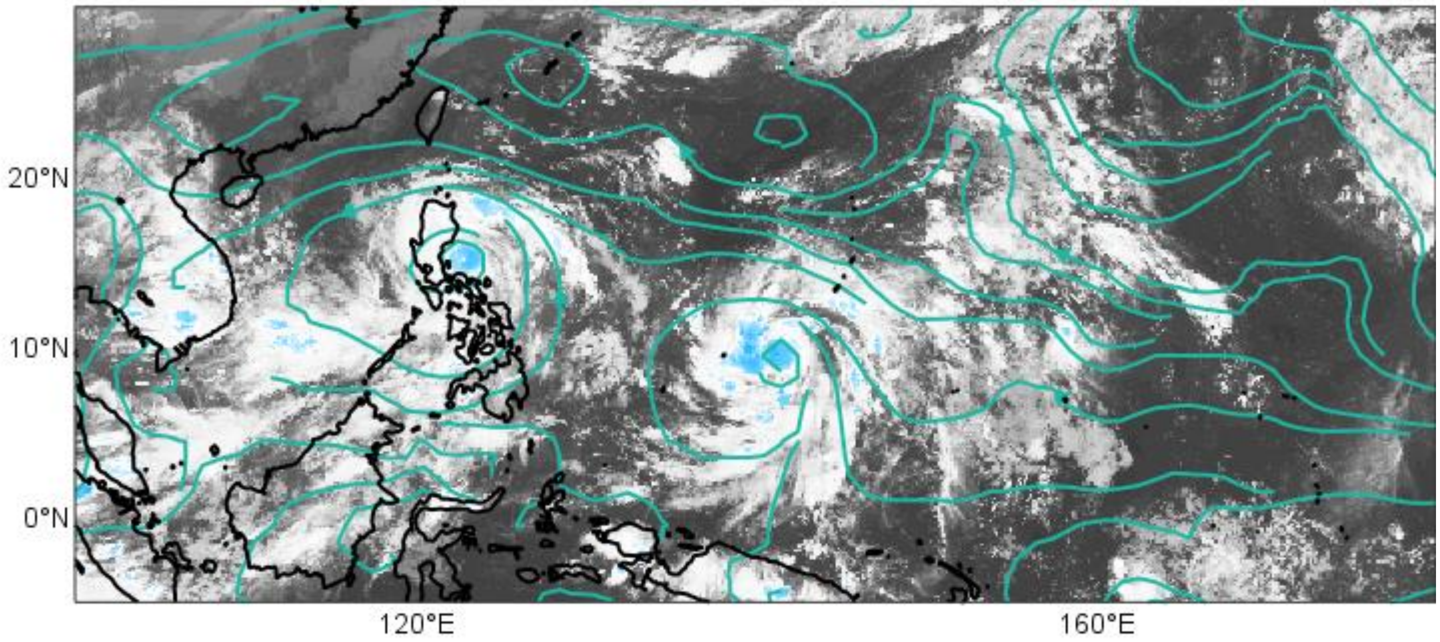
“Winds of convection”

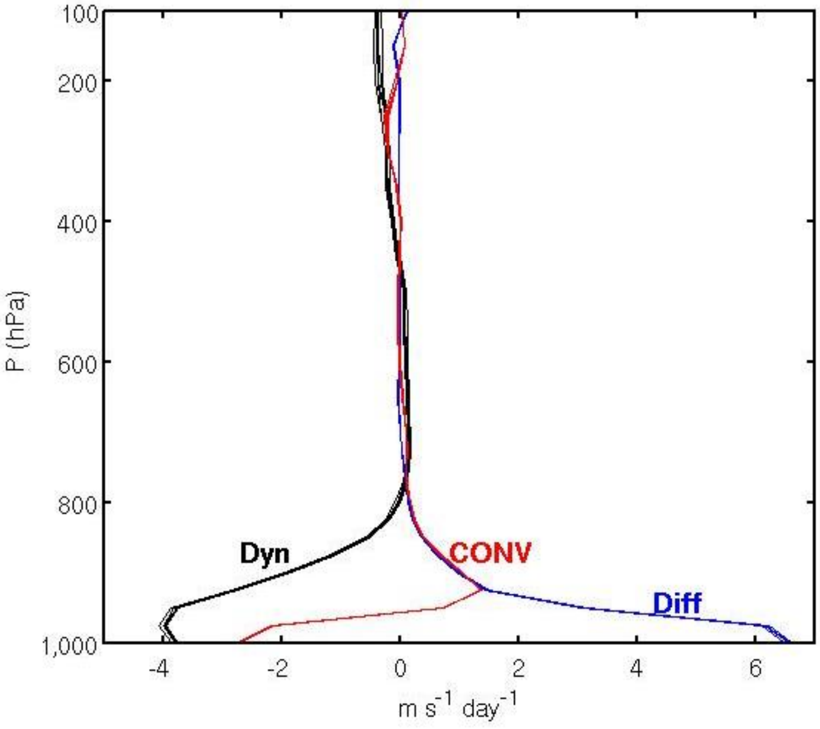


Peter Bechtold with special thanks to Martin Steinheimer , Michael Hermann&King-Fai Li

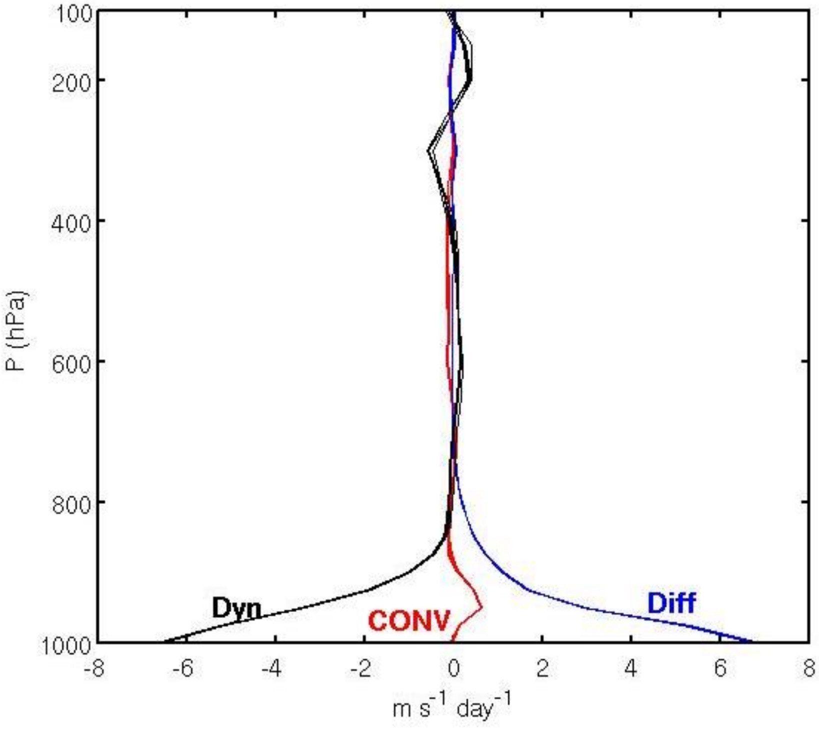
and J. Bidlot, E. Holm, A. Beljaars, R Forbes, Ž. Fuchs, L. Isaksen, D. Kim, J.-E Kim, M. Leutbecher, S-J Lock, P. Lopez, L. Magnusson, P. Ollinaho, I. Sandu, L. Schlemmer, S. Malardel, M. Rennie, M. Rodwell, A. Subramanian, F. Vitart, N. Wedi, N. Žagar, C. Zhang

Tropical momentum tendencies

U average -20° - +20°

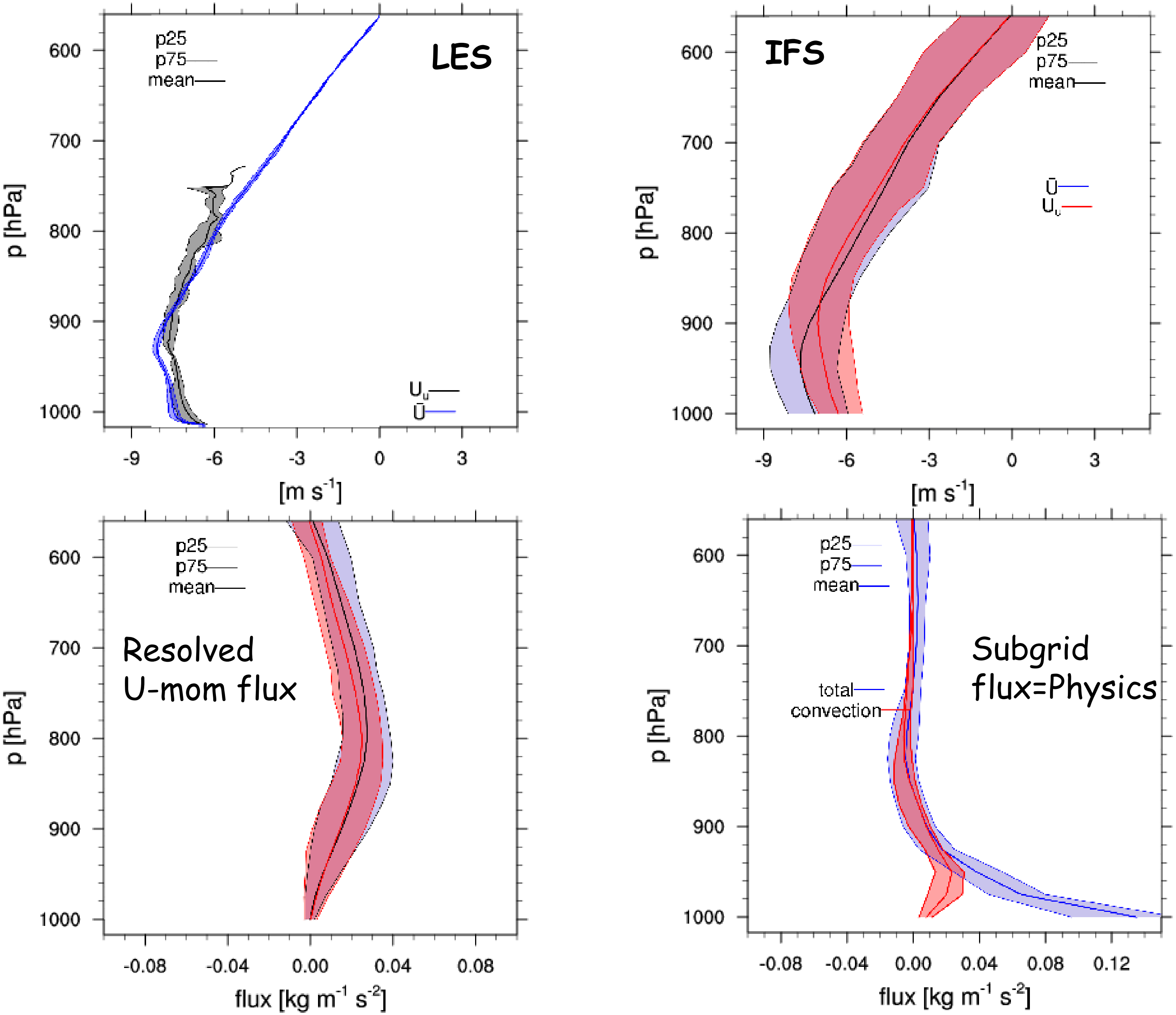


V average 0° - +20°



U, V compensate (conservation export/import of angular momentum)
Upper troposphere not balanced (in model)

(subtropical convective) momentum and fluxes against LES



The full system and the omega (balance) equation

$$\frac{\partial u}{\partial t} + \vec{V}\vec{\nabla}u - fv = -\frac{\partial \phi}{\partial x} + g\frac{\partial}{\partial p}(F_{frict} + F_{conv})$$

$$\frac{\partial v}{\partial t} + \vec{V}\vec{\nabla}v + fu = -\frac{\partial \phi}{\partial y} + g\frac{\partial}{\partial p}(F_{frict} + F_{conv})$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$

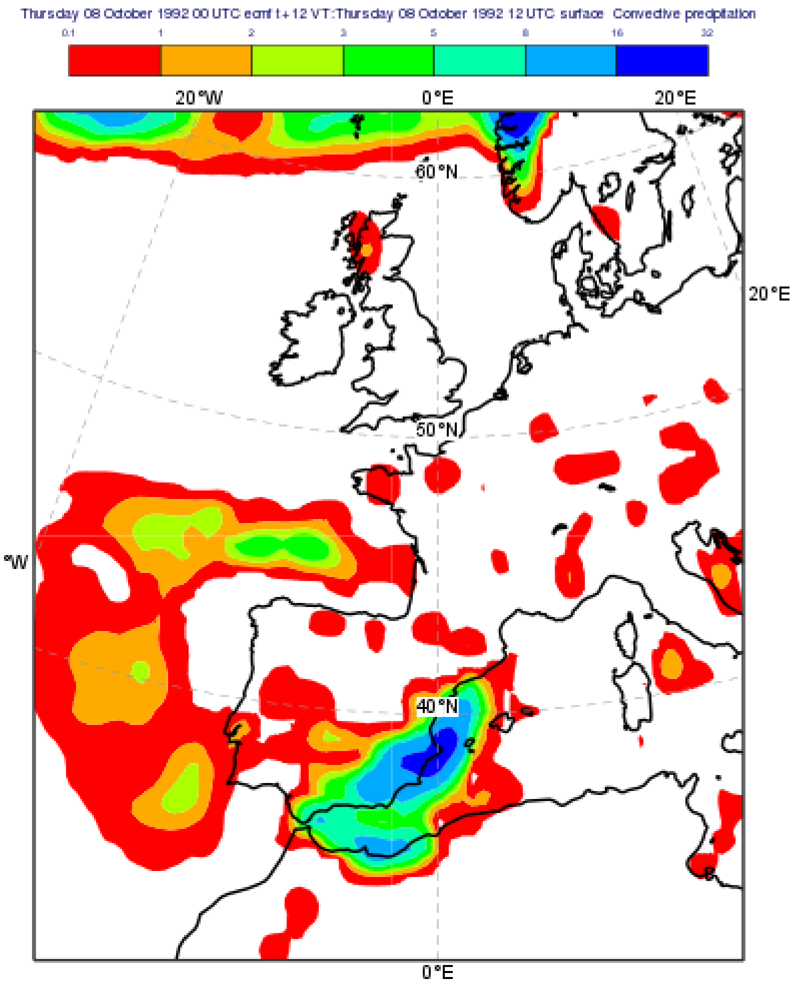
$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + \omega\frac{T}{\theta}\frac{\partial \theta}{\partial p} = c_p^{-1} g \frac{\partial J}{\partial p}$$

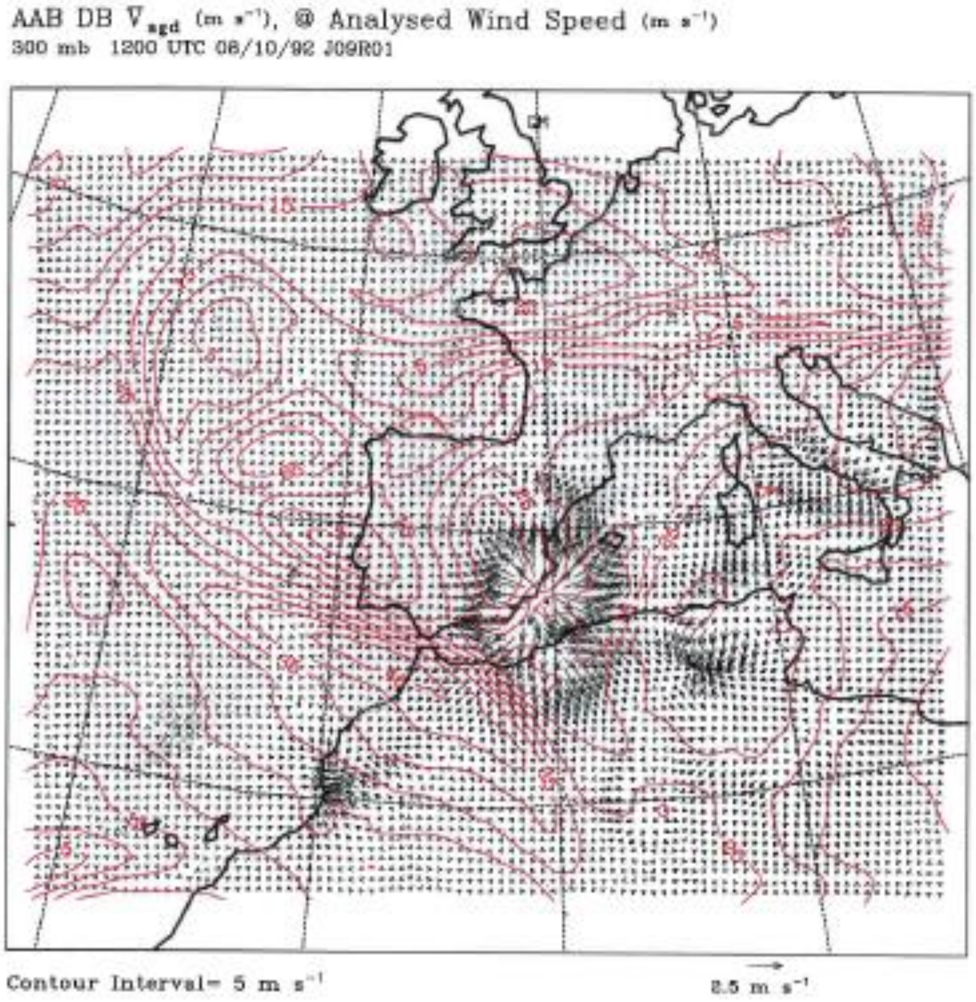
(J.R, Holton) Neglect **J and F** and via **quasi-geostrophic vorticity equation** get from geopotential tendency a diagnostic for **ω, ie obtain divergence from temperature and rotational wind**

$$\left(\sigma\vec{\nabla}^2 + f_0^{\,2}\frac{\partial^2}{\partial p^2}\right)\omega = f_0\frac{\partial}{\partial p}\left[\vec{V}_g \bullet \nabla\left(\frac{1}{f_0}\nabla^2\phi + f\right)\right] + \nabla^2\left[\vec{V}_g \bullet \nabla\left(-\frac{\partial \phi}{\partial p}\right)\right]; \sigma = -\frac{\alpha}{\theta}\frac{\partial \theta}{\partial p}$$

more evolved forms include the alternative balance approximation by Davis-Jones (1991). However there is very little on generalised omega equation with application to tropics, could only find Buamhefner (1968) and Dostalek (PhD 2012)

