The physics behind the products
@ECMWF

Richard Forbes
ECMWF Research Department
richard.forbes@ecmwf.int

Thanks to Peter Bechtold and many colleagues at ECMWF!

Outline

The physics behind the products @ ECMWF

Ensemble Mean

Shift Of Tails

Inter-quartile range

Probabilities

Skill Scores

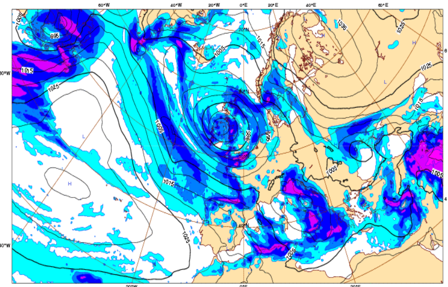
Cost-Loss Ratios

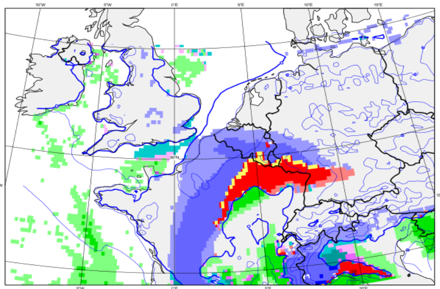
Extreme Forecast Index

Ensemble Spread

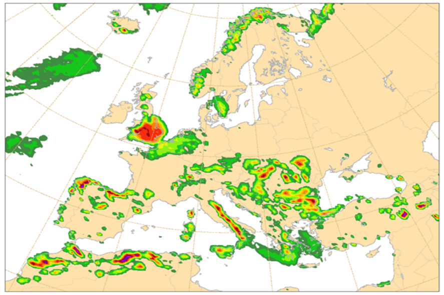
Medium-range forecasts

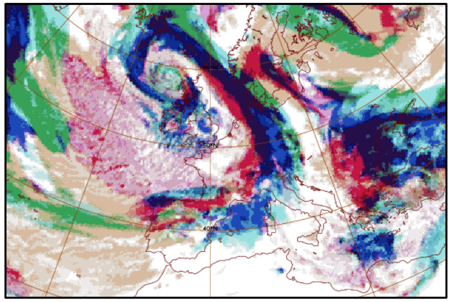
Extended-range



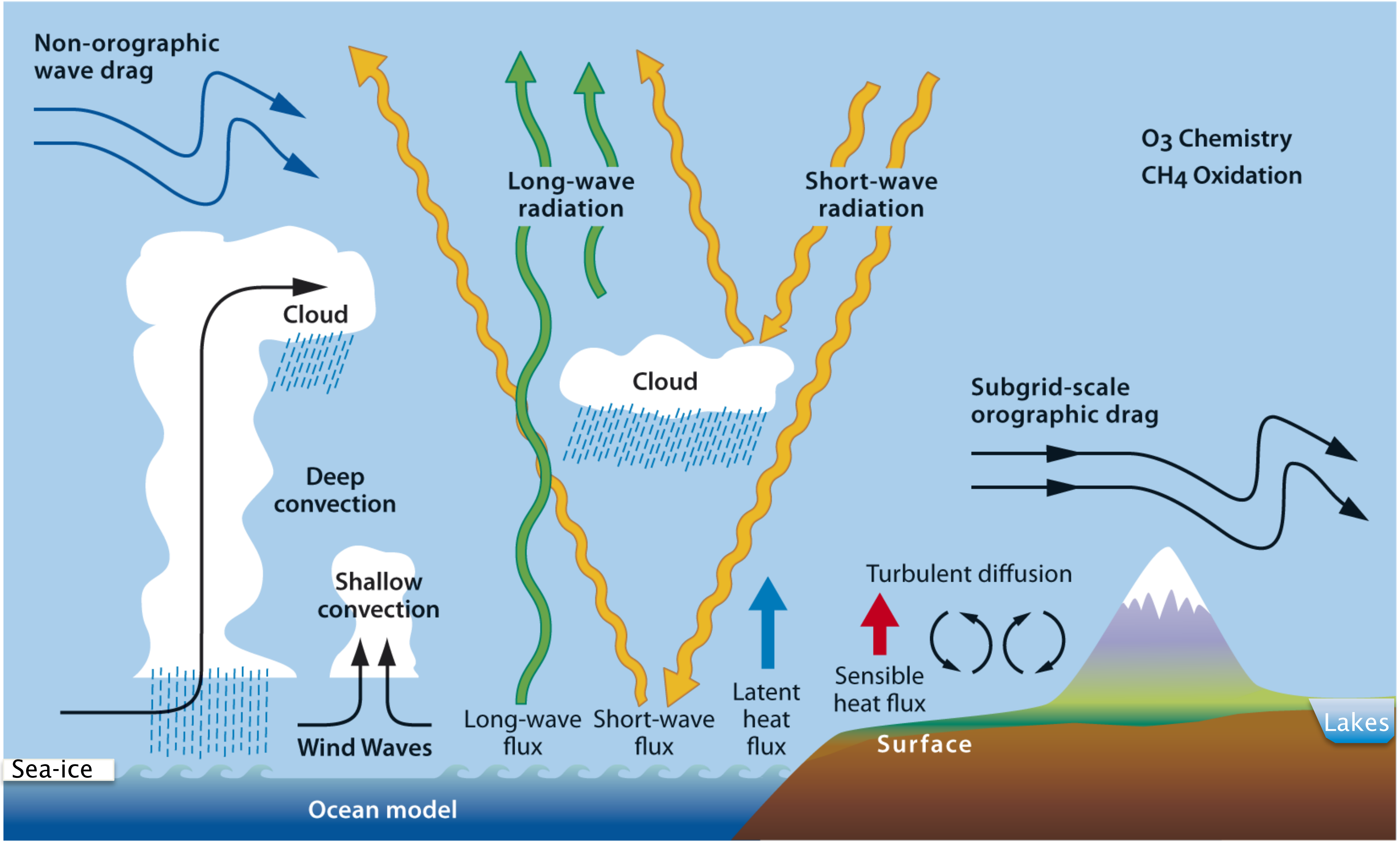


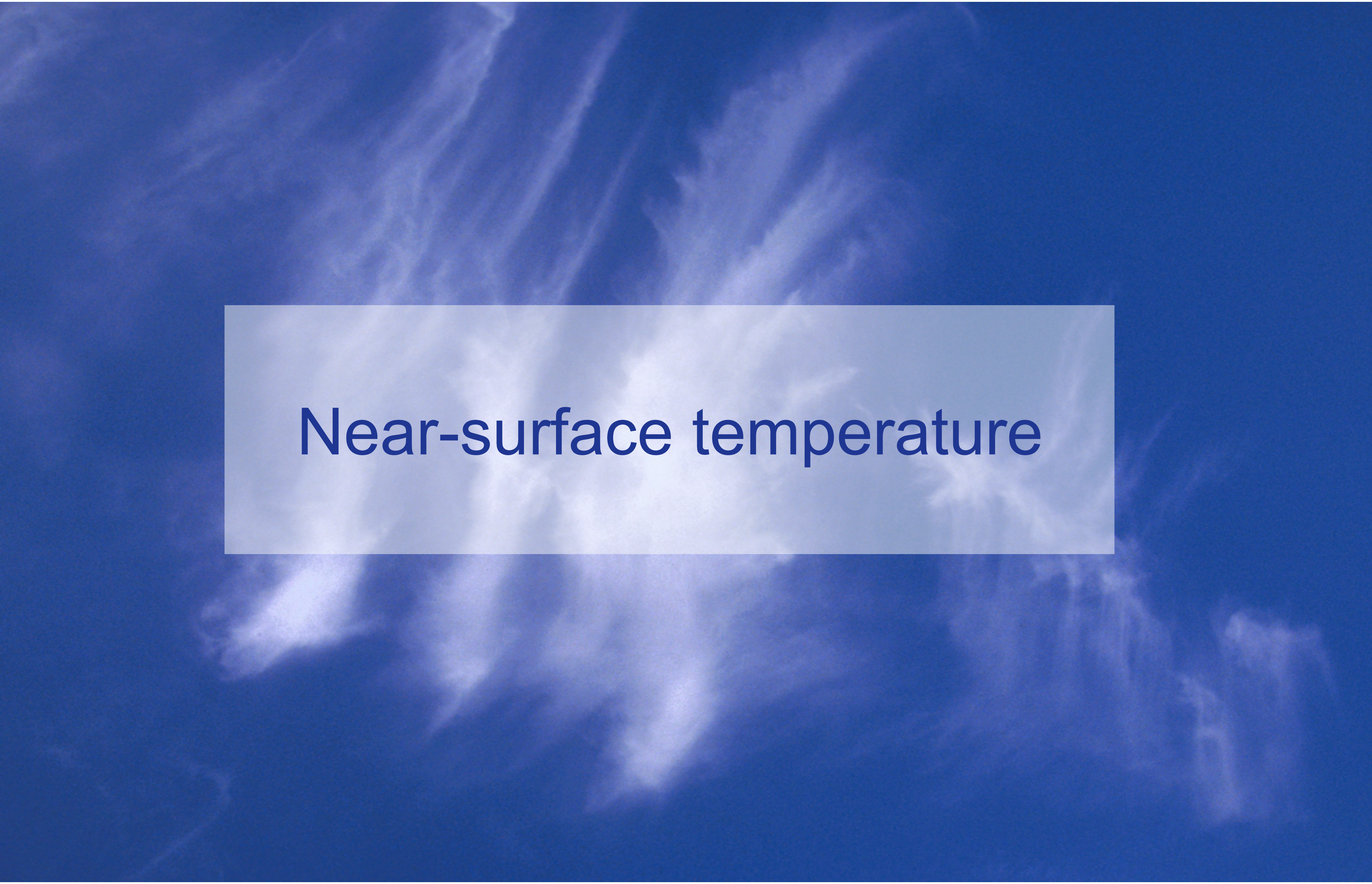
- 2m temperature
- 10m wind, windgusts
- Cloud and precipitation
- Winter precipitation
- Visibility/fog
- Lightning





Parameterized processes in the ECMWF model




Near-surface temperature

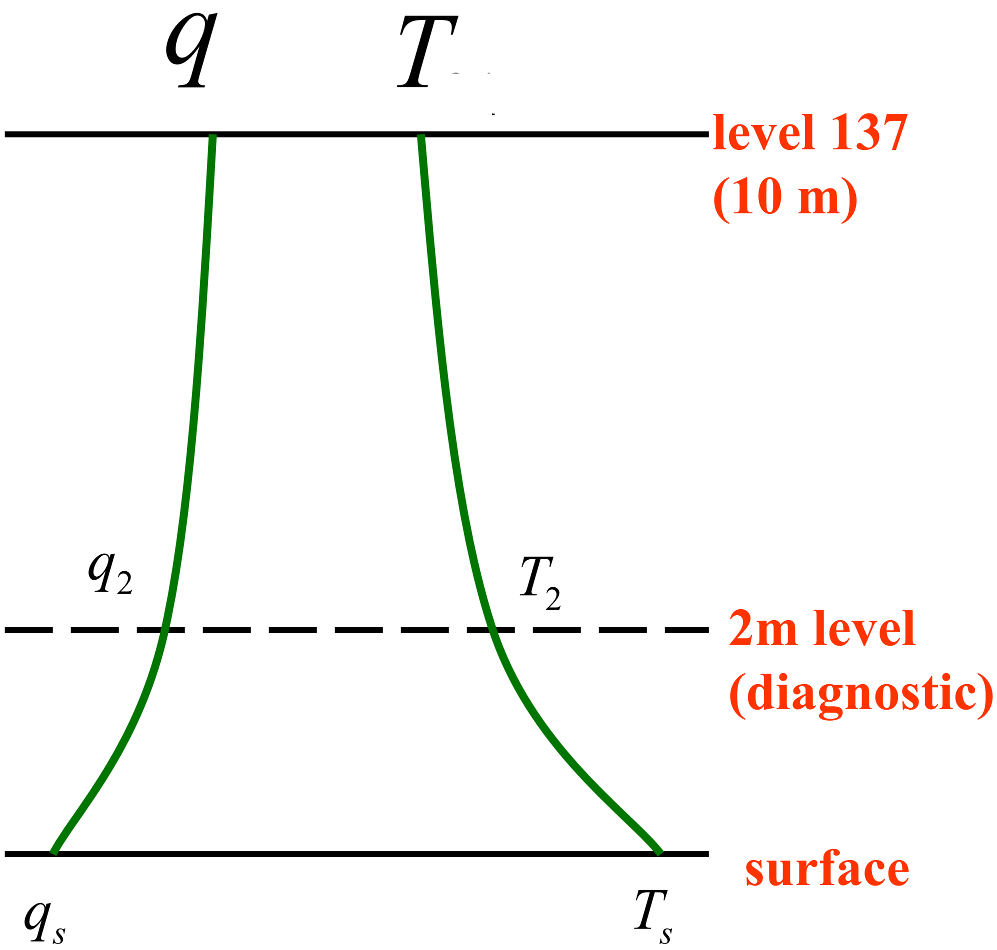
ear-surface temperature

Influenced by:

- radiation
- cloud, aerosol, humidity
- stability - wind speed
- surface – surface type, lakes
- orography
- snow cover/depth
- soil characteristics, vegetation
- ground temperature profile, ground water profile

- New headline score ENS CRPS T2m>5deg
- Focus on T2m improvement

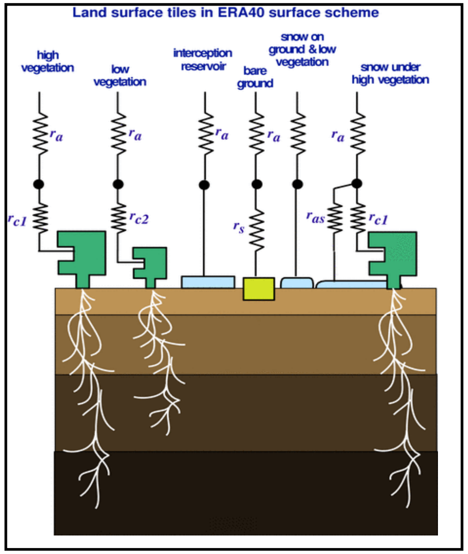
and q interpolation to the 2m level



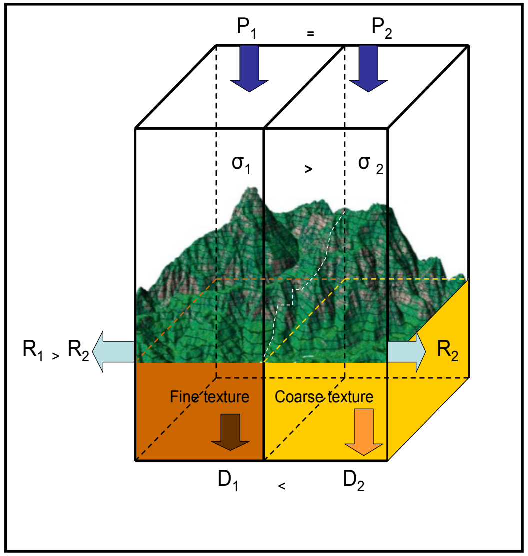
- q_s and T_s are determined by the land surface scheme or by SST.
- Main purpose of land surface scheme is to provide correct area averaged fluxes of heat and moisture.
- Land surface scheme considers different sub-areas (tiles).

nd surface model

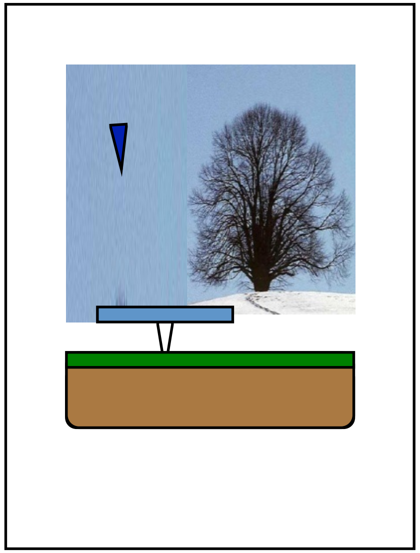
TESSEL



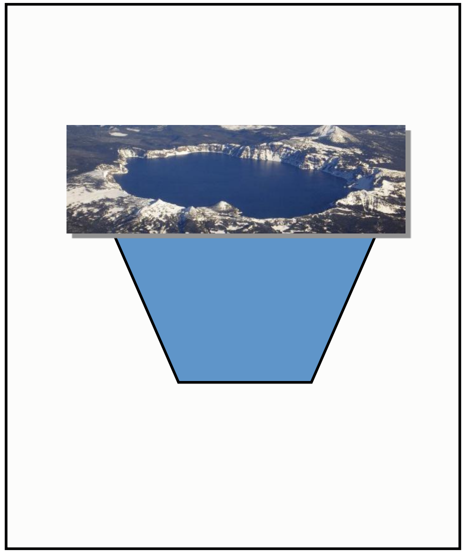
Hydrology-TESSEL



Snow



Lakes (FLAKE)



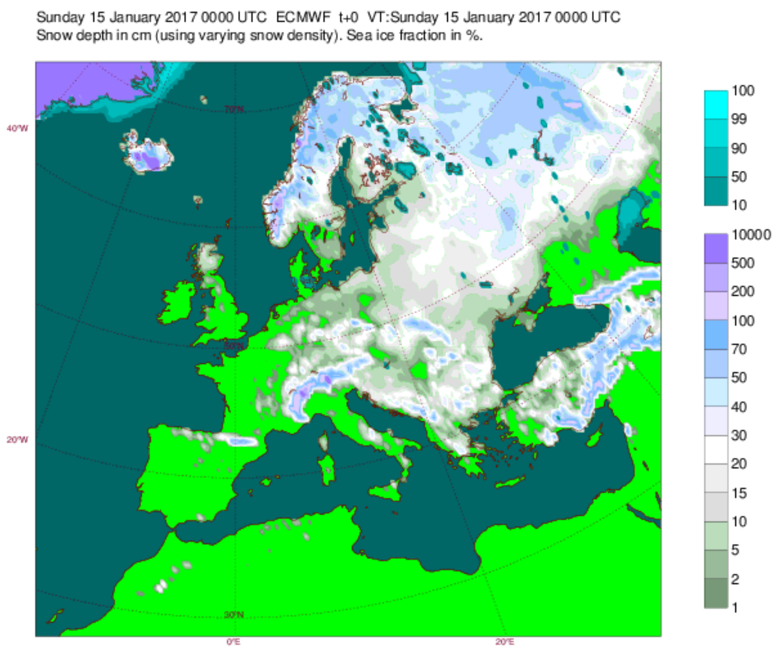
urface Snow

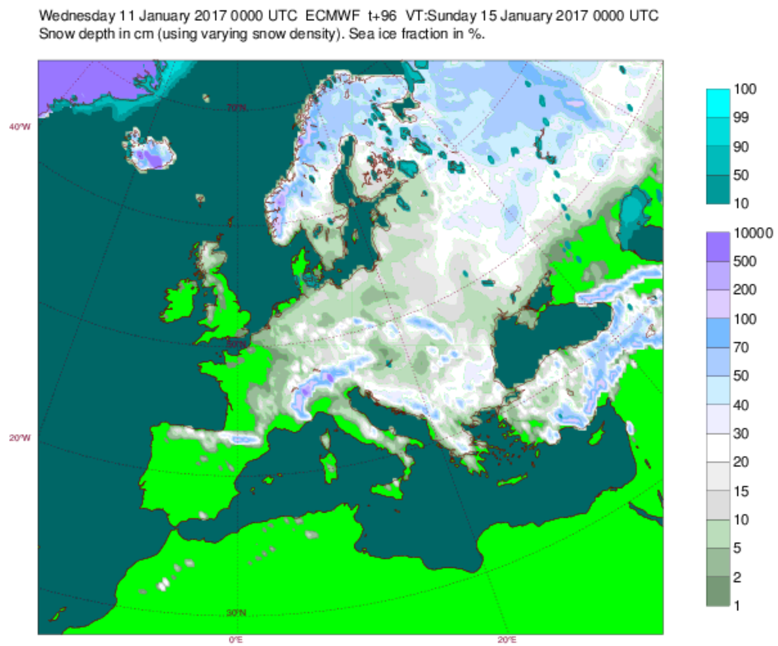
Snow analysis using SYNOP and satellite observations

