Land-atmosphere interactions and water balances for major basins of the Americas

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Themes

- **ERA40; ERA-Interim reanalyses**
- *Betts, A. K., M. Köhler and Y-C. Zhang, 2009: Comparison of river basin hydrometeorology in ERA-Interim and ERA-40 with observations. J. Geophys. Res. [ECMWF tm568.pdf]*

- **VAMOS/IASCLIP/MESA**

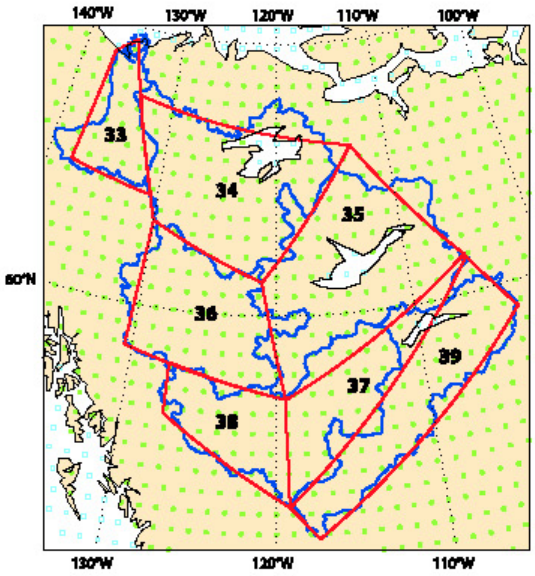
  - ***diagnostic for errors in SWCF & Precip. forcing***

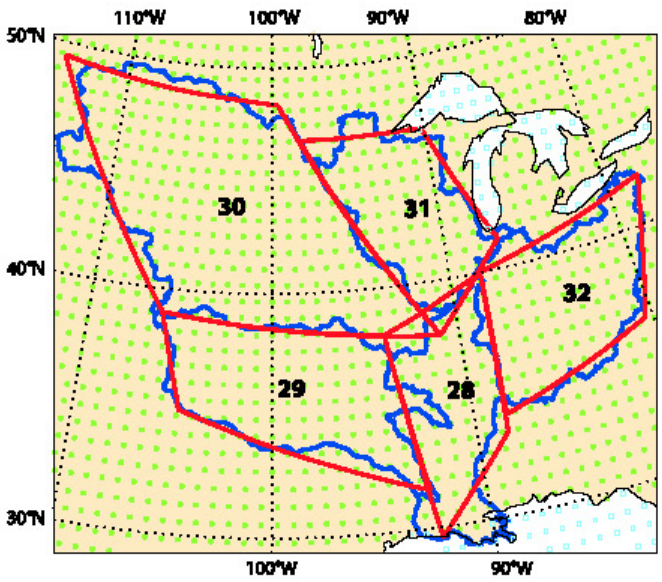
  - ***coupling between CO_2 ,water fluxes and BL clouds***

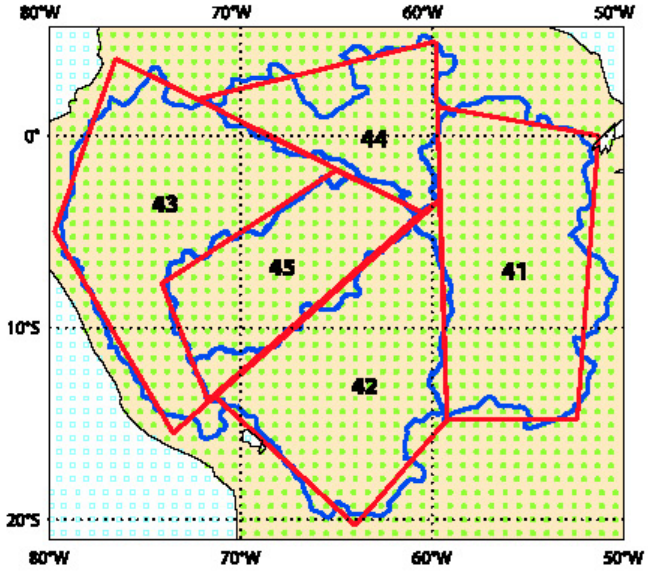
[Betts, A. K. (2009), Land-surface-atmosphere coupling in observations and models. JAMES, in press. http://adv-model-earth-syst.org/index.php/JAMES/article/view/10/18]

