Severe Weather Prediction at ECMWF – Recent Developments and Future Challenges

Tim Hewson

ECMWF

Thanks to Ivan Tsonevsky, Fernando Prates, Richard Forbes, …

Introduction

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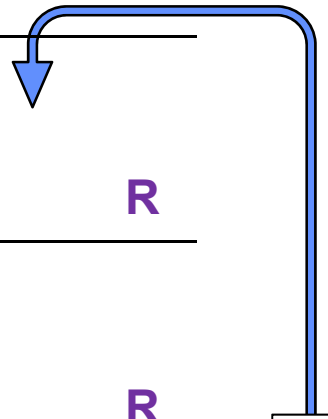
What is “Severe Weather” ?

- Weather of any type that has the potential to have an adverse impact on population / infrastructure / economy
- So impacts are important. Whilst ECMWF doesn’t forecast impacts directly, various products indirectly focus on this
  - However there is always a need for forecasters to add interpretation and bring ‘local factors’ into play (e.g. recent weather, population density)
- There are of course many types of severe weather
- Some types ECMWF forecasts ‘well’, others ‘poorly’
- Our aim is to improve related probabilistic predictions across the board, in particular:
  - Extending the lead times for features that are relatively well-forecast
  - Improving the representation of aspects that are now poorly forecast

Types of severe weather and current status..

- Extreme rainfall	
▪ Long period	
▪ Short period	R
- Windstorms	
▪ Cyclone-related	
▪ Topography-related	R
▪ Convection-related	R
- Snowstorms	
▪ Large-scale snowfall	
▪ Convection-related	R
- Freezing rain	
- Fog	
- Extreme cold	
- Extreme heat	
- Drought	
- Tropical cyclones	R
- Hail and thunderstorms	R
- Air Quality	



How good are ECMWF forecasts currently?

R= clearcut resolution dependance

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Current / Future Activities – Model improvement and Products

- **1. Indirectly targetted**
  - From resolution / analysis / process / ensemble improvements
  - E.g. to better represent convective storms and winds

2015: HRES from 16 to 10km
ENS from 32 to 20km

- **2. Directly targetted**
  - Aiming to get better representation of particular phenomena
  - E.g. freezing rain
- **3. Impact-related**
  - Trying to place meteorological events in model output into a climatological context
  - E.g. EFI (Extreme Forecast Index)
- **4. Tailored output (forecaster-oriented)**
  - Recognising that synoptic features correlate with severe weather
  - E.g. Cyclone tracking

Layout

- *1. Impact-related developments*
  - Extreme forecast index (EFI) and Shift-Of-Tails (SOT)
    - Formulation
    - Strengths and weaknesses
    - Upcoming improvements
    - Verification
  - Return periods
- *2. Tailored output*
  - Extra-tropical cyclone products
    - Identification strategy
    - Product strategy
  - Tropical cyclone products
- *3. Targetted model improvements*
  - Freezing rain example
- *Summary*

1. Impact-related – EFI / SOT

Principles

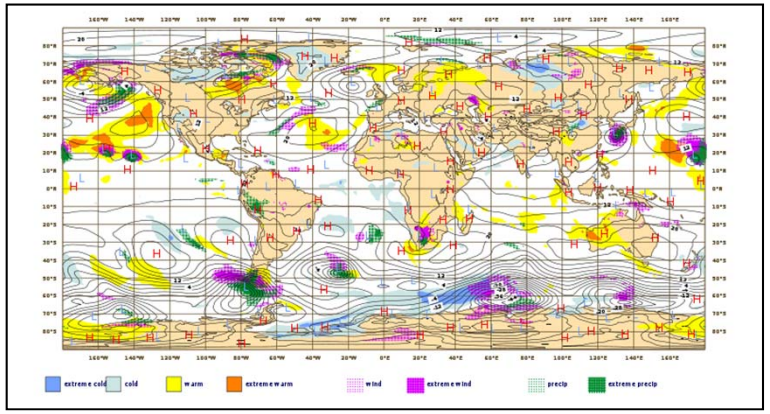
- **Infrastructure, society, economies, in so far as they relate to weather, are configured to take account of the normal range of variability. For example:**
  - **Drainage systems are limited in arid regions**
  - **Building regulations specify snow-loading capacity and wind-gust thresholds for roofs, based on locally observed extremes**
  - **…**

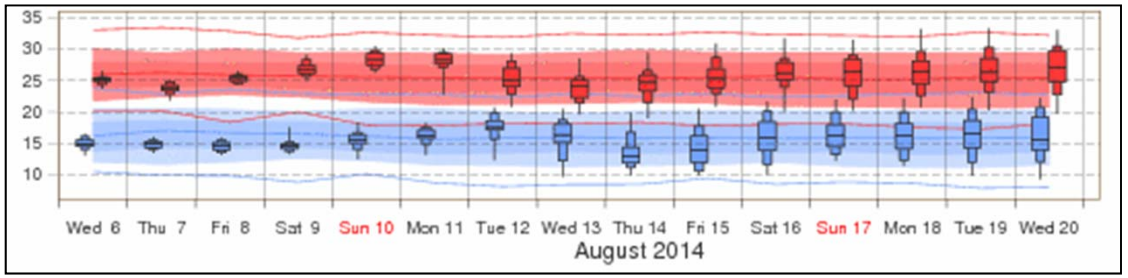
- **So any weather out of the ordinary has the potential to generate impacts. For example:**
  - **A slight rainfall (eg a few mm) around harvest time can completely destroy a cotton crop**

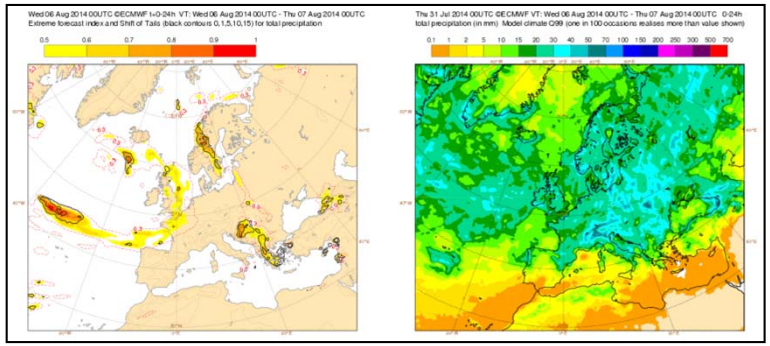
Tools for impact forecasts: EFI and SOT

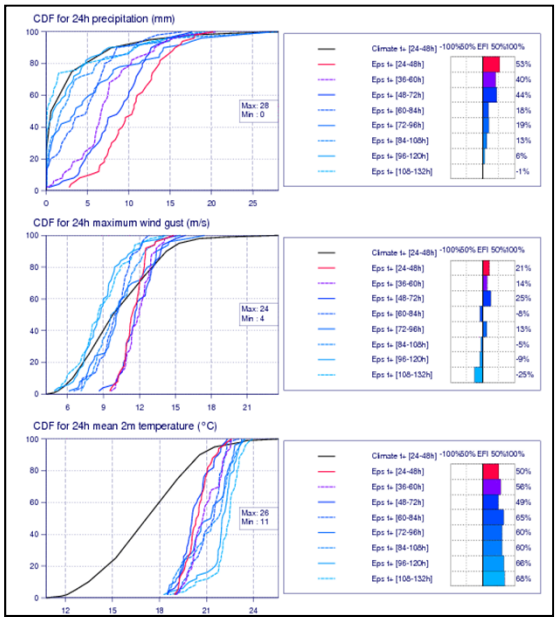
- **EFI = Extreme Forecast Index** **SOT = Shift Of Tails**
- Non-dimensional indices designed to represent how extreme the weather that is forecast (by the ensemble) is likely to be
- We divide up into parameters (rainfall, temperature, max gust etc)
- The reference point is what is the normal range of variability, at a given location, at a given time of year
- Observation coverage is insufficient to define local climate everywhere
- So instead the reference point is model climate, or 'M-Climate'
- Added advantage is that model unrepresentativeness, biases and drifts are accounted for… (M-Climate is a function of lead time)
- ECMWF always computes M-Climates from the current operational model version
- For EFI and SOT we compare ENS forecasts with the M-Climate

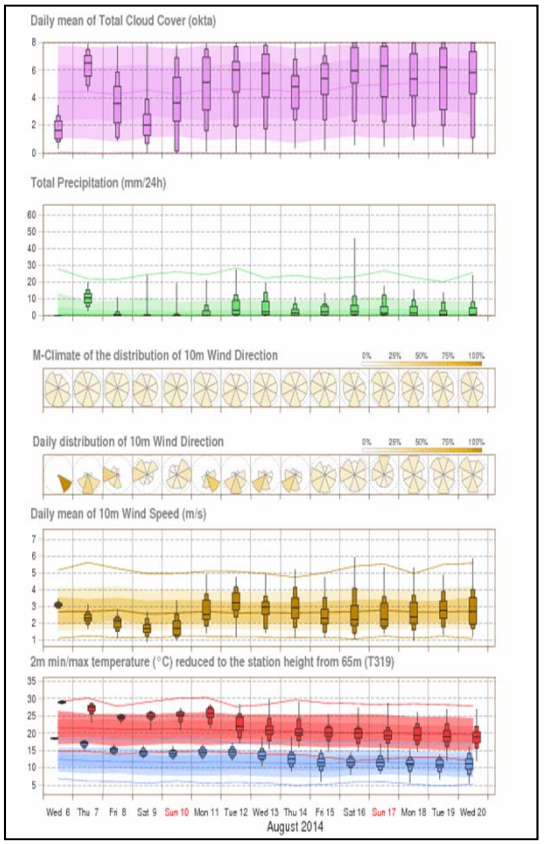
Some products related to EFI / SOT / M-Climate

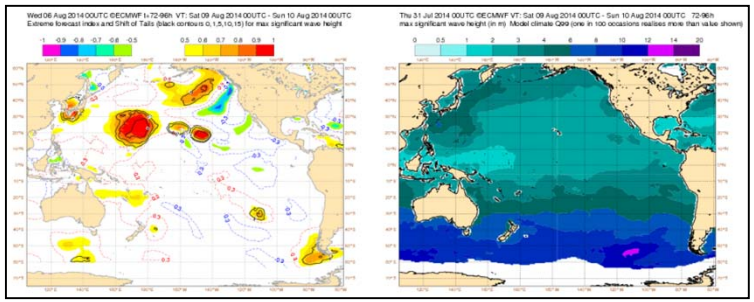


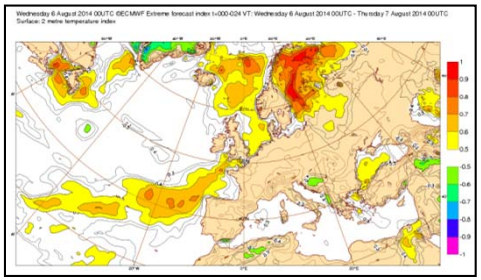












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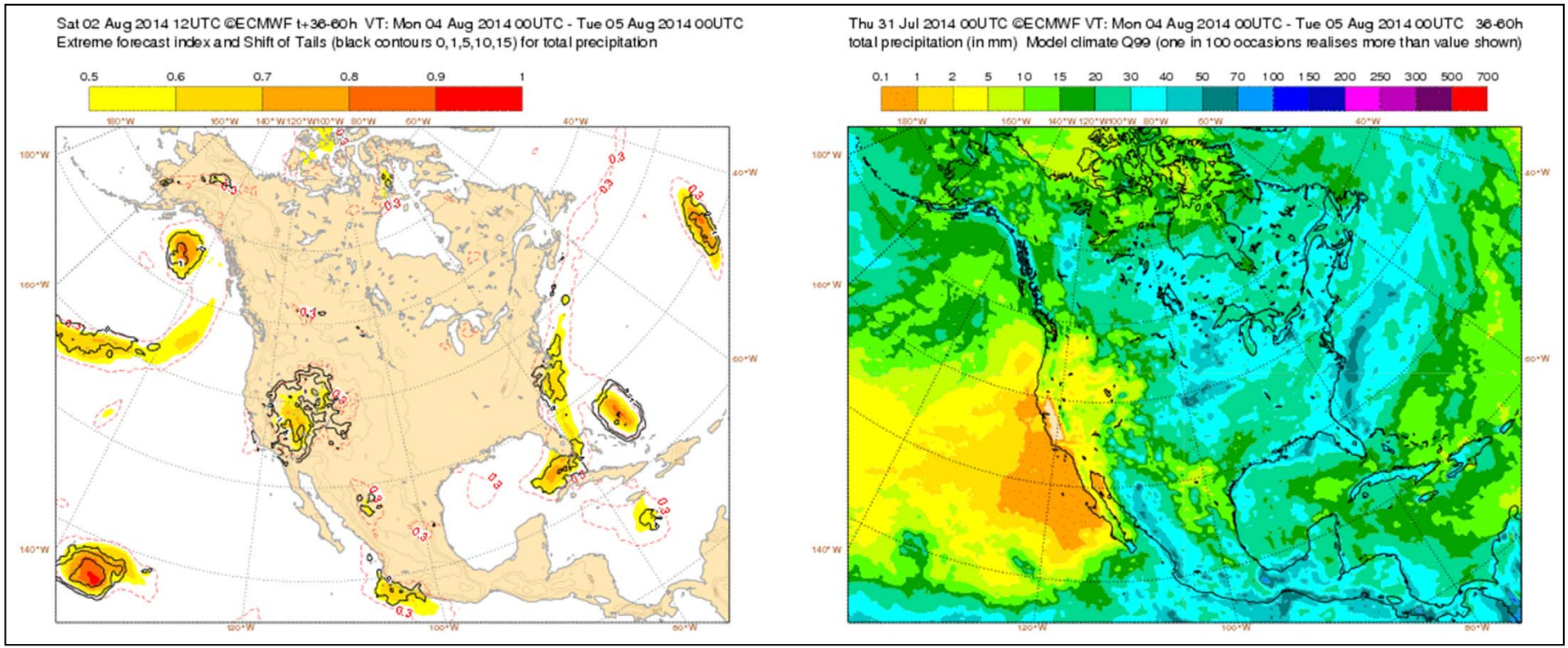
Example for 1-day precipitation: EFI (colours) and SOT (black contours)



EFI and SOT

M-Climate 99th percentile

For 36-60h precipitation forecasts

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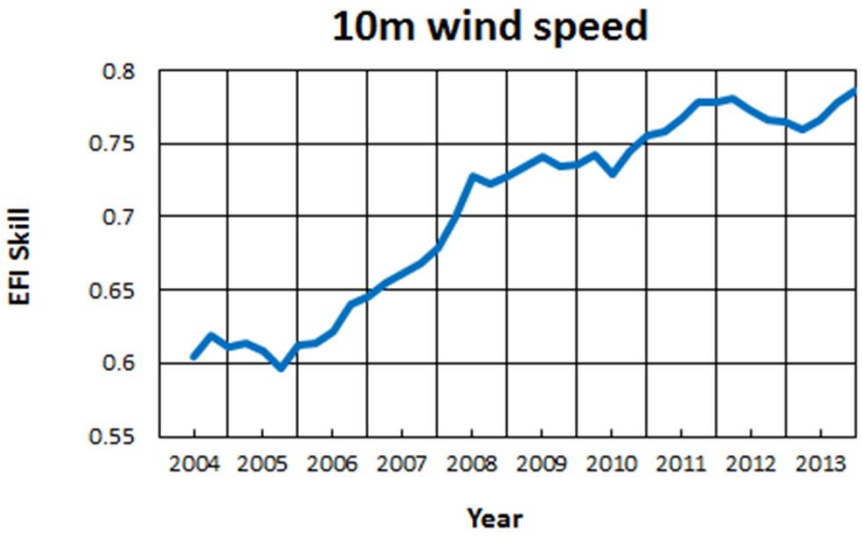
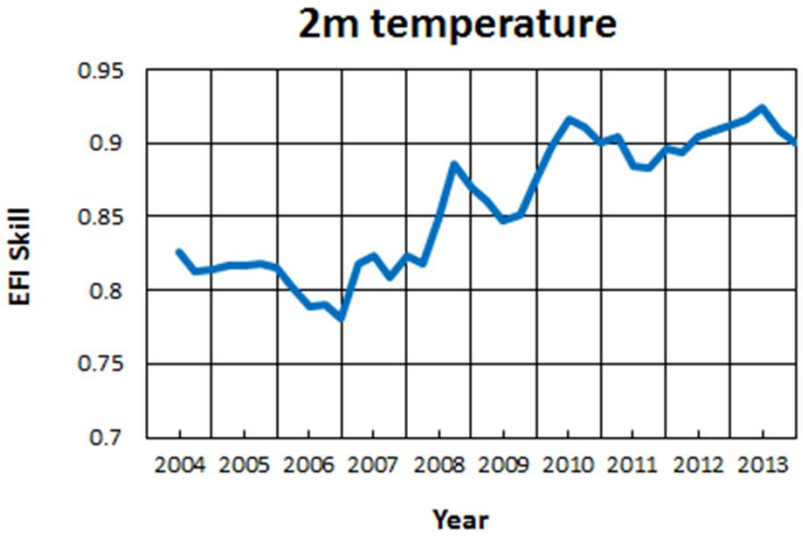
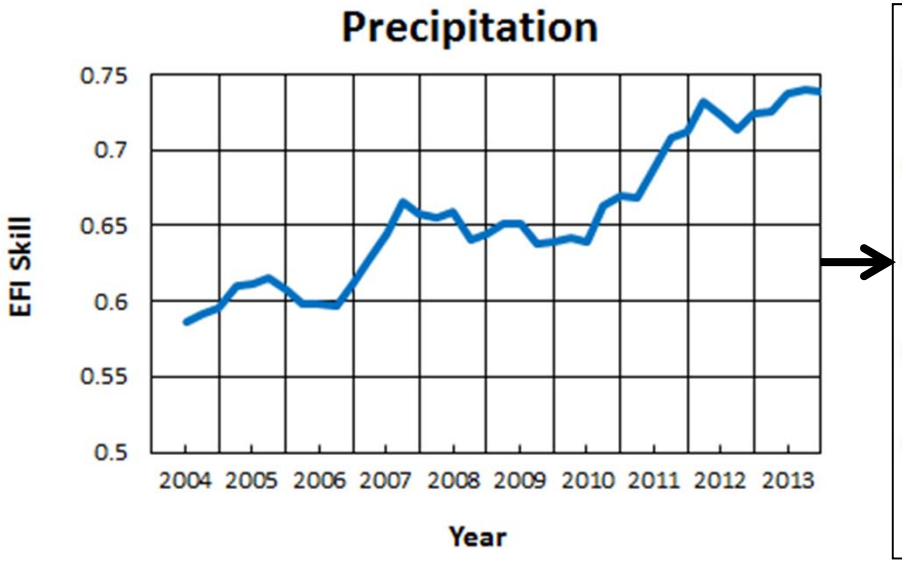
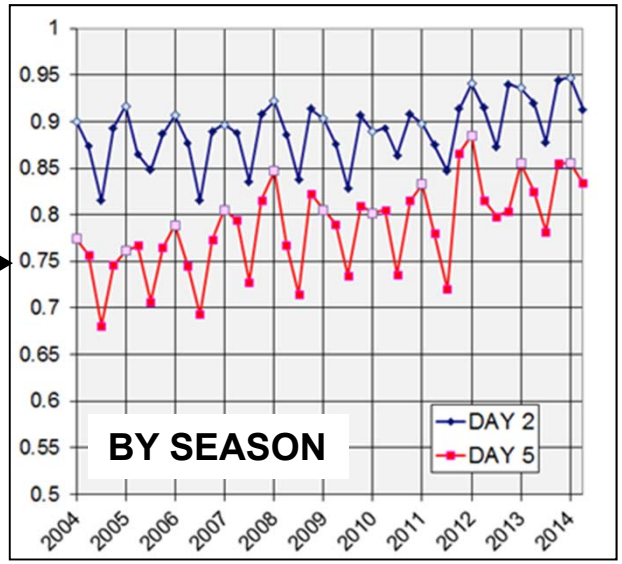
Verification: EFI skill 2004 – 2013 - Europe









Much lower skill in summer

As convection is much more often the cause of large totals

D5 winter skill ≈ D2 summer

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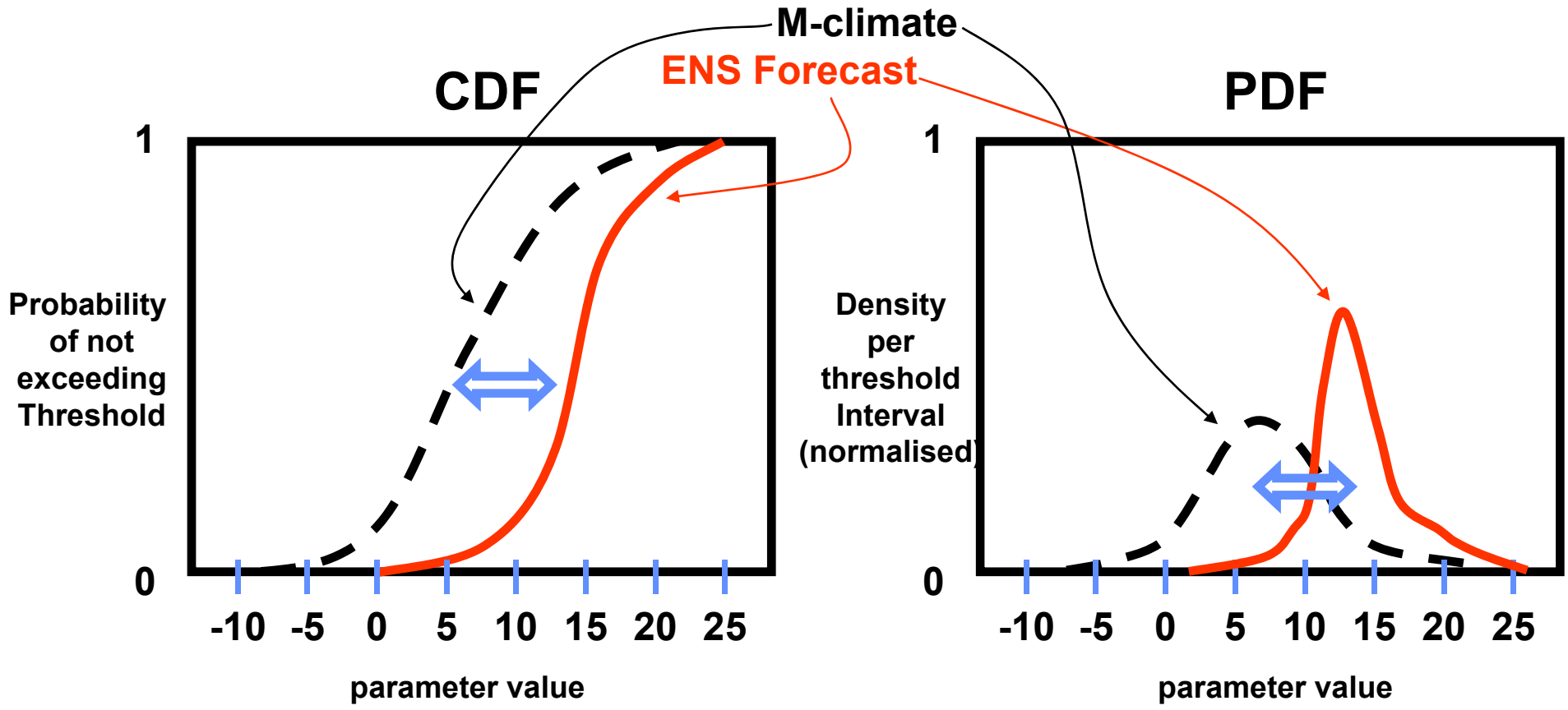
Extreme Forecast Index (EFI)

- EFI is defined on the basis of Cumulative Distribution Functions (CDF). The unusualness of the ensemble is assessed according to the relative positions and shapes of the distributions.



