Numerical Weather Prediction
Parameterization of diabatic processes

Convection IV: Forecasting and diagnostics

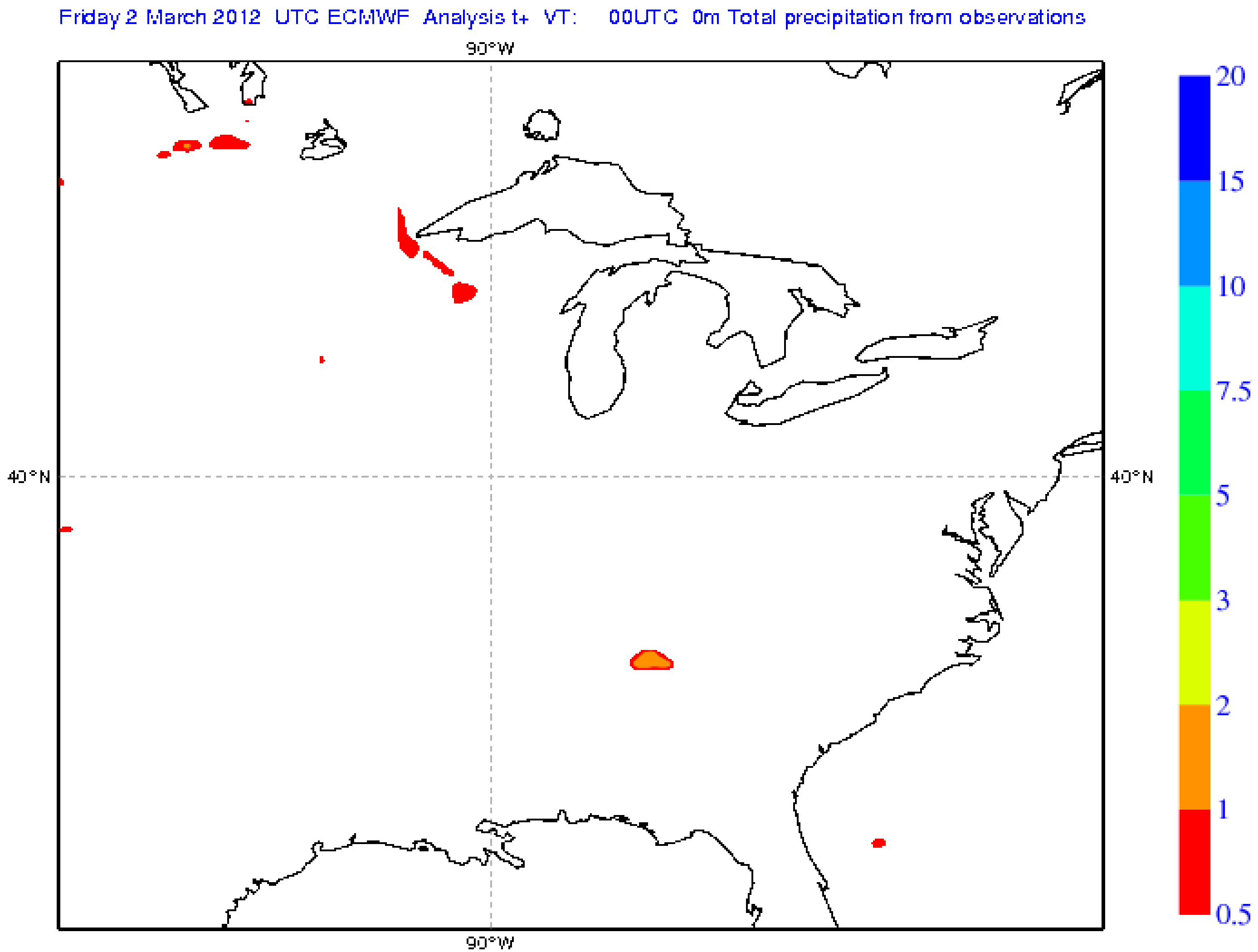
Peter Bechtold

Outline

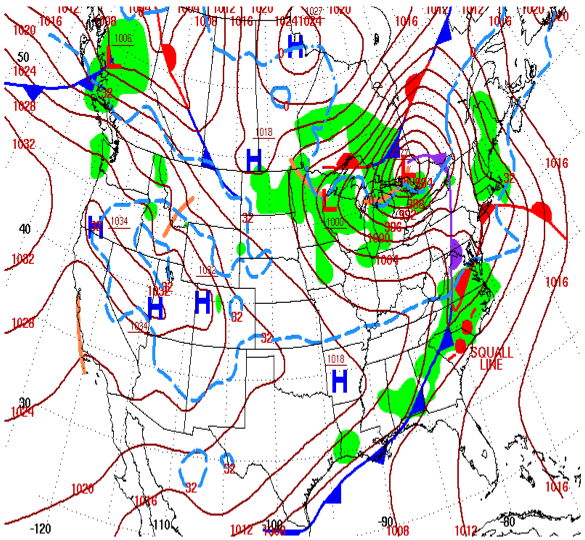
- Problems and Model sensitivity to convective parameterization: “Grid point storms”, model biases, diurnal cycle, advection of showers, wind gusts
- Examples of Weather Maps, and forecasting of mesoscale convective systems

For more information, see also Rodwell et al. 2013, BAMS 94
ECMWF Newsletter No 98 Summer 2003, No 114 Winter 2007/8, No 131 Spring 2012, No 136 Summer 2013

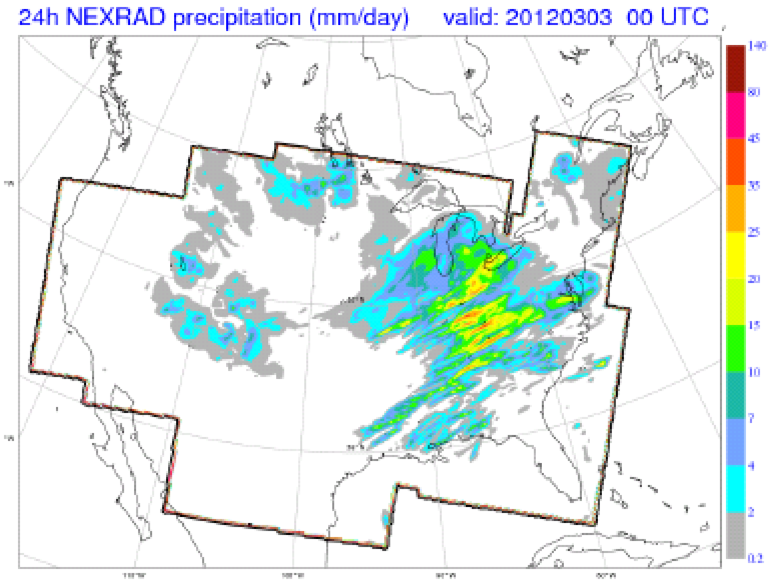
Radar animation (hourly) Tornado outbreak
2-3 March 2012 one of strongest in US history

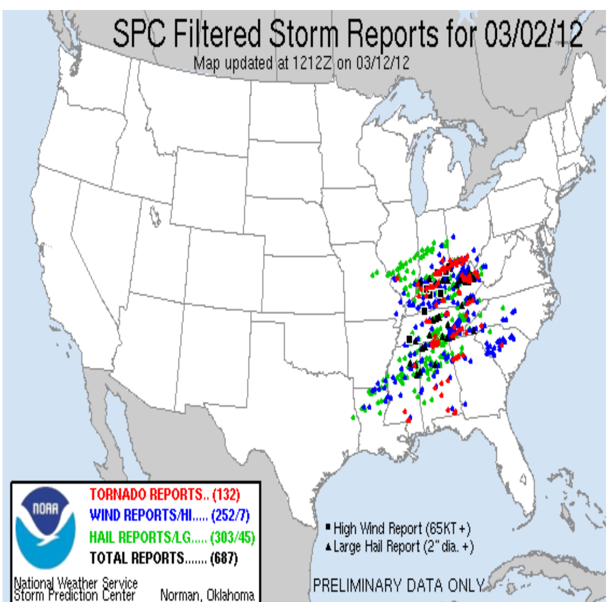


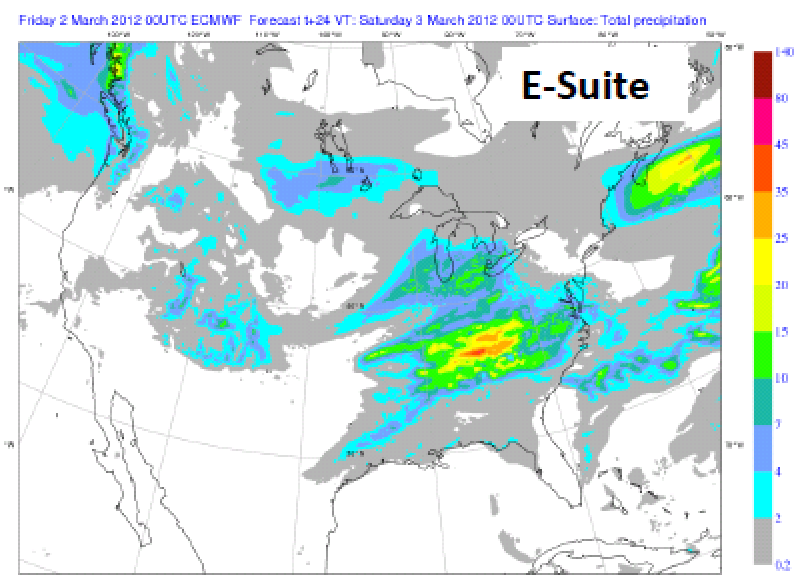
Storm reports, maps and EC-forecast for 2 March 2012
(courtesy Fernando Prates)



Surface Weather Map at 7:00 A.M. E.S.T.







"Grid-point storms"

- If convective heating/mixing (stabilisation) is not adequately represented in the model, the model might get saturated under moist and/or strong forcing conditions – it then develops an explicit turnover to get rid of the instability. However, these resolved-scale updrafts are not at the right scale in models with grids larger than say 5-10 km (actual convective updraft radius are generally smaller than 1-2 km).

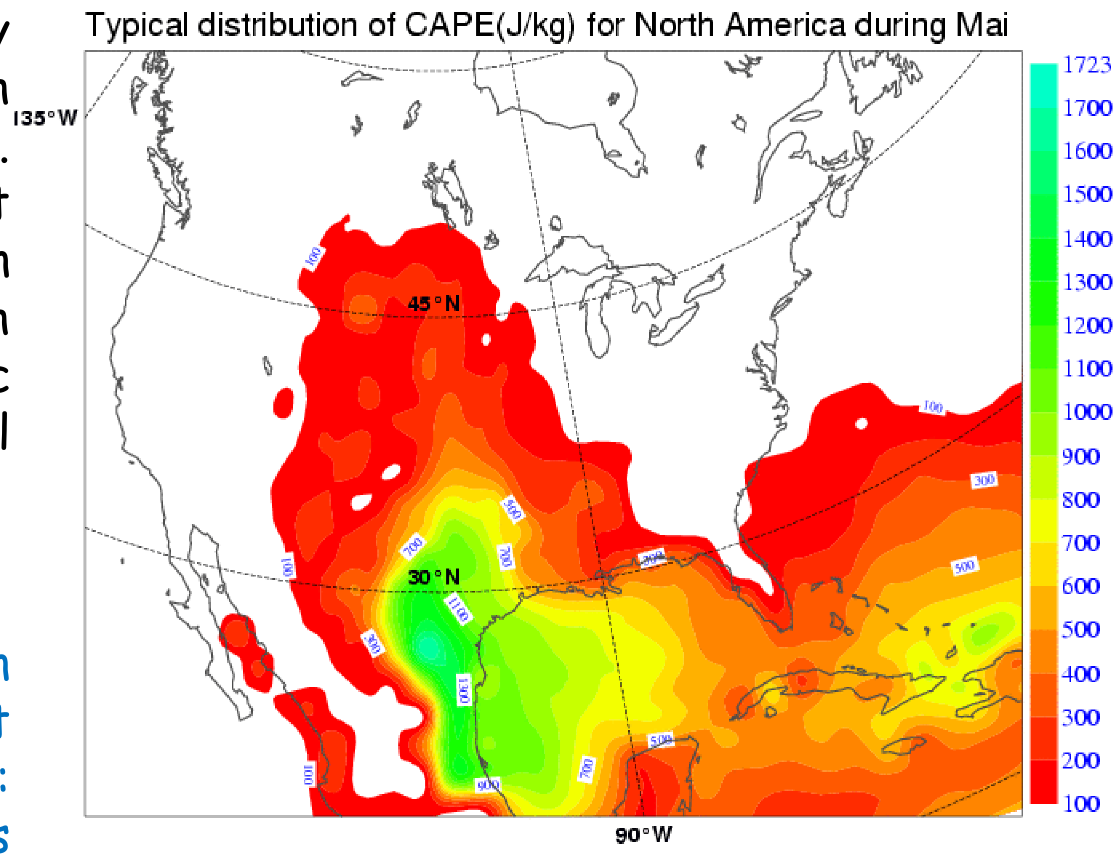
- These unphysical strong ascents (mass fluxes) in the model produce excessive "stratiform" rain, too deep lower tropospheric pressure systems and strong divergence at upper levels, destroying the actual Jet structure – these model errors then propagate and grow quickly, affecting heavily the forecast skill of the model.

“Grid-point storms” as a historical problem

CAPE climatology

This problem is particularly important over regions with high convective instability (CAPE), i.e. over North America (Great Plaines) during Northern Hemispheric Spring, South America (Southern hemispheric spring), but also over the tropical Pacific Ocean (Indonesia region).

Shown is the monthly mean distribution of CAPE for May at 00 UTC over N America- Nota: typical values for Europe for this period are just about half

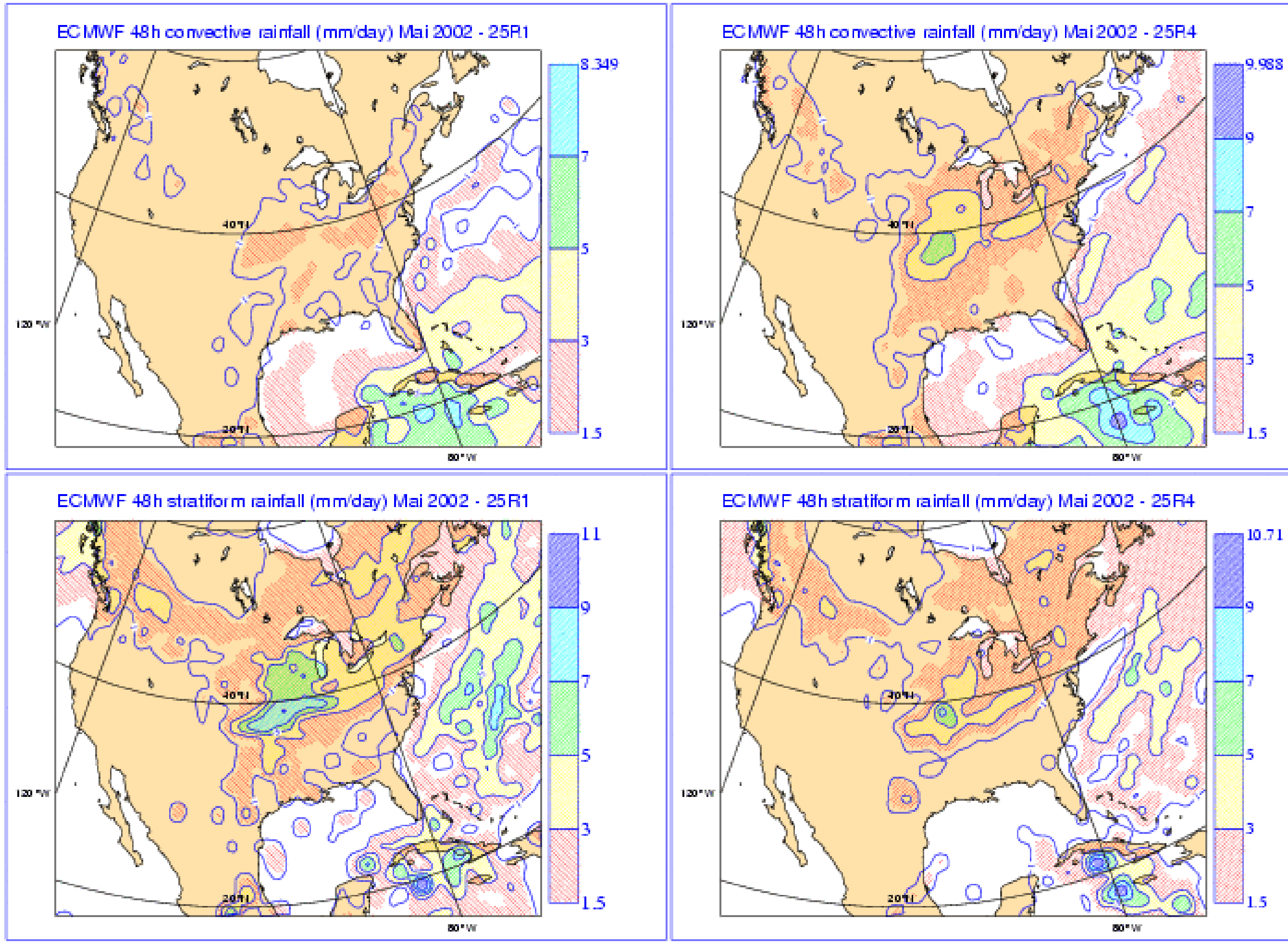


ECMWF

"Grid-point storm": History 2002/2003

48h forecasted convective and stratiform rainfall with different versions of convection scheme/trigger

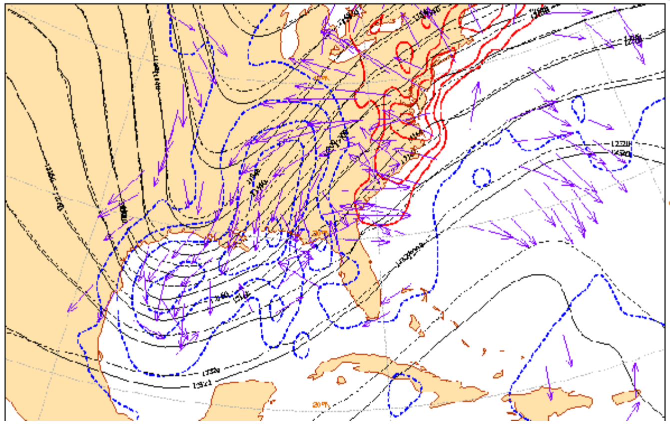
Note the large amount of stratiform rainfall in CY25R1 (2002) over central Great Plaines that is replaced by a smooth distribution of convective rainfall in new cycle (upper left picture)



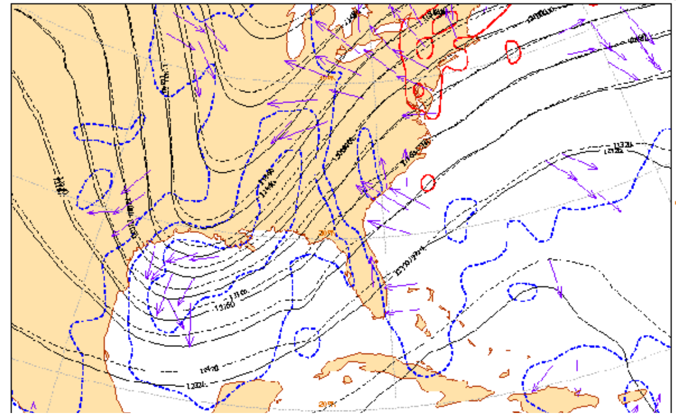
“Grid-point storm”: the Americas

Effect on first guess 200 hPa mass (isolines) and wind Analysis increments

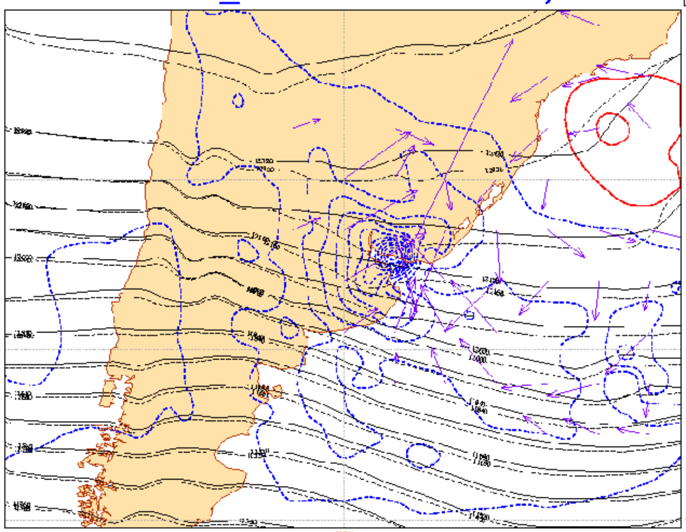
Increments O_SUITE 17/Nov/2002; 00 UTC



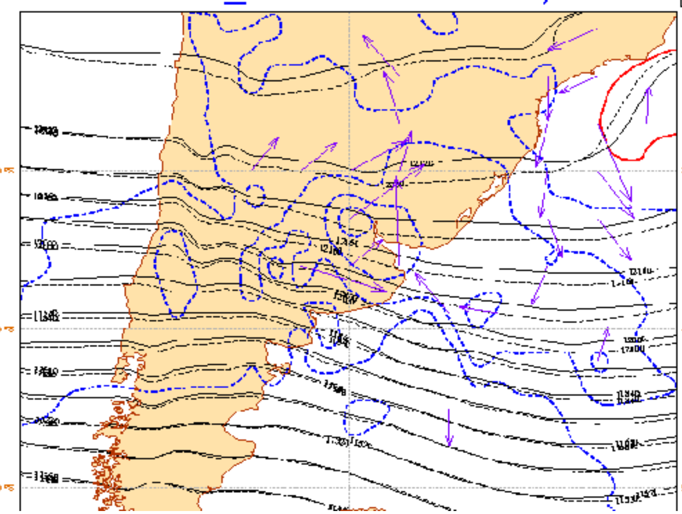
Increments E_SUITE 17/Nov/2002; 00 UTC



Increments O_SUITE 18/Nov/2002; 00 UTC



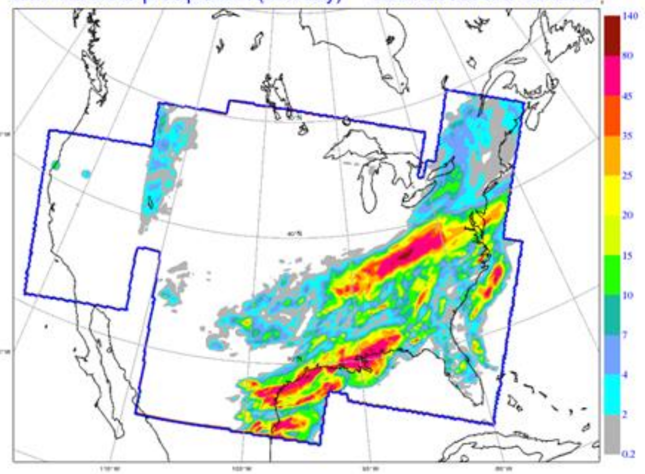
Increments E_SUITE 18/Nov/2002; 00 UTC



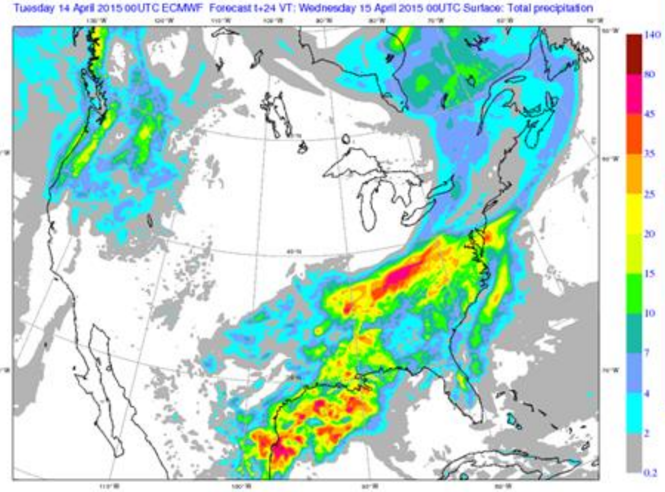
Overestimated resolved rainfall produces excessive heating and upper-level divergence
=> convergent increments

