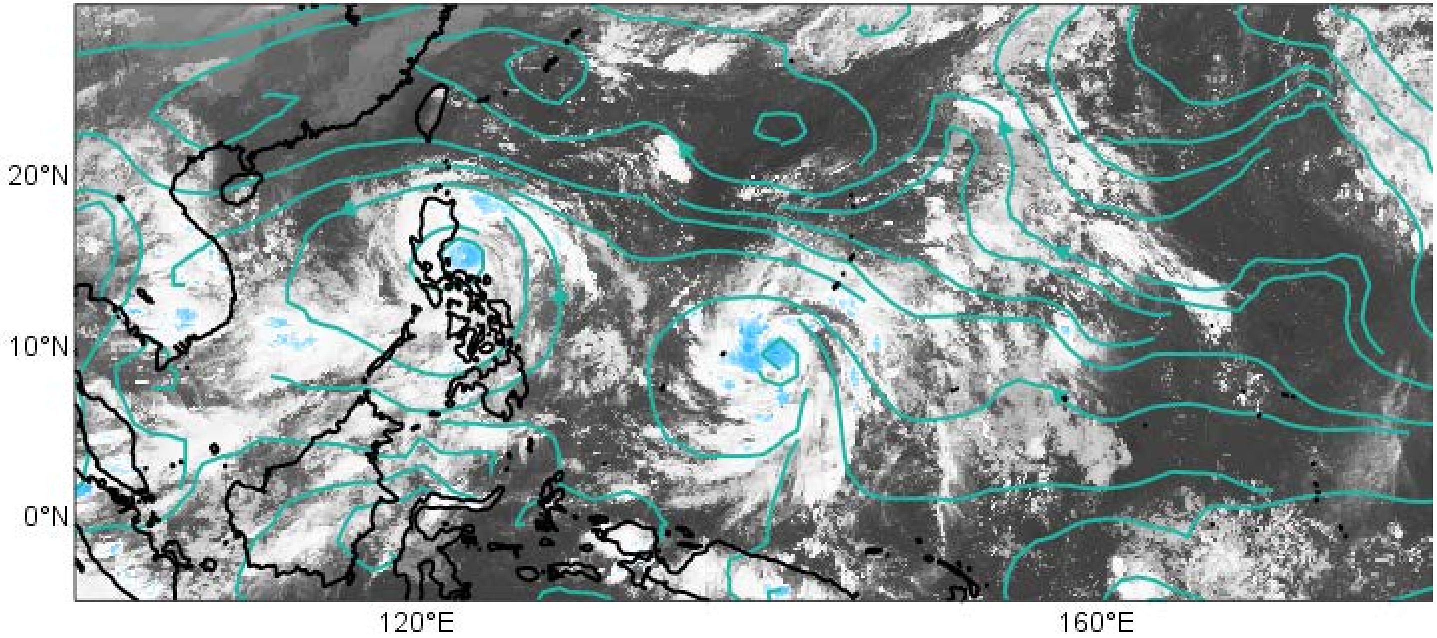
“Winds of convection”



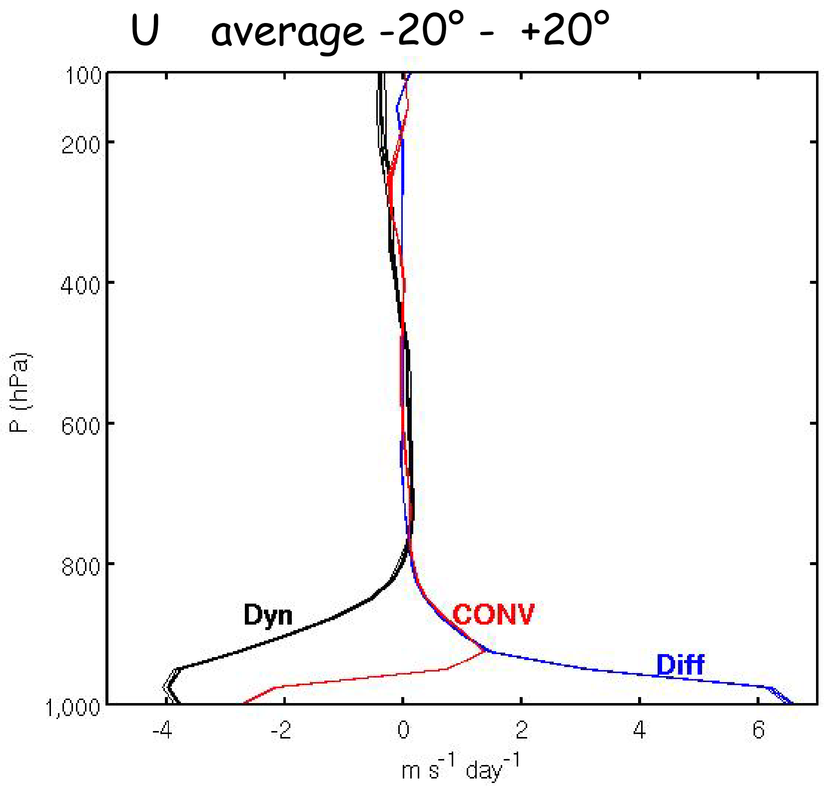
Peter Bechtold

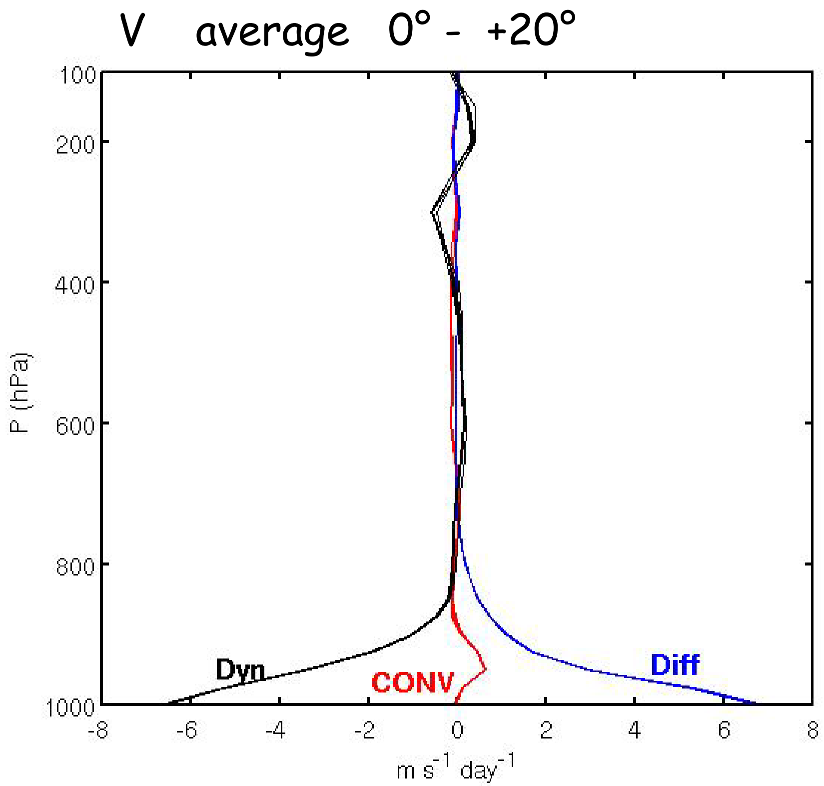
with special thanks to Martin Steinheimer , Michael Hermann, Ž. Fuchs, King-Fai Li, L. Schlemmer, A. Subramanian, F. Vitart, N. Žagar, C. Zhang

and our excellent organizer Parthasarthi Mukhopadhyay

ECMWF

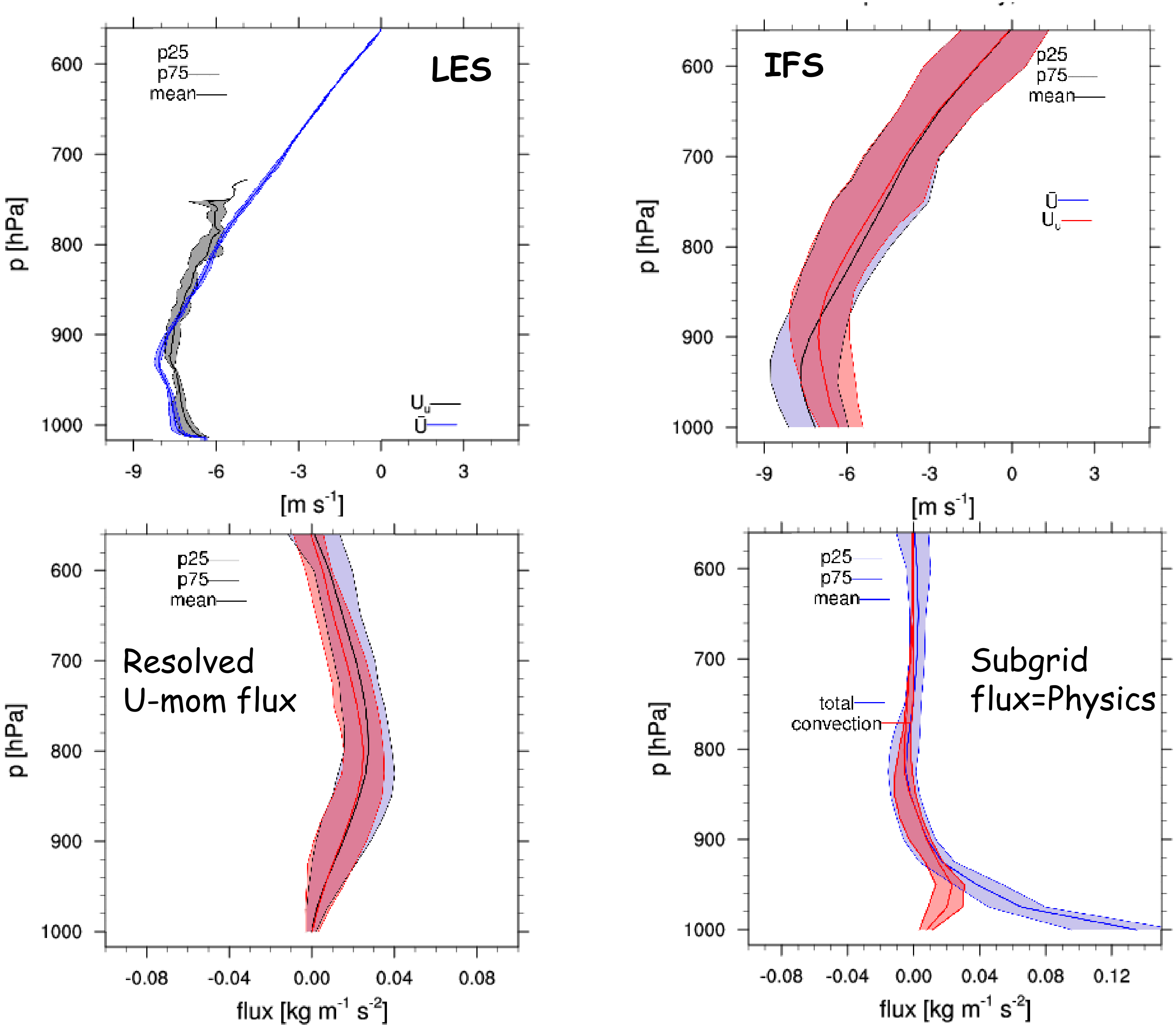
Tropical momentum tendencies





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

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

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

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

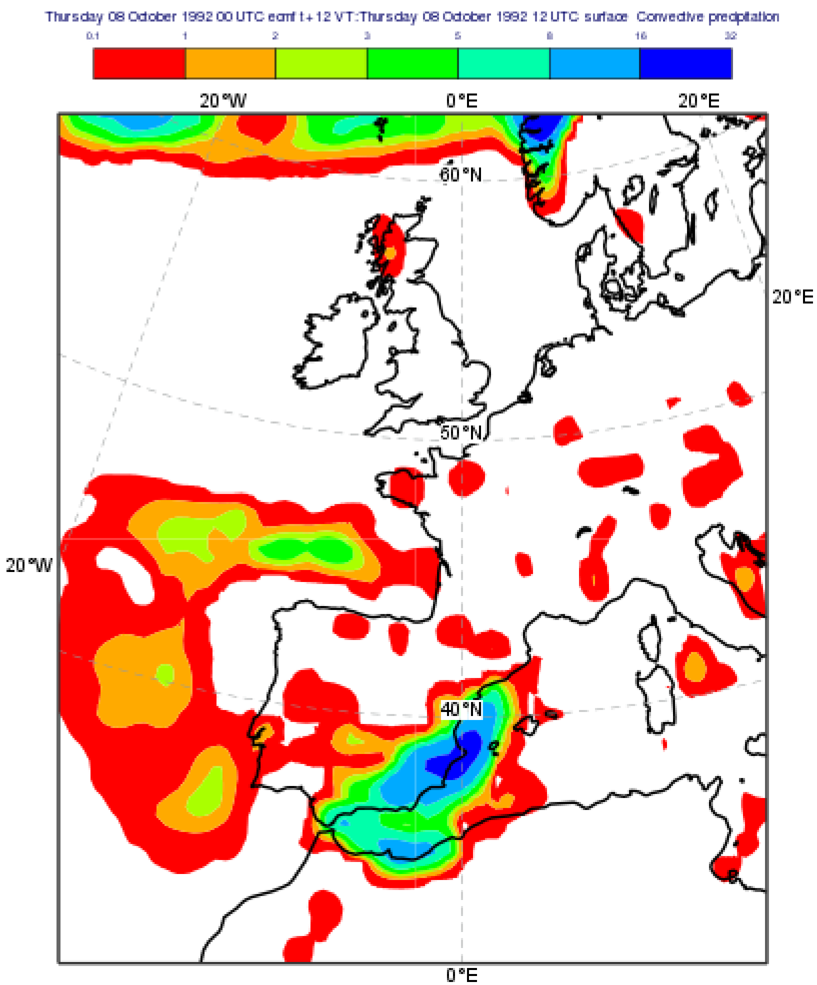
$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + \omega\frac{T}{\theta}\frac{\partial \theta}{\partial p} = c_p^{-1} g\frac{\partial J}{\partial p}$$

