# Global and continental/basin scale energy budgets

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(Goal: Stimulus discussions )

# Basic approach

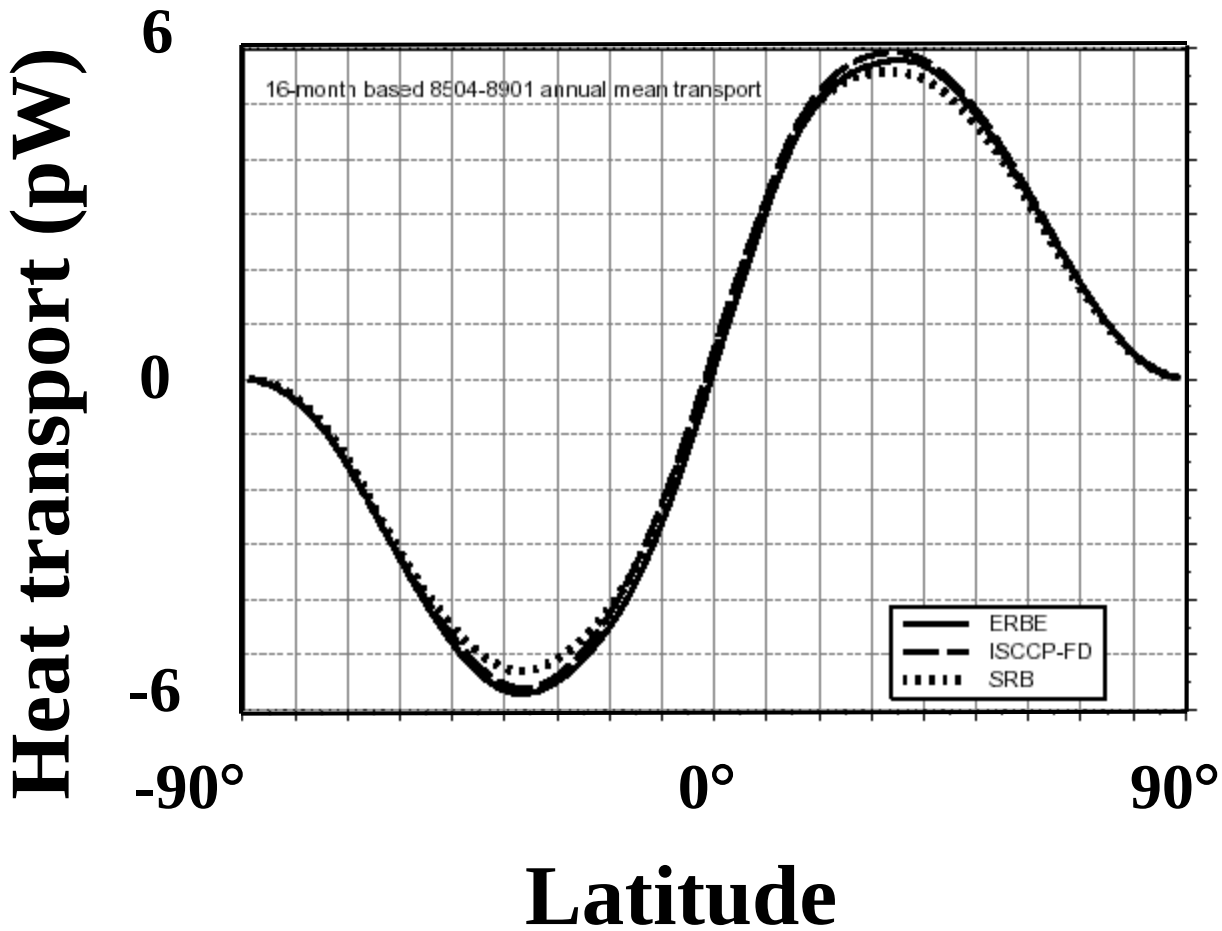
- Radiation data
- SRB, CERES and ISCCP (most from SRB

- Ocean surface turbulent fluxes
- satellite measurements of meteorological conditions & turbulent models (bulk formula)

- Atmospheric heat fluxes
  - TOA & surface (sfc) radiation
  - precipitation latent heat & sfc turbulent heat

Lin et al. , Assessment of global annual atmospheric energy balance from satellite observations, JGR, 2008.

