Global view of shallow convection … in the IFS

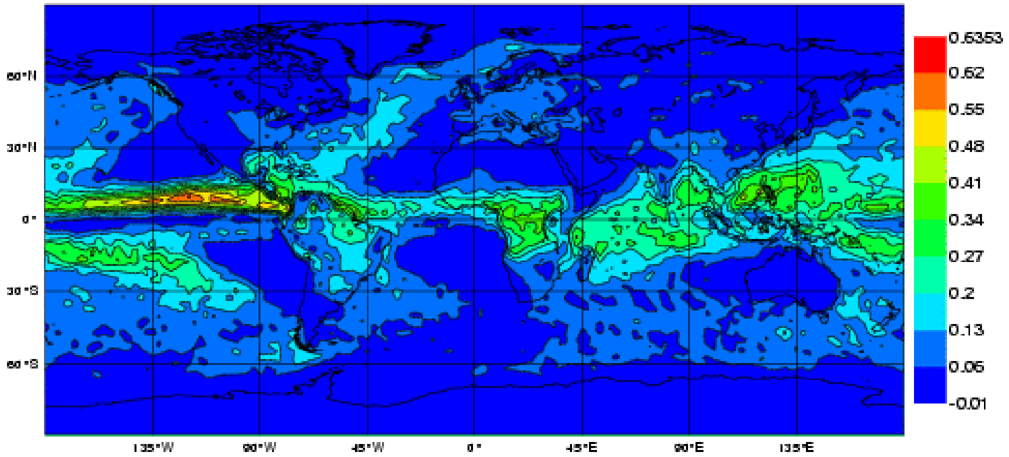
- Global distribution of convection – clouds, and no shallow
- Interpreting Budgets
- Shallow convection in IFS (closure and Numerics)
- Shallow convection and Model Dynamics
- Momentum transport
- 10 m winds and Observations

Peter Bechtold *(Martin Köhler to follow tomorrow with Sc, diffusion scheme and some outlook)*

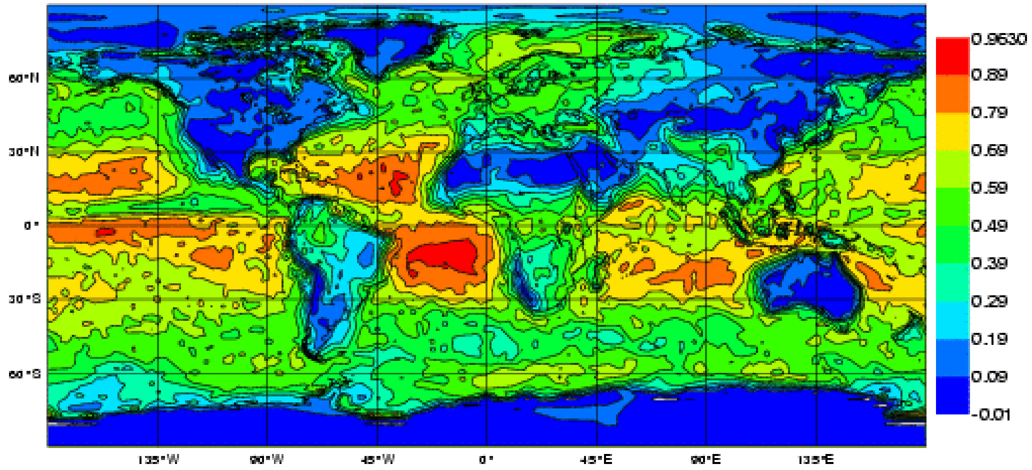
Thanks to Eric and Dmitrii for invitation

Frequency Distribution of Deep and shallow convection in IFS

a) Deep mean=0.1013



b) Shallow mean=0.4829

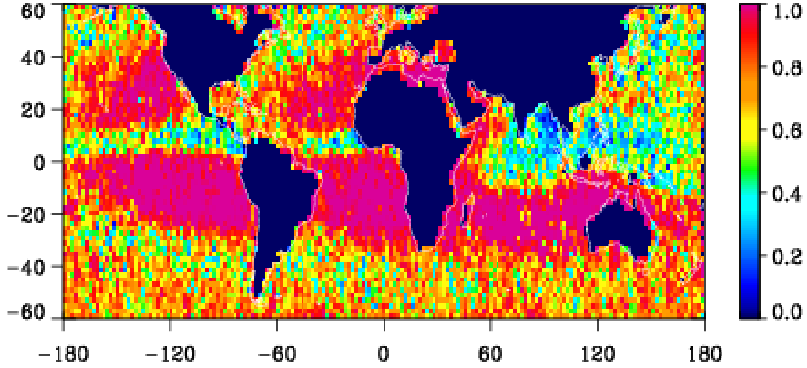


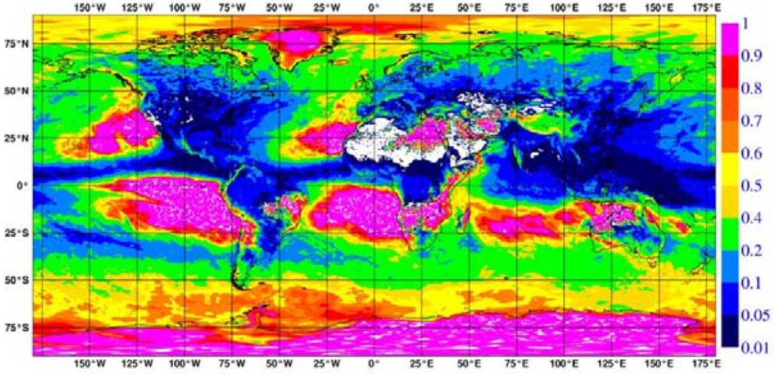
Cloudsat - IFS Cy31R1

Fraction of total rainfall: CTL < 4.75 km

JDAY 188-251, 2006 (2B)

f=0.690

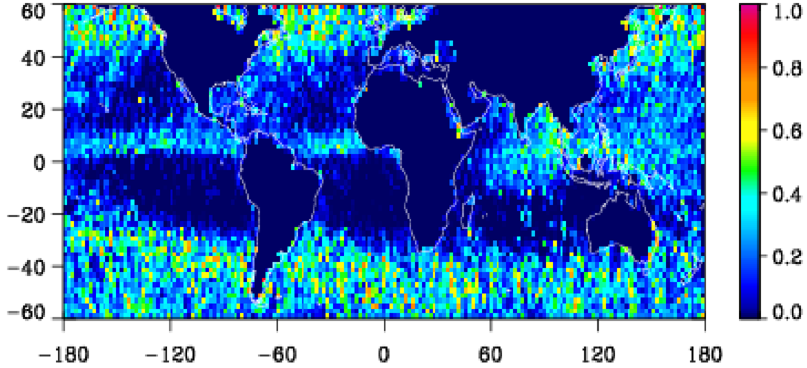


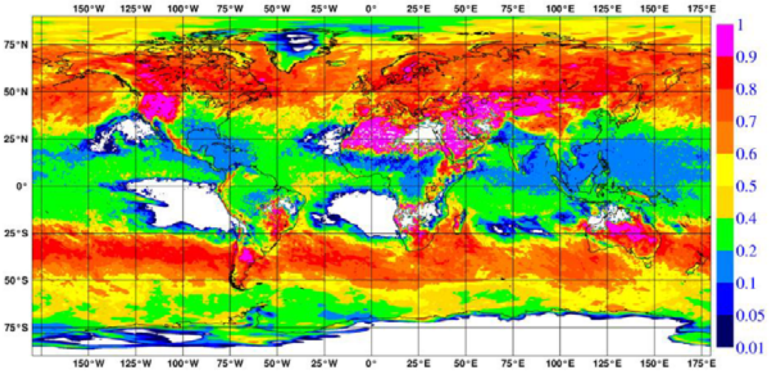


Fraction of total rainfall: 4.75 < CTL < 11 km

JDAY 188-251, 2006 (2B)

f=0.230

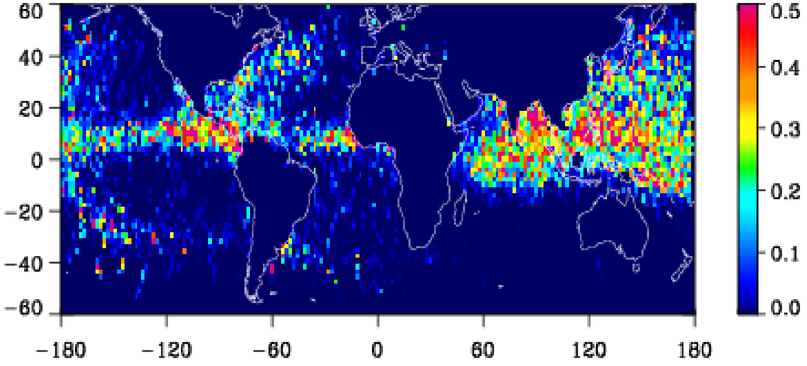


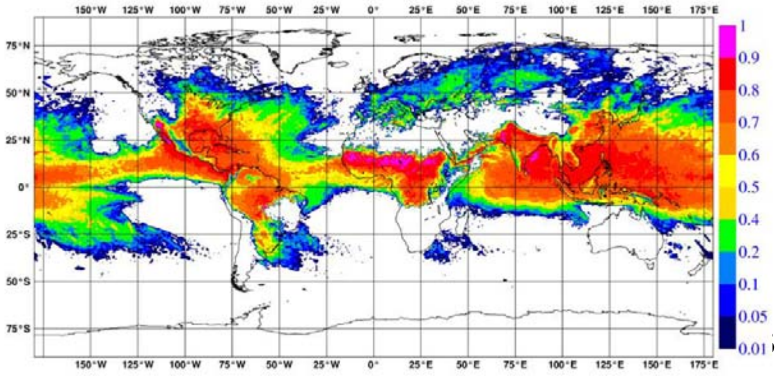


Fraction of total rainfall: CTL > 11 km

JDAY 188-251, 2006 (2B)

f=0.080

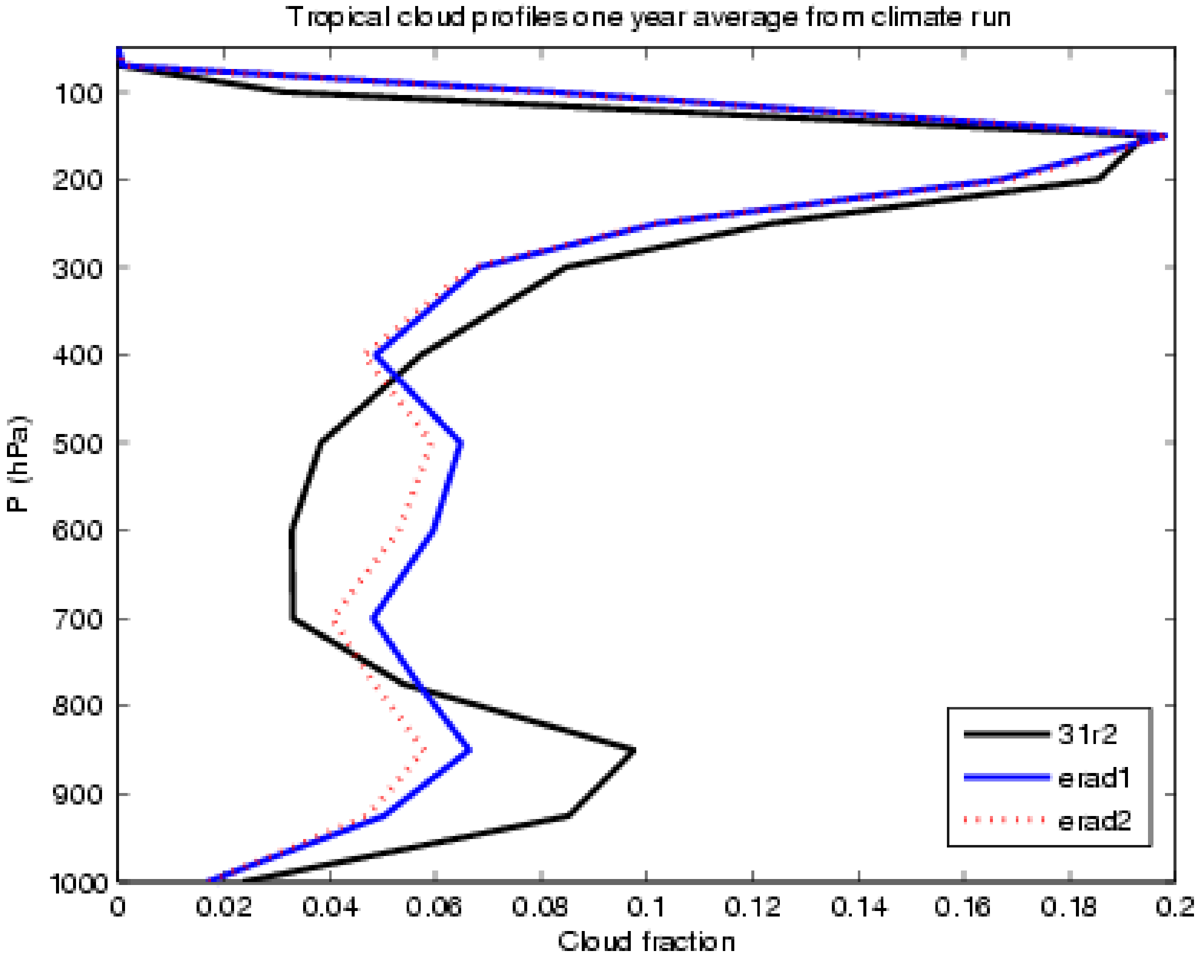




Angela Benedetti, Graeme Stephens

Climate runs: Cloud fraction profiles

In the Tropics now a tri-modal cloud distribution becomes apparent, with a strong increase in mid-level clouds



