Diagnostic evaluation of the ECMWF model using observations

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Tony Hollingsworth Symposium

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*[*Contributors: Beljaars, Miller, Viterbo, van den Hurk, Jakob, Kőhler & Zhang]*

Tony Hollingsworth's vision

- For 17 years I have visited ECMWF annually

  - to work on the evaluation of the model physics using observational data, especially field data.

  - A time of rapid model development.

  - Tony was an early enthusiastic supporter. He would say:

"The more errors you find, the more we can fix!"

- He understood the science

- ***He understood science management***

Brief Timeline

- 1984: Betts-Miller scheme
- 1992: FIFE data comparison [Kansas prairie; 1987-89]
  - soil & vegetation model, BL model.
- 1994: ASTEX [Atlantic stratocumulus transition]
- 1993-1996: BOREAS [Boreal forest, SK & MB, Canada]
  - snow albedo, forest processes, frozen ground
- 1997-1999: ERA-15 - Mississippi [GCIP] comparisons
- 1999-2002: LBA [Amazon forest]
  - diurnal precipitation, clouds and model climate
- 2000-2007: ERA-40 comparisons
  - new land-surface scheme
  - river basin hydrometeorology
  - biases against flux-tower data [BERMS]
  - coupling of land-surface processes to clouds – “cloud albedo”
  - shortwave cloud forcing against ISCCP data
  - NBL, diurnal cycle and LW_{net}
- 2007-2008 ERA-Interim
  - hydrometeorology and SWCF

FIFE-1987 data

- 30-min averaged surface data time series prepared for 15 x 15 km FIFE site; Konza prairie, KS; summer, 1987.

  [10 AMS sites and 20 flux sites: *downloaded at 2400 baud & manually edited*] *[Betts & Ball, 1994, 1995, 1998]*

- Compared with 48 hr forecasts from ECMWF model; July, Aug., Oct. 1987 *[Betts et al. 1993]*

- Identified model errors in
  - the incoming short-wave radiation in clear skies [5-10% too high]
  - the ground heat flux [2-3X too large – time truncation]
  - the formulation of surface evaporation [time-scale too fast]
  - the soil moisture model [layering – climate layer control]
  - the entrainment at boundary layer top. [too low – giving BL moist bias]

- Input to new land-surface scheme *[Viterbo & Beljaars, 1995]*
- Input to new BL scheme *[Beljaars & Betts, 1992]*

Error 5 - BL entrainment low

9-day August average

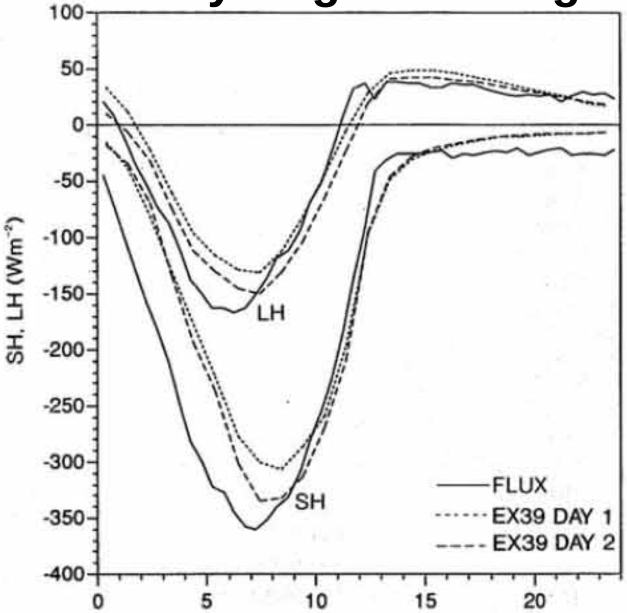


Fig. 11 As Fig. 10 for sensible and latent heat flux.

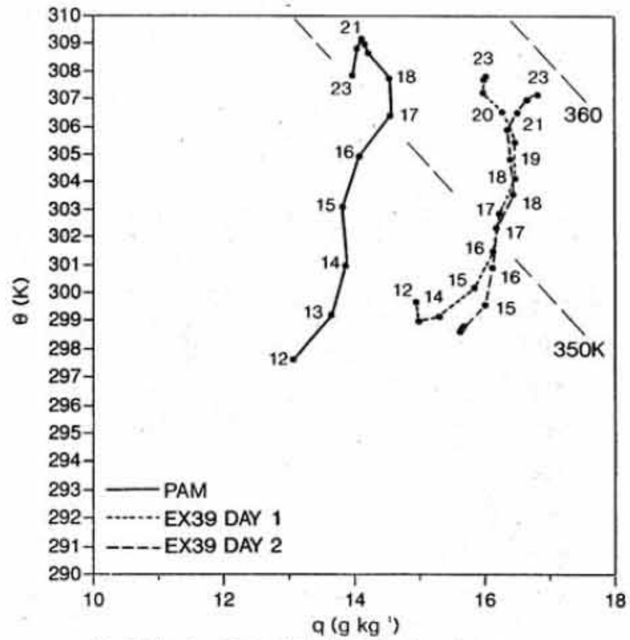
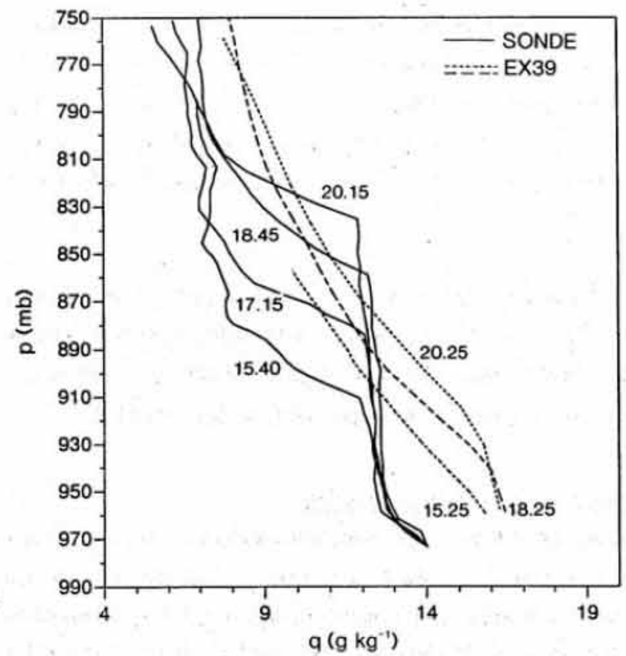


Fig. 14 Daytime (θ,q) plot for the 9 day August average.



Surface fluxes
Agreement good

(θ, q) plot)
Too moist

(q, z) plot
Too shallow BL

[Beljaars & Betts, 1992]

