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 and Forecasted satellite images**
- **Winter special: Snow, 2m Temperature, 10 m Wind, Wind Gusts**
- **Summer special: diurnal cycle of Convection, CAPE, UV Index**
- **Stratosphere**

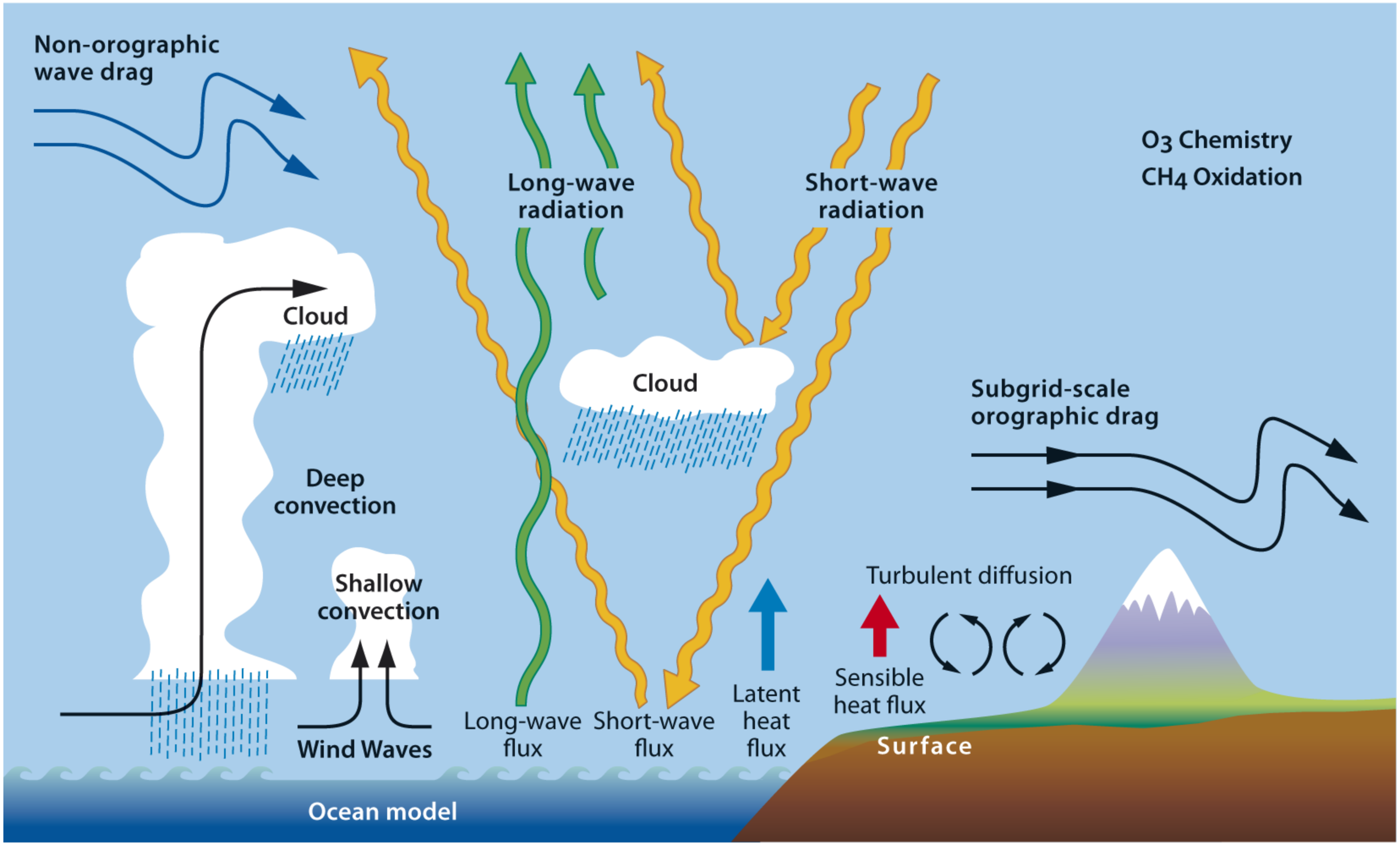
for the physical Aspects Section: Peter Bechtold (peter.bechtold@ecmwf.int)

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

ECMWF

Parameterized processes in the ECMWF model

from the surface to the stratosphere



Physics - and forecast configurations

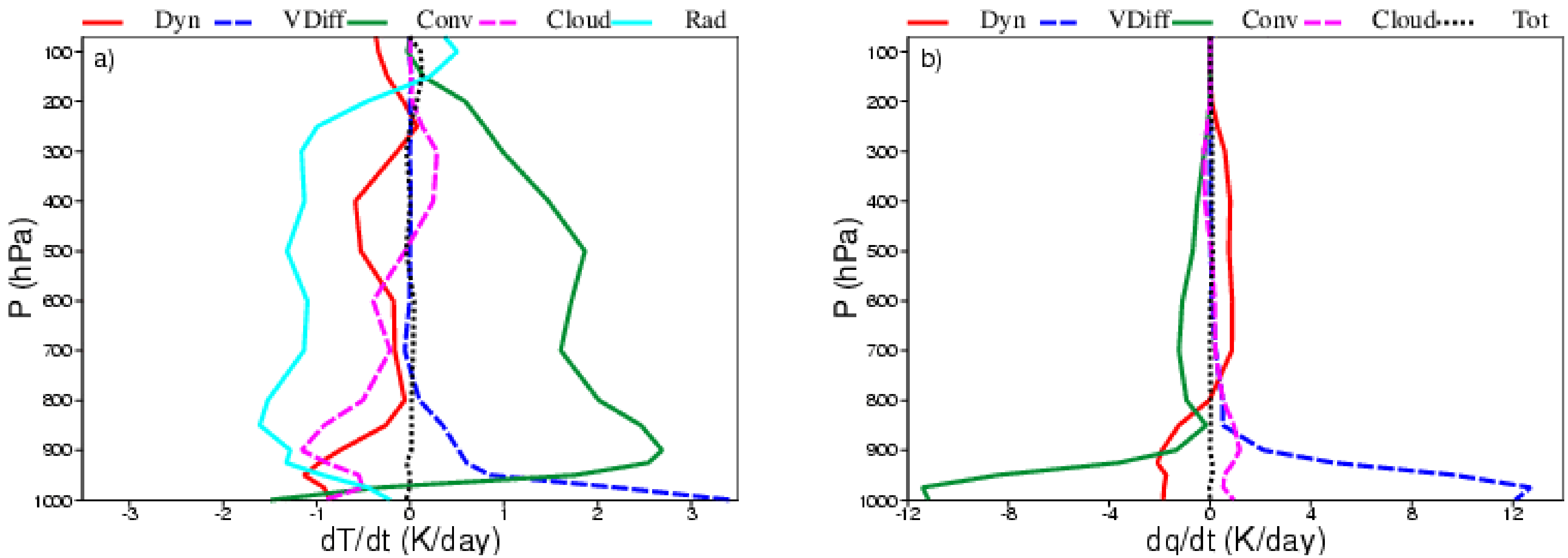
For all model configurations (deterministic forecast, ENS, monthly forecast) and horizontal/vertical resolutions, the identical set of physical parameterisations is used.

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



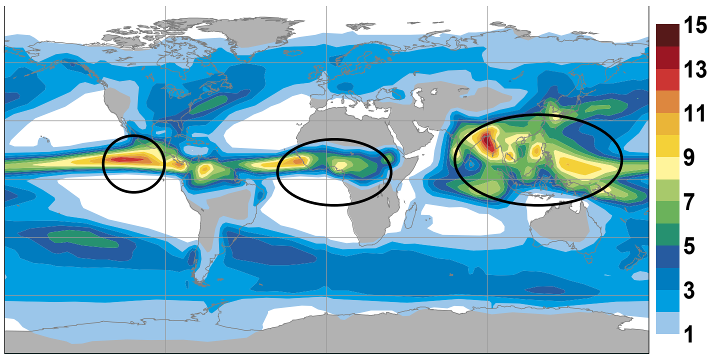
For Temperature, above the boundary layer, there is roughly an equilibrium Radiation-Convection, but Dynamics and Clouds also important, whereas for moisture there is roughly an equilibrium between dynamical transport (moistening) and convective drying. - *Global Budgets are very* similar

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

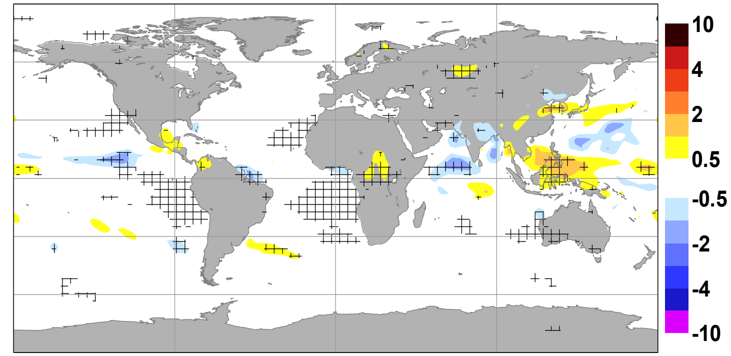
ECMWF

Precipitation JJA: Sensitivity to Model Formulation
Seasonal integrations

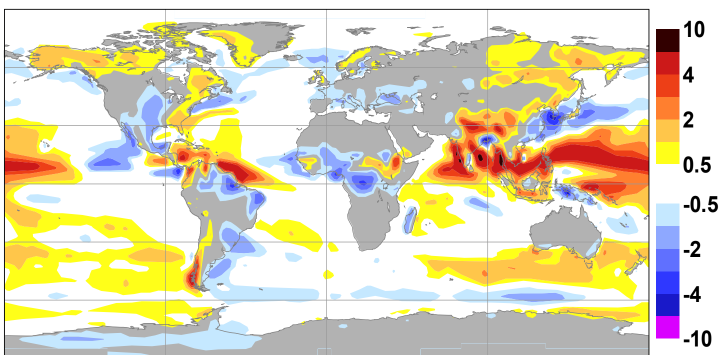
GPCP JJA 1990-2006



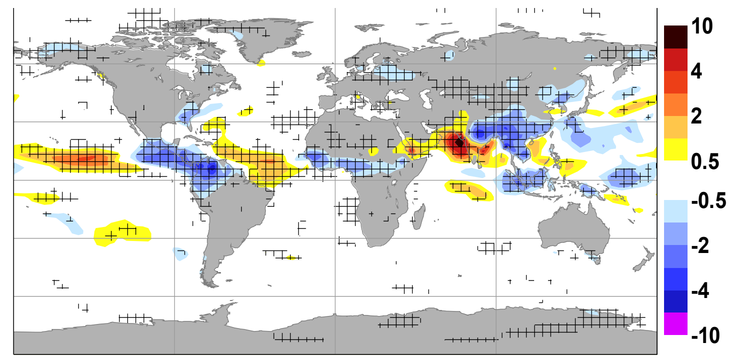
33R1(old vdiff)-33R1



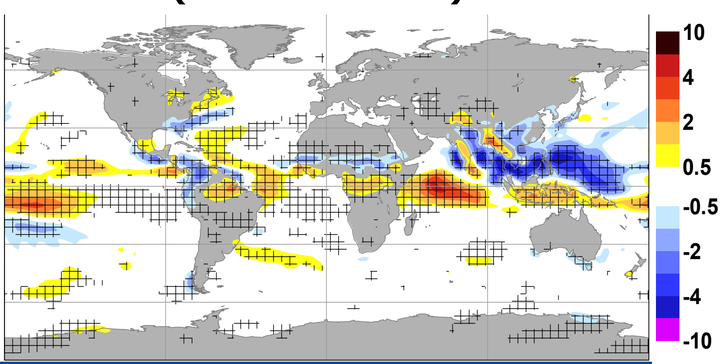
33R1-GPCP



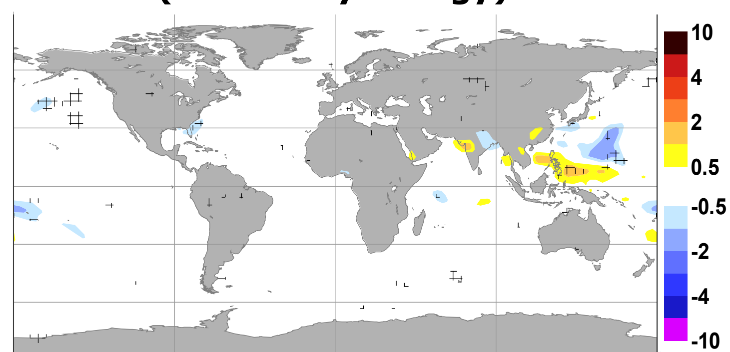
33R1(old radiation)-33R1



33R1(old convection)-33R1



33R1(old soil hydrology)-33R1



The General Circulation and Equilibria

- 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 => $w \sim -.5$ cm/s

The same happens in our regions on a fair weather day (anticyclone)

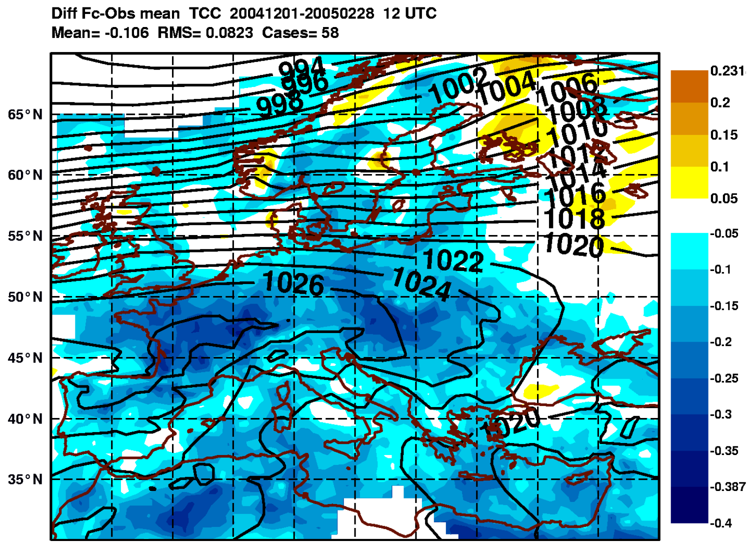
But what happens on a perturbed day, e.g. with thunderstorms?

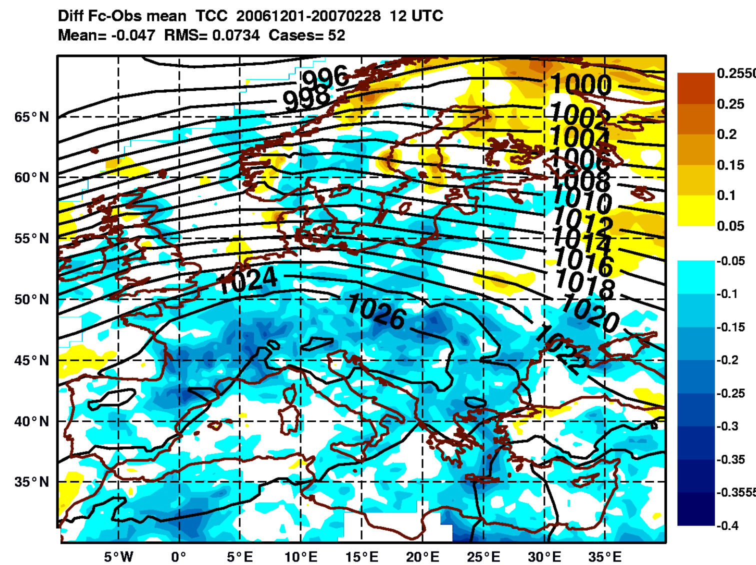
- When precipitation takes place, heating rates are strong; e.g. 100 mm/day precip ~ energy flux of 2900 W/m2 or an average 30 K/day heating of the atmospheric column => $w \sim 8.6$ cm/s. However, this positive mean motion is composed of strong ascent of order $w \sim 1$ m/s in the Cumulus updrafts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

- Daily weather forecasting is much more difficult in Tropics than in middle latitudes (small Coriolis force = large radius of influence of a perturbation), but on the monthly and seasonal scale there is much more skill in the tropics

