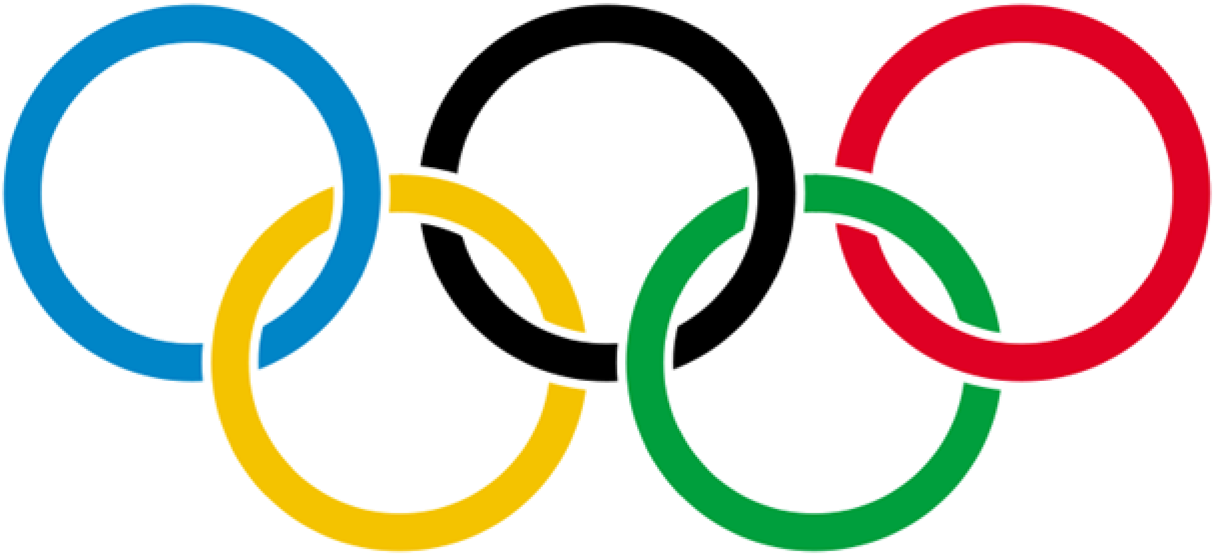
Convection parametrization

content:



Confutius says: Tell me and I will forget,
show me and I might remember

The global Lorenz Energy cycle

including subgrid generation/conversion rates of APE

Generation **Conversion**

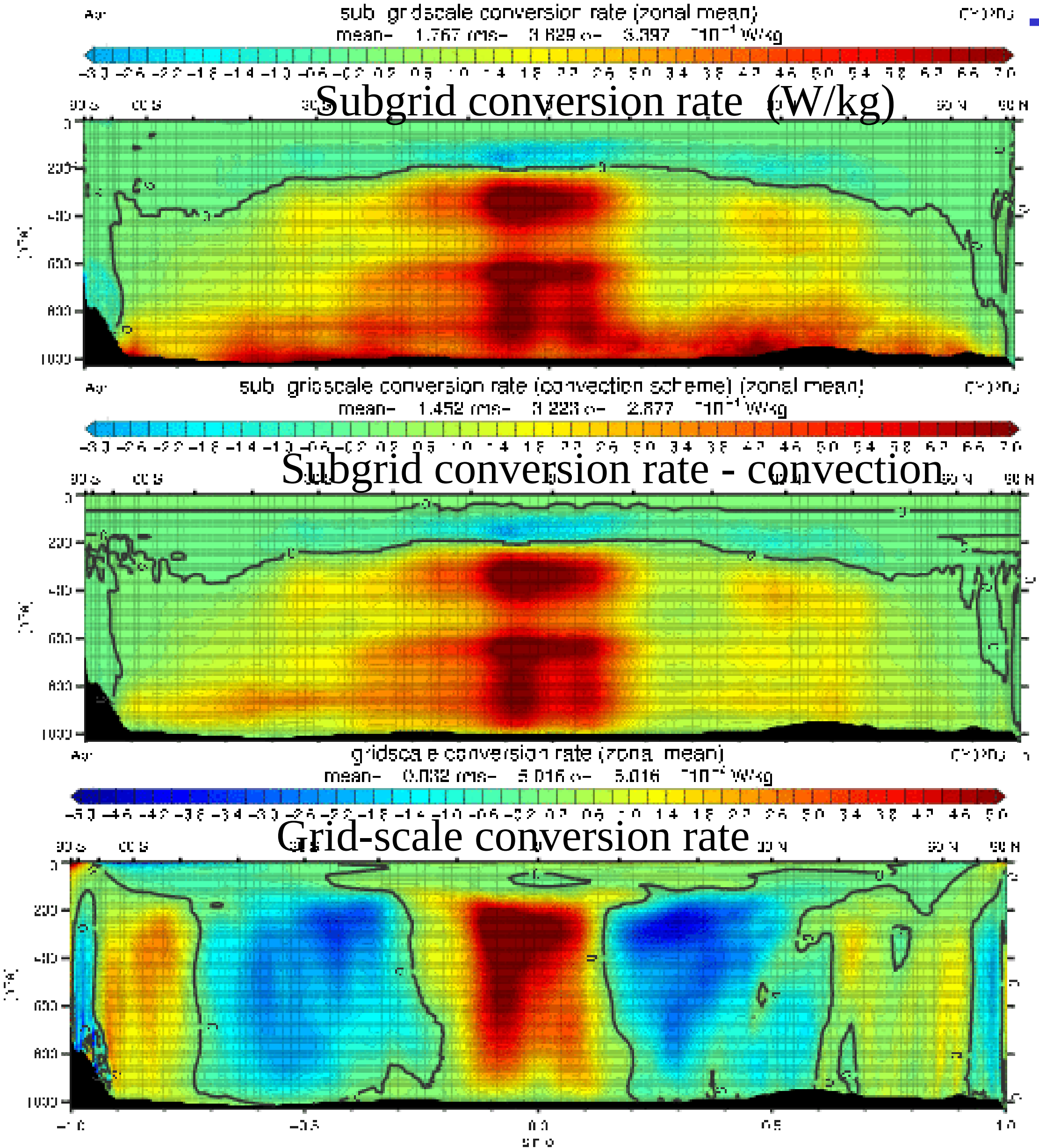
$$\frac{da}{dt} = NQ + \alpha\omega = N\overline{Q} + \overline{\alpha}\,\overline{\omega} + \overline{\alpha'\omega'}$$

Lorenz efficiency factor

Net heating

$$\overline{\alpha'\omega'} = \frac{R}{P}[1+(\varepsilon^{-1}-1)]\,\overline{T'\omega'} + (\varepsilon^{-1}-1)\,\overline{\alpha}\,\overline{q'\omega'}$$

subgrid conversion rates by processes



Subgrid conversion rate (W/kg)

Subgrid conversion rate - convection

Grid-scale conversion rate

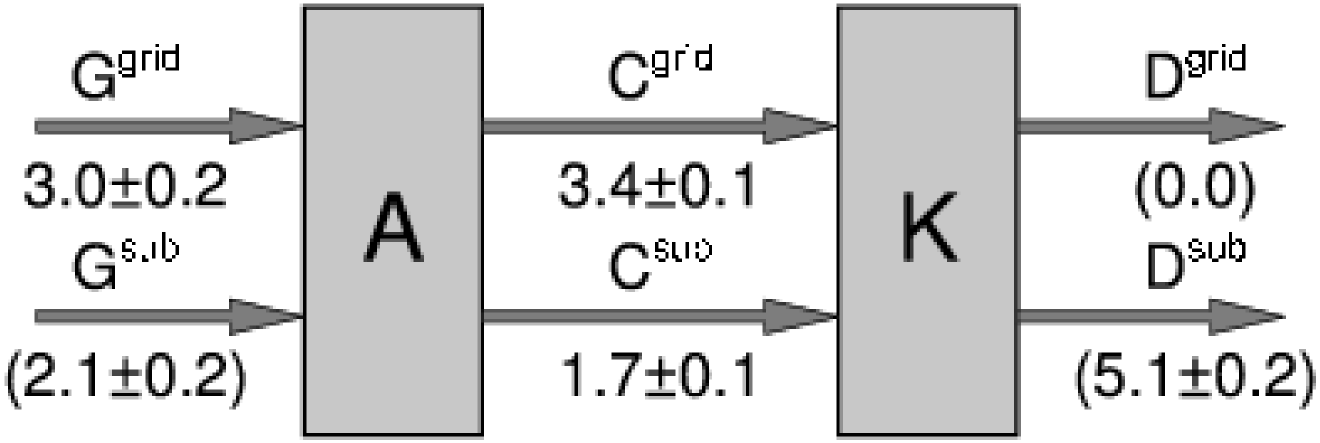
Convection so important because contribution always positive !

Grid-scale has positive and negative contributions to kinetic energy conversion rate

Radiation does not contribute to the conversion rates but to the generation rate, but even there has only at poles a positive contribution (cooling at cold places) but globally a negative contribution (as in Tropics it is cooling where it is warm)

The Lorenz Energy diagram including physical (subgrid-scale) processes

and the small numbers (W/m2)



Subgrid of similar importance than grid-scale, and convection is the most important subgrid process for conversion

The dissipation (D=3.4 W/m2=Cgrid, Csub doesn't exist in model)) is made up of surface dissipation and gravity wave drag (2.3 W/m2), convective momentum transport (0.4 W/m2), interpolation in semi-Lagrangien advection (0.5), and horizontal diffusion (0.2 W/m2)

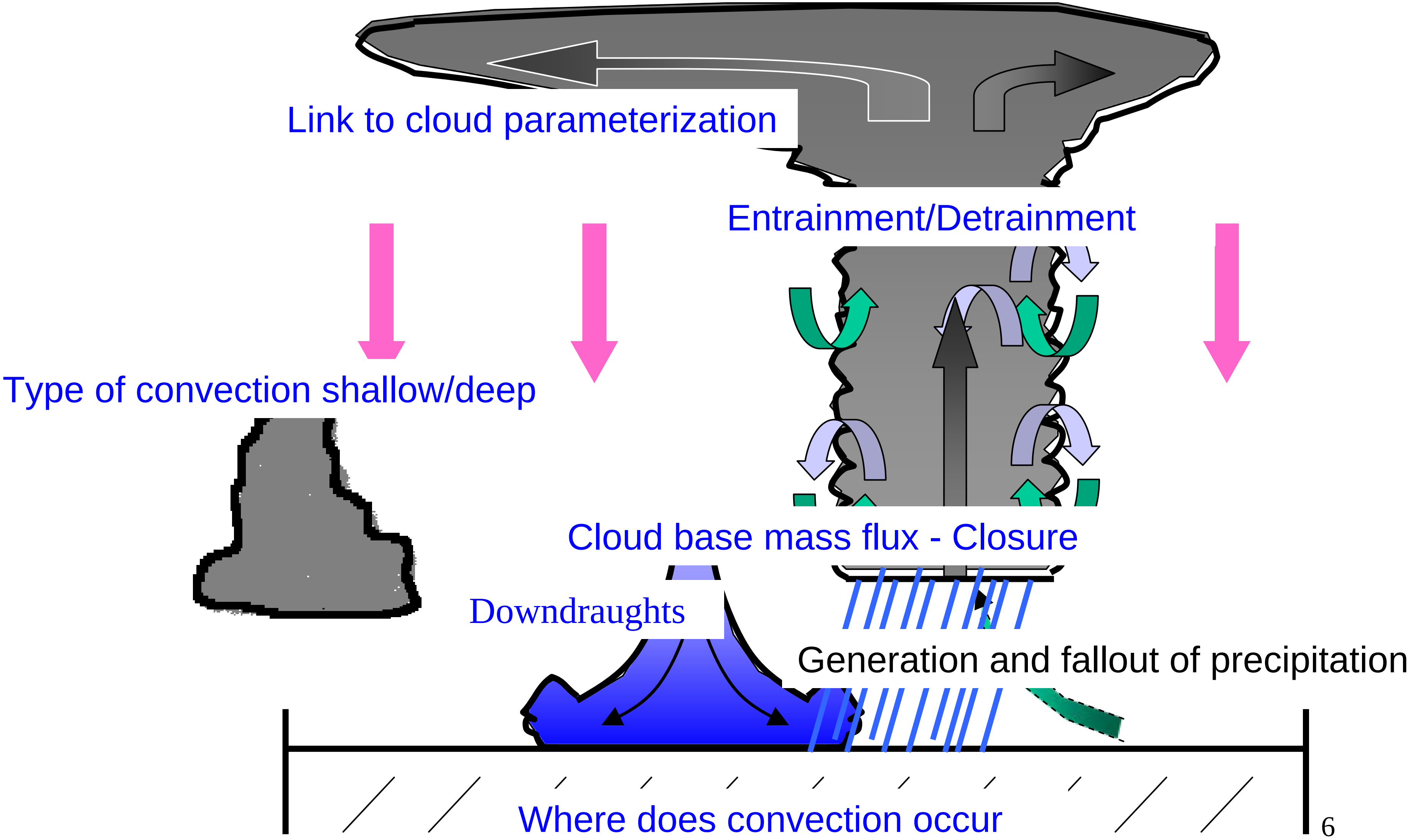
M Steinheimer, M Hantel, P Bechtold (Tellus, Oct 2008)

Working on the production and dissipation part of Available Potential Energy and Kinetic Energy it should be possible to (further) improve the representation of Atmospheric Activity and Variability (=Amplitude and Phase of perturbations)

Convection and Diffusion

(Numerics)

The mass flux concept:
Communication cloud environment



Link to cloud parameterization

Entrainment/Detrainment

Type of convection shallow/deep

Cloud base mass flux - Closure

Downdraughts

Generation and fallout of precipitation

Where does convection occur

Entrainment

$$\varepsilon = \underbrace{c_0}_{turb} F_\varepsilon + \underbrace{c_1 \frac{\bar{q}_s - \bar{q}}{\bar{q}_s}}_{org, buoy>0, deep\ only} F_\varepsilon ; \quad F_\varepsilon = \left(\frac{\bar{q}_s}{\bar{q}_{sbase}} \right)^2$$

Scaling function to mimick a cloud ensemble

$$c_0 ; c_1 ; c_2 = O(10^{-4} - 10^{-3} m^{-1});$$

NB1: This is a simple 1-RH or saturation deficit formulation for the organised entrainment, but formulations using buoyancy or Θ_e, Θ_{es} also work . This work goes back to JL. Redelsperger et al. (JAS 2002) work on TOGA-COARE.

NB2: Specifying a simple constant detrainment rate, the scaling function, rapidly decreasing with height will ensure that from a given height entrainment > detrainment and mass flux starts to decrease.

Closure - Deep convection

$$CAPE = \int_{cloud} g \frac{\overline{\Theta}_v^c - \overline{\Theta}_v}{\overline{\Theta}_v} dz$$

$$\left(\frac{\partial CAPE}{\partial t}\right)_{cu} = g \int_{cloud} \frac{\overline{\Theta}_v \frac{\partial \overline{\Theta}_v^c}{\partial t} - \overline{\Theta}_v^c \frac{\partial \overline{\Theta}_v}{\partial t}}{\overline{\Theta}_v^{\,2}} dz$$

Assume:

$\frac{\partial \overline{\Theta}_v^c}{\partial t} = 0,$ steady state cloud $\frac{\overline{\Theta}_v^c}{\overline{\Theta}_v} \approx 1$

$$\longrightarrow \quad \left(\frac{\partial CAPE}{\partial t}\right)_{cu} = -g \int_{cloud} \frac{1}{\overline{\Theta}_v} \left(\frac{\partial \overline{\Theta}_v}{\partial t}\right)_{cu} dz$$

Closure - Deep convection

$$\left(\frac{\partial\overline{\Theta}_v}{\partial t}\right)_{cu} \approx \frac{M_c}{\rho}\frac{\partial\overline{\Theta}_v}{\partial z}$$

i.e., ignore detrainment

$$\longrightarrow \left(\frac{\partial CAPE}{\partial t}\right)_{cu} = -g\int\limits_{cloud}\frac{M_c}{\rho\overline{\Theta}_v}\frac{\partial\overline{\Theta}_v}{\partial z}dz = -\frac{CAPE}{\tau}$$

$$M_c = M_u + M_d = M_{u,b}\eta_u + M_{d,t}\eta_d \qquad M_{d,t} = -\alpha M_u$$

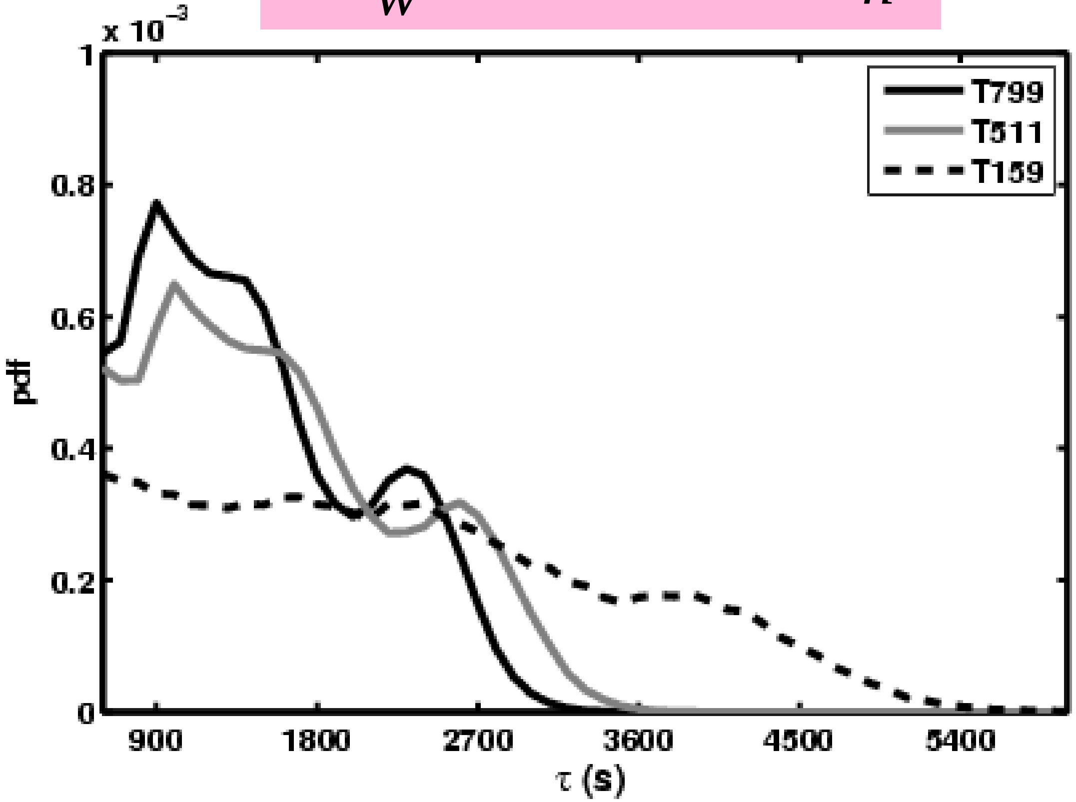
$$\longrightarrow \boxed{M_{u,b} = \frac{\dfrac{CAPE}{\tau}}{g\int\limits_{cloud}(\eta_u - \alpha\eta_d)\dfrac{1}{\rho\overline{\Theta}_v}\dfrac{\partial\overline{\Theta}_v}{\partial z}dz} = \frac{\dfrac{CAPE}{\tau}}{g\int\limits_{cloud}\dfrac{M^{n-1}}{M^{n-1}_{u,b}}\dfrac{1}{\rho\overline{\Theta}_v}\dfrac{\partial\overline{\Theta}_v}{\partial z}dz}}$$

where M^{n-1} are the mass fluxes from a previous first guess updraft/downdraft computation

