Numerical Weather Prediction
Parameterization of diabatic processes

Convection III: Forecasting and diagnostics

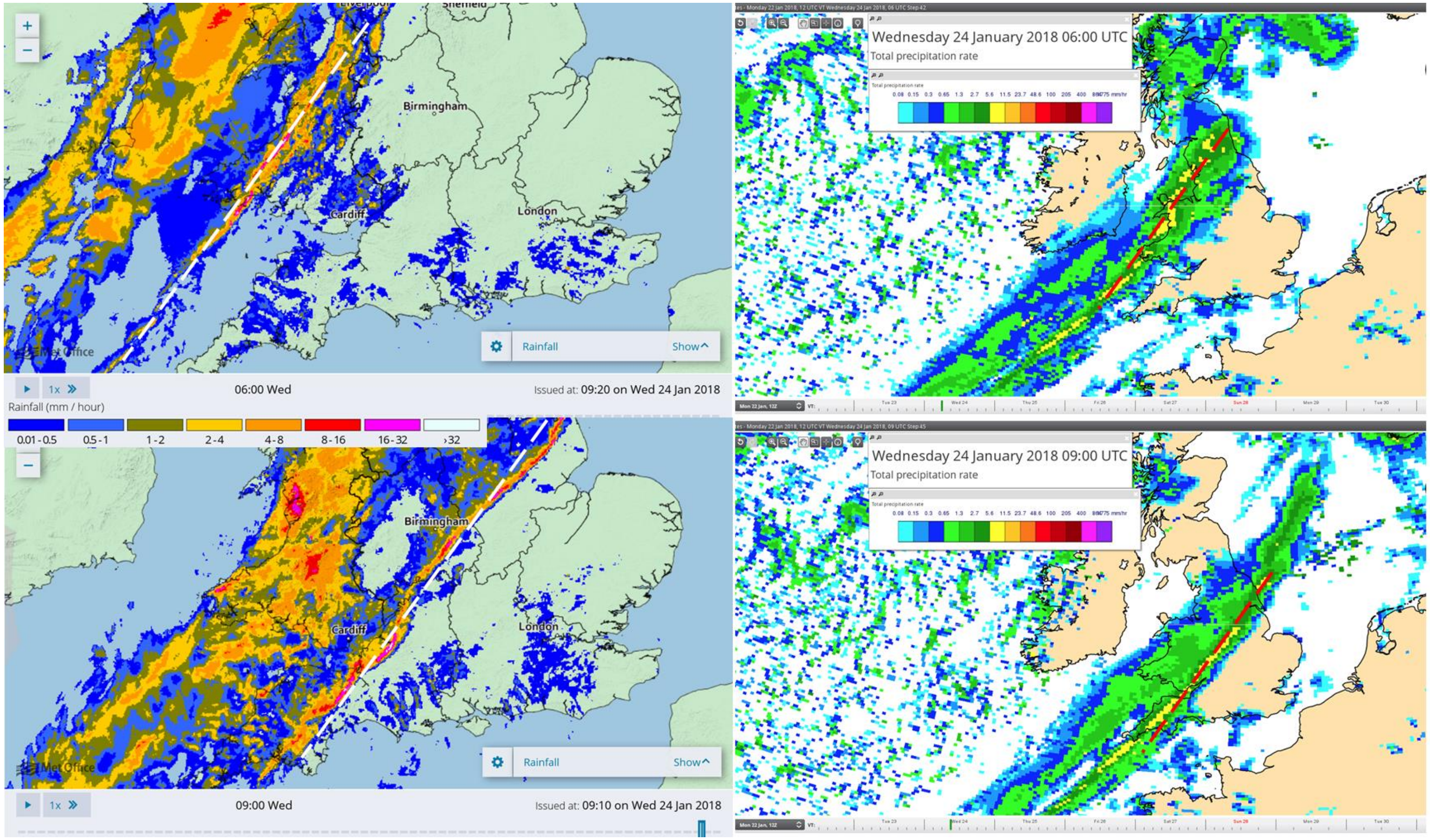
Peter Bechtold

ECMWF

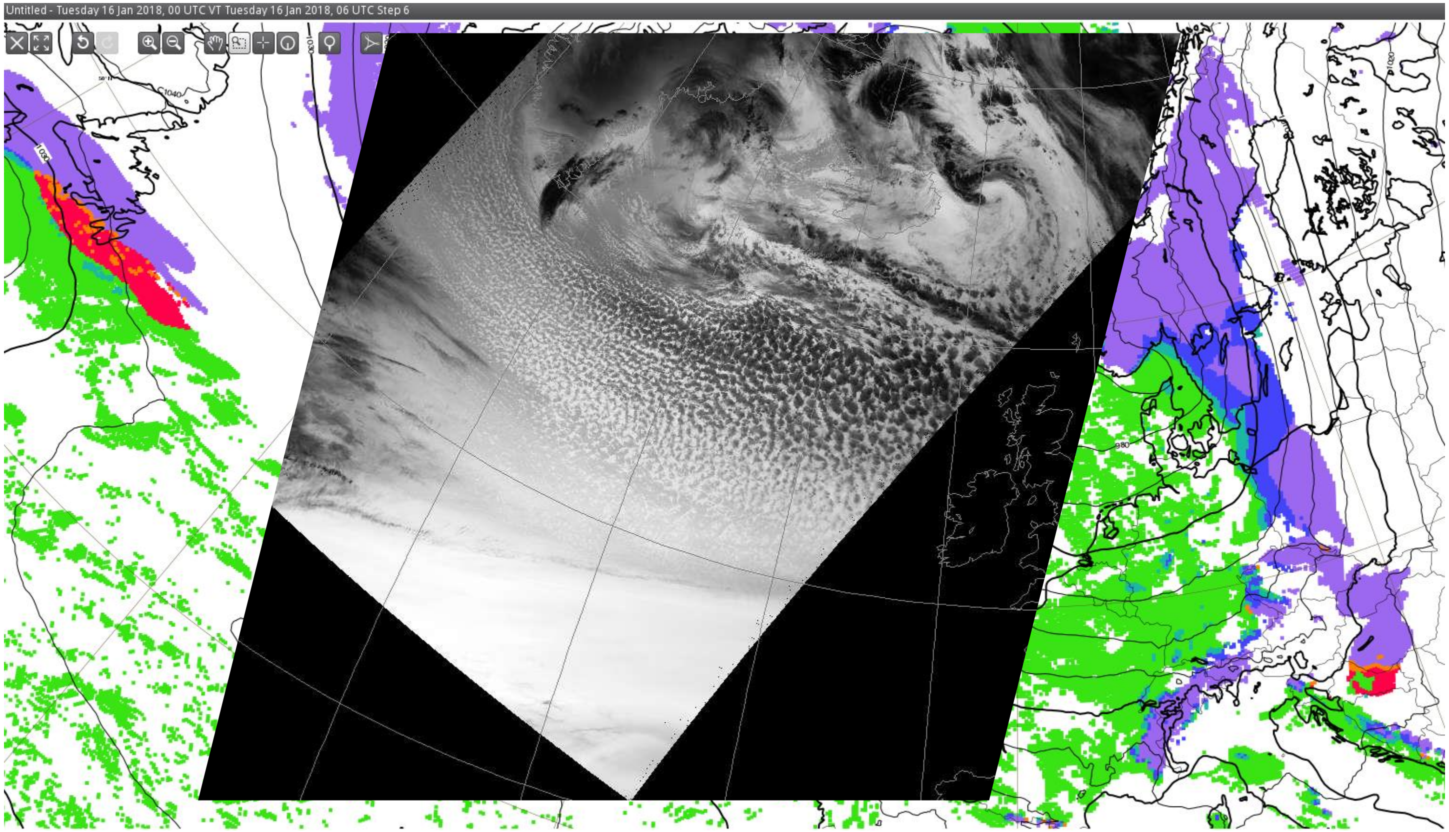
Outline

- Model sensitivity to convective parametrization: analysis increments, heating rates, model biases, diurnal cycle, advection of showers
- Ensemble representation and convection-dynamics coupling
- Convective products and forecasting of mesoscale convective systems

Realism of convective and stratiform precipitation



Realism of convective and stratiform precipitation type



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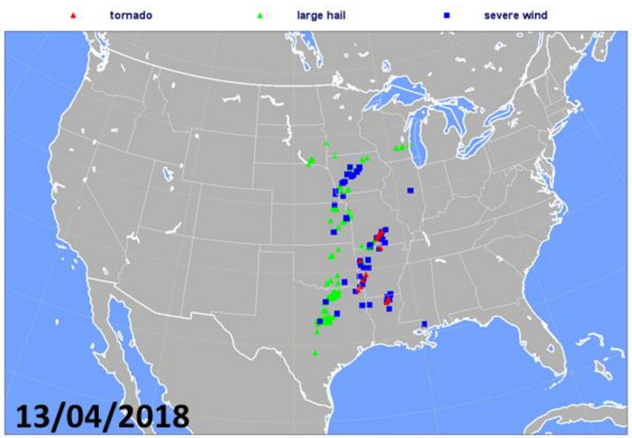
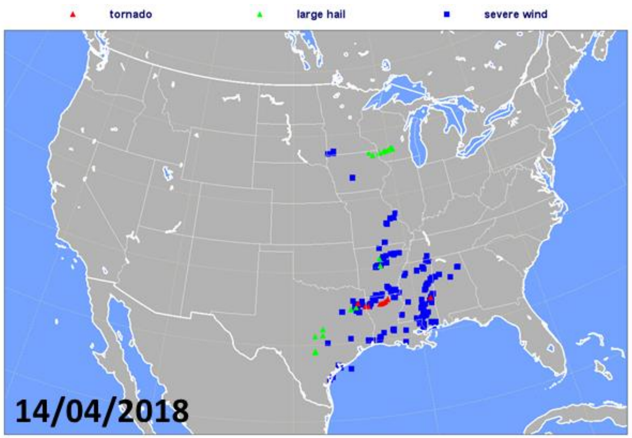
Not always good: errors in intense continental convection can strongly effect upper-level flow (vorticity) and therefore affect the downstream error propagation

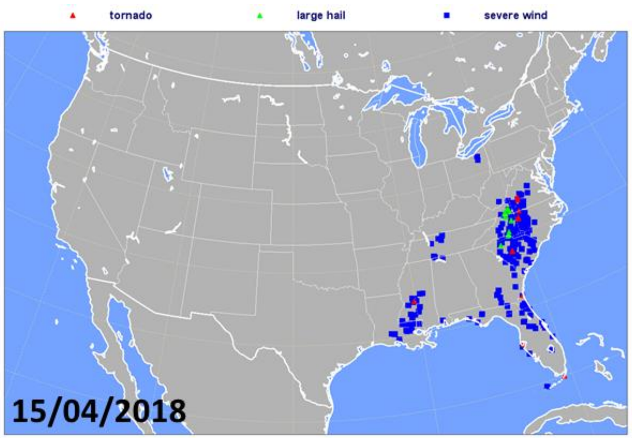
- Under-representation of convection (stabilisation) can lead to very large grid-scale precipitation events with overestimation of upper-level divergent motions =>convergent increments
- Underestimation of convection due to errors in large-scale forcing and convection scheme can lead to an underestimation of divergent outflow and the miss of jets on the downshear side

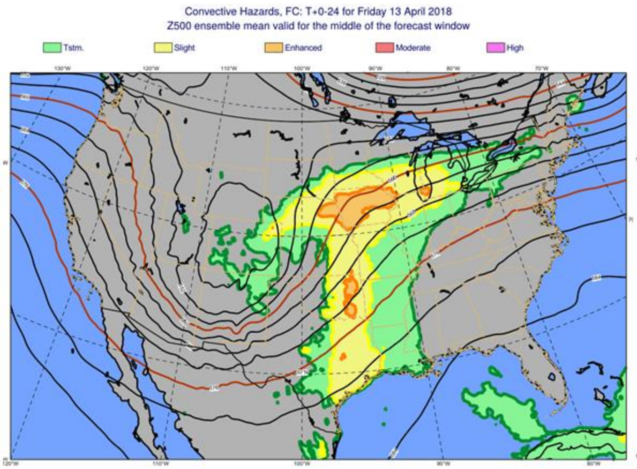
For more information, see also Rodwell et al. 2013, BAMS 94
ECMWF Newsletter No 98 Summer 2003, No 114 Winter 2007/8, No 131 Spring 2012, No 136 Summer 2013

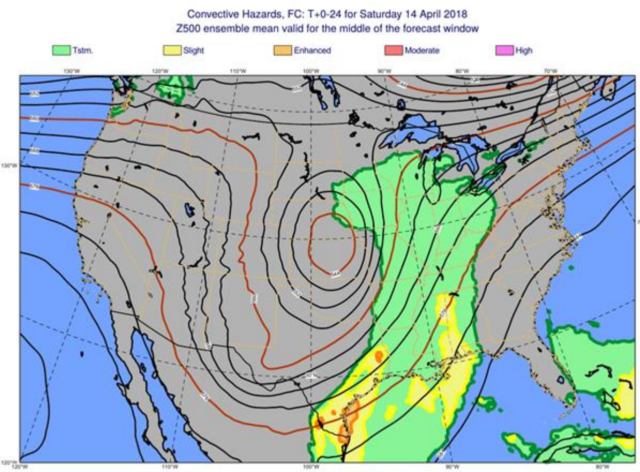
Spring convection US

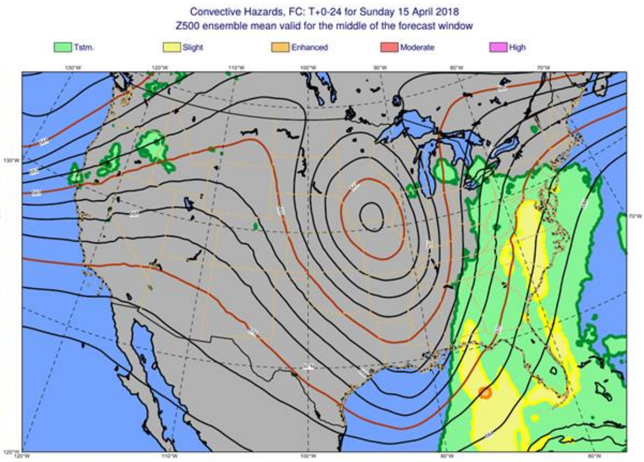






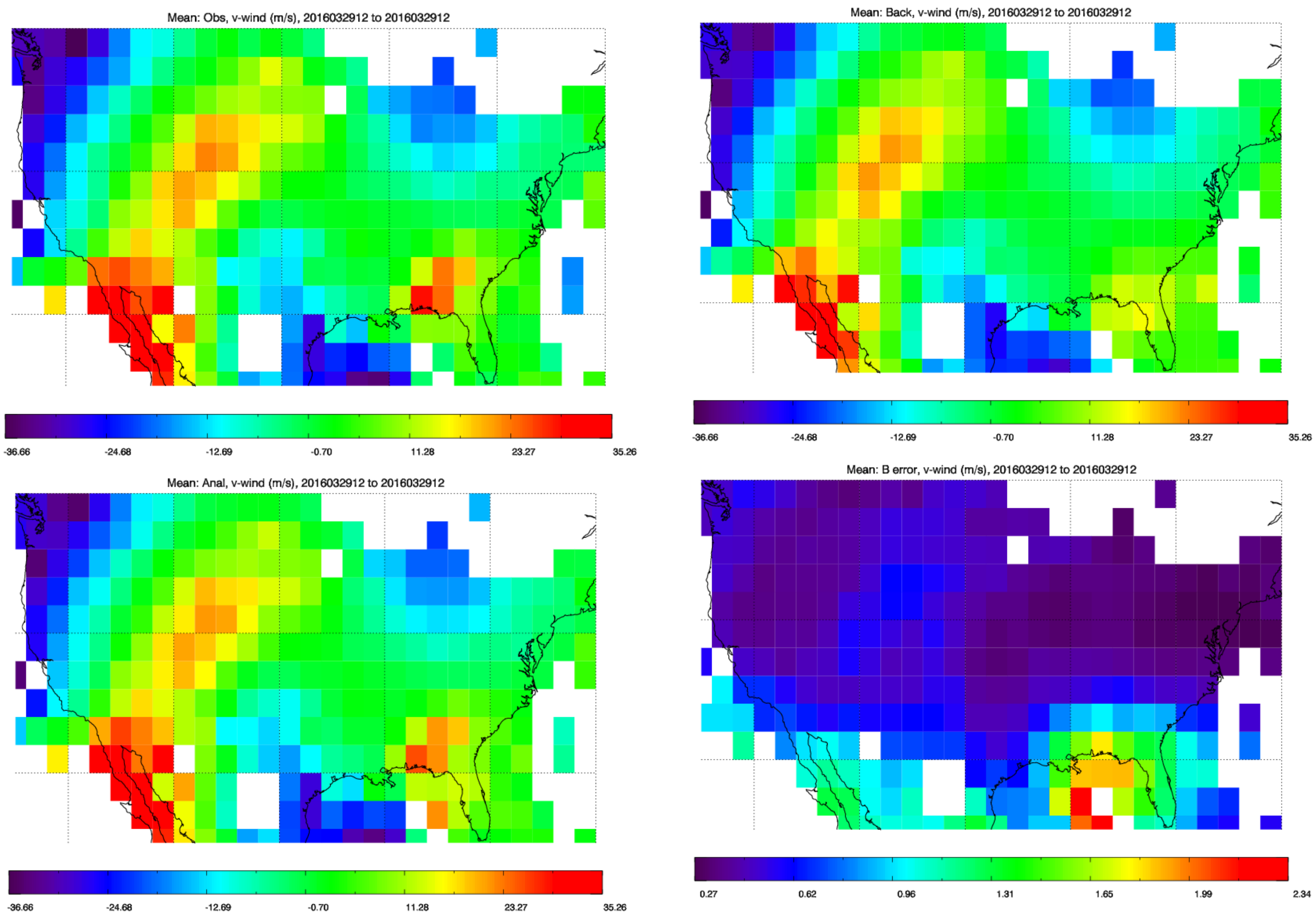






Courtesy Ivan Tsonevsky

Data assimilation: example of "convective" V-wind Obs&first guess



4DVarAnalysis (trajectory+TL evolved increment) able to correct the background (lack of convection) due to available aircraft Obs and background error statistics courtesy Mike Rennie

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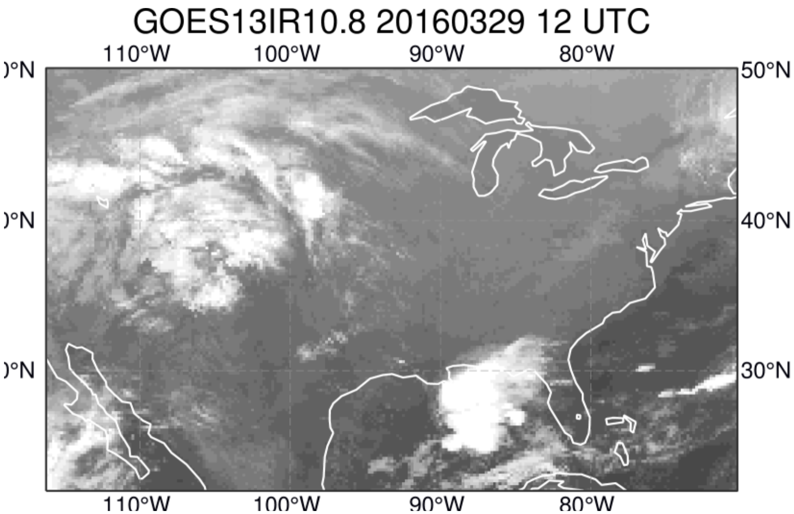
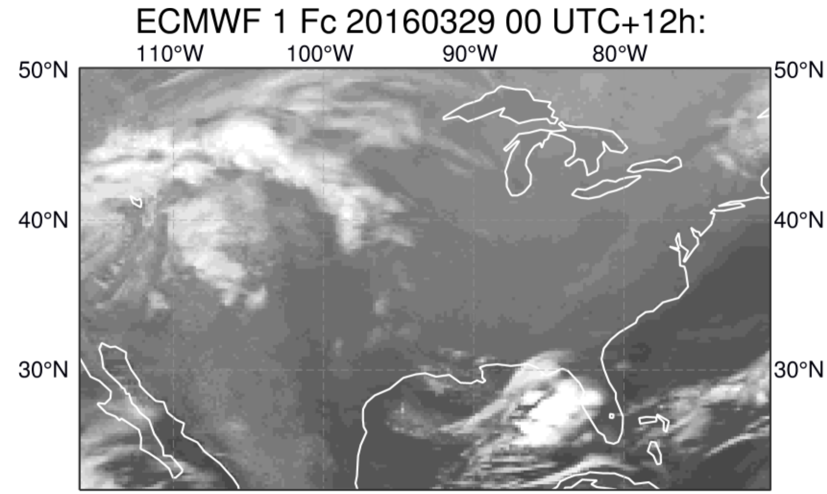
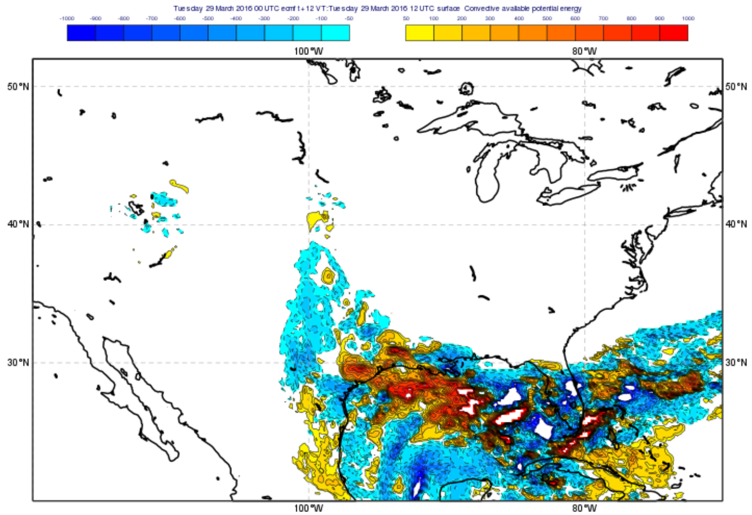
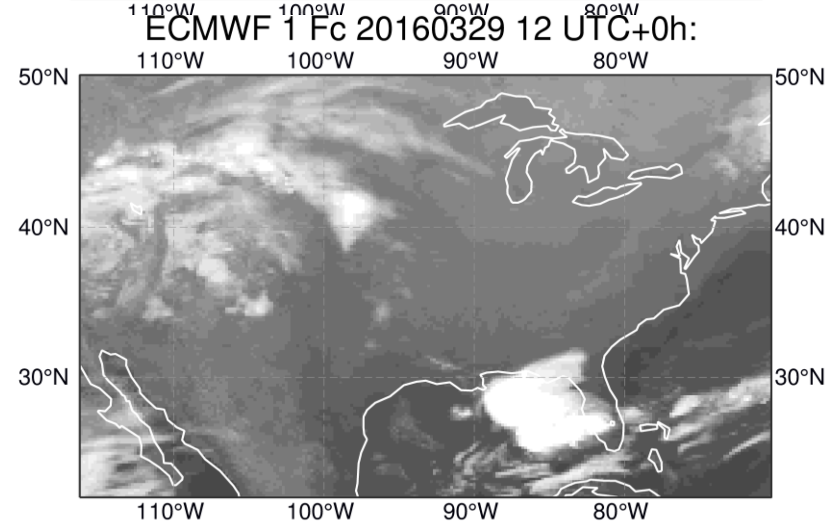
Data assimilation: “convective” analysis increments









