Model Physics

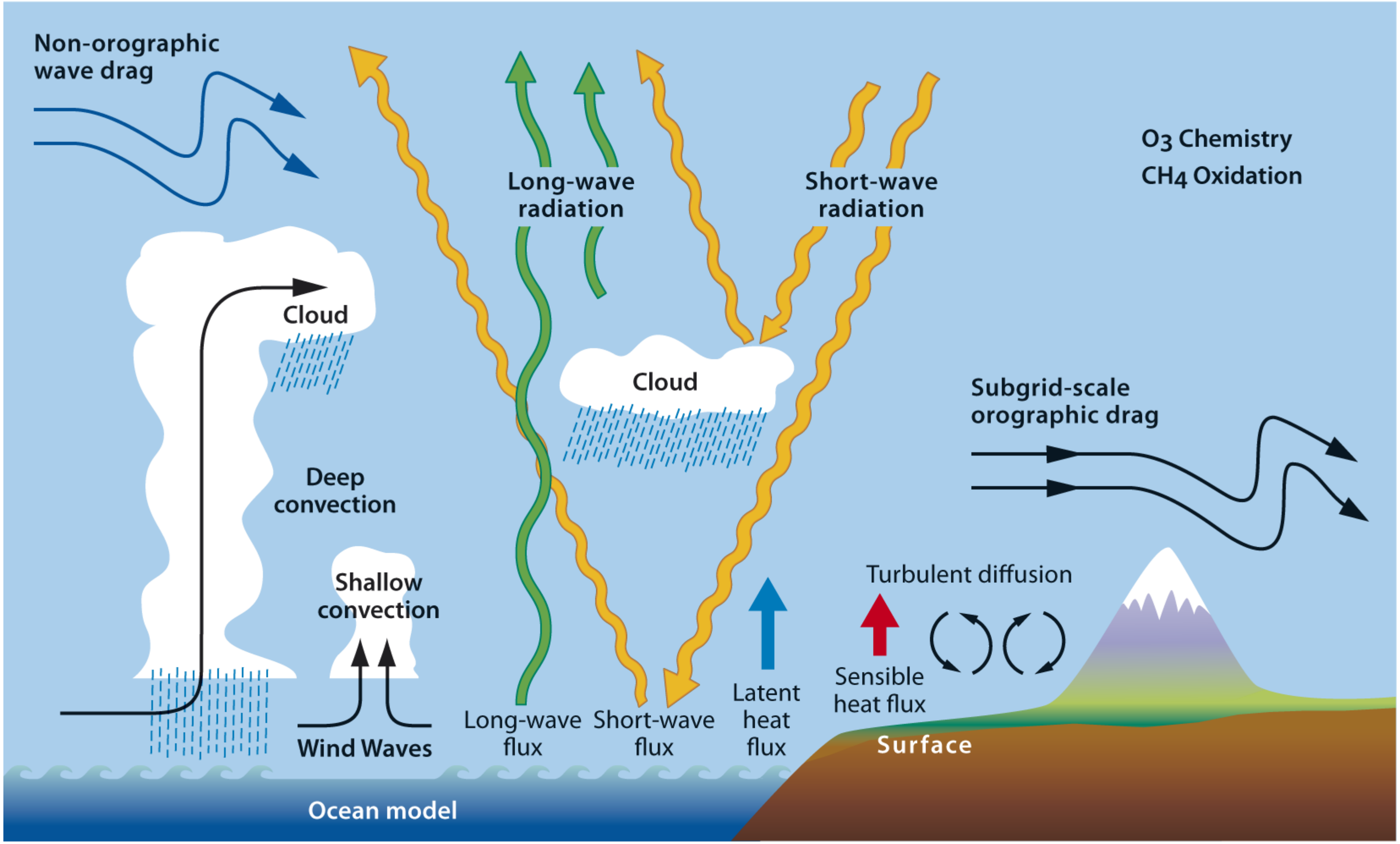
- A few basics
- High resolution
- A few problems
- A few products

for the Model Section: Peter Bechtold

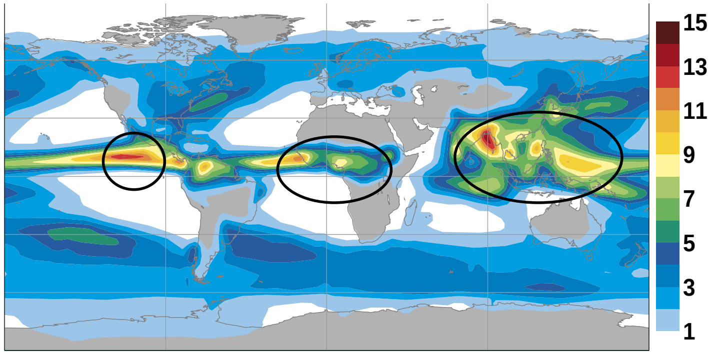
http://www.ecmwf.int/en/learning/education-material/introductory-lectures-nwp

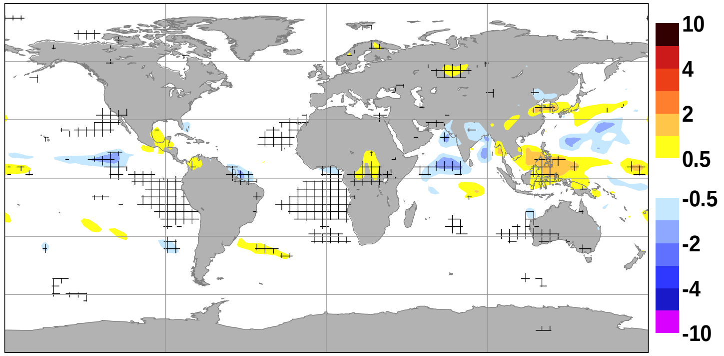
Parameterized processes in the ECMWF model

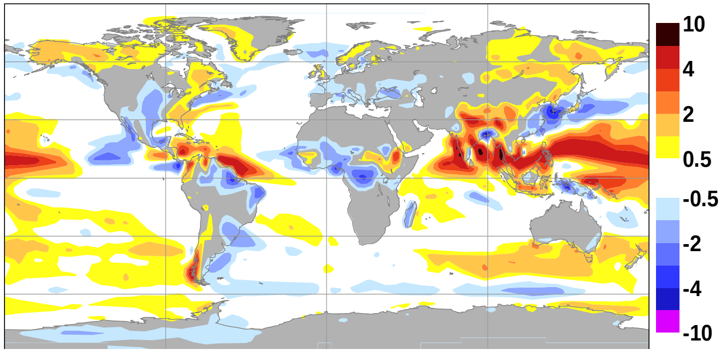
from the surface to the stratosphere

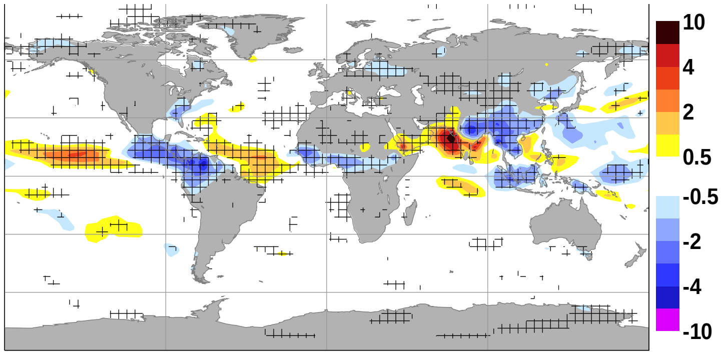


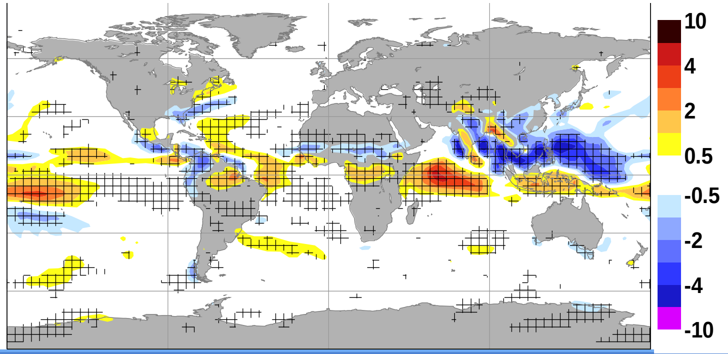
Precipitation JJA: Sensitivity to Model Formulation Seasonal integrations

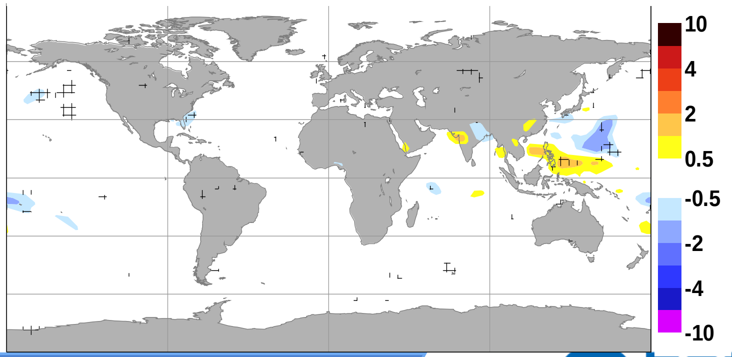

GPCP JJA 1990-2006


33R1(old vdiff)-33R1

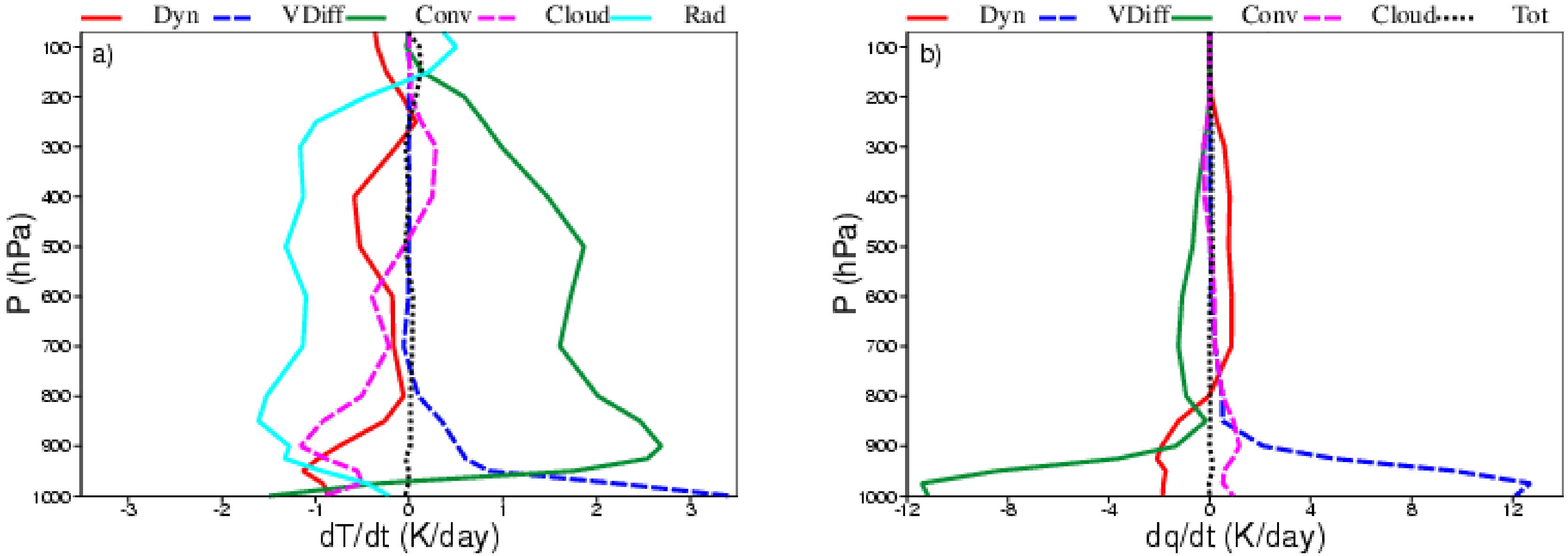

33R1:2008 -GPCP


33R1(old radiation)-33R1


33R1(old convection)-33R1


33R1(old soil hydrology)-33R1

Model Tendencies - Tropics



For Temperature, above the boundary layer, there is roughly an equilibrium Radiation-Convection, but Dynamics and Clouds also important, whereas for moisture there is roughly an equilibrium between dynamical transport (moistening) and convective drying. ***- Global Budgets are very*** **similar**

All processes are important, nevertheless the driving force for atmospheric dynamics and convection is the radiation

The weather and thermal equilibria: exercises

- Suppose we have a series of fine day with an anticyclone, the temperature above the boundary-layer barely changes, Why?

$$\frac{d\theta}{dt} \approx 0 \qquad \Rightarrow w\frac{d\theta}{dz} = \frac{d\theta}{dt}\Big|_{rad} = -\frac{2K}{86400s} \Rightarrow$$

w ~ -0.5 cm/s subsidence

~0.5 K/100 m

- But what happens when it is raining 100 mm/day ?

$$\int_{surf}^{10km} Cp\frac{dT}{dt}\rho_{air}\,dz = L_v\rho_{water}\,Pr(m/s)$$

$$c_p = 1005\,J/kg/K; \quad \rho_{water} = 1000kg/m3; \quad L_v = 2.5x10^6\ \text{J/kg}$$

$$\mathrm{Pr} = 100\frac{mm}{day} = 1.147\,m/s\,x10^{-6}$$

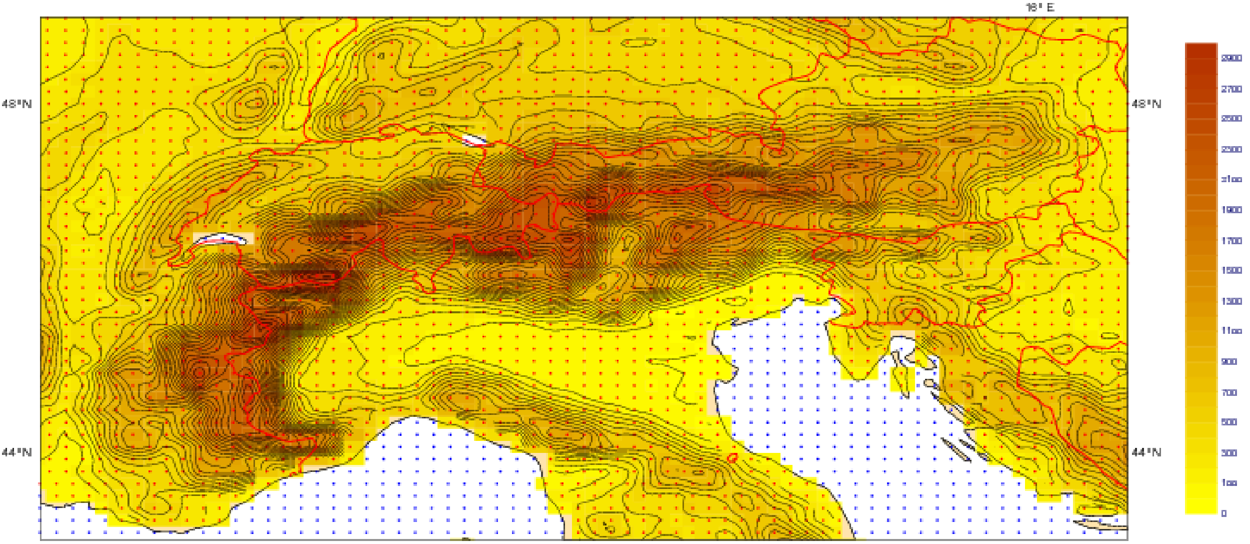
100 mm/day precipitation heats the atmospheric column by 2867 W/m2 or by 25 K/day on average. This heating must be compensated by uplifting of w ~ 10 cm/s ➔ heavy precip/convection requires large-scale perturbation.