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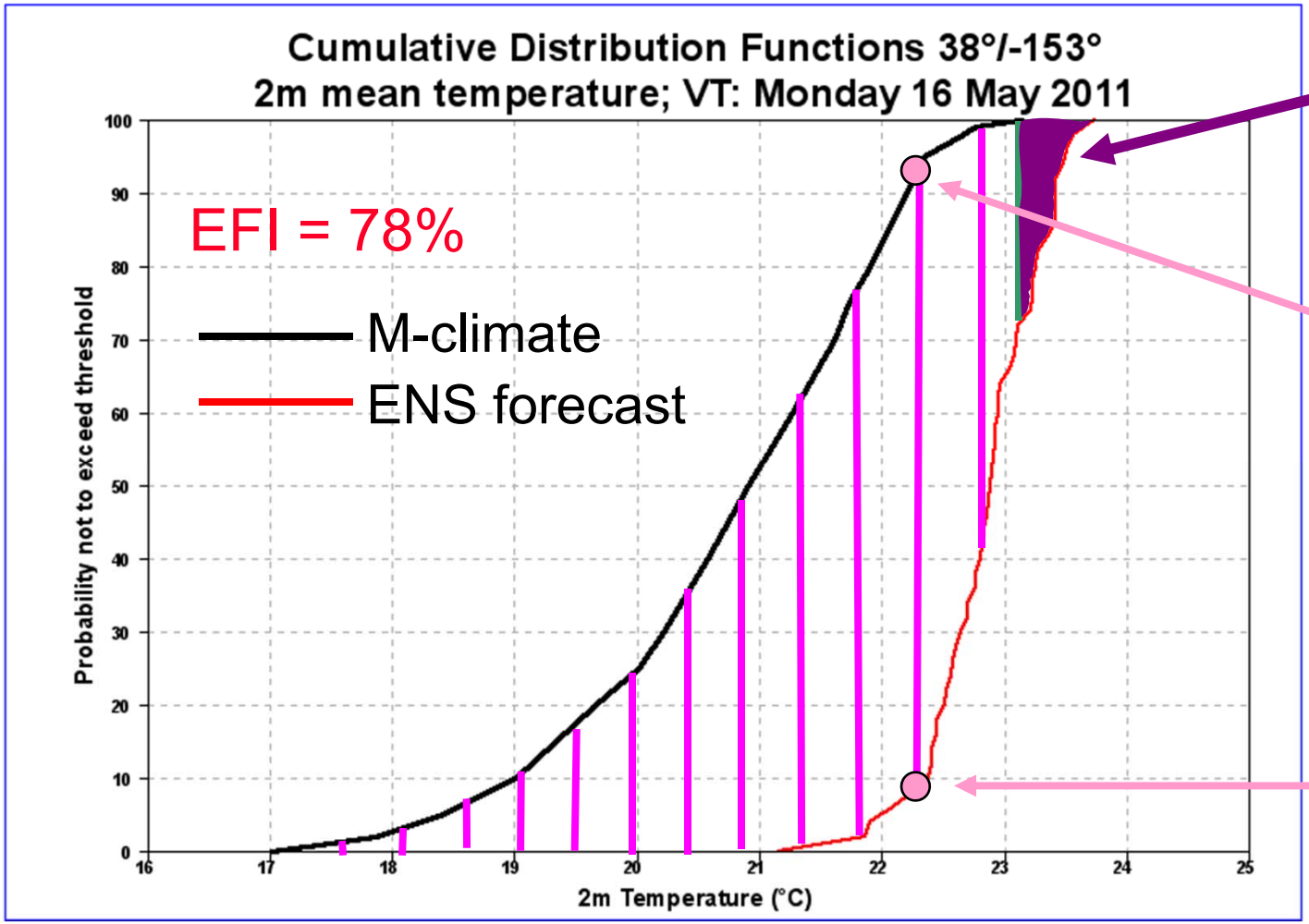
$$EFI = \frac{2}{\pi}\int_0^1 \left(\frac{p - F_f(p)}{\sqrt{p(1-p)}}\right) dp$$

Represented, approximately, by pink lines below..



EFI takes no direct account of any ENS members beyond the M-climate extremes

p

-1 ≤ EFI ≤ 1

-100% ≤ EFI ≤ 100%

$F_f(p)$

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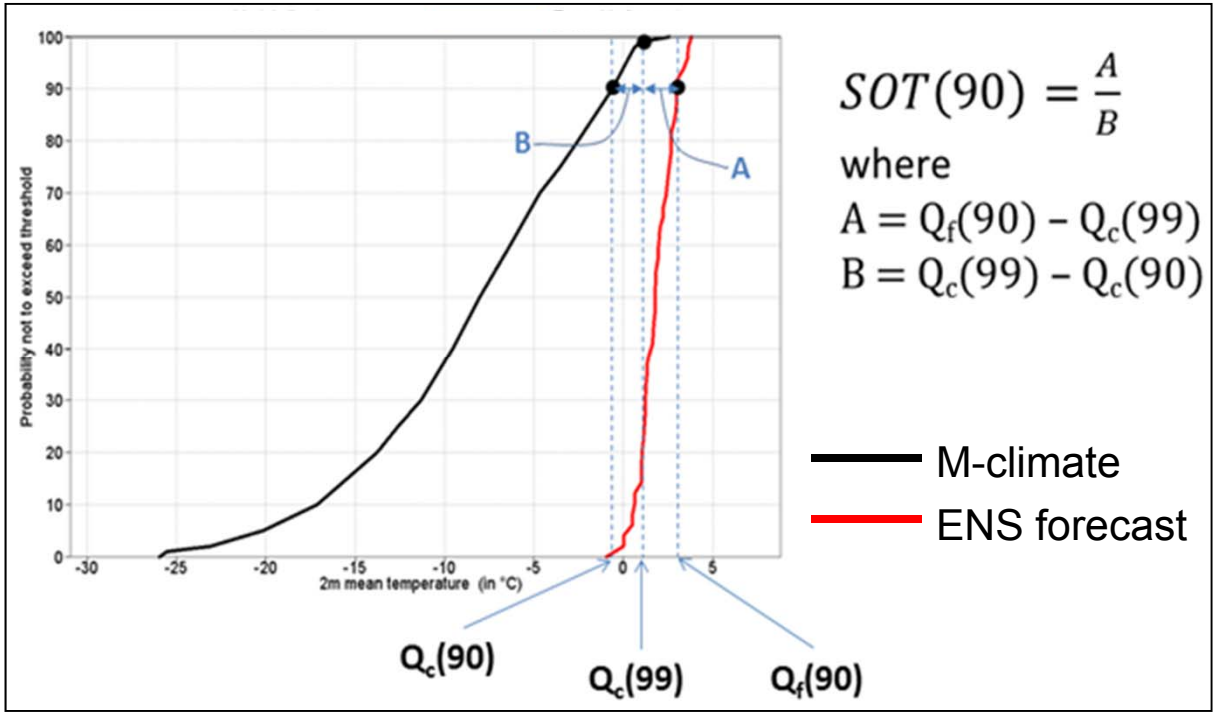
Shift of Tails (SOT)



$$SOT(90) = \frac{A}{B}$$

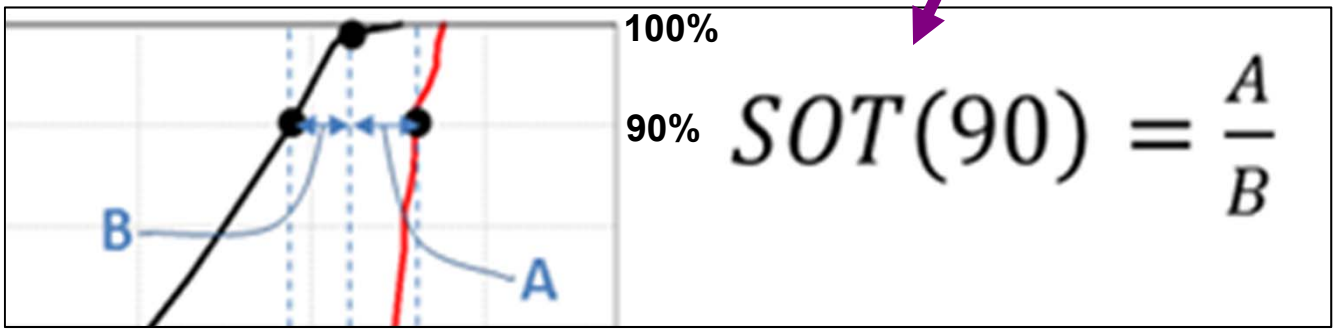
where

$A = Q_f(90) - Q_c(99)$

$B = Q_c(99) - Q_c(90)$

SOT is a measure that compliments the EFI, by defining how far above the M-Climate extreme the extreme members are

(note that SOT=0 is common)



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Limitations

- Clearly both EFI and SOT depend critically on the structure of the M-Climate
  - Throughout the range
  - But especially near the extremes
  - This can be a particular issue with 1-day rainfall and snowfall (which do not have a normal distribution)
- So we want a stable, reliable M-climate, especially near the extremes
  - i.e. percentiles should not change much with increasing lead time (unless there is genuine model drift, as in e.g. the tropics)
- Without this we would get jumpy EFI and SOT values, between consecutive ENS forecasts, even if those consecutive forecasts were no different!
- A Nov/Dec 2014 upgrade aims to improve M-Climate stability, and thus EFI and SOT reliability…

New developments!

A

- Currently the M-Climate comprises 500 realisations (20 years of re-runs * 5 dates * 5 ENS members)
- The Nov/Dec 2014 upgrade will have 1980 realisations (20 years * 11 dates * 9 ENS members)

B

- Lead times of products will be extended out to day 15 (currently they stop at day 10)
  - Yes there is evidence of some skill !

C

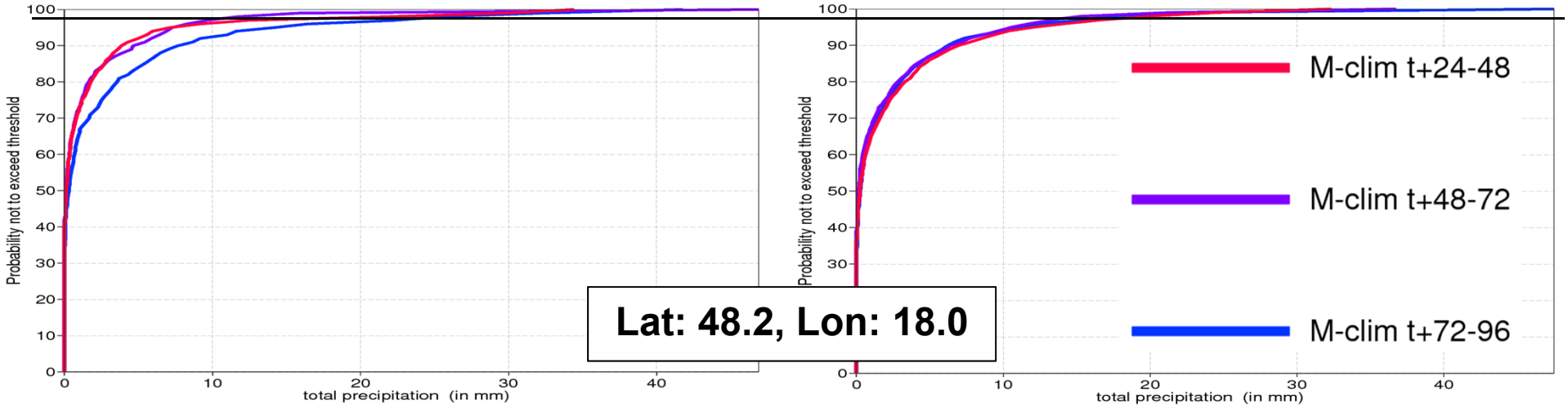
- New CAPE parameter will be made available
  - Aid for predicting extreme convection

A More realisations mean M-Climate stability will improve

Operational

24h PPN

New



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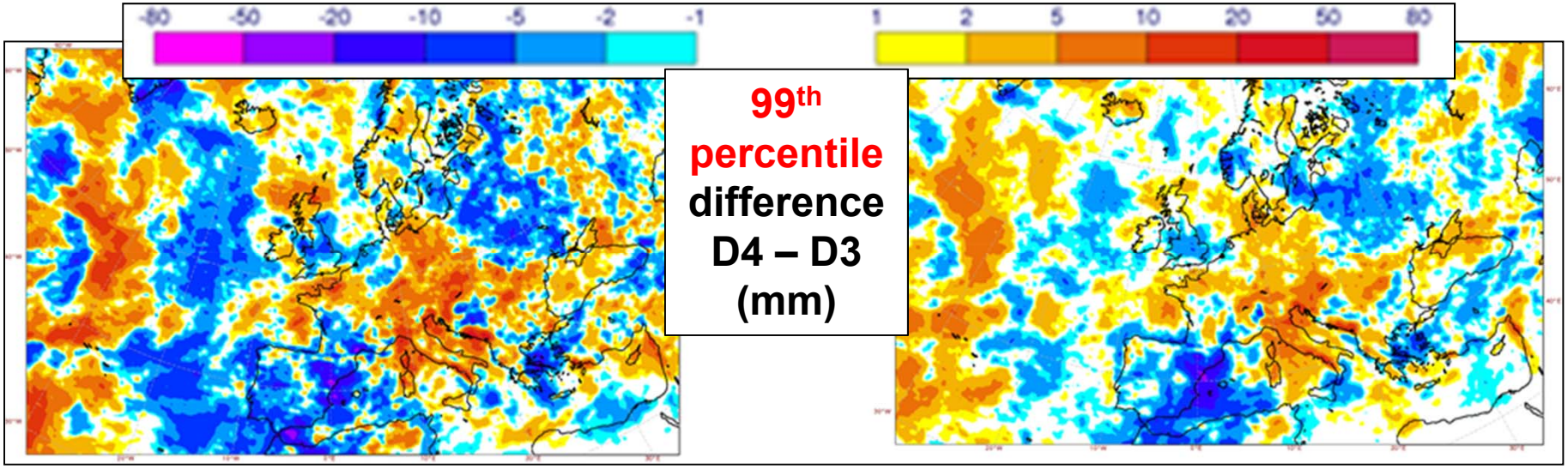

99th percentile difference D4 – D3 (mm)

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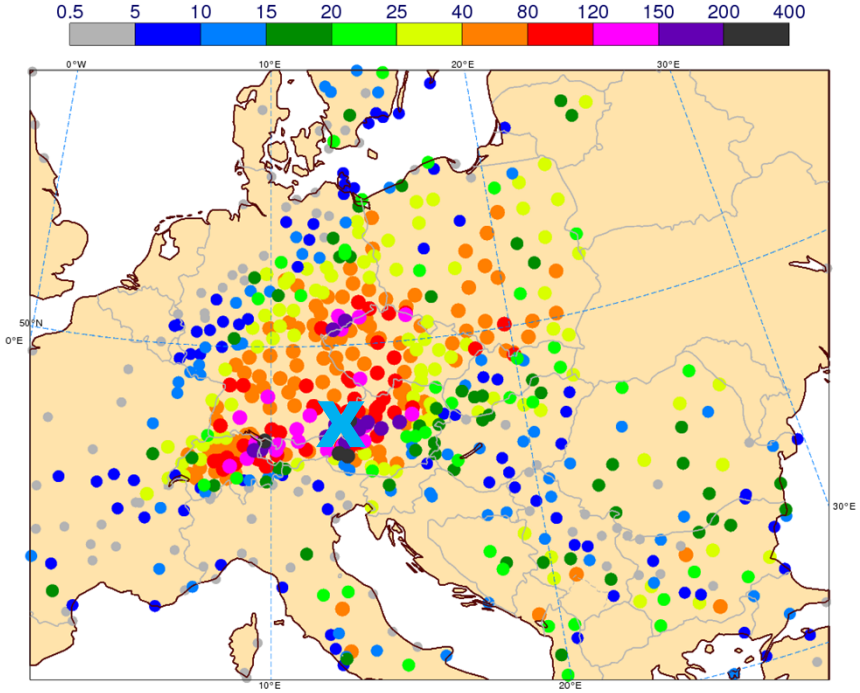
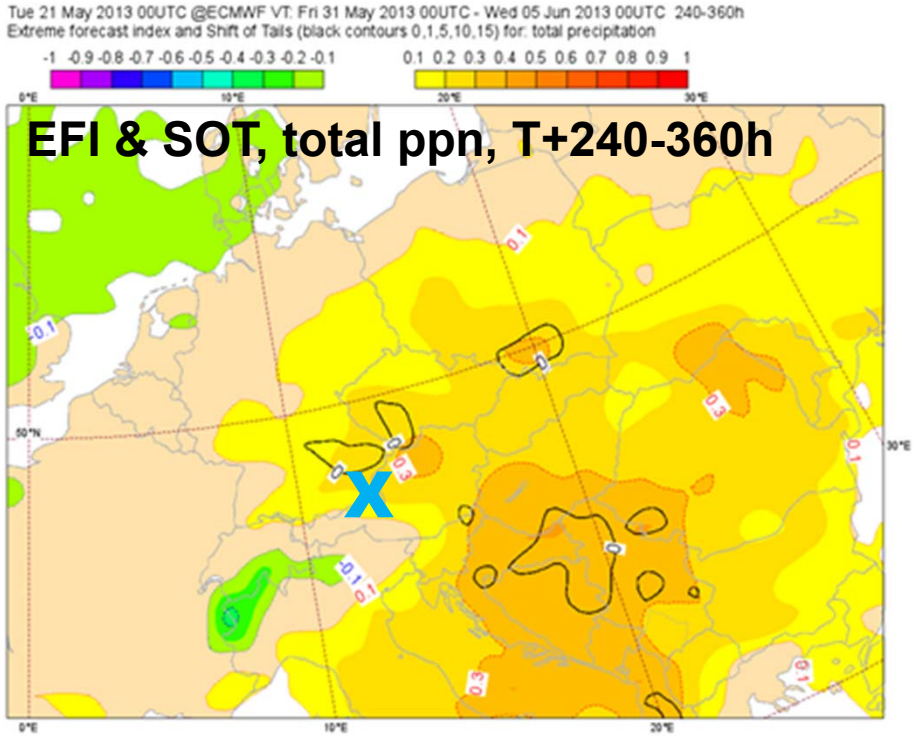
B

Longer lead times – eg EFI & SOT for total ppn, T+240-360h

Observed total rainfall
from 31/05/2013 00UTC to 05/06/2013 00UTC





- Several days of heavy rain led to severe flooding in Central Europe at the end of May and beginning of June 2013.
- An early signal of extreme precipitation appeared in the EFI and SOT forecast for T+240-360 lead time.

