Progress in understanding land-surface-atmosphere coupling over the Amazon

Alan Keith Betts, Atmospheric Research,
akbetts@aol.com

Maria Assuncao Silva Dias, CPTEC,
assuncao@cptec.inpe.br

Amazon in Perspective: Integrated Science for a Sustainable Future

Manaus, November 18, 2008

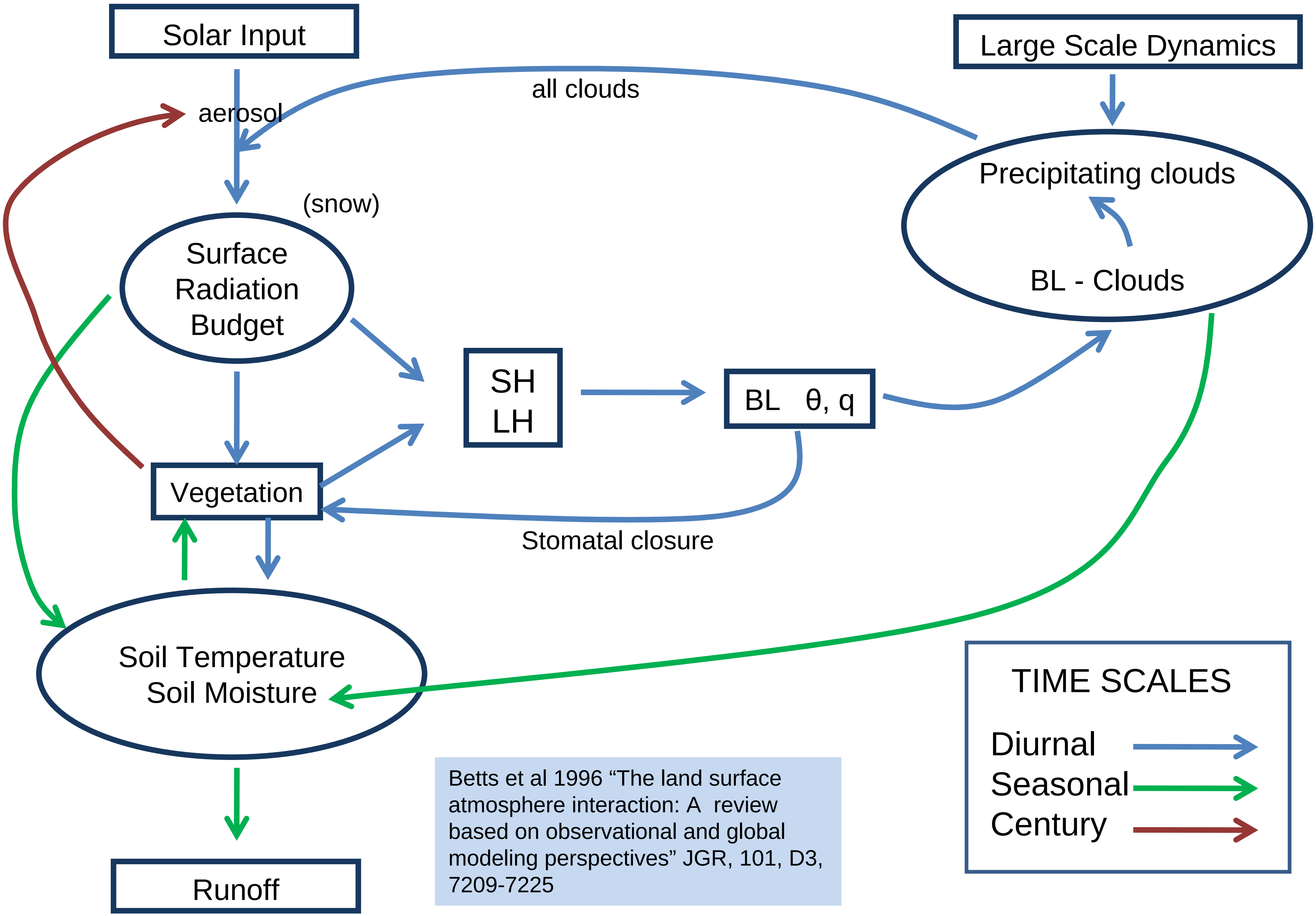
Ten year perspective from LBA

- **Many coupled processes**
- Shortwave and longwave fluxes: clouds

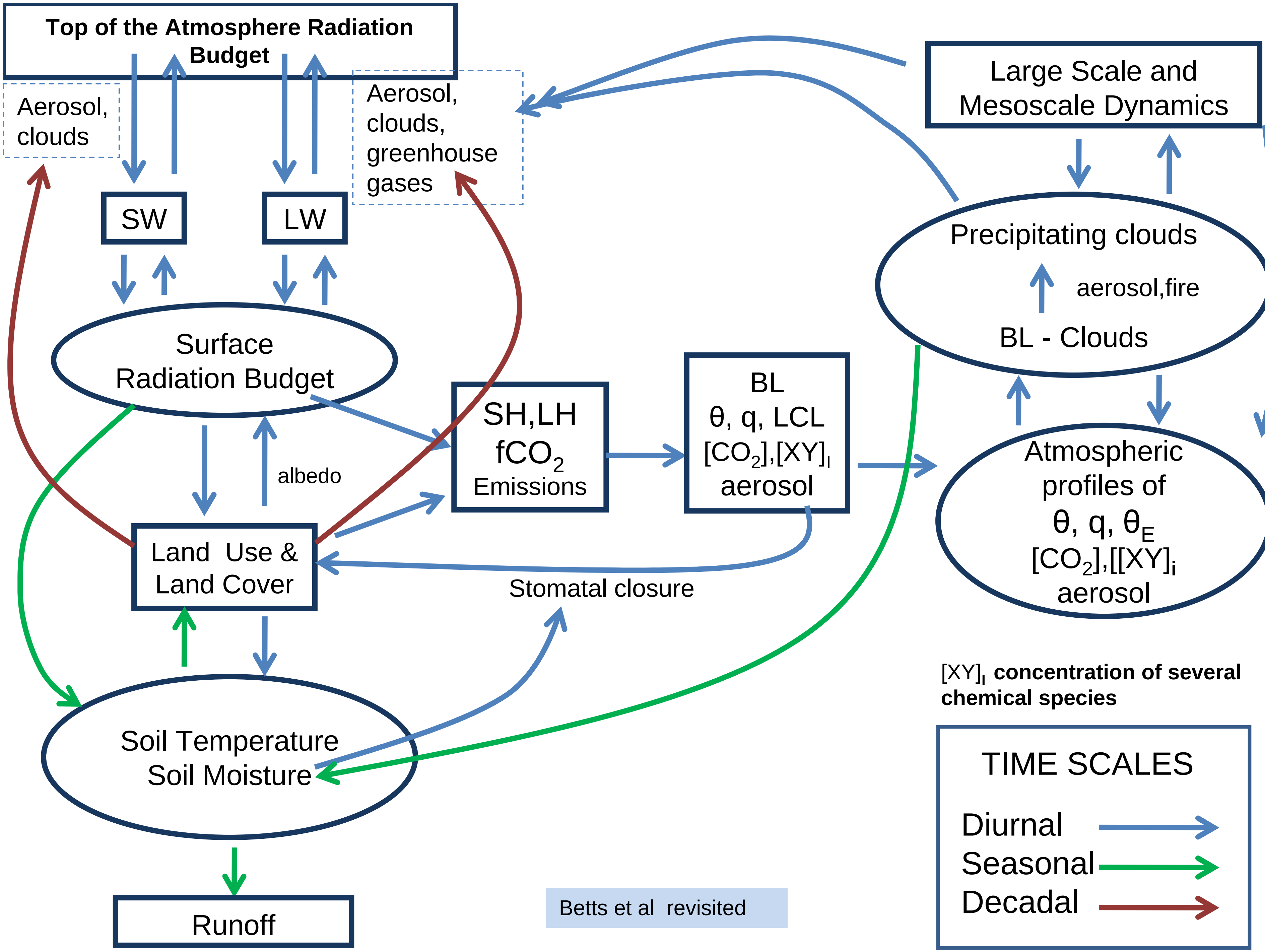
  - Coupling of LW_{net} to diurnal temperature range
- Aerosols

  - role of fires in vertical transport

  - cloud microphysics & precipitation
- Partition of moisture convergence into column water vapor, cloud & precipitation
- Surface-cloud-boundary layer coupling



Betts et al 1996 “The land surface atmosphere interaction: A review based on observational and global modeling perspectives” JGR, 101, D3, 7209-7225



Top of the Atmosphere Radiation Budget
Aerosol, clouds
Aerosol, clouds, greenhouse gases
Large Scale and Mesoscale Dynamics
SW
LW
Precipitating clouds
aerosol,fire
BL - Clouds
Surface Radiation Budget
SH,LH
fCO2
Emissions
BL
θ, q, LCL
[CO2],[XY]i
aerosol
Atmospheric profiles of
θ, q, θE
[CO2],[[XY]i
aerosol
albedo
Land Use & Land Cover
Stomatal closure
[XY]i concentration of several chemical species
Soil Temperature
Soil Moisture
TIME SCALES
Diurnal
Seasonal
Decadal
Runoff
Betts et al revisited

Surface Energy Balance

$$R_{net} = SW_{net} + LW_{net} = H + \lambda E + G$$

- the split between surface processes and atmospheric processes
- the split between SW and LW processes
- the partition between clear-sky, aerosol and cloud processes in the atmosphere
- the partition of the surface R_{net} into H and λE
  - controlled by the availability of water for evaporation and by vegetation