River basin archive

ERA-40 and ERA-Interim







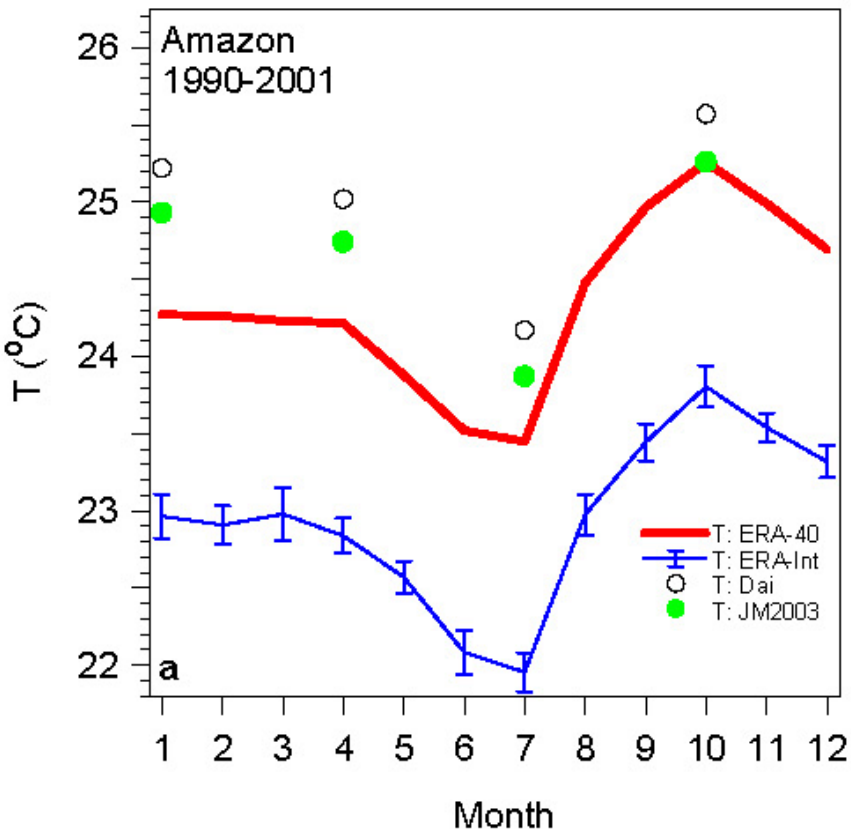
Mackenzie **Mississippi** **Amazon**

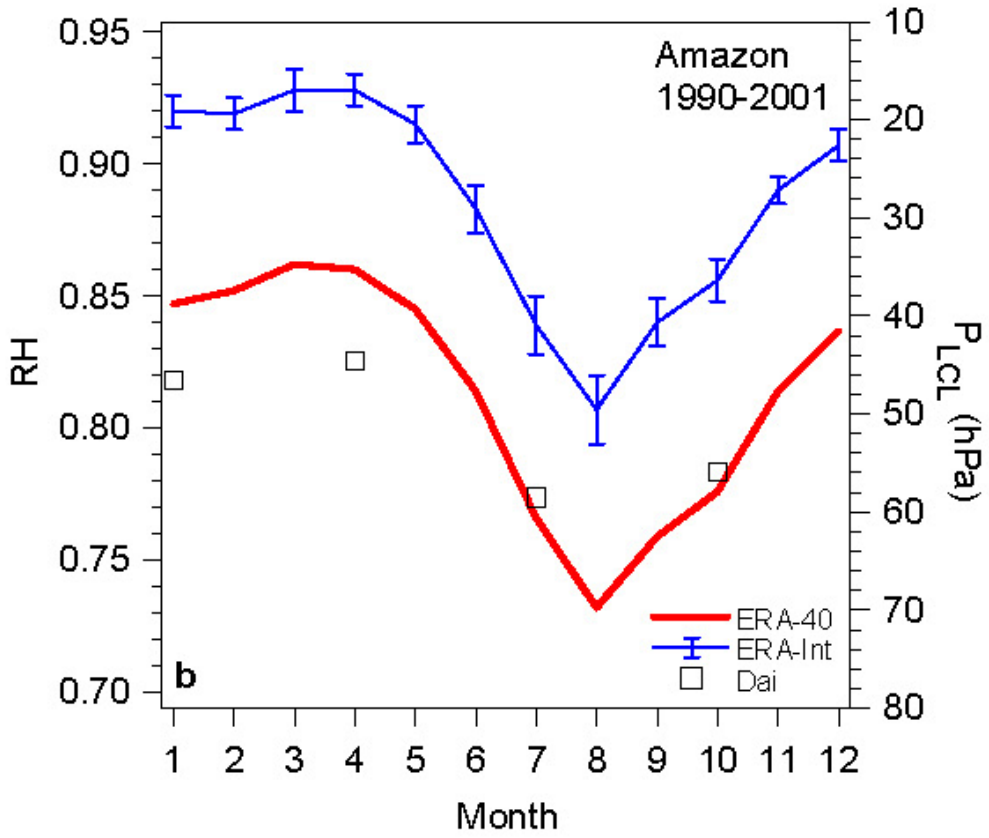
also: LaPlata

Evaluation on river basin scale, starting from **hourly archive**

Amazon: ERA-40 & ERA-Int

Annual T, RH and LCL





- Compared to ERA-40, ERA-Interim has
  - larger cold bias – *too much low cloud*
  - high bias of RH and low bias of cloud-base

