DIURNAL CYCLE OVER LAND

Alan K. Betts [akbetts@aol.com]

– High latitudes to tropics

– Important climate signal: driven by the diurnal cycle of the incoming solar radiation; controlled by
1) surface type [land/ocean][freezing of soil]
2) availability of water for evaporation/condensation
    [vegetation][soil water]
3) coupling to the atmosphere [subcloud layer]
4) the cloud field, controlling SW and especially LW
    [precipitation] [surface water balance]

In models LW_{net}, tightly coupled to model surface and BL physics, and DTR [diurnal temperature range]

– Errors in convection diurnal cycle can feed back on model dynamics, and have global impacts [ECMWF cycle 25R4, 2003]

References.

Betts, A. K., J. H. Ball, and J. H. McCaughey, 2001: Near-surface climate in the boreal forest. *J. Geophys. Res.*, **106**, 33529-33542. *[2001JD900047.pdf]*

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. *[2001JD900056.pdf]*

Betts, A.K., 2001: Soil Moisture Feedbacks. Invited paper at NAS panel meeting on "Climate Change Feedbacks: characterizing and reducing uncertainty, Boulder, CO, August 13-16, 2001. [*CRCBettsAug14_V3.pdf]*

Betts, A. K., J. Fuentes, M. Garstang, and J. H. Ball, 2002: Surface diurnal cycle and Boundary Layer structure over Rondonia during the rainy season, *J. Geophys. Res.*, **107**, 8065, doi:10.1029/2001JD000356, 2002.

Betts, A. K. and C. Jakob, 2002, Evaluation of the diurnal cycle of precipitation, surface thermodynamics and surface fluxes in the ECMWF model using LBA data.. *J. Geophys. Res.*, **107**, 8045, doi:10.1029/2001JD000427, 2002.

Betts, A.K., 2003: Diurnal Cycle. *Encyclopedia of Atmospheric Sciences*, J. R. Holton J. Pyle and J. A. Curry, Eds., Academic Press, London, pp. 640-643.

Betts, A. K. and C. Jakob, 2002, Study of diurnal cycle of convective precipitation over Amazonia using a single column model. *J. Geophys. Res.*, **107**, 4732, doi:10.1029/2002JD002264, 2002.

Bechtold, P., J.-P. Chaboureau, A. Beljaars, A. K. Betts , M. Miller, M. Köhler, M. Miller and J.-L. Redelsperger, 2004: The simulation of the diurnal cycle of convective precipitation over land in a global model. *Q. J. R. Meteorol. Soc*. (2004), **128**, pp. 1–999.   [dcycle_paper.pdf]

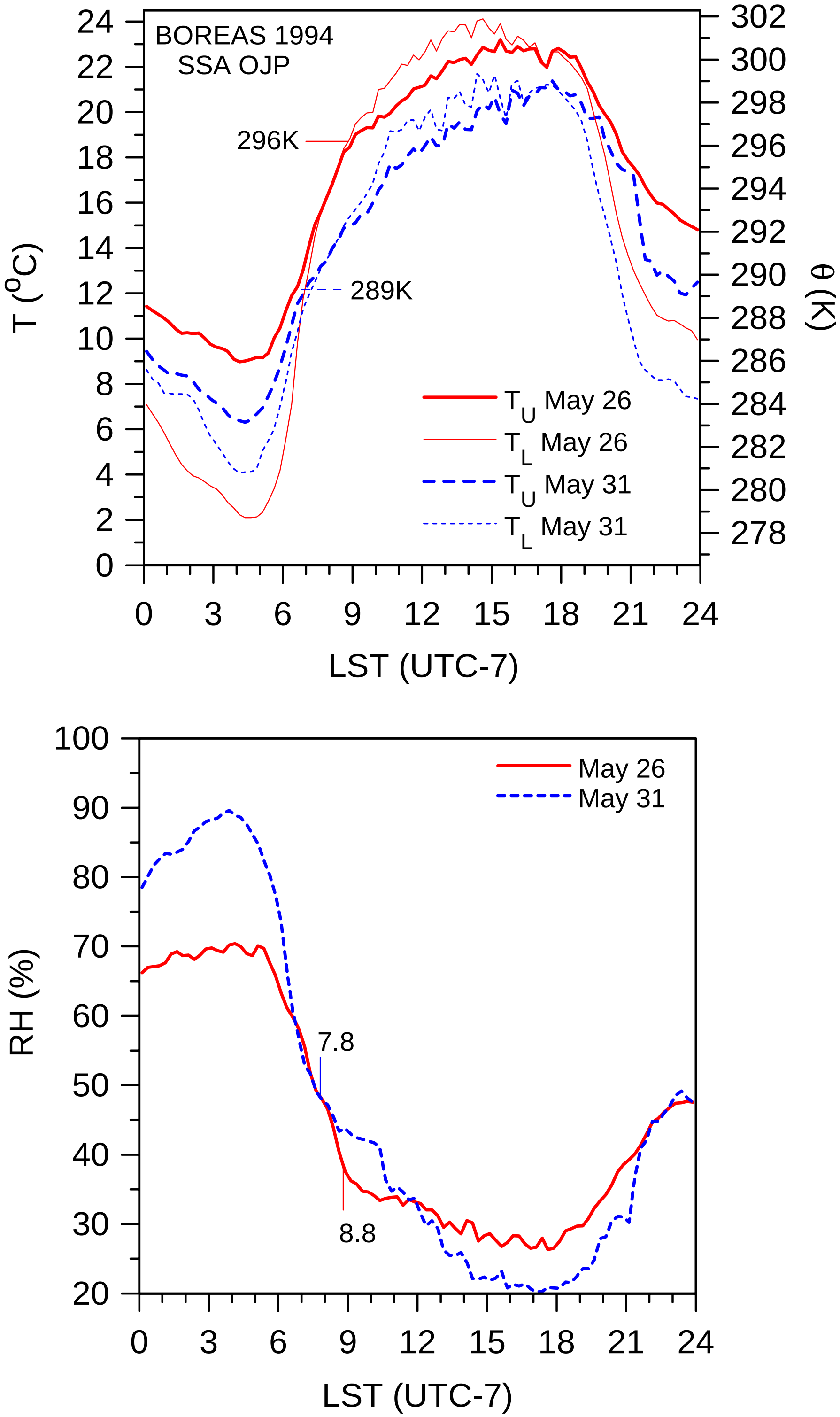


Fig. 2. Diurnal cycle of temperature, above and below a boreal forest canopy (upper panel), and of relative humidity above the canopy (lower panel) for two days in May, 1994.

Surface diurnal cycle for two days in spring.

The upper panel shows for each day the temperature at two levels, an upper level (T_U) which is at 21m, about 5m above the canopy of a jack-pine forest, and a lower level (T_L) about 5m above the forest floor. On both days the surface cools strongly at night and rises steeply after sunrise.
At night on May 26, the winds are lighter, and the atmosphere above is more stable.

There is very little evaporation from either the forest, or the cold lakes at this time in spring. The lower panel shows RH measurements above the canopy. In the late afternoon, RH falls as low as 20% on May 31.

The rate of rise of temperature and fall of RH decrease sharply on May 26 at a local time of 8.8 h, when θ reaches 296K; while on May 31, this occurs at 7.8 h, when θ= 289K .

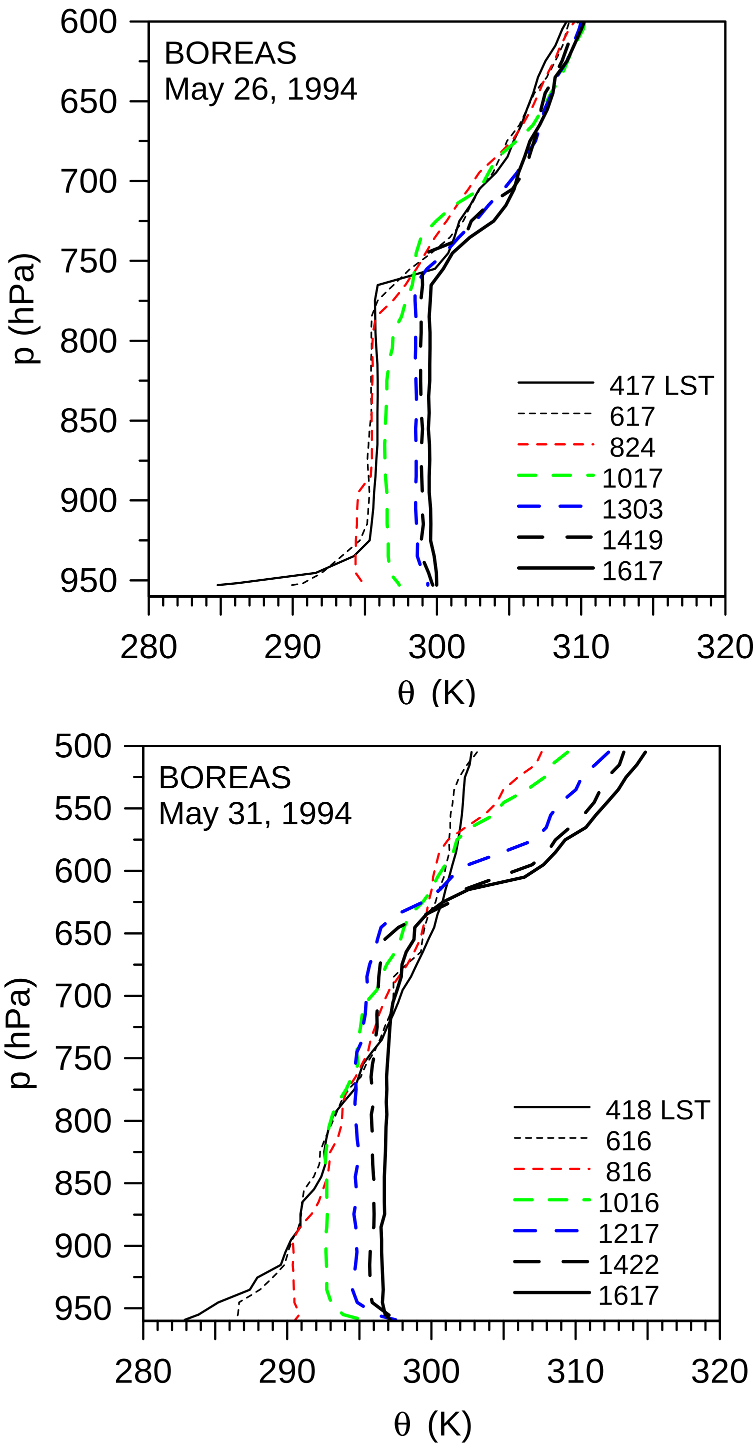


Fig. 3. Profiles of potential temperature in the lower troposphere on May 26 and 31.

Sequences of seven profiles of potential temperature in the lower troposphere for the two days.

The upper panel shows at sunrise a cold (stable) surface layer only about 25 hPa deep (200m), with a deep layer above of constant θ, which is the residual or "fossil" mixed layer from the previous day. At the surface the temperature warms rapidly, as the surface sensible heat flux is trapped in this shallow surface layer. Shortly after 0824 LST, when the surface potential temperature reaches θ= 296K, the new growing boundary layer merges with the deep residual mixed layer.

On May 31, the sunrise profile is quite different. There is a layer from 920 to 650 hPa in which θ increases steadily with height [produced by showers the previous evening with a wet adiabatic structure]. The small change in slope of the early morning profile at 920 hPa is at θ= 289K, and hence we see on Figure 2 a small change in the rate of warming, once the surface reaches this potential temperature.

Diurnal cycle as a function of soil moisture

– Grassland data [FIFE]
– mid-Summer averages
– Net radiation [R_n] constant

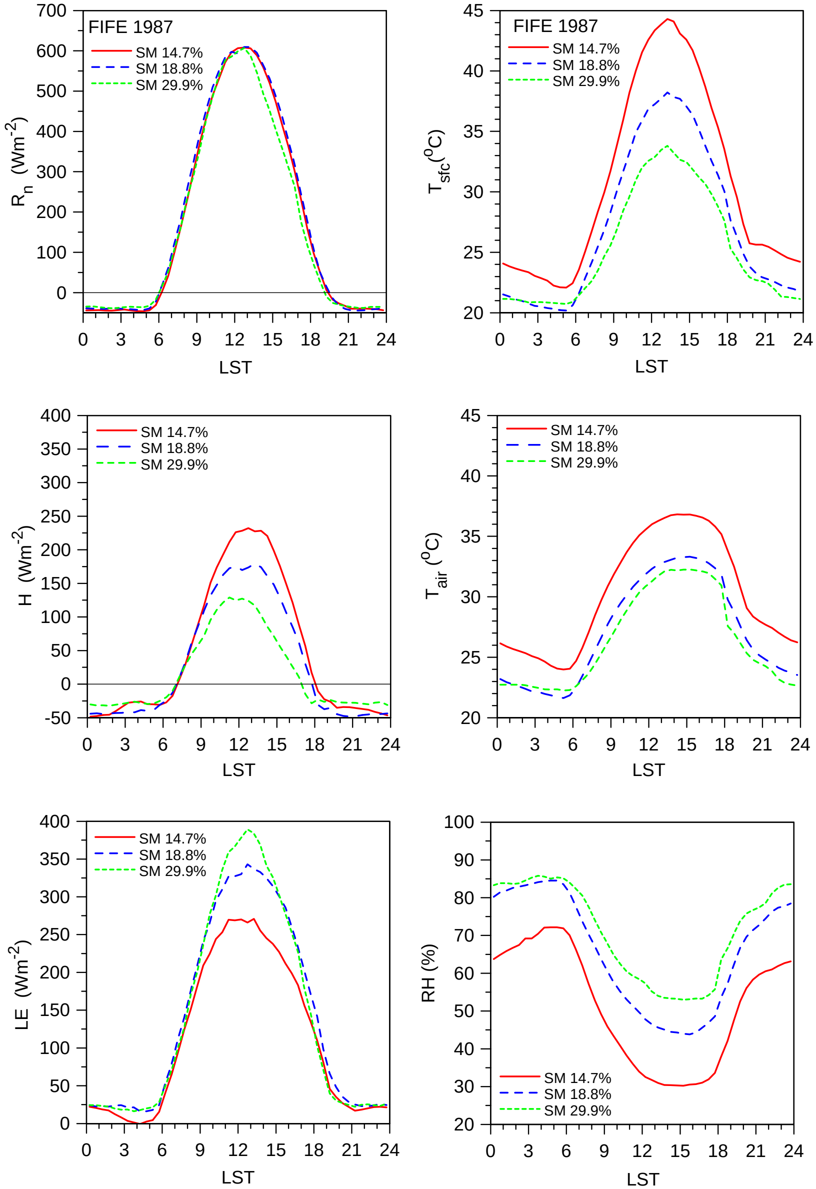
Partition of energy balance different: with dry soils

➔less evaporation, LE

➔ more sensible heat, H

Warmer surface, air at 2m

Lower RH



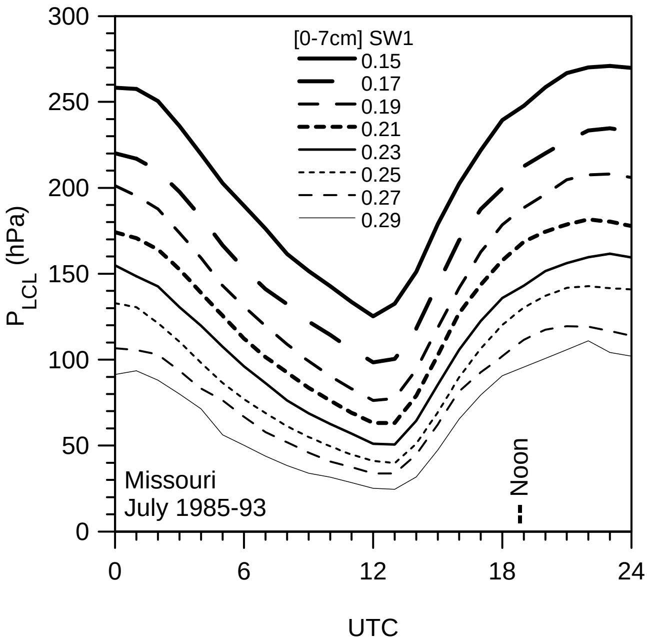


Fig. 5a. Mean diurnal cycle, stratified by soil moisture, for Missouri basin for July 1985-1993
from ERA-15. Local noon (near 1830 UTC) is marked.