# Consistency of radiation data




Zhang et al.
JGR, 2007

meridional heat transports from TOA radiation

# Some Basic Issues

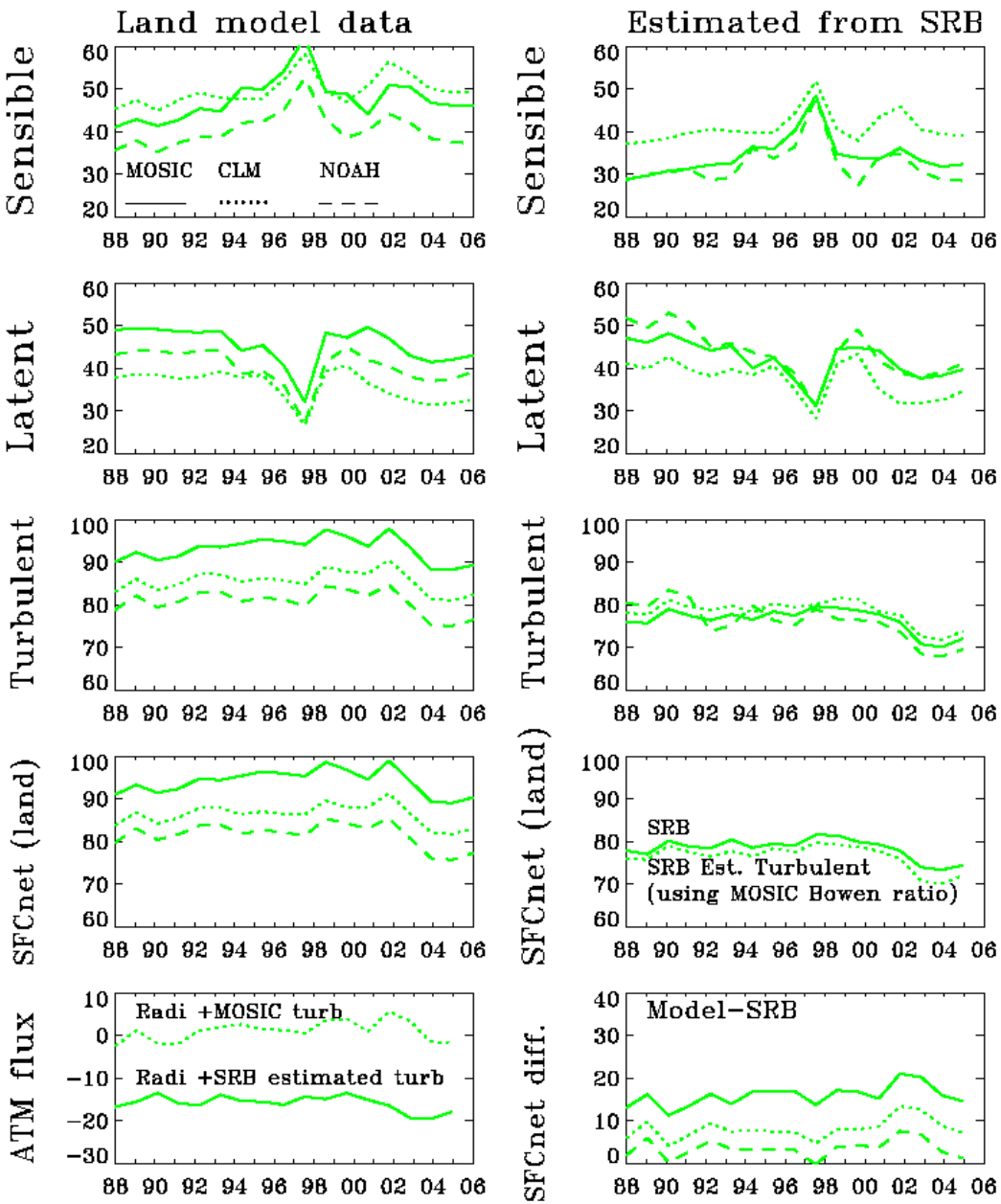
- No large scale observations of land surface turbulent heat fluxes
- situation is changing (Wood's group
- surface radiation data + model results

- Polar & cold region processes
- radiation data & models

- Cross-exam with water cycle
  - precipitation latent heat (Tc= 0°C)
  - no adjustment to produce consistent a dataset

# Land surface fluxes

differences among models are about 15 W/m$^2$: all larger than surface radiation estimates.



# Estimating land sfc LH

- Model results:

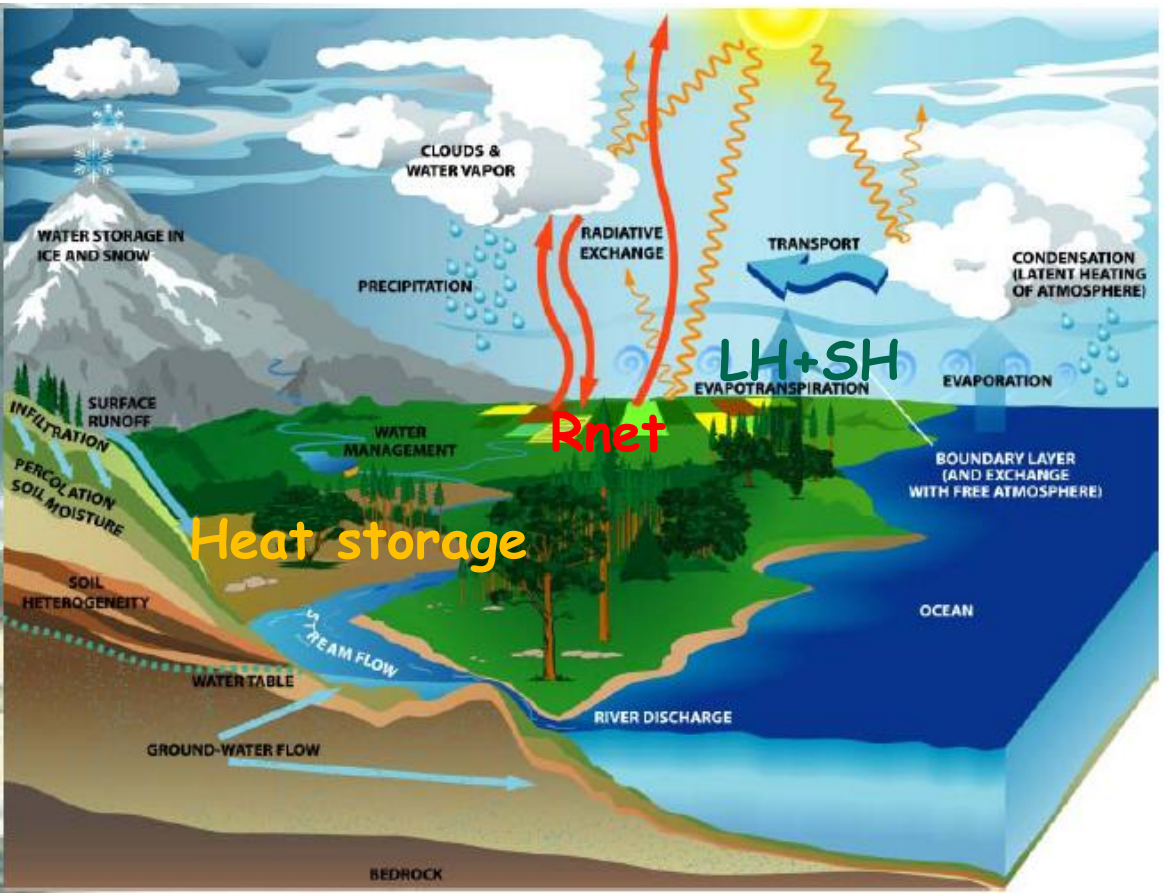
- large bias errors for heat budget in global/large scales

- Observations:

- surface radiation -- surface site val/cal
- much higher confidence than model estimates of sfc radiation

may still need large scale examinations

# Land heat budget




- heat storage S
- Bowen ratio B
- forced by Rnet daily ~ monthly time scales

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

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

# Current study (88-06)

- Radiation: TOA & sfc -- SRB, CERES, ISCCP-FD; errors: ~ 10 $W/m^2$

- Ocean turbulence: HOAPS, RSS, GSSTF

  bias errors: ~ 7 $W/m^2$

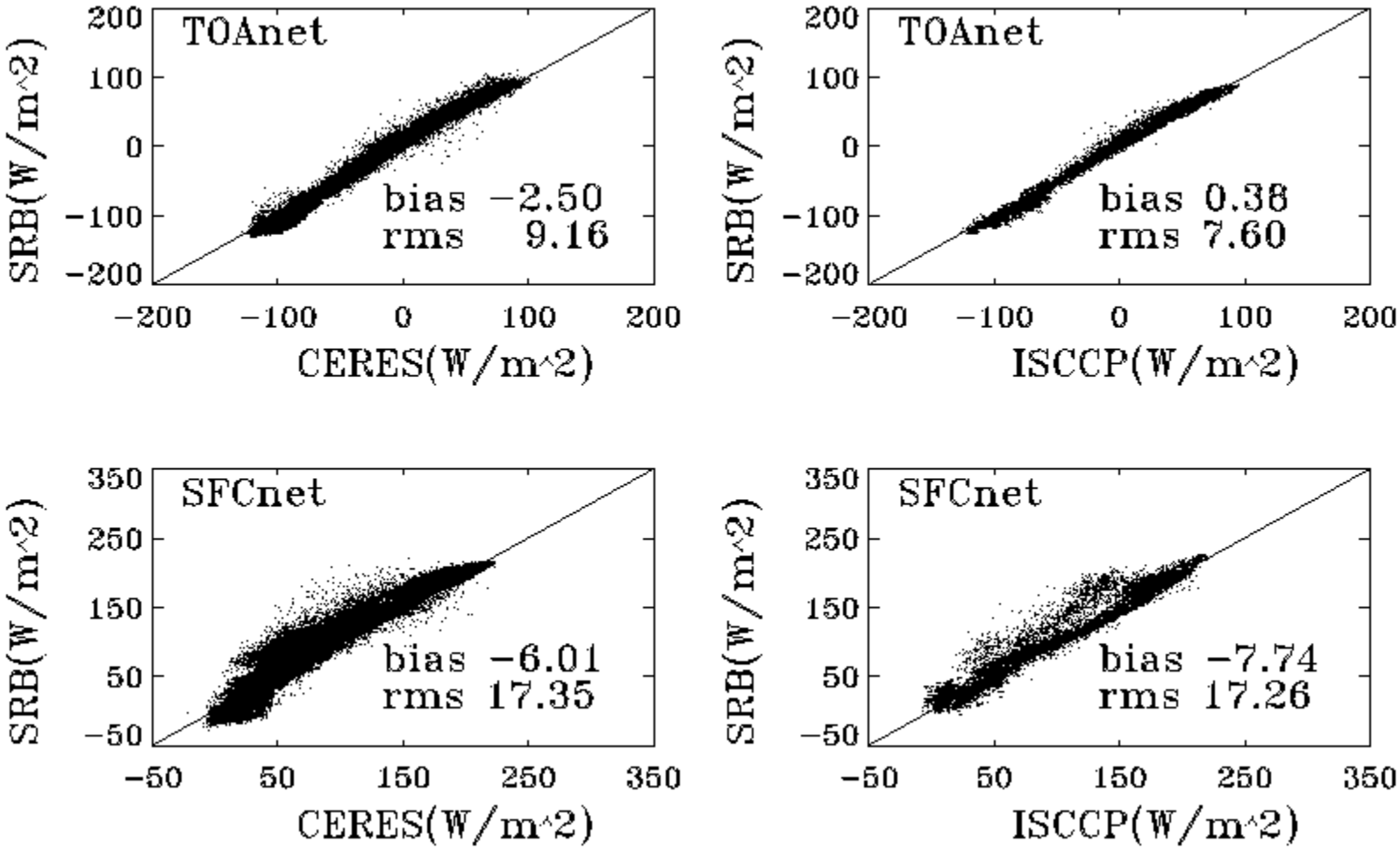
overall< 17 $W/m^2$

- Precipitation: GPCP, atmos. LH (water balance), annual mean errors: 5% or ~4 $W/m^2$