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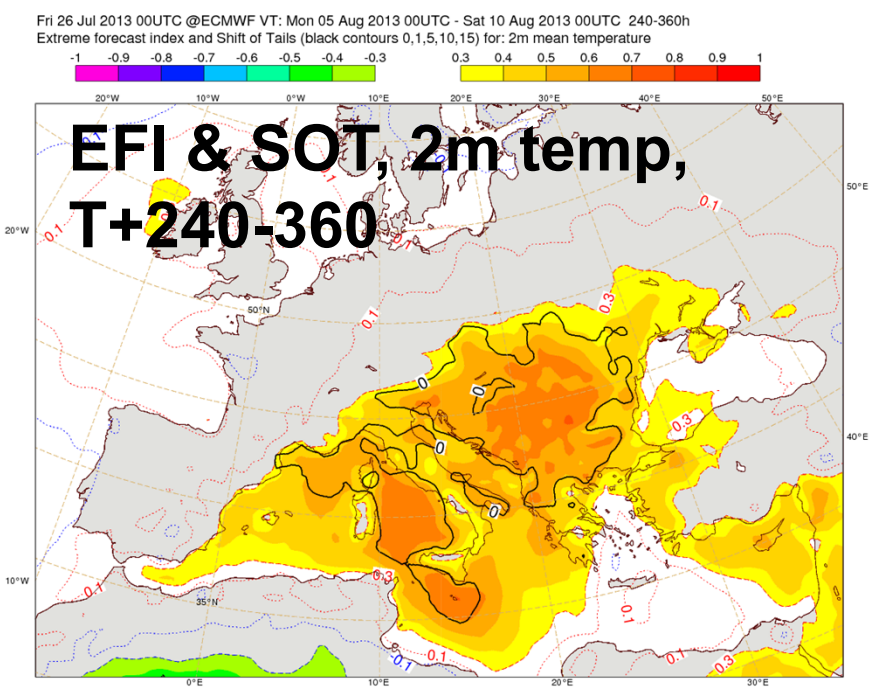
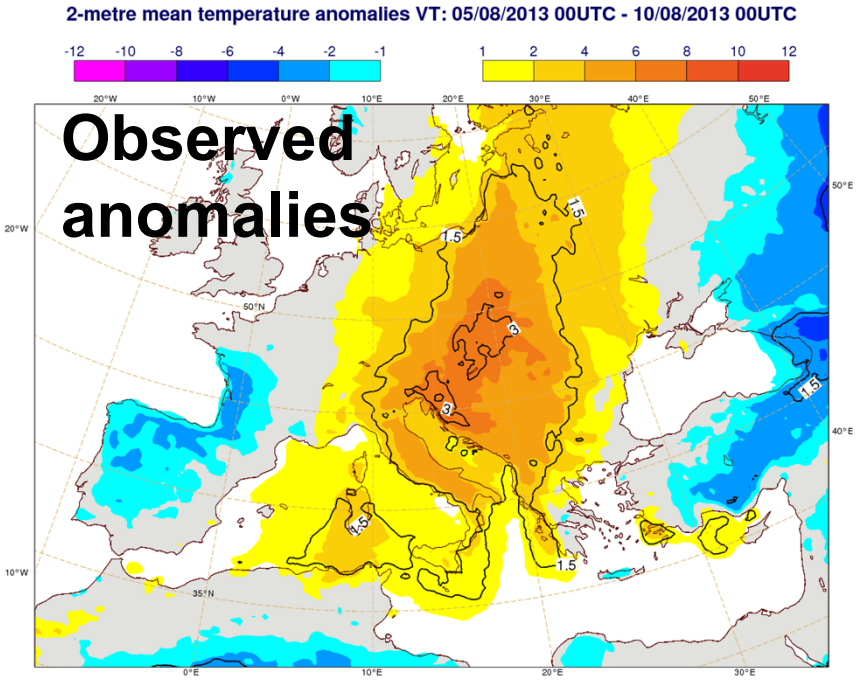
EFI & SOT for temperature, T+240-360h





- A heatwave affected many countries from the Mediterranean northwards to Scandinavia in early August 2013. Austria set a new high temperature record when temperatures in two locations in eastern Austria exceeded 40°C on 8th August.
- EFI gave an early signal of the likelihood of exceptionally hot weather .

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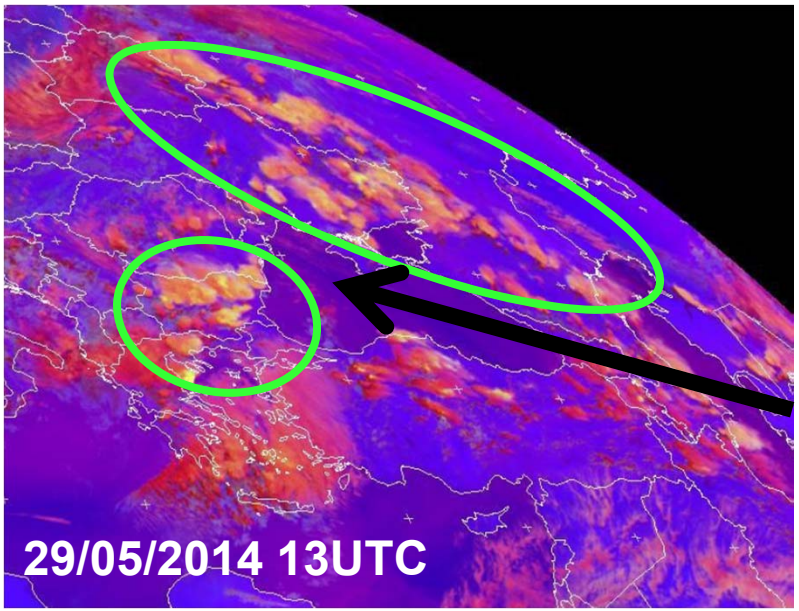
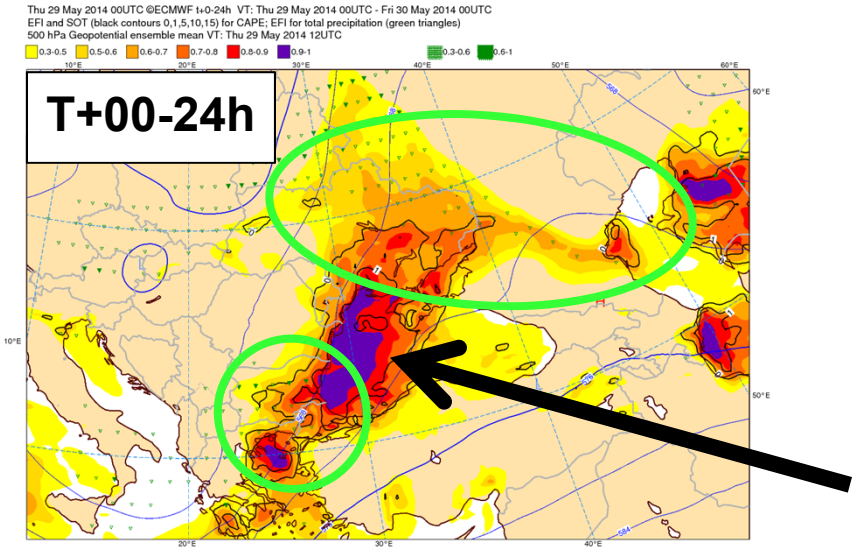
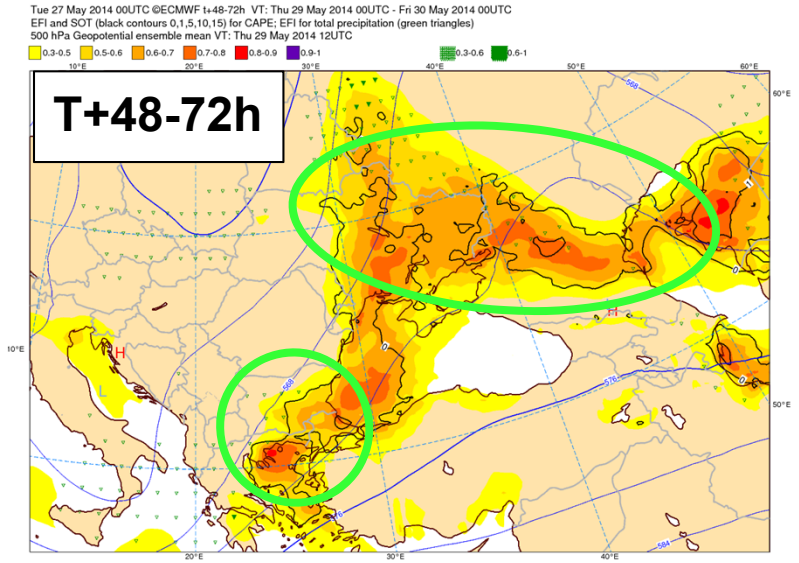
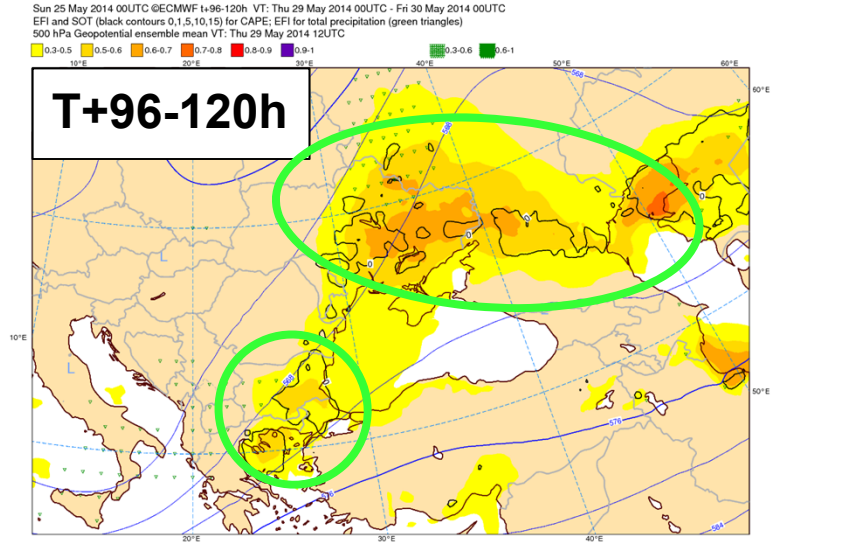
C Severe convection, 29/05/2014, CAPE EFI/SOT









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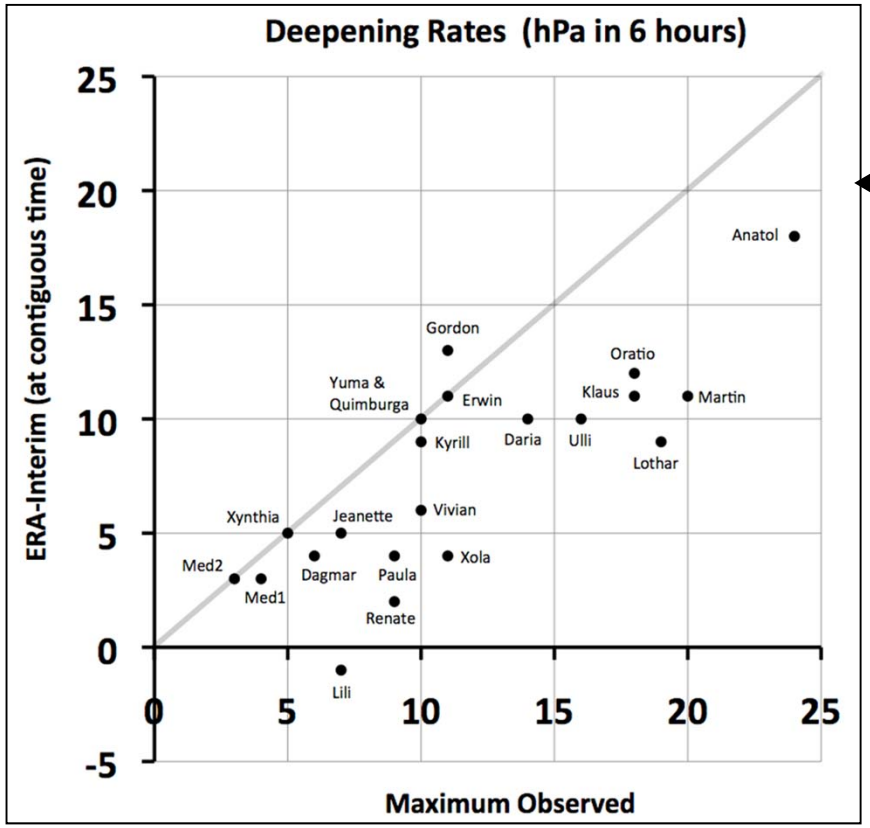
Longer term plans..

- More M-Climate realisations (e.g. daily, 30 years) ?
- Return period products ?
- Improve the initialisation of Hindcasts (for the M-Climate), currently there are incompatibilities:
  - *Resolution*: Currently use ERA-Interim @ 80km resolution. ENS runs at 32km, to become 20km next year.
  - *Model version*: ERA-Interim is also an old model version – 2006
  - *Surface schemes*: differ - affects e.g. soil moisture, snow cover, ..
- 'ERA-next' will have:
  - 40km resolution (or better)
  - New model version (last model version this year, or better)
  - Compatible surface schemes

Another Era-Interim issue…

- **Resolution limits the representation of cyclonic windstorms - too weak, the net result is hindcast spin-up issues on day 1 (again affecting the M-Climate)…**



Maximum deepening rates for major European windstorms underestimated in ERA-Interim

So the upgrade to 'ERA-Next' will also improve the integrity of the hindcasts, for cyclones and related weather, at short lead times

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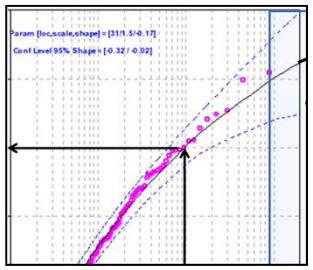
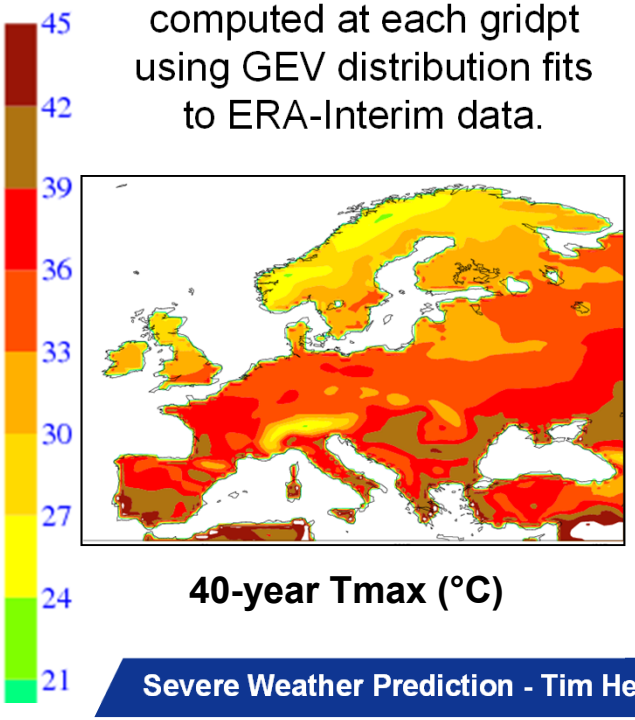
Return Periods: Example - Summer 2003 European heat wave VT: 12th Aug 2003 (Probability of RETurn value)

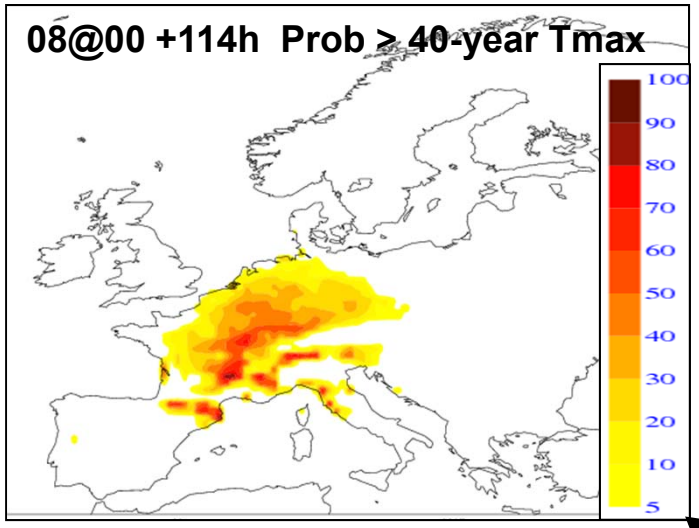


Return period thresholds computed at each gridpt using GEV distribution fits to ERA-Interim data.

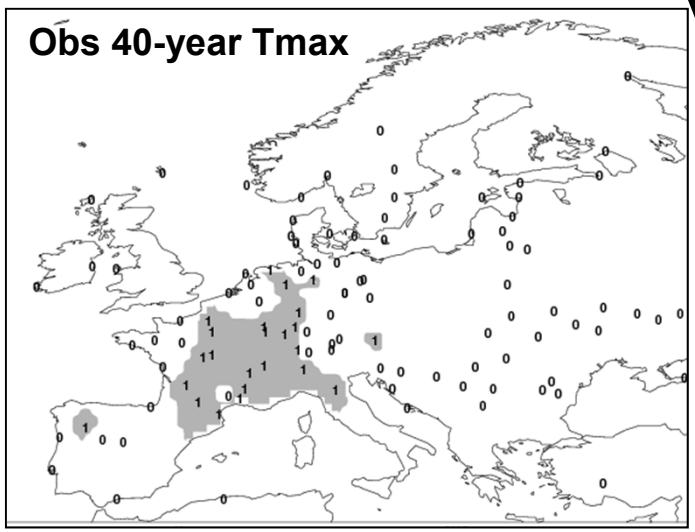


40-year Tmax (°C)

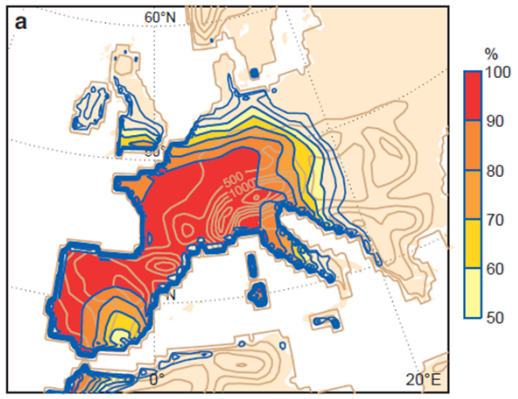
08@00 +114h Prob > 40-year Tmax



Obs 40-year Tmax



EFI 2m temp D+5



EFI saturates

Prob forecasts based on number of ENS members that exceed the N-year return period threshold.