Prognostic snow scheme (single layer scheme – multiple layers planned)

Parameters:

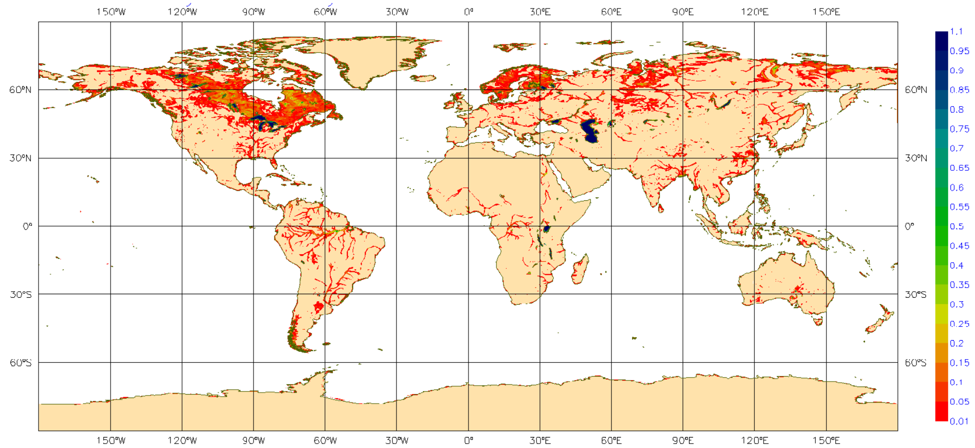
- Snow depth (water equivalent), Sd => actual depth=Sd*(Rliq=1000)/Rsn
  (below 10 cm snow depth, snow cover becomes fractional)
- Snow density (typically factor 10 lower than water-> 1 mm precip~1 cm snow), Rsn
- Snow temperature, Tsn
- Snow albedo, Asn





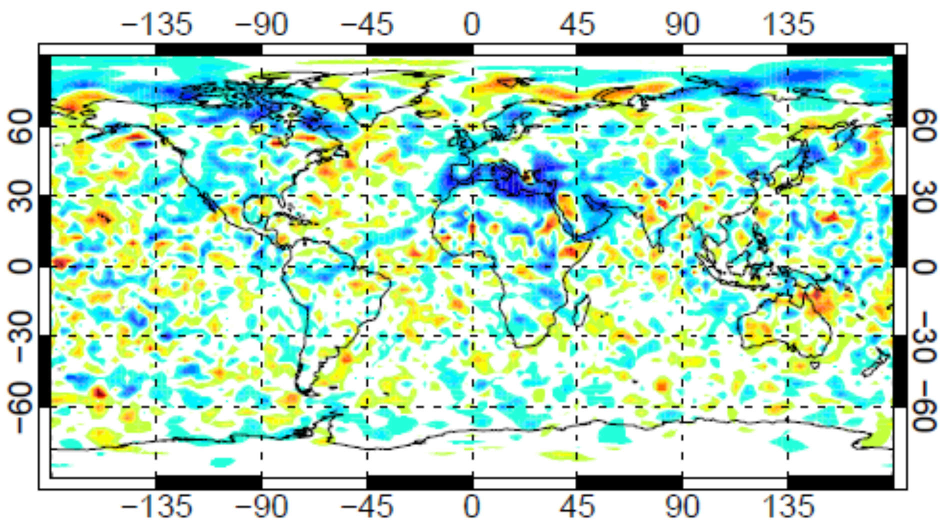
pact of water bodies (lakes/coastal areas)

LAKE COVER FRACTION



T+48; 1000hPa

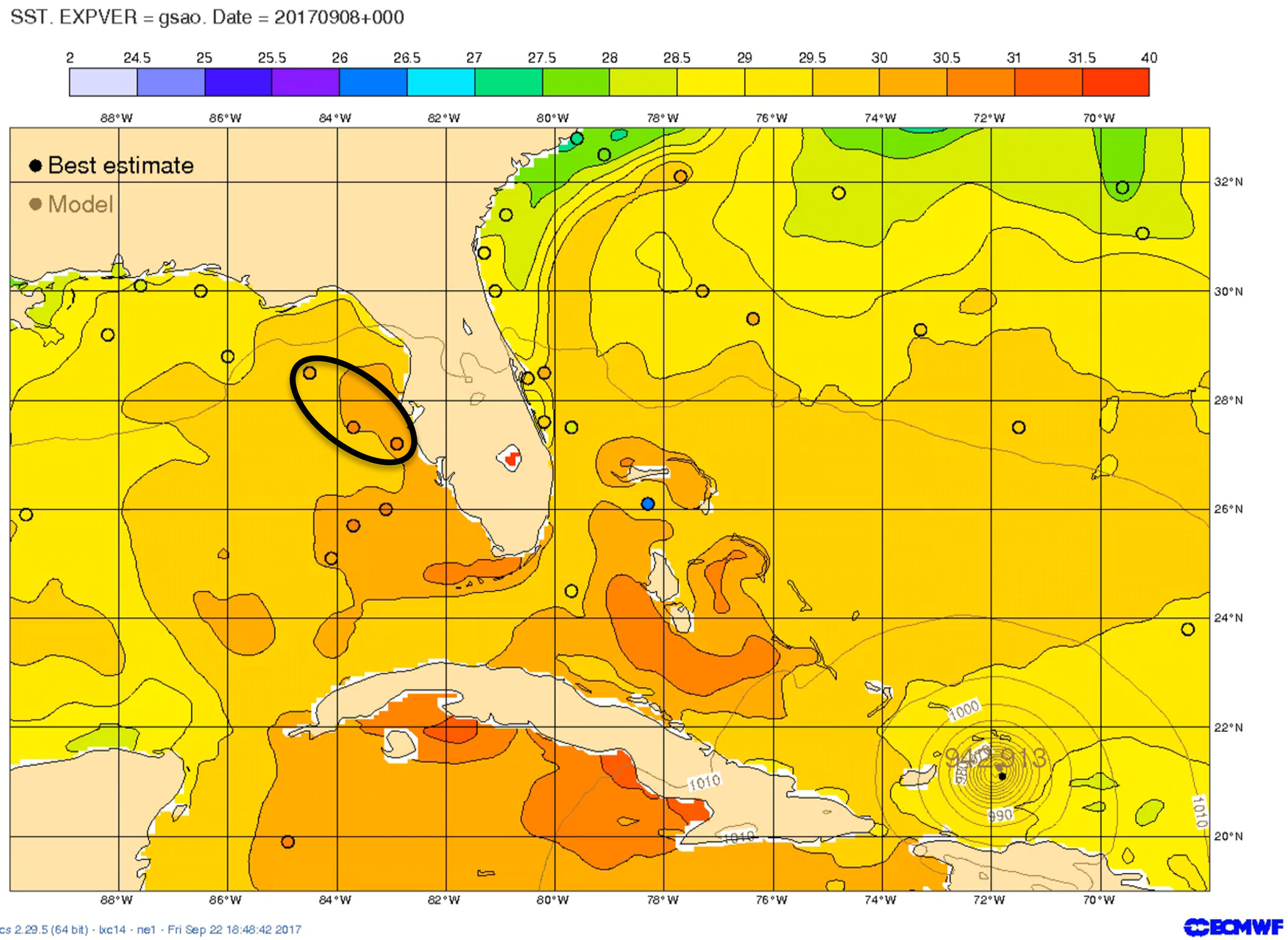
Summer experiment 15−Jun−2013 to 5−Jul−2013

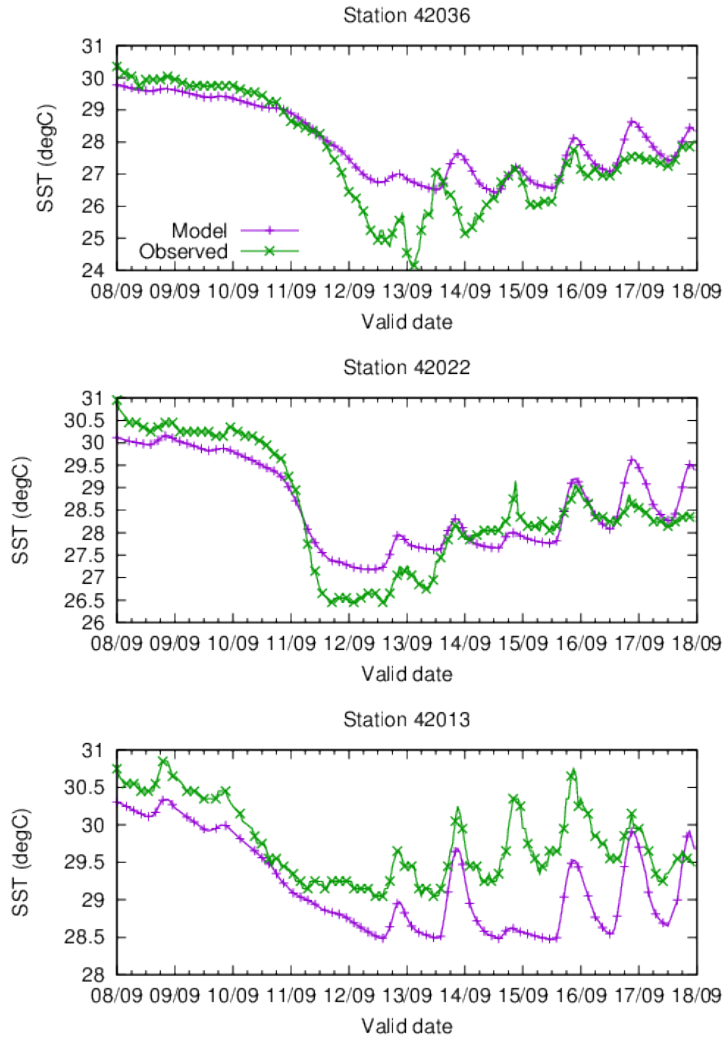


Difference in near-surface temperature when lakes/coastal area modelling implemented.

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

Atmosphere-ocean coupling – impact on near-surface temperature
urricane IRMA (HRES SST):



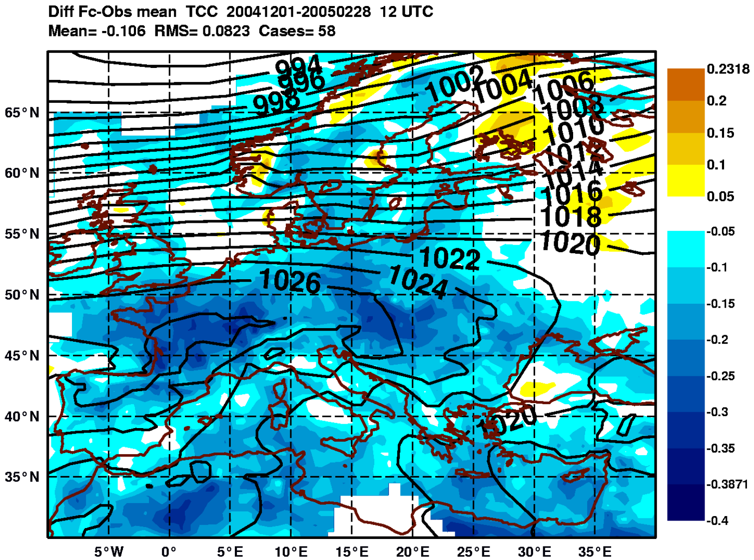


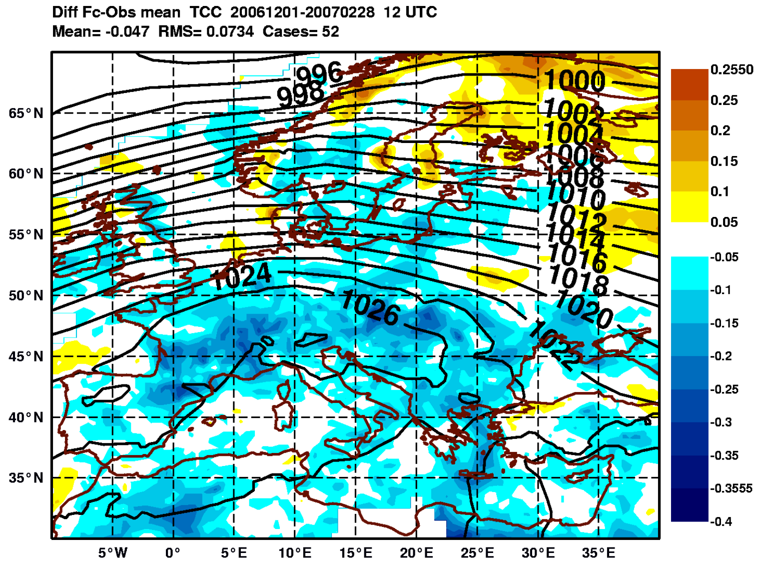
ow cloud cover: 36h forecast versus SYNOP observation