Total rainfall vs NEXRAD 14/04/2015

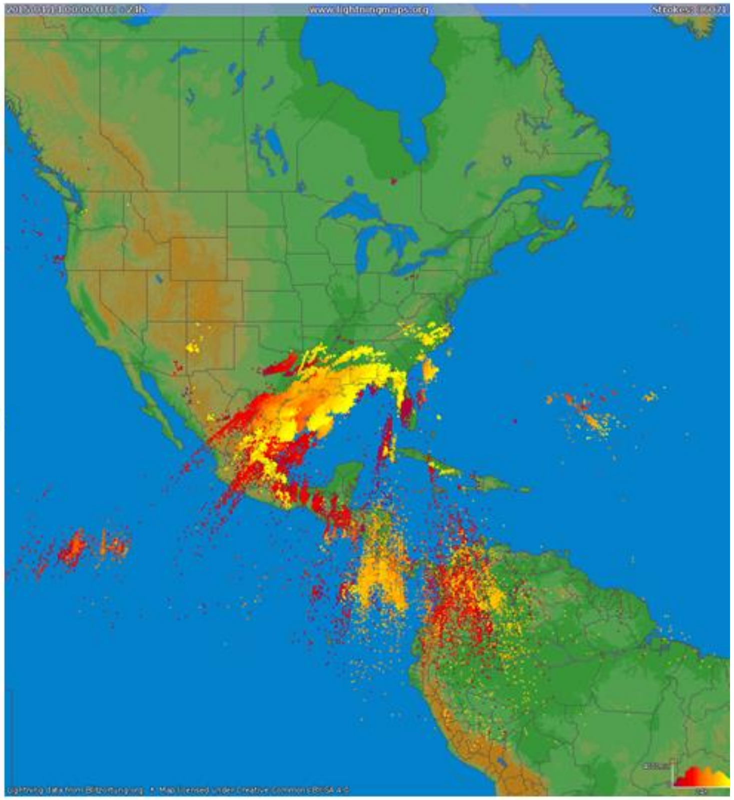
24h NEXRAD precipitation (mm/day) valid: 20150415 00 UTC



Tuesday 14 April 2015 00UTC ECMWF Forecast t+24 VT: Wednesday 15 April 2015 00UTC Surface: Total precipitation

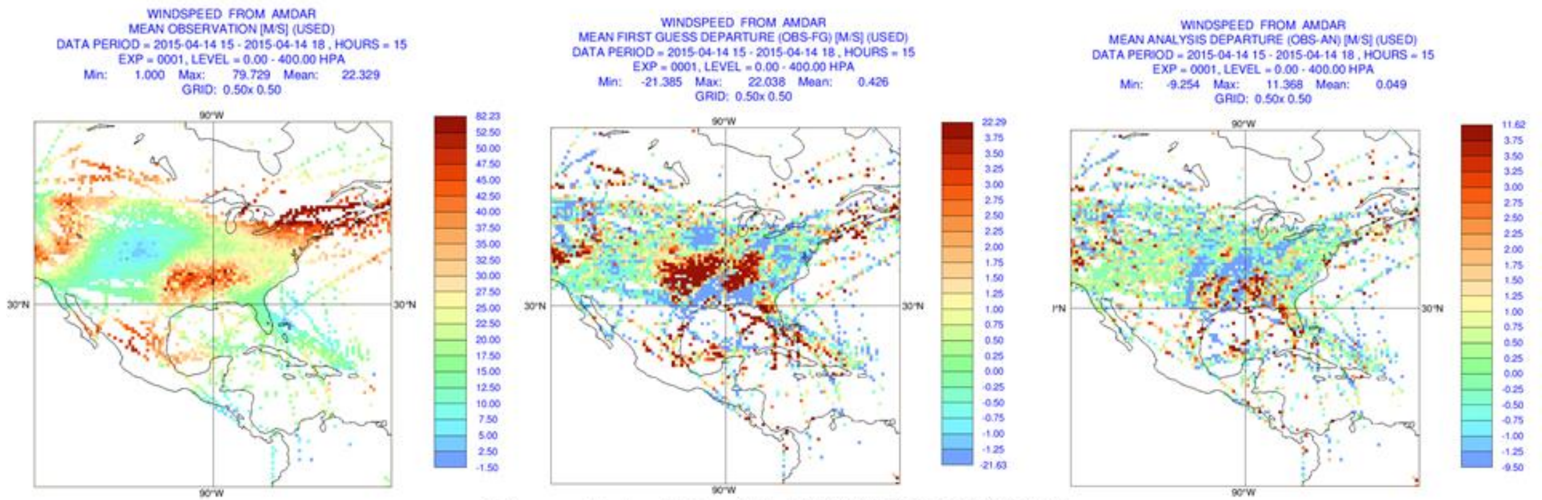


24H lightning VT:14/04/2015

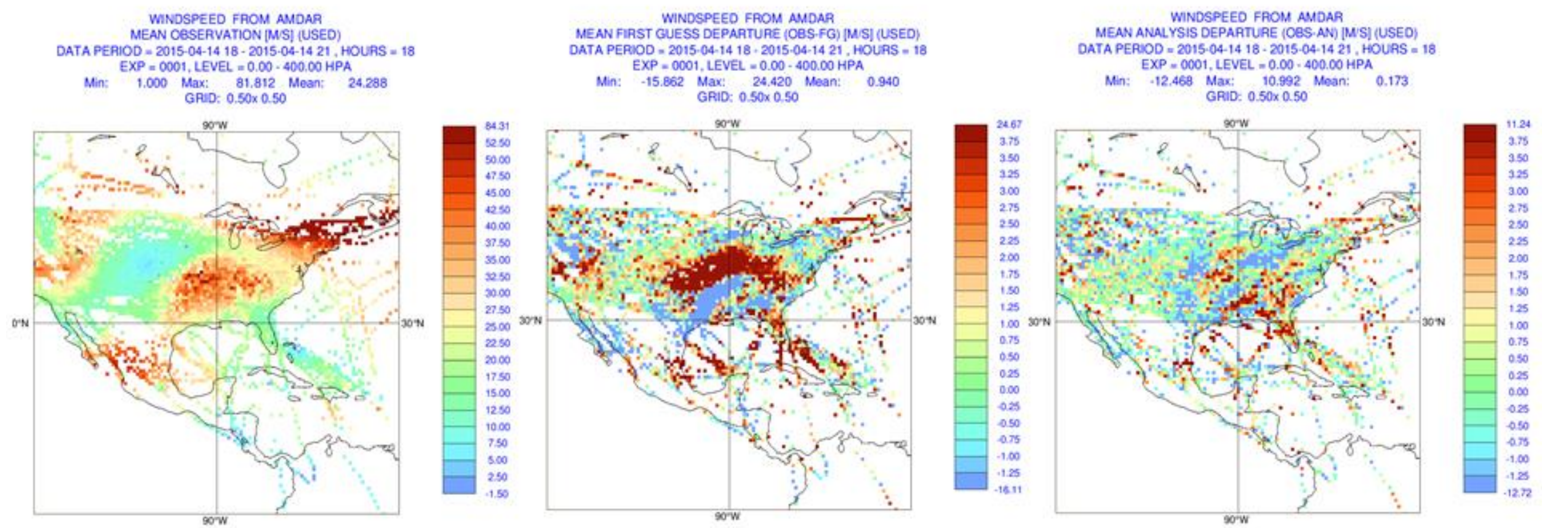


First Guess and Analysis departures against aircraft T and wind

Time slot : 15 – 18 UTC (14/04/2015)

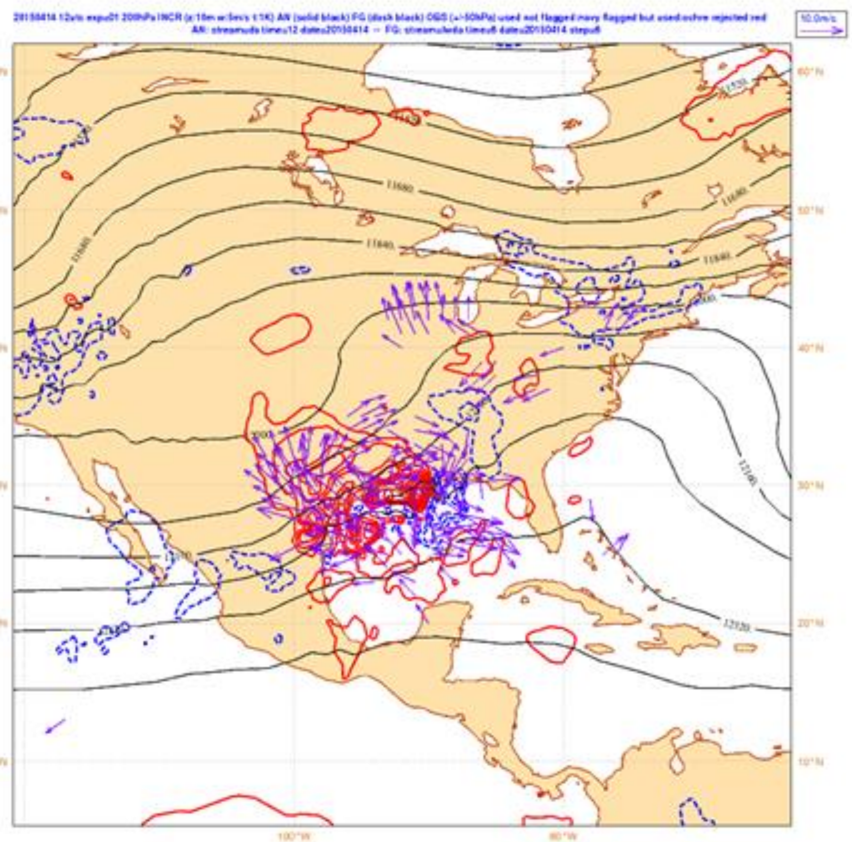


Time slot : 18 – 21 UTC (14/04/2015)

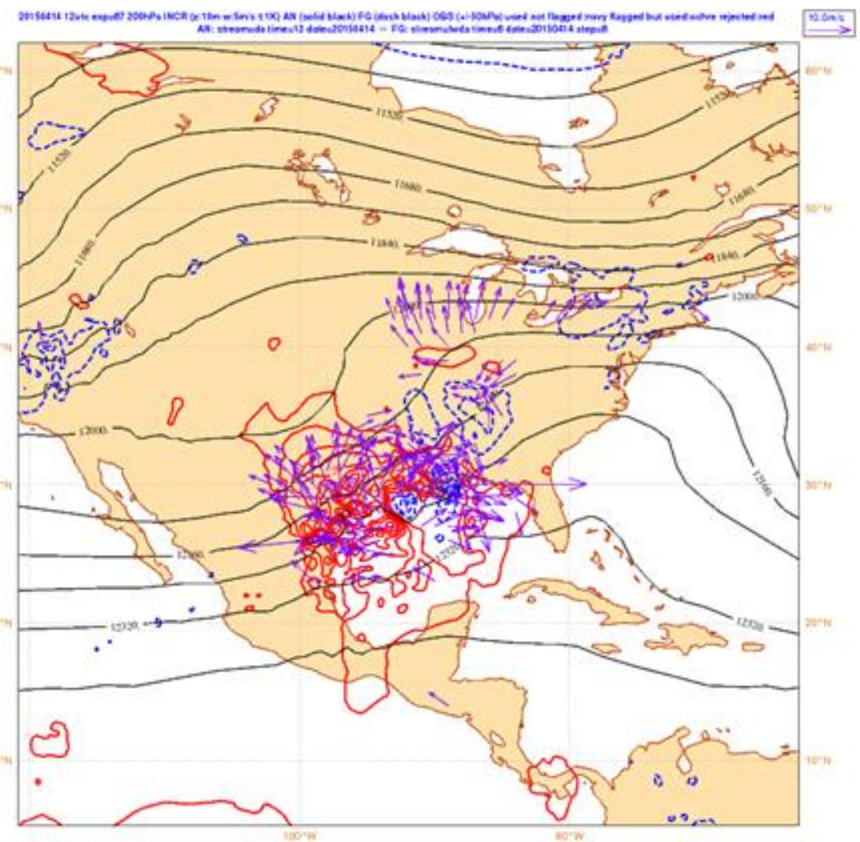


Typical increments in 2015

14/04/2015 12Z (Oper)



14/04/2015 12Z (Esuite)



Increments now mainly convergent = underestimation of intense 'top-heavy' conv heating

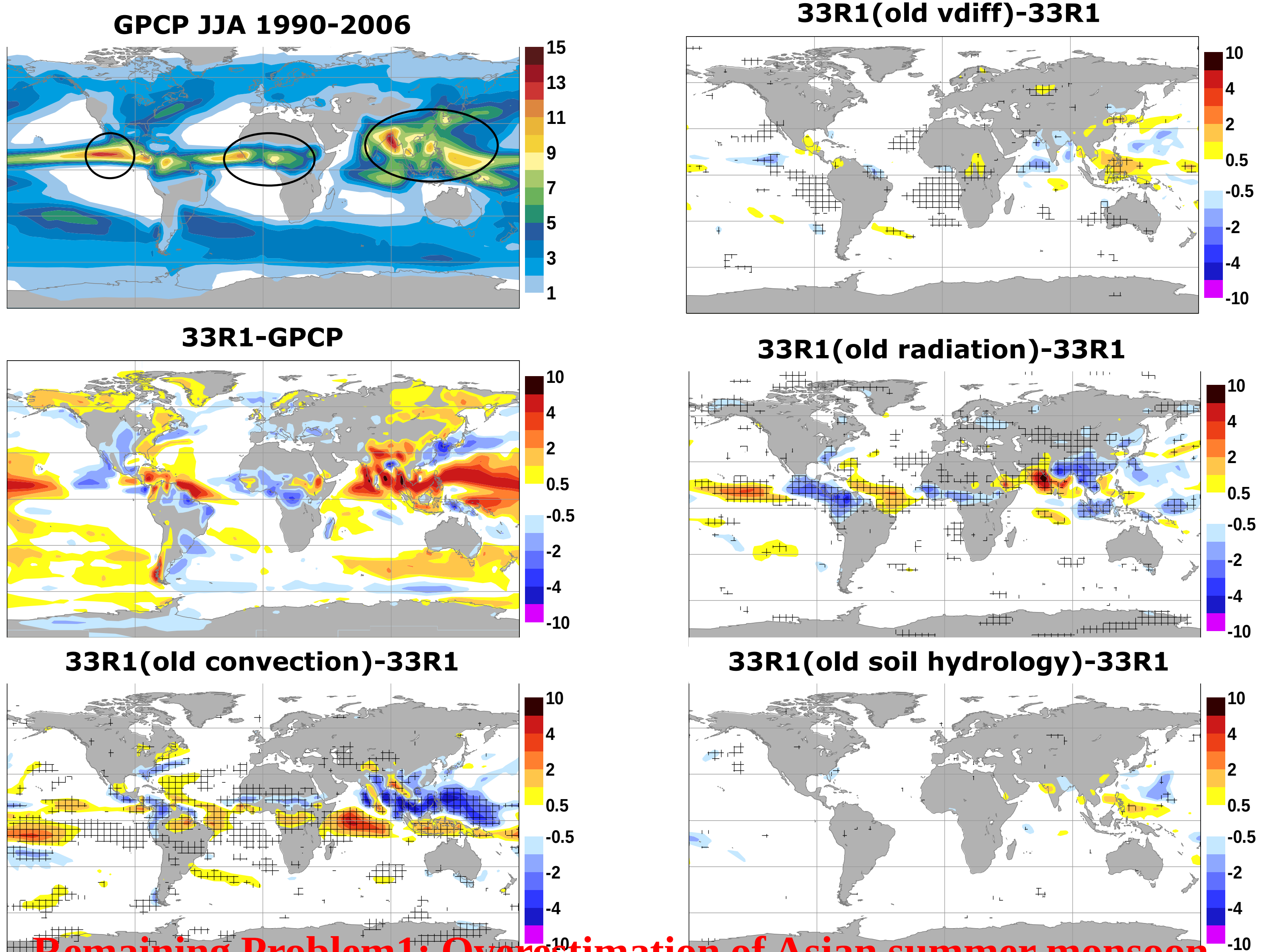
Tropical Forecast Biases and Physics

Forecasts of tropical atmosphere are naturally very sensitive to any changes in the convection scheme

- On the longer term (10-20 days) the tropical atmosphere is in radiative convective equilibrium, so that the detrainment of water substance by the convection significantly affects the upper-tropospheric temperature and moisture biases
- The upper-tropospheric wind biases are also strongly affected by the entrainment coefficient in the momentum flux formulation – "cumulus friction" and organized mass detrainment
- The convergence/precipitation in the ITCZ and Headly/Walker circulations strongly affected by the deep convection, but equivalent important is the representation of shallow convection in the subtropics determining the moist low-level flow in the Tropics
- Furthermore, statistics on tropical variability (cyclones and Madden-Julian oscillation) are also strongly affected by the convection parameterization ….