The 2016 horizontal resolution upgrade:

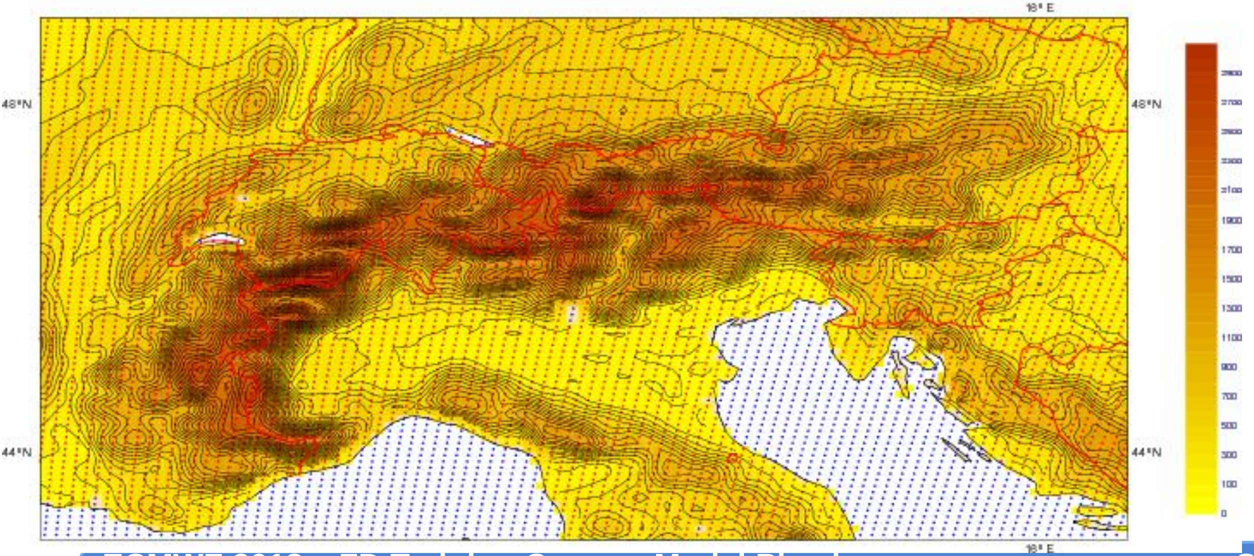
The Grids and effects from improved Numerics

From Tl1279 (16 km) to TCo1279 (9 km)

OROGRAPHY, GRID POINTS AND LAND_SEA MASK FOR N640 ORIGINAL GRID
orography shaded (height in m), land grid points (red), sea grid points (blue)



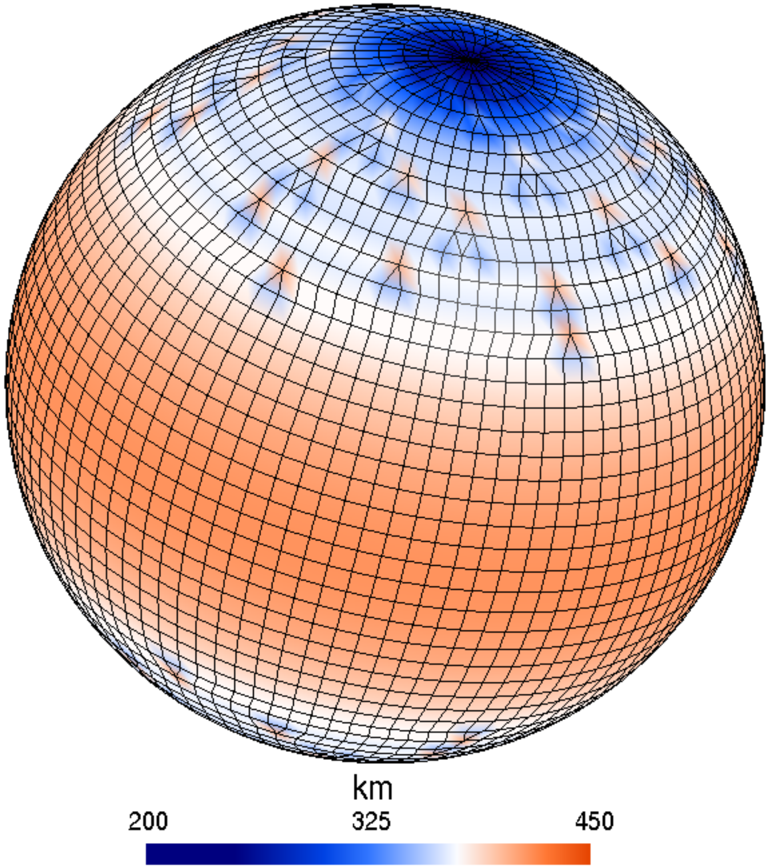
OROGRAPHY, GRID POINTS AND LAND_SEA MASK FOR O1280 OCTAHEDRAL GRID
orography shaded (height in m), land grid points (red), sea grid points (blue)



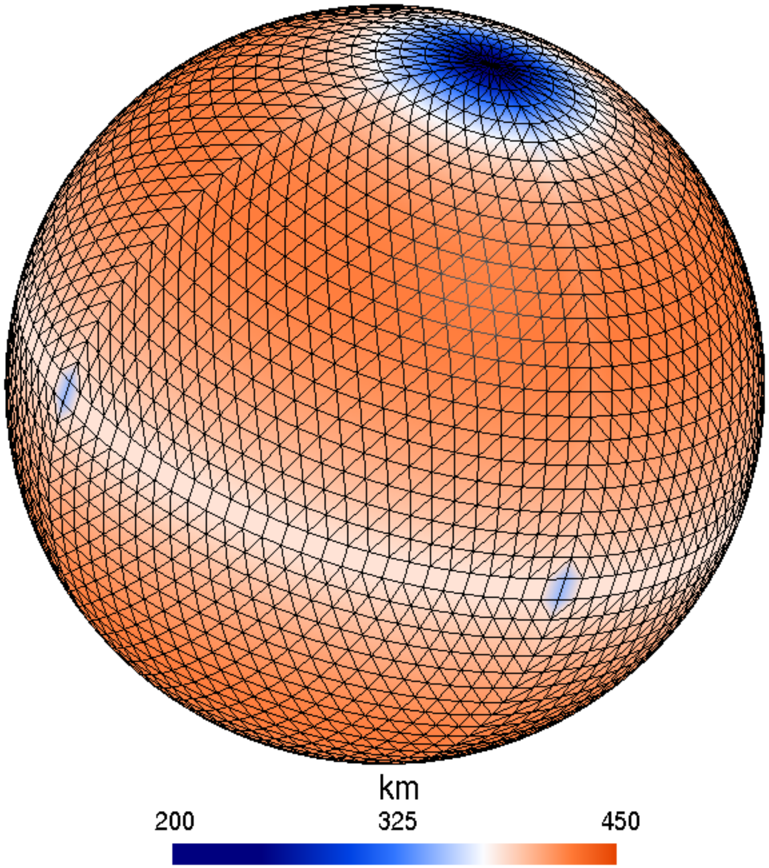
- Same max number of waves on the sphere=1279
- Less spectral smoothing applied to TC1279 orography than in Tl1279
- In the linear=Tl grid 2 grid-points represent one wave, while in the cubic=TC grid, a wave is represented by 4 grid-points =>much more accurate
- note that most computations are done in grid-point space
- The TC Gaussian grid is further reduced to a TC octahedral to save grid points

A new grid ….

and a more uniform resolution, ~9 km over Europe



N24 reduced Gaussian grid

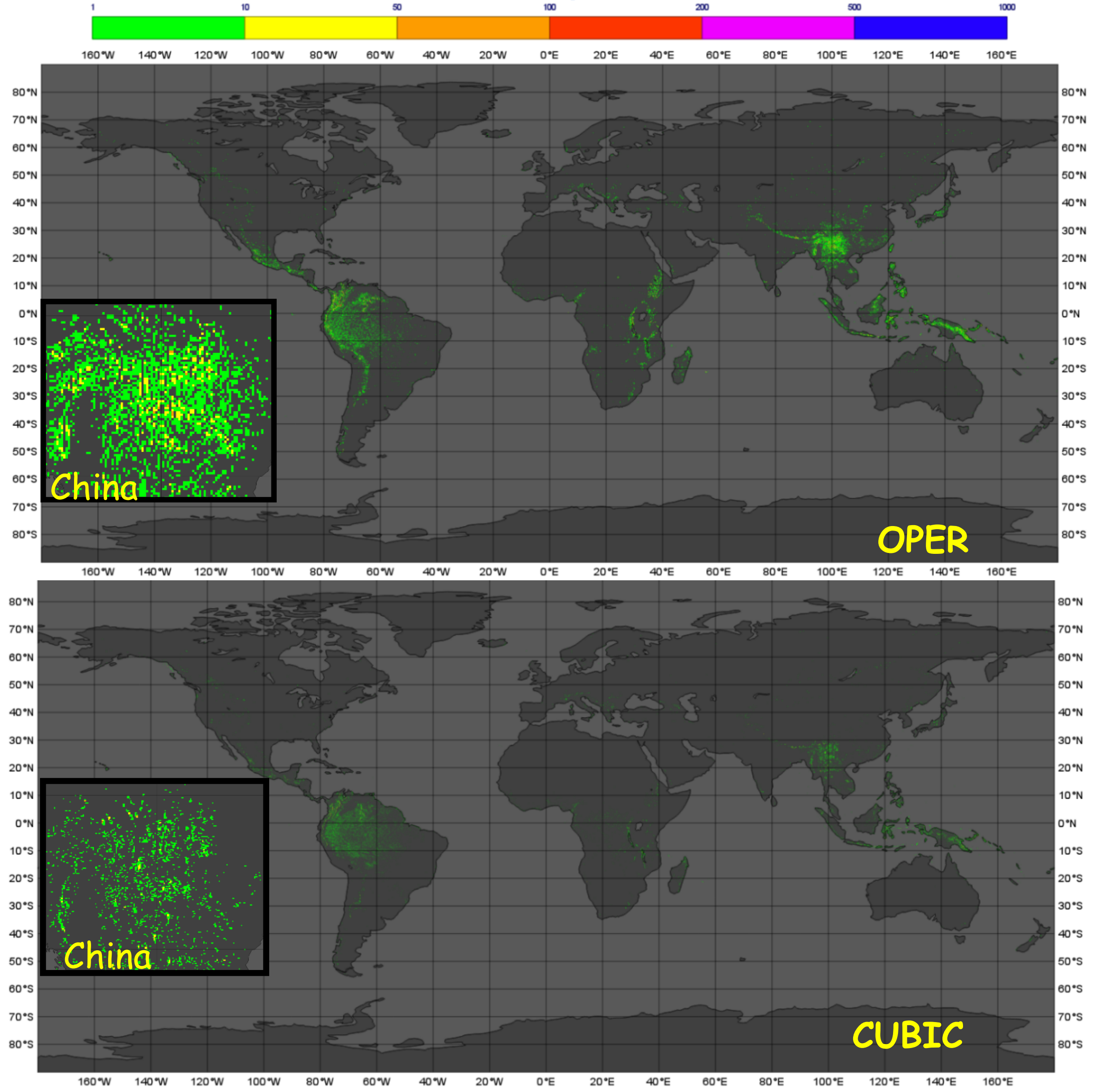


N24 octahedral Gaussian grid

Improvements: ….

Strong reduction of spurious grid-scale rainfall events (LSP)

Frequency of rain events >20mm/6h

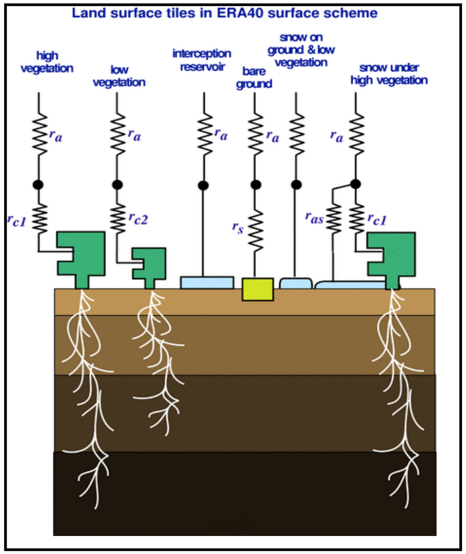


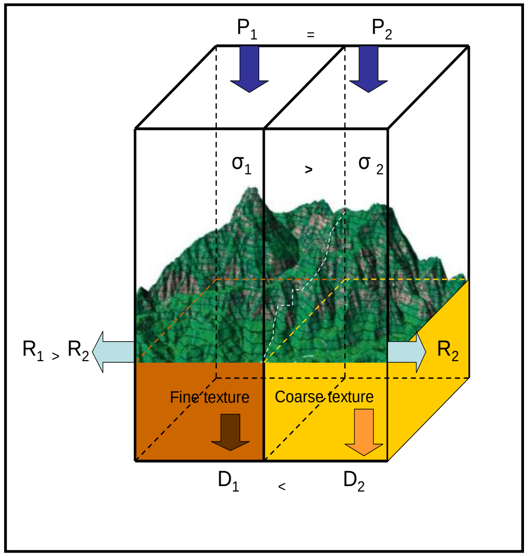
Physical processes: Surface temperatures wind and snow

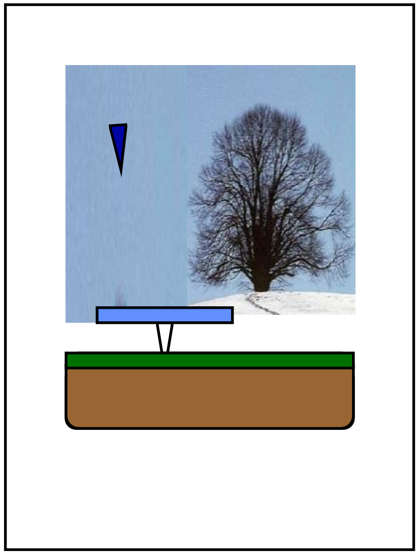
Land surface model evolution

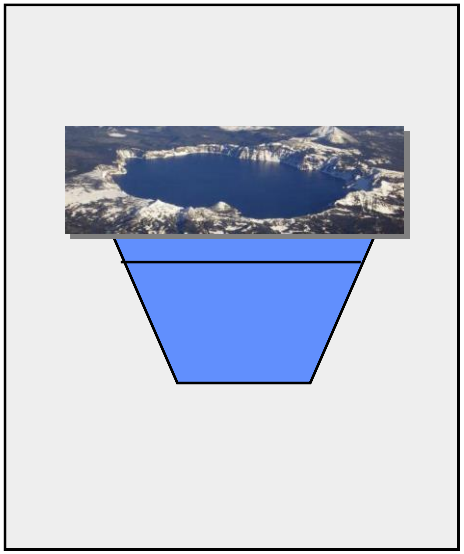
2000/06	2007/11	2009/03	2009 & 2010	2015