Example of extraction of ageostrophic (divergent) wind





see Donadille, Cammas, Mascart, Lambert QJRMS 2001 and Mallet et al. 1999 QJRMS for discussion

Lorenz Energy cycle and global energy flow

α= specific volume

$$TPE = c_v T + \phi; \qquad \frac{dTPE}{dt} = Q + \alpha\omega$$

Net heating

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

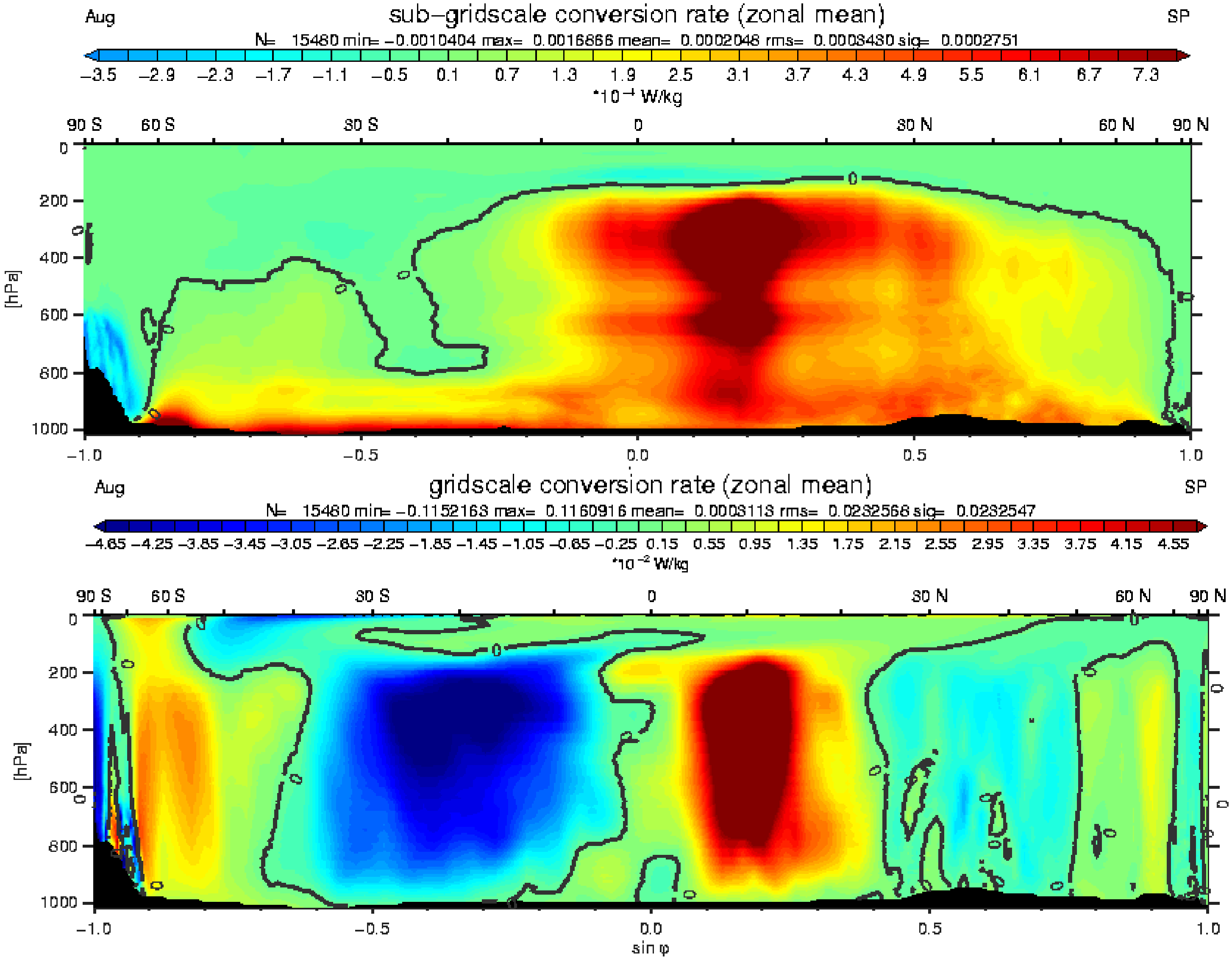
Generation **Conversion**

Lorenz efficiency factor

$$\frac{dK}{dt} = -\alpha\omega - D$$

kinetic energy

Annual cycle of subgrid and grid-scale conversion rates (W/kg)

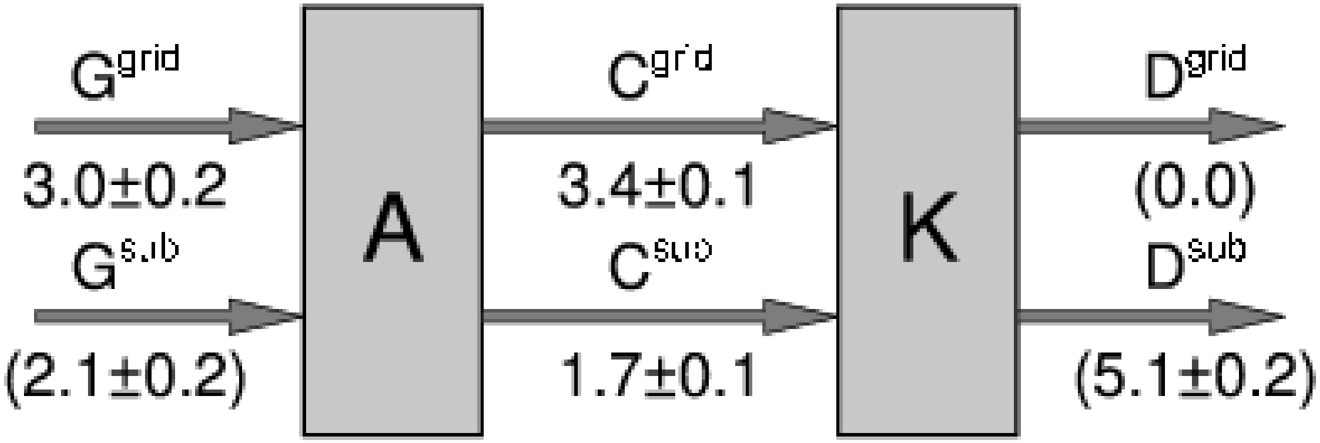


Convection so important because contribution always positive !

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 (W/m2)



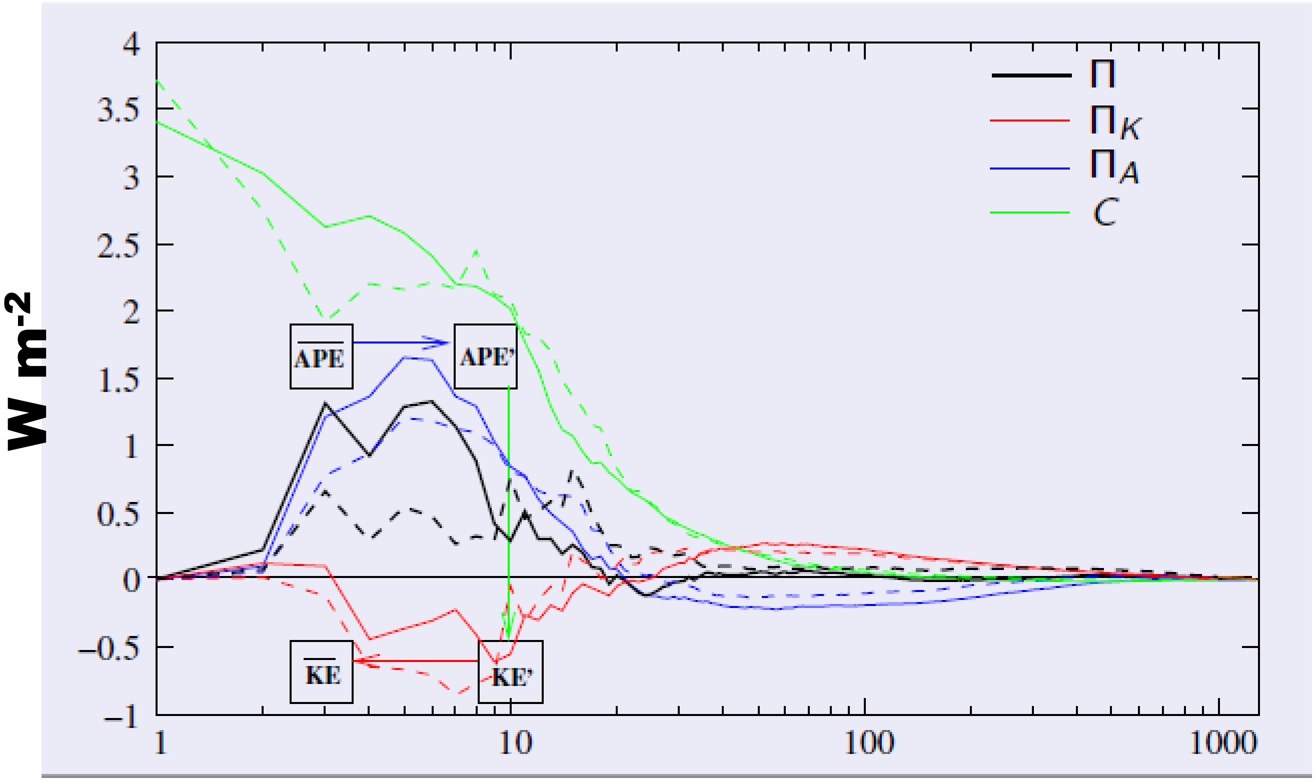
Subgrid of similar importance than grid-scale, and convection is the most important subgrid process for conversion

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)

Scale dependent APE – KE analysis

S. Malardel and N. Wedi following Augier and Lindborg (2013)

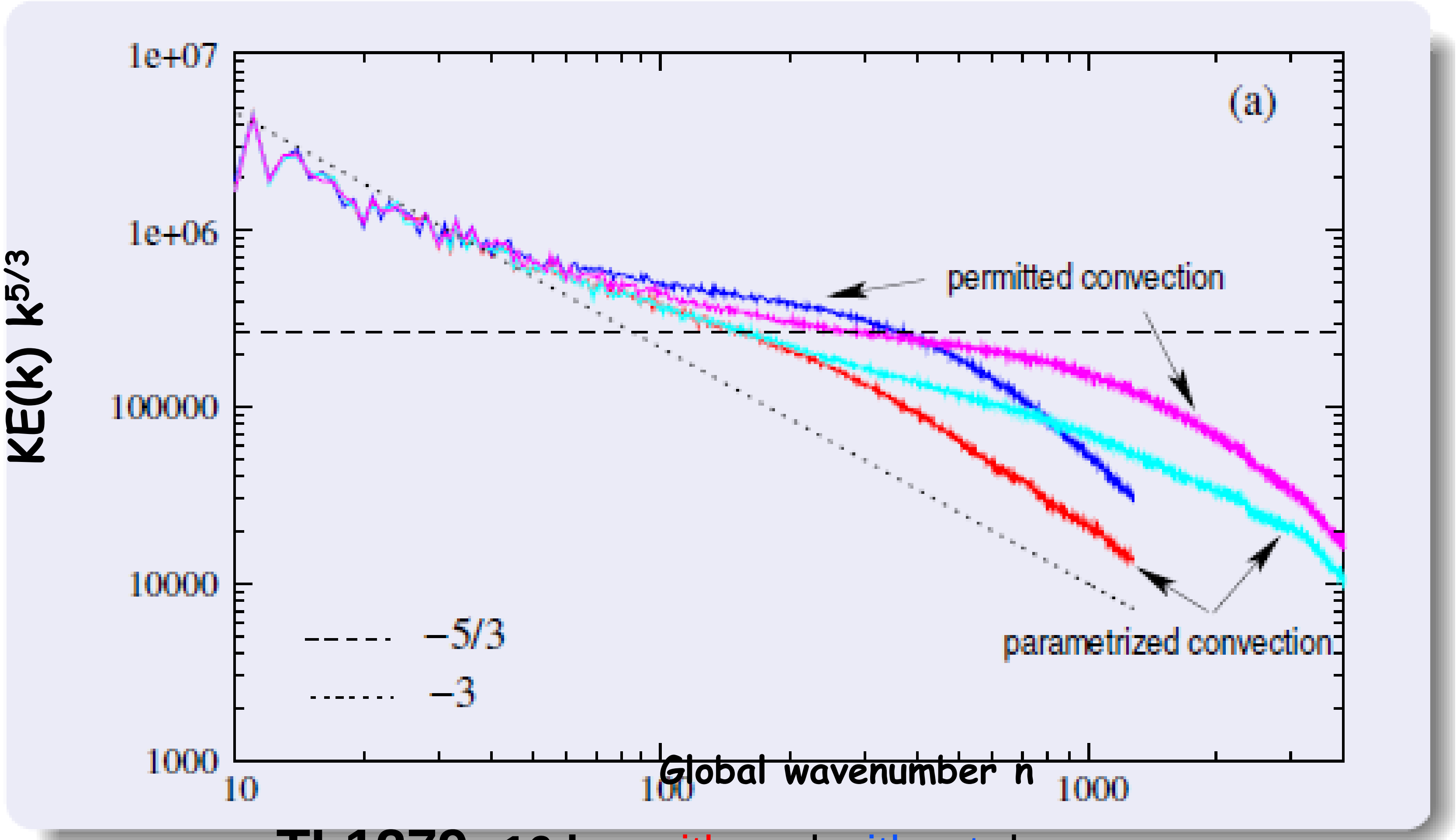


Production/ Flux

Conversion A->K

$$T = -\partial \Pi_l / \partial l \longrightarrow \quad ? \quad ? \quad \longrightarrow$$

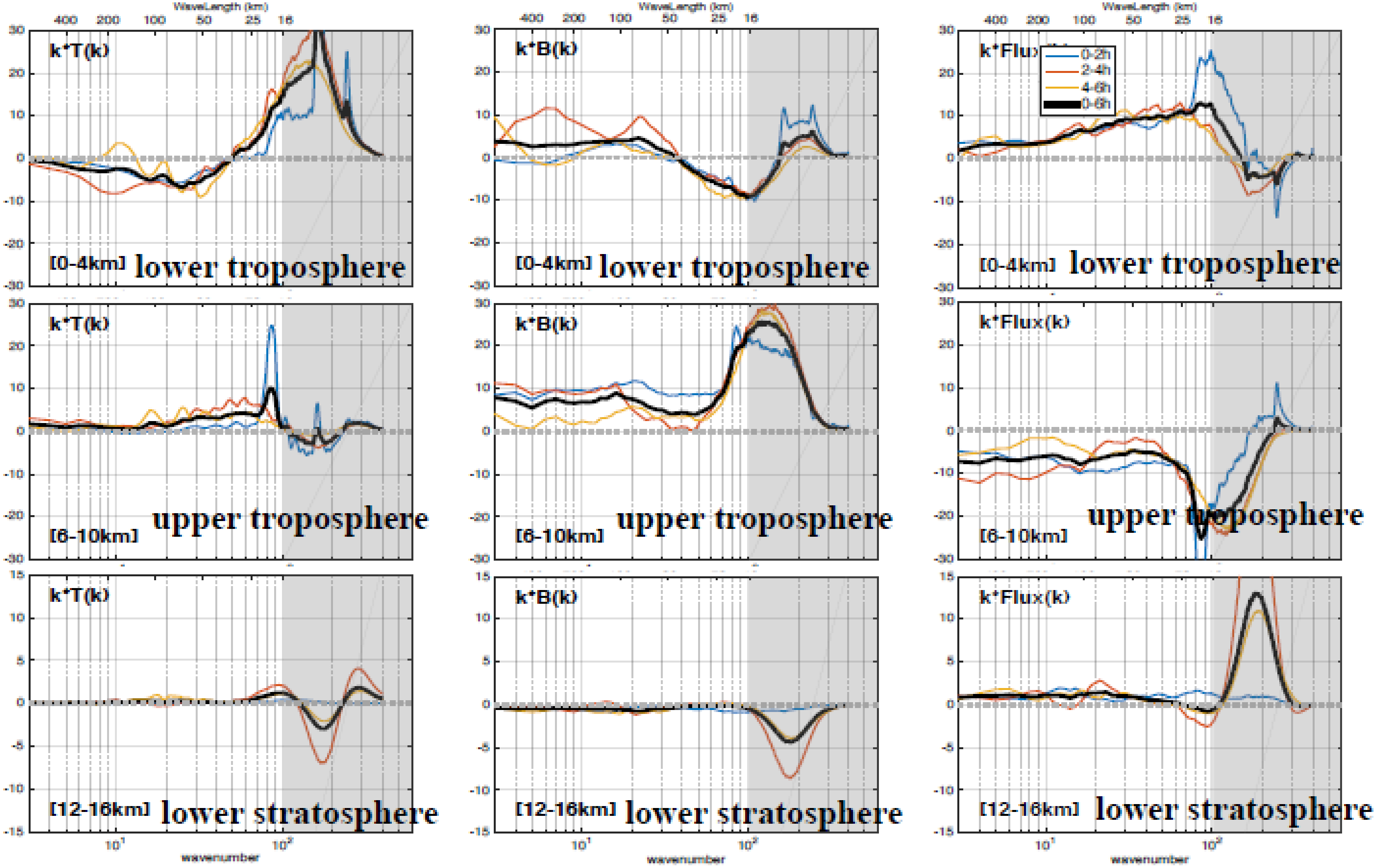
Resolved kinetic energy spectra with and without parametrized deep convection (*S. Malardel & N. Wedi*)



