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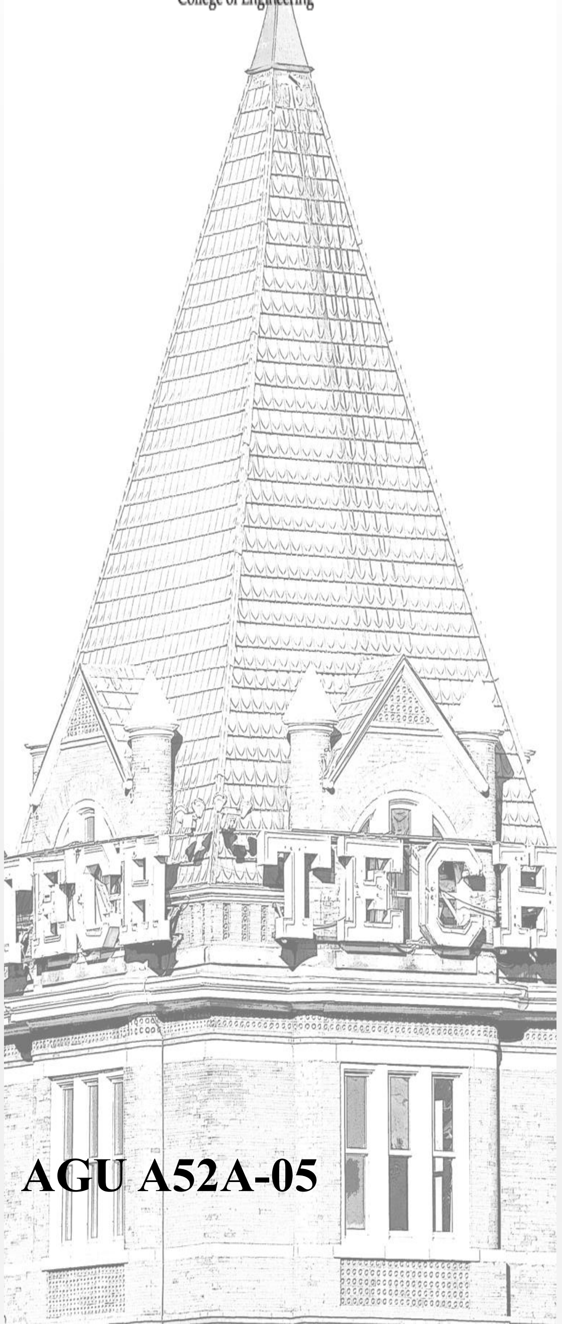

AGU A52A-05

Maximum Entropy Production (MEP) Method for Modeling Surface Energy Budget --- Theory and Applications to Arctic Regions

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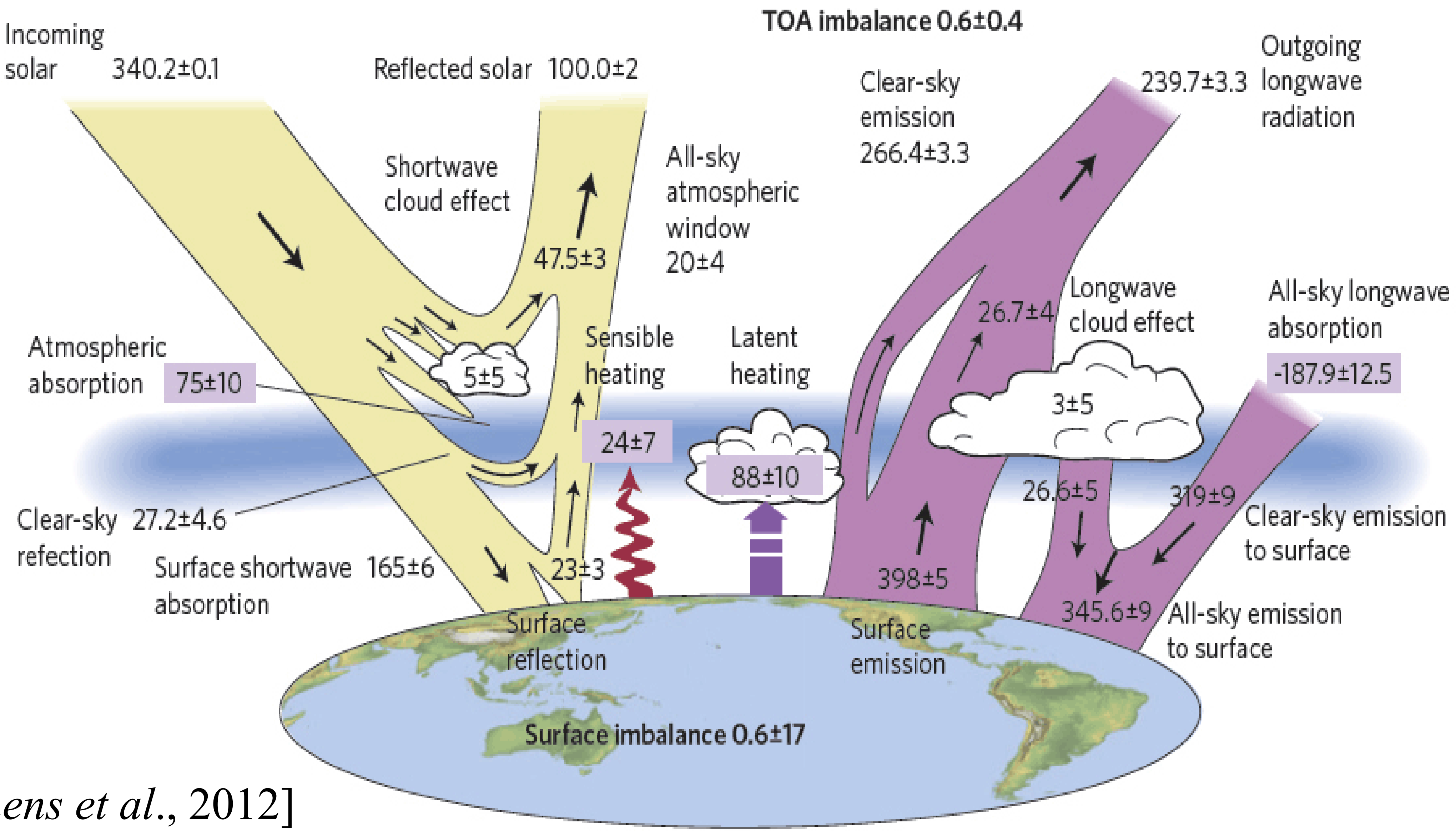


