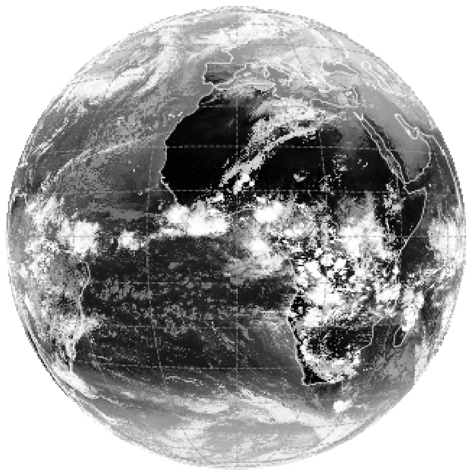
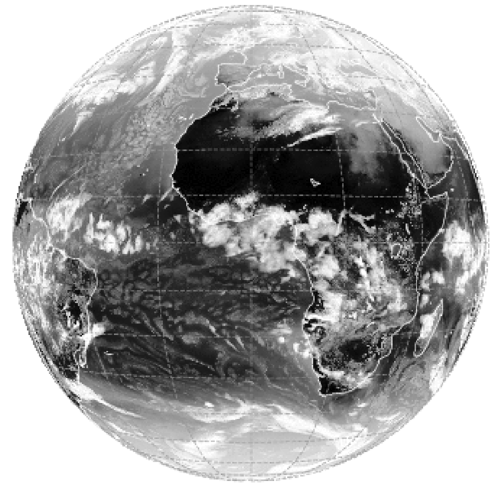
Convection and the Tropics

Meteosat 9 IR10.8 20120220 15 UTC



ECMWF oper Fc 20120220 00 UTC+15h:



Peter Bechtold

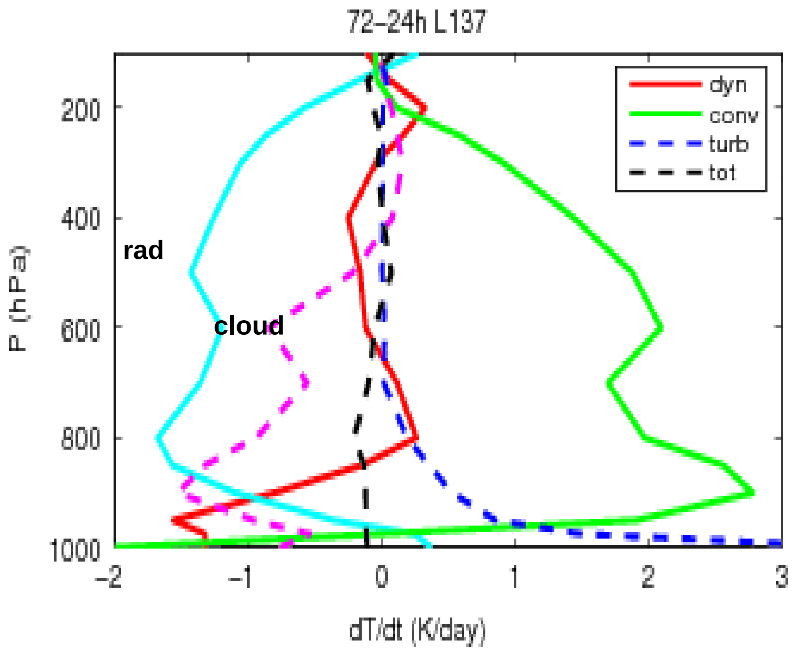
with help from:

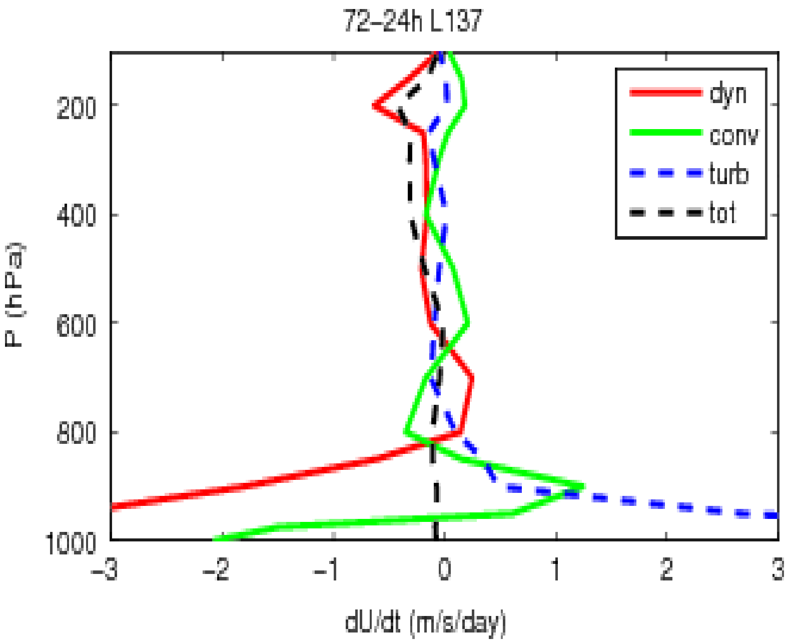
P. Bauer, P. Berrisford, J. Bidlot, C. Cardinali., T. Haiden, L. Hirons, M. Janousek, D. Klocke, L. Magnusson, A. McNally, J-J. Morcrette, S. Malardel, F. Prates, M. Rodwell, I. Sandu., N. Semane, F. Vitart and discussions with many colleagues

What to expect

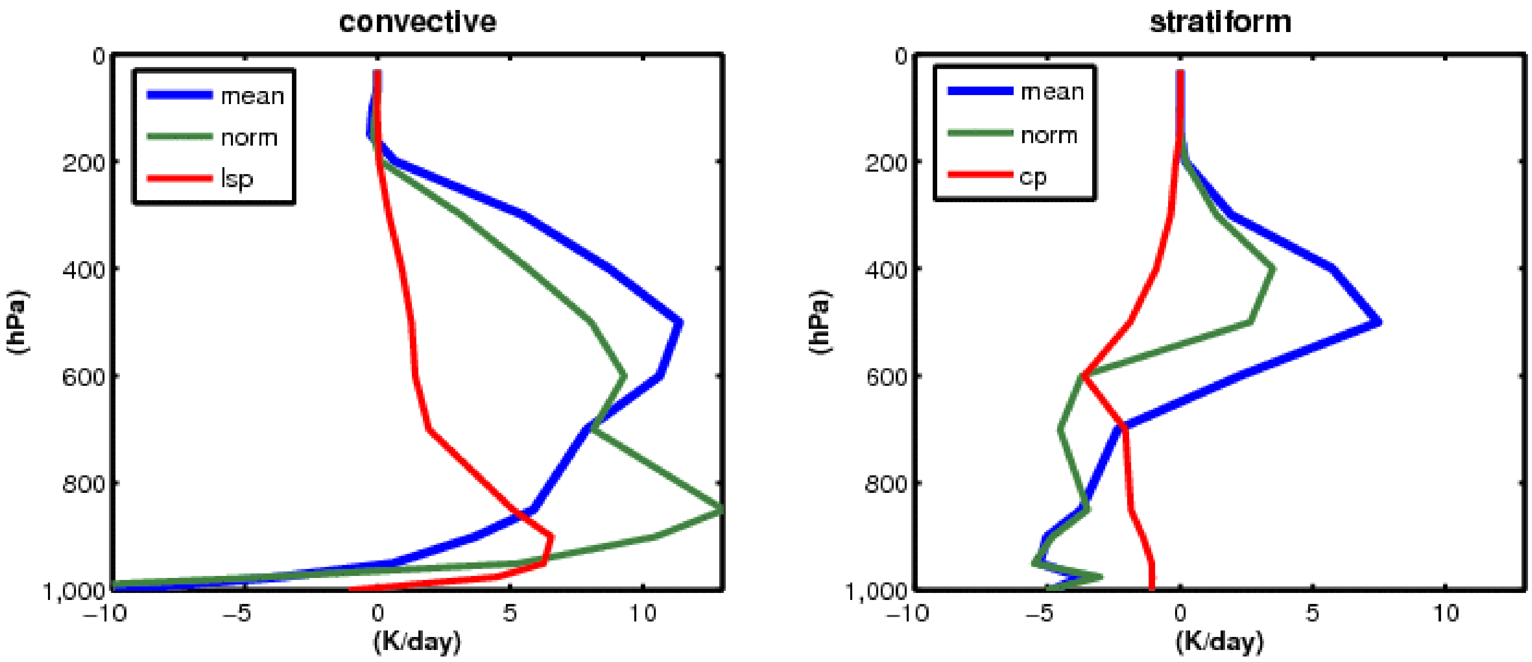
- Convective heating – available energy - waves
- Regions with major forecast errors and uncertainty in the analysis
- Convection and seasonal forecasts: Mean state, diurnal cycle, tele-connections and the QBO
- The MJO, why better now
- The small planet, studying a future high-resolution system

Tropical T and U tendency budgets





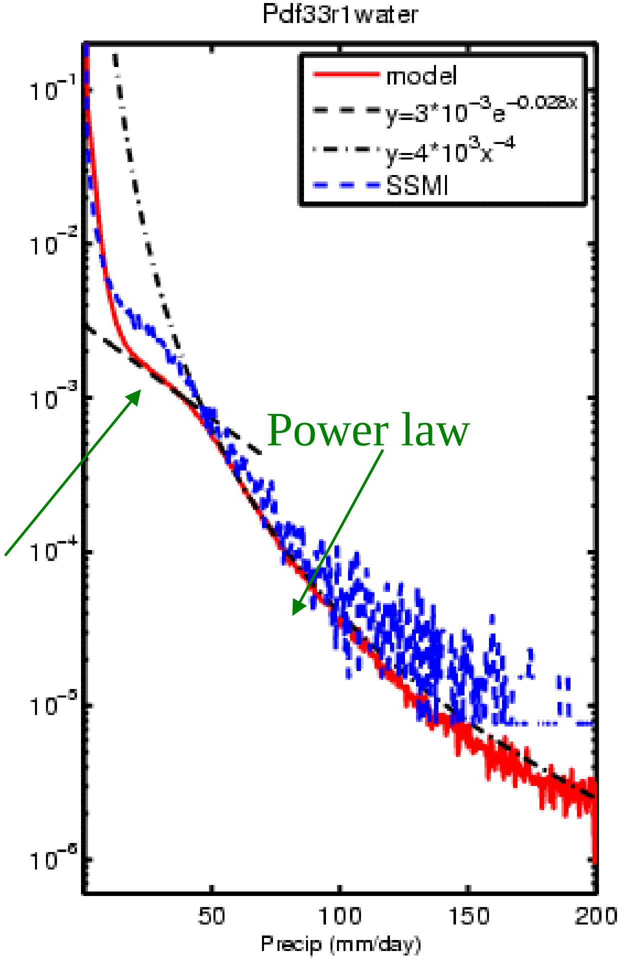
Normalized convective and stratiform heating profiles



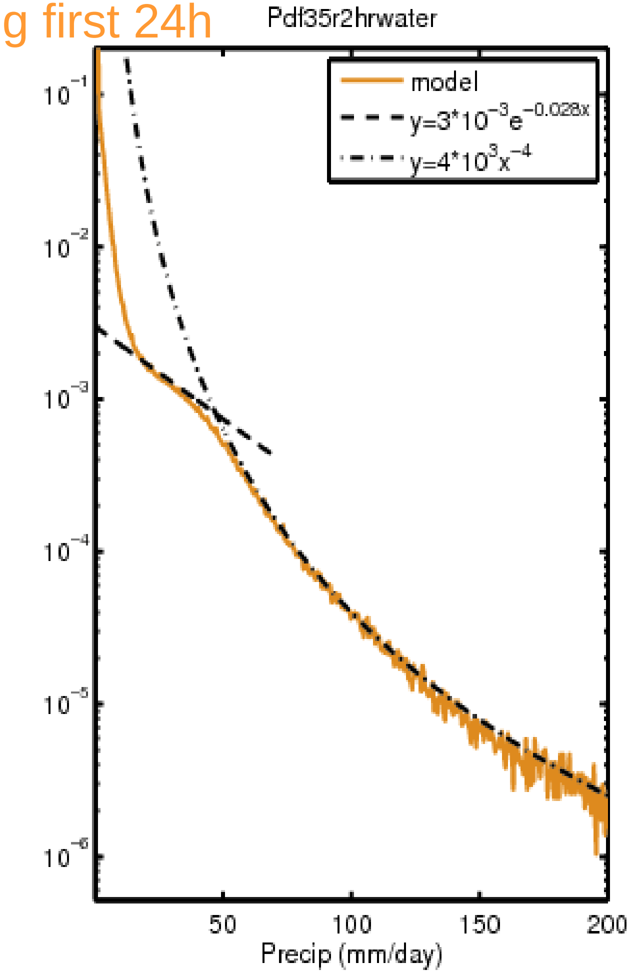
ECMWF

Some statistical properties of convection: Pdfs of instant. Rain rates

from T799 33r1
during first 24h

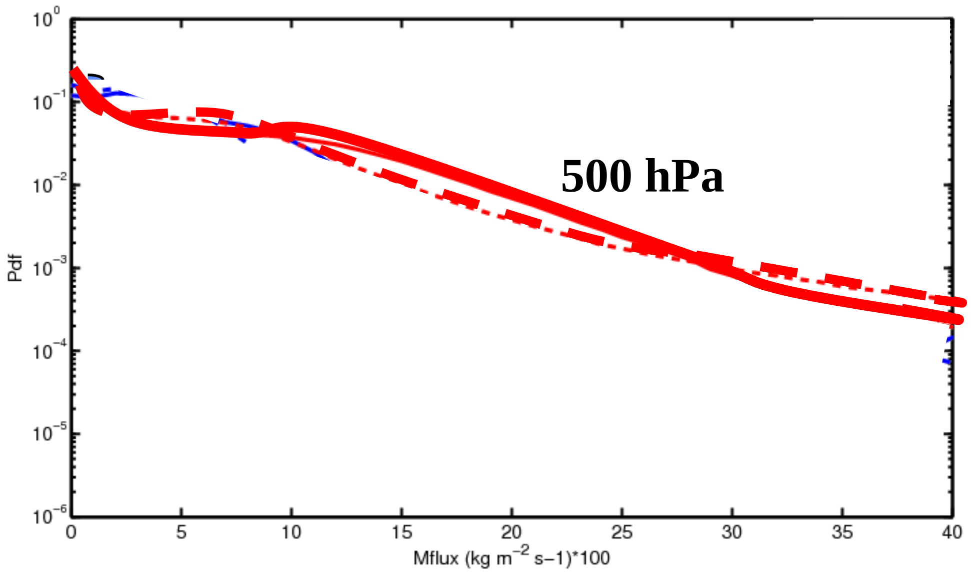


from T1279 35r2
during first 24h



SSMI is from 1D-Var

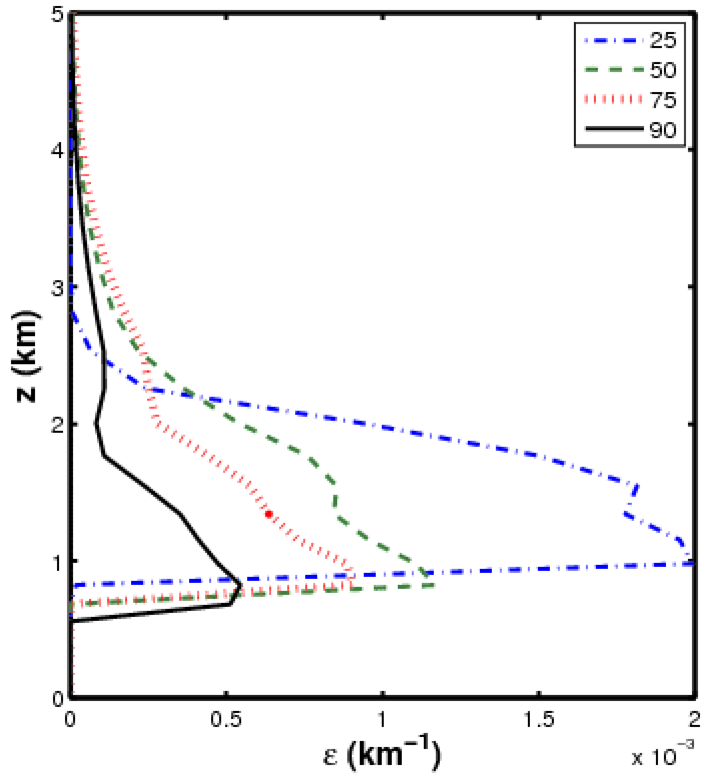
Some statistical properties of convection: Pdfs of mass fluxes T159 & T1279



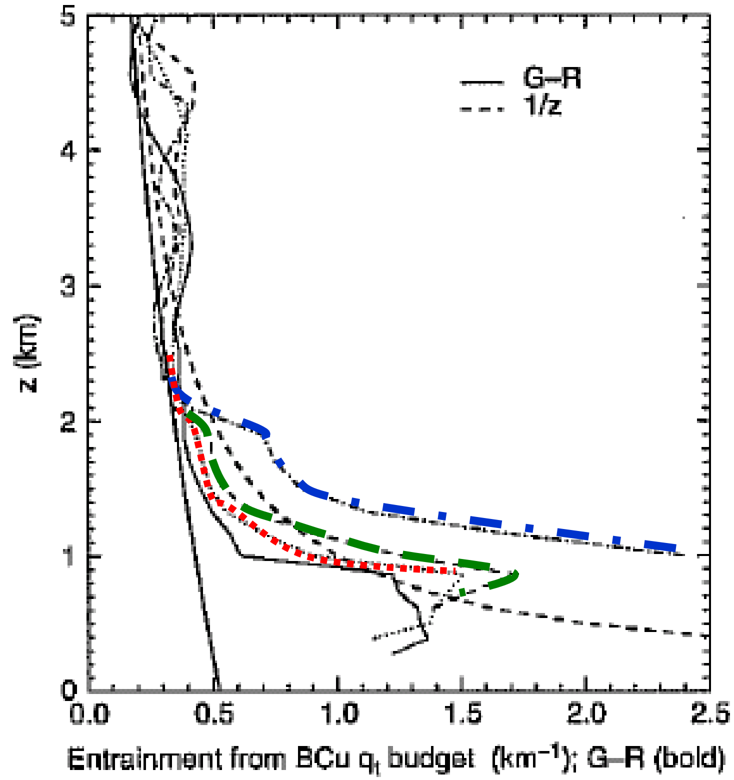
From theory expect exponential Pdf of mass flux, Cohen and Craig (2006)

ECMWF

Entrainment rates versus CRM (UKMO)



See also deRooy (QJ 2012)



Derbyshire et al. (QJ 2011)

