The physics behind the products

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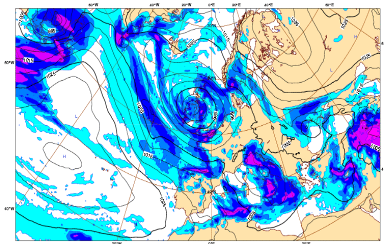
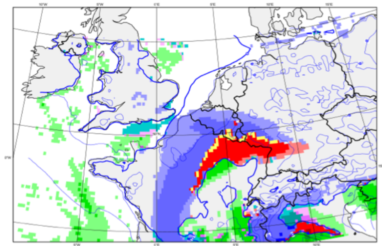
Thanks to Peter Bechtold, Philippe Lopez, Estibaliz Gascon and many colleagues at ECMWF!

Outline

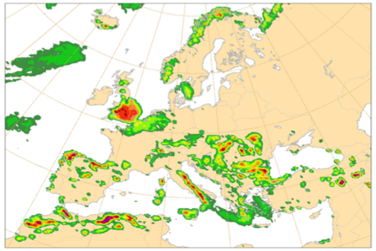
The physics behind the products @ ECMWF

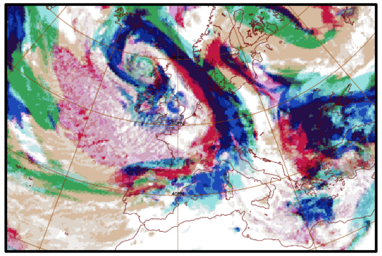
Ensemble Mean
Shift Of Tails
Inter-quartile range
Probabilities
Skill Scores
Cost-Loss Ratios
Extreme Forecast Index
Ensemble Spread
Medium-range forecasts
Extended-range



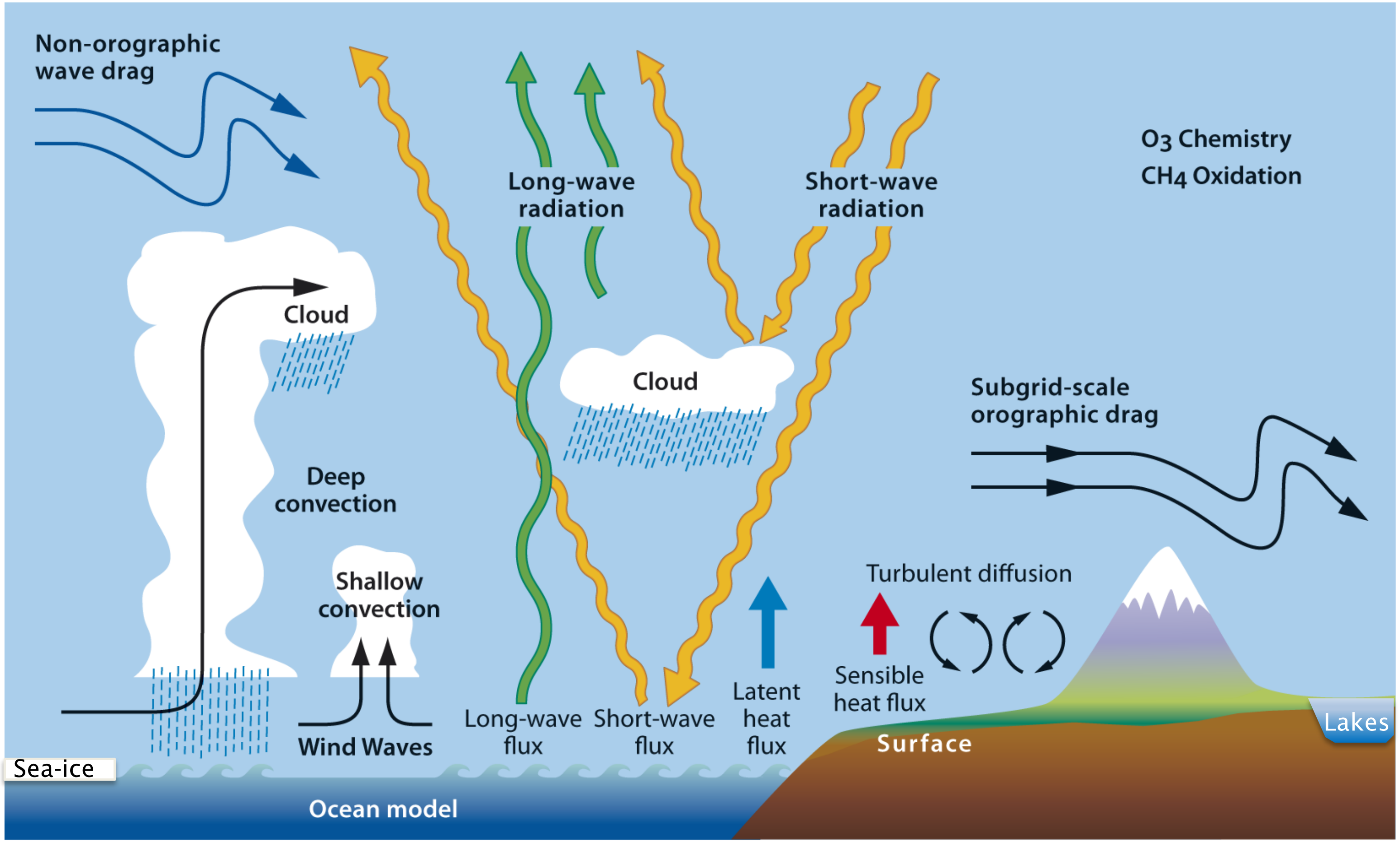


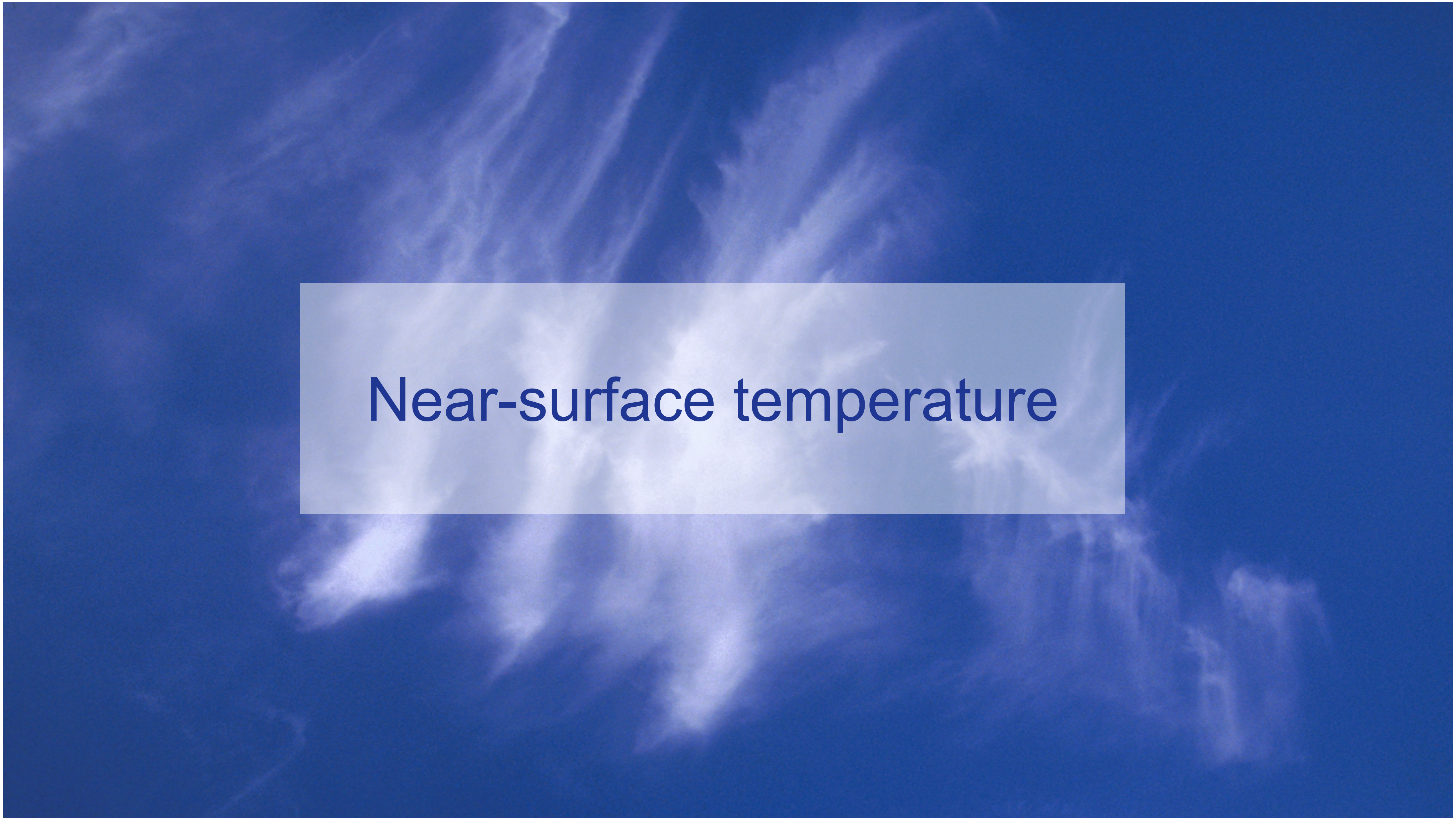
- 2m temperature
- 10m wind, windgusts
- Cloud and precipitation
- Winter precipitation
- Visibility/fog
- Lightning





Parameterized processes in the ECMWF model




Near-surface temperature

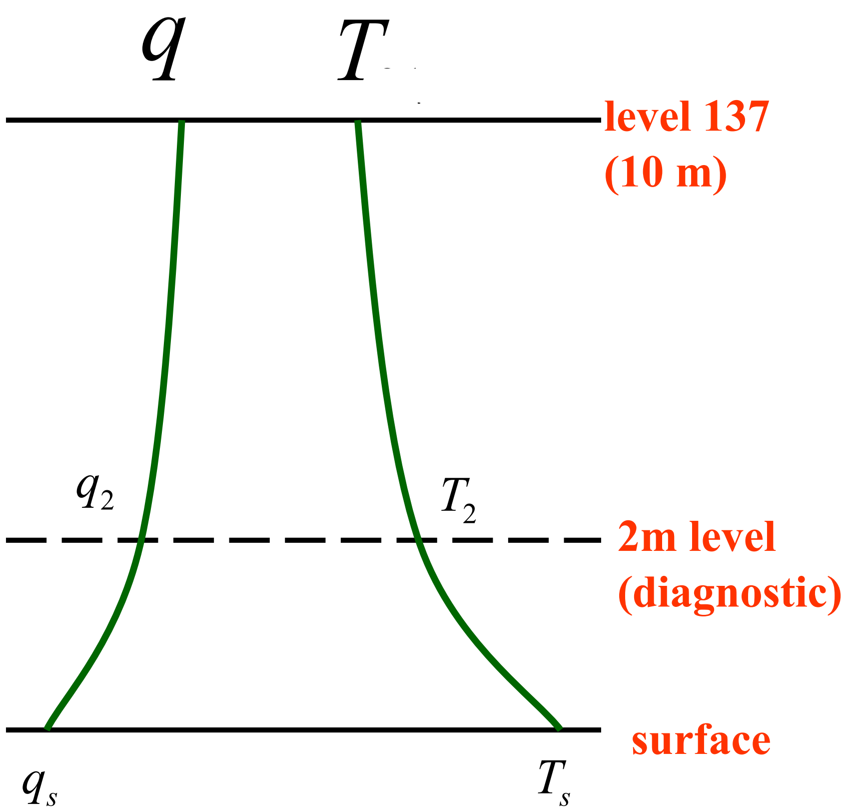
Near-surface temperature

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 > 5degC
- Focus on T2m improvement

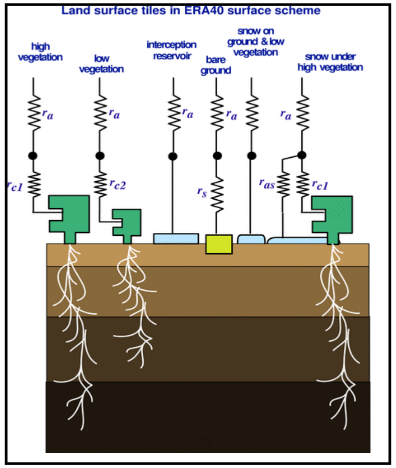
Temperature (T) and humidity (q) interpolation to the 2m level



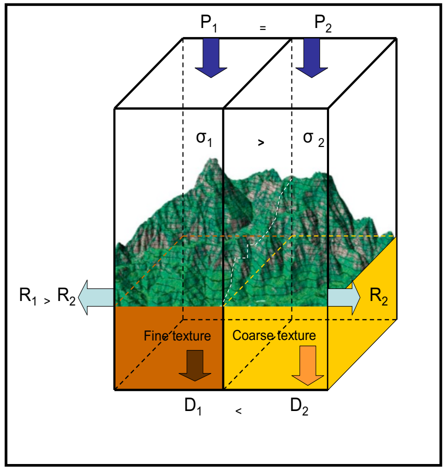
- Surface temperature and humidity (T_s and q_s) are determined by the land surface scheme/sea surface temperature.
- Main purpose of land surface scheme is to provide correct area averaged fluxes of heat and moisture.
- Land surface scheme considers different sub-areas (tiles).

Land surface model

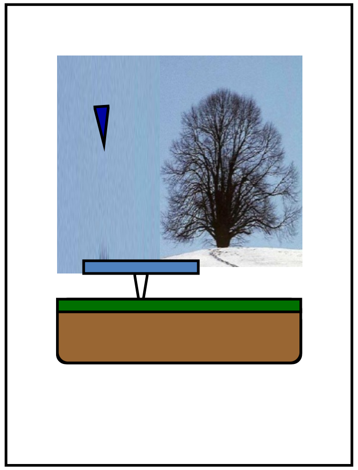
TESSEL



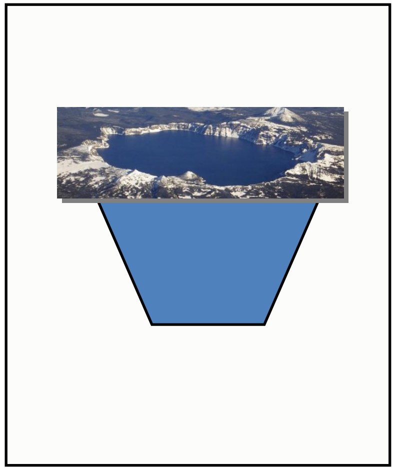
Hydrology-TESSEL



Snow



Lakes (FLAKE)



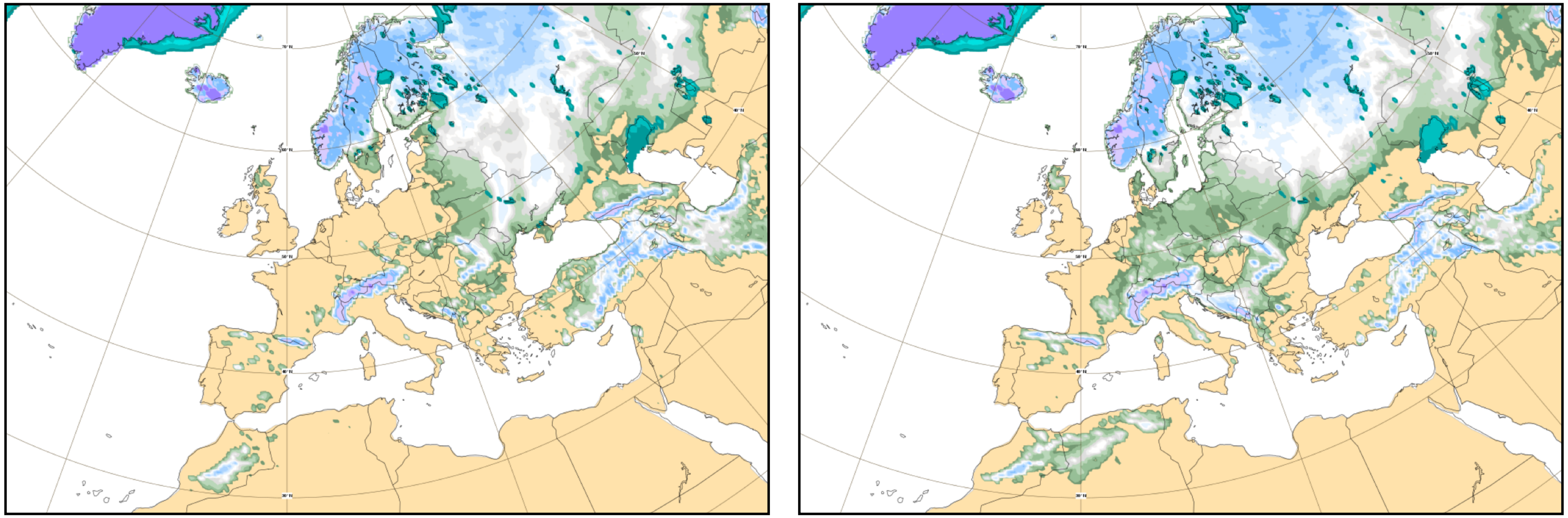
Surface Snow

Snow analysis using SYNOP and satellite observations

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

Parameters:

