Model Physics: concepts, practice, products

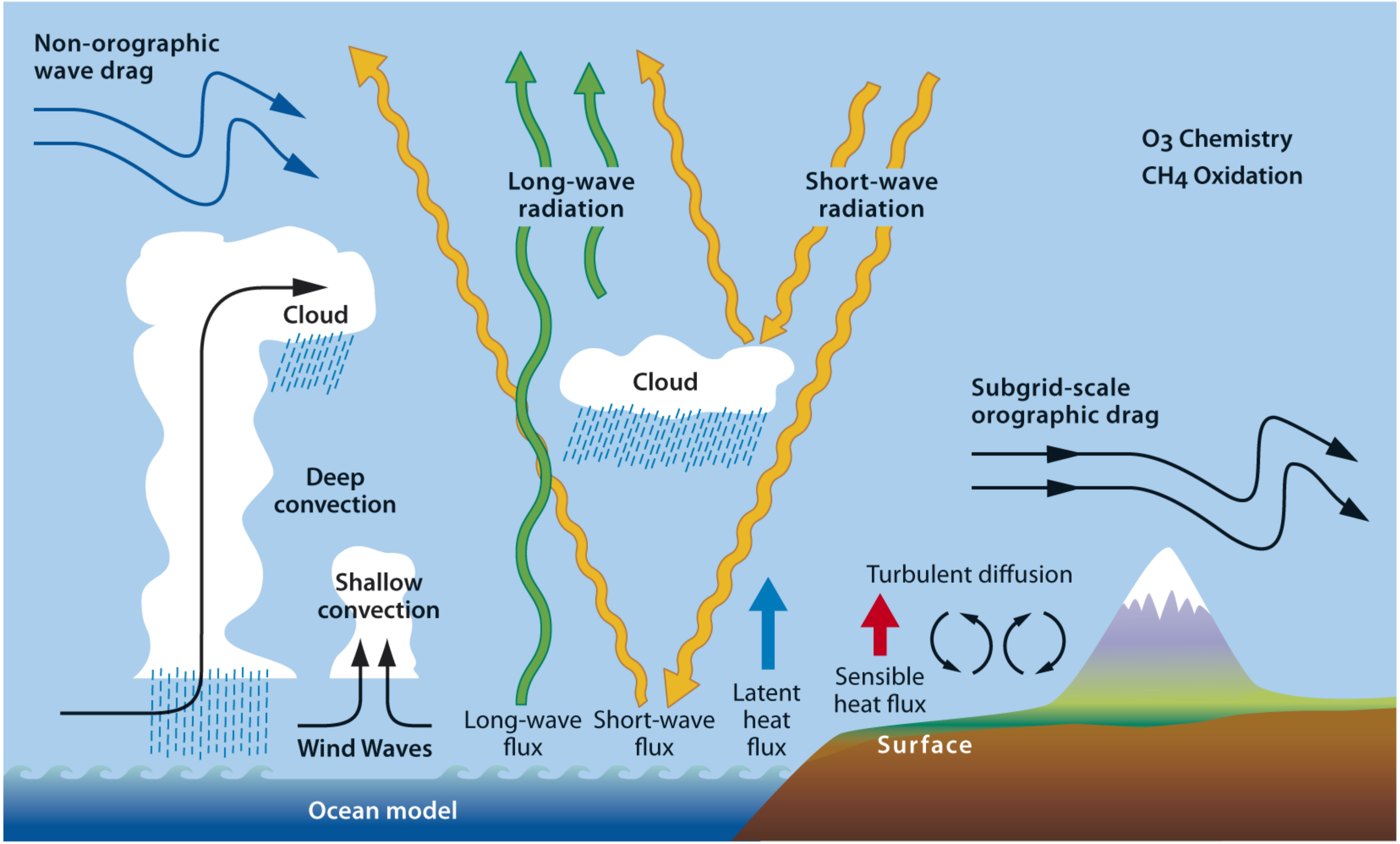
- Physical processes (tendencies) represented in the IFS
- Revision of equilibria in the atmosphere/model
- Forecasted satellite images
- Winter special: Snow, 2m Temperature, 10 m Wind, Wind Gusts
- Summer special: diurnal cycle of Convection, CAPE, UV Index
- Or high resolution (you choose)
- Stratosphere

for the physical Aspects Section: Peter Bechtold (peter.bechtold@ecmwf.int)

http://old.ecmwf.int/newsevents/training/meteorological_presentations/ or
http://old.ecmwf.int/newsevents/training/lecture_notes/

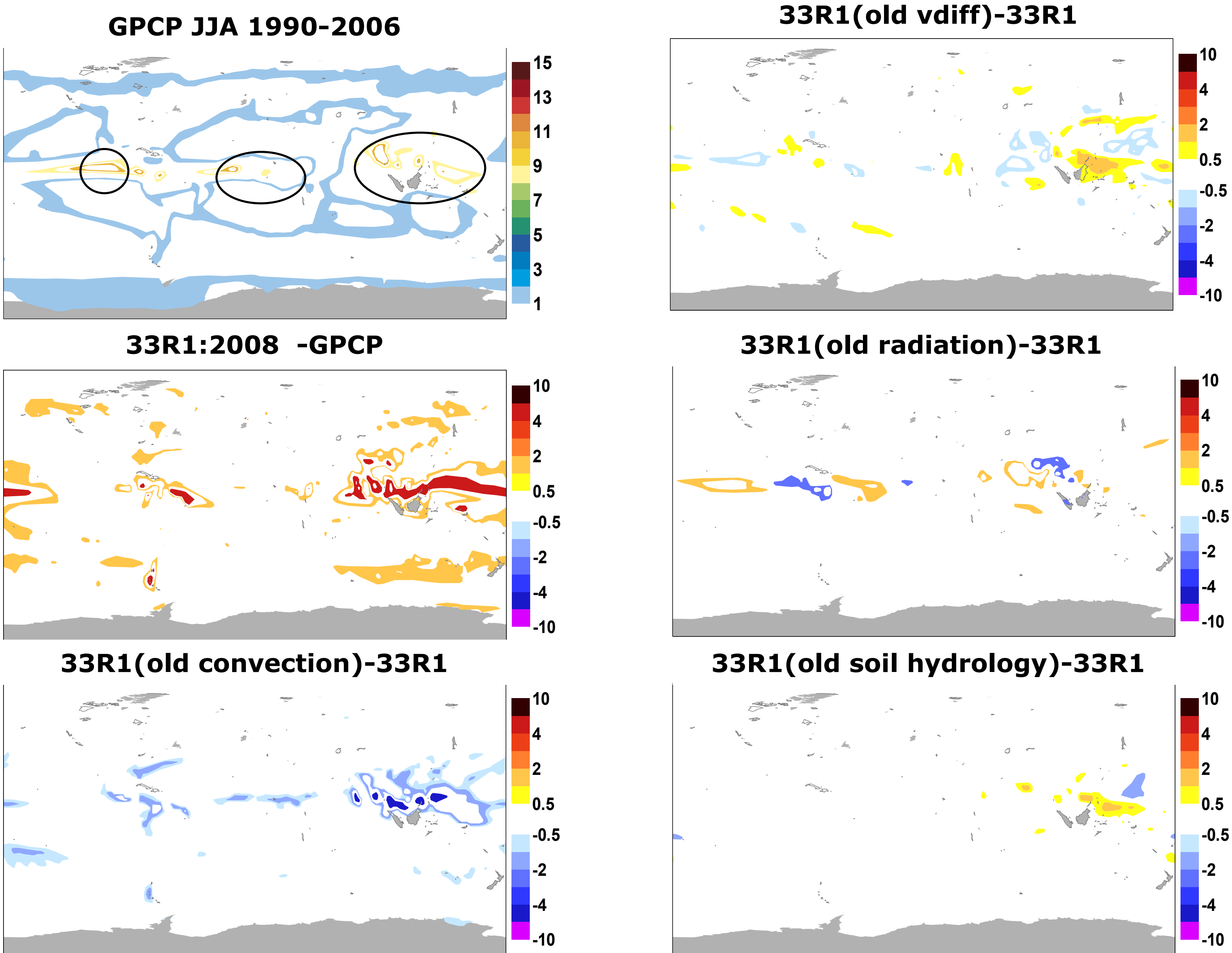
Parameterized processes in the ECMWF model

from the surface to the stratosphere



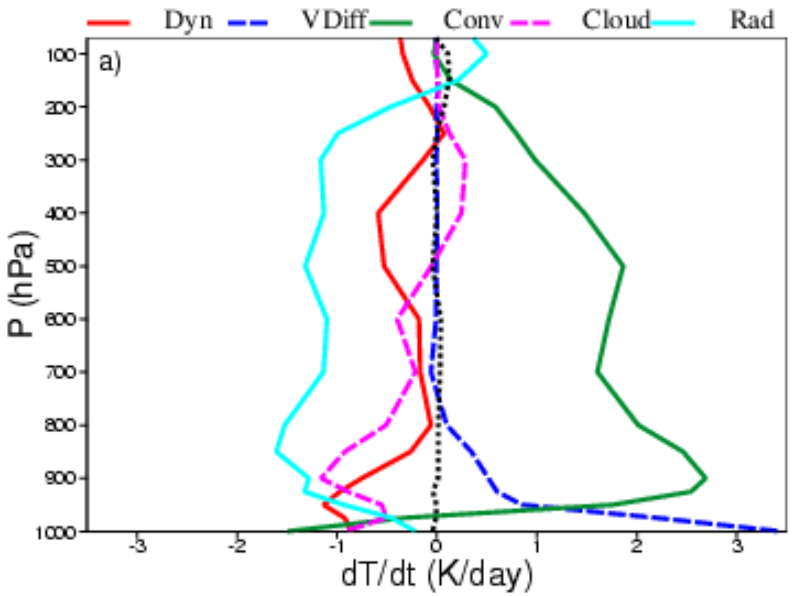
ECMWF

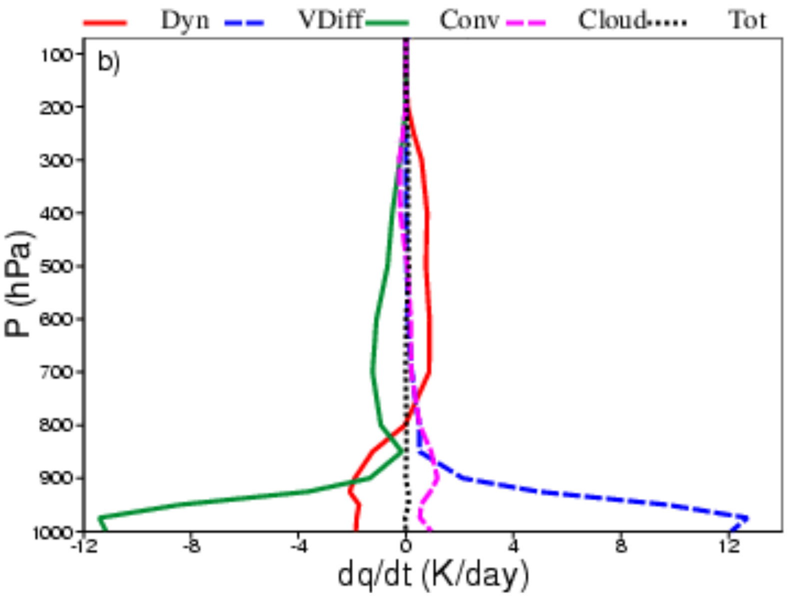
Precipitation JJA: Sensitivity to Model Formulation
Seasonal integrations



ECMWF

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?

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

w ~ -0.5 cm/s subsidence

~0.5 K/100 m

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

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

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

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

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.

Product: Forecasted (“synthetic”) satellite images

How are they produced ?

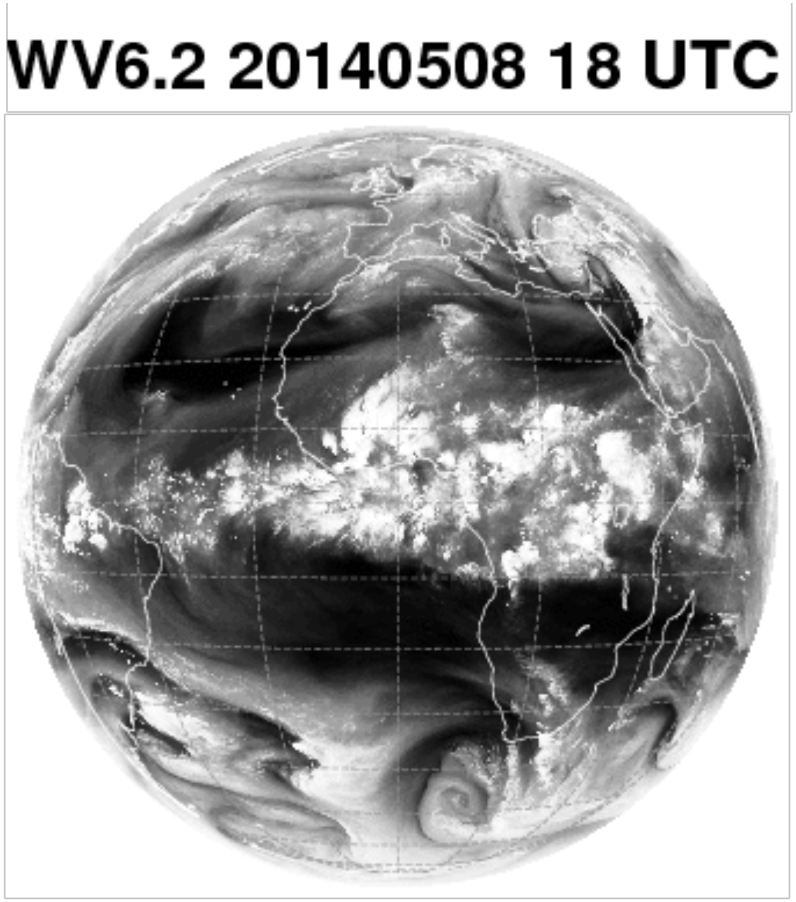
They are generated with the aid of a radiative transfer model (RTTOVS=Radiative Transfer Model for TOVS, ATOVS, and several other atmospheric sounders).

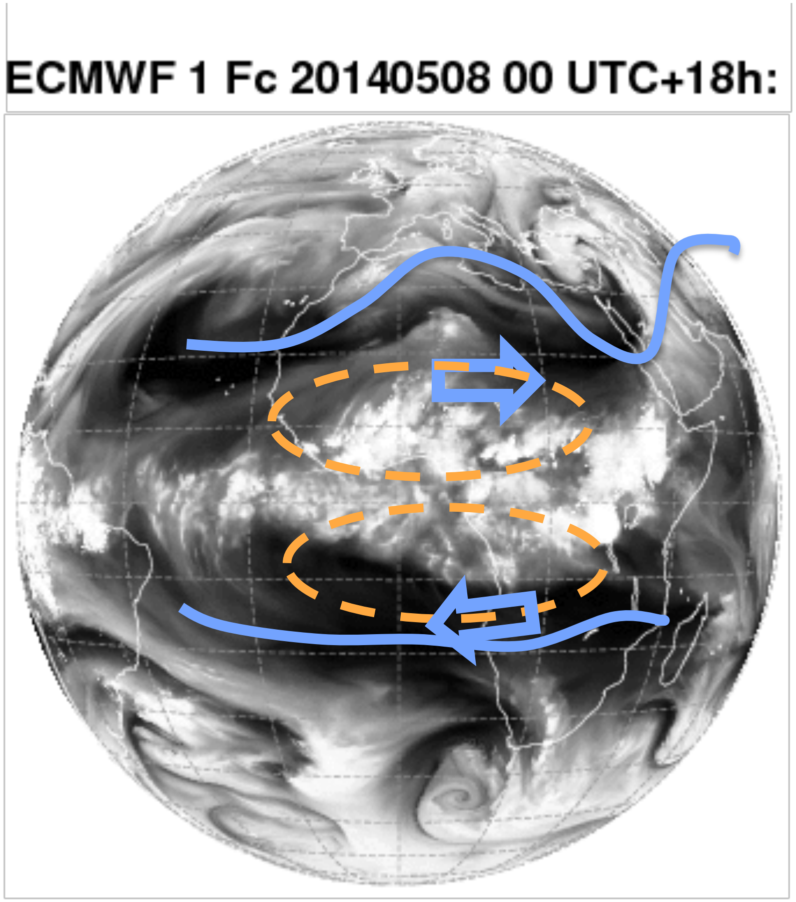
The radiative transfer model produces the radiation a satellite would see given the forecasted model atmosphere (the radiation therefore depends on the pressure, temperature and cloud condensate produced by the forecast, and is very sensitive to the cloud top height and cloud optical thickness).