The global Lorenz Energy cycle

Generation **Conversion**

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

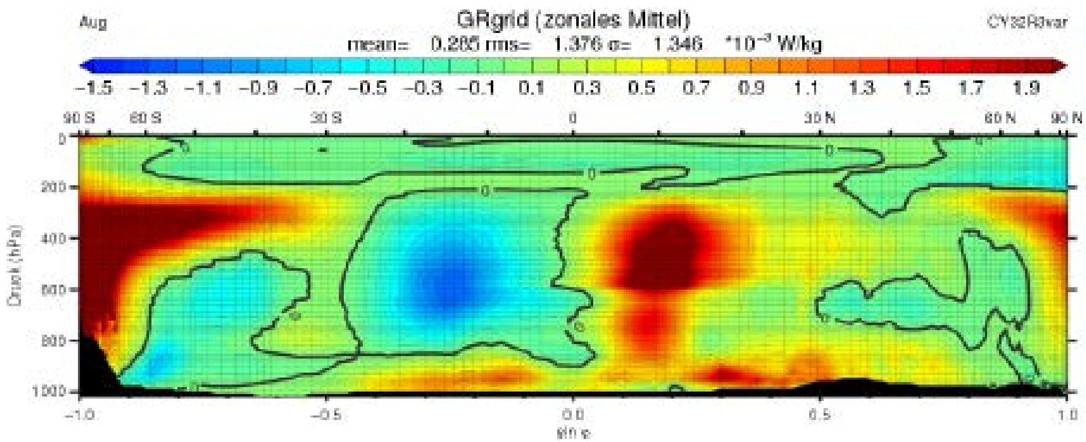
Lorenz efficiency factor

Net heating

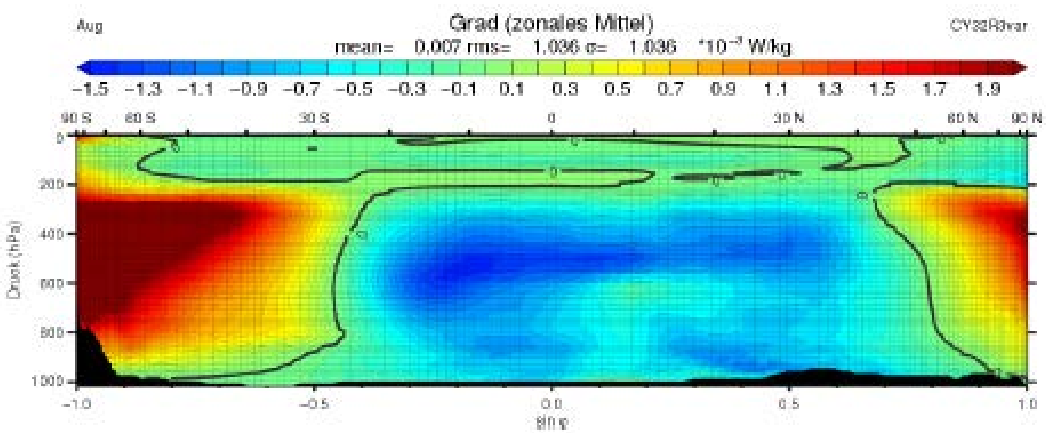
$$\overline{\alpha'\omega'} = \frac{R}{P}[1+(\varepsilon^{-1}-1)]\overline{T'\omega'} + (\varepsilon^{-1}-1)\bar{\alpha}\overline{q'\omega'}$$

Generation rates

Total Generation rate (W/kg)



Generation rate - radiation



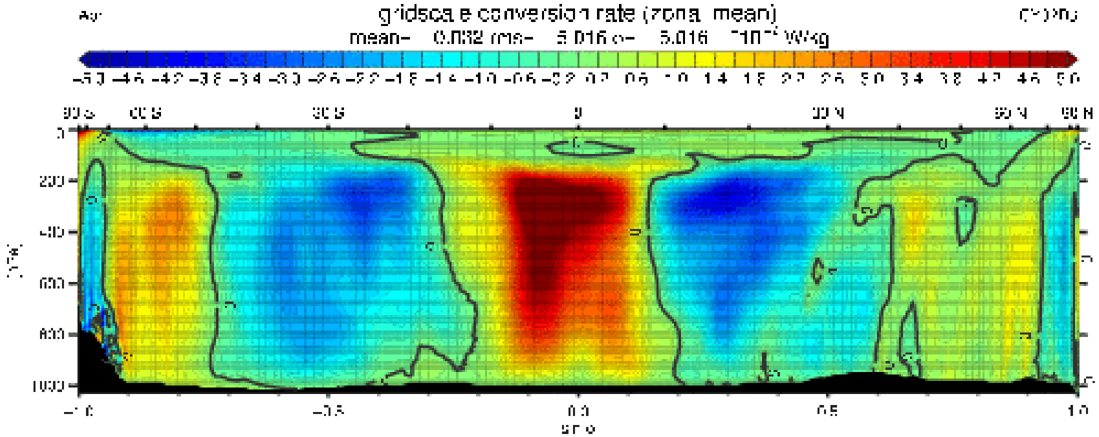
- Generation rates maximum in upper tropical troposphere
- Radiation does not contribute to the conversion rates but to the generation rate, but even there has only at poles a positive contribution (cooling at cold places) but globally a negative contribution (as in Tropics it is cooling where it is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

Steinheimer et al. 2008, Tellus

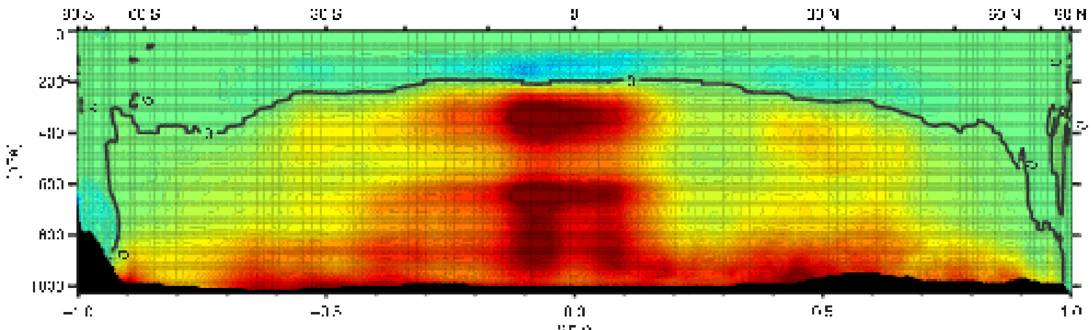
ECMWF

Conversion rates and convection

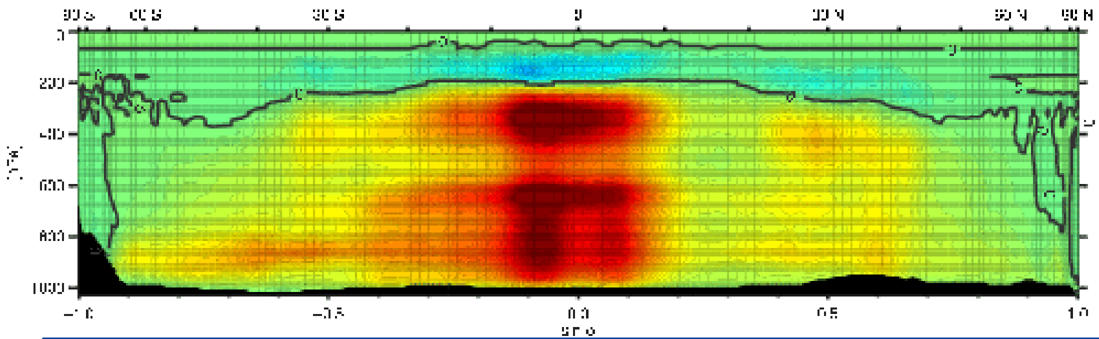
Grid-scale conversion rate (W/kg)



Subgrid conversion rate



Subgrid conversion rate - convection



- Grid-scale has positive and negative contributions to kinetic energy conversion rate, maximum in upper-tropical troposphere
- Convection so important because contribution always positive !

ECMWF

Shallow water system and linear waves

$$V = 0 \Rightarrow U = U_0 e^{-y^2/2} e^{ik(x-ct)} \quad G(z,m)$$

Kelvin wave, geostrophic

$$c = \frac{\omega}{k} = \sqrt{gh}$$

$$V \neq 0 \Rightarrow V(y) = \begin{bmatrix} 1 \\ 2y \\ 4y^2 - 1 \\ \vdots \\ H_n(y) \end{bmatrix} e^{-y^2/2} \quad G(z,m)$$

General, Hermite Polynomials

Modes alternate asymm./symmetric

$$\frac{\omega^2}{c^2} - \frac{k}{\omega} - k^2 = \frac{(2n+1)}{c}, \quad c = \sqrt{gh}; \quad n = 0,1,2,.....$$

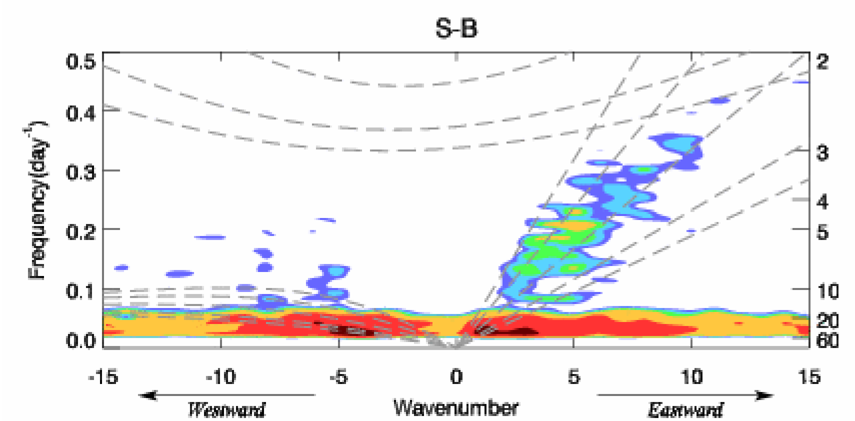
Dispersion relation

$$G(z,m) = e^{-z/(2H_s)} \, \mathrm{Re}(e^{-imz})$$

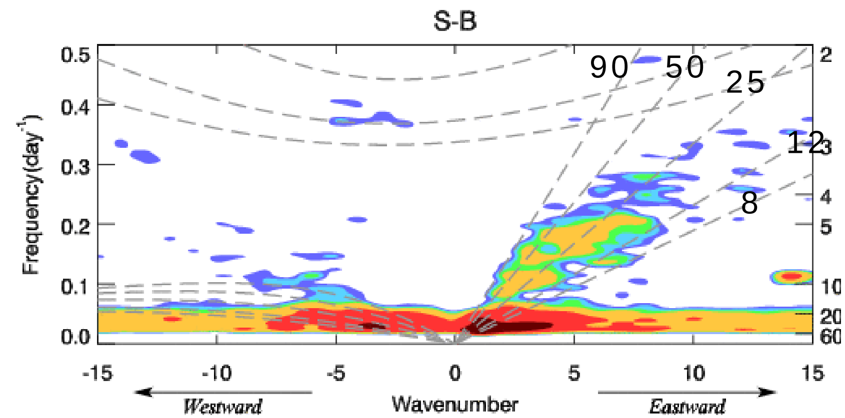
see T. Matsuno. Quasi-geostrophic motions in the equatorial area. Journal of the Meteorological Society of Japan, 44:25-42, 1966.

Wave number Frequency Spectra OLR

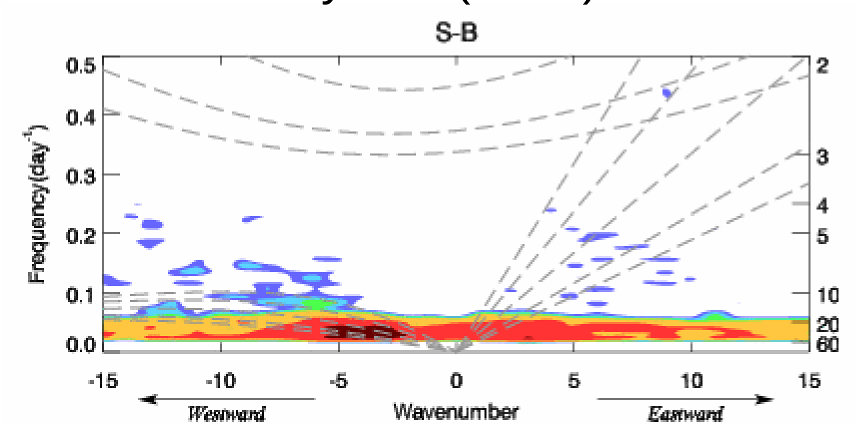
Cy38r1 (2012)



NOAA

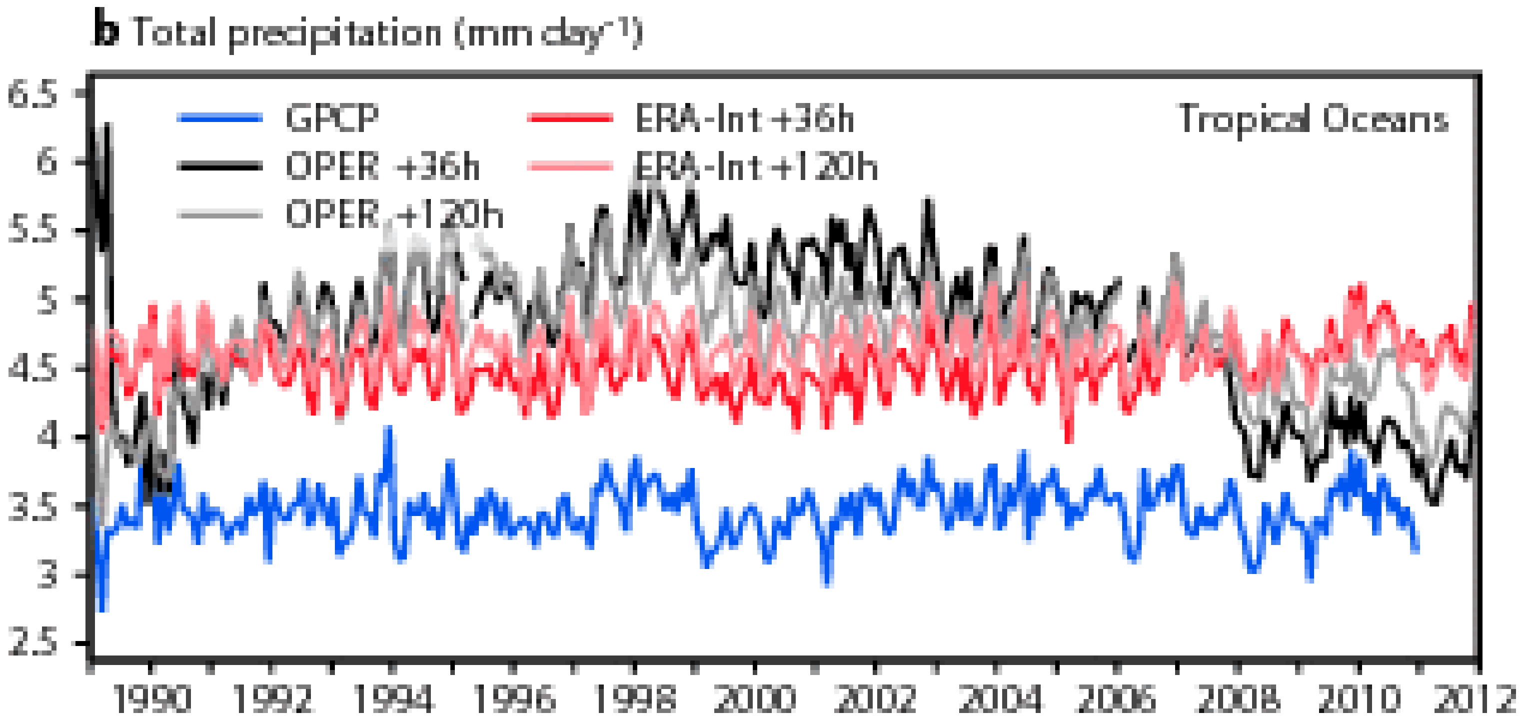


Cy31r1 (ERAI)