- **TESSEL**
- **Hydrology**-TESSEL
- **new SNOW**
- **FLAKE**





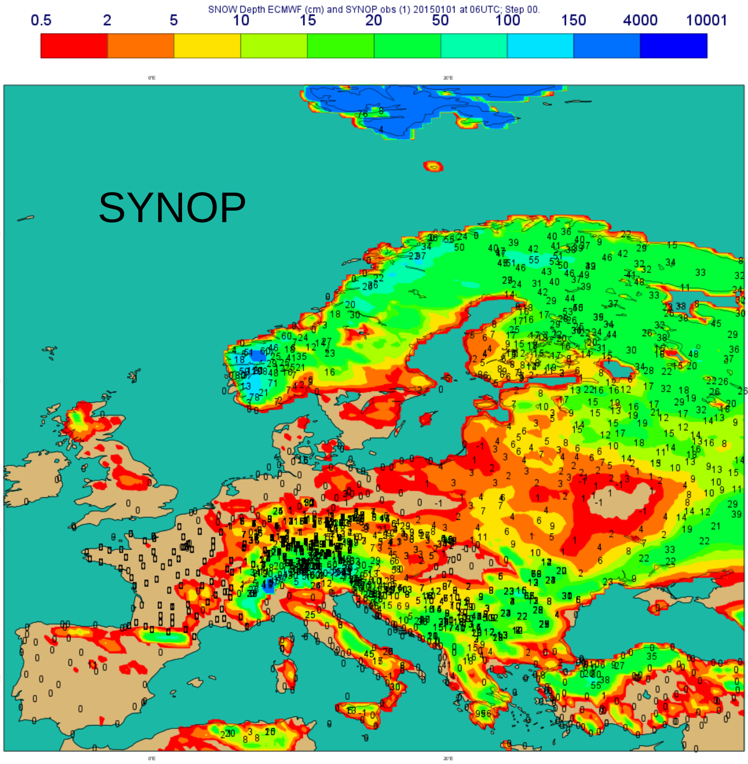




Snow Observations

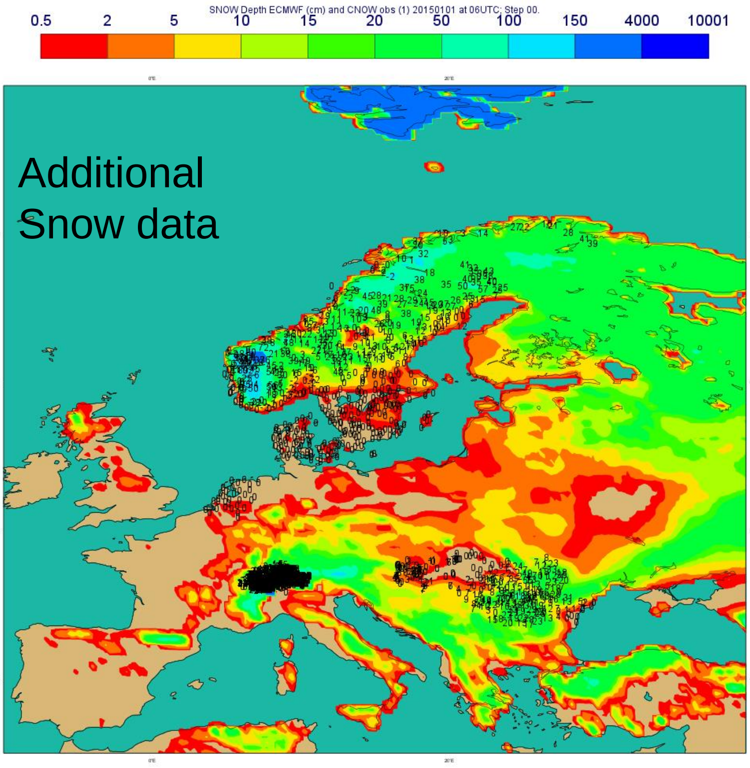
Snow SYNOP and National Network data

Snow Depth (cm)



Available on the GTS (Global Telecommunication System)

2015 01 01 at 06UTC



Additional data from national networks (7 countries):

Sweden (>300), Romania(78), The Netherlands (33), Denmark (43), Hungary (61), Norway (183), Switzerland (332).

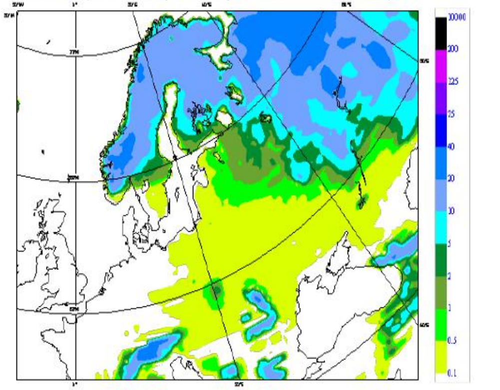
→ **Dedicated BUFR (2011)**

(de Rosnay et al. ECMWF Res. Memo, R48.3/PdR/1139, 2011)

Snow analysis uses Synop and Satellite Obs

MODIS 16/02/2002

Analysis based on SYNOP



Snow extent is overestimated in the analysis when it is based on SYNOP data only

However, satellite only gives snow cover!
And the big change in 2014 was the way satellite data is used, i.e it is assimilated with large observation error, also if
FG =no snow, Sat=snow => Sat snow≈5 cm

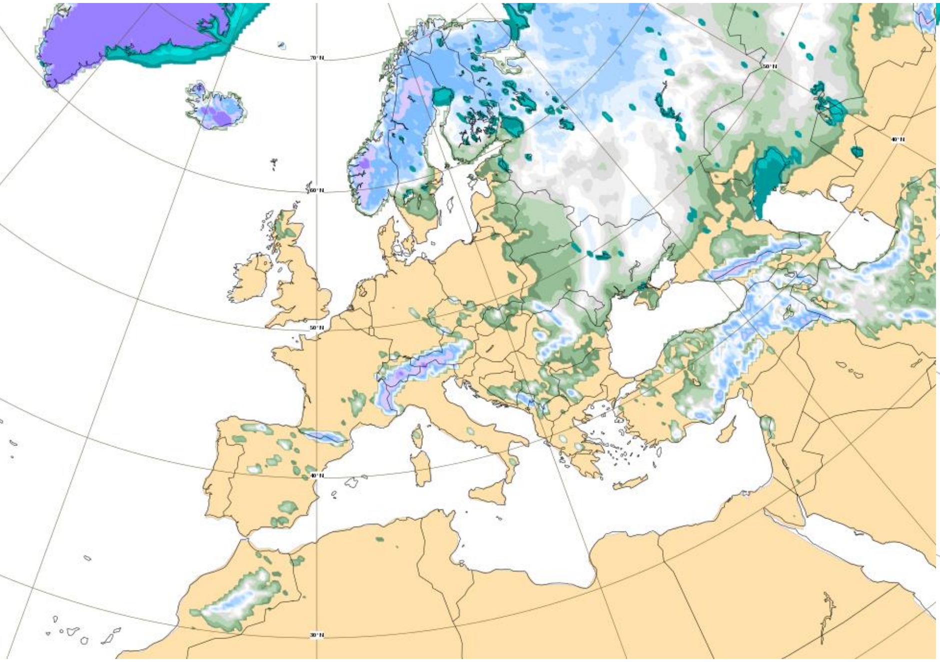
Fc errors (scores) very sensitive to snow (analysis)

See also ECMWF Newsletter no 143, article pp 26-31, Spring 2015

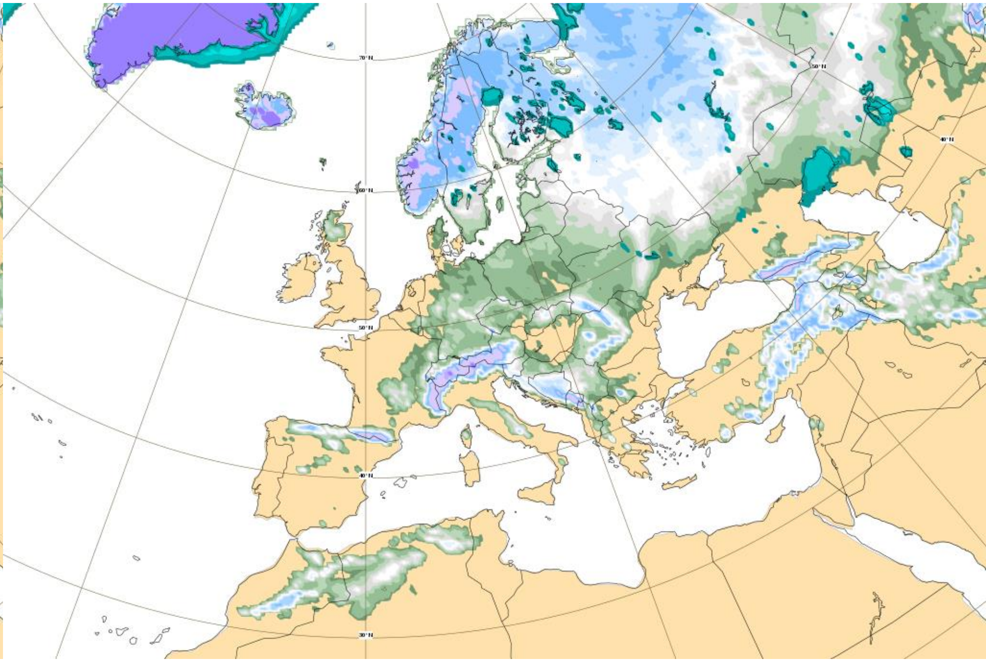
Archived prognostic snow related quantities

- **Snow depth (water equivalent), Sd => actual depth=Sd*(Rl=1000)/Rsn**

  below 10 cm snow depth, snow cover becomes fractional
- **Snow density (typically factor 10 lower than water-> 1 mm precip~1 cm snow), Rsn** (mixture old/new snow, wind compression)
- **Snow temperature, Tsn**
- **Snow albedo, Asn**



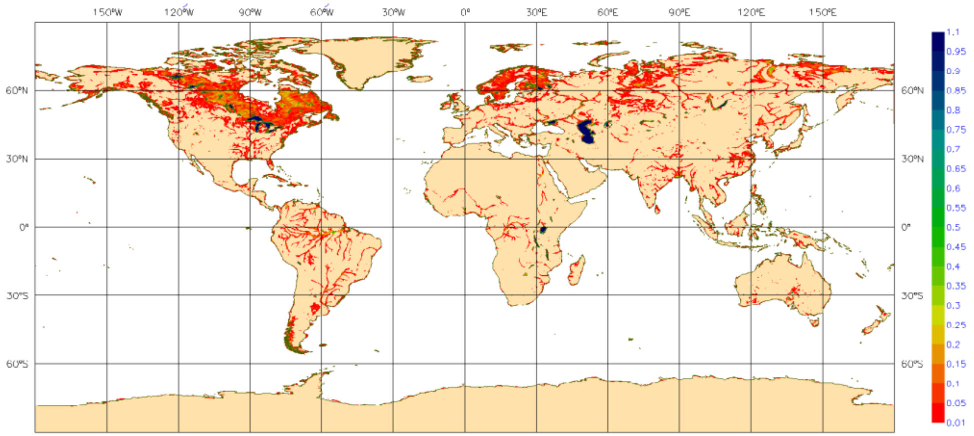
20180129 +12h



+240h=2018020700

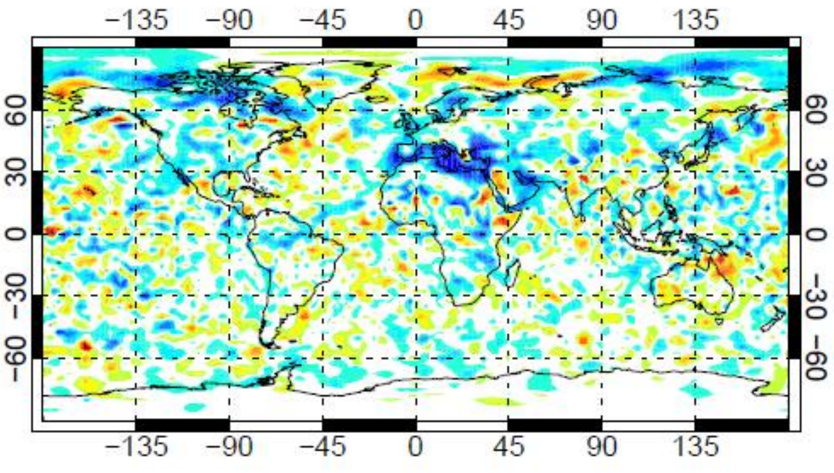
Impact of water bodies in IFS version June 2015

LAKE COVER FRACTION



T+48; 1000hPa

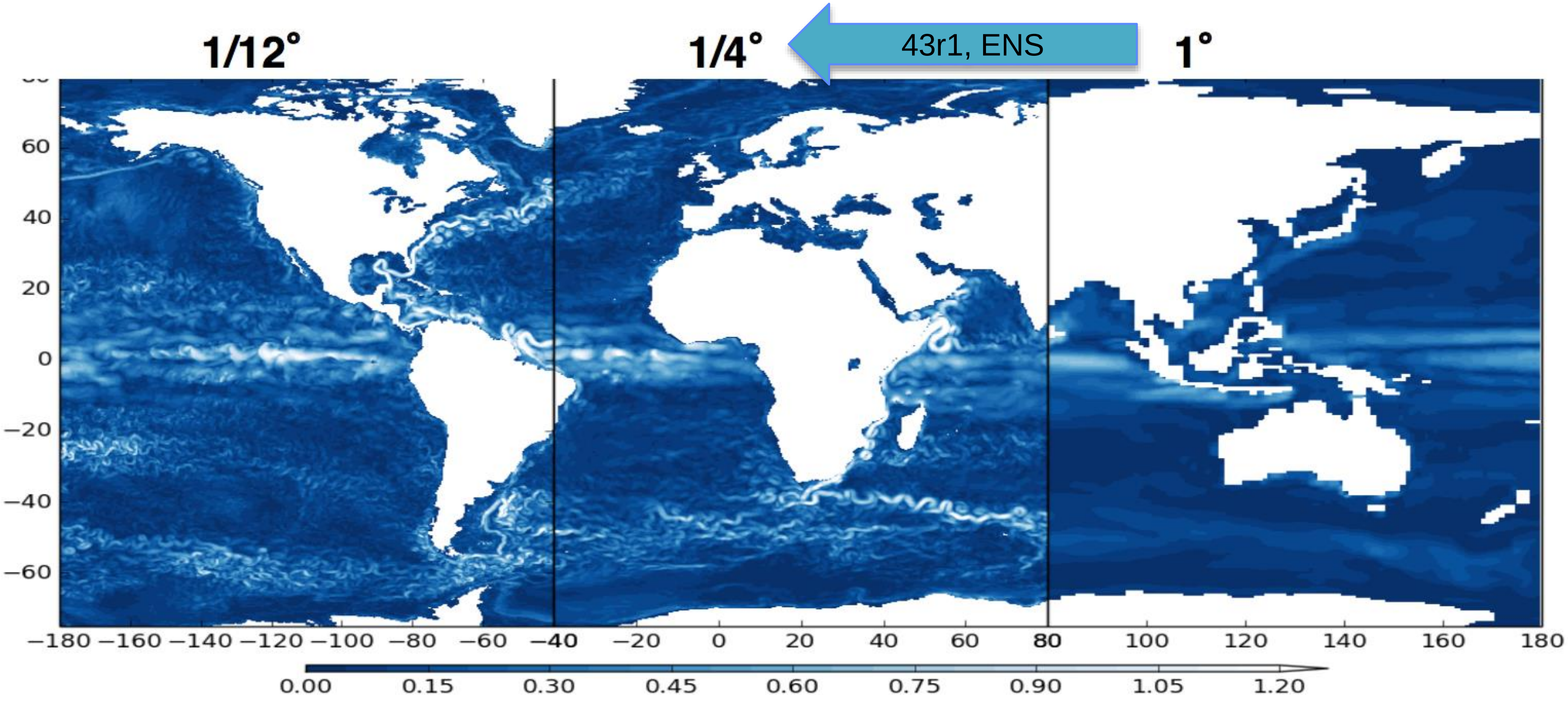
Summer experiment 15-Jun-2013 to 5-Jul-2013



