Numerical Weather Prediction
Parameterization of diabatic processes

Convection III
The many aspects of Forecasting, diagnostics and next higher resolution

Peter Bechtold and Tobias Becker

ECMWF

Outline

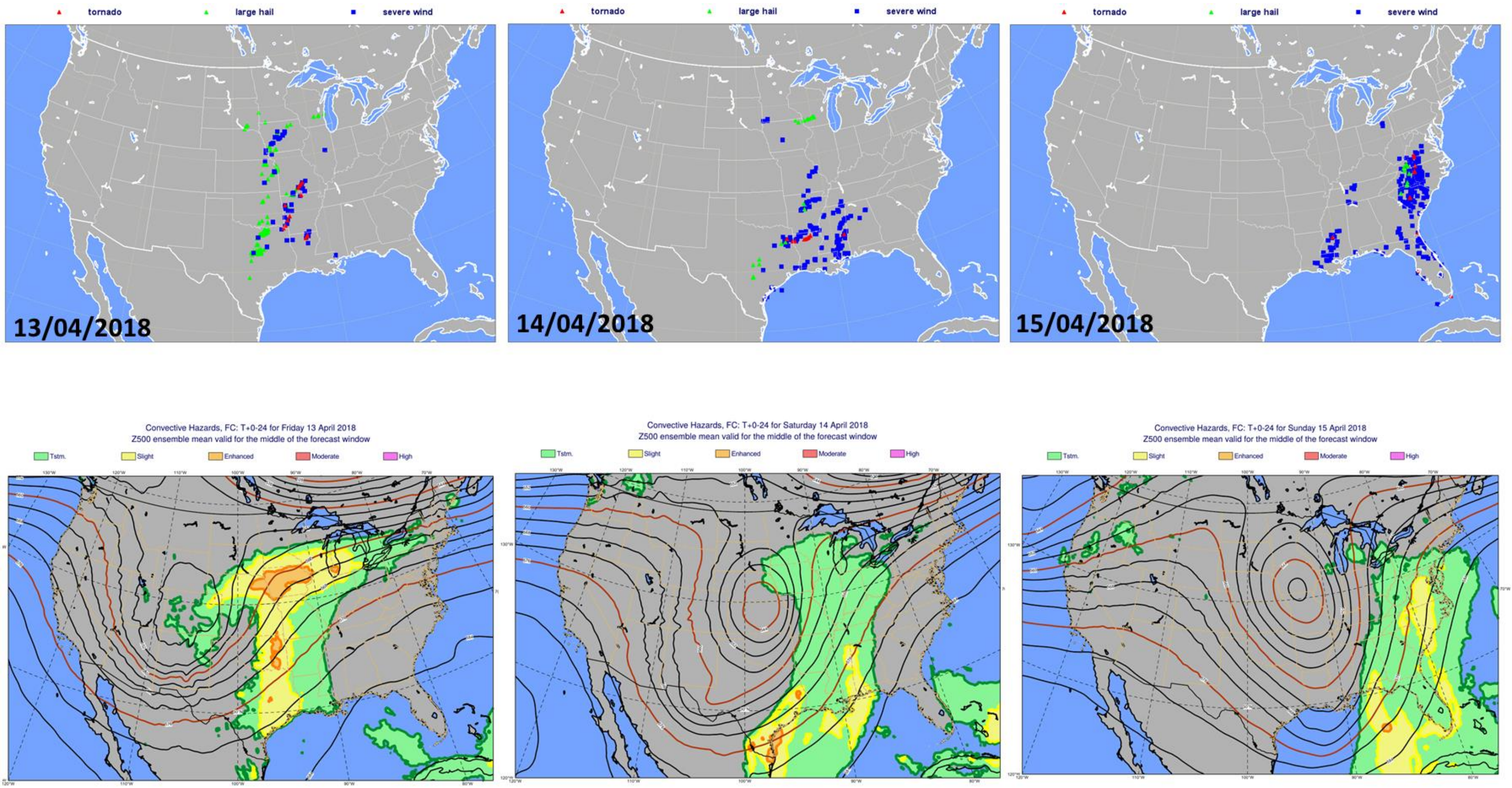
- Model sensitivity to convective parametrization: analysis increments, tropical cyclones, advection of showers/snow, diurnal cycle of convection
- Ensemble representation
- A few convection related products
- Going to higher resolution – what to expect/solve?
- (if time) The beauty of convective events

Not always good: errors in intense continental convection can strongly affect 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 heating and divergent motions =>convergent increments
- Underestimation of convection (heating) due to errors in large-scale forcing and convection scheme can lead to an underestimation of precipitation and divergent outflow and the miss of jets on the downshear side

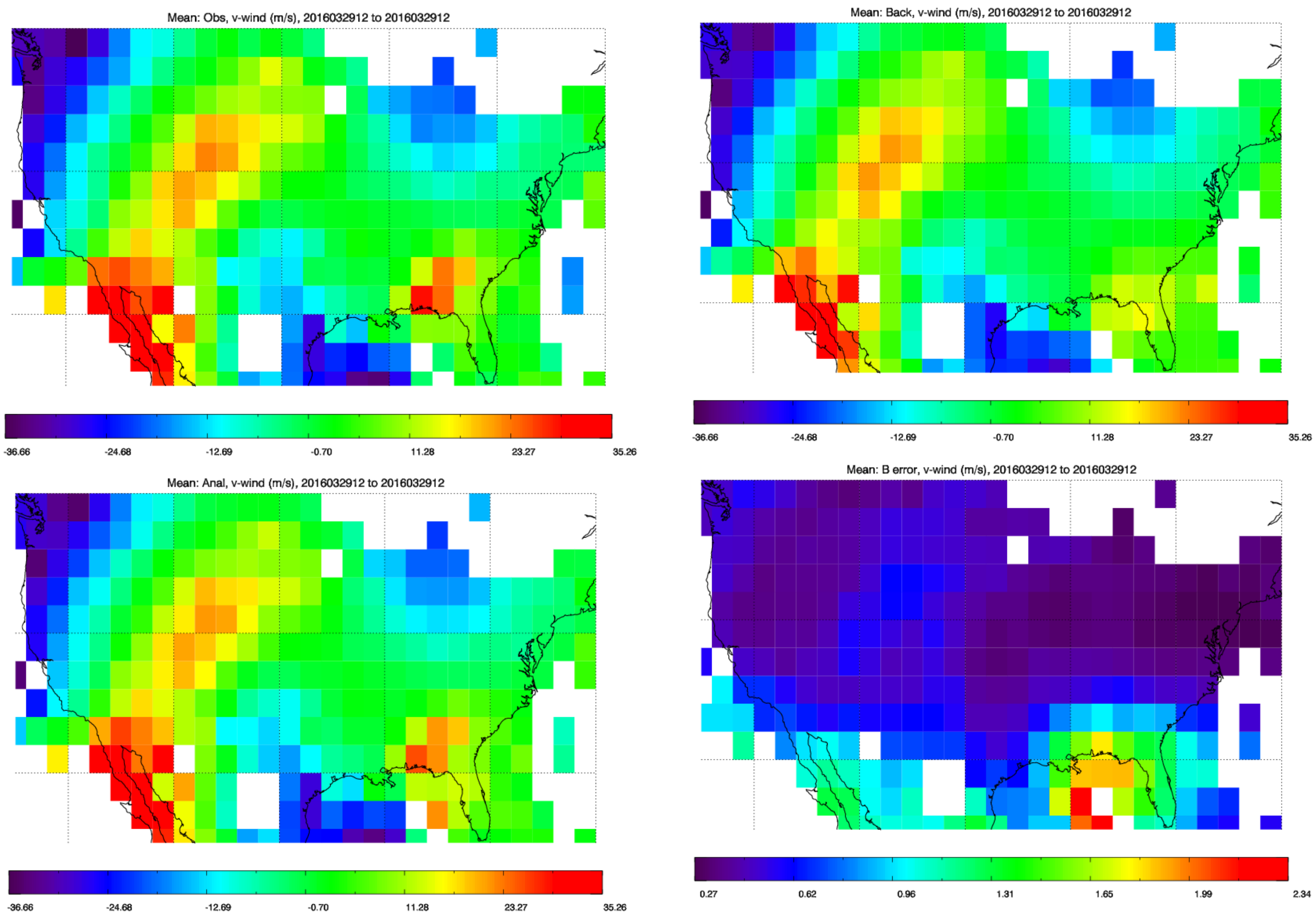
For more information, see also Rodwell et al. 2013, BAMS 94
ECMWF Newsletter No 98 Summer 2003, No 114 Winter 2007/8, No 131 Spring 2012, No 136 Summer 2013

Spring convection US



Courtesy Ivan Tsonevsky

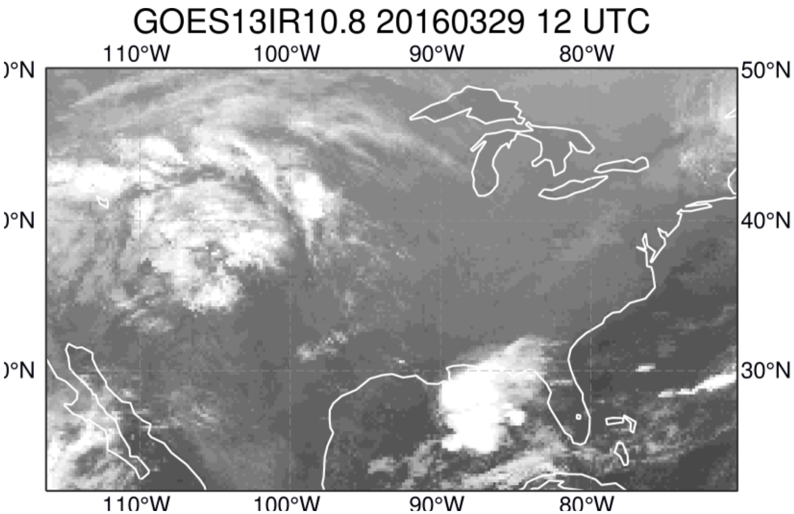
Data assimilation: example of “convective” V-wind Obs&first guess

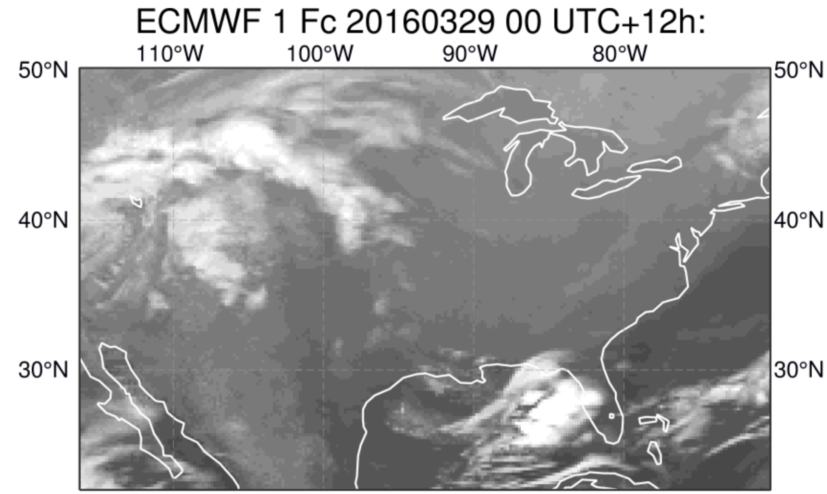


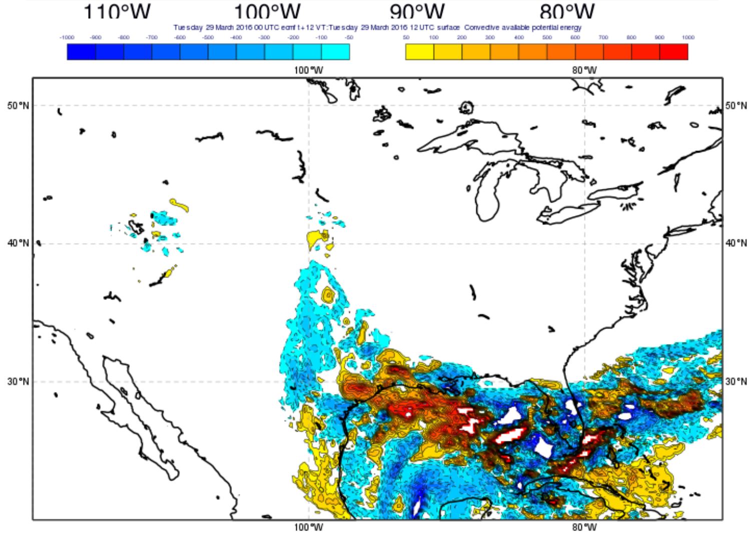
4DVarAnalysis (trajectory+TL evolved increment) able to correct the background (lack of convection) due to available aircraft Obs and background error statistics and due to model physics sensitivity through TL/AD

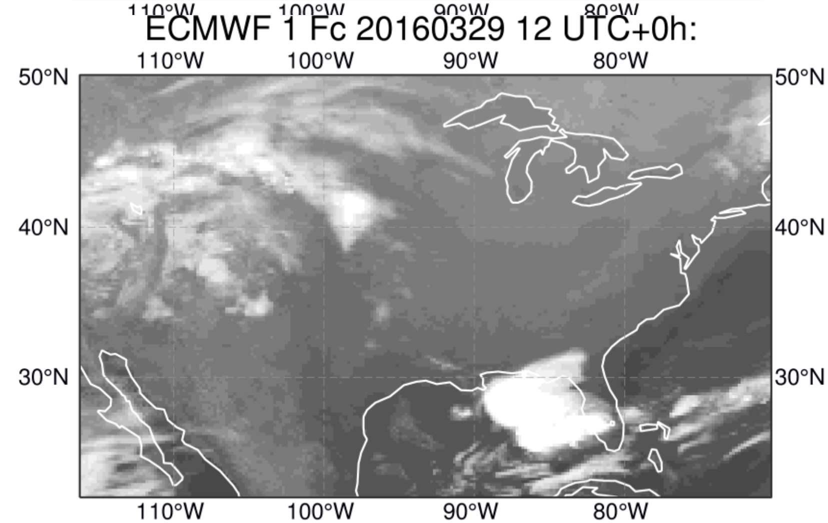
courtesy Mike Rennie

Data assimilation: “convective” analysis increments





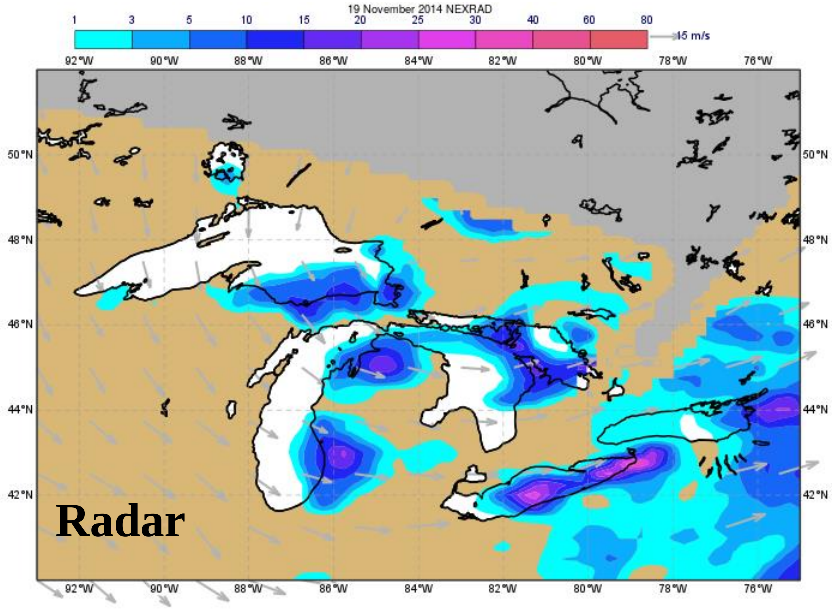


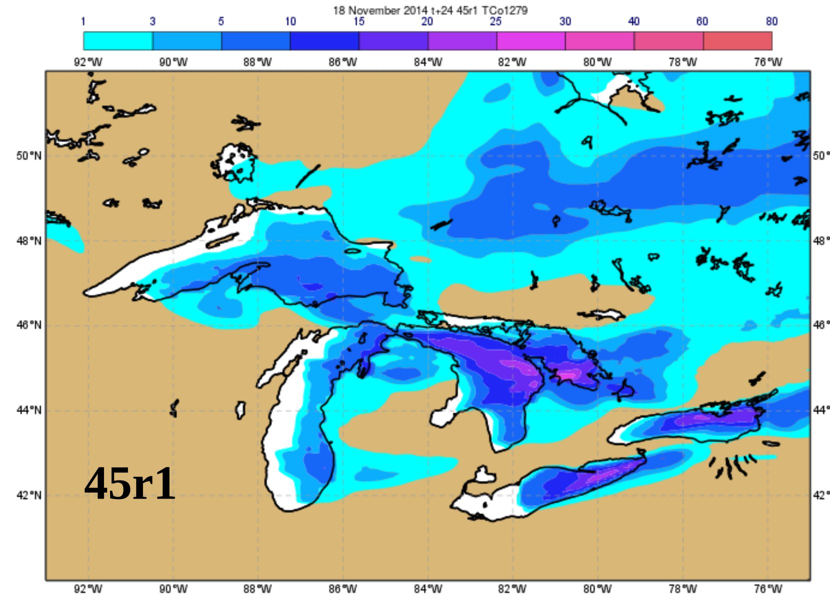


Slight change in large-scale conditions (CAPE/CIN) in analysis and convection is produced with right intensity and produces the 20 m/s outflow

