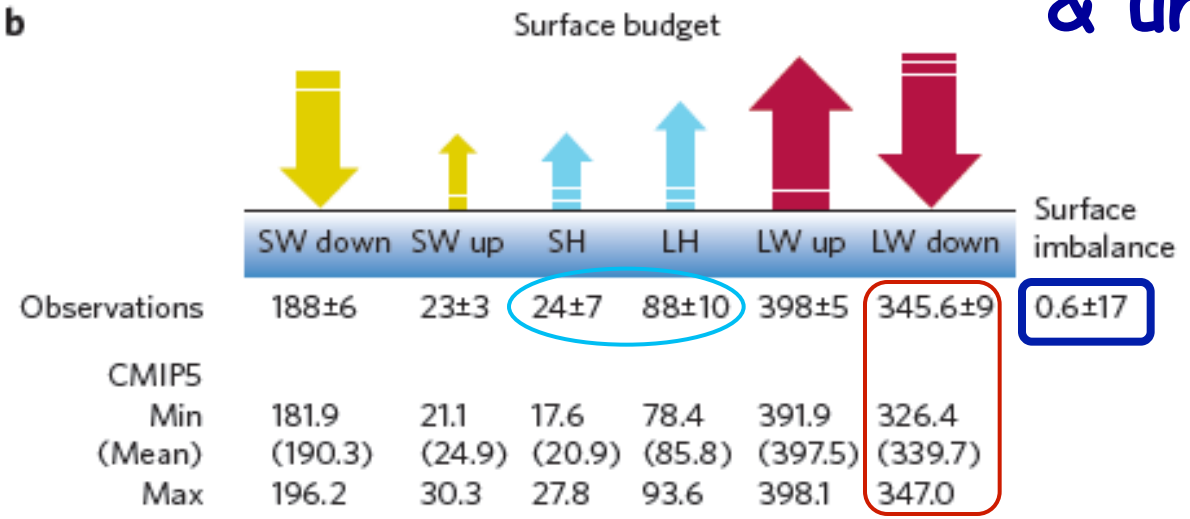

Lin et al. JGR 2008

# Current Understanding

Not directly from measurements!




Potential targets of measurements & uncertainties




Stephens et al.: Nature Geosci. 2012

# Energy Data Sets (2001-2005)

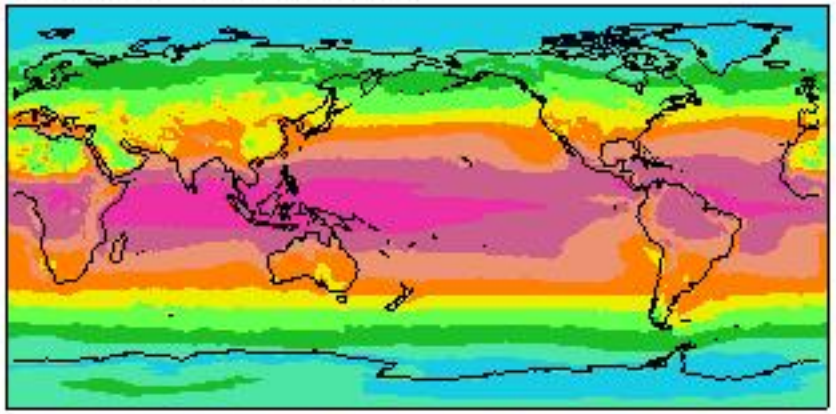
- Radiation:
  - TOA & sfc -- CERES EBAF, SRBAVG
  - regional bias errors: ~ 10 W/m$^2$
- Sea surface turbulent fluxes:
  - HOAPS, GSSTF, OAFlux, RSS
  - regional bias errors: ~ 7 W/m$^2$
- Precipitation: GPCP
  - atmospheric latent heat balance
  - annual mean errors: 5% or ~4 W/m$^2$