Convection: Adjustment time-scale

$$\tau = \frac{H}{\overline{w^u}} \alpha; \quad \alpha = 1 + \frac{264}{n}$$

n = spectral truncation



Intuitively it must be something on the order of the life cycle of the cloud and the gravity wave propagation time through the model grid

$$\tau \approx \Delta x / \sqrt{gH}$$

Closure - Shallow convection

Based on PBL equilibrium : what goes in must go out - including downdraughts

$$\mathit{With} \qquad \int_0^{cbase} \frac{\partial \overline{h}}{\partial t} \rho dz = 0$$

$$\int_0^{cbase} \left[-\frac{\partial \left(\overline{w'h'} \right)_{conv}}{\partial z} + \left(\frac{\partial \overline{h}}{\partial t} \right)_{turb} + \left(\frac{\partial \overline{h}}{\partial t} \right)_{dyn} + \left(\frac{\partial \overline{h}}{\partial t} \right)_{rad} \right] \overline{\rho} dz = 0$$

$$\overline{\rho} \left(\overline{w'h'} \right)_{conv,cbase} = M_{u,b} \left(h_u - \varepsilon h_d - (1-\varepsilon)\overline{h} \right)_{cbase} ; \quad \varepsilon = M_u / M_d ; \qquad and$$

$$\left(\overline{w'h'} \right)_{conv,0} = 0$$

$$\boxed{M_{u,b} = \frac{\int_0^{cbase} \left[\left(\frac{\partial \overline{h}}{\partial t} \right)_{turb} + \left(\frac{\partial \overline{h}}{\partial t} \right)_{dyn} + \left(\frac{\partial \overline{h}}{\partial t} \right)_{rad} \right] \rho dz}{\left(h_u - \varepsilon h_d - (1-\varepsilon)\overline{h} \right)_{cbase}}}$$

Physics numerics in the Semi-Lag

Sequential Splitting: order is important, better balance than parallel approach, especially for long time steps (720s – 3600s)

- **Dynamics** update dT/dt, dq/dt, du/dt, dv/dt
- **Radiation** update T*, update dT/dt
- **Diff+Gwd** update T*, q*, u*, v*, dT/dt, dq/dt, du/dt, dv/dt
  Implicit solver with dynamics tendencies as RHS
- **Cloud** first guess cloud, no conv detr, update T*, q*
- **Convection** update T*, q*, dT/dt, dq/dt, du/dt, dv/dt
  Implicit advection
- **Cloud** full cloud, input conv detr, update dT/dt, dq/dt
  Implicit solver

The final physics tendencies for the update of the arrival point =
d/dt_physics= 0.5* d/dt_departure + 0.5*d/dt_arrival

Nearly ready, the scheme seems to be reasonable sensitive (to environmental humidity), numerically robust, and hopefully produces quasi resolution independent results but ….

Come the people from data assimilation, and ask

Is the scheme also sufficiently simple and linear, so that a reasonable Tangent Linear Model can be written that closely fits the non-linear model.

Note: The Adjoint version can always be formally developed, but it doesn't always make sense (is useful)

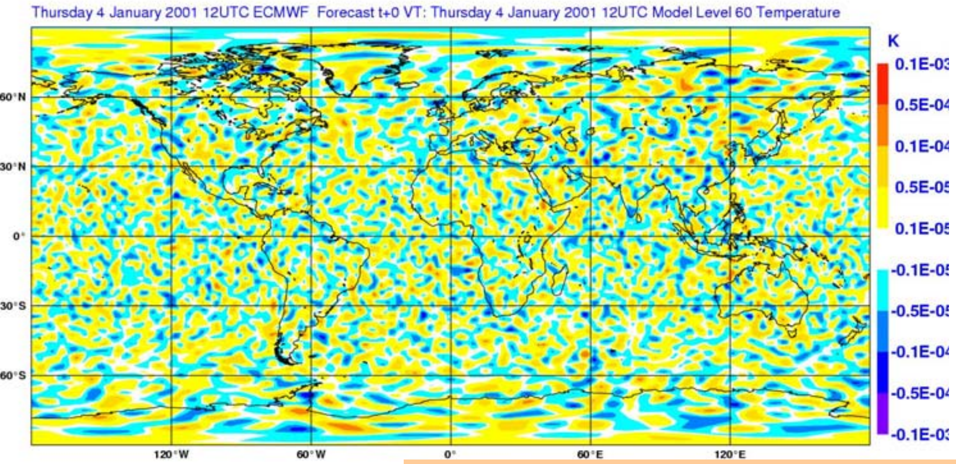
Physics parametrizations and Data assimilation: Constraints

Philippe Lopez

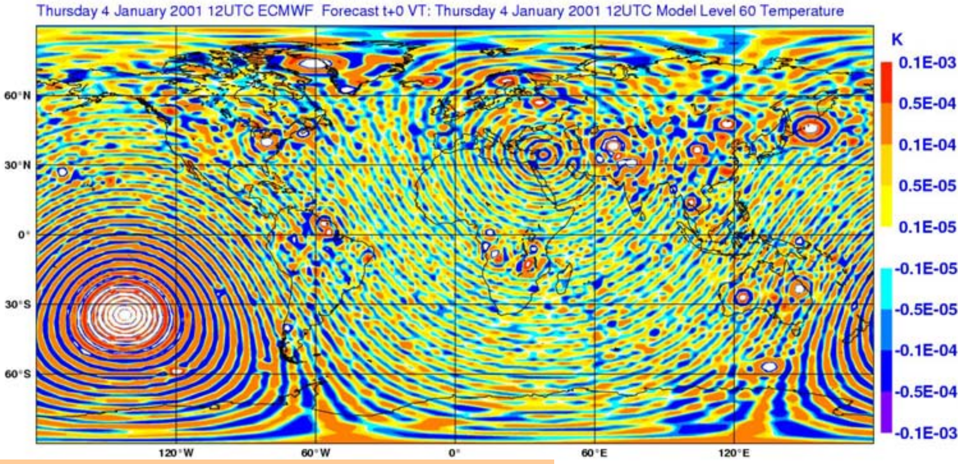
Evolution of a small size initial perturbation with nonlinear (NL) and tangent-linear (TL) model (dynamics + full physics)

Initial perturbation = white noise with max amplitude ≈ 10^{-5} K and m s^{-1}

TL evolution (1 step)

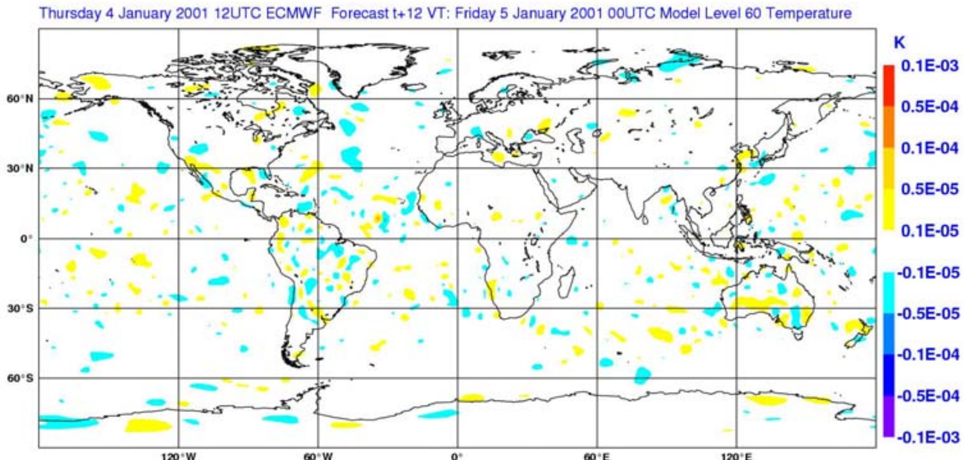


Difference between two NL runs (1 step)

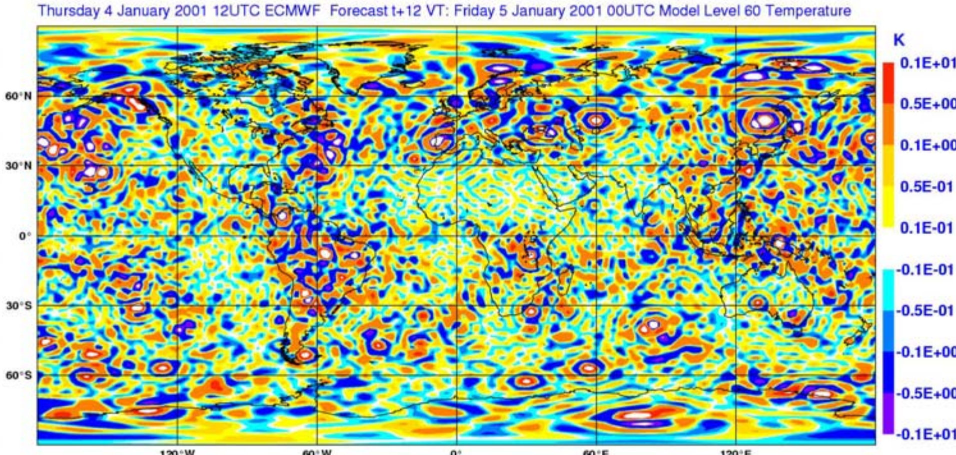


Temperature on model level 60, T95 L60, CY32R3

TL evolution (24 steps)

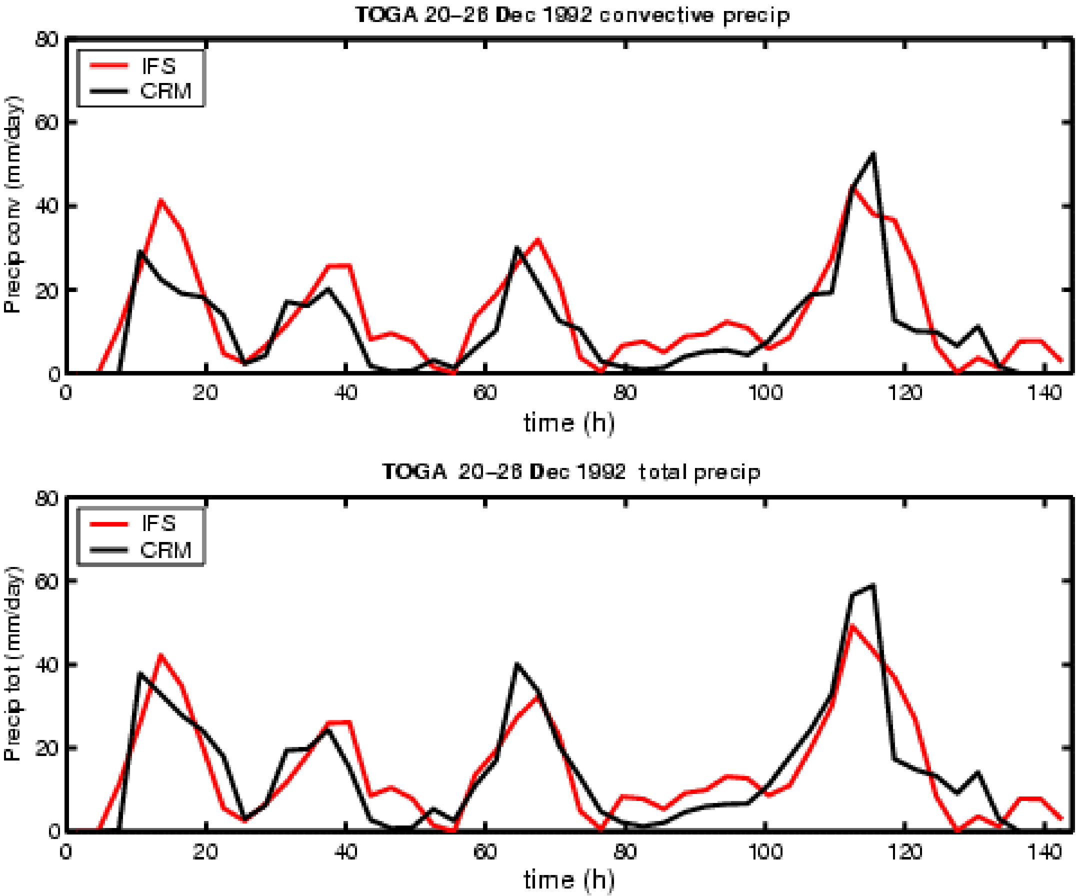


Difference between two NL runs (24 steps)



Tracer transport experiments

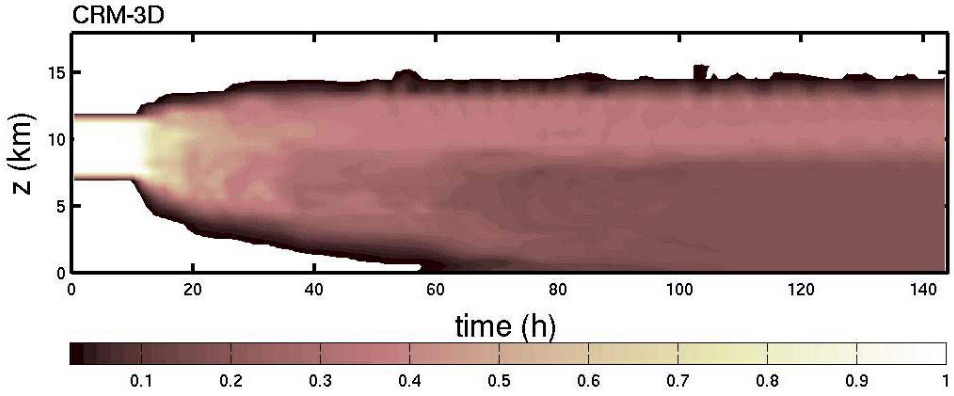
Single-column against CRM

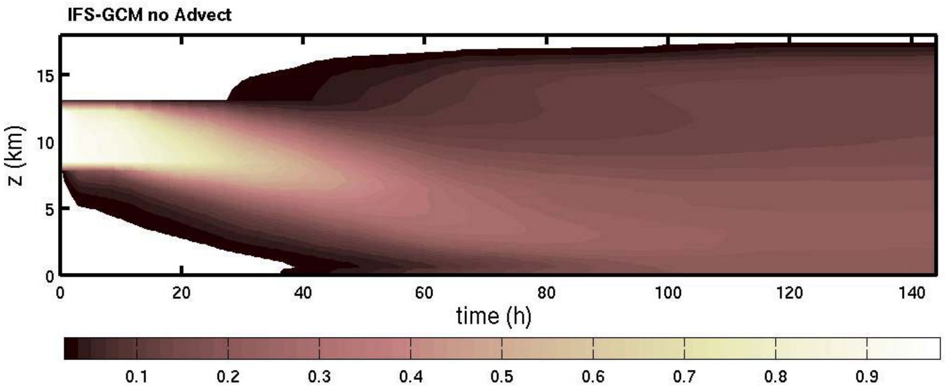

TOGA 20–26 Dec 1992 convective precip

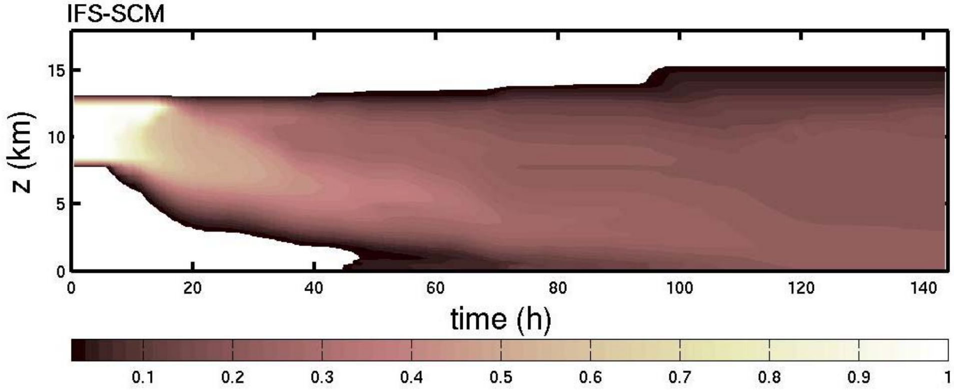
TOGA 20–26 Dec 1992 total precip

Tracer transport experiments
IFS Single-column and global model against CRM

Mid-tropospheric Tracer

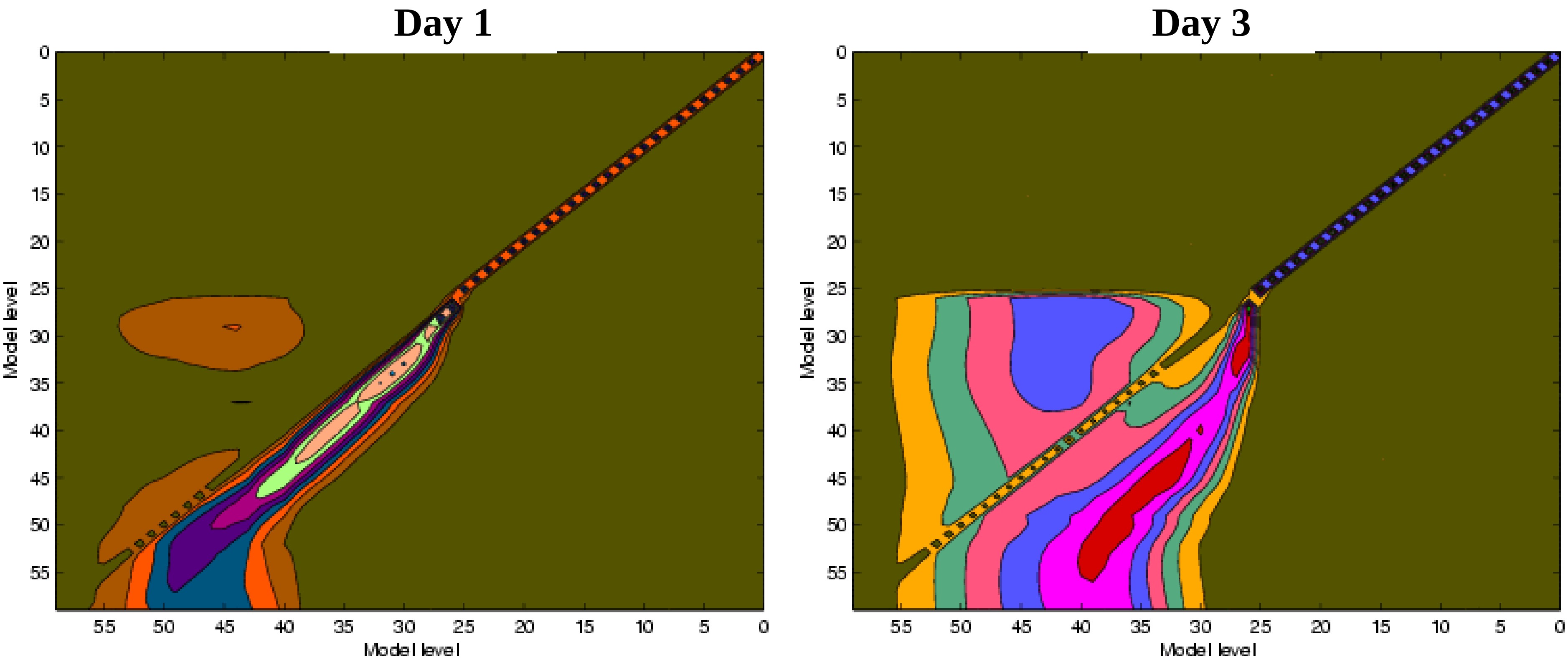






- Mid-tropospheric tracer is transported upward by convective draughts, but also slowly subsides due to cumulus induced environmental subsidence
- IFS SCM (convection parameterization) diffuses tracer somewhat more than CRM

The mixing Matrix

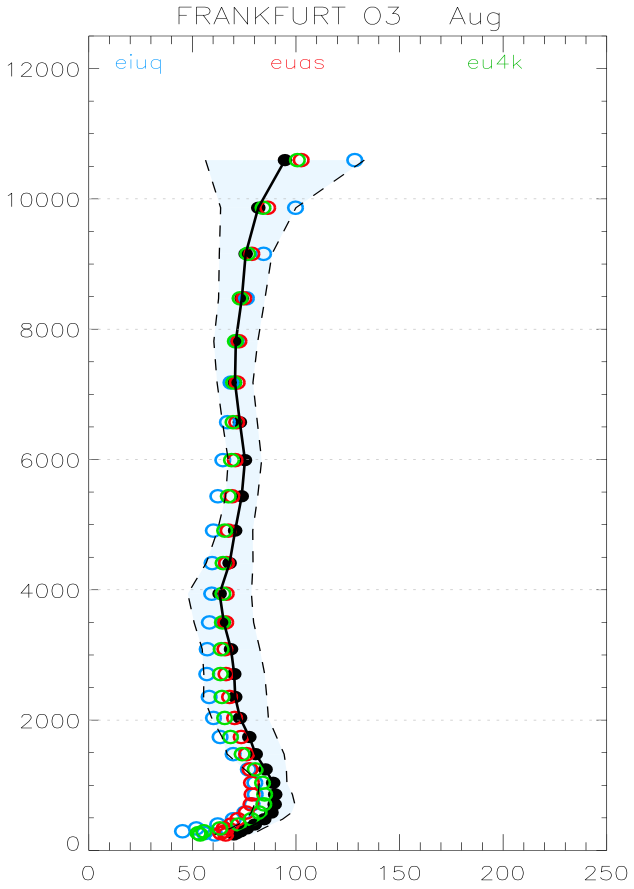


Due to **entrainment/detrainment** processes the **Mixing Matrix** becomes singular after a few hours showing that **Demixing** is unphysical.

