Development of model physics at ECMWF

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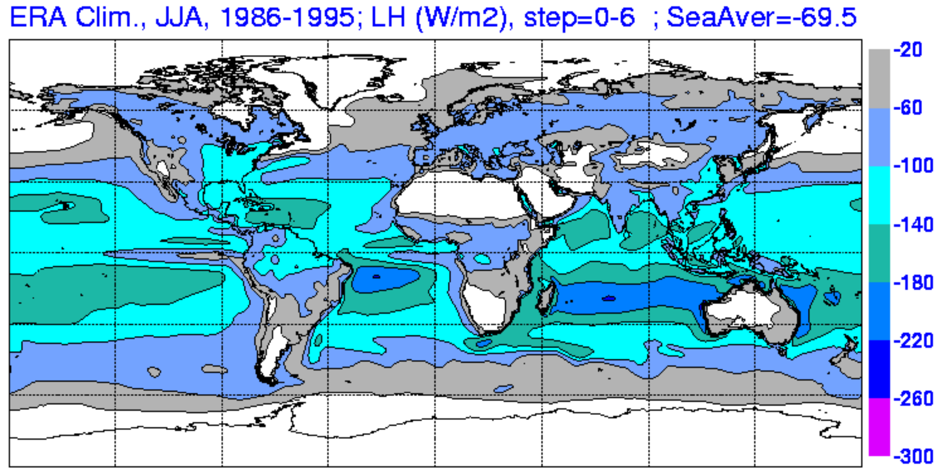
(ECMWF)

- Example of physics related output
- Physics changes after ERA-40 (CY23R4)
- Evolution of spin-up in operations after CY23R4
- Examples of changes with respect to ERA-40

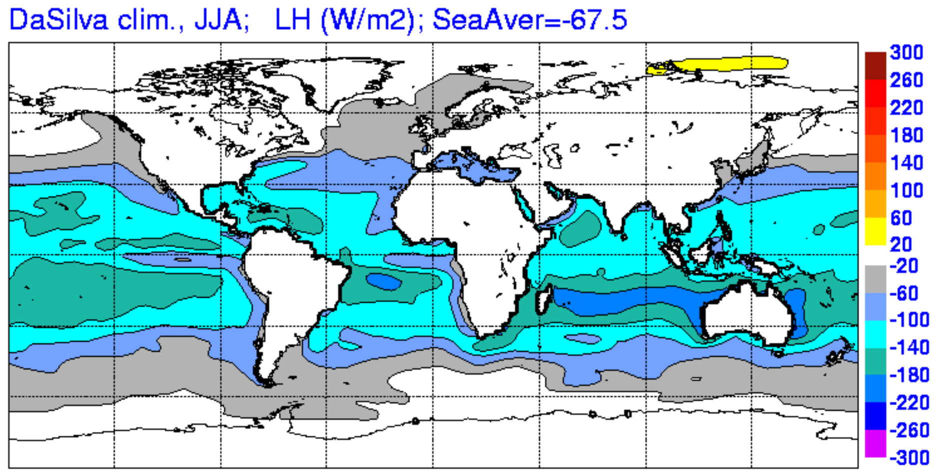
Thanks to: Peter Bechtold, Alan Betts, Martin Koehler, Adrian Tompkins

Latent heat flux (downward is positive): ERA-40 (JJA, 10 year ISLSCP-II period) versus DaSilva climatology

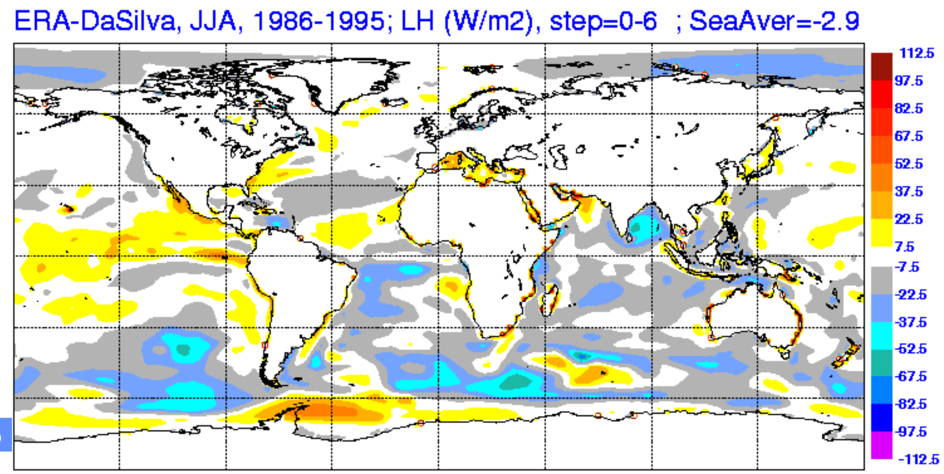
ERA-40



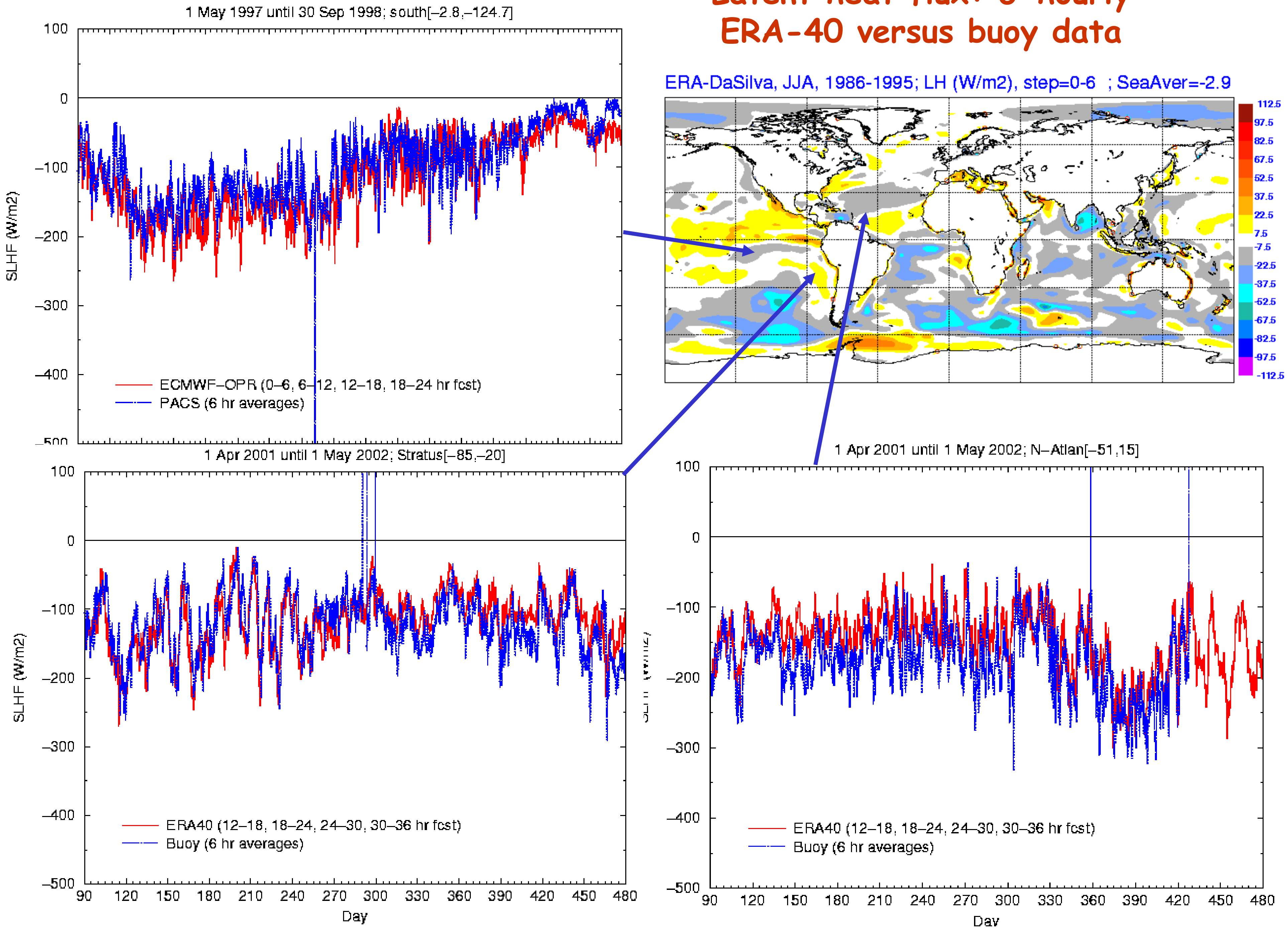
DaSilva



ERA-40 -DaSilva



Latent heat flux: 6-hourly ERA-40 versus buoy data



Changes in model physics since ERA-40, I

- 24r3 (22/01/2002)

  finite elements in vertical, minor mods to convection

- 25R1 (09/04/2002)

  Revised short wave radiation (6 spectral intervals, interactive computation of effective radius of water clouds), re-tuning of land surface scheme, improved wind-gust processing, bugfix convective momentum transport.

- 25R3 (14/01/2003)

  improved cloud numerics, revised cloud physics, mixing of total water in cloud top entrainment, major revision of convection, convective precipitation efficiency increased,

- 26R3 (07/10/2003)

  HALO radiation sampling, new aerosol climatology, new products UVB, PAR, CAPE, relaxation of convective mass fluxes limiter for long time steps.

- 28R1 (09/03/2004)

  minor fixes in convection (conservation, negative precip),

Changes in model physics since ERA-40, II

- 28R3 (28/09/2004)

  revised convection scheme numerics, call cloud scheme twice, hourly radiation, improved numerics of surface tile coupling,
- 29R1 (05/04/2005)

  new moist boundary layer scheme, bugfix in first time step of semi-Lagrangian physics, revision of snow tile coupling at low tile fractions.
- 29R2 (28/06/2005)

  convection changes (positive mass flux, implicit momentum transport, 1 m/s perturbation in updraft momentum).
- 30R1 (01/02/2006)

  91 levels, minor corrections in convection.
- 31R1 (??/??/2006)

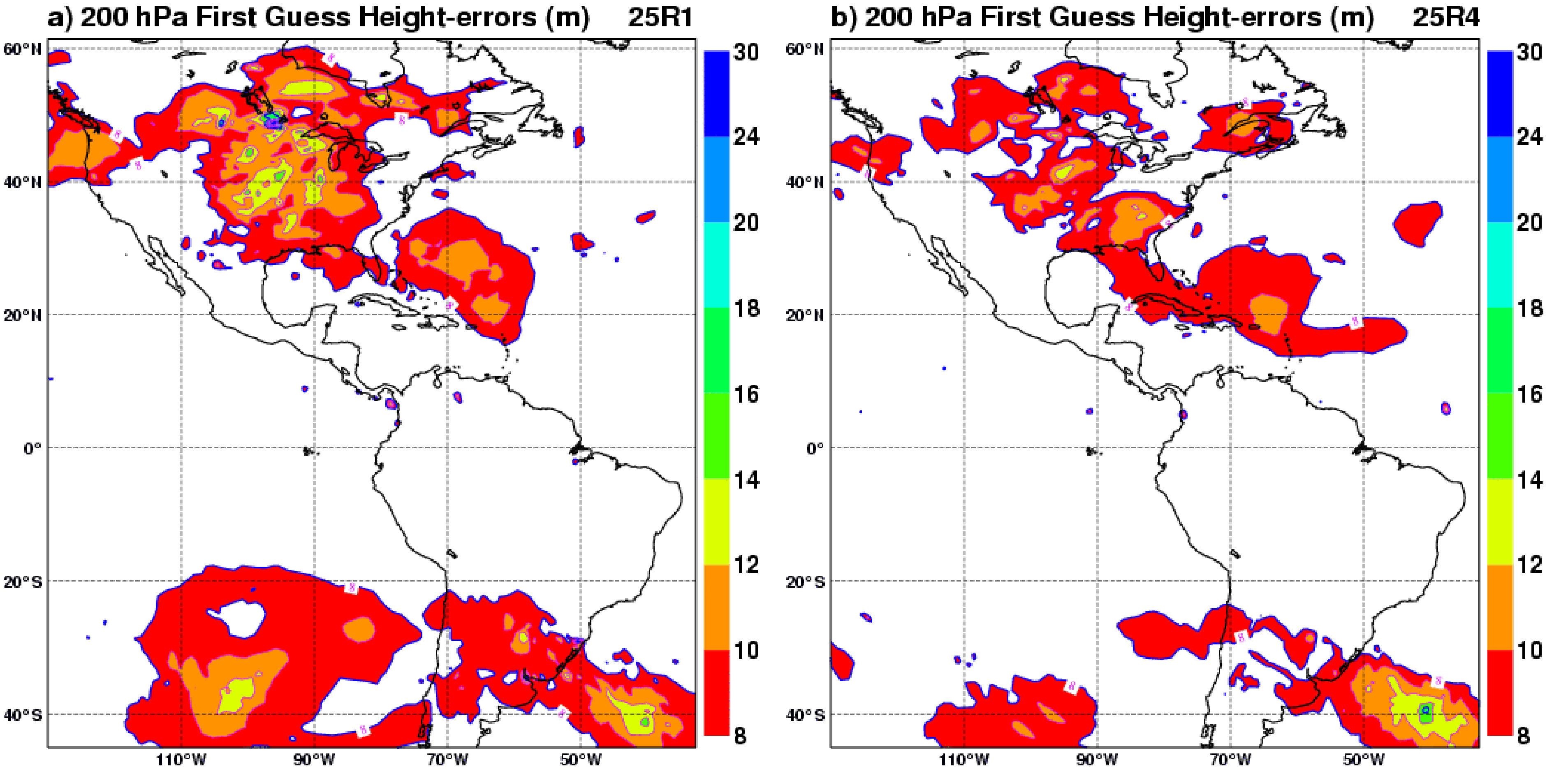
  Revised cloud scheme: ice supersaturation, autoconversion to snow as an explicit process, ice settling as an advective process. implicit convection (U,V,T,q), 0.3 m/s excess in convective updrafts, turbulent orographic form drag instead of orographic roughness, GWD forcing by subgrid mountain cutoff by blocked layer, implicit solution of combined subgrid orography and turbulent diffusion, ocean surface at 0.98*qsat (salinity effect), revised gust formulation (more stable).

CY25R3

- improved cloud numerics (consistent implicit formulation) ,
- revised cloud physics (constant vertical velocity for small particles, Heymsfield/Donner for large particles),
- mixing of total water in cloud top entrainment,
- revised convection (test for deep/shallow convection with dilute plume),
- deep convection parcels initialized with mixed layer values,
- convection can be initiated from all levels below 700 hPa,
- convective precipitation efficiency increased,
- increased entrainment and modified initialization of cloud base winds to improve upper level winds.