TL1279 =**16 km** with and without deep

TL4000=5 km with and without deep

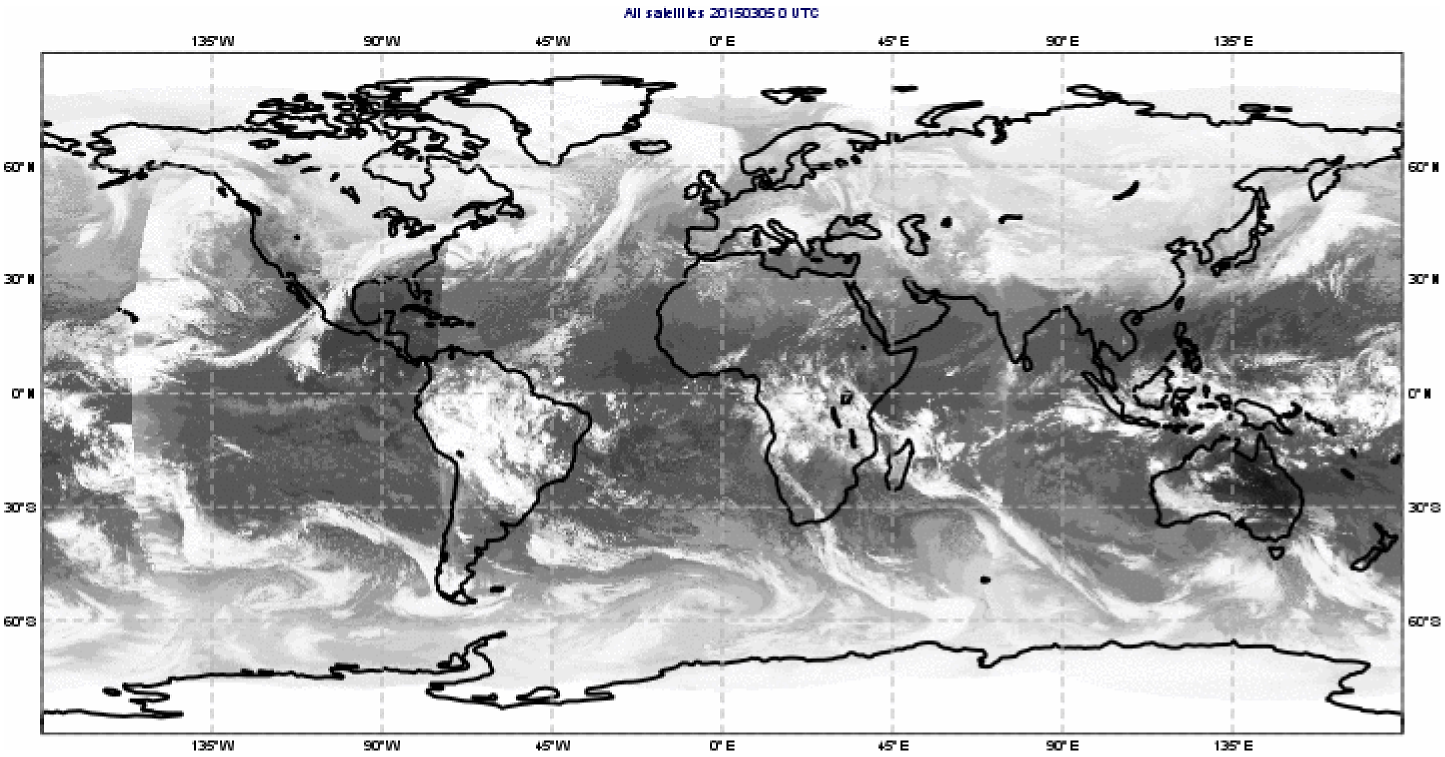
KE Spectra budget across scales at different altitudes



T(k): nonlinear transfer term across scales; B(k) buoyancy term; Flux(k): vertical transport

From F. Zhang 2016 ECMWF presentation, in revision for JAS

The global circulation and its modes (waves)



Analytical: solve shallow water system (e.g Ortland and Alexander, 2011, Žagar et al. 2015)

$$U = U_0\ f(y)\ e^{i(kx-\omega t)}\ G(z); \quad f(y) = e^{-\frac{y^2}{2}};\ G(z) = e^{-\left(\frac{z}{2H}\right)} Re\left(e^{imz}\right)$$

$$V = \breve{V}(y)\ f(y)\ e^{i(kx-\omega t)}\ G(z); \quad \breve{V}(y) = Legendre\ polynomial$$

(Hermite)

The shallow water system, the Gill (1980) model and the weak temperature gradient

Dissipation+Heating

$$\frac{\partial u'}{\partial t} - \beta y v' = -g\frac{\partial h'}{\partial x} - \varepsilon u'$$

$$\frac{\partial v'}{\partial t} + \beta y u' = -g\frac{\partial h'}{\partial y} - \varepsilon v'$$

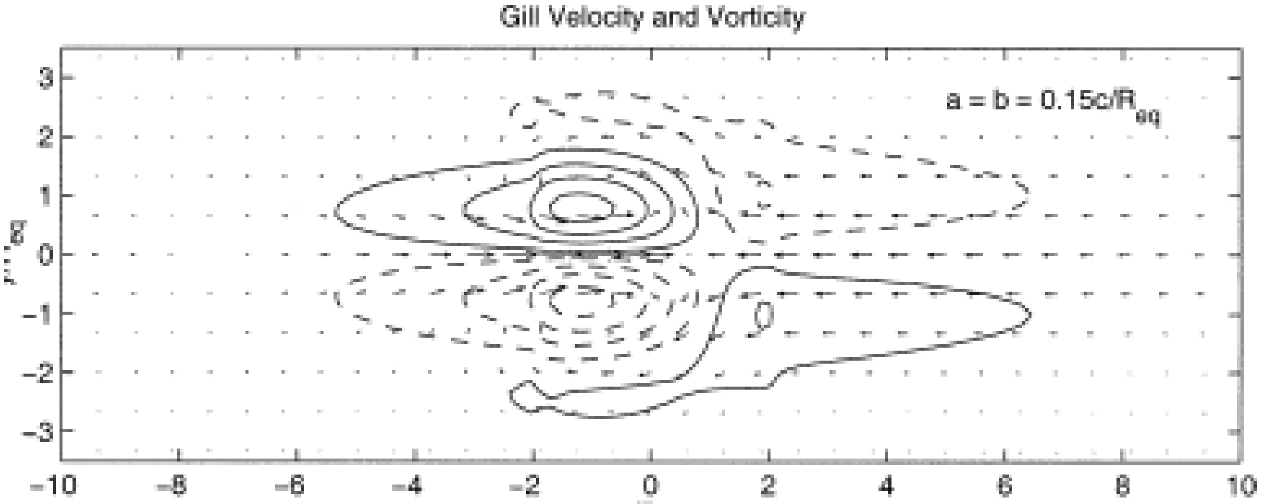
$$\cancel{\frac{\partial h'}{\partial t}} + H\left(\frac{\partial u'}{\partial x} + \frac{\partial v'}{\partial y}\right) = +HQ - \varepsilon h'$$

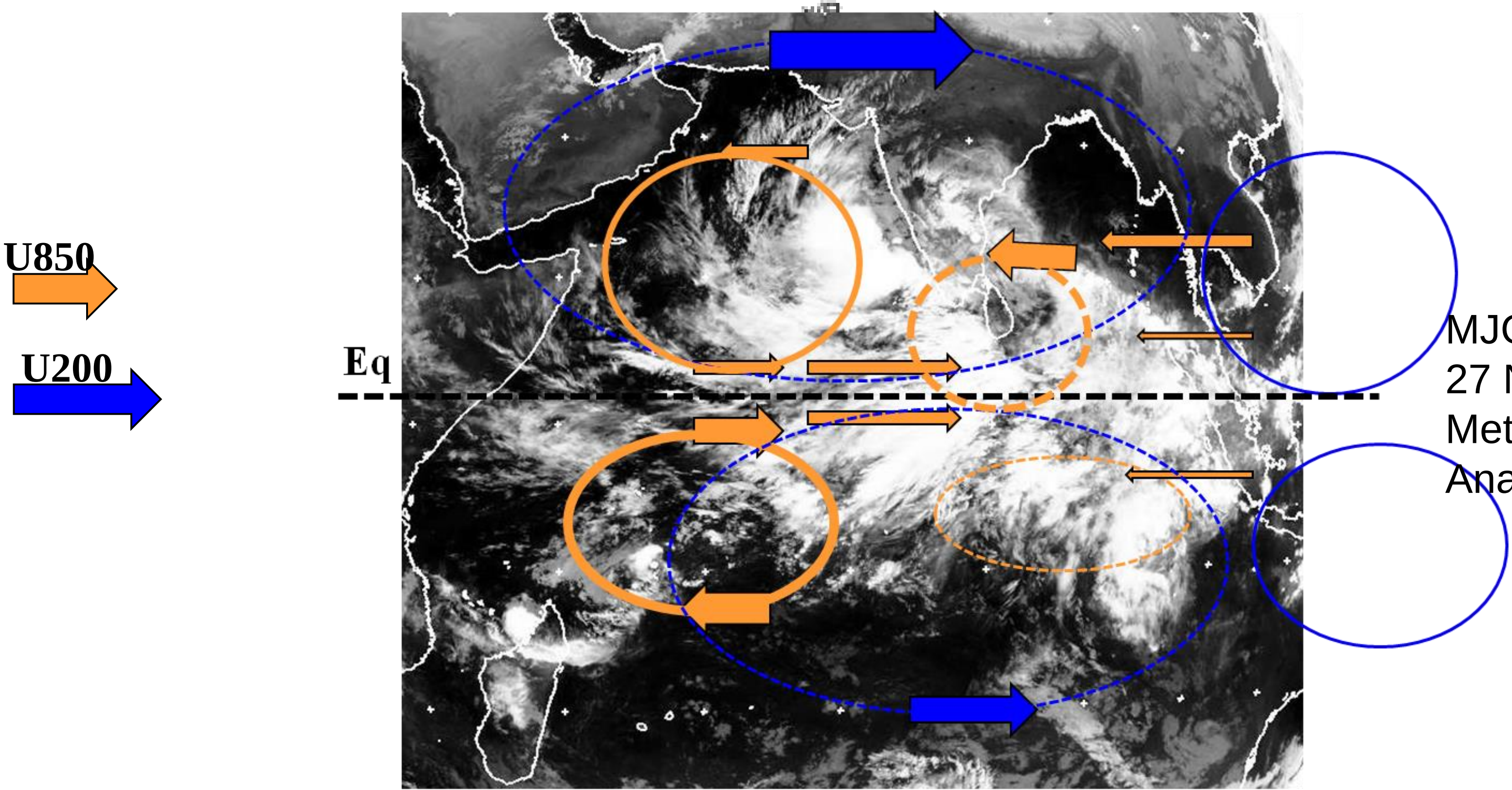
WTG

$$Q = J/\left(\rho c_p H \frac{d\theta_0}{dz}\right)$$

See Gill (QJRMS 1980), Bretherton and Sobel (JAS 2003)

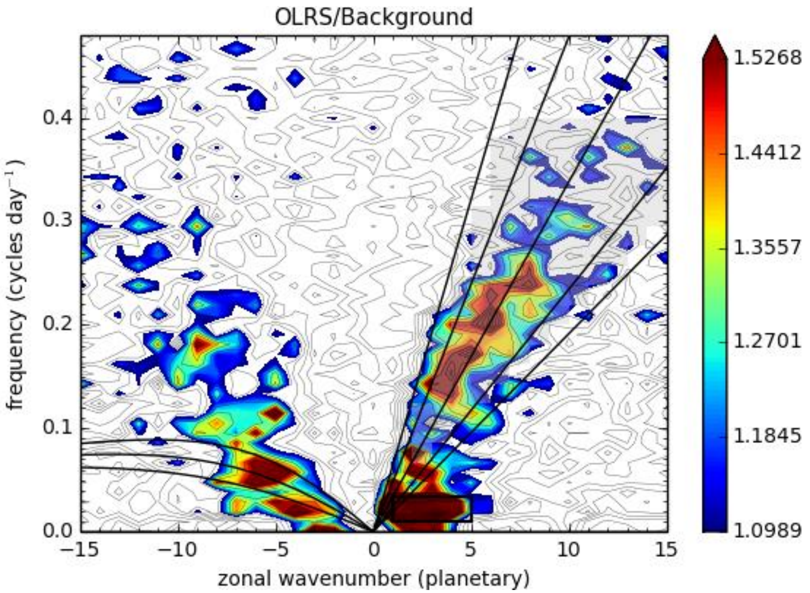
Response to symmetric heating at the Equator



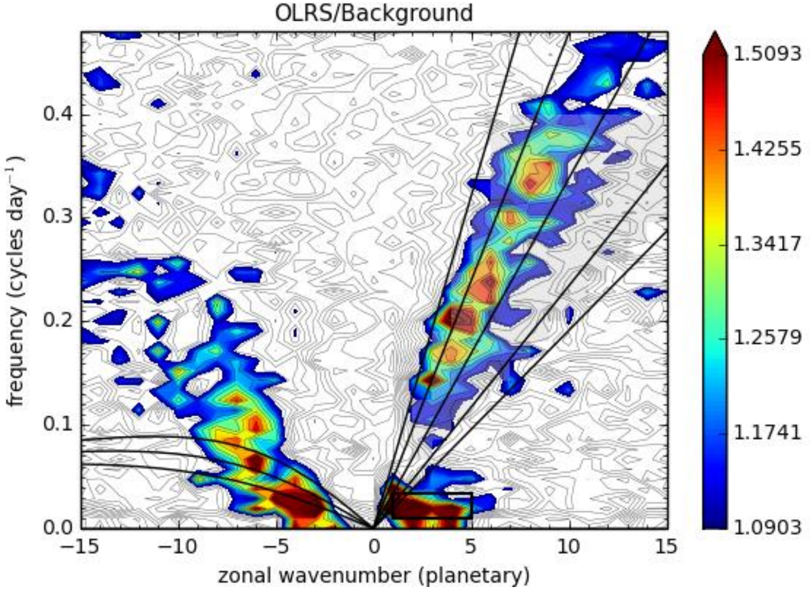


MJO during DYNAMO
27 November 2011:
Meteosat 7 + ECMWF
Analysis

Wavenumber frequency Diagrams of OLR



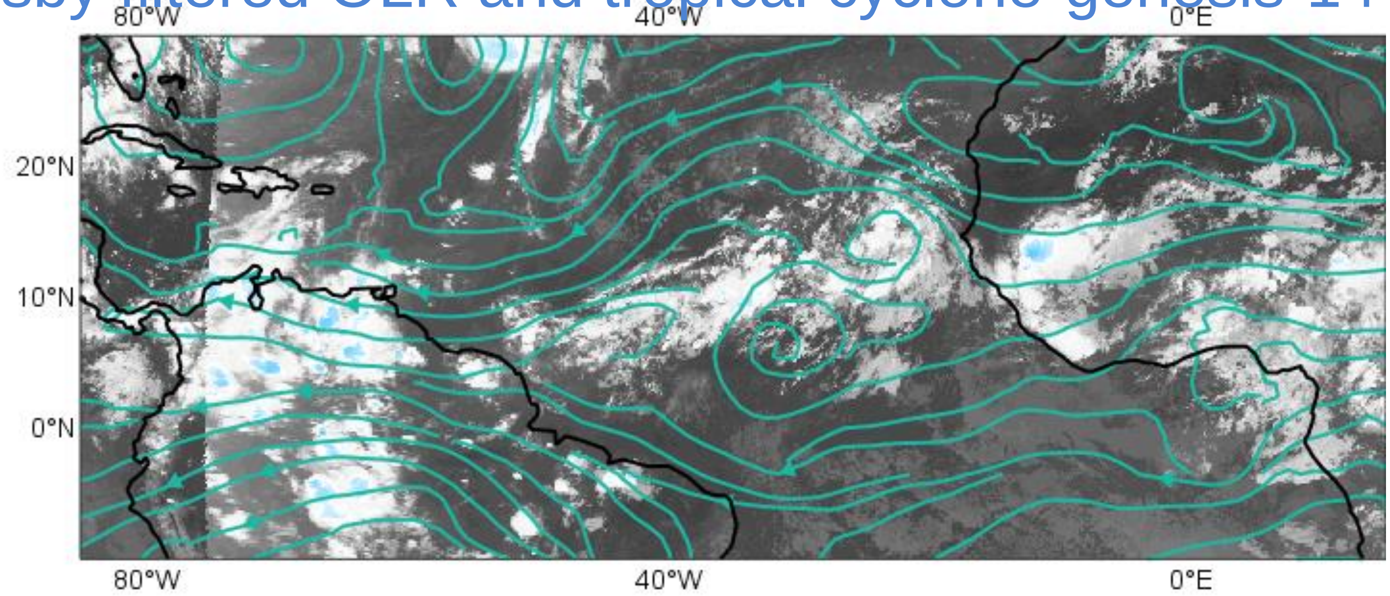
ECMWF Analysis (2008-2013)