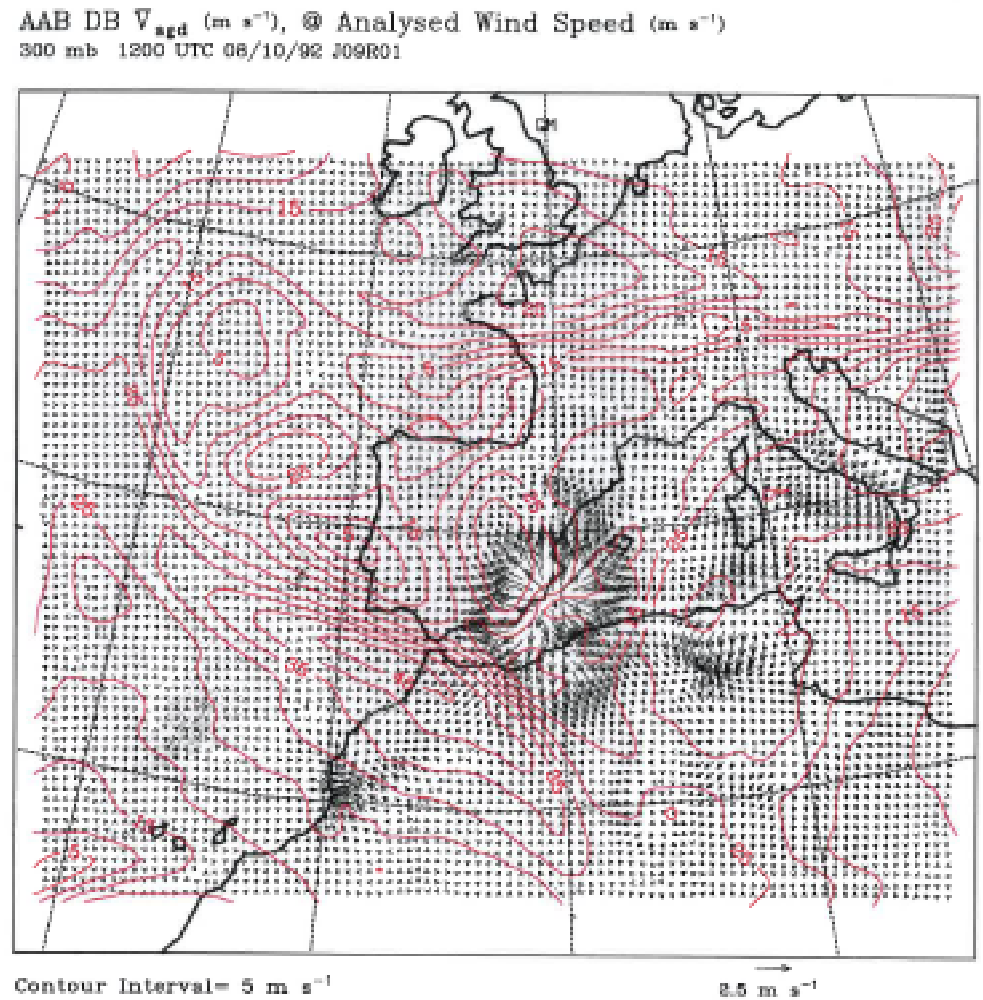
(J.R, Holton) Neglect **J and F** and via **quasi-geostrophic vorticity equation** get from geopotential tendency a diagnostic for **ω, ie obtain divergence from temperature and rotational wind**

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

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

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

Net heating

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

Generation **Conversion**

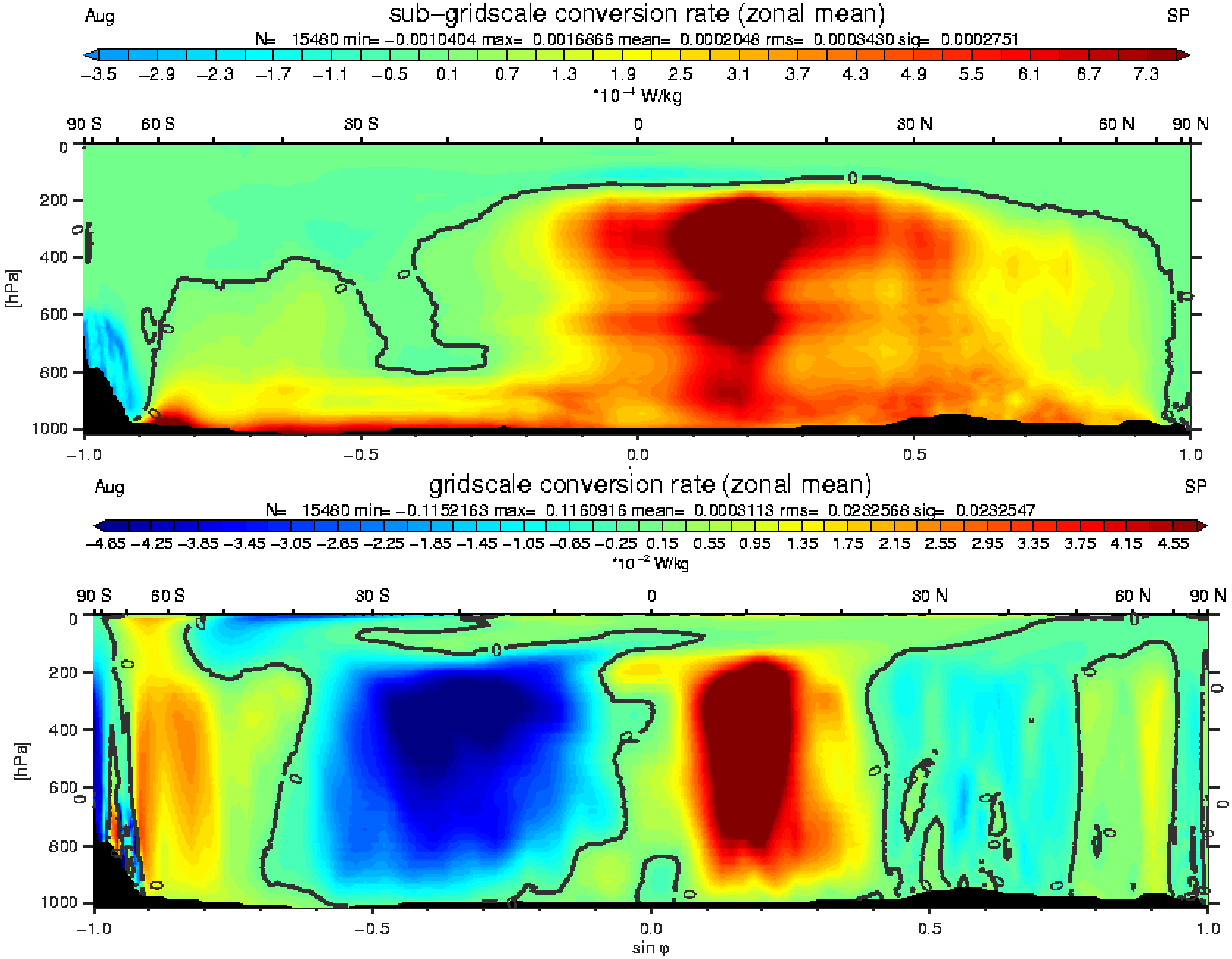
Lorenz efficiency factor

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

kinetic energy

ECMWF

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

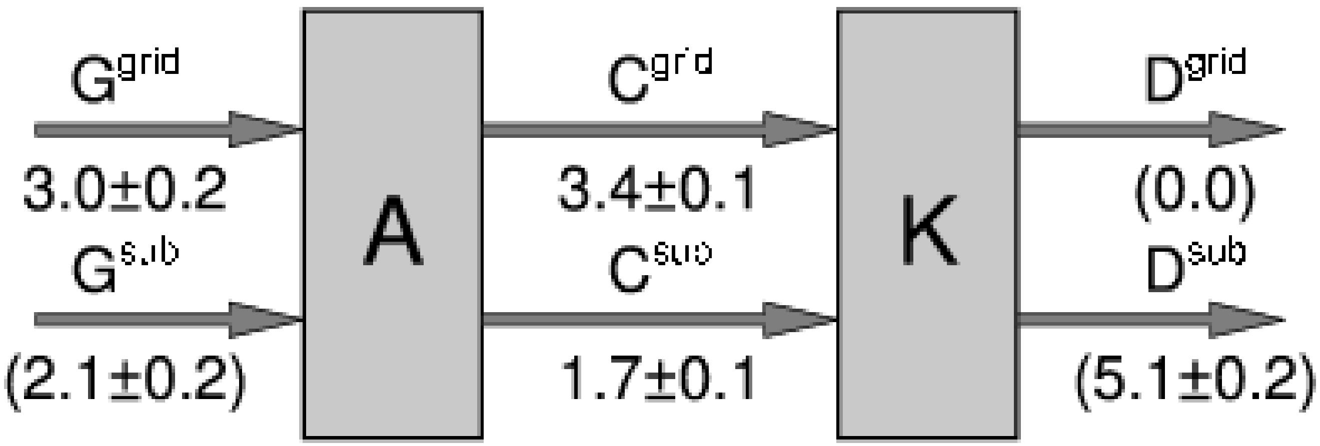


Convection so important because contribution always positive !

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)

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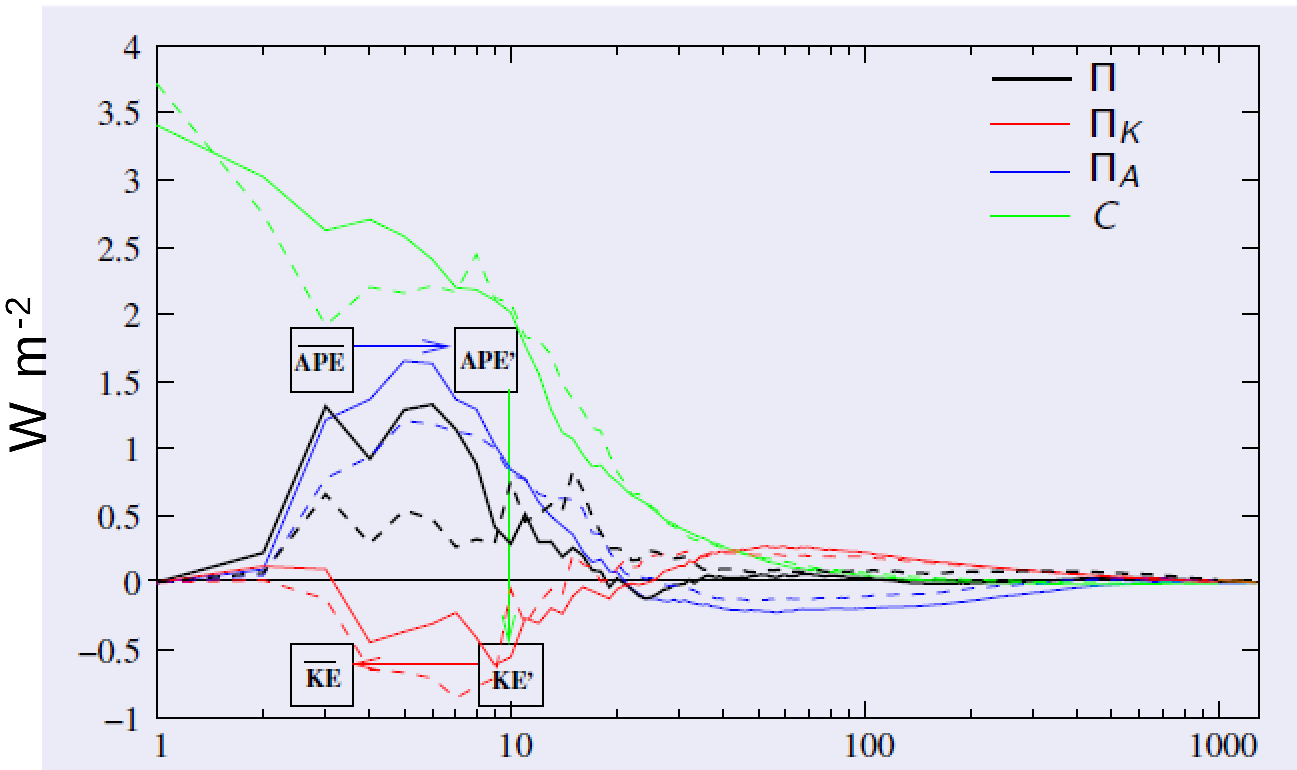
Scale dependent APE – KE analysis

S. Malardel and N. Wedi

following Augier and Lindborg (2013)



Production/ Flux

Conversion A->K

$$T = -\partial \Pi_l / \partial l$$

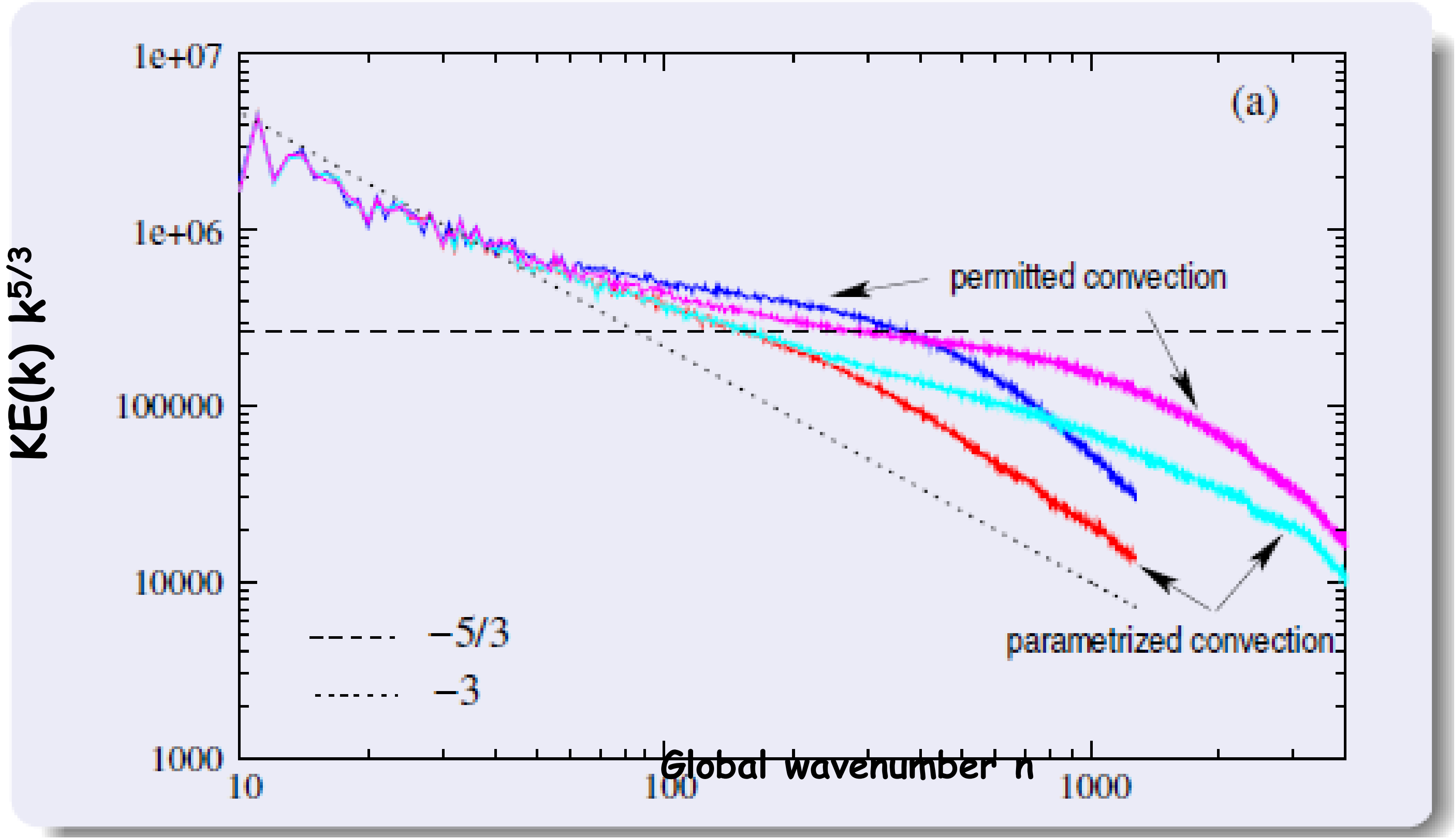
? ?