**Overall: < 17 W/m$^2$**

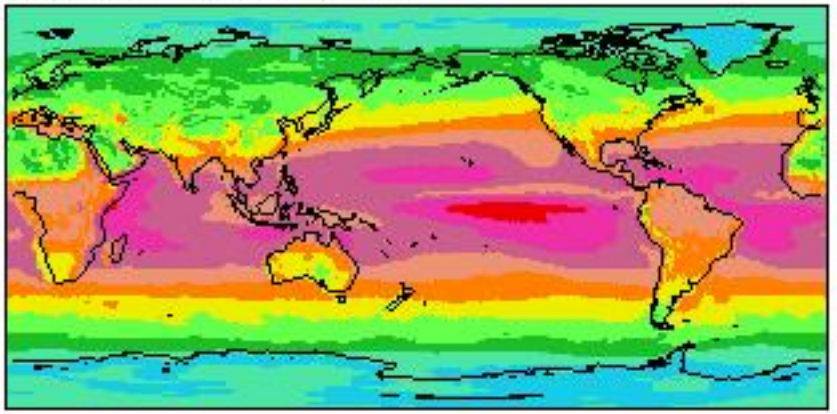
# Radiation Energy Budget

EBAF (total sky) 2001–2005

TOAnet Downward

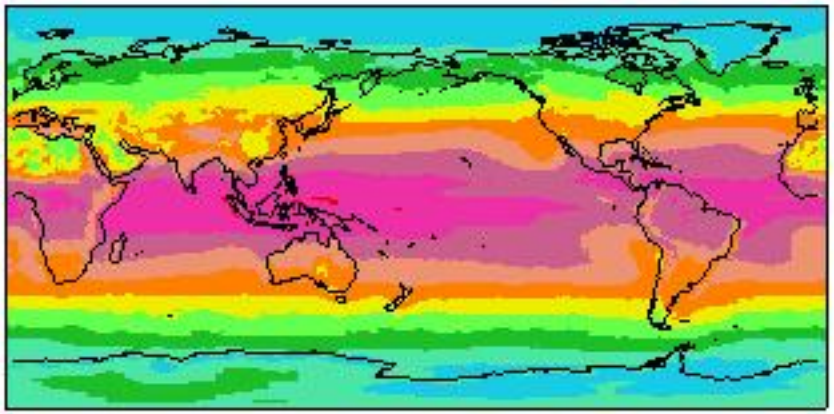


SFCnet Downward

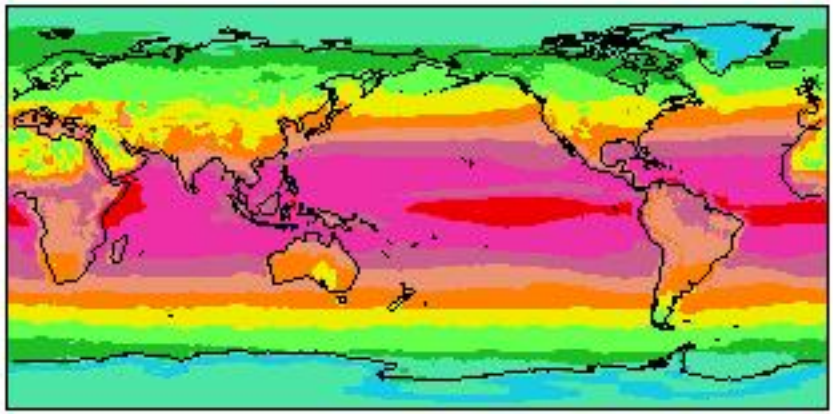


SRBAVG (total sky) 2001–2005

TOAnet Downward



SFCnet Downward



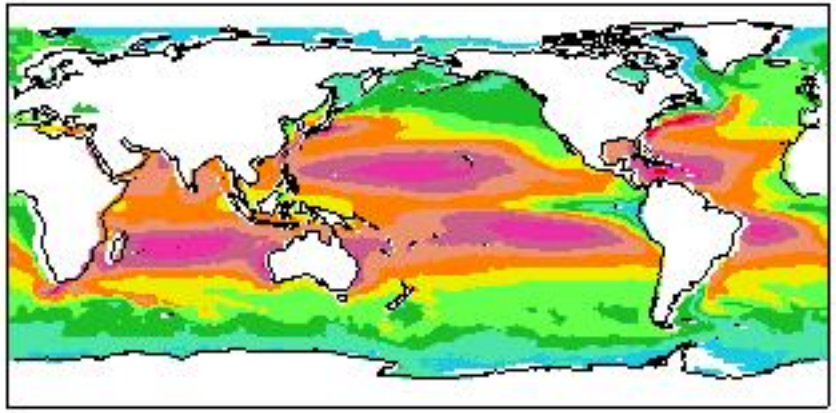

# Basin/Continent Radiation

| SRBAVG | TOA down | SFC down | ATM radi (TOA-SFC) | EBAF | TOA down | SFC down | ATM radi (TOA-SFC) | TOA diff | SFC diff | ATM diff |
|---|---|---|---|---|---|---|---|---|---|---|
| N_Pacific | 36.0 | 154.5 | *-118.5* | | 28.4 | 136.2 | *-107.8* | | | |
| India | 19.2 | 139.9 | *-120.7* | | 12.6 | 125.6 | *-112.9* | | | |
| S_Pacific | 15.1 | 136.0 | *-120.9* | | 8.9 | 123.3 | *-114.5* | | | |
| N_Atlantic | 8.9 | 130.9 | *-122.0* | | 1.0 | 113.1 | *-112.1* | | | |
| S_Atlantic | -0.5 | 124.3 | *-124.9* | | -7.0 | 111.0 | *-118.1* | | | |
| Ocean | 15.0 | 136.0 | *-121.0* | | 7.8 | 120.9 | *-113.0* | 7.2 | 15.1 | -8.0 |
| SRBAVG | TOA down | SFC down | ATM radi (TOA-SFC) | EBAF | TOA down | SFC down | ATMO radi (TOA-SFC) | | | |
| S_America | 42.3 | 136.1 | *-94.8* | | 32.6 | 119.3 | *-86.7* | | | |
| Africa | 24.7 | 123.4 | *-98.8* | | 17.8 | 99.2 | *-81.4* | | | |
| Australia | 24.7 | 124.2 | *-99.5* | | 15.3 | 104.9 | *-89.6* | | | |
| Eurasia | -22.3 | 83.0 | *-105.3* | | -30.4 | 65.8 | *-96.2* | | | |
| N_America | -28.7 | 76.8 | *-105.5* | | -36.1 | 68.5 | *-104.6* | | | |
| Land | -10.4 | 91.3 | *-101.7* | | -17.9 | 74.9 | *-92.8* | 7.5 | 6.4 | -8.9 |
| Globe | 7.6 | 123.0 | -115.4 | | 0.745 | 108.2 | -107.5 | 6.9 | 14.8 | -7.9 |