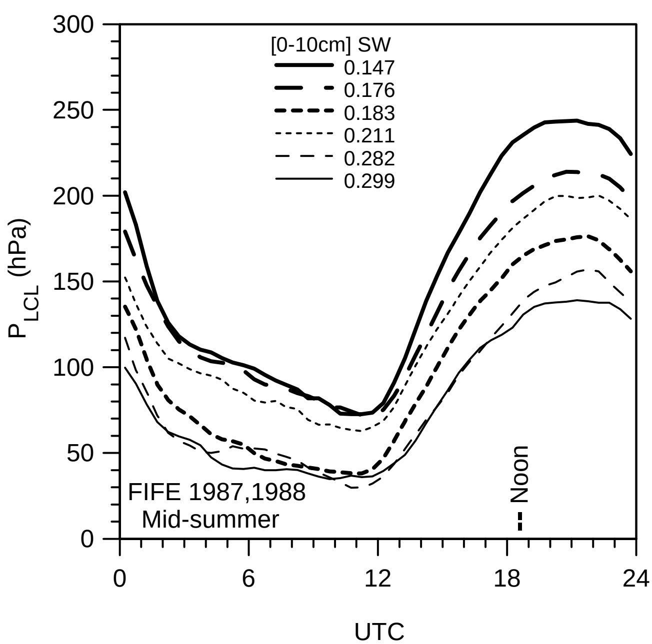


Fig 5b. As Fig. 5a for FIFE 1987 and 1988 mid-summer composites.

Soil water, which is a primary control on "resistance to evaporation" over land, controls the diurnal cycle of LCL (and RH.)

Fig. 5a. (from *Betts*, 2000) is the mean diurnal cycle of P_{LCL} from ERA-15 averaged for nine Julys over the Missouri river basin, and binned by soilwater in the first model layer below ground (0-7cm). There is a monotonic shift of the diurnal cycle of P_{LCL} , and an increase in its amplitude for drier soils. RH goes down and LCL/cloud-base goes up as the resistance to evaporation at the surface, controlled by soilwater, decreases. (The model resistance actually depends on the whole root zone soil water with bounds at the permanent wilting point of 0.171, and the field capacity of 0.323).

Figure 5b, for composites for the two summers of 1987 and 1988 from FIFE (1987 was shown in Figure 1), shows that the data shows a similar behaviour, although rather less pronounced than the model.

Dependence of P_{LCL} on surface water availability.

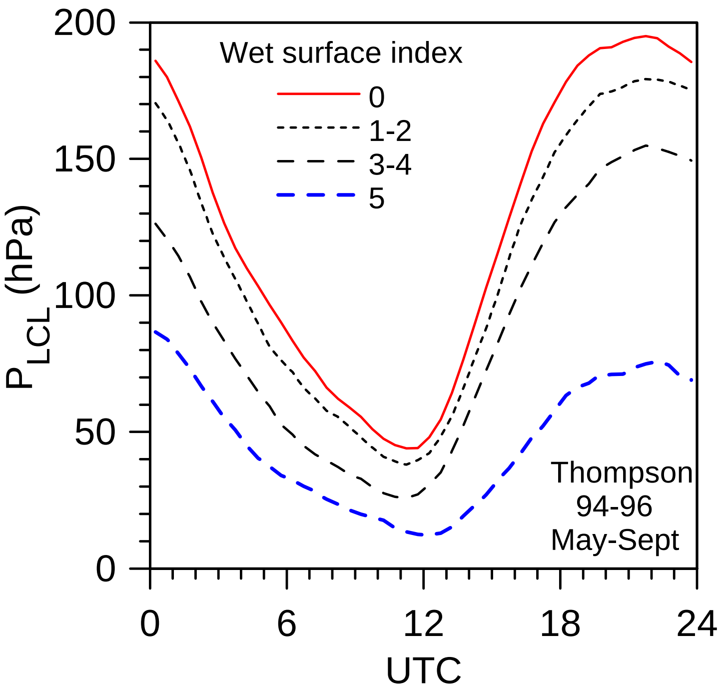


Fig. 8. Diurnal cycle of P_{LCL} for Thompson, MB, stratified by wet surface index.

The BOREAS site near Thompson has a stand of mixed spruce and poplar with a thick surface cover of moss. This acts as a reservoir for surface water, which has a large impact on evaporation.

WS = 0 represents days when the moss has dried out (negligible rain for 5 days), and WS = 5 represents days when ≥5mm of rain fell the preceding day.

Within a few days following large rain events, mean afternoon cloud-base height rises dramatically as the surface dries out, until the characteristic deep dry BLs over the summer boreal forest are again established.

Diurnal cycle of CO_2

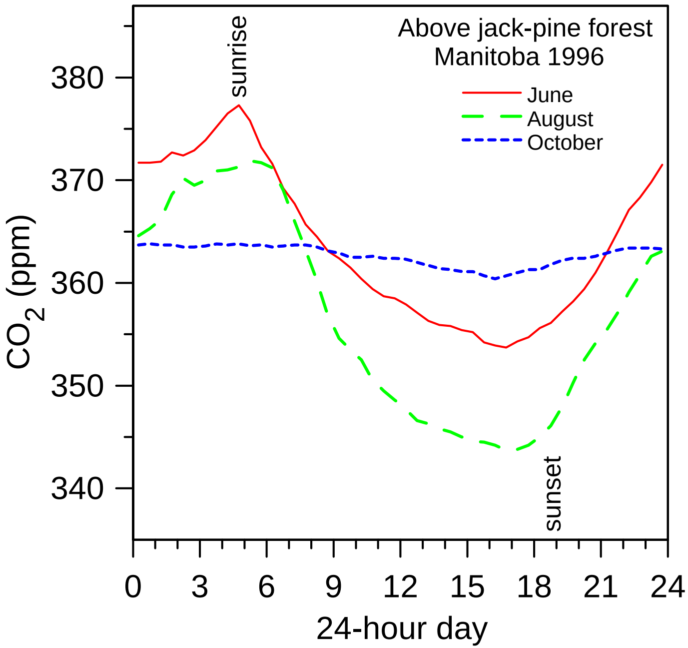
Photosynthesis in daytime and respiration at night

Monthly means

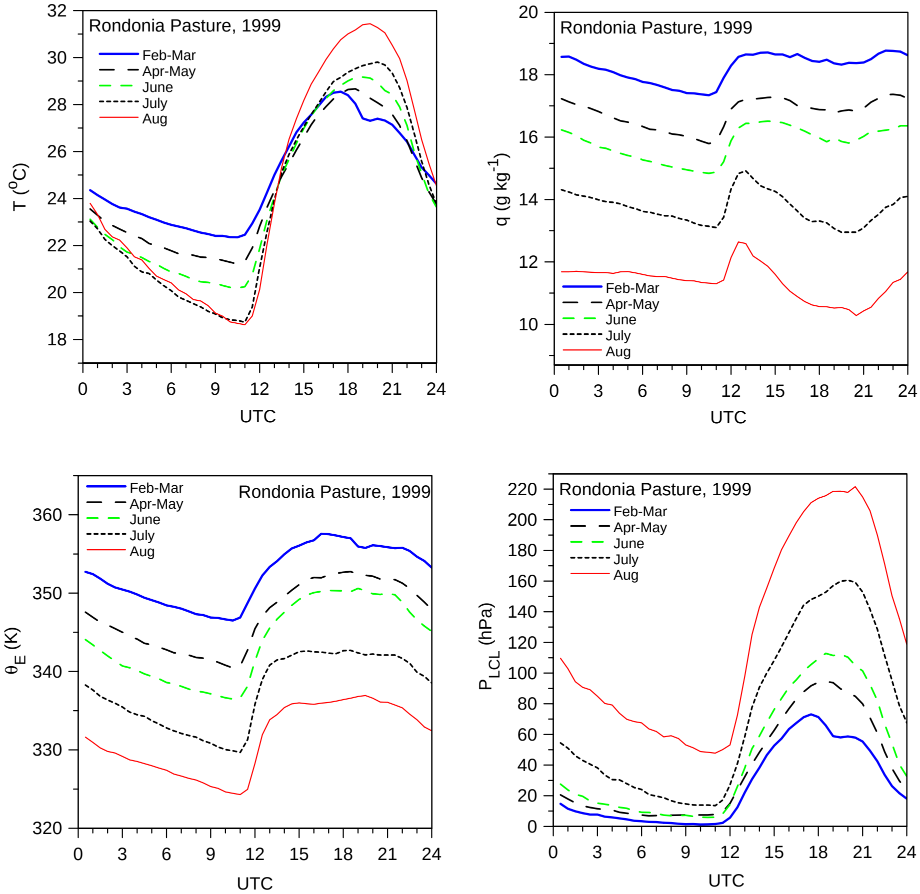
Flat when vegetation has died

Maximum photosynthesis in August

Mean shifted lower in August by N. Hemisphere uptake of CO_2



Seasonal transition from wet to dry season over Rondônia pasture

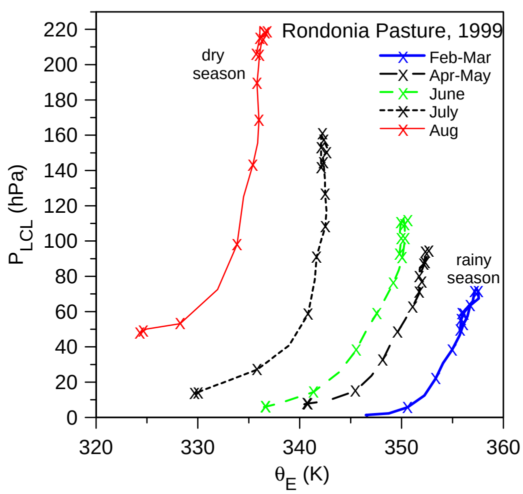


As soil and atmosphere dries, change of mean temperature is small, but diurnal cycle doubles. [R_n falls in dry season, as surface albedo increases: not shown]

Mixing ratio and θ_E fall, and P_{LCL} [cloudbase] goes up by factor of three

Figure 7. Diurnal cycle of surface thermodynamics from "Wet to Dry for Abracos pasture tower in Rondonia for 1999.

[data from Celso von Randow]

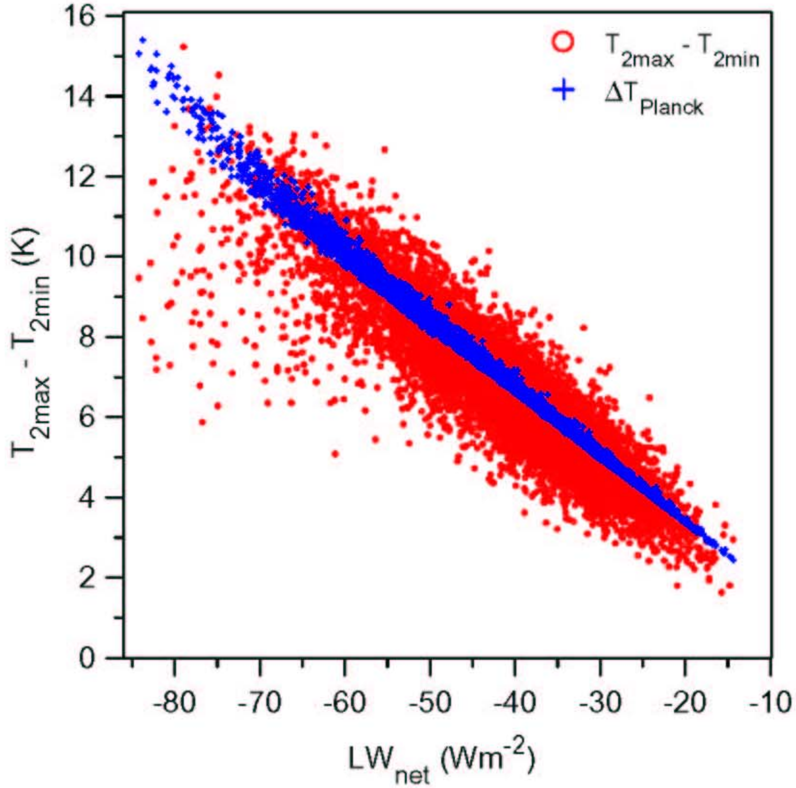


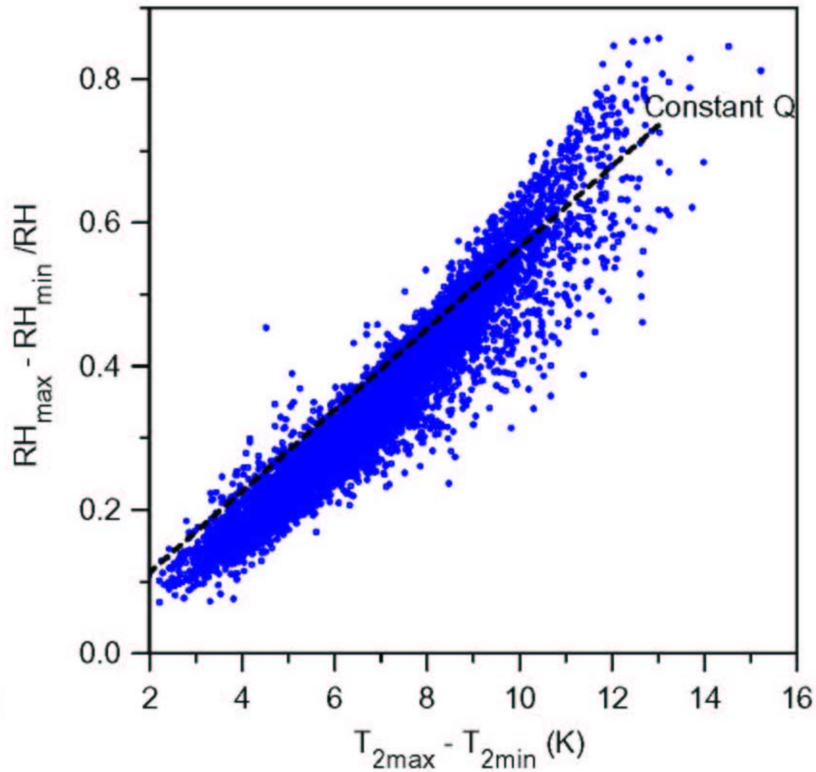
Contrast the larger seasonal transition here as the soil dries down with the smaller range in FIFE mid-summer composite.