down

up

ECMWF

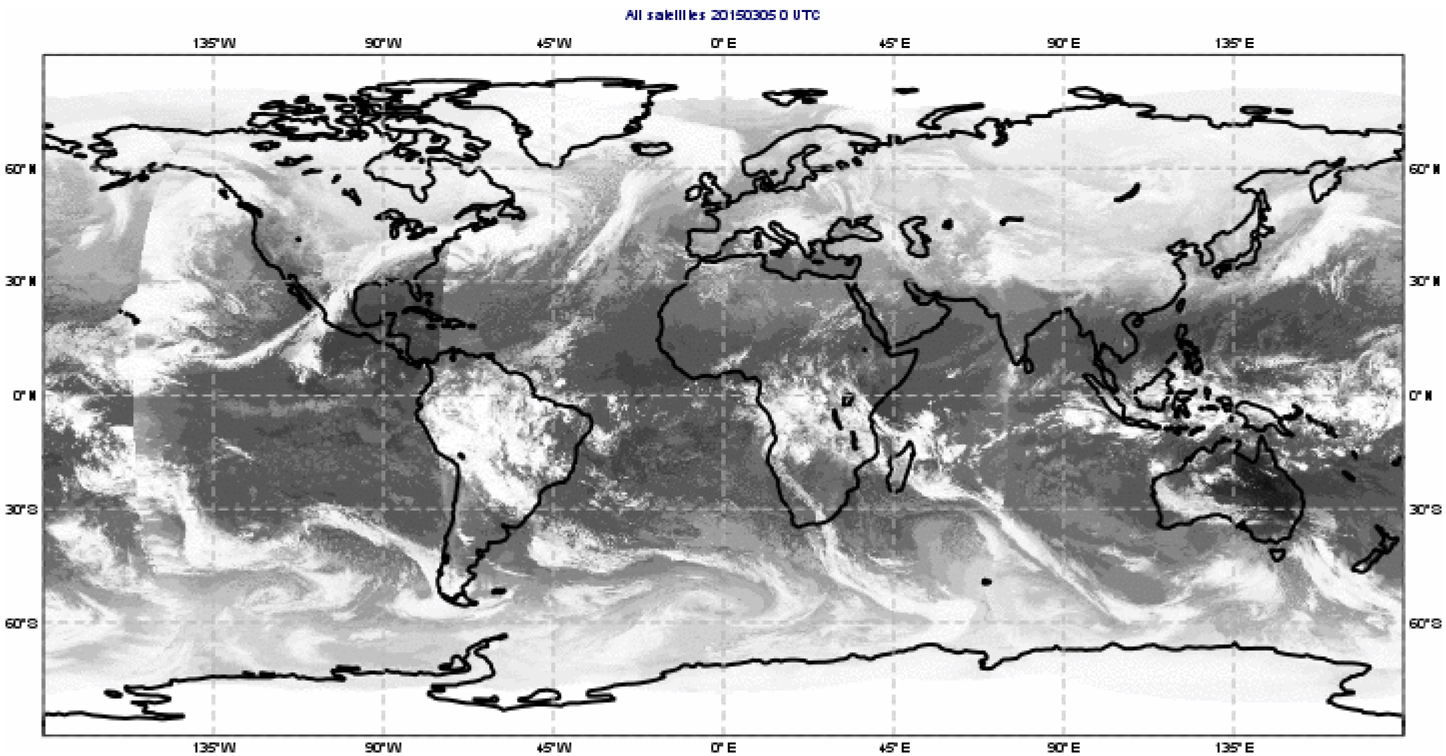
Resolved kinetic energy spectra with and without parametrized deep convection (*S. Malardel & N. Wedi*)



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

TL4000=5 km with and without deep

The global circulation and its modes (waves)



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

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

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

(Hermite)

ECMWF

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

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

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

$$\cancel{\frac{\partial h'}{\partial t}} + H\left(\frac{\partial u'}{\partial x} + \frac{\partial v'}{\partial y}\right) = 0$$

WTG

Dissipation+Heating

$$-\varepsilon u'$$

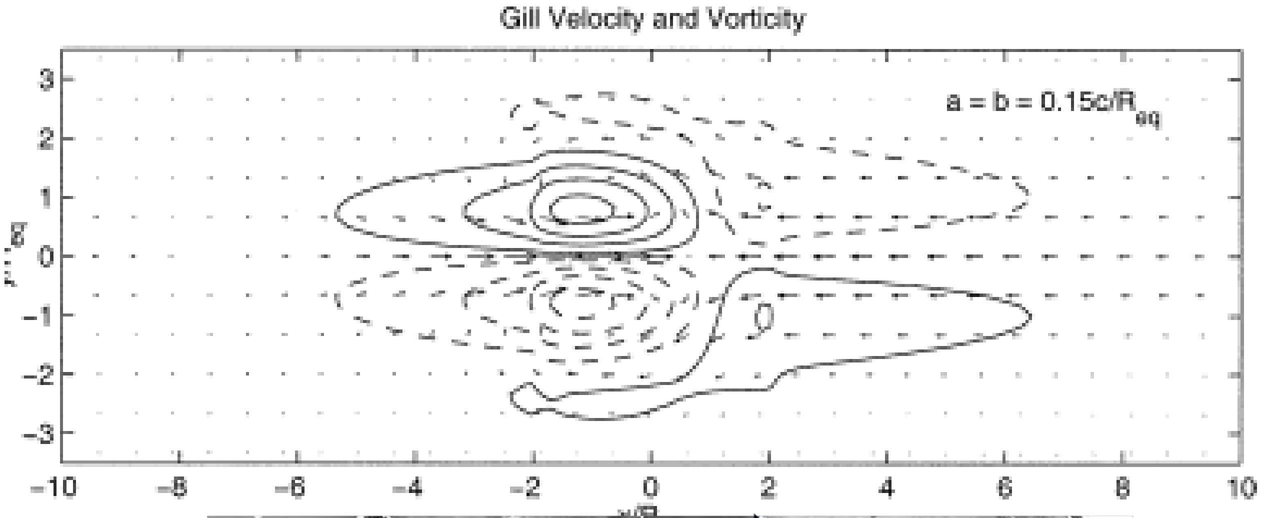
$$-\varepsilon v'$$

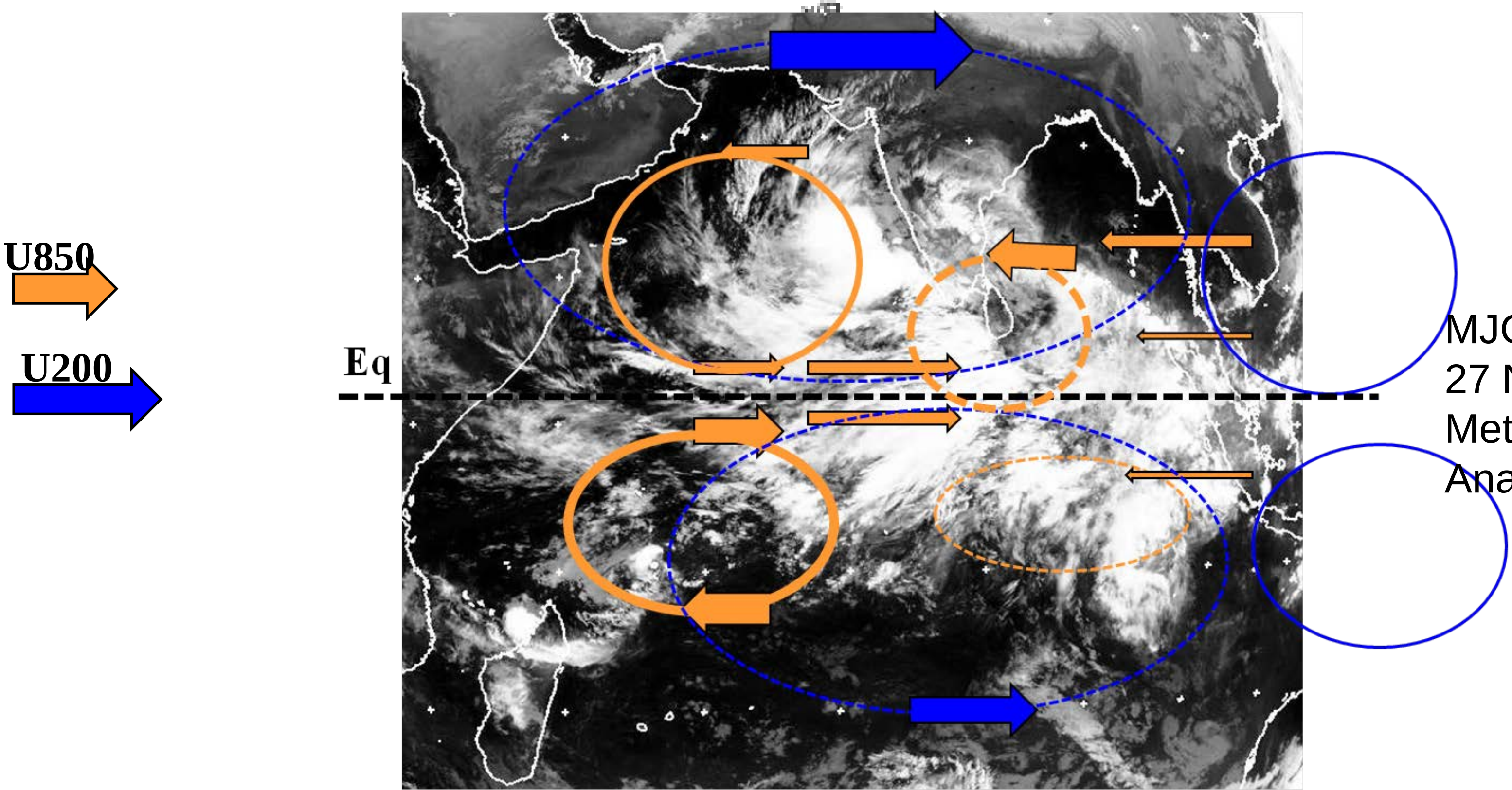
$$+HQ - \varepsilon h'$$

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

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

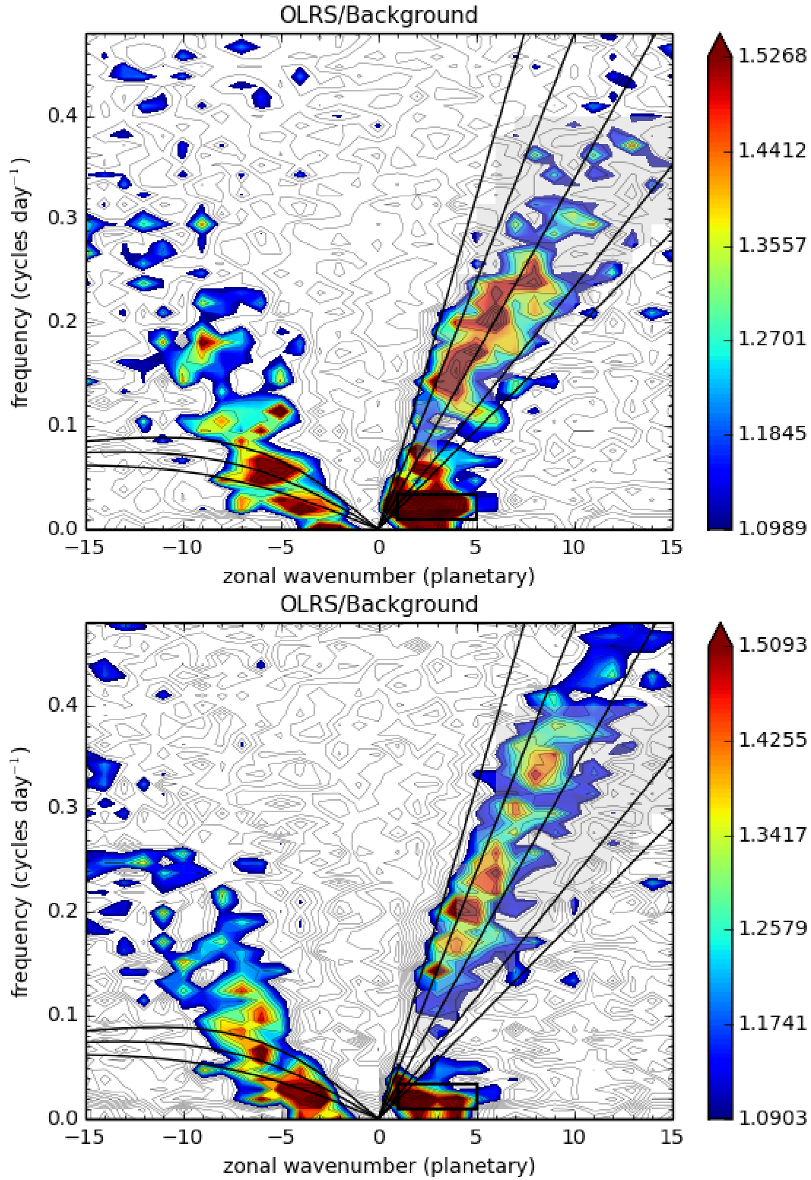
Response to symmetric heating at the Equator





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

Wavenumber frequency Diagrams of OLR

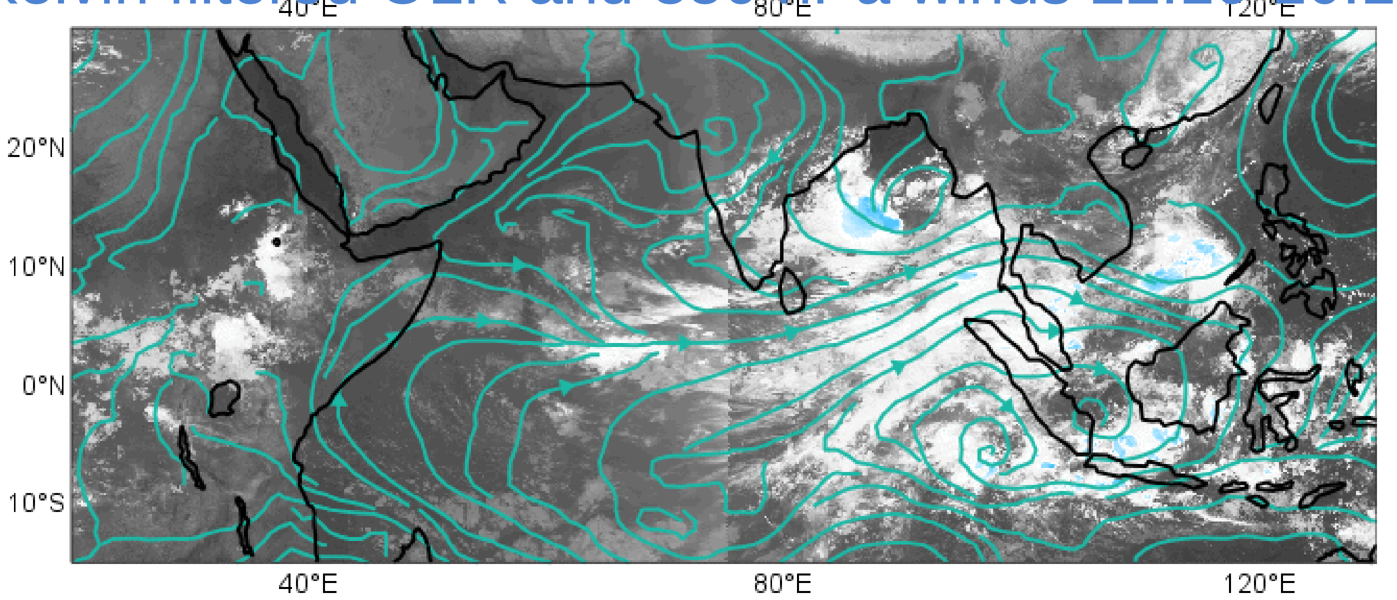


ECMWF Analysis (2008-2013)