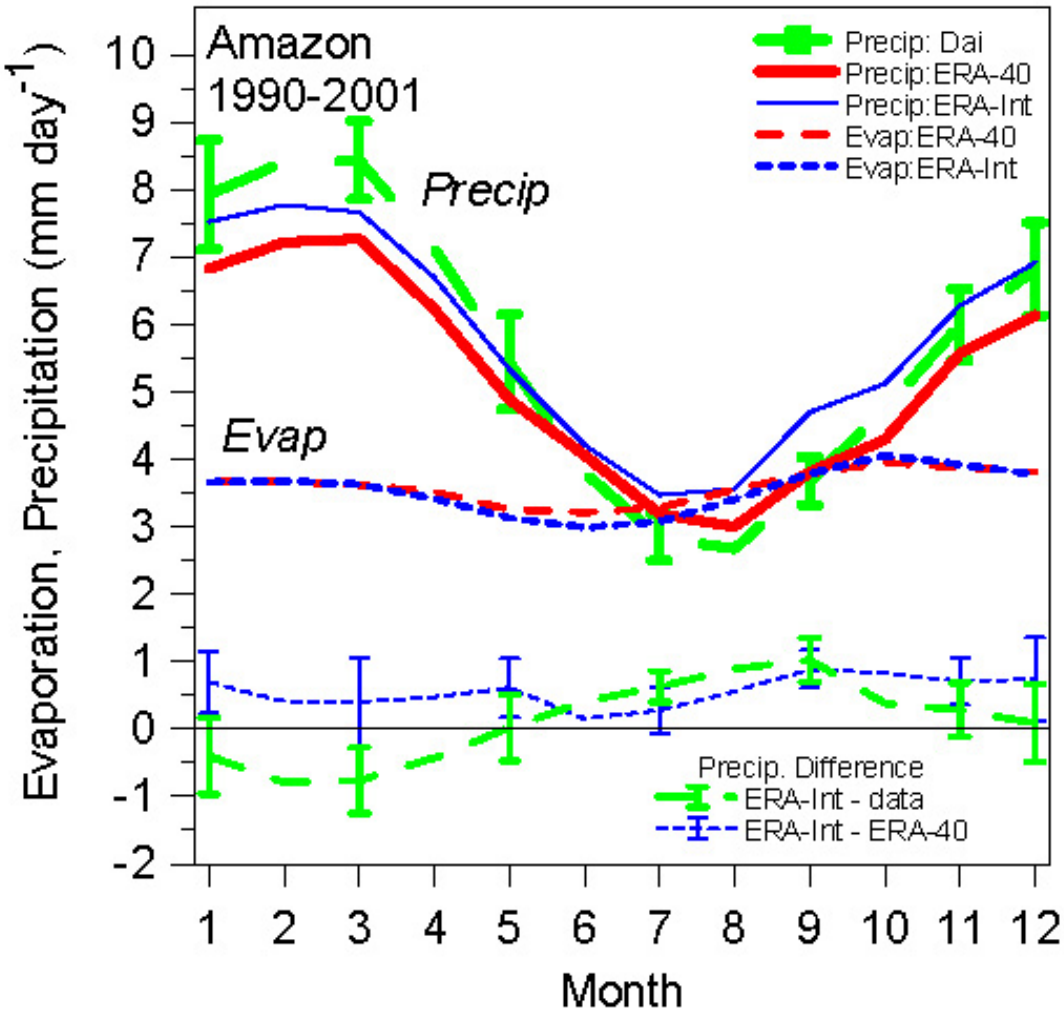
Amazon

Precipitation & Evaporation

Data

ERA-Int

ERA-40

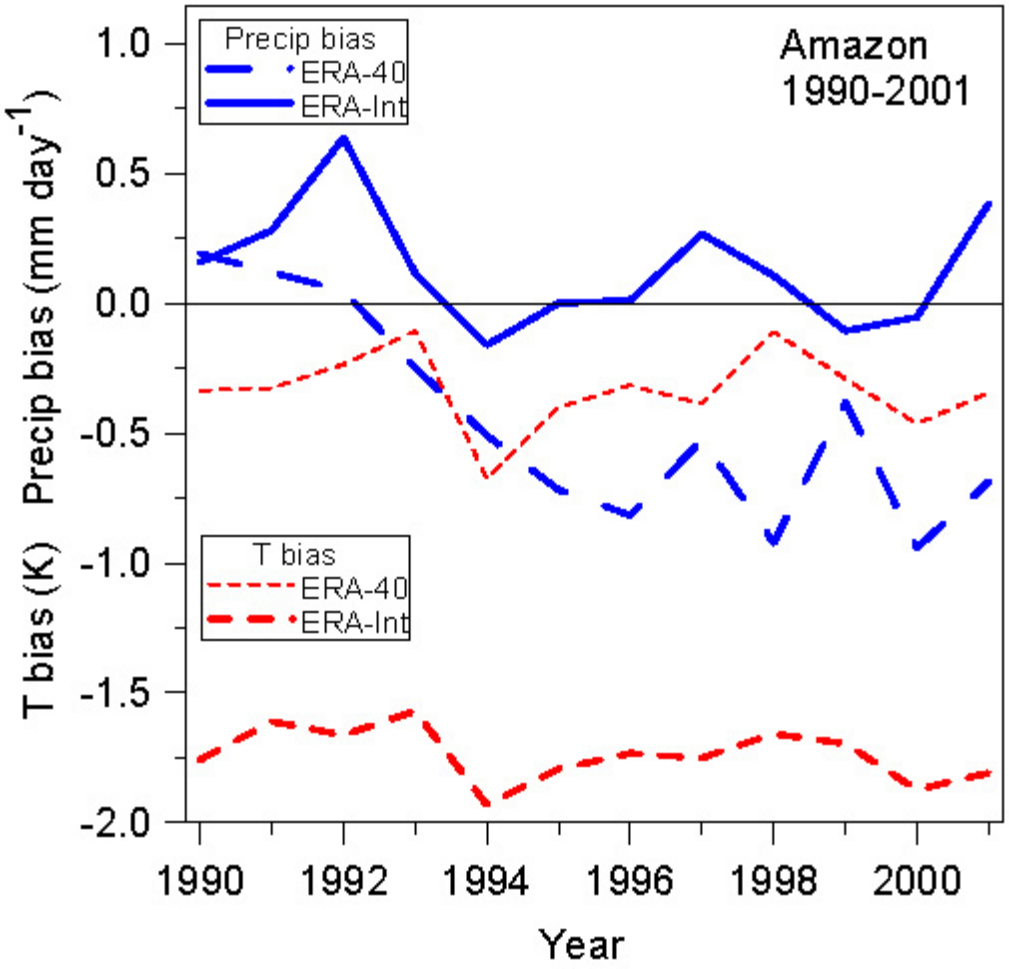


- ERA-Interim precipitation increased
- Seasonal amplitude remains too small

Annual biases

Precip

Temp



- Interannual drift of precipitation reduced
  - annual precipitation largely unbiased
  - *from improved humidity analysis* *[Uppala et al., 2008]*
- Cold temperature bias increased substantially

Clouds & Surface SW_{net}

$$SW_{net} = SW_{down} - SW_{up} = (1 - \alpha_{surf})(1 - \alpha_{cloud})\, SW_{down}(clear)$$

- *surface albedo*

$$\alpha_{surf} = SW_{up} / SW_{down}$$

- ***effective cloud albedo***

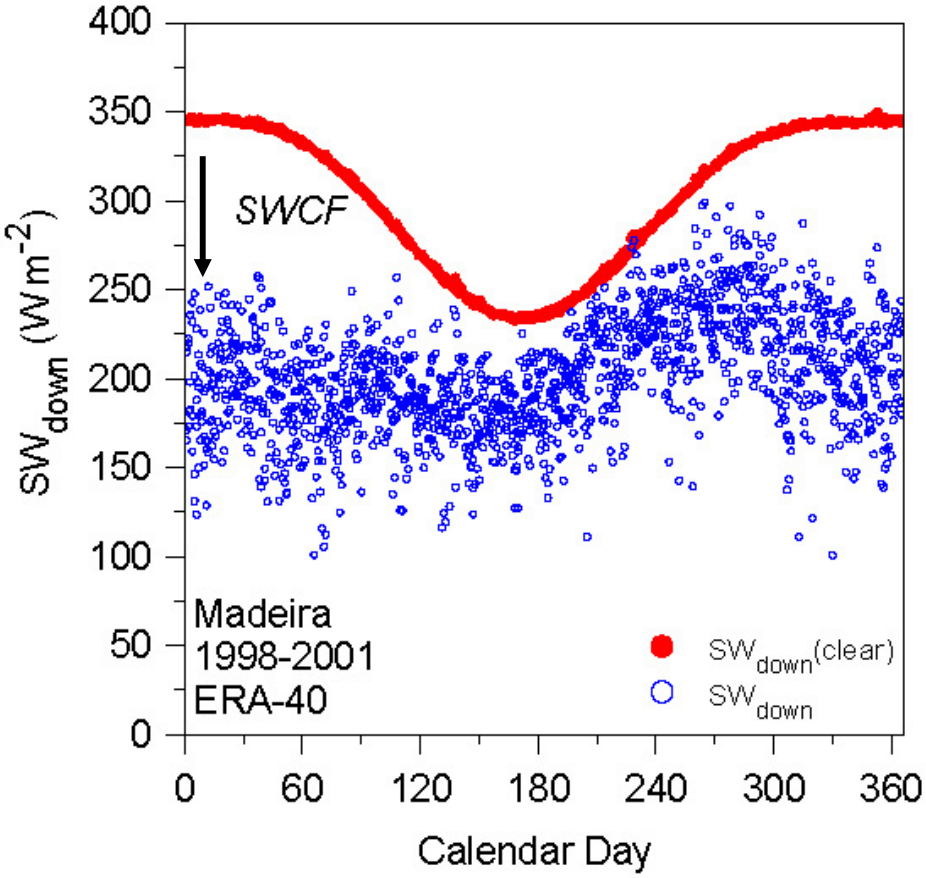
  - scaled surface **short-wave cloud forcing, SWCF**