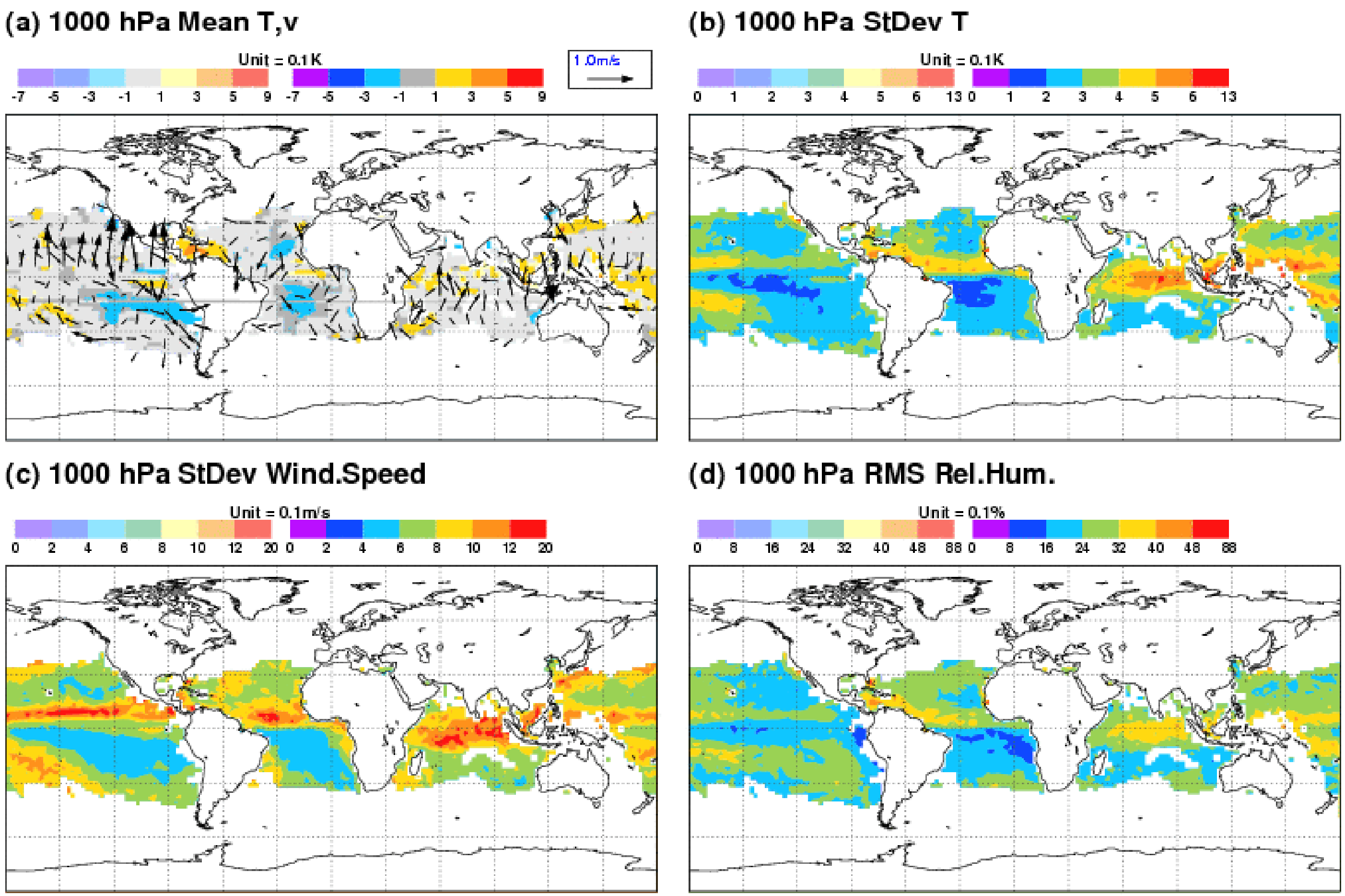


ECMWF

Time-series: Precipitation

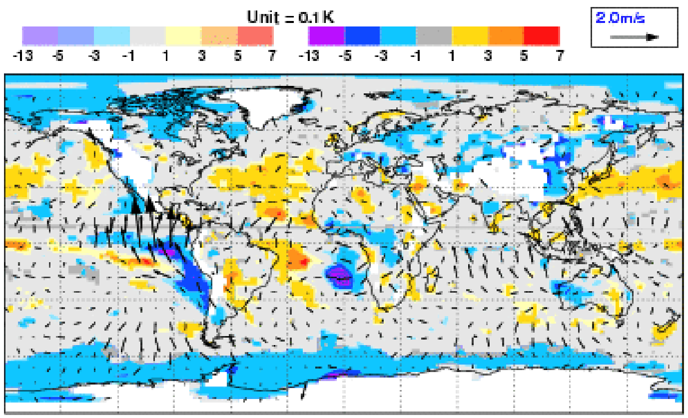


Analysis increments SON 2011

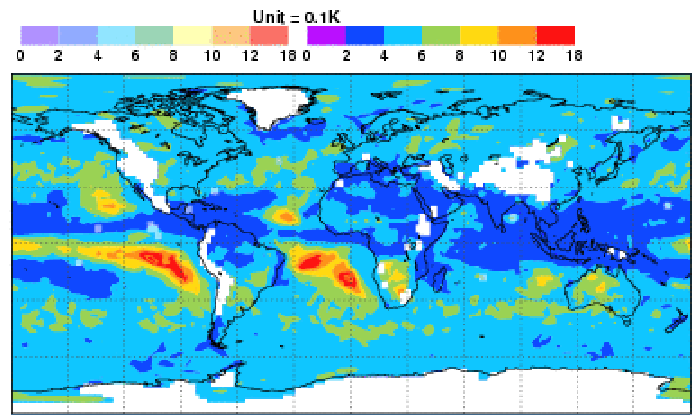


Analysis increments SON 2011

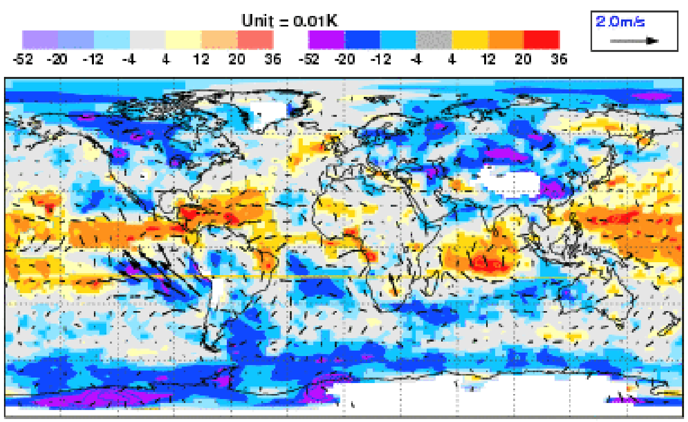
(e) 850 hPa Mean T,v



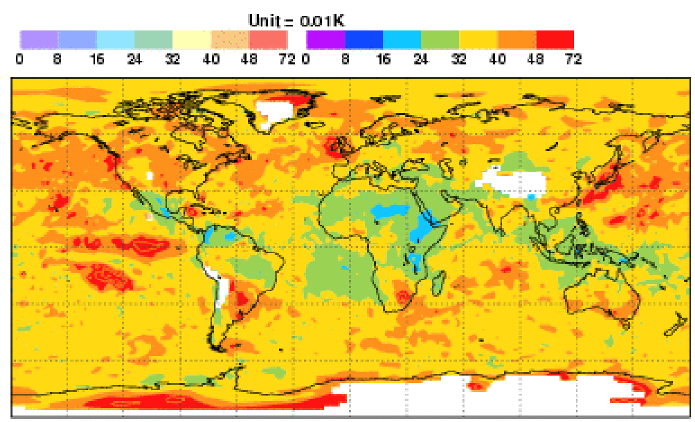
(f) 850 hPa StDev T



(a) 700 hpa Mean T,v

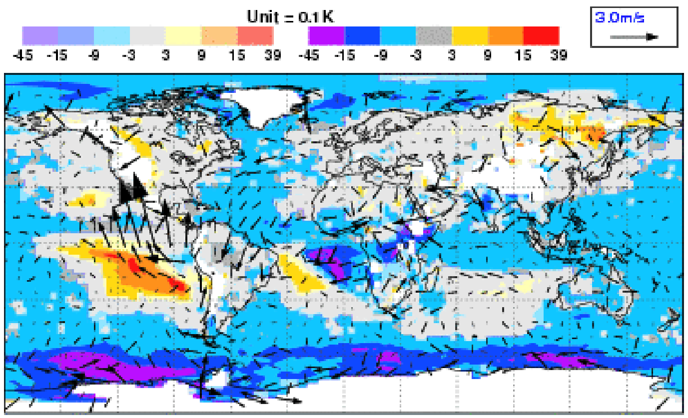


(b) 700 hPa StDev T

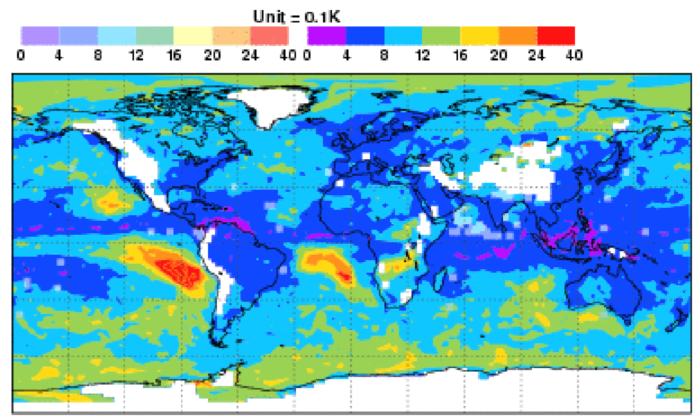


Analysis difference ECMWF-UKMO for OND 2011

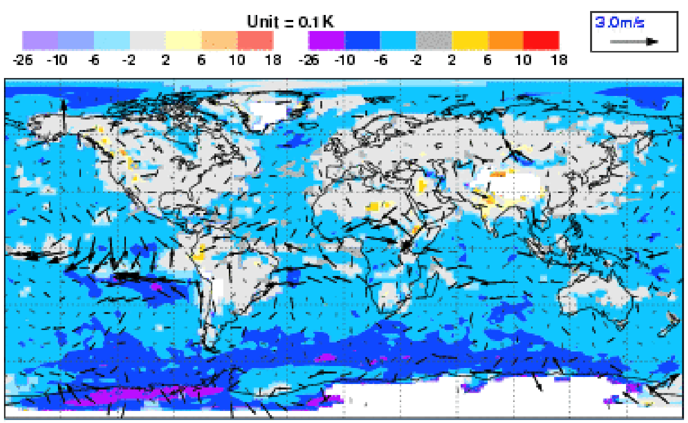
(a) 850 hPa Mean T,v



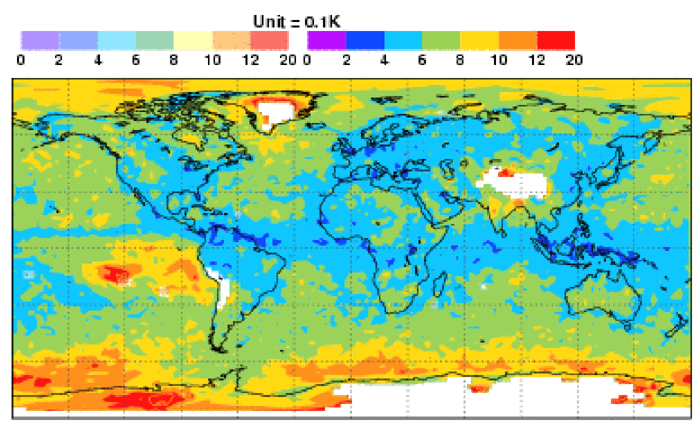
(b) 850 hPa StDev T



(a) 700 hPa Mean T,v

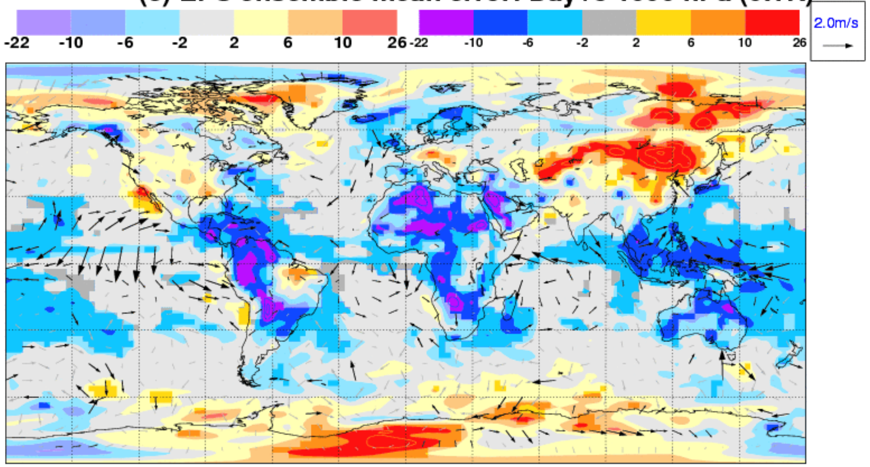


(b) 700 hPa StDev T

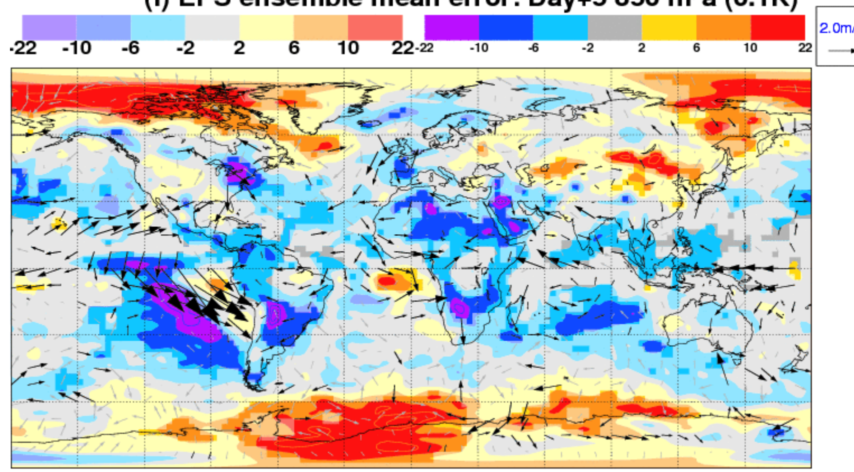


Day+5 Forecast errors: EPS ensemble mean vs. high-resolution

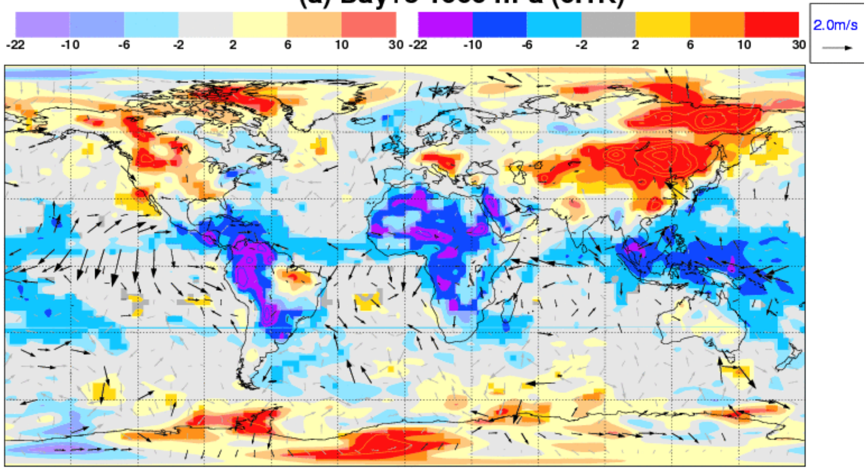
(e) EPS ensemble mean error: Day+5 1000 hPa (0.1K)



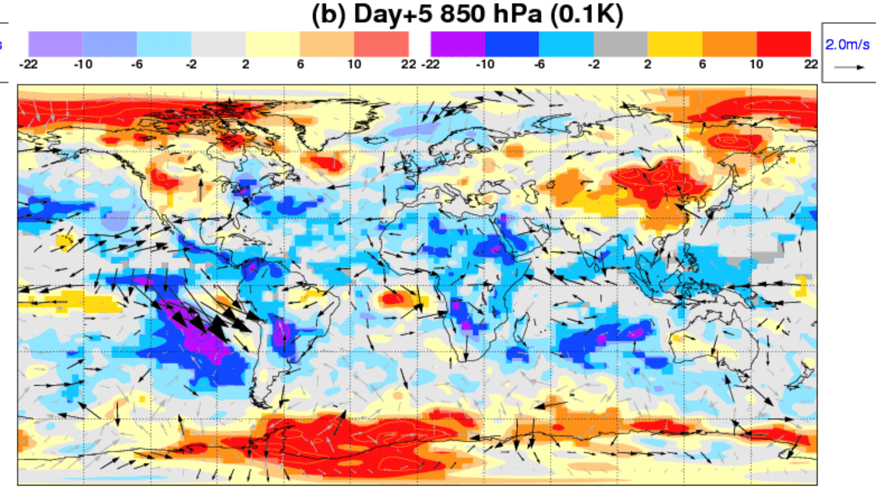
(f) EPS ensemble mean error: Day+5 850 hPa (0.1K)



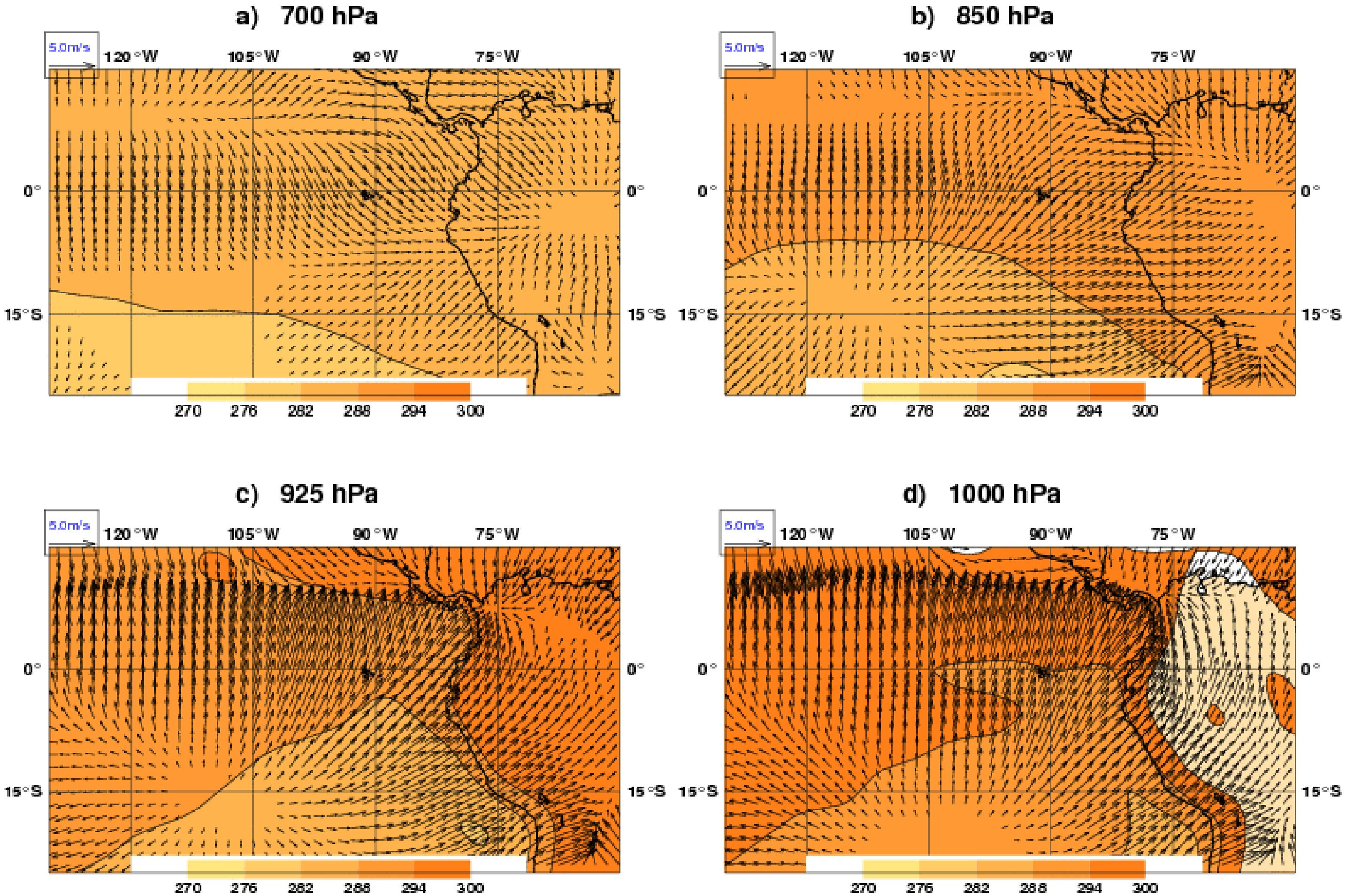
(a) Day+5 1000 hPa (0.1K)