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

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

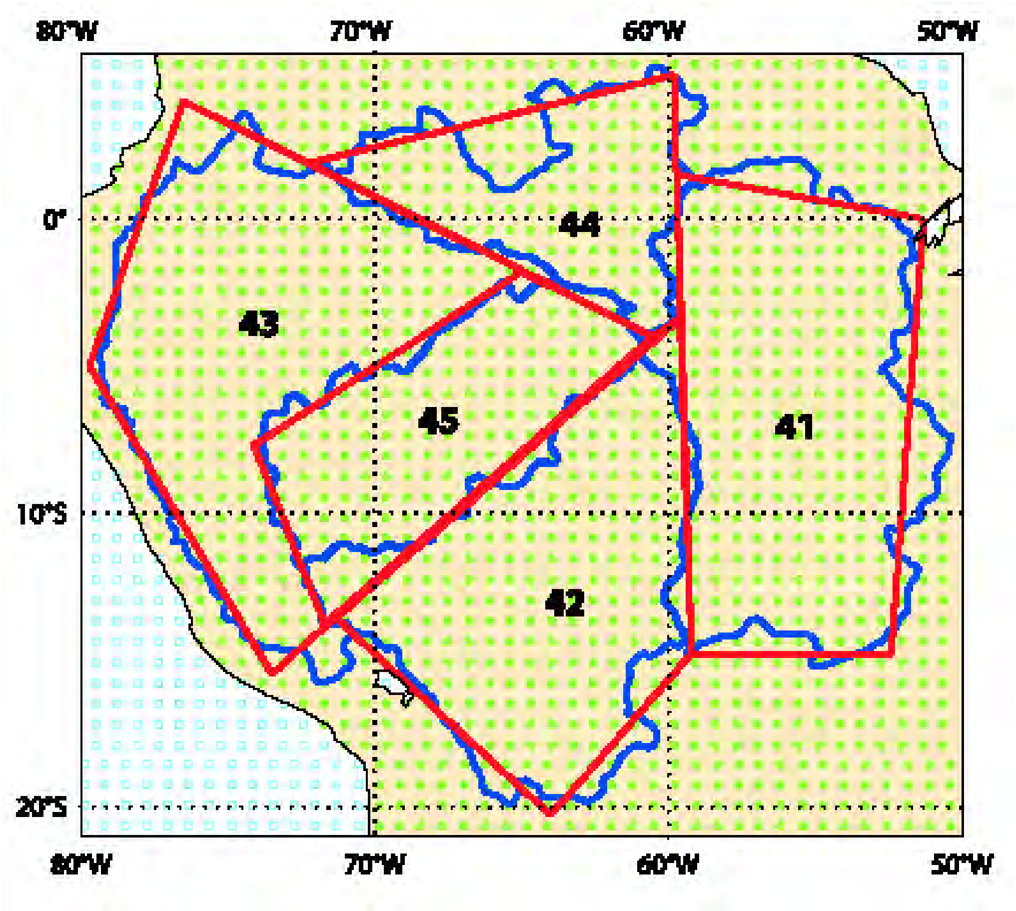
where

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

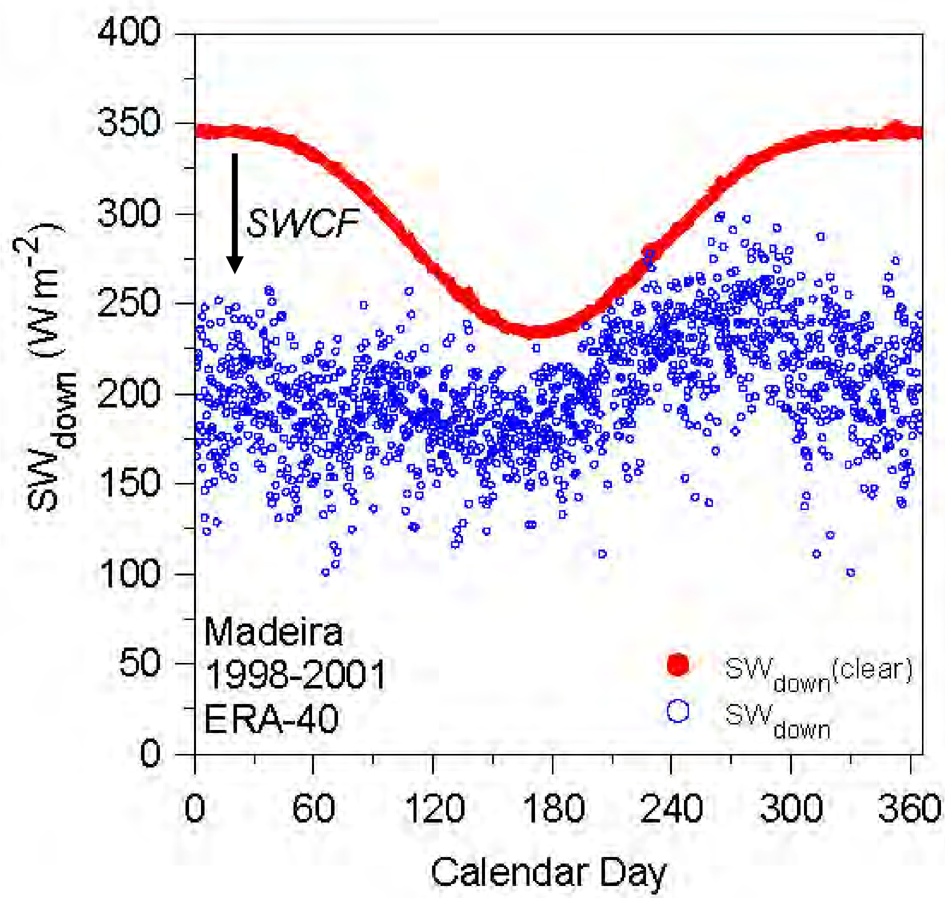
[Betts and Viterbo, 2005; Betts, 2007]

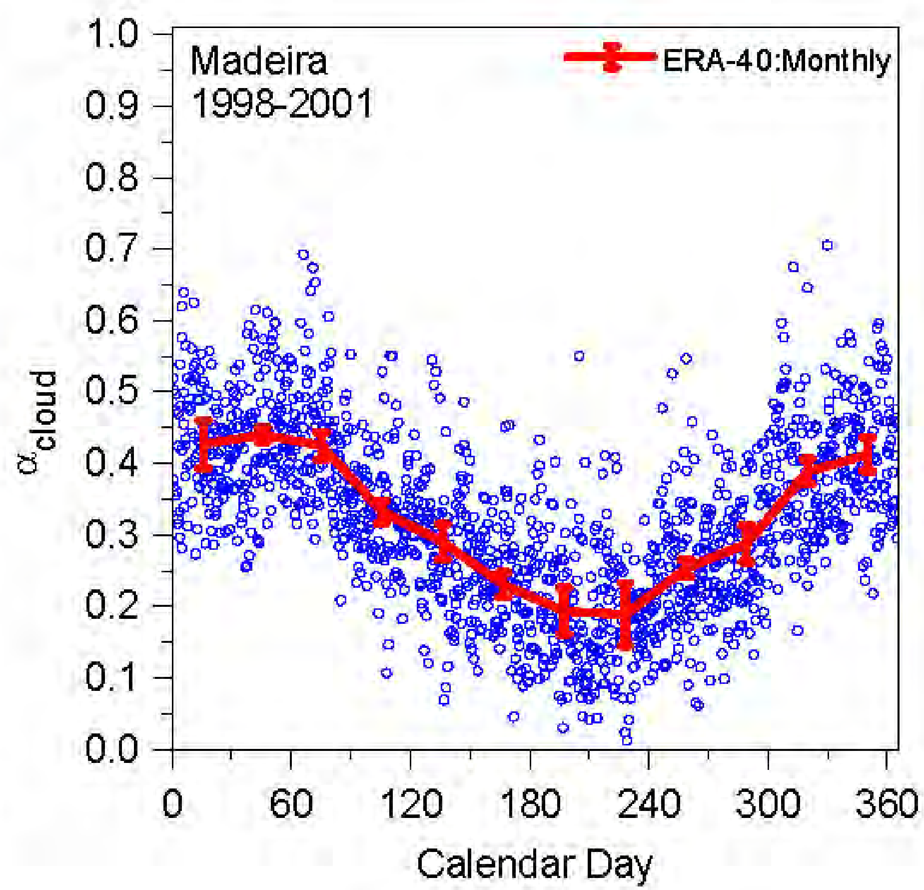
Amazon sub-basins

- 41: Tapajos, Xingu..
- 42: Madeira
- 43: Amazonas
- 44: Negro
- 45: Purus, Jurua…



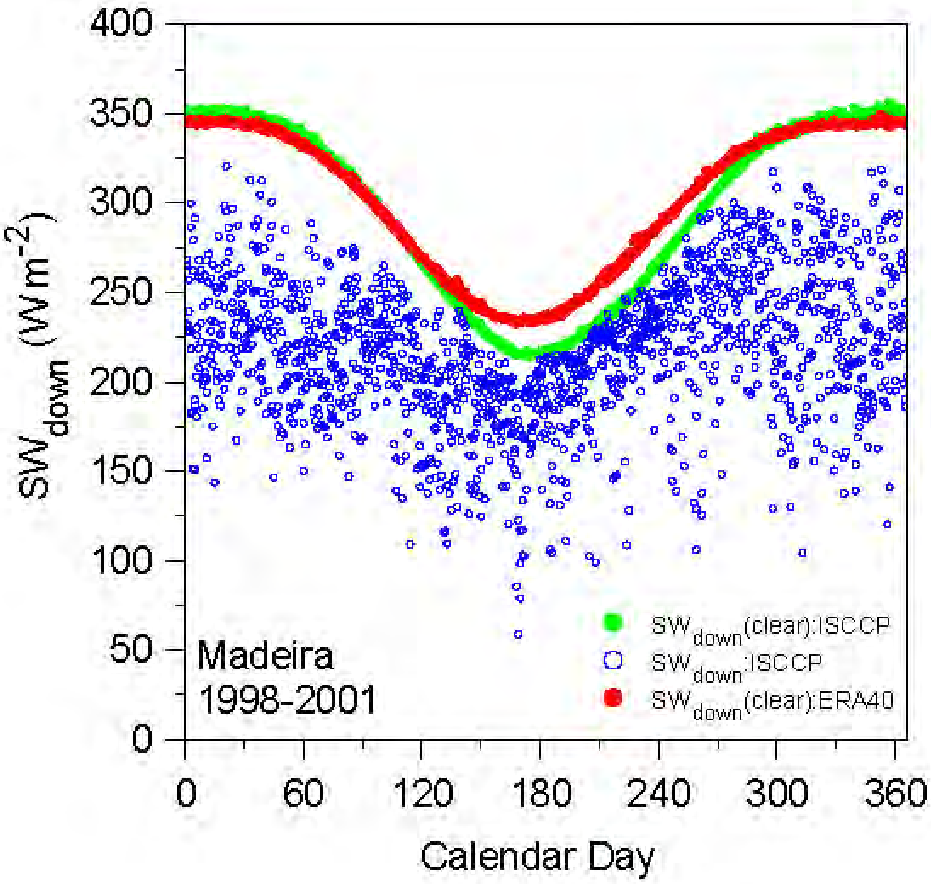
Cloud albedo: ERA-40 data

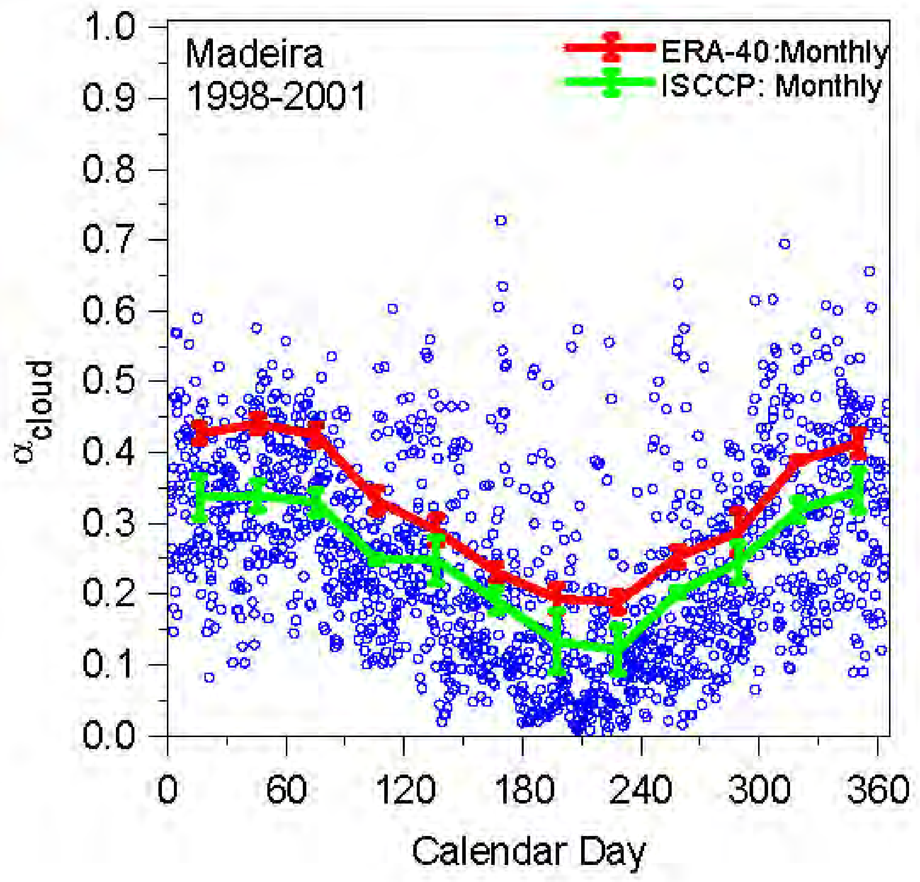




- Transformation of SWCF to α_{cloud}
- Seasonal cycle OK: small daily variability: biased???