oud errors reducing over time for high pressure days over Europe during winter

DJF
2004/5
58 cases

EDMF PBL
M-O diffusion

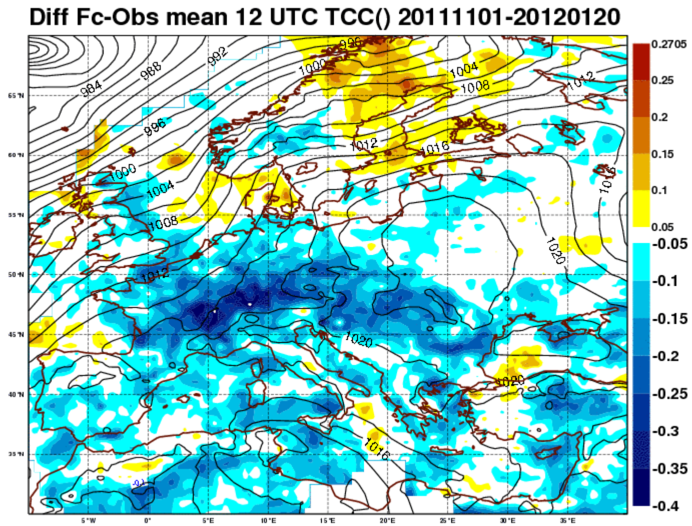




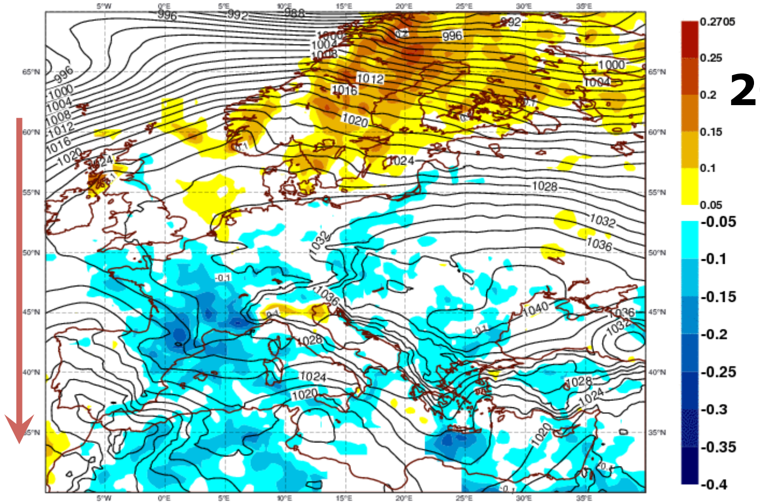
DJF
2006/7
52 cases

NDJ
2011/12

NEW MICROPHY



REVISED CLOUD

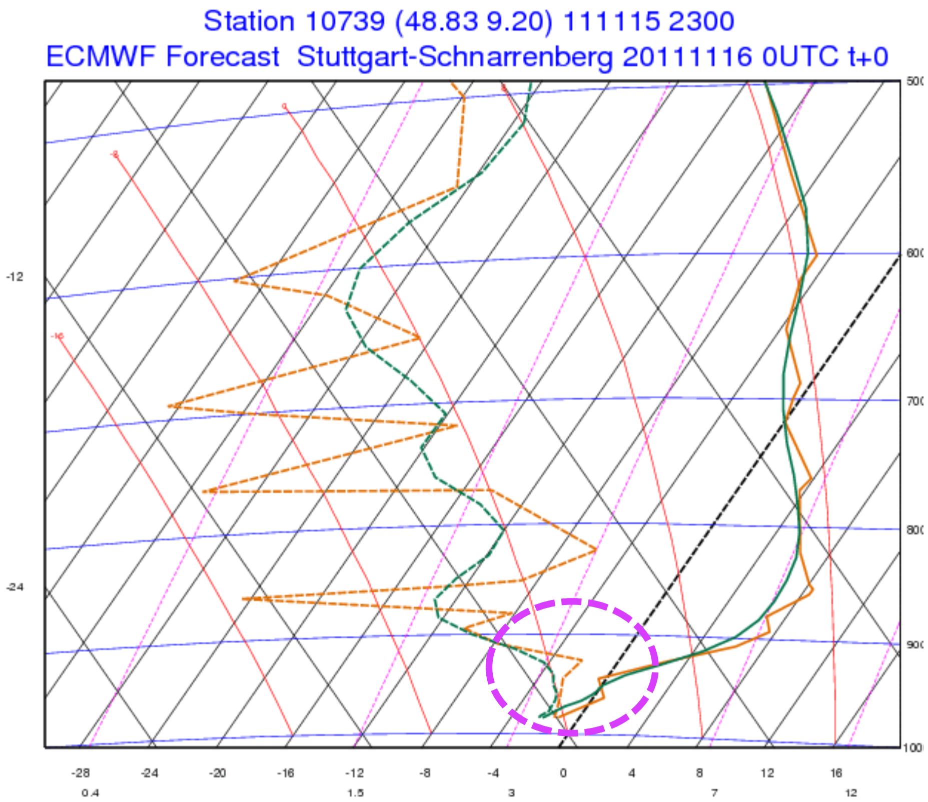


NDJ
2015/16

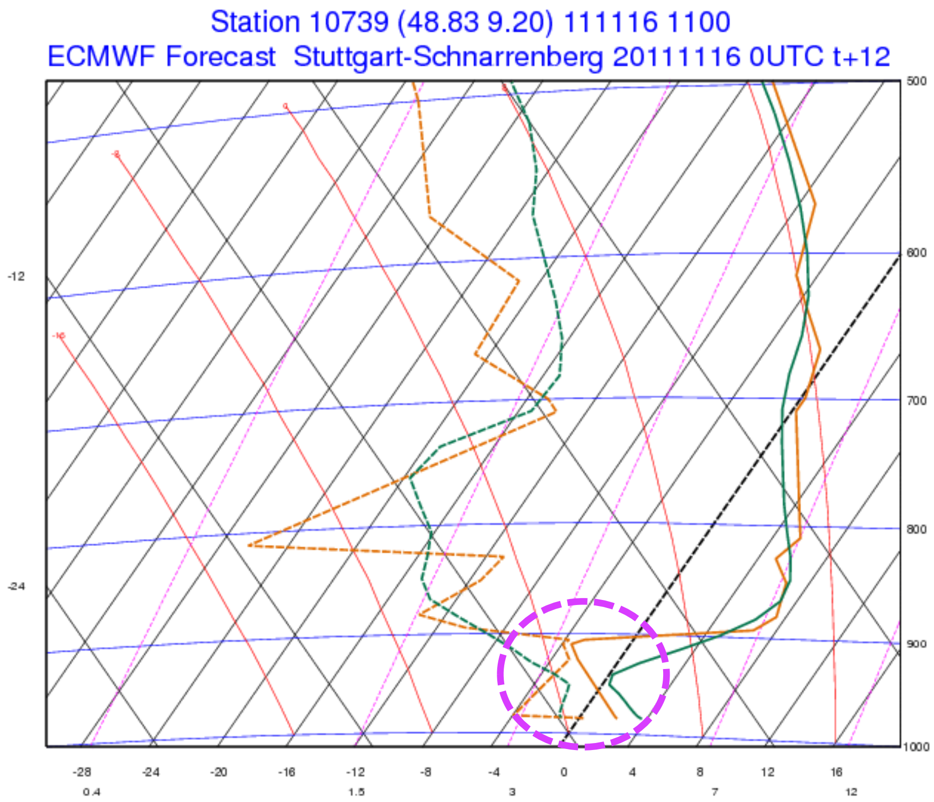
ow cloud cover: Too little in fog rising to stratocumulus example

Sounding Stuttgart 16 Nov, 2011

Too little cloud cover leads to warm bias in central Europe.



Obs Analysis



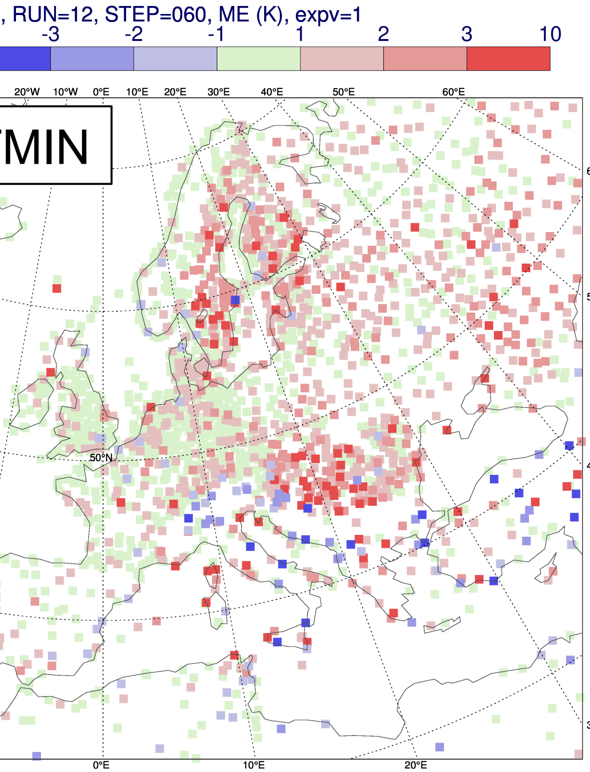
Obs Fc T+12h

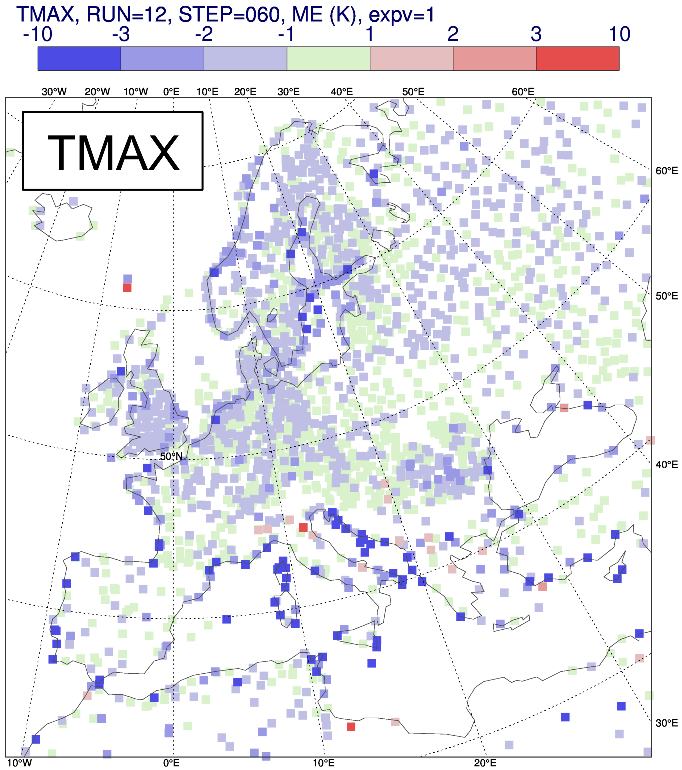
Fog rising developing into stratocumulus deck could not be properly represented

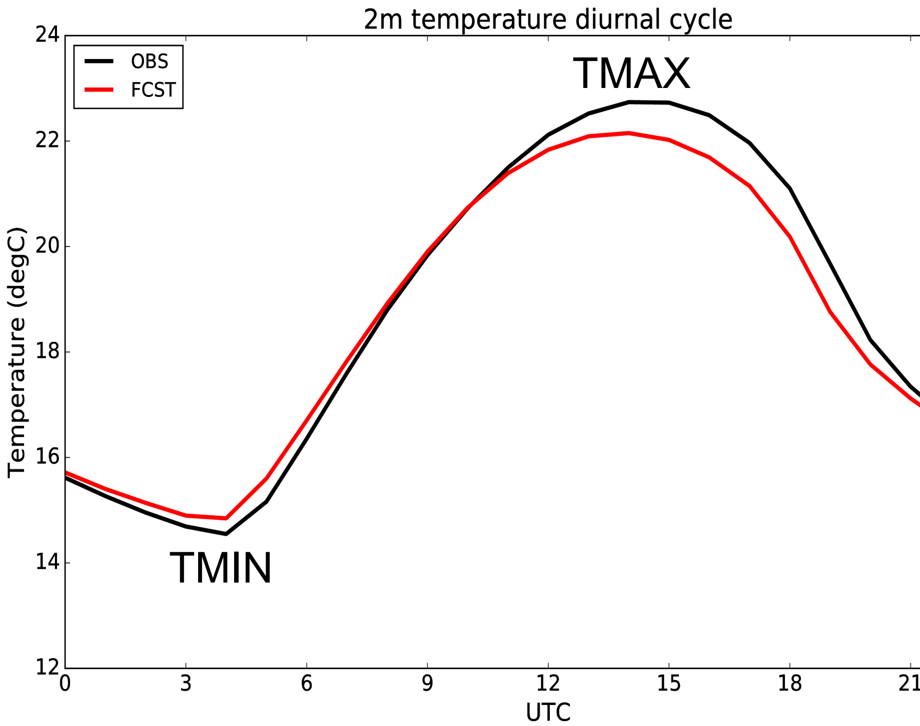
TMIN and TMAX bias

iurnal cycle underestimated

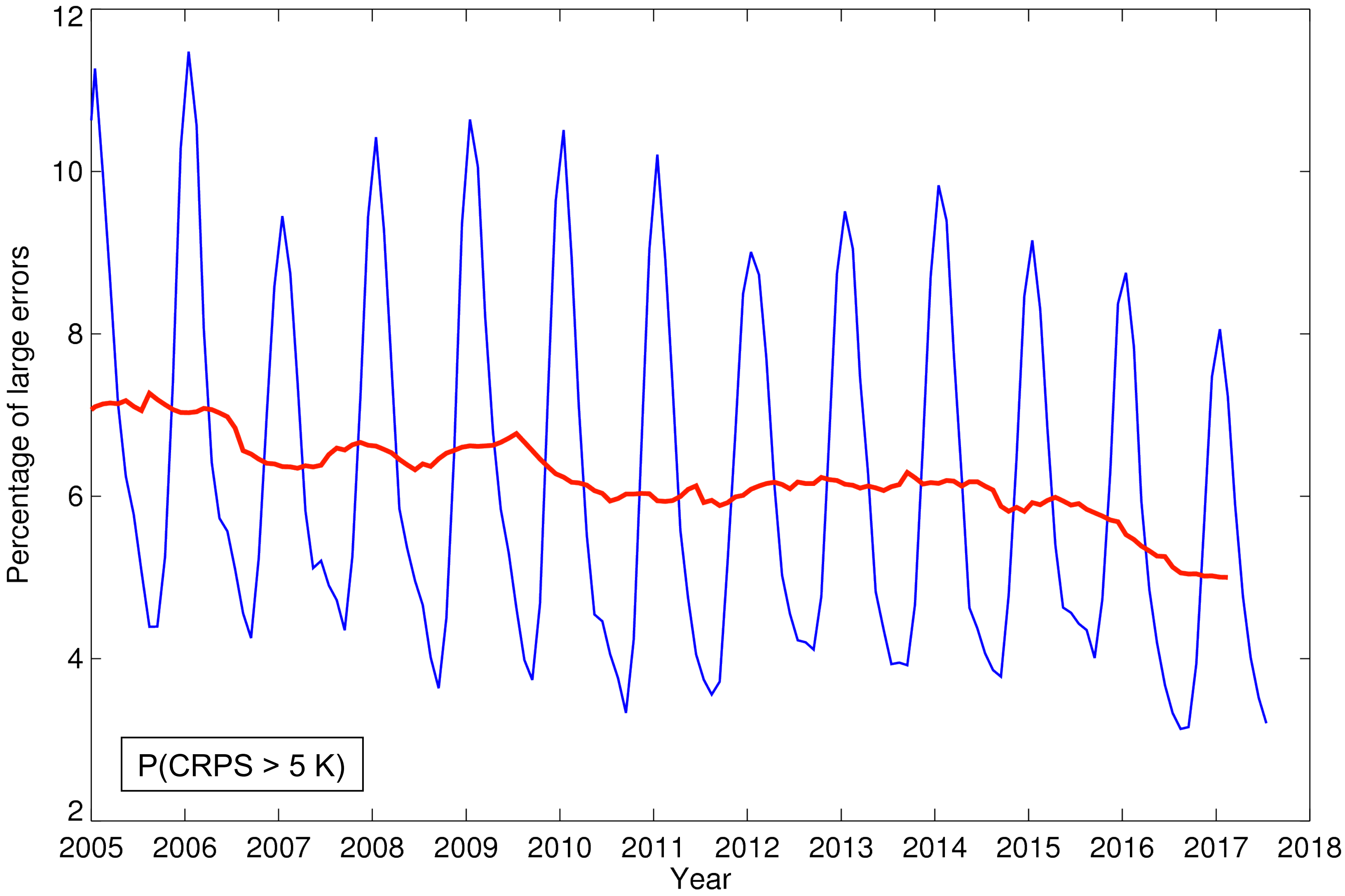
Summer 2017 Europe







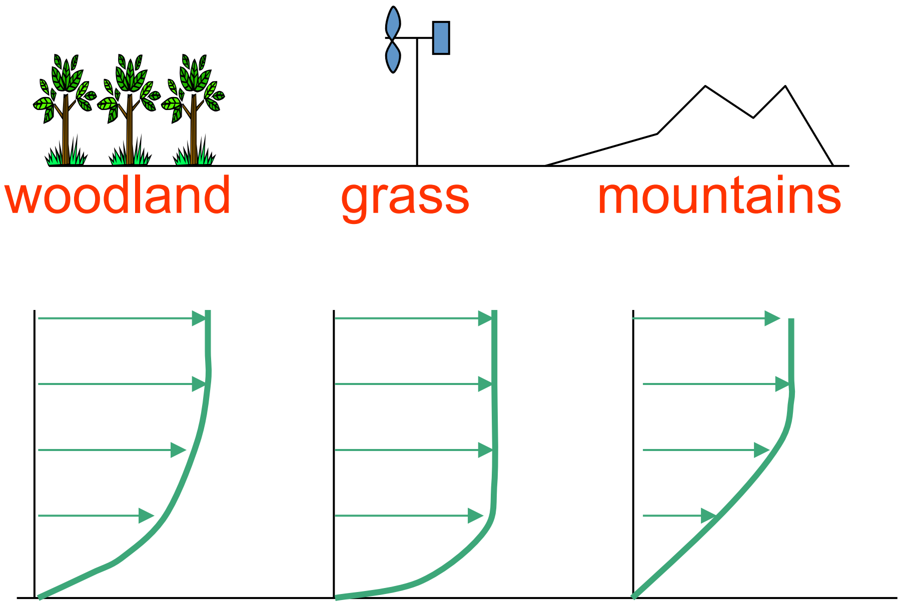
roposed headline score for ECMWF
requency of large (>5K) T2m errors – ENS day 5



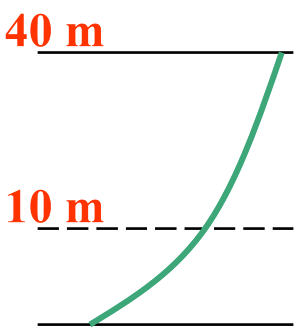
Extra-tropics
Day 5


Wind and Gusts

0 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 (neutral blending height) assuming roughness length fo grassland.
- Note: this exposure correction is only a partial correctio to account for local effects (which tend to be more complex).

0m Wind Gusts in the IFS

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

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

U_{10} is the 10m wind speed (interpolated down from 40m level),

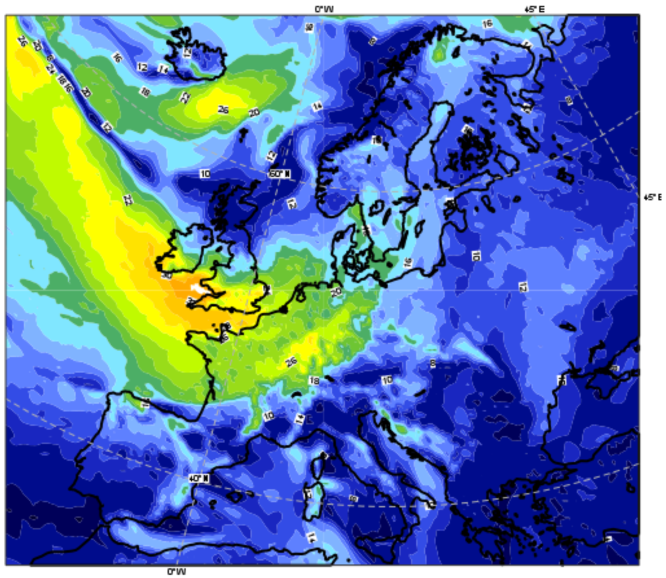
U_* is the friction velocity (obtained from the wind speed at the first model level)

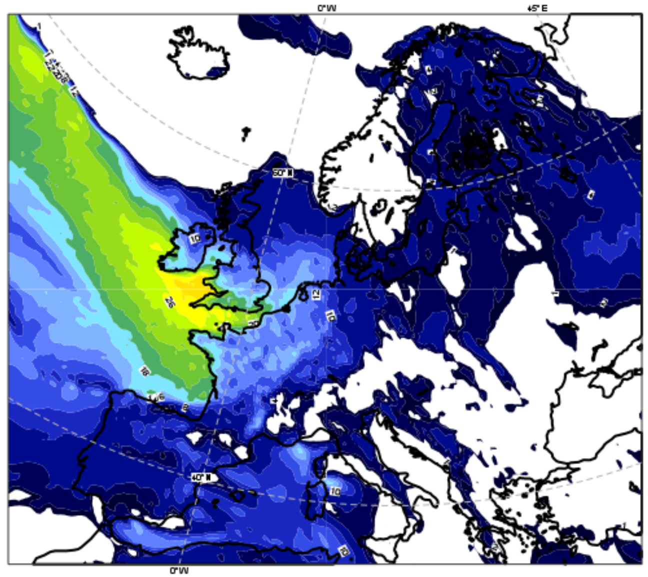
L is a stability parameter.

The convective contribution is set proportional to the wind shear between model levels corresponding to 850 hPa and 925 hPa when deep convection is active.