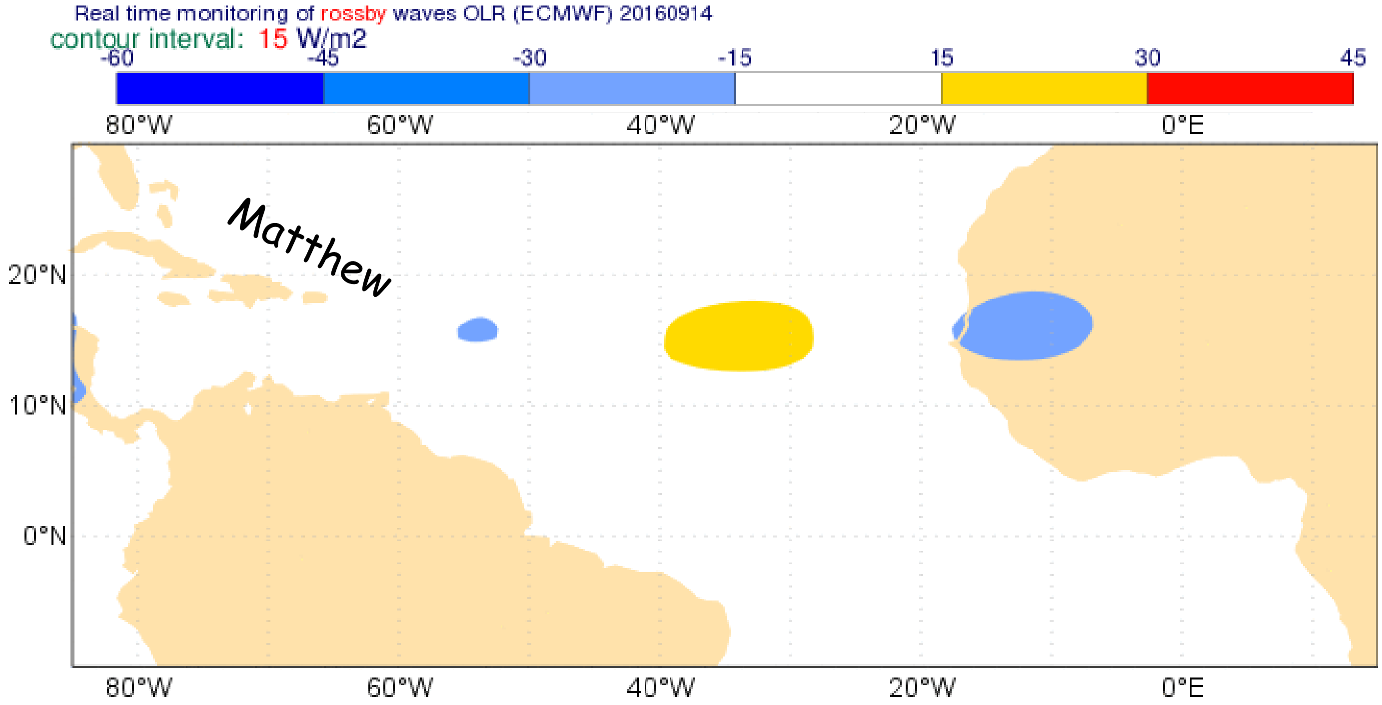
Cy40r1 6 years

(all spectra have been divided by their own= smoothed background)

Rossby filtered OLR and tropical cyclone genesis 14-29.9 2016



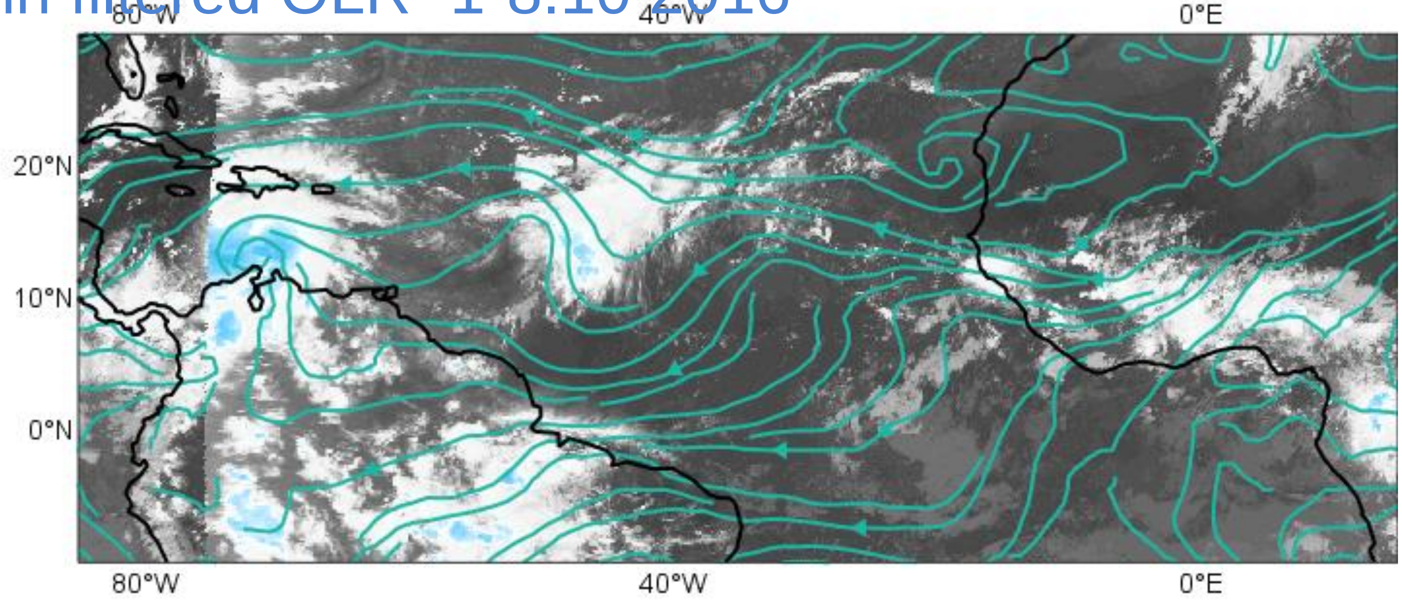
+streamlines
500 hPa



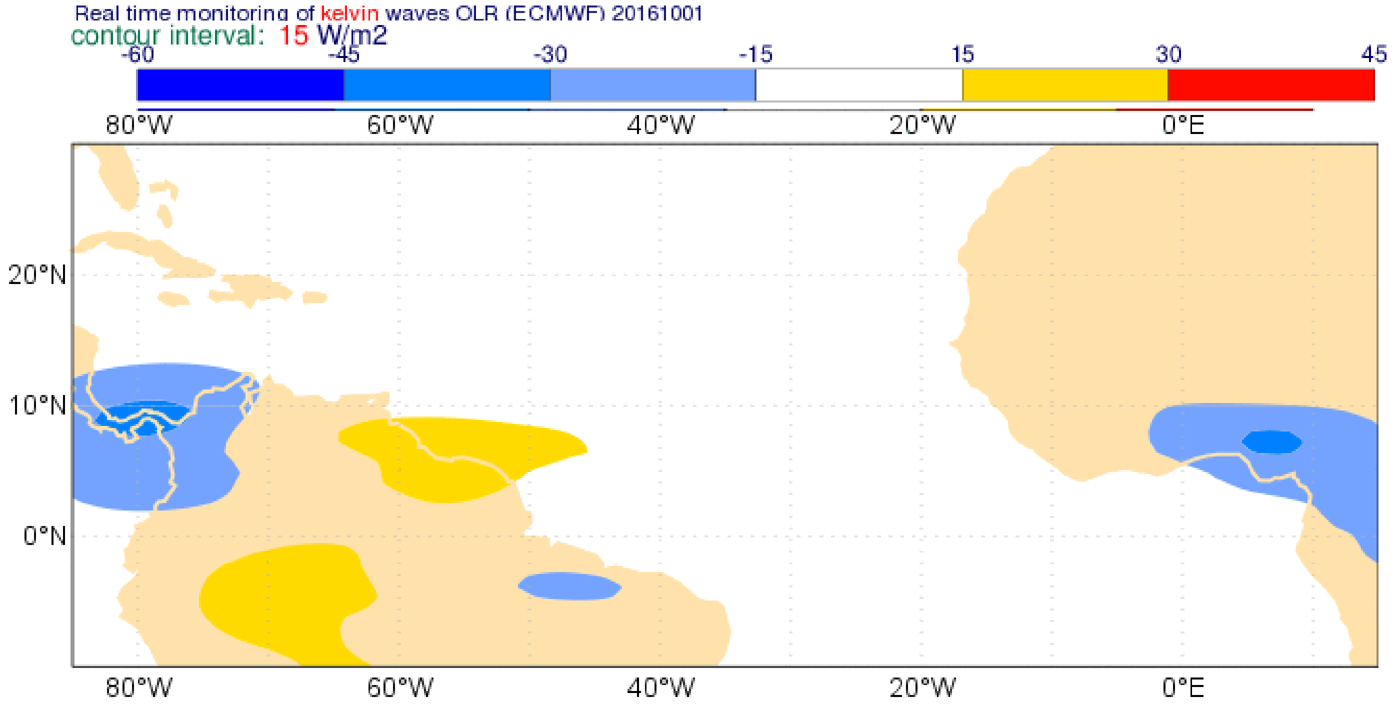
Real time monitoring of rossby waves OLR (ECMWF) 20160914