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

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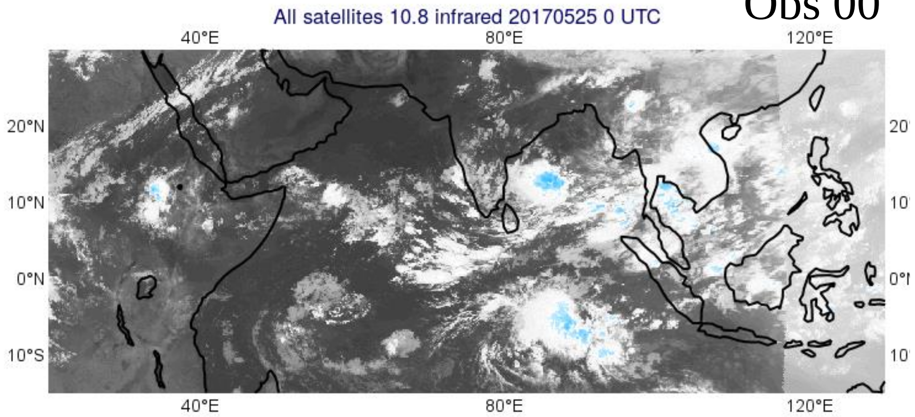
Tropical Forecast Biases and Physics

Forecasts of tropical atmosphere are naturally very sensitive to any changes in the convective heating rates

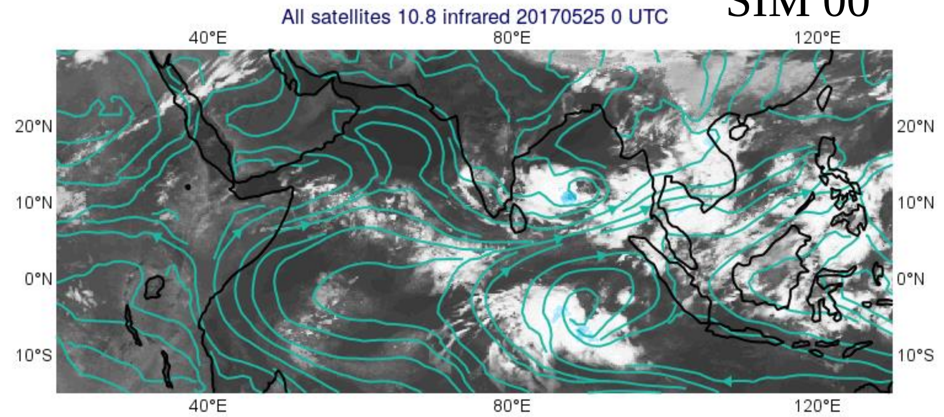
- Tropical variability (waves, cyclones and Madden-Julian oscillation) are strongly affected by the convective heating
- The convergence/precipitation in the ITCZ and Headly/Walker circulations strongly affected by the deep convection, but equivalent important is the representation of shallow convection in the subtropics determining the moist low-level flow in the Tropics
- 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

Large-scale waves and diurnal cycle

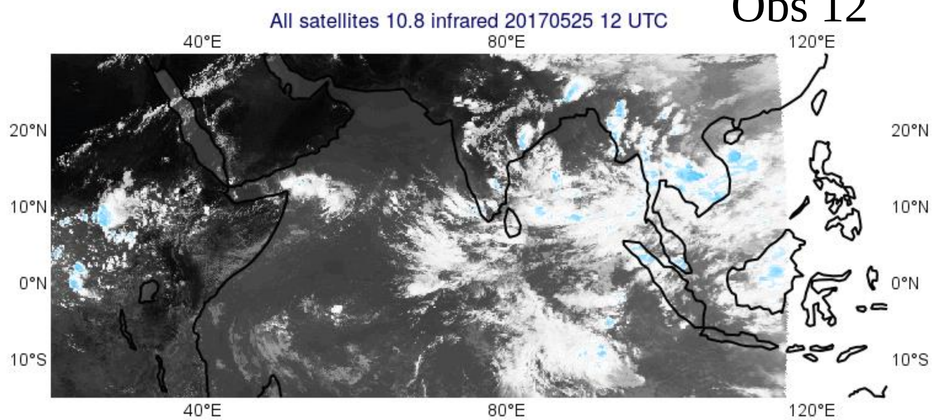
Obs 00



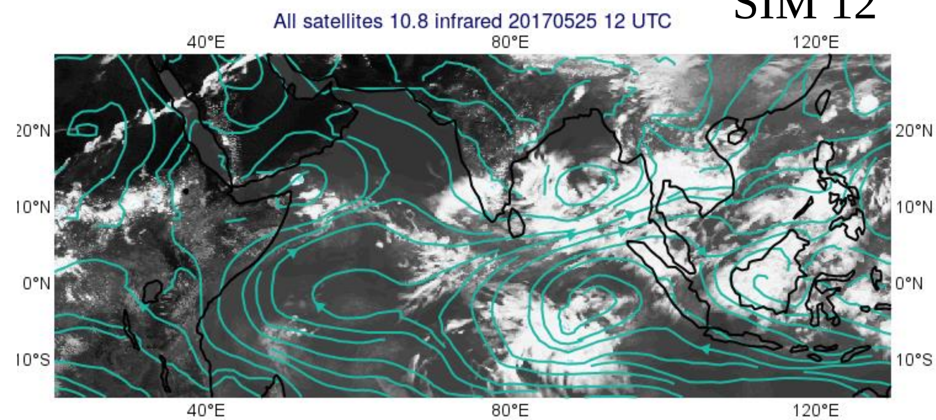
SIM 00



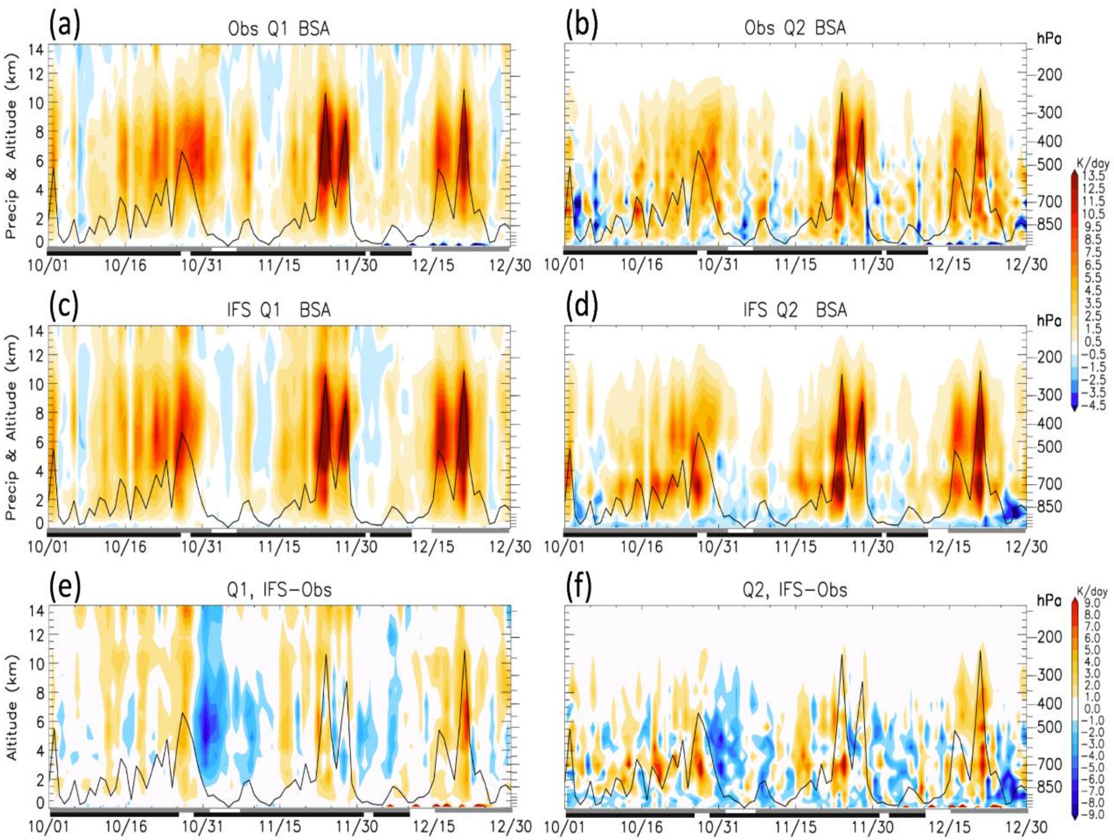
Obs 12

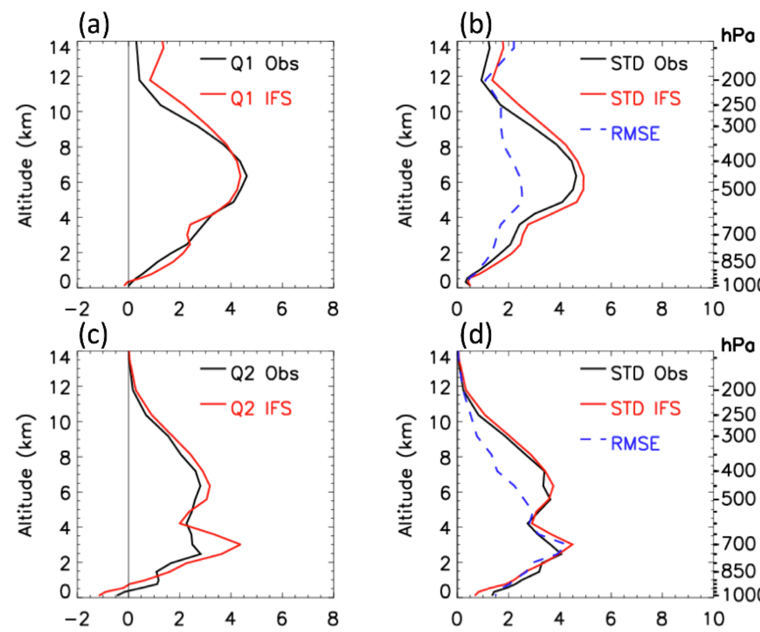


SIM 12



Heating rates from DYNAMO: getting it right and importance of mixed phase –melting level





J.-E Kim et al. 2017, JAS

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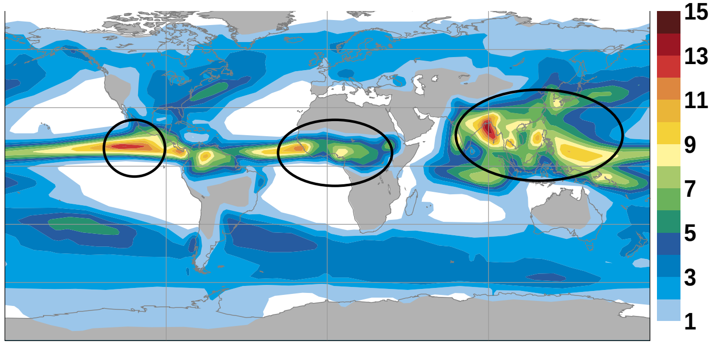
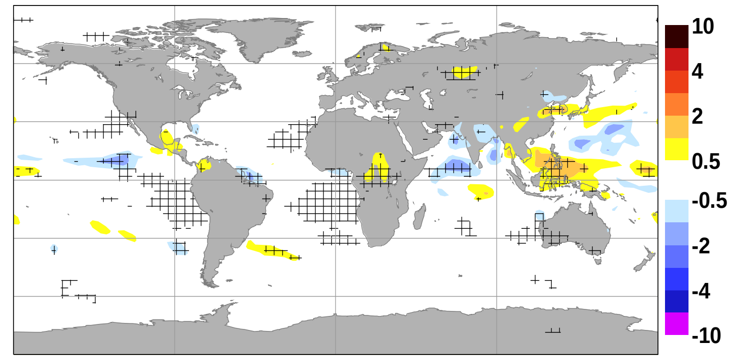
Precipitation JJA: Sensitivity to Model Formulation

Seasonal integrations

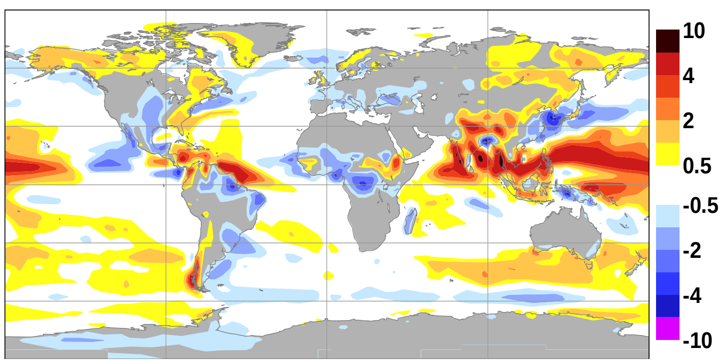
GPCP JJA 1990-2006



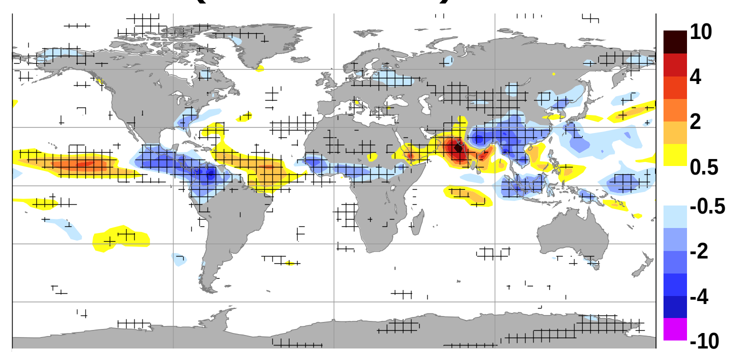
33R1(old vdiff)-33R1



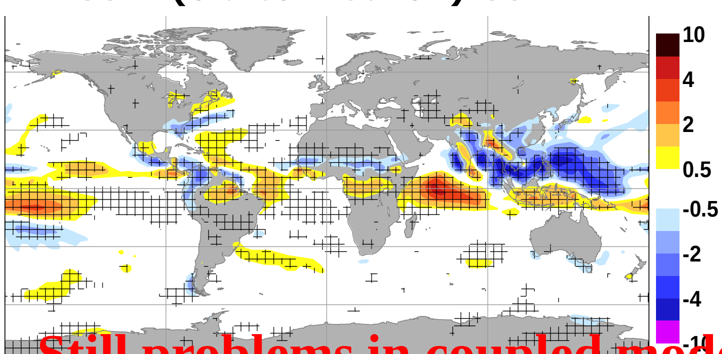
33R1-GPCP



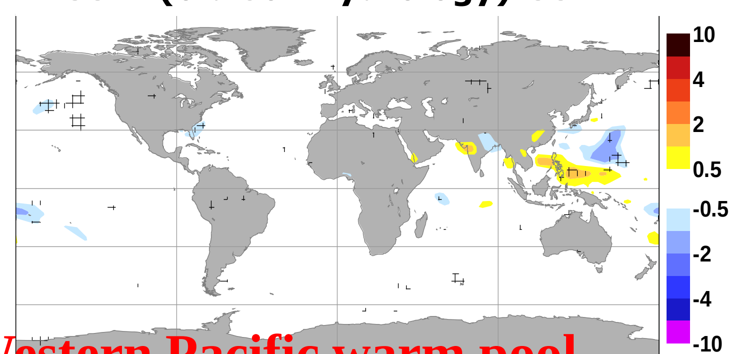
33R1(old radiation)-33R1



33R1(old convection)-33R1



33R1(old soil hydrology)-33R1



Still problems in coupled mode in Western Pacific warm pool

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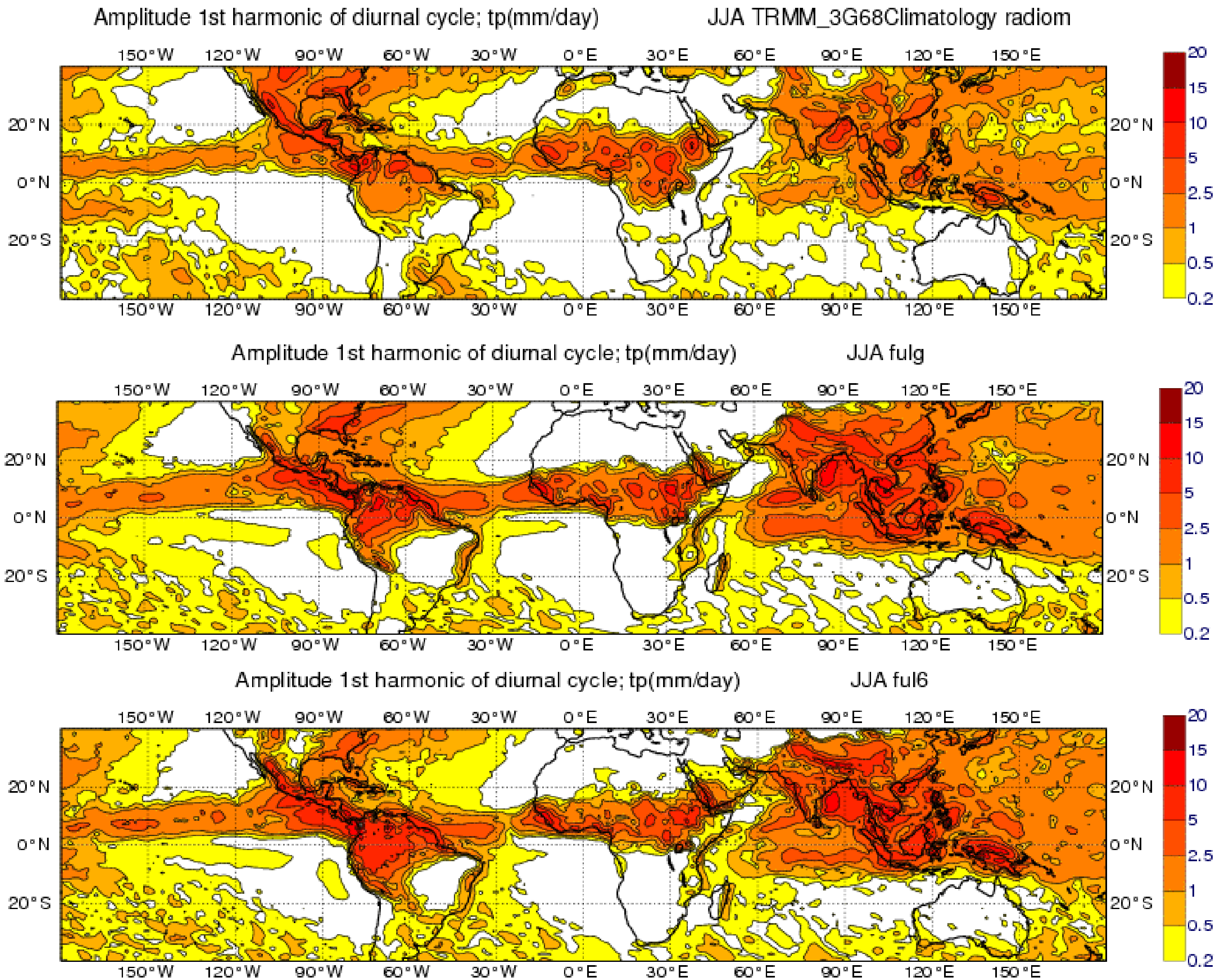
Diurnal cycle of Precipitation JJA: Amplitude (mm/d)

