Clouds and precipitation:
From models to forecasting

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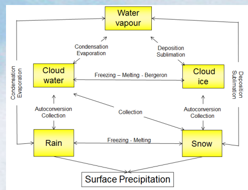
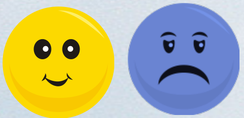
Thanks to Tim Hewson, Ivan Tsonevsky, Thomas Haiden, Peter Bechtold

Outline
Clouds and Precipitation: From models to forecasting

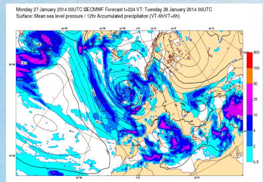
This seminar will (hopefully!) help you to …



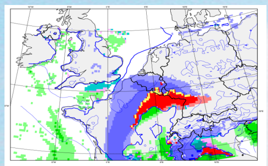
- describe how cloud and precipitation is represented in the ECMWF global model.



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



- interpret cloud and precipitation related forecast products.

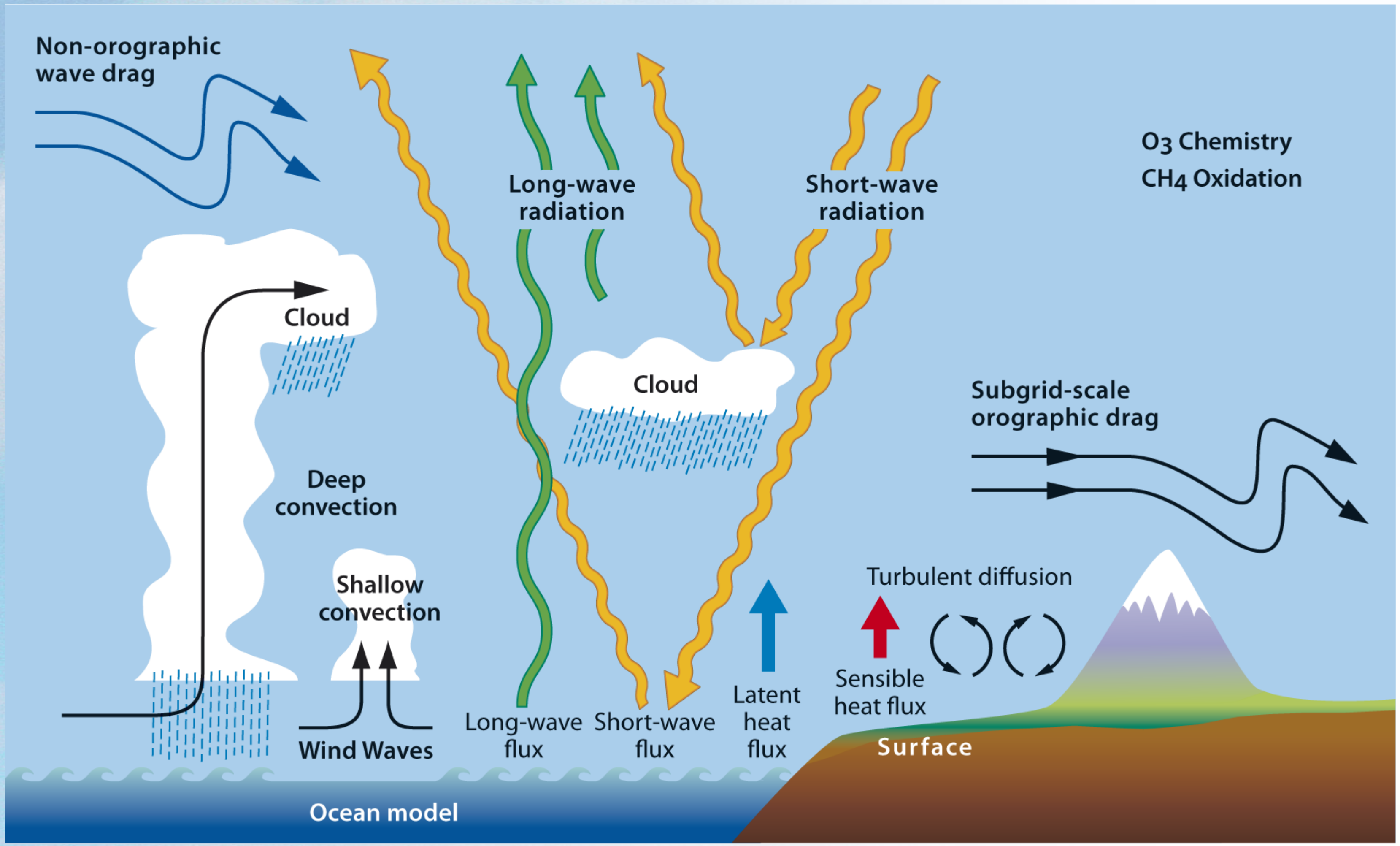


- learn about future developments from a forecast users perspective …

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

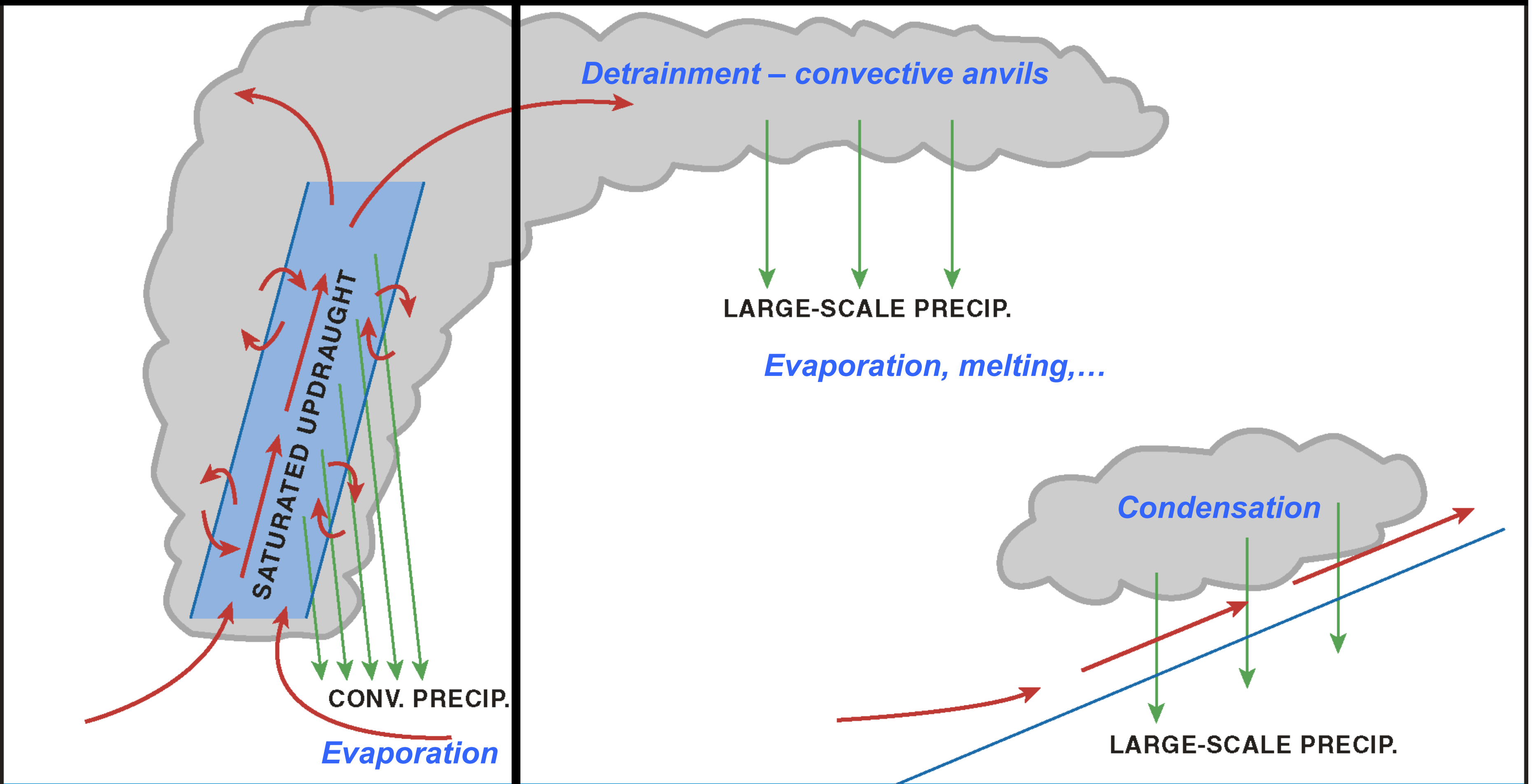
Parameterized processes in the ECMWF model

from the surface to the stratosphere



Convective and stratiform precipitation and clouds

Convection parametrization	“Large-scale”/stratiform cloud/precipitation parametrization

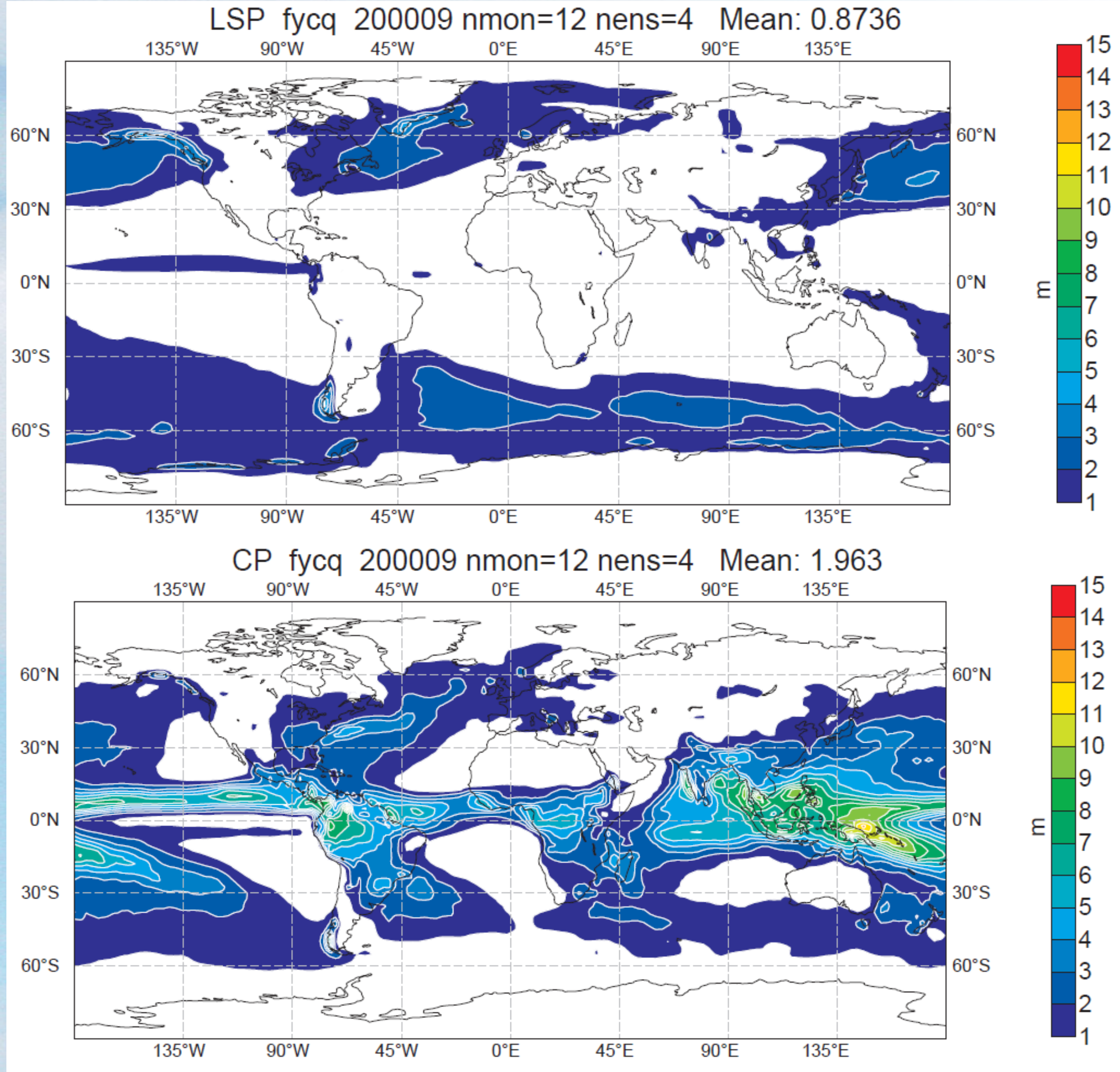


Convective surface precip (CP)	Stratiform (large-scale) surface precipitation (LSP) Cloud cover (TCC, HCC, MCC, LCC)

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

Stratiform (large-scale) surface precip (LSP)

Convective surface precip (CP)

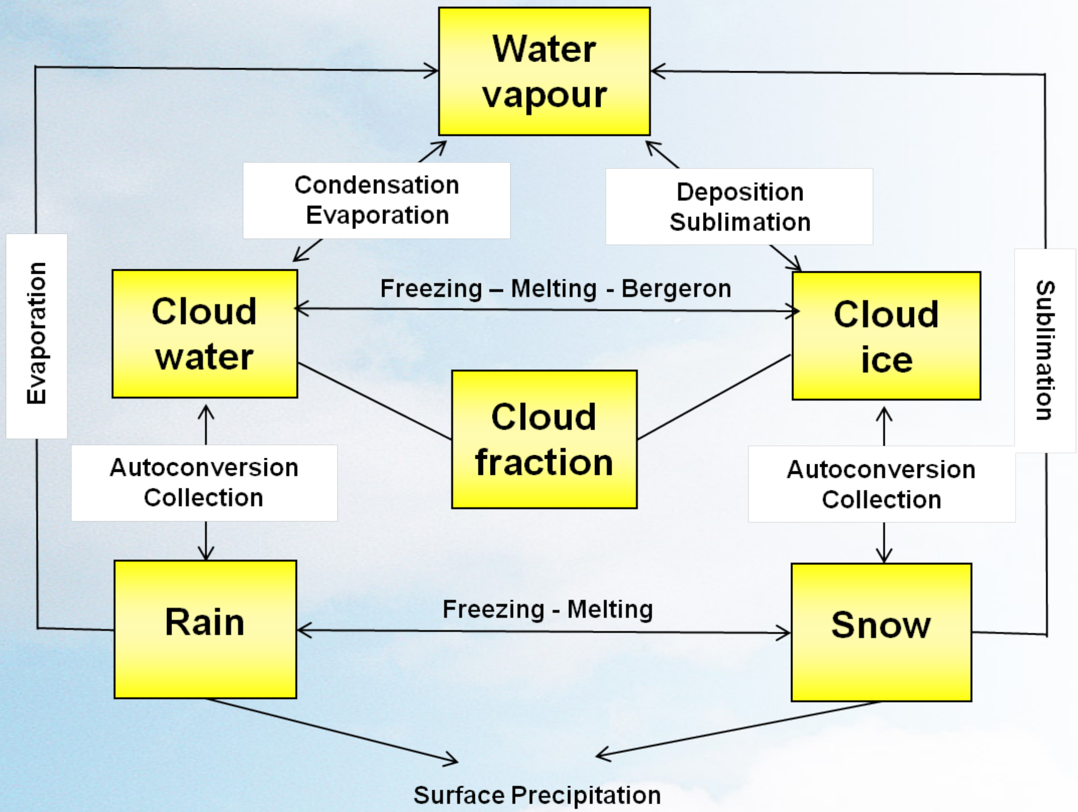


- This is for low resolution T159, but not too different for higher resolutions
- CP is ~2/3 of global precipitation
- but LSP dominant or similar to CP in extratropics

ECMWF

IFS stratiform cloud scheme

(operational from 9th Nov 2010, Cy36r4 onwards)