[*Stephens et al.*, 2012]

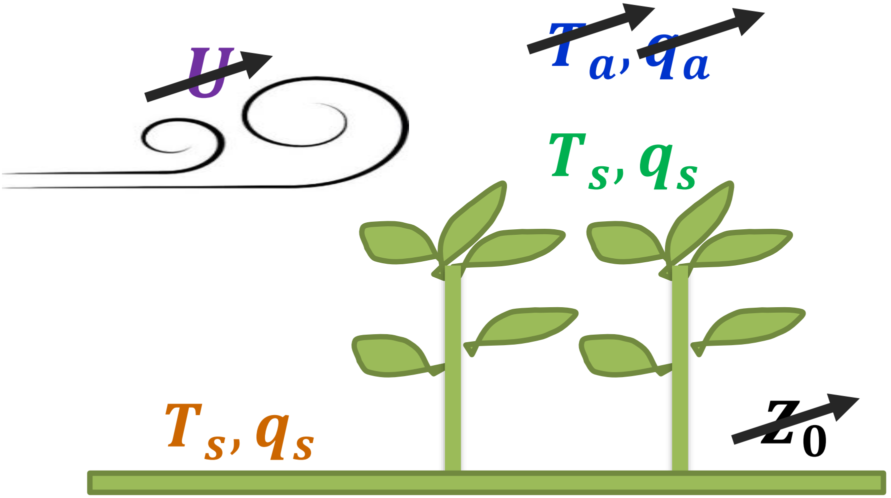



Goals

- Physically based for all types of surfaces (sea-ice, snow, vegetation, frozen ground)
- Closing energy budget at all space-time scales
- Reducing model inputs and parameters
- Using remote sensing data.

Maximum Entropy Production (MEP) Theory

- The Maximum Entropy Production (MEP) Model (Wang and Bras, 2009, 2011)
  - close surface energy budget automatically
  - does not use wind speed, air temperature and humidity, and surface roughness lengths explicitly
  - has reduced uncertainty in surface heat fluxes bounded by that of surface radiations.



- Model Formulation

$$\left[1 + B(\sigma) + \frac{B(\sigma)}{\sigma}\frac{I_s}{I_0}|H|^{-\frac{1}{6}}\right] H = R_n$$

$$E = B(\sigma)H$$

$$Q = R_n - E - H$$

with

$$\sigma = \frac{\lambda^2 q_s}{c_p R_v T_s^2}$$

$$B(\sigma) = 6\left(\sqrt{1 + \frac{11}{36}\sigma} - 1\right)$$

Land Surface

$$\min_{\{E,H,Q\}} \left\{ I(E,H,Q) \middle| E+H+Q=R_n \right\}$$

$$Q = \frac{B(\sigma)}{\sigma} \frac{I_s}{I_0} |H|^{-\frac{1}{6}} H$$

$$E = B(\sigma) H$$

$$E + H + Q = \boxed{R_n}$$

$$B(\sigma) = 6\left(\sqrt{1 + \frac{11}{36}\sigma} - 1 \right), \quad \sigma = \sqrt{\alpha_K} \frac{\lambda^2}{c_p R_v} \frac{\boxed{q_s}}{T_s^2}$$