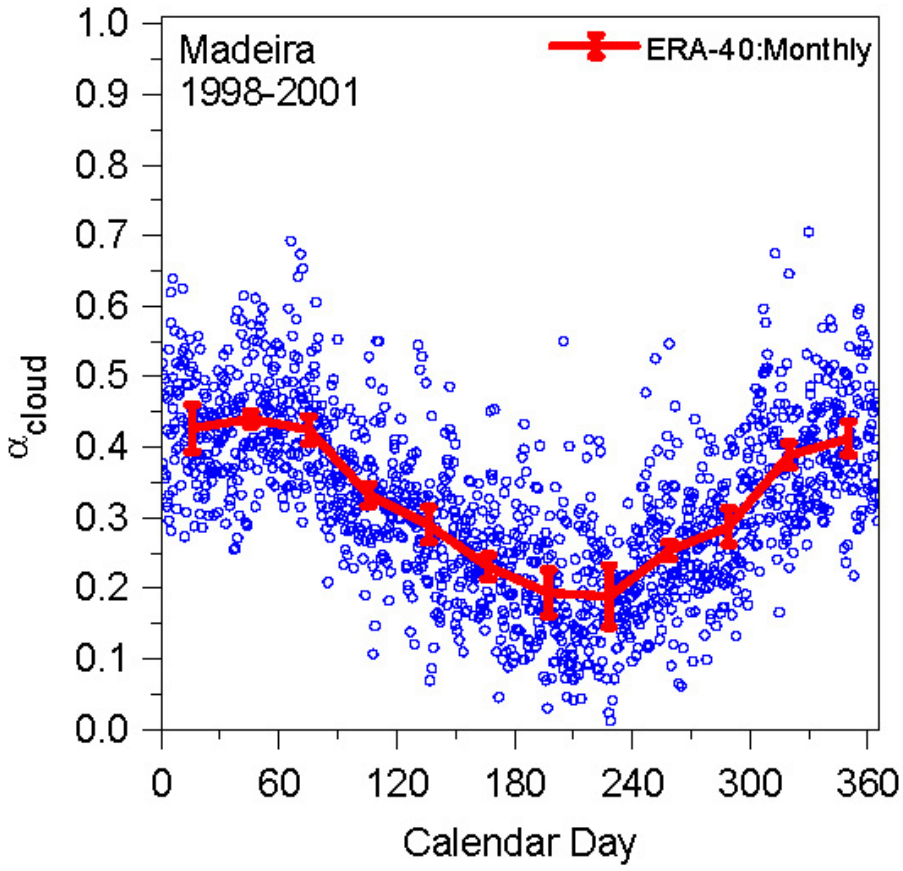
$$SWCF = SW_{down} - SW_{down}(clear)$$

$$\boldsymbol{\alpha_{cloud} = - SWCF / SW_{down}(clear)}$$

[Betts and Viterbo, 2005; Betts, 2007]

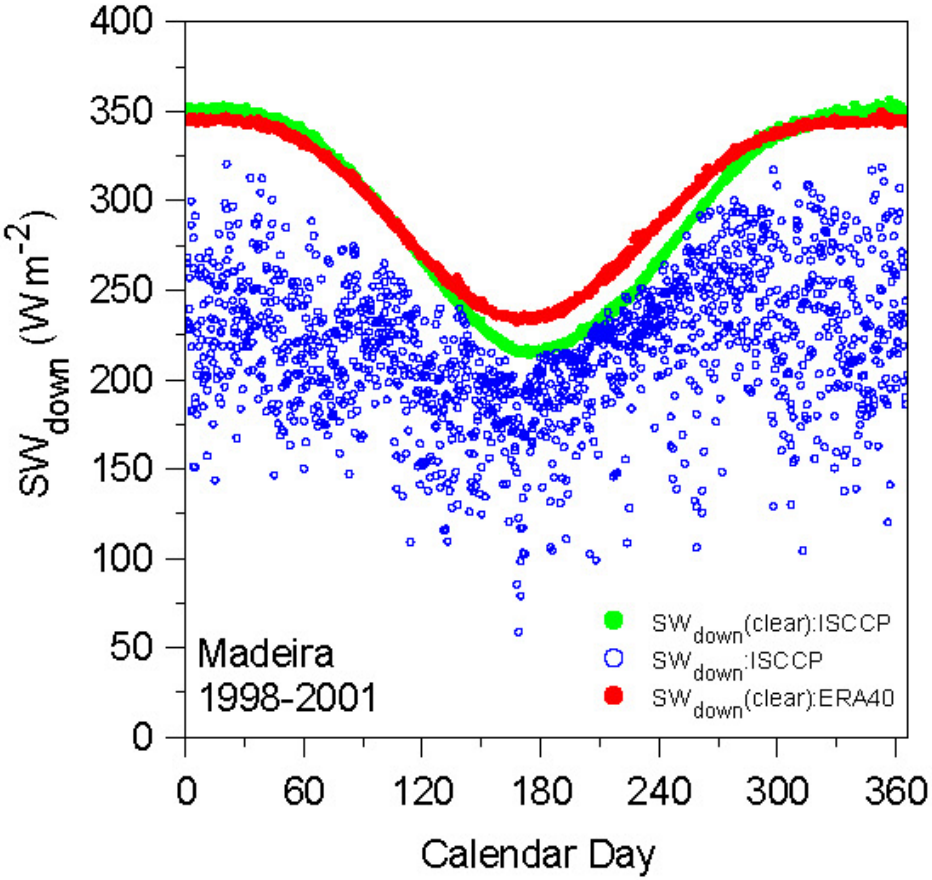
"Cloud albedo": *ERA-40 data*

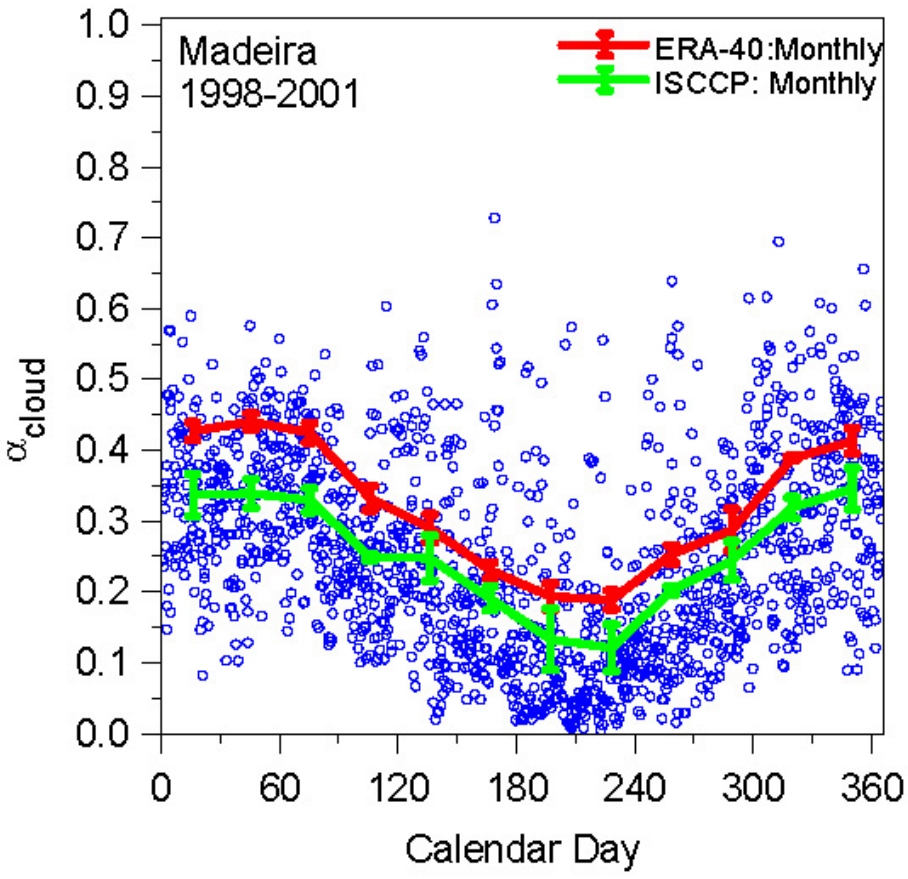




- Transformation: α_{cloud} = SWCF/ SW$_{down}$(clear)
- Seasonal cycle OK: small daily variability: Is it biased?