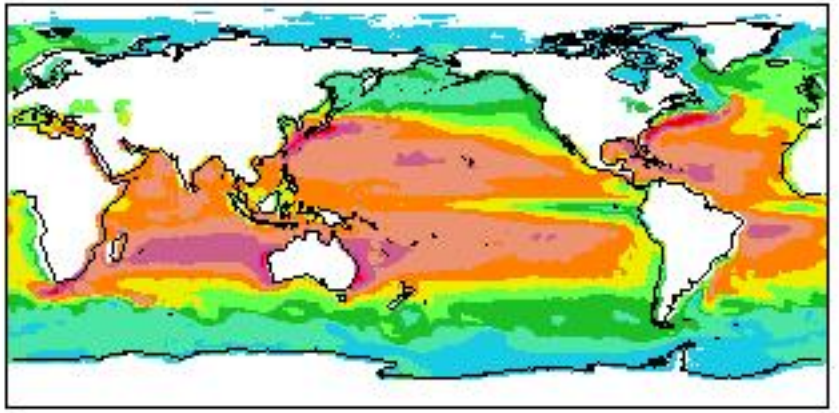
# Latent and Sensible Heat Fluxes

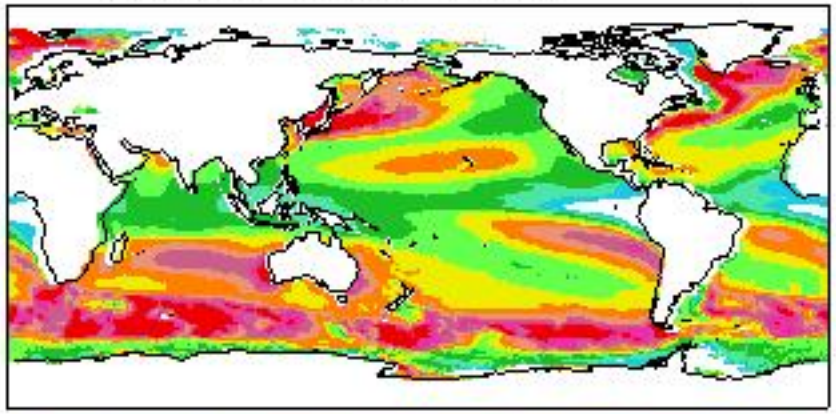
## (ocean)