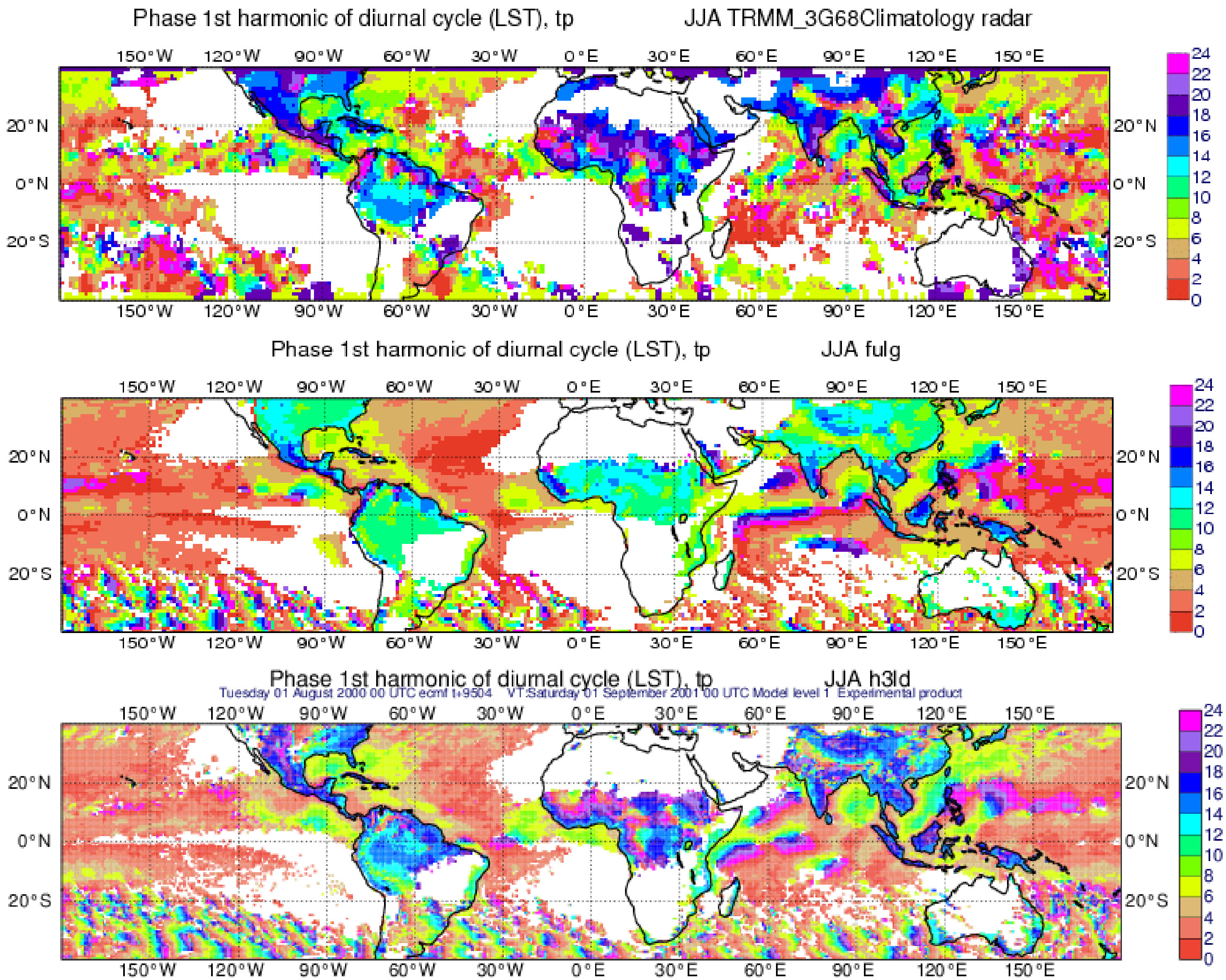


TRMM

until November 2013

Exp= Cy40r1

Diurnal cycle of Precipitation JJA: Phase (LST) was a remaining problem until recently



TRMM

until November 2013

Cy46r1 2019

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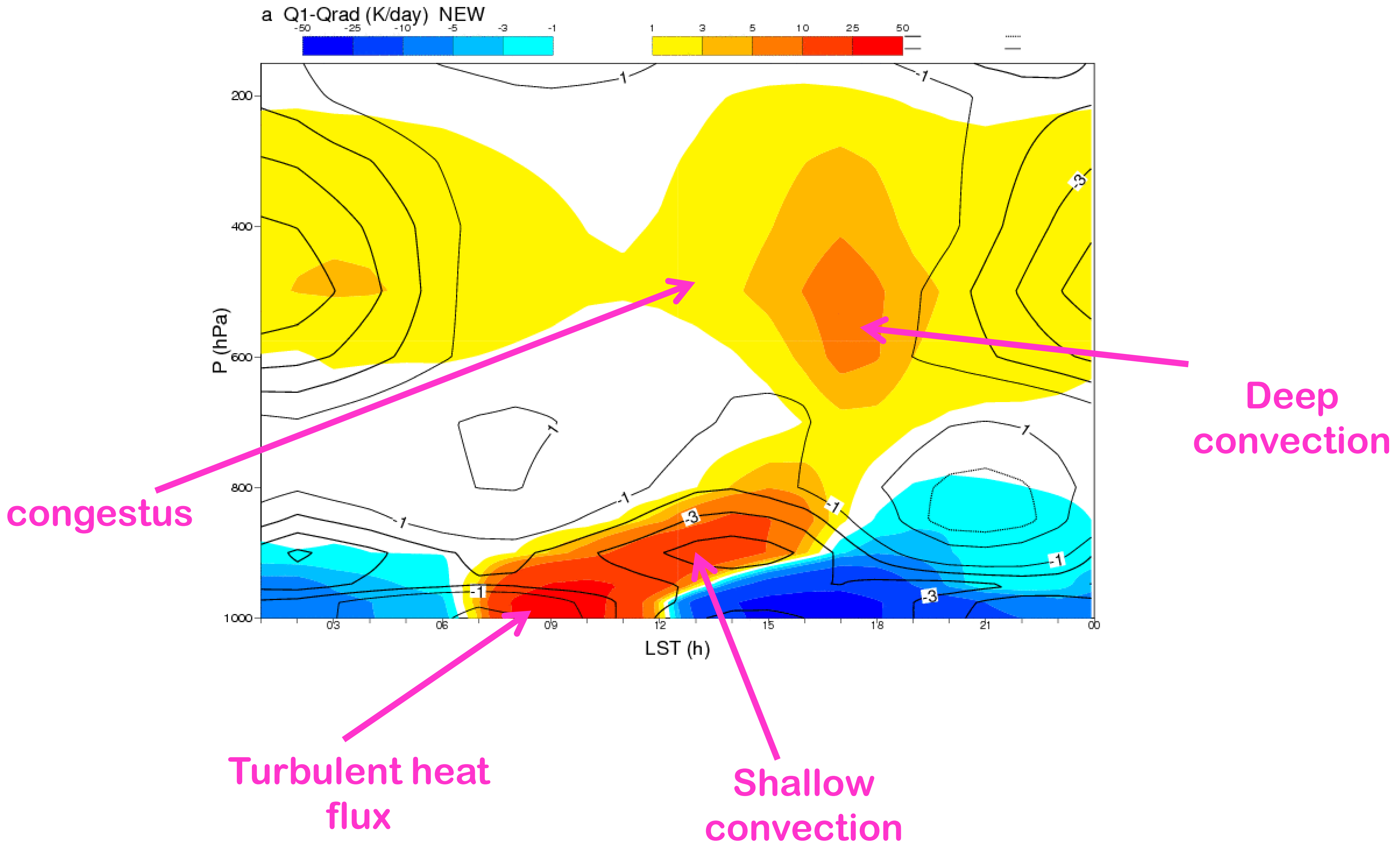
Diurnal evolution of total heating profile minus radiation



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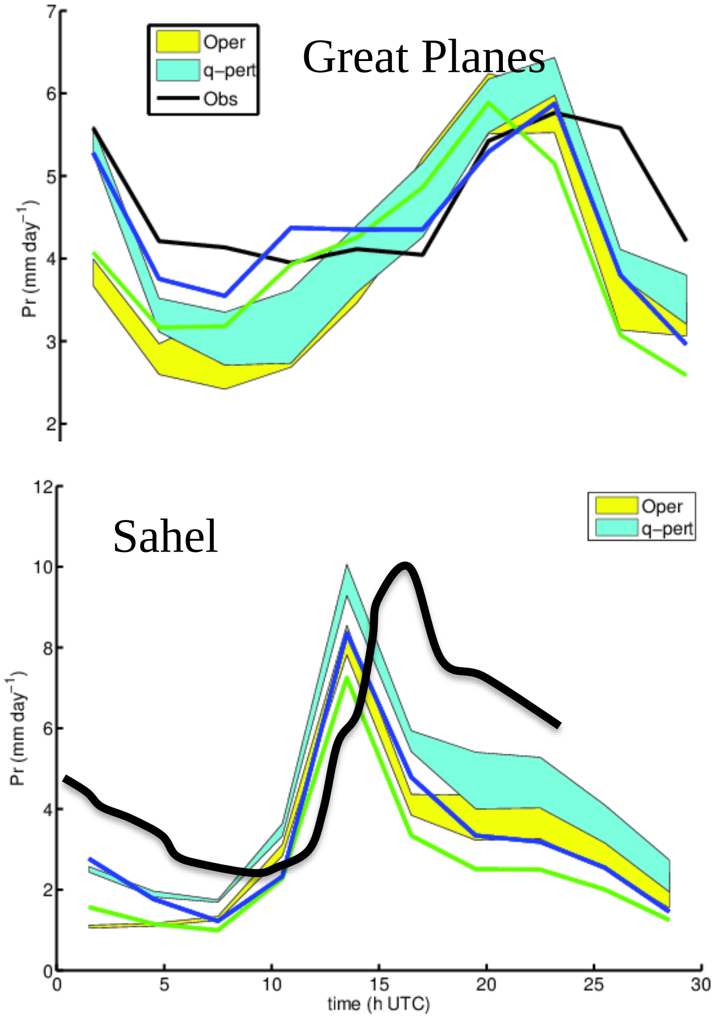
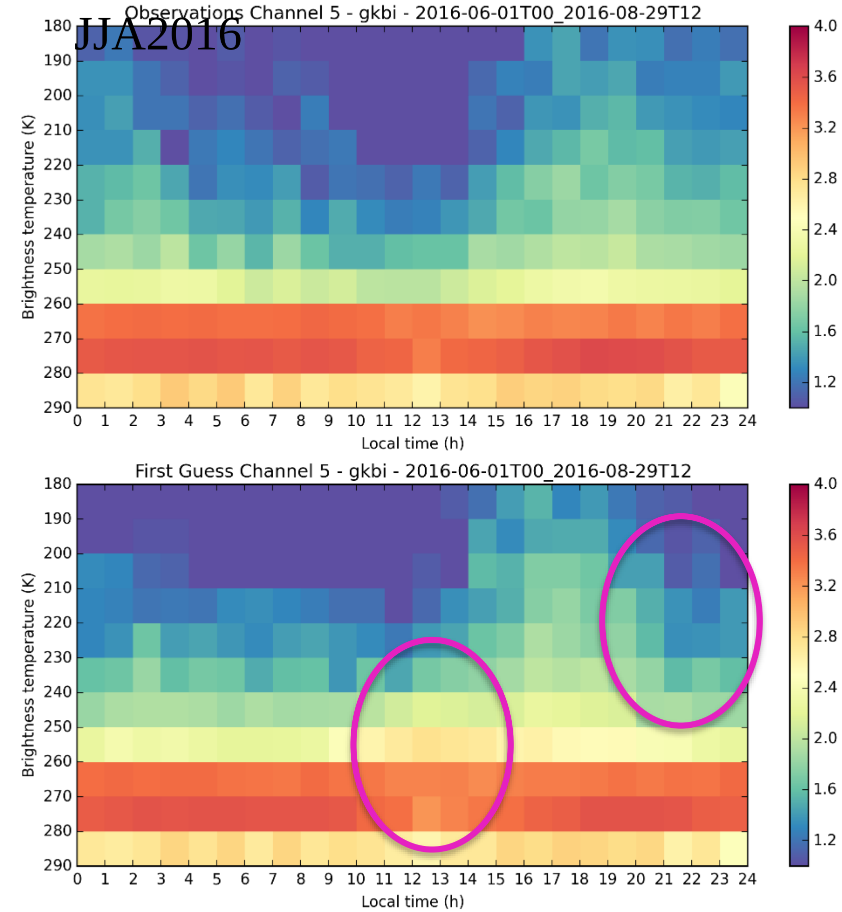
Looking closer: Major bias in night-time convection over land and uncertainty (Sahel) still exists



SSMIS channel 6 Obs and First Guess JJA2016



courtesy A. Geer

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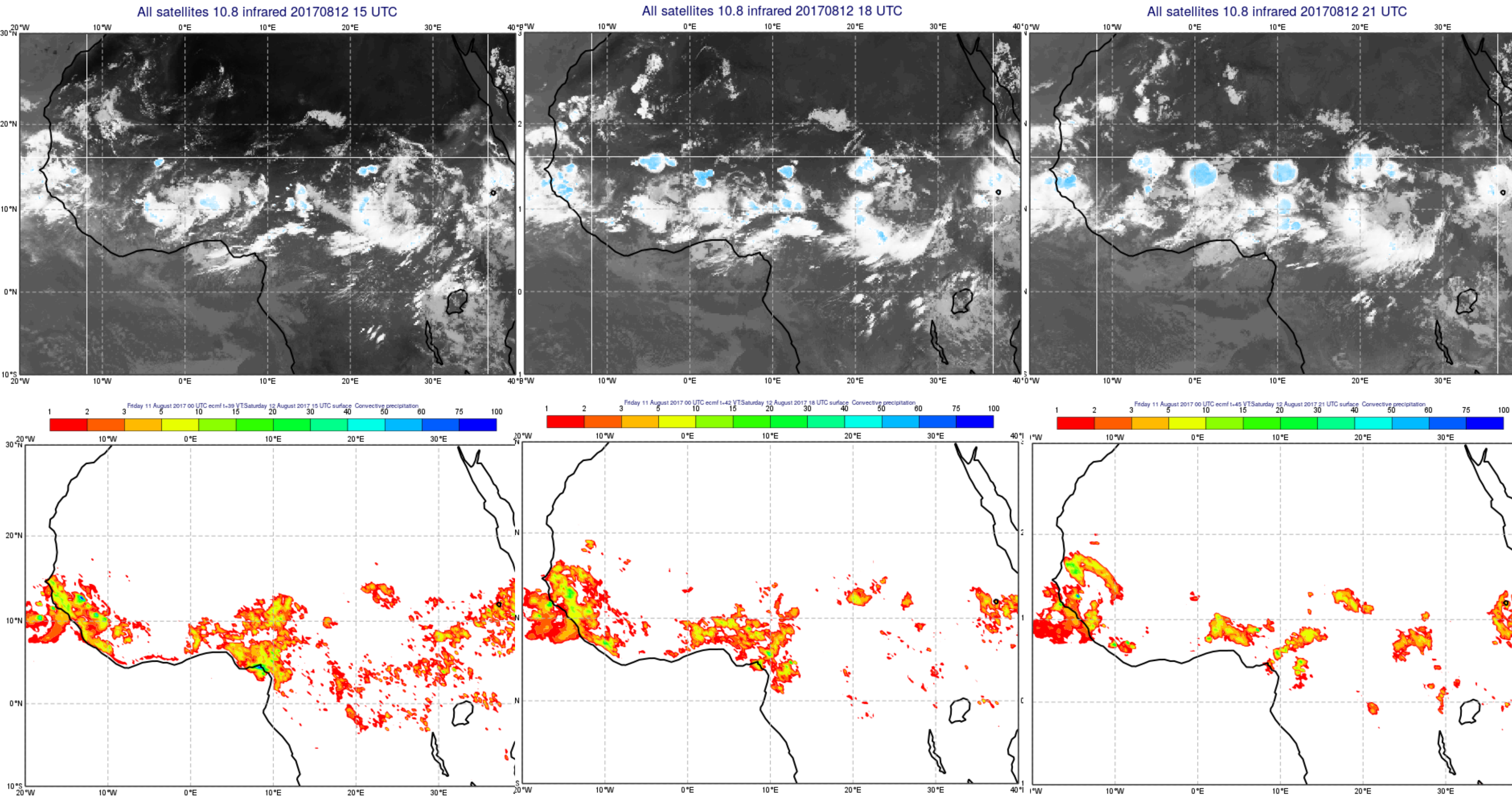
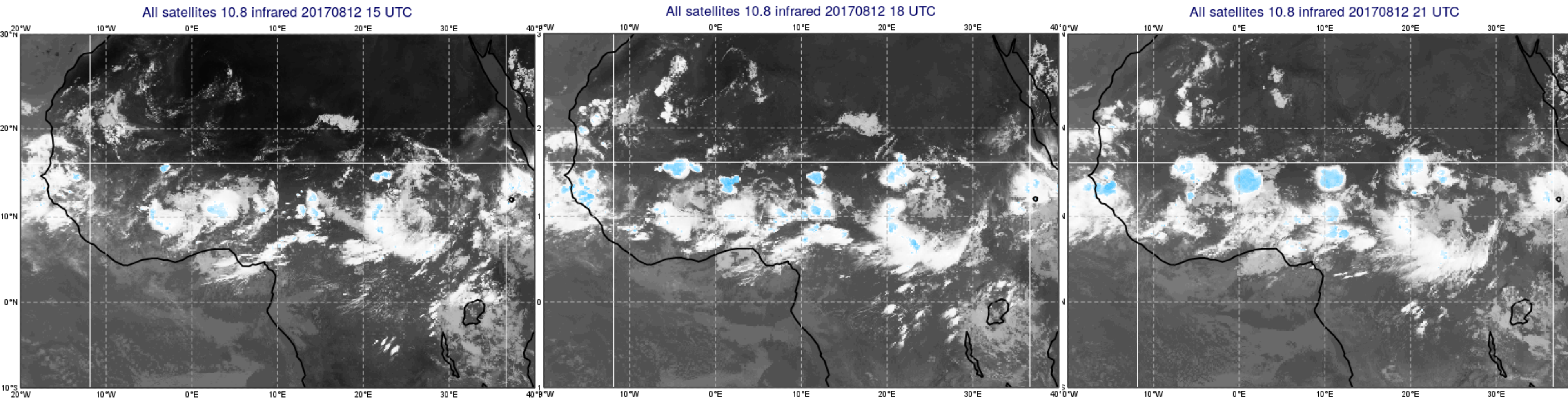
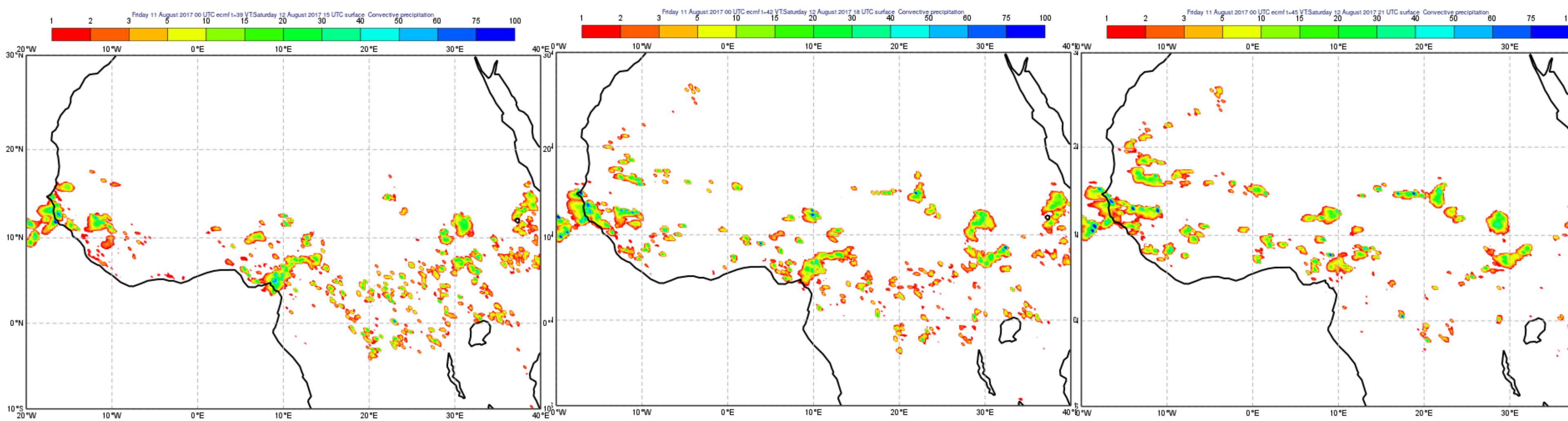