Cloud albedo: *ISCCP data*

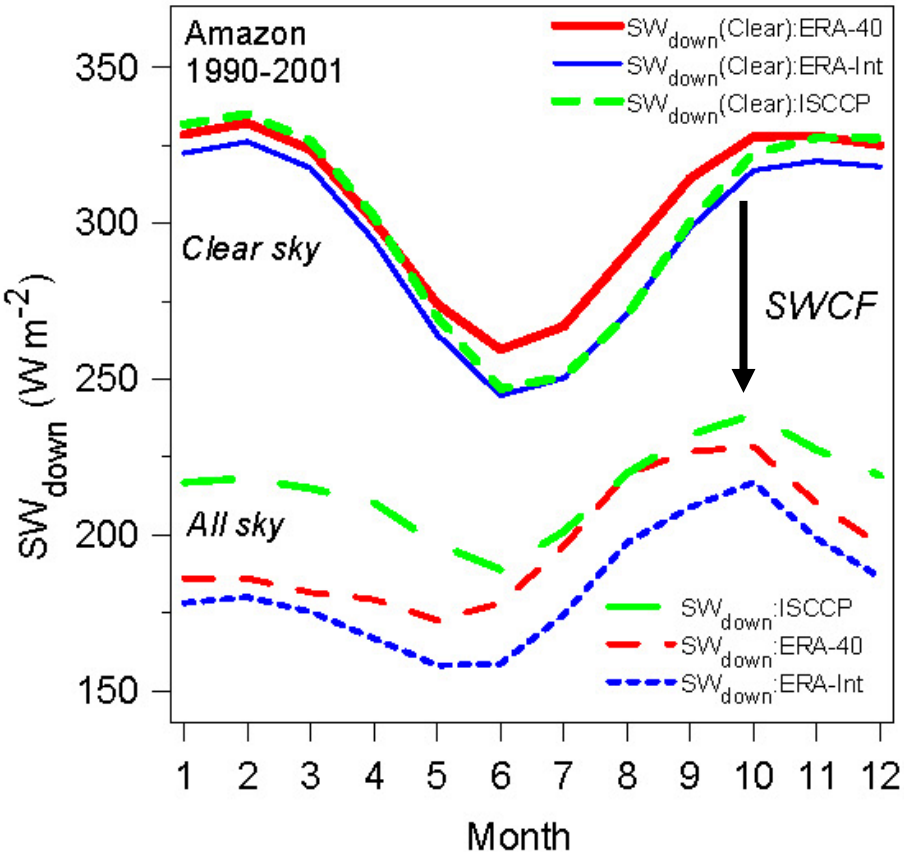




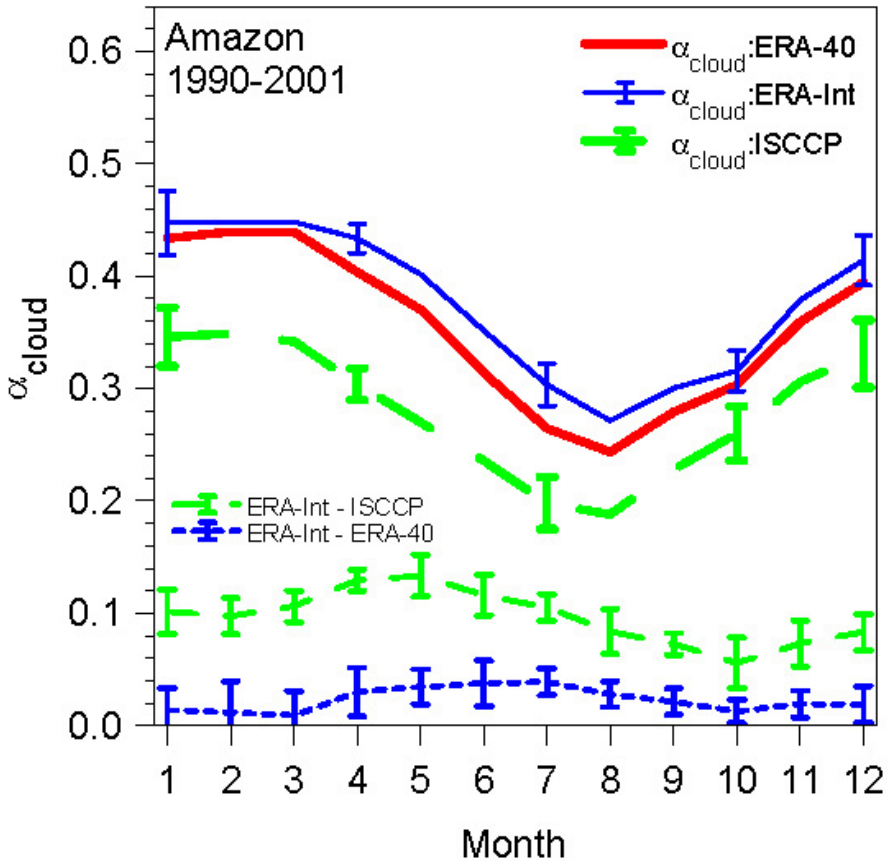
- Different clear-sky flux: Aerosol differences
- ERA-40 systematic high bias in α_{cloud} ≈ +7%
- ISCCP has more daily variability