Precipitation JJA: Sensitivity to Model Formulation

Seasonal integrations



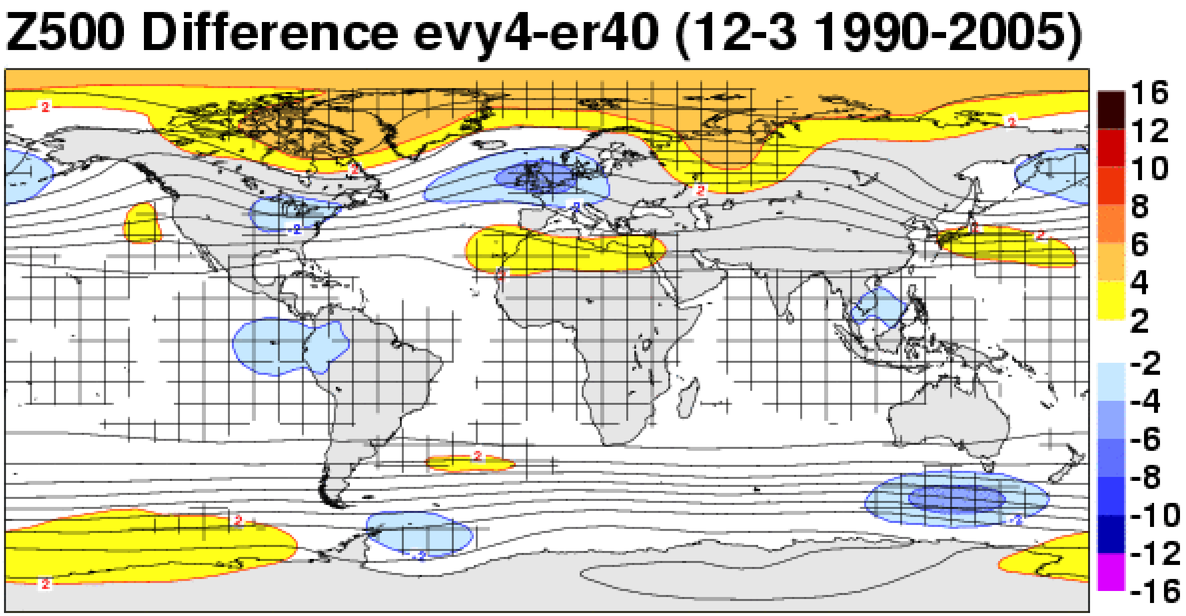
Remaining Problem1: Overestimation of Asian summer monsoon

ECMWF

Middle latitudes: sensitivity to physics formulation

500 hPa Geopotential against ERA40, tropical influence on middle latitudes

CY32R3 Nov 2007



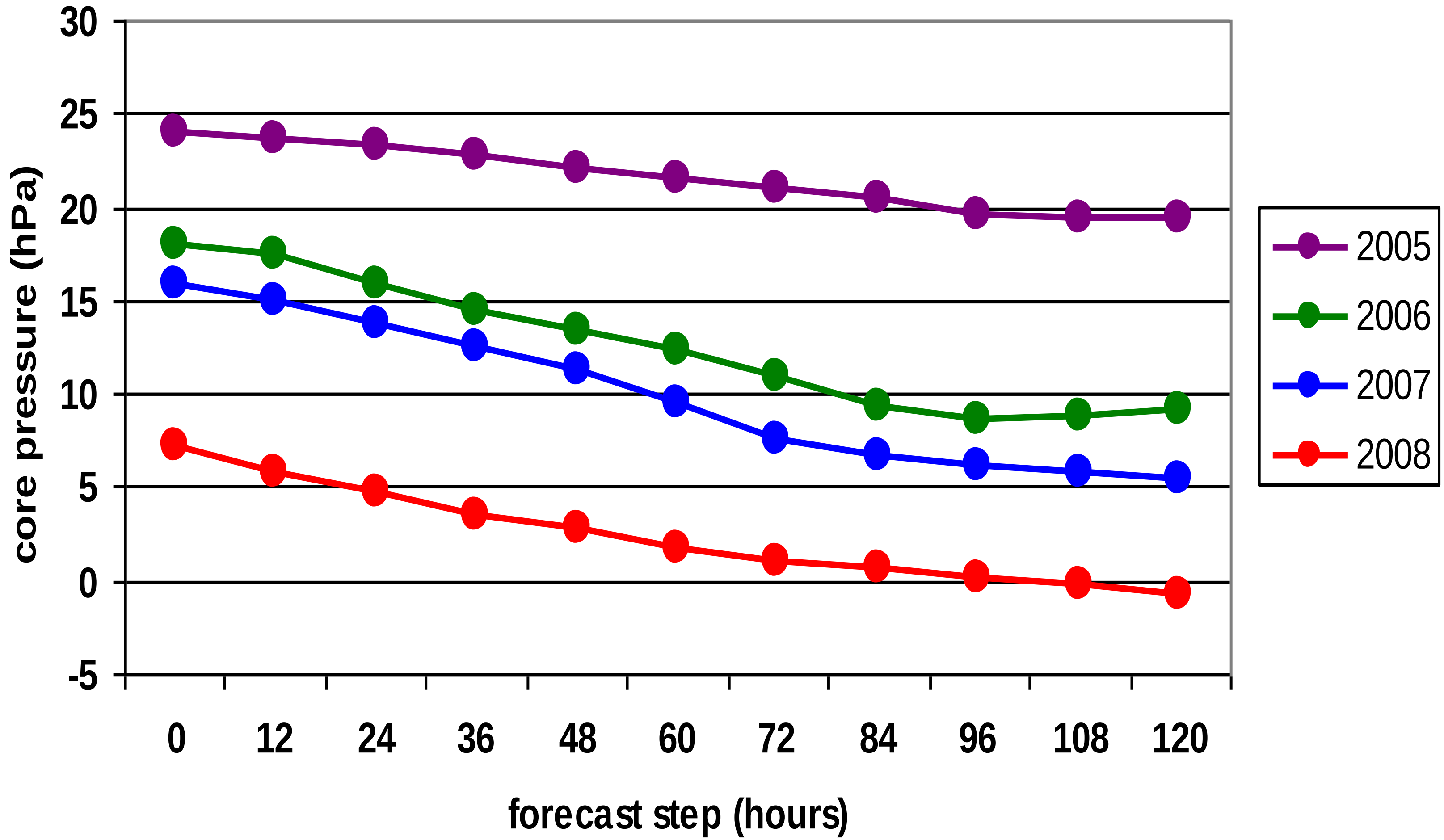
Hatched areas denote statistically significant differences

It is difficult to assess the impact of improved Tropics on midlatitue meteorology but it seems that improvement over Indian Ocean – Indonesia (also in tropical variability – MJO) projects on the North East Pacific

Tropical Cyclone Intensity Error

(mean of 365 days ending at 15 August)

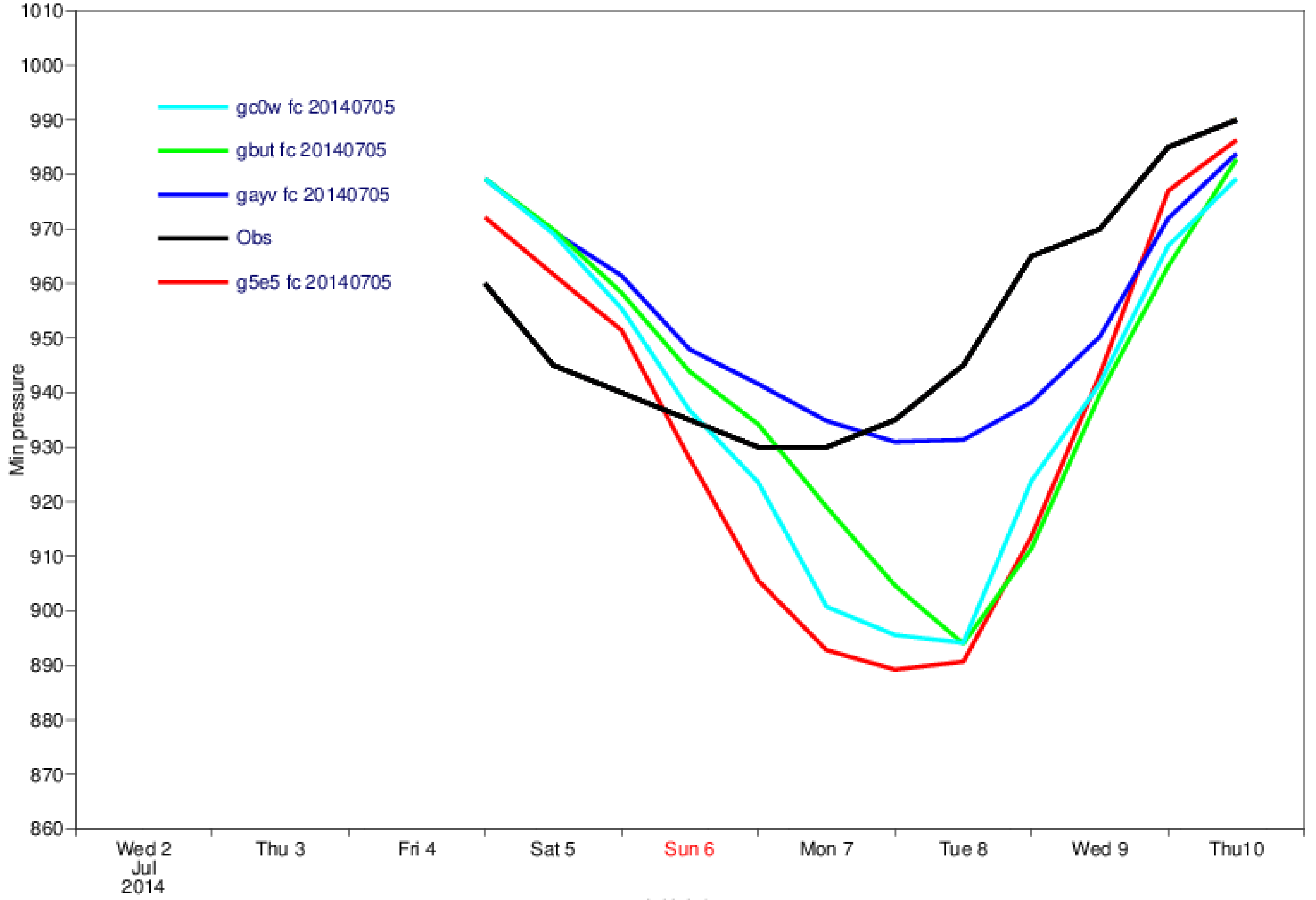
Dependency on model resolution, data assimilation and Physics



2006 Resolution change T511 (40 km) -> T799 (25 km)

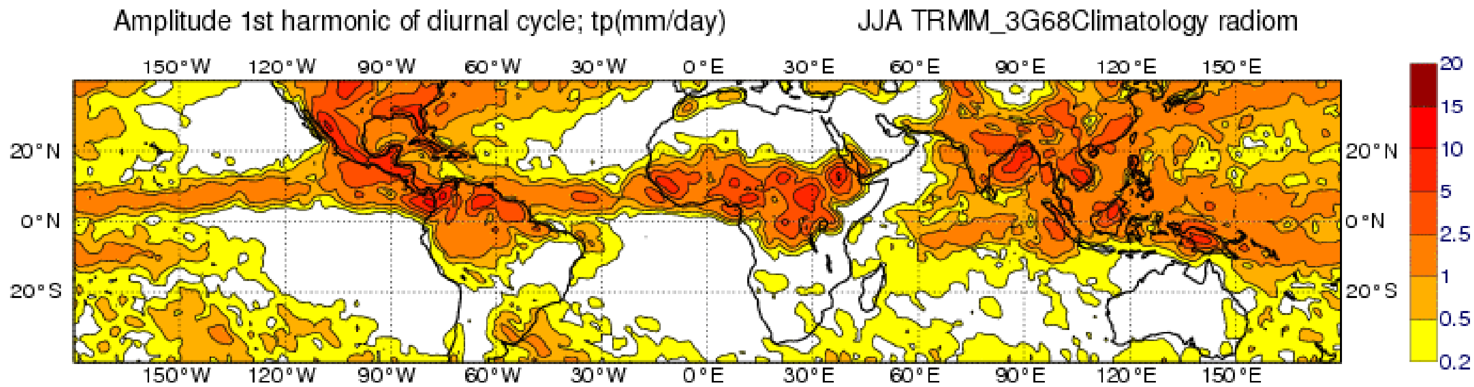
2008 Physics change (mainly convection)

Sensitivity of cyclone depth to Physics=convection example Cyclone Neoguri

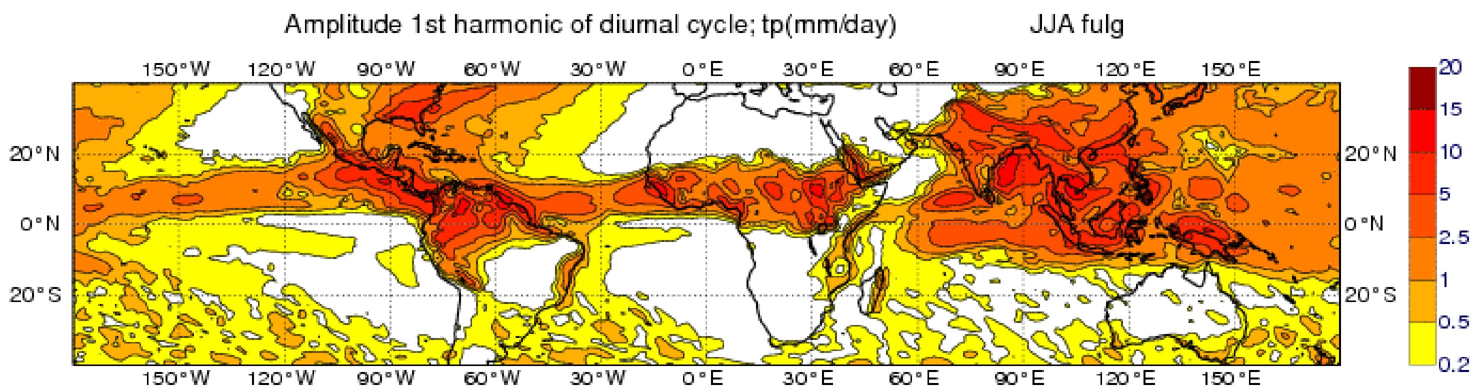


far too deep cyclone forecast could be addressed with increasing parcel perturbation in convection (blue curve) –also it is shown that it is a model (fc) problem and not due to initial conditions

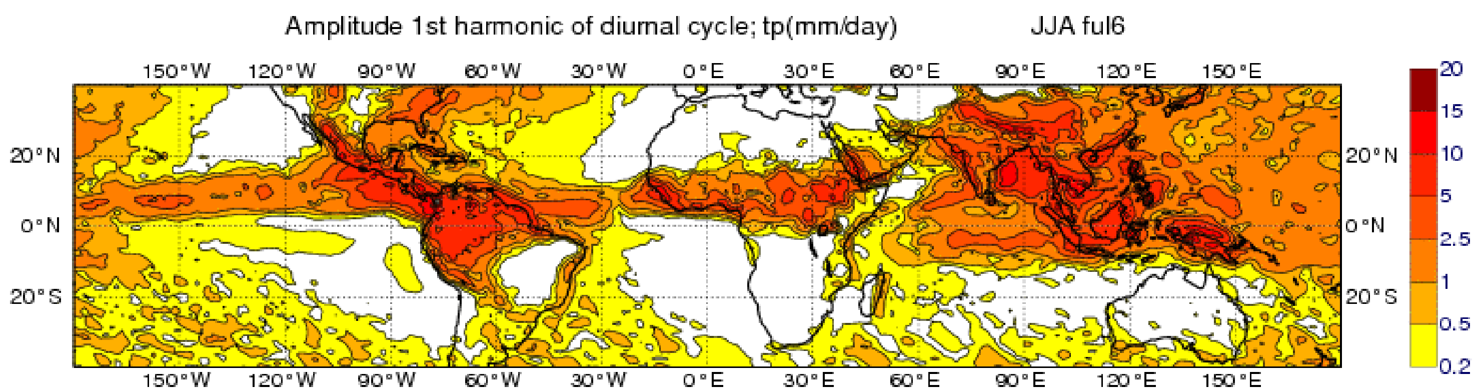
Diurnal cycle of Precipitation JJA: Amplitude (mm/d)



TRMM



until November 2013

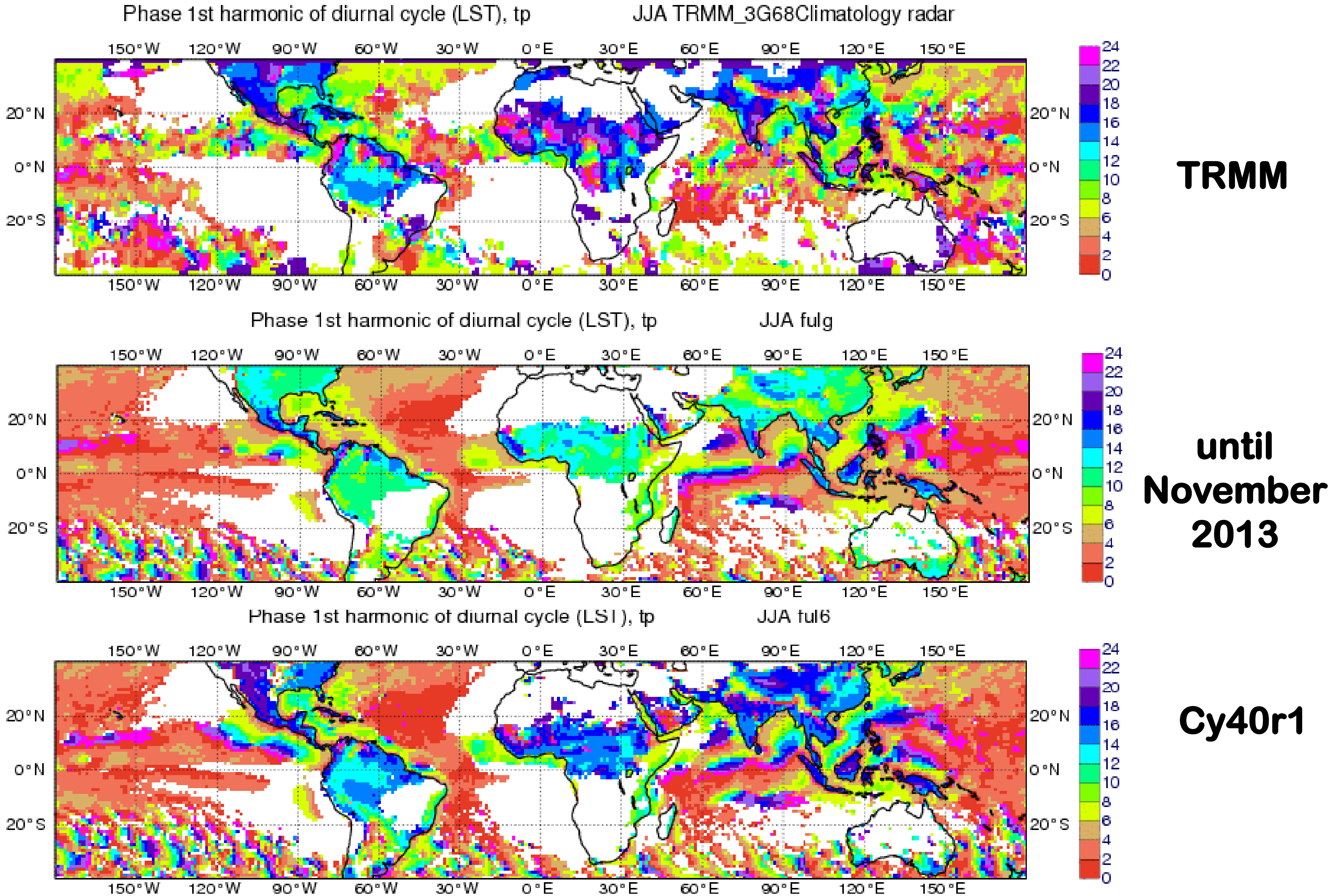


Exp= Cy40r1

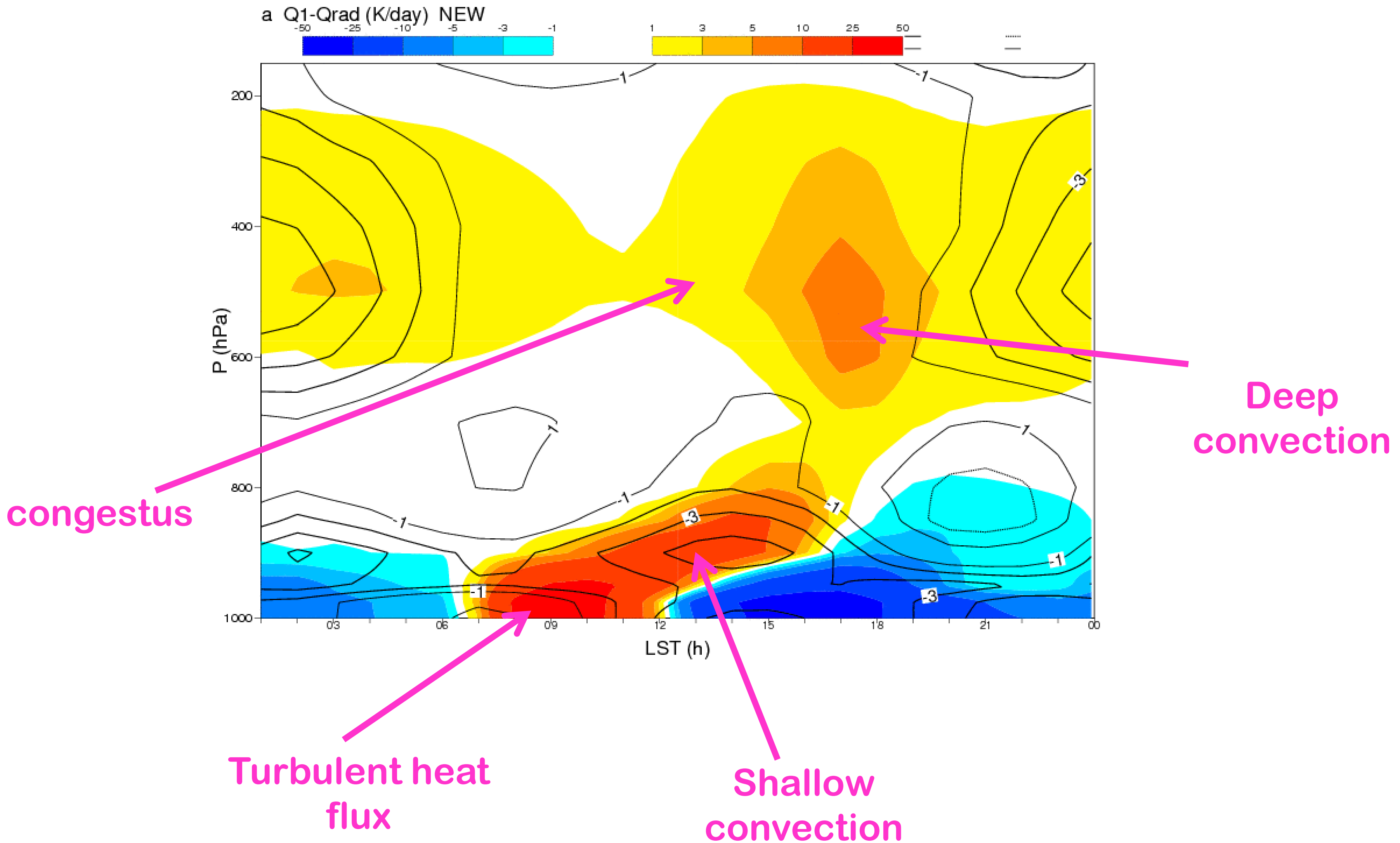
ECMWF

Diurnal cycle of Precipitation JJA: Phase (LST)

was a remaining problem until recently



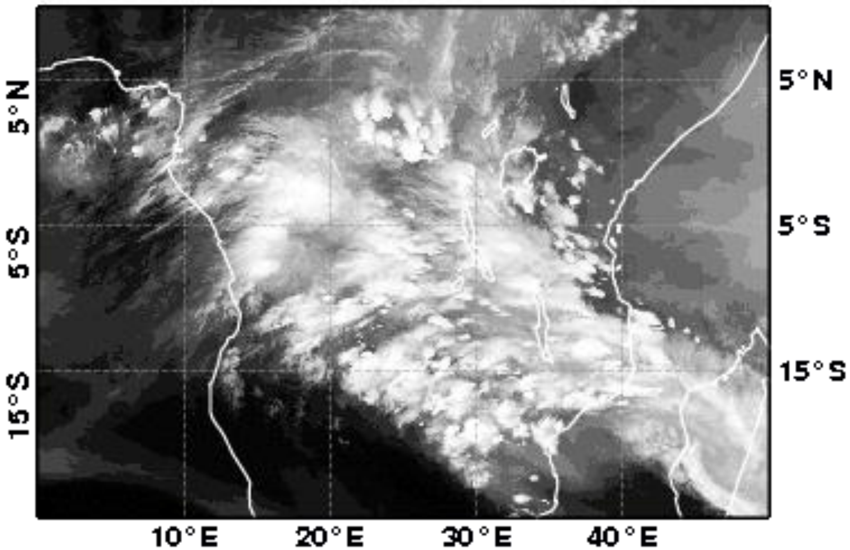
Diurnal evolution of total heating profile - radiation