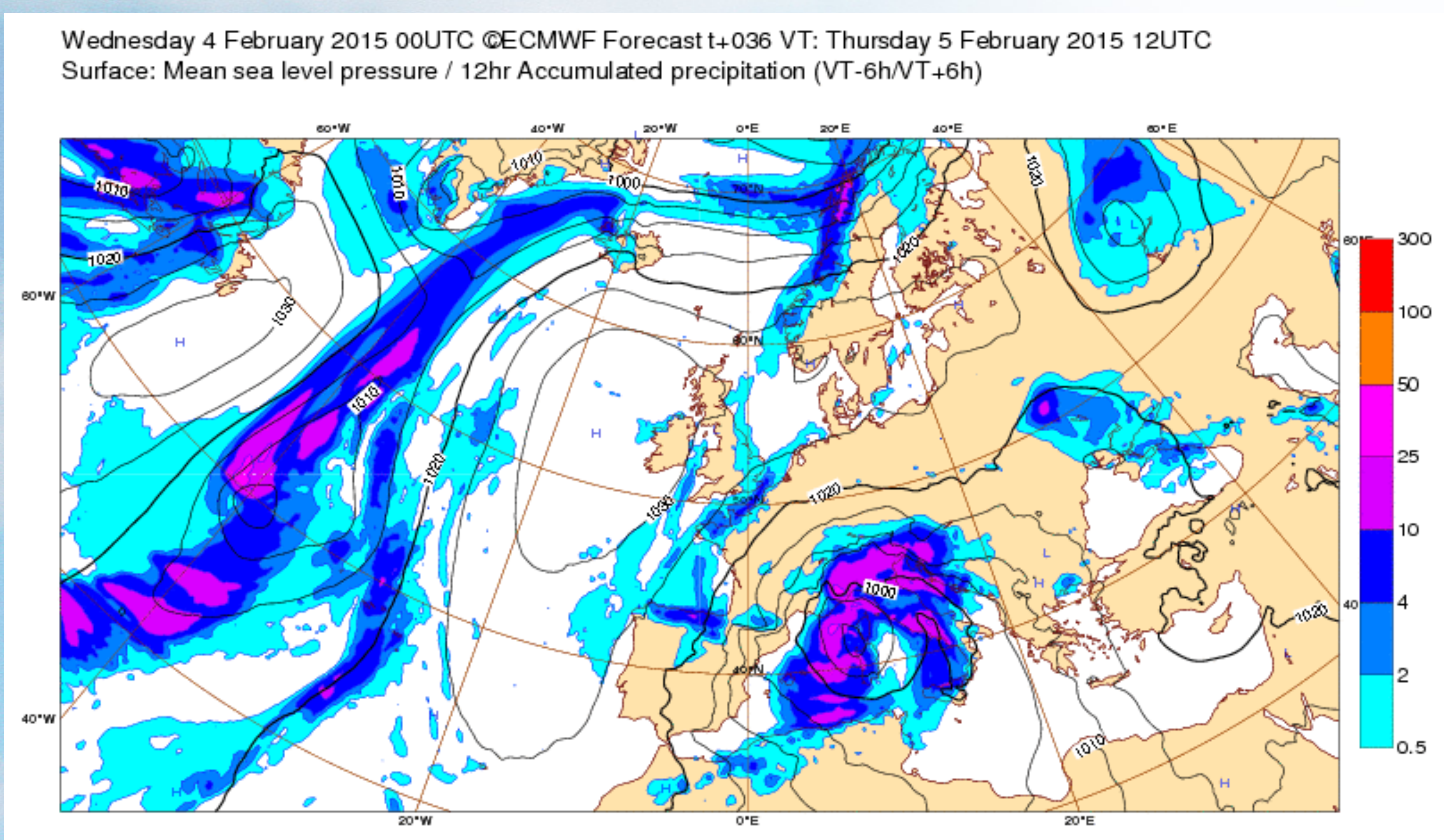


- 5 prognostic cloud variables + water vapour
- Ice and water independent variables
- Snow/rain prognostic, advected with the wind
- Physically based, increasing realism

ECMWF

Example 12 hour precipitation accumulation

Forecast for Thu 5th February 2015



Large-scale rain + convective rain + large-scale snow + convective snow

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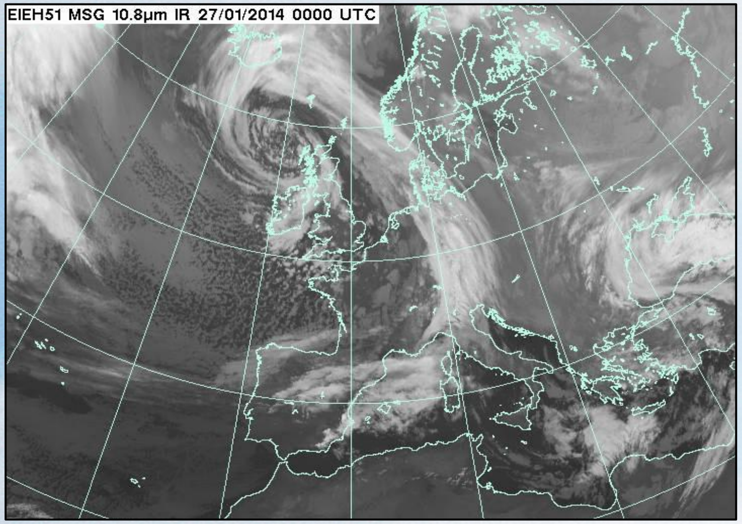
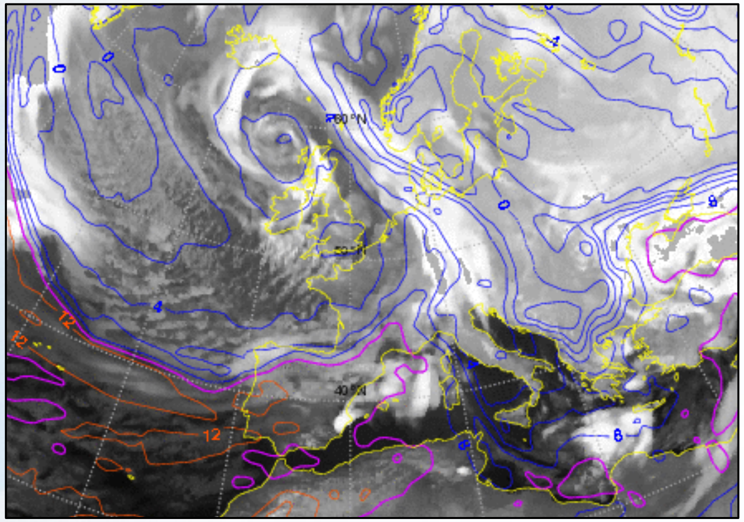
Cloud: 00Z Monday 27 January 2014

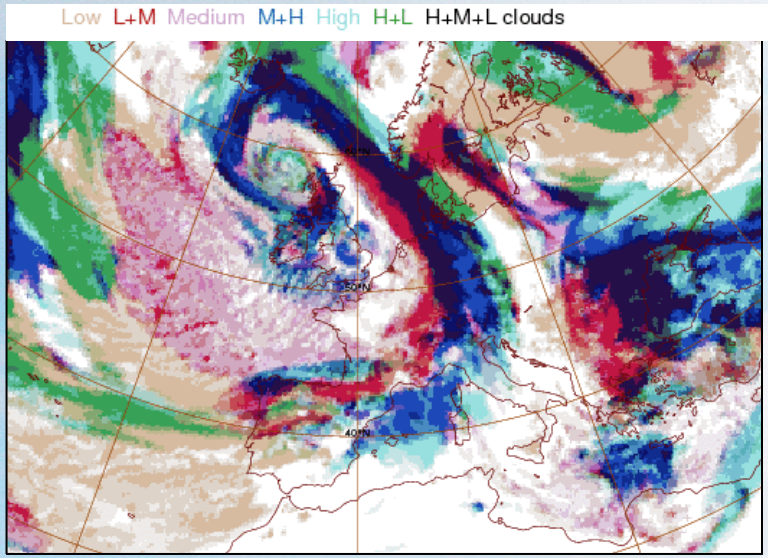
Meteosat IR 10.8μm



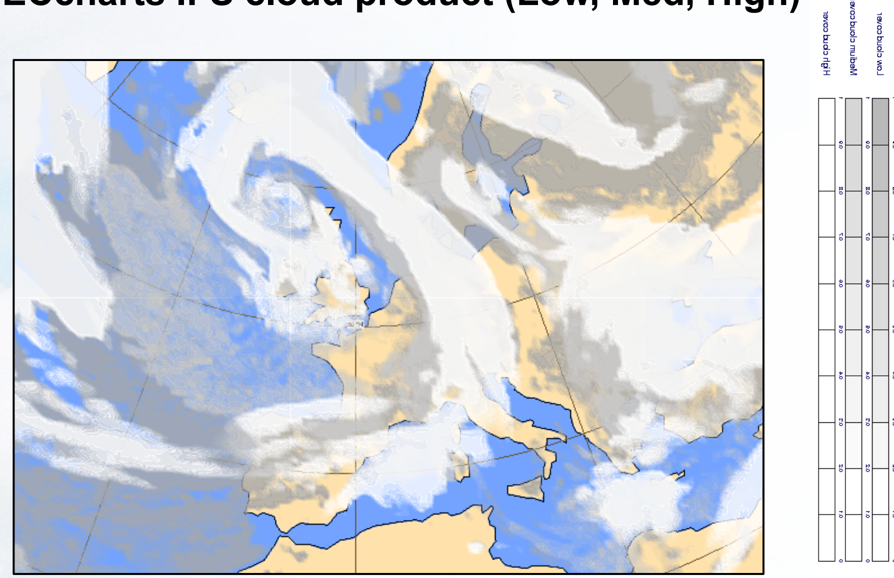
IFS Pseudo-IR 10.8μm



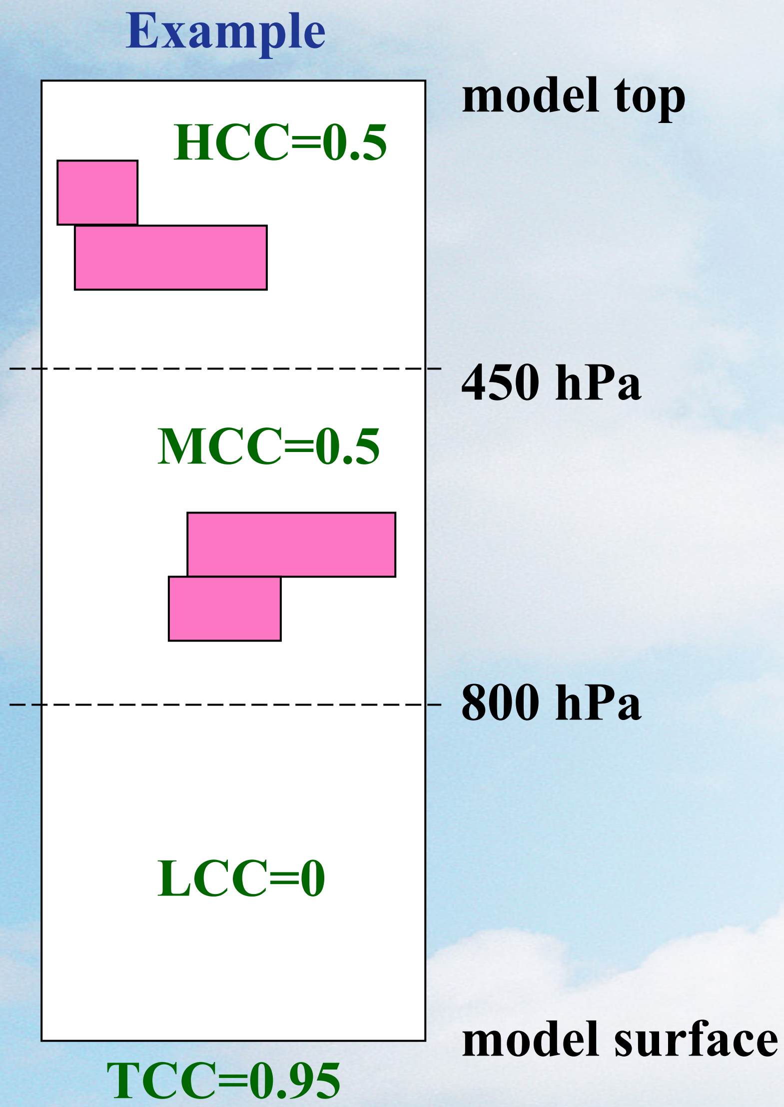
IFS cloud product (Low, Med, High and mixed)



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 a generalised overlap **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.
- NOTE: TCC <= LCC+MCC+HCC

2. How do we evaluate the forecast cloud and precipitation ?

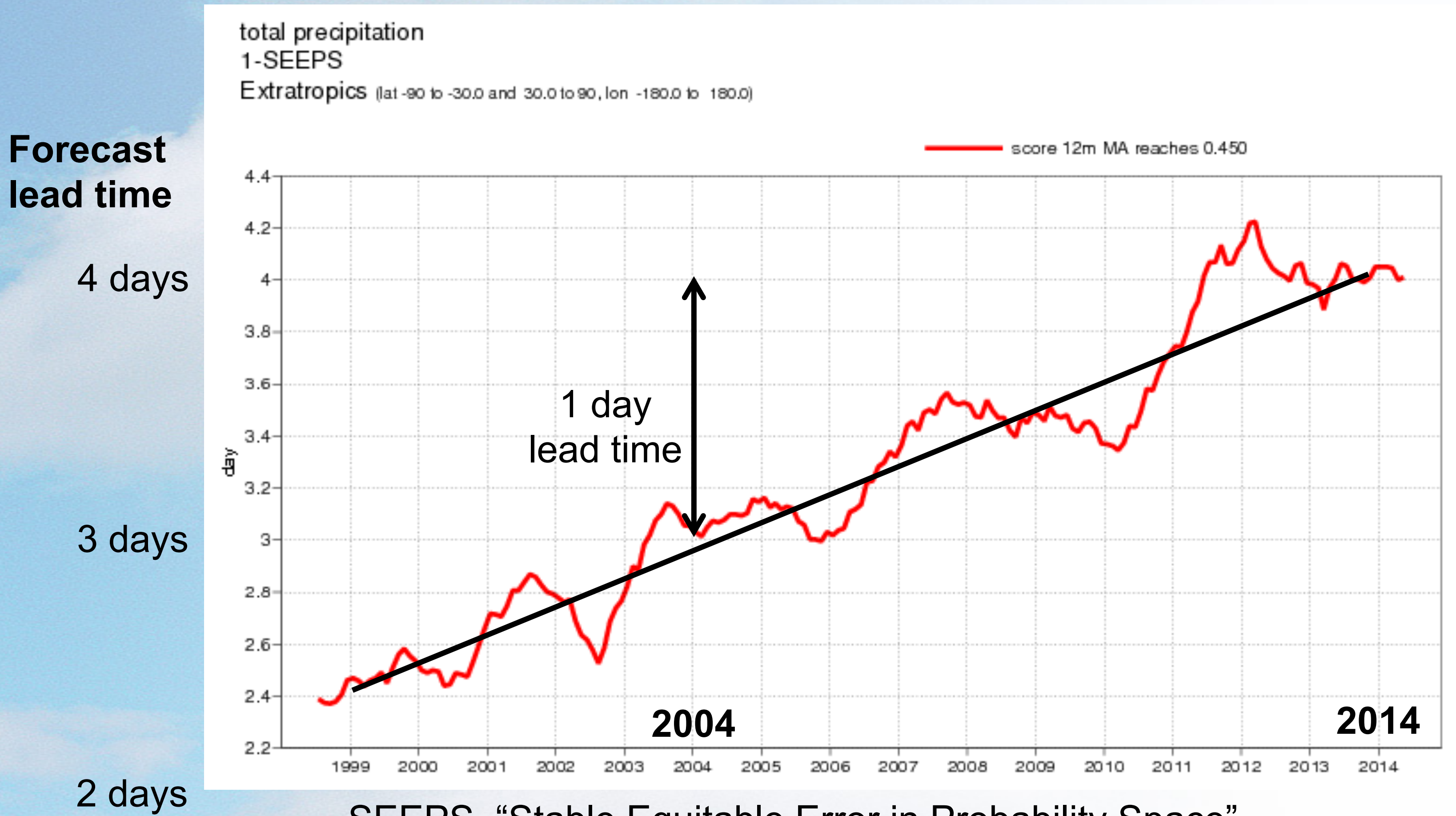
How do we evaluate cloud and precipitation?

In many different ways…

- Operational verification scores – SYNOP precipitation and cloud cover
- SW and LW radiation at the surface (BSRN stations) and top of atmosphere (satellite)
- Observations in the data assimilation system (e.g. microwave)
- Ground-based (Cloudnet, ARM sites) and satellite (CloudSat/CALIPSO) remote sensing (radar/lidar)
- Observational campaigns (aircraft, remote sensing, satellite)
- Case studies, composites, statistics and climatology…

Precipitation skill score: Highlights progress over time

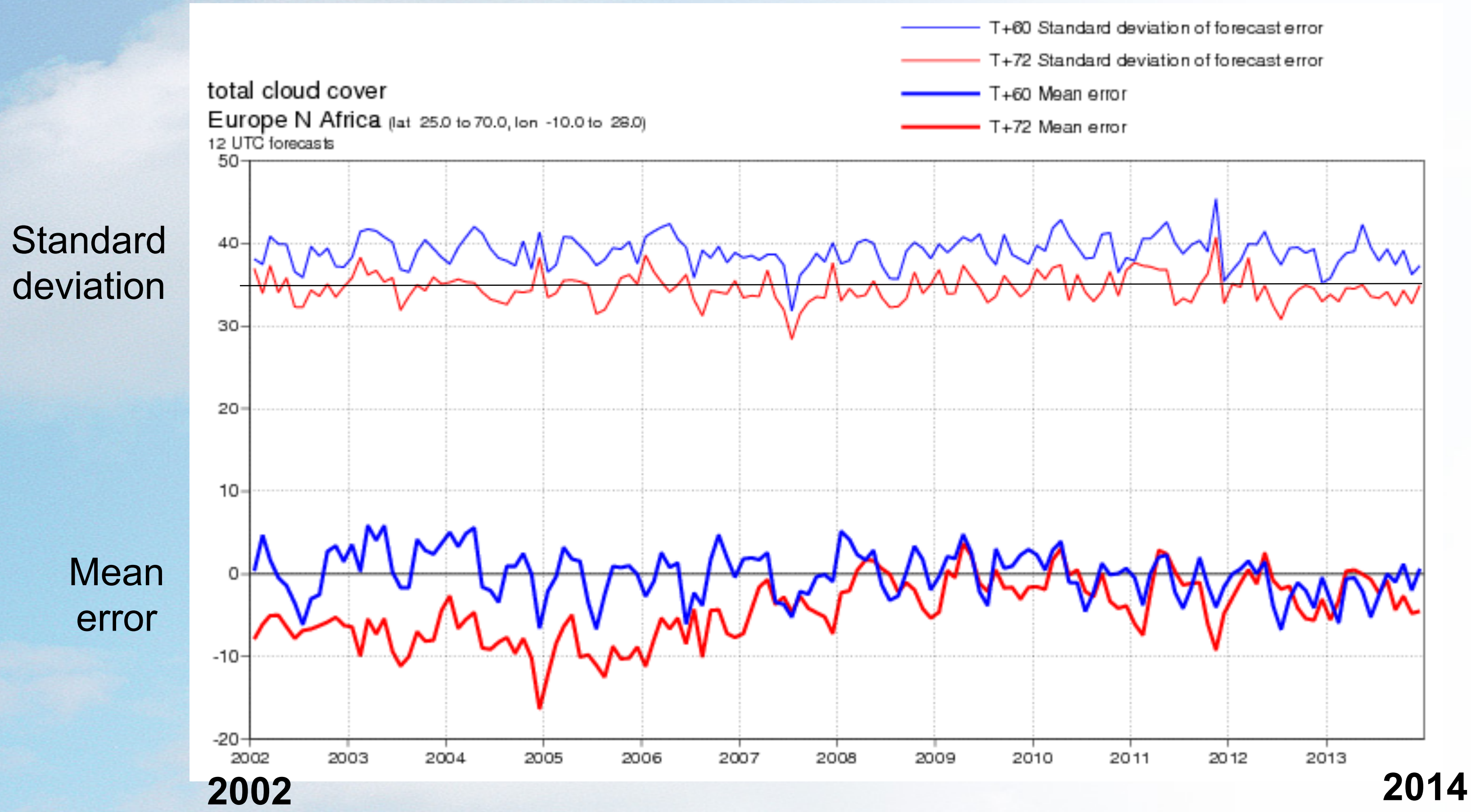
Skill score (1-SEEPS) for 24 hr precipitation for operational IFS (lead time that score reaches 0.45), shows improvement of ~1 day per decade.