Only the IR and water vapor bands are provided. For the visible channel it is too difficult as one would need to know perfectly the albedo of the surface.

The radiative bands provided can be directly compared to the specific Meteosat channels

Observed and forecasted +15h WV satellite imagery

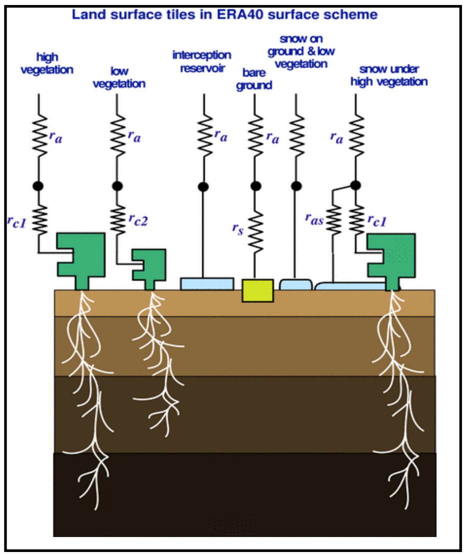


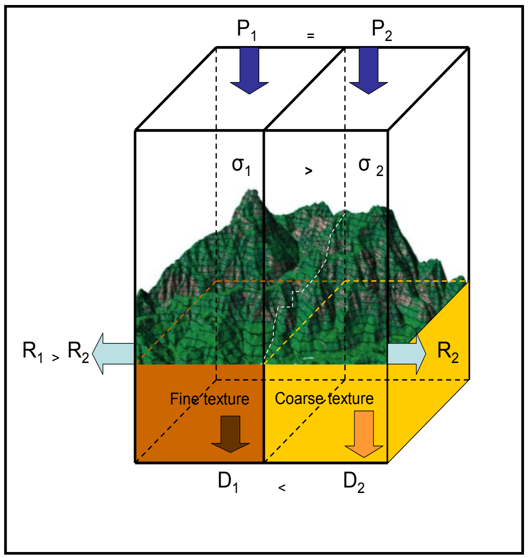


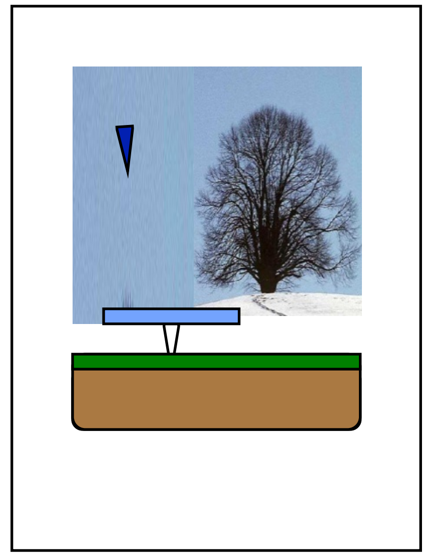
Land surface model evolution

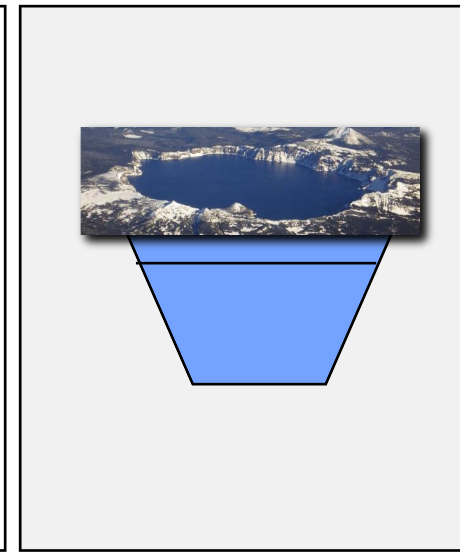
2000/06	2007/11	2009/03	2009 & 2010	2014

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



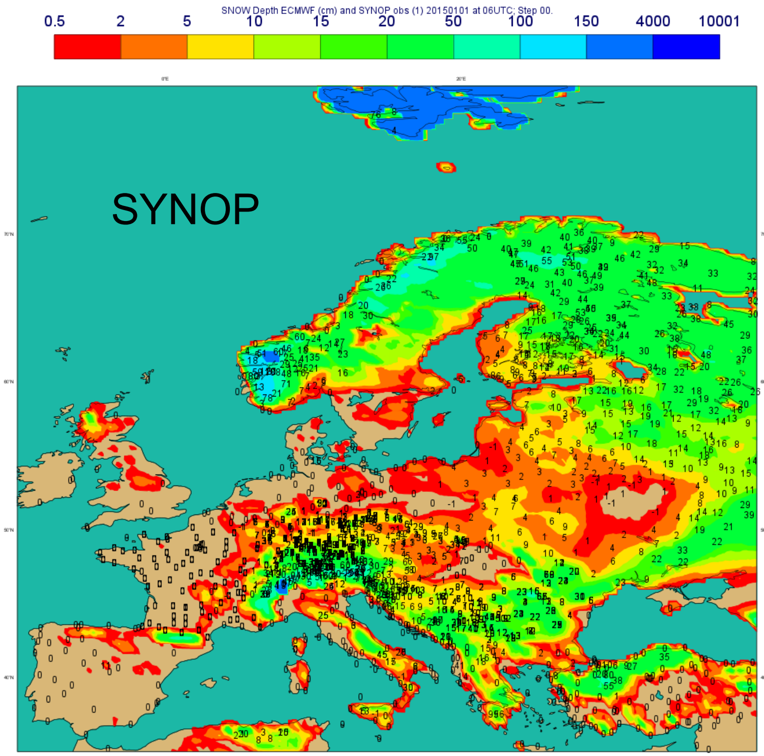






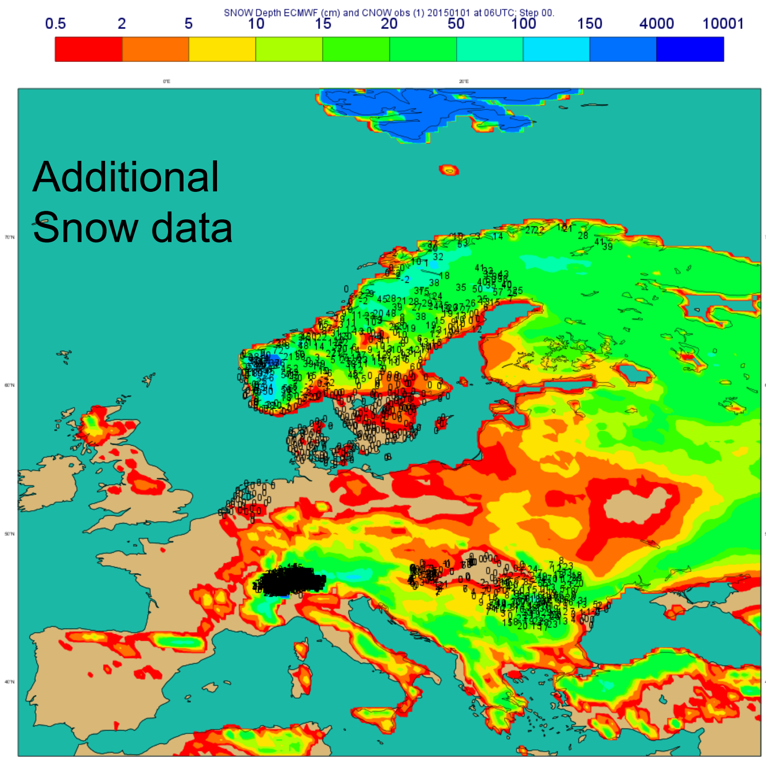
Snow Observations
Snow SYNOP and National Network data

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)**

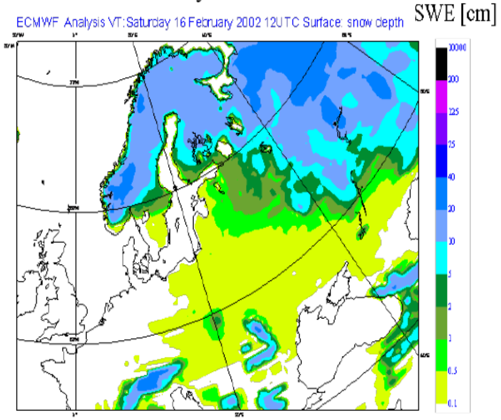
(de Rosnay et al. ECMWF Res. Memo, R48.3/PdR/1139, 2011)

ECMWF

Snow analysis uses Synop and Satellite Obs

MODIS 16/02/2002

Analysis based on SYNOP



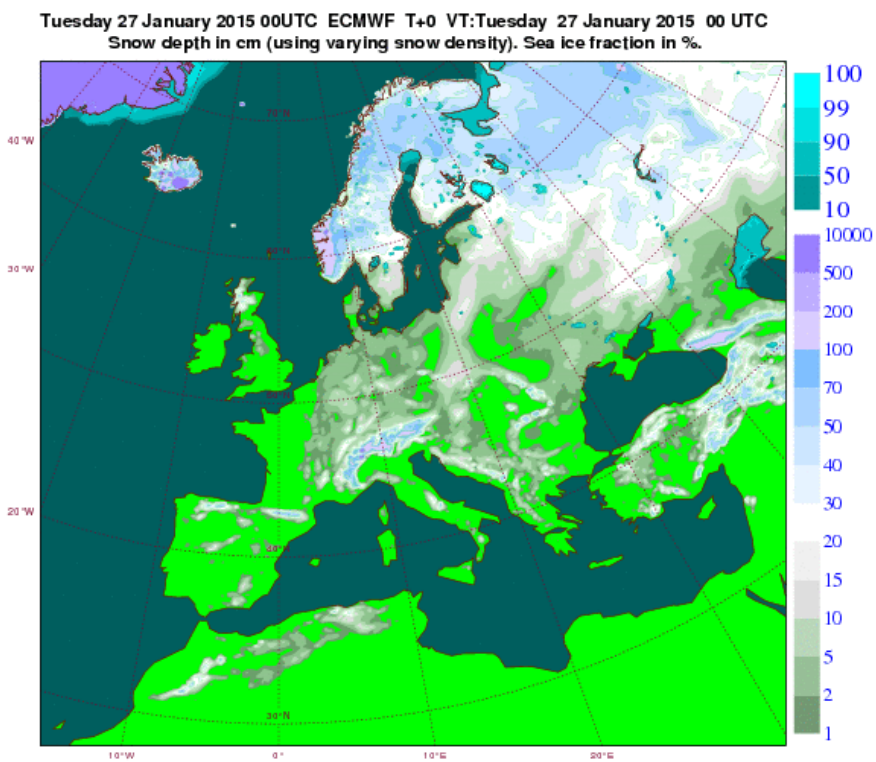
Snow extent is overestimated in the analysis when it is based on SYNOP data only

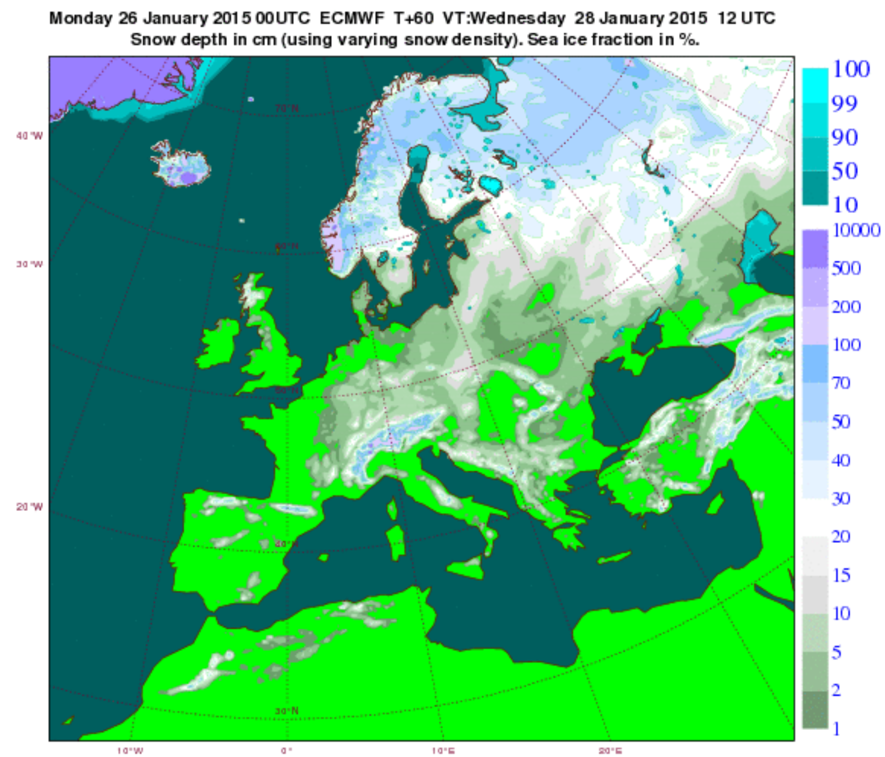
However, satellite only gives snow cover!
And the big change this year was the way satellite data is used, i.e it is assimilated with large observation error, also if FG =no snow, Sat=snow => Sat snow≈5 cm

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

Archived prognostic snow related quantities

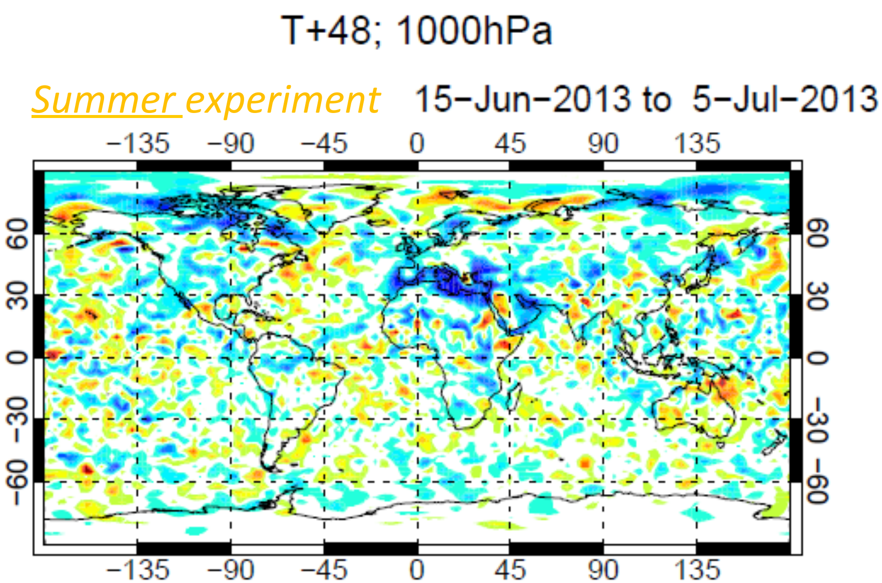
- Snow depth (water equivalent), **Sd => actual depth=Sd*(Rl=1000)/ Rsn**
- Snow density (typically factor 10 lower than water-> 1 mm precip~1 cm snow), **Rsn**
- Snow temperature, **Tsn**
- Snow albedo, **Asn**