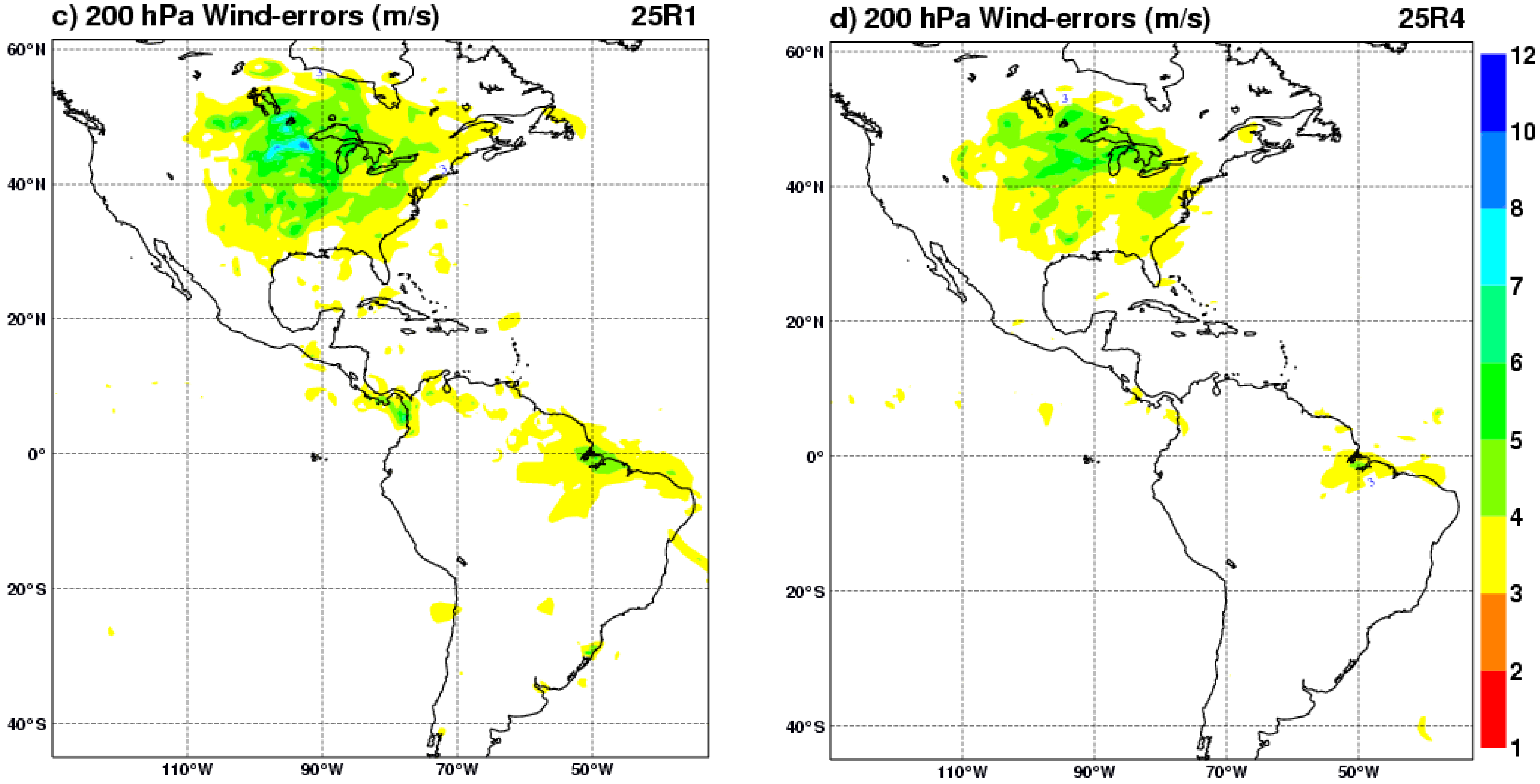
Effect of CY25R3:
The convection scheme became more active with less spurious events at the grid point scale resulting in smaller mass errors.

First guess (12 hr forecasts) 200 hPa height errors averaged over May 2002



Effect of CY25R3:

First guess (12 hr forecasts) 200 hPa RMS wind errors averaged over May 2002



Effect of CY25R3 on the diurnal cycle of precipitation

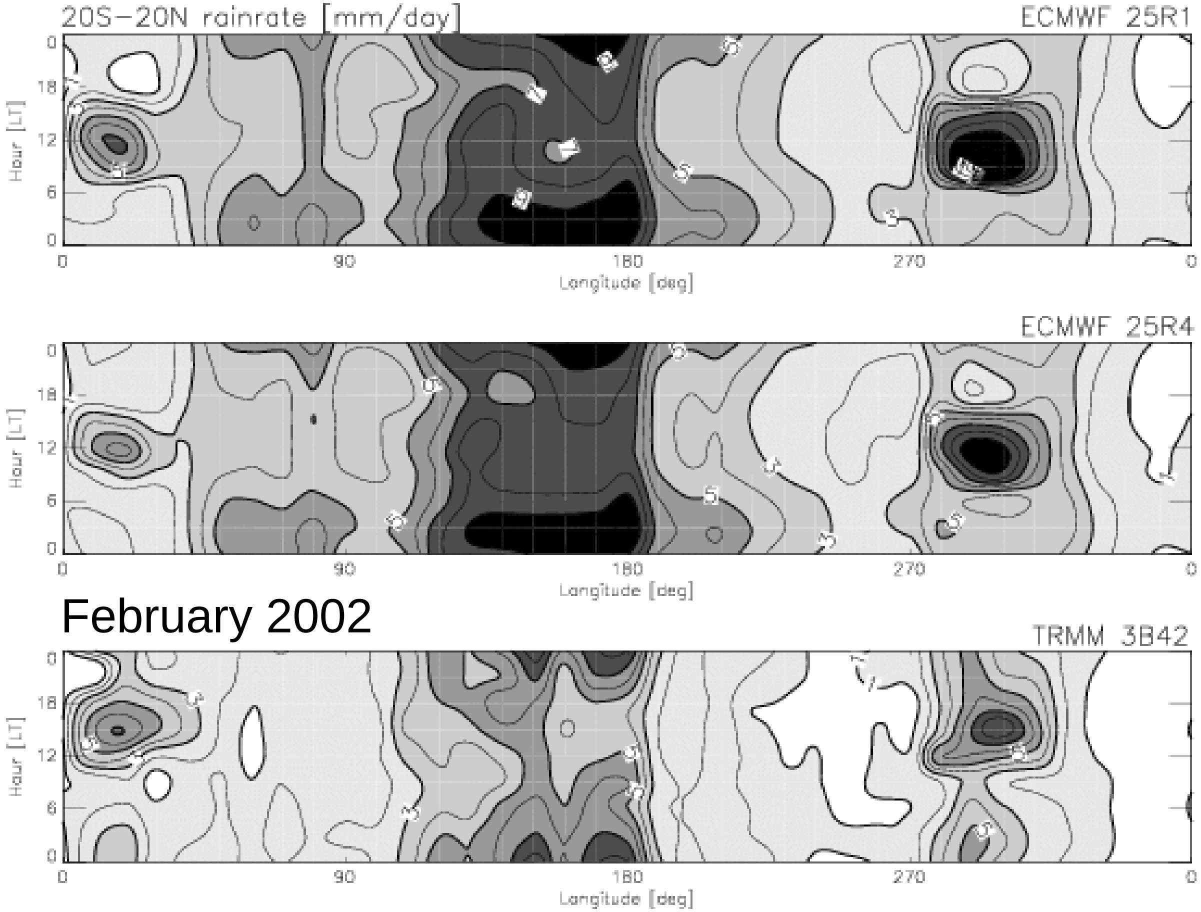
Diurnal Cycle

Precipitation: Model – Obs (TRMM radar)

Model versus observations from TRMM radar

Oper cycles before Jan 2003

Oper cycles after Jan 2003



Africa SE Asia-Indon. S. America

The simulated diurnal cycle of (convective) precipitation over land still precedes the observed one by about 3 hours

ECMWF

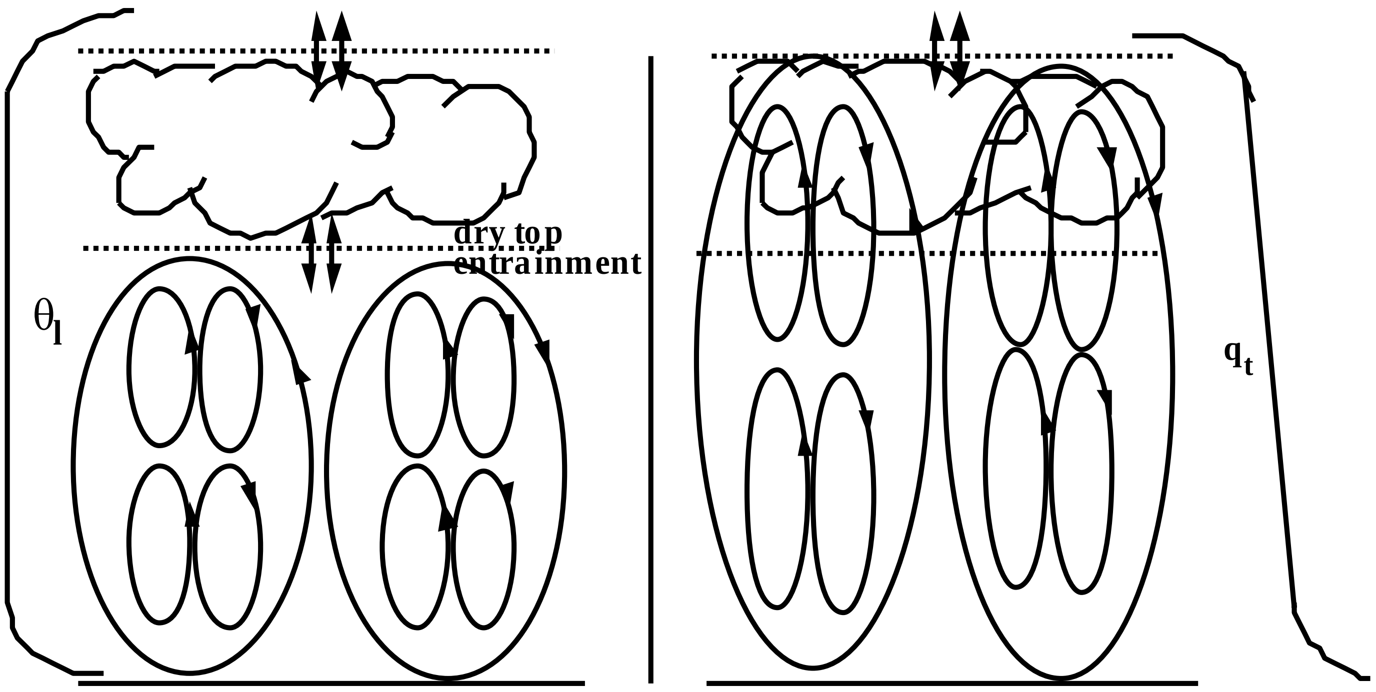
CY29R1 Moist boundary layer scheme: Mass flux/K-diffusion MK-scheme)

Old:

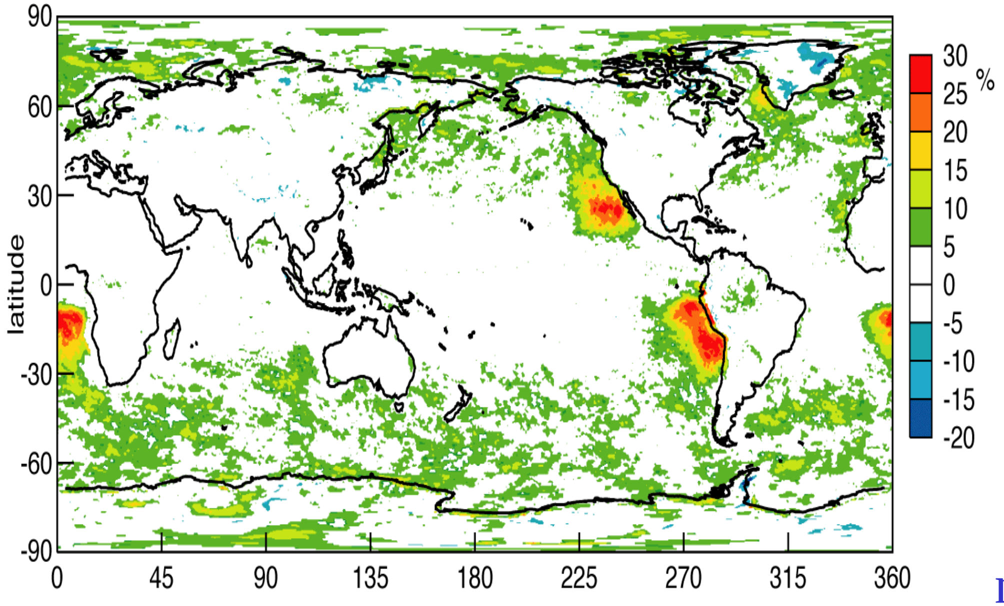
- Mixing of dry variables in sub-cloud layer
- Dry BL entrainment
- Separate handling of stratocumulus in cloud scheme
- Cloud top entrainment

New:

- Mixing of moist conserved variables in cloud- and sub-cloud layer
- Mass flux term to represent large eddies
- Cloud top entrainment
- Switching between stratocumulus and shallow convection scheme based on inversion strength

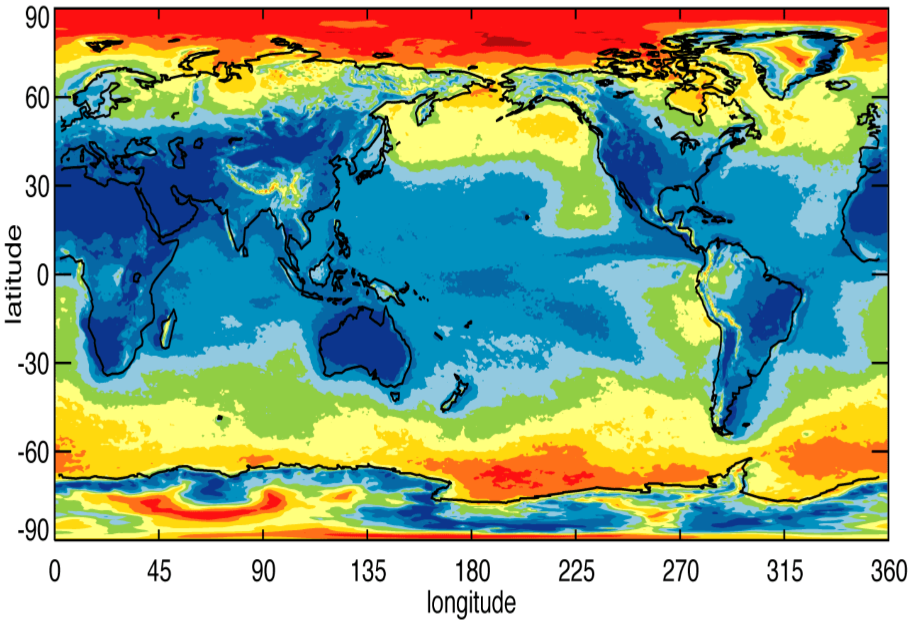


Improved marine stratocumulus (MK - old)