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

DJF 2004/5
58 cases



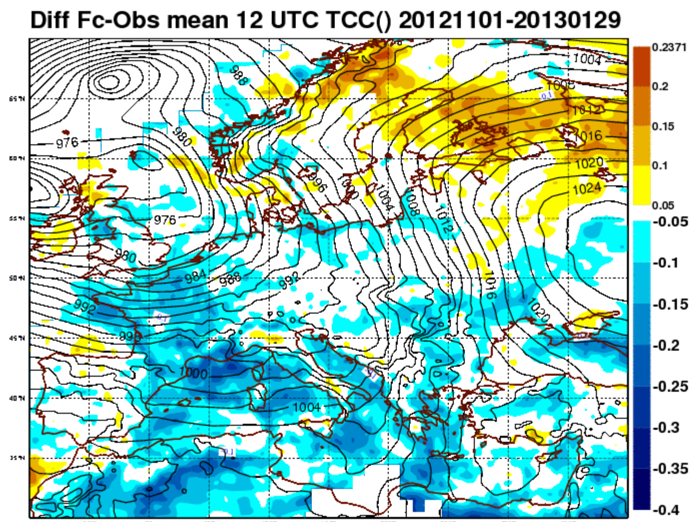


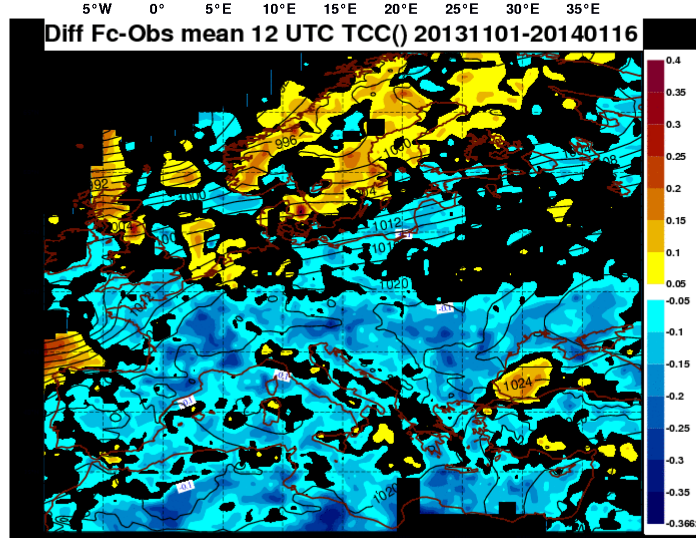
DJF 2006/7
52 cases

EDMF PBL
M-O diffusion

NEW MICROPHY

NDJ 2012/



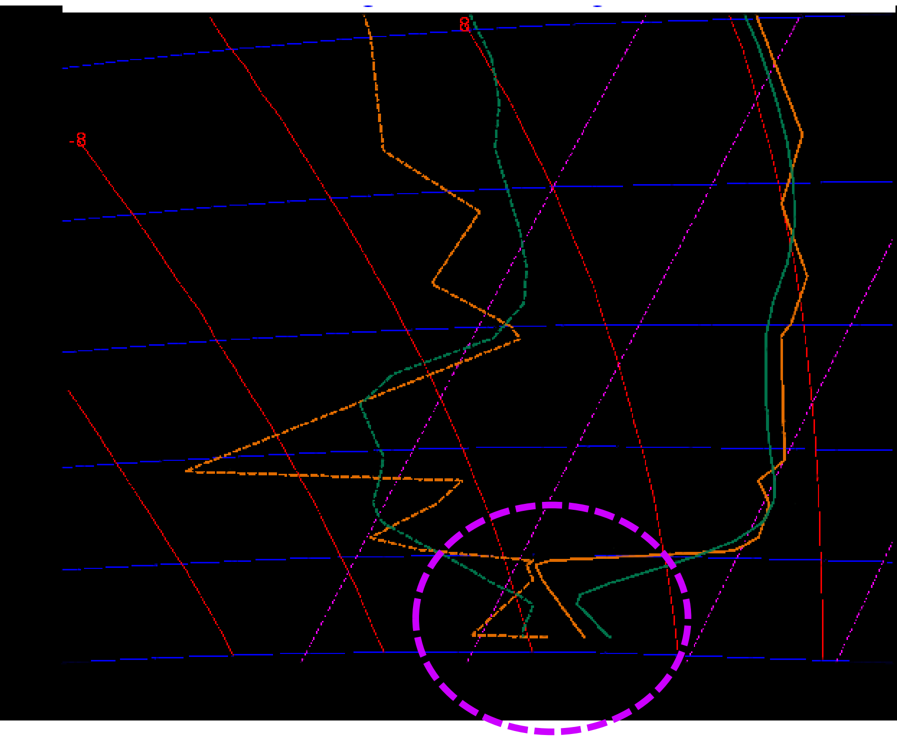


NDJ 2013/14

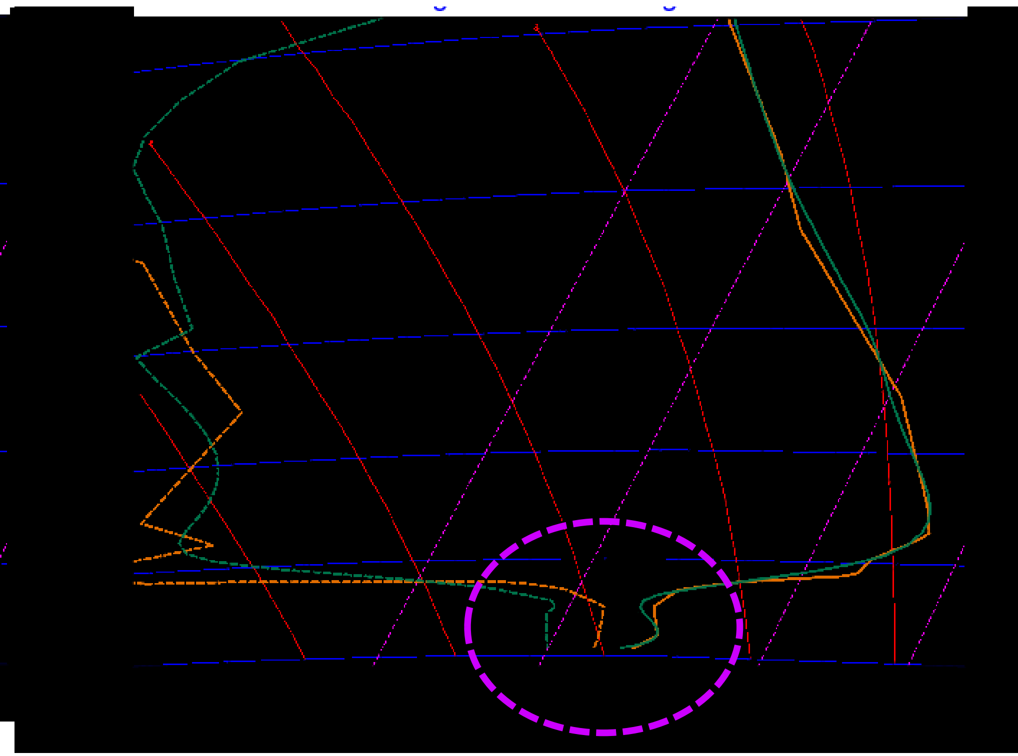
Sc and inversion strength: examples of variable success

Obs Fc

Stuttgart 16 Nov 2011 t+12



Stuttgart 2 Dec 2013 t+24



ECMWF

Product: Forecasted ("synthetic") satellite images

How are they produced ?

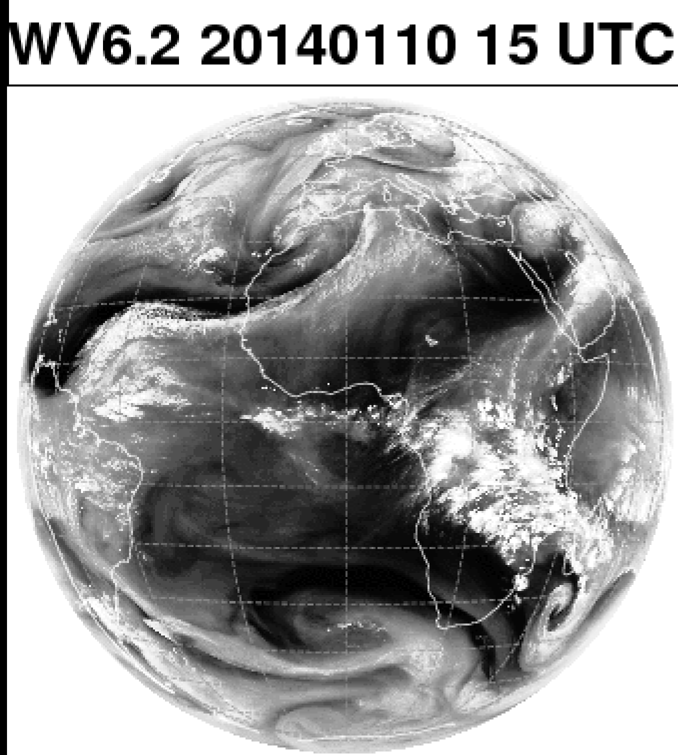
They are generated with the aid of a radiative transfer model (RTTOVS=Radiative Transfer Model for TOVS, ATOVS, and several other atmospheric sounders).

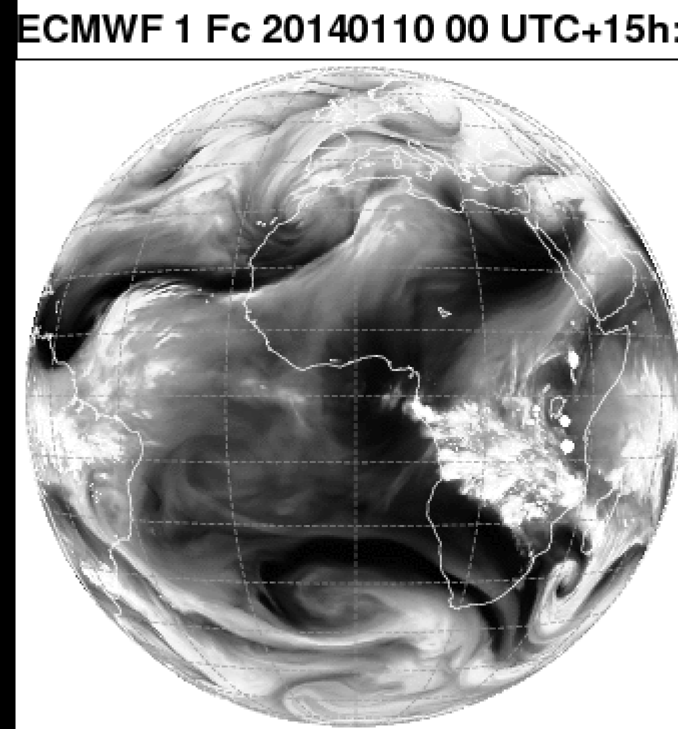
The radiative transfer model produces the radiation a satellite would see given the forecasted model atmosphere (the radiation therefore depends on the pressure, temperature and cloud condensate produced by the forecast, and is very sensitive to the cloud top height and cloud optical thickness).

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





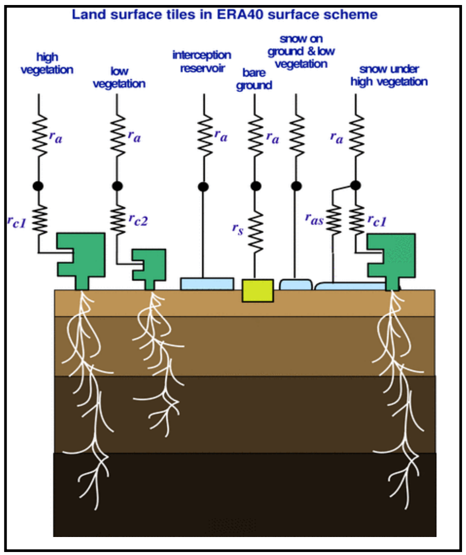
[redacted]

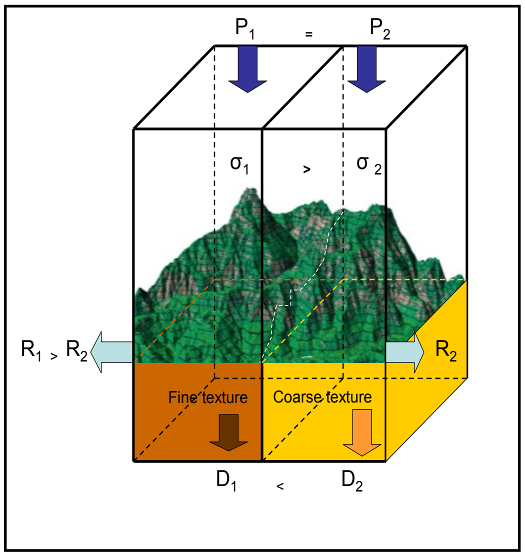
Midlatitude cloud systems are well represented, (tropical) convection is more difficult, but best we ever had (see later)

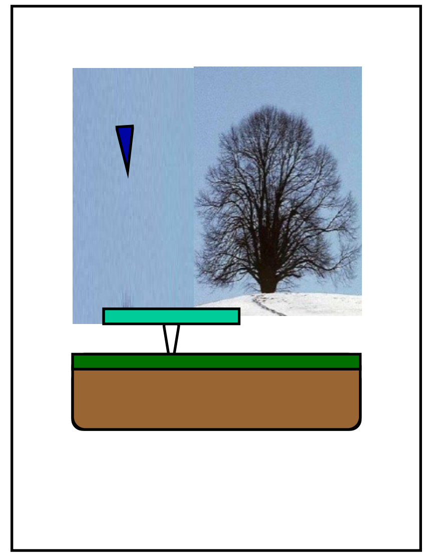
Land surface model evolution

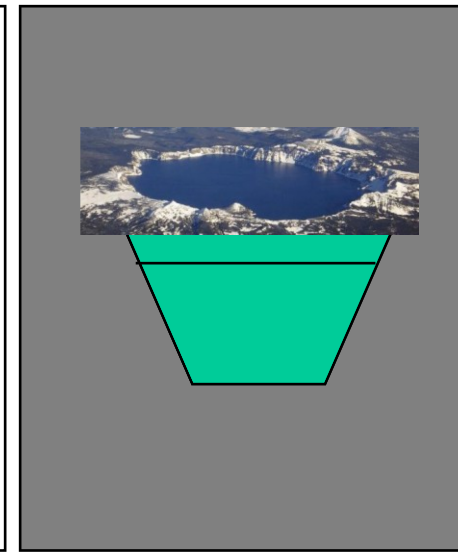
2000/06	2007/11	2009/03	2009 & 2010	2014

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





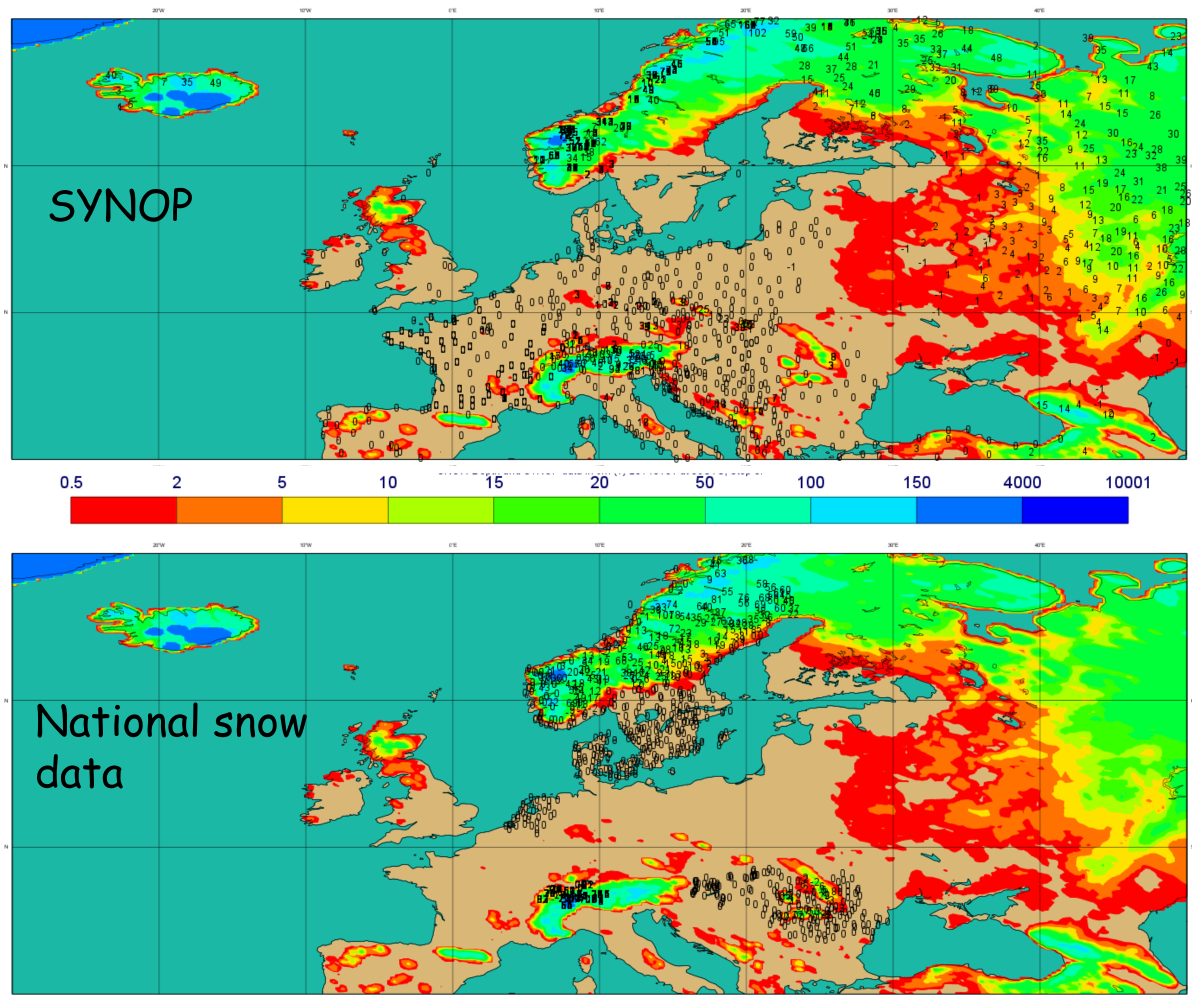




ECMWF

Snow analysis SYNOP and National Network data

2014 01 01 at 06UTC



Additional data from national networks from 7 countries:

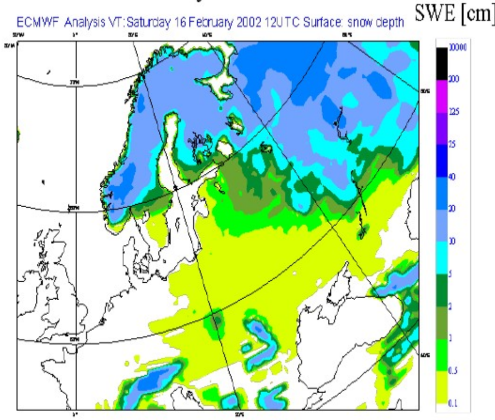
Sweden (>300), Romania(78), The Netherlands (33), Denmark (43), Hungary (61), Norway (183), Switzerland (332).

→ Dedicated BUFR

Snow analysis uses Synop and Satellite Obs

MODIS 16/02/2002

Analysis based on SYNOP



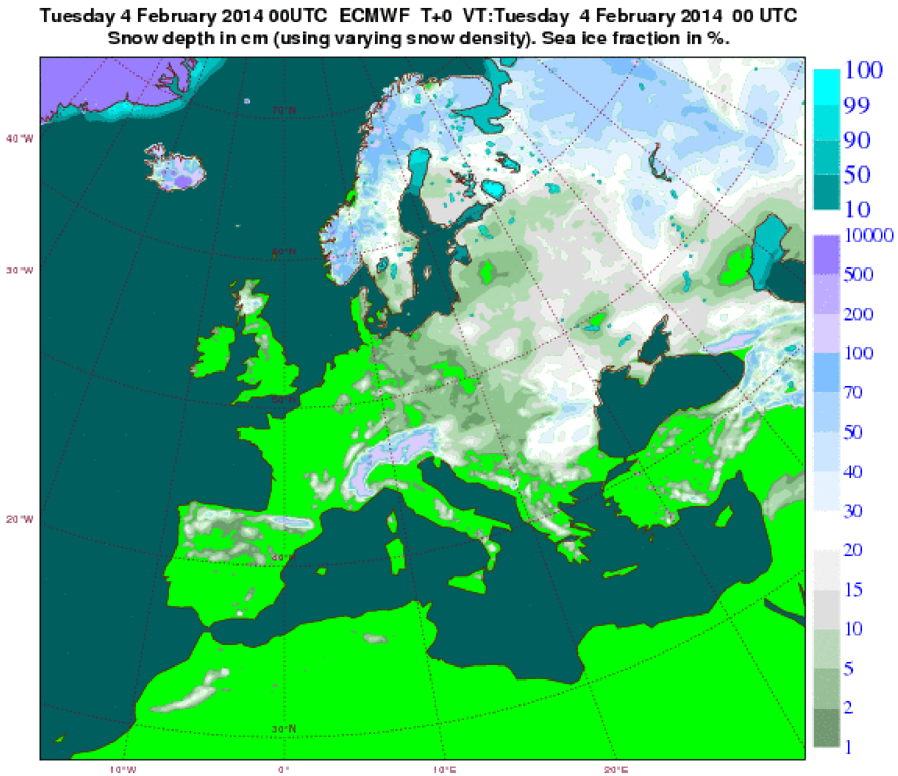
Snow extent is overestimated in the analysis when it is based on SYNOP data only

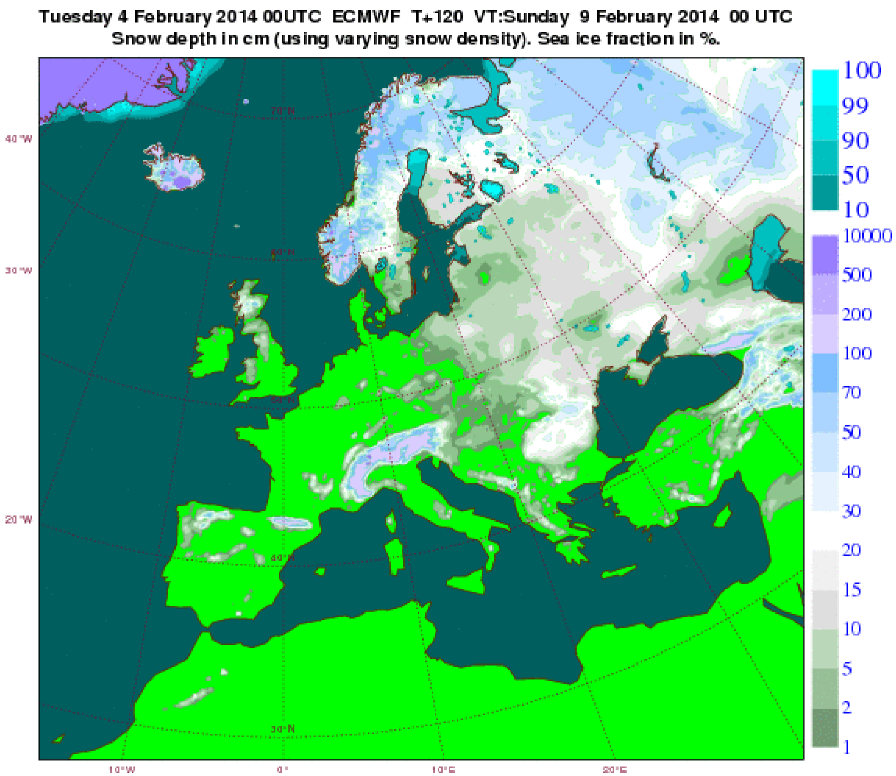
However, satellite only gives snow cover!
And the big change this year was the way satellite data is used, i.e it is assimilated with large observation error, also if FG =no snow, Sat=snow => Sat snow=5 cm