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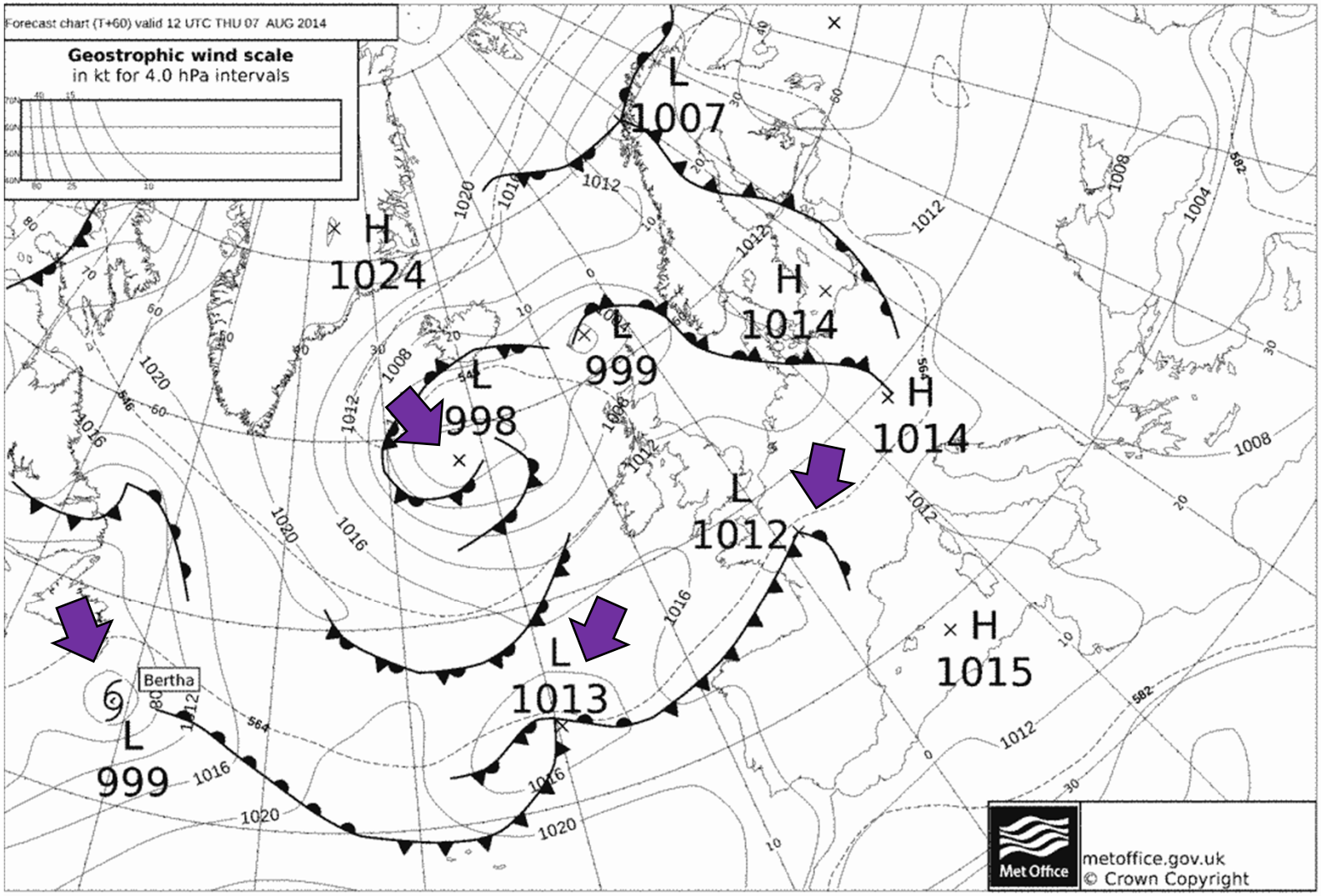
2. Tailored Output – Fronts / Cyclones

Synoptic Charts – a key tool in forecasting



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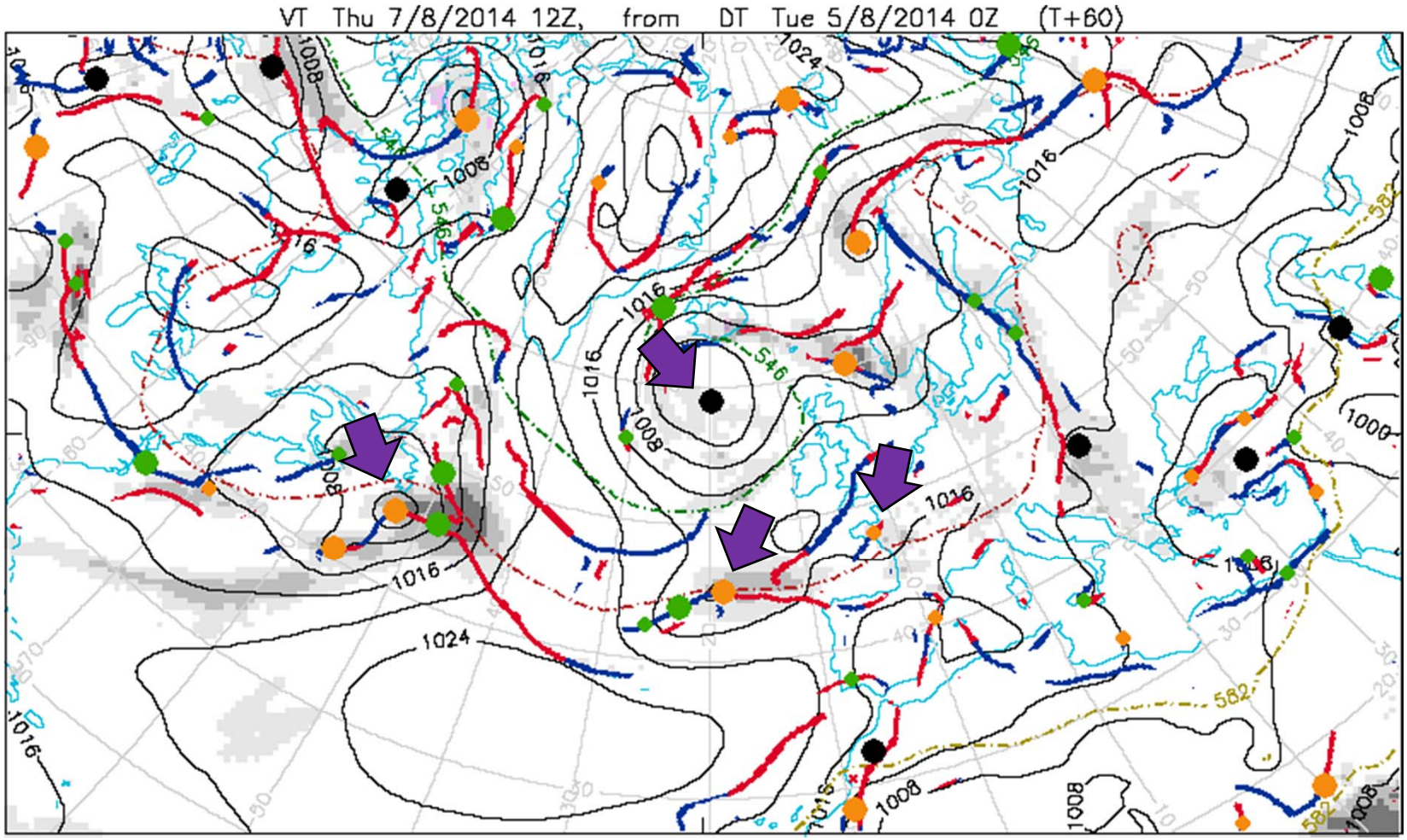
Mathematical/graphical algorithms have been devised to identify cyclonic centres and fronts automatically:



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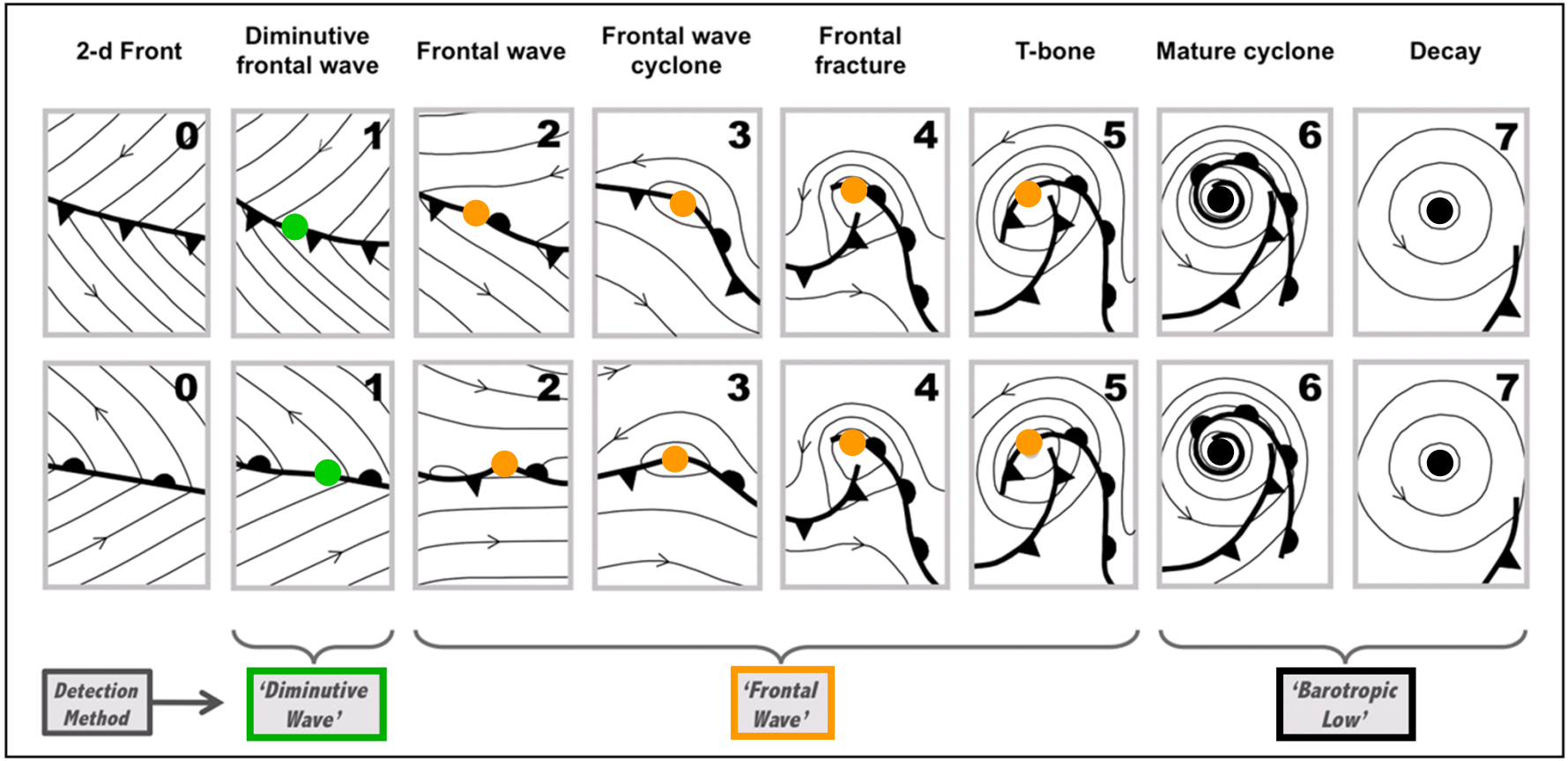
- **Identification methods are broadly based around this conceptual model of extra-tropical cyclone development (but are not constrained by it)**
- **Tracking is also performed to 'join the dots' between successive times**



After Shapiro and Keyser (1990) and Hewson and Titley (2010)

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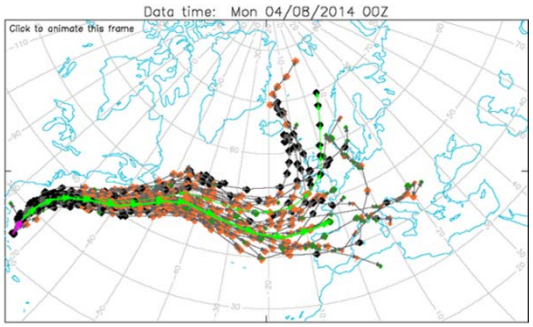
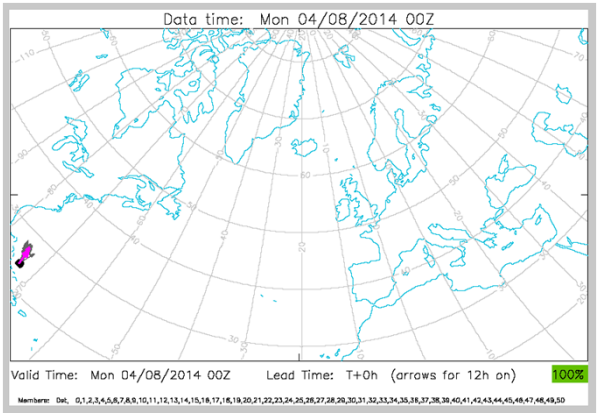
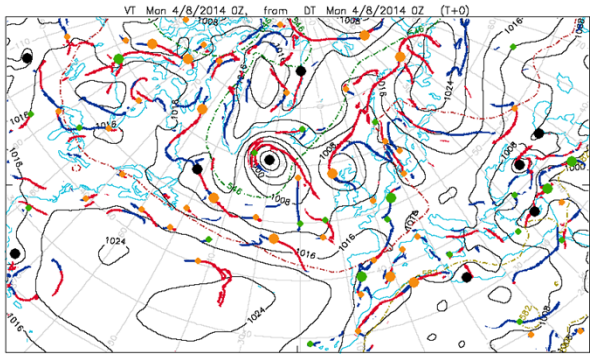
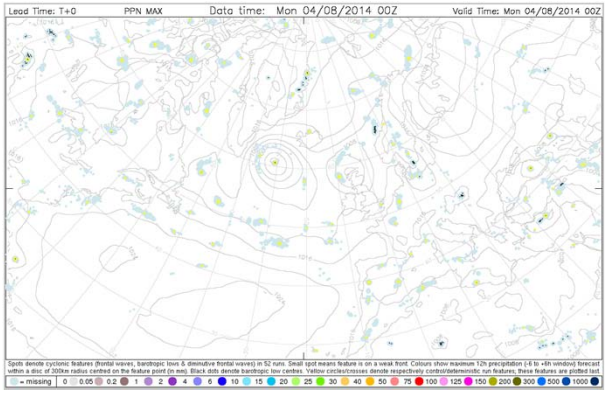
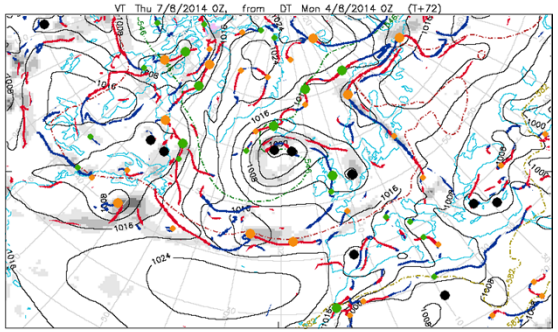
Algorithms are applied to HRES and ENS output, to provide many forecaster-oriented products in real time, with a severe weather focus

