A maximum-entropy-production perspective of the surface energy budget

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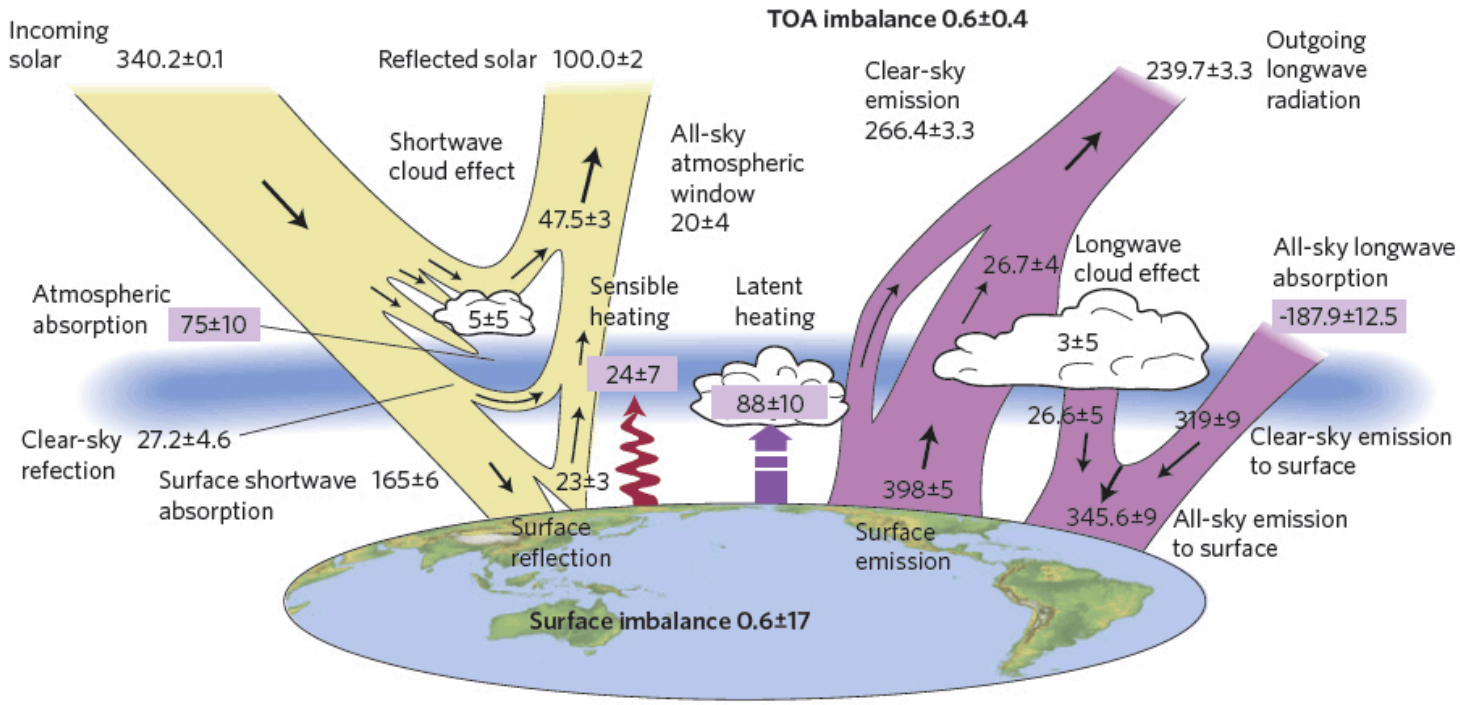
Outline

- Background and motivations
- Using maximum entropy production (MEP) principle to estimate LH and SH flux
- LH and SH flux estimated using the MEP principle and CERES-constrained surface radiative flux
  - Global mean statistics
  - Spatial patterns
- Discussions and outlooks

This is a "work-in-progress" report

Surface Energy Budget



(Stephens et al., 2012)

LH: 88±10 (11%)
SH: 24±7 (29%)
compared to
DW LW: 345.6±9 (2.6%)
UP LW: 395±5 (1.3%)
DW SW: 165±6 (3.6%)
UP SW: 23±3 (13.0%)

As a result: surface imbalance is 0.6±17

Surface LH and SH flux

- Observations: flux tower
- The (kinetics) bulk aerodynamic formulae: gradient approach

$$F_{Hs} = C_H |V| (T_s - T_{air})$$

$$F_{water} = C_E |V| [q_{sat}(T_s) - q_{air}]$$

$$F_{water} = \gamma F_{Es} = (\rho_{liq}/\rho_{air}) E$$

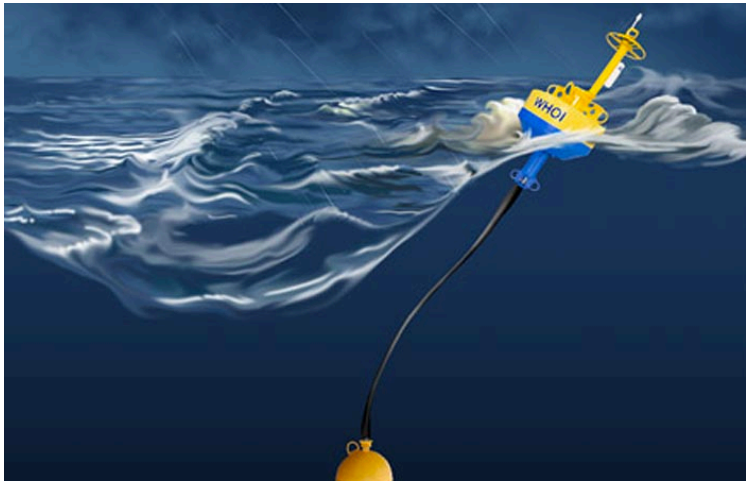
(Atmospheric Science: An Intro. Survey, 2nd Edition)

From ORNL website

- Above formulas are used in NWPs, GCMs, reanalyses.
  - T_{air} & q_{air} and |V| are not resolved by the models: not predicted but diagnosed at each step