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

Archived prognostic snow related quantities

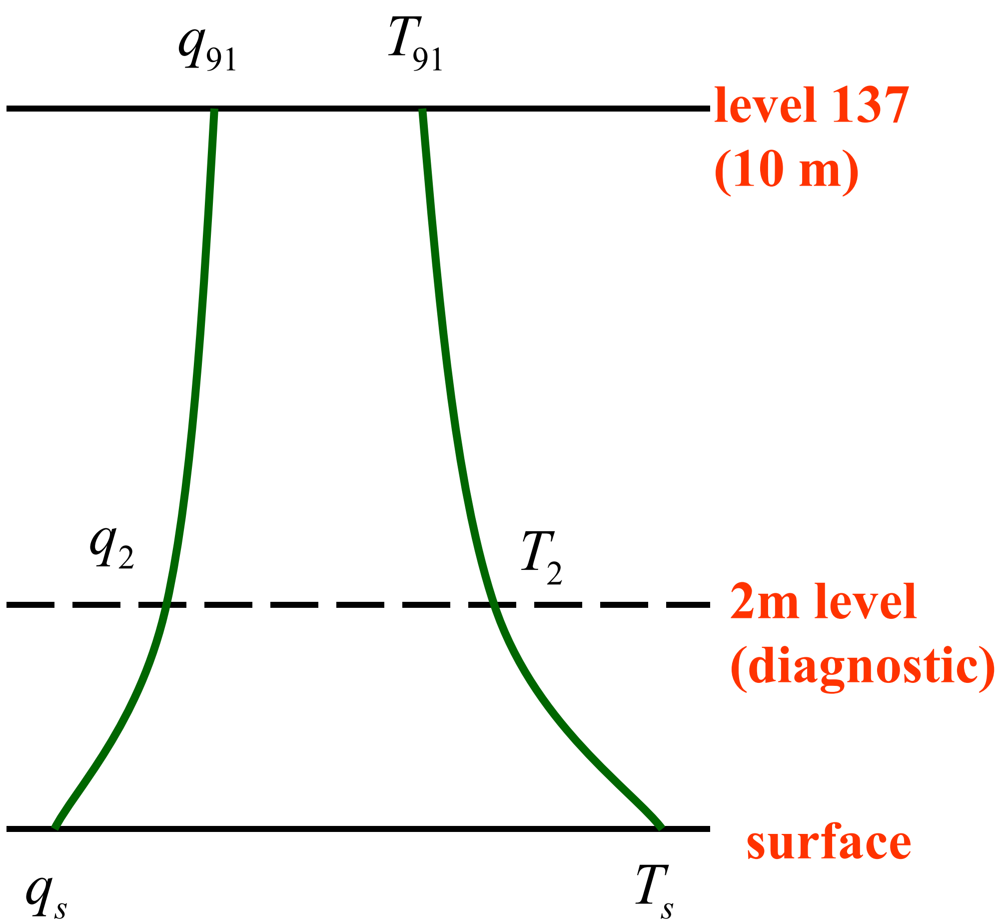
- Snow depth (water equivalent), Sd => actual depth=Sd*(Rl=1000)/Rsn
- Snow density (typically factor 10 lower than water-> 1 mm precip~1 cm snow), Rsn
- Snow temperature, Tsn
- Snow albedo, Asn





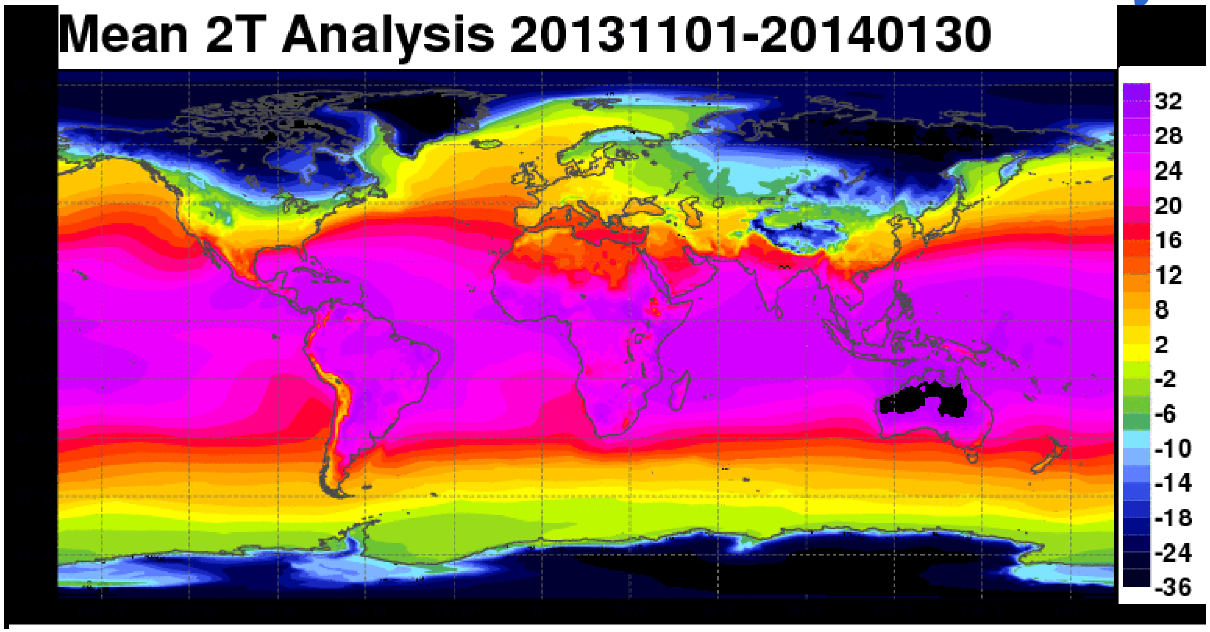
http://www.ecmwf.int/products/forecasts/d/charts/medium/analysis/

T and q interpolation to the 2m level

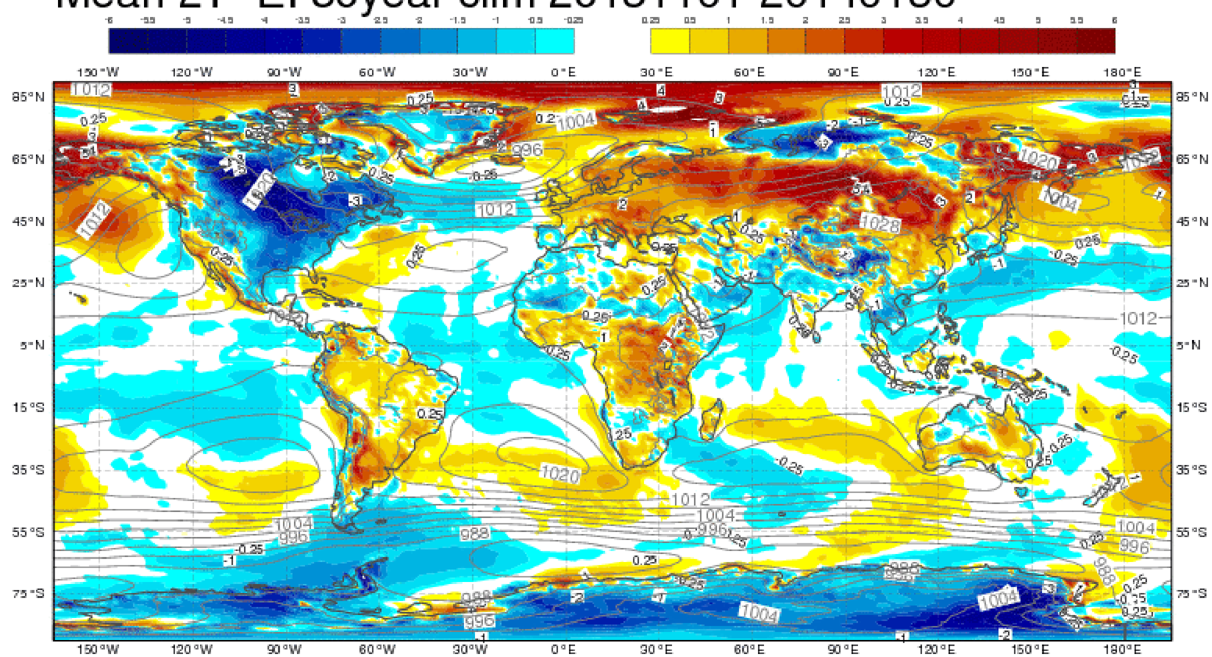


- q_s and T_s are determined by the land surface scheme or by SST.
- Main purpose of land surface scheme is to provide correct area averaged fluxes of heat and moisture.
- Land surface scheme considers different sub-areas (tiles) but effect on screen level variables is not accounted for yet.

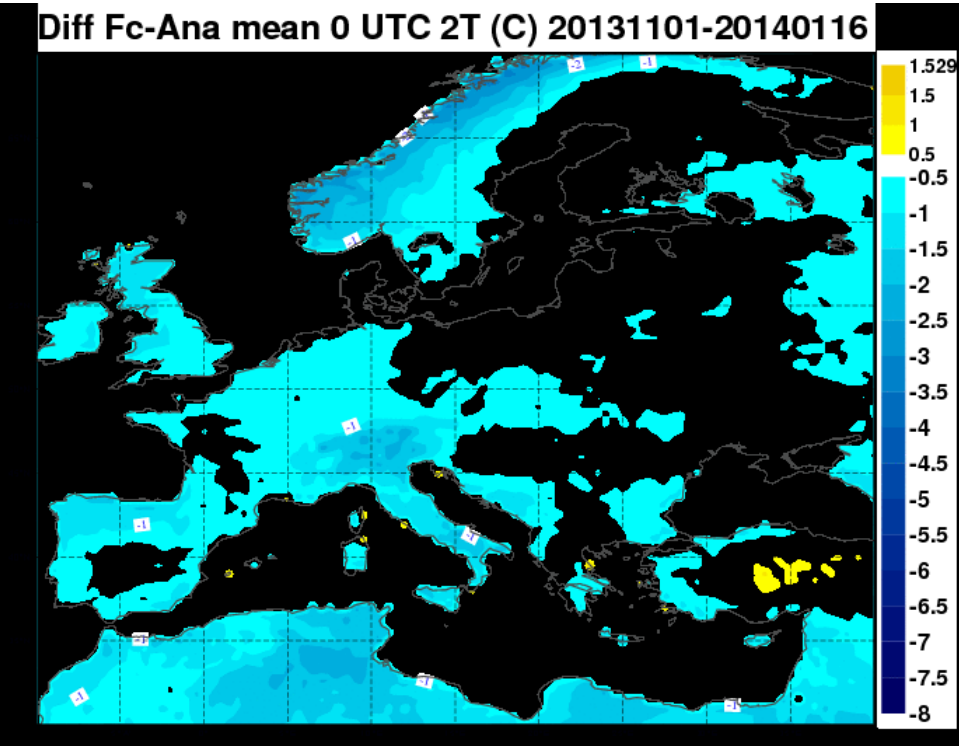
This winter mean and clim anomaly

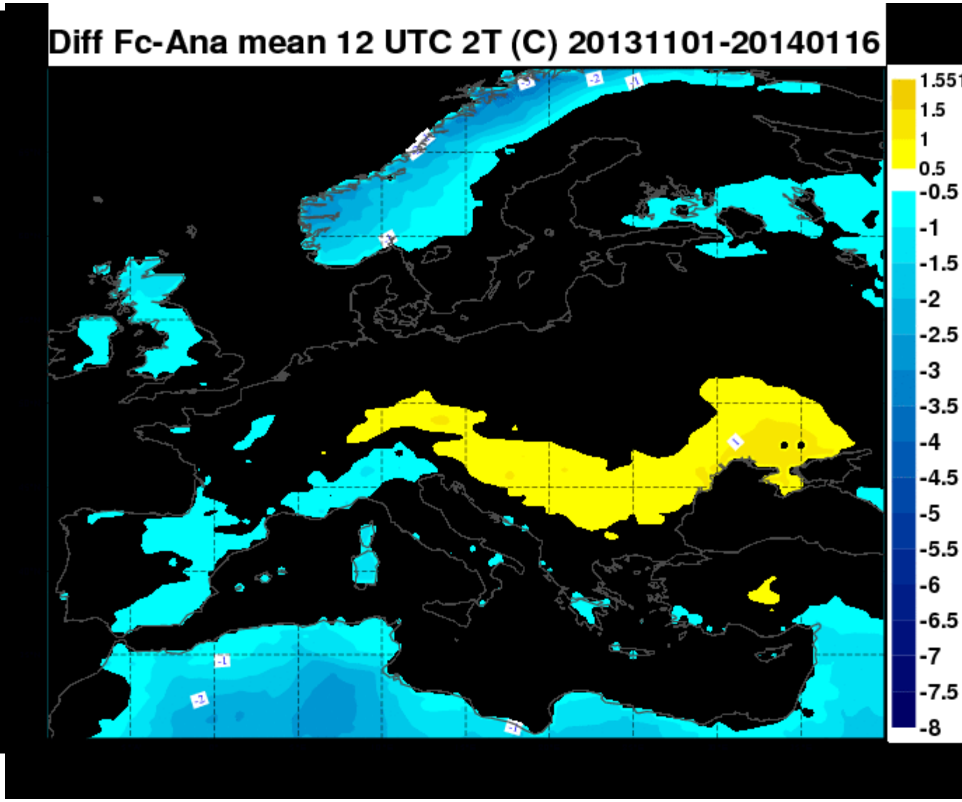


Mean 2T- EI 30year clim 20131101-20140130



T2m mean and errors (K) Nov 2013- Jan 2014 00 & 12 UTC

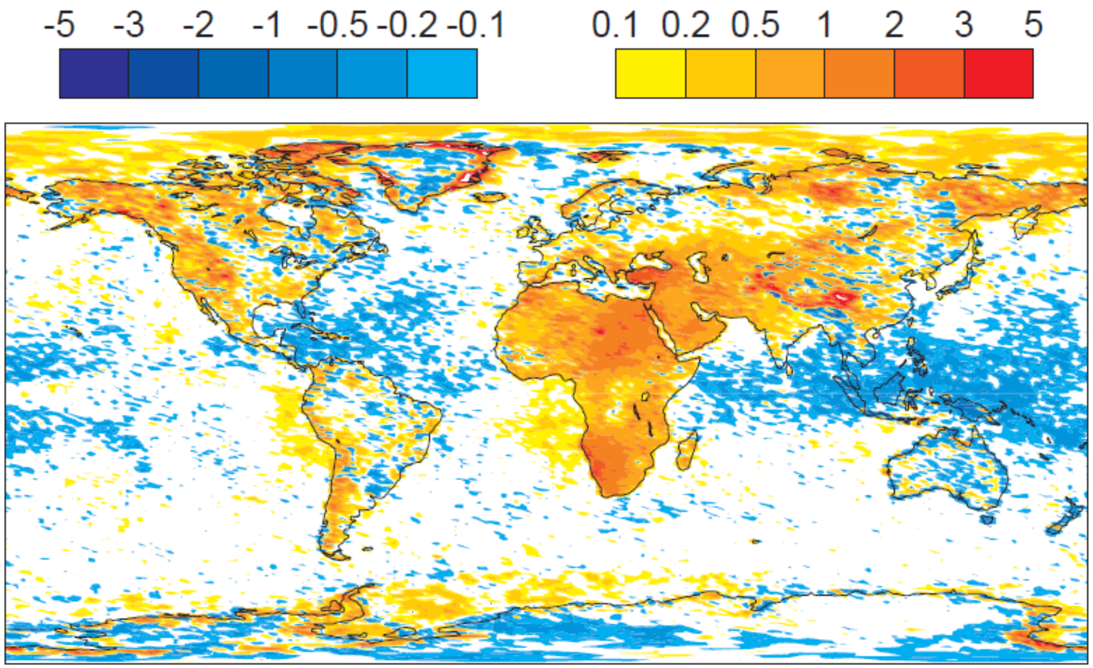




land mask applied

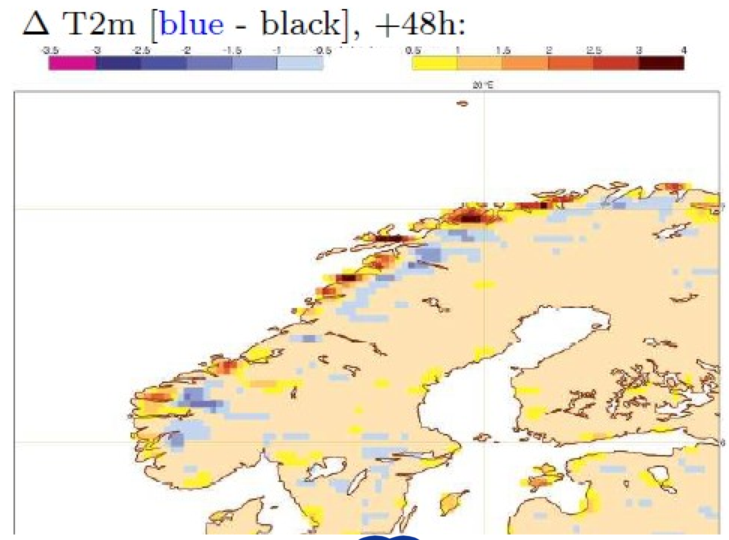
Nighttime/morning T2m difference between HRES and CF of ENS

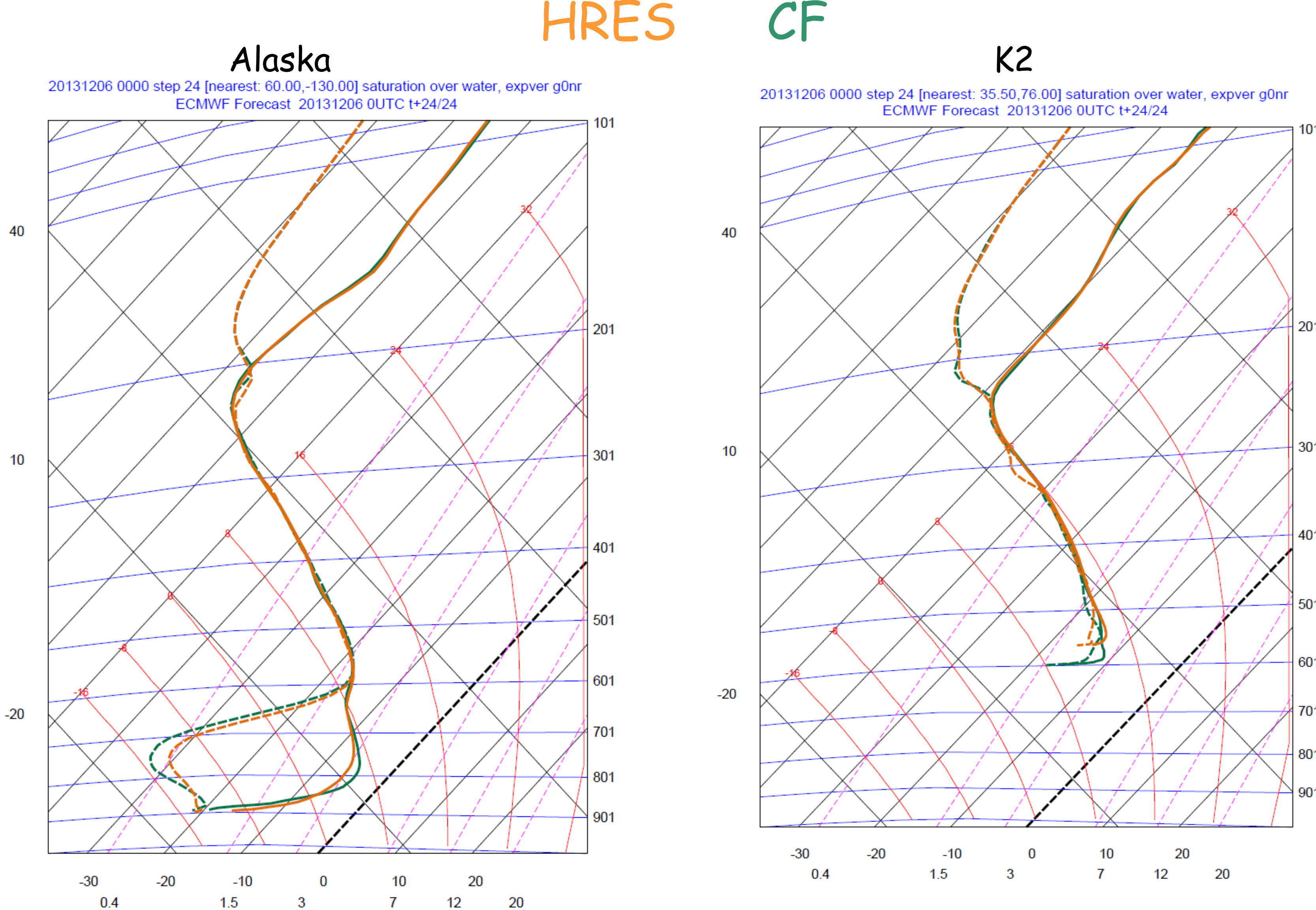
HRES-CF,
1.11-12.11,
step 30 (6utc)