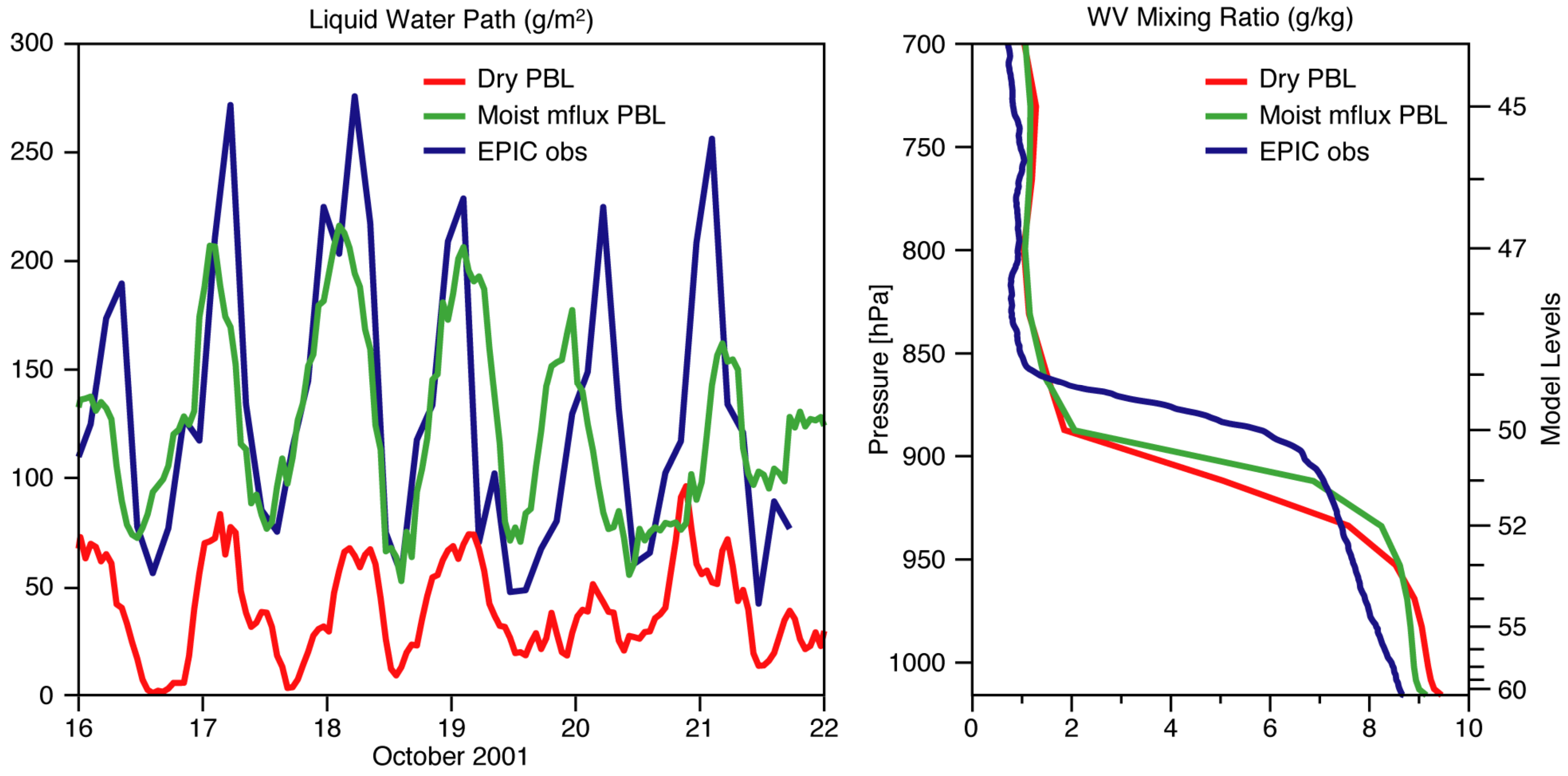
T511
time=10d
n=140

old: CY28R4

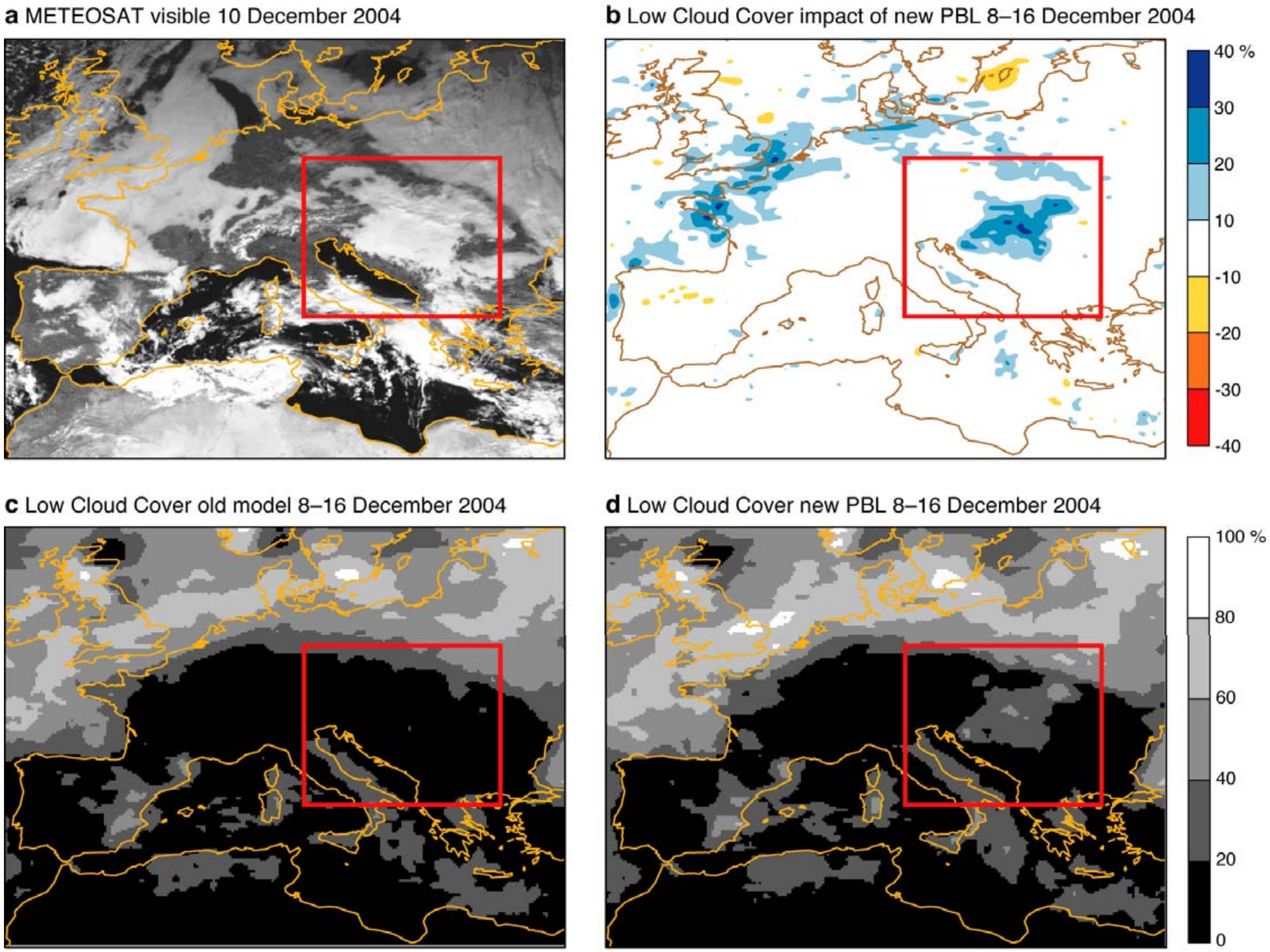


new MK PBL

Peruvian stratocumulus: model column vs EPIC observations



European Stratus in December 2004

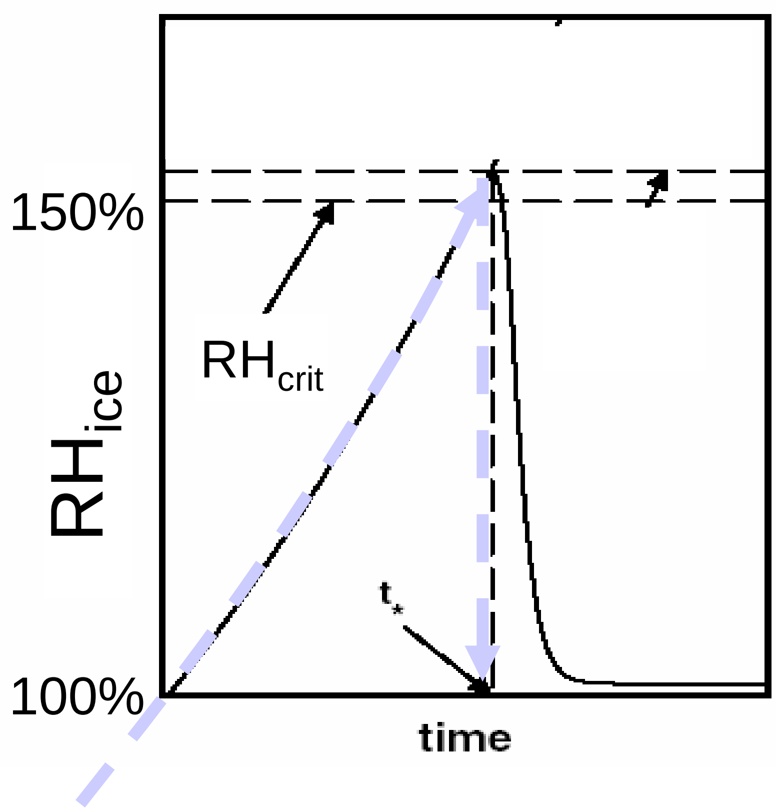


CY31R1 (currently in esuite)

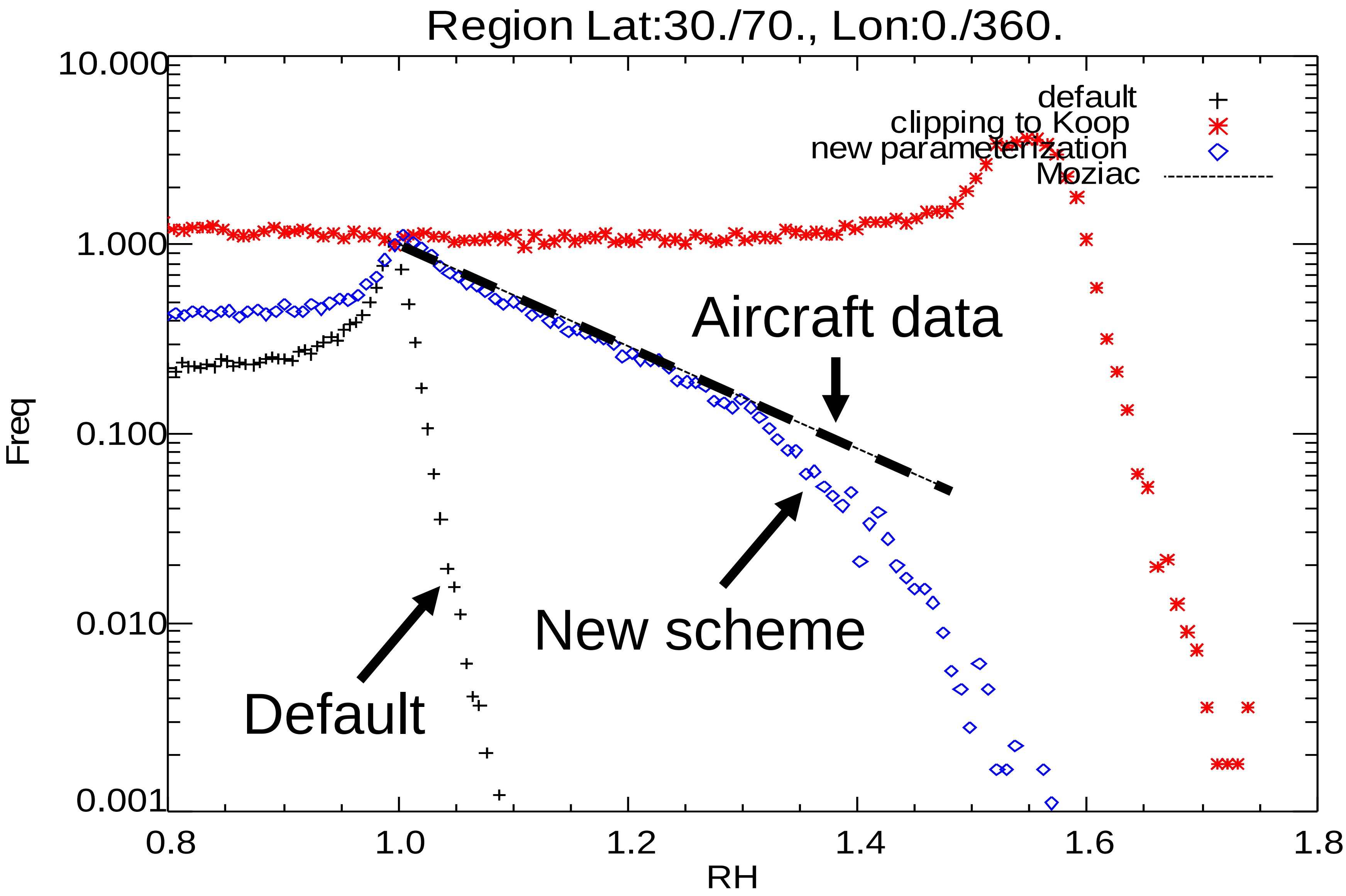
- 31R1 (??/??/2006)
  - Revised cloud scheme: ice supersaturation, autoconversion to snow as an explicit process, ice settling as an advective process.
  - implicit convection (U,V,T,q)
  - 0.3 m/s excess in convective updrafts,
  - turbulent orographic form drag instead of orographic roughness,
  - GWD forcing by subgrid mountain cutoff by blocked layer.
  - implicit solution of combined subgrid orography and turbulent diffusion,
  - ocean surface at 0.98*qsat (salinity effect),
  - revised gust formulation (more stable),

CY31R1: super saturation with respect to ice

- New scheme allows super saturation up to homogeneous nucleation limit in clear sky region
- But once cloud forms deposition instant: no supersaturation within the cloudy region is allowed.

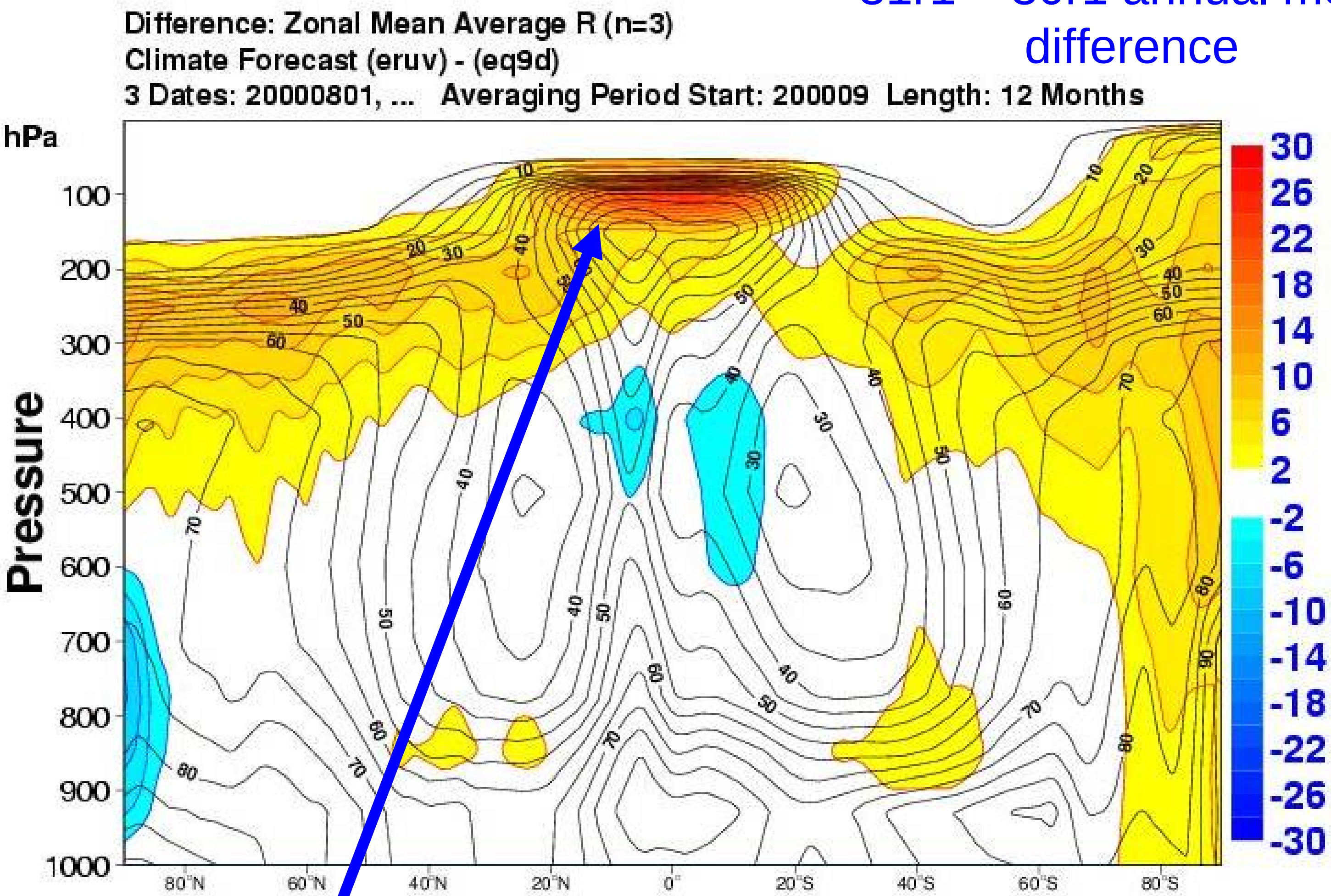


Simple ECMWF scheme: comparison to Mozaic aircraft data (from Gierens et al.)