'Flat' afternoon θ_E structure illustrates shallow cumulus control

Figure 8. Seasonal trend of daytime thermodynamic cycle of θ_E, P_{LCL}.
[Ticks are hourly]

Diurnal range of 2-m T and RH





) $T_{Planck} = - LW_{net} / 4FT^3$ gives diurnal range of T

Diurnal range of RH and T coupled: Q variation small

Evaluation of the diurnal cycle of precipitation, surface thermodynamics and surface fluxes in the ECMWF model using LBA data.

Alan K. Betts[1] and Christian Jakob[2]

J. Geophys. Res., 107, 8045, doi:10.1029/2001JD000427, 2002. [LBA]

[1]Atmospheric Research, Pittsford, VT 05763
[2] ECMWF, Reading, UK

Abstract

The mean diurnal cycle of precipitation, near-surface thermodynamics and surface fluxes from short term forecasts of the ECMWF model are compared with corresponding observations from the Large-scale Biosphere-Atmosphere Experiment in Amazonia wet season campaign in 1999 in Rondônia. Precipitation starts about two hours after sunrise in the model, several hours earlier than observed, because the model does not simulated well the morning growth of the non-precipitating convective boundary layer. However the mean daily precipitation during the wet season compares well with observed rainfall. On most days, maximum early afternoon temperature and cloud base height are lower in the model than observed. Maximum equivalent potential temperature is close to that observed. The model surface evaporative fraction is higher than observed, and rises to near unity in the late afternoon. Work is in progress to evaluate and integrate the parameterizations for shallow and deep convection.

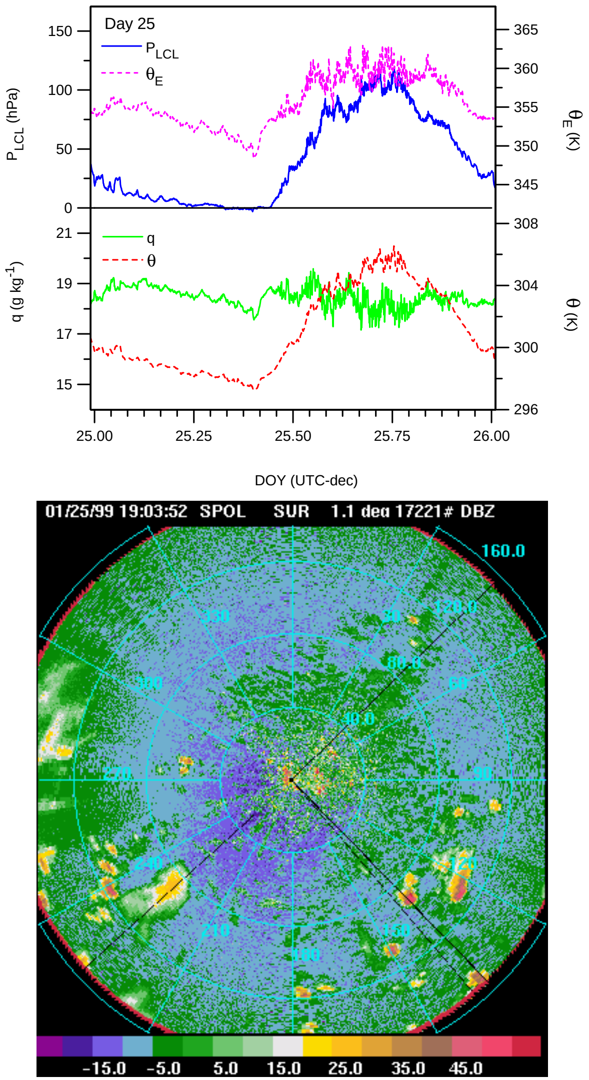


Figure 1a. Diurnal cycle of θ, q, θ_E, and P_{LCL} on Julian day 25 (above) and (below) S-Pol radar scan at 1903 UTC (1503 LST).

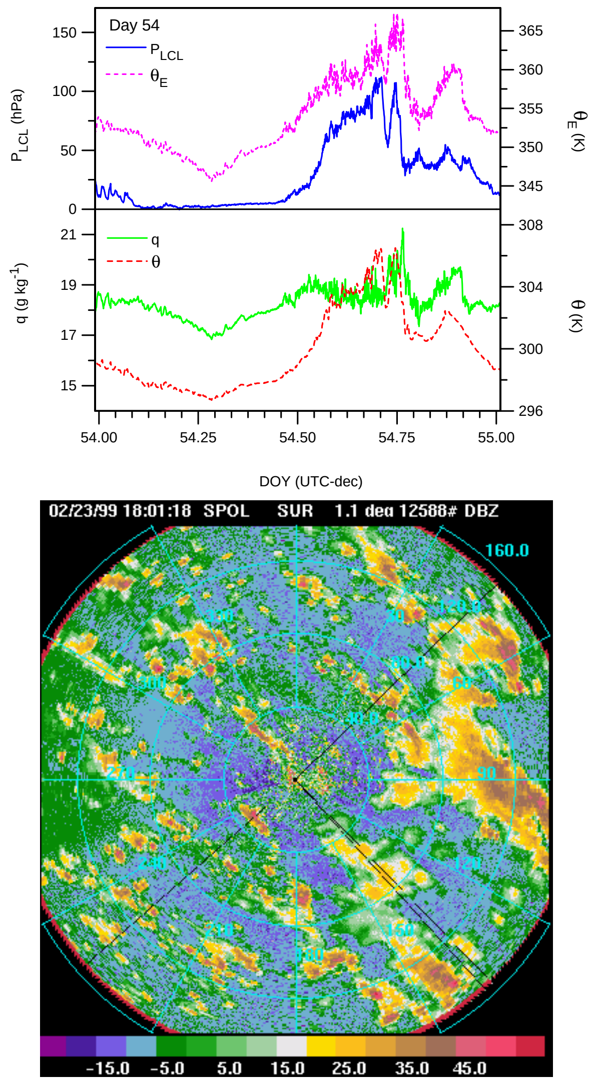


Figure 1b. Diurnal cycle of θ, q, θ_E, and P_{LCL} on Julian day 54 (above) and (below) S-Pol radar scan at 1801 UTC (1401 LST).

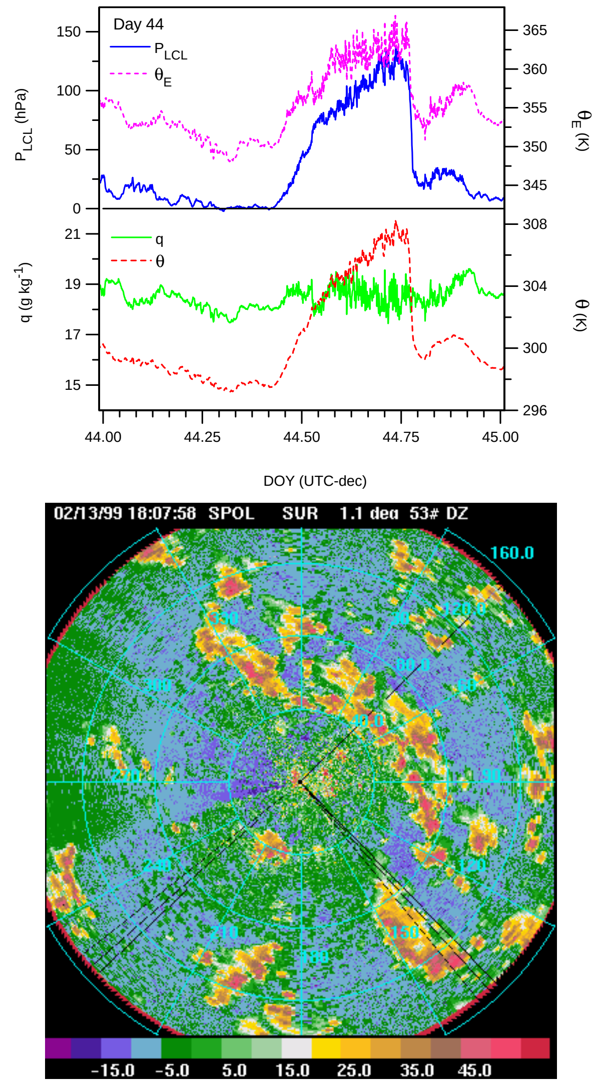


Figure 1c. Diurnal cycle of θ, q, θ_E, and P_{LCL} on DOY 44 (above) and (below) S-Pol radar scan at 1807 UTC (1407 LST).

Diurnal thermodynamic cycle at surface and typical radar picture for (a) undisturbed day, (b) westerly wind regime and (c) easterly wind regime

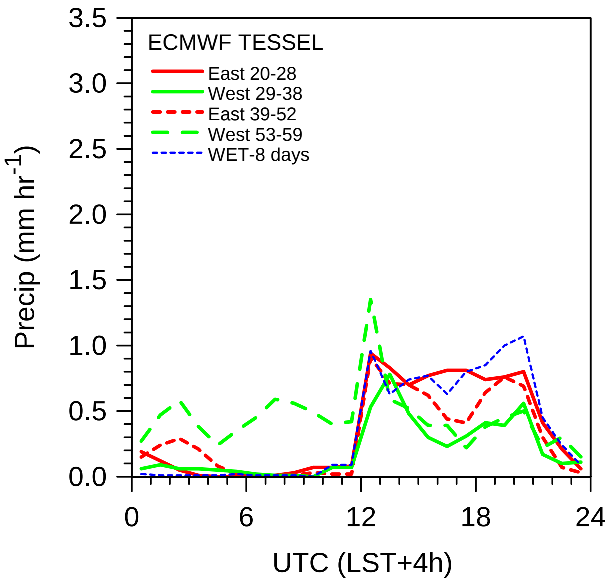


Figure 1a. Mean diurnal cycle of precipitation over Rondonia for 5 convective classifications for current ECMWF model.

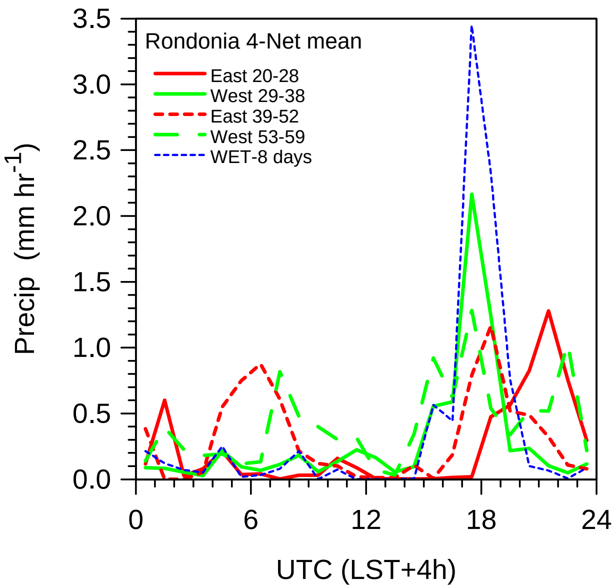


Figure 1b. As Fig. 1a for observed mean diurnal cycle of precipitation over Rondônia; an average of four raingage networks.

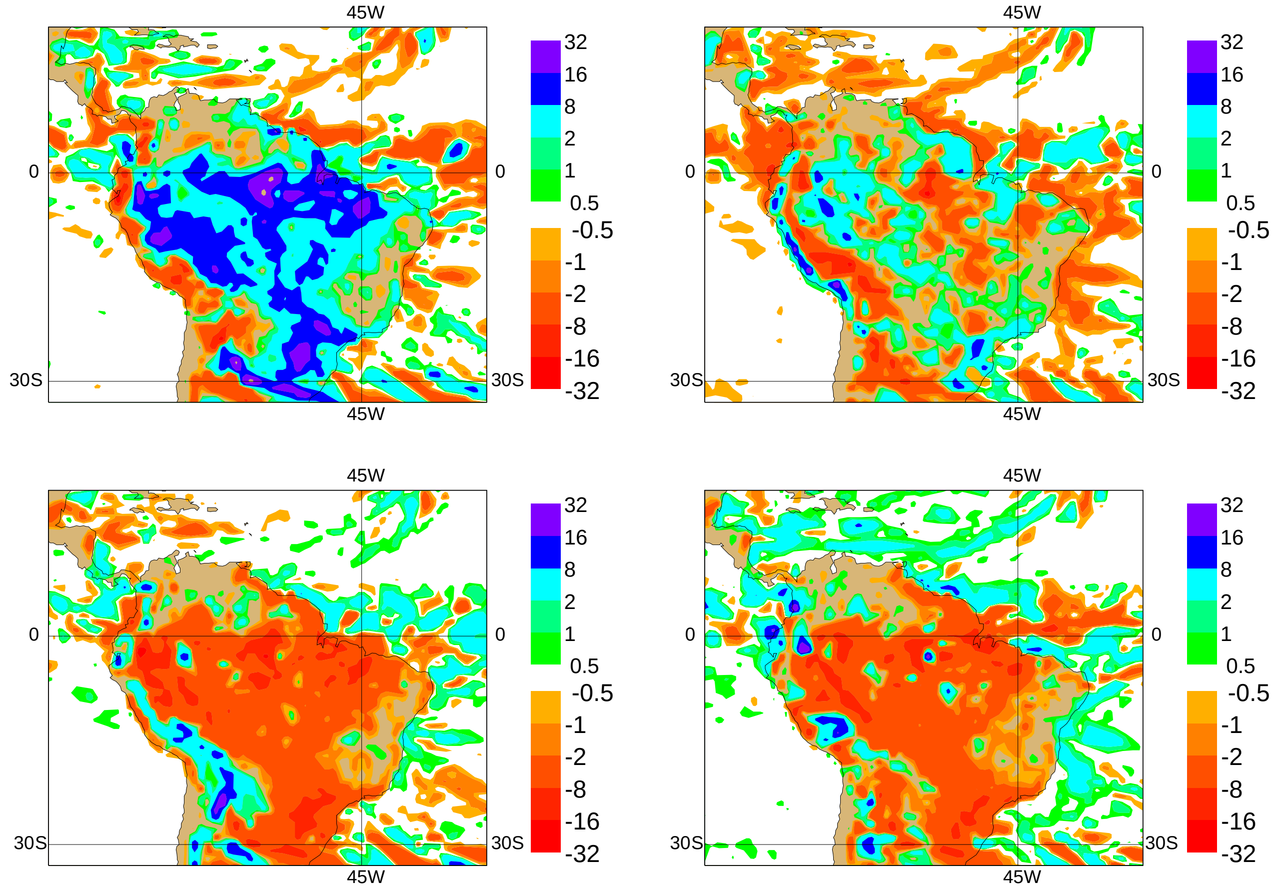


Figure 2. Diurnal cycle of precipitation anomaly from daily total over S. America from operational ECMWF model for 1-7 February, 1999. Shown are the 6-hour averages from 12-18 UTC (8-14 LST, top left), 18-00 UTC (top right), 00-06 UTC (bottom left), 06-12 UTC (bottom right). The units are mm day^{-1}.