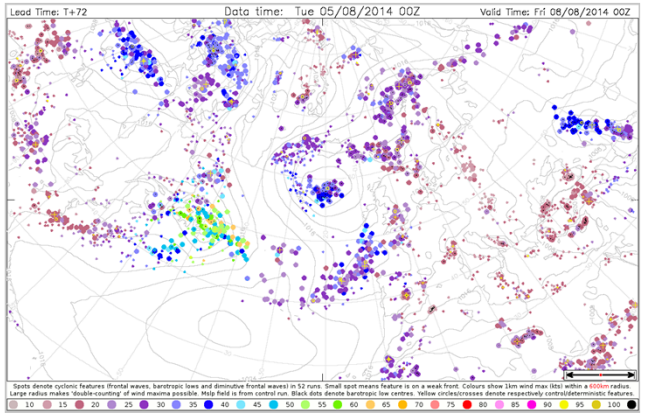


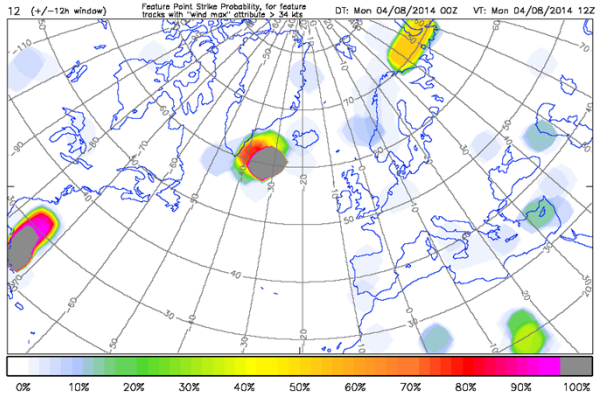


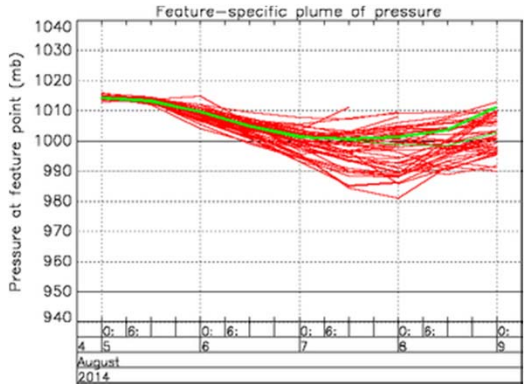


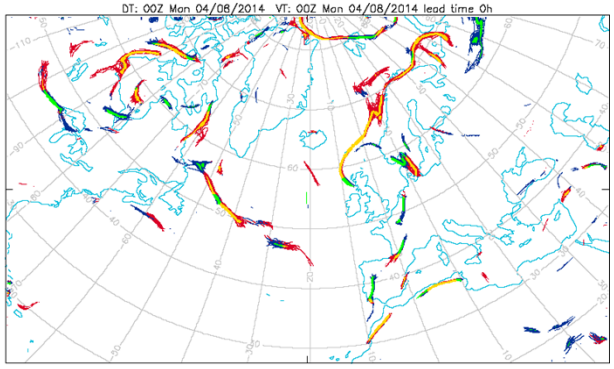






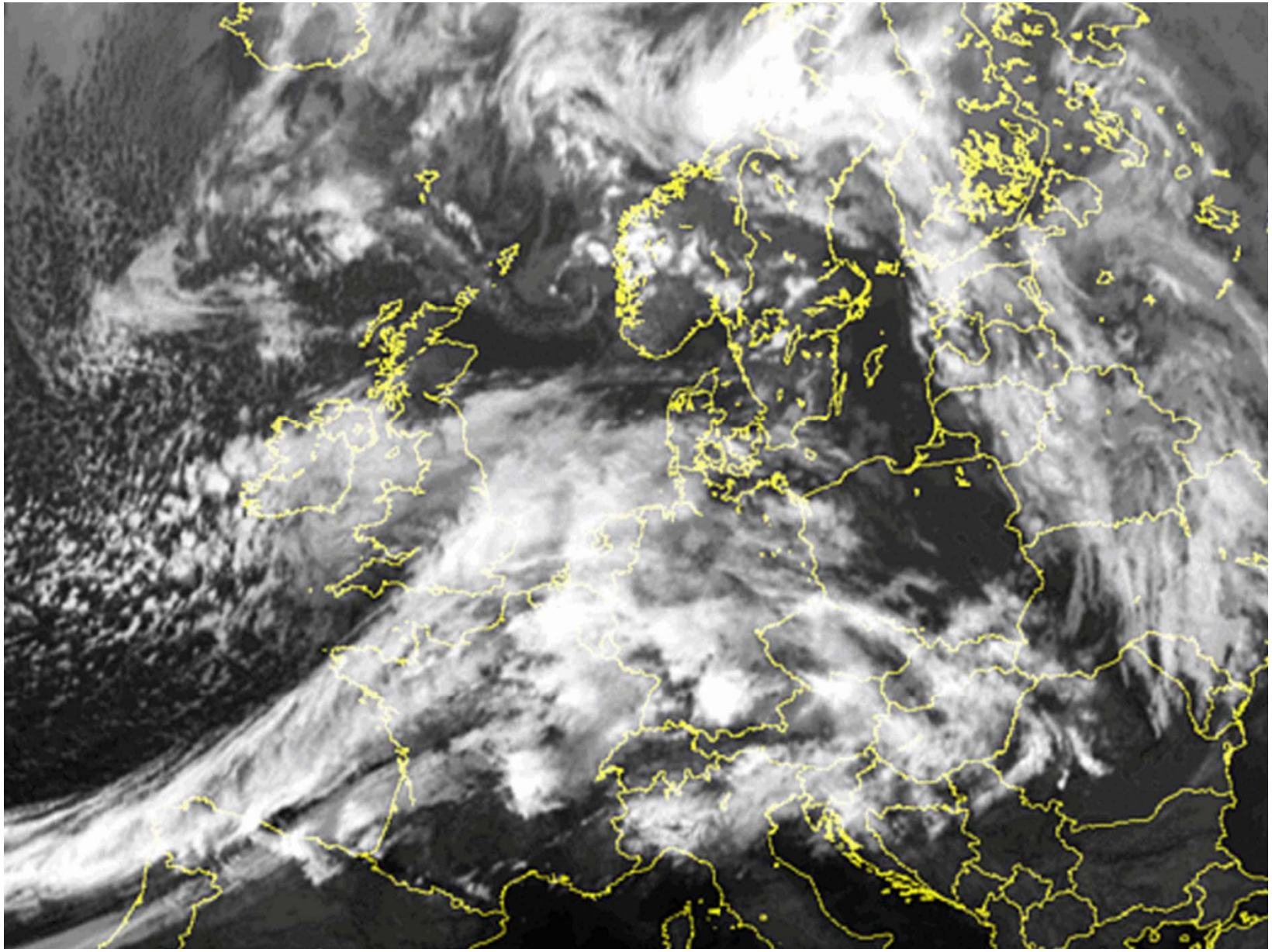






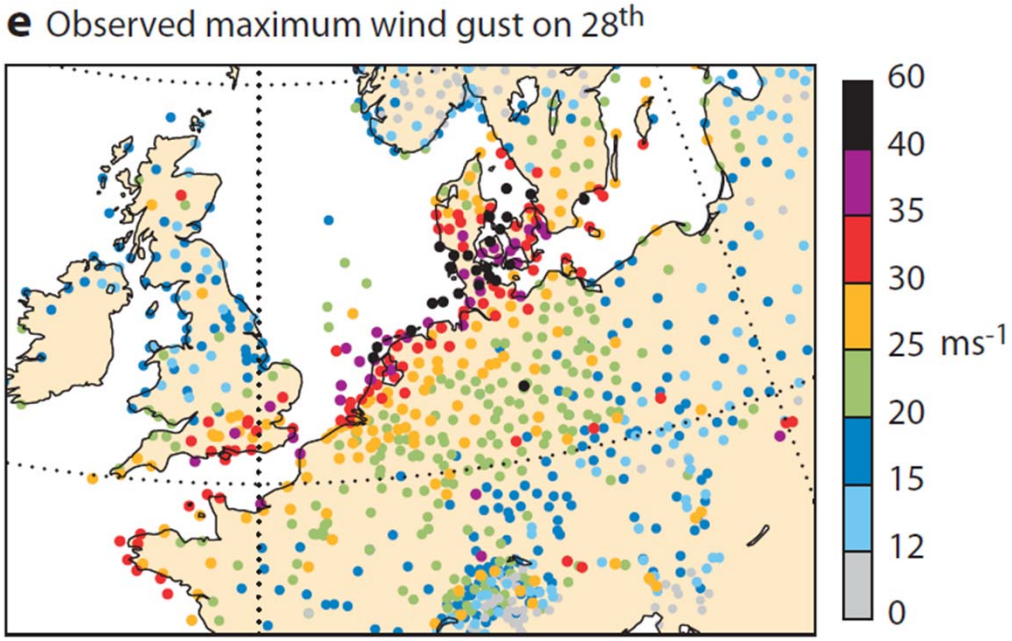
ECMWF

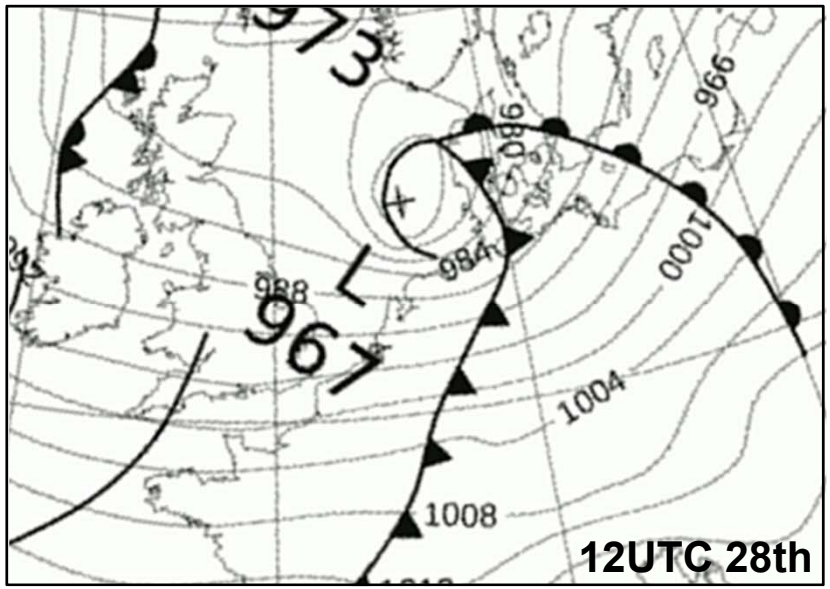
Example: Windstorm ‘Christian’, 28 Oct 2013



Example: Windstorm ‘Christian’, 28 Oct 2013

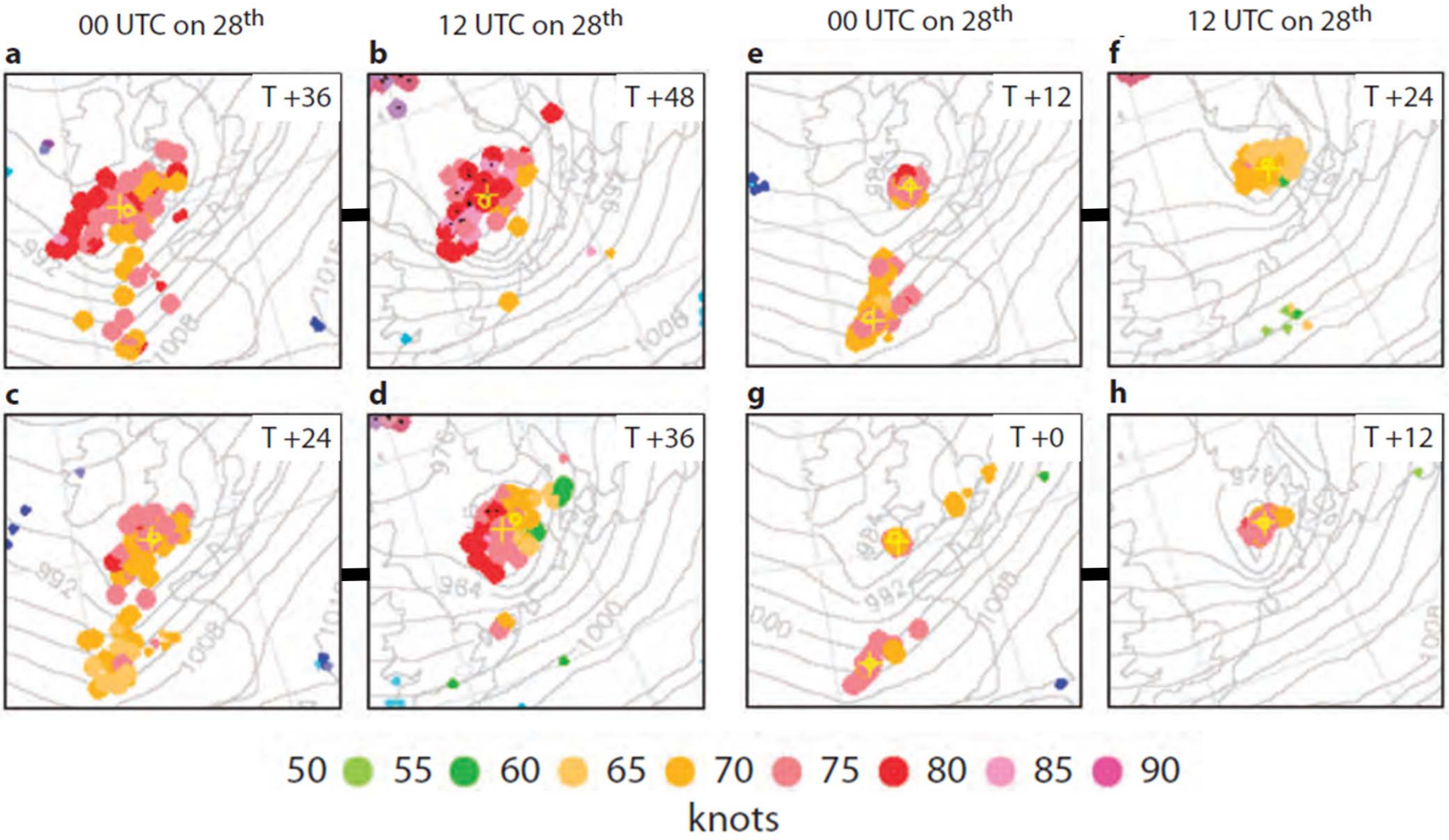
From Hewson et al (2014)





Caused the strongest gust ever recorded in Denmark (53m/s)

ECMWF ‘Dalmatian charts’, showing cyclonic centre forecasts from 4 data times. Colours show maximum wind associated, at 1km altitude.

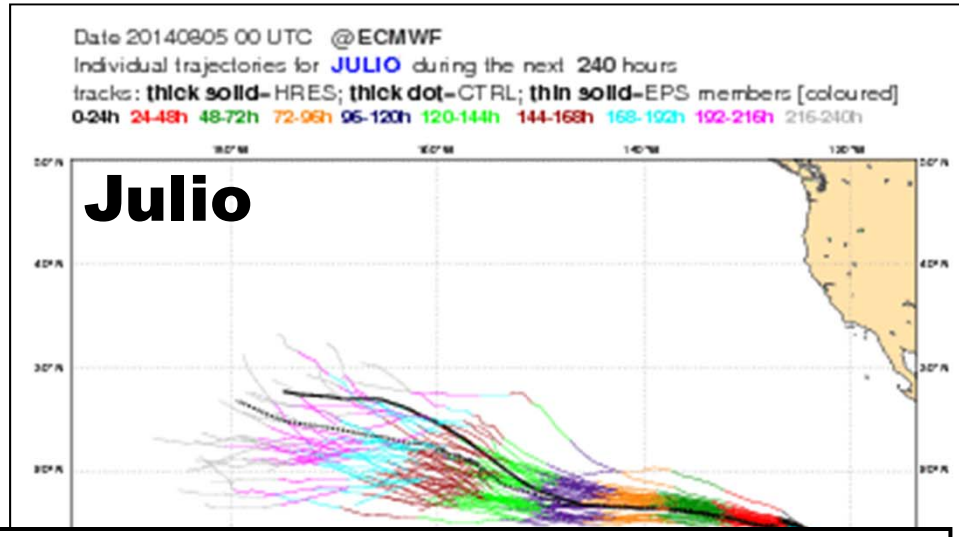


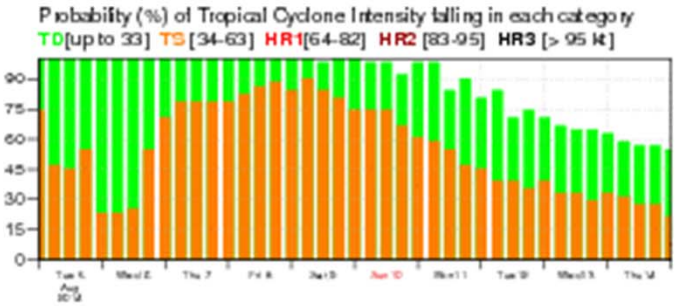
ECMWF

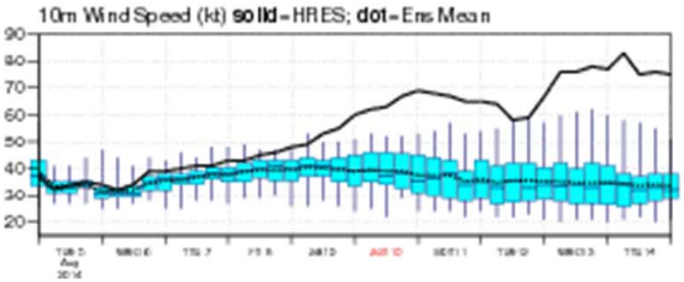
Benefits for the forecaster

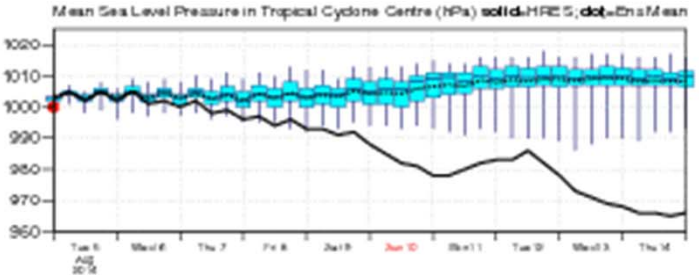
- Provides a very compact view of massive amounts of information (here 52 runs), using the ‘synoptic language’ of forecasters
- Depicts the salient points from a severe weather perspective
- Instantly the forecaster can uncover the full range of possible outcomes, and then delve deeper if need be…

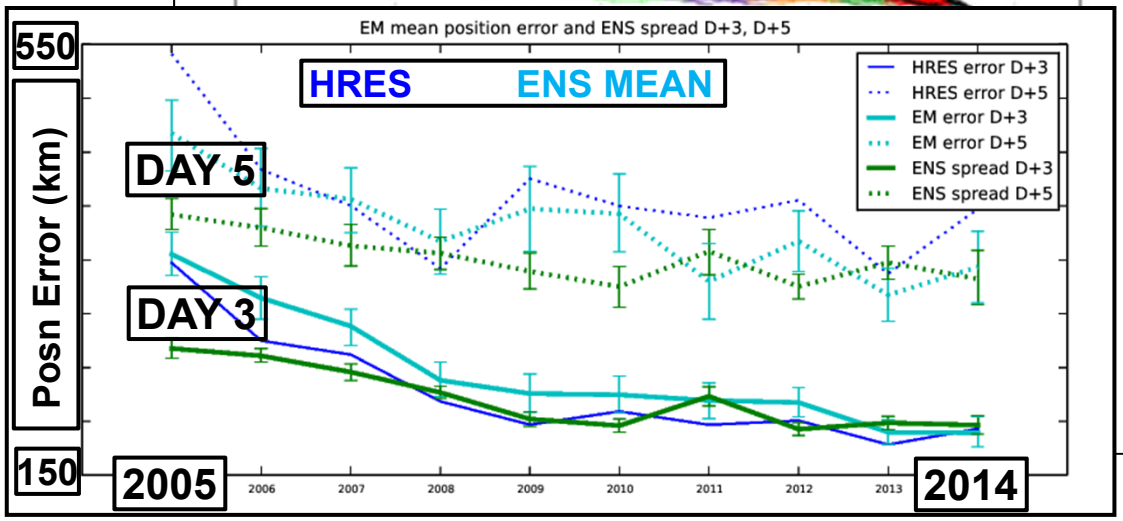
Tropical Cyclones







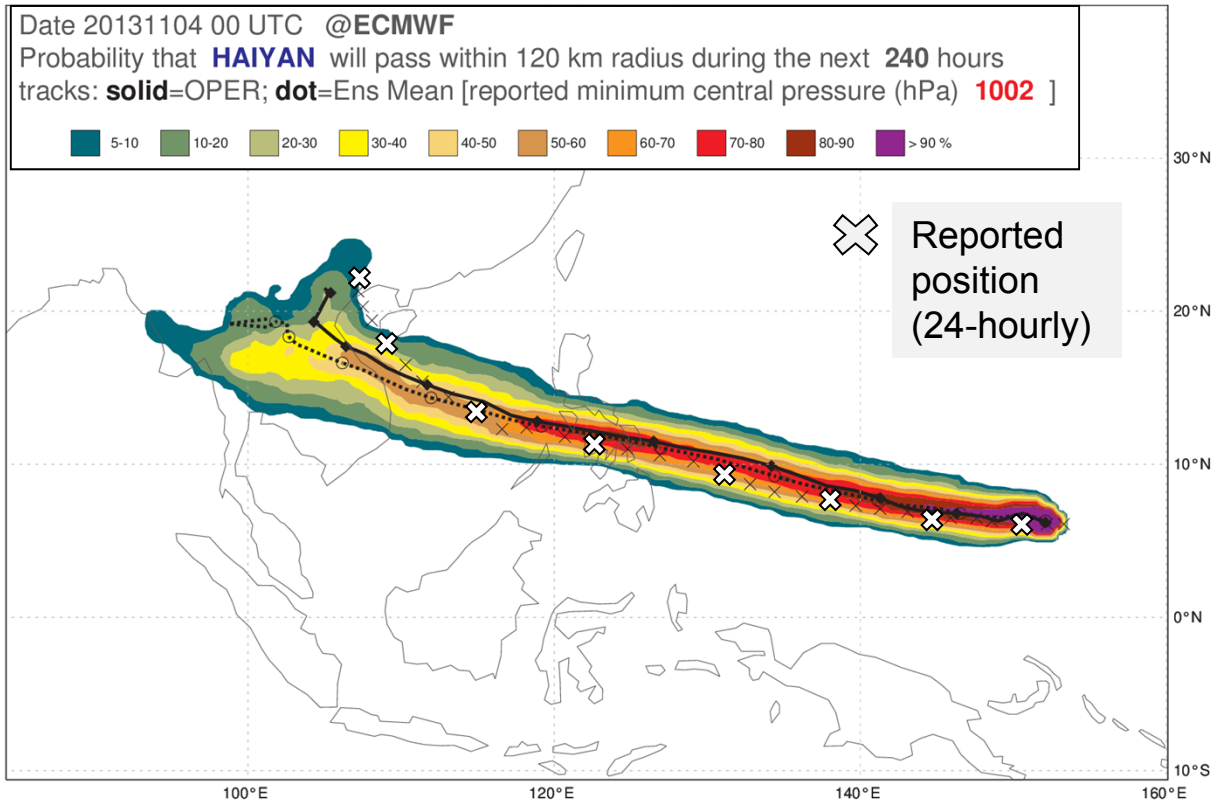




- Cyclone-specific products upgraded in Dec 2013 to span 10 days

ECMWF

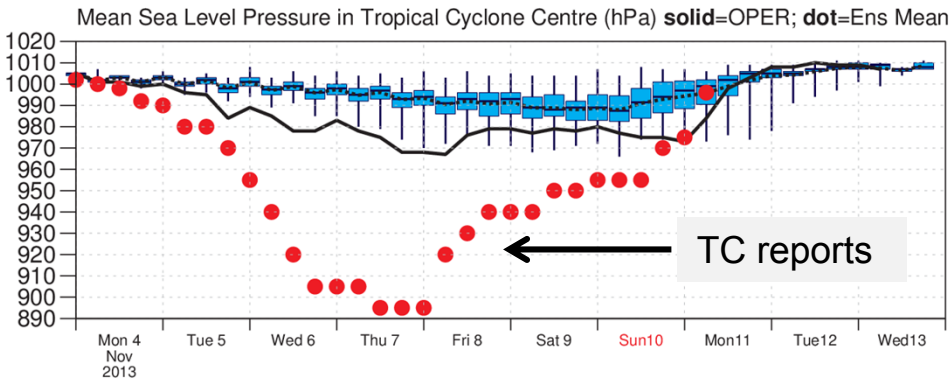
SUPER-TYPHOON HAIYAN, NOVEMBER 2013



A new tracking algorithm for tropical cyclones was implemented on 1st December 2013.

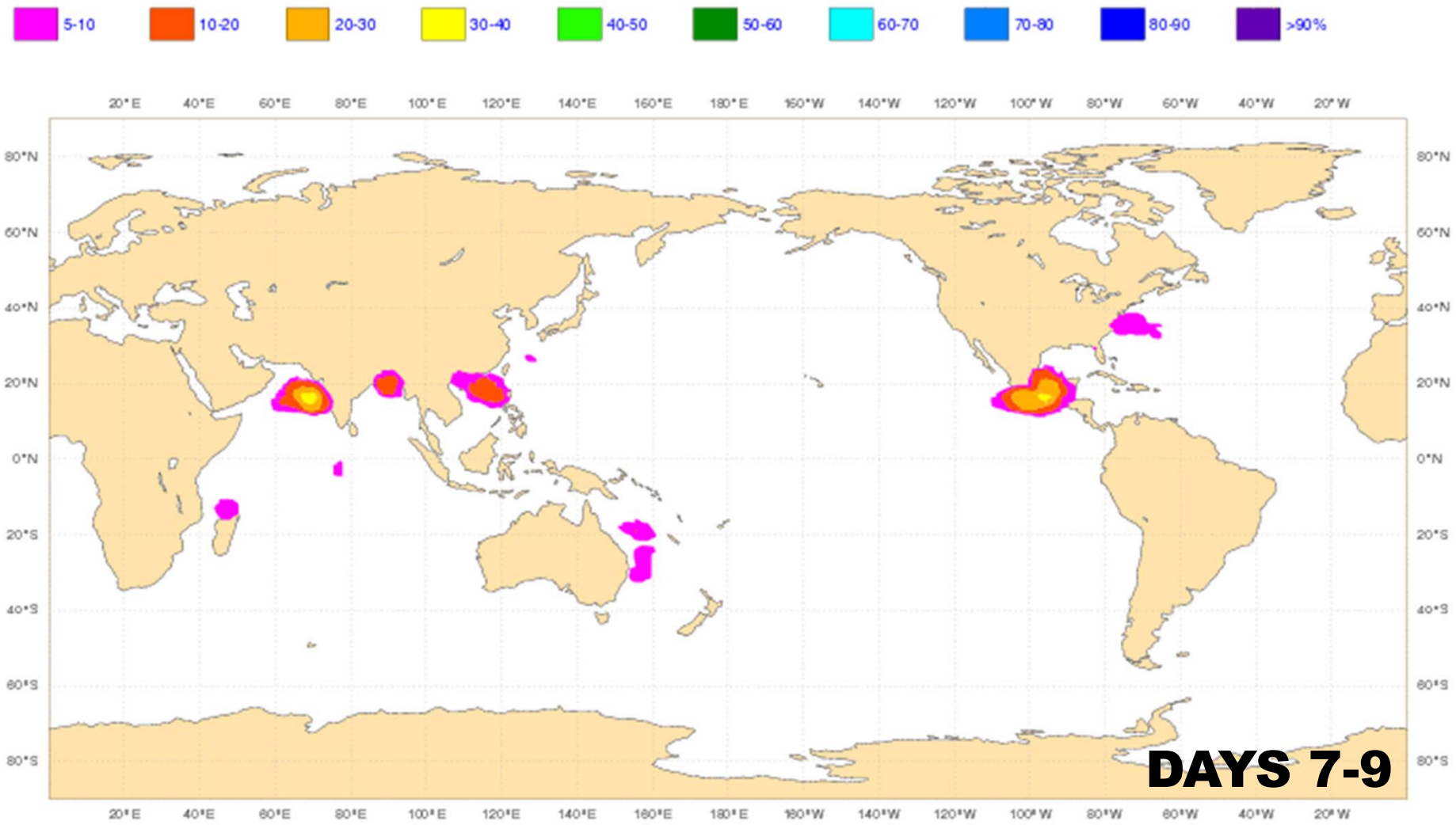
The new TC tracks are produced for forecasts up to 240 hours (previously to 120 hours), or until the tropical cyclone dissipates if earlier.