- Land surface: model results

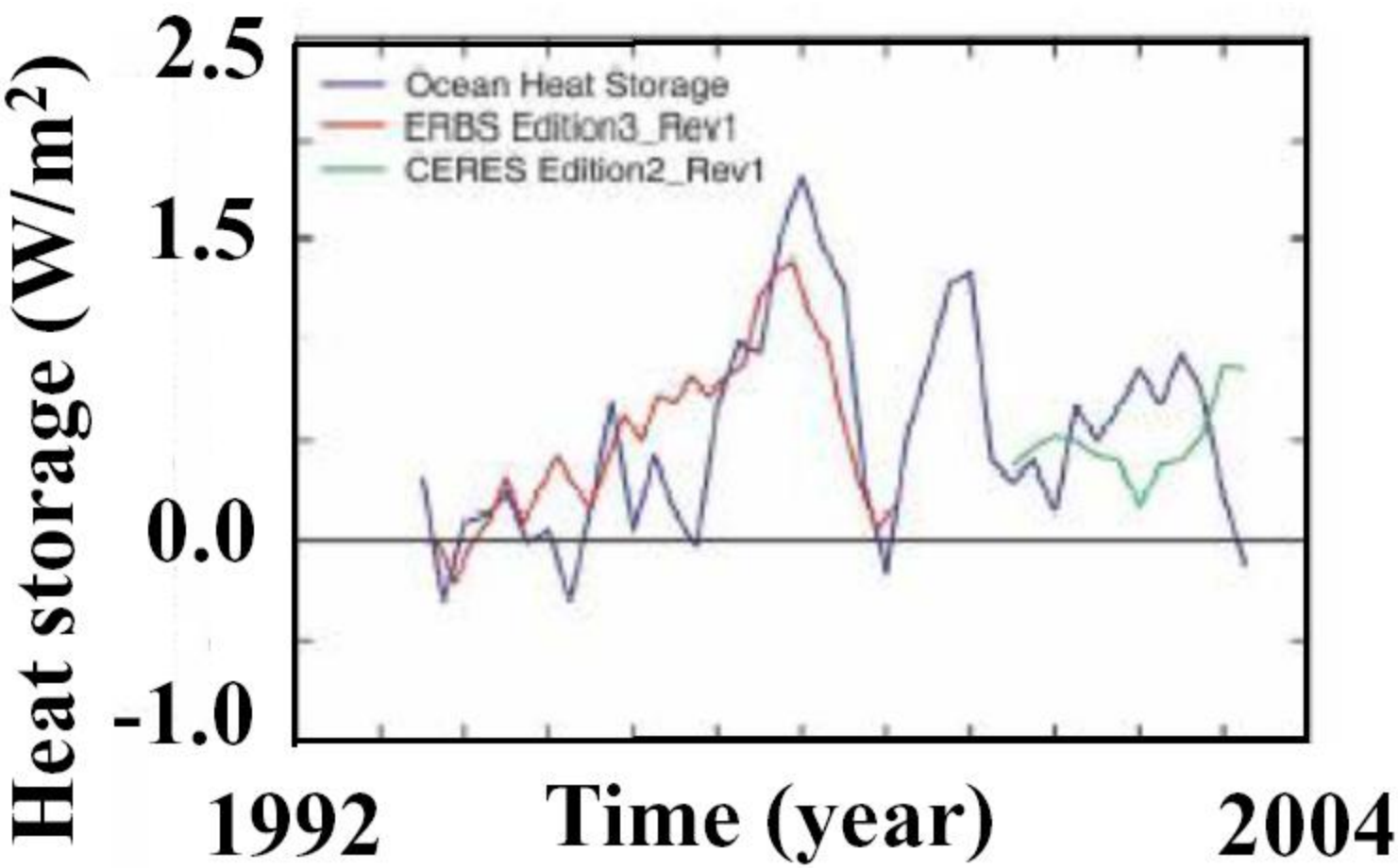
  interrelationships >> SRB + Bowen ratio