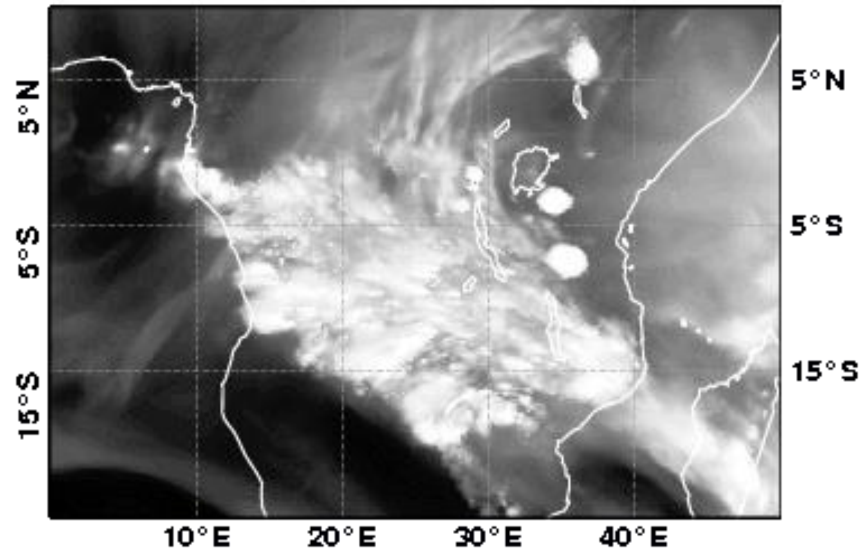
ECMWF

Impact on simulated structure of convective systems

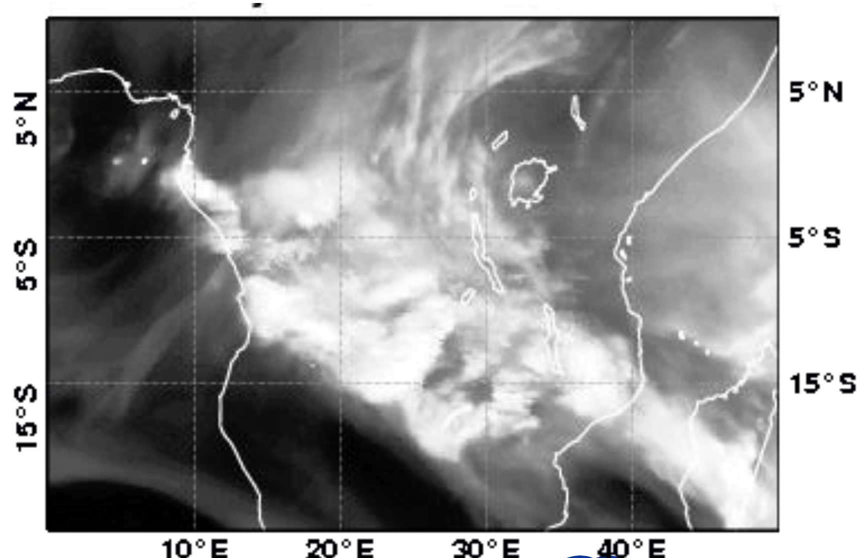
WV6.2 20140110 15 UTC



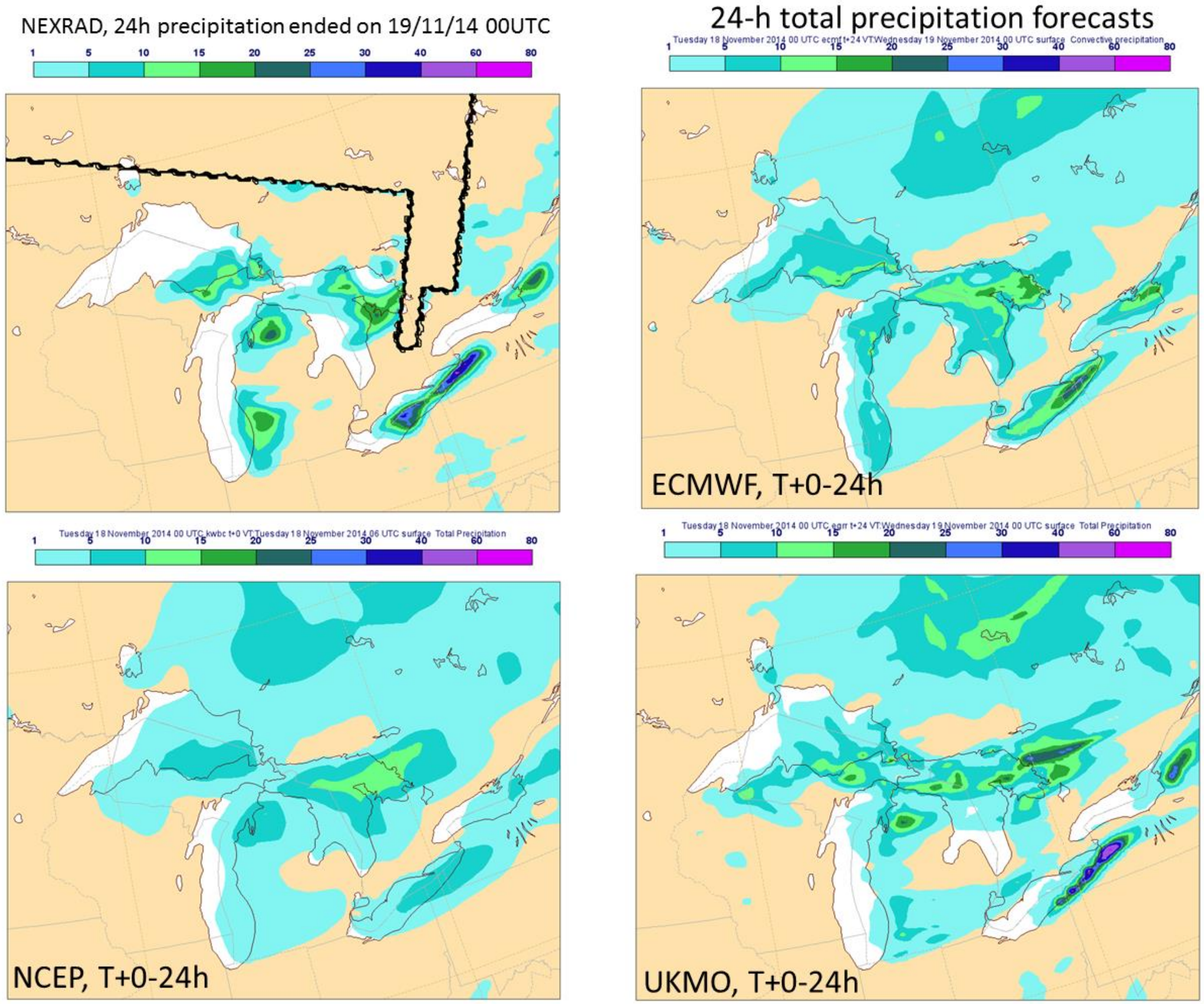
ECMWF 1 Fc 20140110 00 UTC+15h:



without diurnal cycle add in closure



Winter convection: Lake effect and advection

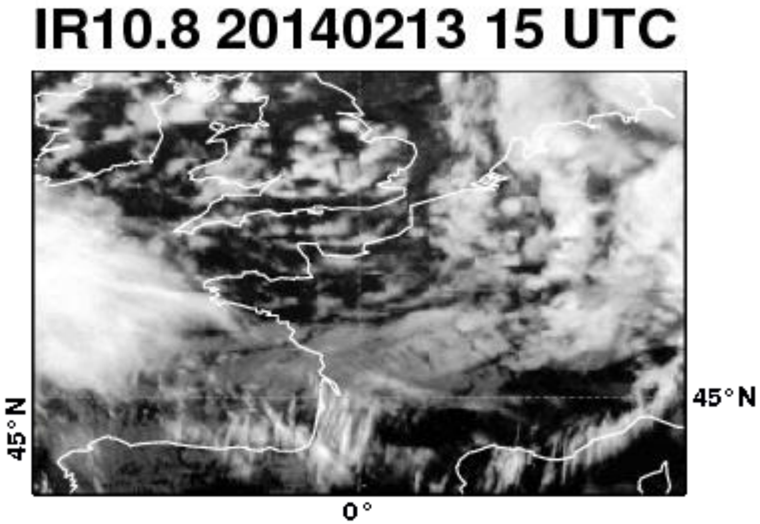


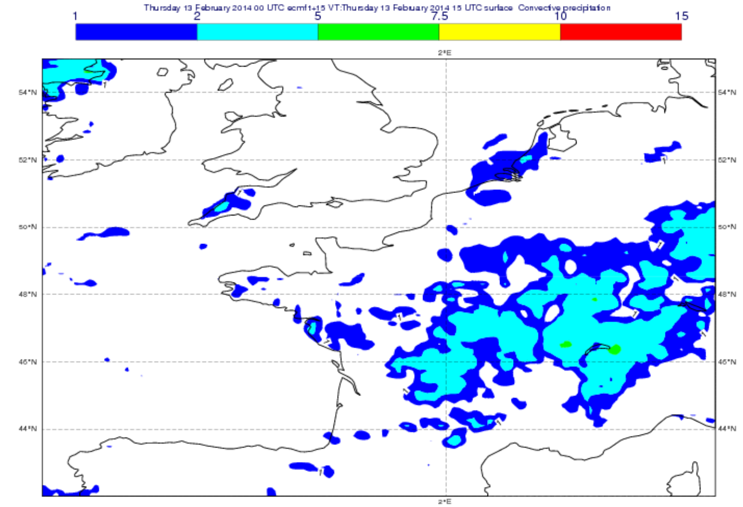
Remaining Problem 2: advection of snow

What is valuable detail?

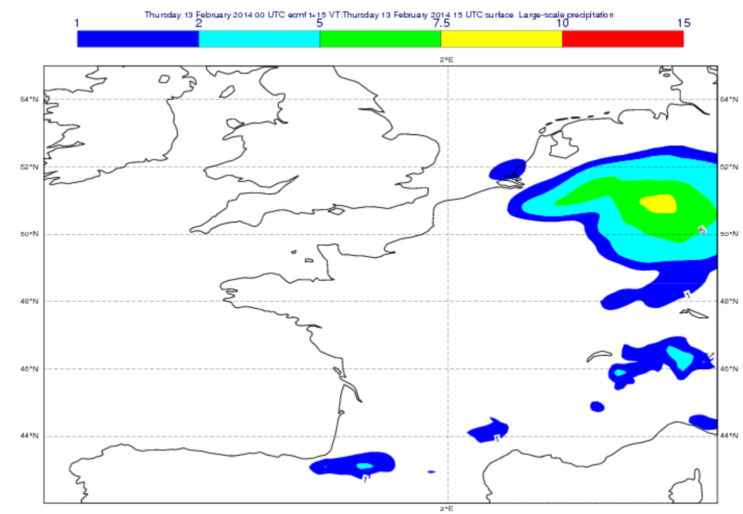
which convective systems (effects) are missing and what is good filtering?

E.g 13 February 2014 15 UTC





CP



LSP

Wind Gusts in the IFS

Gusts are computed by adding a turbulence component and a convective component to the mean wind:

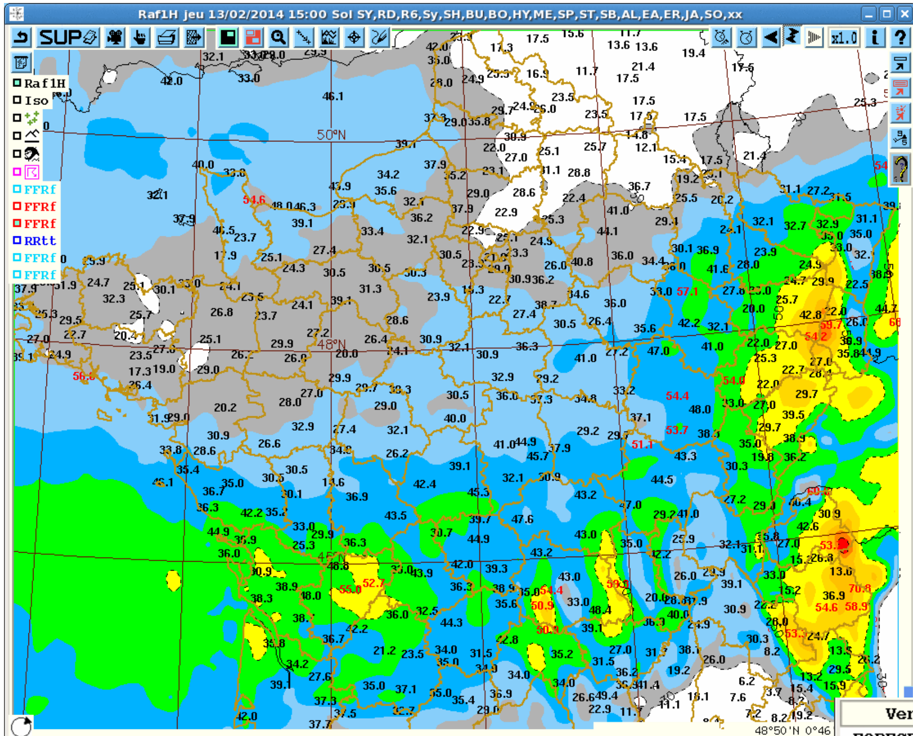
$$U_{gust} = U_{10} + 7.71 U_* \ f(z/L) + \underbrace{0.6 \max(0, U_{850} - U_{925})}_{deep \quad convection}$$

where **U_{10}** is the 10m wind speed (obtained as wind speed at first model level, or interpolated down from 75m level), **U_*** is the friction velocity – itself obtained from the wind speed at the first model level, and **L** is a stability parameter.

The convective contribution is computed using the wind shear between model levels corresponding to 850 hPa and 950hpa, respectively.

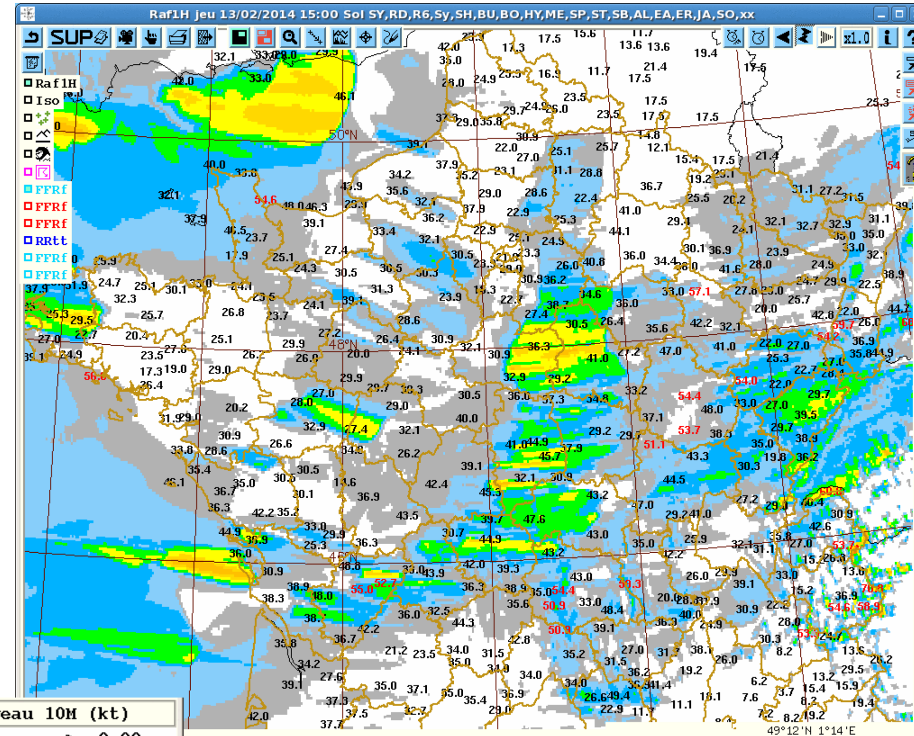
Wind Gusts (‘turbulent’ & ‘convective gusts’)

Wind gusts on 13 February 2014 15 UTC: Figures courtesy Meteo France Previ



ECMWF 16 km

Vent Niveau 10M (kt)	
FOREGROUND	> 0.00
GREY	> 30.00
VAL_BLUE	> 35.00
GREENISH_BLUE	> 40.00
GREEN	> 45.00
YELLOW	> 50.00
ORANGE_YELLOW	> 55.00
YELLOWISH_ORANGE	> 60.00
REDDISH_ORANGE	> 65.00
RED	> 70.00
OCHRE	> 75.00
PURPLE	> 80.00
PURPLISH_RED	> 85.00
CHESTNUT	> 90.00

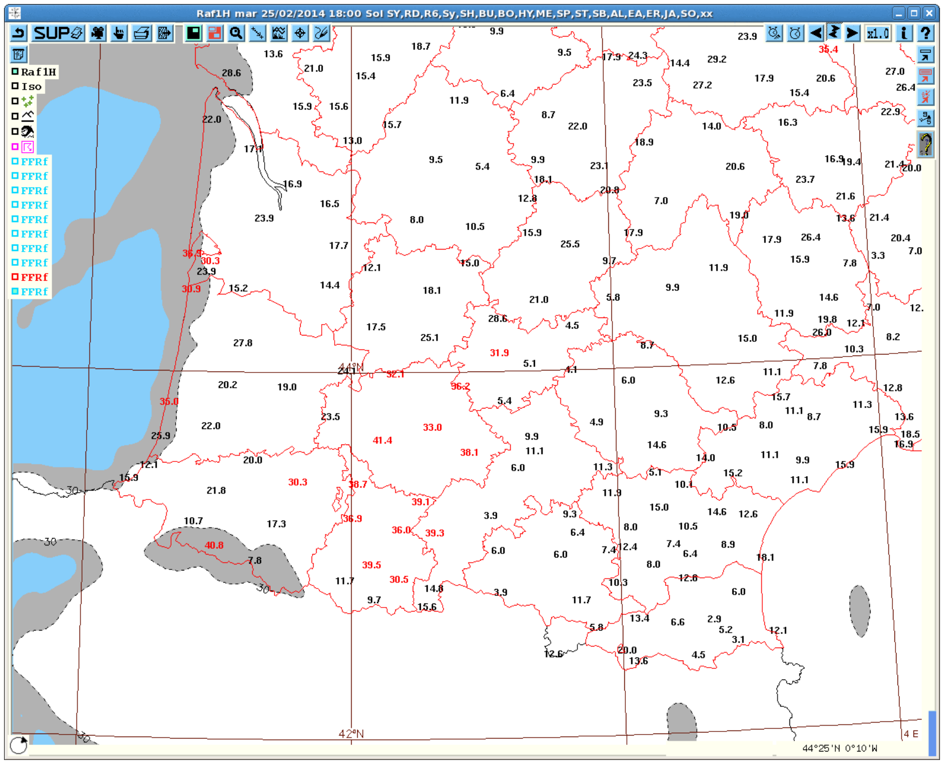


AROME 2.5 km

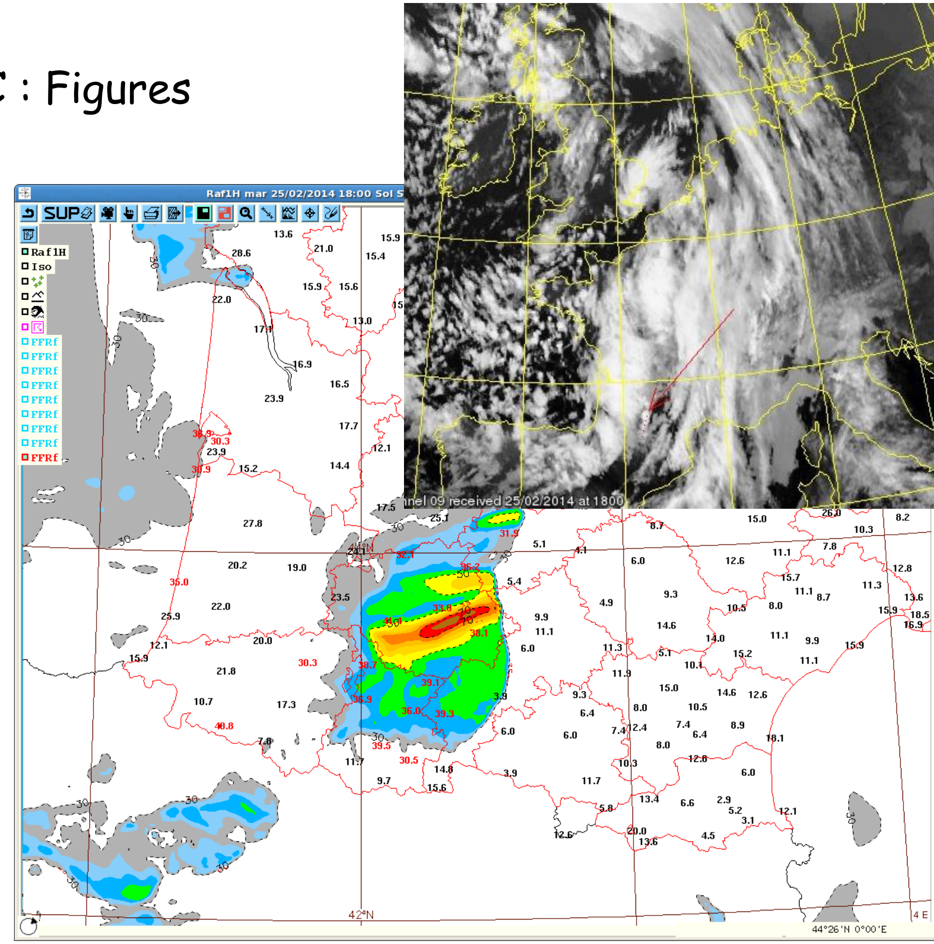
ECMWF

Wind Gusts (‘turbulent’ & ‘convective gusts)