July 1993 Mississippi flood

CY 47 **CY 48 Viterbo & Beljaars land model**

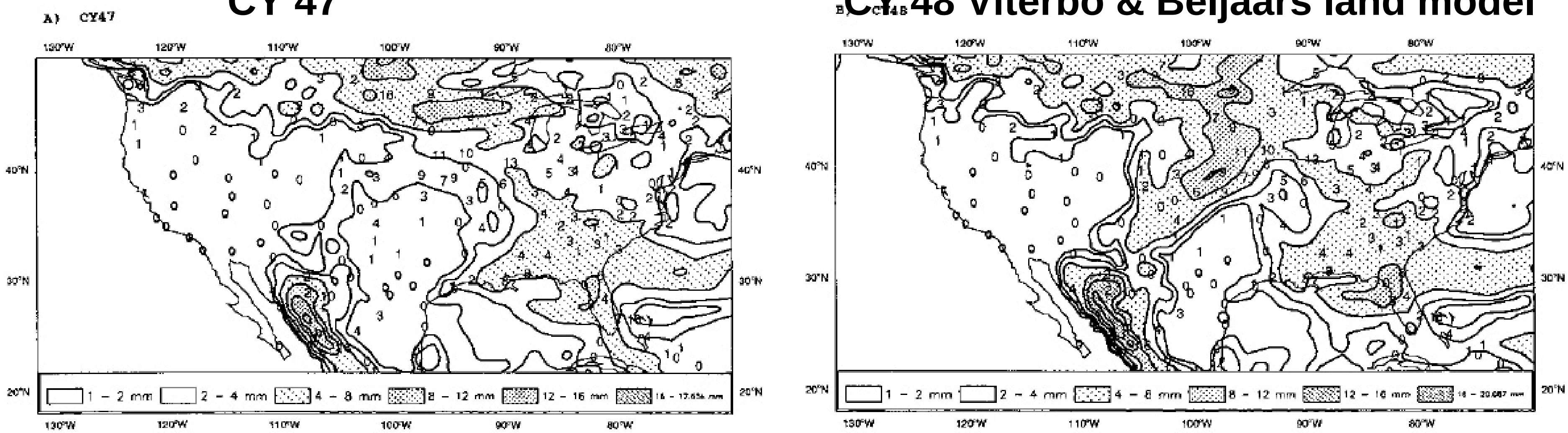
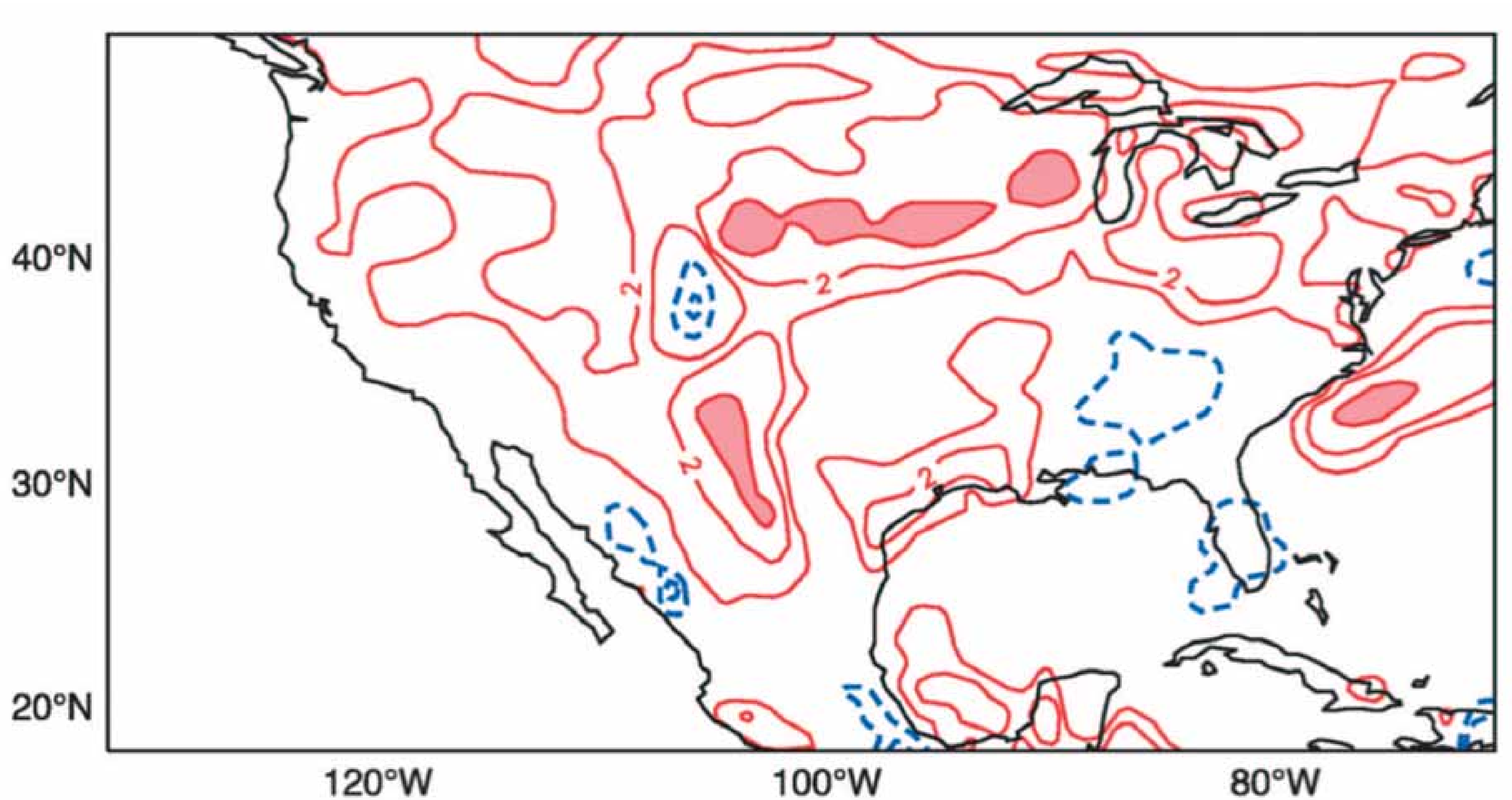


FIG. 2. Mean forecast precipitation of all 48–72-h forecasts verifying between 9 and 25 July, with (a) CY47 and with (b) CY48. The contours are at 1, 2, 4, 8, . . . mm day^{-1}. The printed numbers are station observations in millimeters per day.

- Vast improvement in 48-72h forecasts of 1993 flood; July 9-25

Evaporation-precipitation feedback



- Difference in monthly forecast precip. (July 1993) starting with wet and dry soils

[Beljaars et al. 1996]

Impact of BOREAS

- **Tony was my co-I on my NASA BOREAS grant**
- For years the ECMWF model had had high-latitude surface temperature errors
- Surface scheme had been changed

  - Viterbo and Beljaars [1995]
- *During BOREAS we realized*

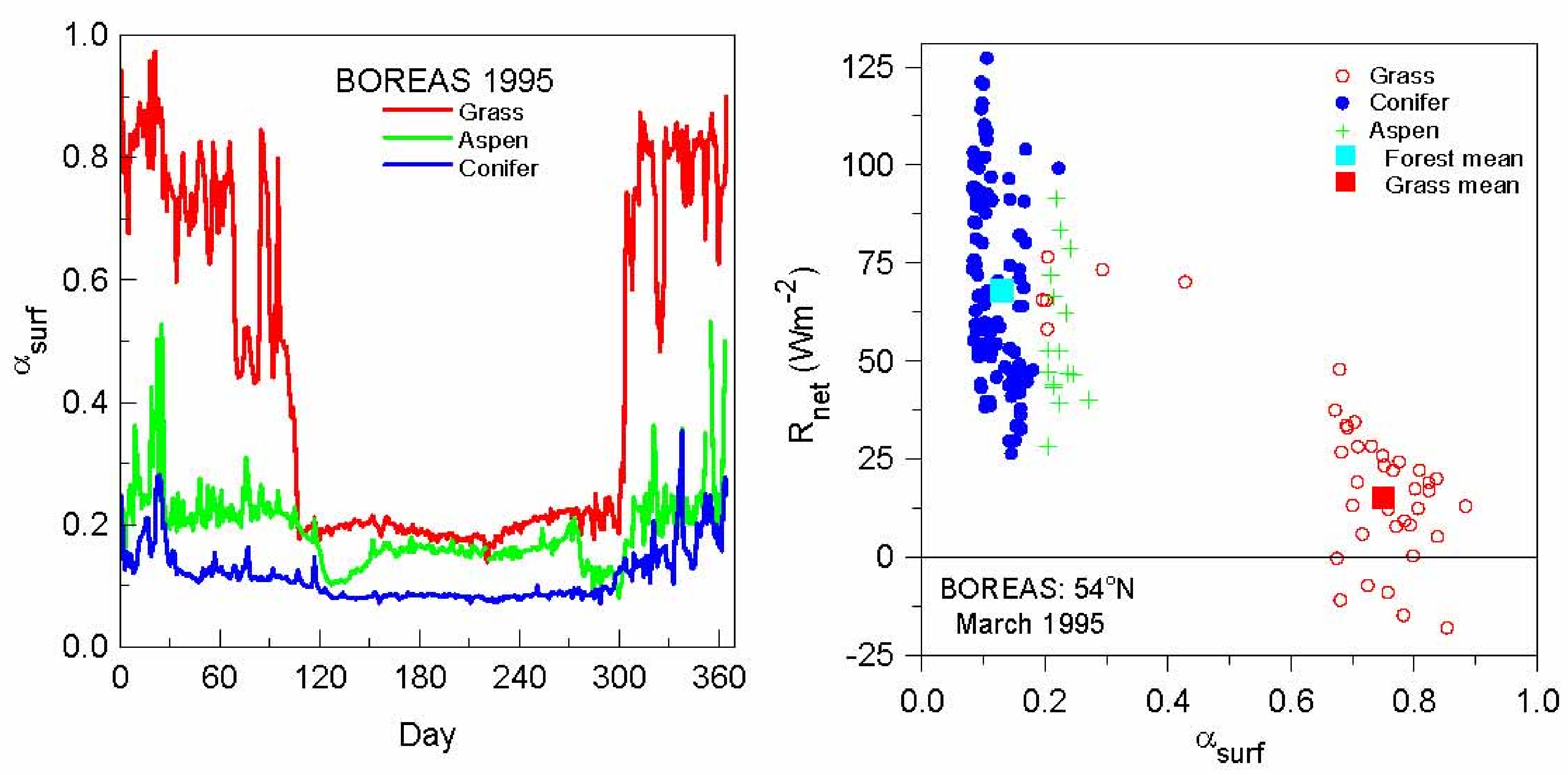
  - surface albedo with snow was too high

  - surface evaporation was too high
- *Input to the new tiled land-surface model for ERA-40 [TESSEL]*

Van den Hurk, B.J.J.M., P. Viterbo, A.C.M. Beljaars and A. K. Betts, 2000: Offline validation of the ERA40 surface scheme. ECMWF Tech Memo, 295.