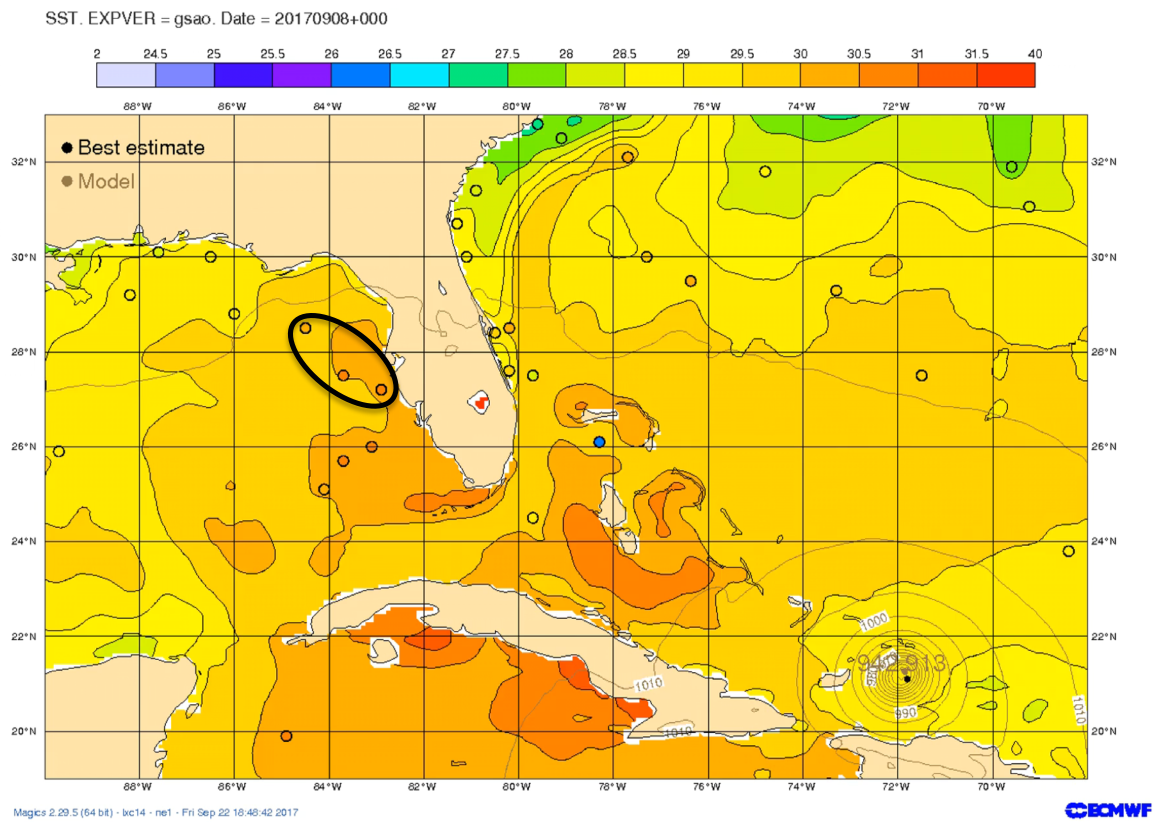
- Snow depth (water equivalent), Sd => actual depth=Sd*(Rliq=1000)/Rsn
  (below 10 cm snow depth, snow cover becomes fractional)
- Snow density (typically factor 10 lower than water-> 1 mm precip~1 cm snow), Rsn
- Snow temperature, Tsn
- Snow albedo, Asn

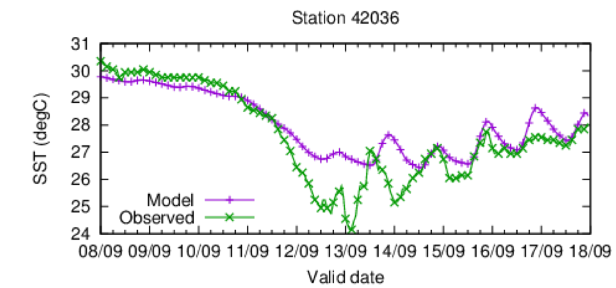


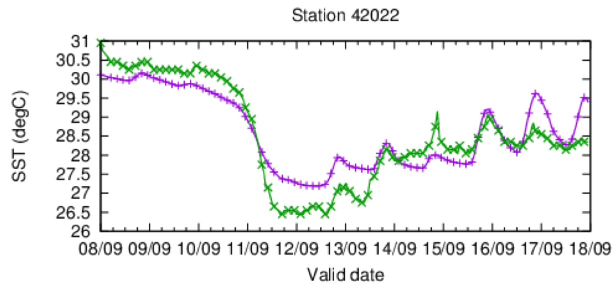
20180129 +12h +240h=2018020700

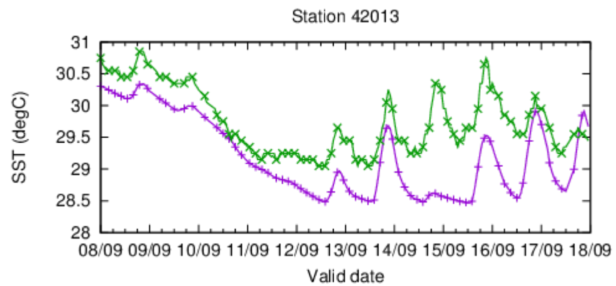
Atmosphere-ocean coupling – impact on near-surface temperature

Hurricane IRMA (HRES SST):



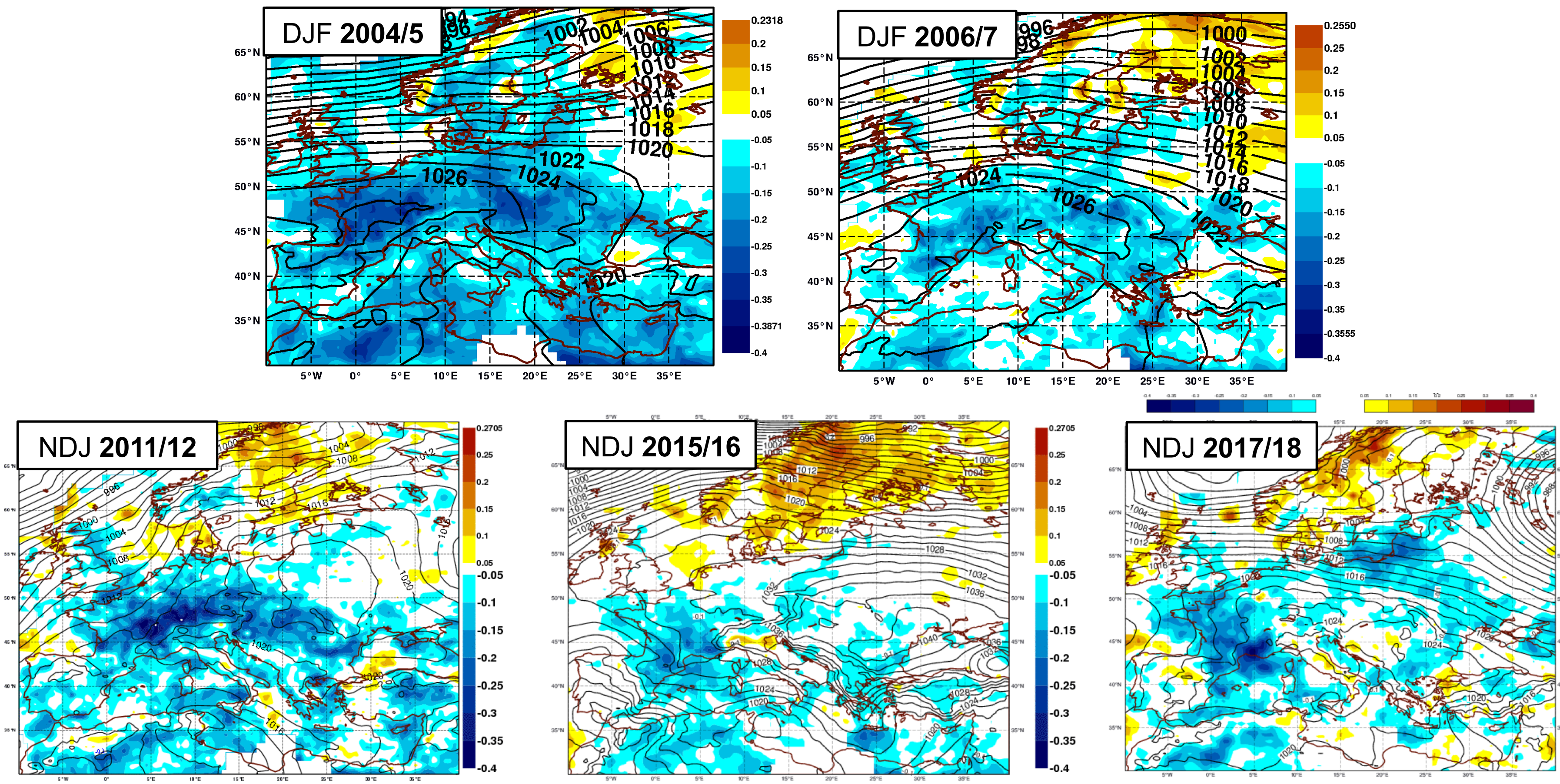






Low cloud cover in winter anti-cyclones: 36h forecast versus 12 UTC SYNOP observations

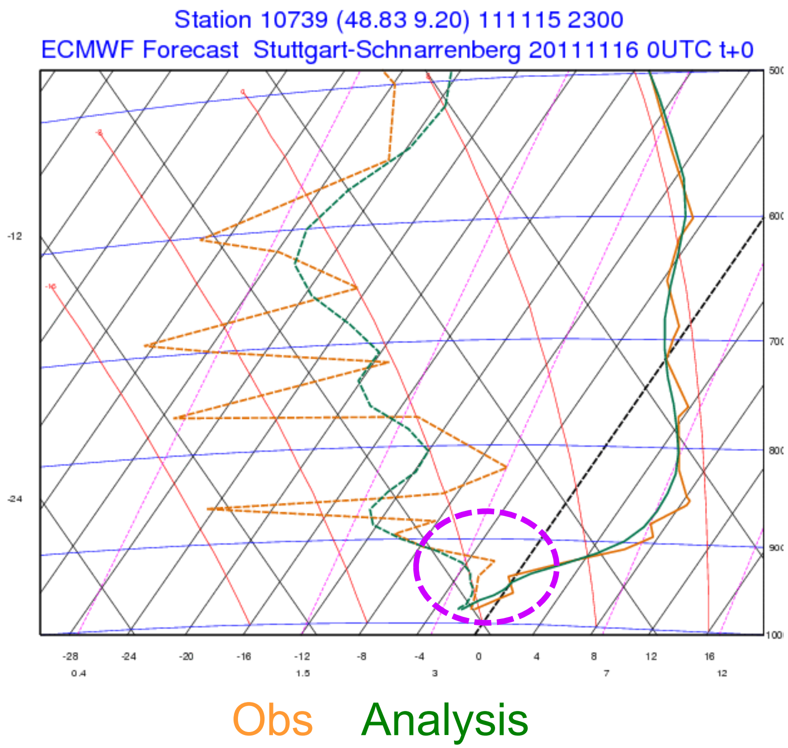
Cloud errors reducing, but still some underestimate of cloud cover on high pressure days over Europe during winter

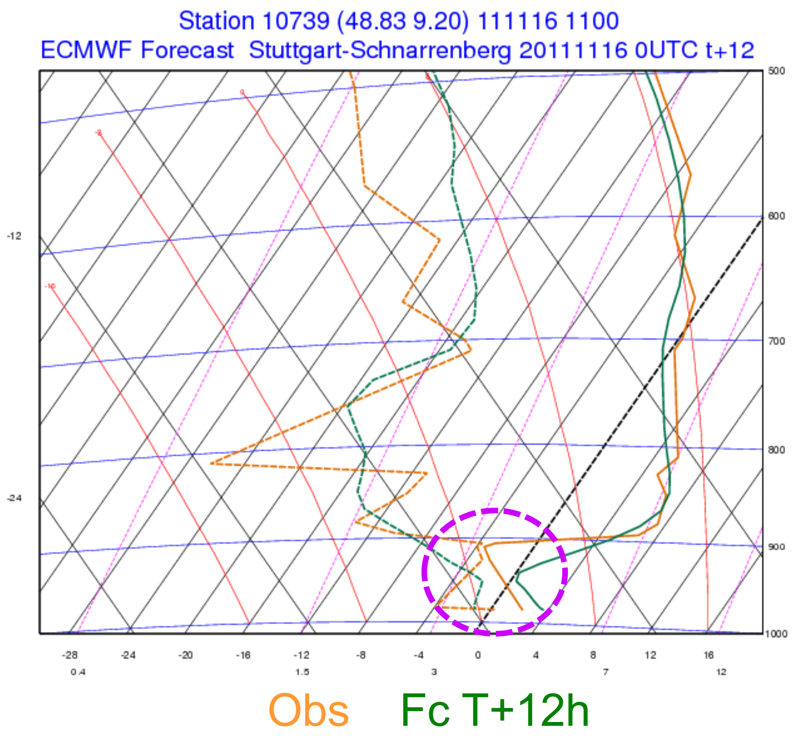


Low cloud cover: Too little in fog rising to stratocumulus example

Sounding Stuttgart 16 Nov, 2011

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



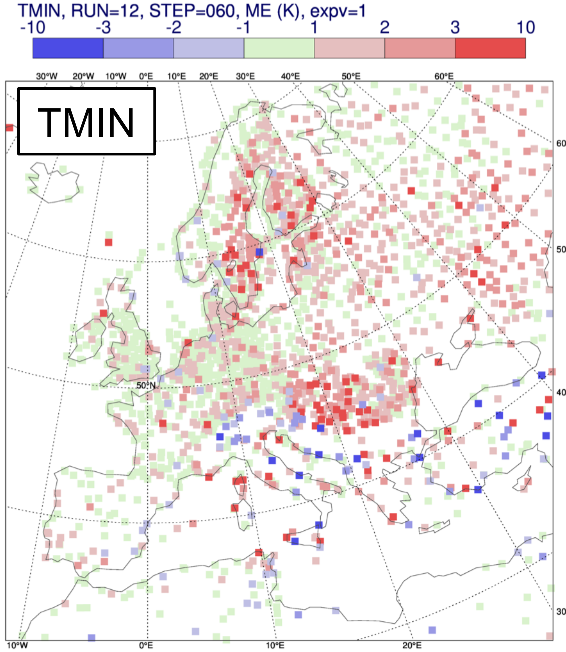


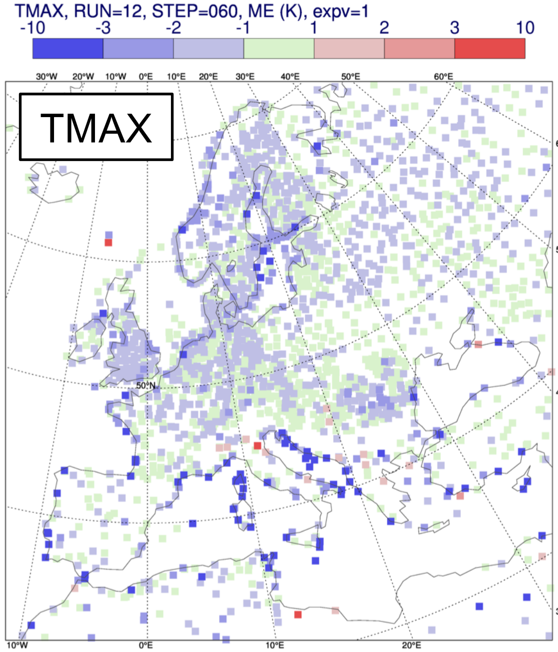
Fog rising developing into stratocumulus deck could not be properly represented