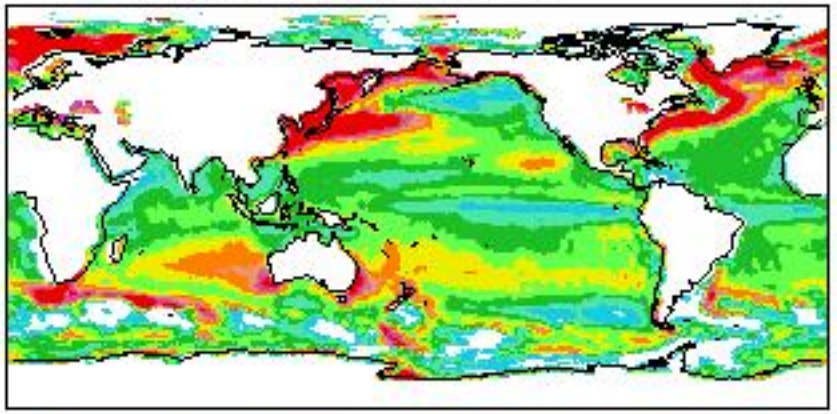
HOAPS 1988–2005



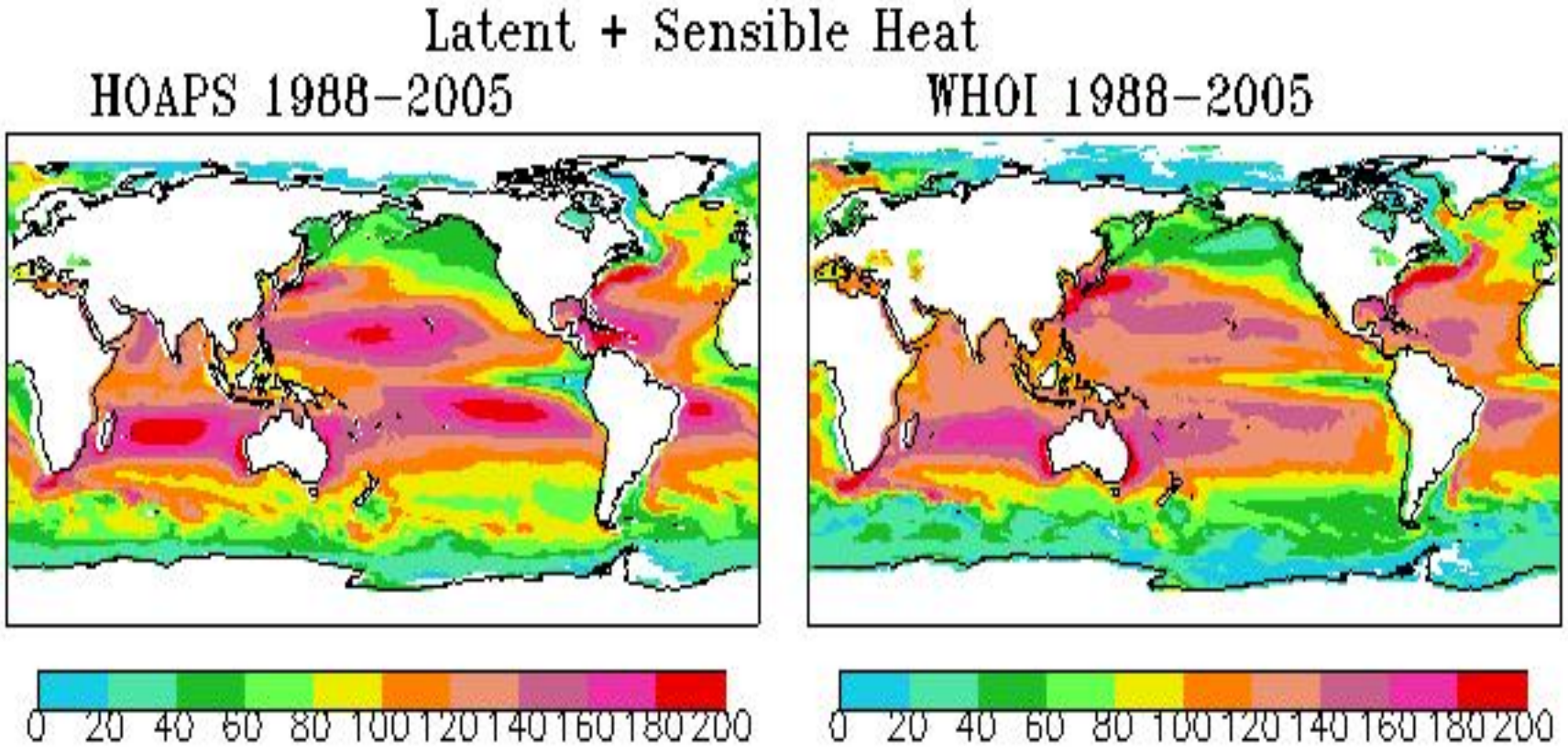

WHOI 1988–2005



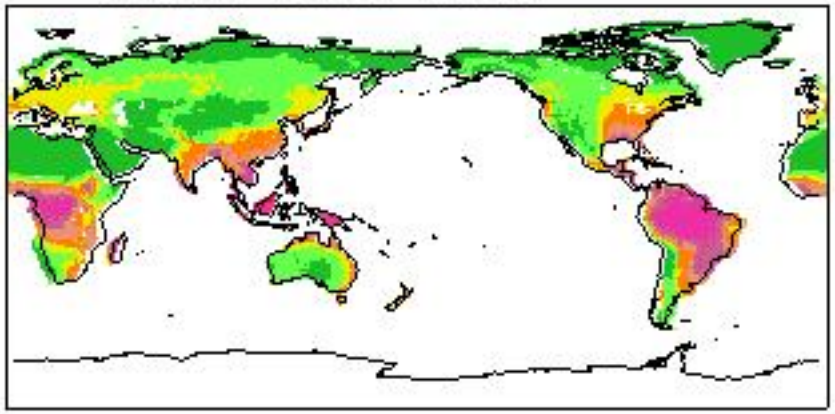
# Oceanic Turbulent Fluxes



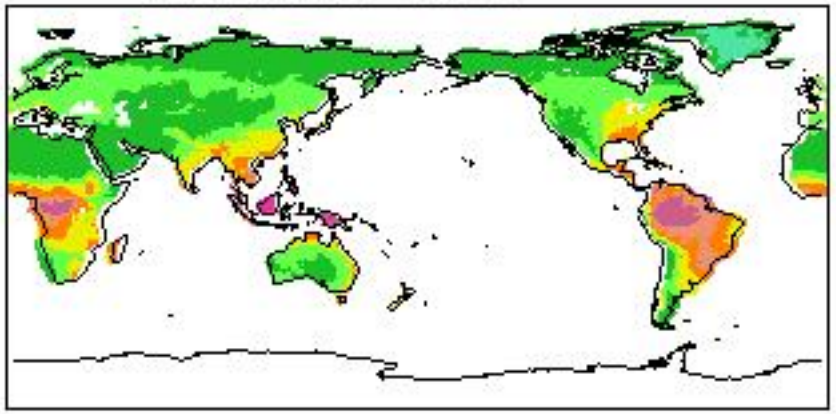
# Latent and Sensible Heat Fluxes

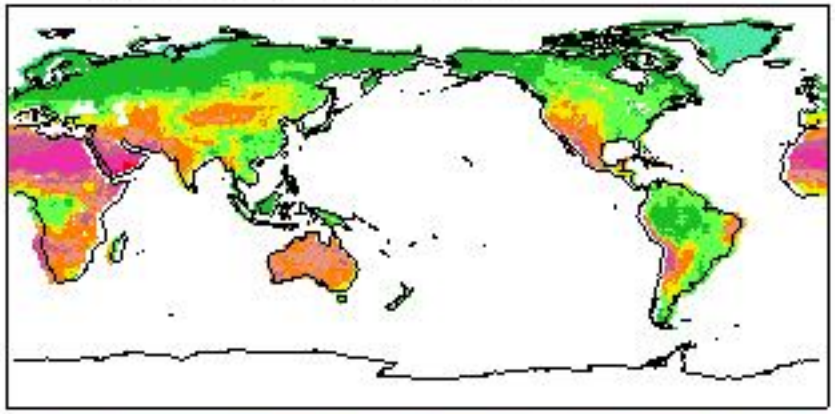
## (land)