All satellites 10.8 infrared 20170812 15 UTC
All satellites 10.8 infrared 20170812 18 UTC
All satellites 10.8 infrared 20170812 21 UTC

17

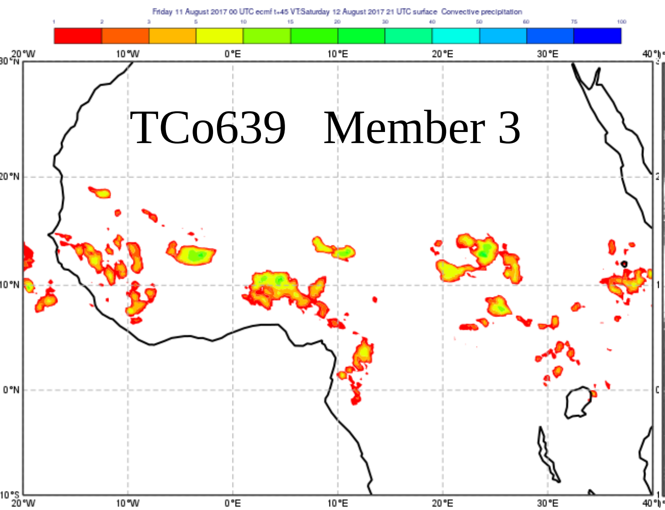
TCo1999

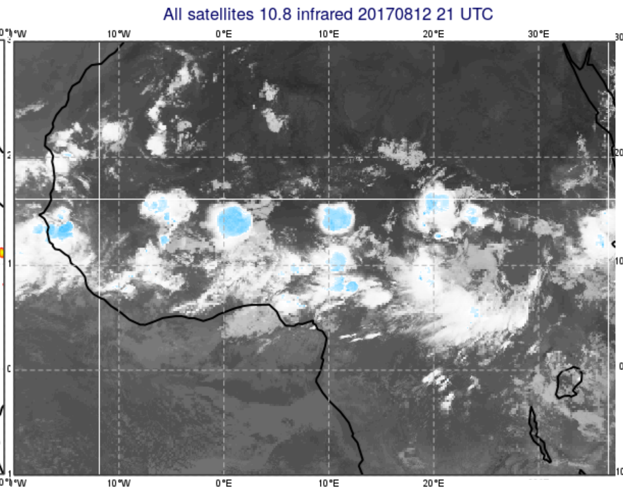


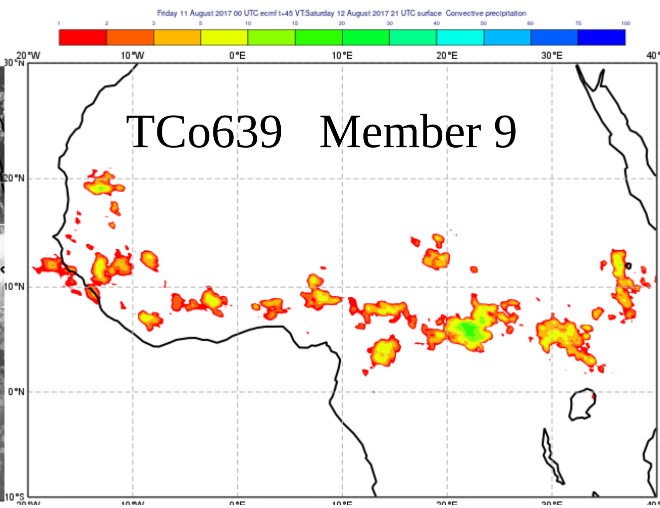


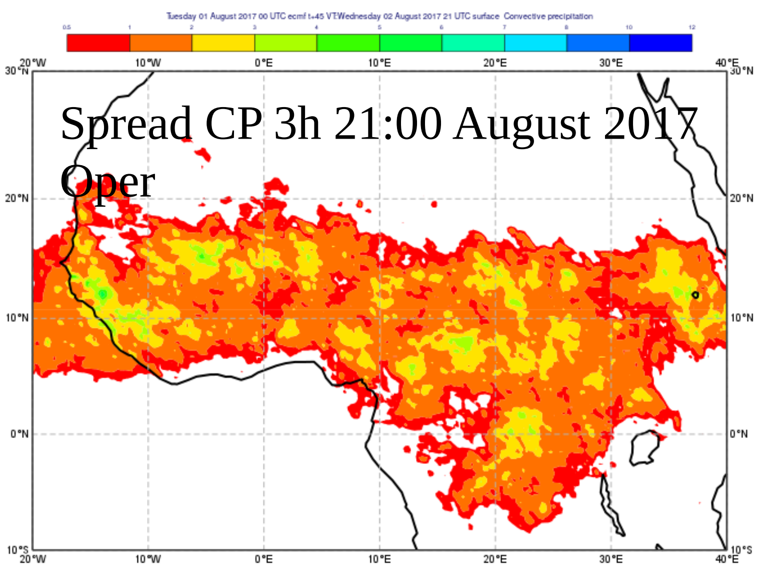
18

TCo1999 no deep

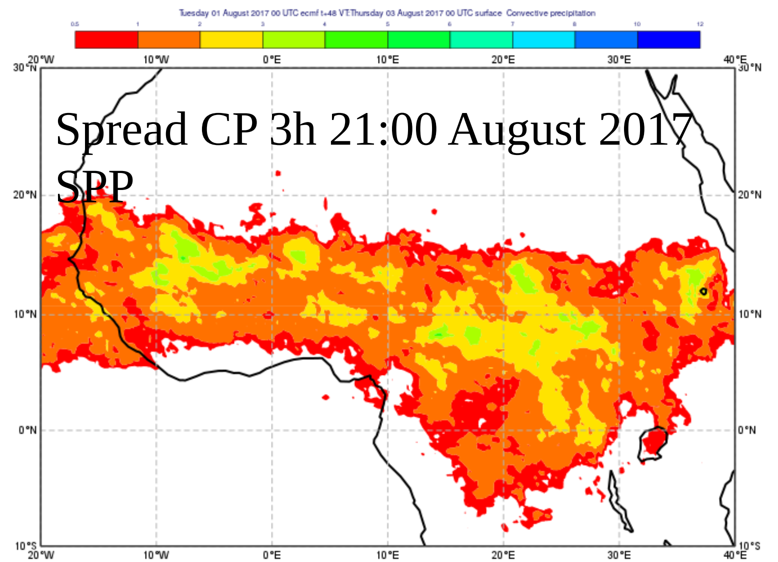








SPPT: Total physics tendency perturbation



SPP: Convective parameter perturbation

Convection-Dynamics: Mass flux (A)dvection to be done by explicit dynamics

with **Sylvie Malardel**, earlier work by N. Wedi; Kuell, A. Gassmann and Bott 2007

$$\left.\frac{\partial \overline{\psi}}{\partial t}\right|_{conv} = g\frac{\partial}{\partial p}\left[M^u(\psi^u - \overline{\psi}) + M^d(\psi^d - \overline{\psi})\right] + S; \quad \overline{M} = M^u + M^d + M^{env} = 0$$

$$\left.\frac{\partial \overline{\psi}}{\partial t}\right|_{conv} = g\frac{\partial}{\partial p}\left[M^u\psi^u + M^d\psi^d\right] - g\frac{\partial(M^u + M^d)}{\partial p}\overline{\psi} + S + A$$

$$A = -g(M^u + M^d)\frac{\partial \overline{\psi}}{\partial p} = \omega\frac{\partial \overline{\psi}}{\partial p}; \quad Div[s^{-1}] = -g\frac{\Delta M}{\Delta p}$$

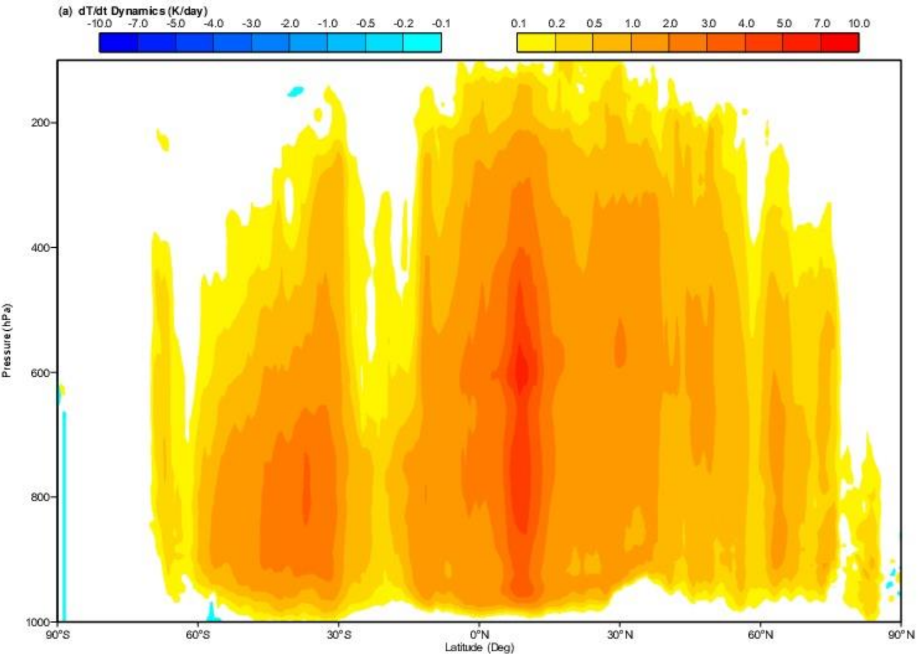
$$\Delta p = p_{k+1/2} - p_{k-1/2}$$

Difficulty: (1) Term A computed differently in Physics and SL dynamics: non-conservation (abandoning flux form, different time levels)

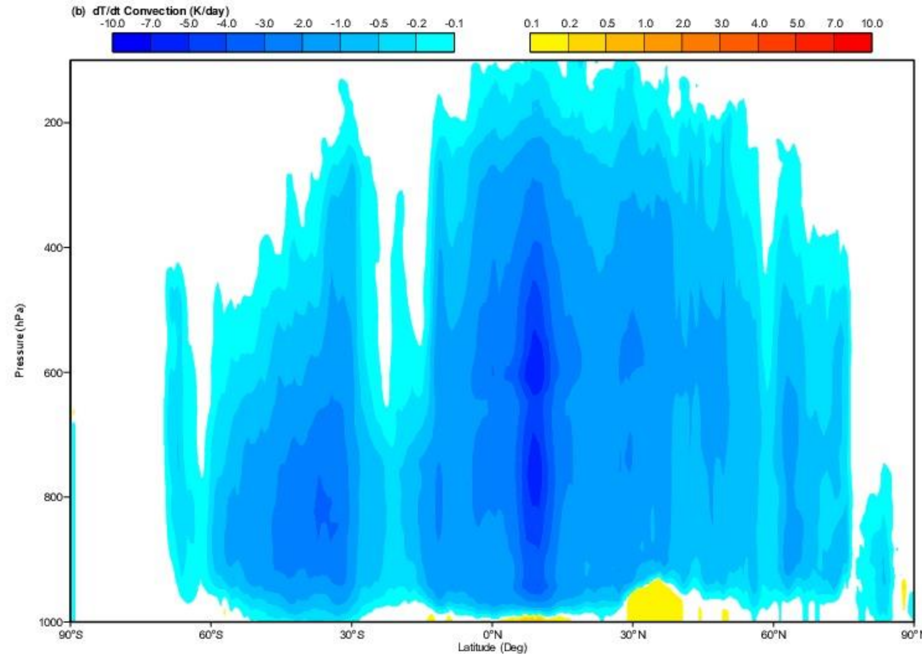
(2) Coupling with microphysics

Change in T Budgets, how much of total is **A** doing ?

Change in Dynamics



Change in Convection



	REF	NEW
Continuity equation	$\frac{\partial \bar{\rho}}{\partial t} = -\nabla.(\bar{\rho}\bar{u}) + \left[-\frac{\partial M}{\partial z} + \frac{\partial M}{\partial z}\right]$	$\frac{\partial \bar{\rho}}{\partial t} = -\nabla.(\bar{\rho}\bar{u}) + \left[-\frac{\partial M}{\partial z}\right]$

from which follows in IFS new (diagnostic values) for advection velocities $\omega, \quad \eta^\circ$

Malardel and Bechtold, QJRMS, 2019

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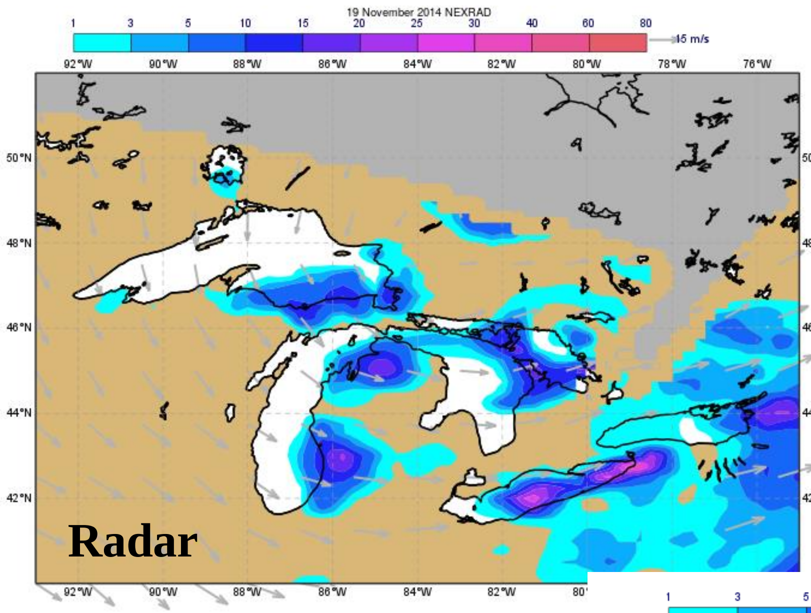
Convective products, forecasting and discussion of weather maps

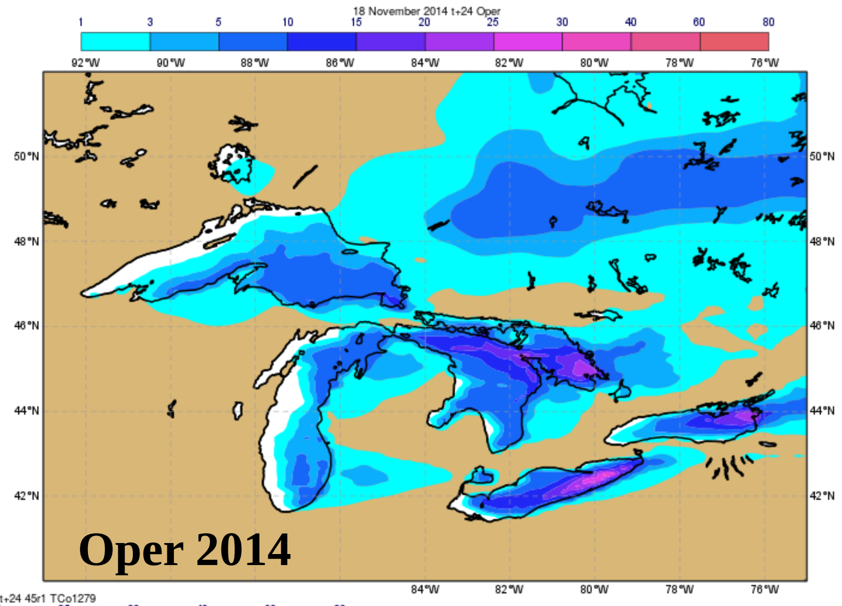
The prediction of (convective) rainfall by the model is not always perfect, but ! The large-scale situation is generally well-forecasted by the model. Therefore, a good forecaster should be able to predict regions of convective activity from the large-scale fields

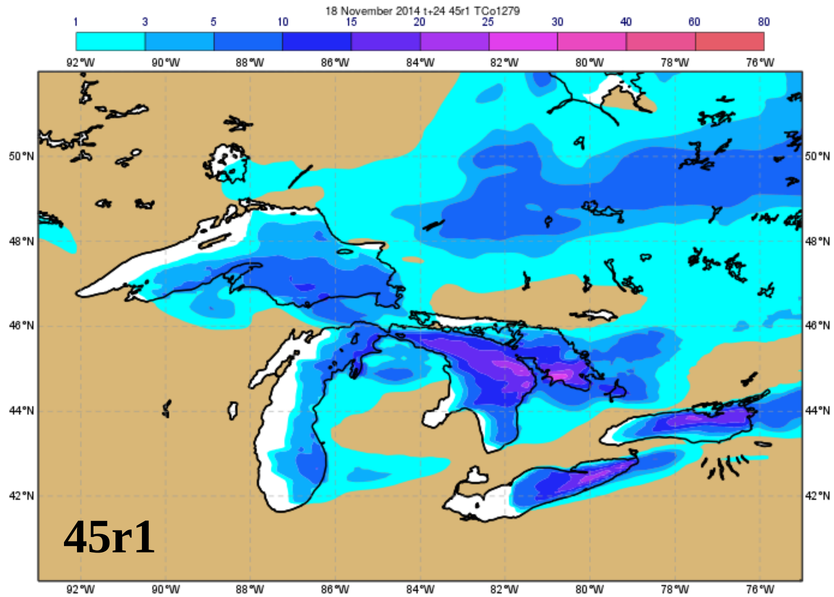
……. it will be shown that with the present forecast system (8-30 km resolution) strongly forced mesoscale convection with trailing stratiform area can be reasonably well predicted typically a few days in advance

Wintery lake convection –snow

importance of advection and example of limitation of the scheme







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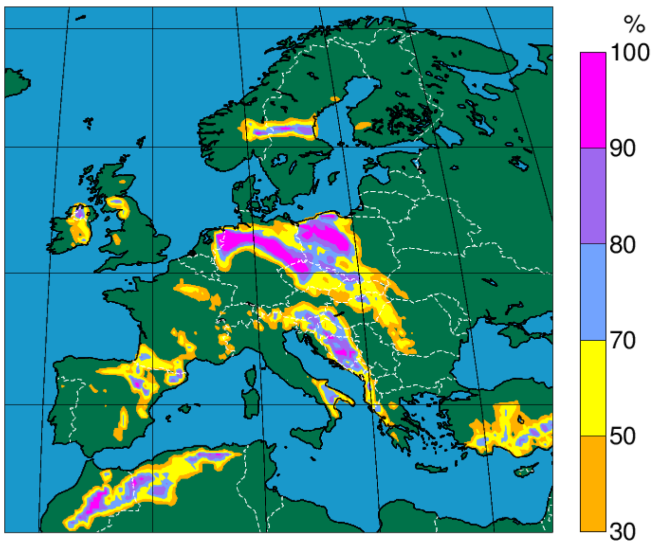
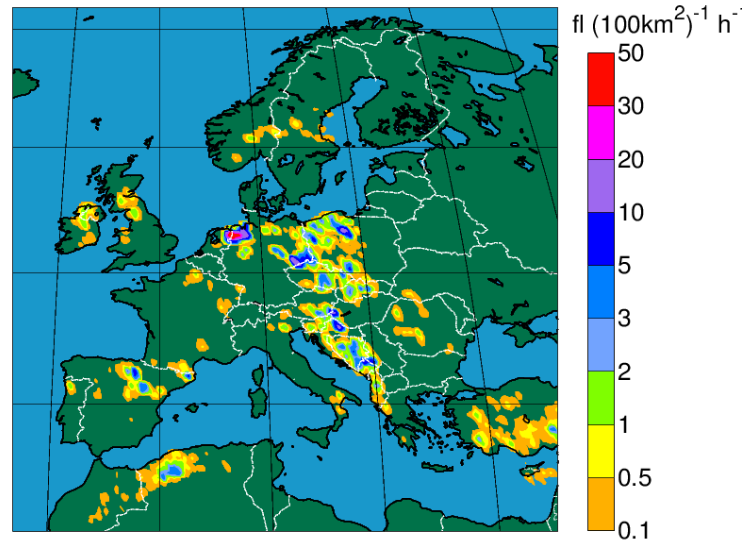
Probabilistic lightning prediction from ensemble forecasts

Ensemble forecast from oper 45r1 esuite
Probability[flash density > 0.1 fl/100km^2/h]
Base: 1 June 2018 00Z, range: **T+12 to T+15h**



Observations:
ATDnet lightning flash densities
1 June 2018 from 12Z to 15Z



The lightning parametrisation strongly depends on the convection parametrisation as it takes as input: CAPE, convective cloud base height and frozen water content (P. Lopez, MWR, 2016)

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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.

