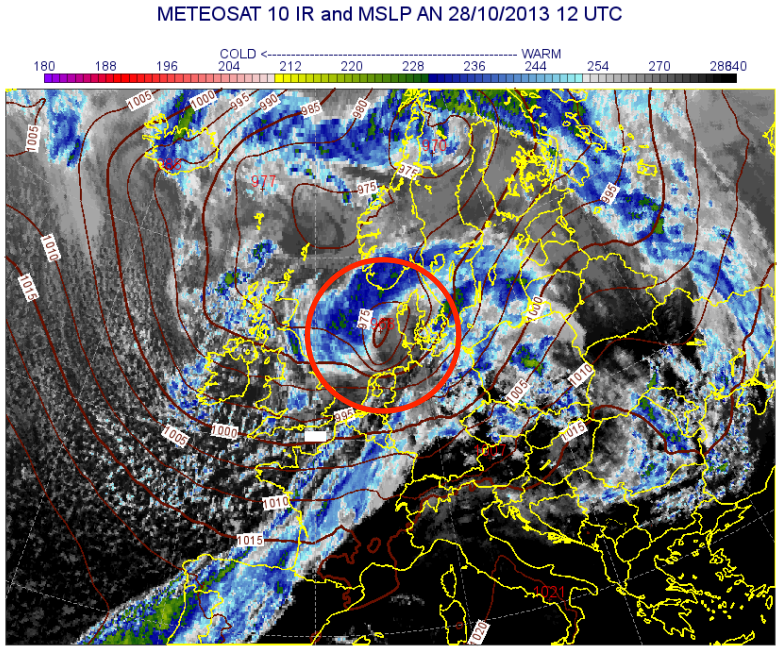
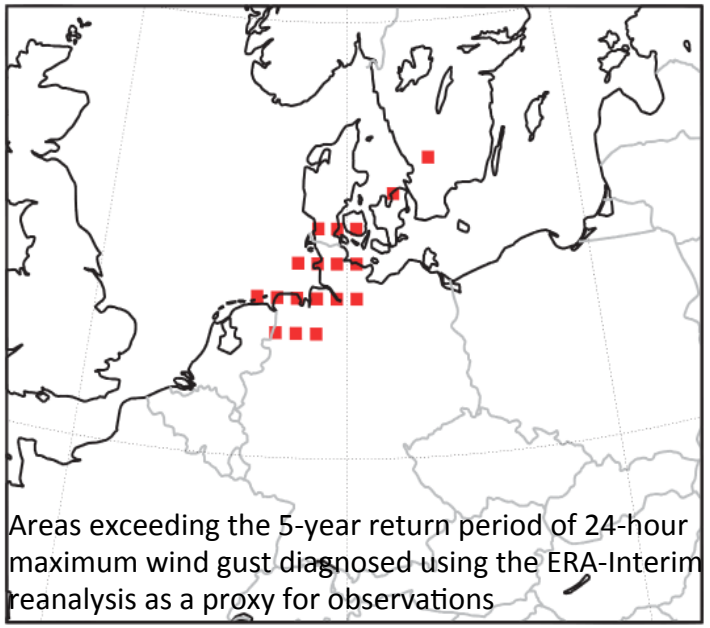
Extreme Forecast Inde (EFI)

Ivan Tsonevsky,

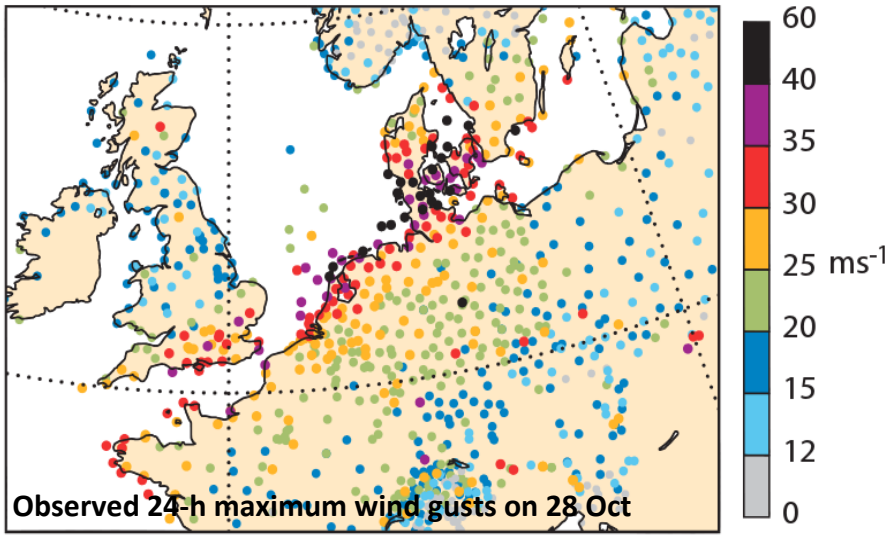
ivan.tsonevsky@ecmwf.int

St Jude Storm, 27-28 Oct 2013



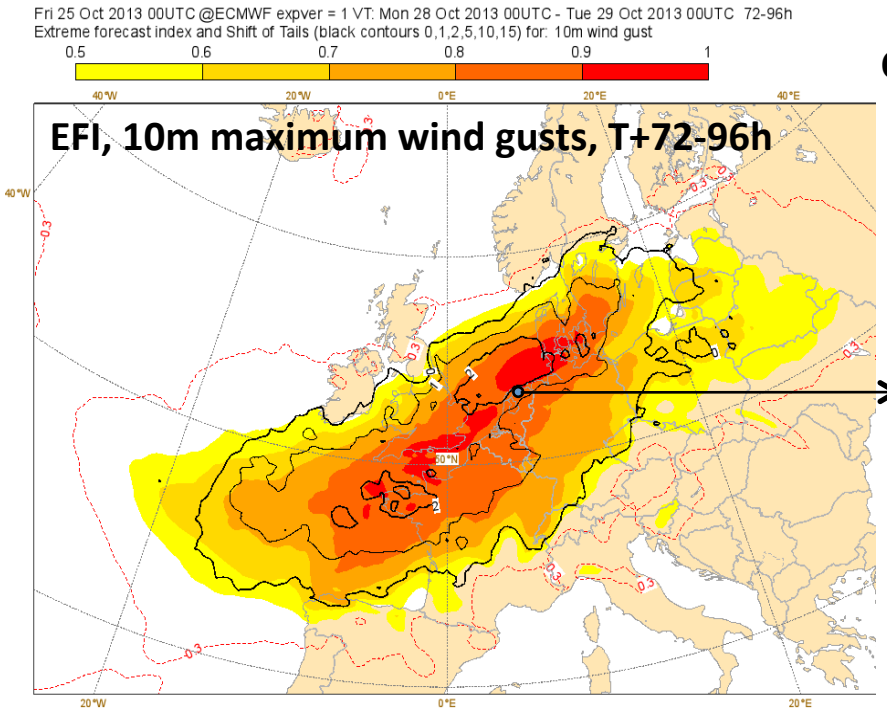


Areas exceeding the 5-year return period of 24-hour maximum wind gust diagnosed using the ERA-Interim reanalysis as a proxy for observations

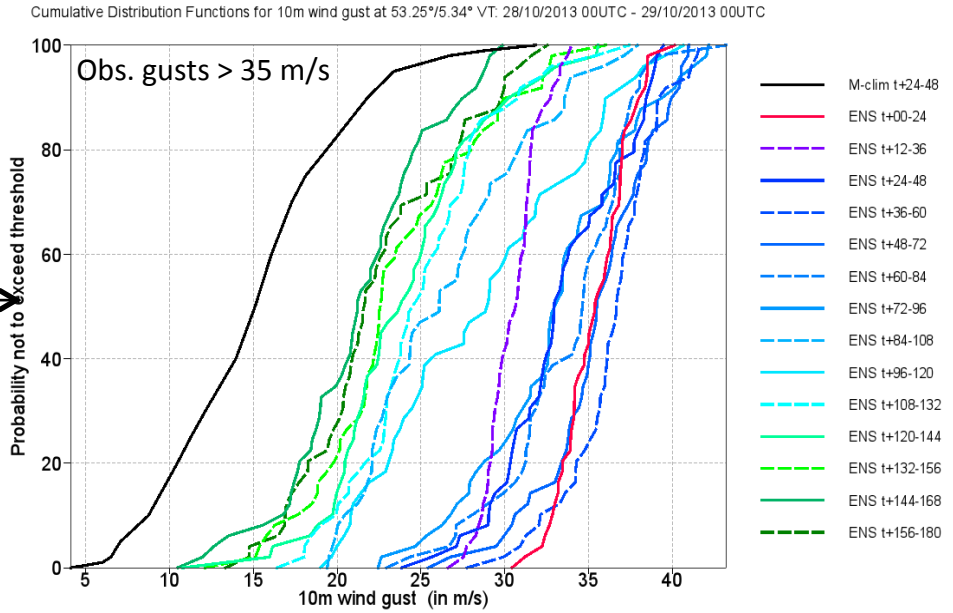


Observed 24-h maximum wind gusts on 28 Oct

St Jude Storm, 27-28 Oct 2013



Cumulative Distribution Functions (CDF)

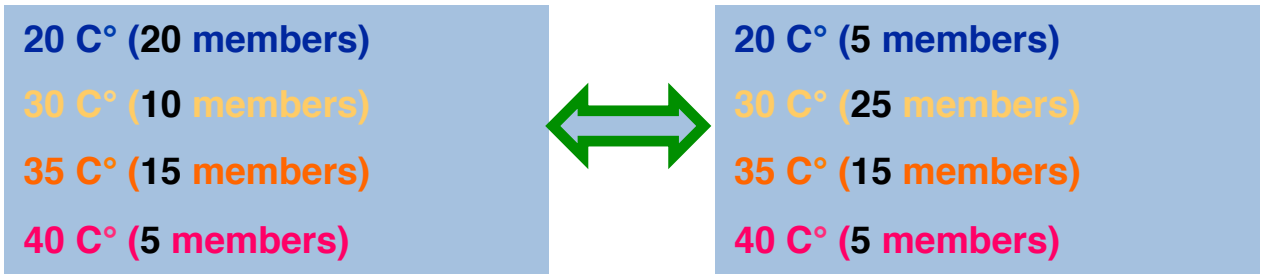


- EFI indicated a risk of a windstorm in the medium range. Positive SOT (black contours) showed that an exceptionally strong windstorm was likely.
- There was a sign of windier-than-normal conditions 7 days in advance with the last 7 runs predicting extreme wind (see CDF).

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.



The Model climate (M-climate)

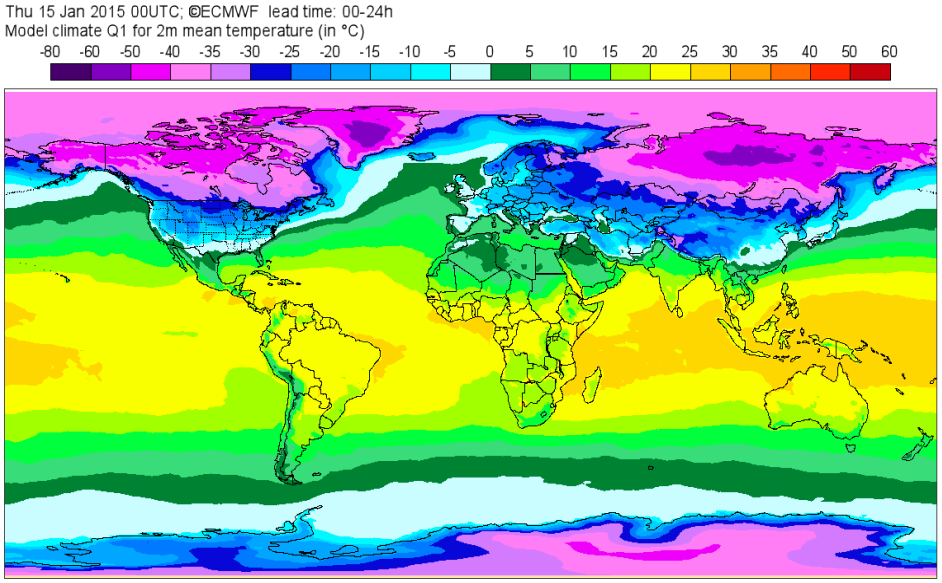
For climate related products like the EFI a reliable model climate is essential.

