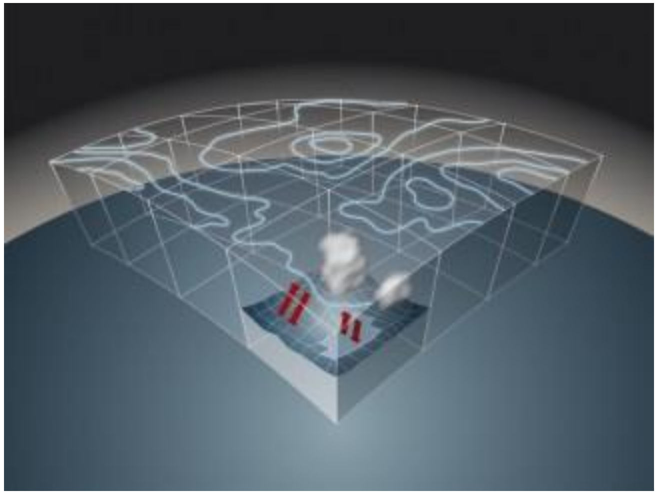
Convection: from the large-scale waves to the small-scale features



Peter Bechtold with thanks to

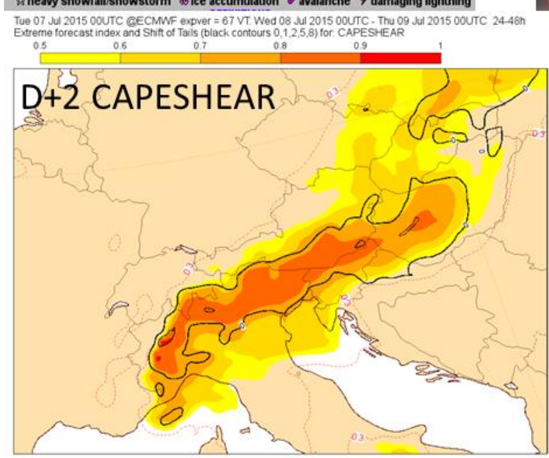
L. Magnusson, S. Malardel, M. Herman (NMexico Tech), King-Fai Li (Caltech), F. Vâna, P. Lopez, F. Prates, F. Li,

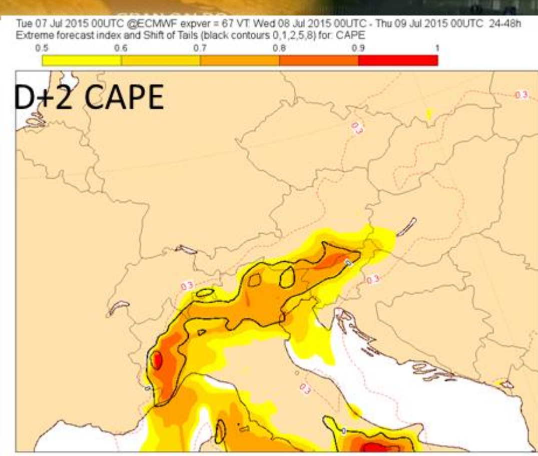
Physics and Numerics section, Gabor+Deborah+Paul, Metops section, management and many colleagues

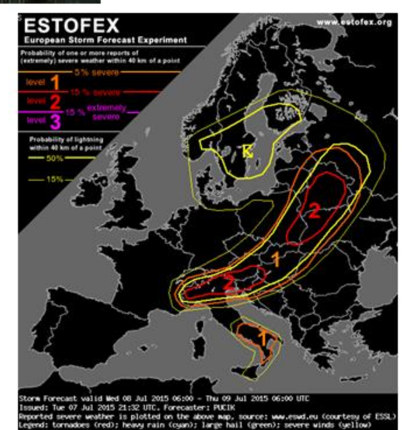
and for projects with T. Komori, Shaocheng Xie, N. Semane, A. Subramanian

CAPE and Shear as useful predictors

Ivan Tsvonetzky
Daily Report







ECMWF

CAPE's useful predictors for convection parametrization?

$$\frac{1}{2}V^2 + \frac{\delta p}{\bar{\rho}} - LCAPE; \qquad LCAPE = \int_{zref}^{z} b(x,y,z)\, dz$$

Montcrieff and Miller (1976) defined LCAPE as part of Bernoulli integral

$$CAPE = g\int_{zb}^{zt} \frac{T_v^{up} - T_v^{env}}{T_v^{env}}\, dz = \int_{base}^{top} b\, dz$$

$$PCAPE = -\int_{Pb}^{Pt} \frac{T_v^{up} - T_v^{env}}{T_v^{env}}\, dp$$

Yano and Bechtold in rev. (2015)

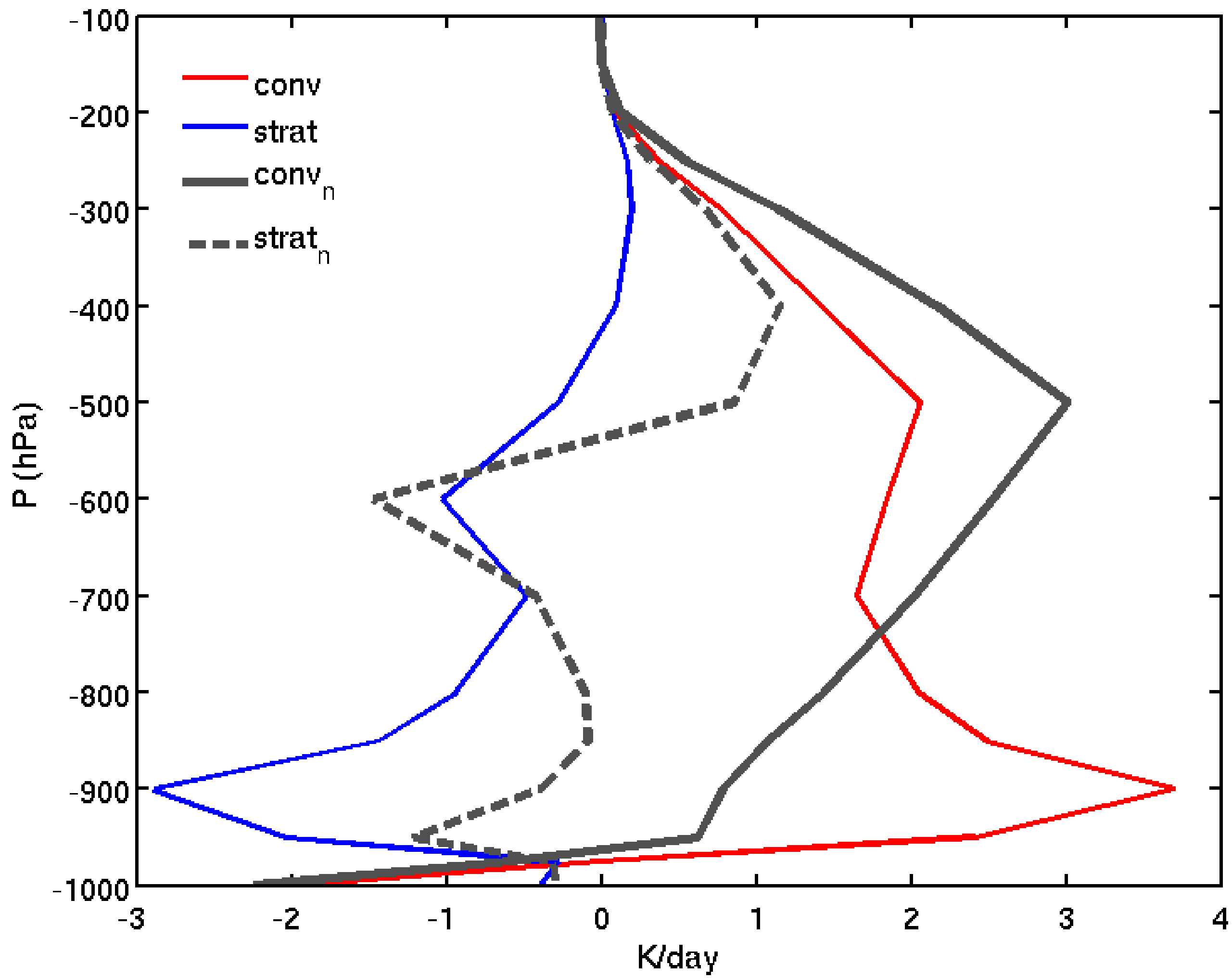
Conservation of enthalpy

$$< \frac{dH}{dt} >= - \int_{Ps}^{Pt} \left[c_p \frac{d\overline{T}}{dt} + L \frac{d\overline{q}}{dt} \right] dp = LPr;$$

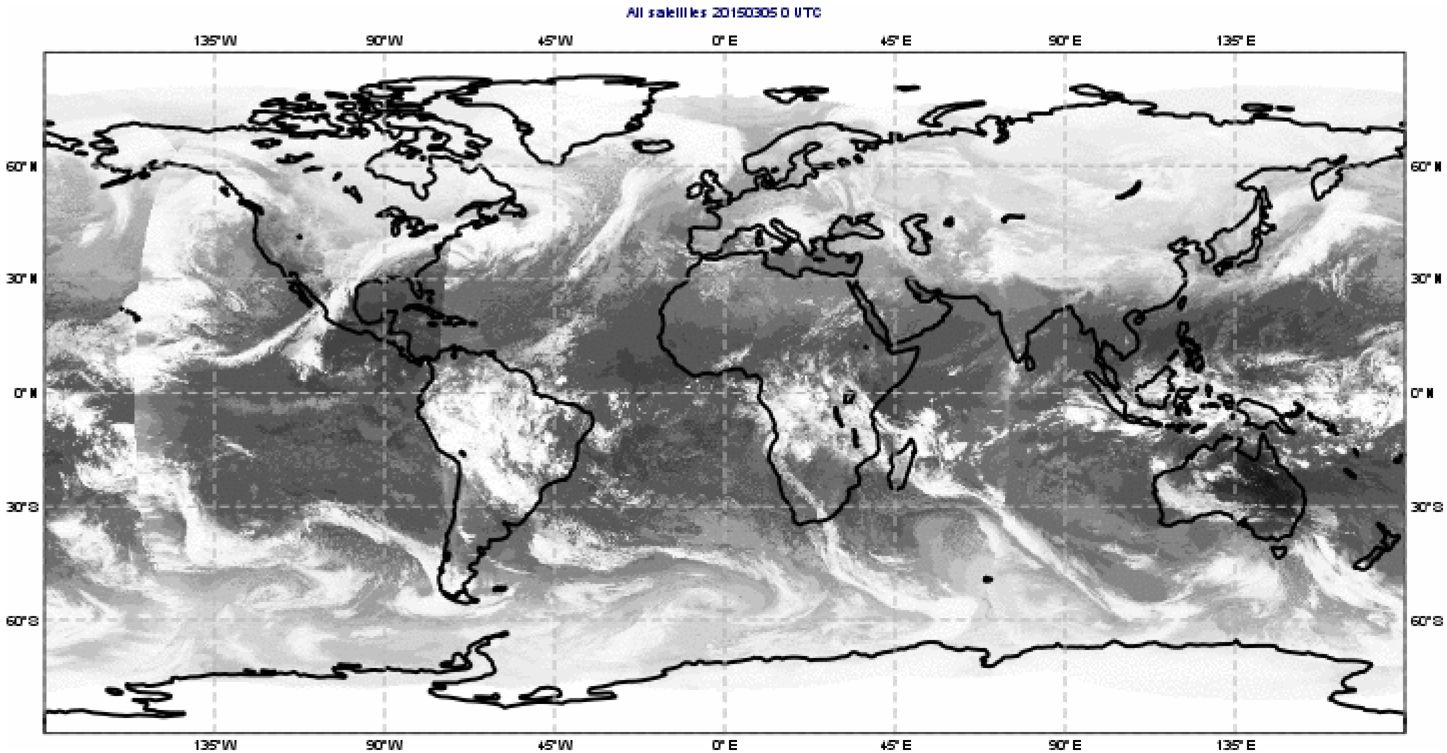
$$c_p = (1 - q_t) c_{pd} + q_t c_{l;} \quad L = L(T)$$

ECMWF

Normalised convective and stratiform heating profiles



The global circulation and its modes (waves)



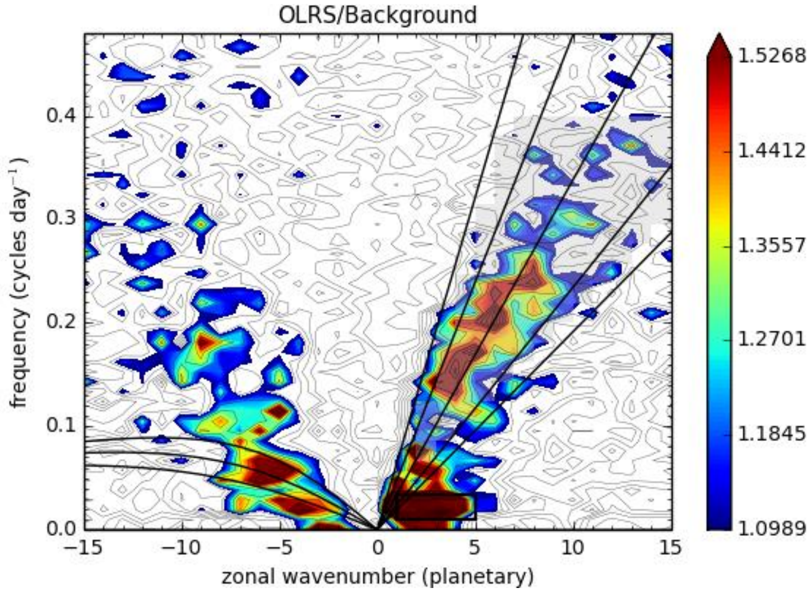
Analytical: solve shallow water equations

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

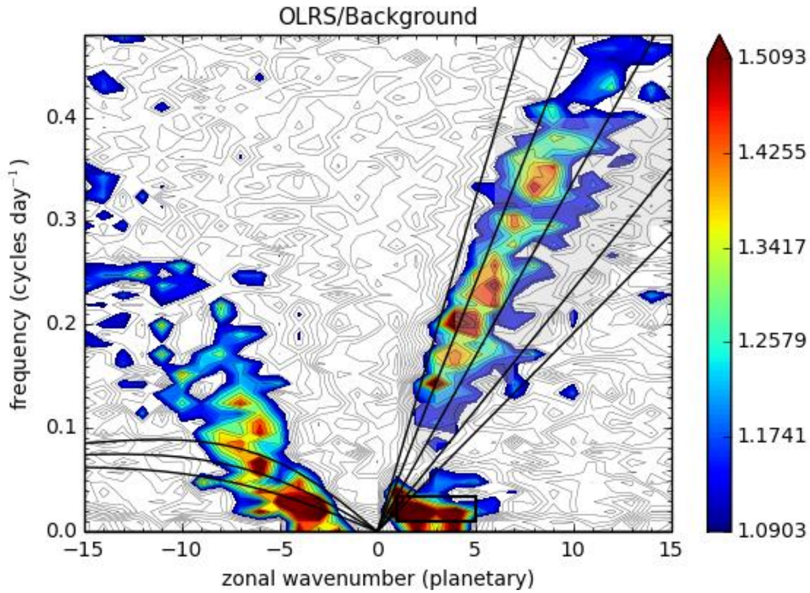
$$V = \breve{V}(y) \; f(y) \; e^{i(kx-\omega t)} \; G(z); \qquad \breve{V}(y) = Legendre\,polynomial$$

ECMWF

Wavenumber frequency Diagrams of OLR



ECMWF Analysis (2008-2013)



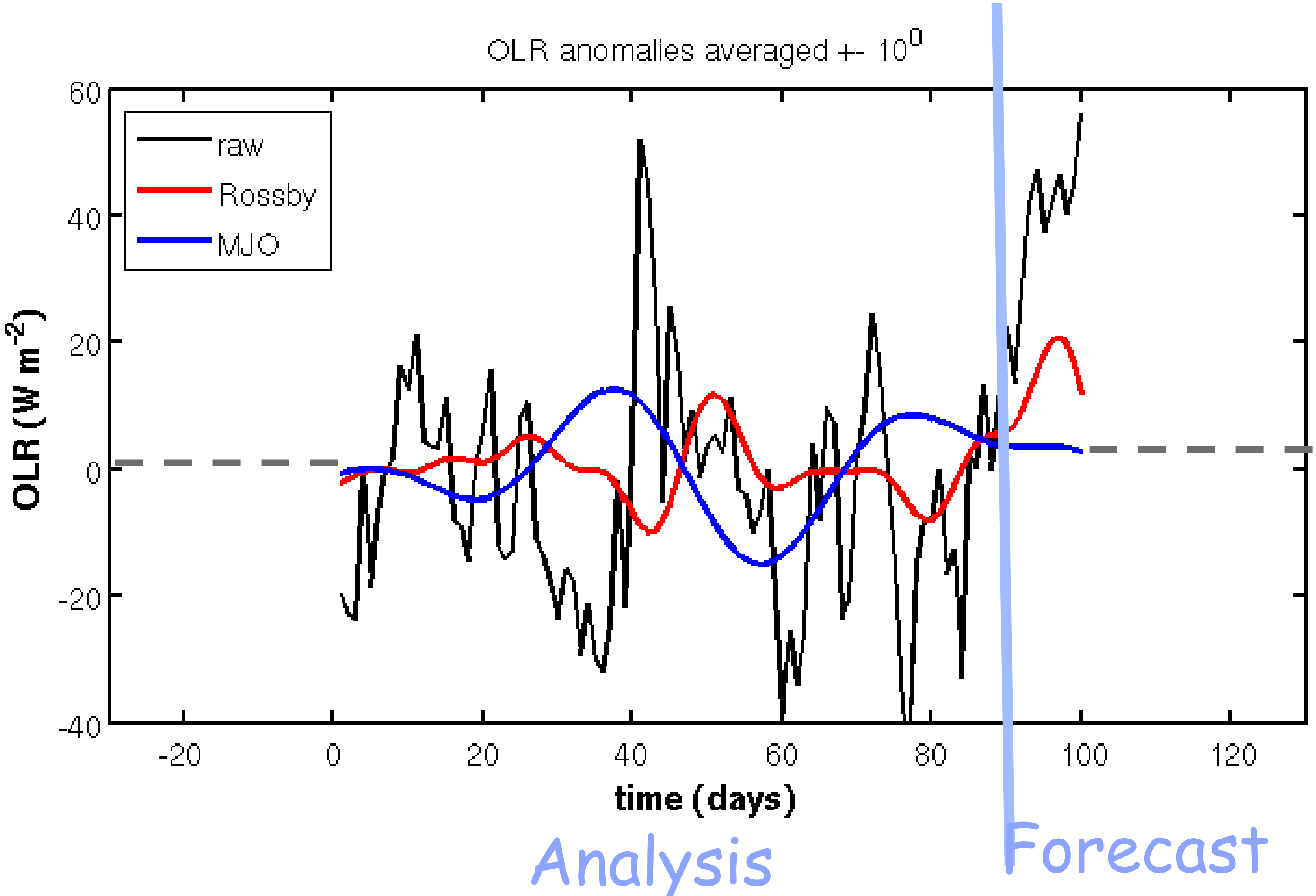
Cy40r1 6 years

software courtesy Michael Herman (New Mexico Institute)

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

ECMWF

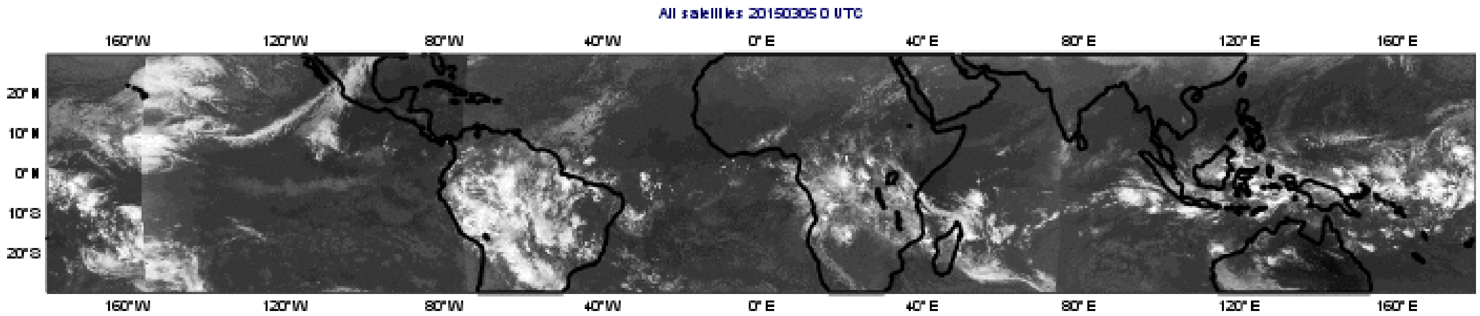
Monitoring and real time prediction of waves



Forecast base time

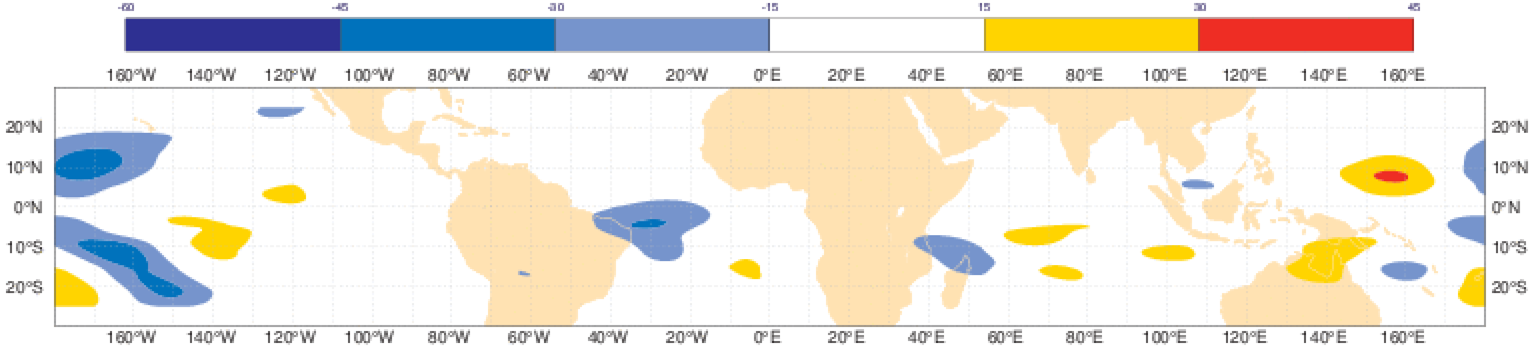
following Wheeler and Weickmann (2001, MWR), courtesy software M. Herman