Cloud albedo: ISCCP data

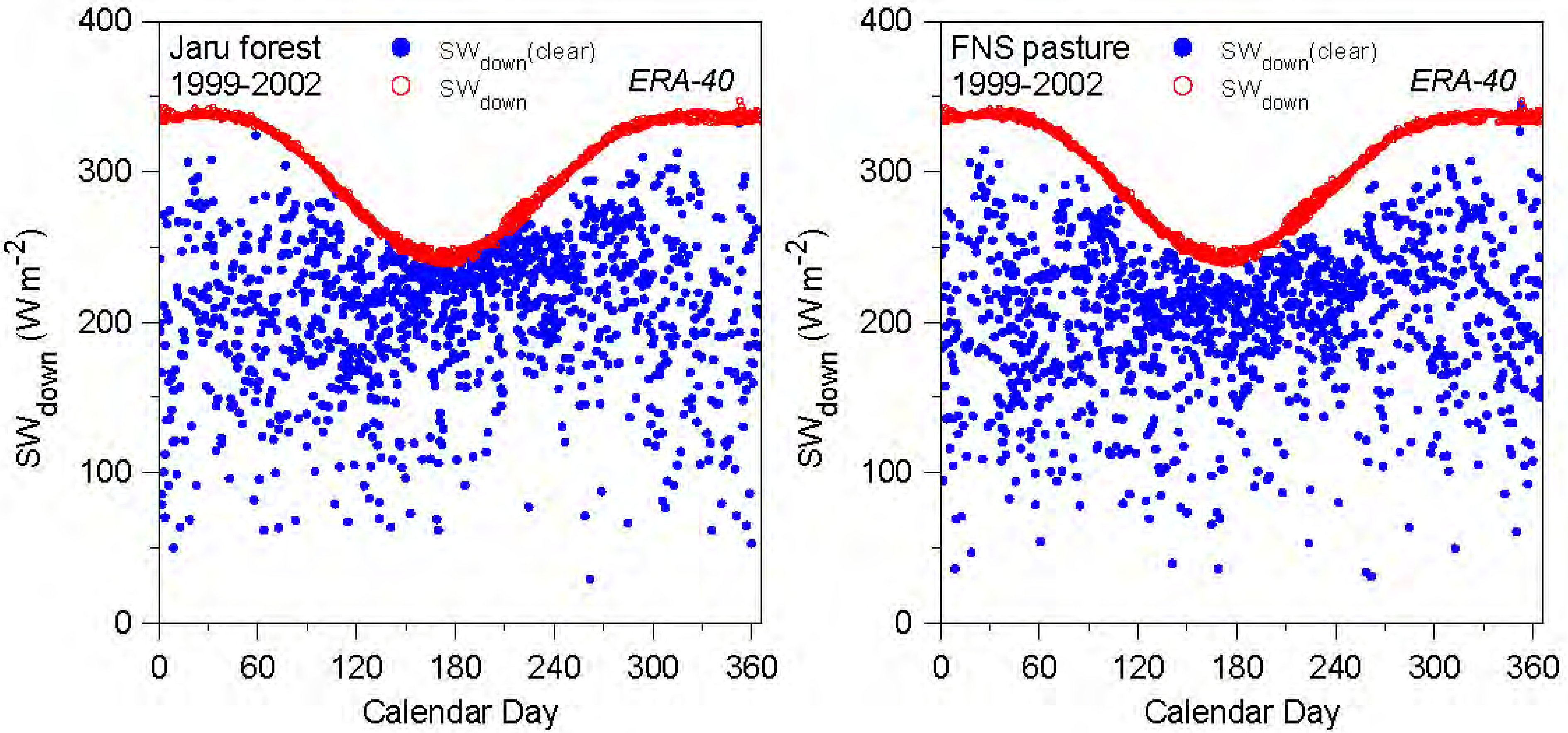




- Different clear-sky flux: Aerosol differences
- ERA-40 systematic high bias in α_{cloud} $\approx +7\%$
- ISCCP has more daily variability

Rondonia forest & pasture : SWCF

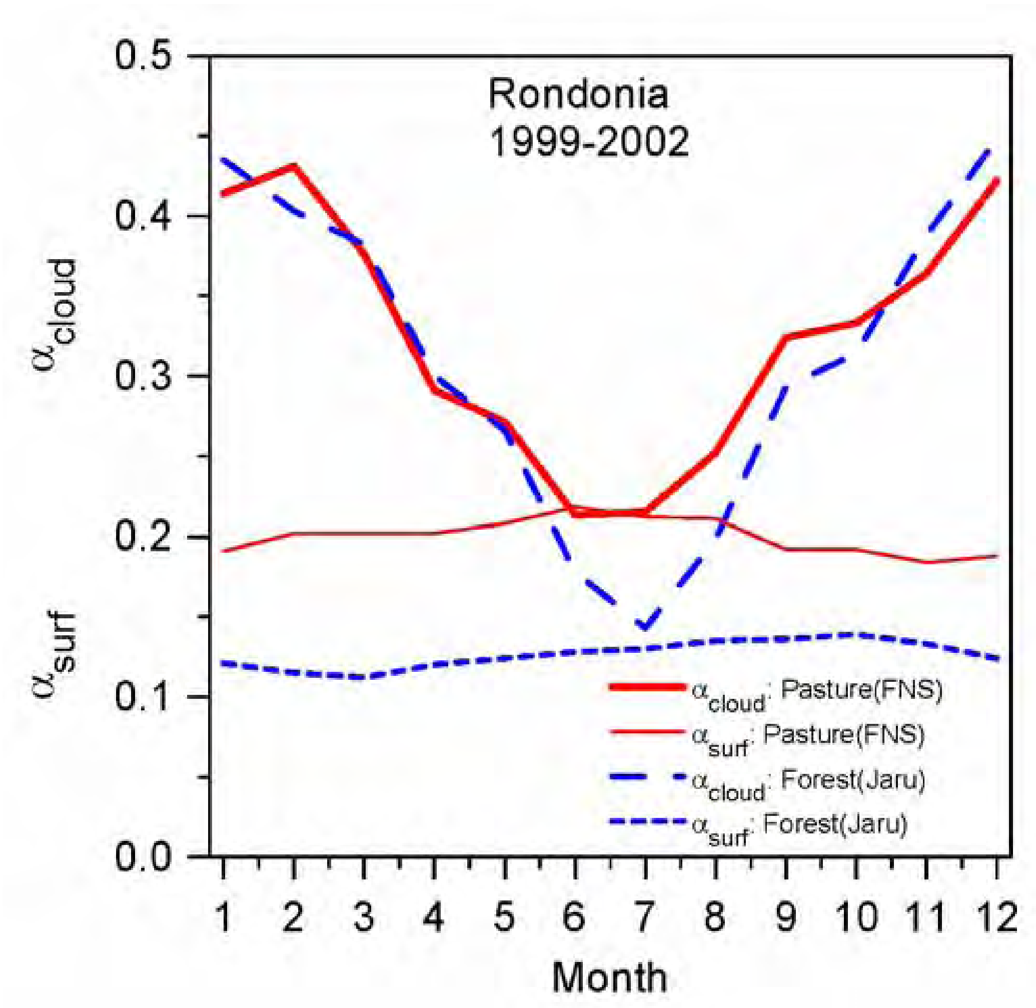
[data: von Randow et al 2004]



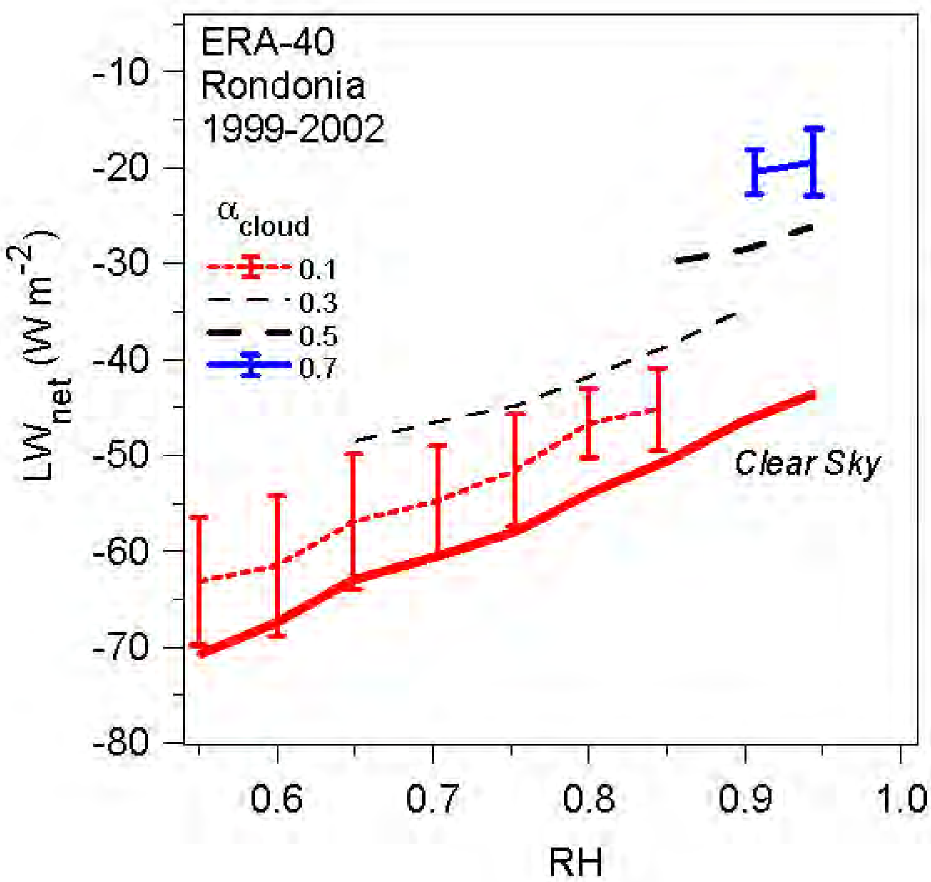
- More dry season cloud over pasture
- Aerosol ‘gap’ in September burning season

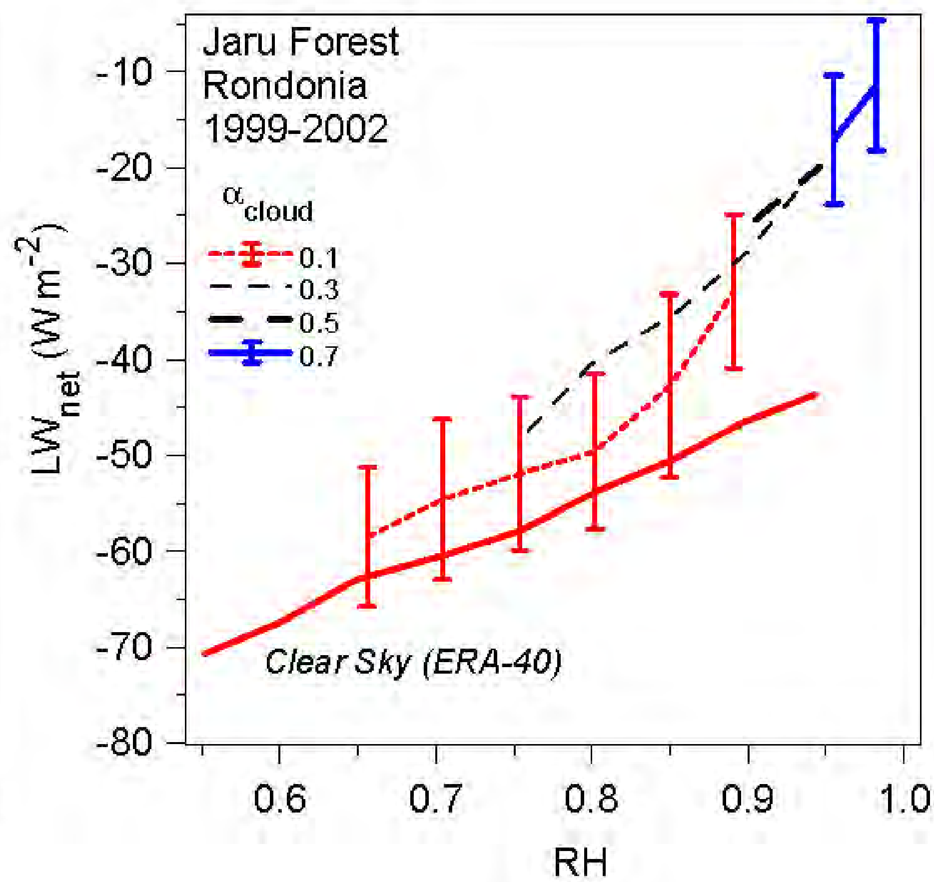
Energy balance: forest and pasture

- In July, pasture has 8% higher surface albedo and 7% more cloud
- Pasture LW_{net} is greater (surface warmer, BL drier)
- Pasture $R_{net} \approx 15\%$ less than forest