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 46 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

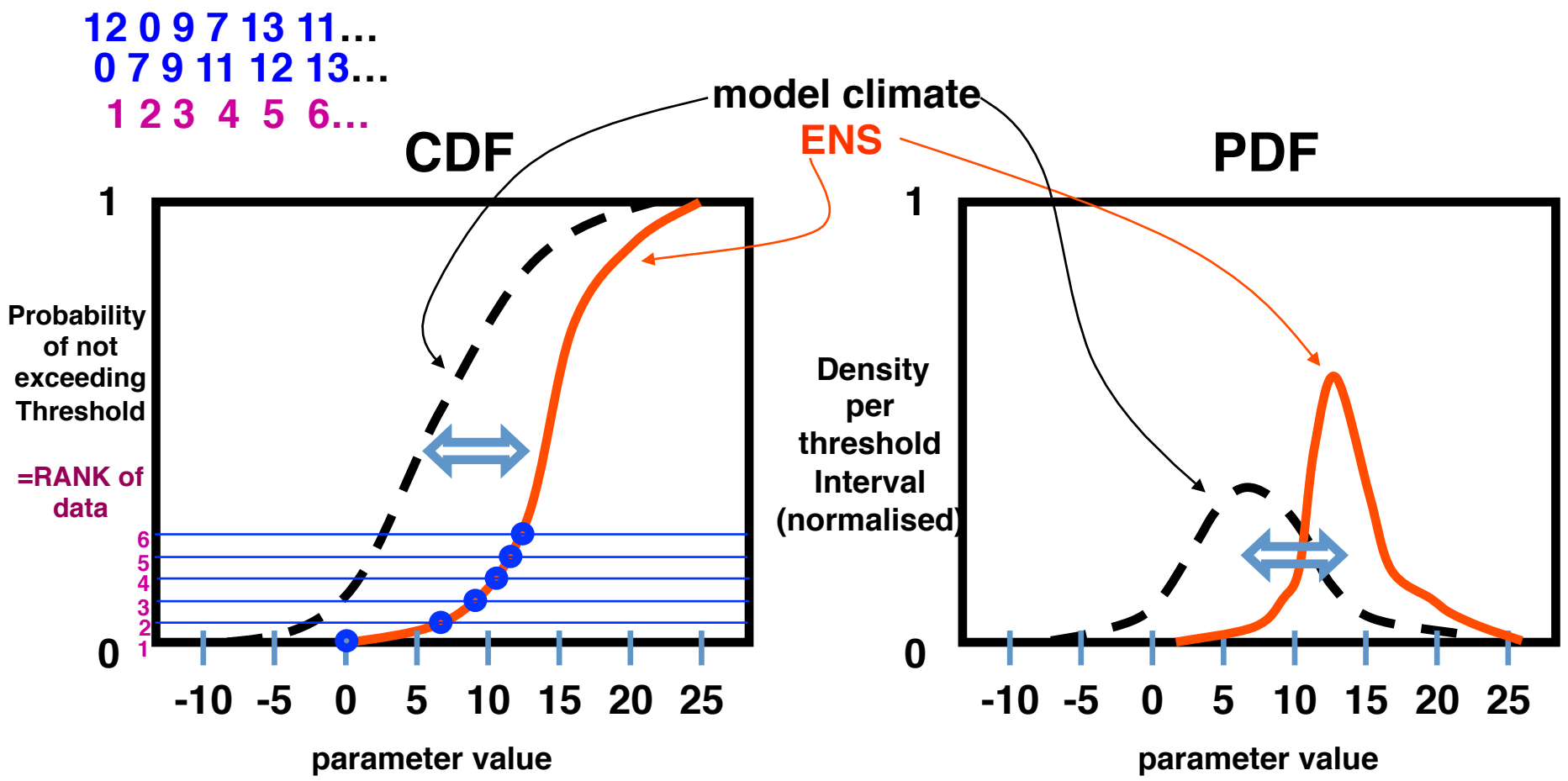
Model climate (M-climate)



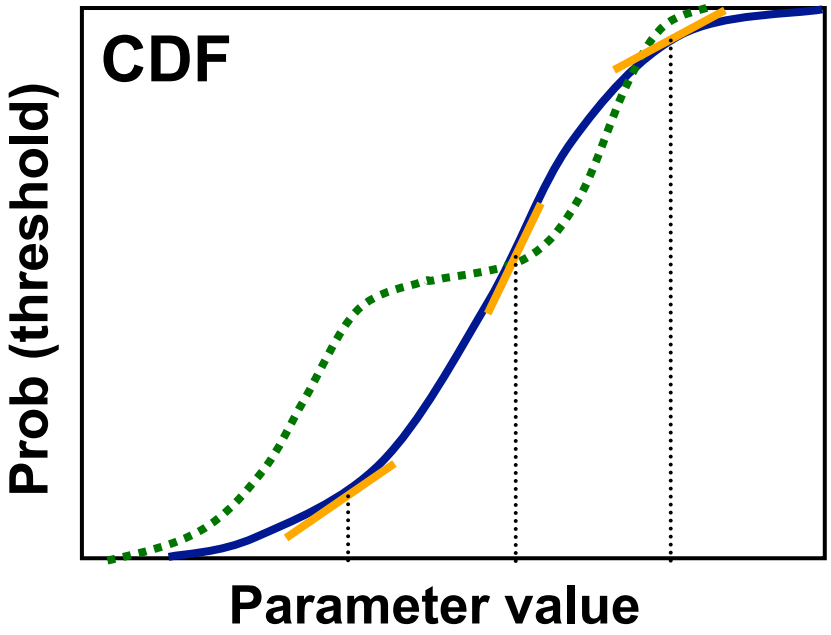
- To provide a robust, less noisy M-Climate, we do not use just one set of re-forecasts, but all nine set within 5-week period centred on the week in question.
- M-climate sample size is: 20 years * 11 ensemble members * 9 re-forecast runs = 1980 re-forecast fields (were 500)
- Recent changes lead to:
  - ✓ 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.

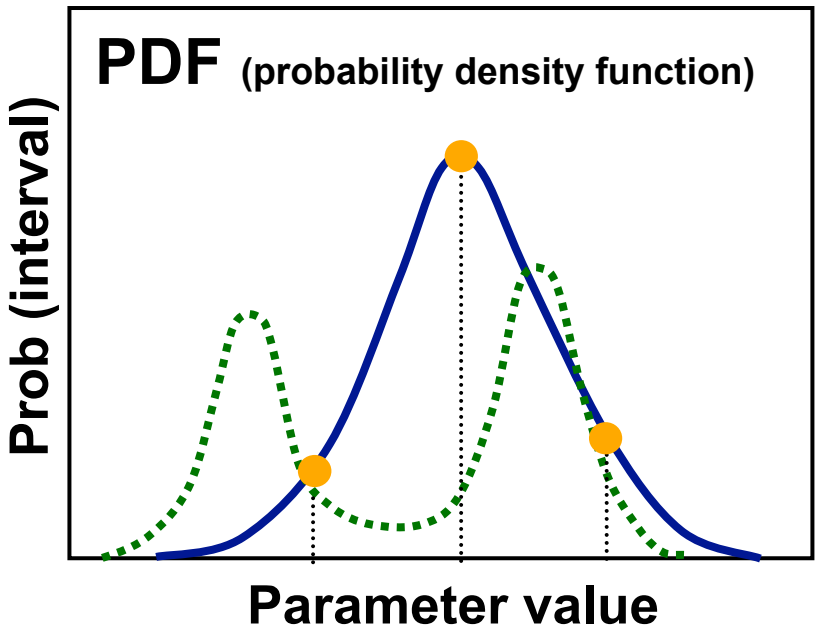
Extreme Forecast Index (EFI)

- 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?



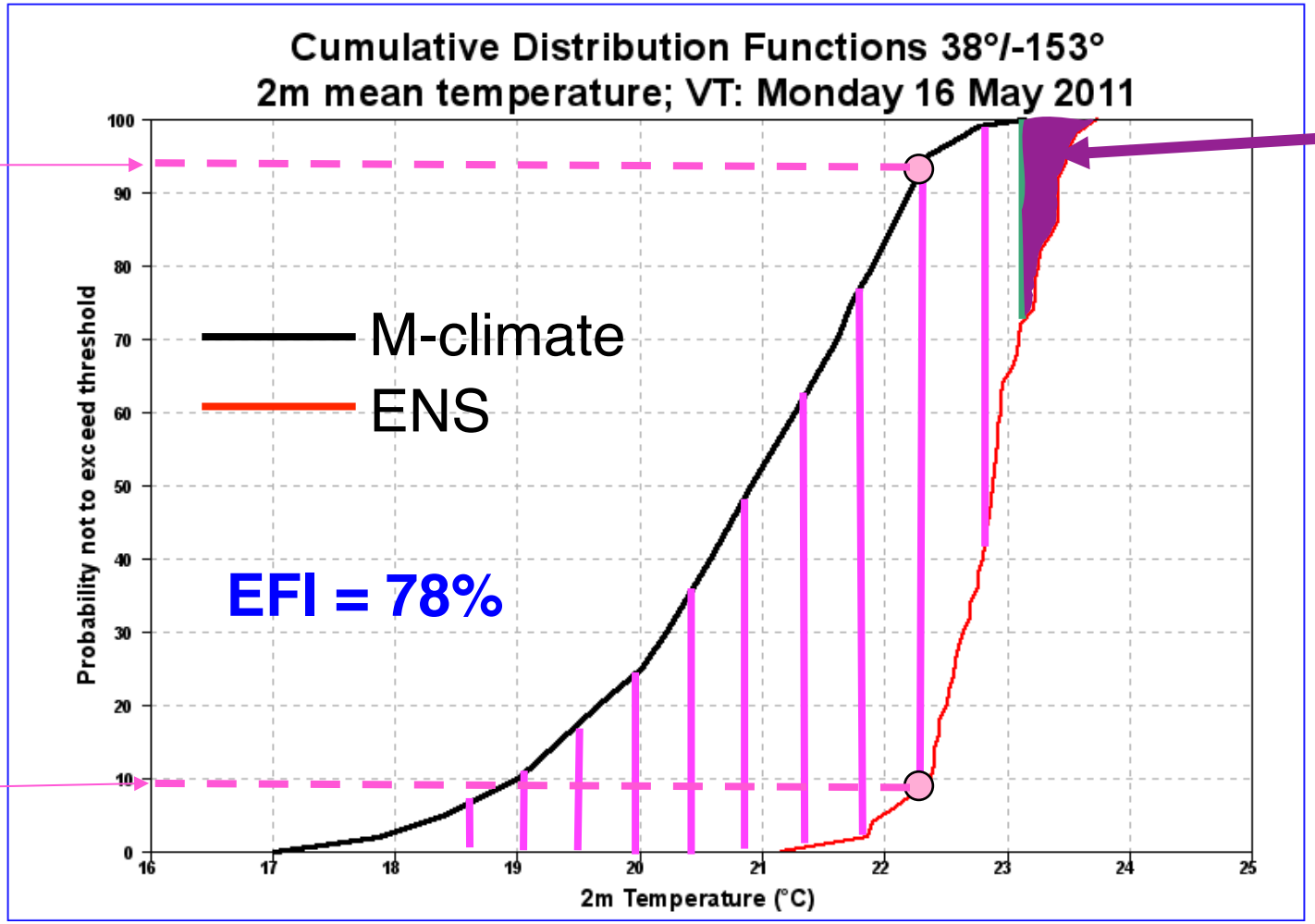


- The PDF (y-axis) value equals the slope of the CDF
- **Steeper** CDF = **narrower** PDF = higher confidence in the forecast
- A step in the CDF means a bimodal PDF

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

Represented by pink lines below

More weight to extremes of M-climate being a quadratic function of p



p

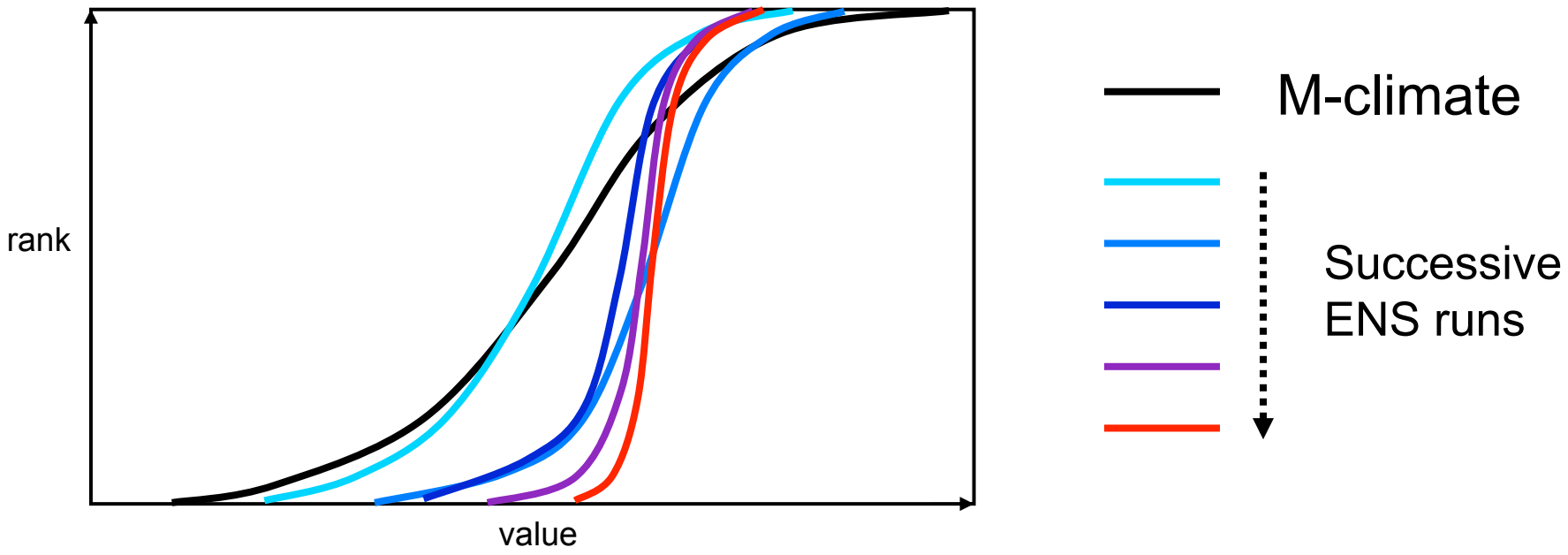
$F_f(p)$

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

$-1 \leq EFI \leq 1$

$-100\% \leq EFI \leq 100\%$

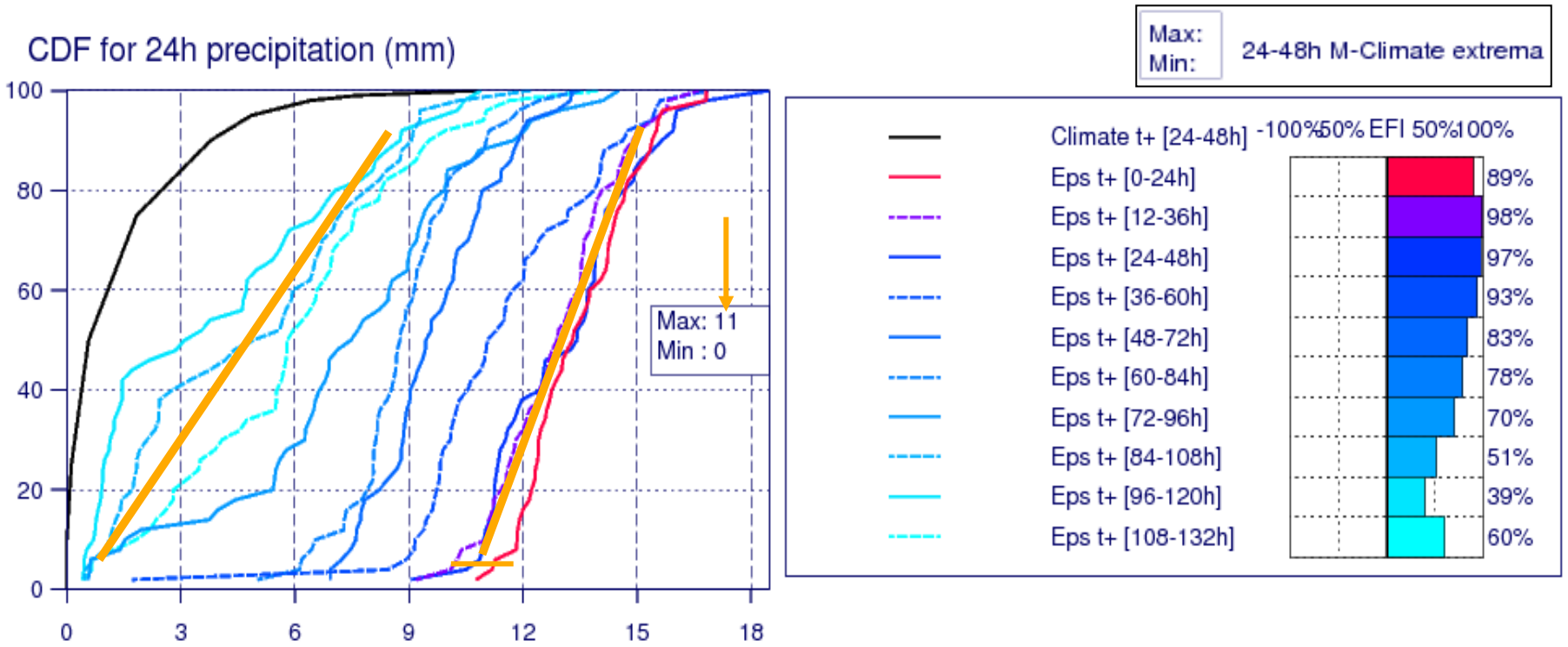
How ‘should’ CDFs behave in successive ENS runs?