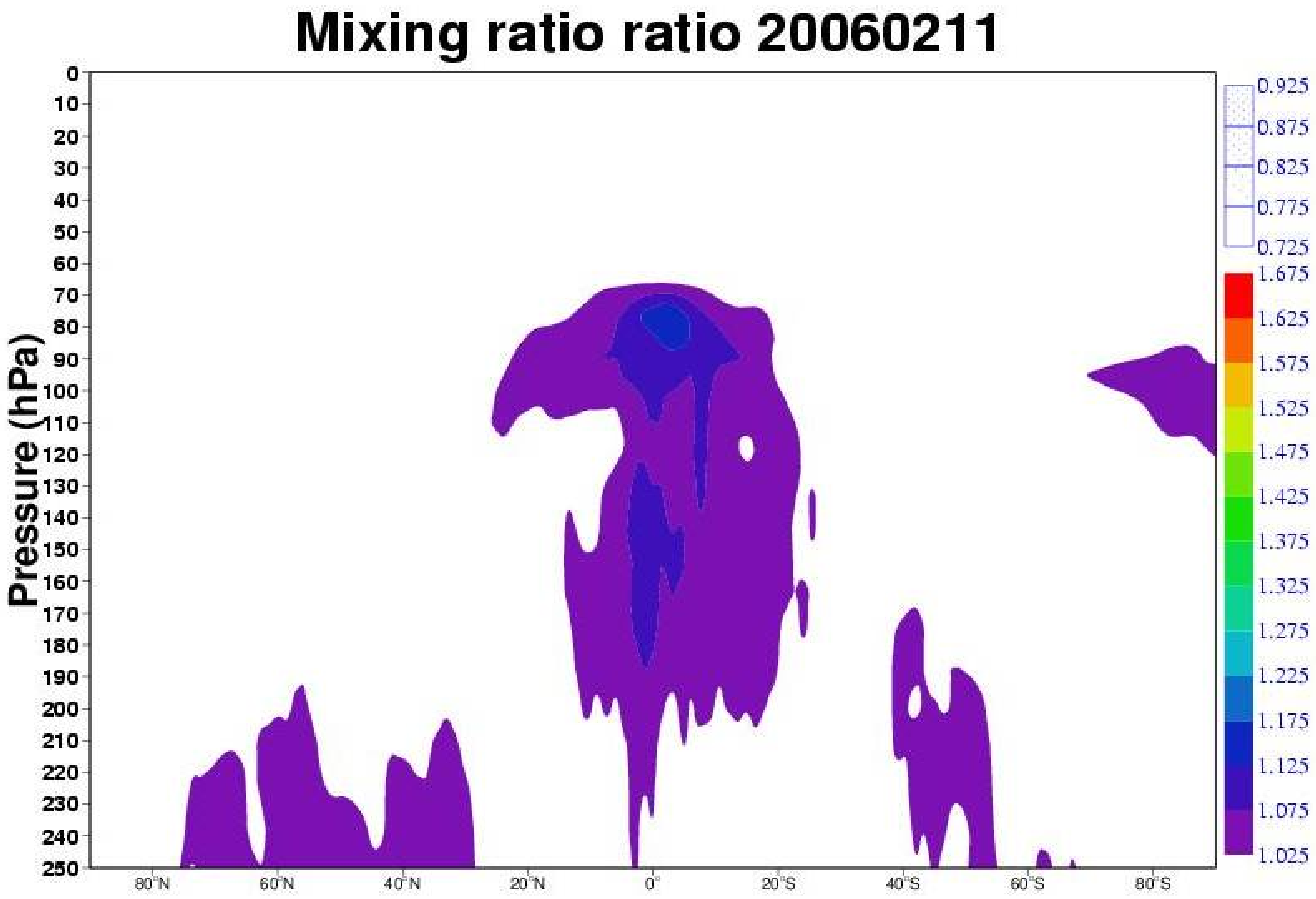
Impact on relative humidity (RH) climatology

31r1 – 30r1 annual mean difference

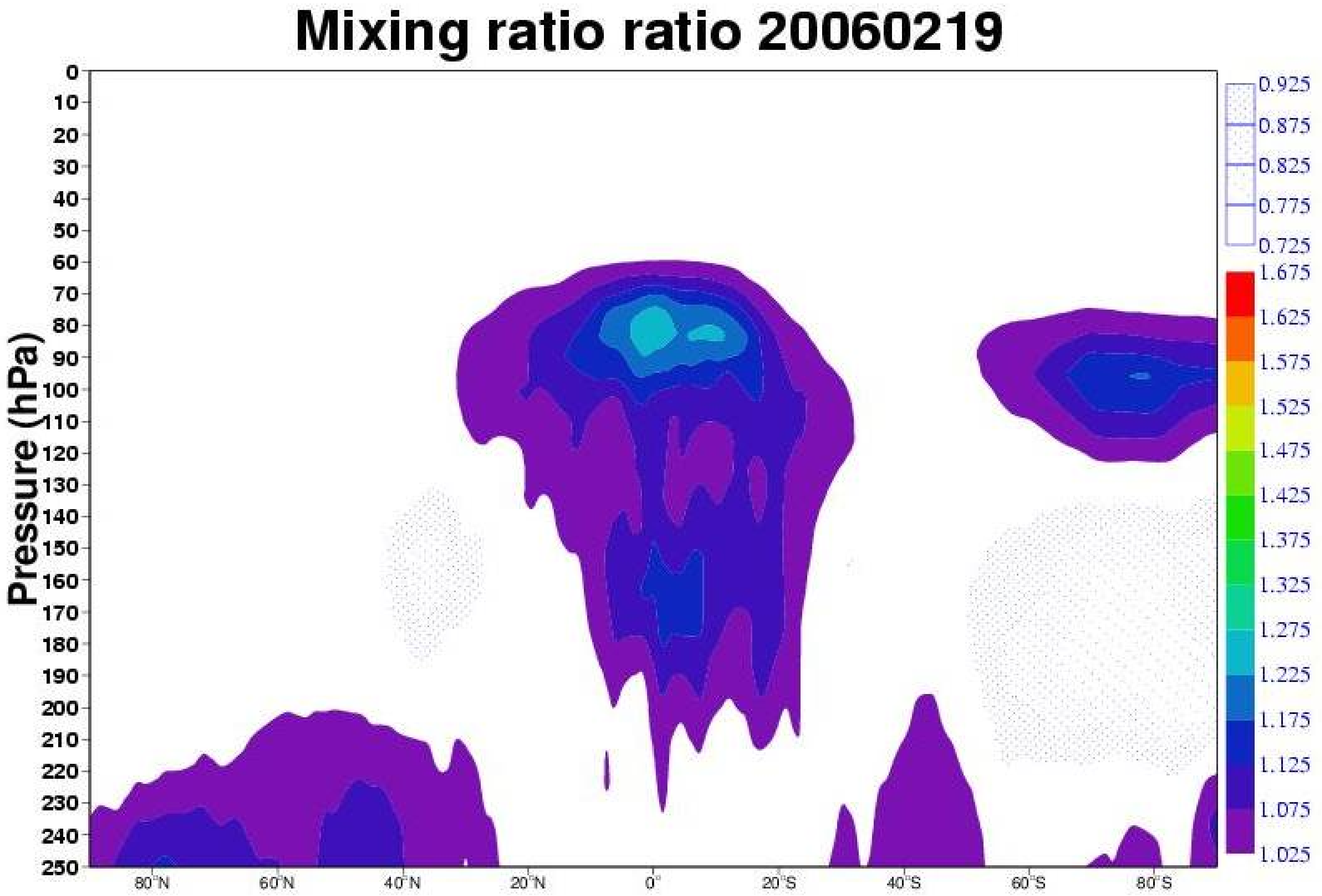


Largest changes in the tropical upper troposphere

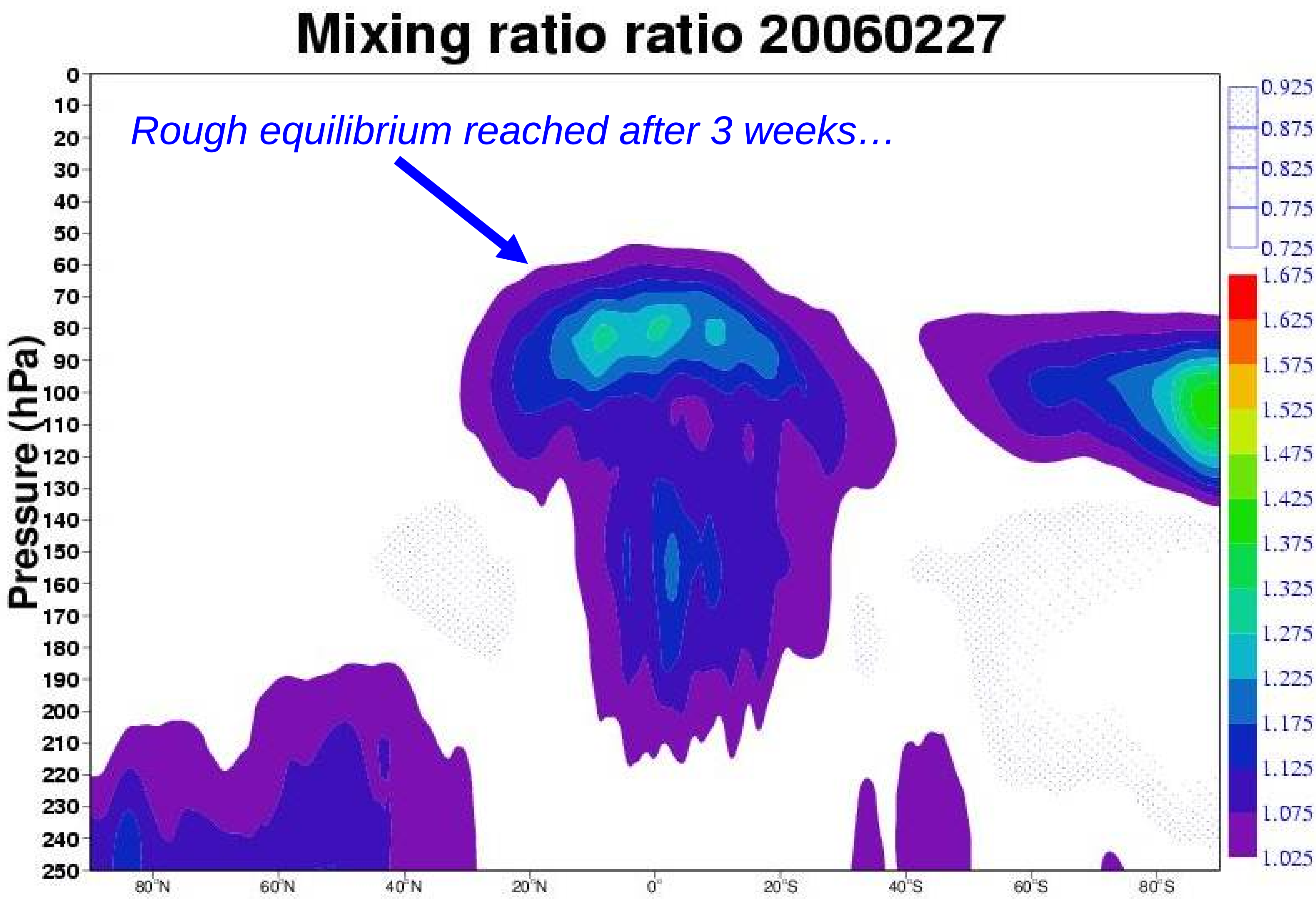
Analysis, humidity RATIO (new/default) – Day 1



Analysis, humidity RATIO (new/default) – Day 9



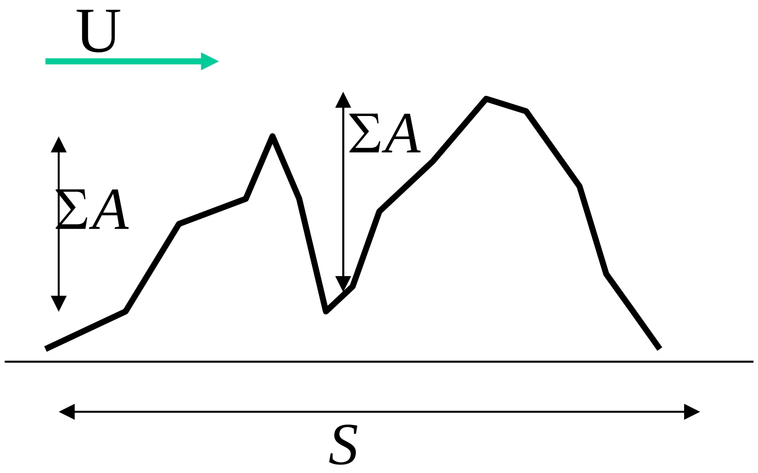
Analysis, humidity RATIO (new/default) – Day 18



Roughness length over land (old)

•Vegetation roughness length from Baumgartner et al. (1977) climatology.
•Orographic effects parametrized through enhancement of surface roughness ("effective roughness"; Mason 1985).

•Orographic drag coefficient is determined by "silhouette area" per unit surface area,
•silhouette area currently from US-Navy 10' data set.
•1 km GTOPO30 could be used, but
• 1km is also not sufficient and results are highly sensitive to resolution of orographic data set.

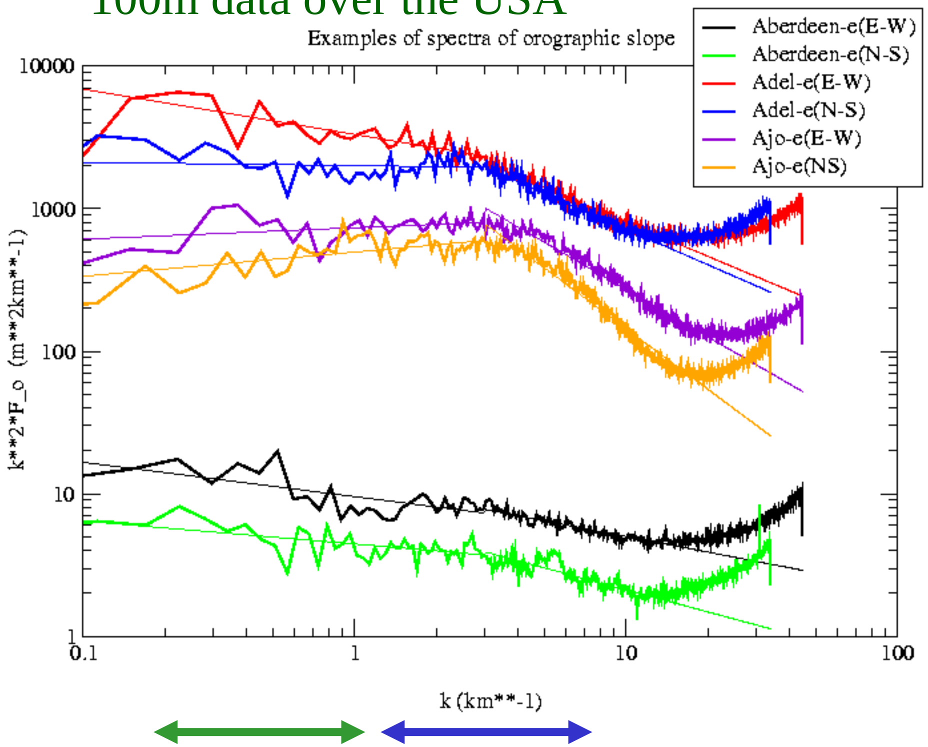


$$drag = C_d U^2 \frac{\Sigma A}{S}$$

$$\{\ln(\frac{h + z_{oeff}}{z_{oeff}})\}^{-2} = \{\ln(\frac{h + z_{oveg}}{z_{oveg}})\}^{-2} + \frac{C_D}{\kappa^2}\frac{\Sigma A}{S}$$

CY31R1: New vegetation roughness + turbulent orographic form drag scheme (TOFD)

Examples of orographic spectra from 100m data over the USA



Measure spectral amplitude from 1 km data.

