Studying Uncertainties in Climate-Terrestrial Biogeochemical interactions (in the Northern High Latitudes) using a Flexible Earth System Modeling Framework

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OBJECTIVES

1. **Intercomparison** of terrestrial biogeophysics-biogeochemistry coupling using multiple land surface models, in an Earth System Modeling Framework:
   - ❖Quantification of land surface – climate feedbacks, and uncertainty analysis

2. Coupling of the **Integrated Science Assessment Model** (ISAM) with NCAR’s **Community Earth System Model** (CESM), the **CESM-ISAM**

- ❖**Identification & attribution** of areas of major disagreement between CESM-CLM and CESM-ISAM;
- ❖**Gain better understanding** of the **impact of alternative representations** of terrestrial biogeochemistry formulations in climate feedbacks

THIS TALK

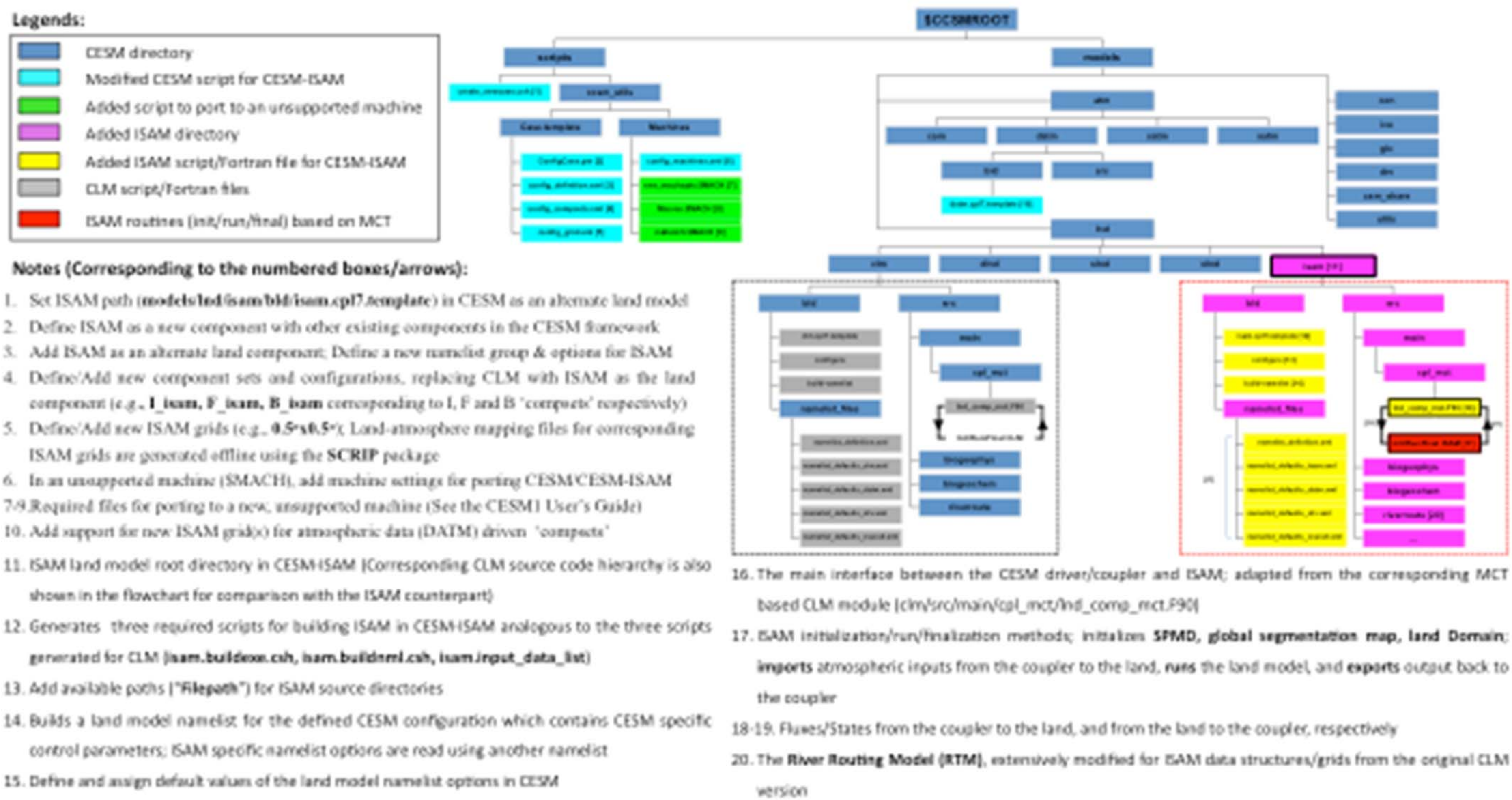
1. **Comparison** of Energy, Water and carbon fluxes between ISAM and CLM using the CESM framework:
   - ❖Gross Primary Production
   - ❖Latent Heat
   - ❖Sensible Heat

2.Results of Improvement of ISAM using FLUXNET products

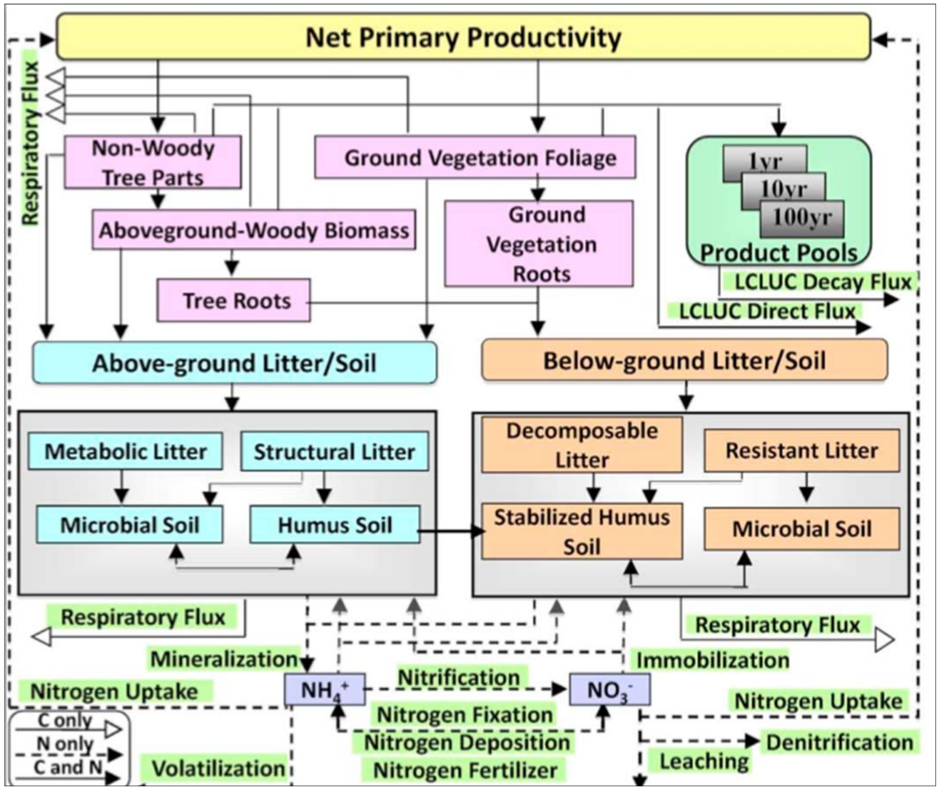
3. Preliminary Results of soil biogeochemistry spin-up using ISAM

