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Improving the Amazonian Hydrologic Cycle in a Coupled Land-Atmosphere, Single Column General Circulation Model

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Modeling the Hydrologic Cycle

- Use of a land-surface model to force a general circulation model should improve the simulation of surface fluxes and the surface water budget.
- A previous version of CSU's coupled models (SiB2-GCM) showed drought and catastrophic dieback of the Amazon rain forest.
- Since that study, many improvements have been made to both SiB and the GCM, warranting a new look at their performance in the Amazon.
- Test site is in the Tapajos National Forest at a monitoring station located near km 83 of the Santarém-Cuiaba highway (3°S, 305°W). Half-hourly observations are available for 2000-2004 as part of the LBA-ECO project.

BUGS5

- **Several improvements since 1996 including:**
  - **Multiple-cloud-base cumulus parameterization (Ding, 1995)**
  - **Adams-Bashforth time-stepping used for dynamics**
  - **Revised vertical differencing (Suarez and Arakawa, 1977)**
  - **Implementation of flux coupler**
  - **New option for radiation scheme (BUGSRAD)**
  - **New microphysical scheme in cumulus parameterization (Fowler and Randall, 2002)**

SiB2

- **Ecophysiological process model describing land-air exchanges of radiation, heat, water, and momentum.**
- **For full model description see P. Sellers, 1996**