Wintery lake/sea convection with Snow

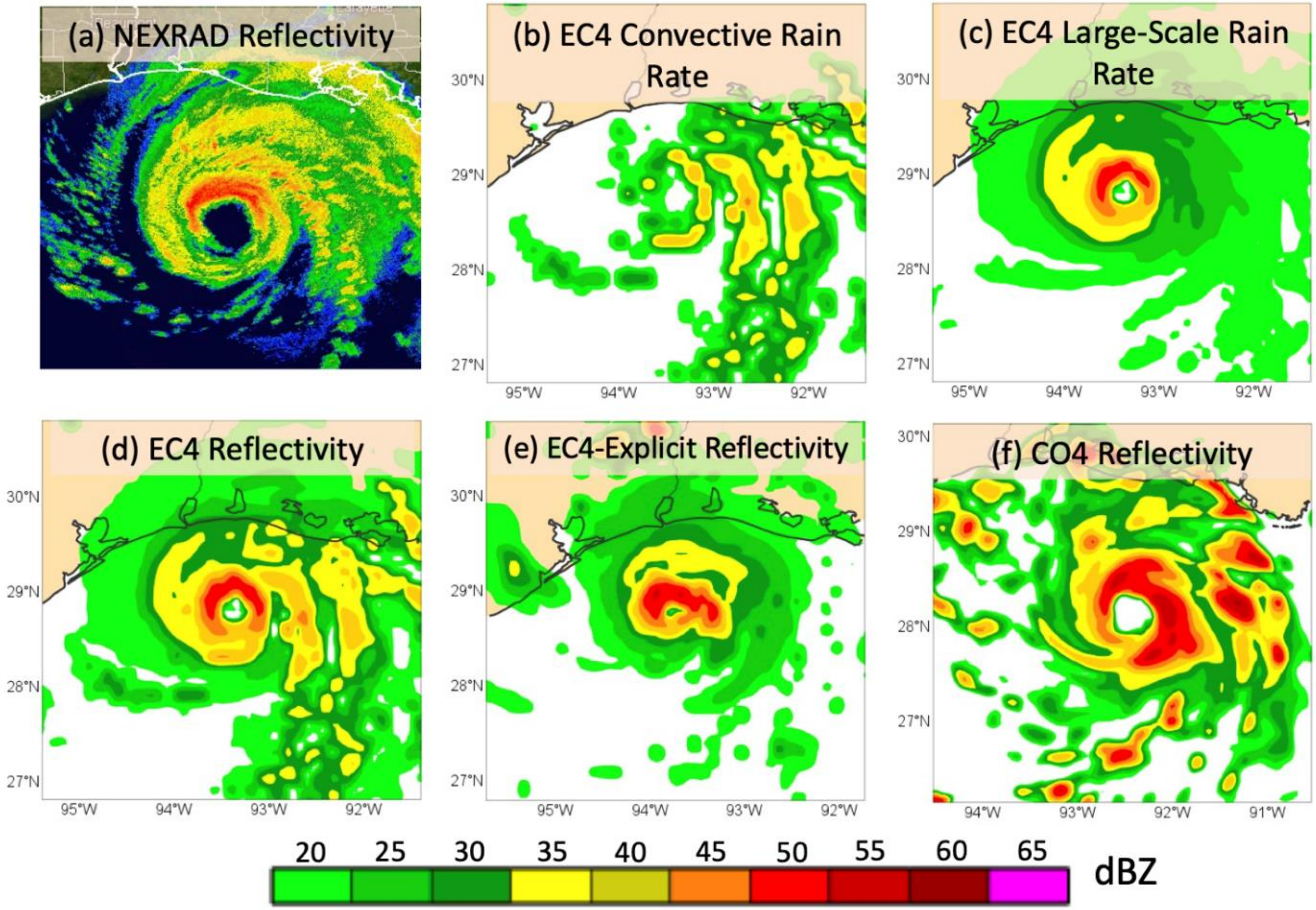
importance of advection and example of limitation of the scheme





Advection over cold land becomes important, model cannot "initiate" convection there but overestimates over water

Tropical cylones (e.g. Laura 27.8.2020): sensitivity to convective stabilisation and resolution



9 km too weak, 4 km needed, little improvement beyond, explicit too deep, conv scaling active up to 1 km

Majumdar S., L. Magnusson, P. Bechtold, J.-R. Bidlot, J. Doyle, MWR 2023

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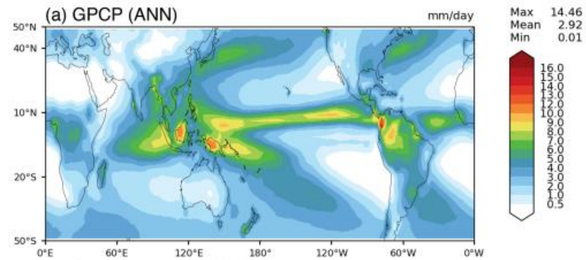
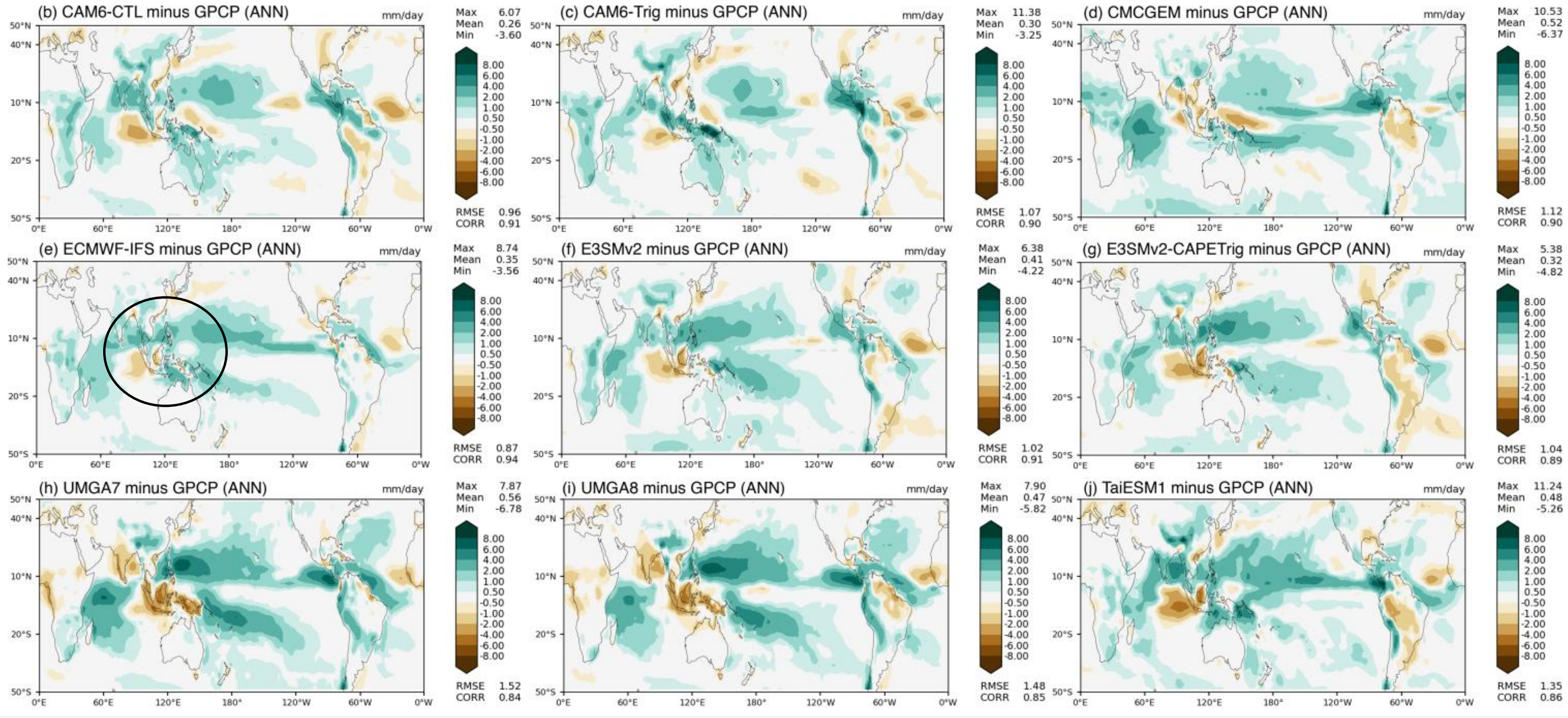
The GEWEX diurnal cycle project and what we can learn from global models/circulation

Something general across models ???
IFS 47r3

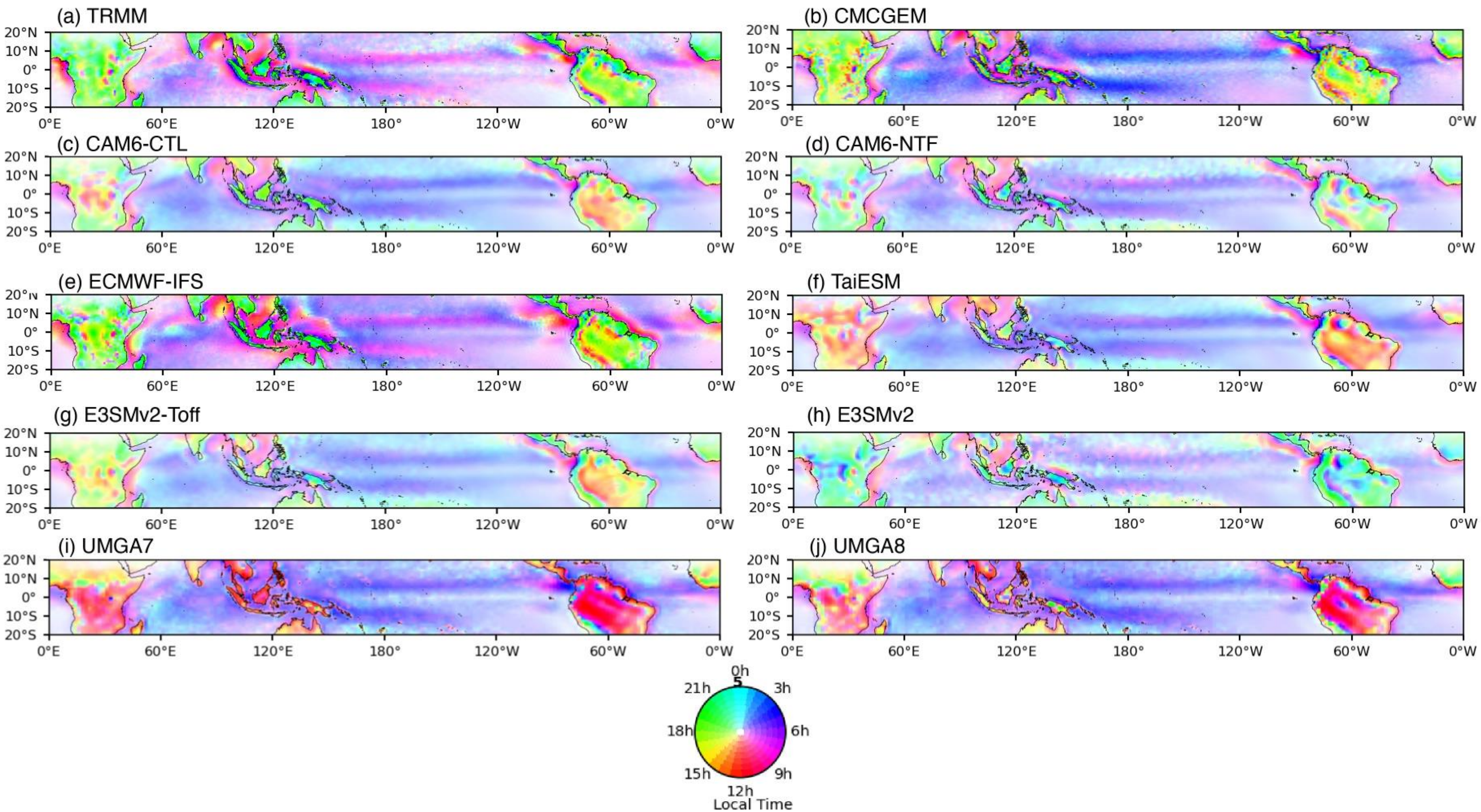


Precip-SST coupling good!
Precip-wind coupling ??

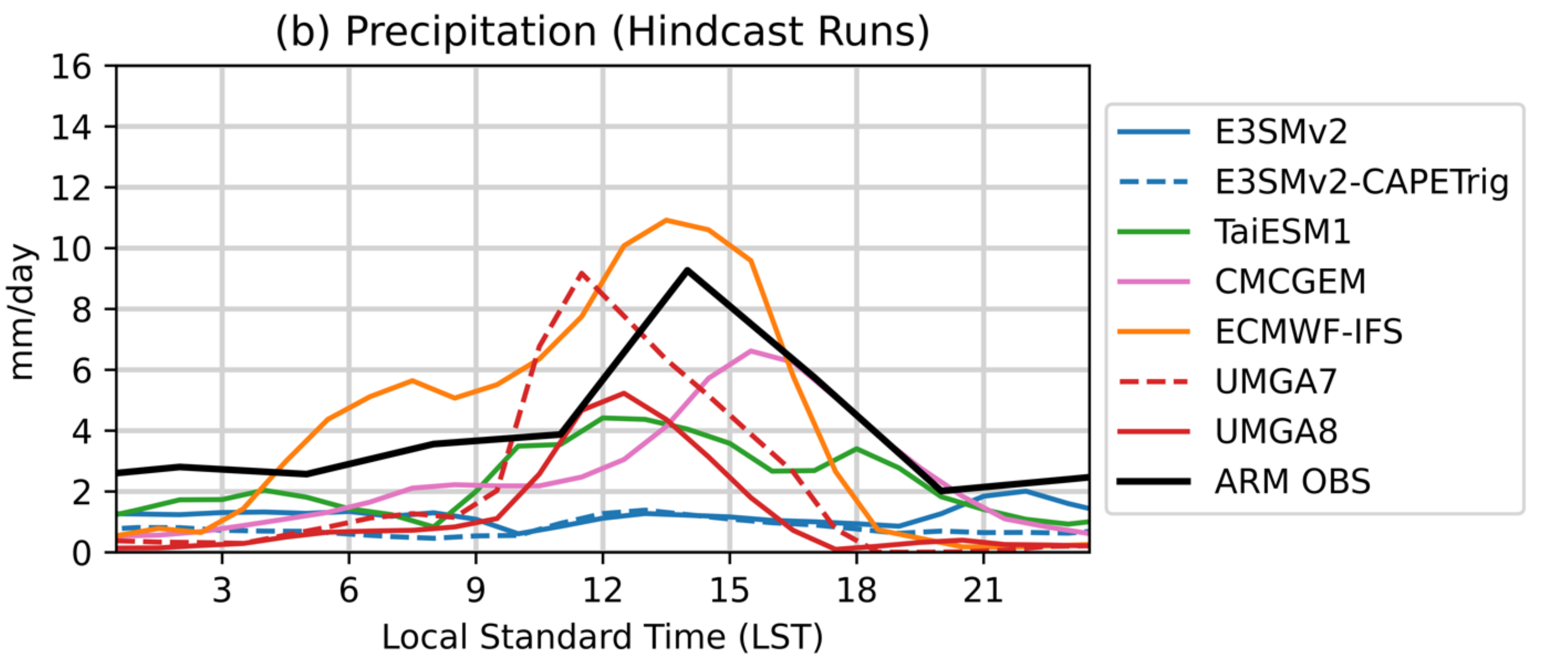


Tao, C, S. Xie, H.-Y. Ma, P. Bechtold et al. QJRMS 2024

Diurnal cycle: phase of precip vs Obs, all models

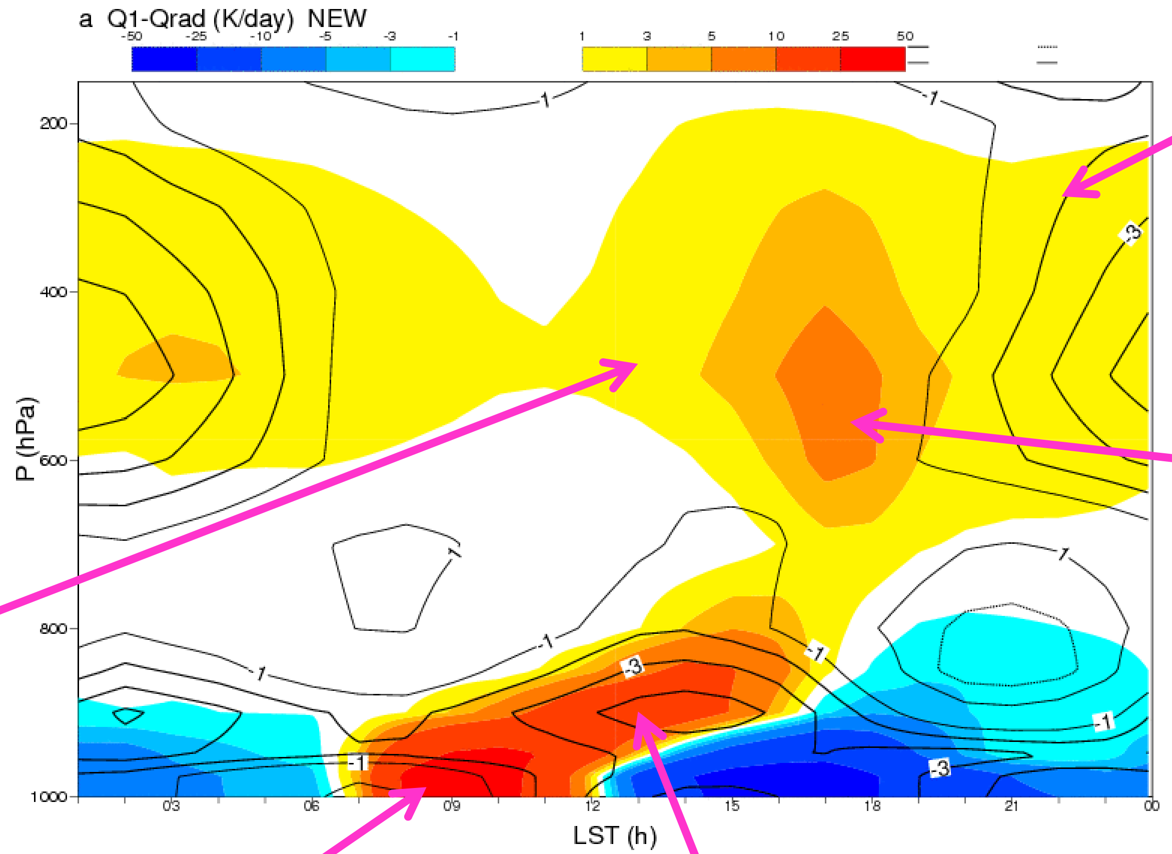


Diurnal cycle: looking closer, composite over Great Planes



IFS performing reasonably but underestimating night-time convection. Getting phase and amplitude difficult for models.