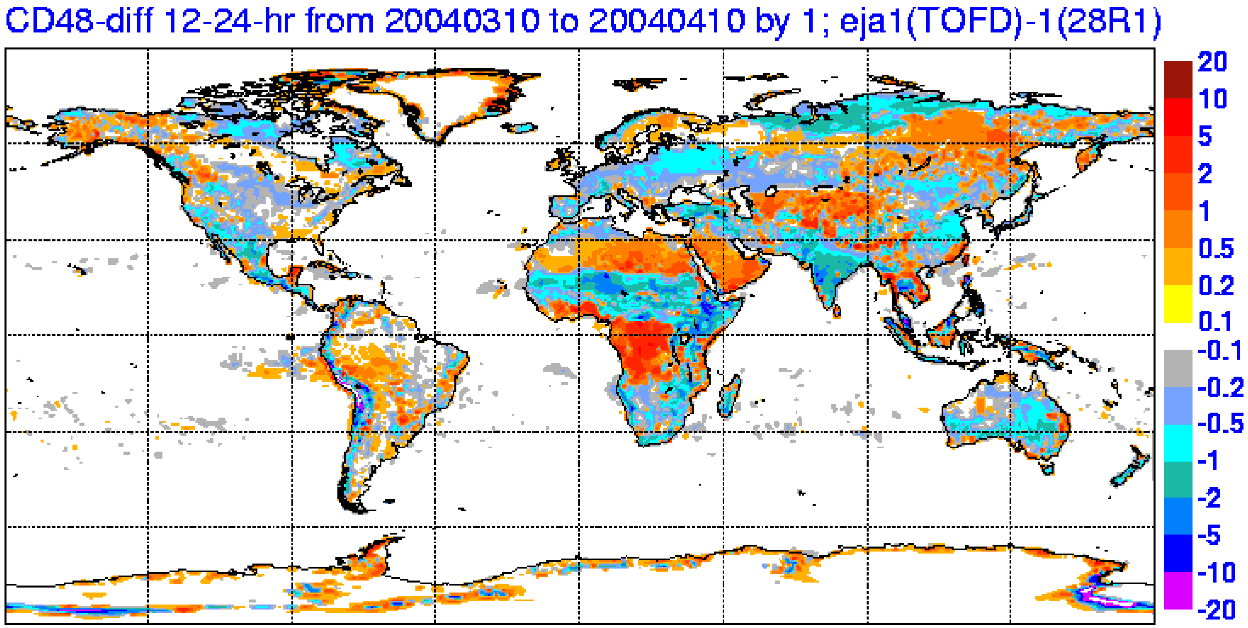
Extrapolate spectrum by making assumption about power law. Scales of interest are from 5 km down to 10 m

- Vegetation roughness from correspondence table linked to dominant land use type (Mahfouf et al. 1995)
- Scales of interest are below 5 km
- Use most recent 1 km orographic data
- Wood and Mason (1993) parametrization for surface drag
- Drag distribution over model levels rather than effective roughness length concept (Wood, Brown and Hewer, 2001)
- Parametrize orographic scales from 5 km to the smallest scales as an integral over an empirical orographic spectrum (Beljaars et al. 2004

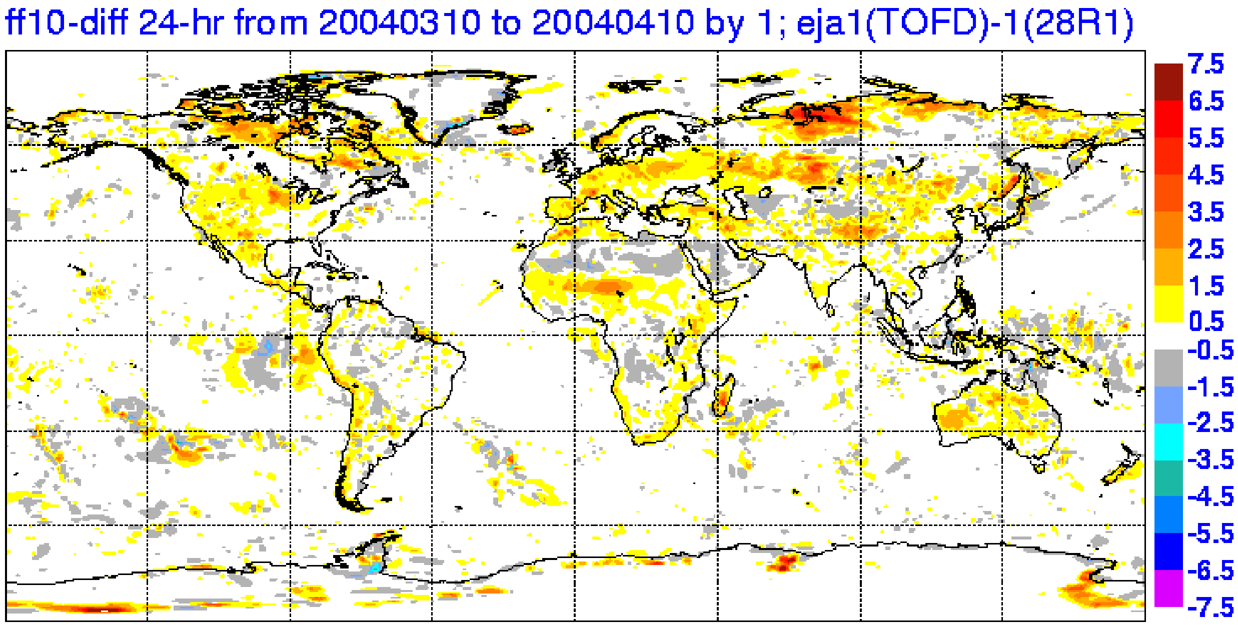
$$\frac{\partial \tau}{\partial z} = -2\rho\alpha\beta C_m \int_{k_o}^{\infty} k^3 F(k) U^2 (c_m / k) e^{-zk/c_m} dk$$

Impact of TOFD + new roughness lengths

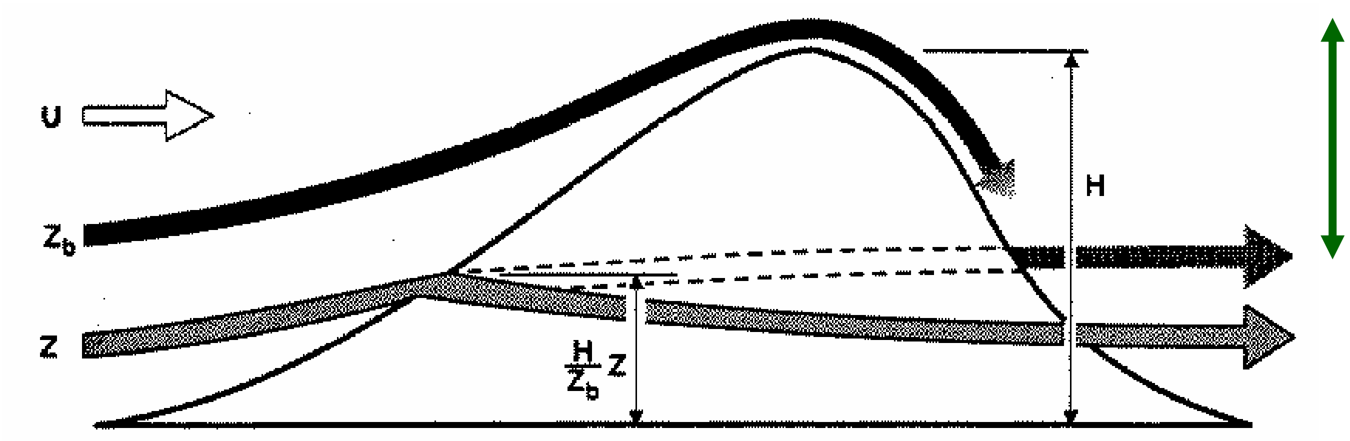
Smaller drag coefficients: diff stress/wind(level48)^2



Higher 10m wind



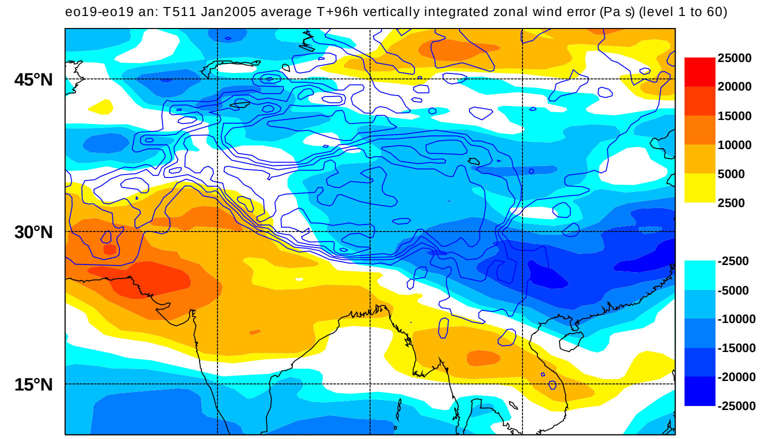
CY31R1: only non-blocked part of subgrid orography excites gravity waves (cutoff mountain)



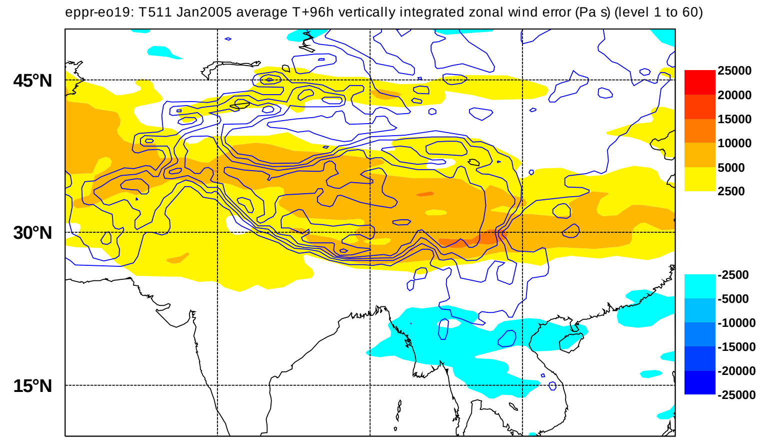
Only this height is used to excite gravity waves.

Lott and Miller 1997

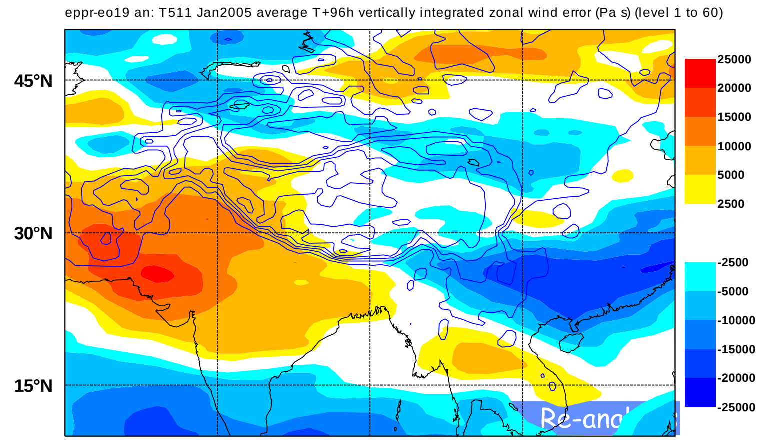
Impact of cutoff mountain in GWD parametrization



Error: FC-AN
Old



Diff:
FC_new-FC_old



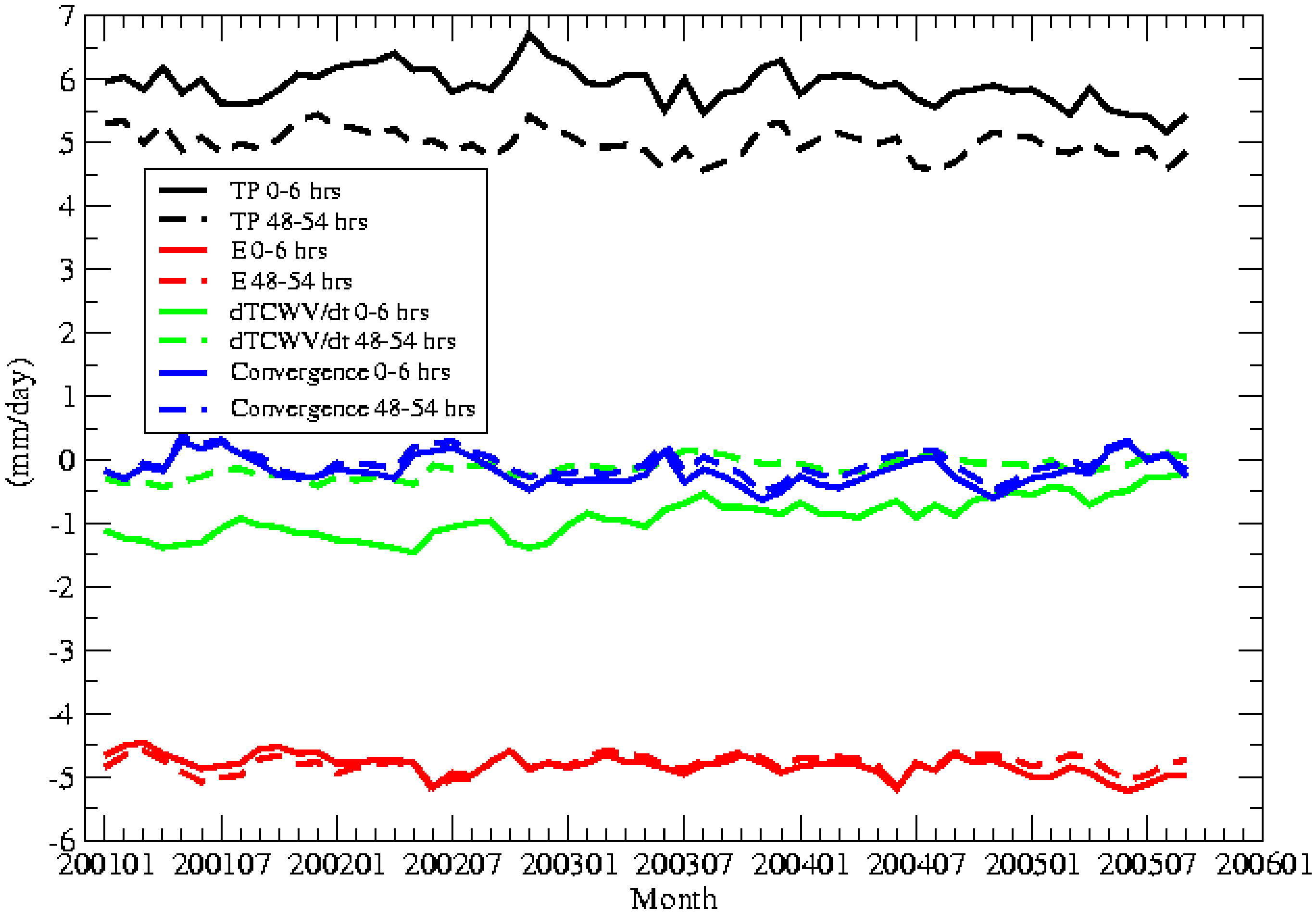
Error: FC-AN
New

T511 average vertically integrated zonal wind error from 96h CY29R1 forecasts from 12Z on each day of January 2005 using the new turbulent orographic drag scheme and cutoff mountain.