SEEPS, "Stable Equitable Error in Probability Space",
Rodwell et al., 2011, ECMWF Newsletter 128

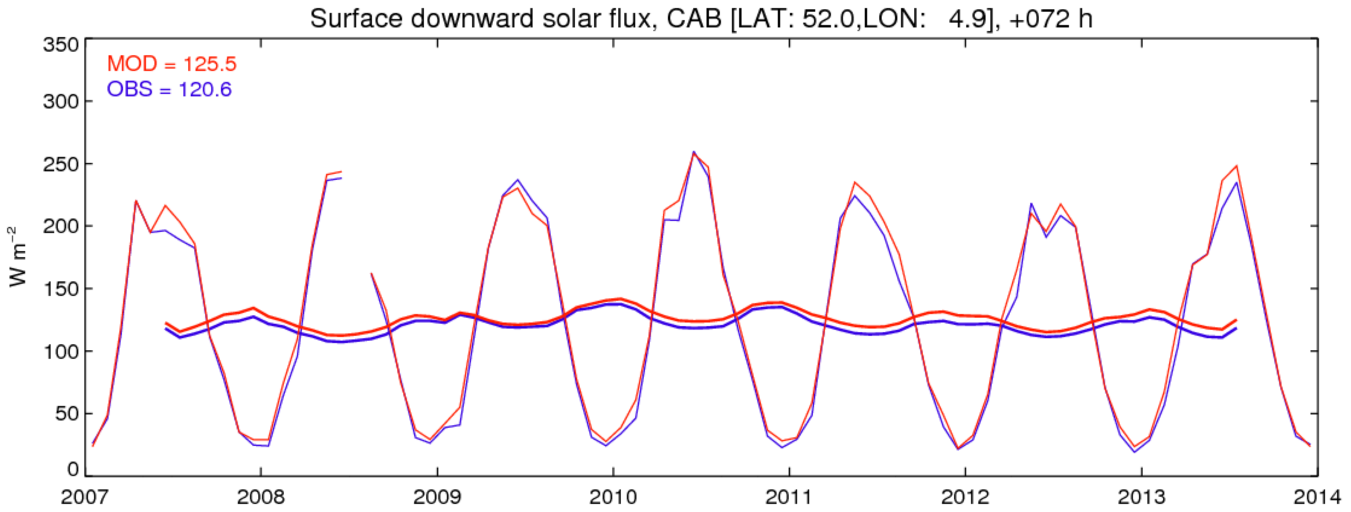
Total cloud cover: Mean error and standard deviation

Oper versus SYNOP TCC for Europe/N Africa T+60 (00Z) an T+72 (12Z)

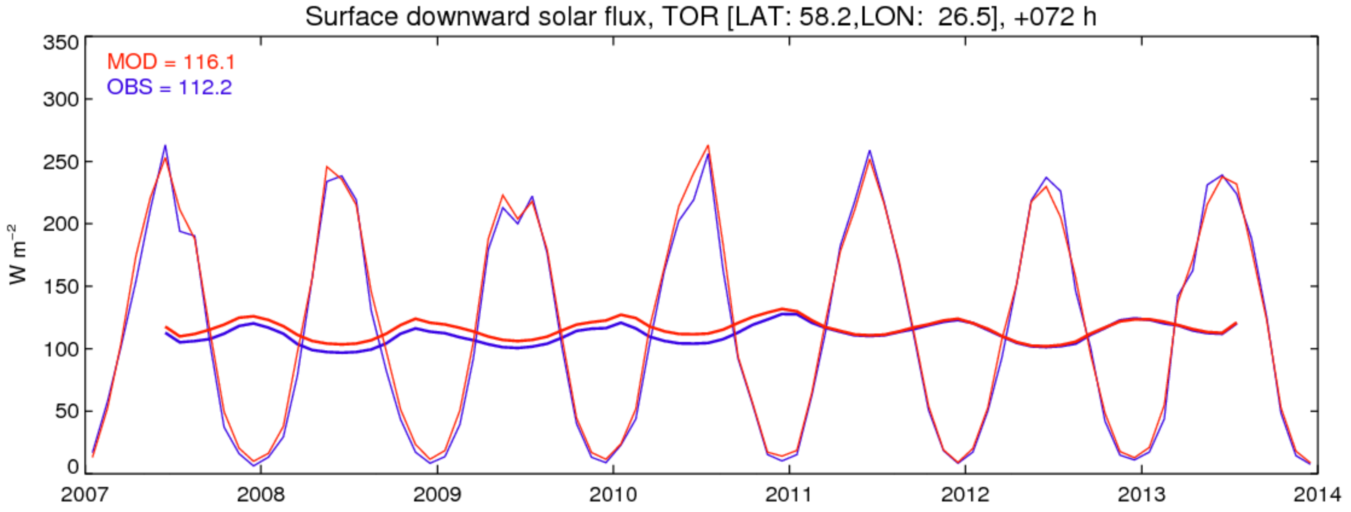


Radiation: Surface irradiance example
Improvement at some stations, not at others

Cabauw
(Netherlands)

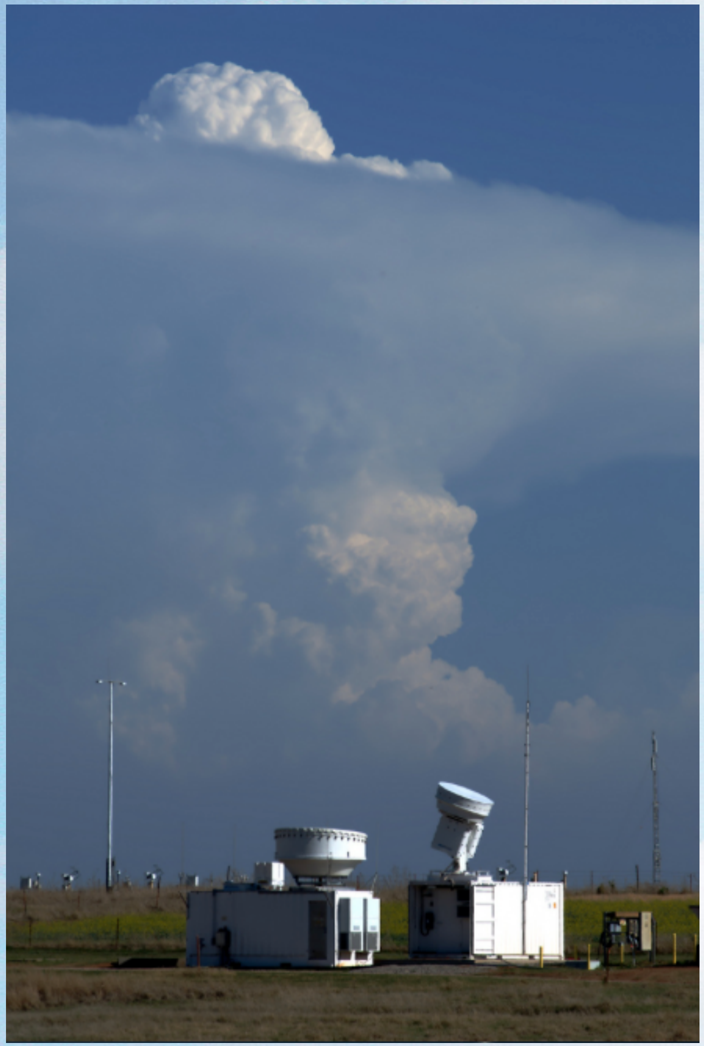


Toravere
(Estonia)

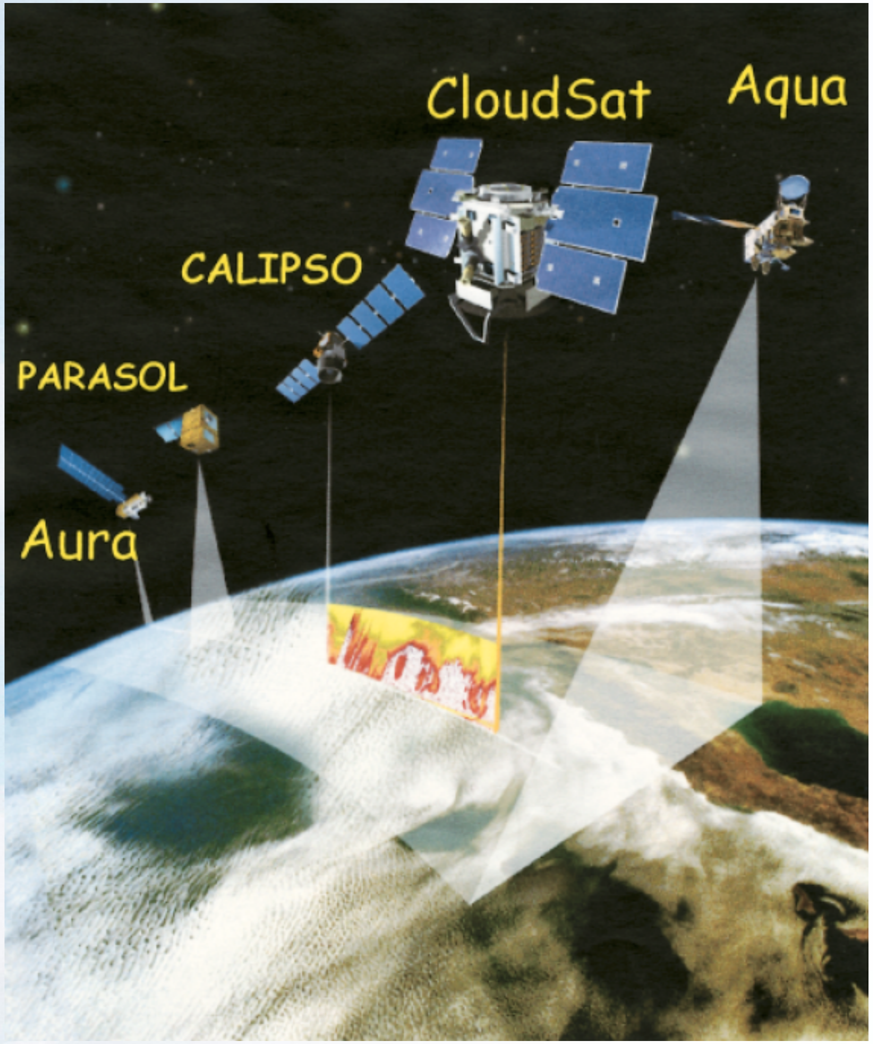


Remote Sensing (radar, lidar, radiometers)

Ground-based remote sensing



Satellite remote sensing



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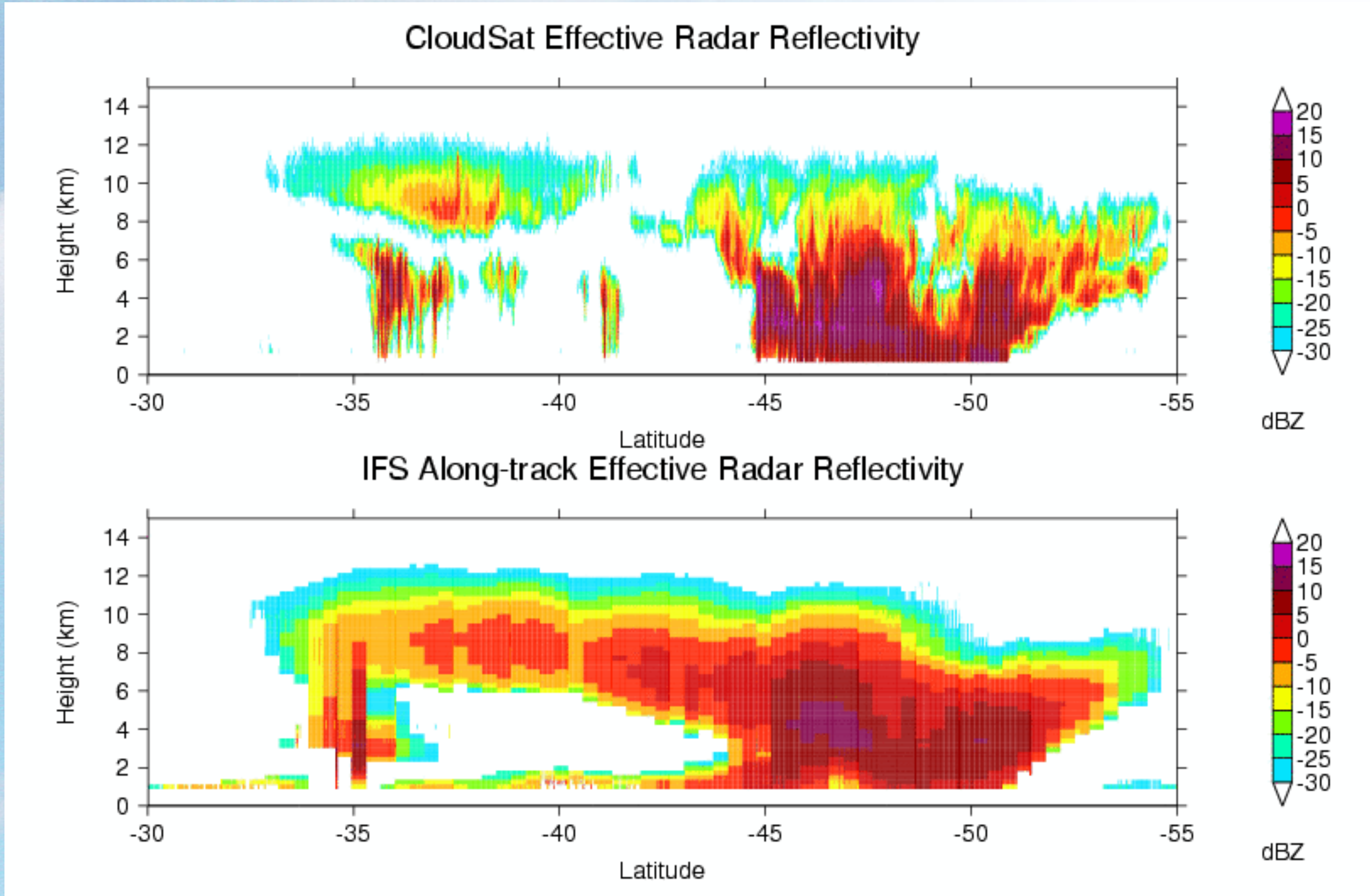
Example cross-section through a front
Model vs CloudSat radar reflectivity