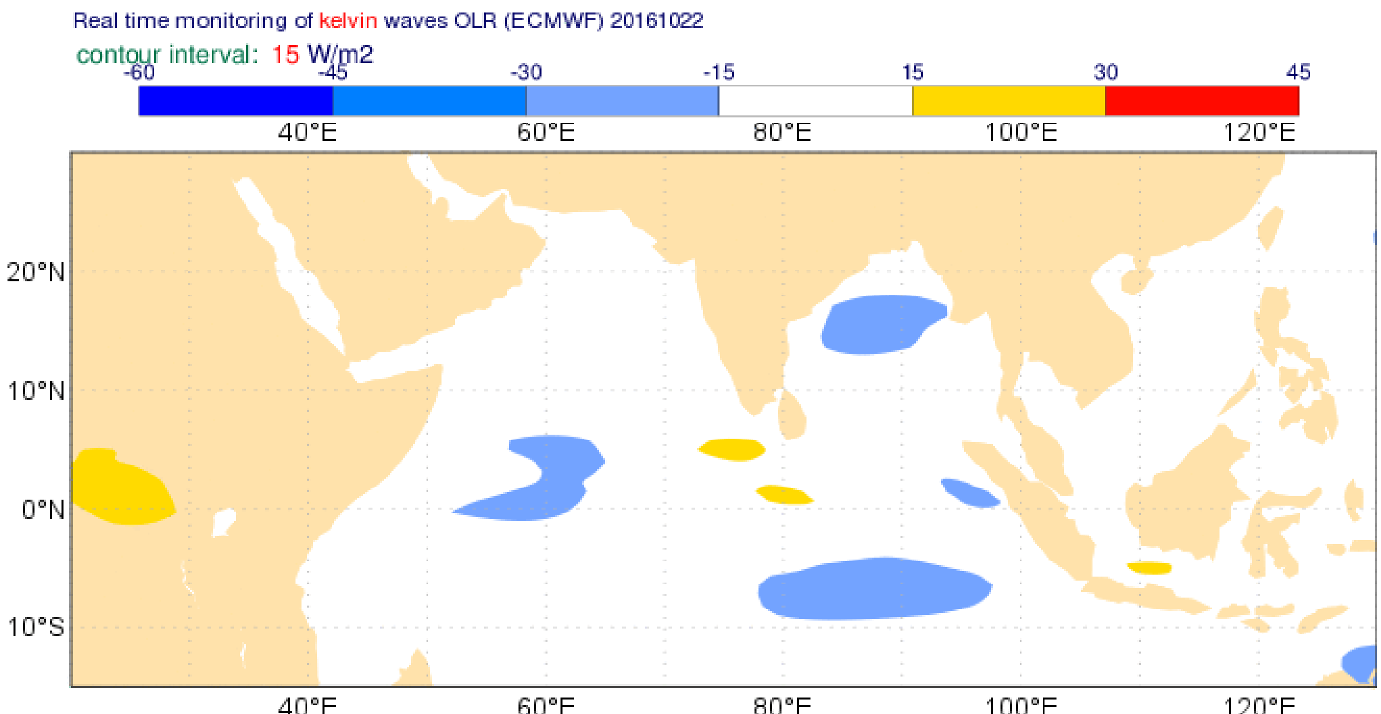
Cy40r1 6 years

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

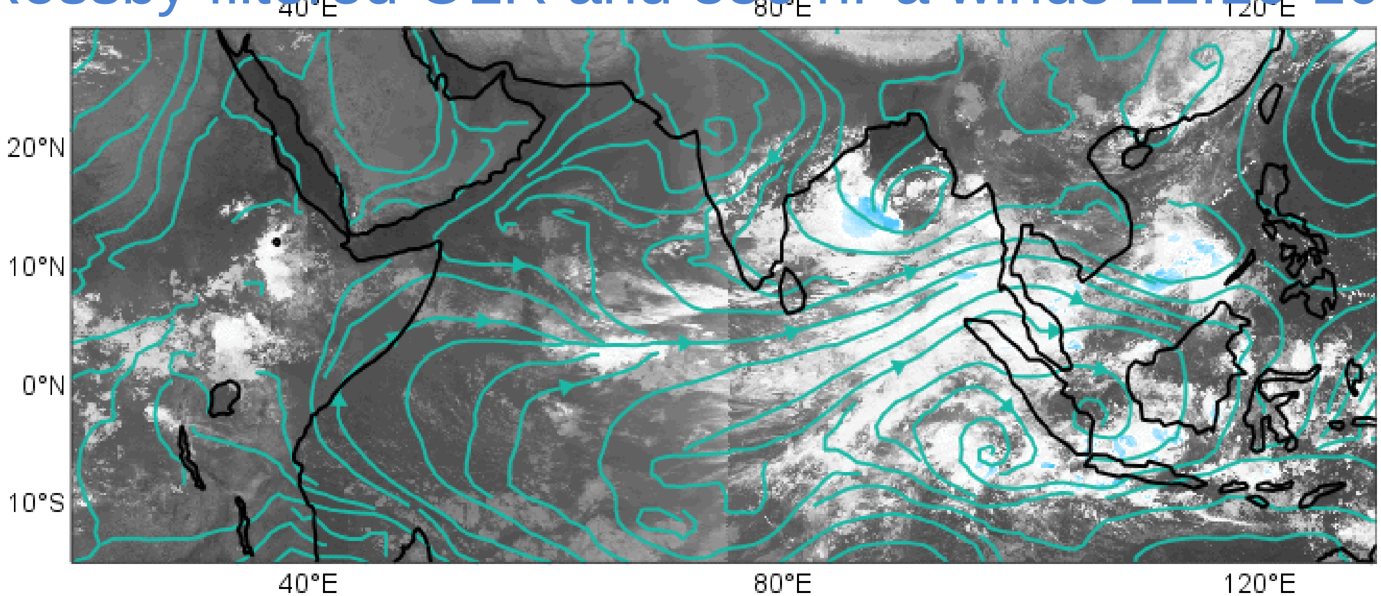
Kelvin filtered OLR and 850 hPa winds 22.10-10.11 2016



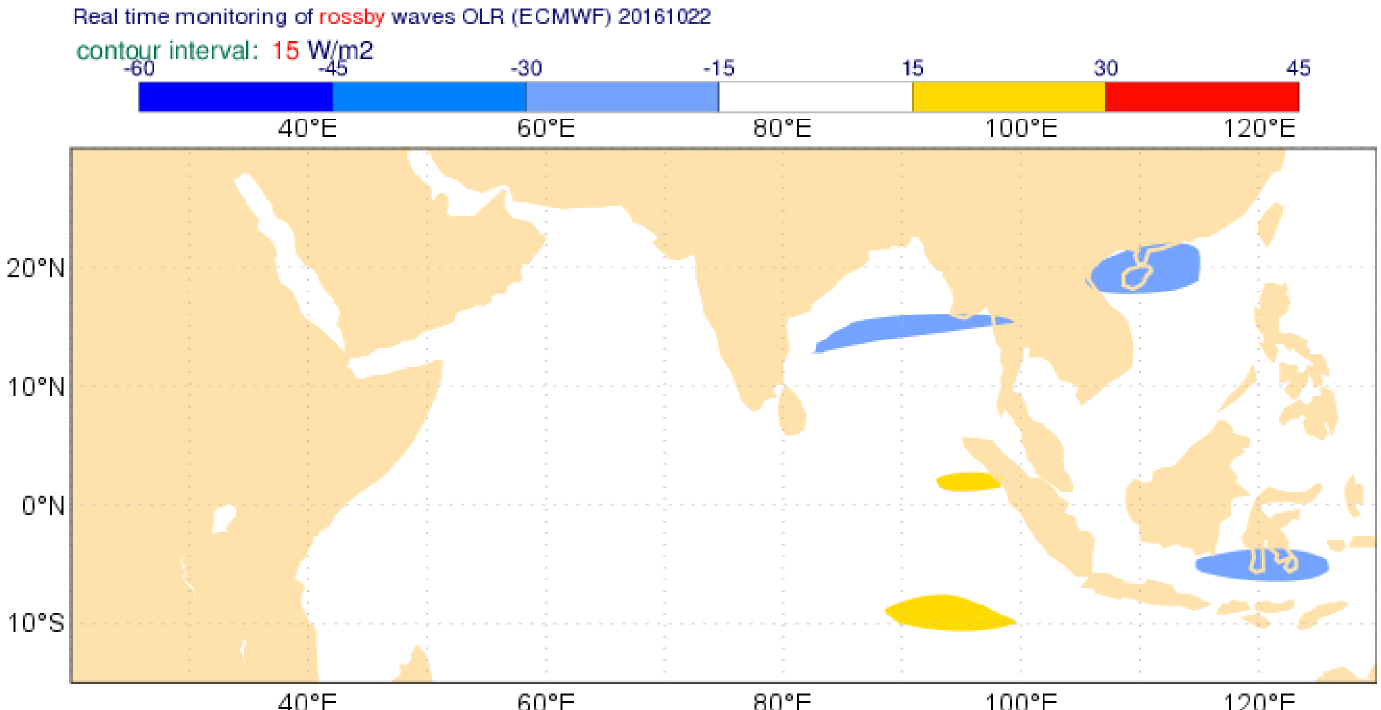
+streamlines 850 hPa



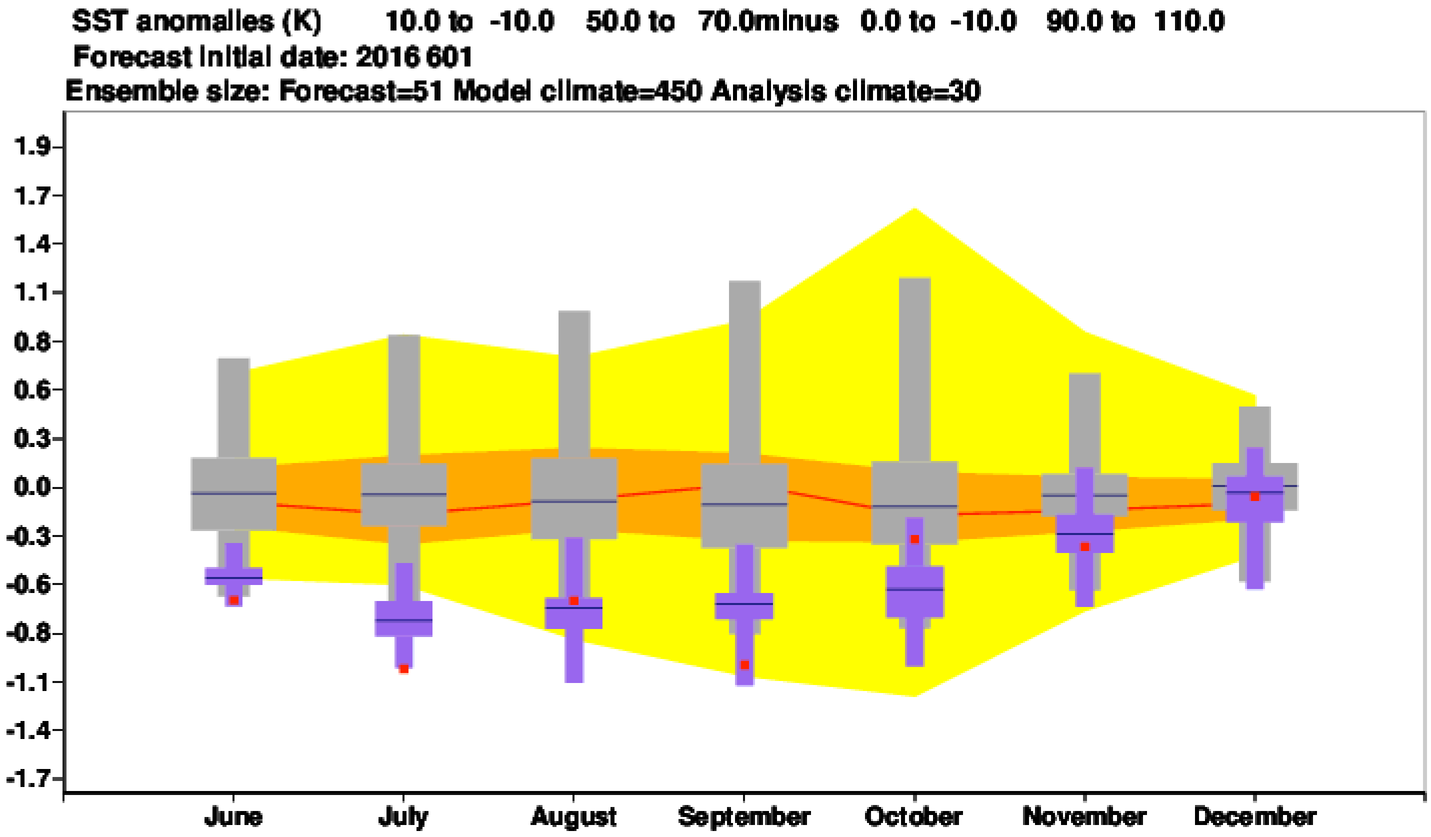
Rossby filtered OLR and 850 hPa winds 22.10-10.11 2016



+streamlines
850 hPa

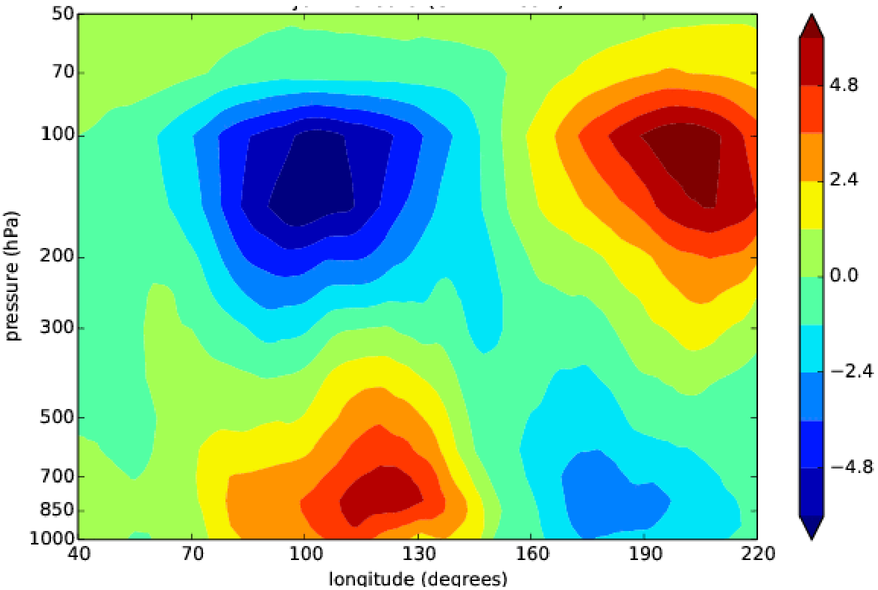


very little convection in Indian Ocean this Autumn, weak tropical cyclone / Rossby wave activity related to cold SSTs as predicted by the seasonal forecast system