This problem concerns nearly only the near surface =first model level

Two main reasons: difference in **radiation** timestep (1h vs 3h), radiation grid –coastline effect, and **orography**, but not what one might think=difference in mountain height but difference in shear





The profiles are similar, but the cooling at the surface is weaker at high resolution. Possible causes: smoother subgrid orography, but also more wind shear at HRES, so smaller Richardson numbers, more mixing , less cooling near the surface…

ECMWF

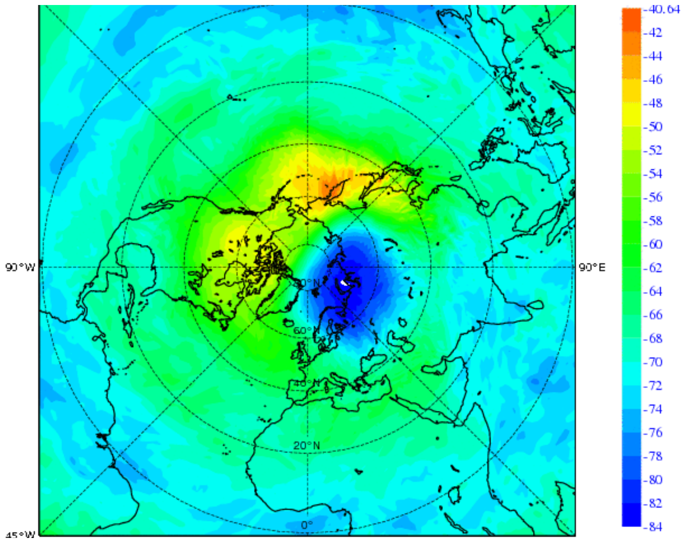
Summary of wintertime 2m T errors

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

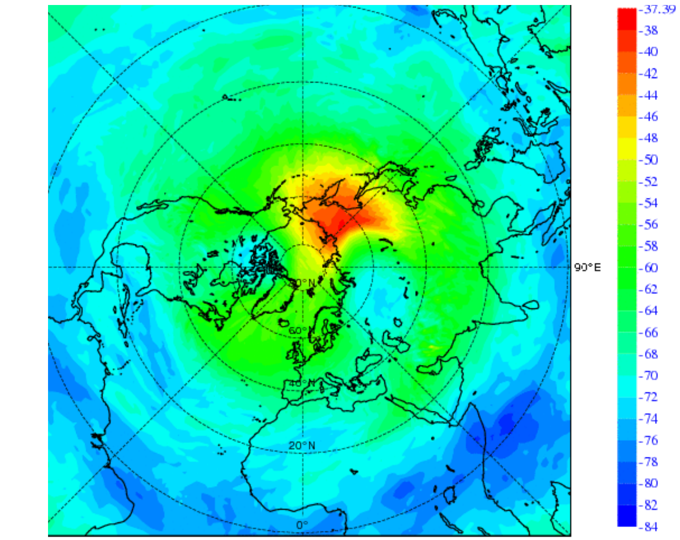
- Too low, particular night-time problem
- Stable boundary-layer (mixing)
- daytime overestimation related to underestimation of LCC
- otherwise cold bias easily enhanced over snow (if wrongly analysed/forecasted - not melting quickly enough)

The winter Temperatures and the polar stratospheric Vortex Example of Sudden Stratospheric warming with wind reversal

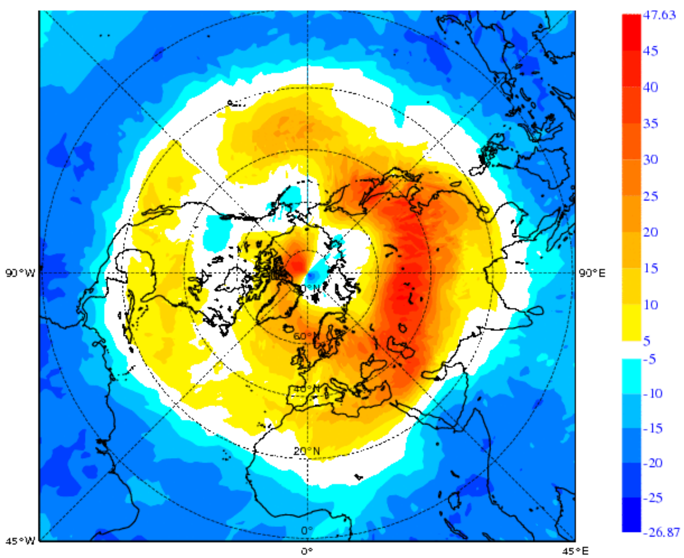
31.12.2012 T 50 hPa



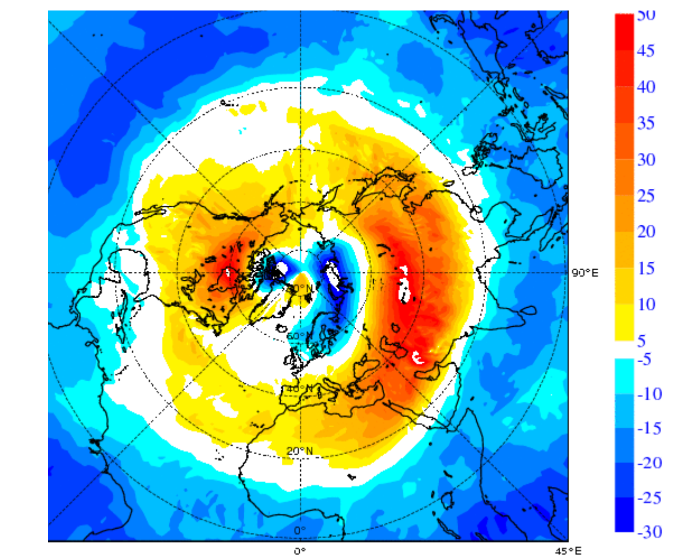
11.1.2013 T 50 hPa



31.12.2012 U 50 hPa

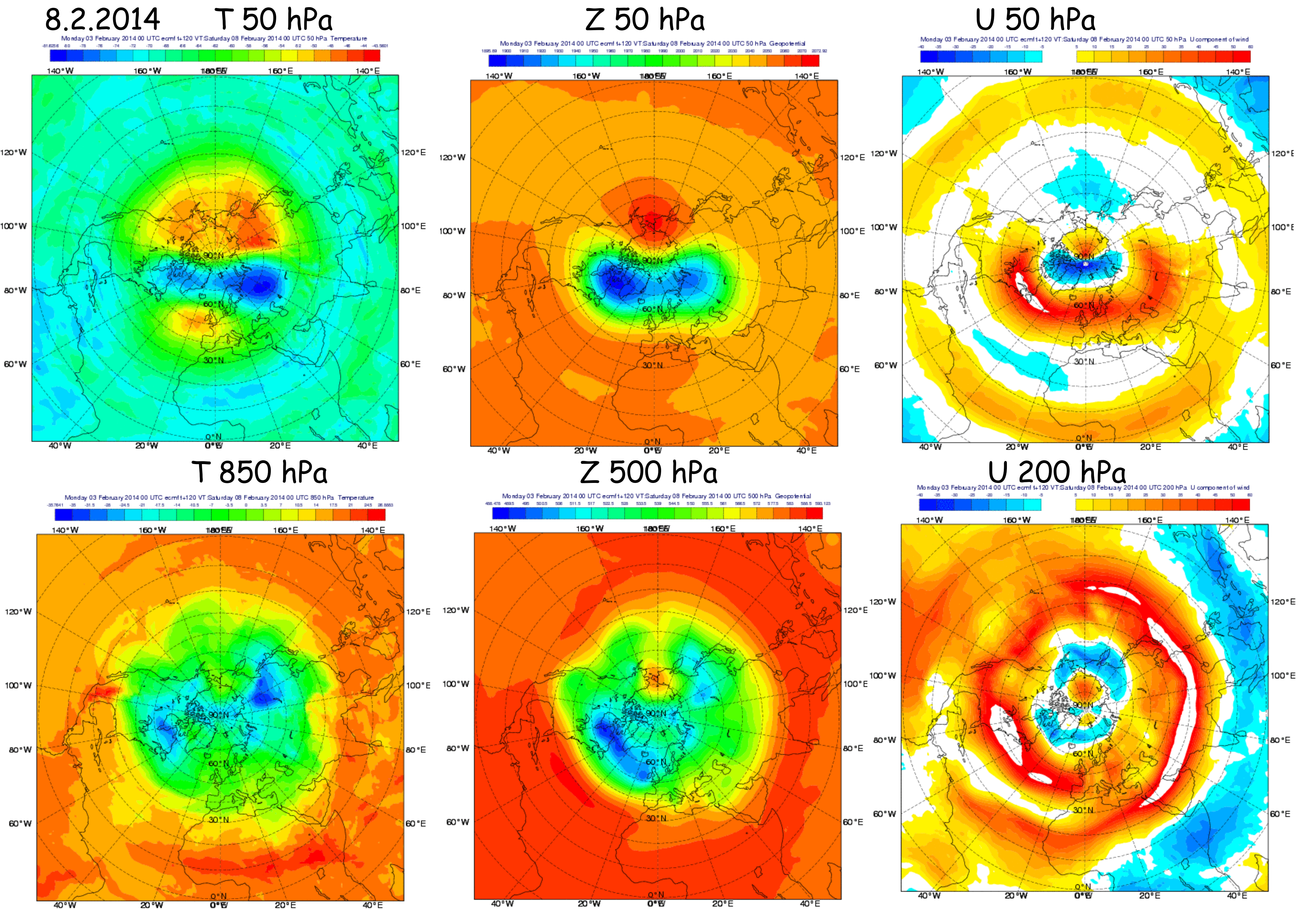


11.1.2013 U 50 hPa

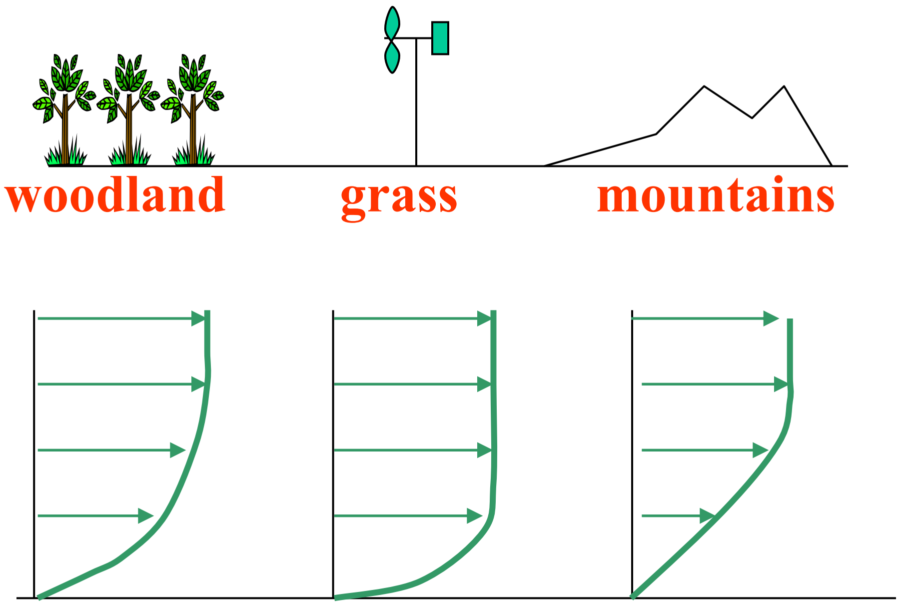


The stratospheric warming precedes the low-level, 850hPa cooling by 5-10 days

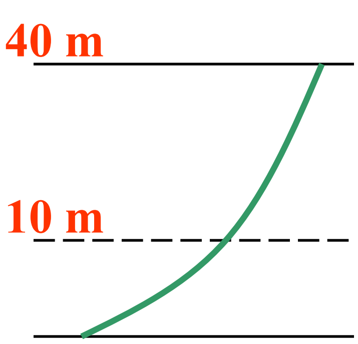
This winter Temperatures and the polar stratospheric Vortex



10 m wind



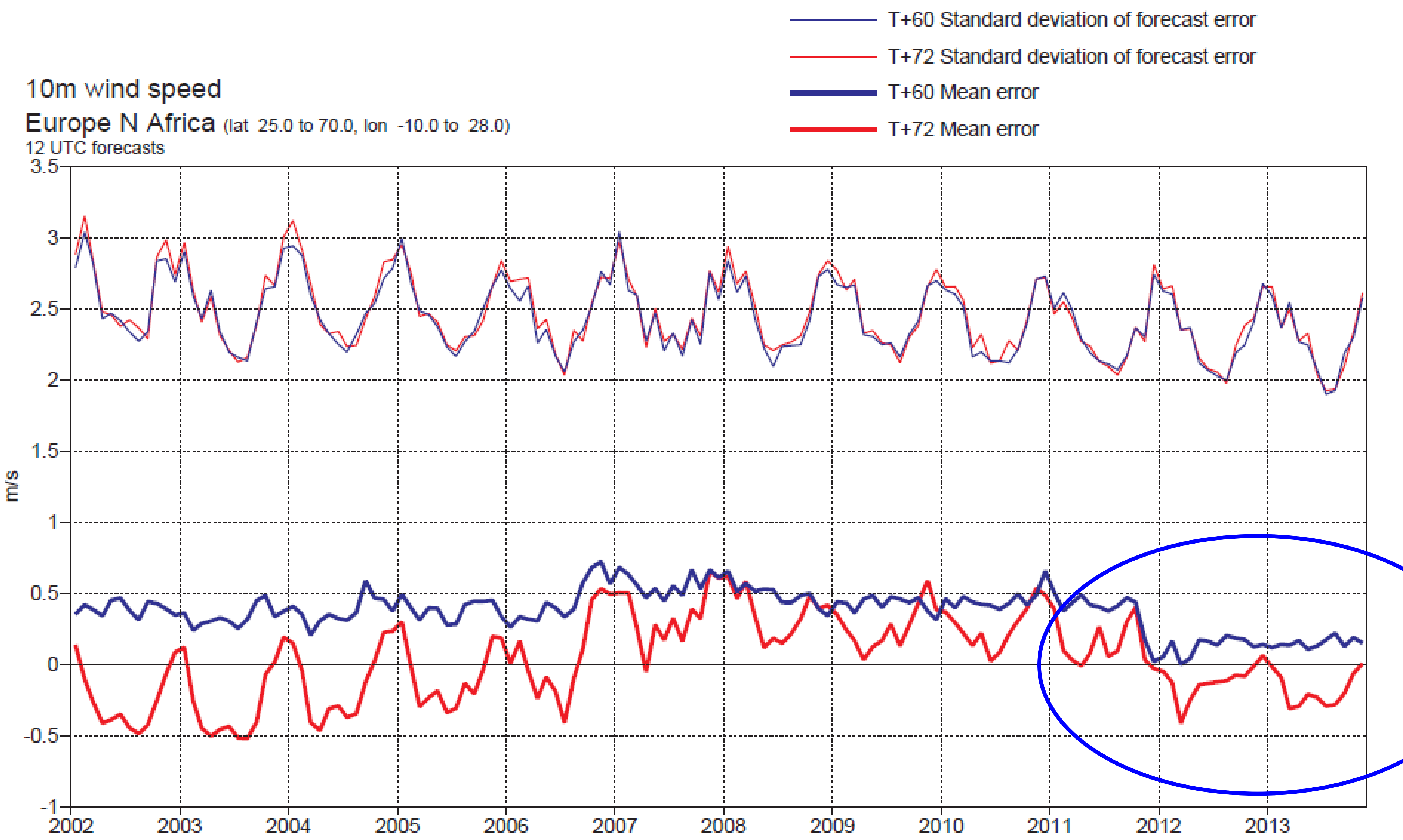
- Local wind depends strongly on local exposure.
- ECMWF model has roughness length parametrisation to obtain realistic "area averaged" surface drag.
- Resulting wind is low over land because rough elements dominate.



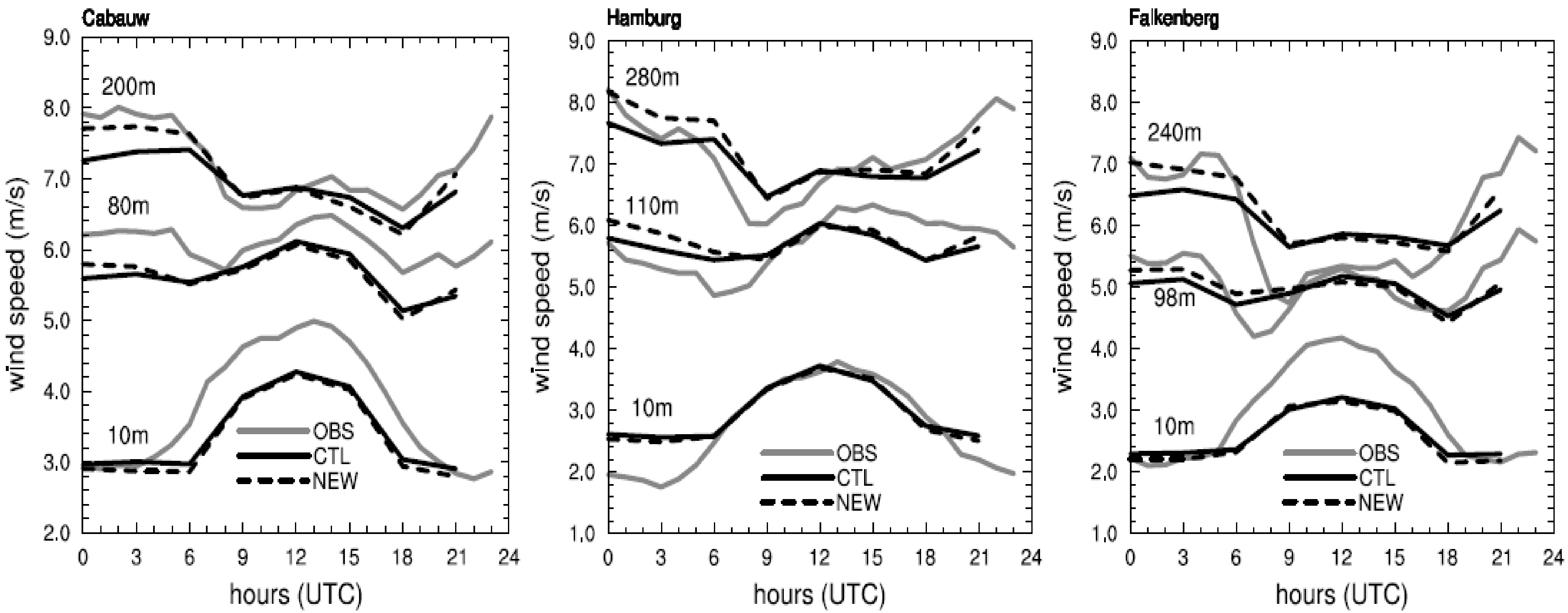
Post-processing of wind at 10 m

- 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).

37r3: Changes to the roughness length table (nov 2011)



Diurnal cycle of winds:
Changes to the turbulence closure in stable conditions (Nov 2013)



Improvement of mean wind speed at low level jet height (100-200m), compared with tower observations

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.

