Forecasting Extreme Events

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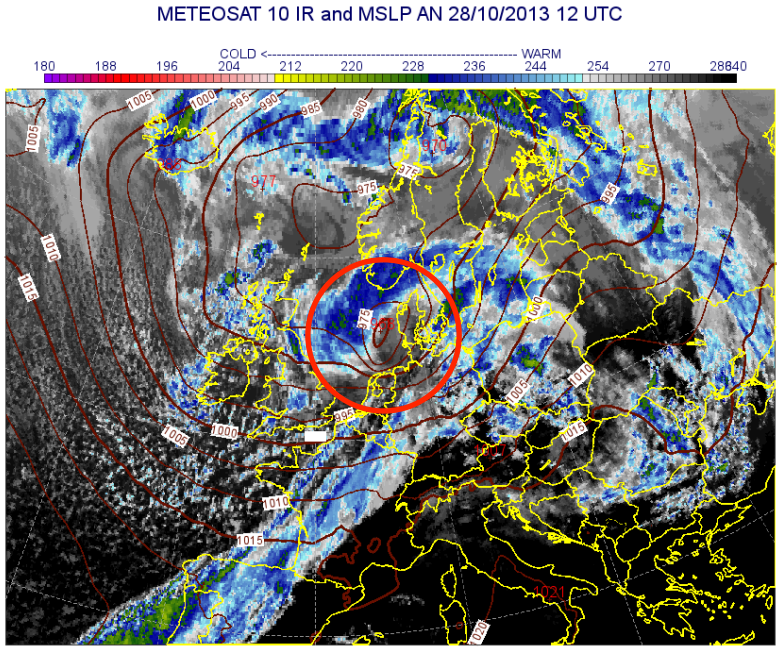
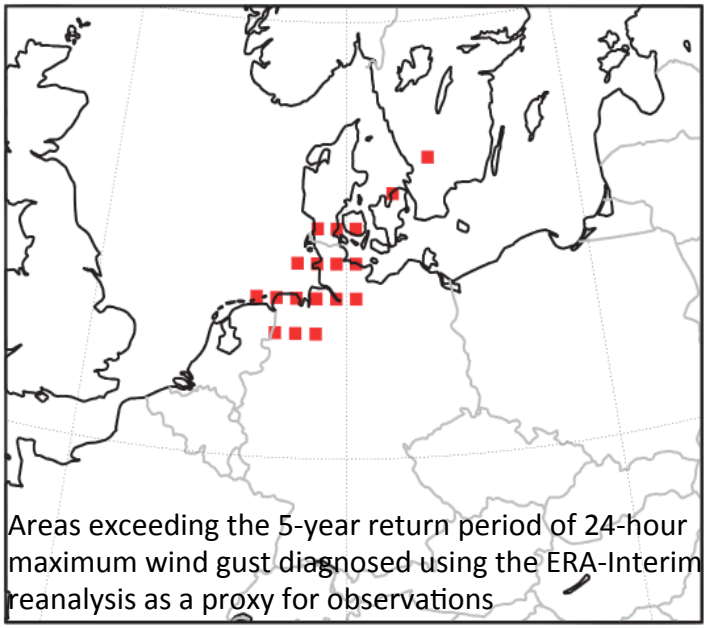
Use and interpretation of ECMWF products, Oct. 2016

Outline

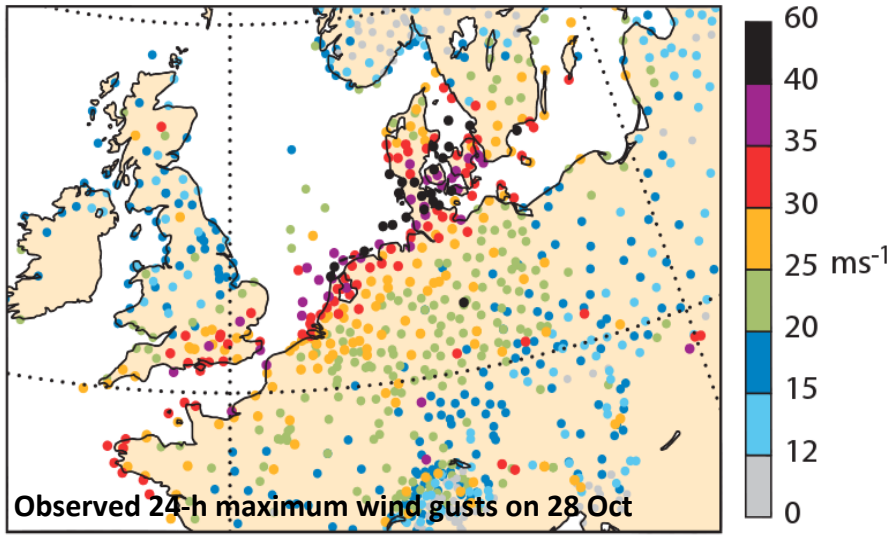
- An example of severe weather – St. Jude Storm, end of October 2013
- Extreme Forecast Index (EFI) and the Model climate (M-climate)
- Shift Of Tails (SOT) – an index to complement the EFI
- Operational products and verification
- EFI for forecasting severe convection
  - ✓ CAPE and CAPE+SHEAR
  - ✓ Verification
  - ✓ Case study
- EFI in the extended range

St Jude Storm, 27-28 Oct 2013



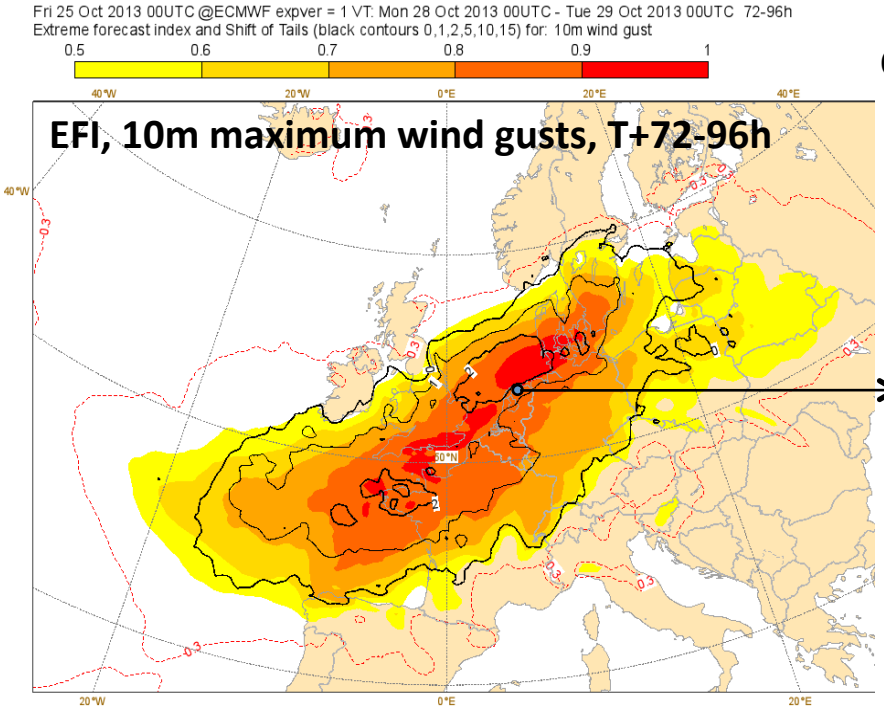


Areas exceeding the 5-year return period of 24-hour maximum wind gust diagnosed using the ERA-Interim reanalysis as a proxy for observations

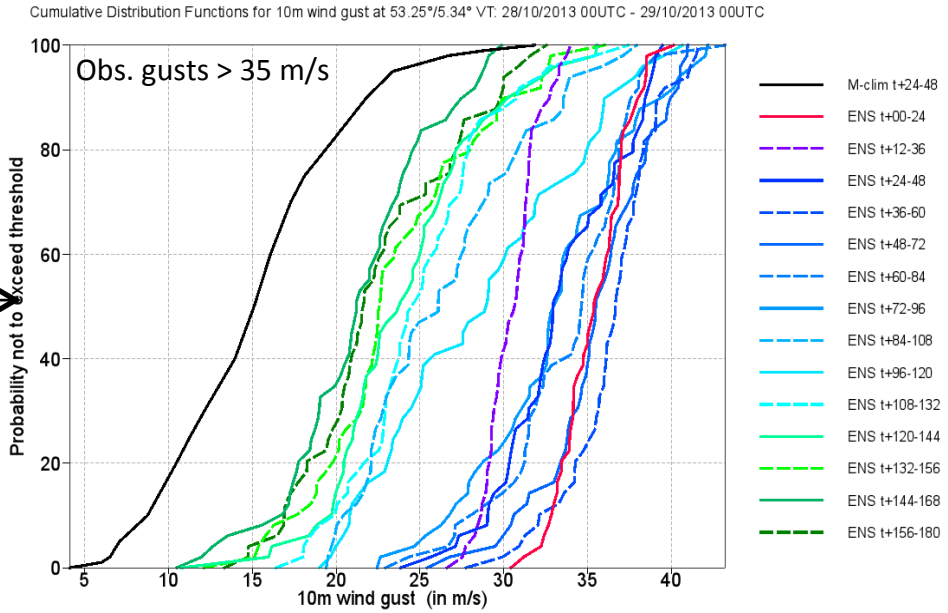


Observed 24-h maximum wind gusts on 28 Oct

St Jude Storm, 27-28 Oct 2013



Cumulative Distribution Functions (CDF)



- EFI indicated a risk of a windstorm in the medium range. Positive SOT (black contours) showed that an exceptionally strong windstorm was likely.
- There was a sign of windier-than-normal conditions 7 days in advance with the last 7 runs predicting extreme wind (see CDF).

Windstorms in northwest Europe in late 2013, *ECMWF Newsletter* ***No. 139***, 22-28

Extreme Forecast Index (EFI)

- **Extreme Forecast Index (EFI)** is designed to measure how extreme a given ensemble forecast is.
- EFI is a measure of the difference between the ensemble forecast distribution and a reference distribution - **model climate (M-climate)**.
- EFI delivers model-climate-related information, therefore it can be used as an "alarm bell" for extreme weather situations over any area without defining different space- and time-dependent thresholds.
- Simple probabilities (e.g. > 32°C) will not highlight the differences in the distributions below. EFI will, by accounting for the distribution of all the ensemble members.

20 C° (20 members)	20 C° (5 members)
30 C° (10 members)	30 C° (25 members)
35 C° (15 members)	35 C° (15 members)
40 C° (5 members)	40 C° (5 members)

The Model climate (M-climate)

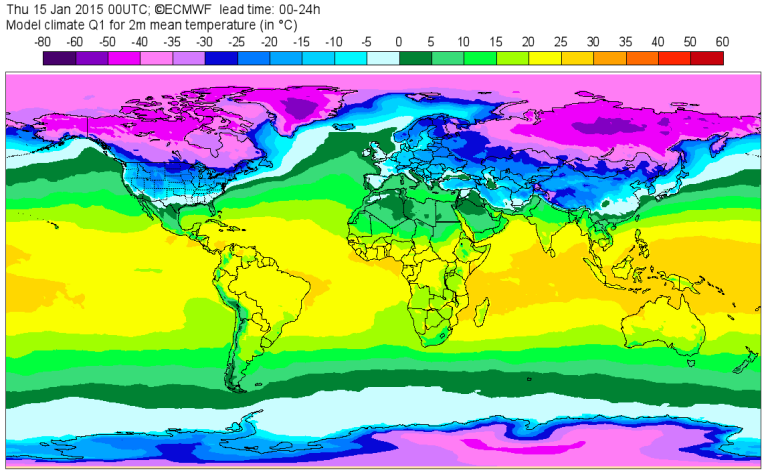
For climate related products like the EFI a reliable model climate is essential.

Ideally the model climate (M-Climate) is a large set of ensemble re-forecasts with the latest model configuration (used operationally) for a long enough period (e.g. 30 years).

The current M-climate (**since 12 May 2015**):

- Running an ensemble re-forecast suite with 10 perturbed ensemble members and the Control **(was 4 perturbed member + Control)**
- Always for the most recent 20 years with initial conditions taken from the ECMWF global atmospheric reanalysis ERA-Interim
- Re-forecast runs every Monday and every Thursday. Therefore climate files from the closest preceding run are taken. **(only Thursday runs before)**
- Model run for 32 days, post-processed fields as for ENS (data every 6 hours)
- Uses the latest model cycle (resolution/ physics / etc.)
- Allows an immediate adaptation of the EFI and other model climate related products to any upgrade of ENS

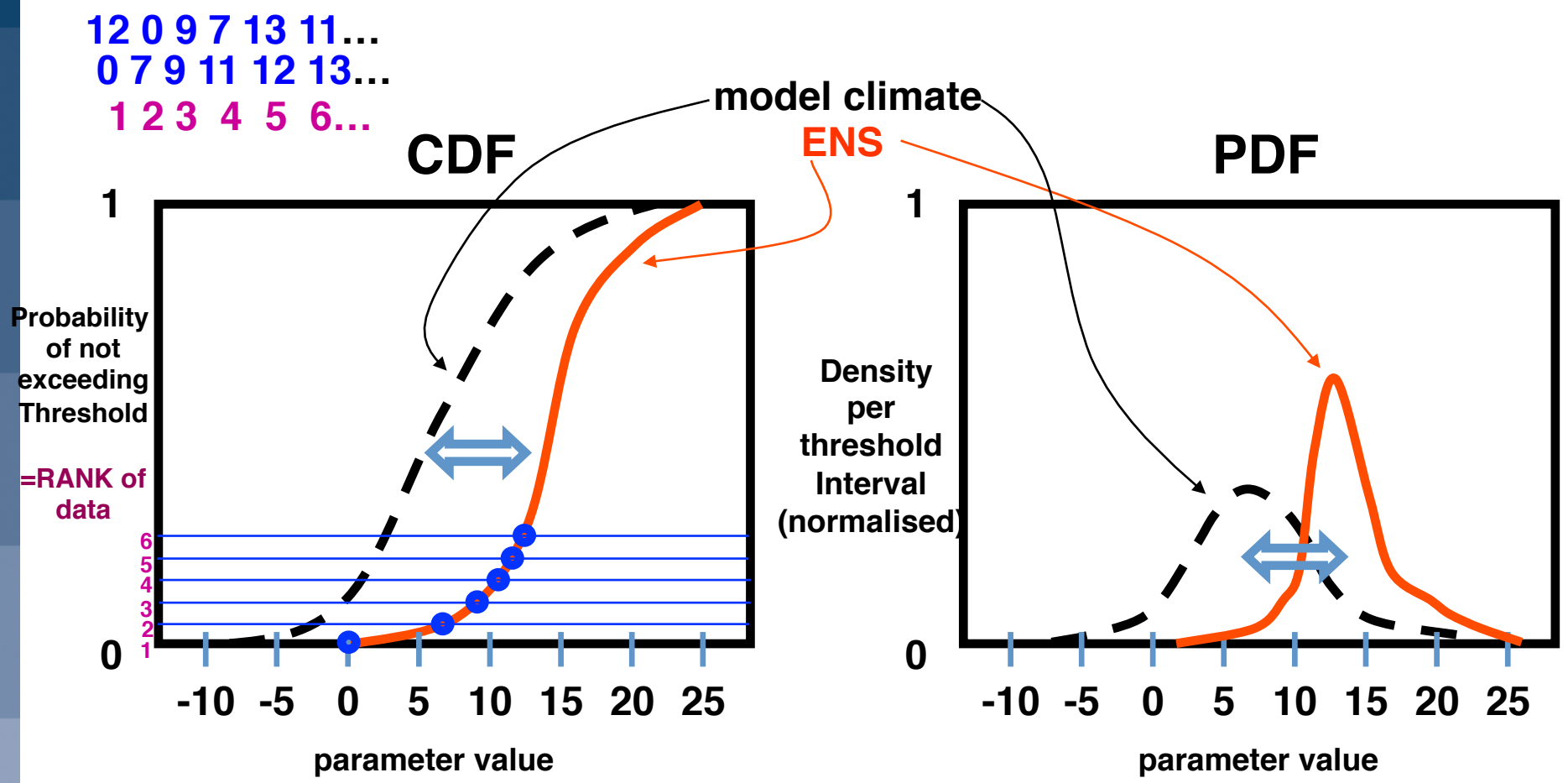
Model climate (M-climate)



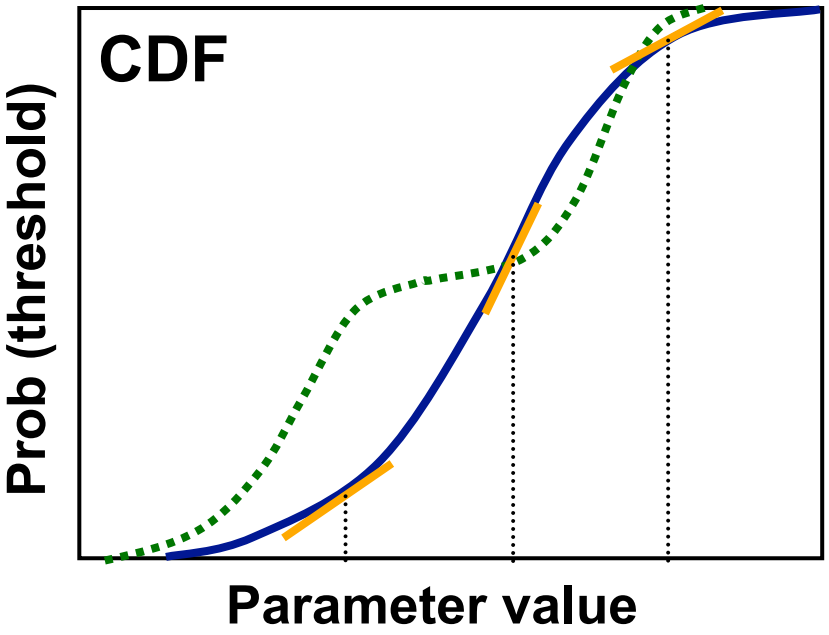
- To provide a robust, less noisy M-Climate, we do not use just one set of re-forecasts, but all nine sets within 5-week period centred on the week in question.
- M-climate sample size is: 20 years * 11 ensemble members * 9 re-forecast runs = 1980 re-forecast fields (were 500)
- Recent changes lead to:
  - ✓ Decrease of the noise in the tails of the M-climate distribution and considerable increase of the consistency of SOT forecasts;
  - ✓ Decrease of the jumpiness of the EFI forecast due to the seasonal trend.

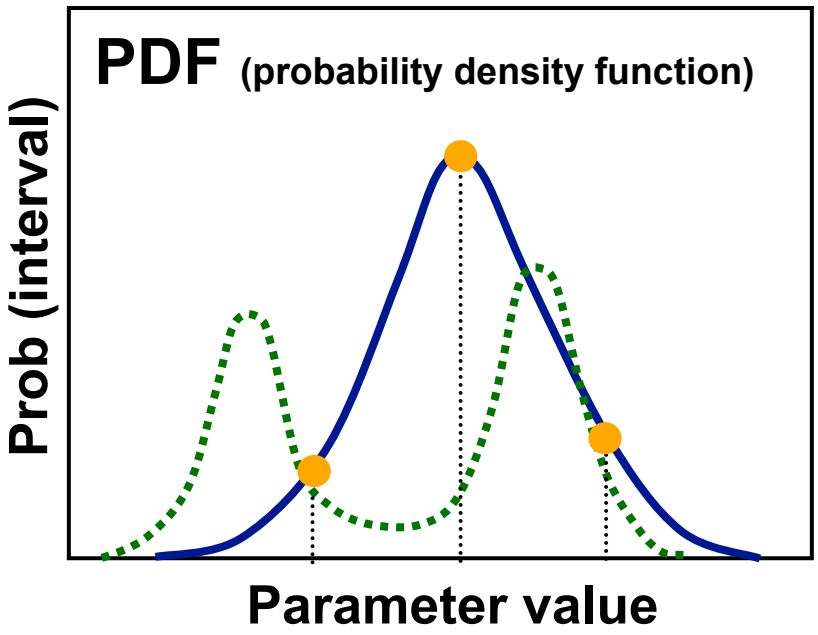
Extreme Forecast Index (EFI)

- The EFI is defined on the basis of the Cumulative Distribution Functions (CDF). The abnormality level in the ensemble is determined based on the position and shape of the distributions.



How do CDFs and PDFs relate?



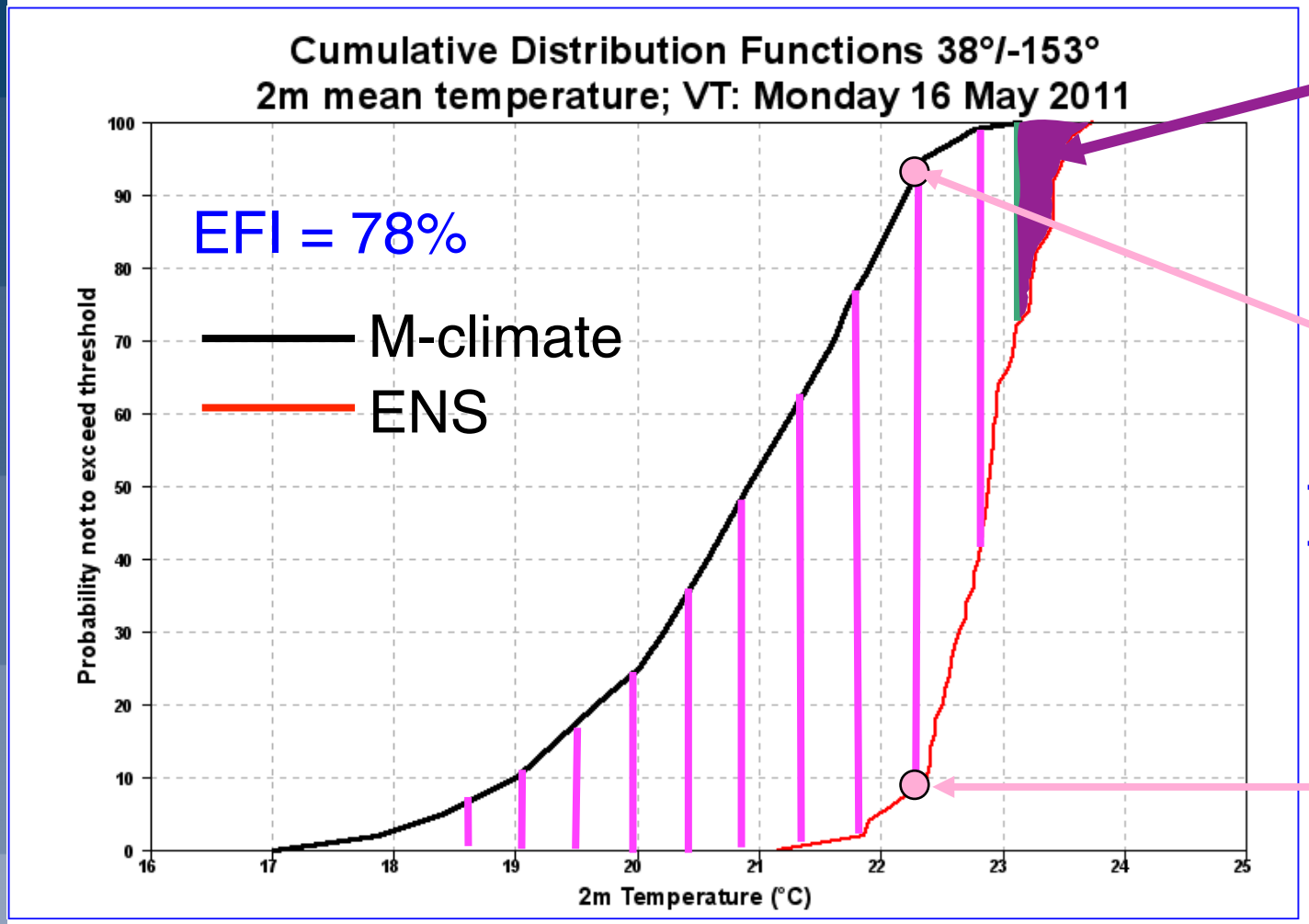


- The PDF (y-axis) value equals the slope of the CDF
- **Steeper** CDF = **narrower** PDF = higher confidence in the forecast
- A step in the CDF means a bimodal PDF