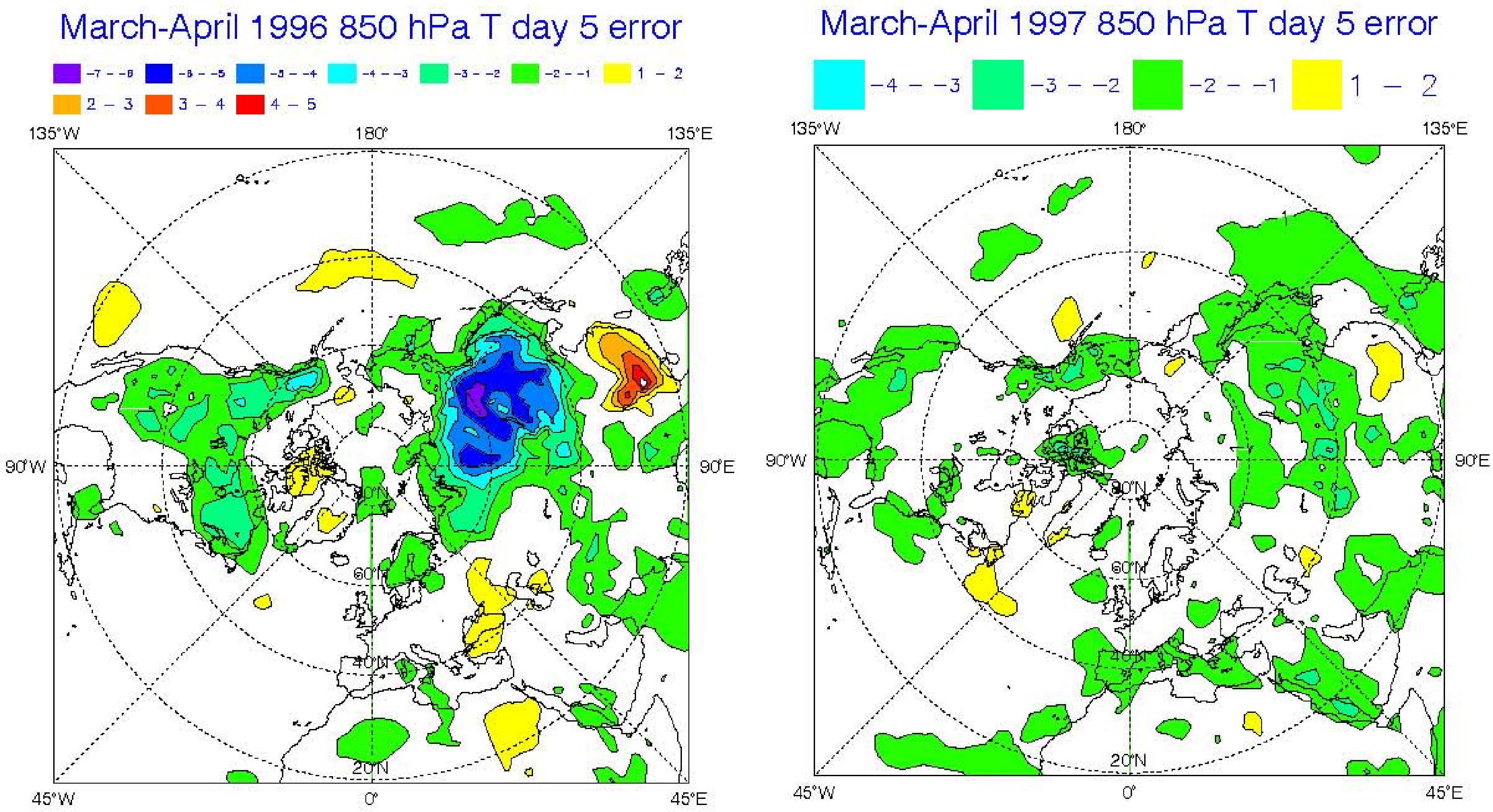
*Betts , A. K.,, P. Viterbo, A.C.M. Beljaars and B.J.J.M. van den Hurk,, 2001: Impact of BOREAS on the ECMWF Forecast Model. J. Geophys. Res., **106,** 33593-33604.*

Surface albedo



- Impact of landscape differences (forest/grass) on R_{net} are large in spring

Impact of reducing boreal forest α_{surf} from 0.8 to 0.2 (snow)



- Large systematic bias reduction; NH forecast skill improved

Aside on ECMWF 4-10 year plans

- Bottom-up & top-down planning

  - Real strategic plans, carefully drafted with detailed, realistic timelines and budgets; reviewed and updated regularly

  http://www.ecmwf.int/about/programmatic/index.html

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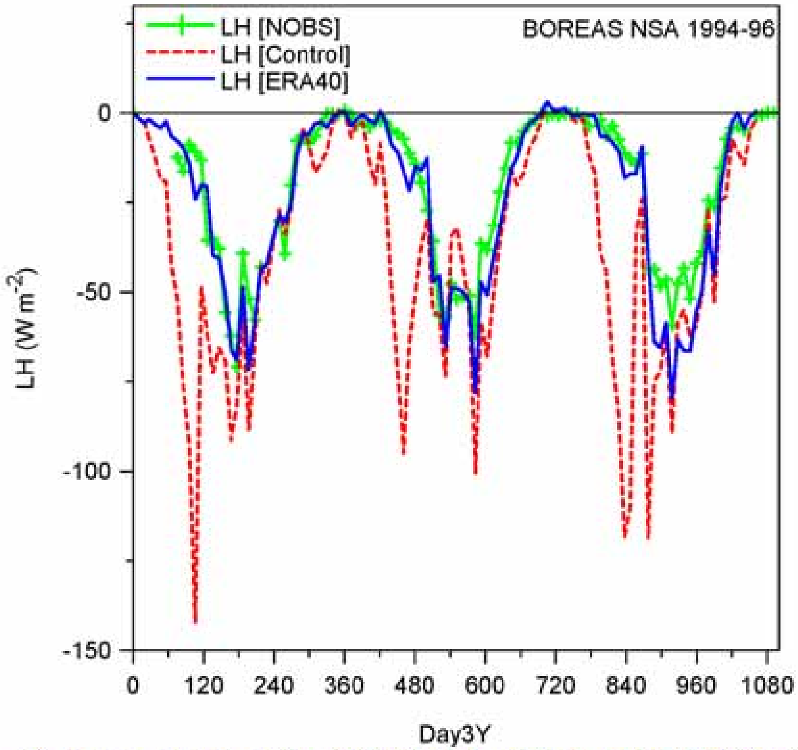
- Pedro Viterbo over-ruled the 'plan'

  - **tested snow albedo changes** for two months, and presented a 'fait accompli' to Tony

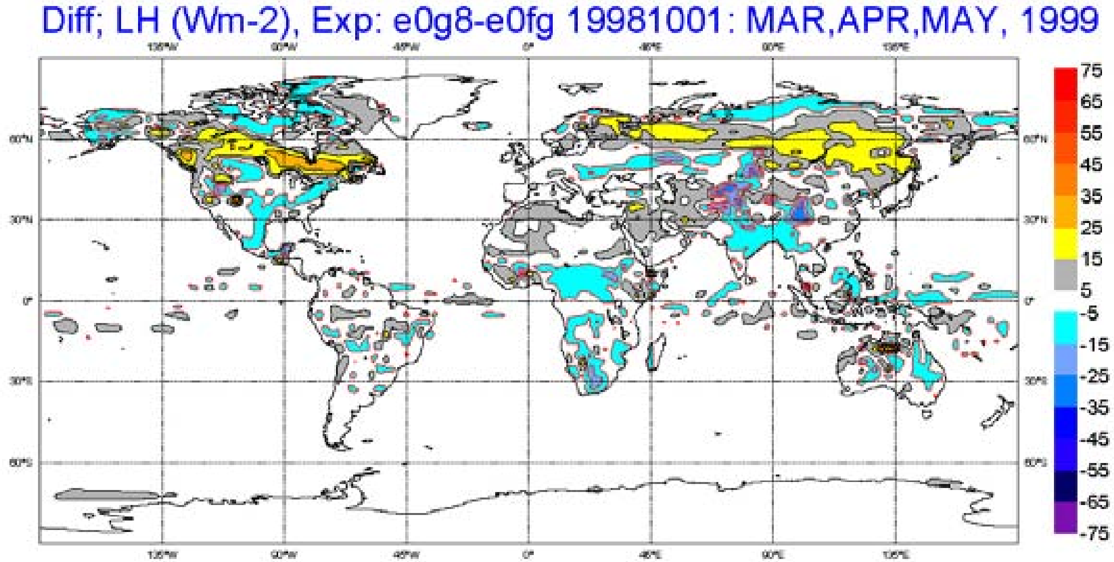
- *Tony was first annoyed and then grateful!*