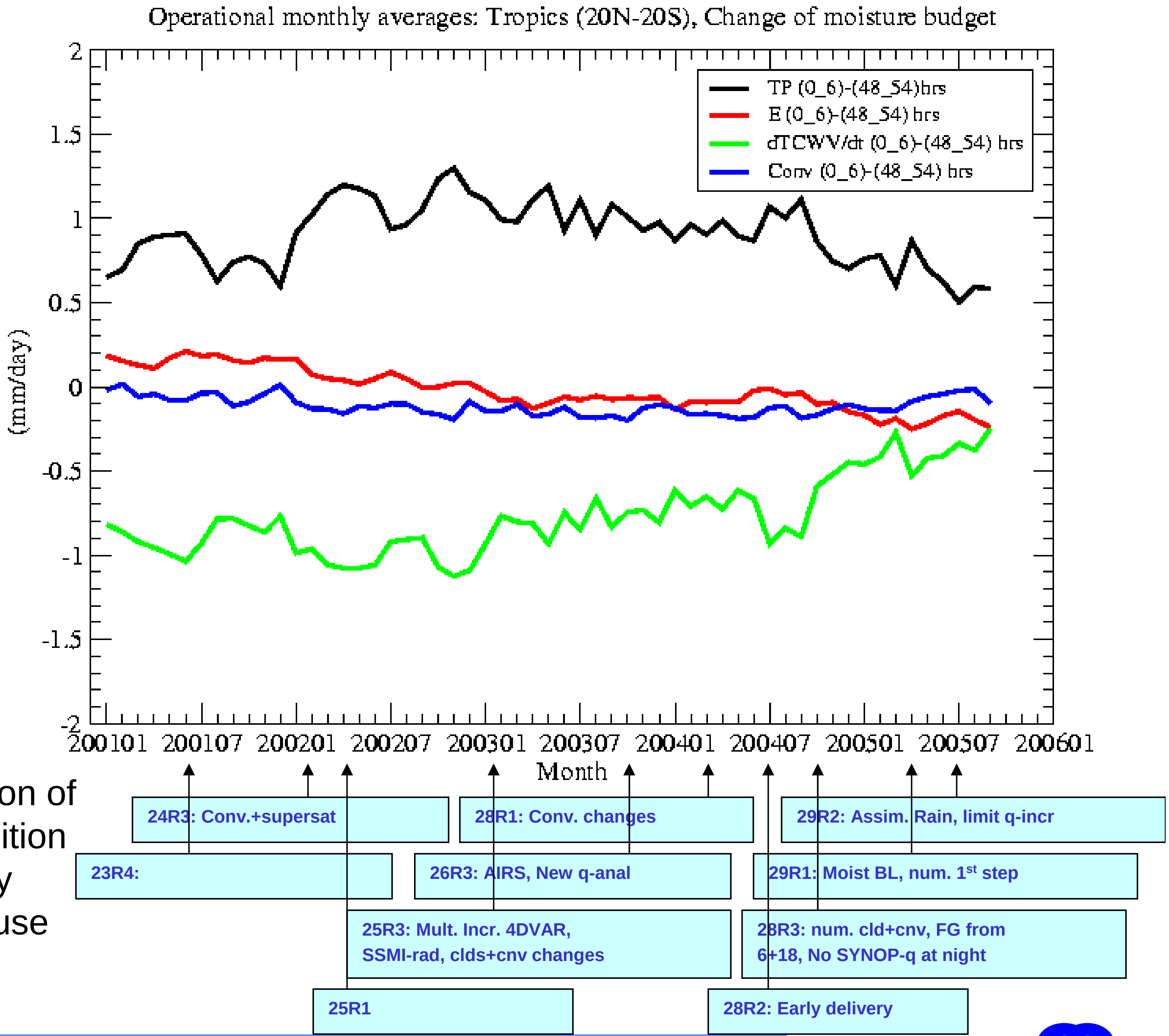
History of spin-up after CY23R4 (20N-20S)

$$\frac{dTCWV}{dt} = -P - E + Convergence$$

Operational monthly averages: Tropics (20N-20S), Moisture budget

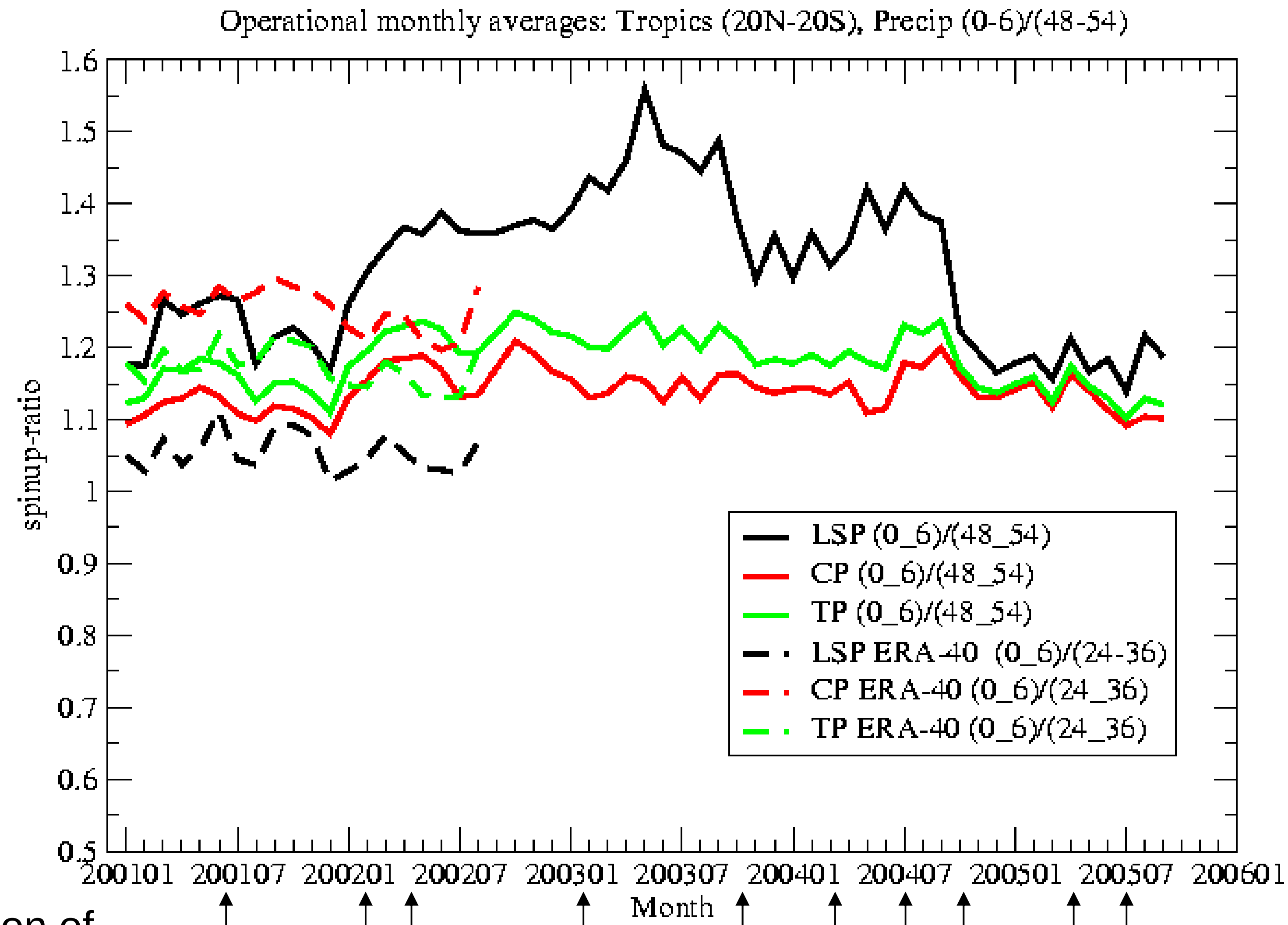


History of spin-up (20N-20S)



List with selection of changes. In addition there were many changes to the use of satellite data.

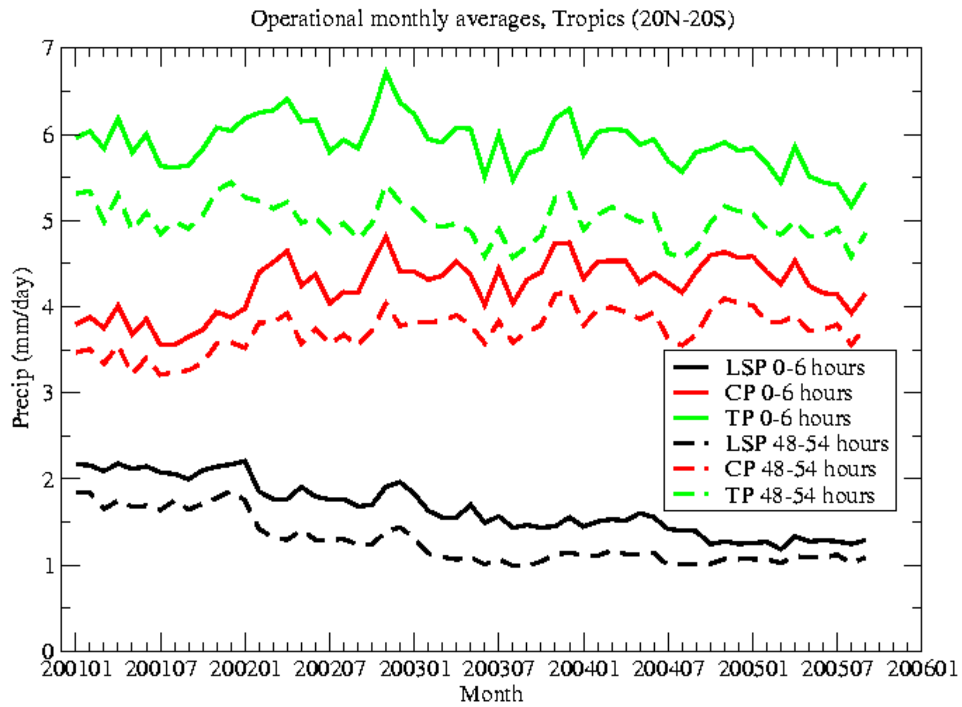
History of spin-up (20N-20S)

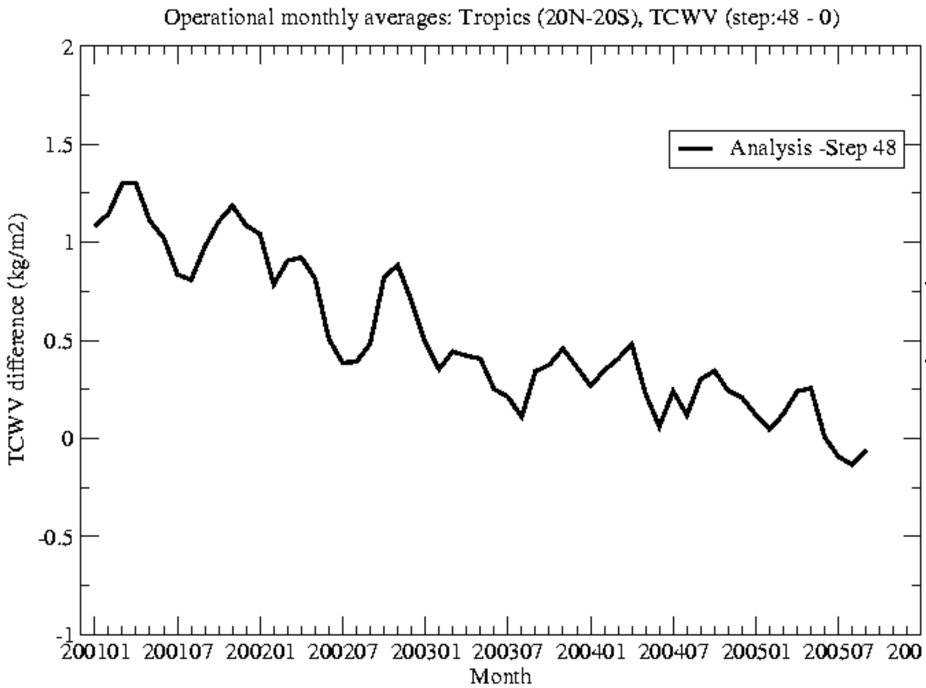


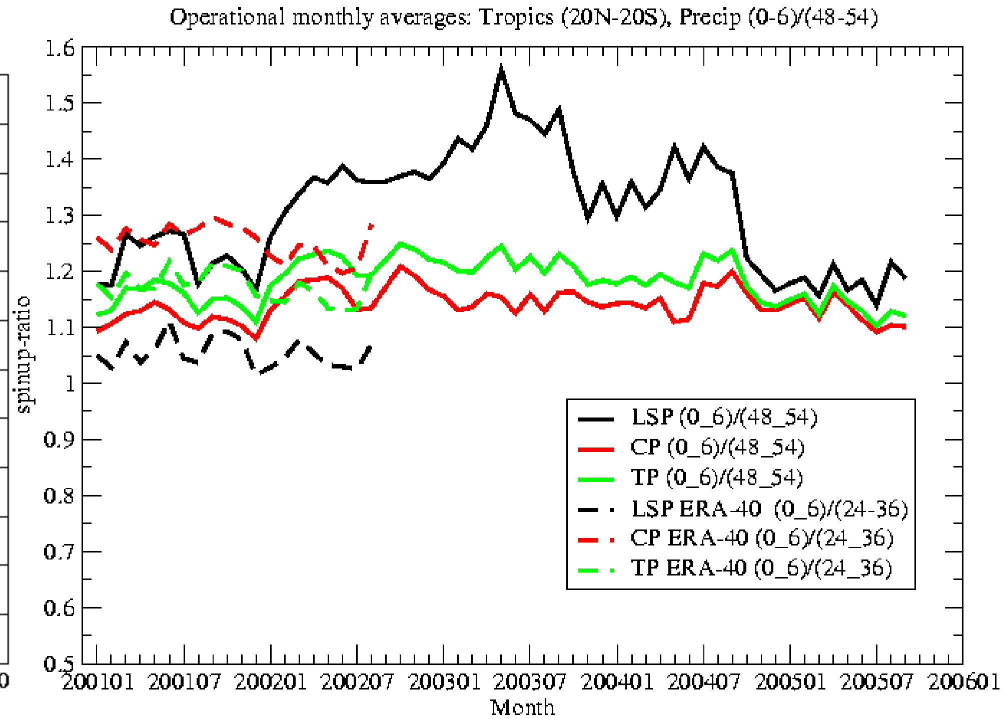
List with selection of model changes. In addition there were many changes to the use of satellite data.