# comparison of radiation data




**Lin et al. JGR, 2008**

# radiation and heat storage

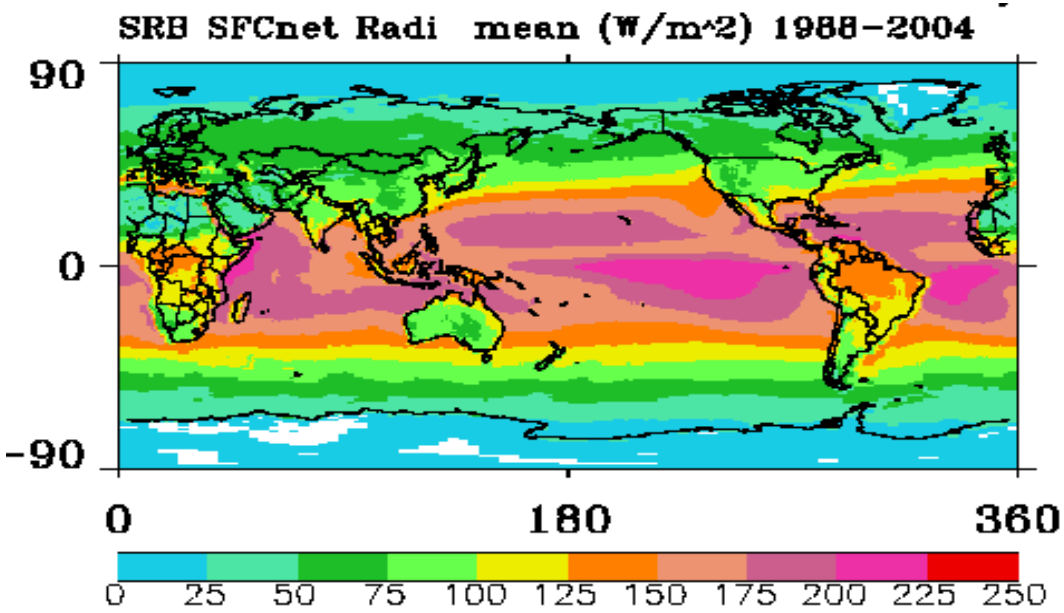


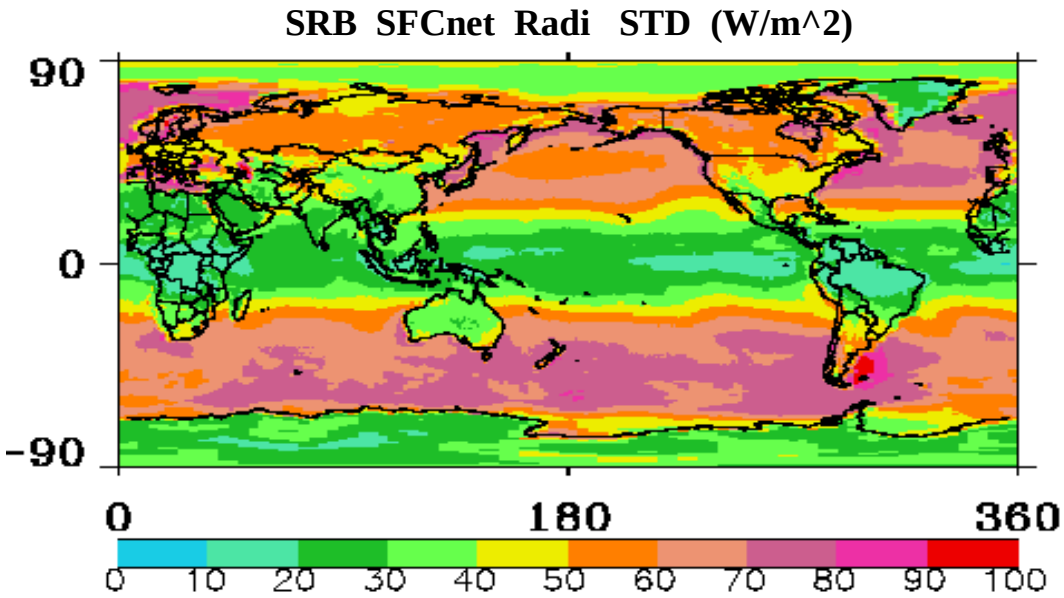

Wong et al. JC, 2006

# Energy Cycle 1988-2004 (SRB, HOAPS, GLDAS)

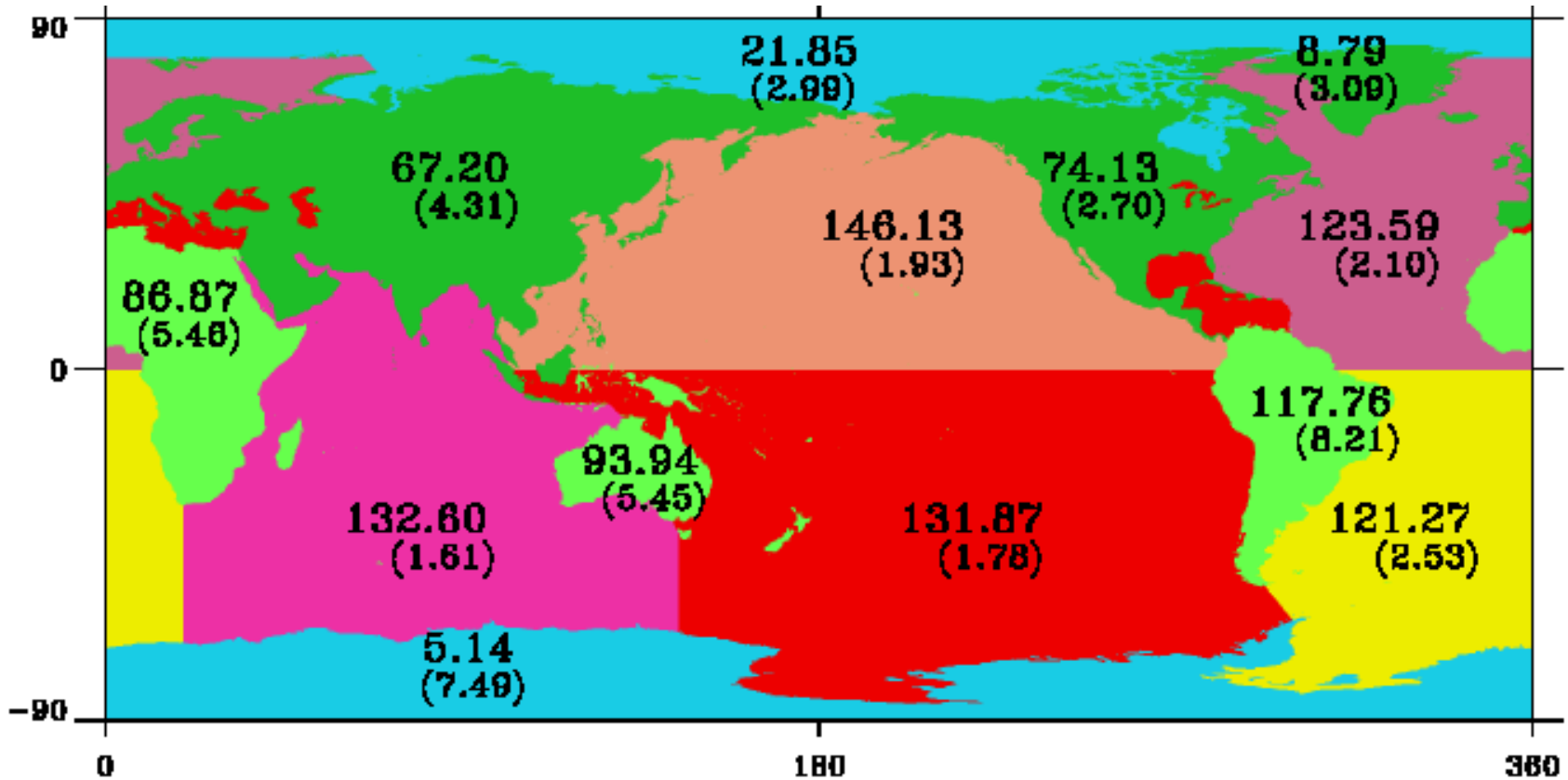
| | TOA net radiation | | SFC net radiation | | Latent heat | | Sensible heat | | SFC net flux | | atmos. Net radiaion | | GPCP | | TOA dn SW | | TOA up SW | | TOA up LW | | SFC Dn SW | | SFC up SW | | SFCnet SW | | SFC Dn LW | | SFC up LW | | SFCnet LW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std | mean | std |
| globe | 0.30 | 1.40 | 113.96 | 1.72 | 82.23 | 2.52 | 18.78 | 1.91 | 12.95 | 3.38 | -113.66 | 0.97 | 75.38 | 0.84 | 345.22 | 0.04 | 103.1 | 1.44 | 240.45 | 0.66 | 190.81 | 1.18 | 23.11 | 0.56 | 167.73 | 1.62 | 343.13 | 0.94 | 396.12 | 1.06 | -52.84 | 0.91 |
| World Land | -8.45 | 1.62 | 81.42 | 2.90 | 47.82 | 5.47 | 32.63 | 5.61 | 0.97 | 0.11 | -89.87 | 1.68 | 59.47 | 1.49 | 343.98 | 0.03 | 110.53 | 1.09 | 241.48 | 1.17 | 188.91 | 0.79 | 36.59 | 0.80 | 152.34 | 1.13 | 325.88 | 1.37 | 396.55 | 2.69 | -70.08 | 2.07 |
| world ocean | 7.27 | 1.50 | 130.33 | 1.46 | 96.02 | 4.04 | 13.60 | 0.91 | 20.70 | 4.60 | -123.05 | 0.94 | 82.10 | 1.18 | 350.01 | 0.05 | 98.24 | 1.59 | 243.45 | 0.70 | 192.79 | 1.51 | 14.48 | 0.50 | 178.34 | 1.83 | 357.27 | 0.84 | 404.70 | 0.63 | -47.43 | 0.75 |
| South America | 30.87 | 5.41 | 117.76 | 8.22 | 86.68 | 8.04 | 30.46 | 9.50 | 0.62 | 0.13 | -86.89 | 3.75 | 118.10 | 5.87 | 395.83 | 0.02 | 121.71 | 6.17 | 243.26 | 2.54 | 205.96 | 3.50 | 29.47 | 5.17 | 176.49 | 7.87 | 375.64 | 1.60 | 434.37 | 2.65 | -58.56 | 2.09 |
| North America | -29.67 | 2.05 | 74.14 | 2.71 | 48.03 | 6.21 | 25.16 | 7.35 | 0.94 | 0.16 | -103.81 | 1.27 | 54.15 | 1.91 | 295.00 | 0.04 | 101.44 | 2.96 | 222.19 | 1.60 | 155.64 | 1.78 | 27.52 | 2.14 | 128.15 | 3.61 | 287.96 | 1.31 | 341.35 | 2.31 | -53.32 | 1.73 |
| Africa | 13.04 | 3.07 | 86.87 | 5.46 | 37.69 | 4.55 | 48.16 | 5.04 | 1.02 | 0.14 | -73.82 | 3.18 | 53.04 | 3.72 | 398.74 | 0.04 | 118.60 | 2.40 | 267.09 | 1.63 | 237.15 | 1.79 | 55.30 | 1.65 | 181.86 | 2.72 | 364.54 | 2.30 | 459.53 | 4.48 | -94.10 | 3.80 |
| Eurasia | -27.93 | 2.79 | 67.20 | 4.31 | 41.66 | 6.64 | 24.22 | 5.86 | 1.32 | 0.13 | -95.13 | 1.85 | 53.95 | 1.26 | 309.99 | 0.04 | 107.08 | 1.69 | 230.24 | 1.25 | 163.48 | 1.36 | 31.73 | 1.63 | 131.77 | 1.93 | 298.67 | 1.57 | 362.89 | 2.84 | -63.37 | 2.08 |
| Australia | 10.32 | 4.33 | 93.94 | 5.45 | 40.31 | 5.19 | 53.07 | 4.06 | 0.55 | 0.11 | -83.62 | 1.81 | 60.79 | 9.26 | 381.55 | 0.05 | 104.18 | 5.18 | 267.04 | 3.20 | 227.67 | 5.82 | 39.51 | 3.34 | 188.16 | 8.26 | 353.76 | 2.89 | 447.98 | 5.19 | -94.03 | 6.34 |
| Antarctica | -90.34 | 6.20 | 5.15 | 7.49 | n/a (land models only cover from -60 to 90 degree latitudes) | | | | | | -95.48 | 2.31 | 16.16 | 1.17 | 240.17 | 0.35 | 159.22 | 6.77 | 153.01 | 1.59 | 165.87 | 2.91 | 120.56 | 6.64 | 45.54 | 7.05 | 141.48 | 2.41 | 171.05 | 1.92 | -29.57 | 2.76 |