The tracker software is also now applied to forecast output every 6 hours (previously it was every 12h)



ECMWF

Tropical Cyclone Strike Probability Start date:Monday 02 June 2014 at 00 UTC
valid for 48hours from Monday 09 June 2014 at 00 UTC to Wednesday 11 June 2014 at 00 UTC
Probability of a Tropical Cyclone passing within 300km radius



ECMWF

3. Targeted model improvements

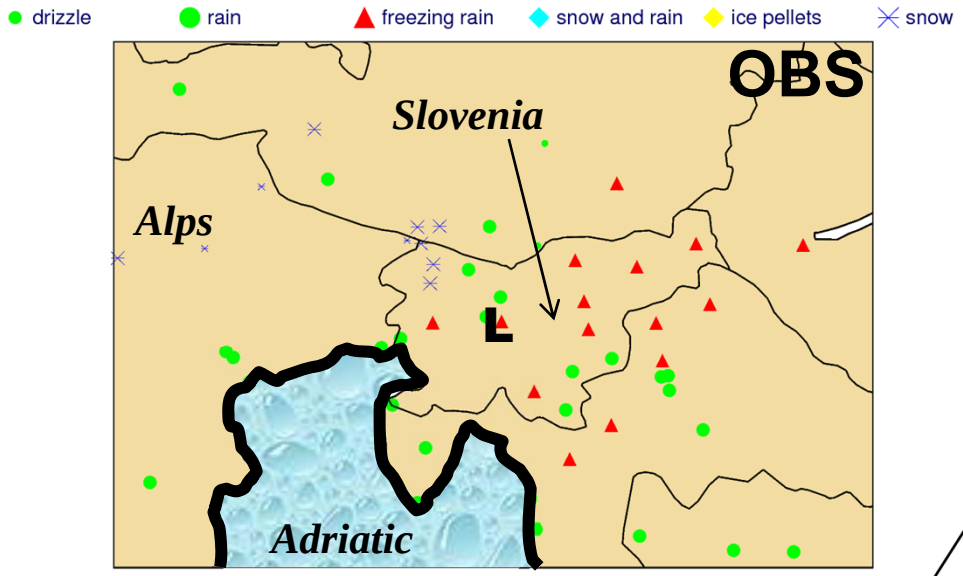
New Initiatives to predict Freezing Rain…

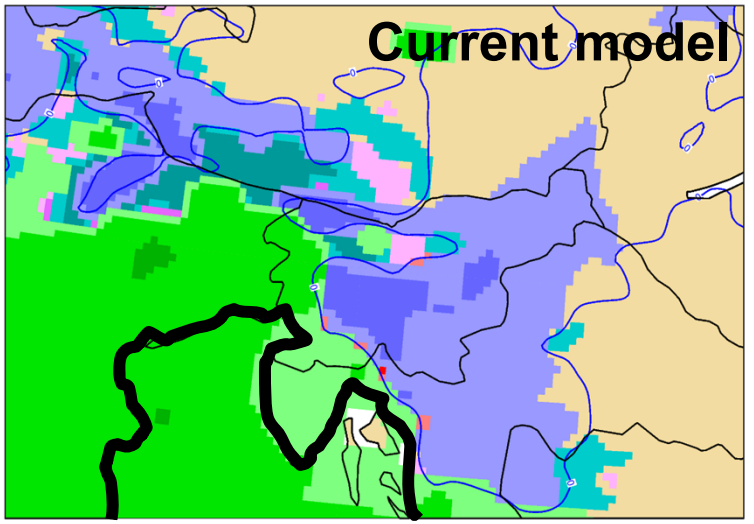
In Slovenia

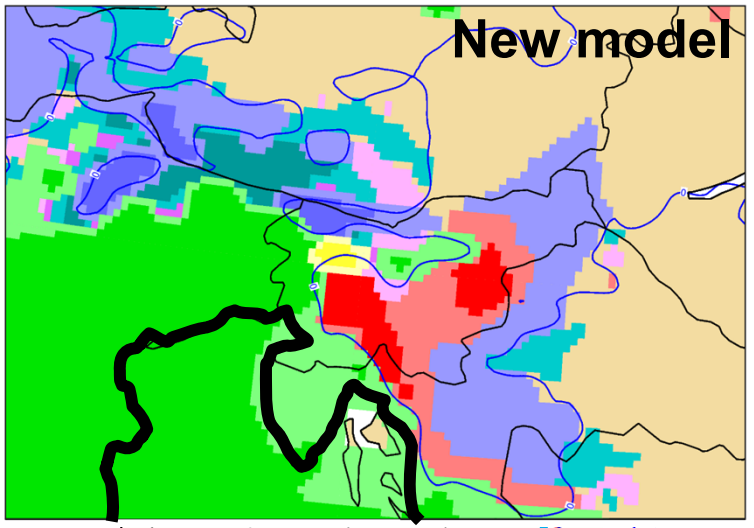
- An ice storm hit at the beginning of February 2014
- More than 40% of Alpine forests were damaged
- One in four homes left without electricity.

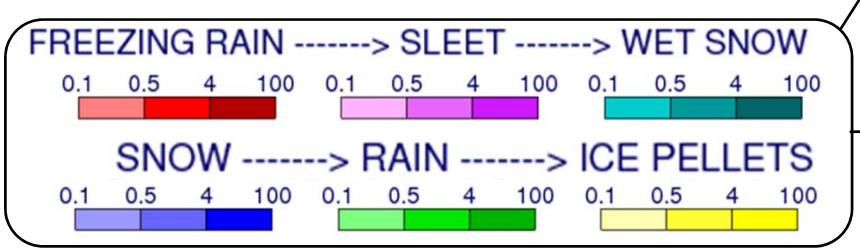
ECMWF

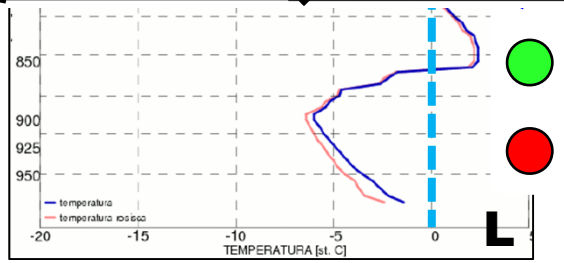
2nd Feb 2014 12UTC









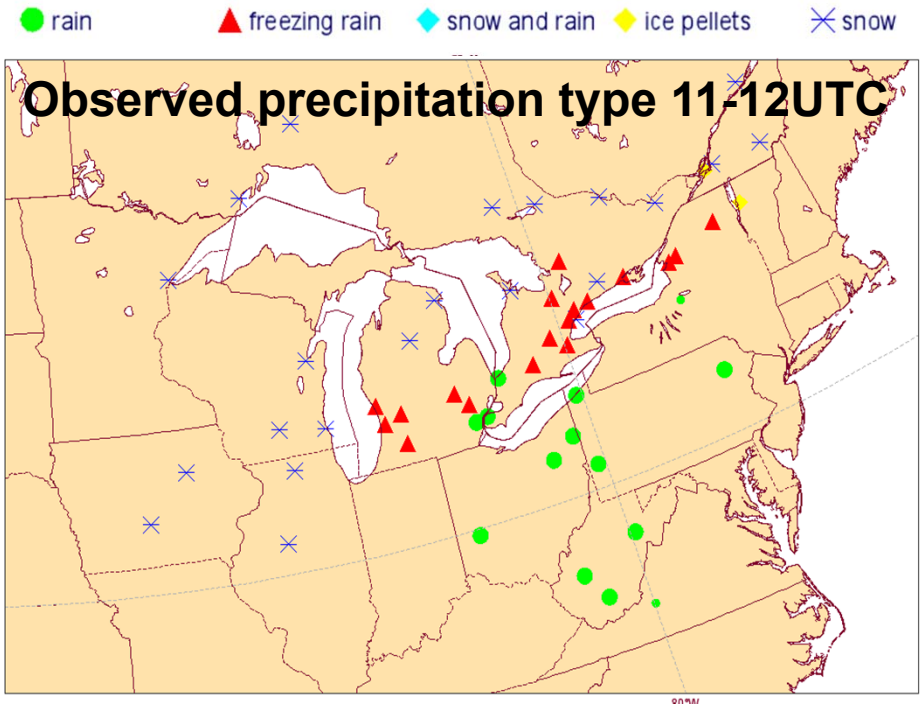


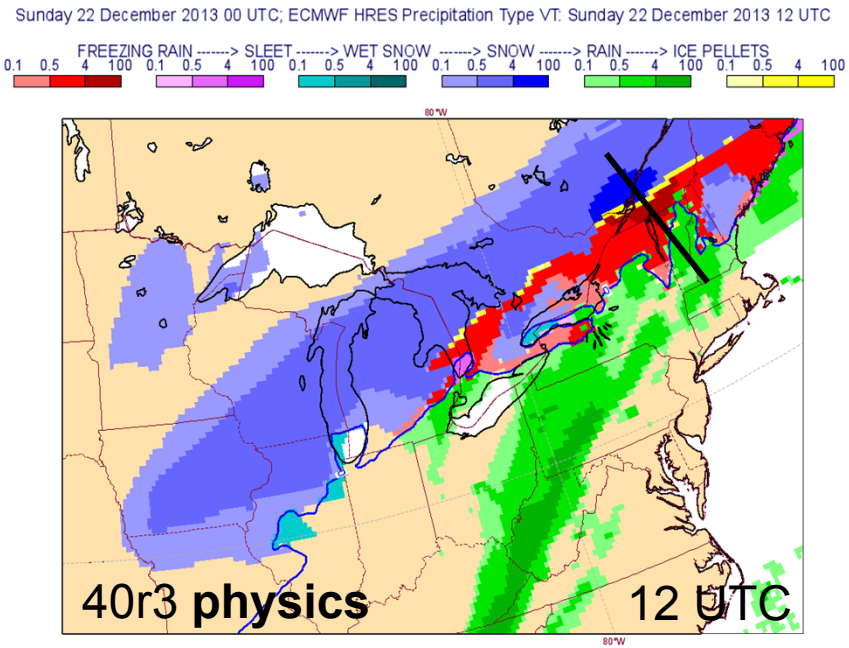
Two new ECMWF developments:

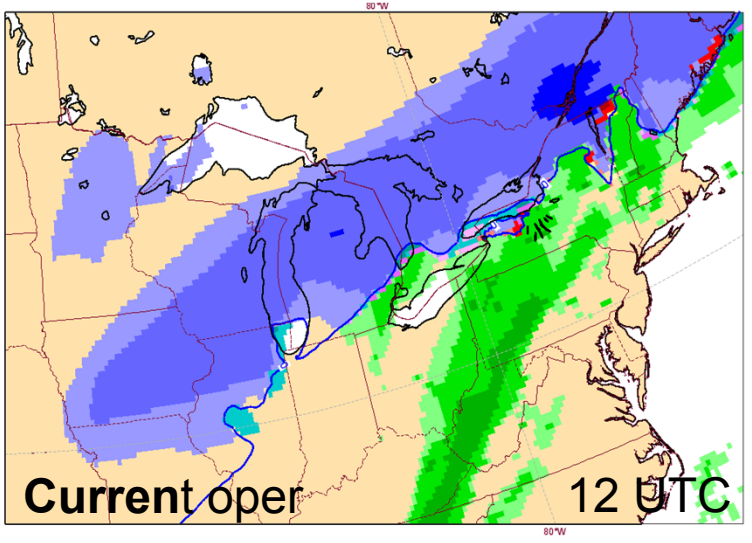
- **Precip type/rate diagnosis/diagnostics**
- **<u>Model physics changes</u> to markedly slow down the re-freezing of melted precipitation**

ECMWF

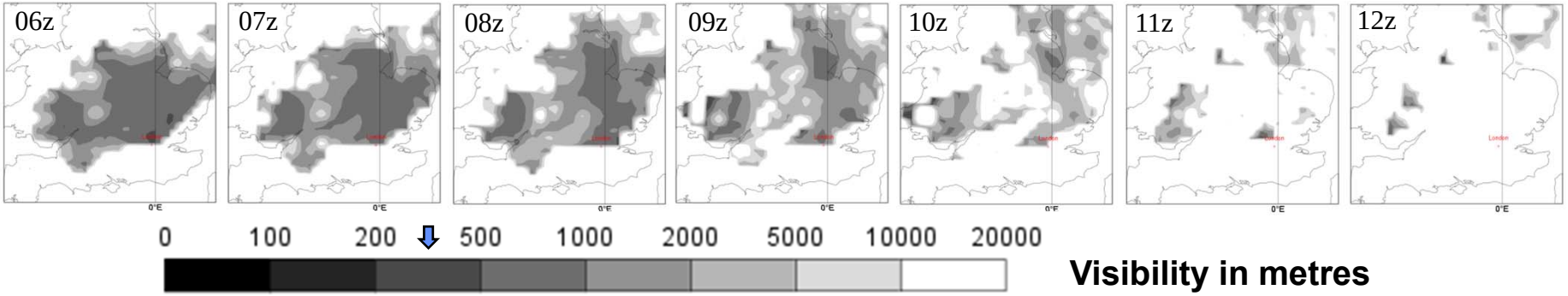
Prediction of Severe Weather: Freezing Rain
Case study: Toronto 22 Dec 2013



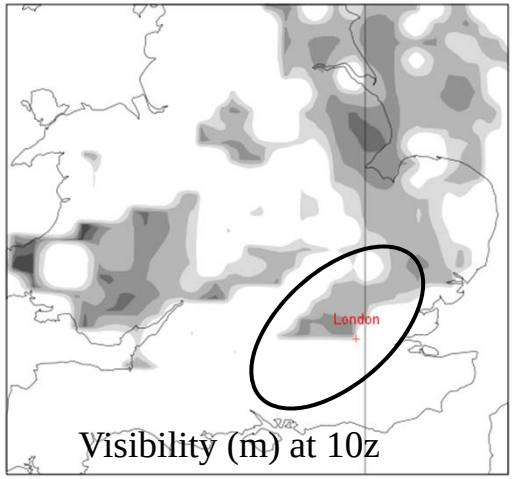




Visibility/Fog - Case study: UK 11 Dec 2013, HRES 12 hour forecast



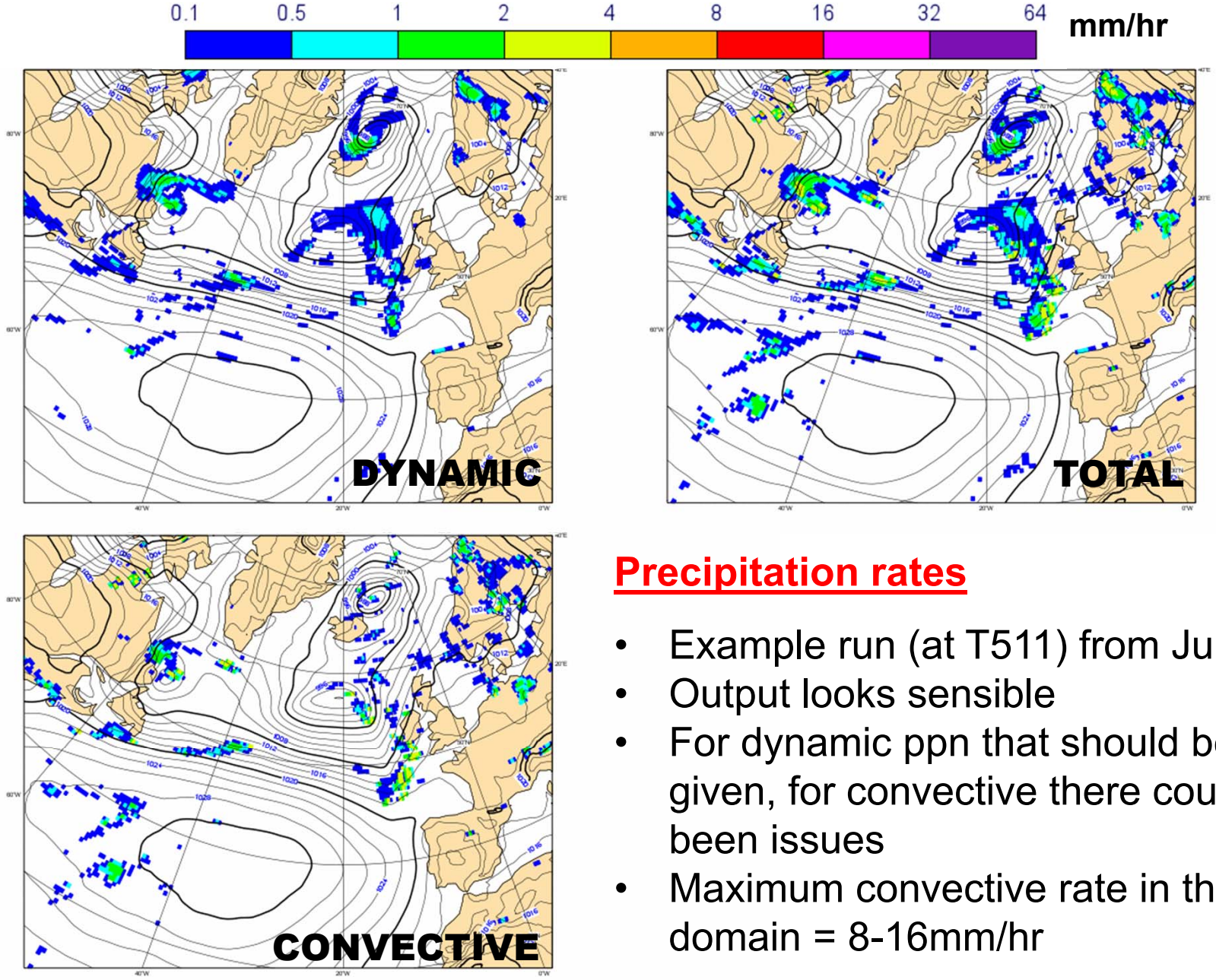
MODIS visible at ~10z



- Visibility is a new diagnostic for the next model version (primarily for fog/precip)
- For this case, observed fog in London (+elsewhere) overnight.
- IFS gives indication of low visibilities in generally the right area, and dissipates fog through the morning.
- Diagnostic most useful in probabilistic mode

ECMWF

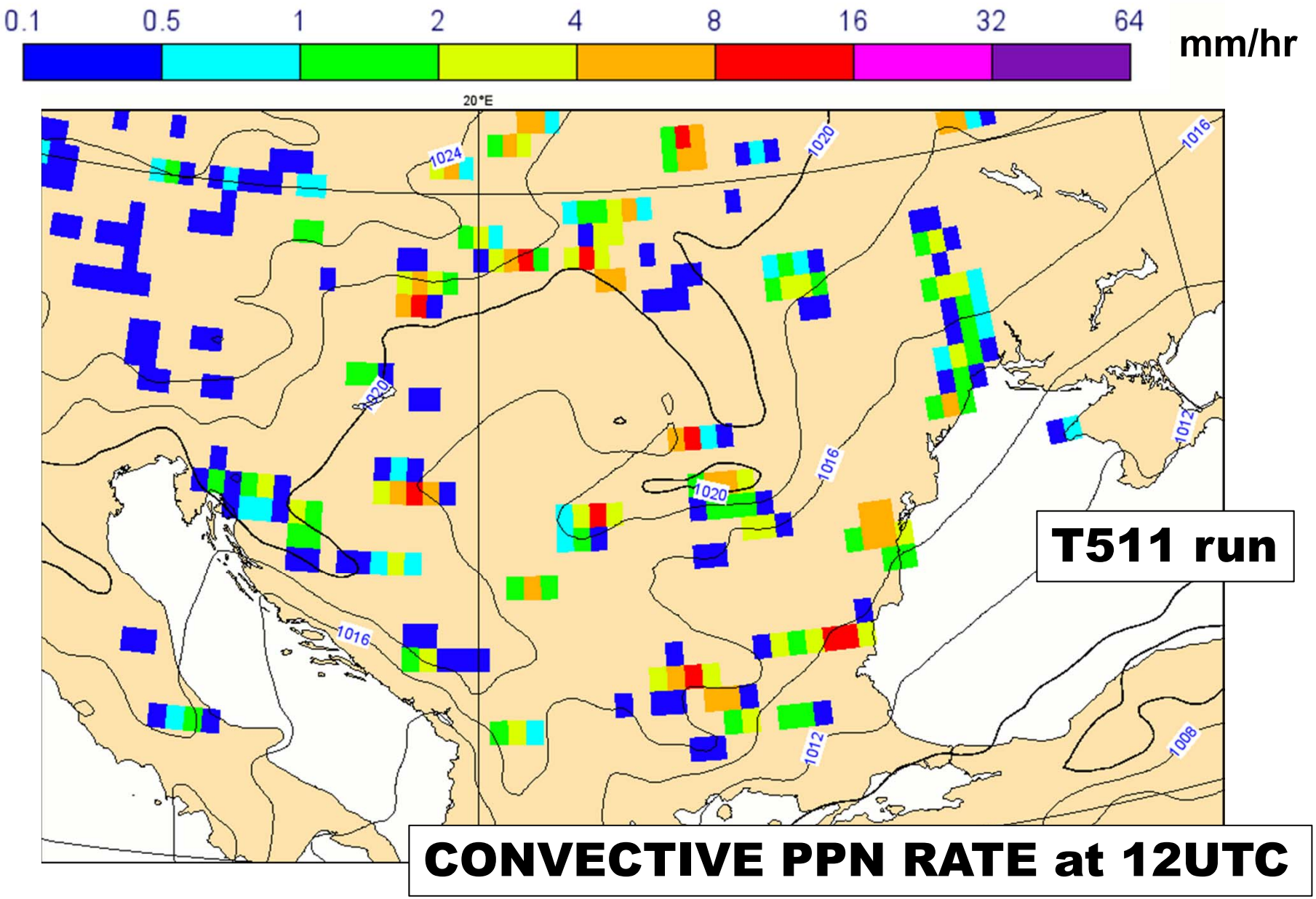
4. More New Products...



