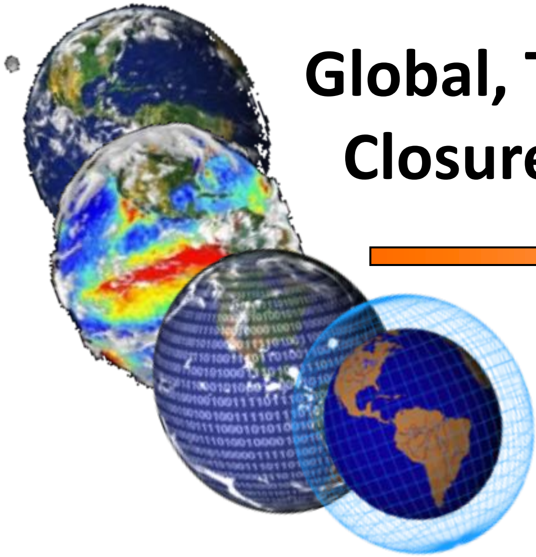

# Global, Terrestrial Energy Budget Validation and Closure using Remotely-Sensed Satellite Data


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in collaboration with
Amanda Siemann and Ming Pan



Open Science Conference on the Global Water and Energy Cycles
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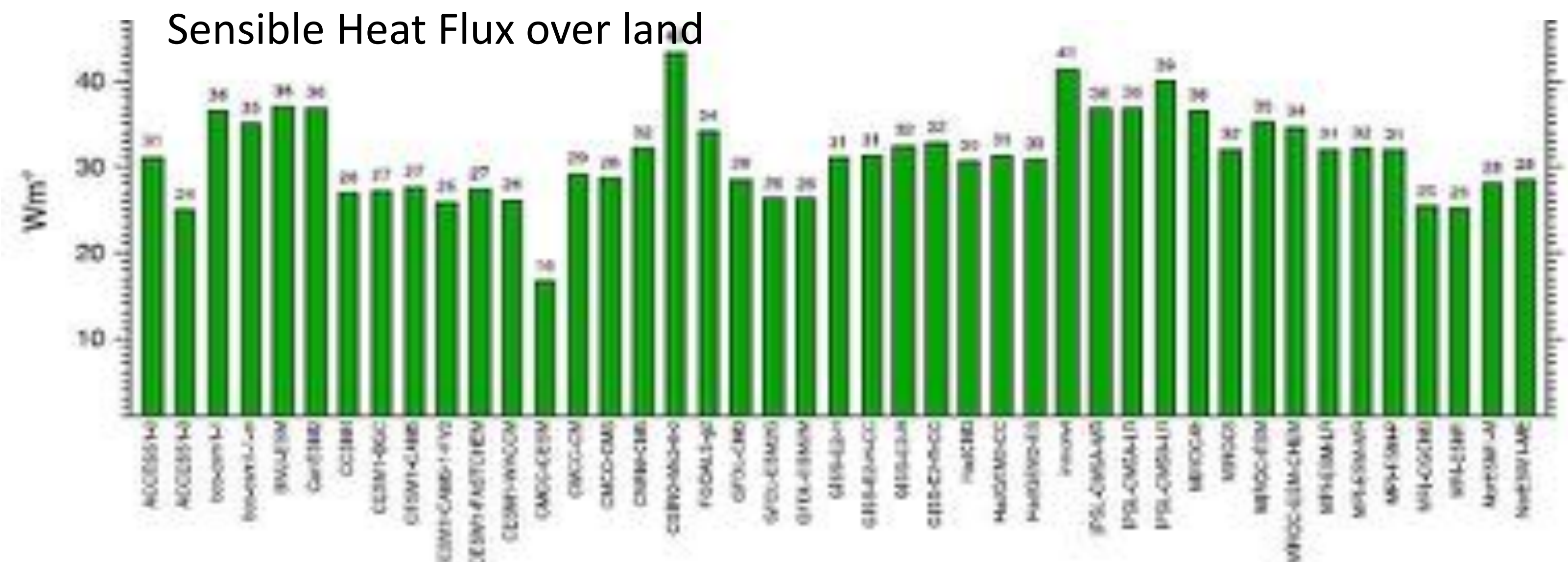
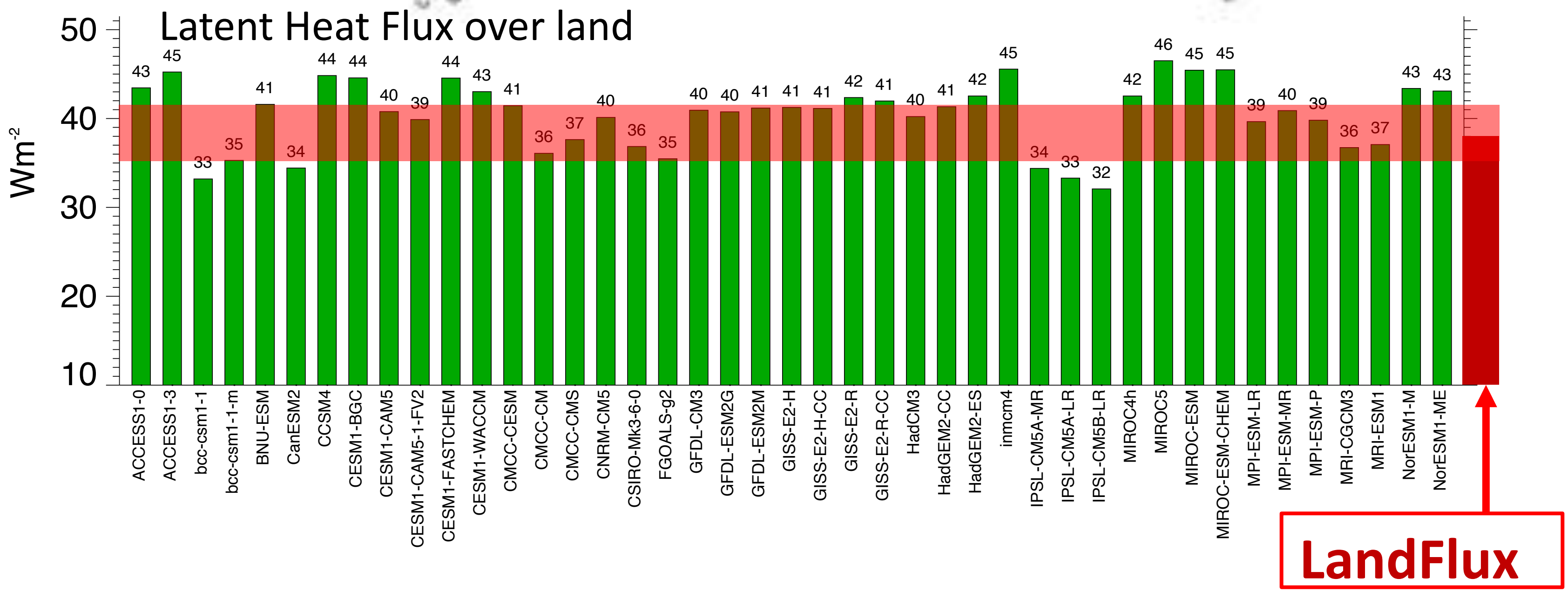
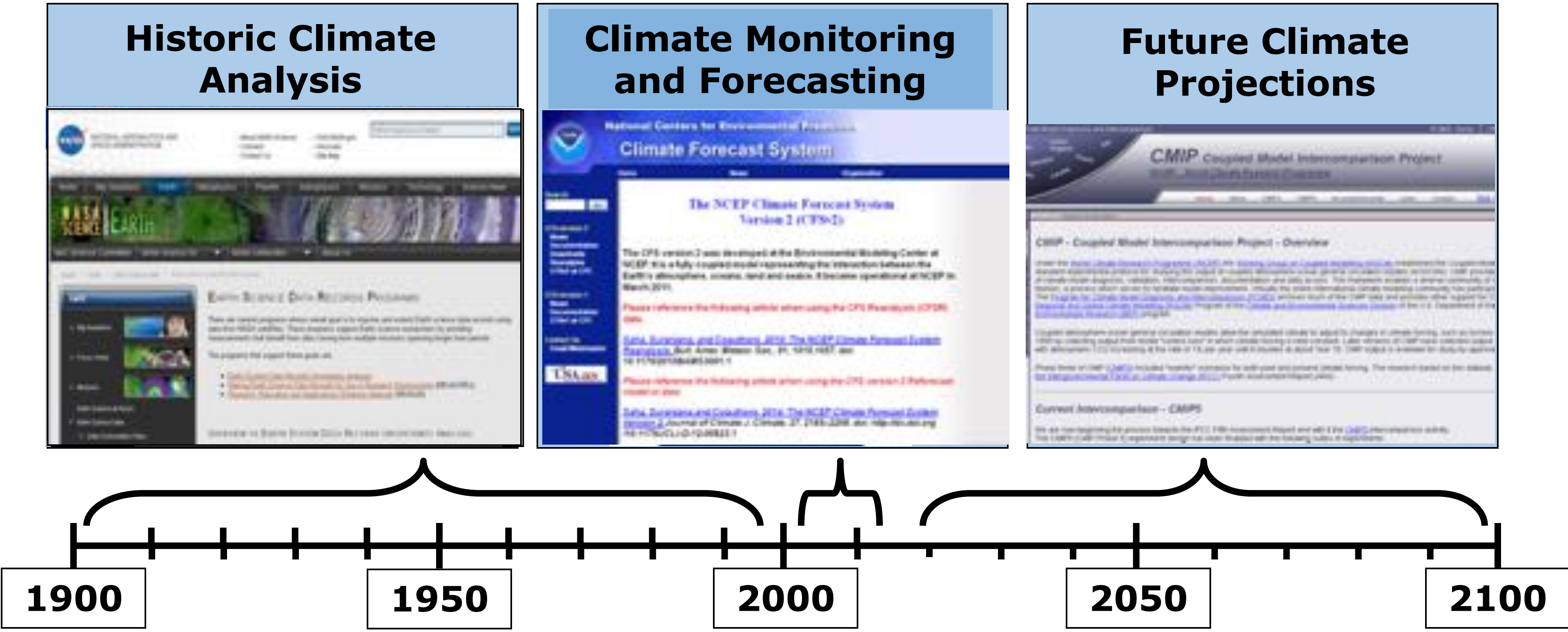
# Motivation