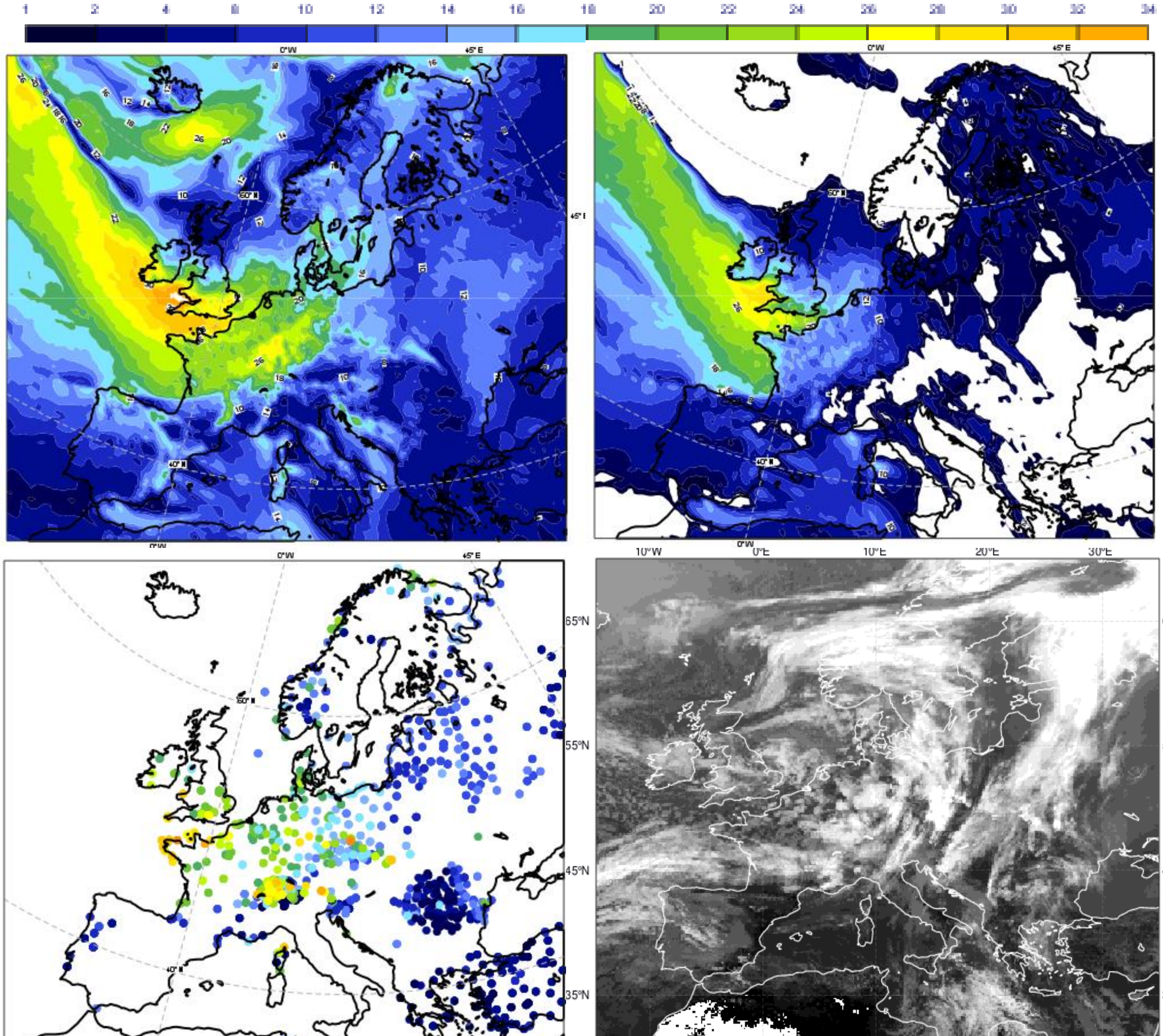
The convective contribution is computed using the wind shear between model levels corresponding to 850 hPa and 950hpa, respectively.

Wind gusts 8 Feb 2016 12 UTC

Gust

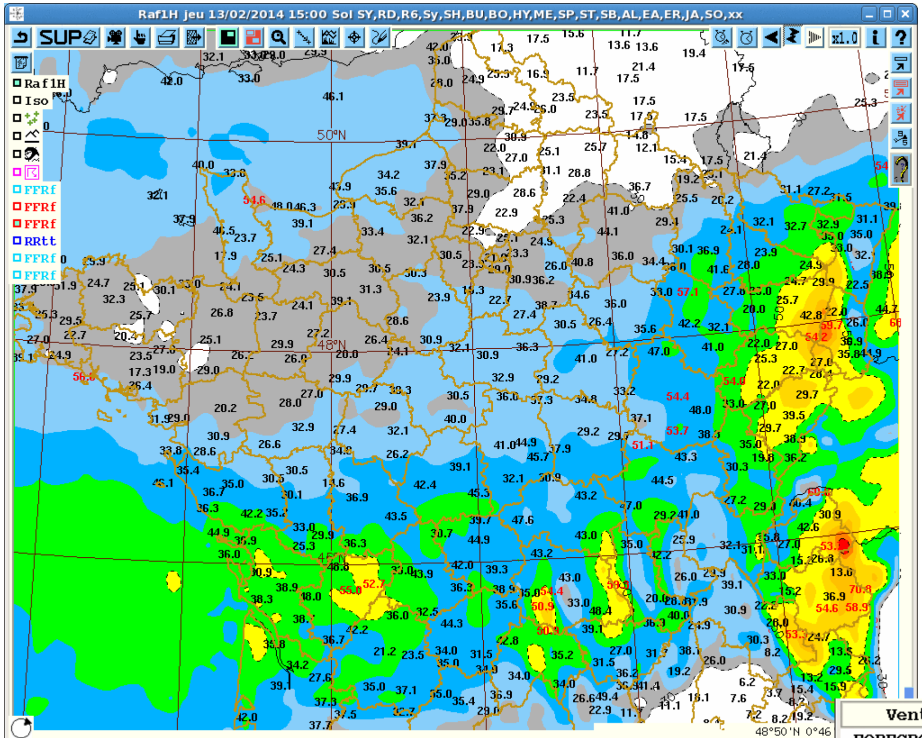
Wind speed

Obs

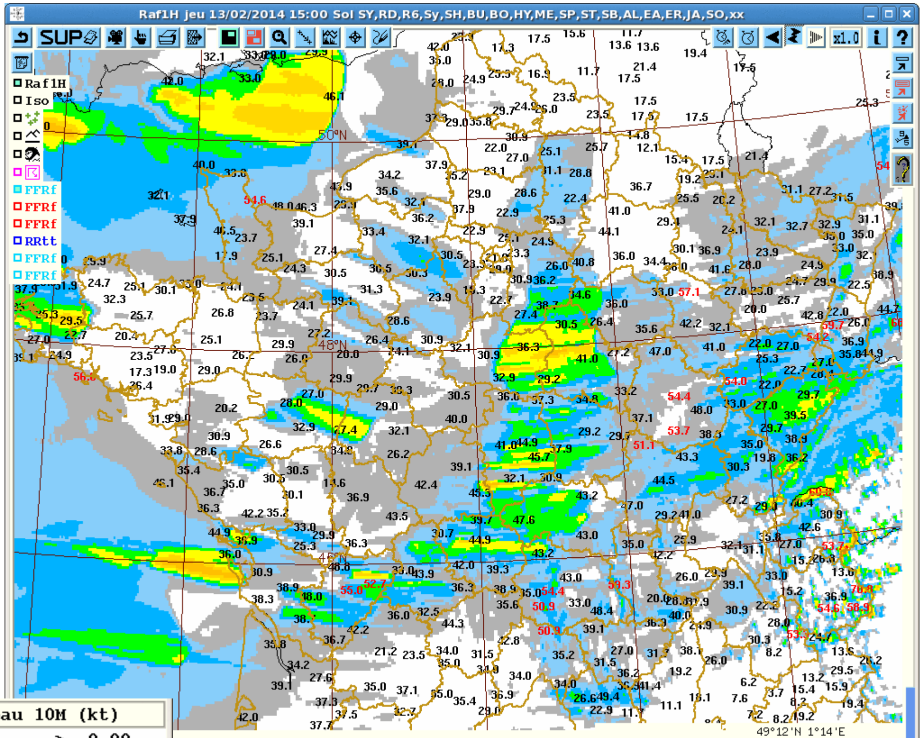


Wind Gusts (‘turbulent’ & ‘convective gusts’)

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



ECMWF 16 km



AROME 2.5 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

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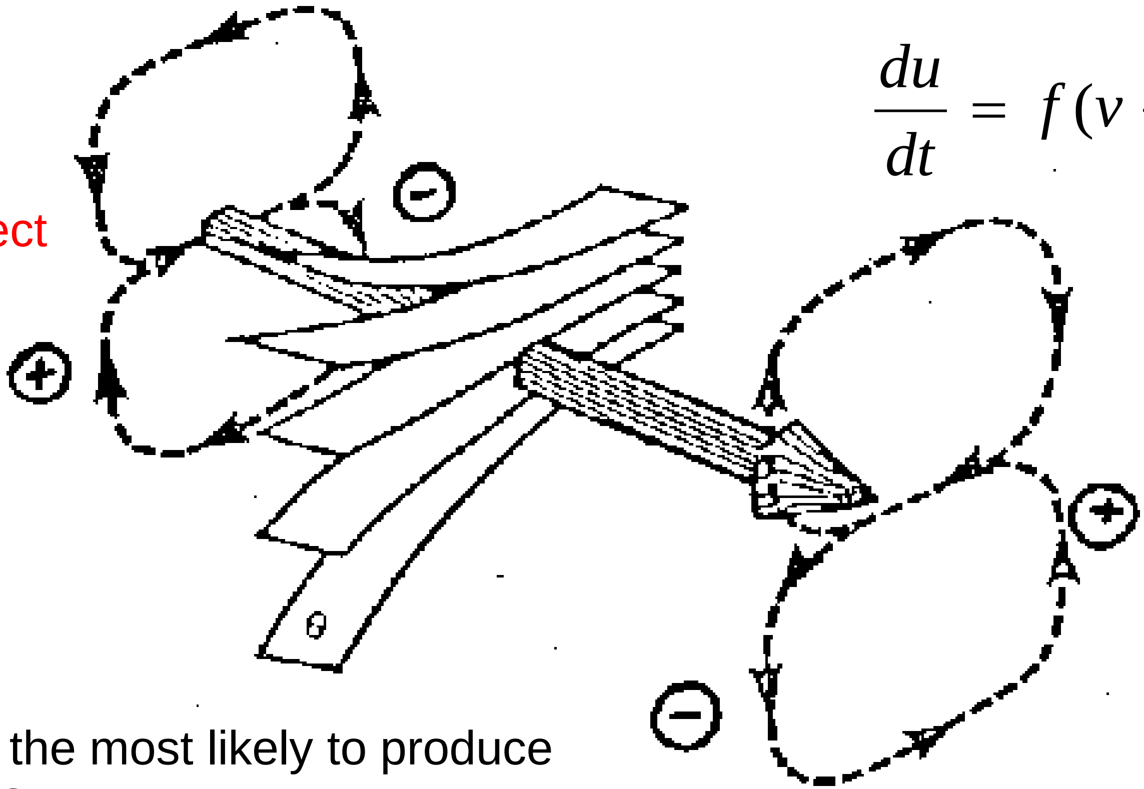
Reminder: Midlatitude Convection

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

Acceleration/deceleration of Jet

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

Thermally indirect circulation



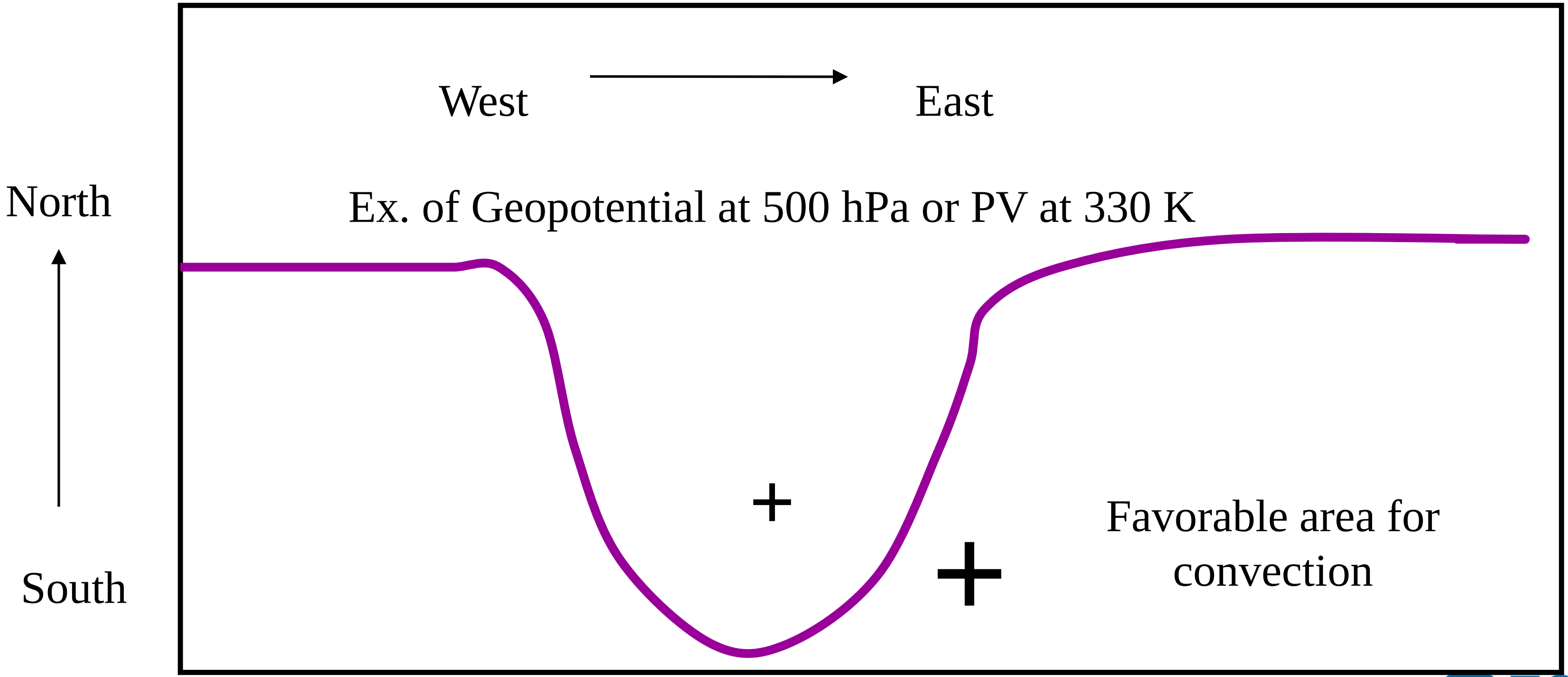
Thermally direct circulation

Which area (+ -) is the most likely to produce intense convection?

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 (derivatives) instead of Geopotential we will see more structure



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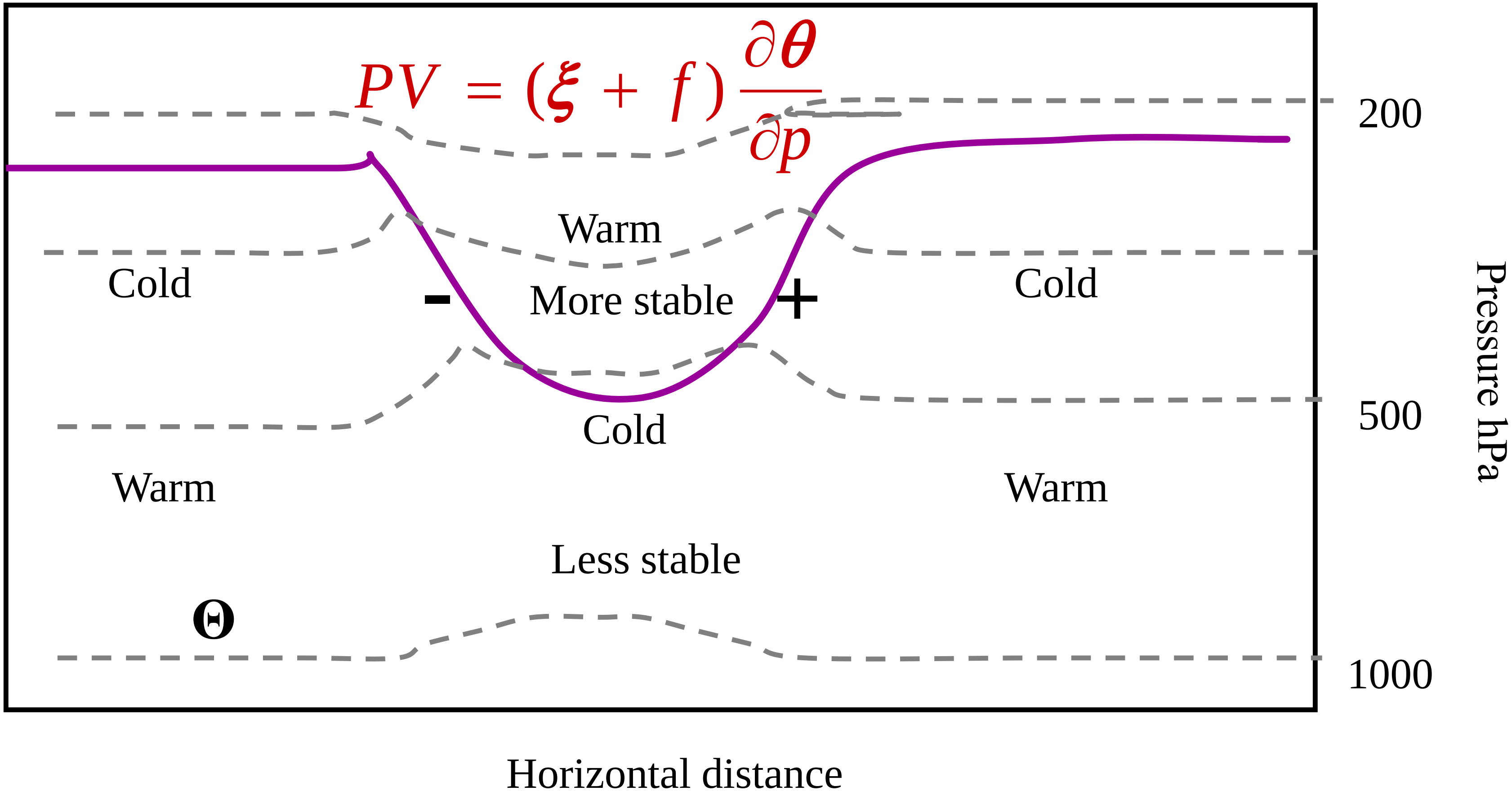
Reminder: PV thinking

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



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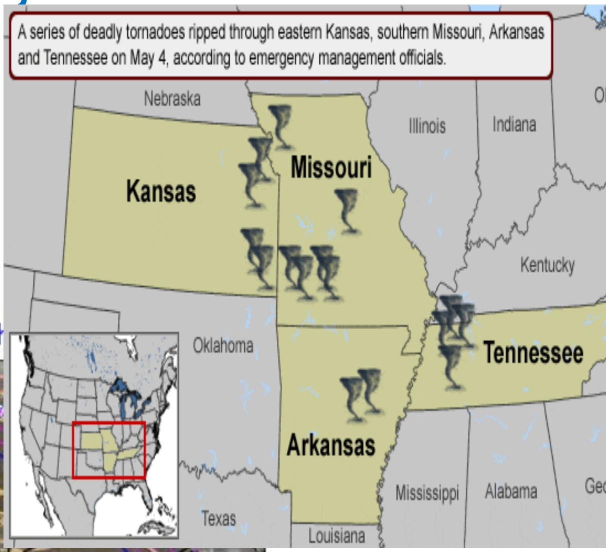
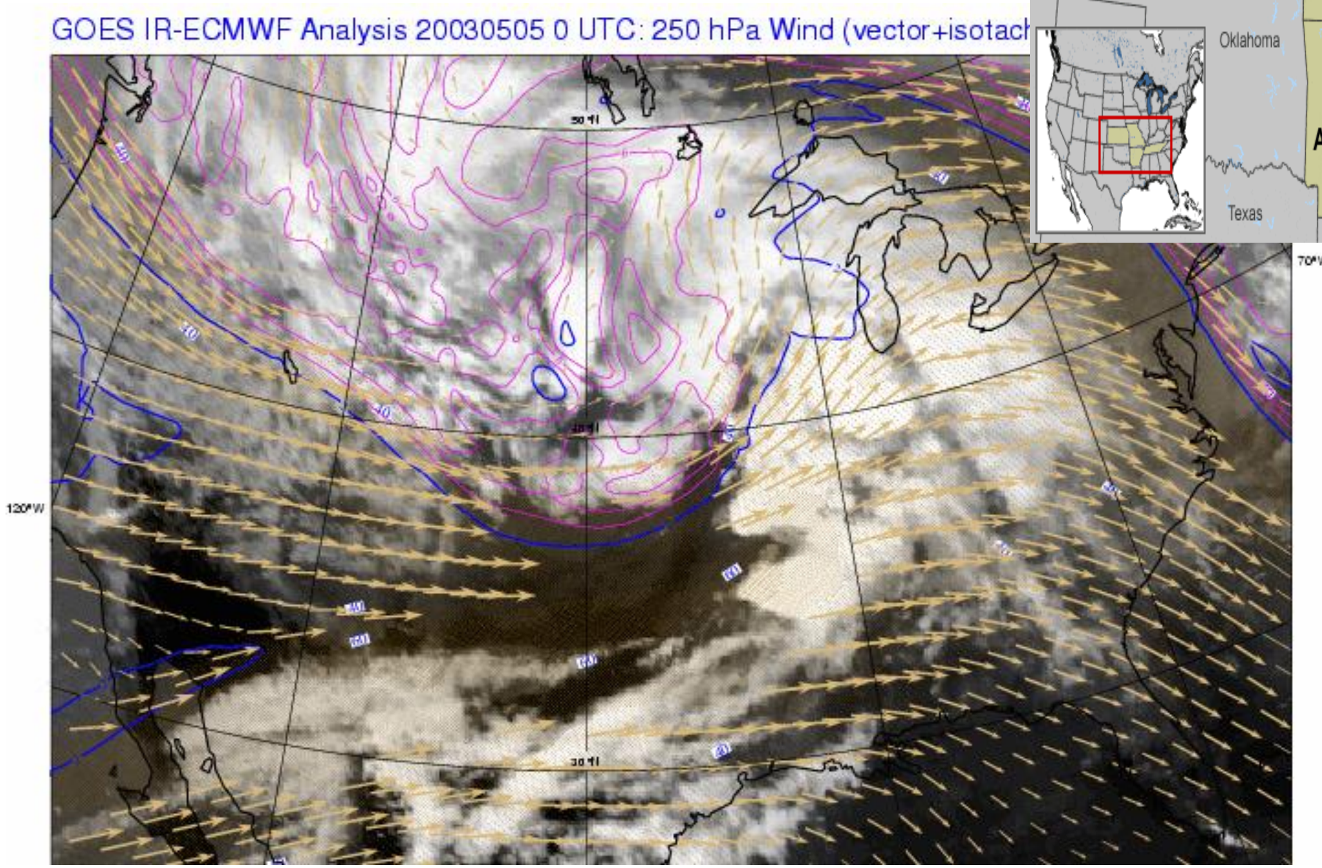
Tornadic case from 4 May 2003