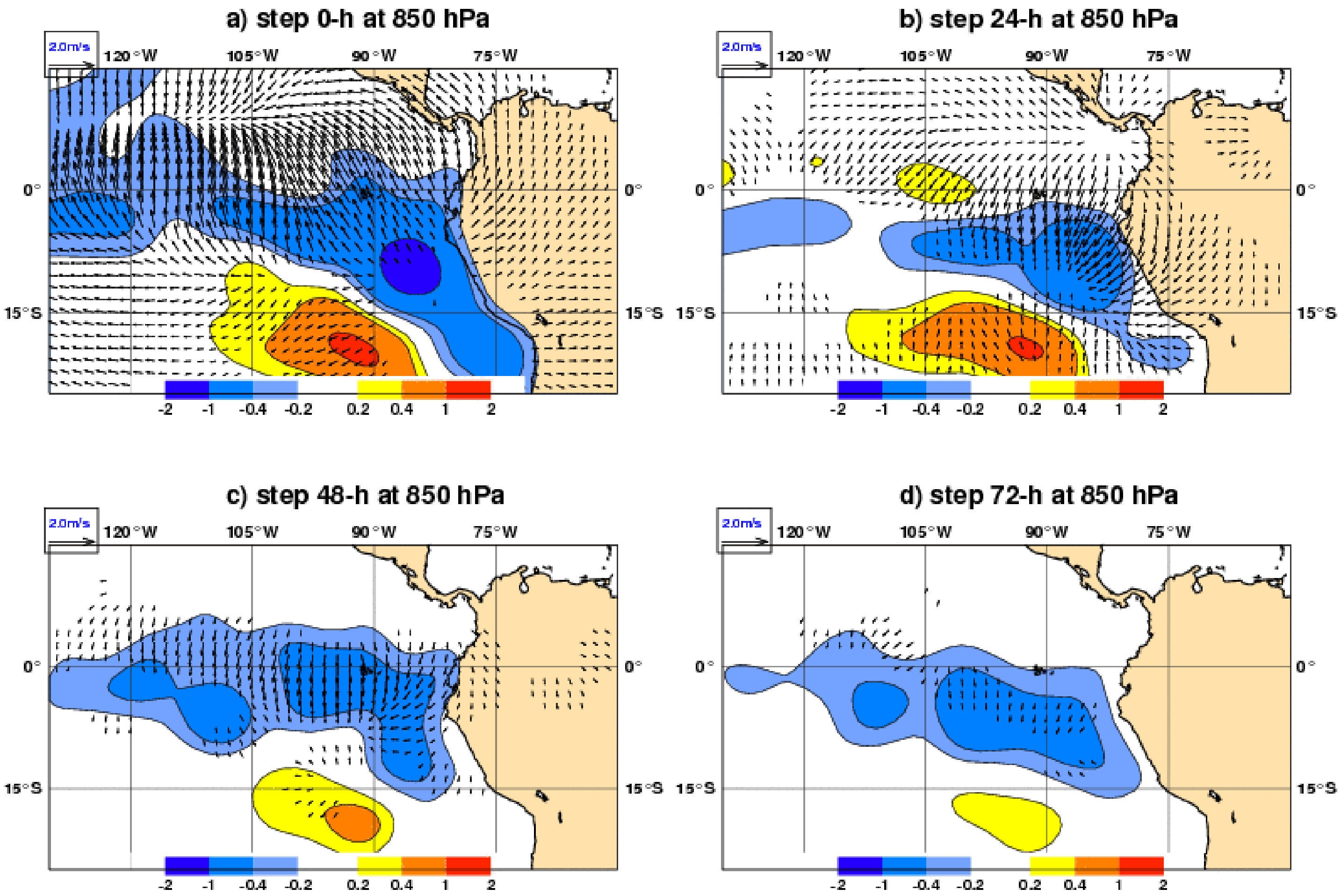
(b) Day+5 850 hPa (0.1K)



East Pacific: Mean wind & T in ON 2011

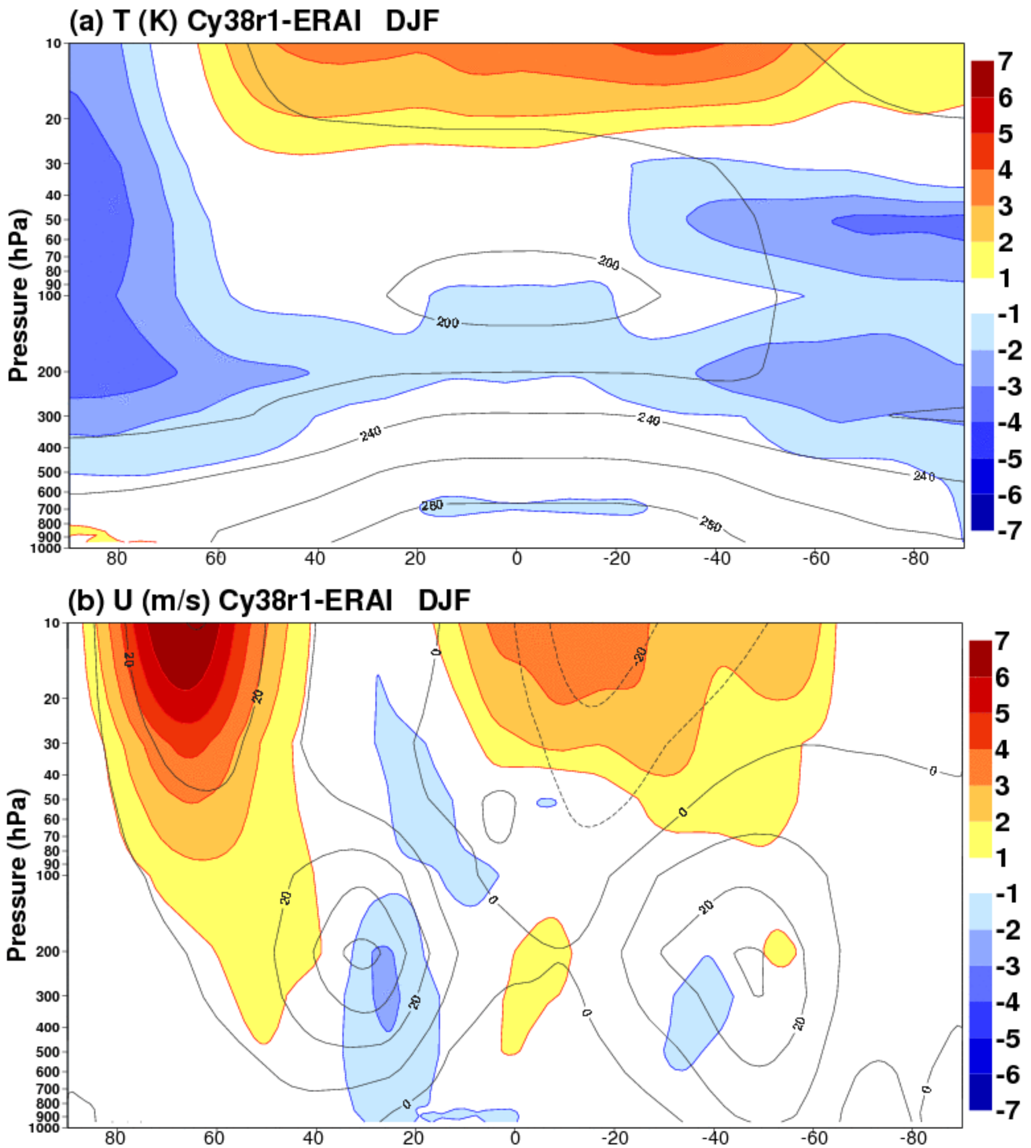


Analysis difference: control – GOES13 AMV denial



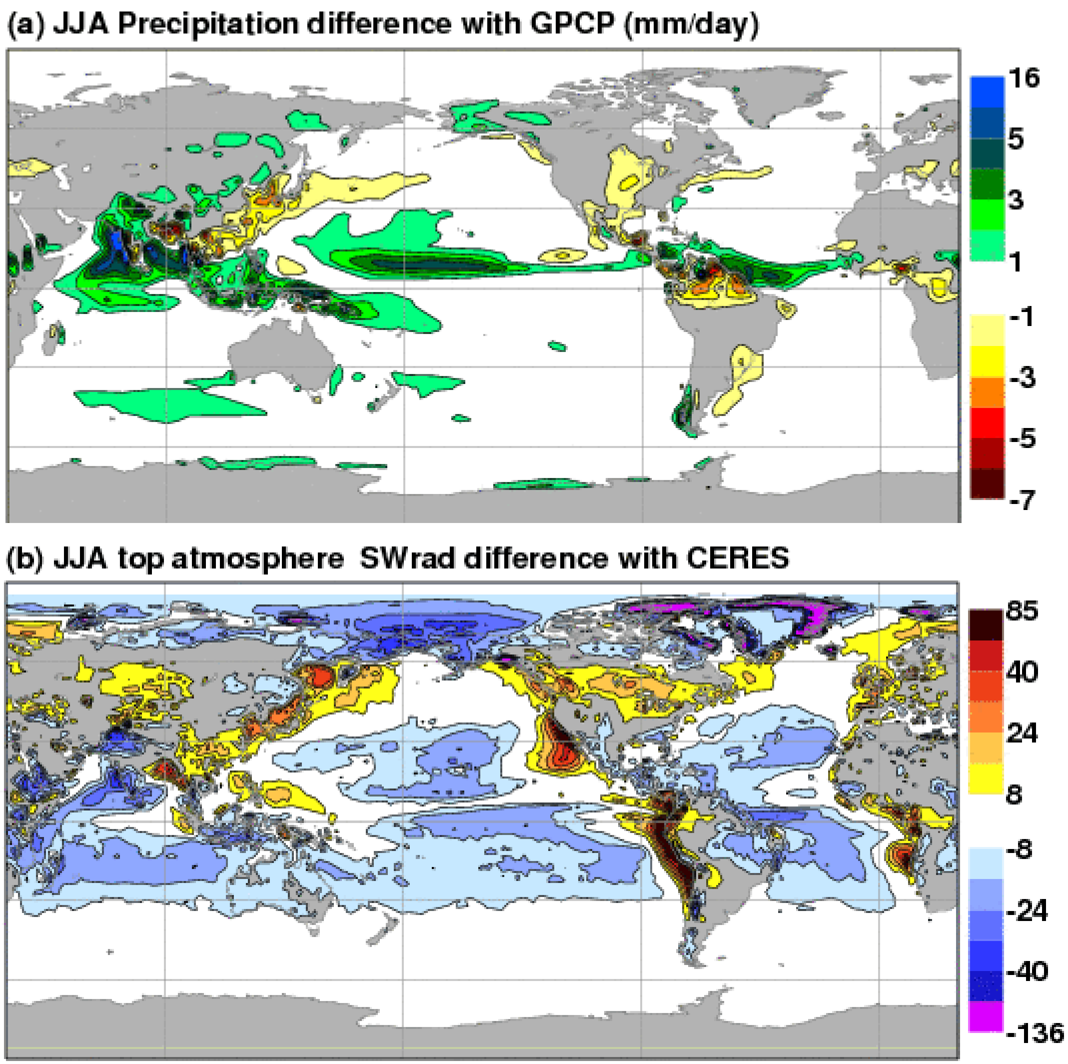
ECMWF

Zonal mean T and U erorrs in DJF *uncoupled*

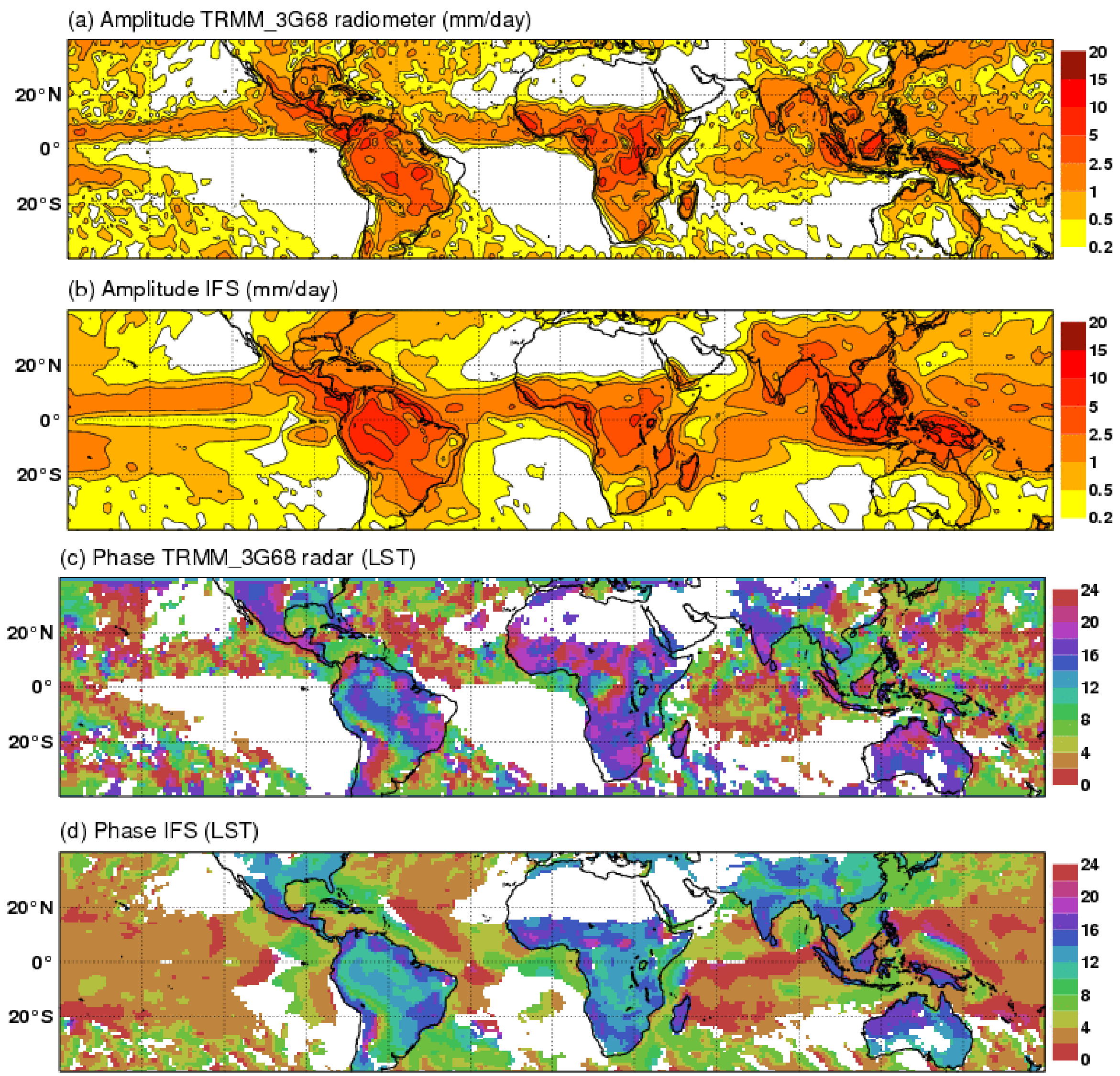


ECMWF

JJA Precip and SWnet errors *uncoupled*

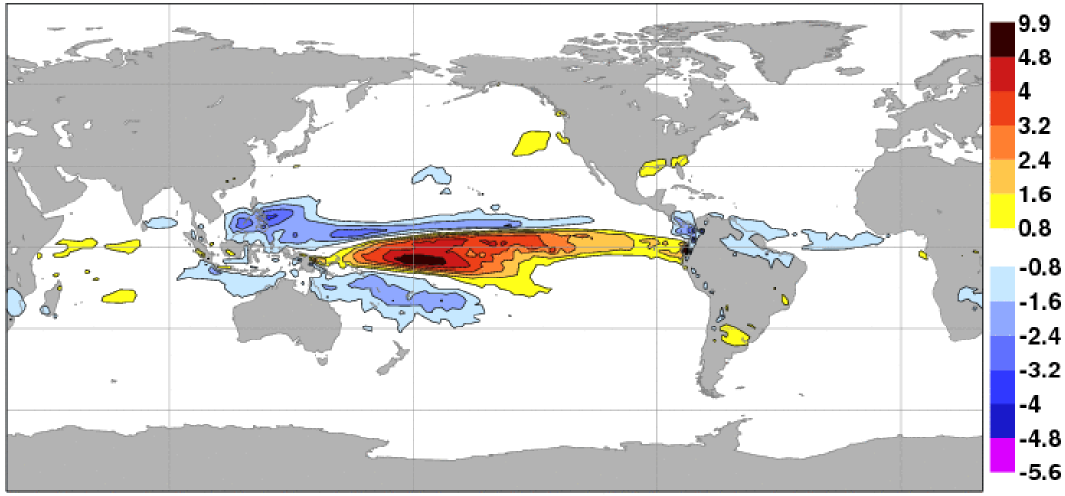


Diurnal cycle of Precipitation vs. TRMM

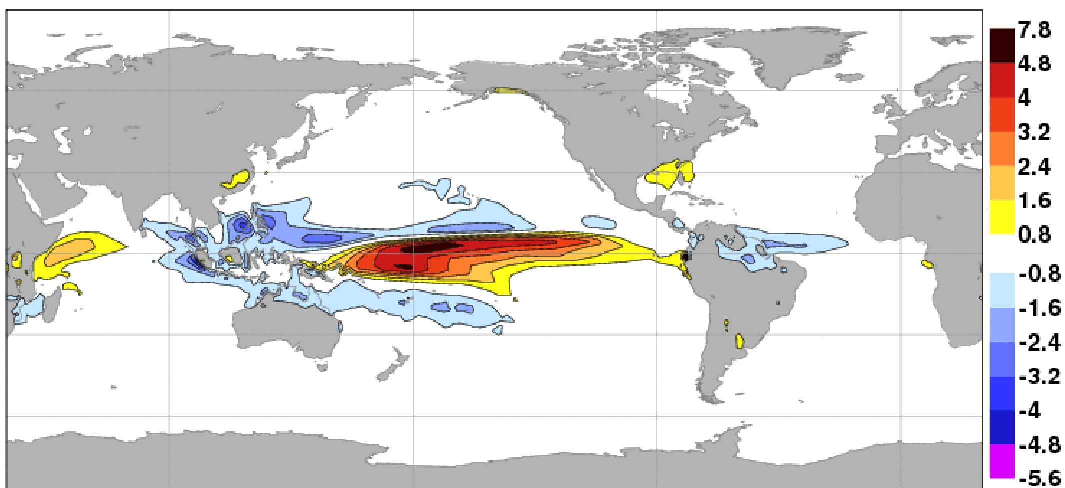


Covariance Nino3.4 STT & Prec. for DJF

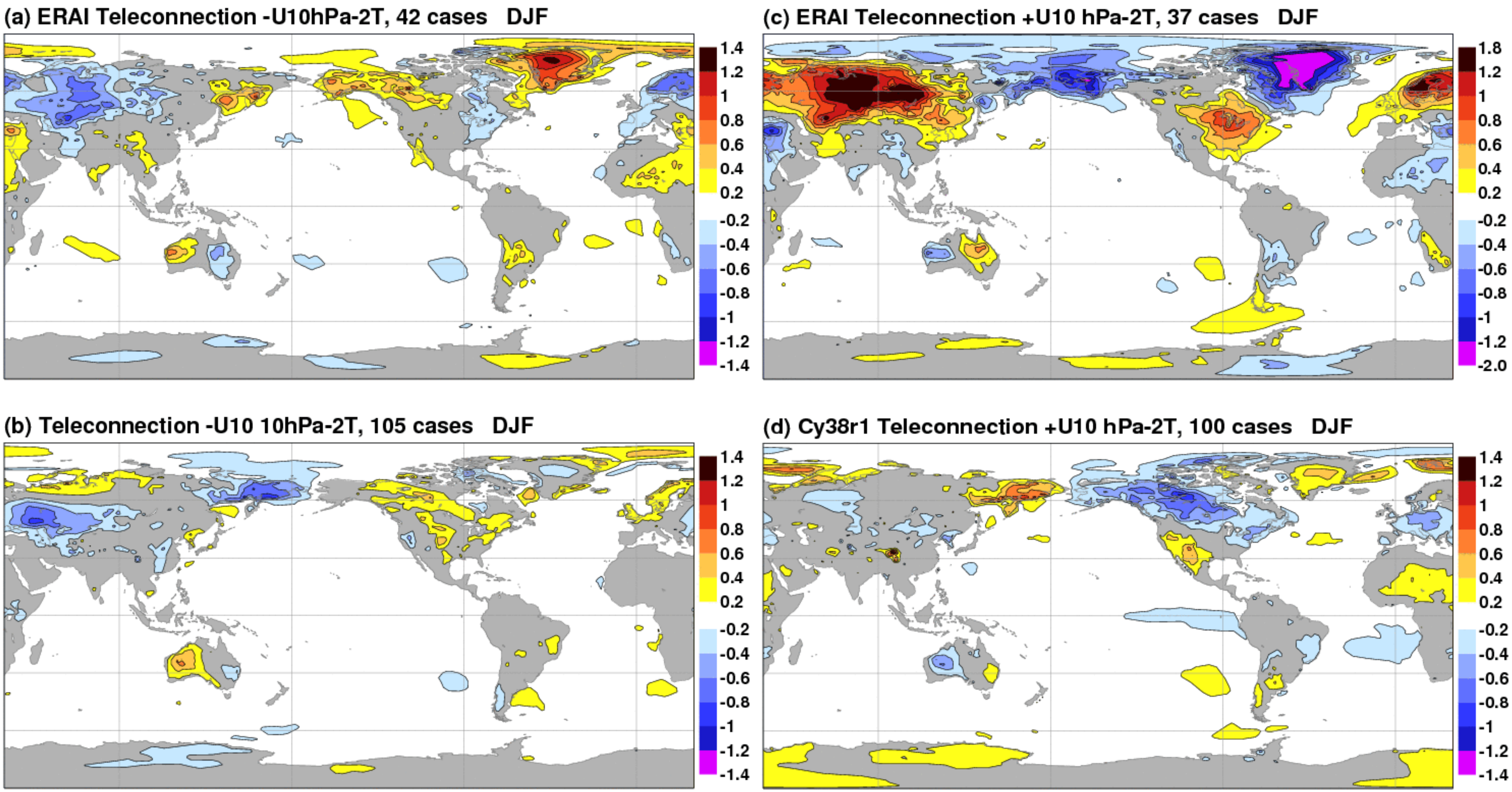
(a) ERAI Covariance Nino3.4SST-Precip DJF