What are limitations of models and reanalysis data for estimating energy fluxes?



# Programs supporting the development of global water and energy cycle data systems

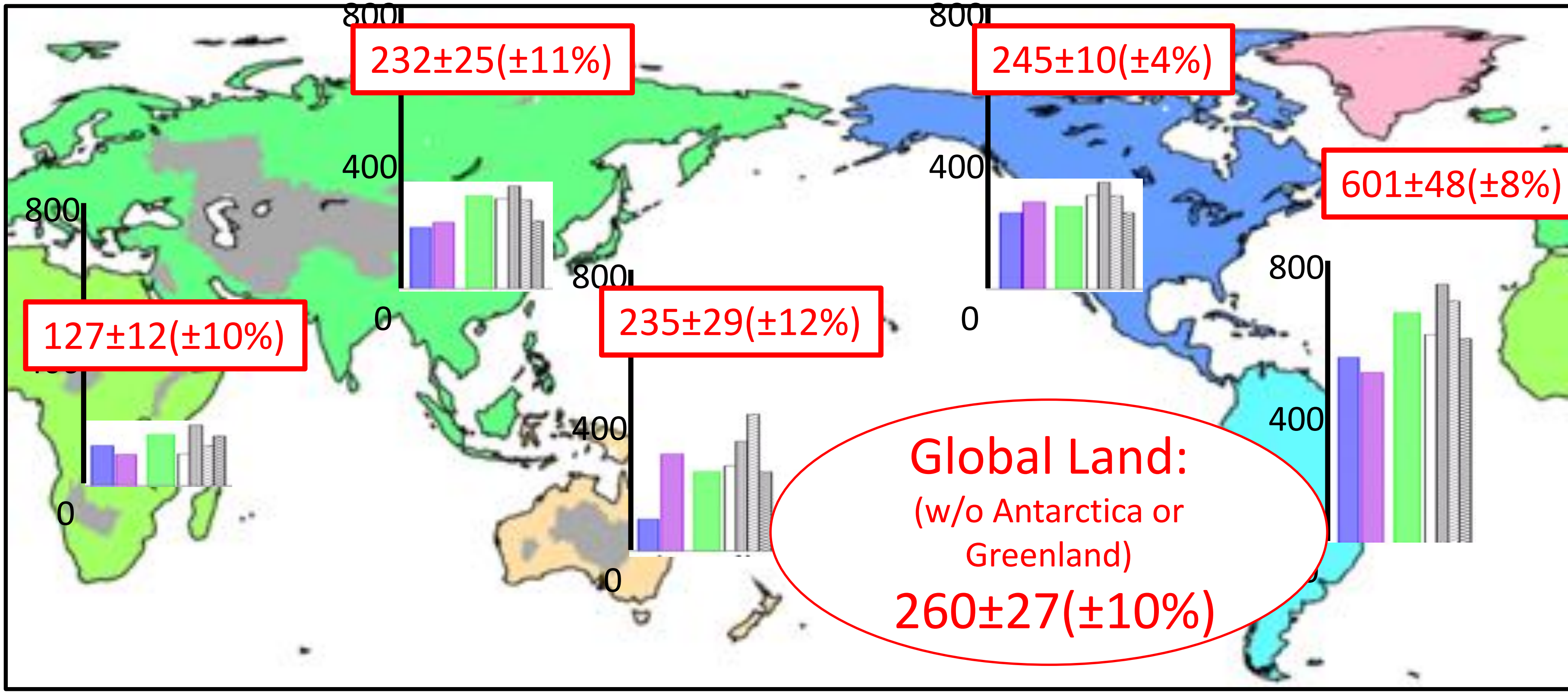


# Summary of the Global Water Cycle

Using the global data sets:

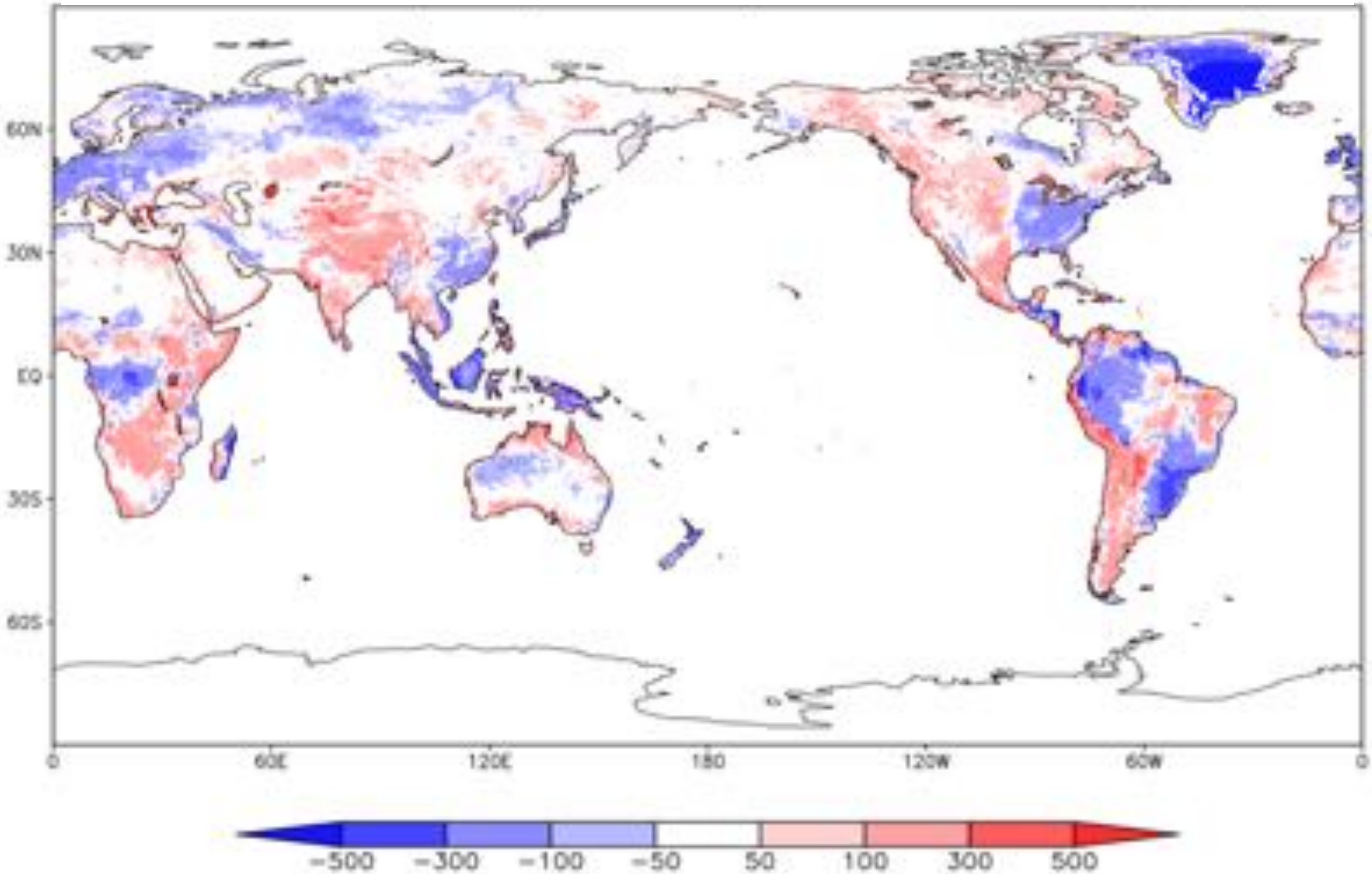
What are the variability and trends of the global water cycle

Closure among 3 Flux Terms: -∇·q, P-E, and Q (1984-2007, mm/year)