contour interval: 15 W/m2

Kelvin filtered OLR 1-8.10 2016

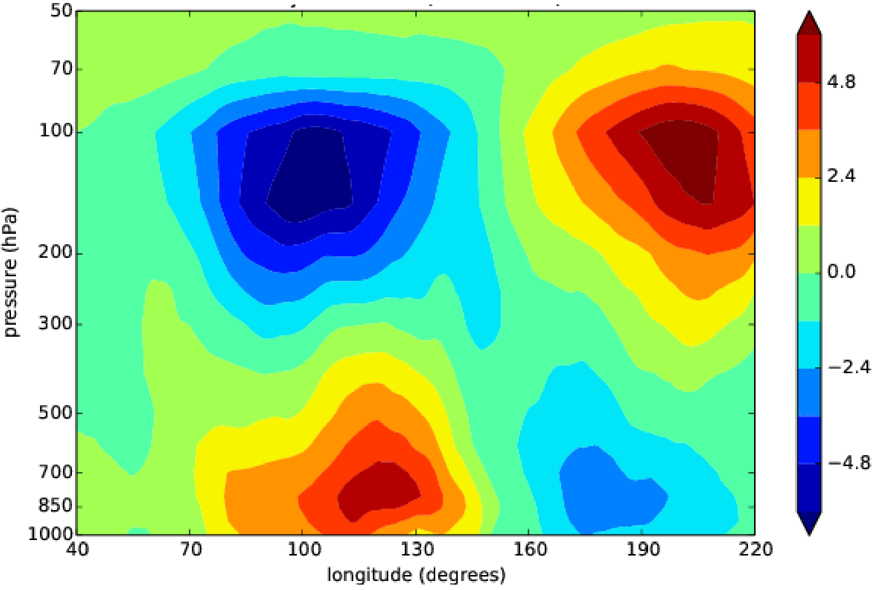


+streamlines
850 hPa

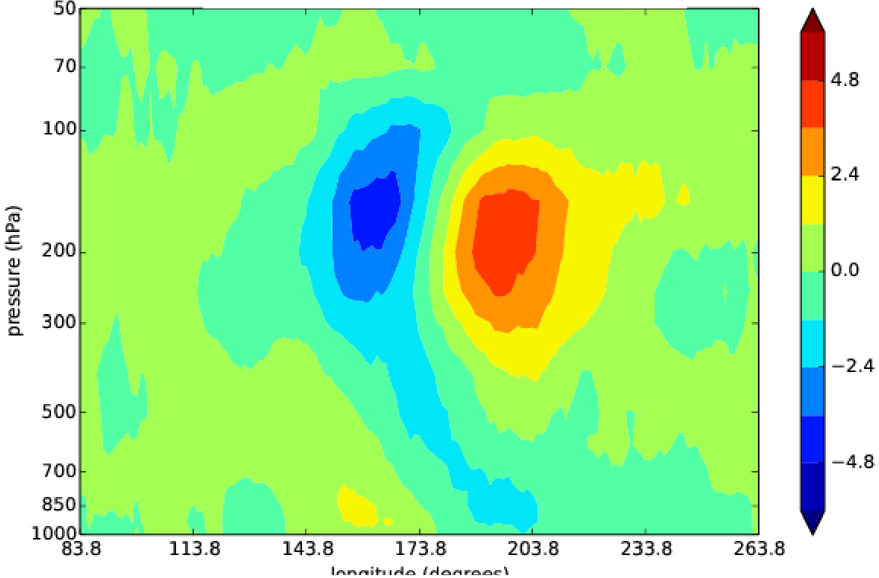


U-anomalies: vertical structure

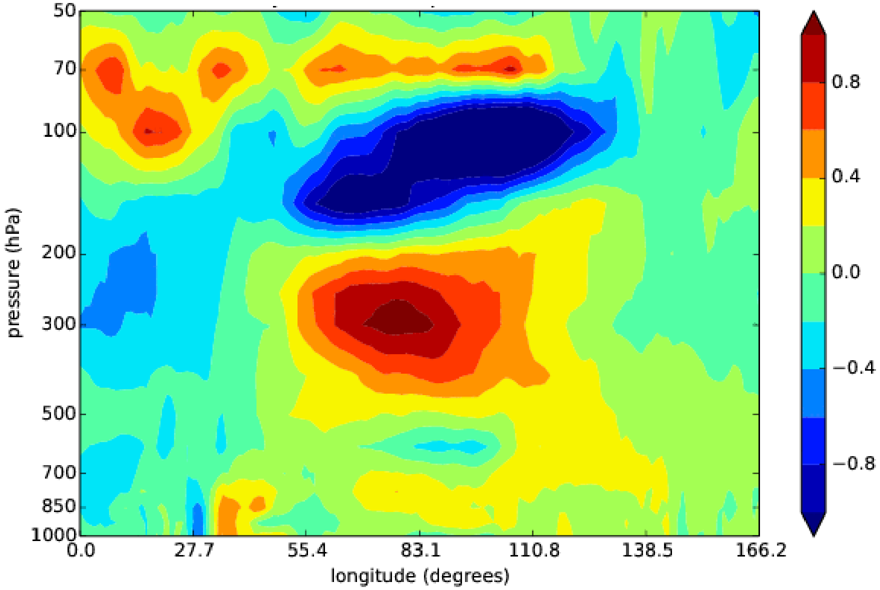
MJO U anomaly



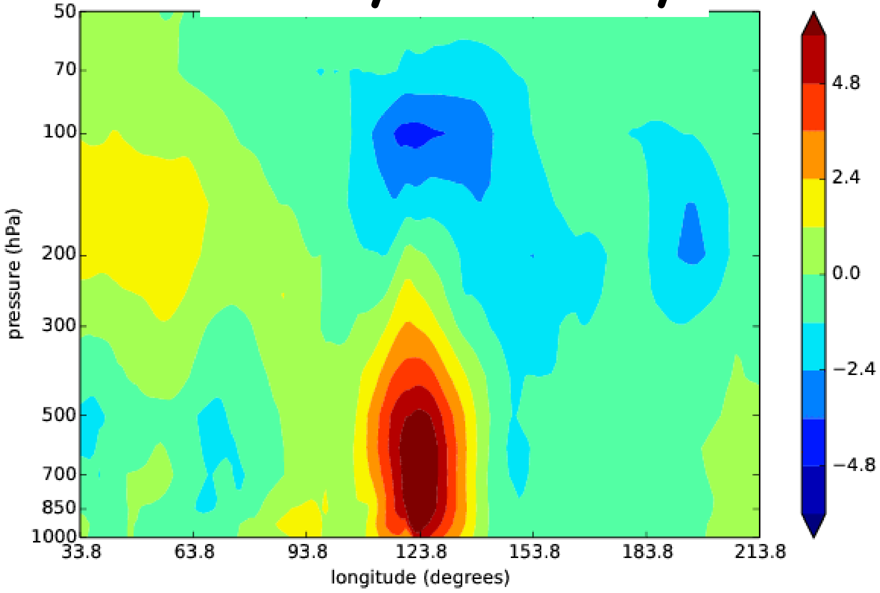
Kelvin U anomaly



MJO T anomaly



Rossby U anomaly

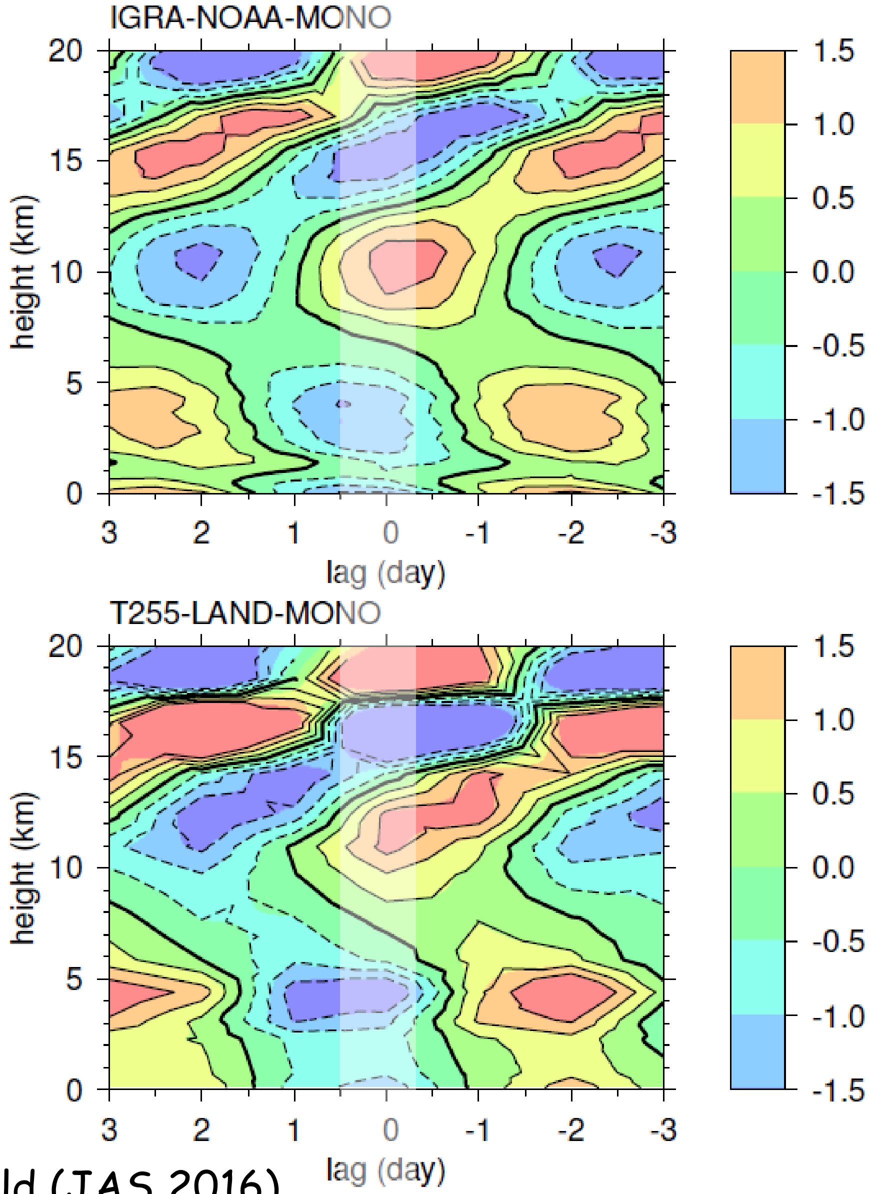


Kelvin waves: vertical structure

At z~10 km, warm anomaly and convective heating are in phase, leading to :

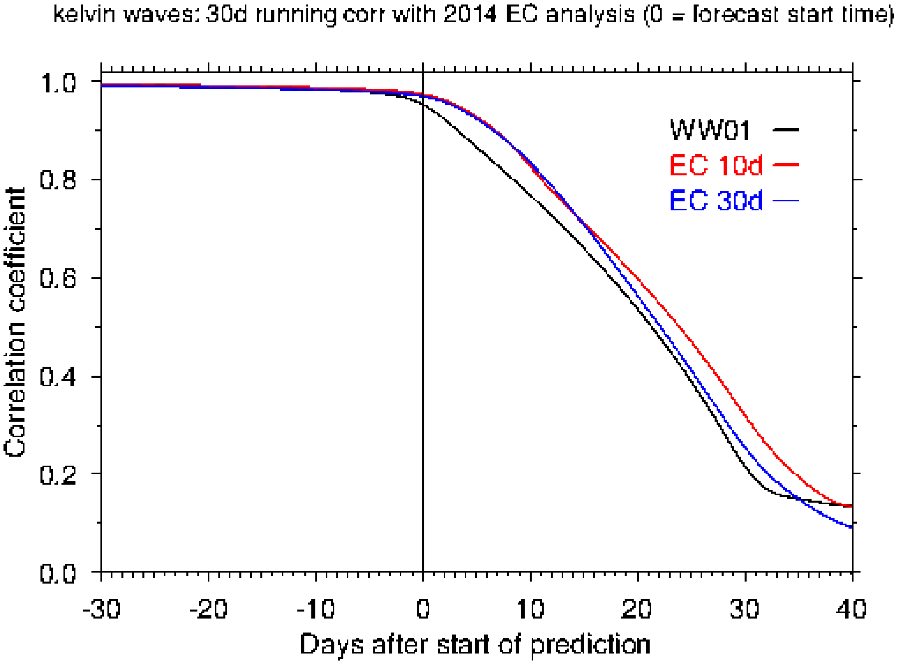
- the conversion of potential in kinetic energy = αω
- The generation of potential energy = N Q

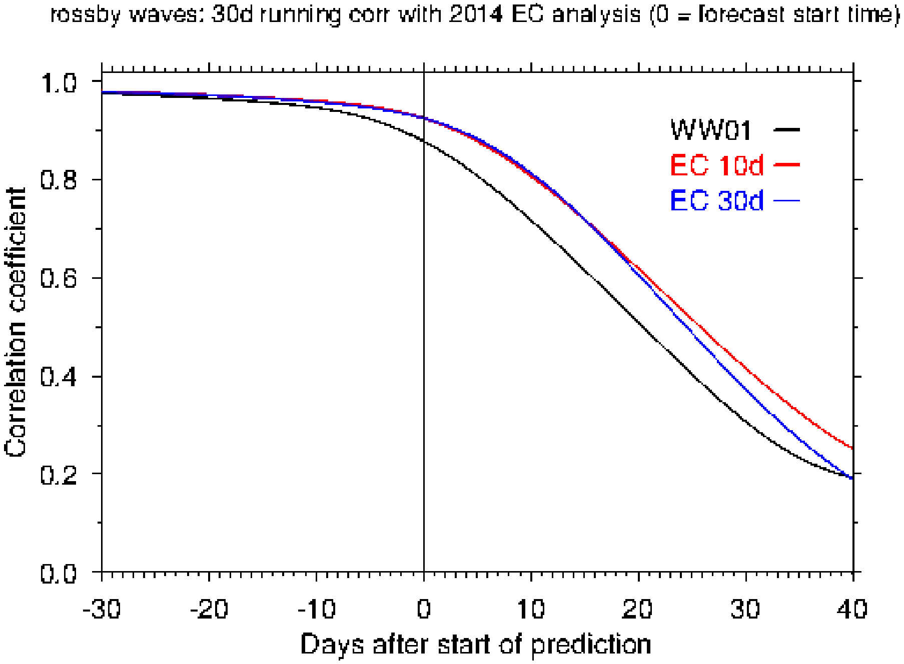
- For inertia gravity waves, horizontal phase and group speed have same sign, but opposite sign for vertical propagation



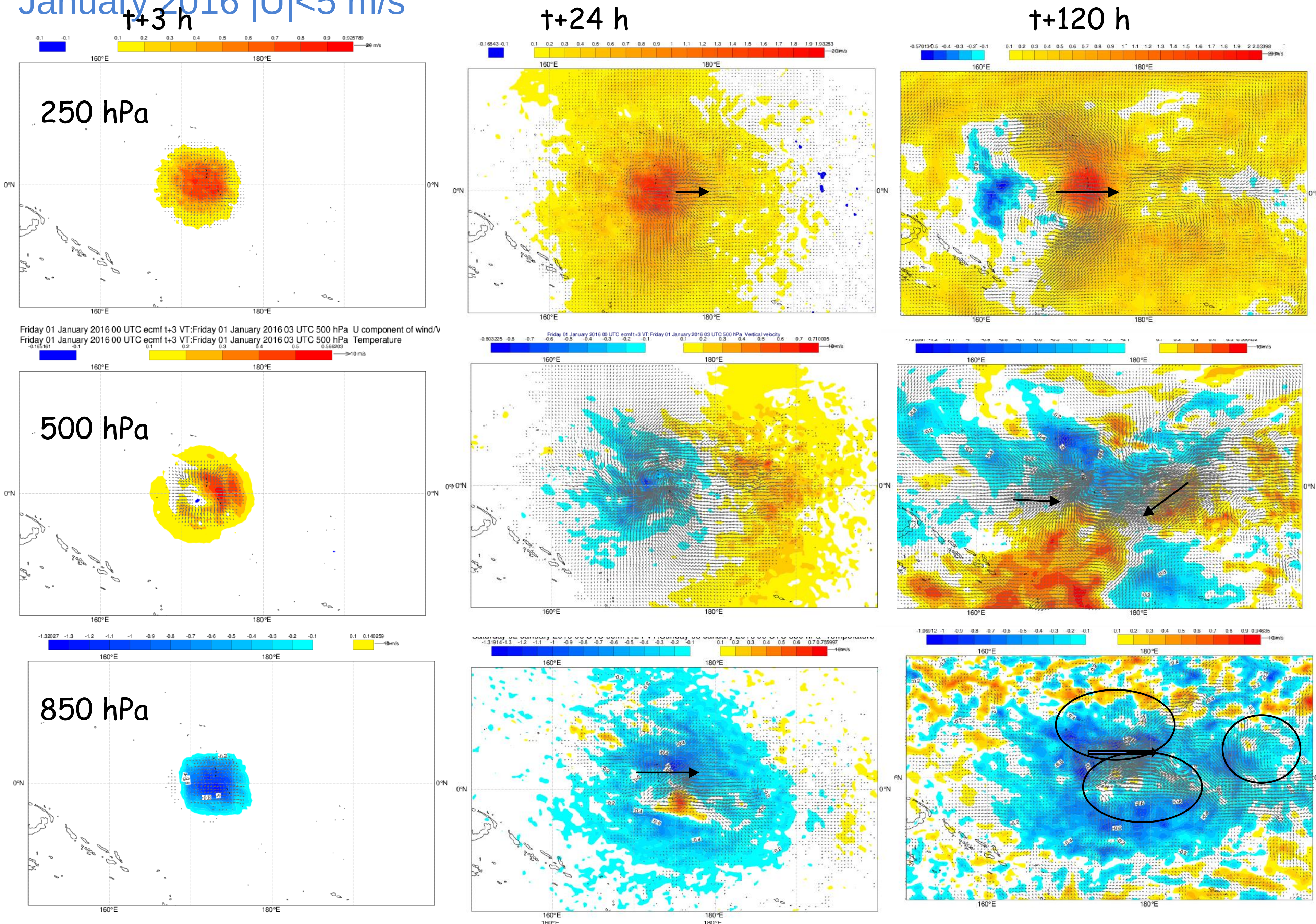
M. Hermann, Z Fuchs, D. Raymond, P. Bechtold (JAS 2016) , see also G. Shutts (2006, Dyn. Atmos. Oc.)

“Predictability” of Kelvin and equat. Rossby waves

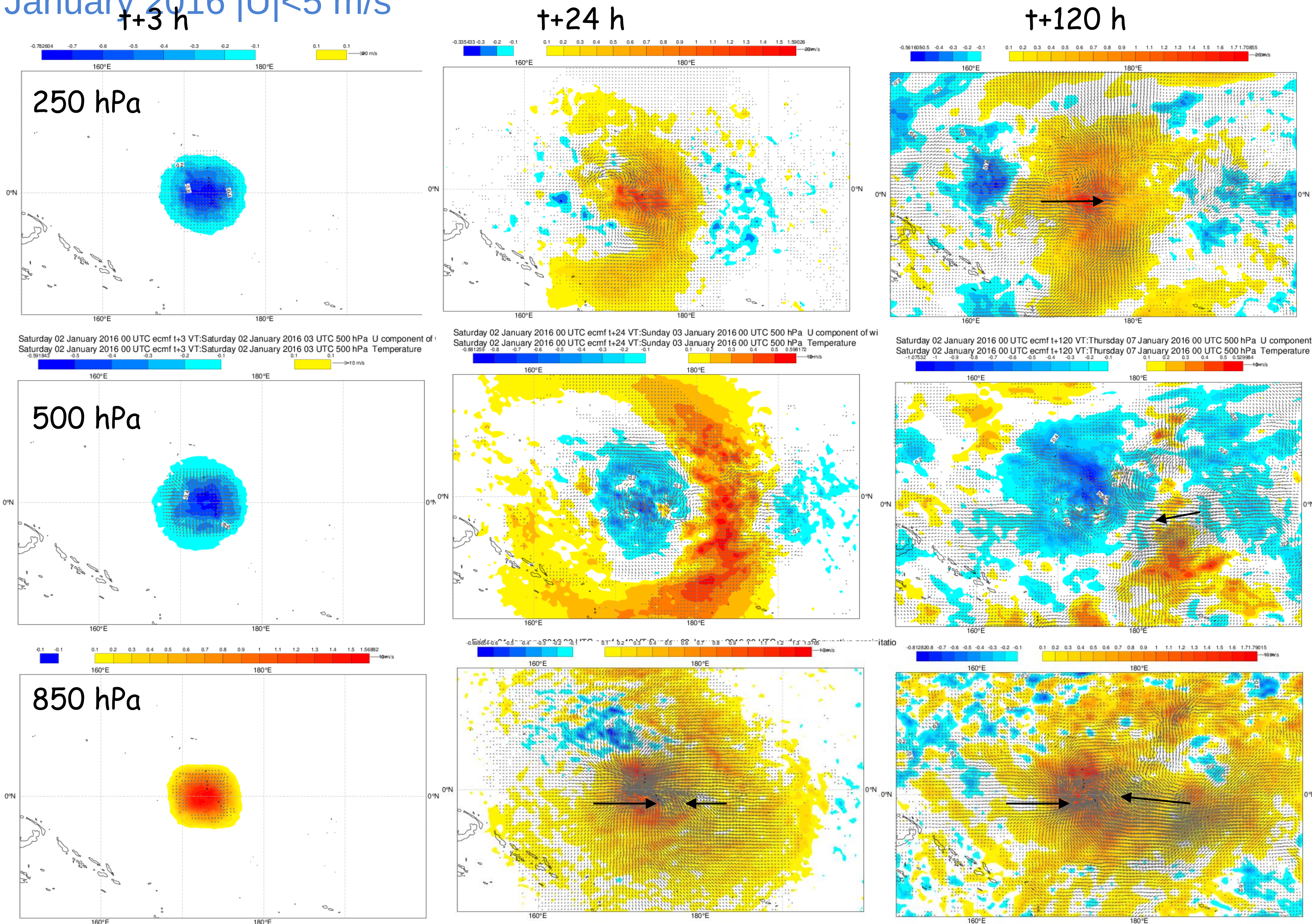




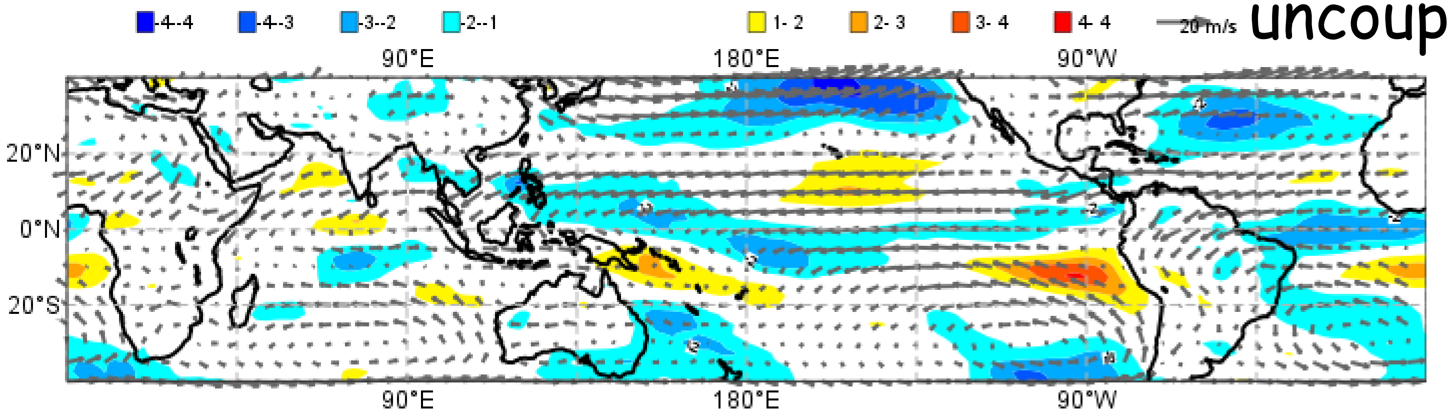
W Pacific equat T perturbation 1: 15 K/d sinus(2π (Ps-p)/(Ps-Pt) , 5x5°, composite January 2016 |U|<5 m/s