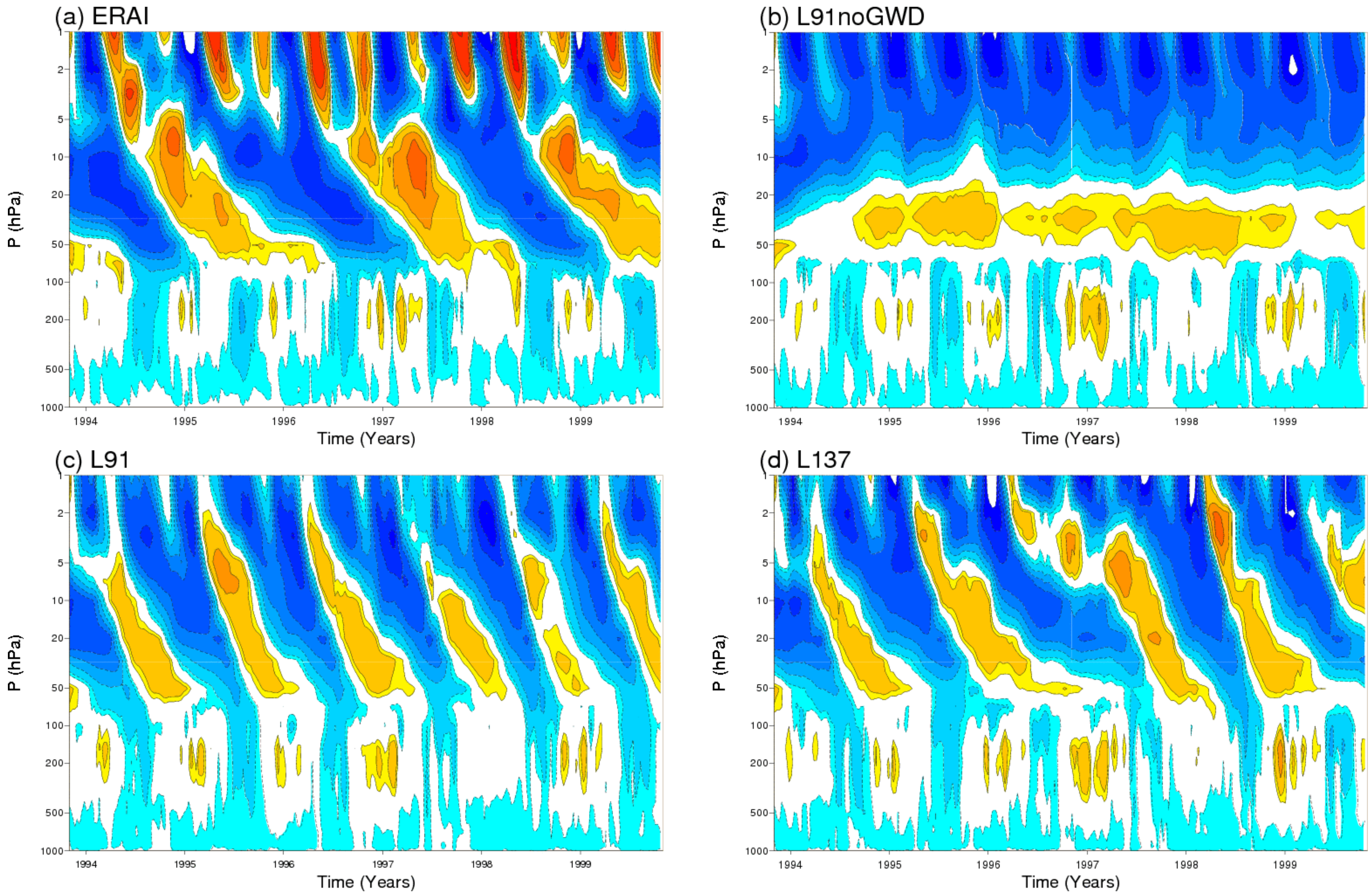
(b) Cy38r1 Covariance Nino3.4SST-Precip DJF



Teleconn. U10hPa Tropics& 2T for DJF

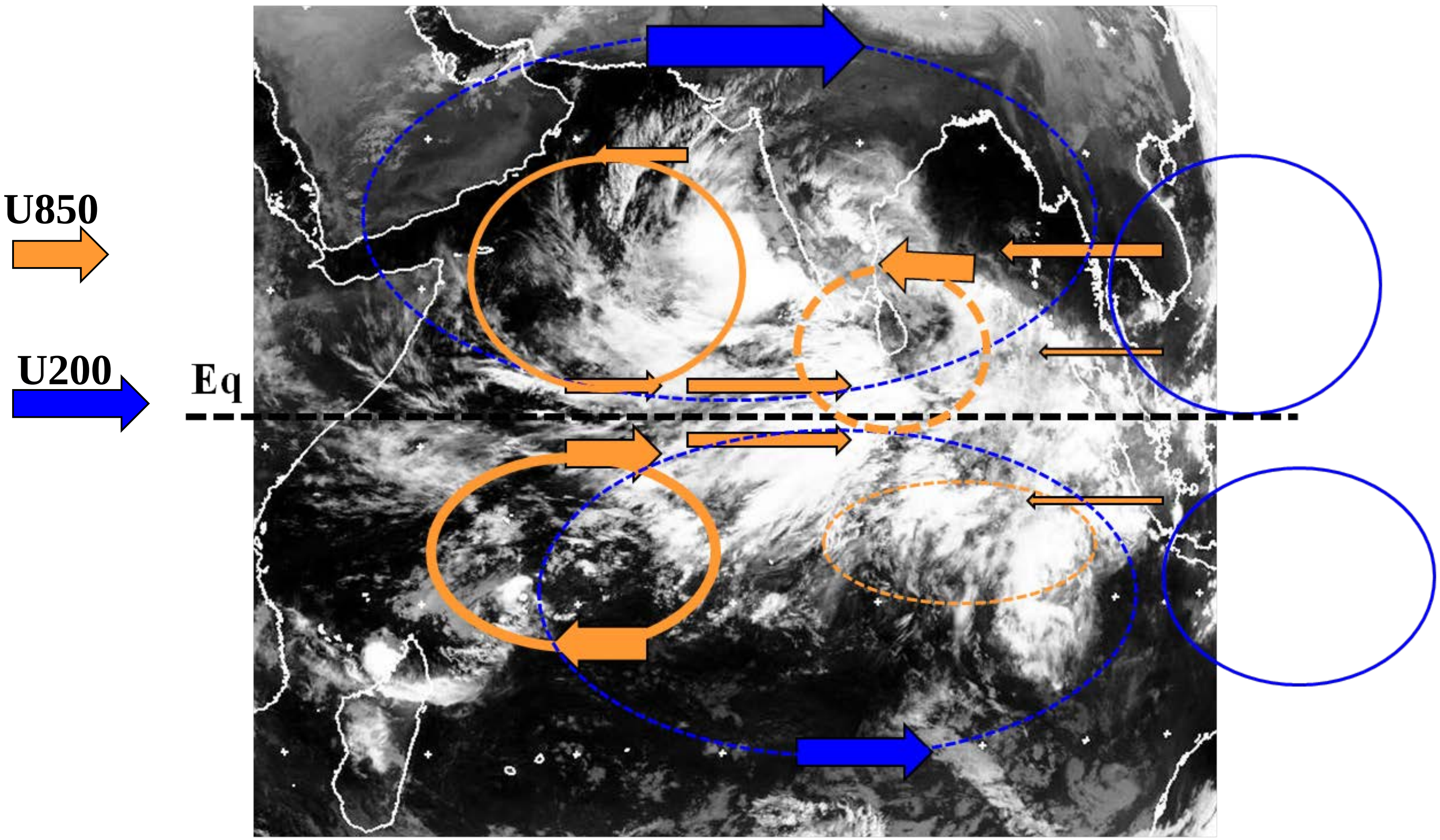


The QBO



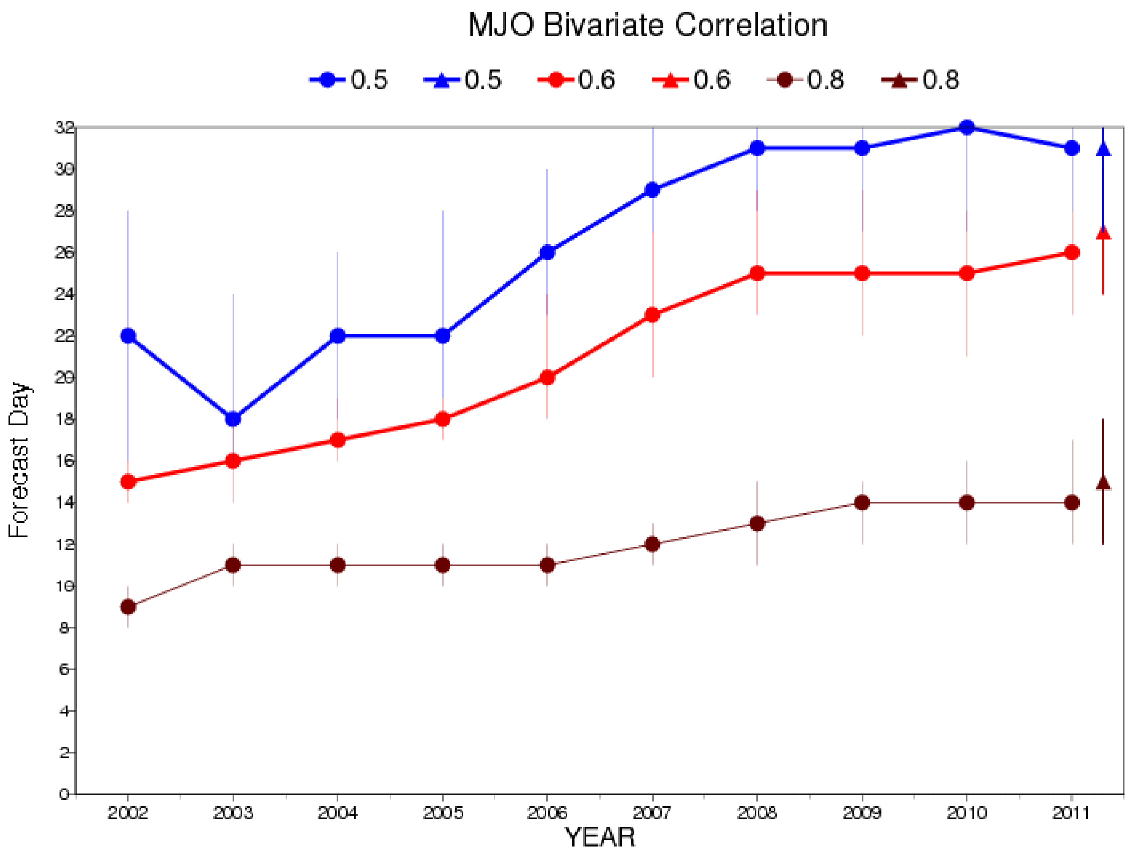
(a) ERAI
(b) L91noGWD
(c) L91
(d) L137
P (hPa)
1
2
5
10
20
50
100
200
500
1000
1994
1995
1996
1997
1998
1999
Time (Years)

The MJO



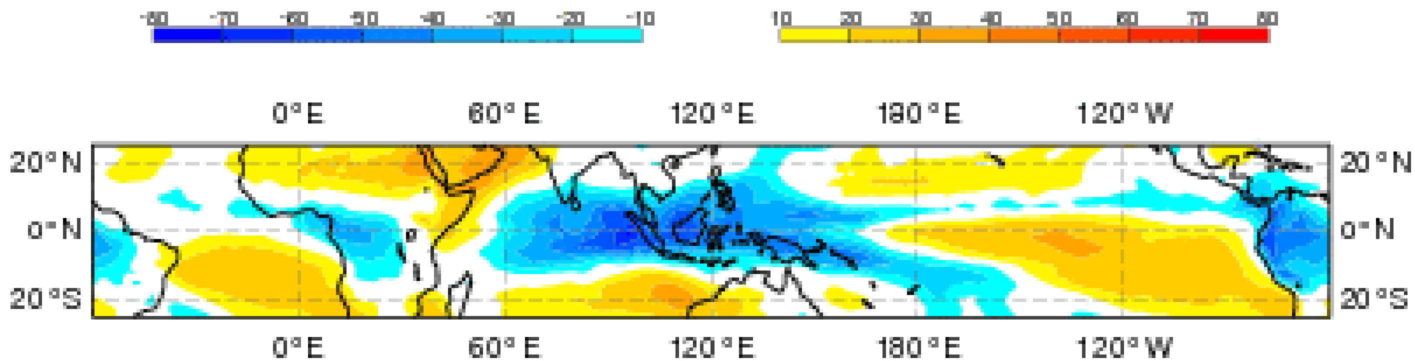
24 November 2011: Meteosat 7 + IFS Analysis