Boreal forest evaporation

- ERA-40 land-surface matches data better

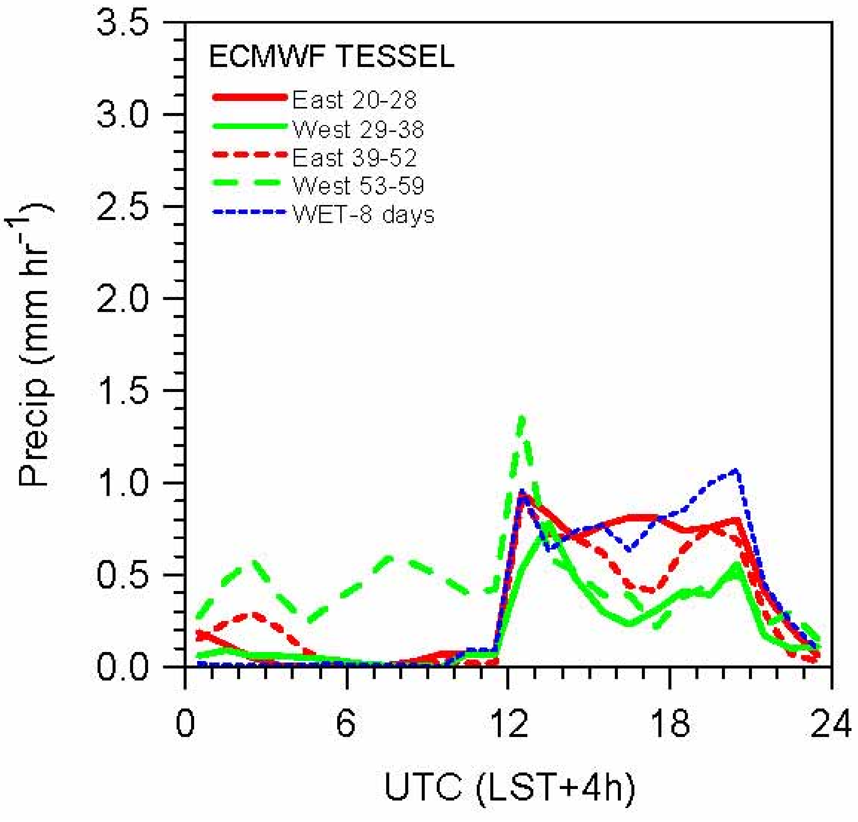


- Global impact:
  - ERA-40 - Control
  - large reduction over boreal forest

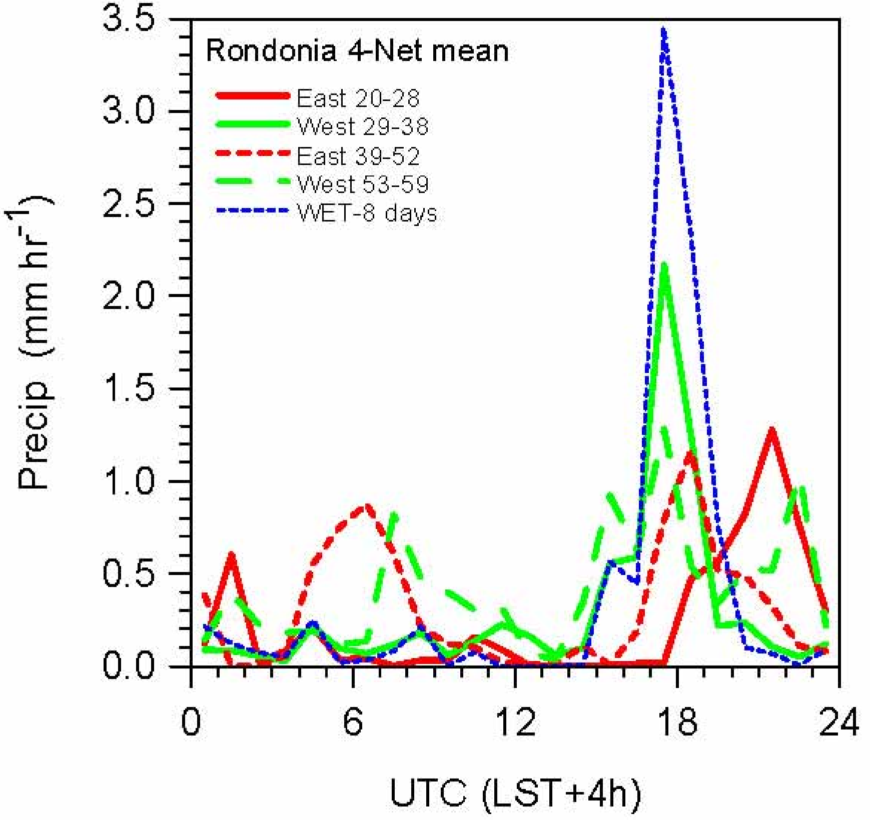


LBA- Brazil

ECMWF model



Data [Raingage networks]



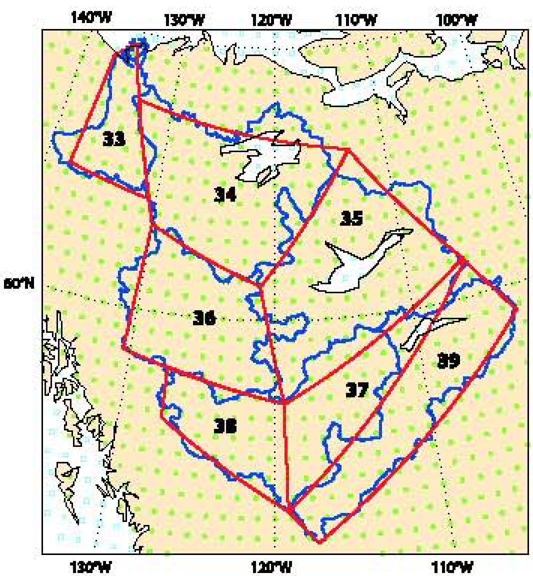
- Spurious model precipitation peak
  2h after sunrise *[Betts and Jakob 2002*]

Surface Energy Balance

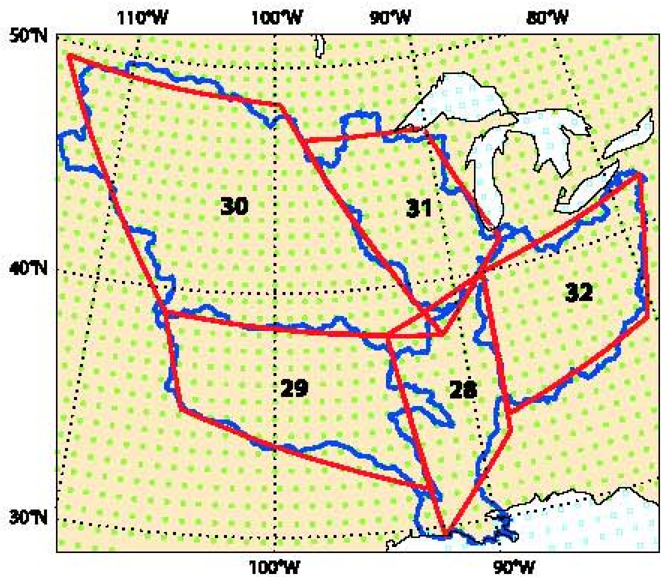
$$R_{net} = SW_{net} + LW_{net} = H + \lambda E + G$$

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

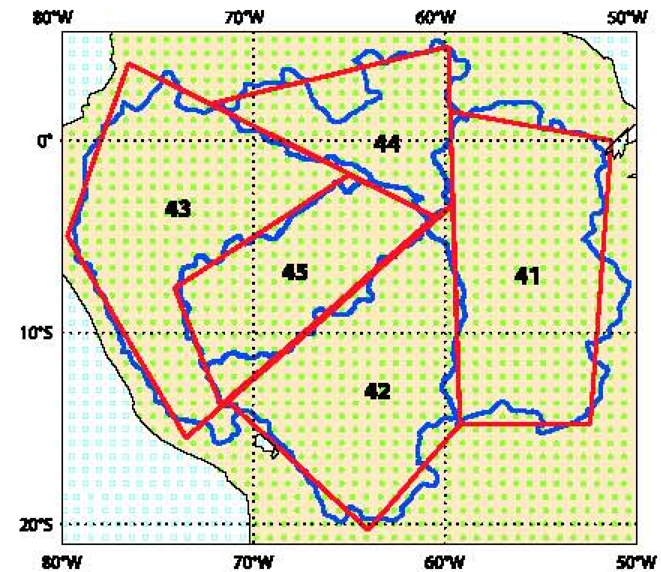
River basin archive
ERA-40 and ERA-Interim