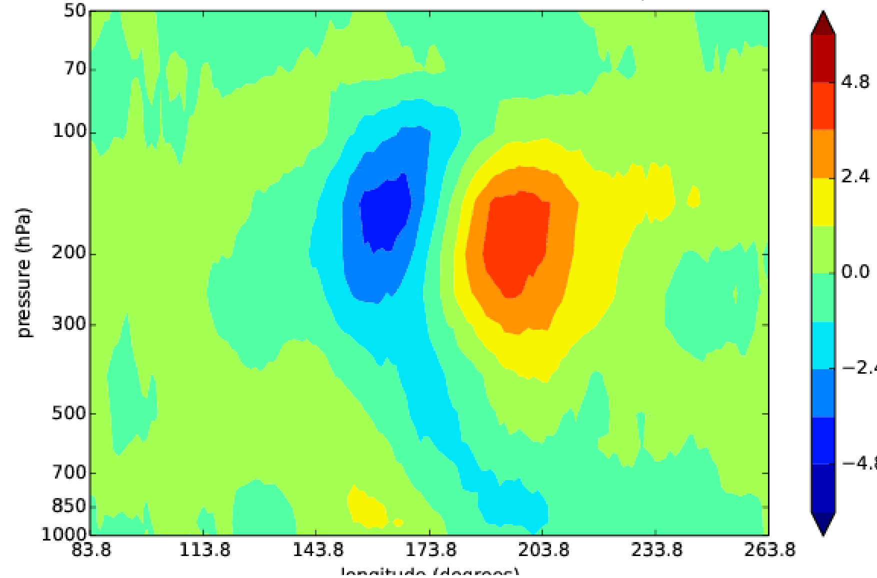


U-anomalies: vertical structure

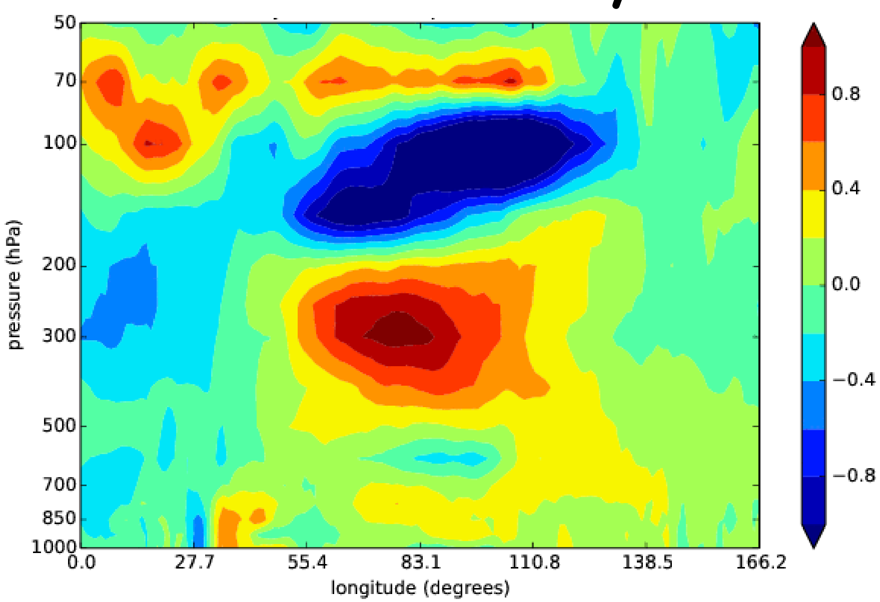
MJO U anomaly



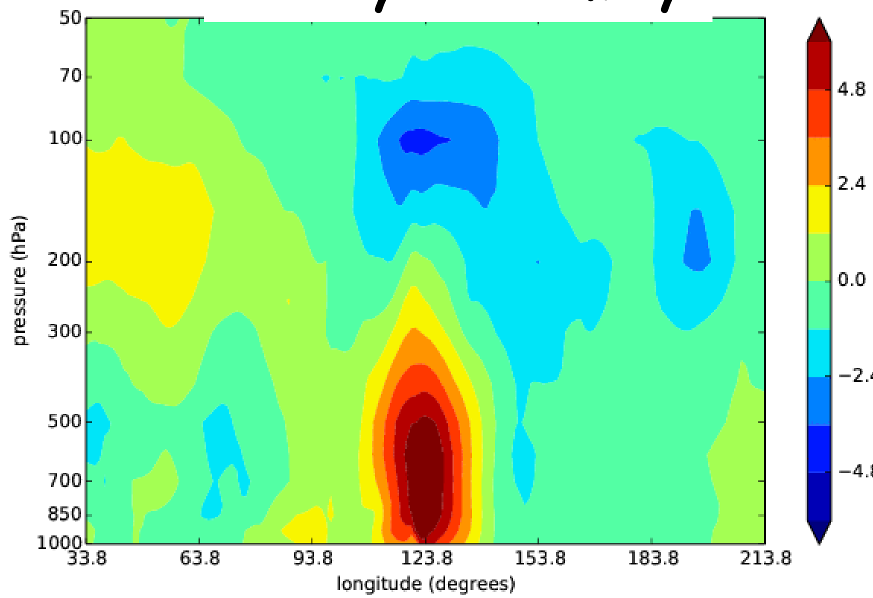
Kelvin U anomaly



MJO T anomaly



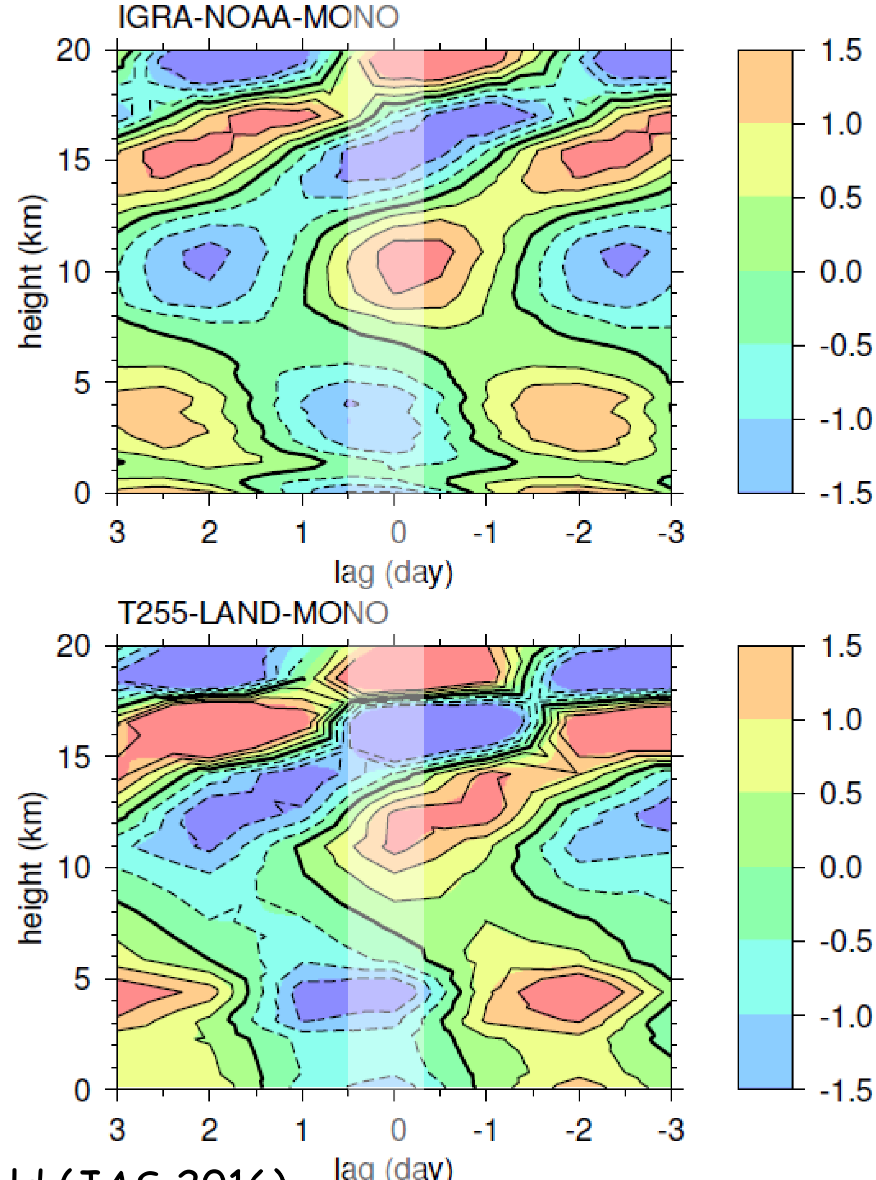
Rossby U anomaly



Kelvin waves: vertical structure

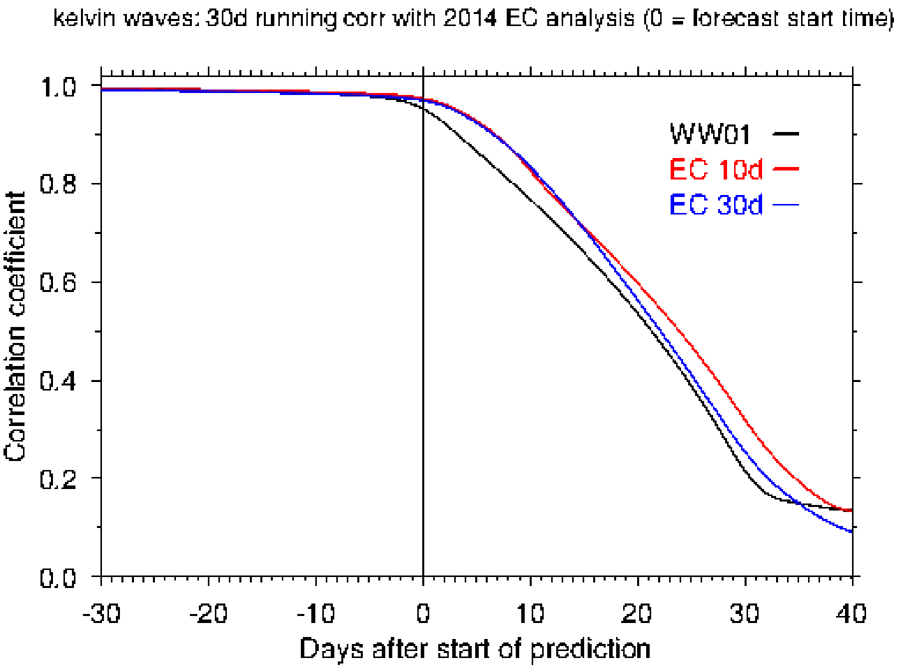
At z~10 km, warm anomaly and convective heating are in phase, leading to :

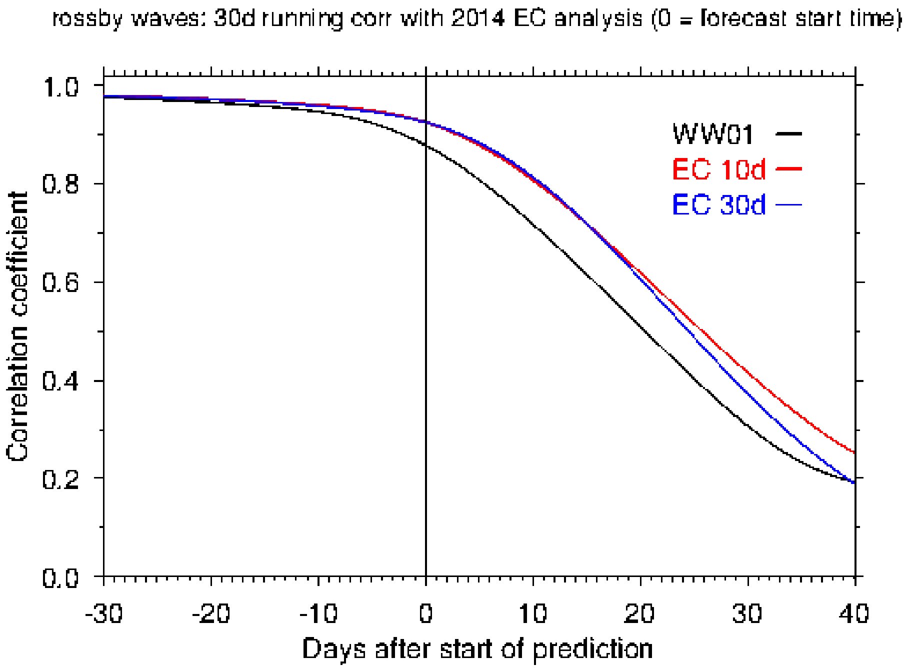
- o the conversion of potential in kinetic energy = $\alpha\omega$
- o The generation of potential energy = N Q
- o For inertia gravity waves, horizontal phase and group speed have same sign, but opposite sign for vertical propagation