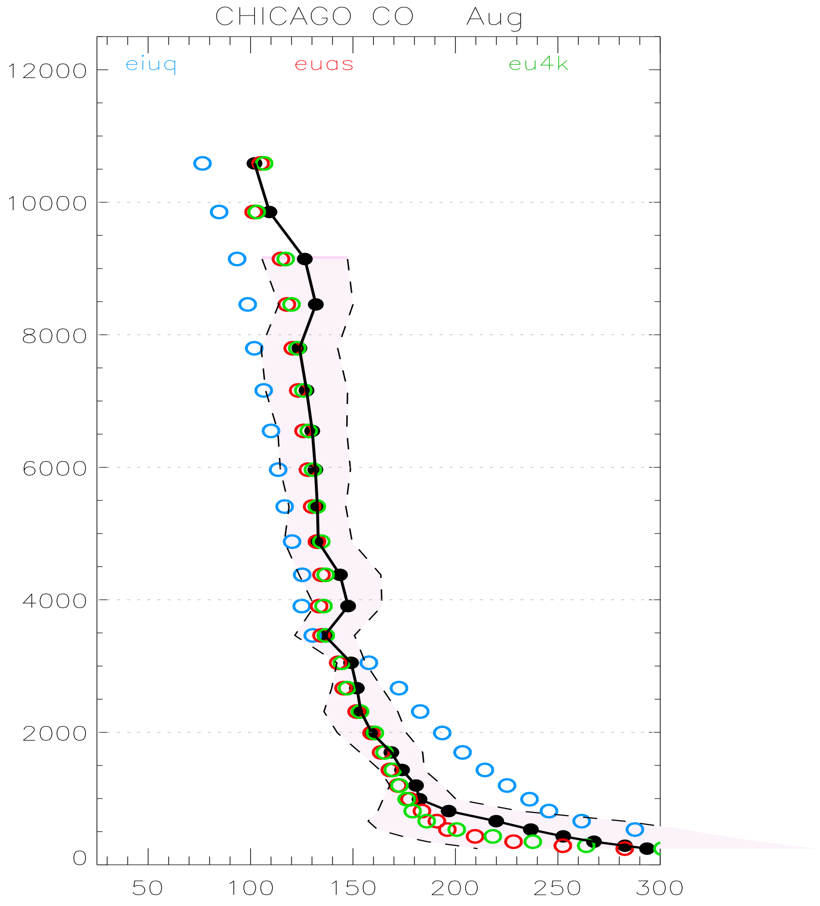
The Adjoint (Transpose), however, always exist. Backtracing tests show that it is useful (Sensitivity) for time-scales of typically 1 day depending on convective events.

IFS vs. MOZART vs. MOZAIC vertical transport as part of GEMS

euiq vertical transport à la MOZART
eu4k IFS convection & MOZART difussion
euas IFS convection and diffusion



ozone

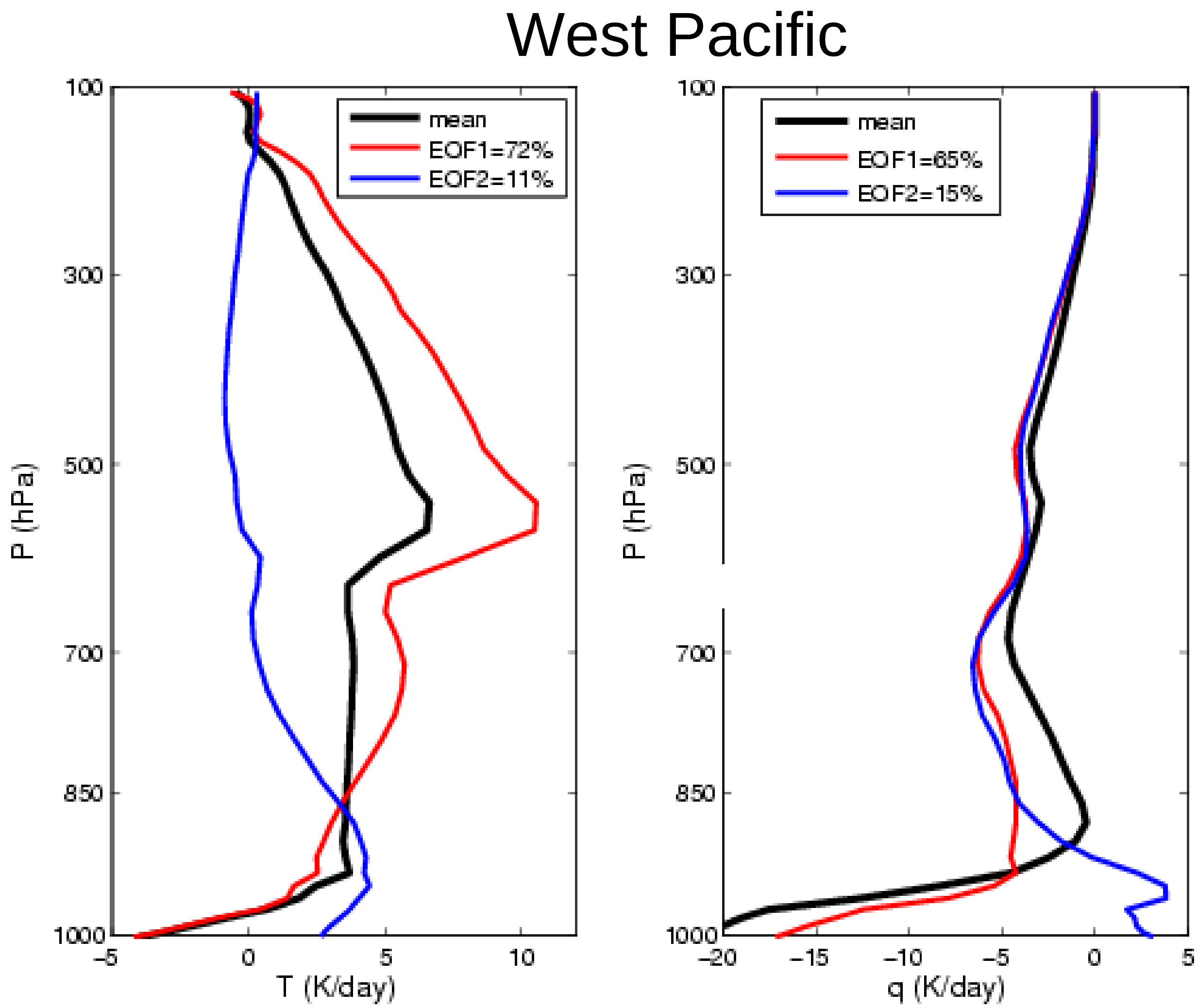


Carbon Monoxide

Questions for MOZART: ask Olaf Stein (Jülich)

Convective Tendencies: mean and EOFs

T and q convection



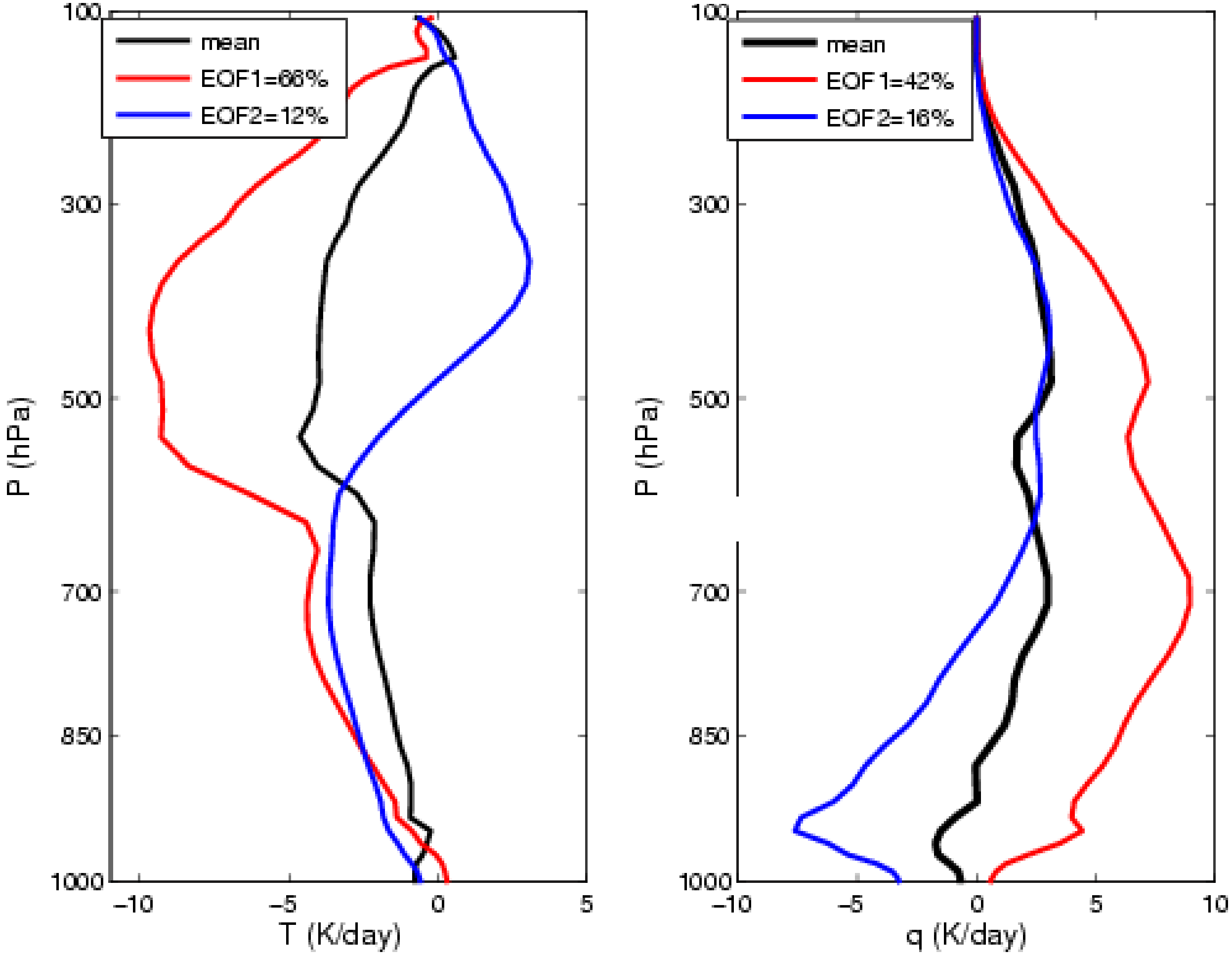
Upper-tropospheric convective heating, dominant EOF1, melting level

Convective drying, importance of levels below 700 hPa

Convective Tendencies: mean and EOFs

T and q dynamics

West Pacific

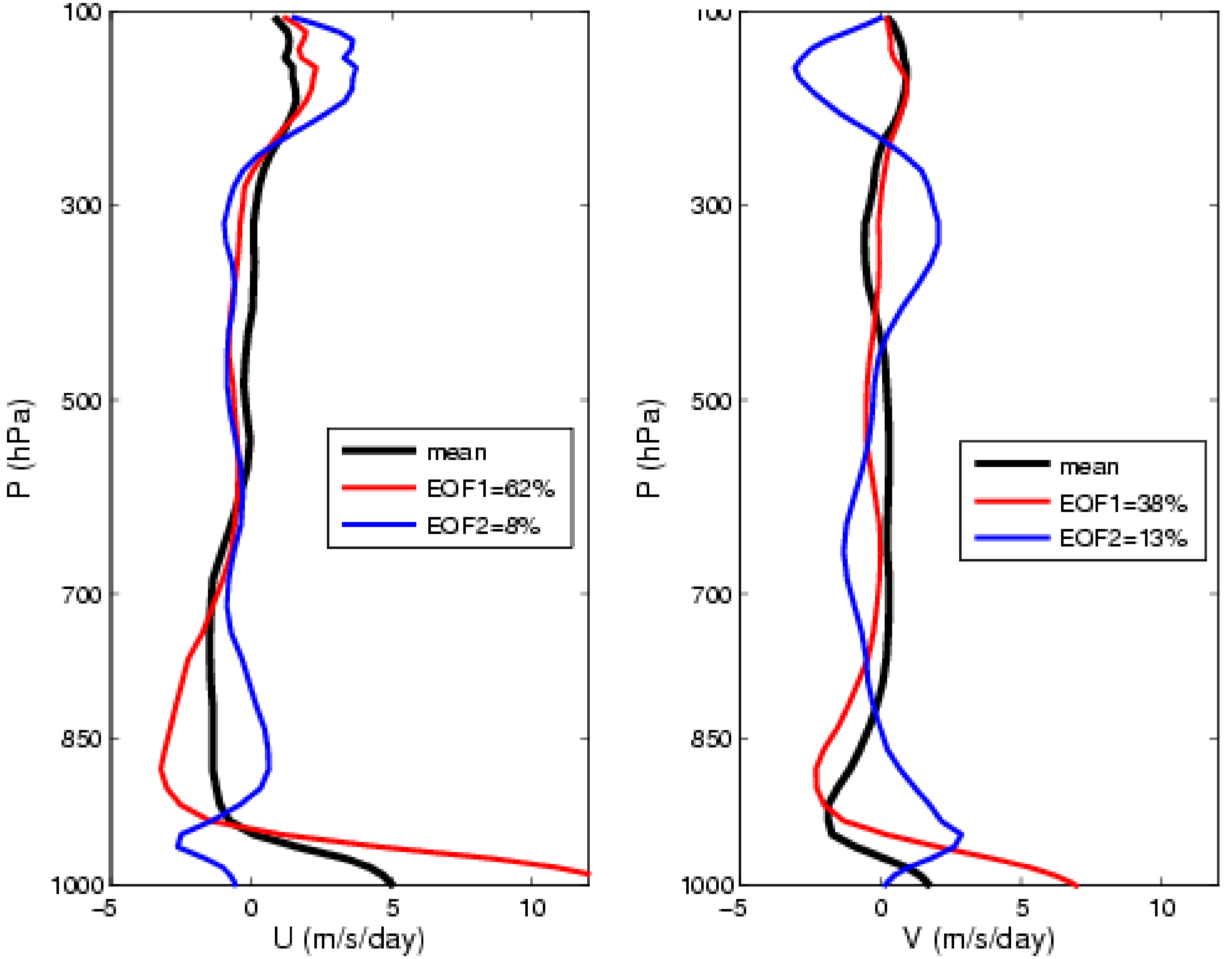


Upper-tropospheric active dynamical cooling (both EOFs)
Large-scale moistening all levels

Convective Tendencies: mean and EOFs

U and V convection

West Pacific

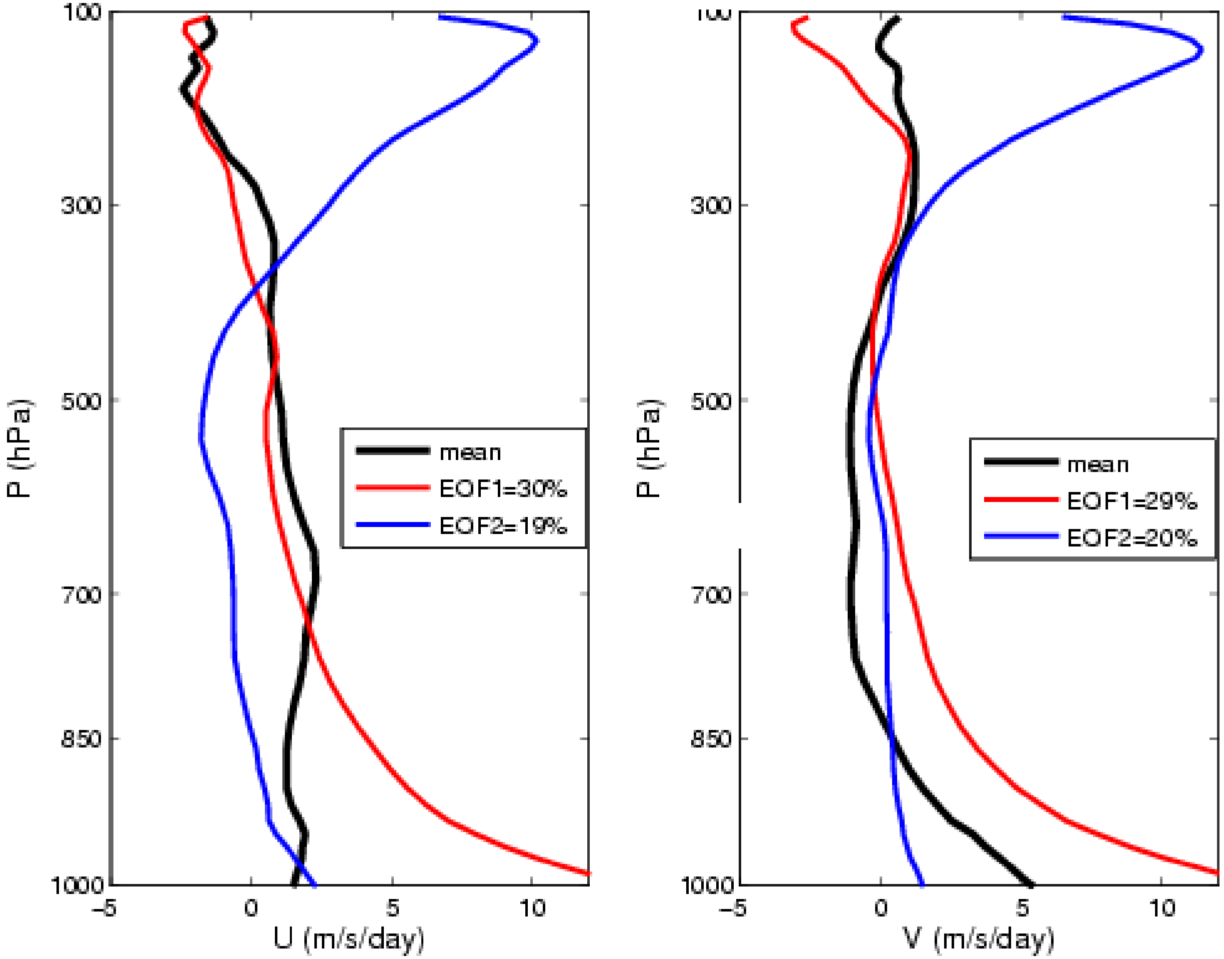


Momentum complicated but always downgradient. Main cumulus friction through shallow convection. Possible problem at upper levels