ECMWF

Wind Gusts in the IFS

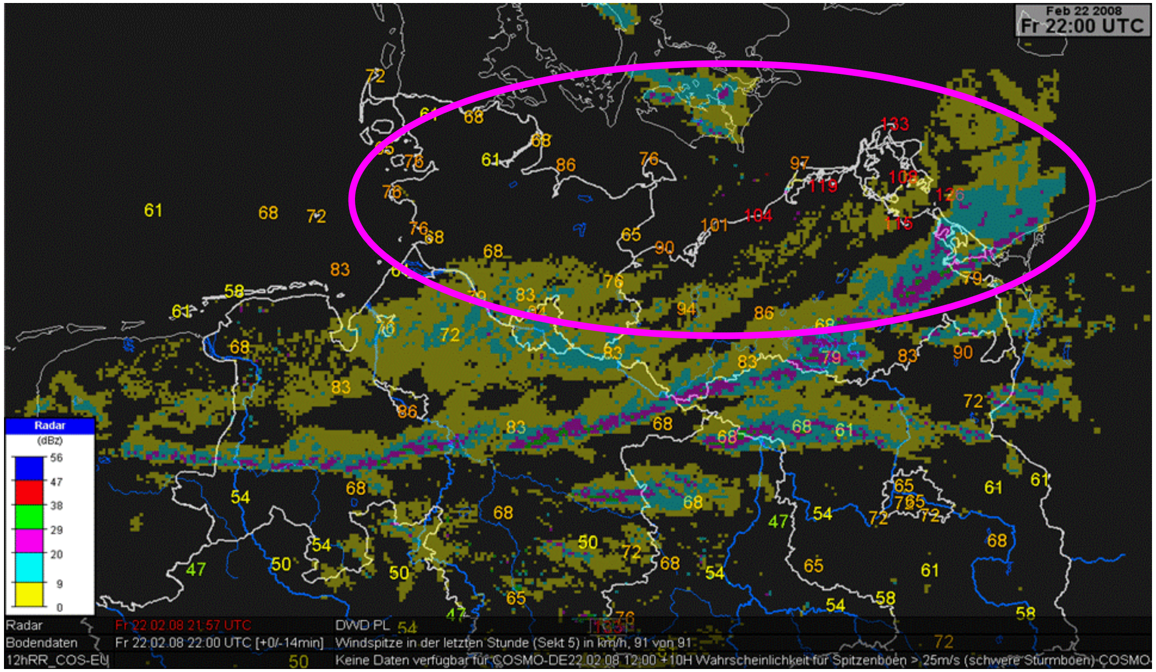
Gusts are computed by adding a turbulence component and a convective component to the mean wind:

$$U_{gust} = \quad + \quad + \underbrace{\quad - \quad}_{deep\ \ convection}$$

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.

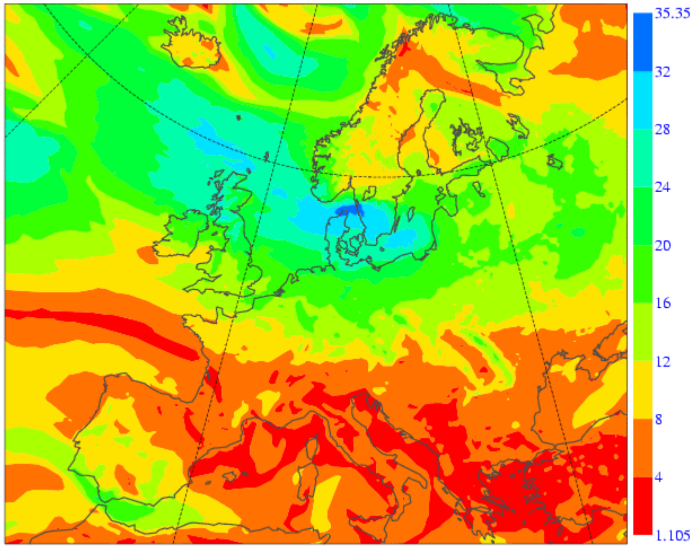
Convective Gusts



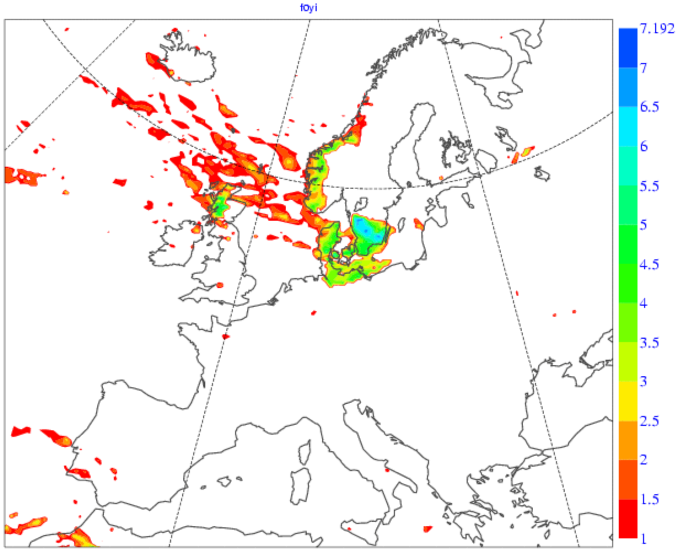
Motivation: report about gust front by DWD

22 February 2008

Oper



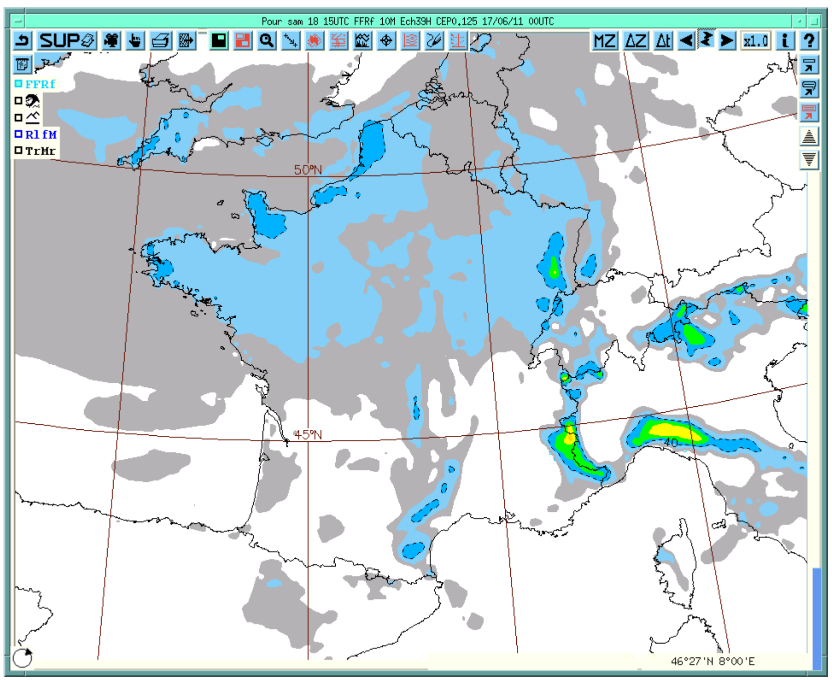
Conv



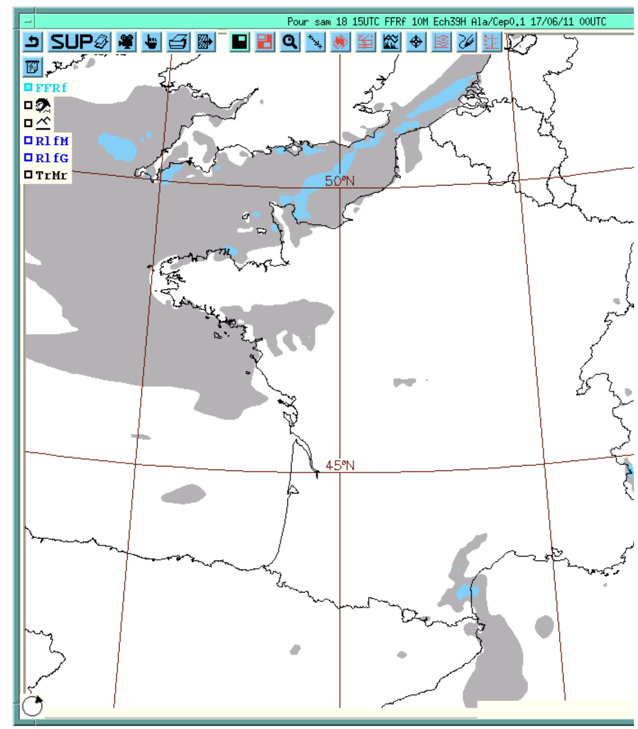
Wind gusts 18 June 2011

- 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

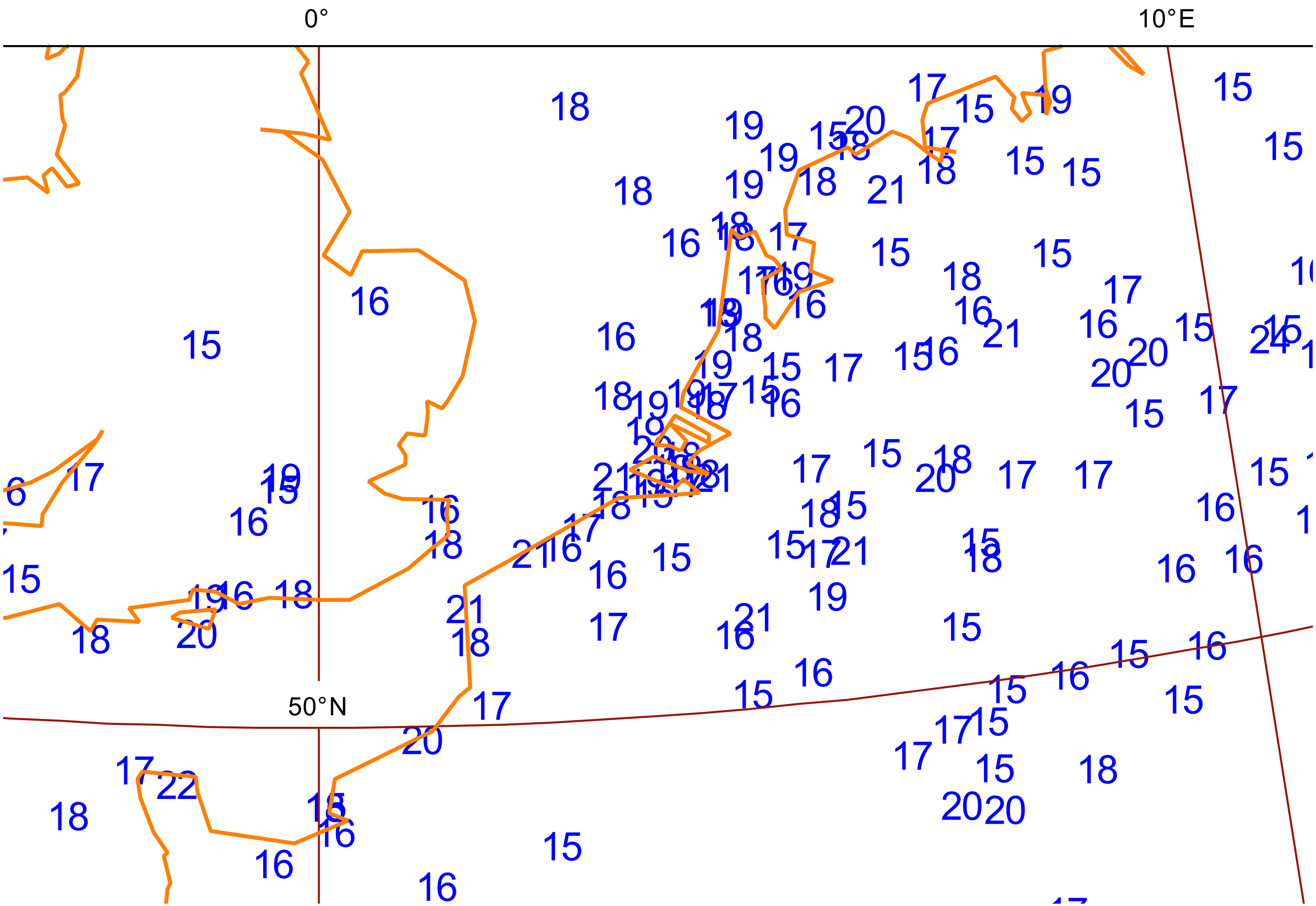
ECMWF



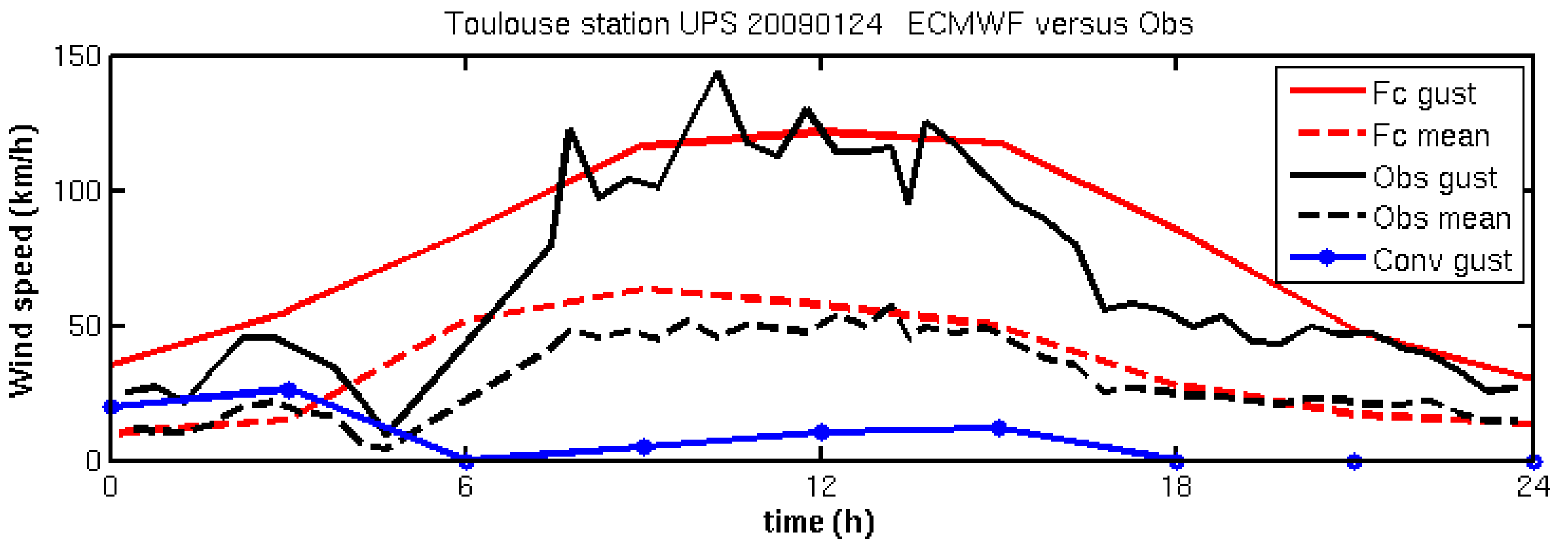
Aladin



Wind gusts 18 June 2011



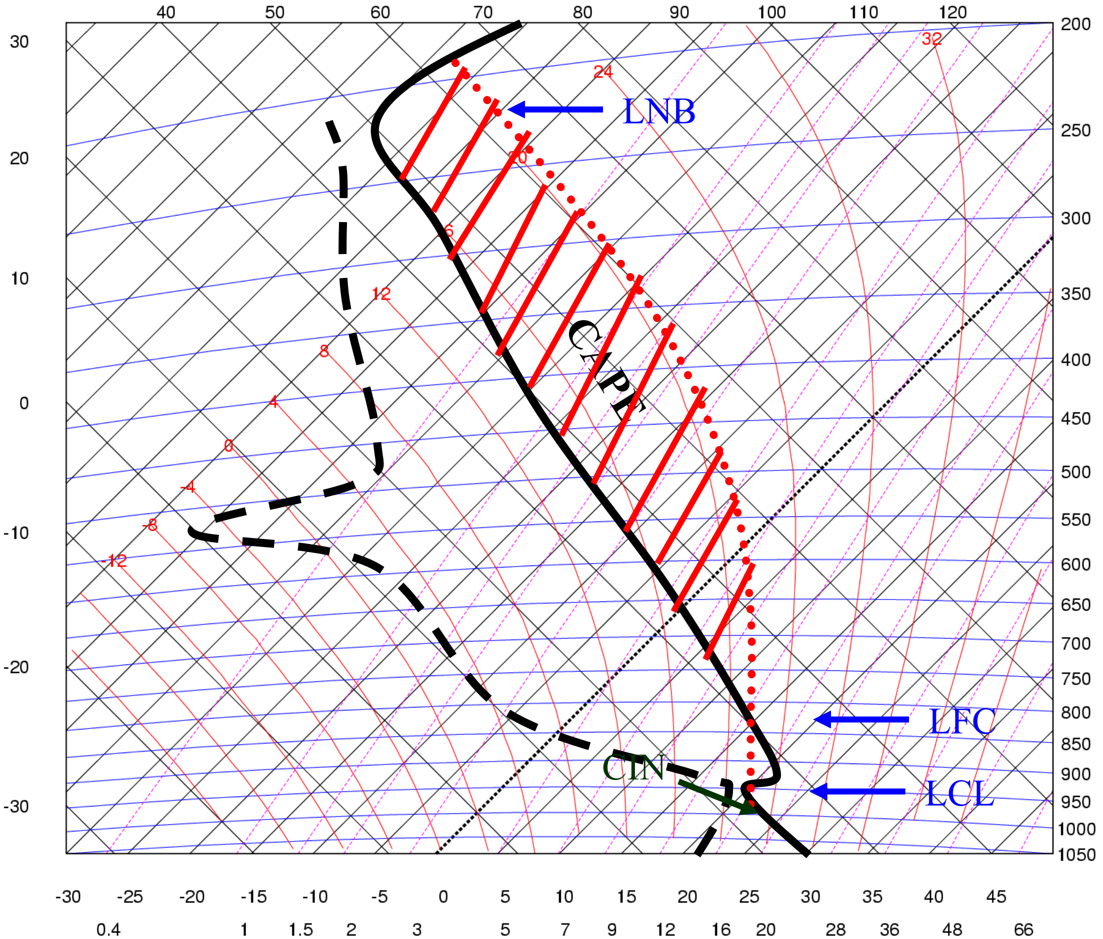
Wind gusts
Time series against anemometer 24 January 2009 (storm Klaus)