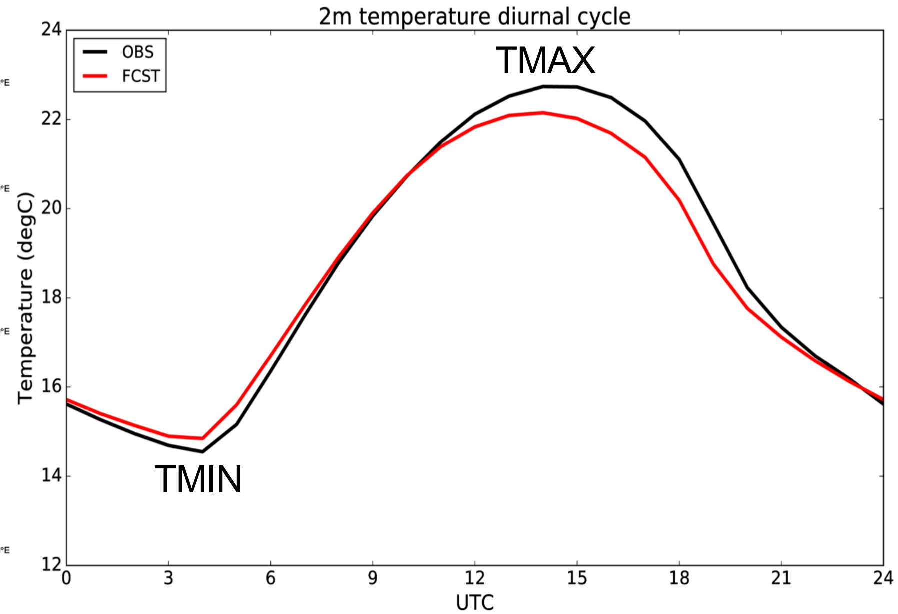
TMIN and TMAX bias

Diurnal cycle underestimated

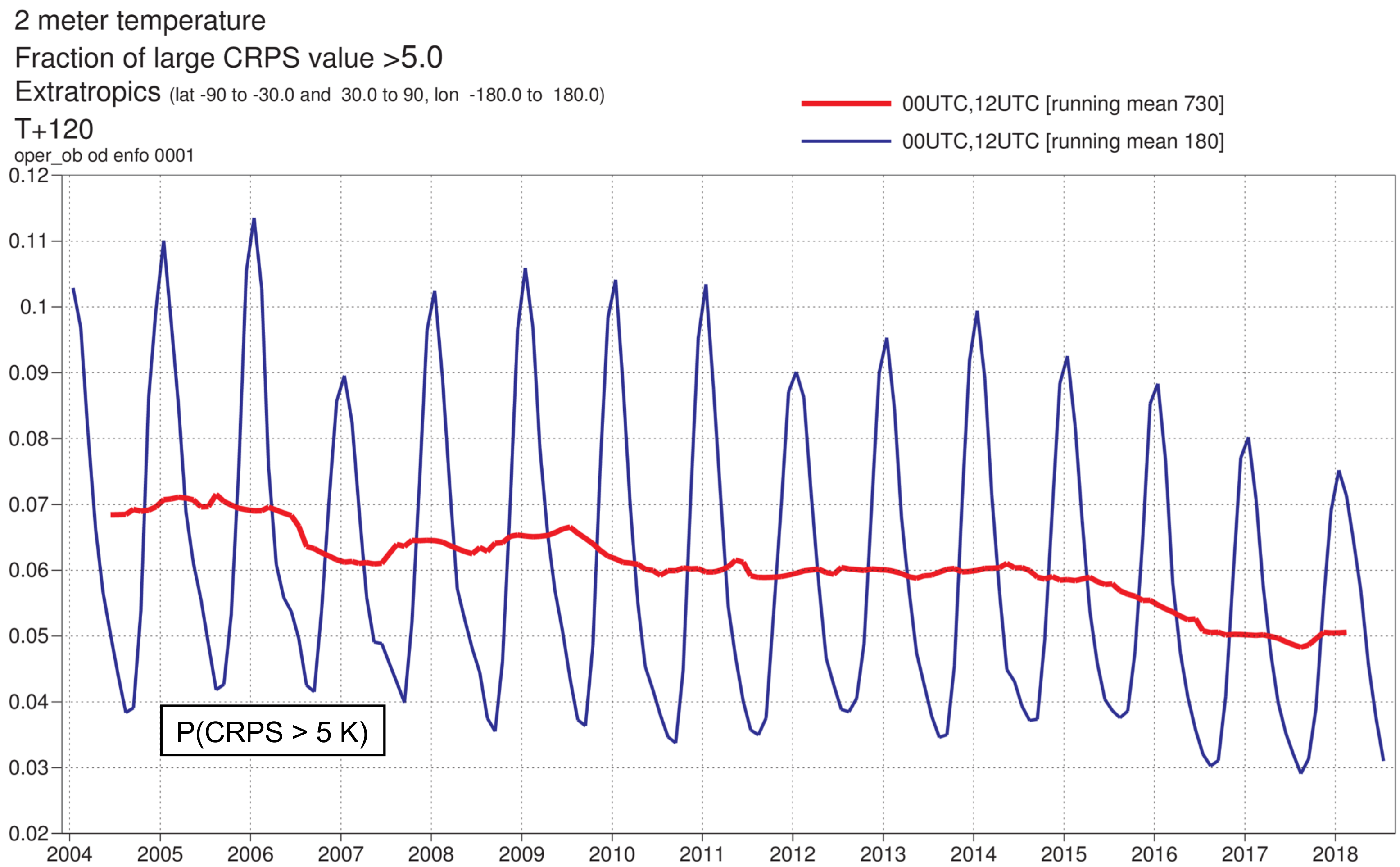
Summer 2017 Europe





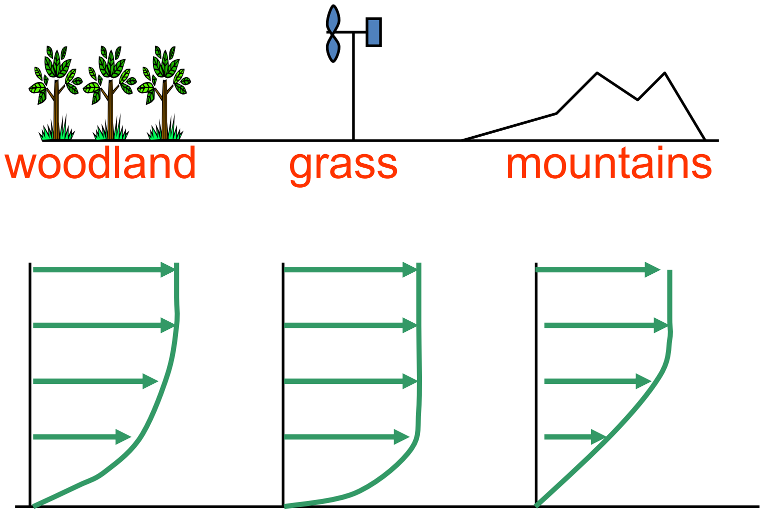


New headline score for ECMWF
Frequency of large (>5K) T2m errors – ENS day 5

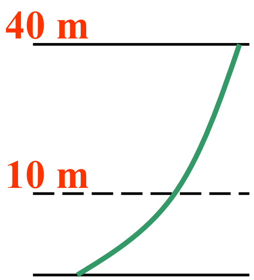



Wind and Gusts

10m wind



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



Post-processing of wind at 10m

- Post-processed 10m wind interpolates wind from 40 m (neutral blending height) 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).

10m Wind Gusts in the IFS

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

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

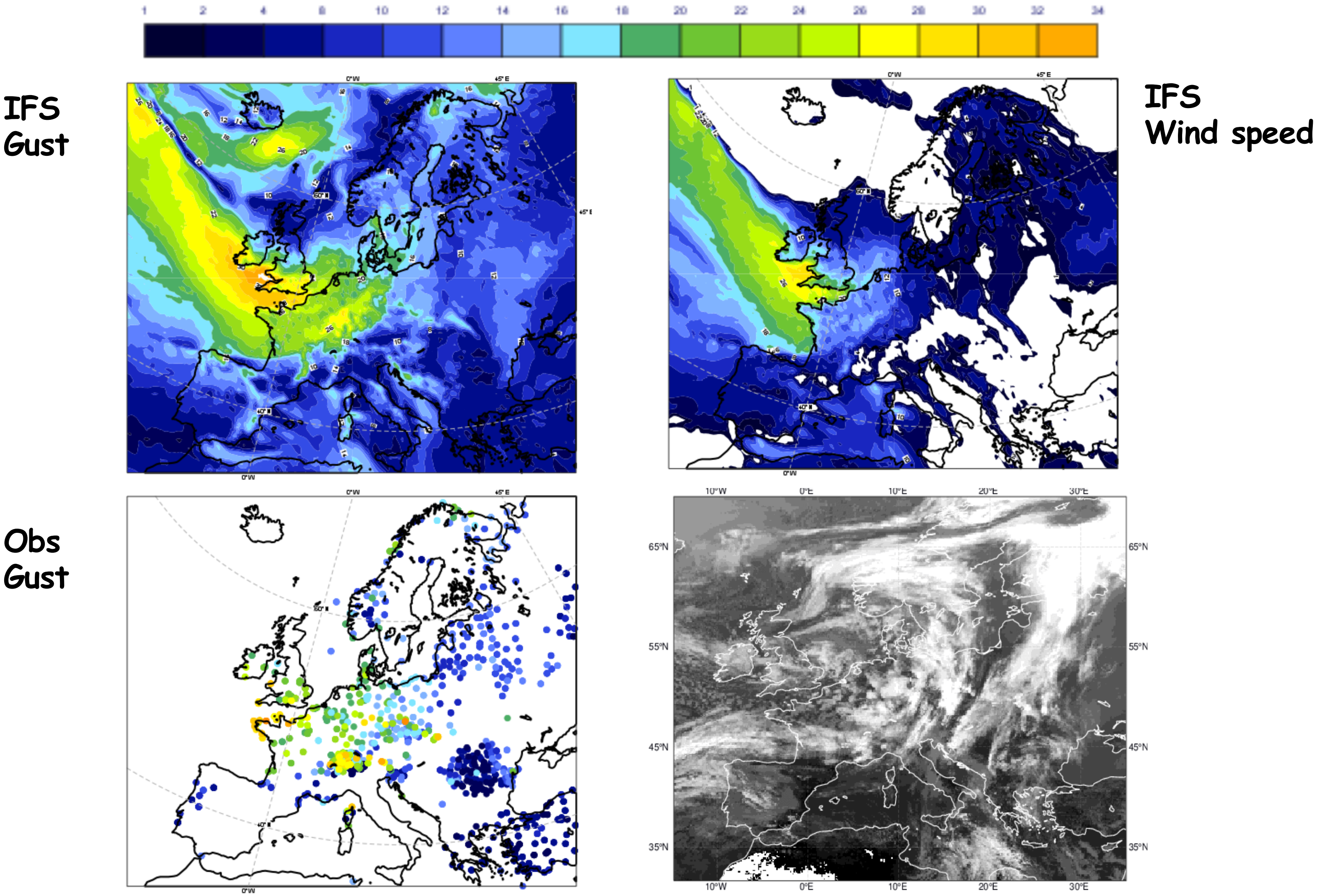
U_{10} is the 10m wind speed (interpolated down from 40m level),

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

L is a stability parameter.

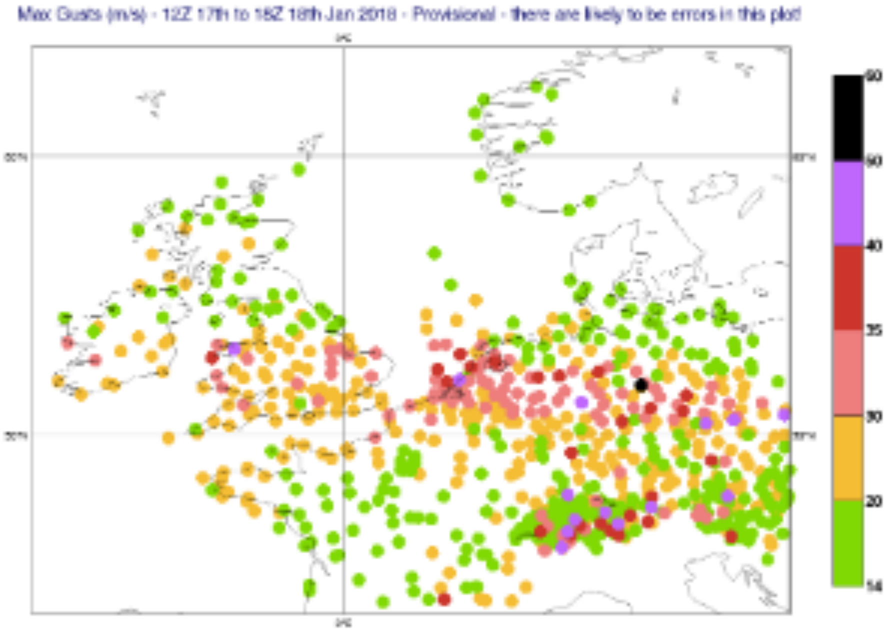
The convective contribution is set proportional to the wind shear between model levels corresponding to 850 hPa and 925 hPa when deep convection is active.

Wind Gusts: 8 Feb 2016 12 UTC

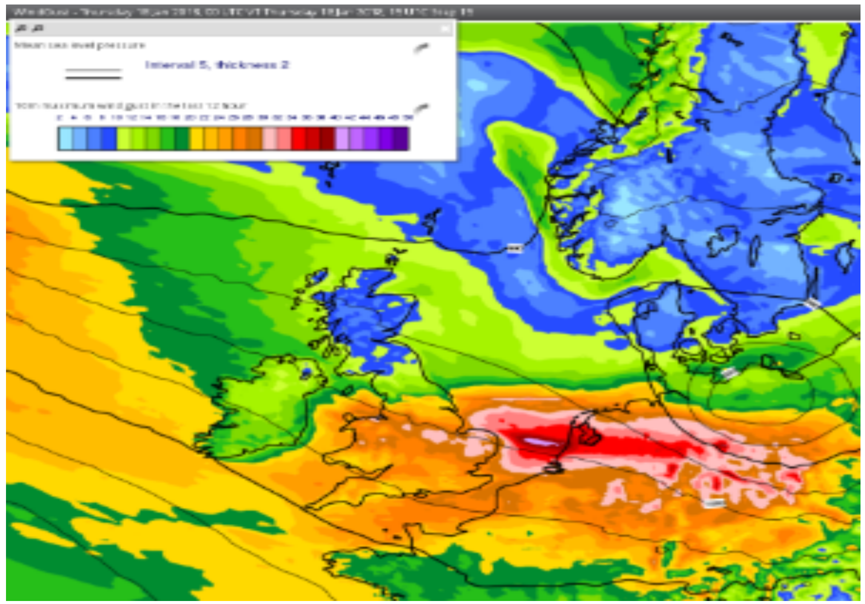


Wind gusts 18 Jan 2018

Obs

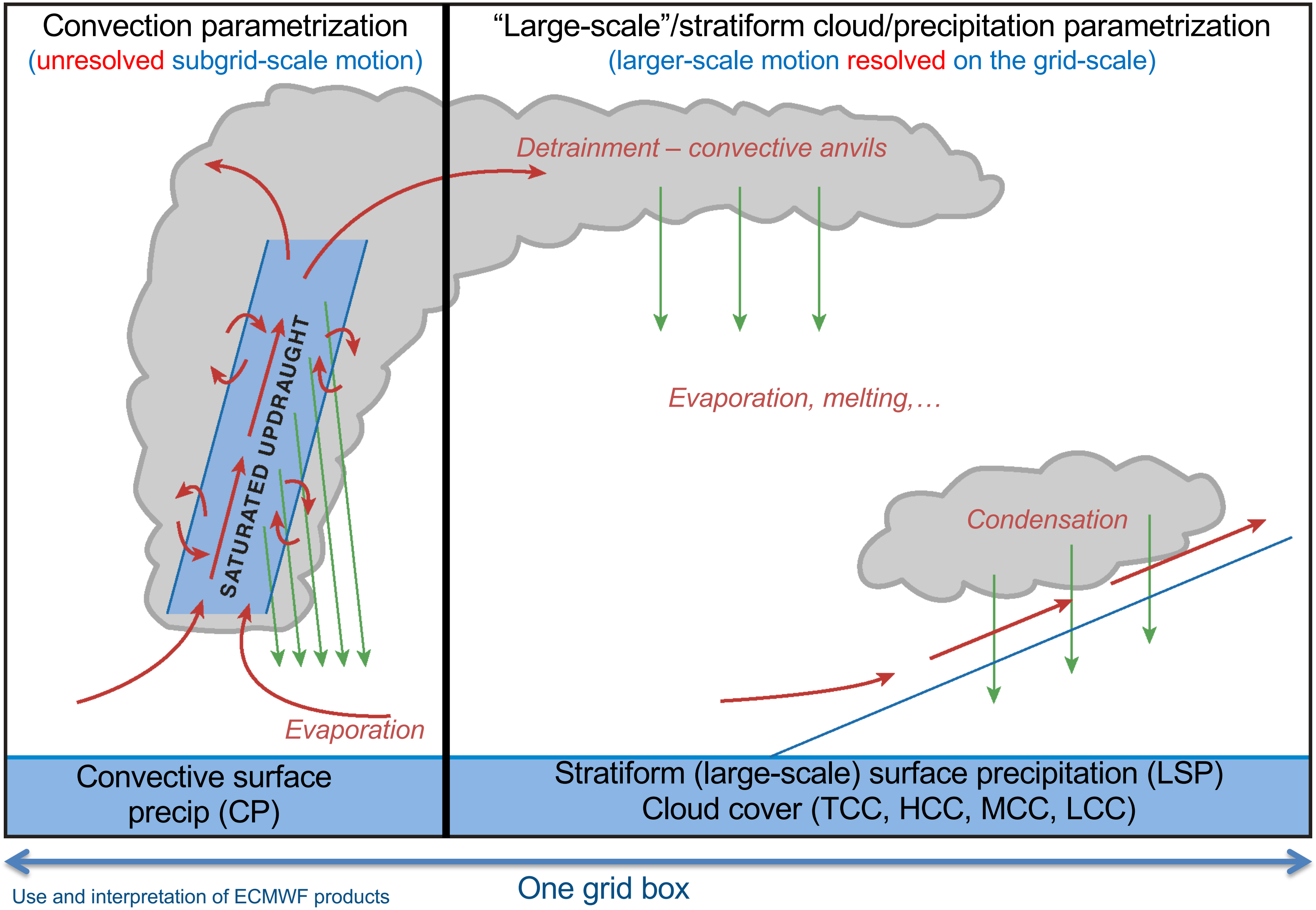


Model

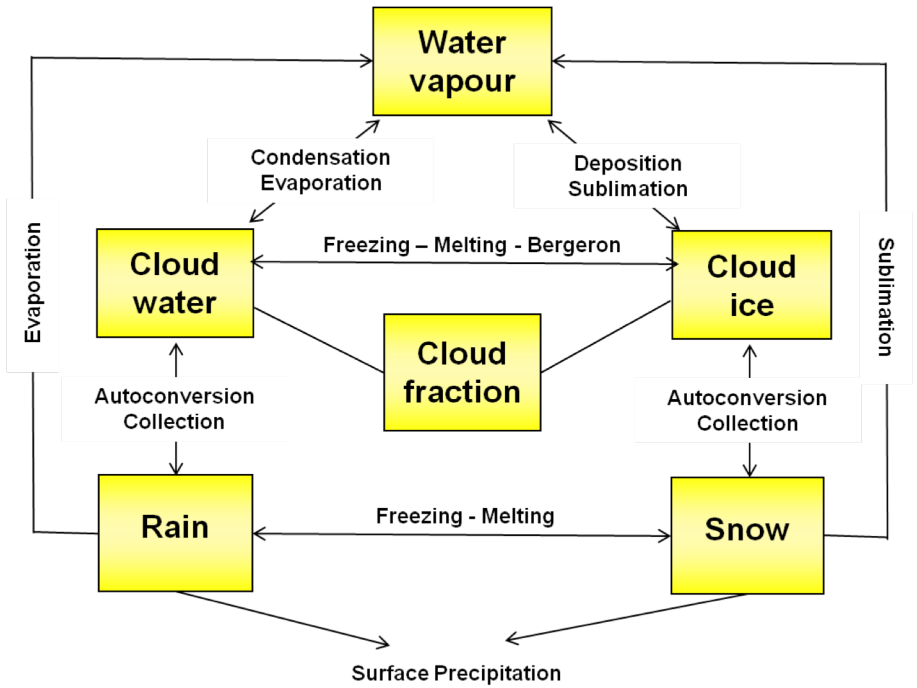



Cloud, Convection and
Precipitation

Convective and stratiform precipitation and clouds



IFS representation of cloud and precipitation



- 5 prognostic cloud (mass) variables + water vapour
- Ice and water independent variables
- Snow/rain prognostic (advected with the wind)
- Physically based, increasing realism
- Diagnosed surface precipitation type (melting, ice pellets, freezing rain etc.