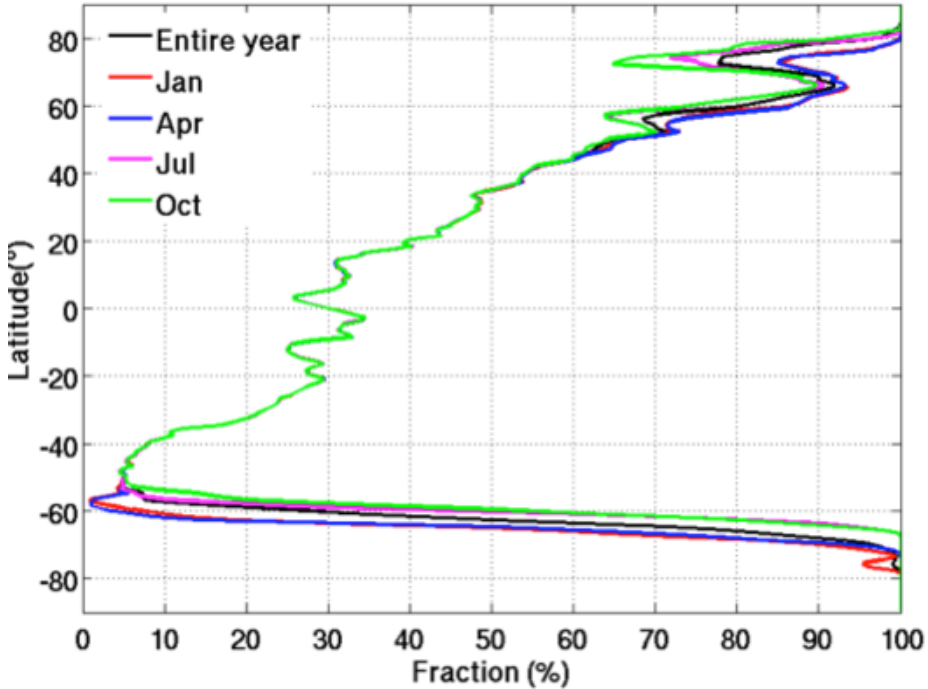
Getting LH and SH over oceans

- Flux-tower approach over oceans: direct validation of modeled LH and SH fluxes is a challenge
- On top of it, data sparsity

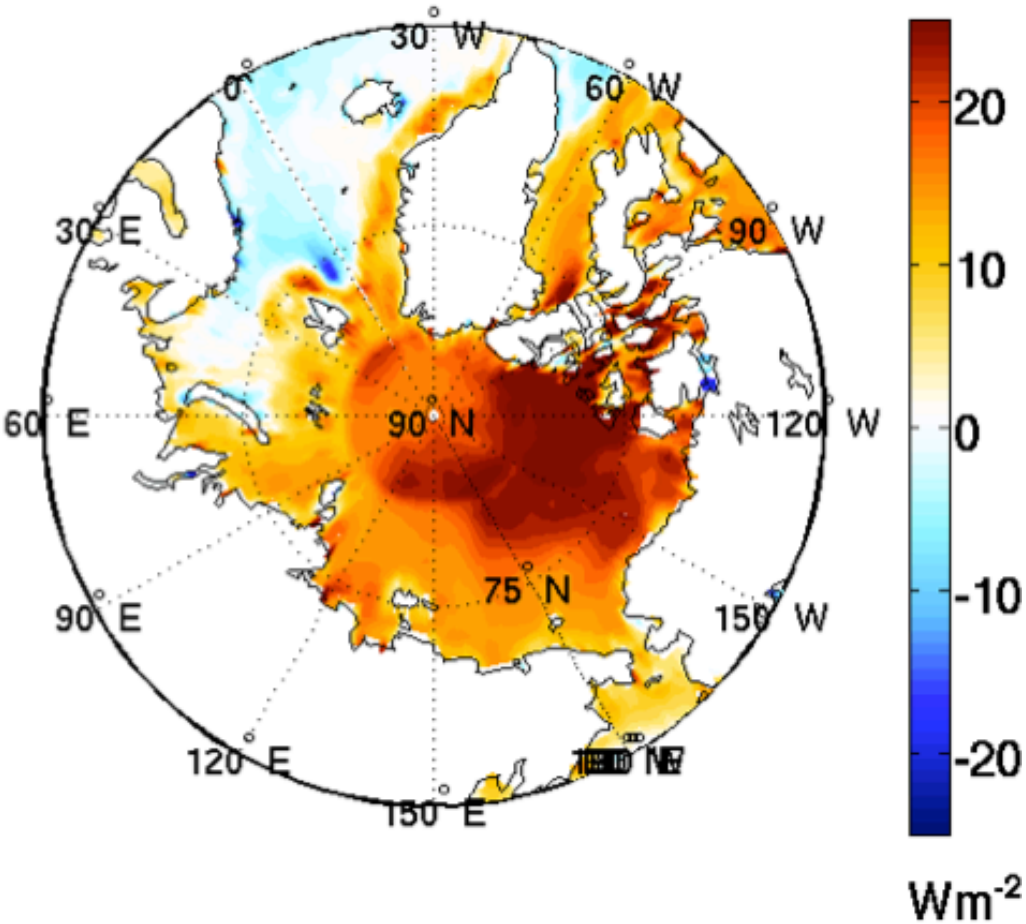


From whoi.edu

Fraction of missing data in 3-hourly SEAFLUX data set



Discrepancies between reanalysis are not small: esp. polar oceans



Difference of SH flux between MERRA-2 and ERA-interim for March (2003-2015)

Regional average
MERRA-2: 27.7 Wm^{-2}
ERA: 15.9 Wm^{-2}

Any other alternative ways to estimate LH and SH flux?

Max Entropy Production (MEP) principle

- *MEP: an organizing principle governing the behavior of non-equlibirum system (Jaynes, 1957; Dewar 2005)*
- *Successfully used in land hydrology, bio-ecological system, etc*
- *Used in modeling heat fluxes over land surfaces (Wang & Bras, 2009; 2011)*
- *Extended to ice, snow, and water surface (Wang et al., 2014)*
- A non-gradient method: input is net radiation flux and net LW flux, and T_{surf}, q_{surf}

MEP formula over water surfaces

$$\left[1 + B(\sigma) + \frac{B(\sigma)}{\sigma}\frac{I_{i,sn,w}}{I_0}\left|SH\right|^{-\frac{1}{6}}\right]SH = R_n,\ LH = B(\sigma)SH$$

$$B(\sigma) = 6\left(\sqrt{1 + \frac{11}{36}\sigma} - 1\right), \qquad \sigma = \sqrt{\alpha_w}\,\frac{\Delta}{\gamma}$$

R_n :the net downward radiation flux, $R\downarrow n\uparrow l$:the net downward long-wave radiation, Q: the conductive heat flux to ground

I : the thermal inertia of the medium with the subscripts "i", "sn" and "w" standing for ice, snow and (still) water, respectively,