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

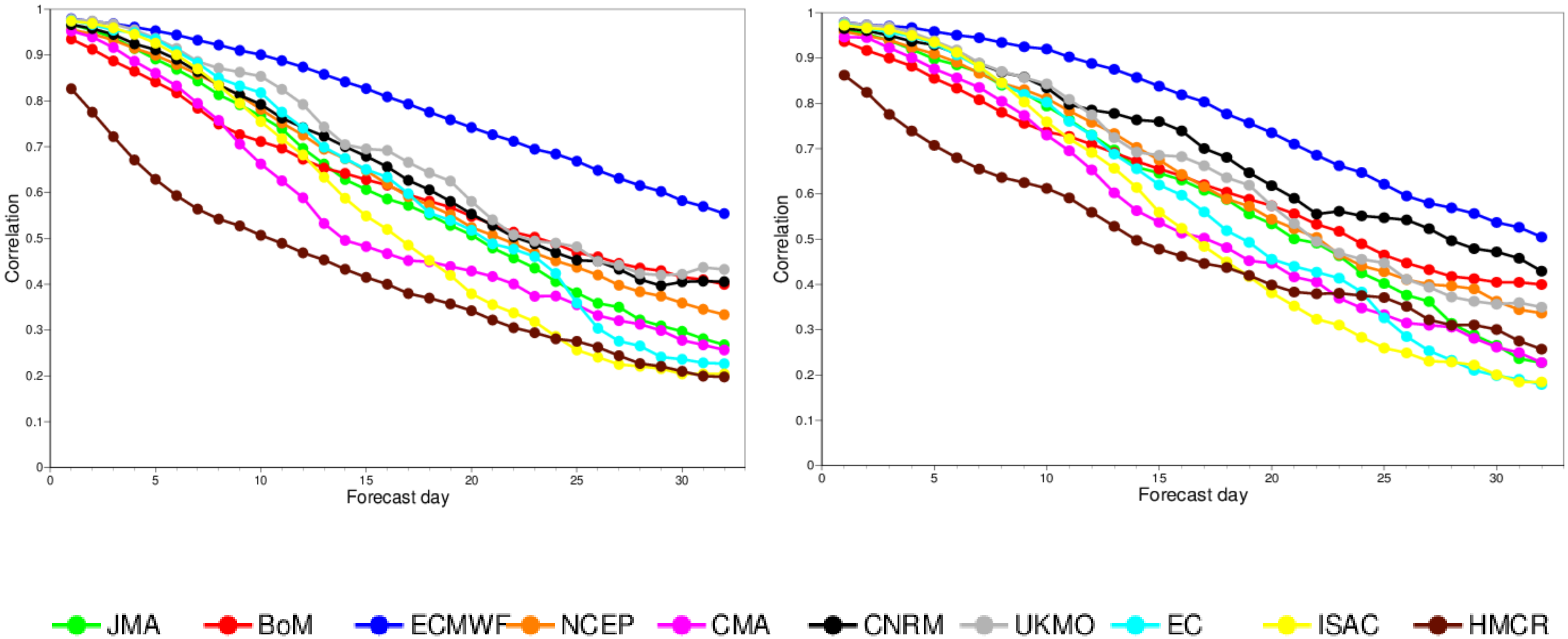




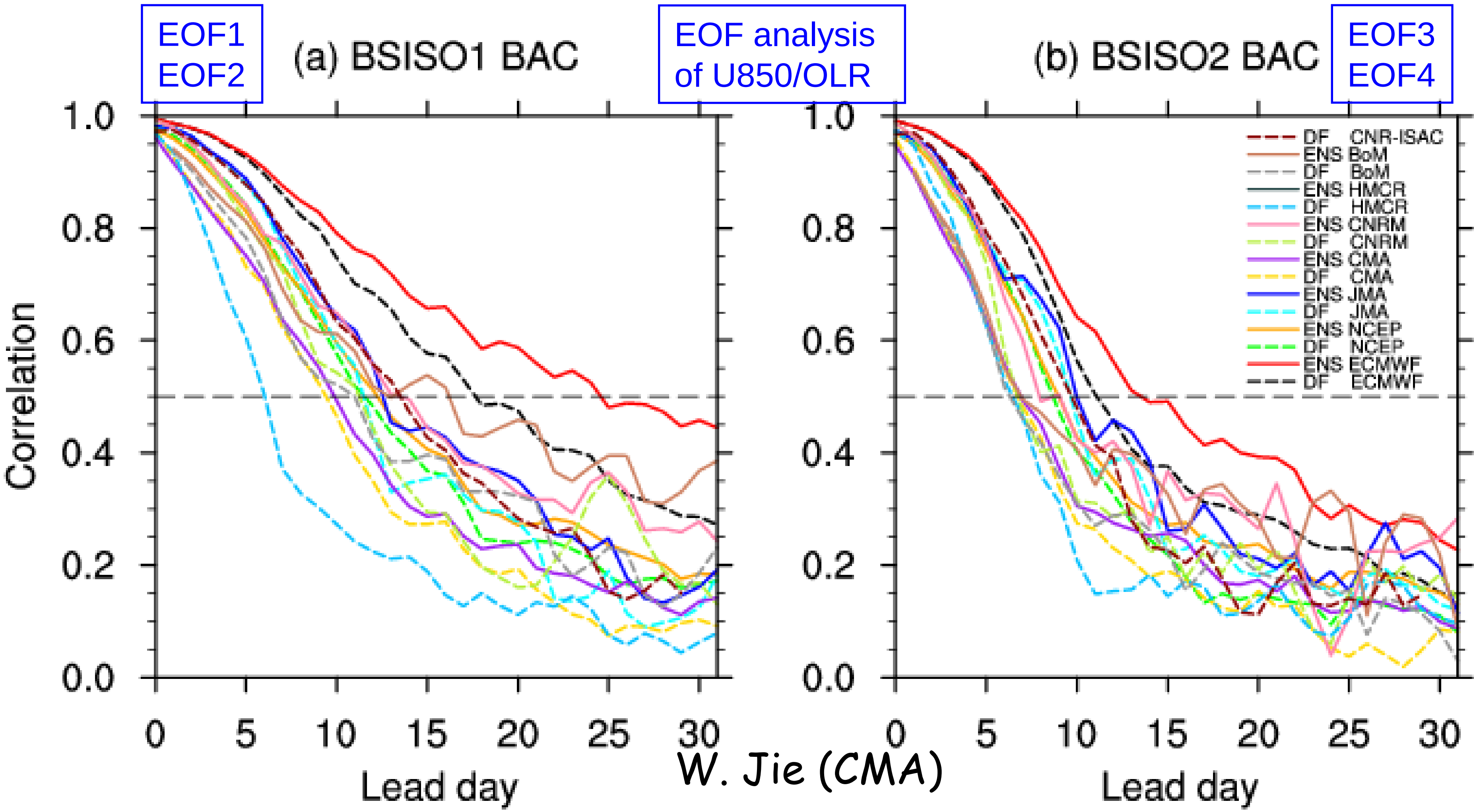
MJO Bivariate Correlation with ERA Interim – Ensemble Mean 1999-2010 re-forecasts

All Year

DJF



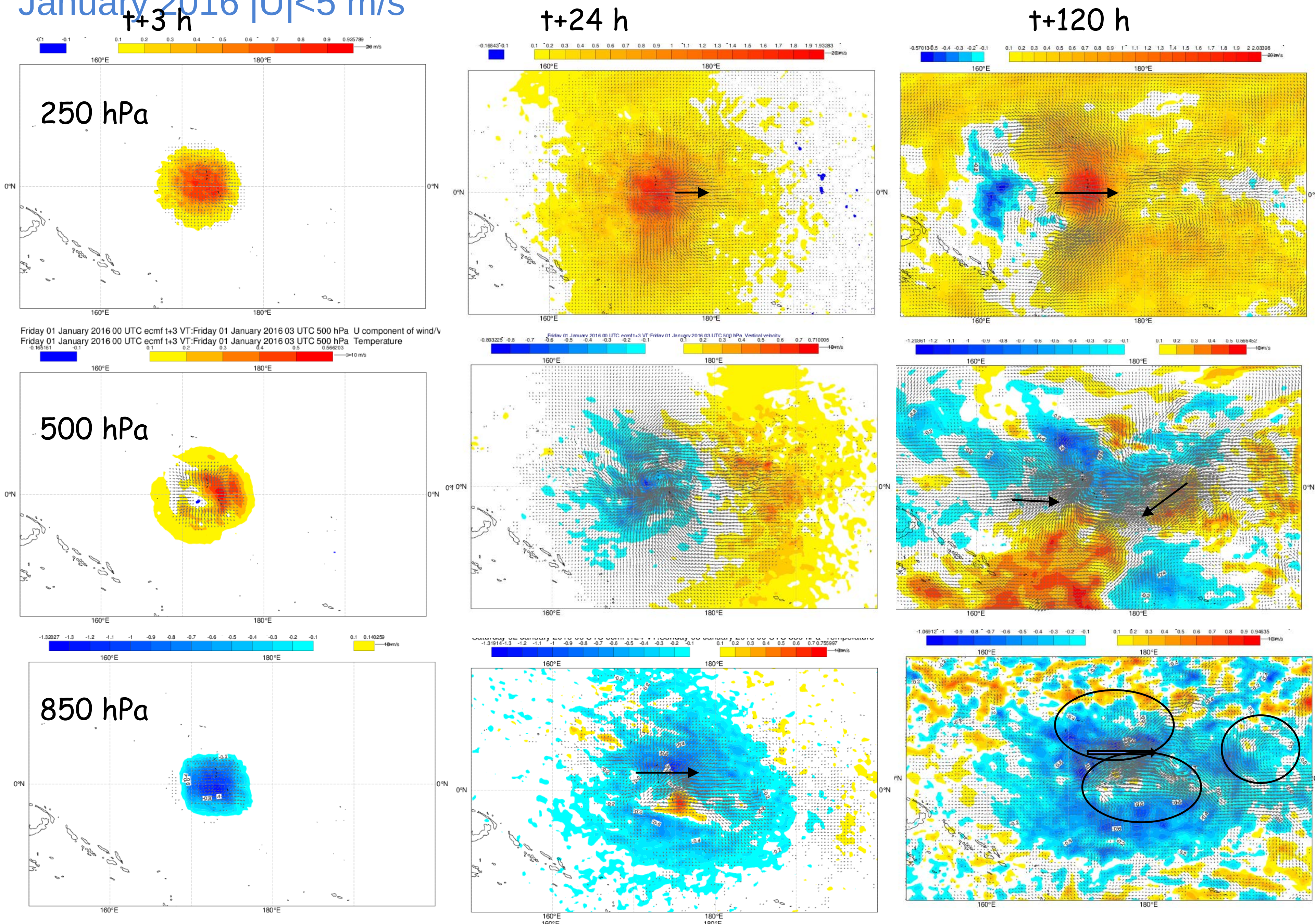
Boreal Summer Intraseasonal Oscillation (BSISO) Index (May to October during 1999-2000)



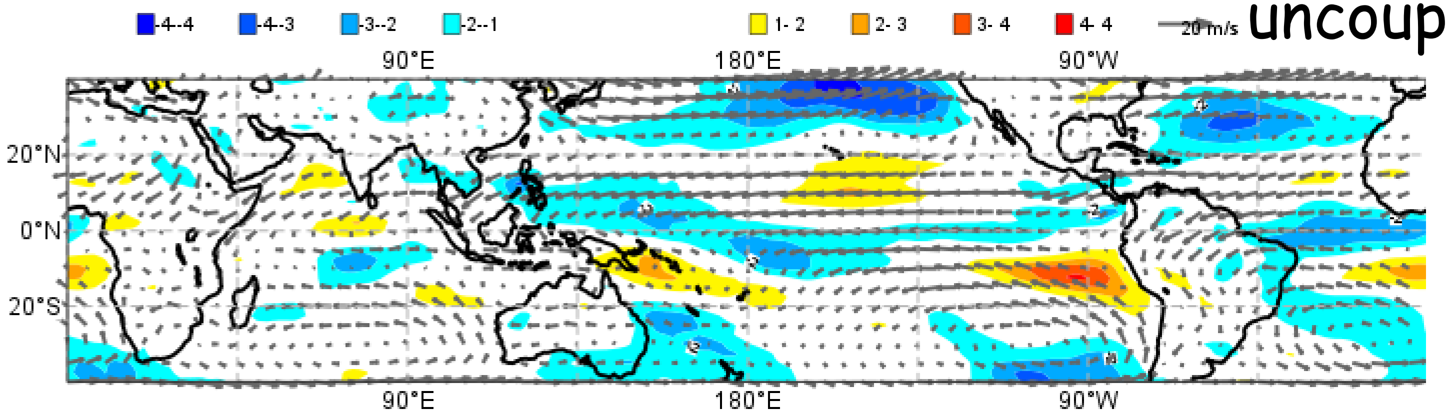
a. **BSISO1** index shows **the predictability of summer MJO** is in range of 7 and 24 days

b. **BSISO2** index indicates the **predictability of Asian Monsoon** is between 7 and 14 days

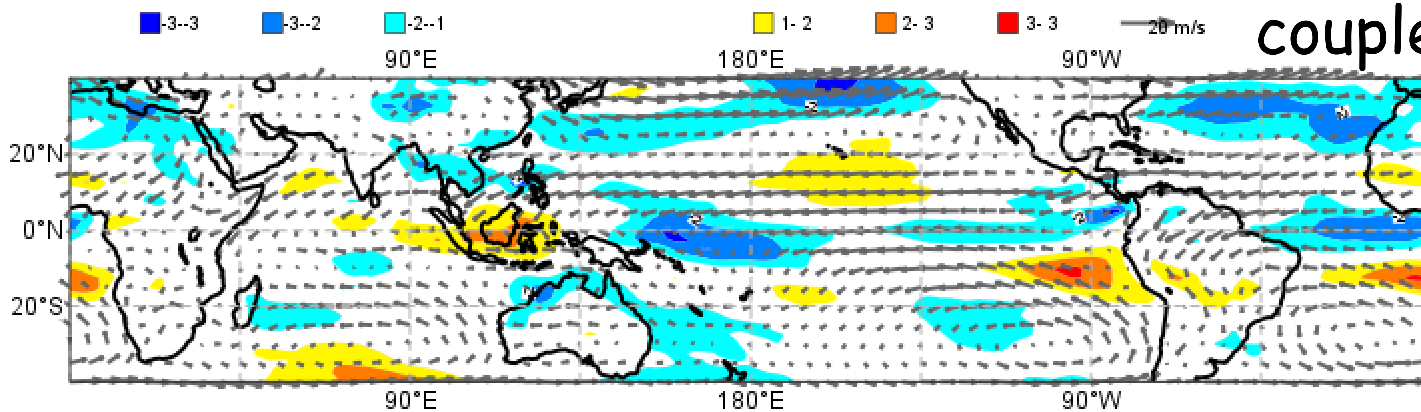
W Pacific equat T perturbation 1: 15 K/d sinus(2π (Ps-p)/(Ps-Pt) , 5x5°, composite January 2016 |U|<5 m/s