Rossby & MJO 5.3.2015-16.3 2015

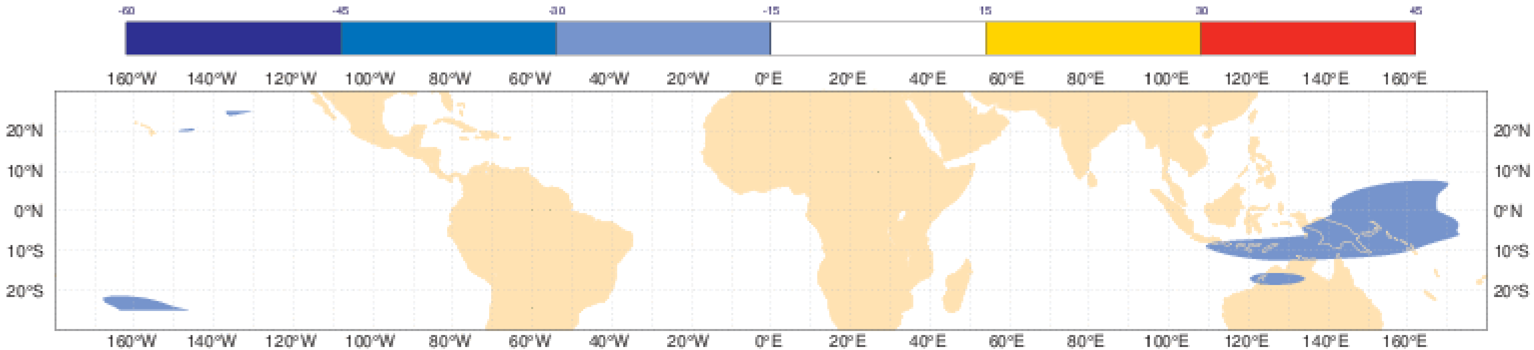


Real time monitoring of rossby waves OLR (ECMWF) 20150305
contour interval: 15 W/m2

Forecast base time 2015 03 09



Real time monitoring of mjo waves OLR (ECMWF) 20150305
contour interval: 15 W/m2



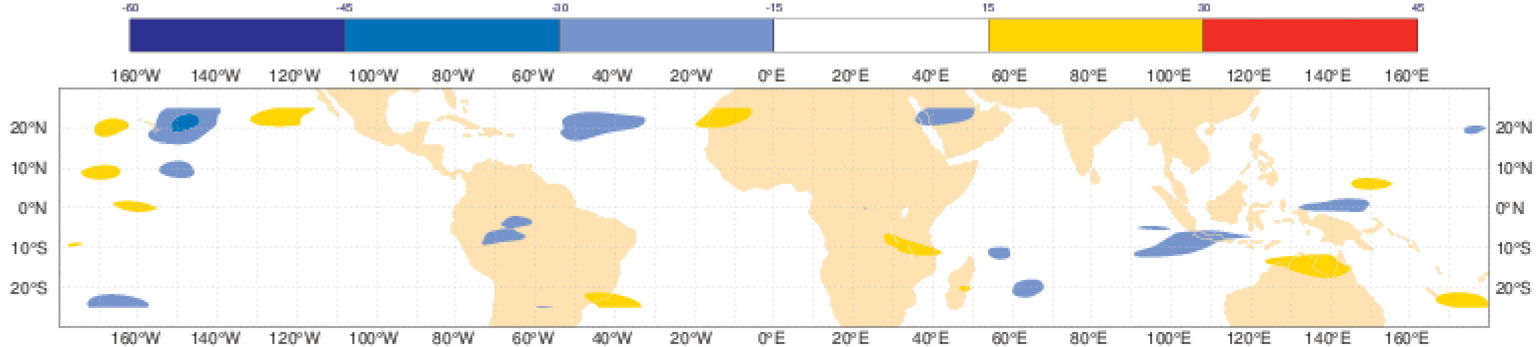
ECMWF

Kelvin Rossby & MJO 5.3.2015-16.3 2015

Real time monitoring of kelvin waves OLR (ECMWF) 20150305

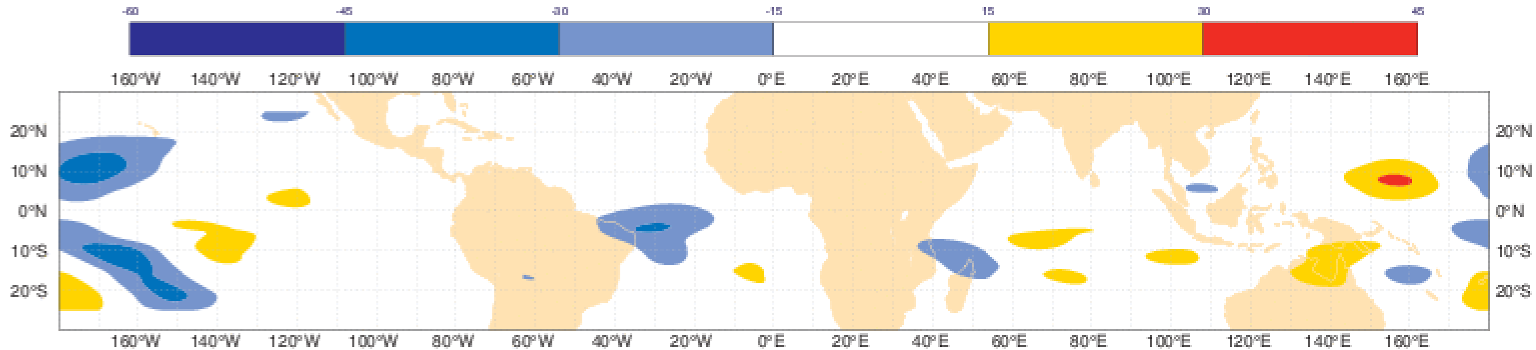
contour interval: 15 W/m2

Forecast base time 2015 03 09



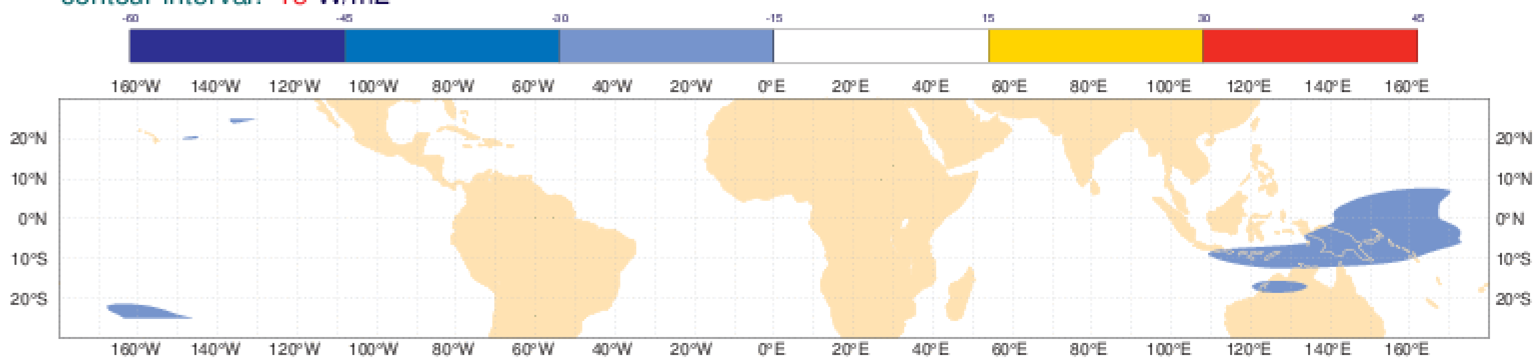
Real time monitoring of rossby waves OLR (ECMWF) 20150305

contour interval: 15 W/m2



Real time monitoring of mjo waves OLR (ECMWF) 20150305

contour interval: 15 W/m2



Normal mode projection and filtering

- First derived by Kasahara and Puri (1981), Tanaka (1985)
- Žagar et al. (2009,2011-2013) and Žagar et al. (2014,2015) applied it to EC MWF system for IG and Rossby modes and made available a general software
- Principle is similar to the analytical solutions to shallow water equations:
  - Requires U ,V, Z and stability
  - Solve for vertical structure equation on model levels, then solve horizontal wave equation (Fourier (longitude) and Legendre (latitude) polynomials
  - IG and Rossby modes are eigen solutions

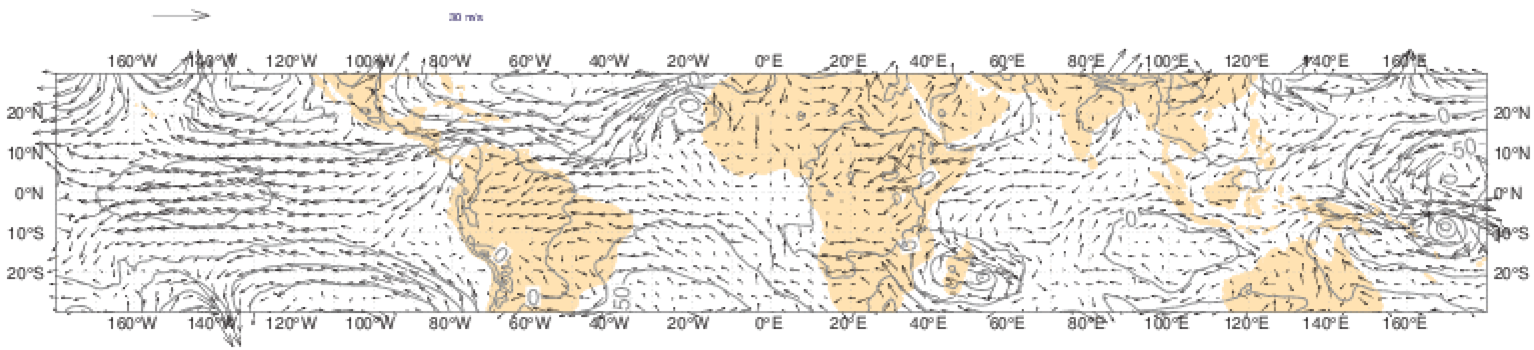
Nota: In contrast to the wavenumber-frequency filtering the projection is done for each time step (output) separately, a time series can be recovered by concatenating, the frequencies are 'hidden' in the eigen solutions

Normal mode projection and filtering

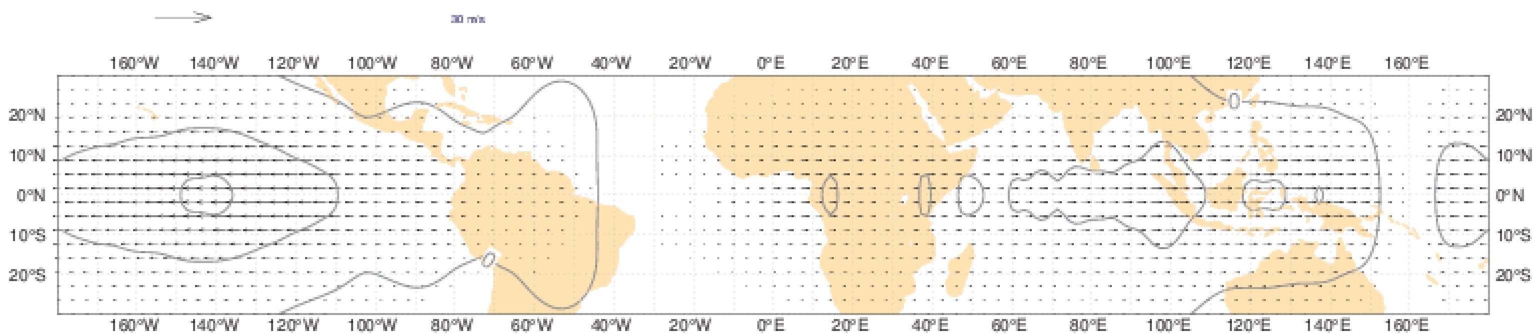
Žagar et al. (Geosc. Mod. Dev. 2015)

850 hPa

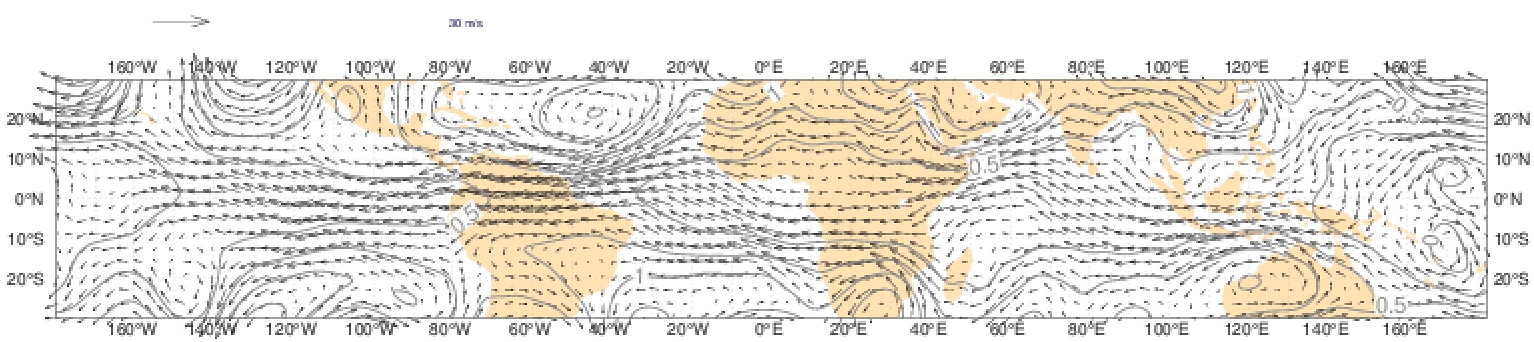
Analysis lev=114 2015030900



kw1 lev=114 2015030900



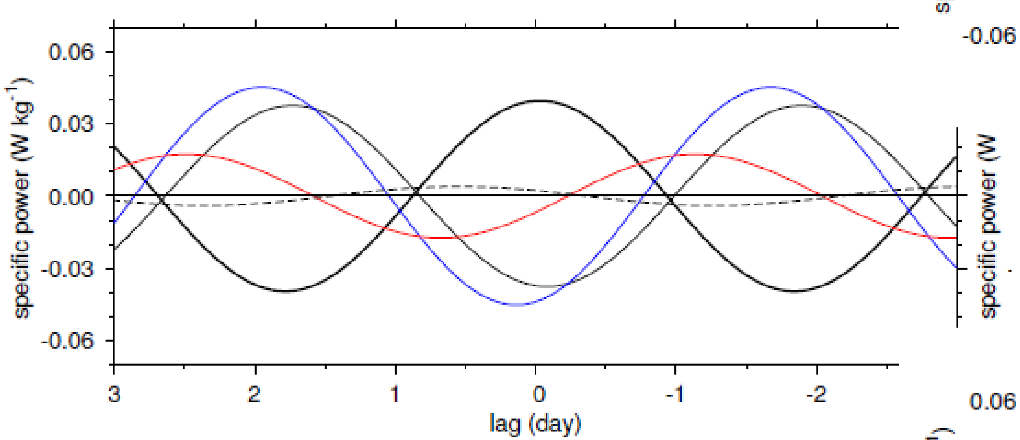
rot-5 lev=114 2015030900

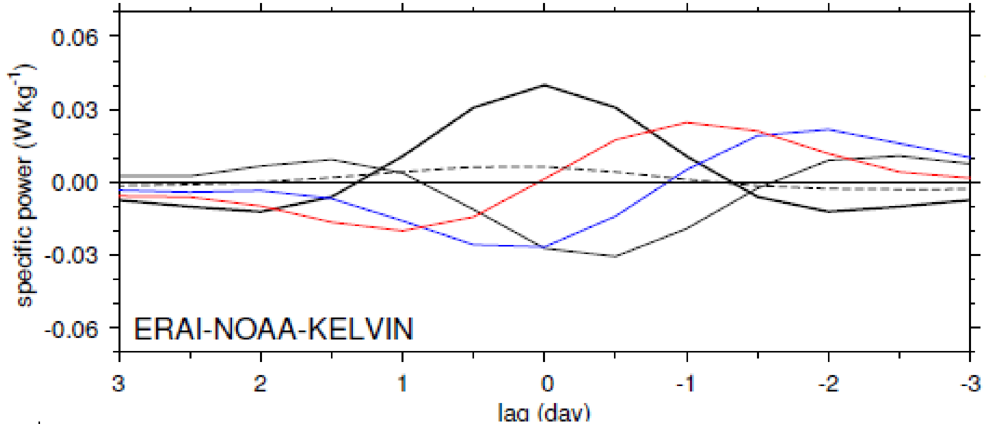


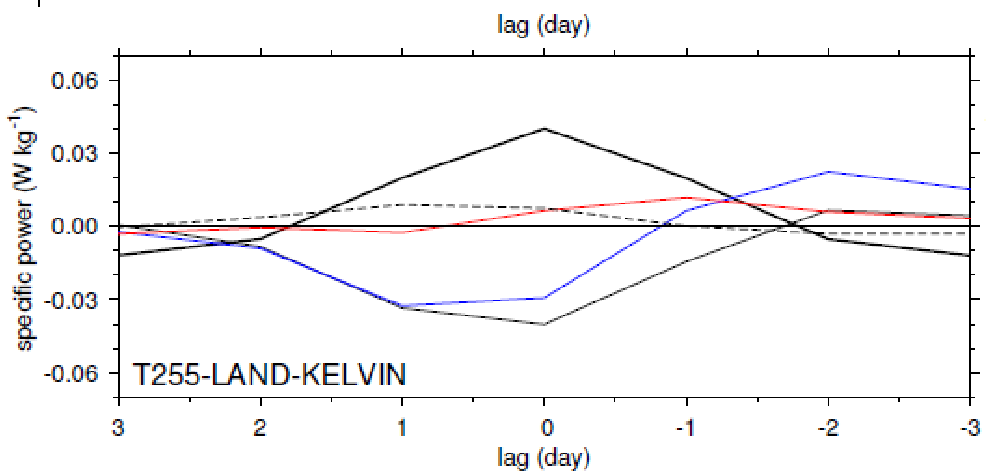
ECMWF

Kelvin waves: Precip, CIN, PBL entropy in linear model, reanalysis and IFS long integrat.

Raymond&Fuchs 2007 Linear Model







Precip CIN PBL entropy

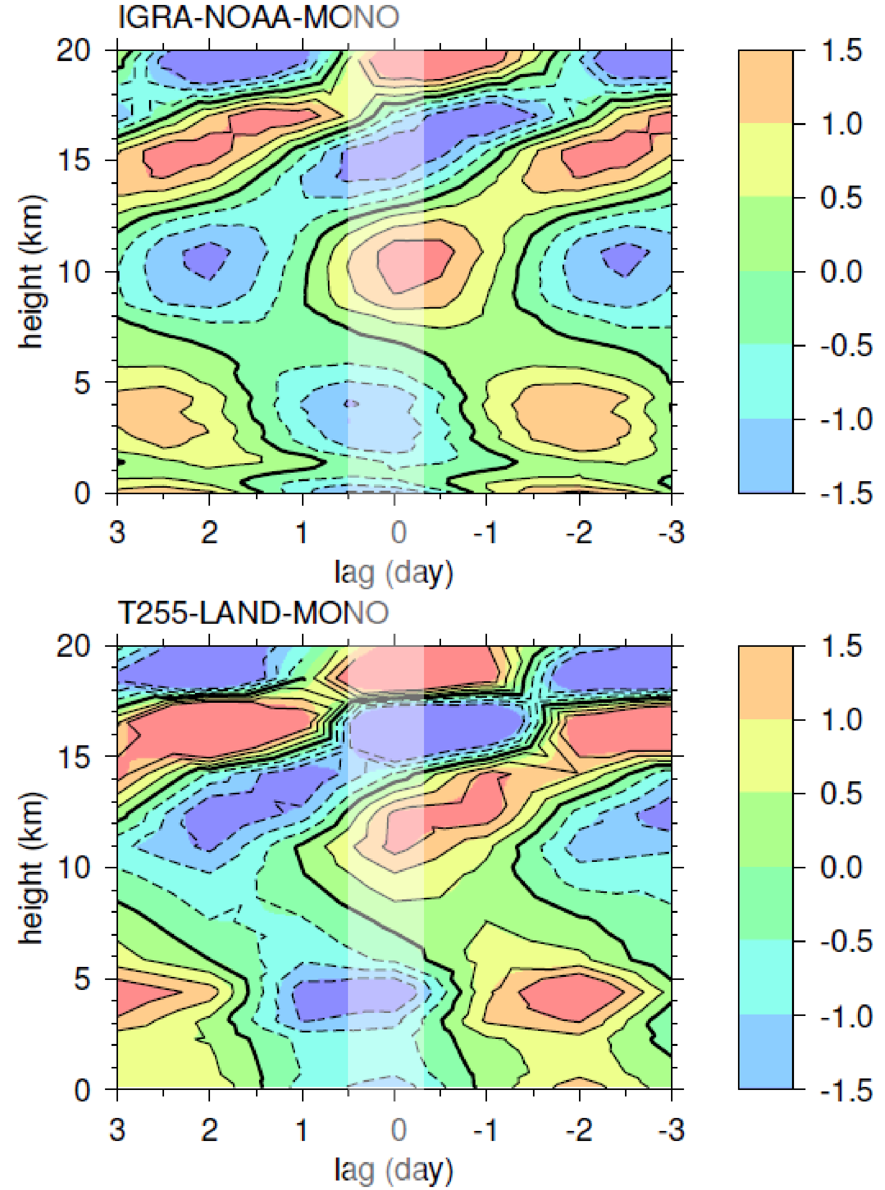
M Herman, Ž. Fuchs, D. Raymond, P. Bechtold, JAS 2015 in rev.