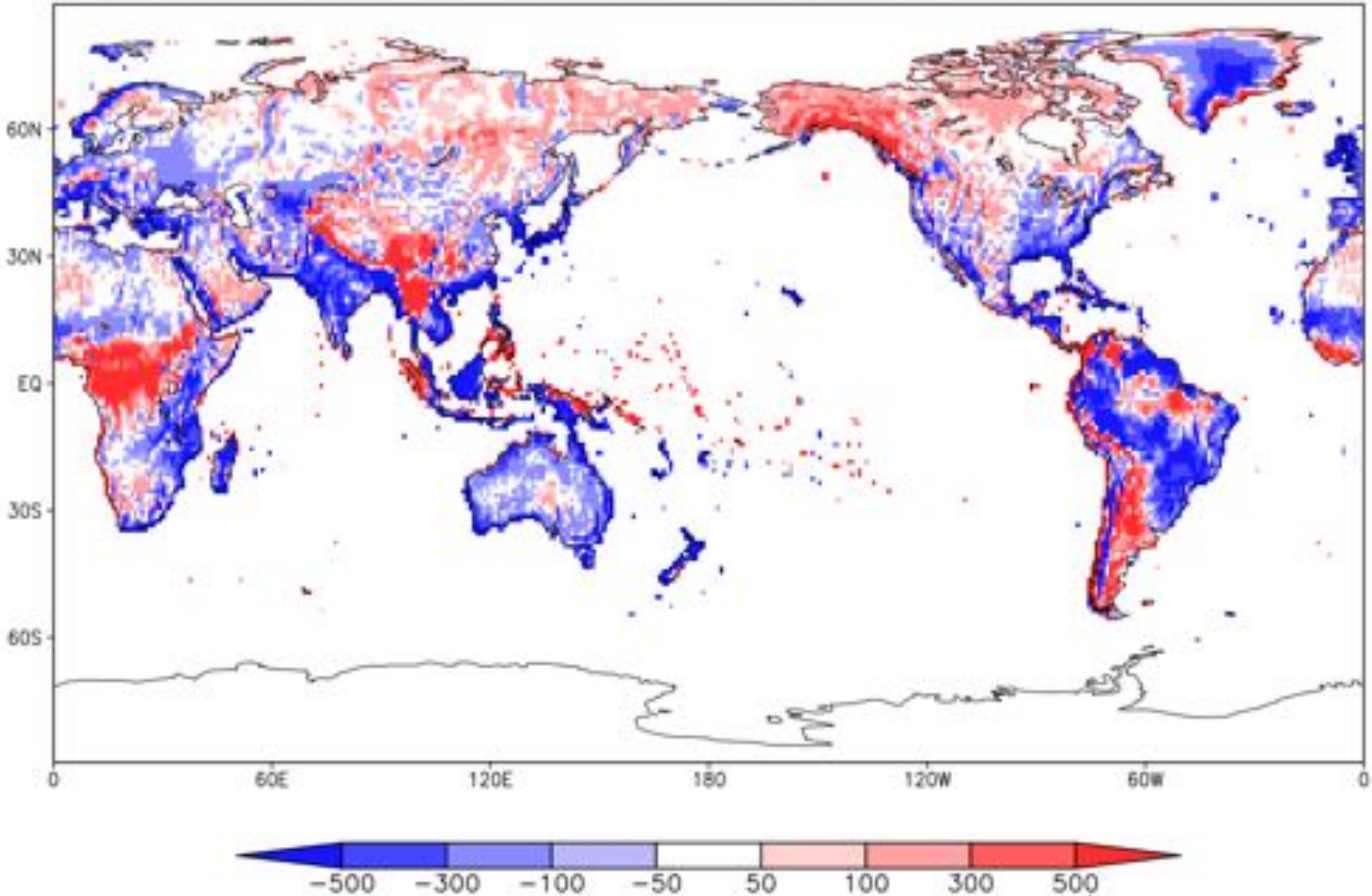



# Closure residual for the global terrestrial water cycle

## Residual Q-(P-E); Average=3 (1984-2007; mm/yr)



# Residual Conv-(P-E); Average=-65 (1984-2007; mm/yr)



# Comparison with SeaFlux and PU Measures/GPCP/LandFlux

| Variable | Source | Land (w/o Antarctica, Greenland) | Ocean | Globe |
|---|---|---|---|---|
| Runoff | PU Measures* | -38.2 | 38.2 | |
| Converg. | Reanalysis | 29.2±**0.78** | -29.2 | |
| **Closure** | | **-9.0±1** | | |
| Precip. | PU Measures (GPCP) | 102.8 | | 486.9 |
| | SeaFlux** | | 384.1 | |
| ET | LandFlux (PM) | -64.9±5 | | 474.4 |
| | **SeaFlux** | | -409.5 | |
| **Closure** | LandFlux | -0.3±**5** **(0.3%)** | | 12.5 (2.5%) |
| | SeaFlux | | 12.8 (3.1%) | |

x1000 $km^3/yr$

* 1984-2007

** 1998-2007(?)

# Summary of the Global Energy Cycle over Land

# Global Annual Average Energy Budget Fluxes 1984-2007

**Available Energy**

| Energy Budget Product | excl. A&G | incl. A&G | Energy Budget Product | excl. A&G | incl. A&G |
|---|---|---|---|---|---|
| RS_Rnet_alM, A&G CFSR | 89.8 | 79.3 | RS_Gflux | 0.0 | 0.1 |
| RS_Rnet_alS, A&G CFSR | 91.8 | 81.1 | Rea_Gflux_CFSR | -1.2 | -1.0 |
| RS_Rnet_alM, A&G CFSR bc | 89.8 | 77.9 | Wild et al., 2015 Gflux | N/A | N/A |
| RS_Rnet_alS, A&G CFSR bc | 91.8 | 79.7 | L'Ecuyer et al., 2015 Gflux | N/A | N/A |
| Rea_Rnet_CFSR | 111.9 | 99.1 | | | |
| Rea_Rnet_CFSR_bc | 98.7 | 85.8 | | | |
| Wild et al., 2015 Rnet | N/A | 70.0 | | | |
| L'Ecuyer et al., 2015 Rnet | N/A | 76.3 | | | |

**Turbulent Fluxes**

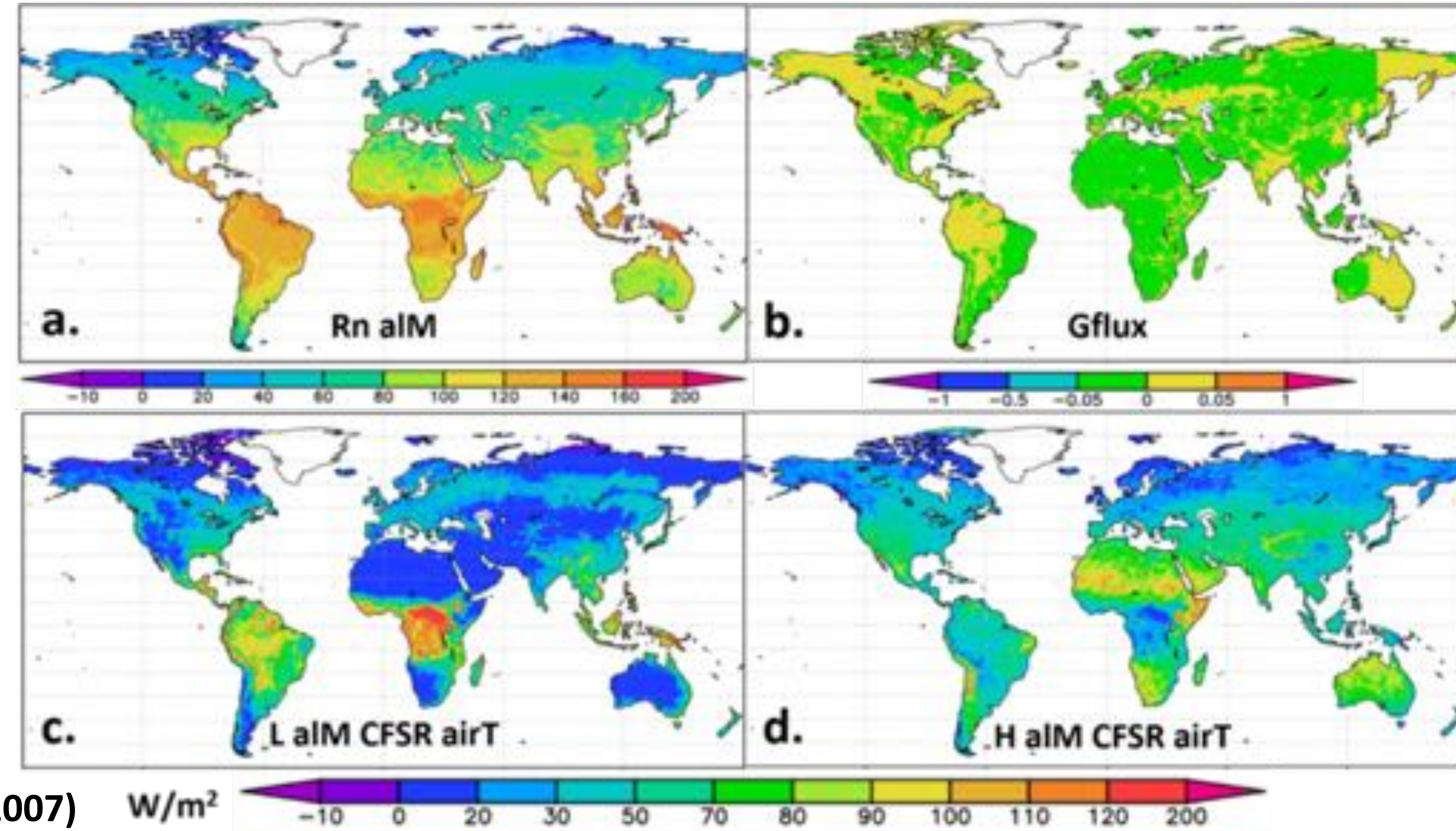
| | | | | | |
|---|---|---|---|---|---|
| RS_L_alM_Gr_CFSR | 45.1 | 40.7 | RS_H_alM_Gr_CFSR | 44.7 | 36.2 |
| RS_L_alM_T_CFSR | 38.2 | 34.5 | RS_H_alM_T_CFSR | 51.6 | 42.4 |
| RS_L_alM_T_MERRA | 40.8 | 36.9 | RS_H_alM_T_MERRA | 48.9 | 40.0 |
| RS_L_alS_Gr_CFSR | 45.4 | 41.0 | RS_H_alS_Gr_CFSR | 46.4 | 37.7 |
| RS_L_alS_T_CFSR | 38.5 | 34.8 | RS_H_alS_T_CFSR | 53.2 | 43.9 |
| RS_L_alS_T_MERRA | 41.2 | 37.2 | RS_H_alS_T_MERRA | 50.6 | 41.5 |
| Rea_L_CFSR | 41.7 | 37.6 | Rea_H_CFSR | 43.0 | 34.7 |
| Rea_L_MERRA | 49.7 | 44.8 | Rea_H_MERRA | 42.2 | 34.0 |
| Wild et al., 2015 L | N/A | 38.0 | Wild et al., 2015 H | N/A | 32.0 |
| L'Ecuyer et al., 2015 L | N/A | 38.1 | L'Ecuyer et al., 2015 H | N/A | 38.1 |