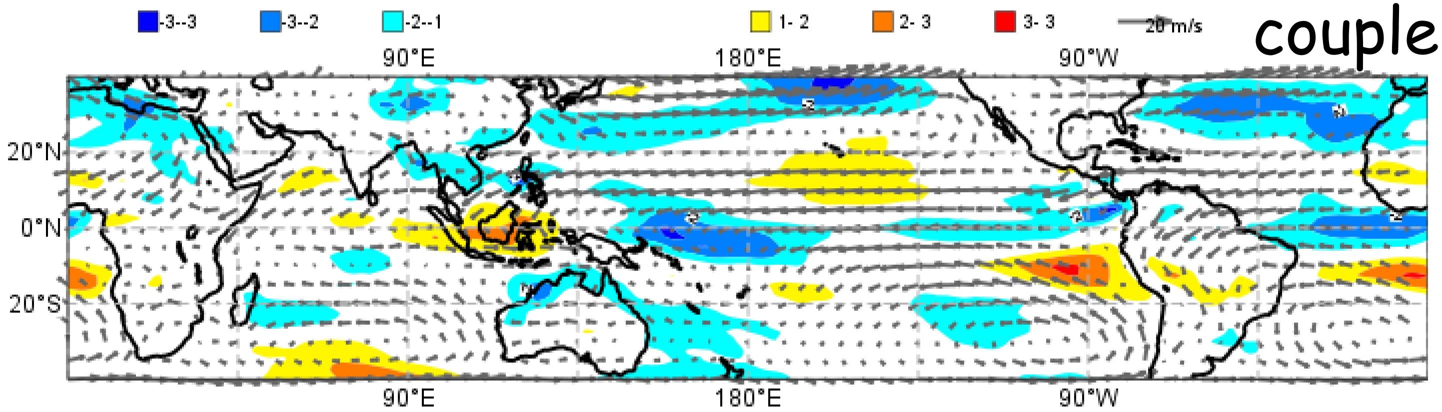
W Pacific equat T perturbation 2: -15 K/d sinus(2π (Ps-p)/(Ps-Pt), 5x5° composite January 2016 |U|<5 m/s



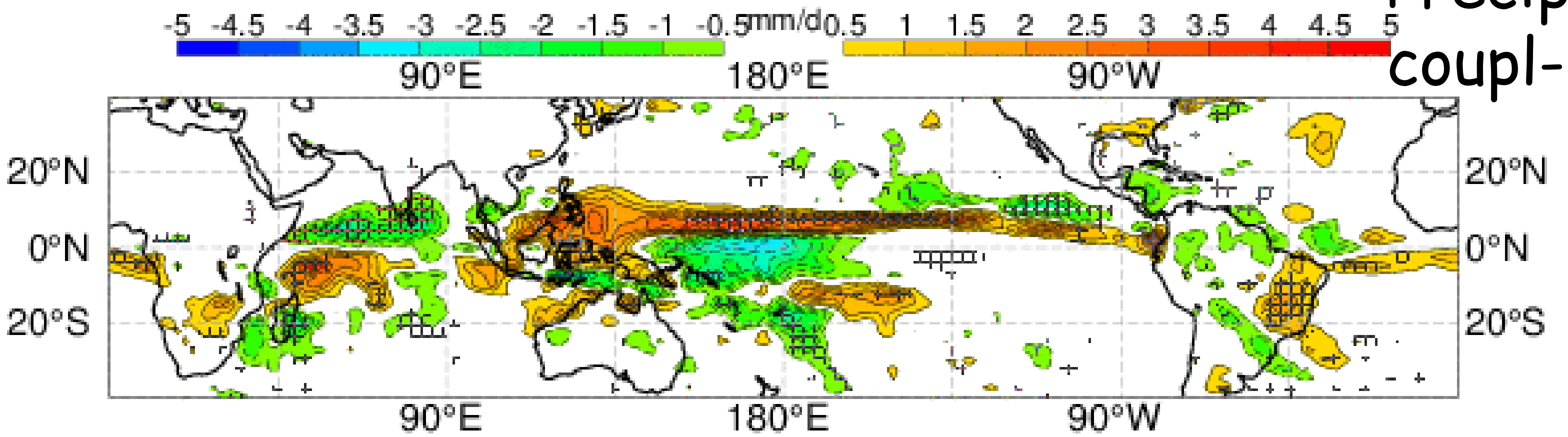
DJF 2000-2004 climatology and U850 hPa errors



uncoupled



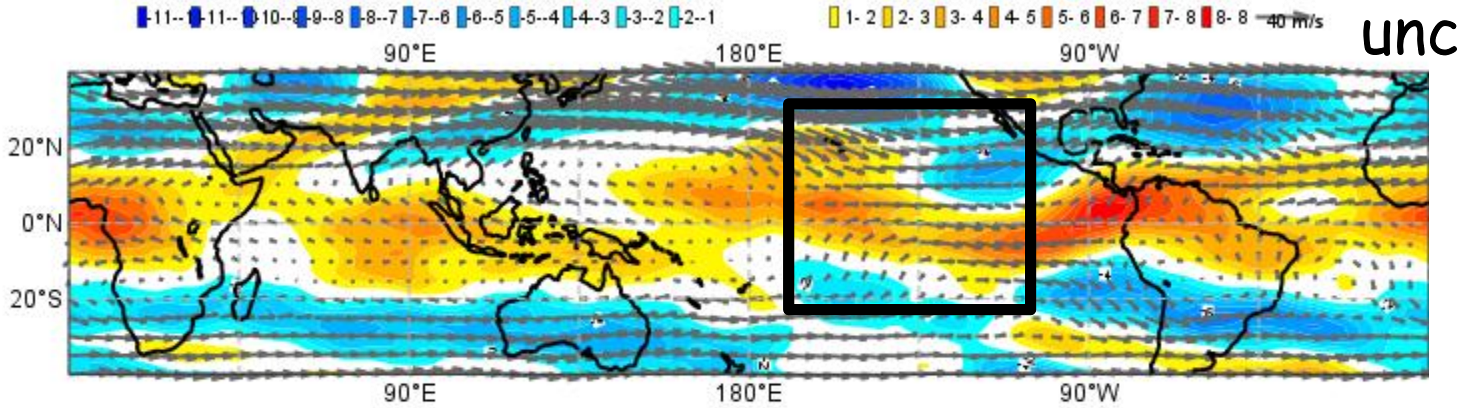
coupled



Precip diff
coupl-uncou

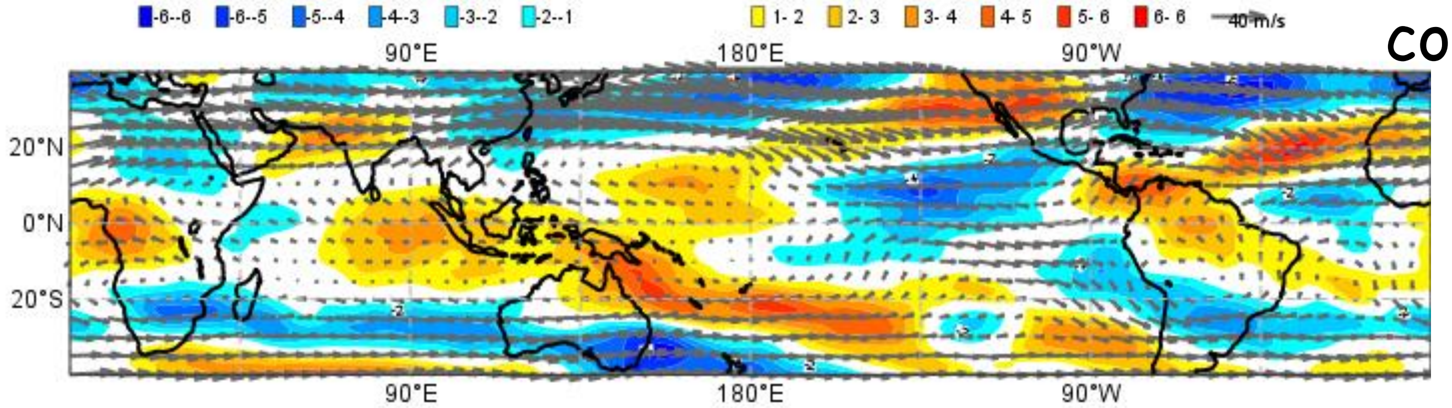
DJF 2000-2004 climatology and U 250 hPa errors

uncoupled



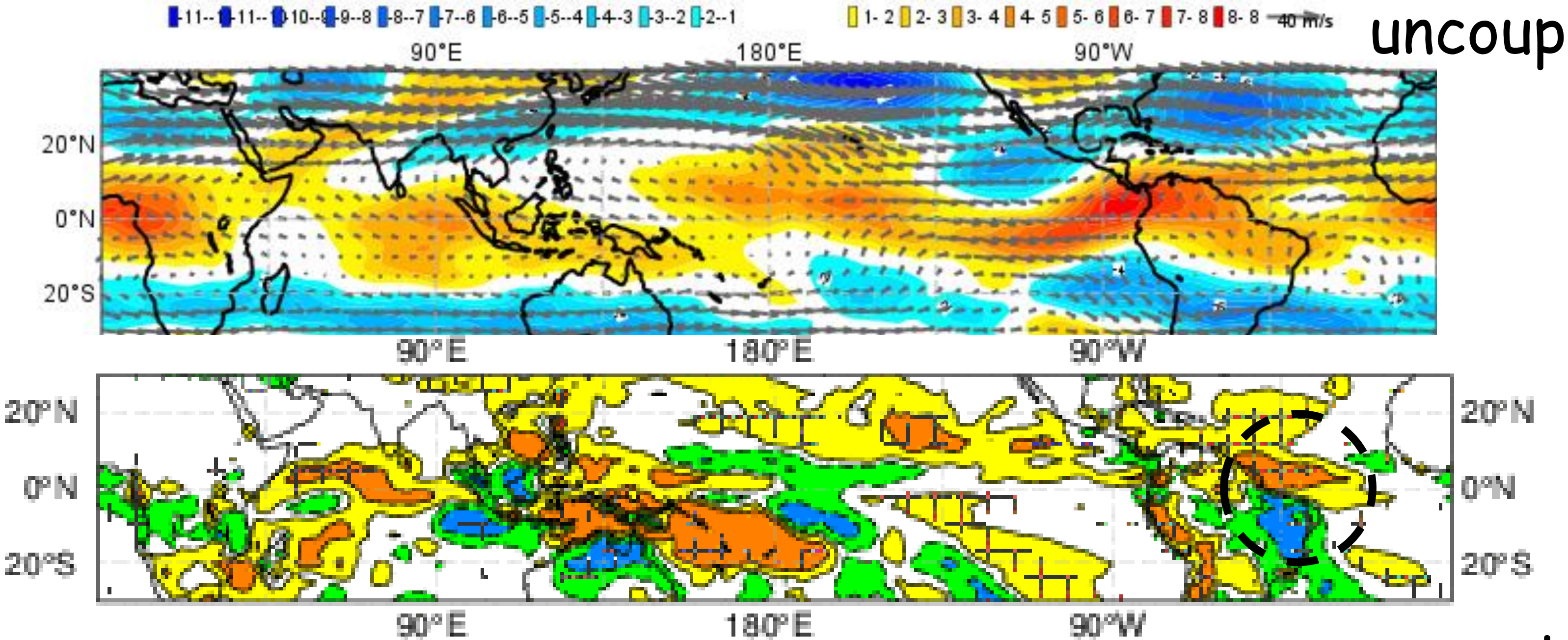
Westerly Jet? (Tomas and Webster 1993)