Wind Gusts: 8 Feb 2016 12 UTC

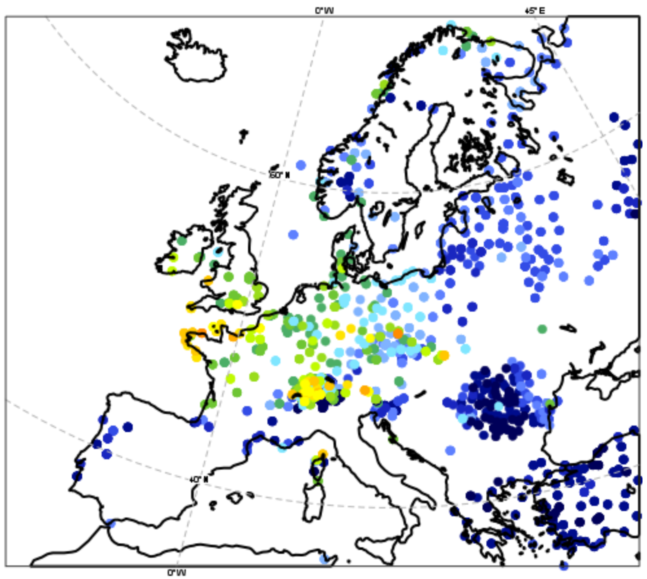
IFS
Gust

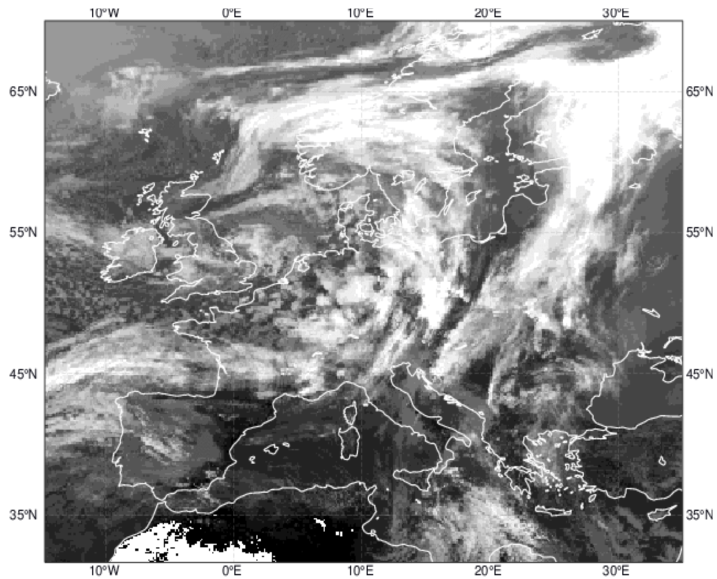




IFS
Wind speed

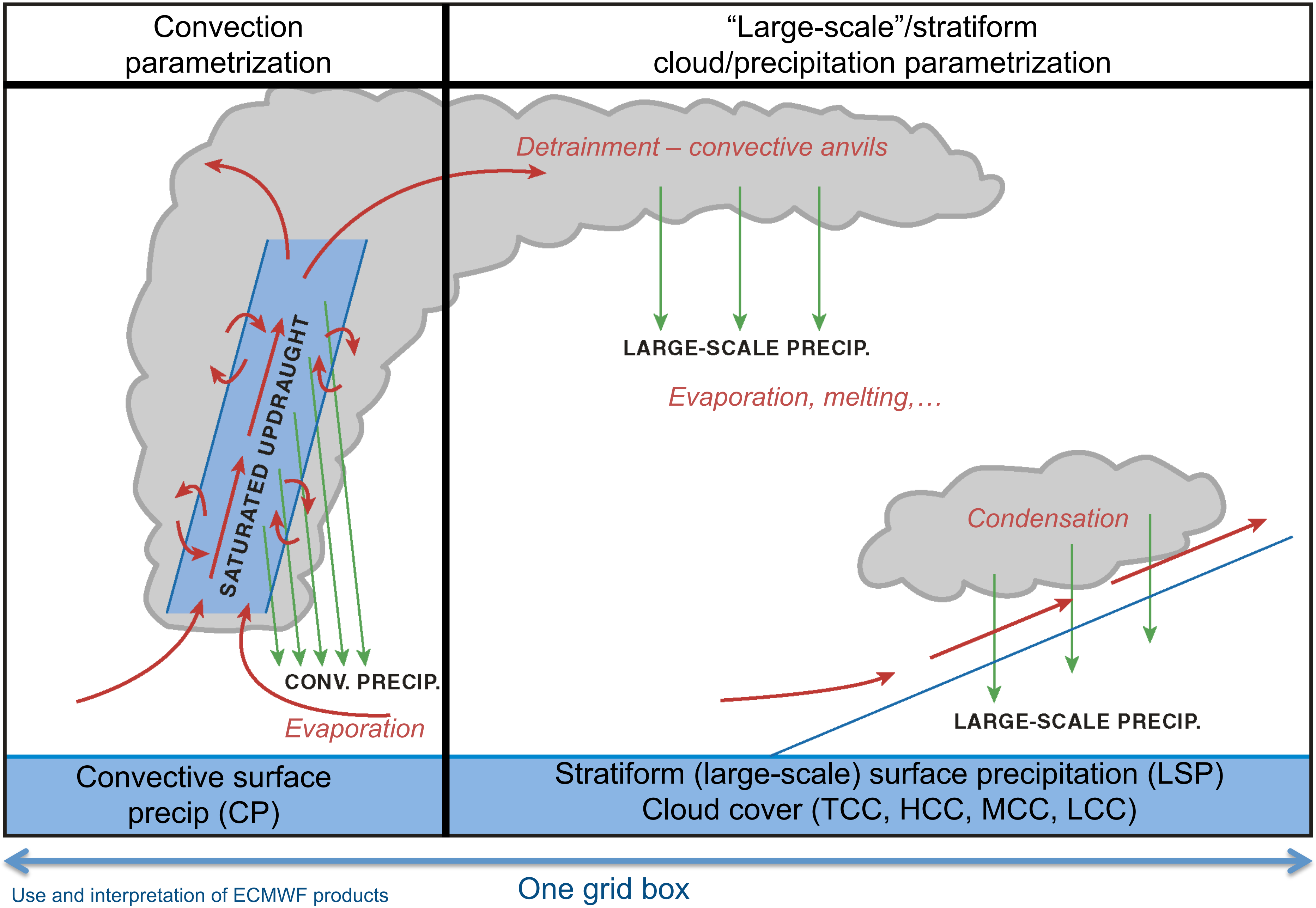
Obs
Gust



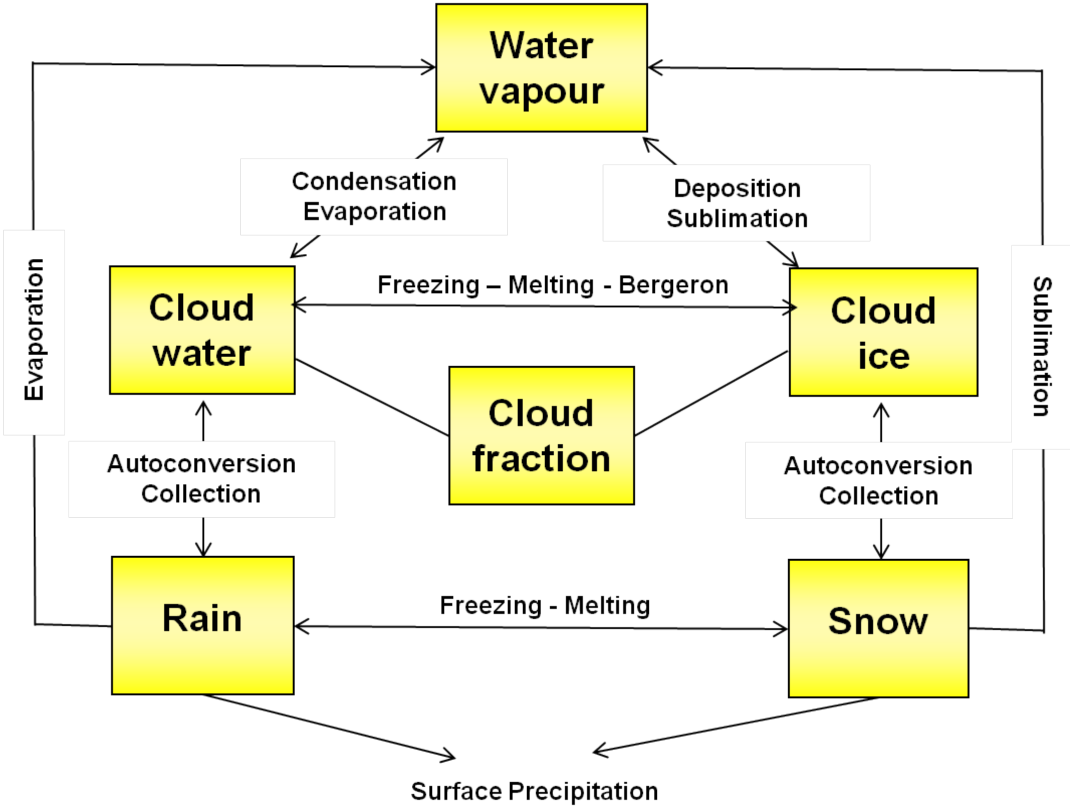


Cloud, Convection and Precipitation

nvective and stratiform precipitation and clouds



S stratiform cloud scheme



- 5 prognostic cloud variables + water vapour
- All advected with the wind
- Ice, snow and rain sediment
- Physically based parametrized processes

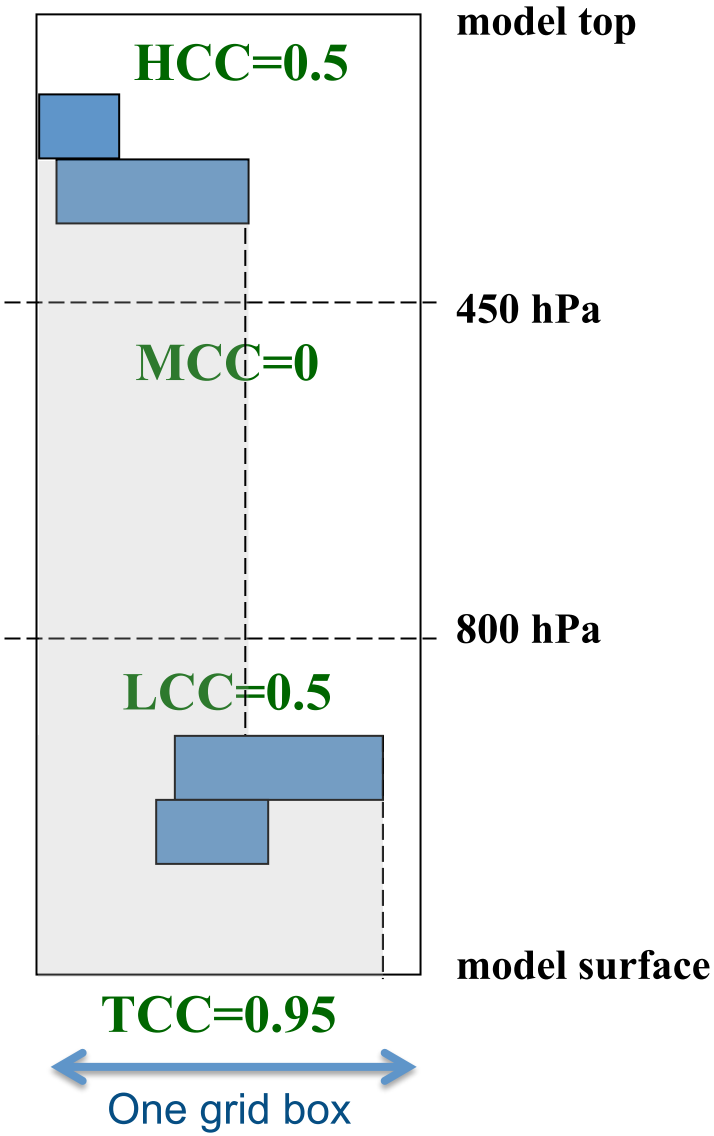
loud overlap

xample with:

o layers of
gh-level cloud (50%)

medium-level cloud

o layers of
v-level cloud (50%)



TCC = Total Cloud Cover

Model level clouds are integrated from surface to top of the atmosphere with overlap assumptions **based on global observations** (degree of randomness depends on distance between layers)

HCC = High-level Cloud Cover

Integrated from top to 450 hPa.

MCC = Medium-level Cloud Cover

Integrated from 450 to 800 hPa.

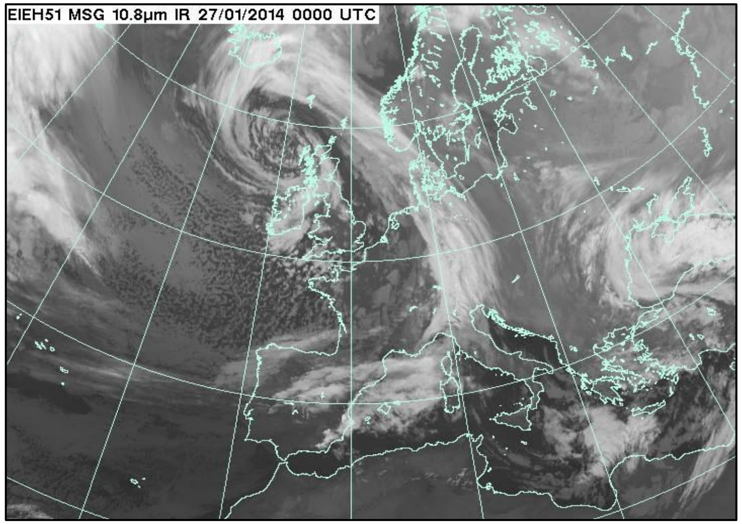
LCC = Low-level Cloud Cover

Integrated from 800 hPa to surface.

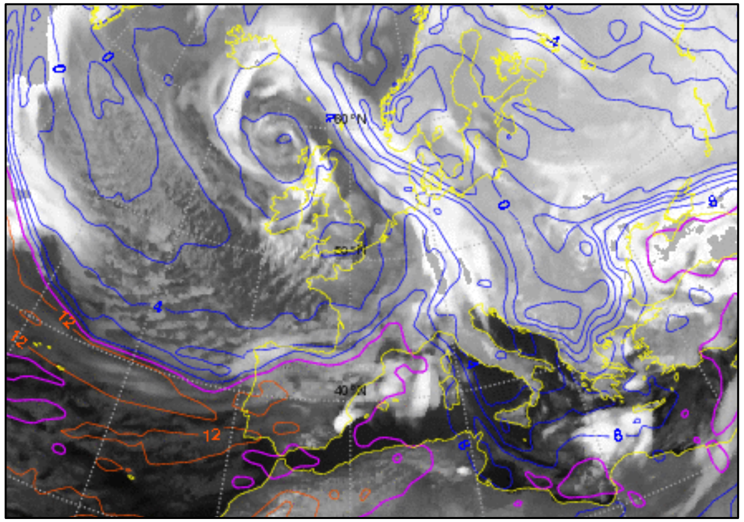
TCC <= LCC + MCC + HCC

oud: 00Z Monday 27 January 2014

Meteosat IR 10.8µm

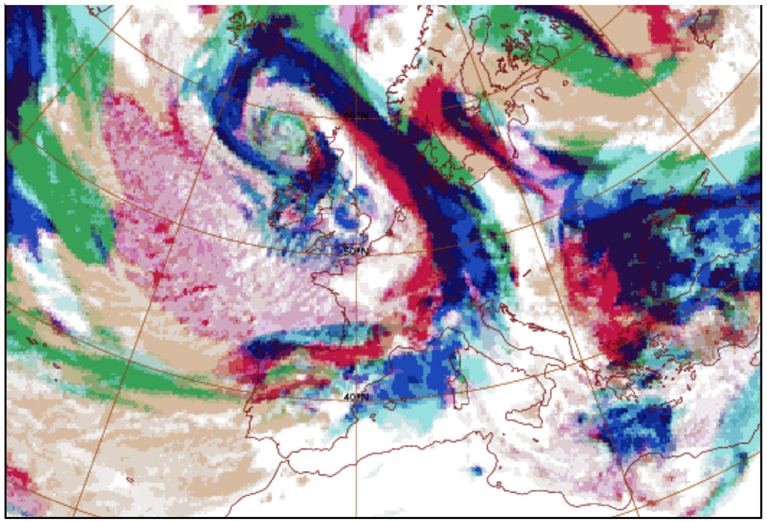


IFS Pseudo-IR 10.8µm

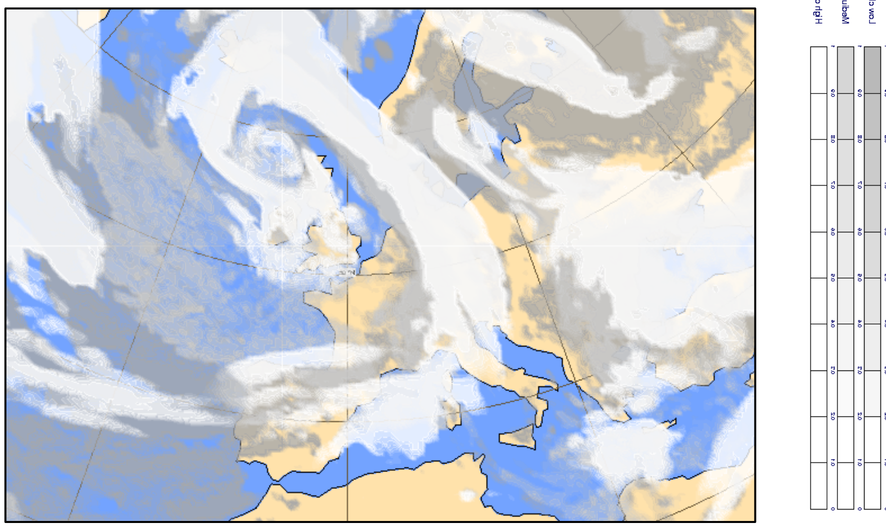


IFS cloud product (Low, Med, High and mixed)

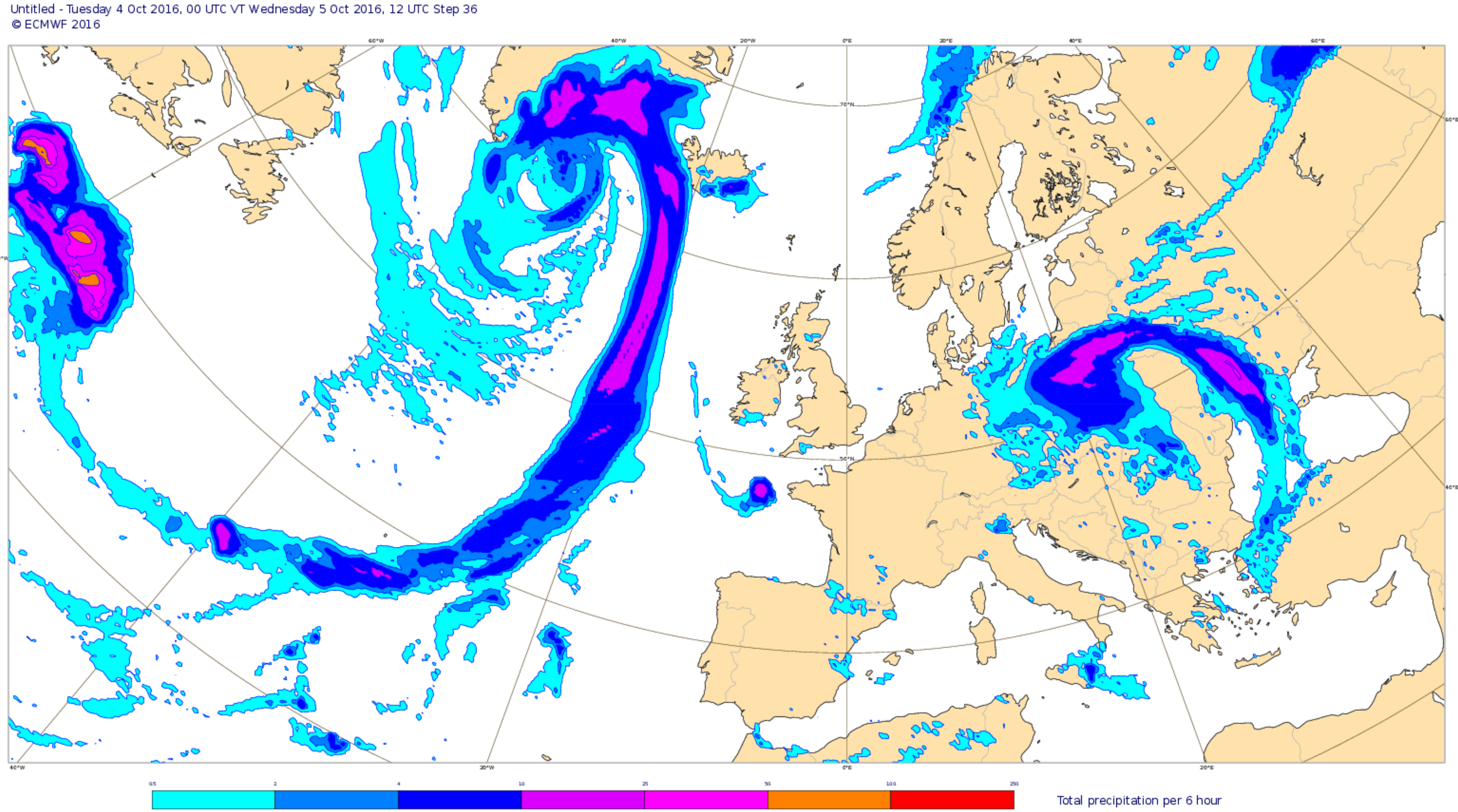
Low L+M Medium M+H High H+L H+M+L clouds