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*, dT/dt, dq/dt, du/dt, dv/dt
  Implicit solver with 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

Closure - Shallow convection

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

With

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

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

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

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

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

Numerics - implicit

$$\frac{\partial \overline{\psi}}{\partial t} = g\,\frac{\partial}{\partial p}\underbrace{\left[M^{u}(\psi^{u} - \overline{\psi})\right]}_{Flux} + S$$

$$\Rightarrow \overline{\psi}_{k}^{\,n+1} = \overline{\psi}_{k}^{\,n} + g\,\frac{\Delta t}{\Delta p}\left[M^{u}(\psi^{u} - \overline{\psi}^{\,n+1})\right]_{k-1/2}^{k+1/2} + \Delta t\, S_{k}^{n};$$

30R2

✓ Tracer

✓ Momentum

$$\overline{\psi}_{k-1/2}^{\,n+1} = \overline{\psi}_{k-1}^{\,n+1}$$

31R1

✓ T

✓ q

$$\overline{s}_{k-1/2}^{\,n} = \overline{s}_{k-1}^{\,n} + \alpha_{k-1/2}\,\overline{s}_{k}^{\,n}$$

$$\overline{q}_{k-1/2}^{\,n} = \overline{q}_{k-1}^{\,n} + \beta_{k-1/2}\,q_{sat}(\overline{T}_{k}^{\,n})$$

same solver

❖ NB: results are very close to explicit solution as draught values below cloud base are computed from linear flux relation; in the dry static energy equation only the temperature, and not the geopotentiel term are formulated implicitly

Convective momentum transport

$$\boxed{\frac{\partial \overline{\vec{U}}}{\partial t} = g\frac{\partial}{\partial p}\left[M_u\left(\vec{U}_u - \overline{\vec{U}}\right)\right]}$$

Total momentum is conserved, but updraught momentum is generally not because of pressure gradient force

$$-g\frac{\partial}{\partial p}\left[M_u\vec{U}_u\right] = E_u\overline{\vec{U}} - D_u\vec{U}_u - \sigma\frac{1}{\overline{\rho}}\overline{\nabla P}^u$$

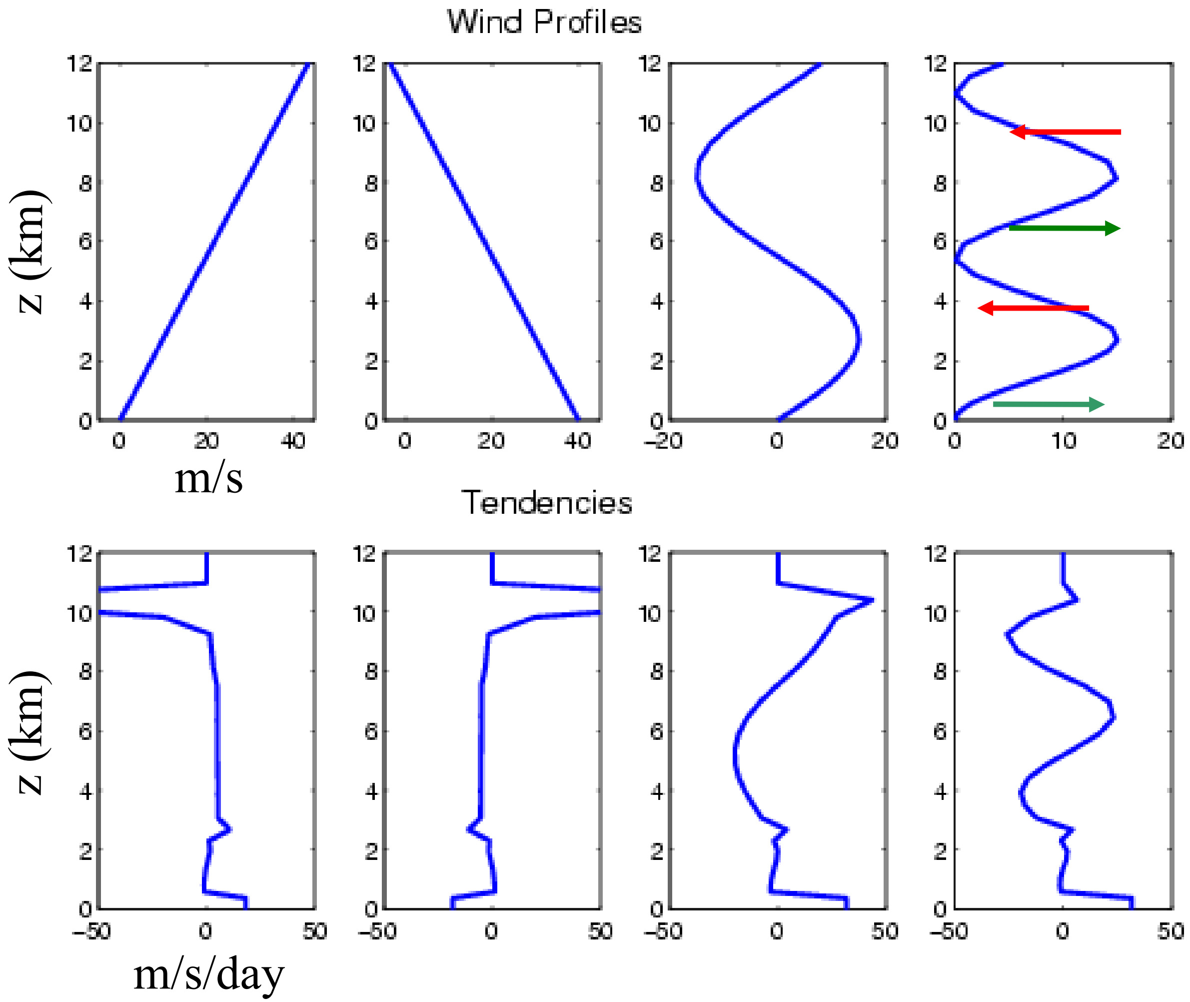
Classic as in IFS

$$-gM_u\frac{\partial \vec{U}_u}{\partial p} = g\frac{\partial M_u}{\partial p}\left(\vec{U}_u - \overline{\vec{U}}\right) - \sigma\overline{\nabla\left[\frac{P}{\overline{\rho}} + \frac{1}{2}\vec{U}\bullet\vec{U}\right]}^u$$

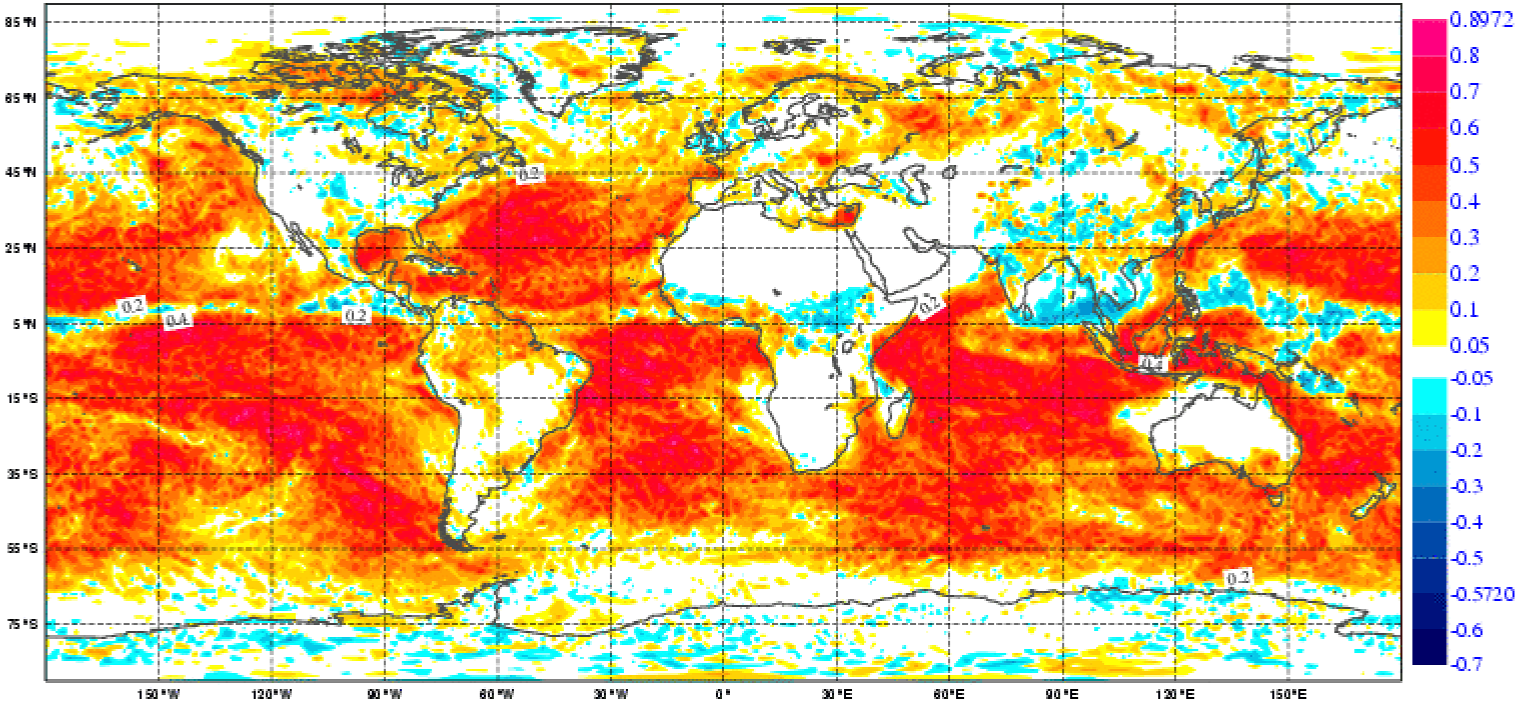
Formulation developed by Zhang and Cho (1991) involving Bernoulli function

$$\nabla^2 P \approx -2\overline{\rho}\nabla_h w_u\frac{\partial \overline{\vec{U}}}{\partial z} + \overline{\rho}\frac{\partial B}{\partial z}$$

Momentum Transport – idealised profiles



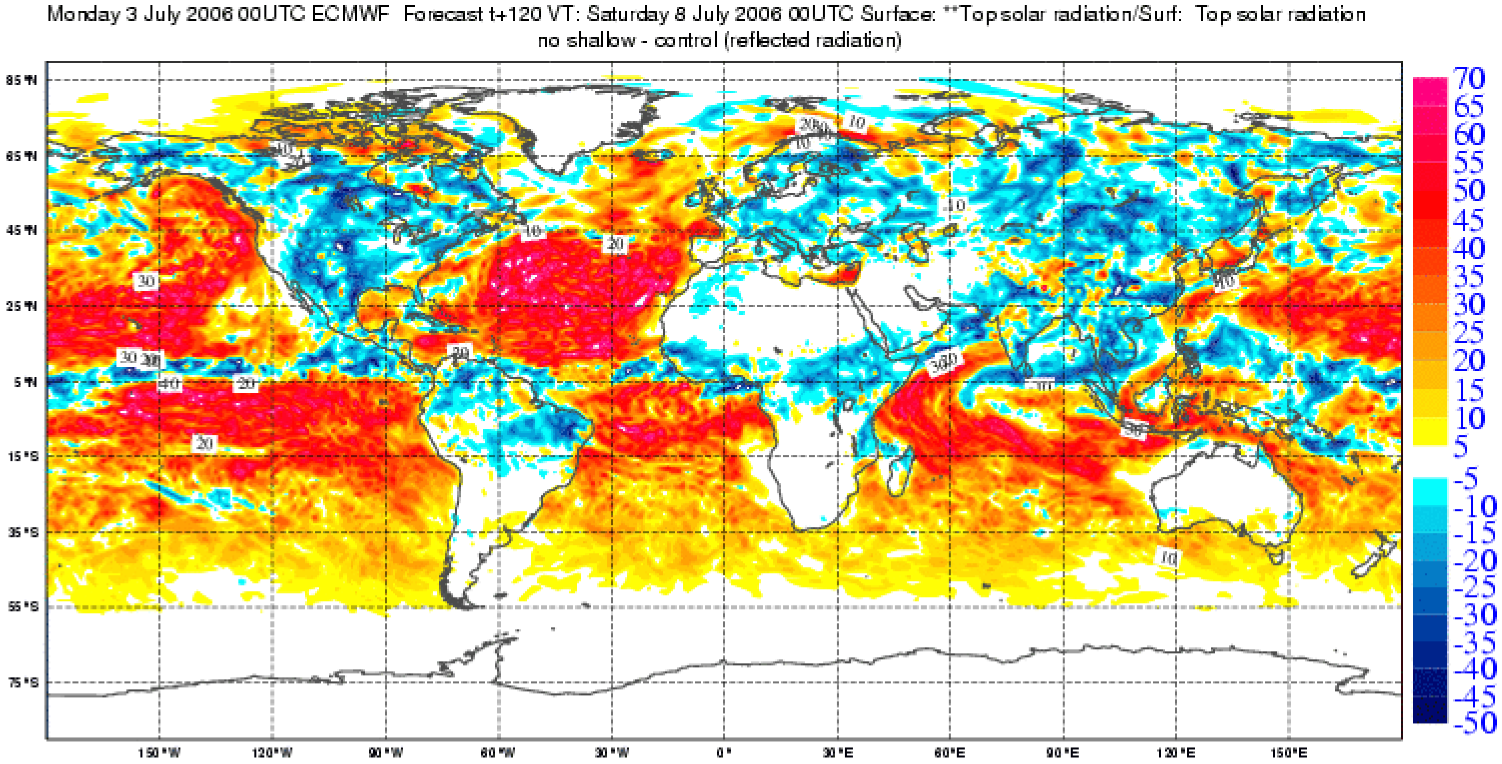
No shallow - shallow: low cloud cover



Monday 3 July 2006 00UTC ECMWF Forecast t+12 VT: Monday 3 July 2006 12UTC Surface: **Low cloud cover/Surf: Low cloud cover
no shallow - control