Water-Snow-Ice Surface

[Wang et al, 2014]

$$Q = \frac{B(\sigma)}{\sigma}\frac{I_{wsi}}{I_0}|H|^{-\frac{1}{6}} - \boxed{R_n^S}$$

$$E = B(\sigma)H$$

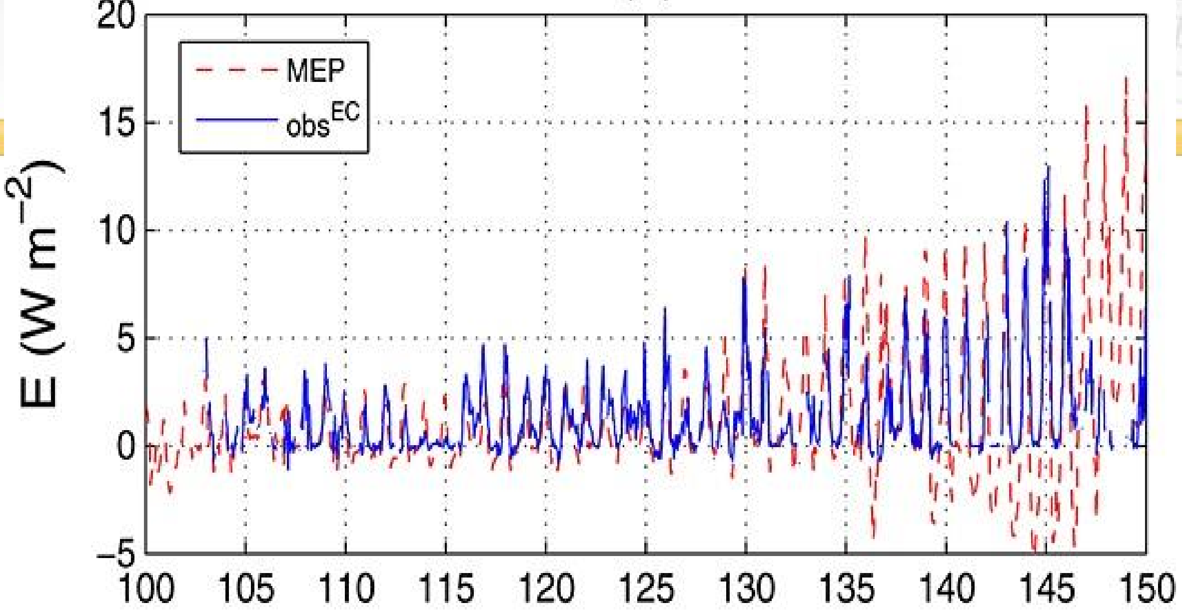
$$E + H + Q = \boxed{R_n^L}$$

$$\sigma(T_s) = \sqrt{\alpha_K \frac{\lambda^2}{c_p R_v}\frac{q_s^{sat}(\boxed{T_s})}{T_s^2}}$$

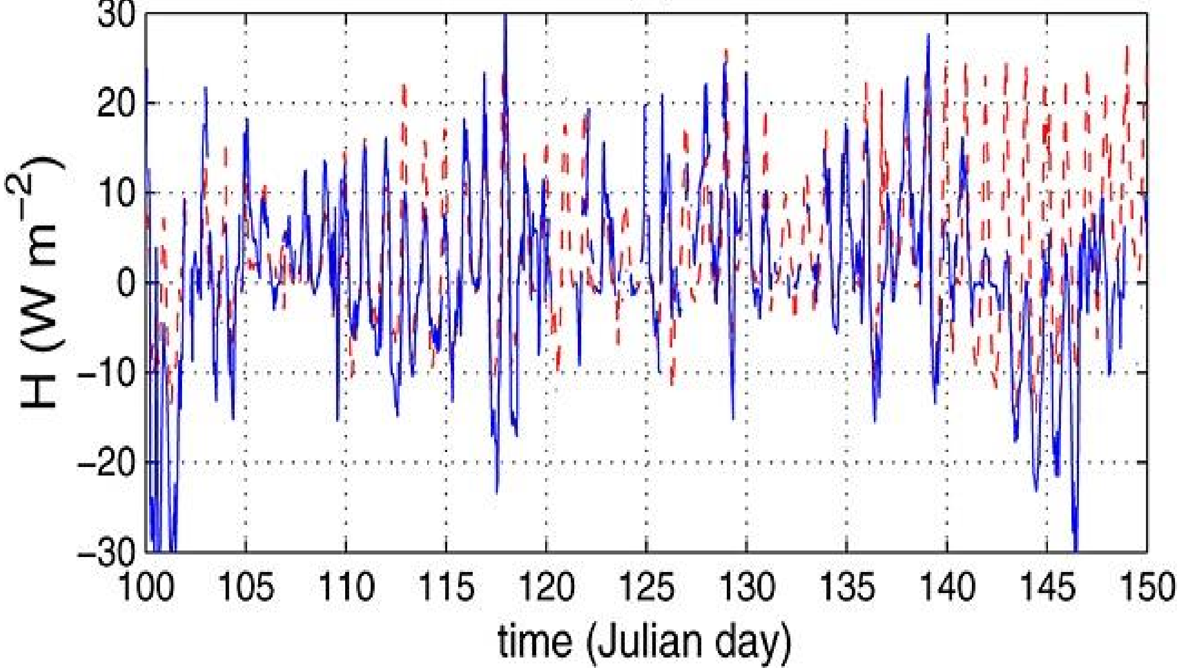
Fluxes	Surface Energy Budget	Bulk Variables	Model Parameters	Modeling Error
Bulk	not closed	temperature & moisture gradient	wind speed, roughness, etc.	semi-empirical (first order closure)
MEP	automatically closed	not used	not used	First-principles (MaxEnt, MEP, MOST)