Progress in MJO prediction

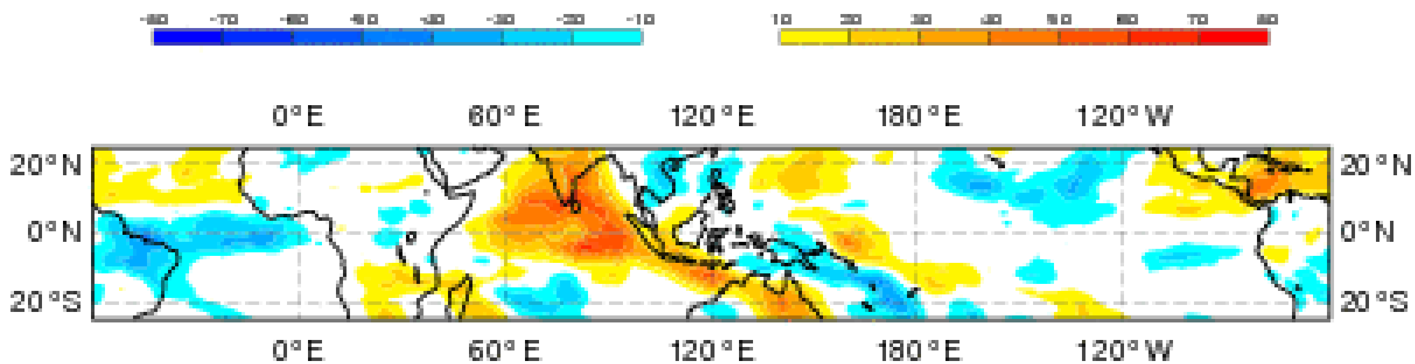


YOTC: OLR anomalies

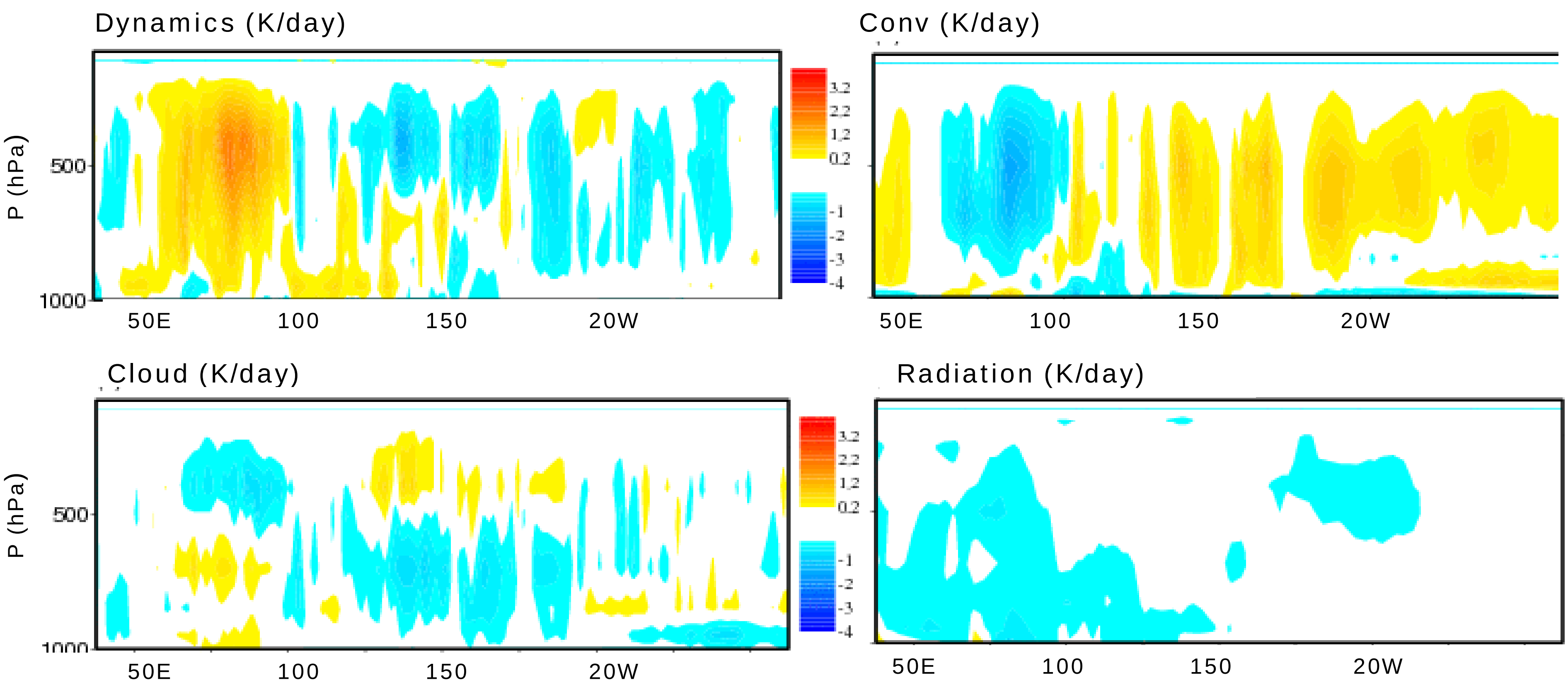
(a) MJO Phase 2/3 36 h OLR anomaly



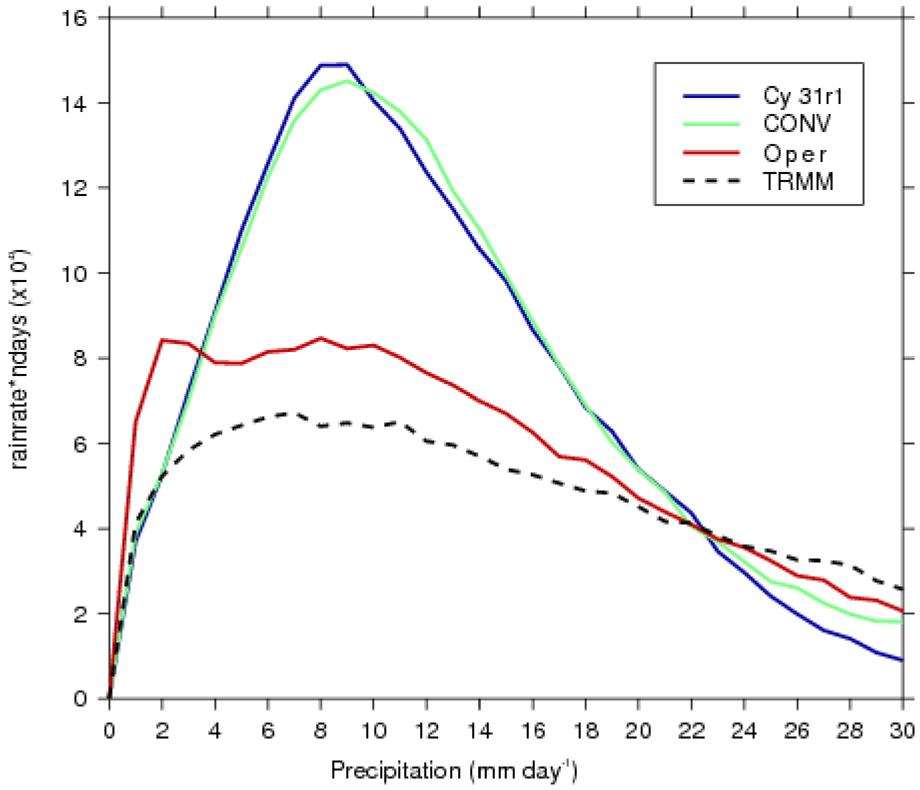
(b) MJO Phase 6/7-2/3 36 h OLR



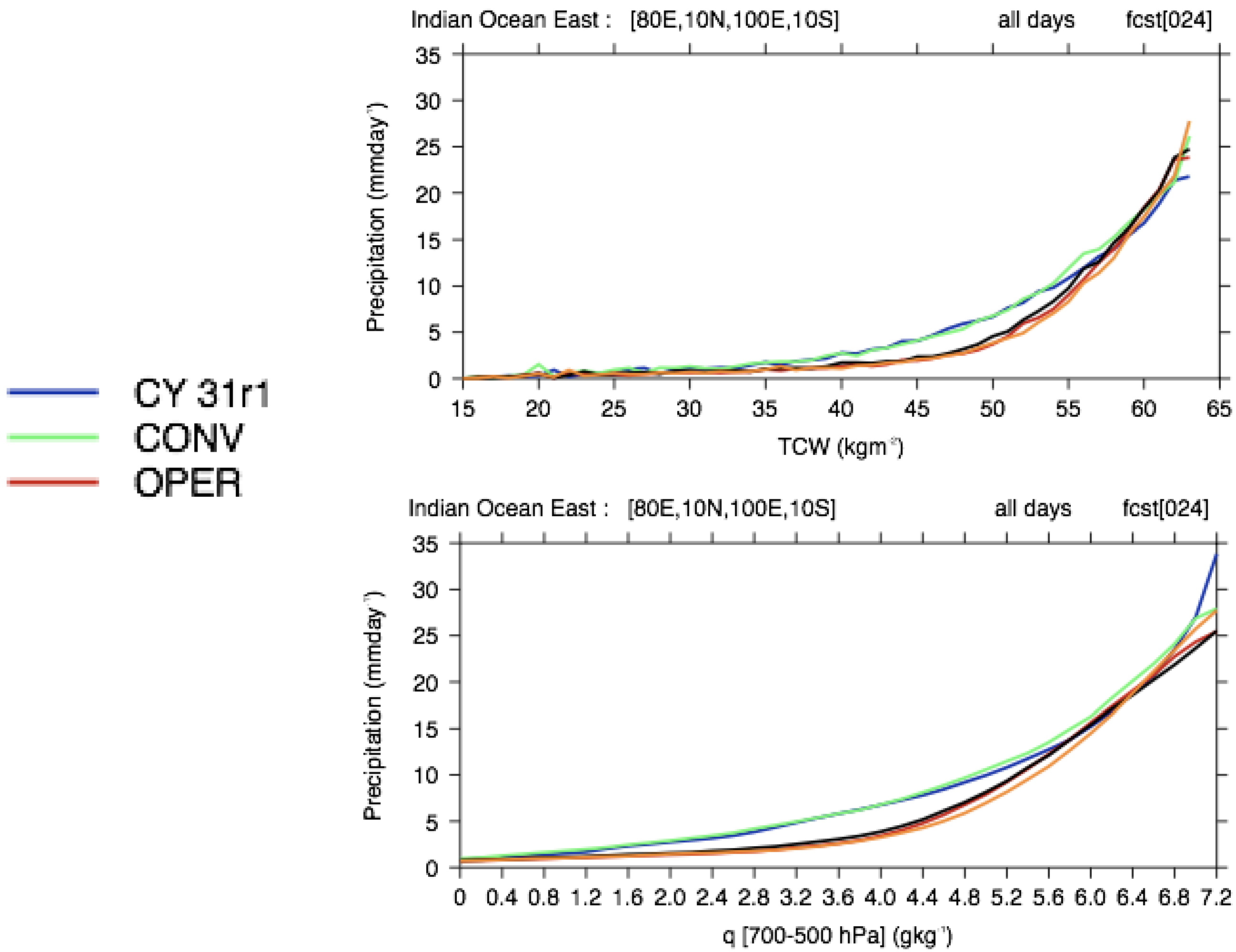
YOTC: Difference in T-tendency: Phase 6/7-Phase 2/3



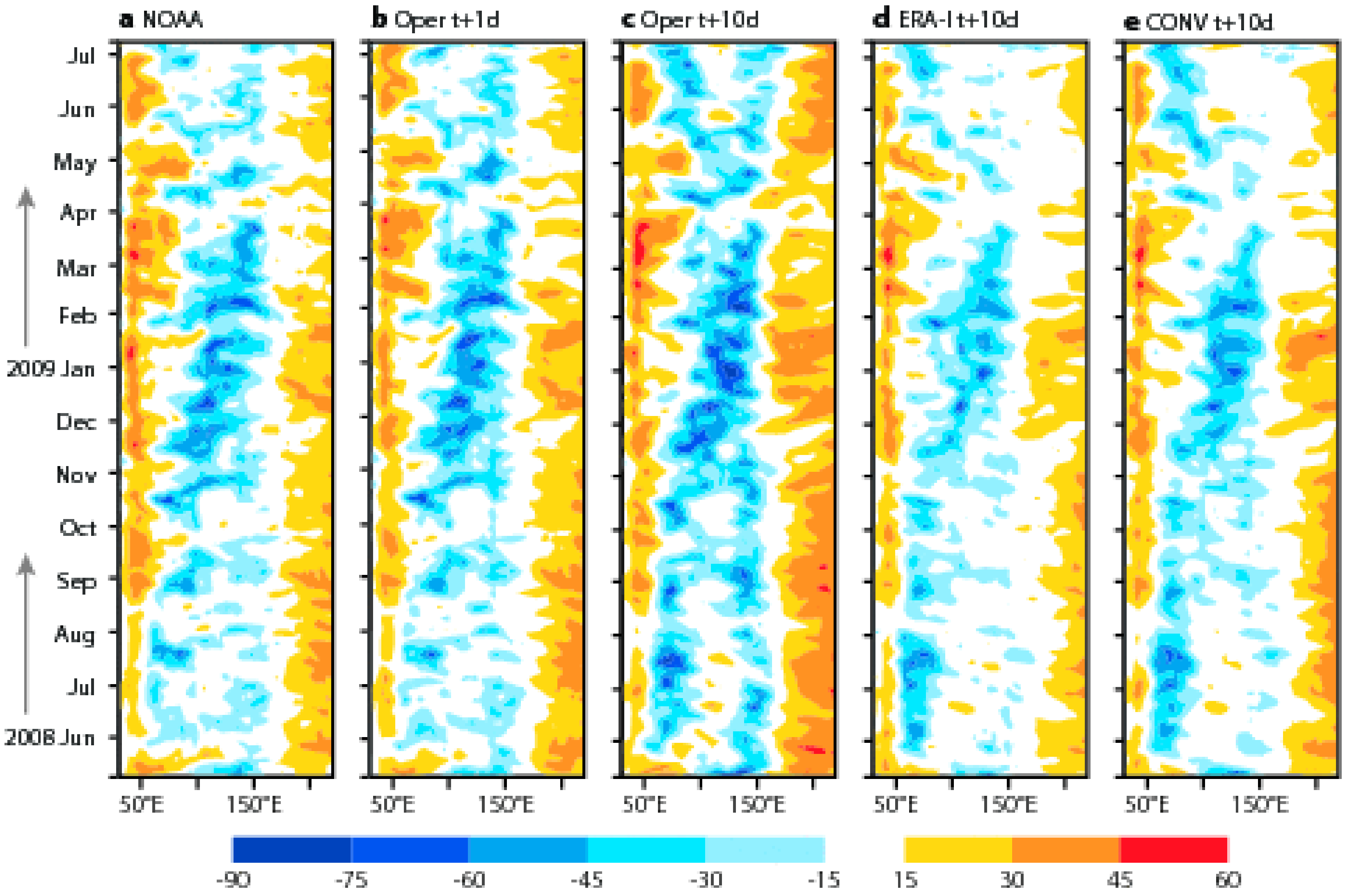
YOTC: Pdf of 24h Precipitation vs TRMM



Indian Ocean: Precip vs TCW & RH

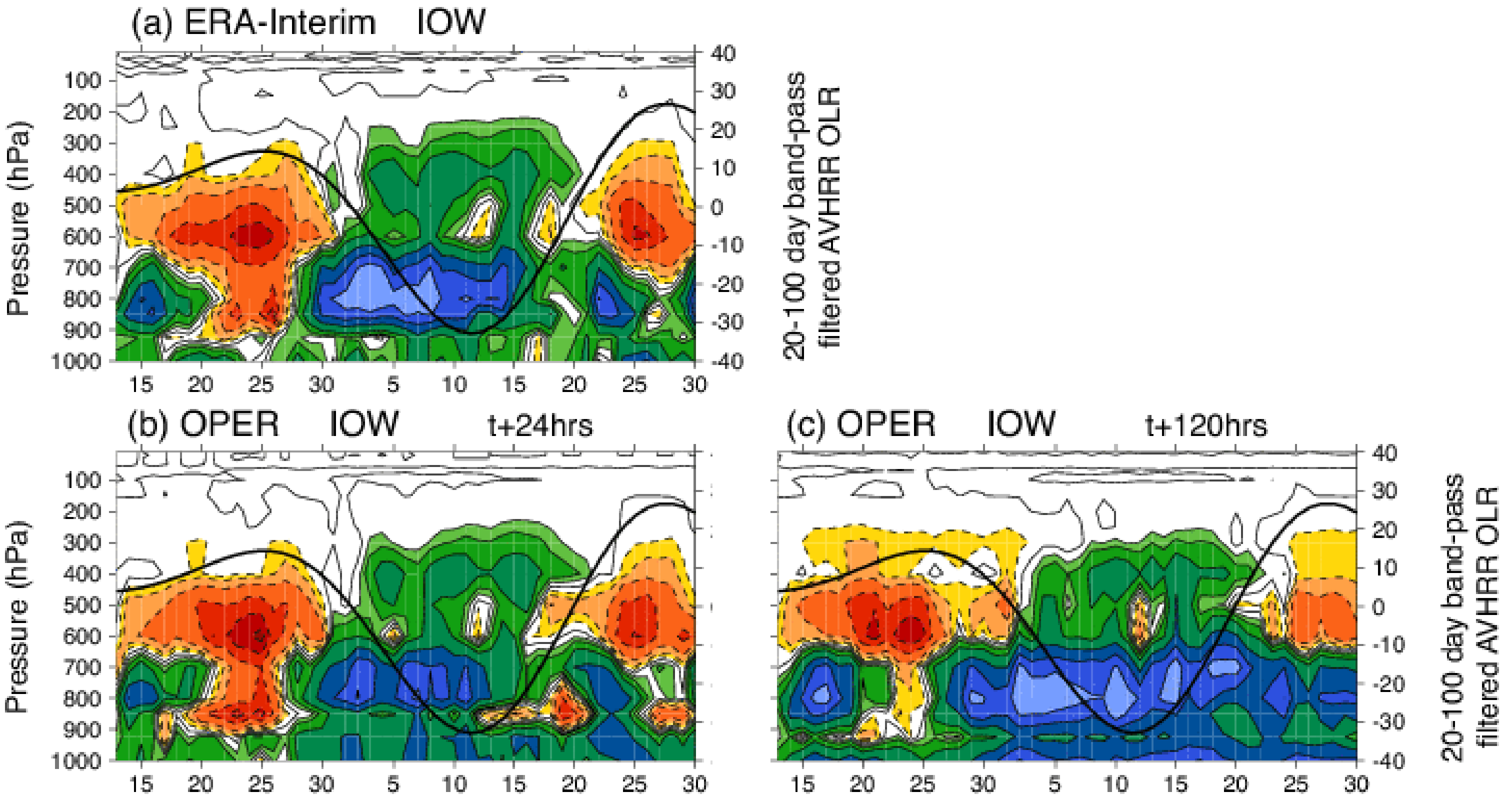


YOTC: Hovmoeller of the OLR anomaly



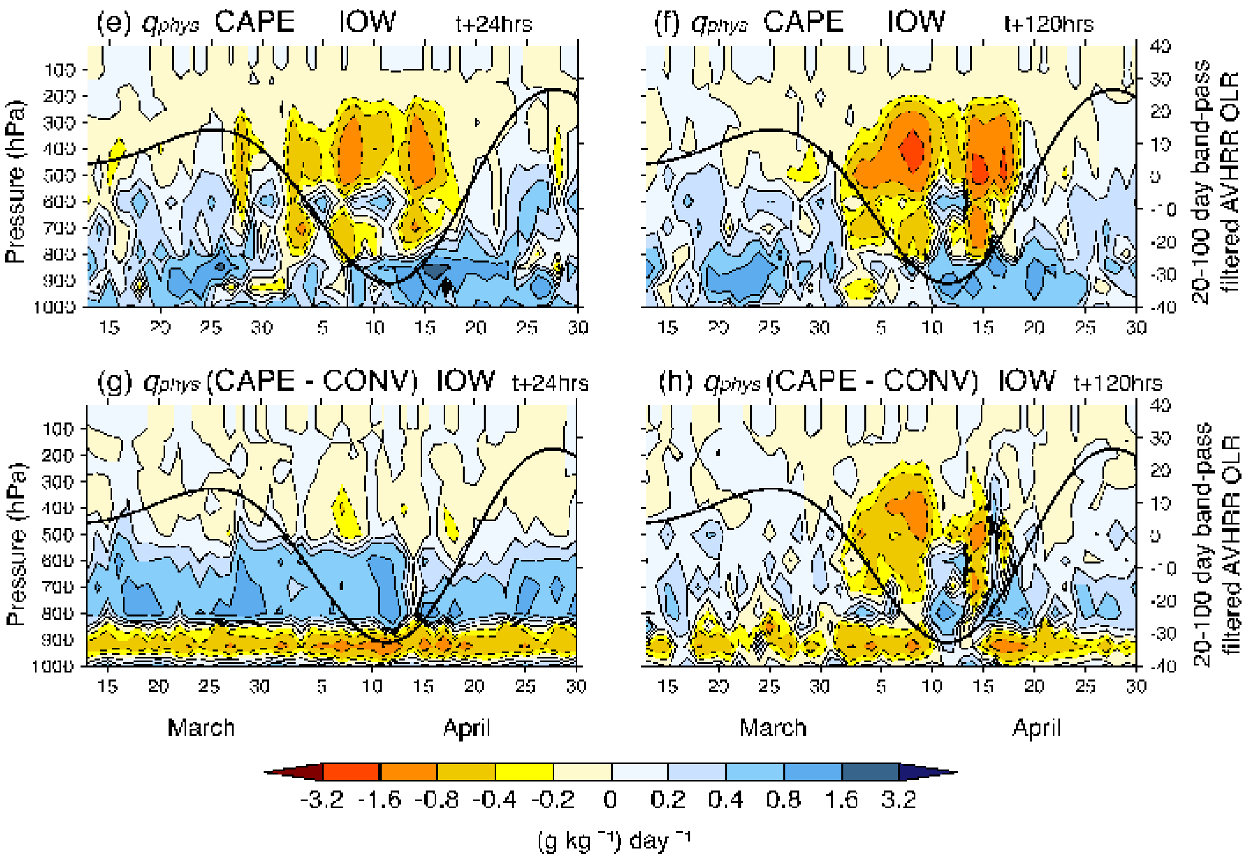
ECMWF

YOTC: MJO event of Indian Ocean time series OLR and q-anomalies



ECMWF

YOTC: Evolution of Indian Ocean OLR anomaly & dq/dt physics

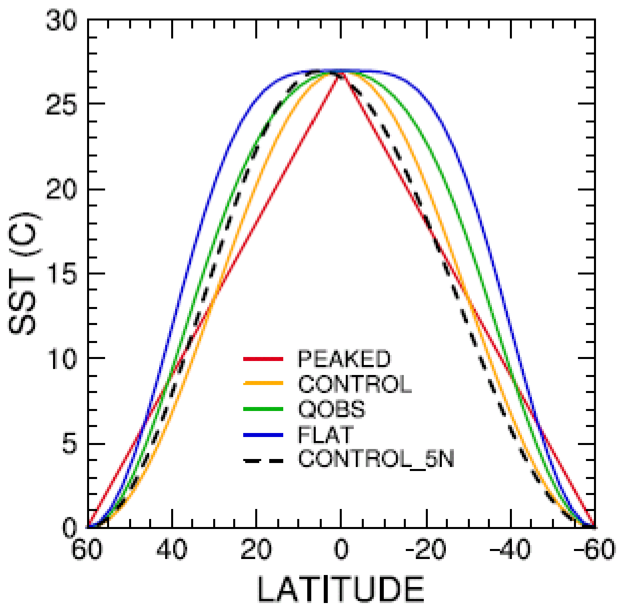


ECMWF

Towards high resolution of global convection: on the AQUA Planet

- prescribed SST distribution
- Perpetual: Sun fixed over the Equator
- prescribed trace gaz concentrations

- **Run 4-member ensemble at T159 for 1-year**
- **start from a balanced state=6-month integration**



see: “The Aqua-Planet Experiment (APE): Control SST simulation” and “Response to changed meridional SST profile” , **Blackburn et al.** 2012, *J. Met. Soc. Japan*