Diurnal evolution of total heating profile Q1 minus radiation and dynamic "response"



Lifting "following" heating – in explicit convection these are in phase

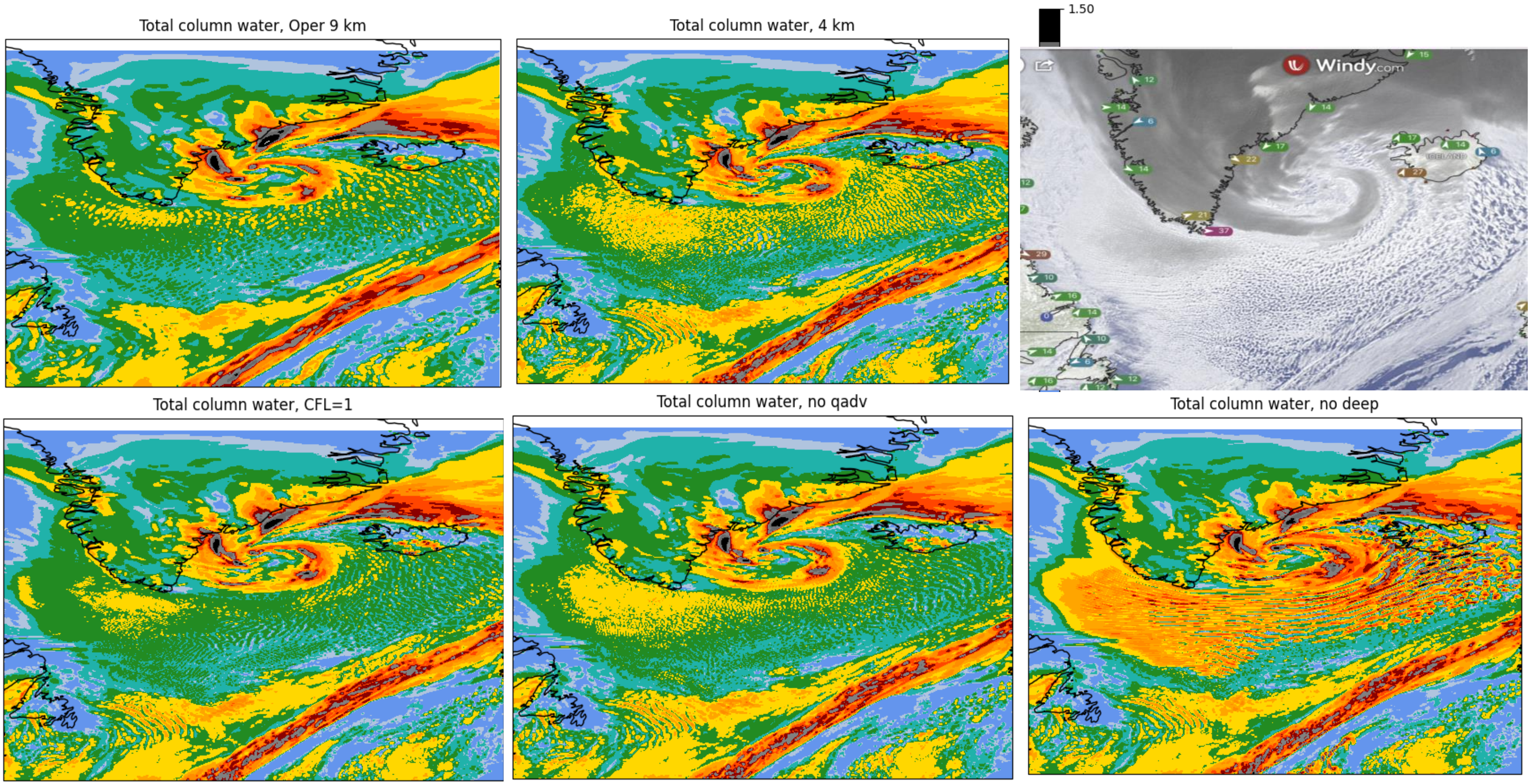
Deep convection

congestus

Turbulent heat flux

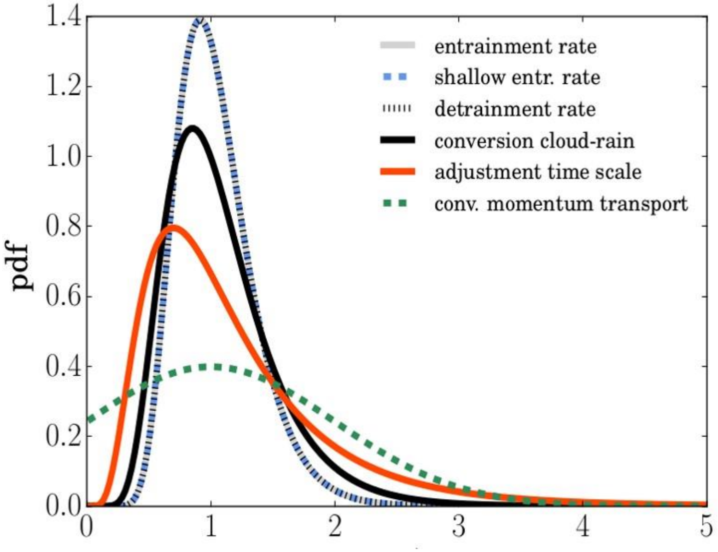
Shallow convection

Realism of convection : cold air outflow 20220207 15 UTC



Structures are created by model dynamics, but physical mixing/heating affects scale and intensity

Ensemble representation SPP=Stochastic Parameter Perturbations (Cy49r1, summer 2024)



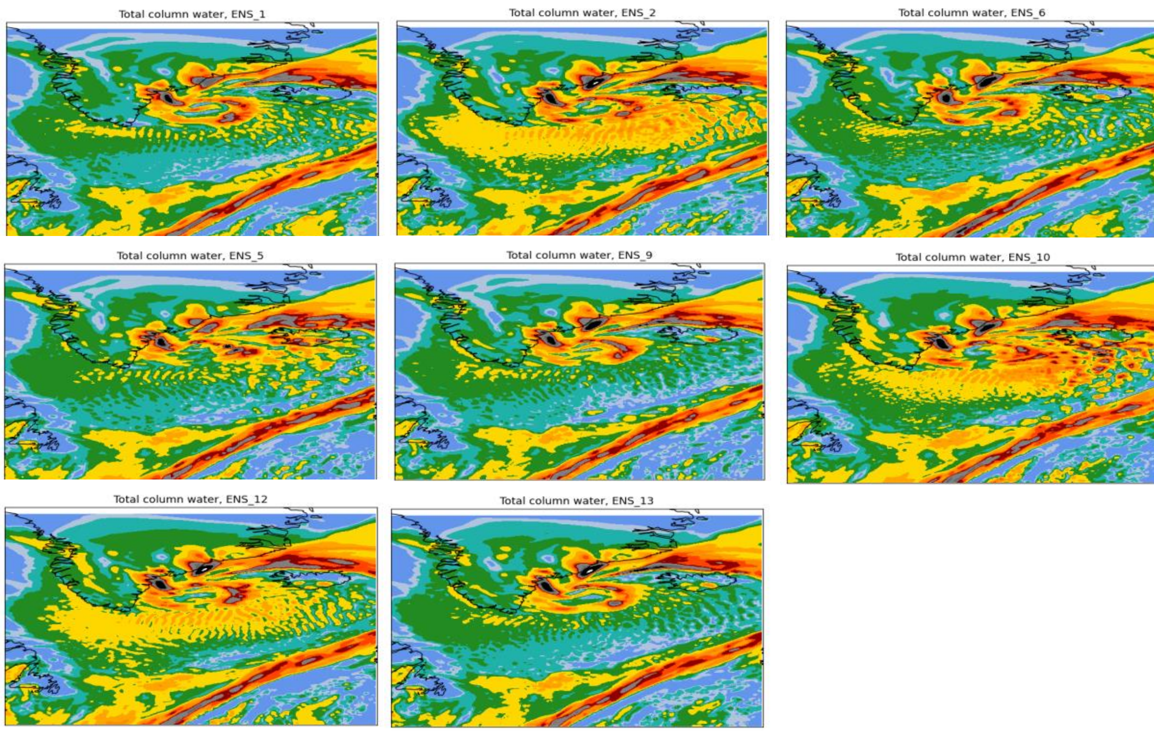


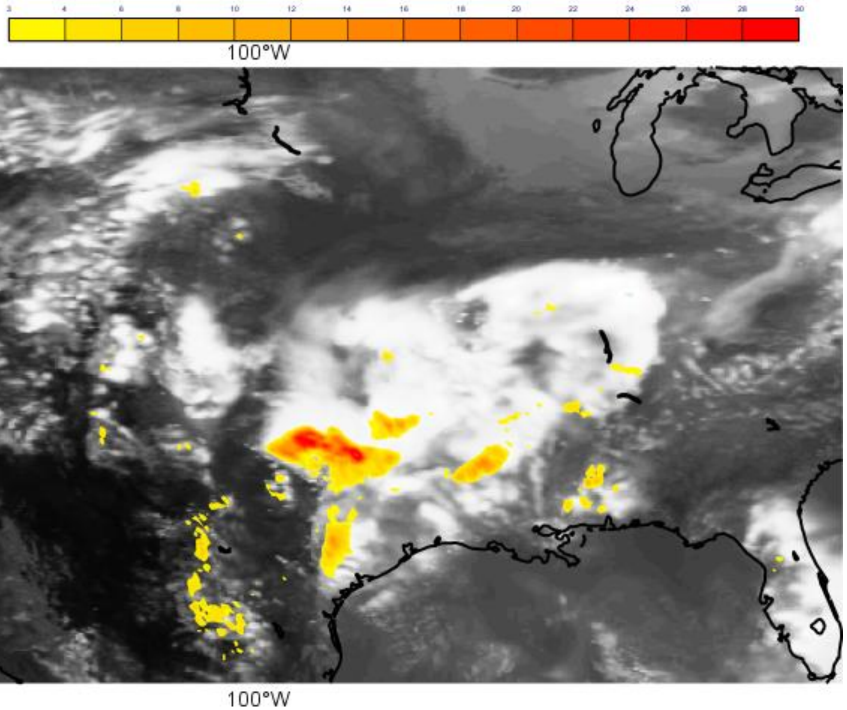
Figure: Pdf of perturbed convection parameters and standard deviation (spread) of total precipitation during August from 15-member ensemble runs

Perturbing the 6-7 convection parameters is enough to represent most tropical variability (even more than Stochastic tendency perturbations), but cannot address systematic convection errors

Lightning

Lopez, P., MWR 2010

(b) Synthetic satellite image 10.8 micron infrared 20190616 0 UTC+21 h



The new parameterization predicts total (cloud-to-ground + in-cloud) lightning flash densities from a set of predictors diagnosed from the convection scheme of the IFS:

CAPE, cloud base height, convective condensate, frozen precipitation flux -> converted into Graupel content

$$f_T = 37.5\, Q_R \sqrt{CAPE}\,[\min(z_{base}, 1.8)]^2$$

$$Q_R = \int_{z_{0°C}}^{z_{-25°C}} q_{graup}\,(q_{cond} + q_{snow})\,\bar{\rho}\,dz$$

$$q_{graup} = \frac{\beta\, P_f}{\bar{\rho}\, V_{graup}} \quad \text{(graupel [kg kg}^{-1}\text{])}$$

$$q_{snow} = \frac{(1-\beta)\, P_f}{\bar{\rho}\, V_{snow}} \quad \text{(snow [kg kg}^{-1}\text{])}$$

β = 0.7 over land and 0.45 over ocean (graupel/snow partitioning).

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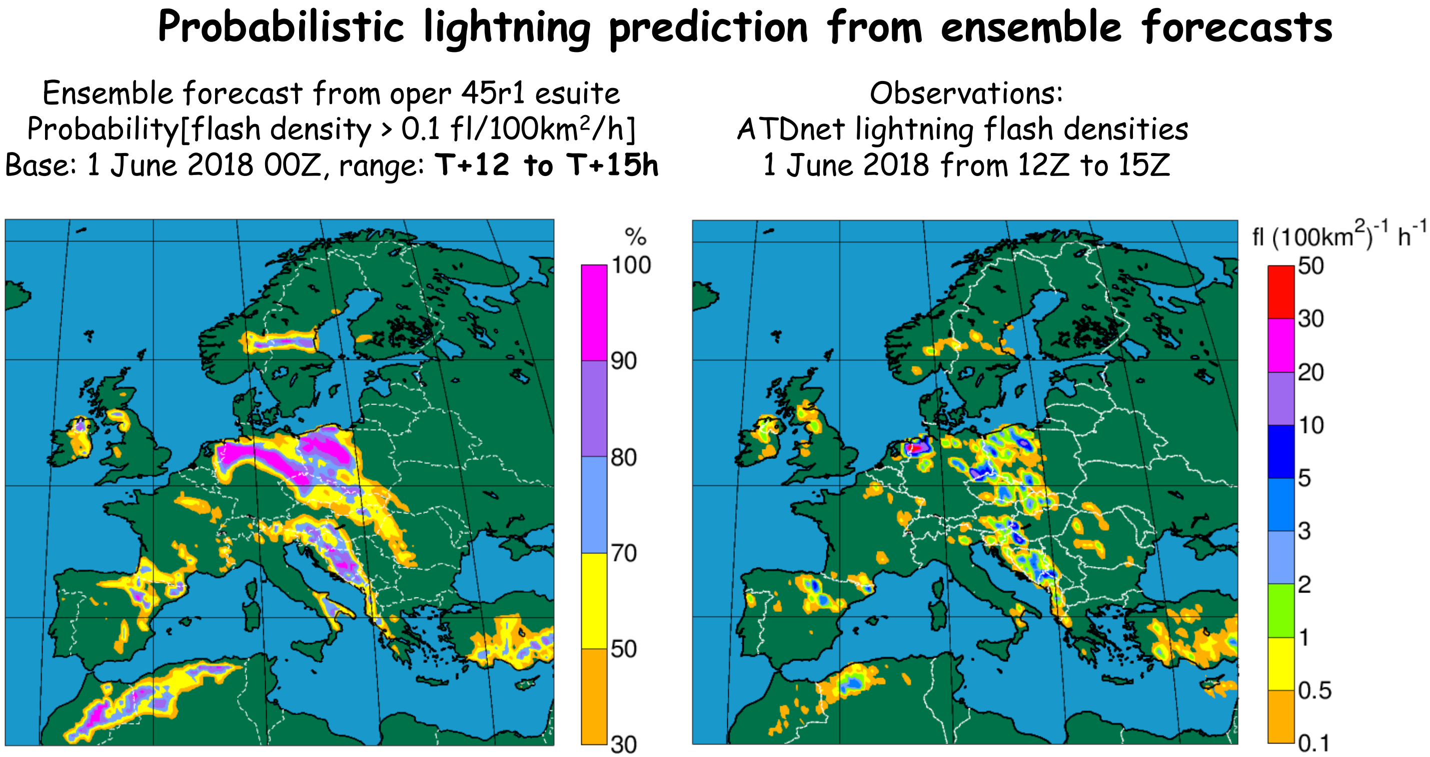

The lightning parametrisation strongly depends on the convection parametrisation

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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:

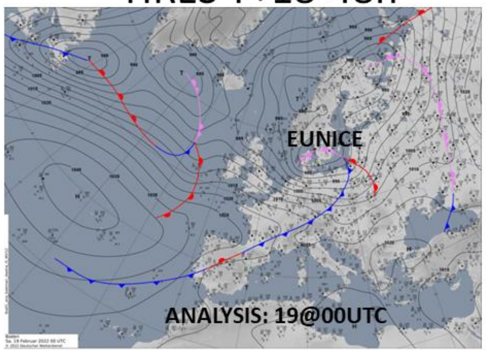
$$U_{gust} = U_{10} + 7.2\ U_{*}\ f(z/L) + \underbrace{0.3\max(0, U_{850} - U_{925})}_{deep\quad convection}$$

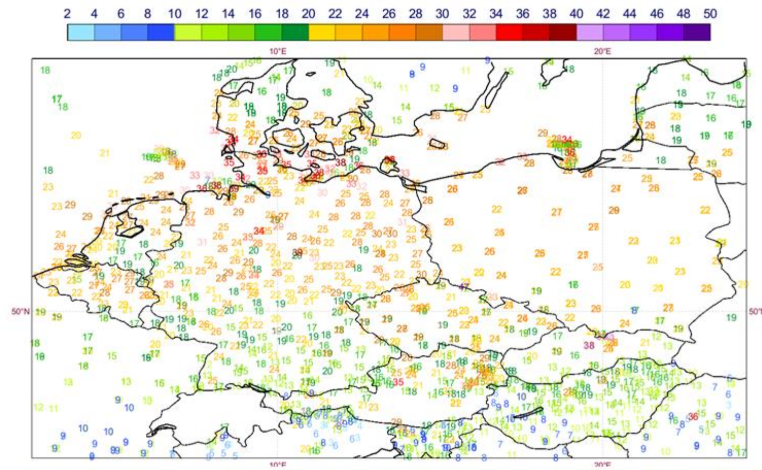
where U_{10} is the 10m wind speed (obtained as wind speed at first model level, or interpolated down from 75m level), U_{*} is the friction velocity – itself obtained from the wind speed at the first model level, and **L** is a stability parameter.