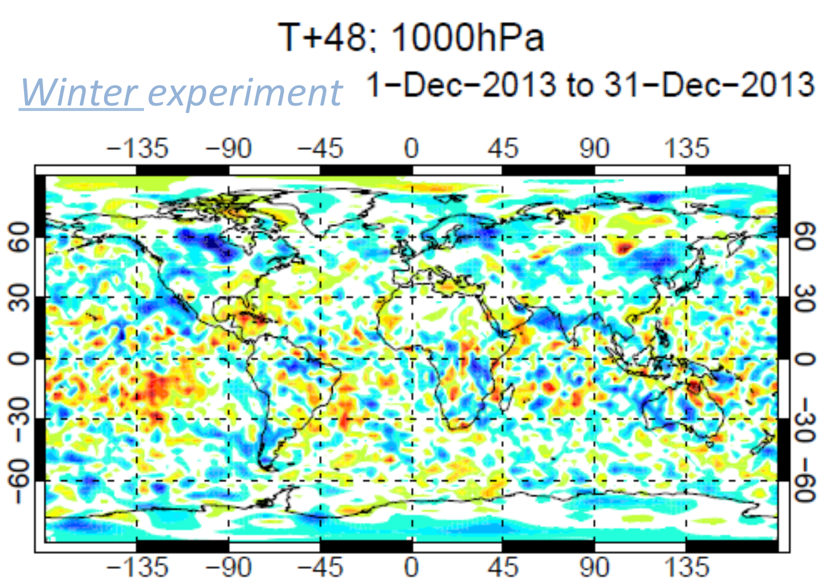




http://www.ecmwf.int/en/forecasts/charts/medium/snow-depth-and-sea-ice

Impact of water bodies in IFS version Spring 2015



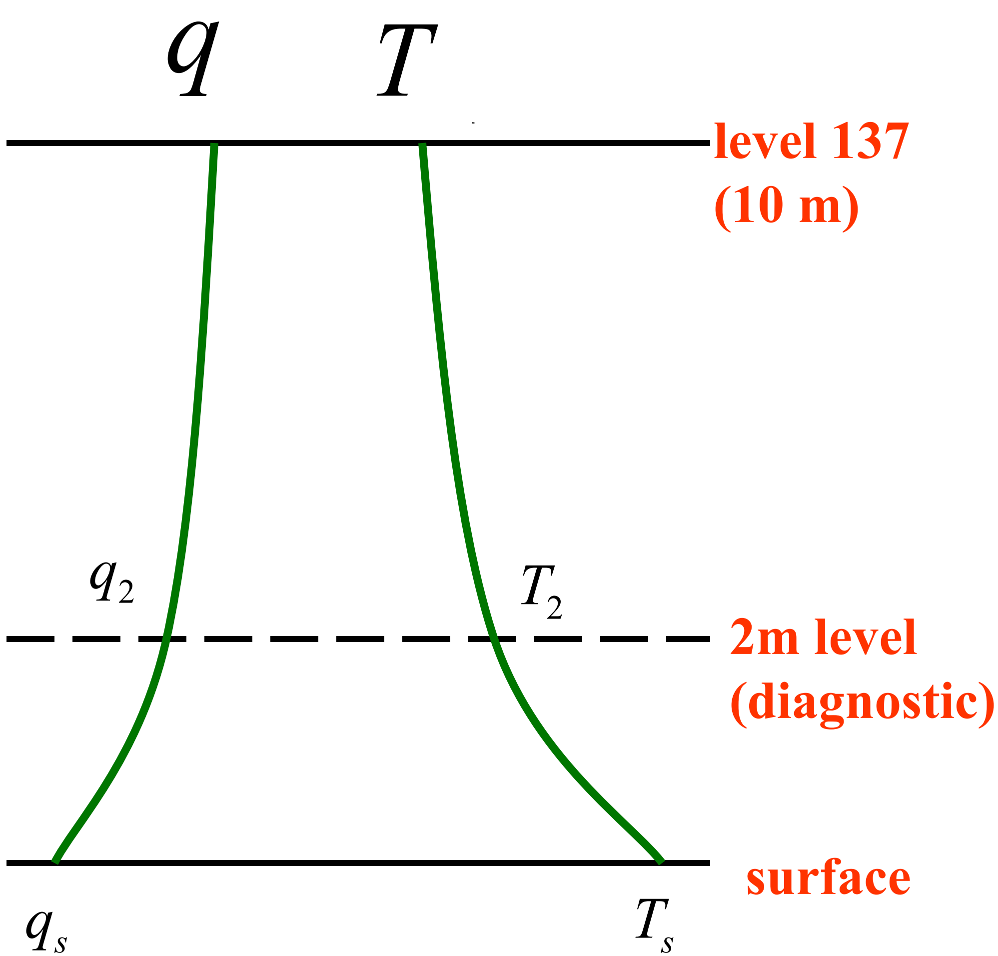


Forecast of 2m temperature are improved in proximity of lakes and coastal areas

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

ECMWF

T and q interpolation to the 2m level

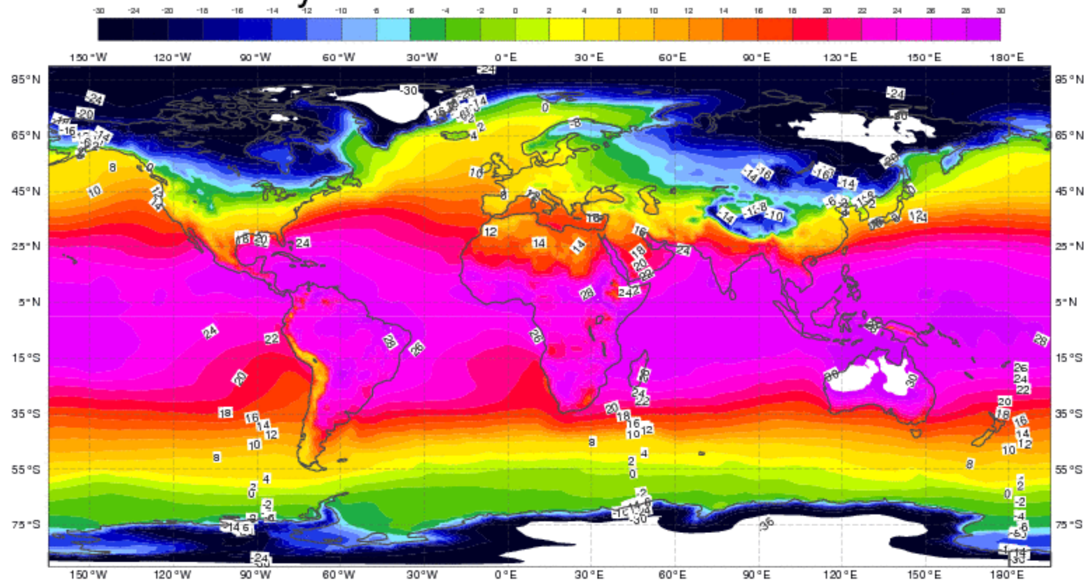


- q_s and T_s are determined by the land surface scheme or by SST.
- Main purpose of land surface scheme is to provide correct area averaged fluxes of heat and moisture.
- Land surface scheme considers different sub-areas (tiles) but effect on screen level variables is not accounted for yet.

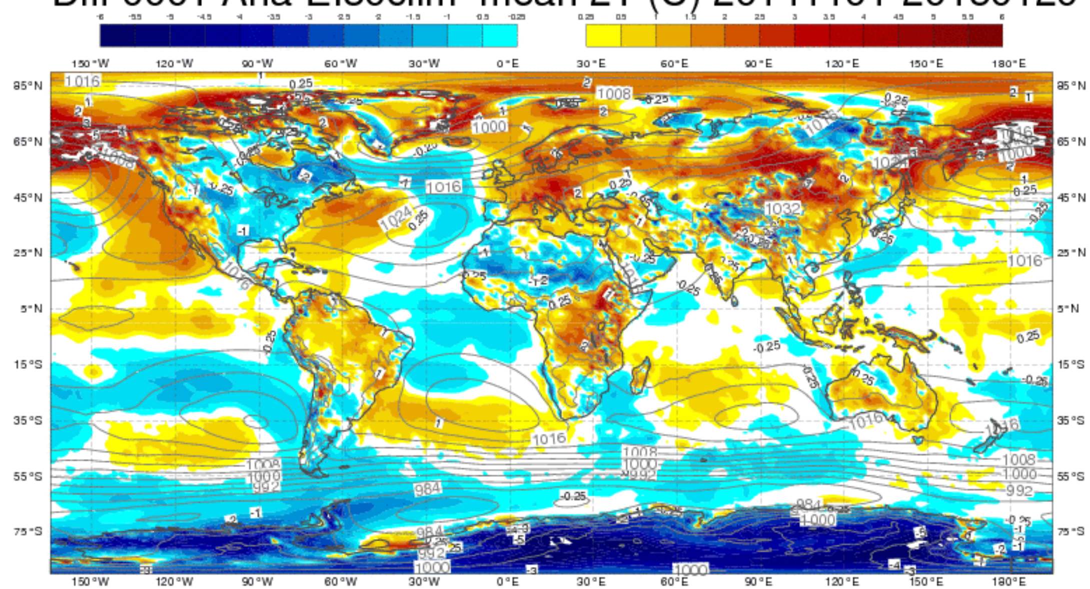
ECMWF

This winter mean and clim anomaly

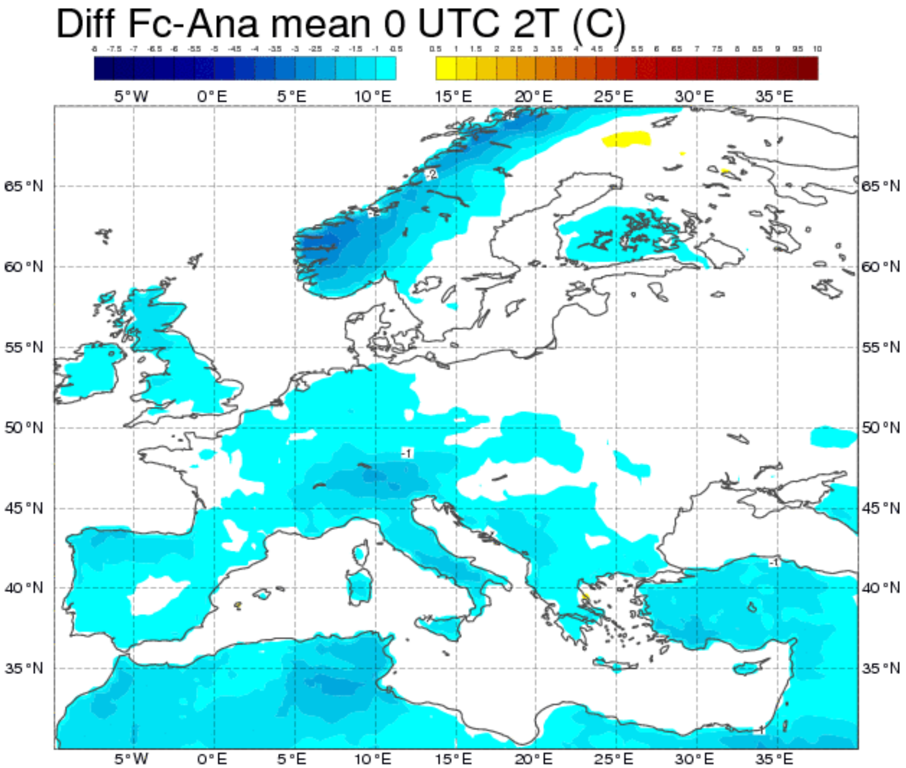
Mean 2T Analysis 20141101-20150120

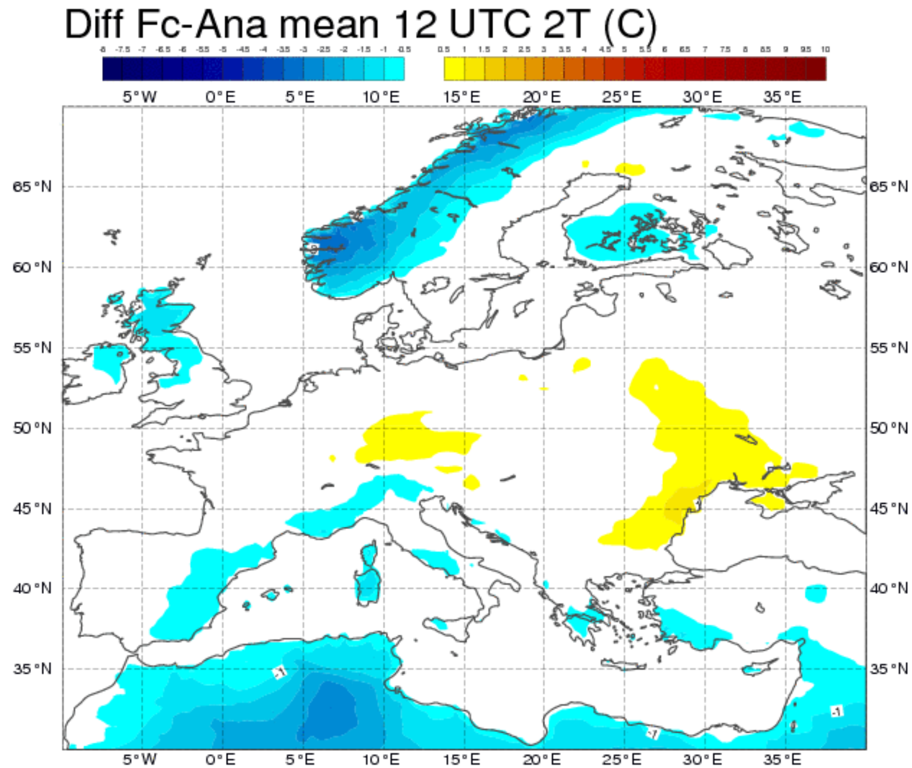


Diff 0001 Ana-EI30clim mean 2T (C) 20141101-20150120



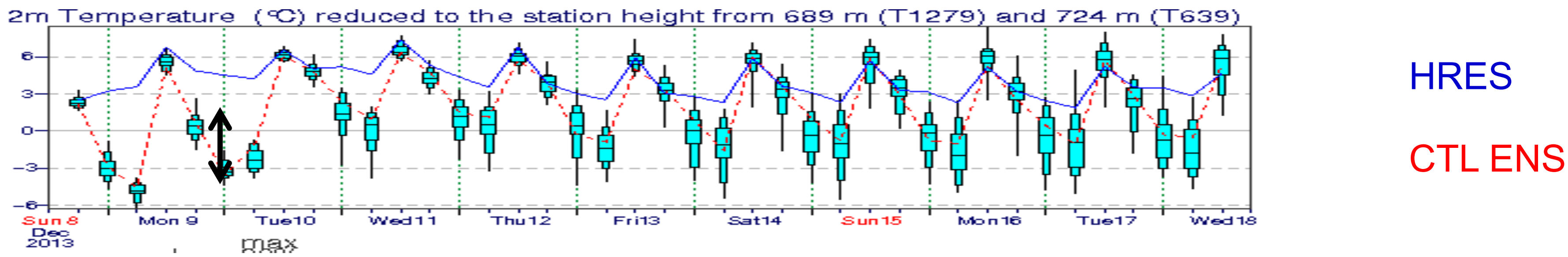
T2m mean errors (K) 1.Nov 2014- 20.Jan 2015 00 & 12 UTC