	Surface Energy Budget	Input data	Model Parameters	Modeling Error
Penman Method	Balanced	Air temperature, humidity, ground heat flux	Wind speed, roughness lengths, etc.	Semi-empirical (first order closure)
Bulk Method	Not balanced	Temperature & moisture gradient	Wind speed, roughness lengths, etc.	Semi-empirical (first order closure)
MEP Method	Balanced	Not used	Not used	First-principles (MaxEnt, MEP, MOST) constrained by radiation data

(a)

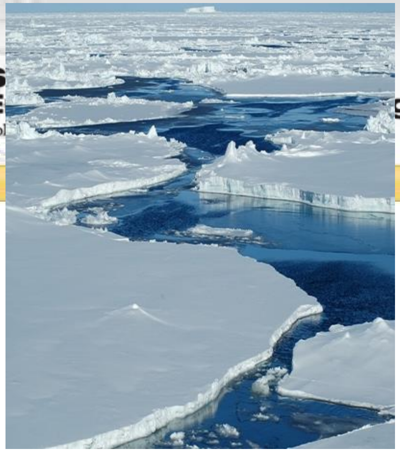


(b)

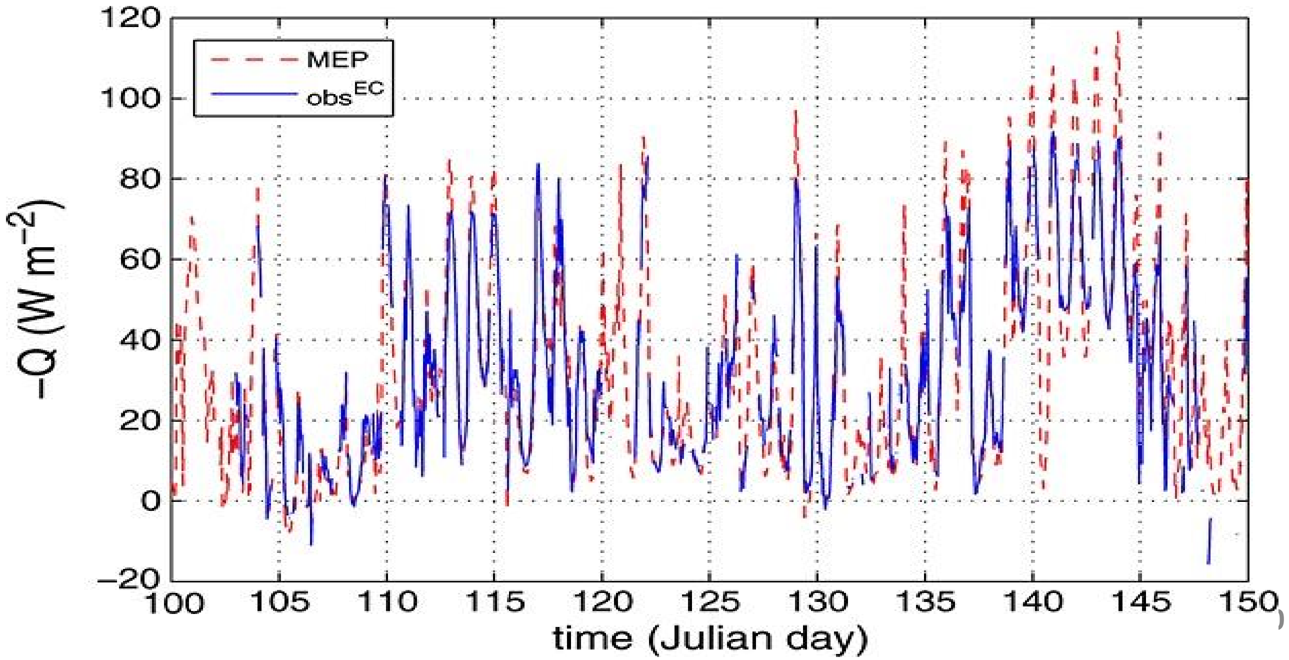


SHEBA field experiment
10 April to 30 May 1998

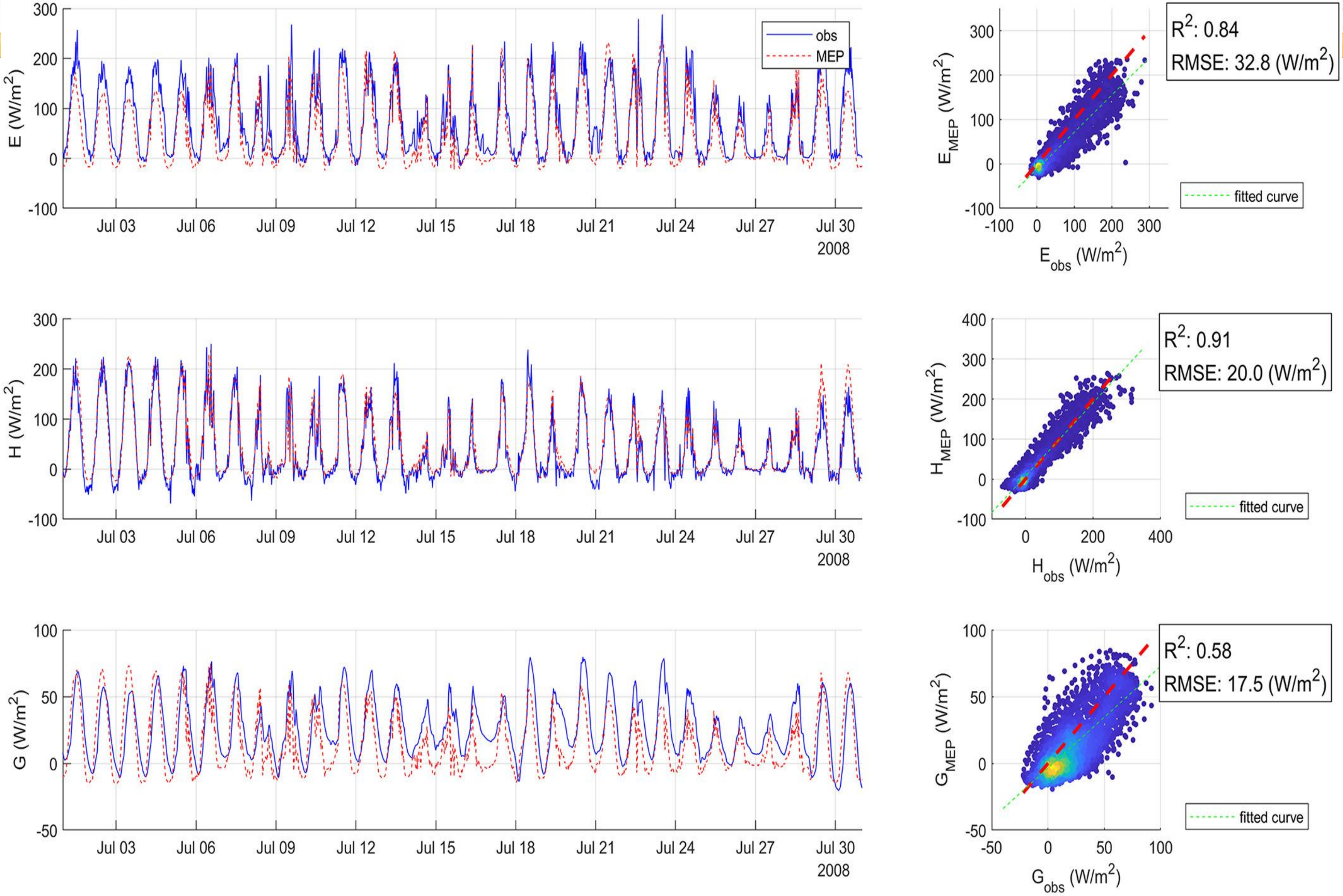
[*Wang et al*., 2014]