Forecast of 2m temperature are improved in proximity of lakes and coastal areas

Why also coastal areas, these are not Lakes ?!...... cause before if land-sea mask>0.5 then only land point……… but doesn't solve T2m coastal problem for Norway

Ocean surface currents at various resolutions



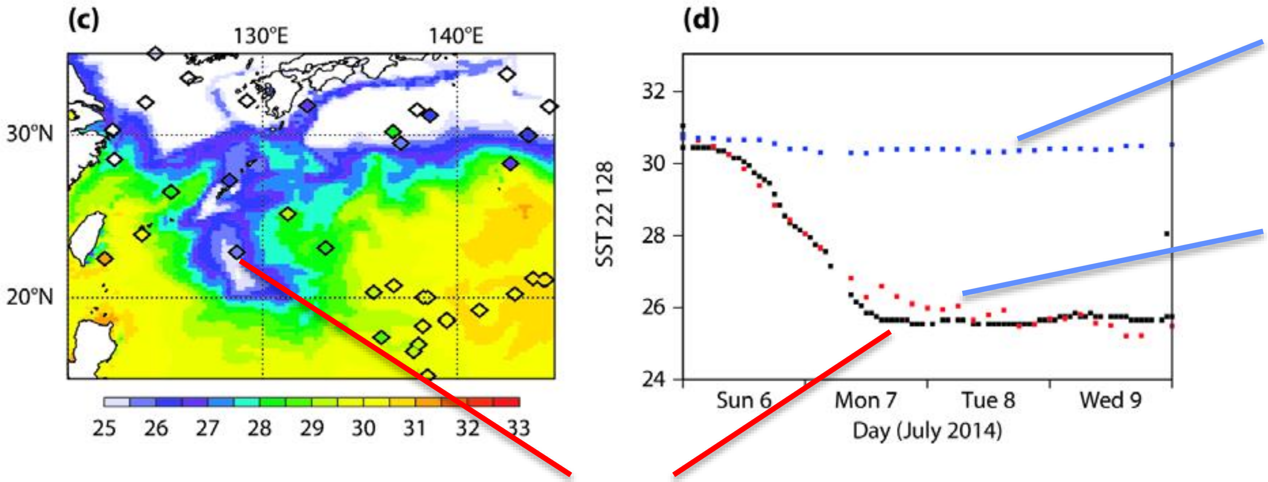
Eddy resolving

Eddy permitting

Eddy parameterising

Coupled ocean vs uncoupled simulation

Tropical cyclone *Neoguri* with TCo1279 (HRES)



uncoupled

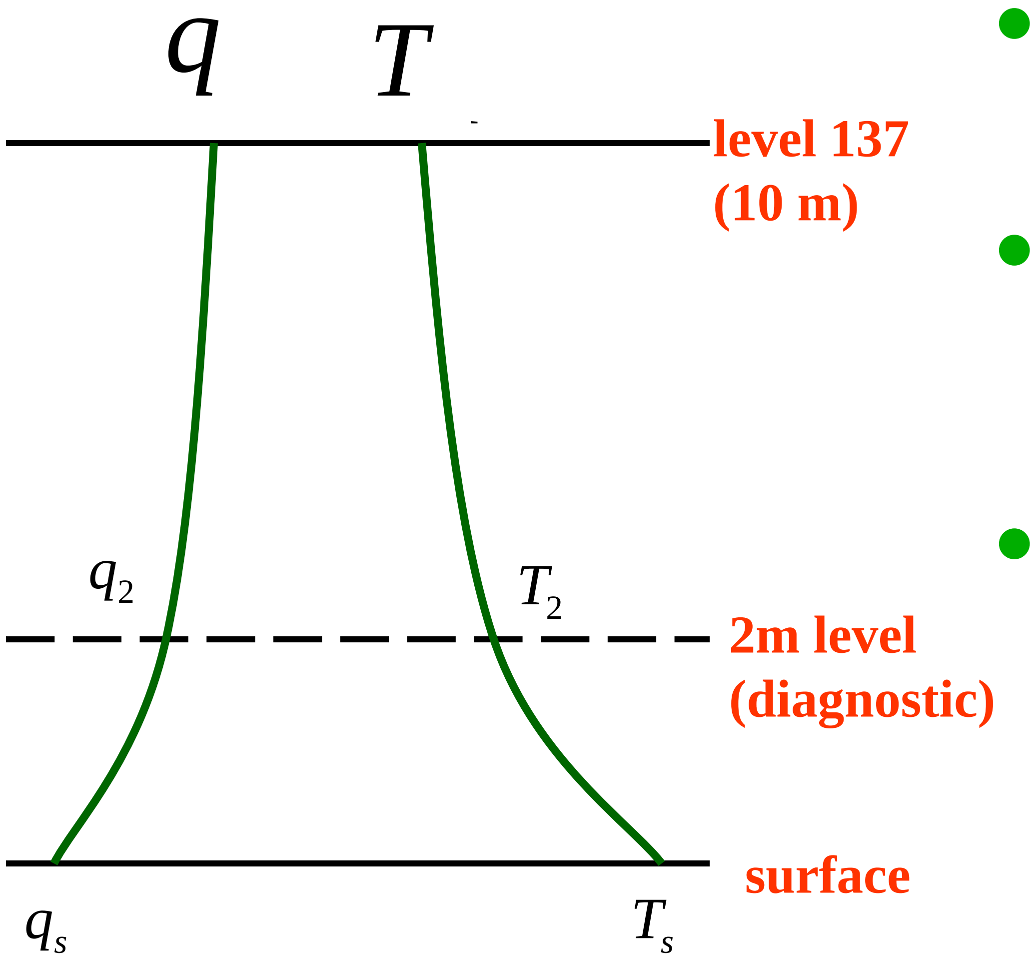
coupled

Buoy observation
at 22°N, 128°E

4-day forecast SSTs from the coupled forecast initialised at 0UTC on 6 July 2014 at the location of a buoy with approximate position 22°N, 128°E.

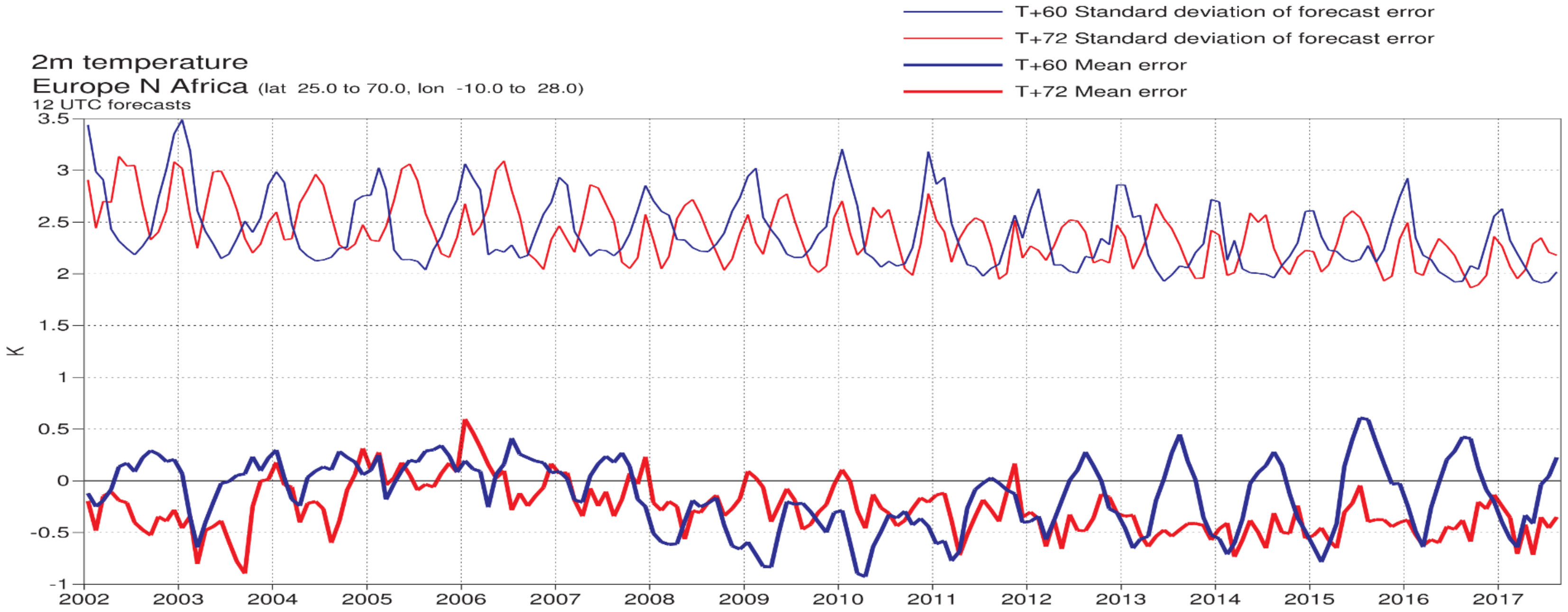
(Rodwell et al, ECMWF Technical Report 759, 2015)

T and q interpolation to the 2m level



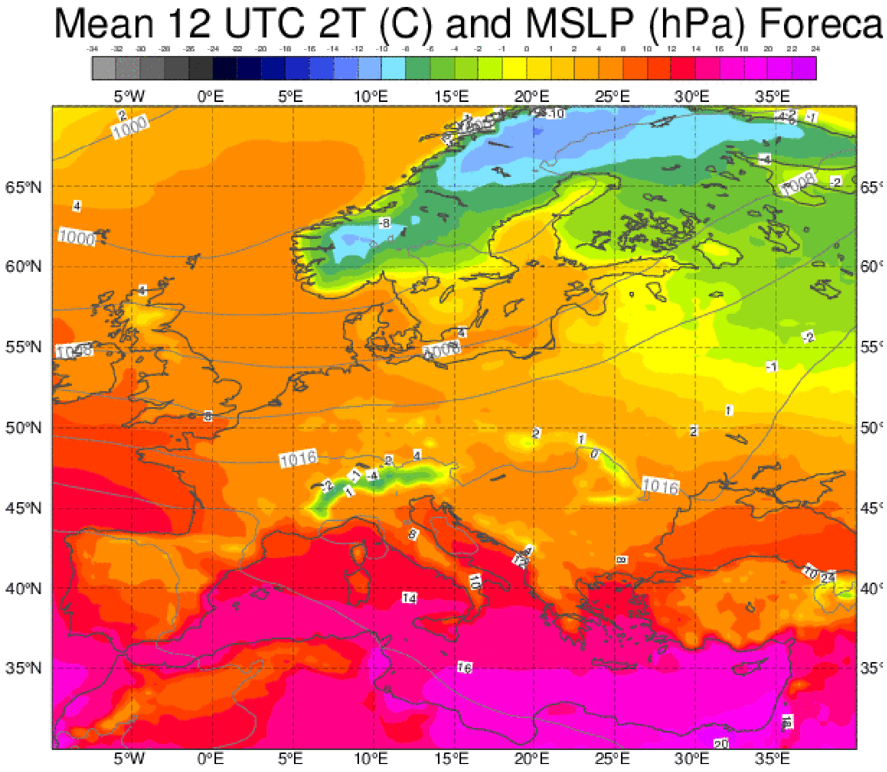
- q_s and T_s are determined by the land surface scheme or by SST.
- Main purpose of land surface scheme is to provide correct area averaged fluxes of heat and moisture.
- Land surface scheme considers different sub-areas (tiles) but effect on screen level variables is not accounted for yet.

Evolution of 00 UTC and 12 UTC T2m errors (K)

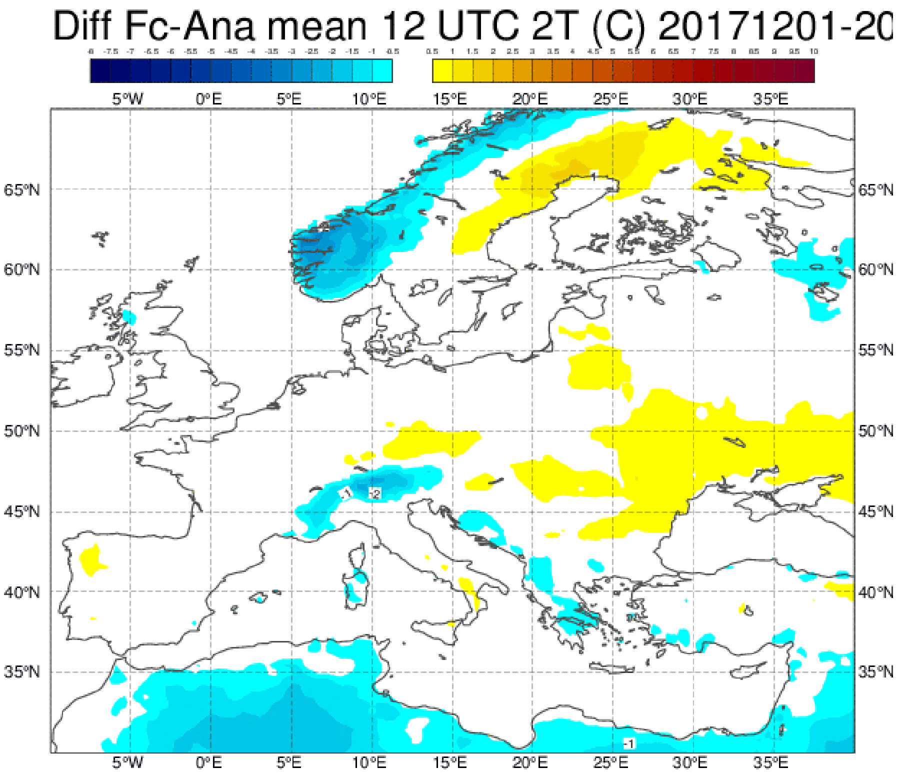


Note cold bias in Spring and too warm night-time temperatures in summer

T2m mean and errors (K) 1 Dec 2017- 23. Jan 2018



Mean 12 UTC 2T (C) and MSLP (hPa) Foreca

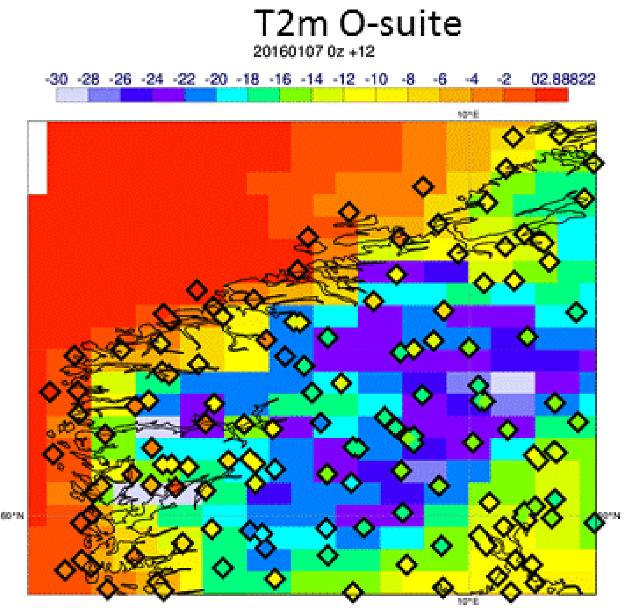


Diff Fc-Ana mean 12 UTC 2T (C) 20171201-20

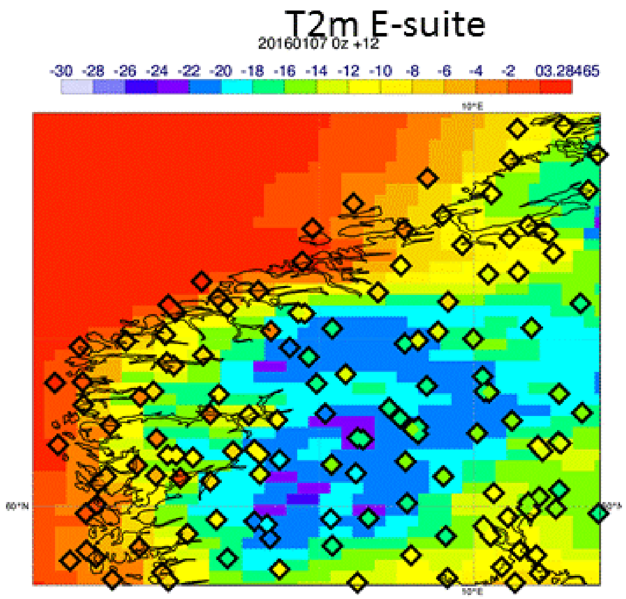
British isles, Iberian peninsula and northern Scandinavia close to climatology, central Europe 1-2 K too warm, West of 30E >5 K anomaly