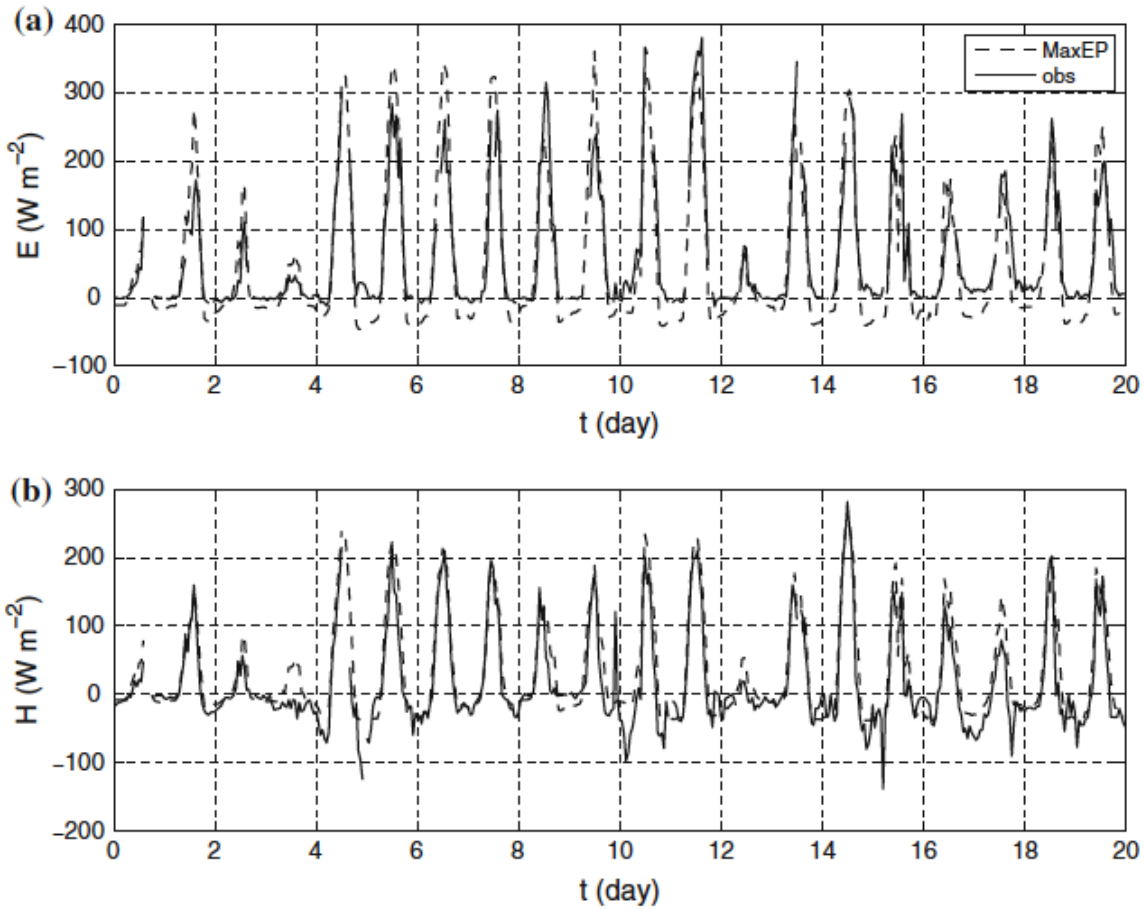
I_0 : the thermal inertia of the turbulent air

α_w : the ratio of eddy-diffusivity of turbulent transport of water vapor to that of heat in the boundary layer

Δ: the slope of saturation vapor pressure at surface temperature according to the Clausius-Clapeyron equation

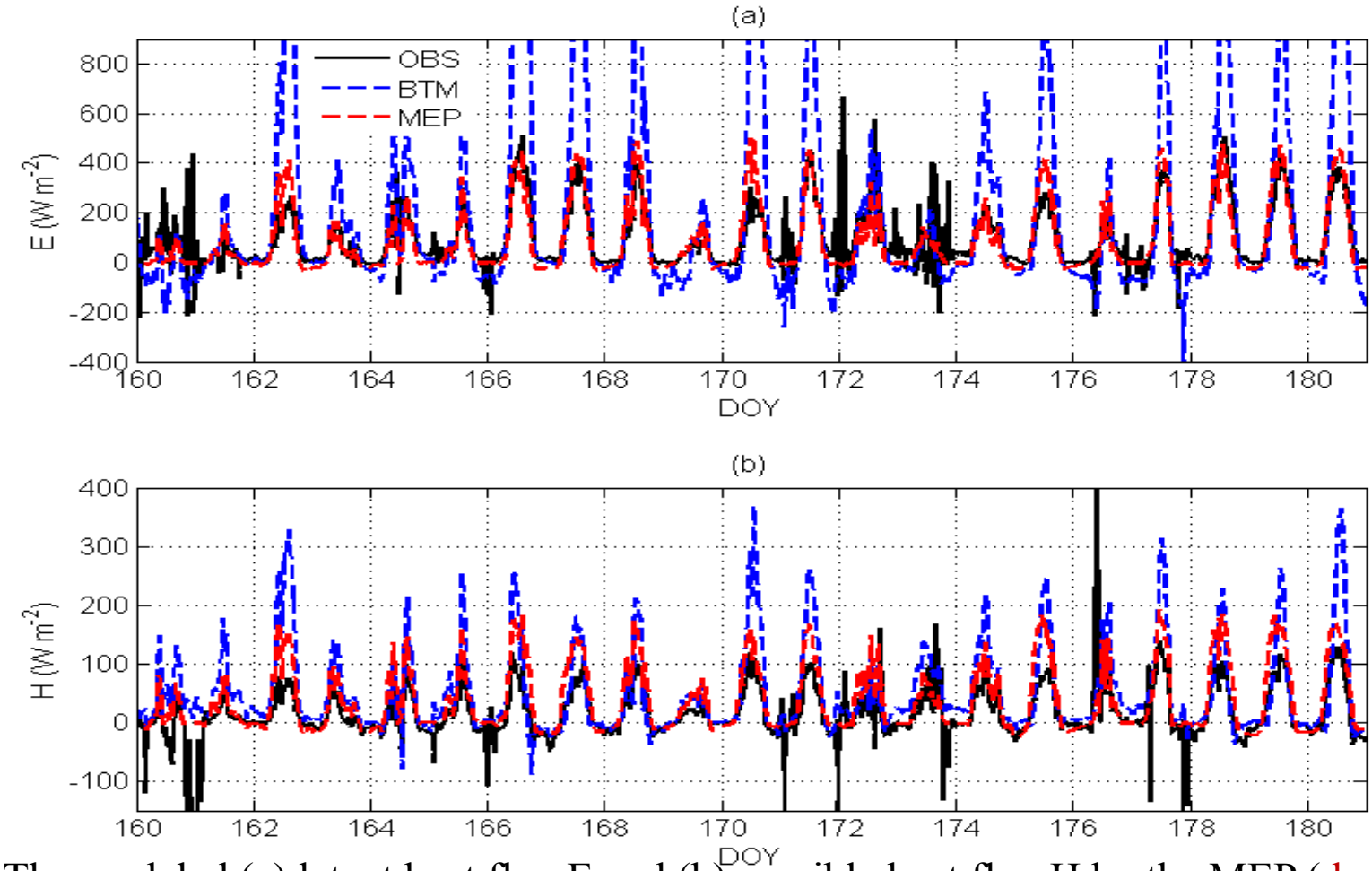
γ: the psychrometric constant.