3. What are some of the problems/difficult situations for cloud and precipitation forecasts

Some of the difficult cloud problems for the model…

1. Under-prediction of stratocumulus cloud cover over land, high pressure situations. Impact on 2m temperatures.

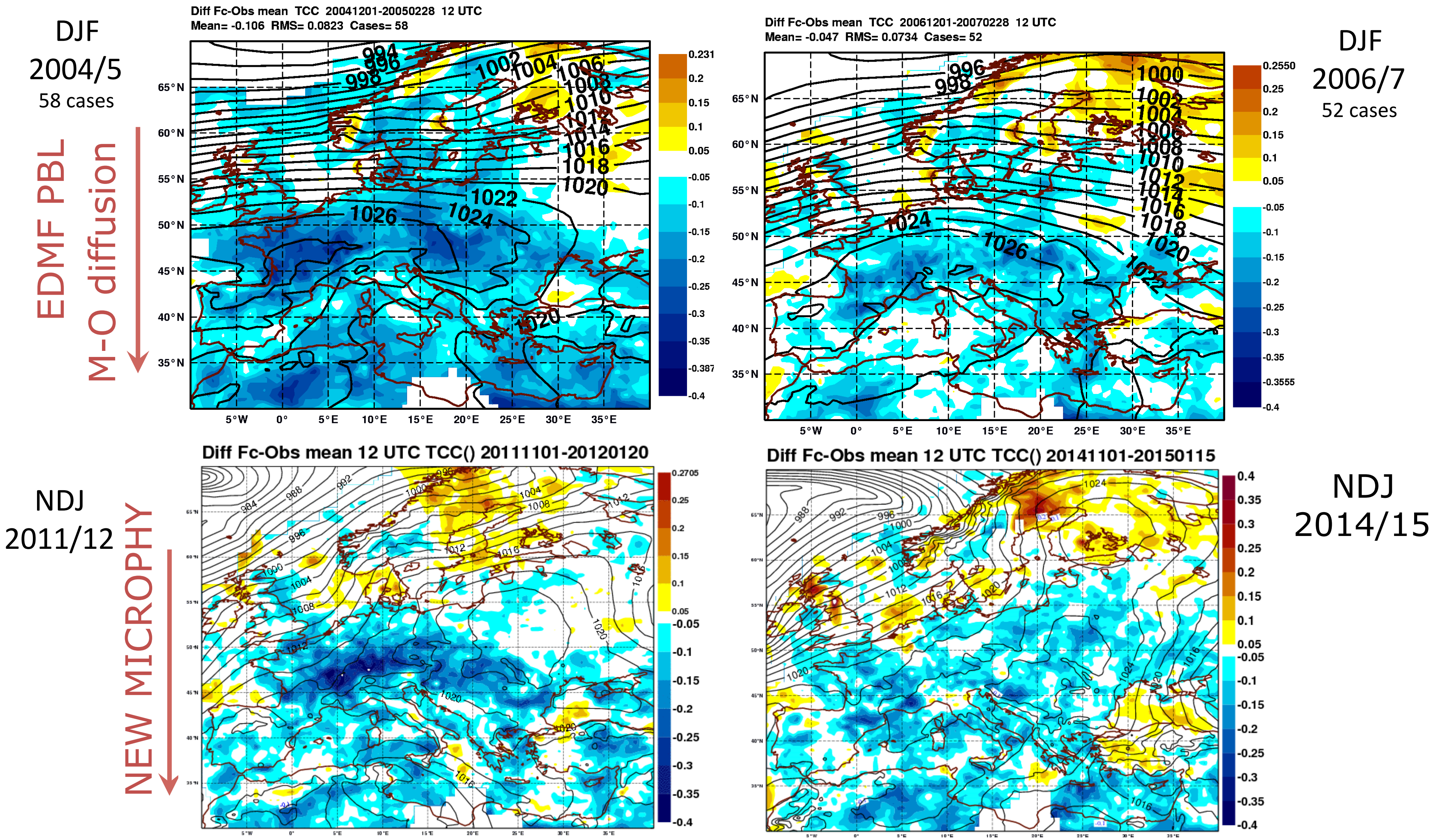
2. Over-prediction of light precipitation (drizzle) occurrence.

3. Snowfall in marginal situations – the melting layer.

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

5. Fog

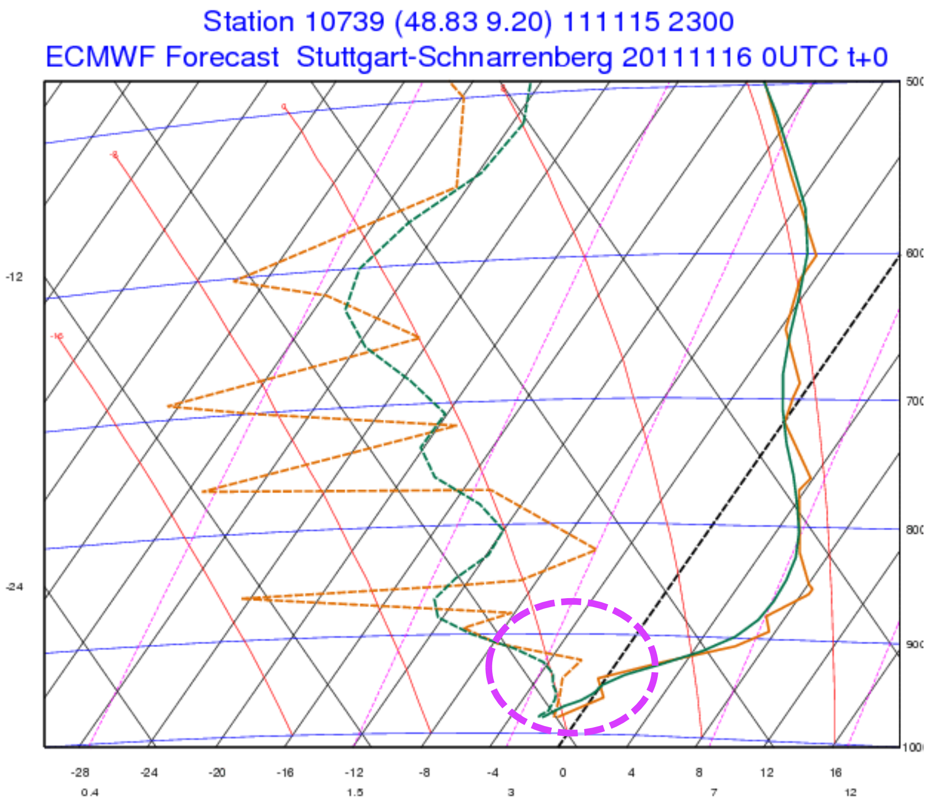
(1) Too little low cloud cover: 36h forecast versus SYNOP observation (for high pressure days over Europe during winter)

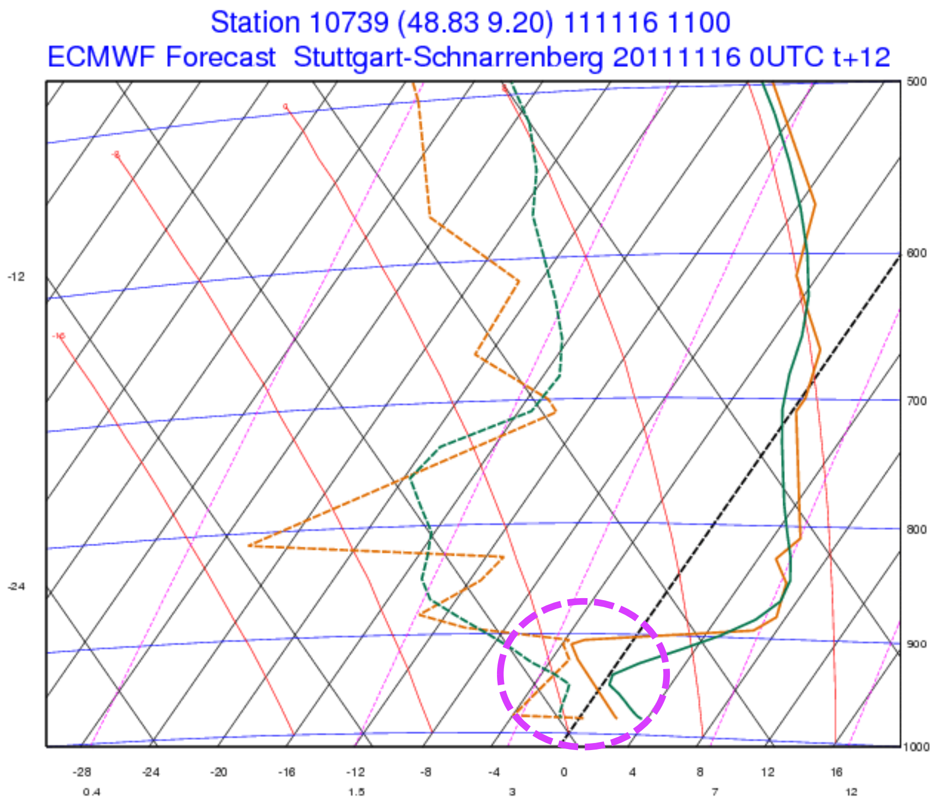


(1) Too little low cloud cover: Fog rising to stratocumulus example

Sounding Stuttgart 16 Nov, 2011

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





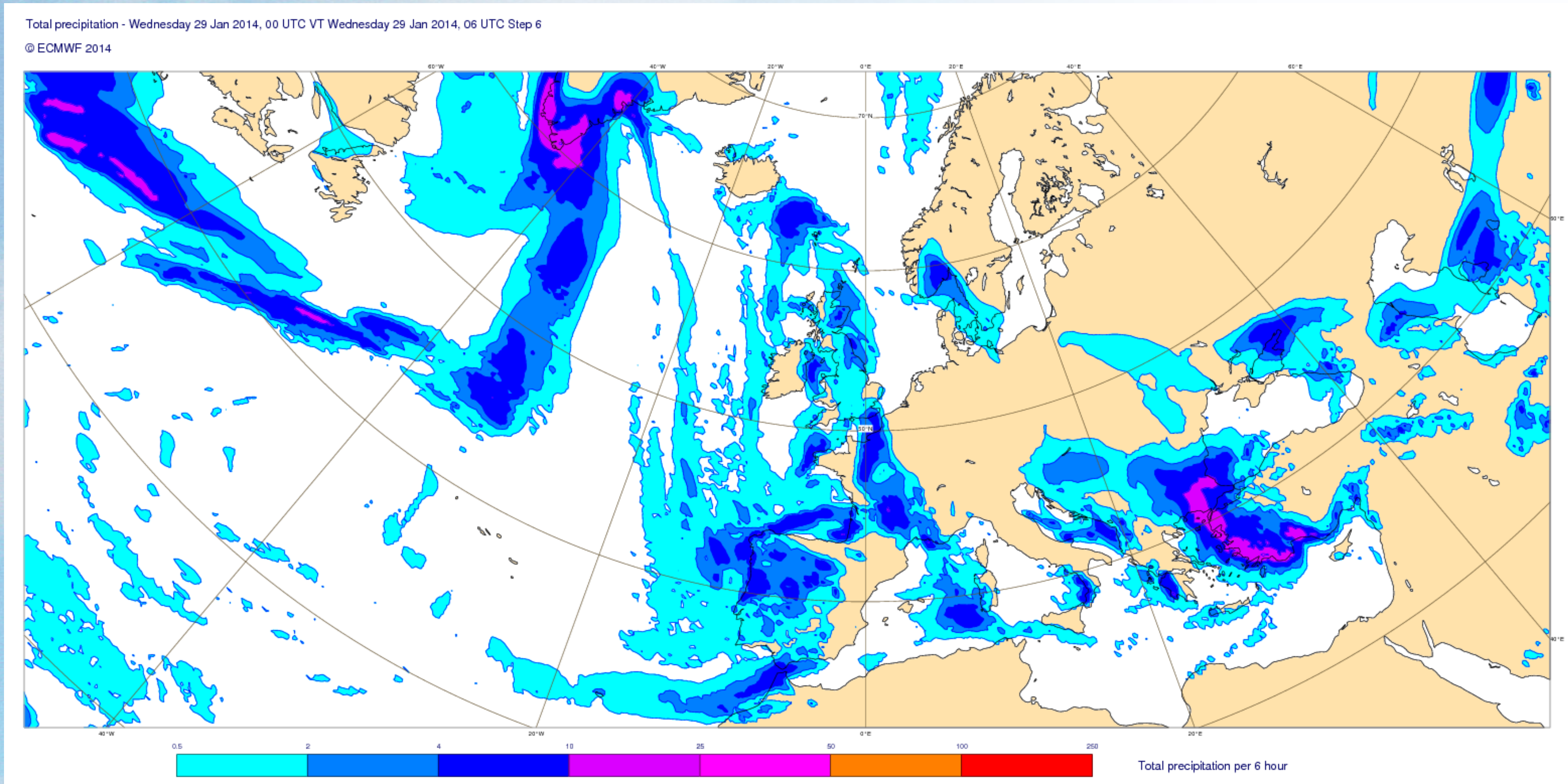
Obs Analysis

Obs Fc T+12h

Fog rising developing into stratocumulus deck could not be properly represented

ECMWF

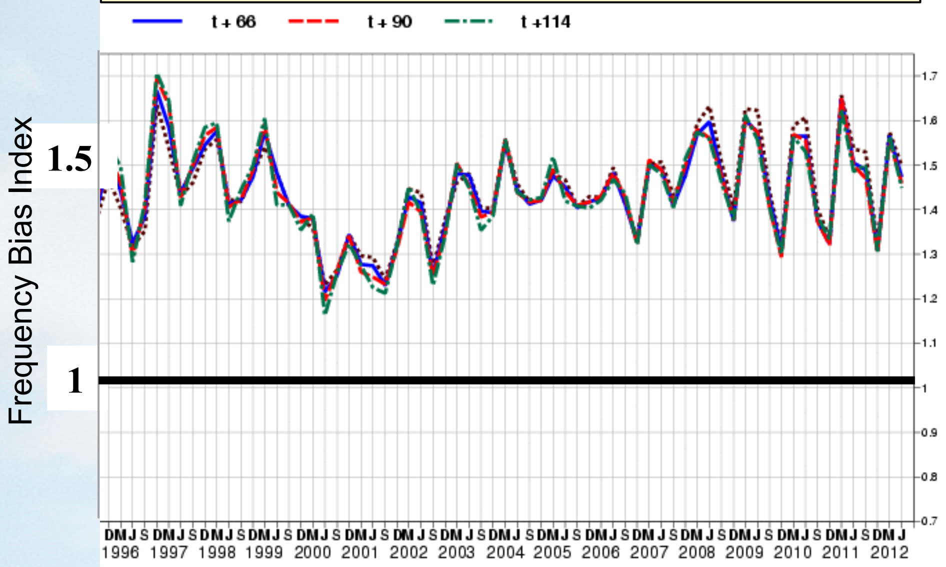
(2) Overprediction of light precipitation occurrence
Example of recent 6 hour precipitation accumulation



(2) Over-prediction of light precipitation occurrence
Model vs. SYNOP

- Timeseries of frequency bias of 24 hour accumulated precipitation from the operational ECMWF IFS model versus SYNOP (global) from 1996 to 2012.
- Highlights 1.5x frequency of occurrence bias in the range 0.25 to10 mm/day. Supported by other obs sources (e.g. CloudSat)
- Bias doesn't depend on forecast range.

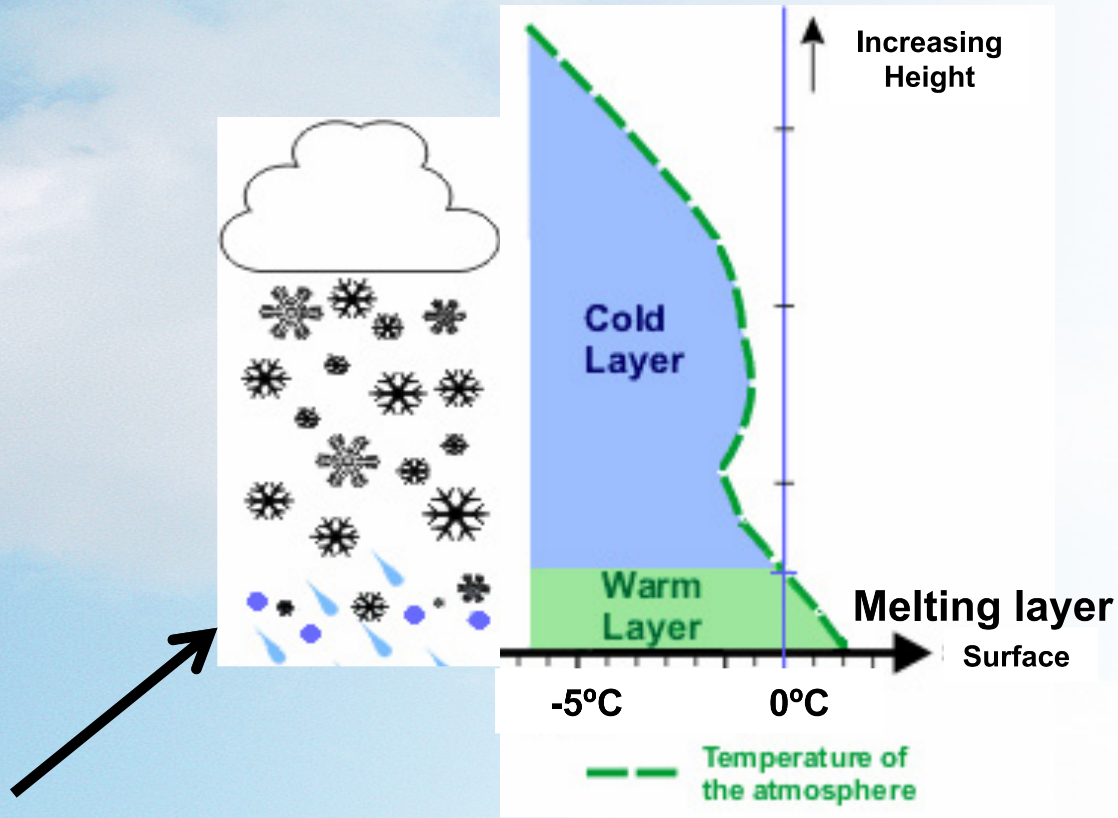
Precipitation exceeding **0.25 mm/24h**



Precipitation exceeding **10 mm/24h**

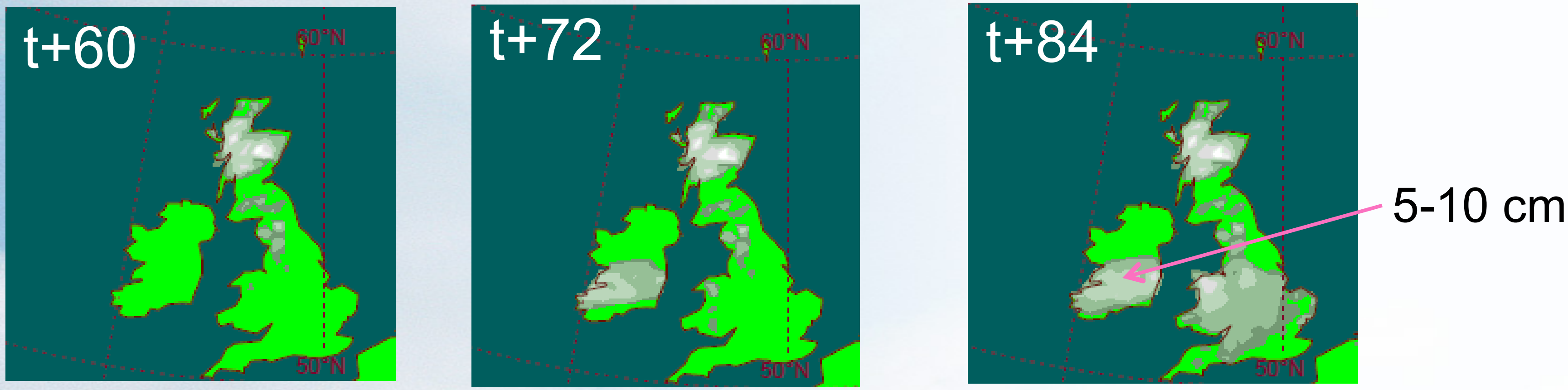
(3) Snowfall in marginal situations: Melting layer