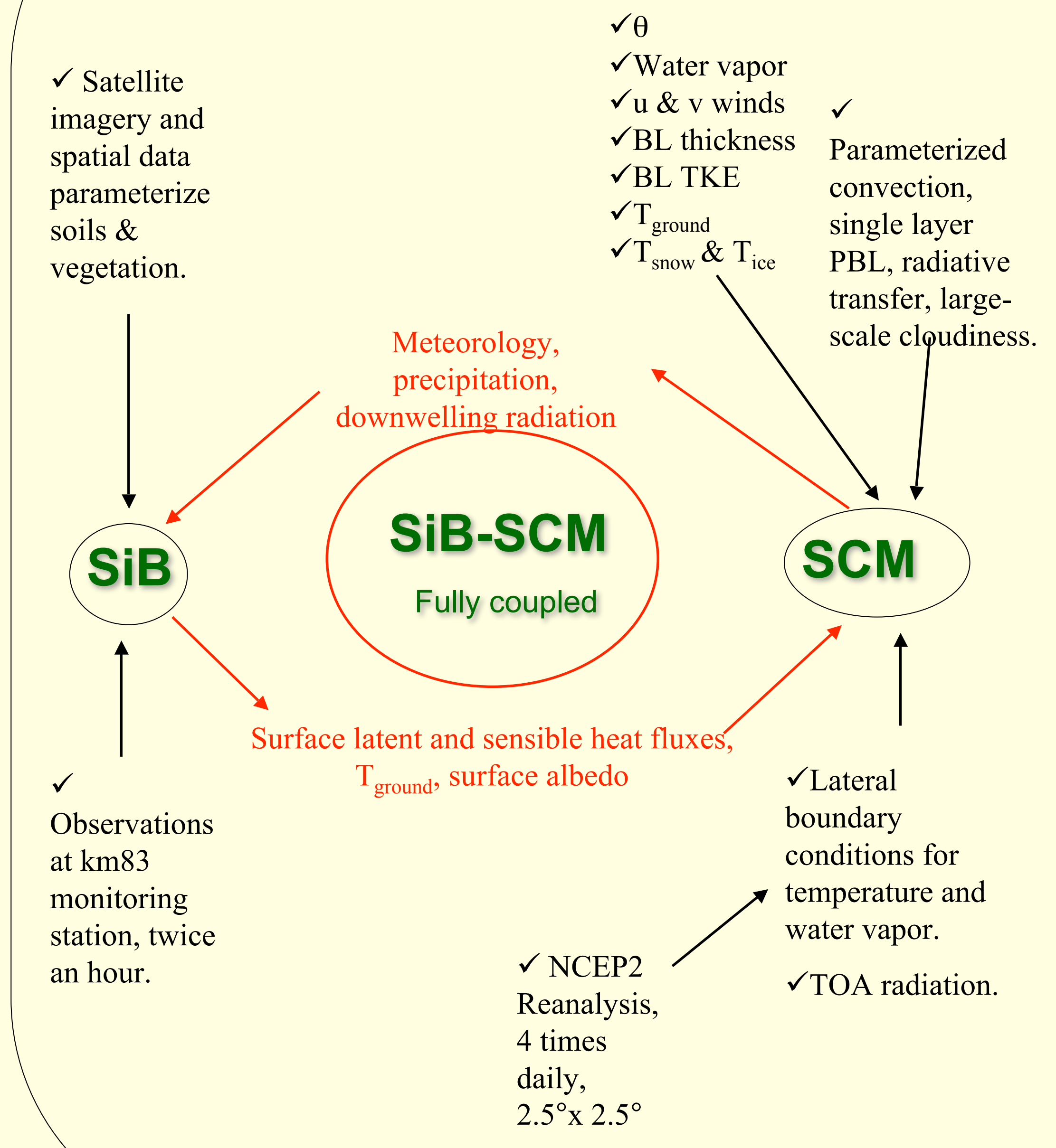
SiB3

- **Prognostic Canopy Air Space**
- **Change from 3 to 10 layer soil, with increasing layer thickness with depth and roots in all layers.**

FURTHER MODIFICATIONS

- **Deepest soil layer moved from 3.5 to 10 meters.**
- **Optimum soil moisture for respiration (w_{opt}) increased to match observations.**
- **Hydraulic Redistribution allows plants to access deep soil water during dry season.**
- **Attend Ian Baker's talk in MCS 270 at 1700h today to hear how these changes affect carbon exchanges.**

Coupling the Models



✓ Satellite imagery and spatial data parameterize soils & vegetation.

✓ Observations at km83 monitoring station, twice an hour.

✓θ
✓Water vapor
✓u & v winds
✓BL thickness
✓BL TKE
✓T_{ground}
✓T_{snow} & T_{ice}

✓ Parameterized convection, single layer PBL, radiative transfer, large-scale cloudiness.

Meteorology, precipitation, downwelling radiation

SiB

SiB-SCM
Fully coupled

SCM

Surface latent and sensible heat fluxes, T_{ground}, surface albedo

✓ NCEP2 Reanalysis, 4 times daily, 2.5°x 2.5°

✓Lateral boundary conditions for temperature and water vapor.

✓TOA radiation.

Relaxation Forcing

$$\frac{\partial q}{\partial t} = \frac{q_{in} - q}{\tau_{adv}} - \omega \frac{\partial q}{\partial p} + P$$

- This equation is used to allow the model-produced values of temperature and water vapor to relax back to the values advected into the column from upstream (Randall & Cripe, 1999).
- Tau is the advective time-scale, calculated with distance between gridpoints and mean wind:

$$\tau_{adv} = \frac{d}{2V}$$

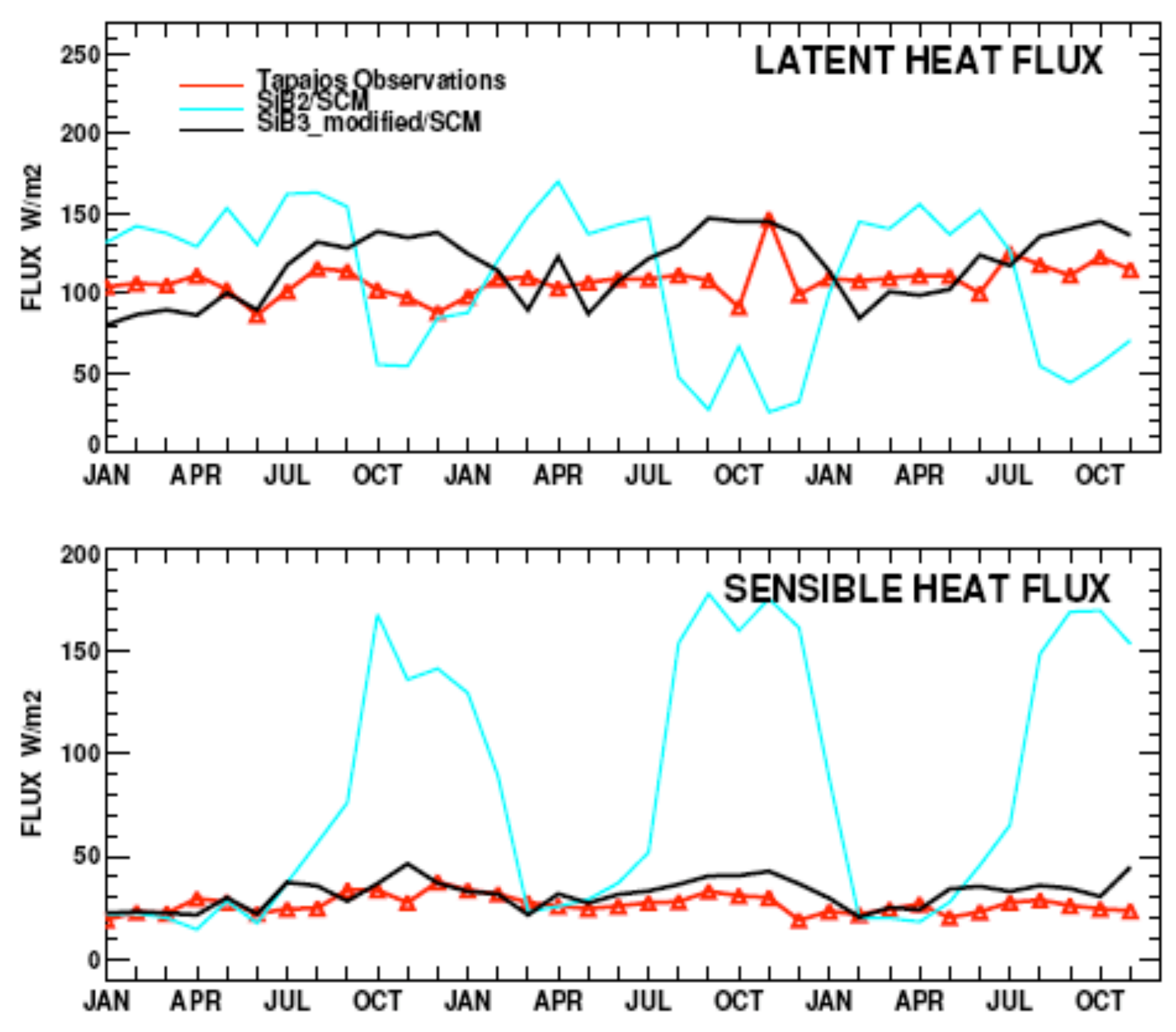
- q_{in} is the upstream value of temperature or water vapor

Model Set-up

- 7.5 minute time-step
- Vertical resolution of 17 layers (up to 100 mb)
- 9 year spin-up of SiB offline to get appropriate initial conditions
- NCEP2 Reanalysis used as driver data

Surface Fluxes

Monthly Fluxes, 2001-2003



- **Observed latent heat flux shows much less variability than SiB2-SCM.**
- **Observed sensible heat flux is also relatively constant throughout the year.**
- **SiB2-SCM could not accurately represent the moisture budget during the dry season, leading to severe canopy stress.**
- **The canopy would get very hot due to lack of moisture and increased incoming solar radiation. Since SiB2 did not include the mechanisms by which Amazonian trees adapt to dry conditions, sensible heat fluxes were too high and latent heat fluxes were too low.**

Modified SiB3 in the SCM

- **By including hydraulic redistribution and deeper soil layers, the latest version of SiB3 coupled to the SCM best represents sensible heat flux throughout the model run.**
- **The seasonal trend of latent heat flux is improved, although it is overestimated in the dry season.**