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

Represented by pink lines below

More weight to extremes of M-climate



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

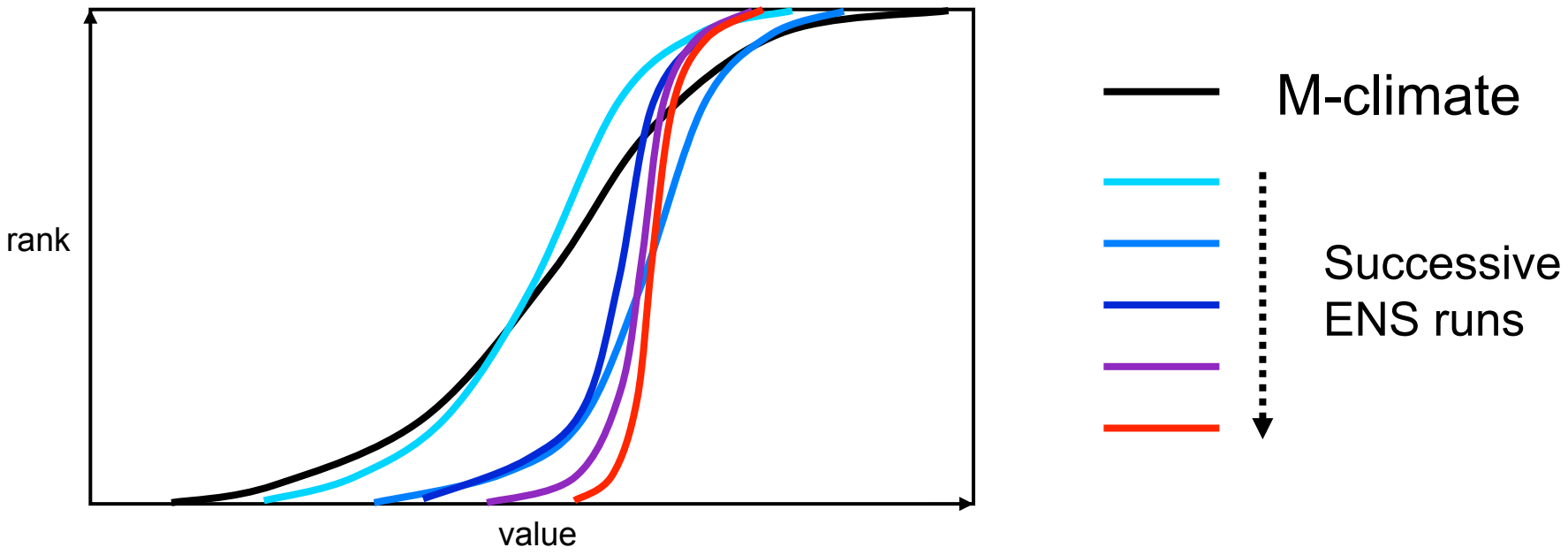
p

-1 ≤ EFI ≤ 1

-100% ≤ EFI ≤ 100%

$F_f(p)$

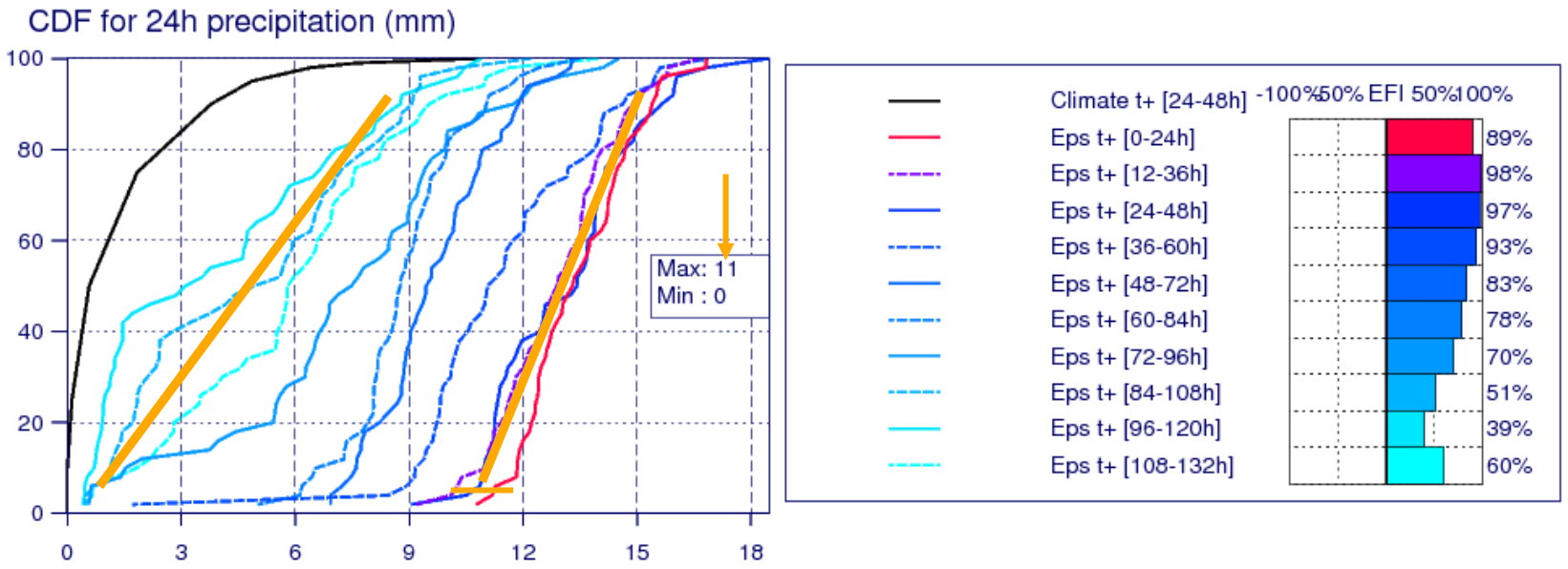
How ‘should’ CDFs behave in successive ENS runs?



- At long lead times forecast CDF may be similar to the M-climate.
- Lateral variations in CDF position between successive runs should, mostly, become less (with time).
- CDF will tend to become steeper (with time), implying higher confidence.

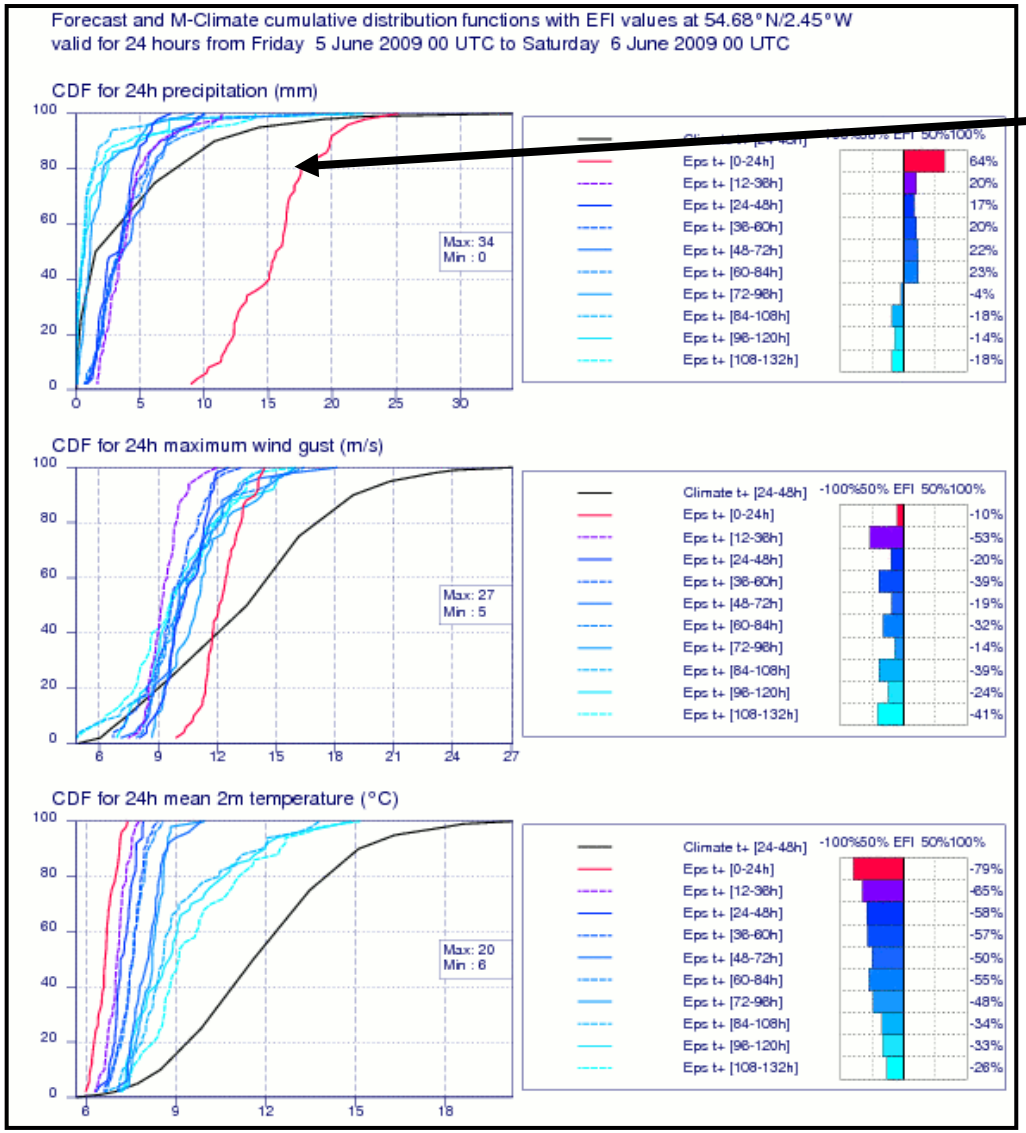
An example

Forecast and M-Climate cumulative distribution functions with EFI values at 59.09°N/41.69°E
valid for 24 hours from Monday 4 February 2013 00 UTC to Tuesday 5 February 2013 00 UTC



- The 16-year return period value of 24h precipitation for ~February is 11 mm (M-climate).
- ~ 95% probability of >11mm (blue line; t+24-48h)
- Steeper CDF slope on more recent forecasts signifies increasing confidence

Counter example

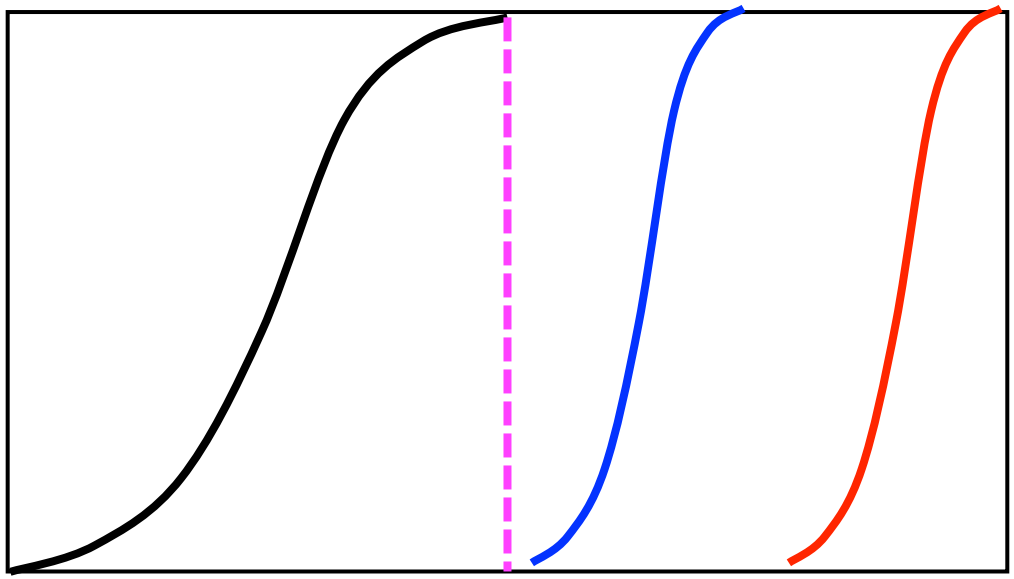


- N England rain – June’09 - low prob alternative became likely at short range.

Some limitations

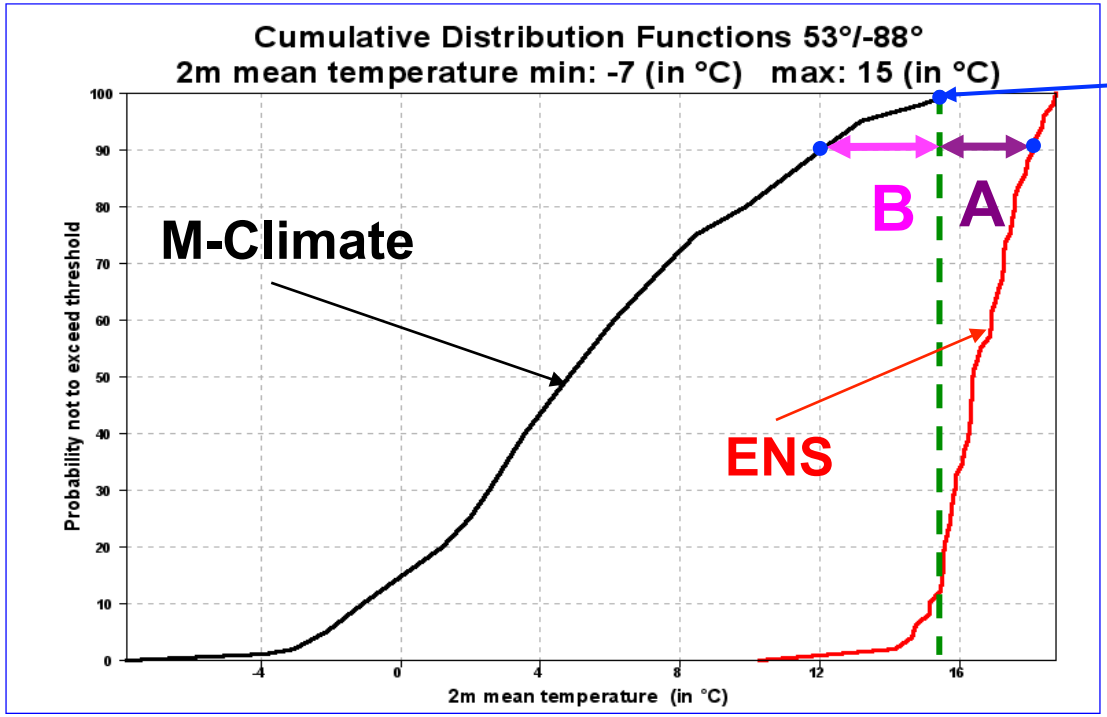
- Extreme does not *necessarily* mean high impact (eg 2mm rain in the desert)
- Past history also important but not directly accounted for (eg heavy rain when ground saturated)
- Windstorm impact can depend on whether trees are in leaf, whether ground is saturated…
- Products are only as good as the model output, e.g.:
  - Tropical cyclone representation is limited by resolution
  - Threat from intense, *very localised* convection unlikely to be fully captured

Shift Of Tails (SOT)



- As EFI does not take direct account for members which are beyond the M-climate, once EFI reaches its maximum value of 1 or minimum value of -1, it does not provide further information about the magnitude of extremity.
- Shift Of Tails (SOT) has been operational since 19 June 2012 to complement EFI by providing information about how extreme an extreme event might be.

Shift Of Tails (SOT)

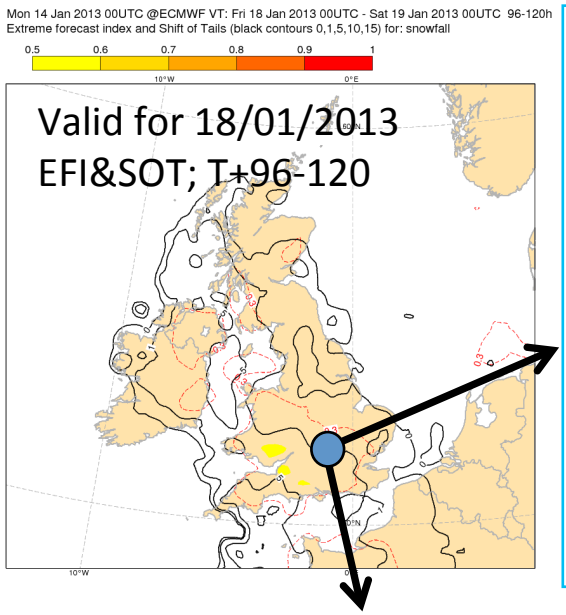


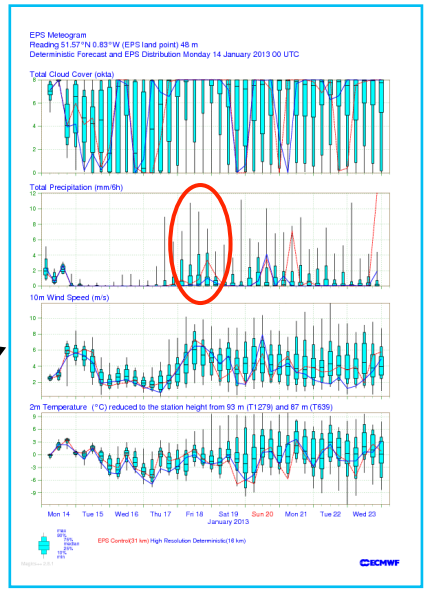
SOT = A/B

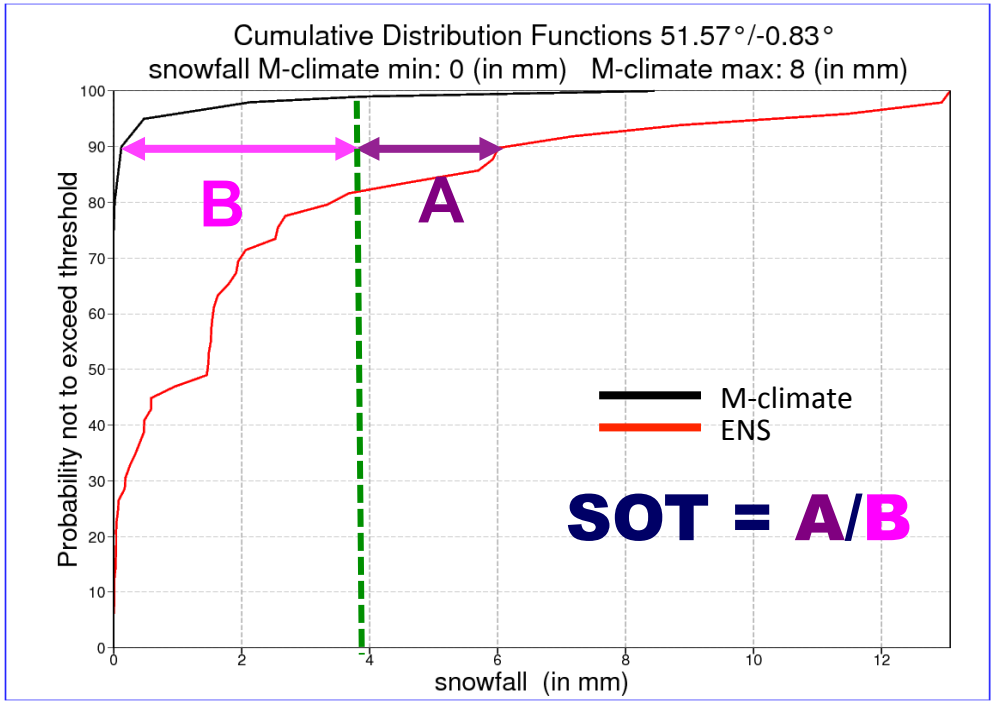
A = Qf(90) - Qc(99)

B = Qc(99) - Qc(90)

- SOT compares the tails of both distributions M-climate and ENS.
- SOT is based on 90th and 99th (upper tail) and 1st and 10th (lower tail for temperature only) percentiles
- **Positive** SOT values indicate that at least 10% of the ensemble is forecasting an extreme event; the higher the SOT the more extreme that top 10% is.







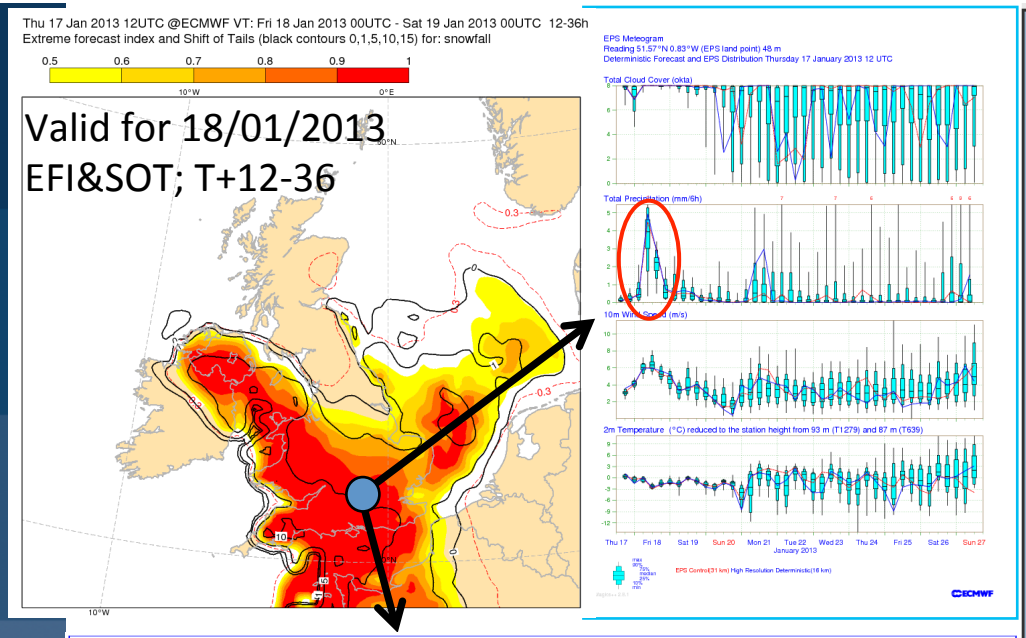
- SOT > 0 → at least 10% of the ensemble members are above the 99th percentile M-climate
- The higher the SOT value is, the further this top 10% of the ensemble forecast is beyond Q99 of the M-climate.

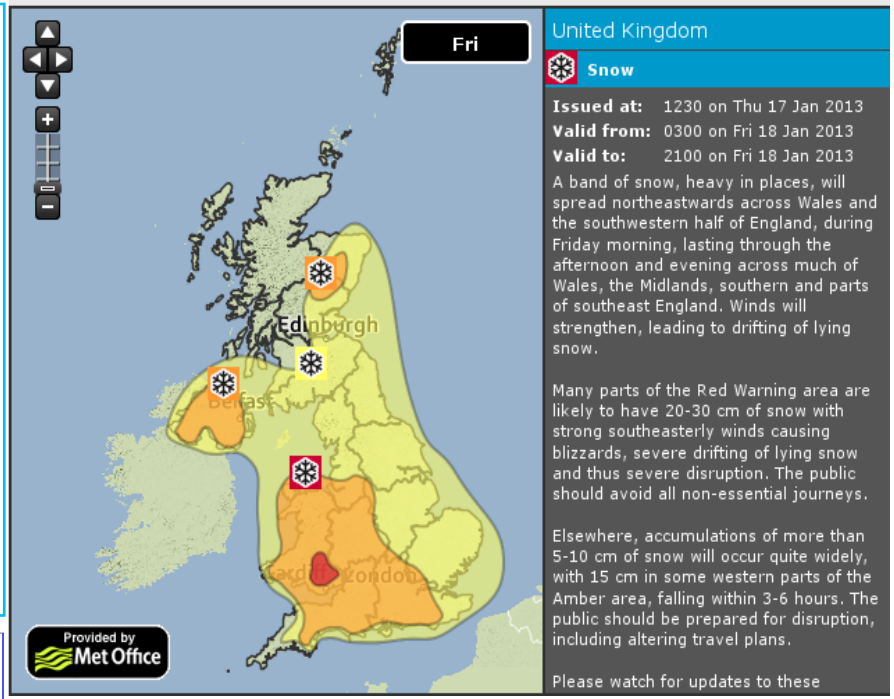
In the example (Reading):

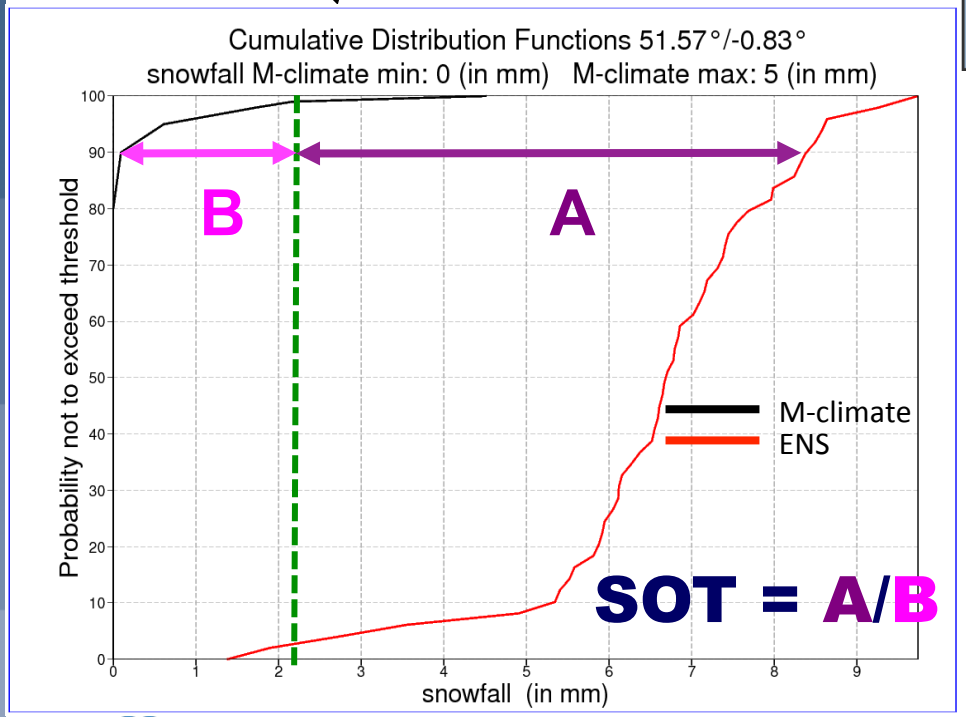
- ✓ EFI = 0.36
- ✓ SOT = 0.8

EFI positive → forecast suggests snowy conditions

SOT >0 → there are ENS members predicting extreme snowfall (above the 99th M-climate percentile) but the forecast is still uncertain (low EFI)







Forecast for Reading:

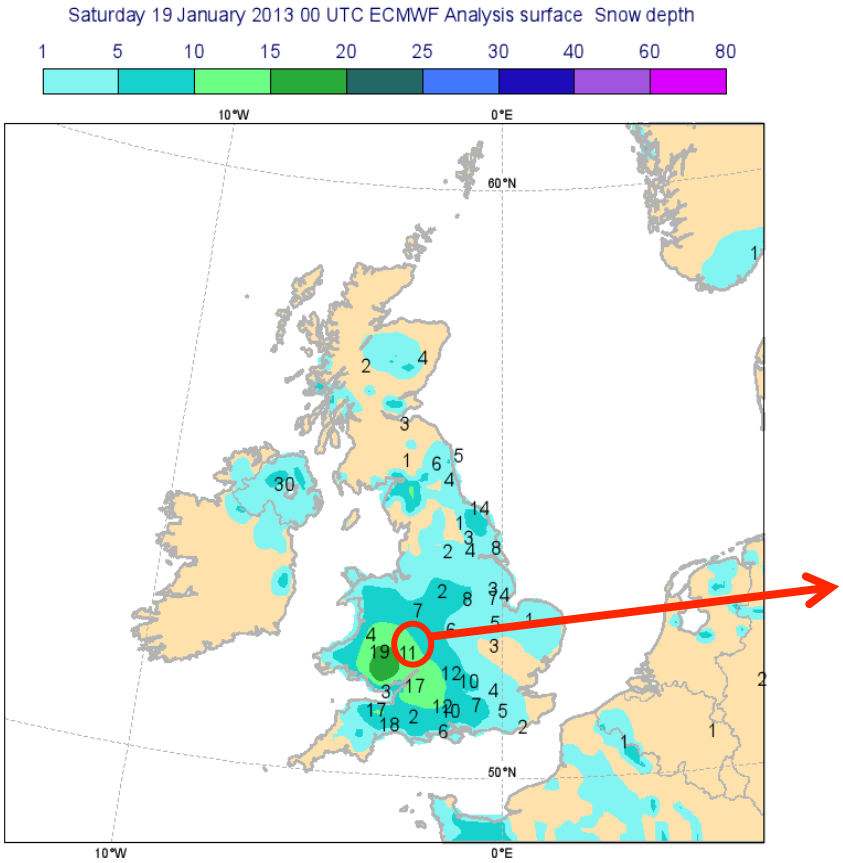
- EFI = 0.96
- SOT = 3.5

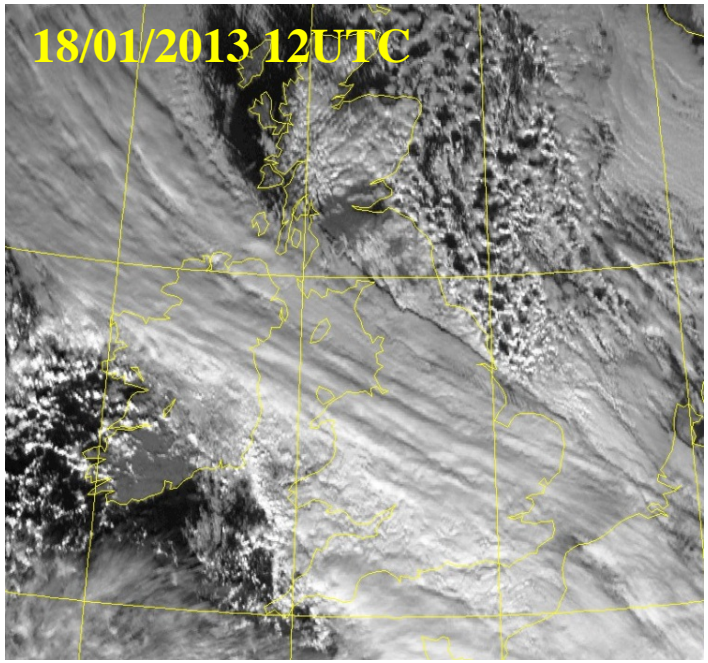
✓ High values of the EFI imply high confidence that extreme snowfall may happen.