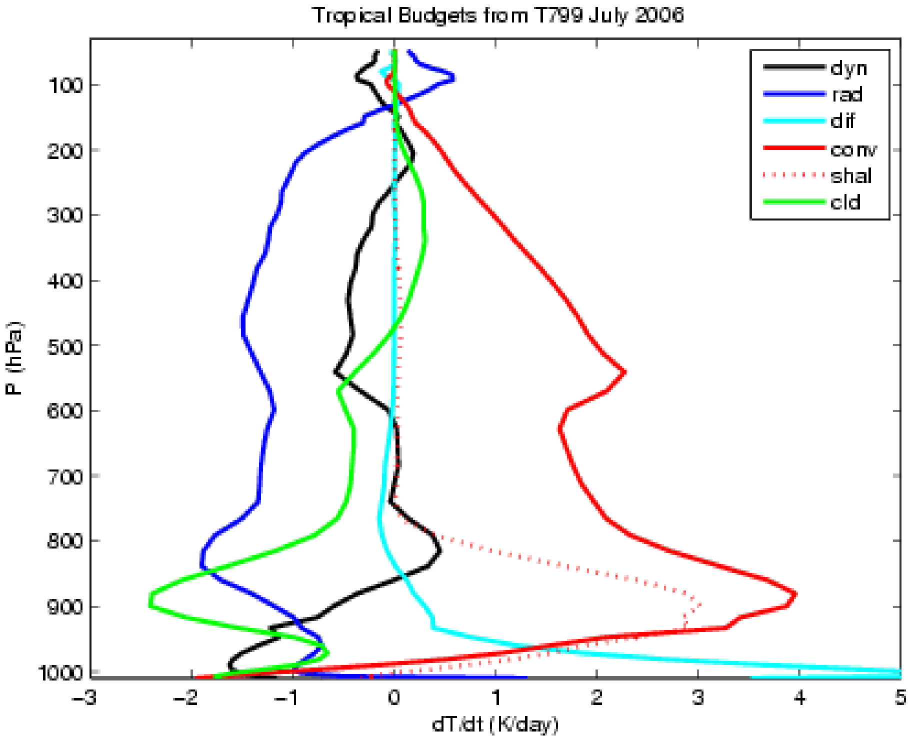
Easily fill out all the Tropics with low-level clouds

No shallow - shallow: SW radiation refl.

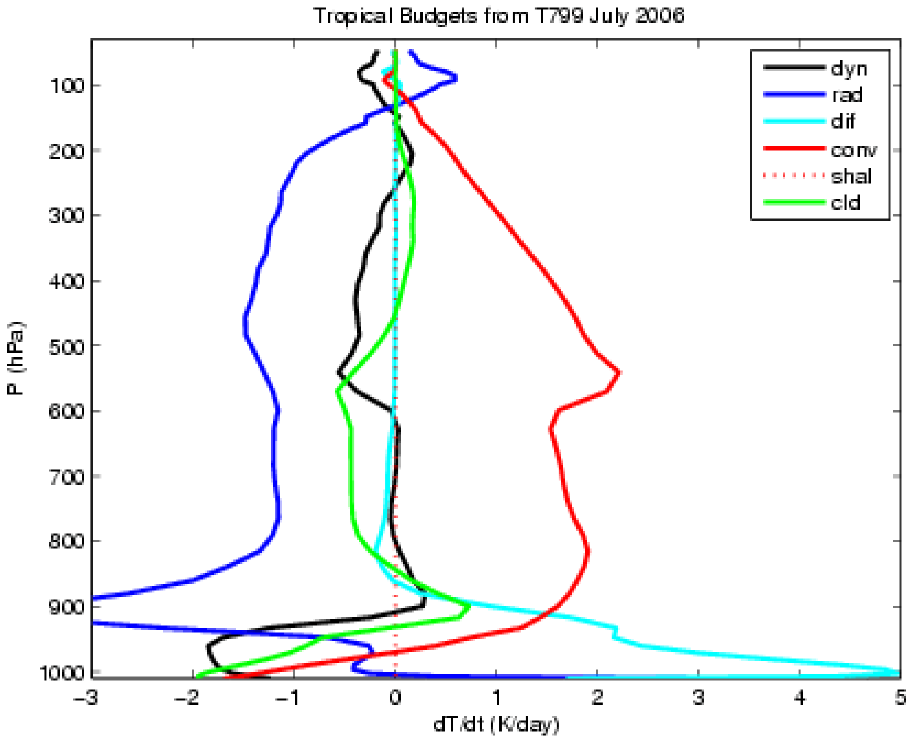


T Budgets Tropics

Ctrl

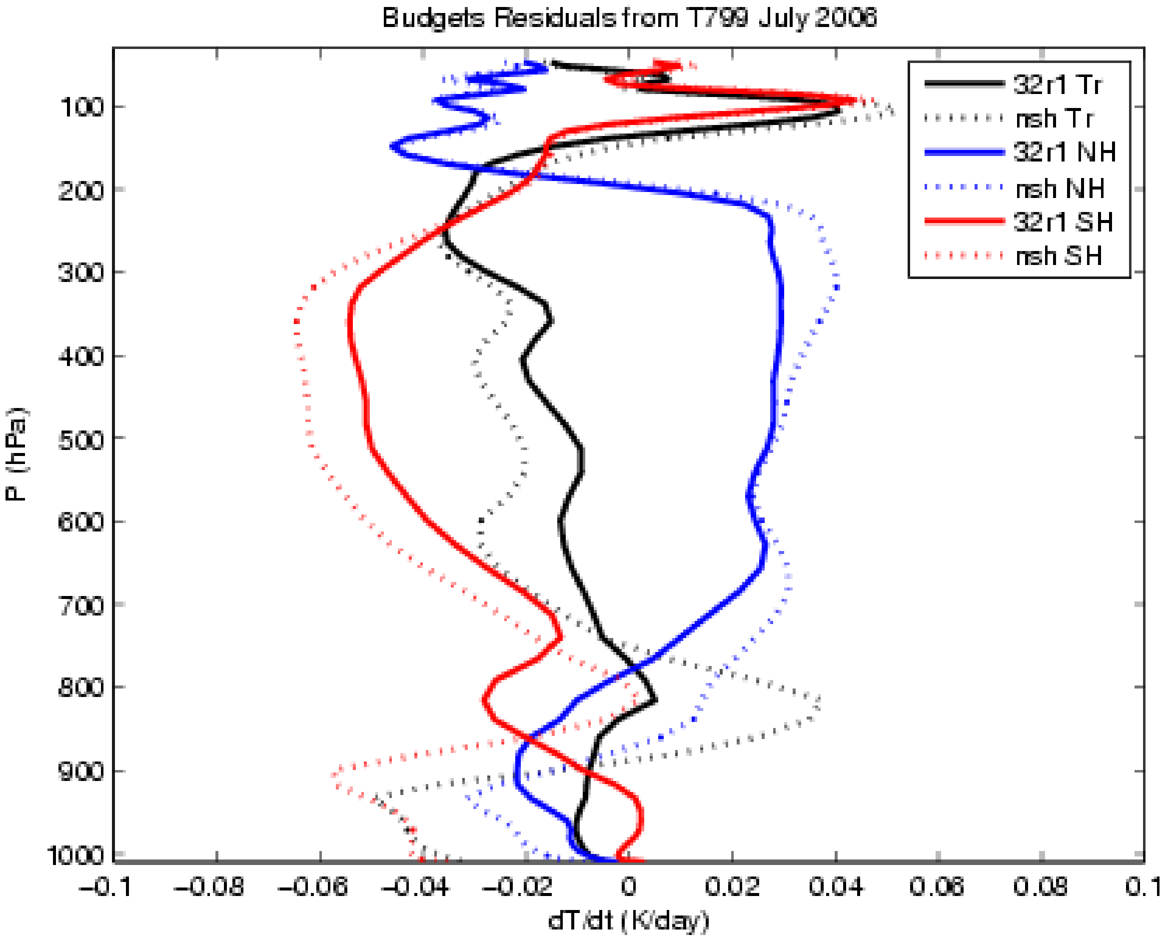


no shallow



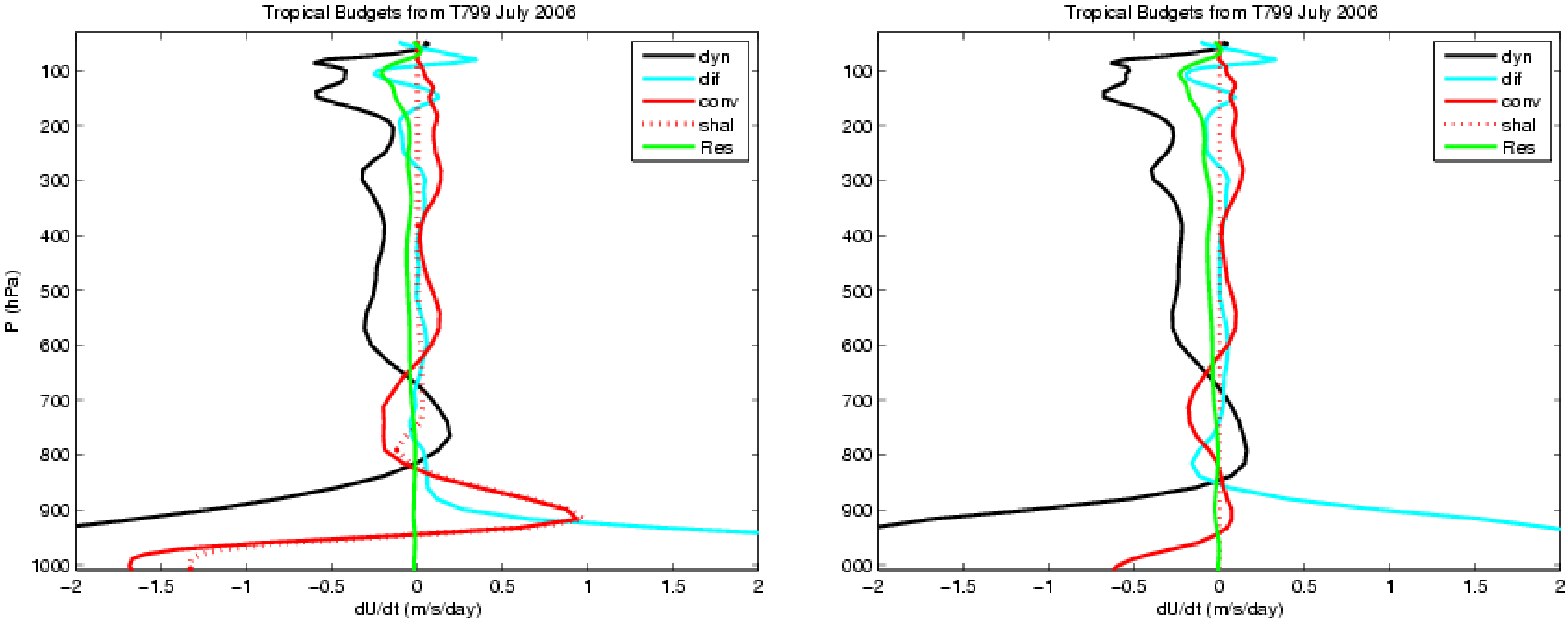
Change in shallow compensated by cloud/radiation/difusion, but already radiation does not appear realistic. Note also the general cooling by the stratiform cloud (evaporation of convectively detrained and stratiform precip).