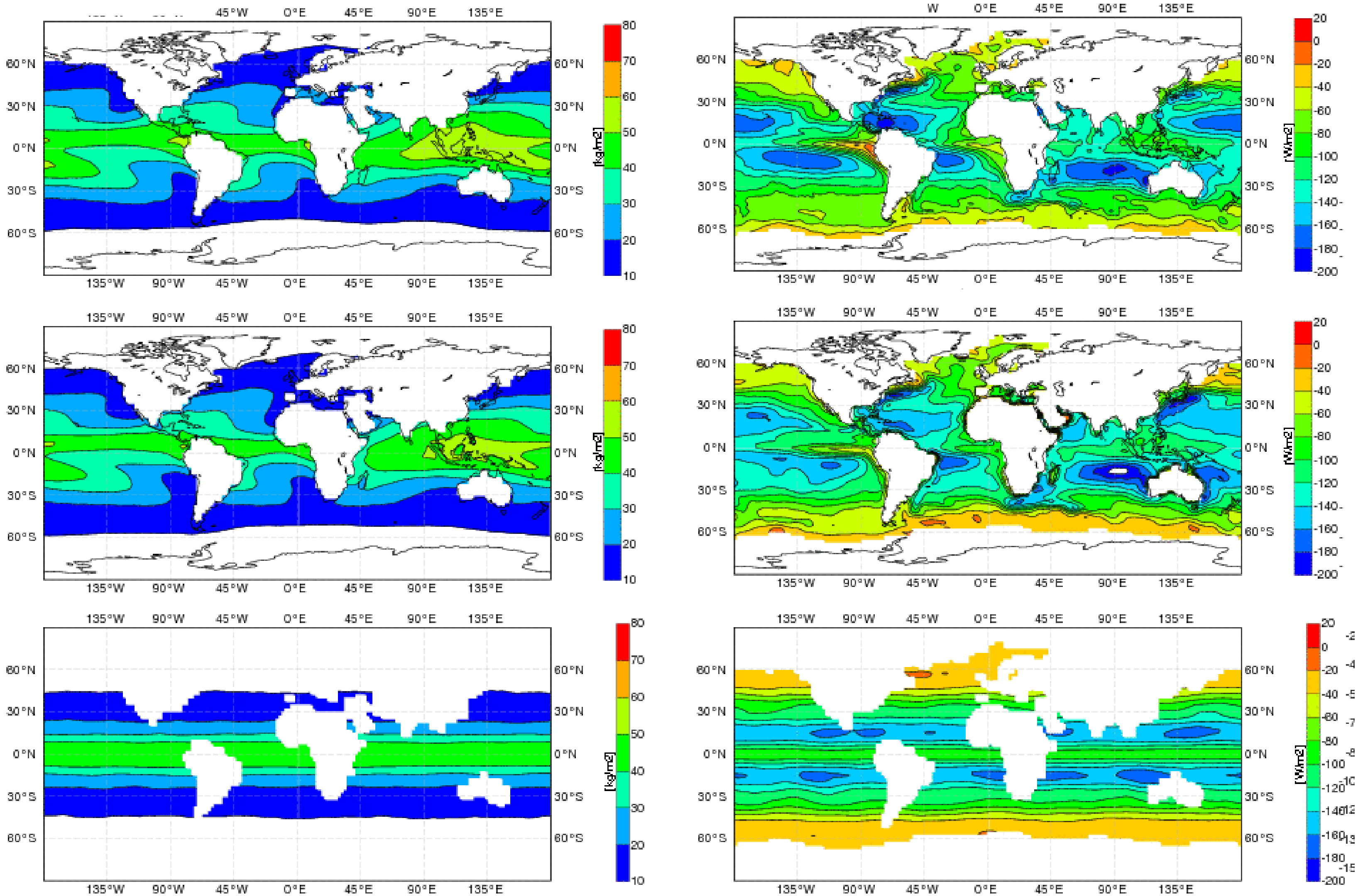
Obs - real Earth – AQUA planet

TCW | Lat. Heat

SSMI | HOAPS

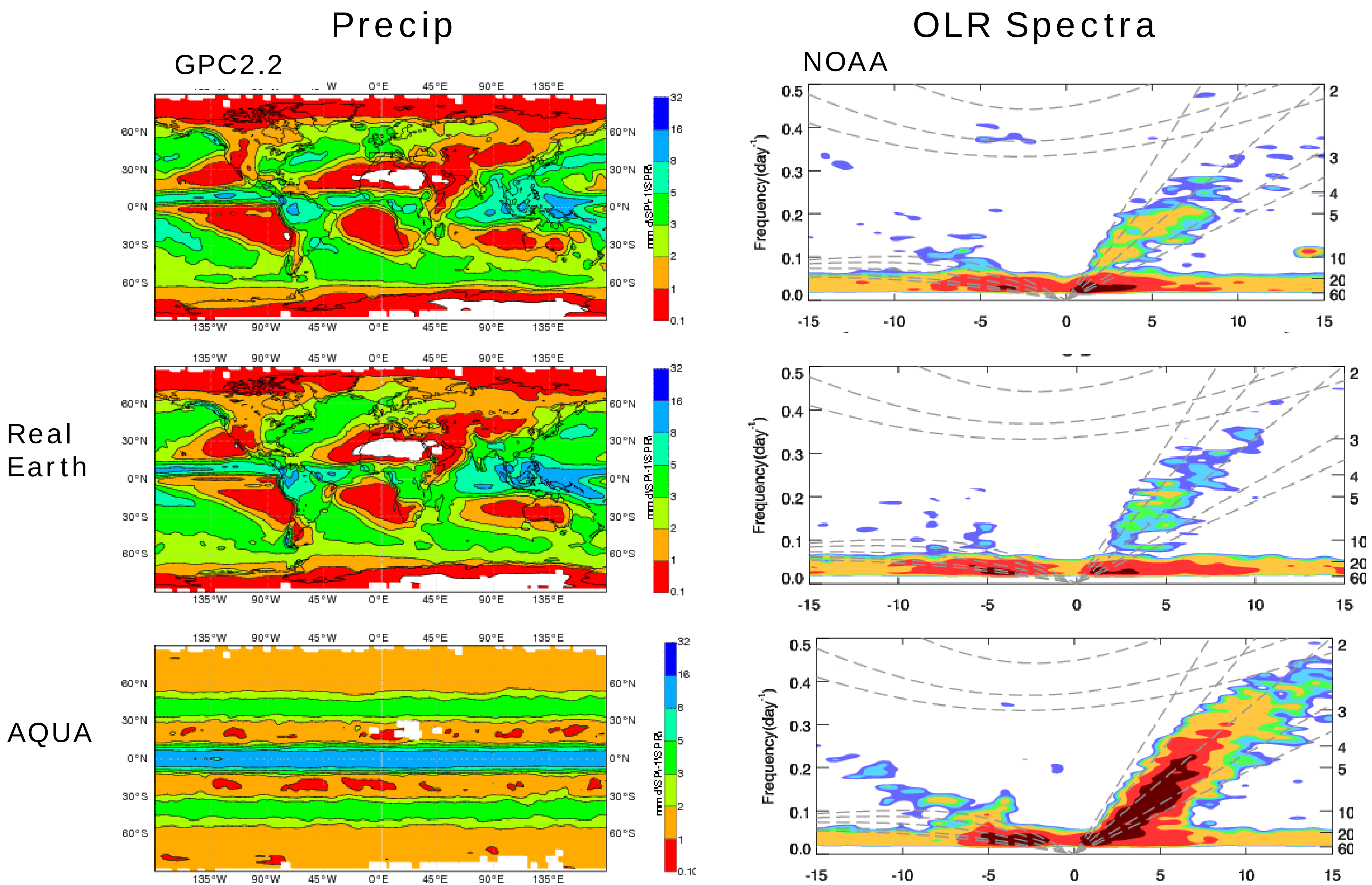
Real Earth

AQUA

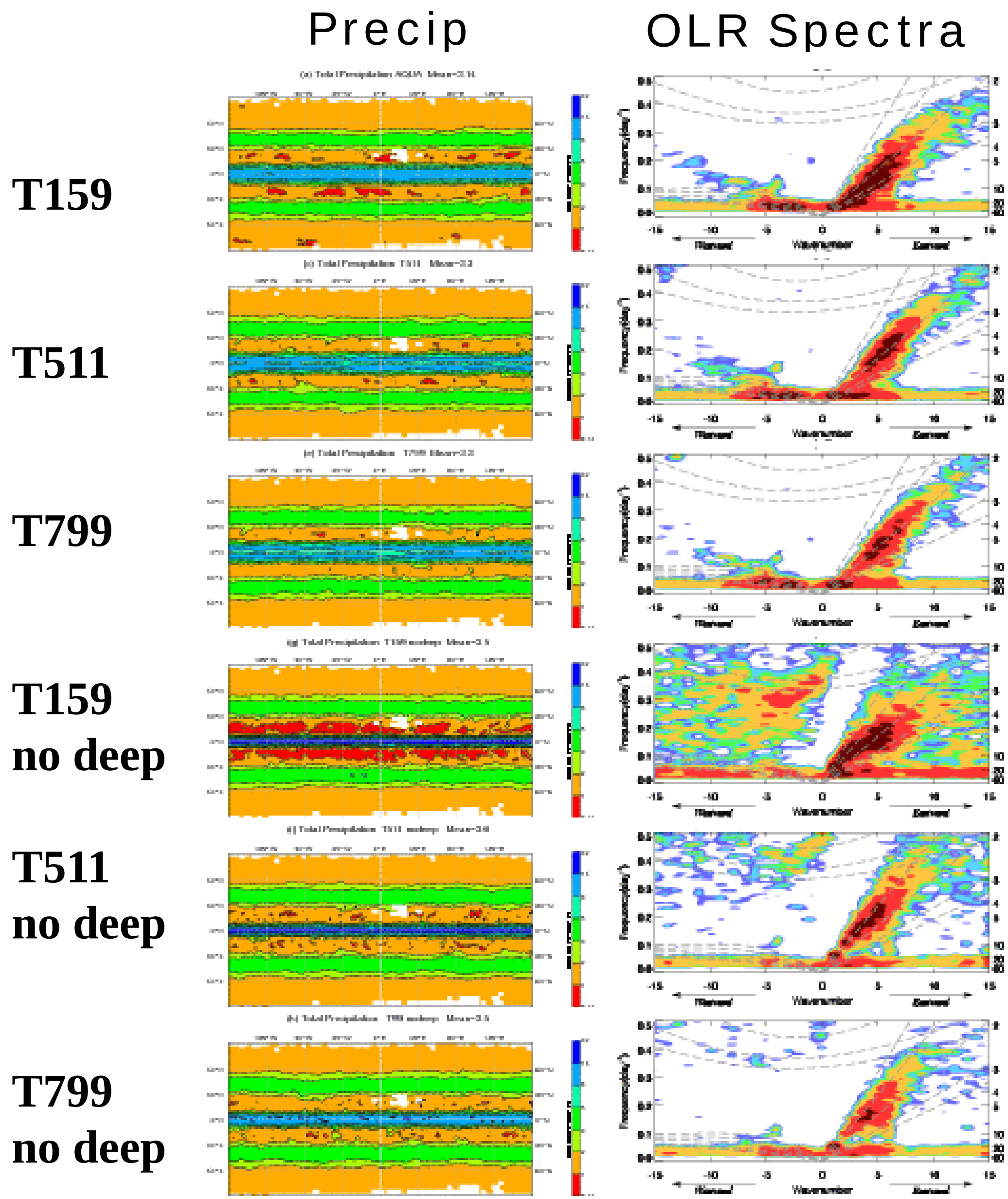


ECMWF

Obs - real Earth – AQUA planet



AQUA planet: resolution +- conv

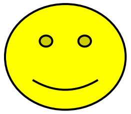


The small Planet: horizontal length-scale and time scale

$$R_a' = R_a / \gamma_r$$

$$f' = f \gamma_t \Leftrightarrow t' = t / \gamma_t$$

$$Ro = \frac{U}{R_a f}$$



But

$$\frac{\partial u}{\partial x'} + \frac{\partial v}{\partial y'} = \gamma_r \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = -\frac{\partial w}{\partial z} = -\frac{\partial \omega}{\partial p}$$

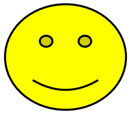
?

also thanks to N. Wedi and S. Malardel for earlier versions of small planet

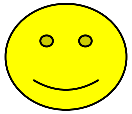
The small Planet: vertical scaling

$$g' = g\,\gamma_g; \quad H = \frac{R\,T}{g} \rightarrow H' = H/\gamma_g$$

$$\gamma_r = \gamma_t = \gamma_g$$



$$Ri = g\,\frac{\delta T}{\bar{T}}\,\frac{H}{U^2} = N^2\,\frac{H^2}{U^2}; \quad c = \sqrt{g\,H}$$



or Lamb parameter

Physics scaling

ECMWF

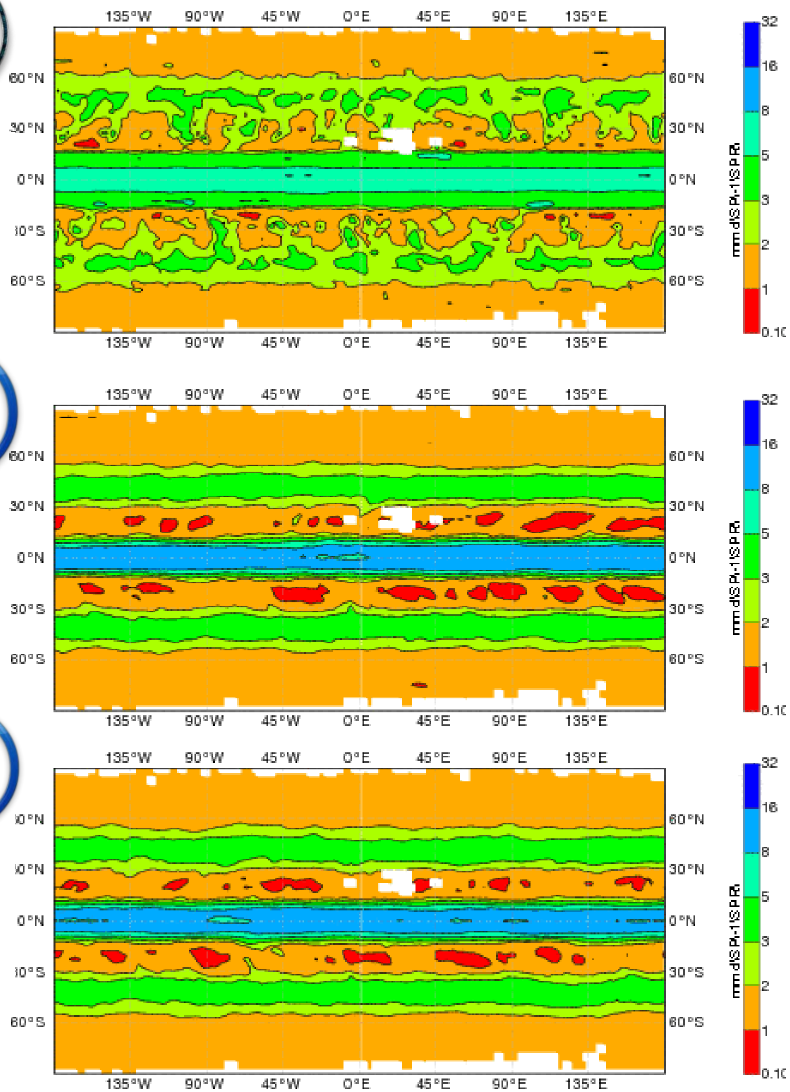
AQUA planet: f=t & g scaling

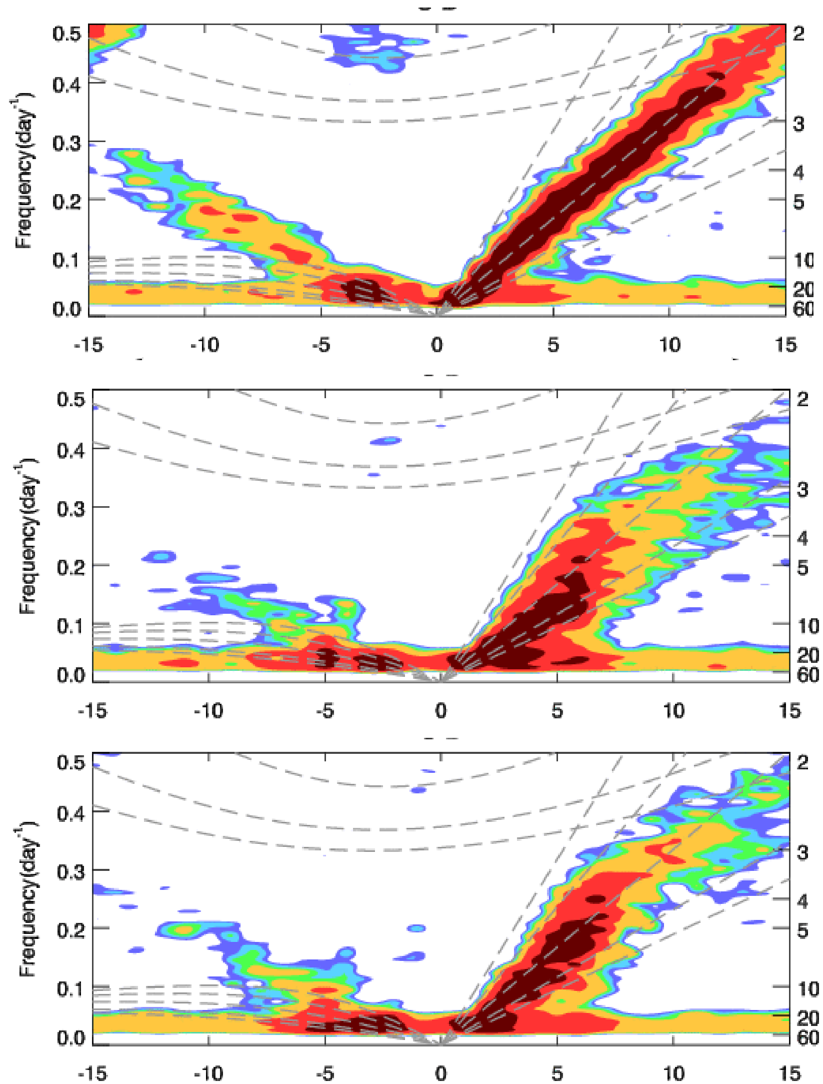
Precip | OLR Spectra

R/4
t/4

R/4
t/4
g*4
physics

R/8
t/8
g*8
physics





Conclusions

- Most important area for energy generation and conversion is the upper-tropical troposphere

- Convective heating must occur in the right phase of the large-scale wave, and as T variations are small must show the right sensitivity to mid-tropospheric moisture

- Main forecast errors concern spindown of Hadley cell (why?), and a too strong SE Asian Monsoon - moistening, easterly wind bias

- Largest low-level wind errors are in the East tropical Pacific where also analysis uncertainty is relatively large for 950-700 hPa winds

- with small Aqua planet nice forecast tool for global convection/waves=scalable Prototype for different planets