✓ Higher SOT values indicate where the most exceptional snowfall amounts might occur (relative to climate).

The outcome

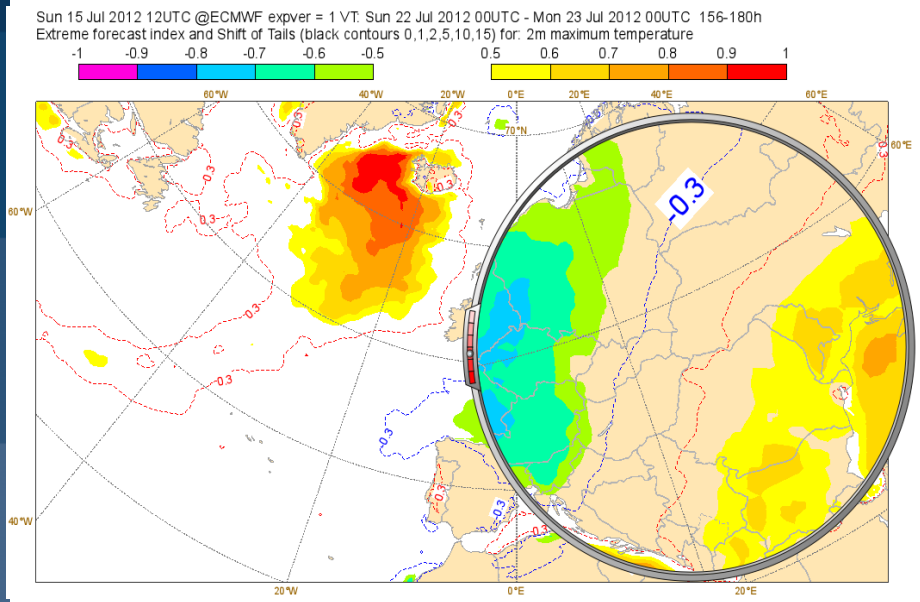
ECMWF snow depth analysis and observations representing the new snow depth for 24-h period from 18/01/2013 00UTC to 19/01/2013 00UTC

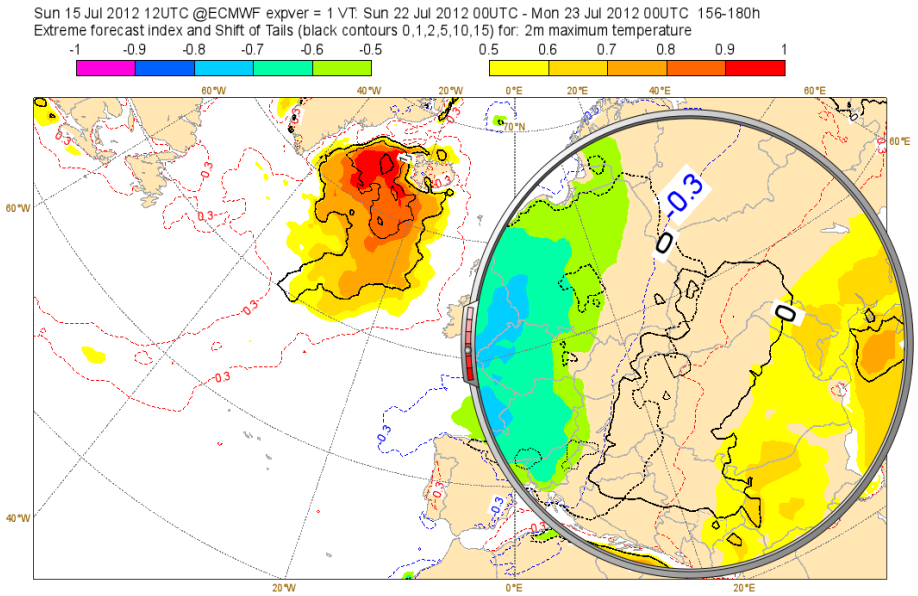




A beer garden in Bromsgrove. Credit: Sue Eden

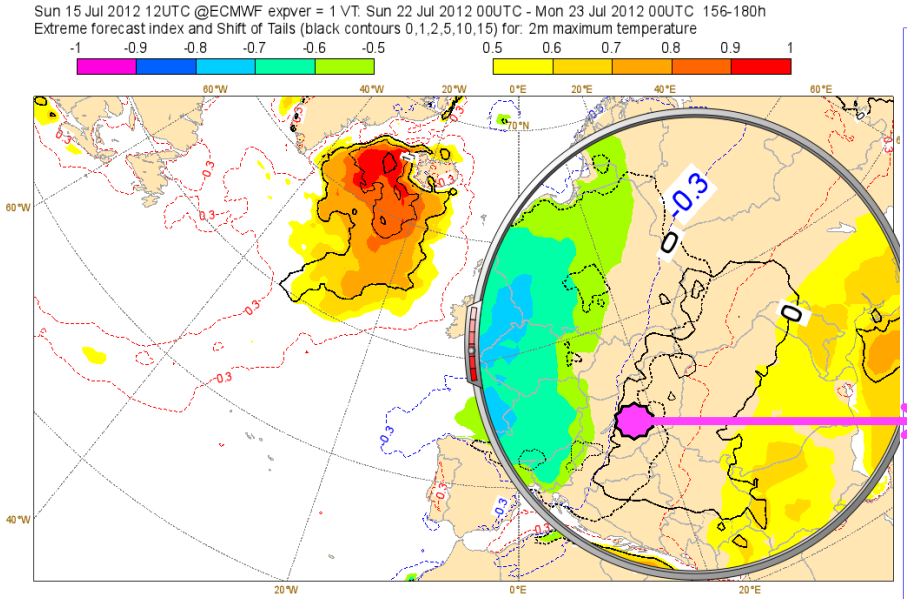
A case of very large uncertainty

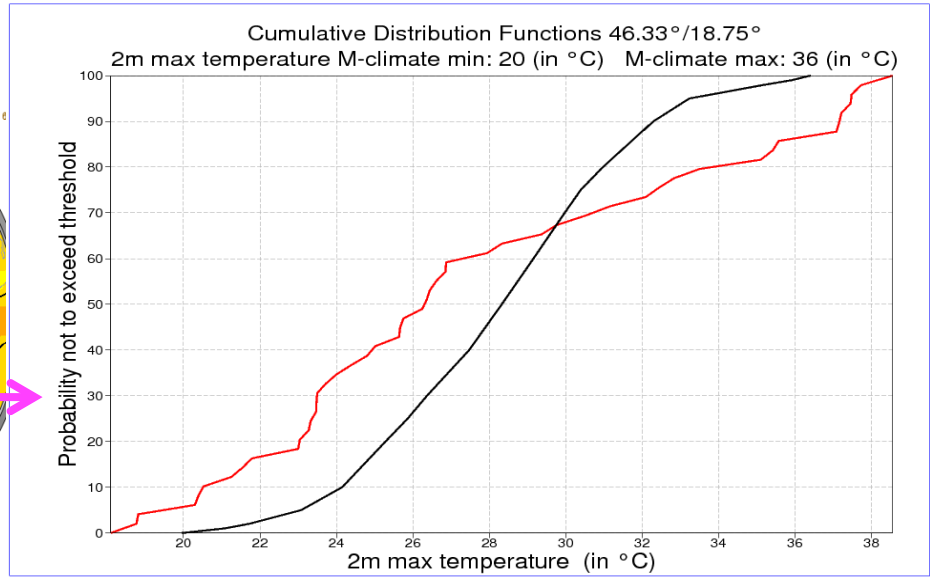


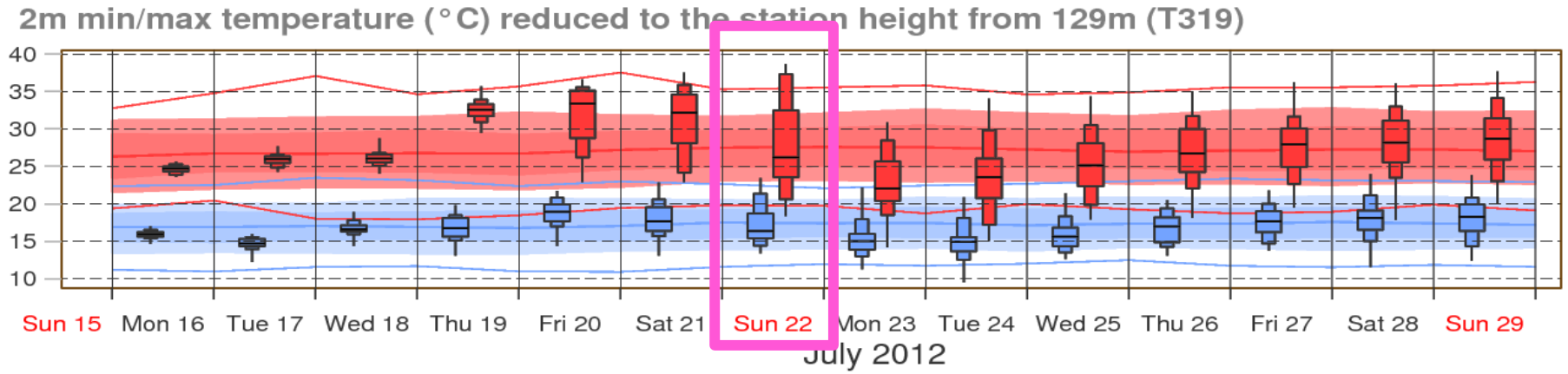


- EFI forecast shows cold conditions over Central Europe and hot weather to the east over the Balkans.
- SOT gives additional information. In the area between the cold and hot weather SOTs overlap. This is a signal of very uncertain forecast – over that area extremely low and extremely high temperatures are possible at the same time.

A case of very large uncertainty



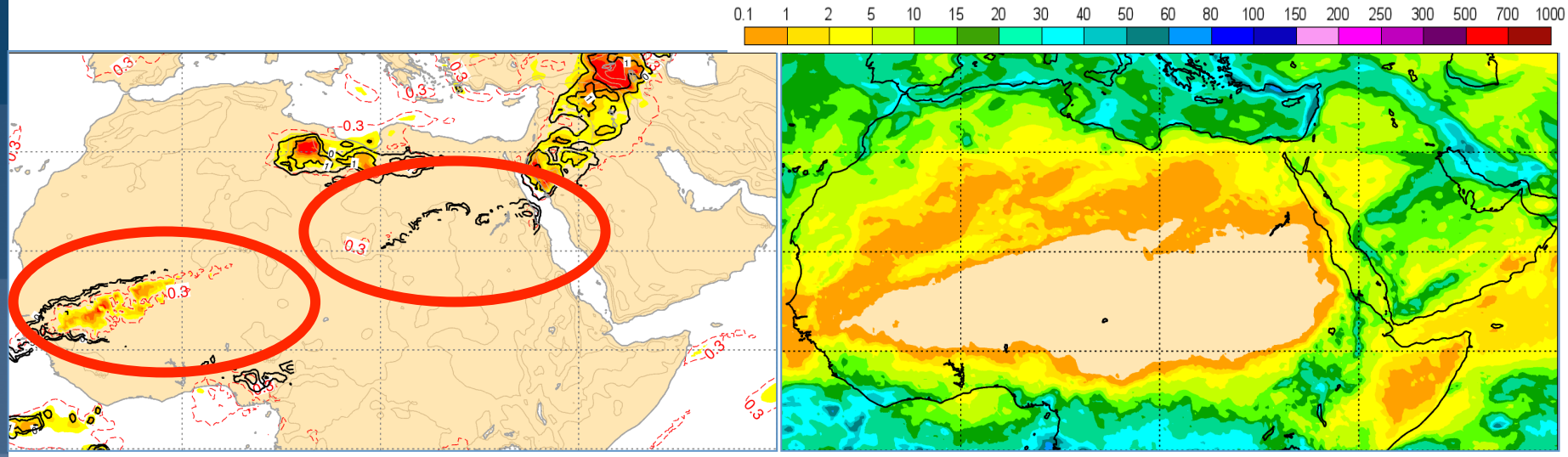




Some ENS members predict maximum temperature below the M-climate minimum, but some – above the M-climate maximum! This large uncertainty is related to the passage of a cold front.

Some limitations

EFI &SOT for precipitation **M-climate Q99**



- SOT is not defined when M-climate Qc(90)= Qc(99) (to avoid division by 0). This leads to some noise on the plots. To avoid this and to close SOT contours for snowfall, SOT is arbitrarily set to -1 where not defined only for plotting purposes.

Operationally available EFI fields

- In the current operational system every EFI field is based on a forecast range of 24 hours or longer.
- Since each meteorological parameter is valid for a period the content is either an accumulated value (e.g. precipitation), a mean over a period (e.g. temperature or mean wind) or an extremum (maximum or minimum) over that period (e.g. wind gust).
- Each 24-hour period variable is worked out as a post-processed value based on four 6-hourly forecast time steps. E.g. a mean over a 00-00 UTC period is a mean of the 06-12-18 and the ending 00 UTC fields.
- *Importantly*, for wind gusts, the 6 hourly wind gust values used are maxima within the preceding 6 hours (diagnosed by interrogating the model run at every time step).

Operationally available EFI fields

EFI and SOT parameters:

- 2-metre mean temperature index (2ti)
- total precipitation index (tpi)
- 10-metre mean wind speed index (10wsi)
- 10-metre maximum wind gusts index (10fgi)
- 2-metre minimum temperature index (mn2ti)
- 2-metre maximum temperature index (mx2ti)
- total snowfall index (sfi)
- maximum significant wave height index (maxswhi)
- CAPE (capei)
- capeshear (capesi)

* Parameters in red available since 19th June 2012
* Parameters in blue available since summer 2015

Operationally available EFI fields

24h interval: parameters 2ti, tpi, 10swi, 10fgi, mn2ti, mx2ti, sfi, maxswhi

- 00 UTC: 00-24, 24-48, 48-72, 72-96, 96-120, 120-144, 144-168*
- 12 UTC: 12-36, 36-60, 60-84, 84-108, 108-132, 132-156, 156-180

72h interval: parameters 2ti, tpi, 10swi

- 00 UTC: 00-72, 24-96, 48-120, 72-144, 96-168, 120-192, 144-216
- 12 UTC: 12-84, 36-108, 60-132, 84-156, 108-180, 132-204, 156-228

120h interval: parameters 2ti, tpi, 10swi

- 00UTC: 00-120, 24-144, 48-168, 72-192, 96-216, 240-360**
- 12UTC: 12-132, 36-156, 60-180, 84-204, 108-228 , 240-360

240h interval: parameters 2ti, tpi, 10swi

- 00UTC: 000-240
- 12UTC: 000-240

360h interval: parameters 2ti, tpi, 10swi

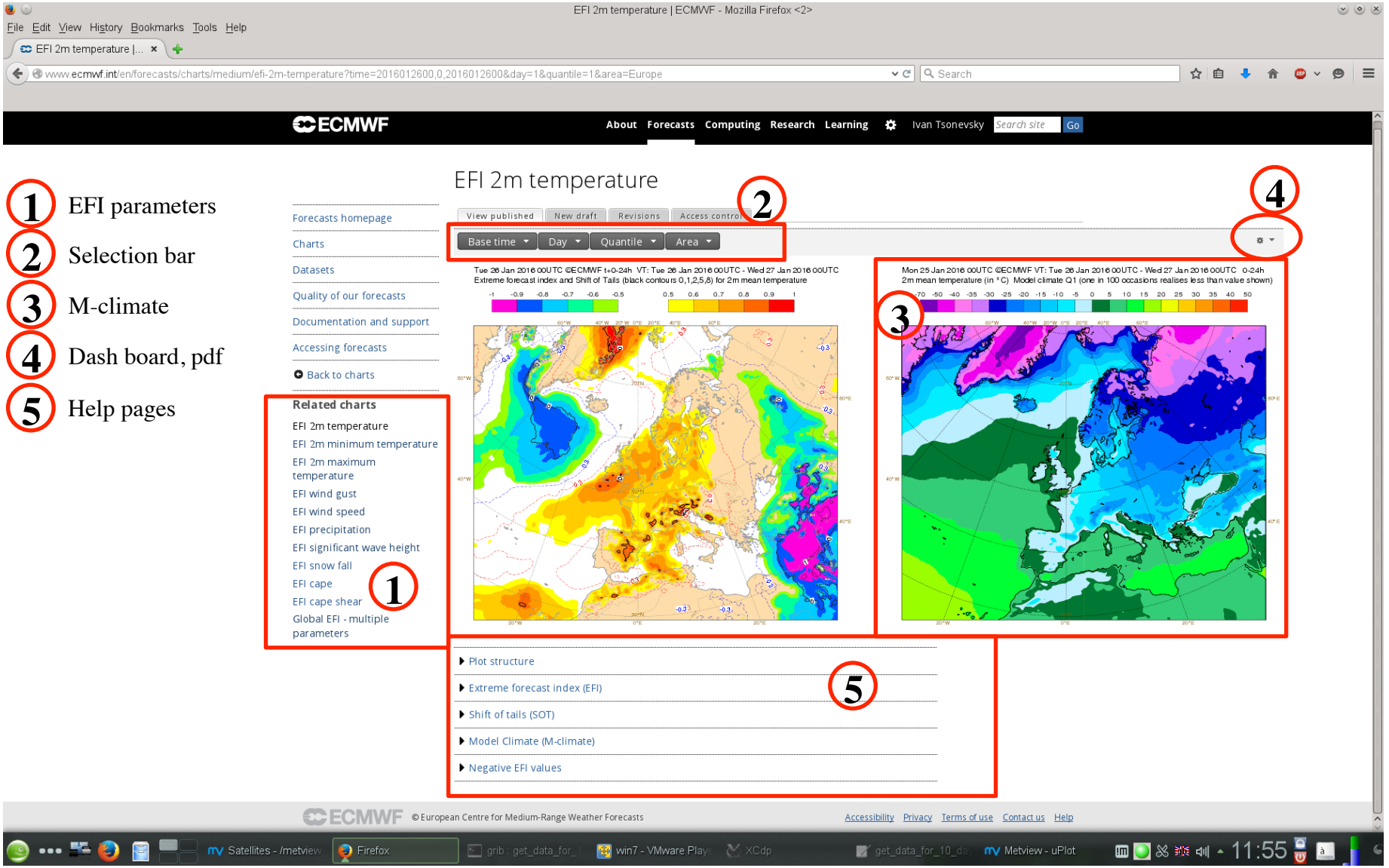
- 00UTC: 000-360

* available since 19th June 2012

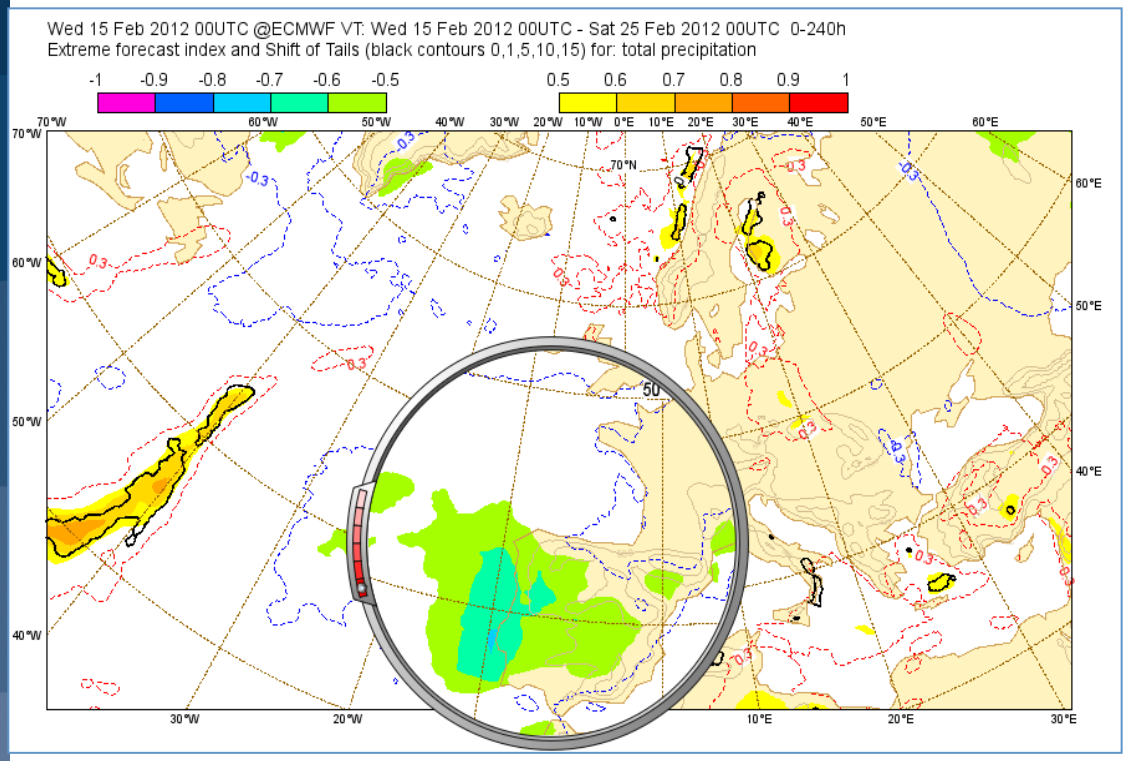
** available since 12th May 2015

http://www.ecmwf.int/en/forecasts/charts/catalogue/efi

1. EFI parameters
2. Selection bar
3. M-climate
4. Dash board, pdf
5. Help pages



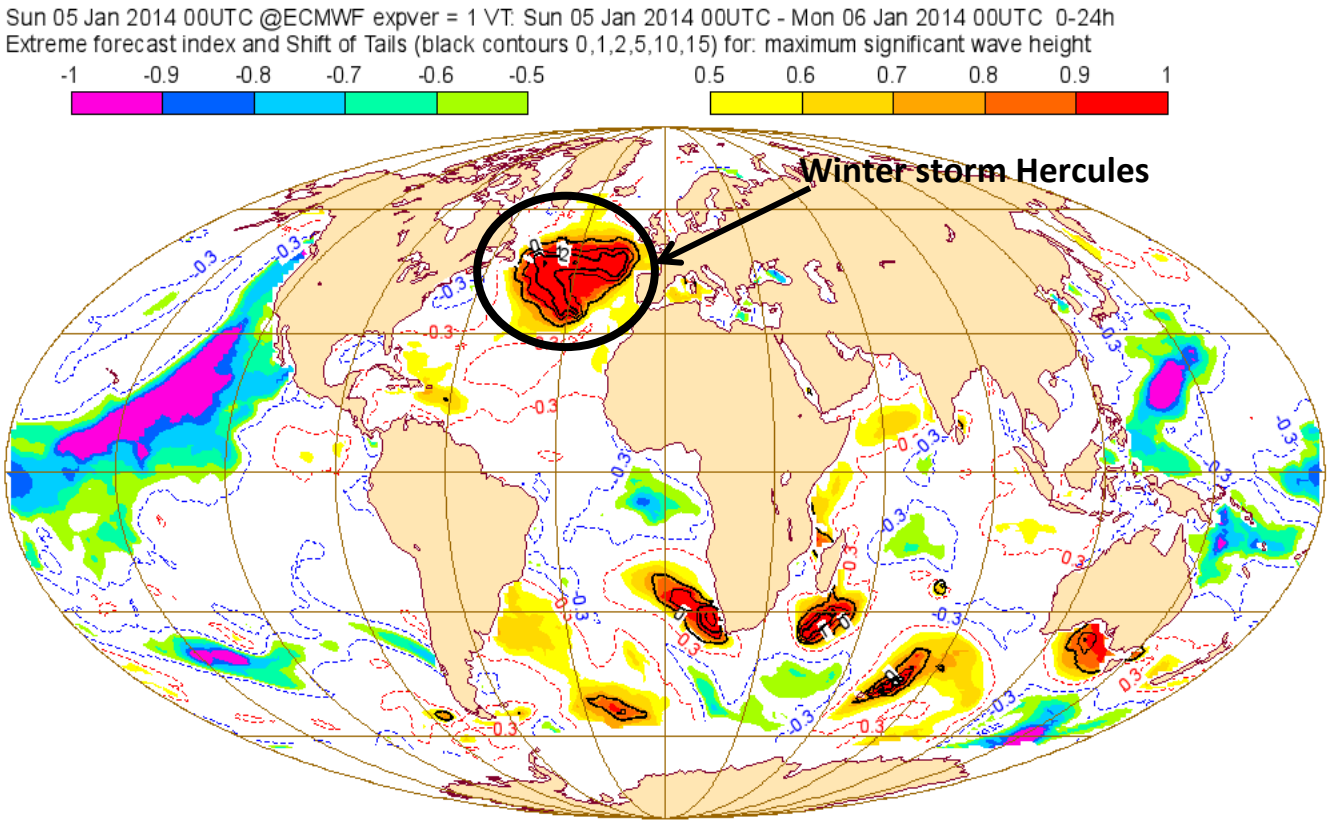
Negative EFI for precipitation



Severe drought in Portugal

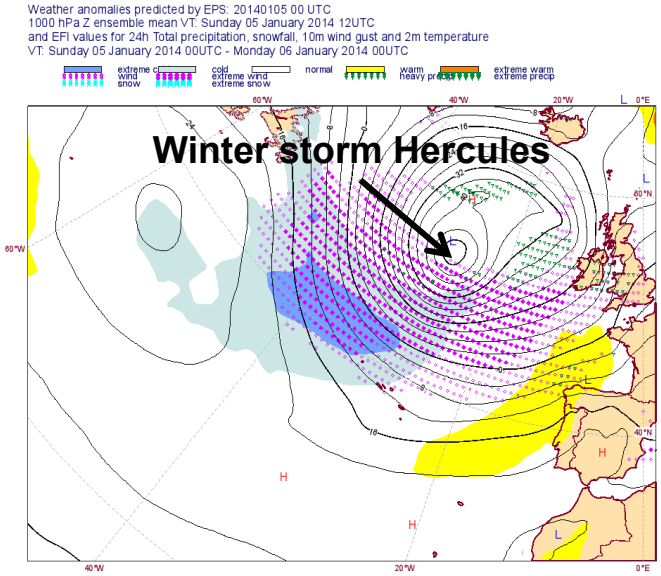
- For 24-hour accumulations negative EFI for precipitation does not make sense because precipitation is bounded by 0.
- For accumulations over longer periods negative EFI does make sense. It shows the risk of dry weather.