$W/m^2$

# Global Annual Average Energy Budget Fluxes Comparisons 1984-2007 ($W/m^2$)

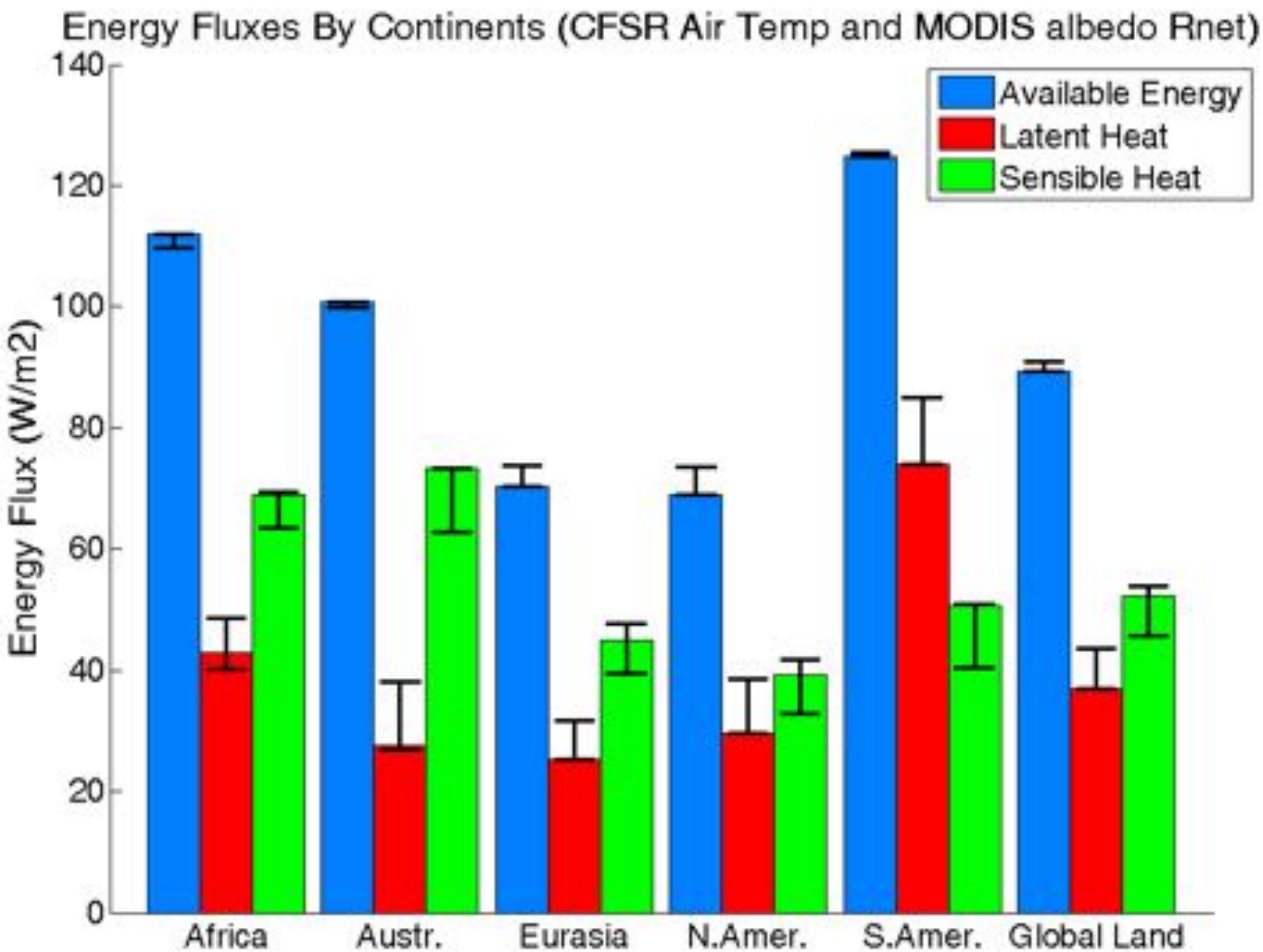
| Net Radiation | excl. A&G | incl. A&G | Latent Heat Flux | excl. A&G | incl. A&G |
|---|---|---|---|---|---|
| Rnet MODIS albedo, A&G CFSR | 89.8 | 79.3 | CFSR airT, MODIS albedo | 38.2 | 34.5 |
| Rnet CFSR reanalysis | 111.9 | 99.1 | L CFSR reanalysis | 41.7 | 37.6 |
| Rnet CFSR bias-corrected reanalysis | 98.7 | 85.8 | L MERRA reanalysis | 49.7 | 44.8 |
| Wild et al., 2015 Rnet | N/A | 70.0 | Wild et al., 2015 L | N/A | 38.0 |
| L'Ecuyer et al., 2015 Rnet | N/A | 76.3 | L'Ecuyer et al., 2015 L | N/A | 38.1 |
| Sensible Heat Flux | | | | | |
| H CFSR Reanalysis | 43.0 | 34.7 | CFSR gradient; MODIS albedo | 44.7 | 36.2 |
| H MERRA Reanalysis | 42.2 | 34.0 | CFSR airT; MODIS albedo | 51.6 | 42.4 |
| Wild et al., 2015; H | | 32.0 | | | |
| L'Ecuyer et al., 2015 constrained | | 38.1 | | | |