Mackenzie



Mississippi



Amazon

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

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***

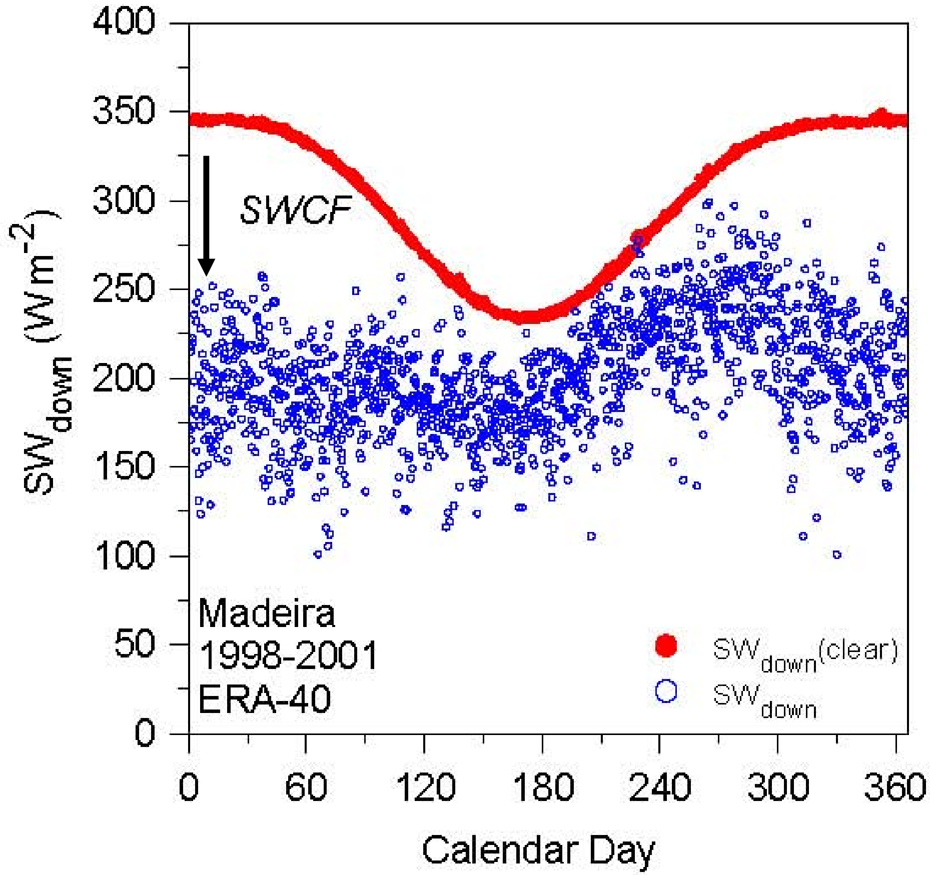
  - scaled surface **short-wave cloud forcing, SWCF**

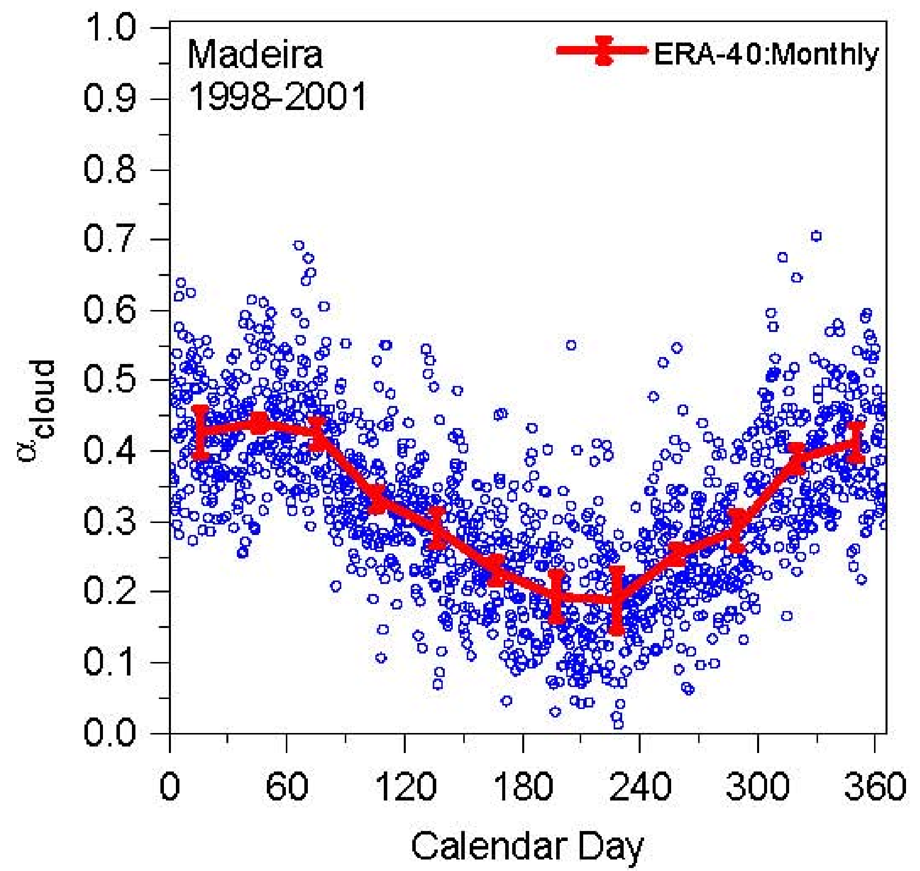
$$SWCF = SW_{down} - SW_{down}(clear)$$

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

[Betts and Viterbo, 2005; Betts, 2007]