T Budgets Residuals (Tropics NH SH)



Main differences below 800 hPa, but still relatively small – compensation, but effect also felt throughout troposphere (deep convection)

U Budgets Tropics



Ctrl

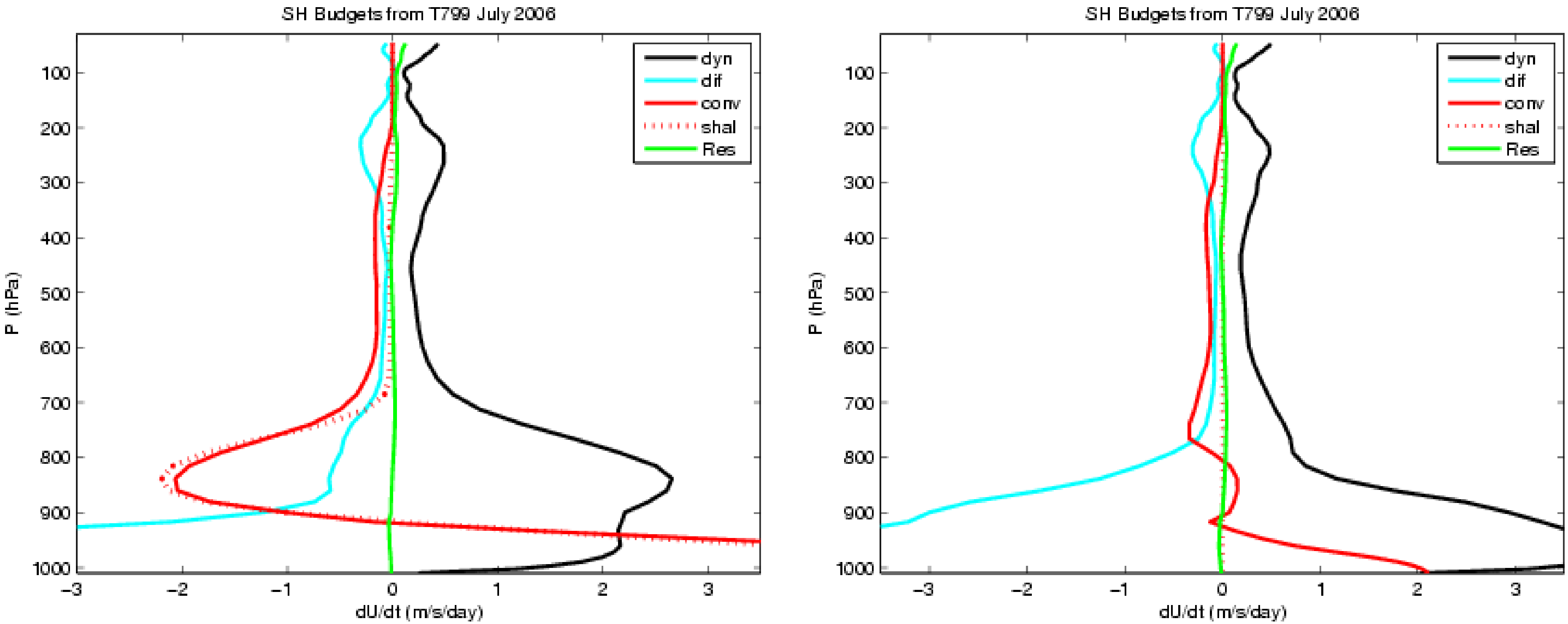
no shallow

Obviously, concerning our wind speed biases (=residuals) PBL not really problem, but upper tropical tropophere

U Budgets SH

Ctrl

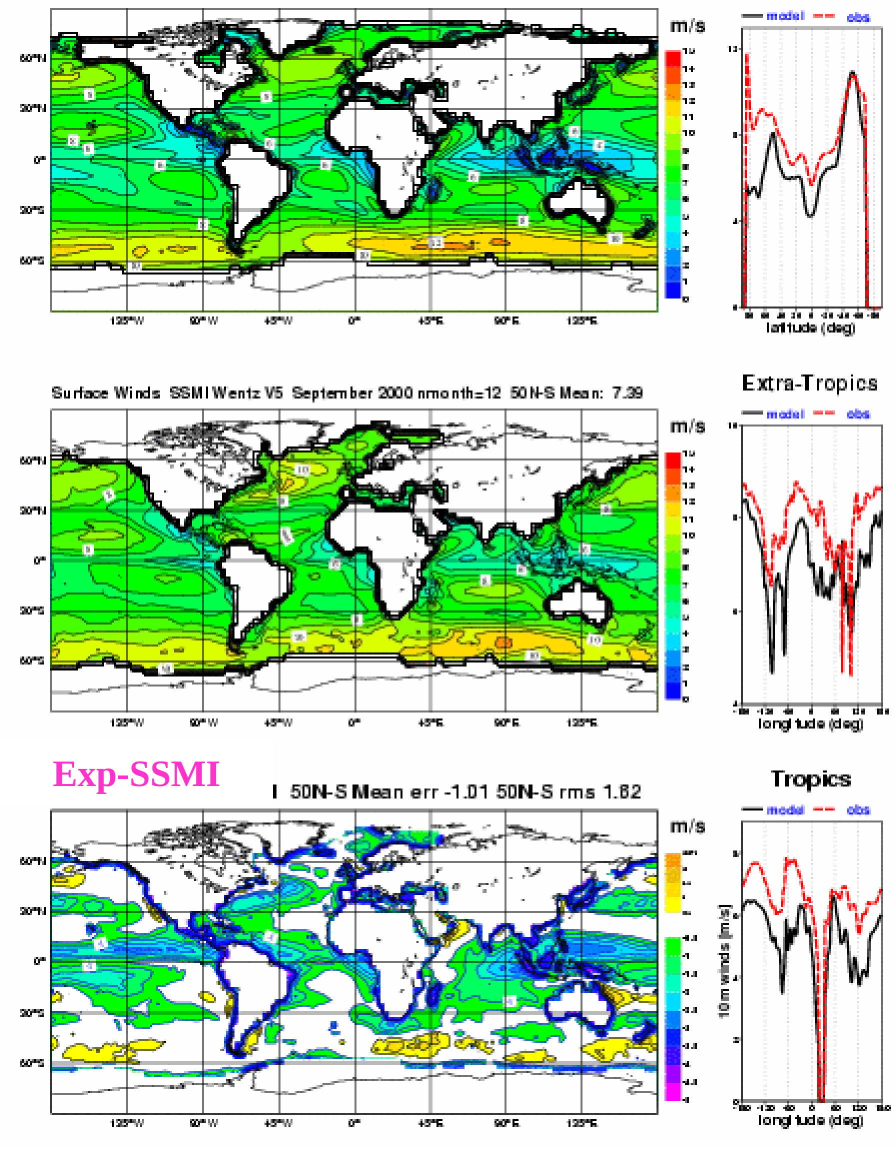
no shallow



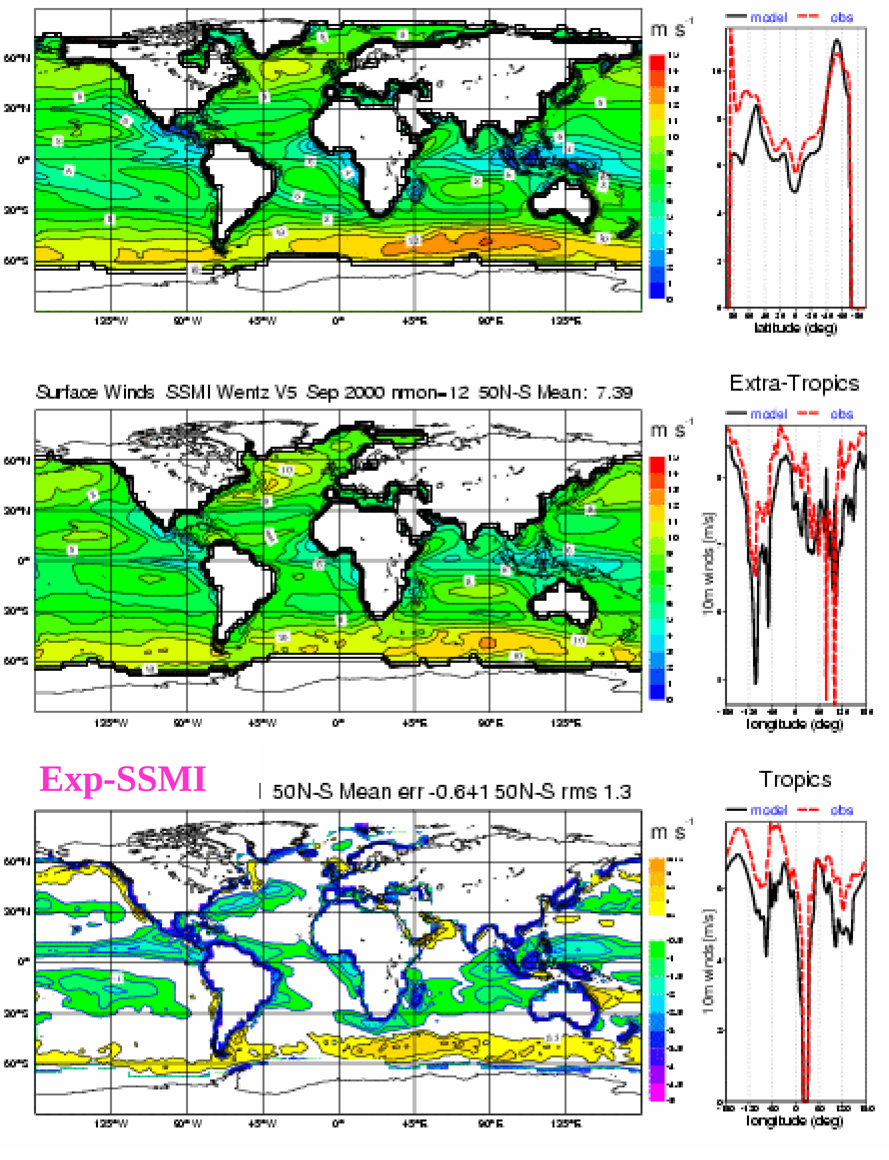
Very strong shallow momentum tendencies in SH, very closely compensated by diffusion/dynamics in no shallow run

Cure the 10m low-wind bias in convective regions (implicit and updraught momentum perturbation)