Temperature negative error reduction in 2016 resolution upgrade:

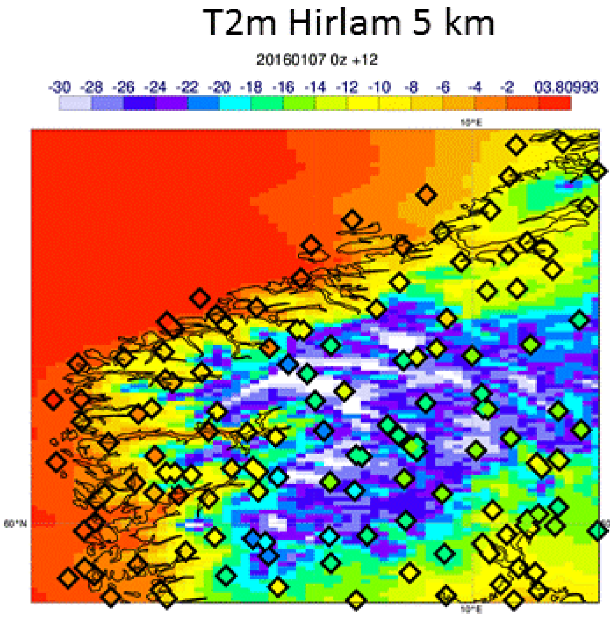
Coastal T-errors reduced through approximate radiation updates in space and time


T2m O-suite

20160107 0z +12


T2m E-suite

20160107 0z +12


T2m Hirlam 5 km

20160107 0z +12

Summary of wintertime 2m T errors

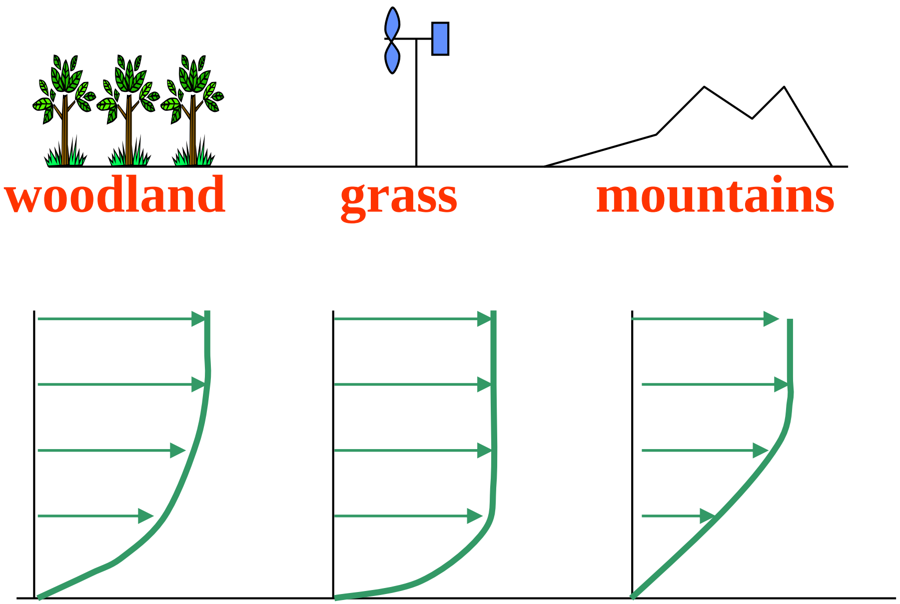
Overall not bad, mean error < 0.5 K, improved over previous years but still

- Regional differences, now mainly too cold, particular night-time problem, especially apparent over orography

Various possible reasons: coupling (coefficient) with ground heat flux, error in lake temperatures (not frozen), stable boundary-layer mixing, low-level clouds, snow

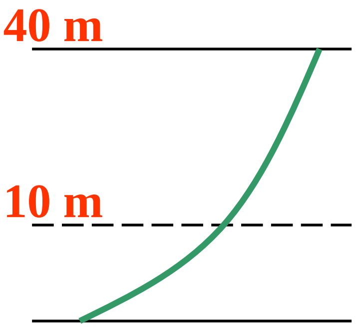
- Overestimation of summertime night temperatures (coupling with soil, vegetation not shown) … should have been partly addressed (to be seen)

10 m wind



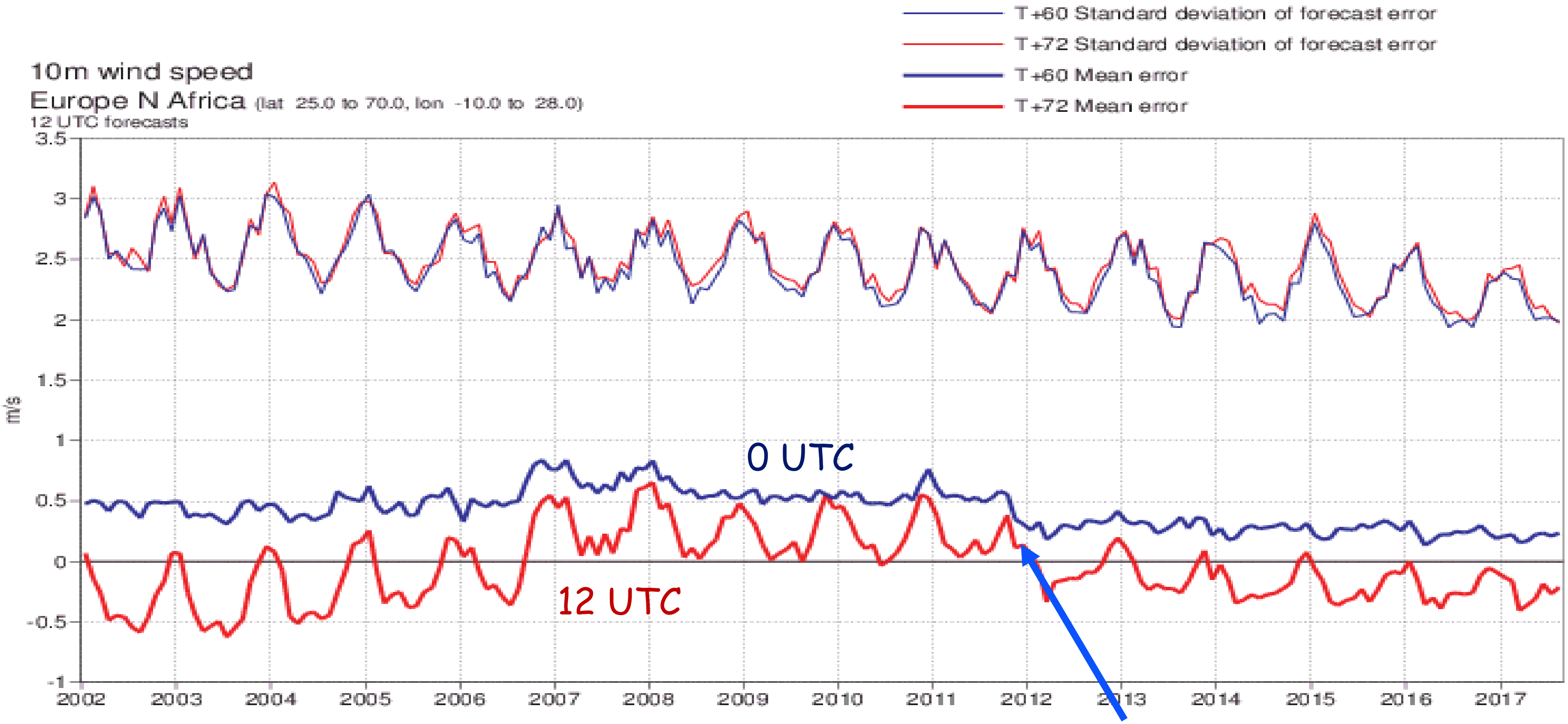
- Local wind depends strongly on local exposure.
- ECMWF model has roughness length parametrisation to obtain realistic “area averaged” surface drag.
- Resulting wind is low over land because rough elements dominate.

Post-processing of wind at 10 m



- Post-processed 10 m wind interpolates wind from 40 m (was 75 m before Nov. 2011)) assuming roughness length for grassland.
- Note: this exposure correction is only a partial correction to account for local effects (which tend to be more complex).

Changes to the roughness length table (Nov 2011)



Implementation
of new
roughness table

ECMWF

Wind Gusts: what is it ?

WMO definition:

Gusts are defined as wind extremes observed by anemometer. A 3 second running average is applied to the data. The report practice is such that gusts are reported as extremes over the previous hour, or the previous 3 or 6 hours.

The mean wind is reported as a 10 min average which is the last 10-minute interval of the hour; it should be comparable with instant output of the model 10 m wind, as it can be interpreted as some space and/or time average.

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 40m level), U_* is the friction velocity – itself obtained from the wind speed at the first model level, and **L** is a stability parameter.

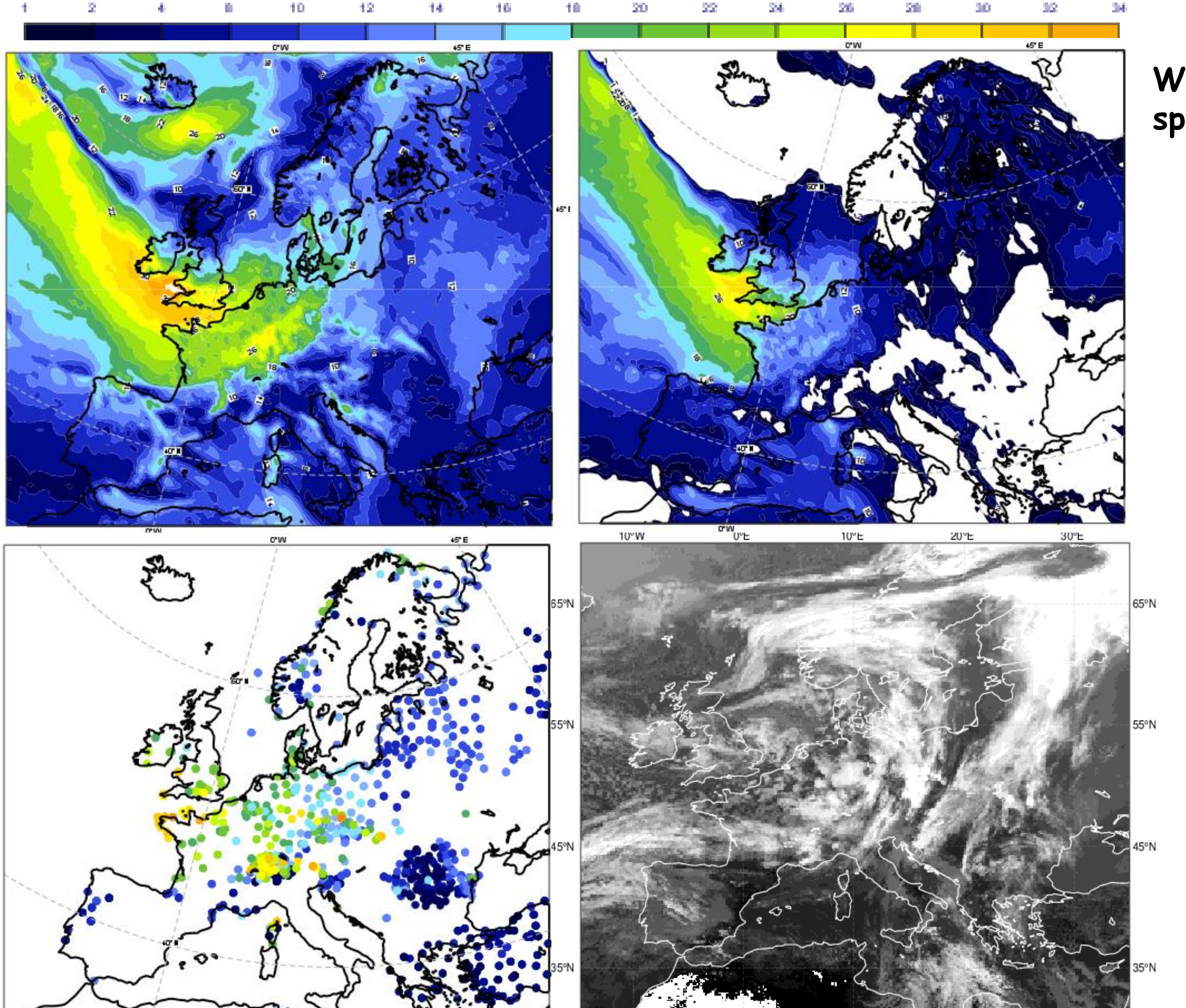
The convective contribution is set proport. to the wind shear between model levels corresponding to 850 hPa and 950hpa, respectively.