E.g wind gusts on 25 February 2014 18UTC : Figures courtesy Meteo France Previ



ECMWF 16 km



AROME 2.5 km

The lower resolution model can easily miss local convective events –though the 2.5 km still tends to overestimate their intensity

Forecasting and discussion of weather maps

The prediction of (convective) rainfall by the model is not always perfect, but ! The large-scale situation is generally well-forecasted by the model. Therefore, a good forecaster should be able to predict regions of convective activity from the large-scale fields

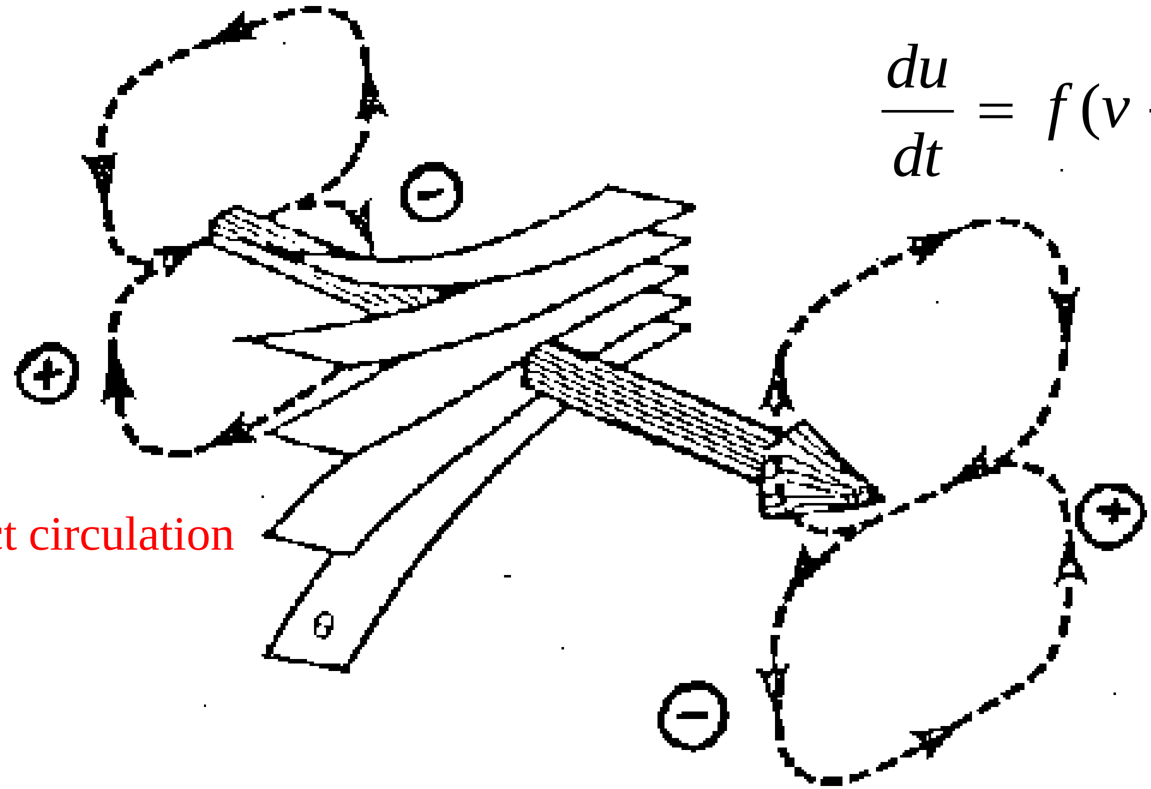
……. it will be shown that with the present forecast system (10-30 km resolution) strongly forced mesoscale convection with trailing stratiform area can be reasonably well predicted typically a few days in advance

Reminder: Midlatitude Convection

Forcing of ageostrophic circulations/convection in the right entrance and left exit side of upper-level Jet

Acceleration/deceleration of Jet

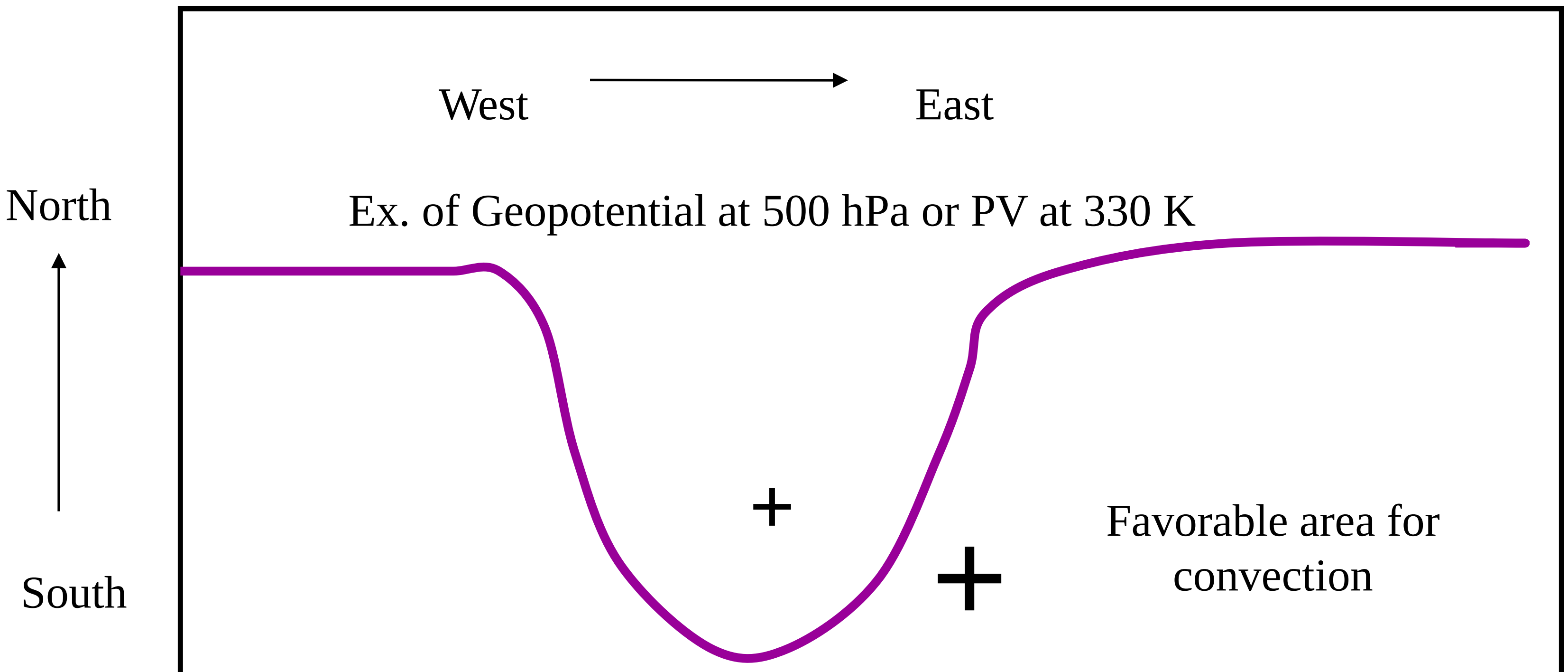
$$\frac{du}{dt} = f(v - v_g) \equiv fv_a$$



Reminder: Troughs or PV anomalies

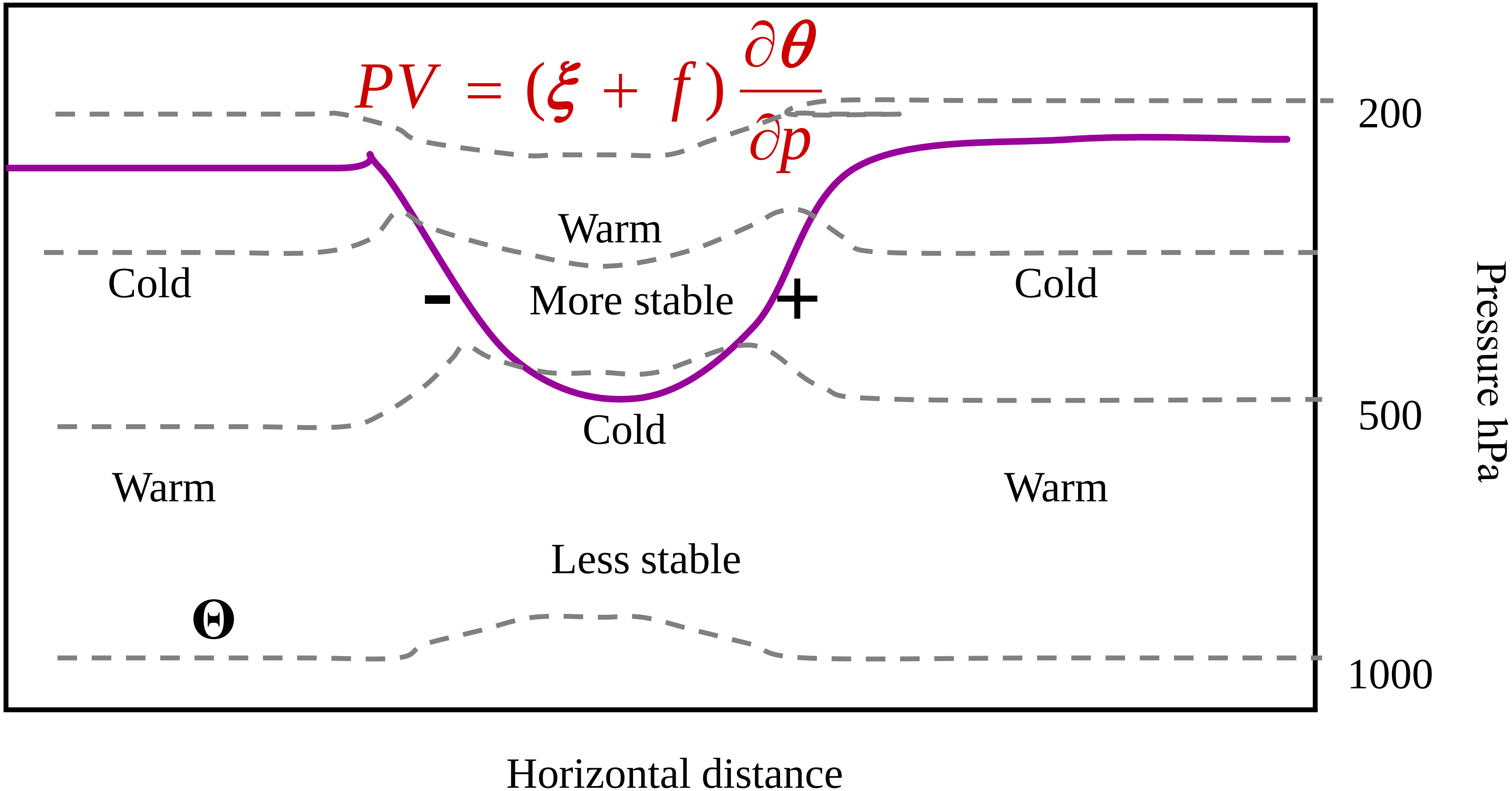
“horizontal” cross section of Geopotential on constant pressure surface or PV on constant potential temperature surface

- It is equivalent to look at Troughs at constant pressure surface or to look at PV at constant potential temperature surfaces
- To know what is going on in the atmosphere it is sufficient to look at the low-level perturbation (flow) and at the upper-level flow (perturbation)
- If we look at PV instead of Geopotential we will see more structure (for reasons not explaine here)



Reminder: PV thinking
the atmosphere below and above a PV anomaly (vertical cross section)

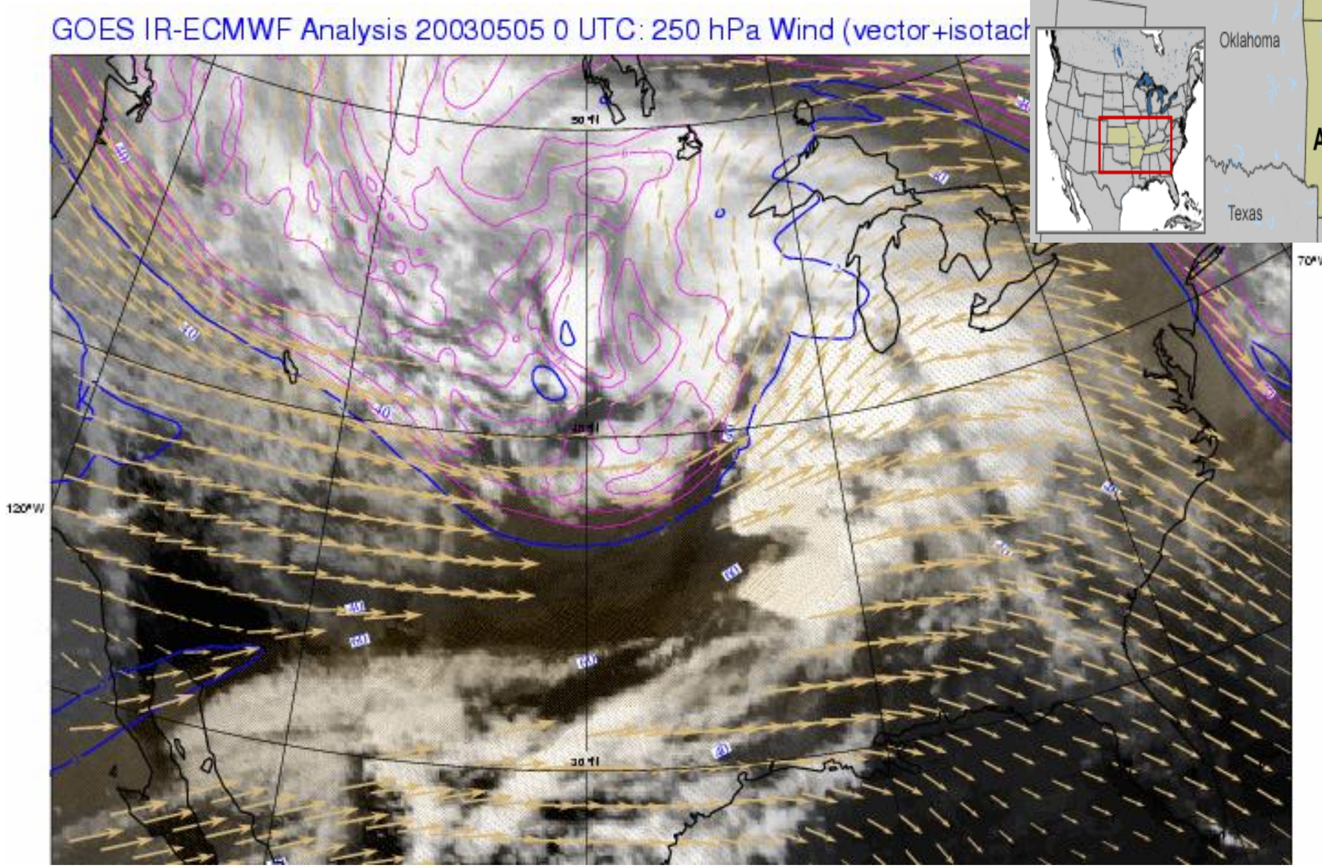
There is a cyclonic vortex around the upper-level PV anomaly (the tropopause is marked by the pink line). The atmosphere below the anomaly is relatively cold and less stable

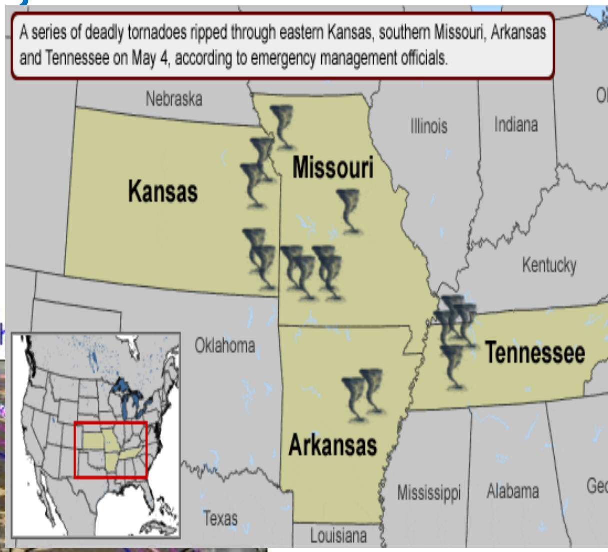


ECMWF

Tornadic case from 4 May 2003

Upper-level flow : 250 hPa Wind vector + isotachs, 330 K PV

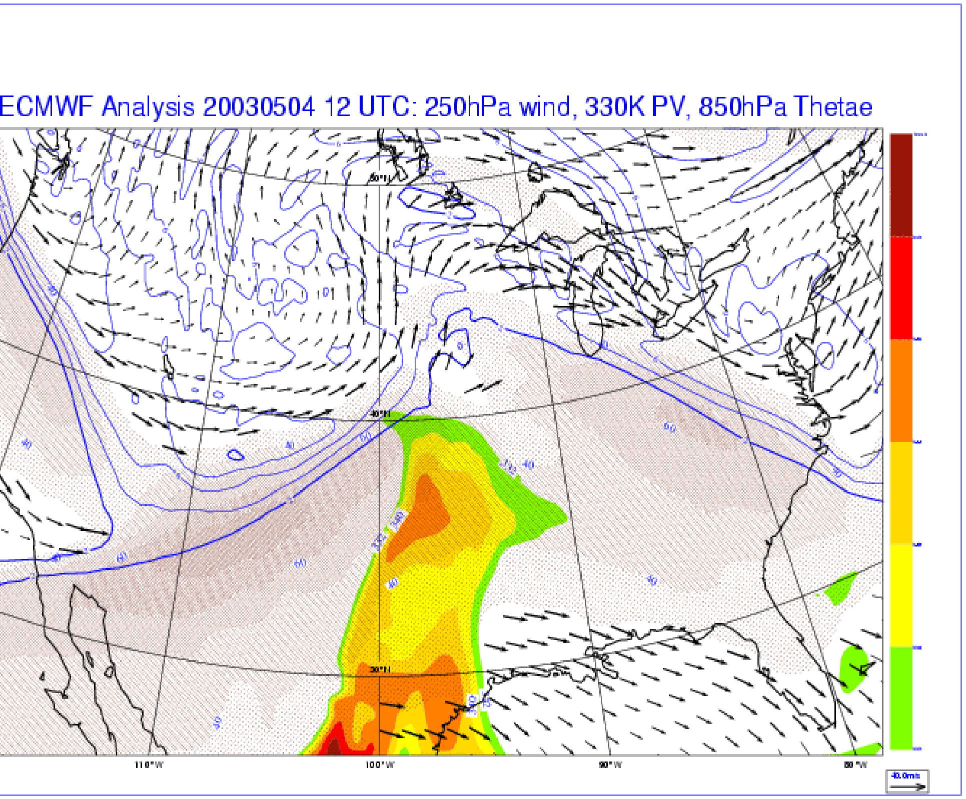




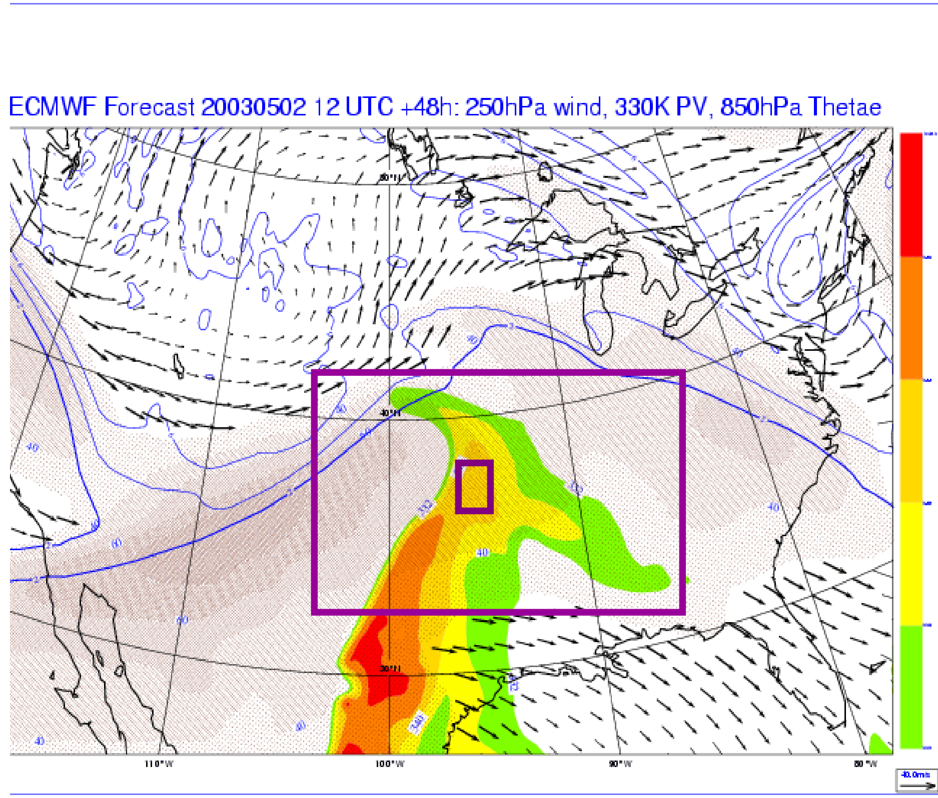
Tornadic case from 4 May 2003

Upper-level flow: 250 hPa Wind vector+Isotachs(shaded), 330 K PV, 850 hPa Thetae

Analysis



48-60h Forecast

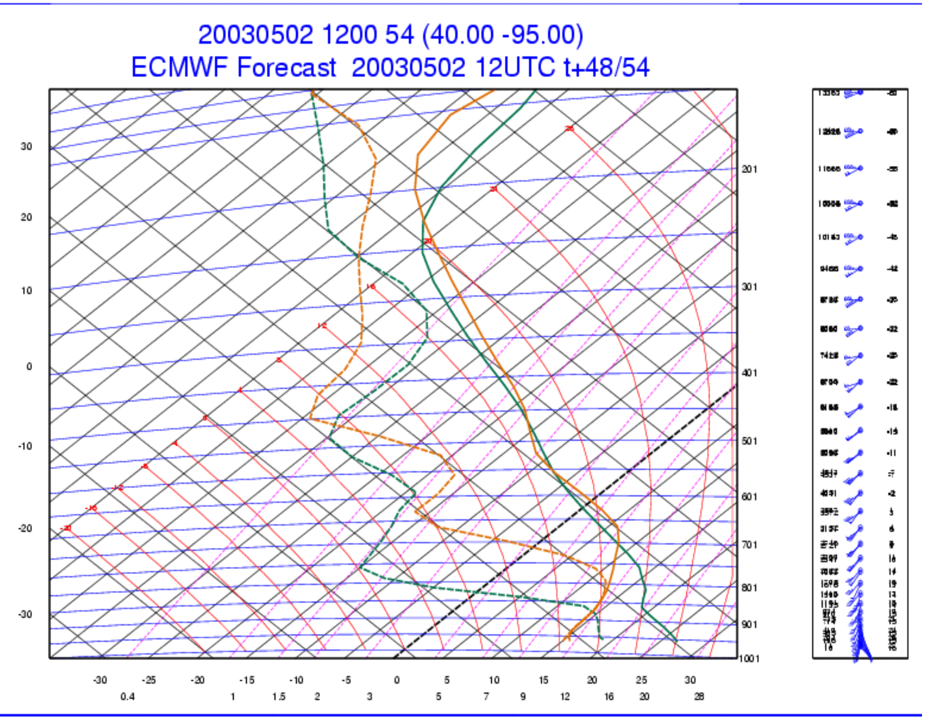


Note: the crossing of the low-level flow (high Thetae=high CAPE) and the upper-level Jet at around 40°N. The region where Tornadoes have been observed is marked by the pink rectangle