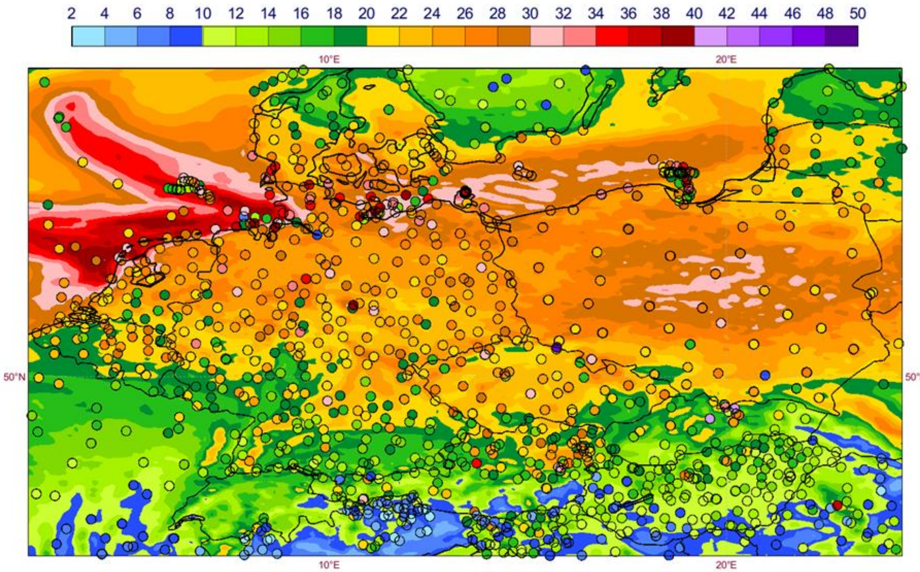
The additional convective momentum transport contribution is computed using the wind shear between model levels corresponding to 850 hPa and 950hpa, respectively.

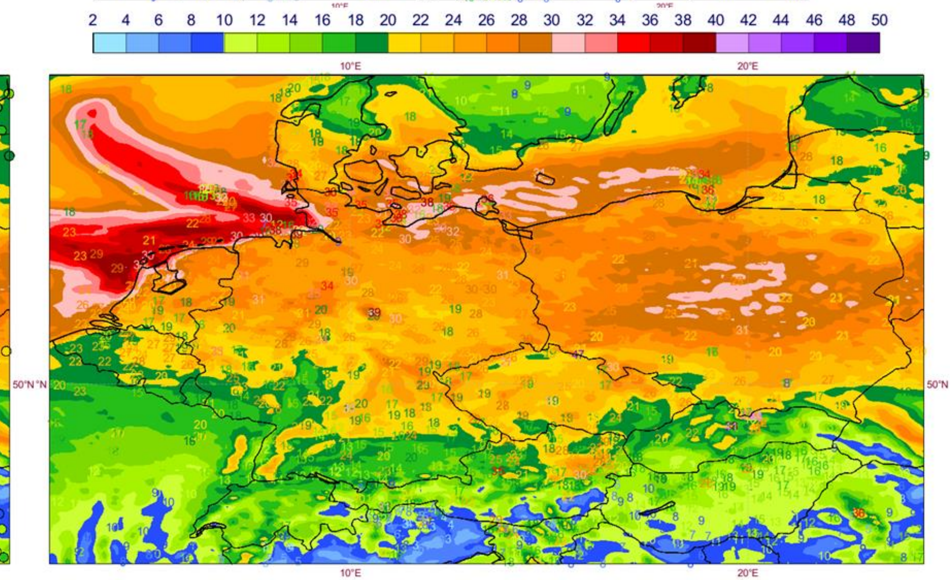
10m Wind gusts: Example storm Eunice

VT: 18/02/22 evening – 20/02/22 00 UTC
HRES T+18-48h









Note: diurnal variations in gusts in model

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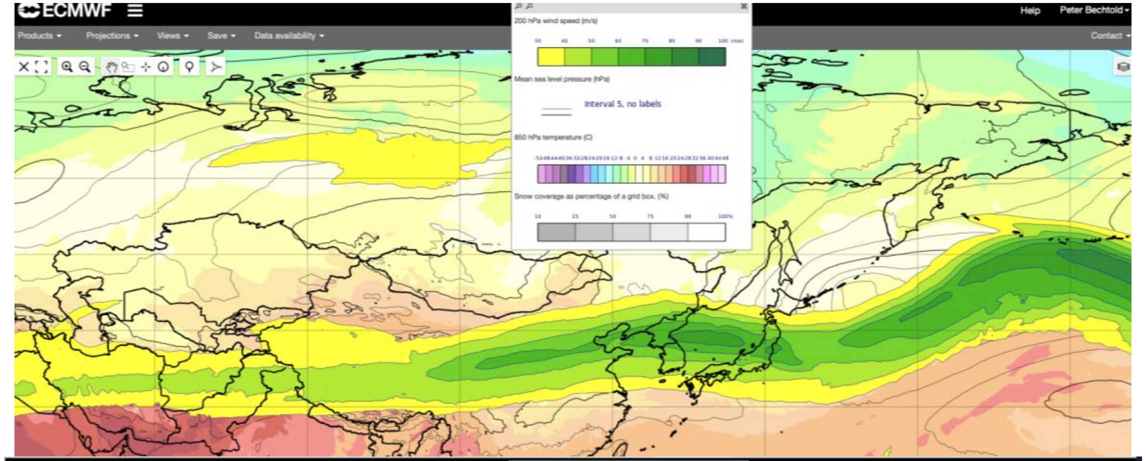
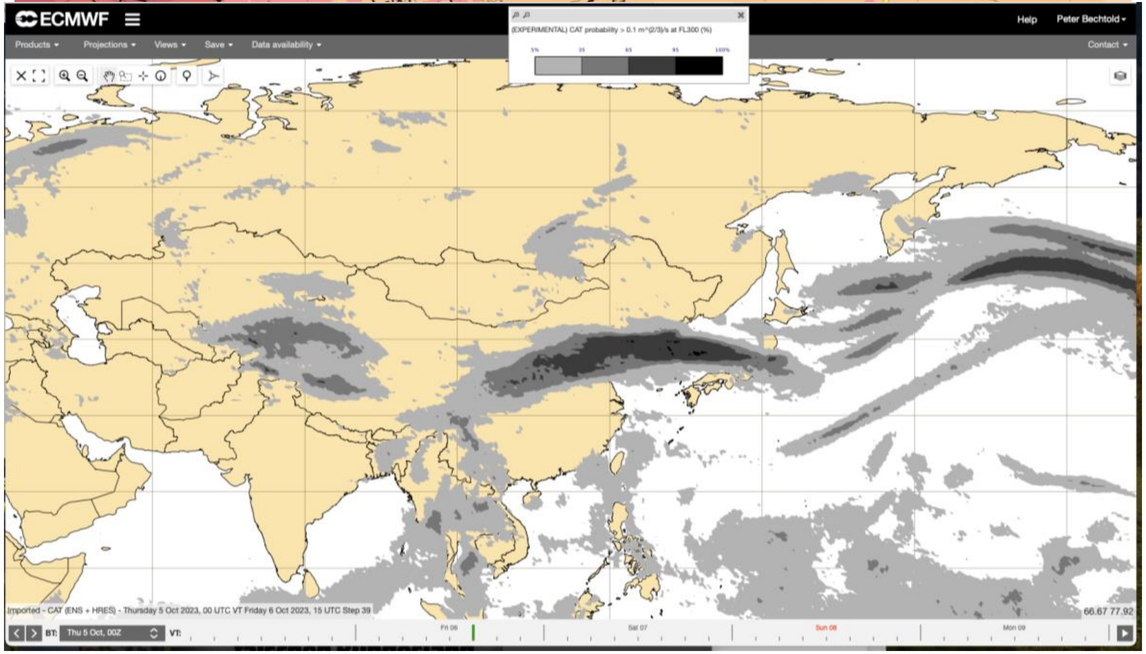
Clear Air Turbulence (CAT) probabilistic

Eddy Dissipation Rate ($m^{2/3}\ s^{-1}$)



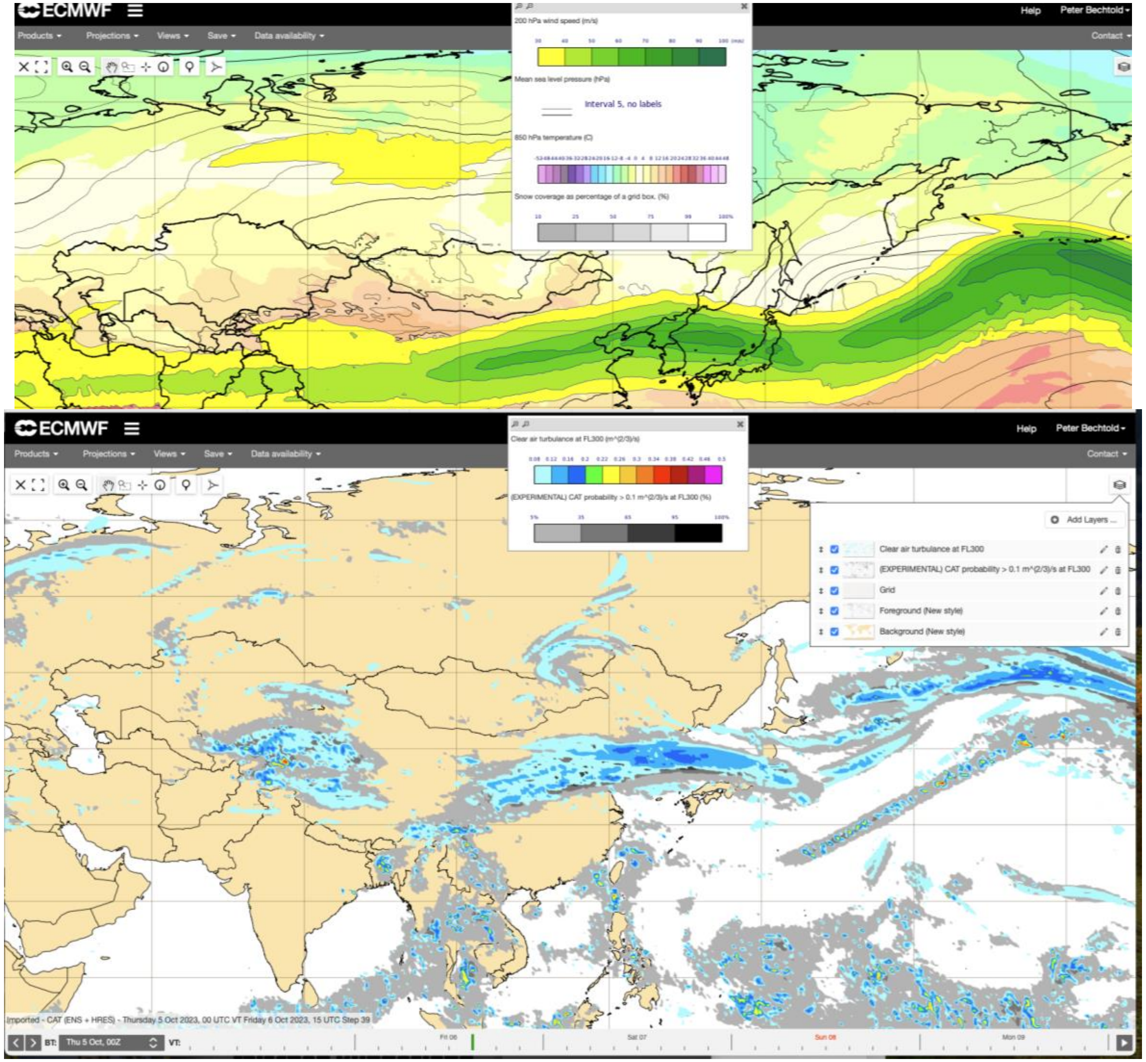
200 hPa



FL300

Clear Air Turbulence (CAT) probabilistic

Eddy Dissipation Rate ($m^{2/3}\ s^{-1}$)



- Correlations good, but maxima likely overestimated
- Overdone model activity (here along frontal waves/noise) reflected in product forecasts
- Would benefit from more continuous evaluation (IATA data costly), radiosonde data (Han-Chang, Hye Yoong et al 2023)
- Ideally one day assimilate data (has information on shear) and have it automatically in 4dVar collocated with model

Simple, try to compute CAT ($m^{2/3}s^{-1}$) from total dissipation (including all sources)

Chosen formalism works with diagnostic K-diffusion (still operational) and or TKE, but ….

$$\mathrm{DISS} = \left| u\frac{\partial u}{\partial t}|_{\mathrm{vdf}} + v\frac{\partial v}{\partial t}|_{\mathrm{vdf}} \right|^{1/3} + \left| u\frac{\partial u}{\partial t}|_{\mathrm{cu}} + v\frac{\partial v}{\partial t}|_{\mathrm{cu}} \right|^{1/3} + \mathrm{GWD}$$

Vdf=turbulent diffusion, including orographic gravity wave drag (blocking+wave breaking)

Cu=cumulus momentum transport

$$\mathrm{GWD} = \left(\left| u\frac{\partial u}{\partial t}|_{\mathrm{gwd}} + v\frac{\partial v}{\partial t}|_{\mathrm{gwd}} \right| \hat{T}_{\mathrm{cu}} \right)^{1/3}; \quad \hat{T}_{\mathrm{cu}} = -\frac{c_{\mathrm{p}}}{\hat{T}_0} \int_{p=500}^{top} \frac{\partial T}{\partial t}|_{\mathrm{cu}} \frac{dp}{g}$$

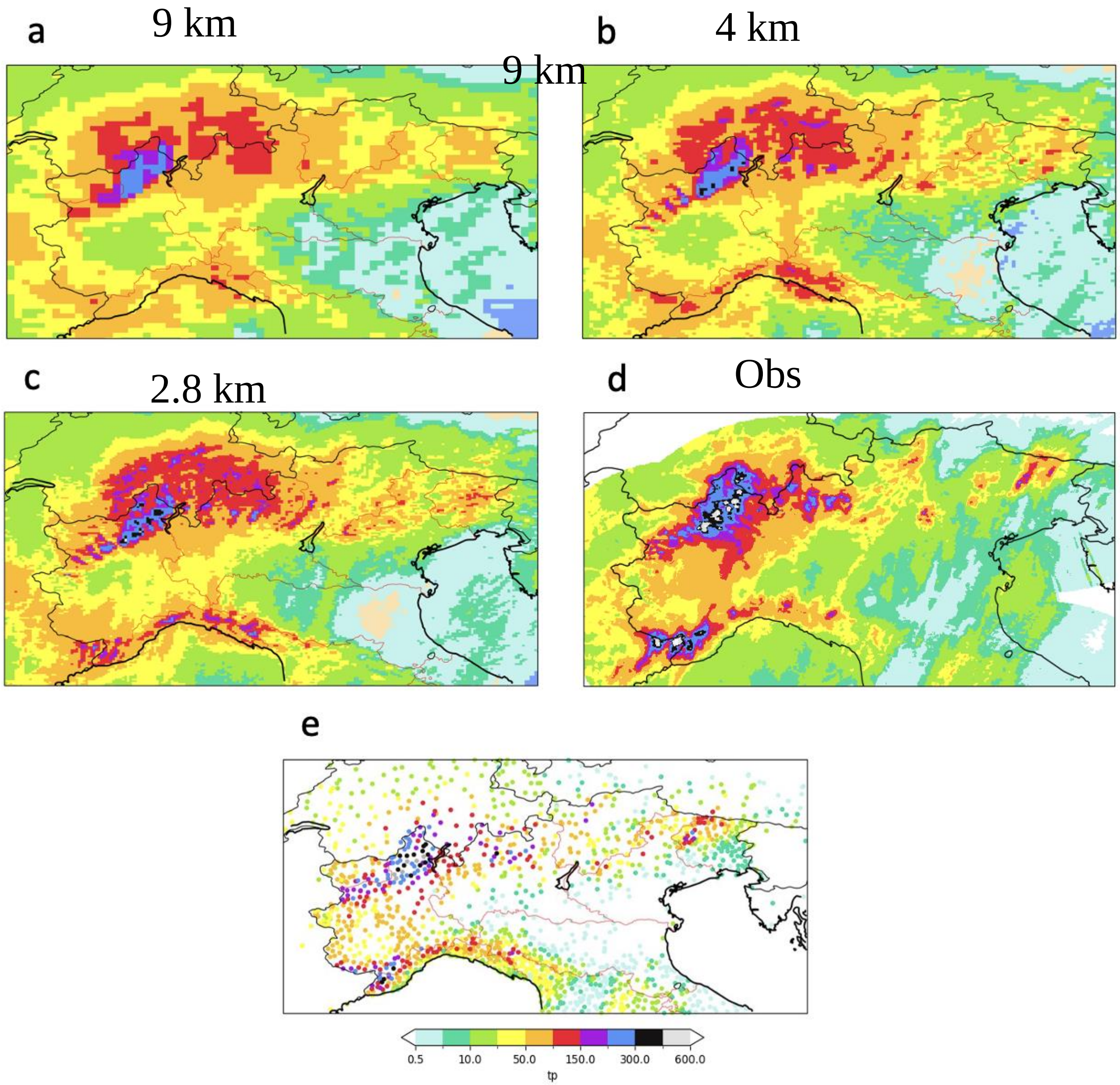
gwd=non-orographic gravity wave drag scaled by convective heating above 500 hPa

Details in: ECMWF Tech Memo 874
ECMWF Newsletter No 168, summer 2021
Dörnbrack, Bechtold, Schumann, JGR 2022
https://www.ecmwf.int/en/elibrary/81370-ifs-documentation-cy48r1-part-iv-physical-processes

Towards global km-scale :

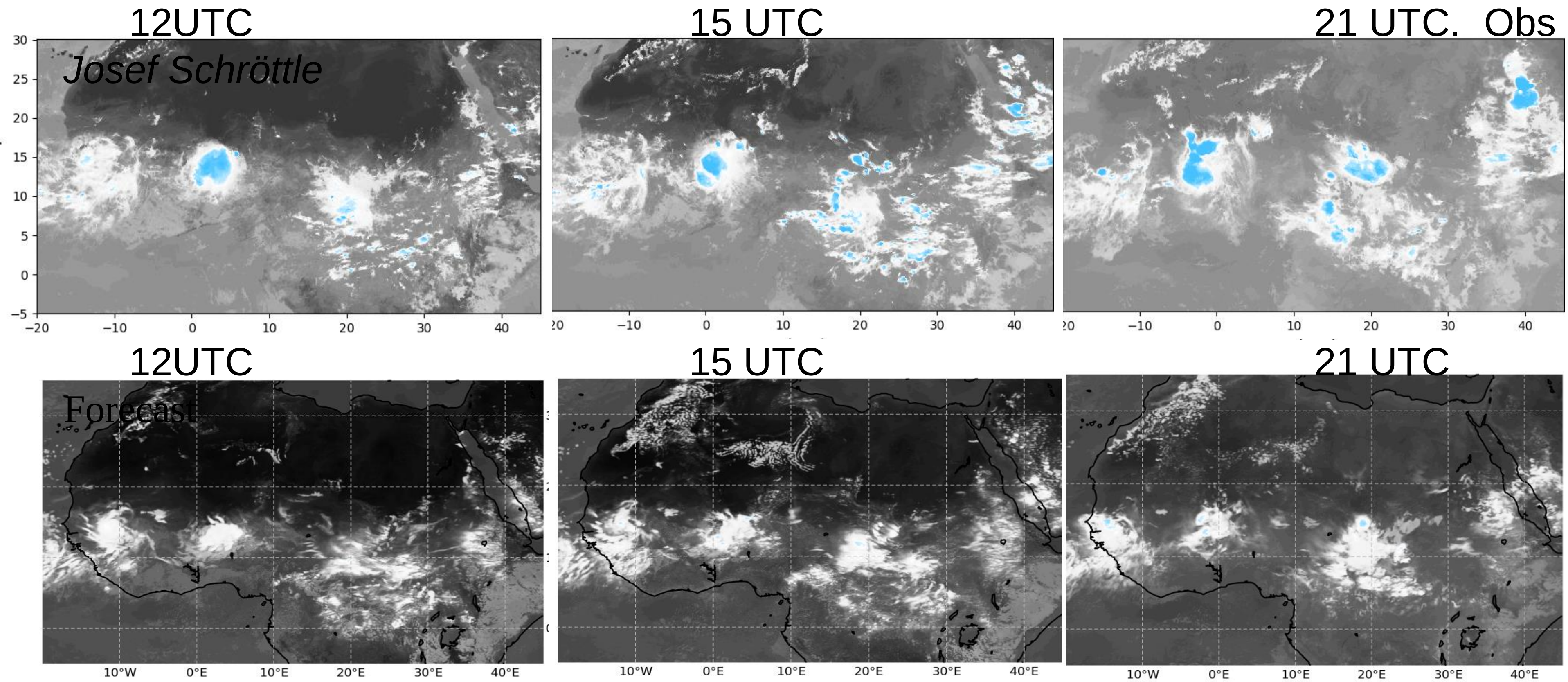
Issues?