- 23R4:
- 24R3: Conv.+supersat
- 25R1
- 25R3: Mult. Incr. 4DVAR, SSMI-rad, clds+cnv changes
- 26R3: AIRS, New q-anal
- 28R1: Conv. changes
- 28R2: Early delivery
- 28R3: num. cld+cnv, FG from 6+18, No SYNOP-q at night
- 29R1: Moist BL, num. 1st step
- 29R2: Assim. Rain, limit q-incr

History of spin-up (20N-20S)



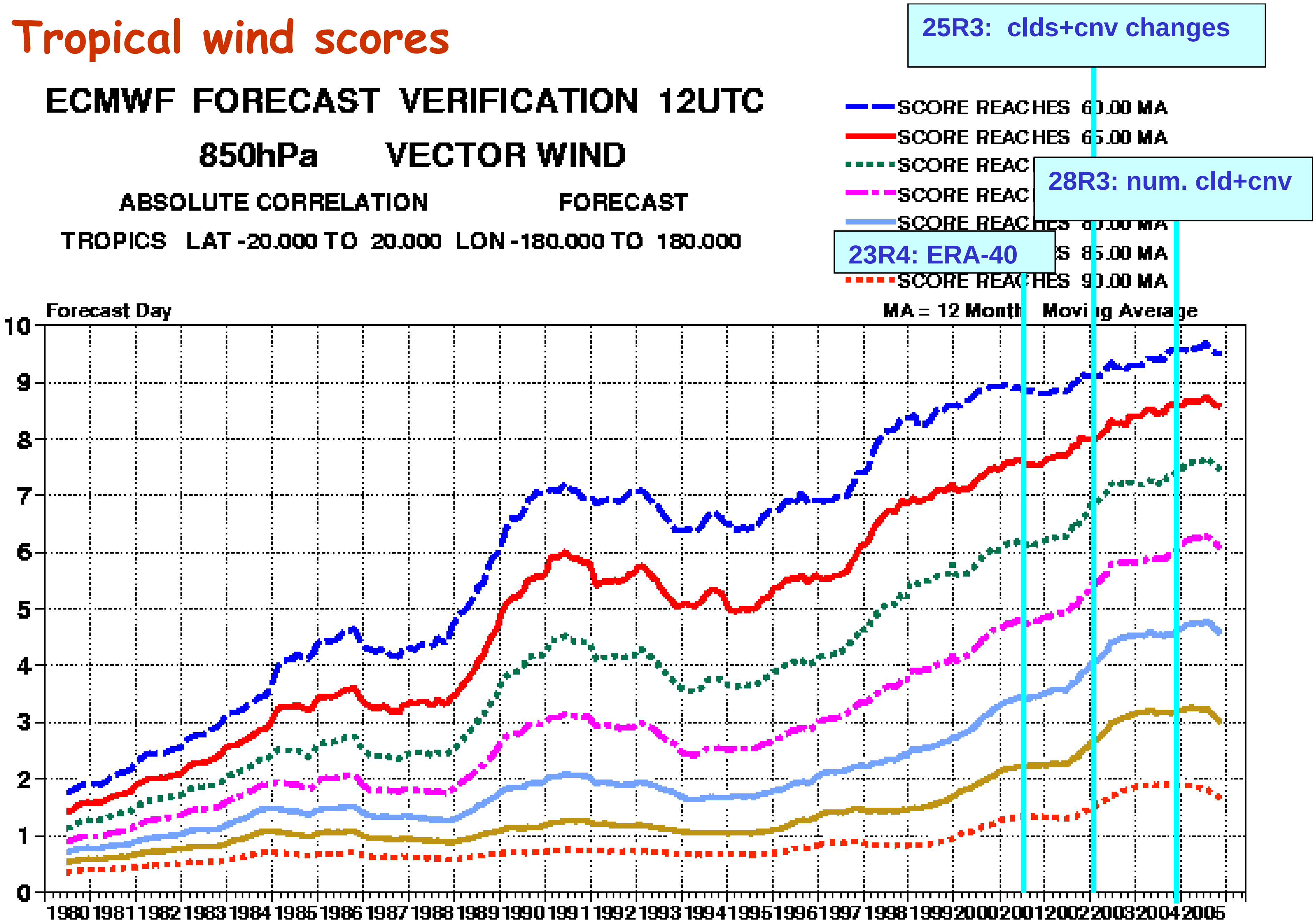




Conclusions on spin-up

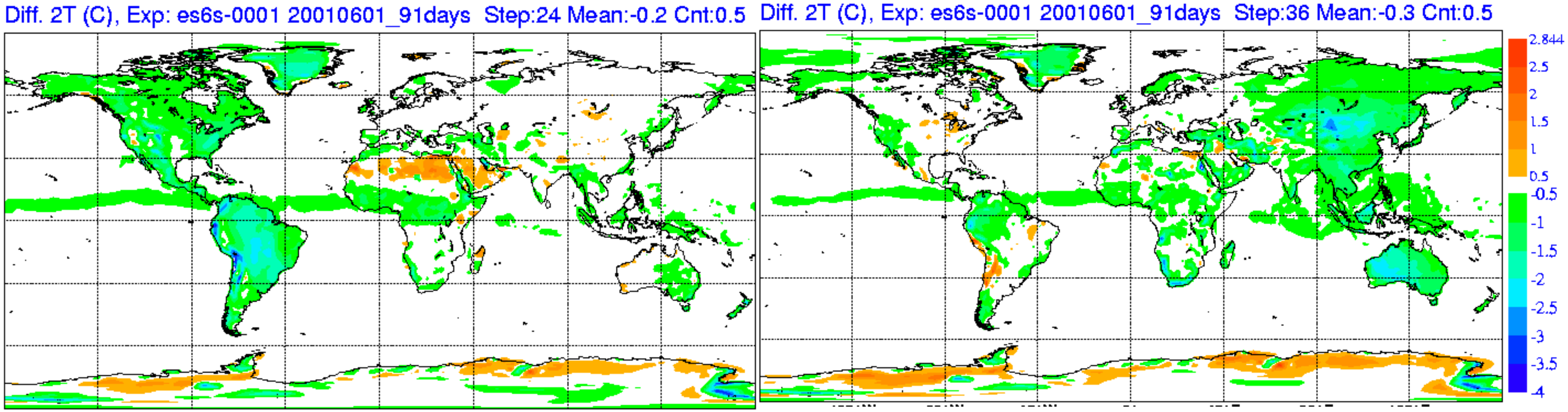
- Spin-up has improved with:
  1. A modest reduction in precipitation spindown
  2. A substantial reduction in TCWV spindown
  3. A change from increase of evaporation during the forecast to a decrease of evaporation. (BL has become more dry in analysis).
- It is difficult to make a precise link between model changes and impact on spin-up
- Model changes and data assimilation changes (including use of satellite data) have contributed
- It is impossible to verify TCWV within 1 kg/m2 using radio sonde data.

Tropical wind scores

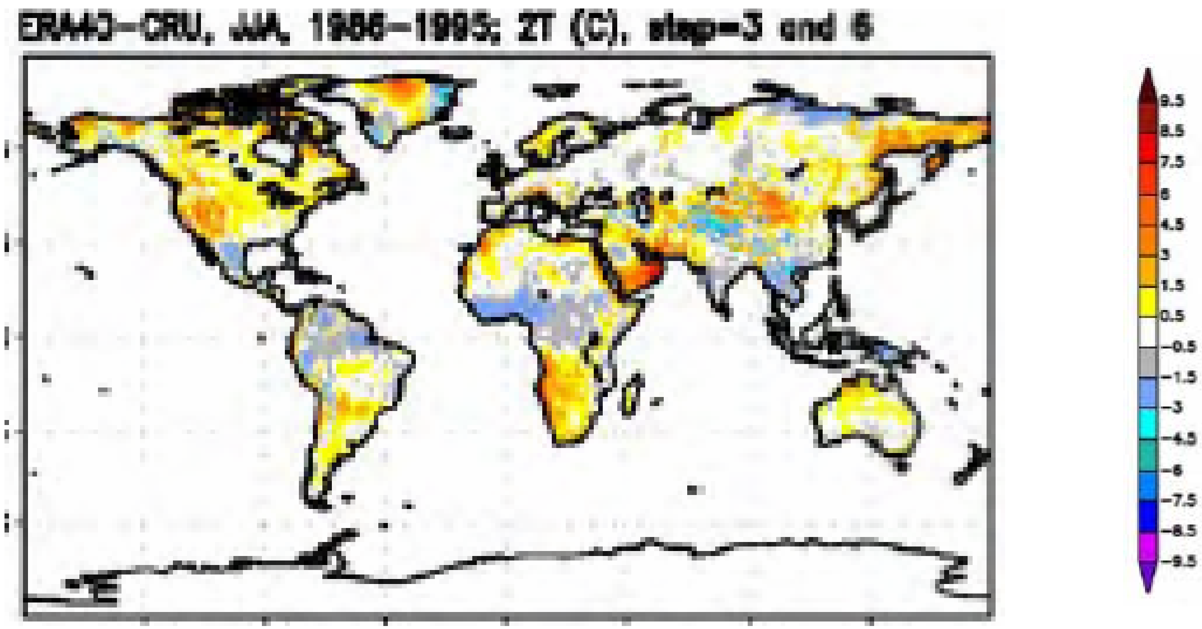


2T: JJA 24/36 hour forecasts (CY31R1- 23R4)

12 UTC **00 UTC**

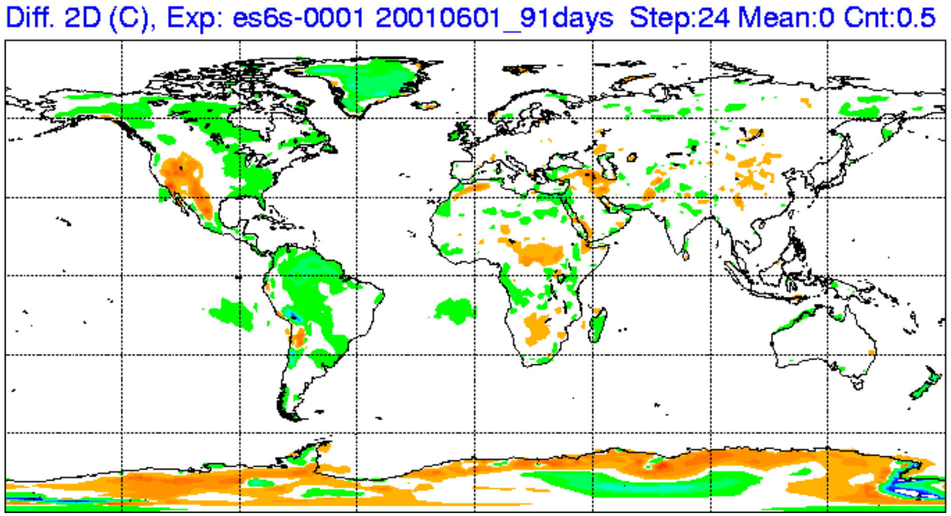


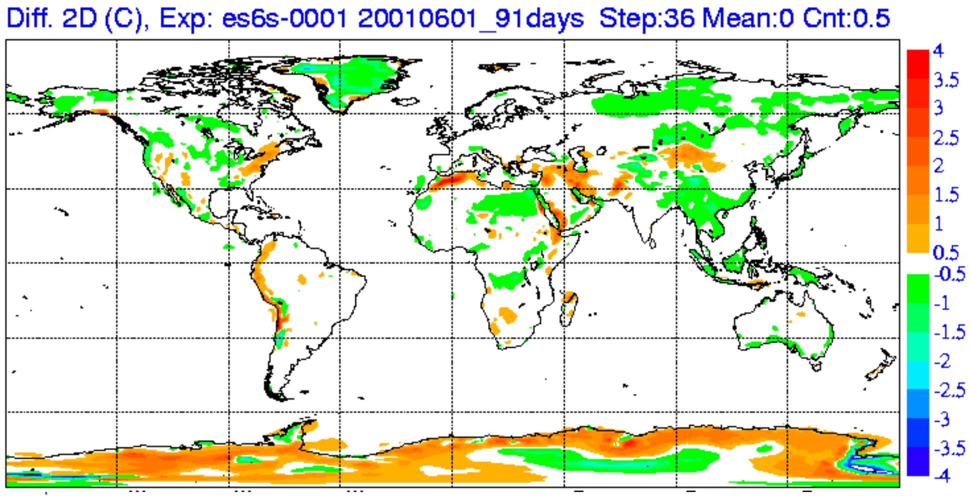
ERA-40 – CRU
JJA (1986-1995)



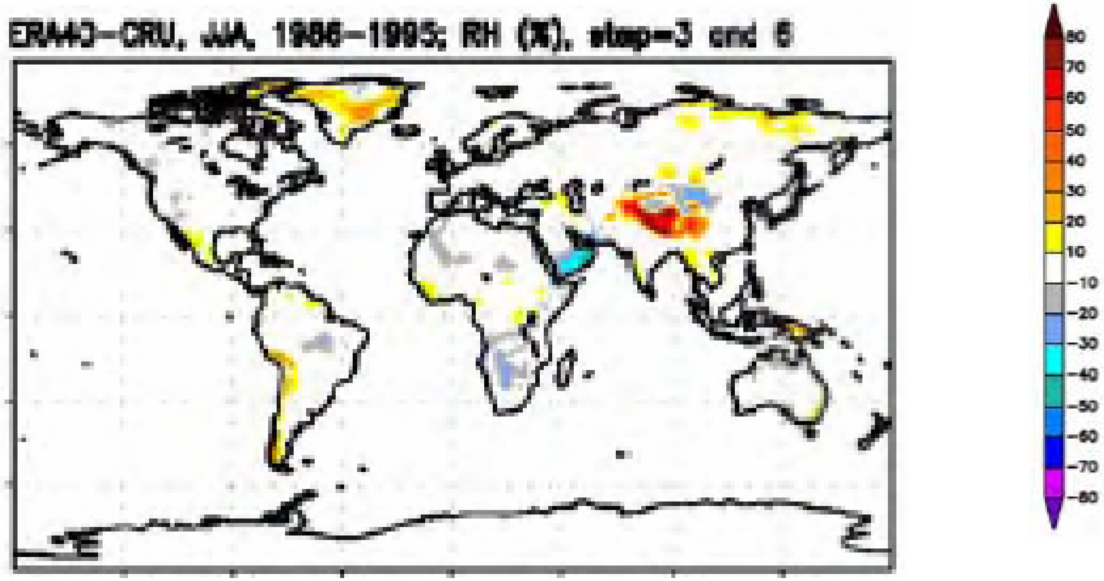
2D: JJA 24/36 hour forecasts (CY31R1- 23R4)