- 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.

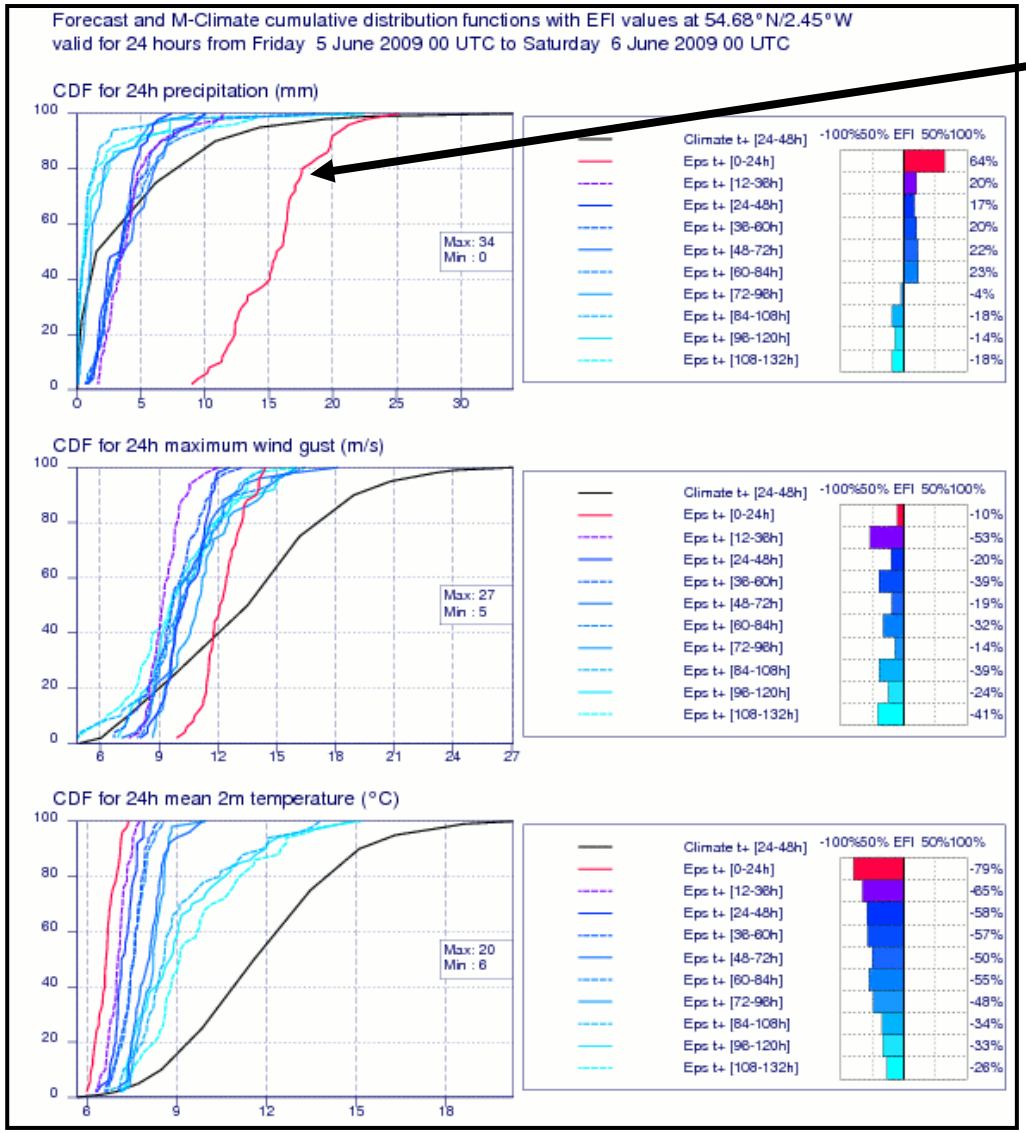
An example

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 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

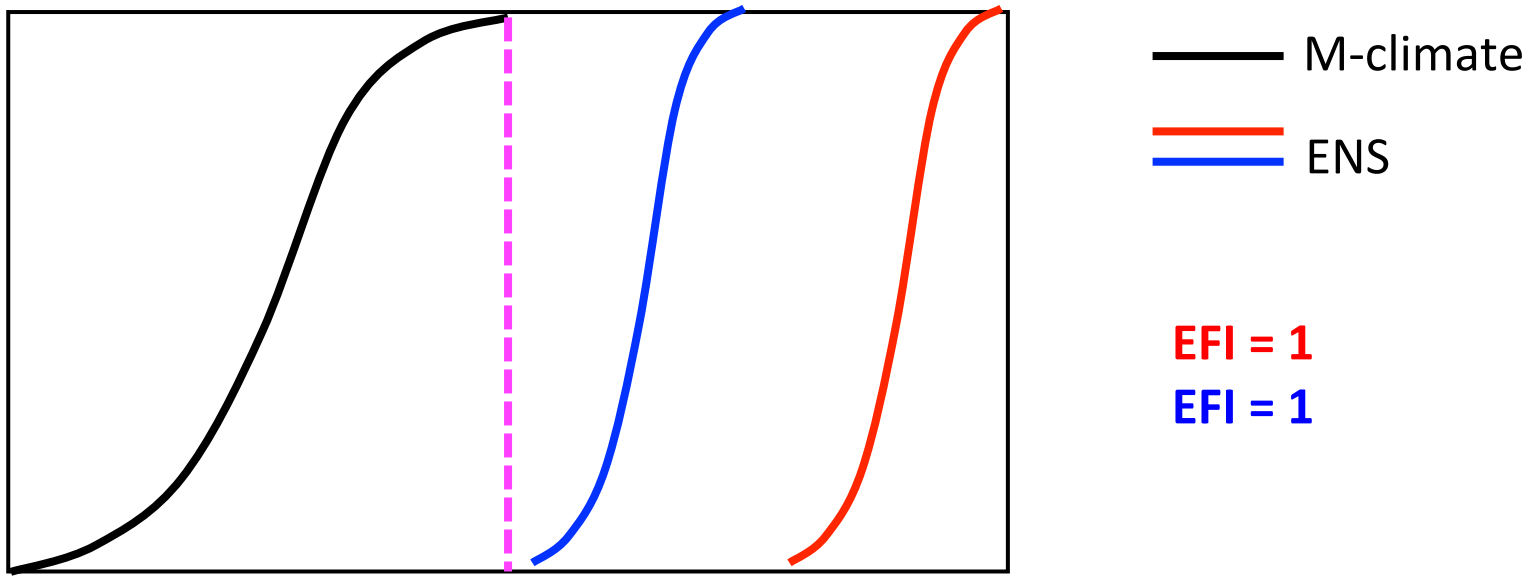


- N England rain – June’09 - low probability alternative became likely at short range.

Some limitations of EFI

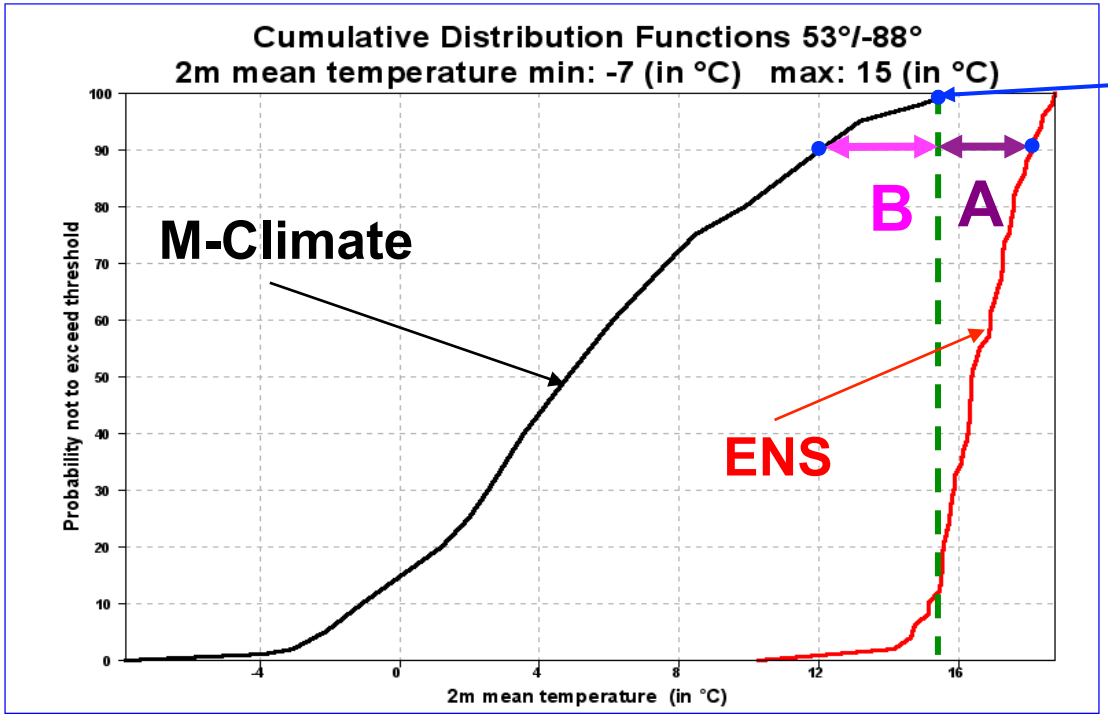
- Extreme does not *necessarily* mean high impact (eg 2mm rain in the desert)
- Past history also important but not directly accounted for (eg heavy rain when ground saturated)
- Windstorm impact can depend on whether trees are in leaf, whether ground is saturated…
- Products are only as good as the 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)

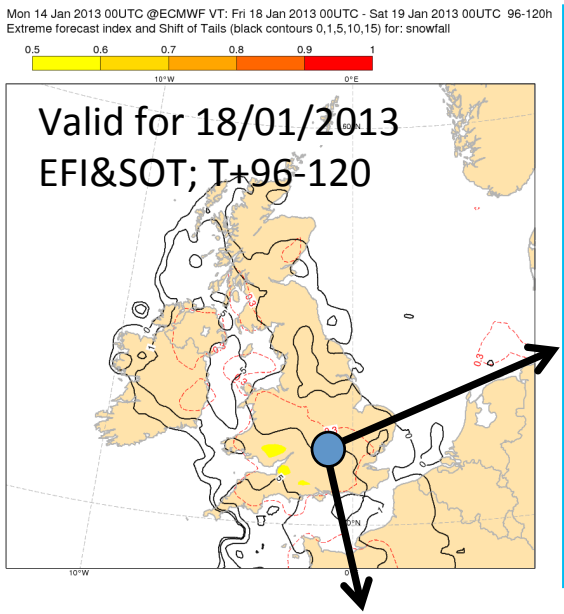


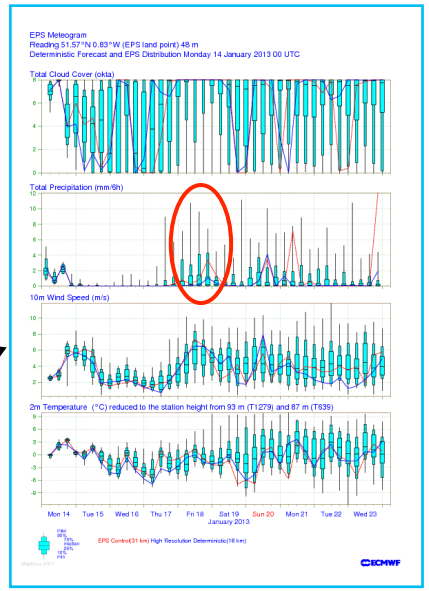
SOT = A/B

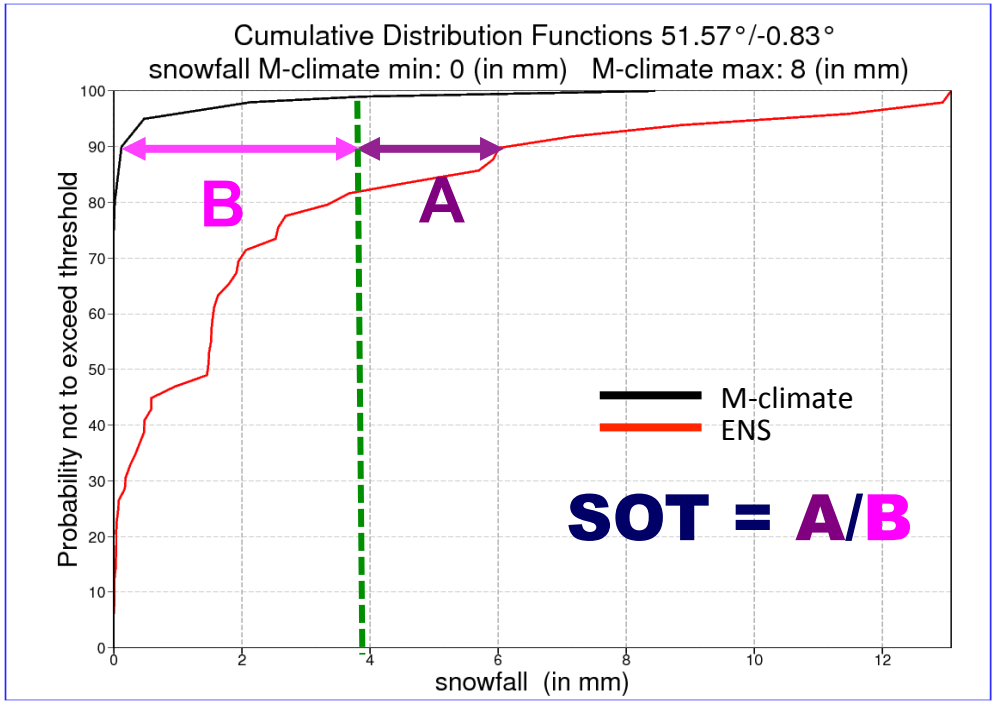
A = Qf(90) - Qc(99)

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 extrem event; the higher the SOT the more extreme that top 10% is.