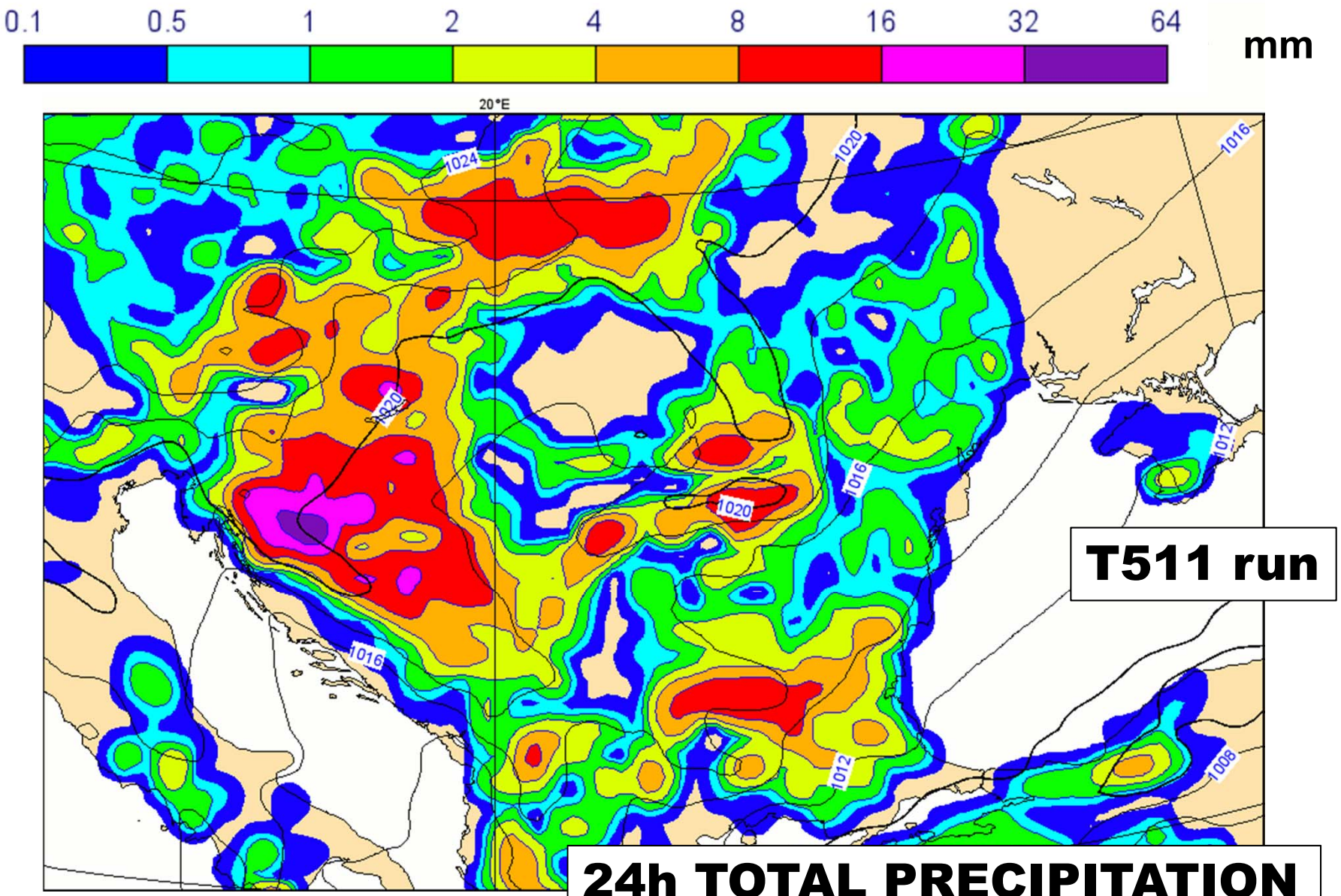
Precipitation rates

- Example run (at T511) from July 2013
- Output looks sensible
- For dynamic ppn that should be a given, for convective there could have been issues
- Maximum convective rate in this domain = 8-16mm/hr

ECMWF


0.1
0.5
1
2
4
8
16
32
64
mm/hr
20°E
1024
1020
1016
1012
1008
T511 run
CONVECTIVE PPN RATE at 12UTC

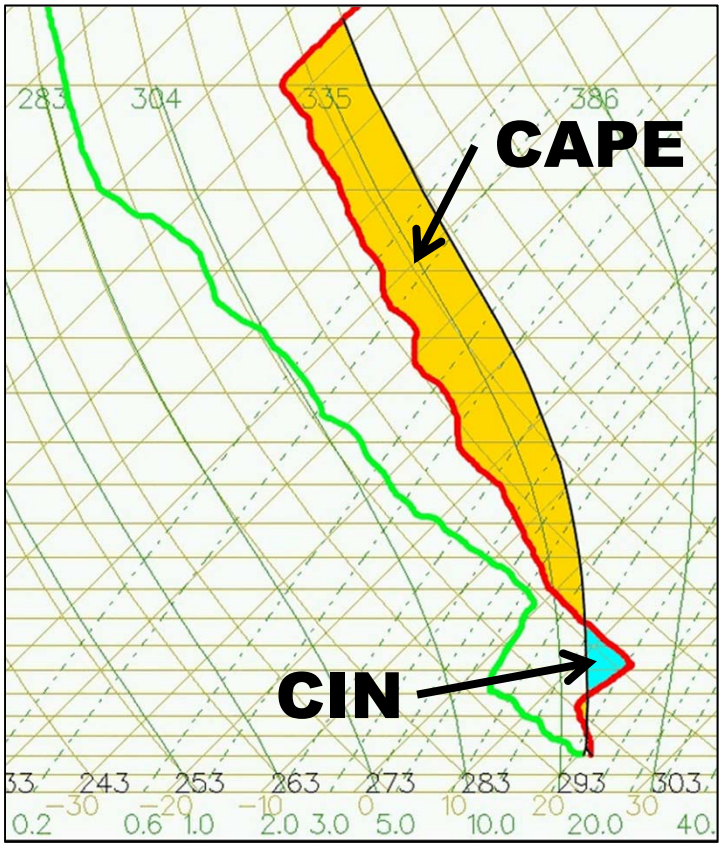
ECMWF


0.1
0.5
1
2
4
8
16
32
64
mm
20°E
1024
1020
1016
1012
1008
T511 run
24h TOTAL PRECIPITATION

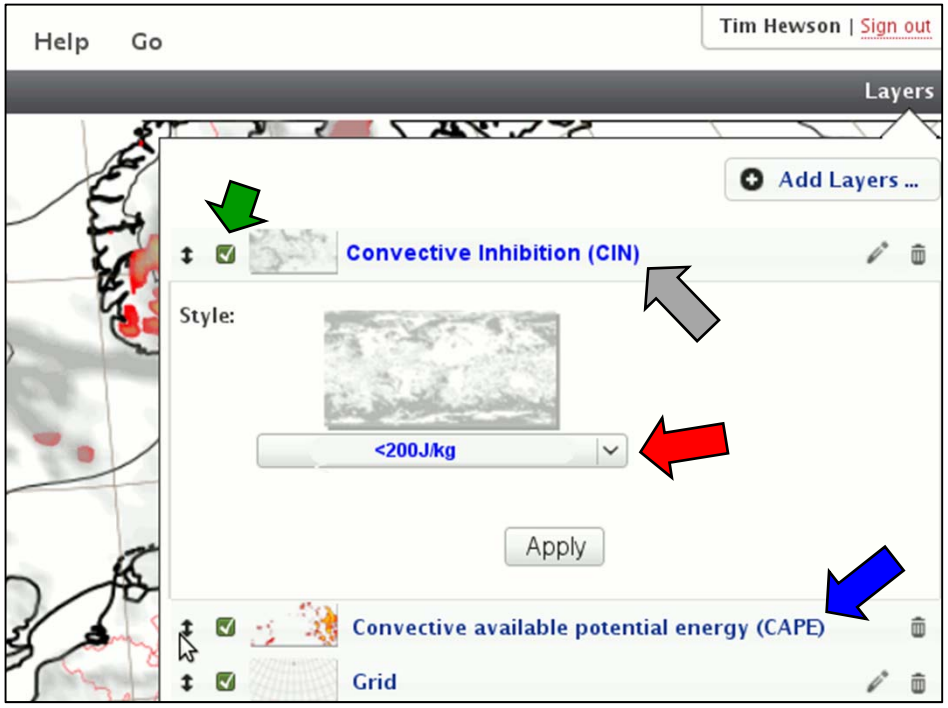
ECMWF

- **“CIN” = Convective Inhibition is being added**
- **“K Index” too, but not illustrated in this talk**

Sig convective activity usually requires **large CAPE**, & CIN **<** x

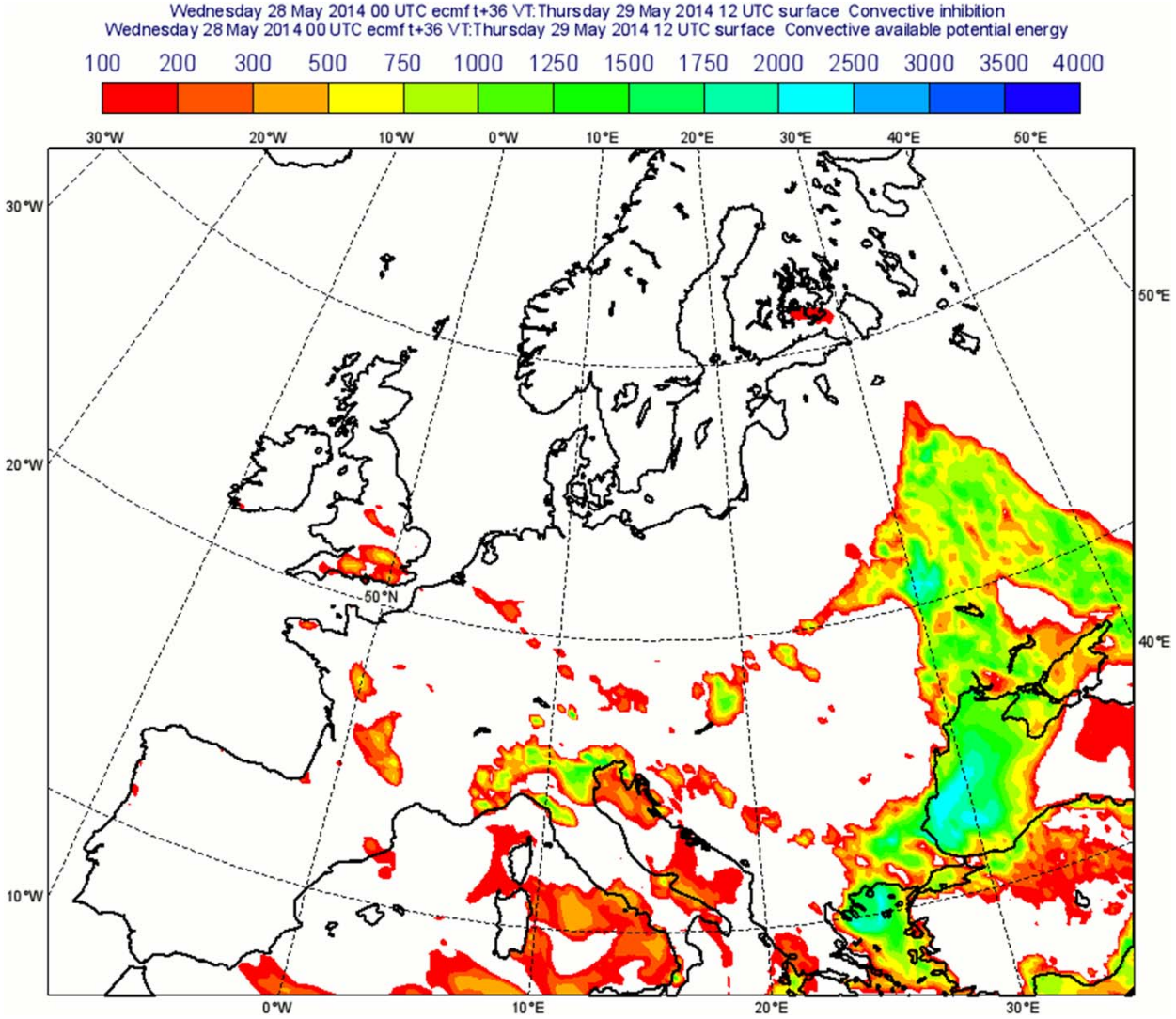


Use ecCharts as overlay tool…



ECMWF

CAPE + CIN (convective inhibition)



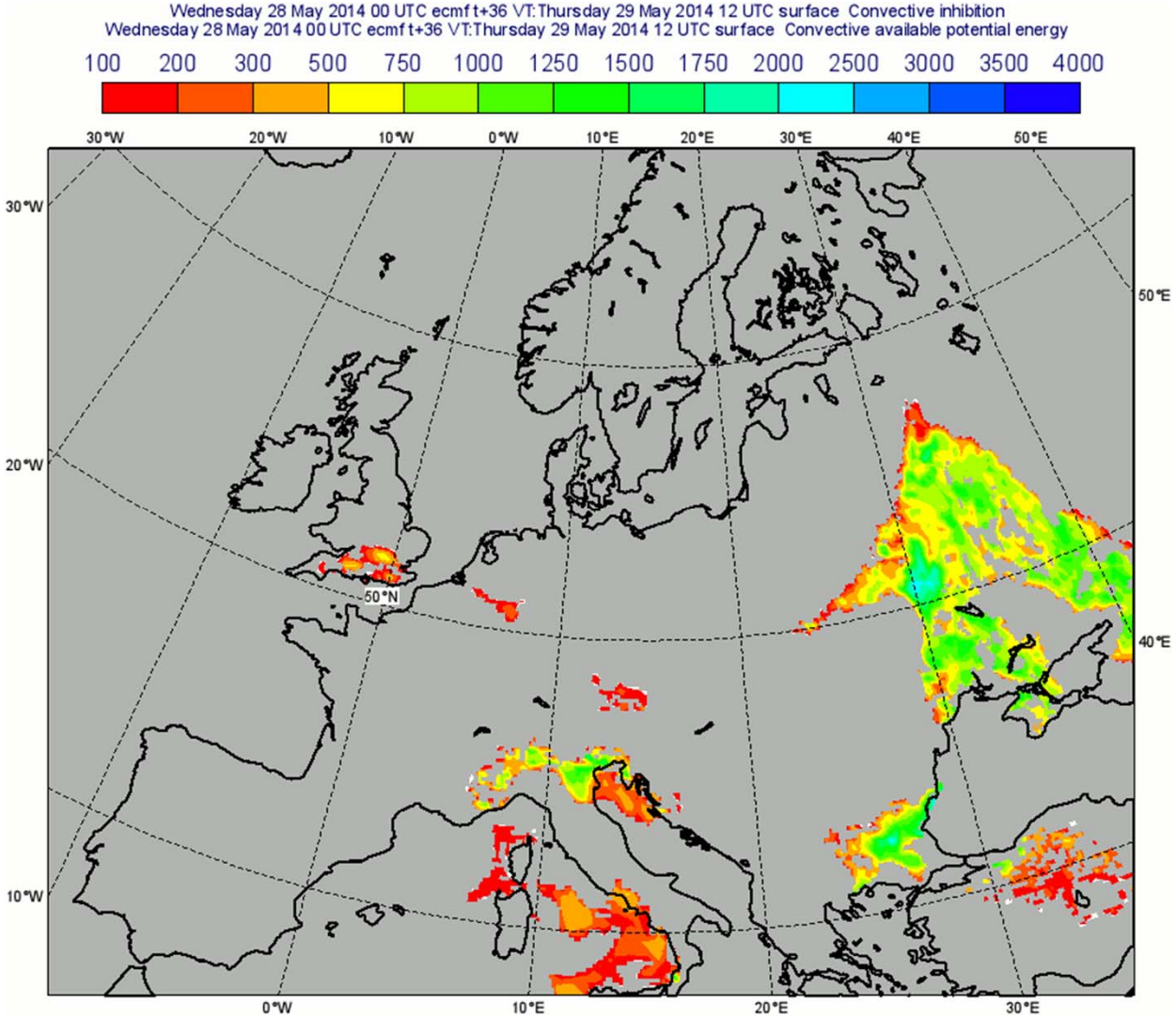
CAPE

where

CIN < ∞

ECMWF

CAPE + CIN (convective inhibition)