Sea Ice



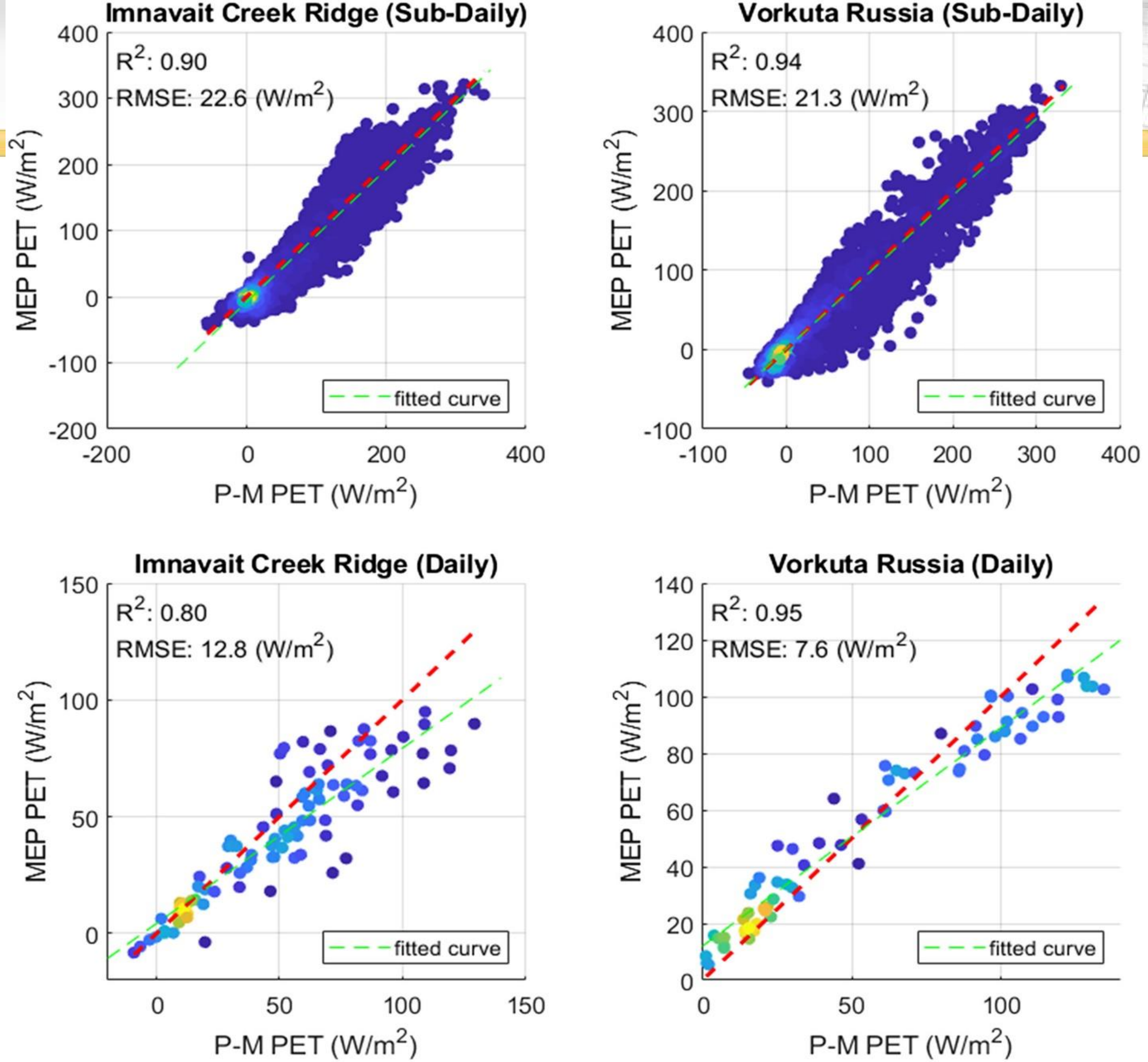
Vorkuta, Russia



Frozen Ground (Permafrost)

E: latent heat flux
H: sensible heat flux
G: ground heat flux

[*El Sharif et al.*, 2019]



Vegetation (Tundra)

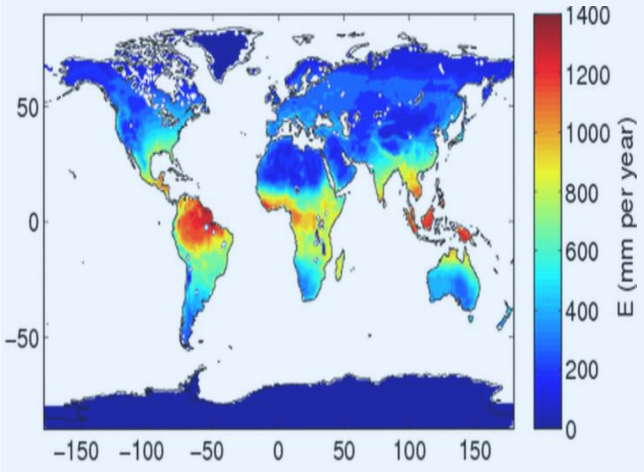
PET; potential evapotranspiration
P-M: Penman-Monteith Model

[*El Sharif et al.*, 2019]