CESM-ISAM COUPLING

1. ISAM coupled to the CESM 1.0.3 through the flux coupler; modification of build scripts to achieve flexile coupling
2. Coupling Spatial Resolution ~ 0.5x0.5 Degrees → The new Trigrid feature allows different Land/Atmosphere/Ocean grid resolutions
3. All existing configurations available as is; new configurations created specific to ISAM



INTEGRATED SCIENCE ASSESSMENT MODEL (ISAM)



◆**Land Surface Model**

❖Spatial Resolution:0.5ºx0.5º

❖Biogeophysics Time step: 30 minutes

❖Biogeochemistry Timestep: 1 Week

◆**Biogeochemical** processes

❖Coupled **Carbon-Nitrogen** cycles,

❖**Land Cover and Land Use Change**

❖**Secondary Forest** Dynamics

◆**Biogeophysical** schemes:

❖Adapted from the **CLM3.5/CLM4** and the **CoLM**

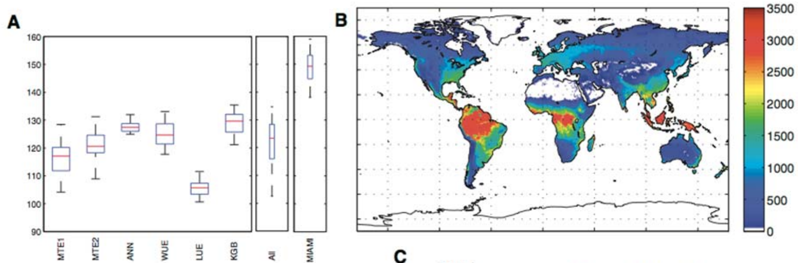
❖Further **modifications** in biogeophysics

◆**CESM-ISAM:**

❖Extends ISAM's capabilities to study terrestrial biogeophysics-biogeochemistry interactions and associated regional and global climate feedbacks

OBSERVATIONAL CONSTRAINTS for LSM CALIBRATION/VALIDATION

[Beer et al., (2010)] GPP ~ 123 +/- 8 GtC/yr



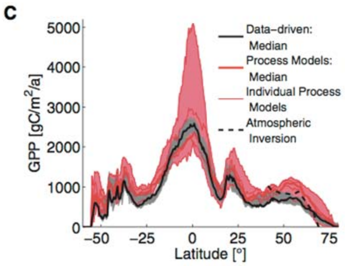


Fig. 1. **(A)** Distributions of global GPP (Pg C year^{-1}) for the five data-driven approaches that are most constrained by data, their combined global GPP distribution, and the GPP distribution by the Miami model. Shown are the median (red horizontal lines), the quartiles (blue boxes), and the 2.5 and 97.5 percentiles (vertical black lines), indicating the 95% confidence interval. MTE is either driven by fAPAR only (MTE1) or by both fAPAR and climate data (MTE2) (*16*). **(B)** Spatial details of the median annual GPP (gC/m^2/a) from the spatially explicit approaches MTE1, MTE2, ANN, LUE, and KGB. **(C)** Latitudinal pattern (0.5° bands) of annual GPP. The gray area represents the range of the diagnostic models MTE1, MTE2, ANN, LUE, and KGB. The red area represents the range of process model results (LPJ-DGVM, LPJmL, ORCHIDEE, CLM-CN, and SDGVM). The thick lines represent the medians of both ranges. The dashed black line shows the result for northern extratropical regions from an independent diagnostic model. In this approach, we combined gridded information about the seasonal NEE amplitude based on atmospheric CO_2 data and an inversion of atmospheric CO_2 transport with empirical relationships between annual GPP and the seasonal amplitude of NEE derived at flux tower sites.

[Jung et al., (2011)] GPP, LE, H, NEE (1982-2004)

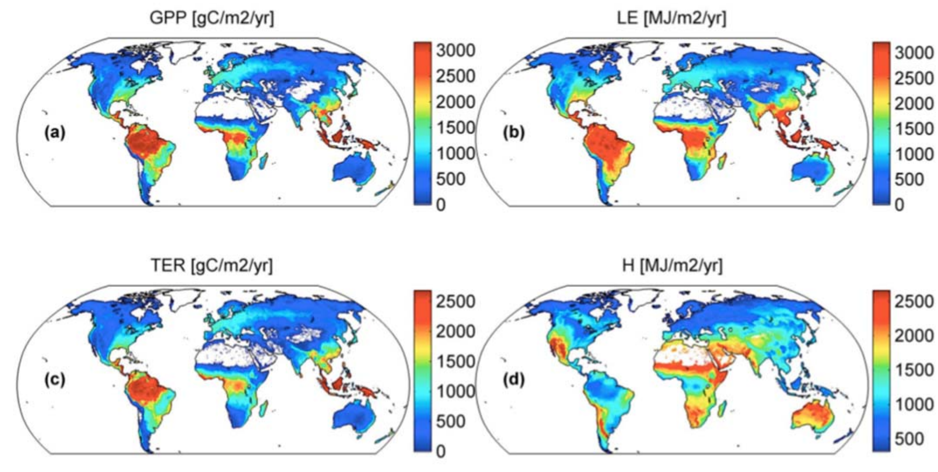


Figure 3. Mean annual (1982–2008) (a) GPP, (b) LE, (c) TER, and (d) H derived from global empirical upscaling of FLUXNET data.

[Bonan et al., (2011)] CLM4a → GPP ~ 130 GtC/yr; CLM4 → 165 GtC/yr [1982-2004]

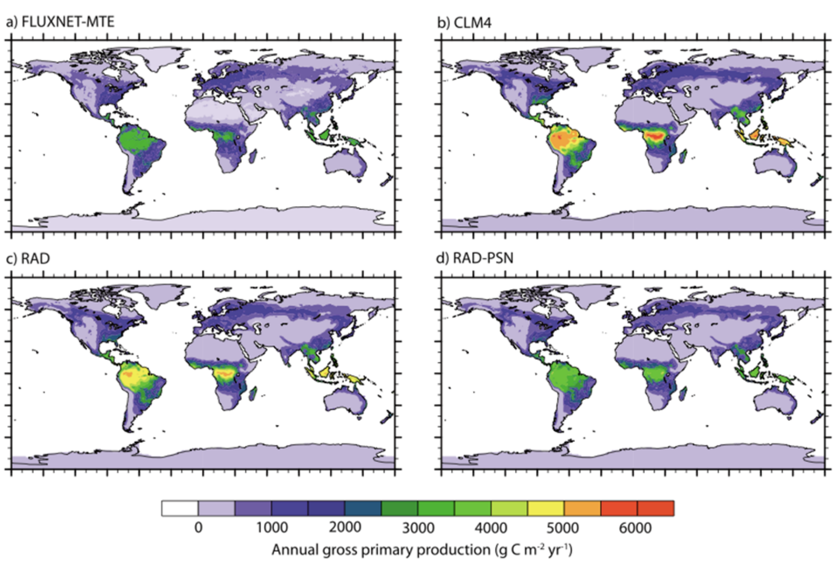


Figure 4. Annual GPP for (a) FLUXNET-MTE and for simulations (b) CLM4, (c) RAD, and (d) RAD-PSN.

