Model Physics

Introduction to some useful dynamical concepts, model practice, products and limits

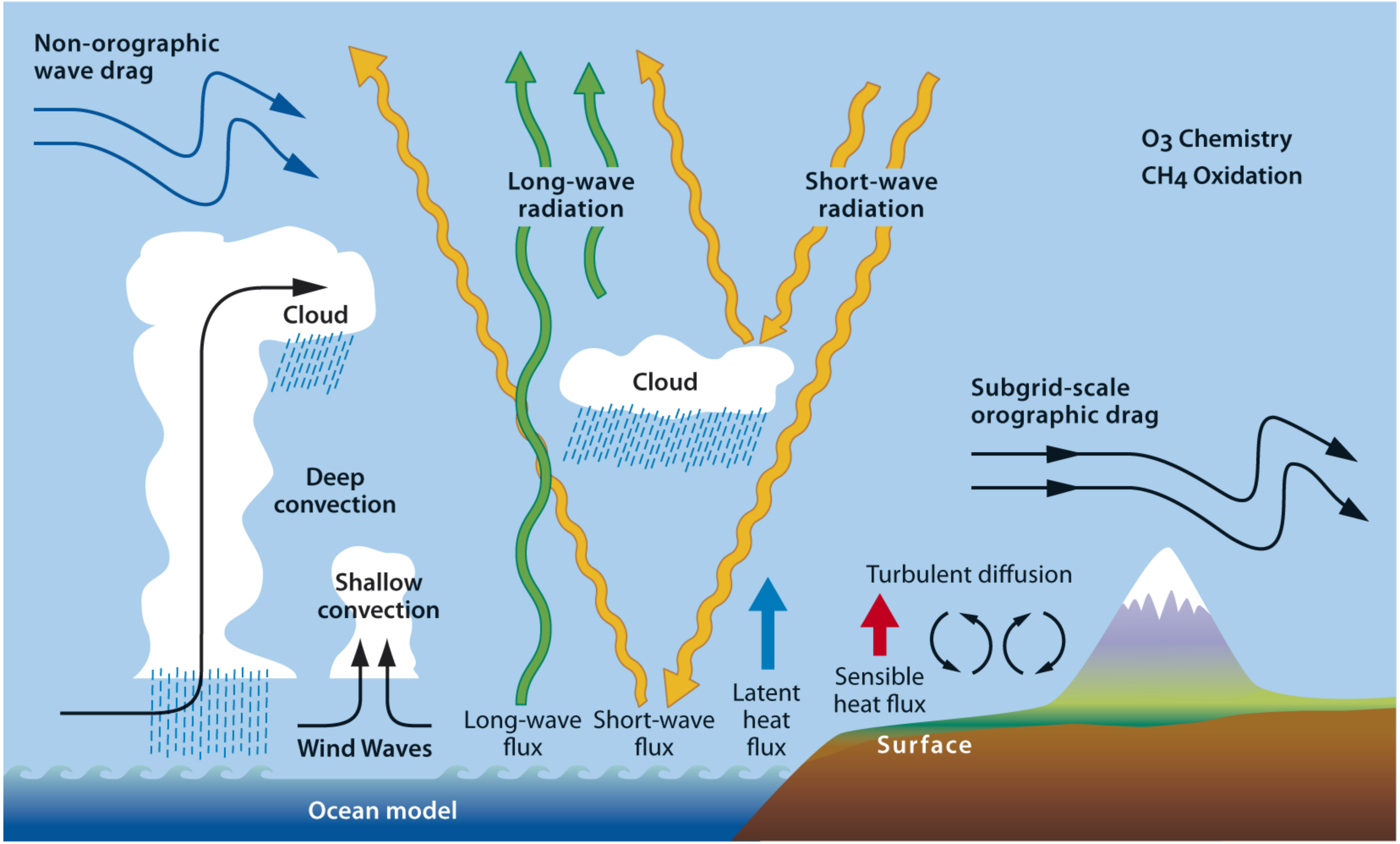
- **Physical processes (tendencies) represented in the IFS**
- **Revision of equilibria in the atmosphere/model**
- **Clouds, Forecasted satellite images**
- **Winter special: Snow, 2m Temperature, 10 m Wind, Wind Gusts**
- **Summer special: Convection, CAPE, UV Index**
- **Stratosphere and Tropics - midlatitude teleconnection**

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

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

ECMWF

Parameterized processes in the ECMWF model



Physics - and forecast configurations

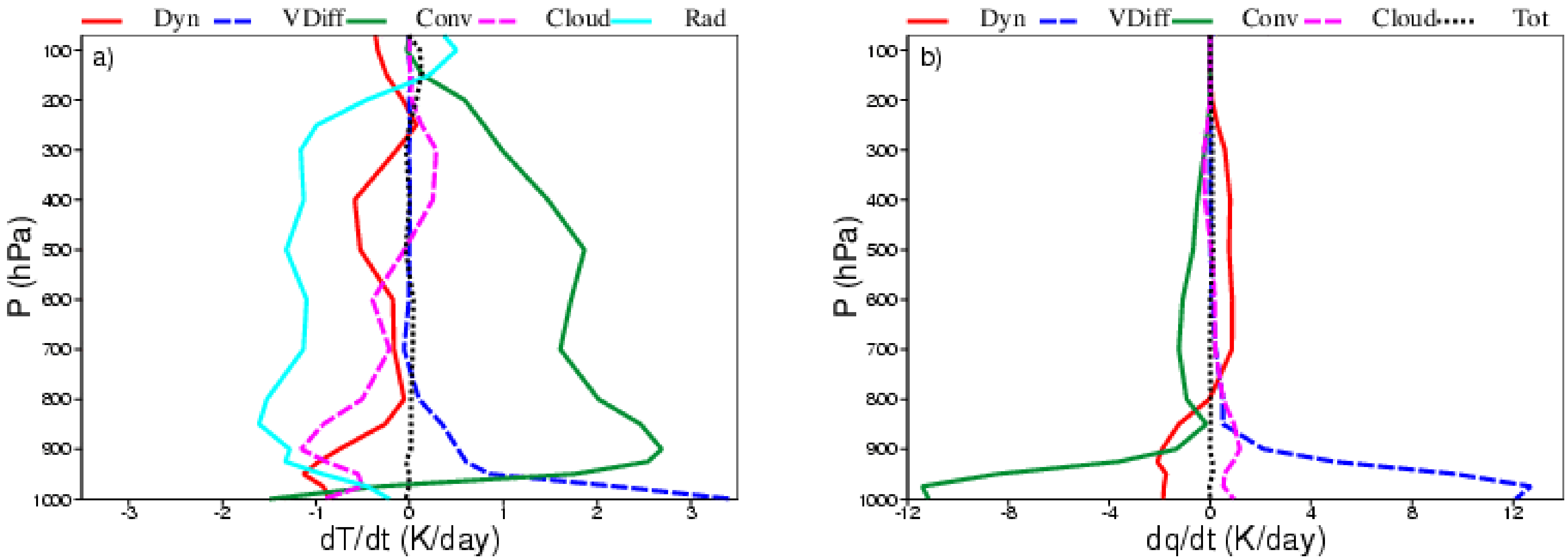
For all model configurations (deterministic forecast, EPS, monthly forecast) and horizontal/vertical resolutions, the identical set of physical parameterisations is used.

The only resolution dependent change concern:

- *The convective adjustment time*
- *The subgrid orography*

REMINDER: IF Something goes wrong with the Forecast BLAME THE PHYSICS

Model Tendencies - Tropics

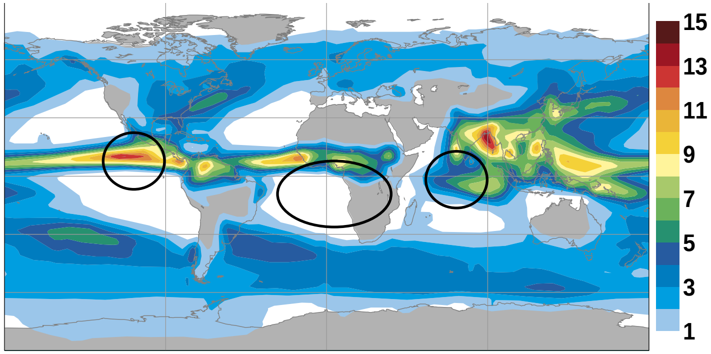


For Temperature, above the boundary layer, there is roughly an equilibrium Radiation-Convection, but Dynamics and Clouds also important, whereas for moisture there is roughly an equilibrium between dynamical transport (moistening) and convective drying. - *Global Budgets are very* similar

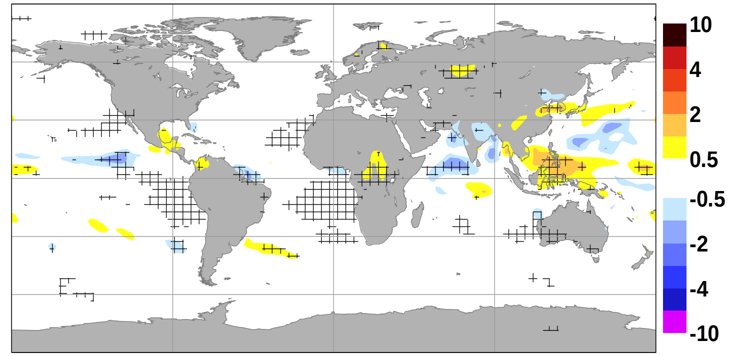
All processes are important, nevertheless the driving force for atmospheric dynamics and convection is the radiation

Precipitation JJA: Sensitivity to Model Formulation
Seasonal integrations

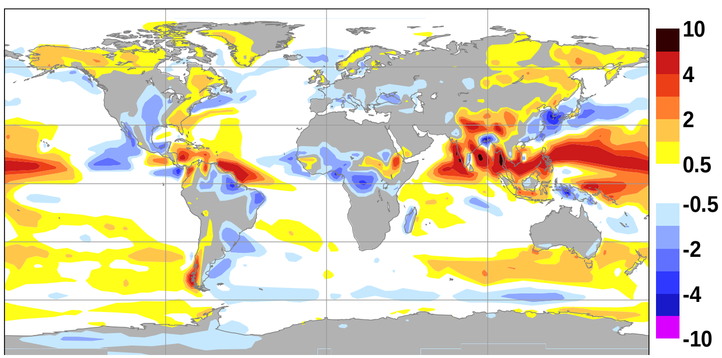
GPCP JJA 1990-2006



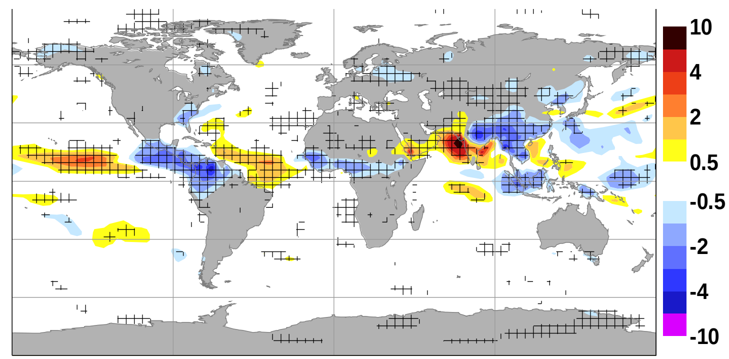
33R1(old vdiff)-33R1



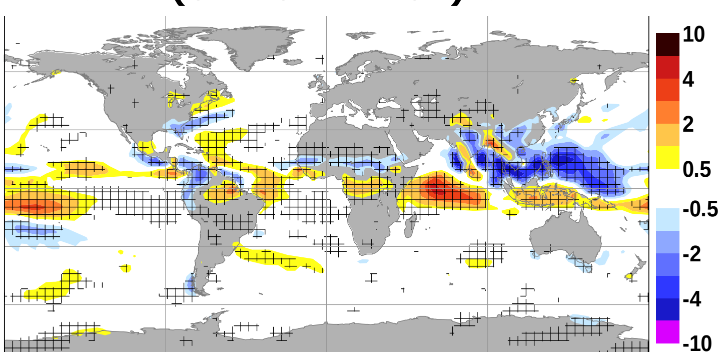
33R1-GPCP



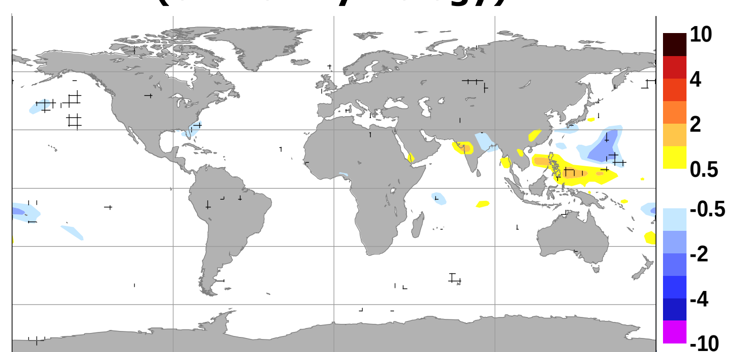
33R1(old radiation)-33R1



33R1(old convection)-33R1



33R1(old soil hydrology)-33R1



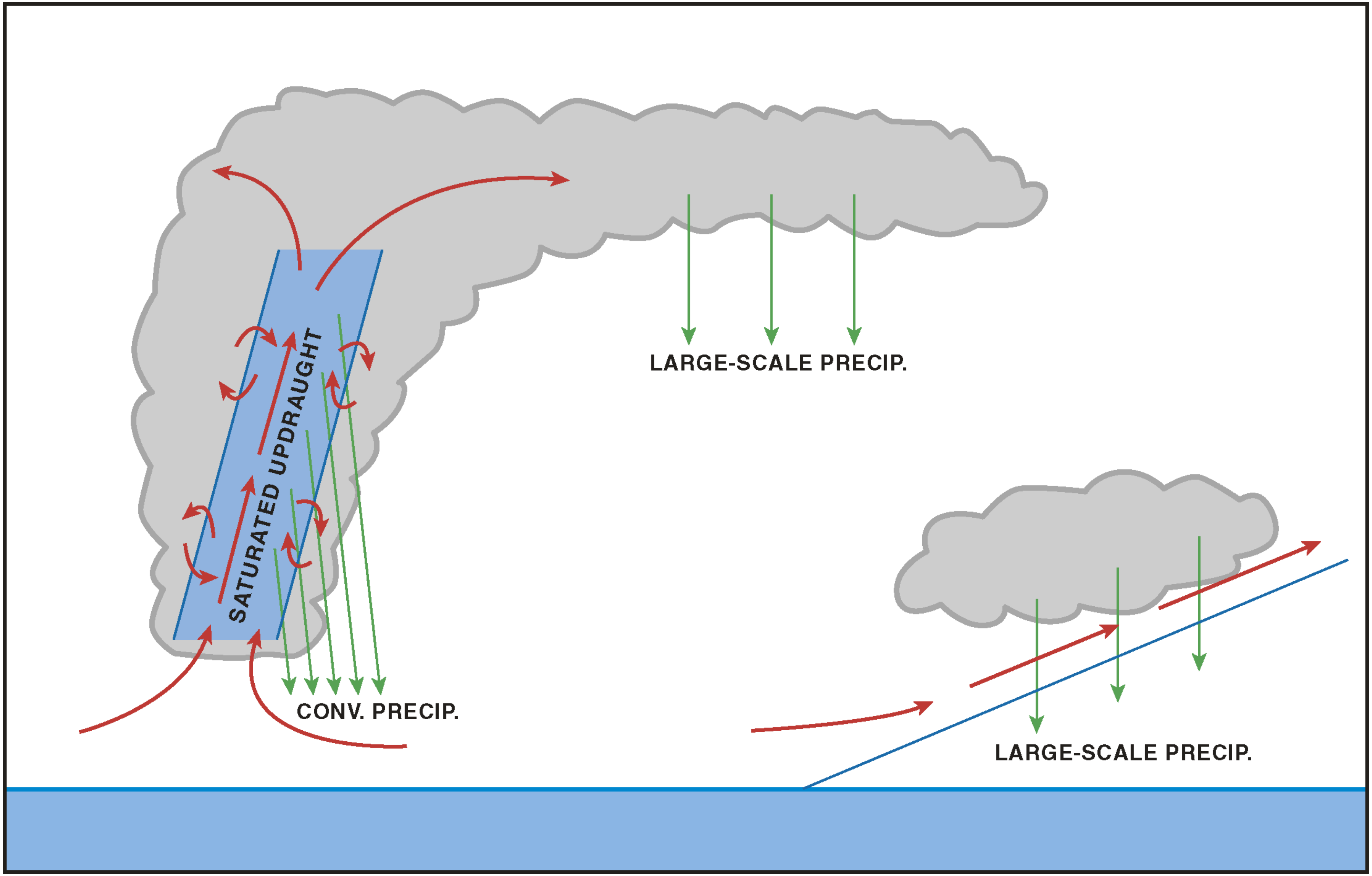
General circulation and equilibrium in the Tropics

- Horizontal temperature fluctuations in the Tropics are small <1K/1000 km; and in the absence of precipitation the vertical motions(subsidence) tend to balance the cooling through IR radiation loss: $w\, d\theta/dz = d\theta/dt\_rad = -1\text{-}2$ K/day => w ~ -.5 cm/s

- When precipitation takes place, heating rates are strong;
e.g. 100 mm/day precip ~ energy flux of 2900 W/m2 or an average 30 K/day heating of the atmospheric column => w ~ 8.6 cm/s. However, this positive mean motion is composed of strong ascent of order w ~ 1 m/s in the Cumulus updrafts and slow descending motion around ("compensating subsidence")

- Ro=NH/f with N the Brunt-Väisälä frequency and H the tropopause height, is the Rossby radius over which a perturbation spreads. In Tropics it is infinite as f->0 , in the midlatitudes it is of O(1000 km).