DJF 2000-2004 climatology and U850 hPa errors

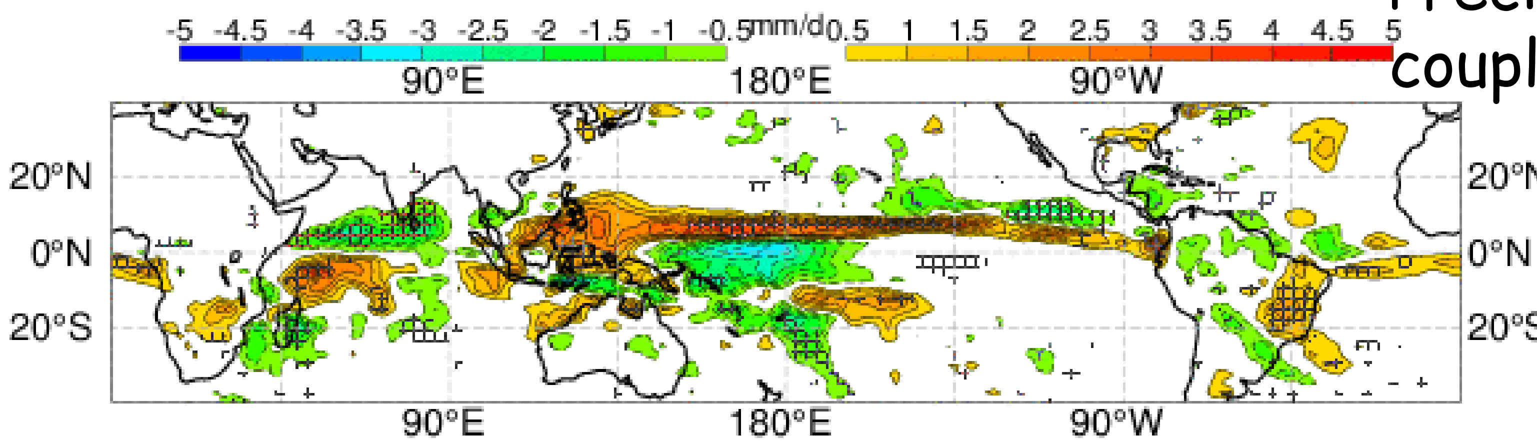


uncoupled



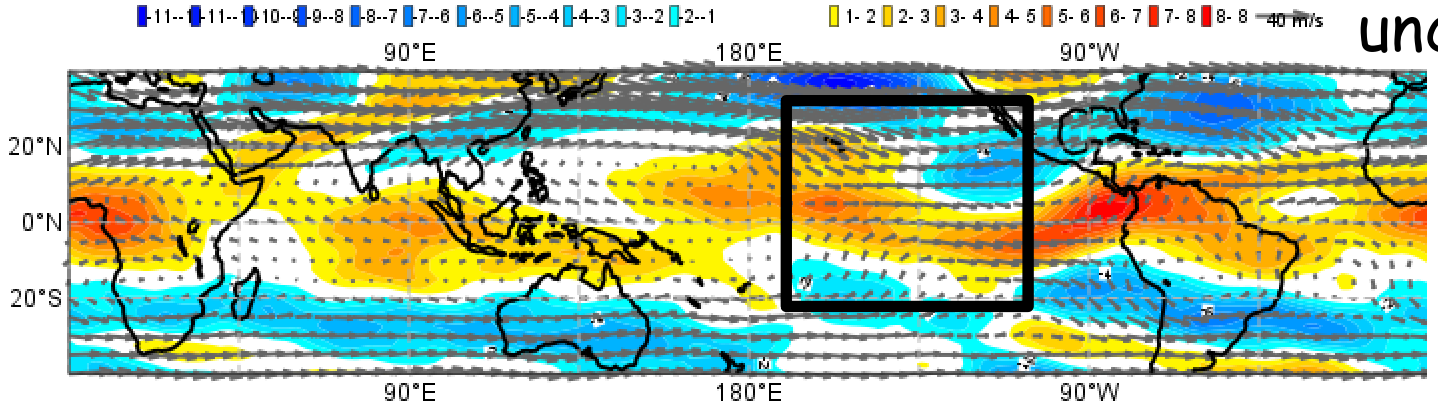
coupled

Precip diff
coupl-uncoup



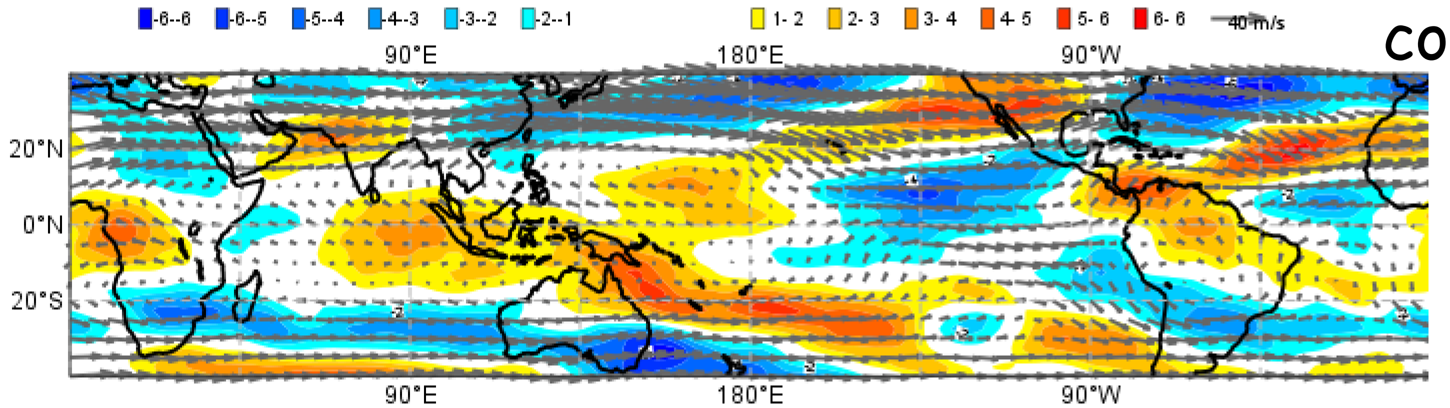
DJF 2000-2004 climatology and U 250 hPa errors

uncoupled

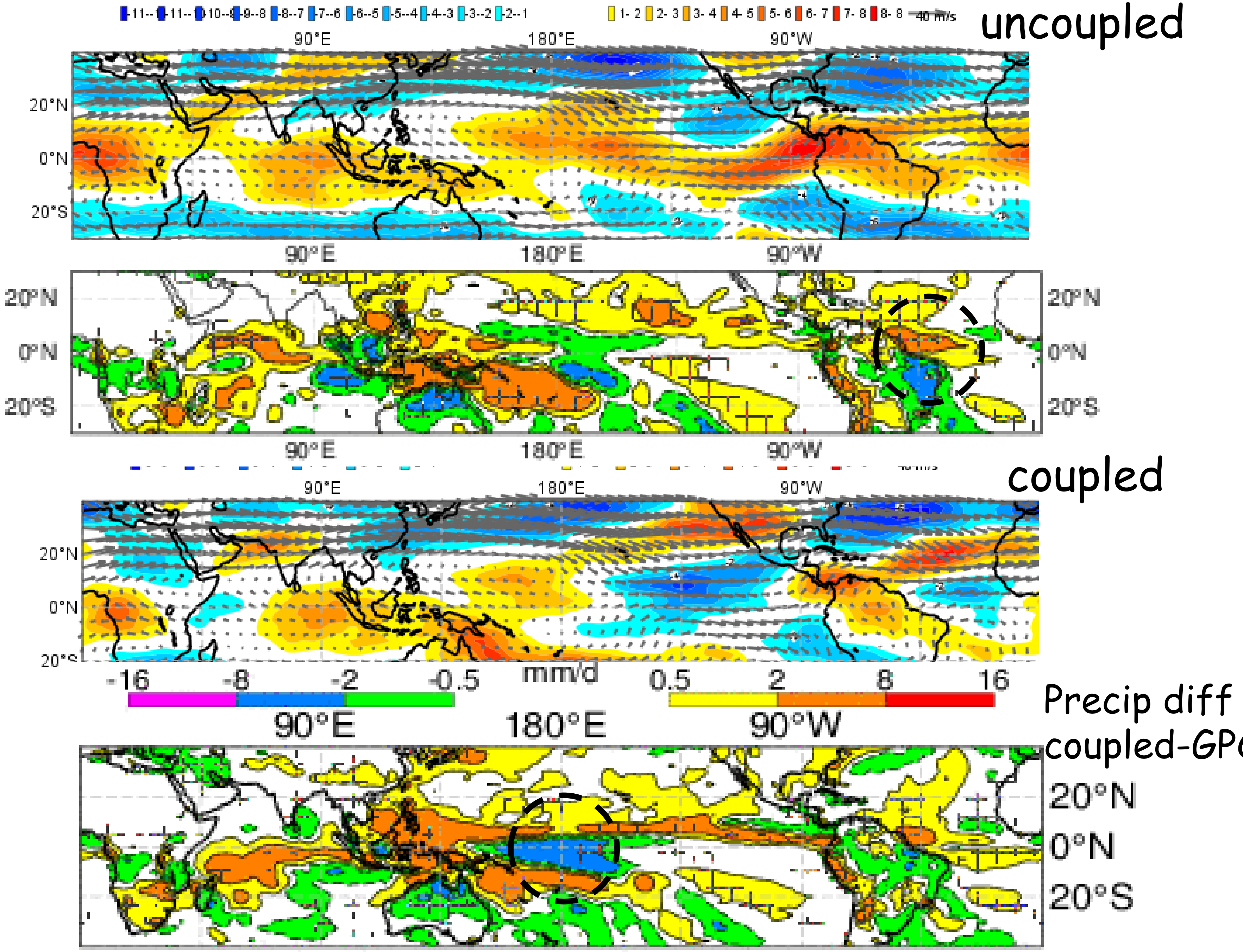


Westerly Jet? (Tomas and Webster 1993)

coupled



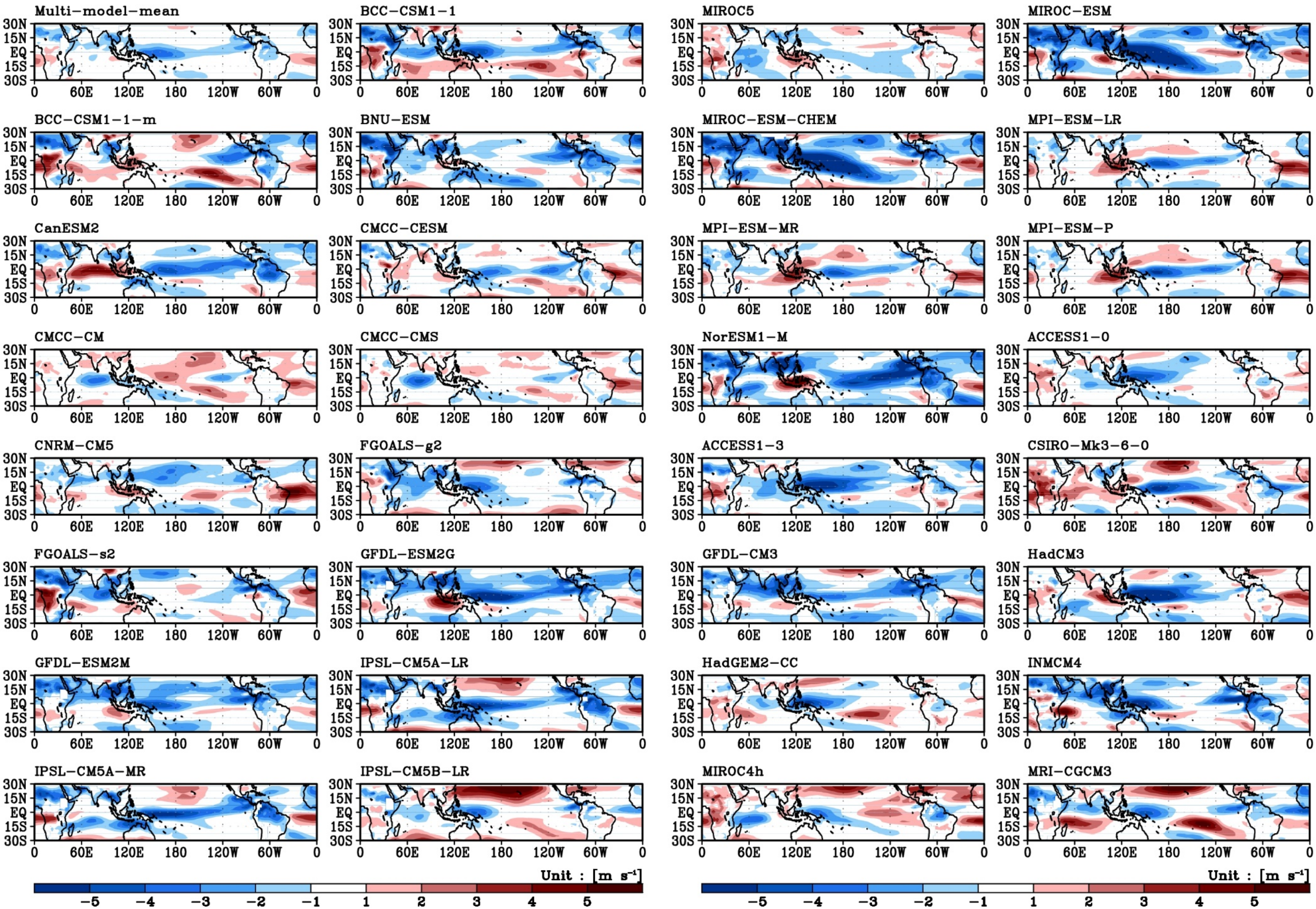
DJF 2000-2004 climatology and U 250 hPa errors



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

U850 bias of CMIP5 models

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



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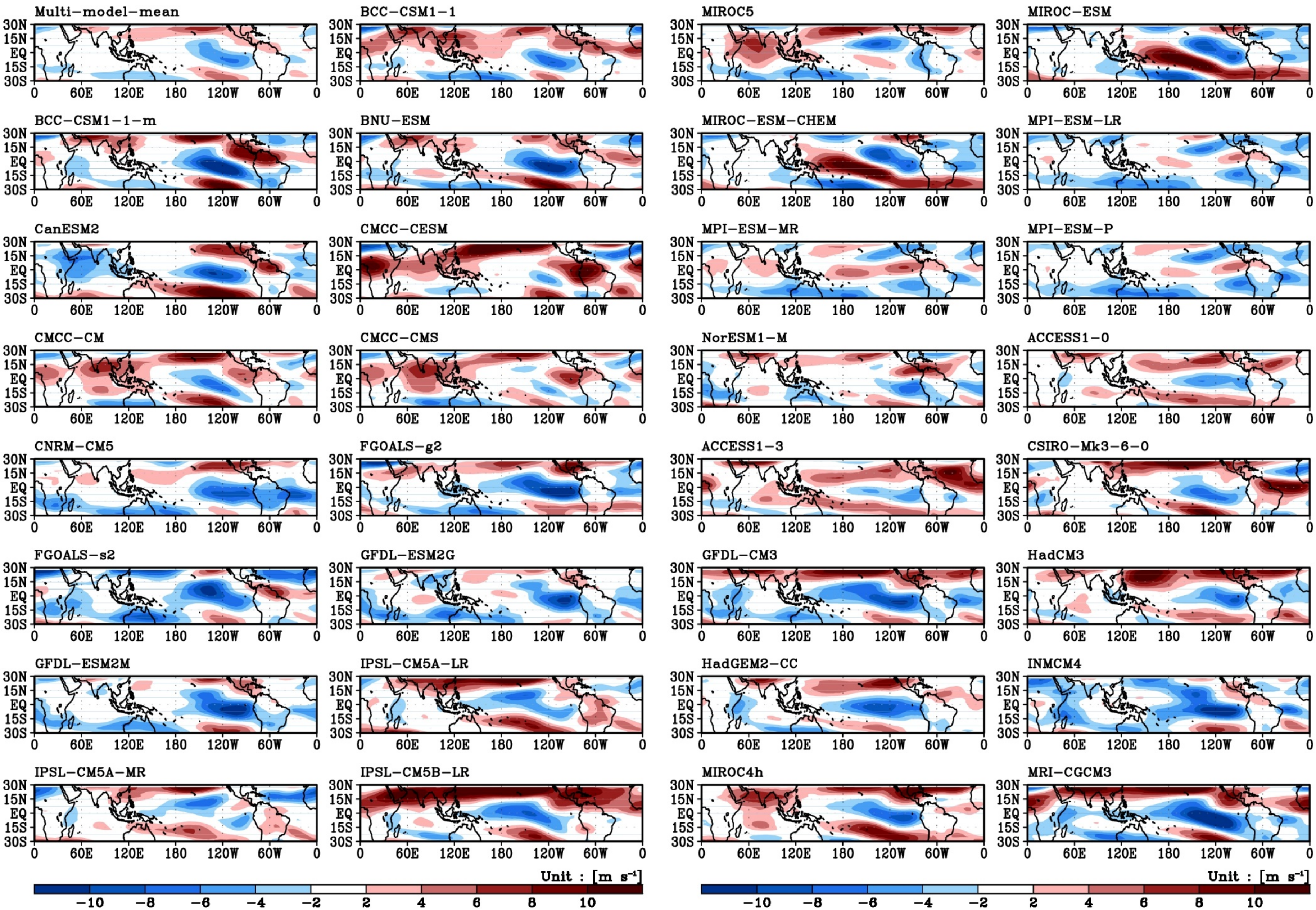