LW_{net} - RH - cloud coupling

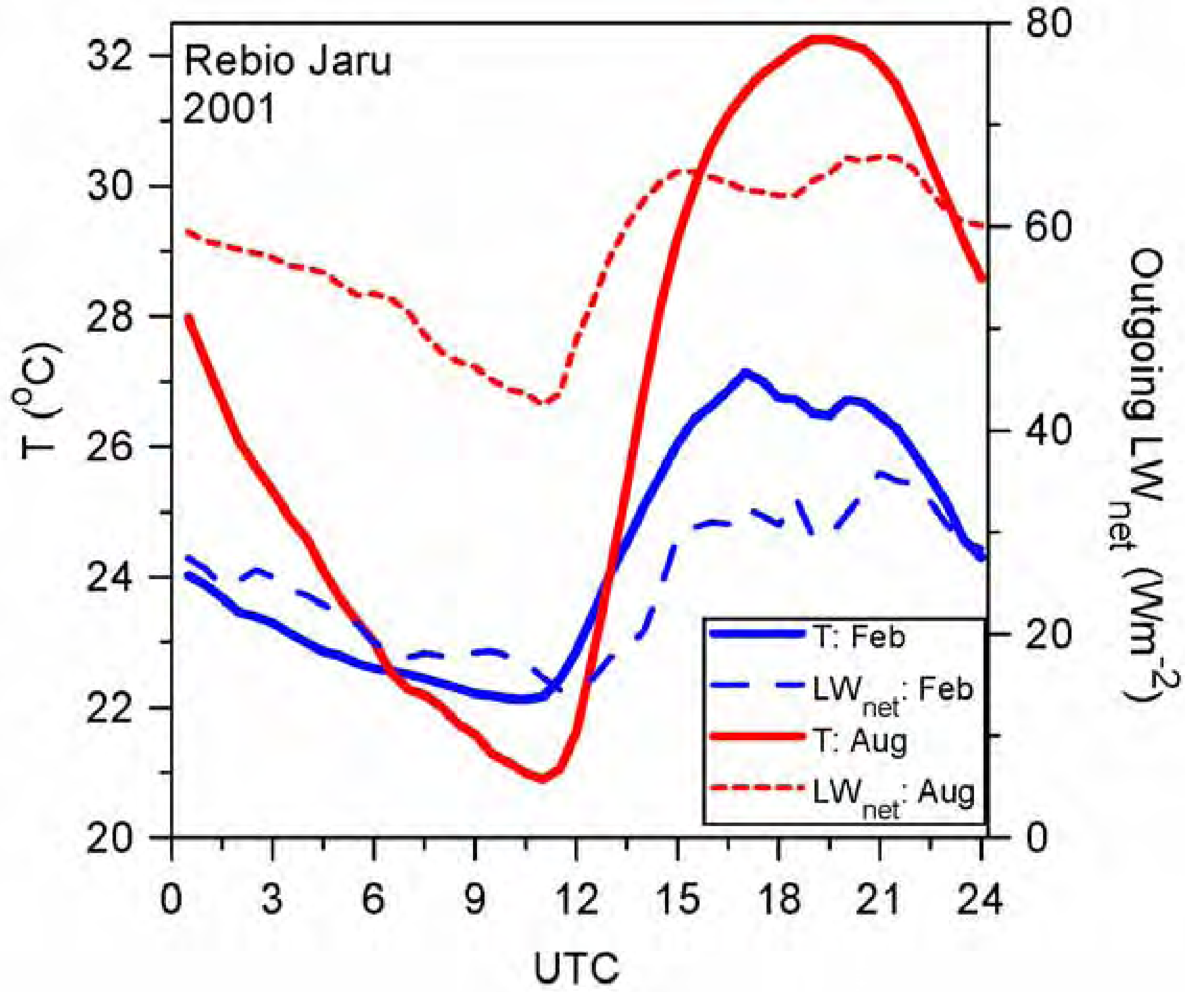




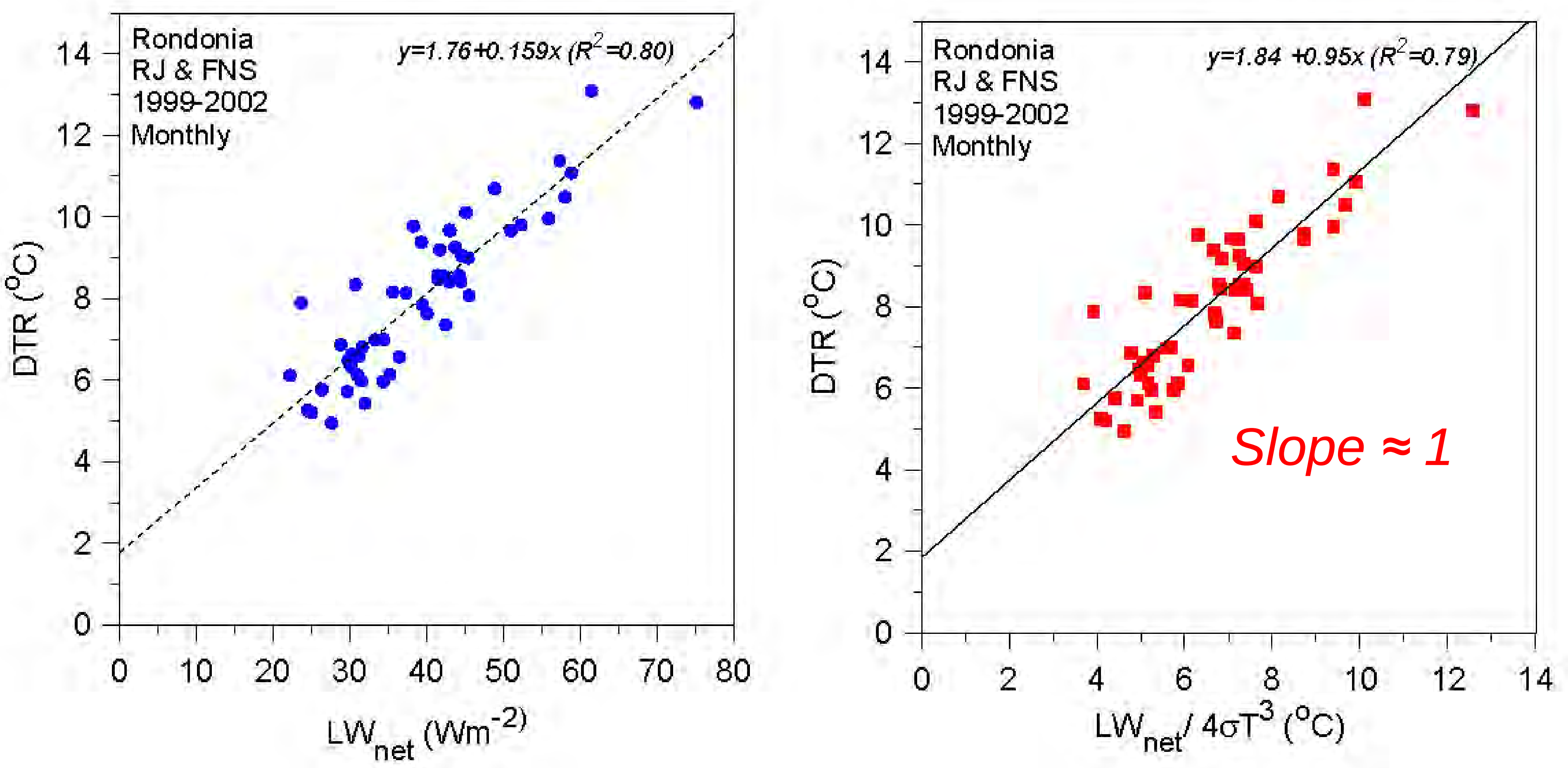
- Point comparison: ERA40 and Jaru tower
- Humidity and cloud greenhouse effects

LW_{net} and diurnal T range (DTR)