Convective and stratiform precipitation and clouds

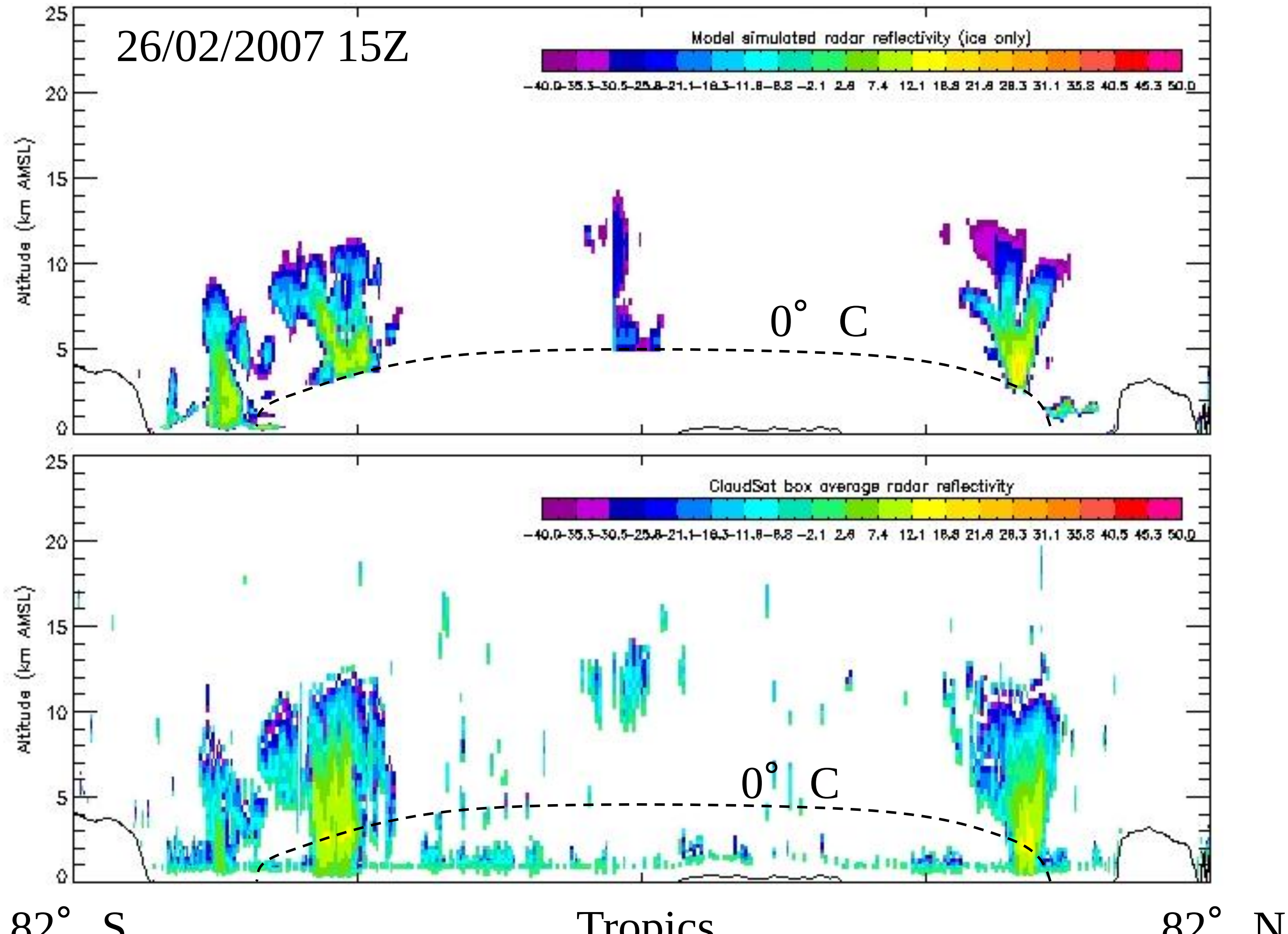


ECMWF

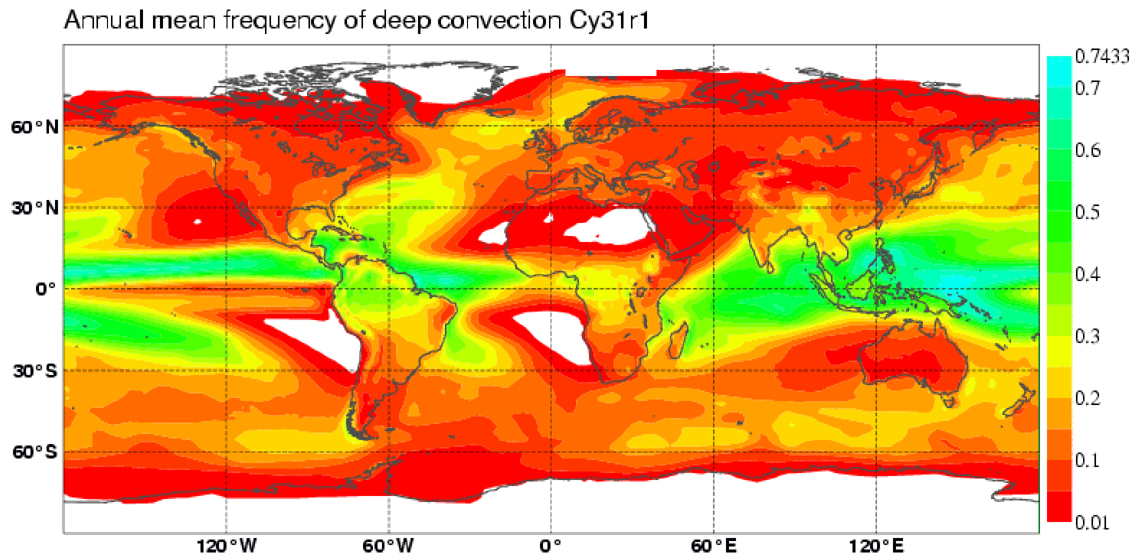
Cloud Verification
Model-to-Obs: Radar reflectivity

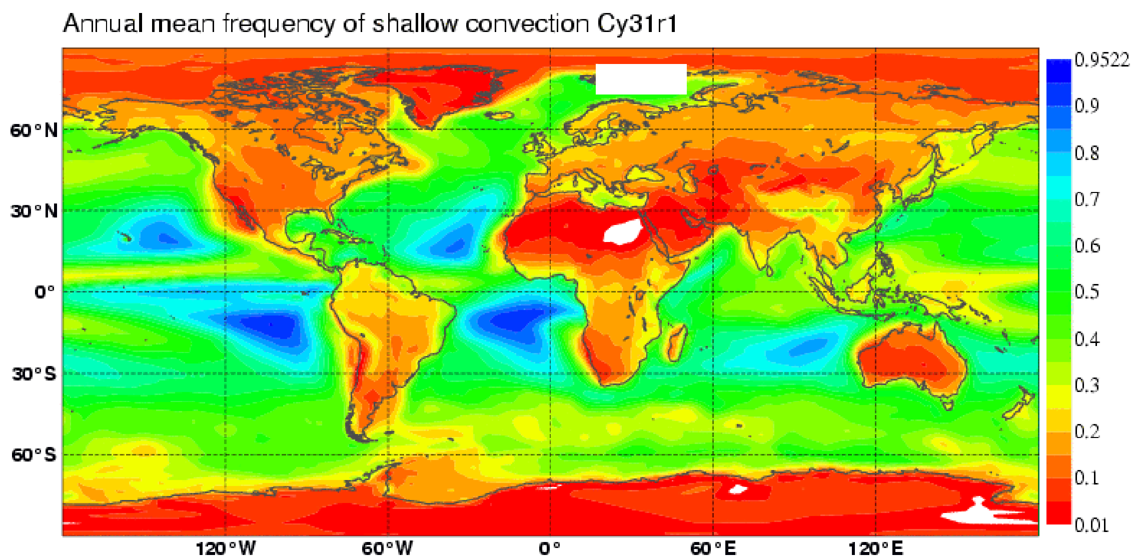
Simulated radar reflectivity from the model.
(ice only)

Observed radar reflectivity from CloudSat
(ice + rain)



Global: Convective cloud types proxy distribution of deep and shallow convective clouds as obtained from IFS Cy33r1 (spring 2008)

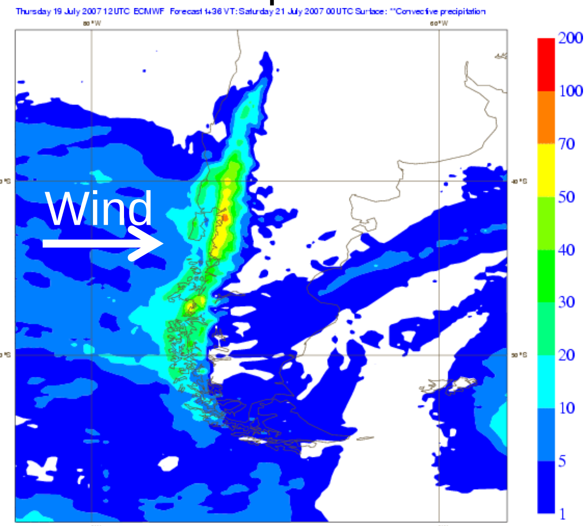




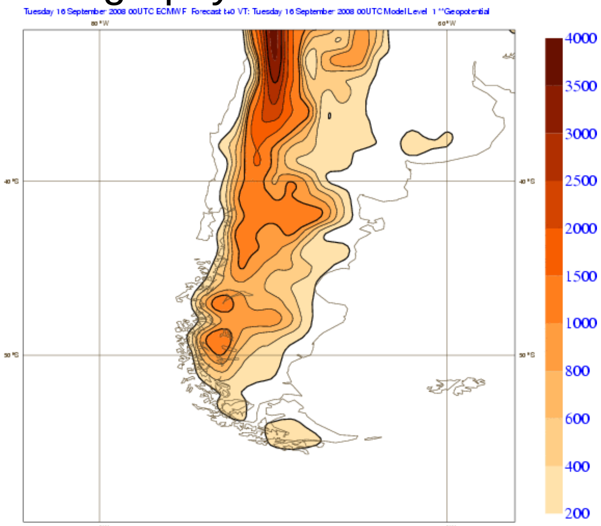
New 5 species prognostic cloud microphysics

Falling snow and orographic forcing

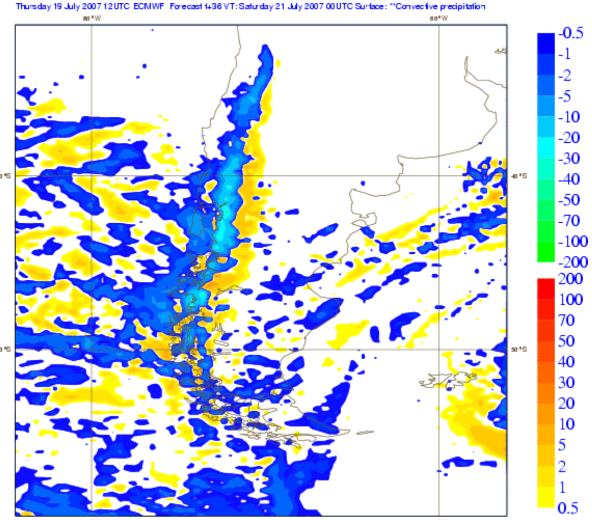
(36 hour acc.) Surface Precipitation



Orography

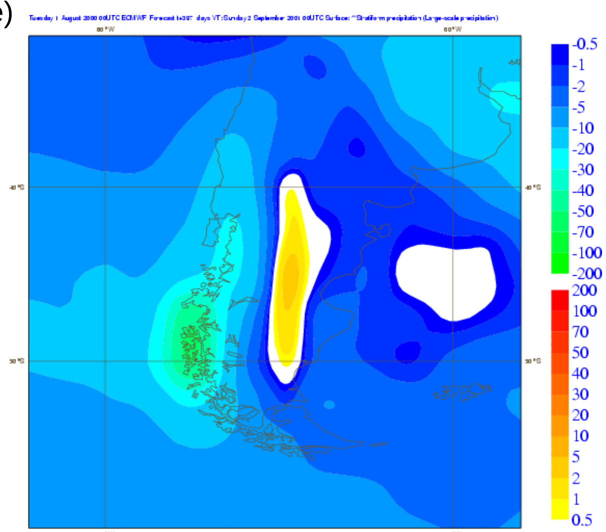


(36 hour acc)



“Prognostic snow scheme” minus “Diagnostic snow scheme”

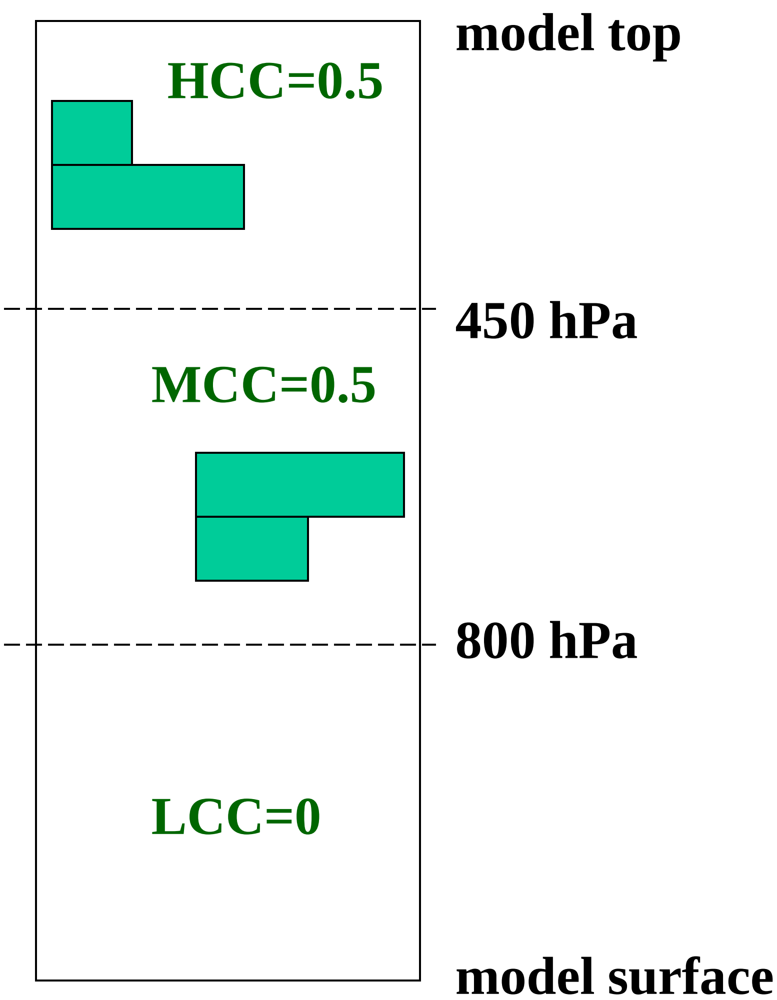
(1 year average)



“Prognostic snow scheme” minus “Diagnostic snow scheme”

Cloud overlap

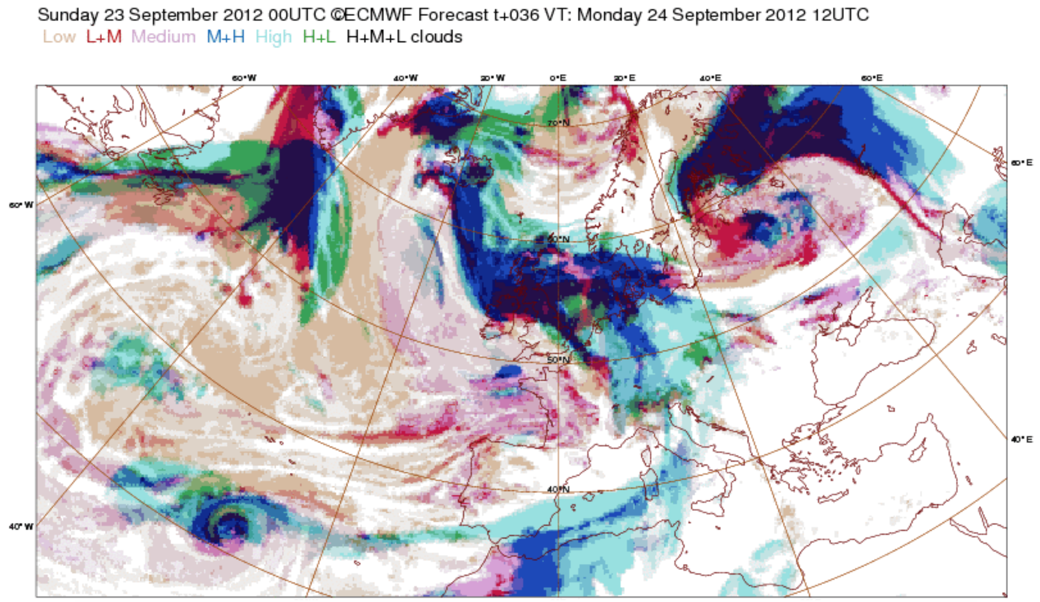
Example

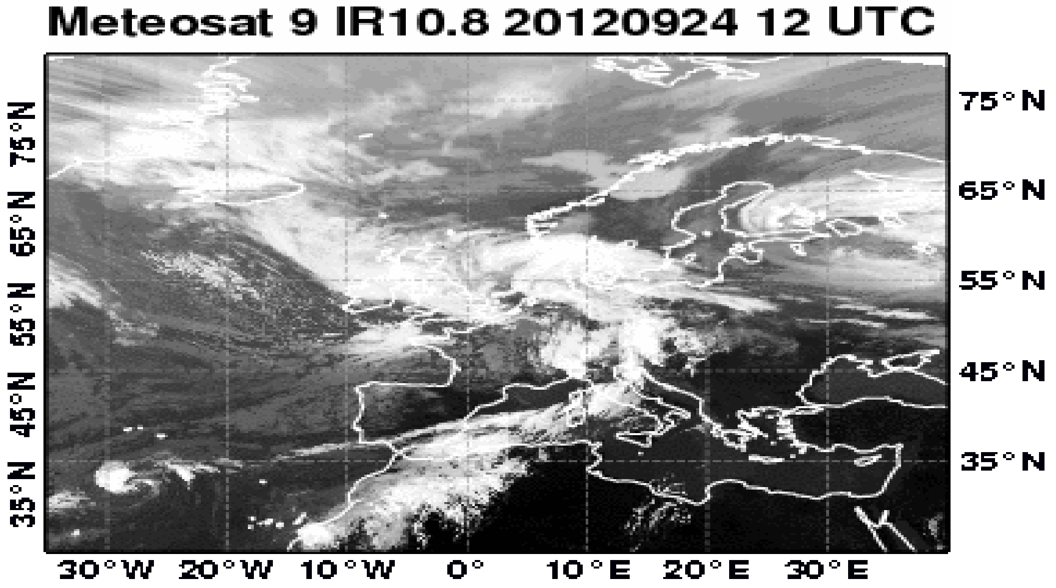


TCC=0.95

- **TCC (total cloud cover). Model level clouds are integrated from surface to top of the atmosphere using maximum/random overlap**
- **HCC (high level cloud cover). Integrated from top to 450 hPa.**
- **MCC (medium level cloud cover). Integrated from 450 to 800 hPa.**
- **LCC (low level cloud cover). Integrated from 800 hPa to surface.**
- **NOTE:**
  TCC <= LCC+MCC+HCC