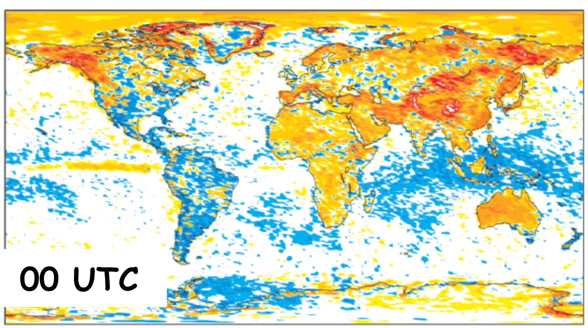


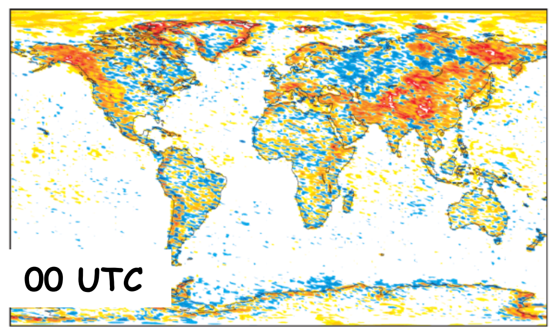
land mask applied (contour interval 0.5 K, start at +- 0.5 K)

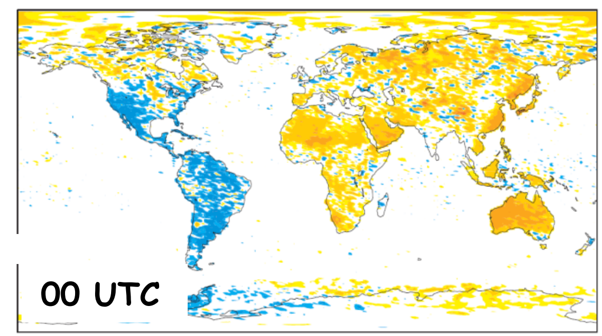
T2m difference between HRES and CF of ENS (I. Sandu et al)

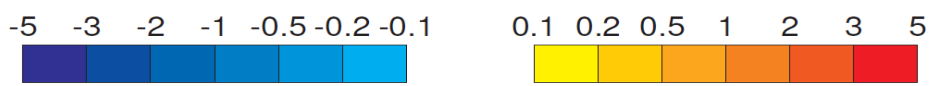


HRES-ENS CTL T2m diff. **Hor. Res. Contrib** **Radiation frequency contrib.**









Two main components:

(a) Diurnal cycle component related to radiation frequency differences (3h instead of 1h)
(b) Orographic component due to horizontal resolution differences (through effects of mean orographic on wind shear, horizontal diffusion)

Other things, i.e. vertical resolution, time step, radiation grid, matter little

Summary of wintertime 2m T errors

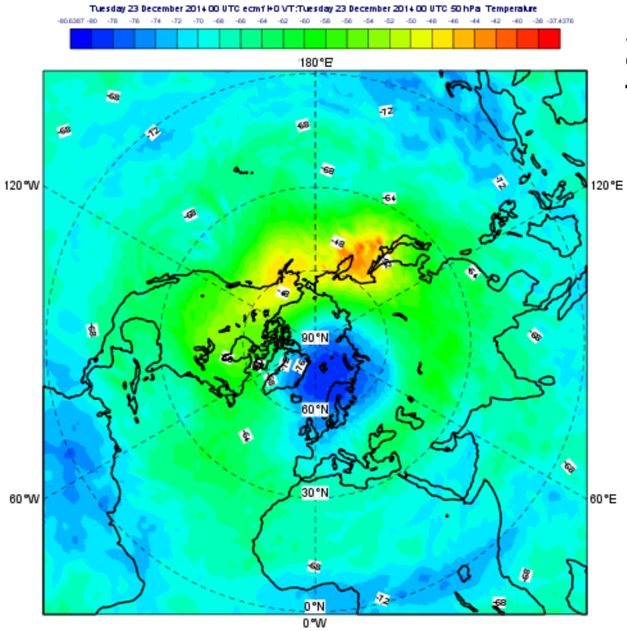
Overall not bad, mean error < 0.5 K, improved over 2010/11 but still

- Too low, particular night-time problem
- Stable boundary-layer (mixing)
- daytime overestimation related to underestimation of LCC
- otherwise cold bias easily enhanced over snow (if wrongly analysed/forecasted - not melting quickly enough)

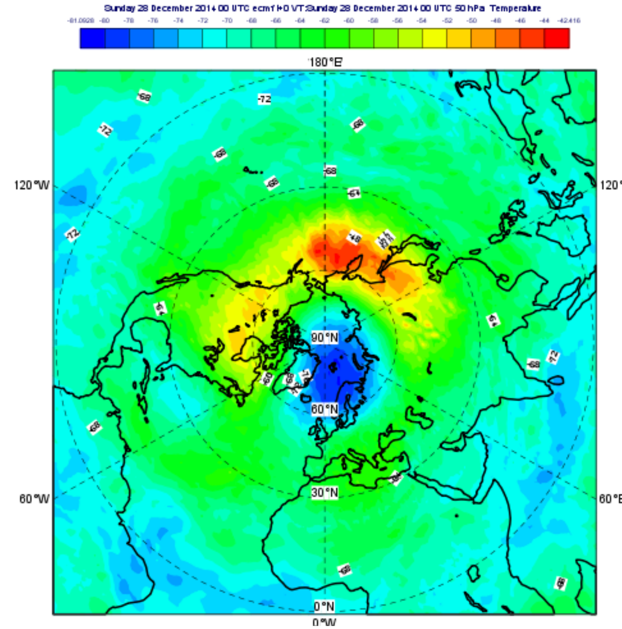
ECMWF

Polar Vortex and lower tropospheric flow: Last year we had sudden stratospheric warming begin January, this year moderate vortex dynamics and cold during Christmas period

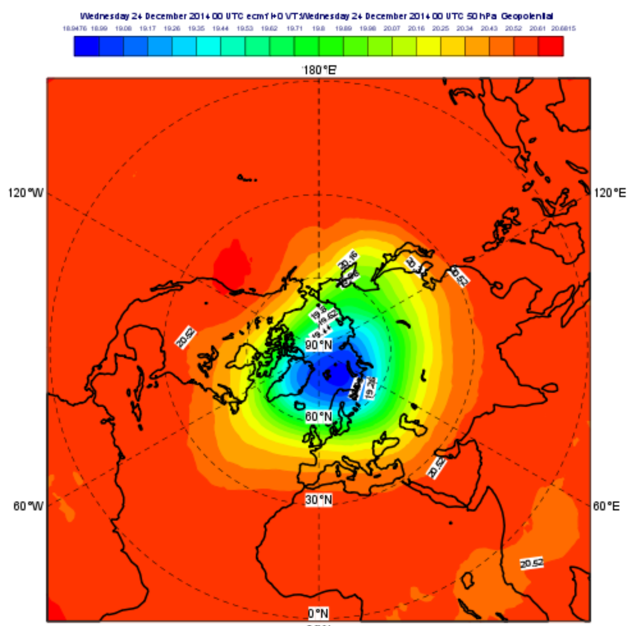
23.12.2014
T50 hPa



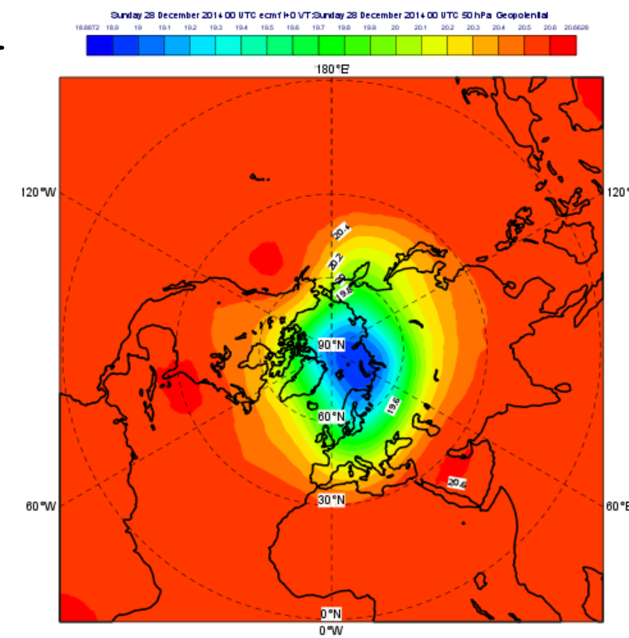
28.12.2014
T50 hPa



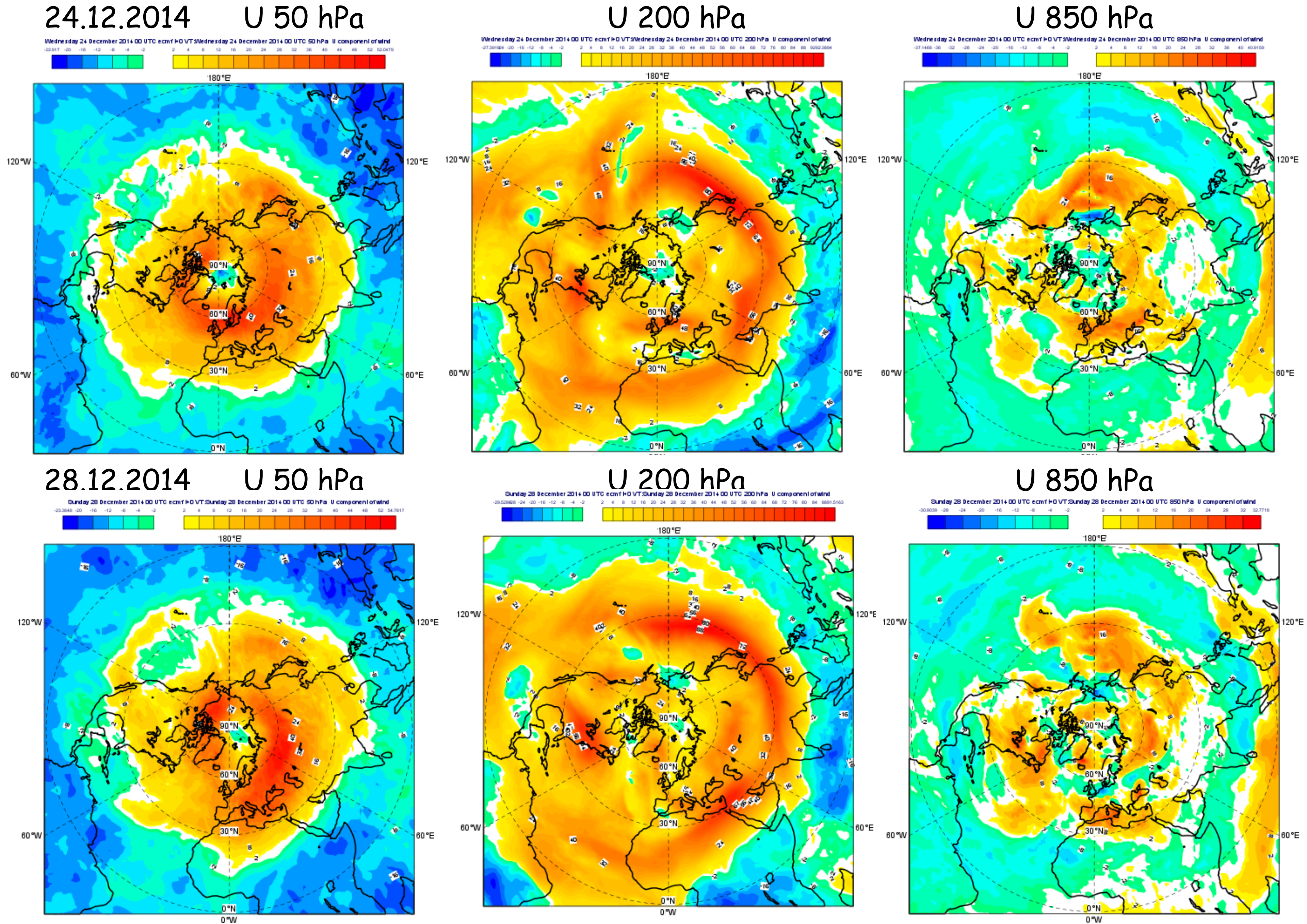
23.12.2014
Z50 hPa



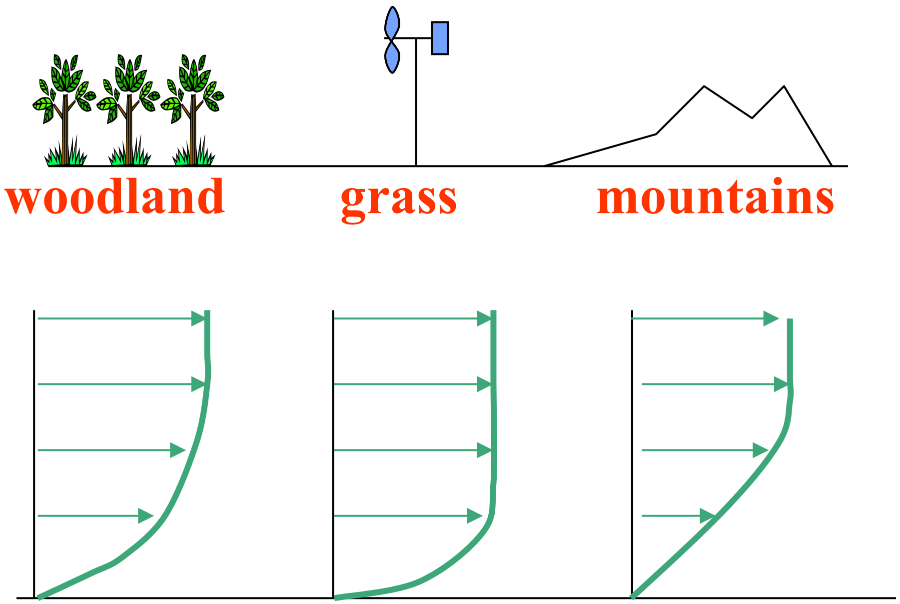
28.12.2014
Z50 hPa



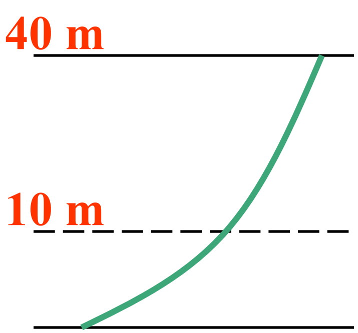
Polar Vortex and lower tropospheric flow



