Clouds and precipitation:
From models to forecasting

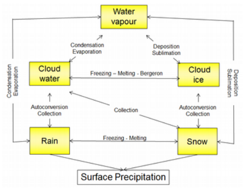
Richard Forbes
ECMWF Research Department
richard.forbes@ecmwf.int

Thanks to Tim Hewson, Ivan Tsonevsky, Thomas Haiden, Peter Bechtold

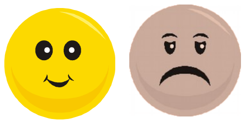
Outline

Clouds and Precipitation: From models to forecasting

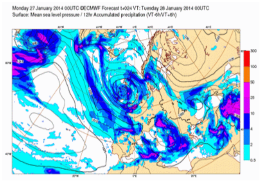
This seminar will (hopefully!) help you to …



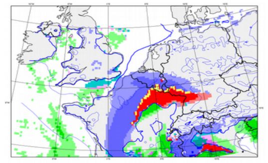
- describe how cloud and precipitation is represented in the ECMWF global model.



- recognise some of the strengths and weaknesses of the forecast cloud/precipitation.



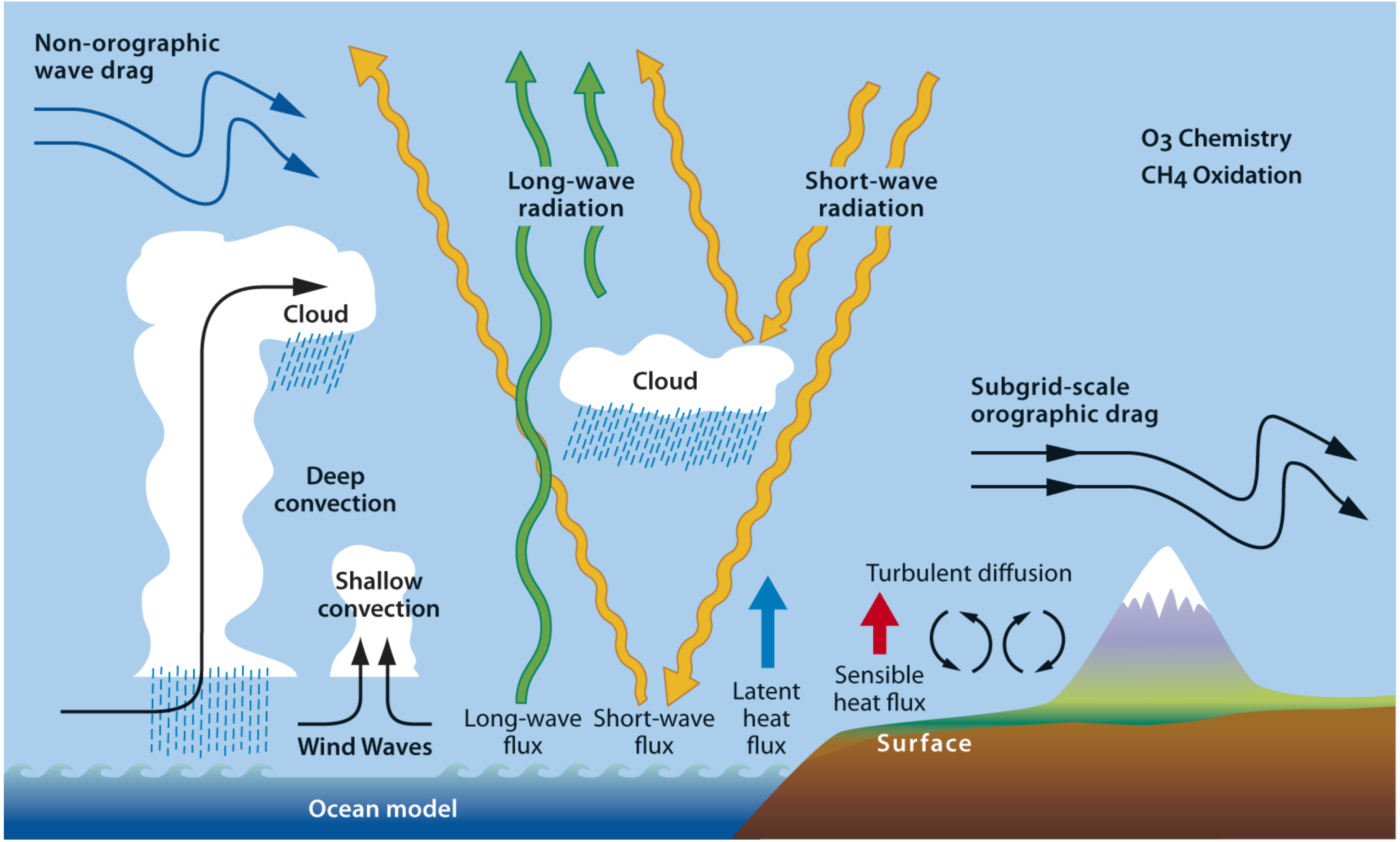
- interpret cloud and precipitation related forecast products.



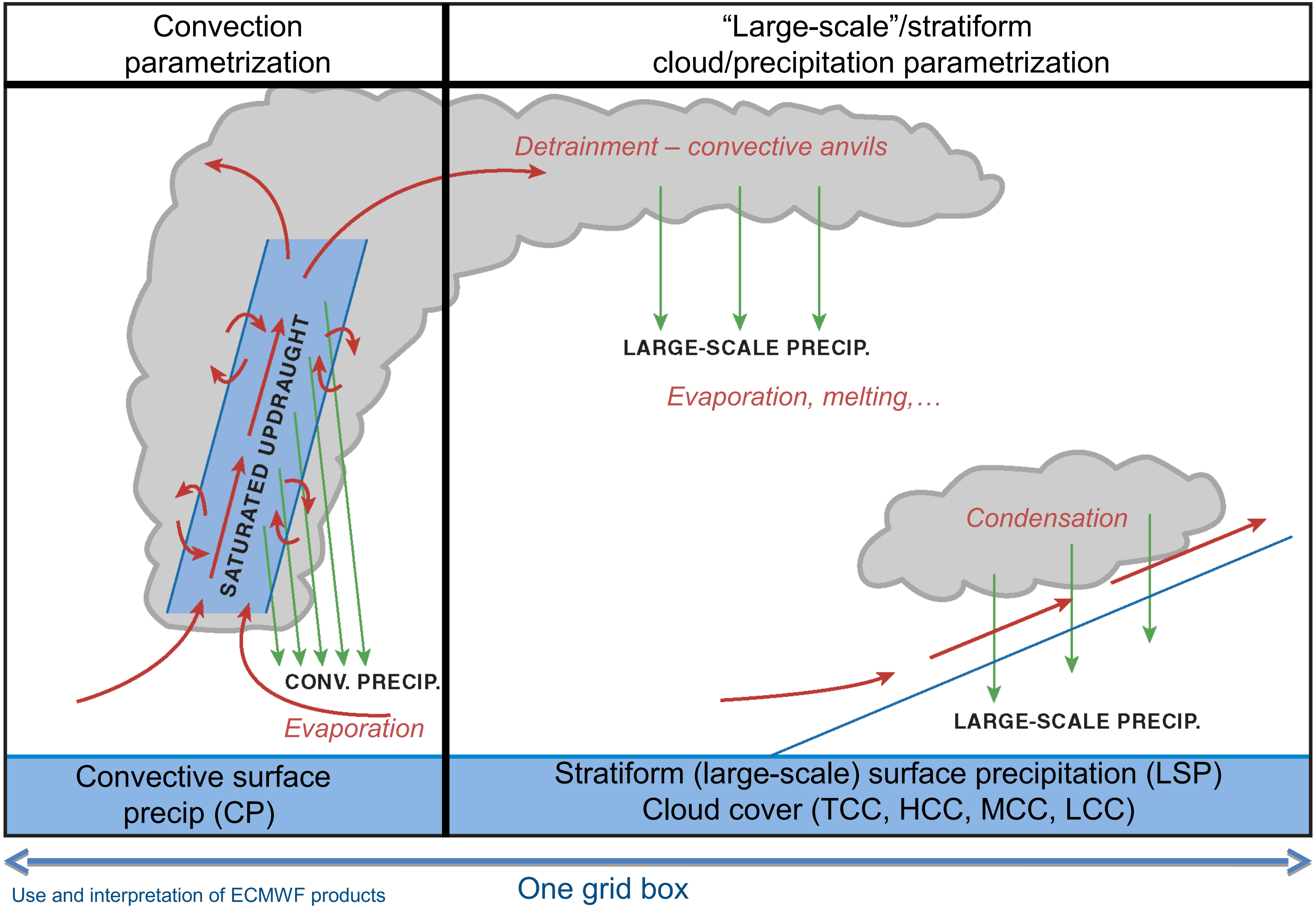
- learn about recent developments from a forecast users perspective …

1. How are cloud and precipitation represented in the ECMWF model?

Parameterized processes in the ECMWF model



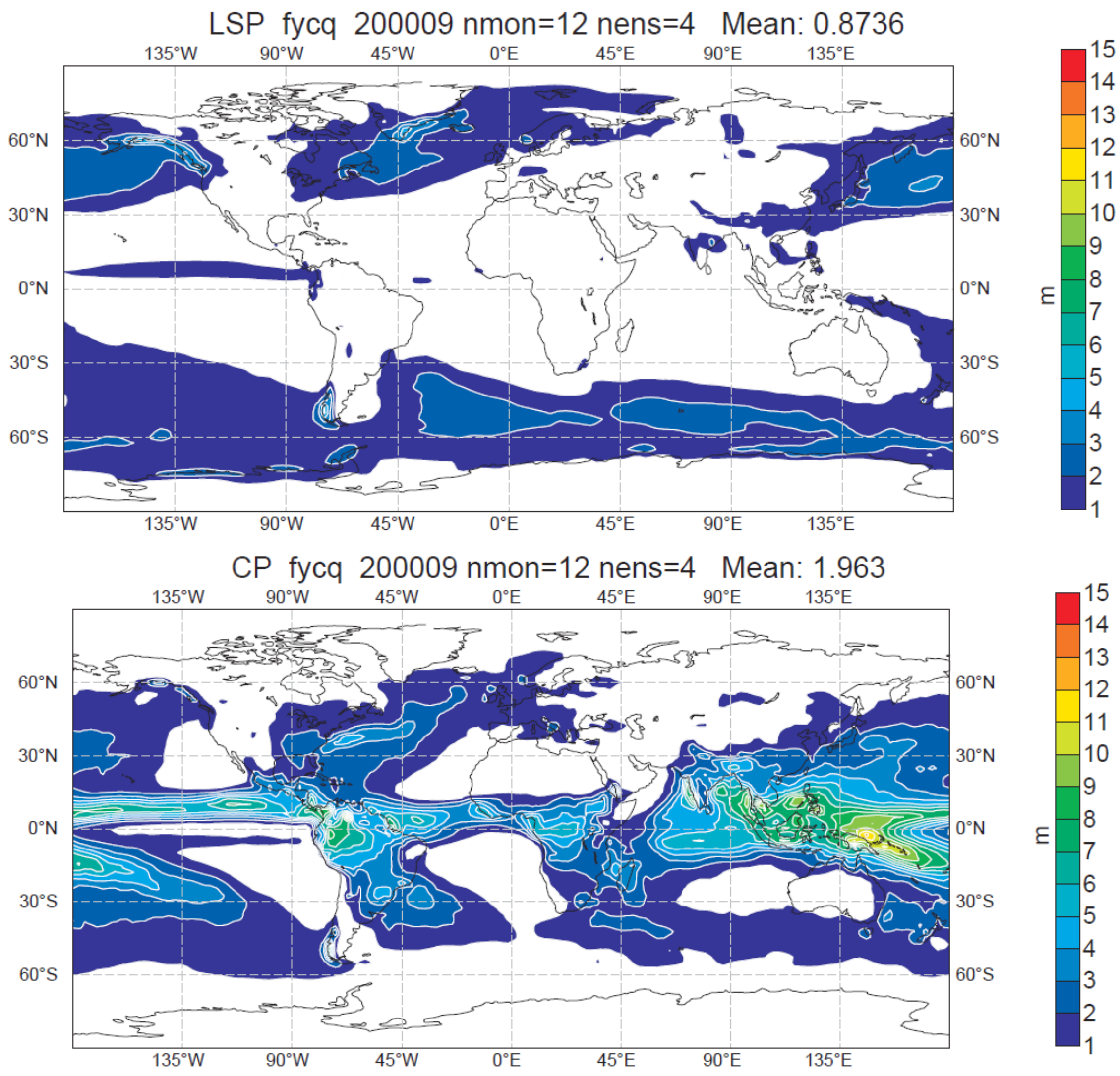
Convective and stratiform precipitation and clouds



Global annual mean surface precipitation LSP/CP (IFS Cy40r1)

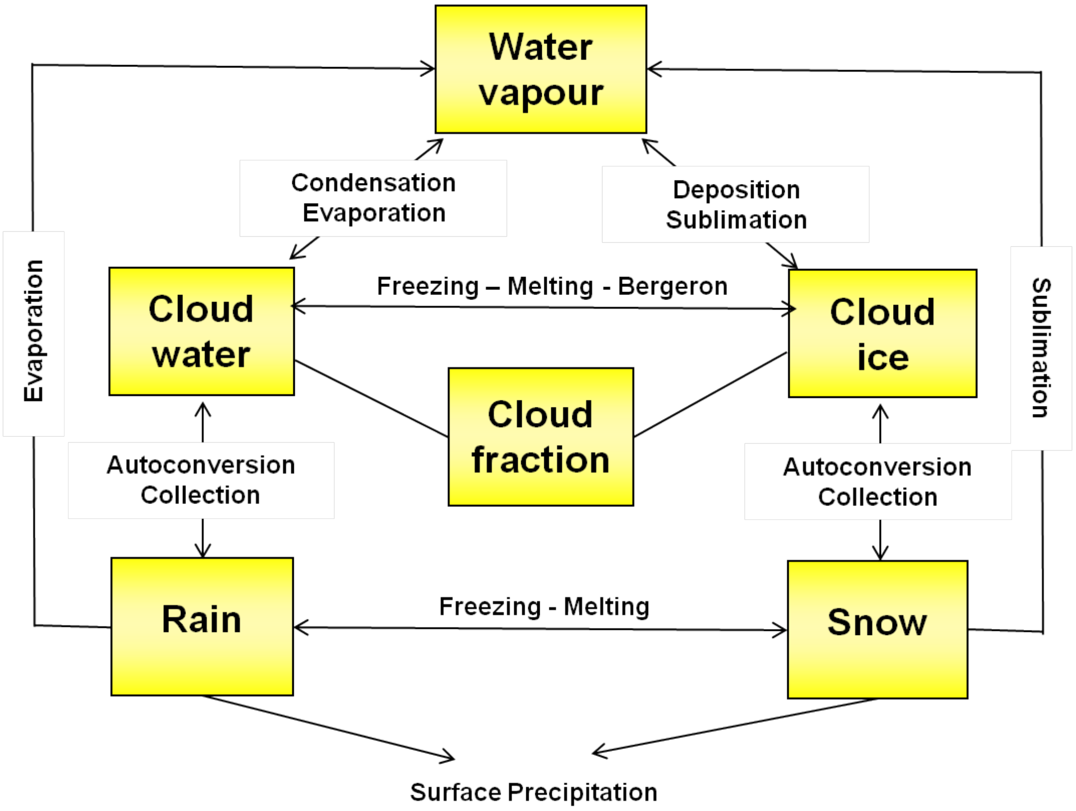
Stratiform (large-scale) surface precip (LSP)

Convective surface precip (CP)