Wind gusts 8 Feb 2016 12 UTC

Gust

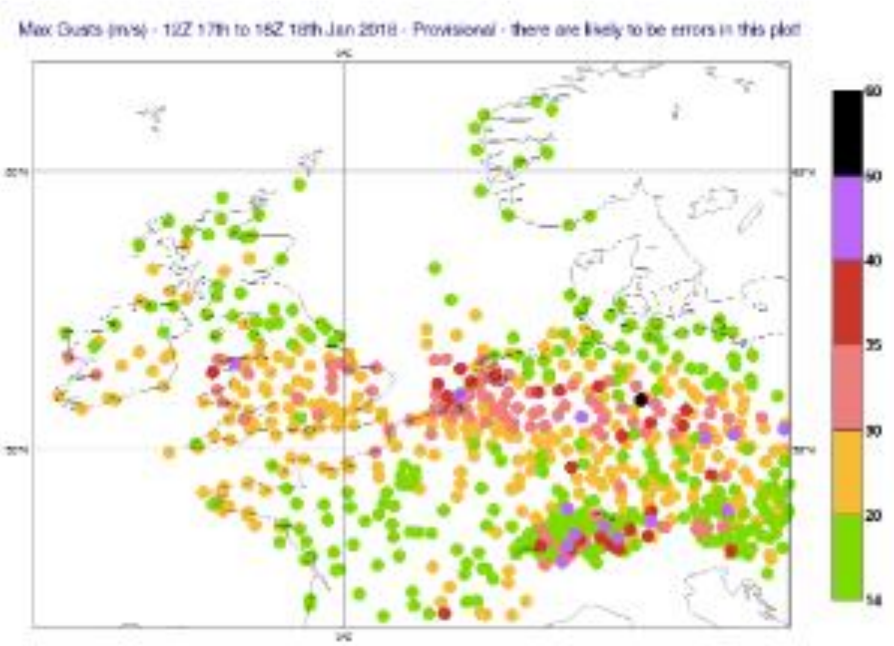
Wind speed

Obs

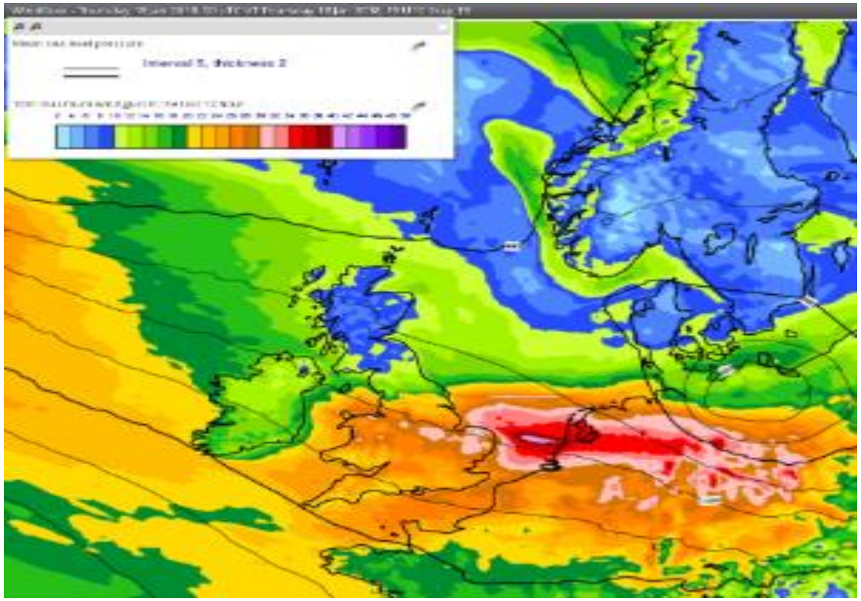


Wind gusts 18 Jan 2018

Obs

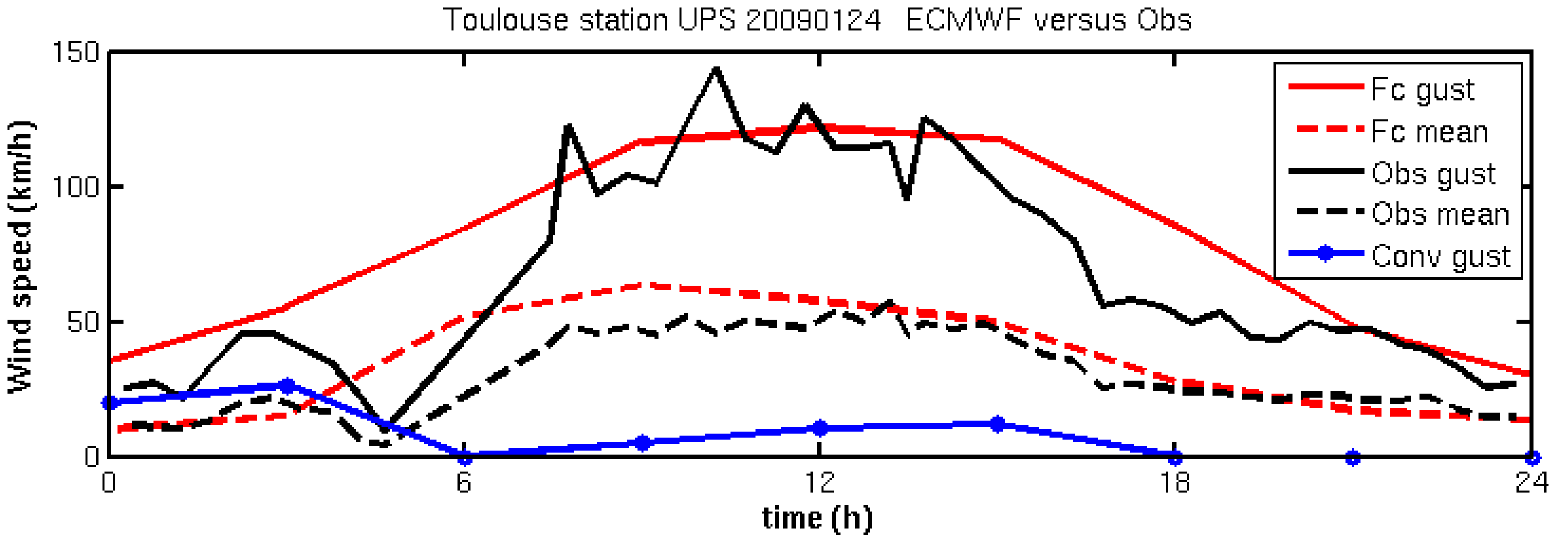


Model



Wind gusts

Time series against anemometer 24 January 2009 (storm Klaus)

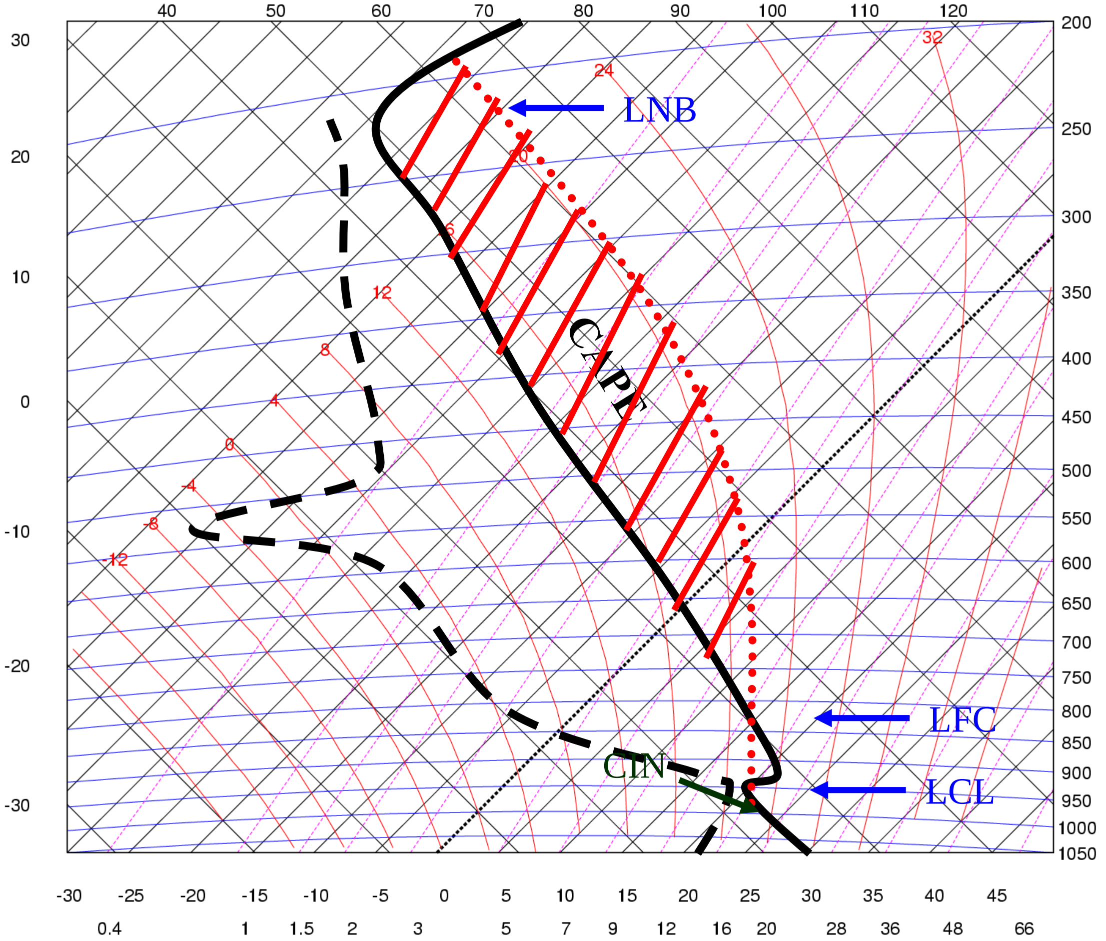


Observed mean wind speed (dashed black line) and maximum wind speed (solid black line) for 24 January 2009 at a meteorological station at Toulouse University, France (courtesy Jean-Luc Attié and Pierre Durand), together with corresponding 3-hourly forecast values (red lines) from the operational deterministic forecast from 23 January 12 UTC. The blue line denotes the convective contribution to the gusts.

Physical processes: Summer and winter convection

Parcel convective In(stability): CAPE (CIN)

Idealised Profile



$$CAPE \approx \int_{base}^{top} g \frac{T_{cld} - T_{env}}{T_{env}} dz$$

In Thermodynamic diagram use T to compute CAPE, otherwise use virtual temperature T_v instead

$$\frac{dw}{dt} = w\frac{dw}{dz} = \frac{1}{2}\frac{dw^2}{dz} \approx g\frac{T'}{\overline{T}}$$

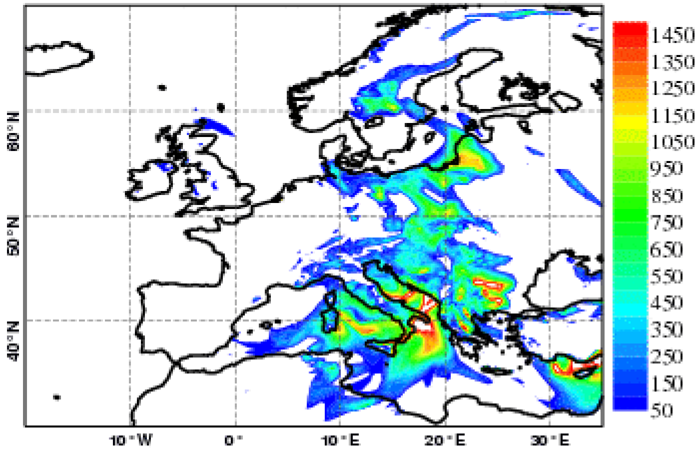
$$w^2(z) = 2\int_0^z g\frac{T'}{\overline{T}}dz = 2 \cdot CAPE$$

Maximum updraught velocity (vertical velocity in cloud) $w = \sqrt{2 \cdot CAPE}$

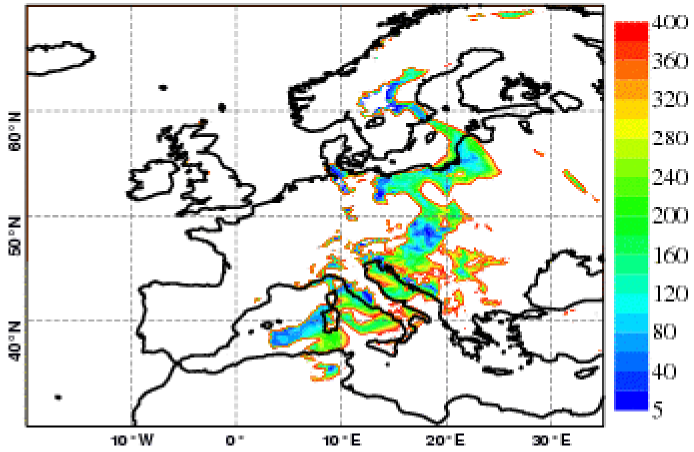
In the IFS convection parameterization the amount of CAPE determines the intensity of convection (rainfall) – the computation of CAPE depends on the specified entrainment and the departure level of the air parcel (LCL=lifting condensation level, LFC=level of free convection, LNB=level of neutral buoyancy)

Convective Indices

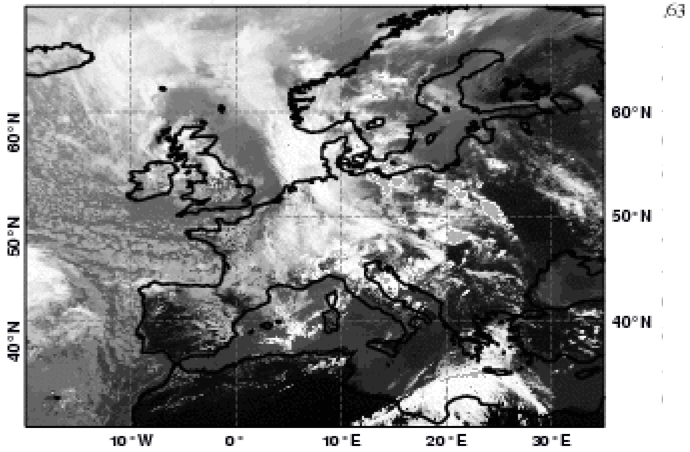
requested by Member States (User Meeting June 2011)



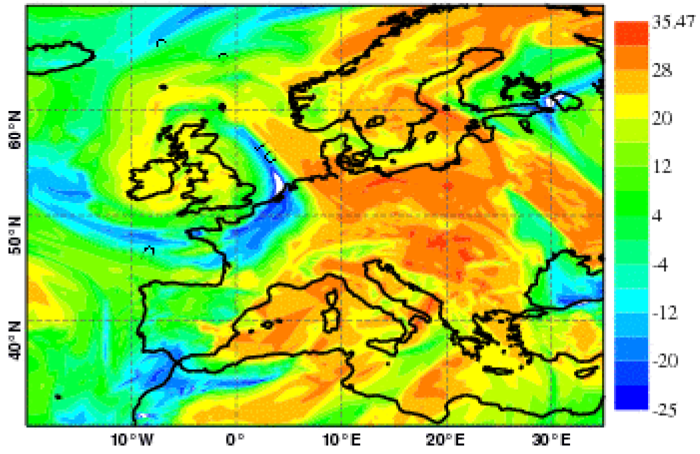
Fc 20110608 00UTC +12h CAPE (J/kg)



Fc 20110608 00UTC +12h CIN (J/kg)