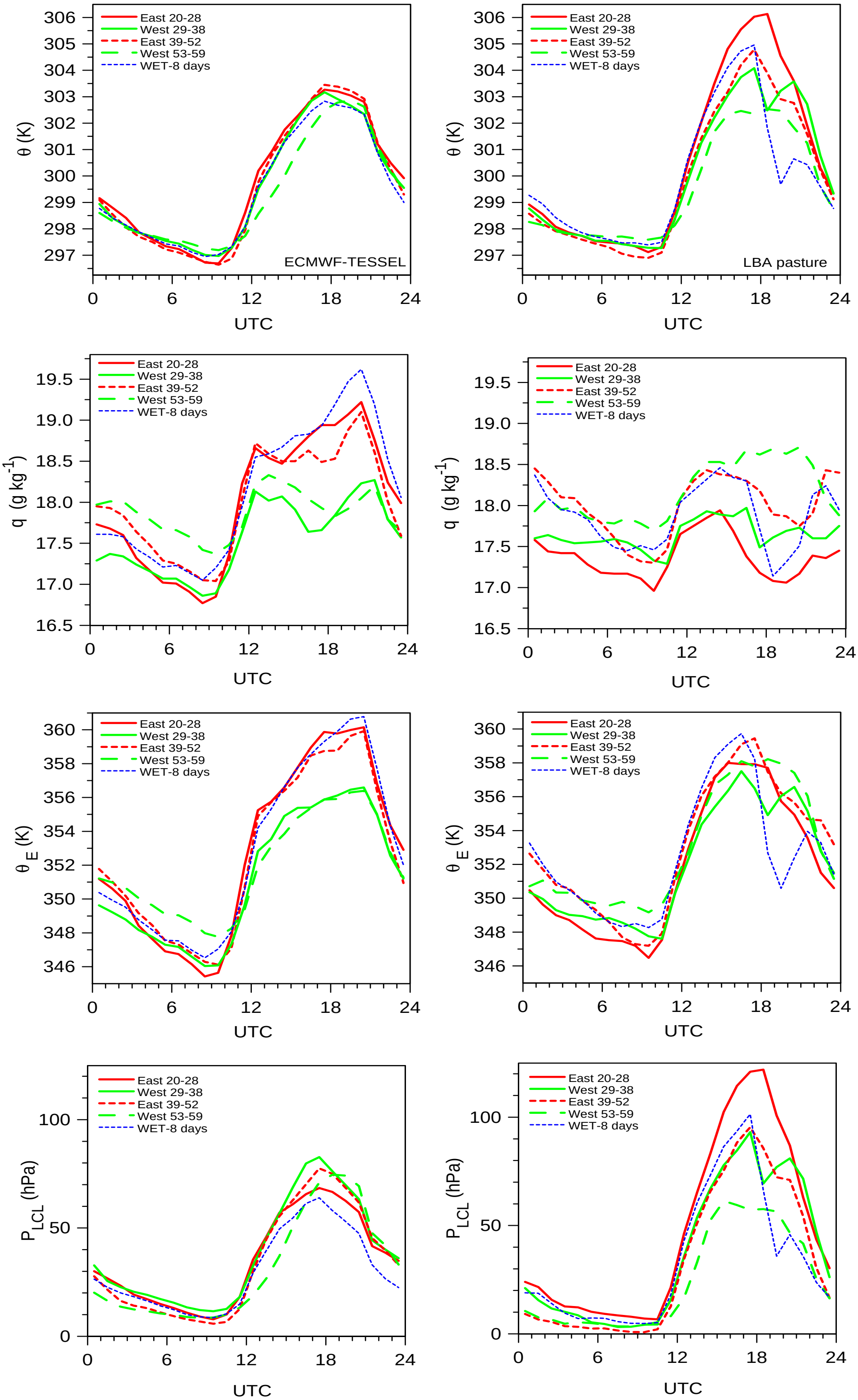


Figure 3. Comparison of surface thermodynamic cycle in ECMWF model (left) with LBA pasture site (right).

Problems in parameterizing convection over Amazonia

Alan K. Betts
Atmospheric Research, Pittsford, VT 05763
akbetts@aol.com

Christian Jakob
BMRC, Melbourne, VIC 3001, Australia

and

Peter Bechtold
ECMWF, Reading RG2 9AX, UK

– Convective precipitation occurs too early in the diurnal cycle over land in the ECMWF forecast model. Why?

– can we use a single column model [SCM] to develop a better cumulus parameterization?

– Changes in Cycle 25R4 which remove precipitation peak after sunrise

Betts and Jakob (2002b); Bechtold et al. (2004)

Acknowledgments. *Alan Betts acknowledges support from NASA under Grant NAS5-8364 and from NSF under Grant ATM-9988618, and from ECMWF for travel.*

2.1 Diurnal cycle of precipitation from the 3-D model, and SCM runs using large-scale forcing from 3-D model

Figure 1 compares the diurnal cycle of precipitation from the control model (CY21R4) for the Rondonia gridpoint [LBA-1999] from

a) an average of the 12-36 hour forecasts [extracted from 48 hour forecasts of the control model, run at T-319] verifying on DOY 30-58

b) an average for days 30-58, extracted from a T-95 global forecast with the control model initialized on DOY 20, 1999

c) an average for day 1 and day 2 of SCM runs of the control model for DOY 30-58, each constrained by the large-scale forcing extracted from the 3D T-319 forecasts for the Rondonia point.

d) an average of the LBA rain nets for DOY 30-58

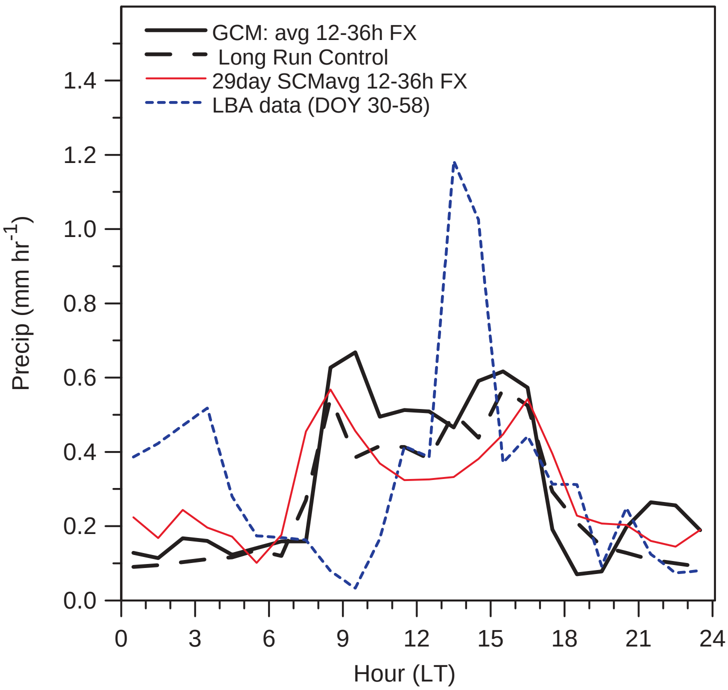


Figure 1 29-day mean diurnal cycle of precipitation from short term forecasts, long run, and SCM runs using large-scale forcing from the 3-D model.

We see that ***all versions of the control model give an early morning precipitation peak and a second peak in the late afternoon***, whereas the characteristic feature of the observations is a morning minimum in rainfall and a mid afternoon maximum, and a secondary night-time peak.

The diurnal precipitation structure from the 12-36 hour forecasts of the 3D model is very similar (although a little higher) than that from the 12-36 hr forecasts from the SCM model. This suggests that the SCM may be a useful (although simplified) version of the full 3D model for the study of the behavior of a parameterization schemes. The long-run average of the 3-D model (at lower resolution) also has a double- peaked precipitation structure, similar to the short term forecasts.

2.2 Mean vertical motion in control model

The large-scale forcing in the 3D model is dominated by the vertical motion field. A key issue in the tropics is the ***phasing of the mean vertical motion of the 3D model in relation to the phase of the diurnal cycle, since this has a large impact on cloudiness and precipitation.***

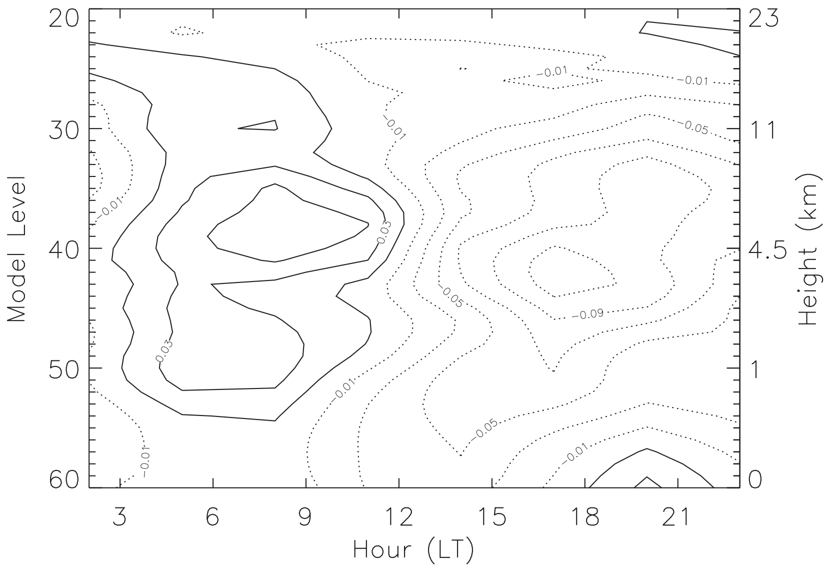


Figure 2. Mean diurnal cycle of omega field for 29-day average from short term forecasts.

Mean motion is up in the afternoon with a peak at 1700LST with the peak in subsidence a little before 0800 LST.
Daily mean motion is upwards in the middle troposphere, which is consistent with this being the rainy season and precipitation exceeding evaporation.

Figure 1 shows two rainfall peaks. The ***spurious morning peak is at the time of the maximum subsidence***, so it is not a response to the larger scale forcing

The omega field in Figure 2 is a stable feature of the 3D model although it is not necessarily “correct”.

3. Impact of idealized forcing on on SCM runs of the control model.

Figure 3 shows
idealized omega forcing for

Φ=0 : subsidence at midnight
M=0 : zero mean ascent
A=2 : 2x 0.05 Pa/sec

Standard forced SCM run was 15 days. Average day 2-15.
Initial conditions: Rondonia

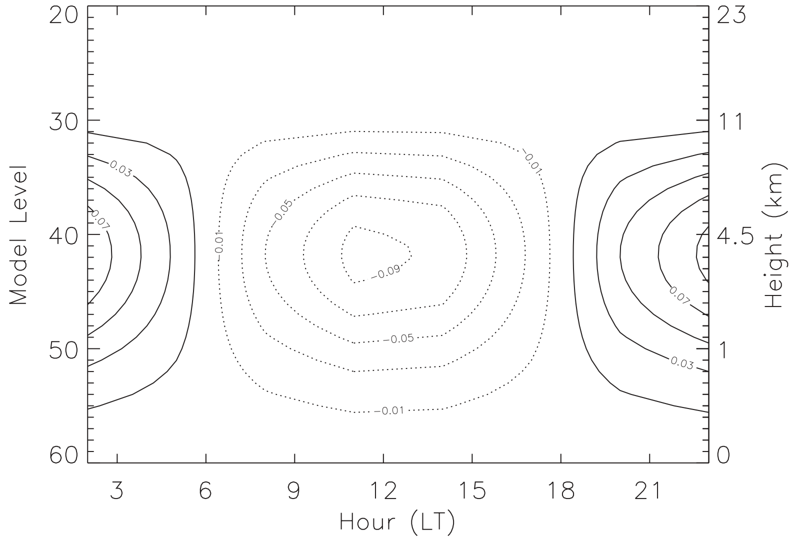


Figure 3 Idealized omega forcing of SCM for Φ=0, M=0, and A=2.

Will diurnal forcing give periodic diurnal cycle of precipitation?

We found that because of the strength of the non-linear interactions between the deep and shallow convection schemes and the radiation scheme, a periodic diurnal response was frequently not the result in this very unstable regime.

– Weak forcing: deep convection somewhat stochastic
– Stronger forcing, and specific phasing, some 1-day and
some near 2-day periodicity
– Mean ascent with some phasing, SCM would cloud over entirely, and drift
to a cooler overcast regime with stratiform rain.
– phase of forcing controls radiation budget, evaporation and precipitation.

3.1 Coupling between precipitation, evaporation and radiation budget

Scatterplot of 14-day mean

Surface net shortwave flux
Net radiation
Latent heat flux
Total daytime cloud cover

against

Mean precipitation

for M=0 (no mean ascent), A=0, 1, 2 and 4 and phase Φ from 0 to 21.

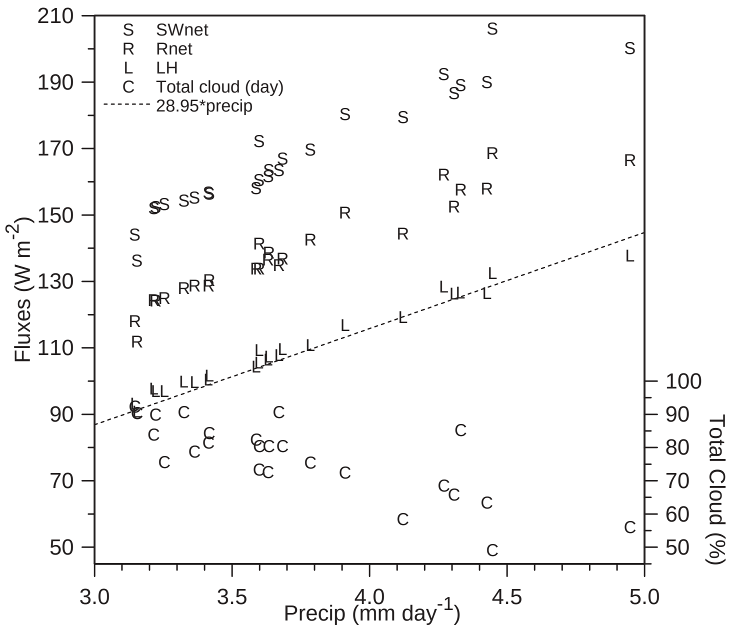


Figure 4 Scatterplot of 14-day mean radiation fluxes, latent heat flux, and total daytime cloud cover against precipitation.

Not surprisingly, precipitation, evaporation, Rnet, SWnet all increase together: loosely coupled with reduced daytime cloud cover.

Without mean forcing:

> ***mean surface evaporation quite closely controls mean precipitation***.
> [dotted line is conversion of precipitation (mm) to energy flux in W m^{-2}]

Large variability, related to the ***surface net radiation***

3.3 Impact of phase of forcing on diurnal cycle of precipitation

$\Phi = 6$ [subsidence peaking at 0600LT and ascent at 1800LT] gives a bimodal pattern by increasing precipitation at sunset and decreasing the morning peak, as A increases.

$\Phi = 12$ [subsidence peaking at noon] actually increases the morning peak, as well as producing more precipitation at night as A increases.

$\Phi = 0$ suppresses the morning peak and produces an afternoon peak as the diurnal omega forcing increases.

$\Phi = 18$, representing peak ascent at sunrise, simply splits the morning peak into a second one near noon.