Tornadic case from 4 May 2003

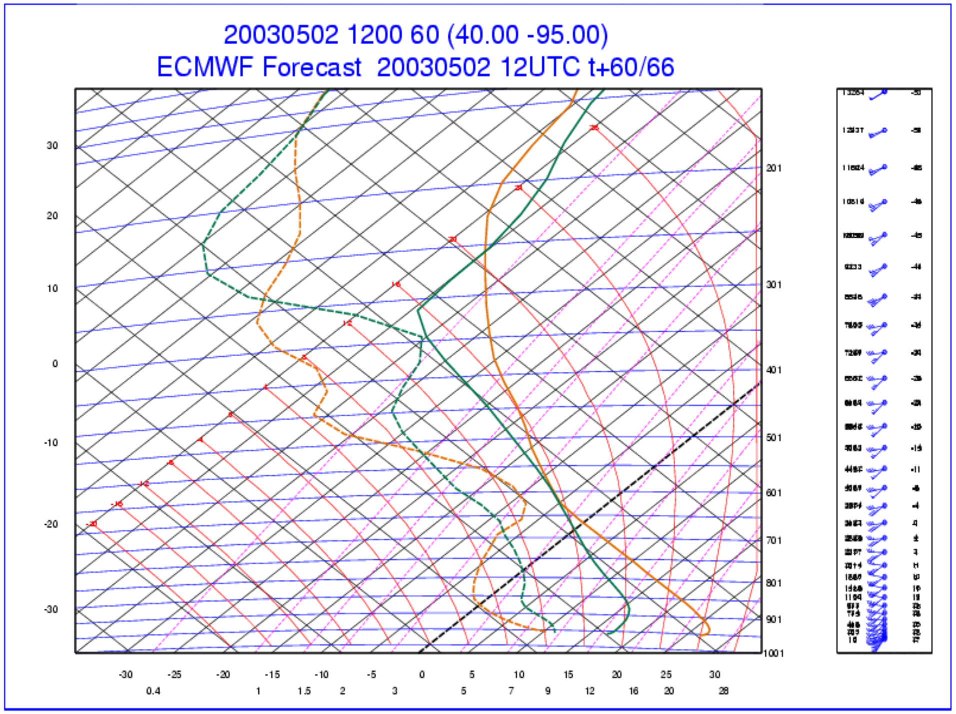
Forecasted Soundings at (40N/95W) at t+48/54/60/66 h

t+48/54



Low-level heating and veering (warm advection) of geostrophic wind for 48h profile; then upper level cold advection and backing of wind (green profile)

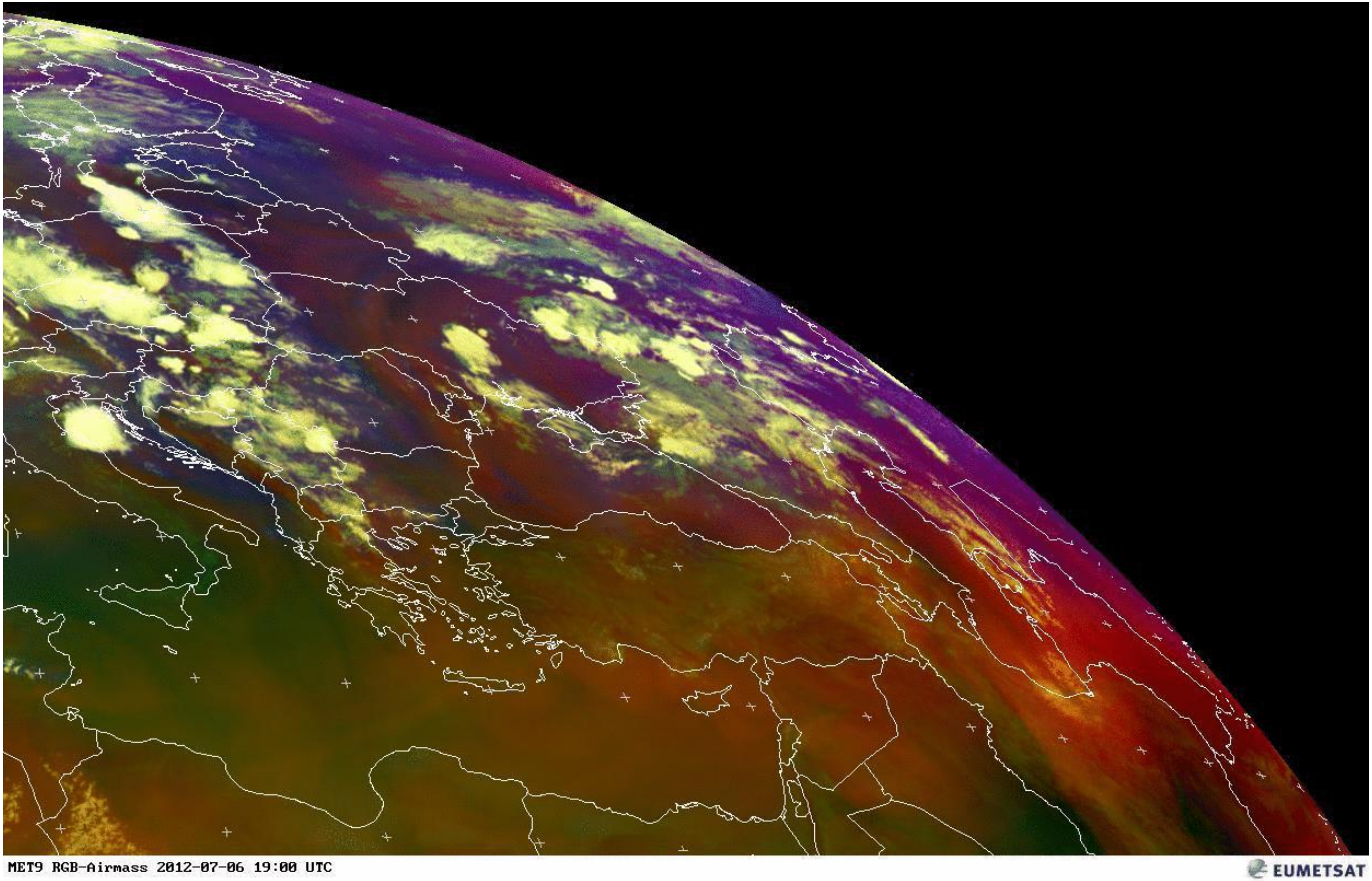
t+60/66



Low-level cooling (downdraughts), and upper-level cooling in stratospheric descent at approaching PV anomaly.

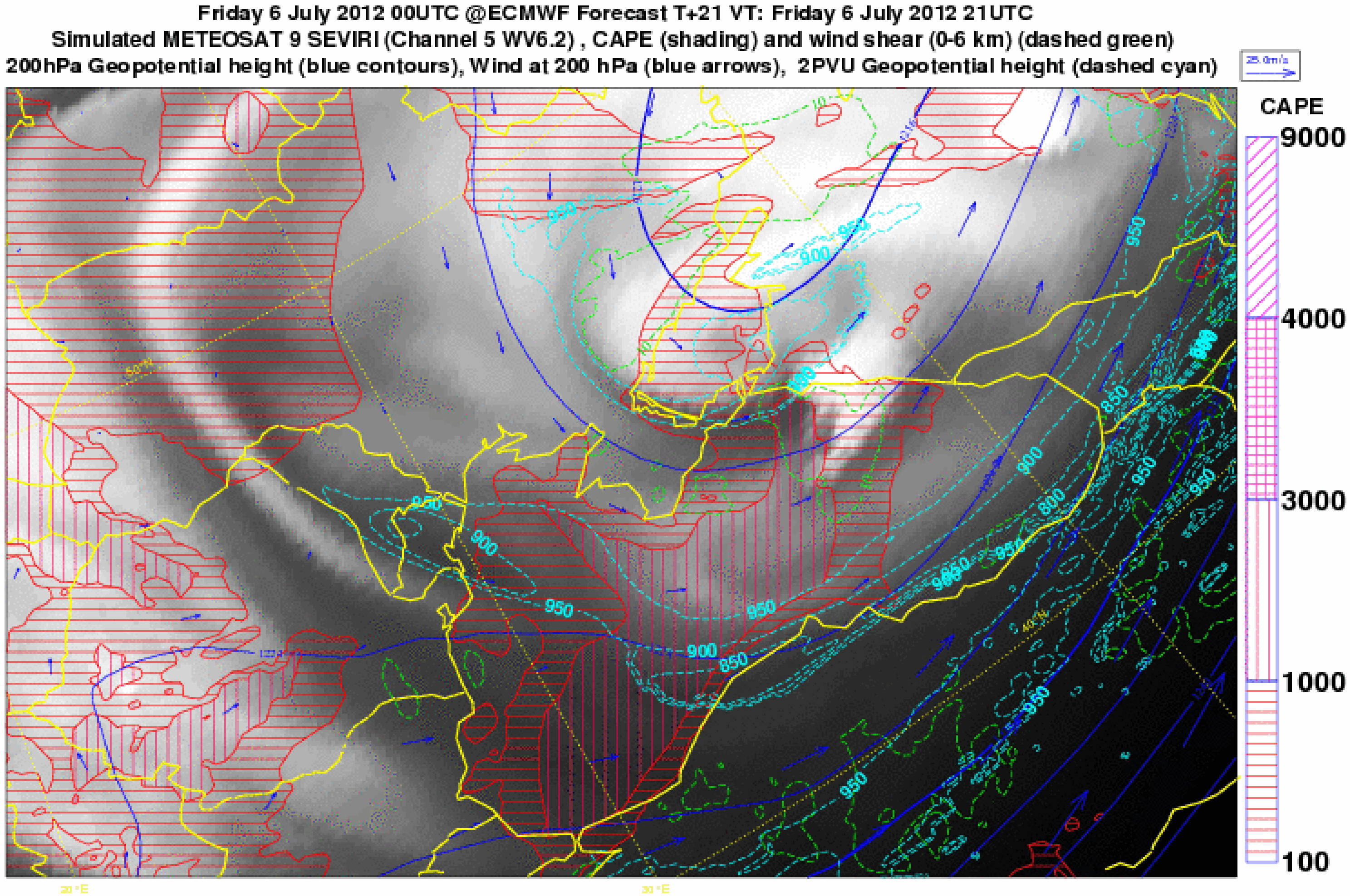
Black Sea system: 6 July 2012

V-shaped System



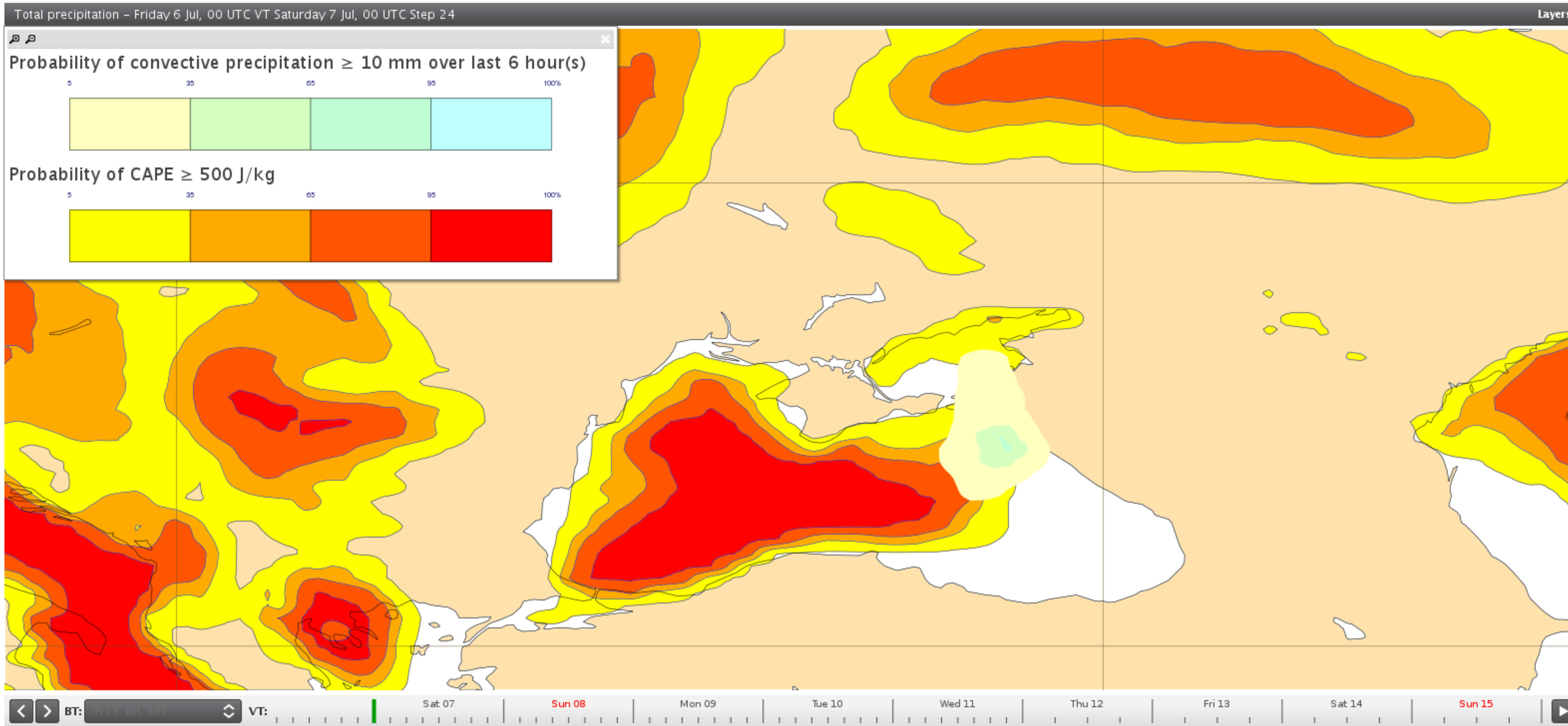
Black Sea system: 6 July 2012 (2)

fc WV image, convective precipiatation and shear



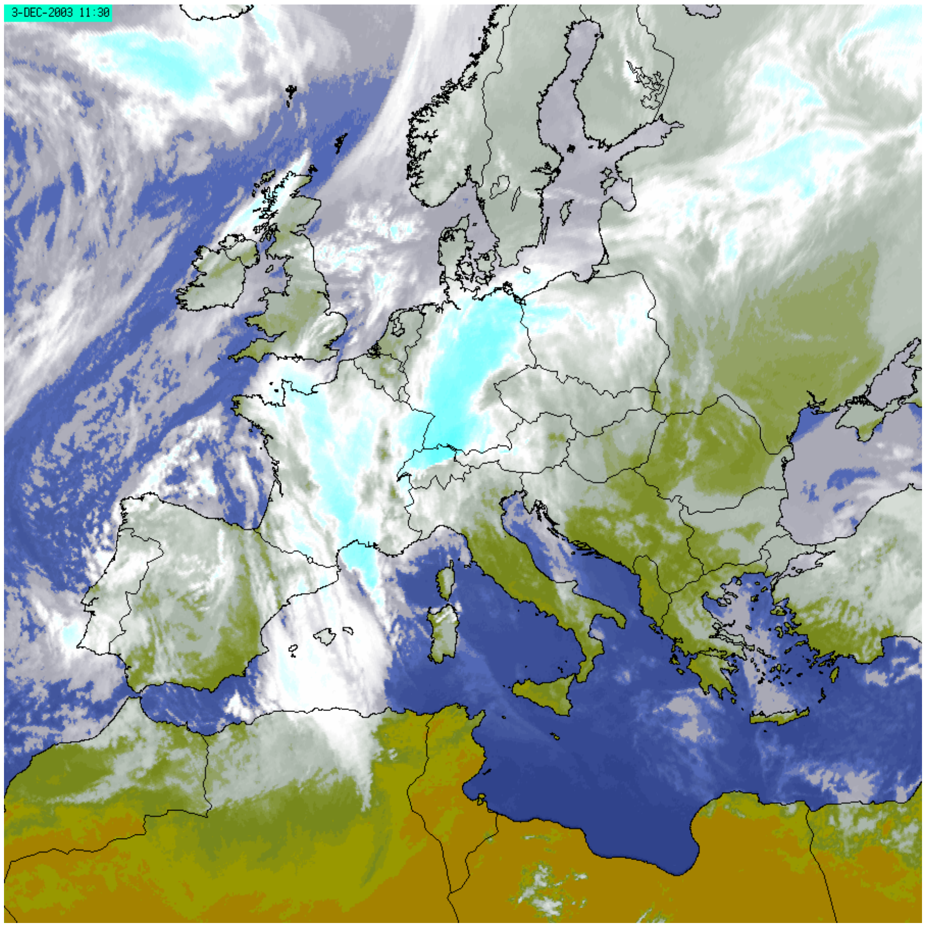
Black Sea system: 6 July 2012 (3)

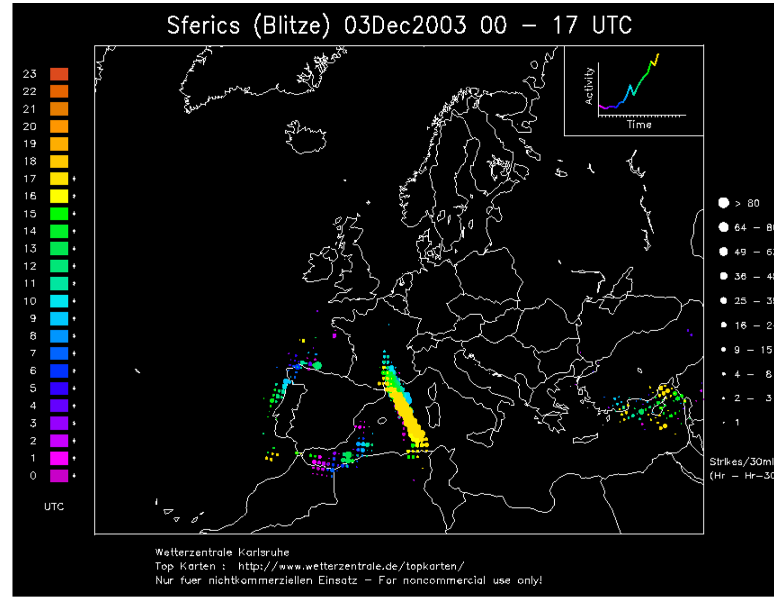
Probabilities CAPE & precipitation

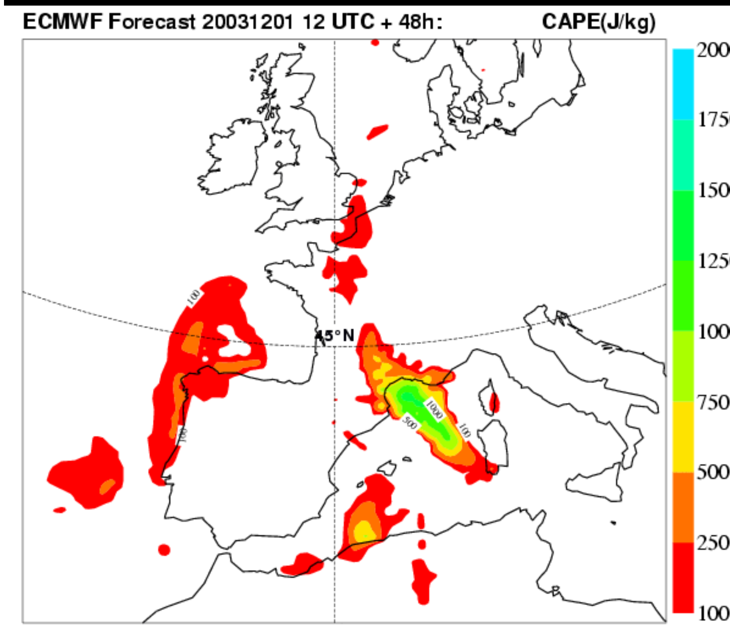


French Floods: 1-3 December 2003 (1)