10 m wind



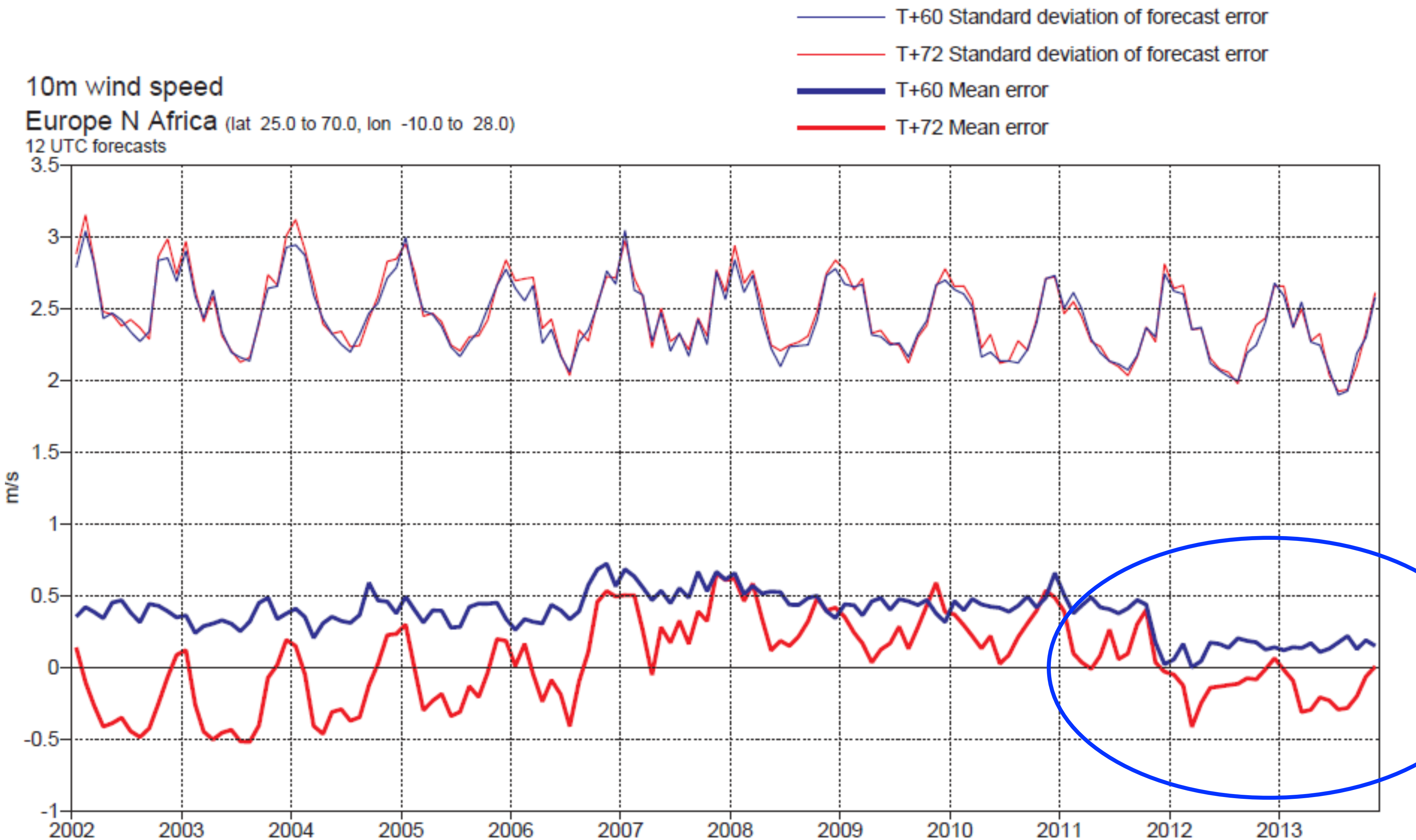
- Local wind depends strongly on local exposure.
- ECMWF model has roughness length parametrisation to obtain realistic "area averaged" surface drag.
- Resulting wind is low over land because rough elements dominate.



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)



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

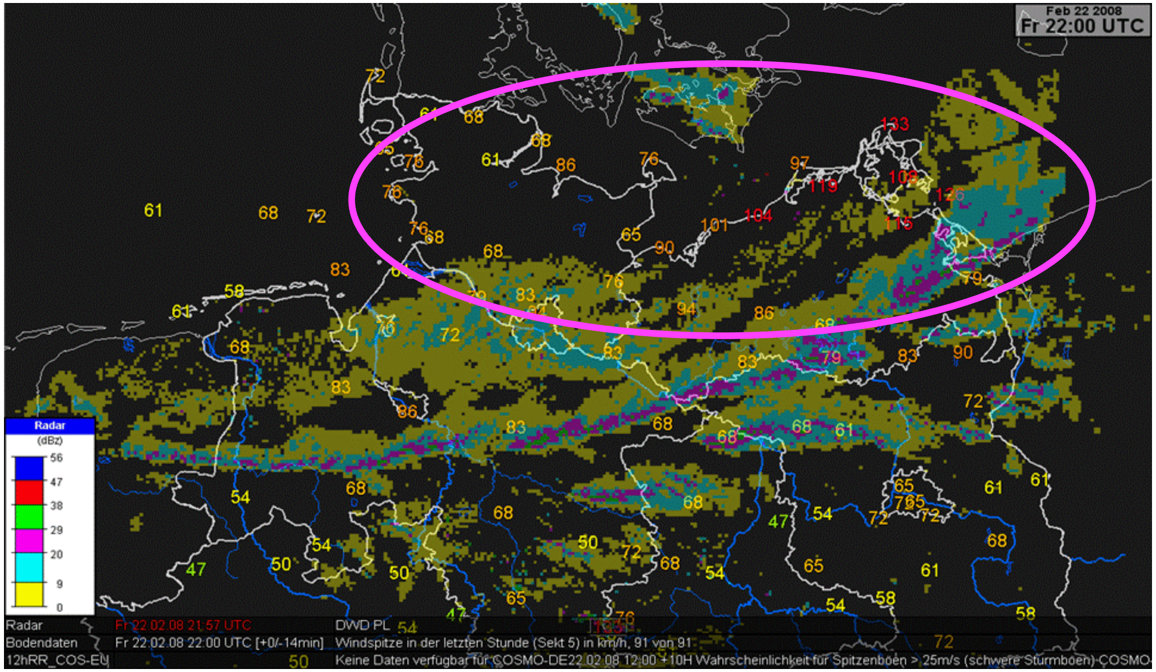
Gusts are computed by adding a turbulence component and a convective component to the mean wind:

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

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.

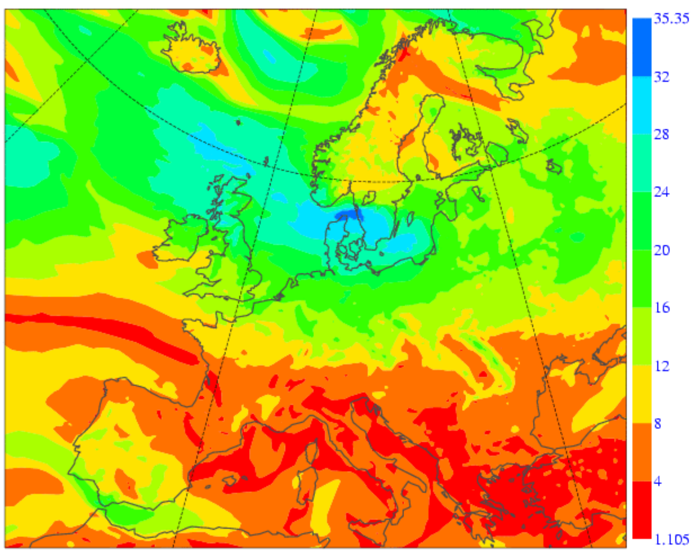
Convective Gusts



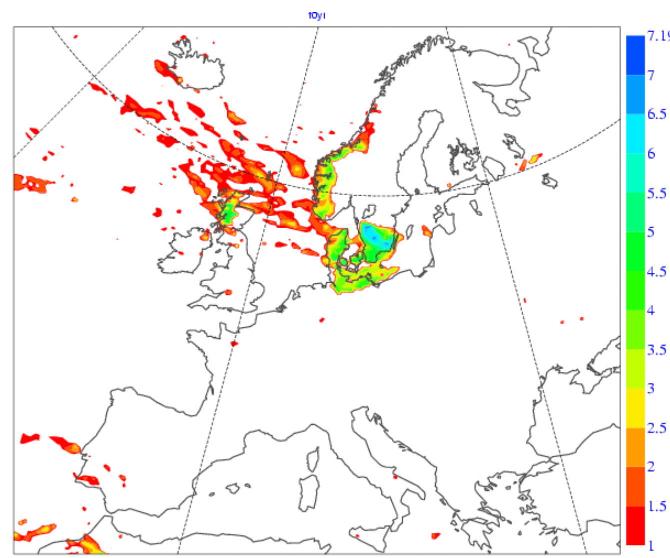
Motivation: report about gust front by DWD

22 February 2008

Oper



Conv

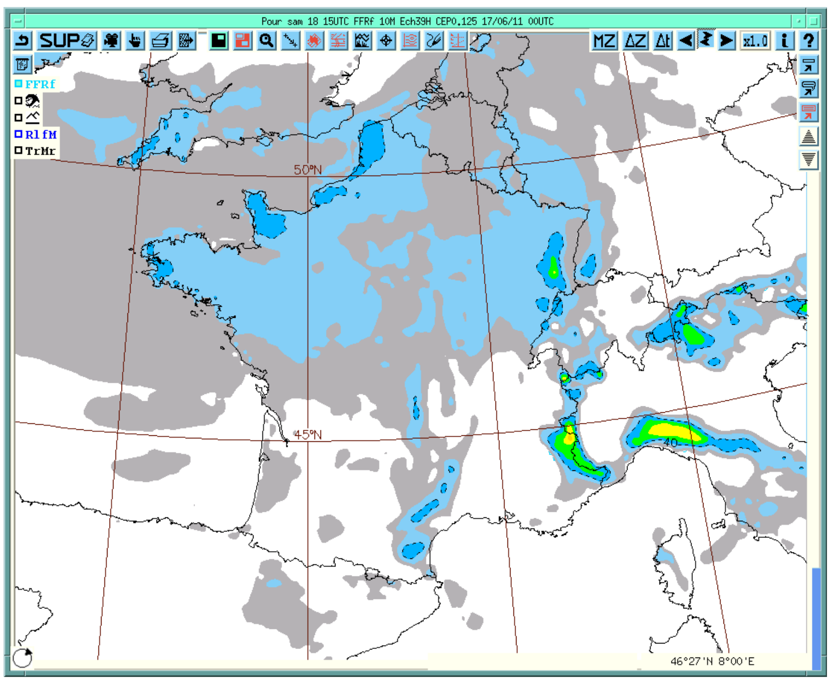


ECMWF

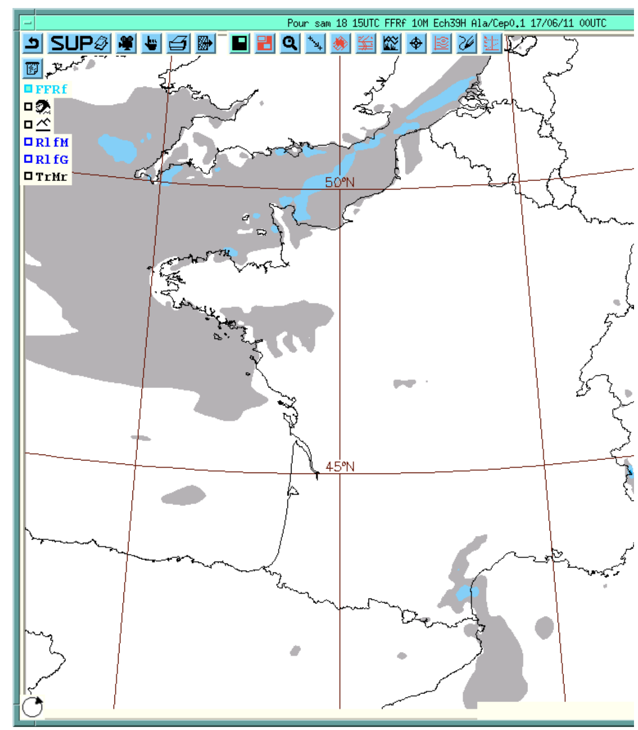
Wind gusts 18 June 2011

- Wind gust forecast for 18 June 15 UTC base 17 June 0 UTC
- ECMWF wind gust maxima are located over land, other models have maxima over the sea
- “It seems really unrealistic” to the Meteo-France chief forecaster