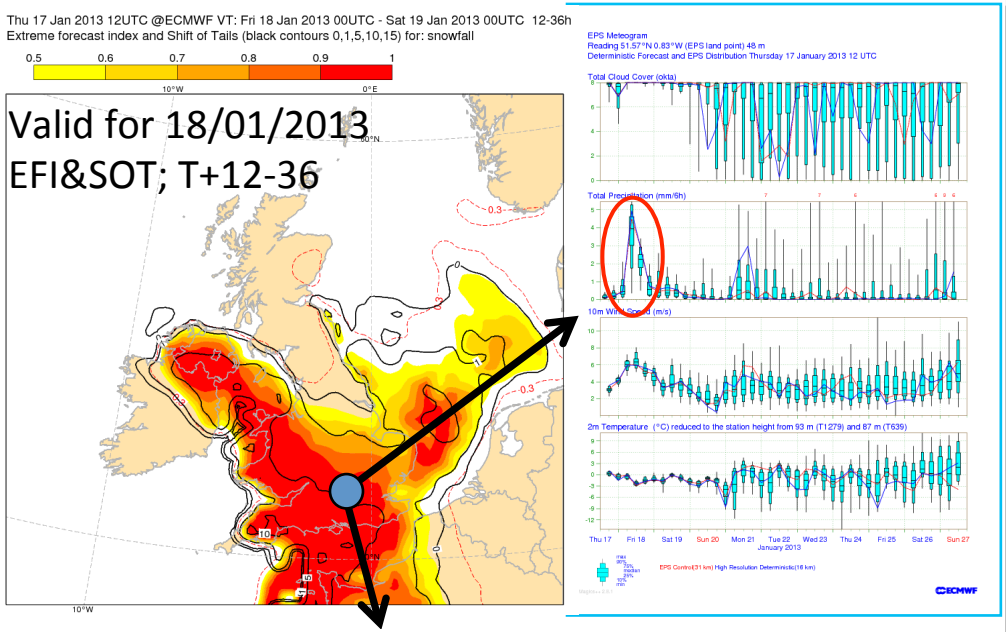
- SOT > 0 → at least 10% of the ensem members are above the 99th M-clima percentile
- The higher the SOT value is, the furth this top 10% of the ensemble forecas beyond Q99 of the M-climate.

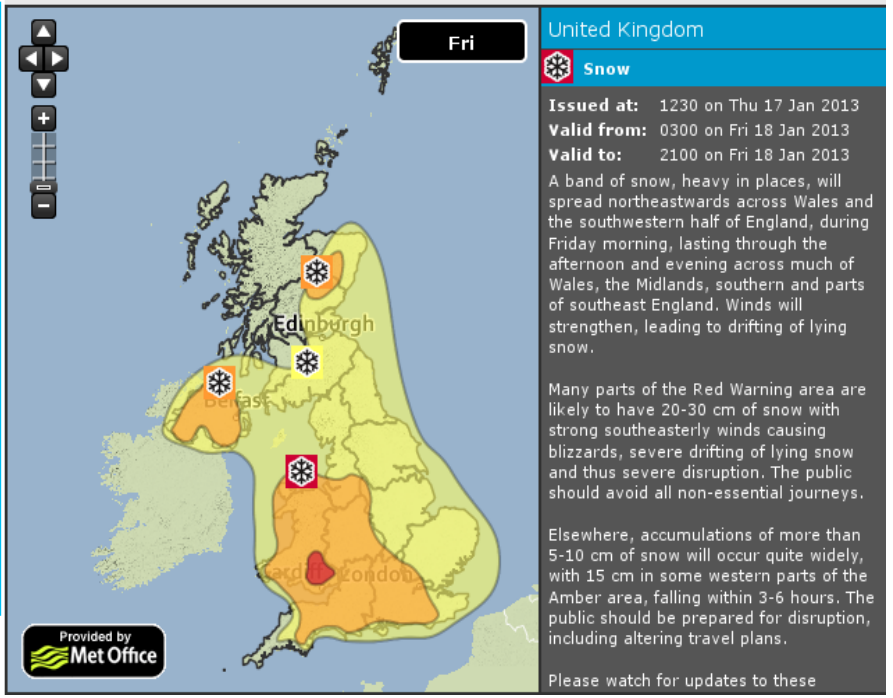
In the example (Reading):

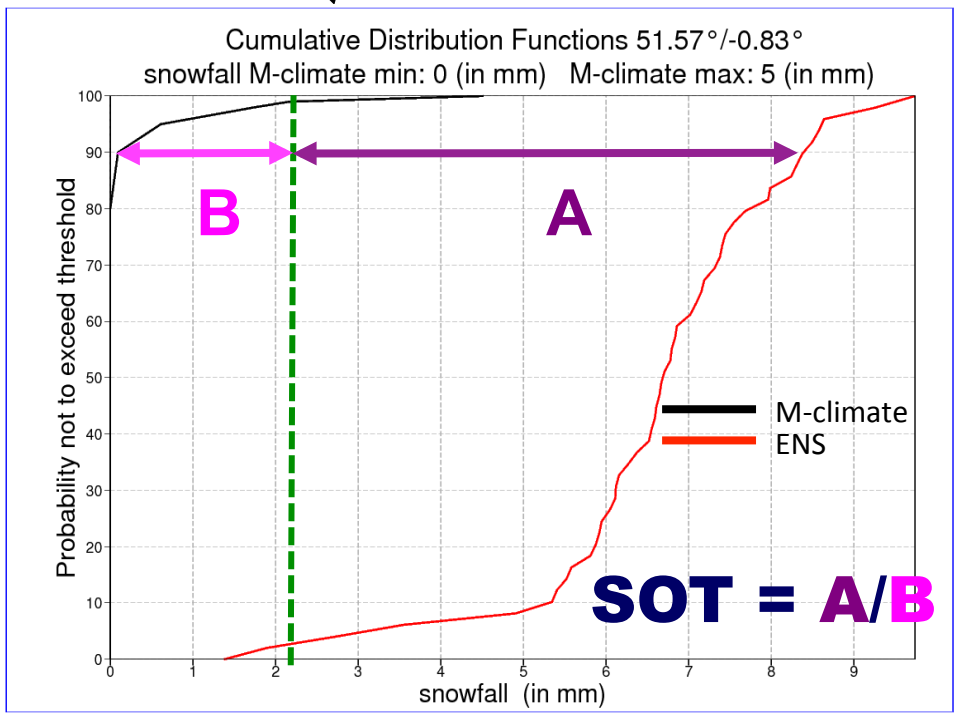
- ✓ EFI = 0.36
- ✓ SOT = 0.8

EFI positive → forecast suggests snow

SOT > 0 → there are ENS members predicting extreme snowfall (above the 9 M-climate percentile) but the forecast is uncertain (low EFI)







Forecast for Reading:

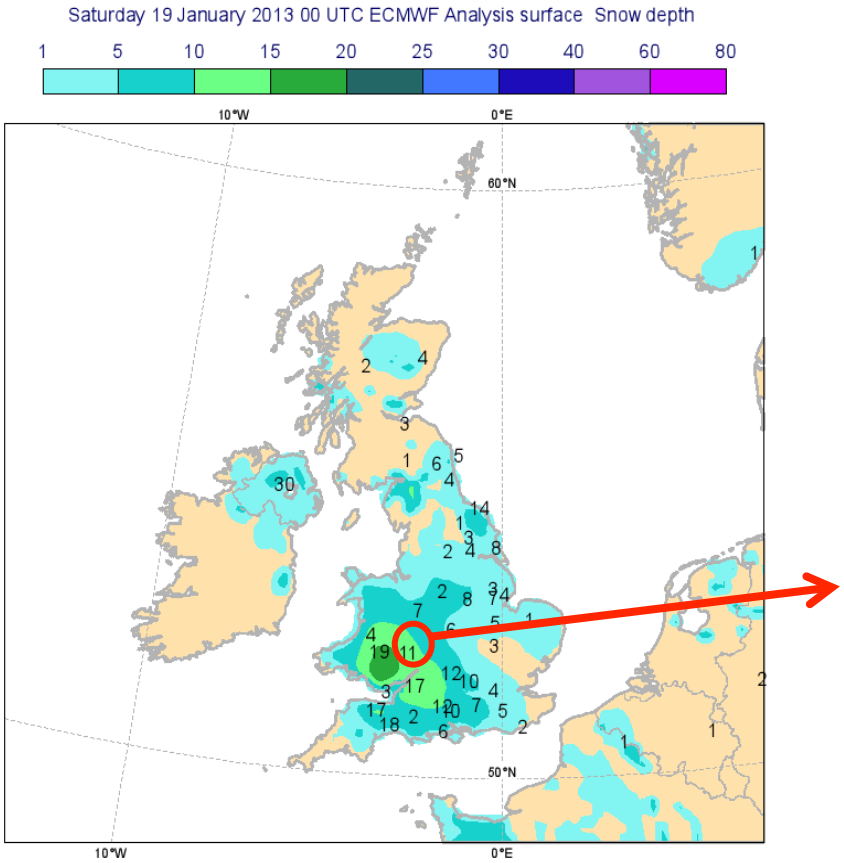
- EFI = 0.96
- SOT = 3.5

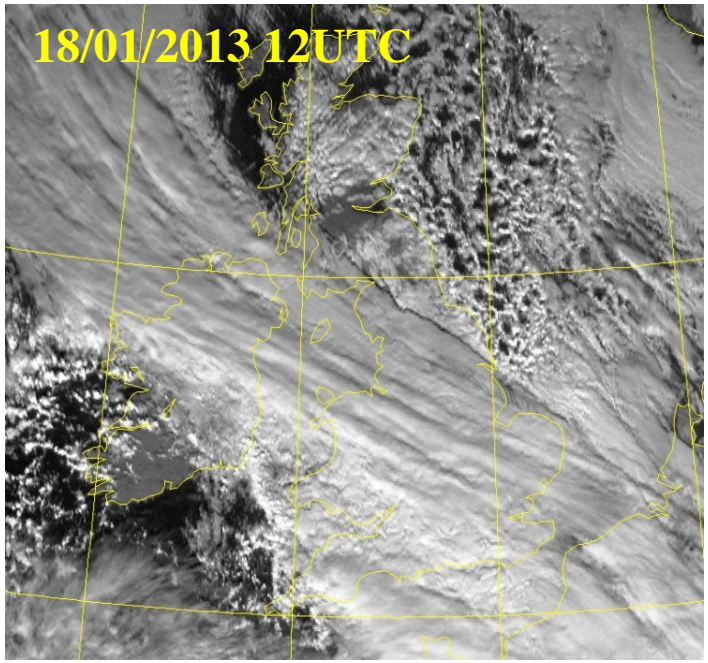
✓ High values of the EFI imply high confidence that extreme snowfall may happen.

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

The outcome

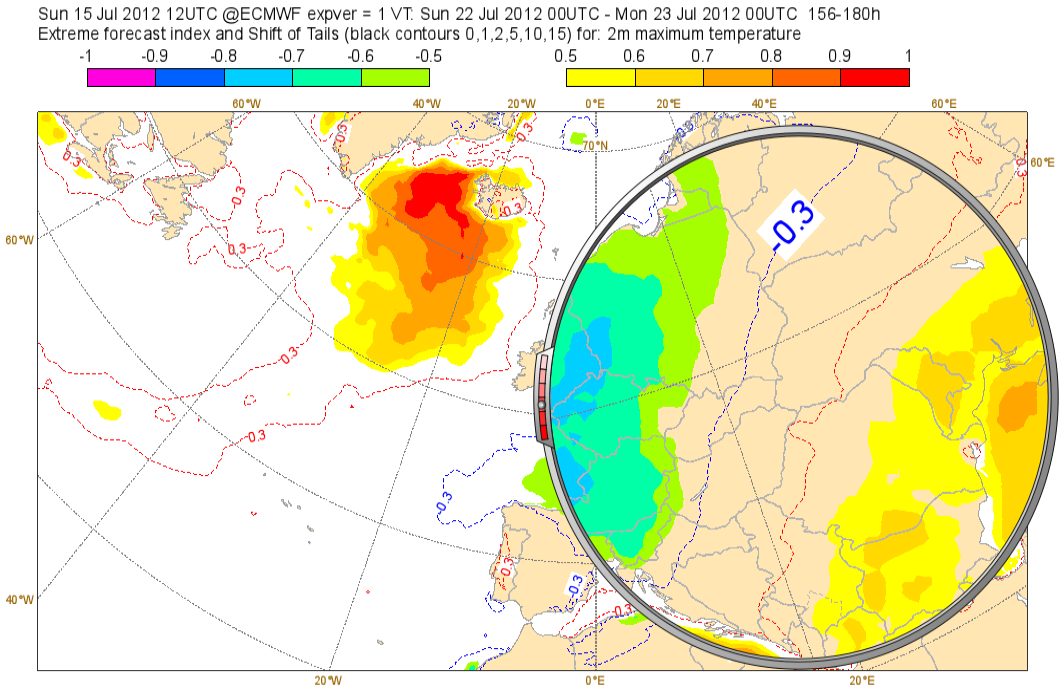
ECMWF snow depth analysis and observations representing the new snow depth for 24-h period from 18/01/2013 00UTC to 19/01/2013 00UTC