| Arctic Ocean | -108.25 | 2.45 | 21.85 | 2.99 | 15.71 | 1.85 | 2.18 | 1.25 | 3.95 | 3.55 | -130.01 | 2.17 | 19.94 | 1.76 | 239.04 | 0.93 | 130.36 | 3.54 | 195.11 | 1.29 | 123.66 | 4.11 | 65.36 | 3.07 | 58.88 | 3.56 | 228.18 | 1.79 | 253.91 | 3.04 | -25.73 | 3.20 |
| Caribbean Sea | 49.59 | 4.33 | 175.25 | 4.01 | 146.71 | 10.44 | 12.83 | 1.57 | 15.66 | 9.53 | -125.61 | 1.57 | 71.79 | 9.27 | 395.87 | 0.07 | 81.29 | 4.59 | 264.98 | 1.41 | 242.13 | 4.48 | 13.31 | 1.47 | 228.82 | 5.54 | 403.17 | 1.70 | 456.79 | 1.00 | -53.61 | 1.90 |
| Mediterranean Sea | 8.78 | 1.39 | 129.14 | 2.03 | 88.06 | 6.78 | 13.18 | 1.37 | 27.89 | 8.41 | -120.35 | 1.50 | 38.24 | 4.17 | 342.40 | 0.10 | 70.51 | 2.45 | 263.09 | 2.21 | 215.70 | 3.13 | 10.96 | 0.88 | 204.74 | 2.94 | 341.77 | 2.03 | 417.36 | 1.72 | -75.59 | 1.93 |
| Black Sea | -13.25 | 2.72 | 97.18 | 3.42 | 51.74 | 4.87 | 8.69 | 1.56 | 36.74 | 4.71 | -110.44 | 2.07 | 66.05 | 8.28 | 315.52 | 0.10 | 90.59 | 4.38 | 238.18 | 2.76 | 169.18 | 5.27 | 8.95 | 0.40 | 160.23 | 5.26 | 324.99 | 3.01 | 388.04 | 2.77 | -63.04 | 2.54 |
| Caspian Sea | -13.06 | 2.19 | 94.80 | 2.97 | n/a (HOAPS does not have the data) | | | | | | -107.86 | 2.69 | 37.21 | 5.58 | 323.98 | 0.10 | 95.76 | 4.22 | 241.28 | 3.66 | 173.60 | 4.71 | 14.25 | 0.48 | 159.34 | 4.78 | 326.48 | 2.99 | 391.03 | 2.81 | -64.54 | 2.72 |
| Great Lakes | -16.34 | 3.31 | 93.82 | 4.11 | n/a (HOAPS does not have the data) | | | | | | -110.17 | 1.61 | 74.37 | 4.87 | 308.64 | 0.10 | 103.70 | 4.96 | 221.28 | 2.51 | 153.39 | 4.48 | 13.79 | 1.73 | 139.60 | 5.53 | 298.34 | 3.37 | 344.12 | 4.06 | -45.77 | 1.93 |
| North Pacific | 26.60 | 1.99 | 146.13 | 1.93 | 103.39 | 4.48 | 11.36 | 0.89 | 31.38 | 4.78 | -119.53 | 1.96 | 107.82 | 4.51 | 374.19 | 0.07 | 99.44 | 2.08 | 248.15 | 1.89 | 205.80 | 2.23 | 12.15 | 0.56 | 193.65 | 2.45 | 382.39 | 1.06 | 429.91 | 0.72 | -47.52 | 0.89 |
| North Atlantic | 0.82 | 2.06 | 123.59 | 2.10 | 91.15 | 5.28 | 12.46 | 0.96 | 19.97 | 5.16 | -122.77 | 1.11 | 81.11 | 3.34 | 338.48 | 0.09 | 92.26 | 2.42 | 243.81 | 1.19 | 186.82 | 2.45 | 12.20 | 0.57 | 174.64 | 2.73 | 357.92 | 1.13 | 407.93 | 1.26 | -50.01 | 1.10 |
| Indian Ocean | 10.22 | 1.48 | 132.60 | 1.61 | 101.89 | 4.05 | 16.33 | 1.02 | 14.37 | 4.81 | -122.37 | 0.66 | 80.60 | 3.10 | 352.12 | 0.06 | 98.08 | 1.68 | 243.80 | 0.55 | 193.01 | 1.85 | 12.41 | 0.45 | 180.59 | 1.92 | 358.83 | 1.00 | 406.81 | 0.66 | -47.98 | 0.62 |
| South Pacific | 8.21 | 1.82 | 131.87 | 1.78 | 95.31 | 4.09 | 14.06 | 1.03 | 22.52 | 4.44 | -123.66 | 1.09 | 80.47 | 3.20 | 349.60 | 0.06 | 96.84 | 1.96 | 243.94 | 0.95 | 194.07 | 1.92 | 13.79 | 0.54 | 180.32 | 2.23 | 355.92 | 1.08 | 404.00 | 0.76 | -48.08 | 0.85 |
| South Atlantic | -6.57 | 2.26 | 121.27 | 2.54 | 80.16 | 3.92 | 13.96 | 1.07 | 27.14 | 6.49 | -127.85 | 1.27 | 60.26 | 2.03 | 335.96 | 0.08 | 101.08 | 2.48 | 240.78 | 0.73 | 181.73 | 2.53 | 15.01 | 0.63 | 166.77 | 2.71 | 337.40 | 0.83 | 382.52 | 0.92 | -45.12 | 1.00 |