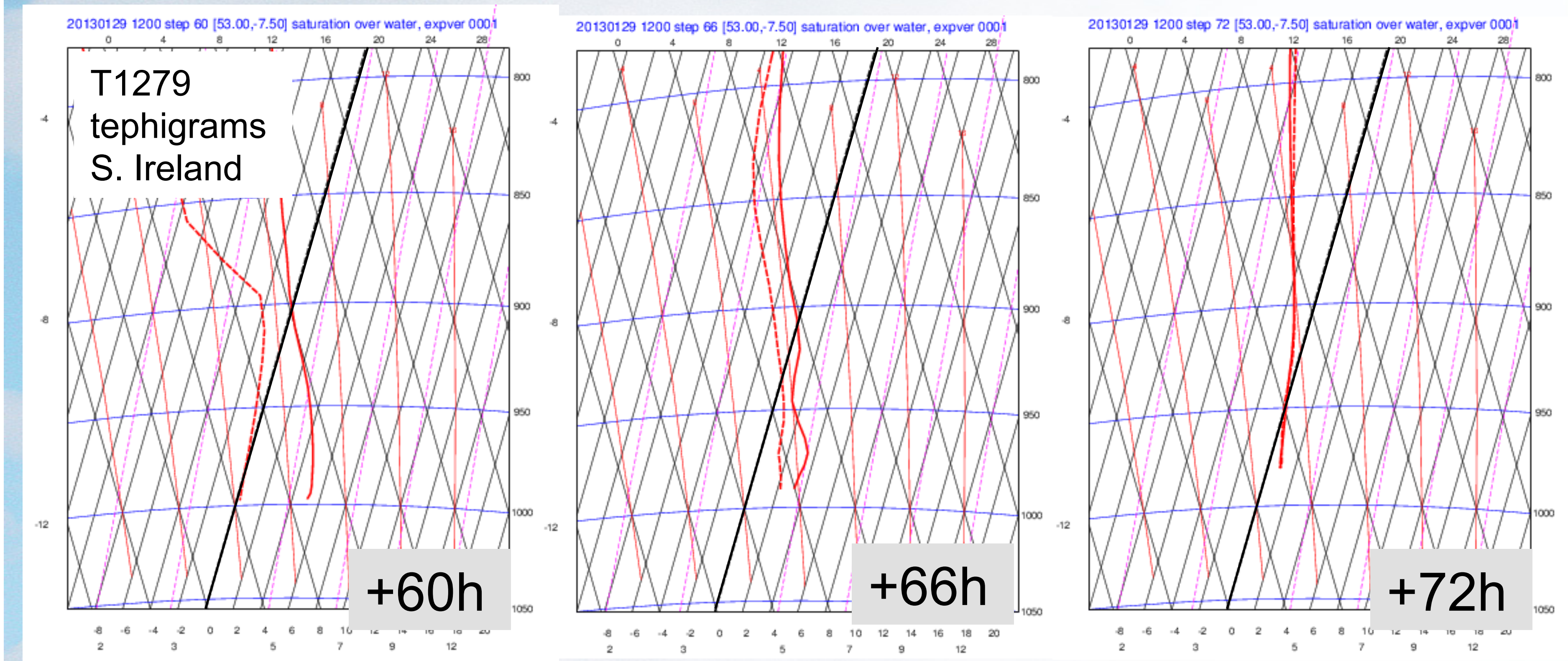
Melting layer often ~ few hundred metres thick
In drier air, snow melts at T > 0°C (due to evaporative cooling)



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)

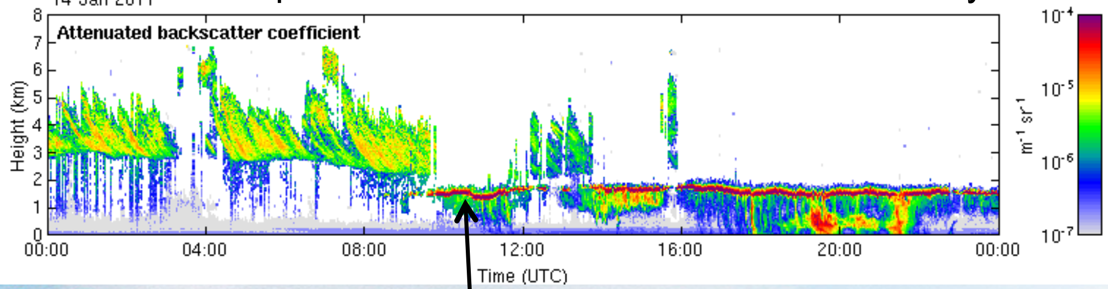
- In the model, **sleet** (melting snow particles) is represented by **a mix of rainfall and snowfall**. Halfway through the melting layer will be 50% snowfall and 50% rainfall. NOTE: IFS diagnostics TP=totalprecip=(rainfall+snowfall), SF=snowfall

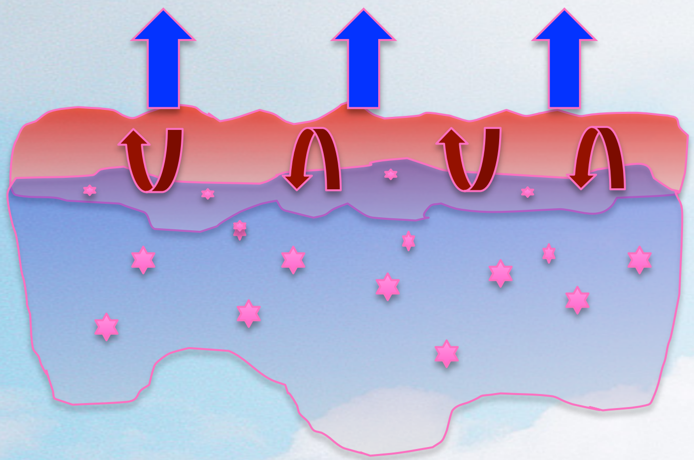
- Once on the ground and temperatures greater than zero, surface snow often takes too long to melt (recognised problem in the ECMWF model)

(4) Super-cooled liquid water

Commonly observed in the atmosphere

Example lidar backscatter timeseries at Sodankylä

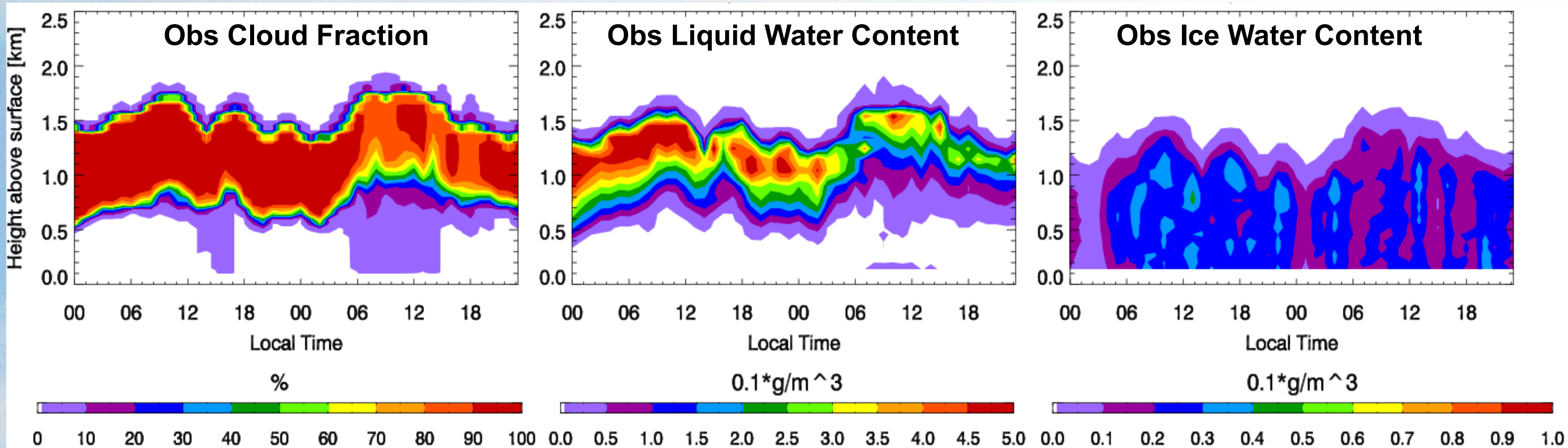




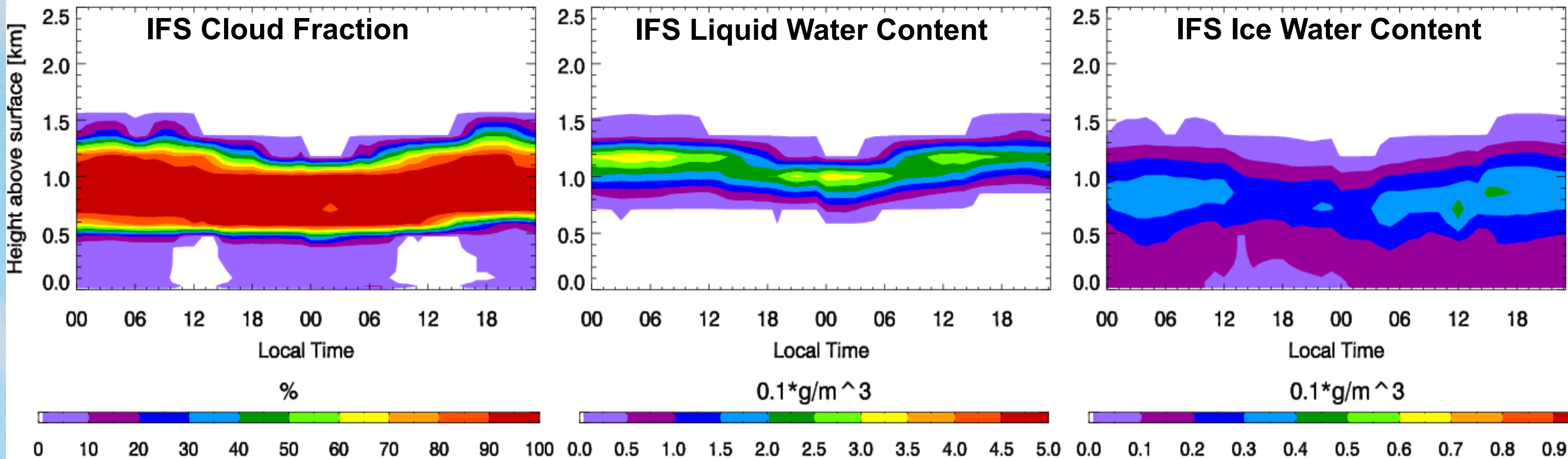
- Super-cooled liquid water (SLW) cloud frequently occurs in atmosphere as observed from aircraft & remote sensing.
- Radiatively important and can increase cloud lifetime (liquid drops suspended, ice crystals grow and fall out)
- Fine balance between turbulent production of water droplets, nucleation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

(4) Mixed-phase cloud and recent IFS model changes

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



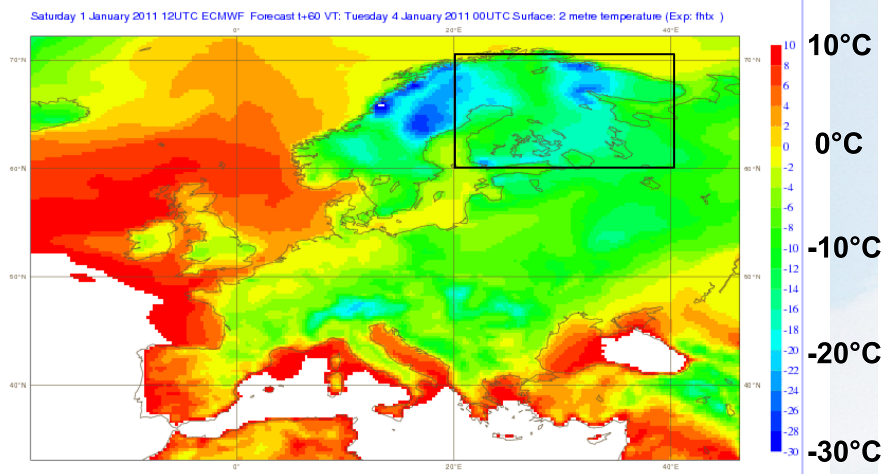
New cloud scheme (revised 37r3+) – SLW at cloud top with ice fallout as obs



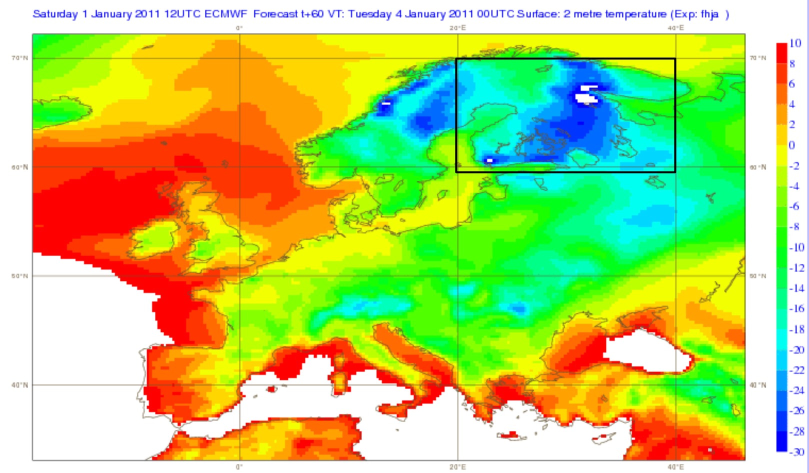
Forbes and Ahlgrimm (2014)

(4) Cold T2m bias in weakly forced mixed-phase
(Example T2mT snapshot from 00Z 4th Jan 2011 – Finland T bias)