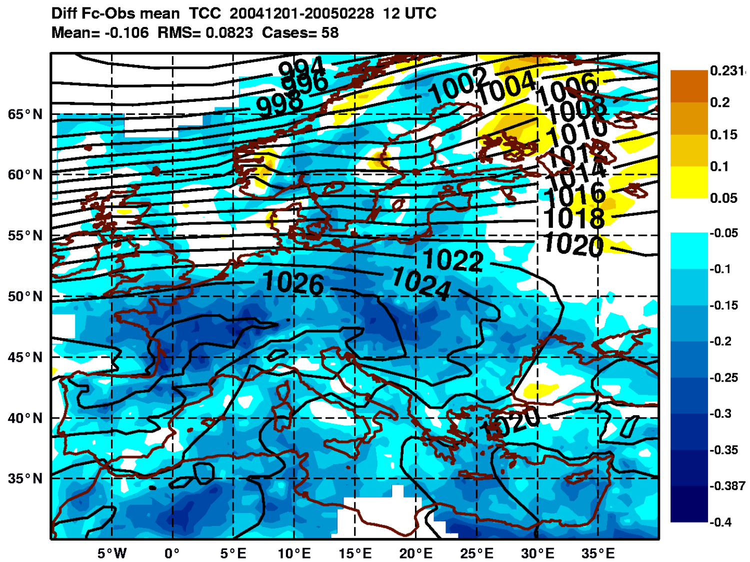
Cloud Overlap



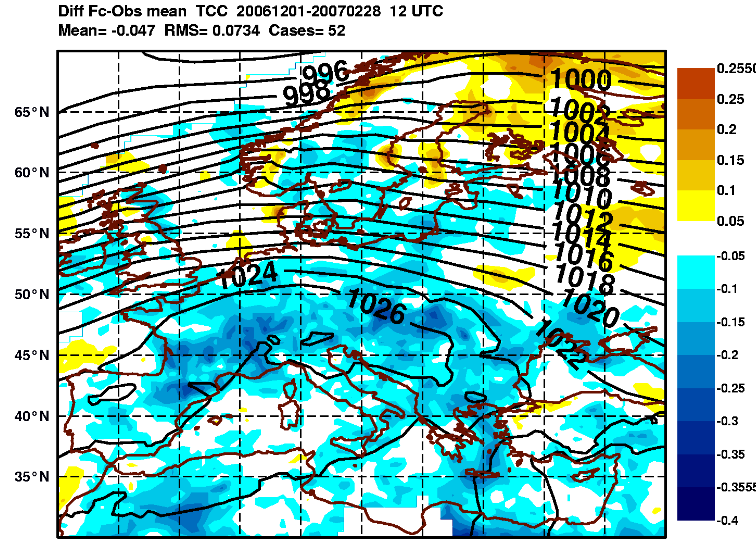


Winter Cloud Cover : 36h forecast versus SYNOP observation (for high pressure days over Europe (last winters)

DJF
2004/5
58 cases

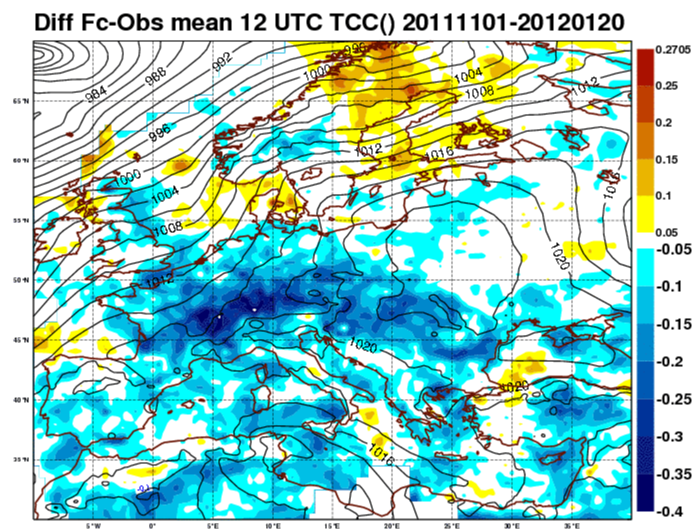


DJF
2006/7
52 cases

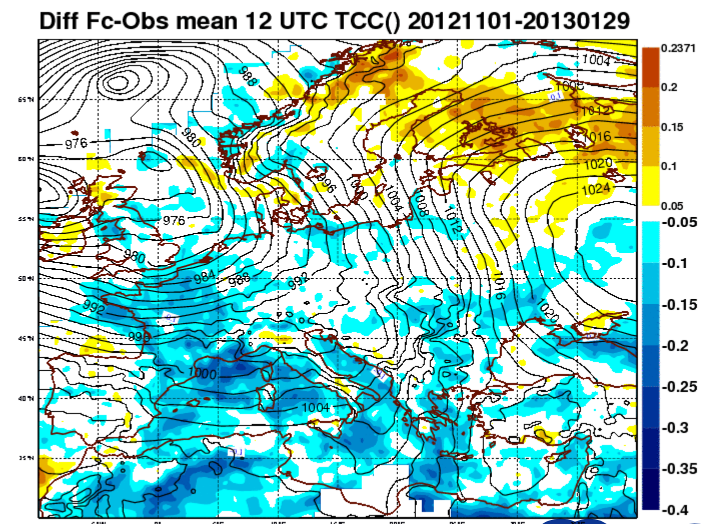


EDMF PBL
M-O diffusion

NDJ
2011/12



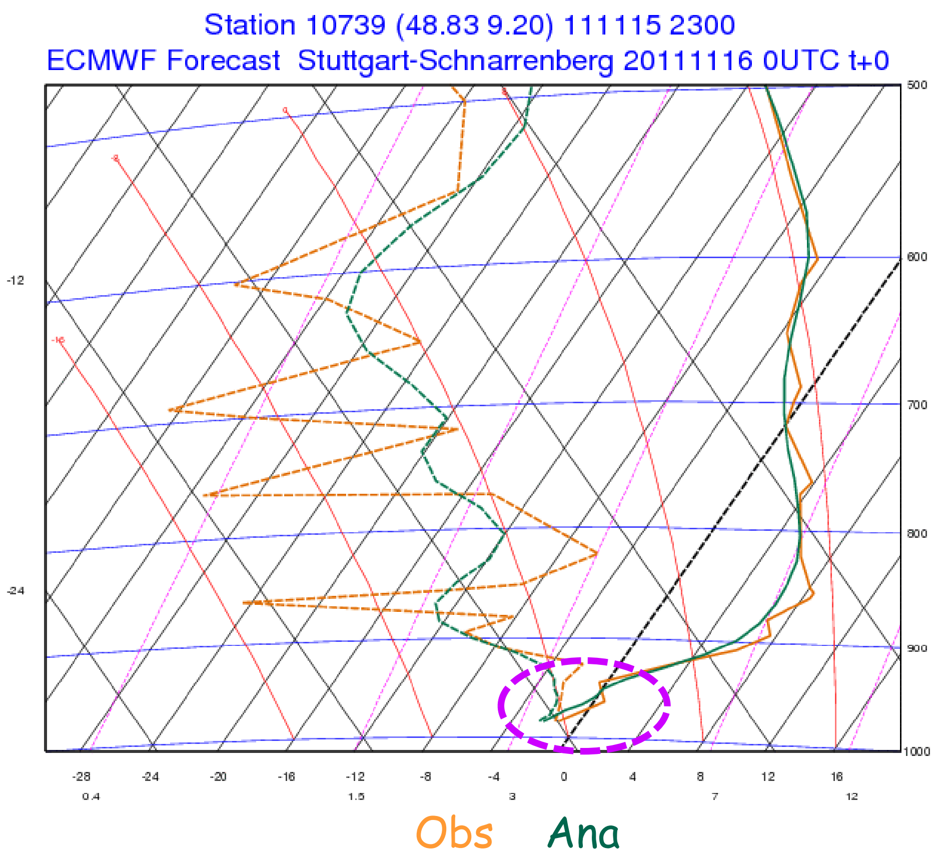
NDJ
2012/13

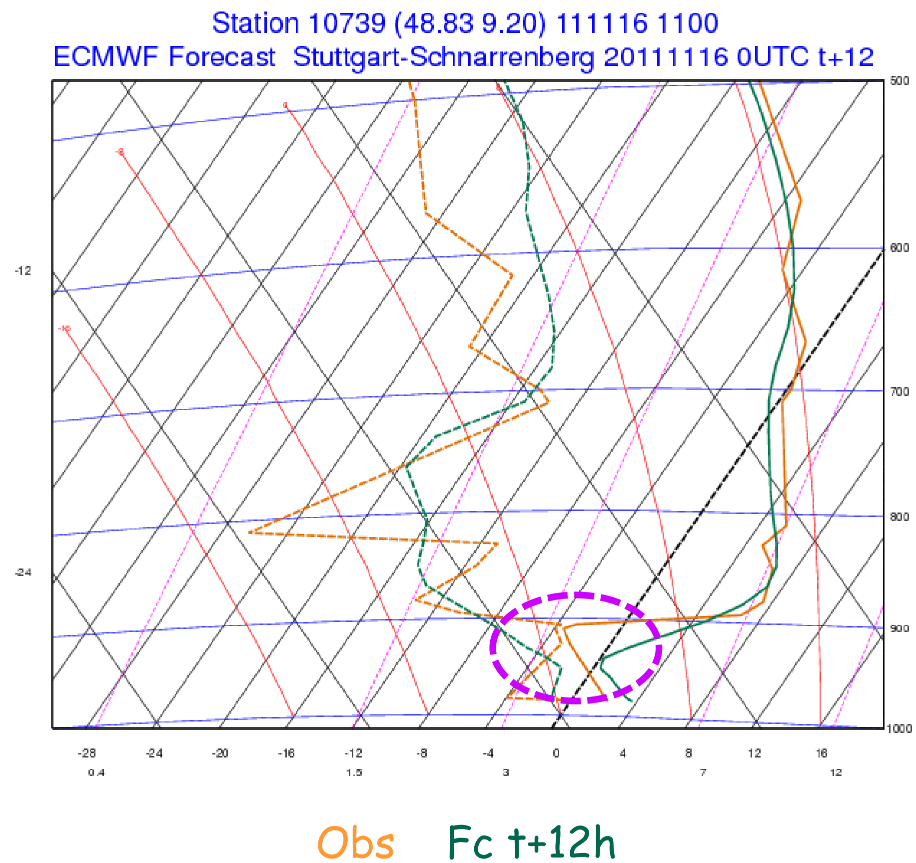


NEW MICROPHY

ECMWF

Sounding Stuttgart 16 Nov, 2011 as example for central Europe daytime warm bias, too little TCC





Fog rising developing into Sc deck could not be properly represented

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).

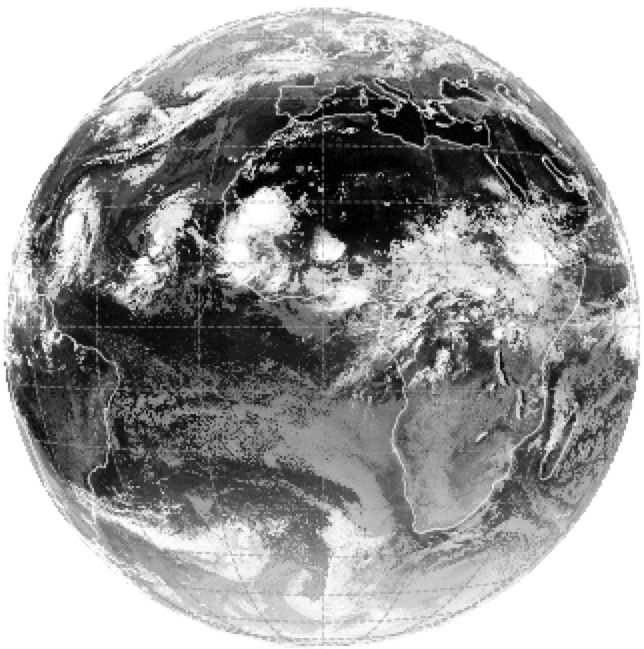
Only the IR and water vapor bands are provided. For the visible channel it is too difficult as one would need to know perfectly the albedo of the surface.

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

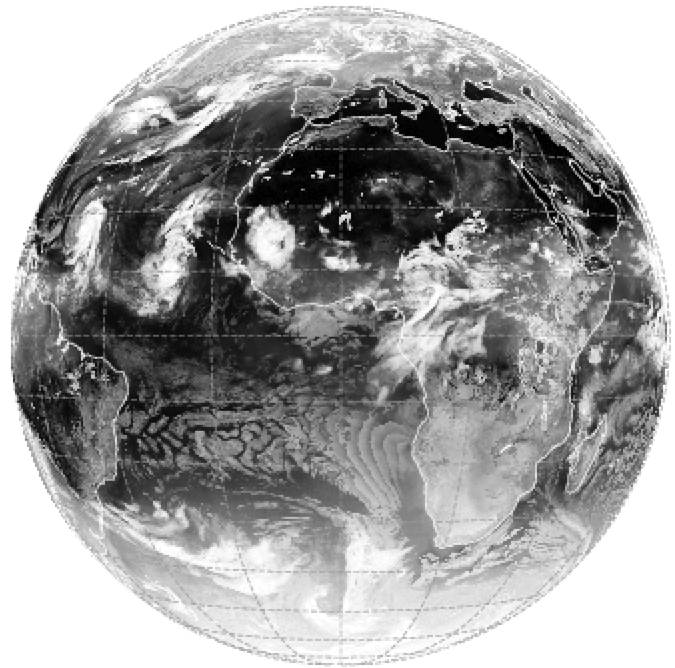
Forecasted 0-120h ("synthetic") and observed IR satellite imagery

Note Tropical Cyclones Danielle, Earl and Fiona

Meteosat 9 IR10.8 20100825 0 UTC

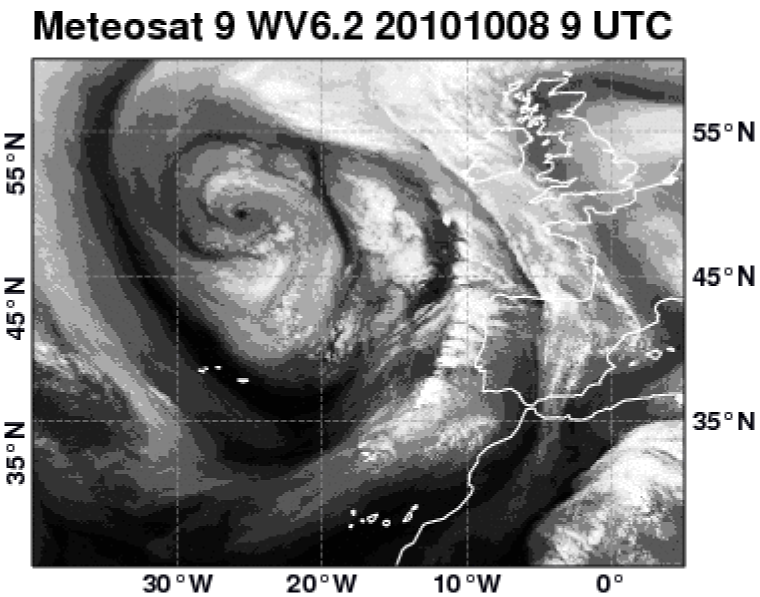


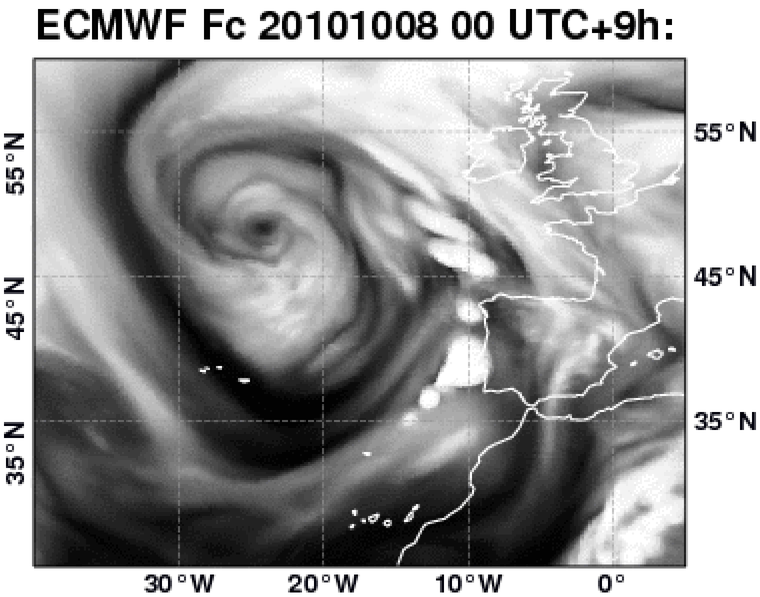
ECMWF Fc 20100825 00 UTC+0h:



Cloud top height and cloud optical thickness (vertically integrated absorption) must be correct. Midlatitude cloud systems are well represented, (tropical) convection is more difficult

WV imagery 950 hPa cyclone



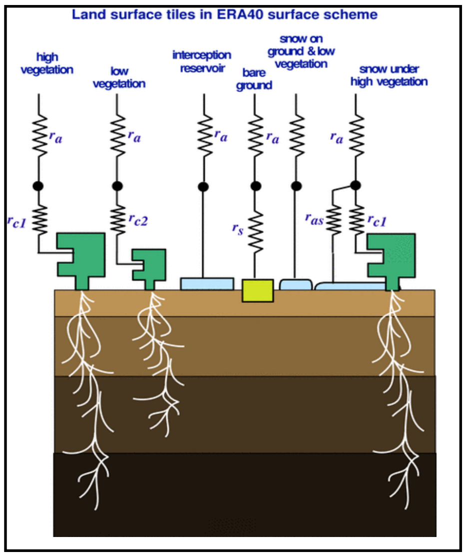


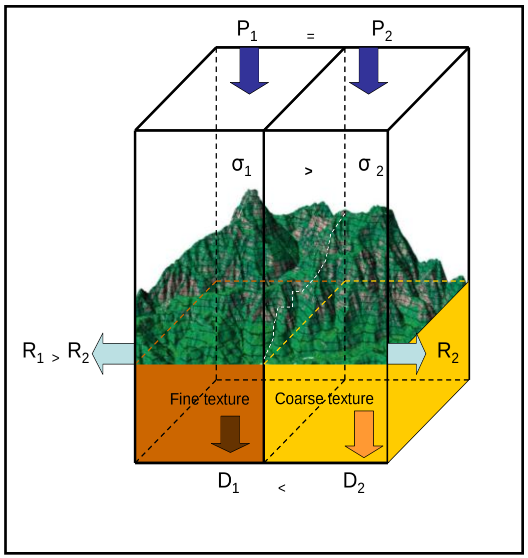
Note the distinctive moist and dry bands, and the organized convective cells in frontal band