ECMWF

Kelvin waves: vertical structure

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

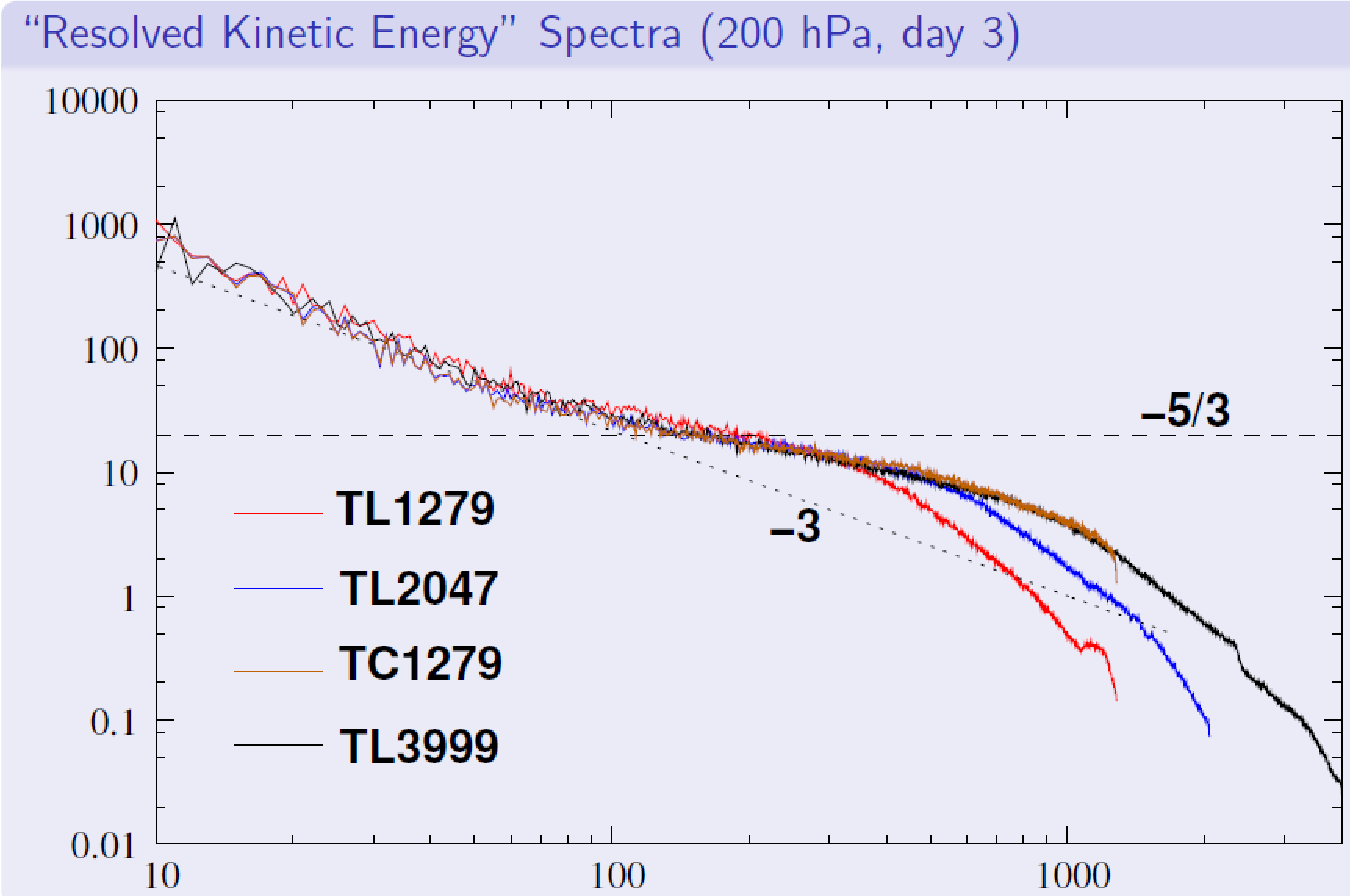
- the conversion of potential in kinetic energy = αω
- The generation of potential energy = N Q



see also G. Shutts (2006, Dyn. Atmos. Oc.)

ECMWF

Effective resolution (S. Malardel & N. Wedi)



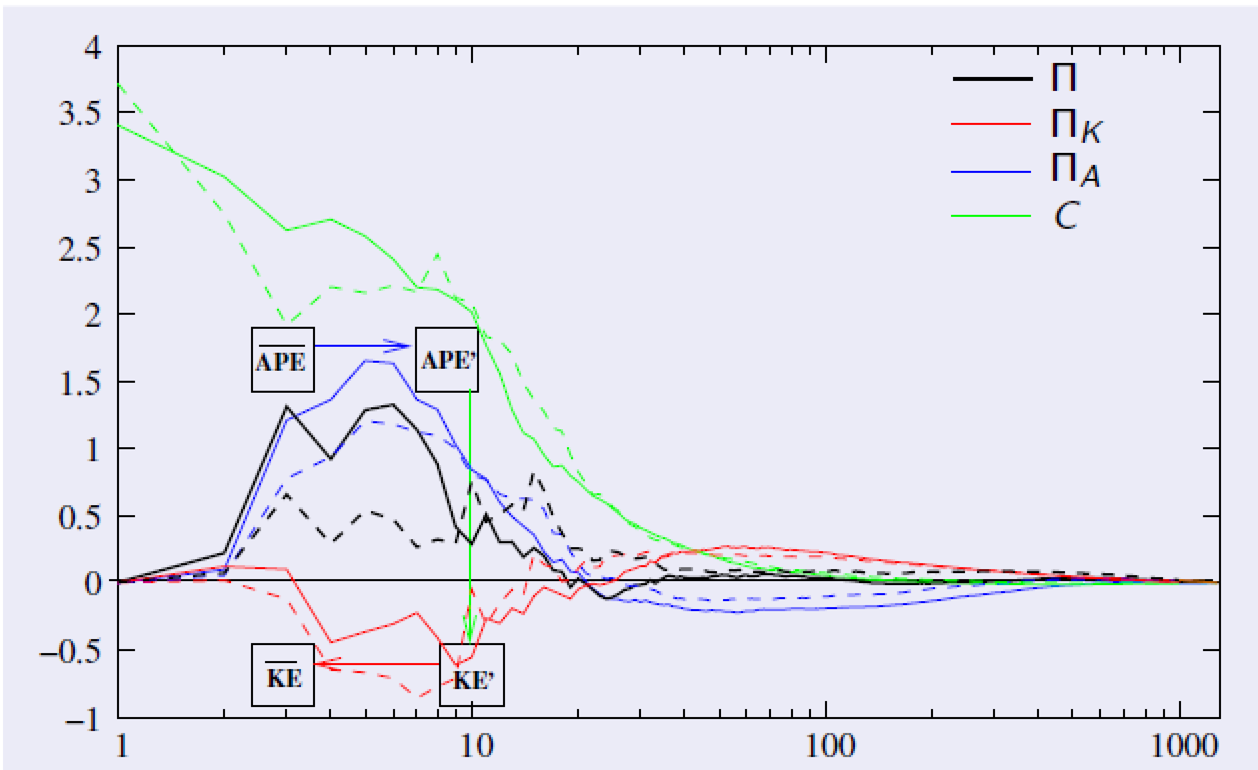
ECMWF

Scale dependent APE – KE analysis

and non-linear spectral transfer in IFS

following Augier and Lindborg (2013)

W m^{-2}



Production/ Flux

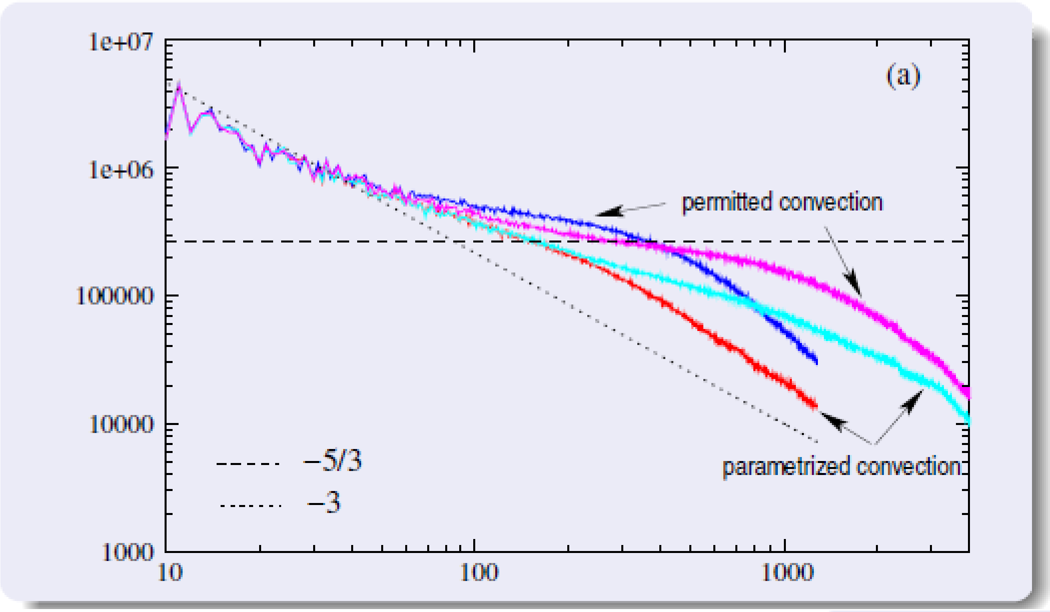
Conversion A->K

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

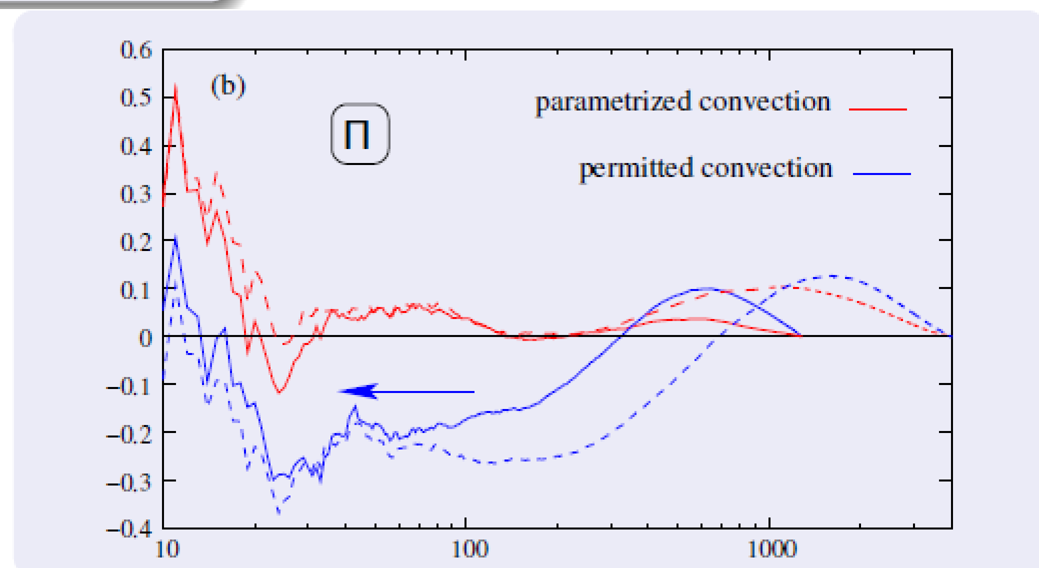
? ?

ECMWF

Spectra and transfer with and without parametrized deep convection



TL1279 =16 km with and without deep
TL4000=5 km with and without deep



ECMWF

The ‘mass flux’ flux approximation

$$\overline{\omega'\varphi'} = \sigma(1-\sigma)(\omega^c - \tilde{\omega})(\varphi^c - \tilde{\varphi})$$

$$\sigma \ll 1 \Rightarrow$$

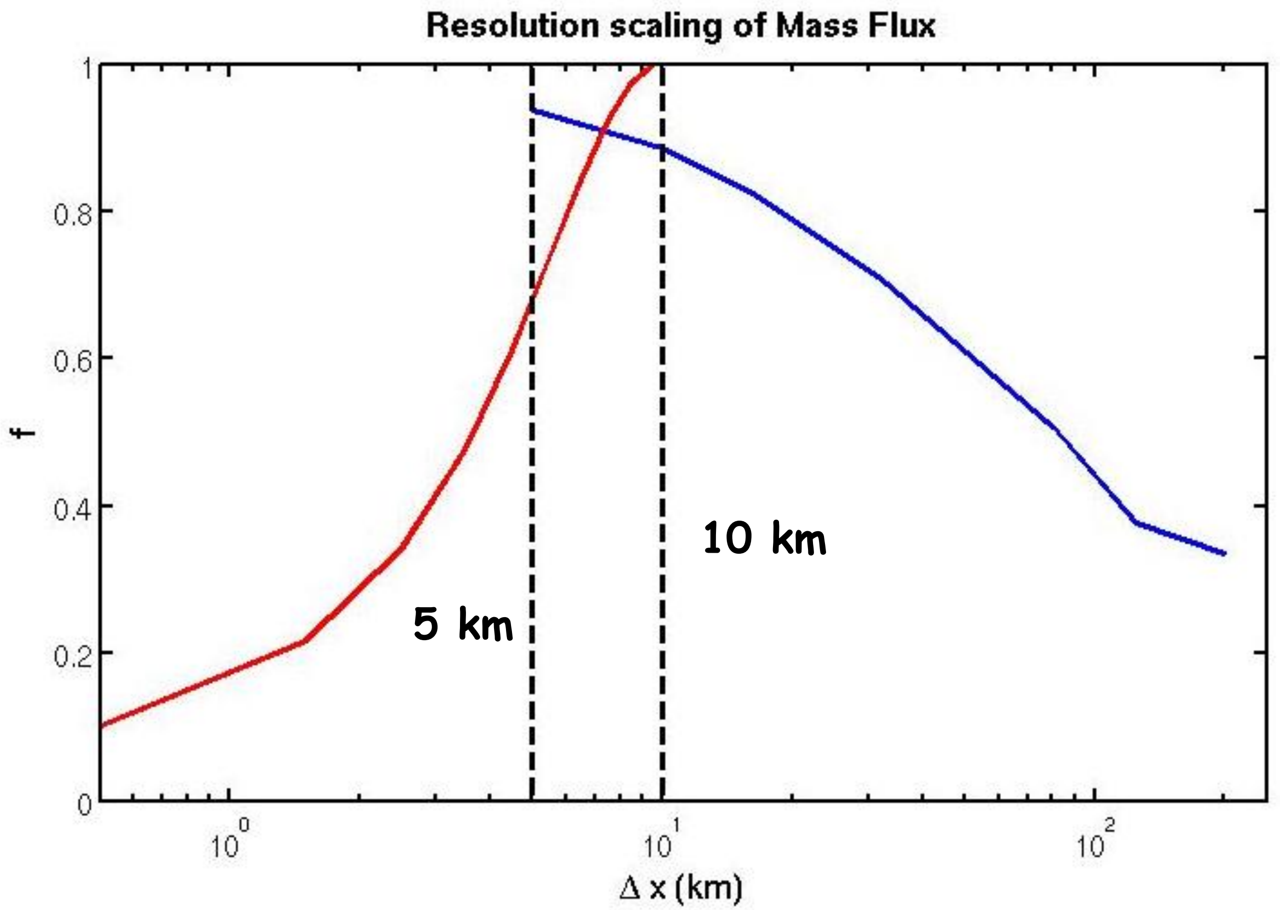
$$\overline{\omega'\varphi'} = \boldsymbol{\sigma\omega^c}(\varphi^c - \bar{\varphi}) = \boldsymbol{M} g^{-1}(\varphi^c - \bar{\varphi})$$

area fraction

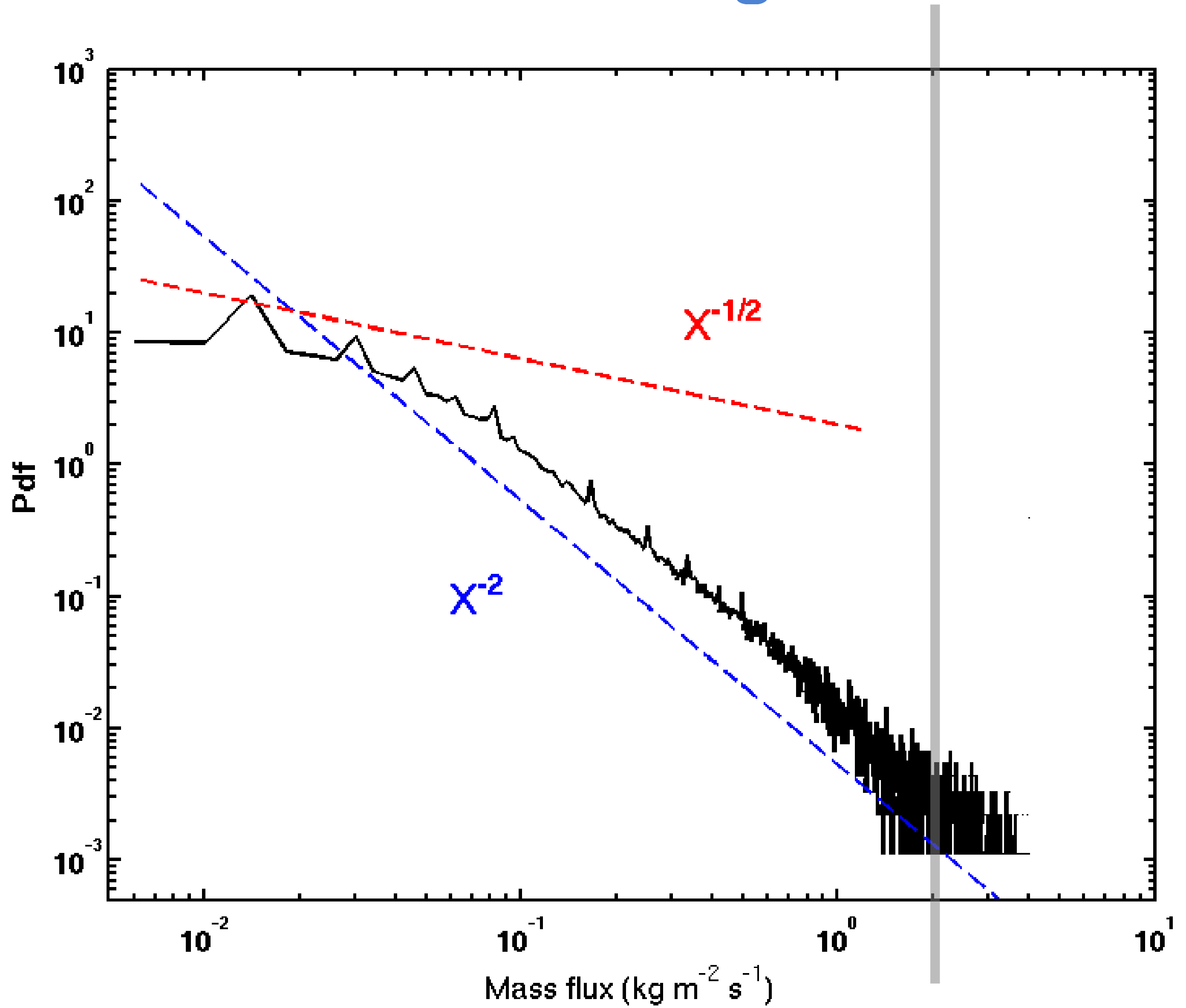
Ensemble mean speed

Resolution scaling

$$M_b = \acute{M}_b \frac{PCAPE}{\tau} \frac{1}{\int_{zb}^{zt} \acute{M} N^2 dz} \qquad f(\Delta x)$$