## Using the global data sets:
## What are the spatial variability of the global energy cycle



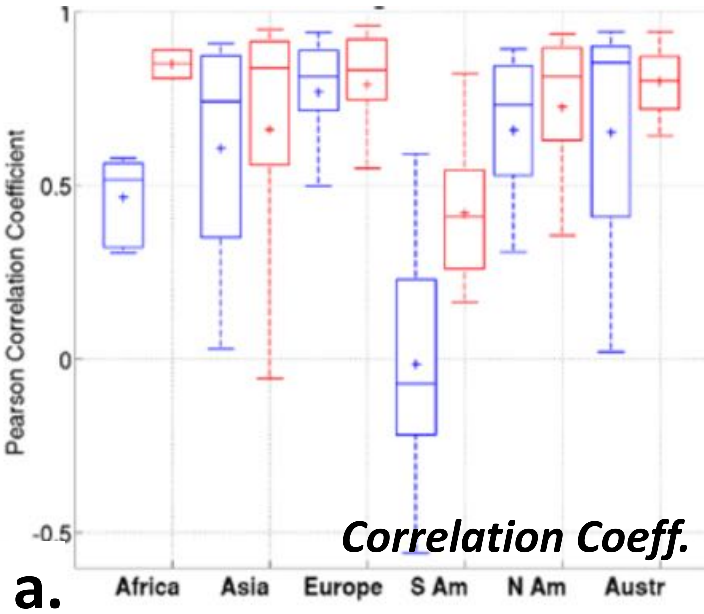

**(1984-2007)**

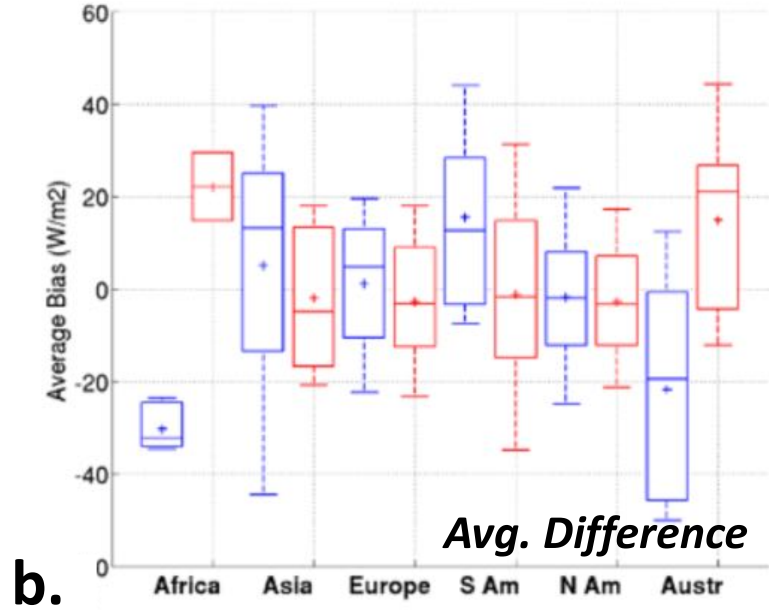
# Continental Annual Average Energy Budget Fluxes 1984-2007




W/m$^2$

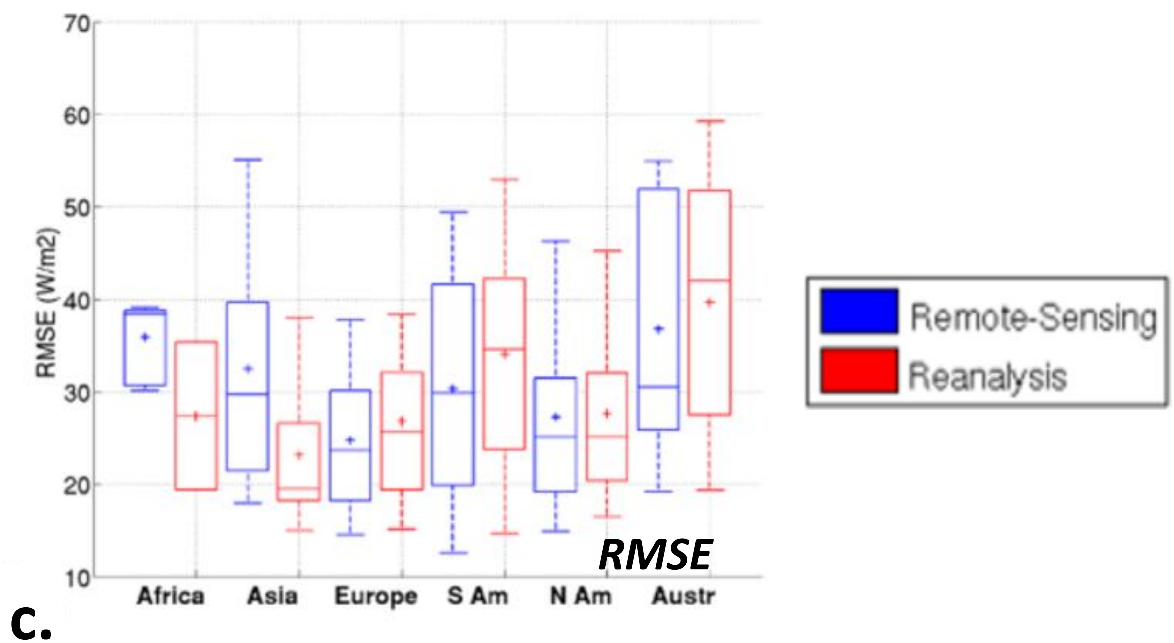
# FLUXNET comparisons Available Energy 1984-2007



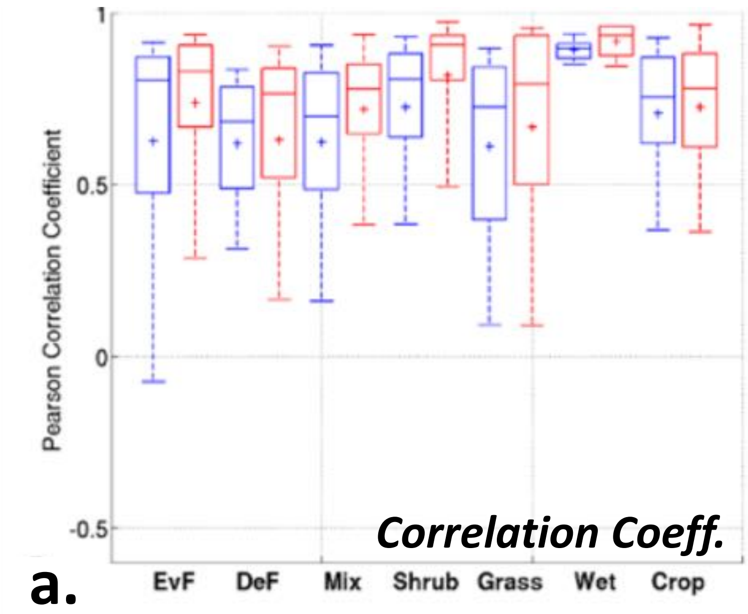



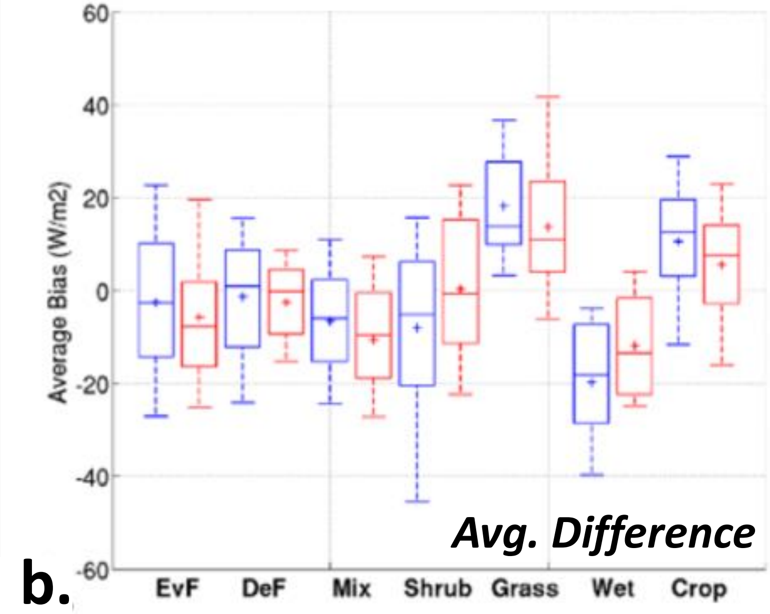

**Statistics by Region**

Our products perform best at the North American, European, and Asian sites



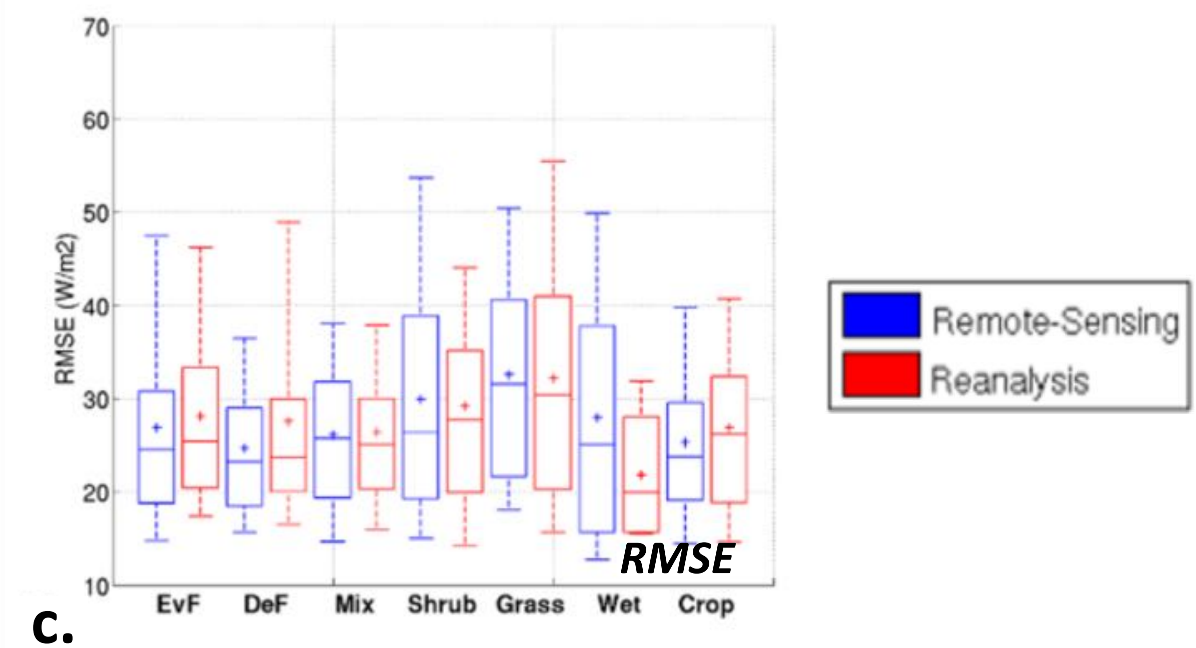
# FLUXNET comparisons Sensible Heat Flux 1984-2007