ECcharts IFS cloud product (Low, Med, High)

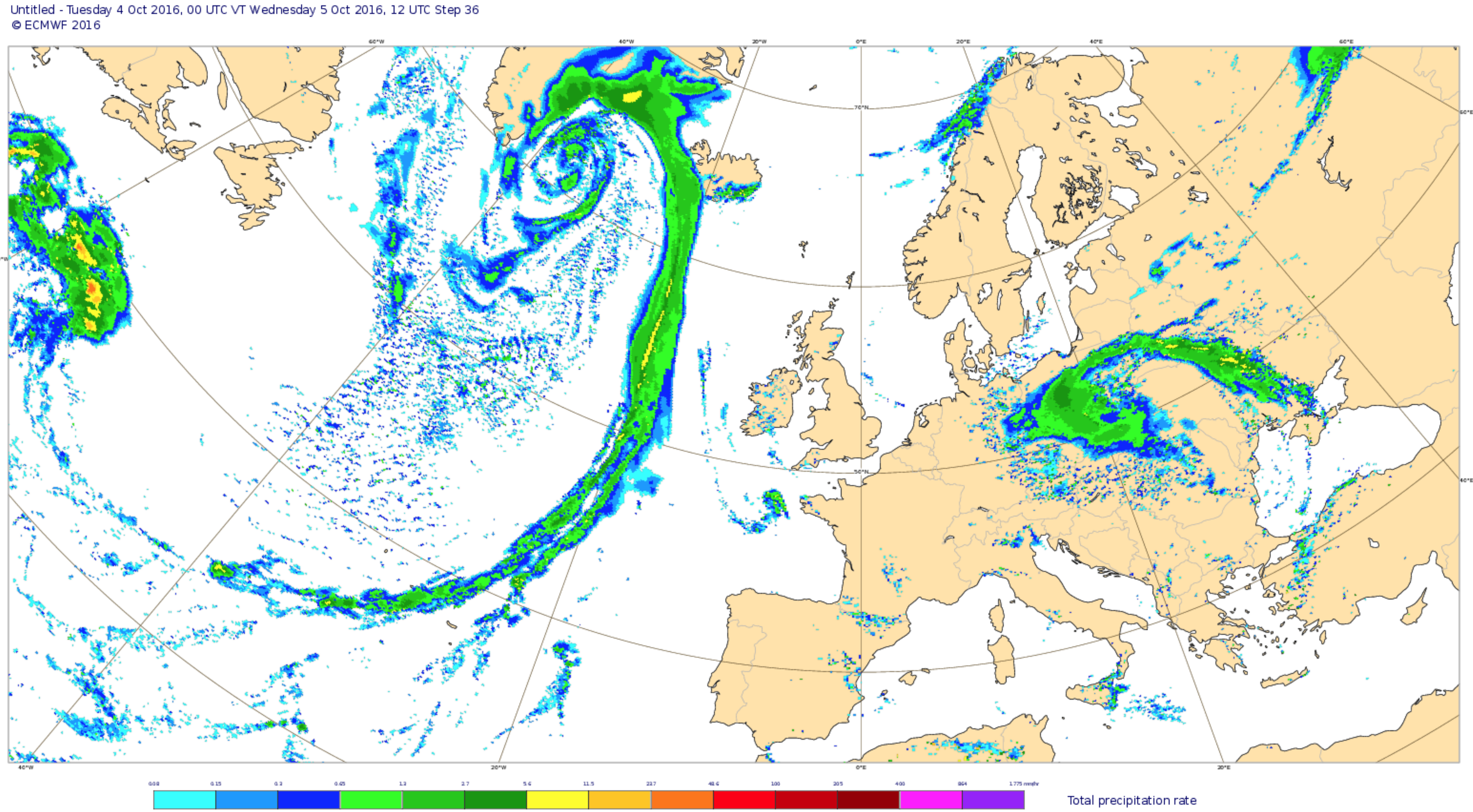


xample 6 hour precipitation accumulation
recast for Wed 5 October 2016



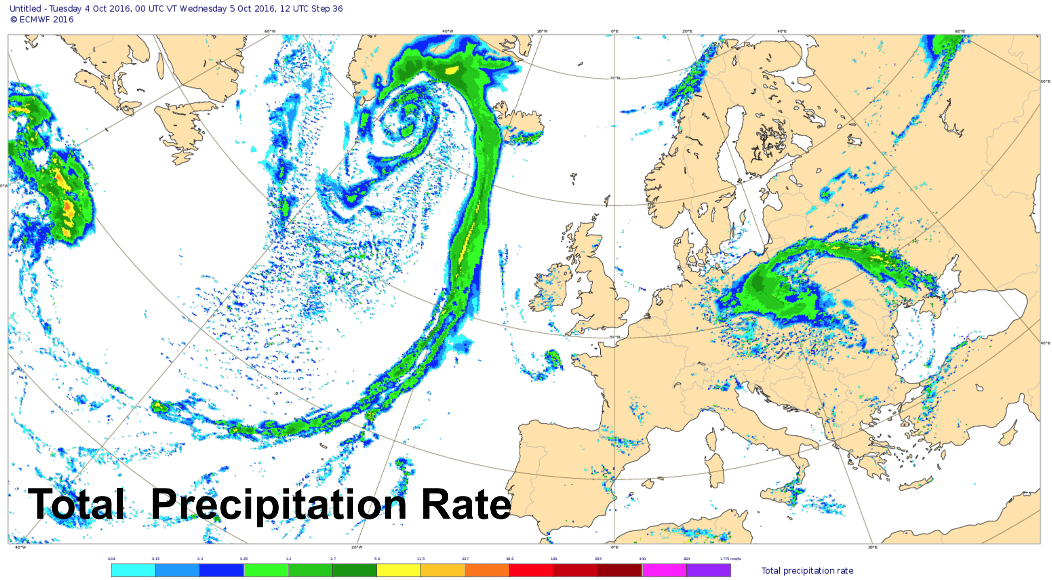
Precipitation Accumulation: Large-scale rain + convective rain + large-scale snow + convective snow

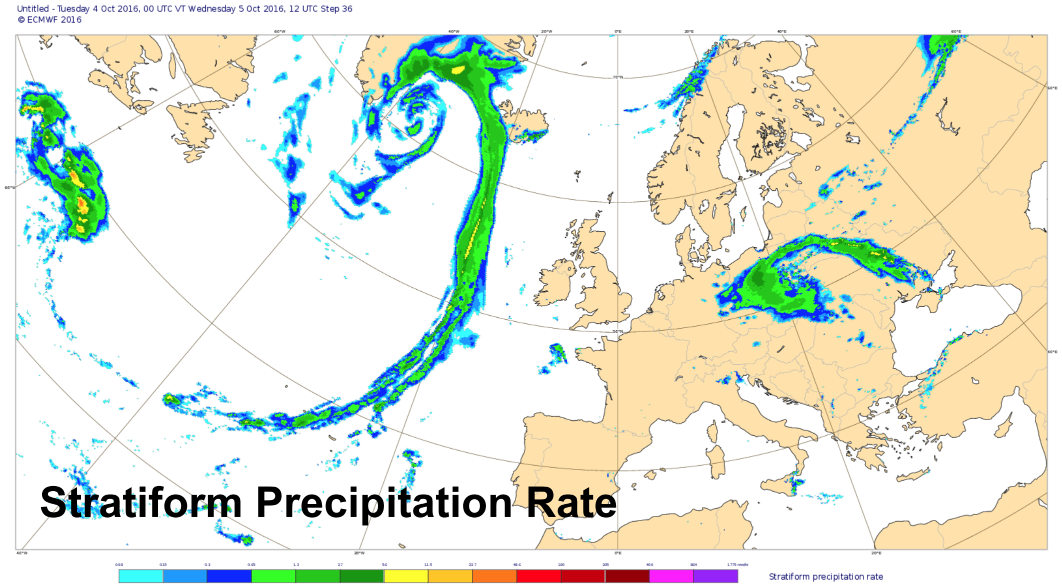
xample precipitation rate
recast for Wed 5 October 2016 12Z

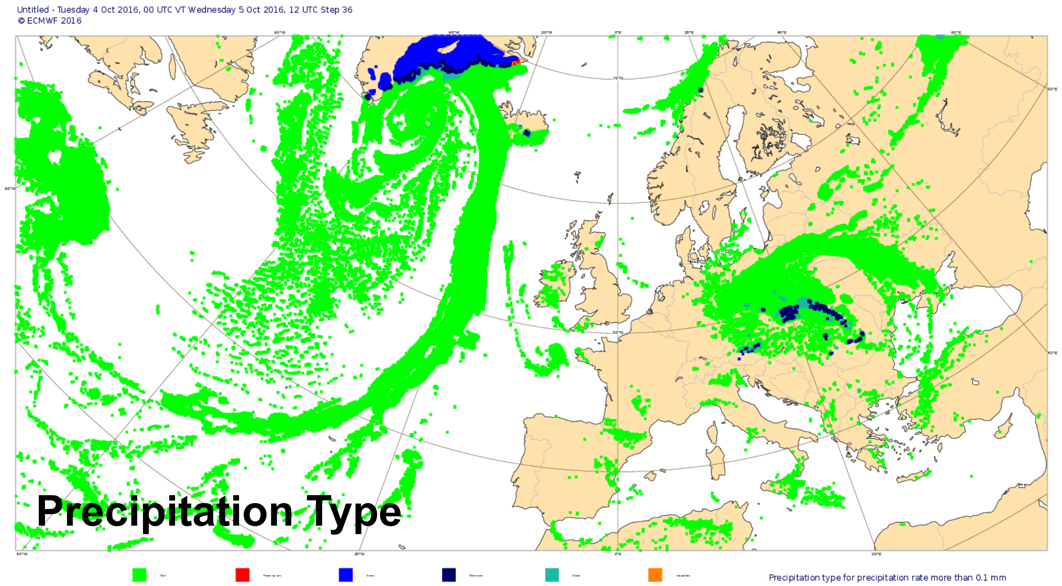


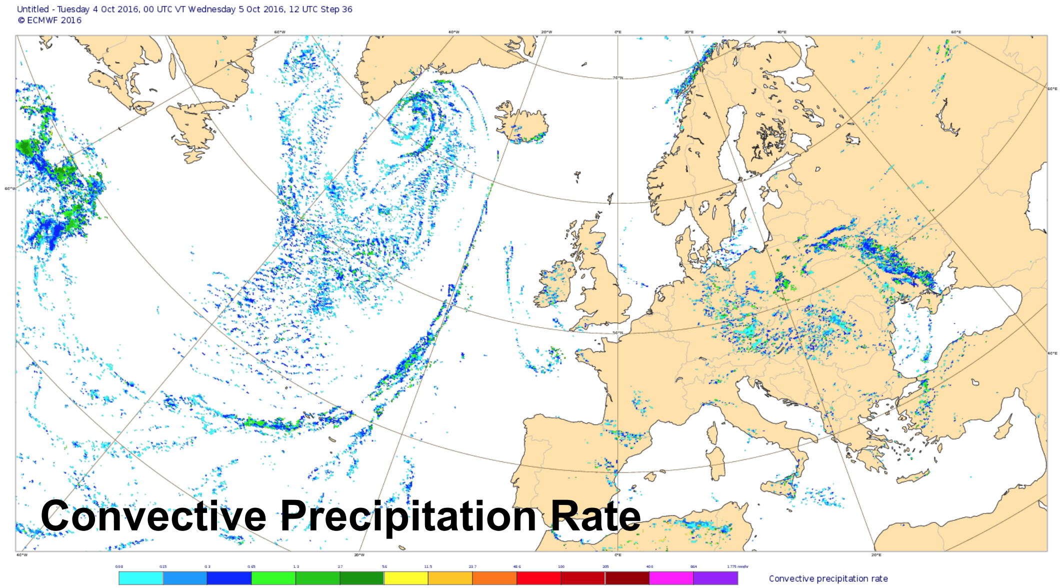
Precipitation Rate: Large-scale rain + convective rain + large-scale snow + convective snow

ecipitation rate and type example: 12 UTC Wed 5 October

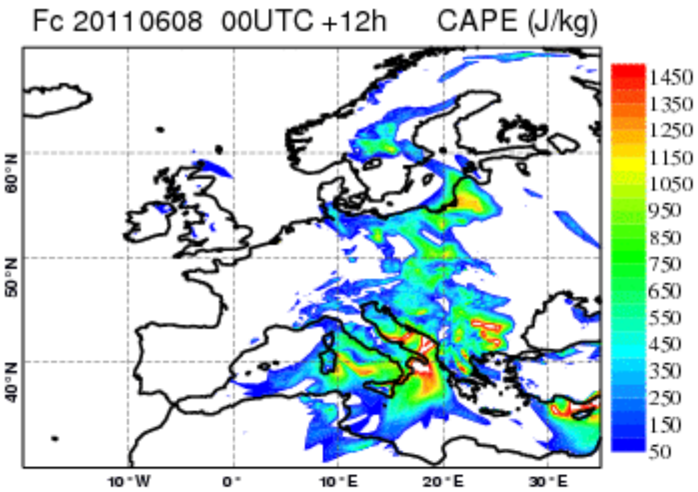


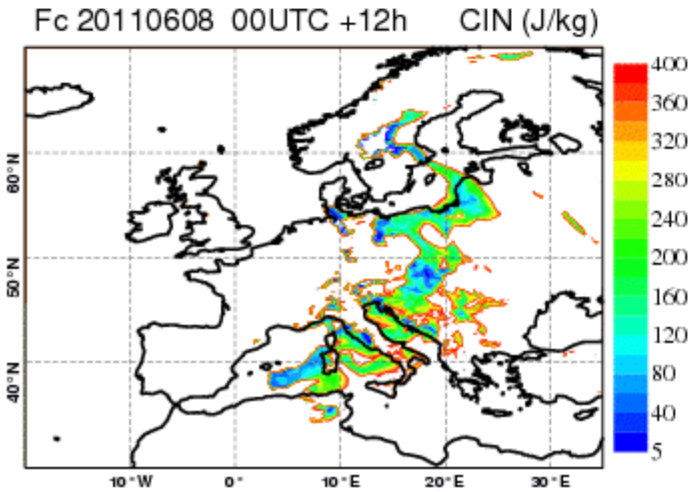


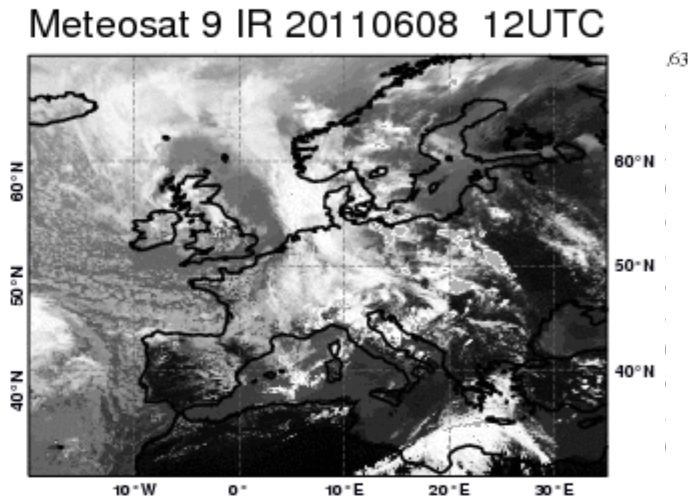


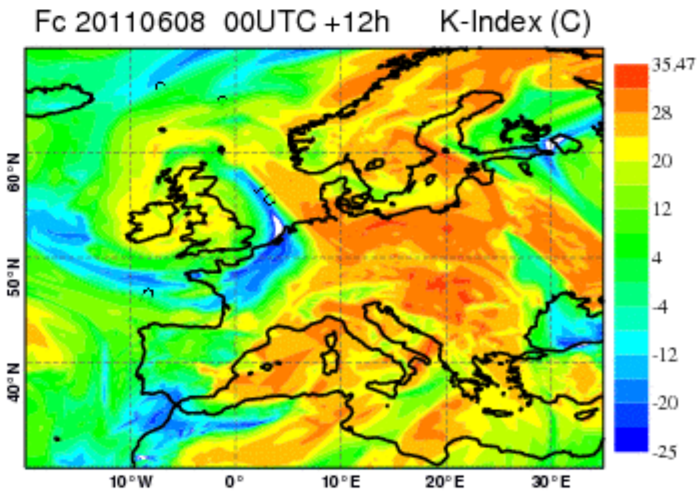


Convective Indices

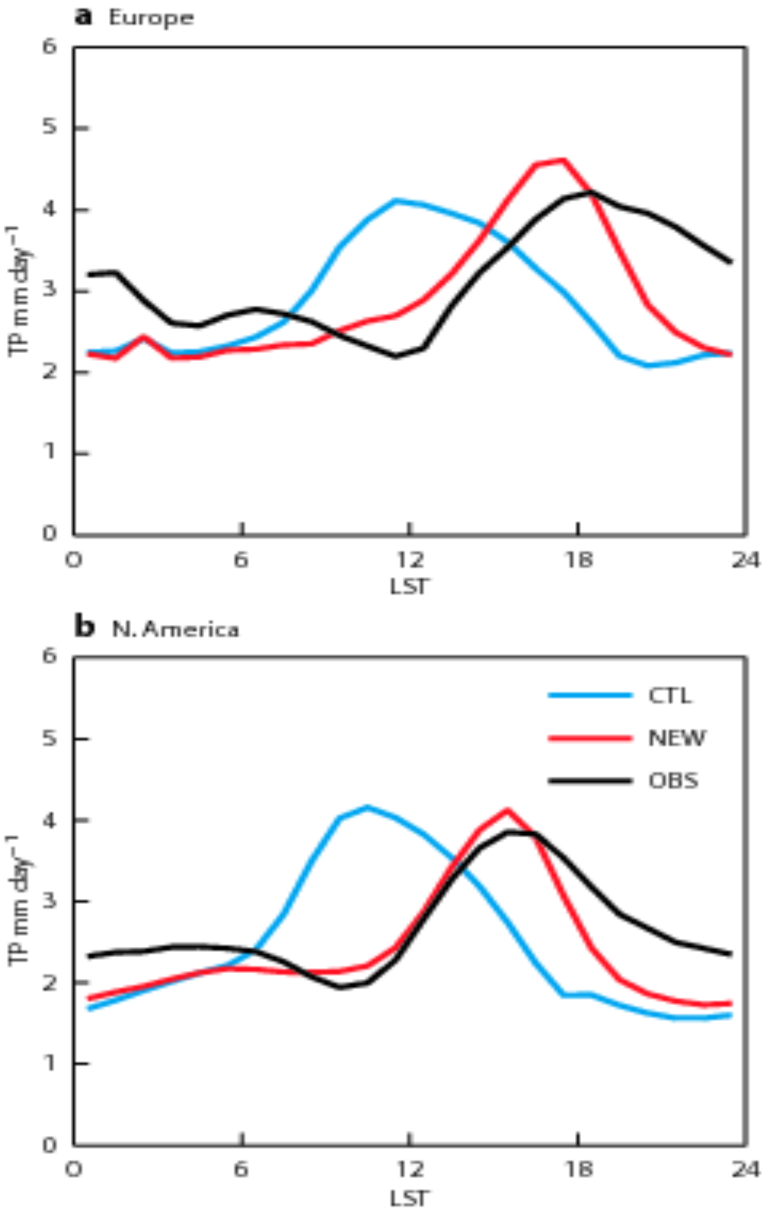








urnal cycle of convective precipitation:
ore realistic since Nov 2013



- Diurnal cycle of convective precipitation improved in IFS i 2013 (blue to red)
- Peak precipitation can still be up to 3 hours too early
- Underestimates evening/night-time precipitation due to lack of organisation