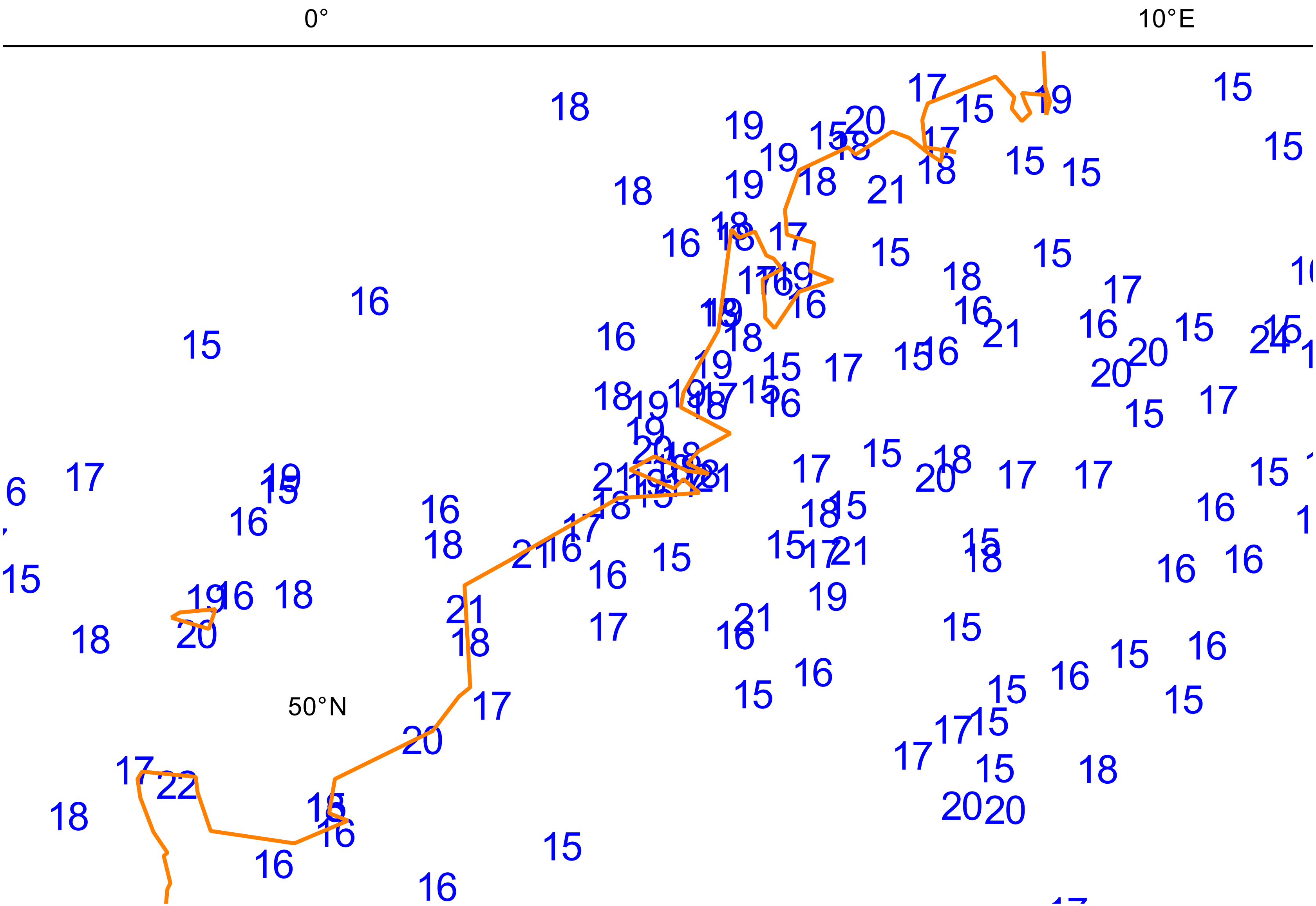
ECMWF



Aladin



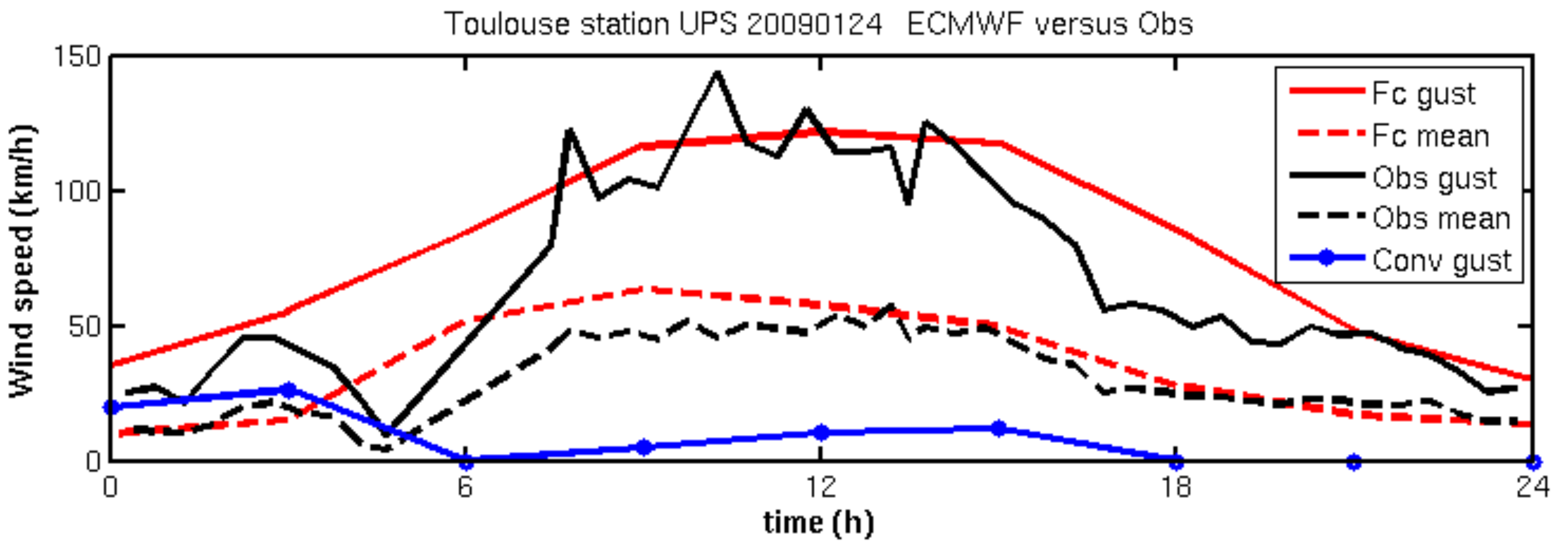
Wind gusts 18 June 2011



ECMWF

Wind gusts

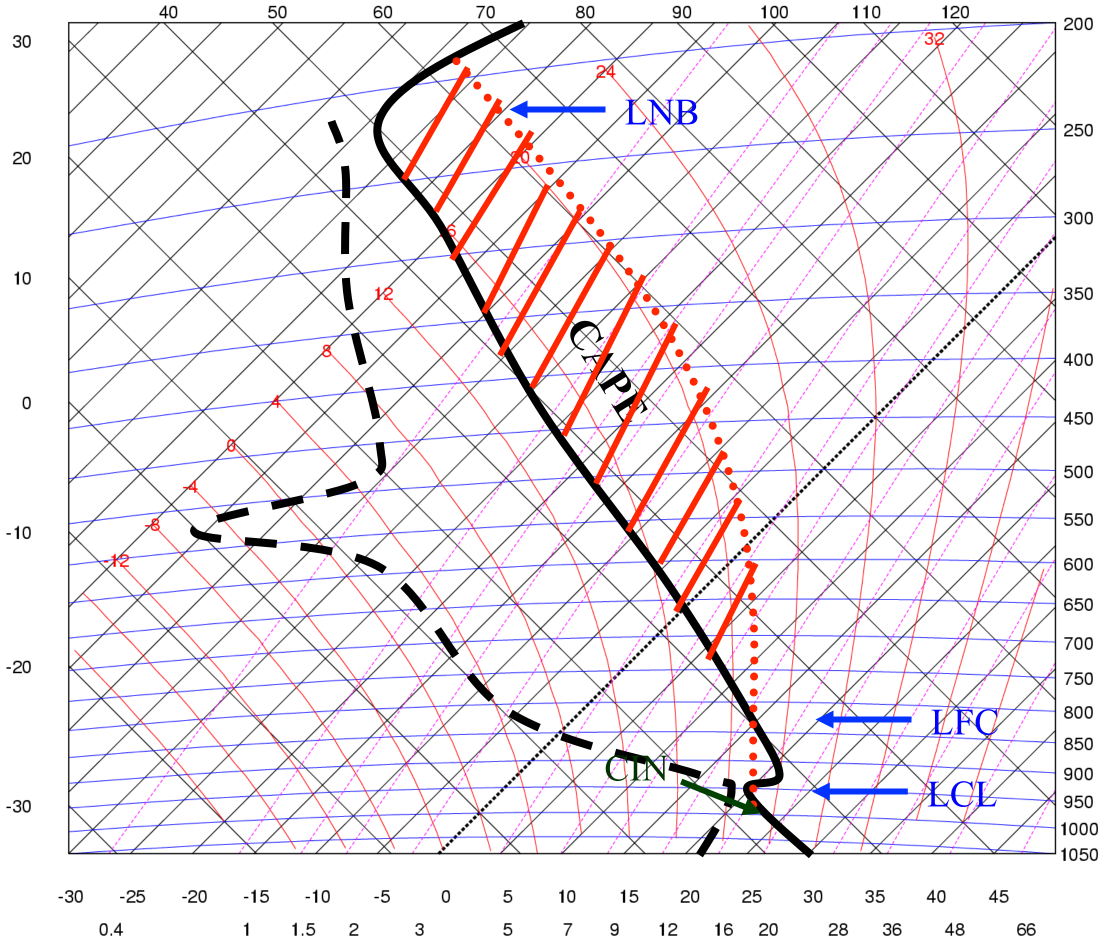
Time series against anemometer 24 January 2009 (storm Klaus)



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.

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

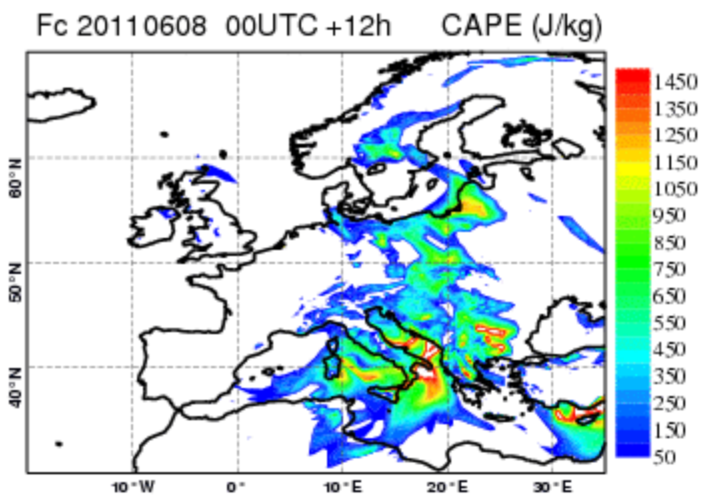
$$\frac{dw}{dt} = w\frac{dw}{dz} = \frac{1}{2}\frac{dw^2}{dz} \approx g\frac{T'}{\overline{T}}$$

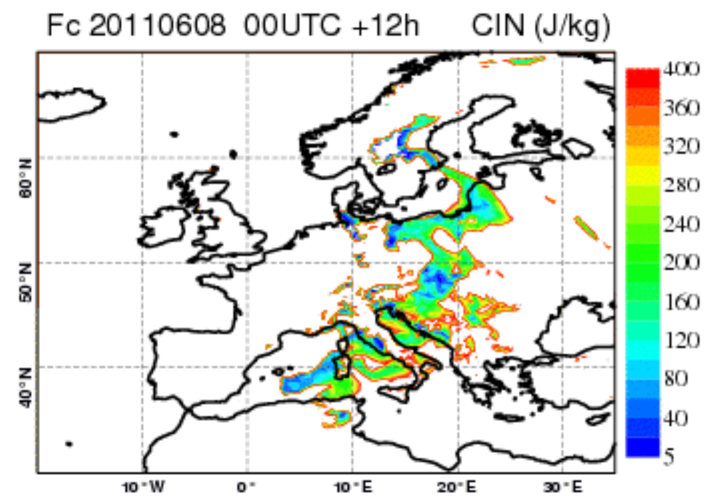
$$w^2(z) = 2\int_0^z g\frac{T'}{\overline{T}}dz = 2 \cdot CAPE$$

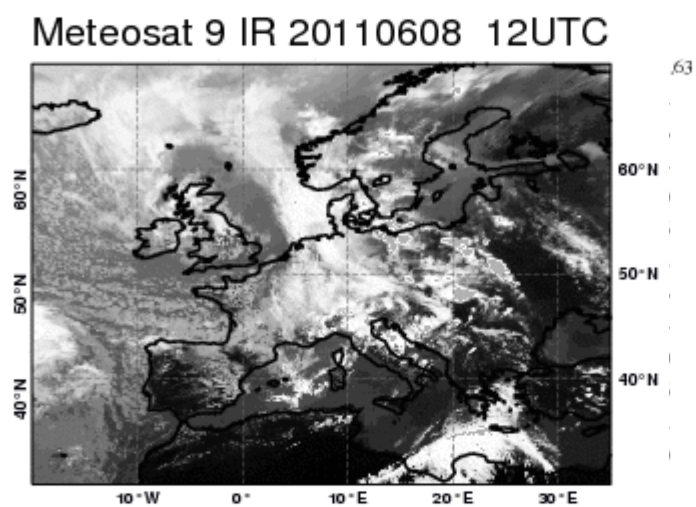
Maximum updraught velocity (vertical velocity in cloud) $w = \sqrt{2 \cdot CAPE}$

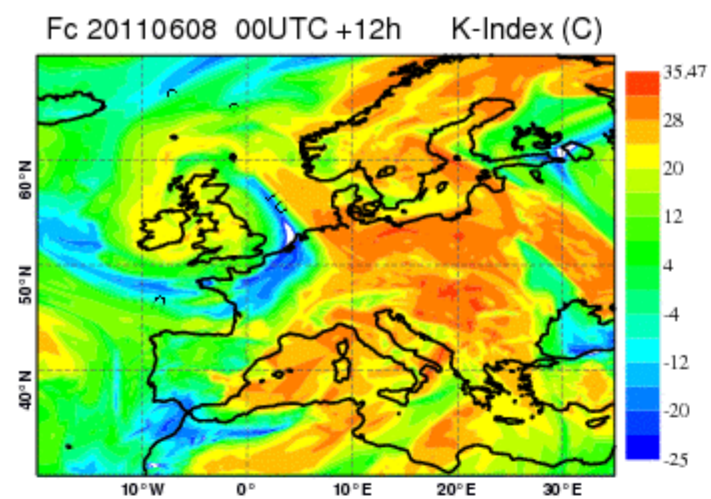
In the IFS convection parameterization the amount of CAPE determines the intensity of convection (rainfall) – the computation of CAPE depends on the specified entrainment and the departure level of the air parcel (LCL=lifting condensation level, LFC=level of free convection, LNB=level of neutral buoyancy)

Convective Indices
requested by Member States (User Meeting June 2011)