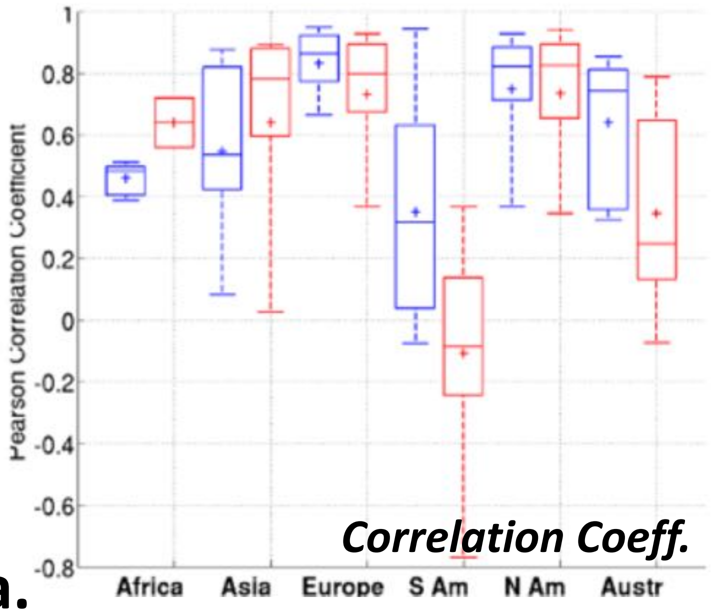

**<u>Statistics by Veg. Type</u>**

Our products perform best at the wetland/water, evergreen forest, deciduous forest, and cropland/bare soil sites

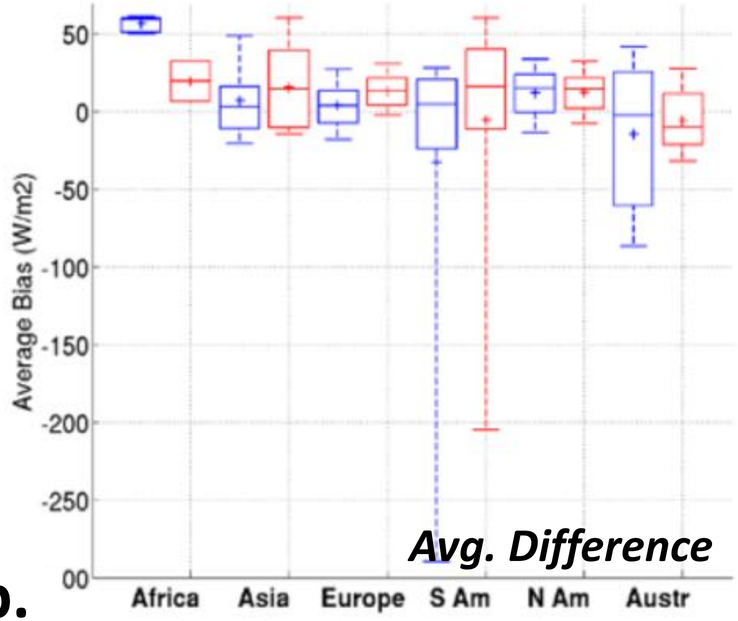


# FLUXNET comparisons Latent Heat Flux 1984-2007

a.



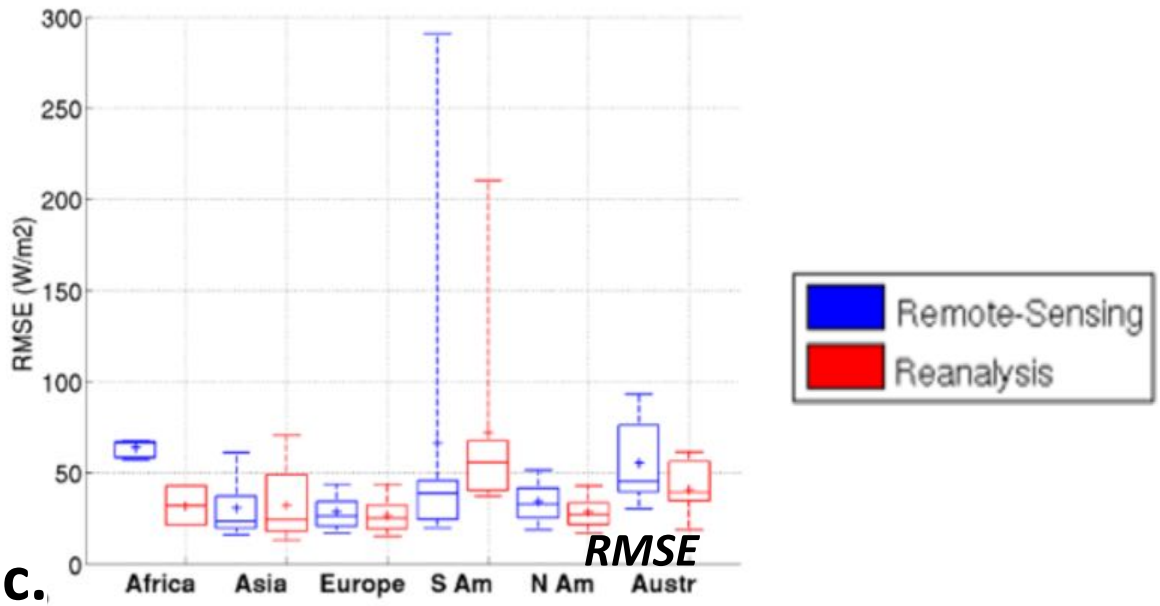

b.




**Statistics by Region**

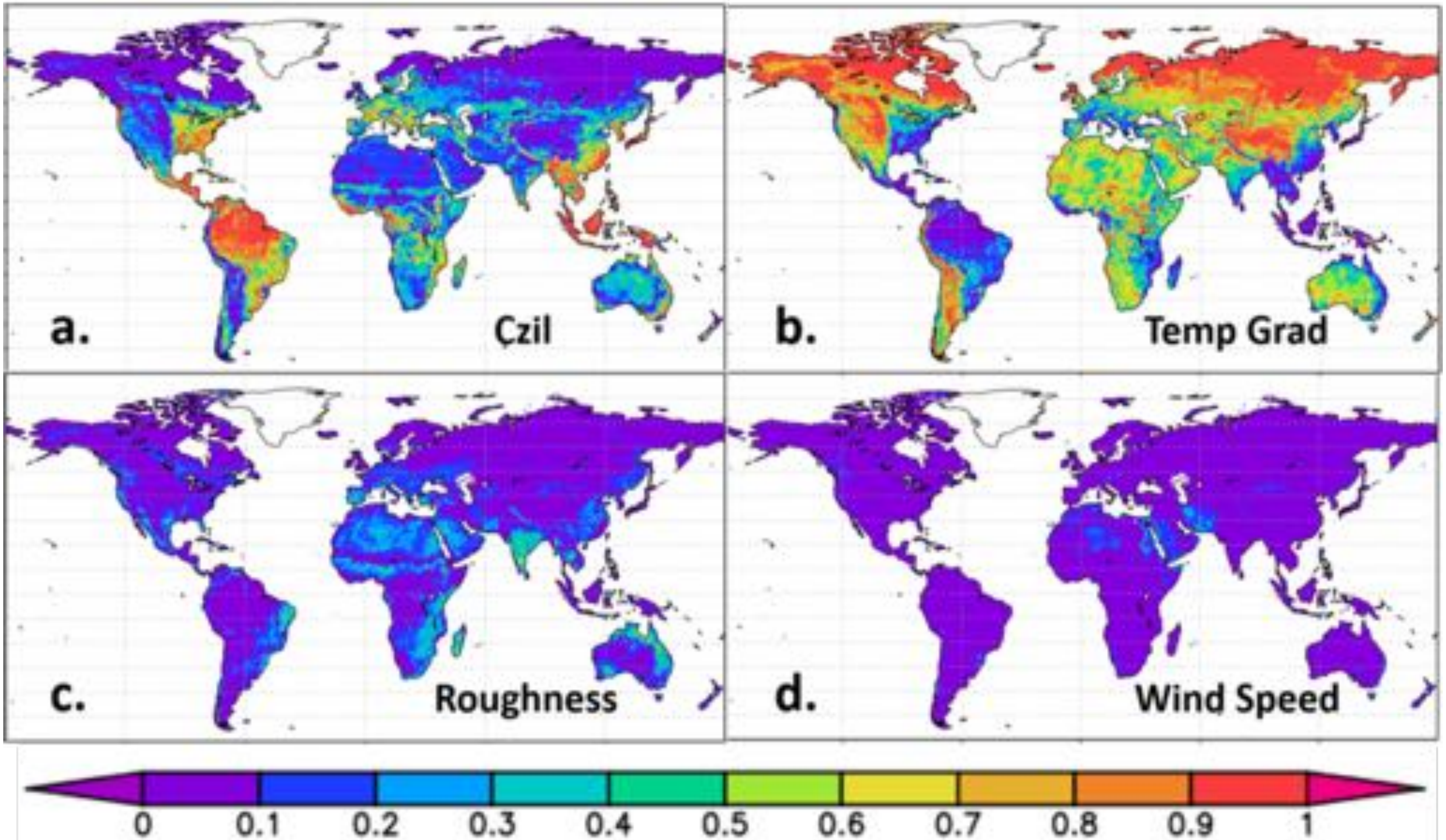
Our products perform best at the North American, European, and Asian sites

c.