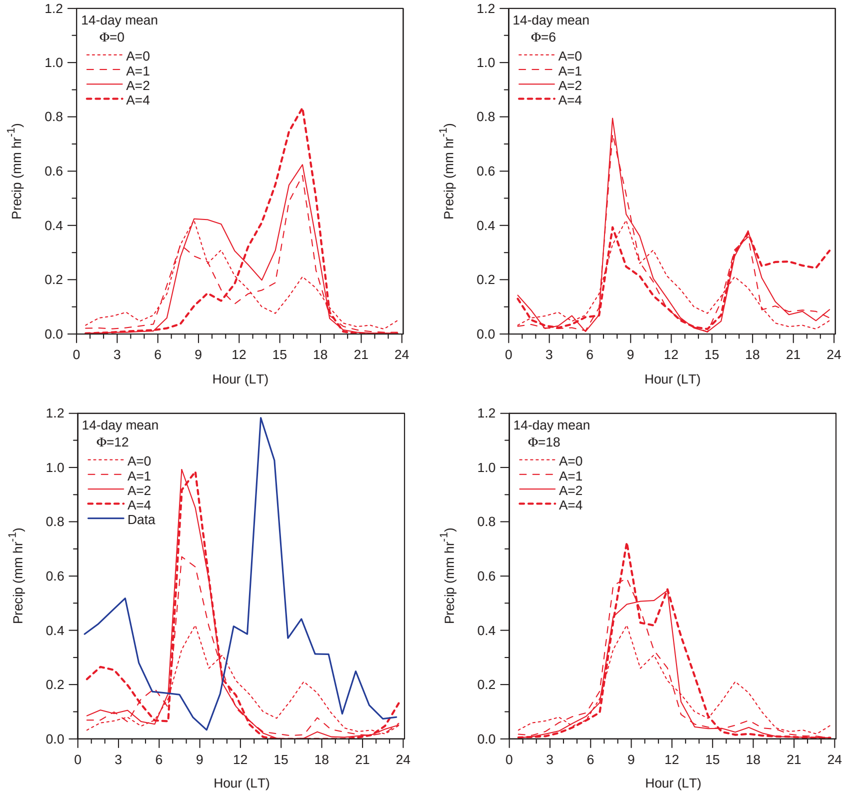


Figure 7. Dependence of diurnal cycle of precipitation on phase and amplitude of omega forcing. Lower left panel shows also the observed mean diurnal cycle.

Overall, the resilience of the morning peak in the model is remarkable.

We get a similar precipitation peak to the data with the control model by choosing $\Phi = 21$: which is almost out of phase with the 3-D model omega field

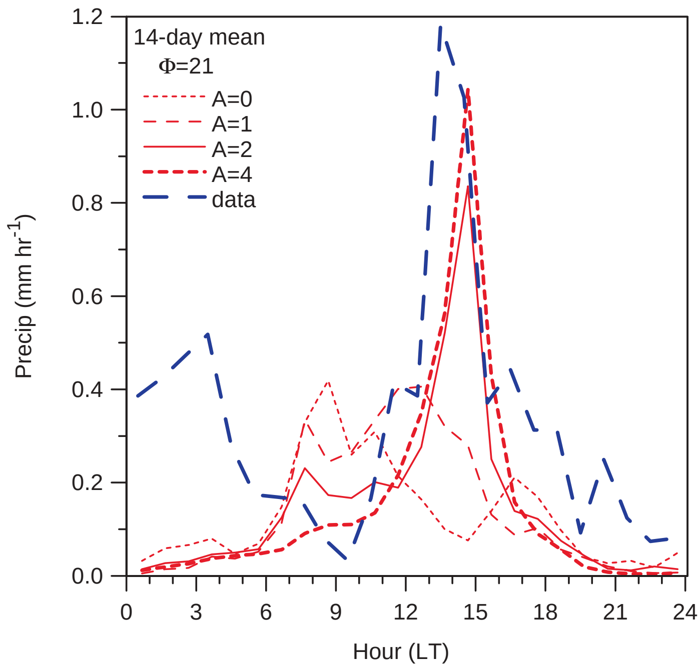


Figure 8. Comparison of observed precipitation and SCM for omega forcing phase $\Phi = 21$.

3.5 Impact on precipitation of imposing mean ascent

The data is banded:

M=0 lie close to the dotted 1:1 line

M=1: dashed line: offset of 4.7 mm

M=2: offset of 9.4 mm.

Observed mean precipitation of 7.4 mm day^{-1} during the rainy season corresponds to M closer to 1.

Note the split on the upper band for M=2 into high and low E.

– some SCM simulations collapse in a few days to 100% cloud cover [stratus and large-scale rain]

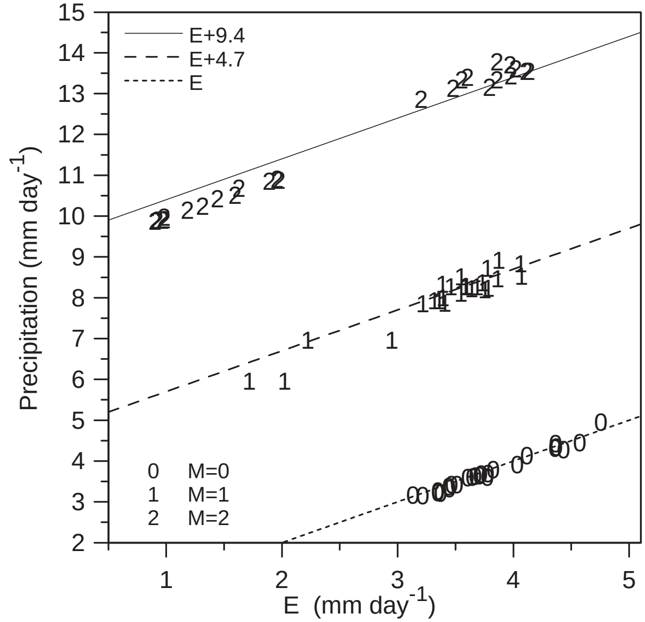


Figure 9a. Scatterplot of 14-day mean precipitation against evaporation for increased mean omega forcing

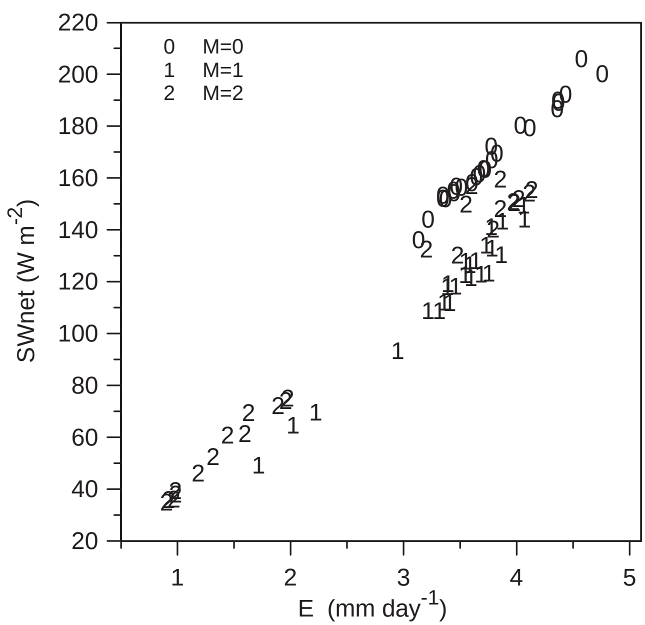


Figure 9b. As Figure 9a for mean net short-wave radiation.

3.7 SCM temperature, LCL and precipitation diurnal cycles

Drift of temperature with time indicates the imbalance of the radiation field associated with the different phasing of the cloud field.

For Φ=12, temperature drifts warmer, and the diurnal variation of P_{LCL}, and precipitation is quite regular.

Φ=18 drifts very slightly cooler and stays nearer to saturation during the daytime.

Φ=0 oscillates between a warmer (and less saturated) and a colder diurnal cycle, in which some days have large precipitation, interspersed with days with very little rain.

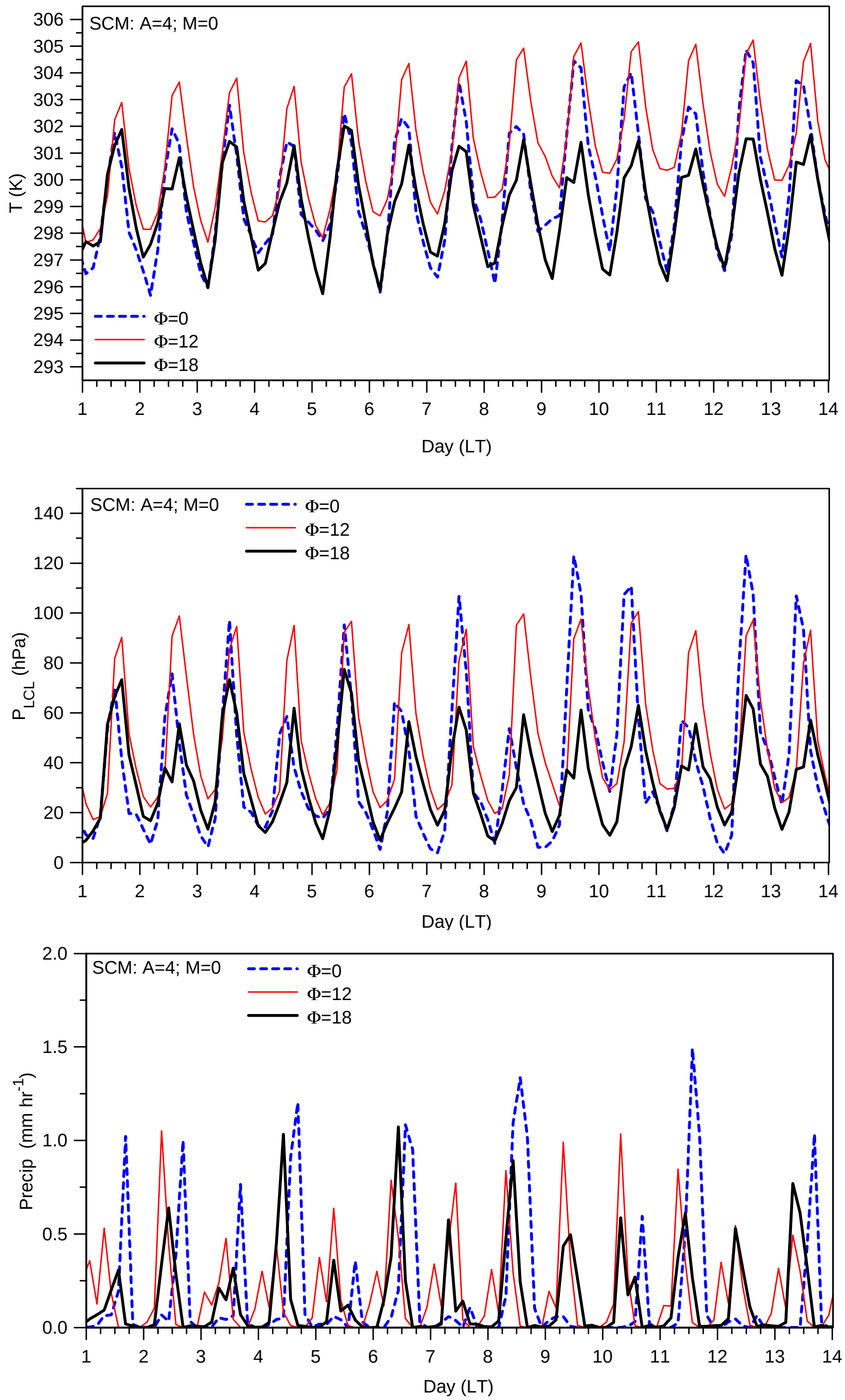


Figure 11. SCM control runs of T, P_{LCL}, precipitation with A=4, M=0

SCM has a complex range of responses, as the relative phase of the diurnal solar forcing and the omega forcing changes.
[Some not obvious, like the quasi-2-day mode]

Mean ascent M=1

Φ=12: periodic warm diurnal temperature: unsaturated
[daytime mean subsidence]

Φ=0, and especially for Φ=18, the model drifts cooler, more saturated
[some recovery second week]

Φ=21 saturates and stays cold and cloudy
[strong daytime ascent]

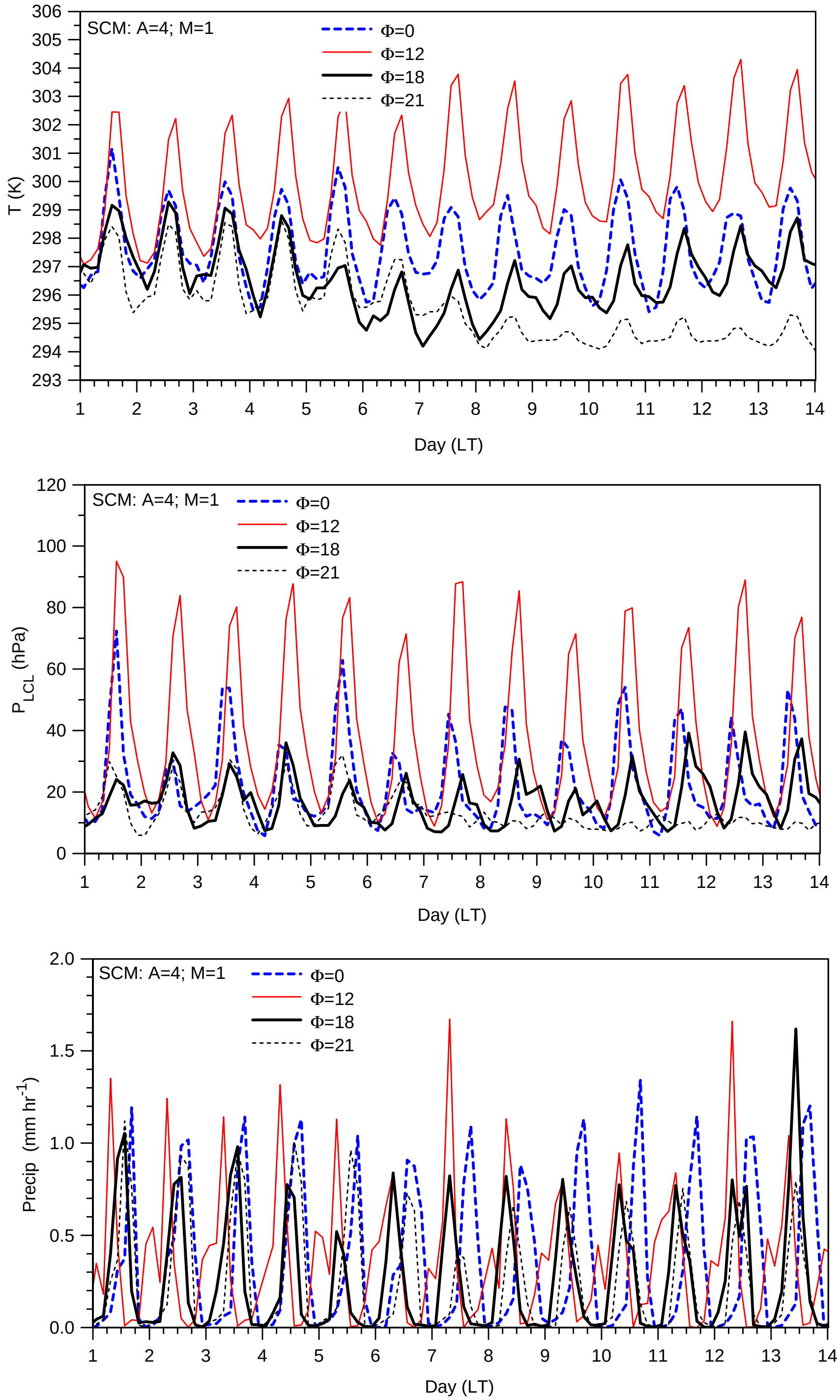


Figure 12. As Figure 11 for M=1, with Φ=21 in addition.