The obvious? Precip getting better over orography …

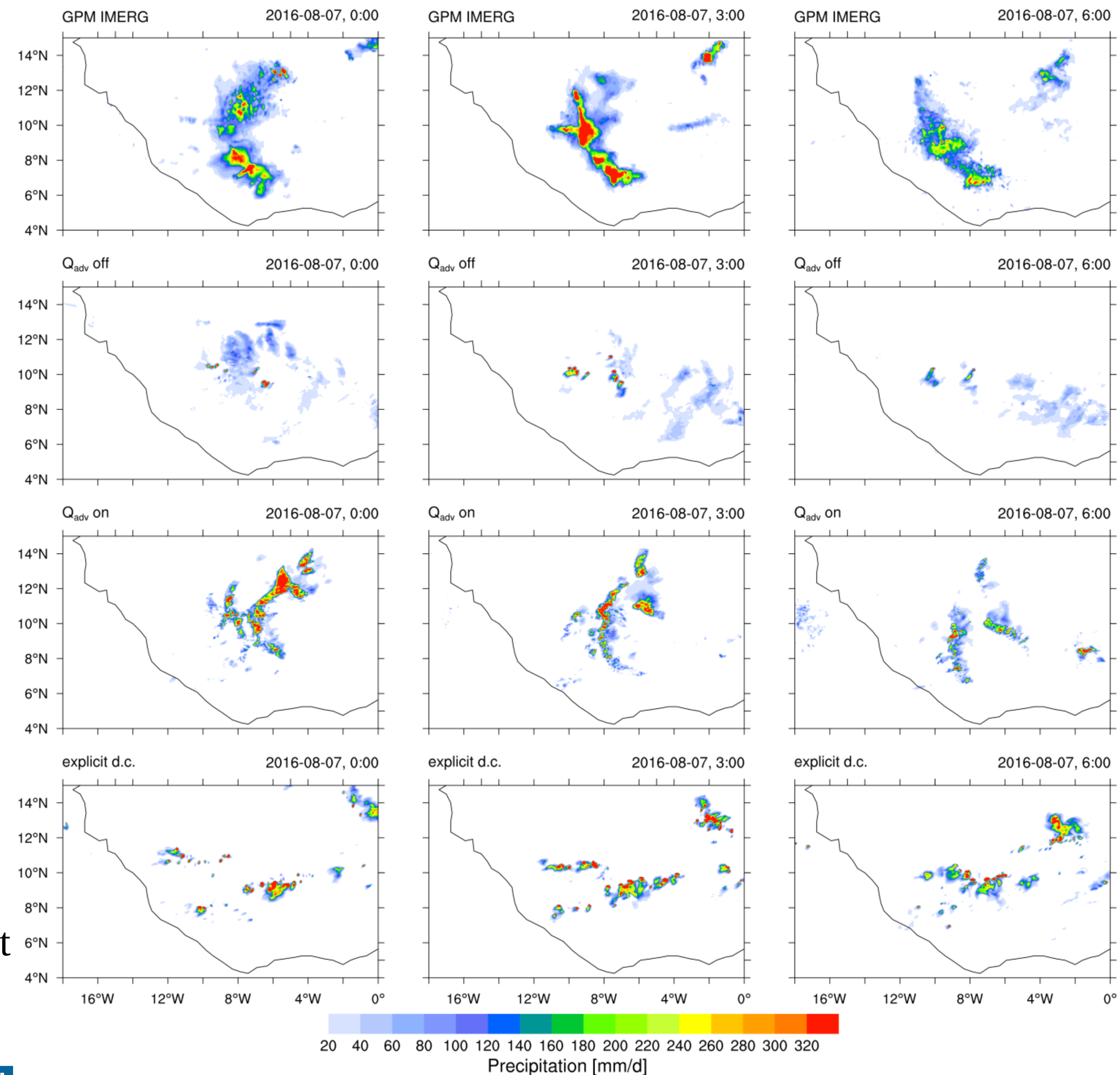


African squall lines

better organization and westward propagation since Cy47r3 (October 2021), moisture convergence, see Becker et al. QJRMS (2021)



Issues: African squall lines no moisture convergence, explicit



not enough organization in IFS explicit

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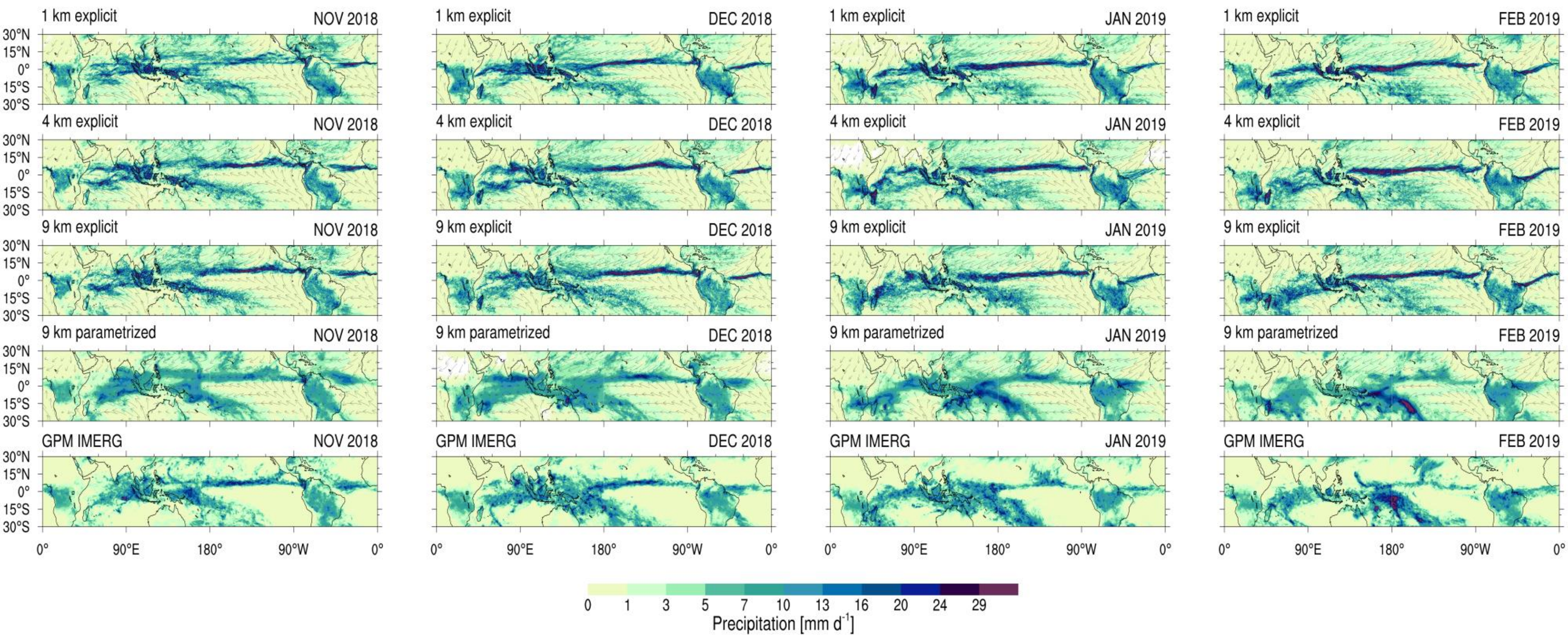
Precip at 1, 4, 9 km vs GPM



with explicit too narrow, stationary ITCZ

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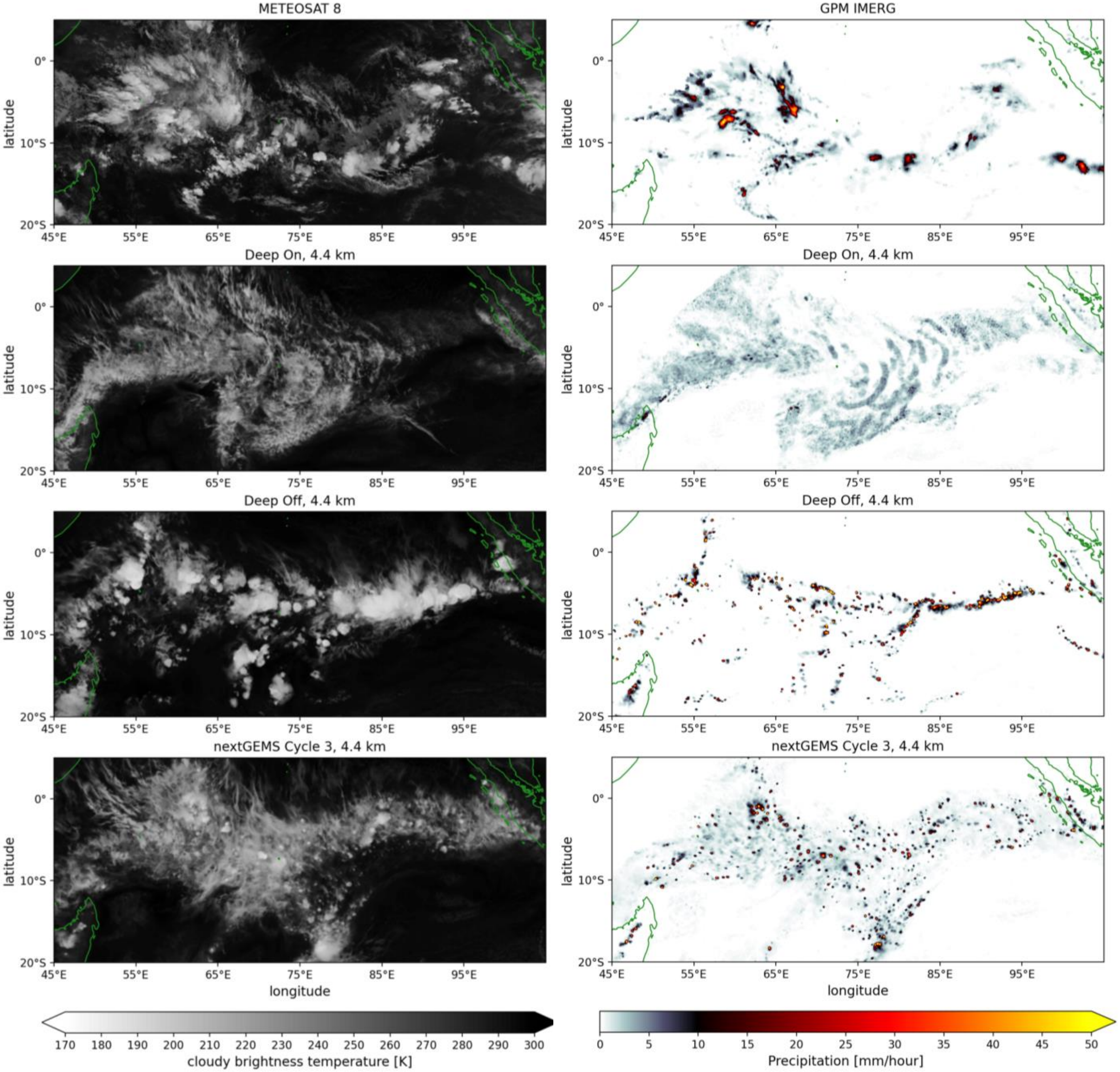
Issues: "ringing" and "blobbing"; gravity waves vs convergence



- **Convection with Deep On (operational):**
  - organises in association with spurious gravity waves rather than in MCS
  - intense precipitation underestimated
- **Convection with Deep Off:**
  - organises in convergence lines and/or too small cells
  - intense precipitation overestimated
- **Convection with reduced M_b:**
  - characteristics in between Deep On and Deep Off but still organises in too small cells
  - intense precipitation realistic but weak precipitation overestimated

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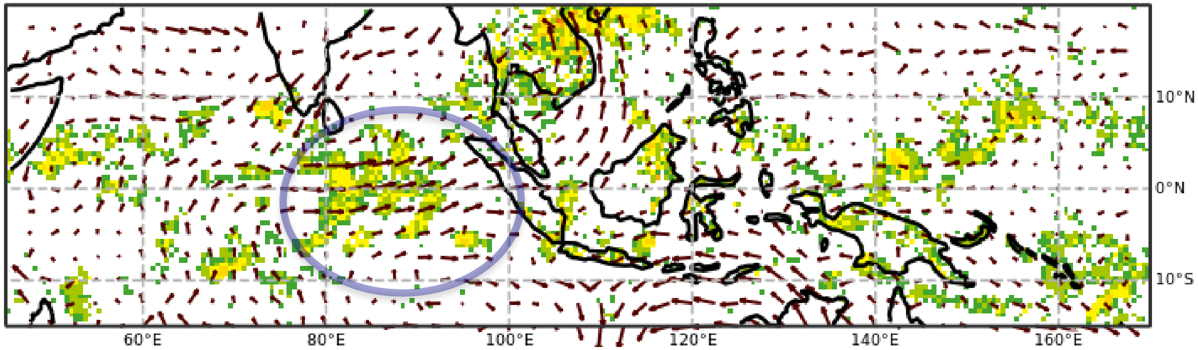
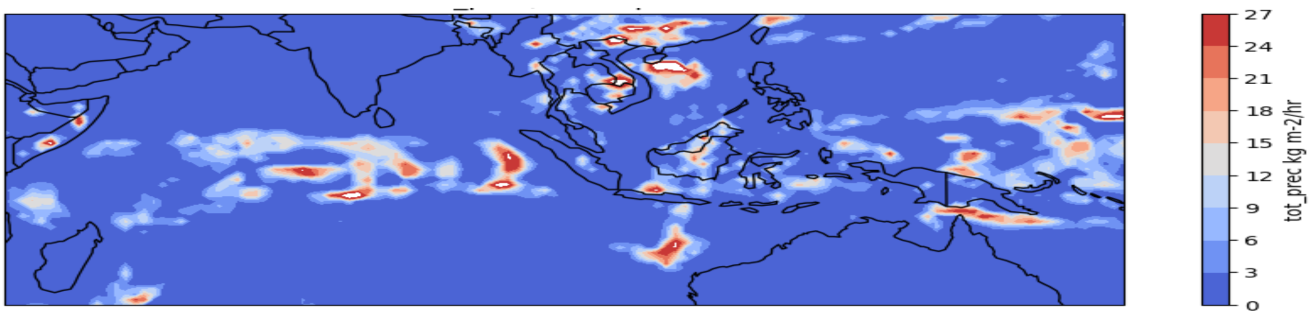
Issues: deep gravity waves – dispersion relation