MEP results over lands: Harvard forest



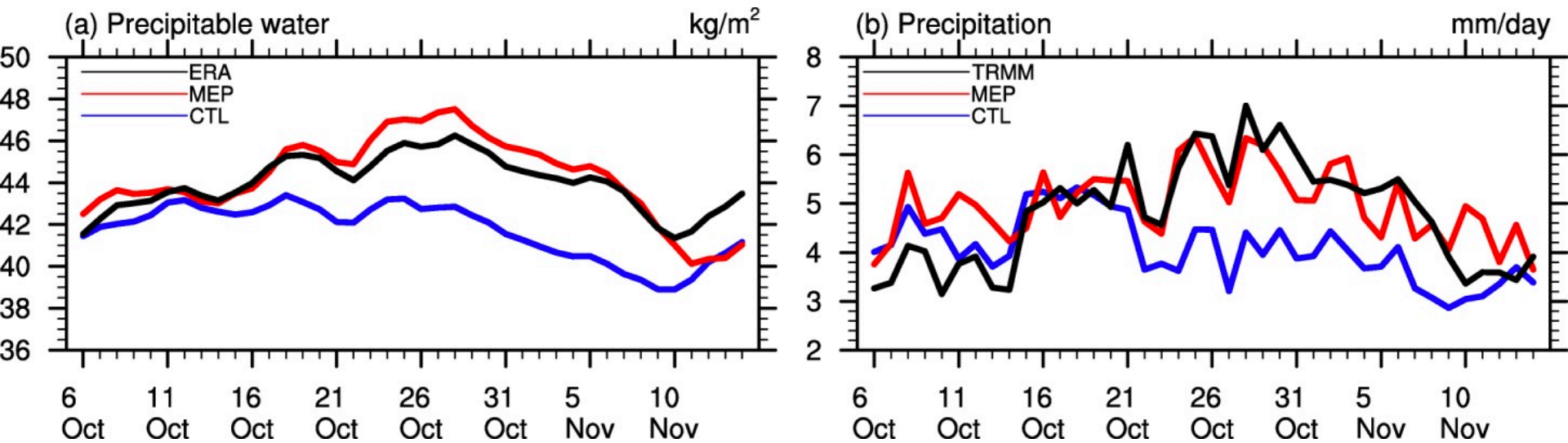
Harvard Forest Experiment (Wang et al., 2014)

MEP results over lands: Brooks field site (corn/ soybean field)



The modeled (a) latent heat flux E and (b) sensible heat flux H by the MEP (dashed red) and bulk transfer model (dashed blue) versus observations (solid black) of the Brooks Field site 10, Iowa, 9-29 June 2011.

When the MEP-based SH/LH scheme is implemented into a WRF model for a MJO hindcast experiment



Chen J., et al., *Hindcasting the Madden-Julian Oscillation With a New Parameterization of Surface Heat Fluxes*, JAMES, 2017

Use the MEP with CERES SYN 1-deg data

- CERES Ed4, 3-hourly SYN 1-degree: radiative flux at surface, Ts
- CERES Ed4, monthly-mean SRB-EBAF: radiative flux at surface, Ts
  - MEP predicts small diff. from 3-hourly results
- Surface q from MERRA-2, so do the surface type, ice fraction, LAI, etc.
- For the entire year of 2010

2010 annual-mean surface energy budget

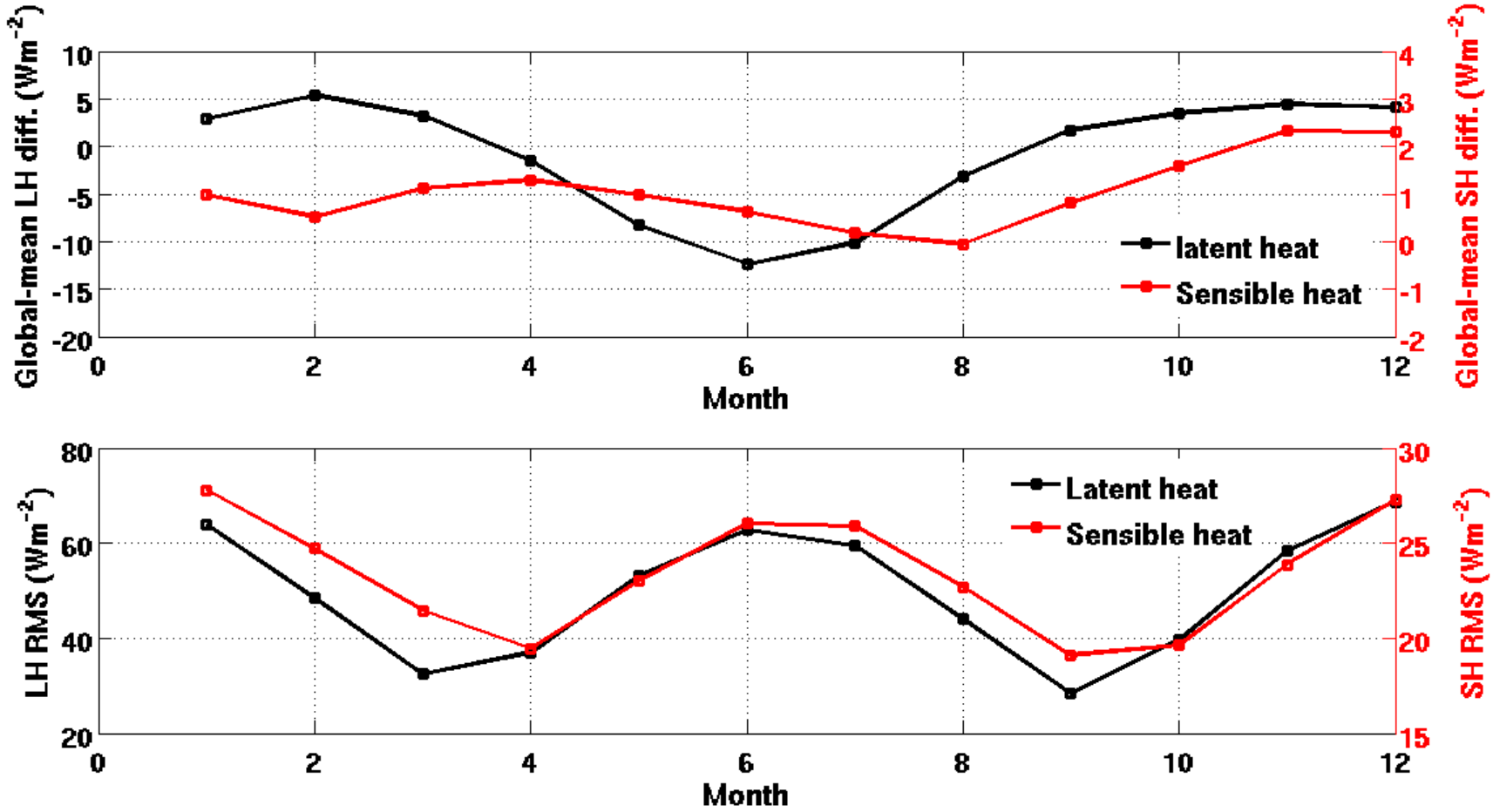
	Down LW	Upward LW	Down SW	Upward SW	LH	SH	Q= Dw (LW+SW) - Up (LW+SW) – LH –SH
3-hourly CERES-SYN1deg	347.6	398.1	183.6	22.3	86.4	19.9	4.5
Monthly EBAF	345.5	398.7	186.4	23.1	84.9	19.1	6.0