Convective Tendencies: mean and EOFs

U and V dynamics

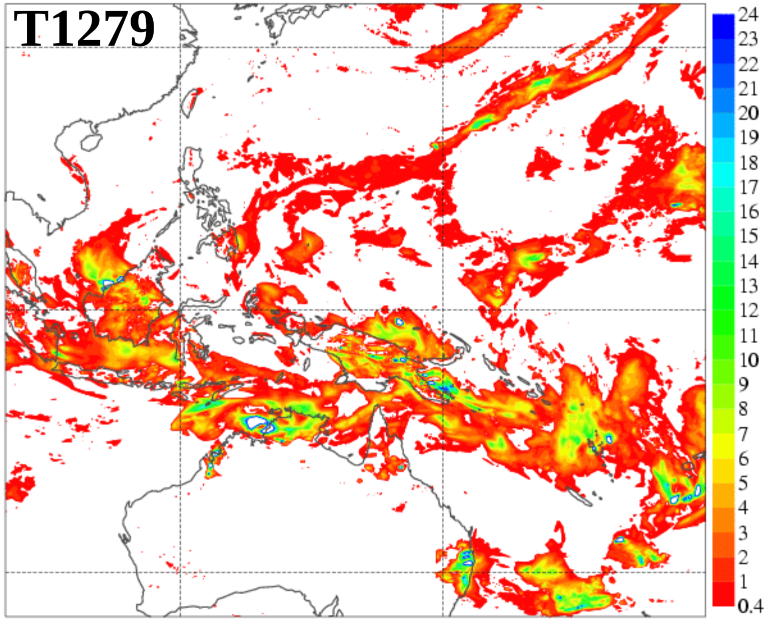
West Pacific



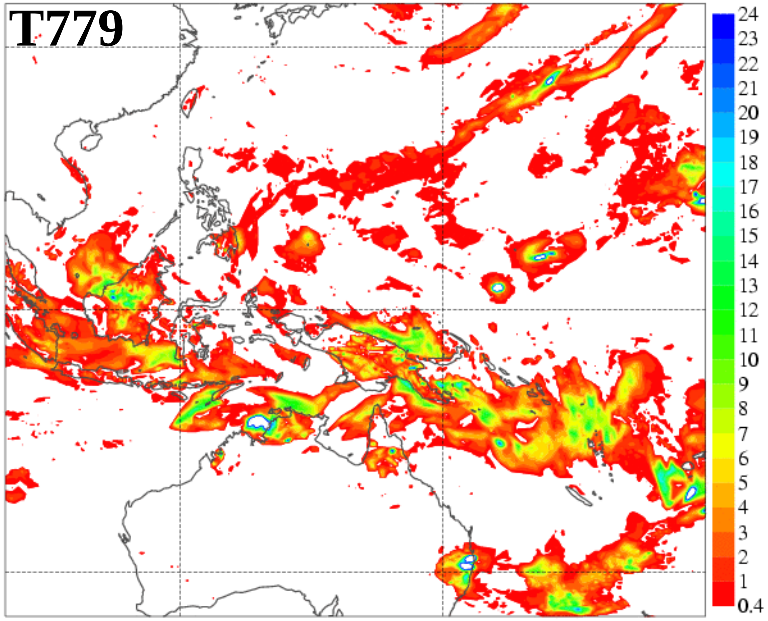
Main dynamical variability in upper and lower tropsophere. No clear dominant mode.

Scale independence of tropical Precip forecast ? (3h accumulation)

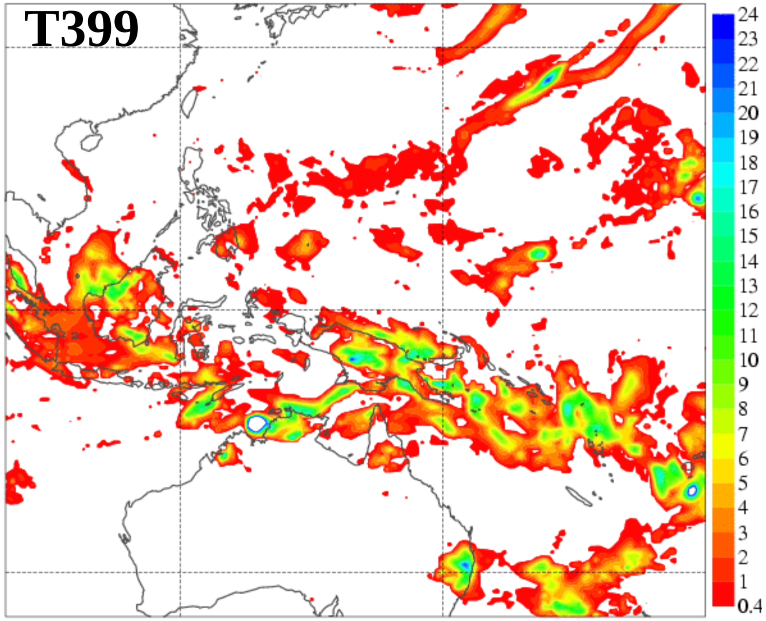
Friday 4 January 2008 00UTC ECMWF Forecast t+12 VT: Friday 4 January 2008 12UTC Surface: **Convective precipitation
T1279 total 12-9h precip (mm)



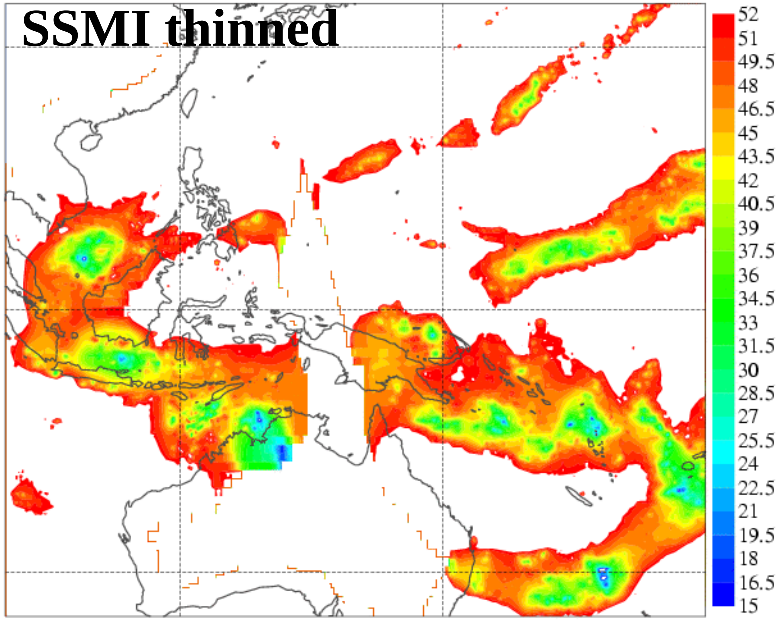
Friday 4 January 2008 00UTC ECMWF Forecast t+12 VT: Friday 4 January 2008 12UTC Surface: **Convective precipitation
T799 total 12-9h precip (mm)



Friday 4 January 2008 00UTC ECMWF EPS Control Forecast t+12 VT: Friday 4 January 2008 12UTC
Surface: **Convective precipitation
T399 total 12-9h precip (mm)

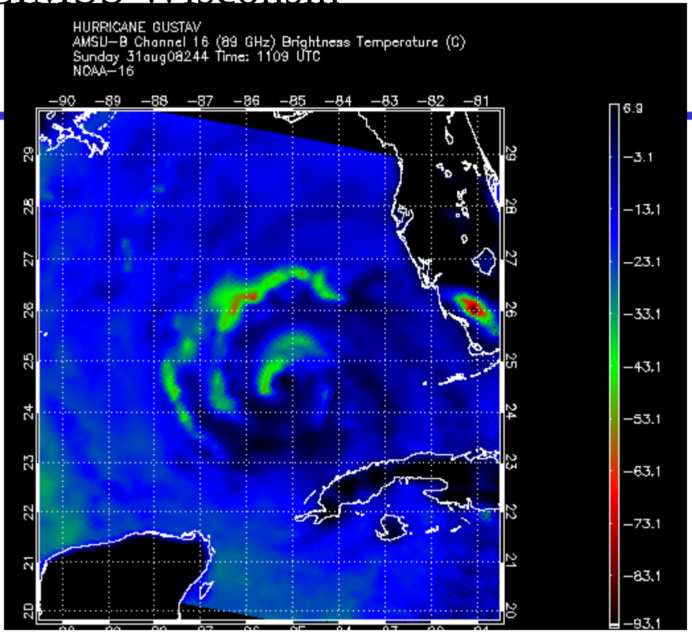


SSMI polarisation difference channels 19v-19h

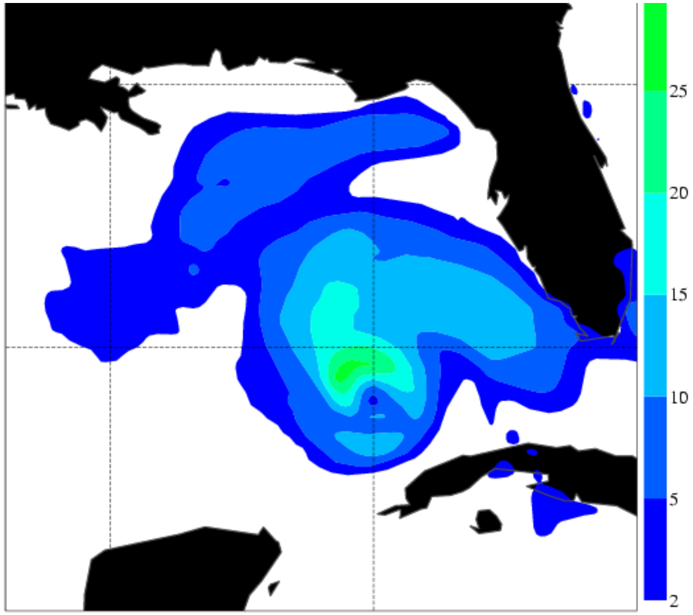


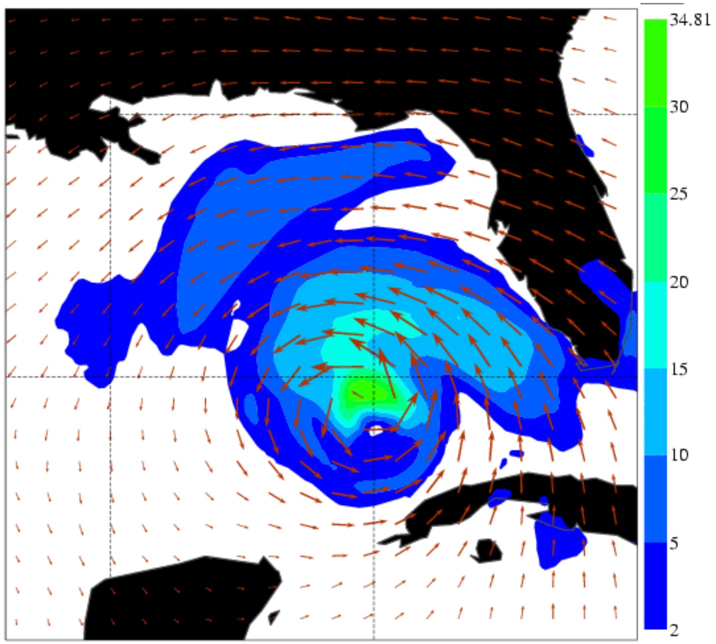
Hurricane Gustave AMSU-B and 9-12h rainfall

from CIMSS Wisconsin



T799 oper 2008083100 +12h

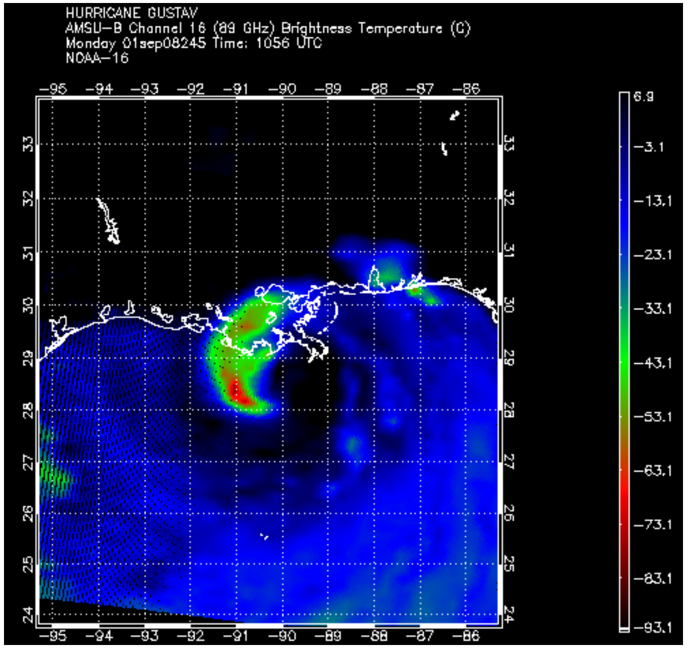




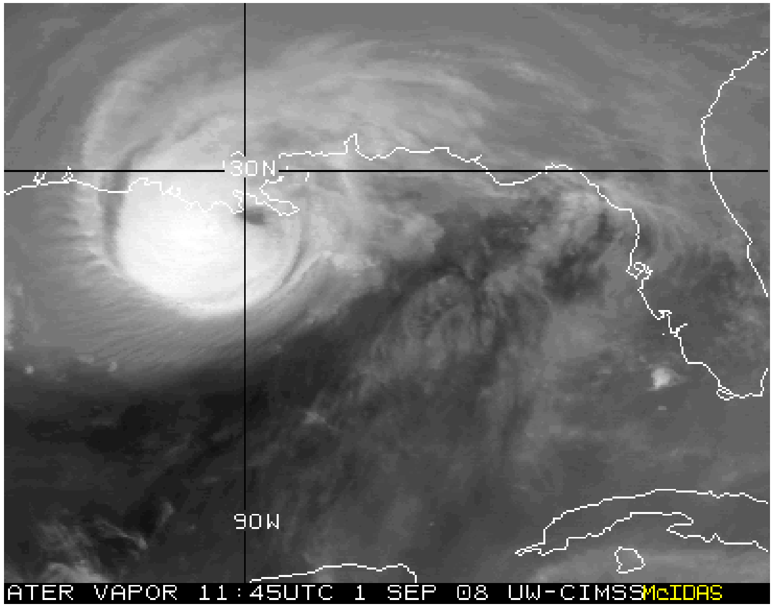
T799 exper. forecast rain+wind 925hPa
without assimilation and wave model

Also “visual” test for adjustment time

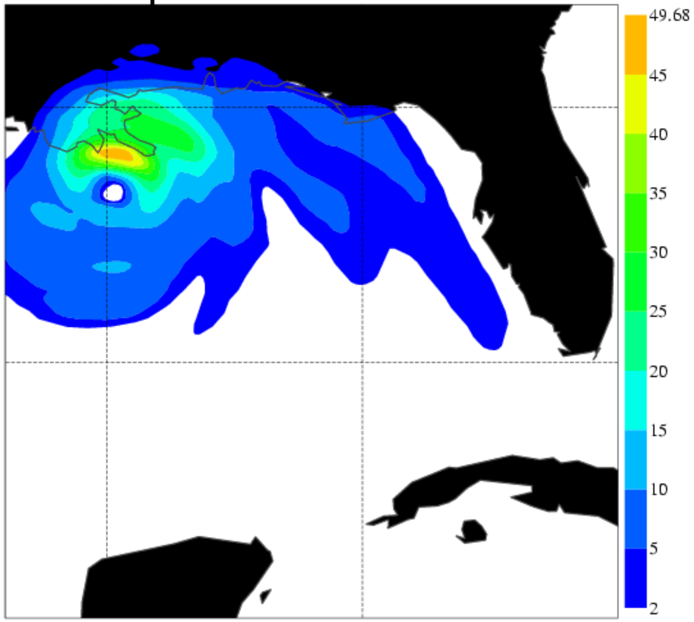
Hurricane Gustave AMSU-B and 33-36h rainfall