Cy30R1



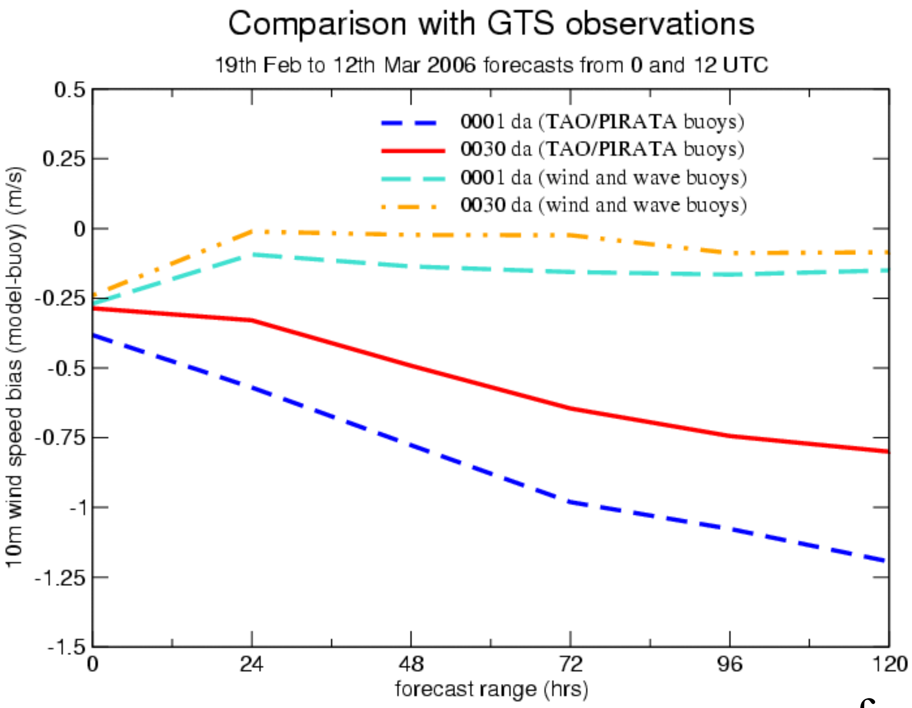
Cy31R2

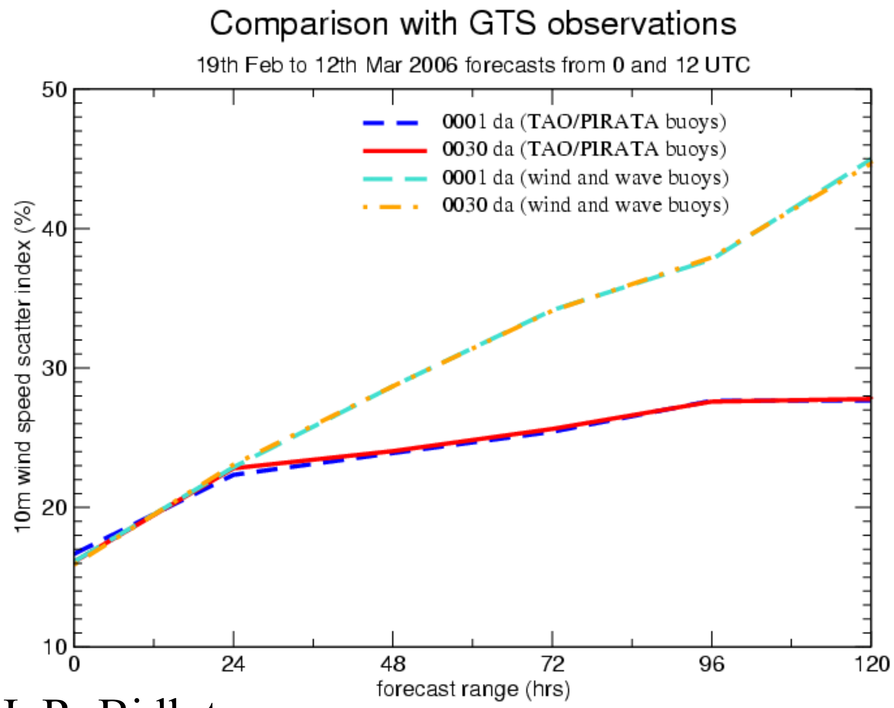


Effect on low-level winds - waves

Tuning exercise : reduce bias keep rms

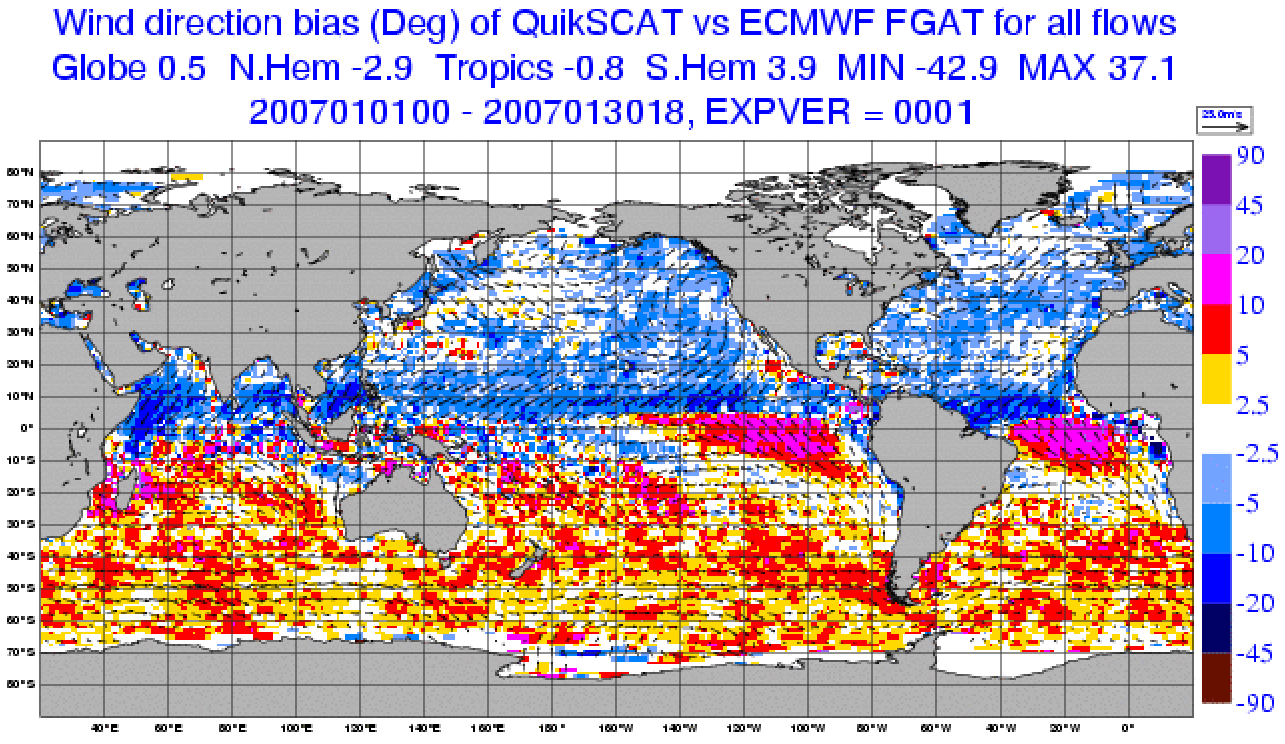
$$u'_u = u_u - \alpha \, sign(u_u); \quad u_u = \bar{u} + \frac{F_{uflux}}{M_u}; \; \alpha = 0.3 \, ms^{-1}$$





from J. R. Bidlot

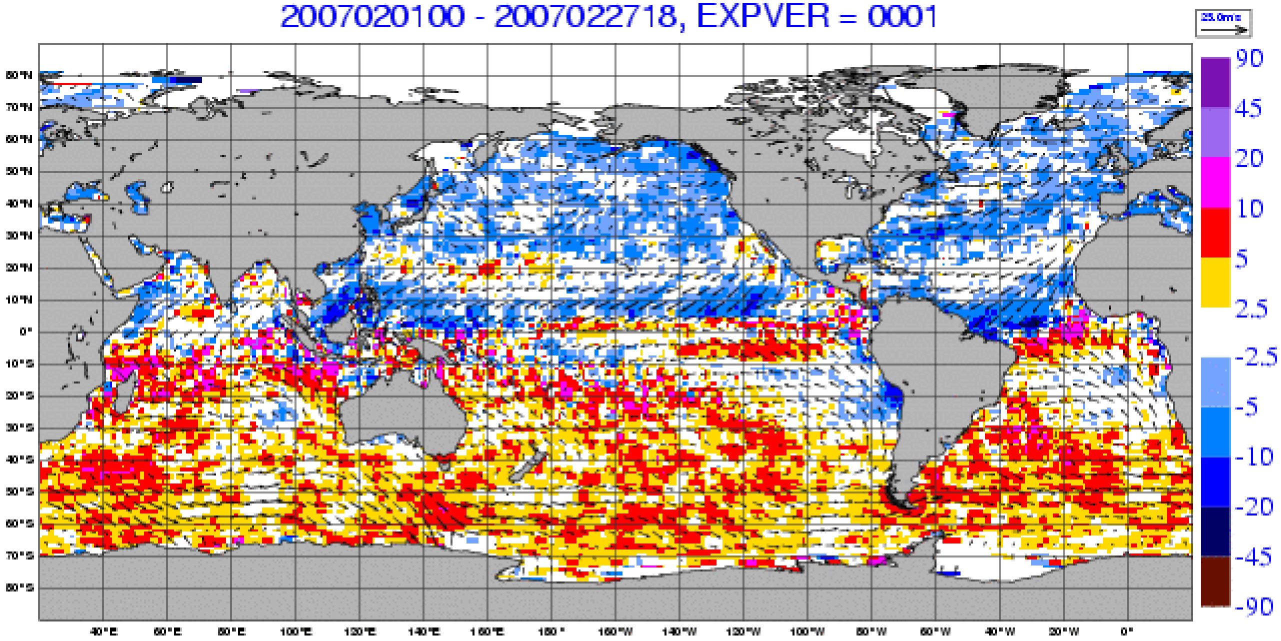
10 m Wind direction: FG - Quickscat



Wind direction bias (Deg) of QuikSCAT vs ECMWF FGAT for all flows
Globe 0.5 N.Hem -2.9 Tropics -0.8 S.Hem 3.9 MIN -42.9 MAX 37.1
2007010100 - 2007013018, EXPVER = 0001

Not enough cross isobaric flow, but problem stability dependent (warm or cold advection, see A. Brown et al. QRMS (2004,2005) for explanation

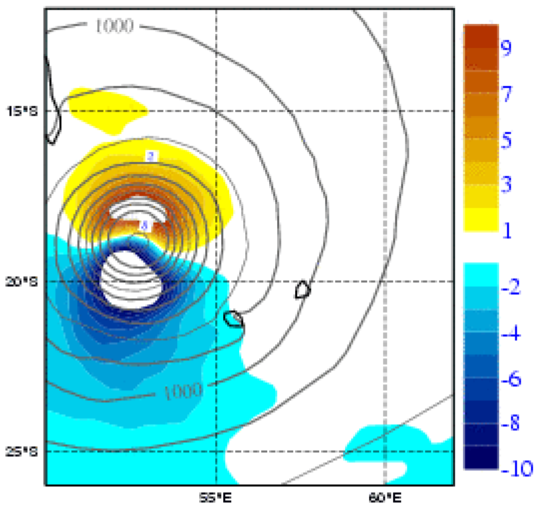
10 m Wind direction: FG - AScat



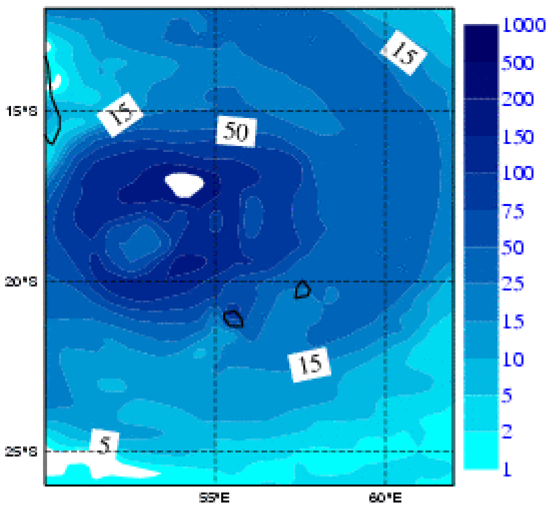
Wind direction bias (Deg) of asca250_bc vs ECMWF First-Guess for all flows
Globe 0.7 N.Hem -3.1 Tropics 0.1 S.Hem 3.5 MIN -44.5 MAX 56.4
2007020100 - 2007022718, EXPVER = 0001