coupled

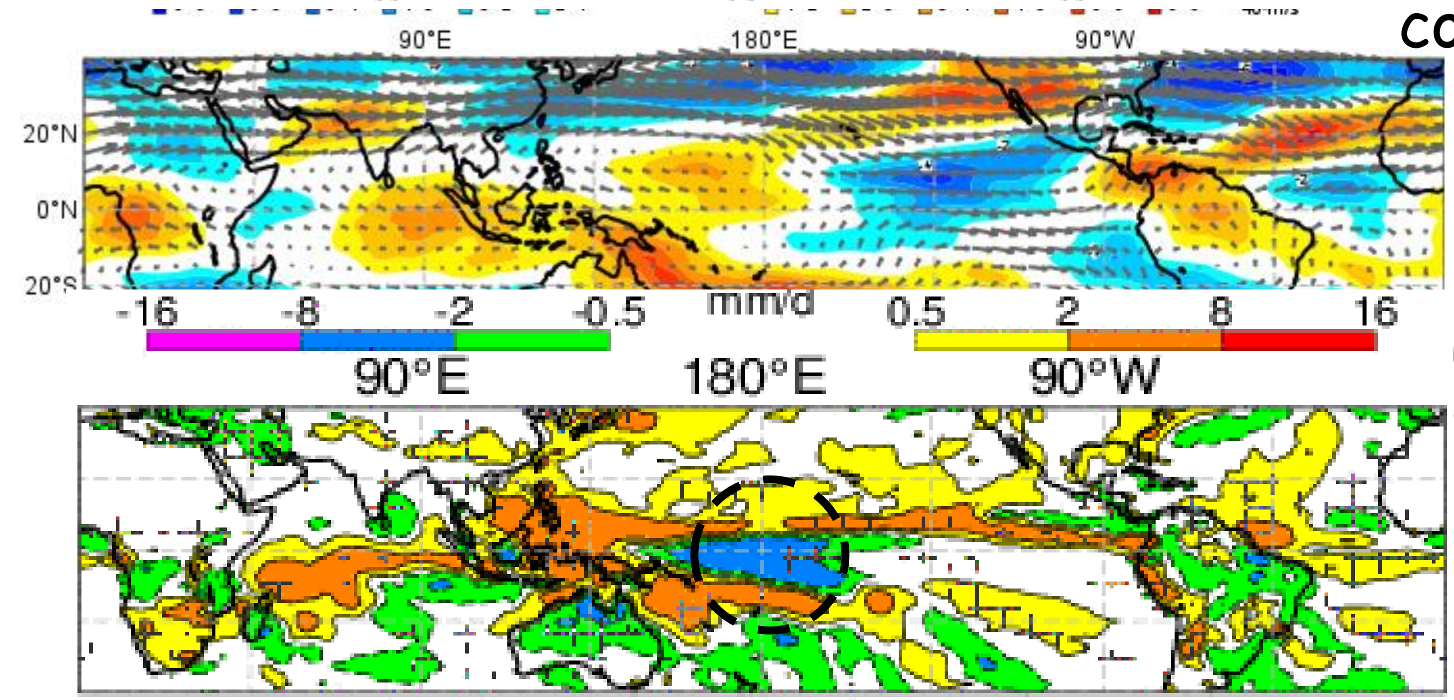


DJF 2000-2004 climatology and U 250 hPa errors

uncoupled



coupled

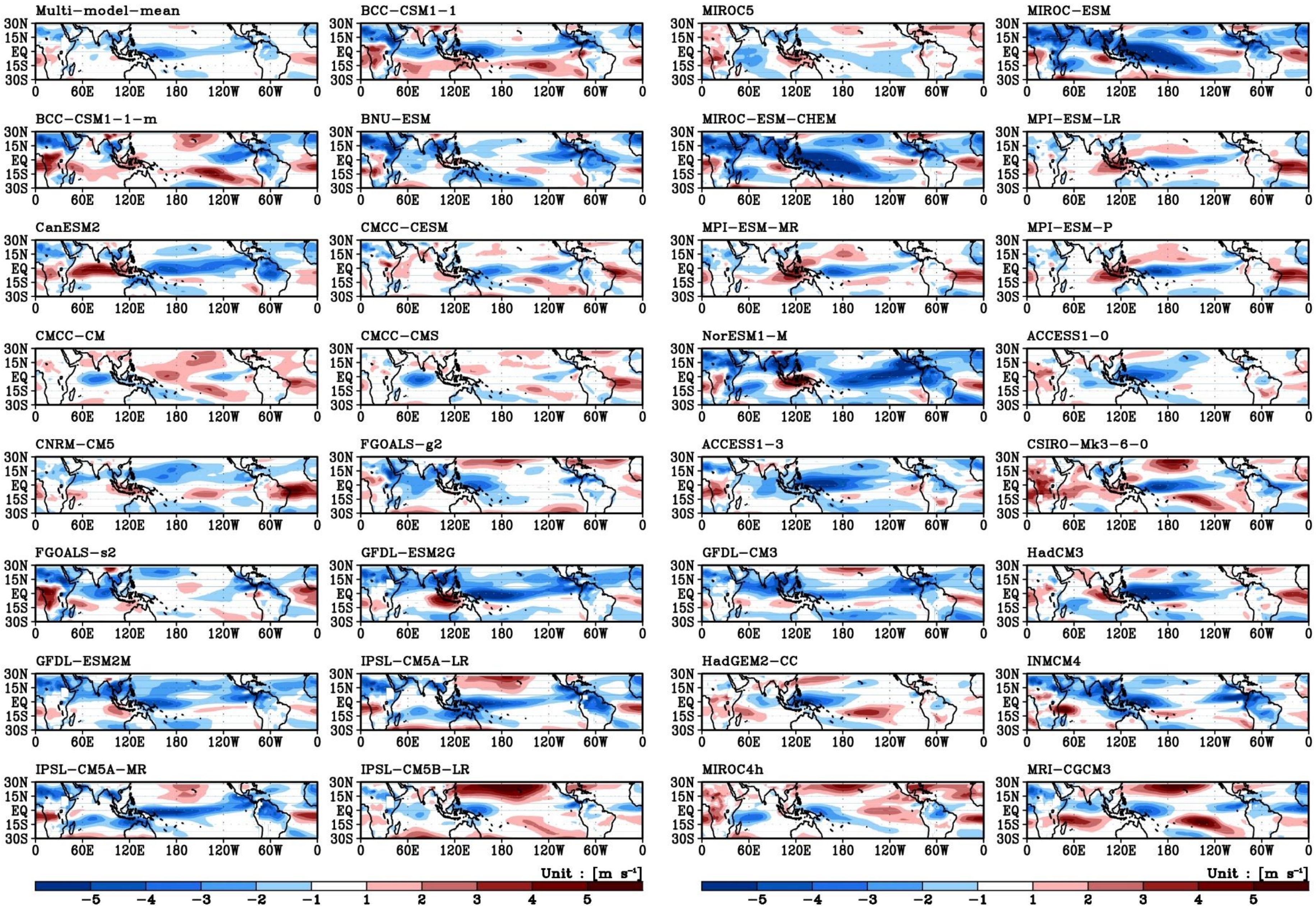


Precip diff
coupled-GP

prepared by D. Kim and M.-S. Ahn

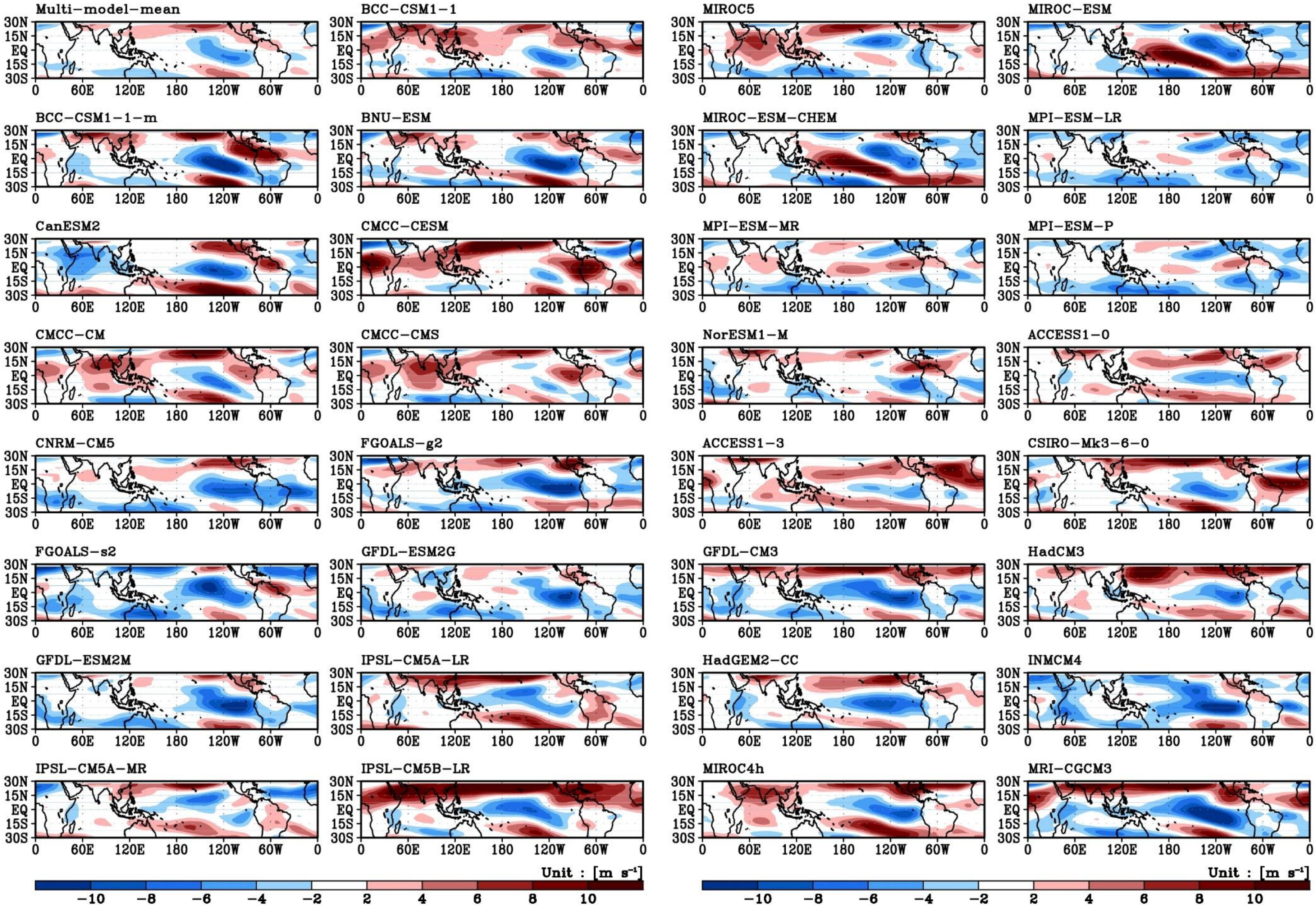
U850 bias of CMIP5 models

1985-2004 (20yrs) boreal winter (NOV-APR) bias against ERA-interim



U250 bias of CMIP5 models

1985-2004 (20yrs) boreal winter (NOV-APR) bias against ERA-interim



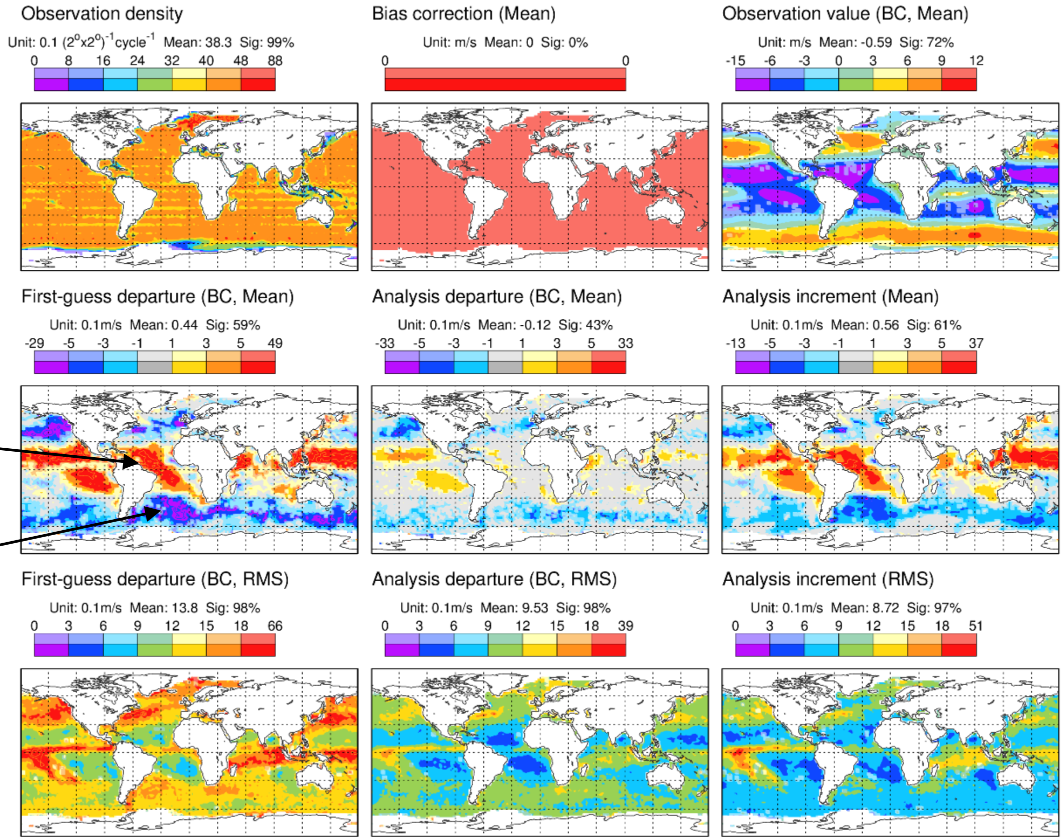
Data assimilation feedback for ASCAT scatterometer surface u

ASCAT considered to have no bias (~0.1ms^{-1}). Certainly small relative to mean first-guess departures (obs-fg)

Tropical/subtropical easterlies too strong ~0.8ms^{-1}

Extratropical westerlies too strong ~0.5ms^{-1}

(Even clearer than in day 1 errors)



Analysis increments strongly correct the first-guess departures

courtesy Mark Rodwell

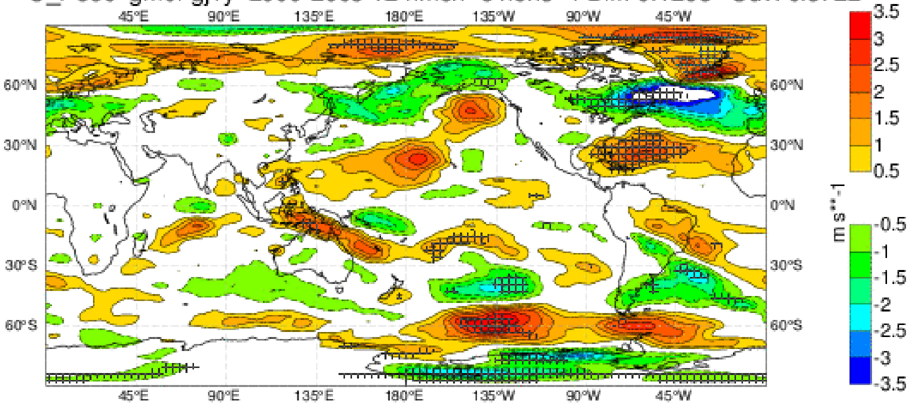
Based on ASCAT observations from all platforms for DJF 2015/16

Sensitivity to Z0_m sea state in heat and/or momentum fluxes

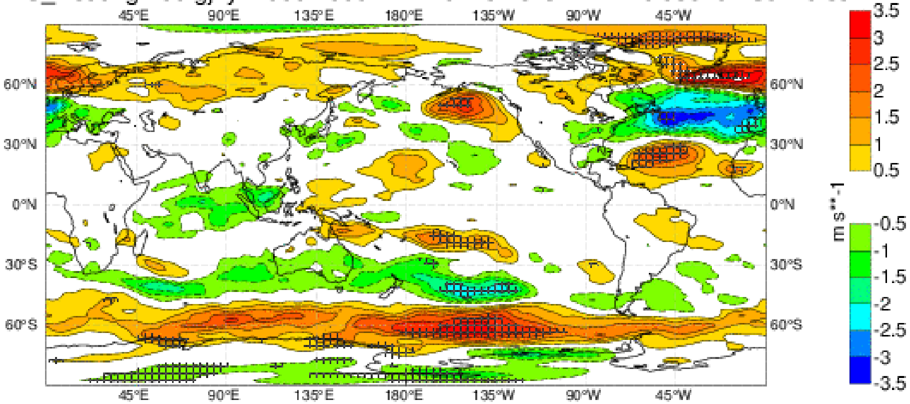
Wave model
switch off = cst
Charnock

cst Charnock=0.018
in heat fluxes only

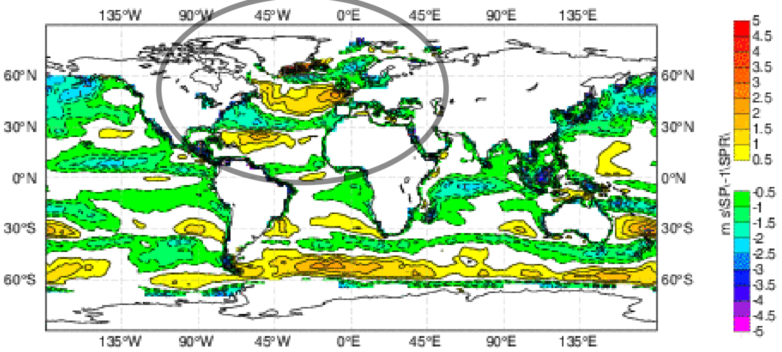
U_P850 gm0i-gj1y 2000-2003 12 nmon=3 nens=4 Diff: 0.1298 Sdv: 0.8722