Meteosat 9 IR 20110608 12UTC



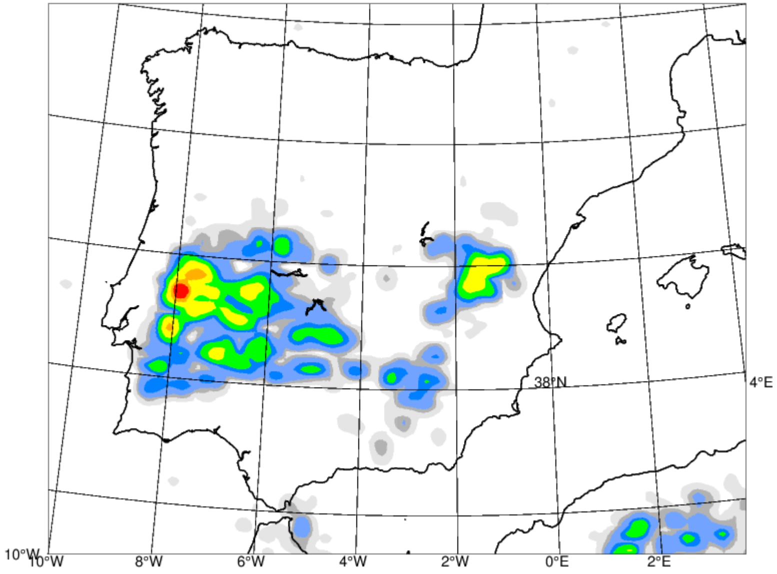
Fc 20110608 00UTC +12h K-Index (C)

Forecasting Lightning : in Cy45r1

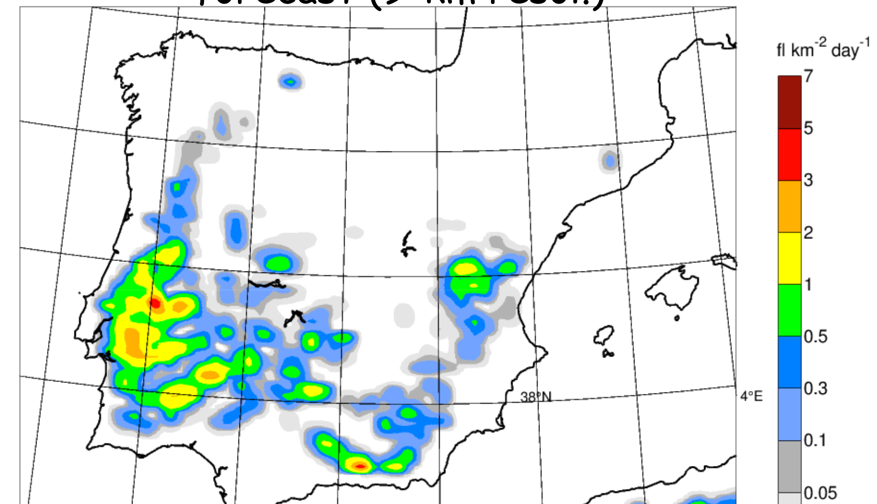
In the model, total (CG+IC) lightning flash densities are diagnosed from CAPE, convective hydrometeor contents and convective cloud base height

P: Lopez, 2016 MWR

Lightning flash densities from ATDnet observations (data from Met Office)

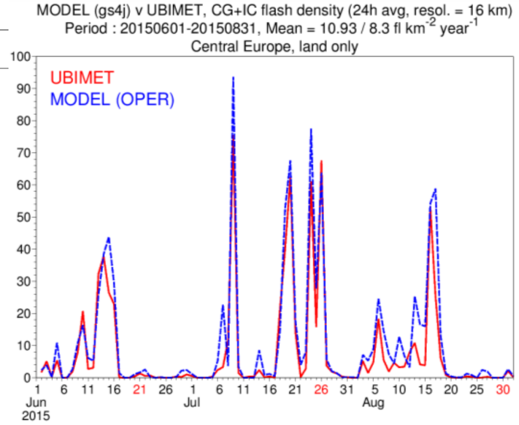


Total lightning flash densities from ECMWF 42h forecast (9-km resol.)



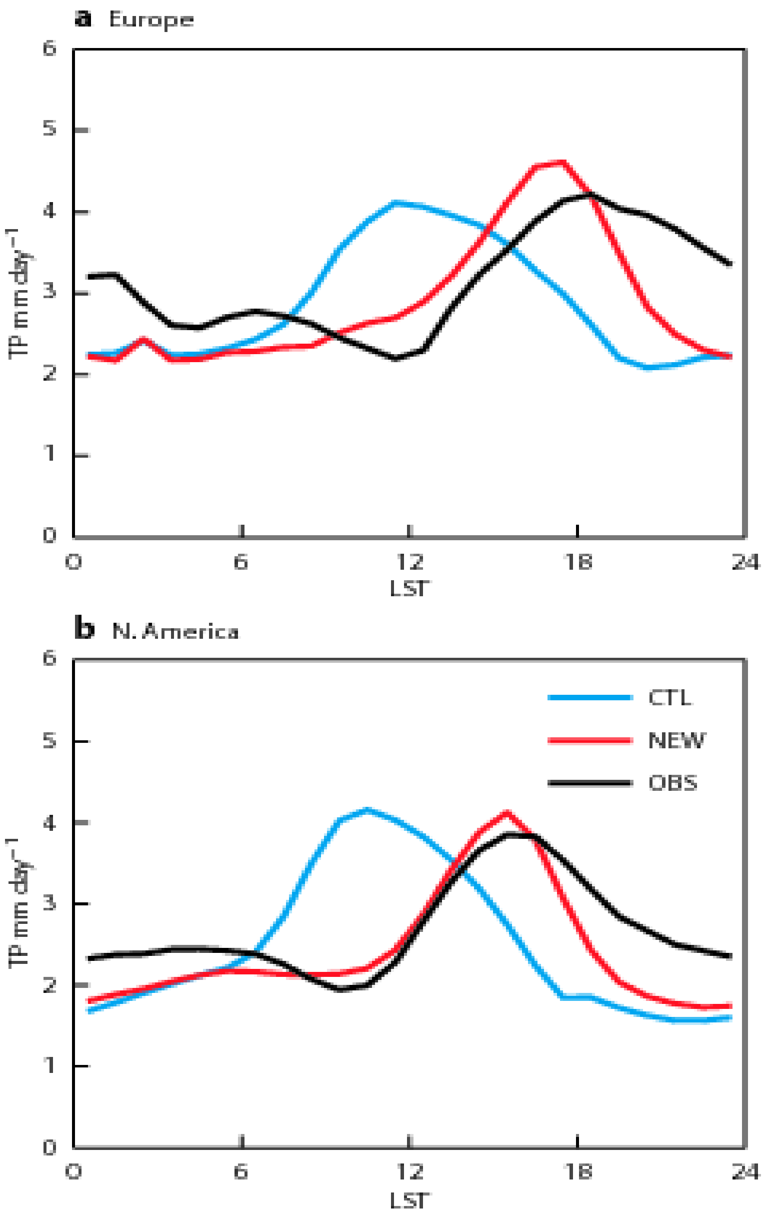
6h-avg lightning flash densities valid 17/06/2017 18 UTC: Portugal Fire

a 50% detection efficiency for ATDnet sensors (mainly cloud-to-ground flashes) has been assumed



ECMWF

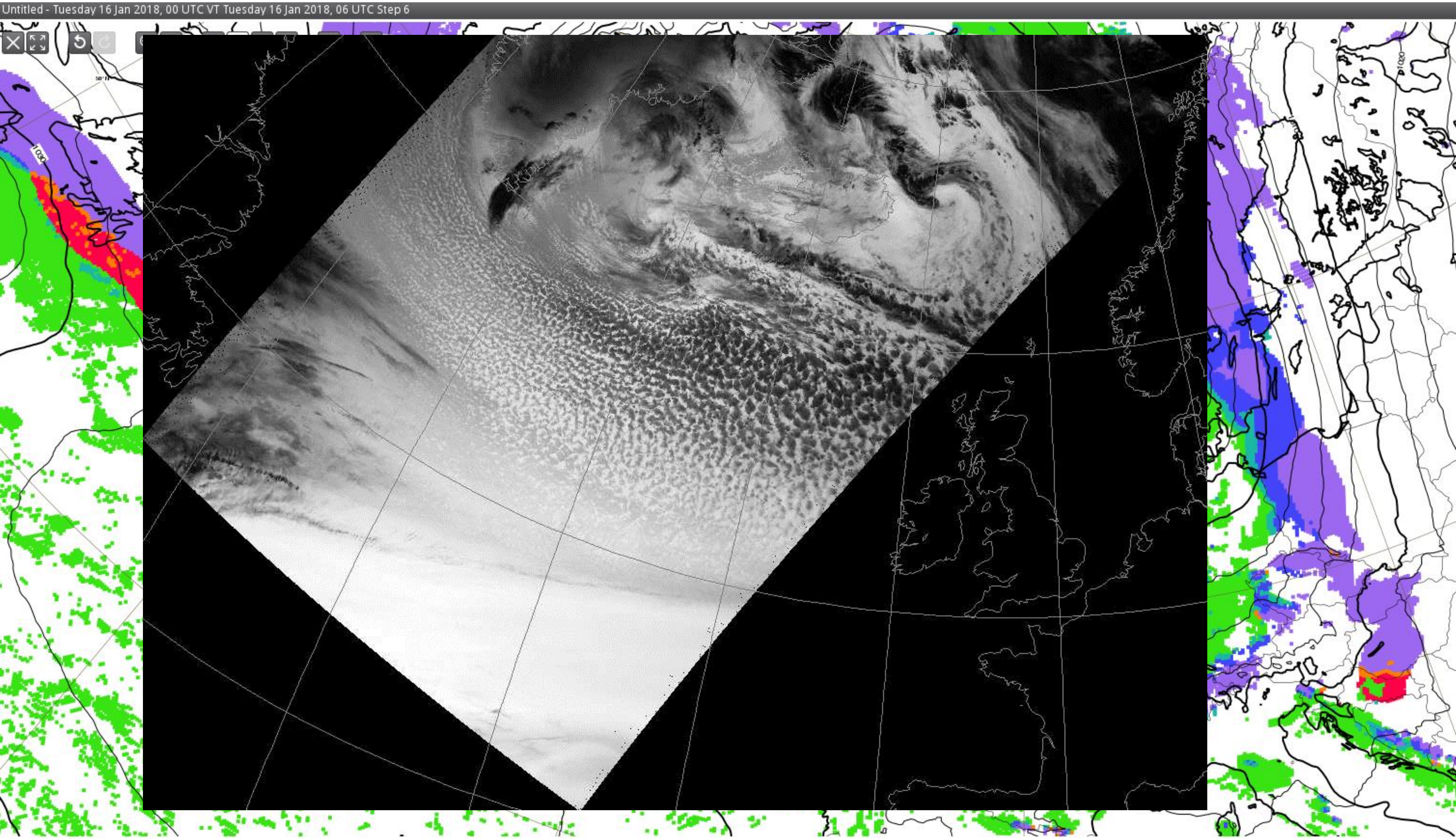
Diurnal cycle: realistic since Nov 2013



JJA 2011-2012 hourly rainfall composite against Radar

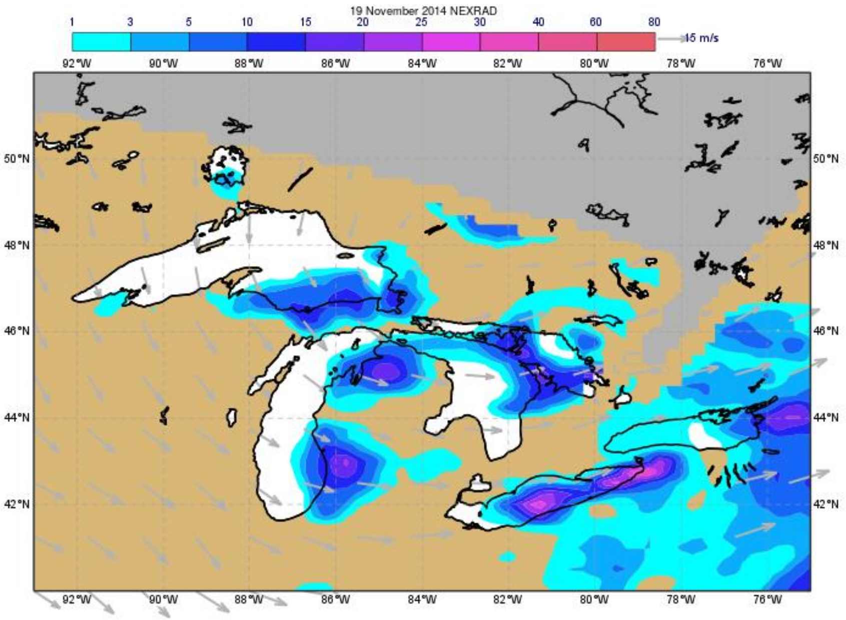
See ECMWF Newsletter No 136 Summer 2013
Bechtold et al., 2014, J. Atmos. Sci.