# Large variability



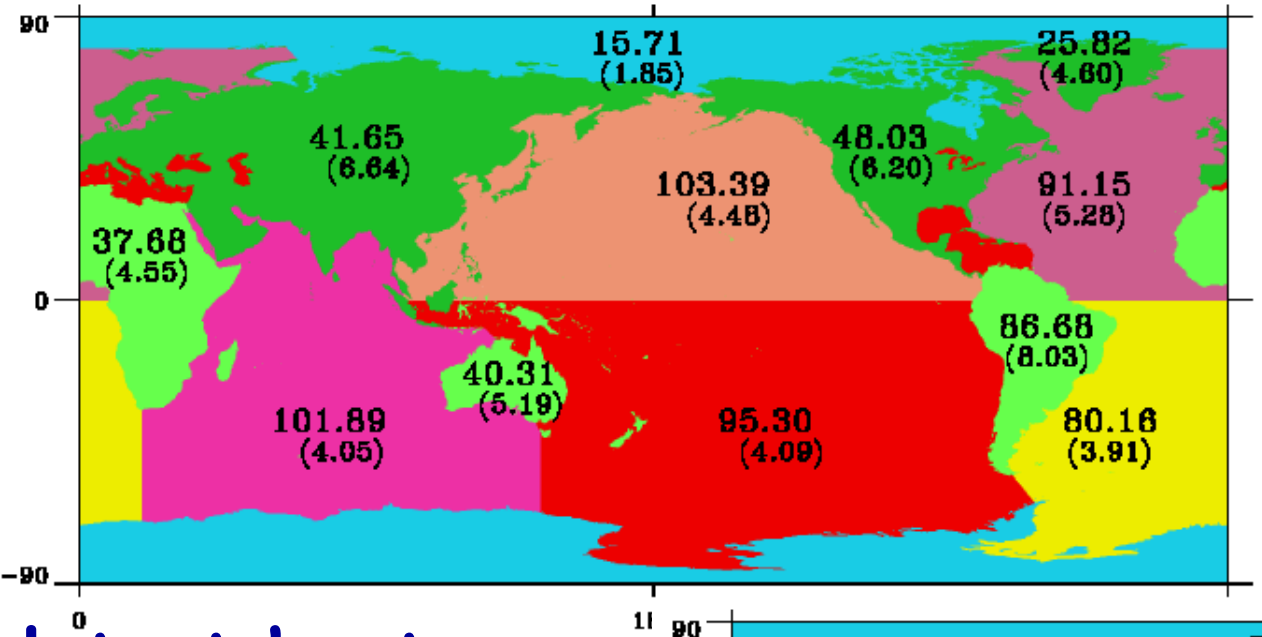



# surface net radiation
## (-114 ± 1.7 W/m²; 1988 ~ 2004)




significant net radiative heating over the surface:
energy source for latent and sensible heat