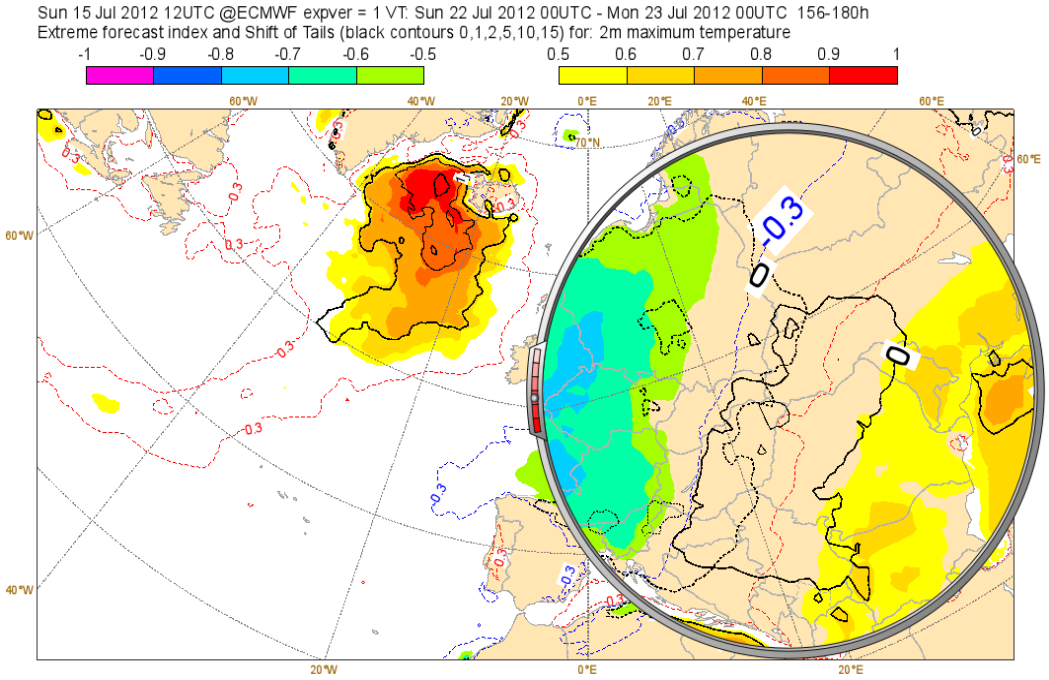




A beer garden in Bromsgrove. Credit: Sue Eden

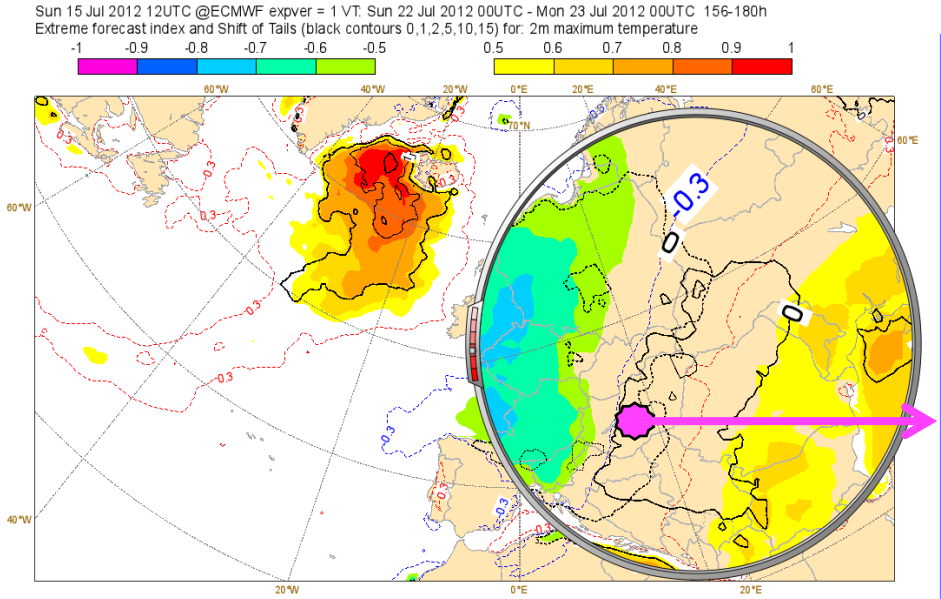
A case of very large uncertainty

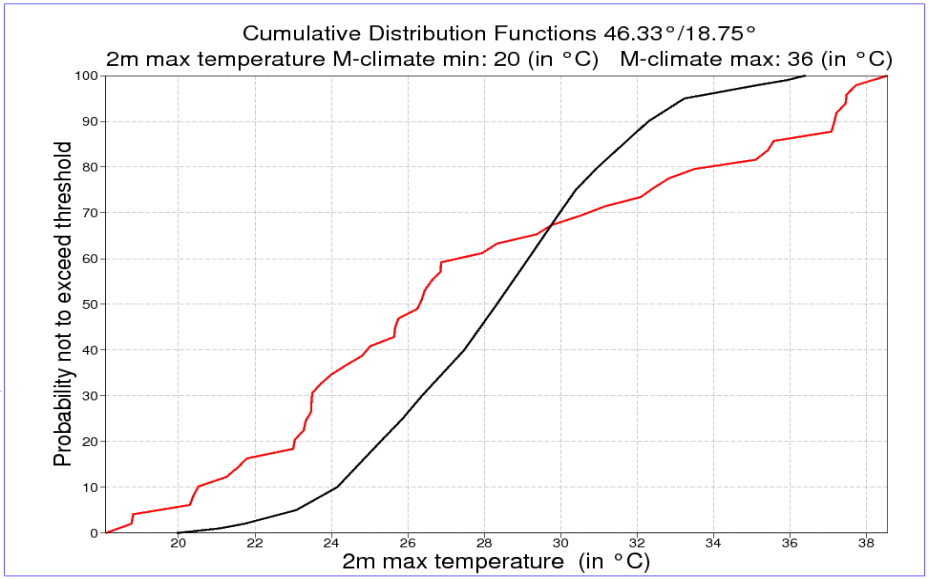


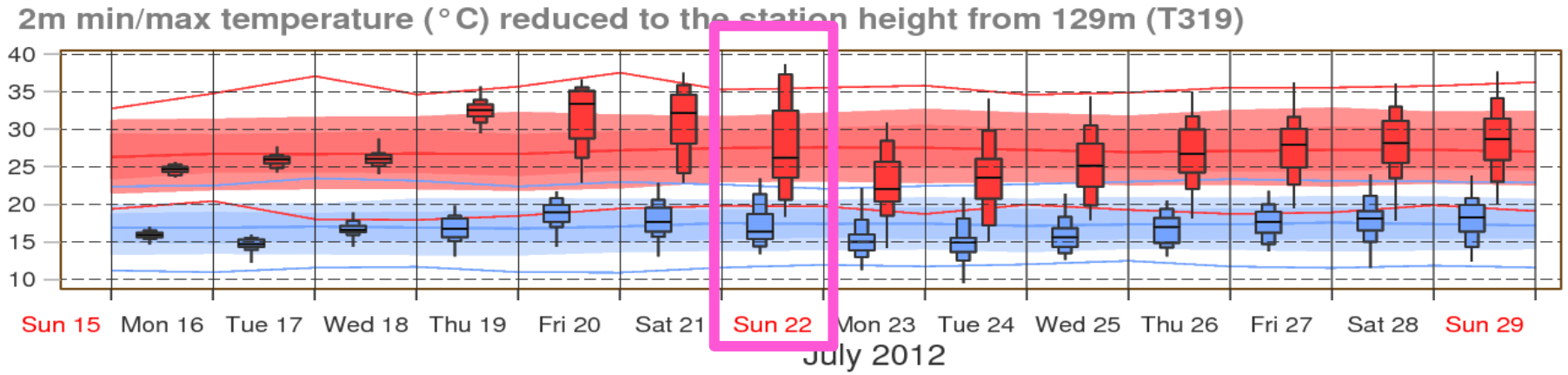


- EFI forecast shows cold conditions over Central Europe and hot weather to the east over the Balkans.
- SOT gives additional information. In the area between the cold and hot weather SOTs overlap. This is a signal of very uncertain forecast – over that area extremely low and extremely high temperatures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

A case of very large uncertainty



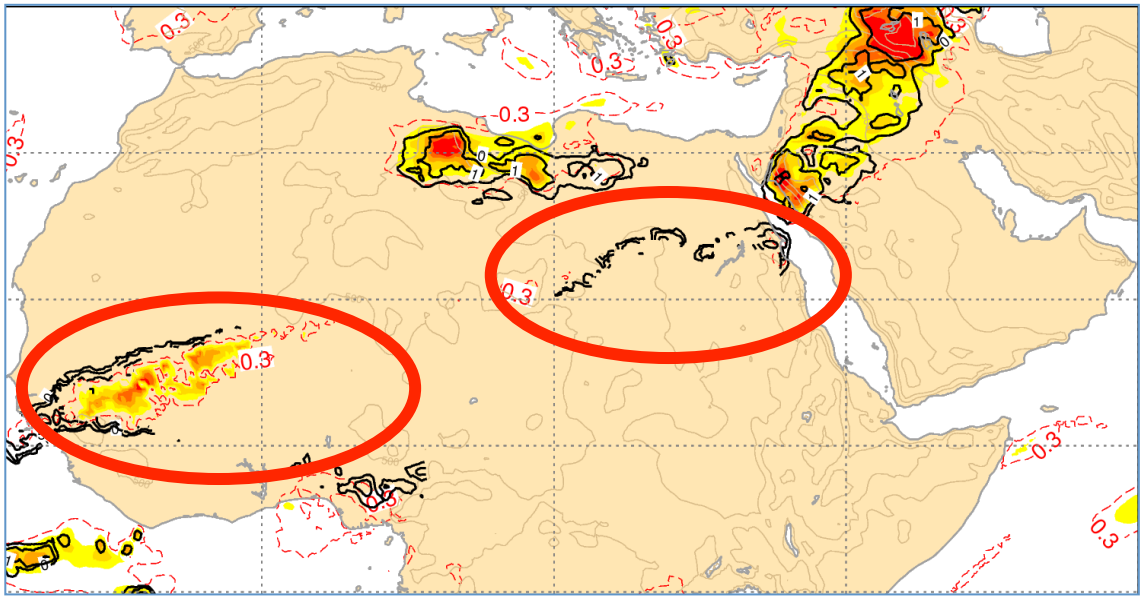




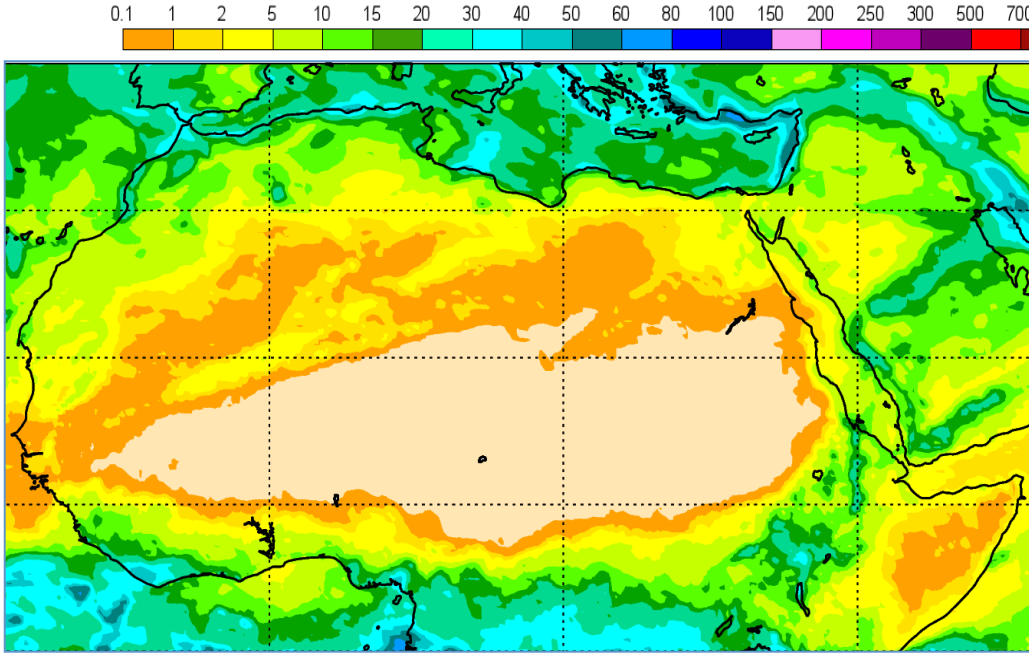
Some ENS members predict maximum temperature below the M-climate minimum, but some – above the M-climate maximum! This large uncertainty is related to the passage of a cold front.