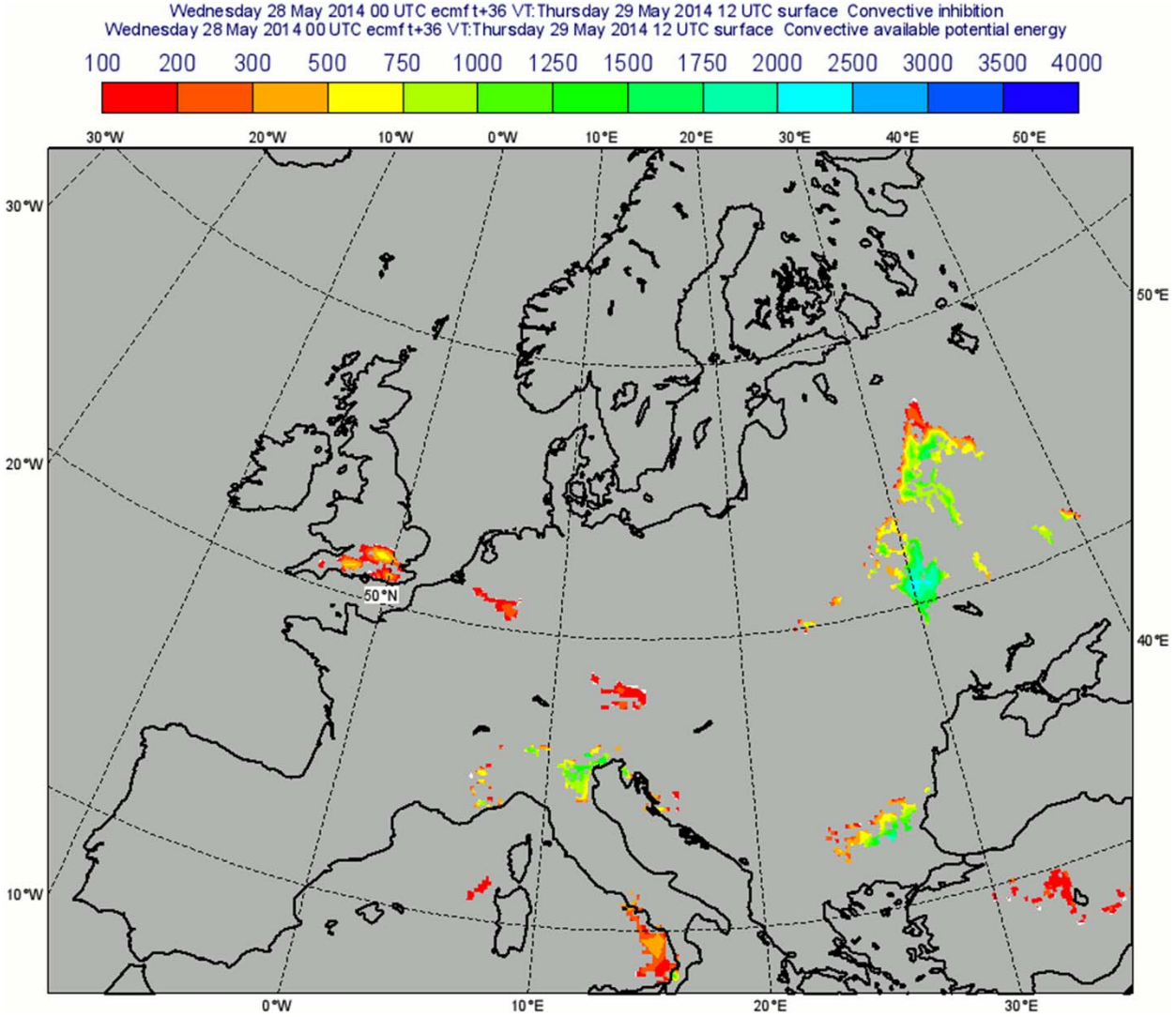
CAPE

where

CIN < 200 (J/kg)

ECMWF

CAPE + CIN (convective inhibition)



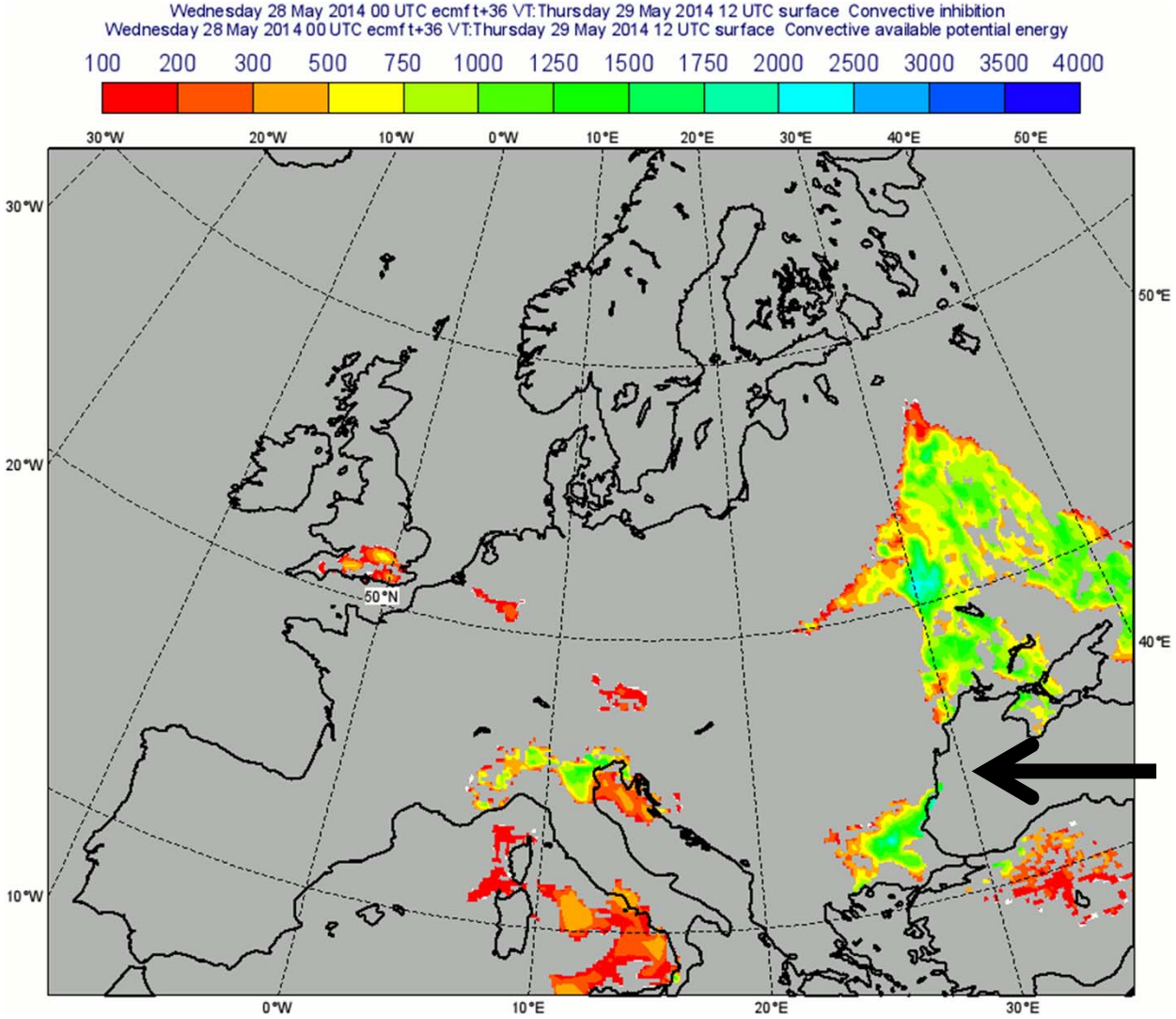
CAPE

where

CIN < 50 (J/kg)

ECMWF

CAPE + CIN (convective inhibition)

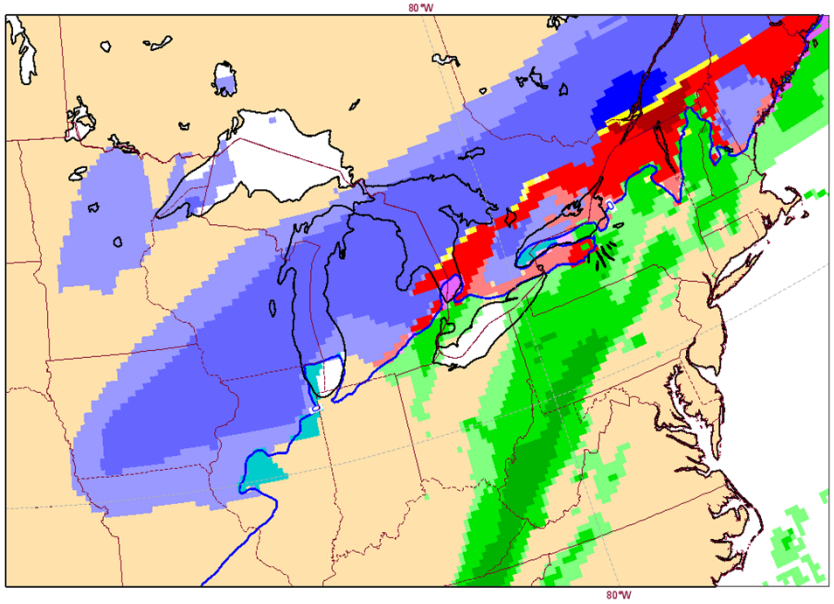


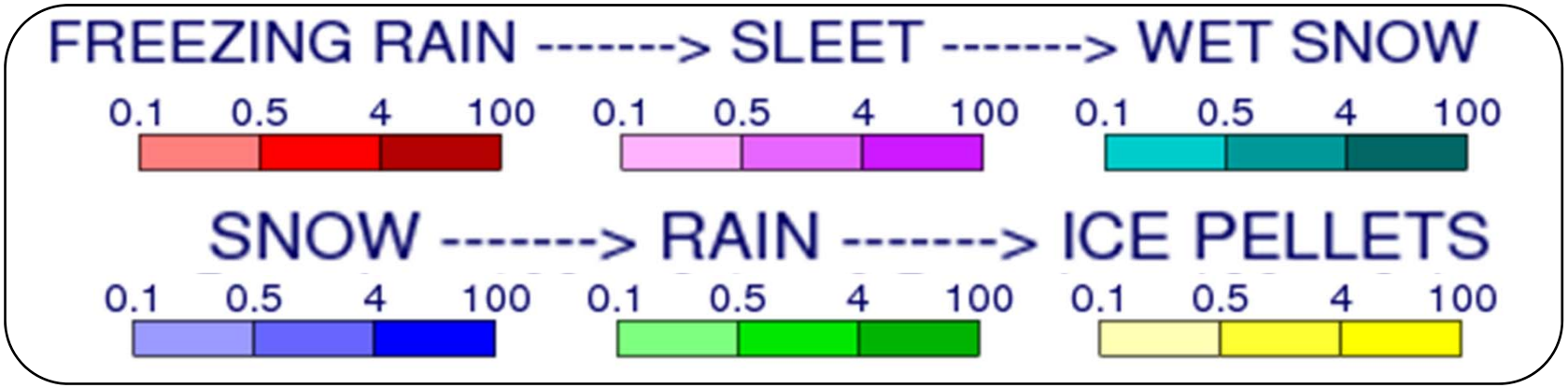
In the earlier CAPE EFI example (same case) there was no convection here despite large EFI and SOT. Precluded by large CIN.

ECMWF

Precipitation Type

- As already illustrated…
- Plot to right shows Dec 2013 Toronto case

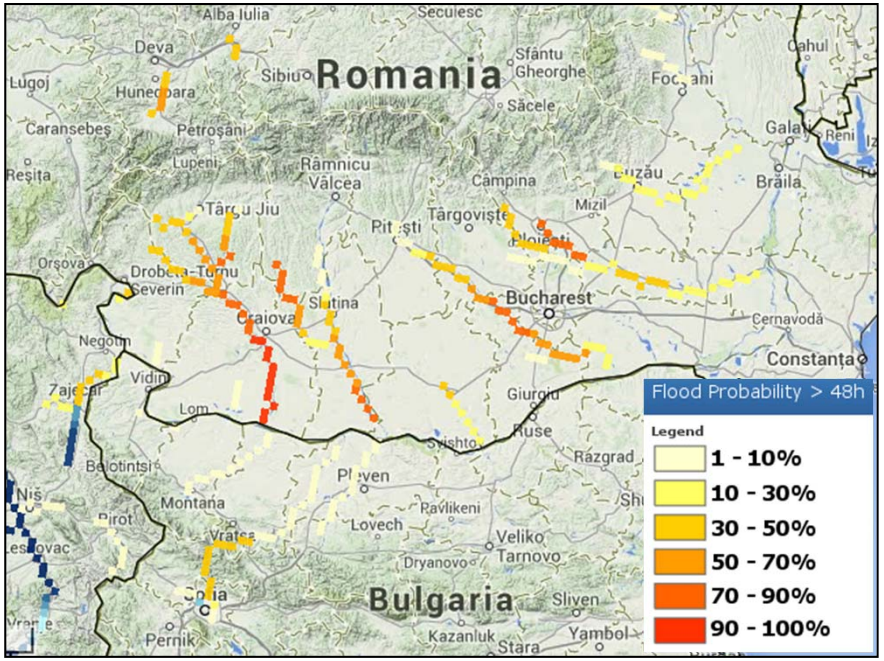




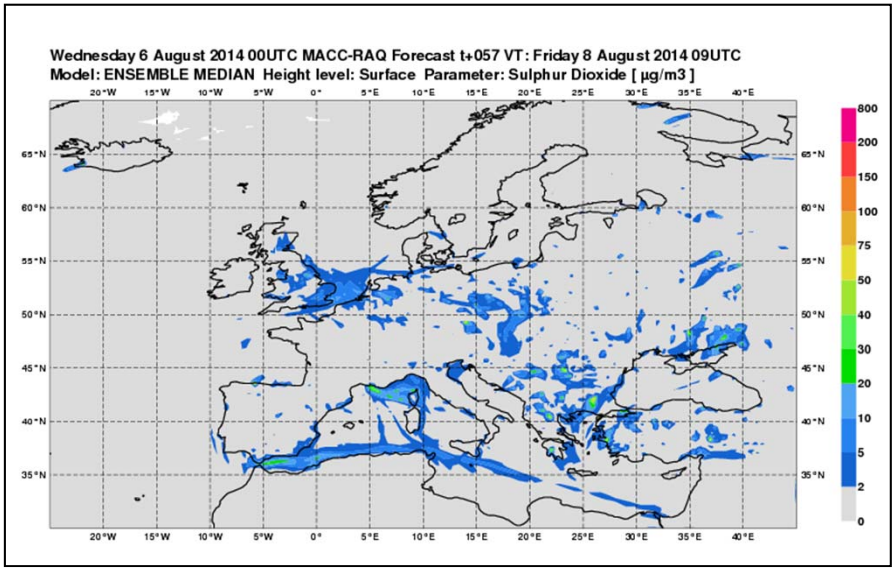
ECMWF

Other Areas...

- EFAS (European Flood Alert System), and GLOFAS (the global equivalent)



- MACC (Monitoring Atmospheric Composition and Climate)
  - Air quality forecasts (pre-operational)



ECMWF

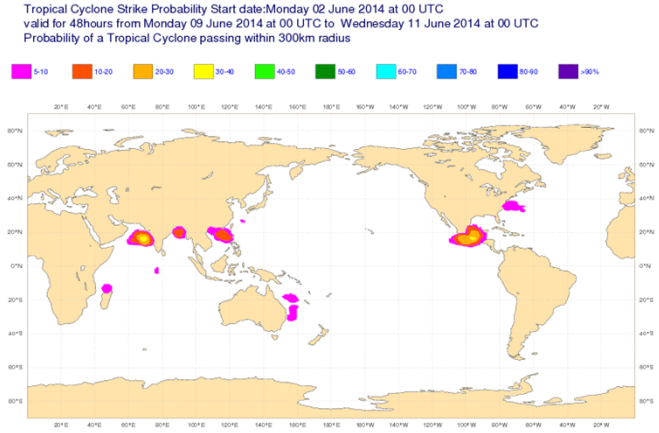
Future Developments

- At short leads (D2-5?) more focus on smaller-scale hazards
  - Aided by resolution improvements
  - E.g. Convection-related
    - Hail / thunderstorms
    - Convective Gusts
- Pushing the limits of predictability for severe weather:
  - Into the monthly time range
  - What do the distribution tails look like ?
  - Address the question "Is extreme weather possible or not ?"
  - And of course are the tails in any sense reliable ?
  - A modified EFI (e.g. colour lower values) may well be appropriate
- More amalgamation with EFAS / MACC activities ?

Summary

- ECMWF has a highly co-ordinated user-driven approach to providing forecasts of severe weather up to ~ day 10
- Larger scale phenomena are well predicted, and verification shows improvement over time
- Predictions of smaller scale phenomena will become better as resolution improves (HRES to 10km in 2015)
- Products for forecasters make considerable use of re-forecasts, to generate the "M-Climate" reference point. The integrity of the M-Climate is another area that we are making improvements.
- In all our 'severe-weather' products we aim to compress huge volumes of model output into manageable formats for forecasters. For example:
  - On a single global chart we can show where in the world 'severe' weather is expected, on a given day, in several different categories
  - On a single 'dalmatian chart' (cyclone database) we show all cyclonic centres in all ENS members, and what weather attributes they all have (eg max wind)
- Partly in response to user requests we also employ a targetted approach, for specific hazards (e.g. freezing rain / fog)
- The future will see more focus on convective hazards & warnings at longer leads

TC tracks to BUFR format



- Are/will be disseminated in BUFR edition 4 (BUFR-4) format for ENS & HRES
- BUFR-4 tracks of tropical cyclones (TCs) for which there are bulletins at analysis time already implemented in this format (1 Dec 2013 change) ("tracks of known TCs")
- BUFR-4 tracks of TCs which develop in forecasts (up to 10 days ahead) will be implemented operationally in due course ("genesis tracks") – a training dataset for this will be made available in advance.
- For genesis tracks an ID number (90, 91, 92,…) is assigned to each new TC feature together with a letter to identify the basin: 'E'-Eastern Pacific; 'W'-Western Pacific; 'L'-North Atlantic; 'S'-South Indian Ocean, etc. (making eg "90E")
- TCs with the same ID in different ENS members *are not necessarily related* (in space and time). We will not post-process to try to cross-reference new TCs between ENS members; users may choose to do this themselves.

ECMWF

BUFR-4 metadata = file header

"Tracks of known TCs"

3 | Data | Data, bitmaps expanded

Name	Value	Units	
IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	9.8E1	COMMONCODETABLEC-1	
IDENTIFICATION OF ORIGINATING/GENERATING SUB-CENTRE	**	COMMONCODETABLEC-12	
GENERATING APPLICATION	1.0E0	CODETABLEDEFINEDBYORIGI	
STORM IDENTIFIER	1.003E3	CCITTIA5 (01E)	1
WMO LONG STORM NAME	5.301E4	CCITTIA5 (AMANDA)	1
TECHNIQUE FOR MAKING UP INITIAL PERTURBATIONS	2.0E0	CODE TABLE 1090	
ENSEMBLE MEMBER NUMBER	1.0E0	NUMERIC	
TYPE OF ENSEMBLE FORECAST	**	CODE TABLE 1092	
YEAR	2014	A	
MONTH	5	MON	
DAY	28	D	
HOUR	0	H	
MINUTE	0	MIN	
METEOROLOGICAL ATTRIBUTE SIGNIFICANCE	1.0E0	CODE TABLE 8005	
LATITUDE (COARSE ACCURACY)	14.5	DEG	2
LONGITUDE (COARSE ACCURACY)	-112.9	DEG	2
METEOROLOGICAL ATTRIBUTE SIGNIFICANCE	4.0E0	CODE TABLE 8005	
LATITUDE (COARSE ACCURACY)	14.7	DEG	
LONGITUDE (COARSE ACCURACY)	-112.8	DEG	
PRESSURE REDUCED TO MEAN SEA LEVEL	9.92E4	PA	
METEOROLOGICAL ATTRIBUTE SIGNIFICANCE	3.0E0	CODE TABLE 8005	
LATITUDE (COARSE ACCURACY)	14.1	DEG	
LONGITUDE (COARSE ACCURACY)	-112.8	DEG	
WIND SPEED AT 10 M	2.11E1	M/S	

1- TC ID and NAME (e.g. 01E AMANDA)

2- Reported position

"Genesis Tracks"

3 | Data | Data, bitmaps expanded

Name	Value	Units	
IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	9.8E1	COMMONCODETABLEC-1	
IDENTIFICATION OF ORIGINATING/GENERATING SUB-CENTRE	**	COMMONCODETABLEC-12	
GENERATING APPLICATION	1.0E0	CODETABLEDEFINEDBYORIGI	
STORM IDENTIFIER	1.003E3	CCITTIA5 (90E)	1
WMO LONG STORM NAME	5.101E4	CCITTIA5 (90E)	1
TECHNIQUE FOR MAKING UP INITIAL PERTURBATIONS	2.0E0	CODE TABLE 1090	
ENSEMBLE MEMBER NUMBER	1.0E0	NUMERIC	
TYPE OF ENSEMBLE FORECAST	**	CODE TABLE 1092	
YEAR	2014	A	
MONTH	5	MON	
DAY	13	D	
HOUR	12	H	
MINUTE	0	MIN	
METEOROLOGICAL ATTRIBUTE SIGNIFICANCE	1.0E0	CODE TABLE 8005	
LATITUDE (COARSE ACCURACY)	**	DEG	2
LONGITUDE (COARSE ACCURACY)	**	DEG	2
METEOROLOGICAL ATTRIBUTE SIGNIFICANCE	4.0E0	CODE TABLE 8005	
LATITUDE (COARSE ACCURACY)	8	DEG	
LONGITUDE (COARSE ACCURACY)	-123	DEG	
PRESSURE REDUCED TO MEAN SEA LEVEL	1.006E5	PA	
METEOROLOGICAL ATTRIBUTE SIGNIFICANCE	3.0E0	CODE TABLE 8005	
LATITUDE (COARSE ACCURACY)	8.5	DEG	
LONGITUDE (COARSE ACCURACY)	-119.6	DEG	
WIND SPEED AT 10 M	1.08E1	M/S	

1- TC ID and NAME (e.g. 90E 90E)

2- Reported position (missing '**')