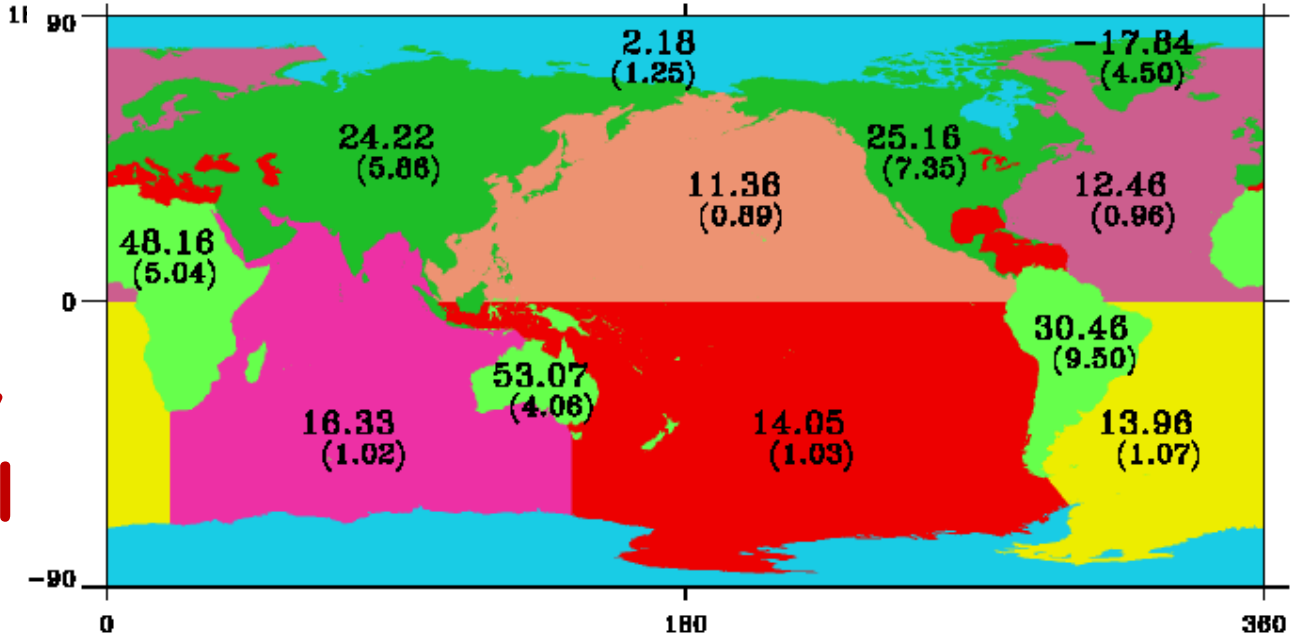
# surface turbulent fluxes




Ocean: HOAPS
Land: GLDAS

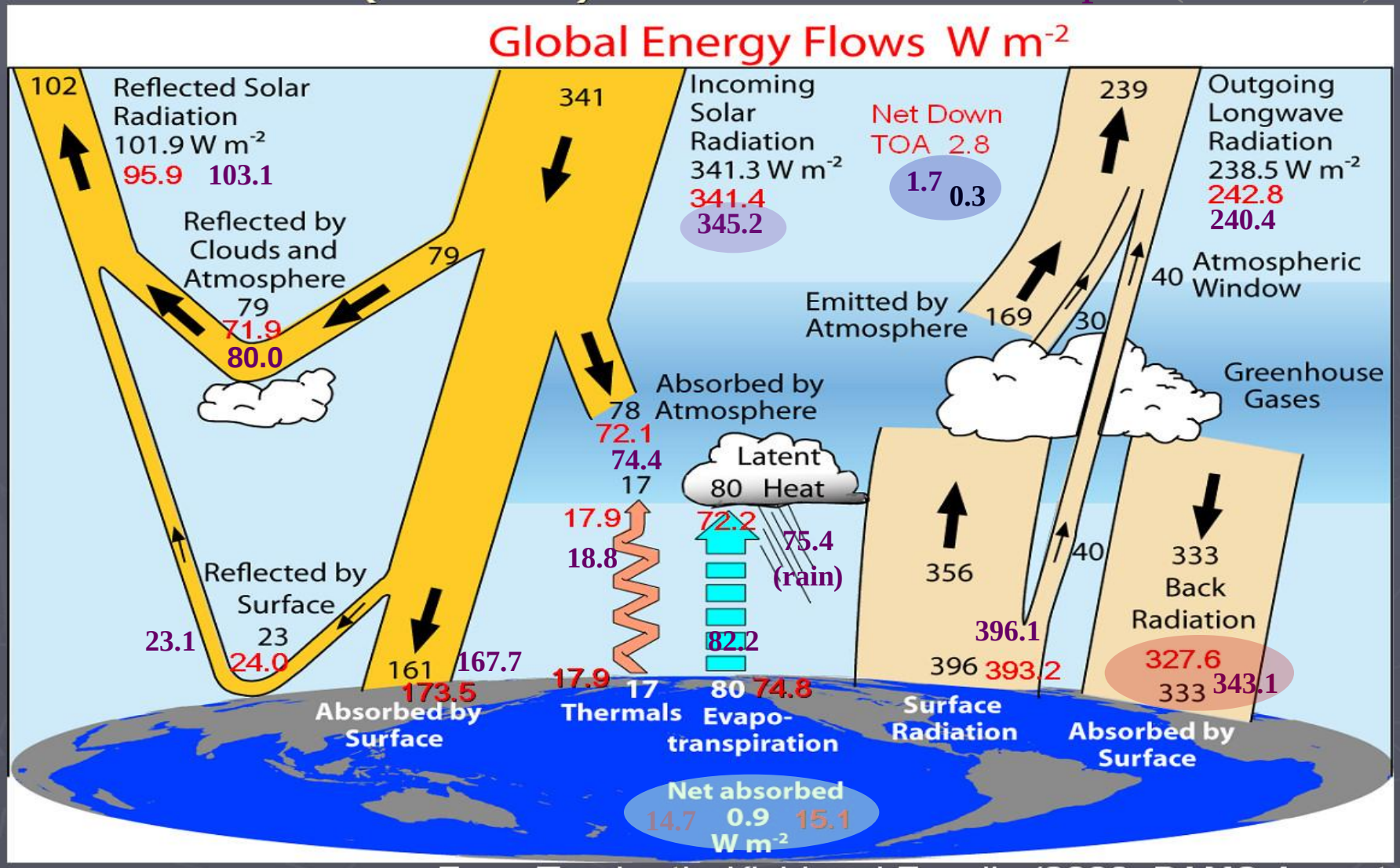
sensible heat
(18.8 ± 1.9 W/m²)

latent heat
(82.2 ± 2.5 W/m²)




small variability
at long temporal
scales!

MERRA in RED (114 mon) Satellite Purple (204 mon)




From Trenberth, Kiehl and Fasullo (2008, BAMS Accepted)

# Summary

- Although satellites can provide invaluable estimates of atmospheric heat fluxes, there are significant observational gaps over land surfaces and cold regions.

- Bias errors are large (10 ~ 15 W/m2). Considerable differences when observed radiation, precipitation and turbulent fluxes are existed.

- Adjustments in individual energy (and water) components may be needed, potentially even for our short-term goals.