- Rainy season
  DTR and LW_{net} small
- Dry season
  DTR and LW_{net} large



LW_{net} and DTR – monthly mean data



- Mean LW_{net} and DTR correlated *[Betts: JGR, 2006]*

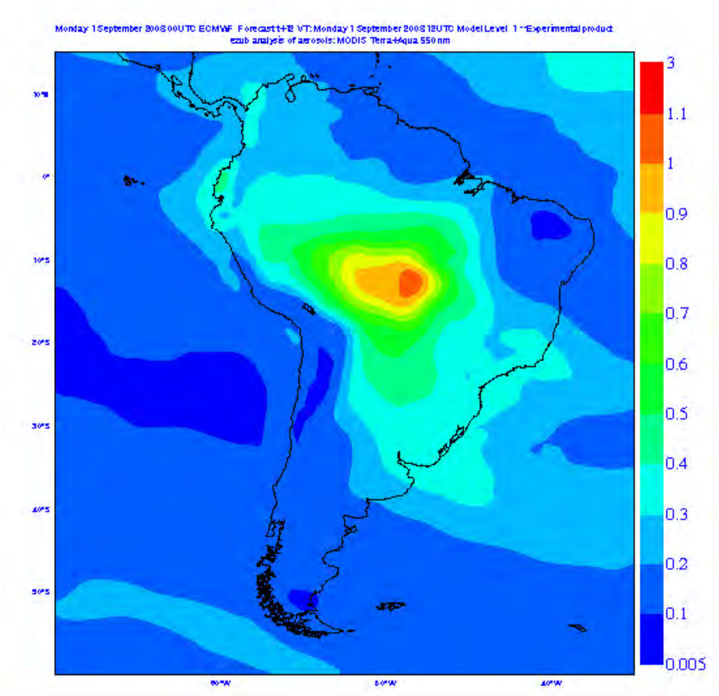
Aerosol-biomass burning issues

- role of fires in vertical transport

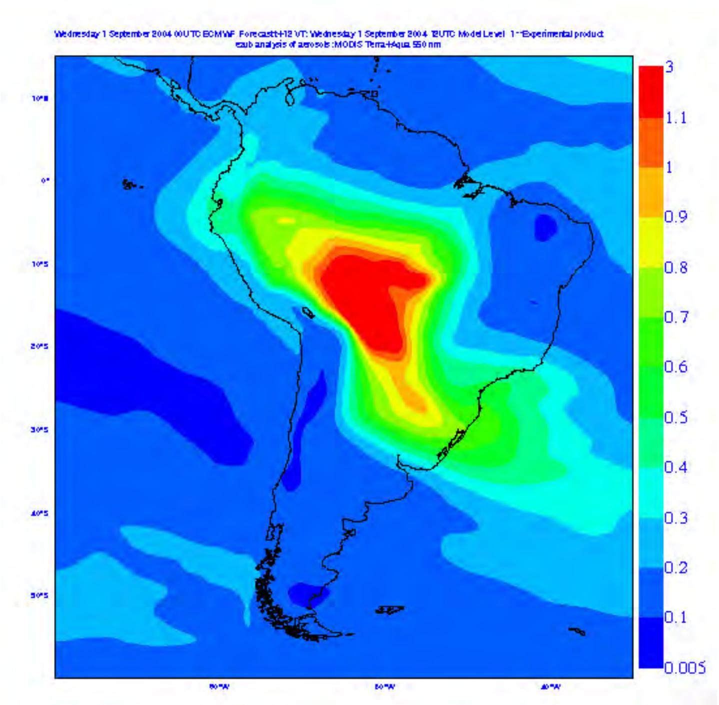
- cloud microphysics & precipitation

ECMWF experimental monthly aerosol analysis using MODIS 550nm data

- Sept. 2003



- Sept. 2004



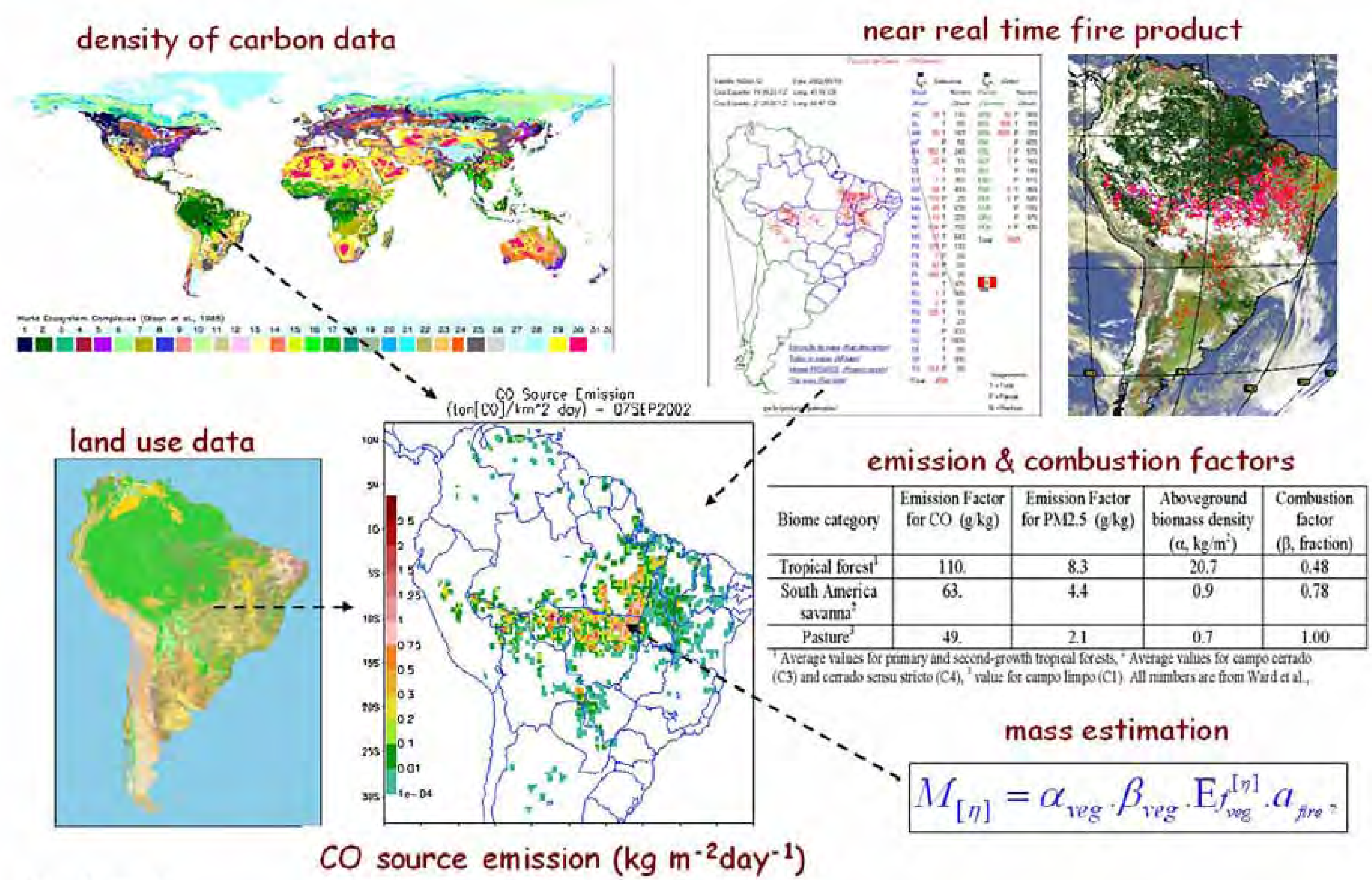
Sea salt
Desert dust
Black carbon
Organic matter
Sulphates

Morcrette, 2008, personal communication

& Benedetti et al., ECMWF Newsletter #116

Biomass Burning

Longo et al. ACPD, 2007;CATT-BRAMS



Biome category	Emission Factor for CO (g/kg)	Emission Factor for PM2.5 (g/kg)	Aboveground biomass density (α, kg/m^2)	Combustion factor (β, fraction)
Tropical forest[1]	110.	8.3	20.7	0.48
South America savanna[2]	63.	4.4	0.9	0.78
Pasture[3]	49.	2.1	0.7	1.00

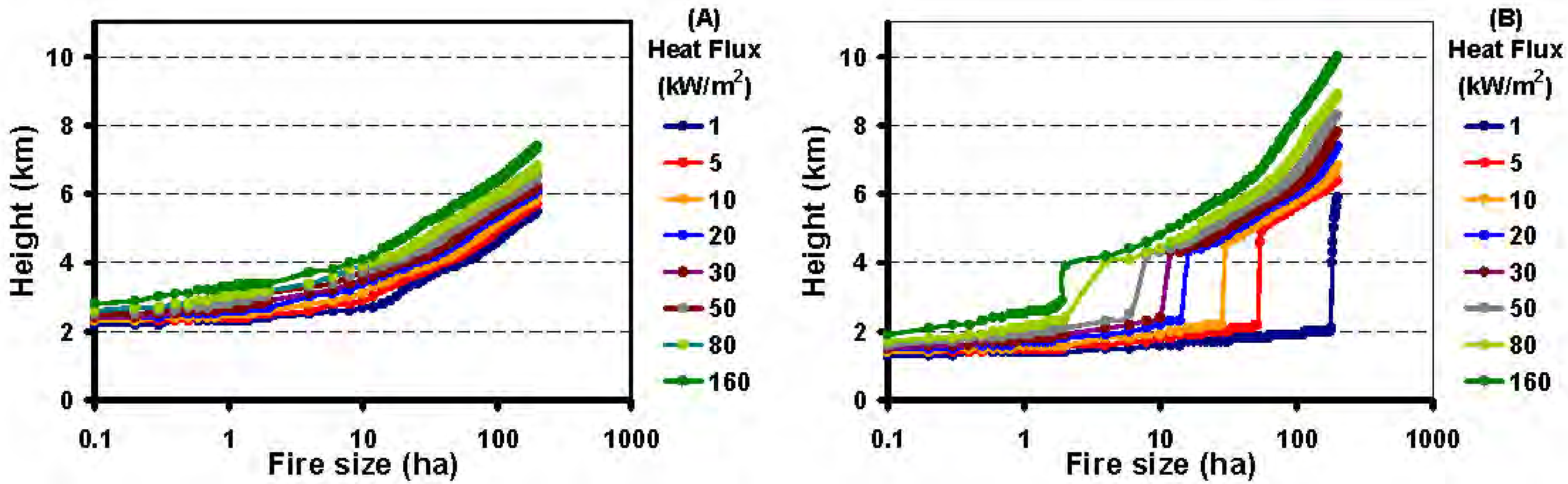
[1] Average values for primary and second-growth tropical forests, [2] Average values for campo cerrado (C3) and cerrado sensu stricto (C4), [3] value for campo limpo (C1). All numbers are from Ward et al.,

$$M_{[\eta]} = \alpha_{veg} \cdot \beta_{veg} \cdot \mathrm{E}f_{veg}^{[\eta]} \cdot a_{fire}$$

Plume Rise of Vegetation Fires

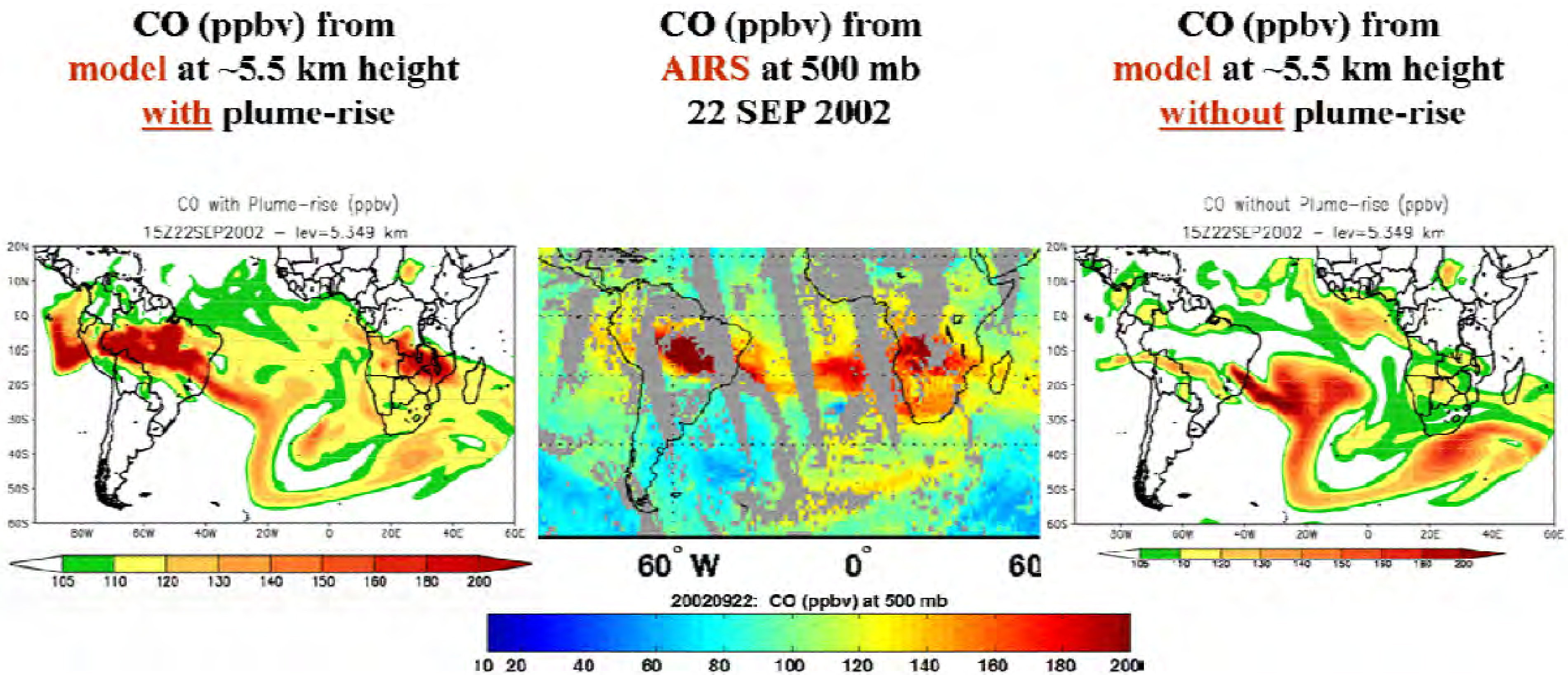
S. R. Freitas et al.: Including the plume rise of vegetation fires

SMOCC 'Dry': 20 Sept. 2002 'Wet': 27 Sept. 2002



- Heat flux: Forest: 30-80kWm^{-2};
  Savannah: 5-25 kWm^{-2}
- Fire size distribution broad: 13 (±15)ha
  - fire plume reaches 4-8km

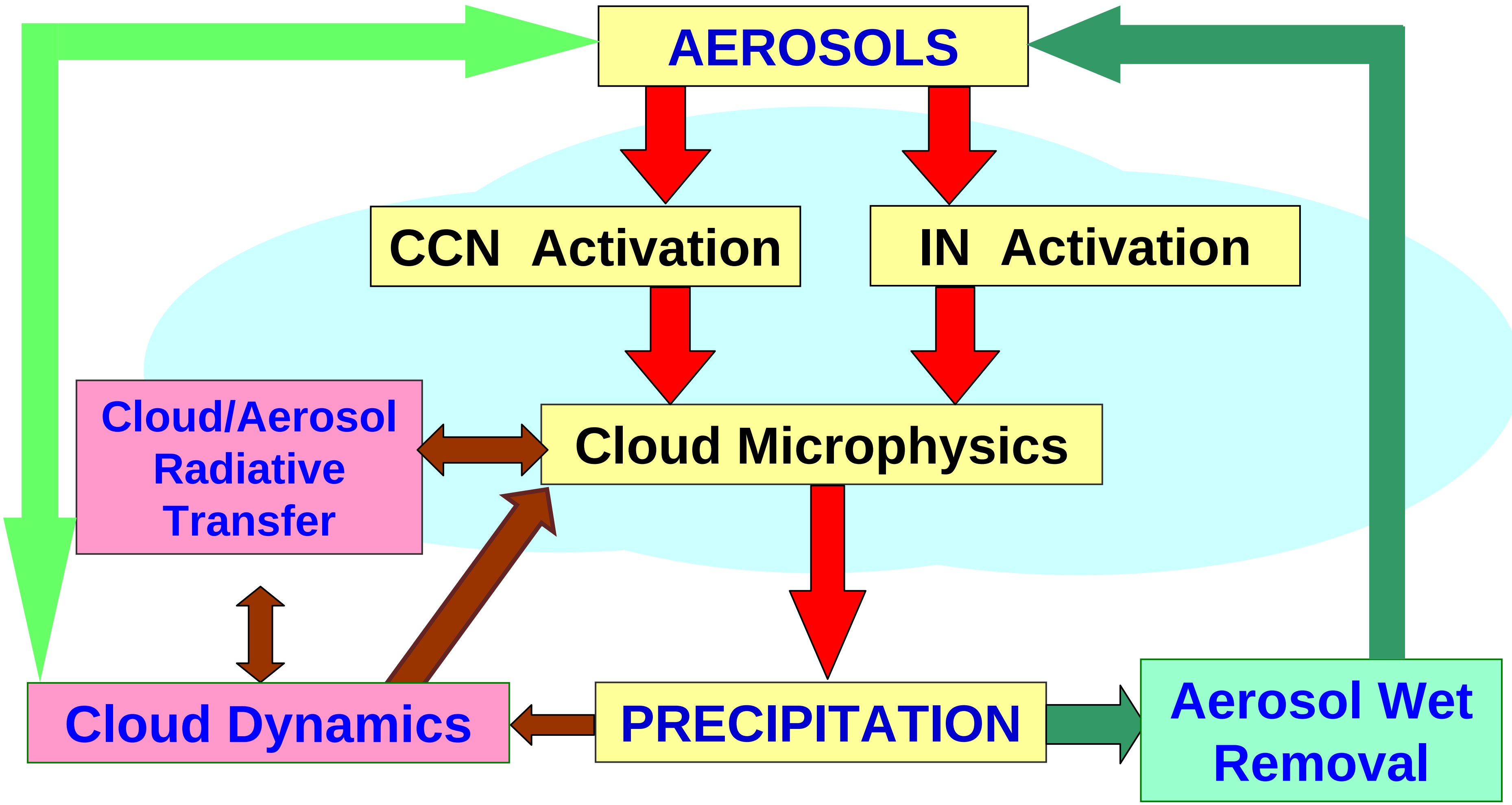
1-D plume model, driven by Fire Emission model & coupled to 3-D CATT-BRAMS gives realistic dispersion