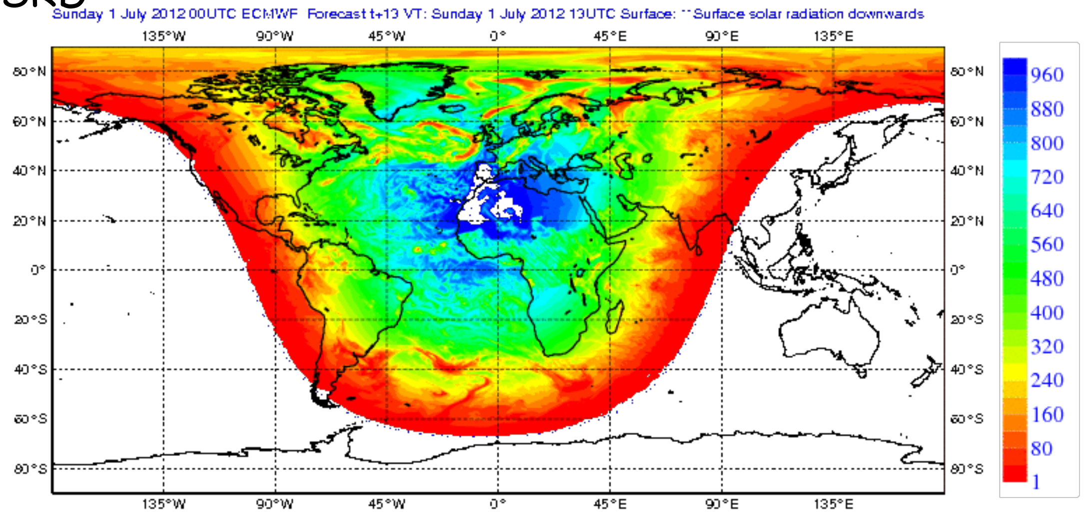




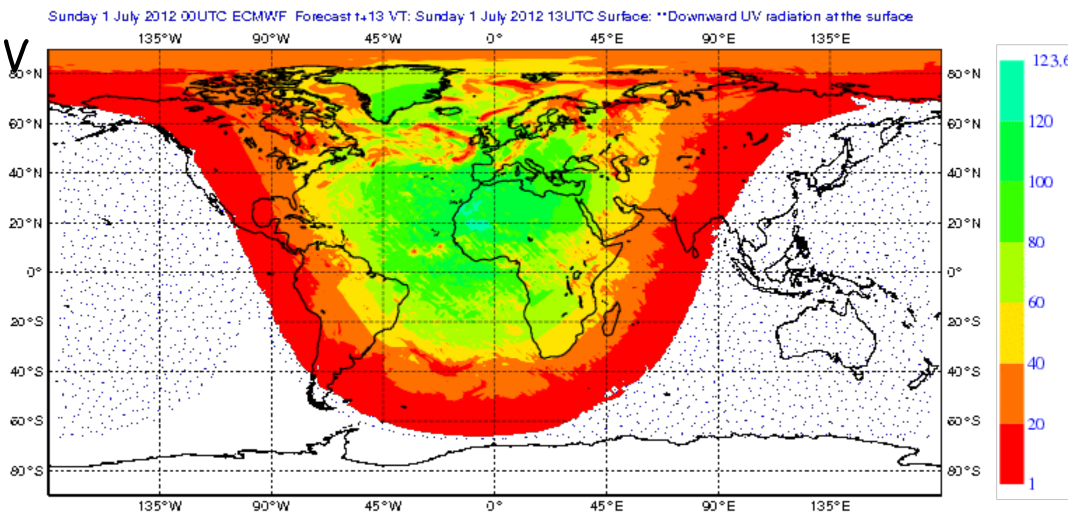
ECMWF

Surface incoming solar radiation and UV (W/m2

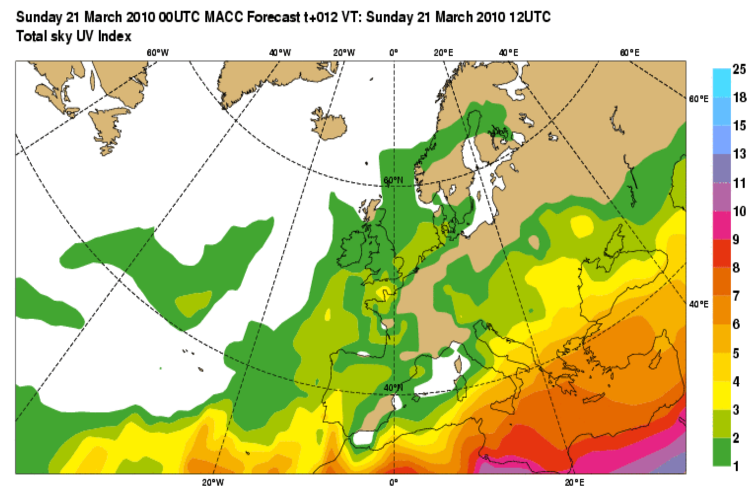
SSRD



UV



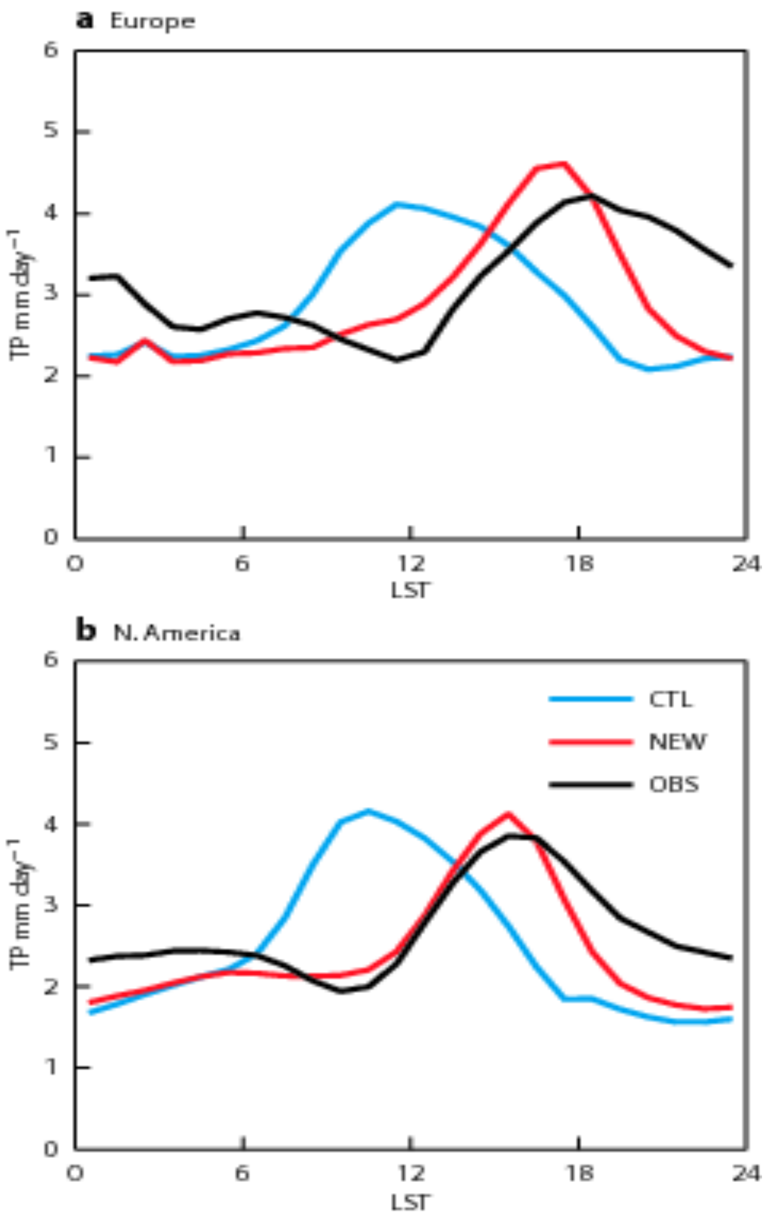
for UV Index see http://www.gmes-atmosphere.eu



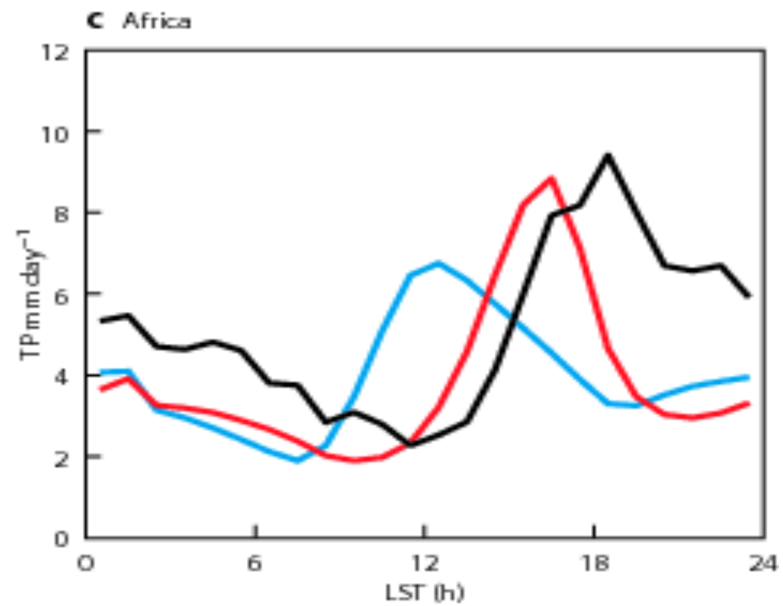
UV=10-15% of SSRD. The biological effective dose is the convolution of UV radiation with reaction of the human skin -> UV Index: 100 W/m2 ~ UV Index 8

ECMWF

Diurnal cycle: realistic since Nov 2013



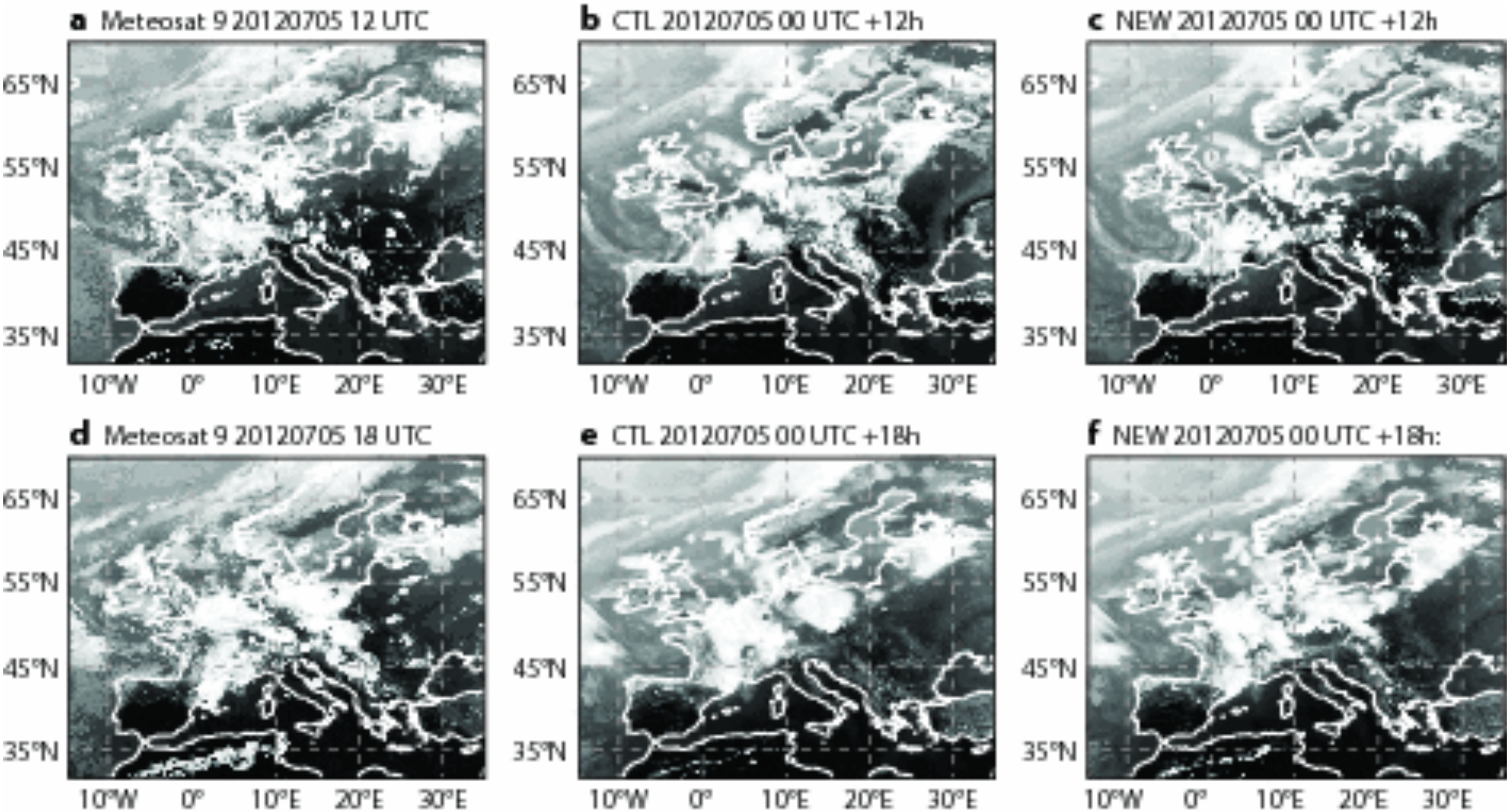
JJA 2011-2012 against Radar



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

ECMWF

Diurnal cycle: Impact on weather forecasts

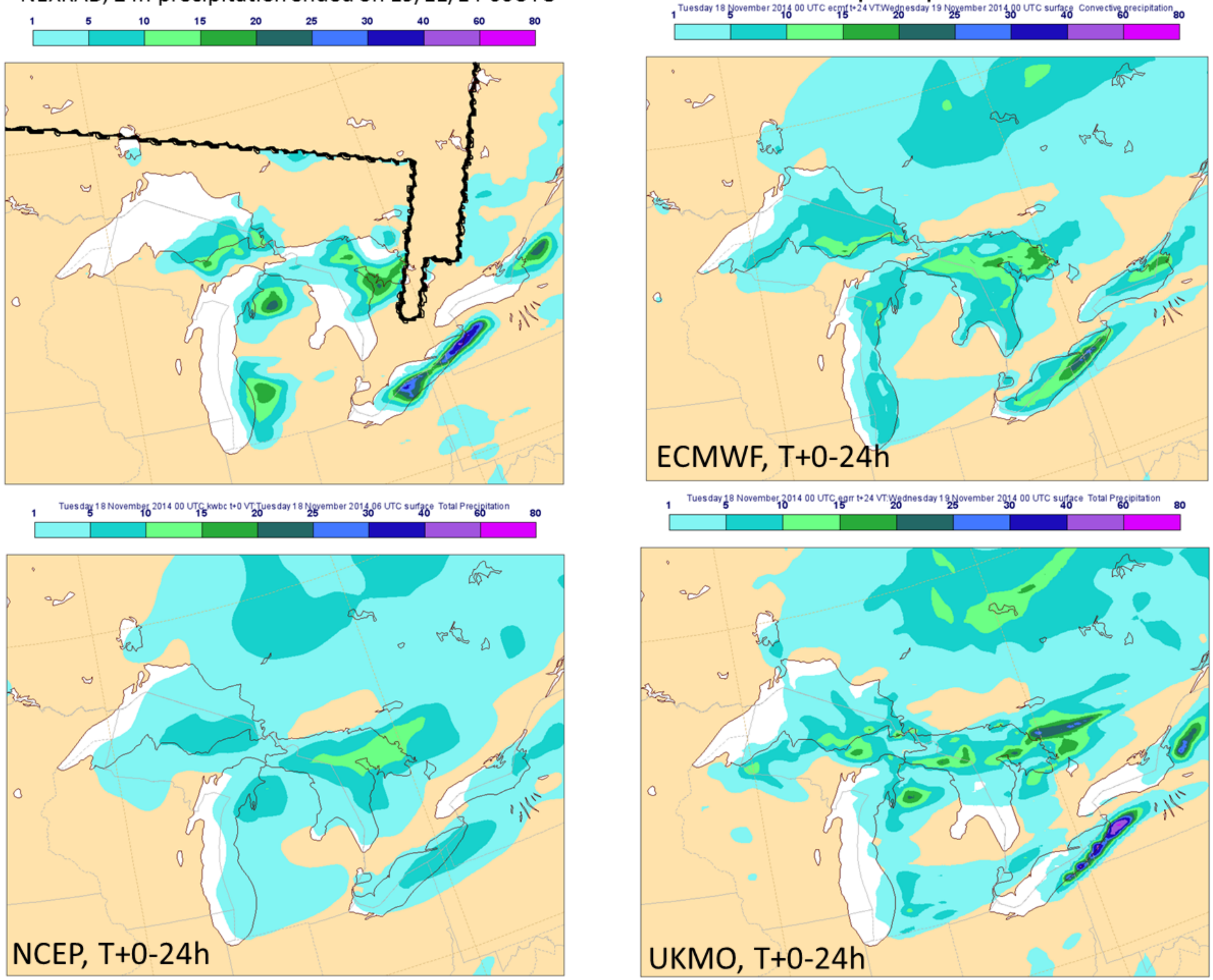


ECMWF

Winter convection: Lake effect and advection

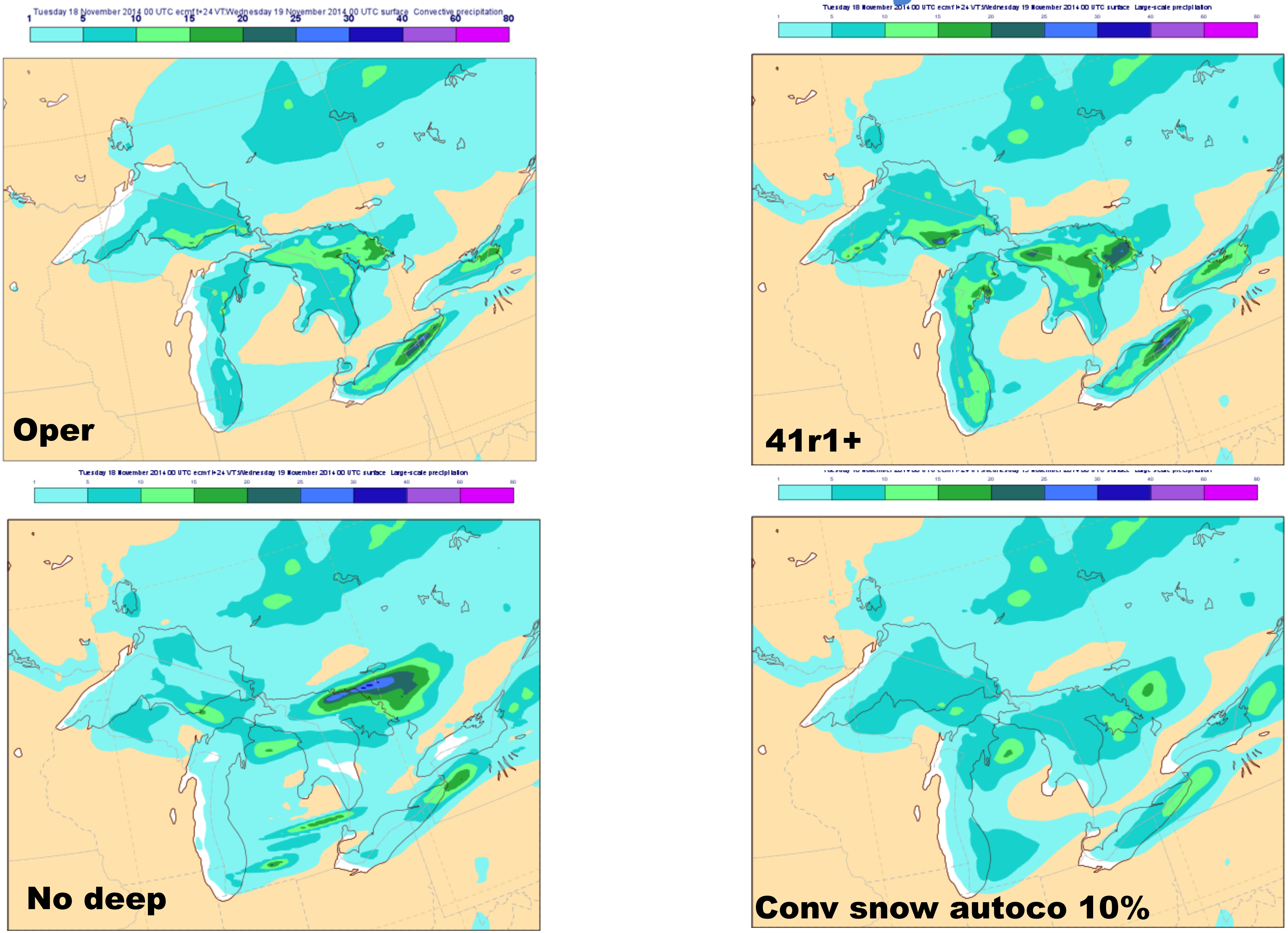
NEXRAD, 24h precipitation ended on 19/11/14 00UTC