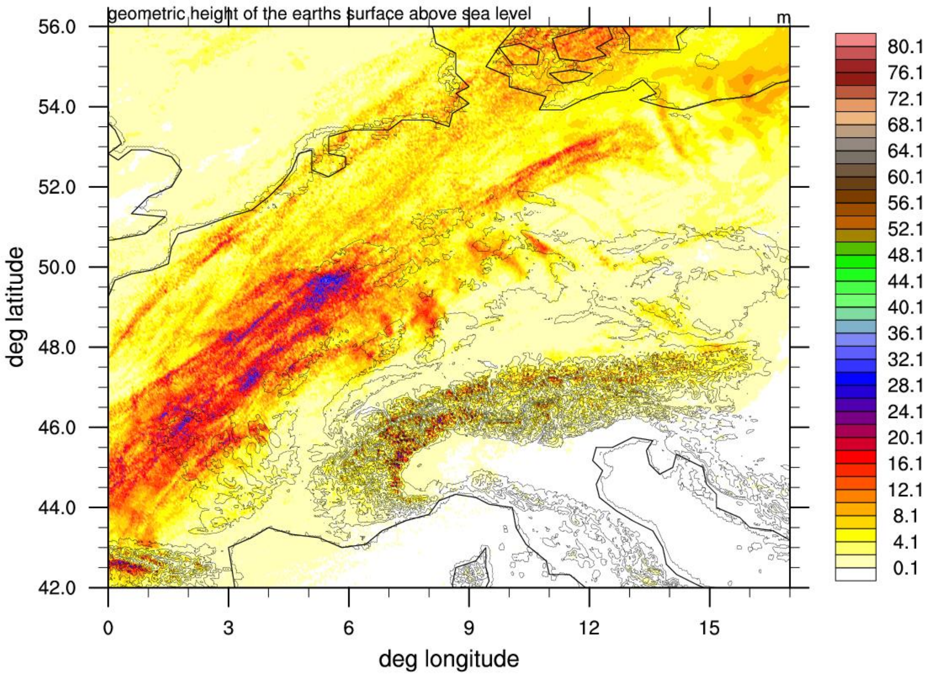
Cloud base mass flux global T1279



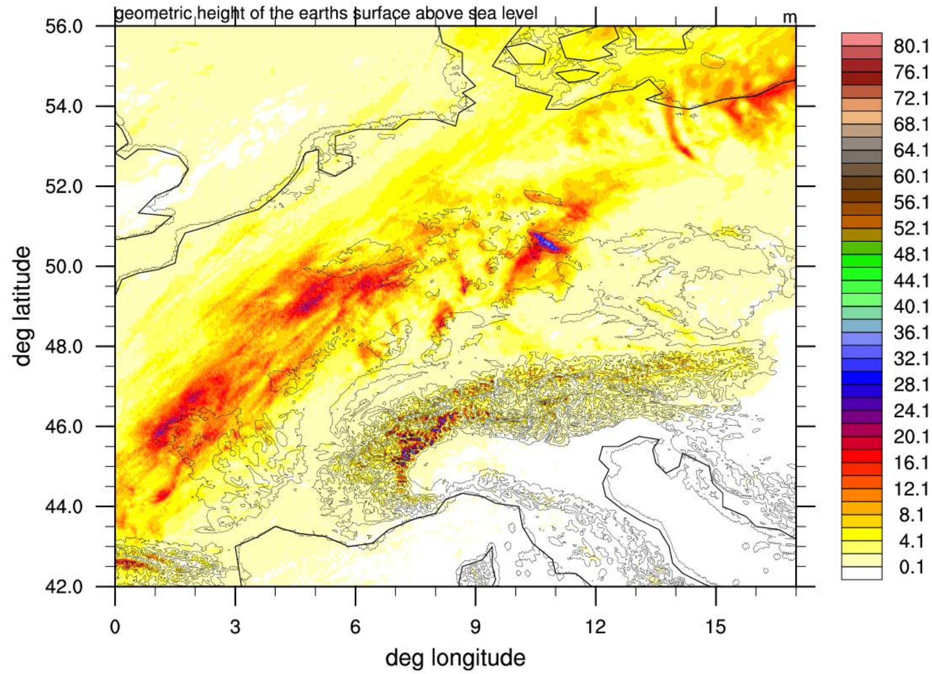
ECMWF

DWD ICON with 13 to 3.25 km nesting convective precip 17.6.2012+72h

Guenther Zaengl



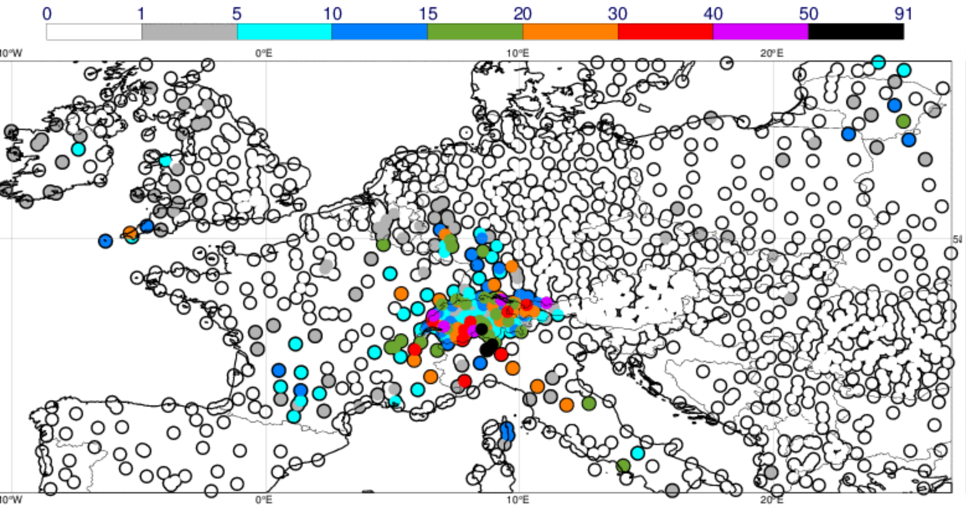
noisy, too strong



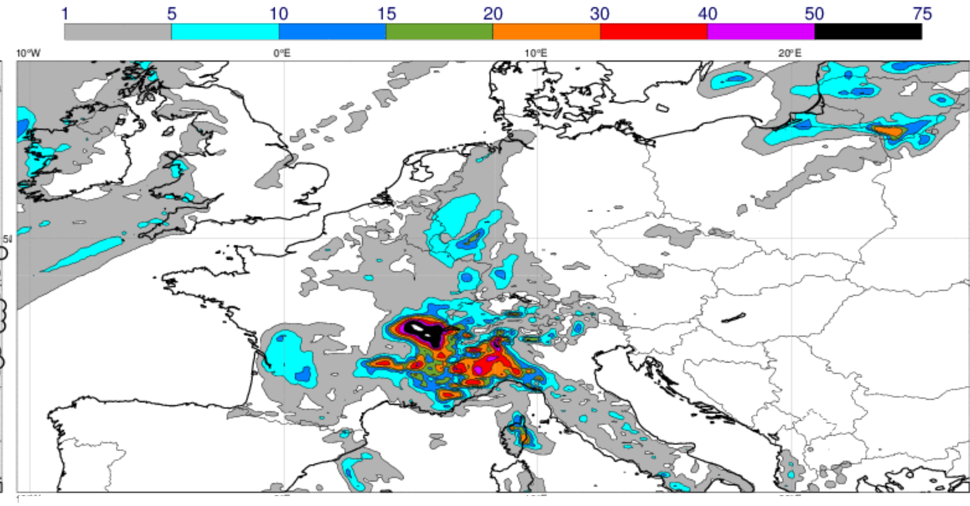
smooth

Example of (convective) precipitation forecast and resolution

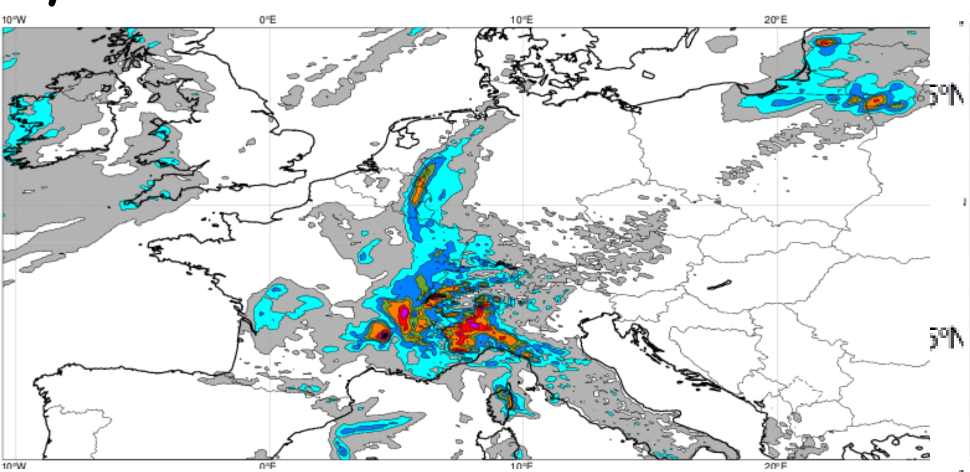
Obs 9 Aug 2015



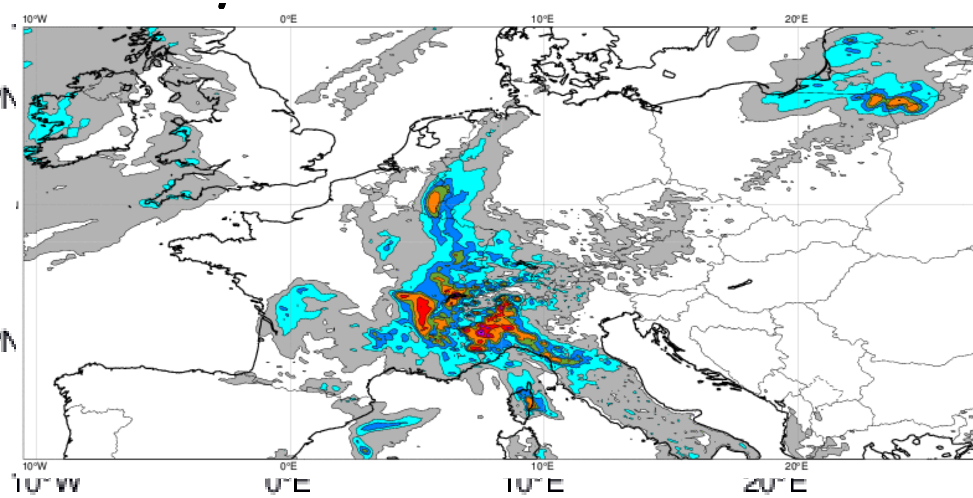
Oper Cy41r1 Tl1279 16 km



Cy42r1 TCo1279 9 km



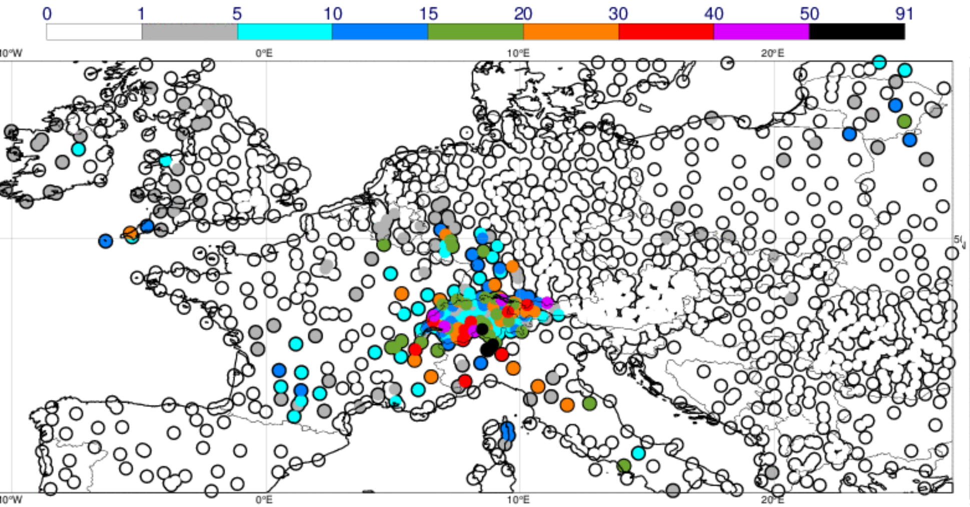
Cy42r1 TCo1279 9 km mfl scale



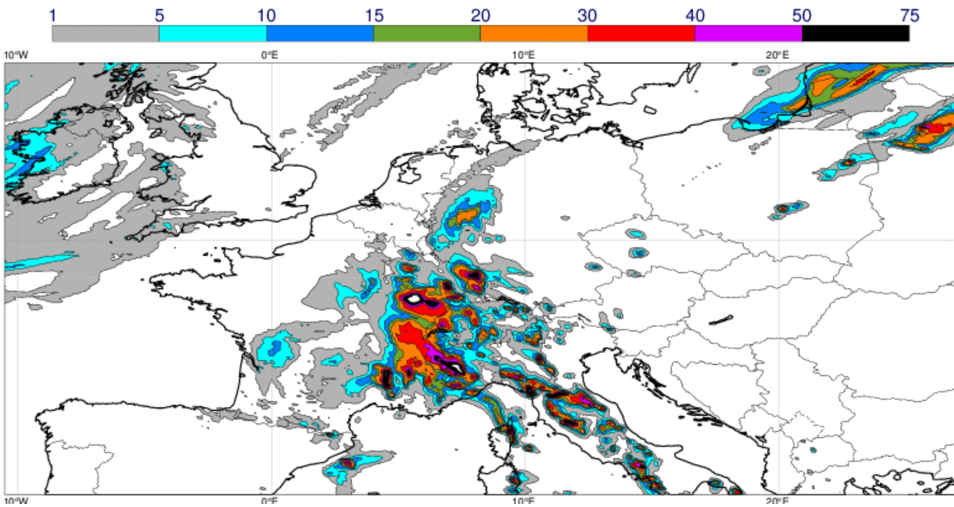
ECMWF

Example of convective precipitation forecast and resolution

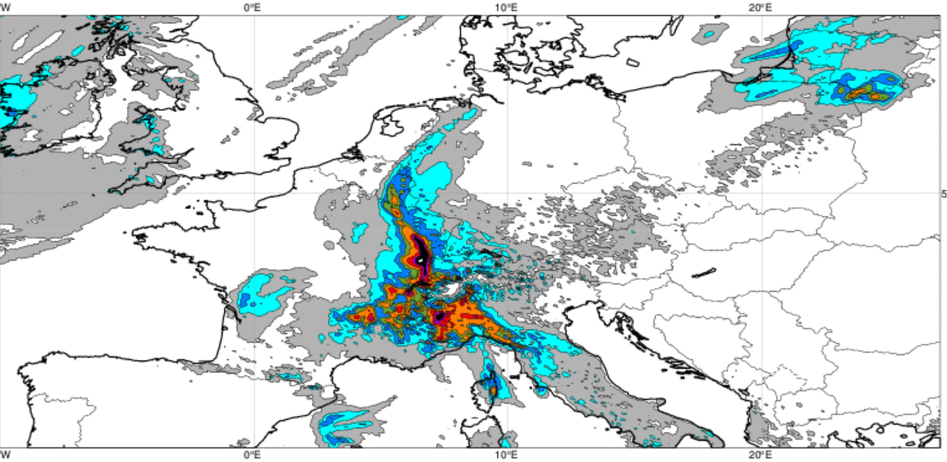
Obs 9 Aug 2015



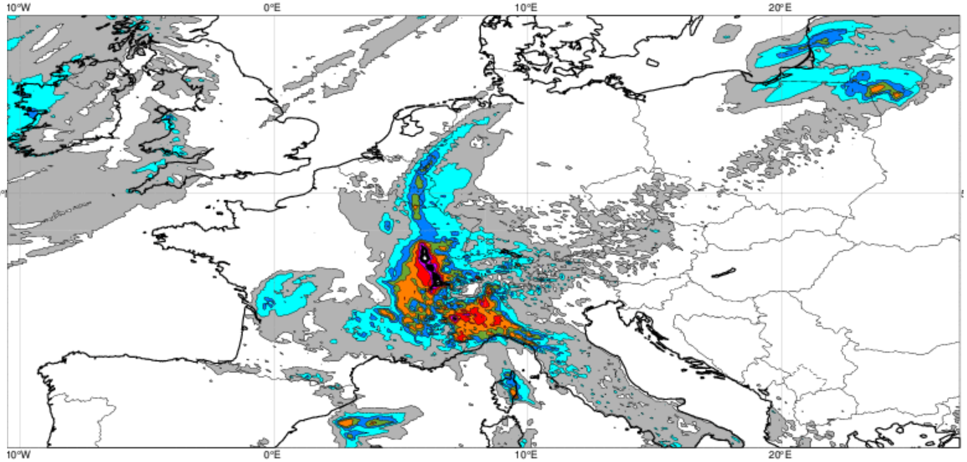
Cy42r1 Tco1999 no deep



Cy42r1 TCo1999 5 km

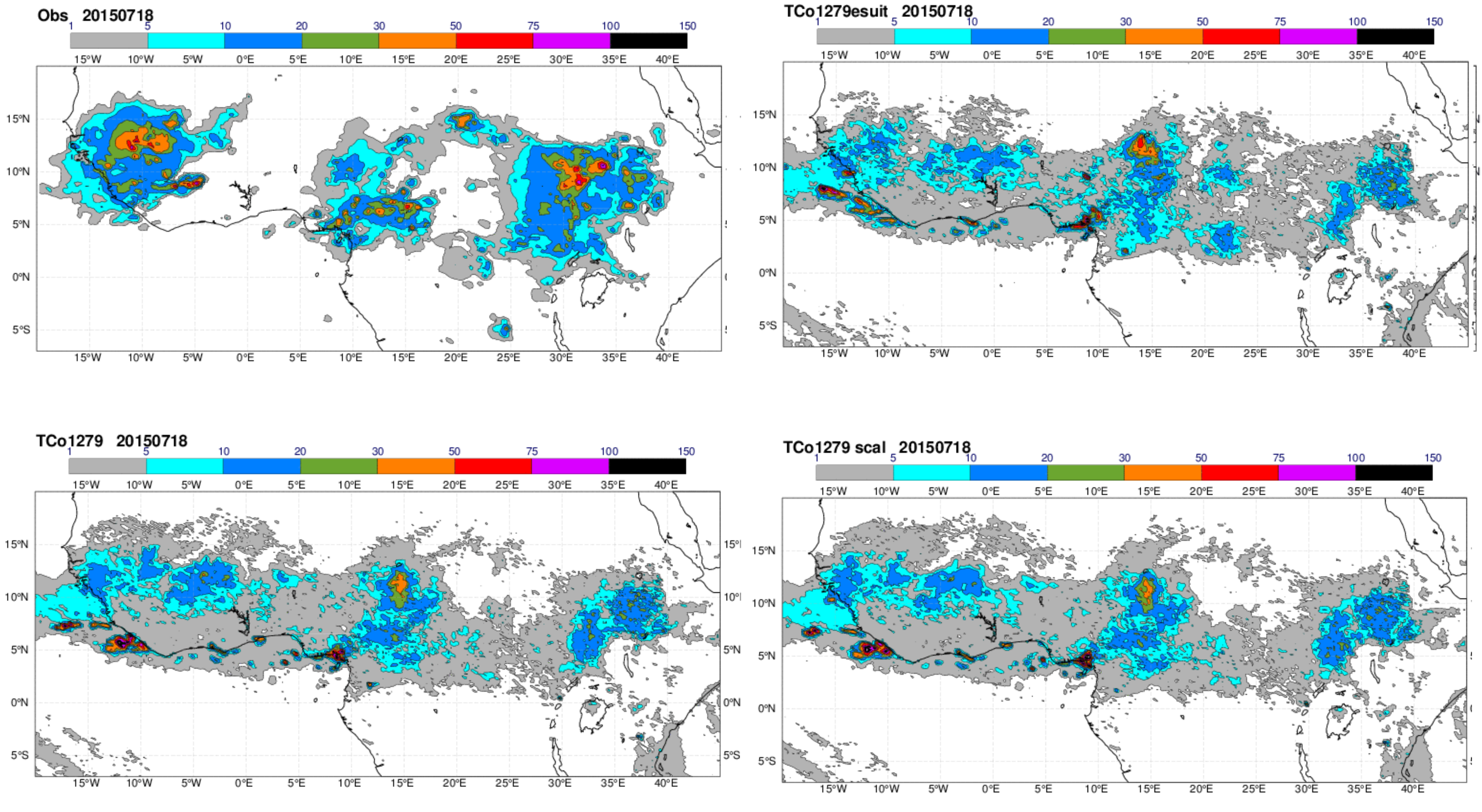


Cy42r1 TCo1999 5 km scaled Mfl