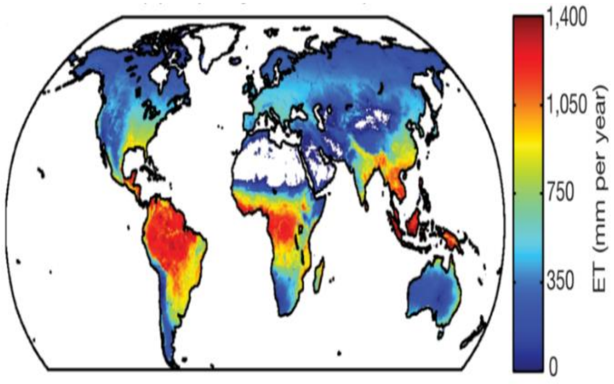
Results

Climatology – Latent Heat Flux

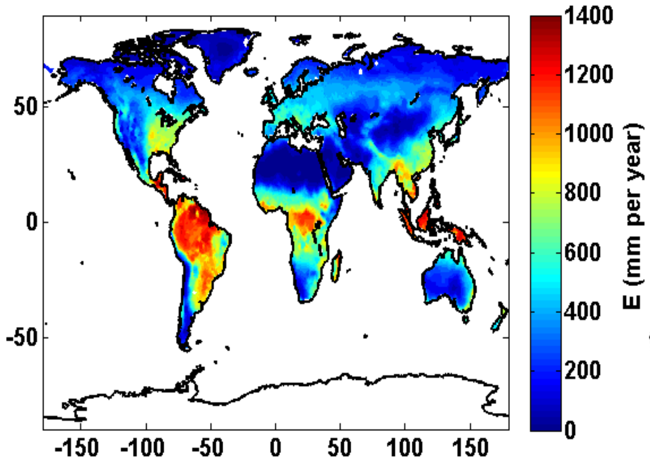
E (MEP)



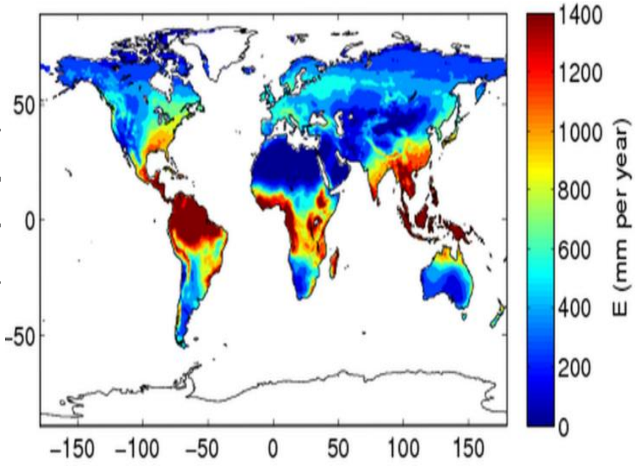
E (Jung et al., 2010)



E (GLDAS)

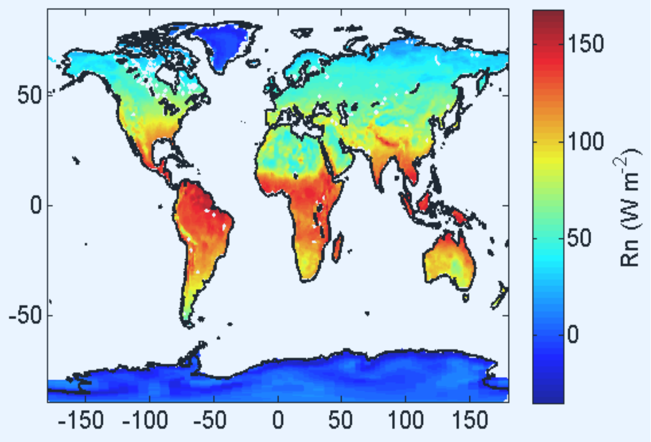


E (MERRA)

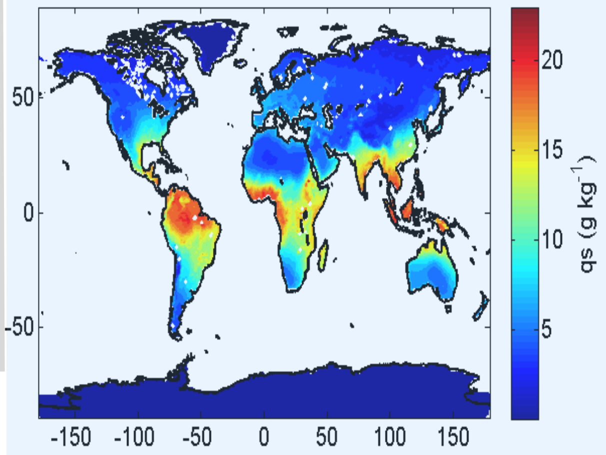


Model Inputs

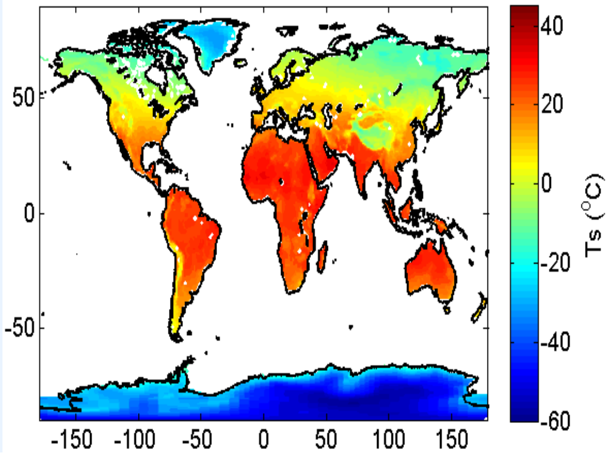
R_n (CERES)



q_s (MERRA)