Amazon – *Shortwave & α_{cloud}*

SW_{down}



Cloud albedo

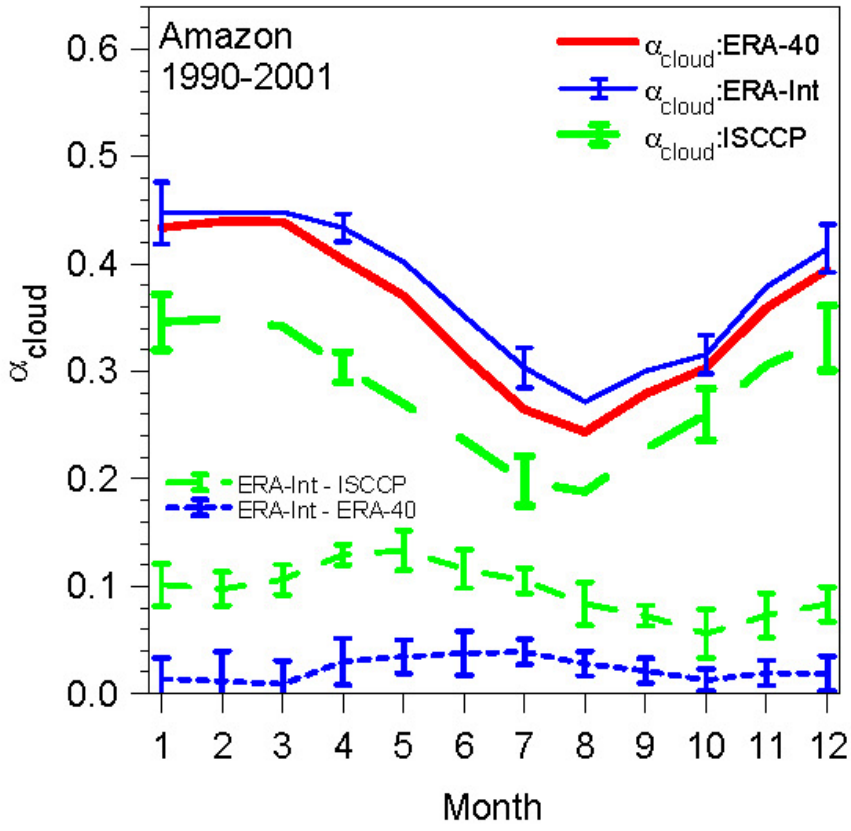


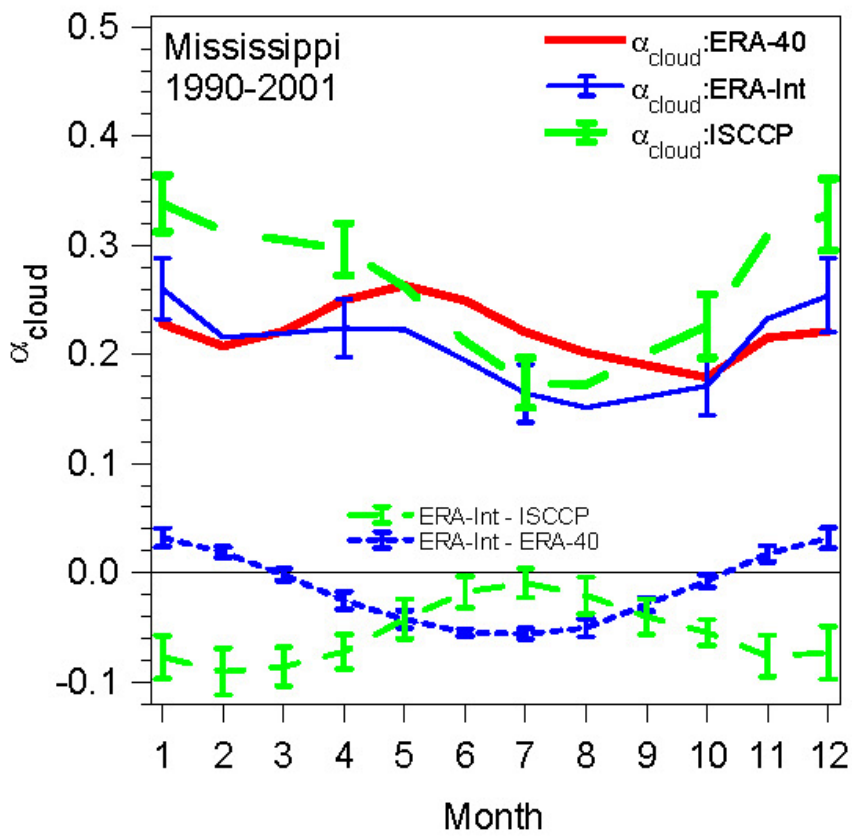
Clear-sky differences

All-sky differences are larger

ERA-Int > ERA-40 > ISCCP

Tropics *vs.* mid-latitudes





- Amazon: *reanalyses α_{cloud} biased high*
- Mississippi: *too little winter stratiform cloud*

ERA Conclusions

- **Tropics**
  - Amazon: interannual drift of precipitation reduced In ERA-Interim
  - Annual precipitation improved: seasonal amplitude of precipitation remains too small.
  - ERA-Interim has increased low cloud and large cold 2-m temperature bias [bias in SWCF is worse]
  - Diurnal cycle of precipitation better, but still rains too early in day

- **Mississippi** (& Mackenzie)
  - Temperature biases are small in both reanalyses
  - Summer precipitation and evaporation too high
  - ERA-Interim has less reflective cloud cover in summer and more in winter – an improvement
  - Spinup of precipitation in 24h forecasts greatly reduced in ERA-Int

- *[More recent model cycles have improved Amazon seasonal precipitation, and cloud cover]*

[Betts, A. K., M. Köhler and Y-C. Zhang, JGR, 2009]

IASCLIP (2005)

- Many, if not all, global climate models suffer from large errors in their ***simulations of precipitation*** in the IAS region. … *Only if a climate model represents well* ***convective and boundary-layer processes over both ocean and land*** *and reproduces well both local climate processes and global climate model variability, can it do well in the IAS region.* The IAS is, therefore, an ***ideal natural laboratory*** *to test the overall fidelity of climate models*.

- **Were it that easy! But it is what we have got!**

IASCLIP

- Focus on water: from oceans to precipitation [to runoff]
- The winds & jets that carry the water
- The coupling between land & ocean
- The recycling of water over land

- **OK, but what is missing?**
- **Challenge to write documents in terms of the known to study the unknown!**
- **Complex fully interactive system**