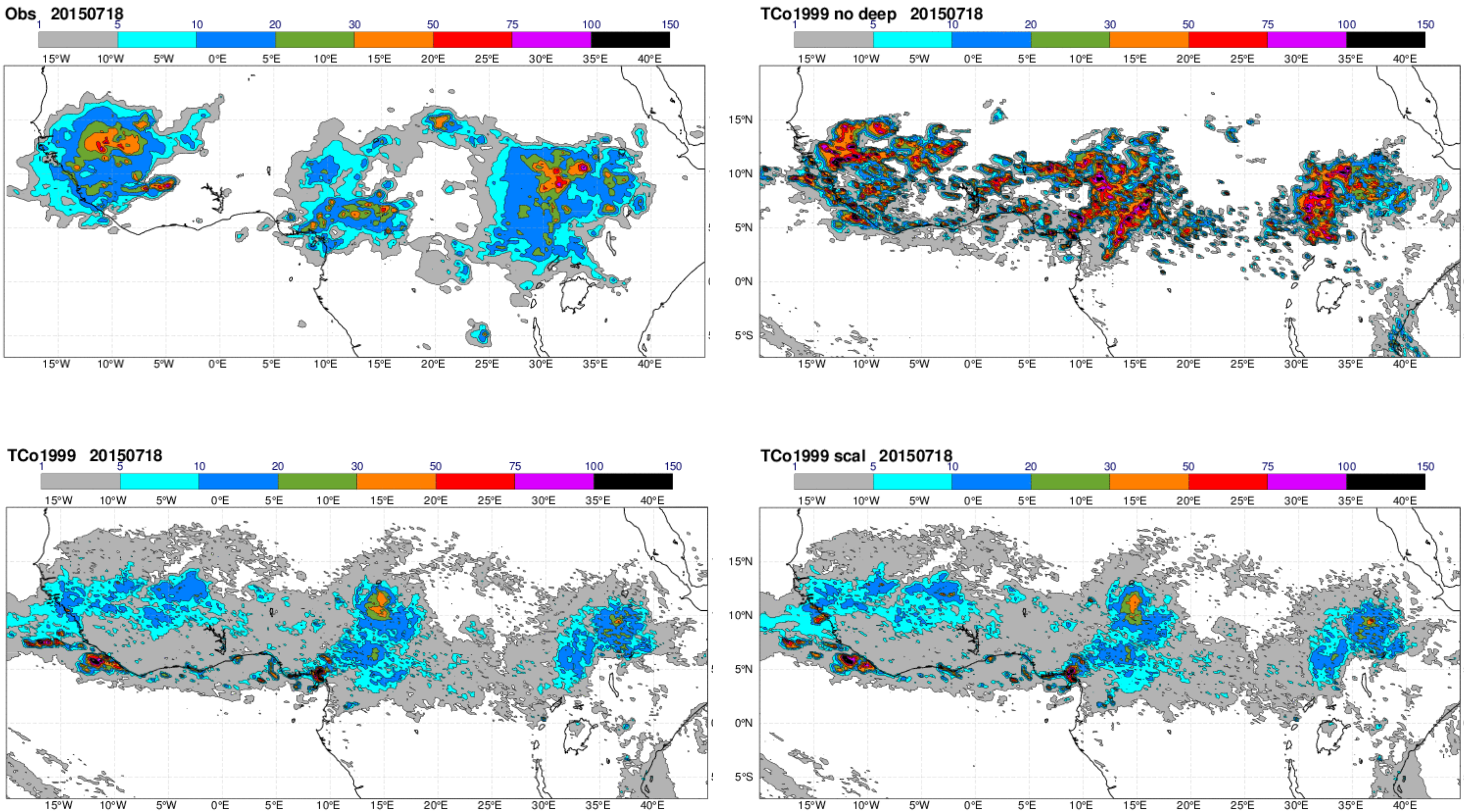


ECMWF

Africa using NOAA FEWS rainfall estimate



Africa using NOAA FEWS rainfall estimate

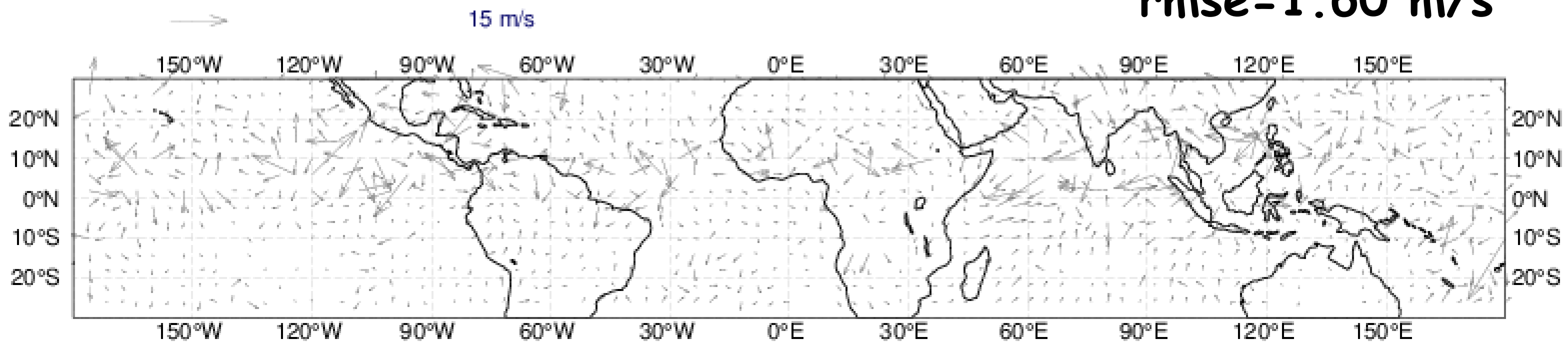


ECMWF

Tropical t+12h wind errors against oper. analysis

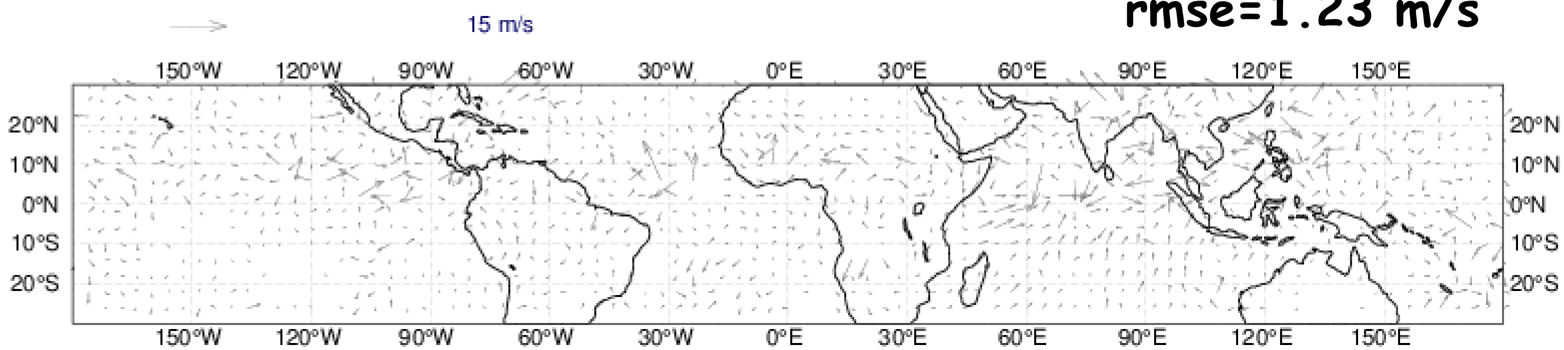
TCo1999 no deep 20150718 +12

rmse=1.60 m/s



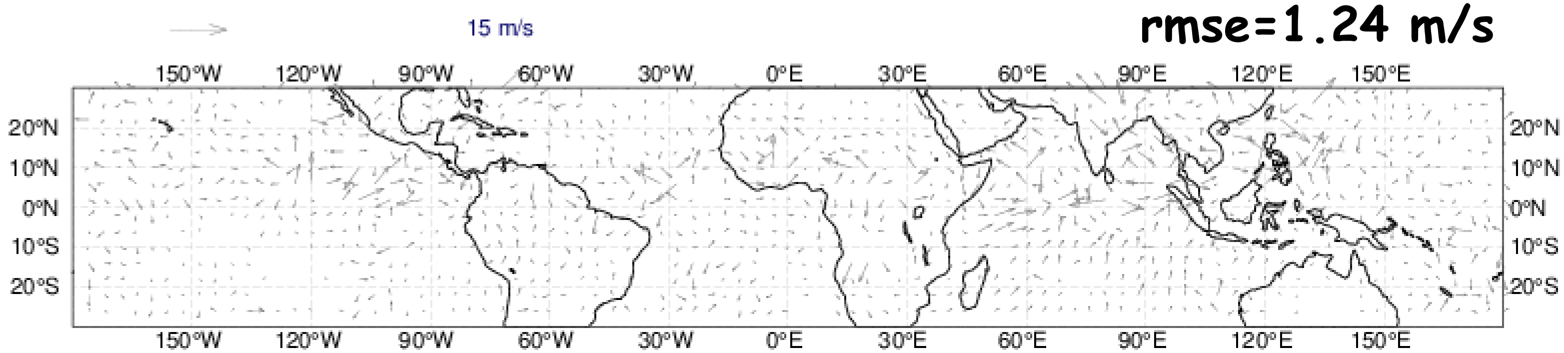
TCo1279 20150718 +12

rmse=1.23 m/s

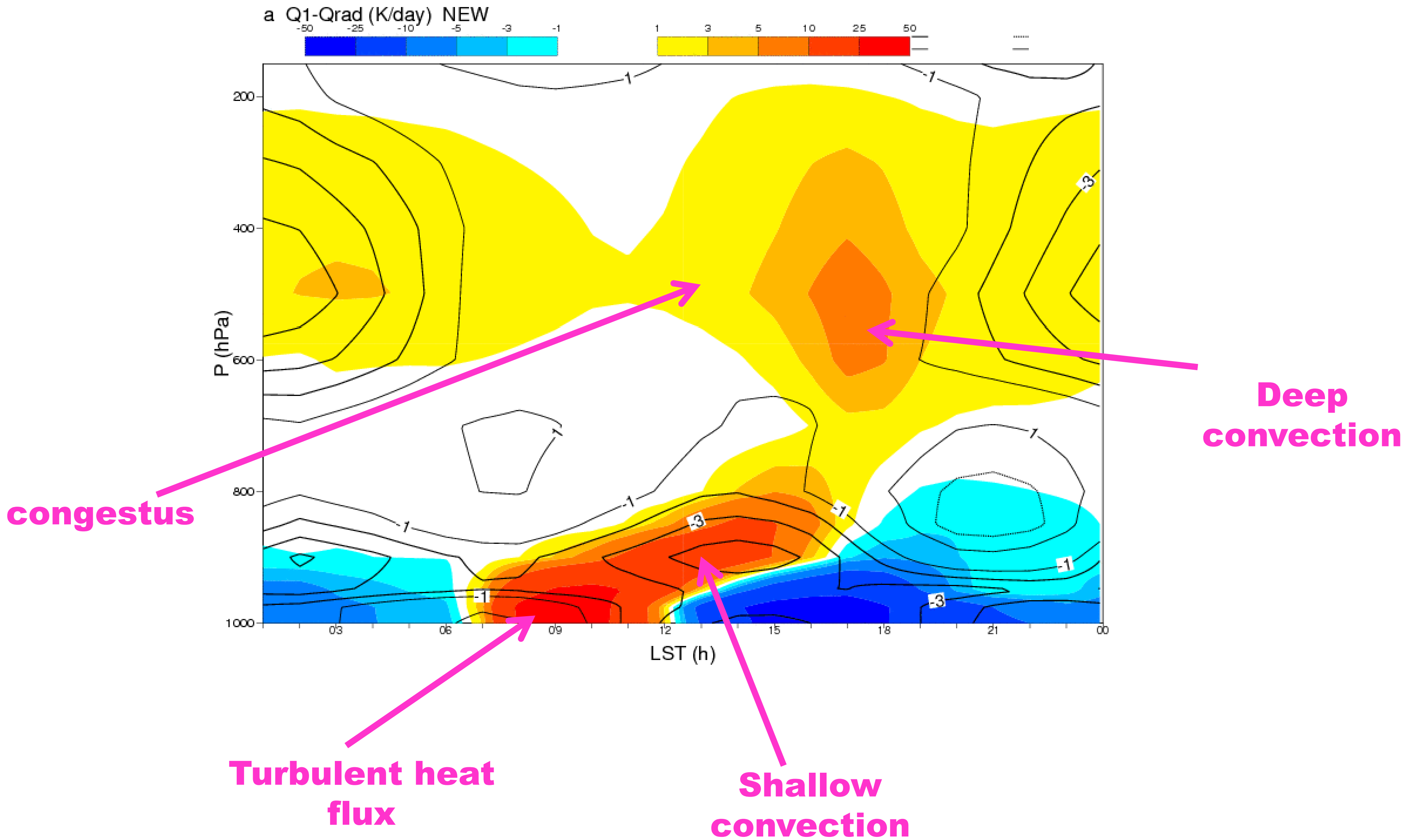


TCo1999 scal 20150718 +12

rmse=1.24 m/s

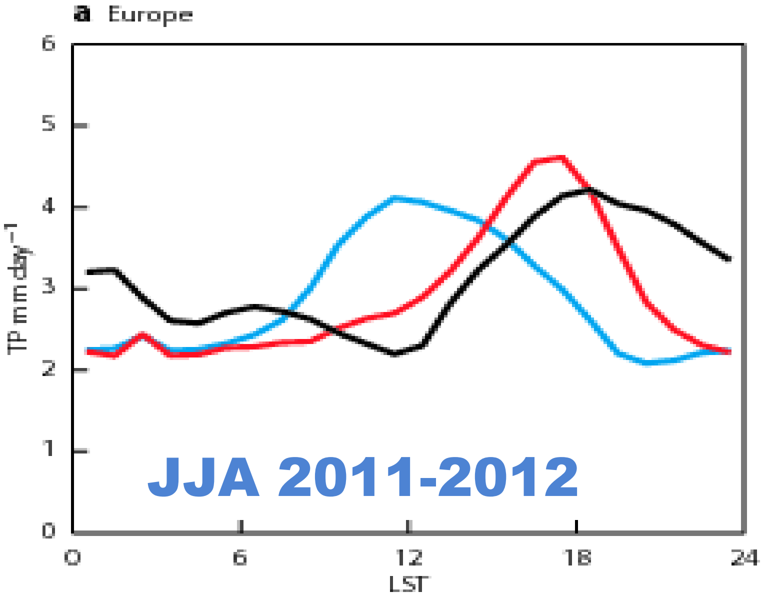


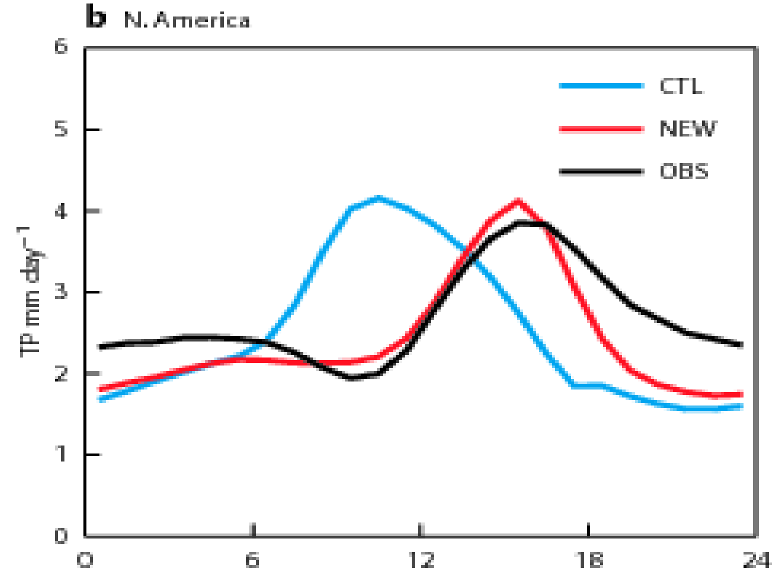
Recent improvements: diurnal cycle Evolution of total heating profile -radiation



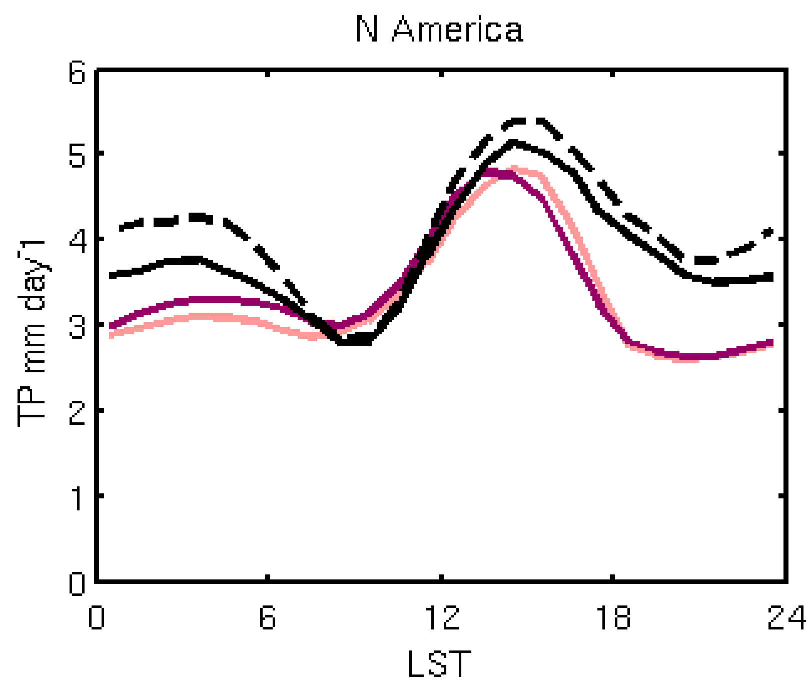
ECMWF

Diurnal cycle: JJA more realistic since Nov 2013

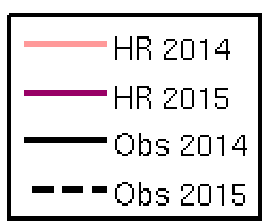




NEXRAD data
Philippe Lopez



And since? And in HRES 16 km ?

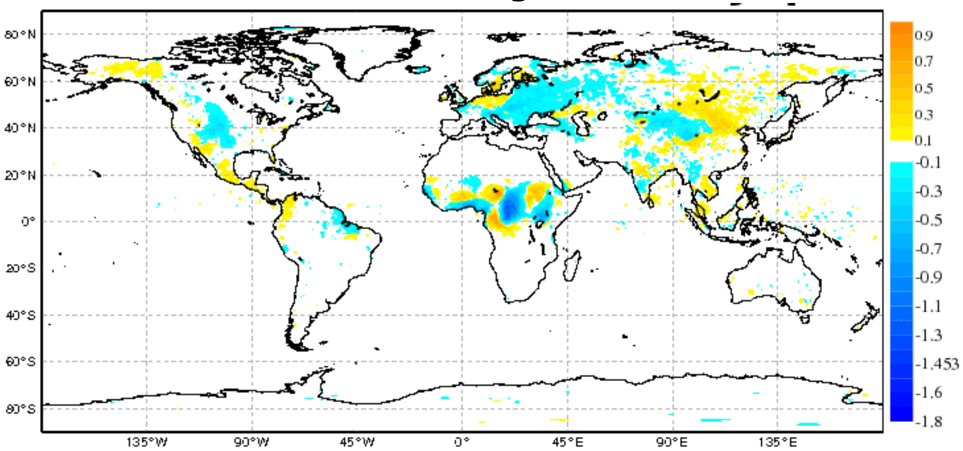


Bechtold et al., 2014, J. Atmos. Sci.