- Mid-tropospheric CO matches AIRS much better with sub-grid 1-D plume rise model

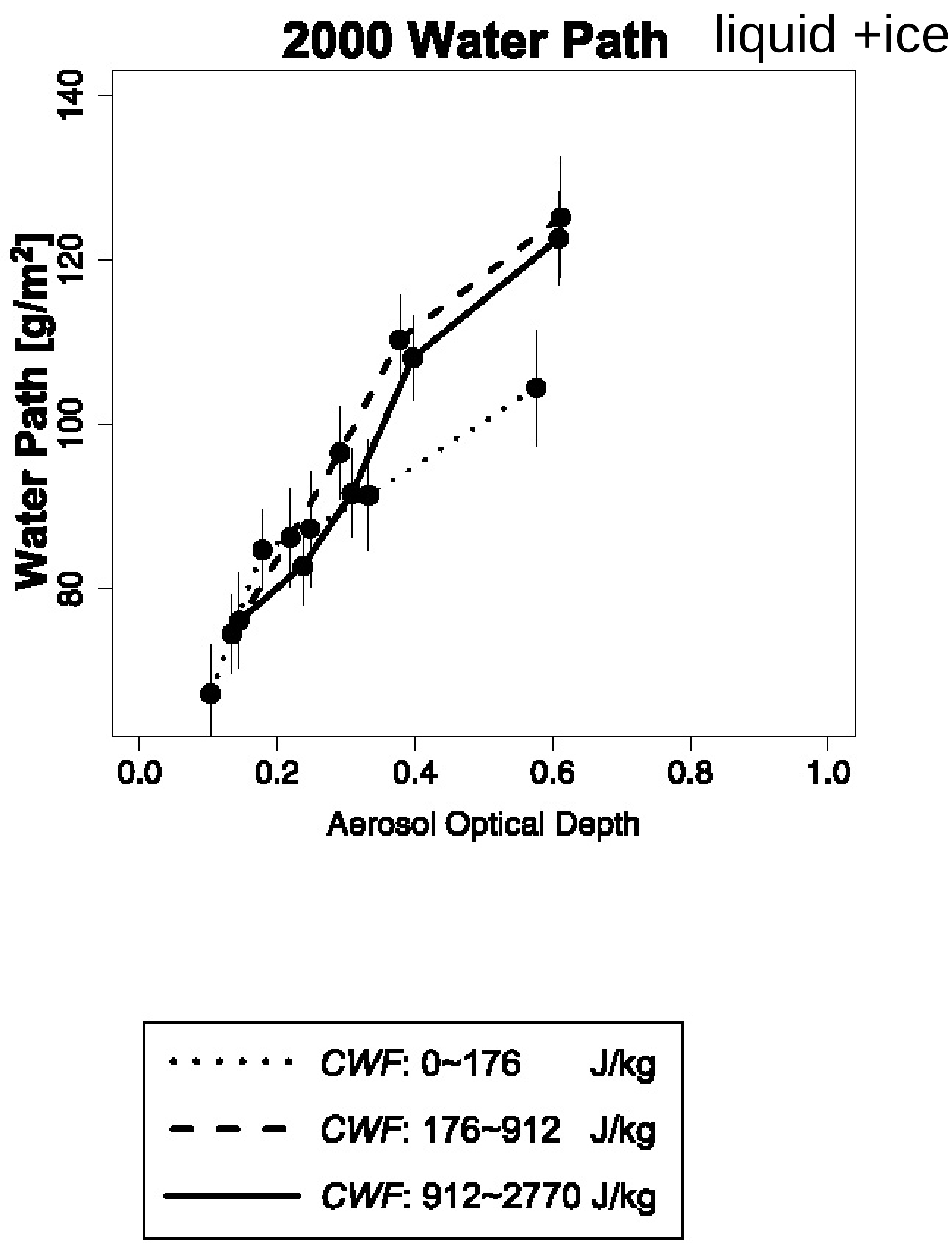
[Freitas et al. 2006]

Aerosol-cloud-precipitation feedbacks



TRMM Precipitation Radar vs MODIS AOT

Lin et al 2006



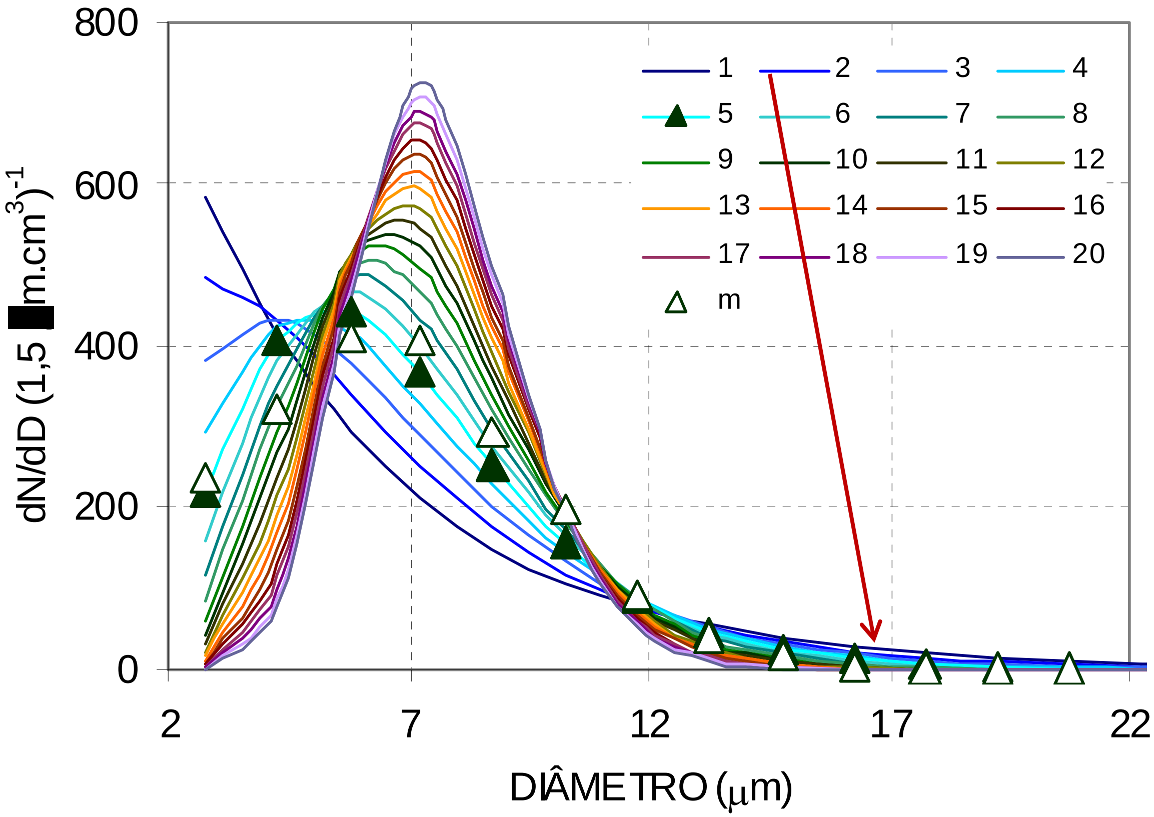
CWF ~ CAPE

Series of papers on Aerosol-Precipitation coupling

- **Martins**, Silva Dias, Gonçalves (2008):Modeling the impacts of biomass burning aerosols on precipitation in the Amazonian region using BRAMS: a case study for 23 September 2002 – *JGR* (*accepted)*
- **Martins** et al 2008 : Cloud condensation nuclei from biomass burning during the Amazonian dry-to-wet transition season – *Meteo. Atmos . Phys. (accepted)*
- Gonçalves, **Martins,** Silva Dias, 2007 – Shape parameter analysis using cloud spectra and gamma functions in numerical modelling during LBA in Amazon – *Atmos Research. (in press)*

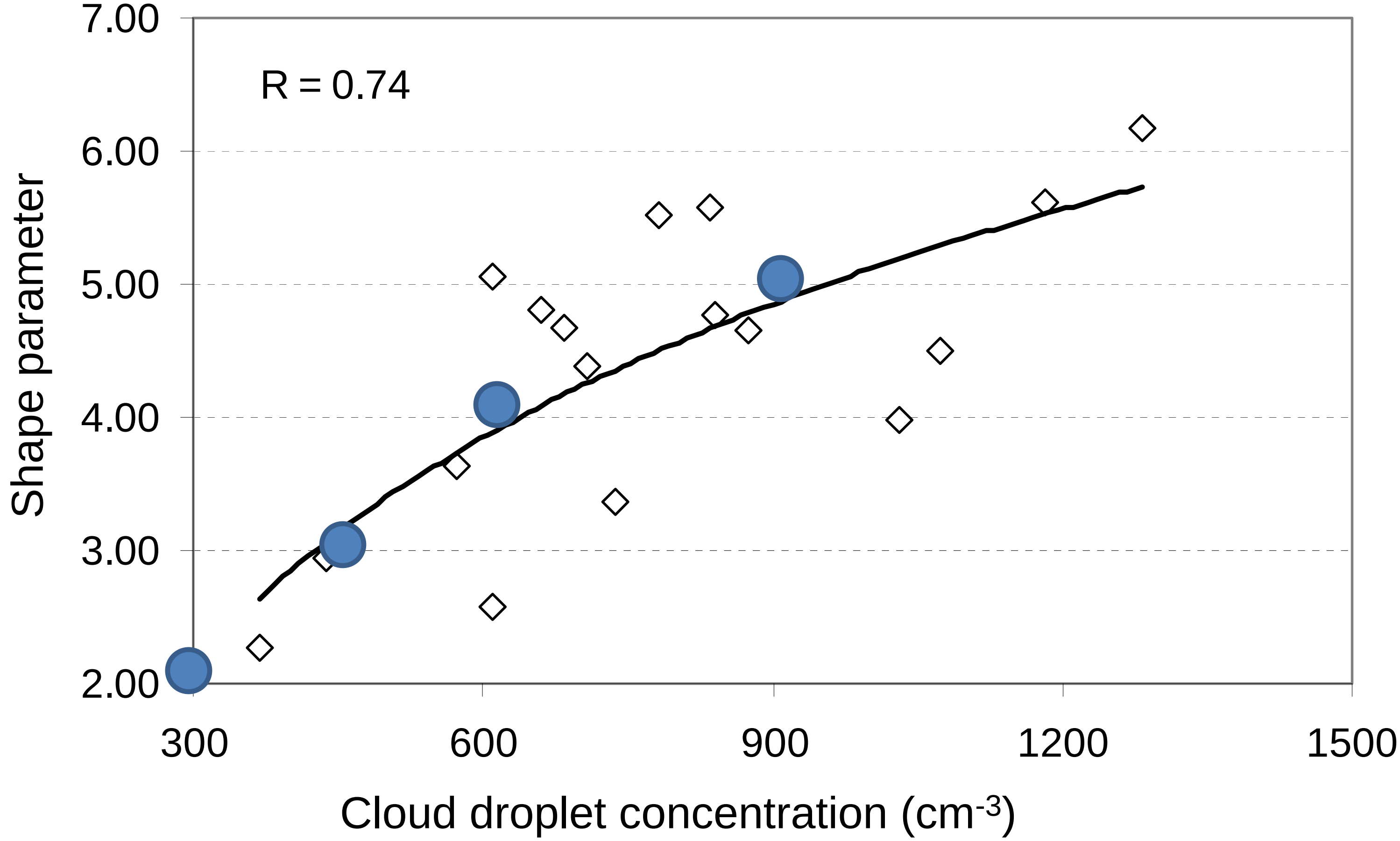
Shape parameter in cloud droplet diameter distribution

$$n(D) = \frac{N_t}{\Gamma(\nu)}\left(\frac{D}{D_n}\right)^{\nu-1}\frac{1}{D_n}\exp\left(-\frac{D}{D_n}\right)$$