Precipitation

Intensity of Dry Season

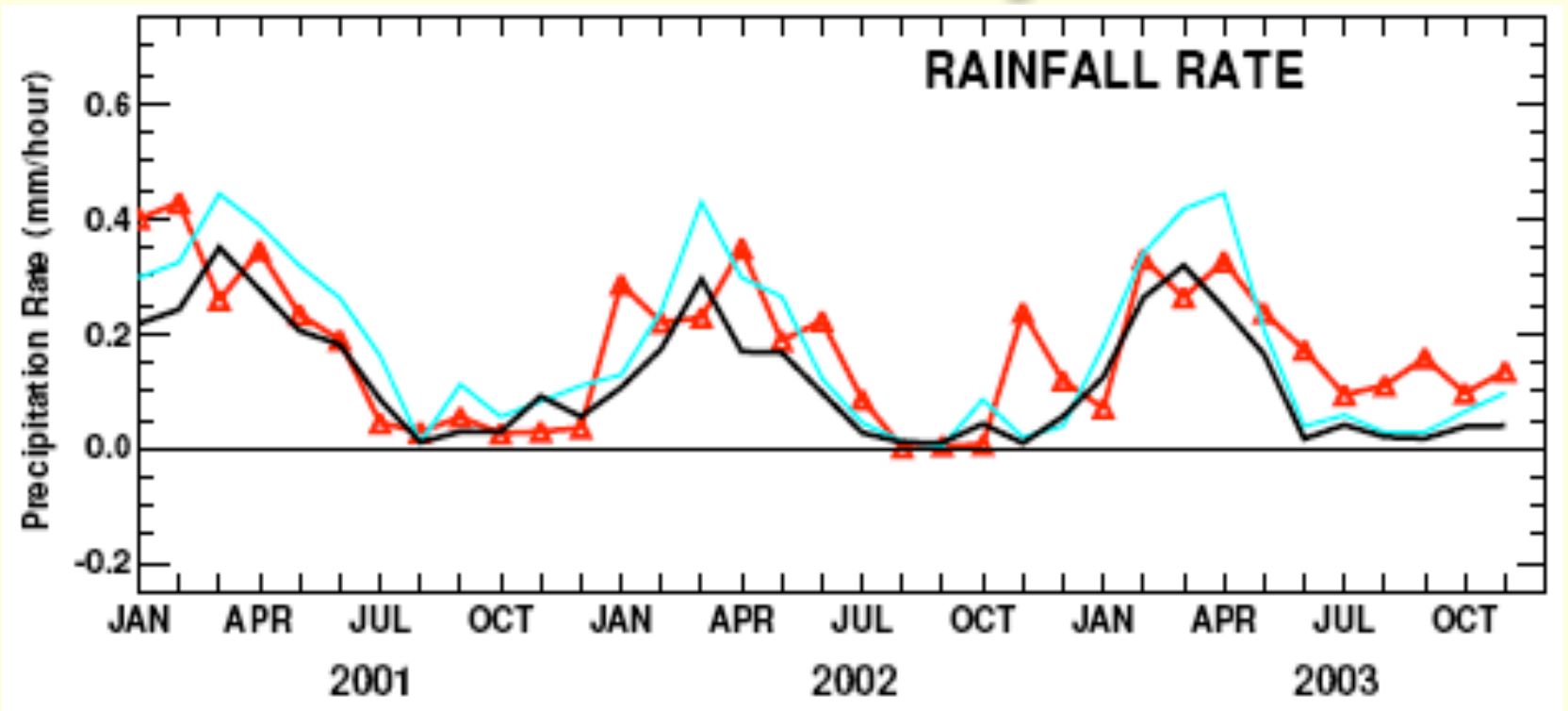
Average Monthly Rainfall Totals, 2001-2003 (mm)

	Observed	SiB2-SCM	Modified SiB3-SCM
January	187.69	150.31	111.33
February	219.32	202.74	152.07
March	186.02	319.90	238.87
April	244.92	271.44	165.82
May	163.41	195.62	132.98
June	140.02	101.59	70.99
July	55.80	65.79	38.37
August	34.94	**12.72**	**10.52**
September	52.39	34.70	13.82
October	**32.17**	50.91	27.38
November	96.53	47.66	33.67
December	66.89	62.69	47.02
Annual Total	**1480.09**	**1516.10**	**1042.84**

Key:
Orange = <100 mm
Red = < 50 mm
Bold Red = driest month
Blue = wettest month

- **Define dry season as months with less than 100 mm of rain (Huete, 2006).**
- **Observed dry season is July-December.**
- **Overall, SiB coupled to the SCM simulates the correct dry season length.**
- **The modified version of SiB3 overestimates the intensity of the dry season.**