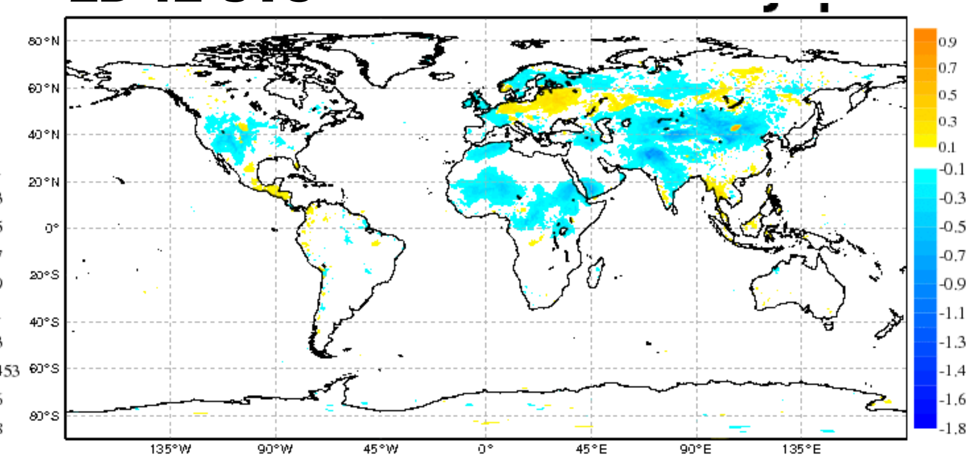
ECMWF

Diurnal cycle and 2T/2D error reduction:
MABS(Exp)-MABS(CTL) [K] own analysis

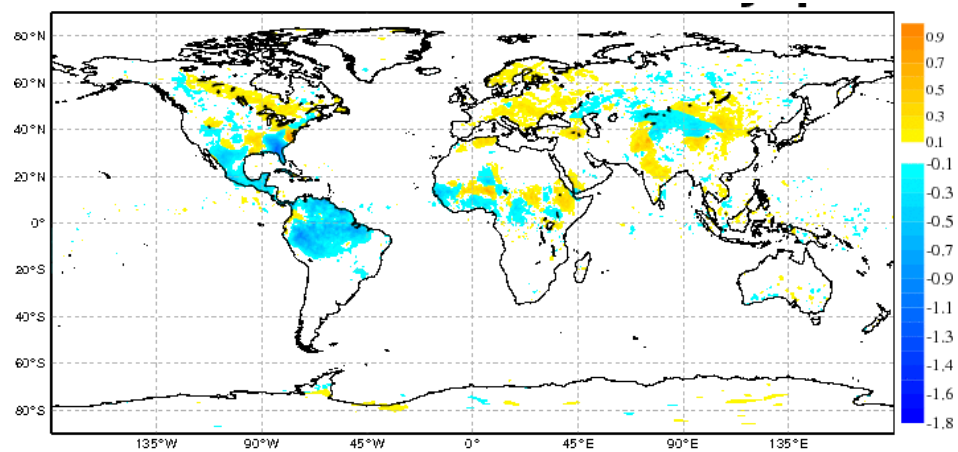
2T 12 UTC June-July 2012 T511



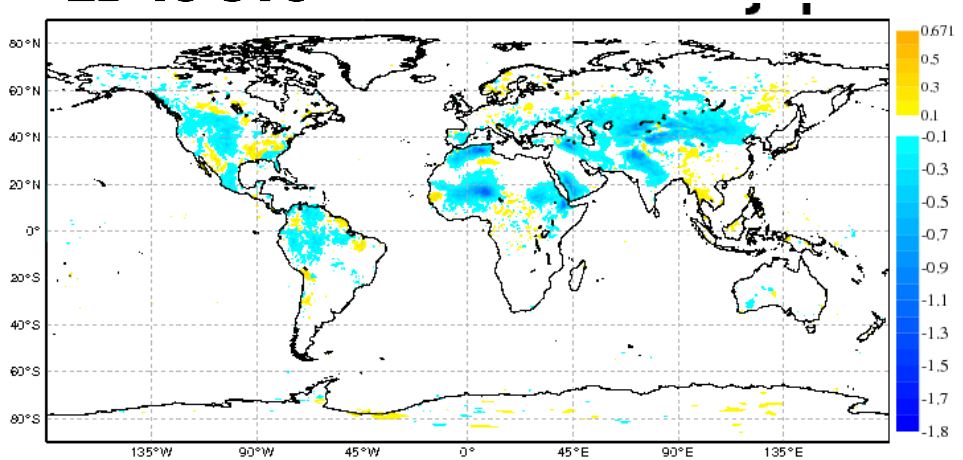
2D 12 UTC



2T 18 UTC

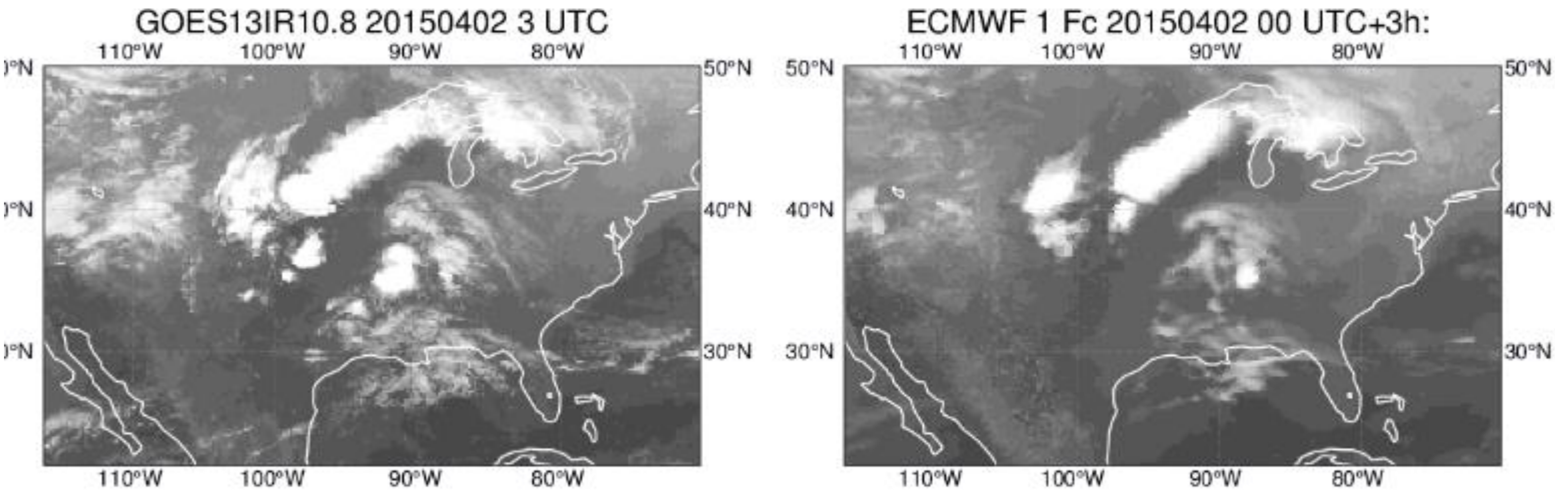


2D 18 UTC

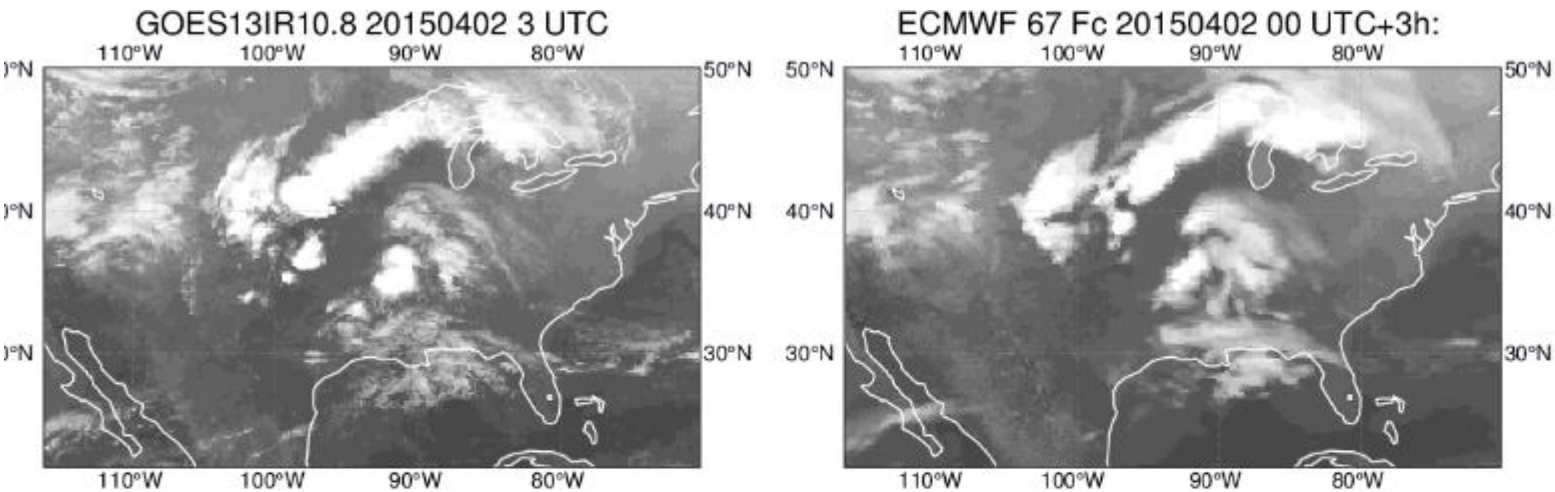


Examples of recent improvements: detrainment/microphys

O-suite 40r1



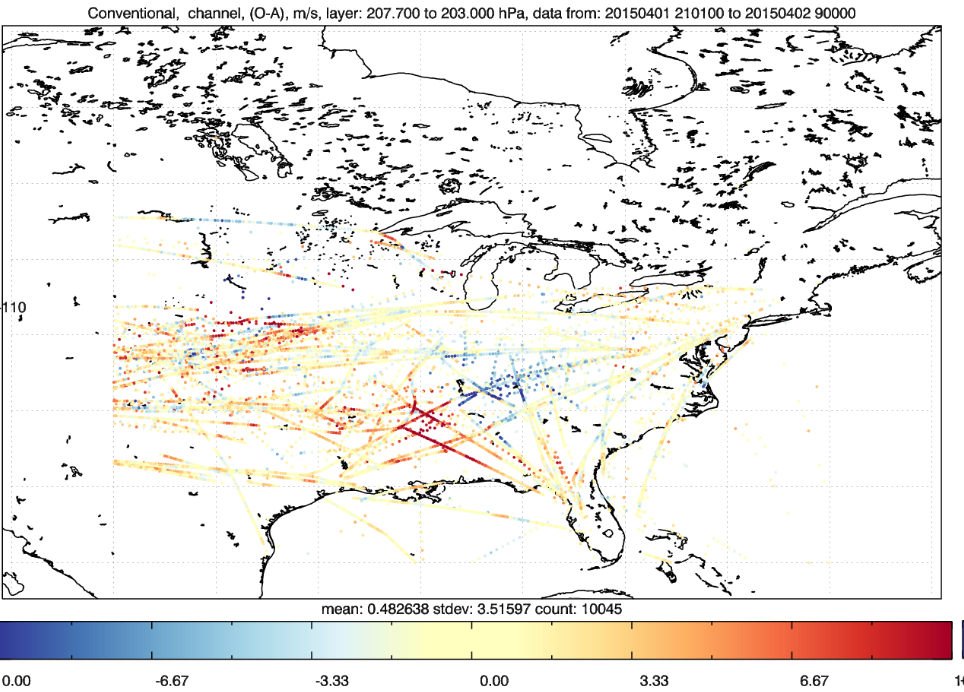
E-suite 41r1



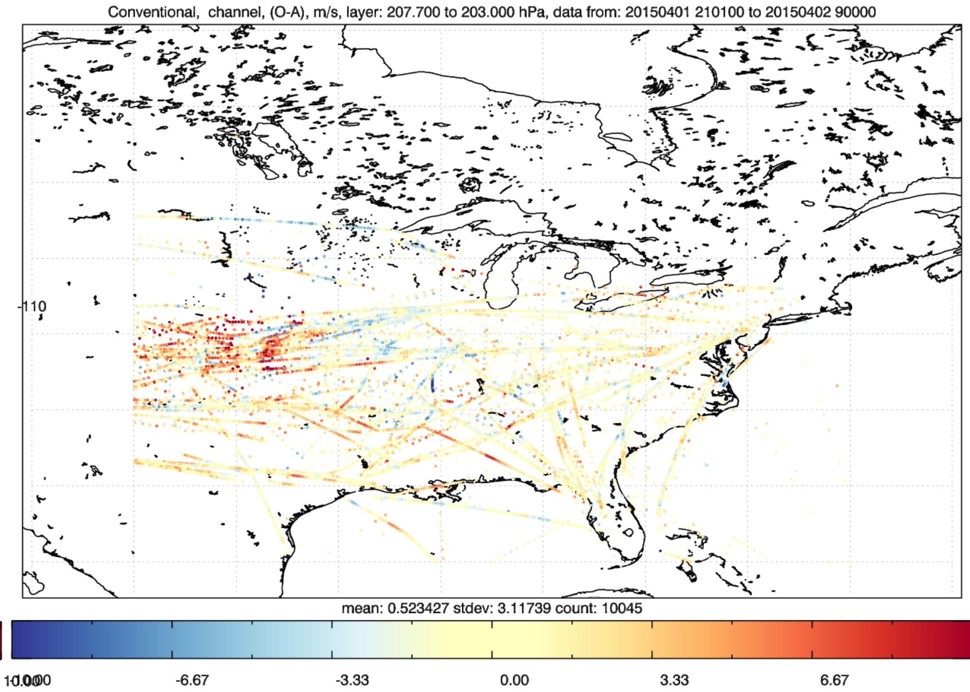
ECMWF

corresponding Aircraft statistics

O-suite 40r1



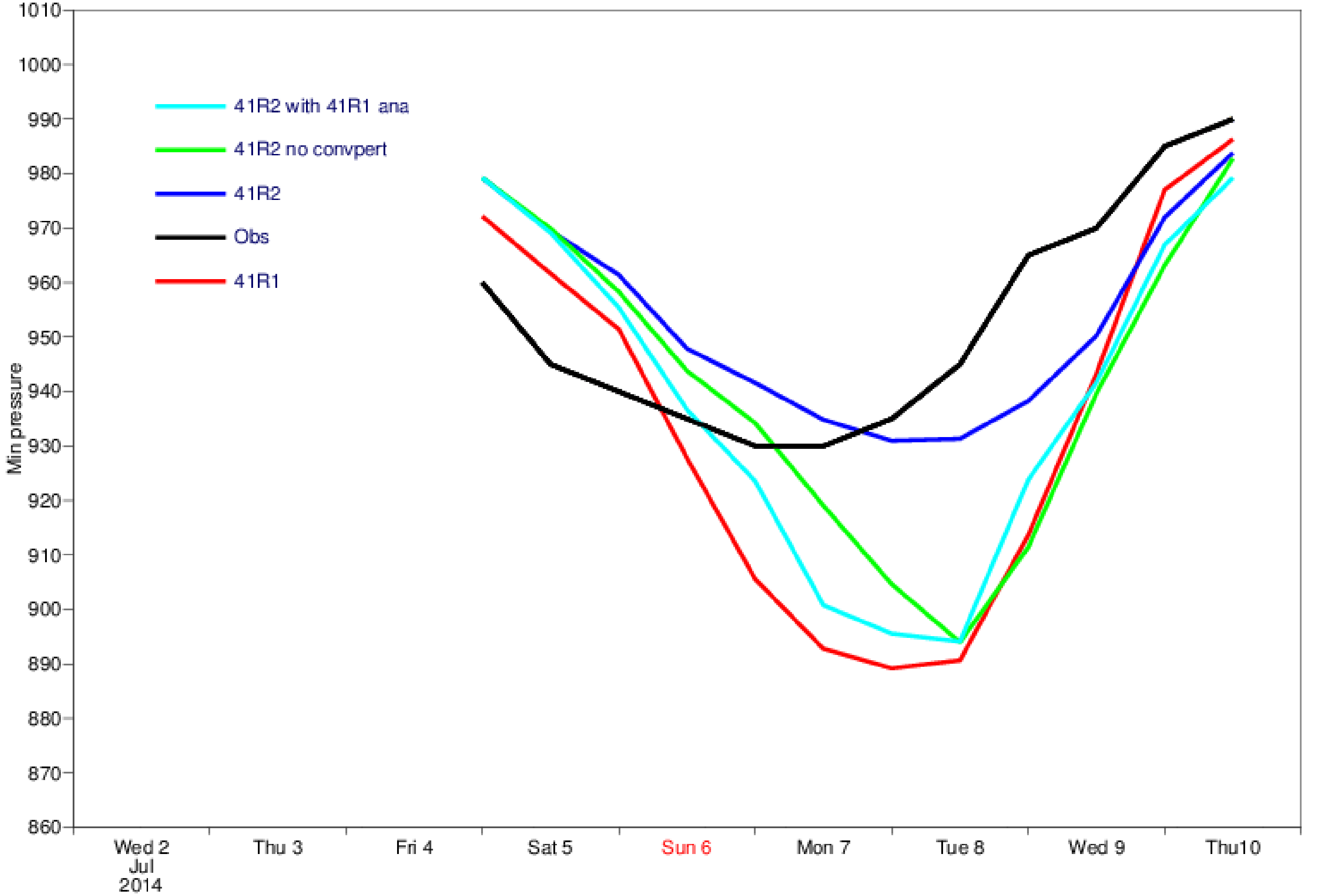
E-suite 41r1



Michael Rennie

ECMWF

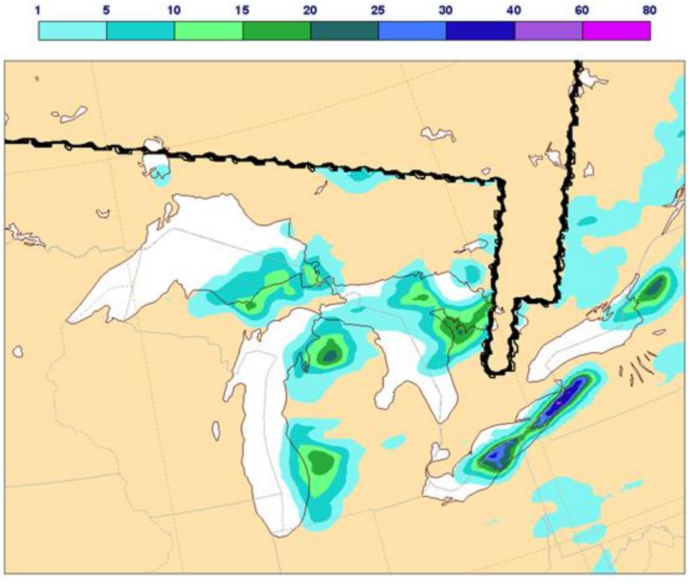
Sensitivity of cyclone depth to parcel perturbations in convection: Cyclone Neoguri



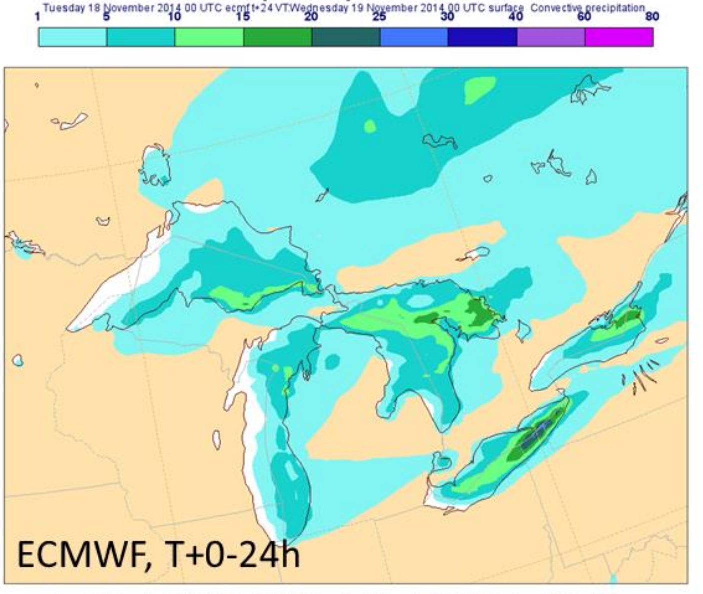
far too deep cyclone forecast could be addressed with increasing parcel perturbation in convection (blue curve) –also it is shown that it is a model (fc) problem and not due to initial conditions

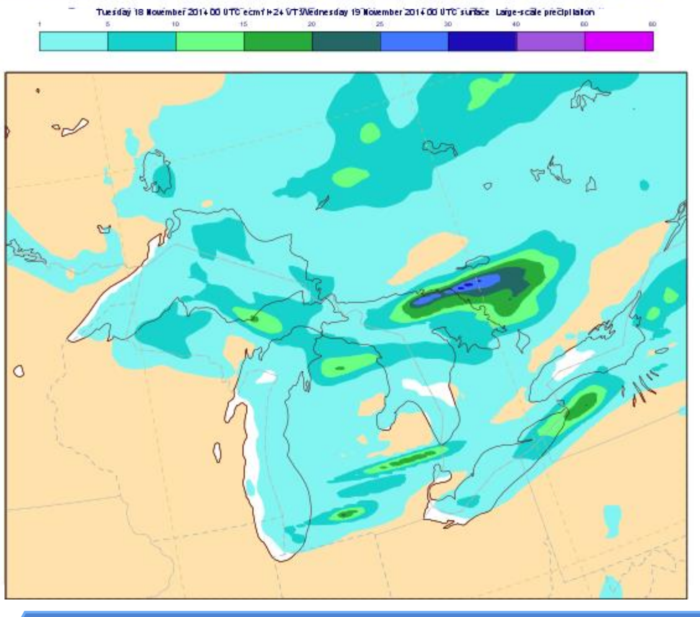
Winter convection: Lake effect and advection

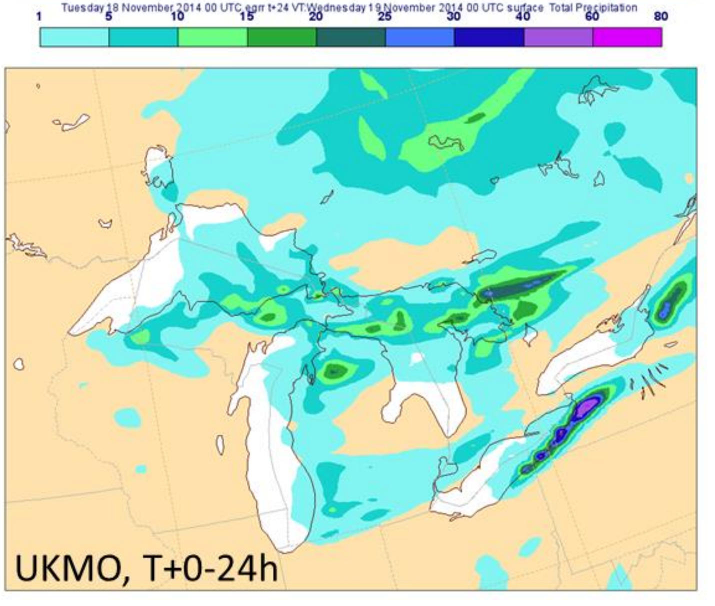
NEXRAD, 24h precipitation ended on 19/11/14 00UTC