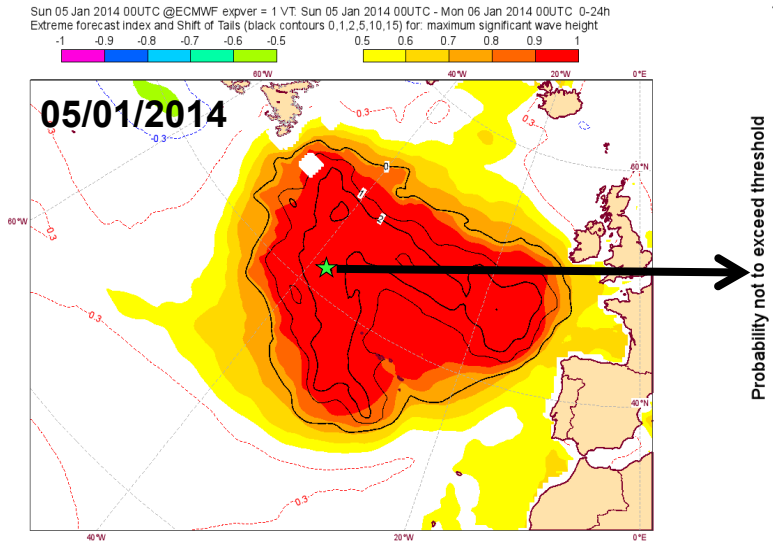
EFI for waves

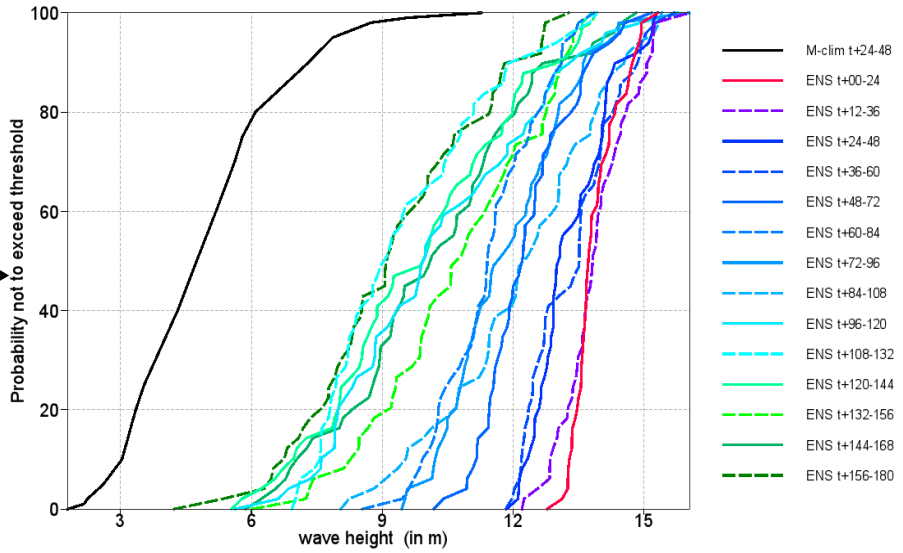


- Negative EFI (calm sea) also plotted on the web.
- The winter storm Hercules generated waves up to 20 m in height on 5 and 6 January 2014.

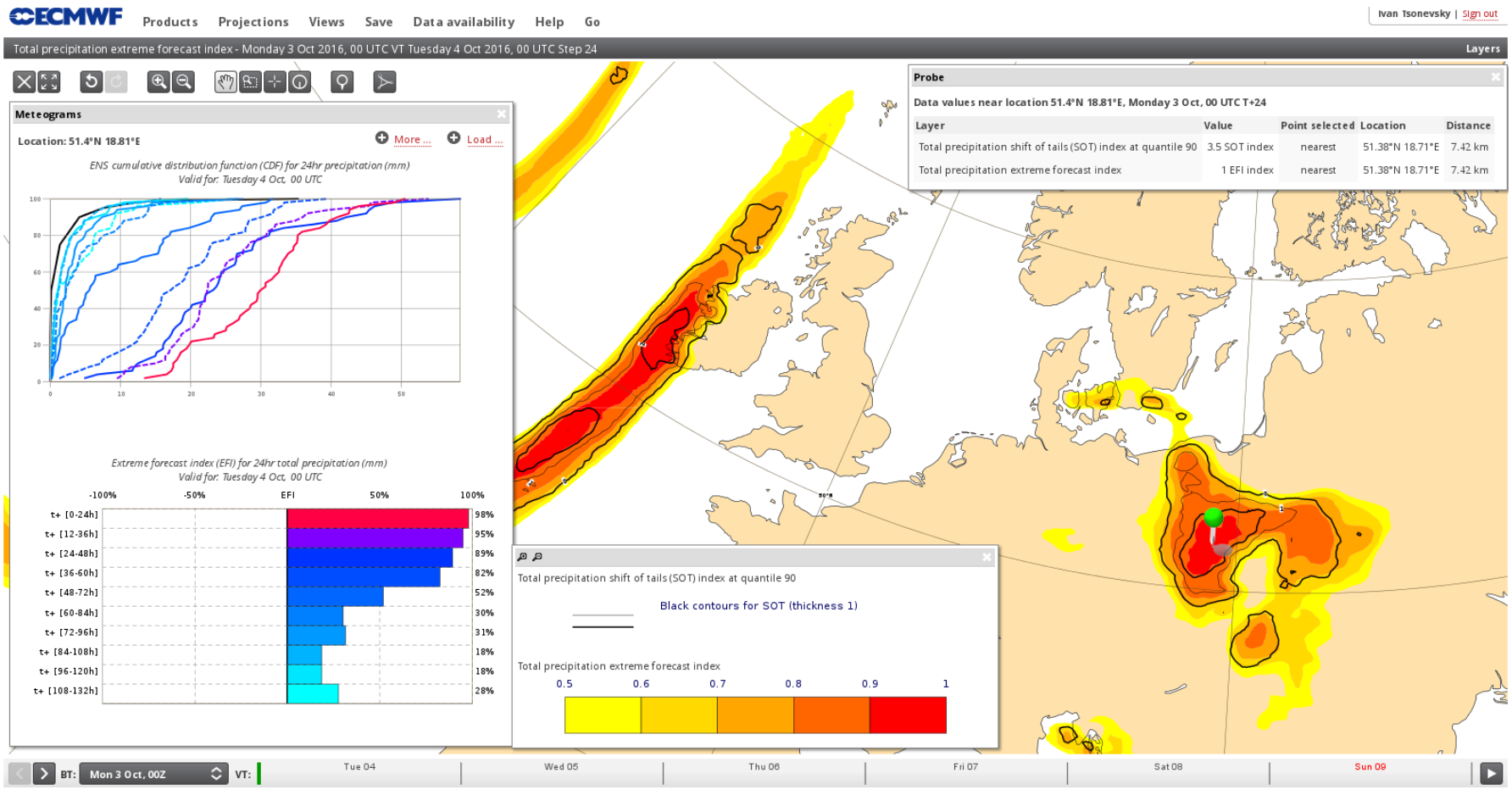
Historic swell – Storm Hercules







EFI on the ecCharts

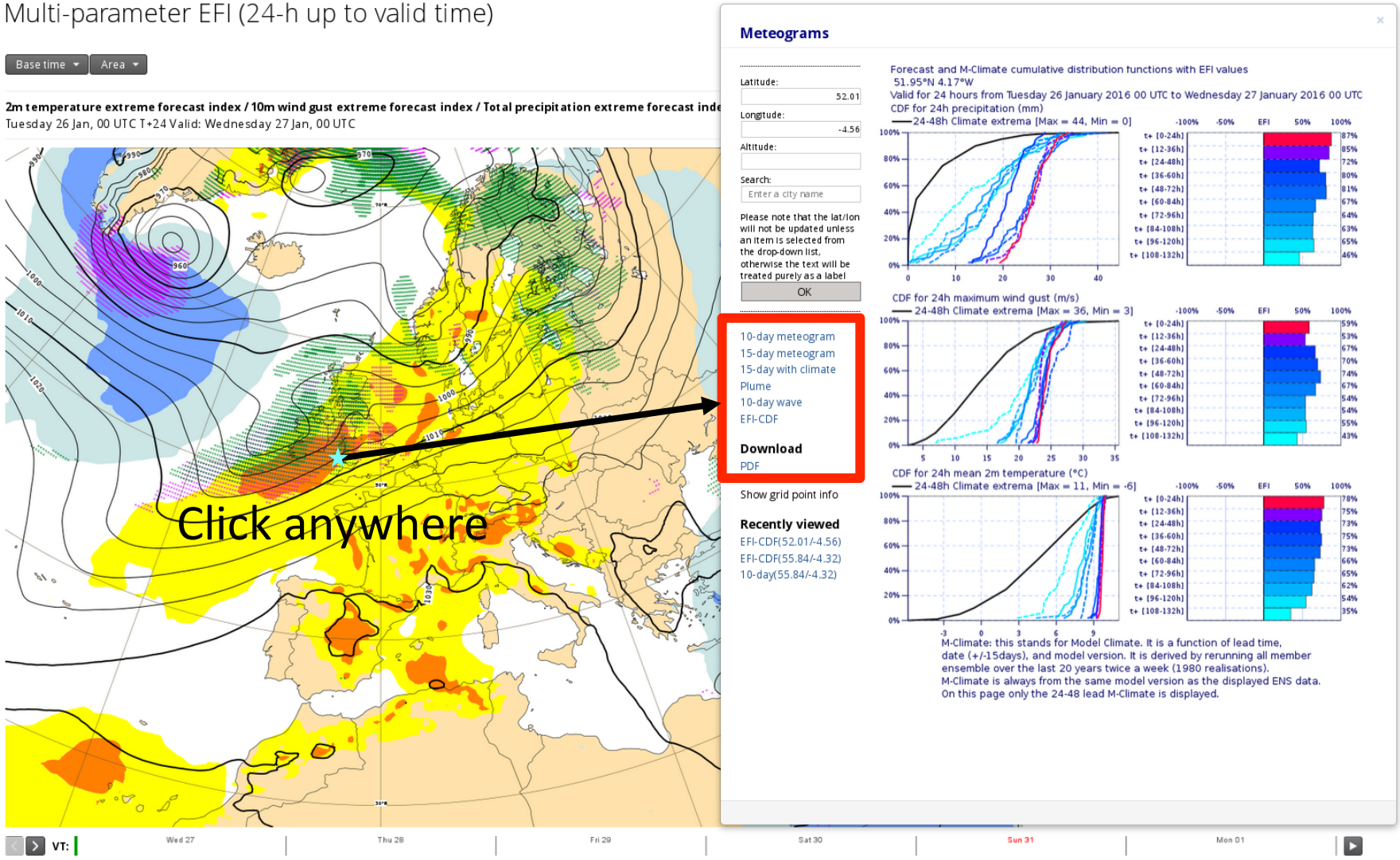


- EFI & SOT
- CDFs just for (2t, 10fg and tp)

Clickable charts

http://www.ecmwf.int/en/forecasts/charts/interactive-charts

Multi-parameter EFI (24-h up to valid time)



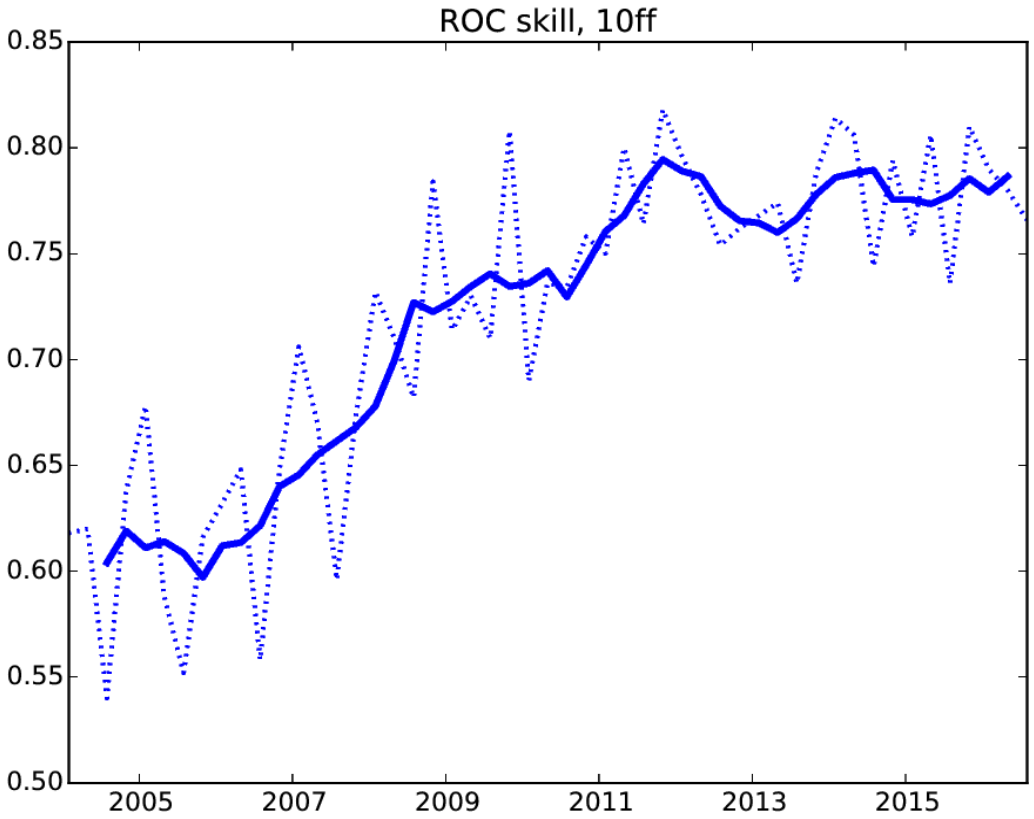
EFI Verification

- Verification of the EFI has been done using synoptic observations over Europe available on the GTS.
- An extreme event is taken as occurring if the observation exceeds the 95th percentile of the observed climate for that station (calculated from a 15-year sample).
- The ability of the EFI to detect extreme events is assessed using the area under the Relative Operating Characteristic (ROCA).
- $$EFI\ skill\ score = score_{forecast} - score_{reference} / score_{perfect\ forecast} - score_{reference} = ROCA_f - 0.5 / 1 - 0.5 = 2ROCA_f - 1$$

  0 → no skill, 1 → perfect score

- The verification is done for 3 parameters: 2m mean temperature, 10m mean wind speed and total precipitation

EFI Verification



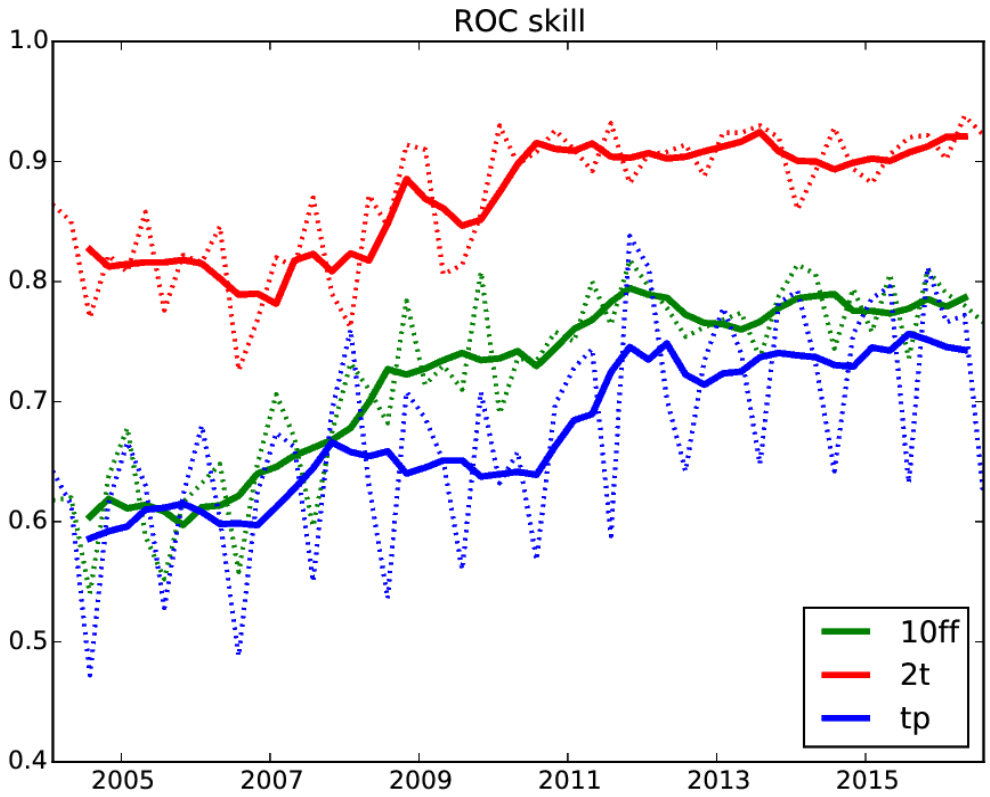
EFI Skill = 2*ROCA-1

EFI Skill = 0 no skill

EFI Skill = 1 perfect score

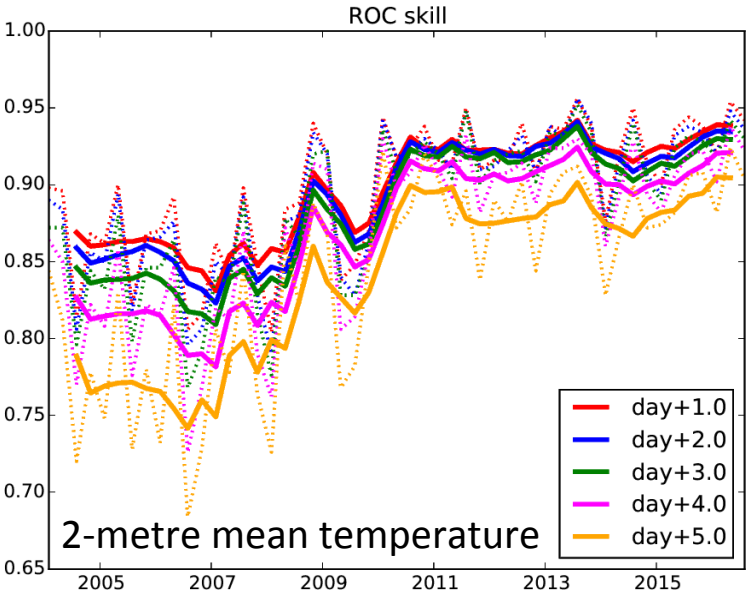
- **The plot shows the skill of the EFI for 10-metre wind speed** (a supplementary headline score adopted by the ECMWF Council) **at forecast day 4** (t+72-96h for 00UTC)**.**
- **The solid curve shows a four-season running mean.**

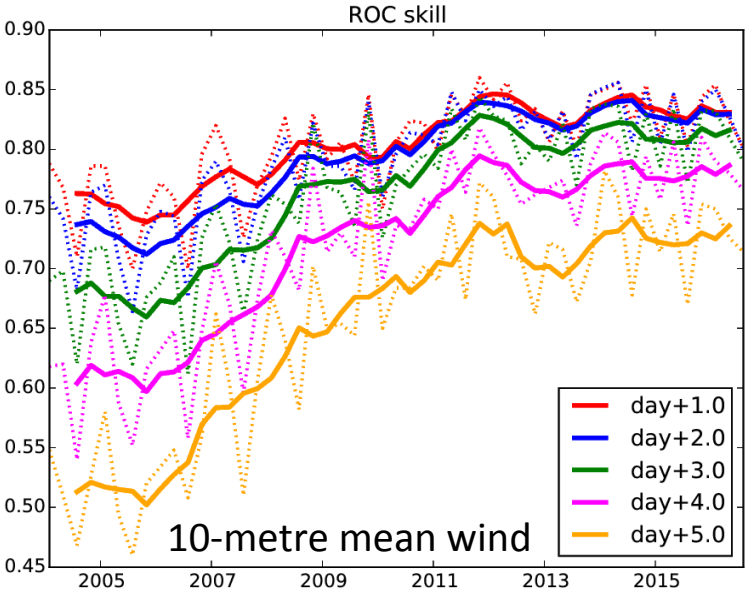
EFI Verification

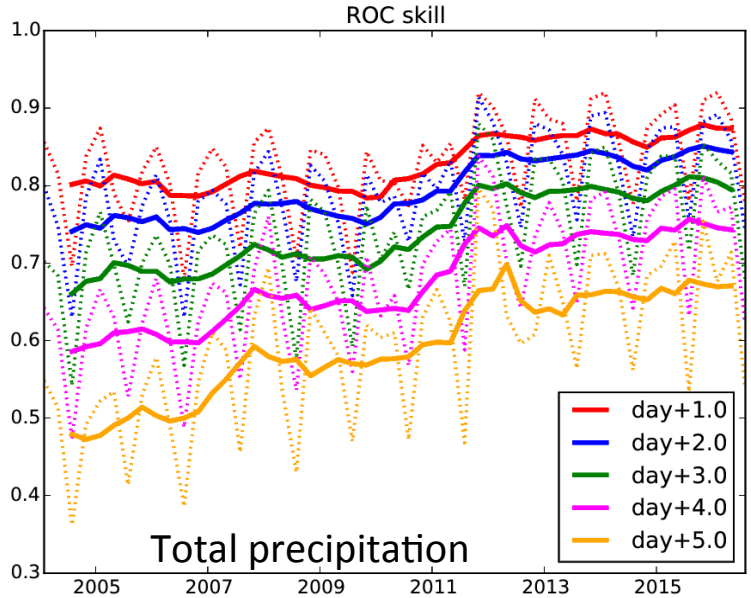


- Solid curves show a four-season running mean and dashed curves show seasonal EFI skill scores for 2m mean temperature (2t), 10 metre mean wind speed (10ff) and total precipitation (tp) for day 4 (t+72-96h for 00UTC).
- The EFI for 2m temperature is more skilful than EFI for the other two parameters.