Seasonal Cycle



Both SiB2 & SiB3 coupled to the SCM get the seasonal cycle of rainfall

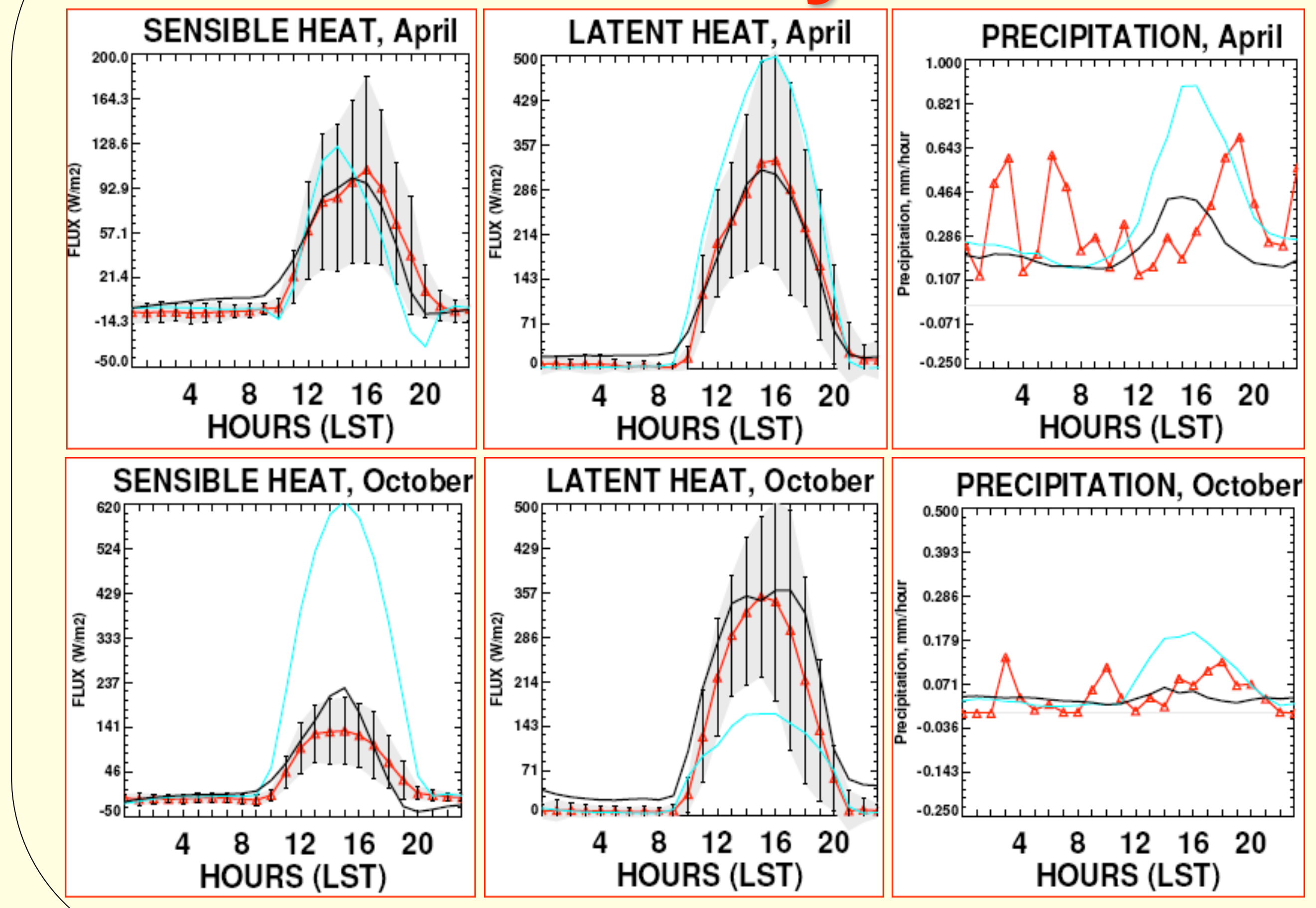
Why does the addition of hydraulic redistribution decrease rainfall?

This is an unexpected result, especially because latent heat flux is increased, leading one to believe that there would be more moisture available for convection.

Possible explanations:

Difference in forcing due to upstream water vapor, mean wind speed, vertical advection.

Diurnal Cycles



April Sensible and Latent Heat Fluxes

One of the wettest months of the year.

Mid-day Bowen Ratio of approximately 1:3.

October Sensible and Latent Heat Fluxes

One of the driest months of the year.

BUT mid-day Bowen Ratio is still approximately 1:3.

SiB2-SCM overestimated sensible heat flux in the dry season.

By including hydraulic redistribution, the modified SiB3 accurately depicts the diurnal cycle of latent and sensible heat during the dry season.

Diurnal Precipitation

Observations don't show a consistent diurnal cycle.

The models show a peak in rainfall around 10-11 AM LST.

References:

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