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





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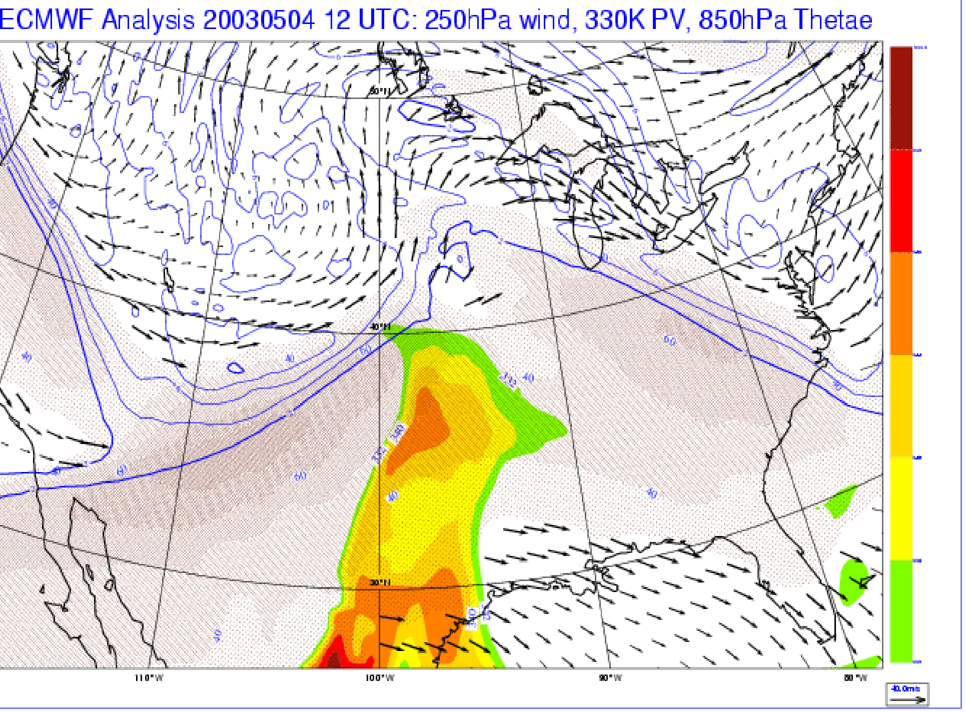
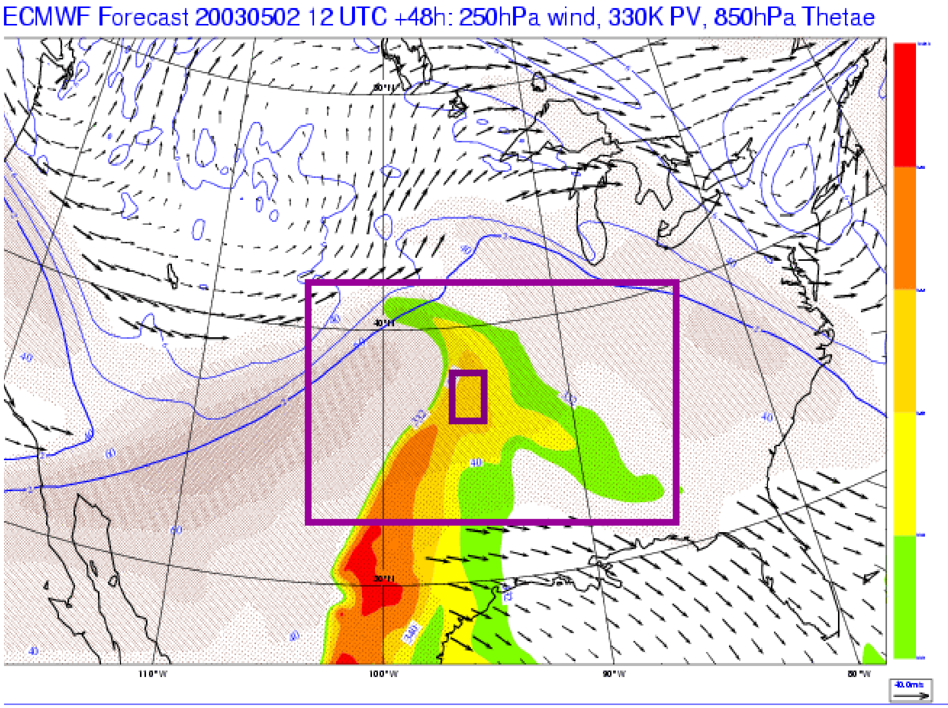
Tornadic case from 4 May 2003

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

Analysis



48-60h Forecast



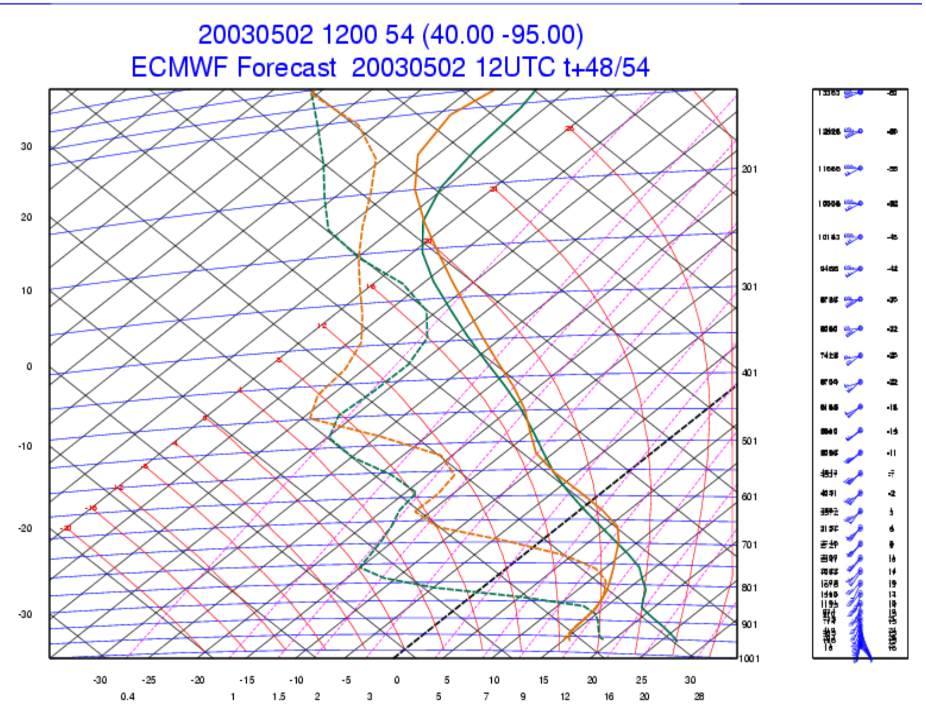
Note: the crossing of the low-level flow (high Thetae=high CAPE) and the upper-level Jet at around 40°N. The region where Tornadoes have been observed is marked by the pink rectangle

ECMWF

Tornadic case from 4 May 2003

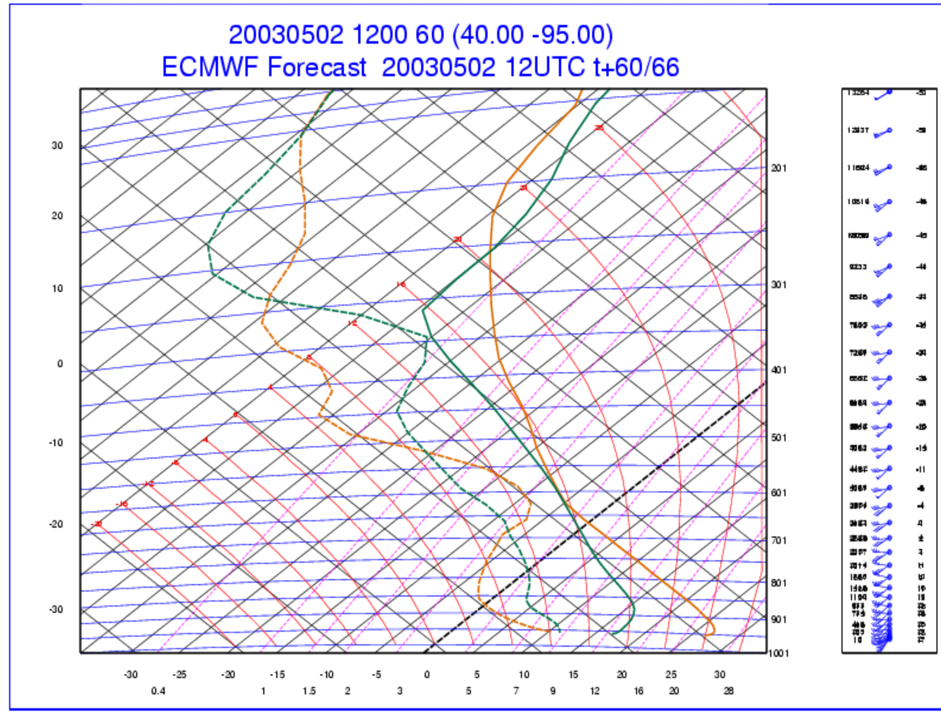
Forecasted Soundings at (40N/95W) at t+48/54/60/66 h

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)

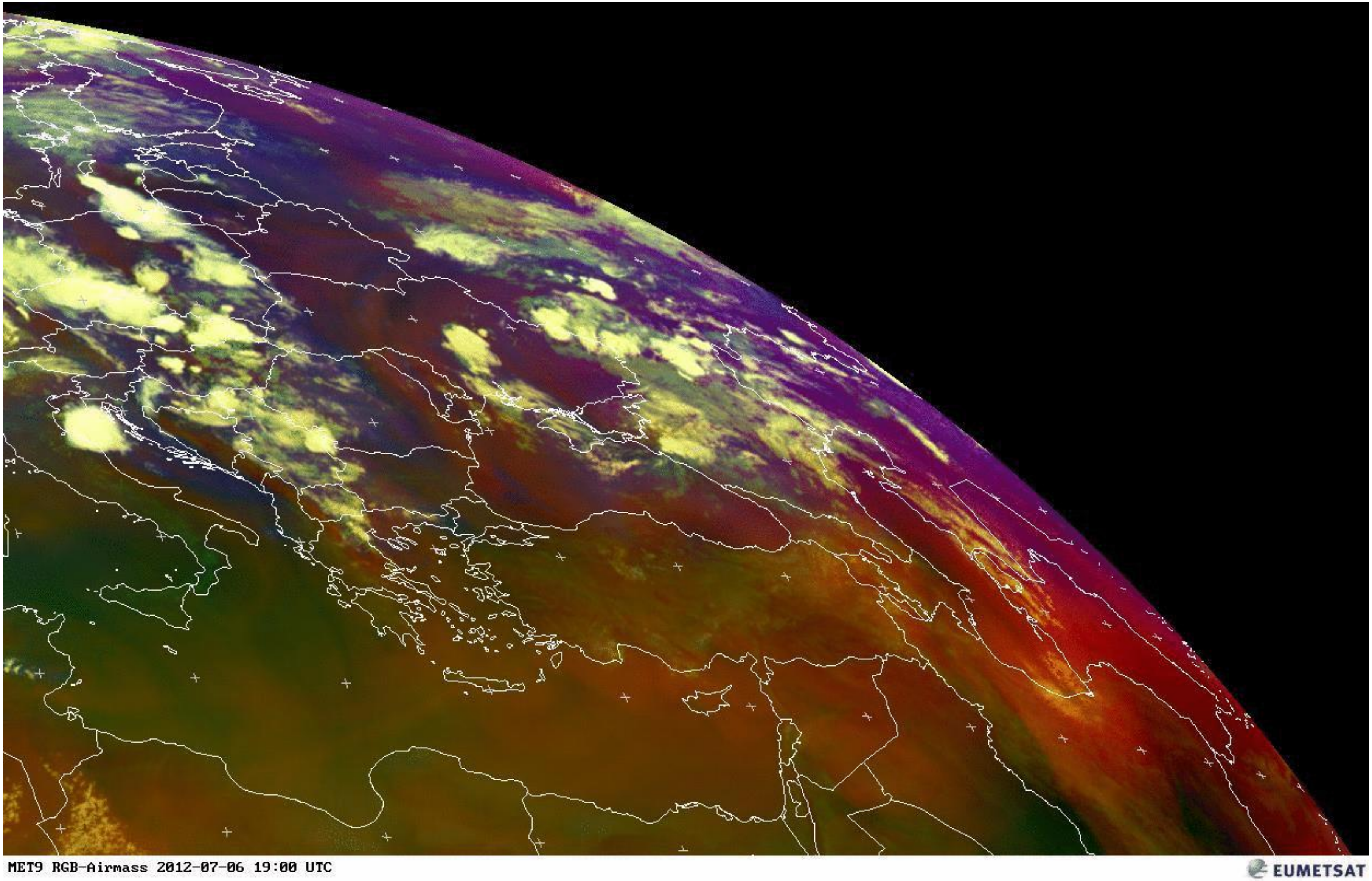
t+60/66



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

Black Sea system: 6 July 2012

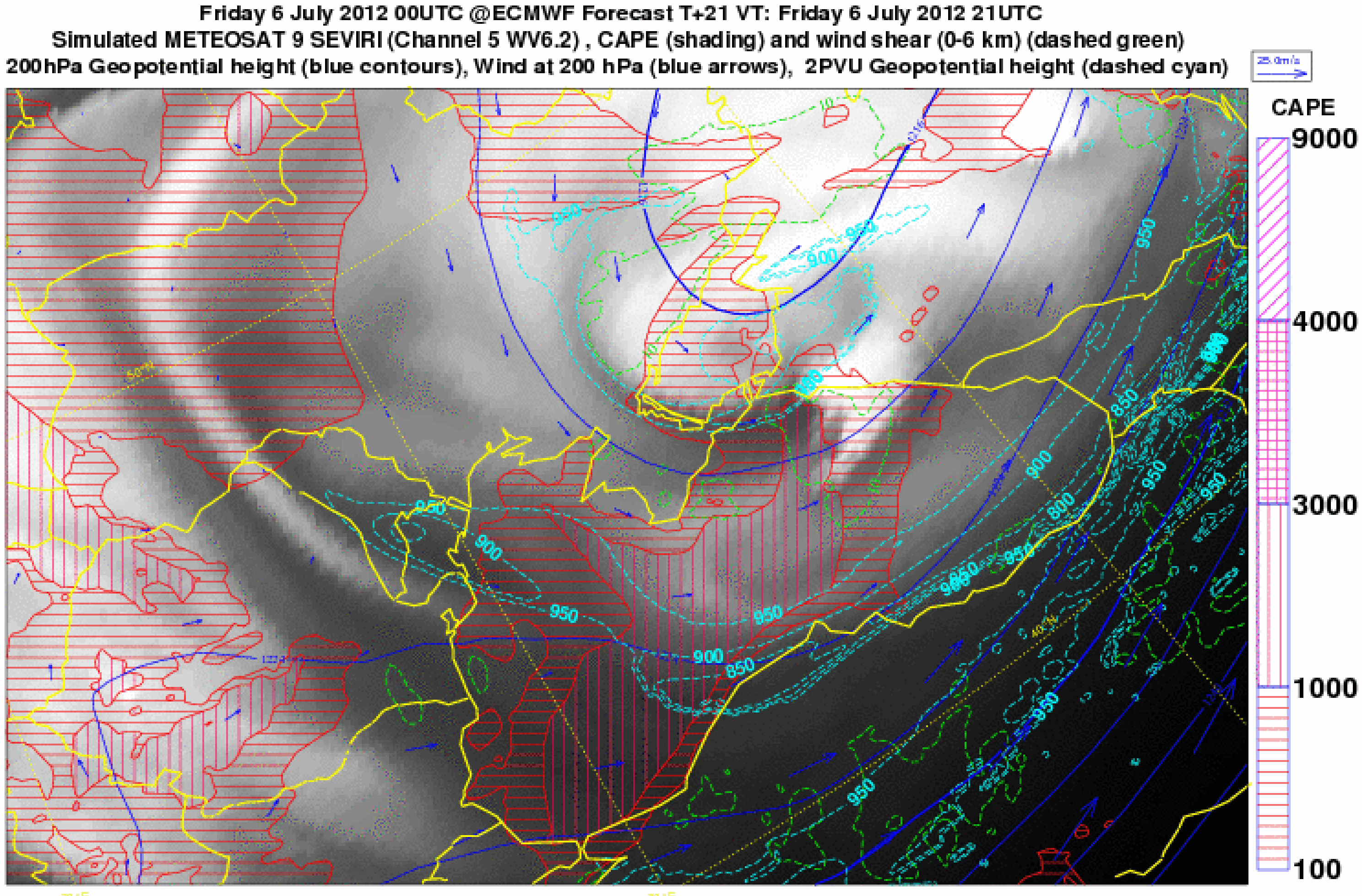
V-shaped System



ECMWF

Black Sea system: 6 July 2012 (2)

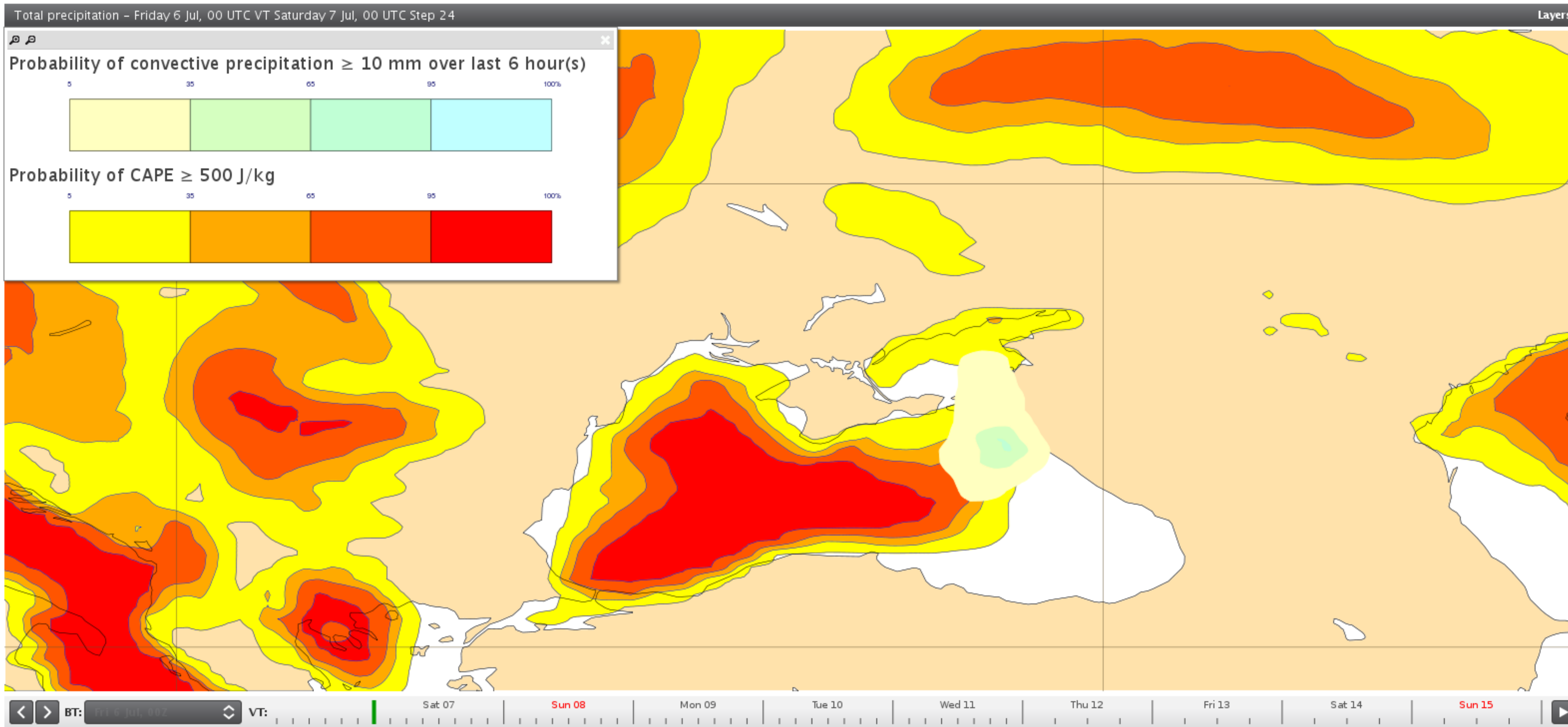
fc WV image, convective precipiatation and shear