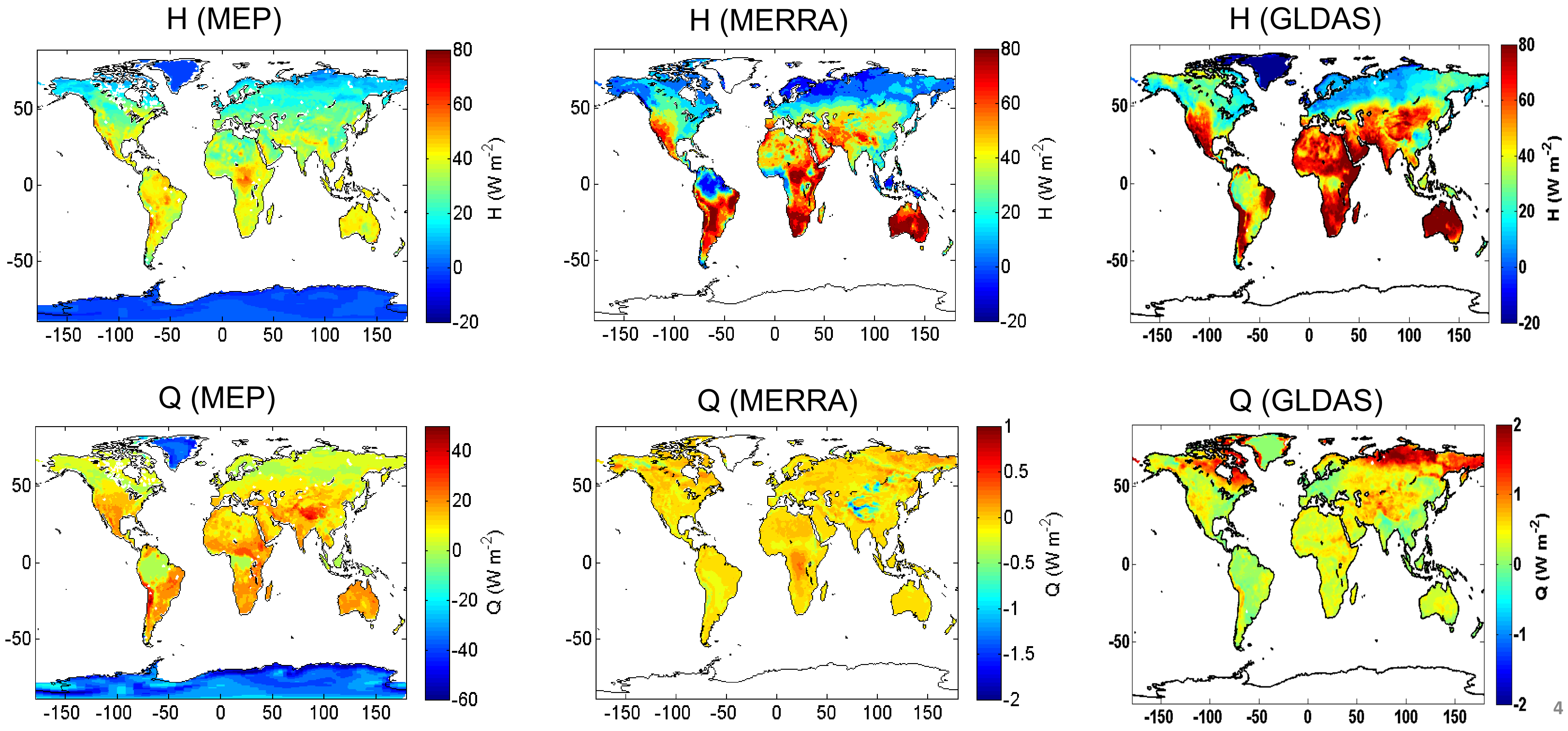


T_s (CERES)



Results

Climatology – Sensible and Ground Heat Fluxes



Methodology – The MEP Model

Methodology – The MEP Model

Conclusions

- The trends of global land evapotranspiration are positive (0.41 ± 0.23 W m^{-2} yr^{-1}) attributed to the increase of surface radiation energy and humidity.

- The trends of sensible heat flux are positive globally but statistically insignificant (0.18 ± 0.18 W m^{-2} yr^{-1}).

- The ground heat flux over continents has positive trend (0.21 ± 0.16 W m^{-2} yr^{-1}) during the model period driven by increase of surface radiation.

- The surplus surface radiation energy is mostly used to increase evapotranspiration.

- The sensible heat flux and surface temperature have opposite trends.