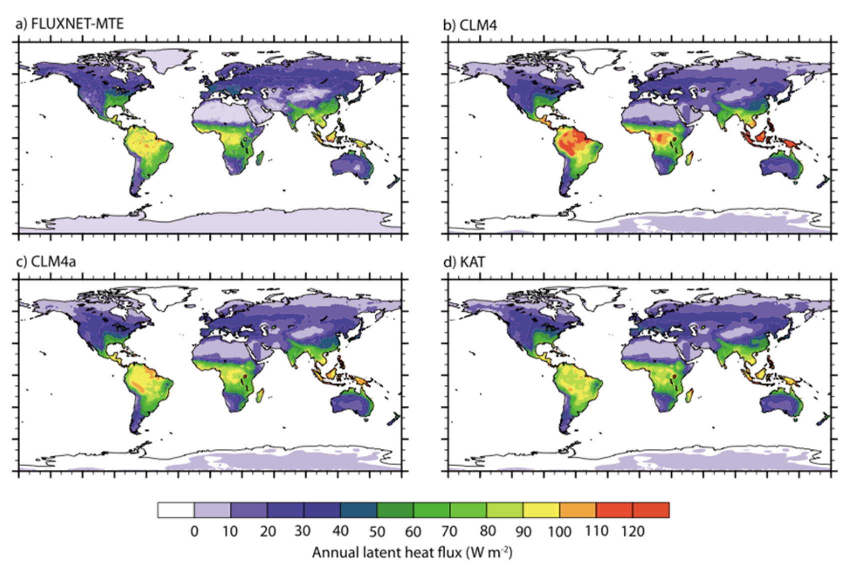
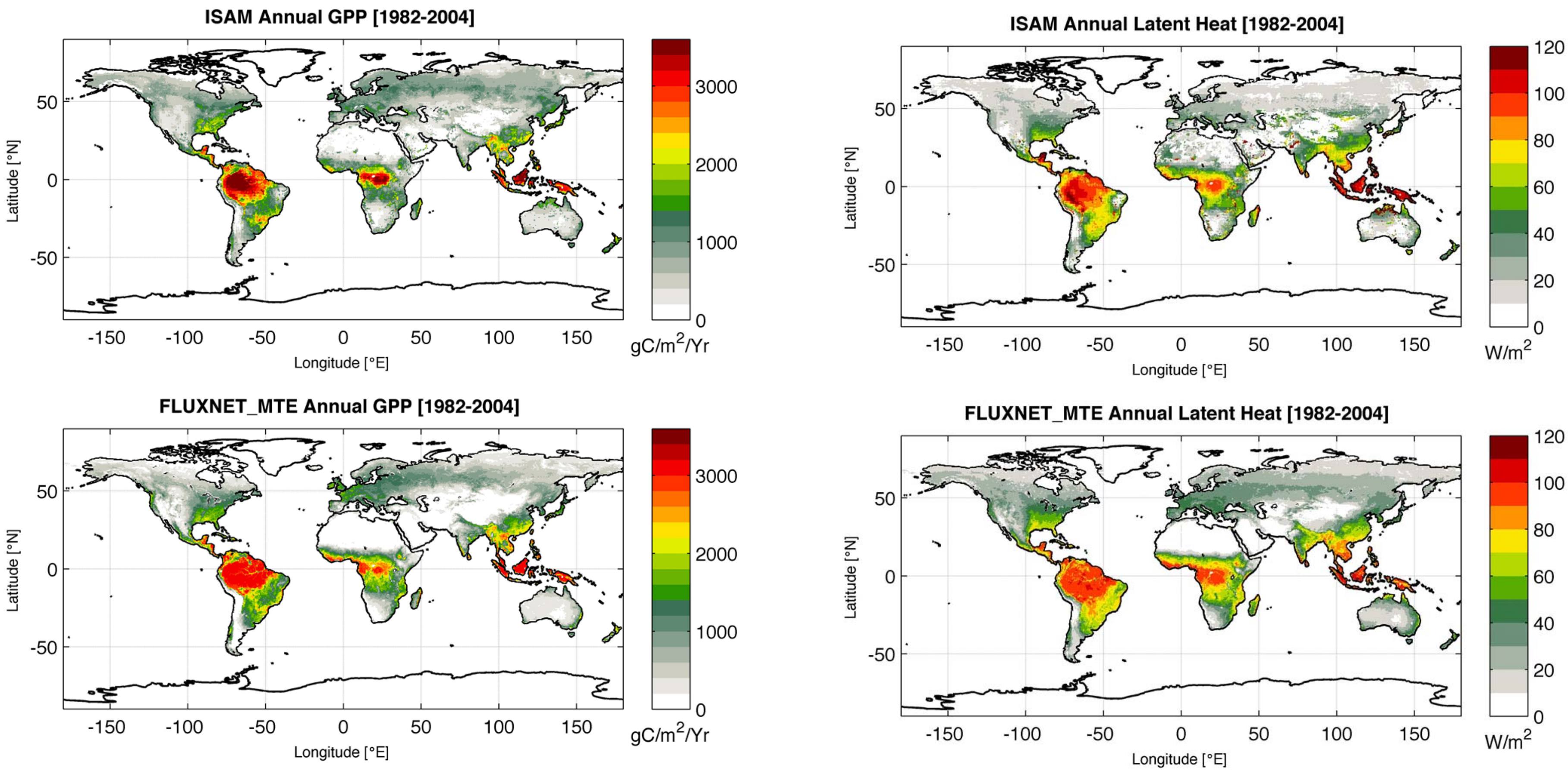