Any further

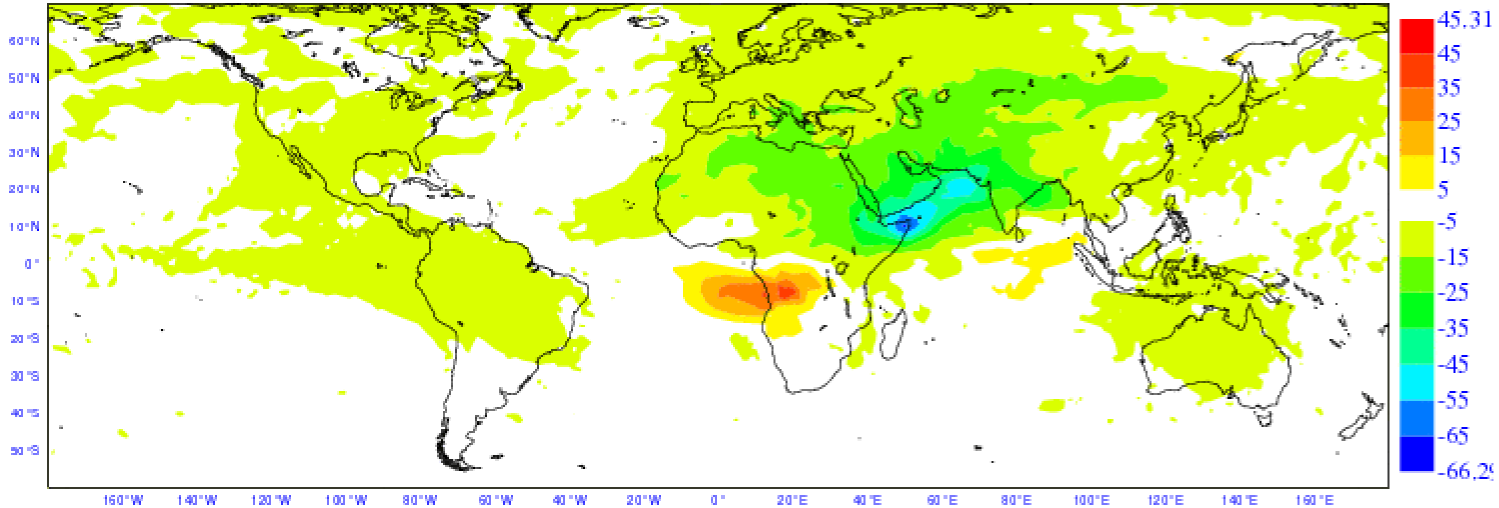
- Diurnal cycle will probably remain problem, address Monsoon heating, slightly overestimated shallow transport (trade Cu, dry PBL) though necessary for predictability, drizzle

- Major analysis impact expected from ADM-AEOLUS wind lidar

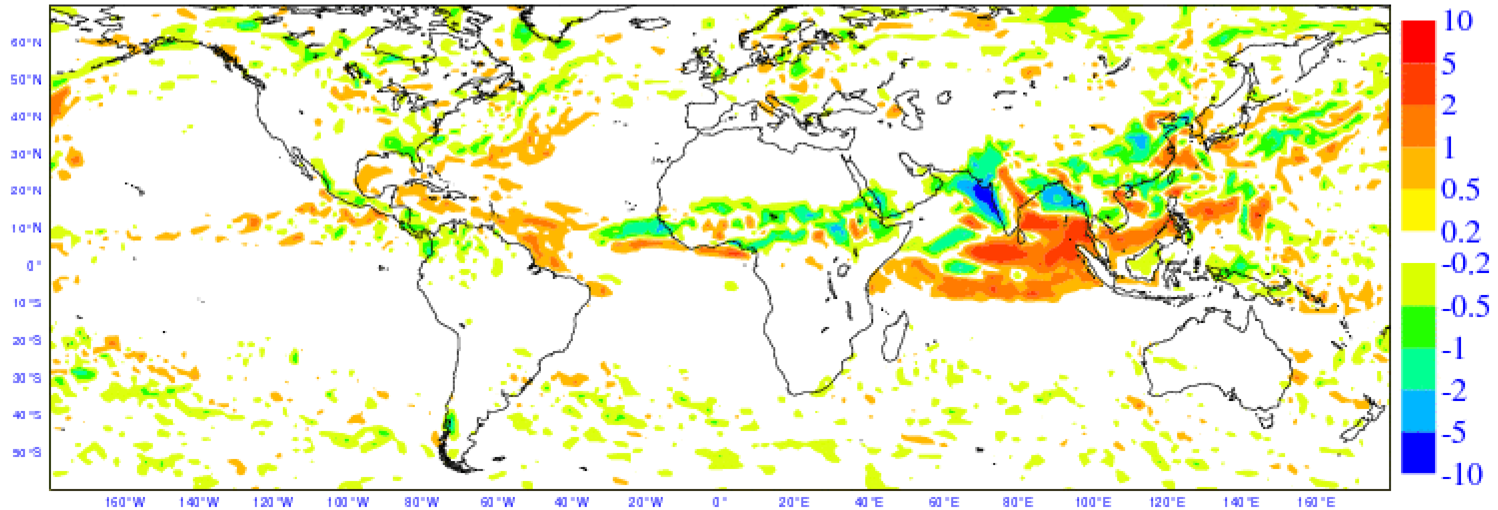
- and ???

Uncertainty in SW flux diverg. due to Aerosols.

Div
W/m2



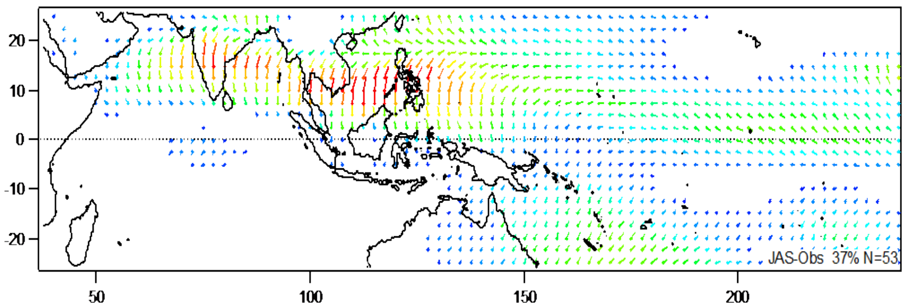
CP
mm/d



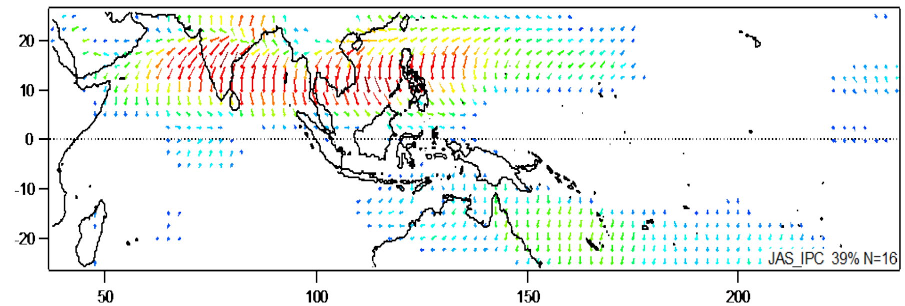
Nota: 10 W/m2~0.35 mm/day

Intraseasonal variability by events

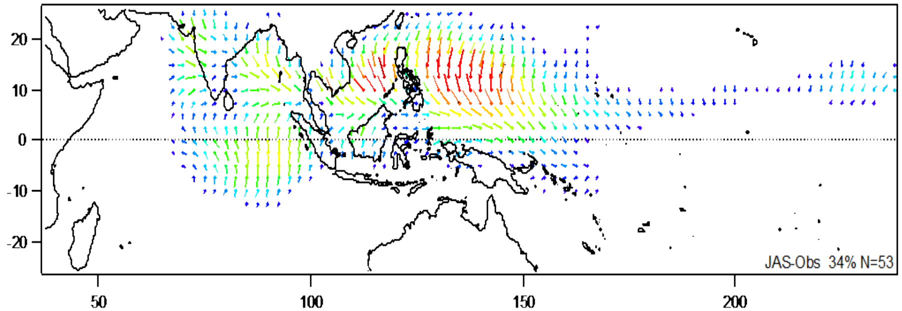
JAS Obs 30 years for U 850 hPa



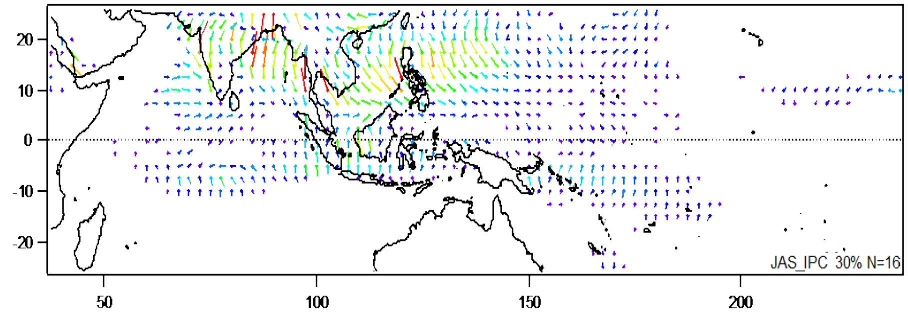
IFS 8x1-year for U 850 hPa



JAS Obs 30 years for Rain



IFS 8x1-year for Rain

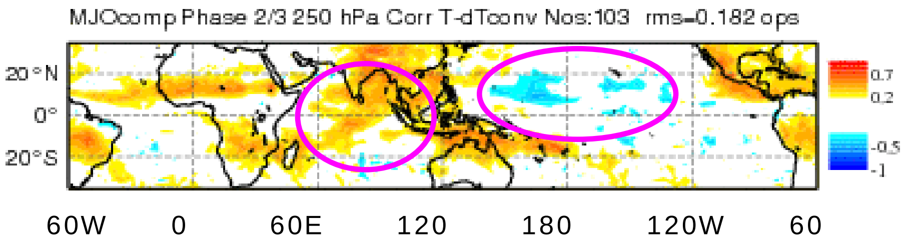


courtesy J.Ph. Duvel see also their (Clim Dyn. 2012)

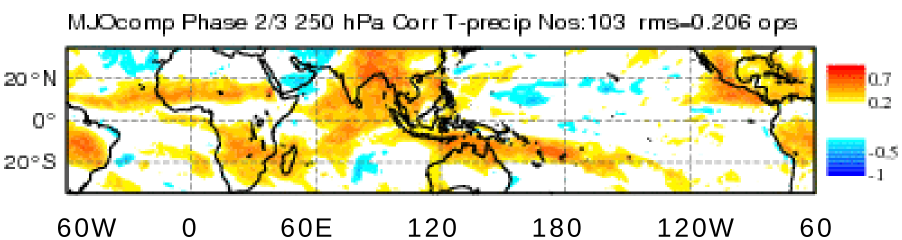
Correlations with T' at 250 hPa for
Phase 2/3 and forecast steps 12-36

Oper

dT/dt_conv

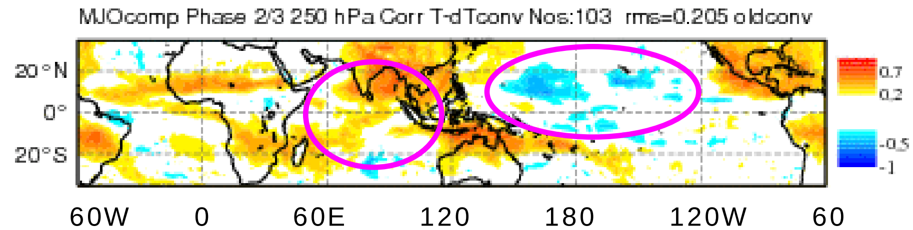


Precip

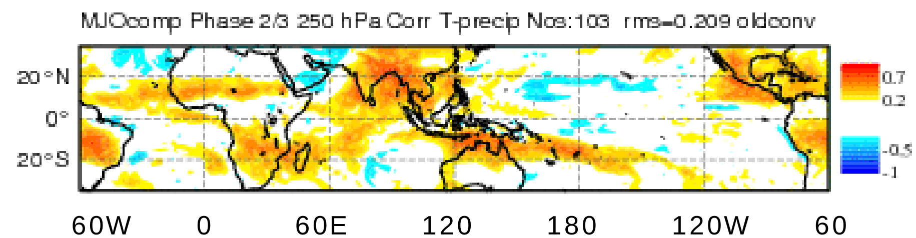


Old Conv

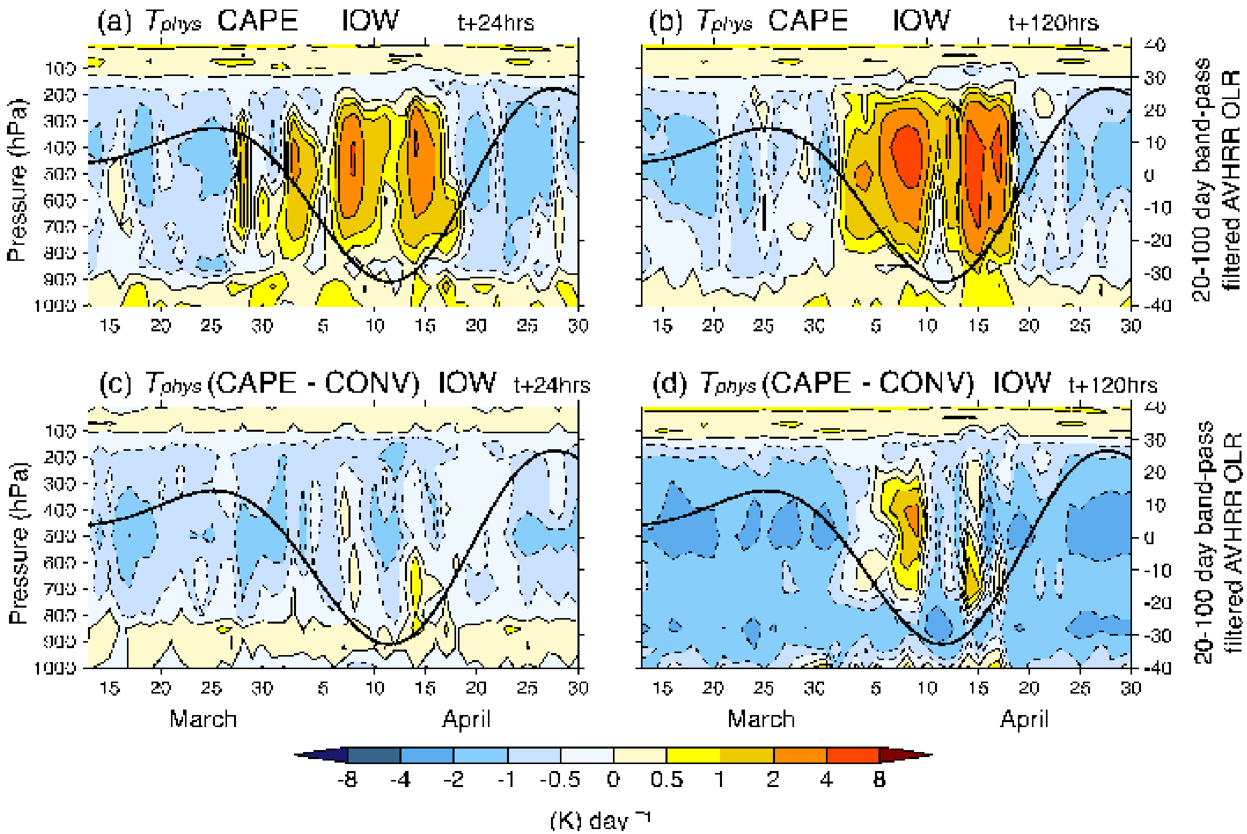
dT/dt_conv



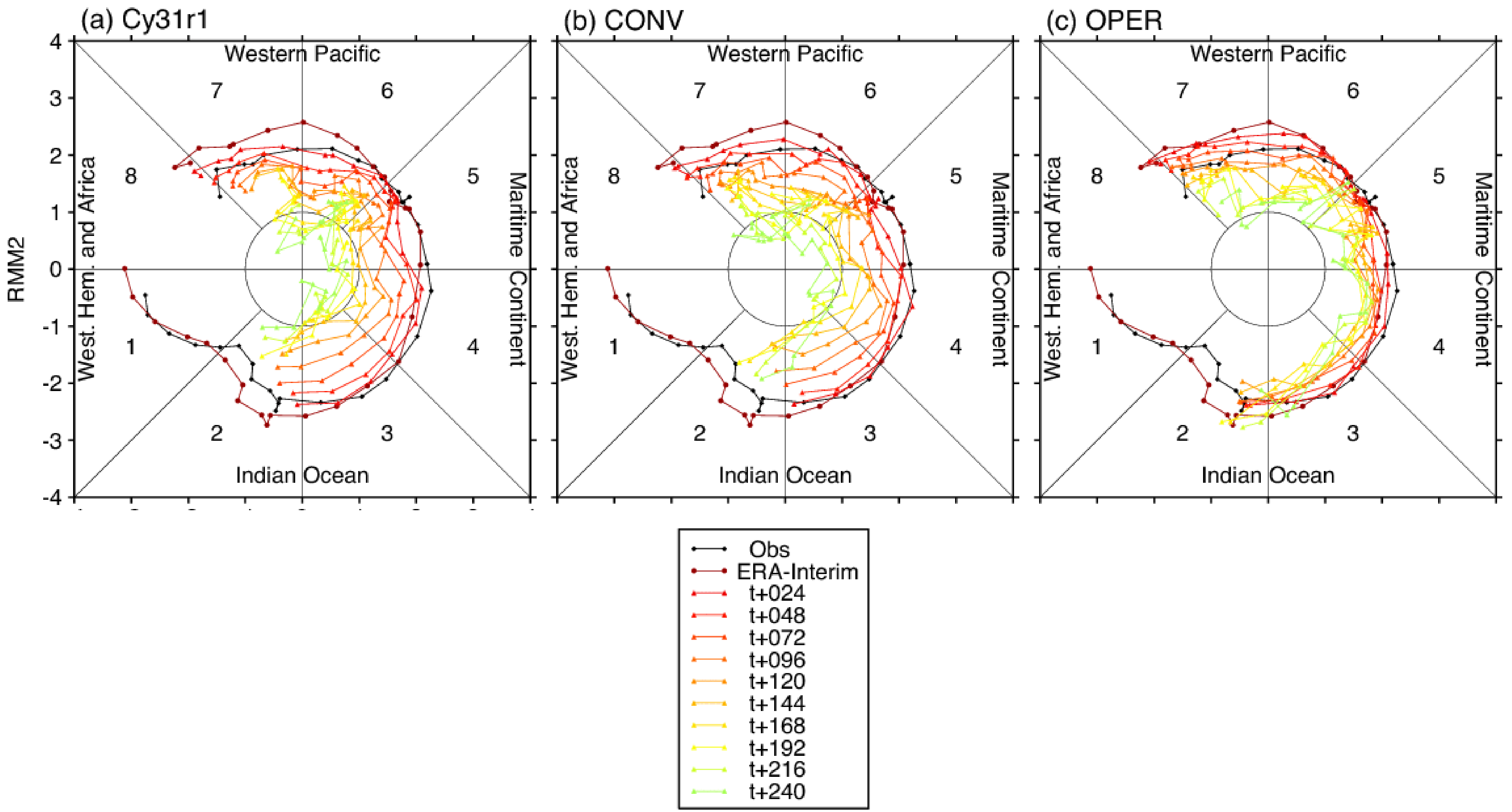
Precip



YOTC: Evolution of Indian Ocean OLR anomaly & dT/dt physics



YOTC: MJO forecasts April 2009: phase and amplitude as function of Fc lead time



ECMWF