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-hour 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

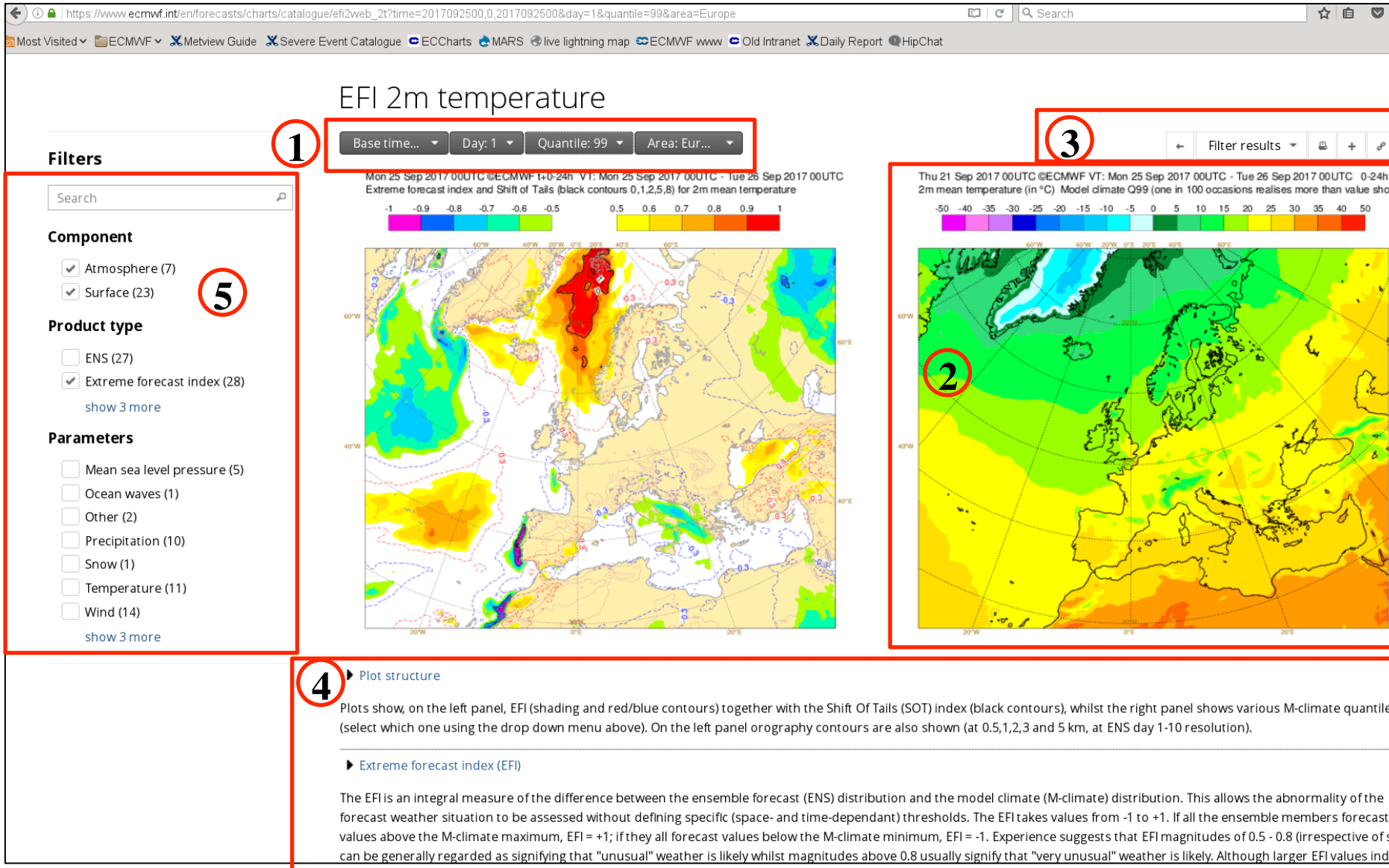
- 00UTC: 000-360

* available since 19th June 2012

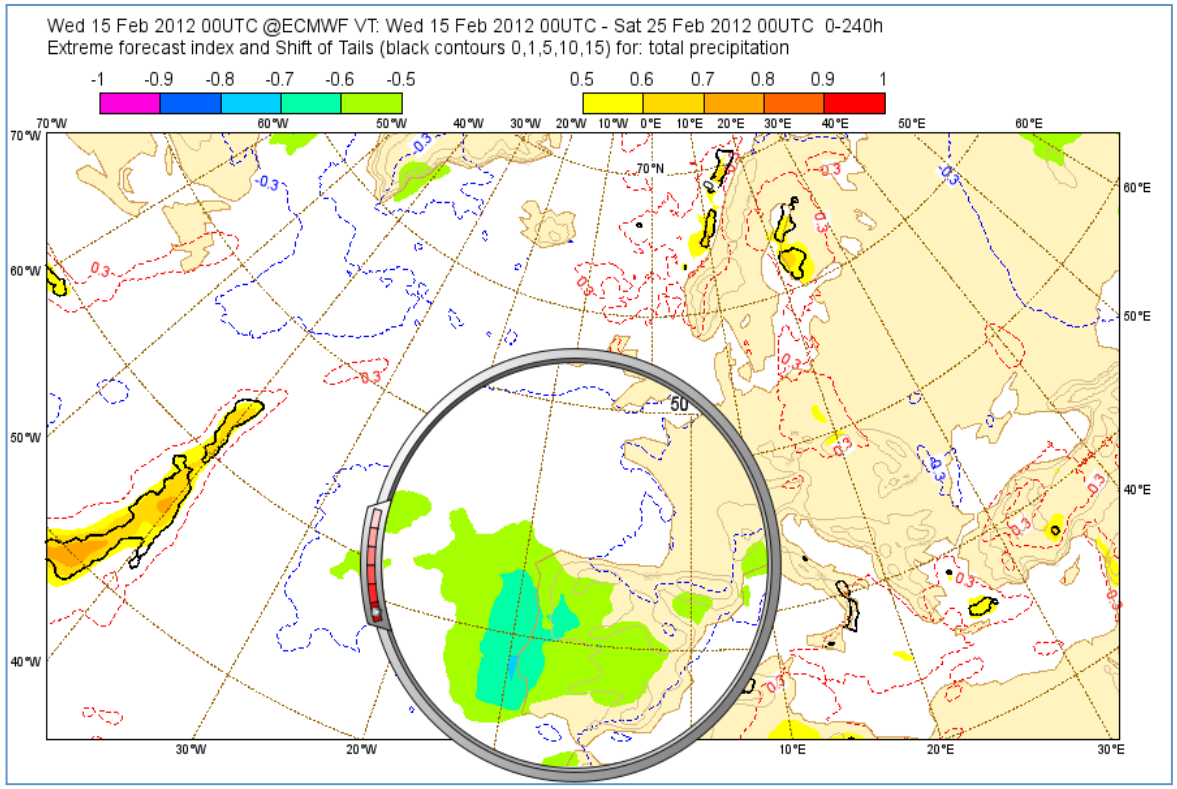
** available since 12th May 2015

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

1. Selection bar
2. M-climate
3. Additional tools
4. Help pages
5. Filters



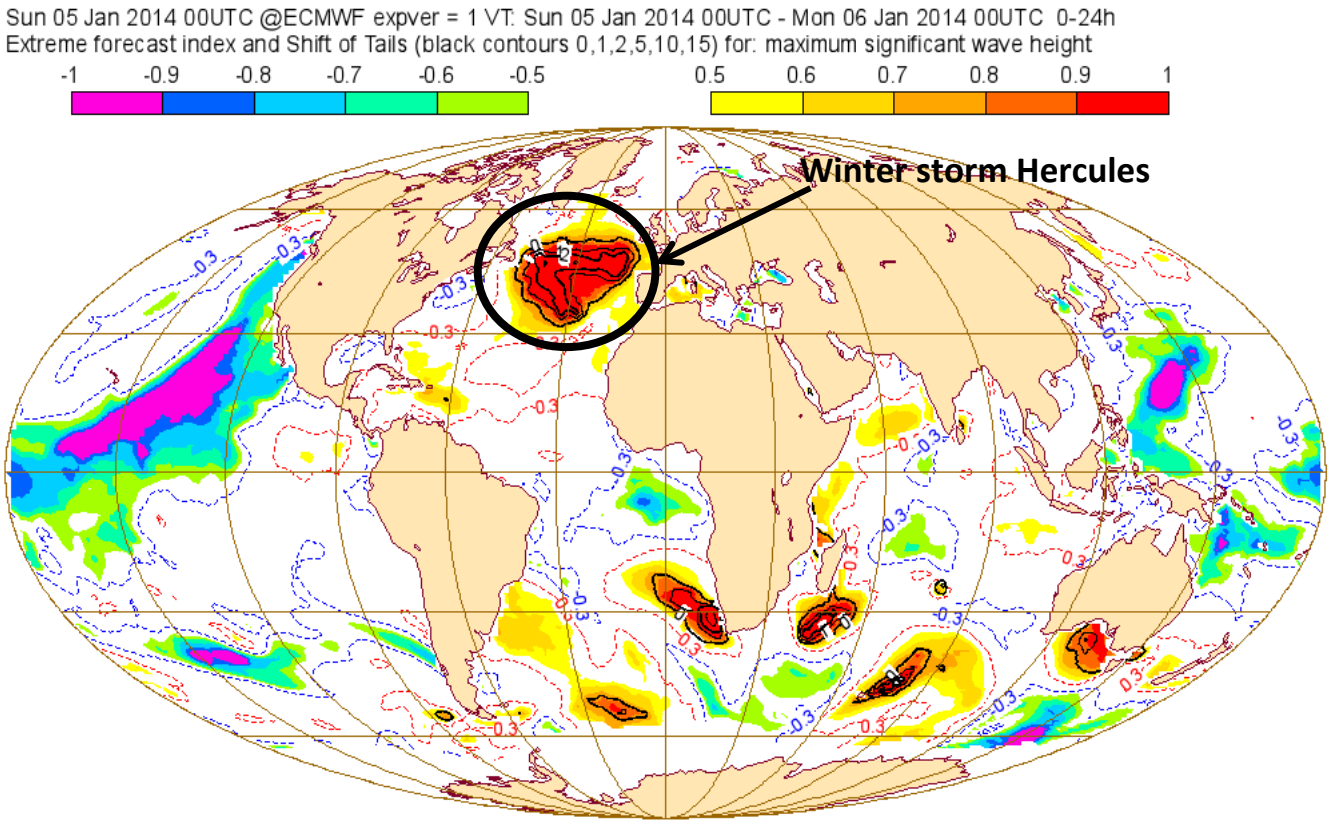
Negative EFI for precipitation



A case of severe drought in Portuga in 2011-2012

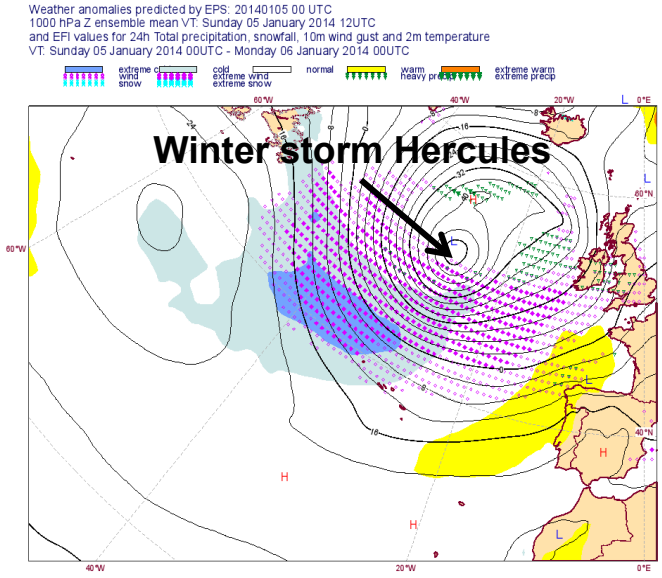
- For 24-hour accumulations negative EFI for precipitation does not make sense because precipitat is bounded by 0 and in most of the places a dry day is not considered extreme anyway.
- For accumulations over longer periods negative EFI does make sense. It gives the risk of dry wea for a relatively prolonged period of time, e.g. 10 or 15 days.

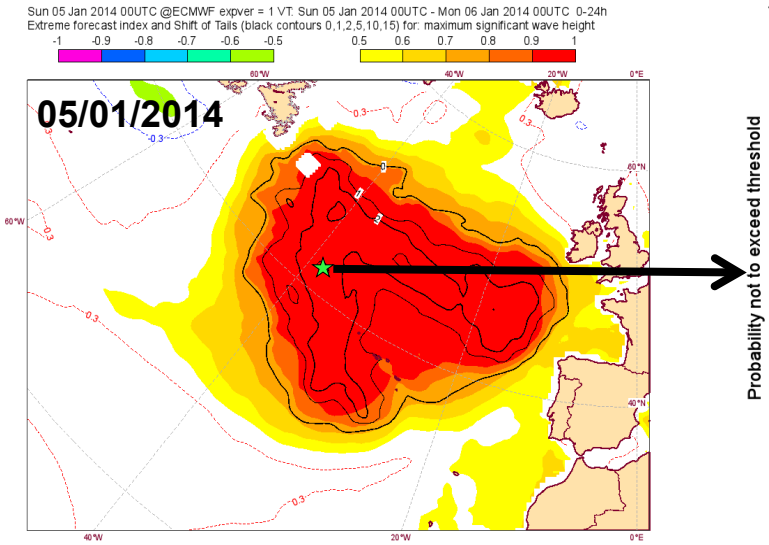
EFI for waves

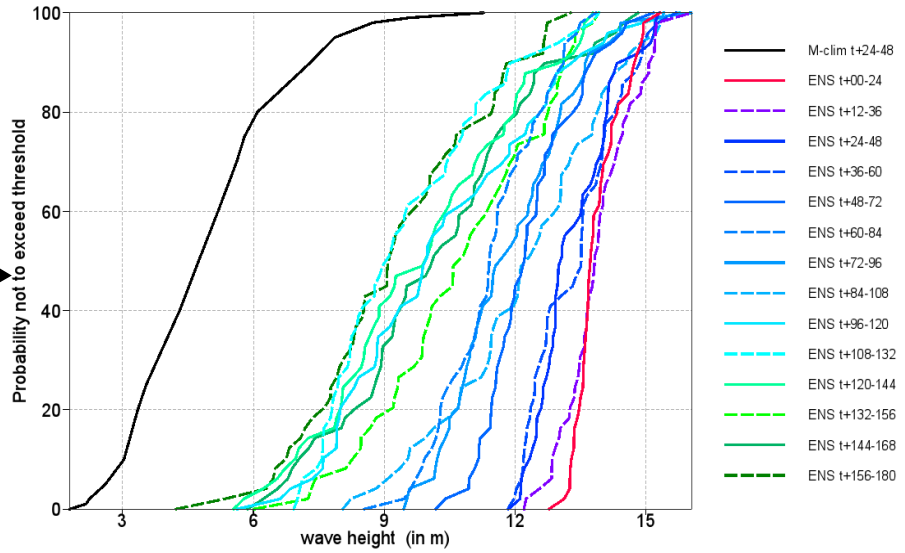


- Negative EFI (calm sea) also plotted on the web.
- The winter storm Hercules generated waves up to 20 m in height on 5 and 6 January 2014.