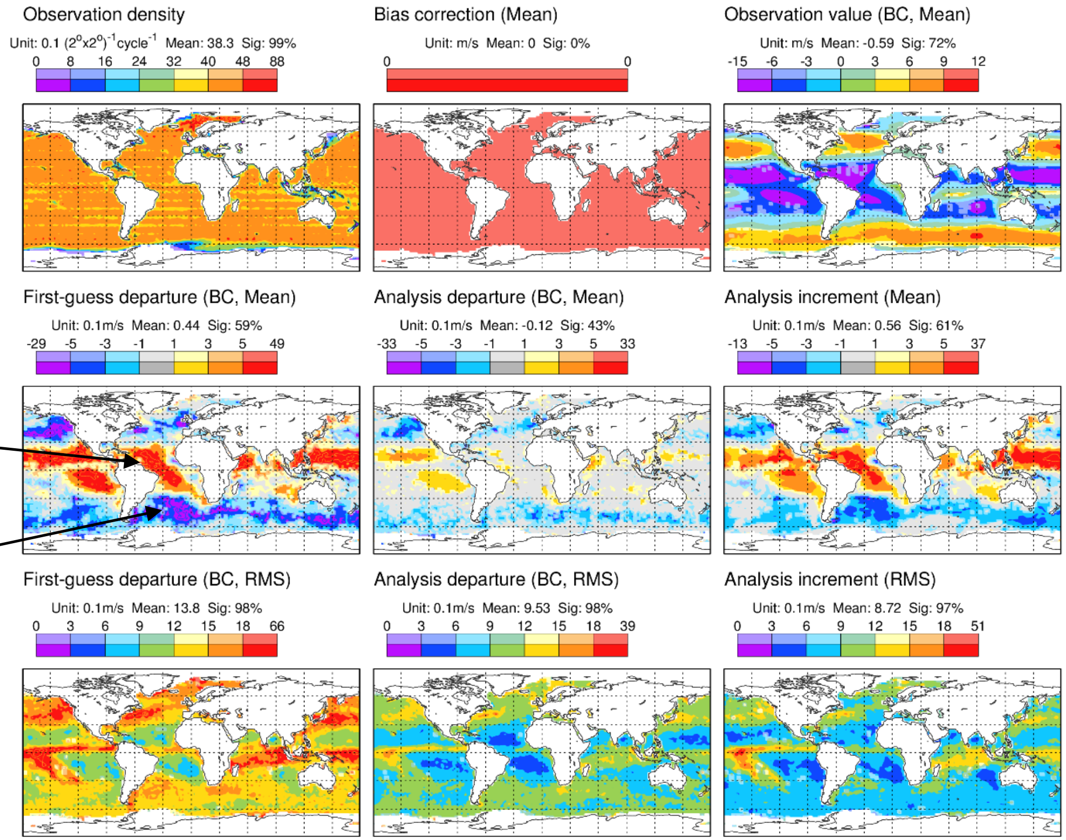
Data assimilation feedback for ASCAT scatterometer surface u

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

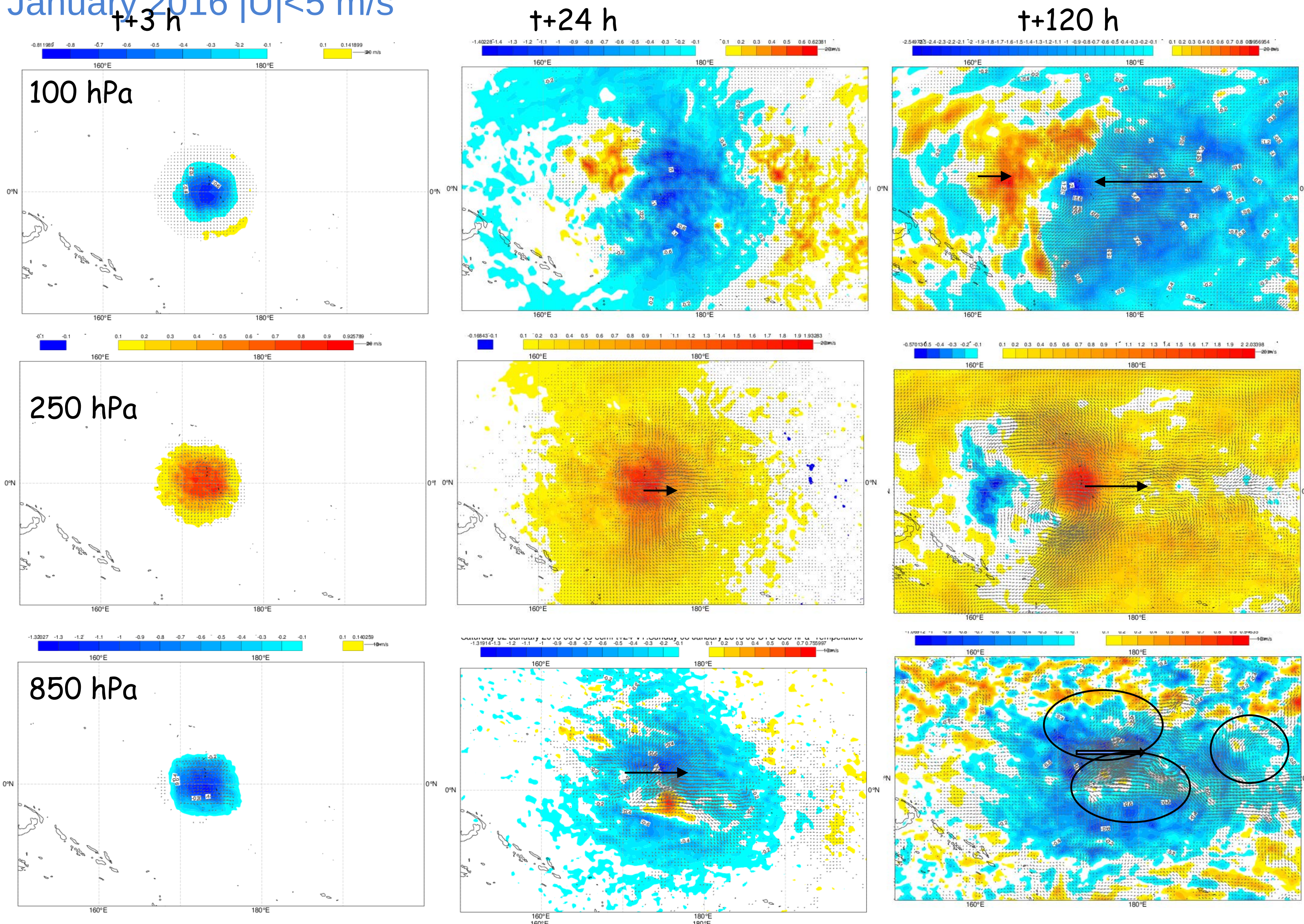
Based on ASCAT observations from all platforms for DJF 2015/16

Summary

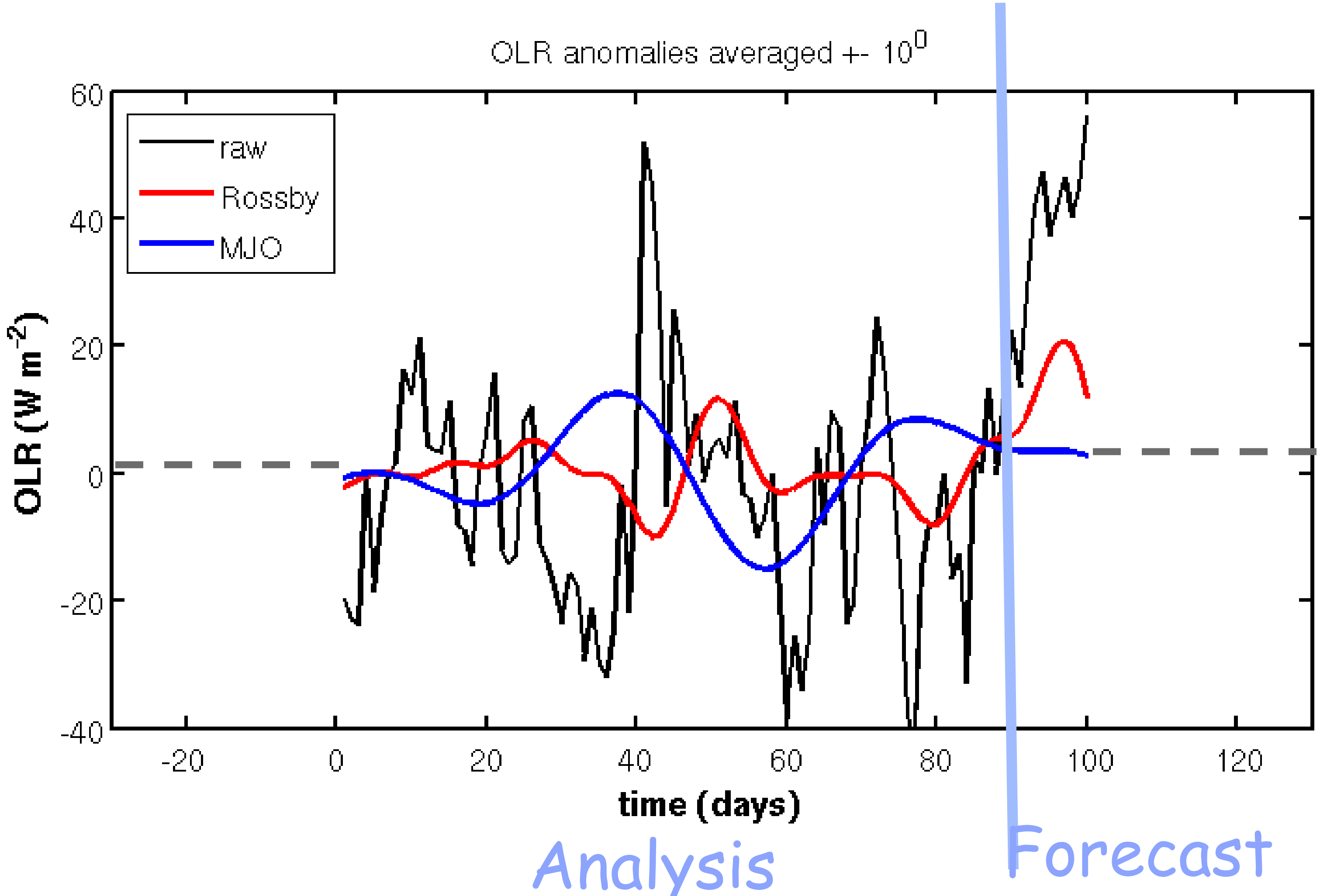
- Energy flow – importance of conversion rate (large-scale) in upper tropical troposphere
- Good (potential) predictability of large-scale tropical waves, equator wave (energy) trapping
- First order balance between wind and temperature, but close to equator heating is essential as T' small < 2K
- Stratiform 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
- General U850 easterly bias, 250 hPa largest over

East Pacific

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

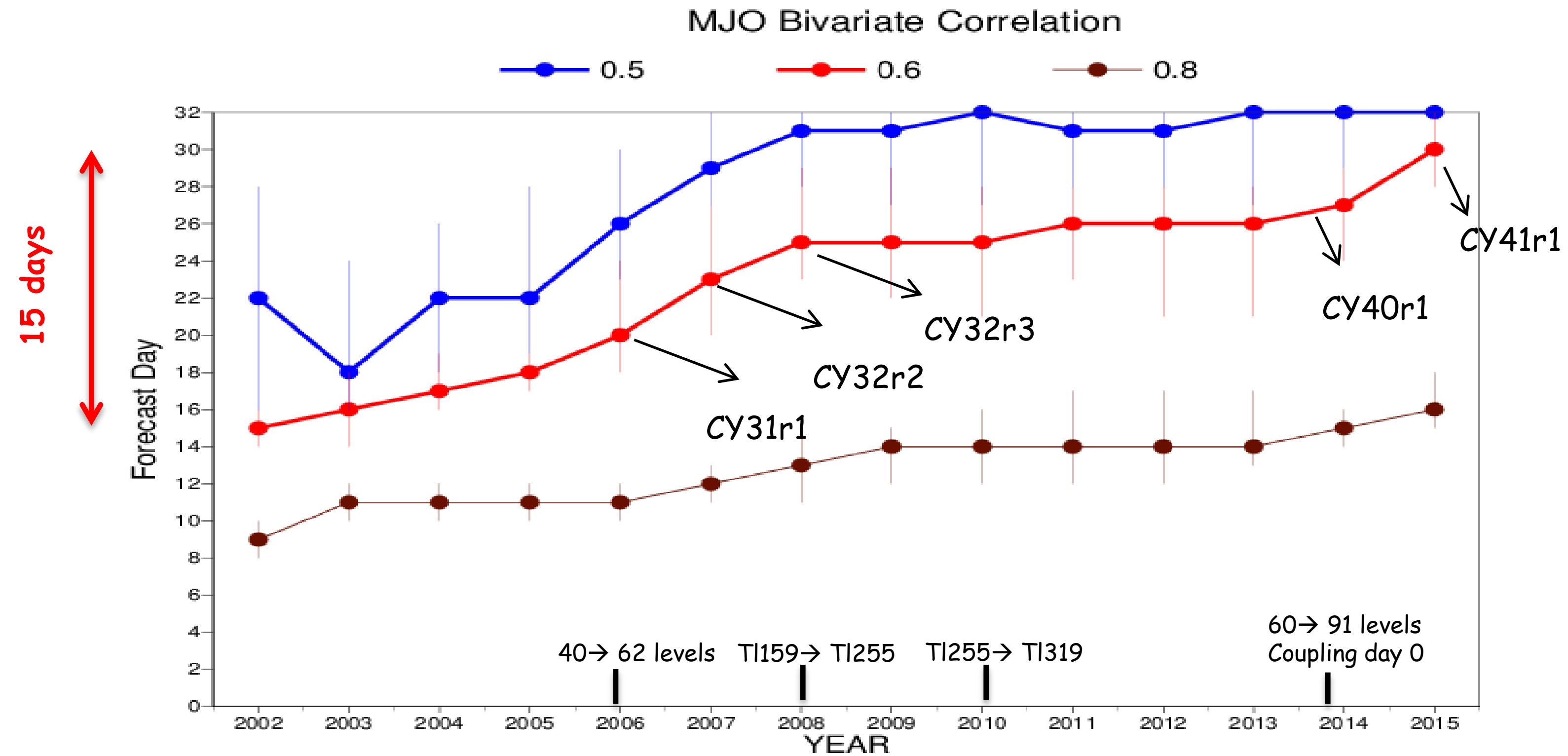


Forecast base time

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

ECMWF

Madden Julian Oscillation prediction at ECMWF



CY31R1: Parameterisation of ice supersaturation
CY32R2: McRAD (radiation scheme)
CY32R3: Changes in convective scheme (Bechtold at al. 2008)
CY40R1: Improved diurnal cycle of precipitation
CY41R1: revised organized convective detrainment and the revised convective momentum transport. ...

Wheeler and Hendon (2003) Index

Improvements in MJO Prediction mostly due to changes in convective parameterization