Shallow closure and tropical cyclone Gamede

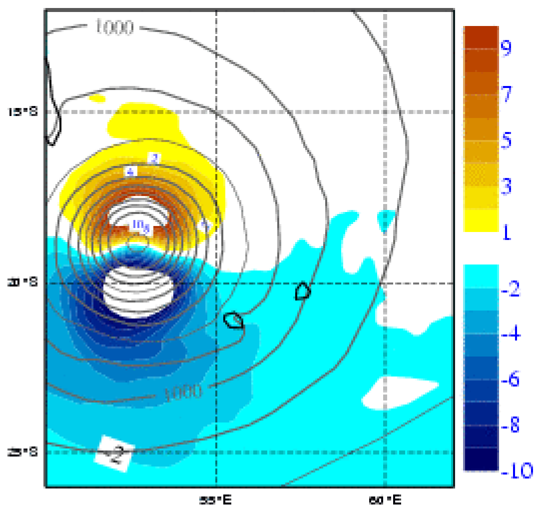
MSLP (hPa) 20070224+72h AN and Fc-An



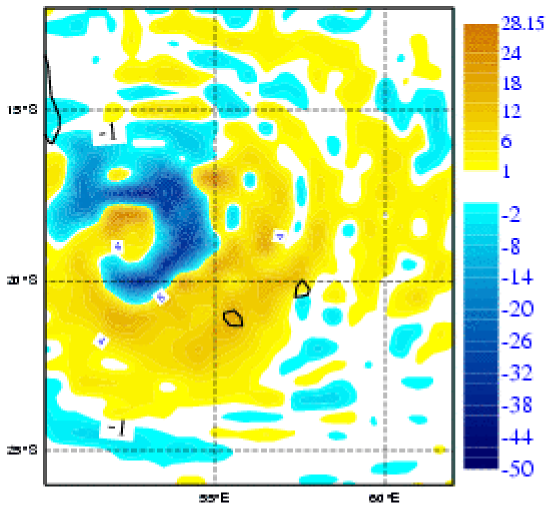
Precip (mm/day) 20070224+72h Fc



MSLP 20070224+72h AN and Exp-An

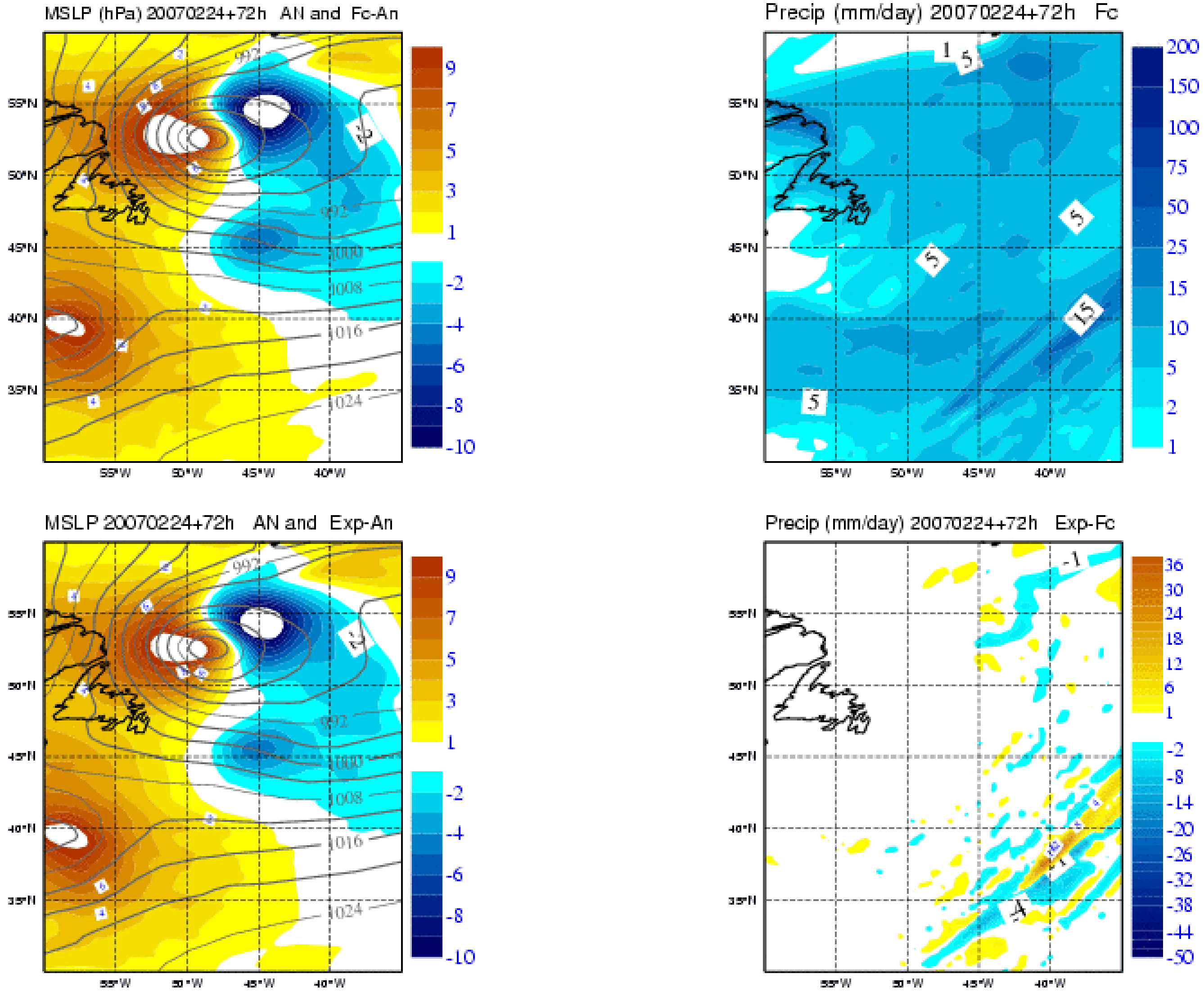


Precip (mm/day) 20070224+72h Exp-Fc



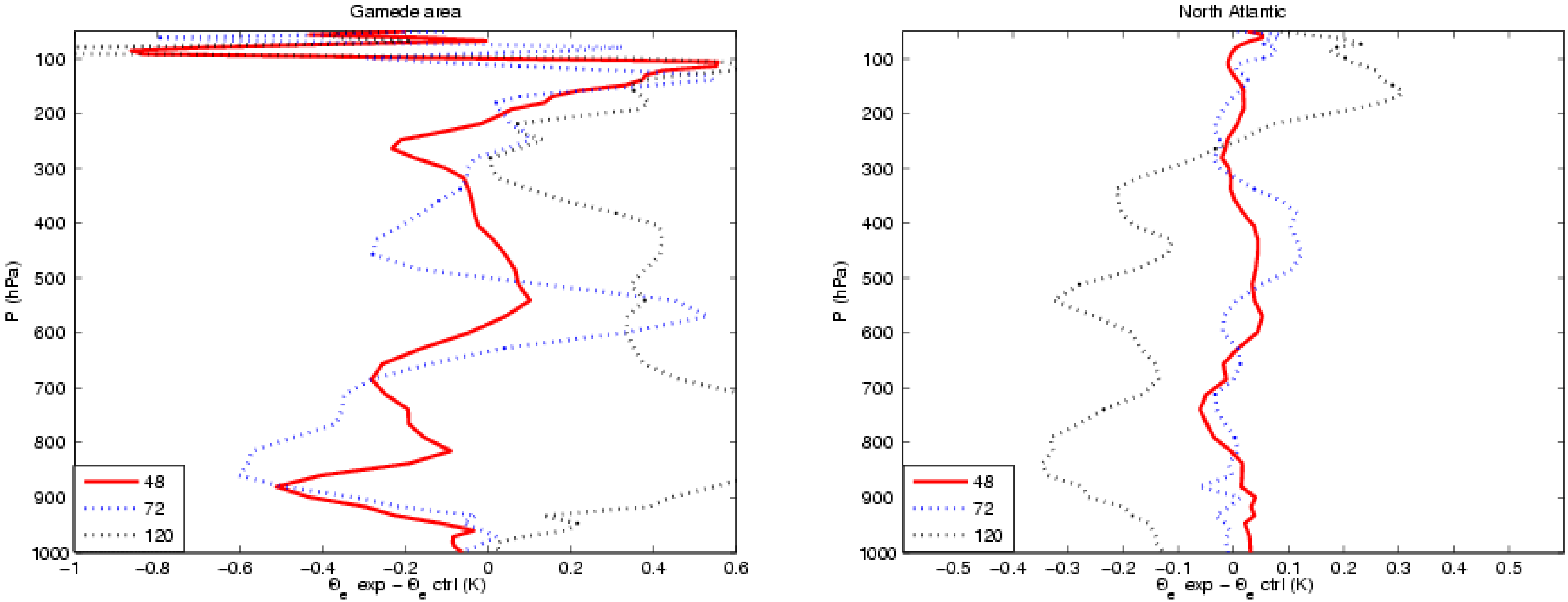
Generally, a decrease of shallow mass fluxes (less boundary-layer drying) leads to deeper tropical cyclones – long time series of tests are necessary

Shallow closure and midlatitude cyclone

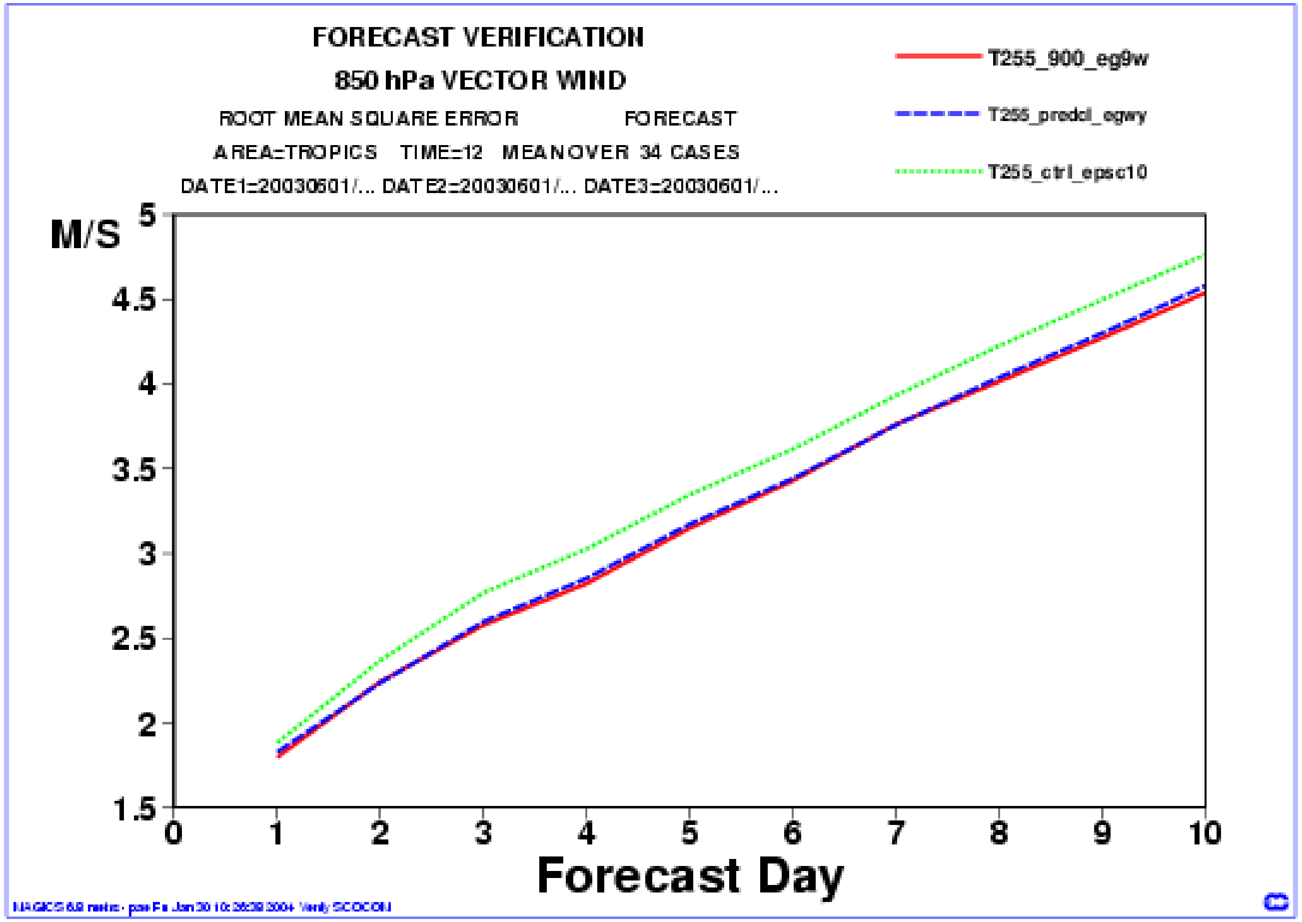


For midlatitude cyclones the (diabatic) effects are much weaker, baroclinicity dominates. However, the mass flux on cyclone development effects become also clear for long time steps > 1800 s

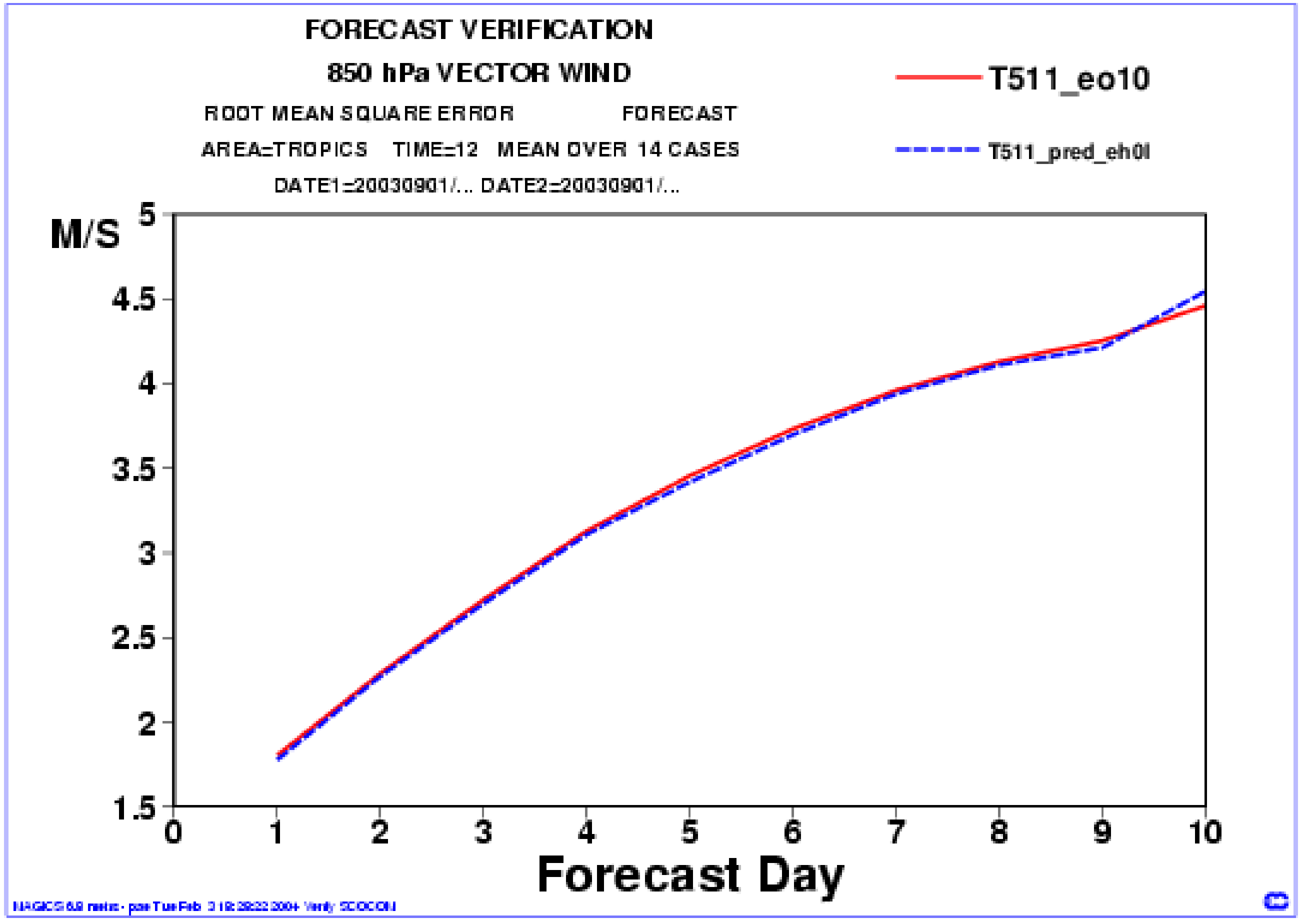
Shallow convection projects on tropospheric and lower stratosphere stability



T255 experiments: EPS_ctrl 2700s, 900 s, time int+mflx increase

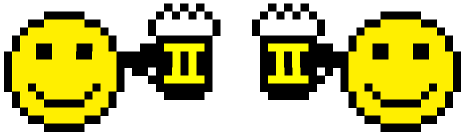


Same but T511 26R3 Ana experiments:



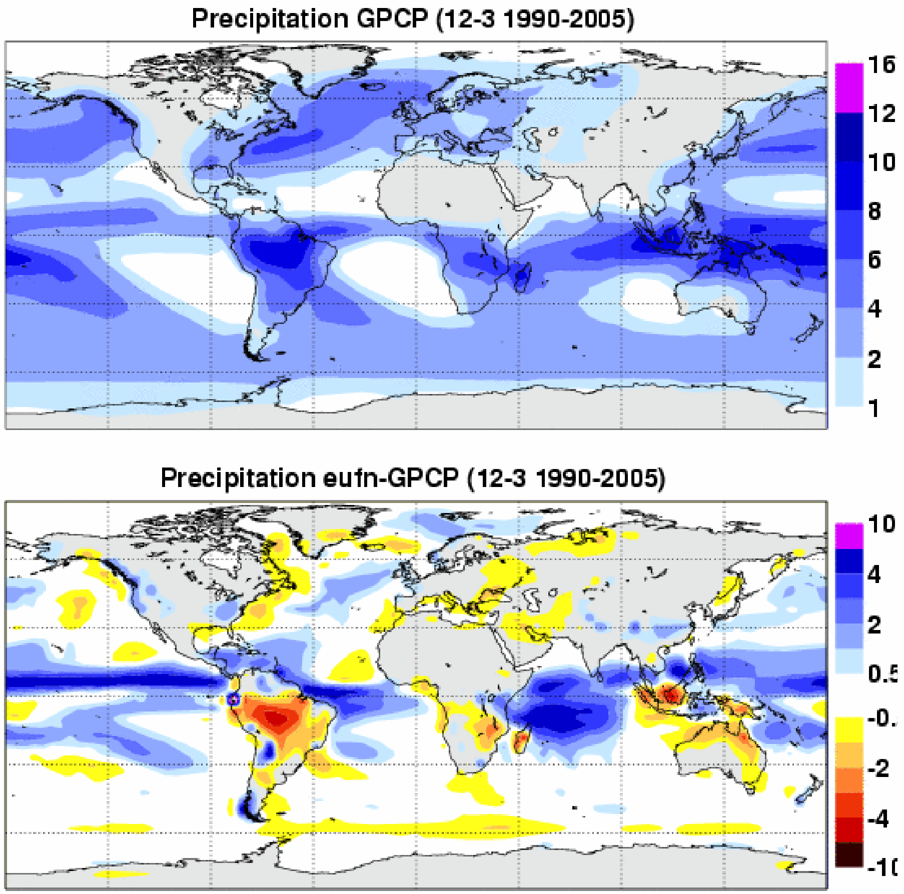
Summary

- Global distribution of shallow clouds already reasonably reproduced
- Budgets allow to identify biases, compensation between processes (but not quite) ….. minimise rms more difficult
- Efficient numerics is important, allow for long time steps
- Encourage use of Satellite data (Quickscat, Ascat, SSMI etc.) and sondes to determine errors in BL winds, i.e. momentum transport
- Shallow convection not only important in tropical meteorology, but also for good midlatitude synoptic forecasts (deepening rate of cyclones), especially when the model time steps become large. "Dynamical verification" !
- Always keep eye on interaction (control) of shallow on deep convection; is this problem in deep convection resolving mode simpler than in deep convection parameterisation ?

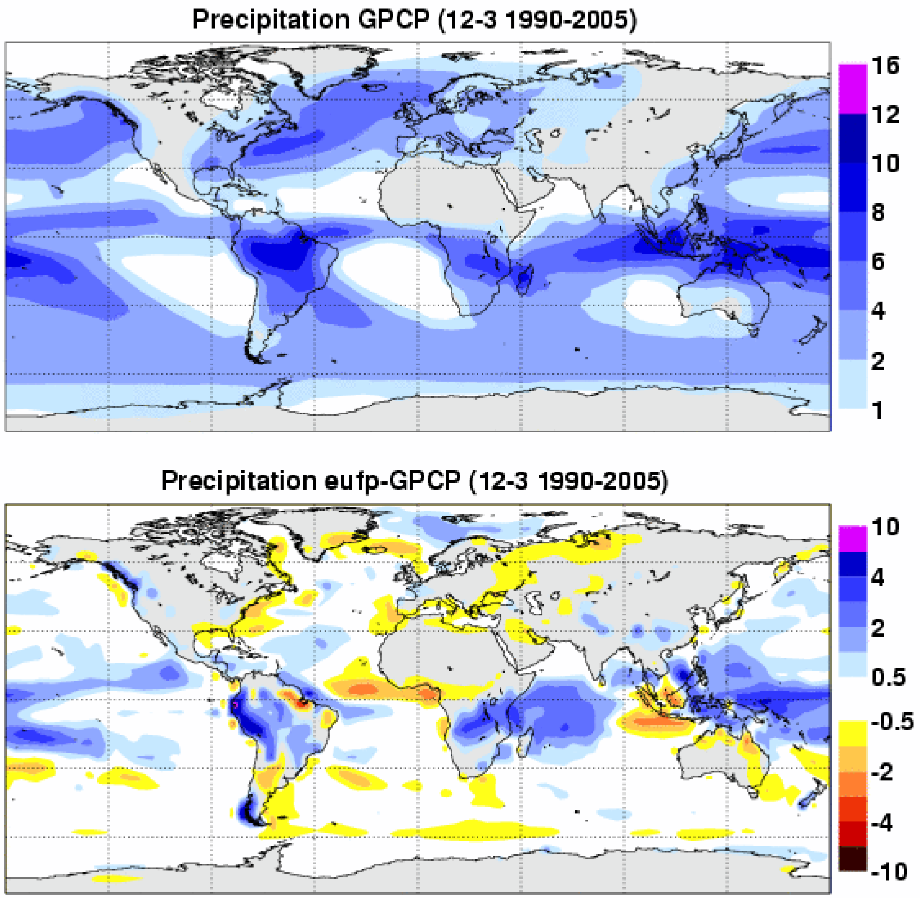


Precipitation in 15year 5-months winter runs (not latest version)

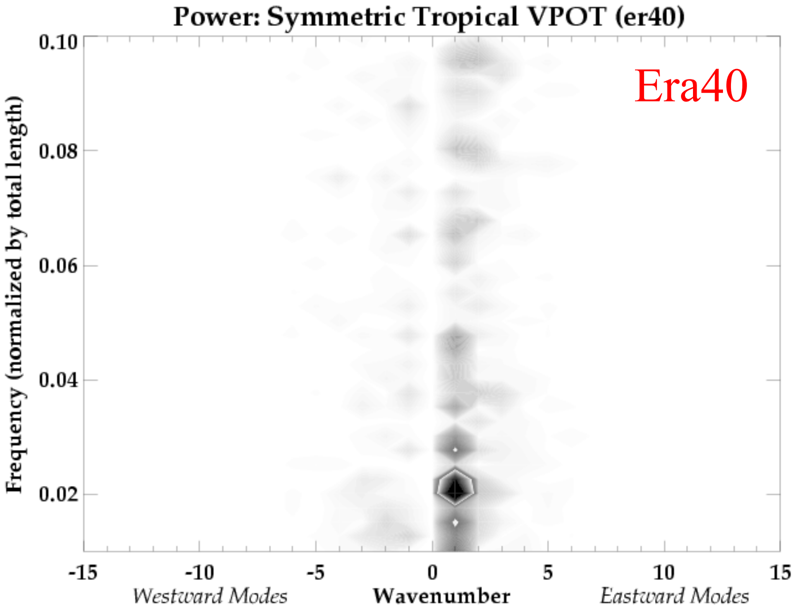
31R1

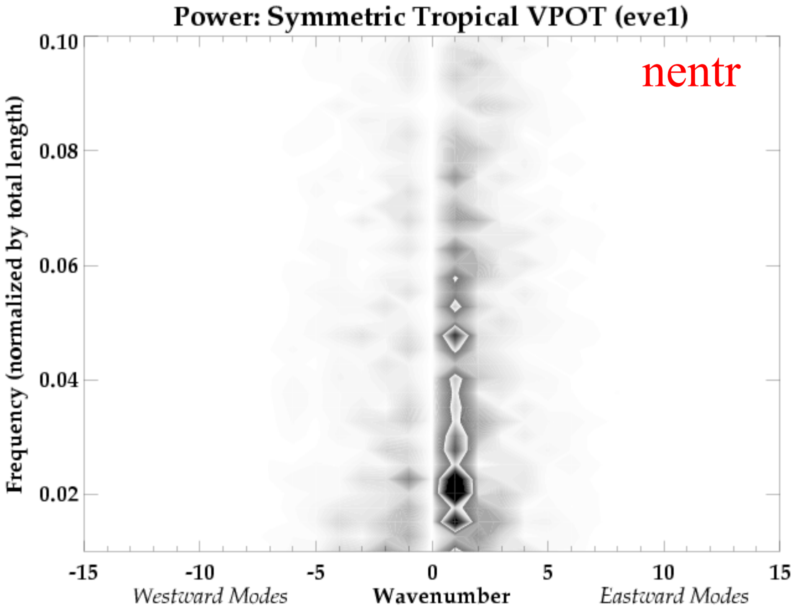


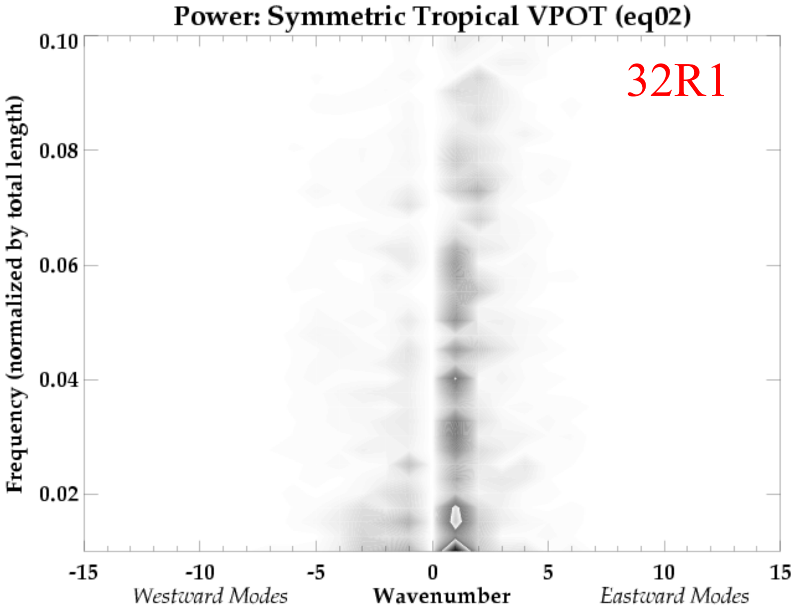
Entr+Rad



Climate runs: Velocity Potential Wavenumber - Frequency diagram







Entrainment (1)

$$\frac{\delta M}{M}\frac{1}{\delta z} = \varepsilon = \varepsilon_{turb} + \varepsilon_{org}$$

Any non-dimensional function or constant possible, but results more or less optimal

$$\varepsilon = \underbrace{c_0}_{turb} F_\varepsilon + \underbrace{c_1 \frac{\overline{q}_s - \overline{q}}{\overline{q}_s}}_{org\,, buoy>0,\, deep\ only} F_\varepsilon;$$

$$c_0 = O(10^{-3});\ c_1 = O(10^{-3}); \quad F_\varepsilon = \left(\frac{\overline{q}_s}{\overline{q}_{s\,base}}\right)^2$$

Constants

Scaling function

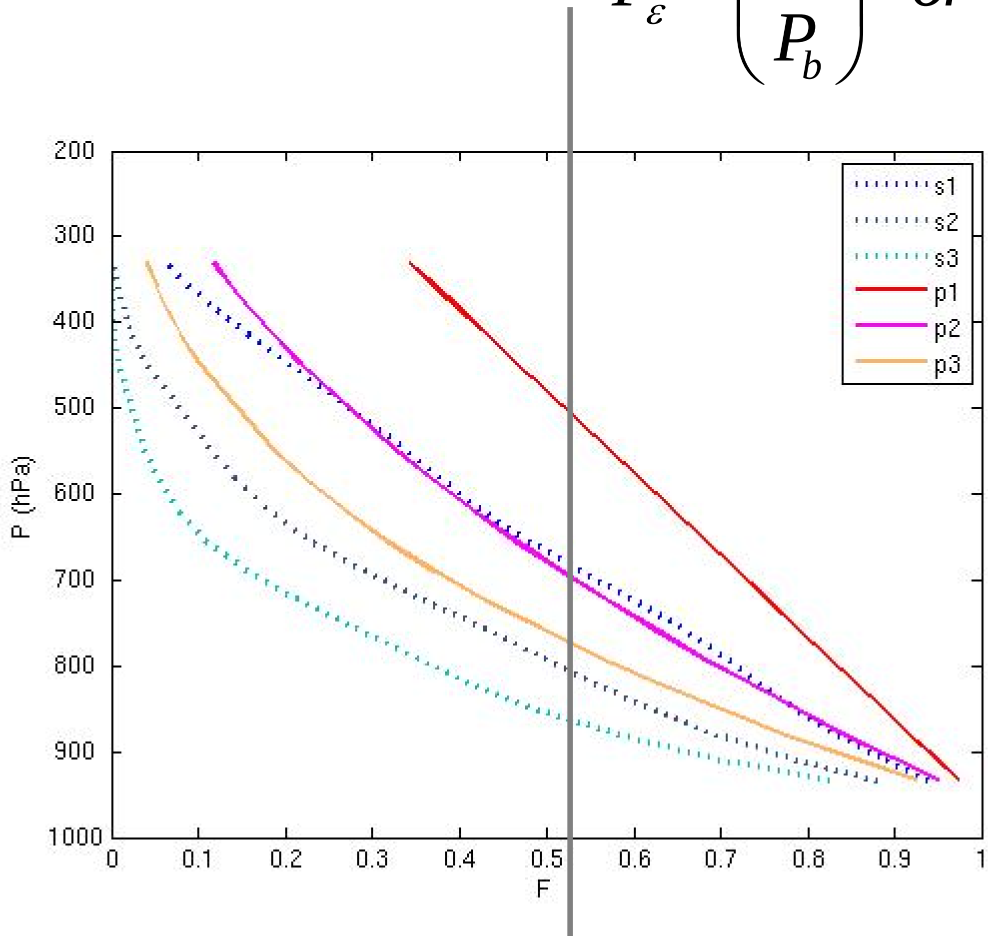
NB: This is a simple RH or saturation deficit formulation for the organised entrainment, but any other formulation using buoyancy or