# Uncertainty of Sensible Heat Flux

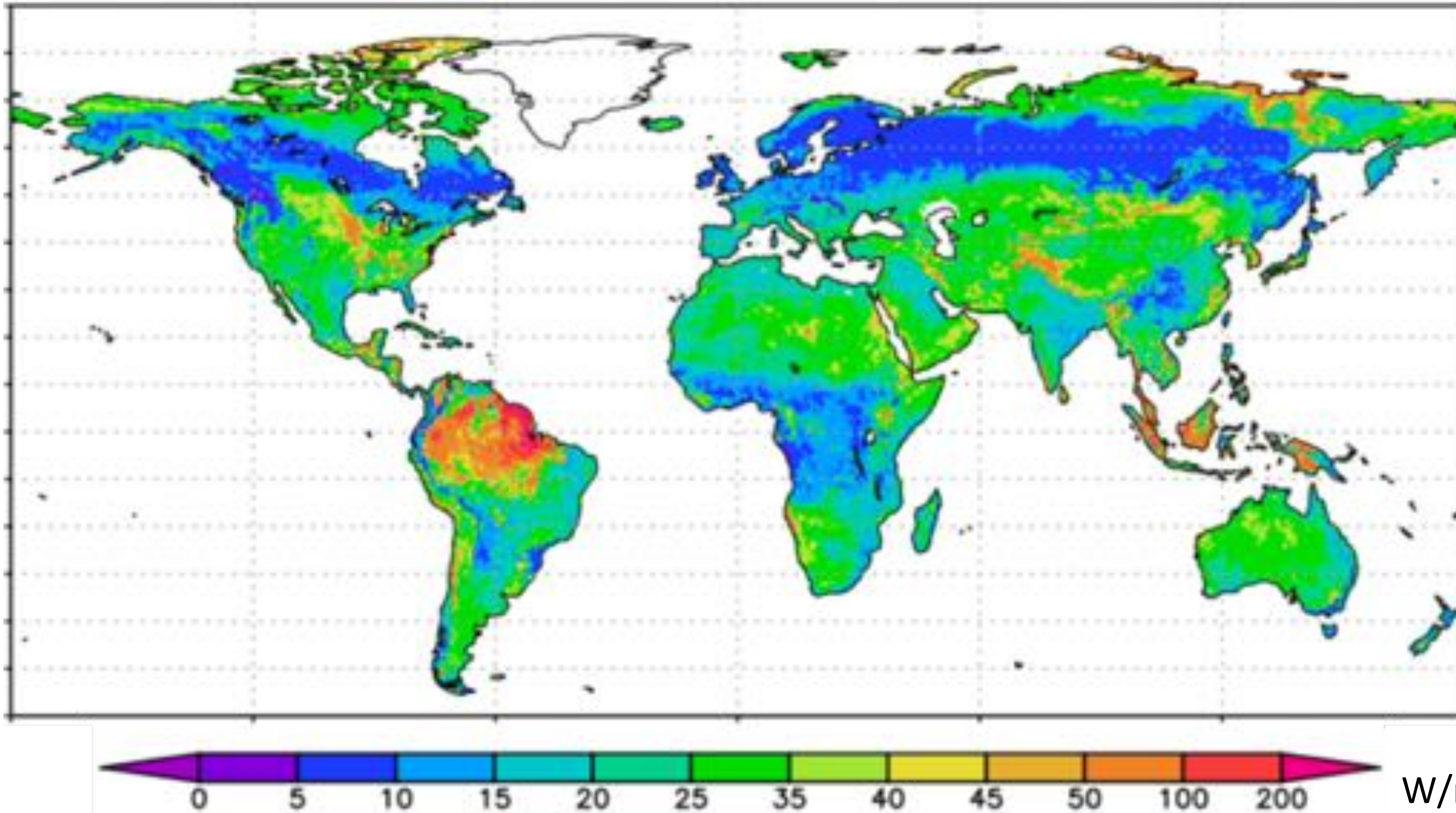
Fraction of uncertainty in H due to inputs