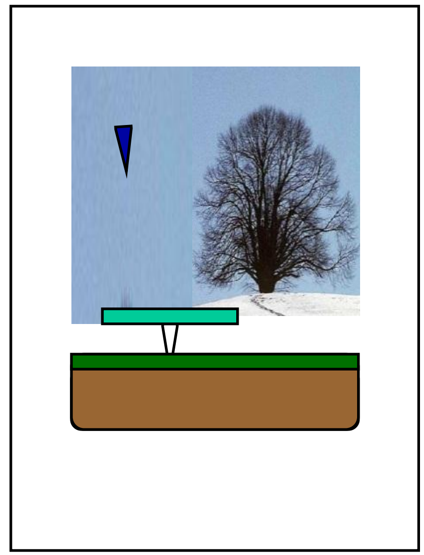
Land surface model evolution

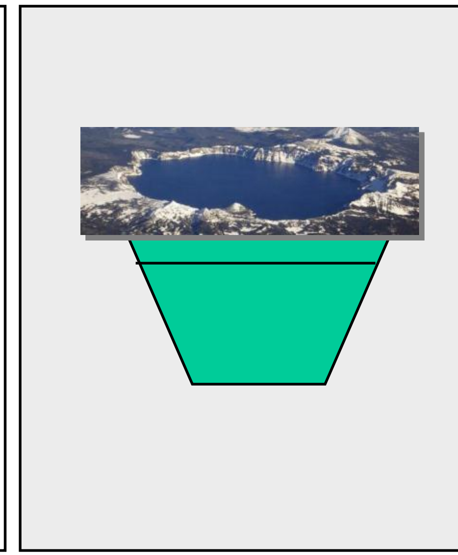
2000/06	2007/11	2009/03	2009 & 2010	2013

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





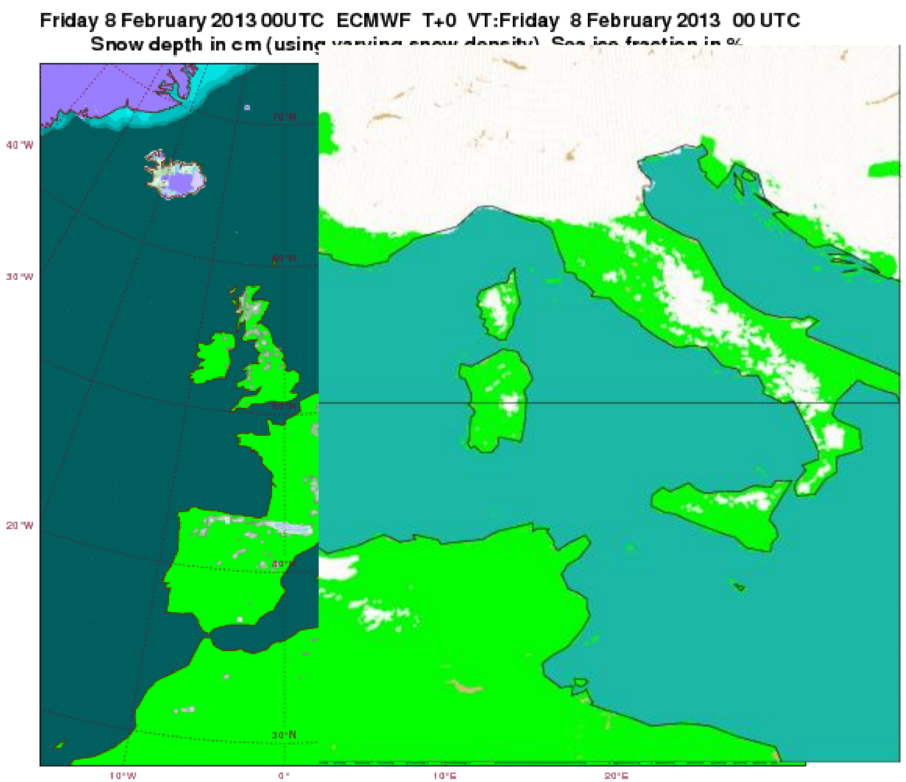


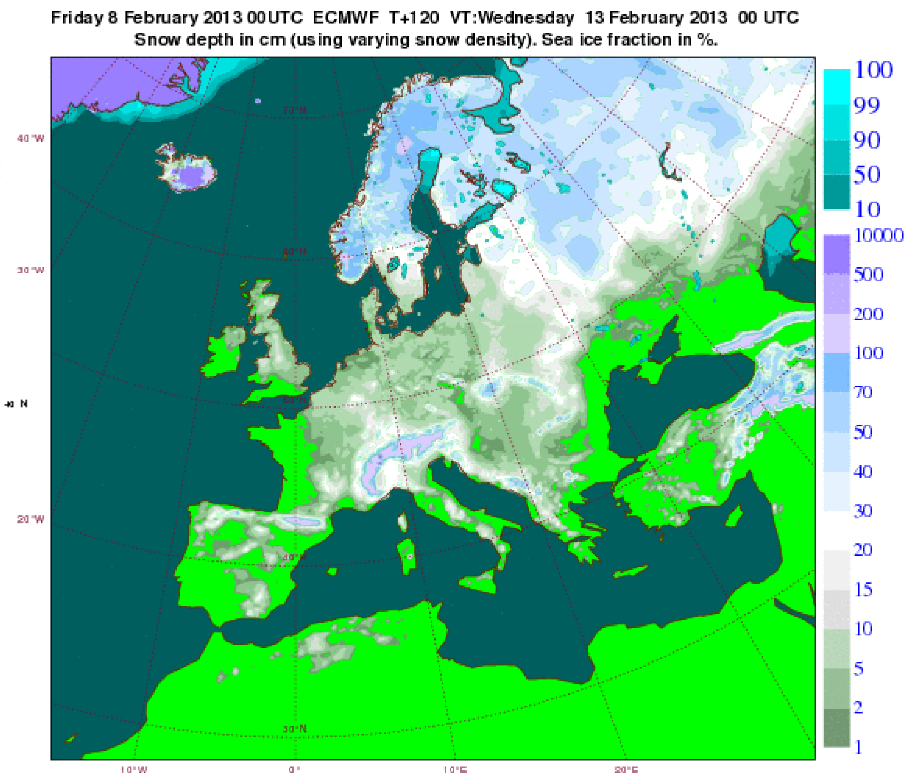


ECMWF

Archived prognostic snow related quantities

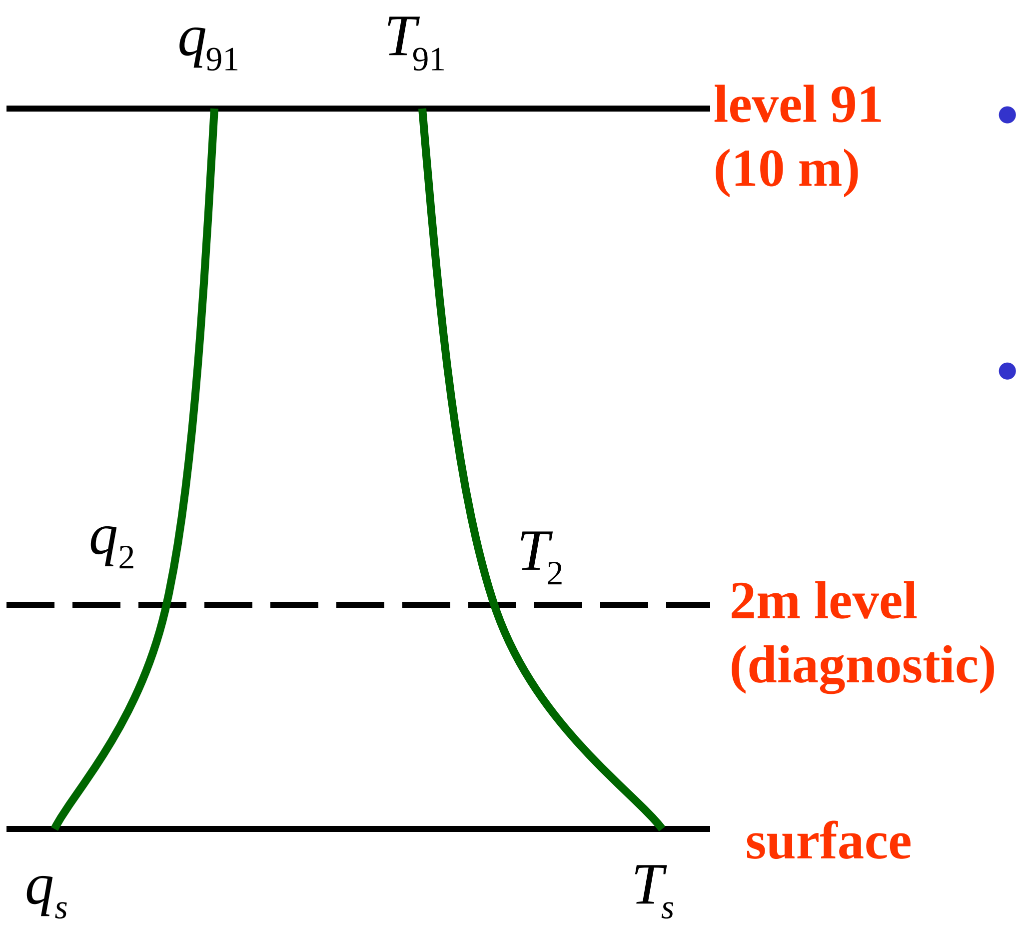
- Snow depth (water equivalent), Sd => actual depth=Sd*(Rl=1000)/Rsn
- Snow density (typically factor 10 lower than water-> 1 mm precip~1 cm snow), Rsn
- Snow temperature, Tsn
- Snow albedo, Asn





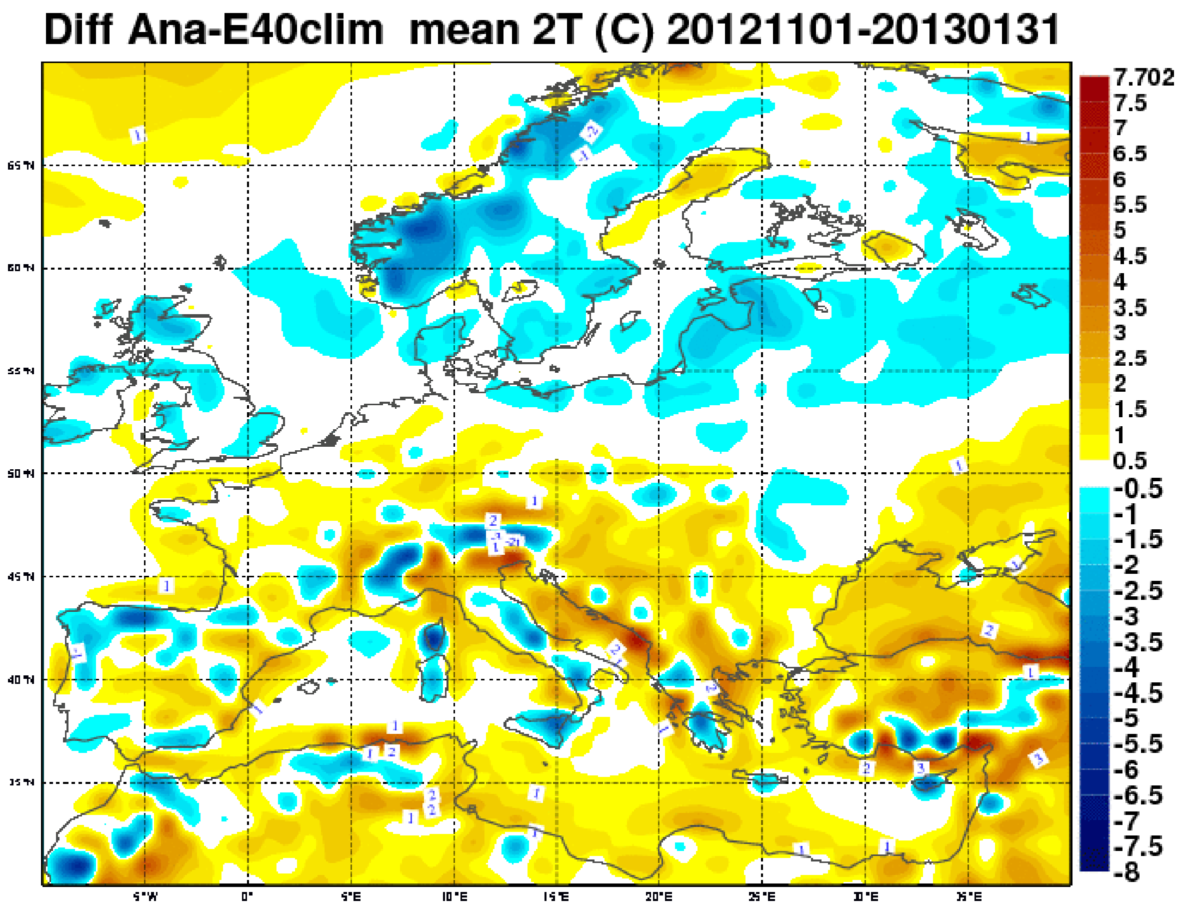
http://www.ecmwf.int/products/forecasts/d/charts/medium/analysis/

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.

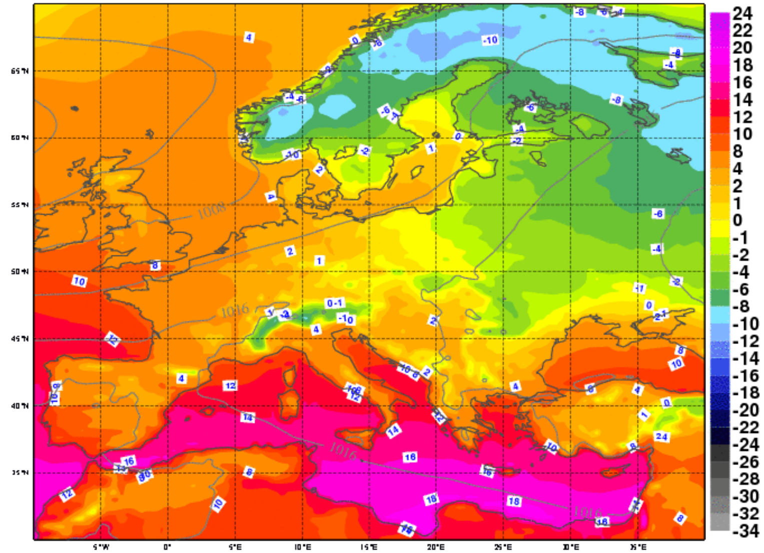
This winter so far versus E40clim



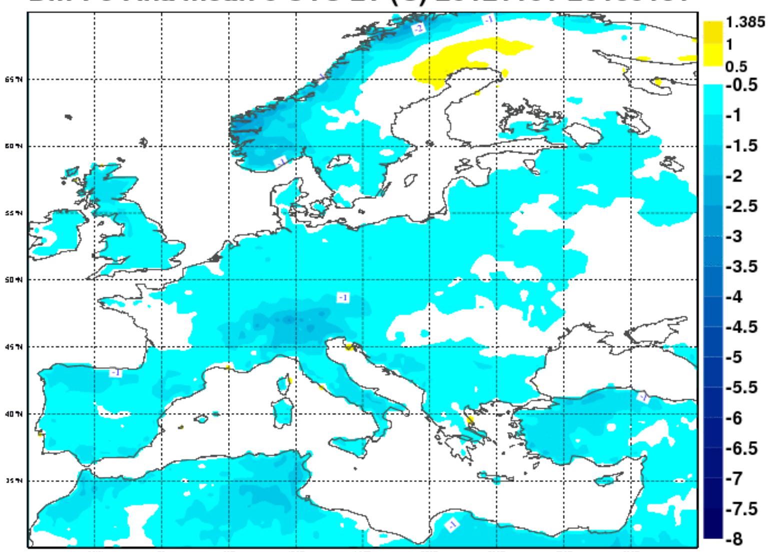
Quite “normal”, a bit warmer than climatology over Balkan and colder in Norway and Baltic states