ECMWF

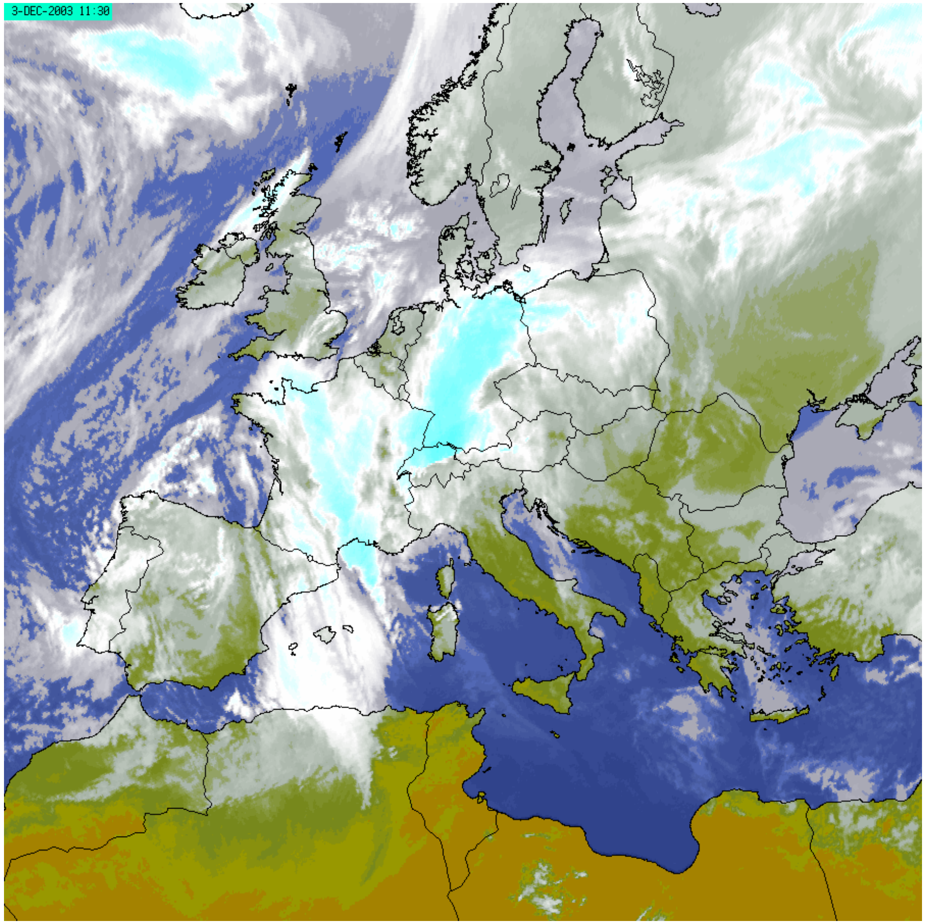
Black Sea system: 6 July 2012 (3)

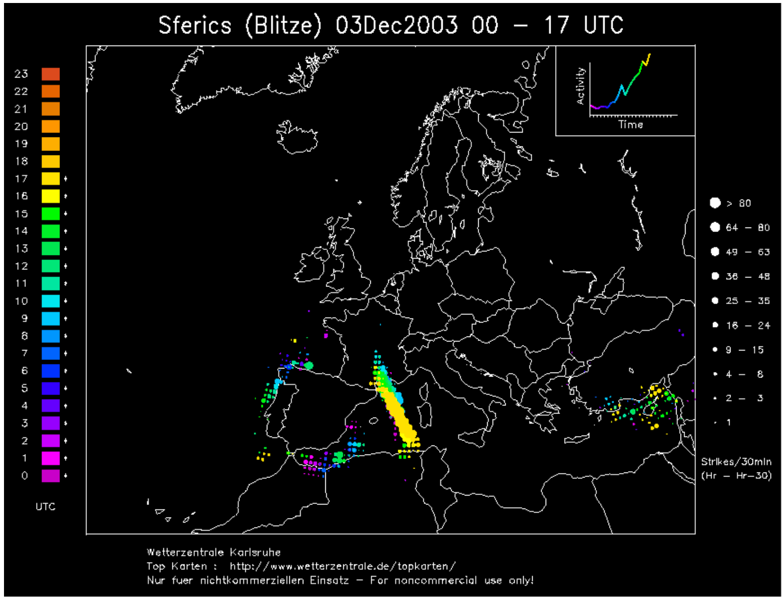
Probabilities CAPE & precipitation

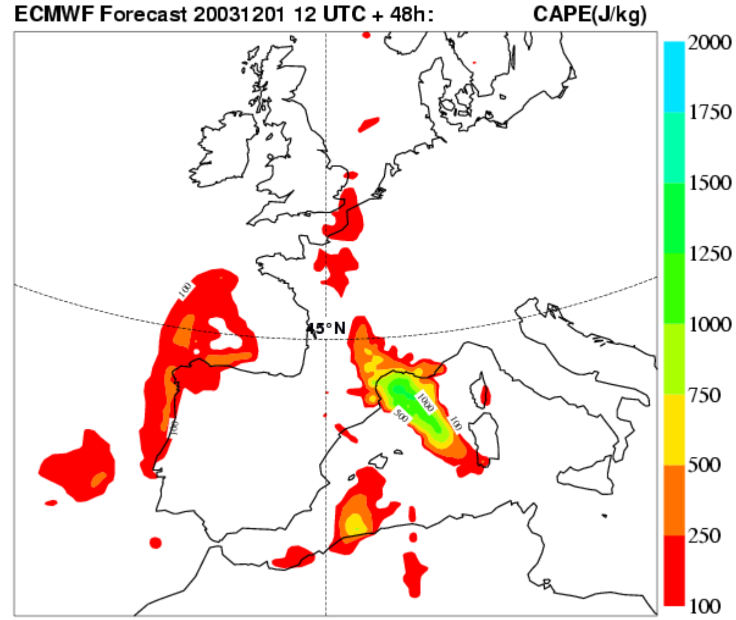


French Floods: 1-3 December 2003 (1)

IR animation V-shaped system



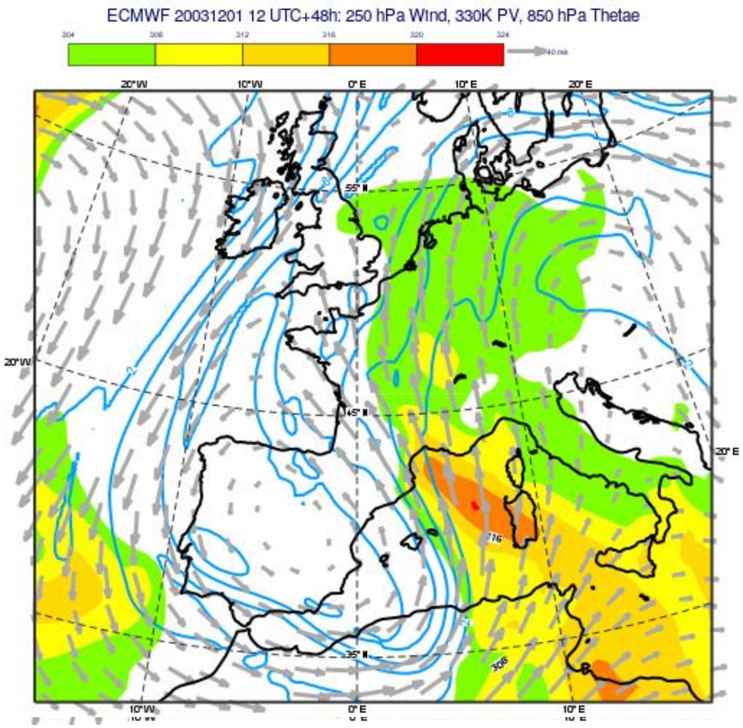


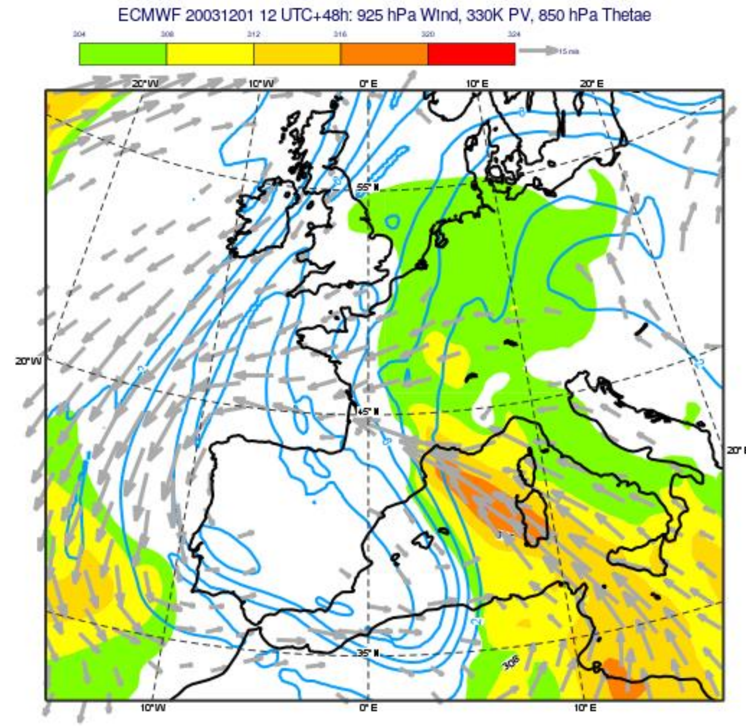


ECMWF

French Floods: 3 December 2003 (2)

upper/lower-level 48h Forecast



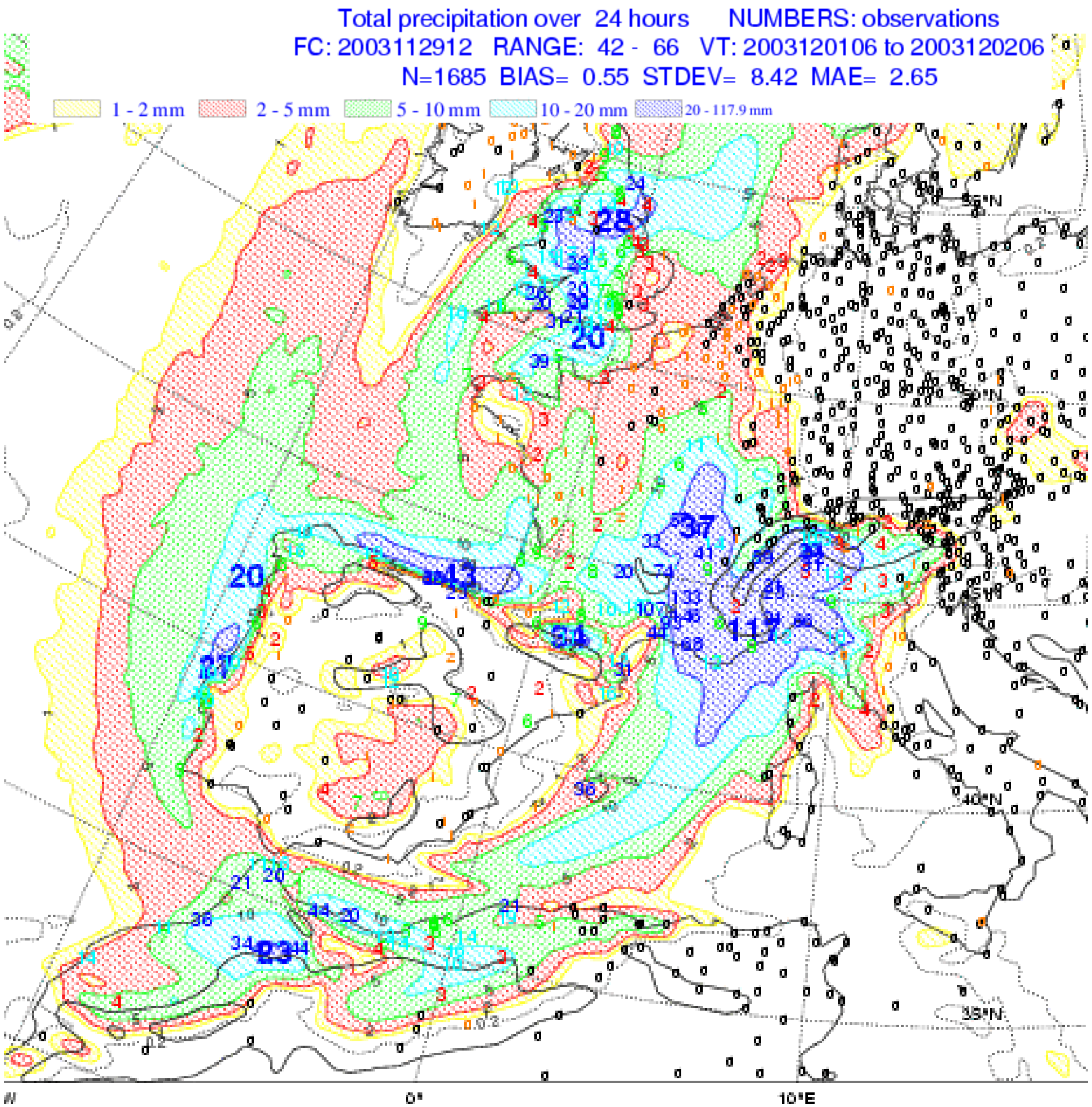


French Floods: 1/2 December 2003 (4)