24-h total precipitation forecasts



ECMWF

Winter convection: sensitivity studies



IFS Spectral and Gridpoint grids and purpose

A time step in the IFS

- SP space: derivatives, semi-implicit correction, horizontal diffusion
- GP space: explicit dynamics, semi-Lagrangian advection, physics

Discretisations

- SP space: truncation of the series of spherical harmonics (NSMAX=1279 in OPER)
- GP space: reduced Gaussian grid ($dx = 16$ km in OPER)

Linear, quadratic or cubic grid

Pairing grid/truncation

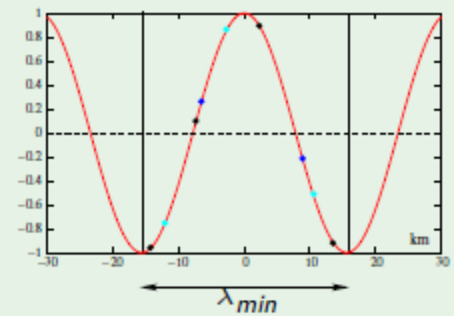
linear: the smallest wavelenght $\lambda_{min} = (2 * \pi * RA)/NSMAX$ is sampled on the grid, along the equator, by 2 points $\Rightarrow (N_L)/2 = NSMAX + 1$

quadratic: by 3 points $\Rightarrow (N_Q)/3 = NSMAX + 1$

cubic: by 4 points $\Rightarrow (N_C)/4 = NSMAX + 1$

$T1279 \Rightarrow N_L = 2560,\ N_Q = 3840,\ N_C = 5120$

$N = 1024 \Rightarrow TL511$ or $TC255$



Why linear, quadratic, cubic?

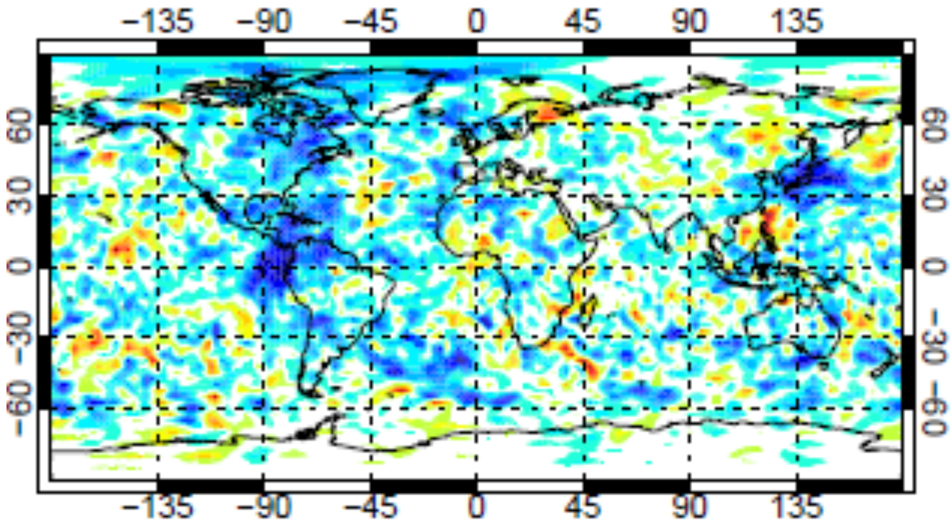
quadratic : no aliasing for quadratic terms (product of 2 variables)

cubic : no aliasing for cubic terms (product of 3 variables)

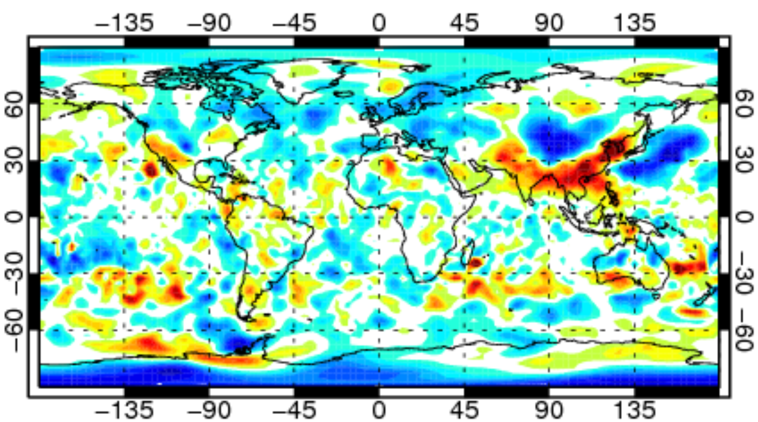
Expected improvement from T1279C vs T1279L

Example T+72h
200 hPa wind

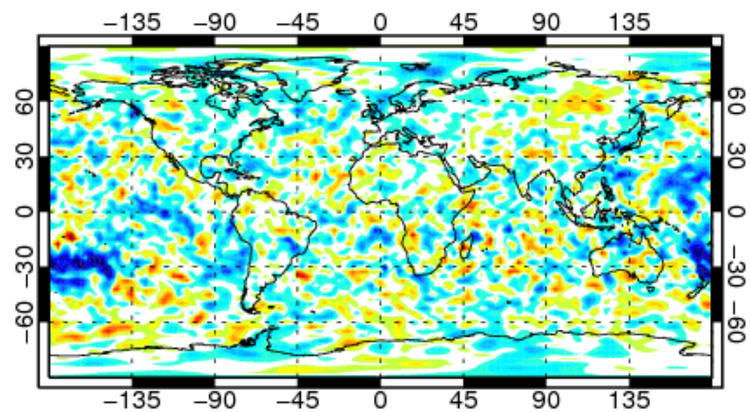
Generally blue=good
Up to 20% error reduction in subtropical SEAsian jet and tropical Jet in east Pacific



T+72; 200hPa



T+72; 100hPa



Impact of 5 vs 3 iterations in SL advection is seen over Tibet plateau and in stratosphere (artificial overshooting in cyclones in current operations)

Physics – Numerics: issues for improvement

- T2m winter can still be difficult: stable boundary-layer <-> snow and low-level clouds
- Overestimation of light precipitation (drizzle)
- Melting of fresh snow on ground somewhat too slow
- Inland penetration of (convective) showers and convective organisation improved but can still be improved
- Too strong Indian and SE Asian Summer Monsoon
- Predictability in monthly and seasonal forecasts ……. coming from the stratosphere and Tropics (MJO)
- Orography

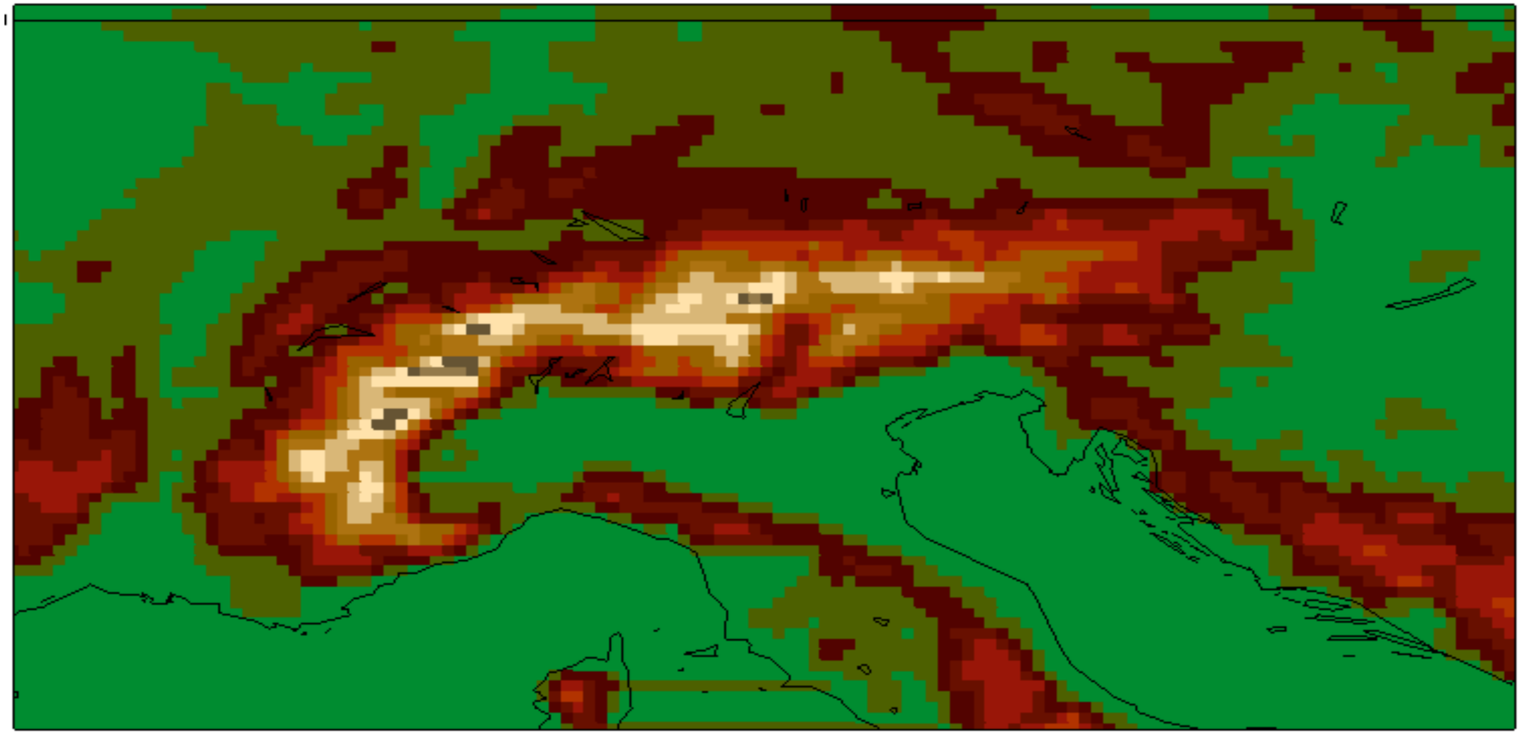
Planned model upgrades in 2015

- Prediction of lake temperatures (Spring 2015)
- Improved (increased) stratiform precipitation, especially orography and tropical upper-level winds (Spring 2015)
- T2m errors in ENS compared to HRES mitigated through revised radiation seeing correct surface (later in 2015)
- Possibly new aerosol climatology for radiation
- Microphysics (see Richard Thursday)
- Resolution increase to 10 or 8 km: 2015 or 2016

ECMWF

Orography – T1279=16 km

Max global altitude = 6503m

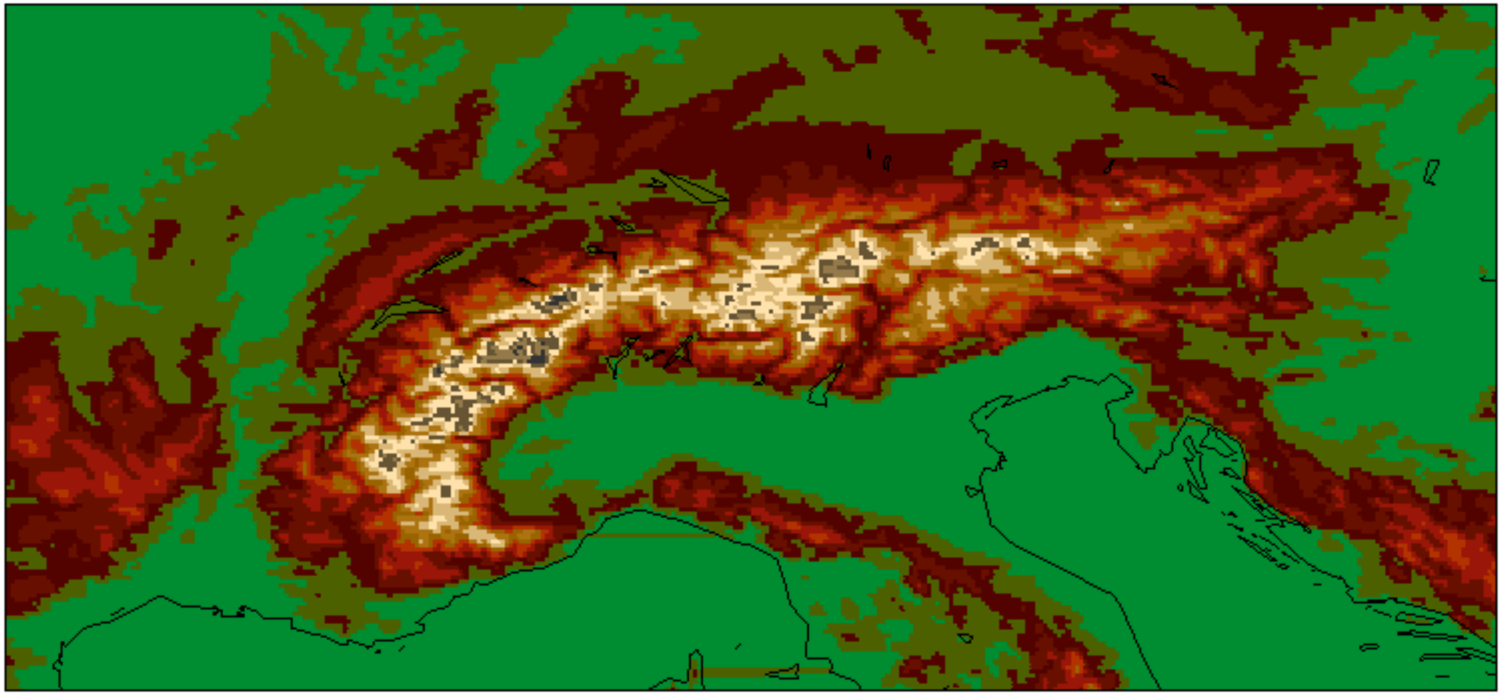


Alps

ECMWF

Orography - T3999=5 km

Max global altitude = 7185m



Alps