3.8 Impact of phase of diurnal omega forcing on convective and stratiform rain.

With sufficient mean ascent [M=2]
– two distinct modes:
high and low precipitation corresponding to convective and stratiform rain,
depending on the phase of the diurnal forcing

Daytime subsidence for Φ= 6 to 18 gives daytime convective rain and high R_{net}.

Daytime ascent for Φ= 21, 0 and 3 gives daytime stratiform rain, and low R_{net}.

[stratiform rain for Φ= 6 to 18: mostly at night, when there is large-scale ascent]

Lower R_{net} gives drop of θ_E from around 360-365K to only 344K, and near-surface air close to saturation.

Very different surface energy balance

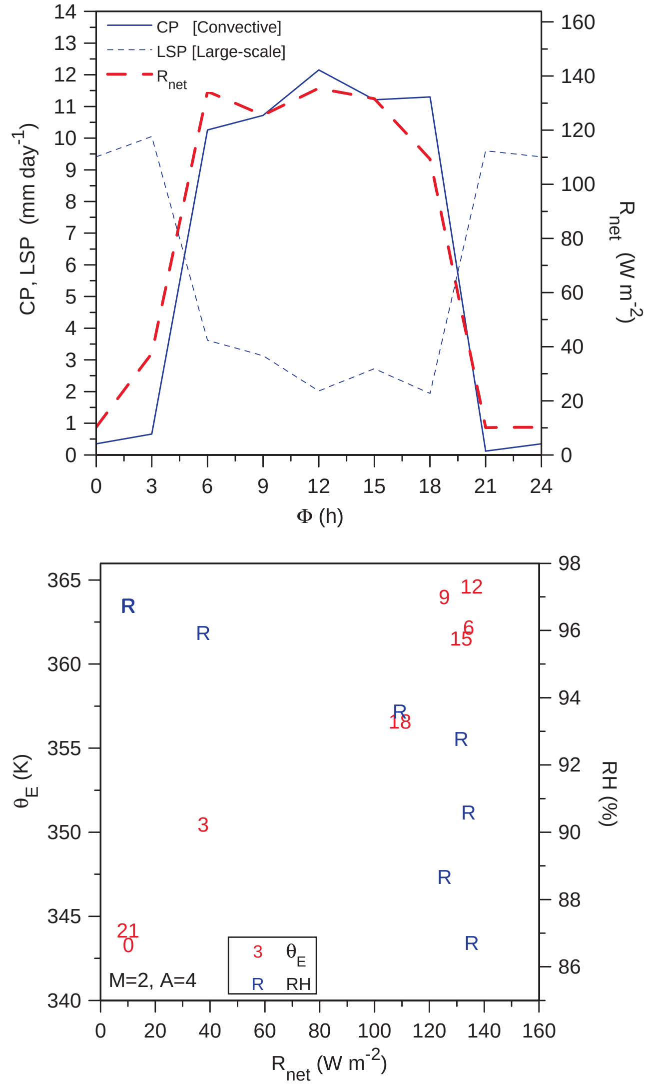


Figure 14. Dependence of convective and large-scale precipitation (mean for days 6-15) and R_{net} on phase (upper panel), and 2-m θ_E and RH on R_{net} (lower panel).

4. Conclusions: Part 1: Assessment of SCM runs

3D problem complex, involves all physics: 1-D SCM simpler to assess

Can 'large-scale' and convection be "uncoupled"?

Is large-scale omega forcing reasonable? **Yes**, from later studies

Is convective parameterization wrong? **Yes**, but precip in 3D and 1D proved rather insensitive to parameterization changes ***[in its 2002 formulation]***

[More cumulus entrainment "solves" morning rain problem, but returns on day 2]
[Failure of afternoon deep convection to stabilize lower troposphere enough?]
[Unsolved mesoscale convection precipitation efficiency]

Radiation diurnal phase interaction important to climate:
Climate "SW cloud feedback" is a diurnal problem

Are SCM runs useful? Yes

– SCM and 3D model runs, whether idealized forcing or composites of model forcing are broadly consistent.
– Can understand some aspects of SCM "climate equilibrium"

– SCM bifurcates [with sufficient mean ascent] into convective rain [daytime subsidence] or stratiform rain [daytime ascent], with profoundly different surface energy balances.

Comparison of diurnal cycle over Amazonia from cycle 25R1 and 25R4. (October 8, 2003)

Subsequent work at ECMWF led to the operational implementation of cycle 25R4 (on January 14, 2003), which improved the diurnal cycle of precipitation over Amazonia, as well as over the central United States (Miller et al., 2003).

Model cycle 25R4 included several changes to the convection scheme.

For deep convection, instead of lifting a surface parcel, sequential ***30 hPa thick*** layers (up to 700 hPa) are mixed, given a perturbation of +0.2K and +0.1 g kg-1 and then ***lifted***, and tested to find a cloud top, based on a parcel w-equation.

The effect of lifting a sequence of 30 hPa layers is to permit evening convection after the surface layer has cooled and stabilized (see talk by Martin Miller), and it ***also removes the spurious morning convection peak over Amazonia*****.**

Simplified equations are used for lifting the test parcels.
For deep convection, entrainment is set by mixing a parcel with 5% of the environment at each level, and 50% of the condensation at each level is removed as rain. The effect of these changes in the tropics is to permit more deep convection, which is turn reduces the frequency of large-scale precipitation.

In the subsequent detailed computation of deep convection, the turbulent entrainment for deep convection was increased to 1.2 10^{-4} (from 10^{-4} in 25R1). This had a significant impact on the upper tropospheric winds, through increased momentum mixing. In the parameterized convection microphysics, the conversion factor from cloud water to rain water was increased by 50% to 1.5 10^{-3}: this reduced typical in-cloud water or ice contents by 60% (which were too high).

Mean February diurnal cycle averaged over Amazonia

(from sub-basins 8-12: 5.7 10^6 km^2)

Operational model basin archive for S. America at T-511

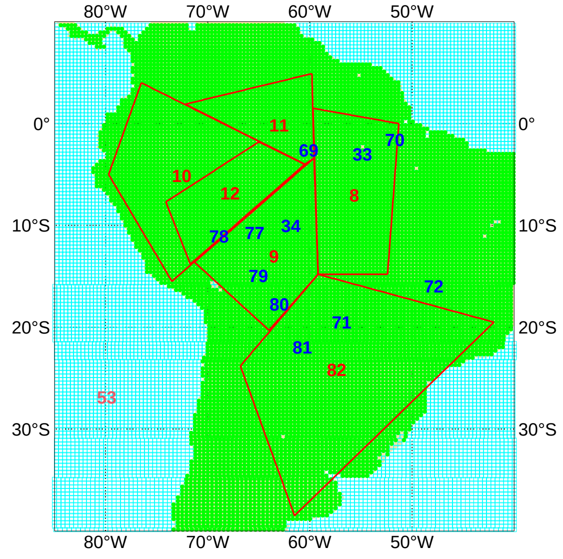


Figure 2.1. Basins (red) and points (blue) in operational archive

Daily 48-72hr T-511 forecasts

(from 1200 UTC analyses)

Feb. 2002 from 25R1 (OPS, control, dotted red)
Feb. 2002 with 25R4 model and analysis from 25R1 (solid red)
Feb. 2003 from 25R4 (analysis and model, dashed blue).

These give us a comparison for the same month from the two model cycles, and a comparison of 2002 with 2003 for the current model cycle, 25R4.

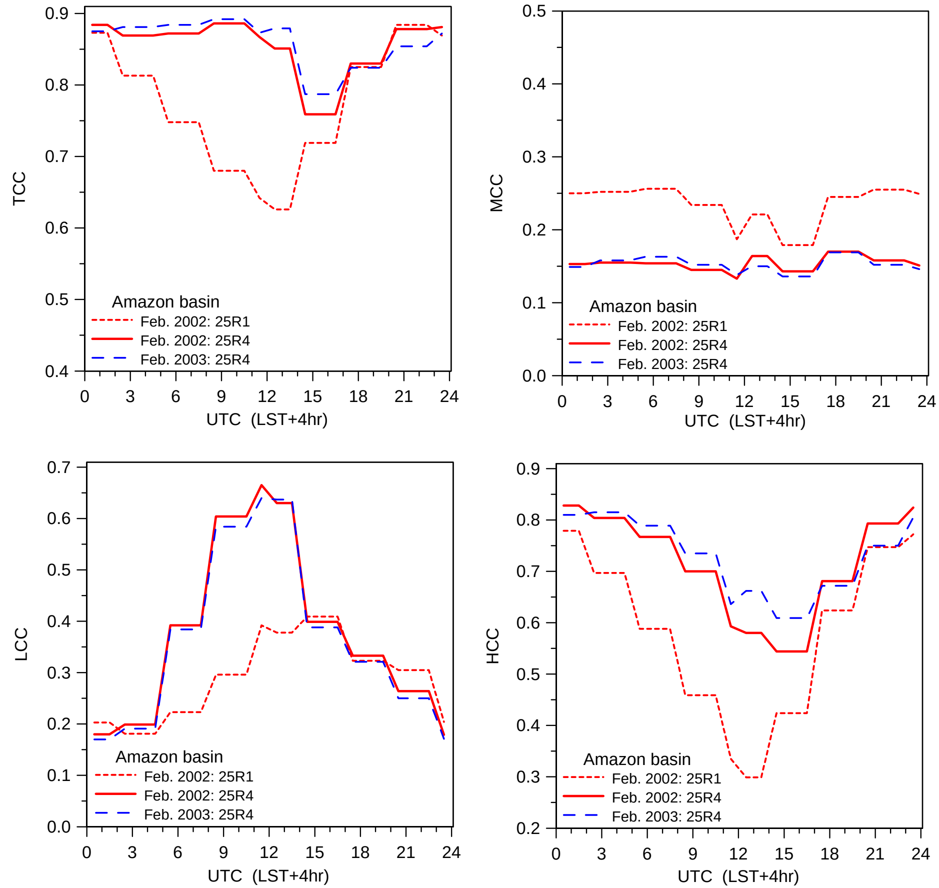
Important differences between model cycles can be seen in the diurnal cycles of precipitation, cloud cover, SW_{net}, LH, and Q.

Cloud cover

TCC: total
LCC: low cloud
MCC: medium-level
HCC: high cloud

25R1 to 25R4
Increased total, low and high cloud cover (primarily in the night and morning hours)

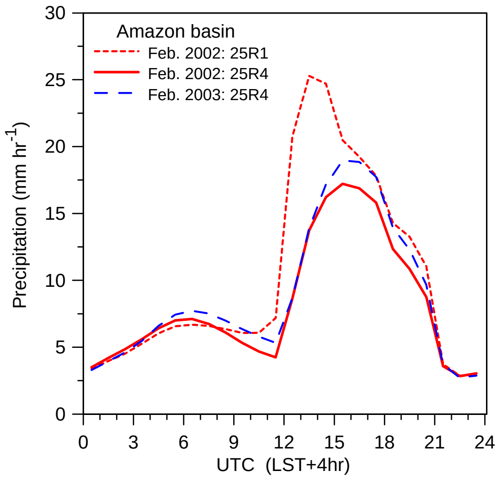
Reduced medium-level cloud cover.

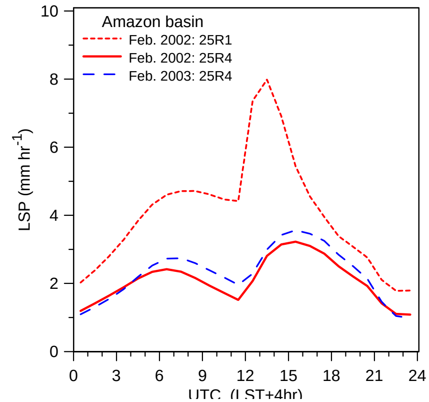


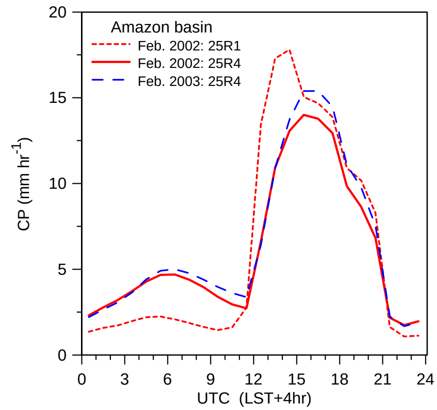
Precipitation:
diurnal cycle

Total

LSP: large-scale
CP: convective







The changes to the deep convection scheme in 25R4 have removed the spurious morning convection peak, and also reduced the large-scale precipitation.

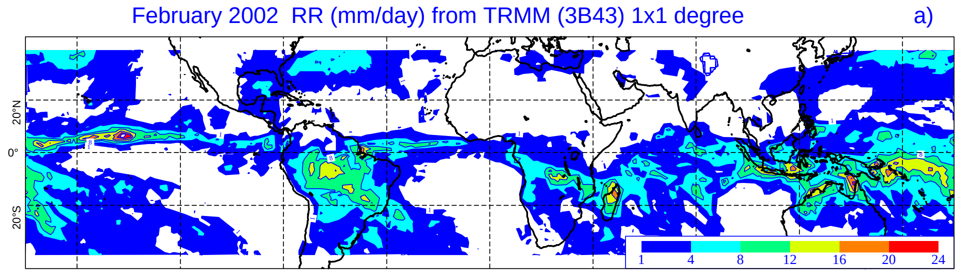
Daytime convective precipitation is in phase with the solar heating.
Night-time peak in cycle 25R4 is at the observed time of 0700 UTC.

[small phase shift in afternoon omega maximum]

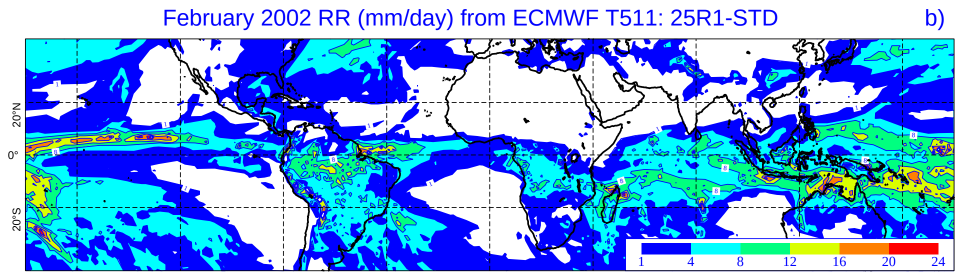
Total precipitation is reduced: is this an improvement?