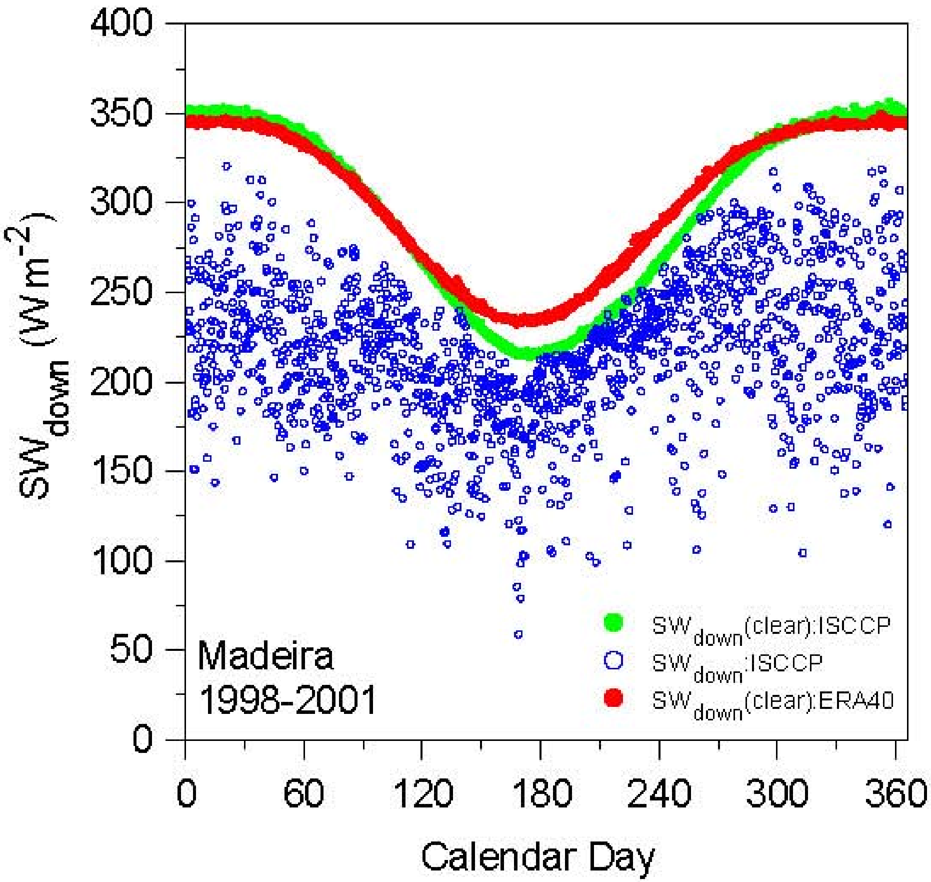
Cloud albedo: *ERA-40 data*

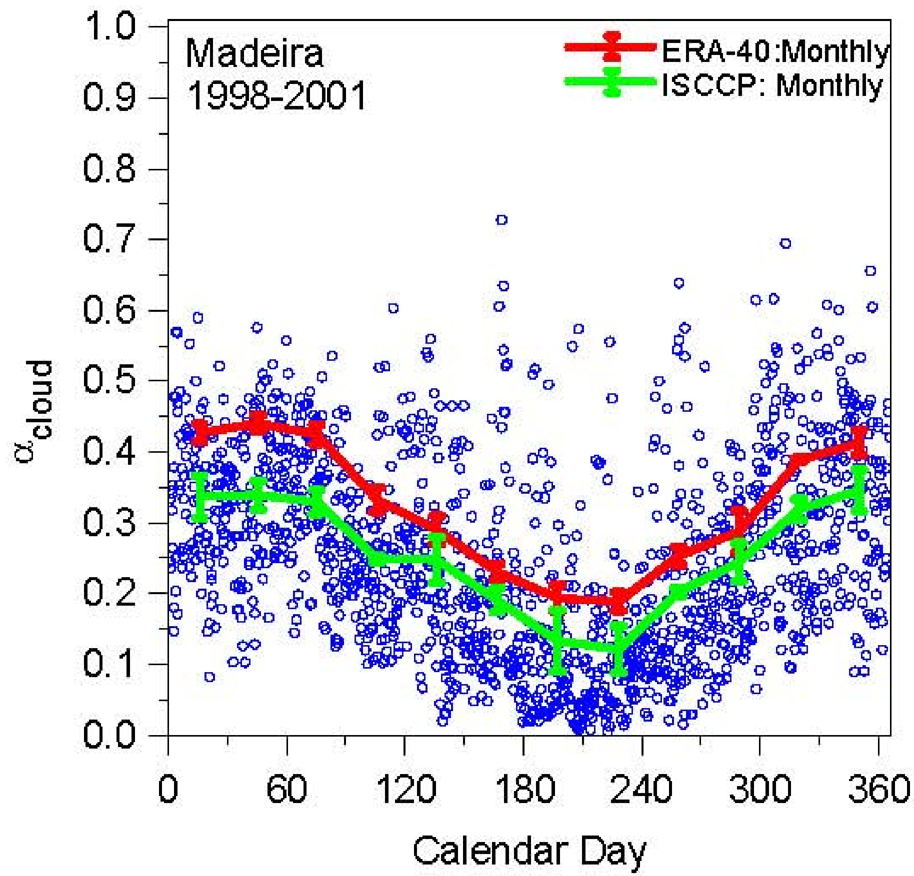




- Transformation: α_{cloud} = SWCF/ SW_{down}(clear)
- Seasonal cycle OK: small daily variability: Is it biased?

Cloud albedo: *ISCCP data*

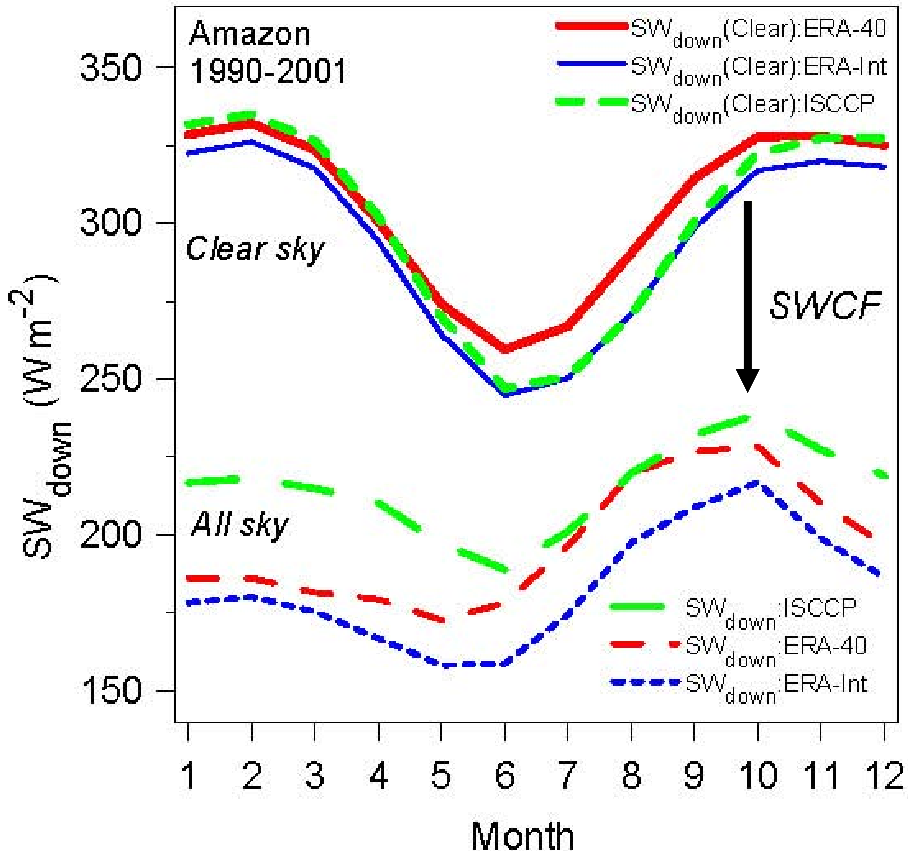




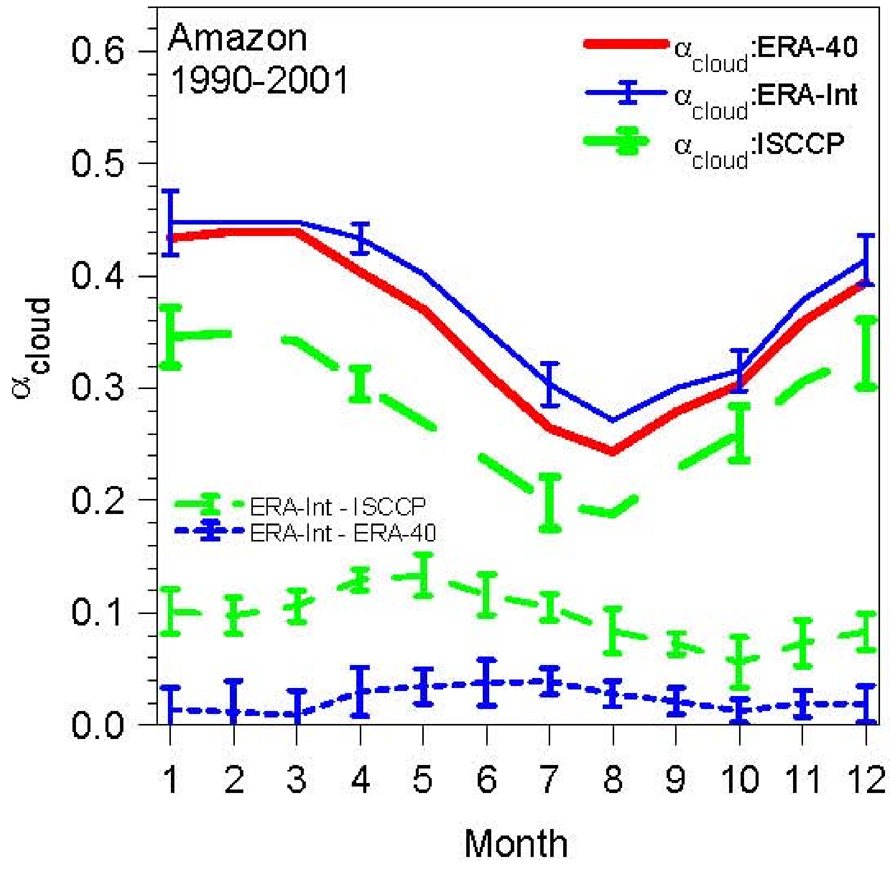
- Different clear-sky flux: Aerosol differences
- ERA-40 systematic high bias in α_{cloud} ≈ +7%
- ISCCP has more daily variability