- This is for low resolution T159, but not too different for higher resolutions
- CP is ~2/3 of global precipitation
- but LSP dominant or similar to CP in extratropics

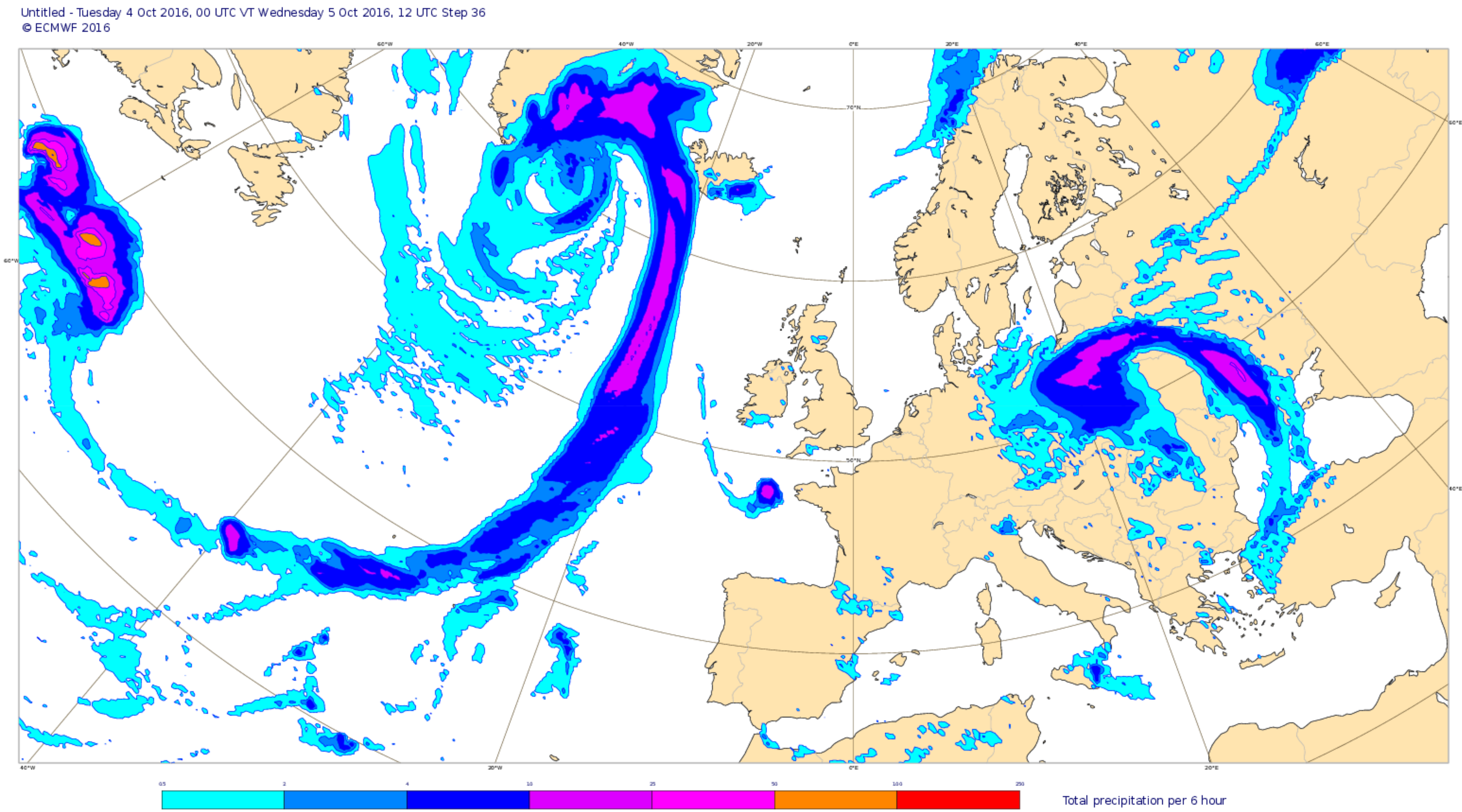
IFS stratiform cloud scheme



- 5 prognostic cloud variables + water vapour
- Ice and water independent variables
- Snow/rain prognostic, advected with the wind
- Physically based, increasing realism

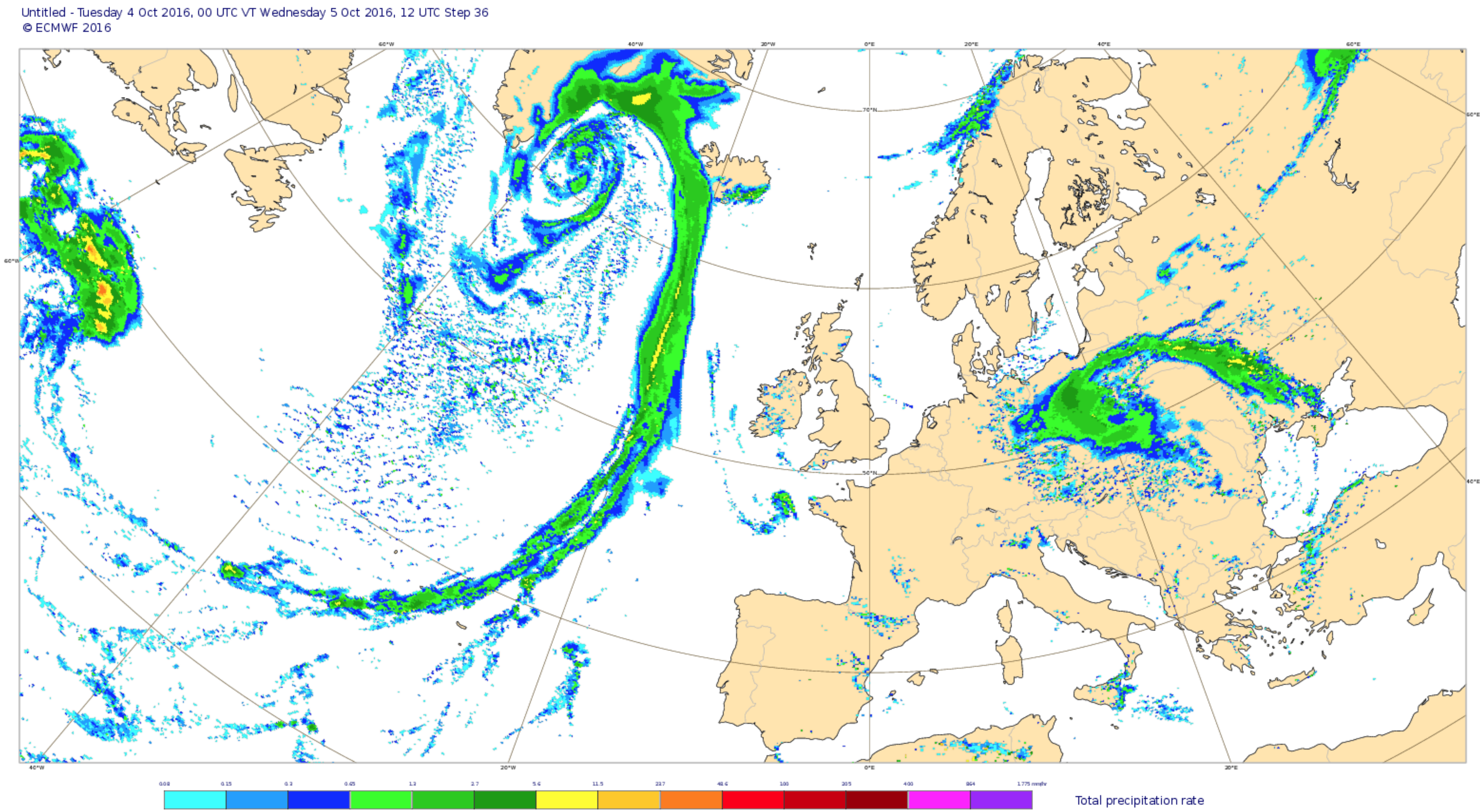
Example 6 hour precipitation accumulation

Forecast for Wed 5 October 2016



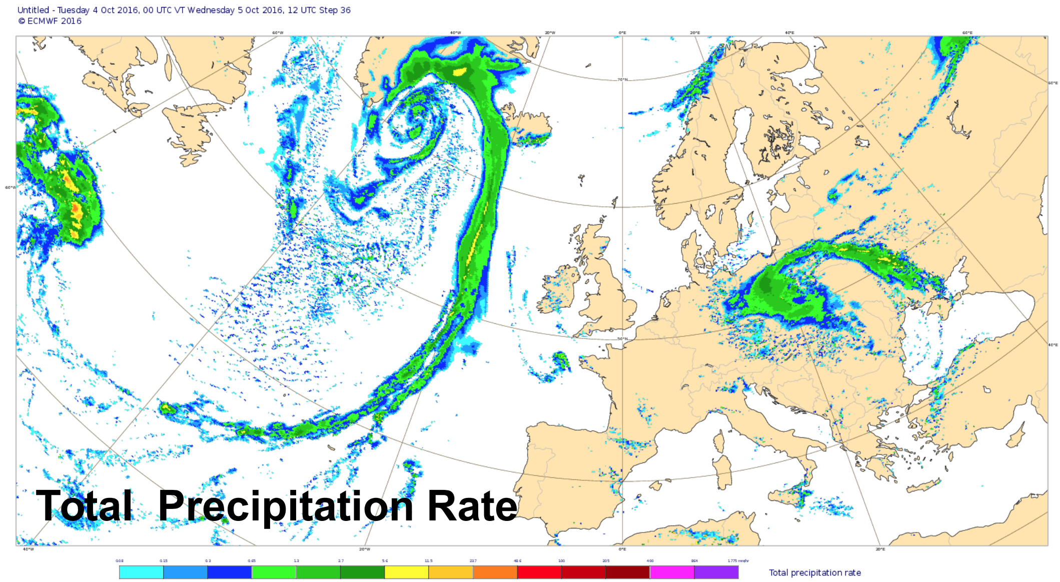
Precipitation Accumulation: Large-scale rain + convective rain + large-scale snow + convective snow

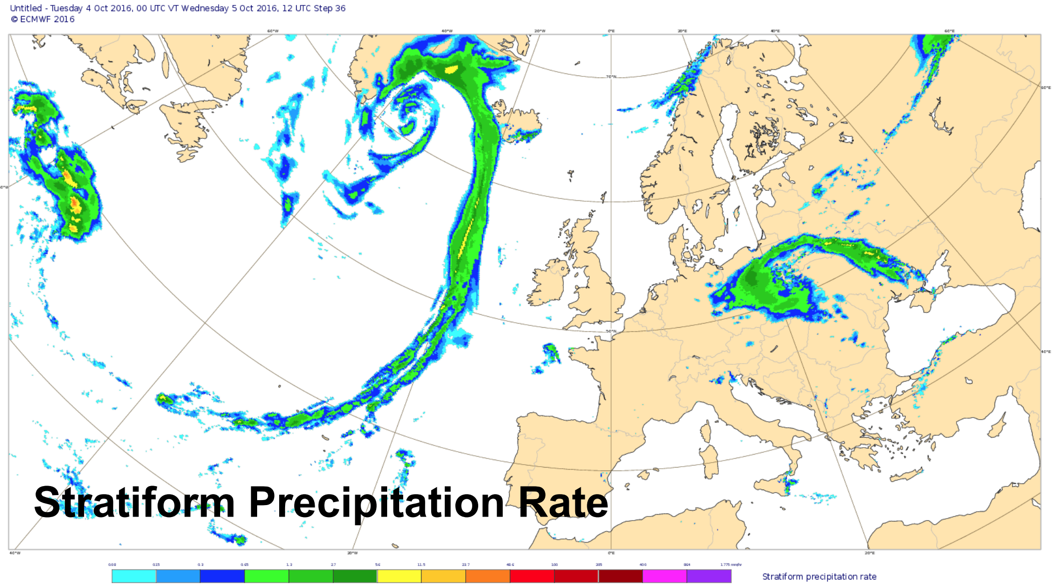
Example precipitation rate
Forecast for Wed 5 October 2016 12Z

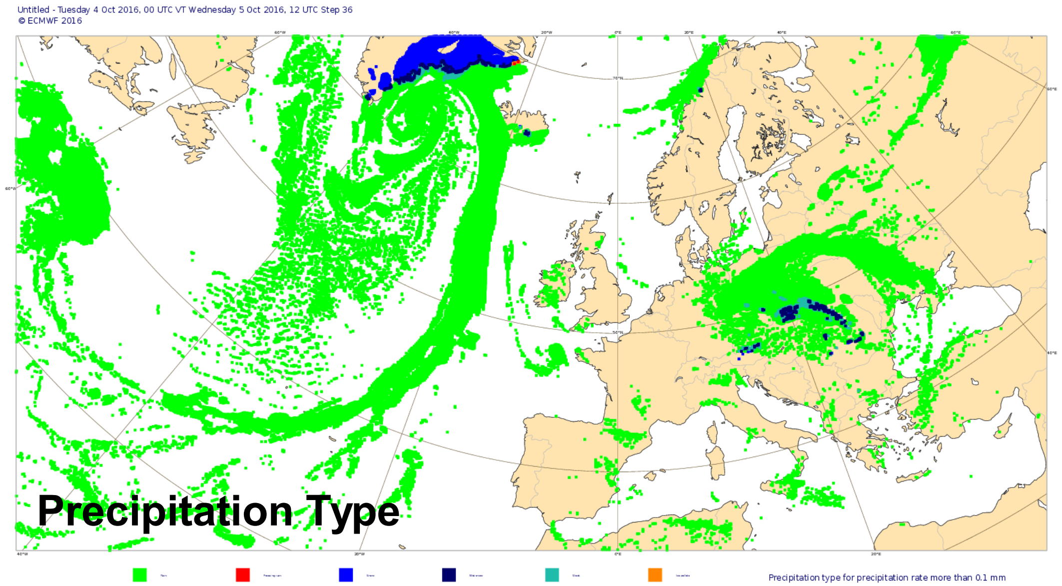


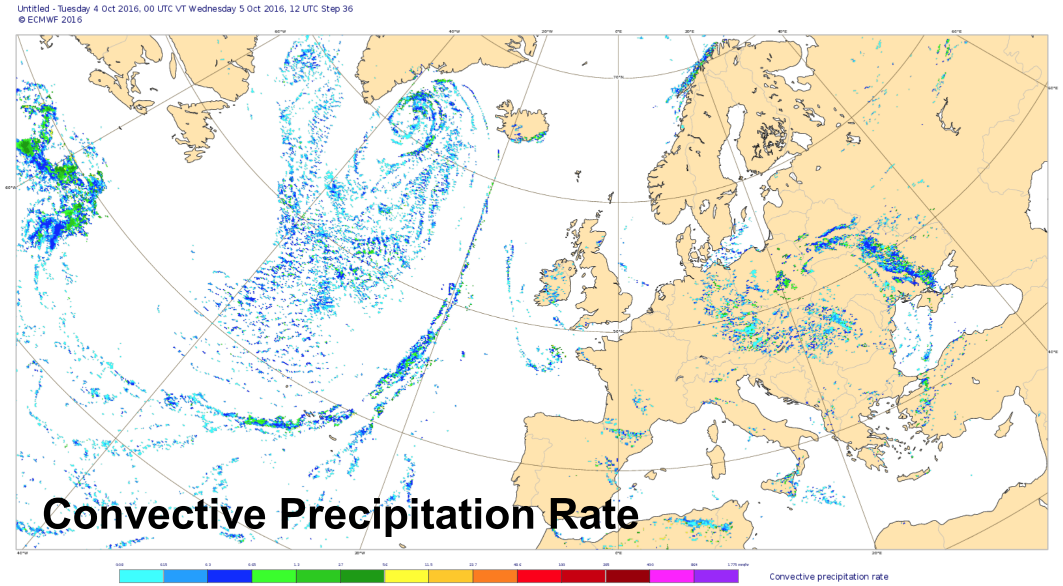
Precipitation Rate: Large-scale rain + convective rain + large-scale snow + convective snow