24-h total precipitation forecasts

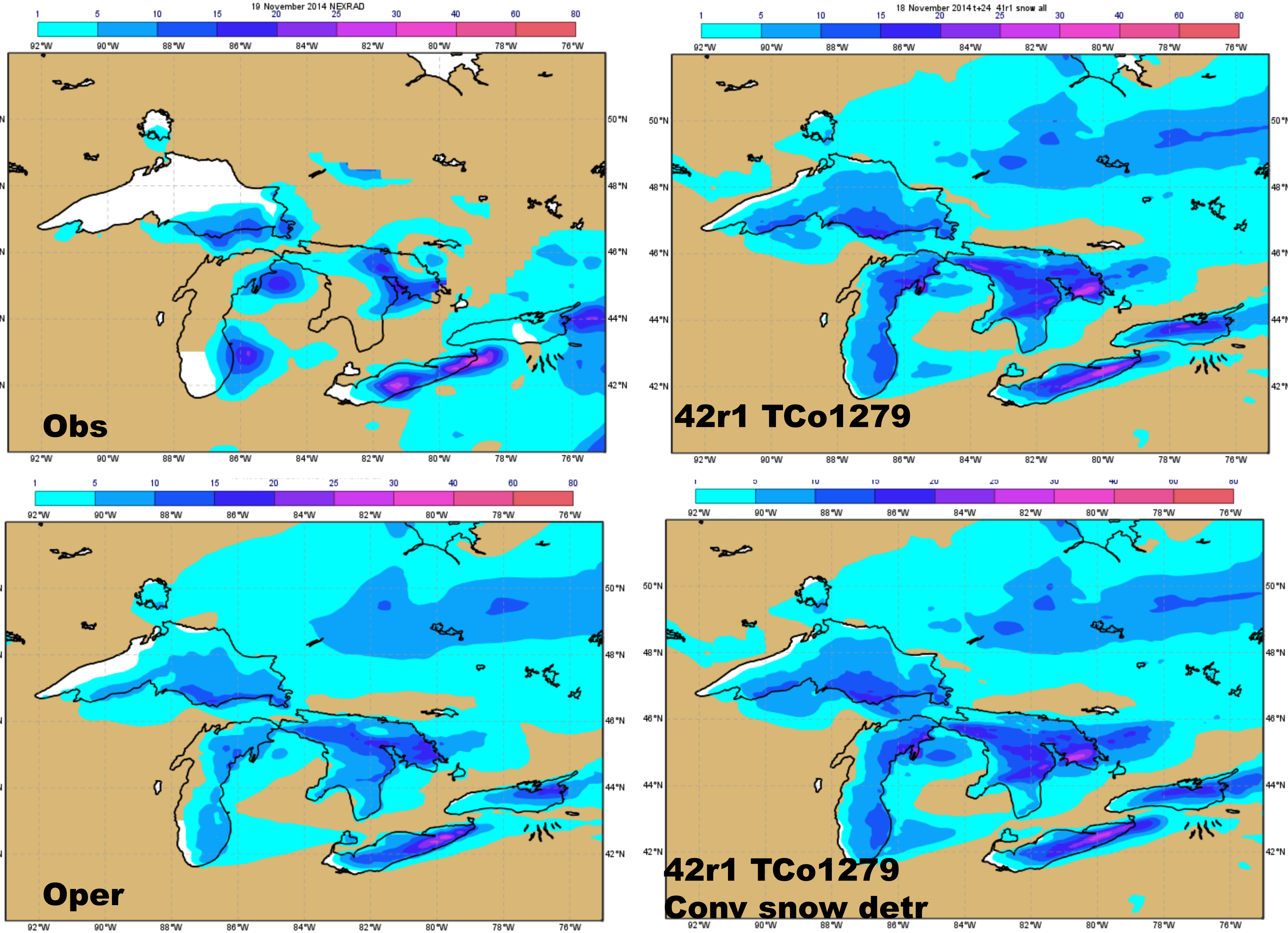






spotted by Ivan Tsvonetky and Richard Forbes

Winter convection: sensitivity studies



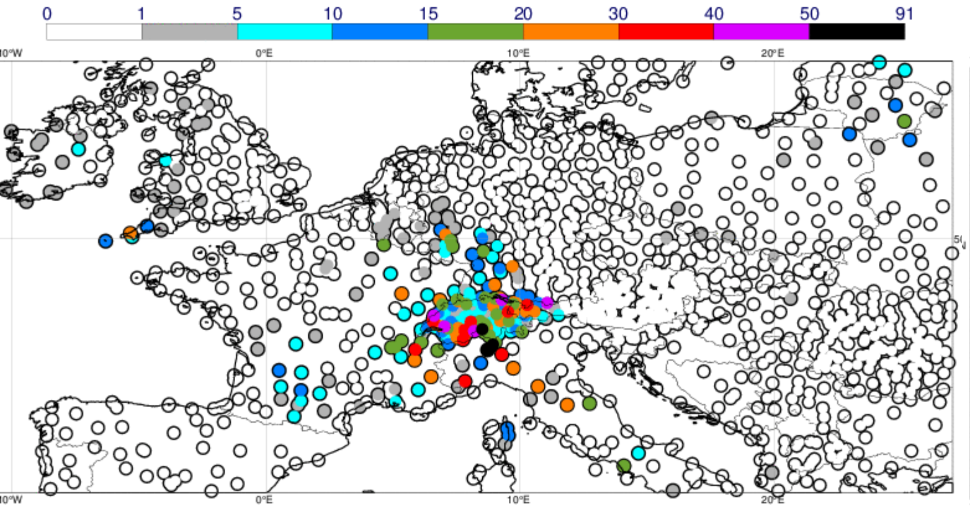
ECMWF

Summary & Plans

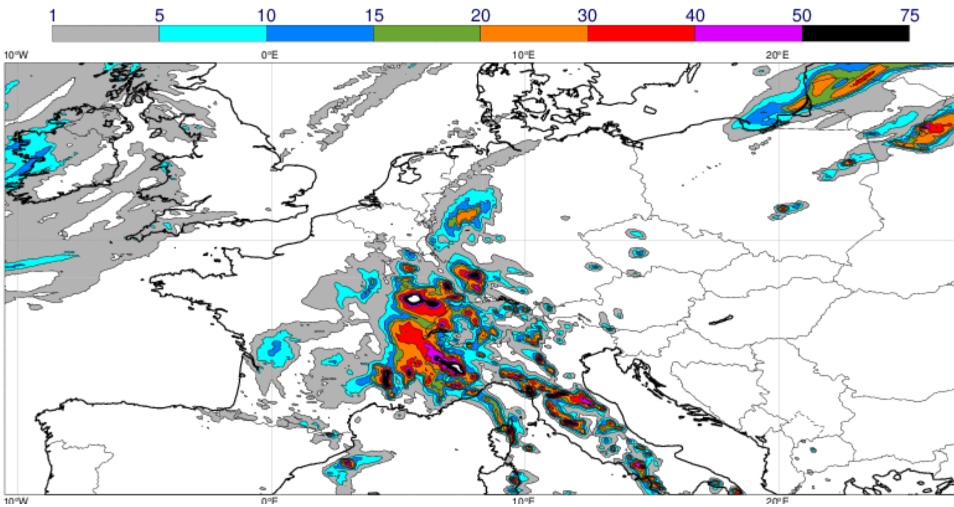
- Convection-large scale feedback: ‘ok’, some lack in early nighttime convection, organization and momentum transfer remains difficult
- Very high resolution: Could do 5 km today with big enough computer!!! issues: mass flux scaling, ‘environmental values’? – mass source in dynamics was not successful (but *Kuell, Gassmann Bott (2007)* did), work by *Gerard (2015), Park (2014), Arakawa and Wu (2013)*
- Microphysics (ice phase + advection of snow) – but always veeery tedious when changing heating profiles
- more efficient coupling of shallow convection, turbulent diffusion and clouds (Irina S.+Maike A.+Richard F.), similar to *Bretherton and Park (2008) based on M Koehler, Ahlgrimm, Beljaars (2011)*
- Continue improving monthly and seasonal forecast range (reduce syst. errors, SPPT/SPPP – momentum forcing)
- non-linear convection close to linearised version in data assimilation

Europe TCo1999 sensitivity to scaling factor

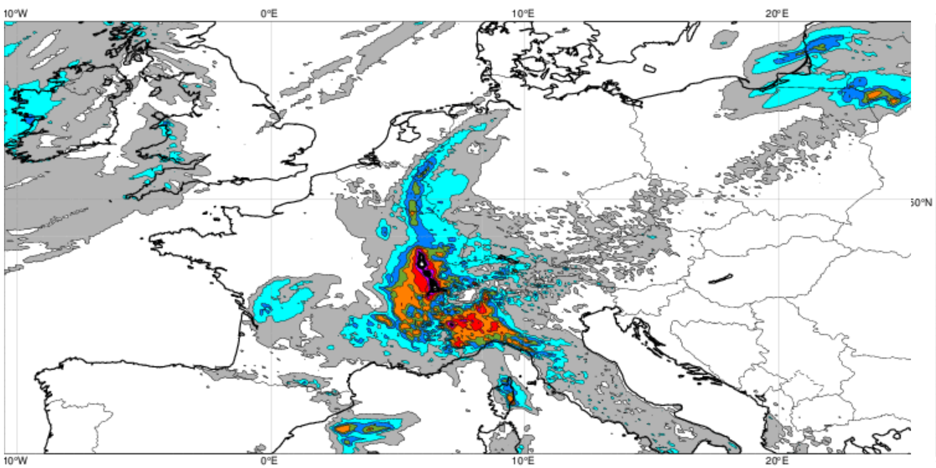
Obs 9 Aug 2015



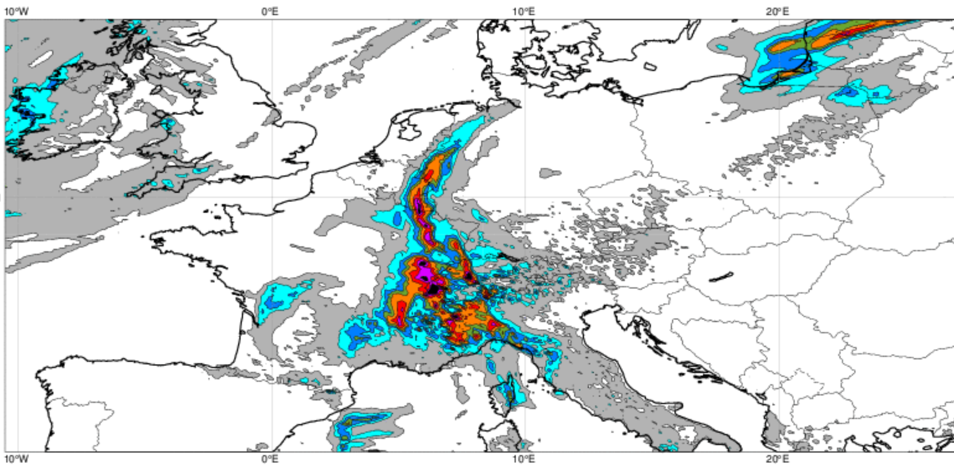
Cy42r1 Tco1999 no deep



Cy42r1 TCo1999 5 km scaled 0.8

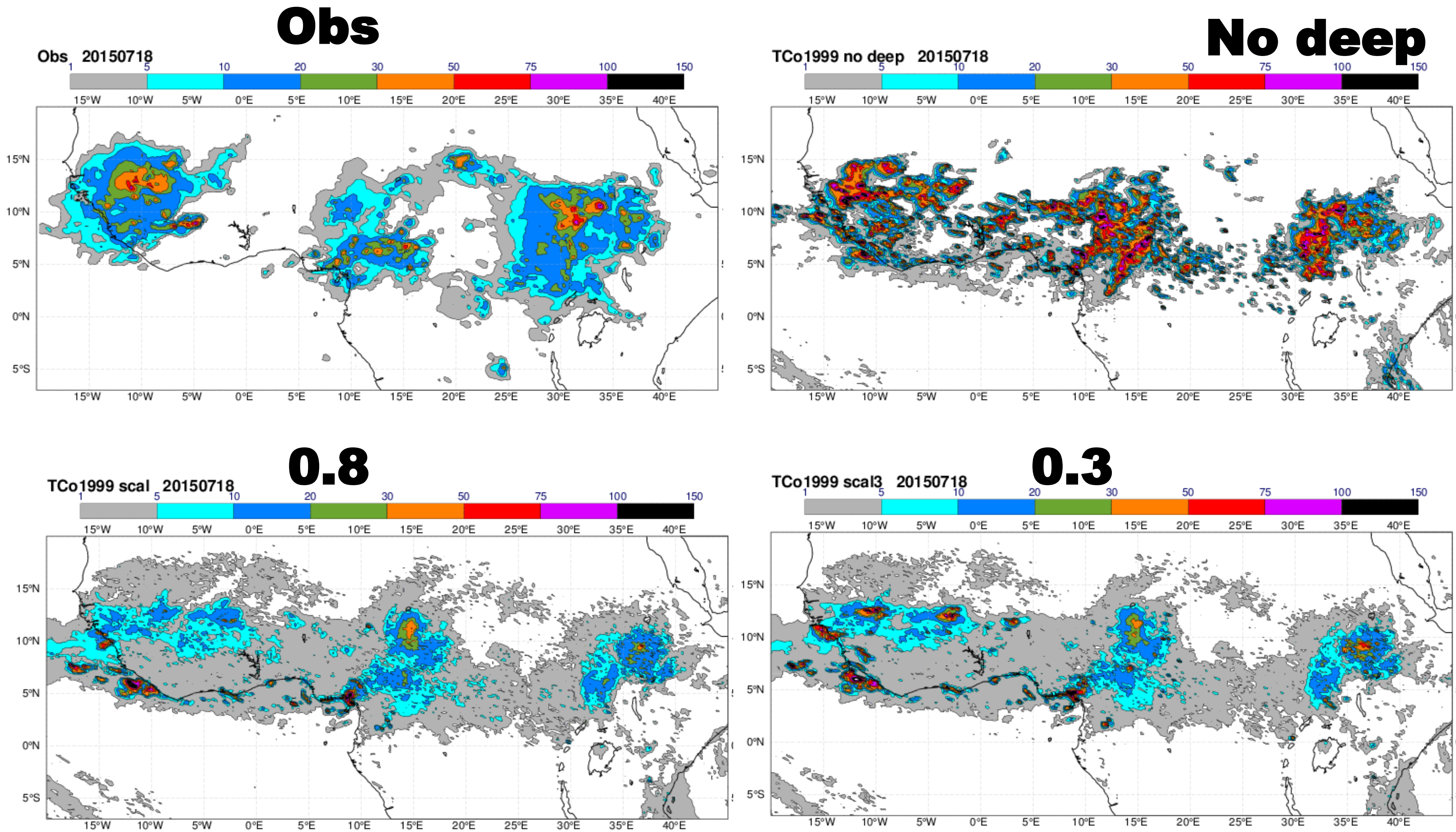


Cy42r1 TCo1999 5 km scaled 0.3



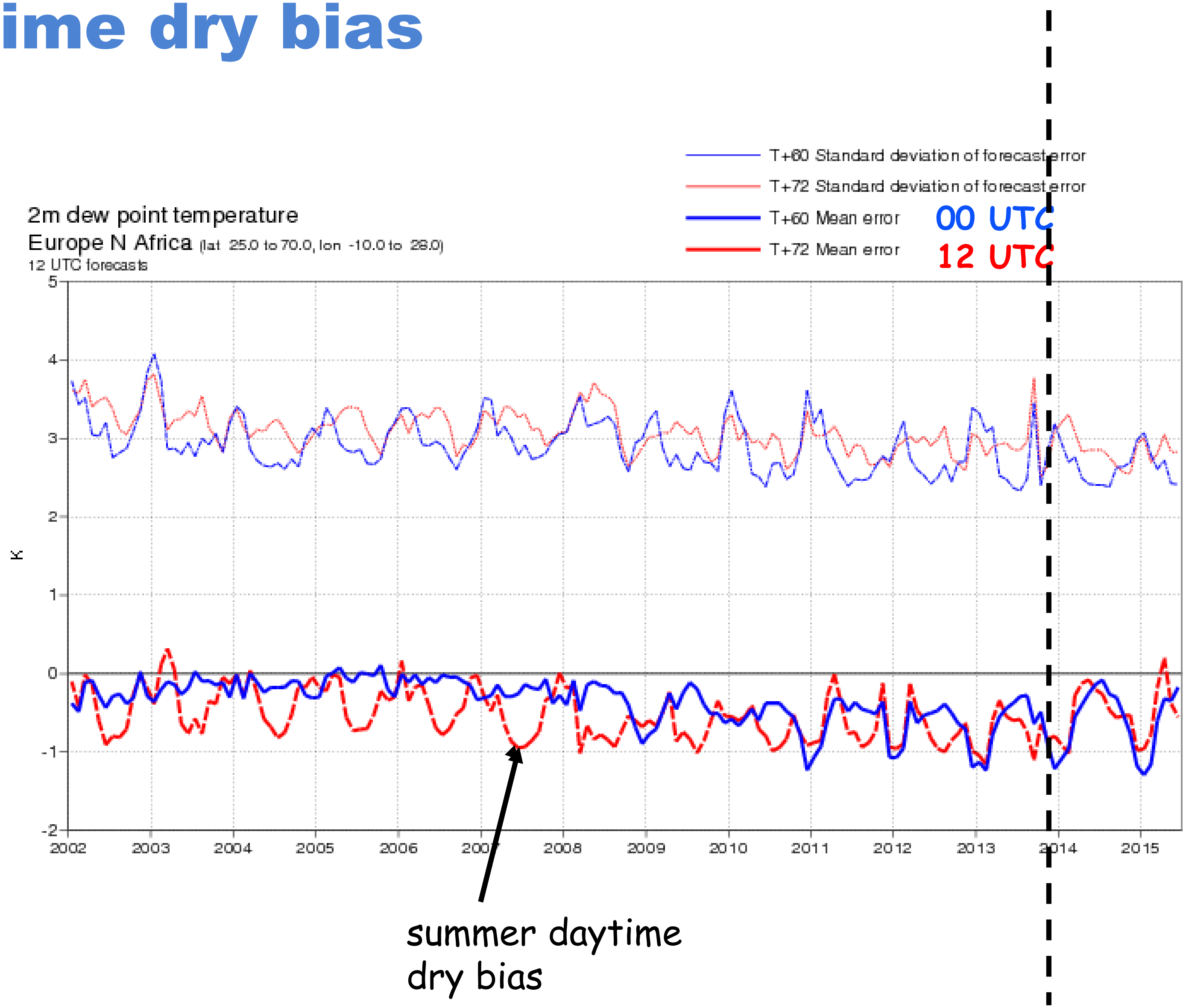
ECMWF

Africa TCo1999 sensitivity to scaling factor



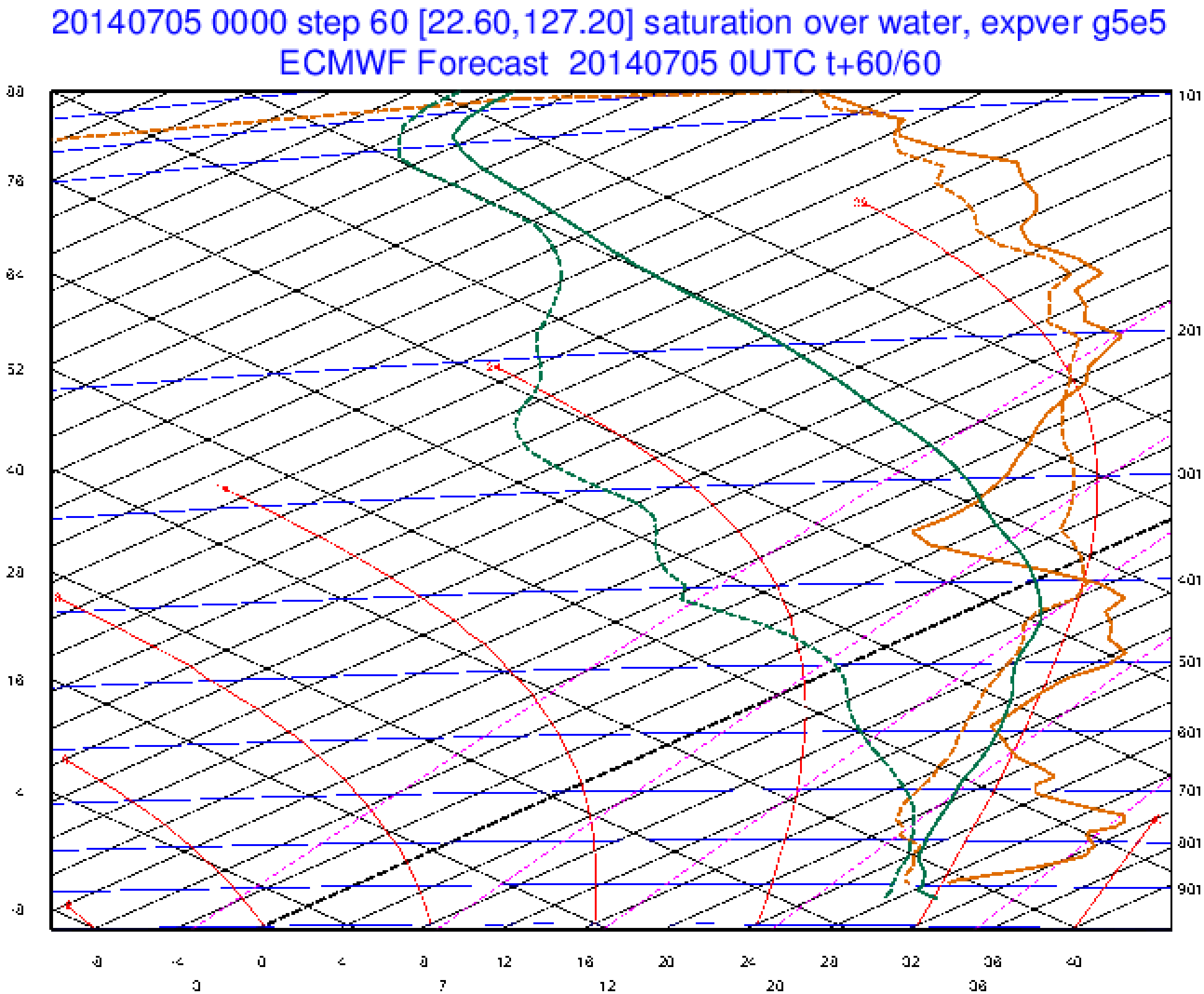
ECMWF

Diurnal cycle of convection and daytime dry bias



ECMWF

Sensitivity of cyclone depth to parcel perturbations in convection: Cyclone Neoguri



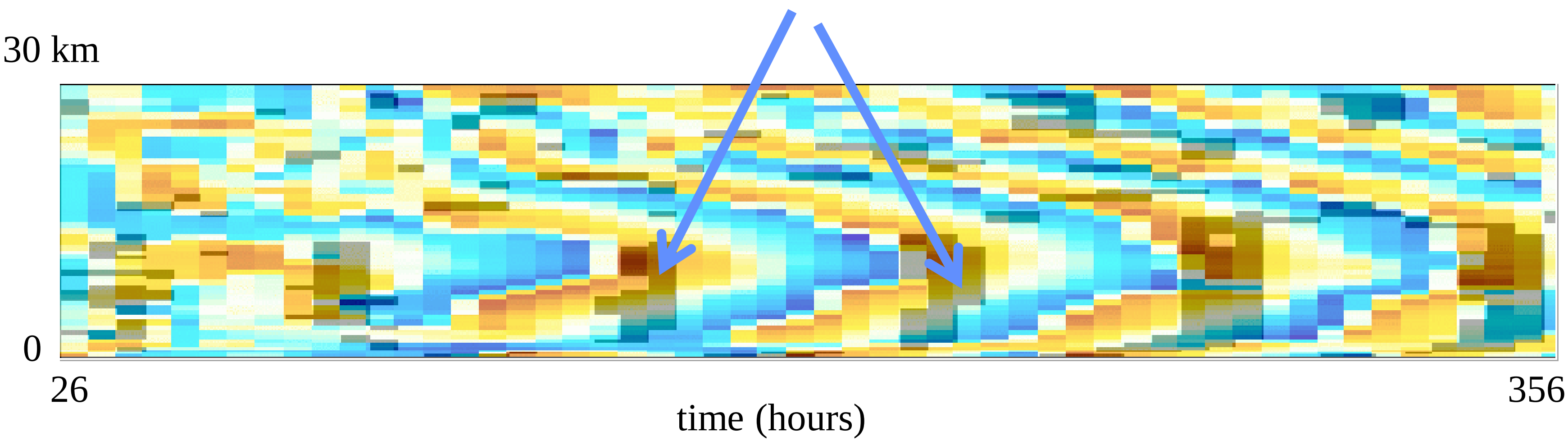
ECMWF

‘Kelvin’ waves: T anomaly for k=10 and convective heating

Glenn Shutts (presented at Martin Miller symposium, Jan 2011)

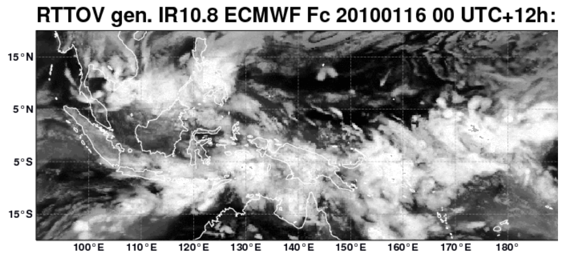
At z~10 km, warm anomaly and convective heating are in phase, leading to :