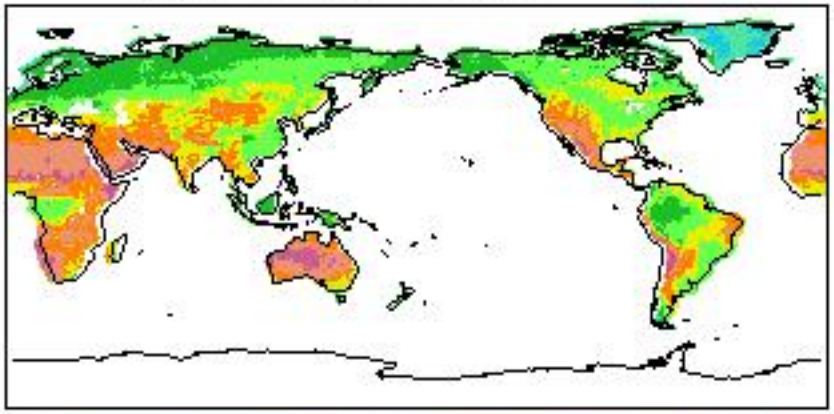
MOSAIC 1988–2005



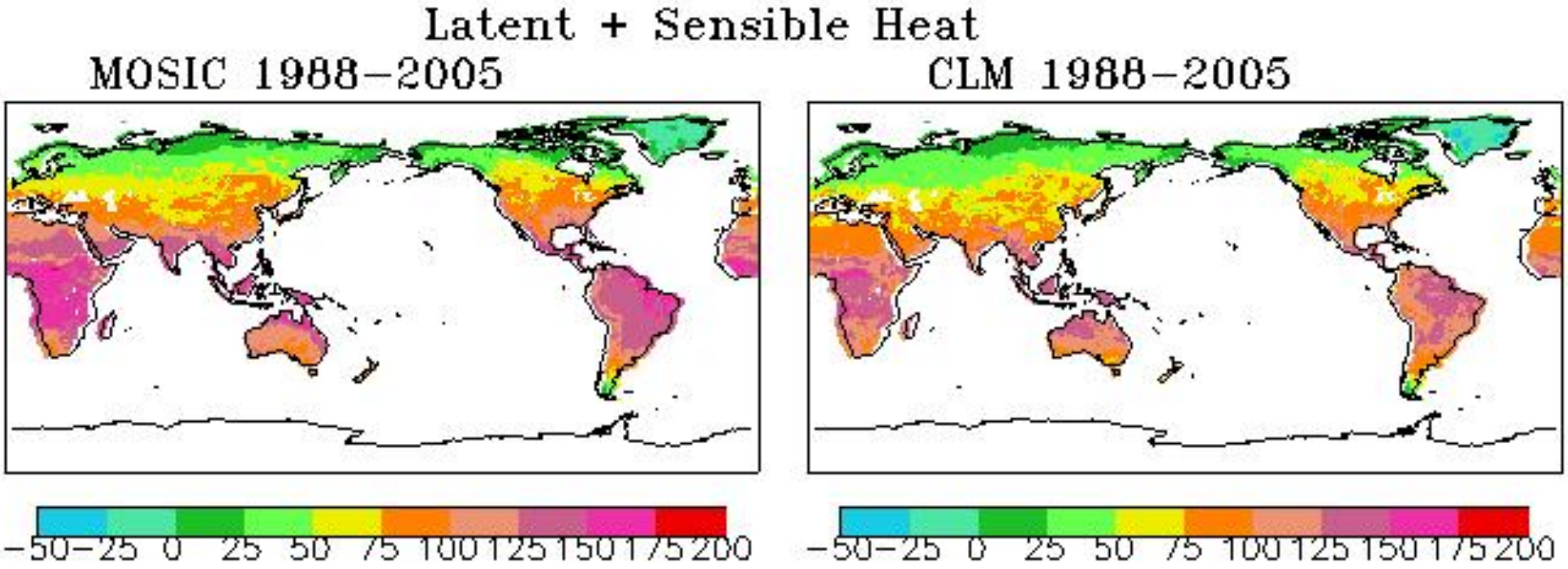

CLM 1988–2005



# Land Turbulent Fluxes

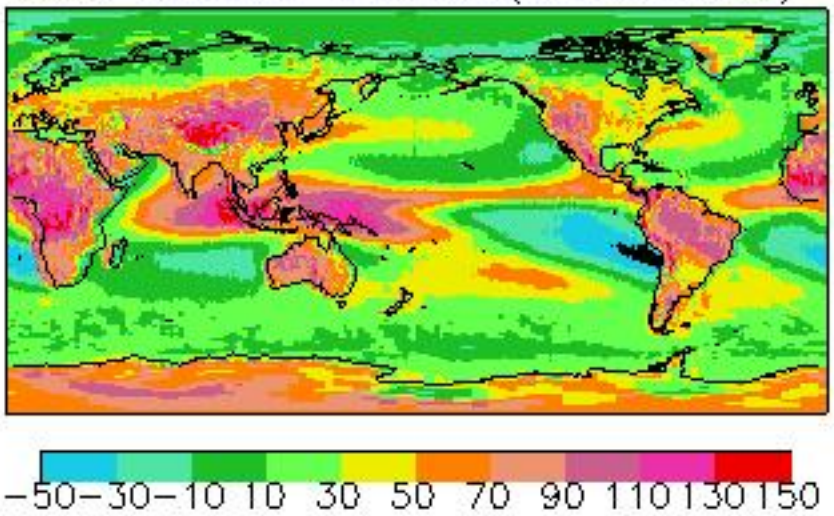



no forced energy balance
used currently

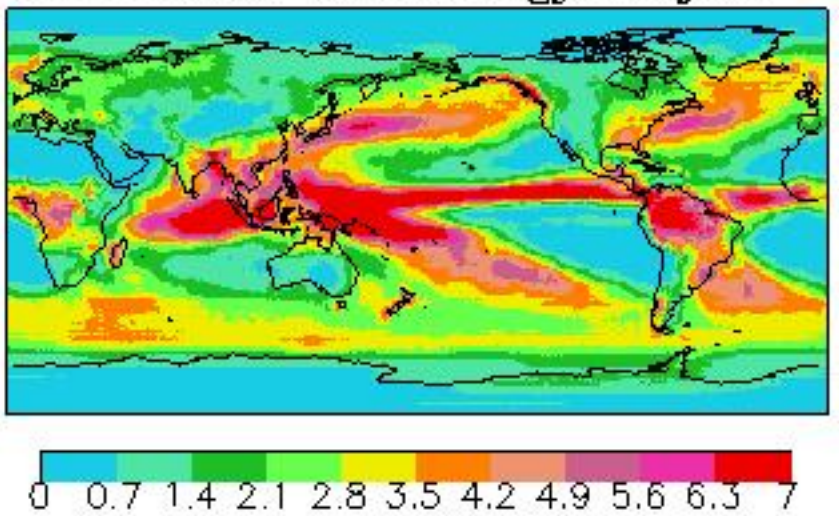