T2m mean and errors (K) Nov 2012- Jan 2013 00 & 12 UTC

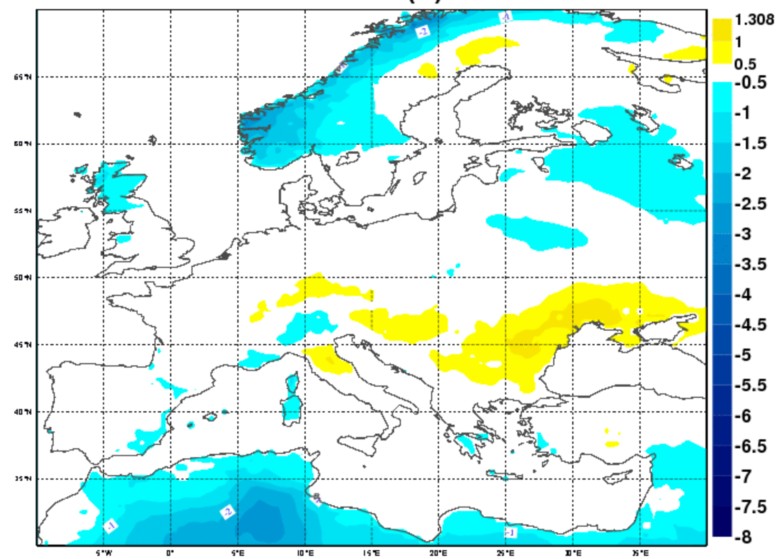
Mean Ana 0 UTC 2T (C) 20121101-20130131



Diff Fc-Ana mean 0 UTC 2T (C) 20121101-20130131



Diff Fc-Ana mean 12 UTC 2T (C) 20121101-20130131



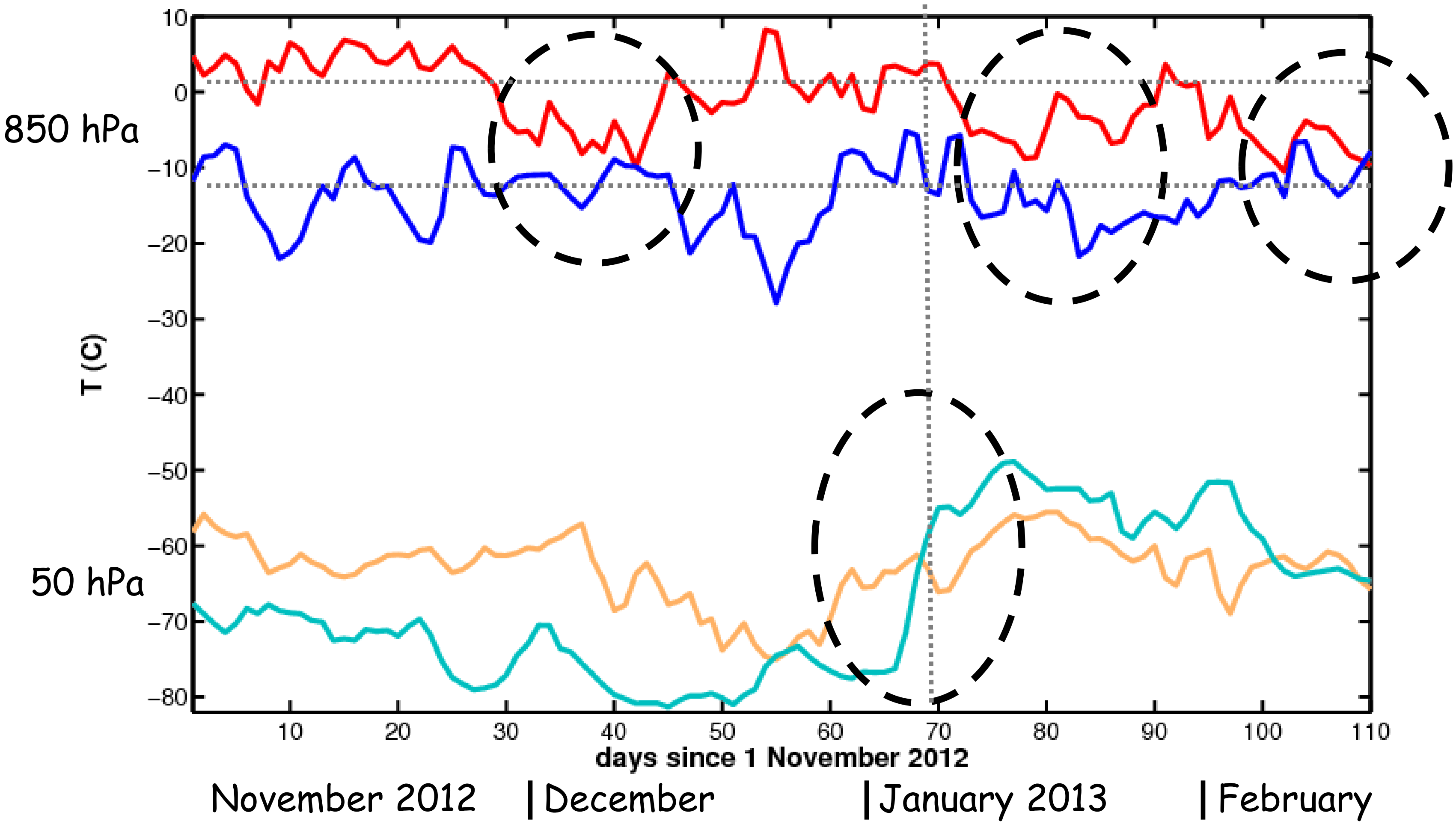
land mask applied

Summary of wintertime 2m T errors

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

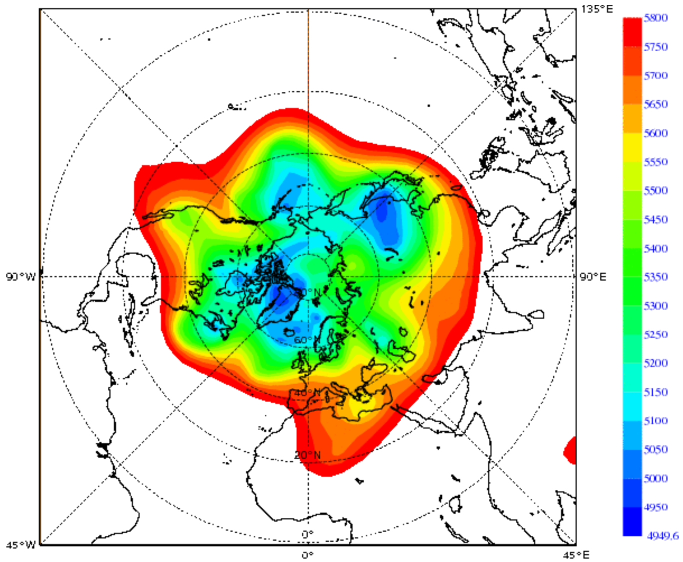
- Too low, particular night-time problem
- Stable boundary-layer (mixing)
- daytime overestimation related to underestimation of LCC
- otherwise cold bias easily enhanced over snow (if wrongly analysed/forecasted – not melting quickly enough)

Time series of 850 hPa and 50 hPa mean T © in central Europe and polar Europe - cold spells & Sudden Stratospheric Warming in January

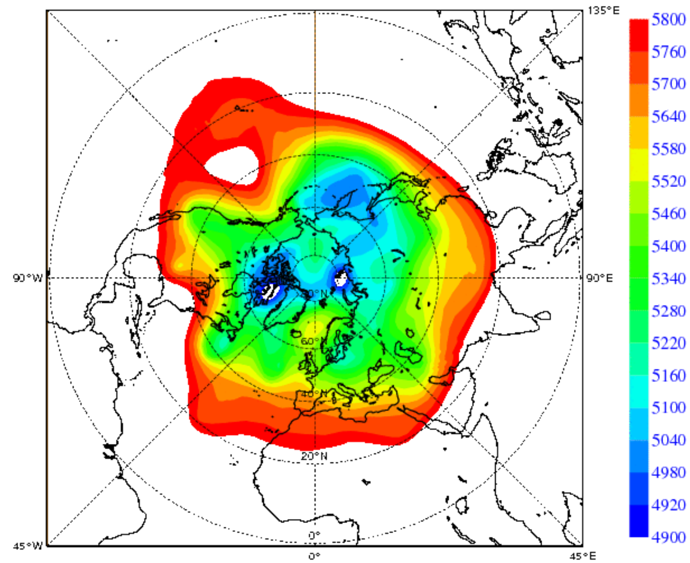


The winter Temperatures and the polar stratospheric Vortex

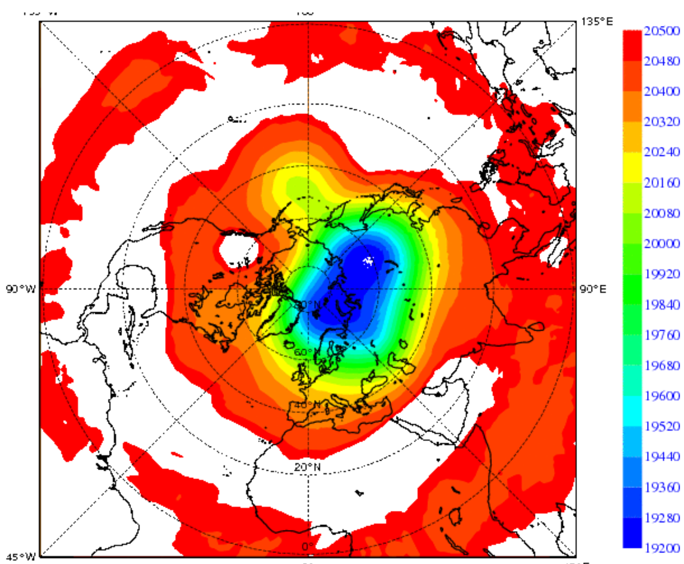
31.12.2012 Z 500 hPa



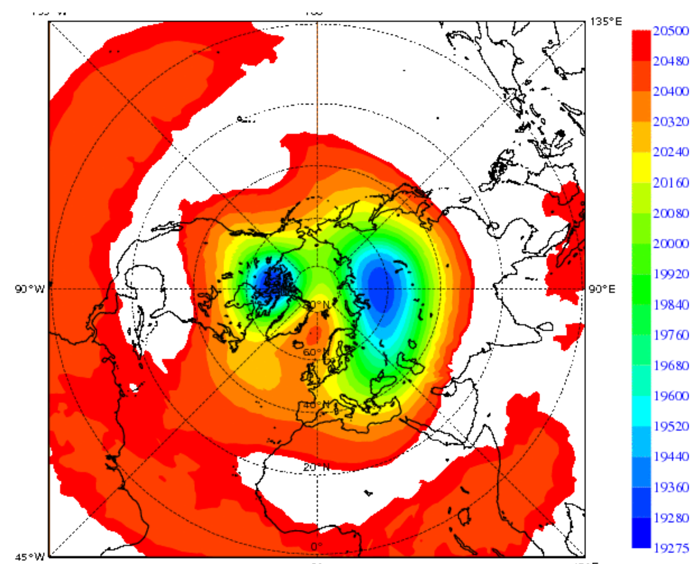
11.1.2013 Z 500 hPa



31.12.2012 Z 50 hPa

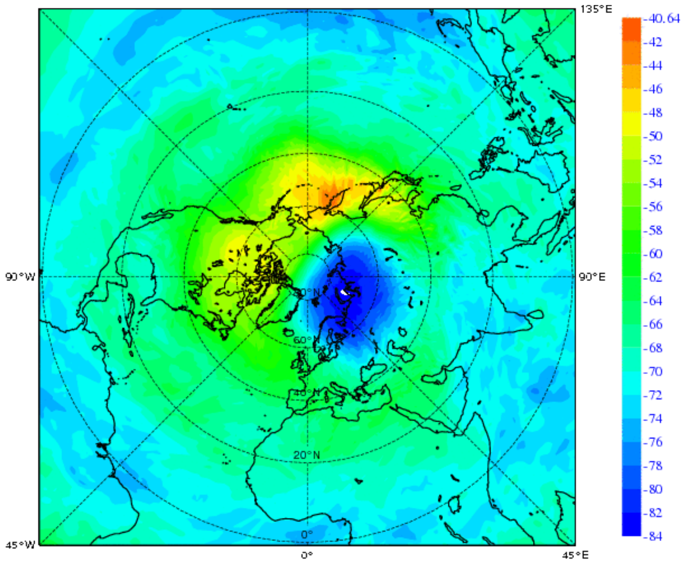


11.1.2013 Z 50 hPa

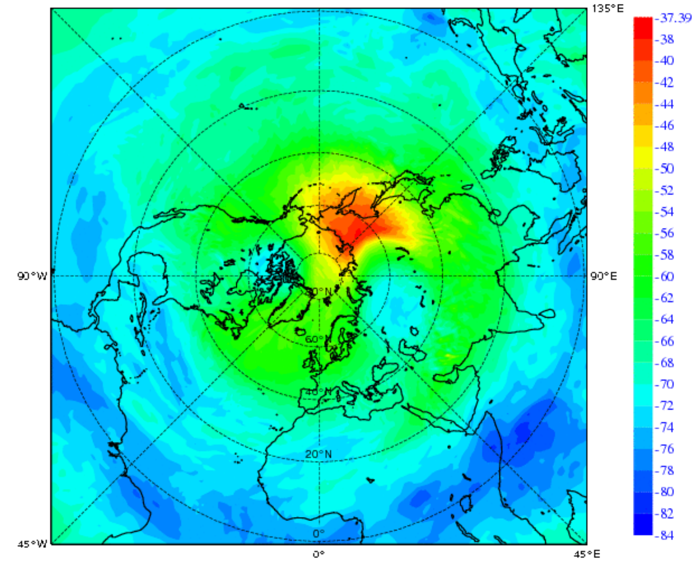


The winter Temperatures and the polar stratospheric Vortex

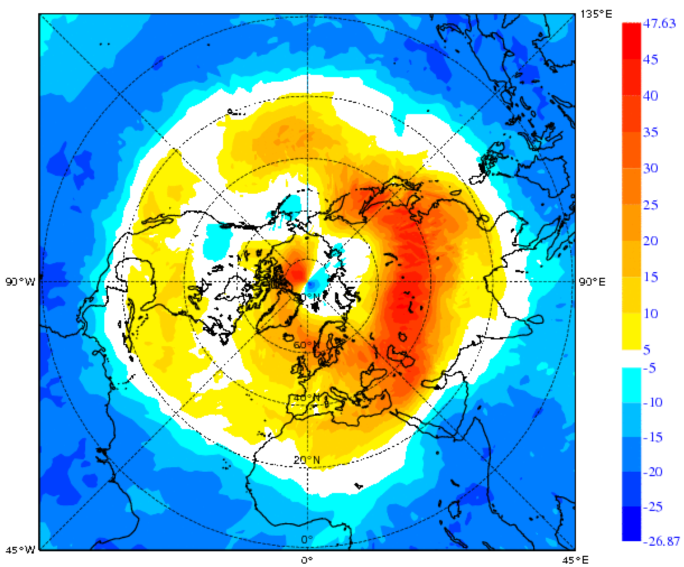
31.12.2012 T 50 hPa



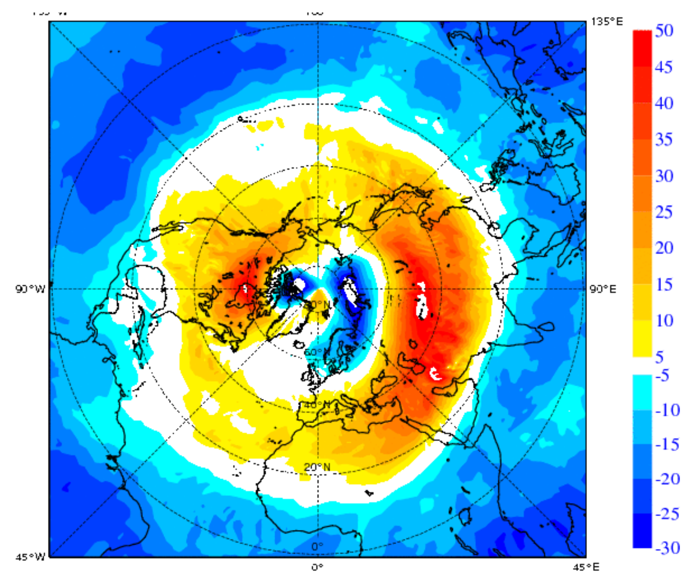
11.1.2013 T 50 hPa



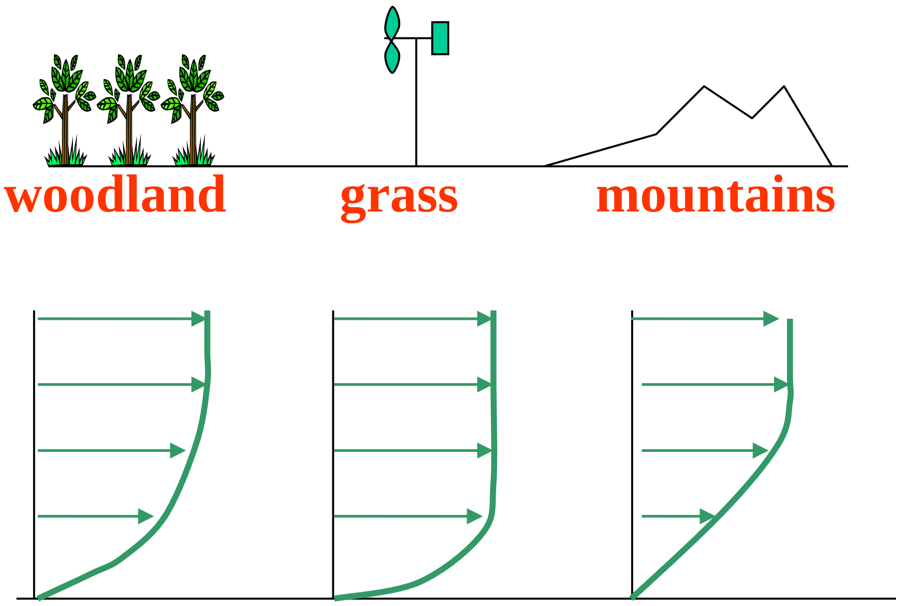
31.12.2012 U 50 hPa



11.1.2013 U 50 hPa

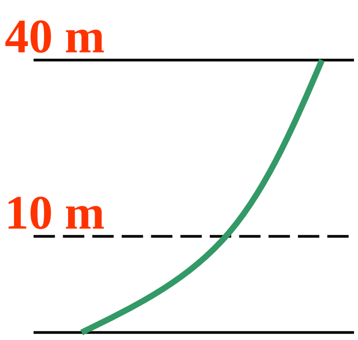


10 m wind



- **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.**

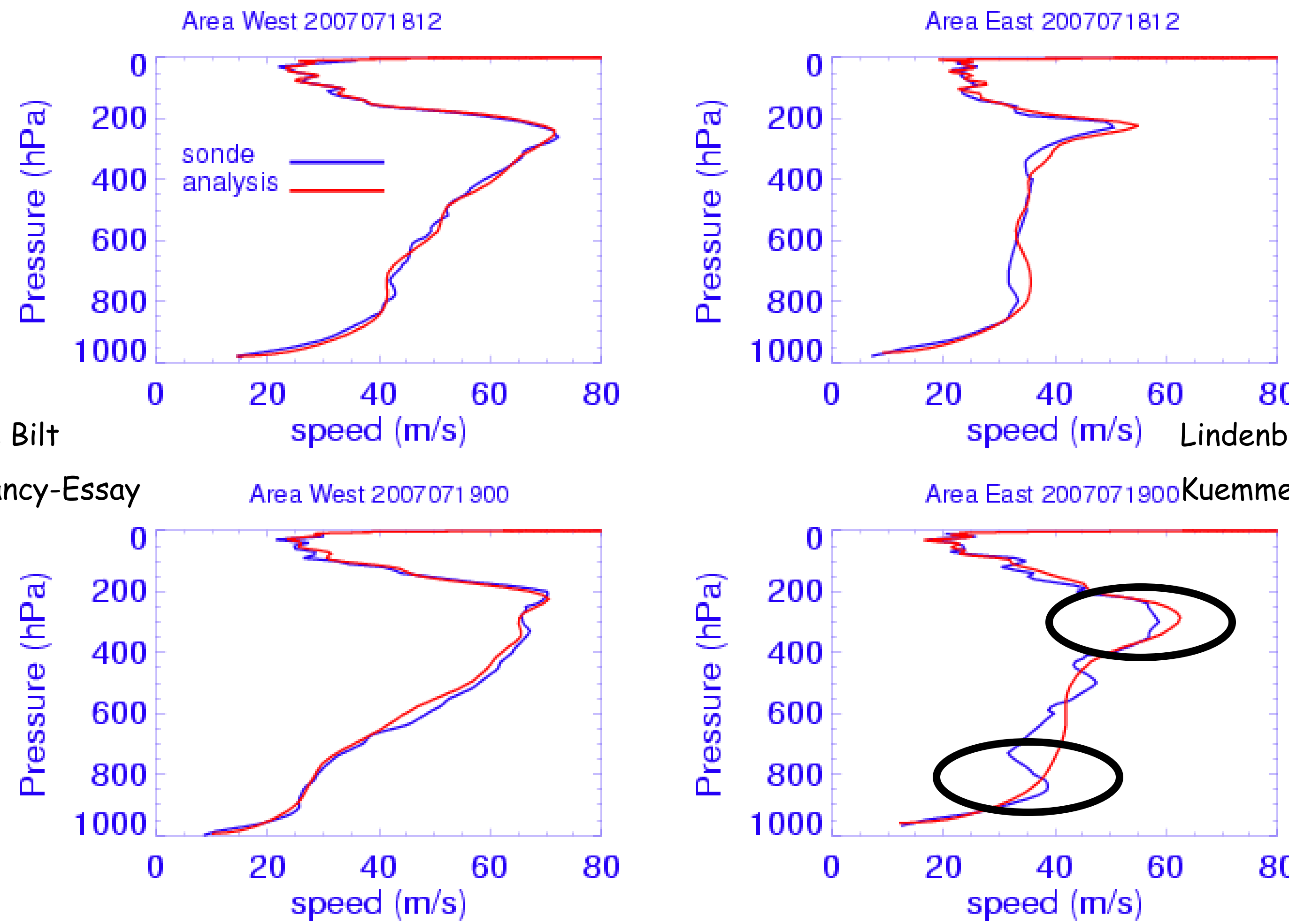
Post-processing of wind at 10 m



- **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).**

Kyrill : Area averaged Wind speed:

Analysis versus Radiosondes 18.1.2007 12 UTC – 19.1.2007.00 UTC



Nottingham De Bilt Lindenberg Wroclaw I

Camborne Nancy-Essay Kuemmersbruck Prostejov

Storm Kyrill: note upper-level Jet (geostrophic wind due to horizontal temperature gradient) and low-level Jet (low-level cyclone=low-level vorticity perturbation)

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

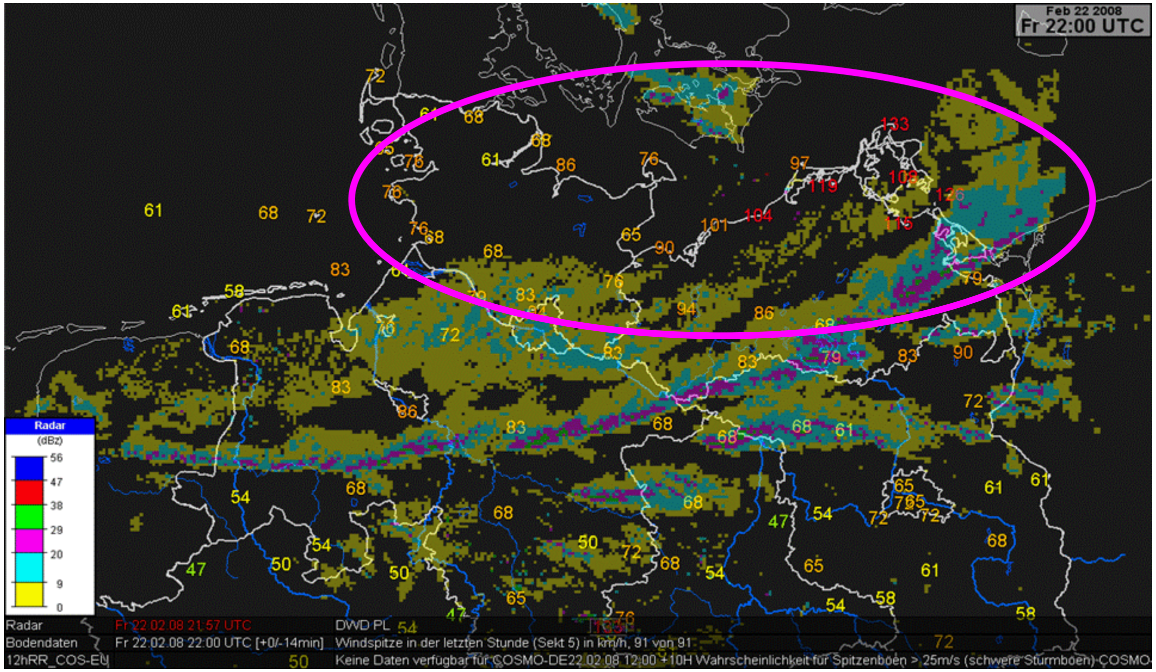
Gusts are computed by adding a turbulence component and a convective component to the mean wind:

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

where U_{10} is the 10m wind speed (obtained as wind speed at first model level, or interpolated down from 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 500 hPa and 850hpa, respectively.

Convective Gusts

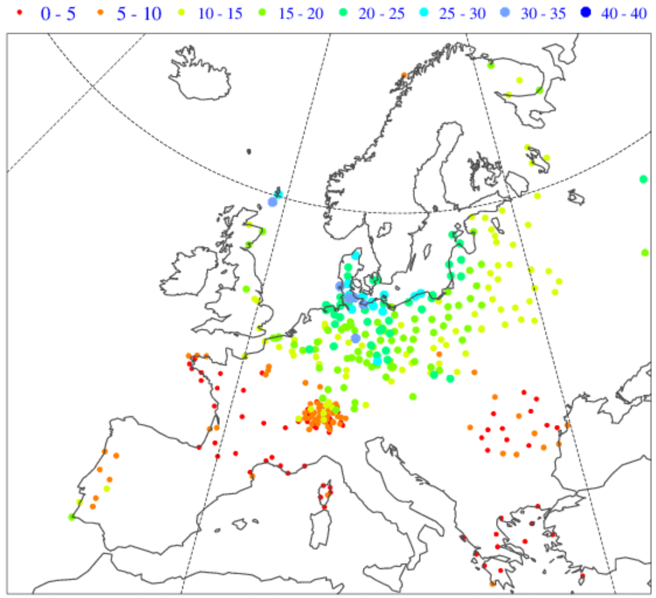


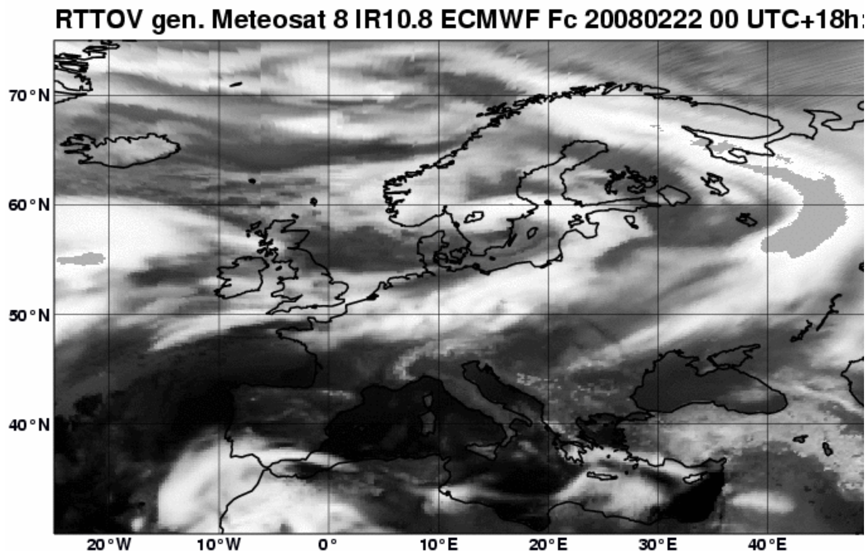
Motivation: report about gust front by DWD

22 February 2008

Wind gusts case 22 February 2008 continued

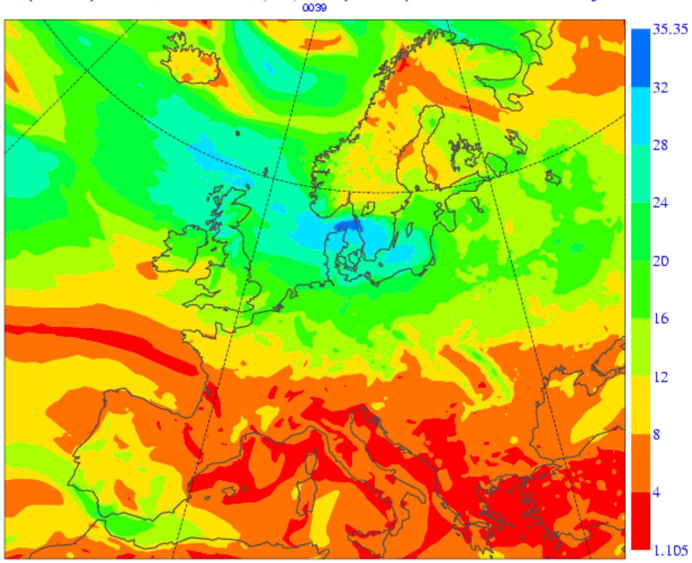
Obs





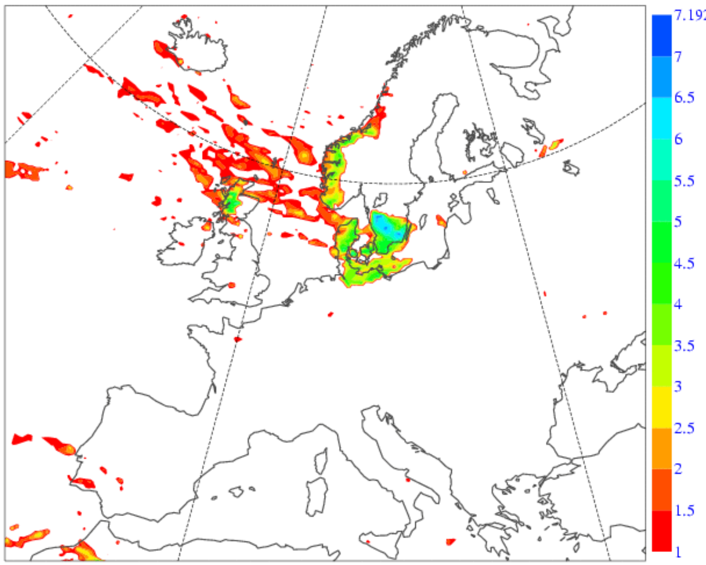
Friday 22 February 2008 00UTC ECMWF Forecast t+(15-18) VT: Friday 22 February 2008 18UTC Surface: 10 metre wind gust
0039

Oper



Friday 22 February 2008 00UTC ECMWF Forecast t+(15-18) VT: Friday 22 February 2008 18UTC Surface: **10 metre wind gust
f0yi