Realism of convective and stratiform precipitation

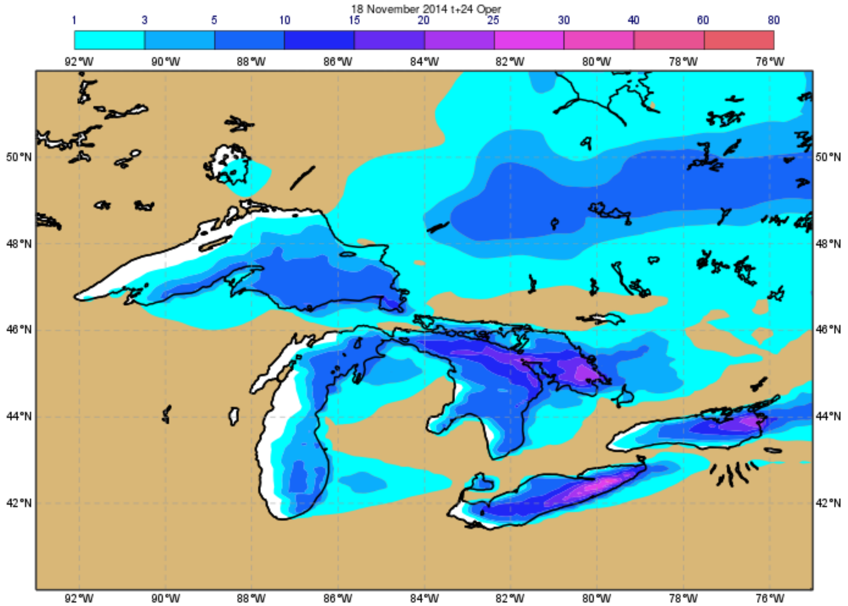


Untitled - Tuesday 16 Jan 2018, 00 UTC VT Tuesday 16 Jan 2018, 06 UTC Step 6

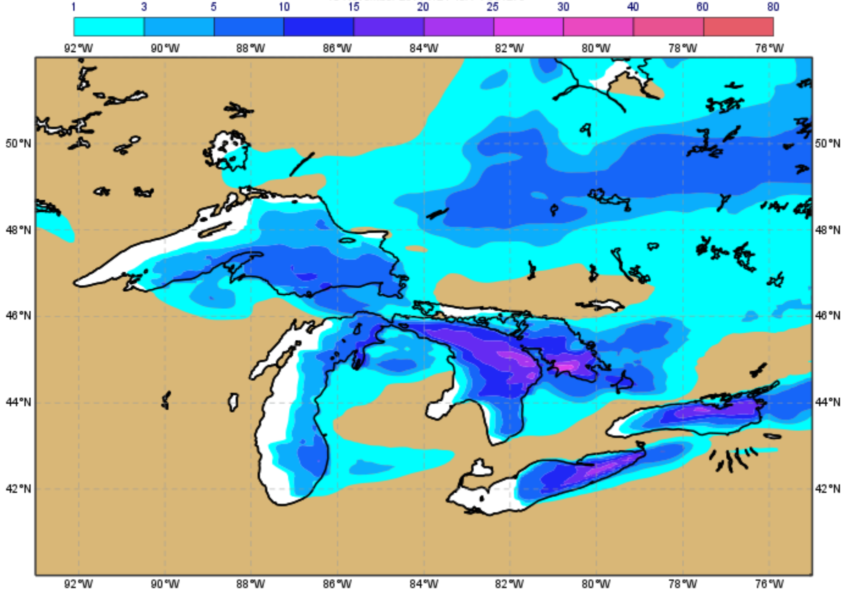
Wintery lake convection -snow



Radar



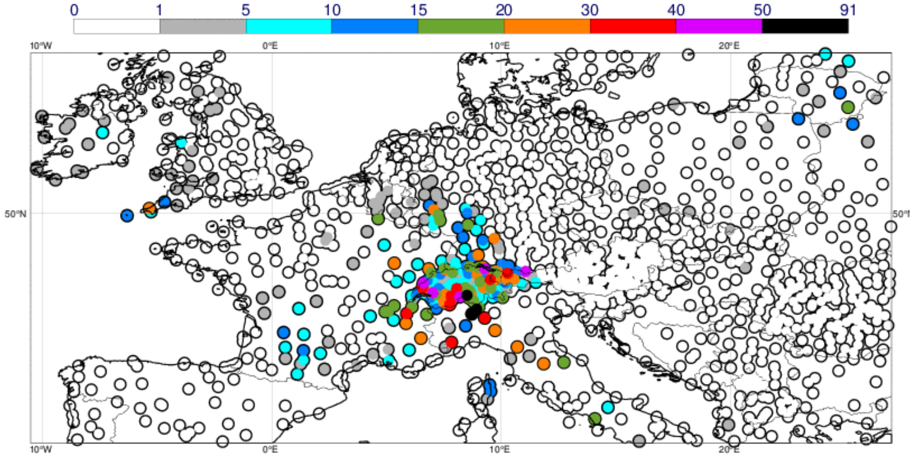
Oper 2014



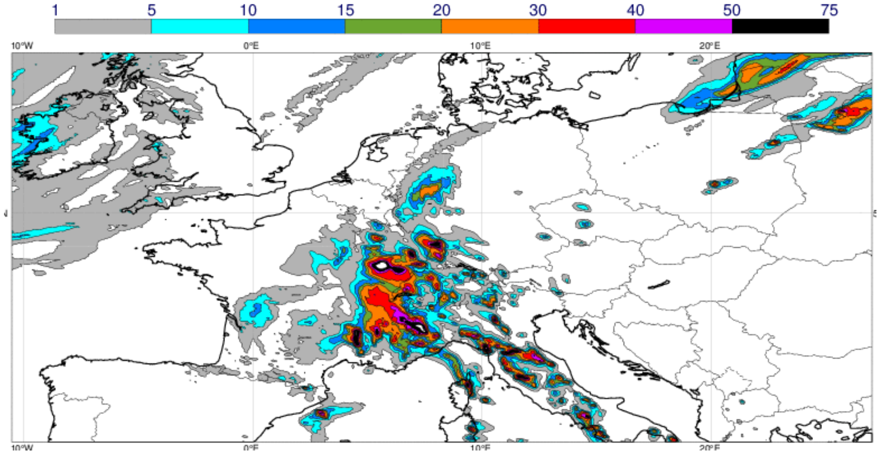
45r1

Convection forecast and resolution: hint to the future

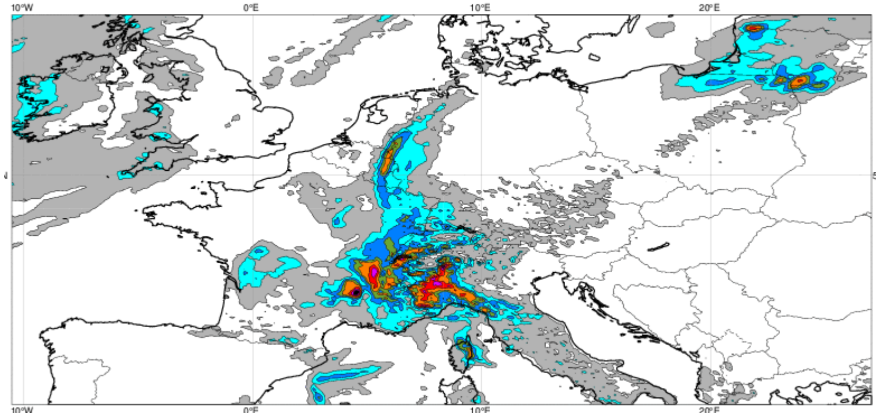
Obs 9 Aug 2015



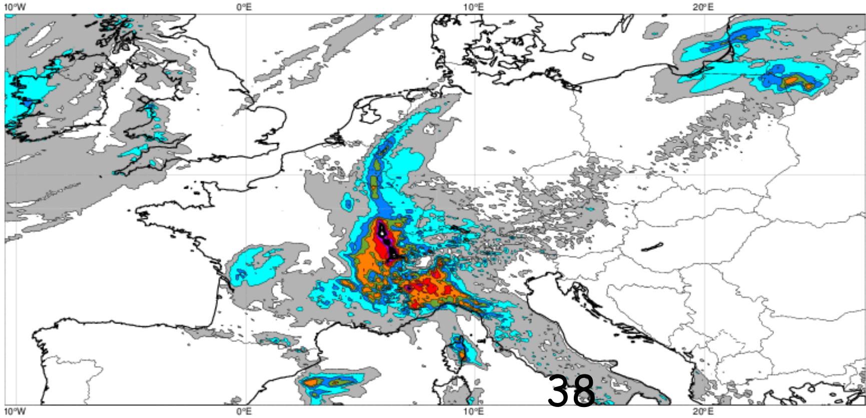
Cy42r1 Tco1999 5 km no deep



Cy42r1 TCo1279 9 km



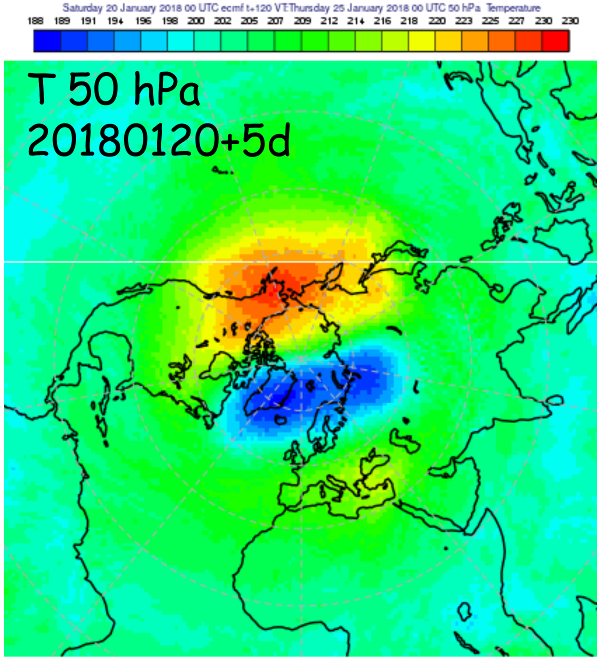
Cy42r1 TCo1999 5 km scaled Mfl



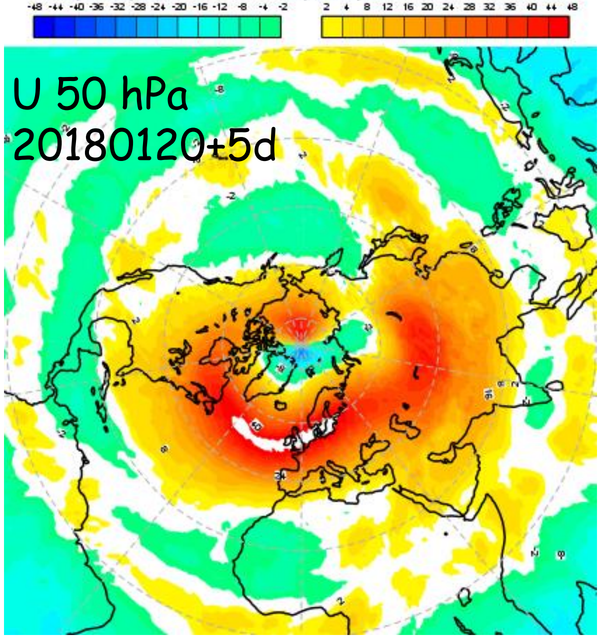
Summary: issues for improvement

- T2m winter can still be difficult: stable boundary-layer, coupling with surface (ground, lakes) and low-level clouds
- Still underestimation of convective night-time precip and some overestimation of light precipitation (drizzle)
- Inland penetration of (convective) showers and convective organisation improved but can still be improved
- Too strong Indian and SE Asian Summer Monsoon (some positive effect from new aerosol climatology in 2017)
- Melting of fresh snow on ground somewhat too slow
- and for long-range forecasts the coupling between the stratosphere and the troposphere

Example of Strato warming -Tropo evolution



T 50 hPa
20180120+5d



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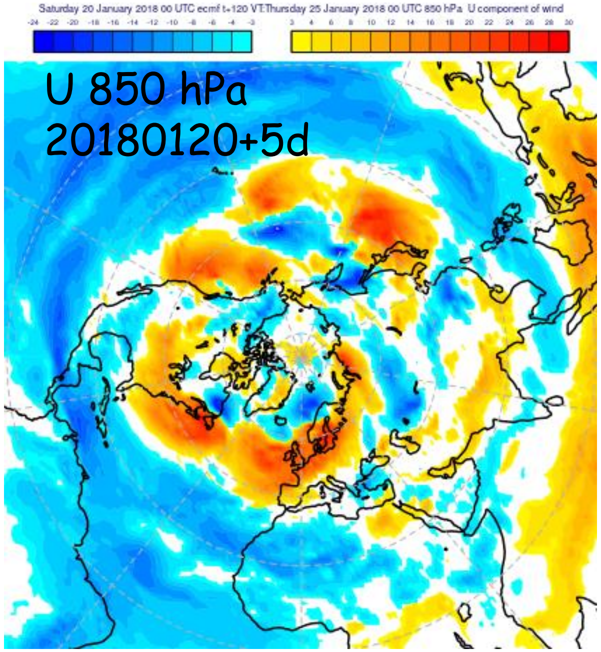
20180120+5d



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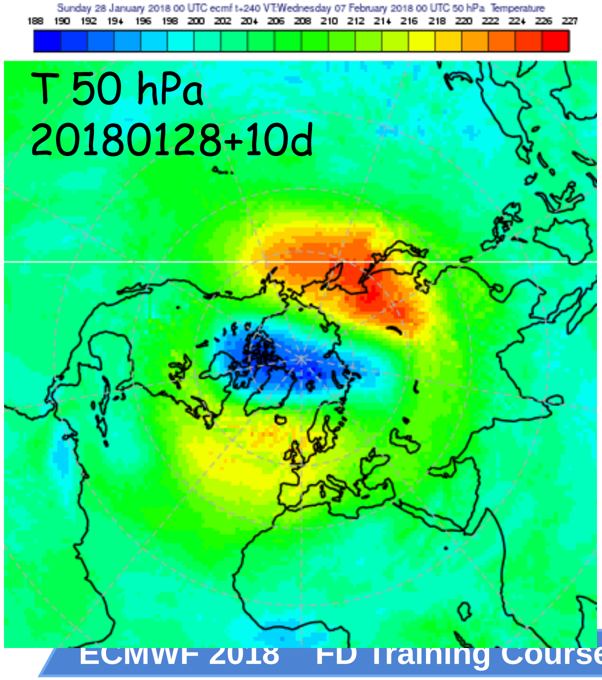
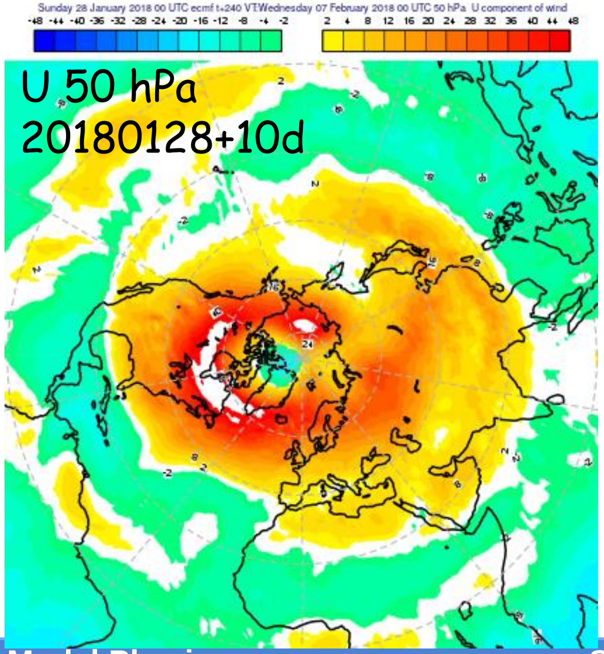
20180120+5d



T 50 hPa
20180128+10d



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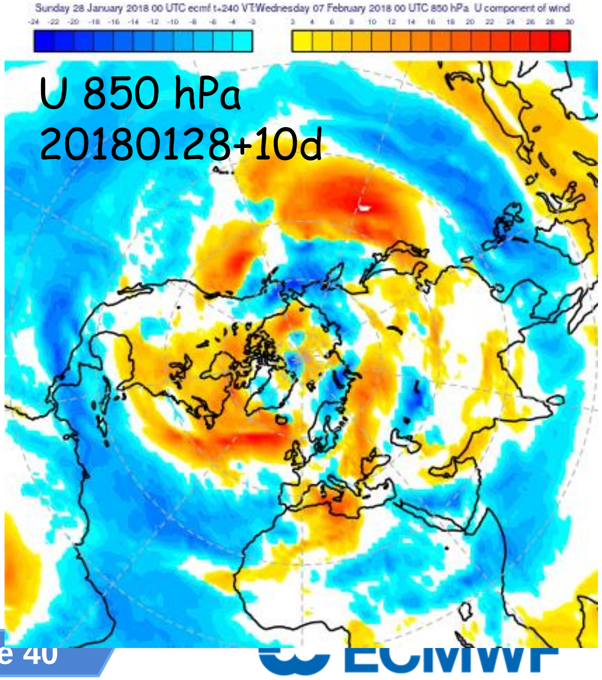
20180128+10d



U 850 hPa
20180128+10d

Some products and things in 2017 (Cy43r3)

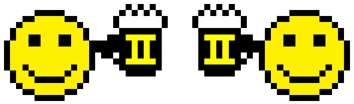
- Products: Ceiling (m), convective cloud top height (m), height of 0 and 1 Deg C wet bulb temperature, direct beam surface radiation
- New radiation scheme and Aerosol climatology -> improved (reduced precipitation) Indian summer monsoon

and in 2018 (Cy45r1)

- Products: Lightning strike densities (including probabilities)
- Stratiform and convective microphysics updates (precipitation and mixed phase) – consequences for cloud SW radiation
- Coupling of HRES
- Revised stochastic physics for ensemble (no SW perturb no backscatter)

longer term plans-developments

- Revision and simplification of cloudy boundary-layer
- No CAT unfortunately



Model tendencies during an inversion situation