# Atmosphere Radiation & Precipitation

(2001-2005)

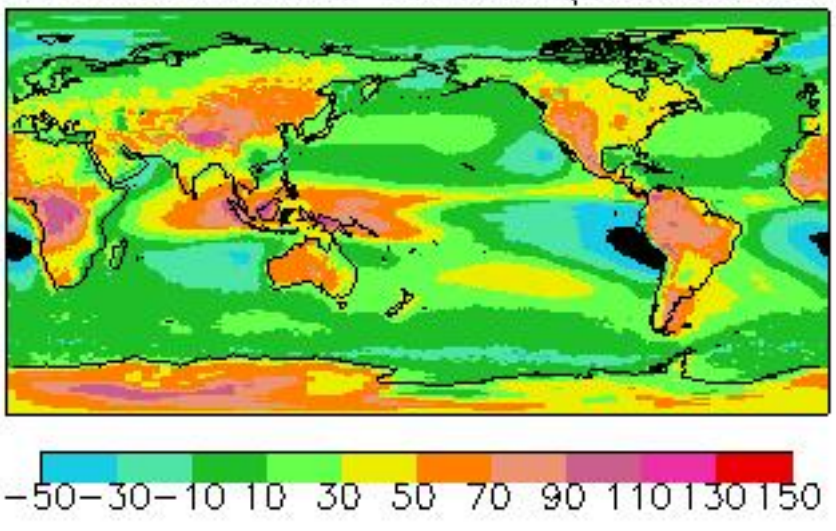
EBAF TOAnet−SFCnet (Atmo. Radi)




Globe Preci. Climatology Project

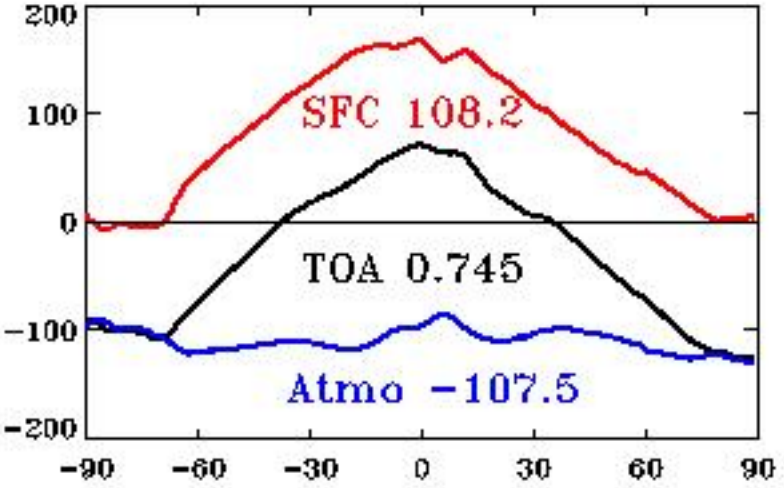


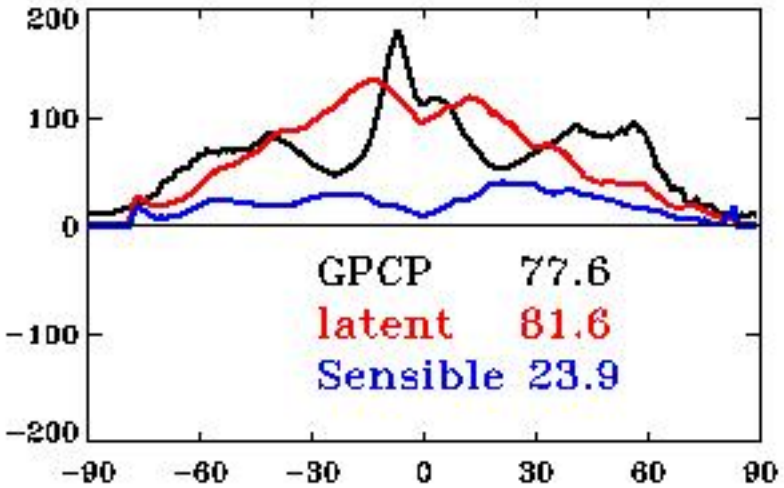

SRBAVG TOAnet−SFCnet (Atmo. Radi)