ICON/DWD
Maike Ahlgrimm

$N = 0.02 - 0.04\ s^{-1}$ ϖ~2π/10800 s
U=10-20 m s^{-1} ;v=0; Lx~600 km   k= 2π/ Lx; m= 2π/ Lz
=> **$\tilde{c}$=c-U=55 m s^{-1} ; Lz~10 km**

$$f^2 < \tilde{\omega}^2 < N^2$$

$$m^2 = \frac{k^2 N^2}{\tilde{\omega}^2} = \frac{N^2}{\tilde{c}^2}$$

wave limit on how fast but not on how slow

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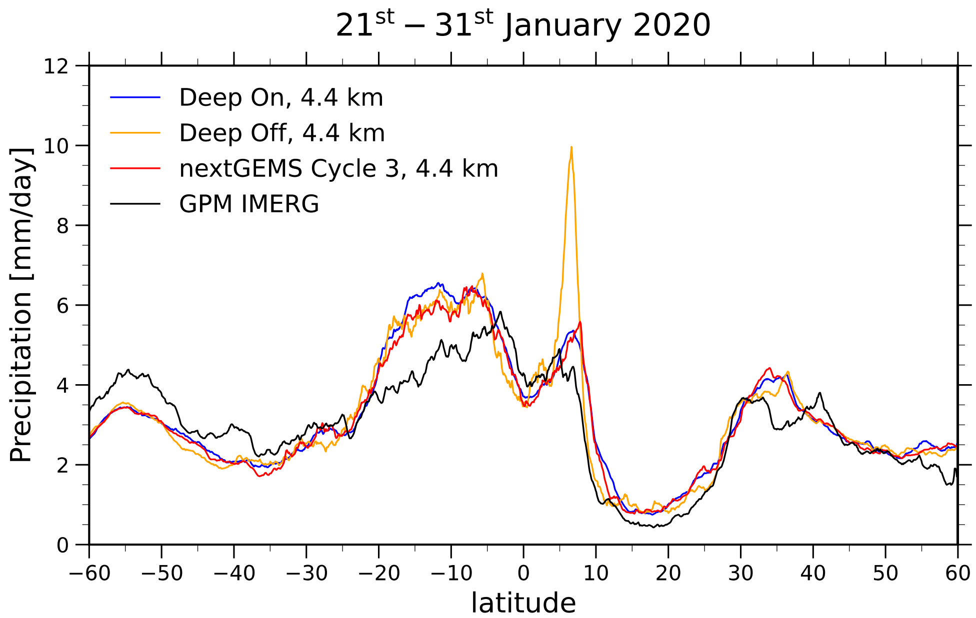
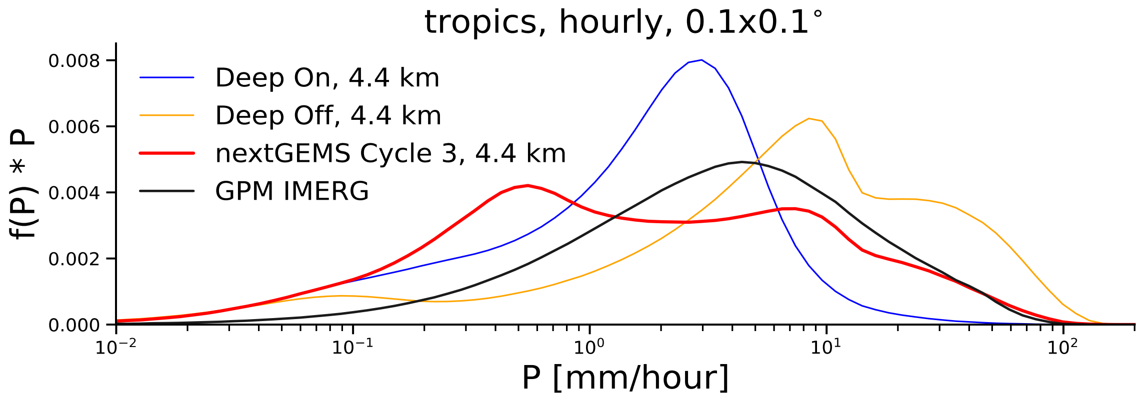
Issues: Precipitation distribution, zonal mean and Pdf





with explicit convection precip is overestimated, both in intensity and zonal mean

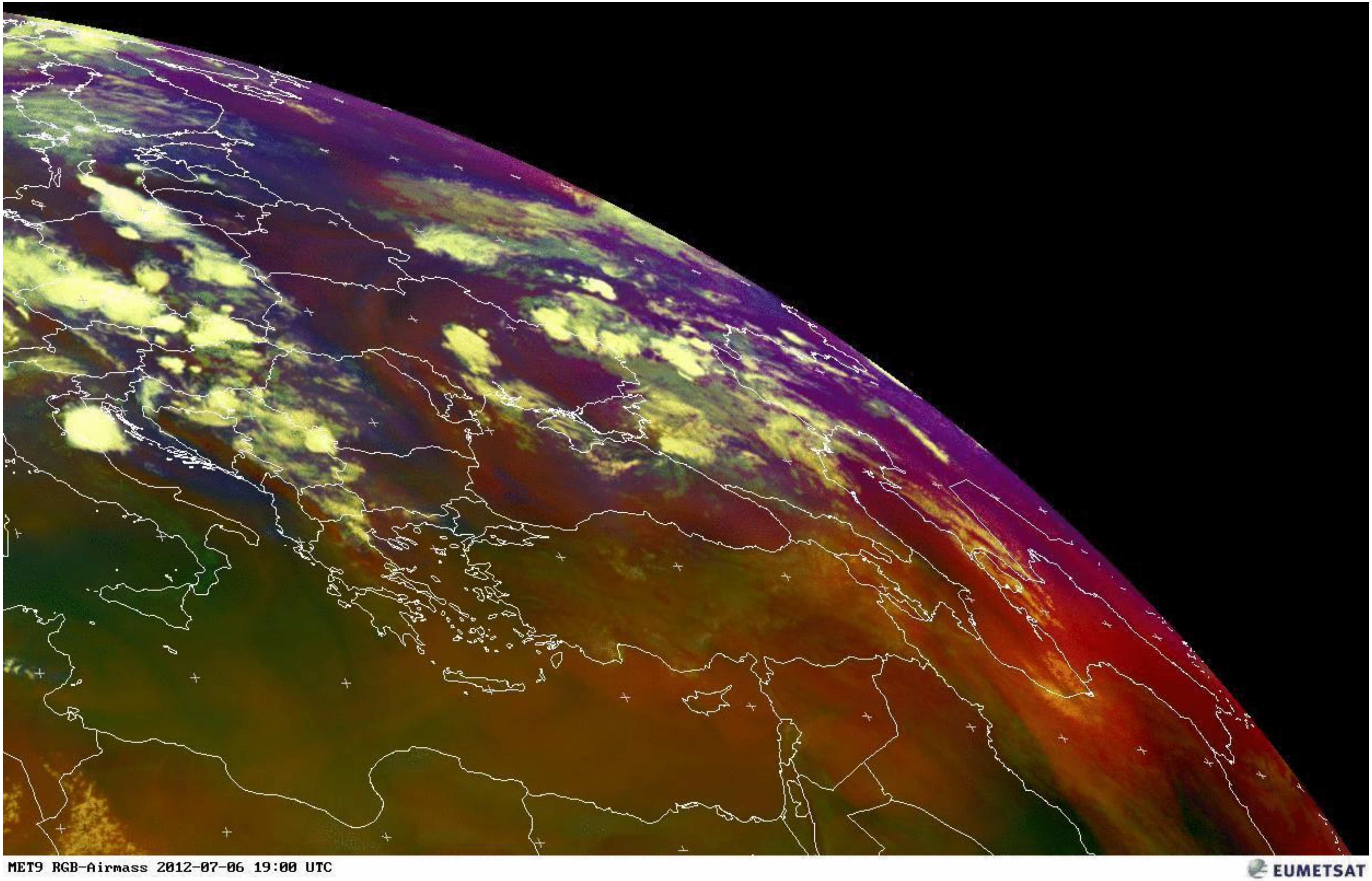
with parametrized zonal mean good, intensities underestimated

with reduced mass flux, result is in between but winds still degraded to standard parametrized

Enjoy some forecasting examples

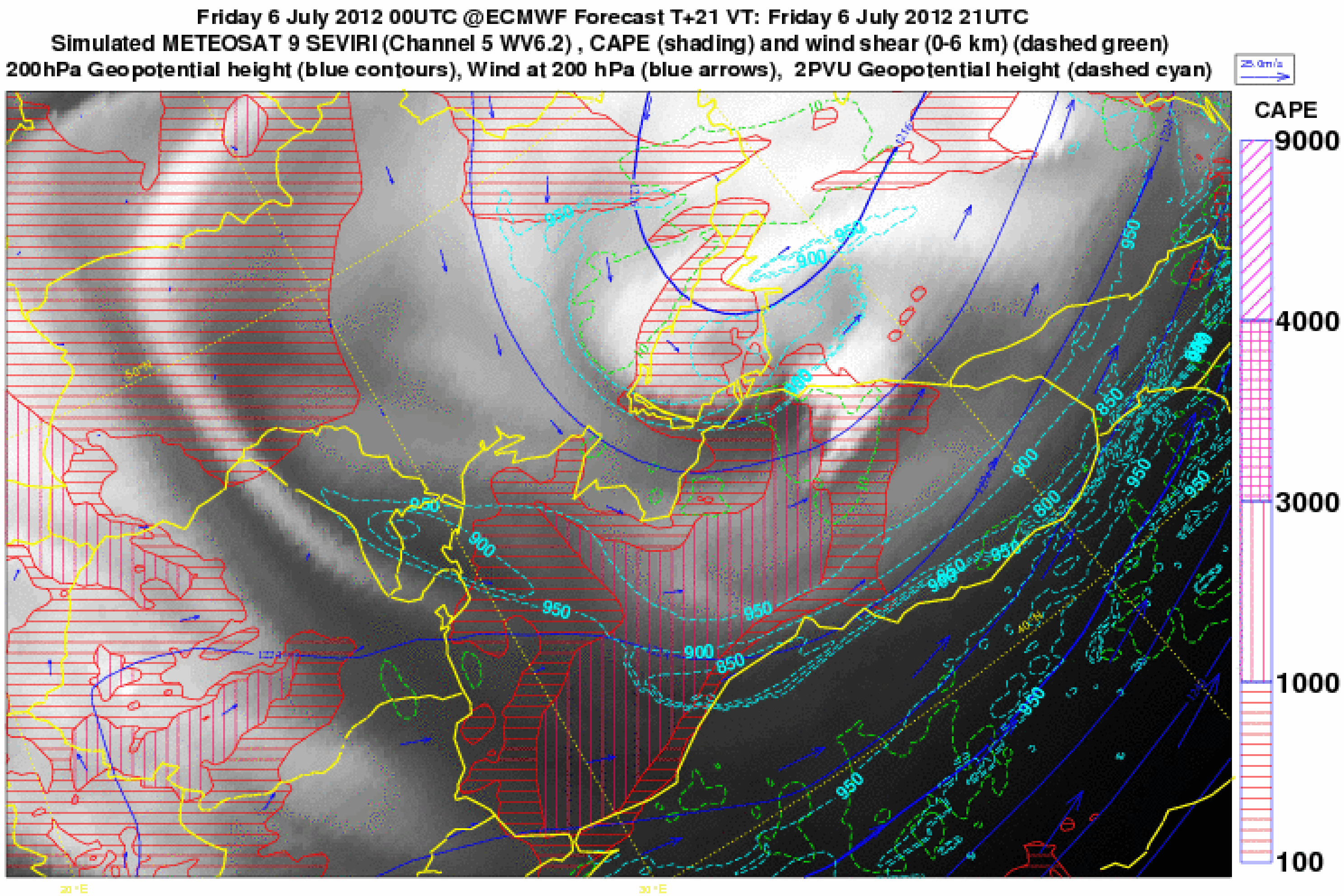
Black Sea system: 6 July 2012

V-shaped System



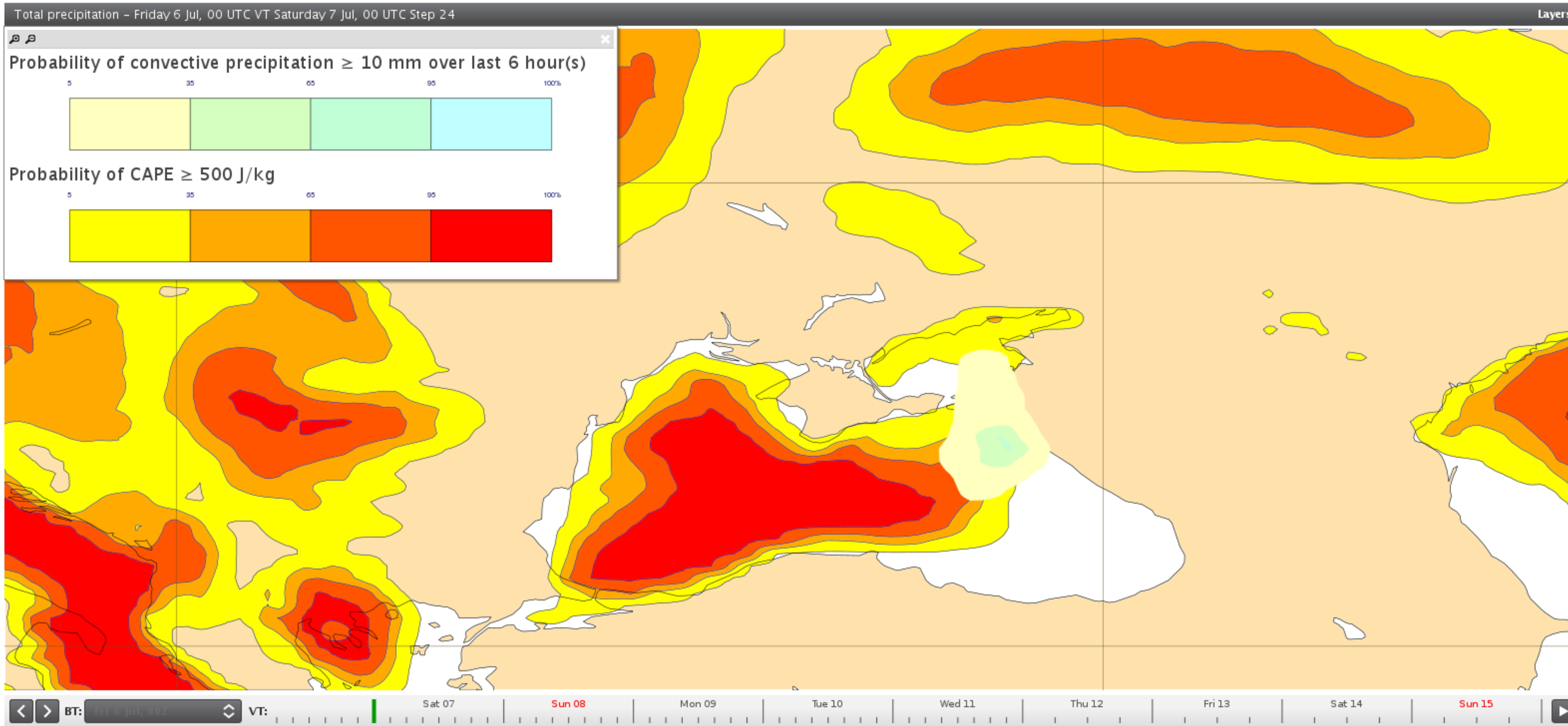
Black Sea system: 6 July 2012 (2)

fc WV image, convective precipiatation and shear



Black Sea system: 6 July 2012 (3)

Probabilities CAPE & precipitation



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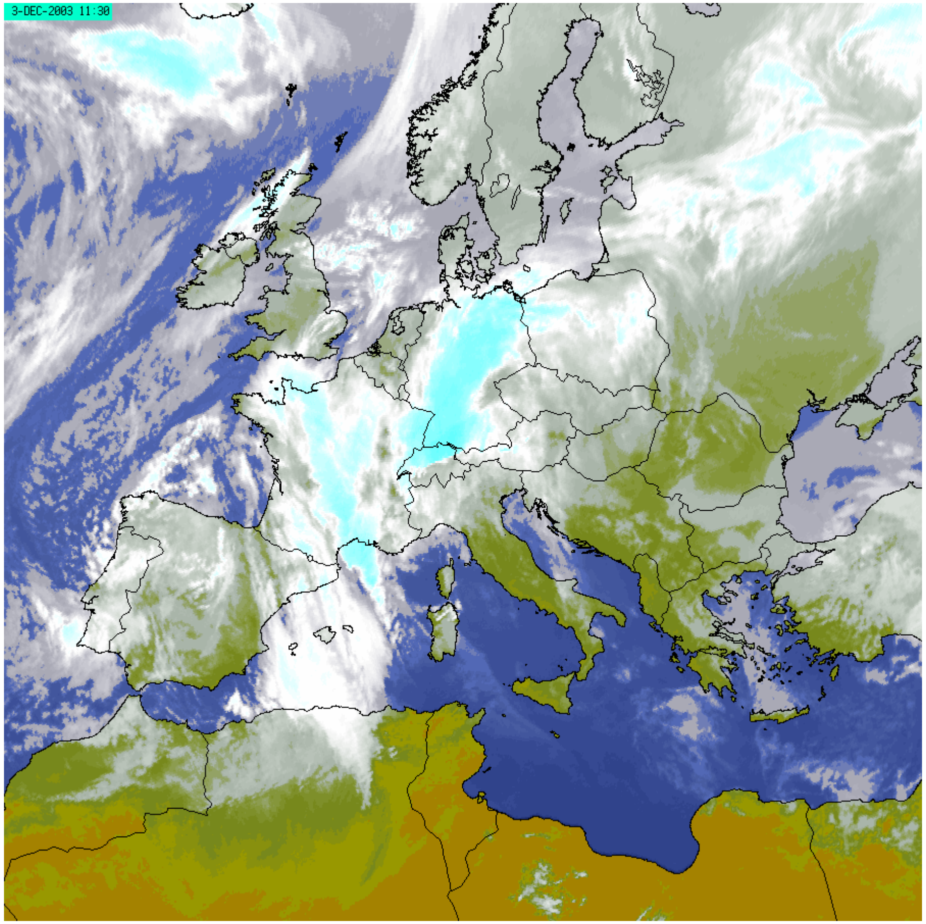
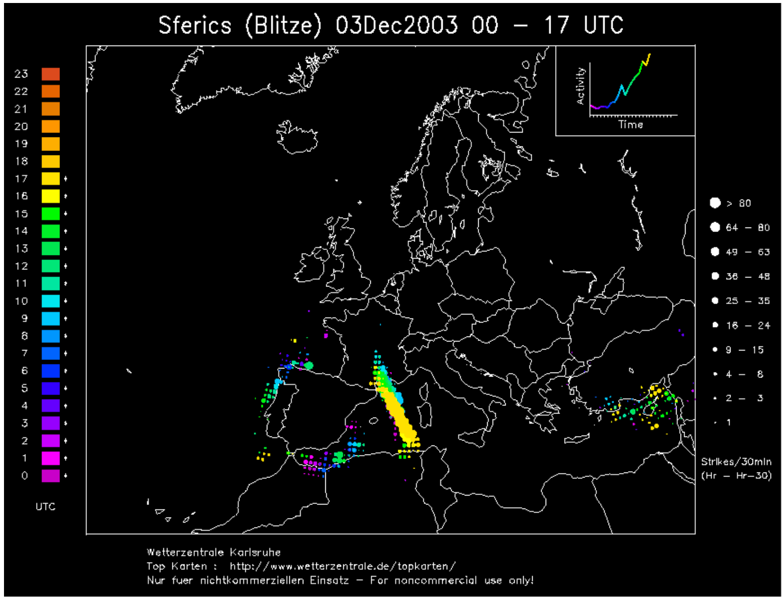
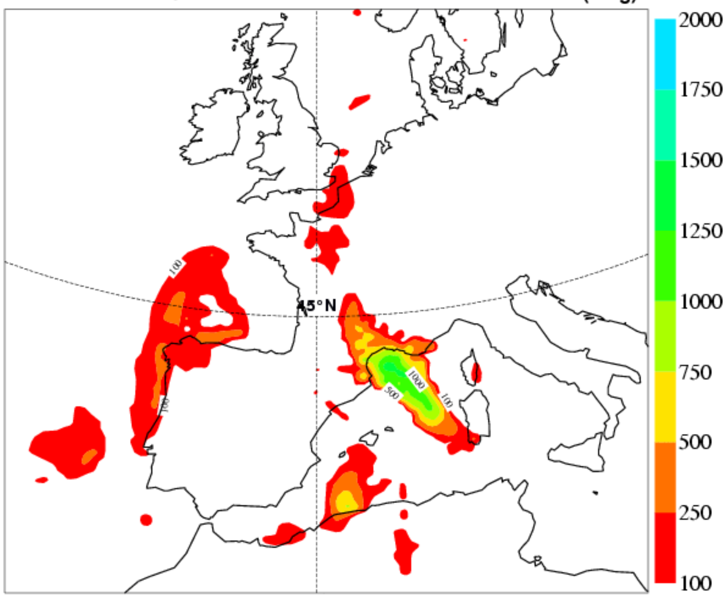
French Floods: 1-3 December 2003 (1)