Cloud overlap

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 $\sigma_s = 0.45$

MCC = Medium-level Cloud Cover

Integrated from $\sigma_s = 0.45$ to 0.8

LCC = Low-level Cloud Cover

Integrated from $\sigma_s = 0.8$ to surface

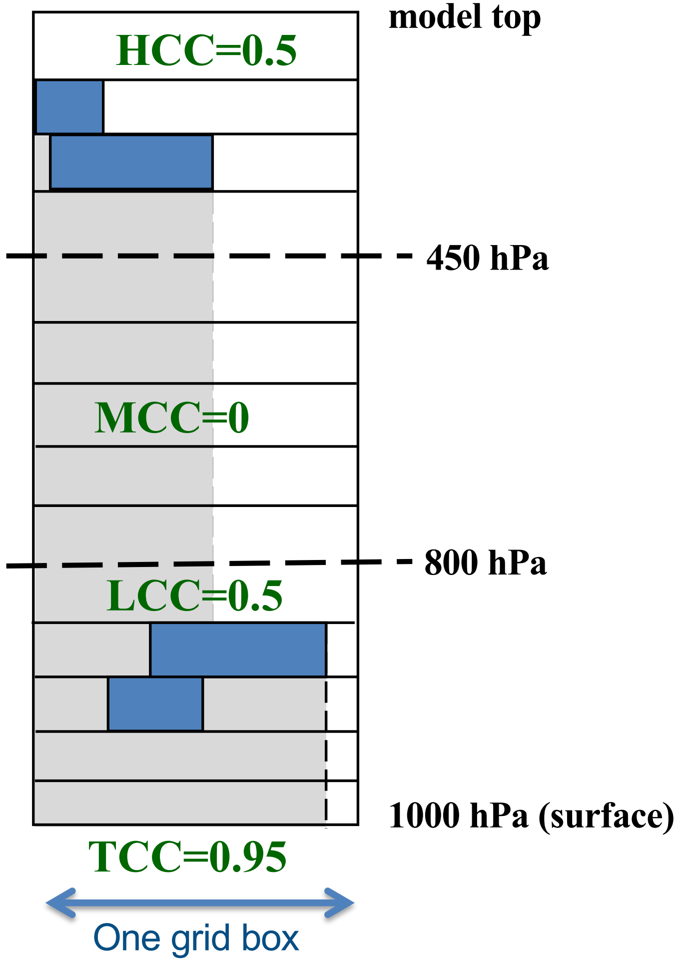
TCC <= LCC + MCC + HCC

An example with:

two layers of high-level cloud (50%)

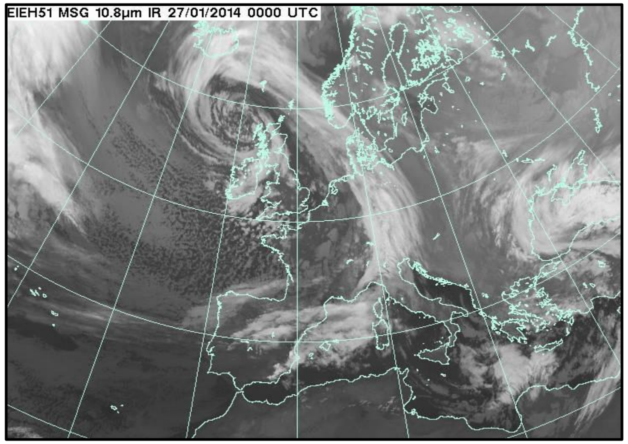
no medium-level cloud

two-layers of low-level cloud (50%)

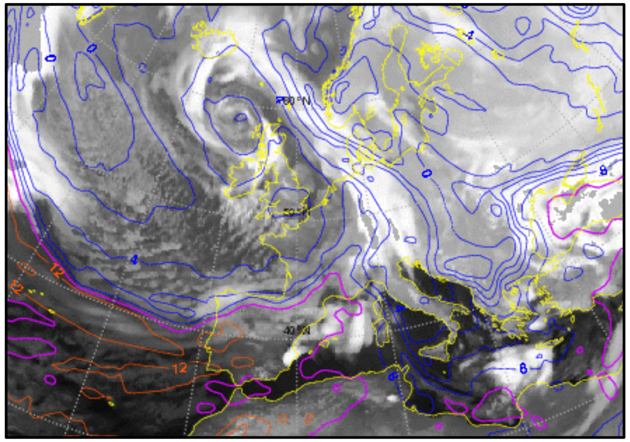


Cloud: 00Z Monday 27 January 2014

Meteosat IR 10.8µm

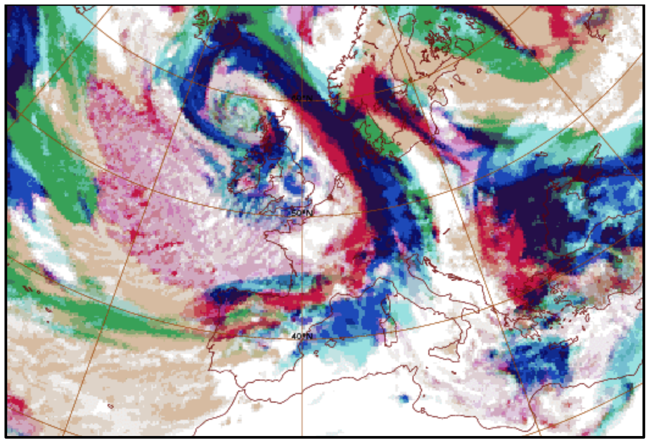


IFS Pseudo-IR 10.8µm

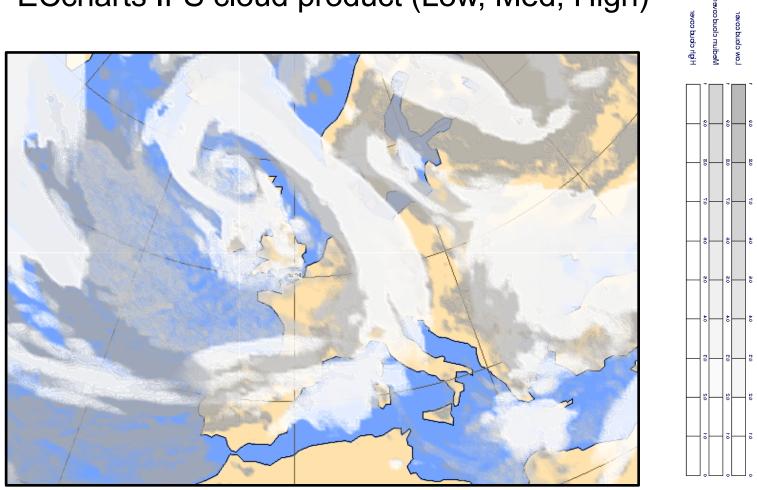


IFS cloud product (Low, Med, High and mixed)

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

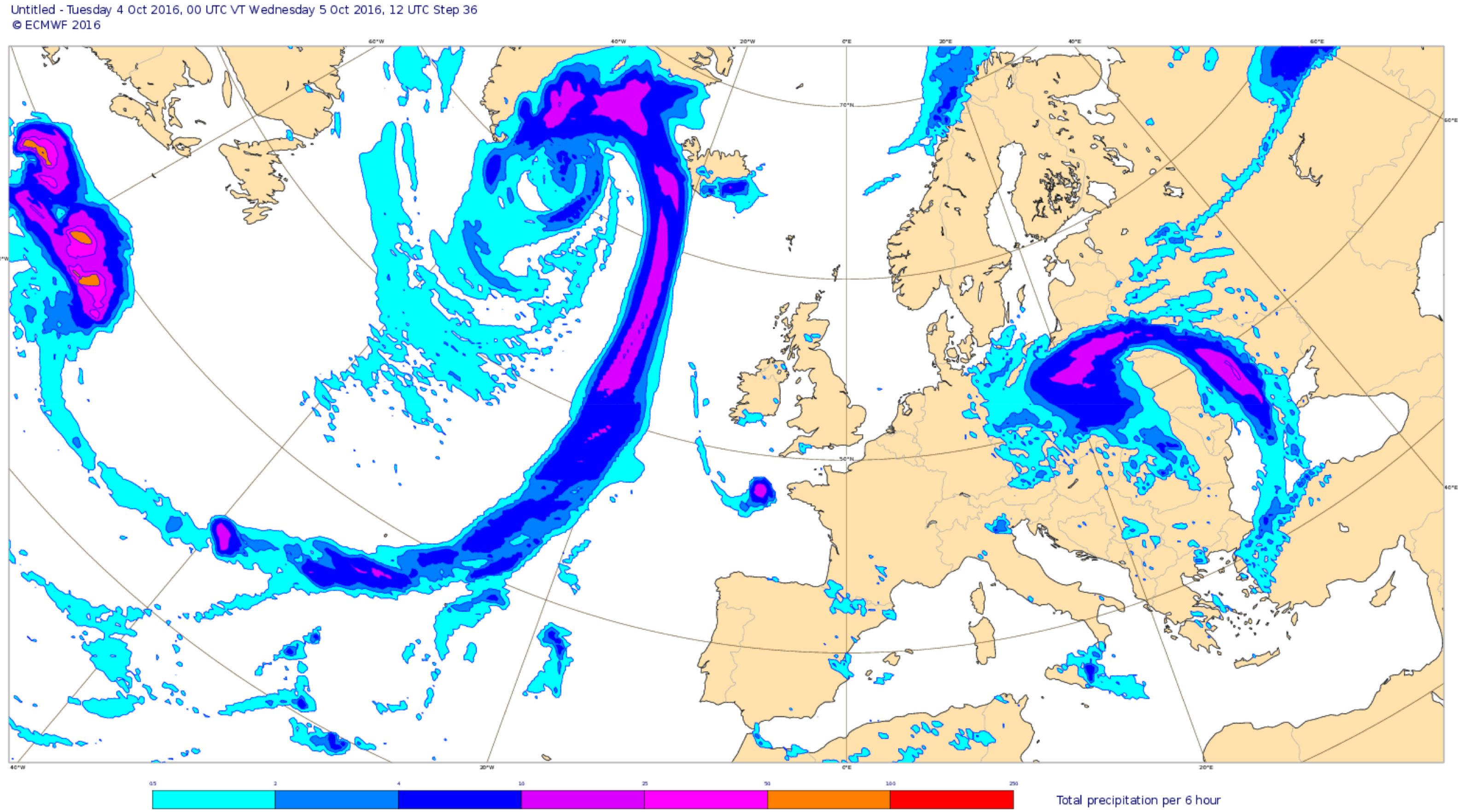


ECcharts IFS cloud product (Low, Med, High)



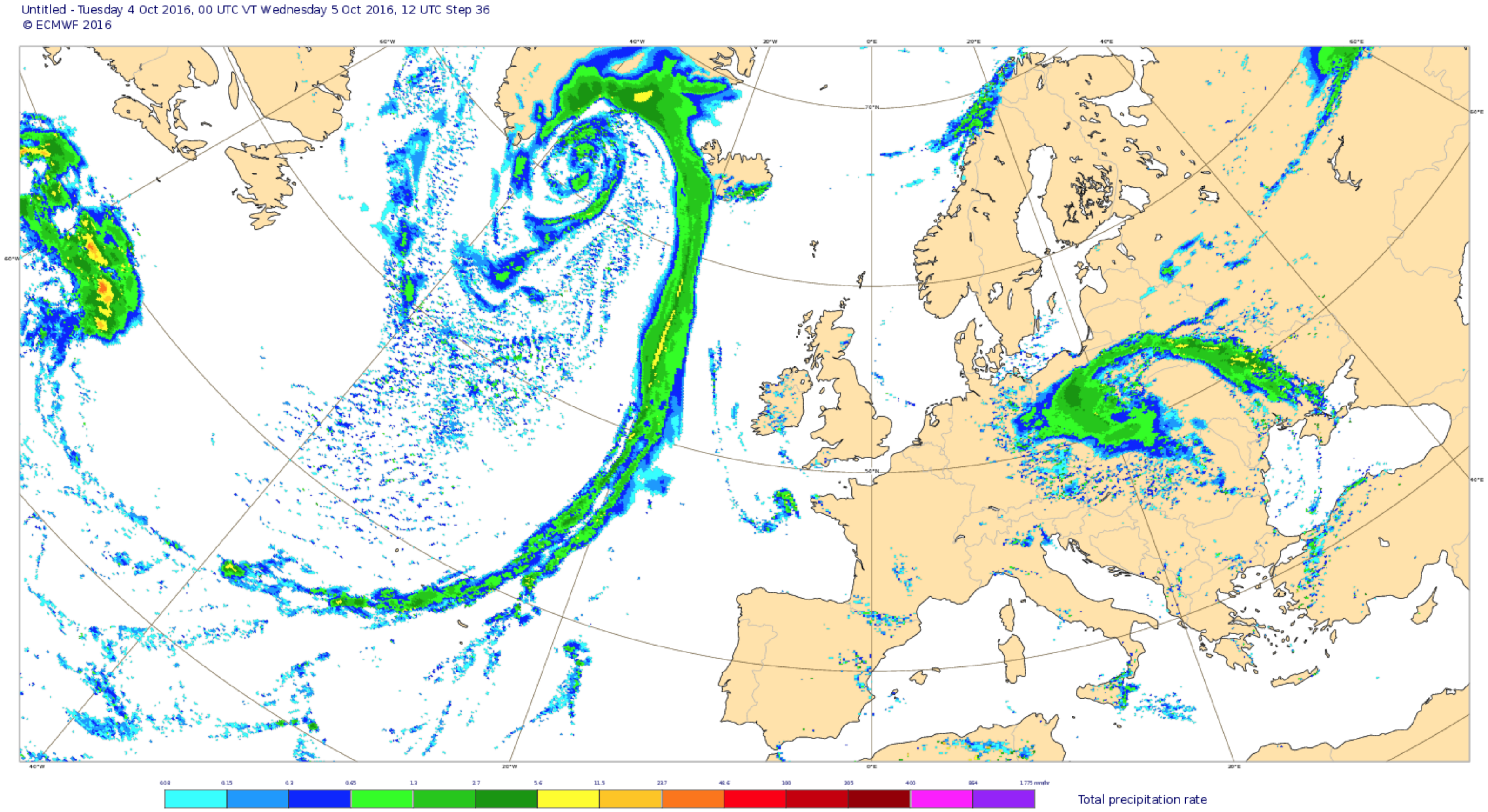
Example 6 hour precipitation accumulation

Forecast for Wed 5 October 2016



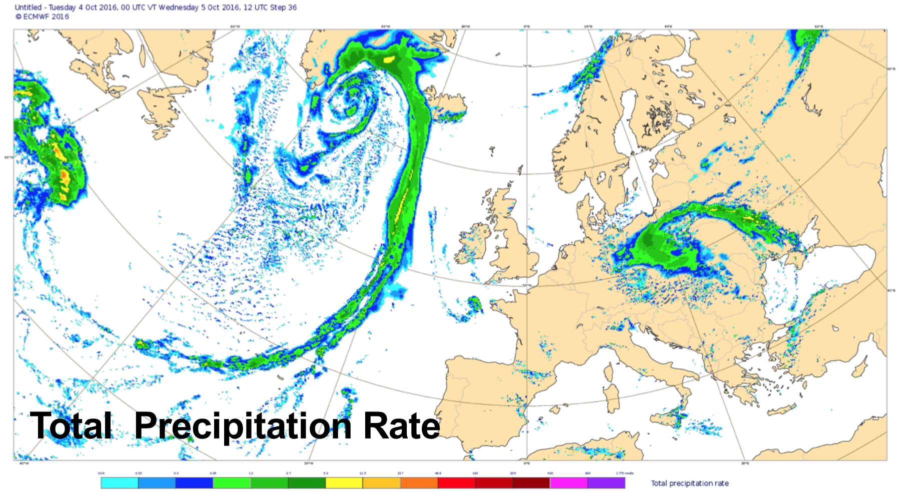
Precipitation accumulation: Large-scale rain + convective rain + large-scale snow + convective snow

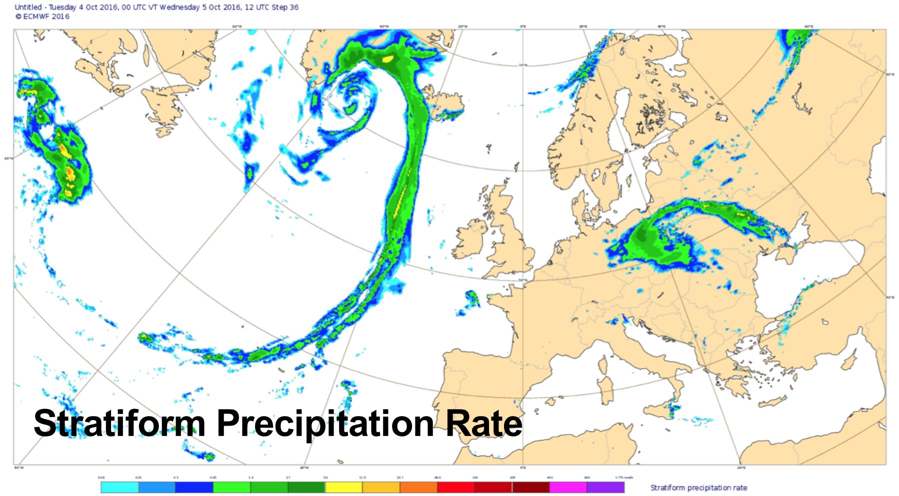
Example precipitation rate
Forecast for Wed 5 October 2016 12Z