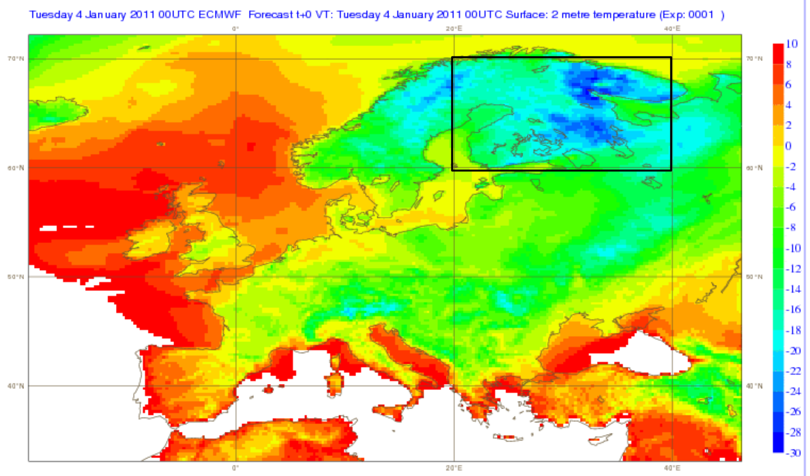
36r3 Diag mixed phase - 2009



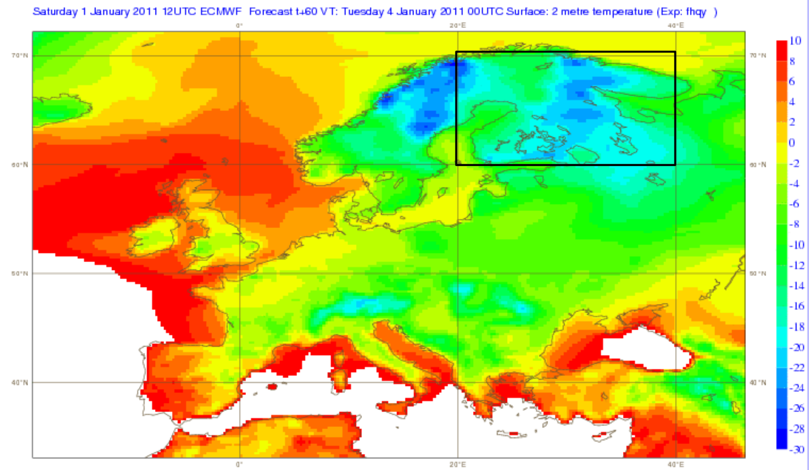
37r1 Prog mixed phase - 2010



Analysis

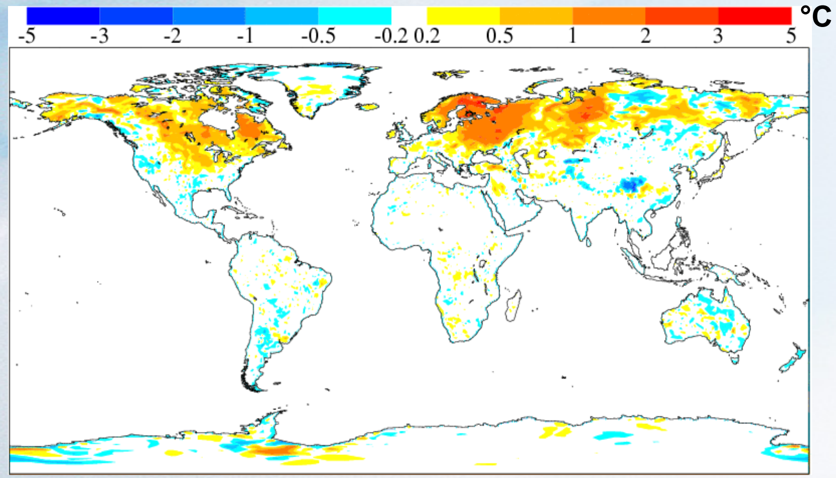


37r3 Prog mixed phase -2011/12

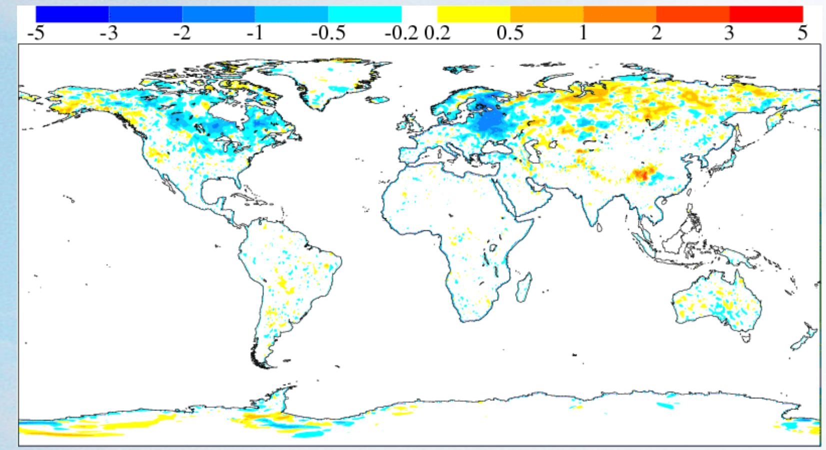


(4) Getting super-cooled liquid water right matters
Radiative impact on low-level temperature over land

Mean T2m change (72hr forecast for Jan 2011) for Cy37r3 SLW cloud changes



As above, but change in mean absolute error (generally reduced)



- Changes to representation of super-cooled liquid water in Cy37r3 positive impact operational Nov 2011.
- General increase in occurrence of super-cooled liquid water, particularly in weakly forced situations.
- Improved temperature bias and reduced errors in winter low cloud over land.
- Impacts clearly seen in NH and European T1000 scores.


4. Future cloud and
precipitation developments:
forecaster perspective?

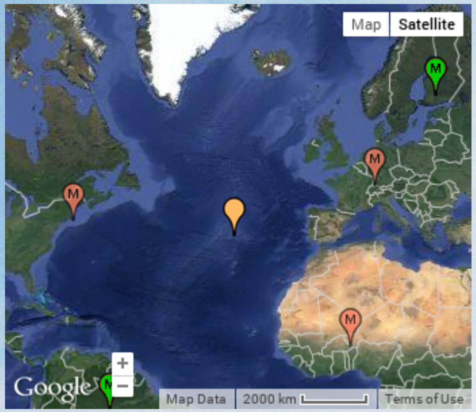
Future developments…

…various improvements to cloud scheme and other parametrizations, in cycle 41r1 (to be operational in March 2015) but I want to mention two aspects relevant to cloud/precipitation forecast products here:

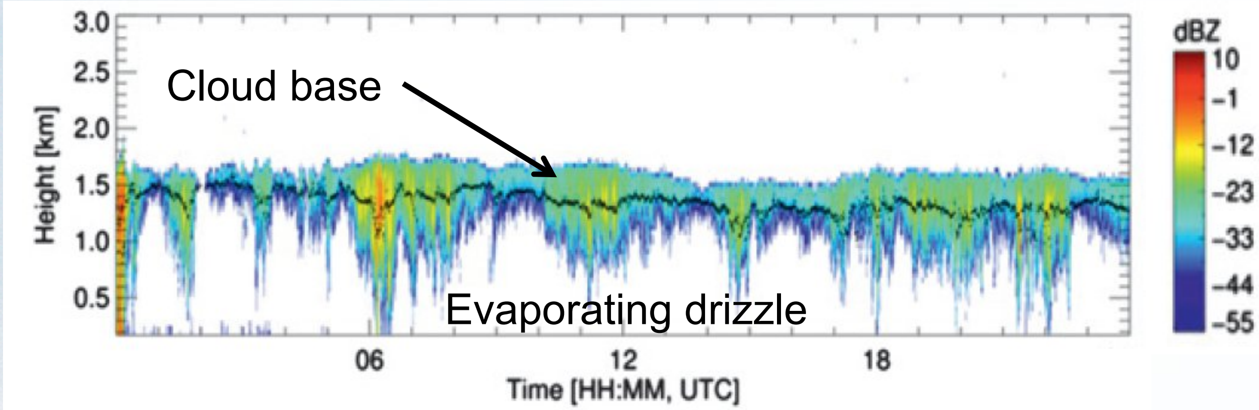
- **Reduction** of overprediction of occurrence of light rain (drizzle) and increase of heavier precipitation

- Precipitation type (freezing rain, melting snow…)

Drizzle occurrence: A case study from the Azores (N. Altantic)

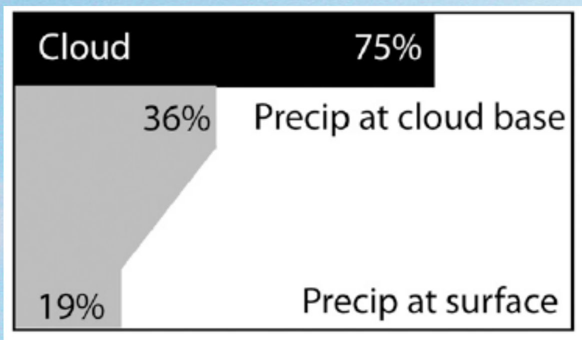


Timeseries of drizzling low cloud at Graciosa Island from Rémillard et al. (2012)

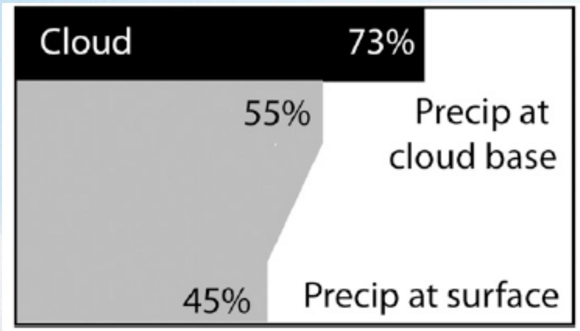


More realistic rain/drizzle formation and evaporation parametrizations in future IFS cycle to reduce light rain at cloud base and at the surface…..

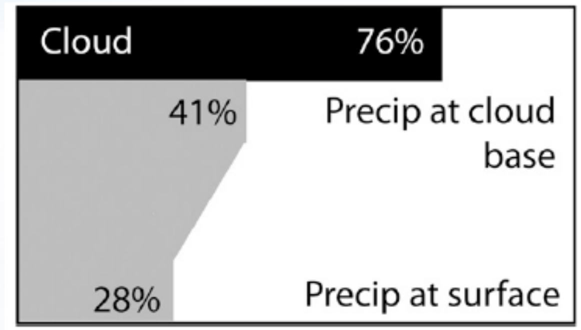
Observations



Control Model



Revised Model



from Ahlgrimm and Forbes (2014)

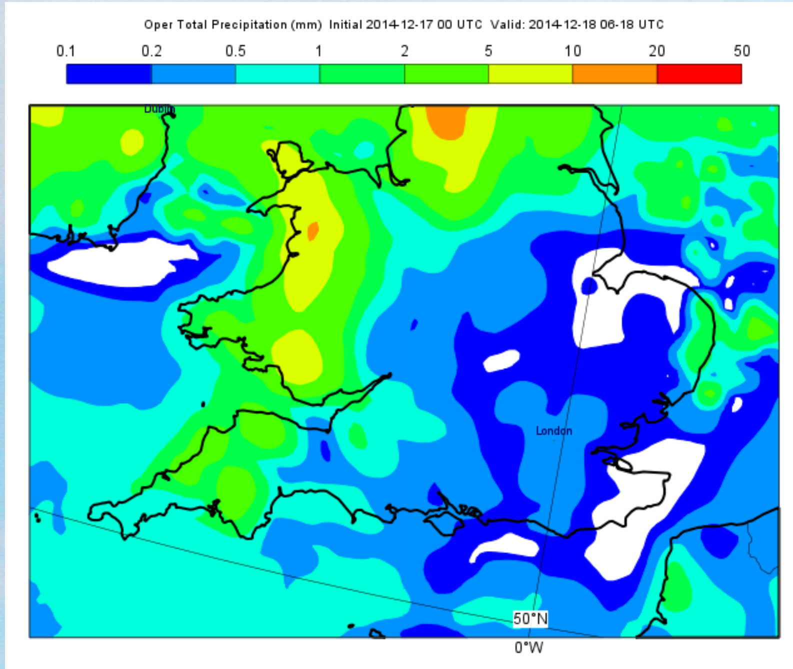
Precipitation
Improvements in upcoming cycle 41r1 (spring 2015)

Improvements to cloud and precipitation physics (rain formation+evaporation)

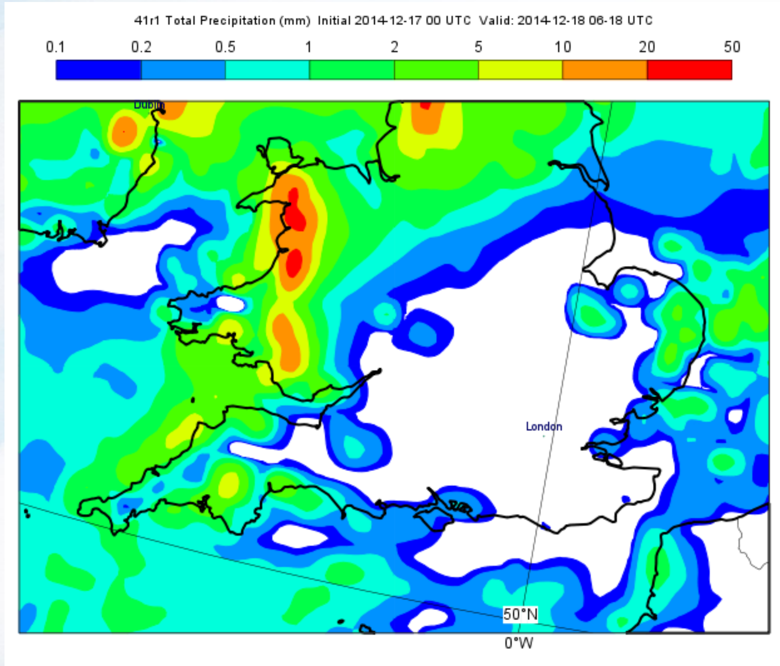
- Reduces occurrence of light precipitation **when stratiform rain dominates** ✓ (but not when convective rain or snow dominate)
- Increases precipitation (+10%) for heavier events (relevant for flooding events) ✓

Example case study for 12 hour rainfall accumulation over UK on 18 Dec 2014

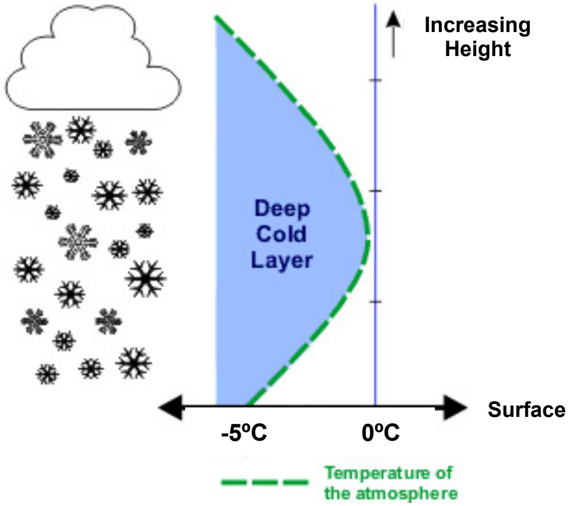
Current oper Cy40r1



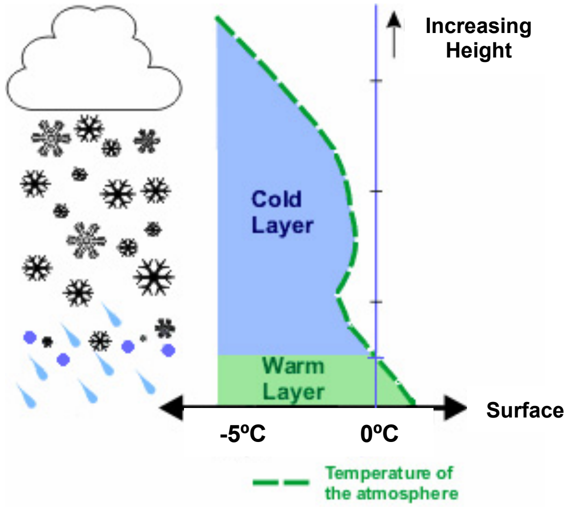
Next oper Cy41r1



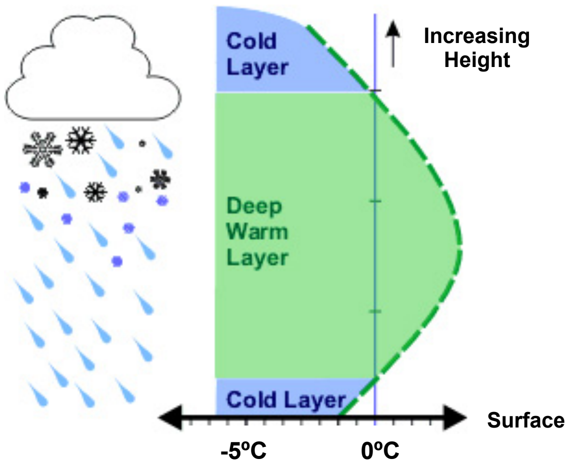
Precipitation type



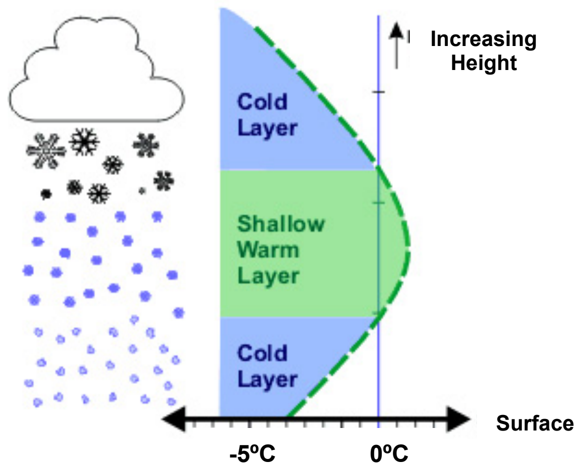
Snow



Sleet (melting snow) or rain



Freezing rain



Ice pellets

ECMWF

New (experimental) precipitation diagnostics (in Cy41r1)