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

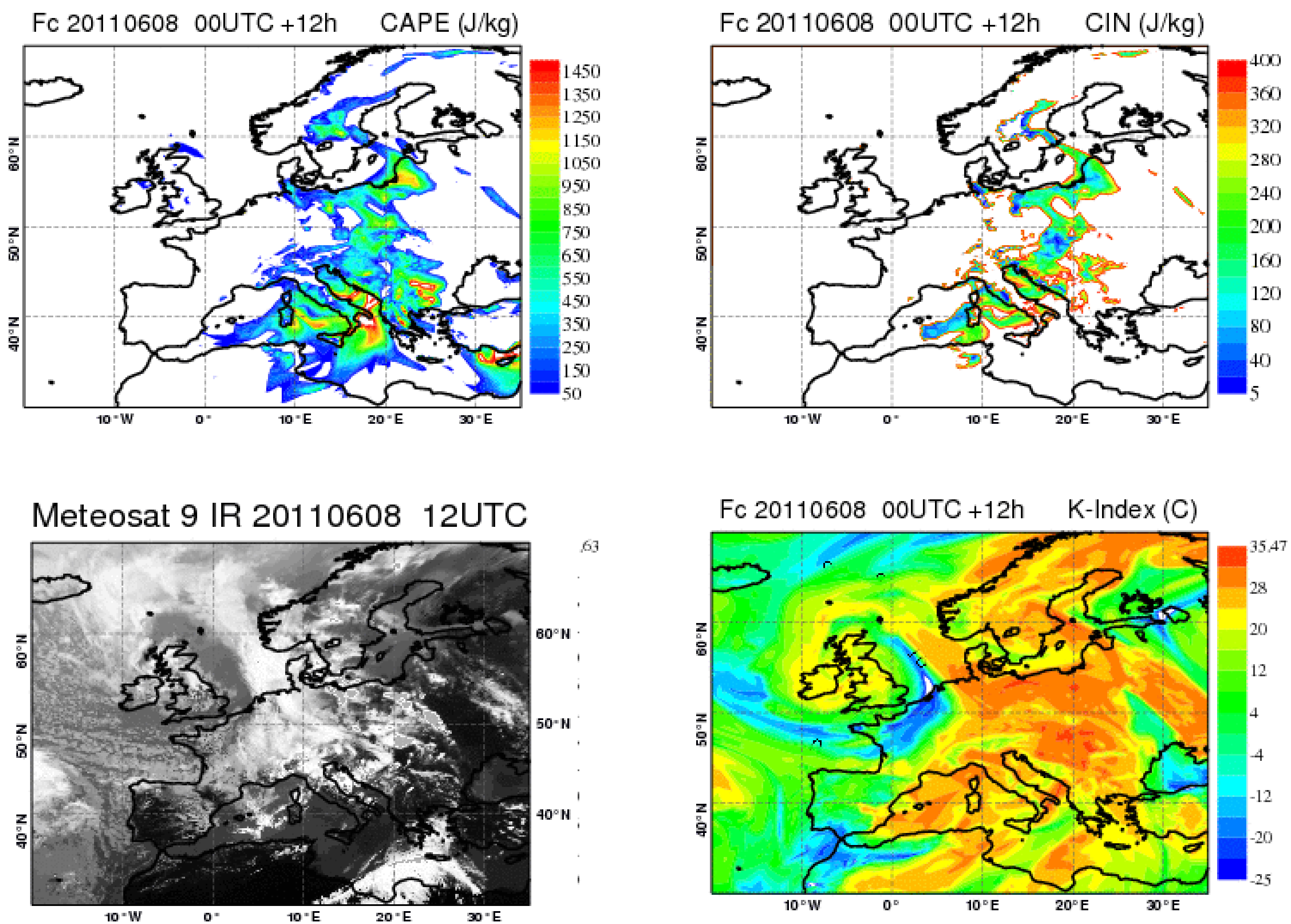
$$\frac{dw}{dt} = w\frac{dw}{dz} = \frac{1}{2}\frac{dw^2}{dz} \approx g\frac{T'}{\overline{T}}$$

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

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)

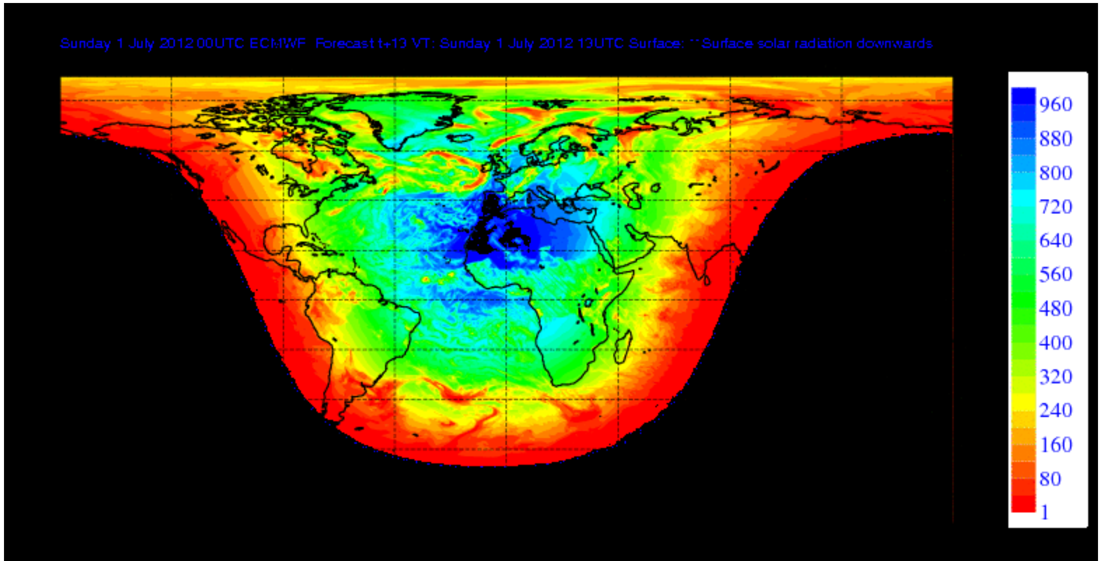
Convective Indices
as requested by Member States (User Meeting June 2011)



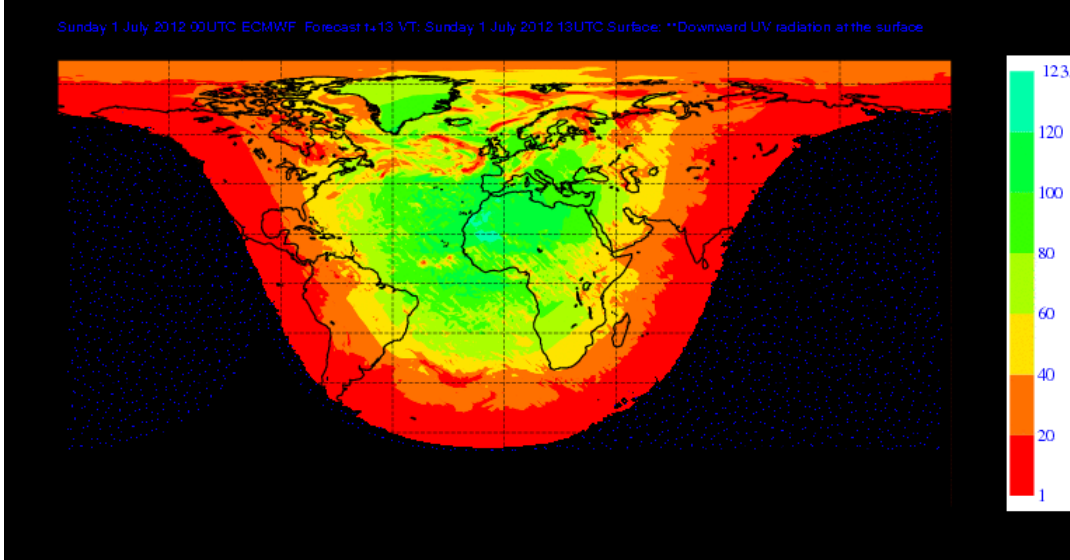
ECMWF

Surface incoming solar radiation and UV (W/m2)

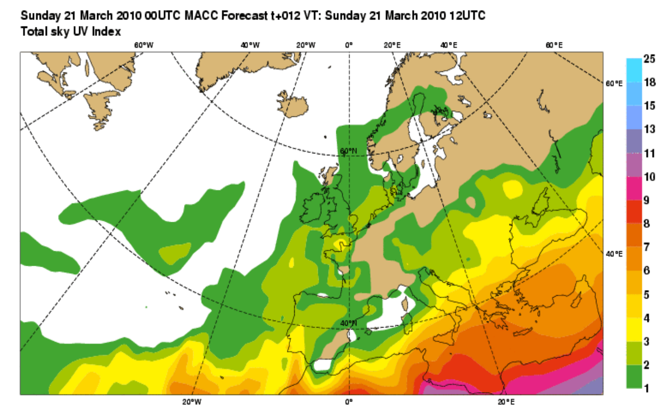
SSRD



UV

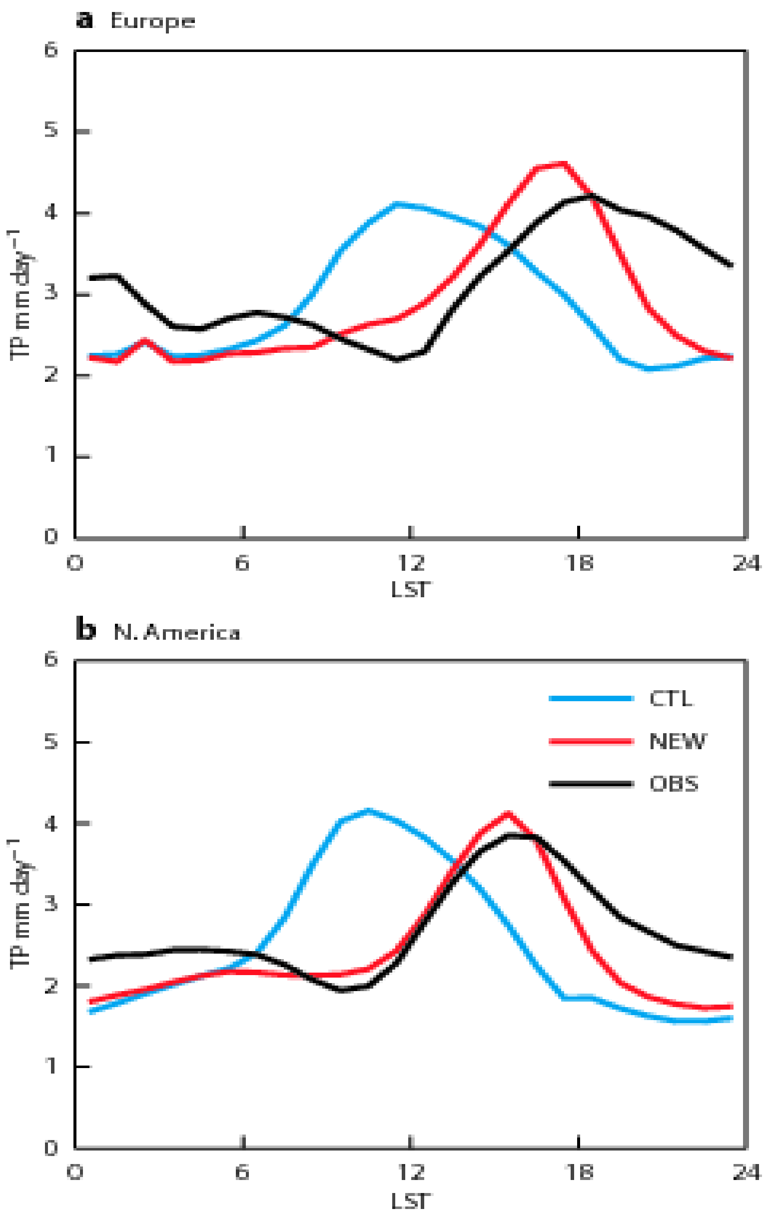


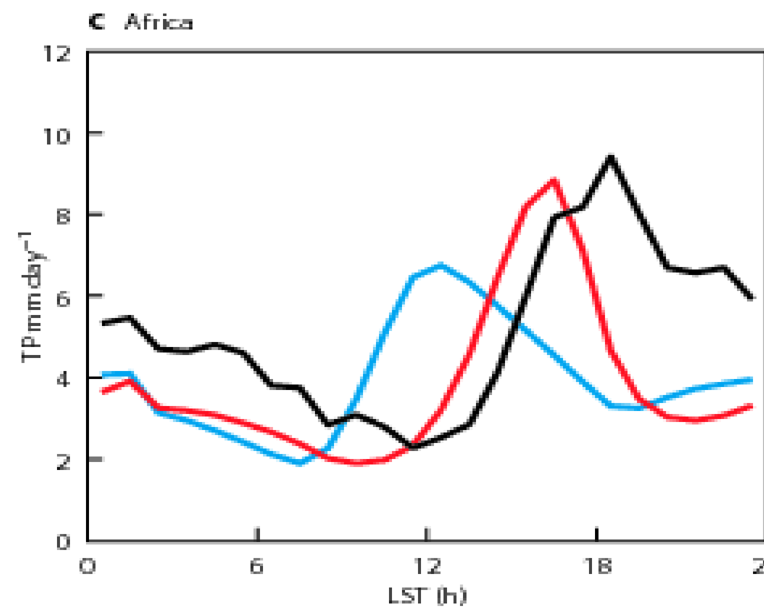
for UV Index see
http://www.gmes-atmosphere.eu



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

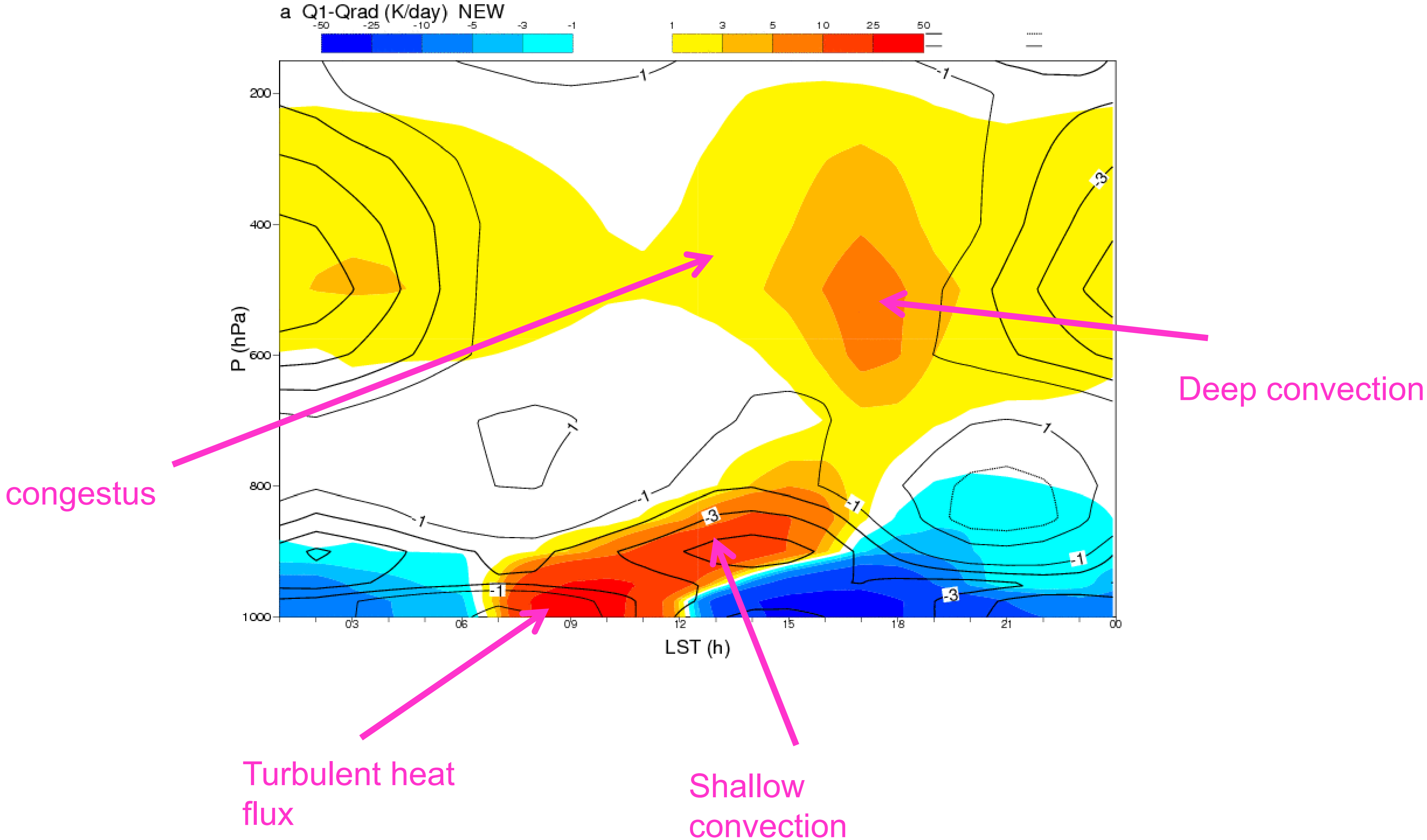
JJA 2011-2012 against Radar



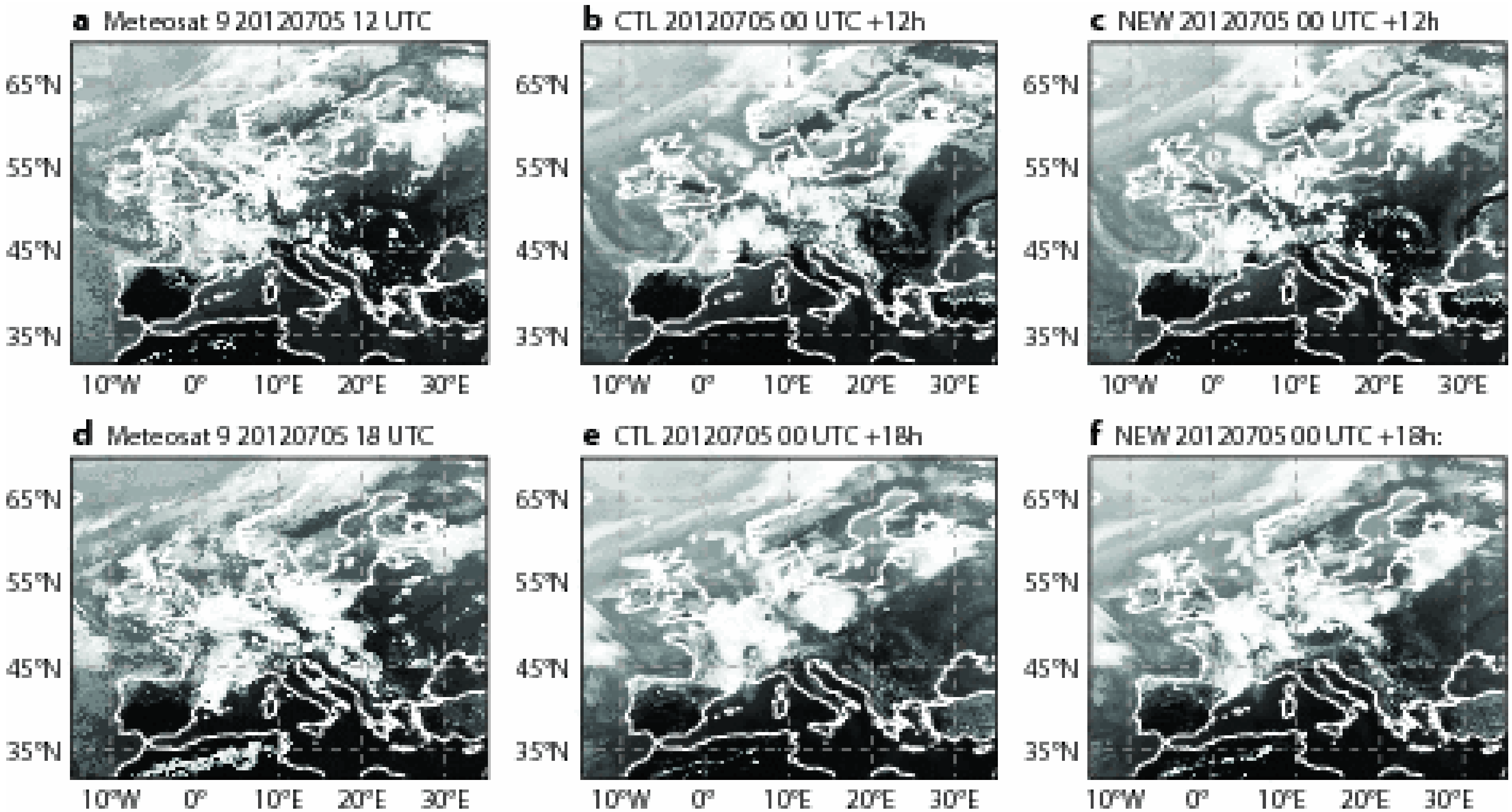


See ECMWF Newsletter No 136 Summer 2013
Bechtold et al., 2014, J. Atmos. Sci.