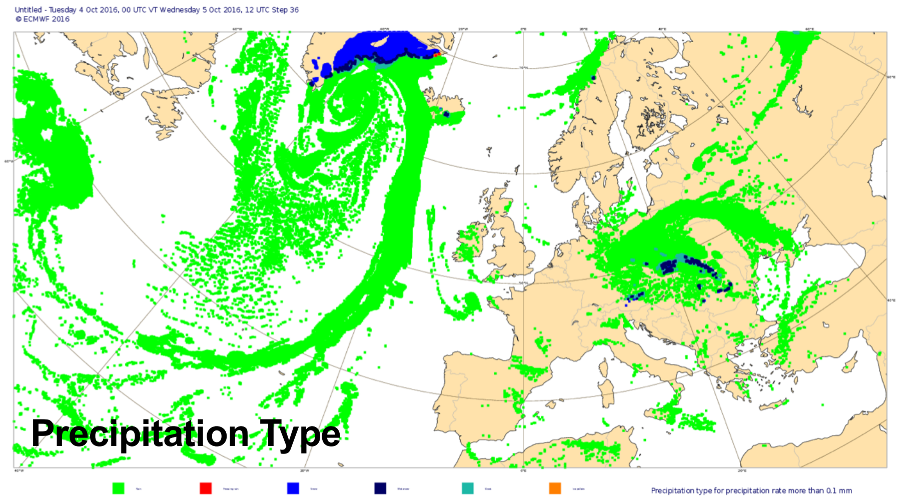


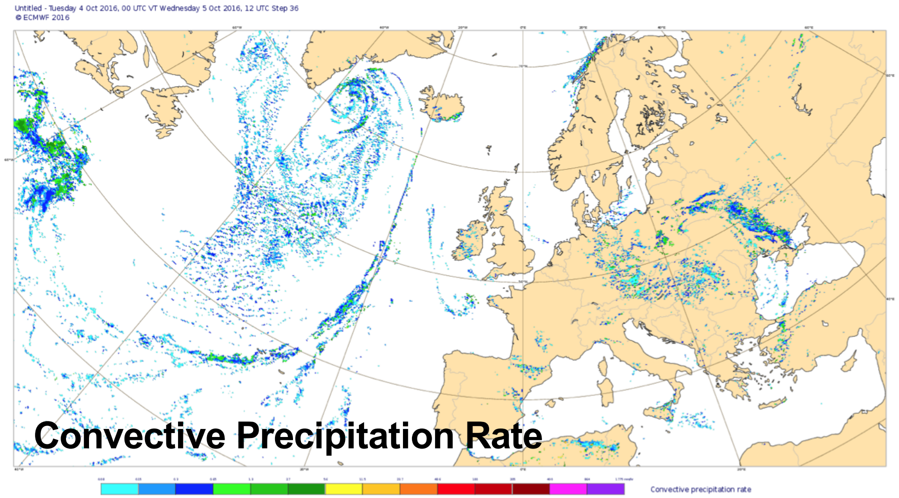
Total precipitation rate: Large-scale rain + convective rain + large-scale snow + convective snow

Precipitation rate and type example: 12 UTC Wed 5 October

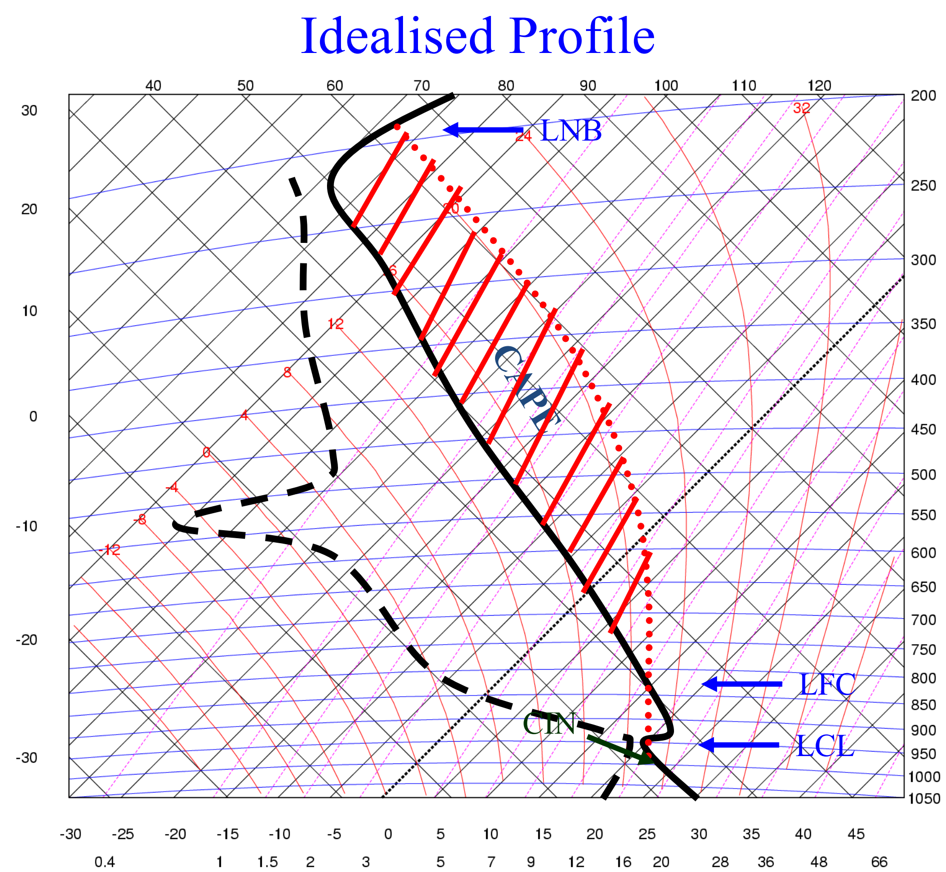








Parcel convective In(stability): CAPE (CIN)

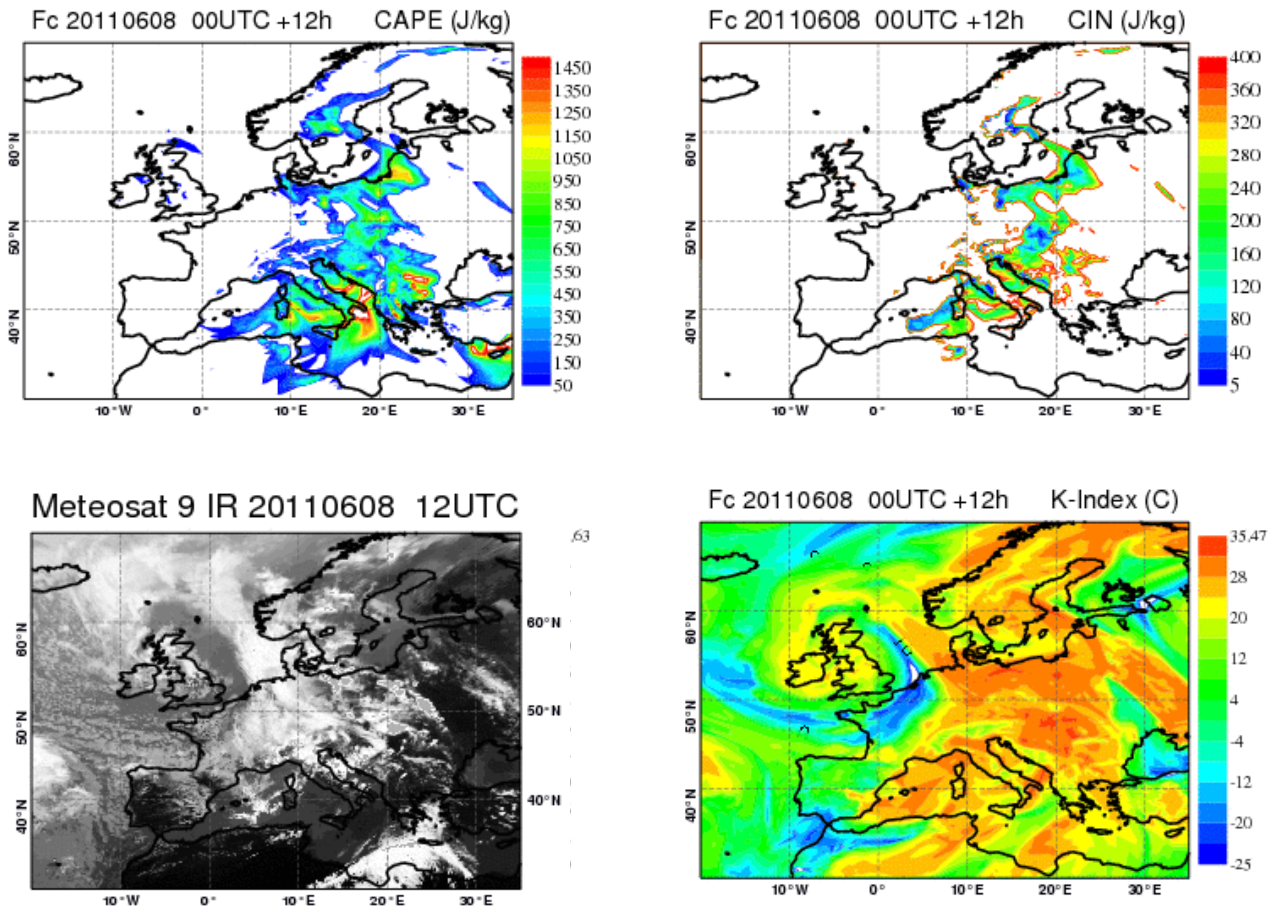


$$CAPE \approx \int_{base}^{top} g \frac{T_{cld} - T_{env}}{T_{env}} dz$$

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

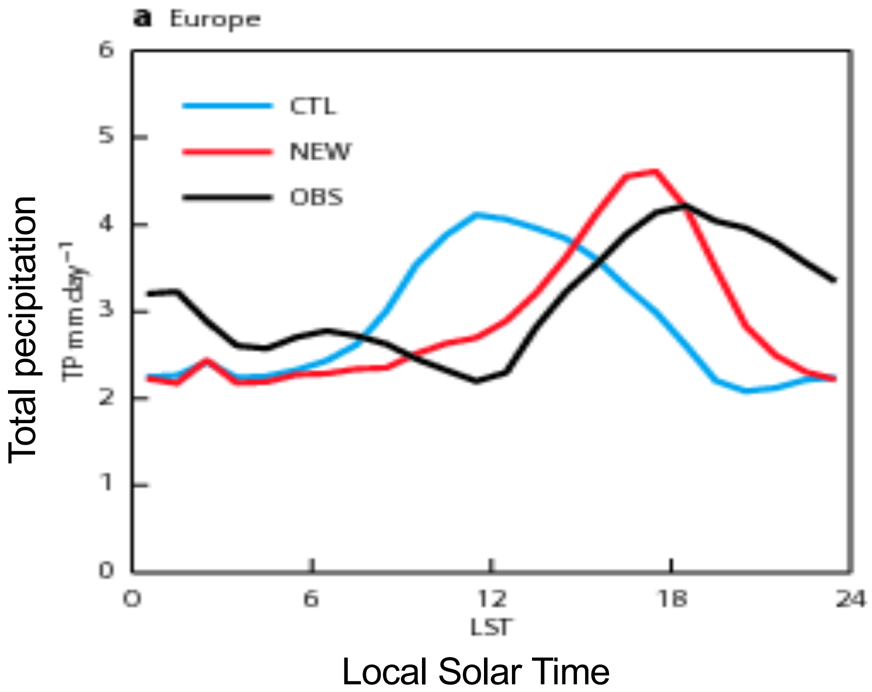
In the IFS convection parameterization the amount of CAPE determines the intensity of convection (rainfall) – the computation of CAPE depends on the specified entrainment and the departure level of the air parcel (LCL=lifting condensation level, LFC=level of free convection, LNB=level of neutral buoyancy)

Convective Indices



Diurnal cycle of convective precipitation:

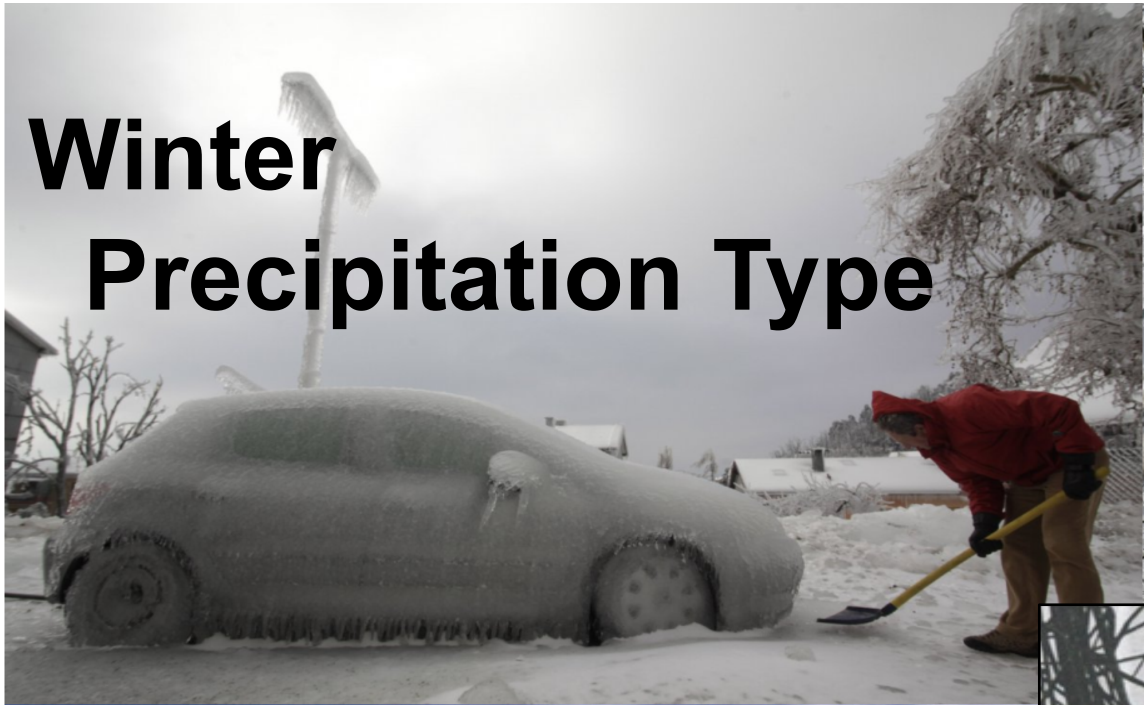
…more realistic since Nov 2013, but still underestimates night-time organised convection

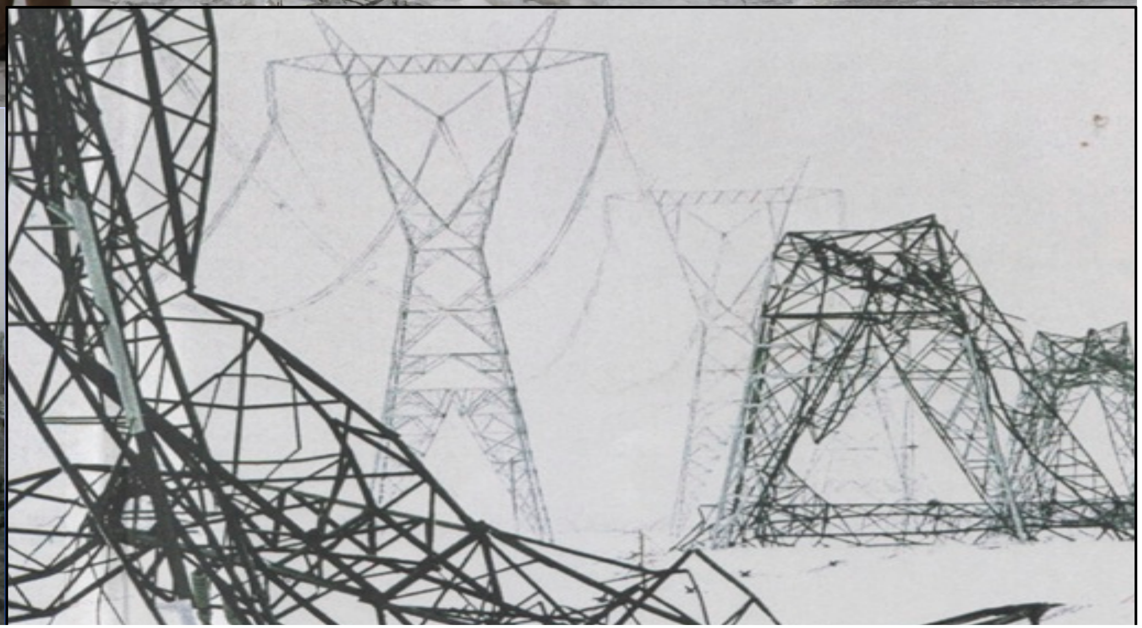


- Diurnal cycle of convective precipitation improved in IFS in 2013 (blue to red)
- Peak precipitation can still be up to 3 hours too early
- Underestimates evening/night-time precipitation due to lack of organisation