Modeling Working Group for VAMOS: 2008 questions

A) Simulating, Understanding and Predicting the Diurnal Cycle

B) Predicting the Pan-American Monsoon Onset, Mature and Demise Stages

C) Modeling and Predicting SST Variability in the Pan-American Seas

D) Improving the Prediction of Droughts and Floods

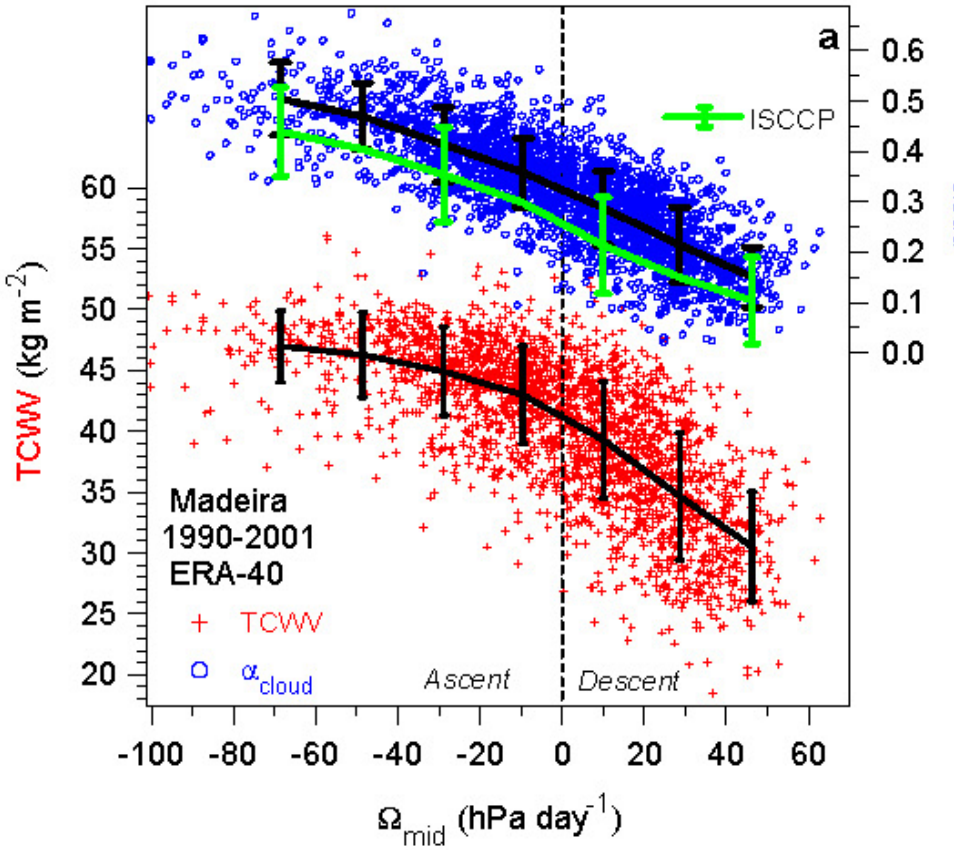
Diabatic heating main source of model errors

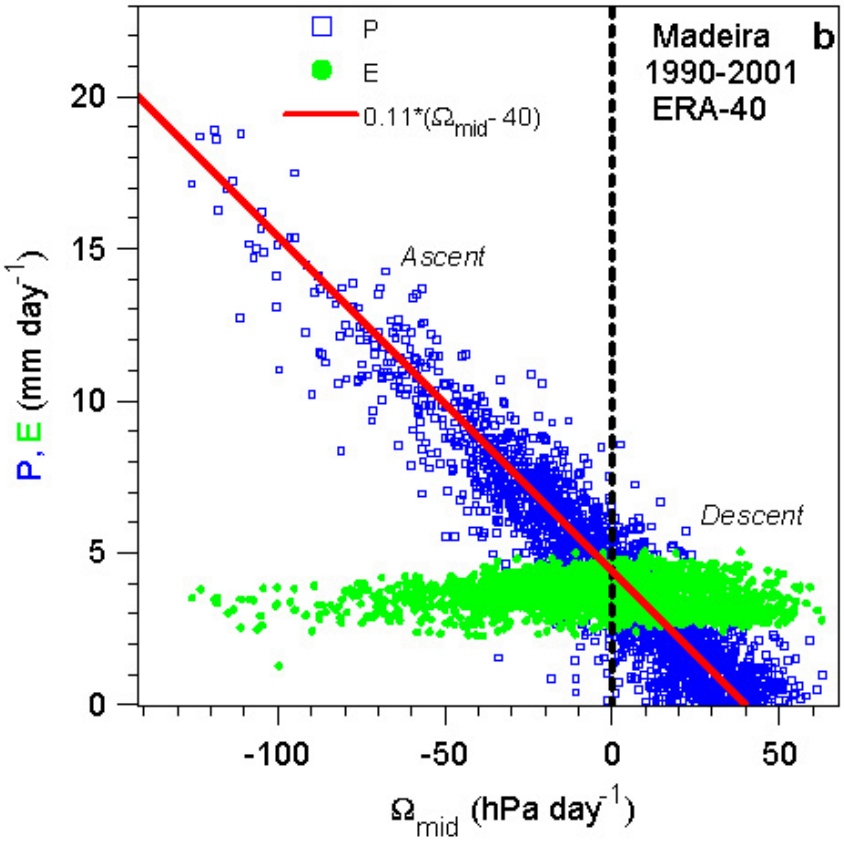
Model Errors

- **Two diabatic** sources related to clouds that are problematic but ***measurable***
- Precipitation & cloud radiative forcing:
  in atmosphere & at surface
- Oceanography sees role of surface SWCF to the WHWP
- Discussion of land-surface SWCF role is ***"missing"***

- ***Just as important over land as over the ocean & fundamental to ocean-land circulation***
  – Monsoon!

Precipitation and cloud coupling to vertical motion *in ERA-40 reanalysis*





- Partition of *moisture convergence* into TCWV, α_{cloud}, and precipitation

[Betts & Viterbo JGR 2005]

- **High bias of α_{cloud} from ISCCP; while precip. generally low**

Comparable additive errors

- Error in the partition of atmospheric water
  [too much cloud and too little precipitation]
  leads to two *'additive'* diabatic errors
  of comparable magnitude

  +10% in cloud albedo ⟶ -25 W m^{-2} [surface]

  -1mm/day in precip ⟶ -30 W m^{-2} [atmos]

Critical diagnostics:

SWCF & Precip. forcing errors

[Betts, 2007; Betts et al. 2009]

IASCLIP/MESA

- *The land surface has an important role in the flow of the region, via both thermal effects (such as surface temperature, dependent on possibly-predictable soil moisture) and mechanical effects (i.e. orographic and frictional).*

- ***OK, but where is the coupling between CO_2 , water fluxes and BL clouds?***

Land-ocean change with ACC

- *"Climate model simulations of doubled CO_2 conditions also suggest an enhancement in the tropical ocean evaporation"* *[VAMOS NL#5]*
- Over land *reduction in transpiration* is likely as *water loss/CO_2 uptake* falls in 2X CO_2
- **Fundamental asymmetry**