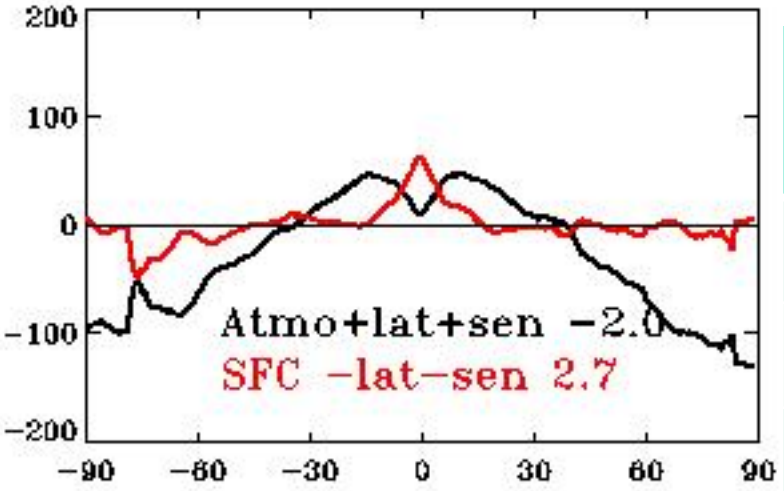



assess the estimates of radiation and latent heat with precipitation observations (atmos. heat transports)

# Atmospheric Heat Balance
## (Rad, LH, SH, rain)




Black: EBAF & HOAPS Blue: WHOI

| | TOA | SFC | Atm | LH | SH | Atm + LH+SH | SFC- LH - SH |
|---|---|---|---|---|---|---|---|
| Ocean | 7.8 | 120.9 | -113.0 | 99.4<br>90.8 | 14.6<br>10.7 | 1.8<br>-11.6 | 6.9<br>19.4 |
| Land | -17.9 | 74.9 | -92.8 | 43.2 | 49.0 | -0.6 | -17.4 |
| Globe | 0.745 | 108.2 | -107.5 | 81.6<br>78.6 | 23.9<br>20.4 | -2.0<br>-8.4 | 2.7<br>9.2 |

# Oceanic Heat Balance Statistics

| | High cld % | SRBAVG Atm | EBAF Atm | WHOI EVP | HOAPS EVP | GPCP Rainfall | E-P |
|---|---|---|---|---|---|---|---|
| N_Pacific | 15.2 | -118.5 | -107.81 | 4.194 | 3.844 | 3.840 | 0.004 |
| India | 10.2 | -120.7 | -112.95 | 2.998 | 3.736 | 2.888 | 0.848 |
| S_Pacific | 9.3 | -120.9 | -114.47 | 2.759 | 3.500 | 2.826 | 0.674 |
| N_Atlantic | 8.5 | -122.0 | -112.11 | 4.145 | 3.431 | 2.810 | 0.621 |
| S_Atlantic | 5.2 | -124.9 | -118.06 | 2.234 | 2.960 | 2.074 | 0.906 |
| Ocean | 9.9 | -121.0 | -113.03 | 3.259 | 3.546 | 2.898 | 0.648 |

| Ocean | GPCP rain | High Cloud % | HOAPS EVP | WHOI EVP |
|---|---|---|---|---|
| SRBAVG | 0.957 | 0.964 | 0.967 | 0.654 |
| EBAF | 0.970 | 0.944 | 0.872 | 0.891 |