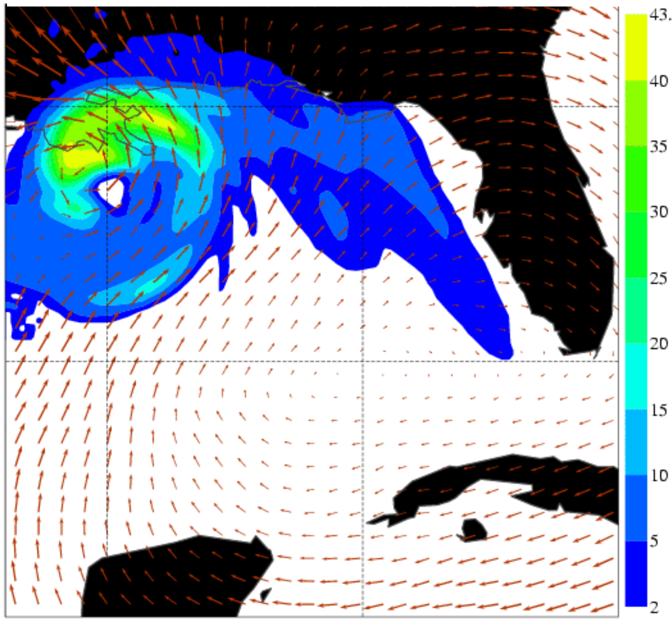
from CIMSS Wisconsin



T799 oper 2008083100 +36h

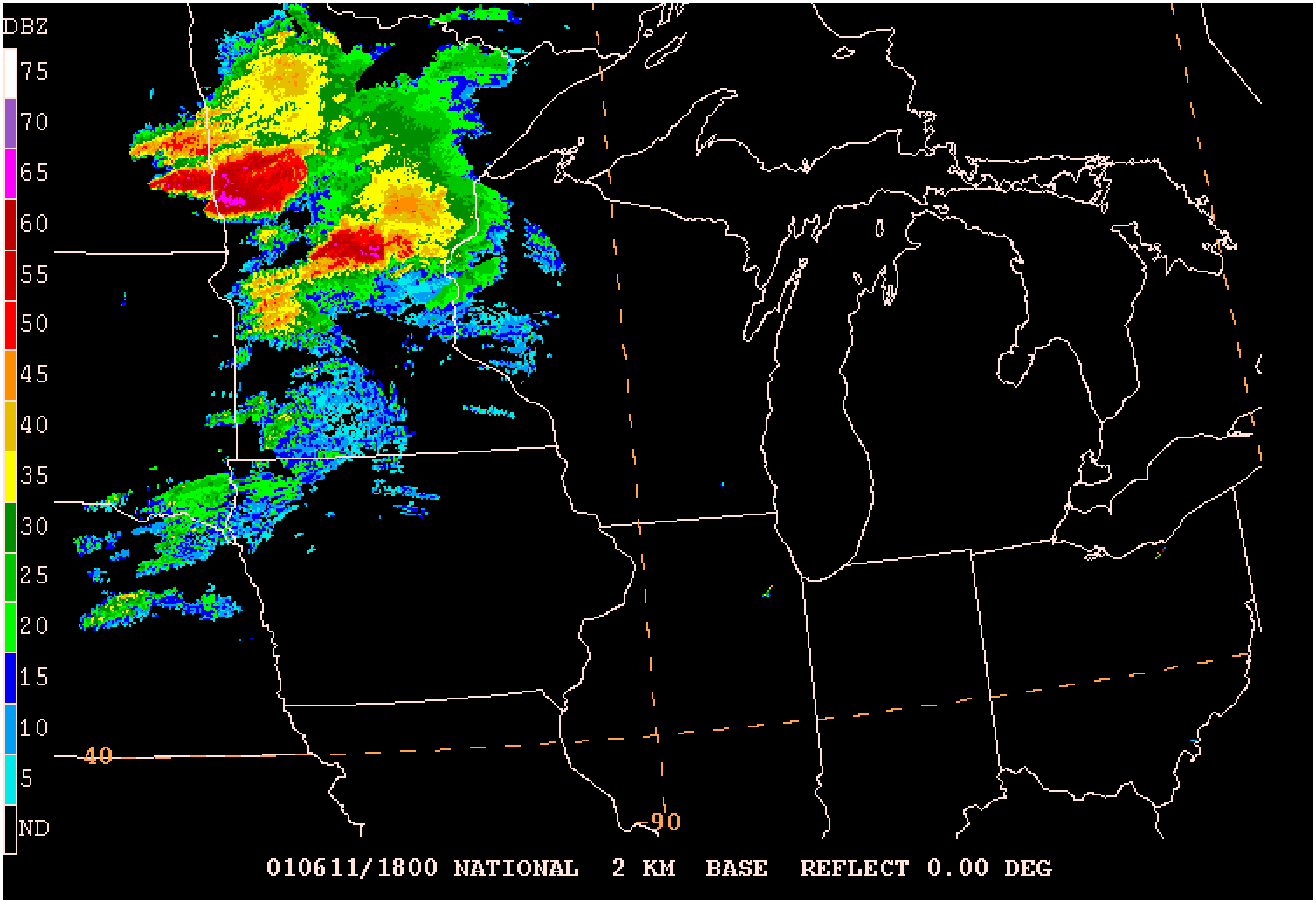


T1279 exper with 200hPa wind

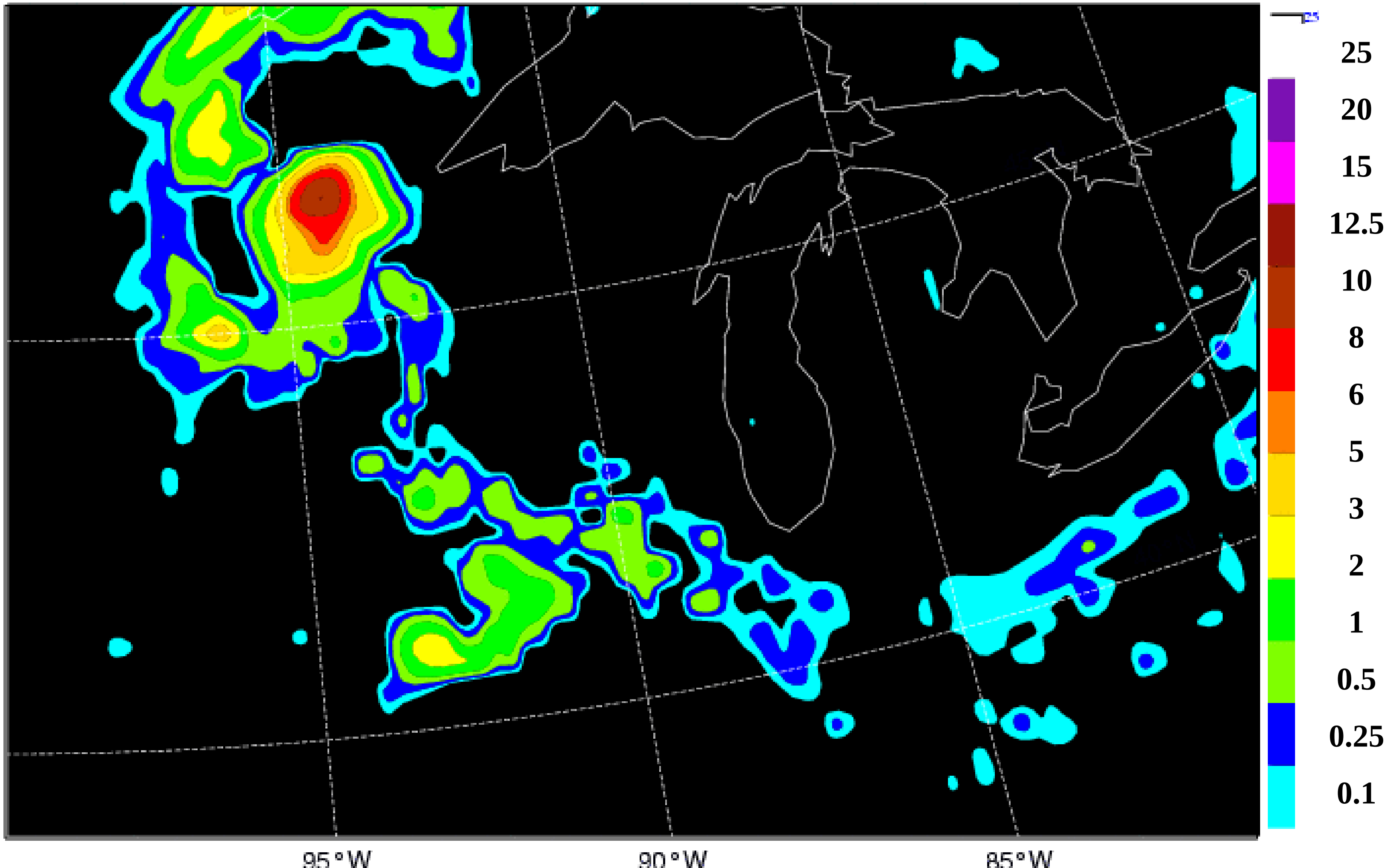


11 June 2001 18UTC-12 June 09 UTC
Radar animation (Courtesy J. Kain)

Radar loop derived from hourly maximum base reflectivity

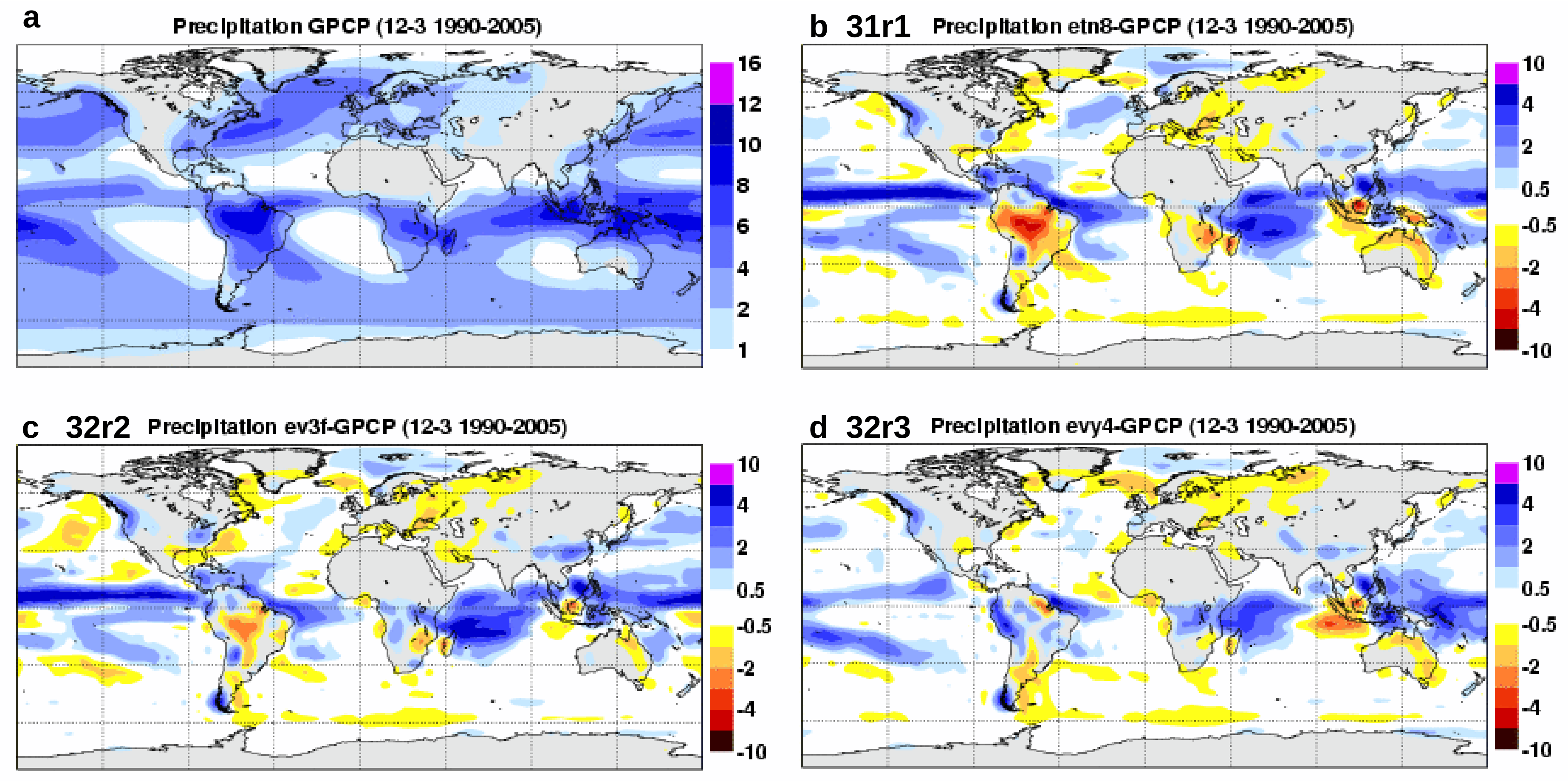


Is the model able to produce realistic convective organisation ? T799 run


ECMWF Forecast 20010611 12 UTC +8h total precip (mm/h)

Model Climate

Precipitation against GPCP for different cycles: from 15 year 5 months integrations for 1990-2005.

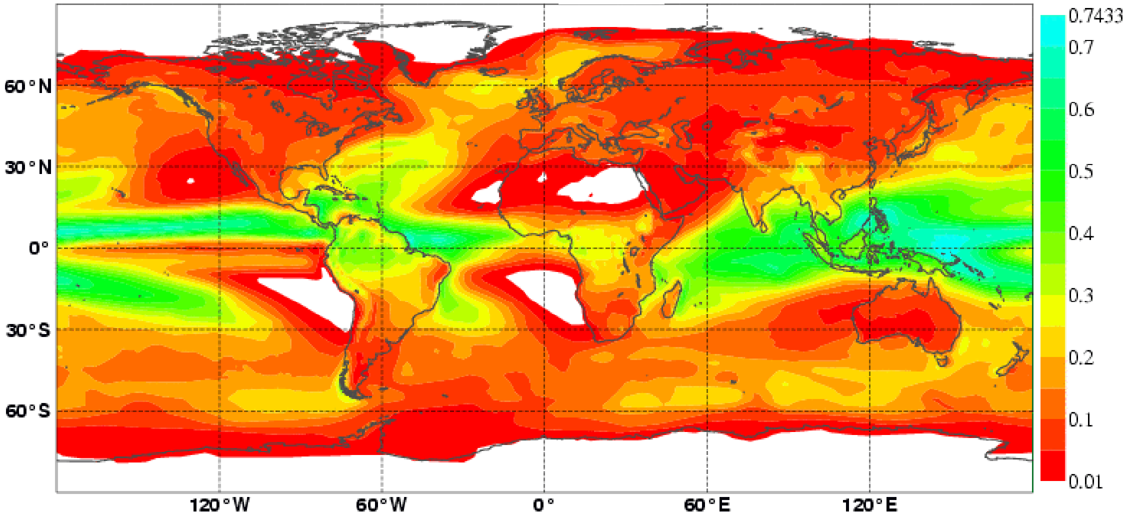


Note the lack of precip over Amazonia and overestimation of precip over the Central Pacific and the Indian Ocean …. and their improvement with radiation and convection changes

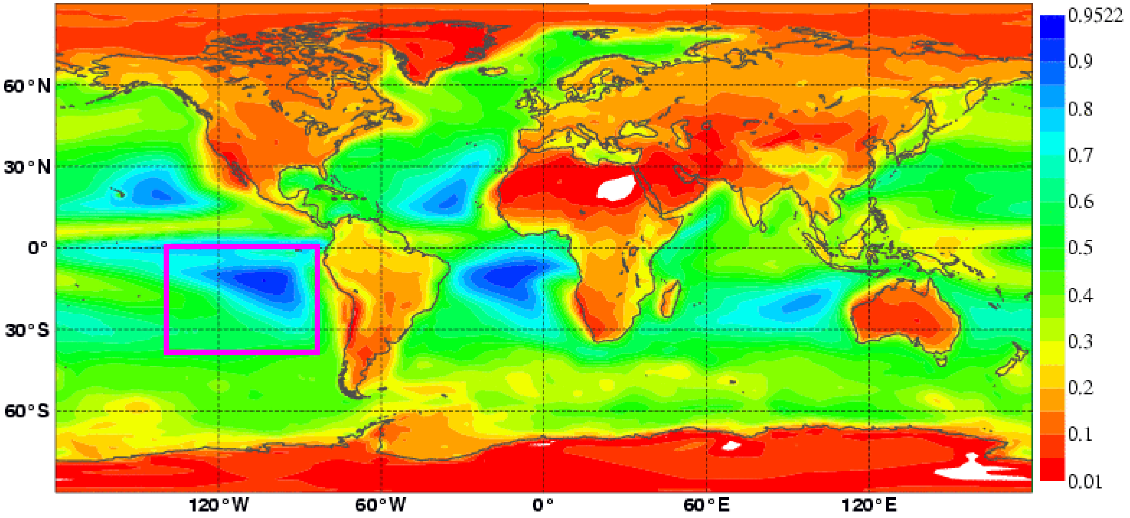
Global: Convective cloud types (2)

model distribution of deep and shallow convective clouds from IFS Cy33r1 (spring 2008)

Annual mean frequency of deep convection



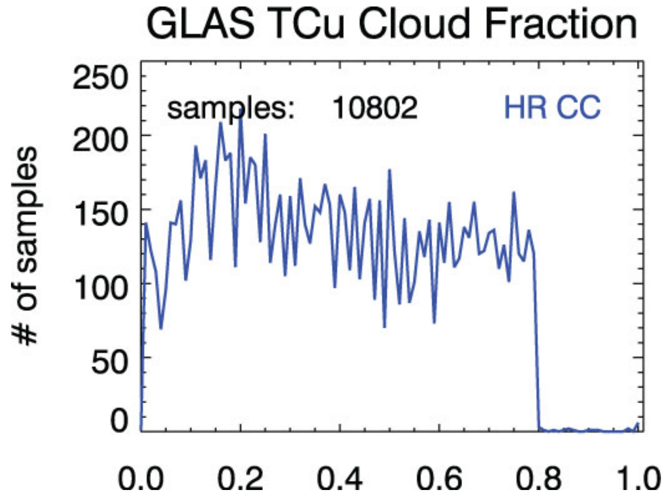
Annual mean frequency of shallow convection