Amazon – *Shortwave* & α_{cloud}

SW_{down}



Cloud albedo

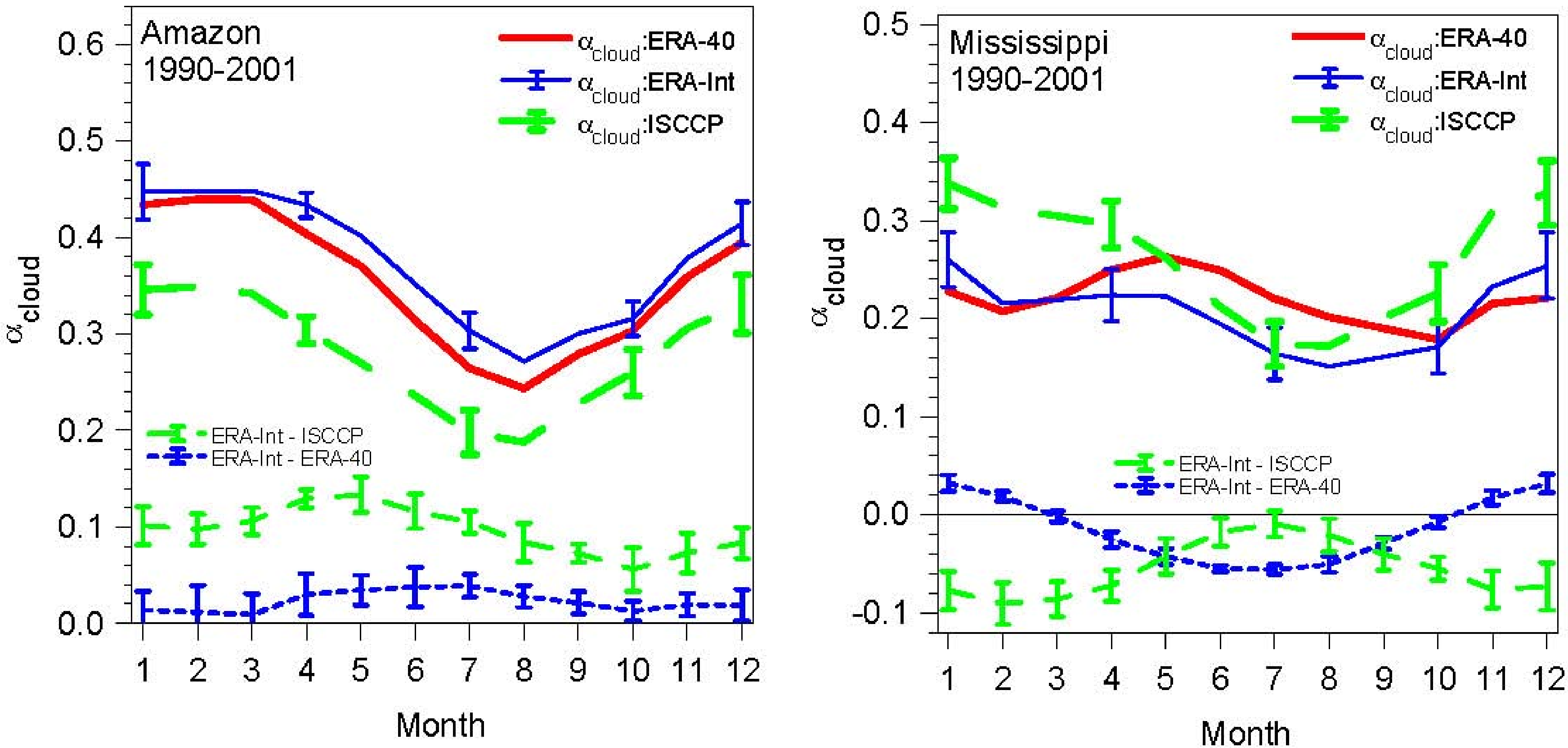


Clear-sky differences

ERA-Int > ERA-40 > ISCCP

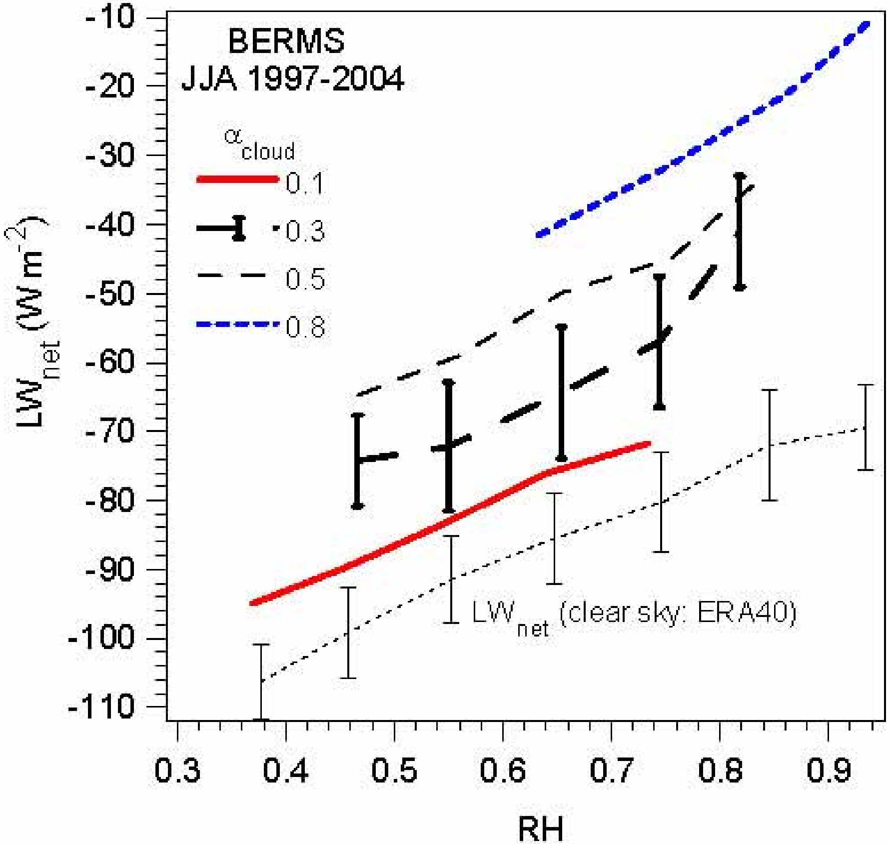
All-sky differences are larger

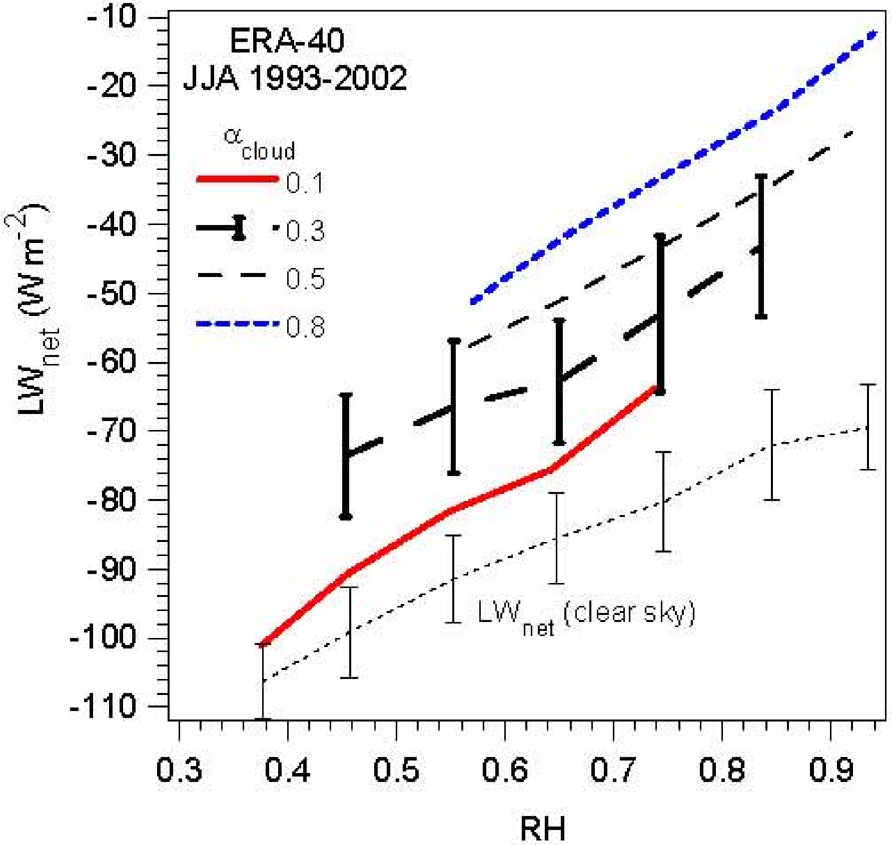
Tropics *vs*. mid-latitudes



- Amazon: reanalyses α_{cloud} biased high
- Mississippi: different bias signature