IR animation V-shaped system







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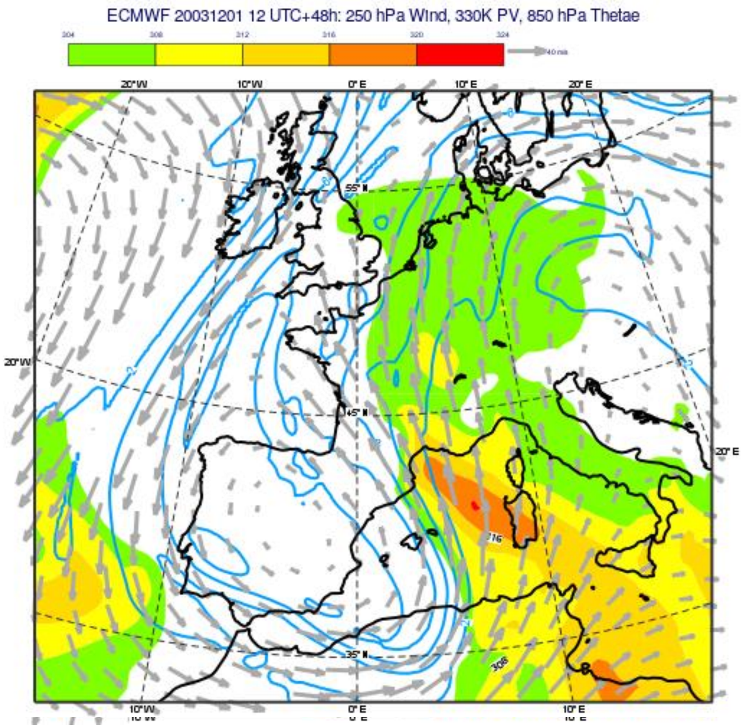
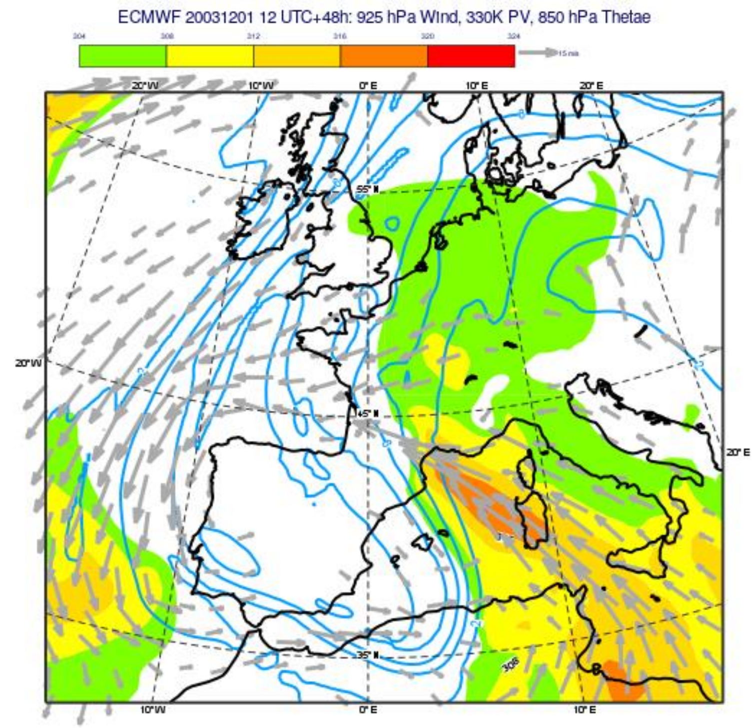
French Floods: 3 December 2003 (2)

upper/lower-level 48h Forecast



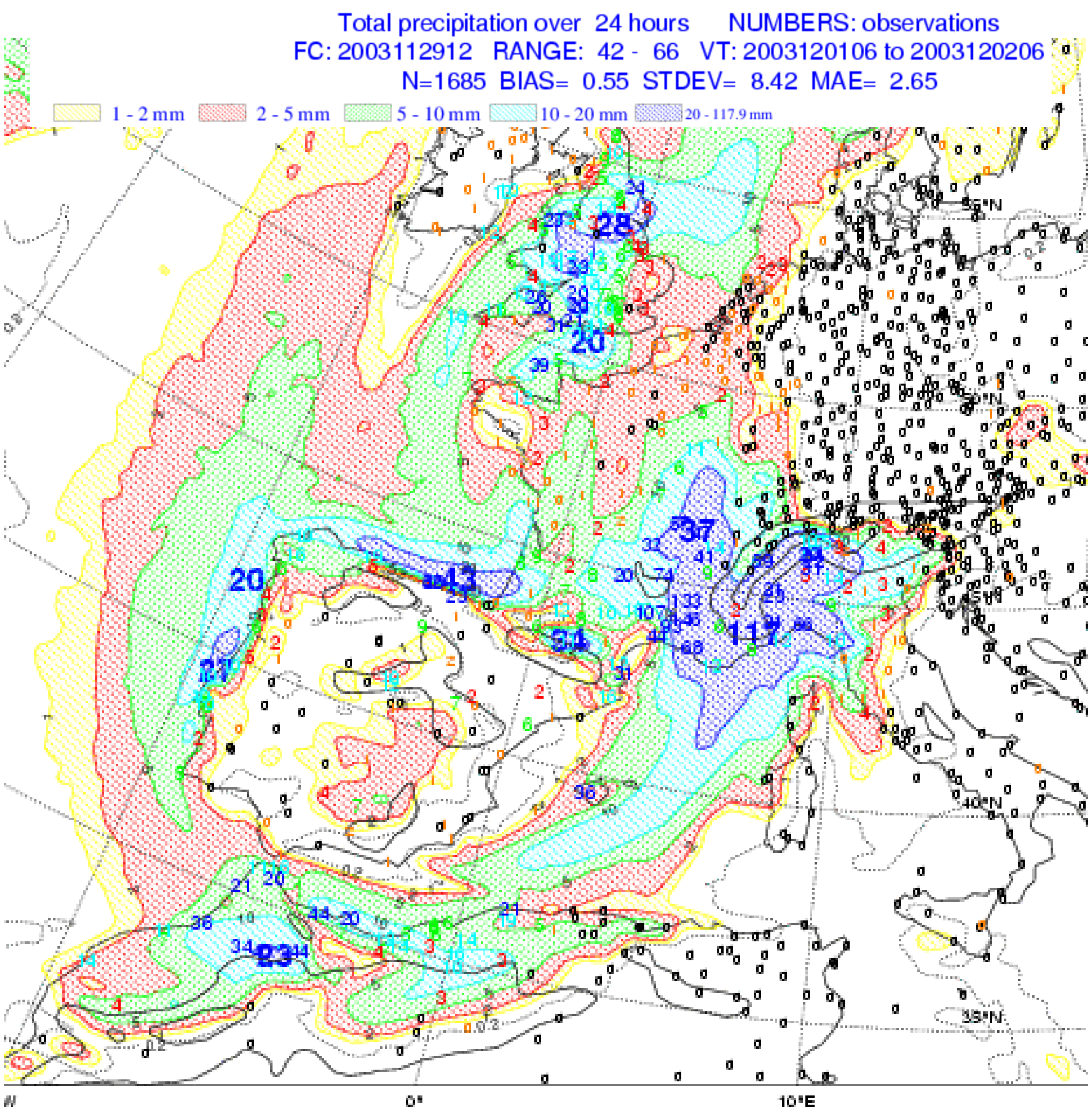


French Floods: 1/2 December 2003 (4)

Precipitation verification

Thin numbers=Obs

Thick numbers= max. Forecast values



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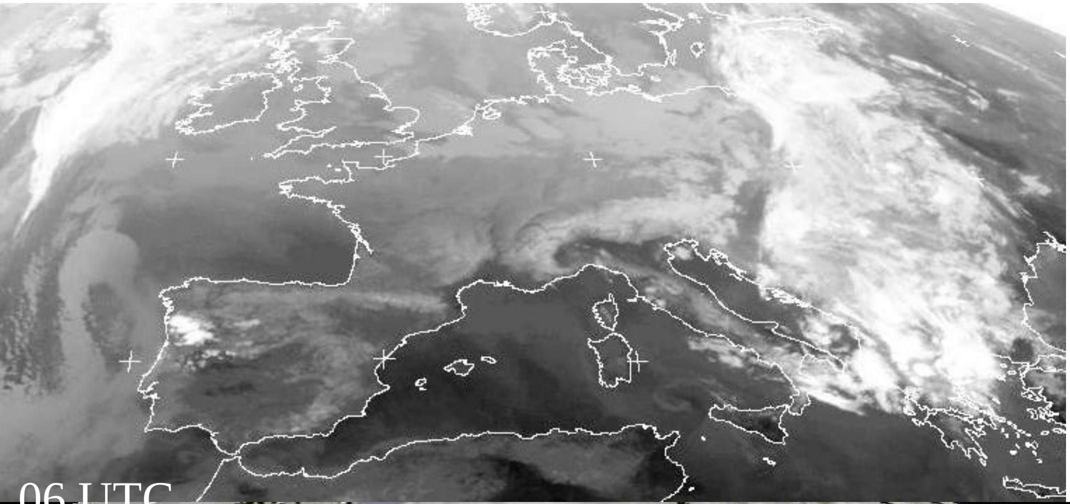
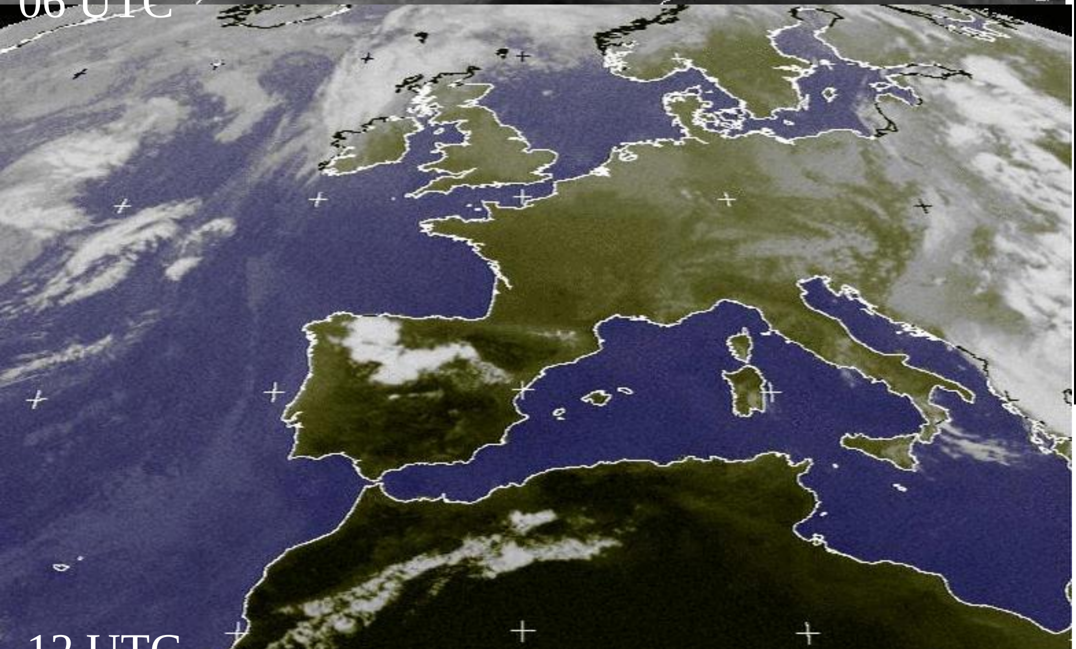
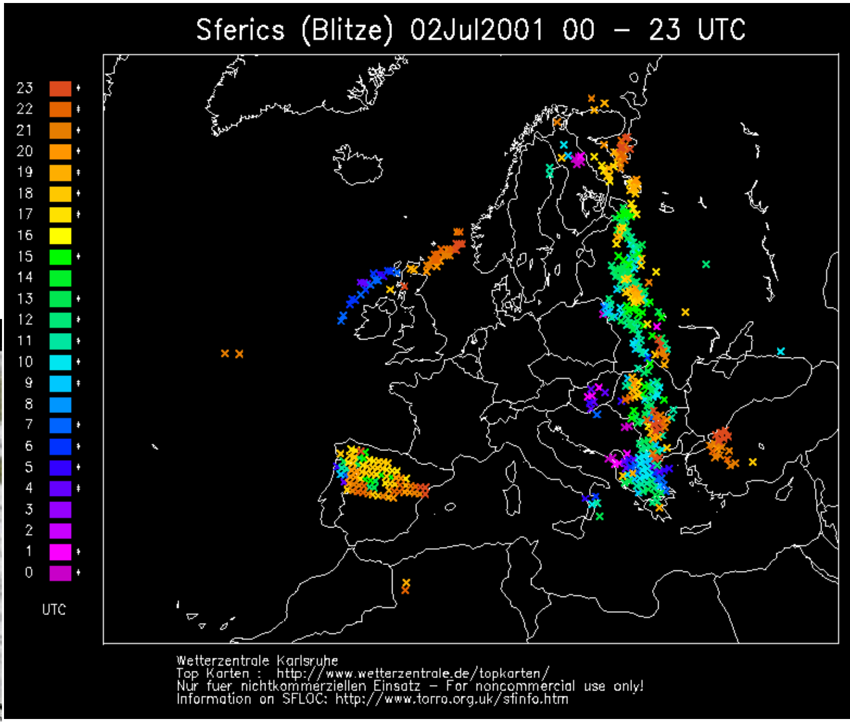
Examples of convective situations over Europe July 2001 –

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



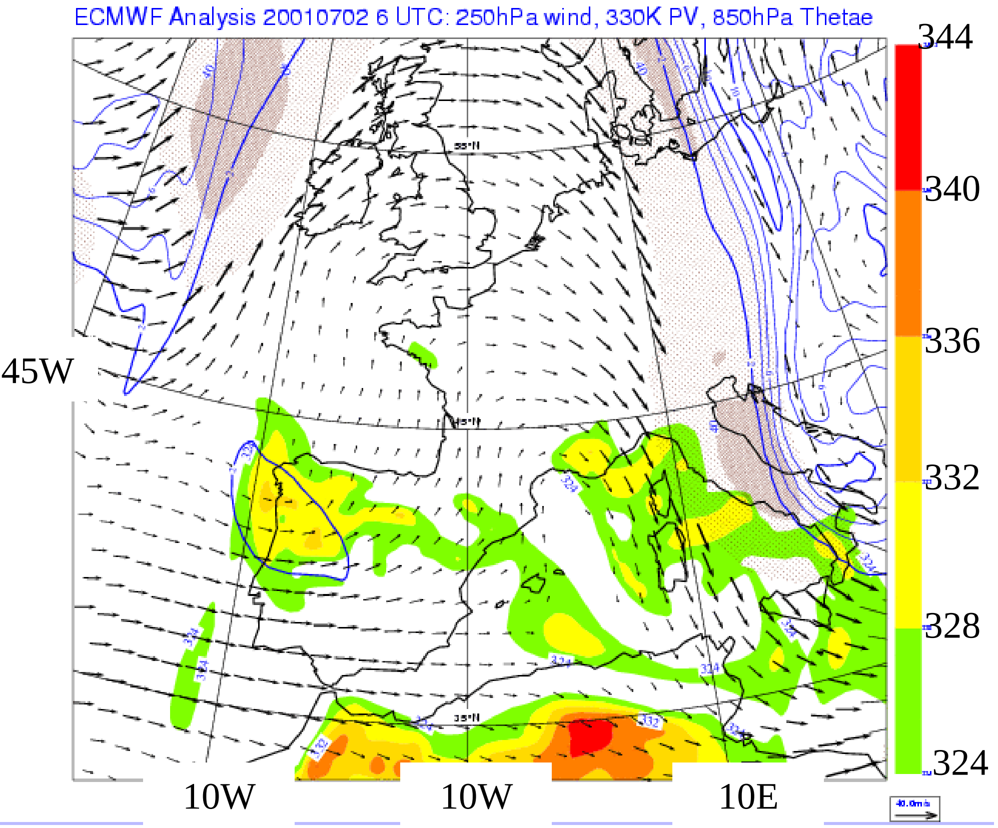




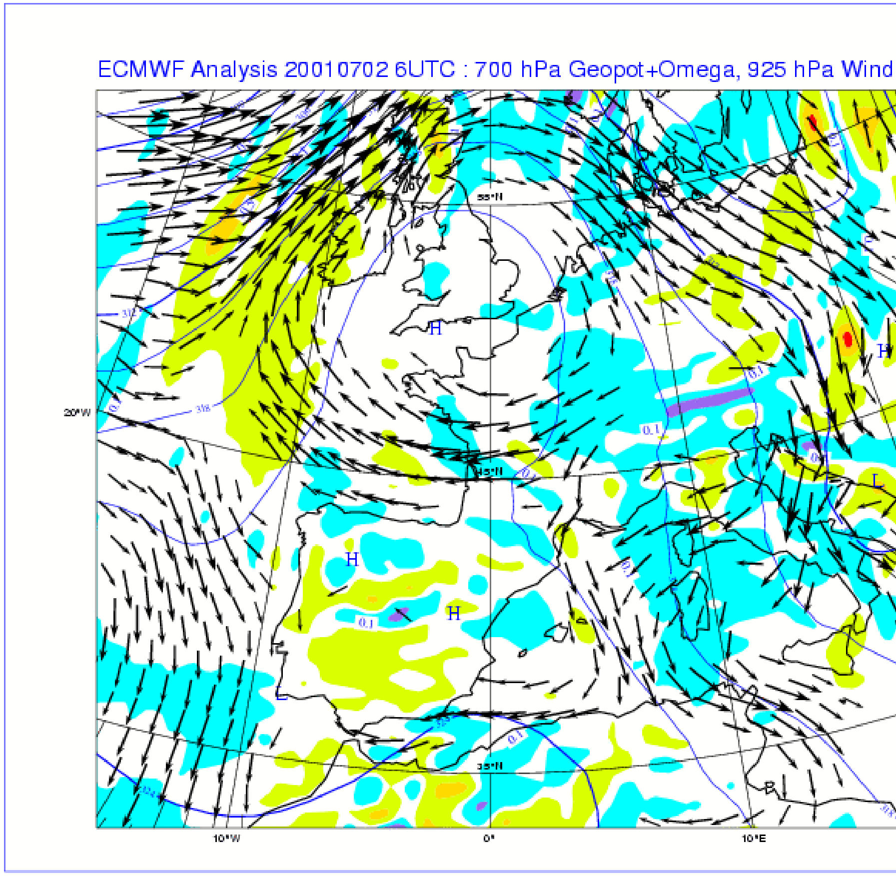
Examples of convective situations over Europe: 2 July 2001 – upper/low level Analysis