*LH and SH are calculated using MEP model (z=20m, α_w=5)

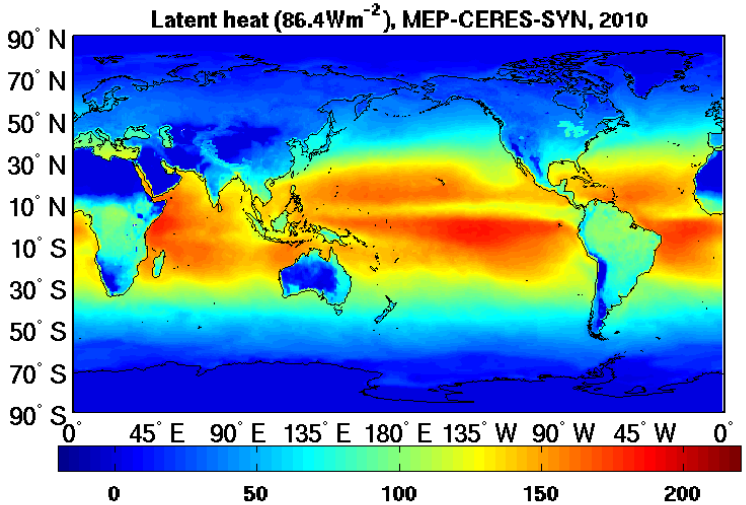
	Down LW	Upward LW	Down SW	Upward SW	LH	SH	Q= Dw (LW+SW) - Up (LW+SW) – LH –SH
3-hourly CERES-SYN1deg	347.6	398.1	183.6	22.3	84.9	19.9	6.0
Monthly EBAF	345.5	398.7	186.4	23.1	82.9	18.8	8.3

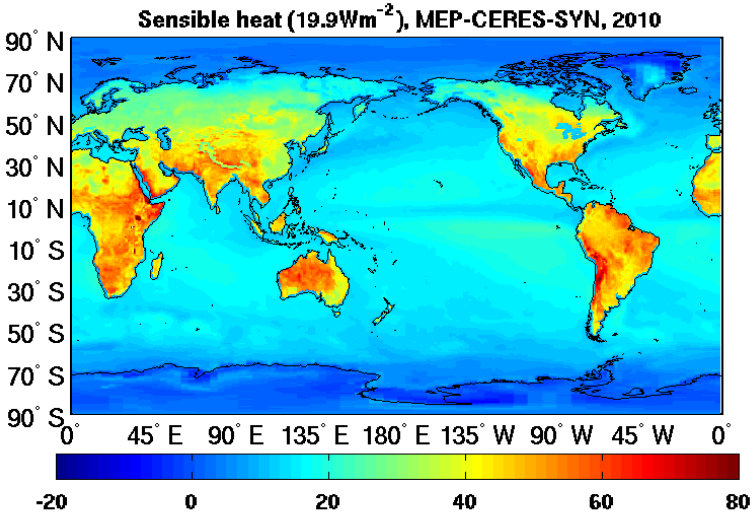
*LH and SH are calculated using MEP model (z=10m, α_w=5)

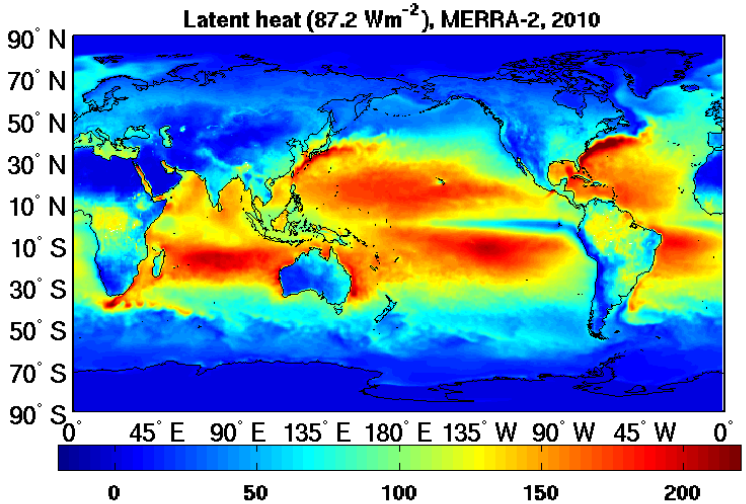
Global-mean difference and RMS: MEP results – MERRA-2 fields