IR animation V-shaped system



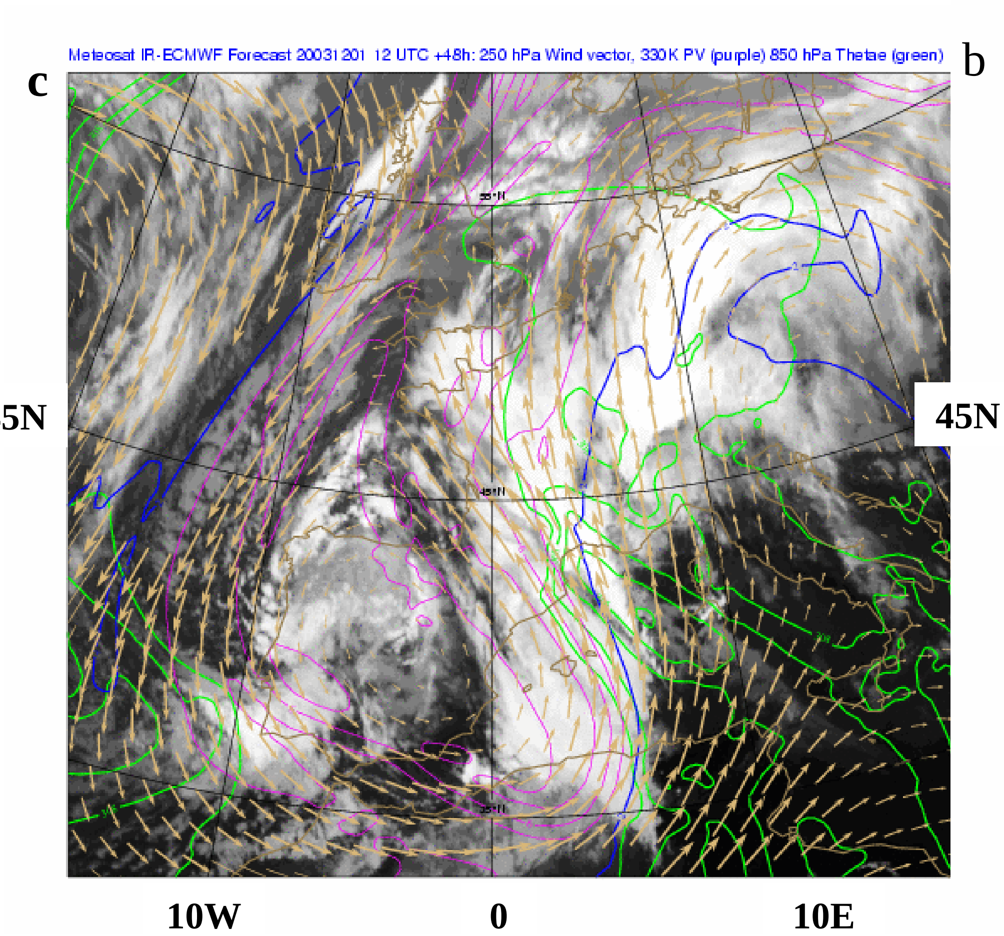


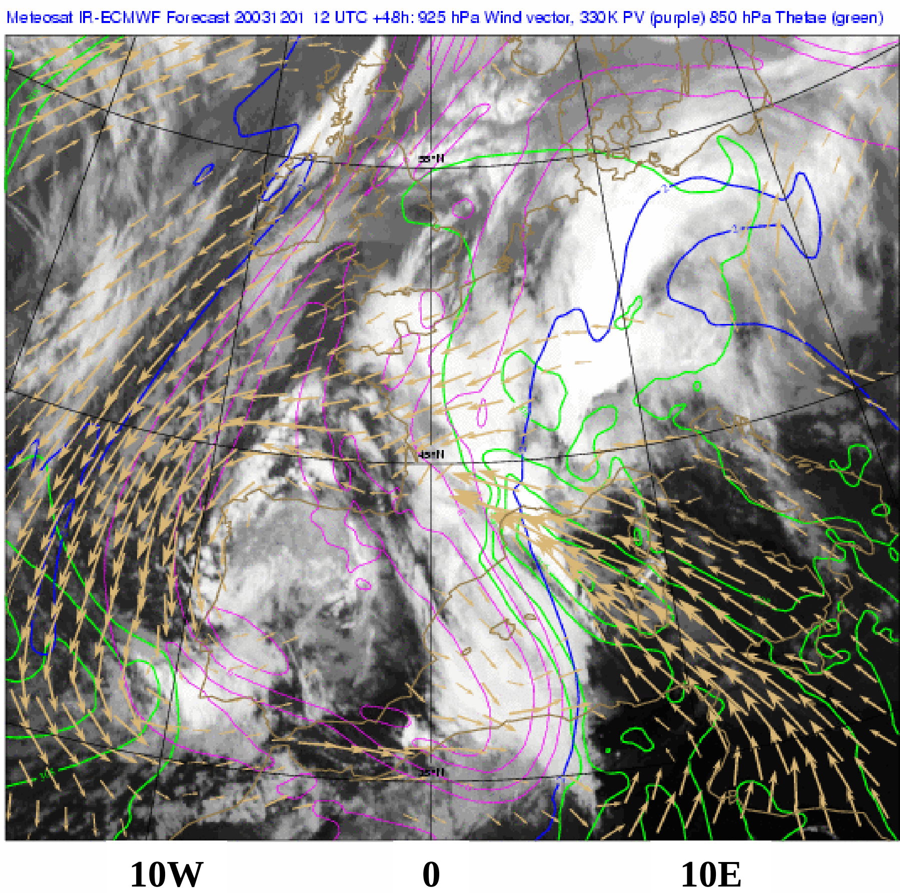


ECMWF

French Floods: 3 December 2003 (2)

upper/lower-level 48h Forecast

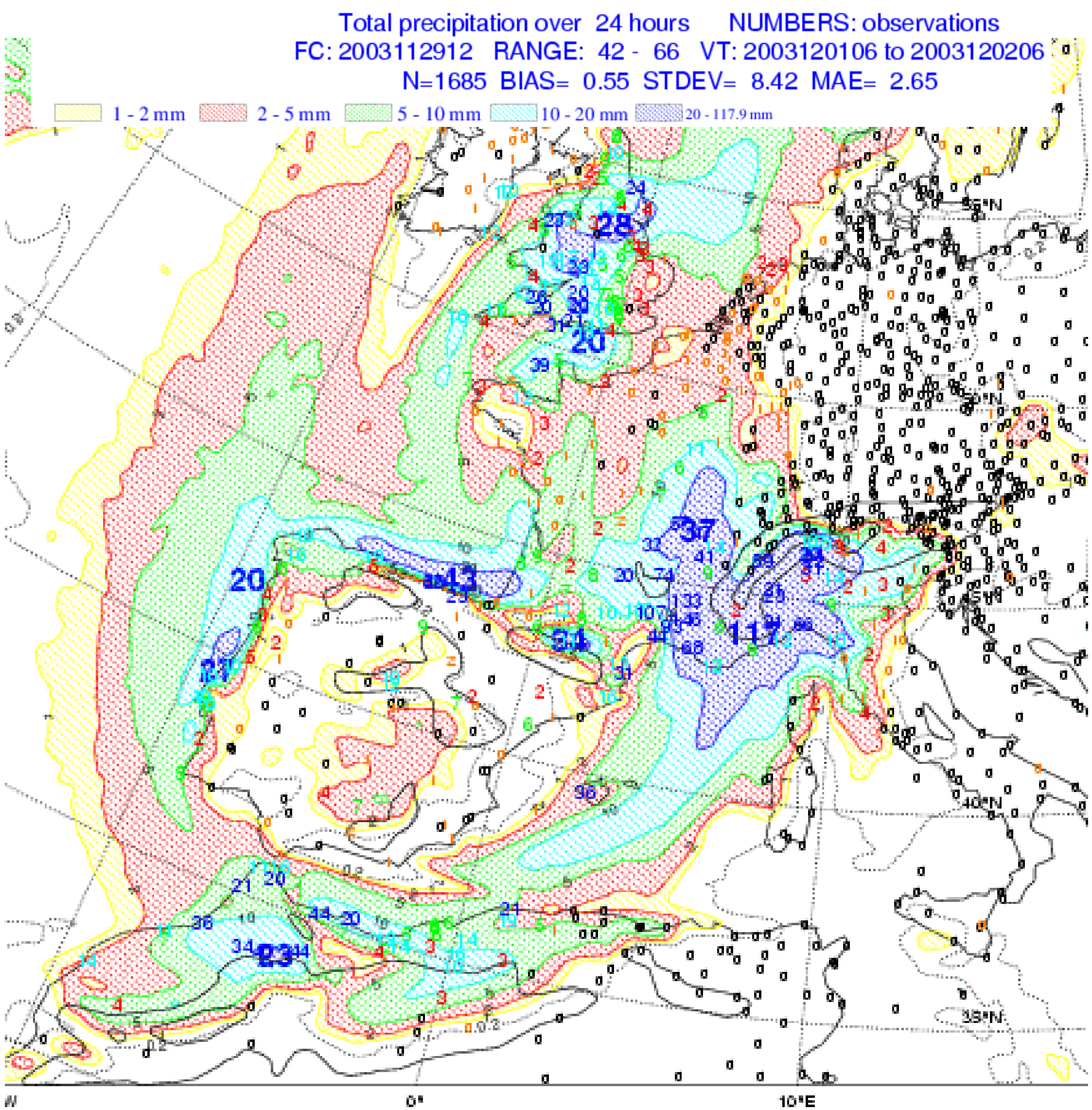




ECMWF

French Floods: 1/2 December 2003 (4)

Precipitation verification



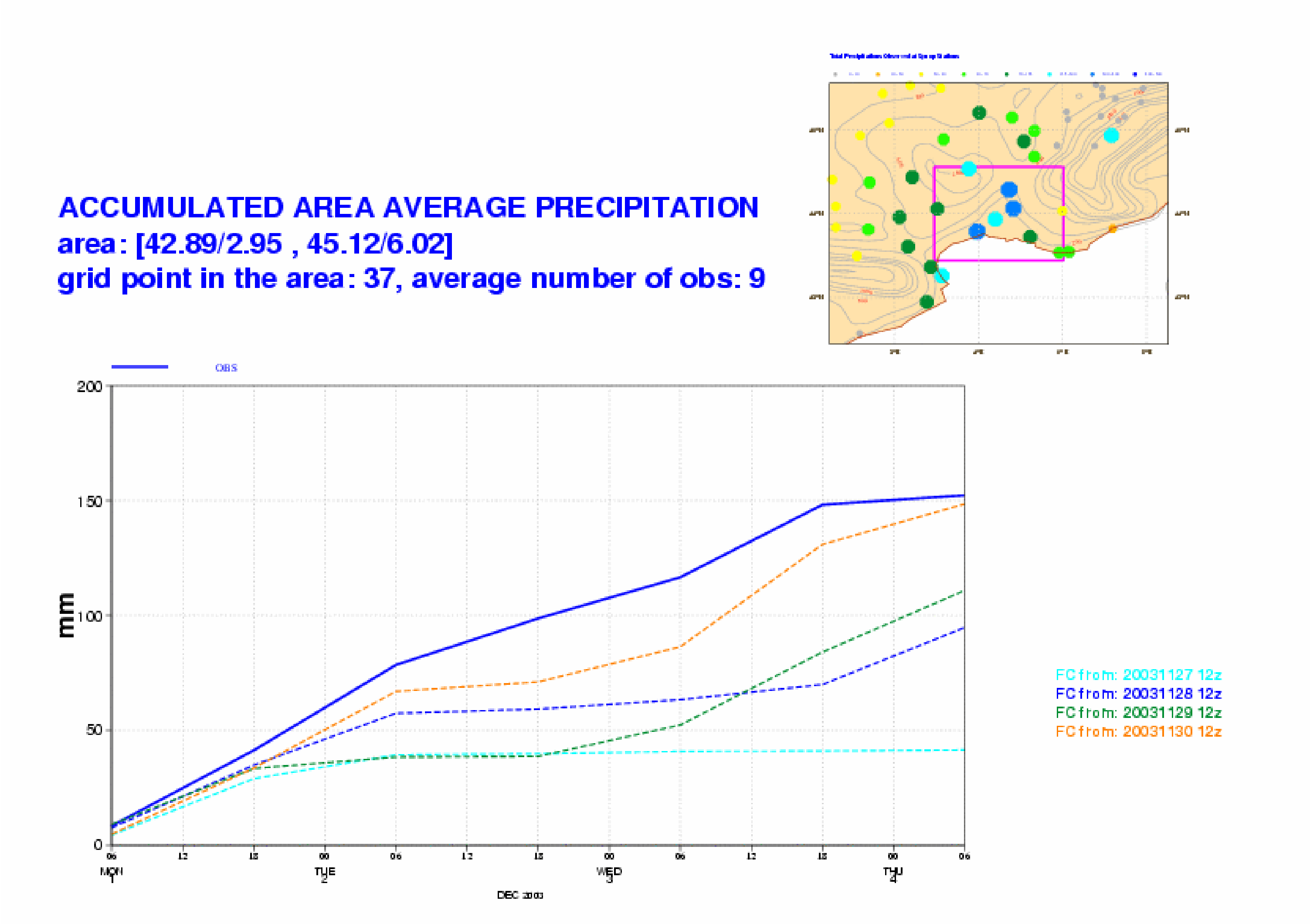
Thin numbers=Obs

Thick numbers= max. Forecast values

ECMWF

French Floods: 1-4 December 2003 (5)

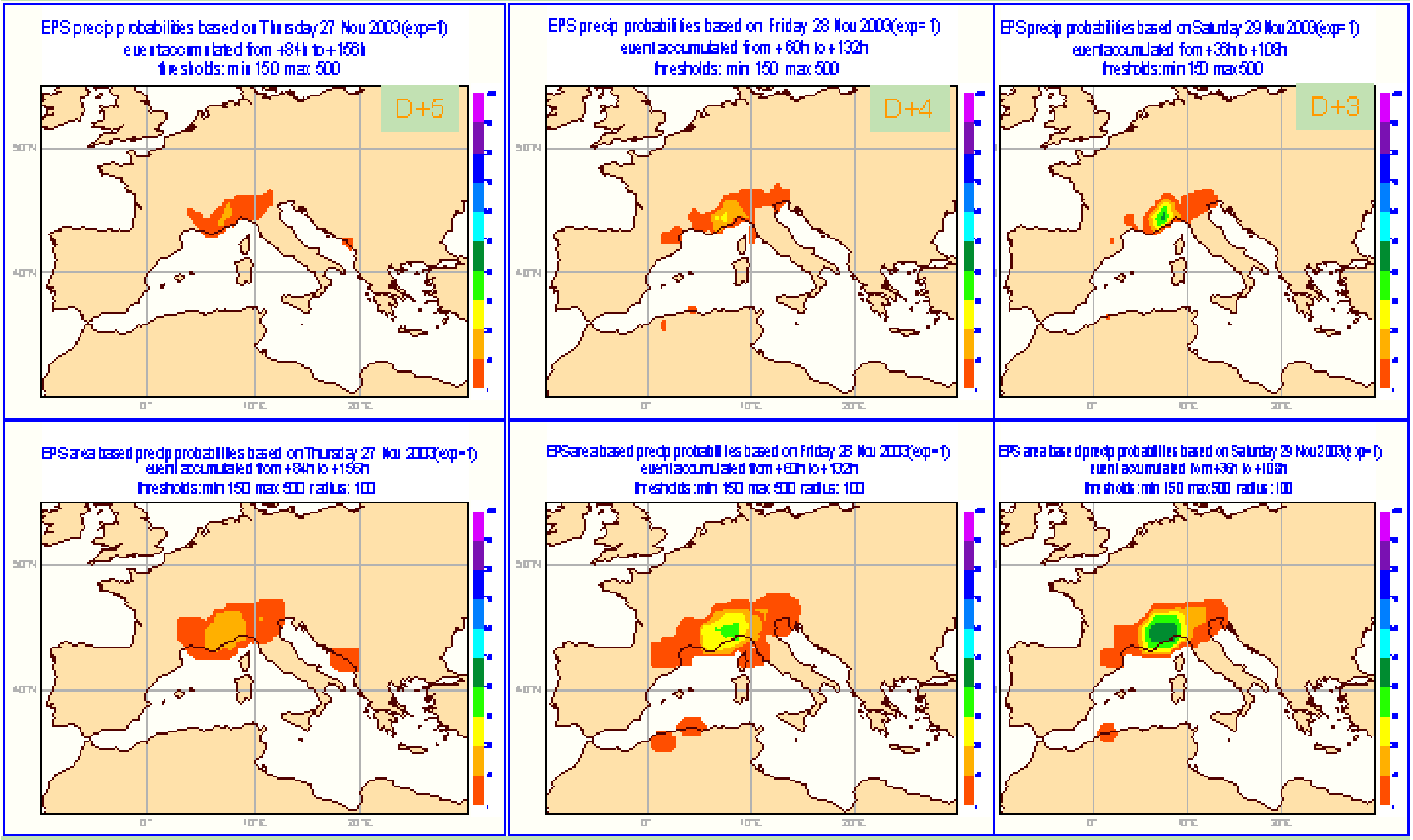
Area averaged precip form 1-4 December as obtained from different (lagged) forecasts: courtesy F.Grazzini



ECMWF

French Floods: 1-4 December 2003 (6)

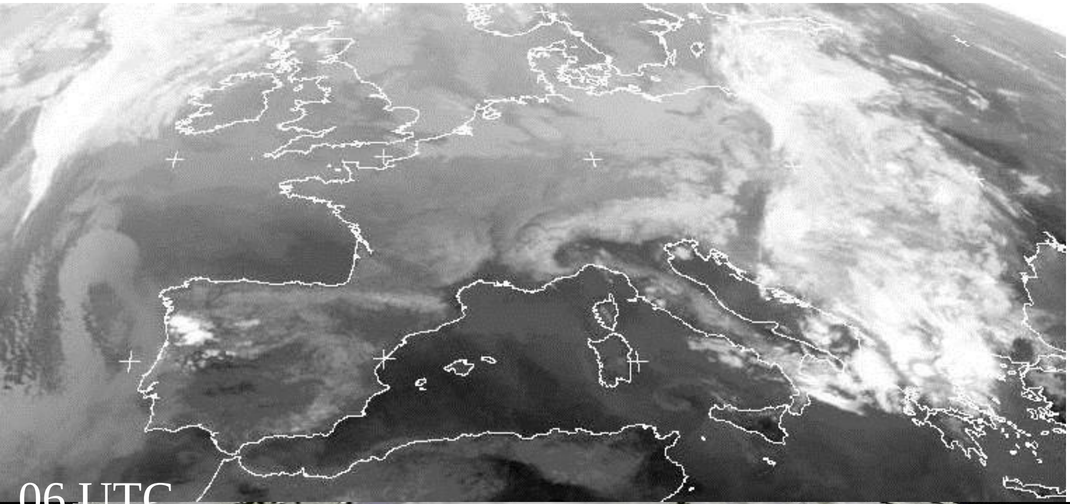
Probabilistic forecast

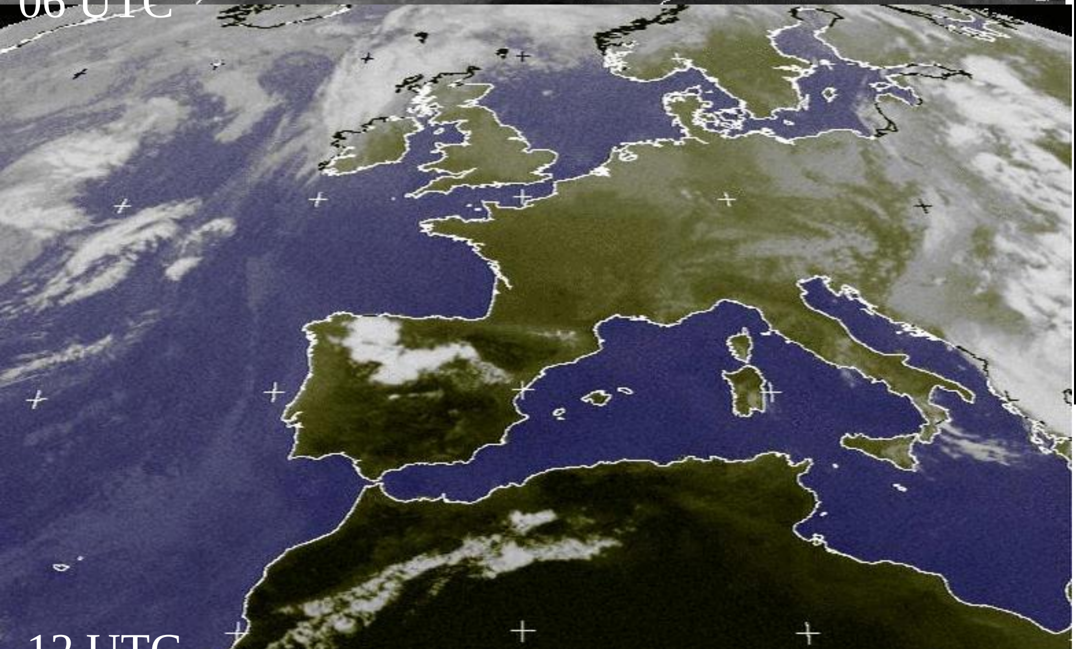


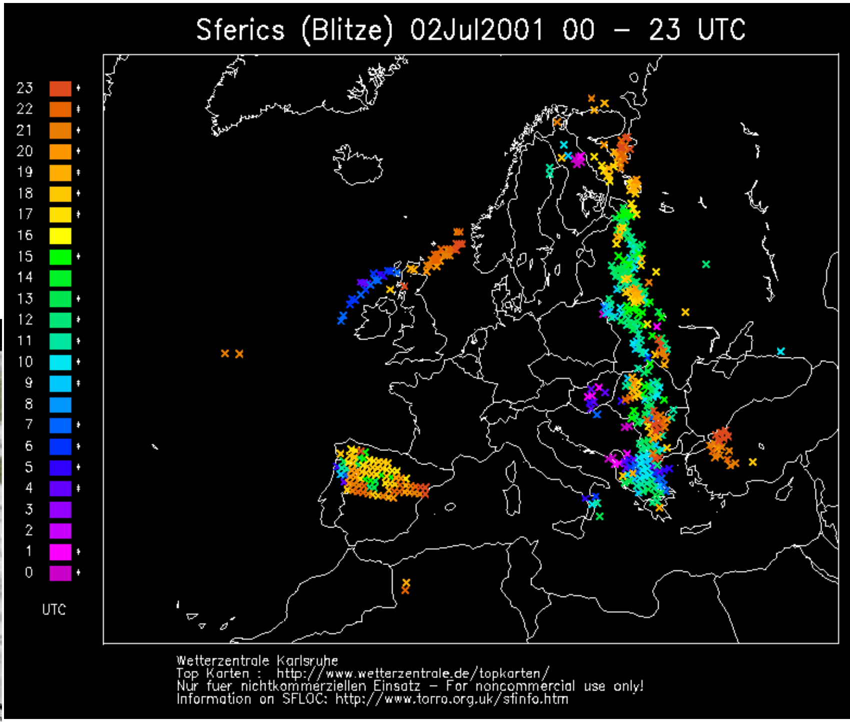
ECMWF

Examples of convective situations over Europe July 2001 –

Convection in cut-off low, partly orographically forced over Iberian Peninsula and frontal/prefrontal convection over Eastern Europe