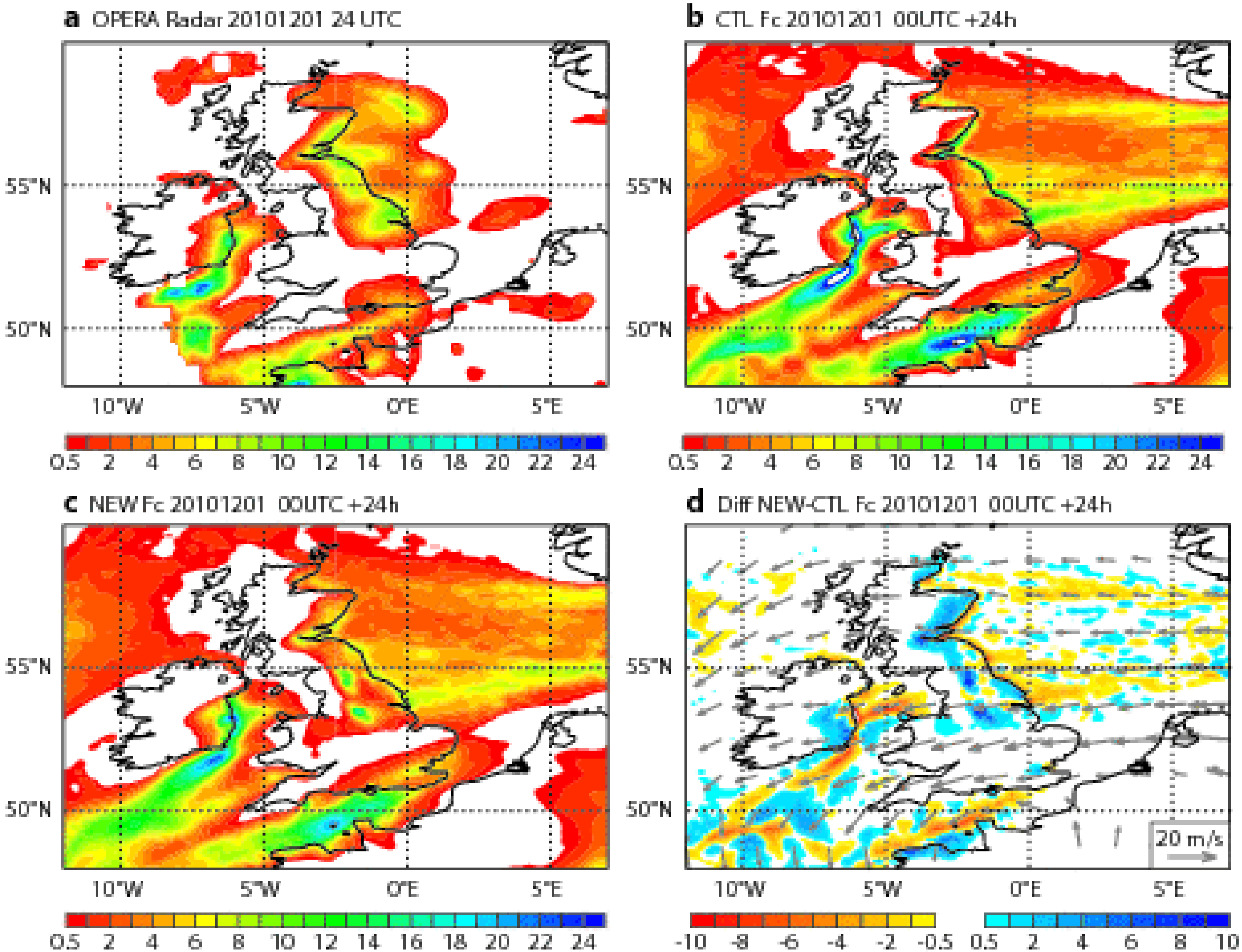
Diurnal evolution of total heating profile -radiation



Diurnal cycle: Impact on weather forecasts



Wintry showers: radar & forecasts



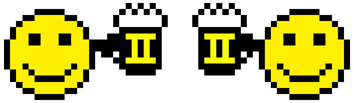
Physics – issues for improvement

- T2m winter can still be difficult: stable boundary-layer <-> snow and low-level clouds
- 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
- Predictability in monthly and seasonal forecasts ……. coming from the stratosphere and Tropics (MJO)

Planned model upgrades in 2014

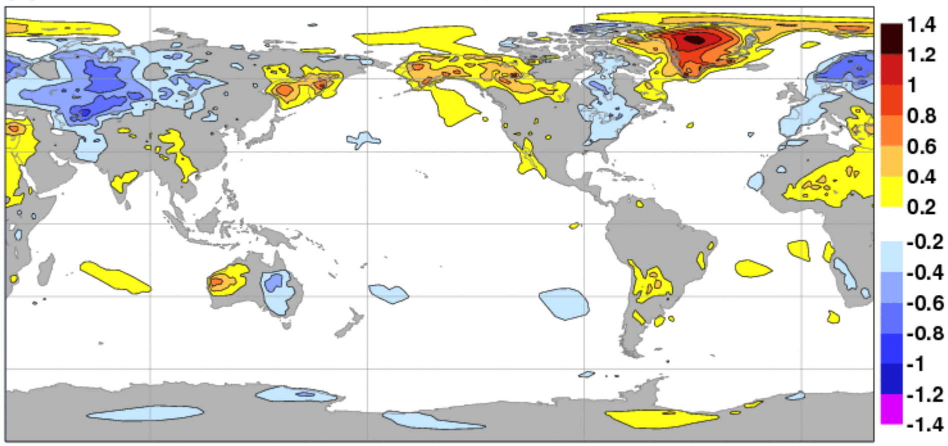
- New greenhouse gas climatology from MACC
- Possibly new aerosol climatology for radiation
- Microphysics (see Richard Thursday)
- Possibly prediction of lake temperatures
- Resolution increase in assimilation: inner loop (see Lars Friday)

ECMWF

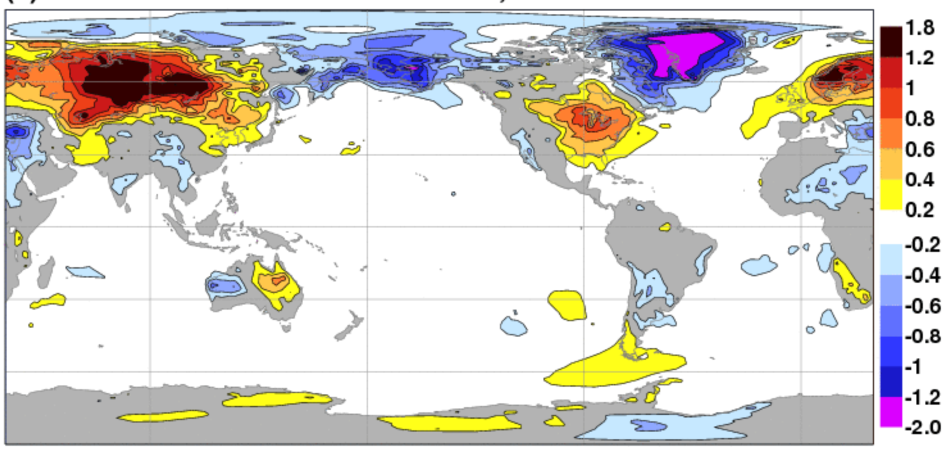


Teleconn. U10hPa Tropics& 2T for DJF

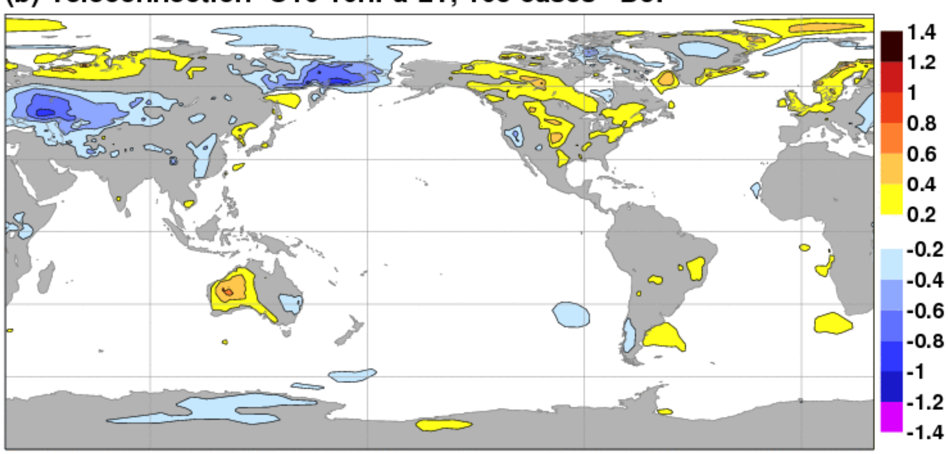
(a) ERAI Teleconnection -U10hPa-2T, 42 cases DJF



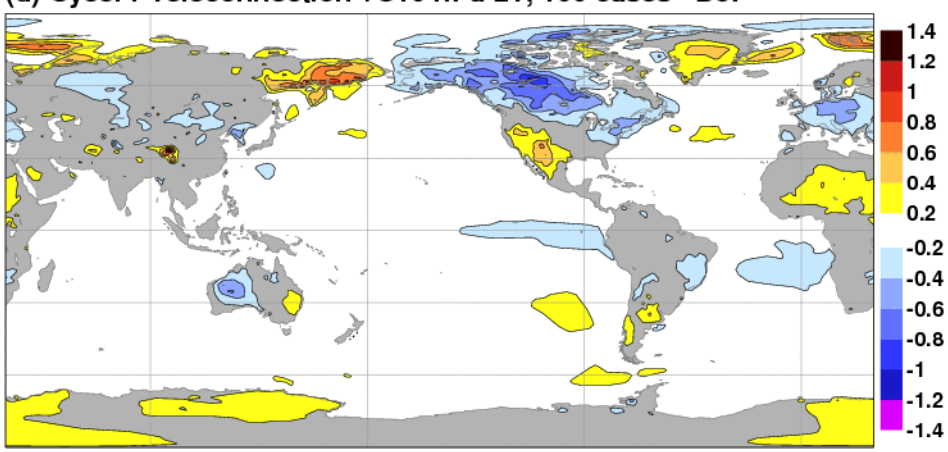
(c) ERAI Teleconnection +U10 hPa-2T, 37 cases DJF



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

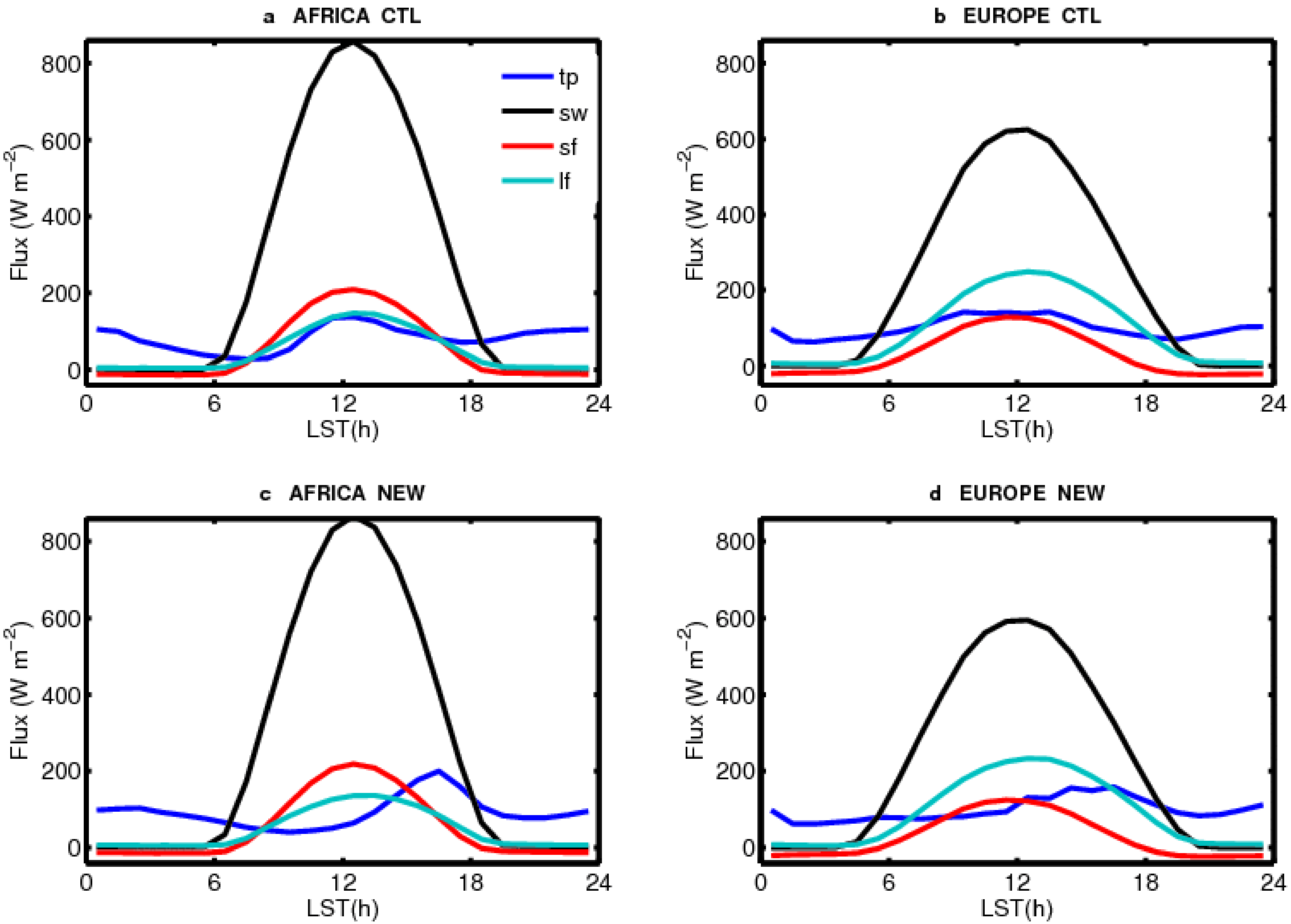


(d) Cy38r1 Teleconnection +U10 hPa-2T, 100 cases DJF



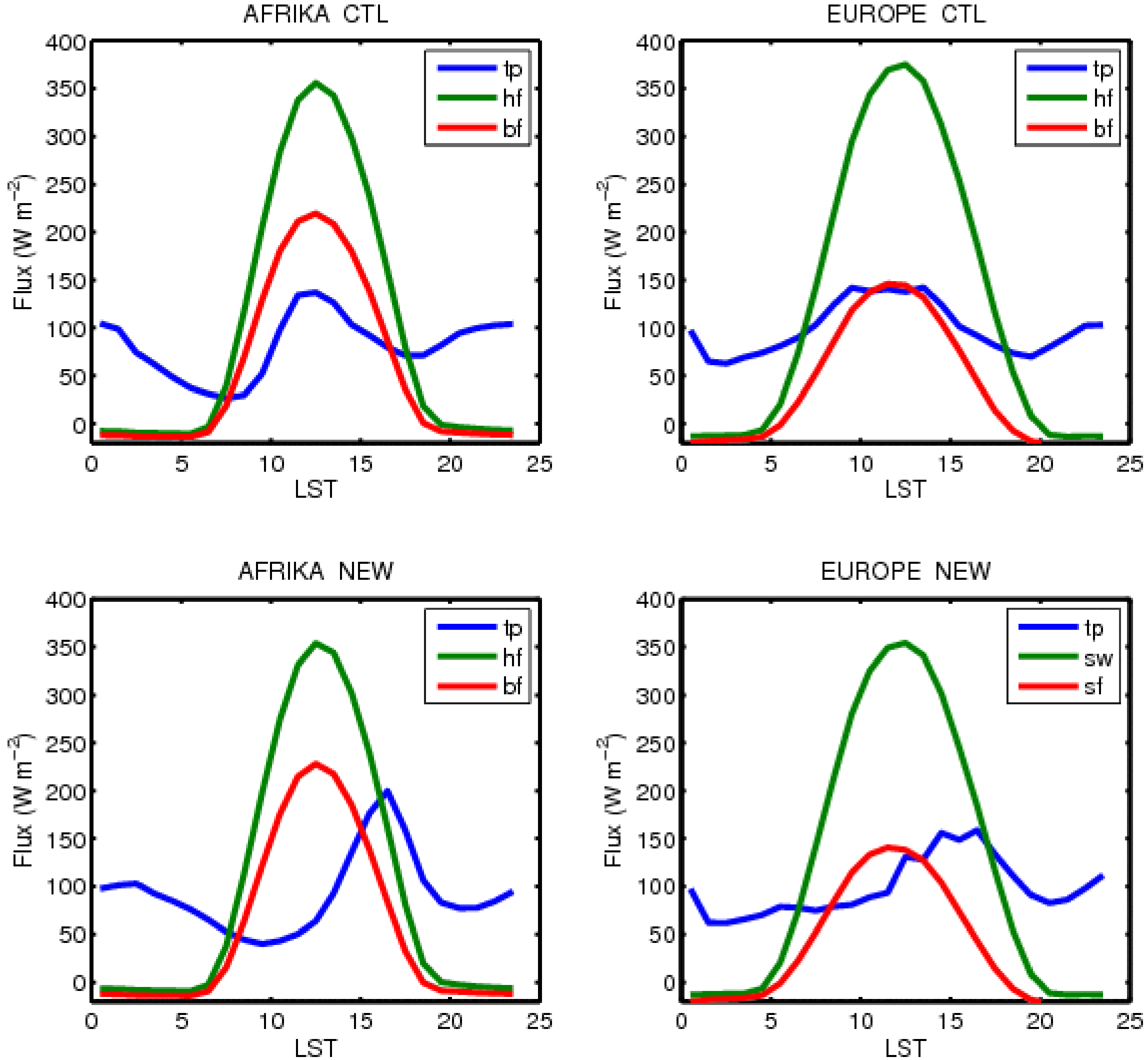
ECMWF

Diurnal cycle: Surface Energy Budgets



TP=total precipitation SW=shortwave radiation   SF&LF=sensible&latent heat flux
Note: (i) shift in TP between CTL and NEW, (ii) TP in CTL in phase with SF+LF=wrong! (iii) for Europe LF>SF, Africa SF>LF

How does diurnal Precip scale?