Precipitation rate and type example: 12 UTC Wed 5 October



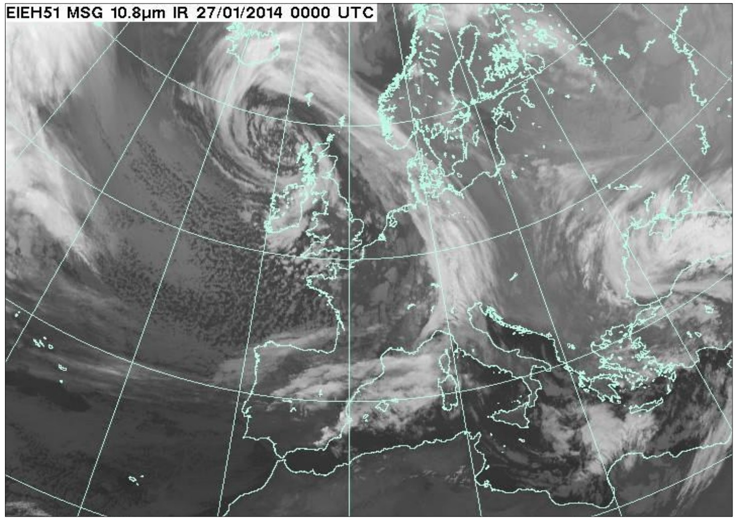




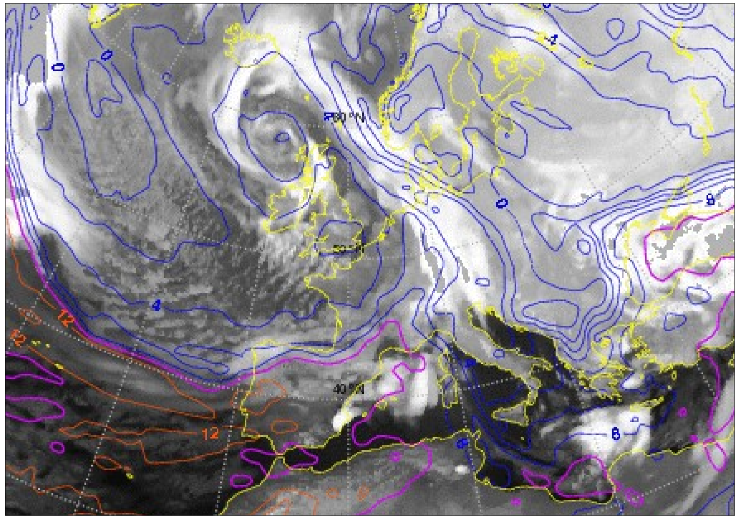


Cloud: 00Z Monday 27 January 2014

Meteosat IR 10.8µm

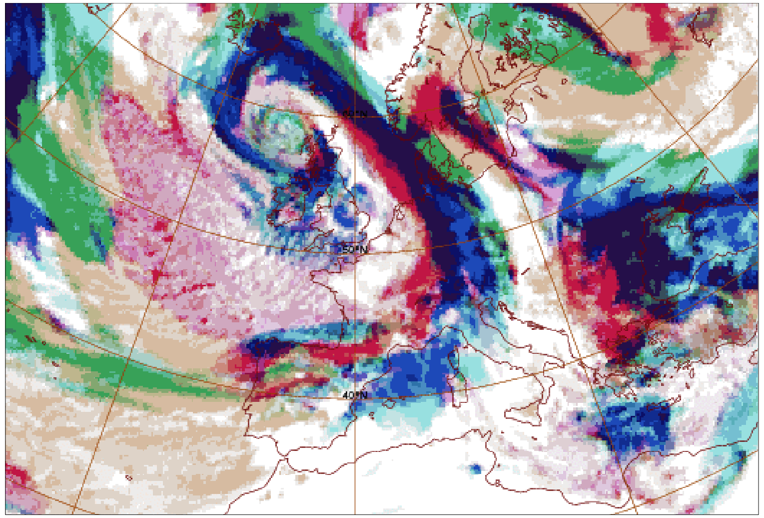


IFS Pseudo-IR 10.8µm

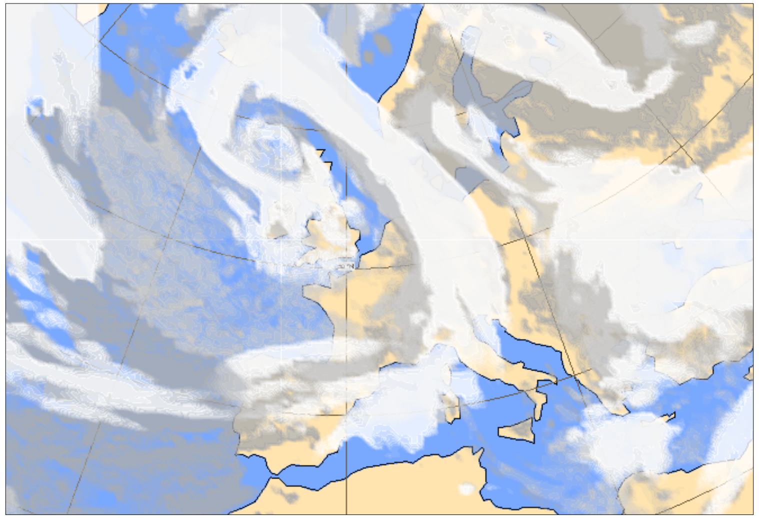


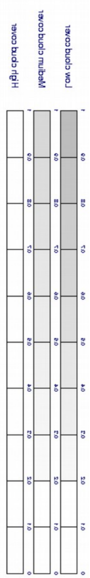
IFS cloud product (Low, Med, High and mixed)

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

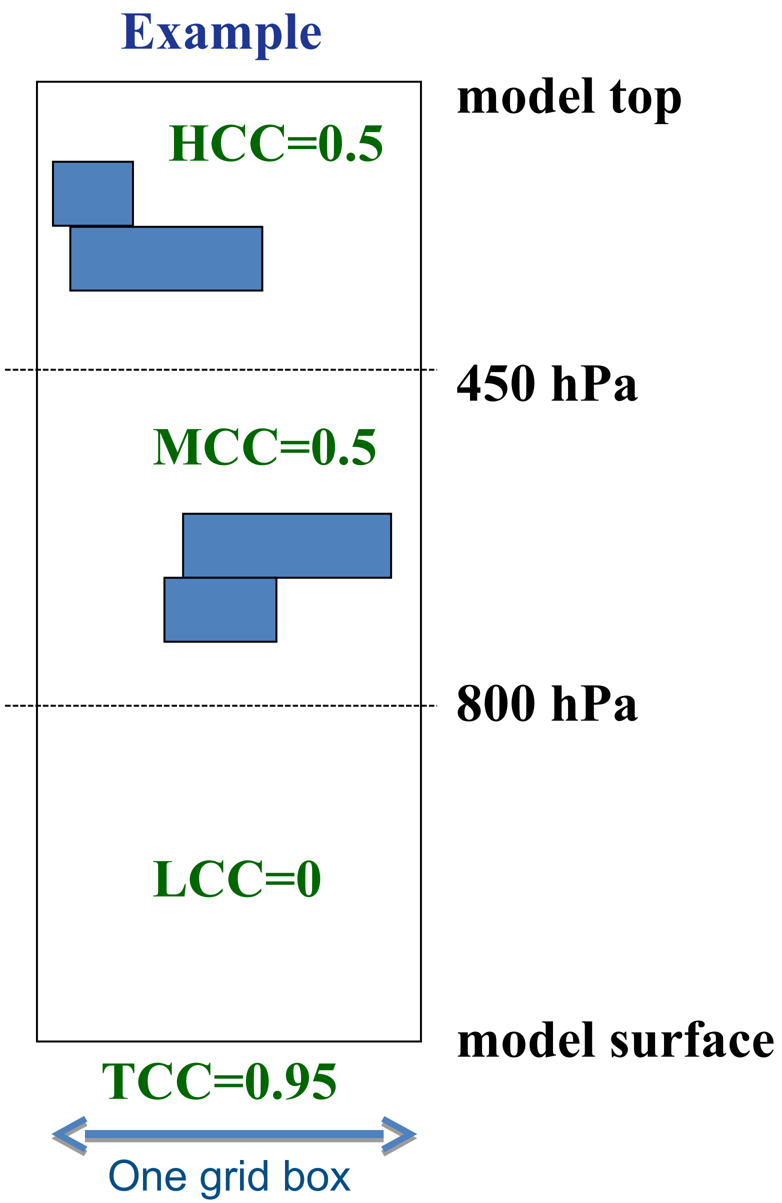


ECcharts IFS cloud product (Low, Med, High)





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 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

2. Difficult situations for cloud and precipitation forecasts

Some of the difficult cloud problems for forecast models…

1. Boundary layer cloud (e.g. high pressure situations).
   Impact on 2m temperatures.

2. Supercooled liquid topped boundary layer cloud.
   Impact on 2m temperatures, particularly higher latitudes

3. Snowfall in marginal situations – the melting layer

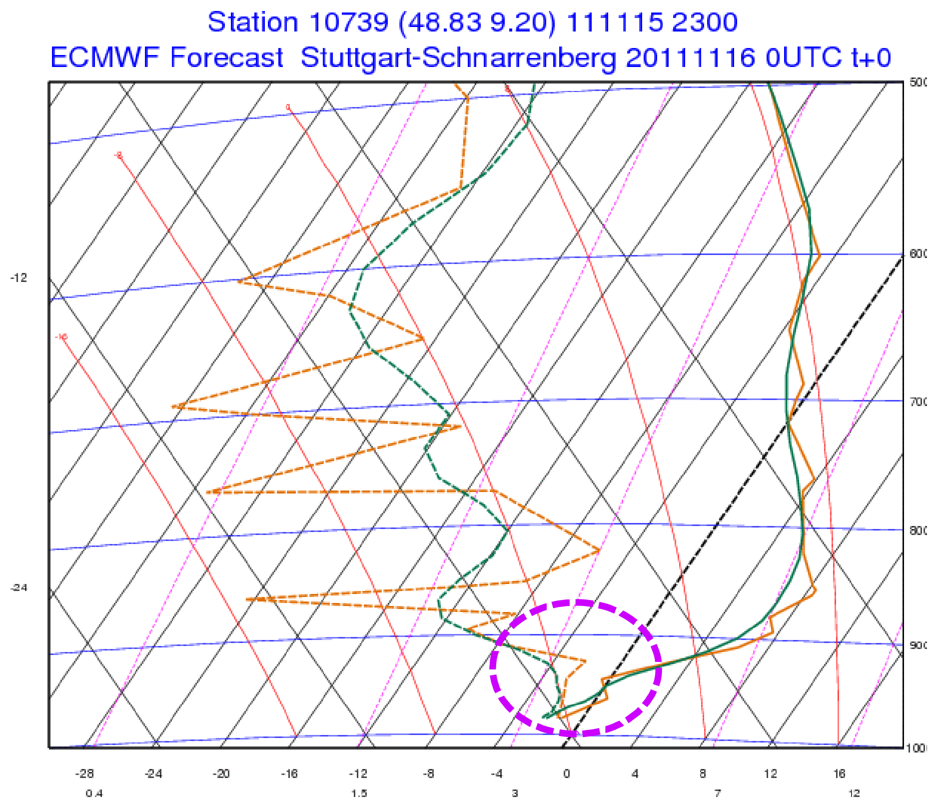
4. Winter precipitation type – freezing rain

5. Fog

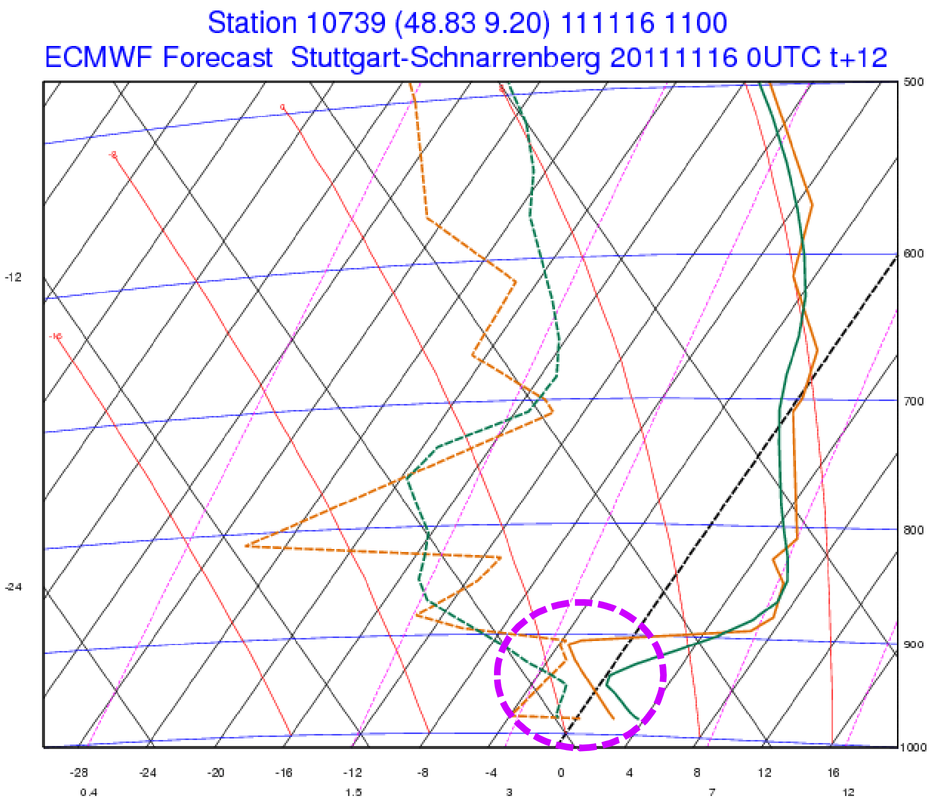
(1) Low cloud cover: Too little in fog rising to stratocumulus example