Precipitation: comparison with TRMM

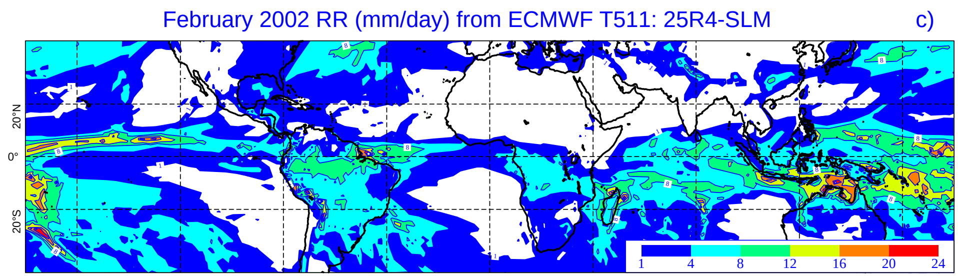
TRMM 3B43 is merge of IR and microwave



25R1 Amazon noisier



25R4 Amazon smoother, but less precip. than TRMM



Surface Thermodynamics

T_2 : 2-m temperature

Q_2 : specific humidity

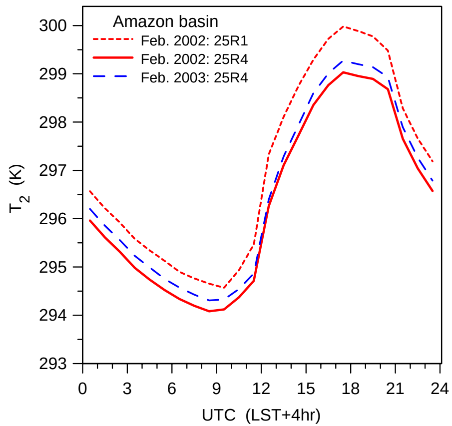
θ_E: equivalent potential temperature

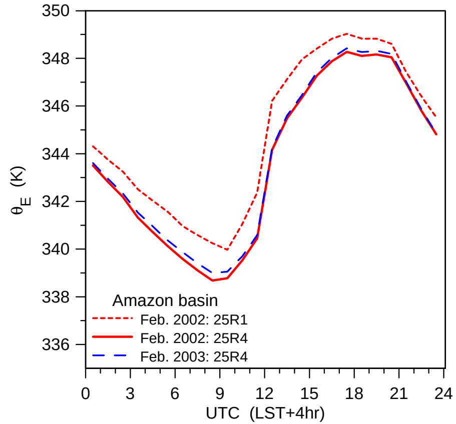
P_{LCL} : pressure height to LCL

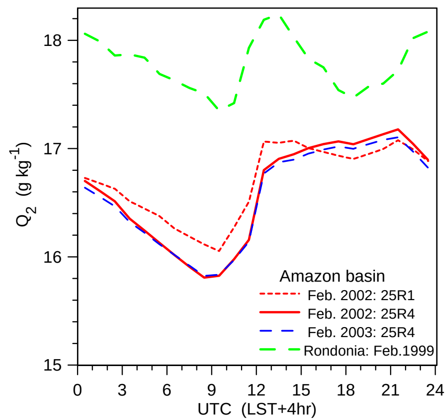
T_2, θ_E and cloud-base reduced

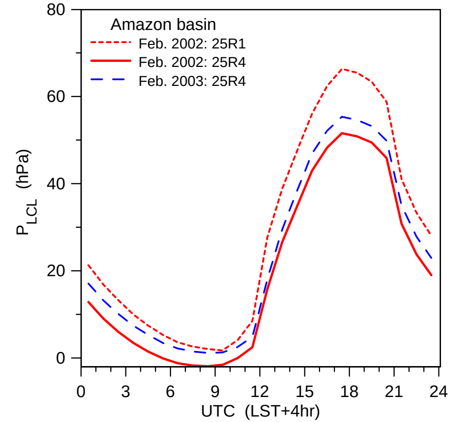
Q_2 rises smoothly during the daytime: no peak after sunrise, no morning fall.

Peak of low level θ_E is 2 hours after precipitation peak









Conclusions

Revised deep convection scheme in cycle 25R4
– removed the spurious morning convection peak
– produced daytime convective precipitation in phase with the solar heating
– reduced the large-scale precipitation

Significant improvements in the diurnal cycle of the model over Amazonia.

Consequent changes (*increased cloud cover, reduced net short-wave, evaporation and total precipitation*) illustrate the complex interaction of the parameterized and resolved water budget and the cloud and radiation fields. We *lack sufficiently detailed data to assess whether they represent any improvement*.

Precipitation is now less than TRMM over Amazonia

Other Issues:

The *smoother behaviour* of the model precipitation (compared with Betts and Jakob, 2002b, for example) may now make it easier now to test sensitivities.

Shallow scheme: increase morning convective mixing? Delay rain?

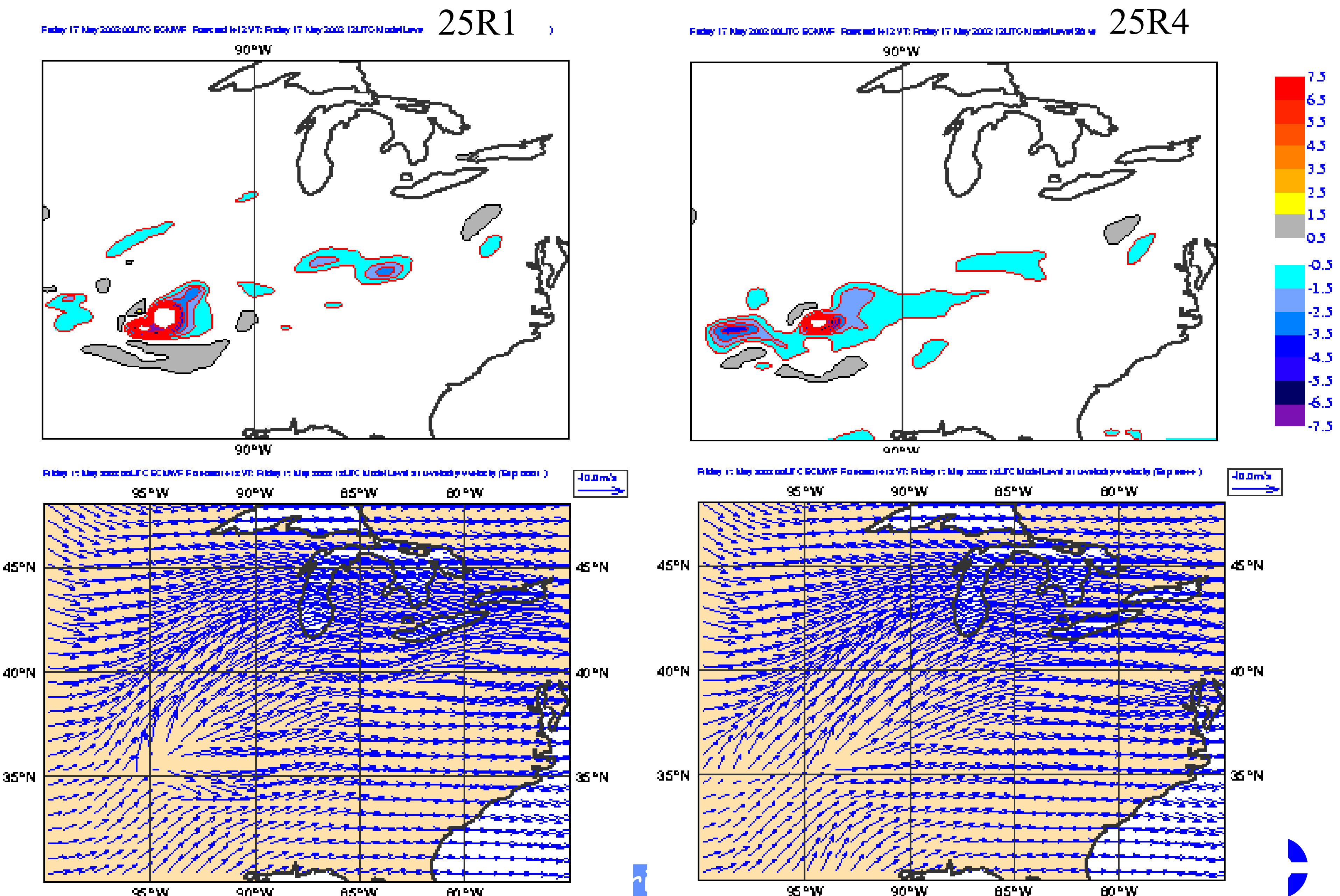
Precipitation efficiency: sensitive to deep convection perturbation?
[since *mesoscale organization* separates updraft and downdraft air, so that updrafts can have a higher θ_E and CAPE than the mean]

Convection and cloud changes ((CY25R4 in Jan 2003)

Martin Miller, ECMWF

- Cloud numerics and revised ice fall speed.
- New algorithm for convection activation and cloud base/top.
- Deep convection can be activated from any level up to 300 hPa from the surface (was from lowest model level only).[also 30hPa thick layers]
- Also precipitation efficiency increased and entrainment rate increased

500 hPa Vertical motion (top, Pa/s) and 200 hPa horizontal wind (bottom) 2002051700+12

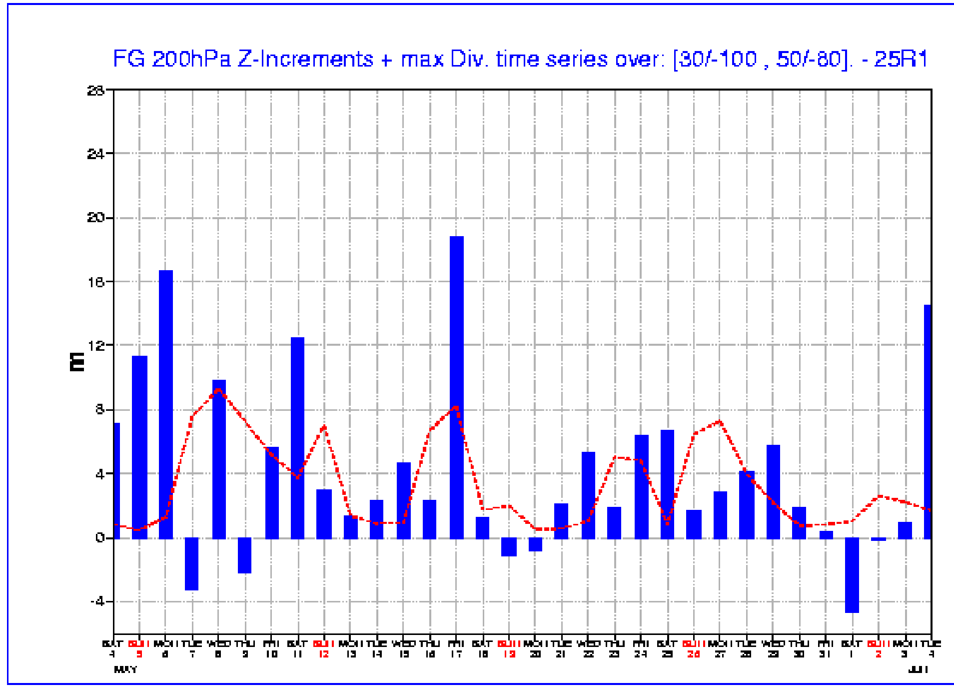


USA (30-50N, 80-100W), 200 hPa:

mean Z-increments

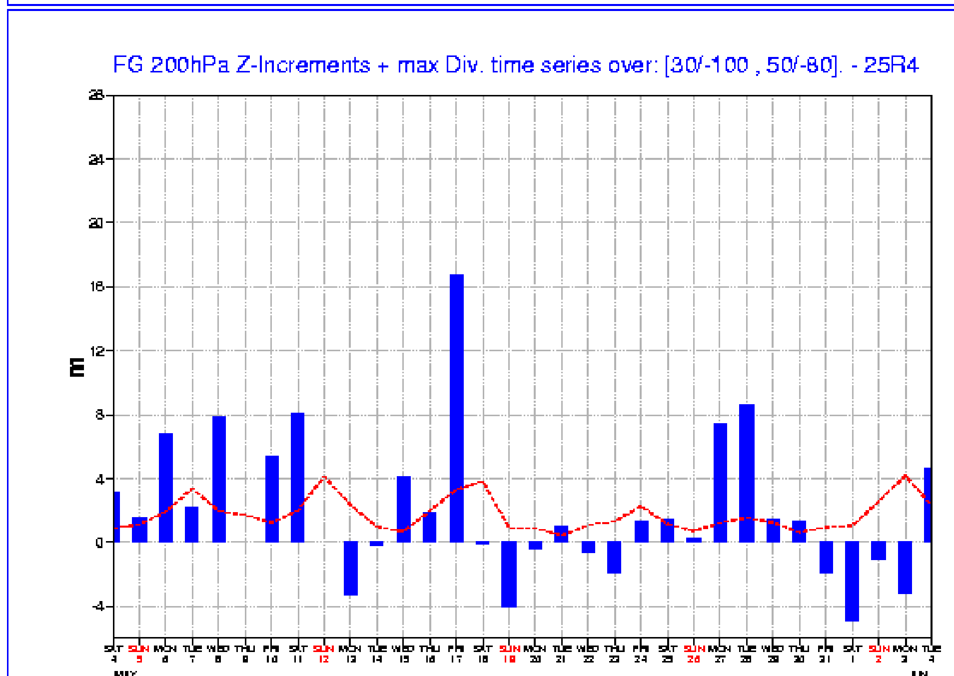
Max divergence (*10^4)