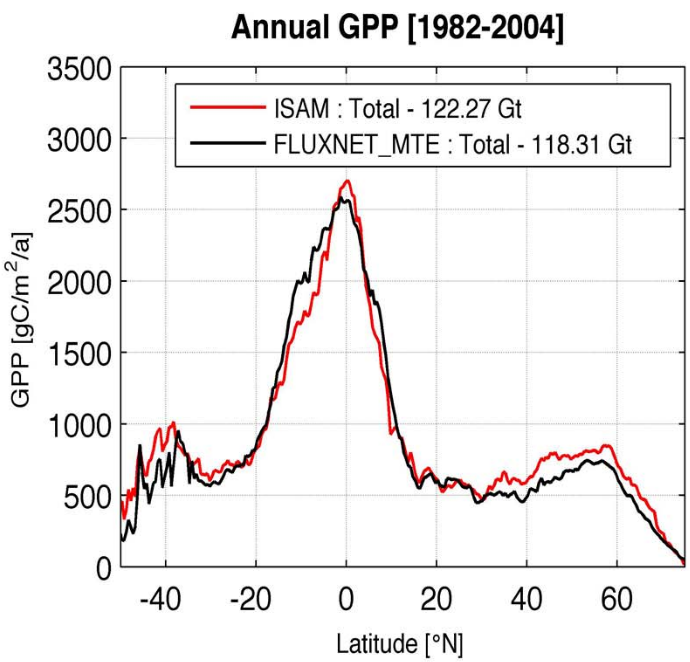
Figure 8. Annual latent heat flux for (a) FLUXNET-MTE and for simulations (b) CLM4, (c) CLM4a, and (d) KAT.

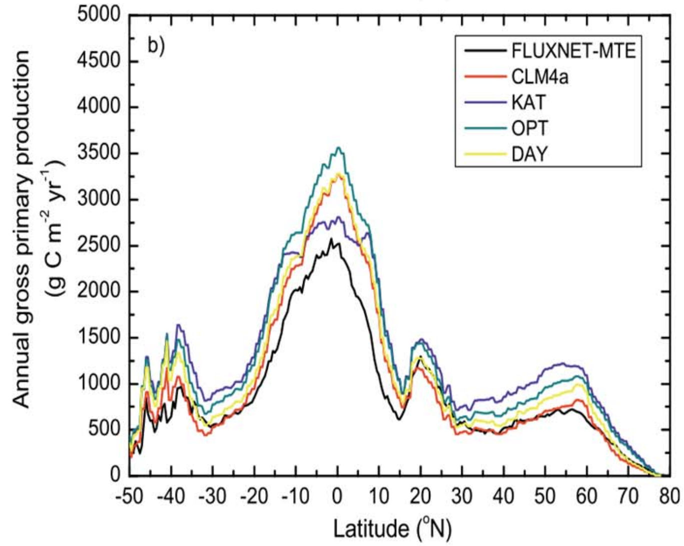
IMPROVING ISAM – USING FLUXNET MTE

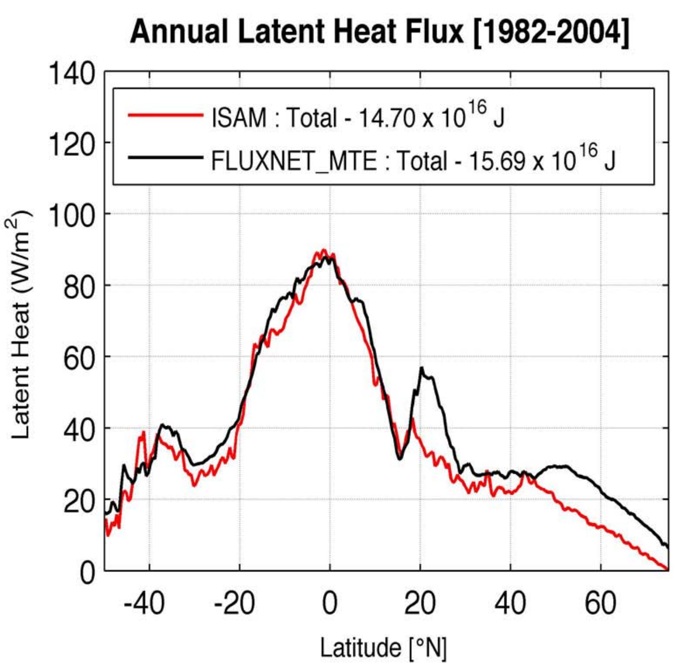


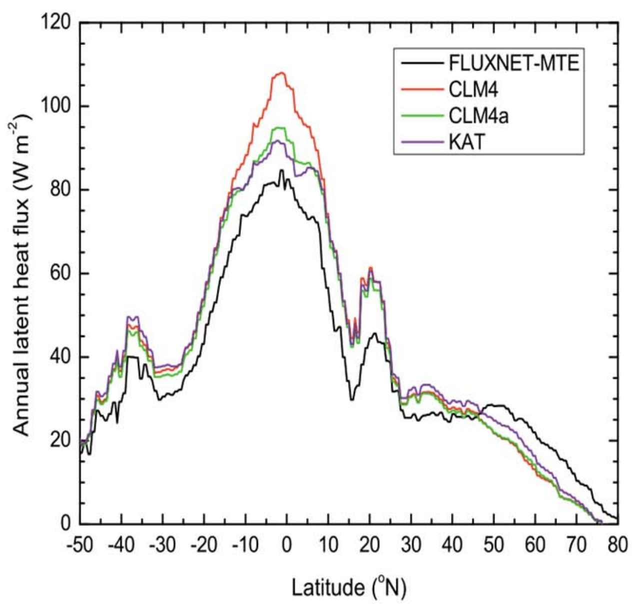
1. ISAM Photosynthesis & Stomatal conductance: ***Dai et al., 2004; Chen et al., 2010; Bonan et a al., 2011***
2. V_{cmax25}^{opt} *f(N)* values in ISAM are same as recommended by ***Kattage at al., 2009*** for tropical/temperate forests [Tropical evergreen ~41; Tropical Deciduous ~ 58; Temperate Evergreen ~ 41; Temperate Deciduous ~ 58], Savanna ~ 70; Lower values used for Boreal ~ 30, Tundra ~ 30, Crop ~ 35; Grassland ~ 40
3. V_{cmax25}^{opt} *f(N)* for ISAM forest ecosystems are in better agreement with Kattage et al., 2009 than CLM4a (Stronger N-limitation)