# Uncertainty of Sensible Heat Flux

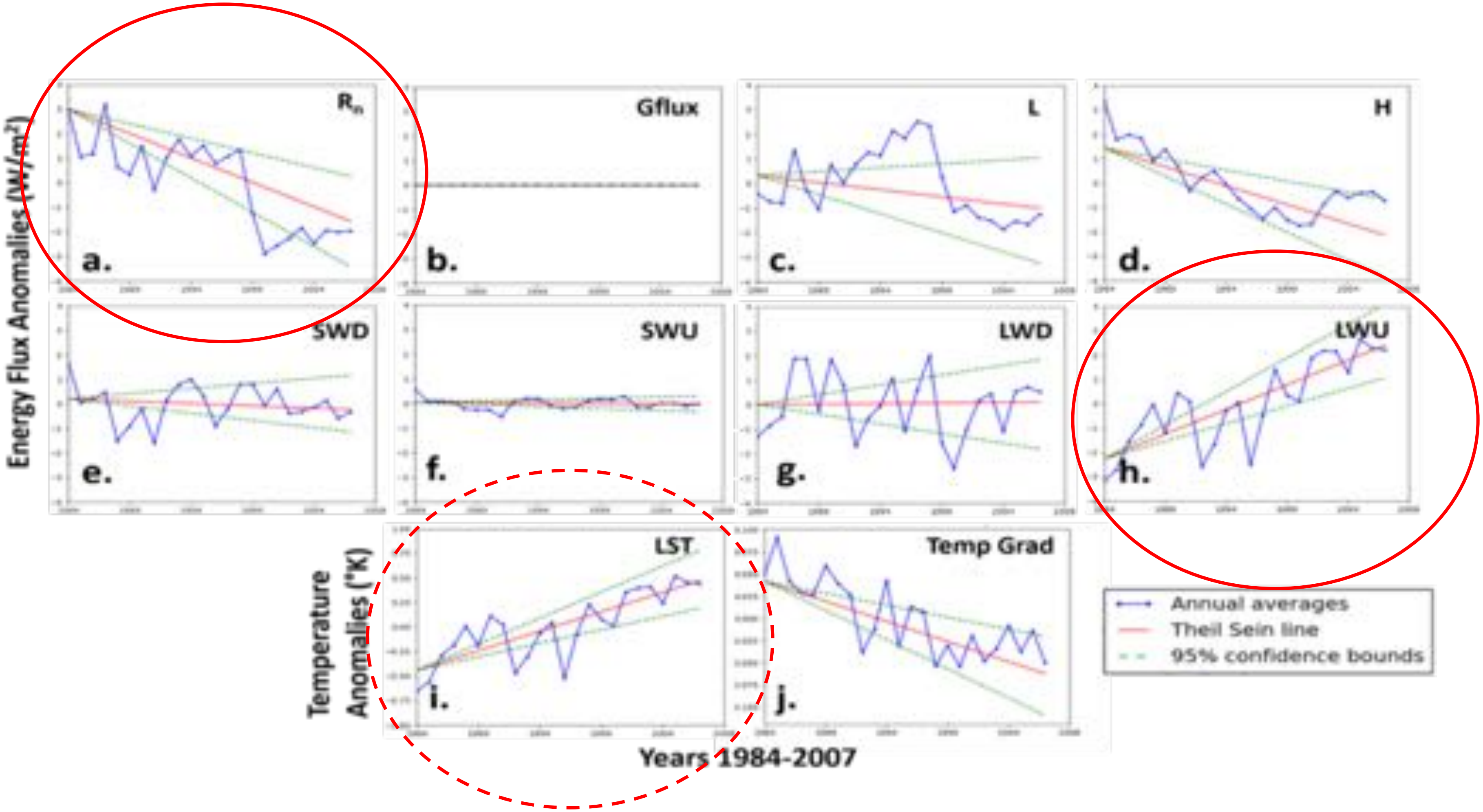
Global Average: 27.4 $W/m^2$

Uncertainty in H due to inputs

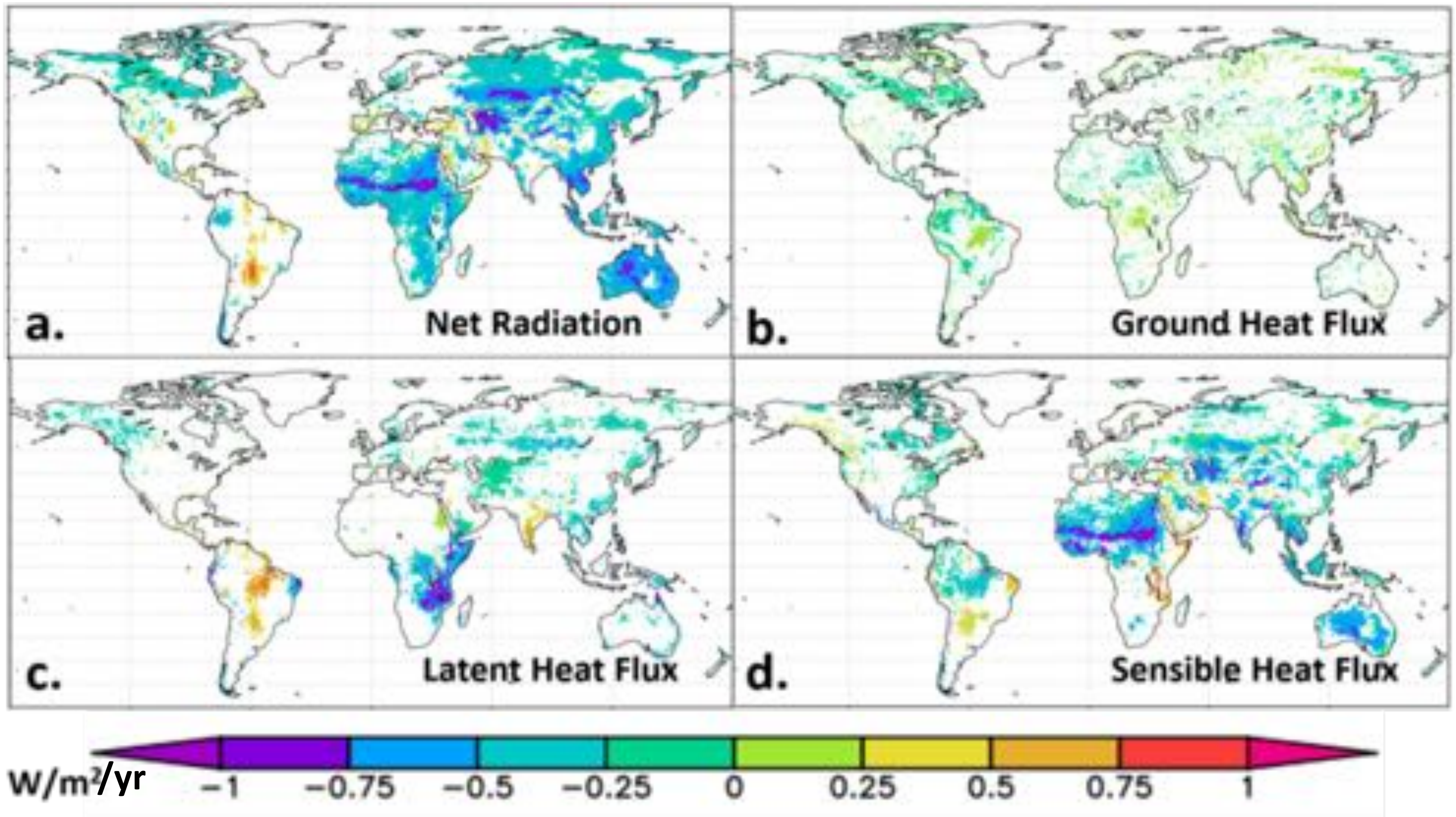



$W/m^2$

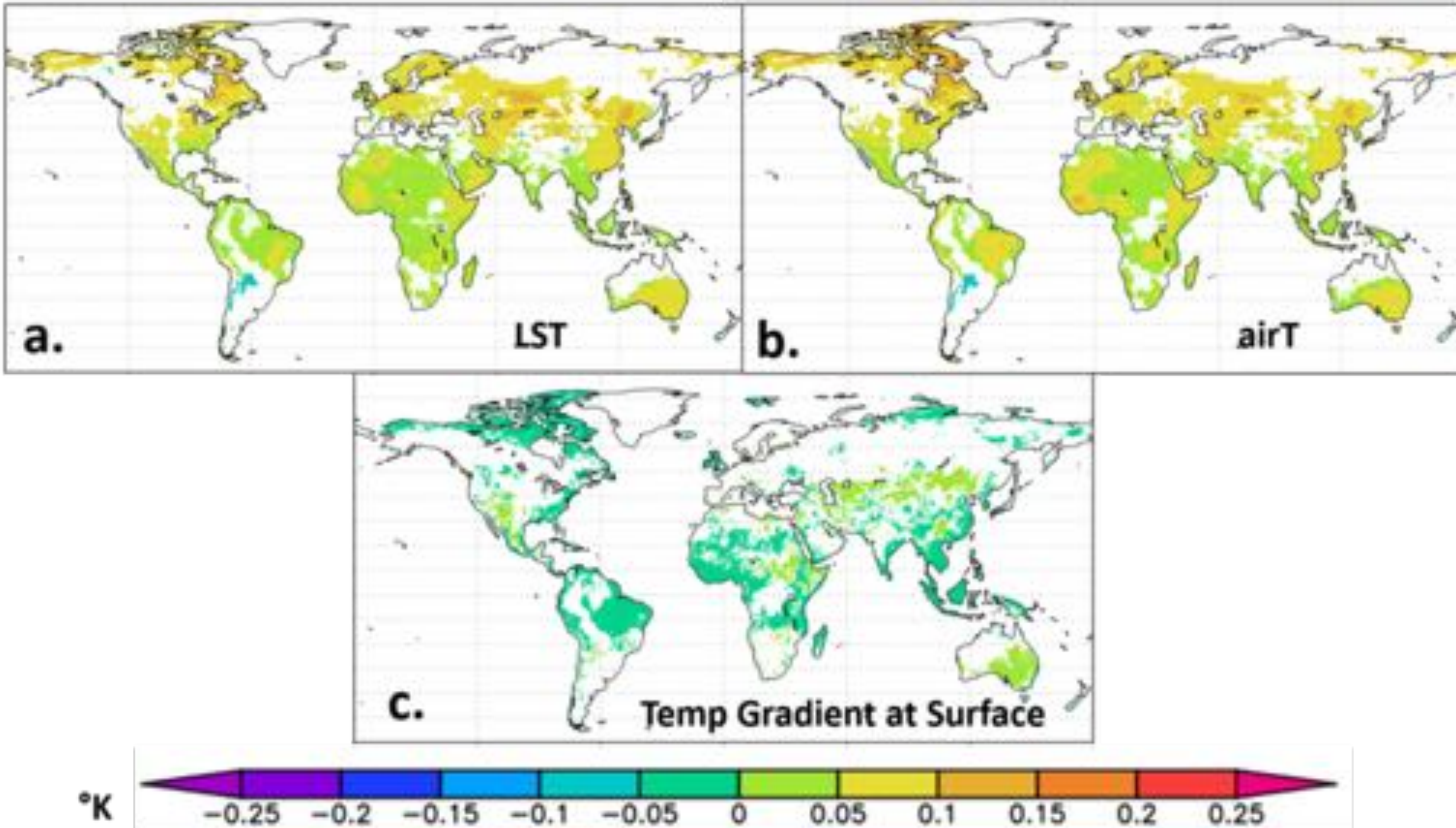
# Using the global data sets:
# What is the trend in the global energy cycle



# Using the global data sets:
# What are the variability and trends of the global energy cycle



# Results – Global Trends




95% confidence ( based on Mann Kendall p-values) significant Theil-Sein trends in °K per yr

# Summary, Conclusions and Future work

1. Using 1984 – 2007 terrestrial water budget variables from land-surface models (calibrated against GRDC observations), GPCP-based precipitation and remotely sensed estimates of terrestrial ET (from LandFlux), the terrestrial water budget can be closed to within 1%.

2. Using GPCP estimates of global precipitation, Terrestrial estimates of ET from LandFlux and Ocean estimates of E from SeaFlux, the global water cycle budget can be closed to within 2.5%.

3. Using 1984-2007 terrestrial surface variables, long-term surface flux data sets can be estimated. Integrating these with SeaFlux is needed to provide a a global estimate to the surface fluxes.

<u>Future Work??</u> The data sets have been offered to GDAP but no reply. How will GEWEX make these data sets available to the community? What are the next steps? Certainly lots of opportunities for analyses.