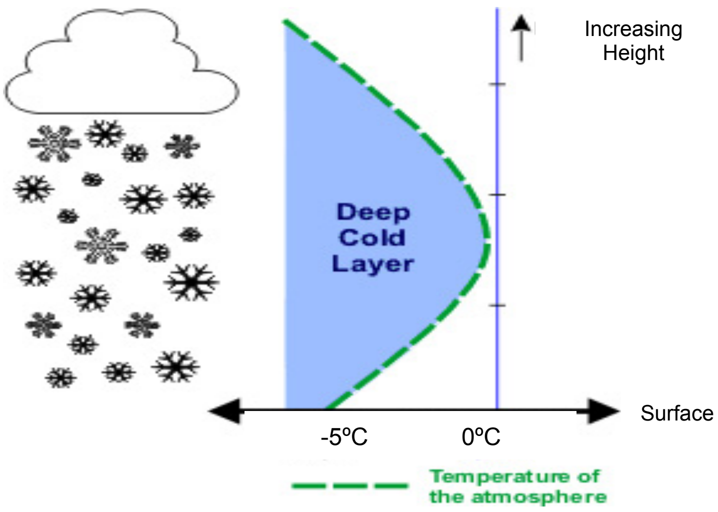
See ECMWF Newsletter No 136 Summer 2013
Bechtold et al., 2014, J. Atmos. Sci.

Winter Precipitation Type

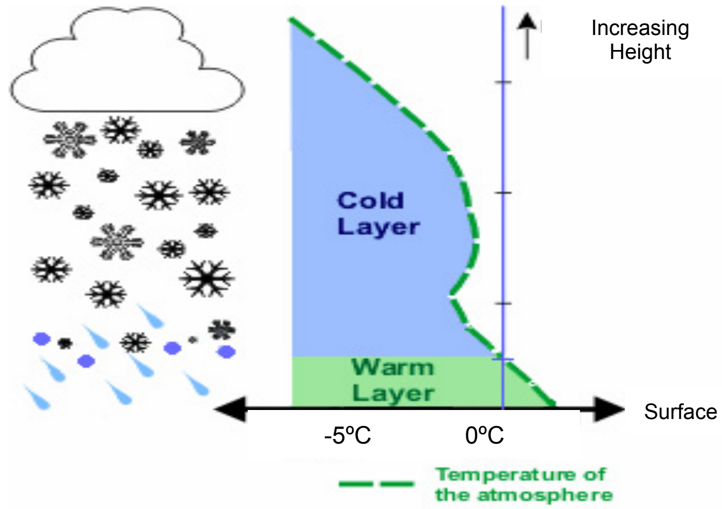
Freezing rain event
(Slovenia 2014)

Precipitation type – a parameter from the IFS

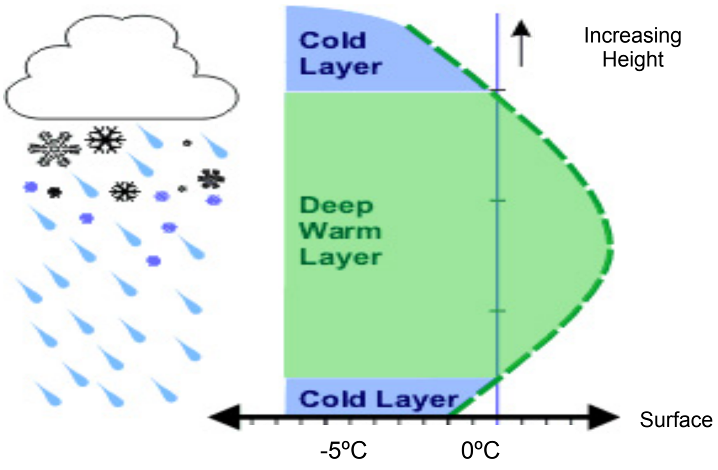
rain / snow / wet snow / mix rain-snow / ice pellets / freezing rain



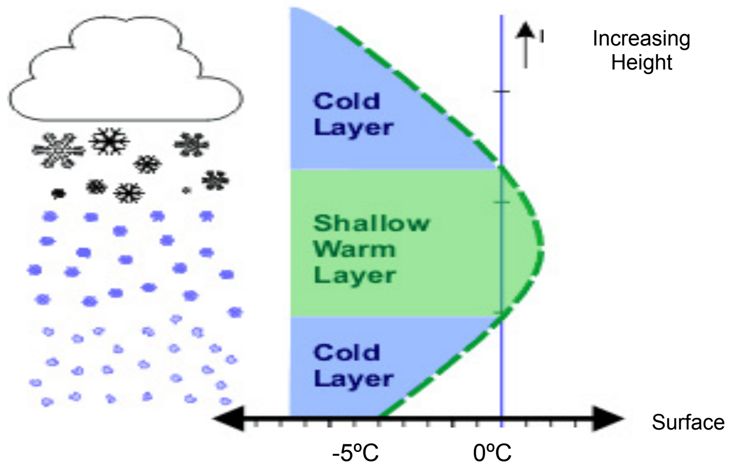
Snow



Sleet (melting snow) or rain



Freezing rain



Ice pellets

ecipitation parameters (from Cy41r1, May 2015)

- Precipitation type (valid at a particular time) (***ptype***)

(=1) Rain	T2m > 0°C, liquid mass more than 80%
(=7) Mixed rain/snow	T2m > 0°C, liquid mass >20% and <80%
(=6) Wet snow	T2m > 0°C, liquid mass less than 20%
(=5) Snow	T2m < 0°C "dry" snow
(=3) Freezing rain	T2m < 0°C supercooled rain from melted particles aloft
(=8) Ice pellets	T2m < 0°C refrozen from partially melted particles aloft

- Height of (uppermost) freezing level (***deg0l***)
- Accumulated freezing rain at the surface (***fzra***)
- Graupel/Hail not available
- Instantaneous precipitation rates (valid at a particular time)
  - Stratiform (large-scale) rainfall rate, and snowfall rate (***lsrr, lssfr***)
  - Convective rainfall rate, and snowfall rate (***crr, csfr***)
- Maximum and minimum total precipitation rates in the last 3 hours/6 hours (***mintpr3,maxtpr3, mintpr6,maxtpr6***)

edicting high-impact freezing rain events

Case Study: Slovenia/Croatia 02 Feb 2014

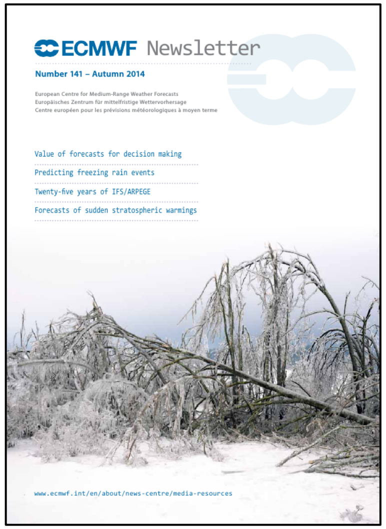
Freezing rain caused severe disruption and damage, tranports/power/forests…

IFS physics at the time (40r1) not able to predict

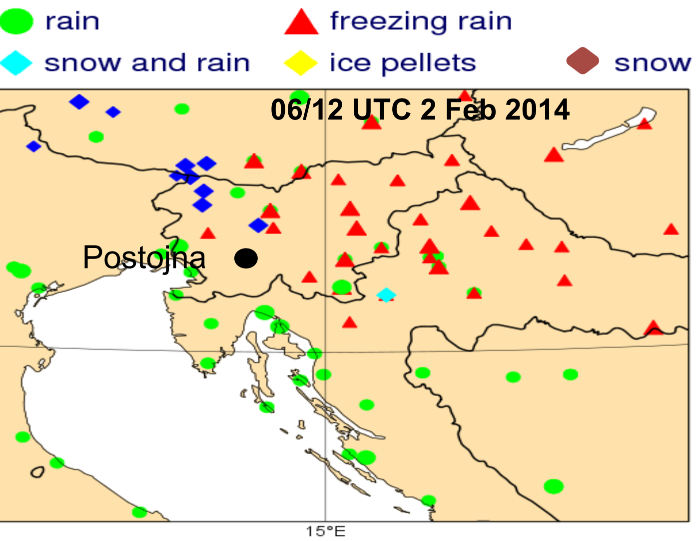
New physics in 41r1 allows prediction of freezing rain events

Evaluation in HRES/ENS shows potential for useful forecasts

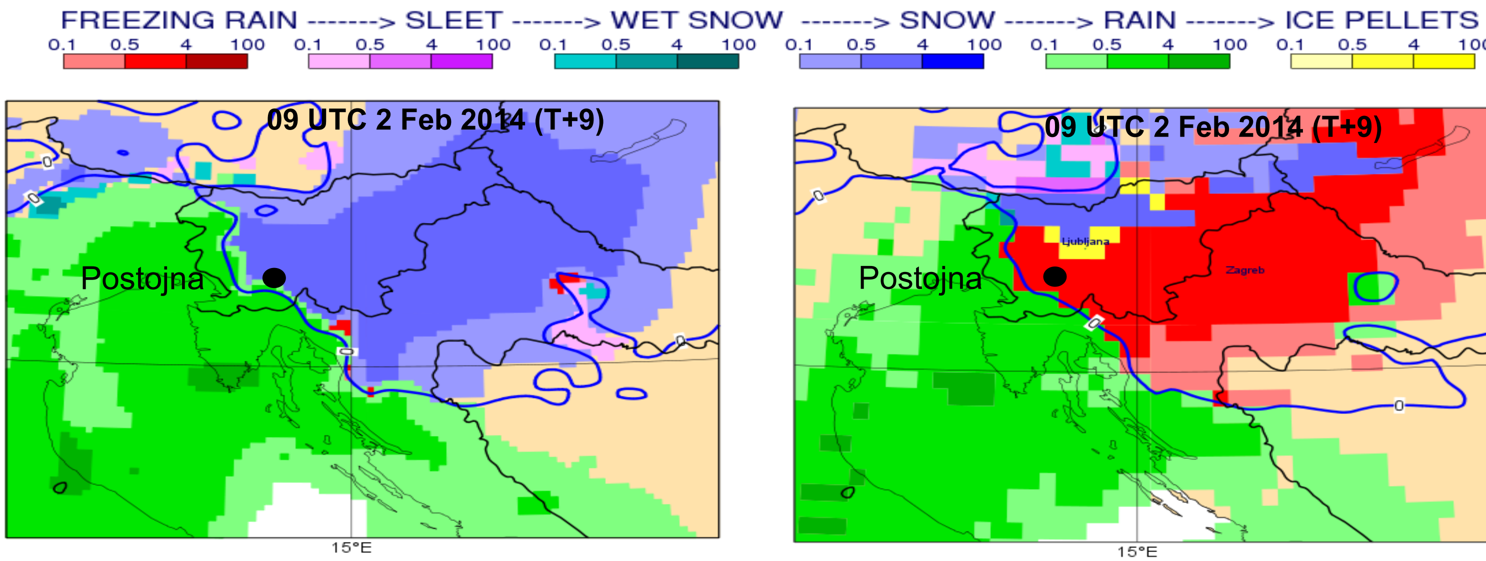
Article in EC Newsletter Autumn 2014 (but note results below are with new rain freezing physics)



ECMWF Newsletter 141



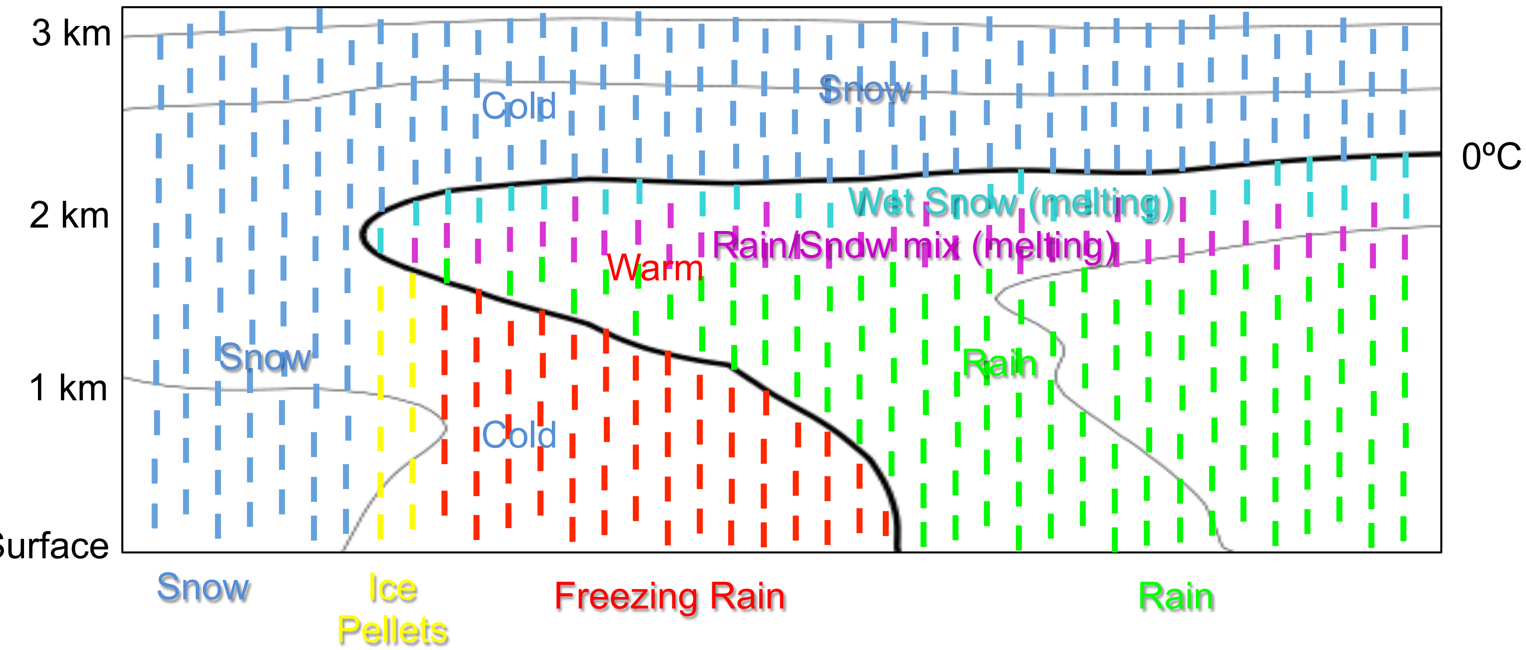
SYNOP Observations

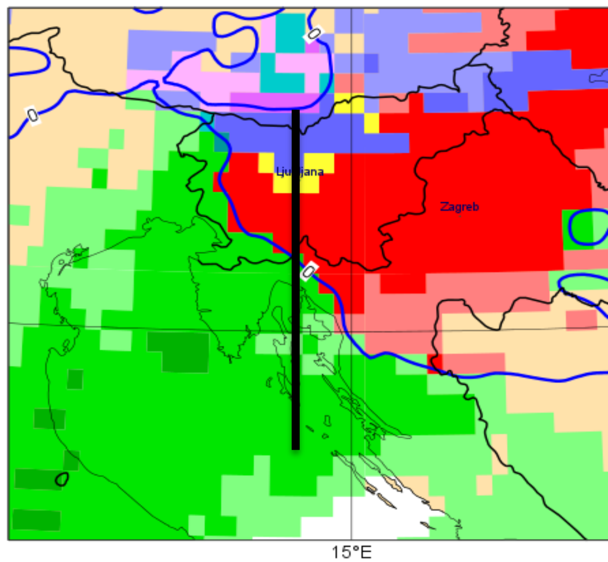


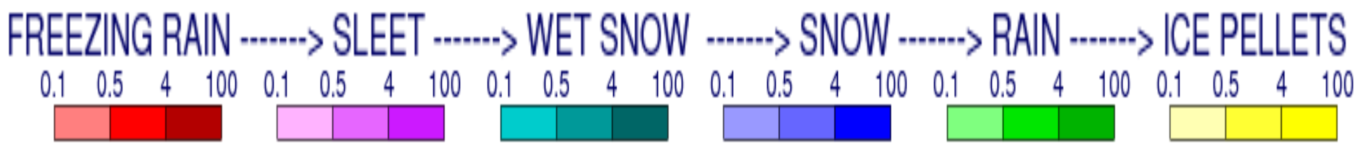
IFS HRES 40r1

IFS HRES 41r1

Schematic cross-section (front with elevated warm layer)