ISAM vs. CLM4a (*Bonan et al., 2011*) – COMPARISON OF ANNUAL GPP & LE



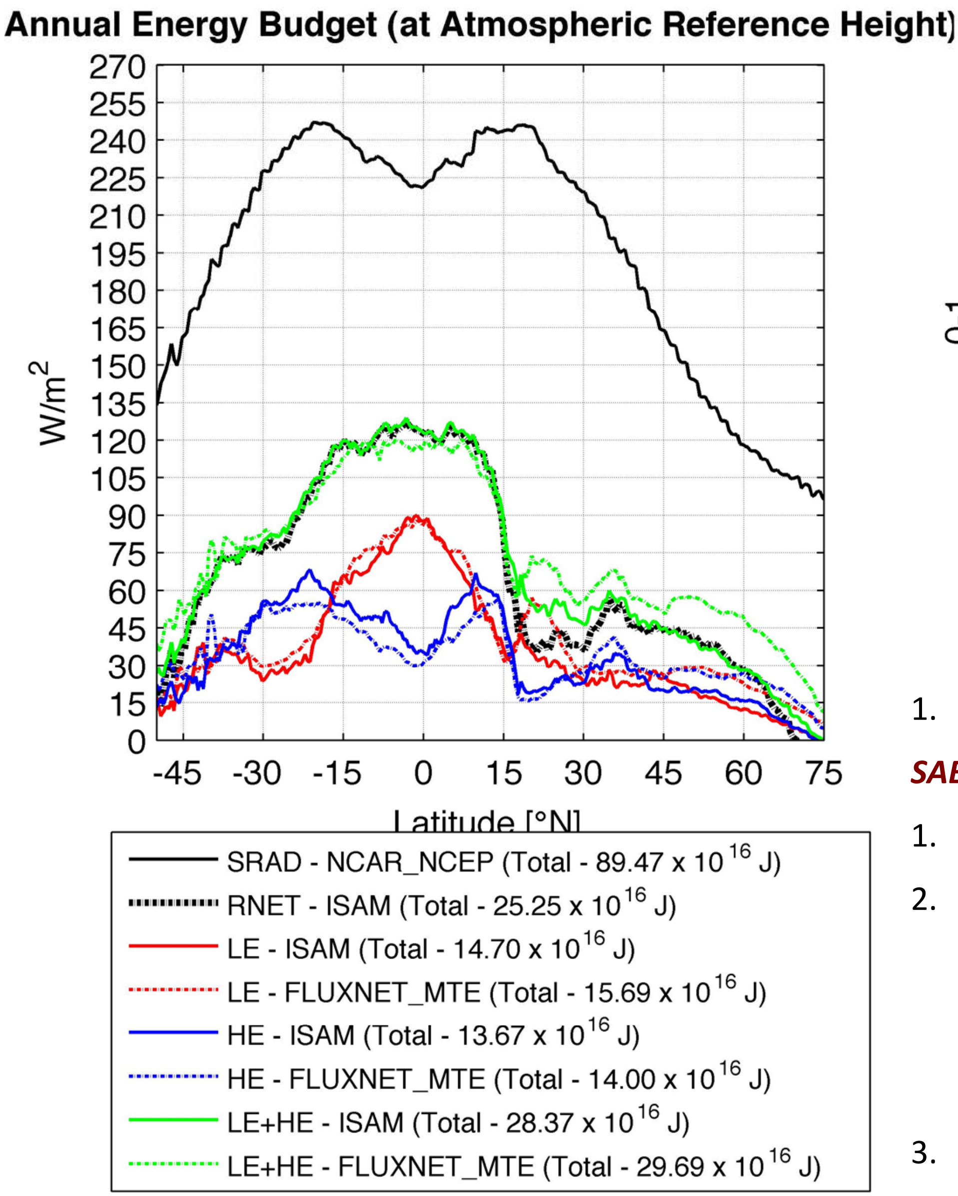


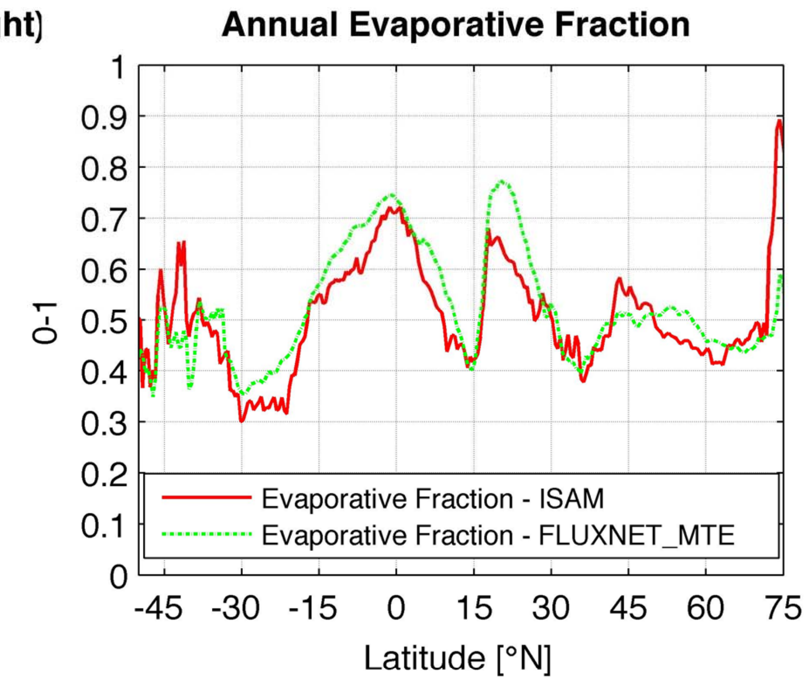




1. Both models overestimate GPP in and significantly underestimate LE in the Northern High latitudes, where GPP-LE coupling do not seem to be as closely coupled (unlike other ecosystems)
2. High concentration of SOM in the CLM4/CLM4a soil dataset → drier surface and top soil layers → reduced plant water uptake, and reduced soil evaporation
3. ISAM implements the new HWSD SOM dataset, with lower carbon concentration; yet the model remains biased low for Northern High Latitude ET; upland soil hydrology the limitation?
4. ISAM misses the ET maxima at 20°N, the 2005 Land cover data used has very high crops/pastureland