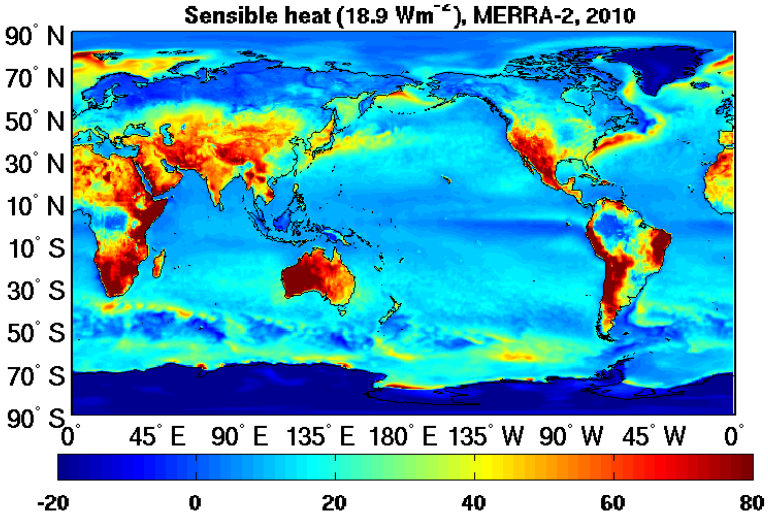


Annual-mean LH and SH fluxes: MEP/3-hourly CERES-SYN vs. MERRA-2

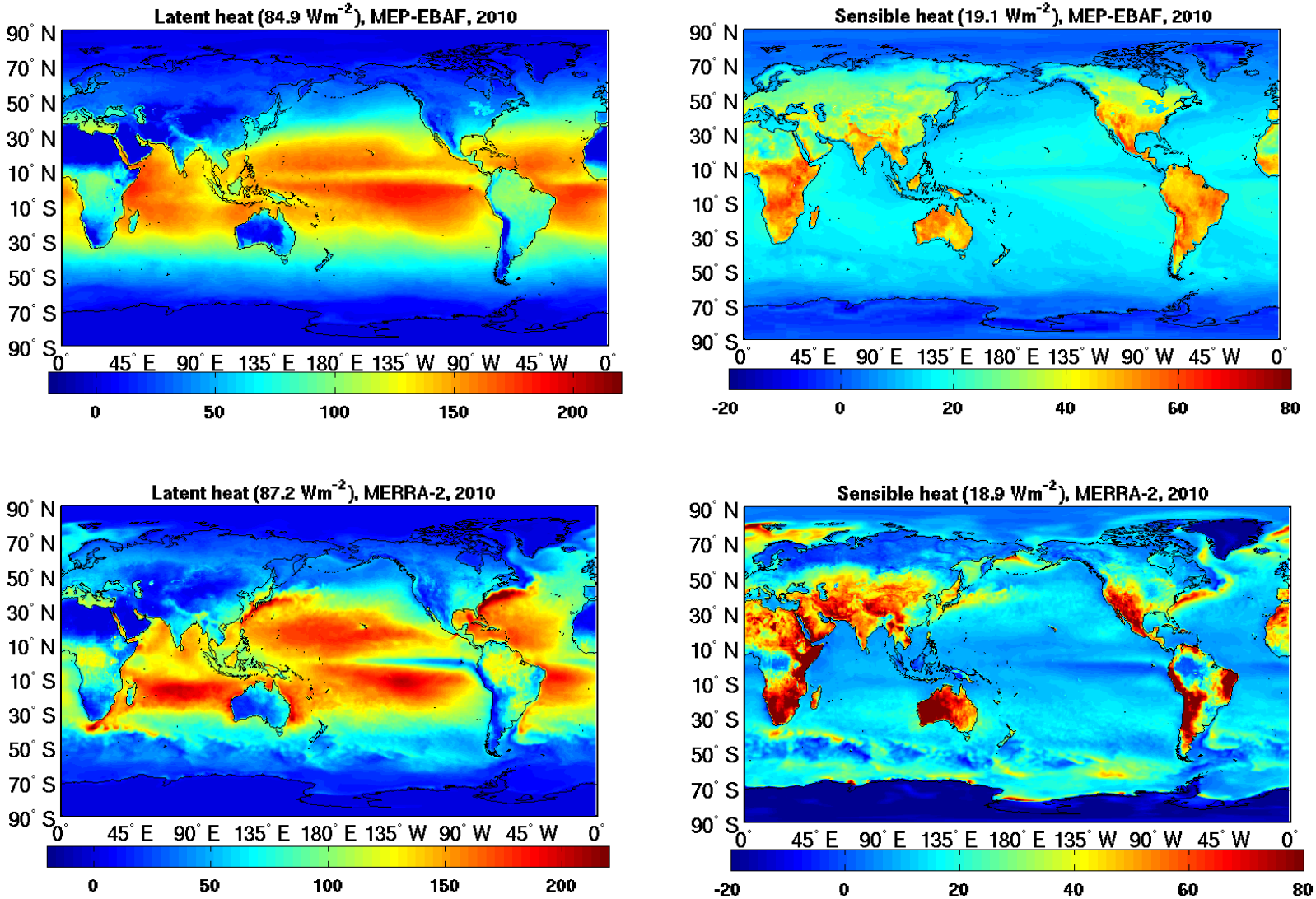




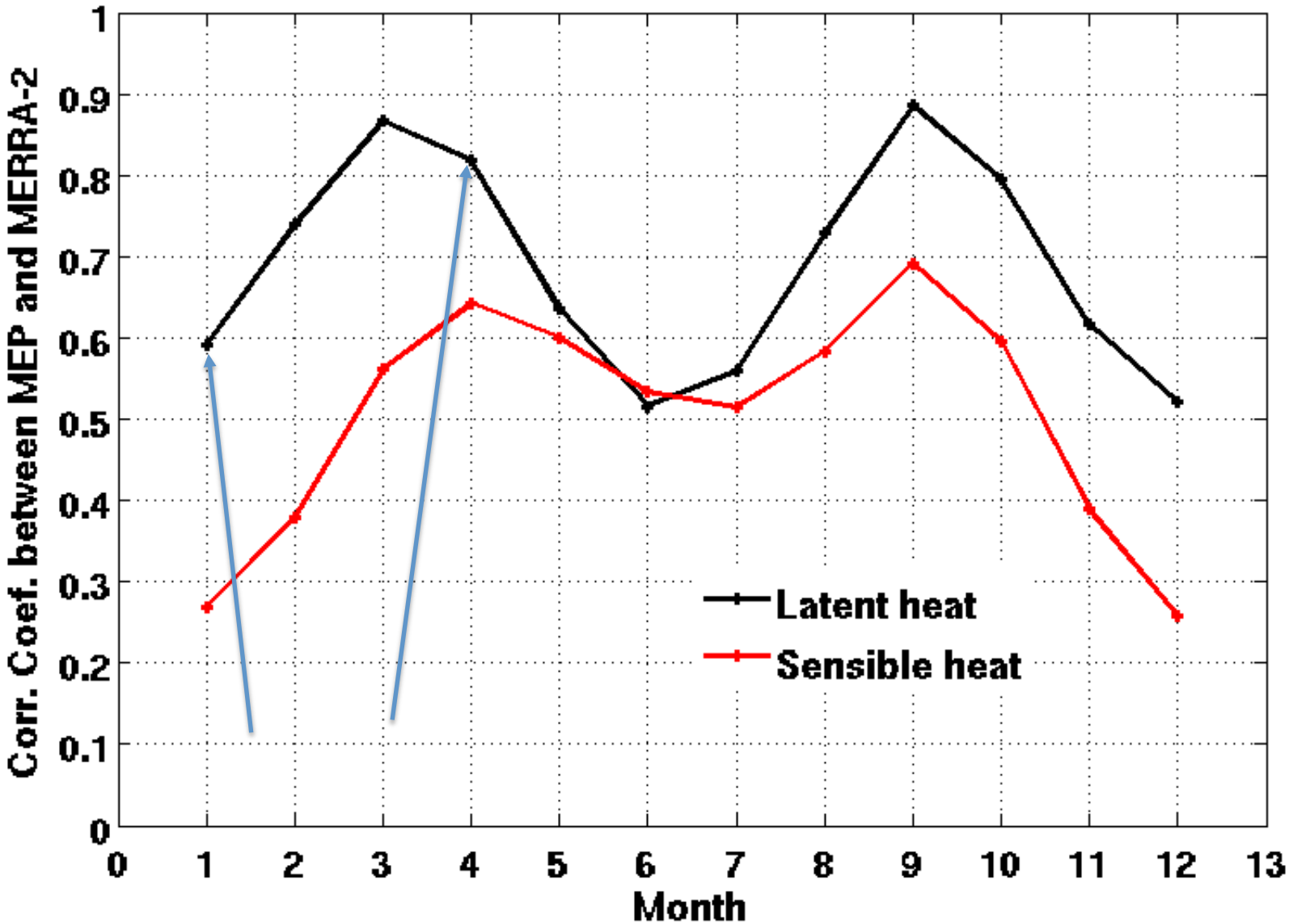




Annual-mean LH and SH fluxes: MEP/CERES monthly-mean SRB-EBAF vs. MERRA-2

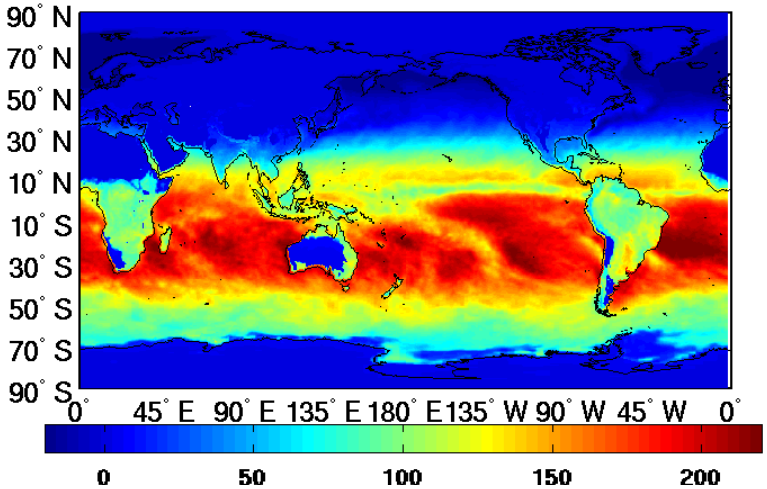


Correlation Coeff. of spatial patterns: MEP results vs. MERRA-2 fields

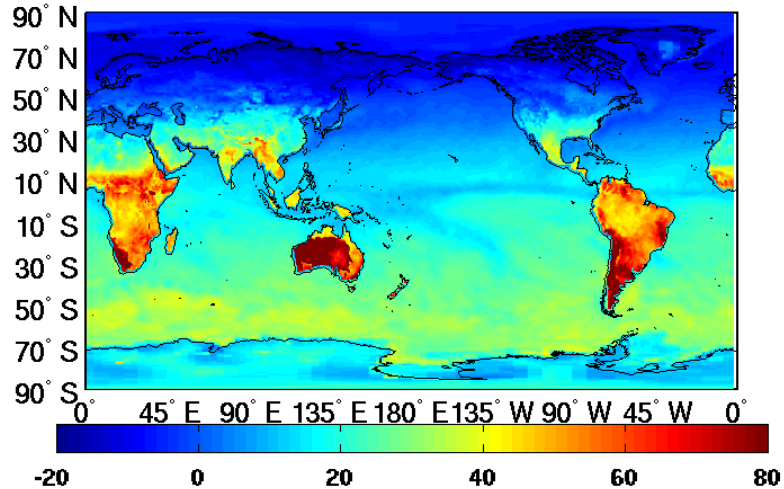


LH and SH fluxes in Jan 2010: MEP/3-hourly CERES-SYN vs. MERRA-2

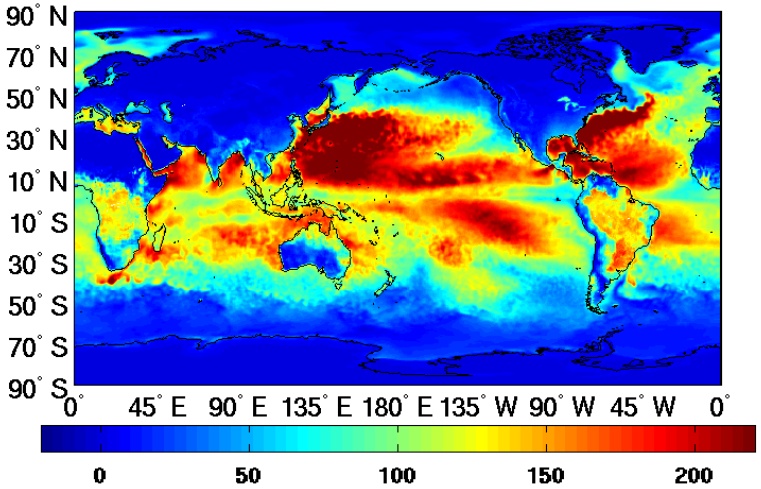
Latent flux (91.6 Wm^{-2}), MEP model



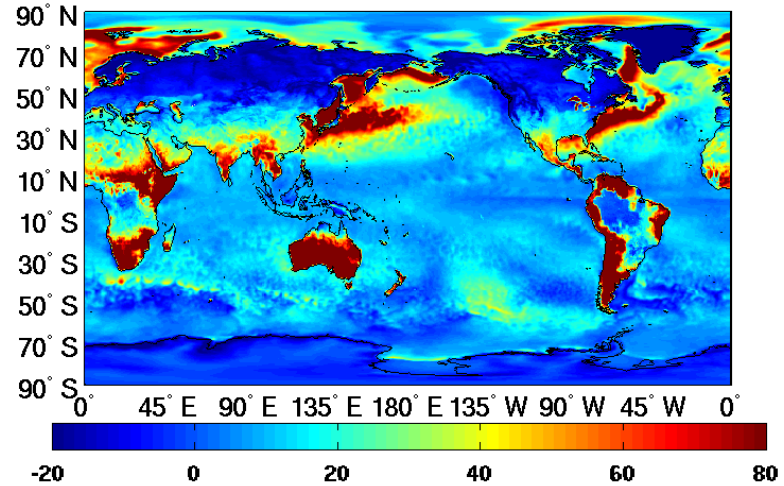
Sensible flux (18.7 Wm^{-2}), MEP model