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

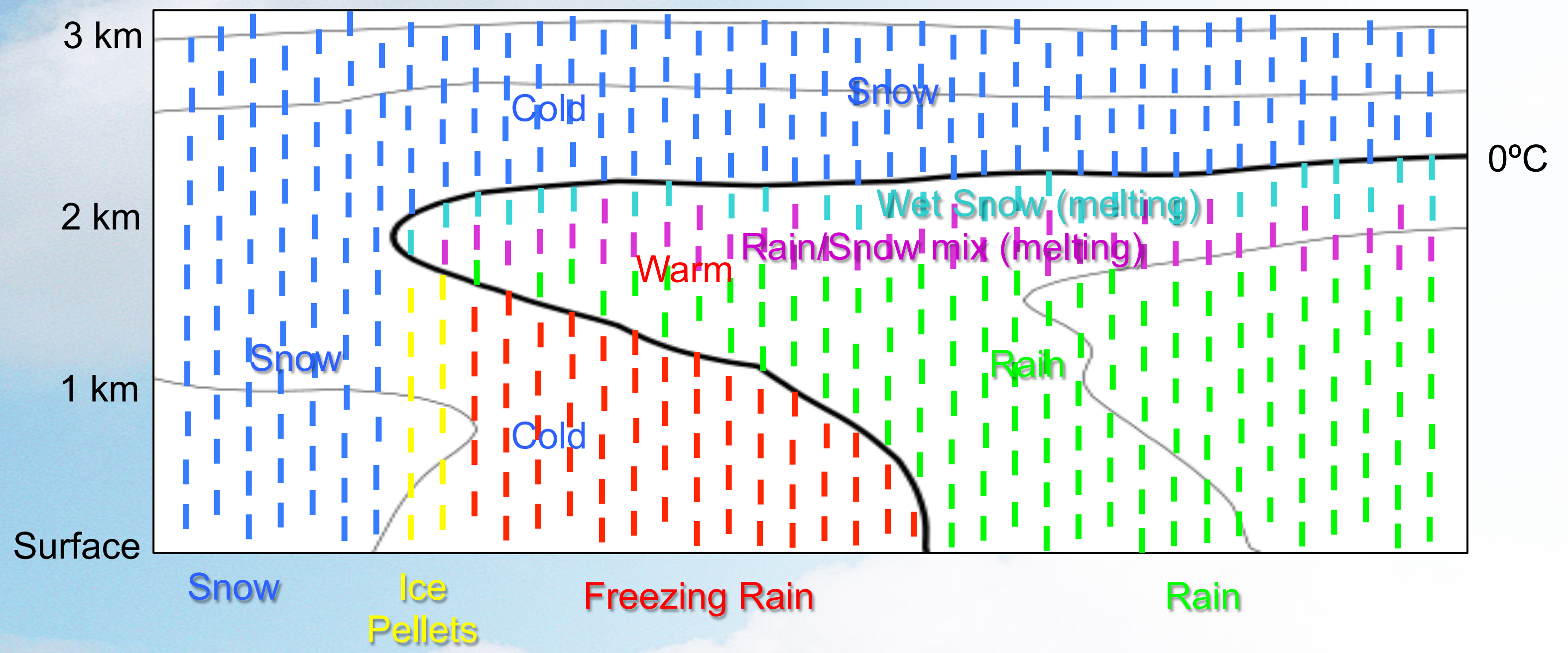
(=1) Rain	T2m > 0ºC, liquid mass more than 80%
(=7) Mixed rain/snow	T2m > 0ºC, liquid mass >20% and <80%
(=6) Wet snow	T2m > 0ºC, liquid mass less than 20%
(=5) Snow	T2m < 0ºC “dry” snow
(=3) Freezing rain	T2m < 0ºC supercooled rain from melted particles aloft
(=8) Ice pellets	T2m < 0ºC refrozen from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

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

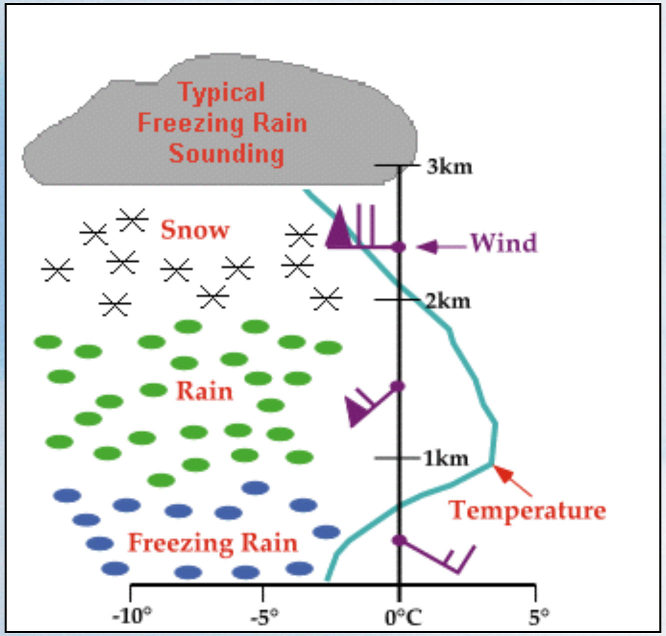
- Instantaneous precipitation rates (valid at a particular time)
  - Stratiform (large-scale) rainfall rate, and snowfall rate (*lsrr, lssfr*)
  - Convective rainfall rate, and snowfall rate (*crr, csfr*)

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

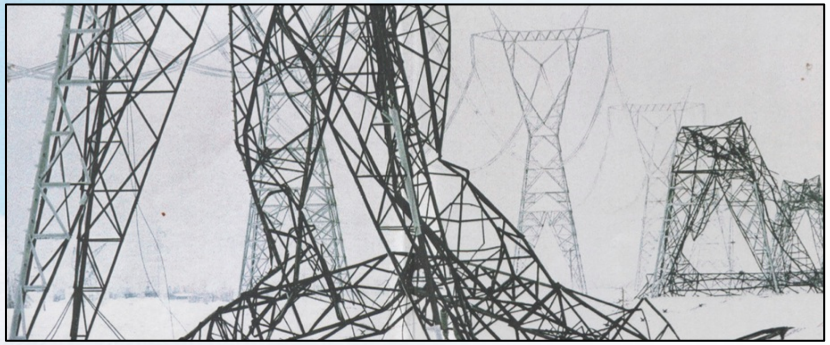
Schematic cross-section (front with elevated warm layer)



Freezing Rain

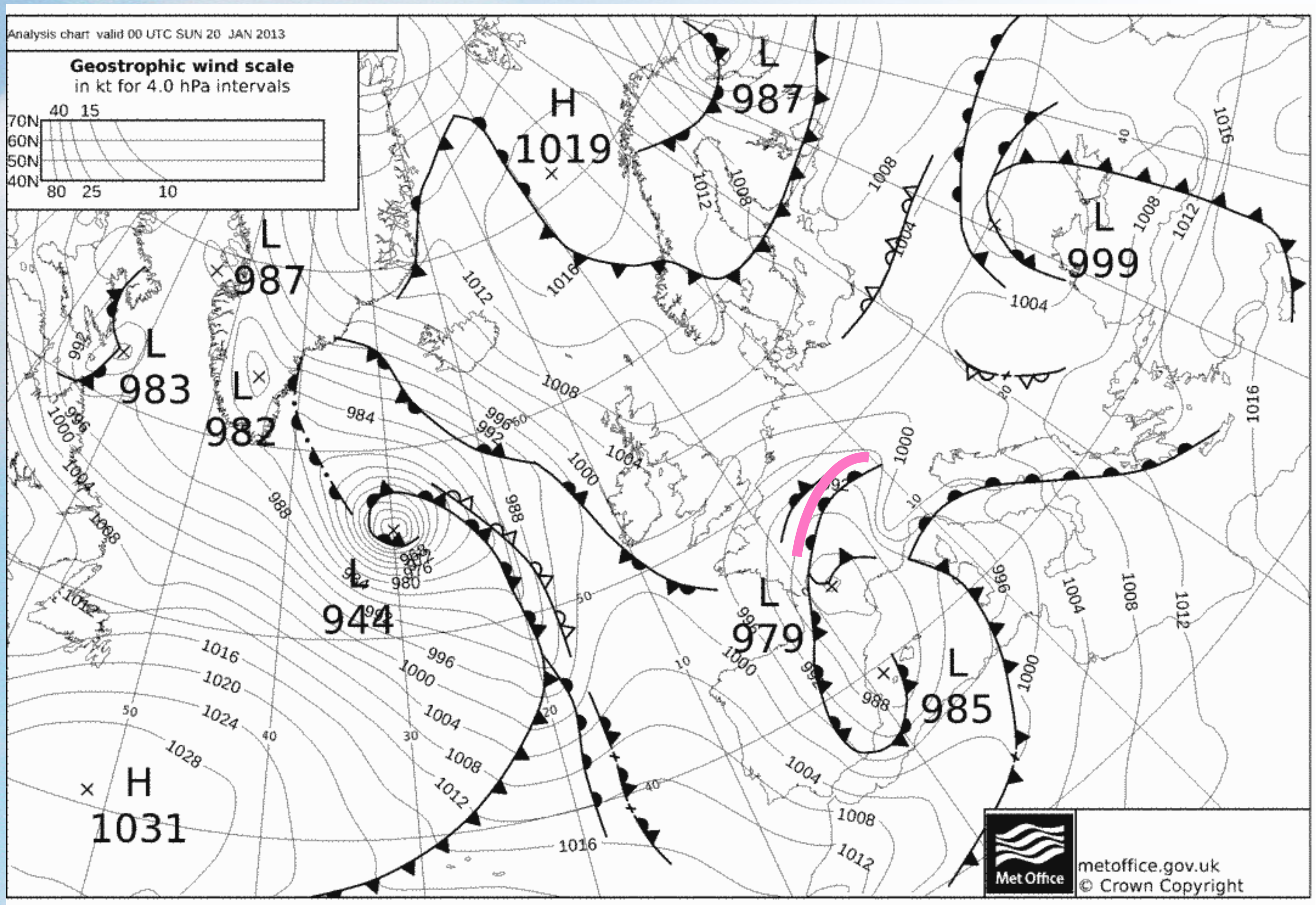


- Freezing rain can result when differential advection brings warm, moist air over colder air.
- This can sometimes occur when warm, moist air flows up and over a warm front in a mid-latitude cyclone.
- Heavy events can cause hazardous surfaces and accumulations of ice, e.g. power line collapse in Canada.



Freezing Rain Case Study: 20 January 2013

"On 20 and 21 January heavy snowfalls, combined with an interval of several hours of freezing rain across broad swathes of south-west and western Germany" - DWD



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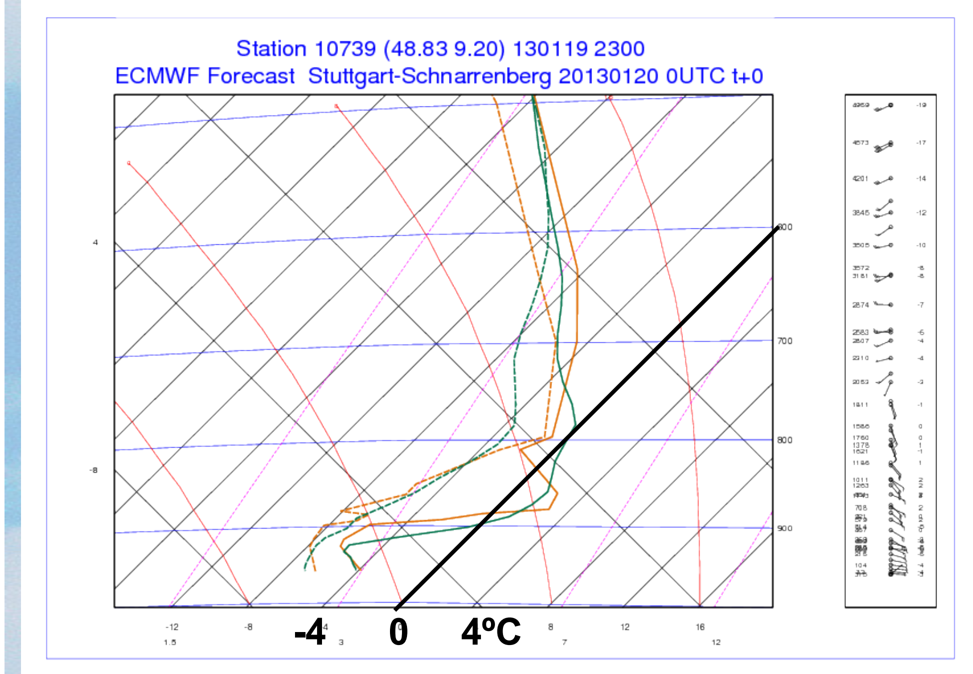
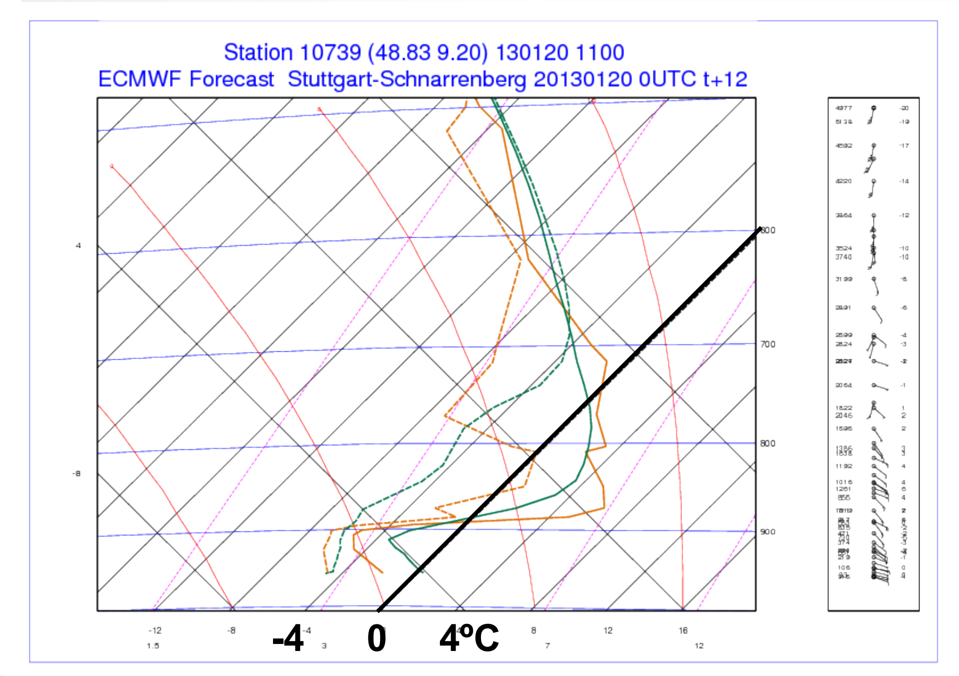
Freezing Rain Case Study: 20 January 2013



00Z 20 Jan 2013



12Z 20 Jan 2013

Stuttgart radiosonde ascent (green) and IFS (orange) analysis (left) and 12 hour forecast (right) showing warm layer above subfreezing layer.