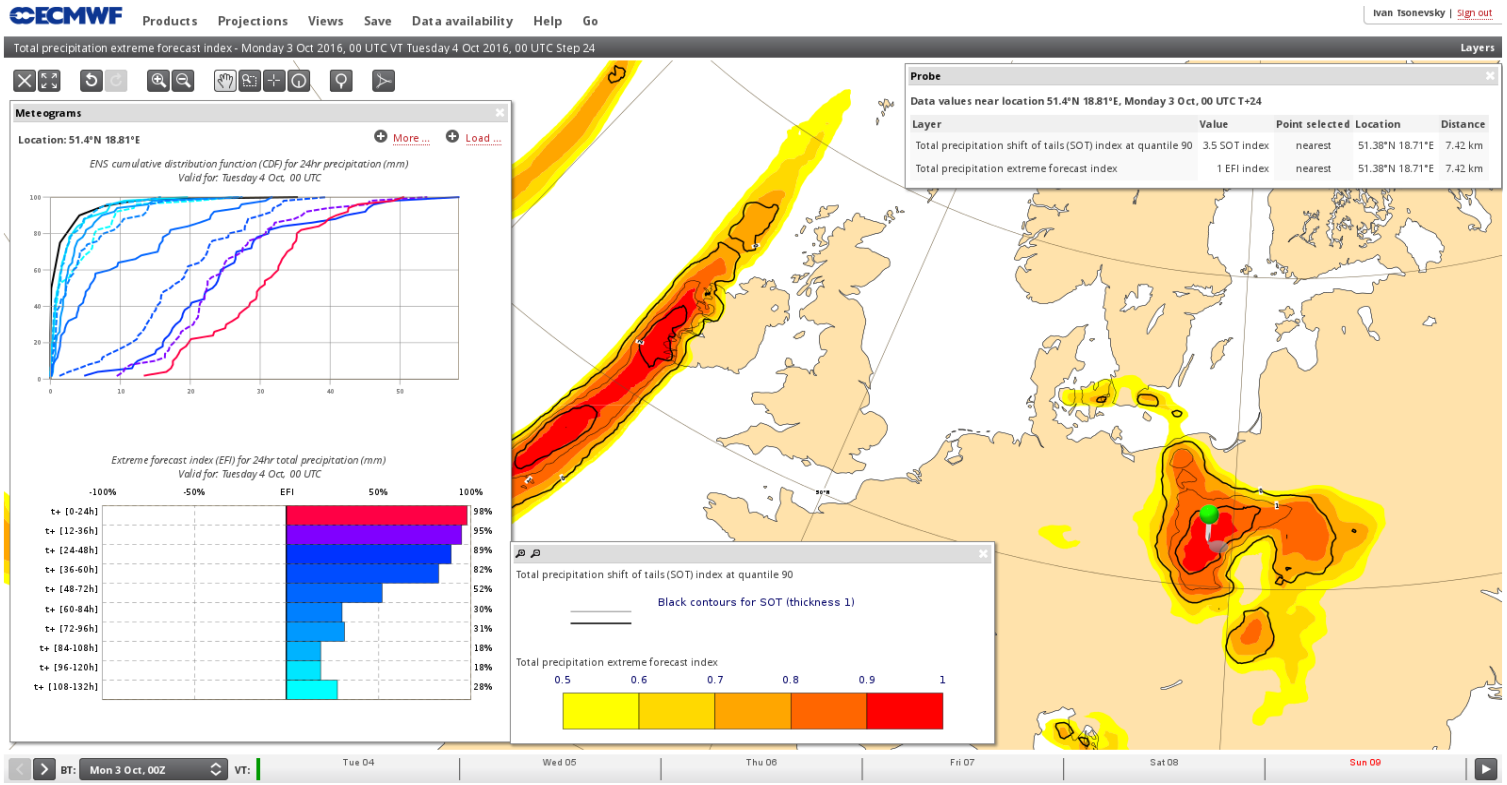
Historic swell – Storm Hercules







EFI on the ecCharts

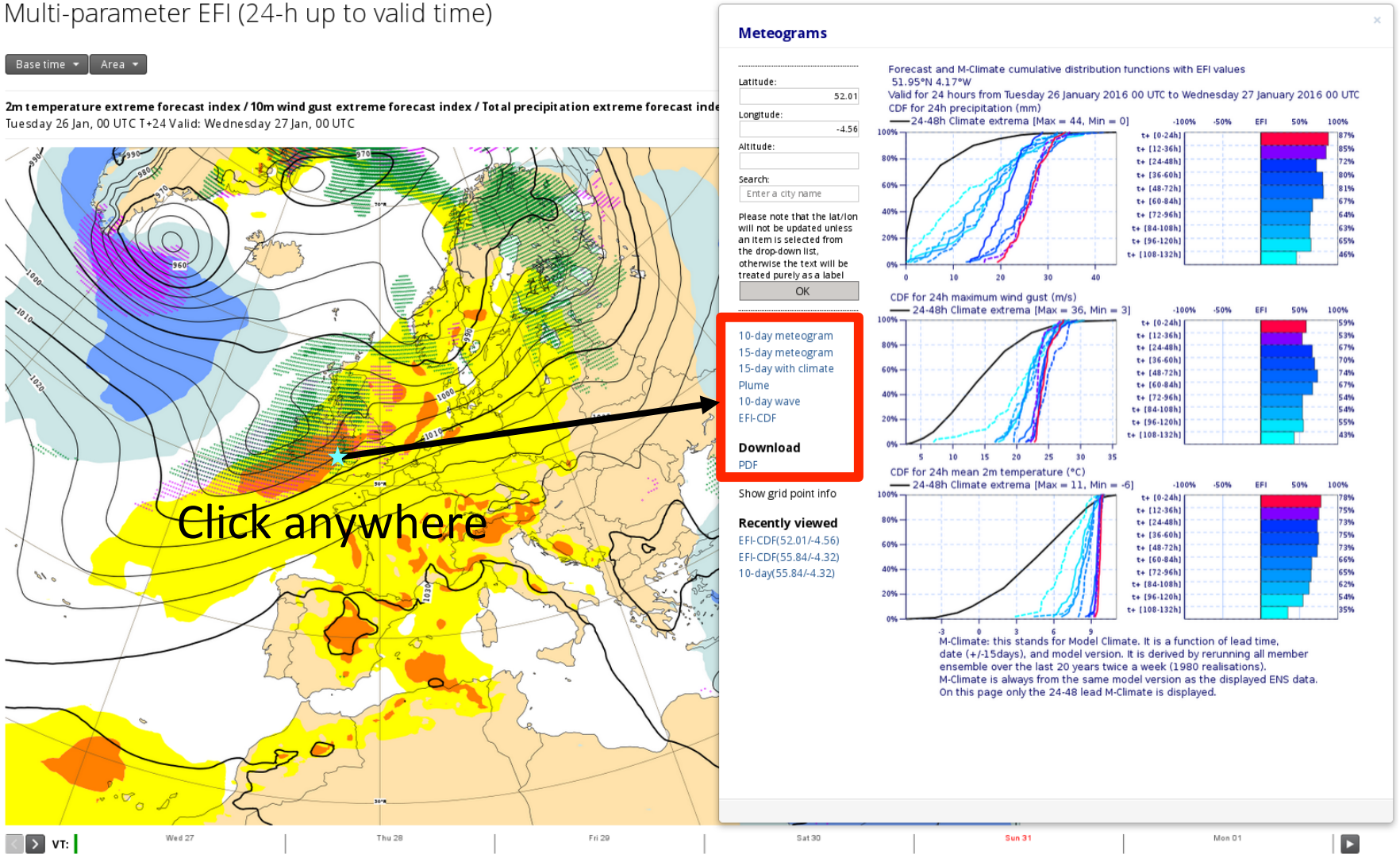


- EFI & SOT can be accessed via ecCharts at http://wrep.ecmwf.int/forecaster/.
- CDFs and EFI bar plot for a given location can be displayed as well, just for (2t, 2tmin, 2tm 10fg, tp) at the moment. More will be added soon.
- M-climate is available as well.

Clickable charts

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

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



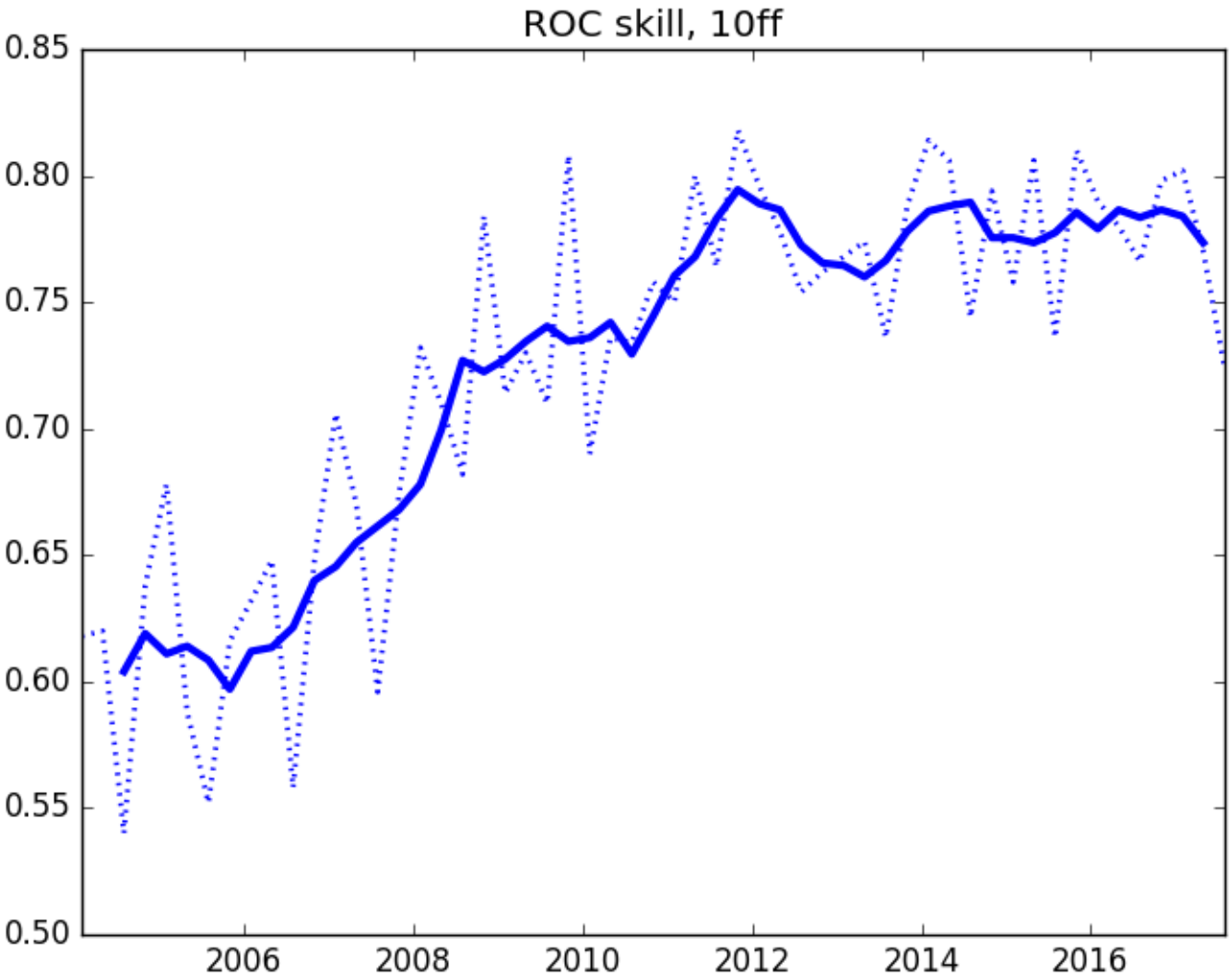
EFI Verification

- Verification of the EFI has been done using synoptic observations over Europe available on the GTS.
- An extreme event is defines when 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). ROCA shows how good the model is at discriminating between severe and non-severe events.
- $$EFI\ skill\ score = score\downarrow forecast - score\downarrow reference\ /\ score\downarrow perfect\ forecast - score\downarrow reference = ROCA\downarrow f - 0.5/1 - 0.5 = 2ROCA\downarrow f - 1$$

  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



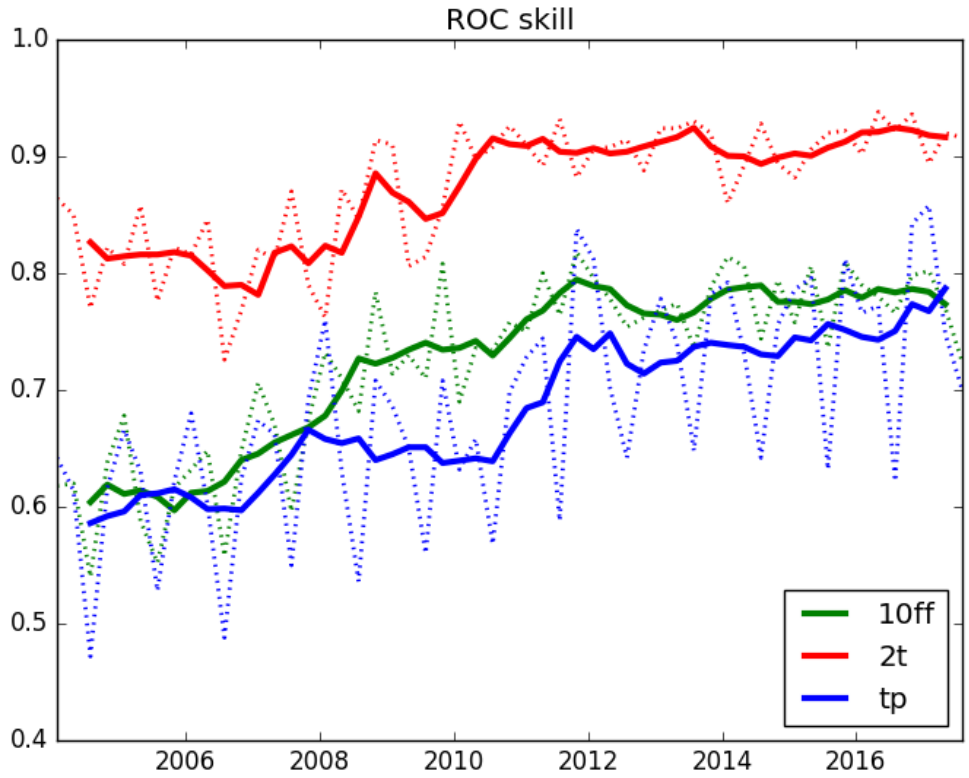
EFI Skill = 2*ROCA-1

EFI Skill = 0 no skill

EFI Skill = 1 perfect sc

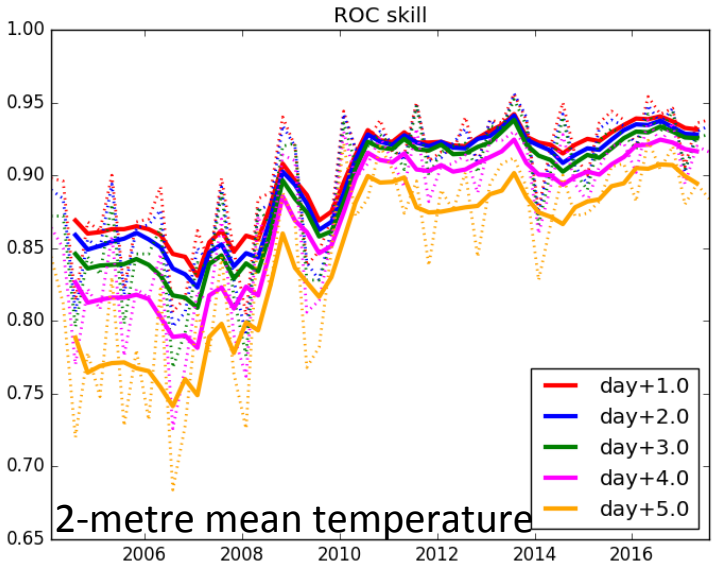
- **The plot shows the skill of the EFI for 10-metre wind speed** (a supplementary headlin score adopted by the ECMWF Council) **at forecast day 4** (t+72-9 for 00UTC)**.**
- **The solid curve depic a four-season runnin mean.**