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



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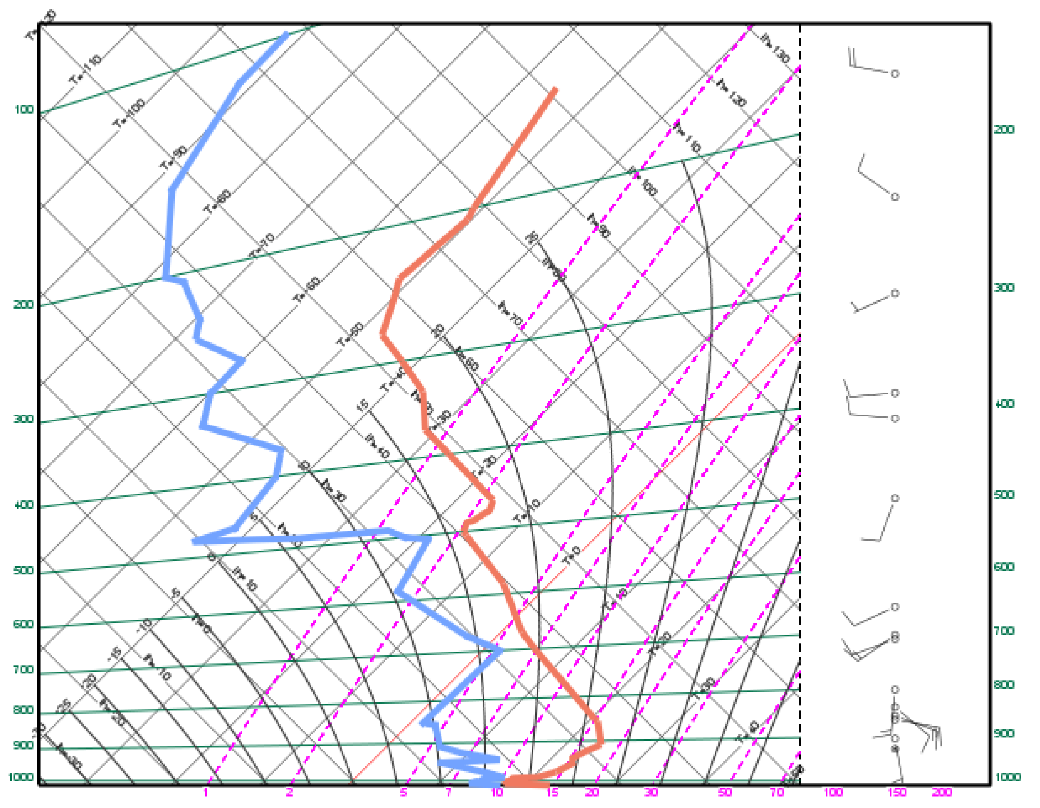
Examples of convective situations over Europe: 2 July 2001 – Sounding

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

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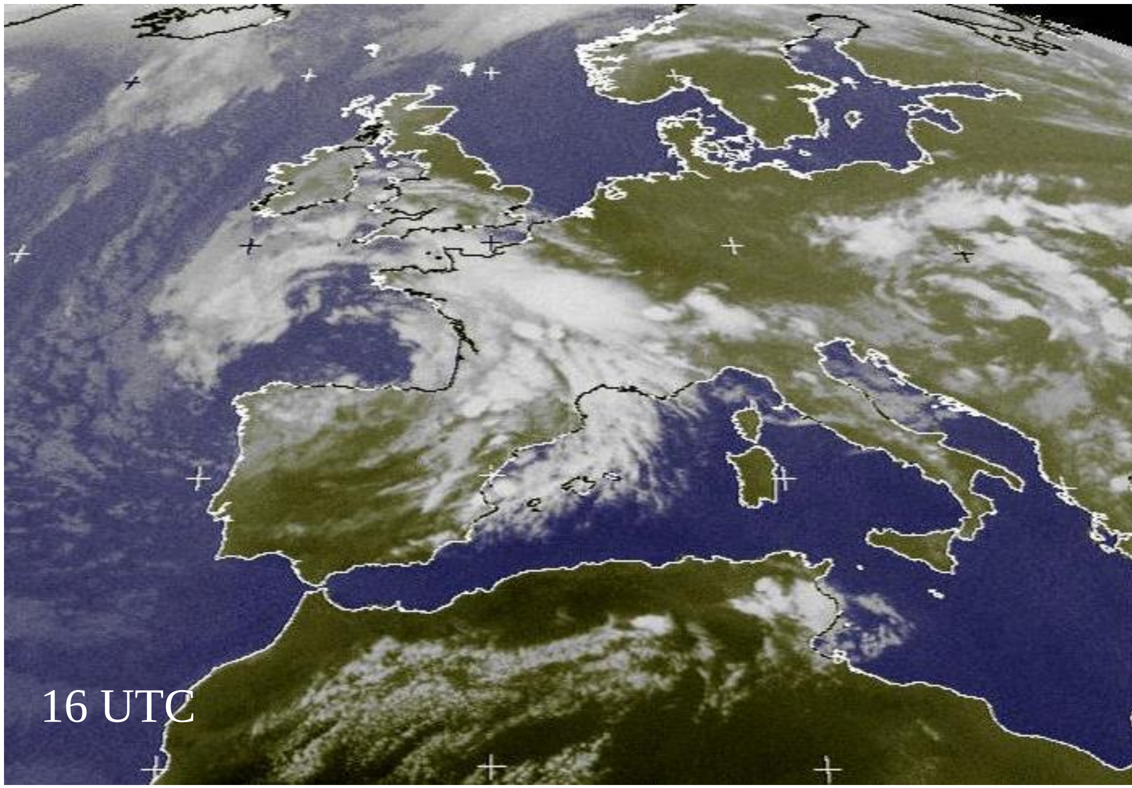
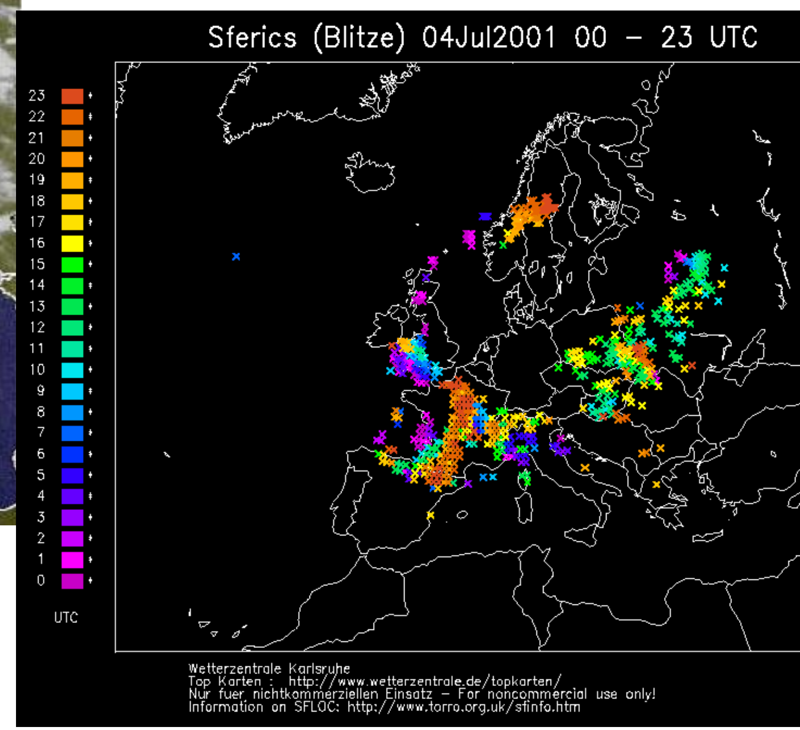
Examples of convective situations over Europe: 4 July 2001

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





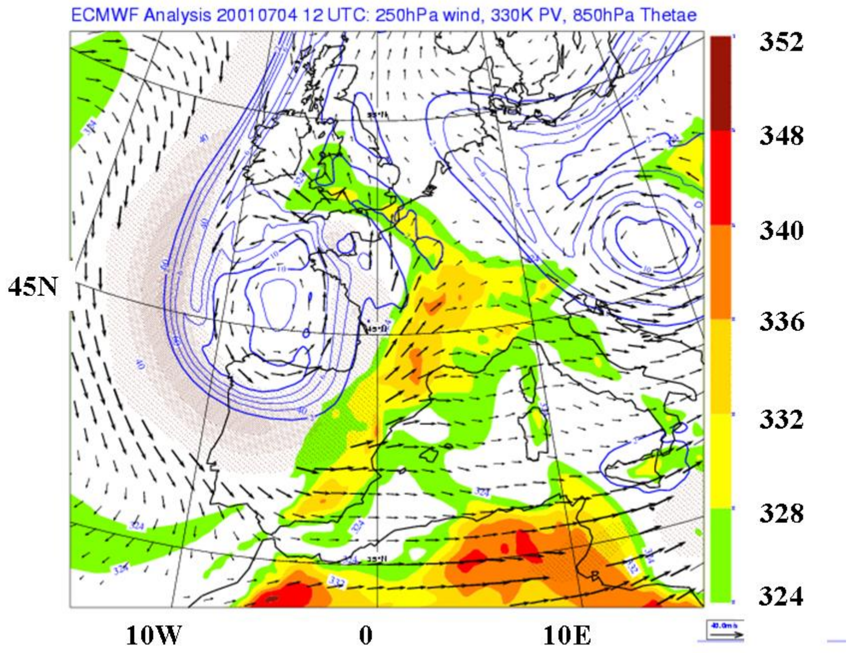
ECMWF

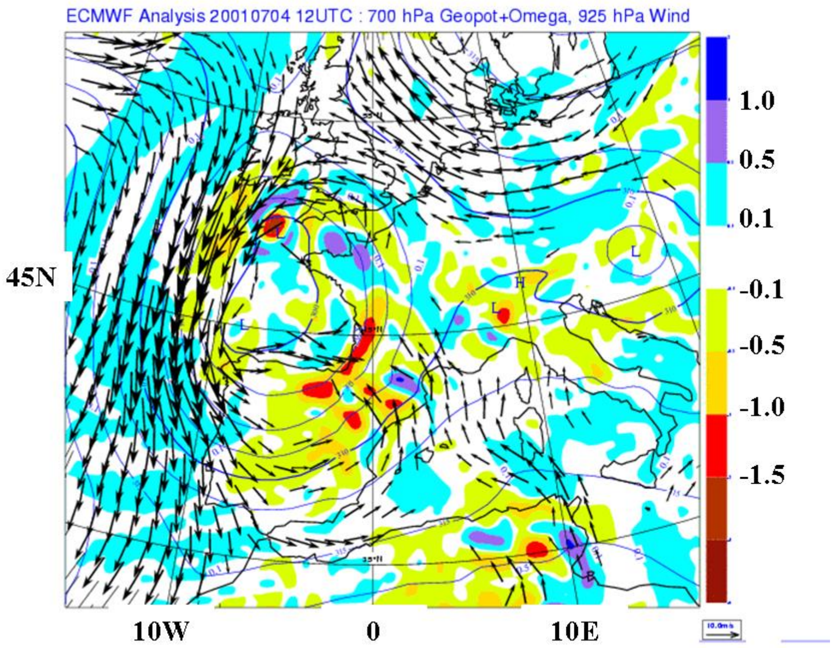
Examples of convective situations over Europe: 4 July 2001 – upper/low level Analysis

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



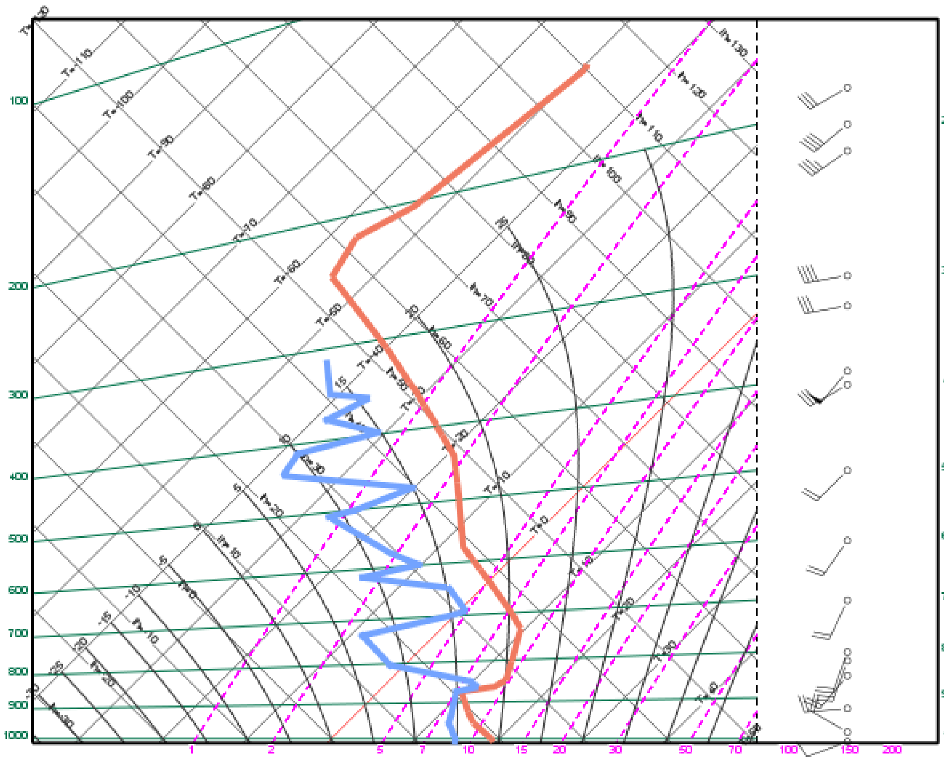


Examples of convective situations over Europe

4 July 2001 – soundings and moist adjustment

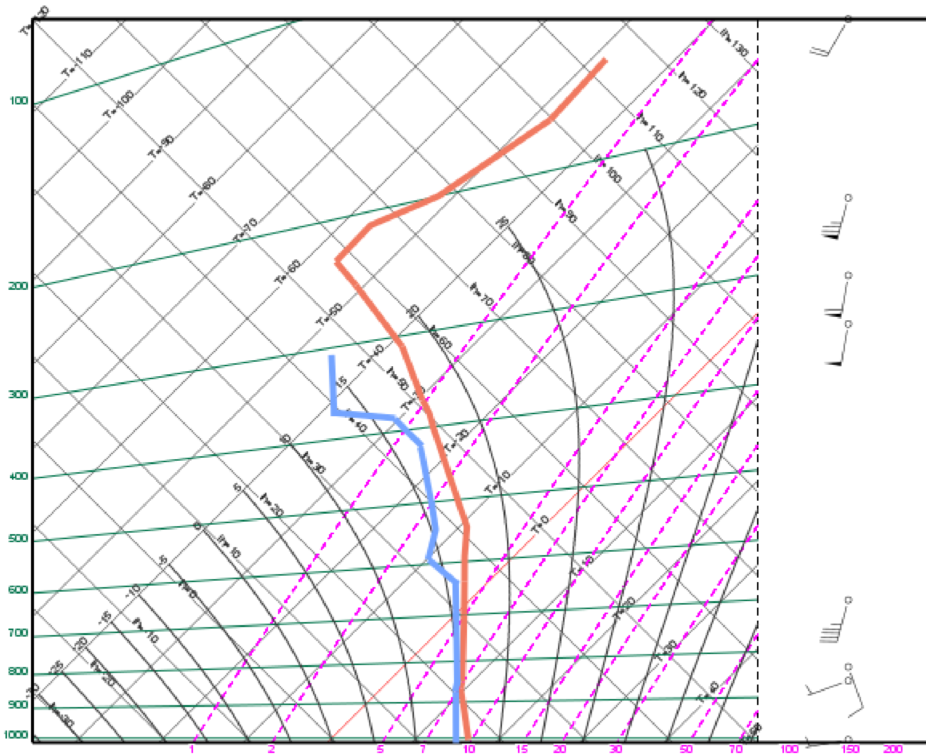
Convection bringing hail in SW France, associated with strong uplift in Trough and high Thetae

Tephigram Bordeaux Merignac 20010704 0 UTC



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

Tephigram Bordeaux Merignac 20010704 12 UTC



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