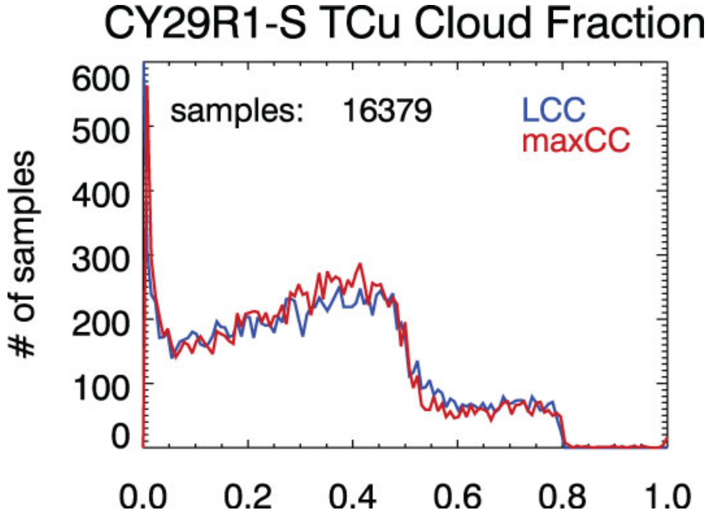


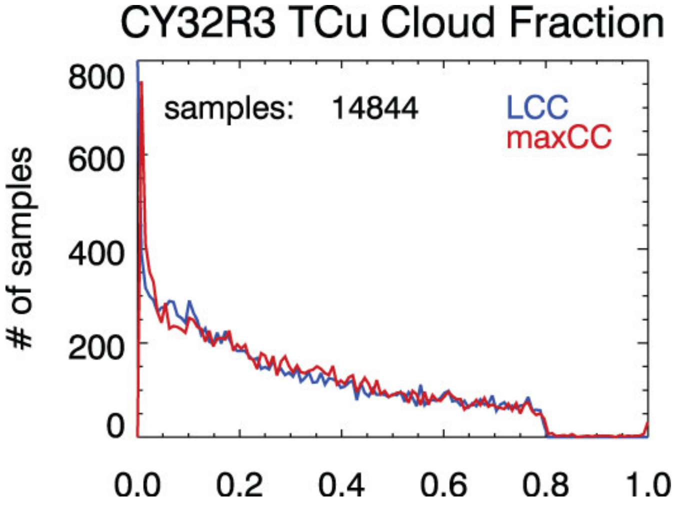
Model Climate

Evaluation of Trade Cumuli Cloud fraction occurences against GLAS space lidar

Mike Ahlgrimm



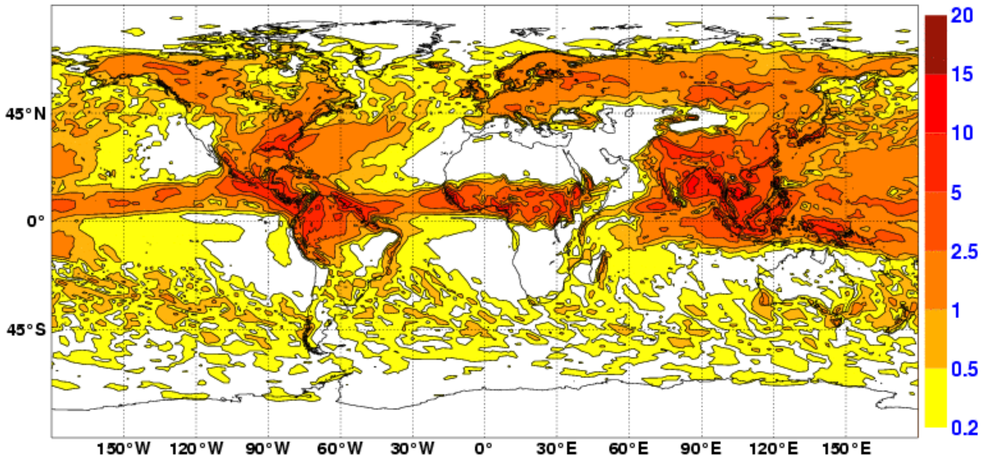




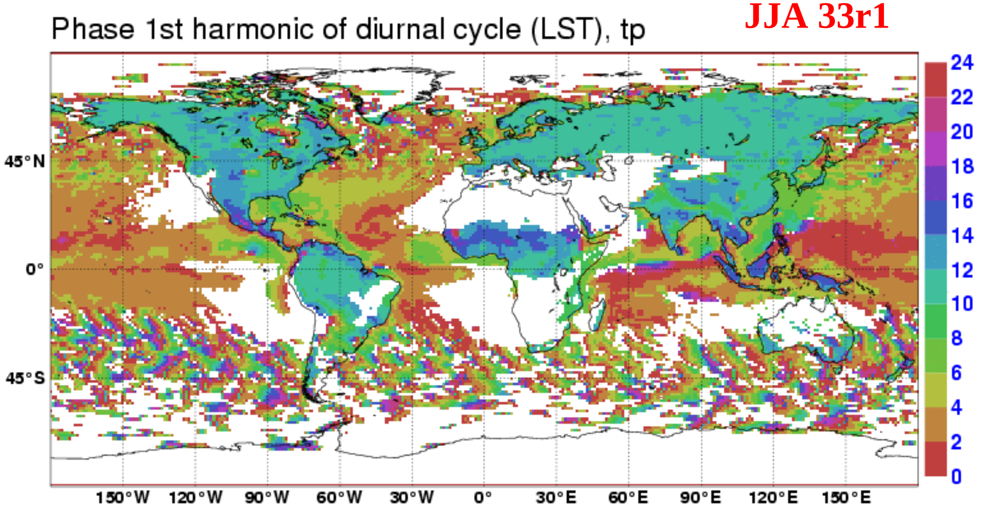
Trade Cu are selected as cloud tops<3km, CF<0.8 and as specific regions. GLAS data show a quasi-uniform distribution which is also reproduced in latest cycle – previously it was modal (jumpy) due to convection algorithm.

Model Climate

Diurnal cycle of Precipitation for JJA


Amplitude 1st harmonic of diurnal cycle; tp(mm/day)

JJA 33r1


Phase 1st harmonic of diurnal cycle (LST), tp

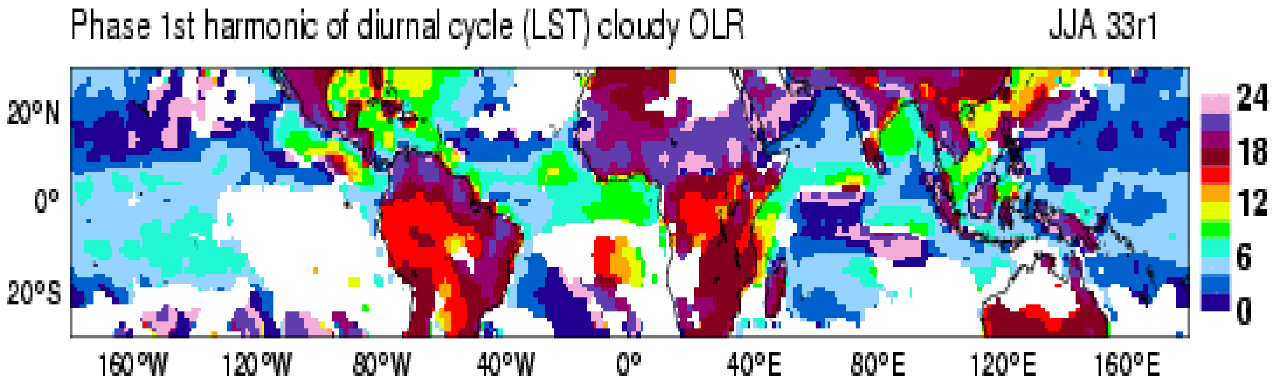
JJA 33r1

Maximum in model precipitation occurs around 12 LST over land and around 2-4 LST over water. Compared to Obs the diurnal cycle over water is very reasonable but over land it occurs 3h too early.

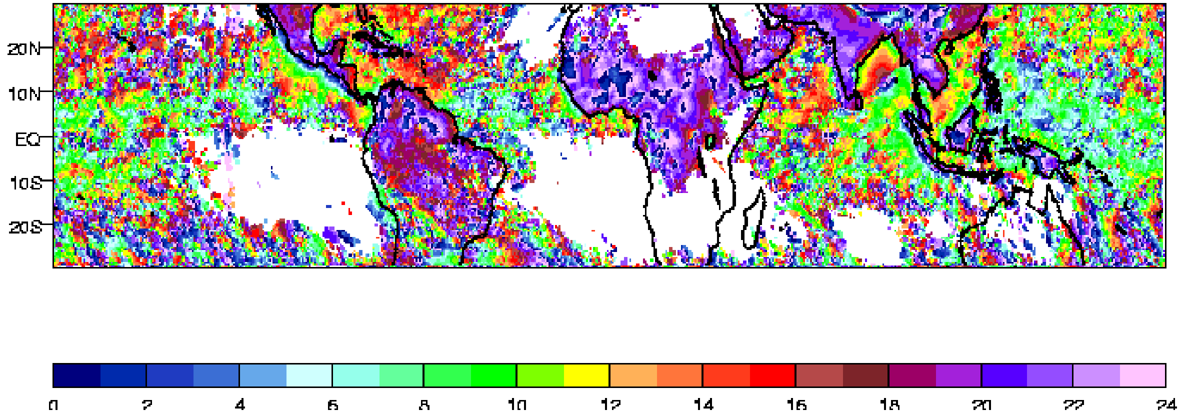
Verification using TRMM 3B42

Model Climate

Diurnal cycle of cloudy OLR (LW cloud radiative forcing) for JJA



Obs=CLAUS data set, Yang and Slingo



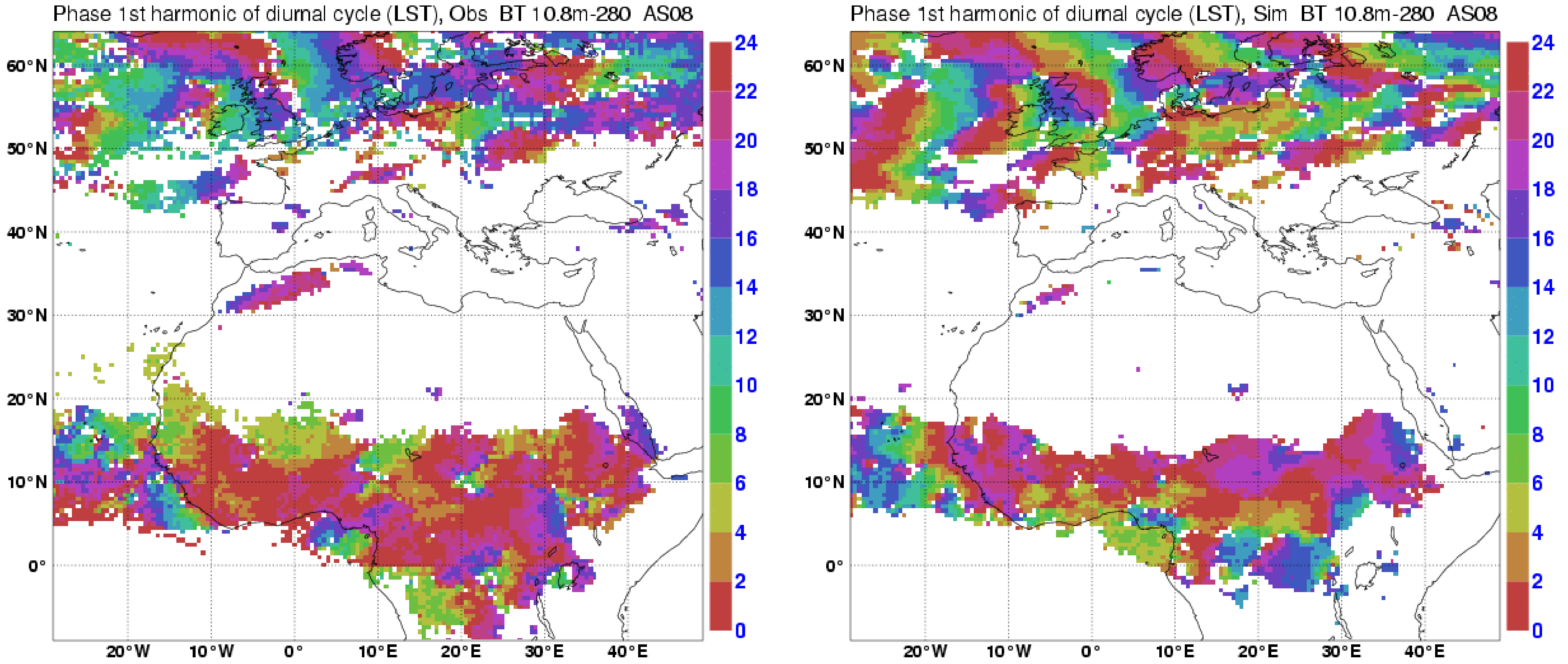
Minimum in model OLR over land occurs several hours later than the maximum in precipitation. This time-shift is reasonable and also supported by observations

Diurnal cycle in day 2 T799 forecasts

Do a “true” apple to apple comparison using Meteosat 9 3h BTs and model simulated BTs in infrared 10.8μ channel

Phase (LST) Meteosat 9 22.8-03.09 2008

Phase (LST) T799 24-48h Fc

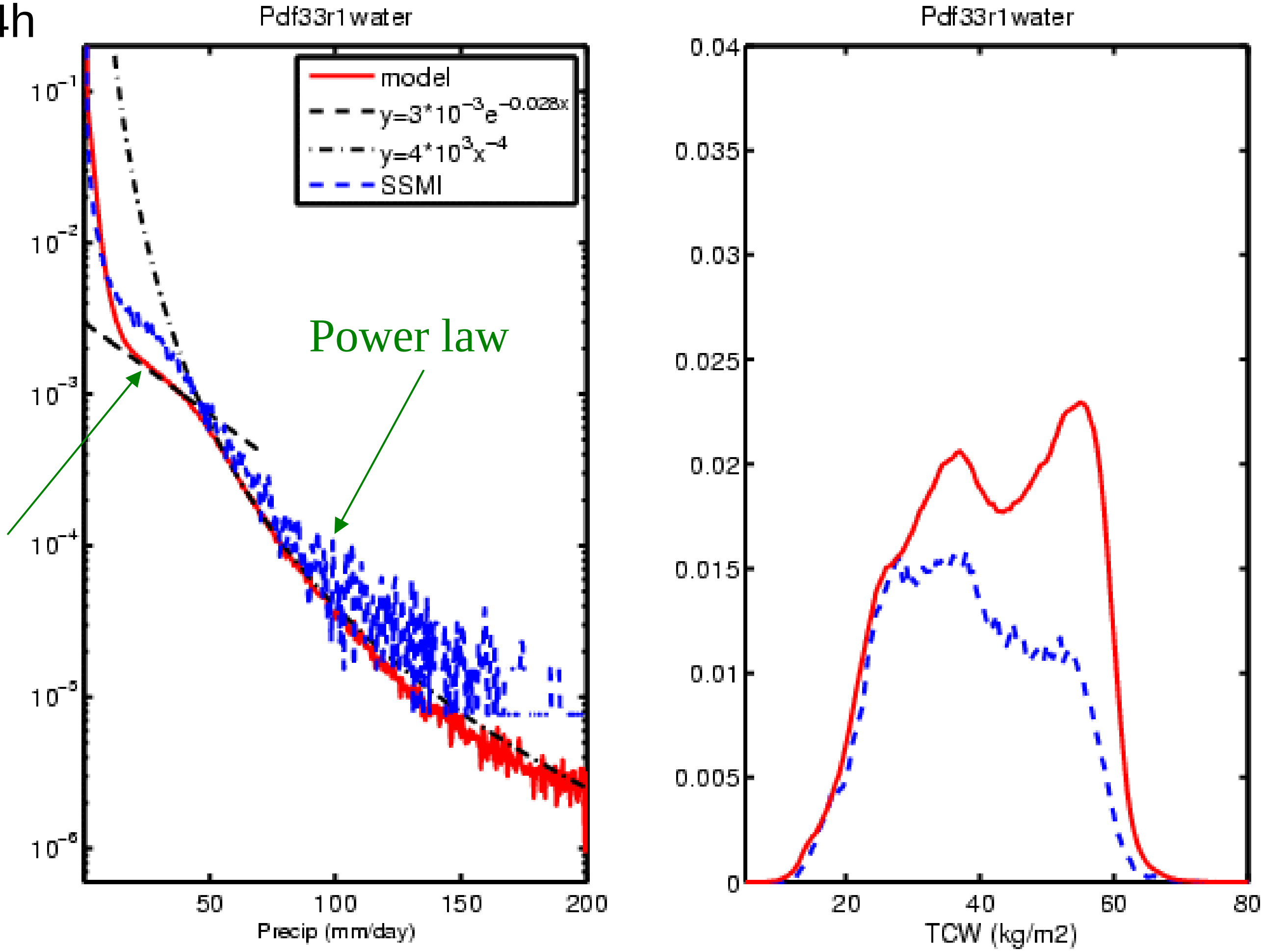


In order to extract the diurnal cycle of clouds, data is bias corrected and a 280 K mask has been applied to daily averaged 3h data to retain only “cold” cloud signal. Cloud extension in model reasonable, no clear phase signal in midlatitudes. Different regimes in Africa (early convection over mountains, coastal regimes). Verification will now go on in real time

Pdfs of instantanous Precip fluxes and TCW

a first verification in the IFS? together with A. Geer

from T799 during
first 24h



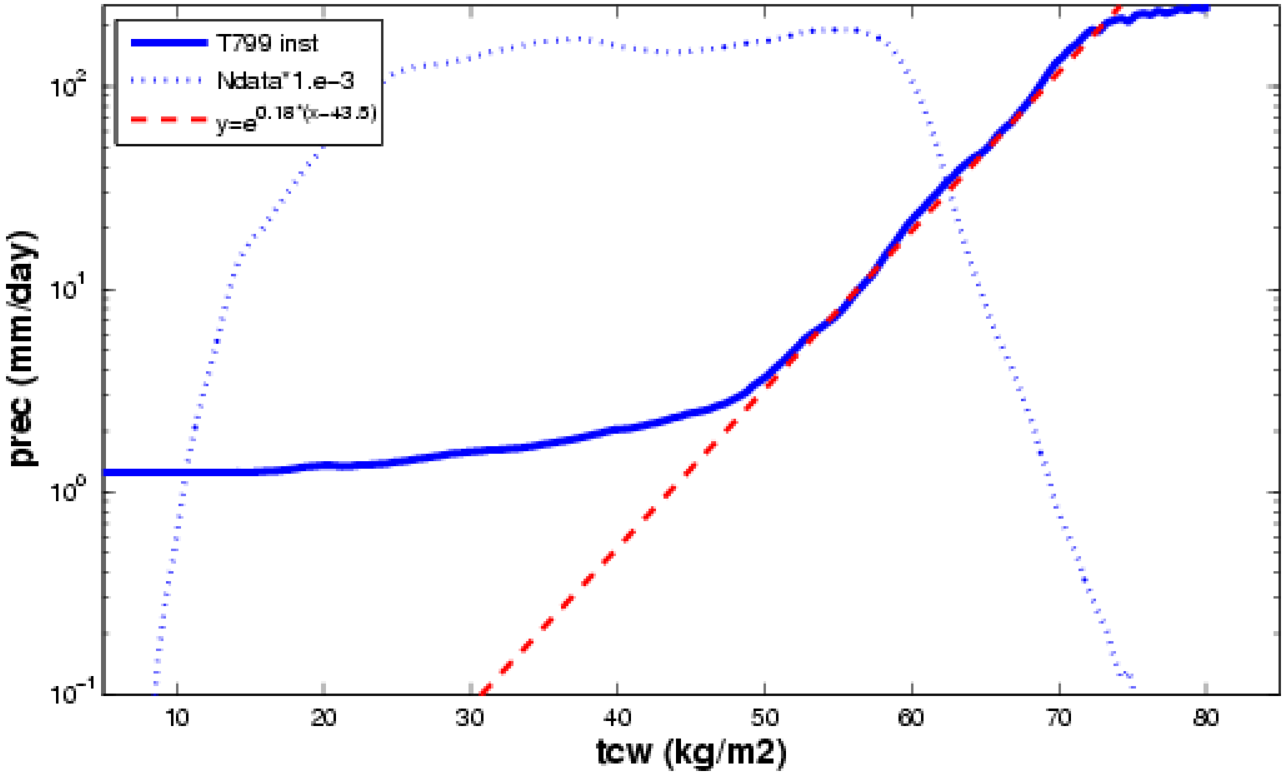
Power law

exponential

SSMI is from 1D-Var, but underestimates high rain rates (high TCW) as columns where more than 1/3 of precip is snow have been discarded

Precip vs total column water relative humidity

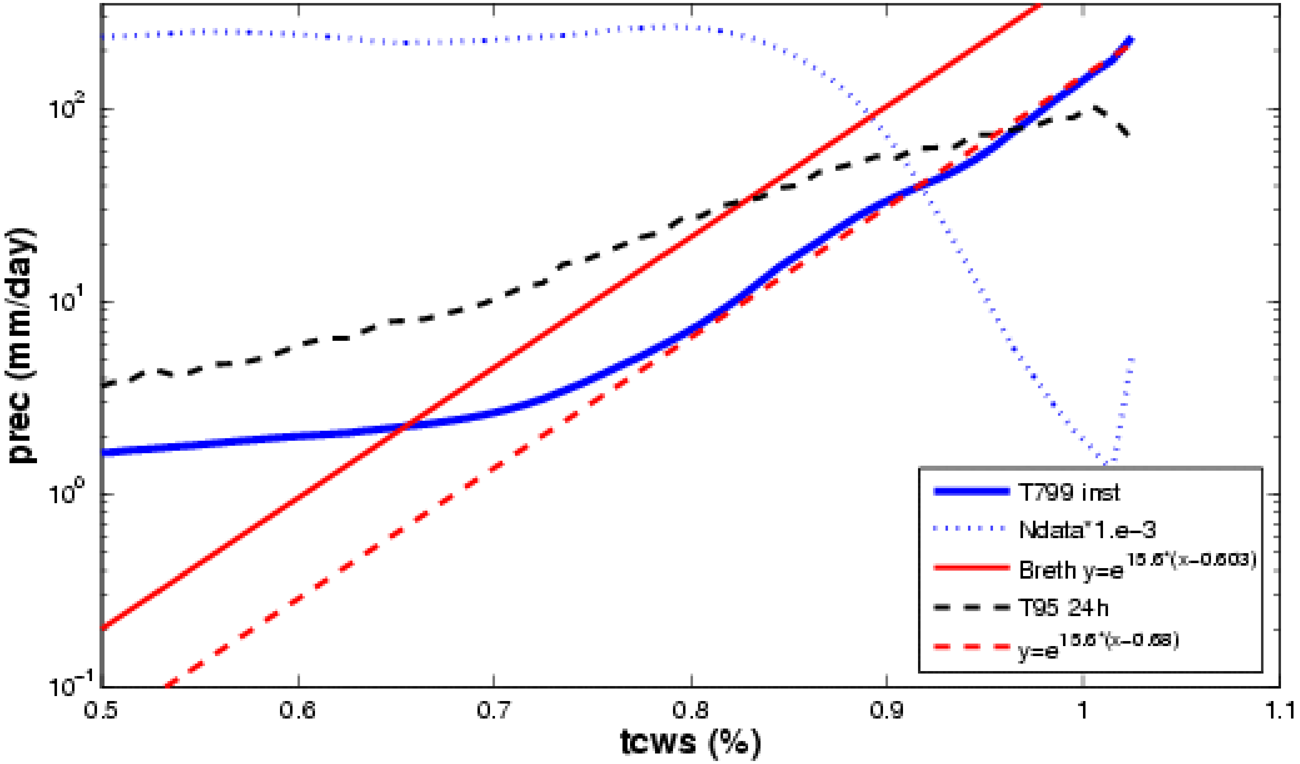
The atmosphere (model) a self-organized critical system ?