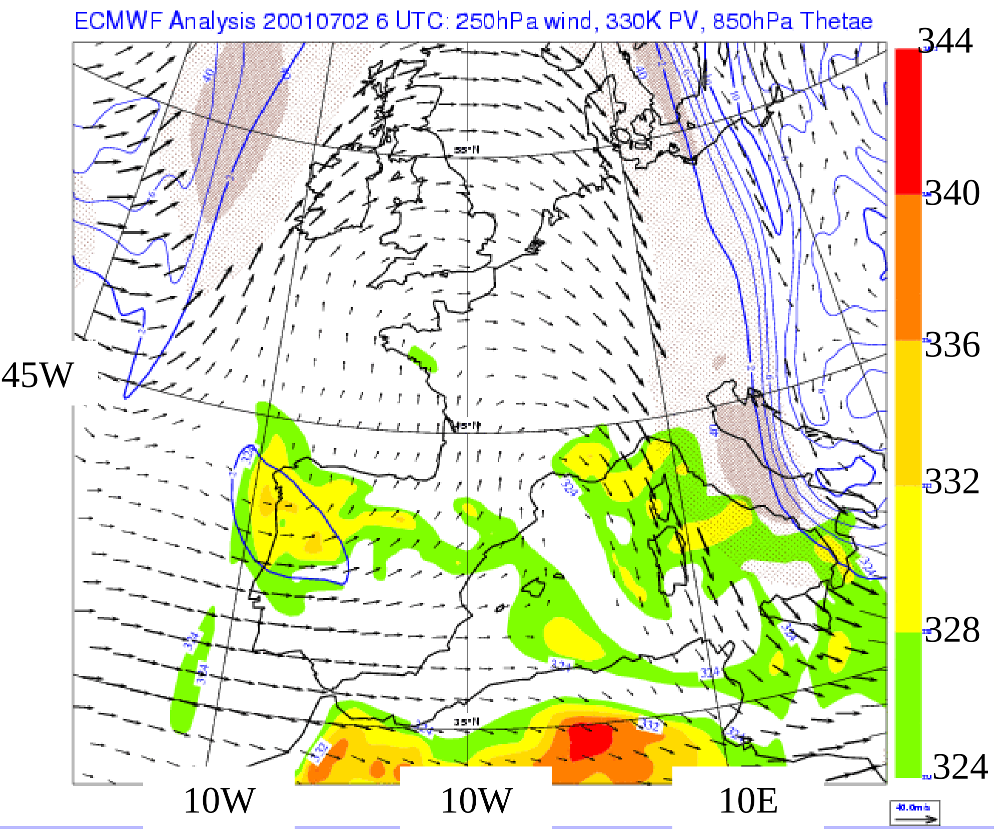




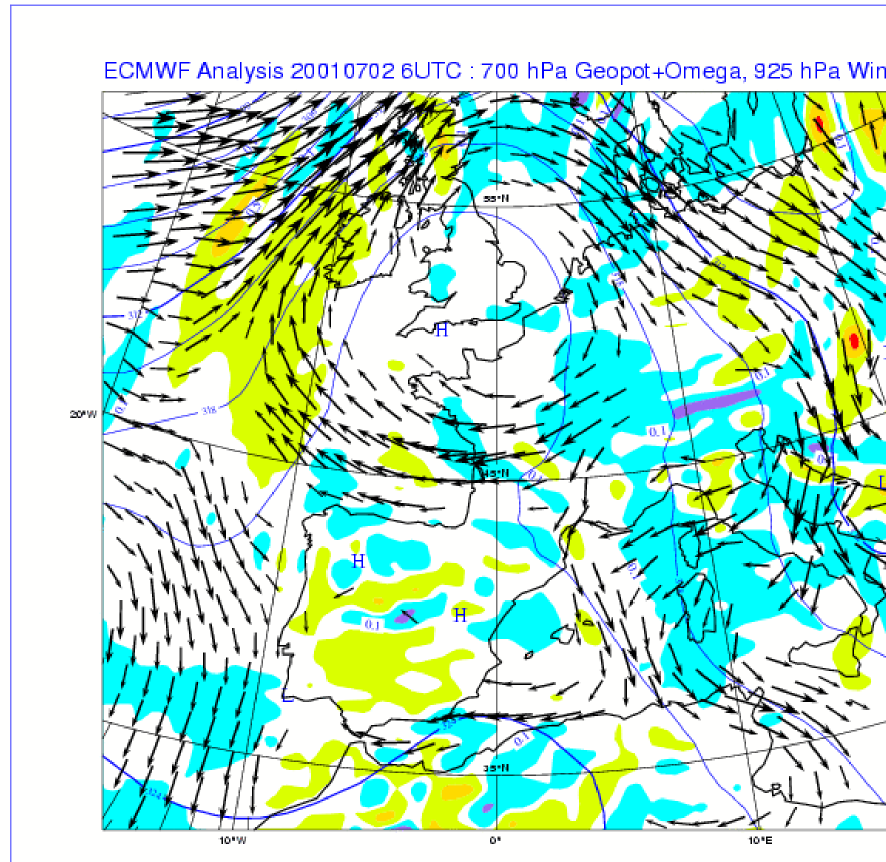
Examples of convective situations over Europe: 2 July 2001 – upper/low level Analysis

Convection in cut-off low, partly orographically forced over Iberian Peninsula and frontal/prefrontal convection over Eastern Europe

330 K PV (blue isolines), 250 hPa wind arrows and isotachs (grey shaded), 850 hPa Thetae (colour



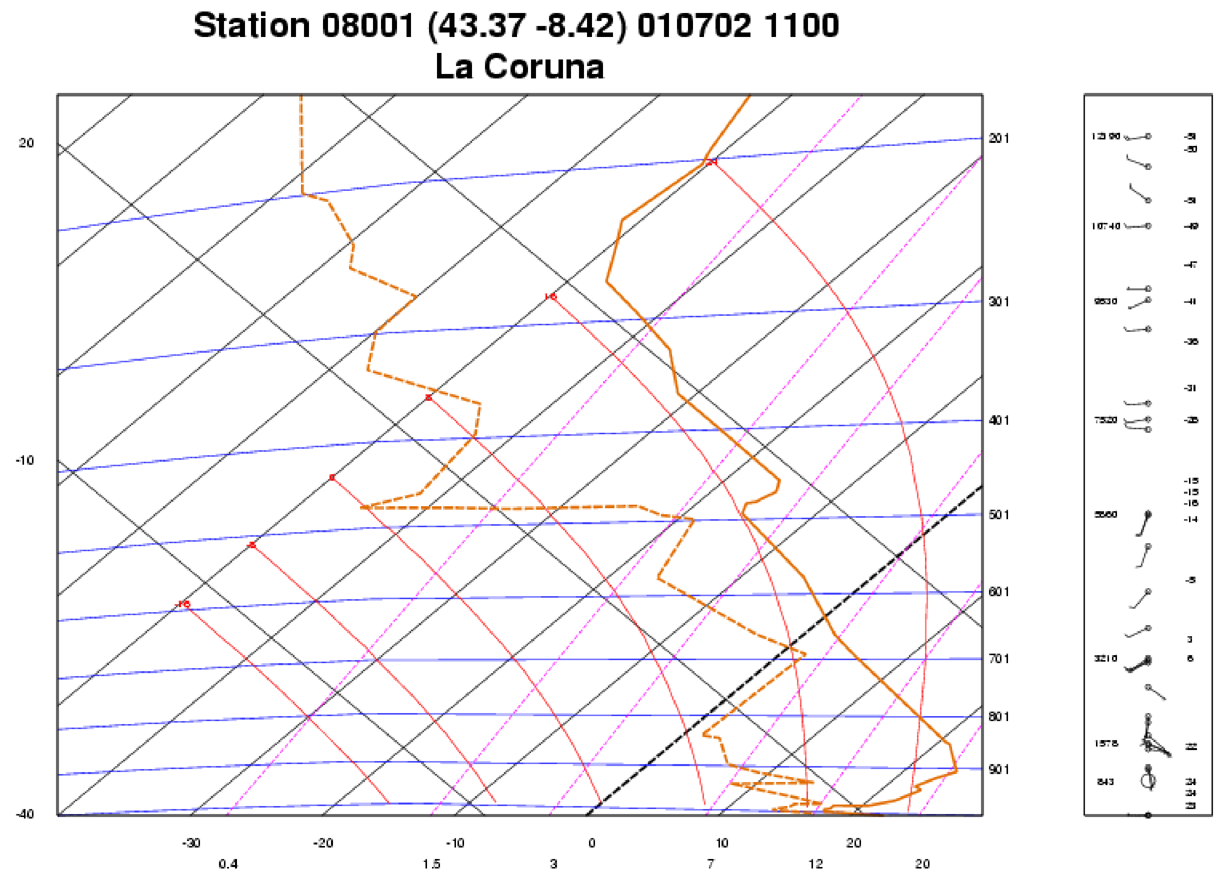
700 hPa Geopot (blue isolines), 700 hPa omega (colour shaded), and 925 hPa wind arrows



ECMWF

Examples of convective situations over Europe: 2 July 2001 – Sounding

Convection in cut-off low, partly orographically forced over Iberian Peninsula and frontal/prefrontal convection over Eastern Europe

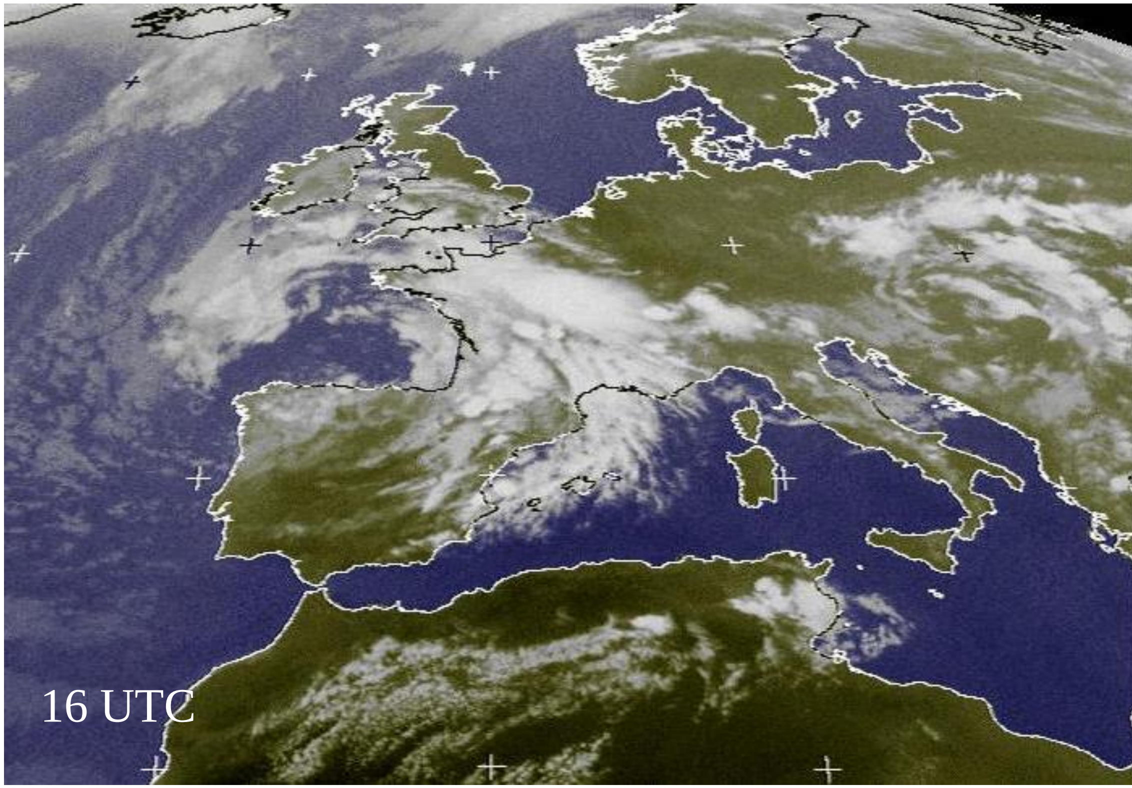


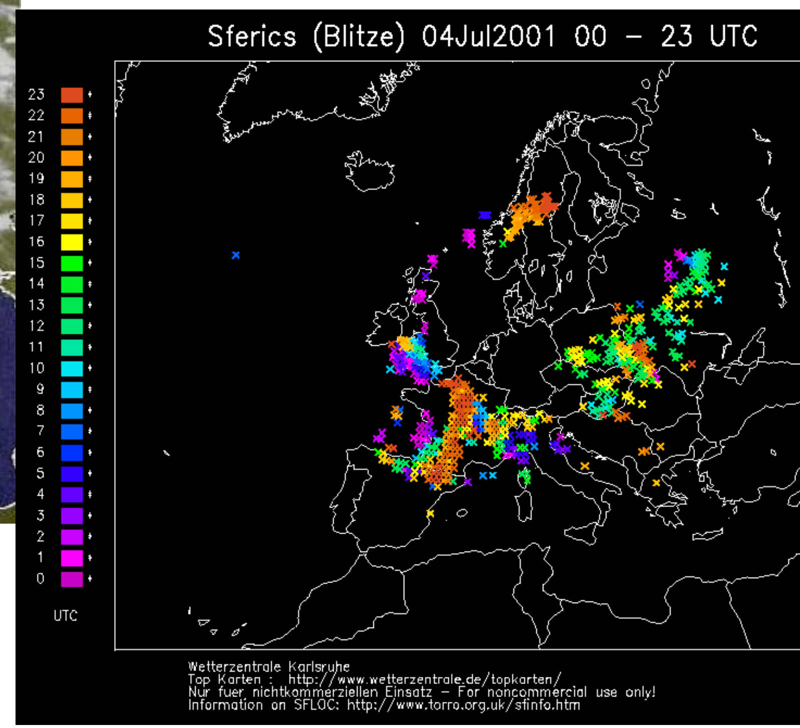
The Sounding for La Coruna (NW Spain close to coast) shows upper-level instability, but low-level inhibition that could be overcome by orographic uplifting or low-level heating of air mass further inside land

ECMWF

Examples of convective situations over Europe: 4 July 2001

Convection bringing hail in SW France, associated with strong uplift in Trough and high Thetae; typical SW-NE propagation of convective systems



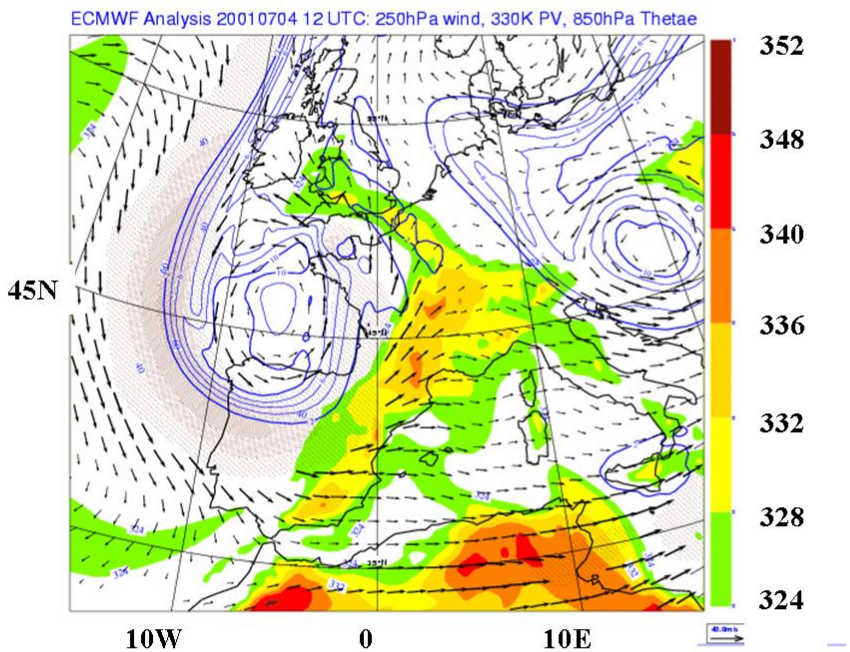


ECMWF

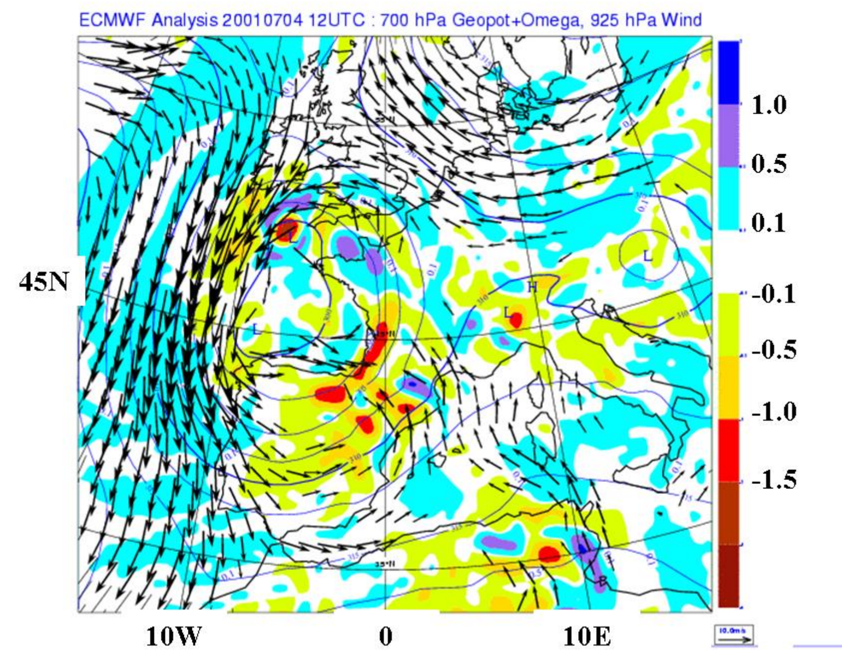
Examples of convective situations over Europe: 4 July 2001 – upper/low level Analysis

Convection over Western, Eastern Europe and Tunisia , bringing hail in SW France, associated with strong uplift in Trough and high Thetae

330 K PV (blue isolines), 250 hPa wind arrows and isotachs (grey shaded), 850 hPa Thetae (colour shaded)



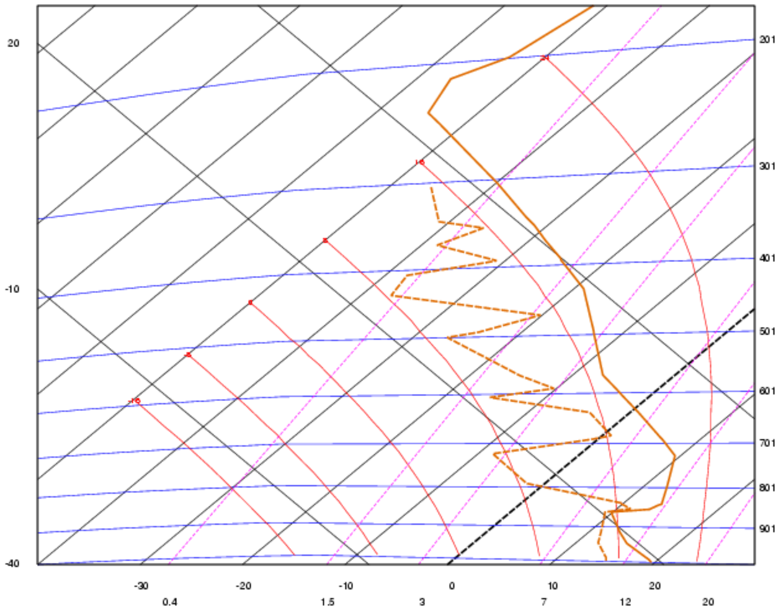
700 hPa Geopot (blue isolines), 700 hPa omega (colour shaded), and 925 hPa wind arrows



Examples of convective situations over Europe
4 July 2001 – soundings and moist adjustment

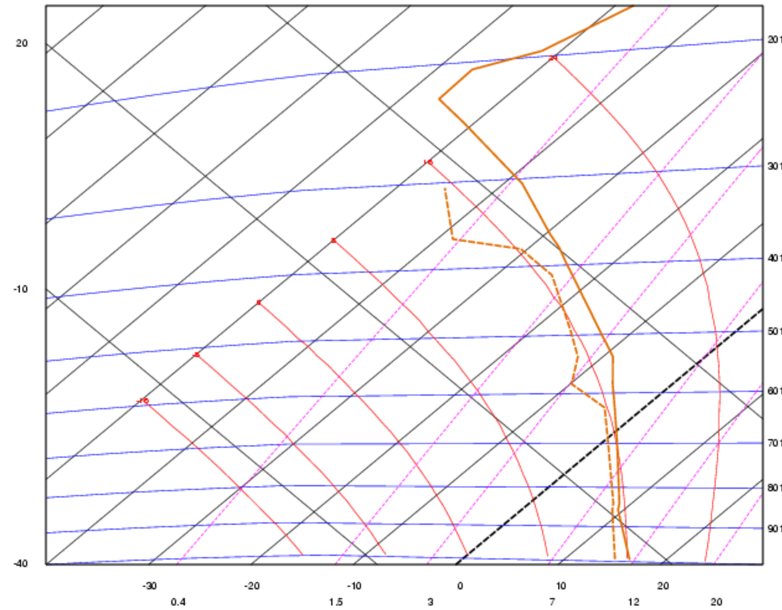
Convection bringing hail in SW France, associated with strong uplift in Trough and high Thetae

Station 07510 (44.83 -0.68) 010703 2300
Bordeaux Merignac



preconvective Sounding with strong inhibition layer and instability above 700 hPa

Station 07510 (44.83 -0.68) 010704 1100
Bordeaux Merignac



during convection significant cooling below 500 hPa: removed inhibition, quasi-moist adiabate, moistening through uplift