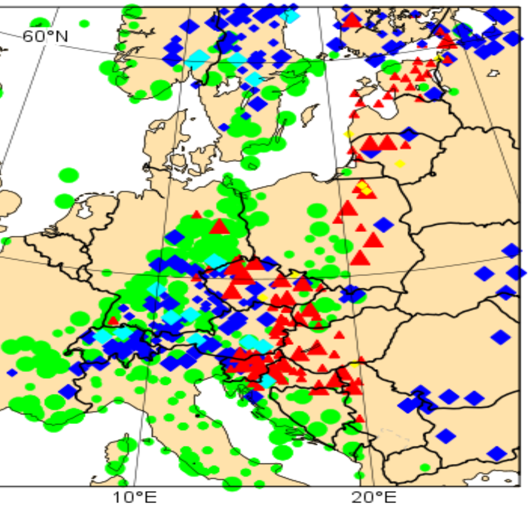






obability of freezing rain accumulation from the IFS ensemble

se Study: 02 Feb 2014



Obs

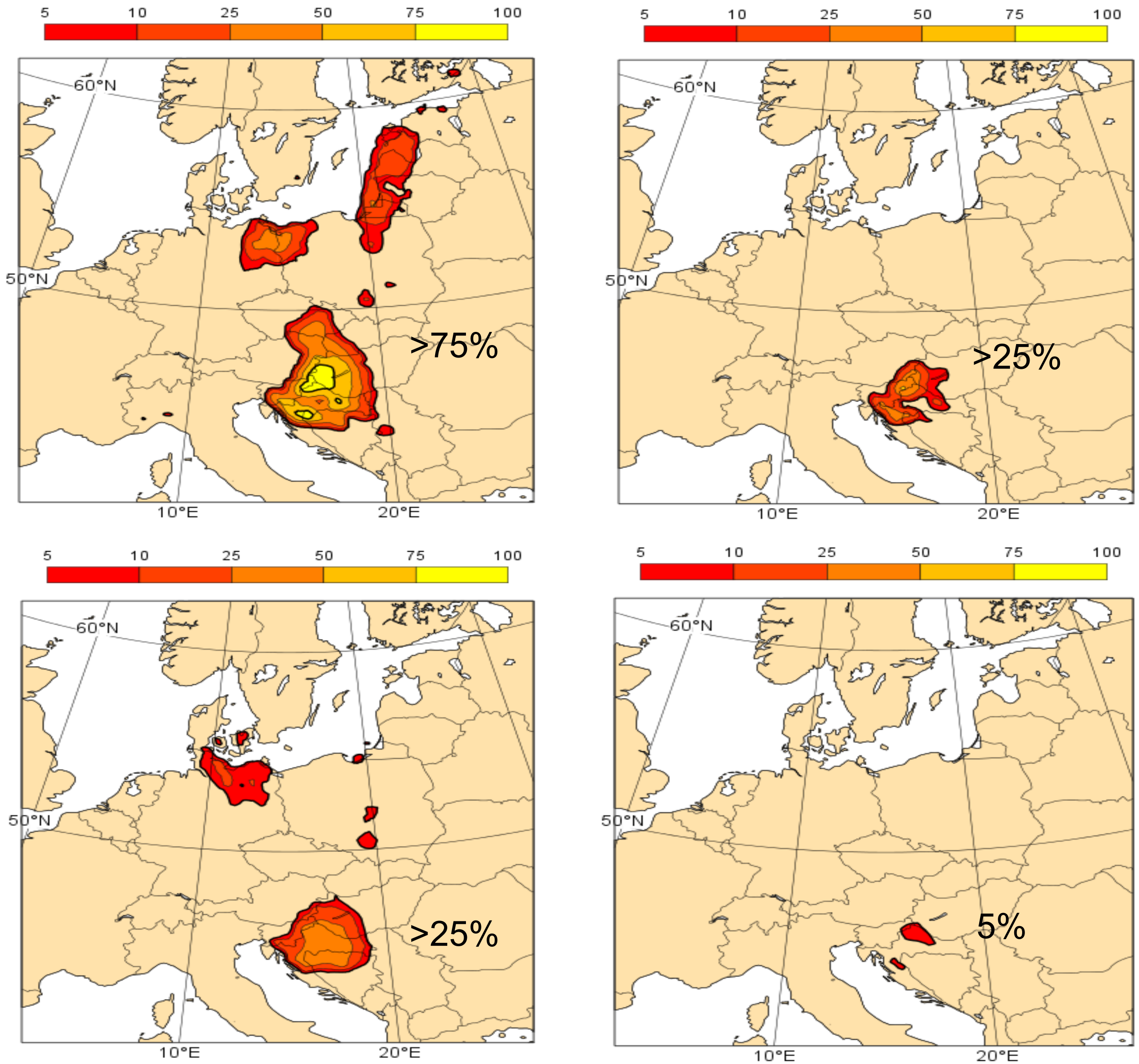
- rain
- snow
- freezing rain
- snow and rain
- ice pellets

Prob (fzra > 1mm)

Prob (fzra > 5mm)

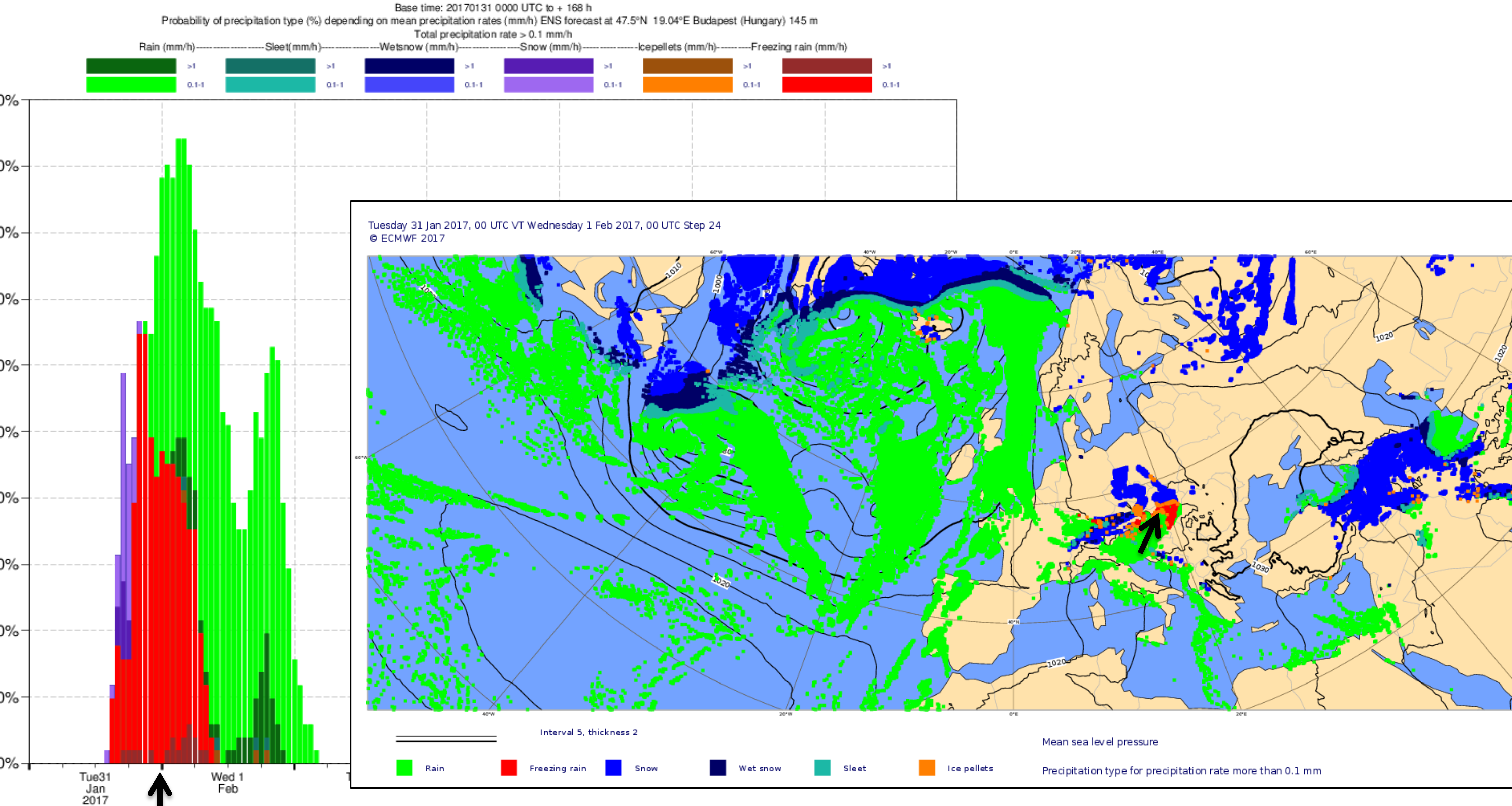
Day 3 forecast

Day 5 forecast



nsemble probability of precipitation type time sequence

udapest, 00Z 31 Jan 2010



Visibility and Fog

isibility (Fog)

ailable operationally since May 2015)

sibility is calculated using an exponential scattering law and a visual range defined by a fixed liminal contra 0.02 based on extinction due to clean air, aerosol, cloud and precipitation near the surface (nominally 10m

Visibility = fn (clear air + aerosol + cloud liquid + cloud ice + rain + snow

Aerosol: seasonally varying based on 10 year CAMS aerosol climatology (since July 2017)
Fog: predicted near-surface cloud liquid water/ice
Precipitation: reduced visibility due to predicted near-surface falling rain and snow

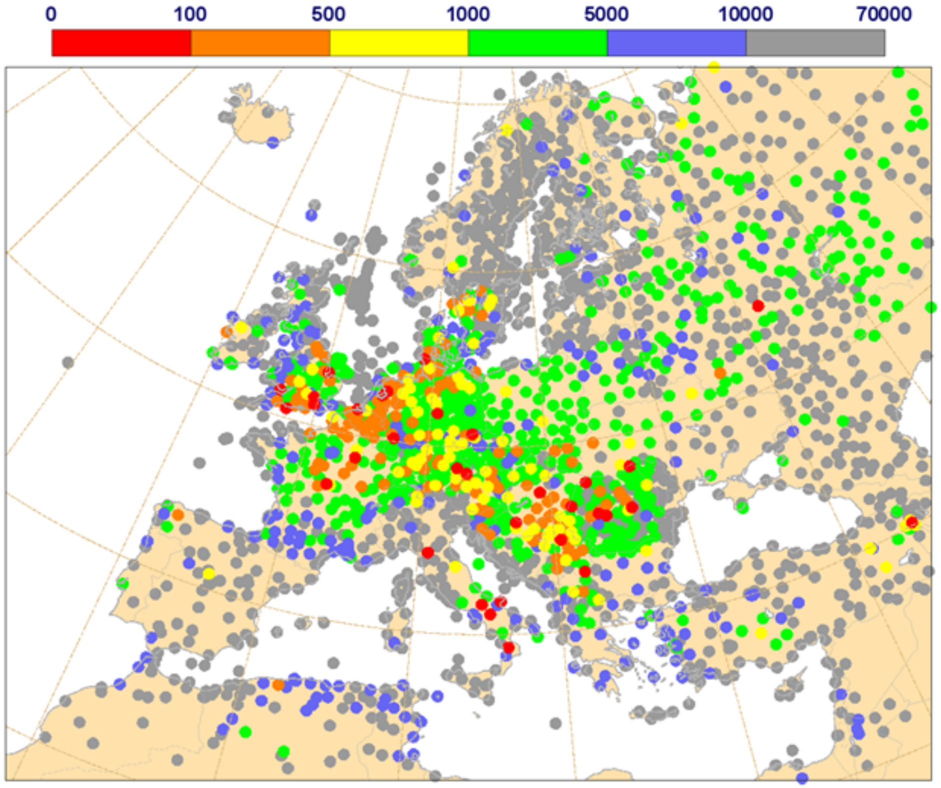
lany limitations!

- "Aerosol climatology" – will not represent reduced visibility with pollution events etc.
- Visibility in fog is on the low side (often < 100m) – need to revisit the assumptions
- Fog is highly spatially variable! – can't capture local effects of orography and surface heterogeneity
- Fog prediction dependent on fine balance of physical processes (radiation, turbulence, microphysics)
- Use of probability of fog (vis < 1 km) from the ensemble potentially useful…

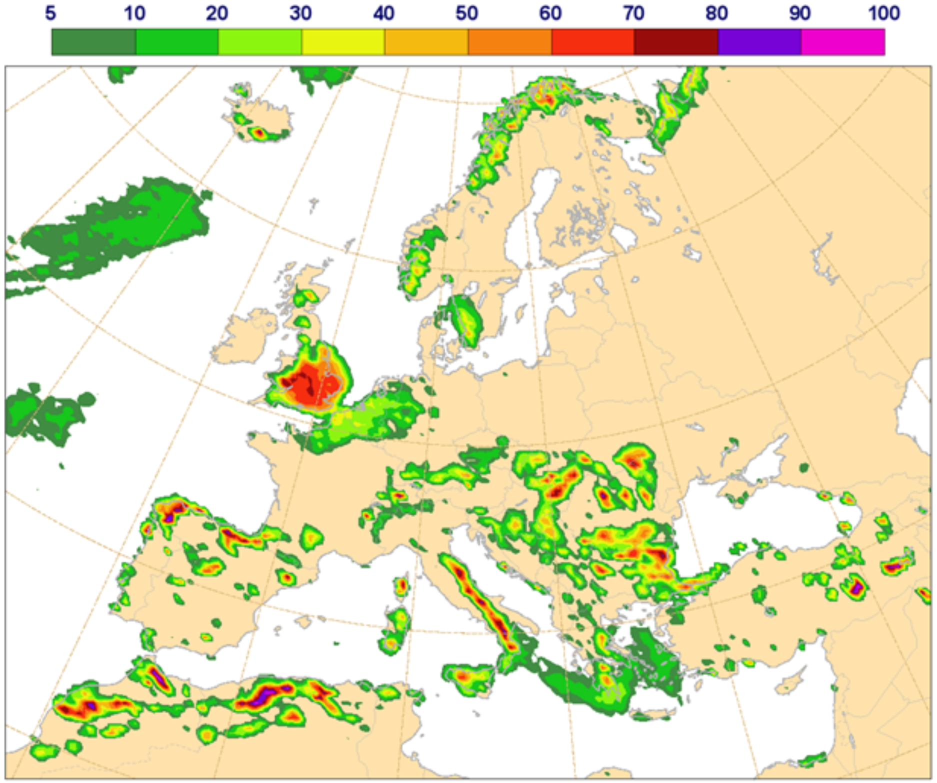
rediction of severe weather: Visibility/Fog

ase study: 24 Jan 2017, 3 day probability forecast from IFS ensemble

Visibility OBS 24/01/2017 06 UTC



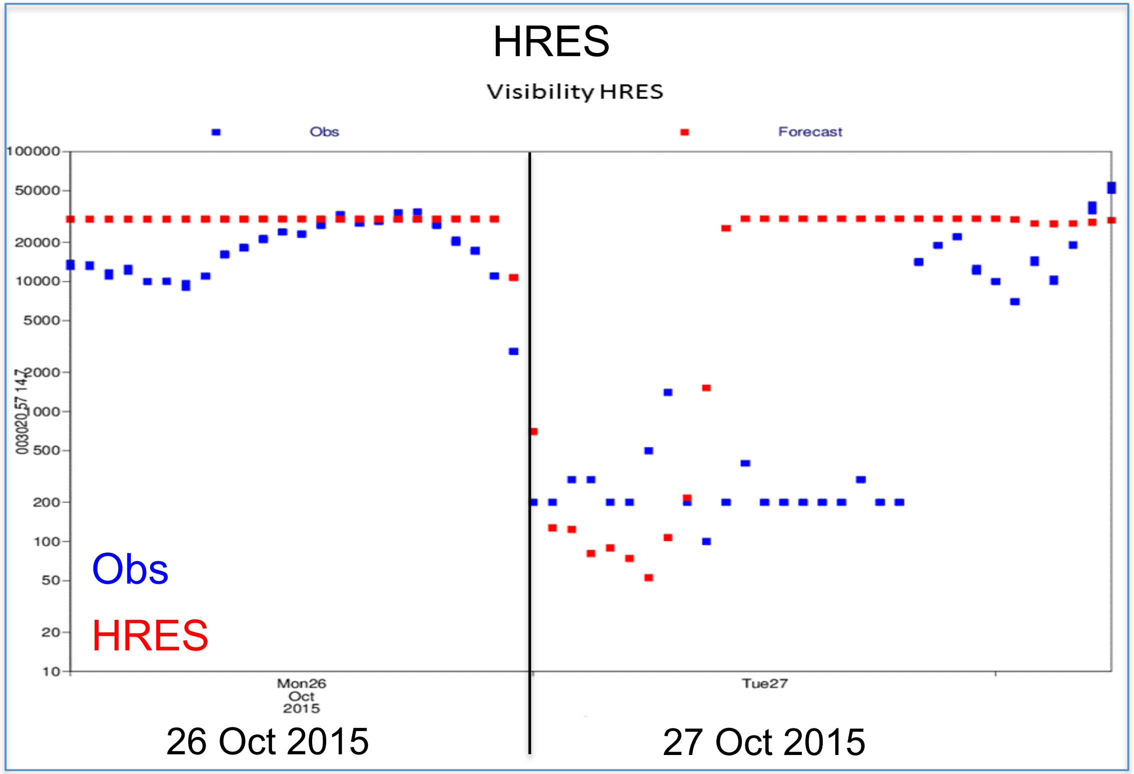
ENS T+78h VT:24/01/2017 06 UTC
Probability of fog (vis. < 1000 m)