ISAM ENERGY BALANCE by LATITUDE – A *CLOSER* LOOK



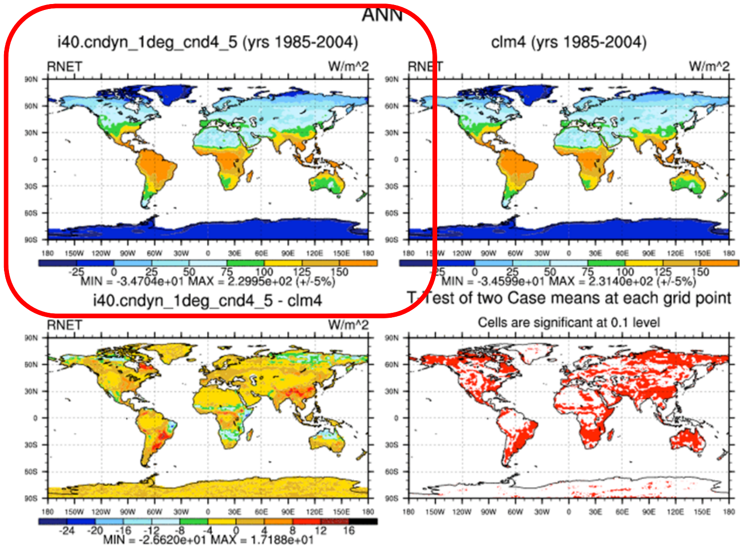


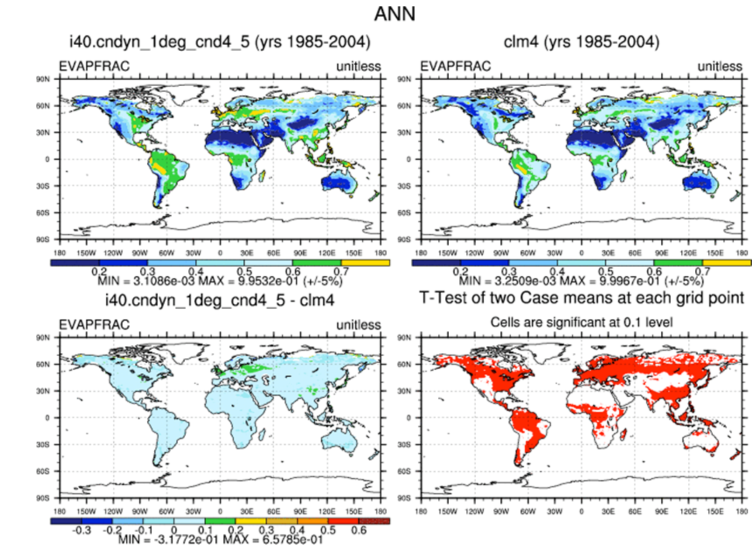
1. Energy Balance:

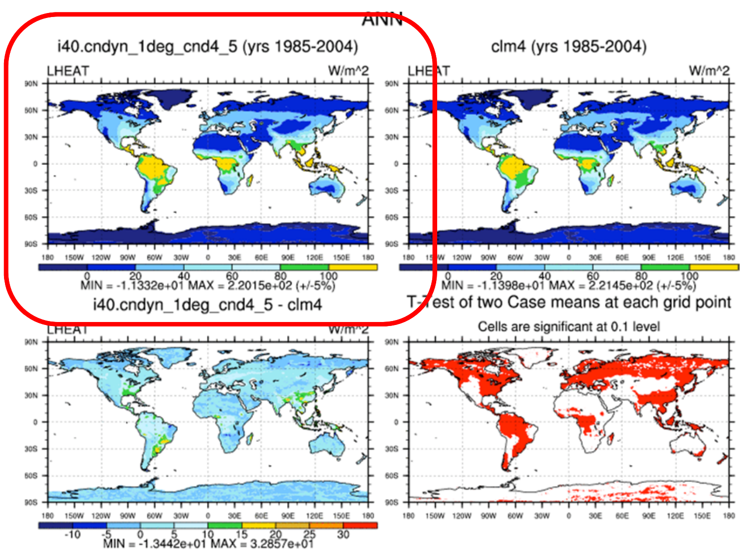
SABG + SABV + FRL – OLRG = LE (Latent) + H (Sensible) + snowmelt

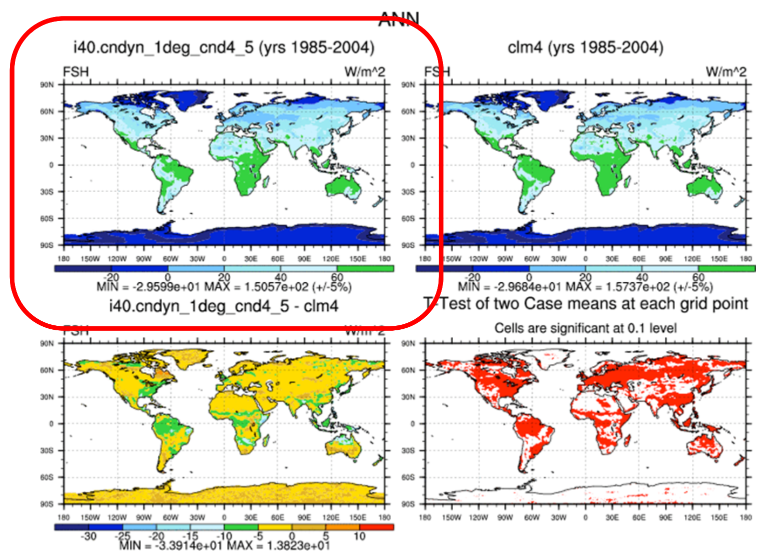
1. ISAM also calibrated H (sensible Heat), besides GPP & LE
2. Achieved by reduction of Net Radiation absorbed by canopy (consistent with FLUXNET estimates) → modification of canopy optical properties (Reflectance, Transmittance); Improved LE/H partitioning through modification of Stomatal conductance & photosynthetic parameters
3. Prier to calibration, ISAM had very high H in the tropics due to high canopy absorption (SABG) → High Leaf Temperature →High Leaf Respiration → Low NPP/GPP ratio

CLM4.5 ENERGY BALANCE (*CLM4.5 Diagnostic Plots*)







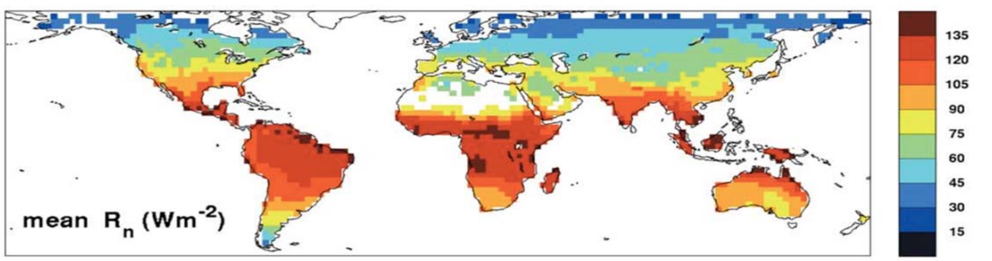


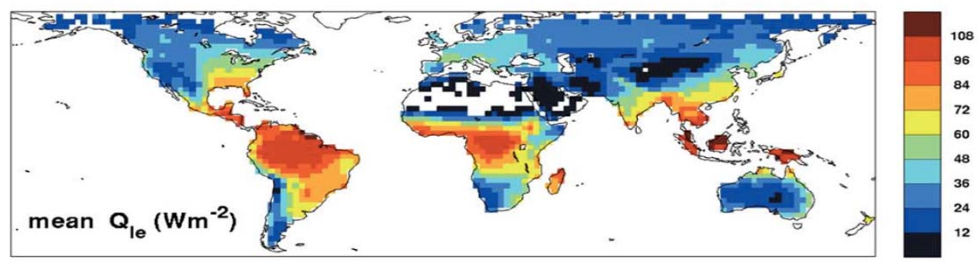
1. Higher Net Radiation at tropics → Higher Sensible Heat (high leaf temperature, lower NPP/GPP ration due to higher leaf growth and maintaince respiration)

OBSERVATIONAL ESTIMATES OF LSM HEAT FLUX (*Jimenez et al., 2011)*

Table 1. Summary of the Flux Estimates Intercompared[a]