Latent flux (88.6 Wm^{-2}), MERRA-2

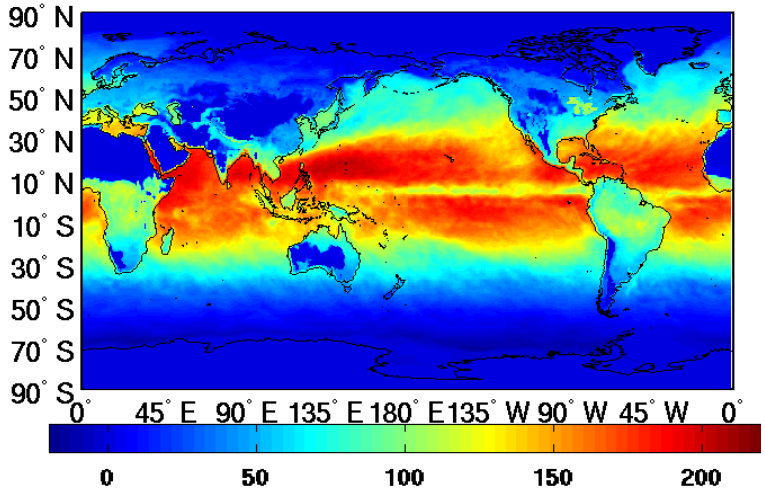


Sensible flux (17.7 Wm^{-2}), MERRA-2

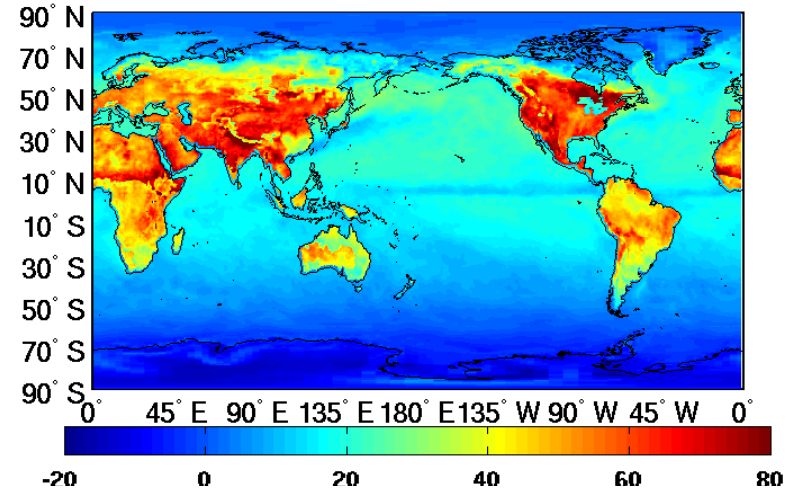


LH and SH fluxes in Apr 2010: MEP/3-hourly CERES-SYN vs. MERRA-2

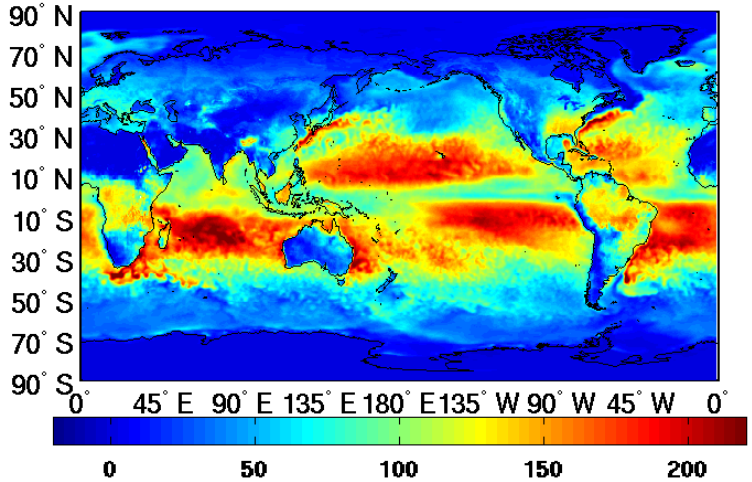
Latent flux (84.4 Wm^{-2}), MEP model



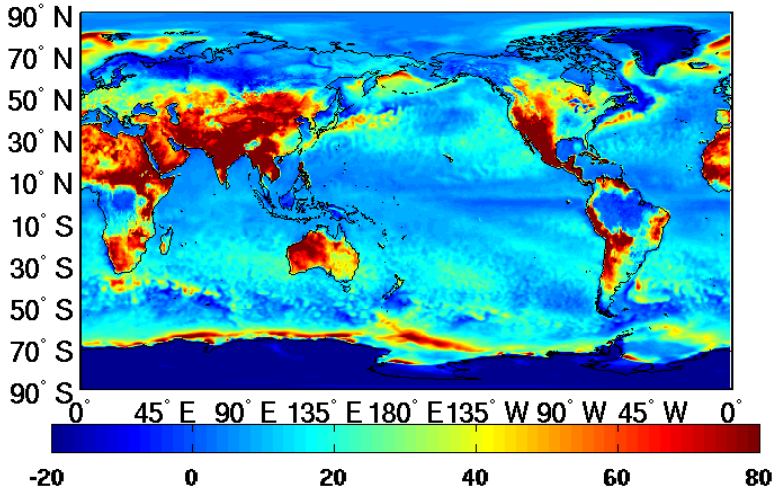
Sensible flux (20.8 Wm^{-2}), MEP model



Latent flux (85.9 Wm^{-2}), MERRA-2



Sensible flux (19.5 Wm^{-2}), MERRA-2



Discussions and Outlooks

- Two most sensitive parameters in the MEP scheme
  - α_w : the ratio of eddy-diffusivity of turbulent transport of water vapor to that of heat in the boundary layer
  - z: the distance from the material surface above which the Monin–Obukhov similarity equations hold (goes into I_0)
- MEP approach has its attraction, but more studies are needed
  - A conjectured criterion for the stationary states of non-equilibrium system or a principle with theoretical basis?
  - What does it tell us when it fails or succeeds?
  - Compared to the bulk aerodynamic formula: more dominated by Ts instead of wind
    - How to validate them over water surfaces?
- If MEP approach is feasible, LH/SH estimations with full consistency with CERES SYN 1-deg or SRB-EBAF products

References

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