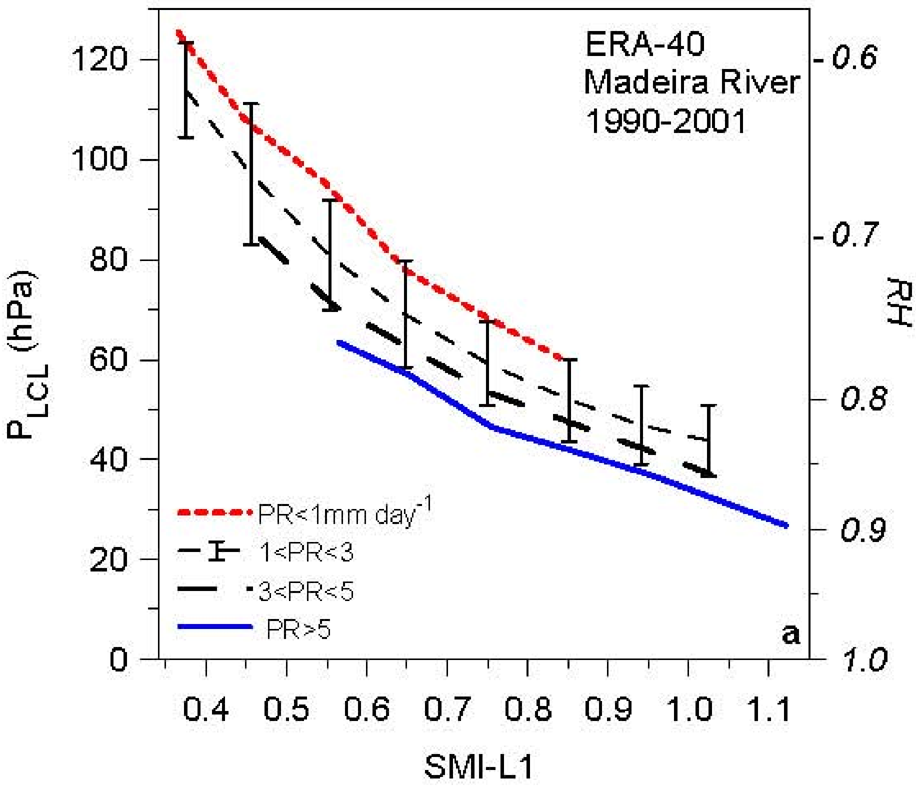
Surface LW_{net}

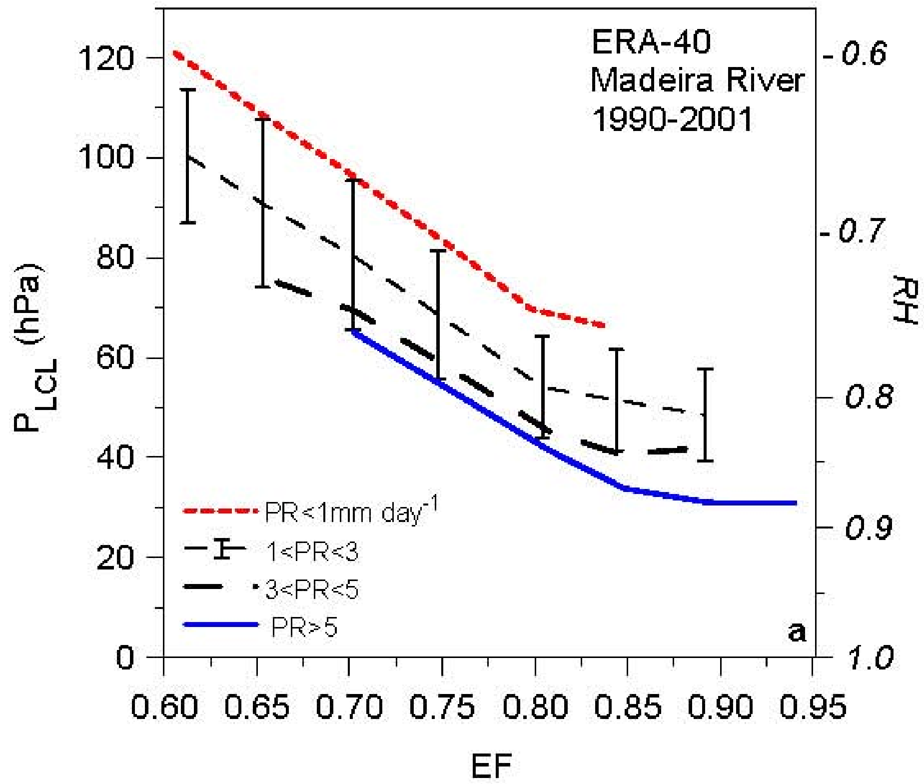




- Point comparison: stratified by RH/LCL & α_{cloud}
- Quasilinear clear-sky and cloud greenhouse effects
- Amazon similar

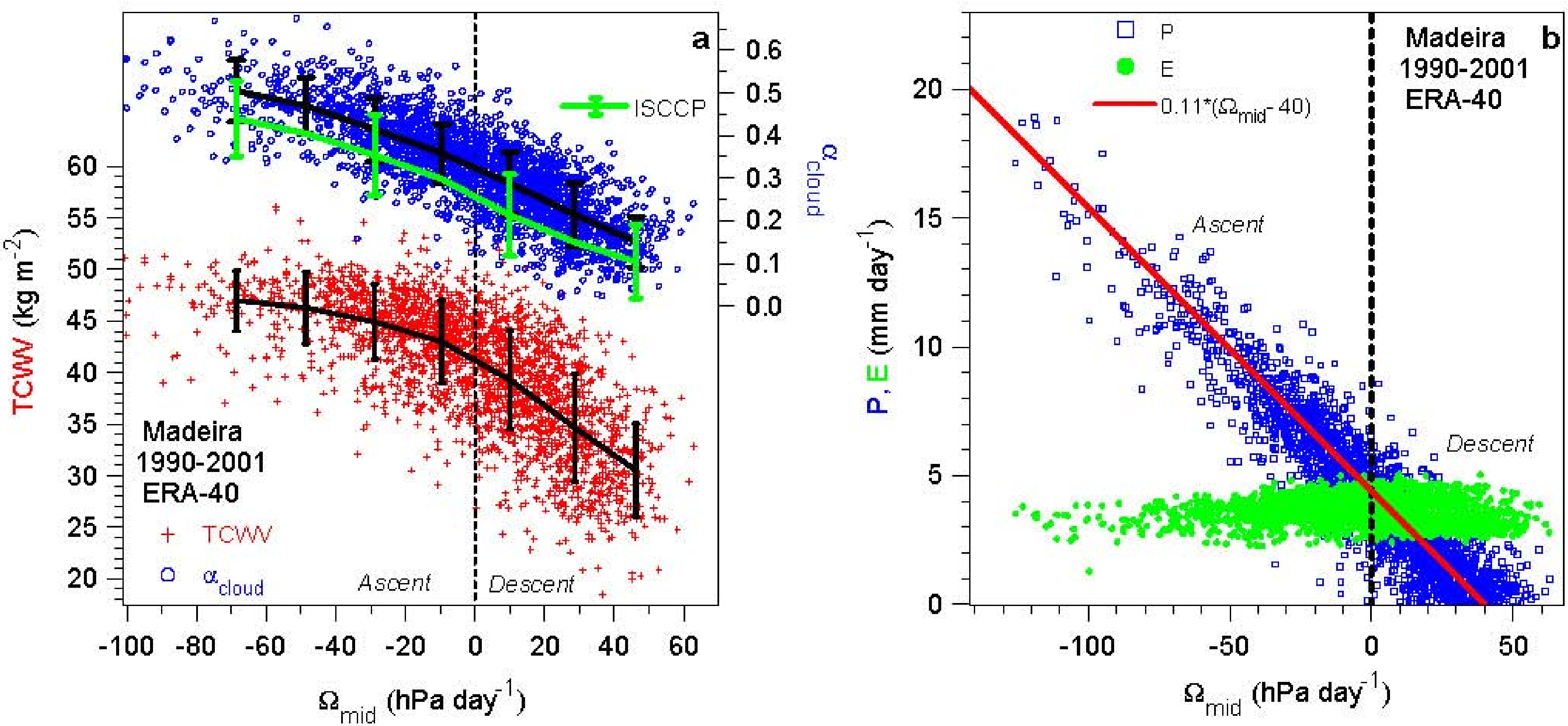
Land-surface-BL Coupling





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

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; while precip. generally low

Themes

- Evaluating models against independent data
- FIFE (grassland);
- BOREAS/BERMS (boreal forest)
- GEWEX (river basins)
- ERA-40 river basin & grid-point comparisons
- ISCCP surface shortwave estimates
- *Land-surface climate*
- Diurnal, daily mean, annual cycle
- *Precipitation, evaporation, dynamics*
- *Cloud radiative impacts*

Philosophical Summary

- Look for relationships and information in the coupling of processes/ observables
- Observations important for evaluation & to suggest processes that are simply missing
- Every model cycle needs analysis of relationships, diurnal, daily mean and seasonal, against observations
- Improved understanding of the coupling of physical processes leads to improved models
- A challenge: but tractable as both global, regional and point time-series datasets improve

- **Tony Hollingsworth deeply understood this challenge**

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