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

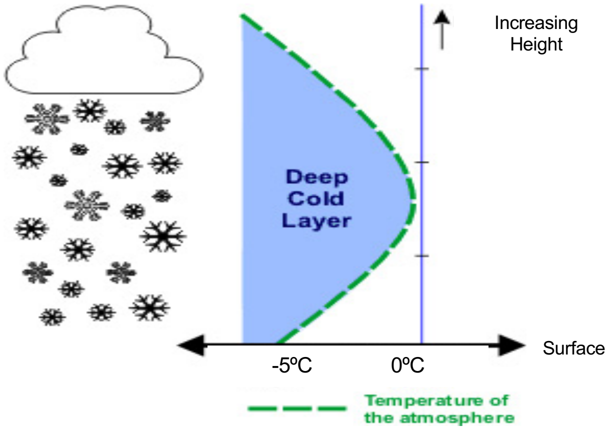
Winter Precipitation Type



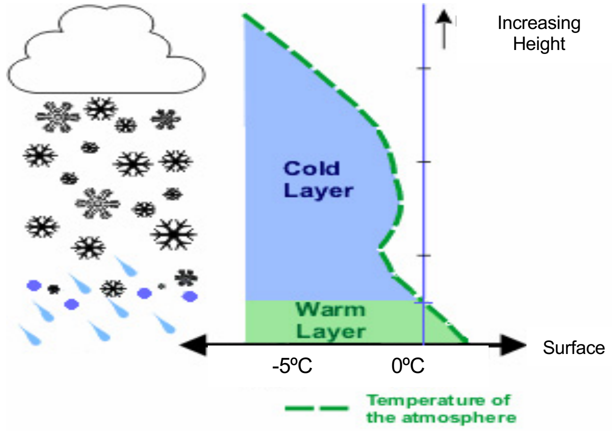


Precipitation type – a parameter from the IFS

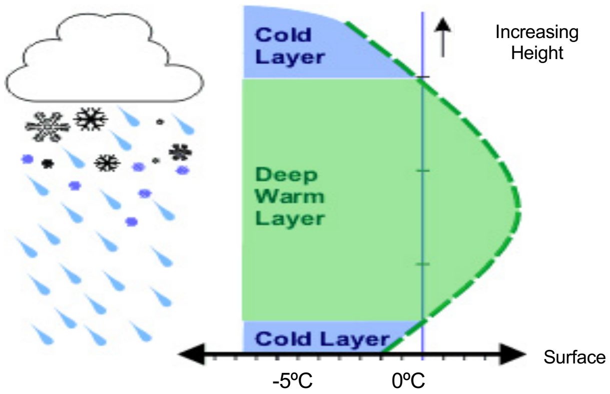
rain / snow / wet snow / mix rain-snow / ice pellets / freezing rain



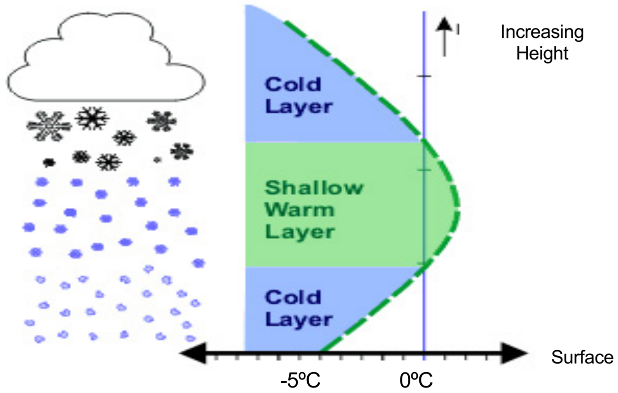
Snow



Sleet (melting snow) or rain



Freezing rain



Ice pellets

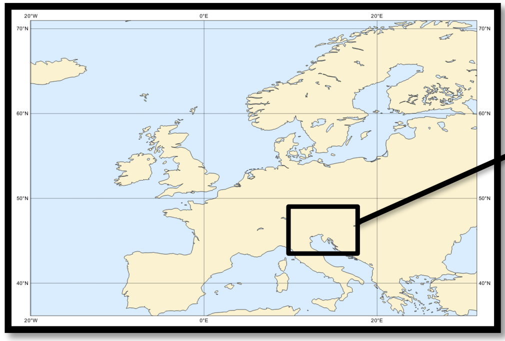
Precipitation parameters (from Cy41r1, May 2015)

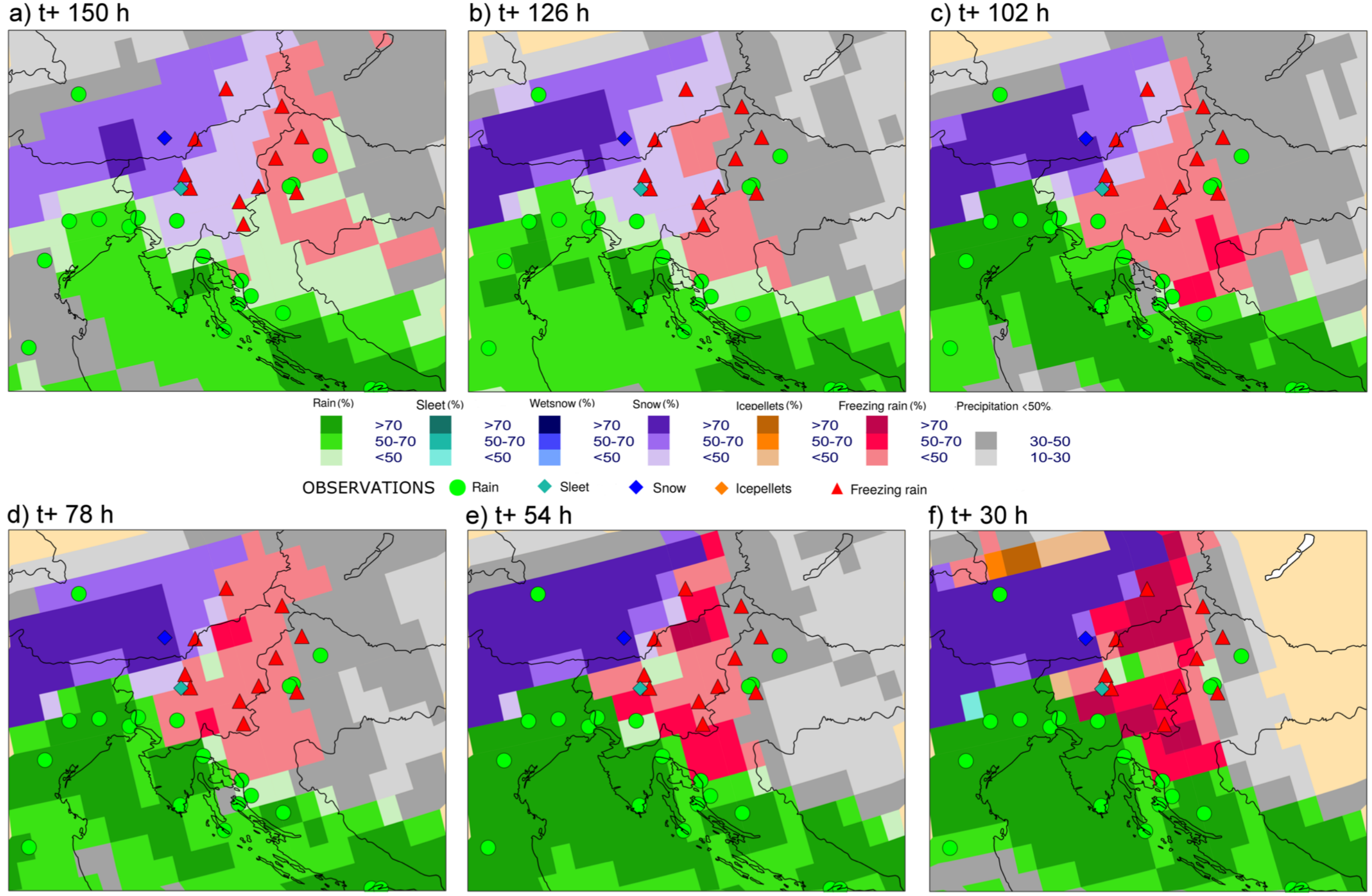
- Precipitation type (valid at a particular time) (***ptype***)

(=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***)
  - Total precipitation rate (***tprate***)
- Maximum and minimum total precipitation rates in the last 3 hours/6 hours (***mintpr3,maxtpr3, mintpr6,maxtpr6***)

CASE STUDY: Slovenia/Croatia 02 Feb 2014
Most probable precipitation type (from IFS ensemble)

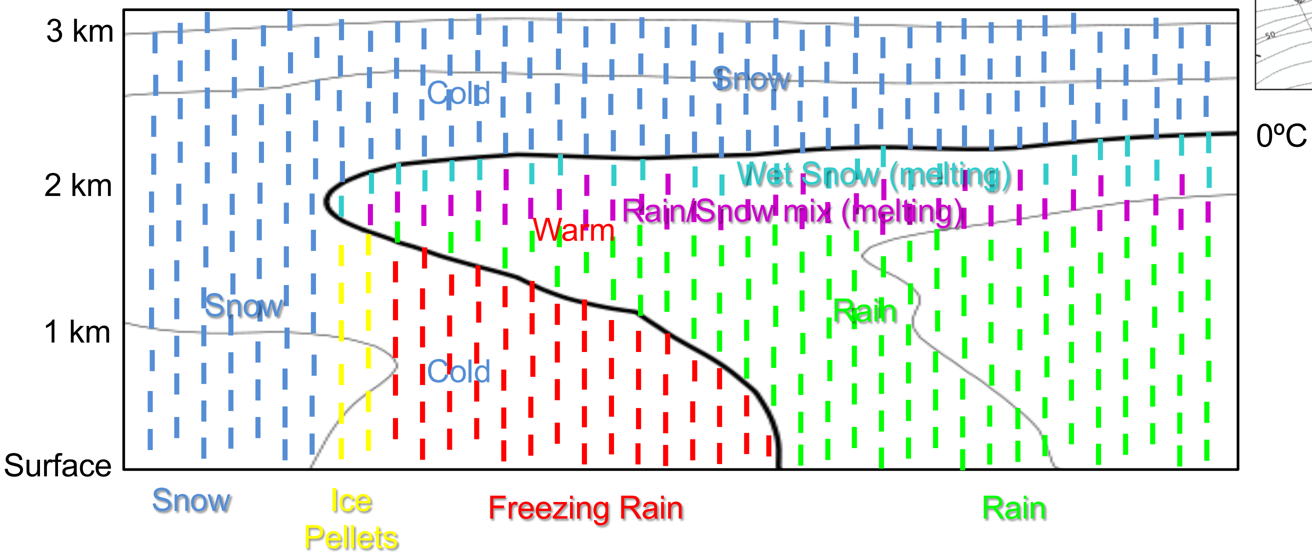




Freezing rain (%)

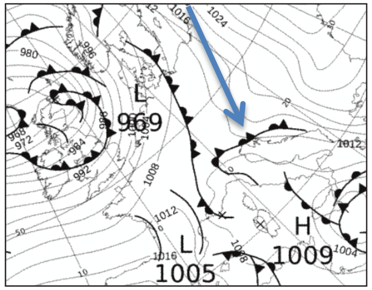
>70
50-70
<50

Schematic cross-section (front with elevated warm layer)

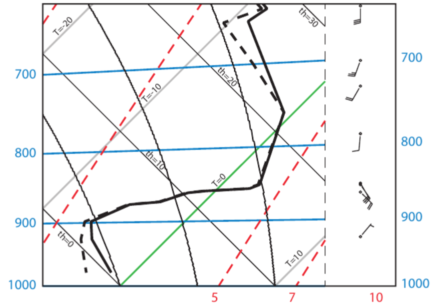


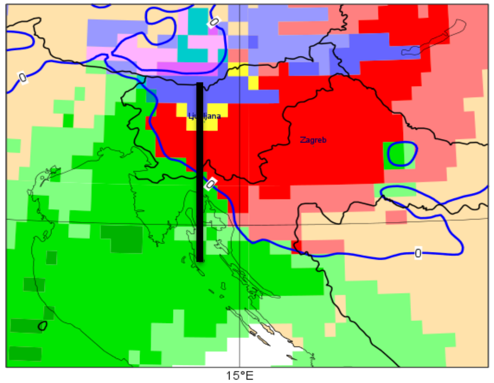
Case Study: 02 Feb 2014

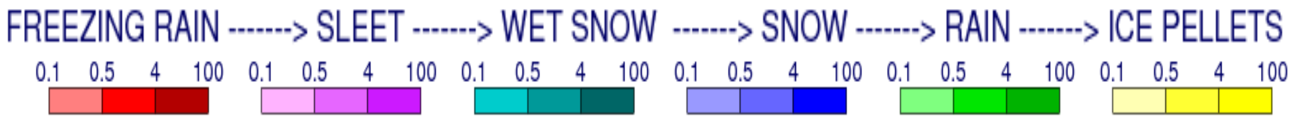
Occluded front



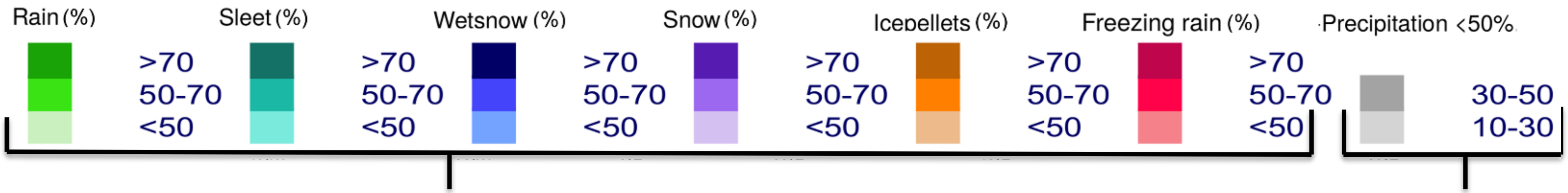
Ljubljana sounding





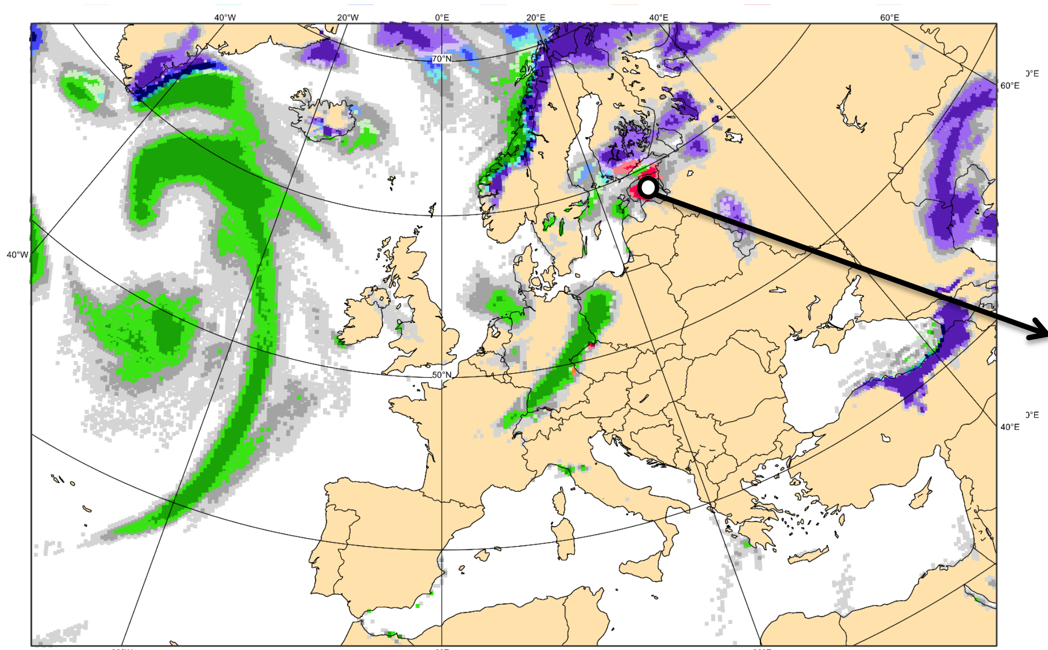


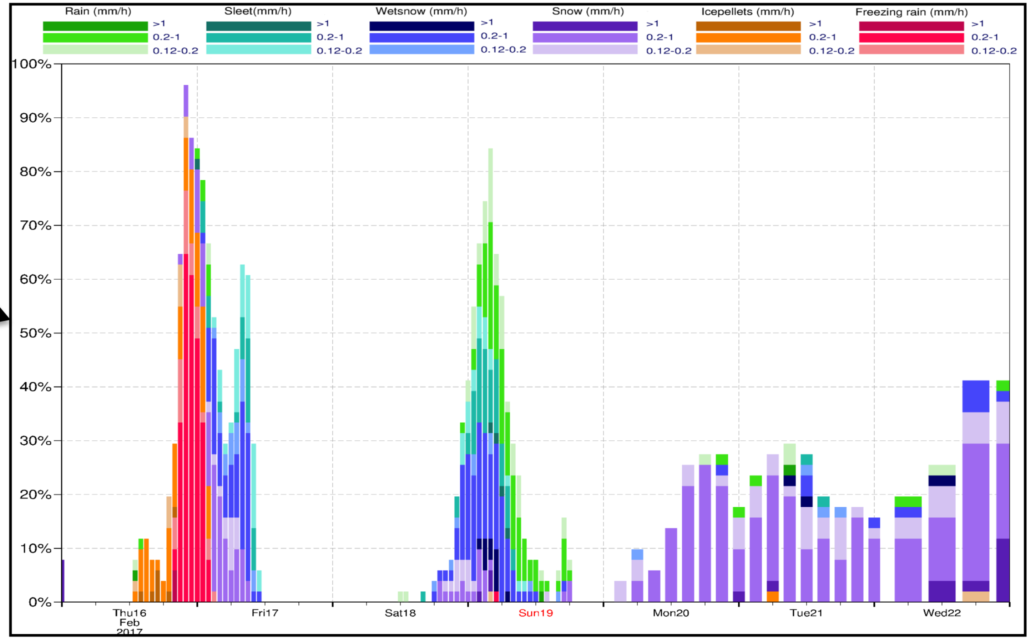
Most probable precipitation type product



Colours: most probable precipitation type if **total precip > 50 %**

Grey shading: when the probability of **any** type of precipitation is **10-30%** or **30-50%.**





Visibility and Fog

Visibility (Fog)

(available operationally since May 2015)

Visibility is calculated using an exponential scattering law and a visual range defined by a fixed liminal contrast of 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)