25R1



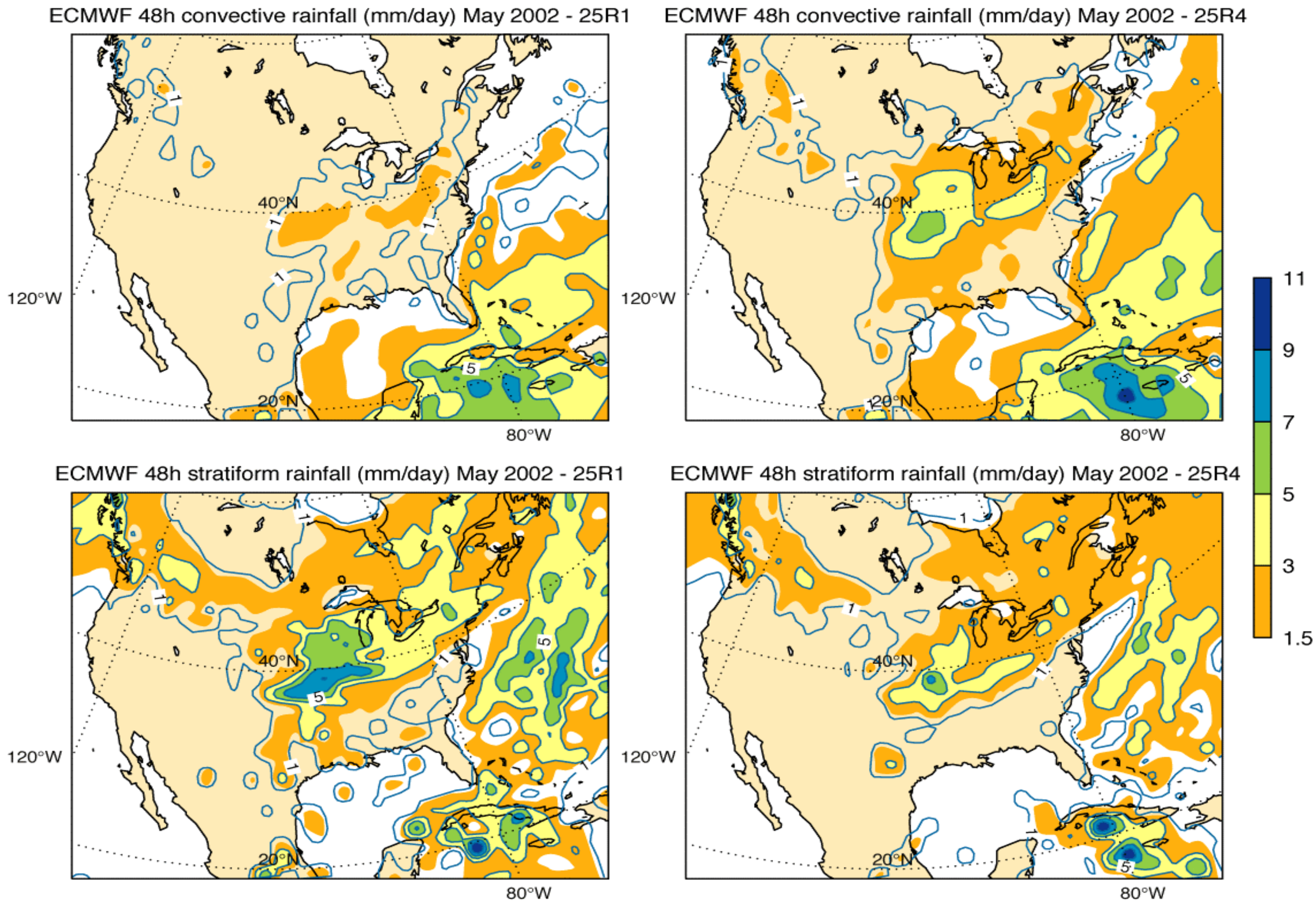
In CY25R4, max divergence is reduced and Z200 increments are smaller

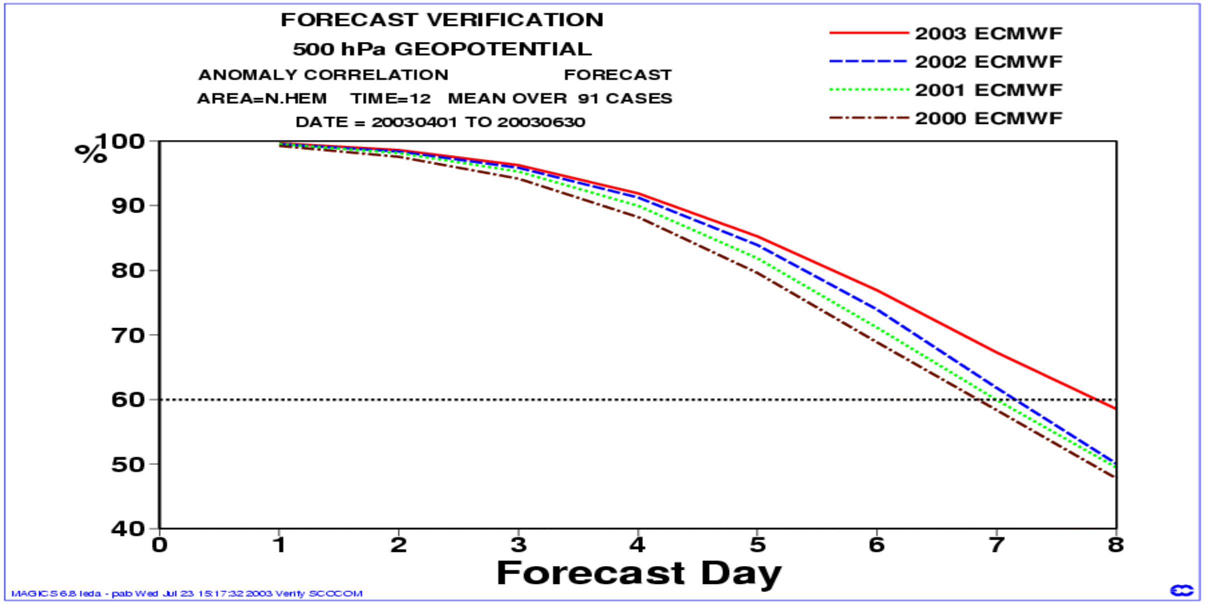
25R4



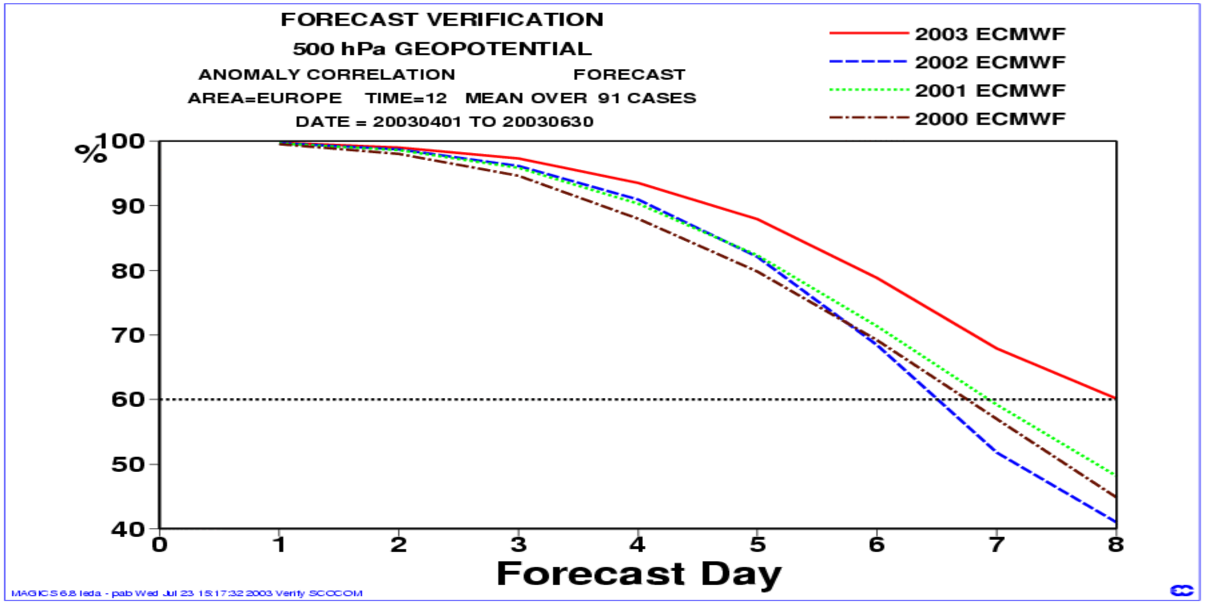
48h forecast convective and stratiform rainfall with different versions of the convection scheme

25R1 25R4

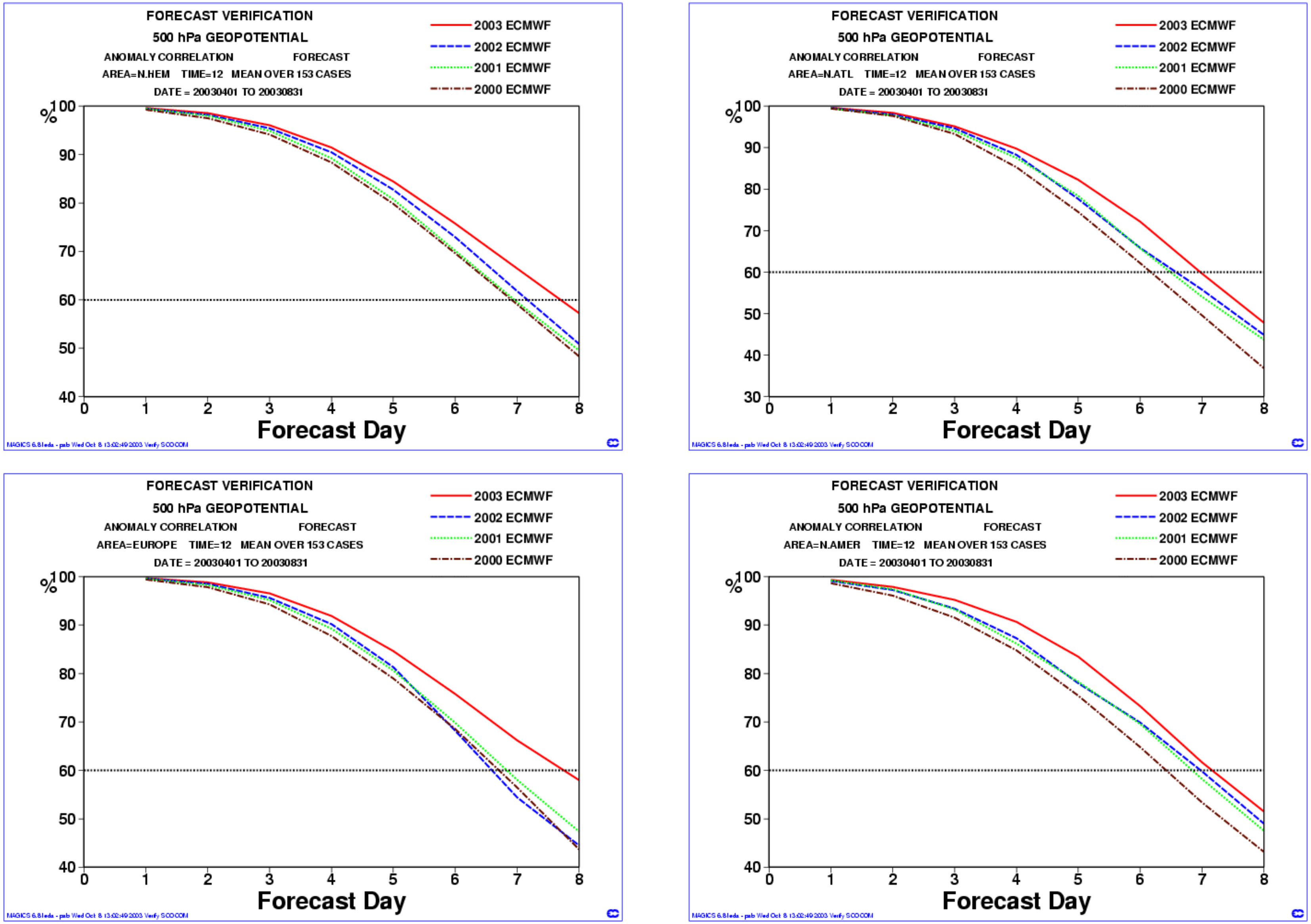




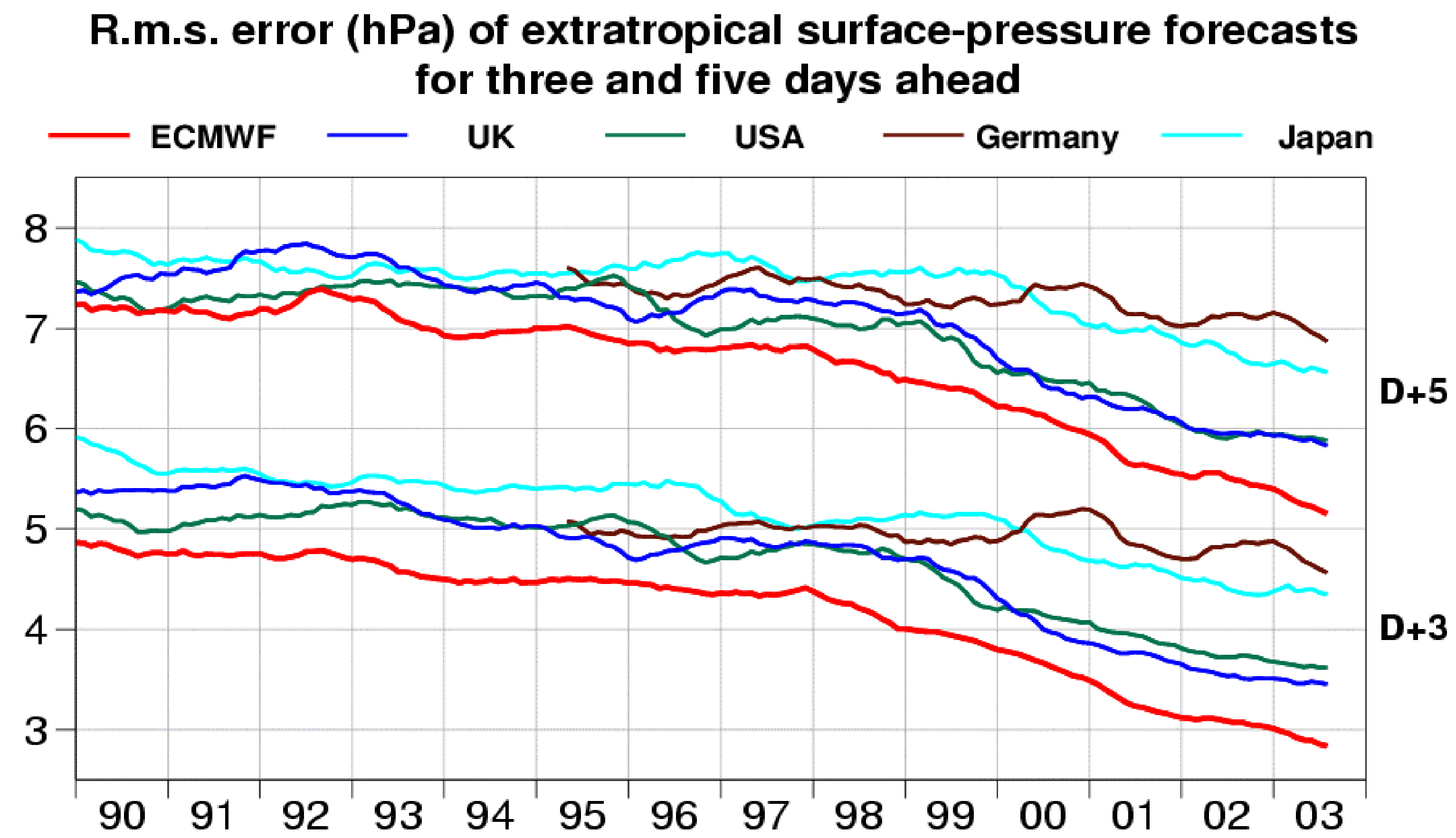
NH
Recent
Springs



Europe
Recent
Springs



Operational scores April-August 2003


R.m.s. error (hPa) of extratropical surface-pressure forecasts
for three and five days ahead
ECMWF
UK
USA
Germany
Japan
8
7
6
5
4
3
90
91
92
93
94
95
96
97
98
99
00
01
02
03
D+5
D+3

CONCLUSIONS

– DIURNAL CYCLE

Important *measurable* climate signal
– driven by the diurnal cycle of the incoming solar radiation, and tightly coupled to LW_{net}

Indicator of correct physics for parameterized processes
– such as BL growth and convection, clouds and radiation

Tricky to get diurnal cycle of precipitation right
– landmark day when diurnal cycle of MCS over US are correctly modeled [and correct phasing over Amazonia]

BL processes, diabatic heating and large-scale dynamics tightly coupled in warm season and in tropics