Observed shape parameter vs CCN concentration

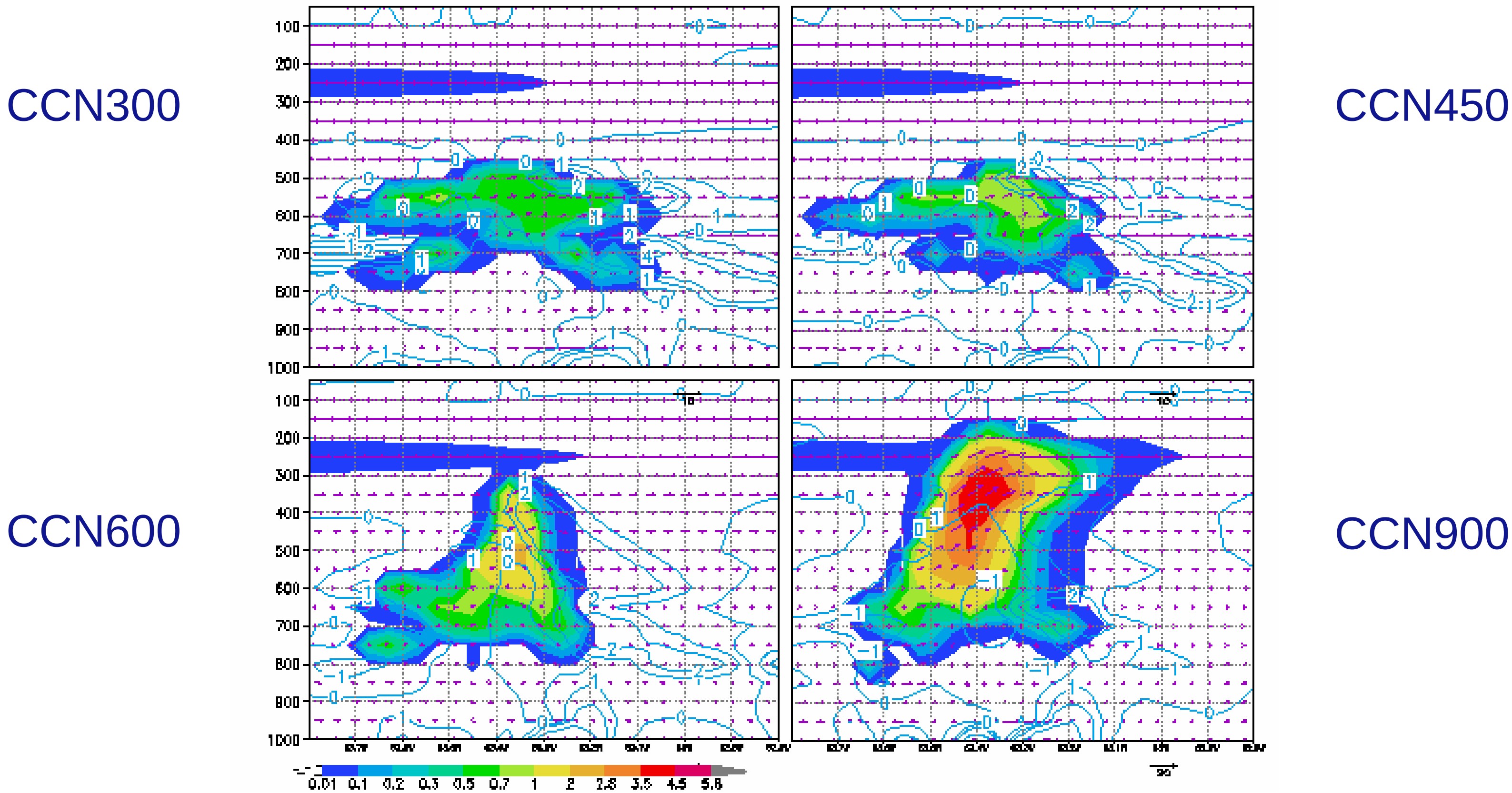
Numerical experiments : BRAMS



Microphysics parameters used in numerical experiments

	CCN300	CCN450	CCN600	CCN900	CCN900R
CCN concentration	300	450	600	900	900
Shape parameter – cloud droplet and pristine ice	2	3	4	5	5
Shape parameter – all remaining water categories	1	1	1	1	1
Radiative effect	None	None	None	None	Absorbing and reflecting

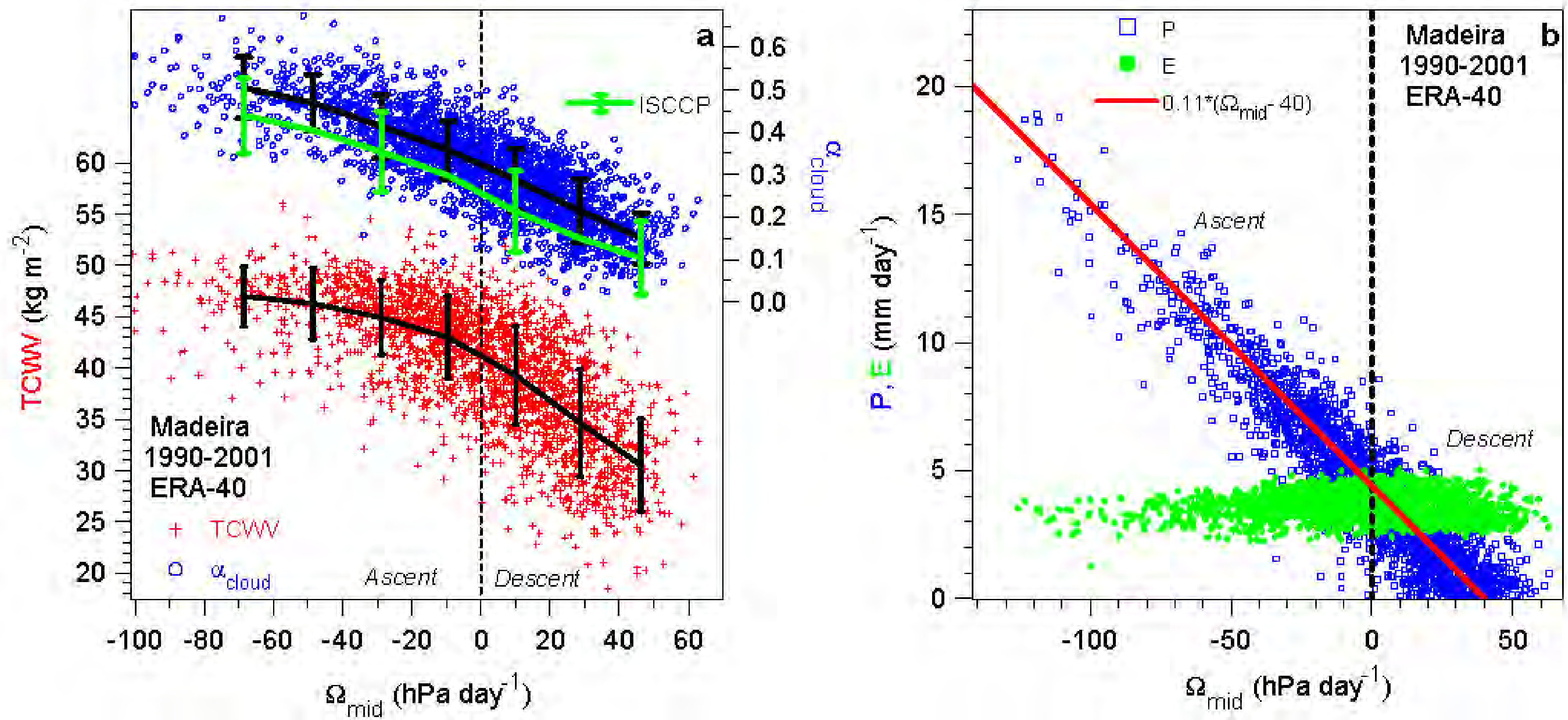
Vertical structure of cloud and ice water mixing rate observed at the time of maximum liquid water path



Vertical transport processes

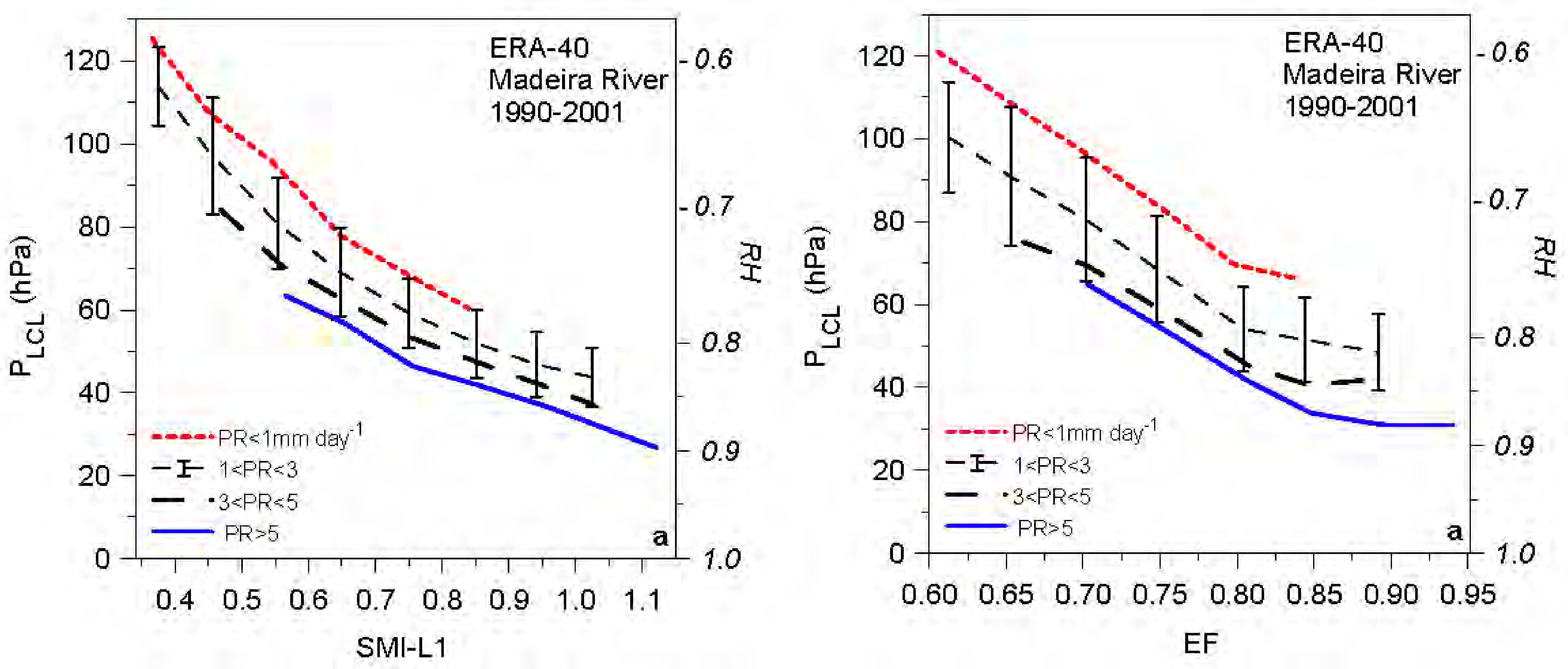
- Local fire-driven transports and convection
- Larger-scale forcing, cloud & precipitation
- Cloud-BL coupling