Sounding Stuttgart 16 Nov, 2011

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



Obs Analysis



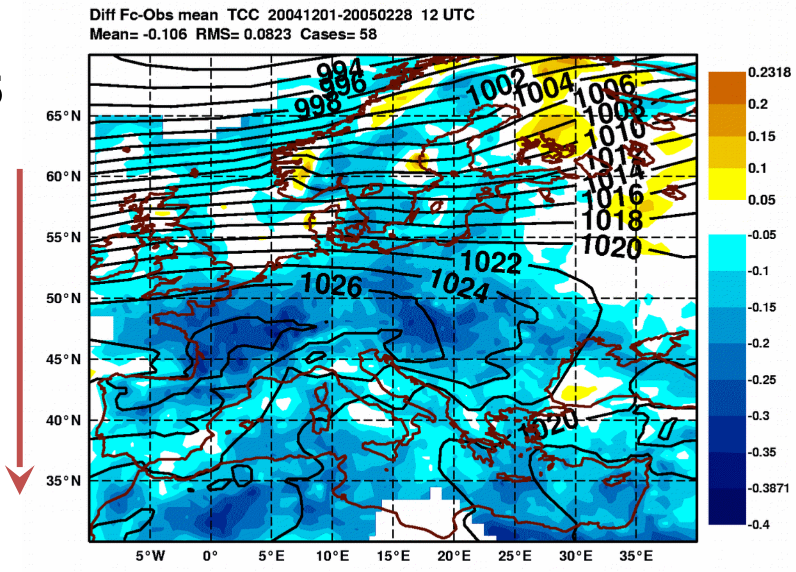
Obs Fc T+12h

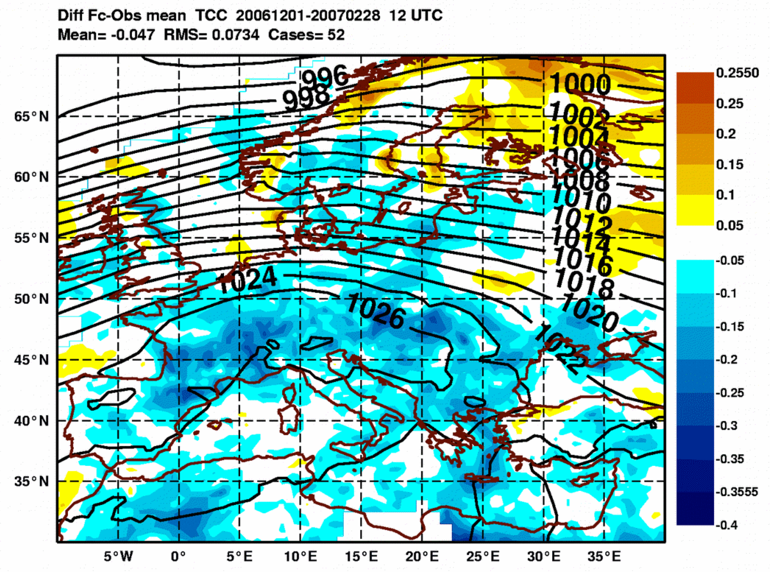
Fog rising developing into stratocumulus deck could not be properly represented

(1) **Low cloud cover**: 36h forecast versus SYNOP observation
(for high pressure days over Europe during winter)

DJF
2004/5
58 cases

EDMF PBL
M-O diffusion

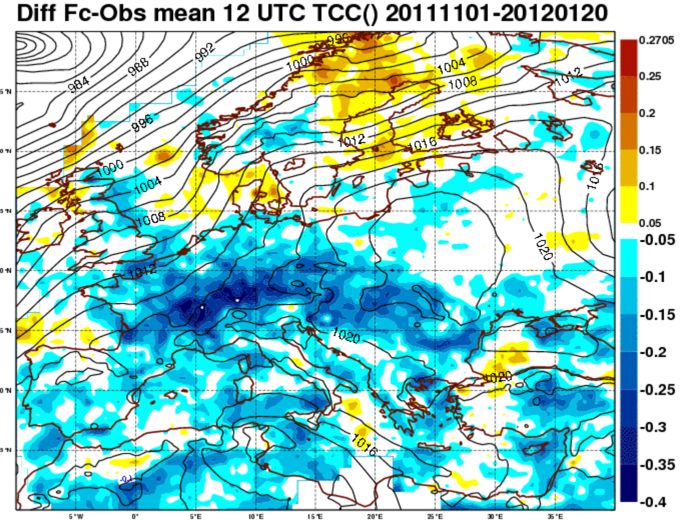




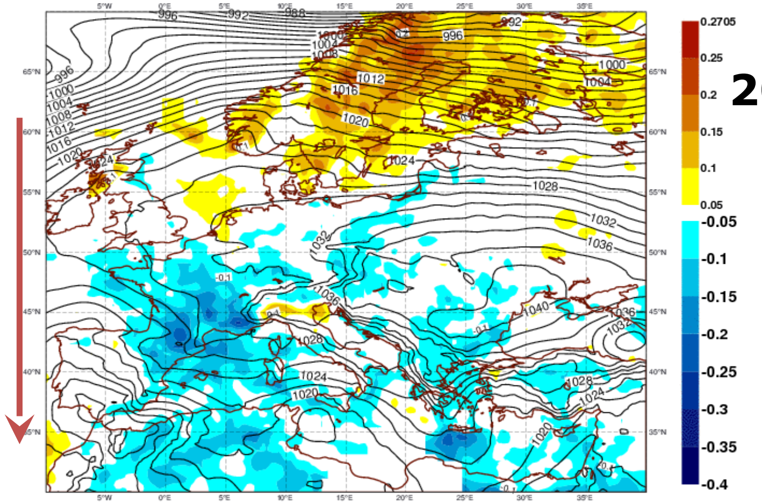
DJF
2006/7
52 cases

NDJ
2011/12

NEW MICROPHY



REVISED CLOUD

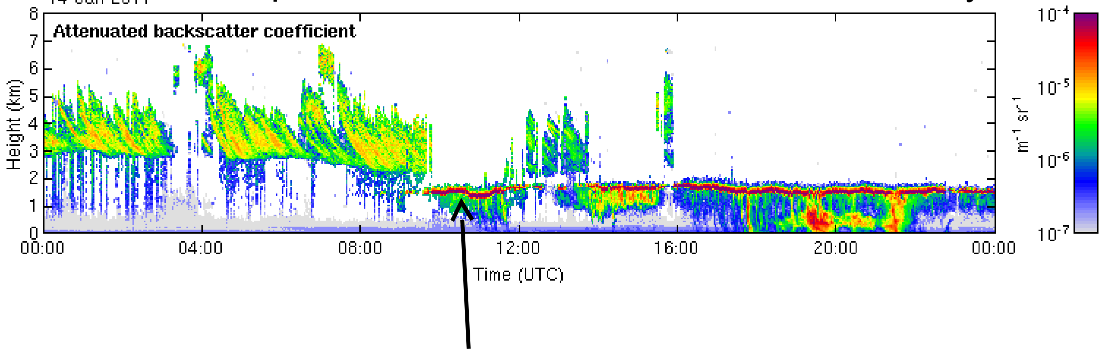


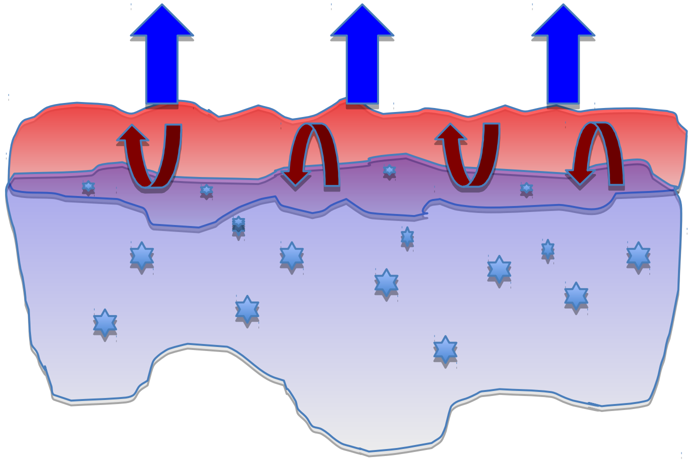
NDJ
2015/16

(2) Boundary layer cloud and super-cooled liquid water

Commonly observed in the atmosphere

Example lidar backscatter timeseries at Sodankylä

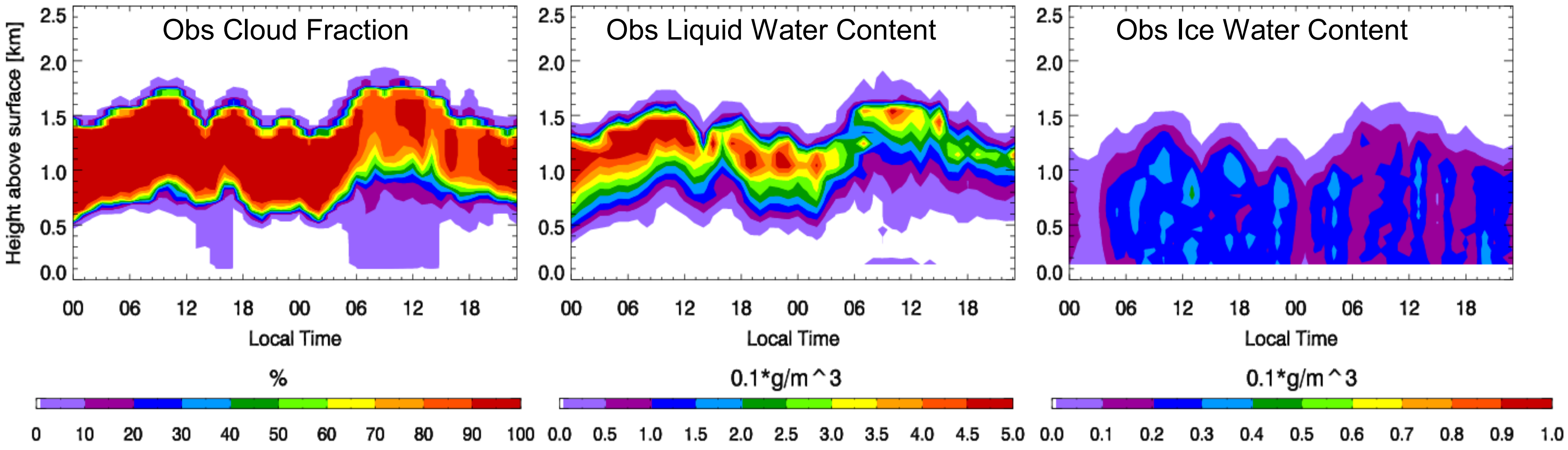




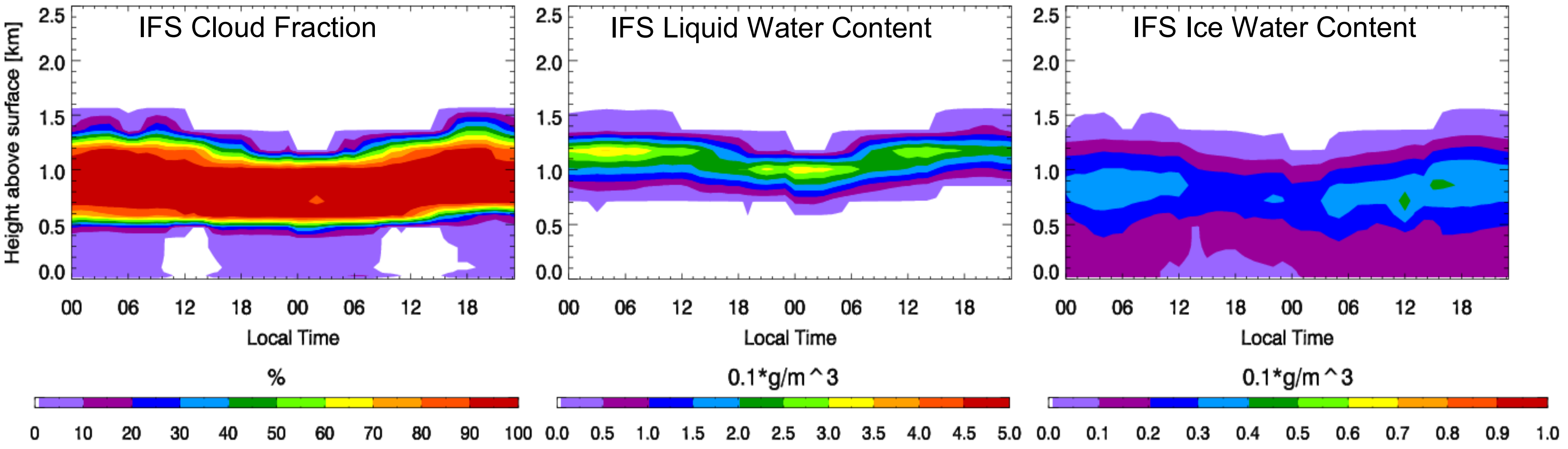
- Super-cooled liquid water (SLW) cloud frequently occurs in atmosphere as observed from aircraft & remote sensing.
- Radiatively important and can increase cloud lifetime (liquid drops suspended, ice crystals grow and fall out)
- Fine balance between turbulent production of water droplets, nucleation of ice, deposition growth and fallout.
- Difficult for models - uncertainties in turbulent mixing, ice microphysics, vertical resolution…
- Can impact 2m temperatures

(2) Boundary layer cloud and supercooled liquid water

Arctic cloud case study (MPACE) – typical of SLW topped cloud with ice fallout



Cy37r3 (2011) – more supercooled liquid water at cloud top with ice fallout

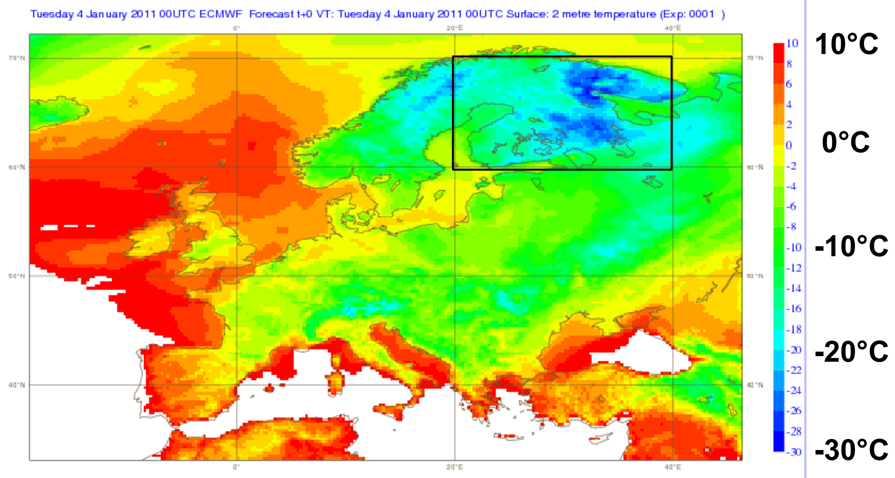


Forbes and Ahlgrimm (2014)

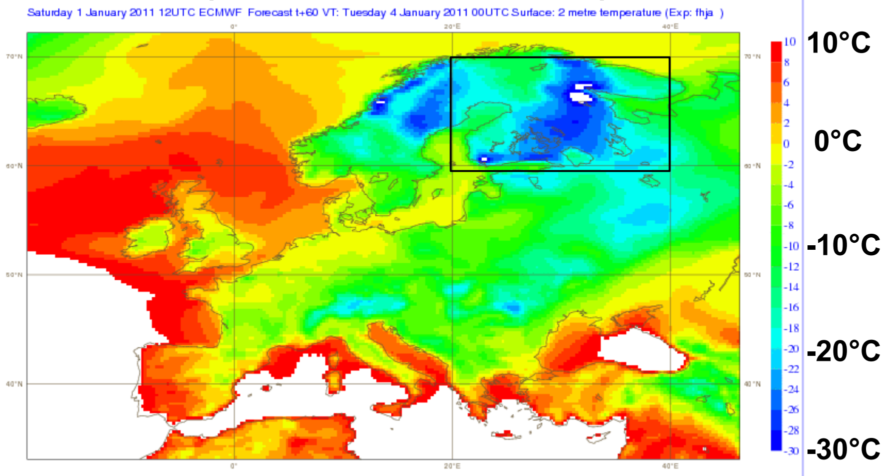
(2) Boundary layer cloud and supercooled liquid water