  → **greater warming over land**

  → **circulation changes**

Idealized Land-BL model: ACC scenarios

Double CO_2

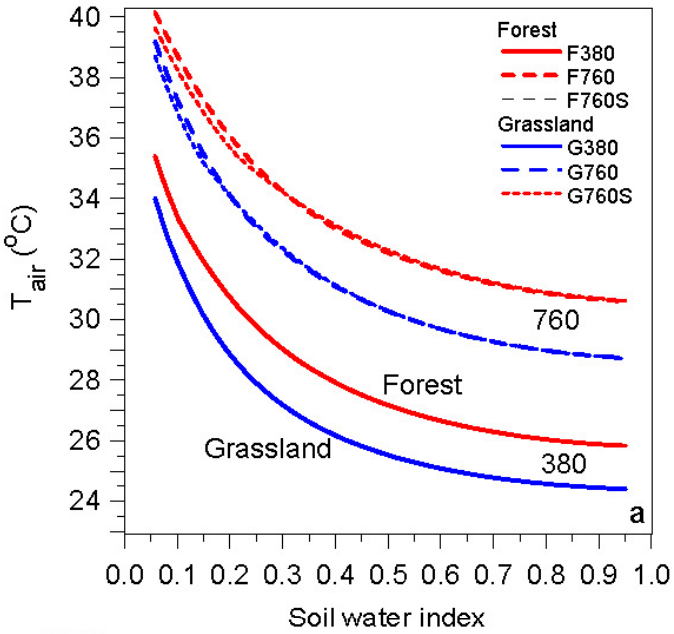
ΔSST= +2K

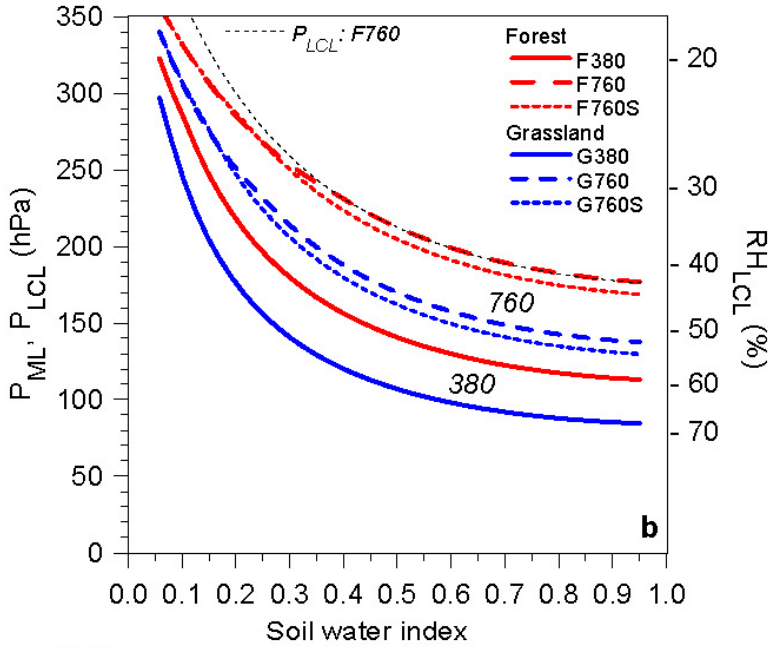
[transpiration from vegetation falls]

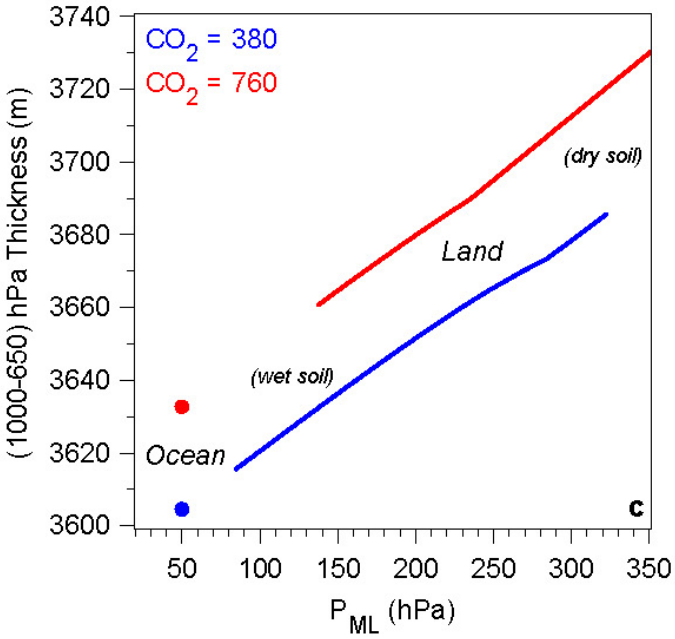
ML gets warmer (5K)

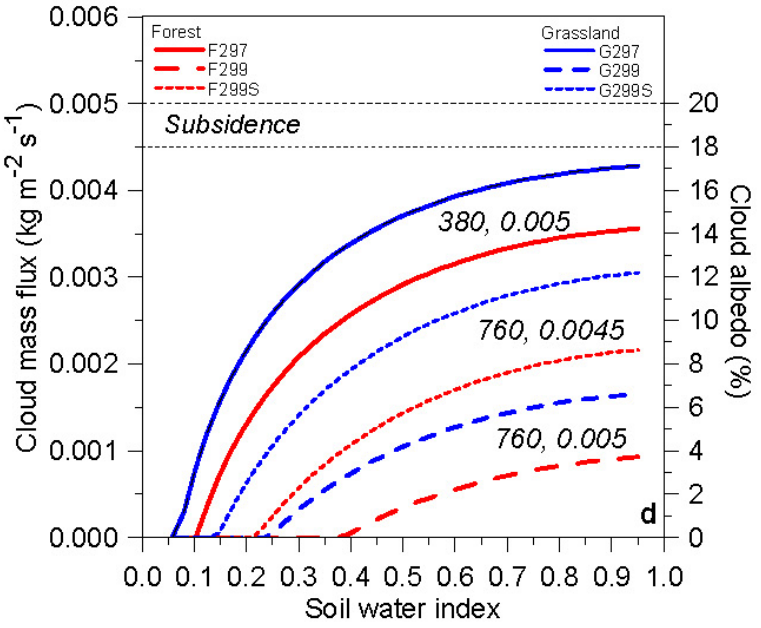
Deeper (60hPa)

BL cloud falls 5 -11%









Betts et al. JGR 2004; Betts (2009)

Conclusions

- VAMOS: ambitious plan for a **complex system**

- In the traditional forest of details, remember that model errors in the tropics come mostly from errors in the **diabatic forcing** and these are mostly from errors in modeling clouds.
- The **cloud radiative forcing errors are as important** to the system as the **precipitation errors** and matter over land as well as the ocean – on all timescales.
- Rising CO_2 **shifts the land-ocean equilibrium** because the evaporation response is asymmetric

References

- Betts, A. K and P. Viterbo, 2005: Land-surface, boundary layer and cloud-field coupling over the south-western Amazon in ERA-40. *J. Geophys. Res*., **110**, D14108, doi:10.1029/2004JD005702.
- Betts, A. K. (2007), Coupling of water vapor convergence, clouds, precipitation, and land-surface processes, *J. Geophys. Res., 112*, D10108, doi:10.1029/2006JD008191.
- Betts, A. K., M. Köhler, and Y. Zhang (2009), Comparison of river basin hydrometeorology in ERA-Interim and ERA-40 reanalyses with observations, *J. Geophys. Res., 114*, D02101, doi:10.1029/2008JD010761.
- Betts, A. K. (2009), Land-surface-atmosphere coupling in observations and models. JAMES, in press. http://adv-model-earth-syst.org/index.php/JAMES/article/view/10/18

- Betts, A. K., B. Helliker and J. Berry, 2004, Coupling between CO2, water vapor, temperature and radon and their fluxes in an idealized equilibrium boundary layer over land. *J. Geophys. Res*., 109, D18103, doi:10.1029/2003JD004420.
- [Betts, A. K. (2009), Idealized model for changes in boundary layer cloud over land in a doubled CO_2 climate. In Preparation.]