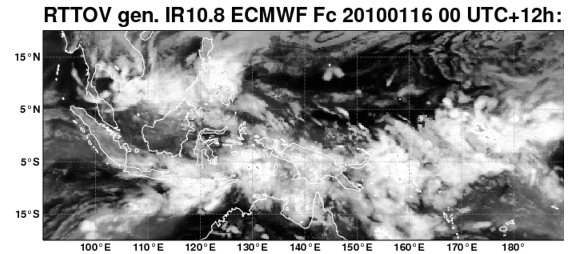
- the conversion of potential in kinetic energy = αω
- The generation of potential energy = N Q



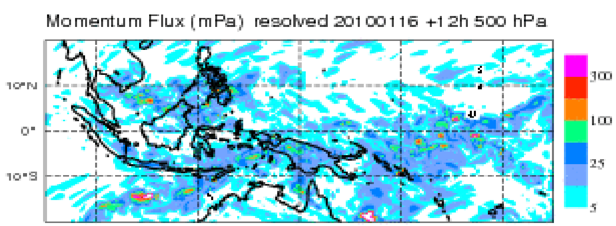
ECMWF

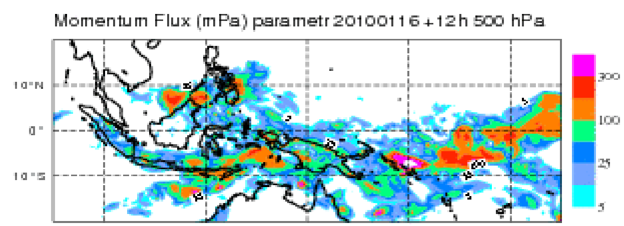
YOTC Momentum fluxes resolved & parametrised



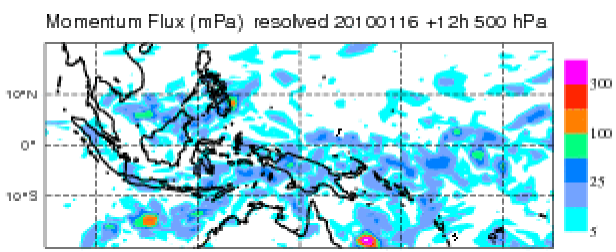


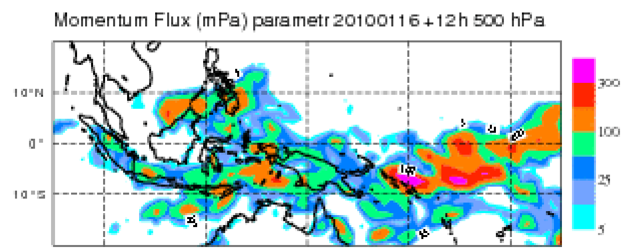
resolved | **parametrised**





T799





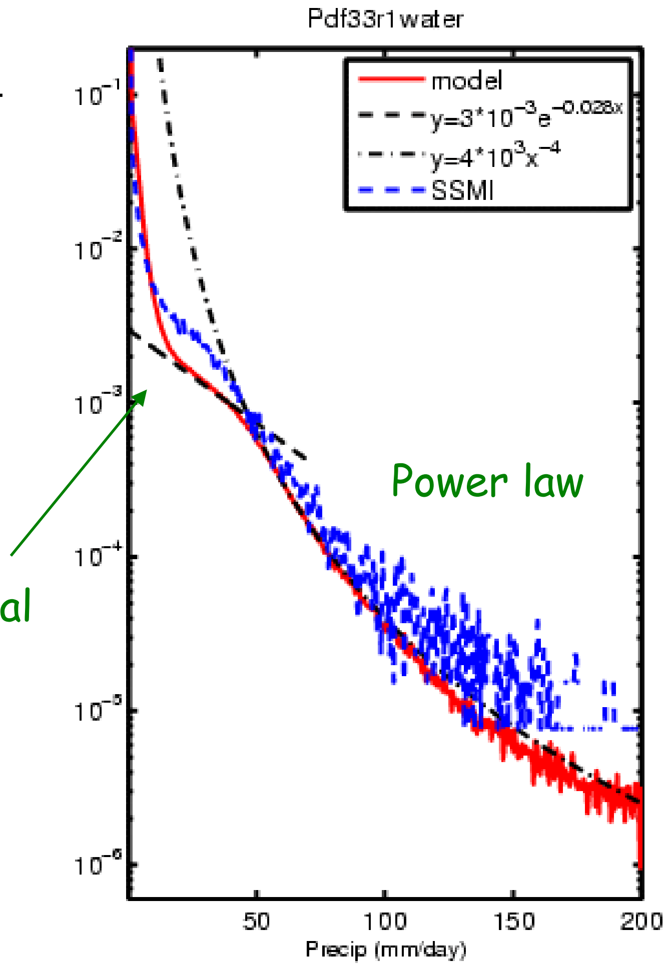
T159

Method: minus time mean state

ECMWF

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

from T799 Cy33r1
during

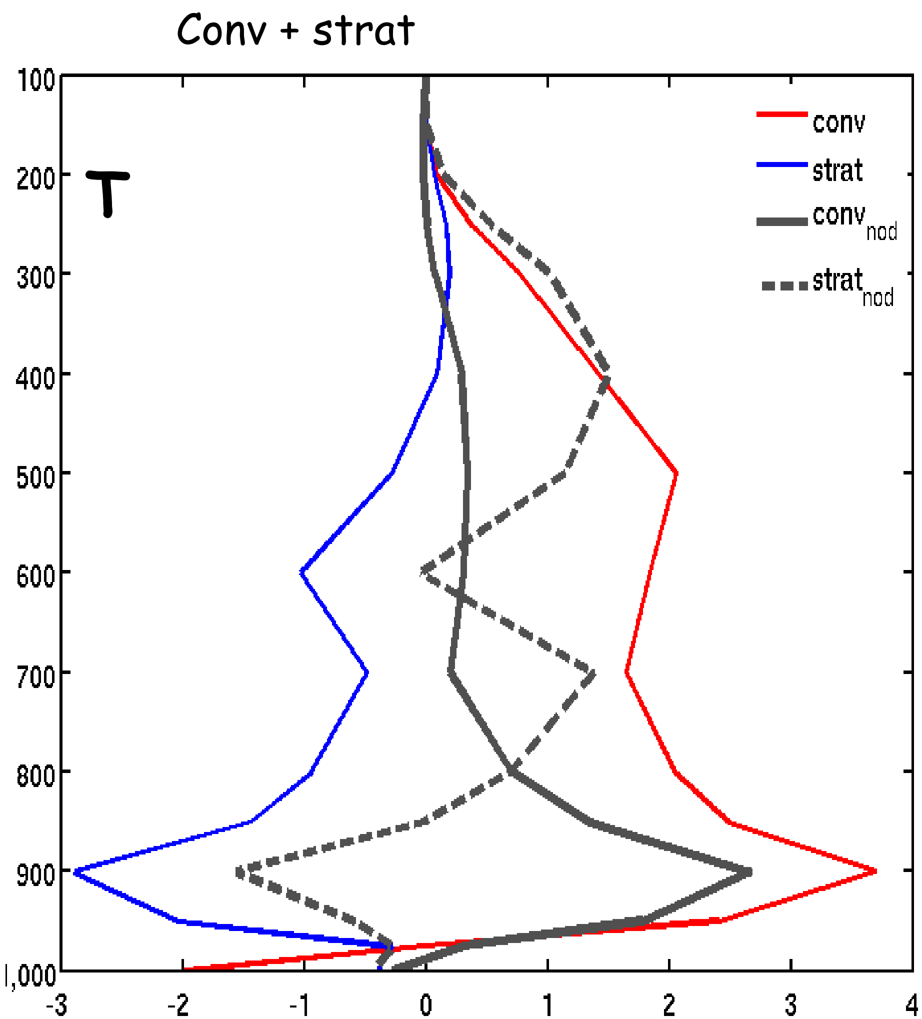


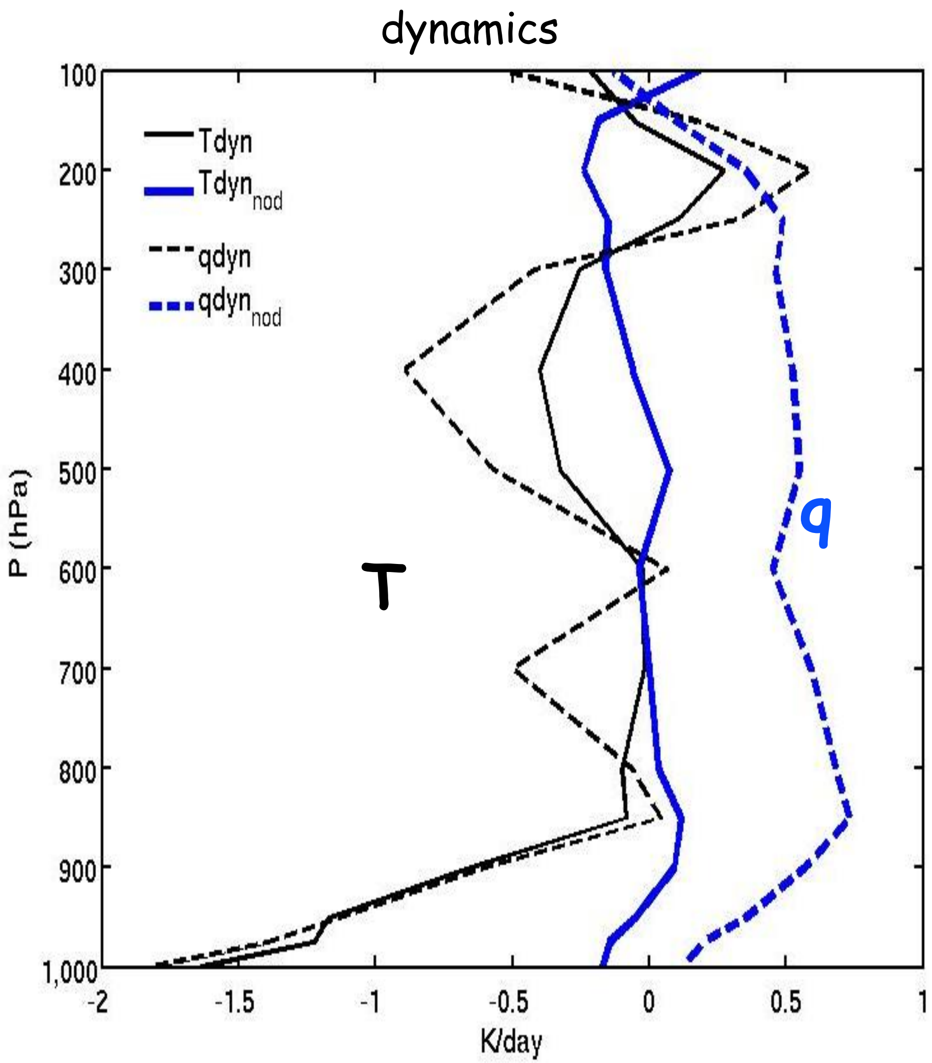
exponential

SSMI is from 1D-Var

ECMWF

What happens to T,q dynamics balance when switch off deep

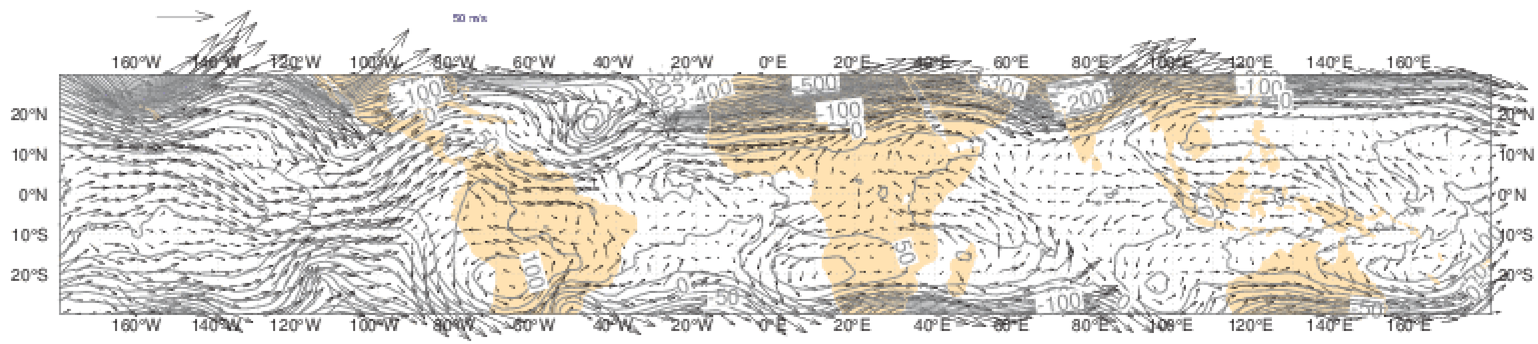




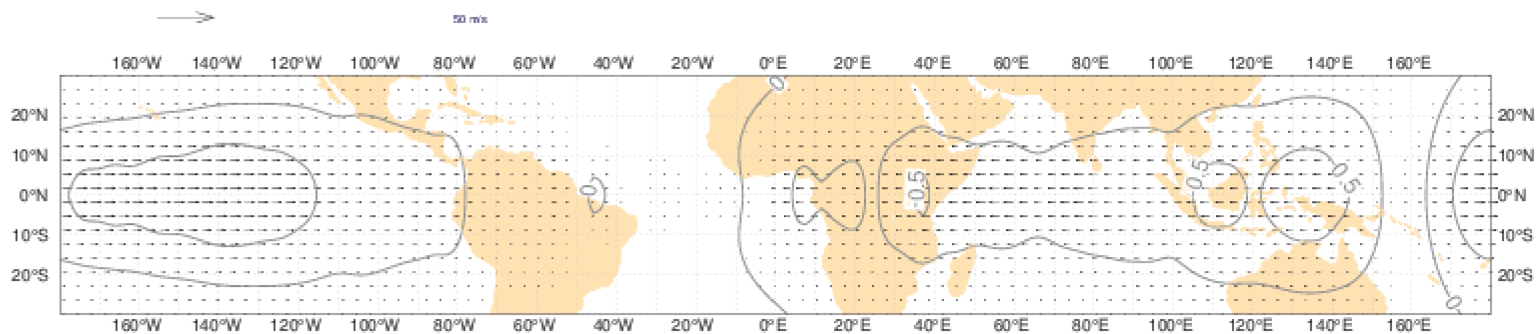
Normal mode projection and filtering

200 hPa

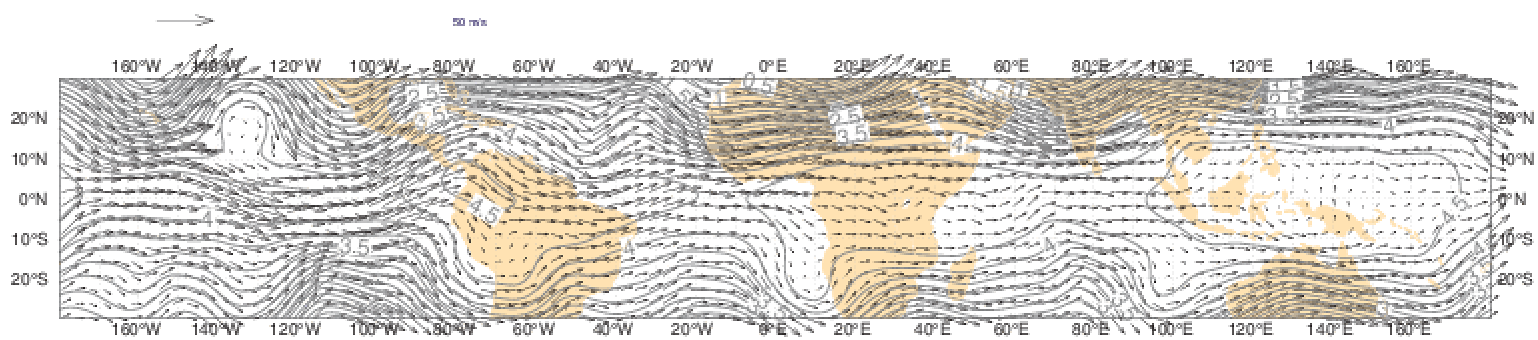
Analysis lev=75 2015030900



kw1 lev=75 2015030900

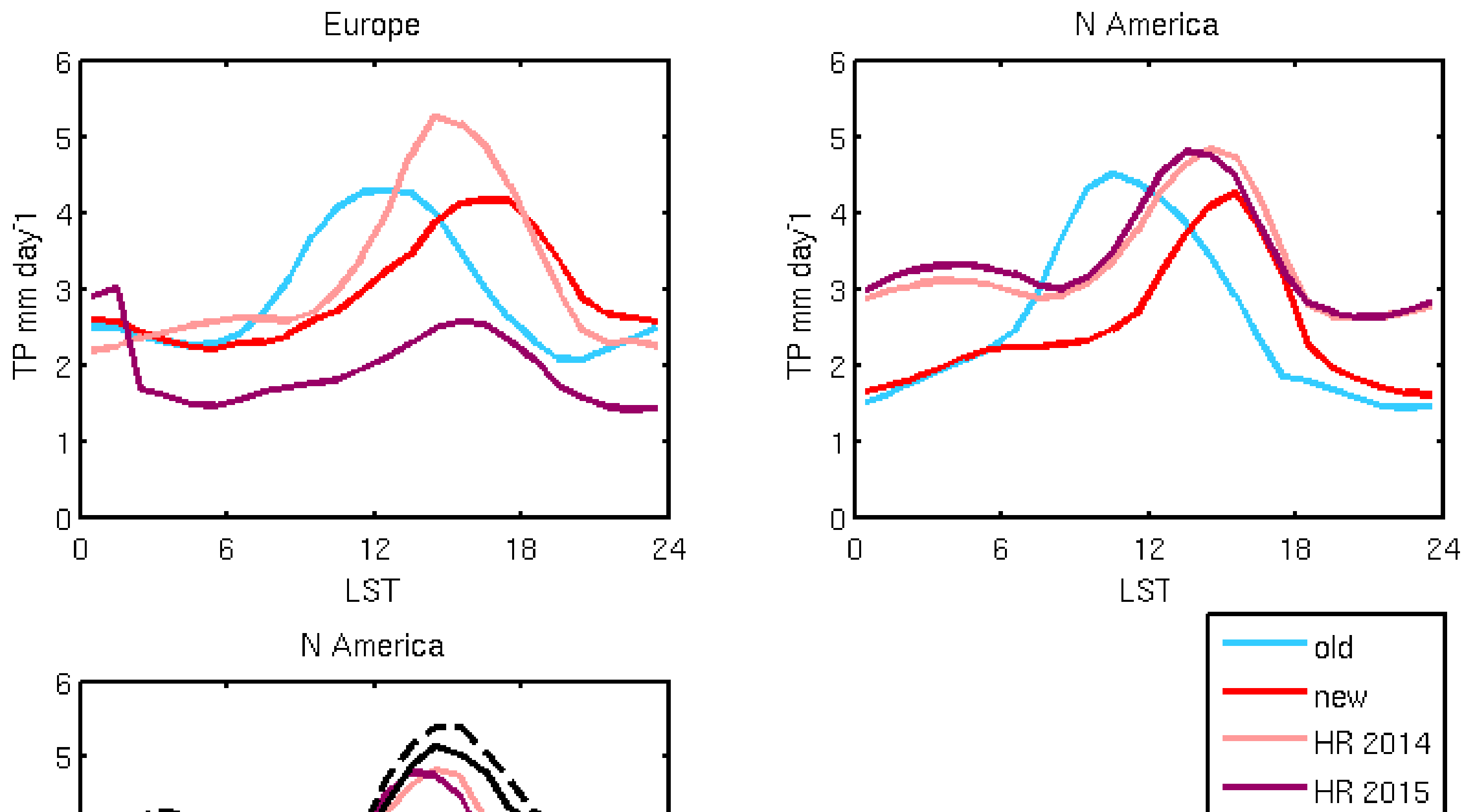


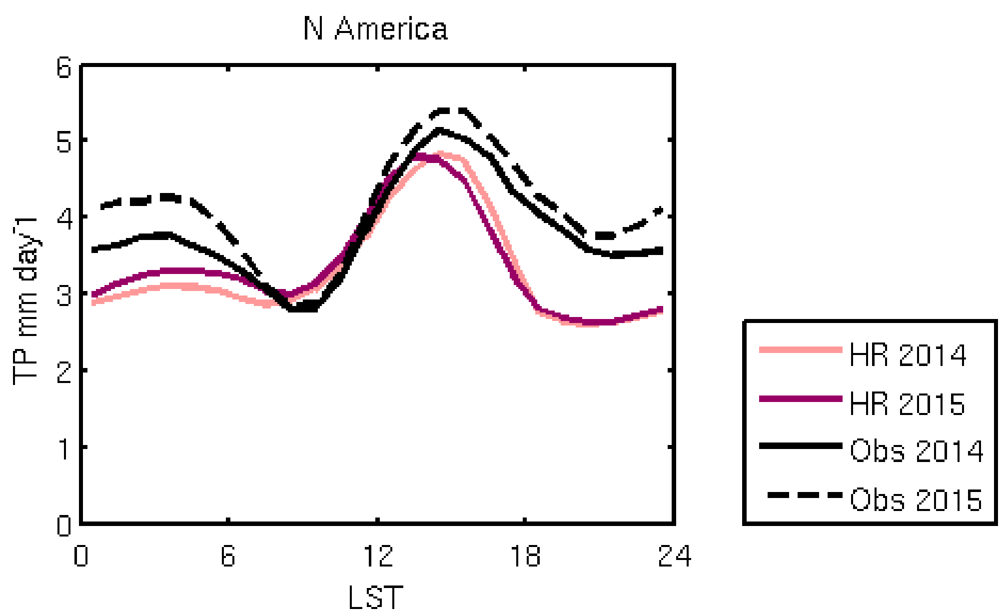
rot-5 lev=75 2015030900



ECMWF

And since? JJA in HRES Tl1279 16 km ?





NEXRAD data
Philippe Lopez