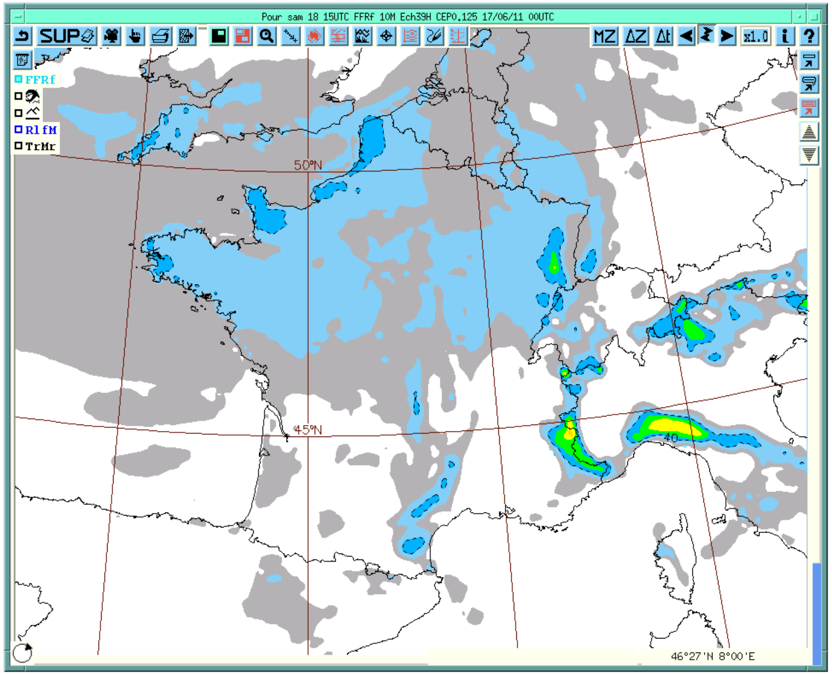
Conv



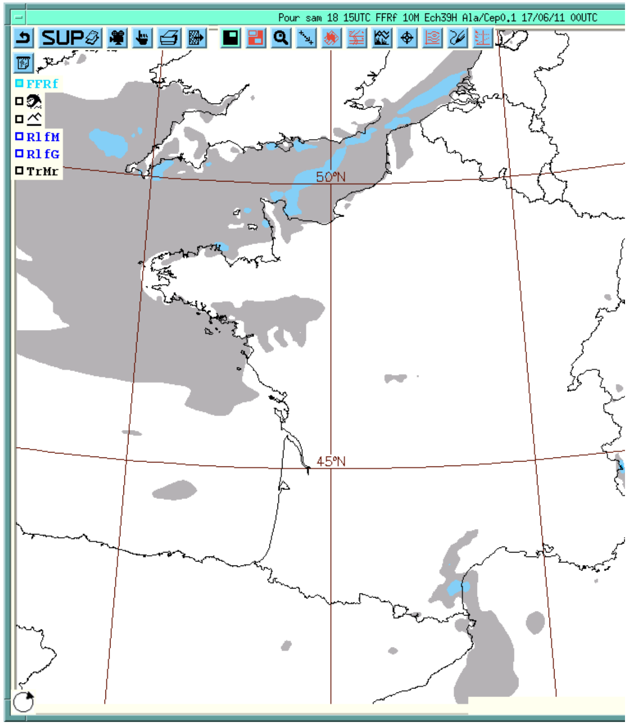
Wind gusts 18 June 2011

- 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

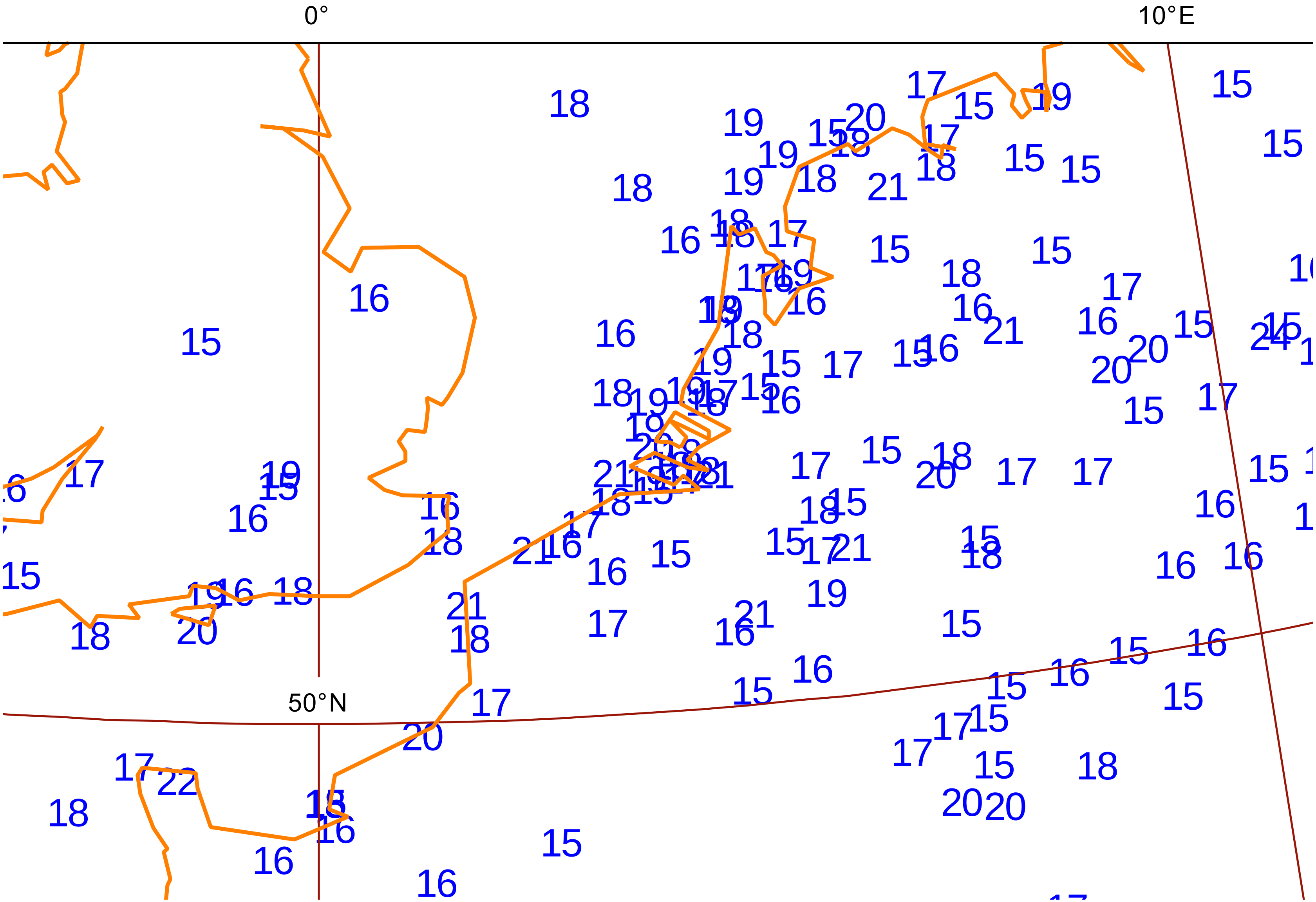
ECMWF



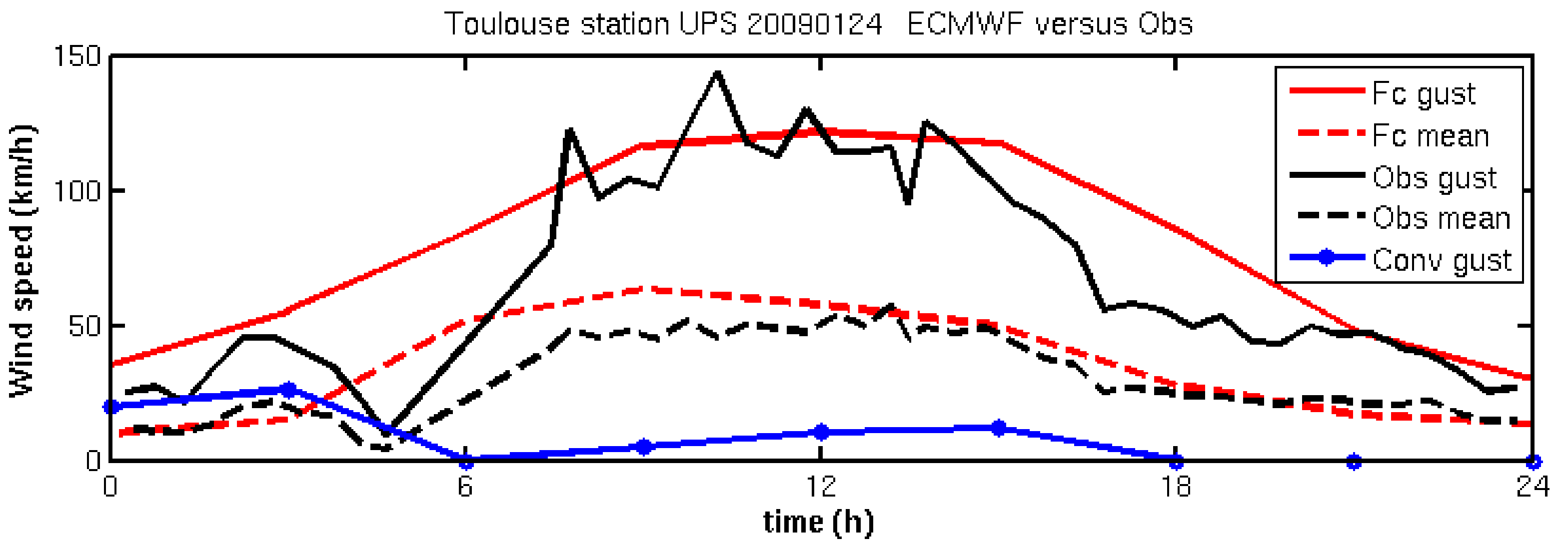
Aladin



Wind gusts 18 June 2011



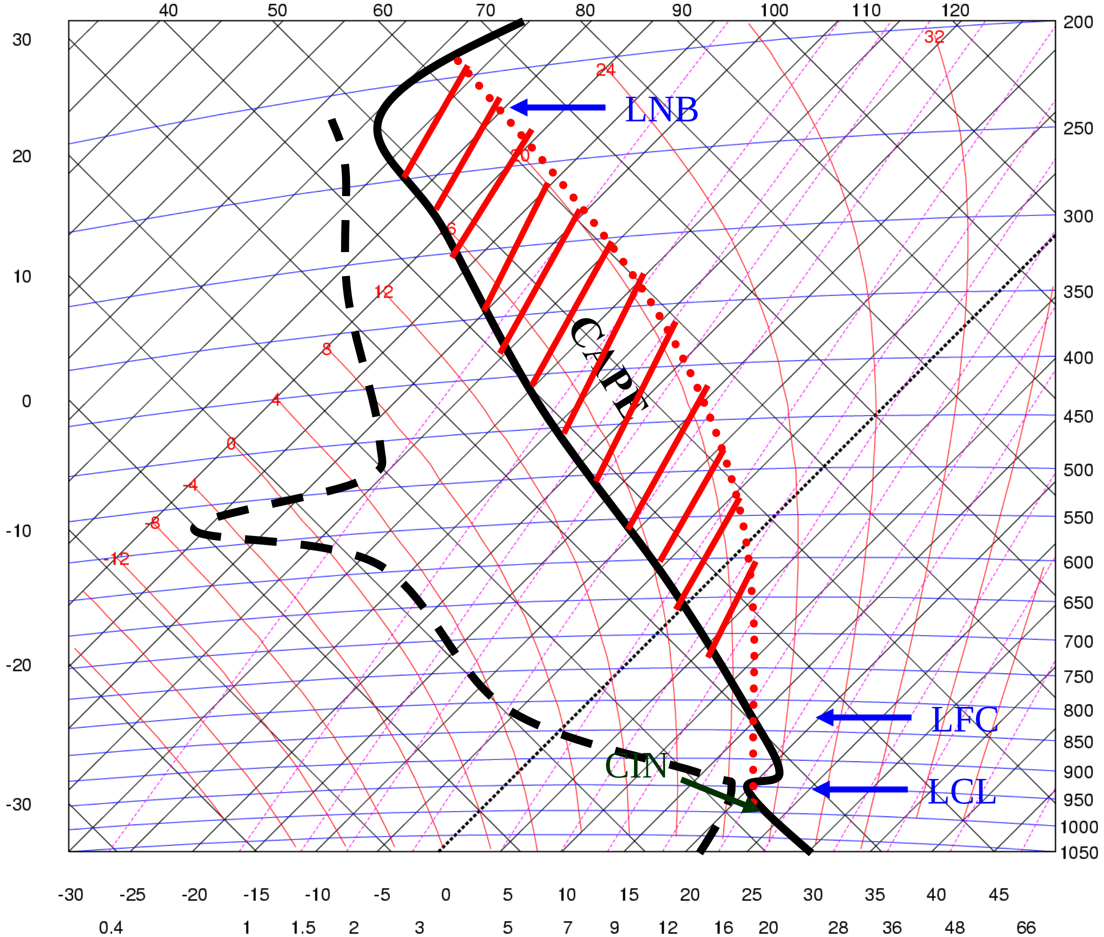
Wind gusts
Time series against anemometer 24 January 2009 (storm Klaus)



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) Instability: CAPE

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

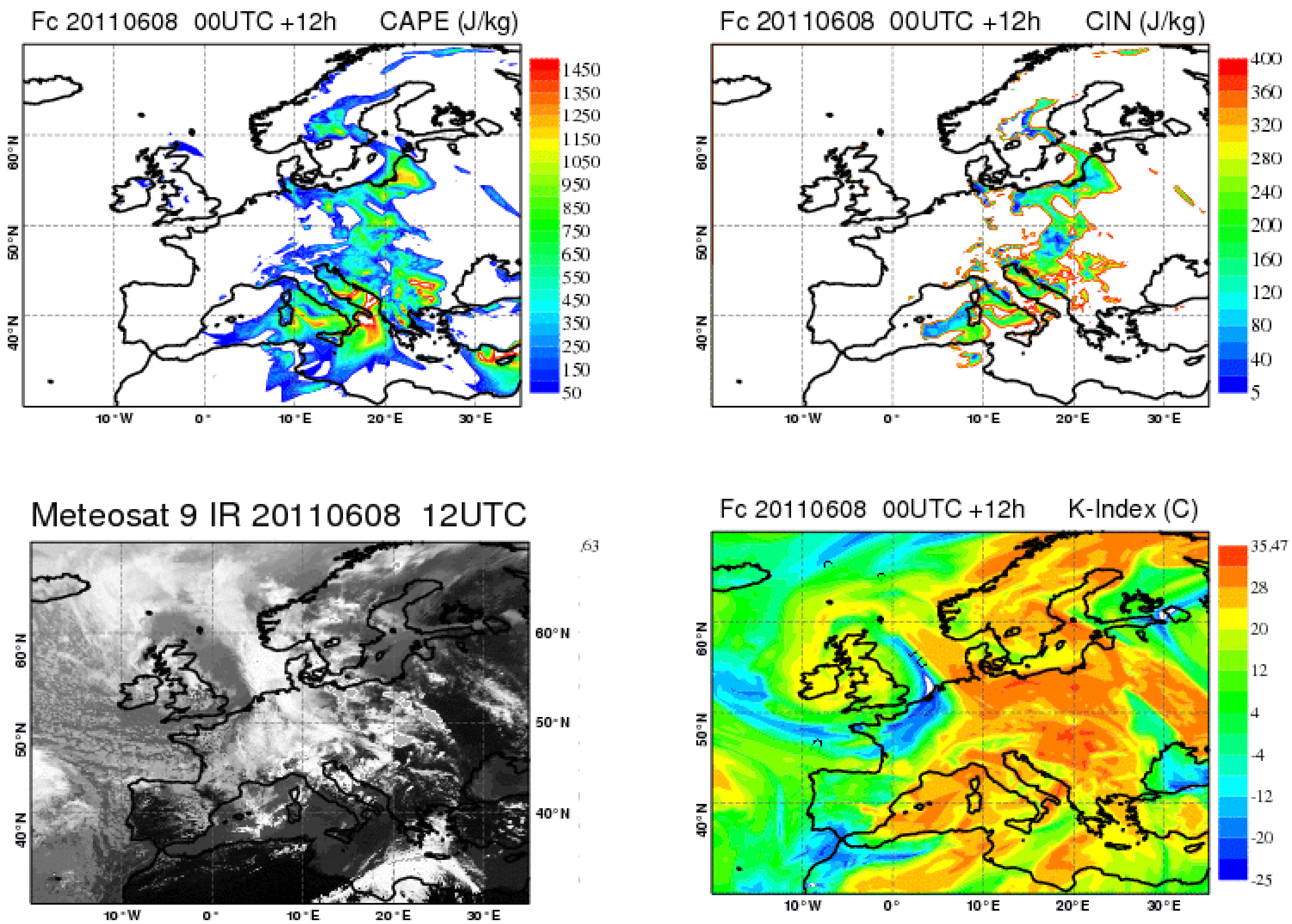
$$\frac{dw}{dt} = w\frac{dw}{dz} = \frac{1}{2}\frac{dw^2}{dz} \approx g\frac{T'}{\overline{T}}$$

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

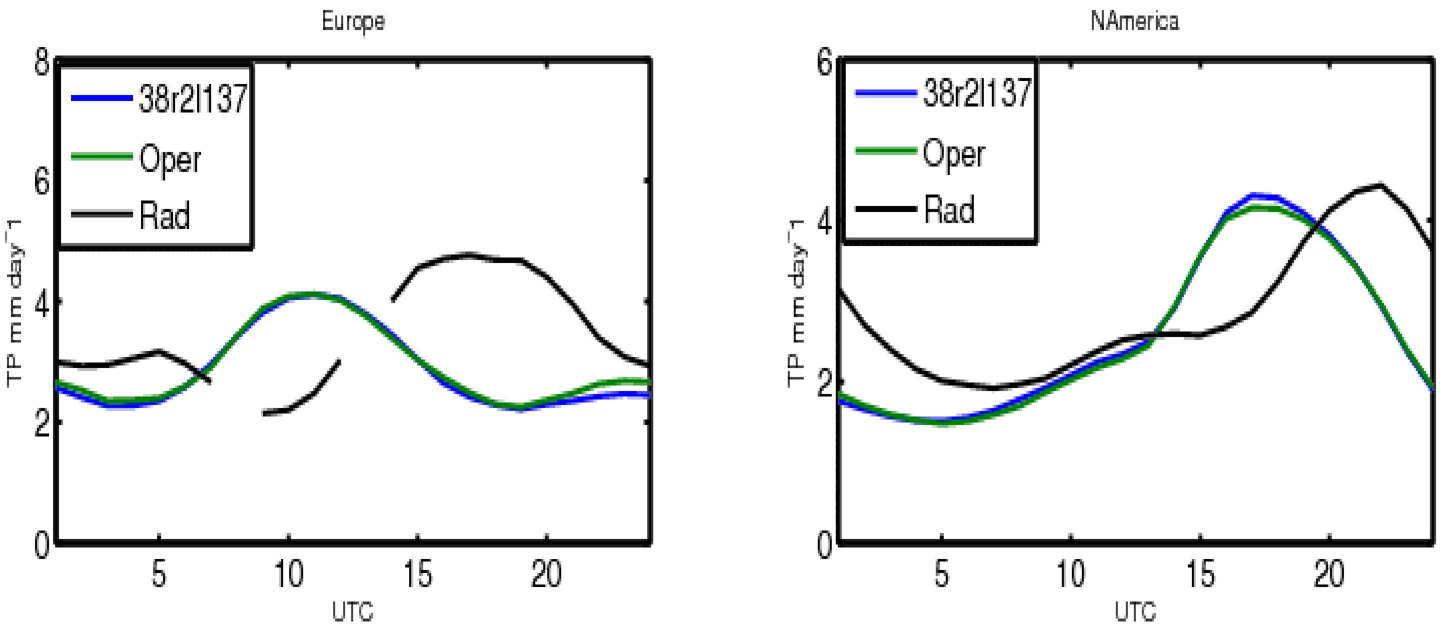
Maximum updraught velocity (vertical velocity in cloud) $w = \sqrt{2 \cdot CAPE}$

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
as requested by Member States (User Meeting June 2011)



Diurnal cycle of convection

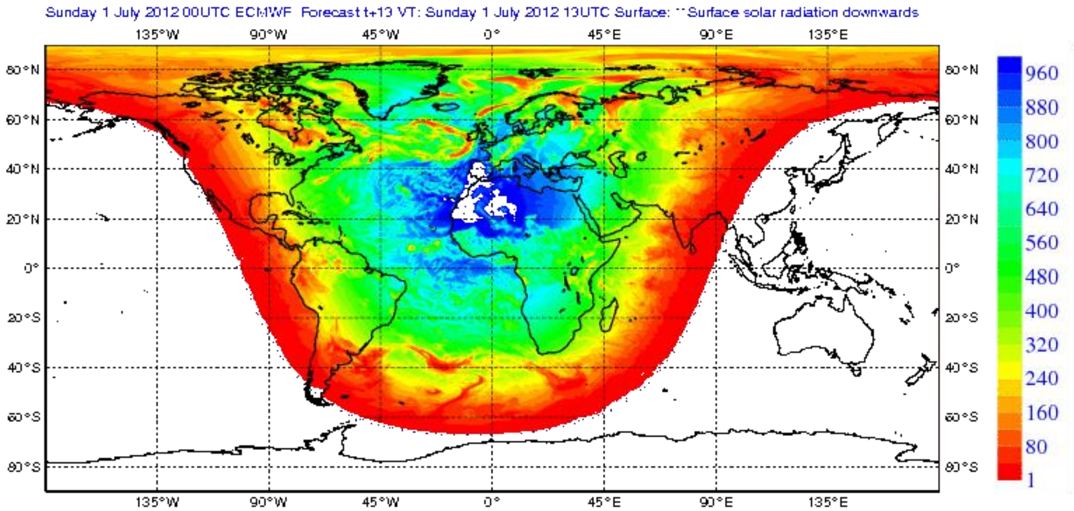


LST=UTC+1

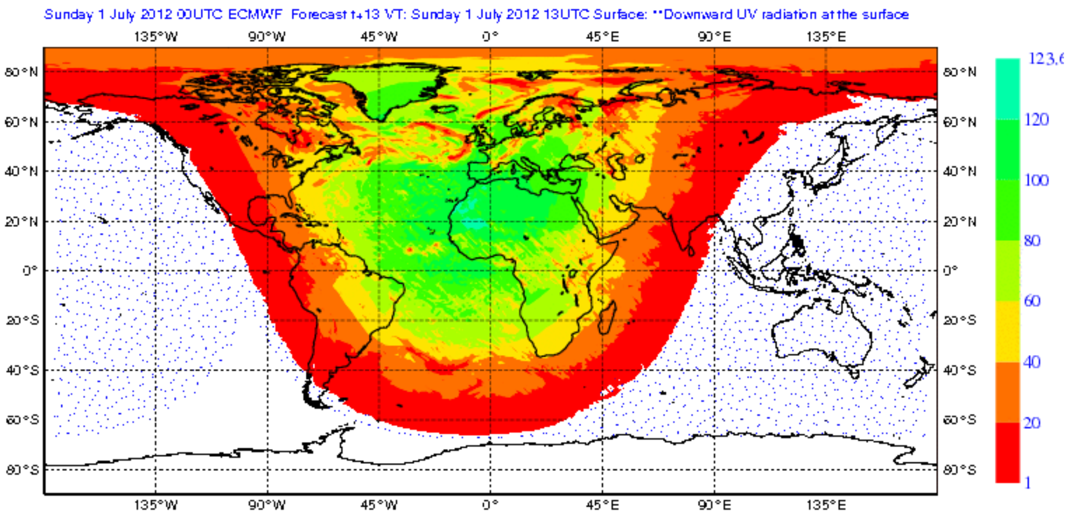
Depending on region diurnal cycle peaks up to 4-5 hours before Radar observations, in Europe this is around noon. Limited area convection resolving models do better there but their results depend very much on horizontal resolution (1 km needed)

Surface incoming solar radiation and UV

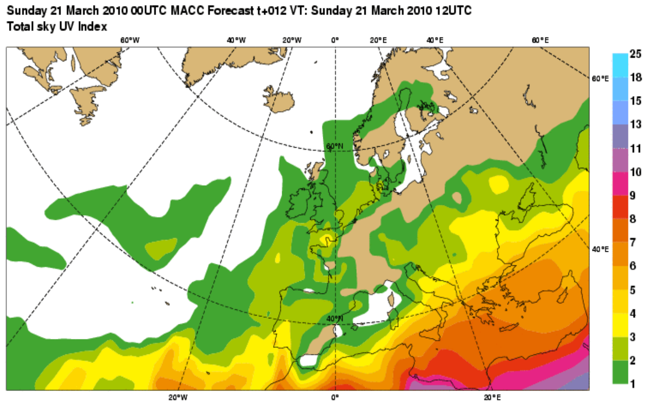
SSRD



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

Physics – remaining model errors

- T2m problems in winter (stable boundary-layer) and problems related to snow and low-level clouds, improved but can still occur
- Diurnal cycle of convective precipitation 3h too early, and too frequent light (<1 mm/day) precipitation (drizzle) events overall
- Inland penetration of (convective) showers
- Too strong Indian and SE Asian Summer Monsoon, largest day 1 850 hPa Temperature errors over Africa (Sahel)

Planned model upgrades in 2013

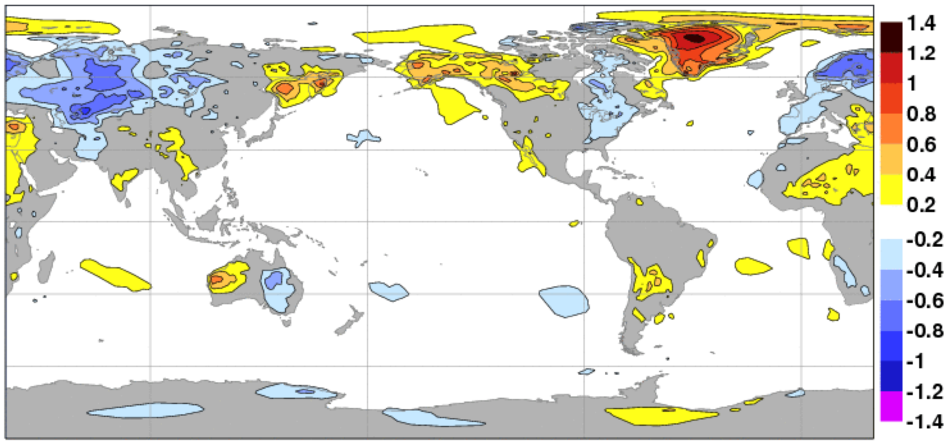
- Cy38r2, June 2013: 137 levels vertical resolution, little impact in troposphere, better stratosphere due to better resolved vertically propagating gravity waves and radiation fix

- Cy39r2, September 2013: hopefully some improvements, maybe drizzle and stable boundary-layer

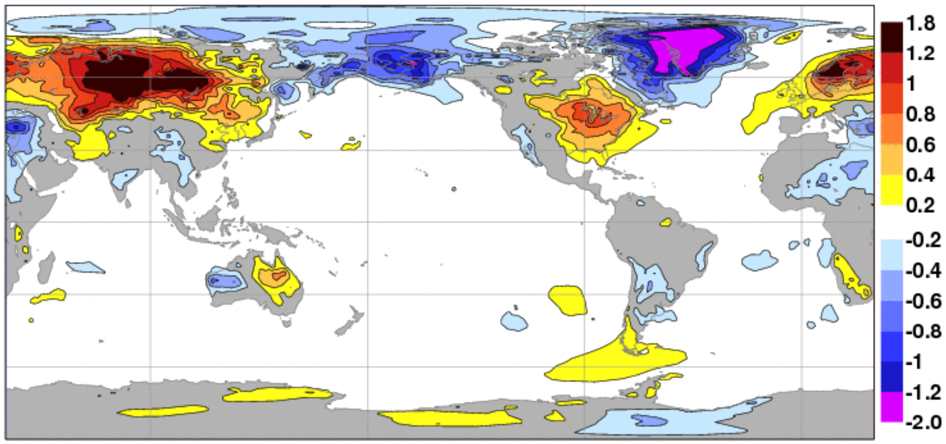
Coffee break ! Questions ?