TP=total precipitation HF=surface enthalpy flux BF=surface buoyancy flux
NOTE: in NEW = revised diurnal cycle surface daytime precipitation scales as the surface buoyancy flux

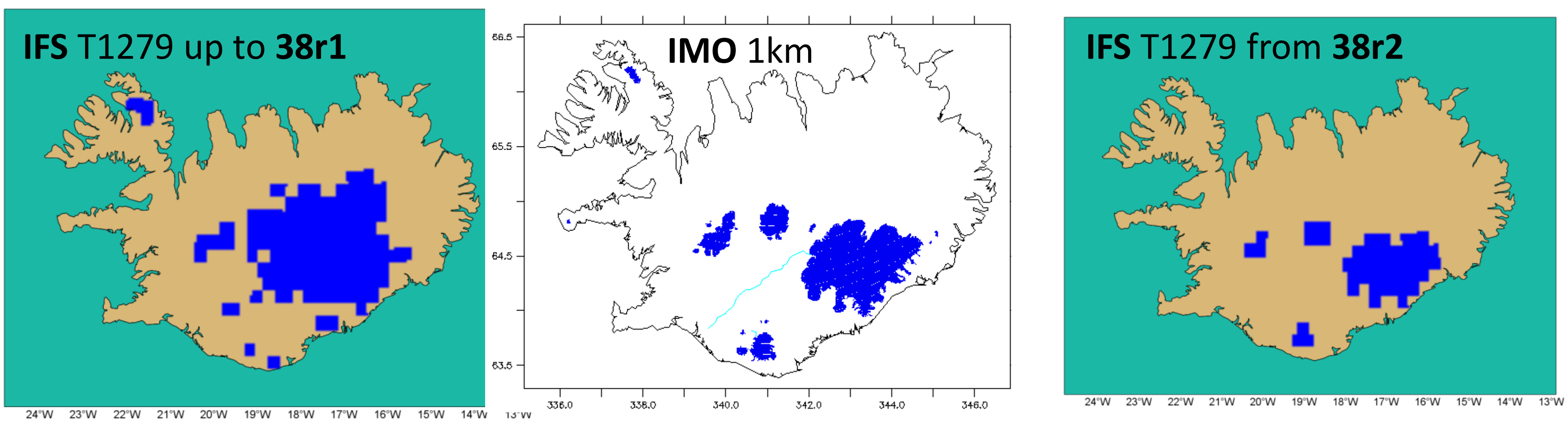
Icelandic Glacier

Issue: IMO: cold bias reported due to spurious glacier over Iceland (→ 10m of snow)

Actions:

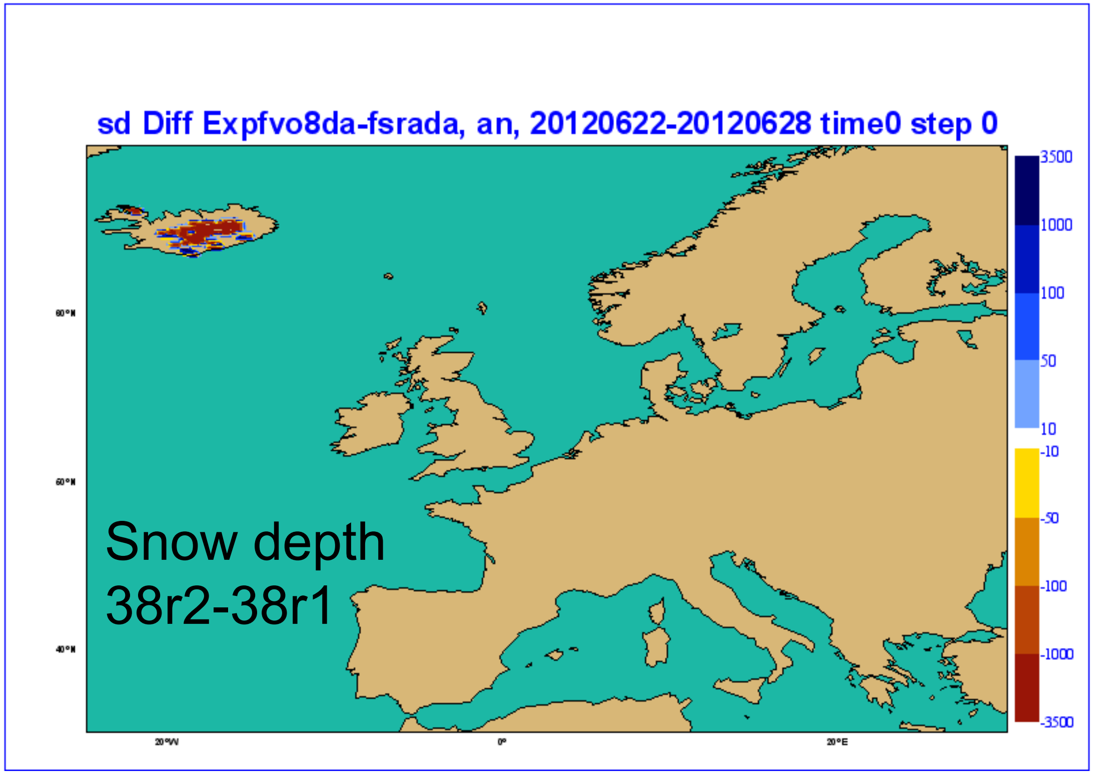
- IMO provided 1km glacier map (Dec 2012)
- ECMWF: GLCC glacier map updated to use IMO data over Iceland, cicecap file generated at all resolutions to be used in the IFS
- ECMWF implementation in the esuite 38r2 on 08 May 2013 at 00UTC
  - Climate data base update, dual config to ensure 38r2 reproducibility
  - Initial Snow Depth hacking: first-guess forecast on 2013 05 07 @ 18UTC +6: replace snow depth field and put back to FDB.
  - HRES and EDA members: first use on 2013 05 08 00 DCDA (script and data base change).

Glacier mask

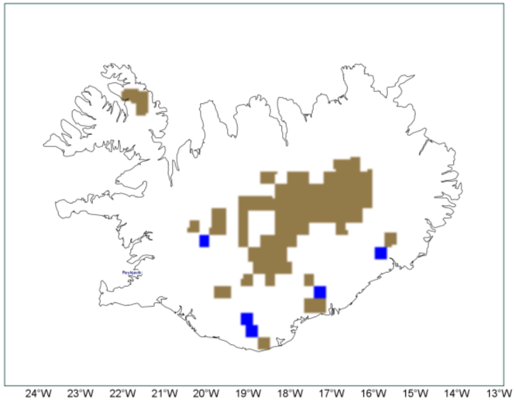


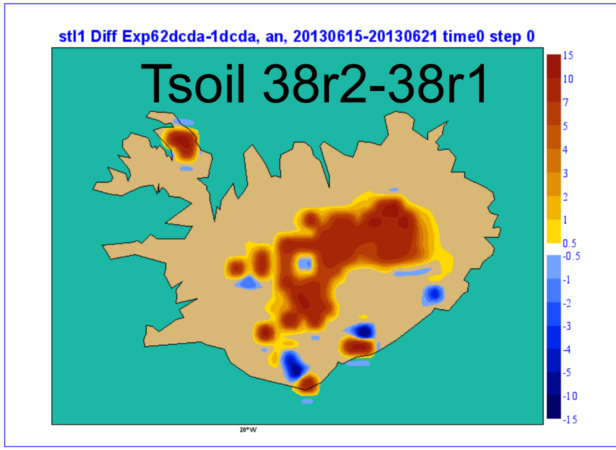
Icelandic Glacier

Difference in Glacier extend between 38r2 and 38r1
→ Difference in snow depth and surface temperature



Glacier 38r2-38r1

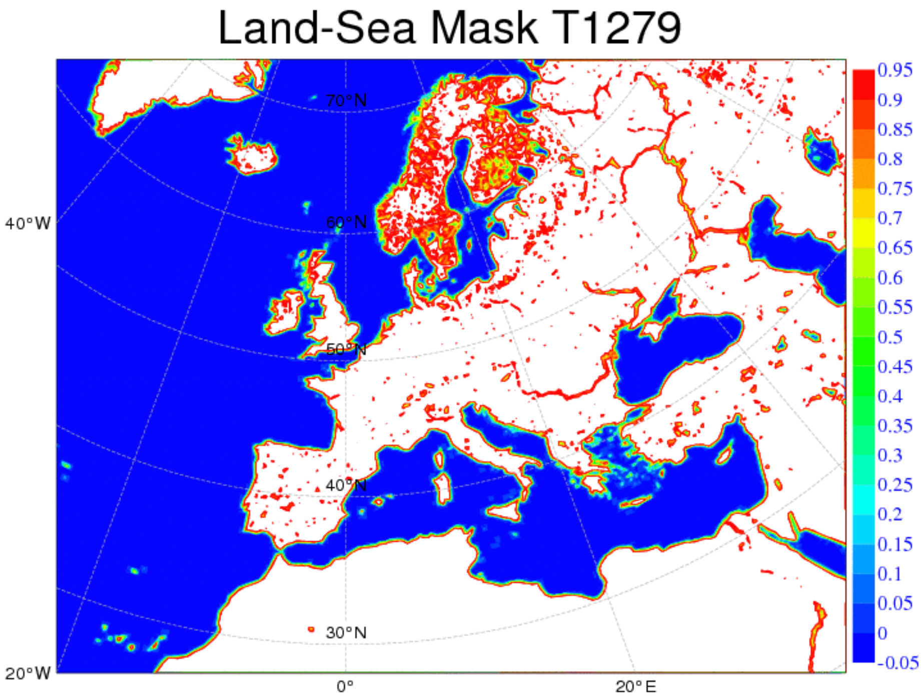


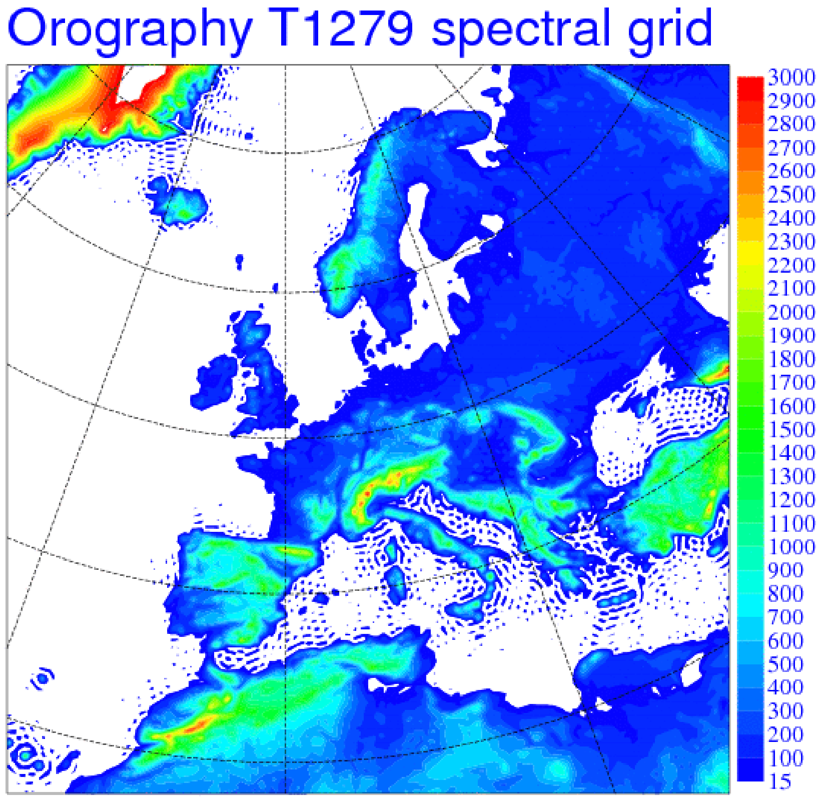


(de Rosnay et al., Res Mem 13-293, 2013)

- Local Impact over Iceland to fix the temperature bias
- Used in HRES, EDA, ENS and ENS re-forecasts
- Efficient collaboration between RD and FD and between ECMWF and IMO
- Good exercise to prepare the future implementation of revised climate data

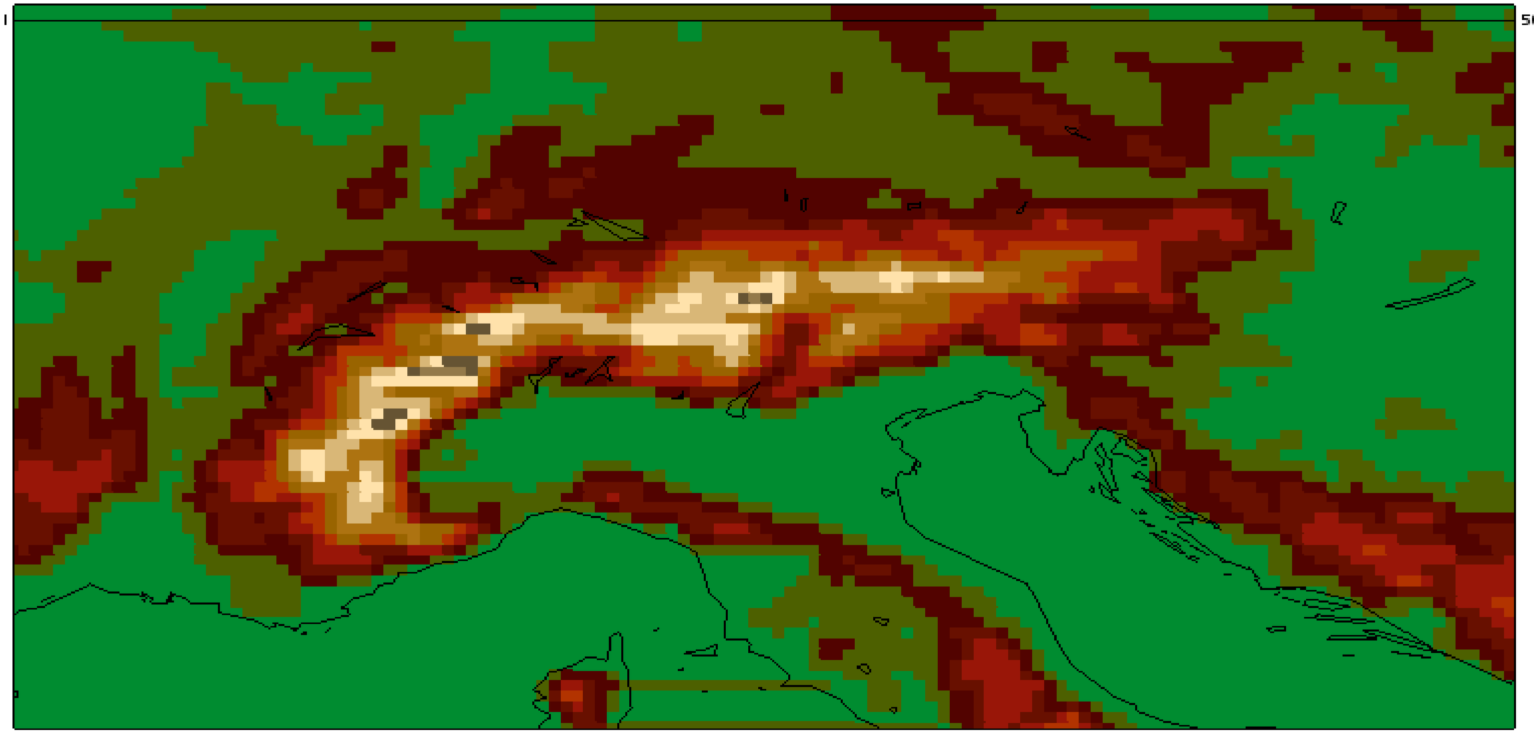
Land-Sea in T1279 (15km) resolution (since 26 January 2010)





Orography – T1279=16 km

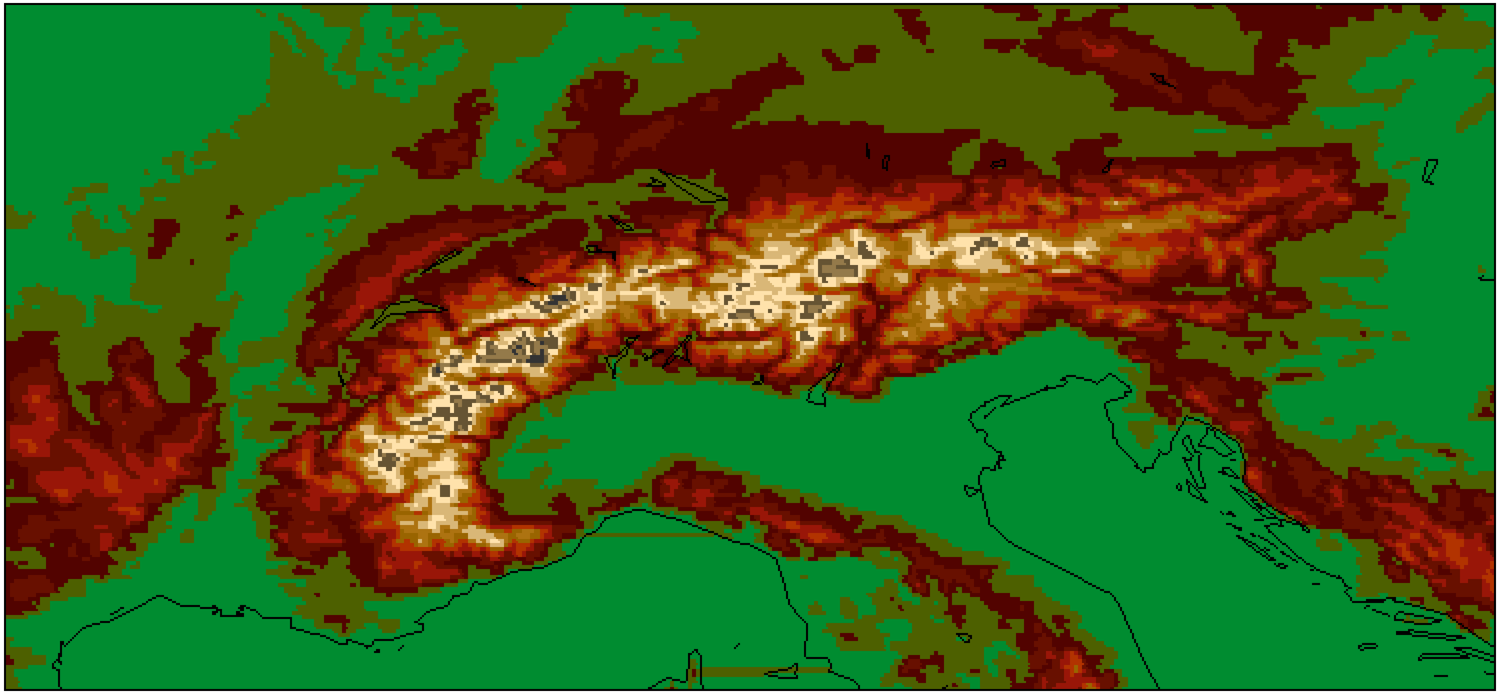
Max global altitude = 6503m



Alps

Orography - T3999=5 km

Max global altitude = 7185m

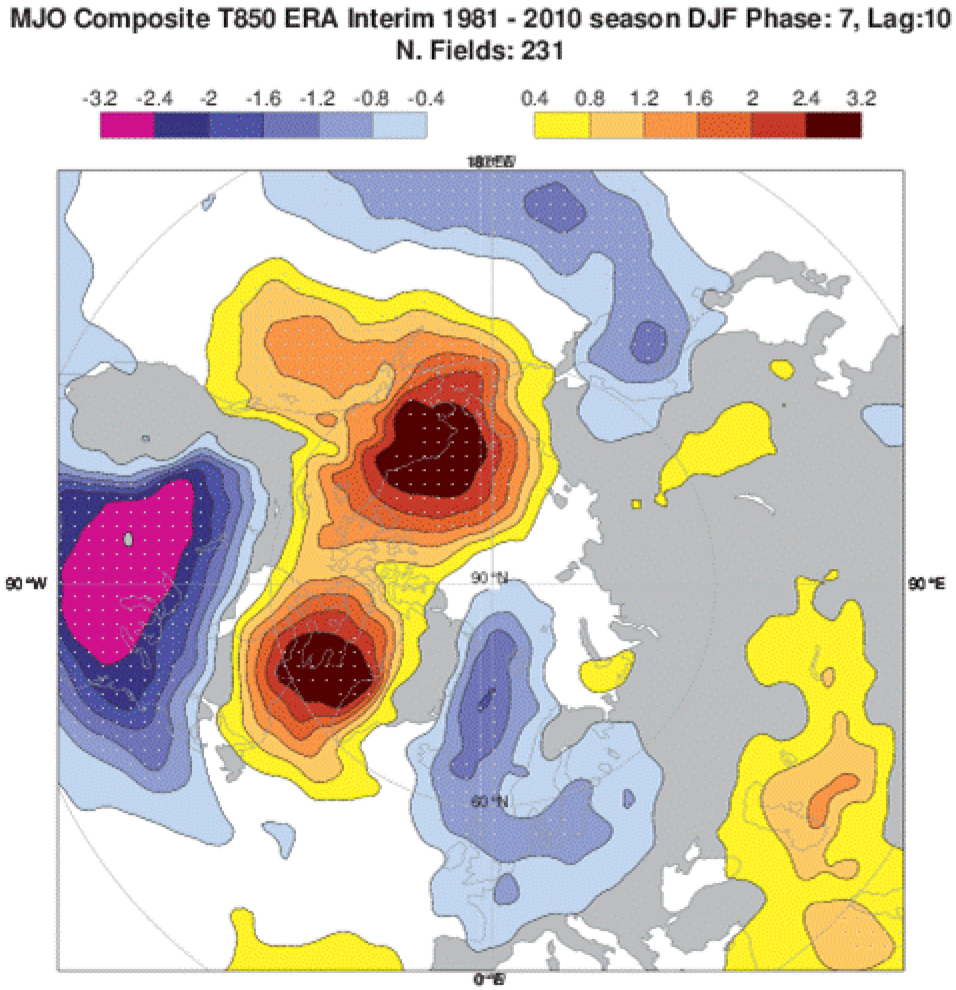


Alps

ECMWF

Composite on MJO Phase 7 onto T850 with 10 days lag

ERA Interim



Model (40r1)