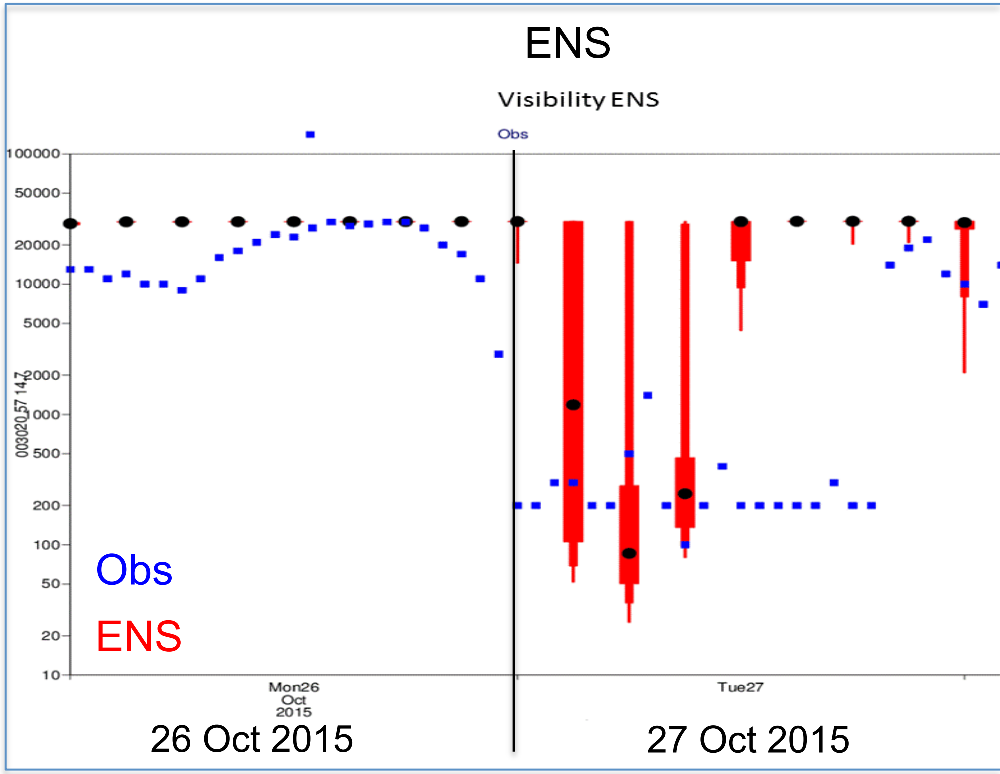


ediction of severe weather: Visibility/Fog
se study: 27 Oct 2015 - Fog in southern Sweden

Onset well predicted by HRES, but clears too early

ENS shows spread early on but also doesn't capture the fog staying later in the day





Recent and upcoming products from the IFS

Recent and upcoming products from the IFS

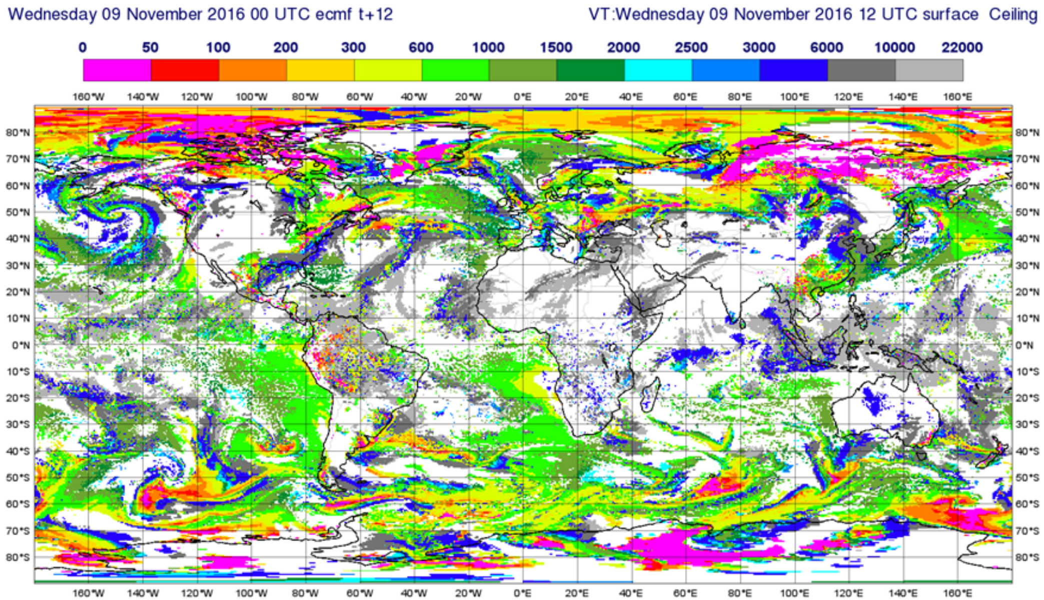
New parameters in IFS 43r1 (from Nov 2016)

- ceiling (m) – cloud base height (>50% cloud cover),
- convective cloud top height (m)
- height of 0 and 1°C wet bulb temperature (m)
- direct beam surface radiation (plane perpendicular to the Sun's direction – accumulated)
- wave energy flux magnitude and direction

New parameters in IFS 45r1 (early 2018):

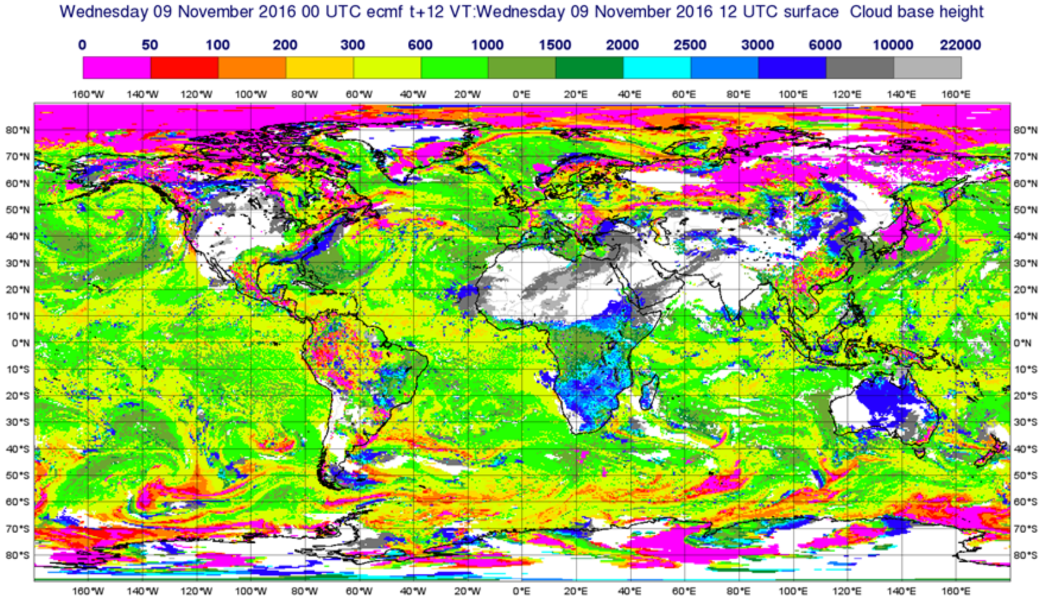
- total lightning flash density (instantaneous and average)
- total precipitation rate (instantaneous)
- maximum CAPE in last 6 hours
- maximum CAPESHEAR in last 6 hours (CAPESHEAR = windshear$^{(925\text{-}500hPa)}$ x SQRT(CAPE))

lew parameters in IFS 43r1 (from Nov 2016)
eiling (for aviation)



Ceiling (m)

= the height above the surface of the lowest la
of cloud covering more than half the sky

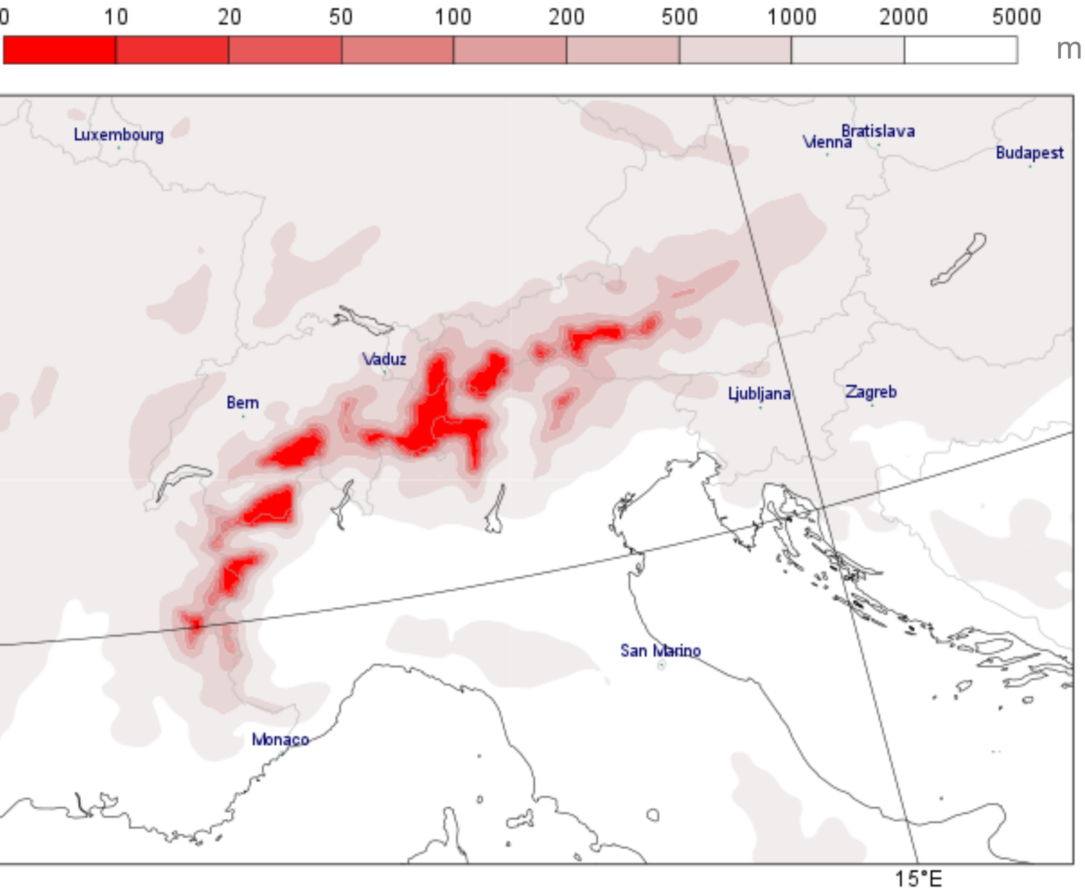


Cloud base height (m)

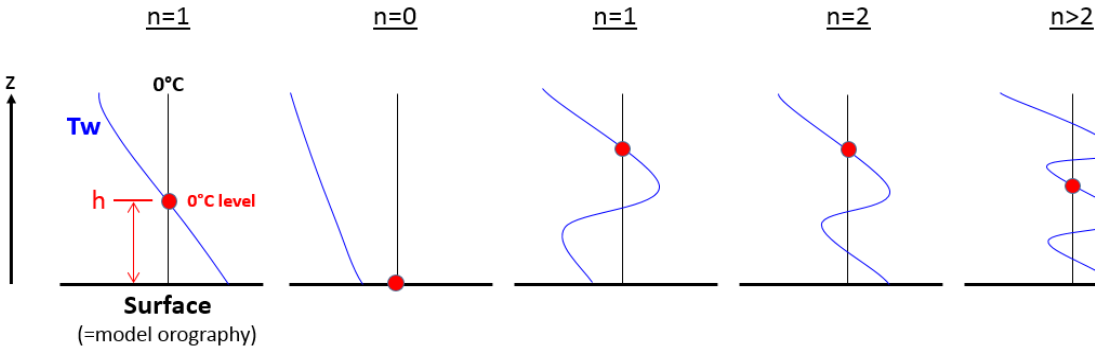
lew parameters in IFS 43r1 (from Nov 2016)

eight of 0°C and 1°C wet bulb temperature

Height of 0°C wet-bulb temperature above surface
Example: 3 day forecast valid 00Z 2017-10-04



…if multiple values in the profile, then it is the heig
of the second decreasing crossover from the surfa

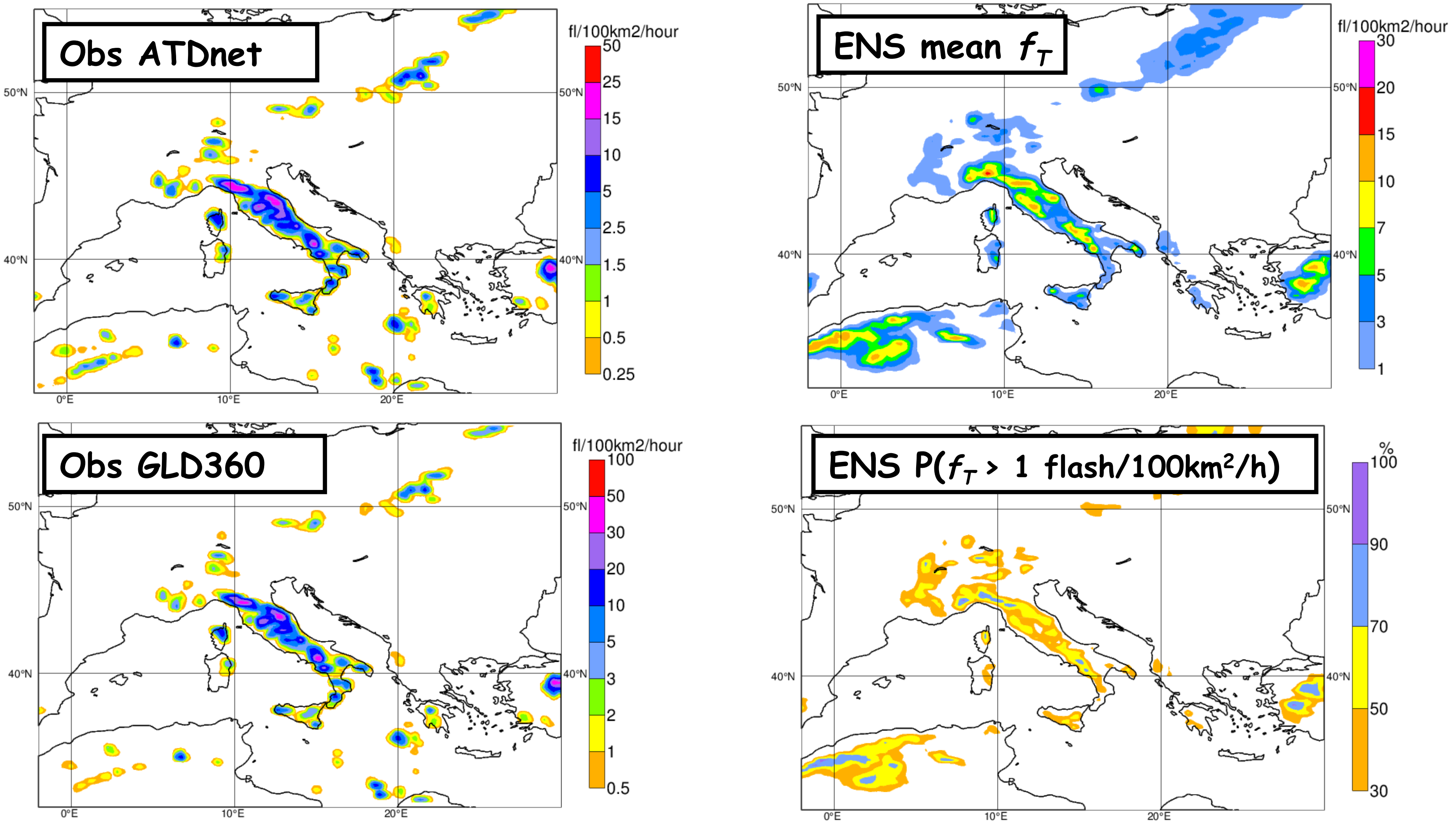


Blue lines show wet bulb temperature profiles, in different scenarios
n = number of levels at which Tw drops below zero when scanning upwards

Stored value = h, where h = height above model orography, or lake/sea (in metres)

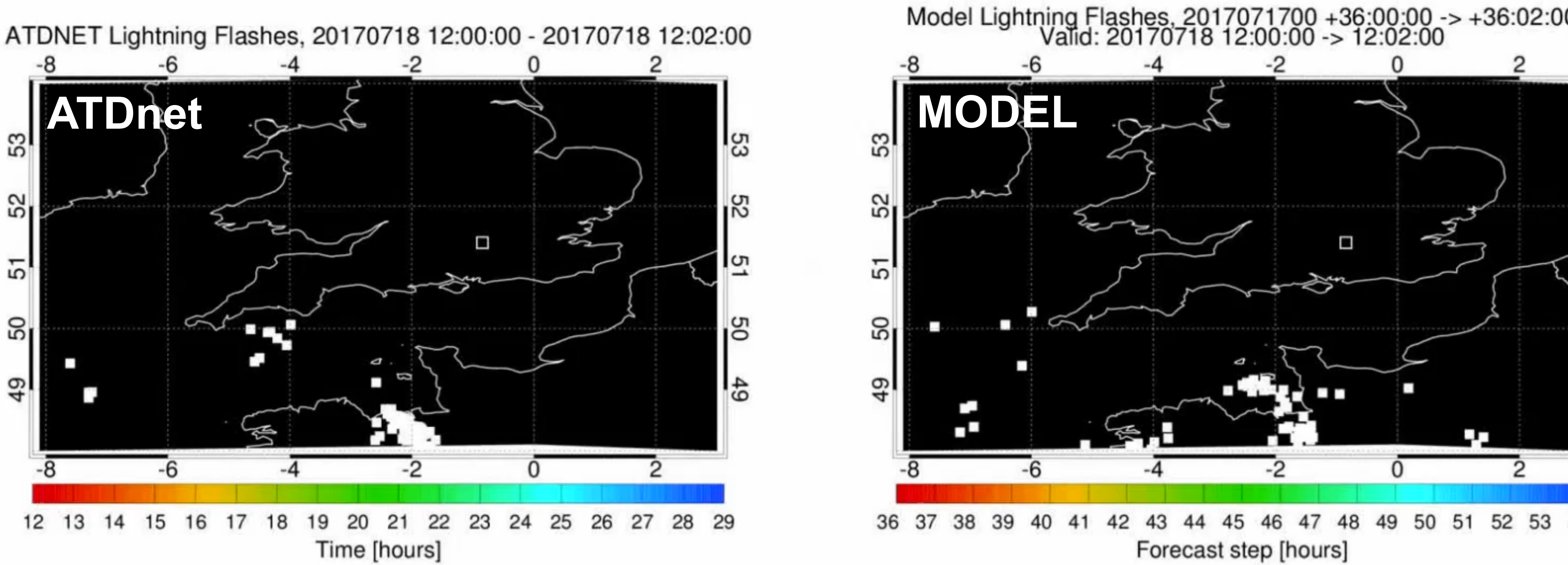
ew parameters in IFS 45r1 (early 2018): Total lightning flash density

Example of 15h ENS global forecasts (31 members) from 9 Aug 2015 at 00Z.



Comparison of model with ATDnet (Met Office) lightning flashes

18h animation of 2-mn flash data starting from 18 July 2017 at 1200 UTC.
TCo1279 L137 model forecast +36h → +54h



Summary

Summary
Some issues for improvement

- T2m can still be difficult, particularly winter: 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 can still be improved
- Melting of fresh snow on ground somewhat too slow
- Visibility in fog too low
- …

ummary
he physics behind the products @ ECMWF

- A bit of background for the physics behind weather parameters
- Some of the difficult forecasting situations and systematic errors in the IFS
- Emphasise use of ensemble products - most useful in medium-range
- Feedback welcome!!!

Thank you for listening! Questions? Feedback?