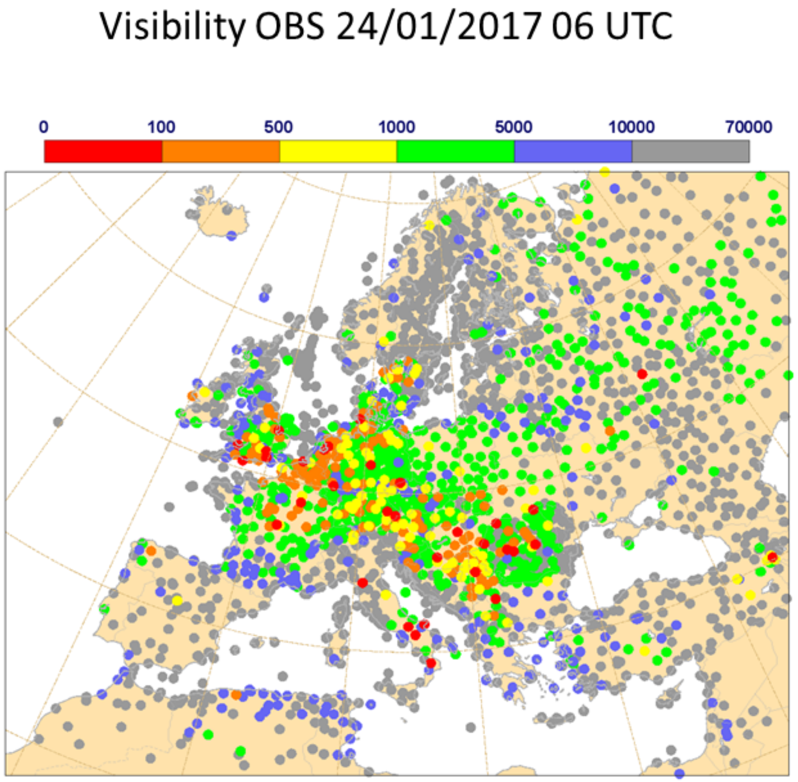
Aerosol: seasonally varying RH-dependent based on 10 year CAMS aerosol climatology (since July 2017)
Fog: predicted near-surface cloud liquid water/ice
Precipitation: reduced visibility due to predicted near-surface falling rain and snow

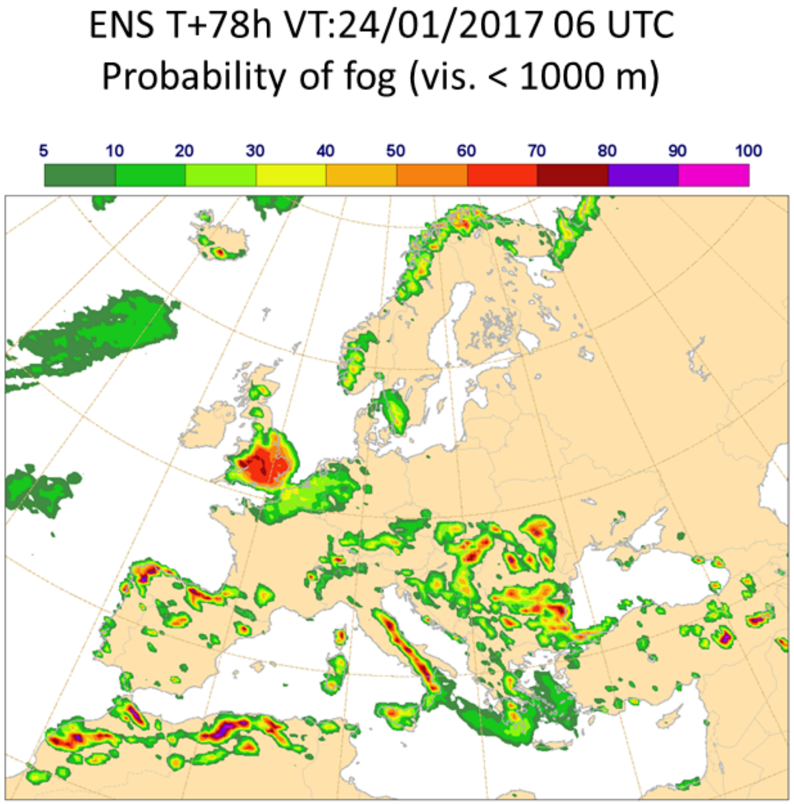
Many limitations!

- "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…

Prediction of severe weather: Visibility/Fog

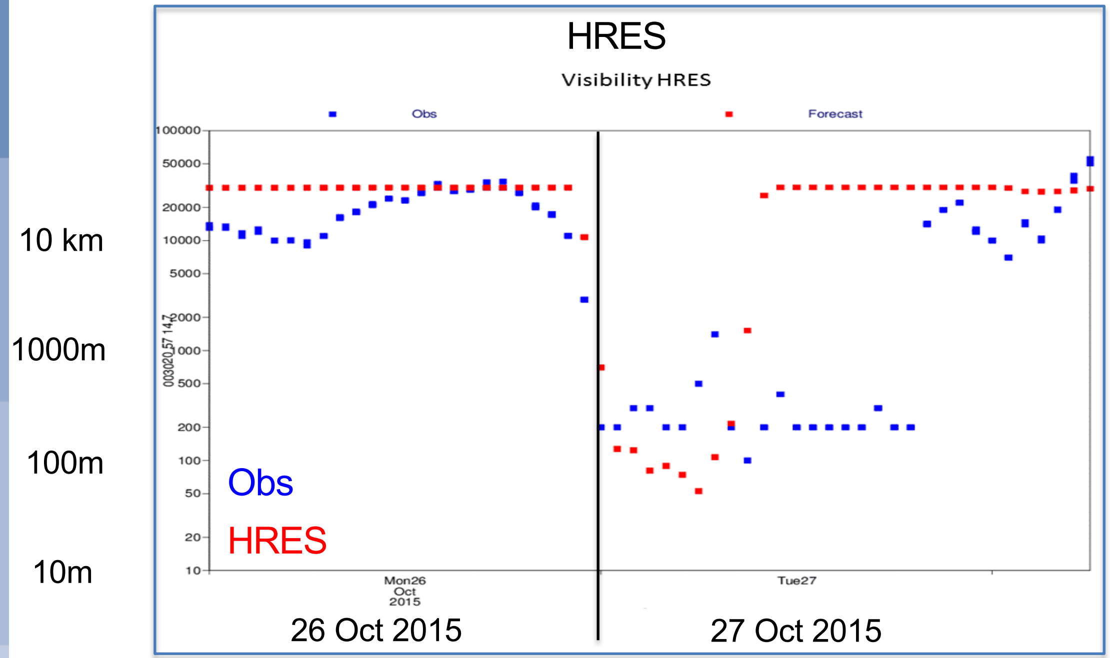
Case study: 24 Jan 2017, 3 day probability forecast from IFS ensemble

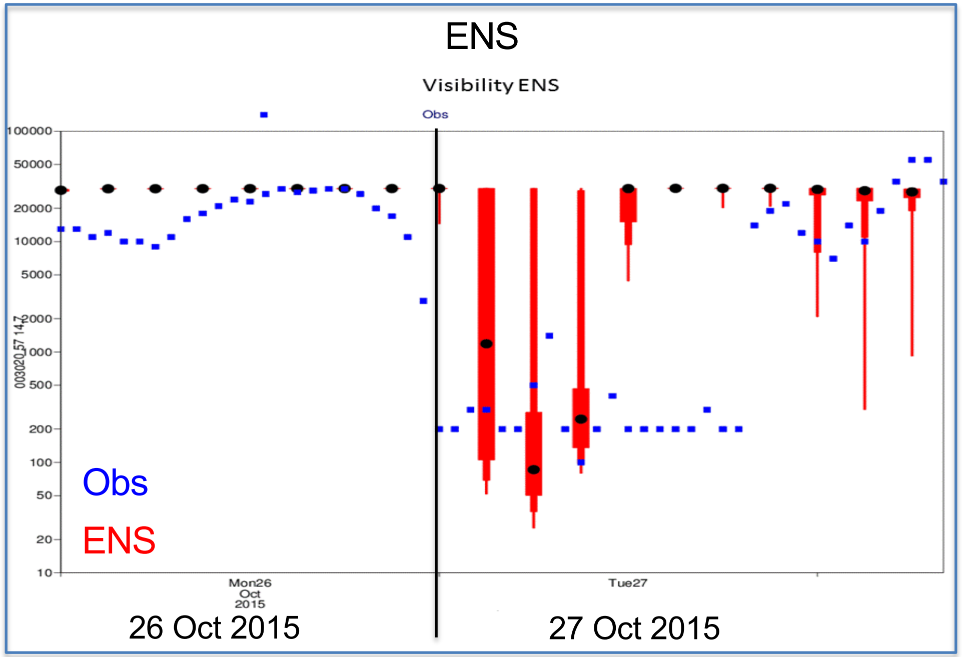




Prediction of severe weather: Visibility/Fog
Case study: 27 Oct 2015 - Fog in southern Sweden

- 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






Lightning

Lightning parameterization in ECMWF IFS

The new parameterization predicts total (cloud-to-ground + in-cloud) lightning flash densities from a set of predictors diagnosed from the convection scheme of the IFS:

$$f_T = 37.5\, Q_R \sqrt{CAPE} \left[\min(z_{base}, 1.8)\right]^2$$

$$Q_R = \int_{z_{0°C}}^{z_{-25°C}} q_{graup} \left(q_{cond} + q_{snow}\right) \bar{\rho}\, dz$$ (proxy for the charging rate)

$$q_{graup} = \frac{\beta\, P_f}{\bar{\rho}\, V_{graup}}$$ (graupel content [kg kg^{-1}])

V_{graup} = 3.0 m s^{-1}

$$q_{snow} = \frac{(1-\beta)\, P_f}{\bar{\rho}\, V_{snow}}$$ (snow content [kg kg^{-1}])

V_{snow} = 0.5 m s^{-1}

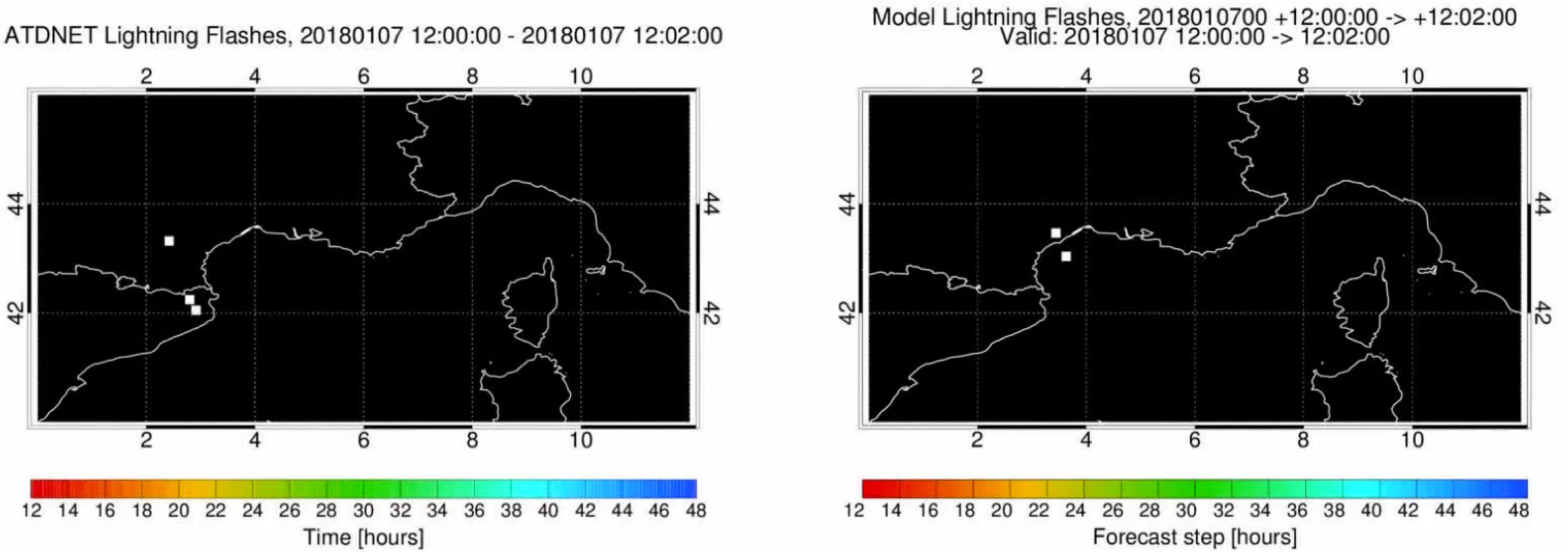
$CAPE$ = convective available potential energy [J kg^{-1}]
P_f = convective frozen precipitation flux [kg m^{-2} s^{-1}],
z_{base} = convective cloud base height [km],
q_{cond} = convective cloud condensate content [kg kg^{-1}],
β = 0.7 over land and 0.45 over ocean (graupel/snow partitioning).

Lopez P., MWR, 2010

Comparison of deterministic forecast with ATDnet lightning flashes.

Winter thunderstorms over northwestern Mediterranean.

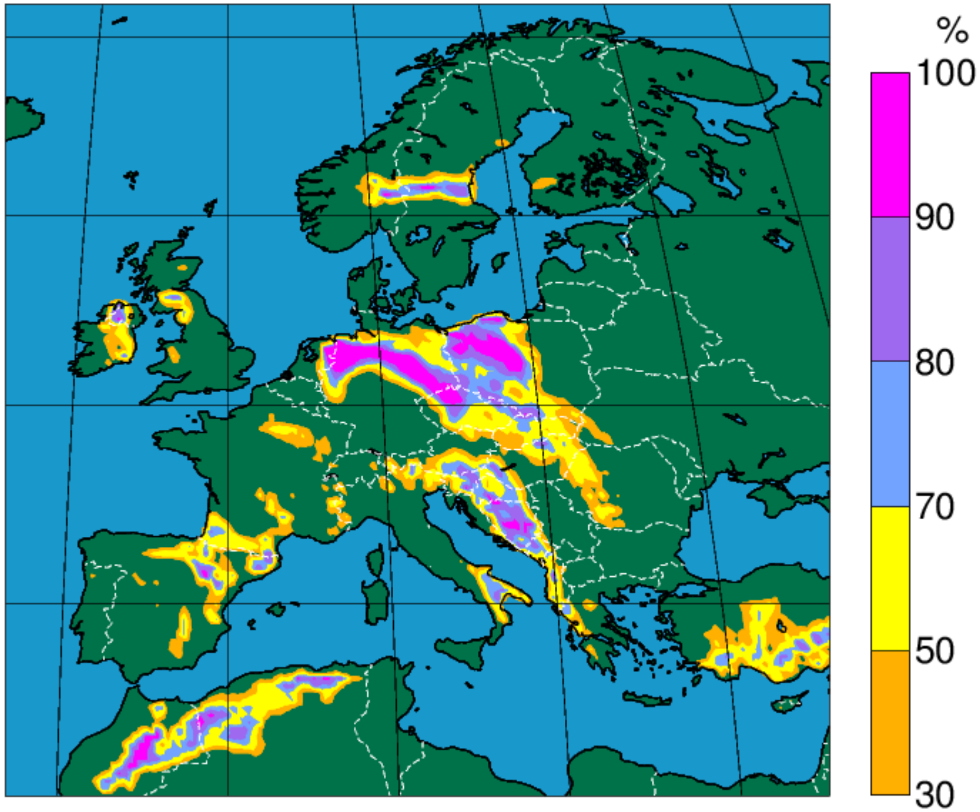
36h animation of 2-mn flash data starting from 7 January 2018 at 12Z.
TCo1279 L137 model forecast from +12h to +48h range.



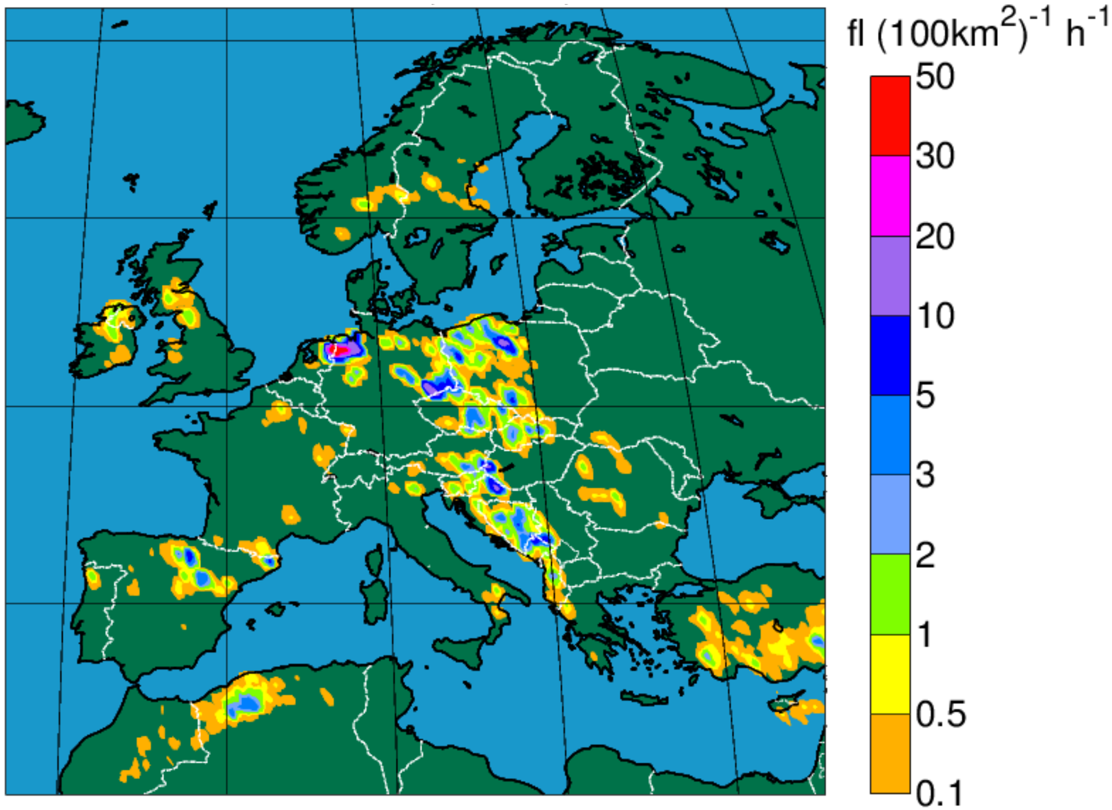
Note: Model flashes are pseudo-flashes randomly generated from simulated flash densities.