EFI Verification







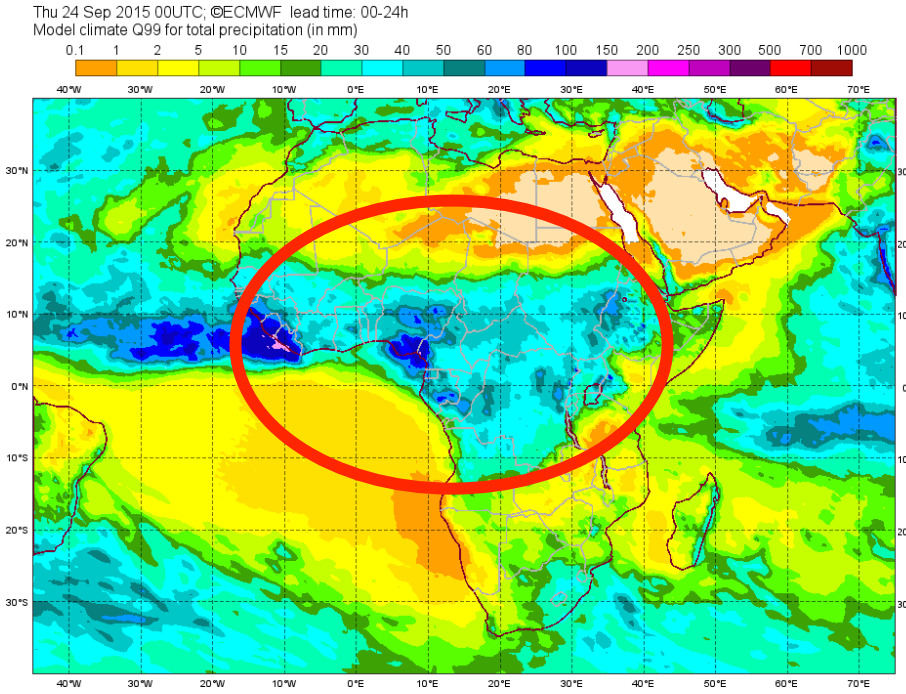
- EFI skill as a function of the lead time
- Notable seasonal cycle in the EFI skill especially for total precipitation with its minimum in summer

Known issues

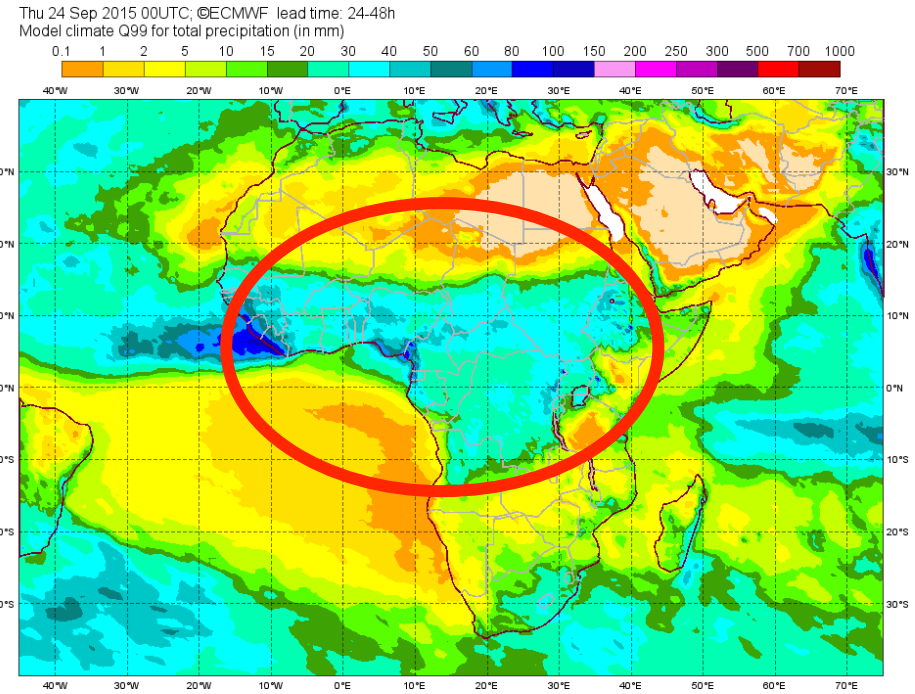
- **Re-forecast sample size is still not sufficient for providing robust climate:**
  - ✓ The increase of the sample size since May 2015 has considerably improved the M-climate but still:
    - There is some noise, especially in the tails of the climate distribution.
- **M-climate is affected by the model biases:**
  - ✓ Jumpiness in the M-climate for different lead times
  - ✓ This does not affect the EFI/SOT

Known issues – an example, tropical Africa

T+0-24h

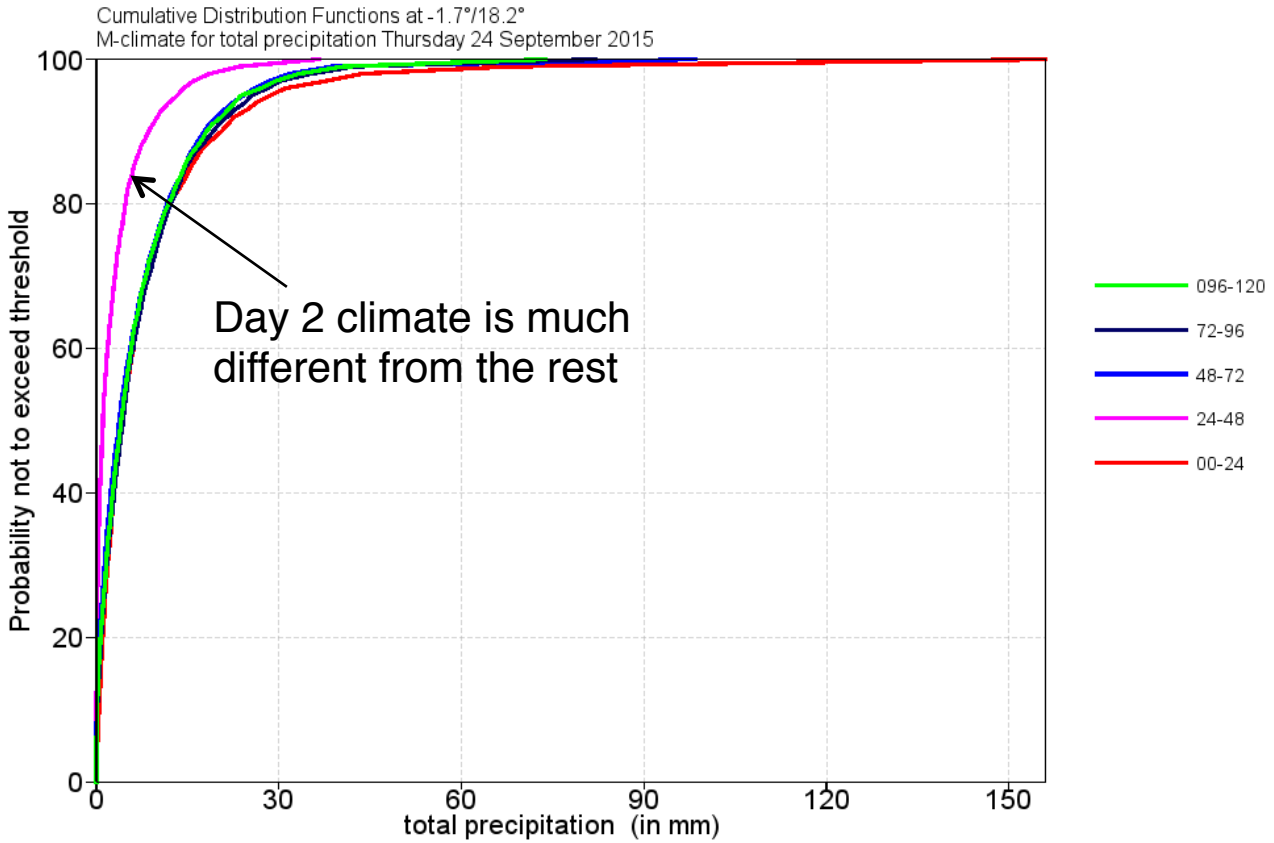


T+24-48h



- The striking difference between t+00-24h and t+24-48h climate is noticeable on these charts which represent 99th model climate percentile. Precipitation amounts corresponding to Q99 for 00-24h are much bigger than those for 24-48h.

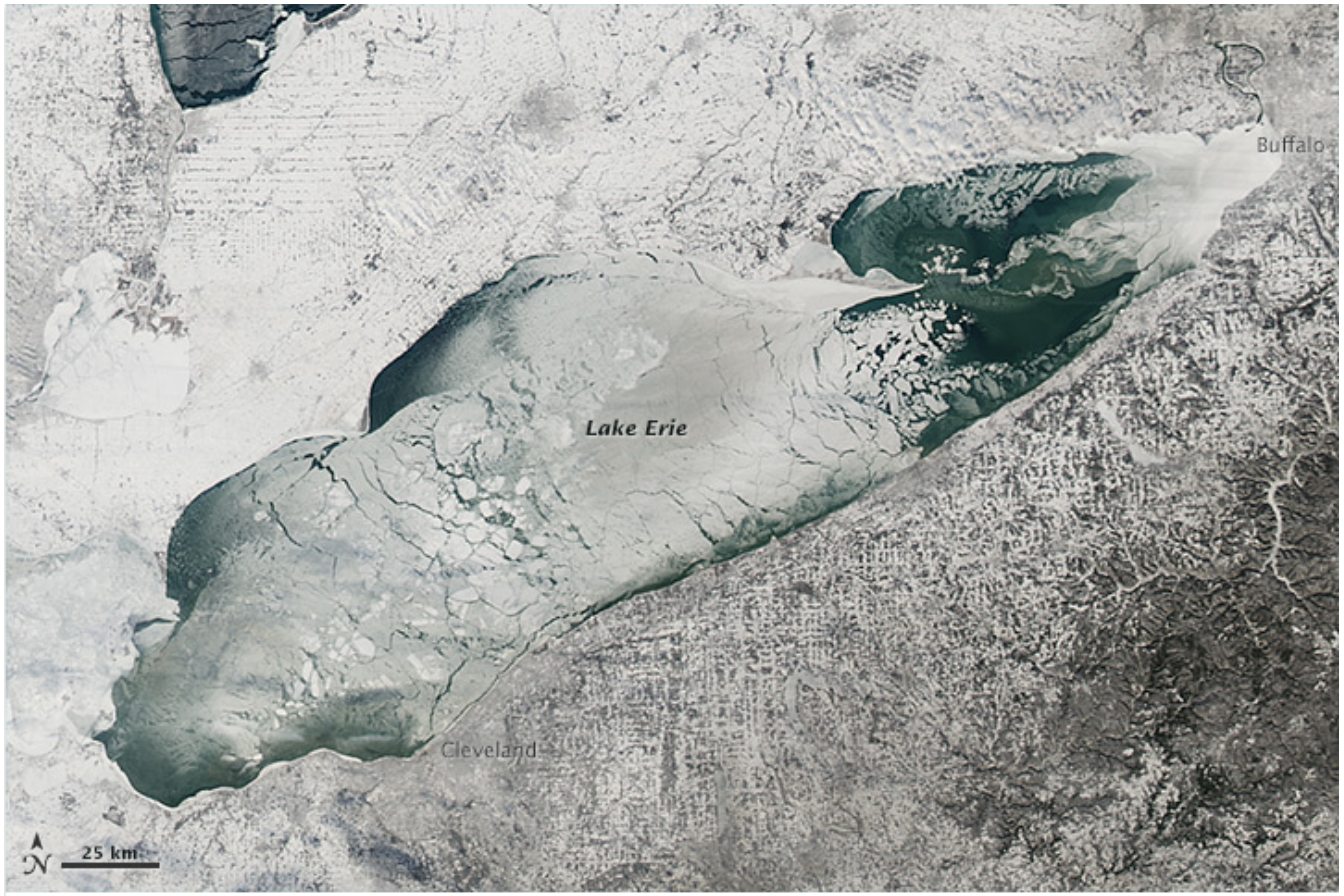
Known issues – an example, tropical Africa



M-climate is not perfect. It is affected by model biases and therefore it depends on the lead time:

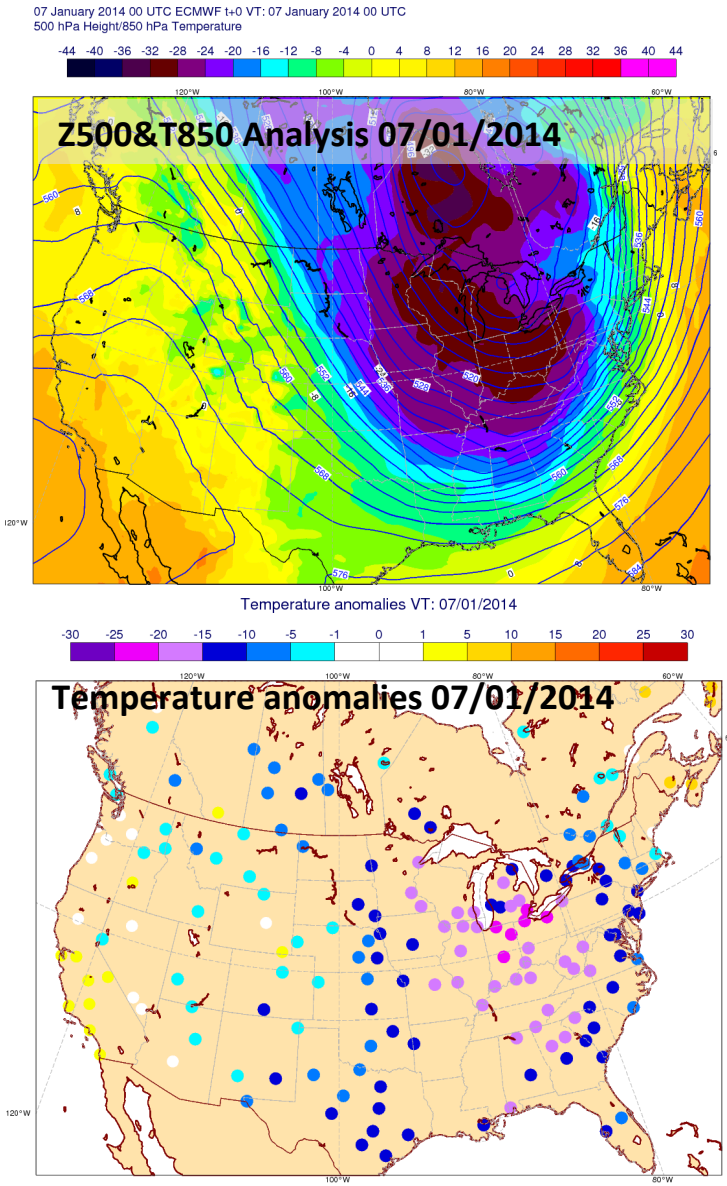
- Jumpiness in the M-climate for different lead times
- Ideally, this shouldn't affect the EFI

US cold snap January 2014



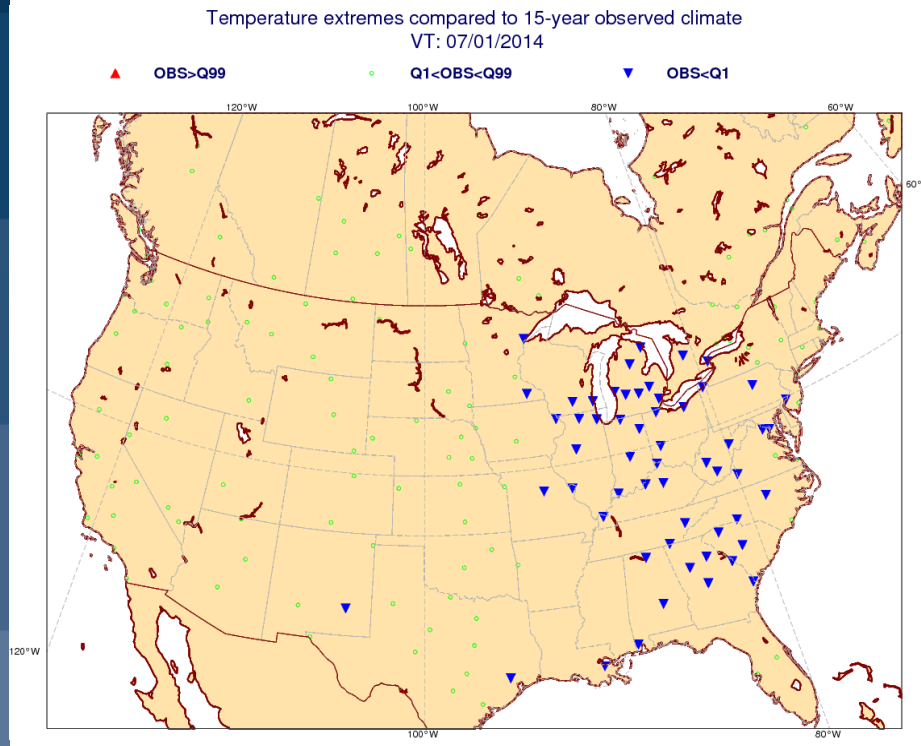
Great Lakes frozen

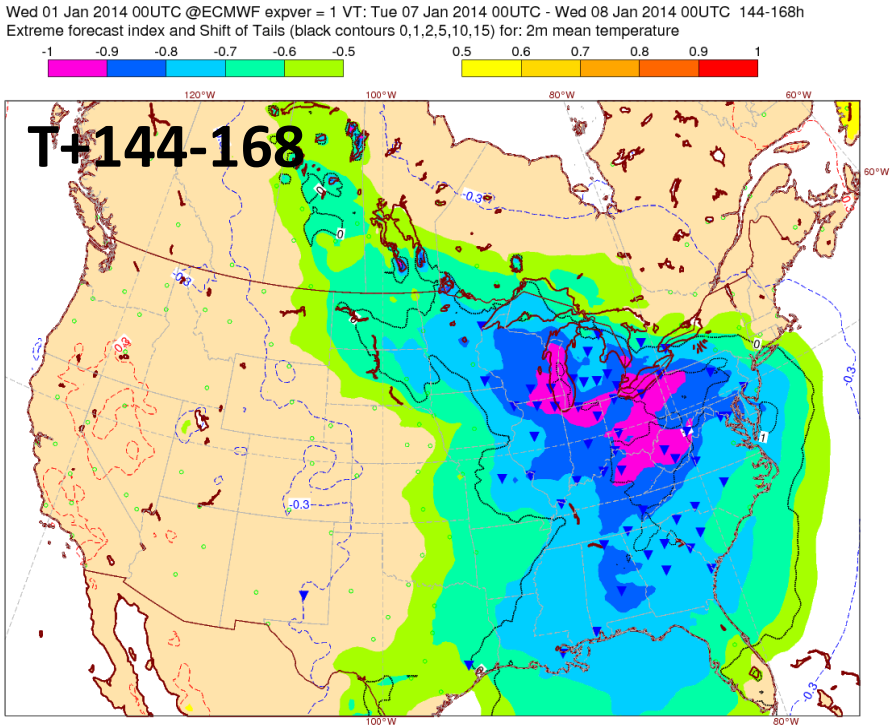
US cold snap, January 2014



- An extremely cold airmass from the Arctic region dropped the temperatures in the US January 5-7, 2014.
- Record freezing temperatures (15 to 22°C below normal) brought many cities to a standstill. Over a dozen deaths were attributed to the cold wave.
- It was the coldest weather since early February 1996.

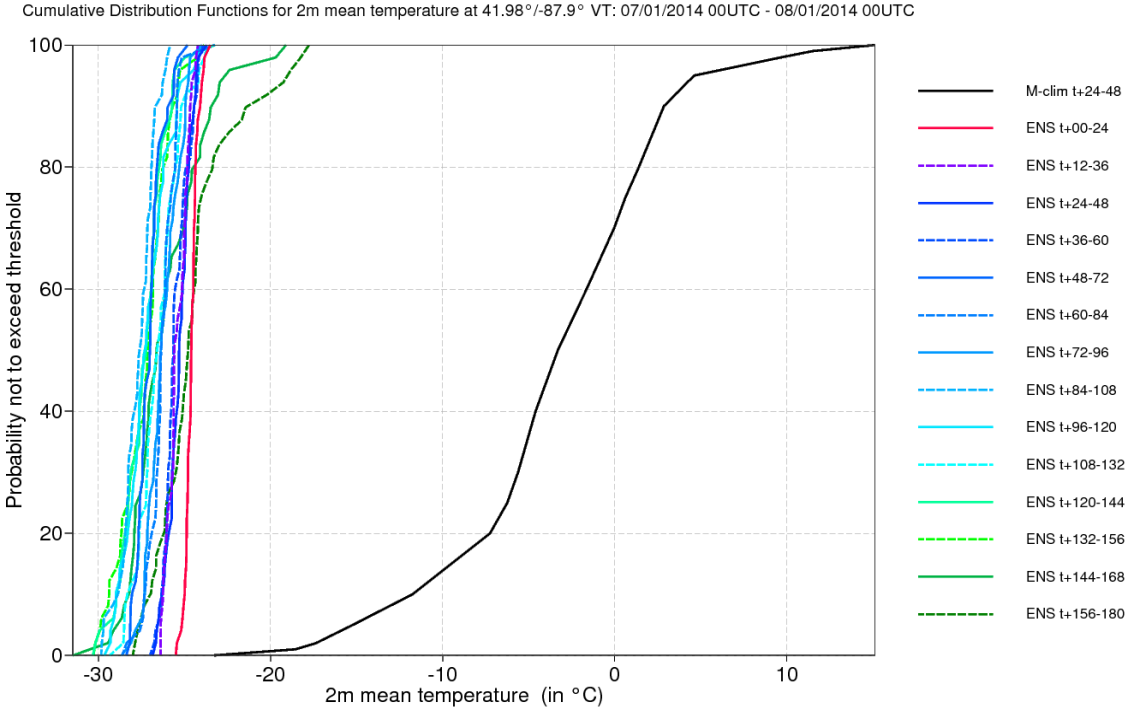
US cold snap, January 2014

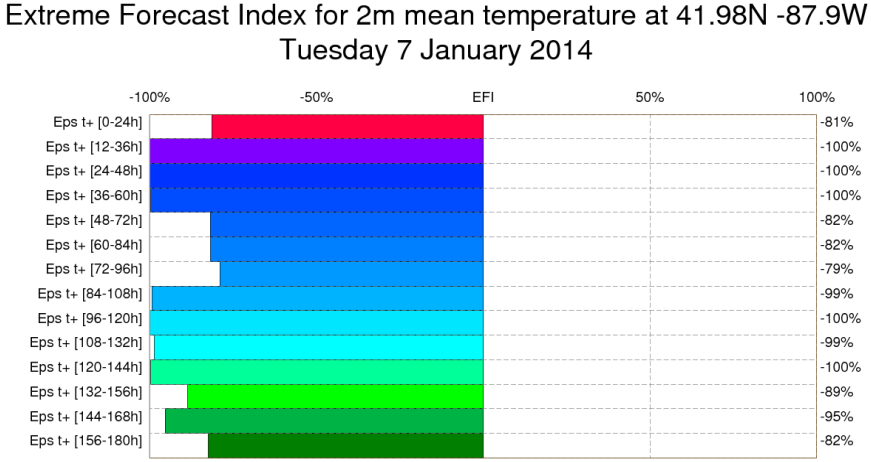




- Blue symbols denote extremely low temperatures below 1st percentile of the 15-year climatology from observations.
- Positive SOT (black contours) and high negative EFI match very well the areas of extremely low temperatures even 7 days in advance.

US cold snap, January 2014





- CDFs and EFI forecast for Chicago
- All the forecast CDFs are closely packed.
- Near vertical CDFs imply high confidence in the forecast.