12 UTC **00 UTC**

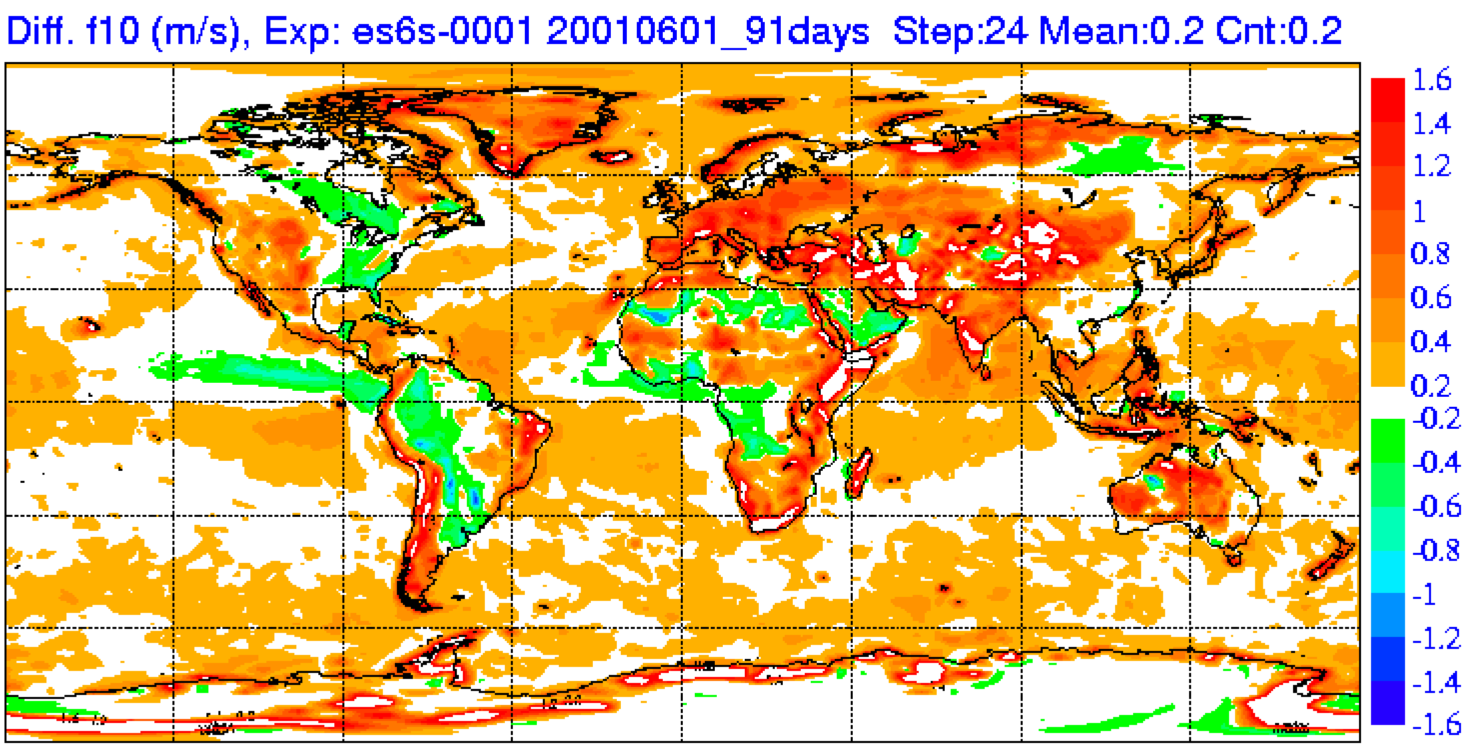




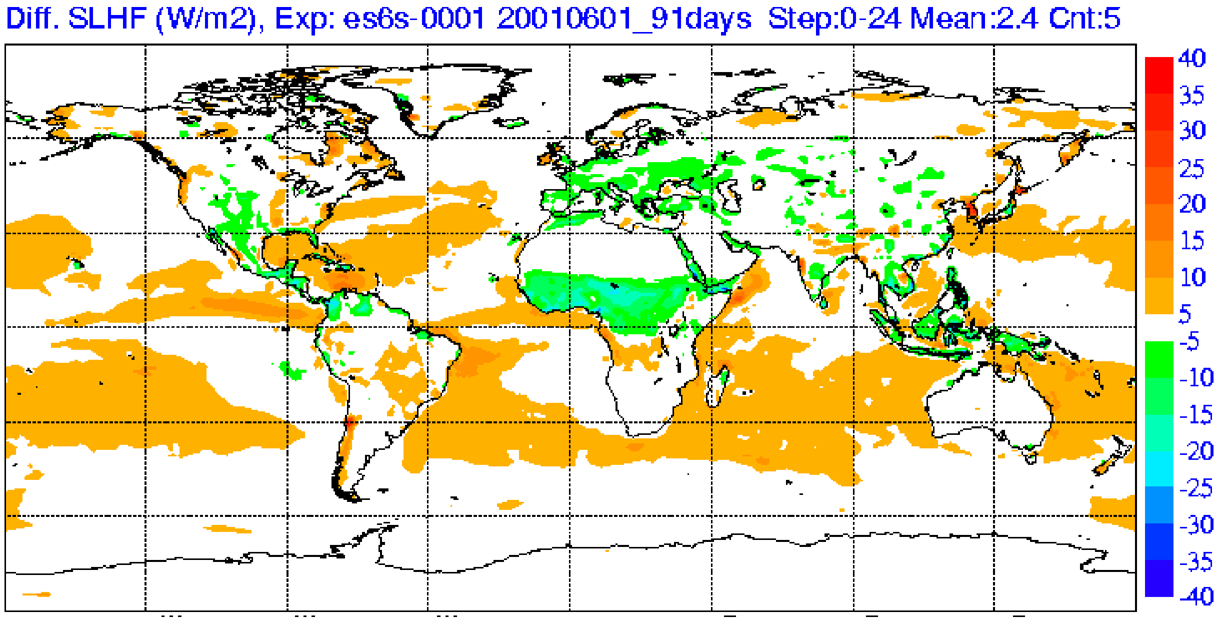
RH
ERA-40 – CRU
JJA (1986-1995)

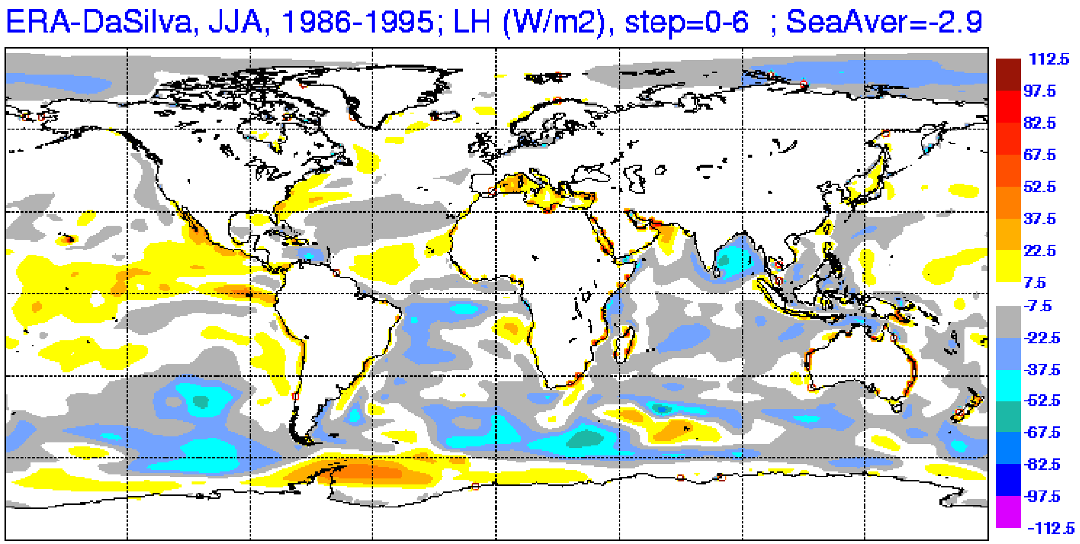


Wind speed: JJA 24 hour forecasts (CY31R1- 23R4)



Latent heat flux: JJA 24 hour forecasts (CY31R1- 23R4)

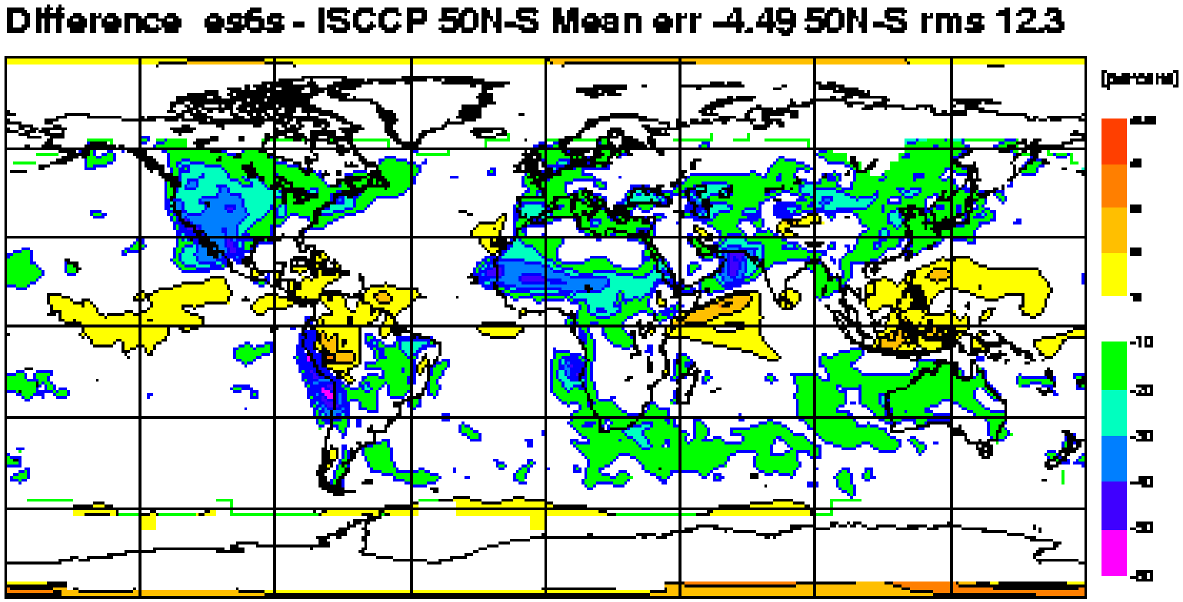




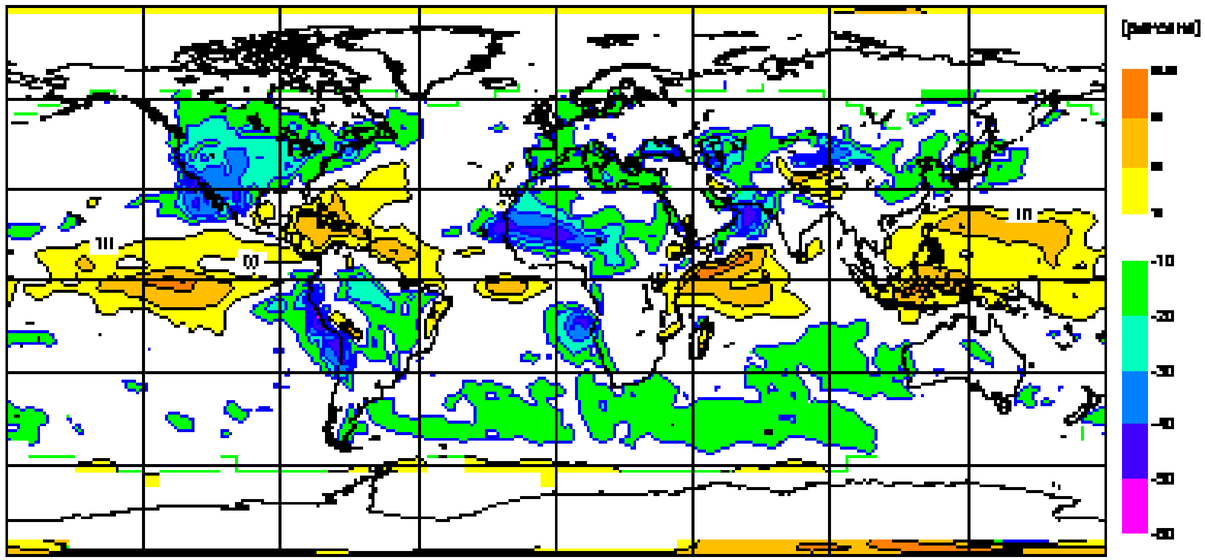
SLHF
ERA-40 – DaSilva
JJA (1986-1995)

Cloud cover: JJA 24 hour forecasts (CY31R1/23R4 - ISCCP)

CY31R1 - ISCCP

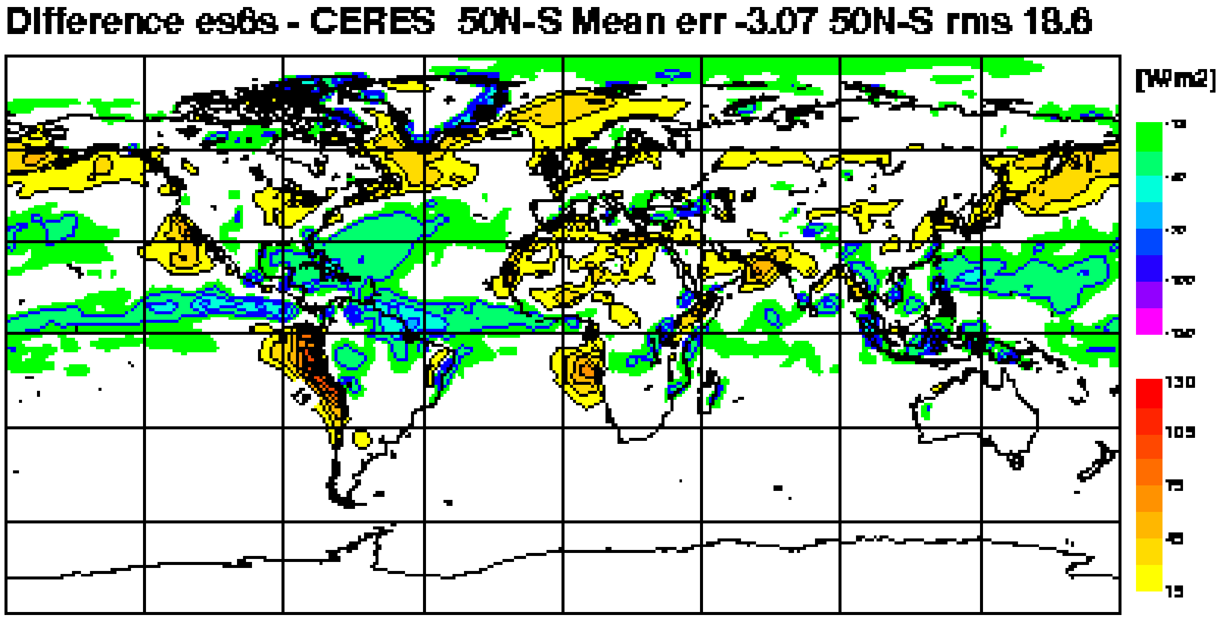


CY23R4 - ISCCP

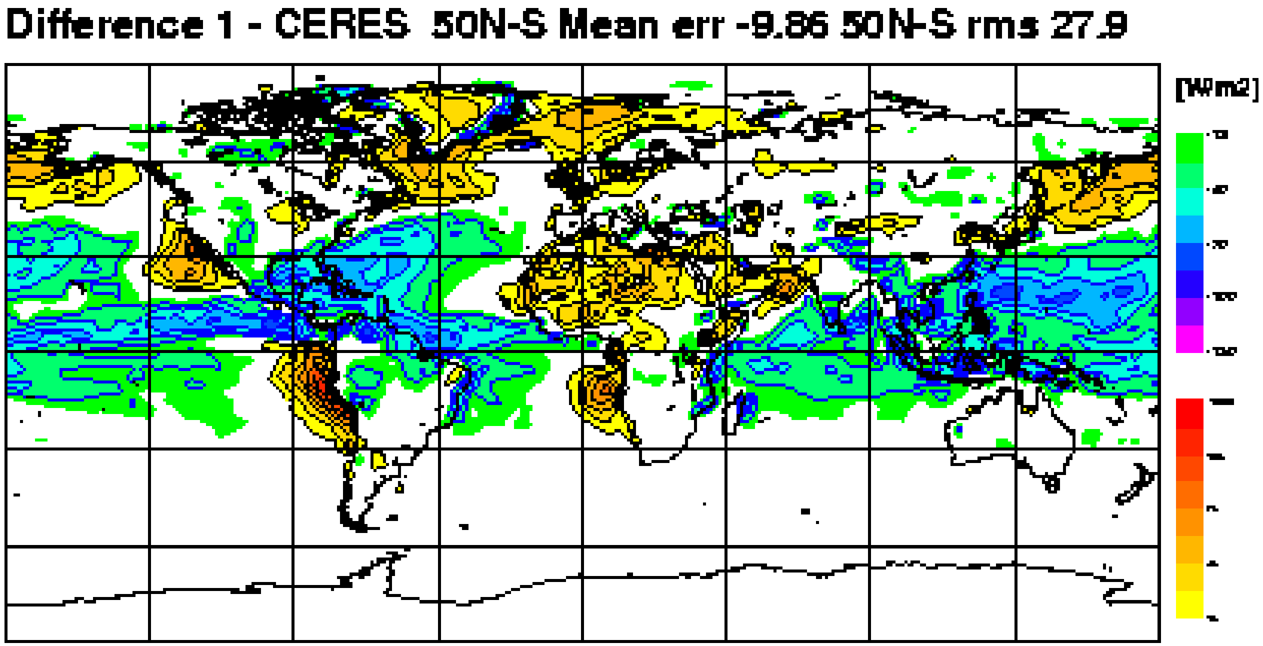


TSR: JJA 24 hour forecasts (CY31R1/23R4 - CERES)

CY31R1 - CERES



CY23R4 - CERES



Conclusions

- Physics derived fields provide a wealth of useful information.
- Synoptic variability tends to be very good, but results may not be bias free (e.g. precip, latent heat flux).
- Model development benefits from re-analysis.
- Substantial progress has been made after ERA-40, e.g. moist BL scheme, ice microphysics, convection.
- Spin-up has been reduced since ERA-40 through physics and data assimilation changes.