Teleconn. U10hPa Tropics& 2T for DJF

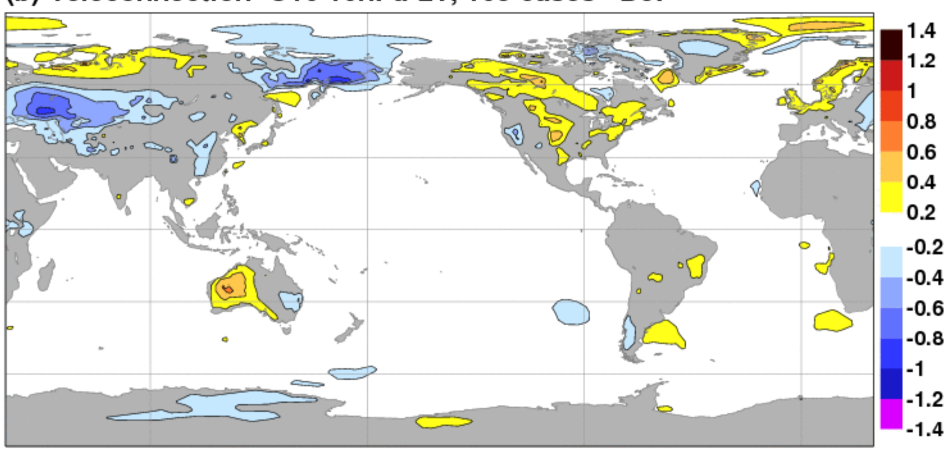
(a) ERAI Teleconnection -U10hPa-2T, 42 cases   DJF



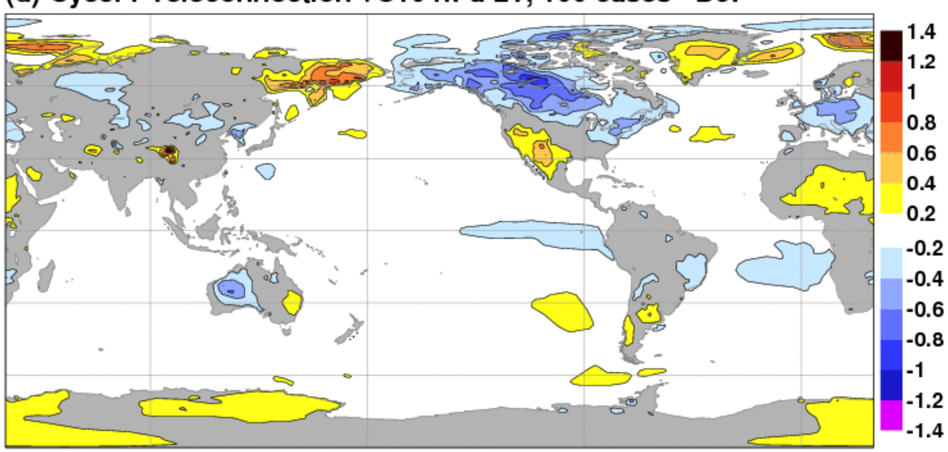
(c) ERAI Teleconnection +U10 hPa-2T, 37 cases   DJF



(b) Teleconnection -U10 10hPa-2T, 105 cases   DJF

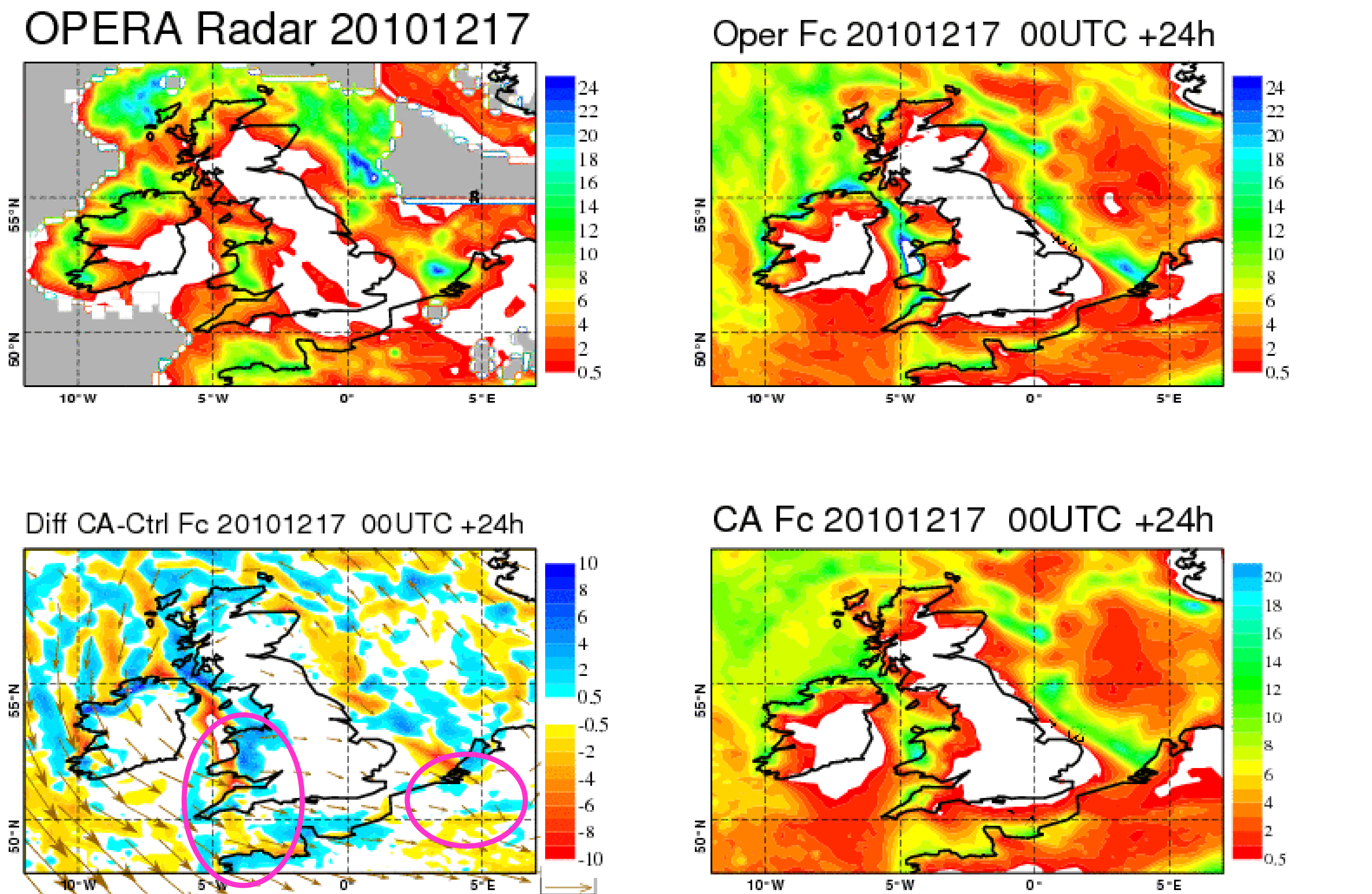


(d) Cy38r1 Teleconnection +U10 hPa-2T, 100 cases   DJF



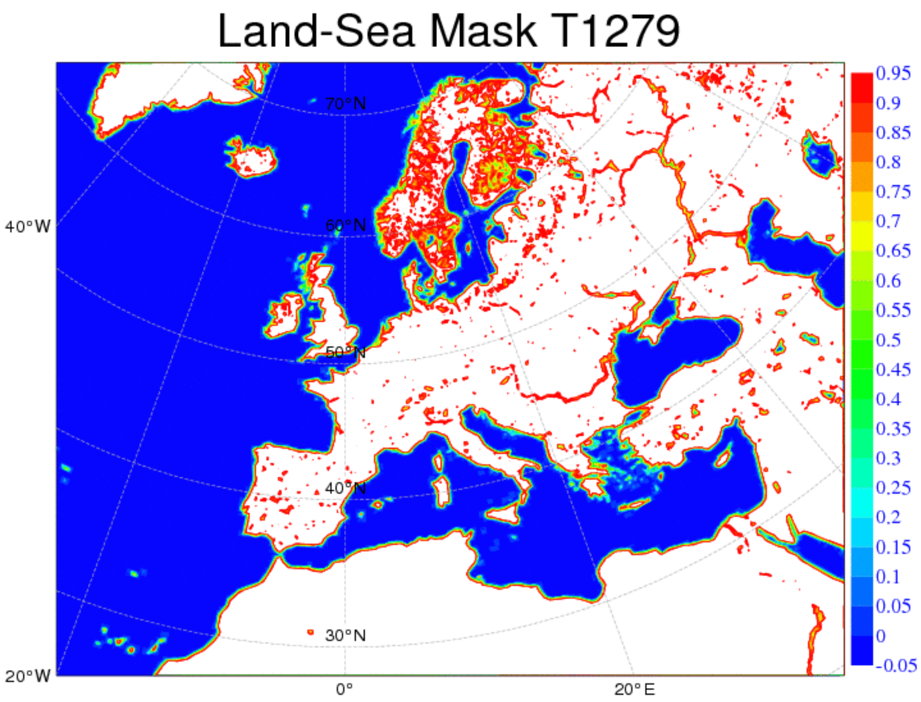
Inland advection of wintery showers

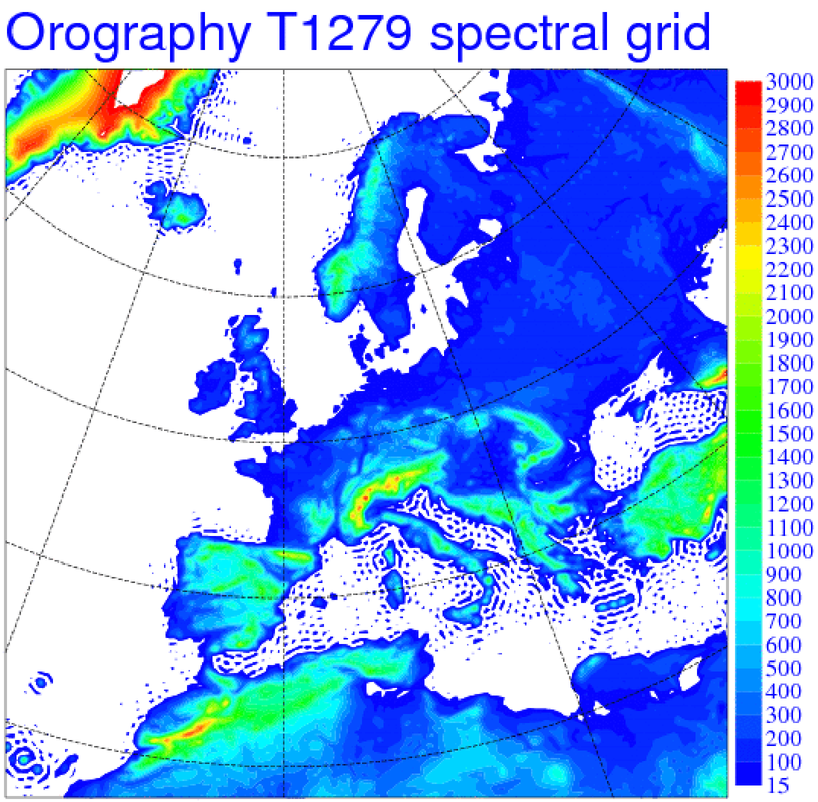
17. December 2010=Dutch Schipol case



Strong snow showers (5-20cm) of mostly of convective type. Wind shown is 500-850hPa mean. It is difficult but in principle possible to allow for inland penetration of showers in convection scheme

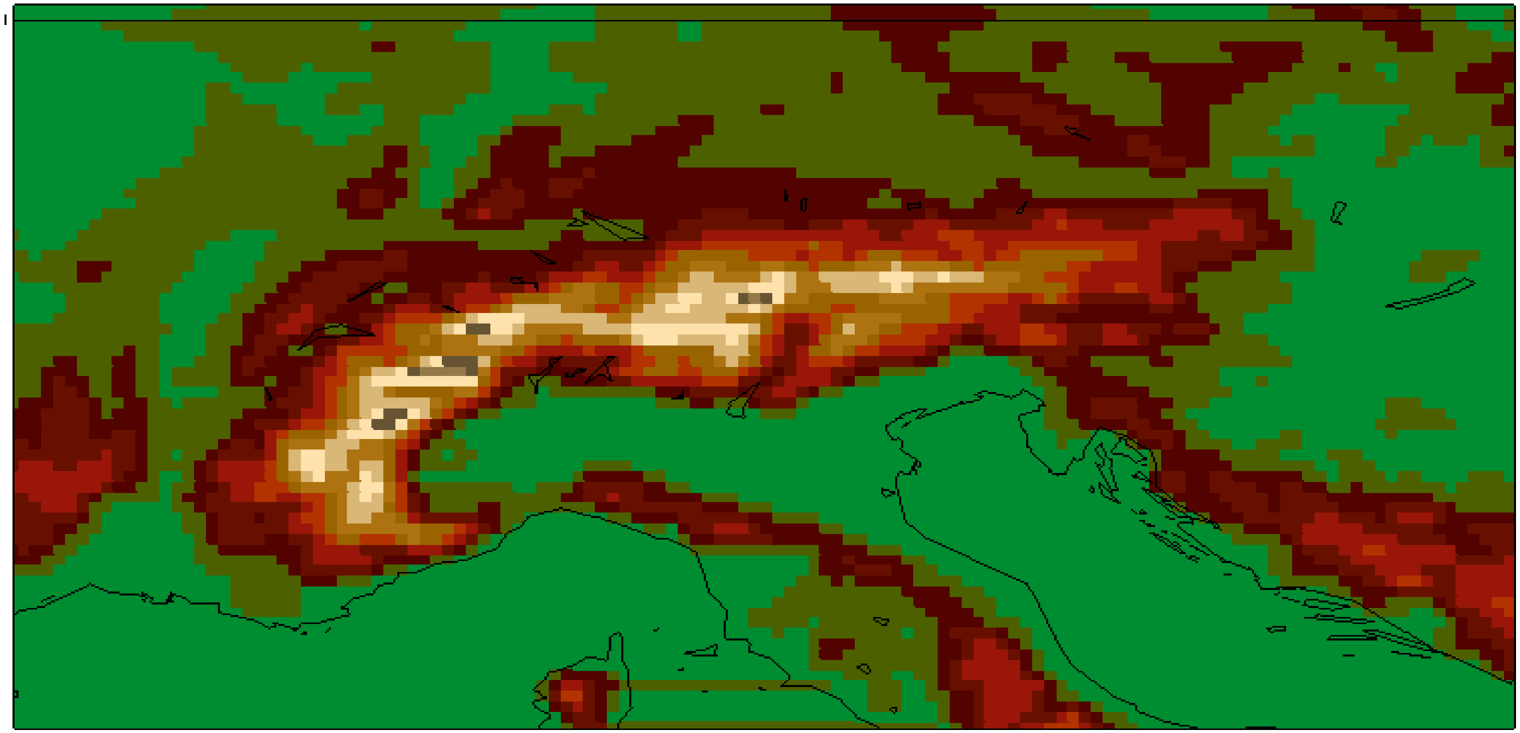
Land-Sea in T1279 (15km) resolution (since 26 January 2010)





Orography – T1279=16 km

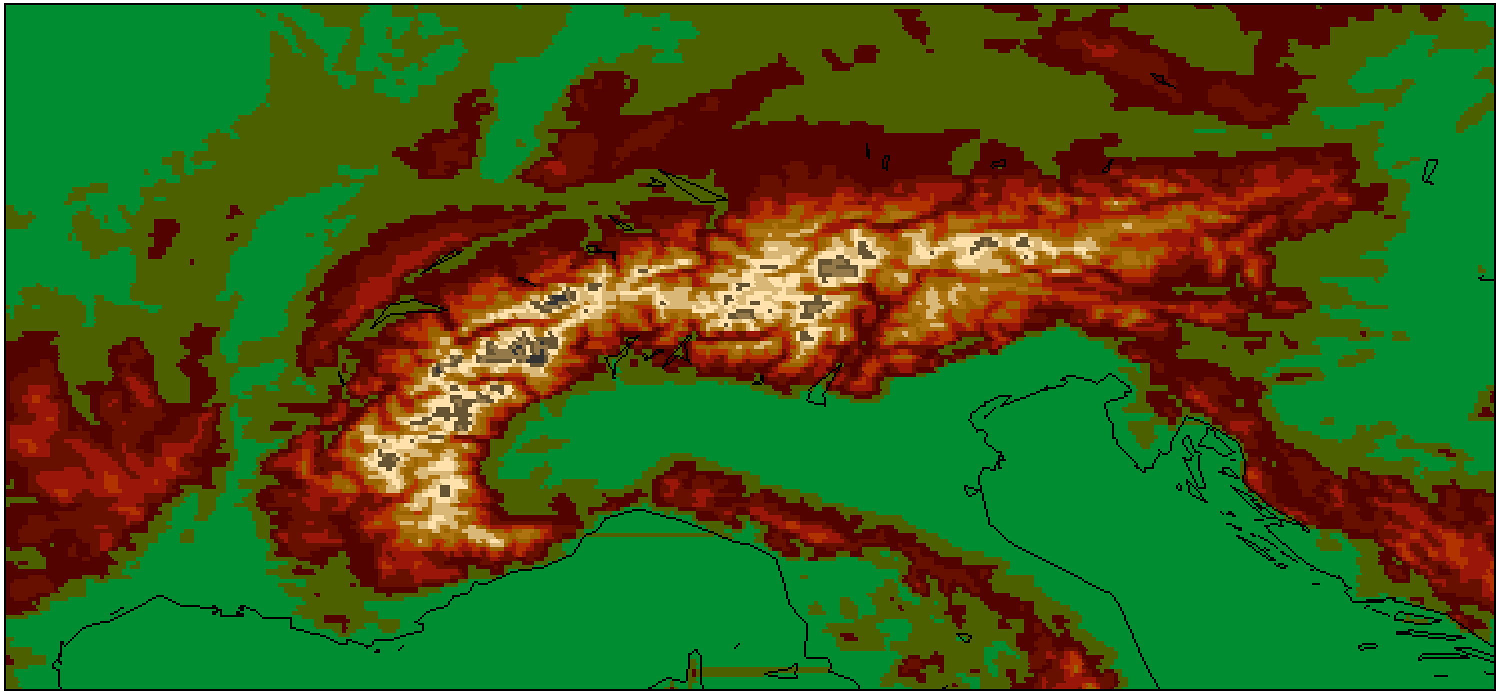
Max global altitude = 6503m



Alps

Orography - T3999=5 km

Max global altitude = 7185m



Alps