Floods in Central Europe

June 2013

TECHNICAL MEMORANDUM

723

ECMWF forecast performance during the June 2013 flood in Central Europe

T. Haiden, L. Magnusson, I. Tsonevsky, F. Wetterhall, L. Alfieri, F. Pappenberger, P. de Rosnay, J. Muñoz-Sabater, G. Balsamo, C. Albergel, R. Forbes, T. Hewson, S. Malardel, D. Richardson

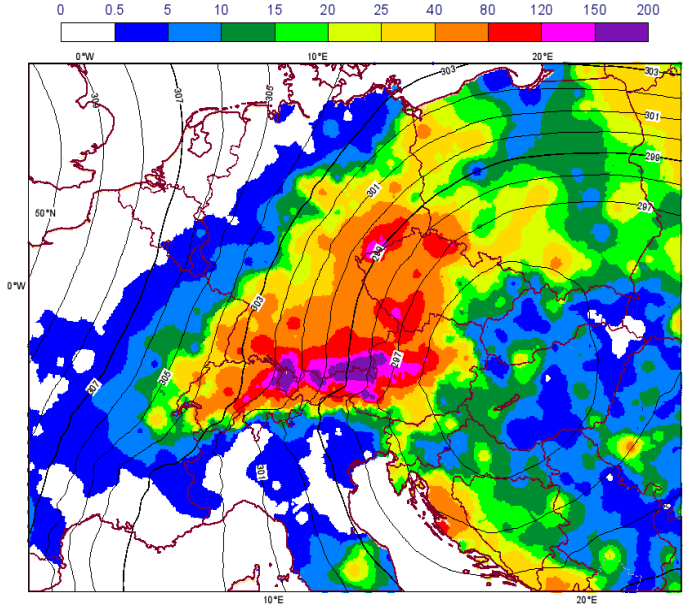
Forecast and Research Departments

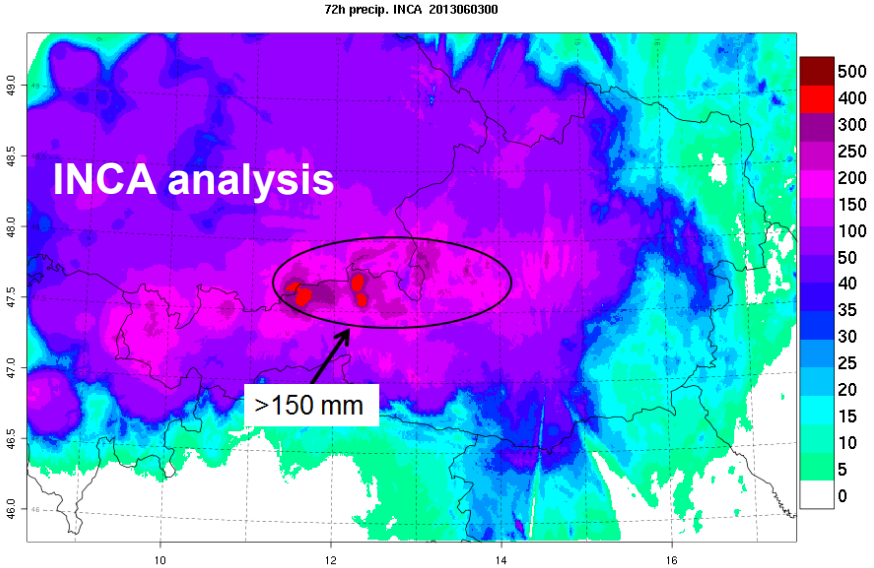
June 2014

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen

Analysis

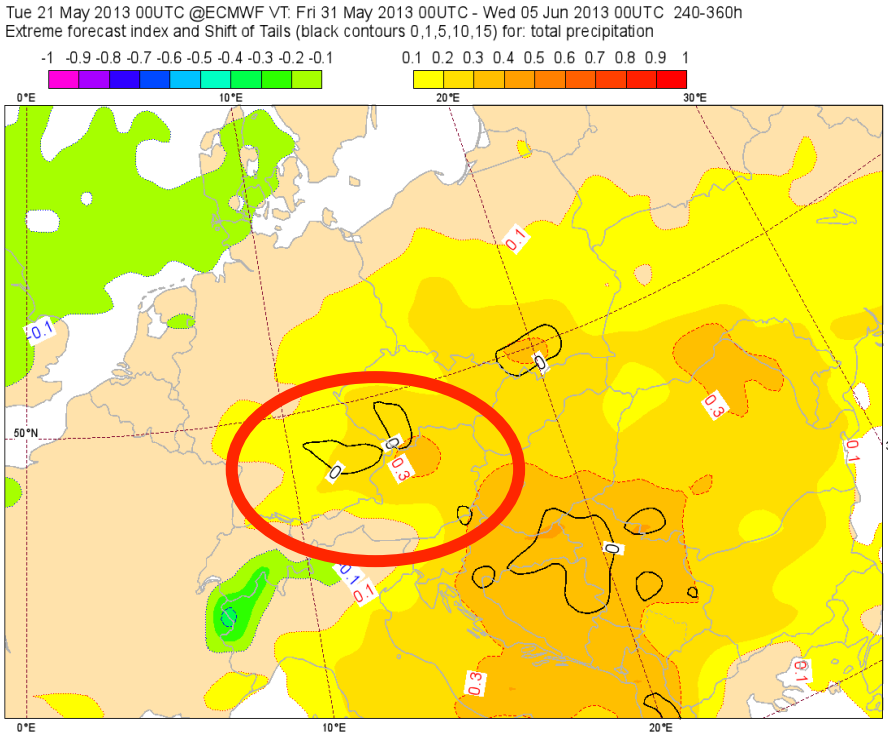
Observed rainfall interpolated on a grid and Z700 (mean over the period) ECMWF analysis
VT: 31/05/2013 06 UTC – 03/06/2013 06UTC

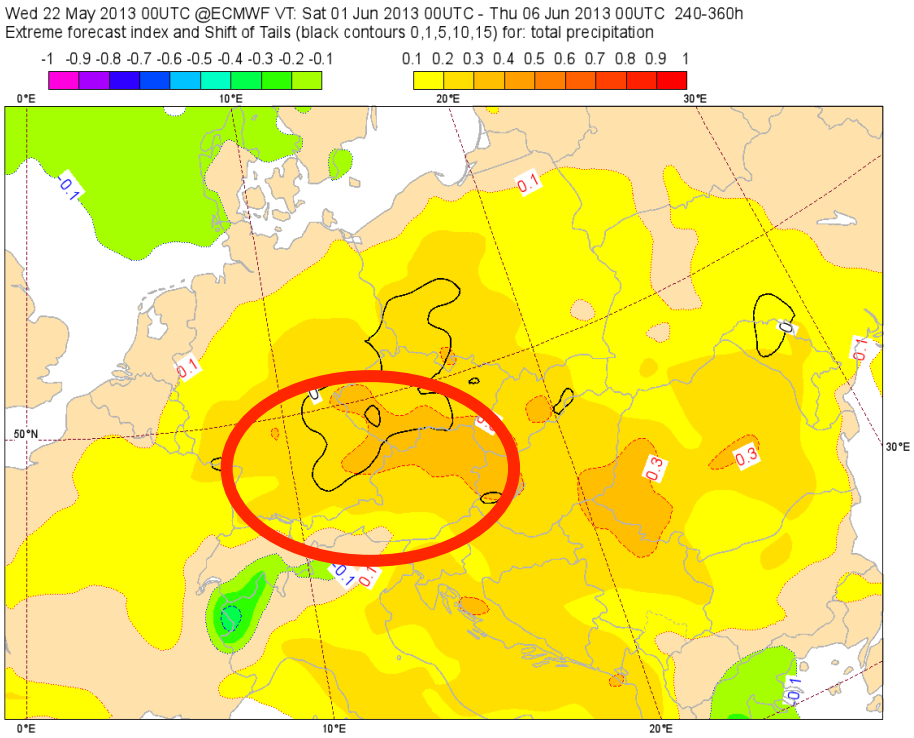




- A quasi-stationary low pressure system brought moist, warm air from the east and northeast into Central Europe causing massive amounts of rain in southern Germany and western Austria.
- Orographic enhancement of precipitation along the northern side of the Alps played an important role.

EFI & SOT, total precipitation, T+240-360





- A remarkably strong signal in the EFI.
- Positive SOT marks the areas where the forecast system predicts exceptionally heavy rain.

EFI/SOT for forecasting severe convection

- Convective Available Potential Energy (CAPE) – MUCAPE in the lowest 350 hPa:

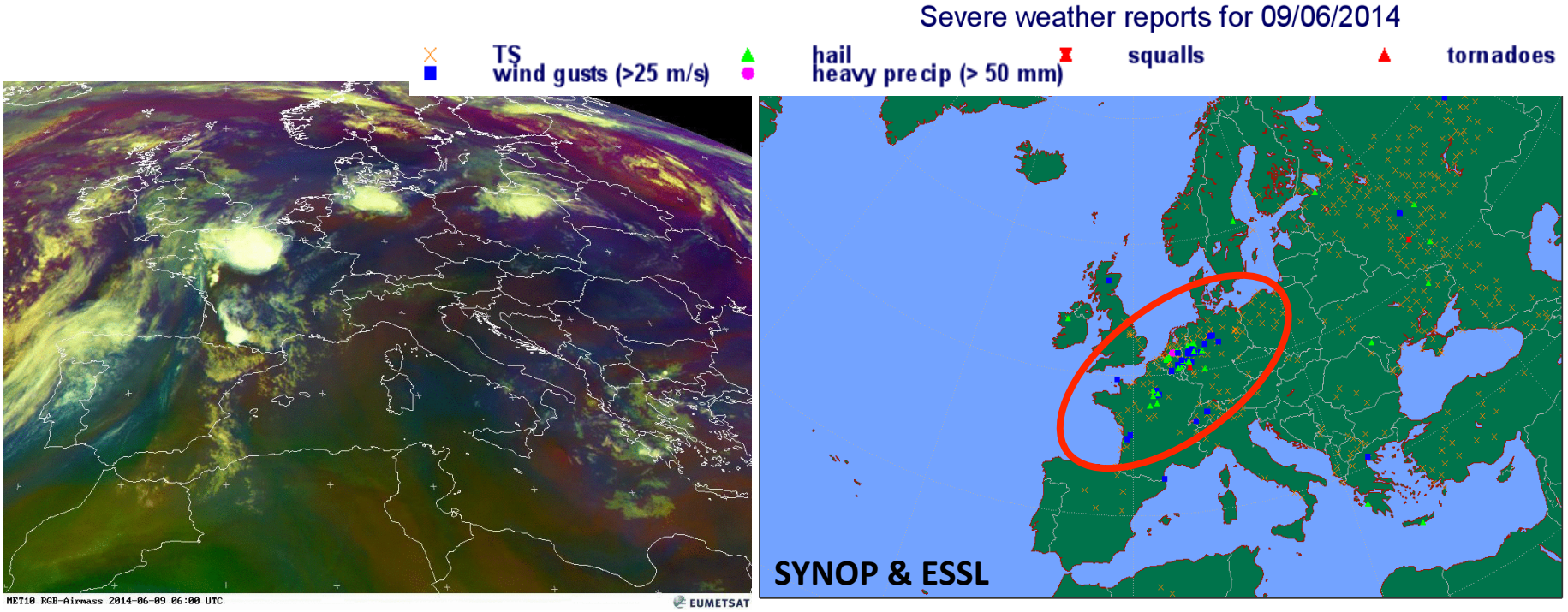
$$CAPE = \int_{z_{LFC}}^{z_{EL}} g\left(\theta_{e,up} - \theta_{e,sat}\right)/\theta_{e,sat}\; dz$$

- CAPE-SHEAR Parameter (CSP):

$$CSP = WS_{l_1 l_2}\sqrt{CAPE}$$

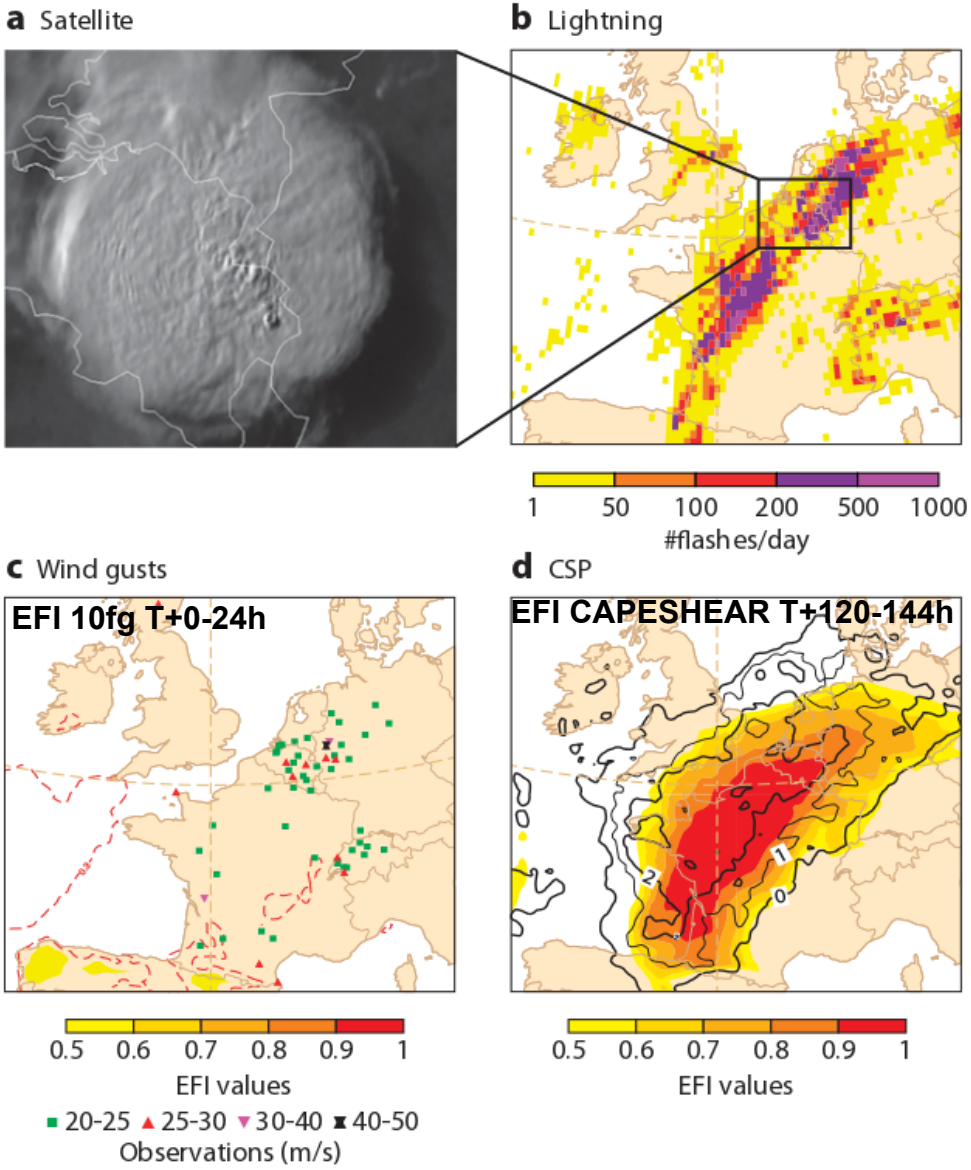
  - $WS_{l_1 l_2}$ - bulk shear between l_1=925 hPa and l_2=500 hPa;
  - $w_{max} = \sqrt{2\,CAPE}$ is the maximum vertical velocity in convective updraughts.
- Four values for each 24-hour period are considered and the maximum of these is retained.
- To avoid noise in the high latitudes, CAPE less than 10 J/kg is filtered out.

Severe convection, 9 June 2014



- Severe convection affected Western Europe on 9 June 2014.
- Deep moist convection developed along the western fringe of a hot air mass.
- Many weather reports of severe wind gusts and large hail.

Severe convection, 9 June 2014

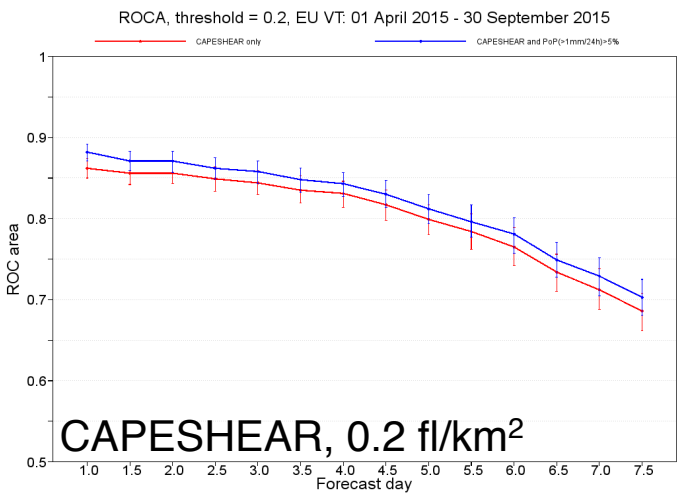


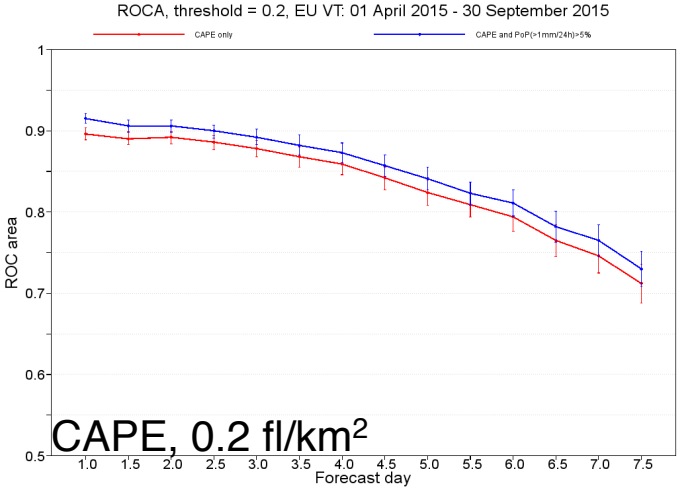
- Strong wind gusts were reported in France, Belgium, the Netherland and Germany.
- The maximum wind gust at Düsseldorf airport was 42 m/s.
- The EFI gave no indication of severe wind gusts even in the short range.
- The EFI for CAPESHEAR reached values close to 1 six days in advance.

Verification

- ROCA skill score to assess the ability of the forecast to discriminate between events and non-events
- Data sources:
  - ✓ Lightning density derived from the ATDnet lightning detection system (UK Met Office) for Europe
  - ✓ Severe weather reports (tornadoes, large hail and high winds) from the NOAA/NWS Storm Prediction Centre (SPC) for the USA
- Verification period: April – September (summer season in the NH)
- Two thresholds for lightning density: 0.2 and 0.5 flashes/km^2 per day (approximately 95th and 99th percentiles of lightning density distribution for the summer season)
- For Europe verification is performed just for land points

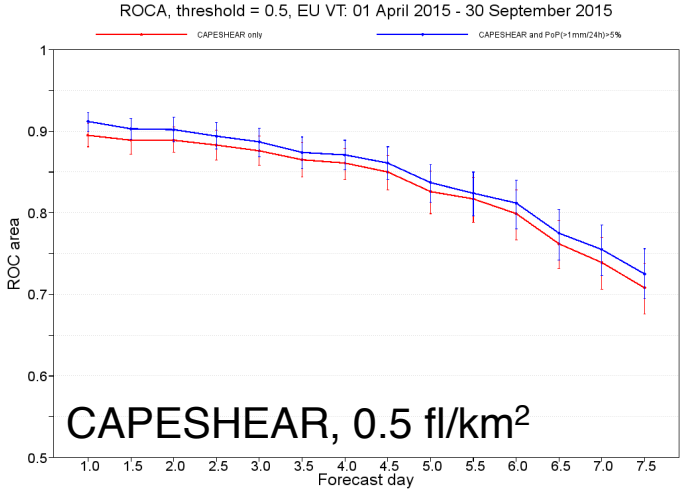
Verification, Europe

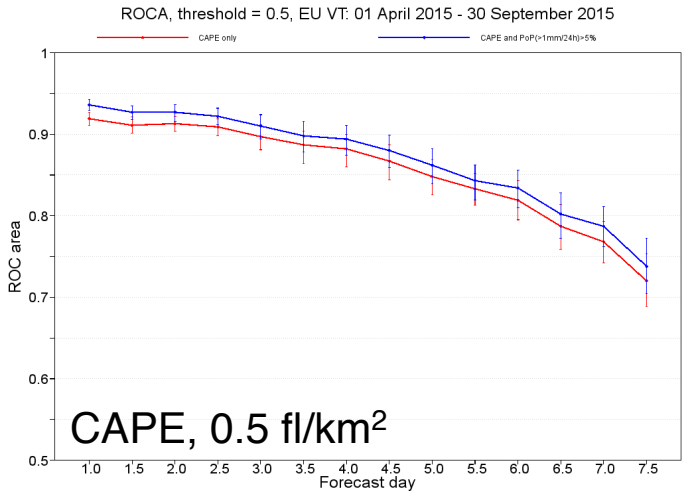




EFI only

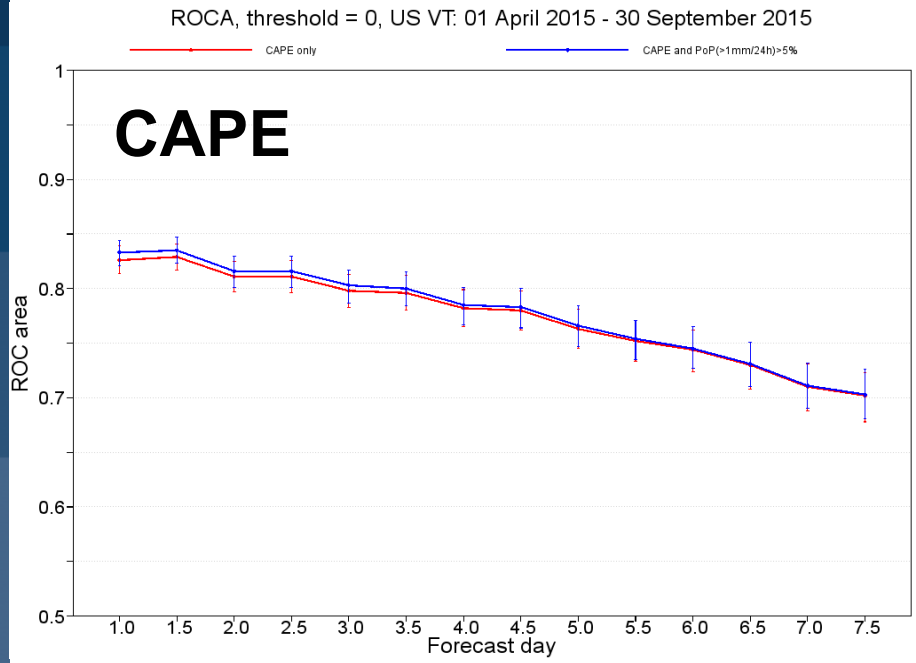
EFI and PoP

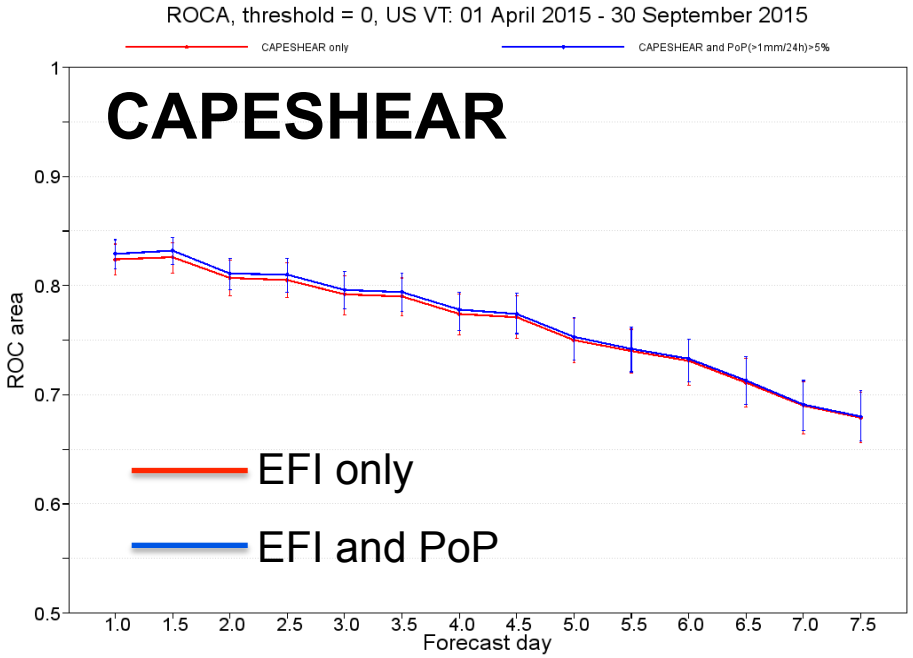




- Verification period 1 April – 30 September 2015
- EFI v. a combination of the EFI and PoP (>1mm/day) > 5%
- Higher skill when the EFI is conditioned by PoP

Verification, USA





- Verification period is 1 April – 30 September 2015
- EFI v. EFI and PoP (>1mm/day) > 5%
- The difference between the EFI only and EFI/PoP is marginal against severe weather reports