Or just more Precip with higher TCW (SSTs = warmer climate)
Is this relation useful as constraint in data assimilation of TCW ?

Precip vs total column water relative humidity

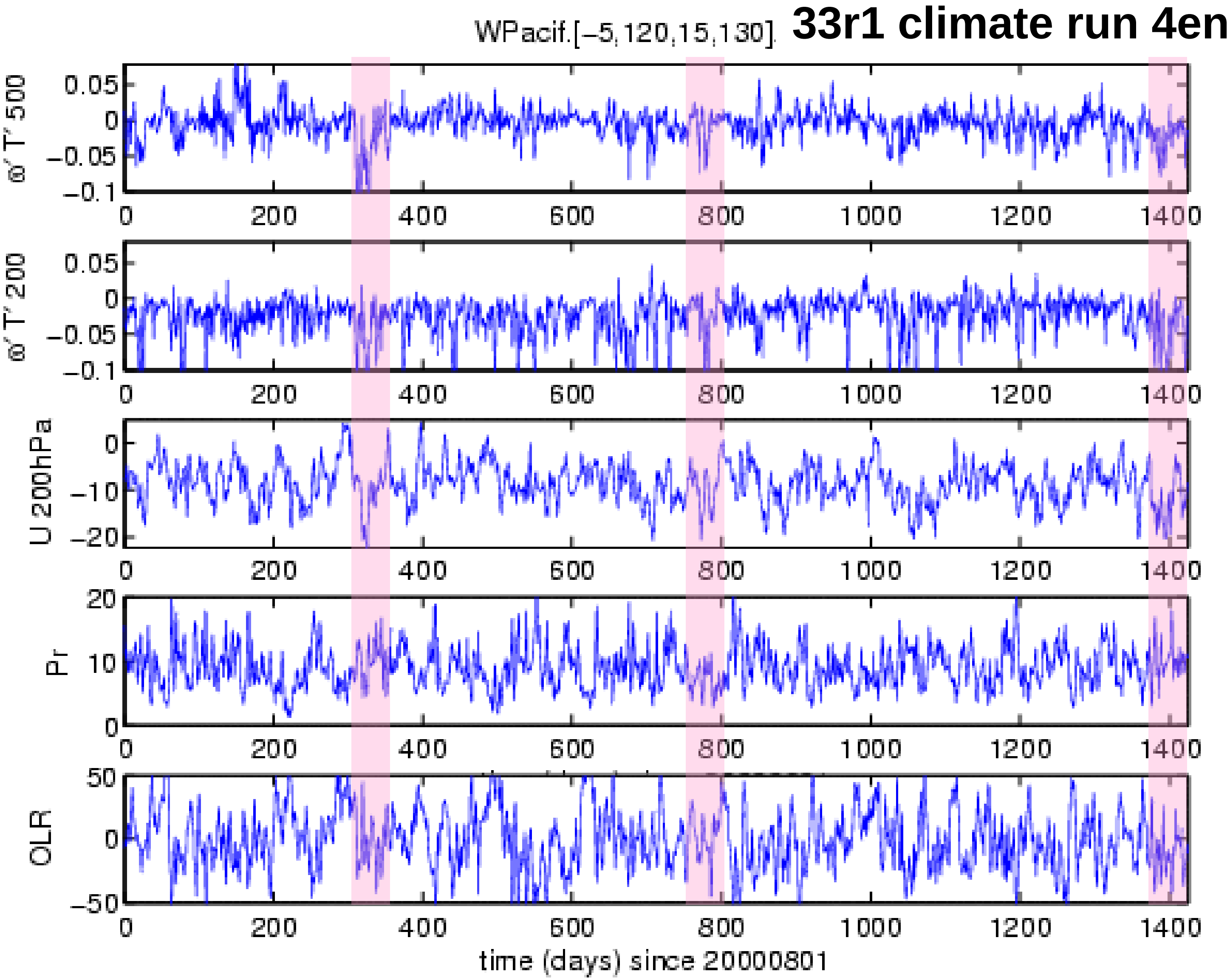
The atmosphere (model) a self-organized critical system ?



Or just more Precip when the entire column becomes saturated ?

see Bretherton et al. (J. Clim. 2004)

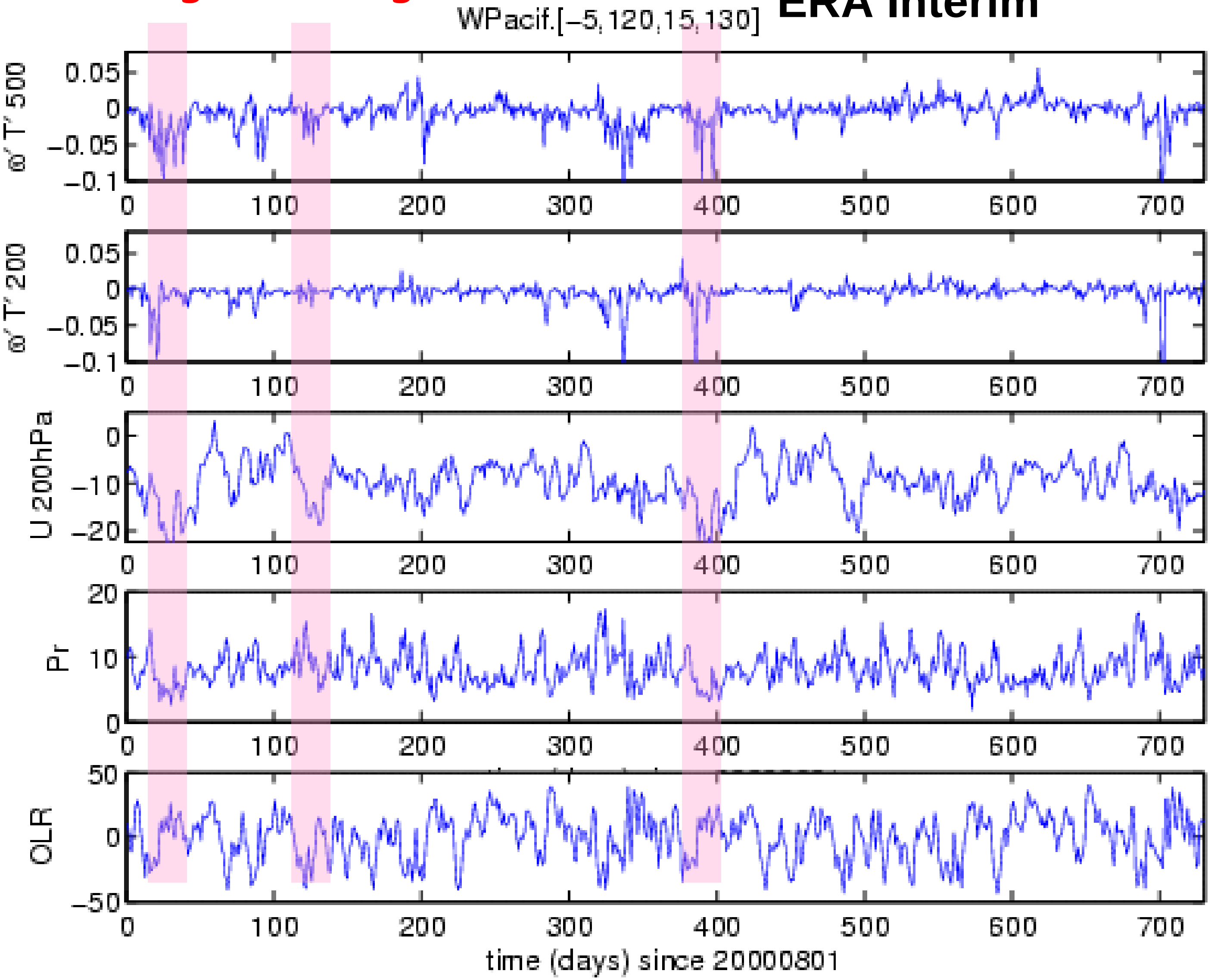
Just for curiosity, a time series of area averag. Correl, U200, Pr and OLR for WPacific



Is there a useful correlation between energy conversion ΩT and upper-level wind speed

Is ERA-Interim good enough for this ?

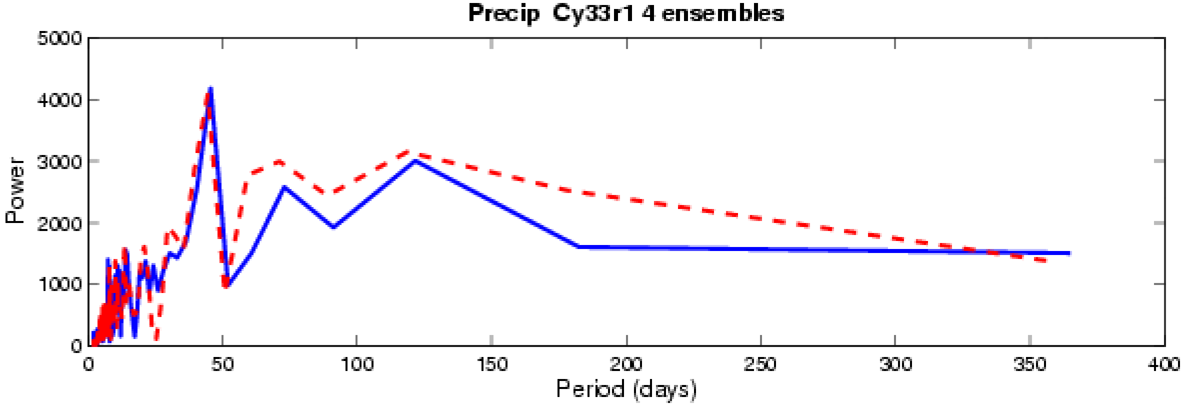
ERA Interim



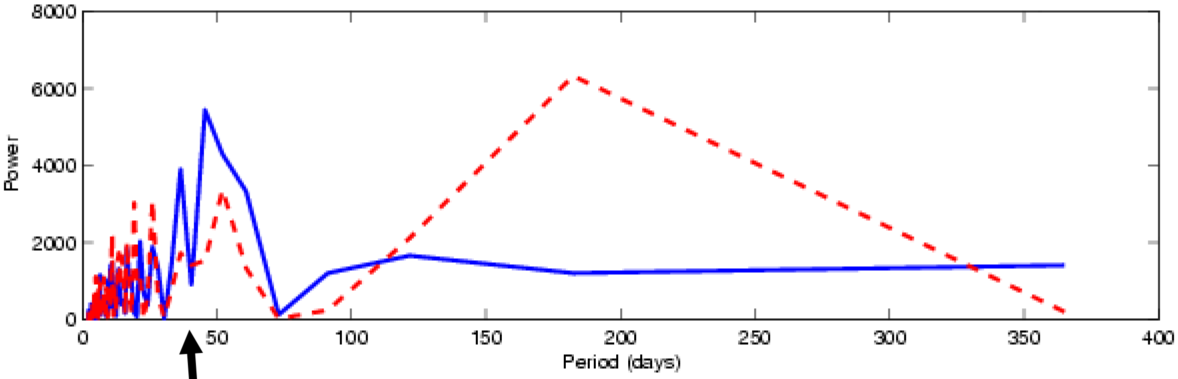
Spectral Analysis of Precip time-series

searching for MJO peaks – two averaging areas

33r1



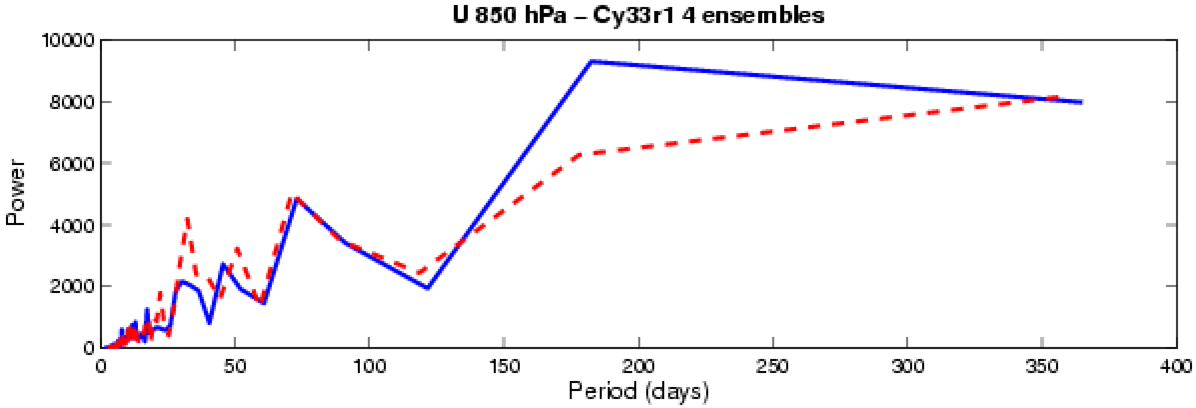
ERA Interim



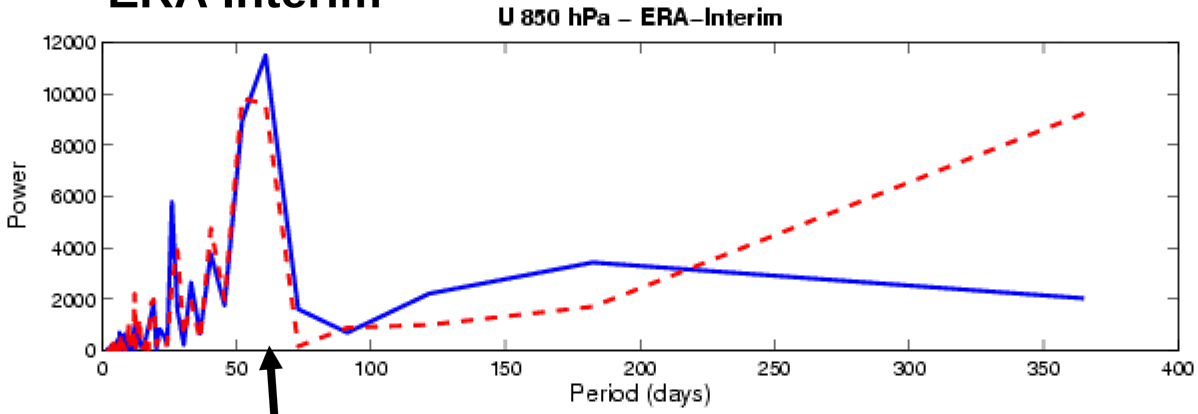
45-50 days

Spectral Analysis of U850 time-series
searching for MJO peaks – two averaging areas

33r1



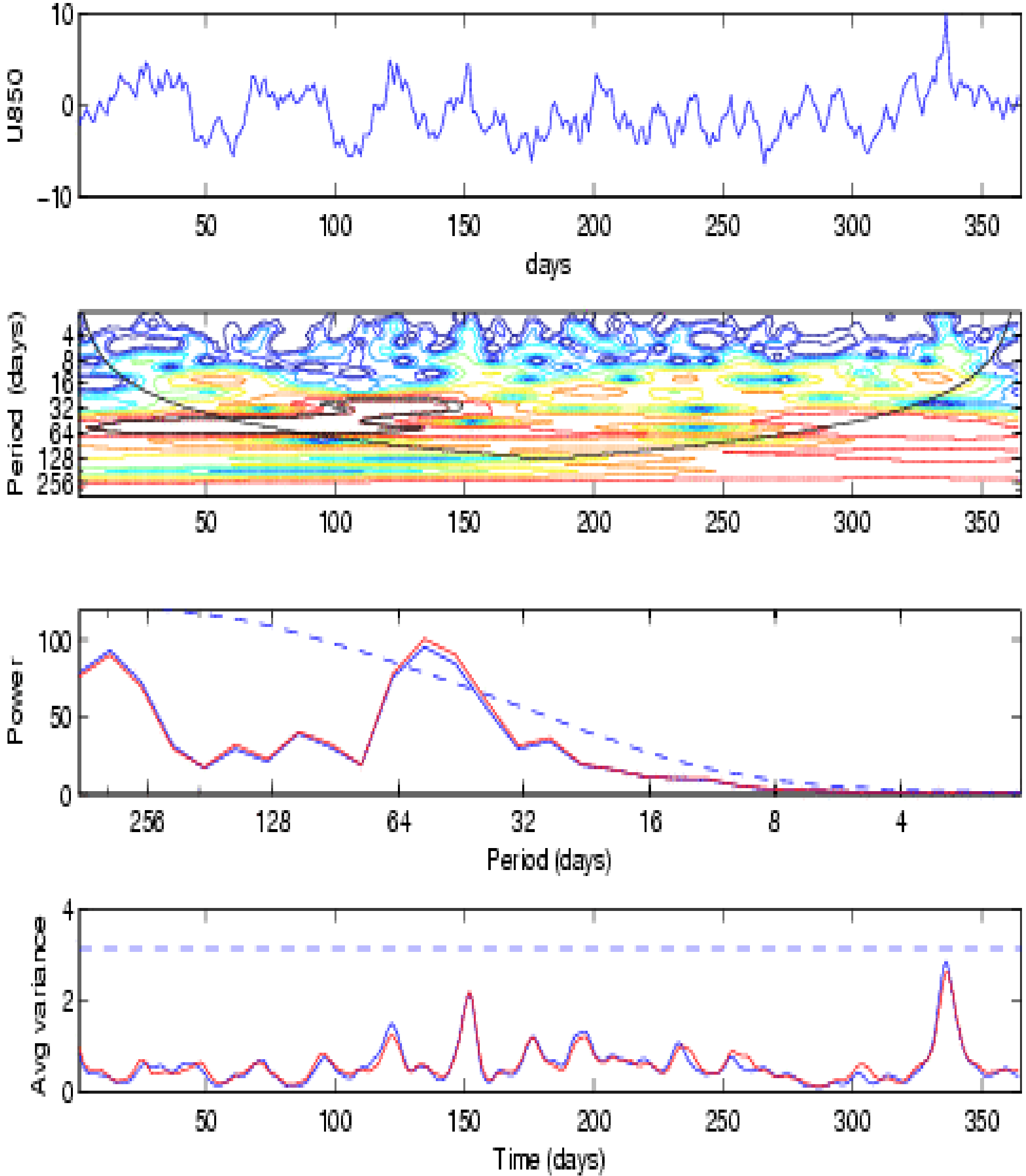
ERA Interim



55-60 days

Wavelet Analysis ofU 850 hPa, significance

ERA Interim



Research project

Run a Cloud Resolving Model initialised with IFS Analysis over large domains and study:

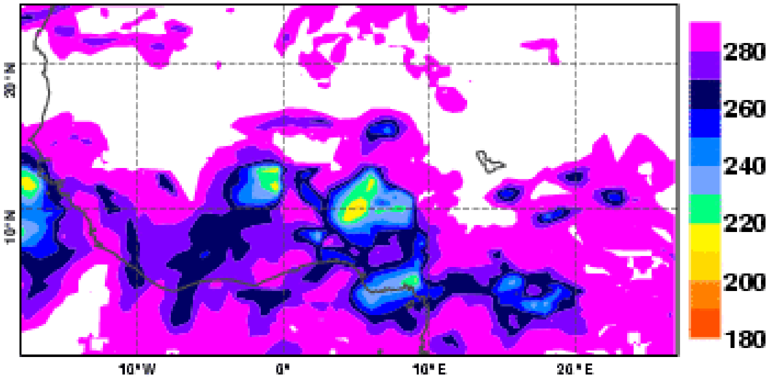
- Interaction of convection and dynamics through “diabatic heating” (including cold pools), and the propagation and upscale evolution of mesoscale convective systems.
- Diurnal cycle
- momentum flux in squall lines (line-normal one is upgradient)
- Identify and possible resolve deficiencies in IFS related to these issues.