Precipitation verification

Thin numbers=Obs

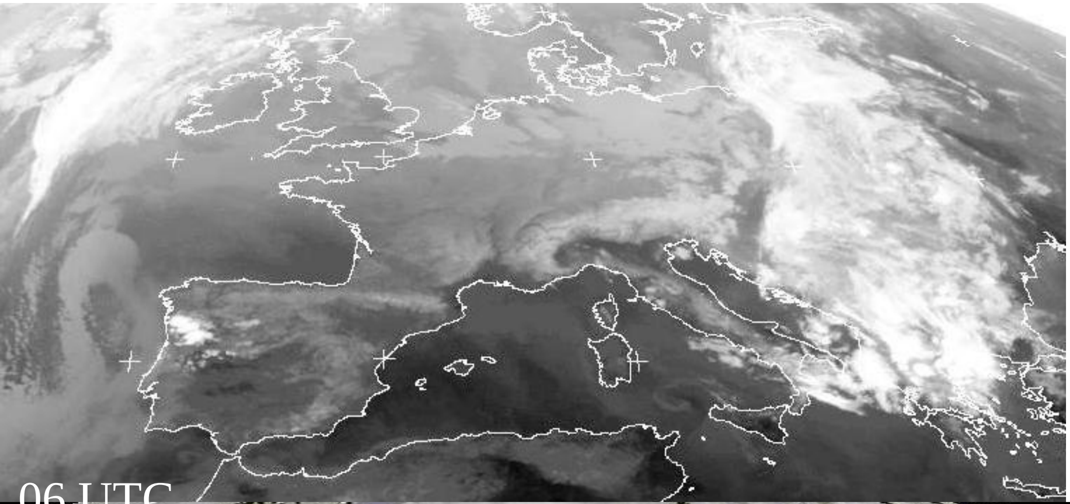
Thick numbers= max. Forecast values

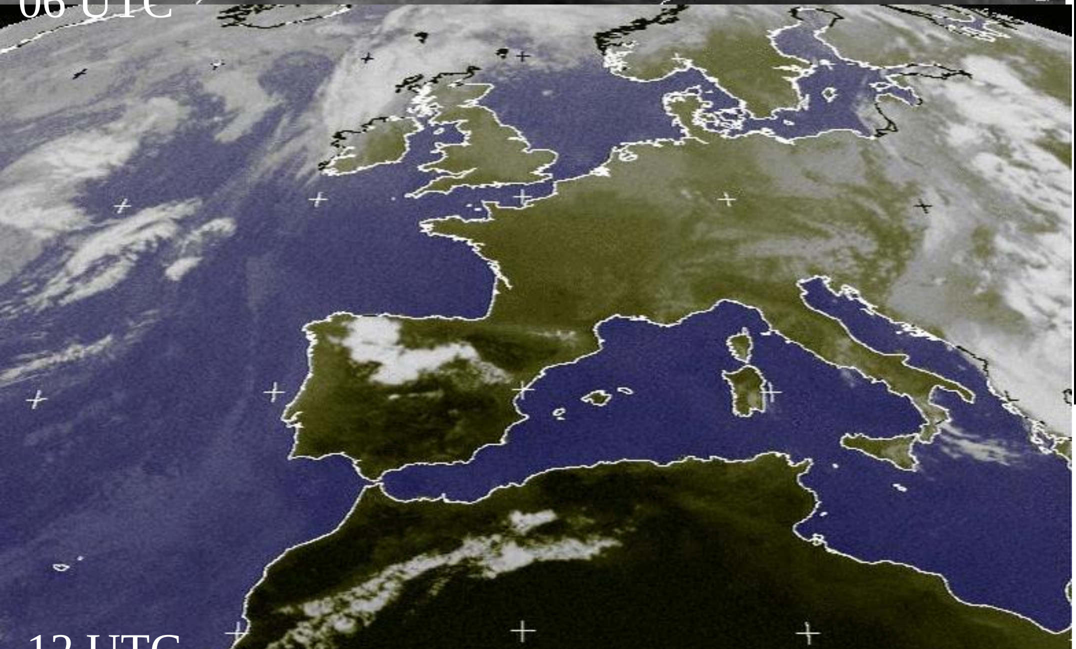


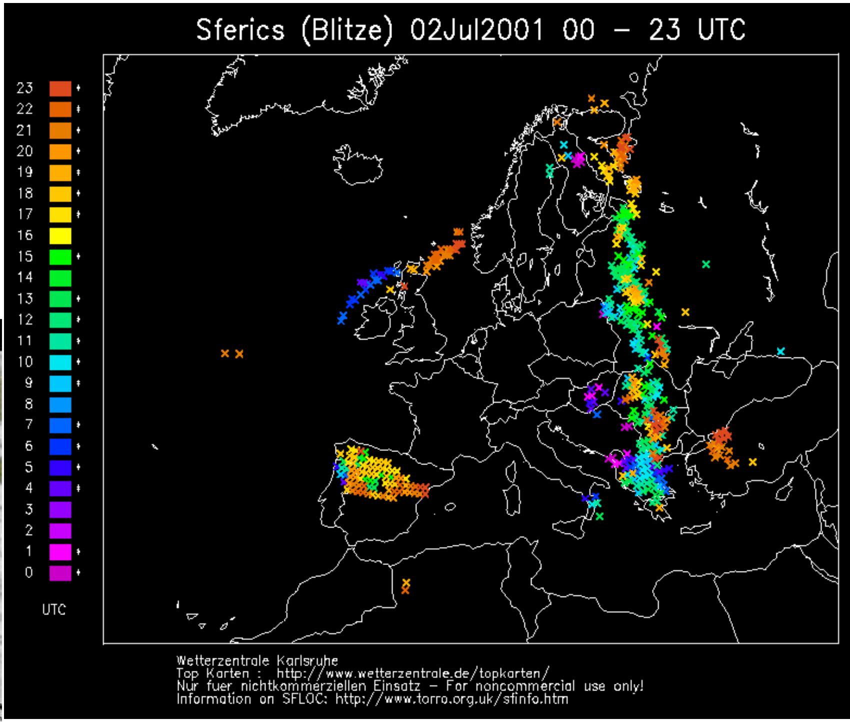
ECMWF

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



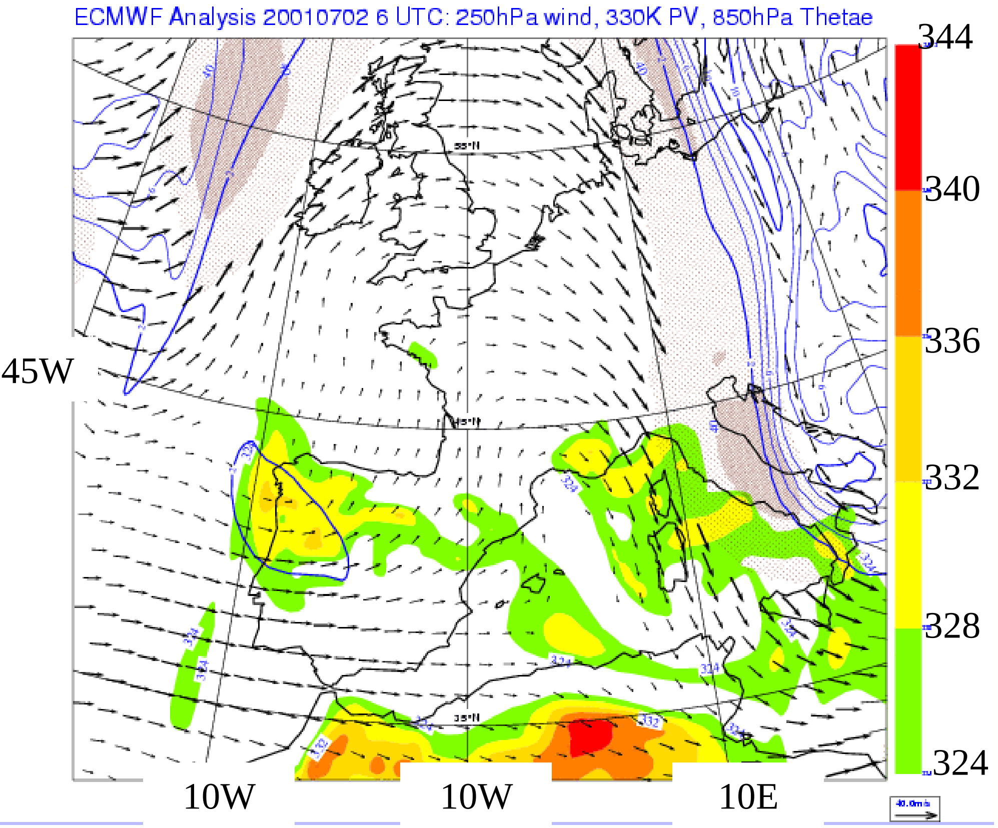




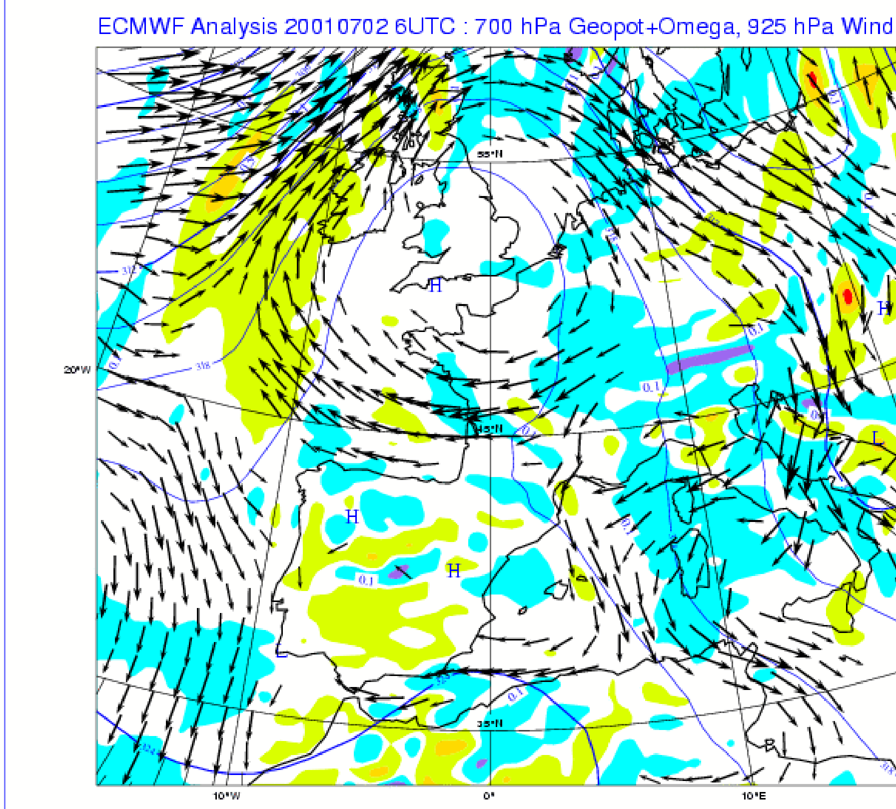
Examples of convective situations over Europe: 2 July 2001 – upper/low level Analysis

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



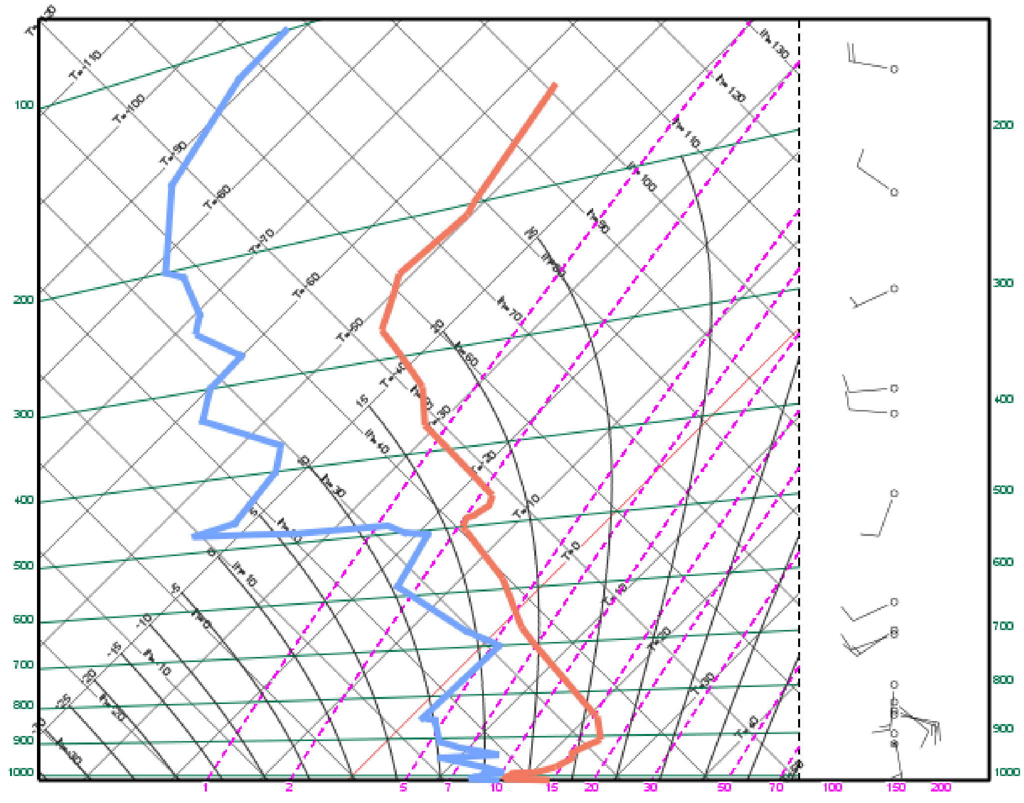
700 hPa Geopot (blue isolines), 700 hPa omega (colour shaded), and 925 hPa wind arrows



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

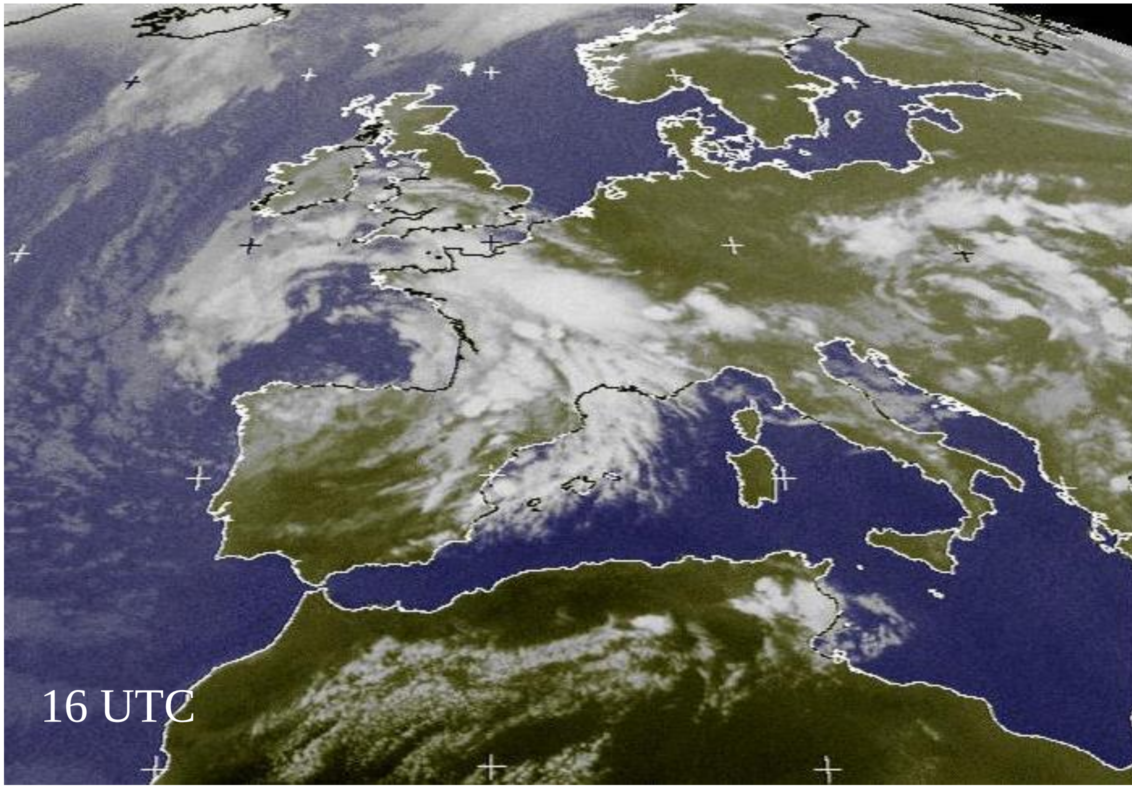
Tephigram La Coruna 20010702 12 UTC

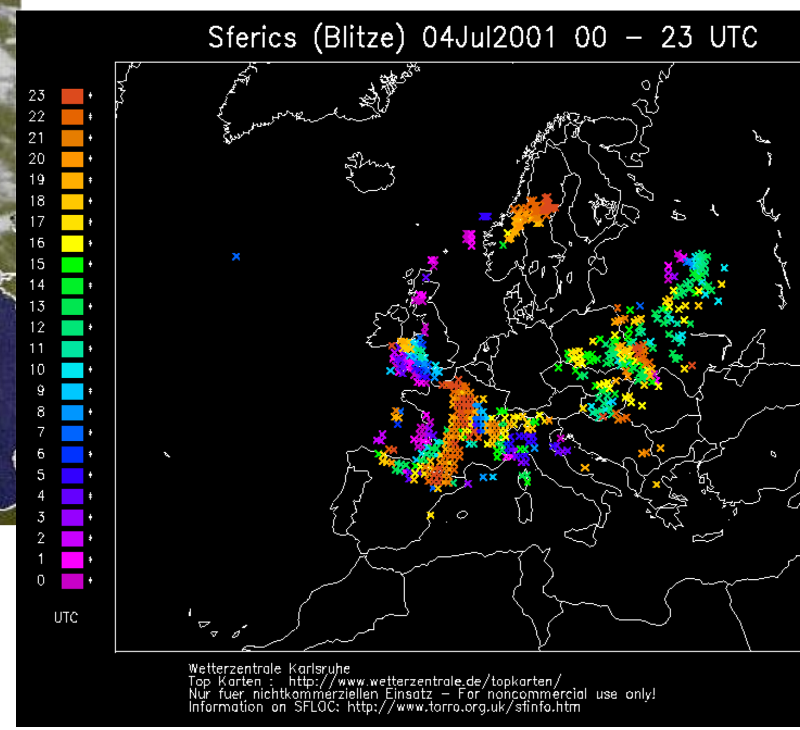


The Sounding for La Coruna (NW Spain close to coast) shows upper-level instability, but low-level inhibition that could be overcome by orographic uplifting or low-level heating of air mass further inside land

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



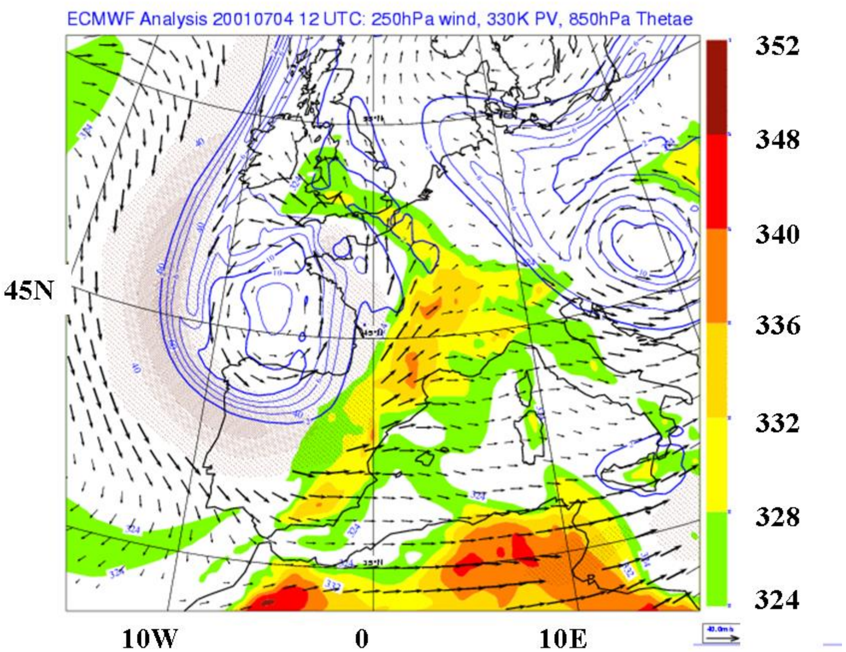


ECMWF

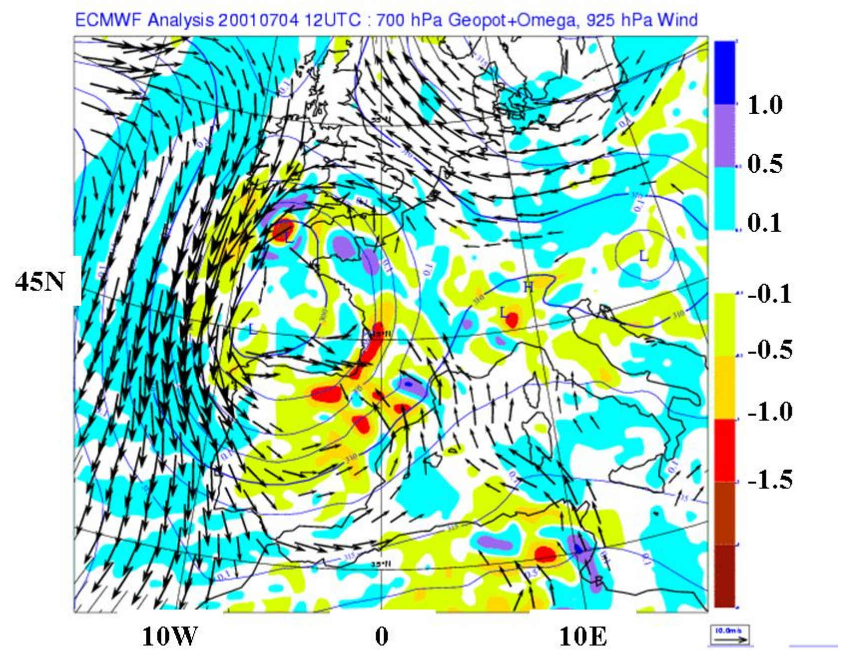
Examples of convective situations over Europe: 4 July 2001 – upper/low level Analysis

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



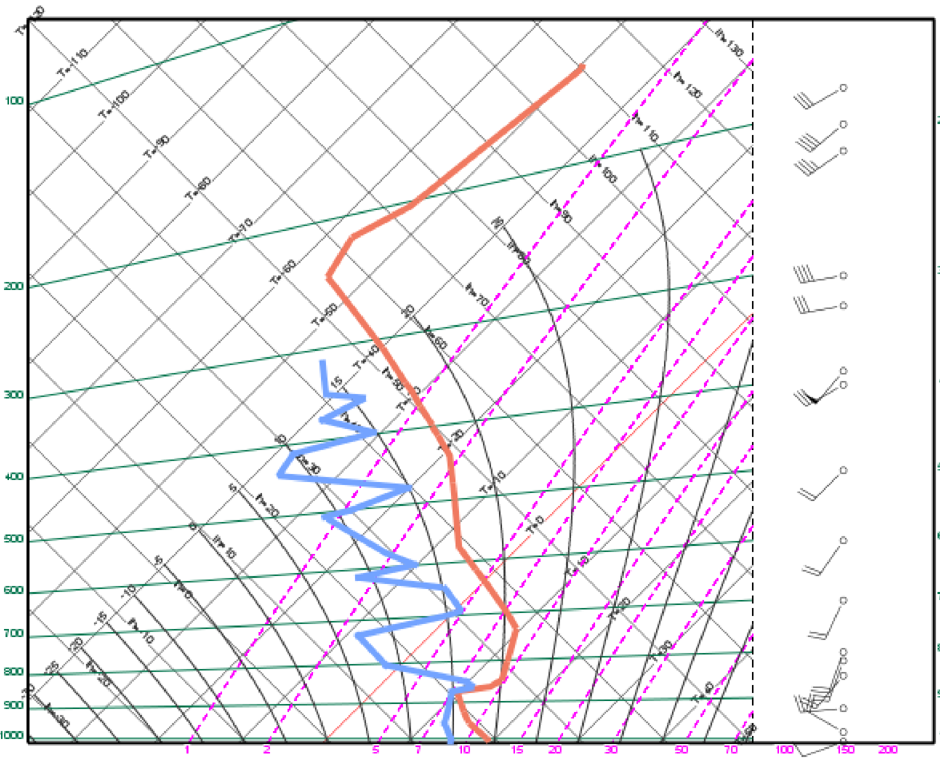
ECMWF

Examples of convective situations over Europe

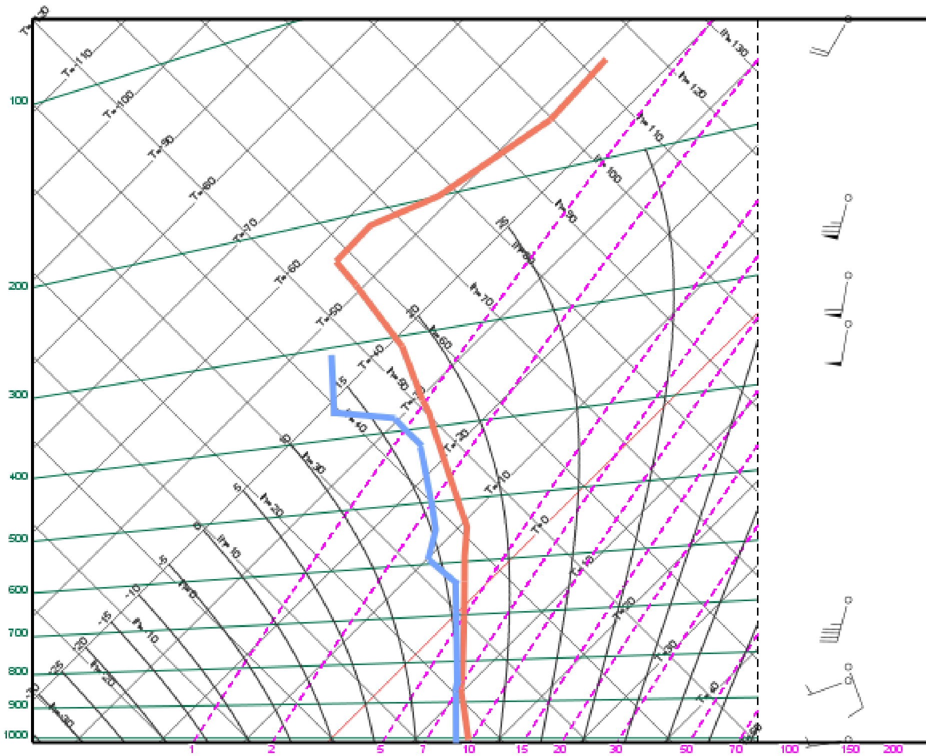
4 July 2001 – soundings and moist adjustment

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

Tephigram Bordeaux Merignac 20010704 0 UTC



Tephigram Bordeaux Merignac 20010704 12 UTC



Pre-convective Sounding with strong inhibition layer and instability above 700 hPa

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

ECMWF