Verification

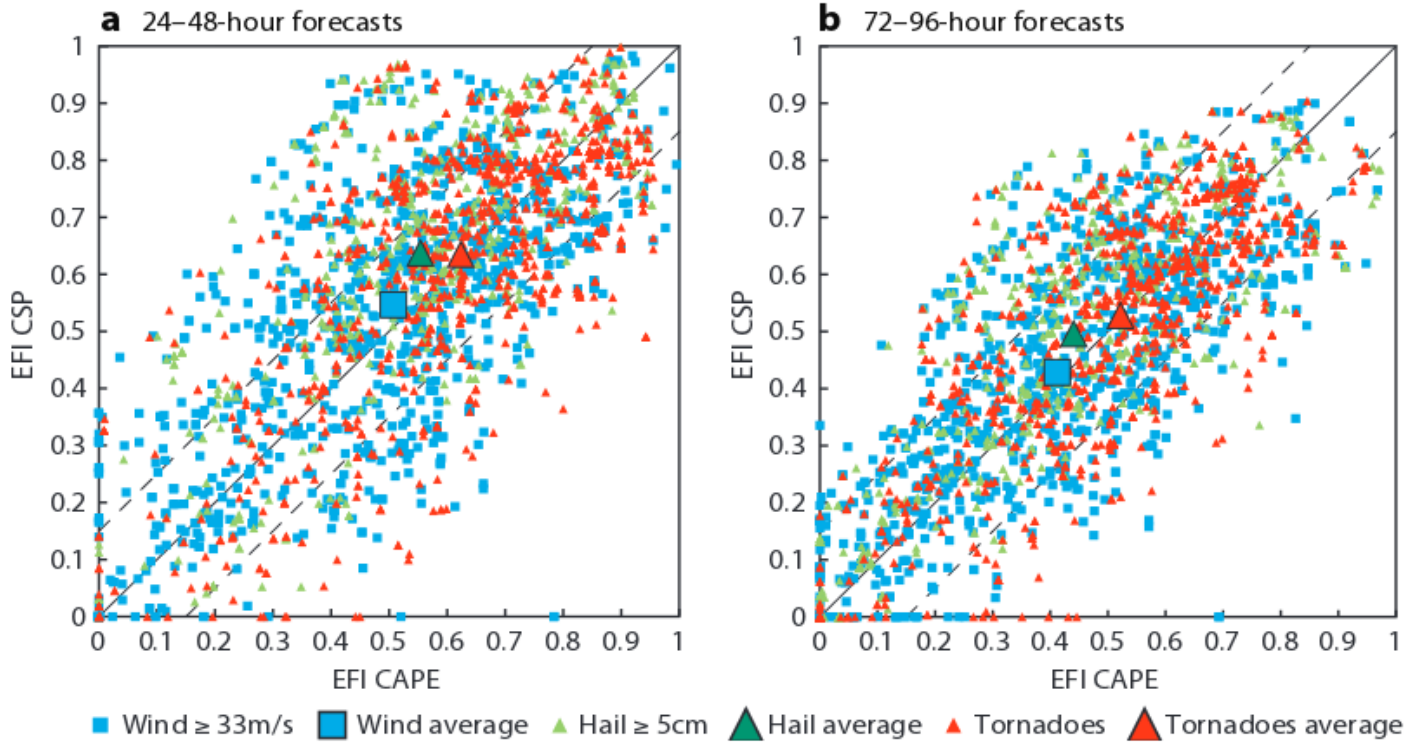


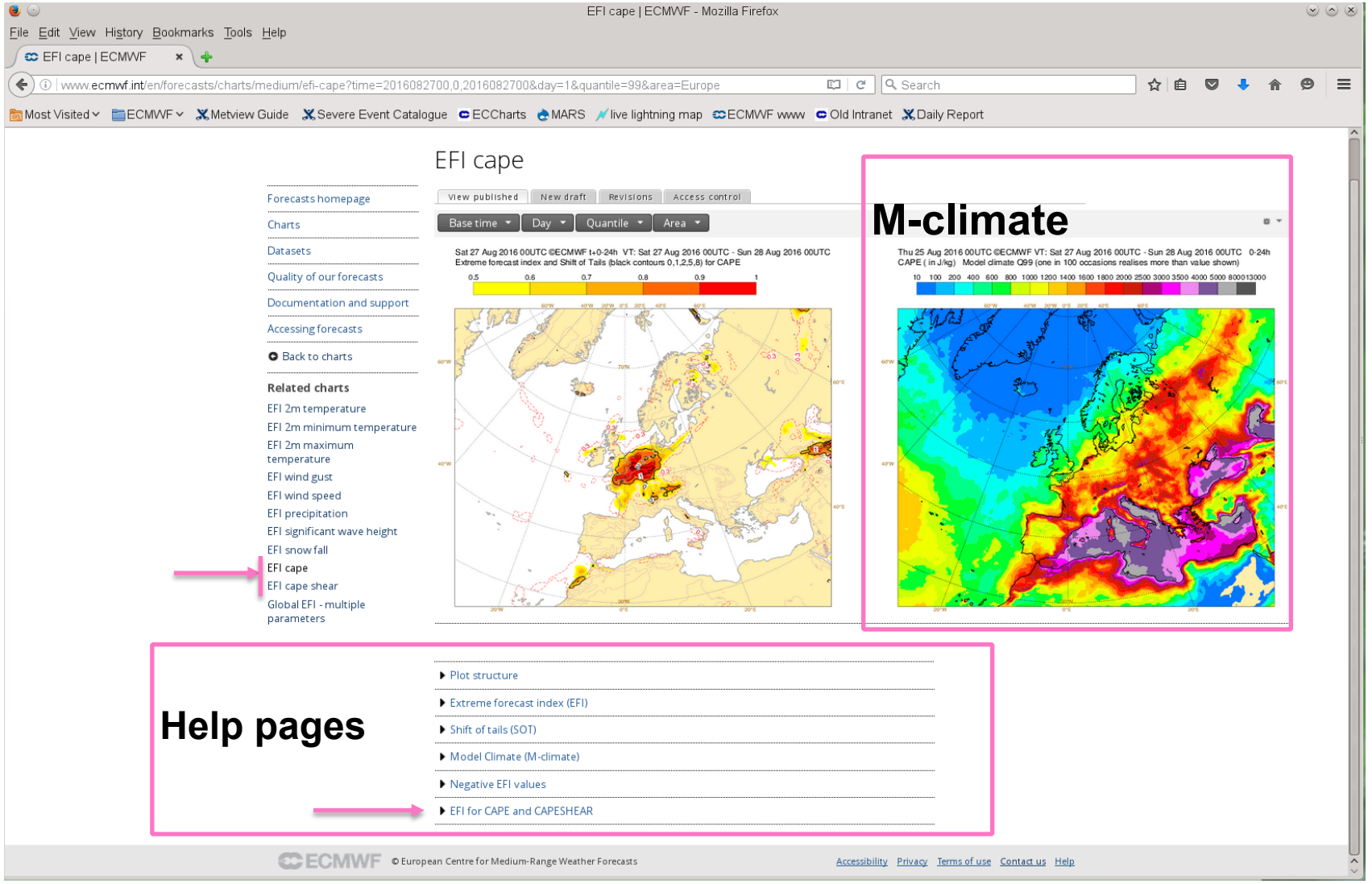
Figure 3 Scatter plot of EFI for CSP versus EFI for CAPE, for 'very' severe thunderstorms, including all reports of tornadoes, hail ≥ 5 cm in diameter and wind gusts ≥ 33 m/s from 1 April to 31 October 2014 over the USA for (a) 24–48-hour forecasts and (b) 72–96-hour forecasts. The EFI is represented by the maximum value within 100 km around each severe weather report. Dashed grey lines represent ±15% deviations from the diagonal as a threshold above which the EFIs differ significantly.

- 'Significant' severe storms tend to occur at higher values of deep-layer vertical wind shear.

Some considerations and future plans

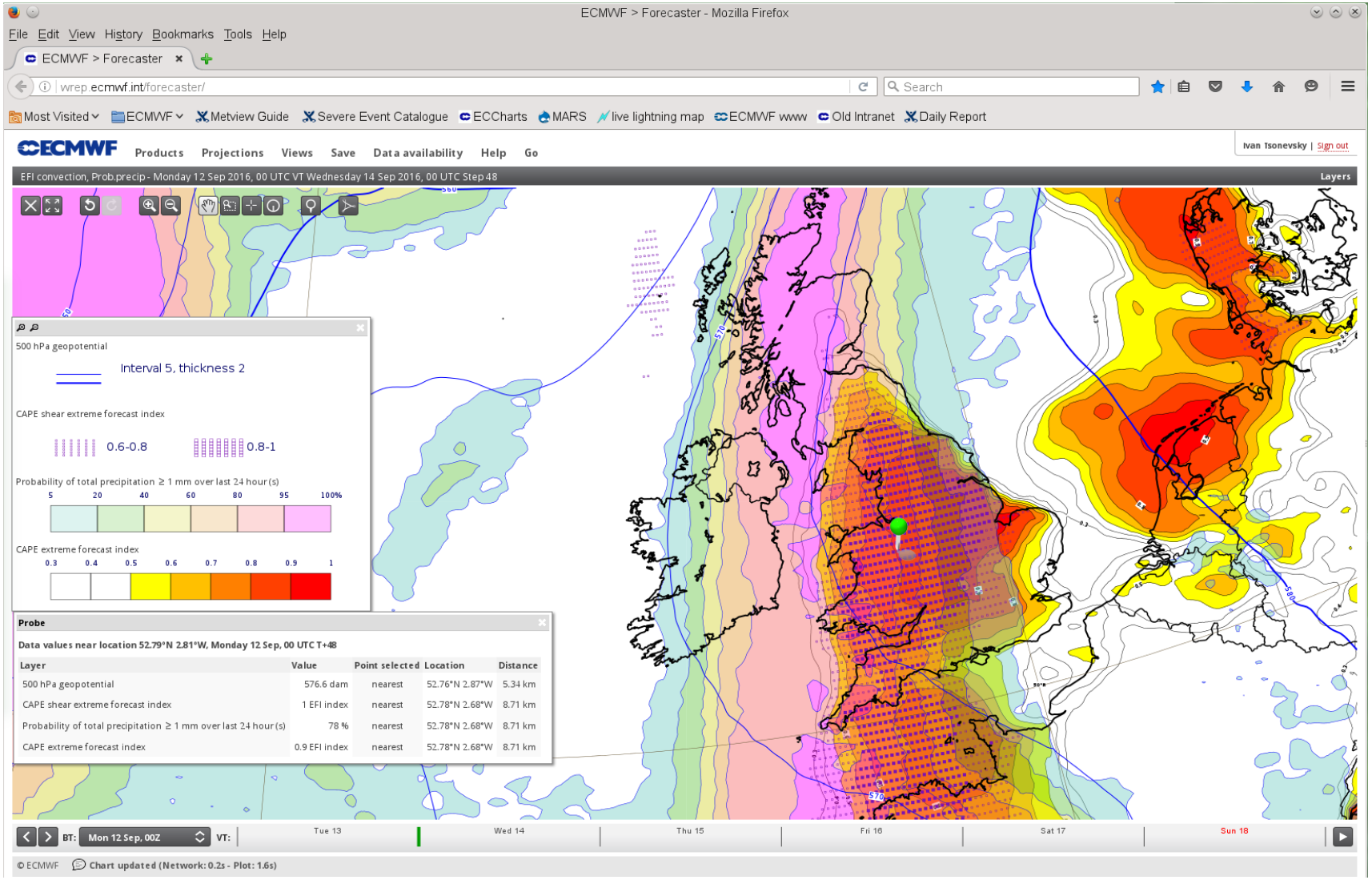
- The EFI provides signals of anomalous weather relative to the model climatology.
  - ✓ very low CAPE values (<10 J/kg) are filtered out to avoid insignificant signals in the areas of low CAPE values in the M-climate (e.g. Arctic in winter)
  - ✓ severe convection unlikely when climatological values of CAPE too low, e.g. continental Europe in winter (climatological maps provided)
- Both convective EFIs give guidance where convection is likely to be severe/anomalous if it could be initiated. Assuming sufficient instability is already present, an important forecast issue is the sufficiency of the lift to overcome CIN. *The challenge of knowing when, where, or even if the capping inversion will be overcome is one of several factors that make forecasting severe convection so difficult! (Charles Doswell III, 2000: Extratropical synoptic-scale processes and severe convection)*
  - ✓ Probability of precipitation could be used in conjunction with the EFI to determine the area where DMC is more likely to occur
- Instantaneous values of CAPE and CAPESHEAR to be replaced with maximum values during previous 6 hours (derived from the hourly model output) for the EFI computation (work in progress).

Web charts



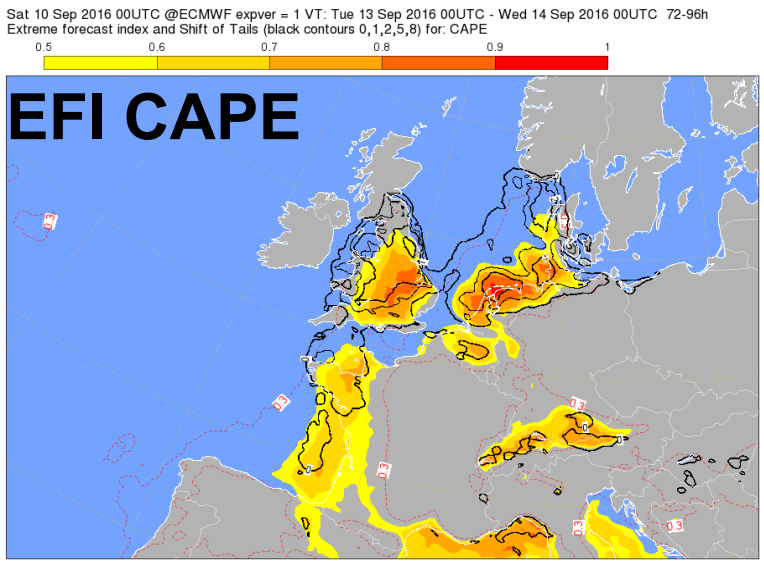
http://www.ecmwf.int/en/forecasts/charts/catalogue/efi

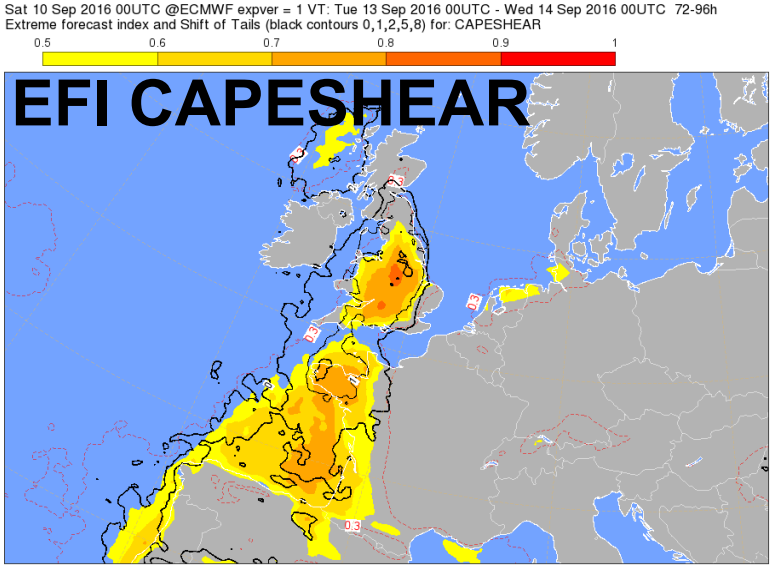
EcCharts

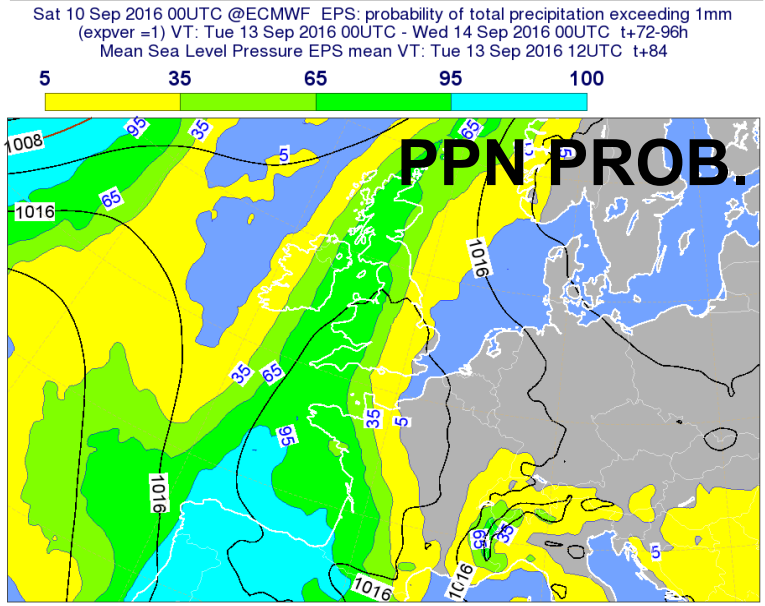


- Create tailored products, e.g. EFI for CAPE (yellow-red shading), EFI for CAPESHEAR (pink symbols), PoP > 1mm/24h (semi-transparent layer)

T+72-96 h FC valid for Tuesday, 13 September 2016



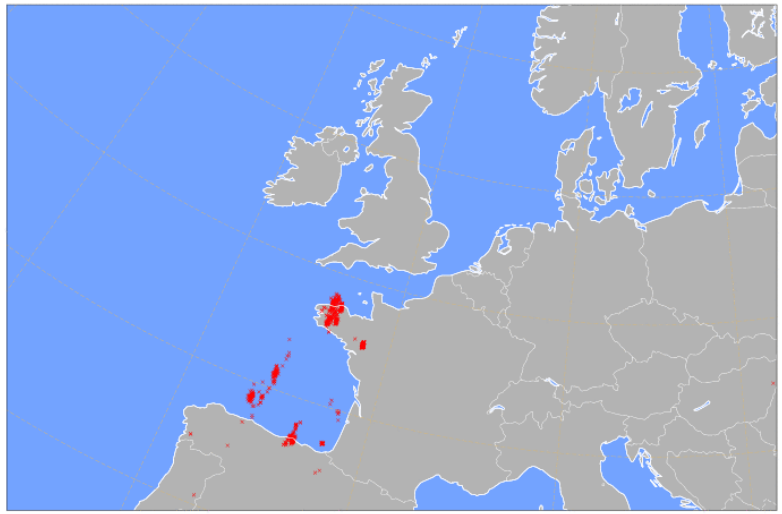


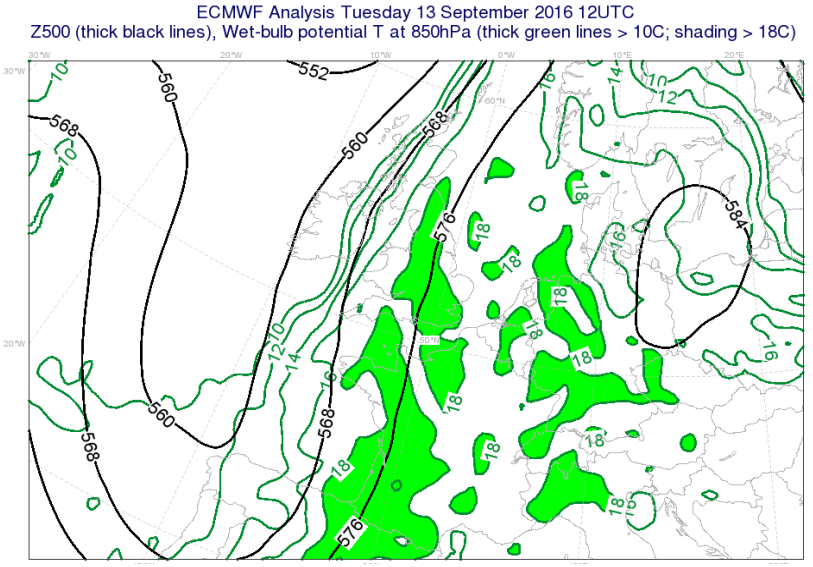


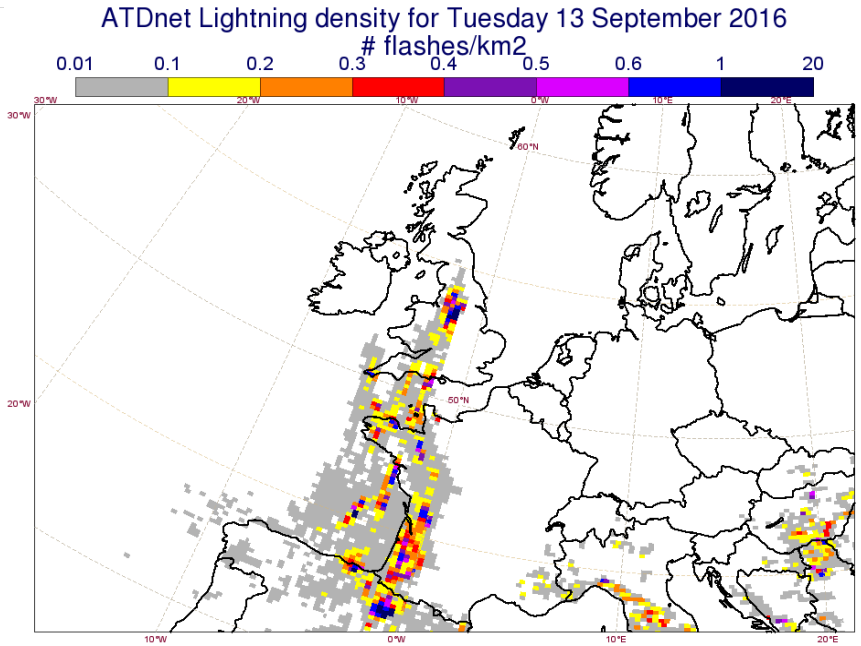
- An area of unstable air mass from Spain to the UK. Anomalously high values of CAPESHEAR suggest well-organised convection if it could be initiated.
- Probabilities of precipitation above 1mm/ 24h point the most western areas of France, Wales and western parts of England where DMC is more likely to occur.
- The instability over Belgium, the Netherlands, part of Germany and Denmark is unlikely to be released.

Lightning strikes (animation)

2016-09-13 06:30:00

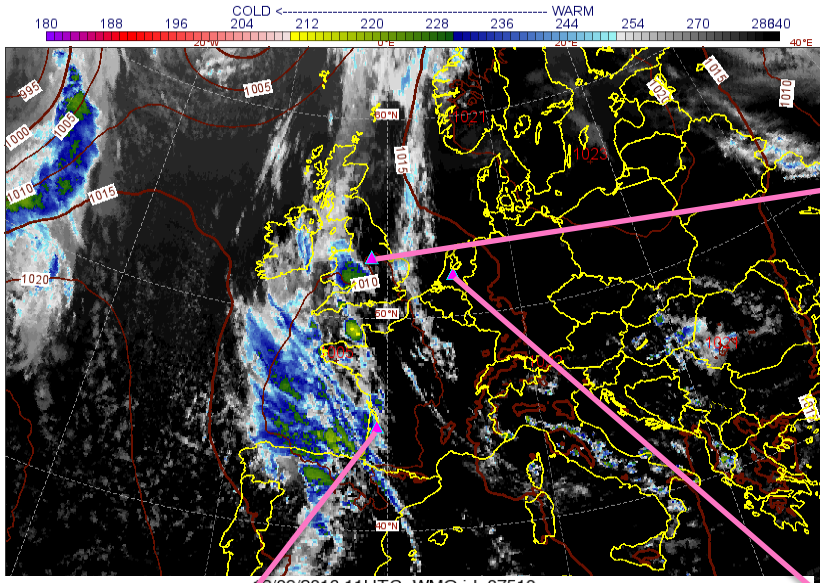


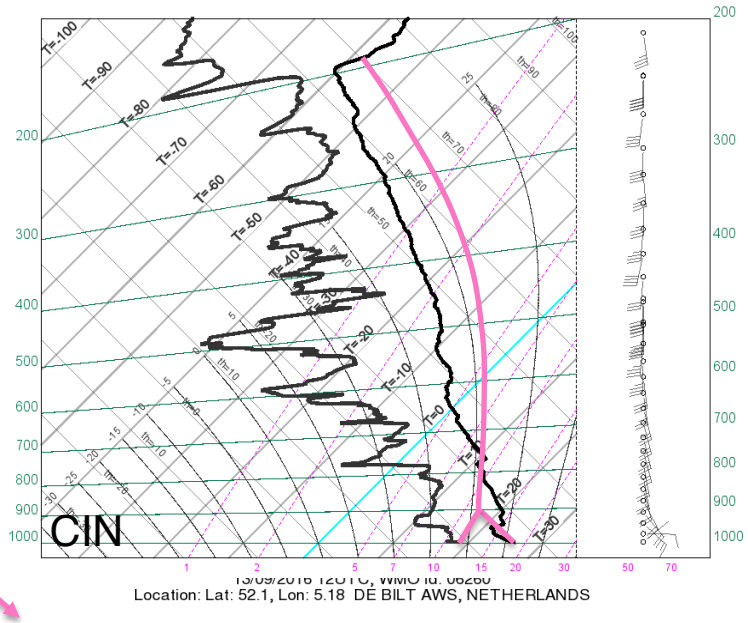


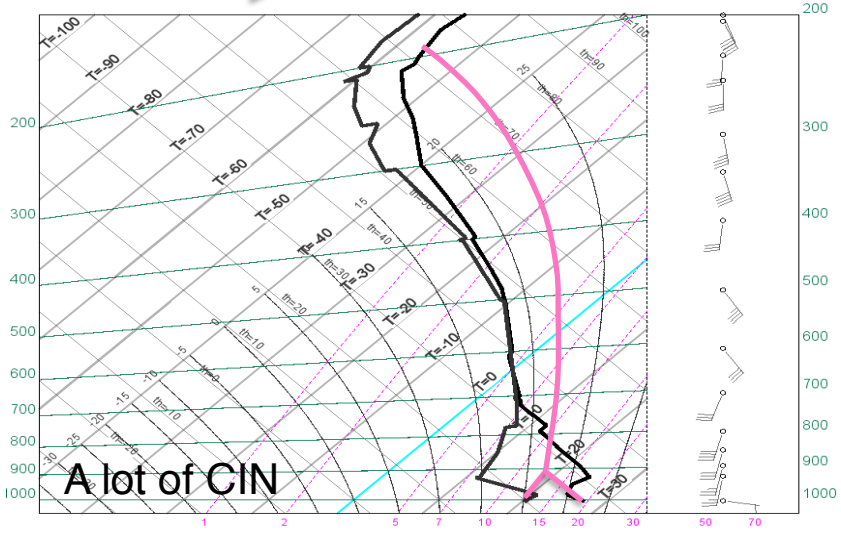


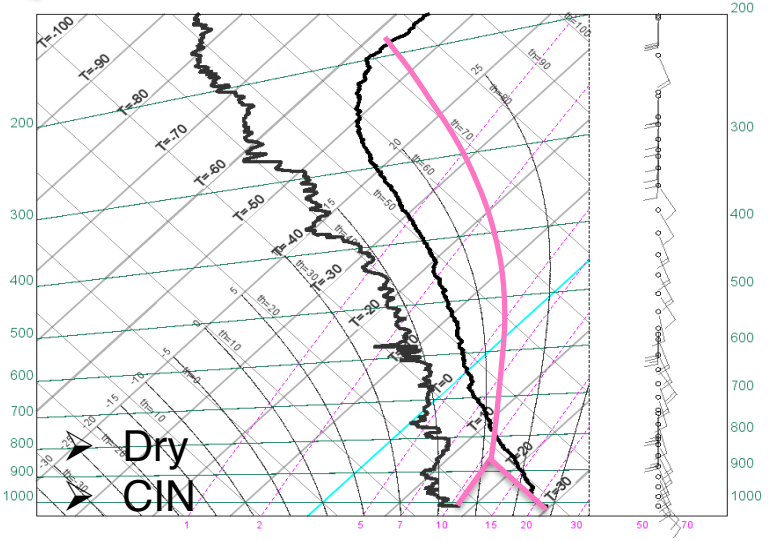
- Severe thunderstorms and heavy rain affected Wales, western England and also the western parts of France.
- Favourable synoptic settings: a deep trough that formed a cut-off low over the bay of Biscay later ; a well-defined frontal zone indicated by the sharp gradient of the wet-bulb potential temperature at 850 hPa (thick green lines).