Θ_e, Θ_{es}

Entrainment (2)   scaling functions

$$\delta_{turb} = \varepsilon_{turb} F_\delta \quad \delta_{org} \approx \frac{\partial K}{\partial z}, buoy < 0 = unchanged$$

$$F_\varepsilon = \left(\frac{P}{P_b}\right)^{c_3} \text{ or } \quad F_\varepsilon = \left(\frac{q_s}{q_{sb}}\right)^{c_3} ; \quad F_\delta = c_4$$



The turbulent detrainment is simply taken constant. From the left diagram it can be seen that from a certain level detrainment>entrainment

> *"What can be controlled is not real, and what is real can not be controlled"* from Nobukov, *"The Cosmic Web"*

Adjustment time scale

$$N = \frac{g}{\theta_v}\frac{\partial \theta_v}{\partial z}; \quad f; \quad \frac{l_x}{U}; \quad \frac{l_z}{W} \Rightarrow \boxed{\frac{l_z}{\overline{W}_u};} \quad or$$

$$\tau = \frac{l}{C} = \frac{l}{\sqrt{g l_z}} \quad or \quad \boxed{\frac{l}{l_z \overline{N}}} \quad with \quad l = \Delta x \; or \; l = U\, f^{-1} \approx 10^5$$

$$Ro = \frac{U}{l_x f}; \quad Ri = N\left(\frac{l_z}{U}\right)^2; \quad l_{Ro} = \frac{N l_Z}{f}$$

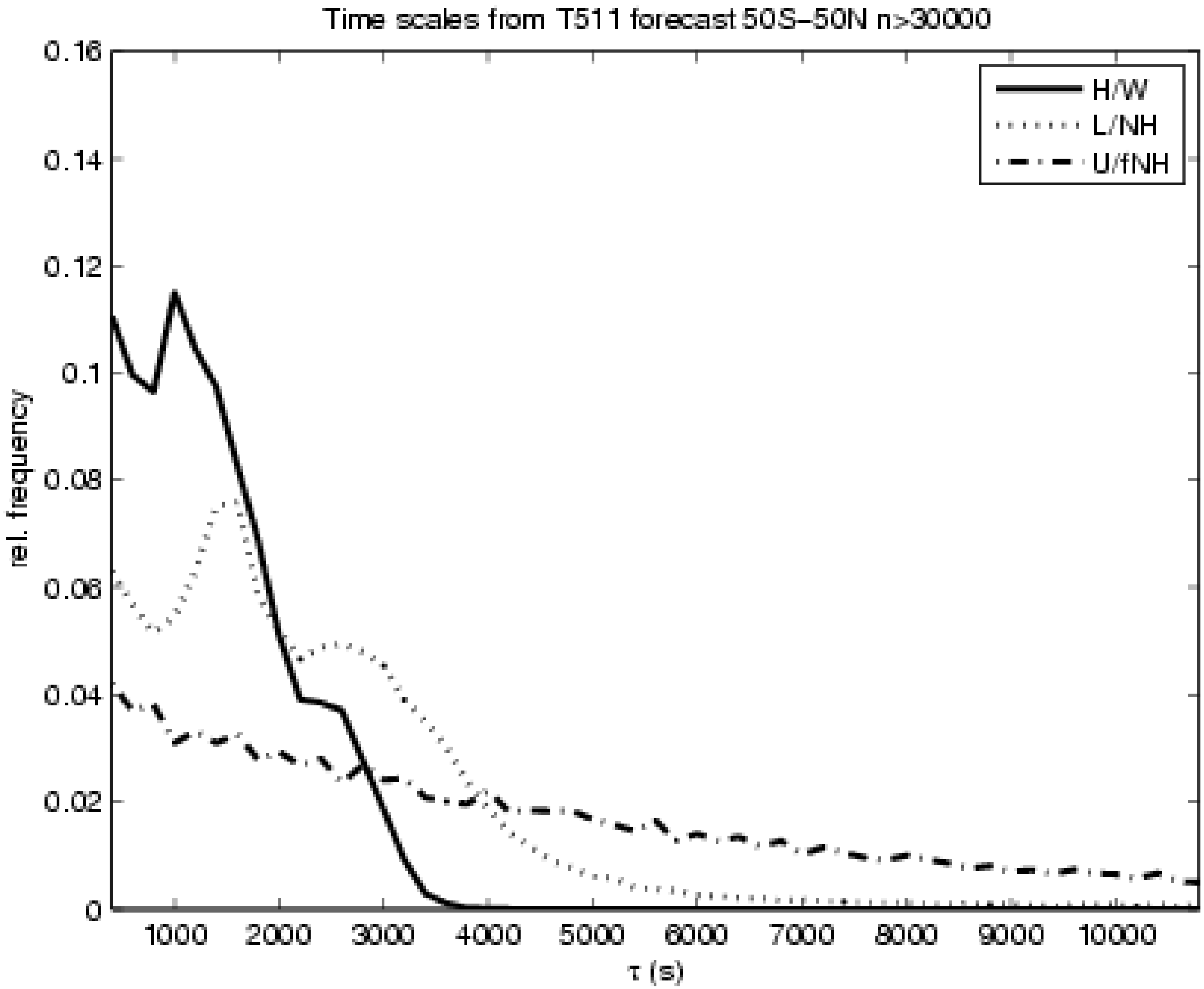
The two time-scales represent a turnover time-scale and one from gravity wave (spreading) theory, in practical applications they produce similar results

Currently, the convective adjustment time scale τ with which CAPE is realeased is constant horizontally but varies with horizontal resolution, i.e 3600s at T159 and 600 s at T799. Instead it is proposed to use

$$\tau = \frac{Z_{cld}}{\overline{W}_{cld}}\alpha; \quad \alpha = 1 + 0.33 * 799 / xxx; \quad \tau = \min[10800, \max(\Delta t)]$$

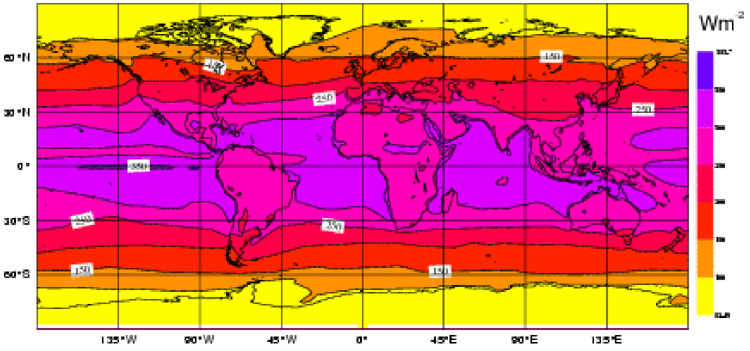
Where the cloud thickness Zcld and the cloud average updraught velocity Wcld are used so that there is only a variation of a factor two between T799 and T159 resolutions.

Adjustment time scale

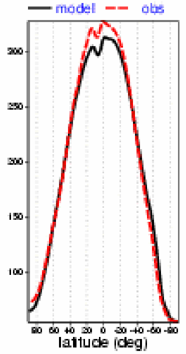


Climate runs: SW and mid-level clouds

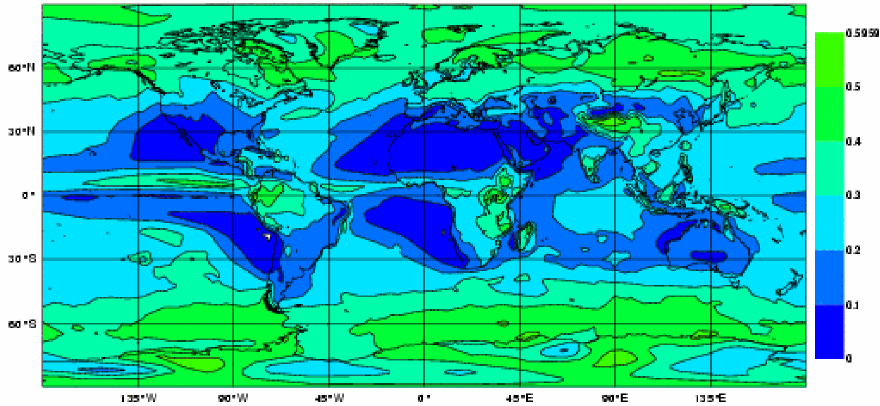
TOA sw euhx Sep 2000 nmon=12 nens=3 Global Mean: 239 50S-50N Mean: 272



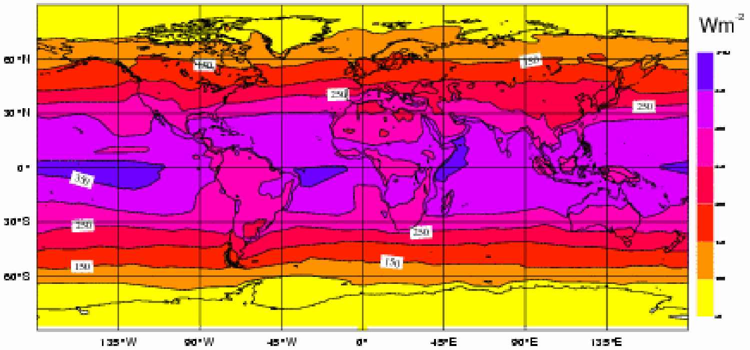
Zonal Mean



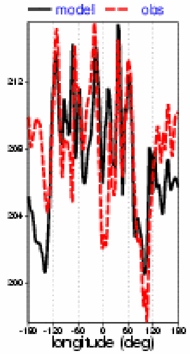
**Medium cloud cover ([(0 - 1))] euhx 200009 nmon=12 nens=3 Mean: 0.2486



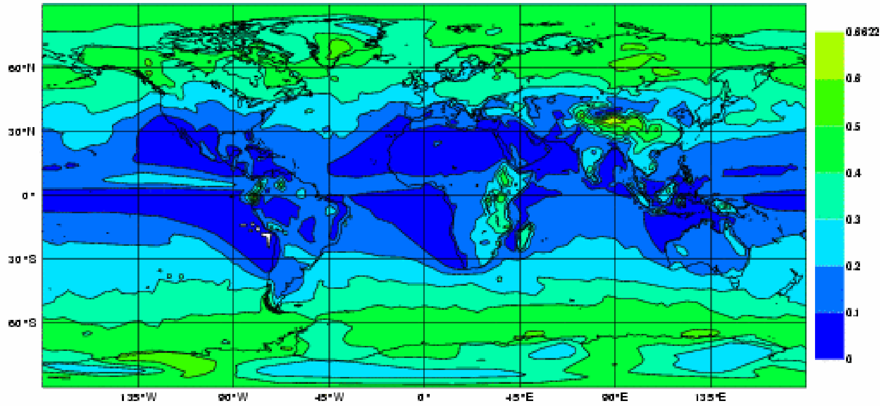
TOA sw CERES Sep 2000 nmon=12 Global Mean: 244 50S-50N Mean: 280



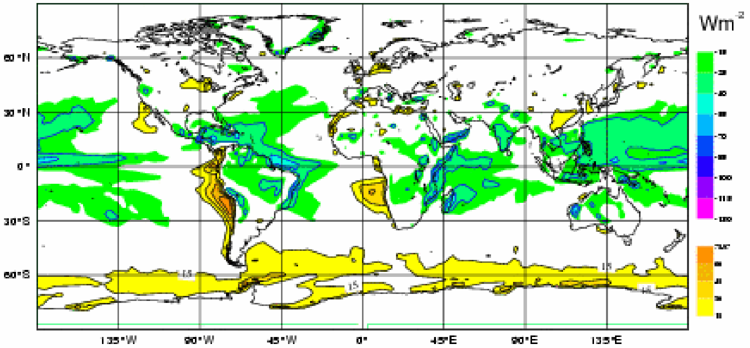
Extra-Tropics



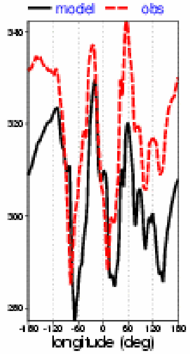
**Medium cloud cover ([(0 - 1))] eu2d 200009 nmon=12 nens=3 Mean: 0.2267



Difference euhx - CERES 50N-S Mean err -7.96 50N-S rms 16.9



Tropics



**Medium cloud cover euhx-eu2d 200009 nmon=12 nens=3 Diff: 0.02189 Stdev: 0.05868