Cold T2m bias in weakly forced mixed-phase 00Z 4 Jan 2011 over Finland

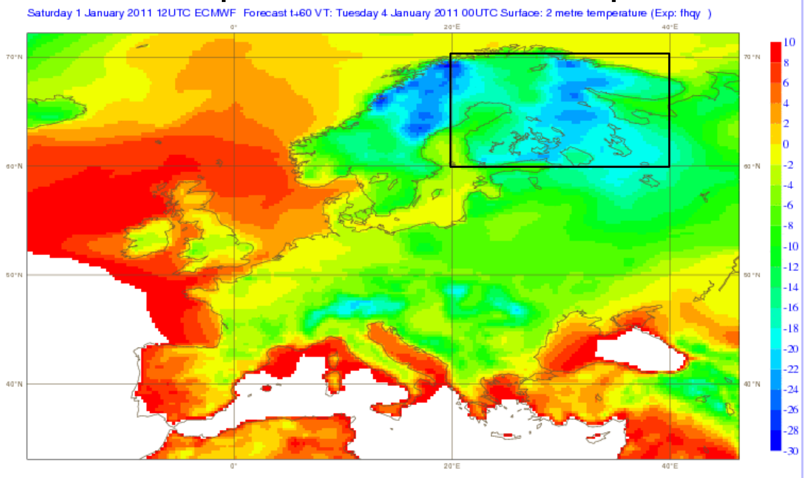
Analysis



Cy37r1 with too little supercooled liquid water at cloud top



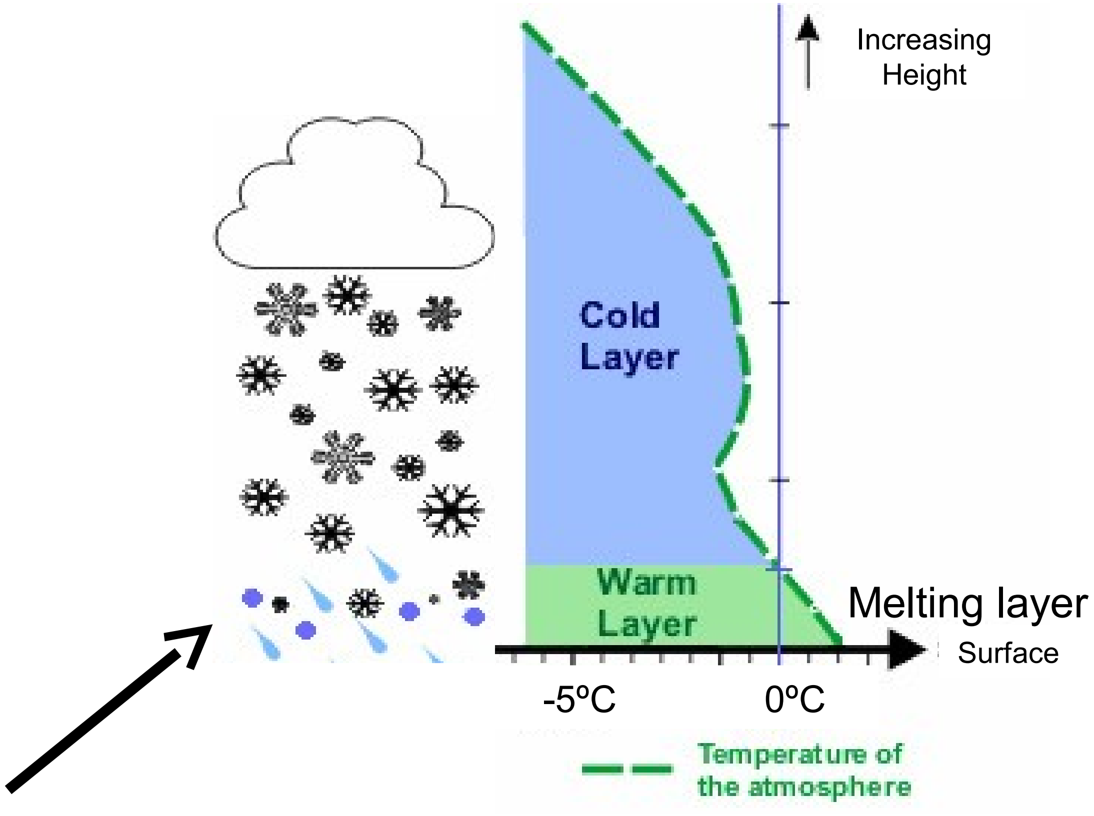
Cy37r3 with more realistic supercooled liquid water at cloud top



(3) Snowfall in marginal situations

(3) Snowfall in marginal situations: Melting layer

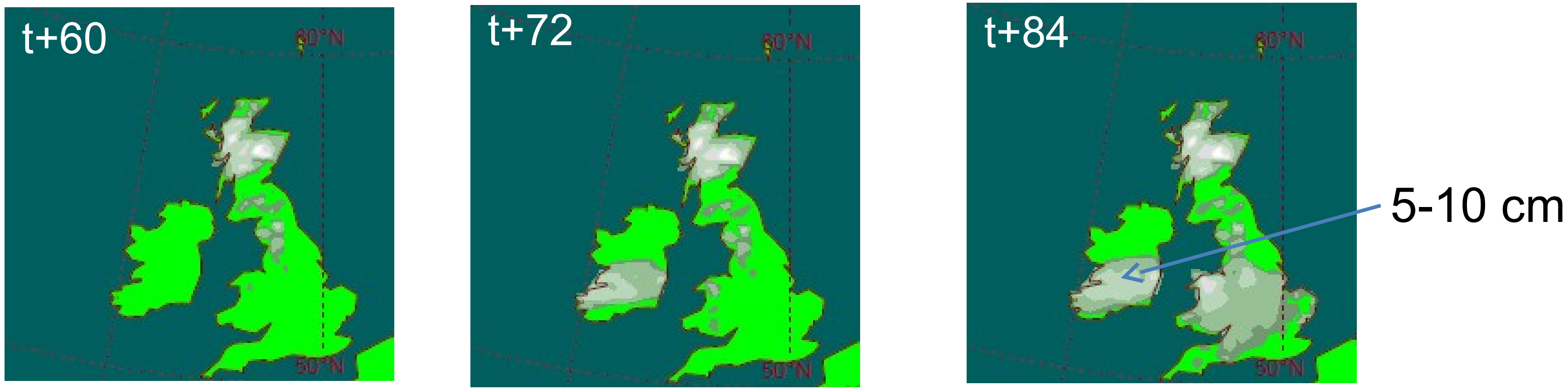
Melting layer often ~ few hundred metres thick
In drier air, snow melts at T > 0°C (due to evaporative cooling)

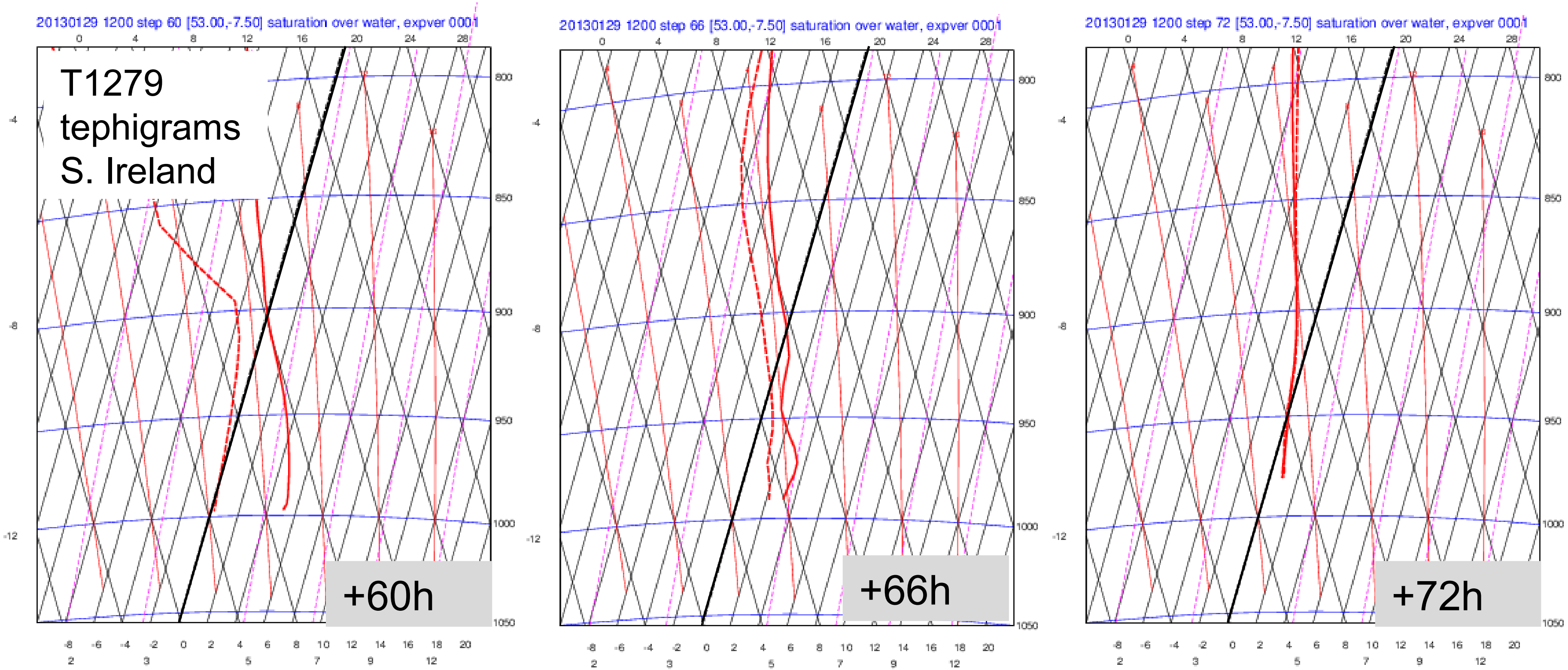


Sleet in melting layer:
Reality = melting particles, liquid surrounding an ice core
In the model = snow gradually transferred to rain variable

(3) Snowfall in marginal situations

Ireland 01 Feb 2013. Snow depth forecast from basetime 12Z on 29 Jan





(3) Snowfall in marginal situations

- Difficult to get right. A difference of 1 or 2ºC makes all the difference between snowfall and rainfall (e.g. errors in large scale flow, surface too cold, precipitation rate incorrect)

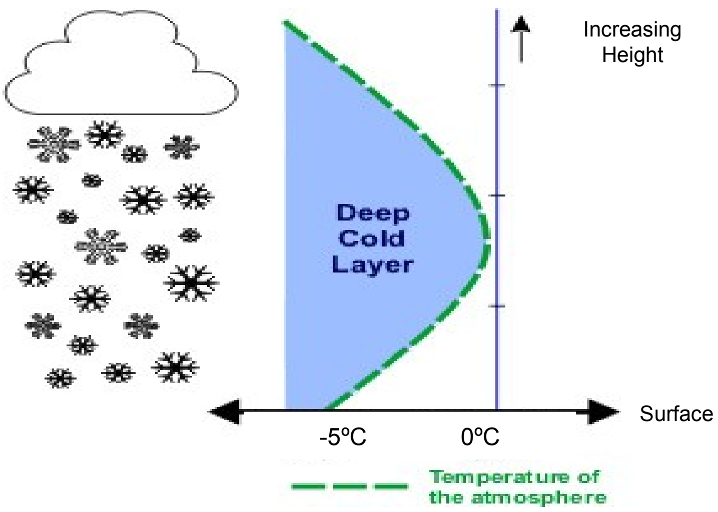
- In the model, sleet (melting snow particles) is represented by a mix of rainfall and snowfall. Halfway through the melting layer will be 50% snowfall and 50% rainfall. NOTE: IFS diagnostics TP=totalprecip=(rainfall+snowfall), SF=snowfall

- Once on the ground and temperatures greater than zero, surface snow often takes too long to melt (recognised problem in the ECMWF model)

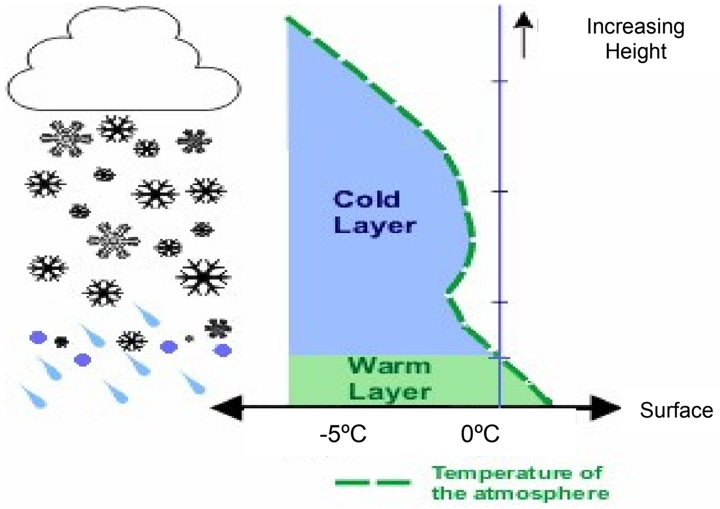
Winter precipitation type (Freezing rain)

Precipitation type – a diagnostic from the IFS

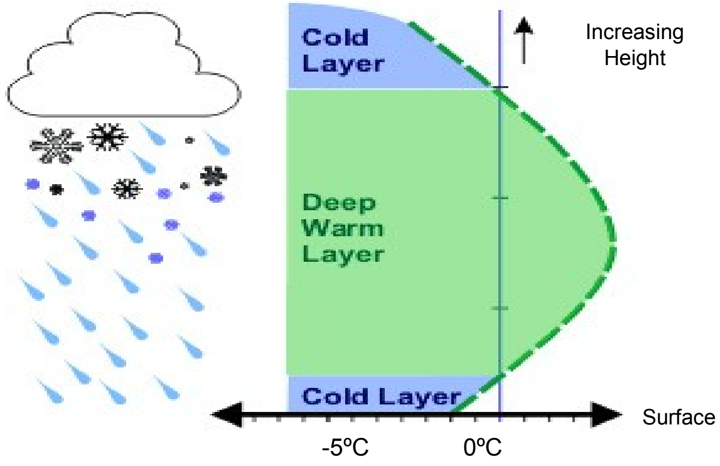
rain / snow / wet snow / mix rain-snow / ice pellets / freezing rain



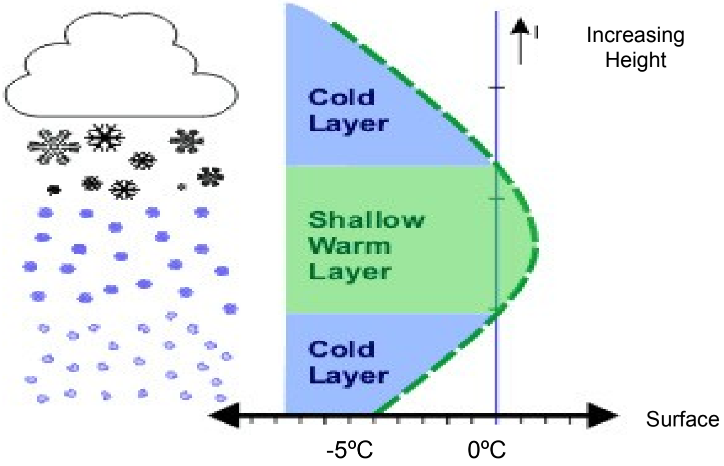
Snow



Sleet (melting snow) or rain



Freezing rain



Ice pellets

New precipitation diagnostics (in Cy41r1, May 2015)

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

  (=1) Rain T2m > 0ºC, liquid mass more than 80%
  (=7) Mixed rain/snow T2m > 0ºC, liquid mass >20% and <80%
  (=6) Wet snow T2m > 0ºC, liquid mass less than 20%

  (=5) Snow T2m < 0ºC "dry" snow
  (=3) Freezing rain T2m < 0ºC supercooled rain from melted particles aloft
  (=8) Ice pellets T2m < 0ºC refrozen from partially melted particles aloft

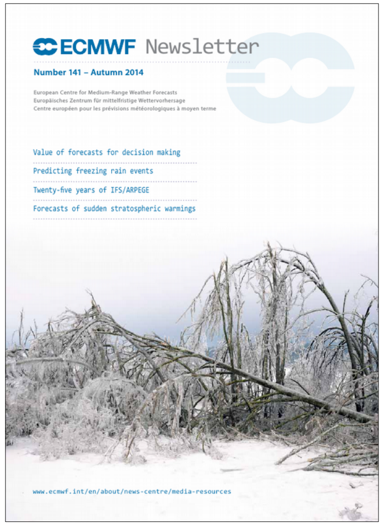
  (Note: height of (uppermost) freezing level (*deg0l*) diagnostic also available)
  (Graupel/Hail not available)