Ingredients: moisture, instability, lift

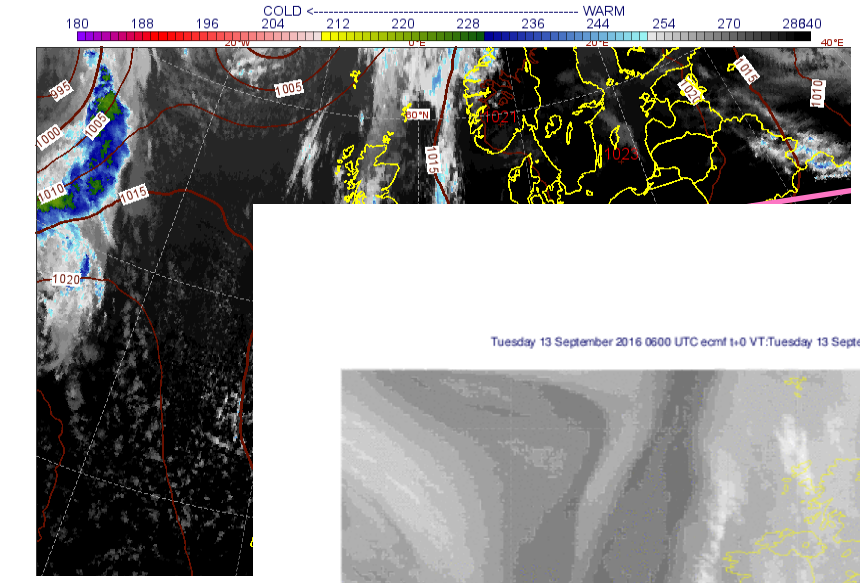


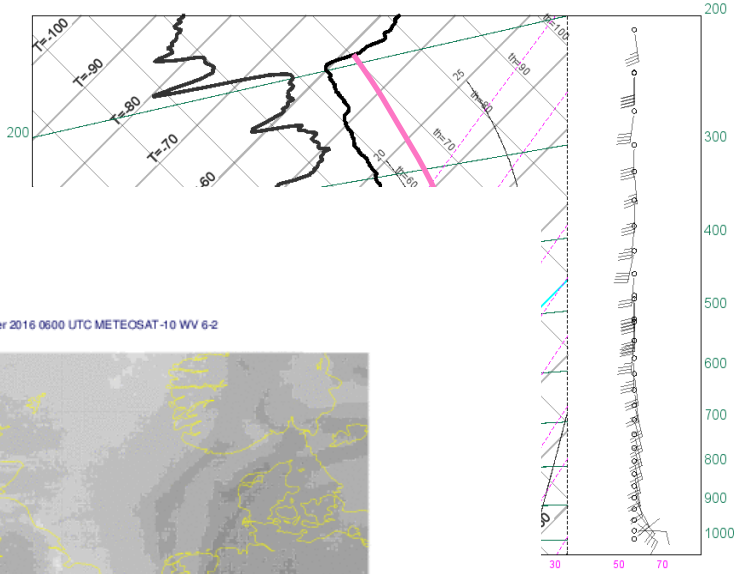


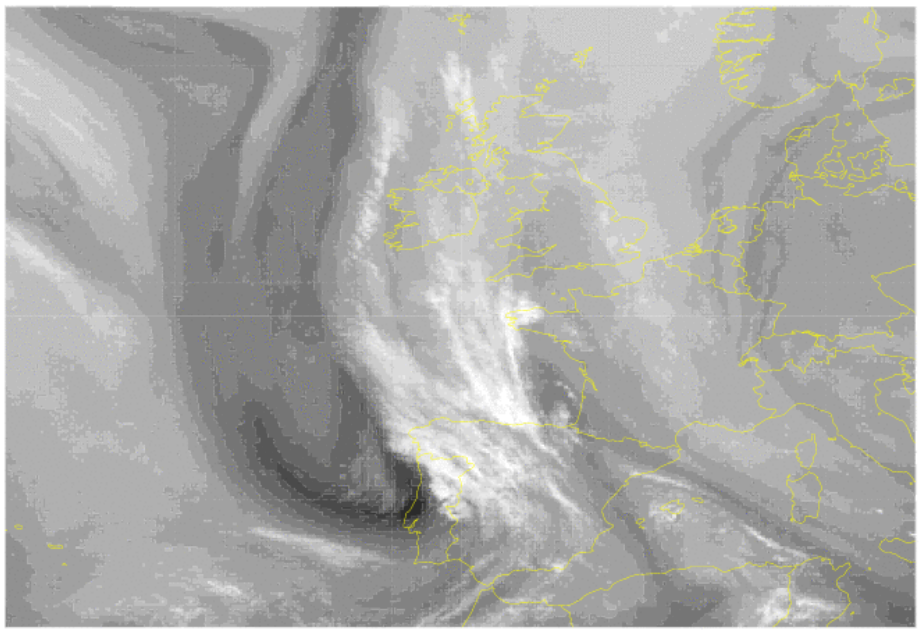


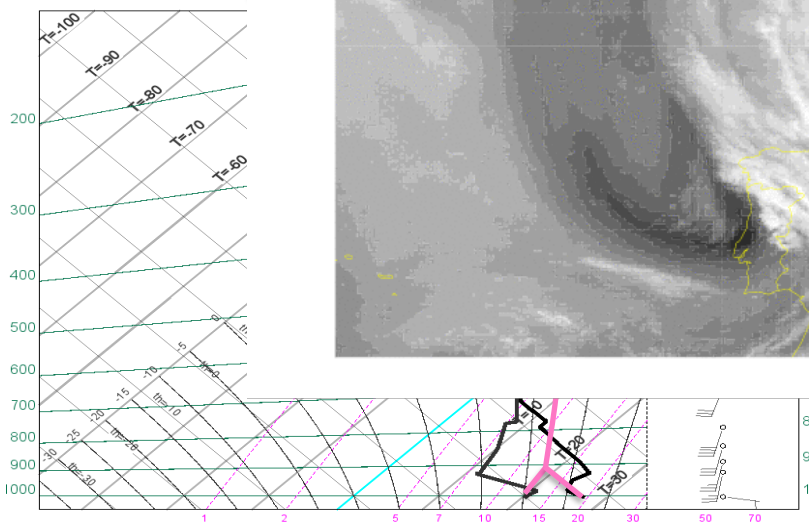


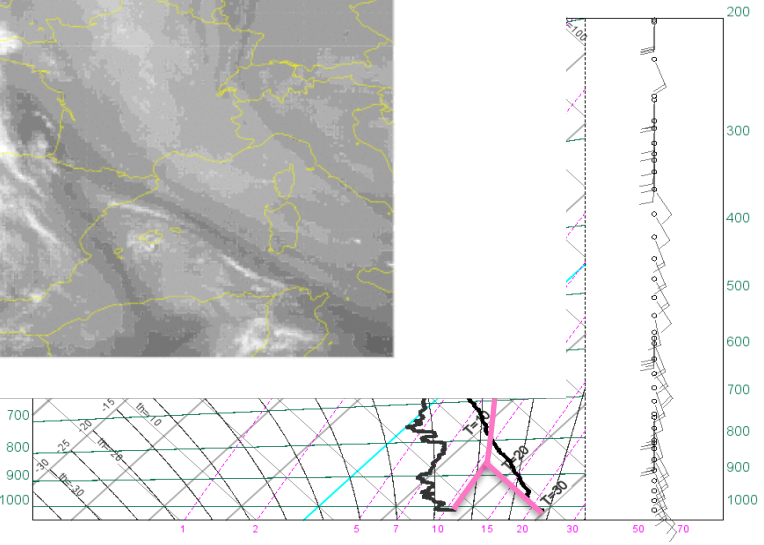
Ingredients: moisture, instability, lift



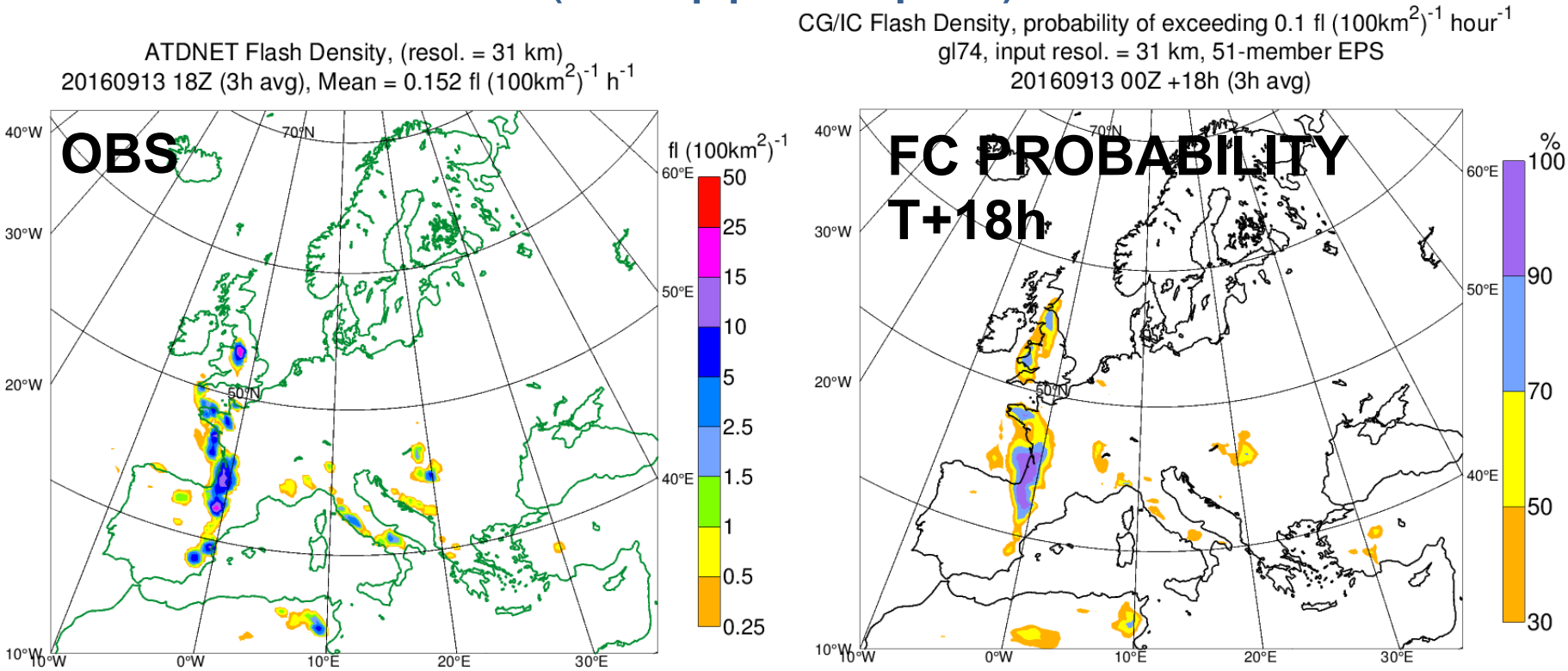






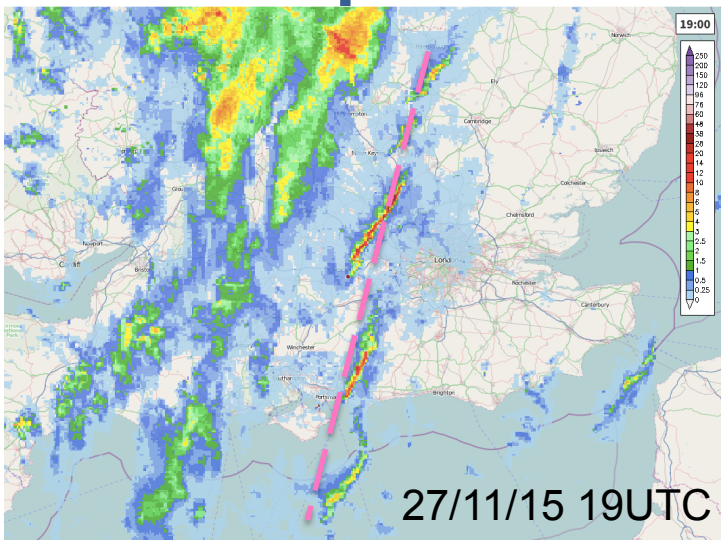


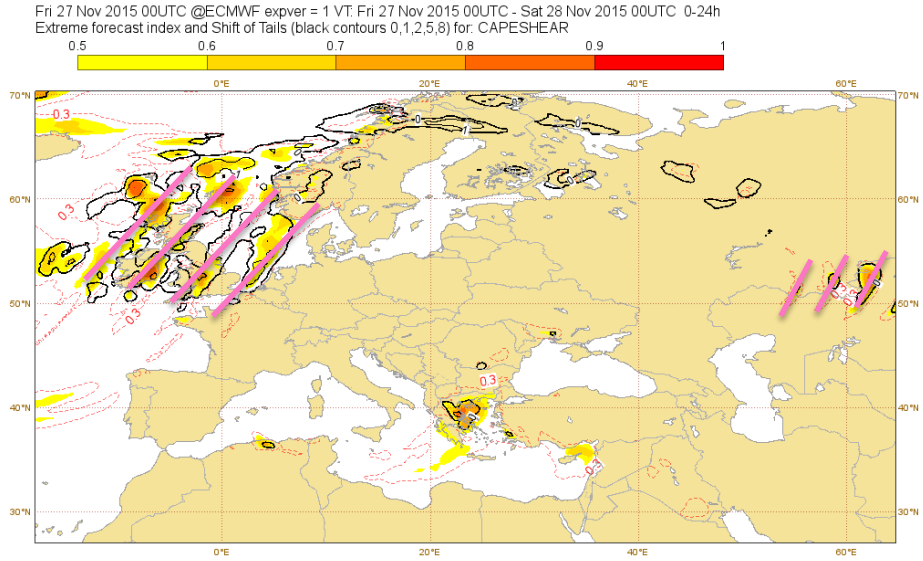
Flash density forecast (experimental) (Philippe Lopez)

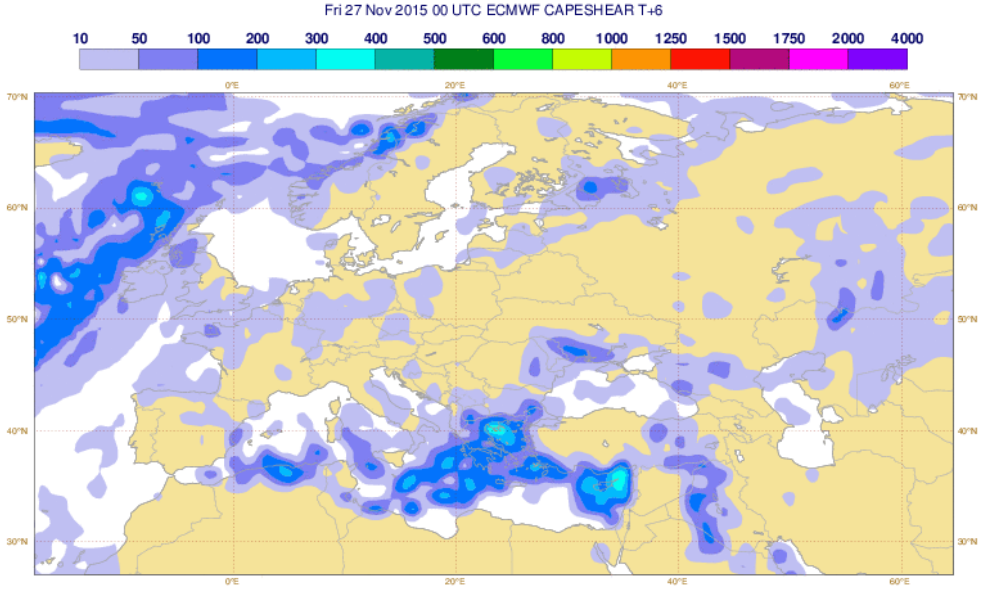


- High probabilities match pretty well the areas of lightning activity over the continent. Note the good forecast for the area of intense lightning activity over northern Spain and France.
- The model correctly indicated some lightning activity over the British Isles although some errors of location are apparent.

A squall line along a cold front

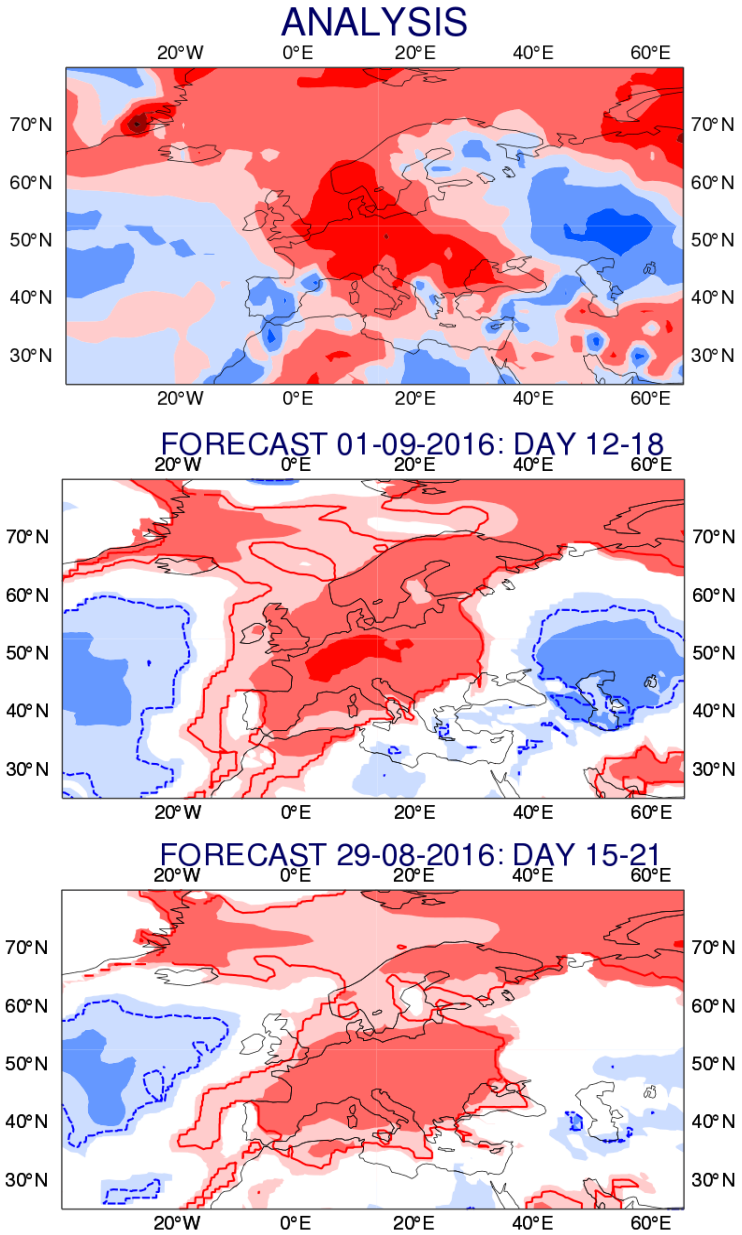




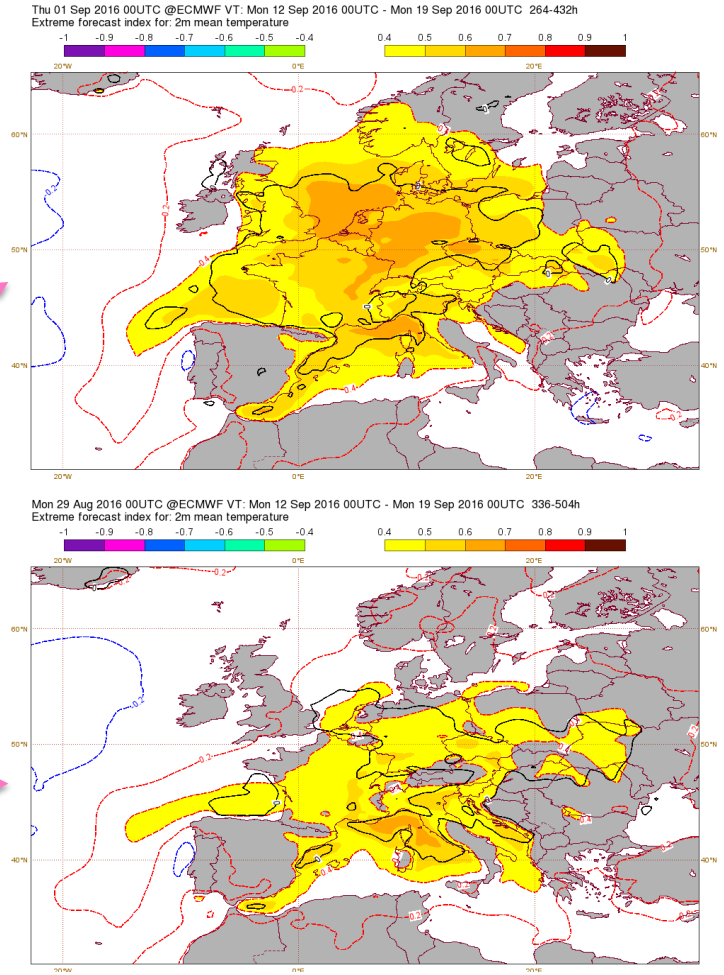


- The stripy structure is due to the combination of a fast moving front and 6-hourly discretization used for the computation
- This feature will disappear once maximum values start to be used instead of the instantaneous values

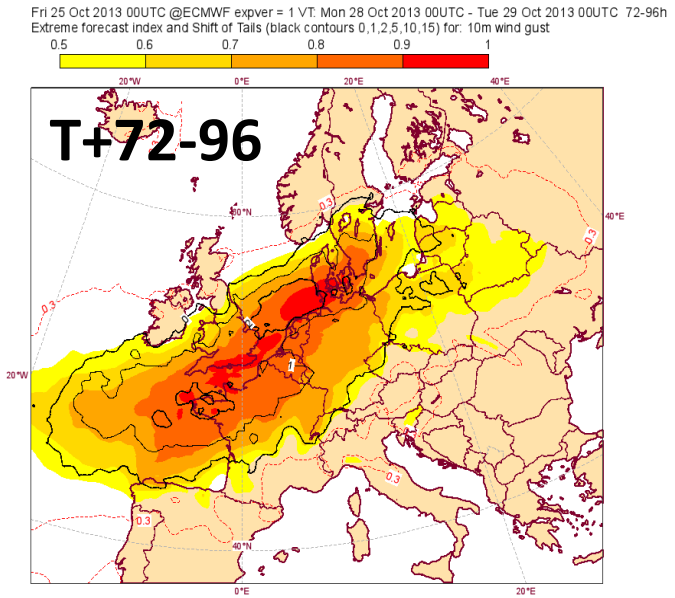
EFI in the extended range (testing)

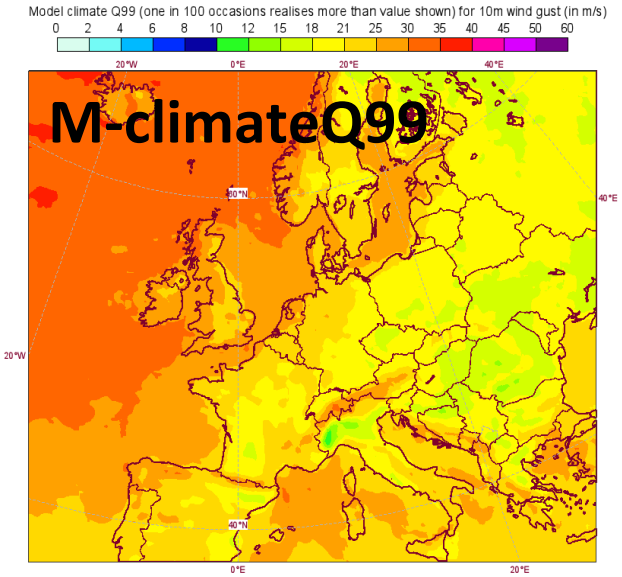


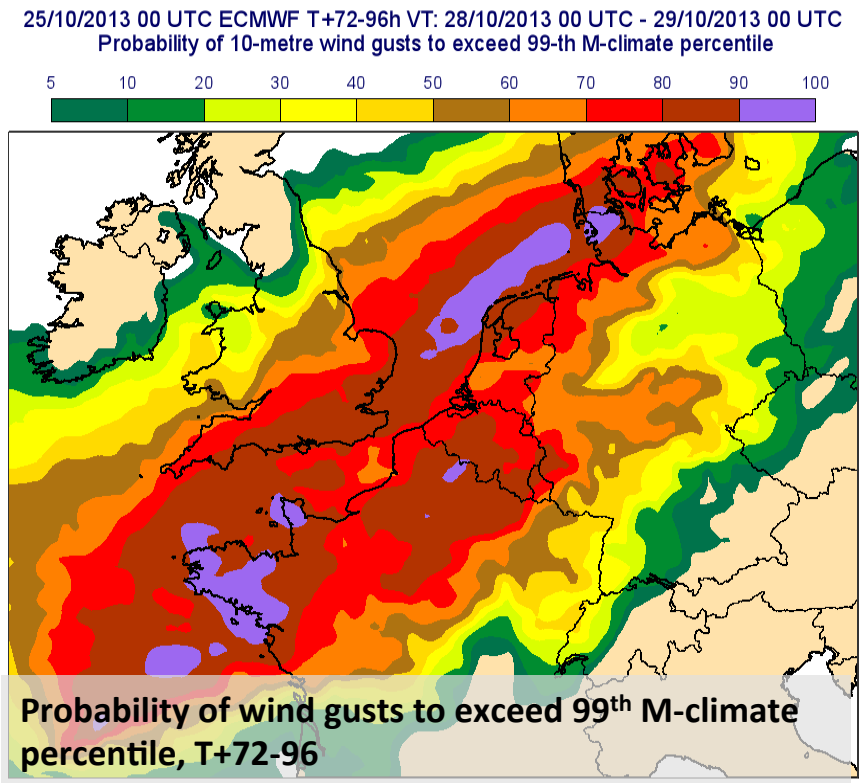
- The EFI gives the level of extremity of the anomalies. Positive SOT is a sign of members that really give an extreme solution.



St. Jude storm case







- M-climate can be used to compute probabilities of exceeding/not exceeding certain M-climate percentiles.

Further Reading:

- ✓ User Guide to ECMWF forecast products, http://www.ecmwf.int/sites/default/files/User_Guide_V1.2_20151123.pdf
- ✓ **Tsonevsky, I., D., Richardson**, 2012: Application of the new EFI products to a case of early snowfall in Central Europe, *ECMWF Newsletter,* **No. 133**, 4.
- ✓ **Tsonevsky, I.**, 2015: New EFI parameters for forecasting severe convection. *ECMWF Newsletter,* **No. 144**, 27-32.

http://www.ecmwf.int/sites/default/files/NL-144.pdf