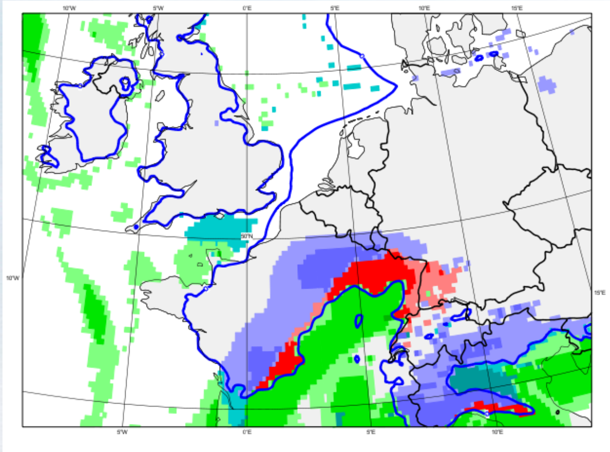
Thanks to Tim Hewson, Ivan Tsonevsky, Peter Bechtold

Freezing Rain Case Study: 20 January 2013

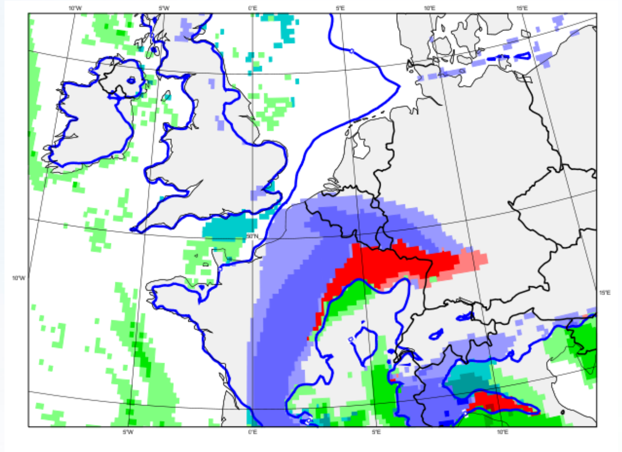
IFS T1279 00Z 20/01/13 forecast with modified physics for freezing rain

Green	= Rain
Turqoise	= Melting Snow
Blue	= Snow
Red	= Freezing rain

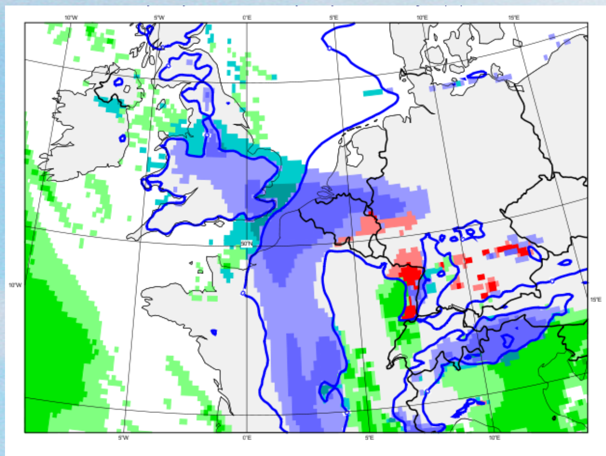
00z/20



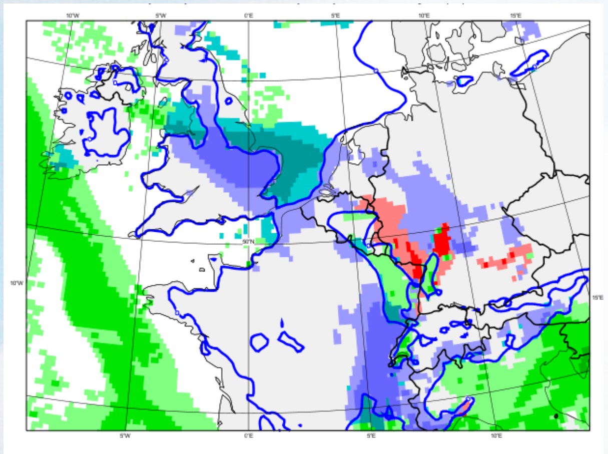
06z/20



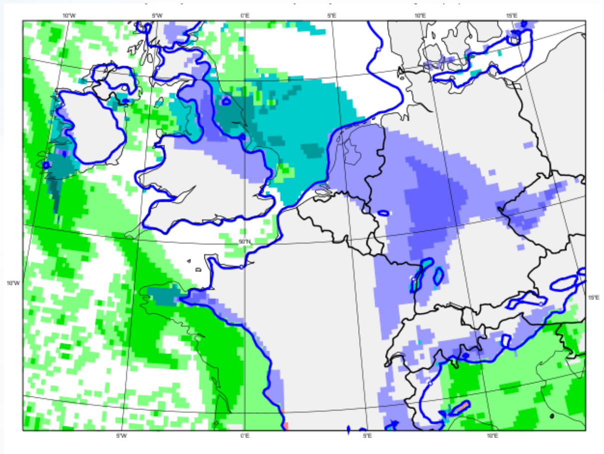
12z/20



18z/20



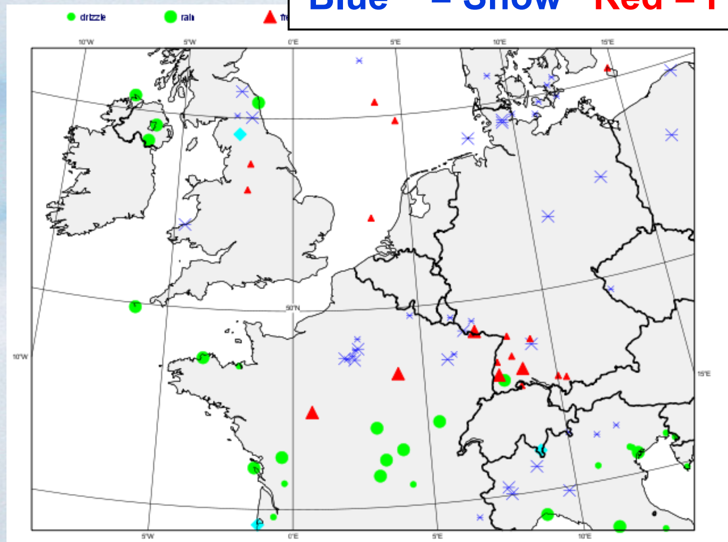
00z/21

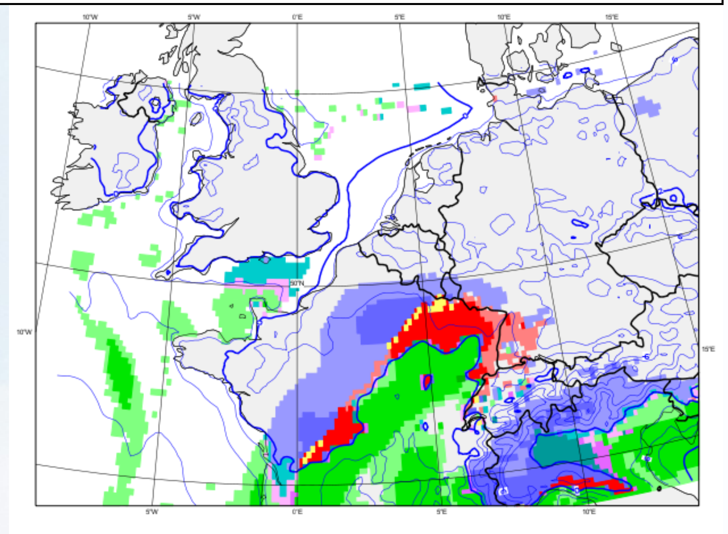


Freezing Rain Case Study: 20 January 2013

Green = Rain　Pink = Melting snow　Turqoise = Wet snow
Blue = Snow　Red = Freezing rain　Yellow = Ice pellets

00z/20

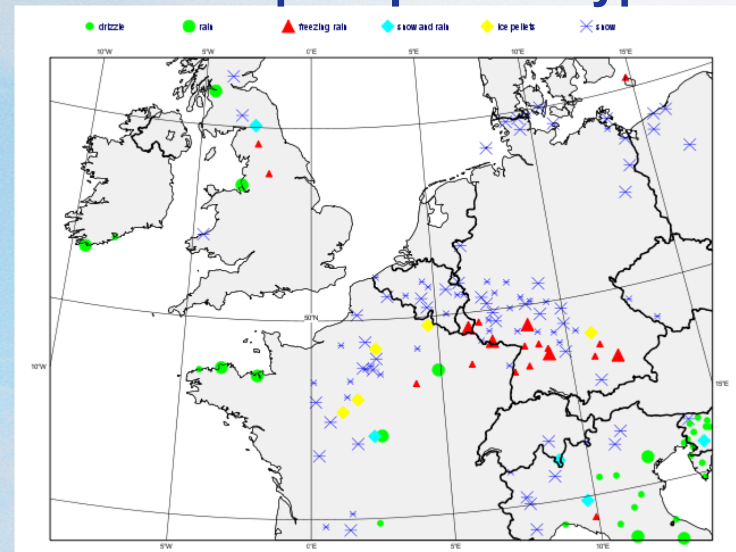


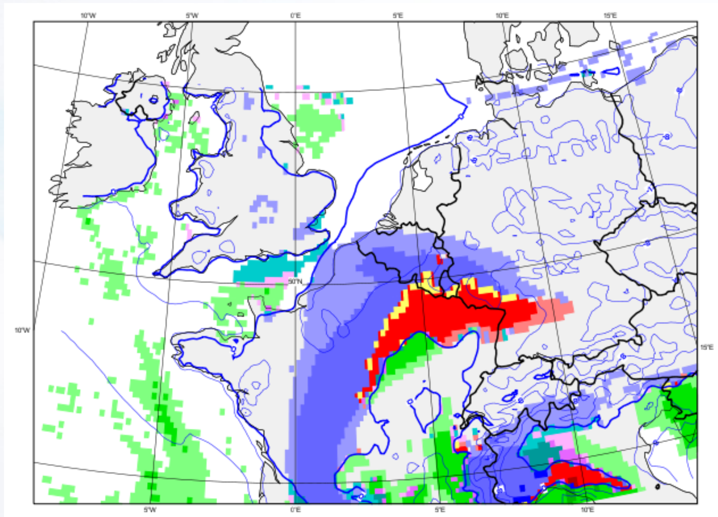


SYNOP precipitation type

IFS precipitation type

06z/20





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Freezing Rain Case Study: 20 January 2013

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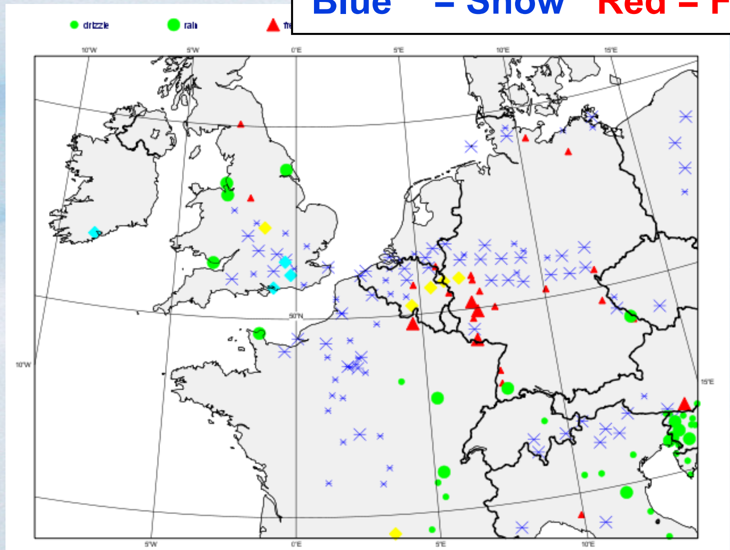
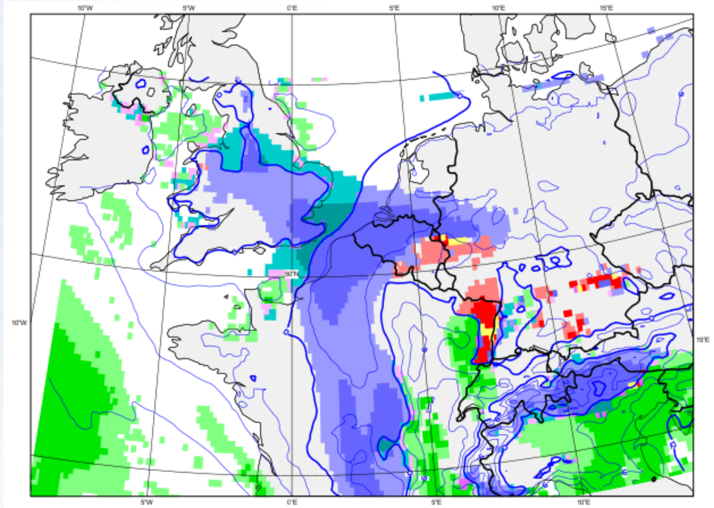
12z/20

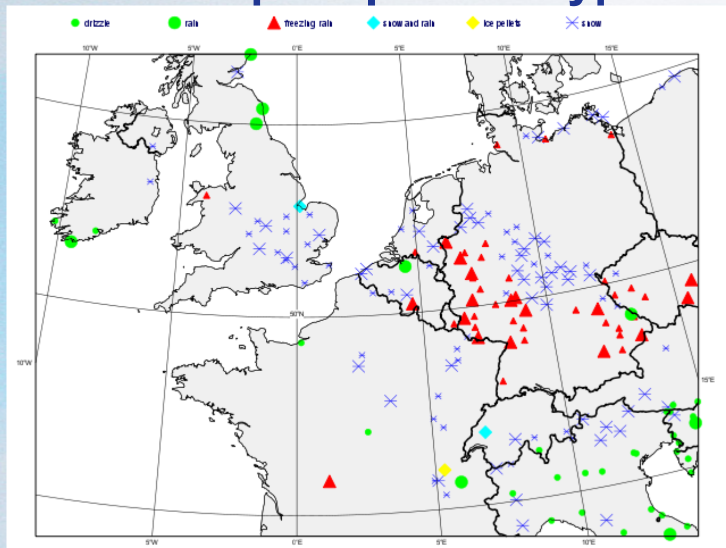


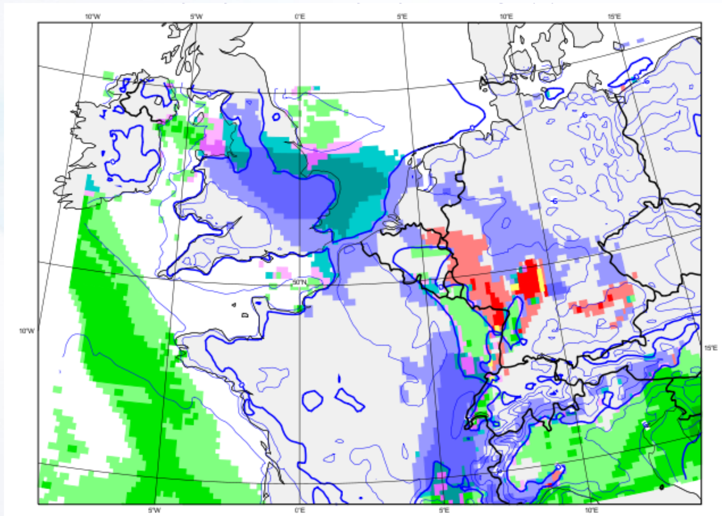


SYNOP precipitation type

IFS precipitation type

18z/20

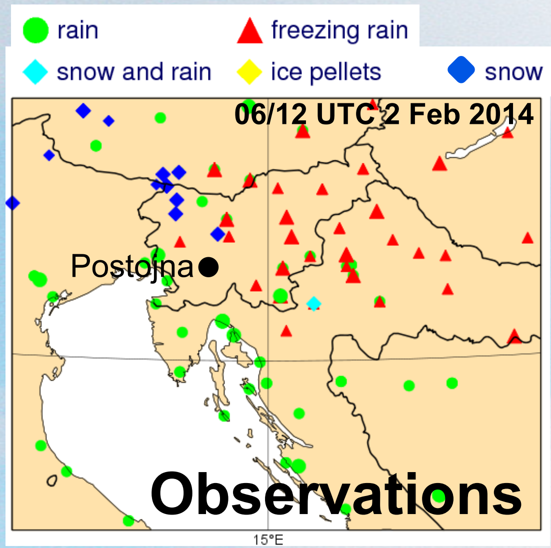


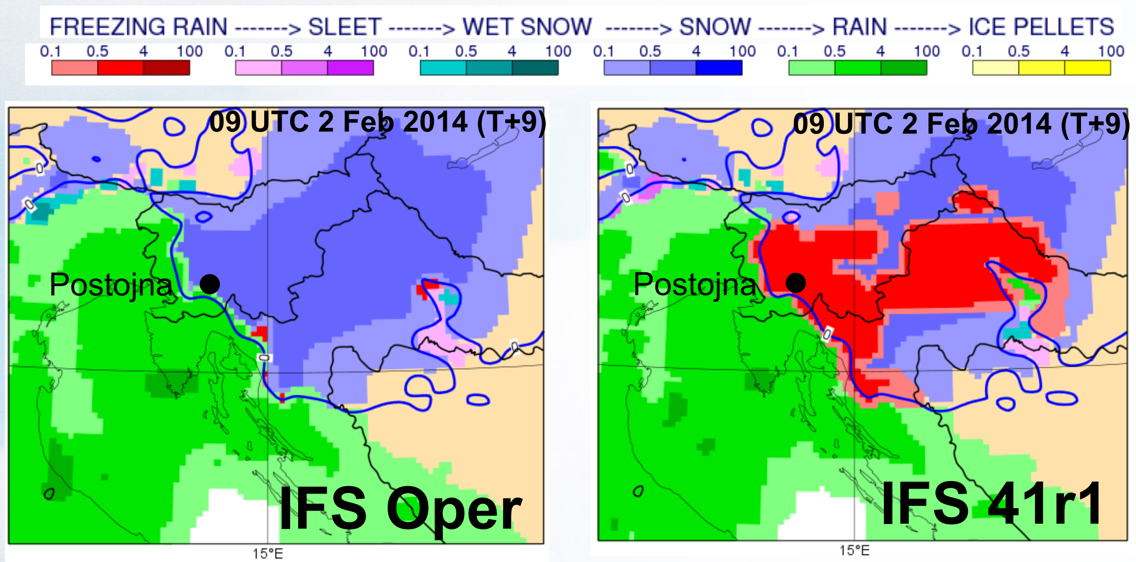


ECMWF

Towards predicting high-impact freezing rain events (41r1)

- Case Study: Slovenia/Croatia early Feb 2014
- Freezing rain caused severe disruption and damage, tranports/power/forests…
- Current IFS physics (40r1) not able to predict
- New physics in 40r3 allows prediction of freezing rain events
- Initial evaluation in HRES and ENS shows potential for useful forecasts
- Article in EC Newsletter Autumn 2014






Summary

Summary
Clouds and Precipitation: From models to forecasting

What we covered…

1. Model parametrizations: Convective and stratiform cloud/precipitation
2. Model prognostic variables, liquid cloud, ice cloud, rain, snow, cloud fraction
3. Precipitation products (LSP and CP), cloud products (TCC,HCC,MCC,LCC)
4. Evaluated against a wide range of observations
5. Some of the difficult "stratiform" cloud/precip regimes for the model – low cloud, light precip, melting layer, mixed-phase, fog
6. Future precipitation type – Melting snow, freezing rain – Feedback?

Hopefully this seminar has helped you to…

1. Describe how cloud and precipitation is represented in the ECMWF global model.
2. Recognise some of the strengths and weaknesses of the forecast cloud/precip.
3. Interpret cloud and precipitation related forecast products.

Thank you for listening! Questions? Feedback?