- 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*)

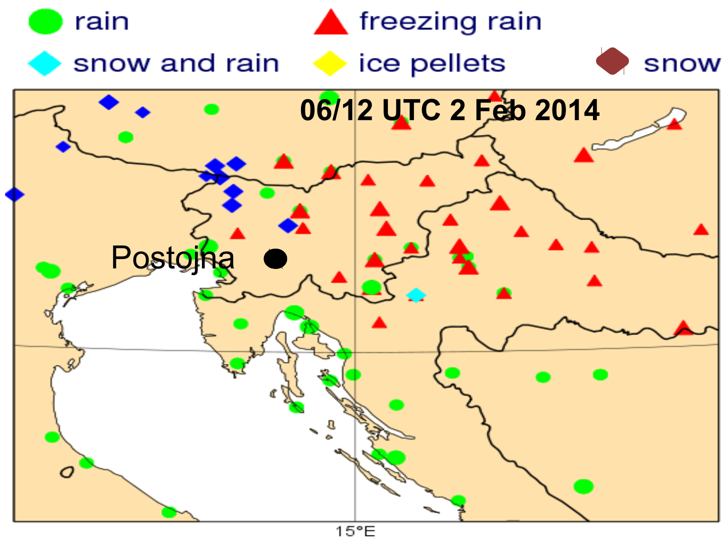
- Maximum and minimum total precipitation rates in the last 3 hours/6 hours (*mintpr3,maxtpr3, mintpr6,maxtpr6*)

Predicting high-impact freezing rain events

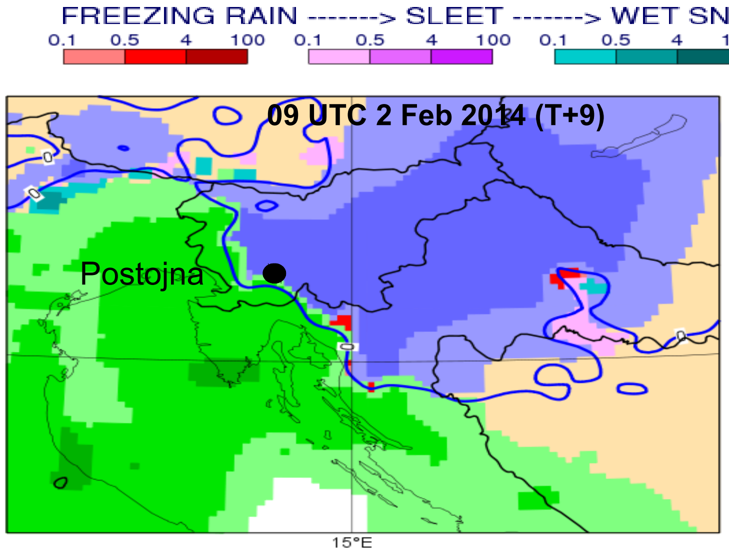
- Case Study: Slovenia/Croatia 02 Feb 2014
- Freezing rain caused severe disruption and damage, tranports/power/forests…
- IFS physics at the time (40r1) not able to predict
- New physics in 41r1 allows prediction of freezing rain events
- Evaluation in HRES/ENS shows potential for useful forecasts
- Article in EC Newsletter Autumn 2014 (but note results below are with new rain freezing physics)



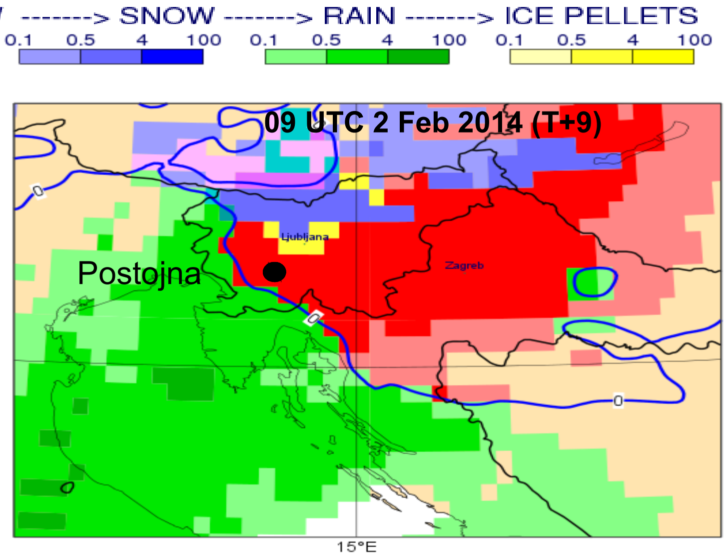
ECMWF Newsletter 141



SYNOP Observations

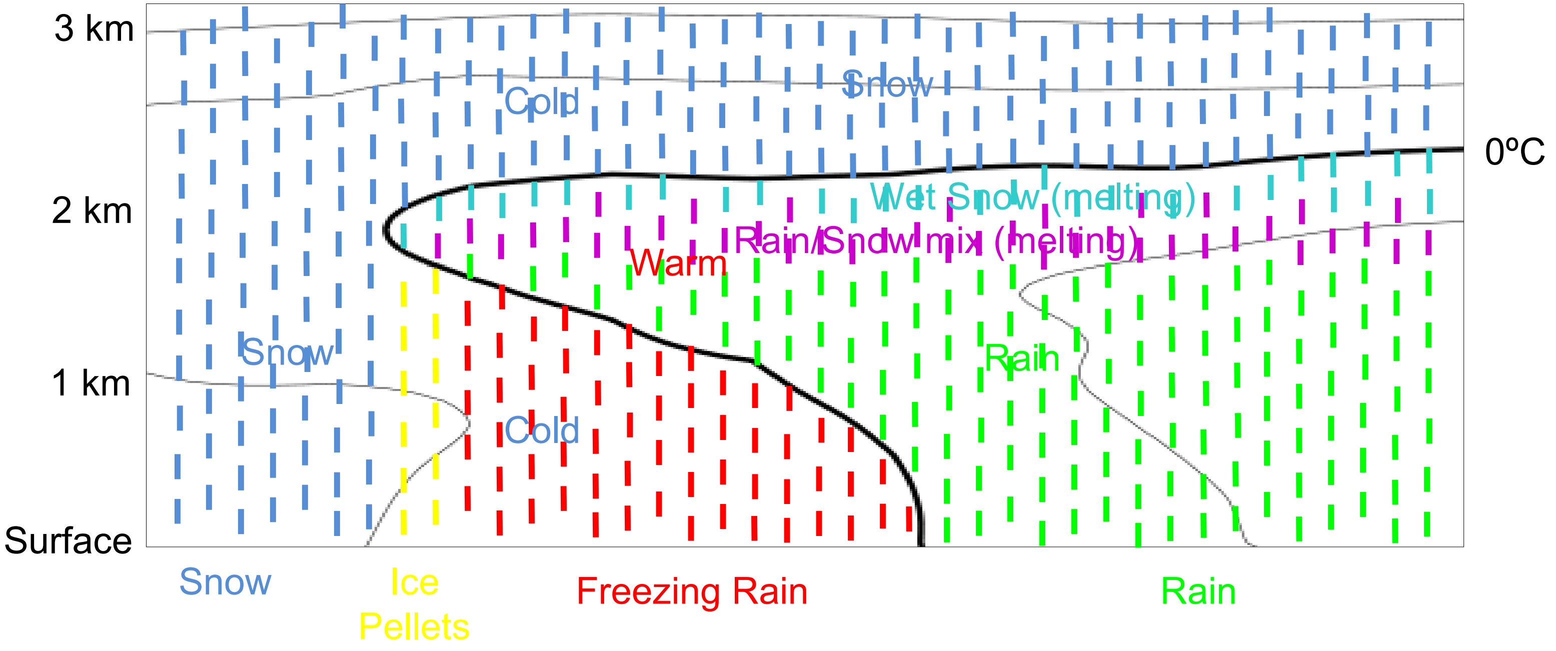


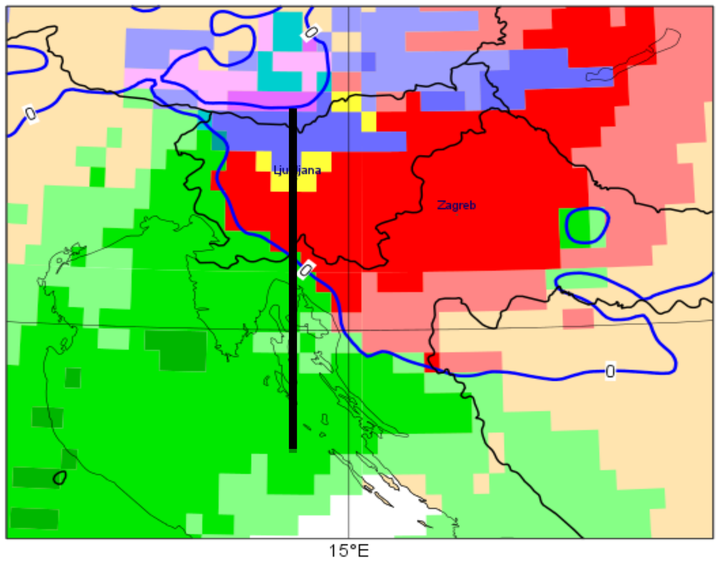
IFS HRES 40r1

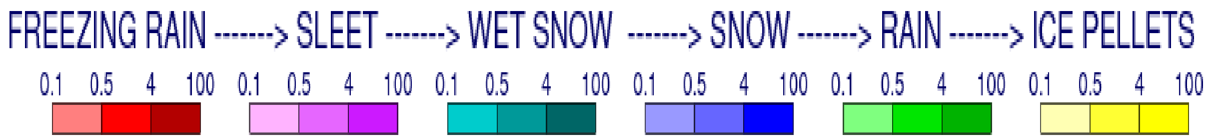


IFS HRES 41r1

Schematic cross-section (front with elevated warm layer)

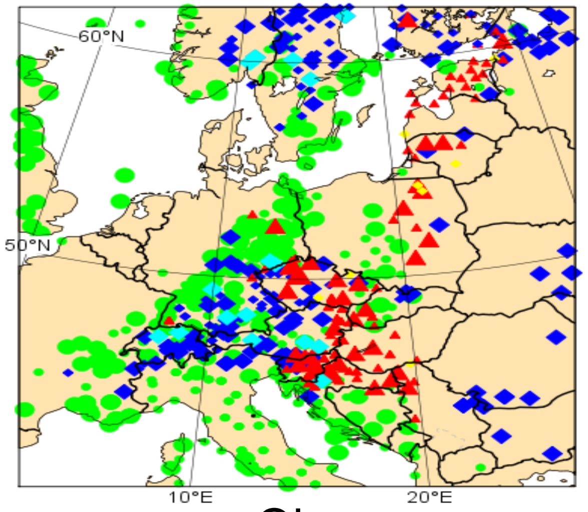






Probability of freezing rain accumulation from the IFS ensemble

Case Study: 02 Feb 2014

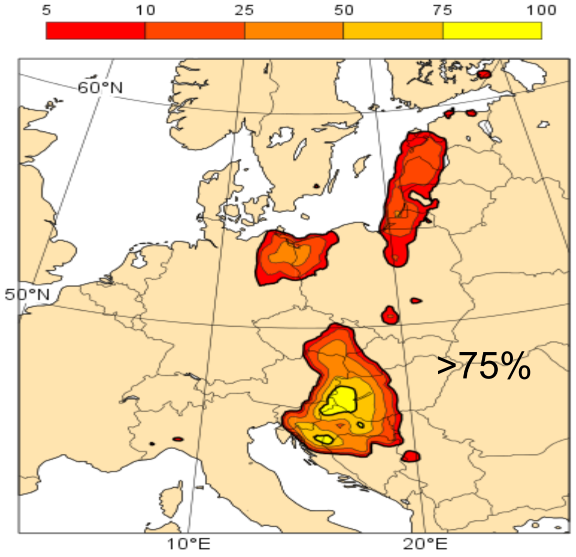


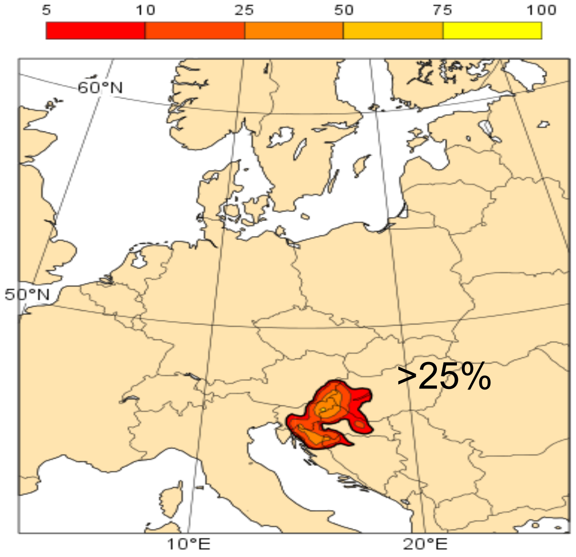
Obs

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

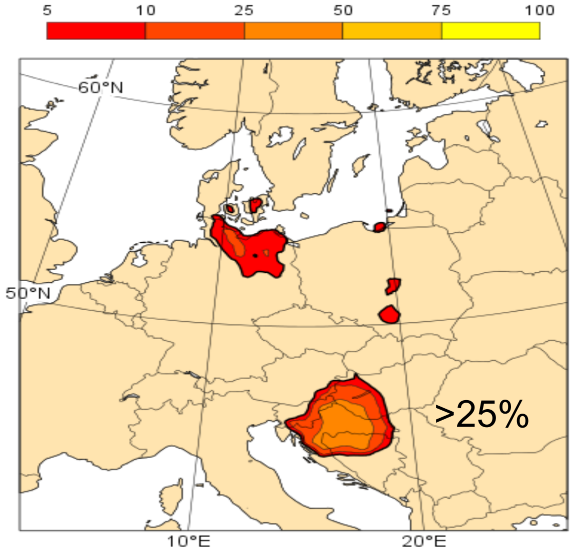
Prob (fzra > 1mm) | Prob (fzra > 5mm)