Probabilistic lightning prediction from ensemble forecasts

Ensemble forecast from oper 45r1 esuite
Probability[flash density > 0.1 fl/100km²/h]
Base: 1 June 2018 00Z, range: **T+12 to T+15h**

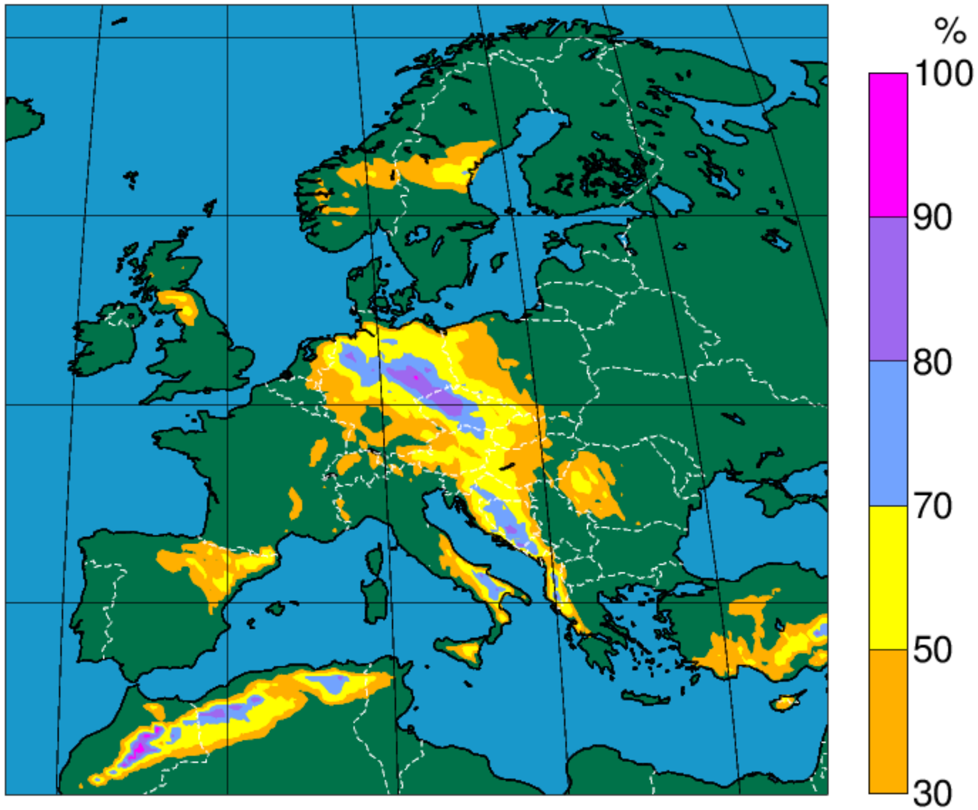


Observations:
ATDnet lightning flash densities
1 June 2018 from 12Z to 15Z

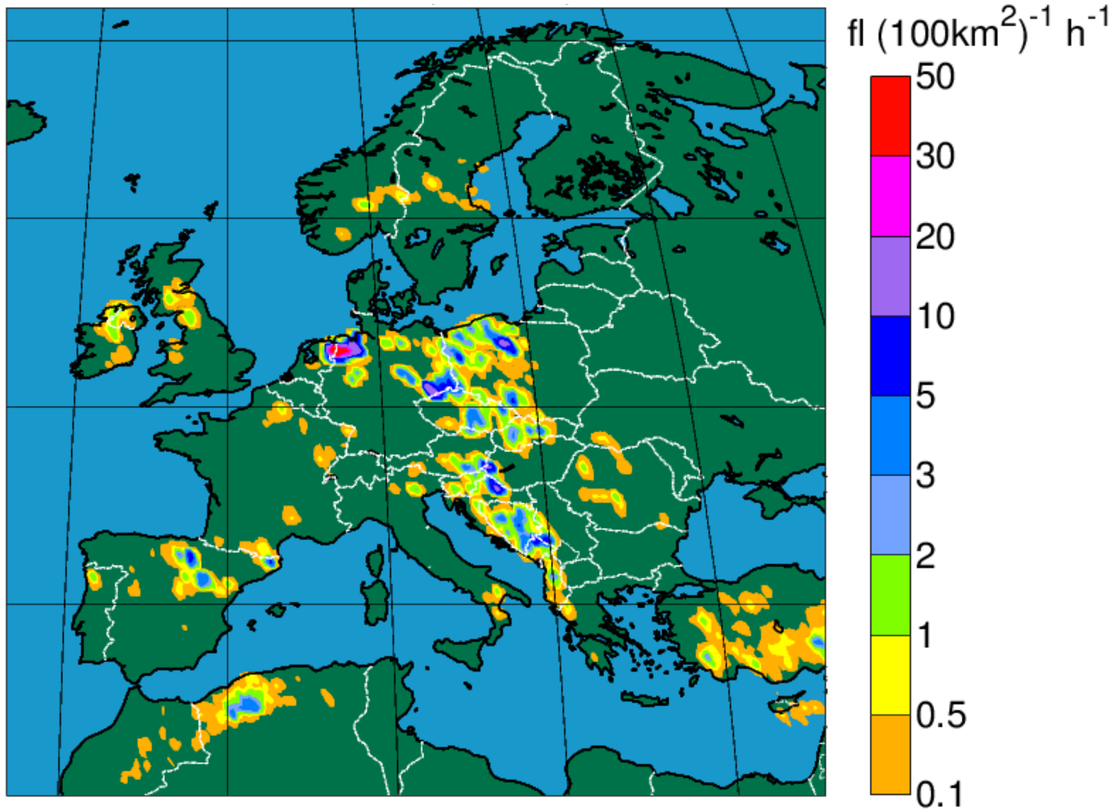


Probabilistic lightning prediction from ensemble forecasts

Ensemble forecast from oper 45r1 esuite
Probability[flash density > 0.1 fl/100km^2/h]
Base: 29 May 2018 00Z, range: **T+84 to T+87h**



Observations:
ATDnet lightning flash densities
1 June 2018 from 12Z to 15Z



ECMWF Use and interpretation of ECMWF products


Summary

Summary

Prediction of "weather" parameters continuing to improve, but still some issues, including:

- 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 related to shallow convection
- Inland penetration of (convective) showers and convective organisation can still be improved
- Melting of fresh snow on ground somewhat too slow
- Issues with visibility: too low in fog, too high when snowing
- …please continue to feed back issues!

Summary
The 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?


Questions ?

Recent and upcoming products from the IFS

New parameters in IFS 43r1 (from Nov 2016)

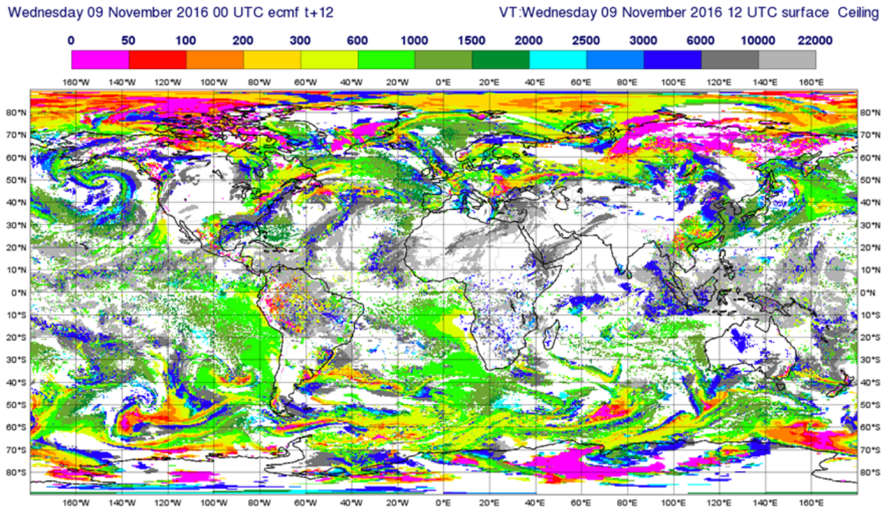
- ceiling (m) – cloud base height (>50% cloud cover),
- convective cloud top height (m)
- height of 0 and 1°C wet bulb temperature (m)
- direct beam surface radiation (plane perpendicular to the Sun's direction – accumulated)
- wave energy flux magnitude and direction

New parameters in IFS 45r1 (from June 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 = $\text{windshear}^{(925\text{-}500\text{hPa})}$ x SQRT(CAPE))

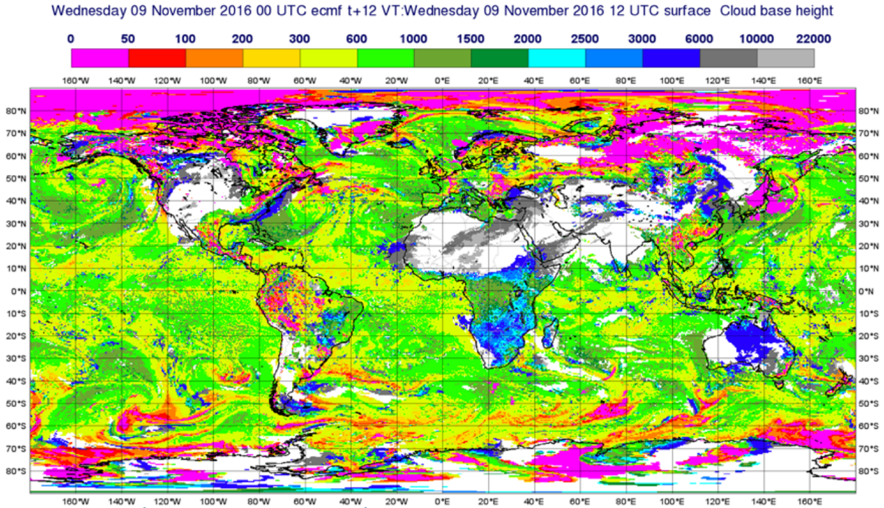
New parameters in IFS 43r1 (from Nov 2016)

Ceiling (for aviation)



Ceiling (m)

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



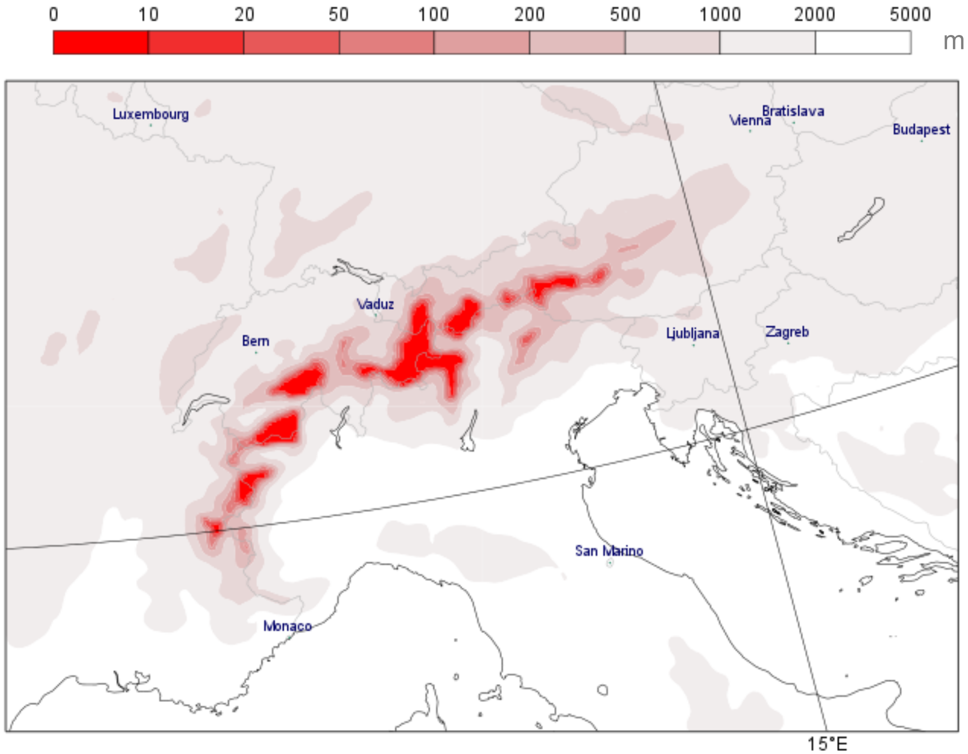
Cloud base height (m)

ECMWF

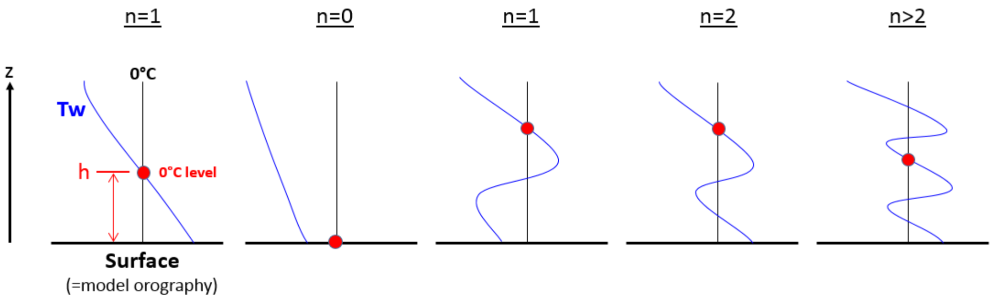
New parameters in IFS 43r1 (from Nov 2016)

Height 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

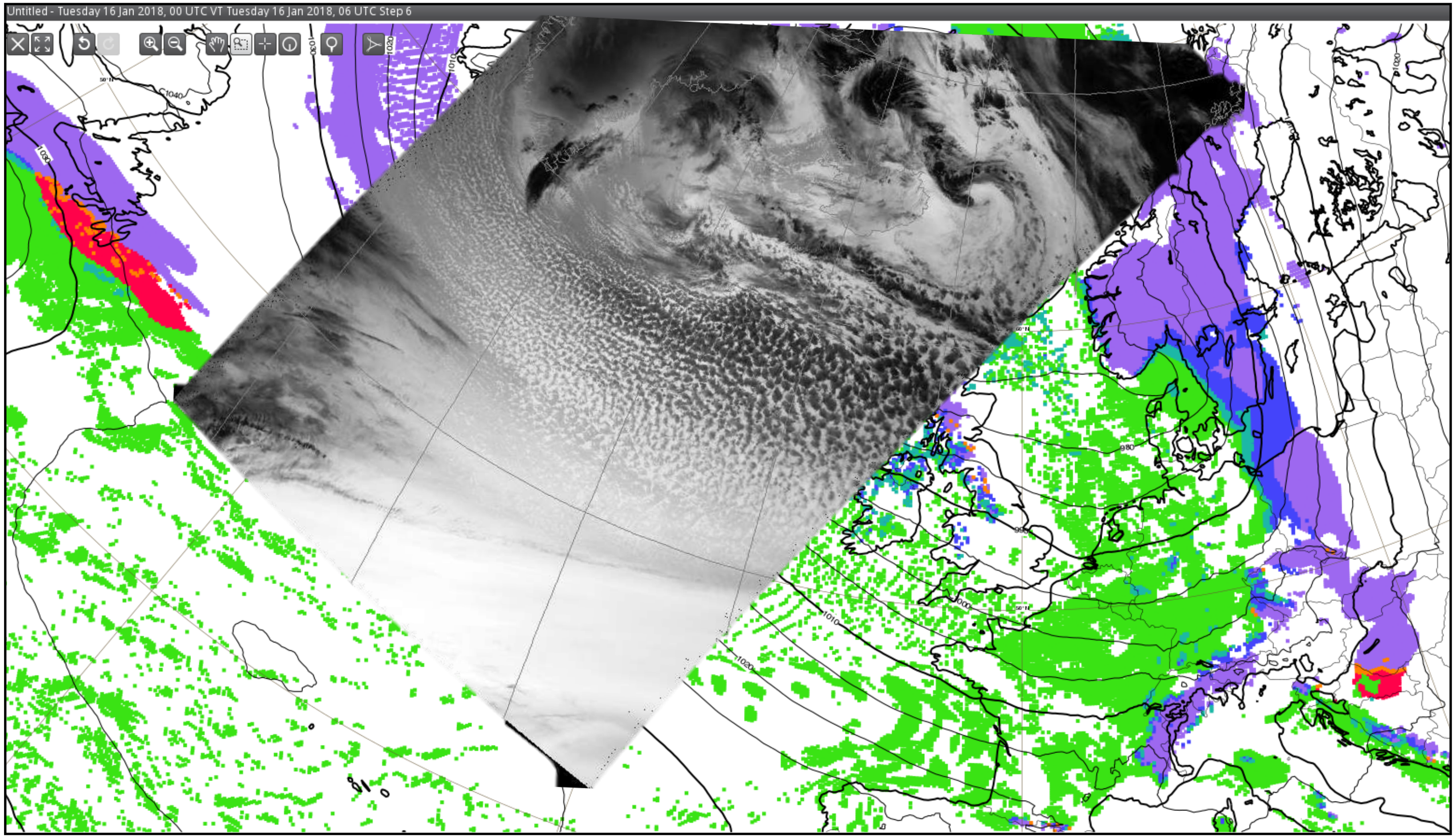


…if multiple values in the profile, then it is the height of the second decreasing crossover from the surface



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)


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