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



- Partition of *moisture convergence* into
  TCWV, α_{cloud}, and precipitation
- Note high bias of α_{cloud} from ISCCP; but precip. generally low

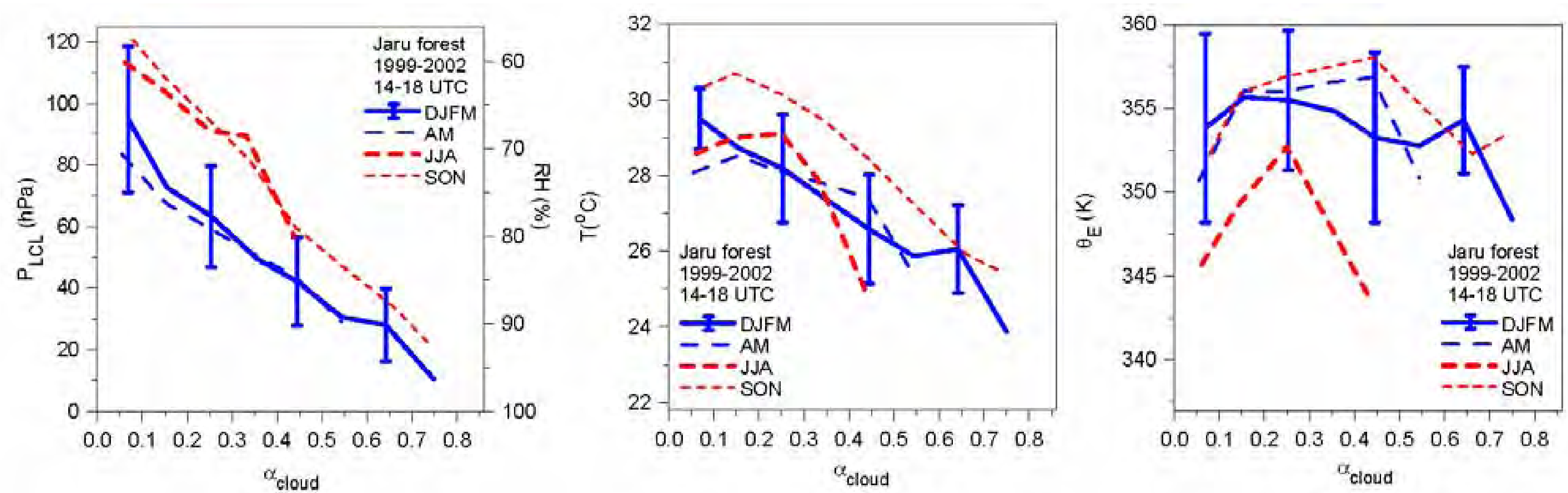
Land-surface-BL Coupling



- SMI-L1 = (SM- 0.171)/(0.323-0.171) ***(soil moisture index)***
- P_{LCL} stratified by Precip. & SMI-L1 or EF
- Highly coupled system: only P_{LCL} *observable: Mixed layer depth*

Cloud - BL coupling

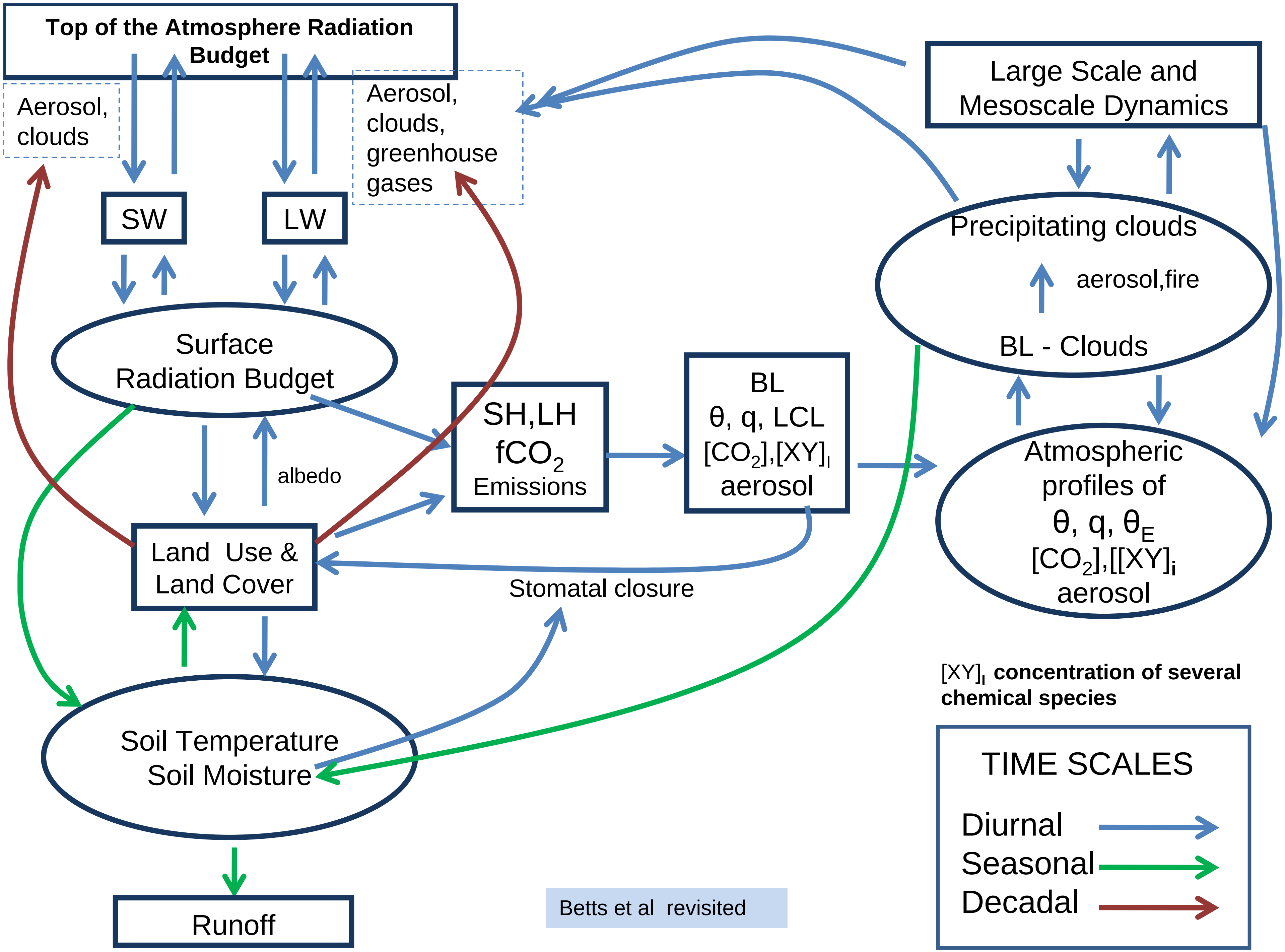
Jaru forest – Noon ±2h



- Cloud amount coupled to cloud-base & RH
- Temperature decreases as cloud increases
- θ_E is flat: regulated by cloud transports

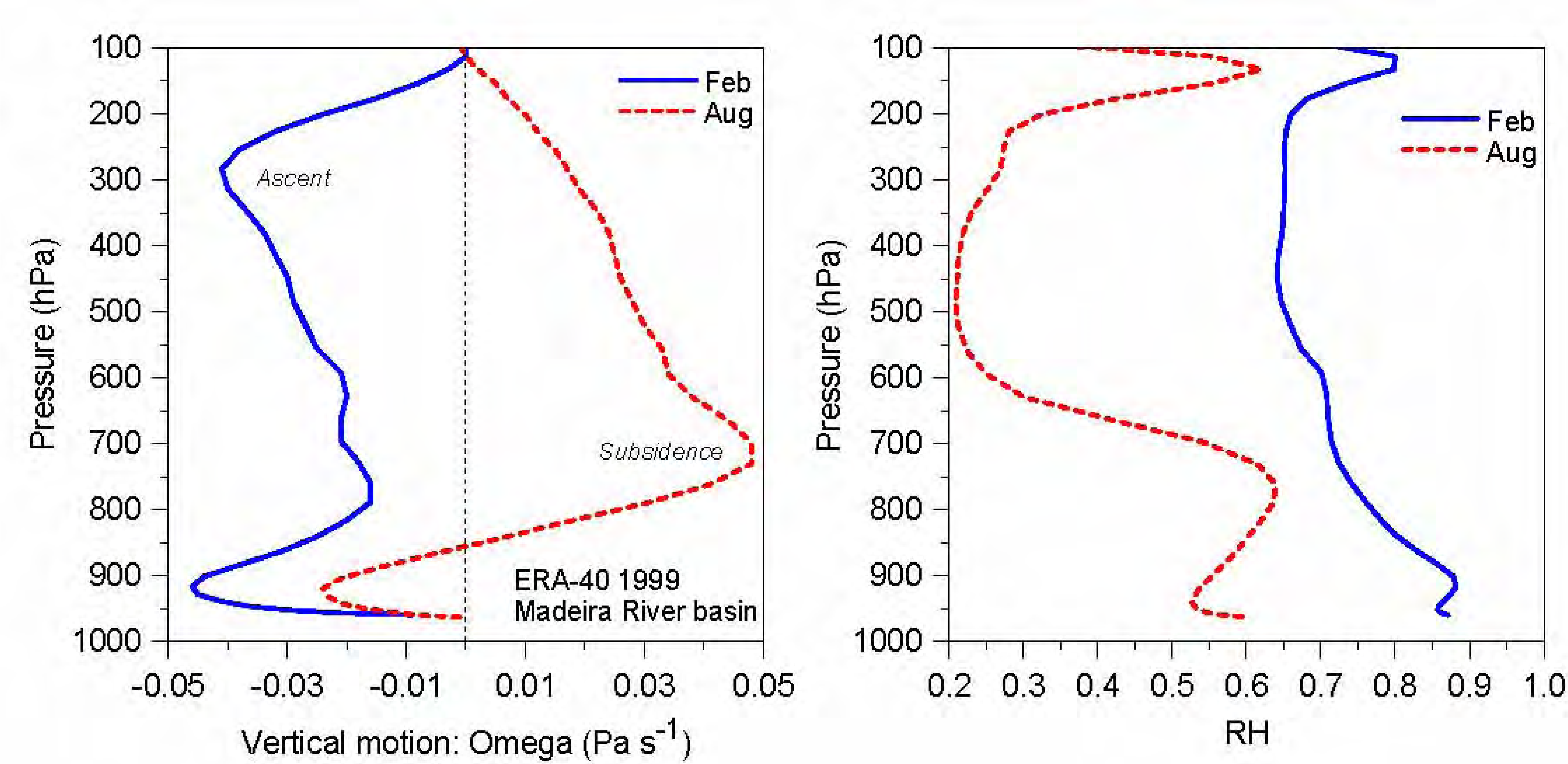
Conclusions

- Our understanding of physical processes has broadened extensively
  - Coupling of clouds to surface, BL and LW processes
  - Aerosol interactions: radiative & microphysical
  - Our ability to assess physical biases in models



Top of the Atmosphere Radiation Budget
Aerosol, clouds
Aerosol, clouds, greenhouse gases
SW
LW
Surface Radiation Budget
albedo
Land Use & Land Cover
Soil Temperature Soil Moisture
Runoff
SH,LH fCO_2 Emissions
BL θ, q, LCL $[CO_2]$,$[XY]_I$ aerosol
Stomatal closure
Large Scale and Mesoscale Dynamics
Precipitating clouds
aerosol,fire
BL - Clouds
Atmospheric profiles of θ, q, $θ_E$ $[CO_2]$,$[[XY]_I$ aerosol
$[XY]_I$ concentration of several chemical species
TIME SCALES
Diurnal
Seasonal
Decadal
Betts et al revisited

Vertical motion and structure



- Ascent and dry in February [wet season]
- Descent and dry in August [dry season]

Stability differences

- Unstable for deep convection in Feb
- Stable for deep convection in Aug