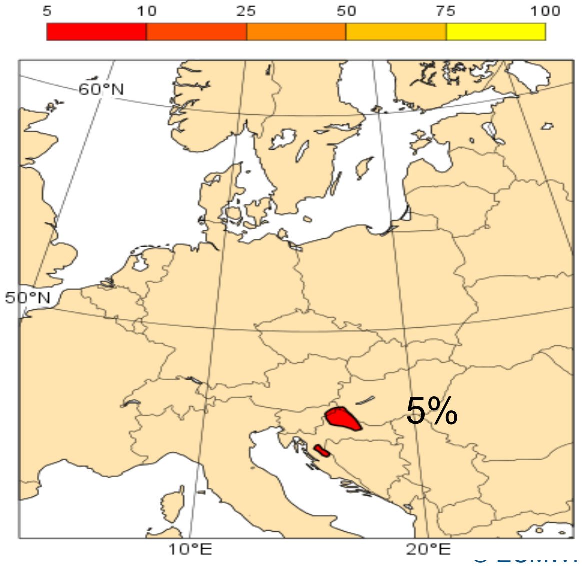
Day 3 forecast





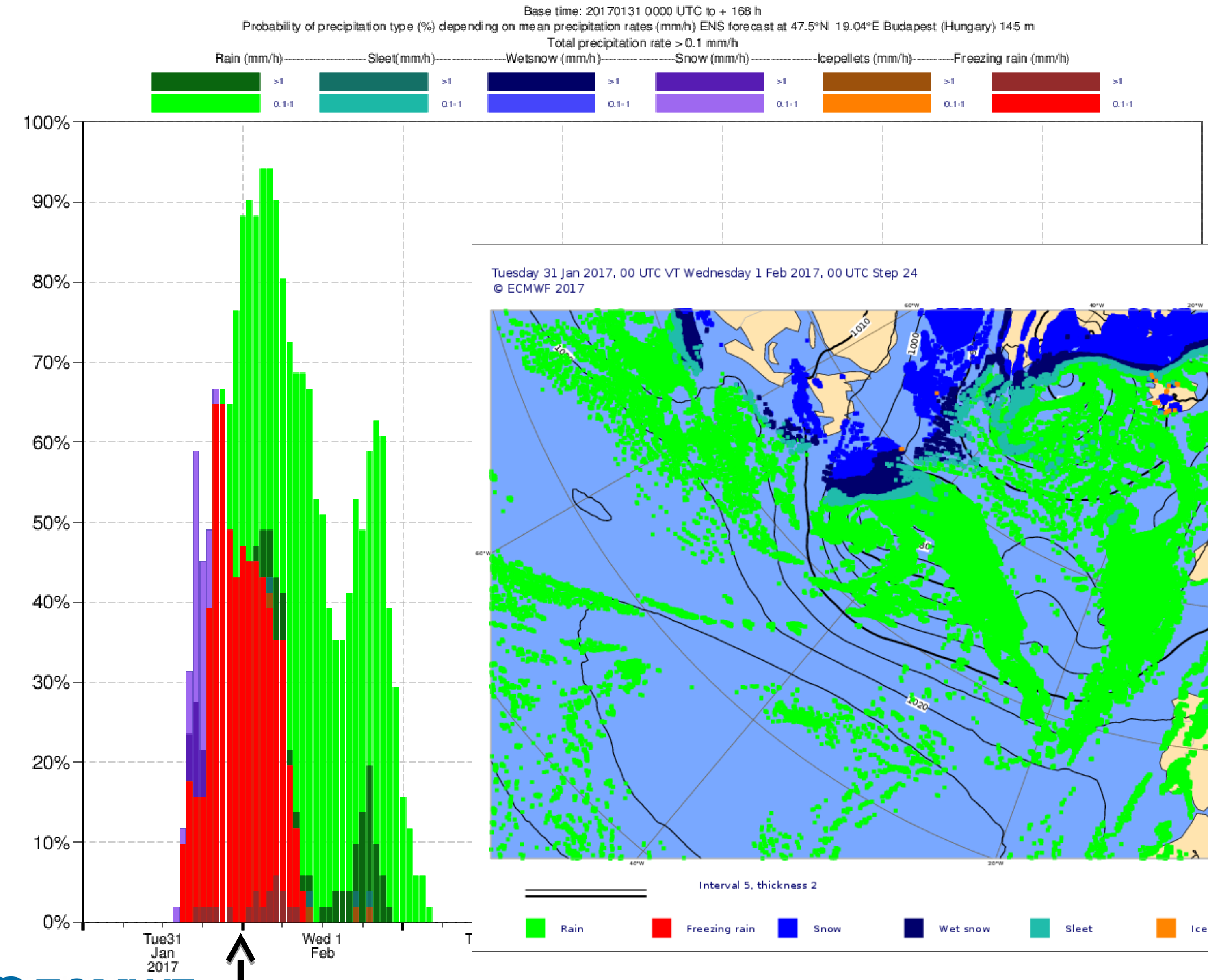
Day 5 forecast

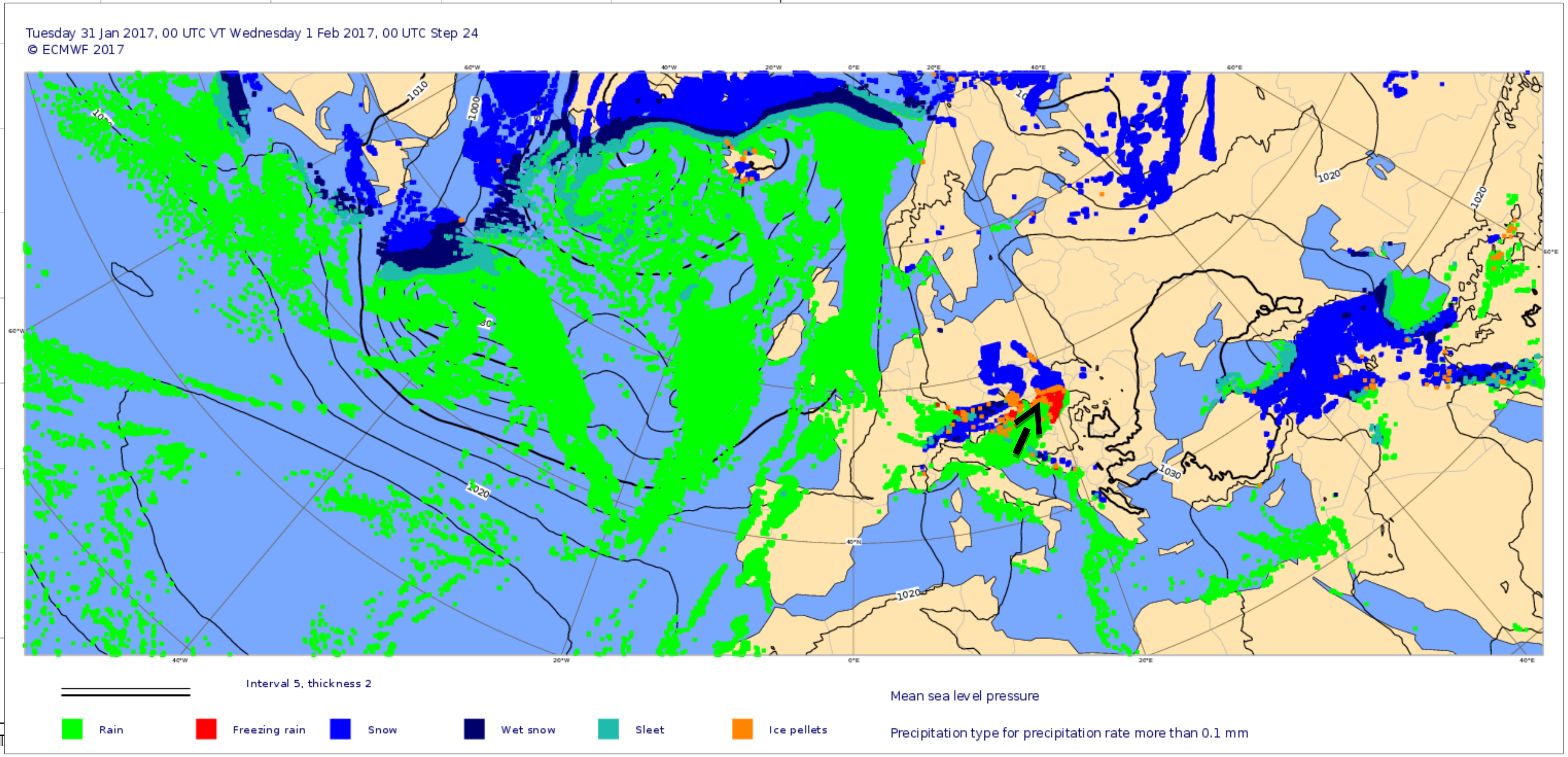




Ensemble probability of precipitation type time sequence

Budapest, 00Z 31 Jan 2010





Visibility and Fog

Prediction of severe weather: Visibility/Fog

Visibility – new diagnostic in IFS Cy41r1 (May 2015-)

1. Background aerosol seasonally varying climatology – currently Tegen et al. 1997
2. Rain and snow precipitation
3. Cloud liquid water/ice (i.e. fog)

4. 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

- Many limitations!

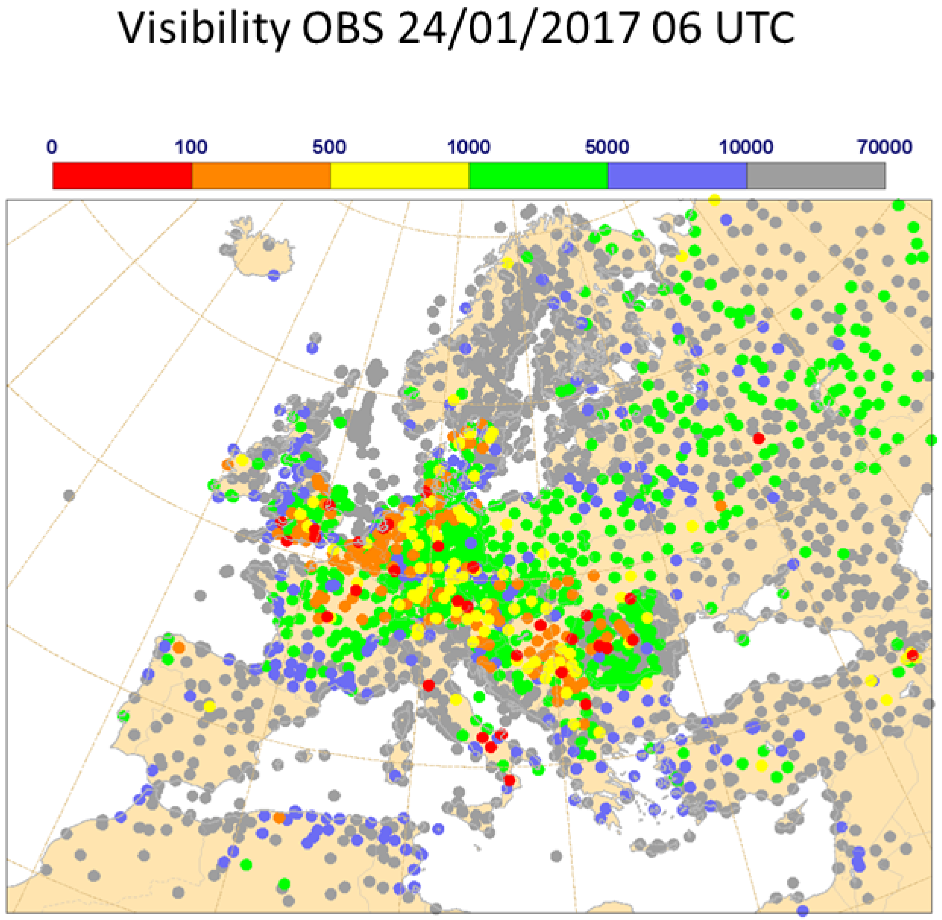
  "Fixed aerosol" – will change to MACC-based aerosol climatology with RH-dependent size distribution (IFS Cy43r3). Use of prognostic aerosol in MACC at some point in the future…

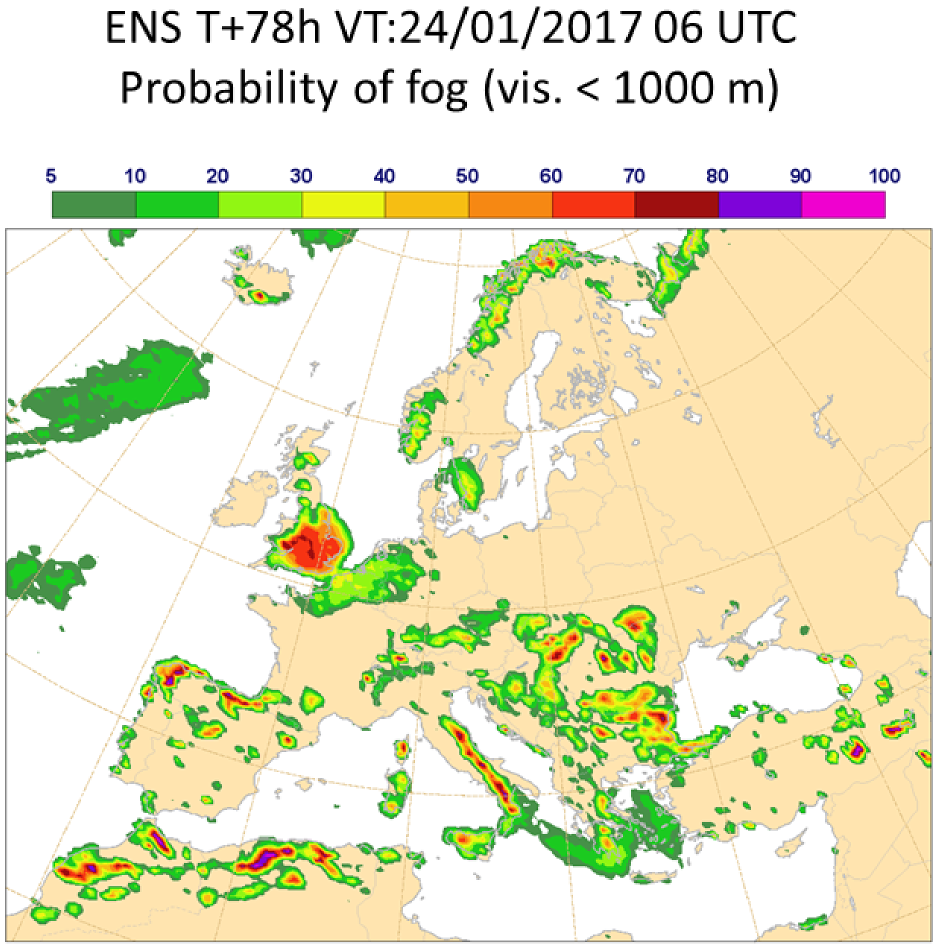
  Fixed particle size for cloud and precipitation particles (single moment microphysics), could introduce variable (diagnostic) particle size distributions

  Relatively low resolution – orography, 10m lowest model level, correct physics??? (turbulence, microphysics, radiation interactions…)

Prediction of severe weather: Visibility/Fog

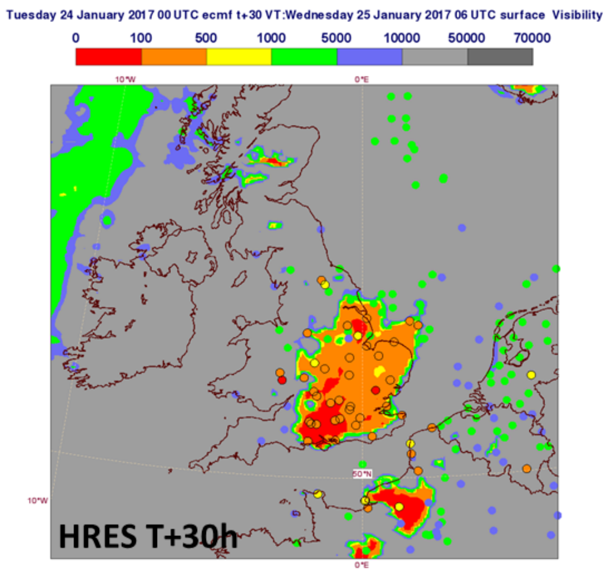
Case study: 24 Jan 2017, 3 day probability forecast from IFS ensemble