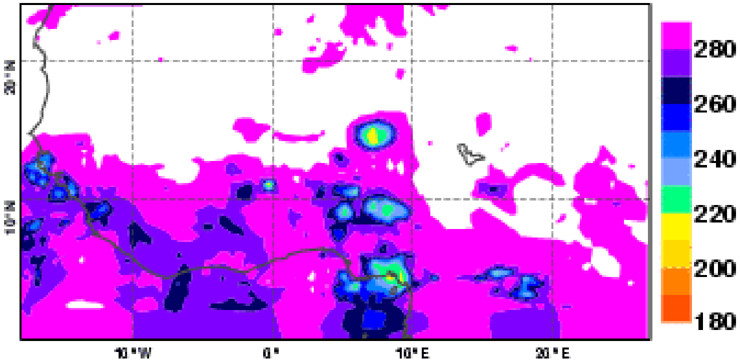
Realisation:

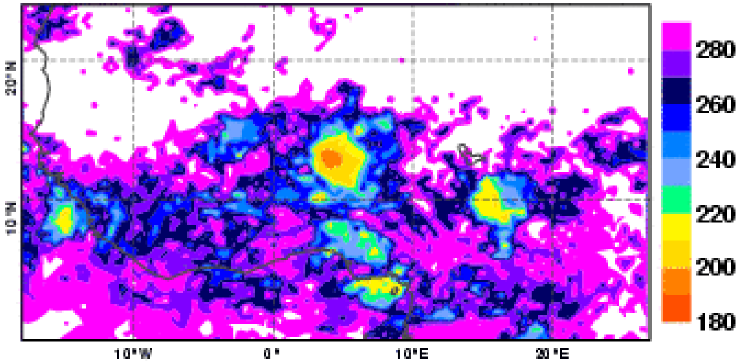
- Use the Meso-nh model in collaboration with J.P Chaboureau
- Focus on large mesoscale systems during AMMA using AMMA (ANNA) reanalyses
- currently CRM resolution is set to 5 km

AMMA non-easterly wave case

BTs 10.8μ

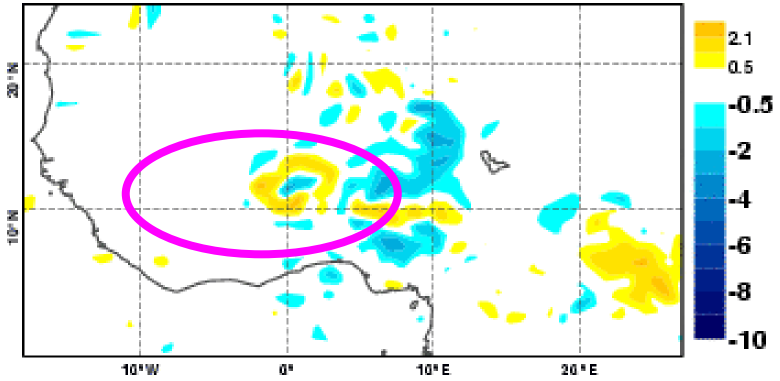

Satsim IFS 10.8m 2006073100 +6h

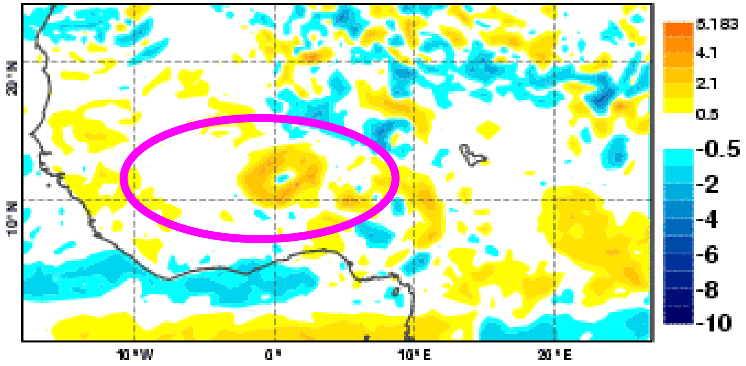

Satsim MNH 10.8m 2006073100 +6h

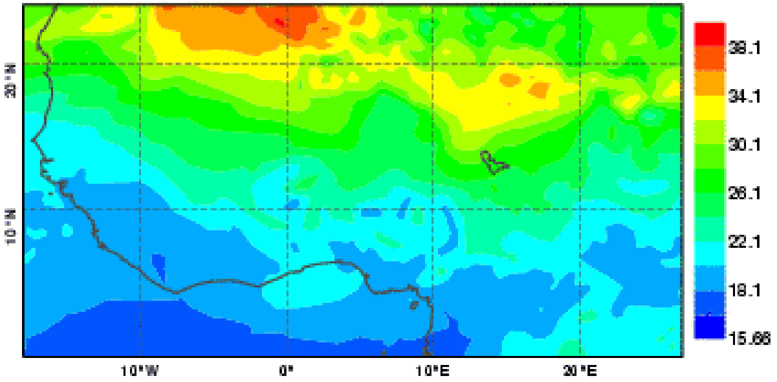

Meteosat 8 10.8m 20060731 06 UTC

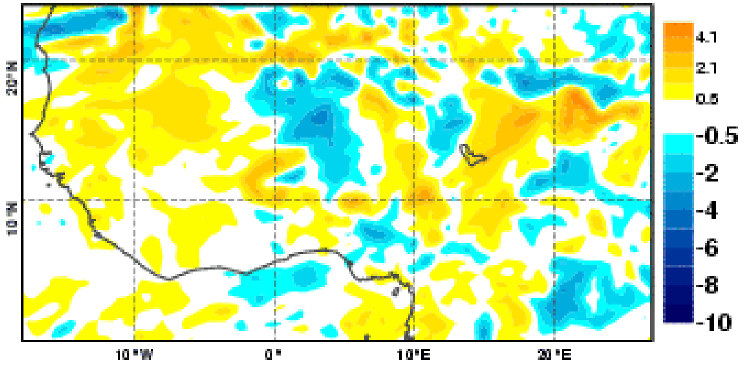
AMMA non-easterly wave case

T 925 hPa

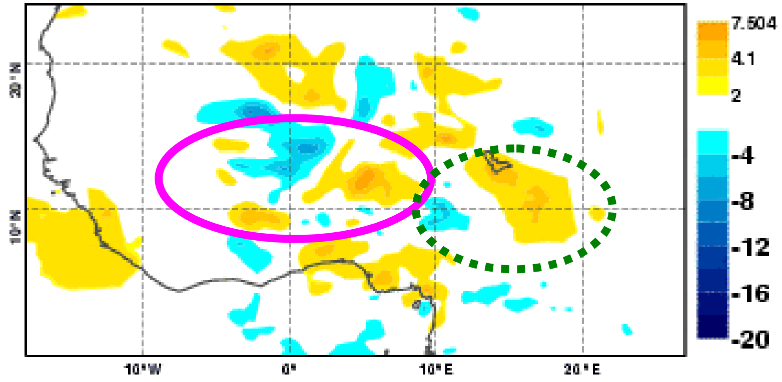

Diff IFS-Ana T (K) 20060731 6 925 hPa


Diff MNH-Ana T (K) 2006073100 +6h 925 hPa

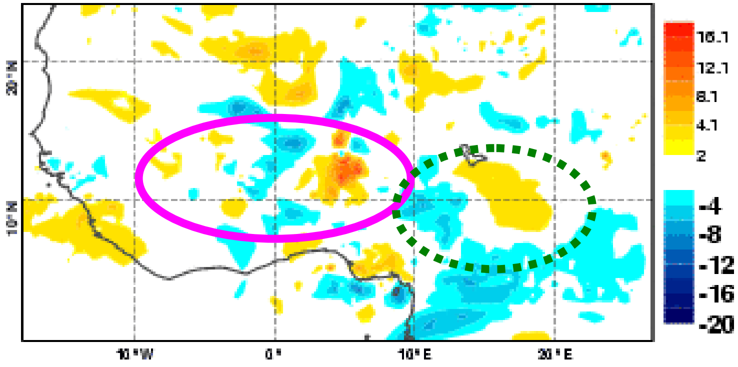

Ana T (K) 20060731 06 UTC 925 hPa


Diff AnaOp - ReAna T (K) 20060731 06 UTC 925 hPa

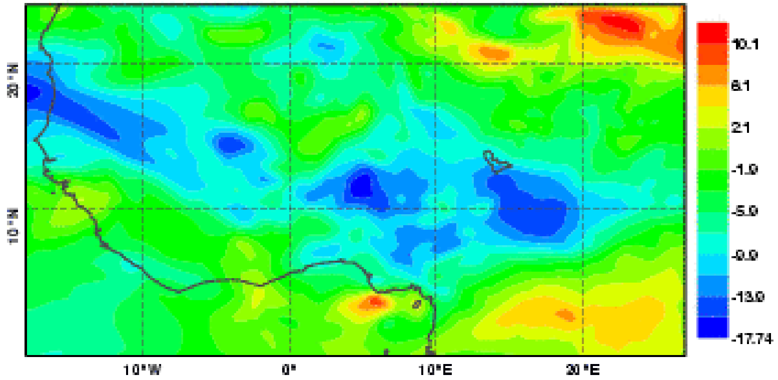
AMMA non-easterly wave case
U 700 hPa



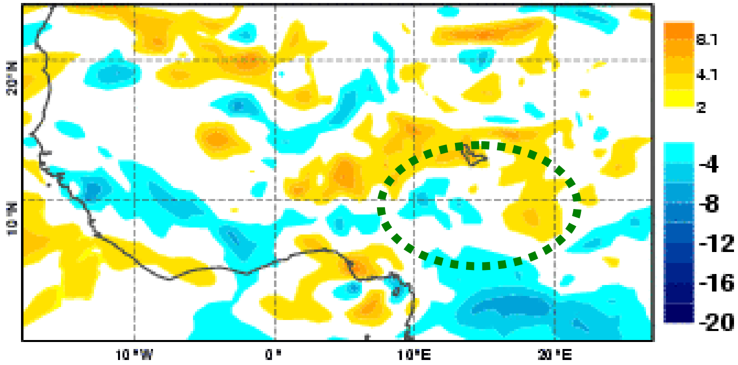
Diff IFS-Ana U (m/s) 20060731 12 700 hPa



Diff MNH-Ana U (m/s) 2006073100 +12h 700 hPa



Ana U (m/s) 20060731 12 UTC 700 hPa

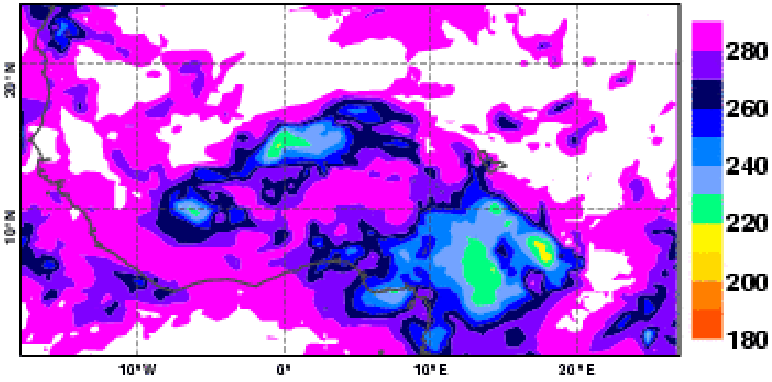


Diff AnaOp - ReAna U (m/s) 20060731 12 UTC 700 hPa

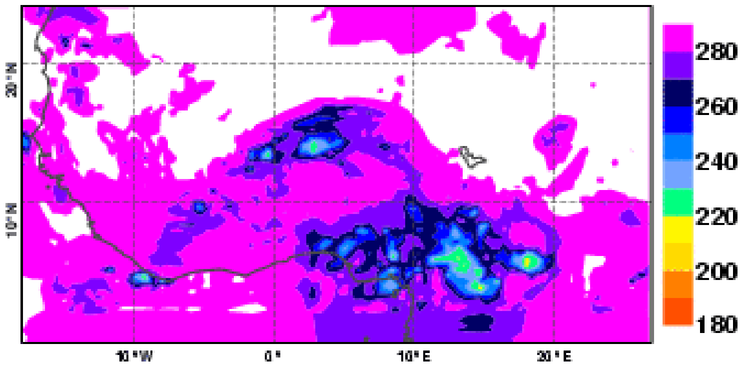
AMMA easterly wave case

BTs 10.8μ

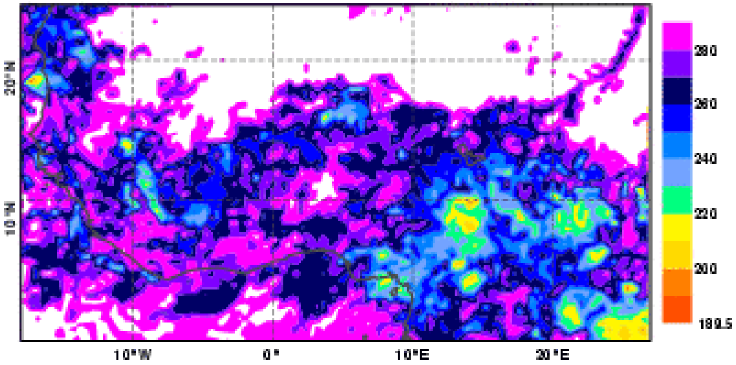
Satsim IFS 10.8m 2006090900 +6h



Satsim MNH 10.8m 2006090900 +6h



Meteosat 8 10.8m 20060909 06 UTC



And what are the other colleagues doing ?

parametrization perspective

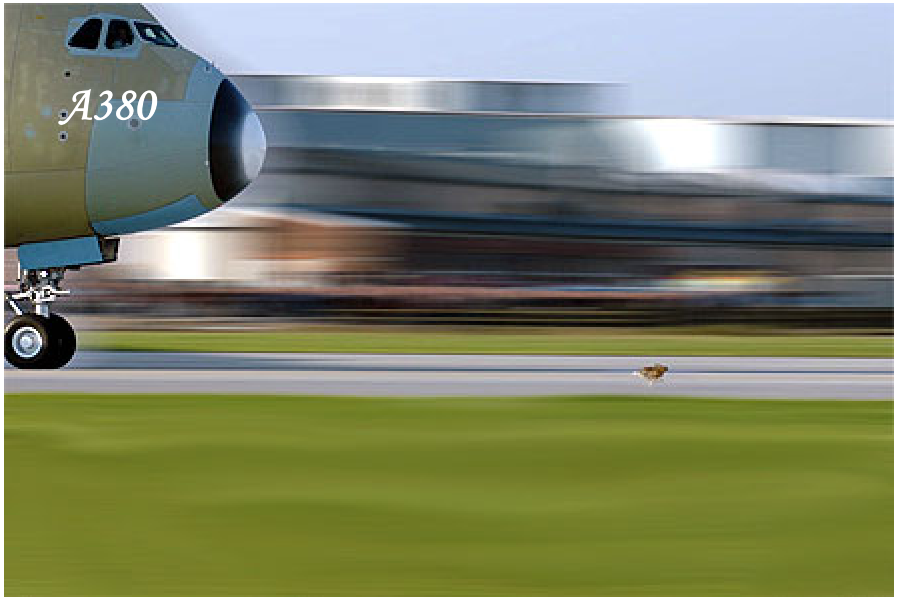
- At the last GEWEX/GCSS meeting there were presentations on similar developments on entrainment by Neale (NCAR) and Wu, resulting in much improved tropical variability in GCMs
- Prognostic mass flux closure (Pan and Randall QJ 1998, Scinoccia and Mc Farlane, JAS 2004). Recently Gerard and Geleyn(QJ, 2007) and Piriou (2005) have developed a prognostic updraught and microphysics framework for the 2-10 km grid scale.
- Pass directly the mass sources/sinks to the (non-hydrostatic) dynamics instead of convective tendencies. Realised in a 2D framework by Kuell et al. (QJRMS, 2007)
- Development of truncated (segmentally constant) CRM for subgrid-scale (Yano)
- Important work on Momentum transport by Montcrieff (up/downgradient) and by Zhang and Cho (JAS 1991), the latter with analytical solution of Bernoulli equation for perturbation pressure
- GEWEX/GCSS deep convection working group led by J. Petch
- European COST project on convection parametrization (led by Yano)

and from the bigger convection (climate) forecasting perspective

- Most National Meteorological Centres (DWD, UKMO, Meteo France, HIRLAM, JMA, Canada, NCEP etc.) now run or will shortly run high-resolution (1-3 km) short-range forecasts. Problem is then the assimilation the filtering of noise, and computer power to support ensembles
- Global forecast/climate models concentrate more on new dynamical cores and numerical grids (e.g. MPI, CMA, ECMWF)
- Japanese Earth Simulator continues to run, and 5 km dataset wait to be analysed and higher resolutions to be done
- Multi-Model Framework continues to be developed (see D. Randall)
- UK has the CASCADE project= learning from large domain explicit simulations of tropical convection
- ECMWF will provide *high-resolution operational Analyses* for the **International Year of tropical Convection** (starting Autumn 2008), with Cy33r1

Convection parametrization (in some form) will still be useful and used in the next 10-20 years or more in NWP and climate models

High resolution is good but doesn't solve everything and doesn't make life necessarily easier



Good luck to you and my thanks to my colleagues, especially in physics and graphics section