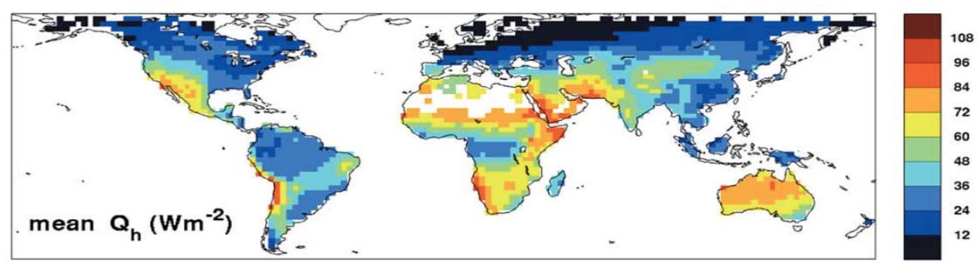
	Institution	Q_{le}	Q_h	R_n	Resolution
		Satellite-Based Products			
UCB	University of California Berkeley	Physical-biological, Priestley-Taylor, inputs from ISLSCP-II (SRB, CRU, AVHRR)	$R_n - Q_{le}$	SRB	1986–95 monthly 1° × 1°
UMD	University of Maryland	Empirical (regression, AmeriFlux Q_{le}), inputs from ISLSCP-II (SRB, CRU, AVHRR)	$R_n - Q_{le}$	SRB	1986–95 monthly 1° × 1°
PRU	Princeton University	Penman-Monteith, inputs from ISCCP, AVHRR, NCEP/NCAR	$R_n - Q_{le}$	ISCCP-FD	1986–06 daily 2.5° × 2.5°
PAO	Paris Observatory	Empirical (neural networks, GSWP modeled Q_{le}), inputs from ISCCP, ERS, SSMI, AVHRR		$Q_{le} + Q_h$	1992–99 monthly 1/4° × 1/4°
MPI	MPI for Biogeochemistry	Empirical (tree ensemble, FluxNet measured Q_{le}) inputs from CRU, GPCC, AVHRR		$Q_{le} + Q_h$	1982–08 monthly 1/2° × 1/2°
		Reanalysis			
MER	NASA-GMAO	MERRA reanalysis, GEOS-5 atmospheric model coupled with Catchment land model			1979– 1-hourly 1/2° × 2/3°
NCE	NCEP/NCAR	NCEP-DOE reanalysis, atmospheric model coupled with OSU land model			1979– 6-hourly 2.5° × 2.5°
ERA	ECMWF	ERA Interim reanalysis, atmospheric model coupled with TESSEL land model			1989–98 6-hourly 3/4° × 3/4°
		Off-Line Land Surface Models			
GSW	GLASS/ISLSCP	Multi-model ensemble, off-line forced with ISLSCP-II		SRB	1986–95 monthly 1° × 1°
NOA	NCAR/OSU/AFWA/HL	Equally off-line forced participating models driven by GLDAS		1993 ERA15 1994/5 NCEP/R1	1979– 3-hourly 1° × 1°
CLM	NCAR +			SRB-bias corrected	
MOS	NASA-GSFC				



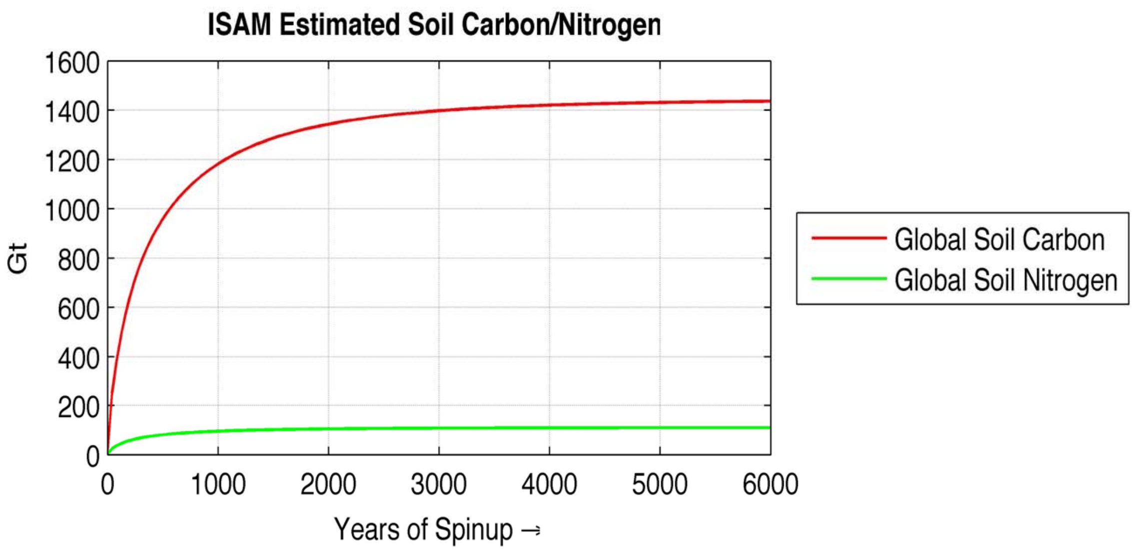


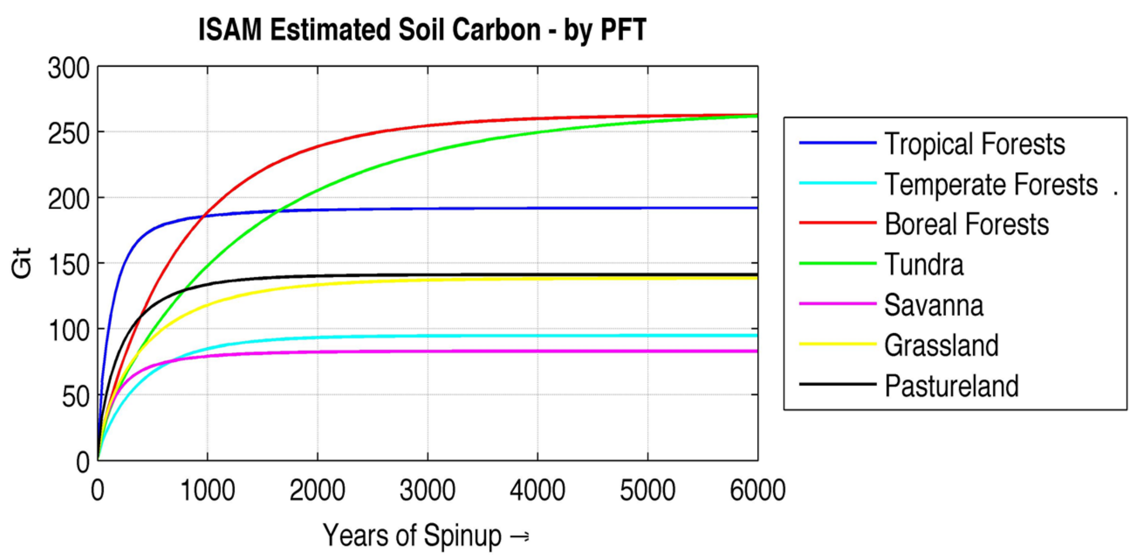
Global intercomparison of 12 land surface heat flux estimates