U_P850 gm00-gj1y 2000-2003 12 nmon=3 nens=4 Diff: 0.08649 Sdv: 0.857

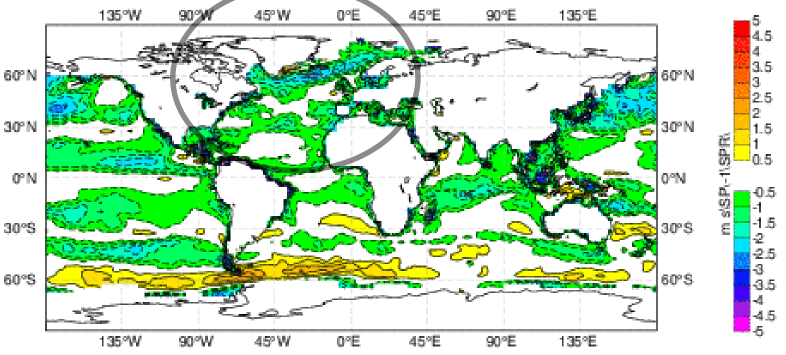


Difference gj1y - Quikscat 50N-S Mean err -0.577 50N-S rms 1.28



Base

Difference gm0i - Quikscat 50N-S Mean err -0.779 50N-S rms 1.29

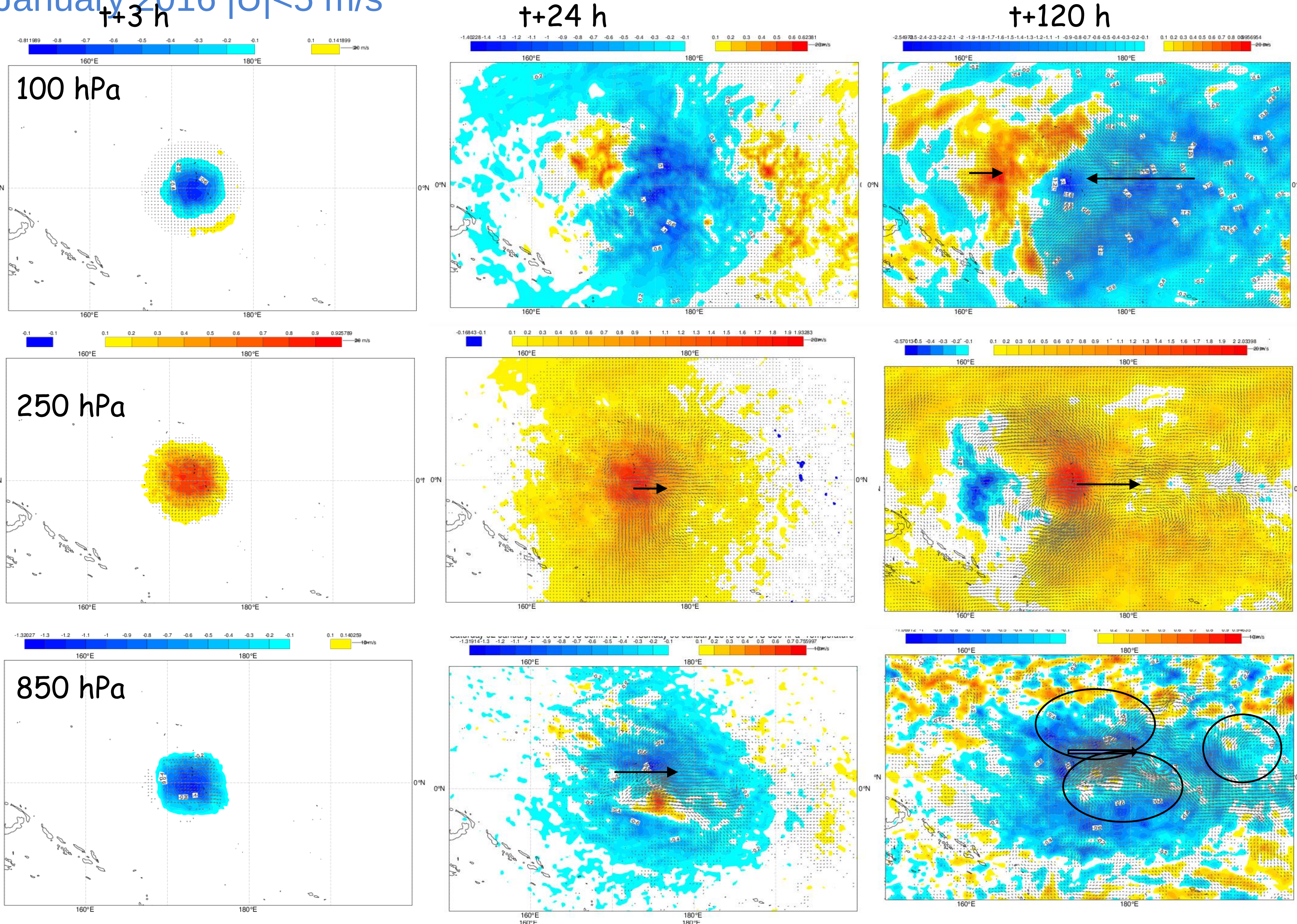


no wave model

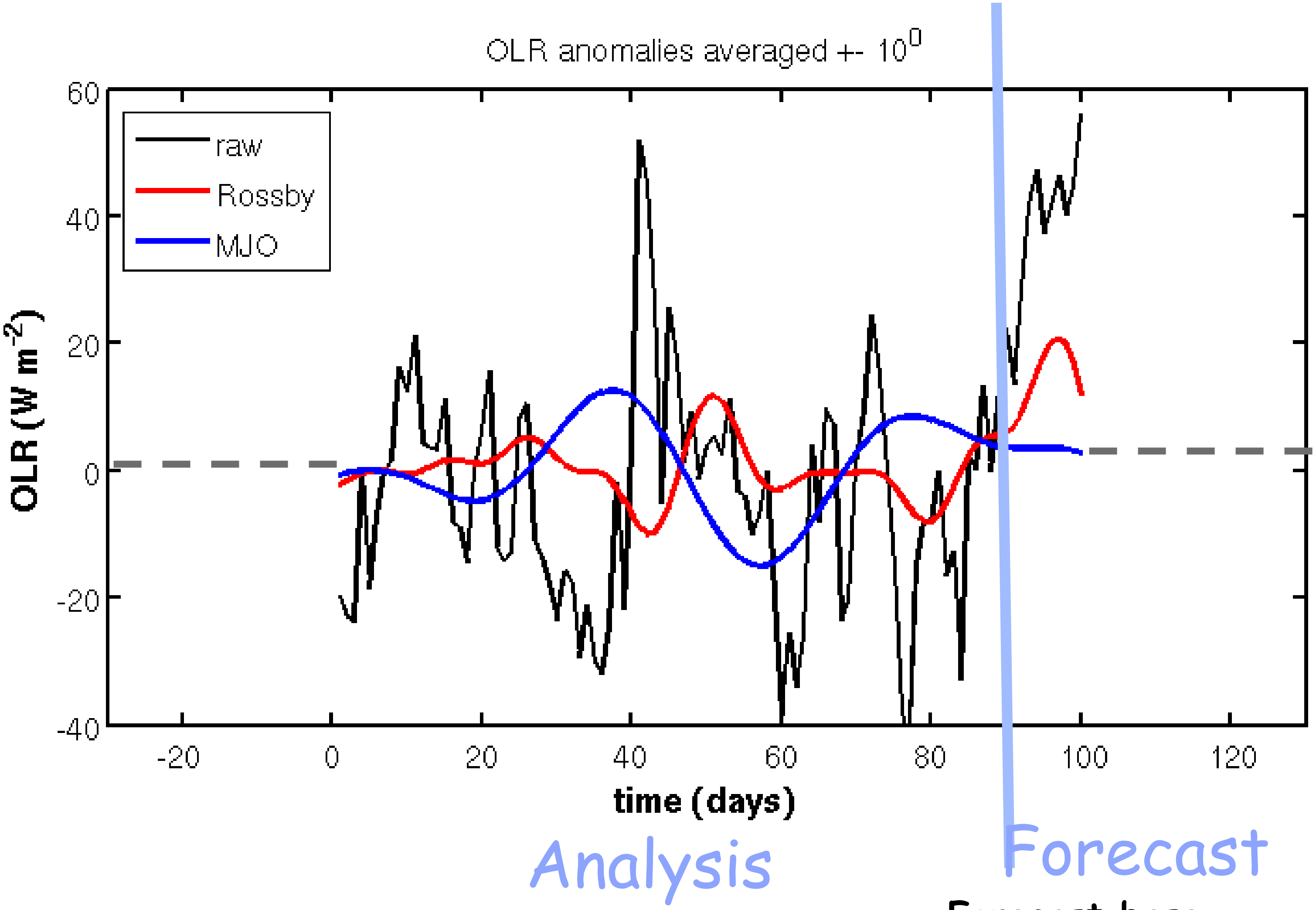
Summary

- Energy flow – importance of conversion rate (large-scale) in upper tropical troposphere
- Good (potential) predictability of large-scale tropical waves, equator wave (energy) trapping
- First order balance between wind and temperature, but close to equator heating is essential as T' small < 2K
- Stratiform perturb. profile generated inertia-gravity wave response with phase speed around 20 m/s, but also MJO like rotational flow –little impact on extra tropics
- Major source for heating (uncertainty) is moisture
- Further uncertainties concern surface roughness and convective momentum transport
- Most important is to get mean circulation right, how errors in heating and dissipation project on it remains a challenge

W Pacific equat T perturbation 1: 15 K/d sinus(2π (Ps-p)/(Ps-Pt) , 5x5°, composite January 2016 |U|<5 m/s



Monitoring and real time prediction of waves



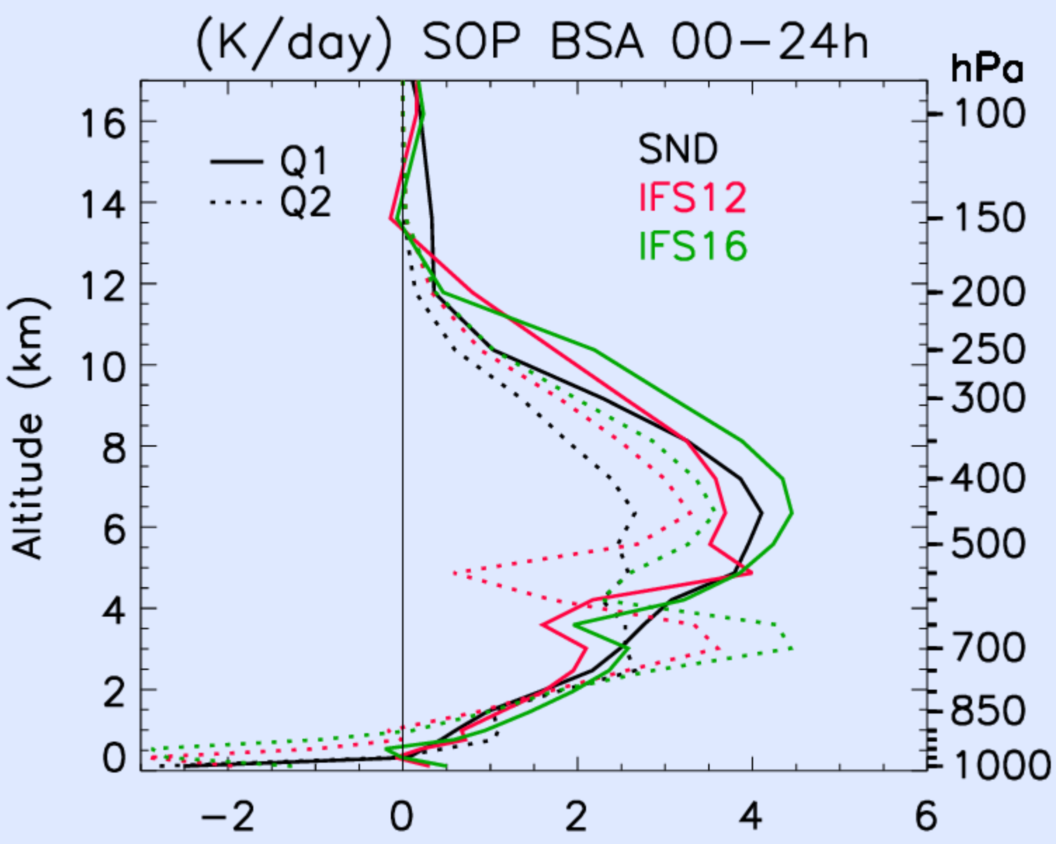
Analysis

Forecast

Forecast base time

following Wheeler and Weickmann (2001, MWR), courtesy software M. Herman

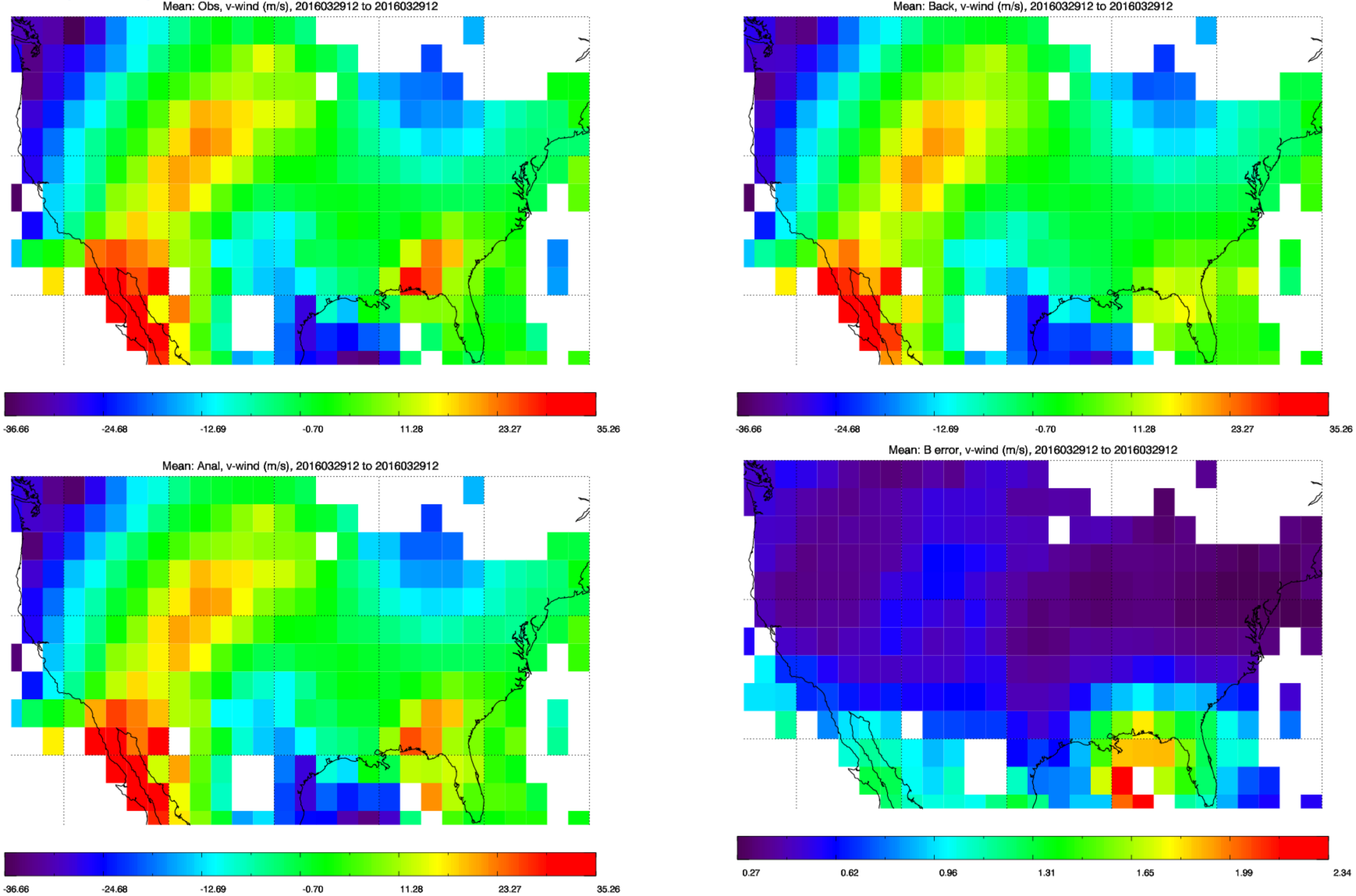
Realism of heating profiles during DYNAMO MJO campaign



- Heating & drying is stronger in 43r3 IFS than in 2012 IFS
- The discontinuity near the melting level is smaller in 43r3 IFS than 2012 IFS.

with J-E Kim and C. Zhang

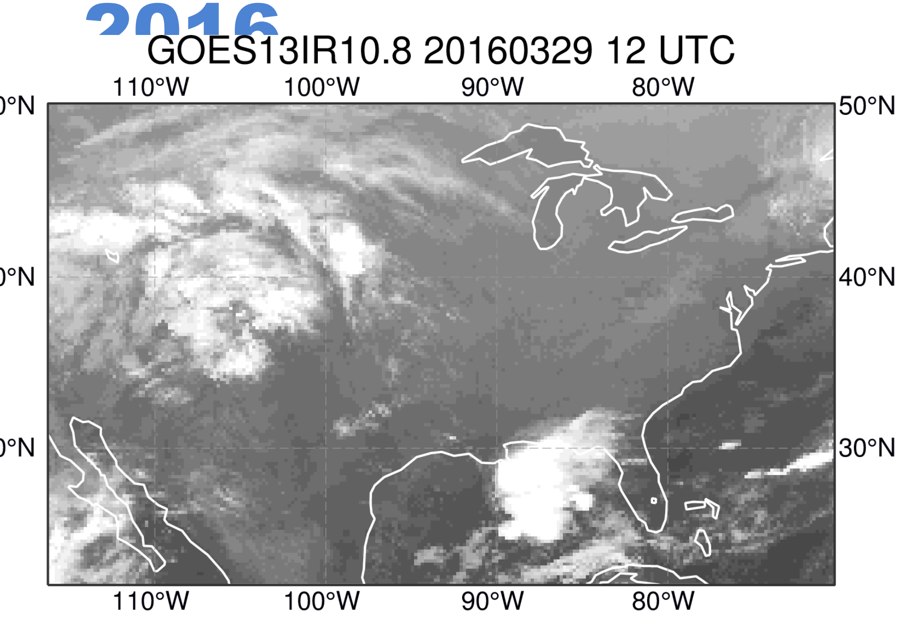
Large "convective" analysis increments in 2016

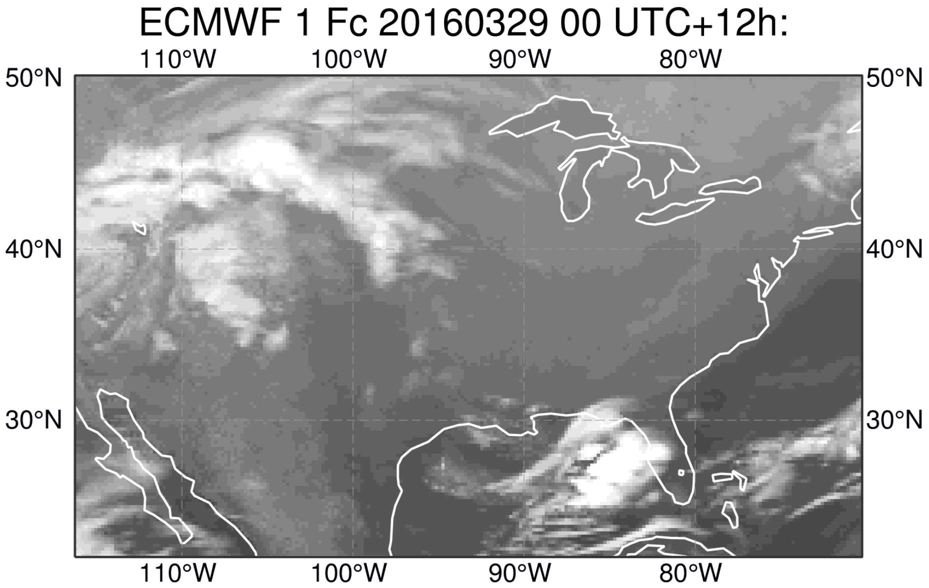


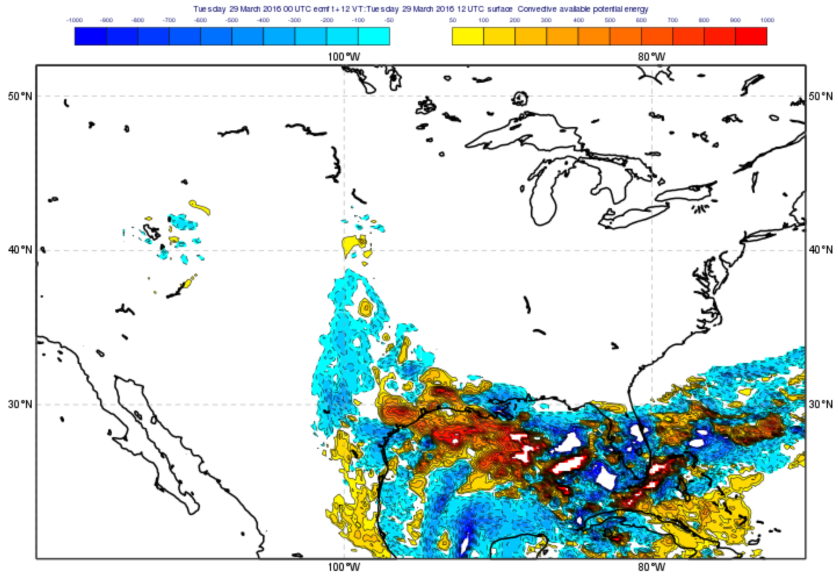
4DVarAnalysis (trajectory) able to correct the background (lack of convection) due to available aircraft Obs and background error statistics

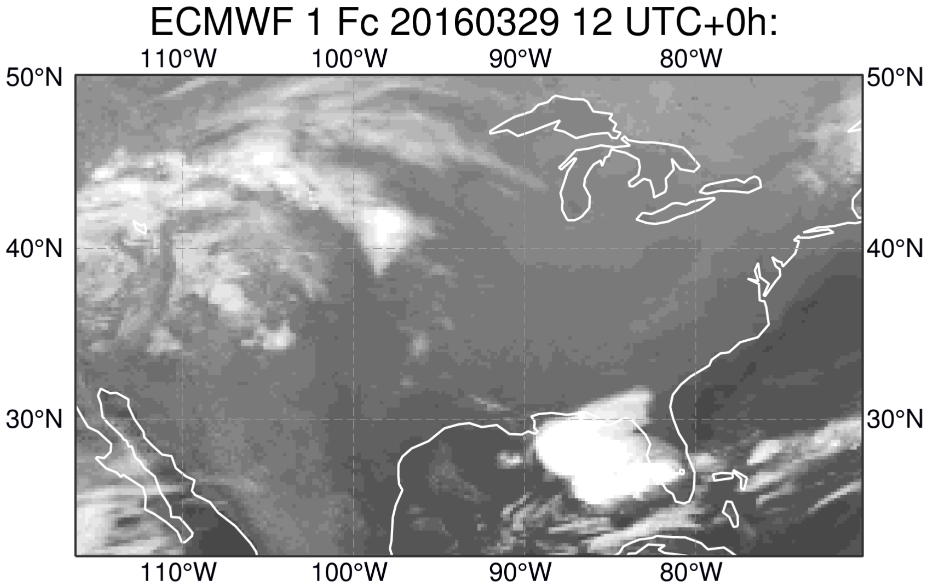
Courtesy Mike Rennie

Large "convective" analysis increments in 2016









Sliht change in large-scale conditions (CAPE/CIN) in analysis and convection is produced with right intensity and produces the 20 m/s outflow Jet

Courtesy Mike Rennie

major uncertainty in heating is in nighttime precip over land