# Basin/Continent Heat Balance

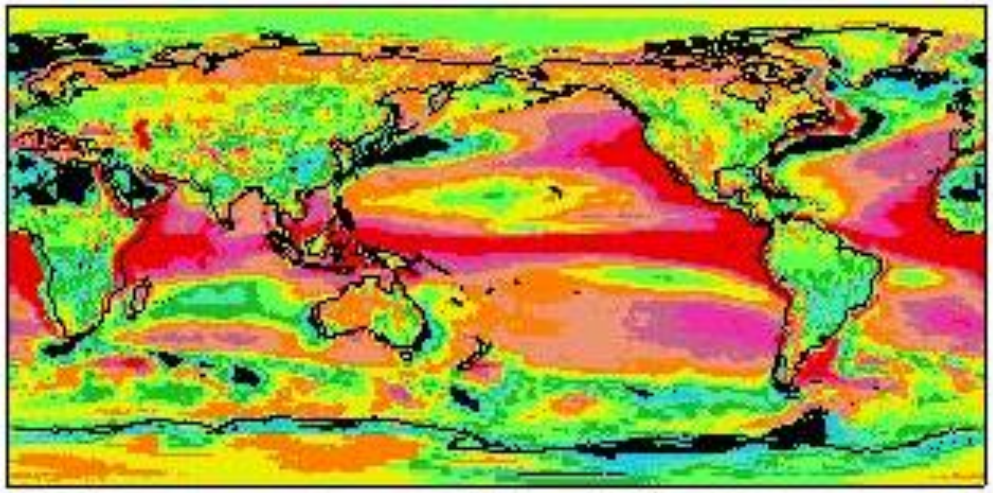
SRBAVG EBAF

| | WHOI LH | WHOI SH | HOAPS LH | HOAPS SH | SFCdn | SFCdn – WHOI | SFCdn – HOAPS | SFCdn | SFCdn – WHOI | SFCdn-HOAPS |
|---|---|---|---|---|---|---|---|---|---|---|
| N_Pacific | 122.8 | 23.2 | 108.7 | 12.3 | 154.5 | 8.5 | 33.5 | 136.16 | -9.86 | 15.16 |
| India | 87.4 | 5.8 | 105.0 | 17.5 | 139.9 | 46.7 | 17.4 | 125.58 | 32.35 | 3.08 |
| S_Pacific | 80.3 | 5.2 | 99.0 | 14.9 | 136.0 | 50.5 | 22.1 | 123.34 | 37.91 | 9.44 |
| N_Atlantic | 122.9 | 31.9 | 95.5 | 13.6 | 130.9 | -23.9 | 21.8 | 113.06 | -41.70 | 3.96 |
| S_Atlantic | 65.1 | 1.9 | 83.8 | 15.1 | 124.3 | 57.3 | 25.4 | 111.03 | 43.99 | 12.13 |
| Ocean | 92.5 | 10.6 | 99.4 | 14.6 | 136.0 | 32.9 | 22.0 | 120.86 | 17.80 | 6.86 |

| | CLM LH | CLM SH | Mosic LH | Mosic SH | SFCdn | SFCdn – CLM | SCFdn – Mosic | SFCdn | SFCdn-CLM | SFCdn-Mosic |
|---|---|---|---|---|---|---|---|---|---|---|
| S_America | 68.2 | 54.6 | 91.5 | 40.2 | 136.1 | 13.3 | 4.4 | 119.3 | -3.5 | -12.4 |
| Africa | 32.1 | 72.5 | 41.1 | 80.5 | 123.4 | 18.8 | 1.8 | 99.2 | -0.9 | -22.4 |
| Australia | 29.6 | 76.2 | 33.8 | 69.6 | 124.2 | -76.2 | 20.8 | 104.9 | -0.9 | 1.5 |
| Eurasia | 25.0 | 42.8 | 34.6 | 38.0 | 83.0 | 15.2 | 10.4 | 65.8 | -2.0 | -6.8 |
| N_America | 24.9 | 42.9 | 34.2 | 35.5 | 76.8 | 9.0 | 7.1 | 68.5 | 0.7 | -1.2 |
| Land | 32.3 | 52.5 | 43.2 | 49.0 | 91.3 | 6.5 | -0.9 | 74.9 | -9.9 | -17.3 |
| Globe | 78.8 | 24.9 | 81.6 | 23.9 | 123.0 | 19.3 | 17.5 | 108.2 | 4.5 | 2.7 |

# Surface Net Heat Distribution

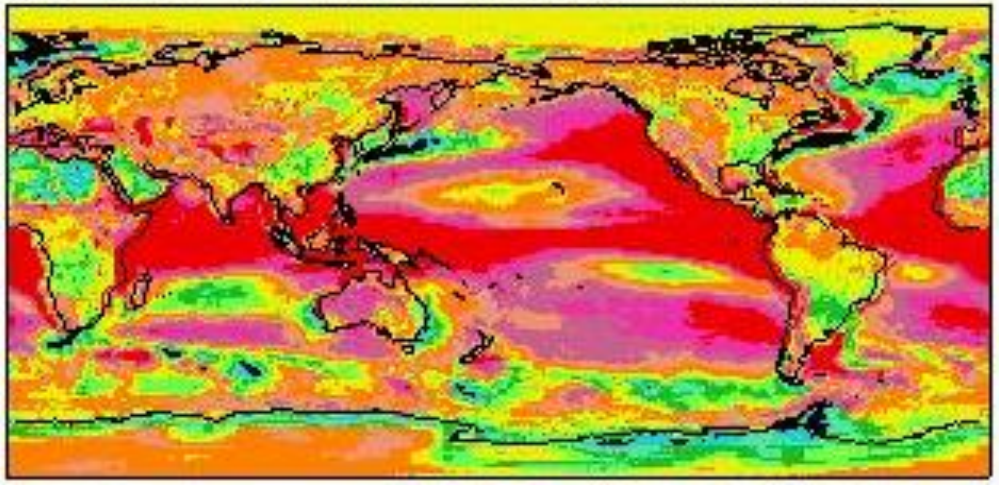
EBAF SFCnet−Latent−Sensible



Land: errors
diff. radiation
GLDAS used

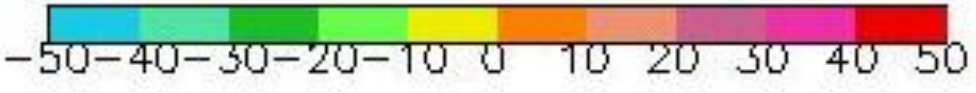
HOAPS
+
Mosaic

SRBAVG SFCnet−Latent−Sensible



Ocean: heat transports

Equator to pole
Ocean currents



# Summary

- Satellites provide invaluable estimates of global surface heat flux distributions. However, certain gaps in global heat observations still exist, especially for those over land surfaces and in cold region processes.
- The errors in annual surface energy balance are within the systematic error range of combined radiative and turbulent fluxes. Progress in satellite observations of radiation and sea surface turbulent fluxes significantly reduces the uncertainties in annual mean energy budgets.

Bias errors: ~ half of previous study!

(progress is seen every 5 ~ 10 years)

# Summary (conti.)

- Systematic errors in surface and atmospheric heat budgets are not negligible. The errors and uncertainties limit current satellite observational data to reach the accuracy wanted.
- There are certain differences among global satellite radiation, evaporation and precipitation estimates. Even for water cycle, significant difference between evaporation and precipitation exists.

**Inter-calibration and Reconciliation is really needed!**


# Thank You!