C. Jiménez,[1] C. Prigent,[1] B. Mueller,[2] S. I. Seneviratne,[2] M. F. McCabe,[3] E. F. Wood,[4] W. B. Rossow,[5] G. Balsamo,[6] A. K. Betts,[7] P. A. Dirmeyer,[8] J. B. Fisher,[9] M. Jung,[10] M. Kanamitsu,[11] R. H. Reichle,[12] M. Reichstein,[10] M. Rodell,[13] J. Sheffield,[4] K. Tu,[14] and K. Wang[15]



ISAM SOIL BIOGEOCHEMISTRY SPINUP @ Weekly time-step





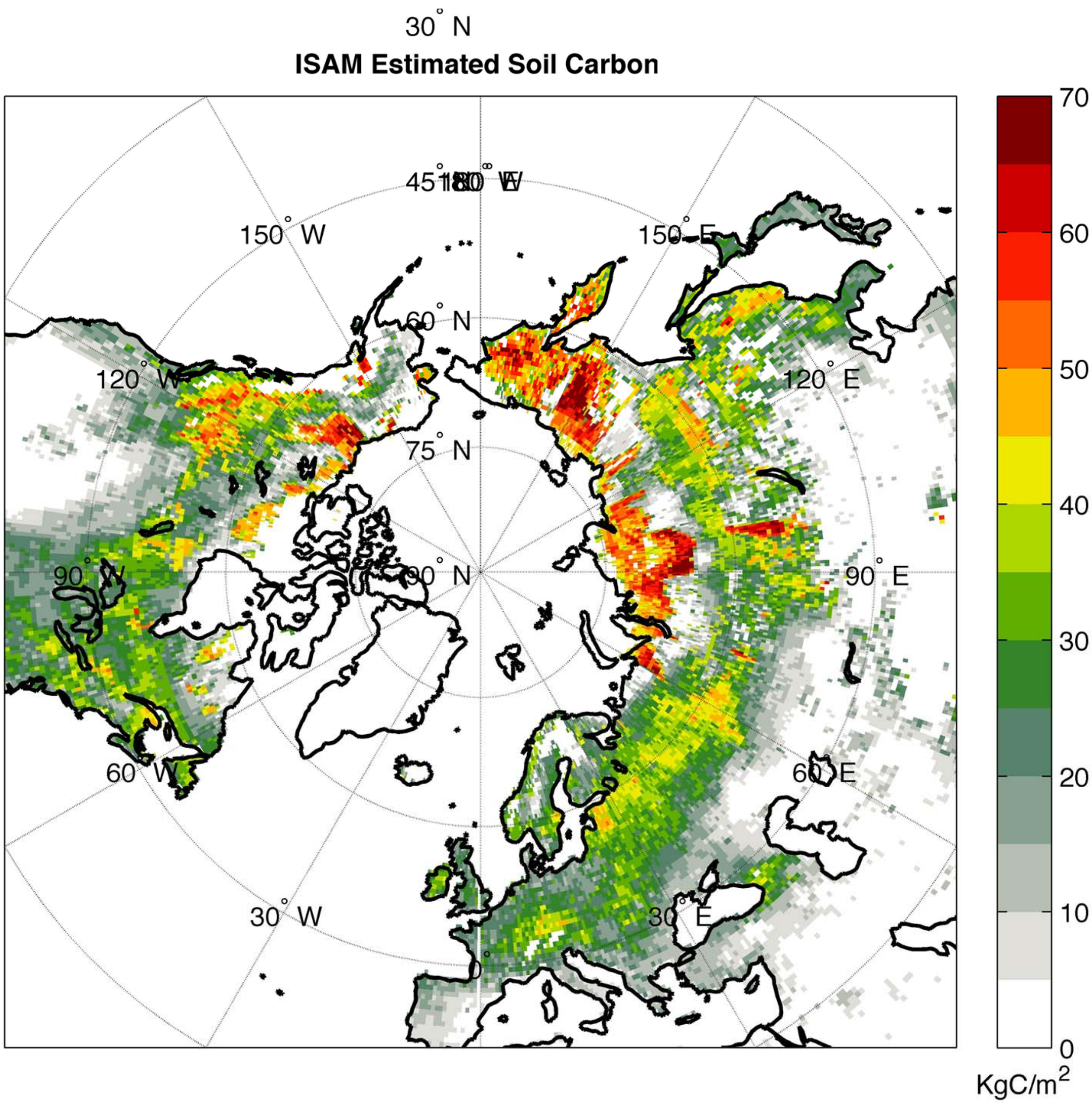
1. ***Tarnocai et al., 2009***

   Northern High Latitudes ~ 495GtC in 0-1m soil; 1024 GtC in 0-3m soil

[4] There are a number of estimates of global soil organic carbon pools. Estimates for the 0–100 cm depth include 1220 Pg [*Sombroek et al.*, 1993], 1395 Pg [*Post et al.*, 1982], 1462 to 1548 Pg [*Batjes*, 1996], 1502 Pg [*Jobbágy and Jackson*, 2000], and 1576 Pg [*Eswaran et al.*, 1993]. *Batjes* [1996] also reports global organic carbon pools for the 0–200 cm depth (2376–2456 Pg) and *Jobbágy and Jackson* [2000] report global organic carbon pools for both the 100–200 cm (491 Pg) and 200–300 cm (351 Pg) depths.

2. ***HSWD Dataset*** **~ 900PgC in 0-30cm, 2100 PgC in 0-1 m soil**
3. **Significant uncertainties in the models and also observational estimates**

ISAM Estimated Northern High Latitude Soil Organic Carbon



ISAM

1. Biogeochemistry → Yang et al., 2009; Jain et al., 2009;
2. Phenology → Arora & Boer, 2005
3. Limitations – Lack of Soil temperature & Decomposition coupling; Pools not resolved with depth; ….

CONCLUSIONS

1. The **Integrated Science Assessment Model** (ISAM) has been coupled with NCAR's **Community Earth System Model** (CESM) → **CESM-ISAM**

1. Here**, we inter-compared offline ISAM and CLM simulations to better understand the characteristics of several Land→atmosphere coupling fluxes**
    - ❖Areas of disagreement exist in biogeophysical and biogeochemical fluxes; however, the models are consistent to be coupled/compared within the CESM framework
    - ❖Biogeochemistry comparisons are preliminary, and needs to be compared more closely

3. Next, onto land-atmosphere simulations …

ISAM LAND COVER (2005) used for Simulating 1982-2004 Simulation