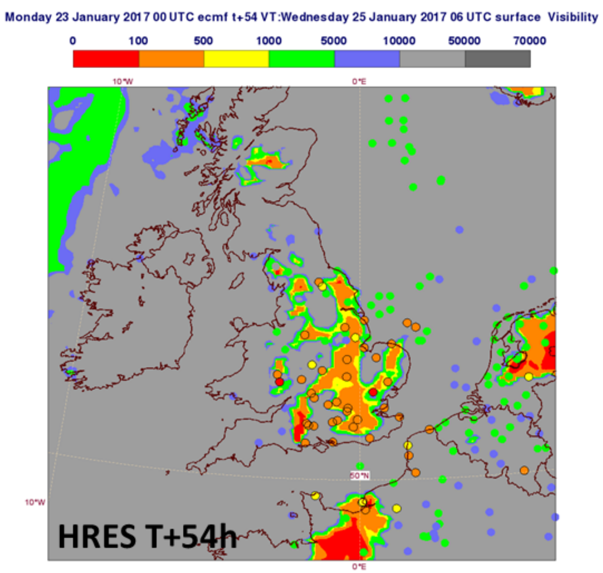


Prediction of severe weather: Visibility/Fog

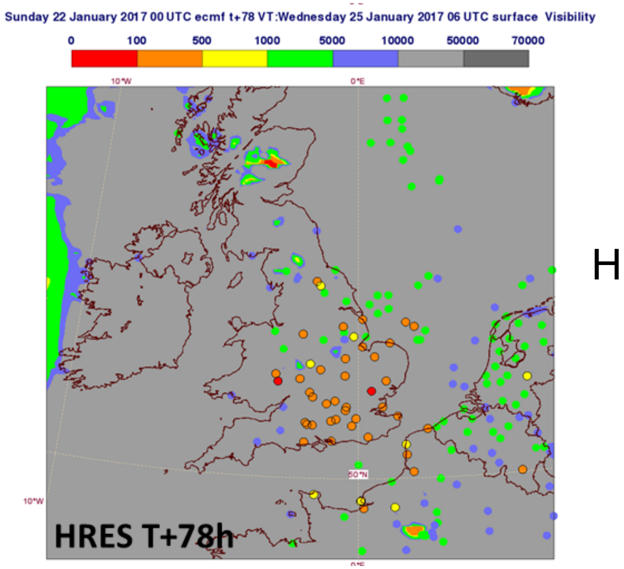
Case study: 06 UTC, 25 Jan 2017



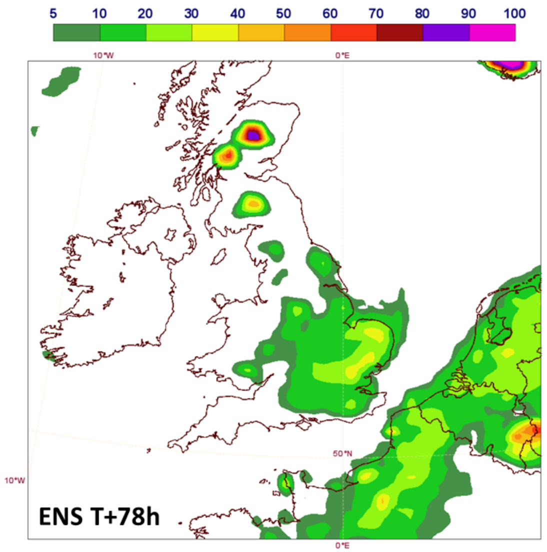
HRES 1 day forecast
Good prediction of fog



HRES 2 day forecast
Less good, some indication of fog



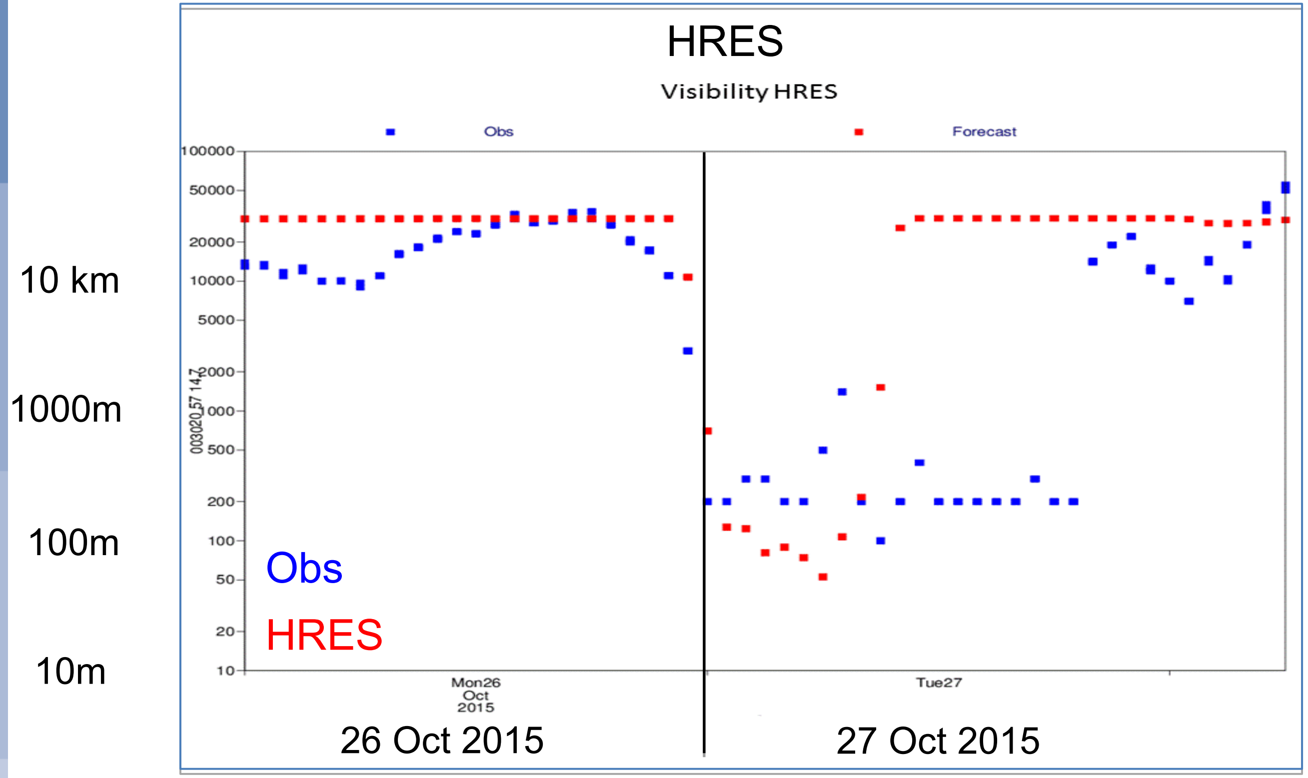
HRES 3 day forecast
No fog predicted

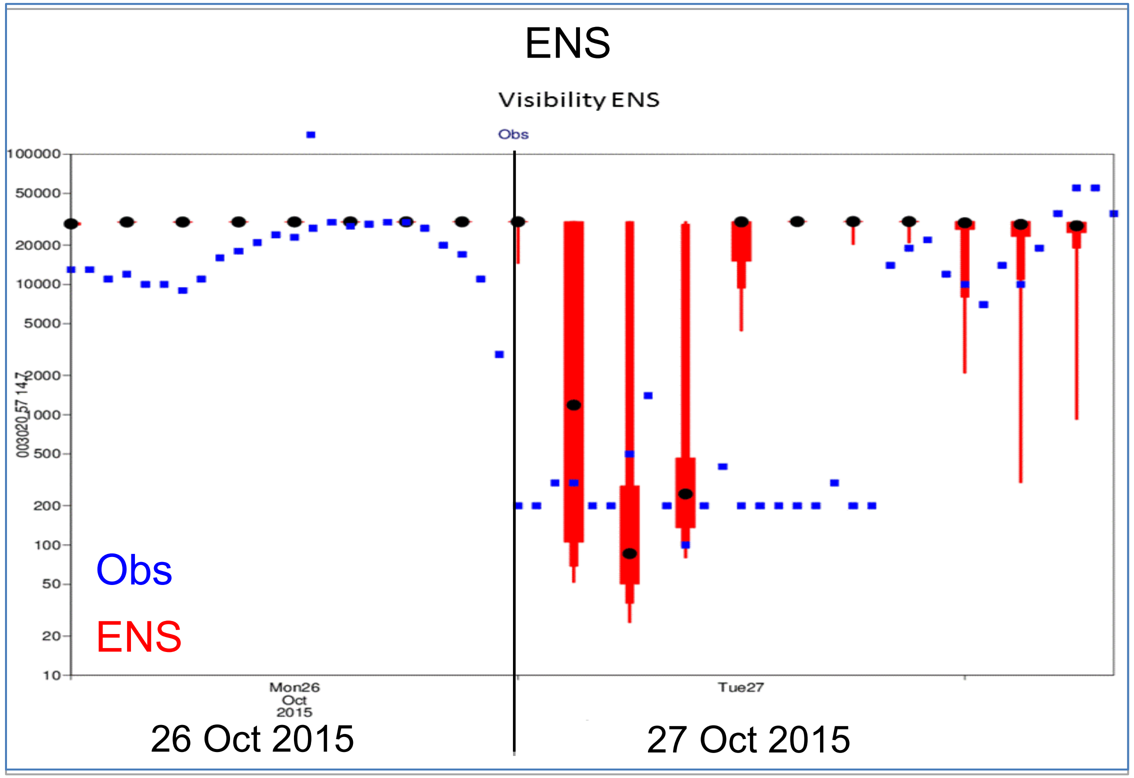


ENS 3 day forecast
20-40% fog probability

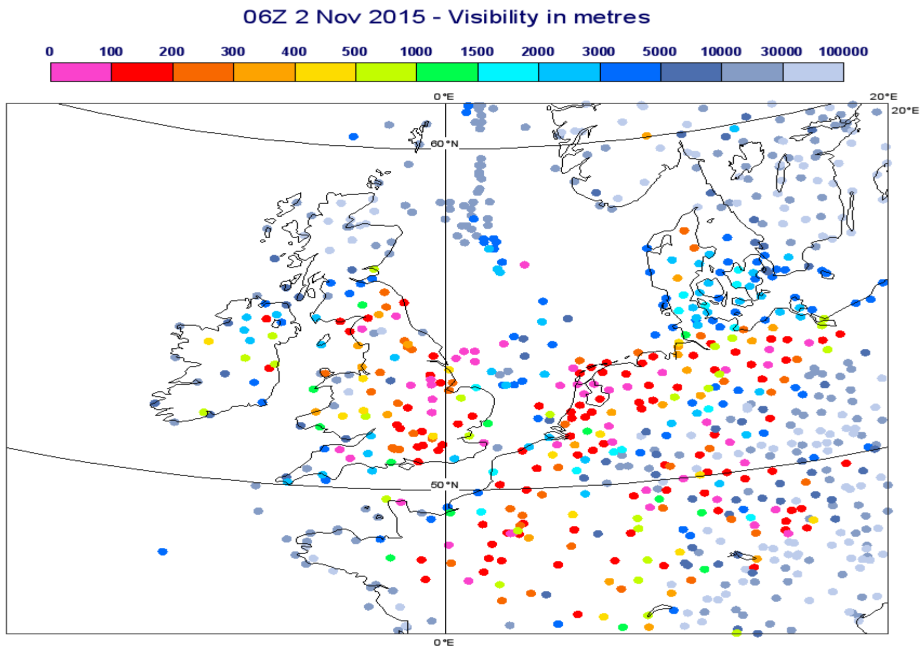
Prediction of severe weather: Visibility/Fog
Case study: 27 Oct 2015 - Fog in southern Sweden

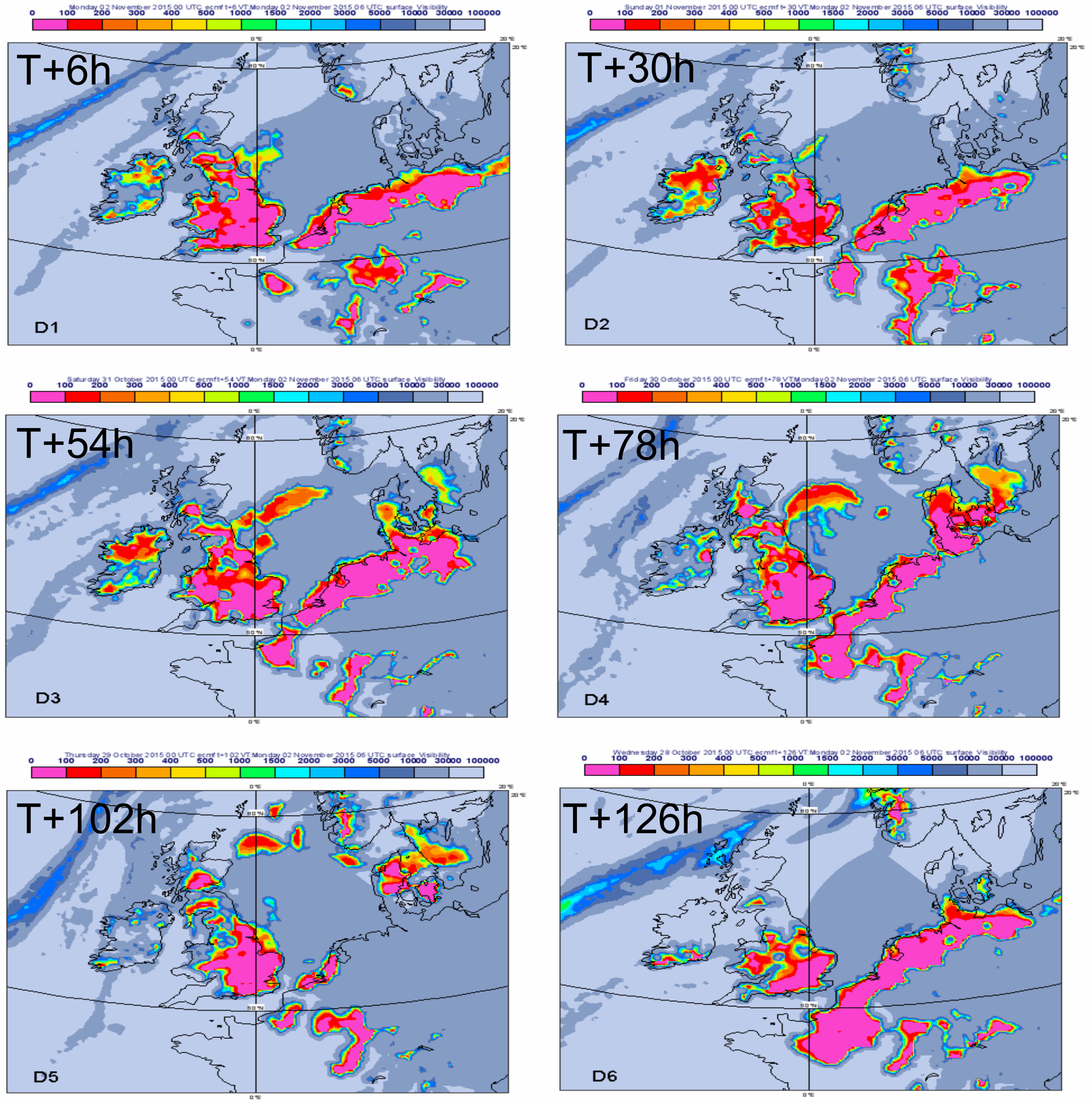
- Onset well predicted by HRES, but clears too early
- ENS shows spread early on but also doesn't capture the fog staying later in the day





Prediction of severe weather: Visibility/Fog
Case study: 02 Nov 2015, 06 UTC





- In this case, indication of widespread fog event out to 6-day forecast
- Not always the case!
- Some regions missed
- Visibilities a bit too low in fog

Summary

What we covered…

1. Overview of parametrization of cloud and precipitation in the IFS
2. Some of the difficult “stratiform” cloud/precip regimes for the model – low cloud, mixed-phase, melting layer, fog
3. New diagnostics
   - Precipitation type – Melting snow, freezing rain
   - Visibility / fog
   - Ensemble probabilities most useful in medium-range
   - Feedback welcome!!!

Thank you for listening! Questions? Feedback?