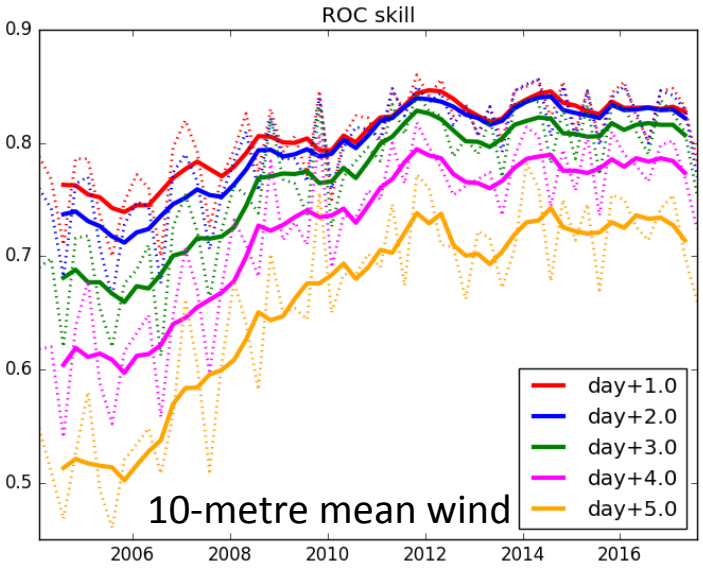
EFI Verification

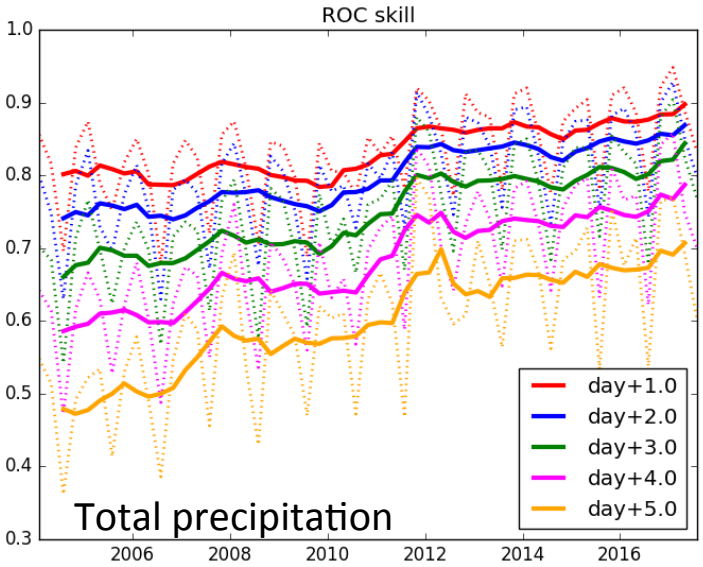


- Solid curves show a four-season running mean and dashed curves show seasonal EFI skill scores mean temperature (2t), 10 metre mean wind speed (10ff) and total precipitation (tp) for day 4 (t+72- for 00UTC).
- The EFI for 2m temperature is more skilful than EFI for the other two parameters.

EFI Verification







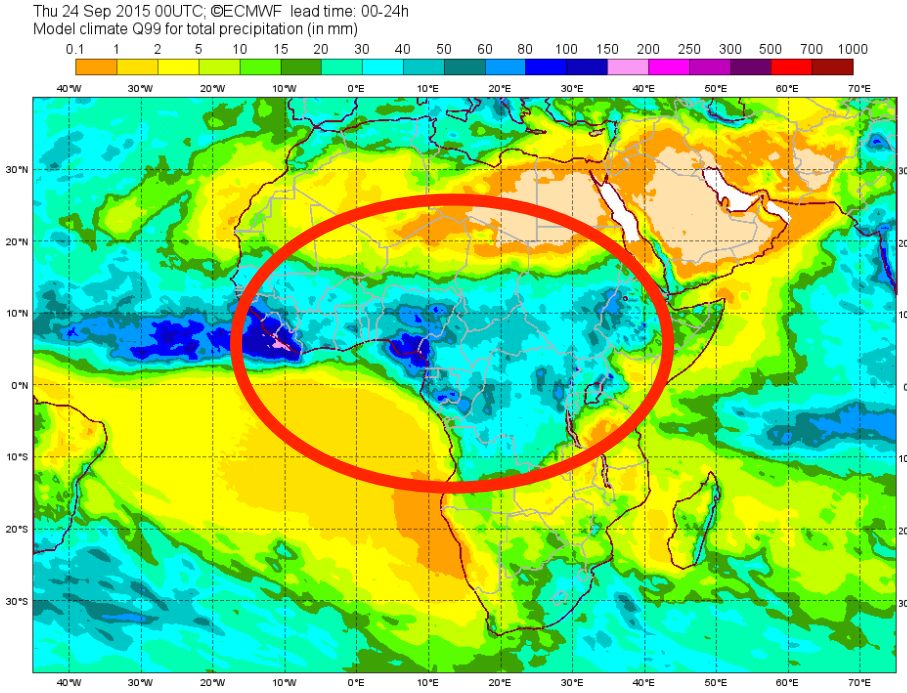
- EFI skill as a function of the lead time
- Notable seasonal cycle in the EFI skill especially for total precipitation with its minimum in summer

Known issues

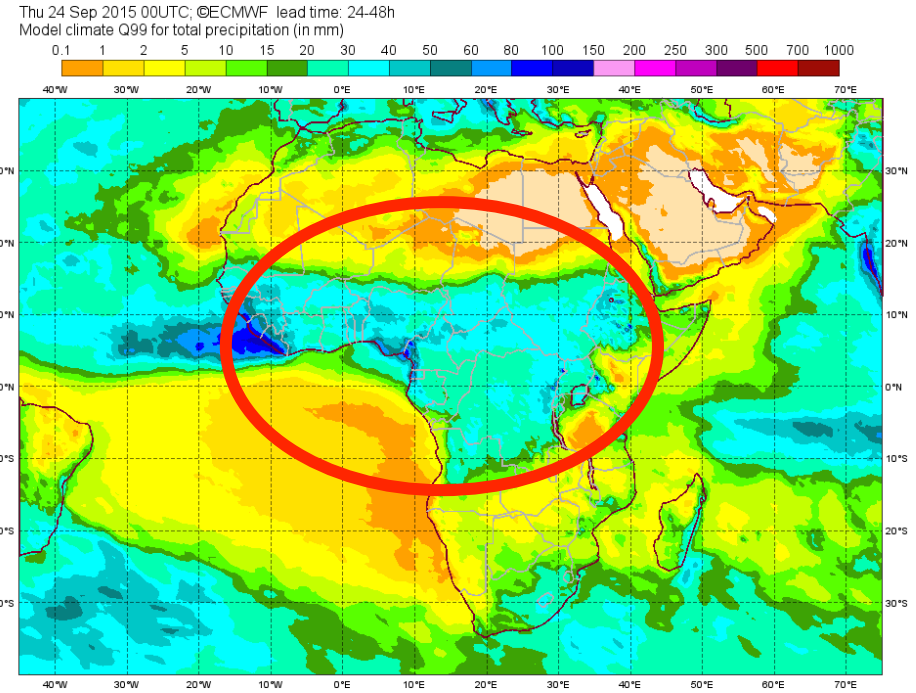
- **Re-forecast sample size is still not sufficient for providing robust climate:**
  - ✓ The increase of the sample size since May 2015 has considerably improved the M-climate but still:
    - There is still some noise, especially in the tails of the climate distribution.
- **M-climate is affected by the model biases:**
  - ✓ Jumpiness in the M-climate for different lead times
  - ✓ This does not affect the EFI/SOT
- **The EFI/SOT might be affected by a seasonal trend due to discrete change of the M-climate during transition seasons (spring and autumn)** – an example will be shown**.**

Known issues – an example, tropical Africa

T+0-24h

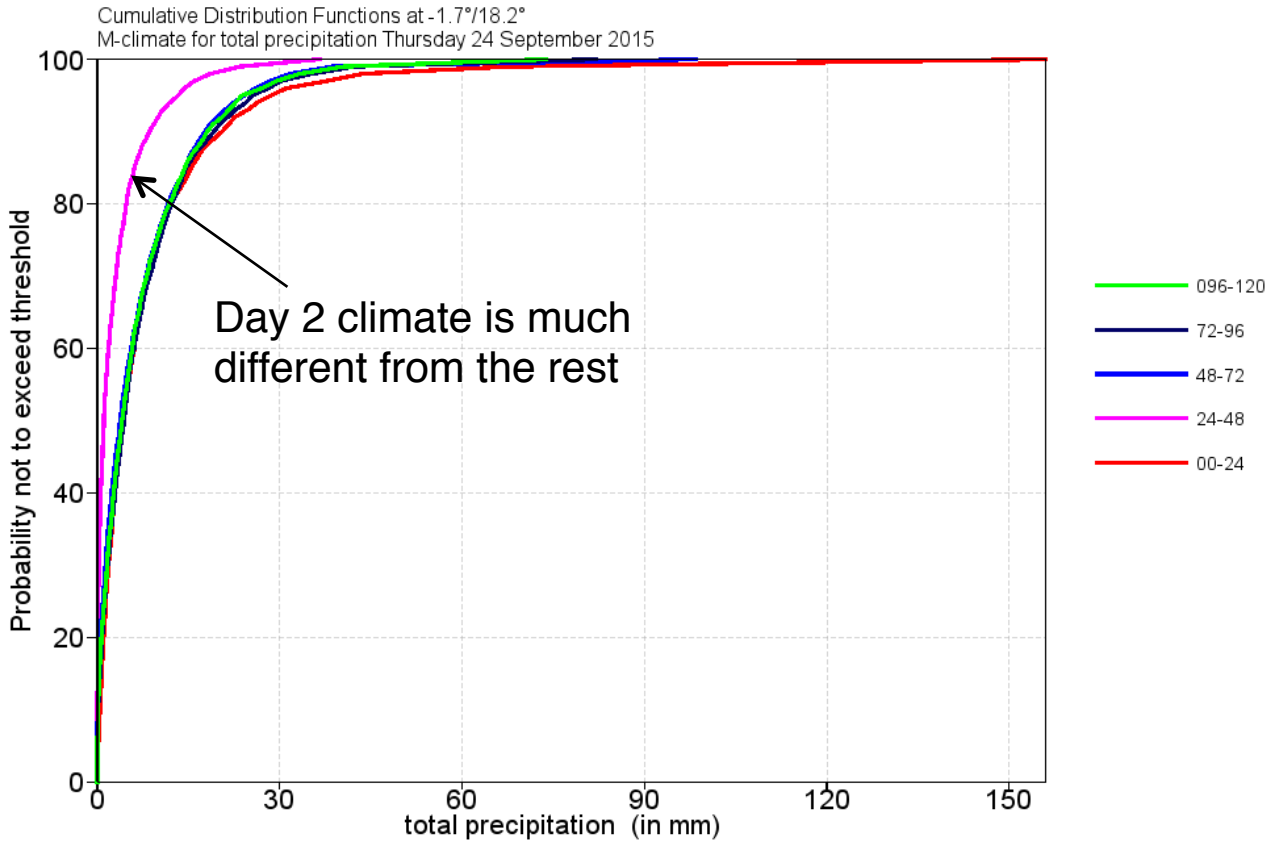


T+24-48h



- 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.

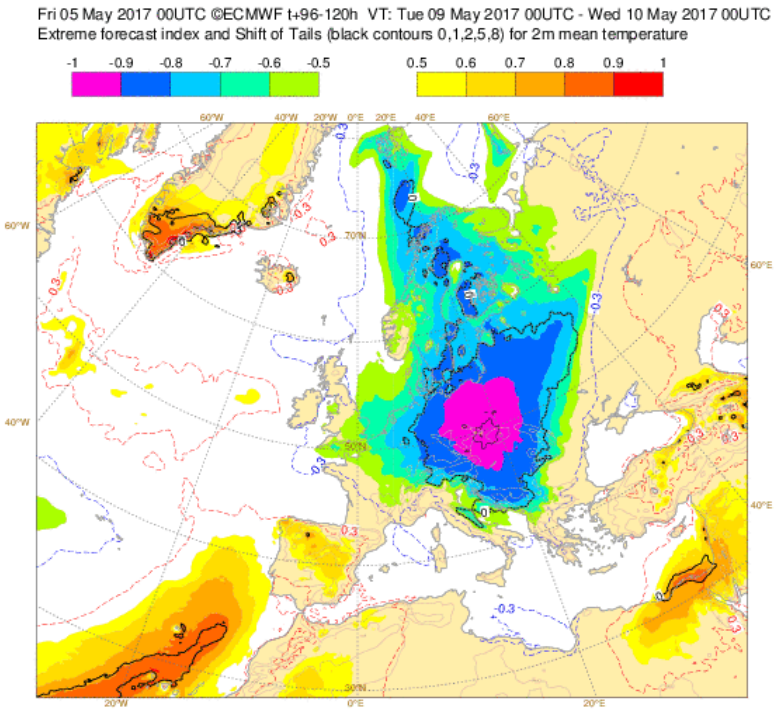
Known issues – an example, tropical Africa

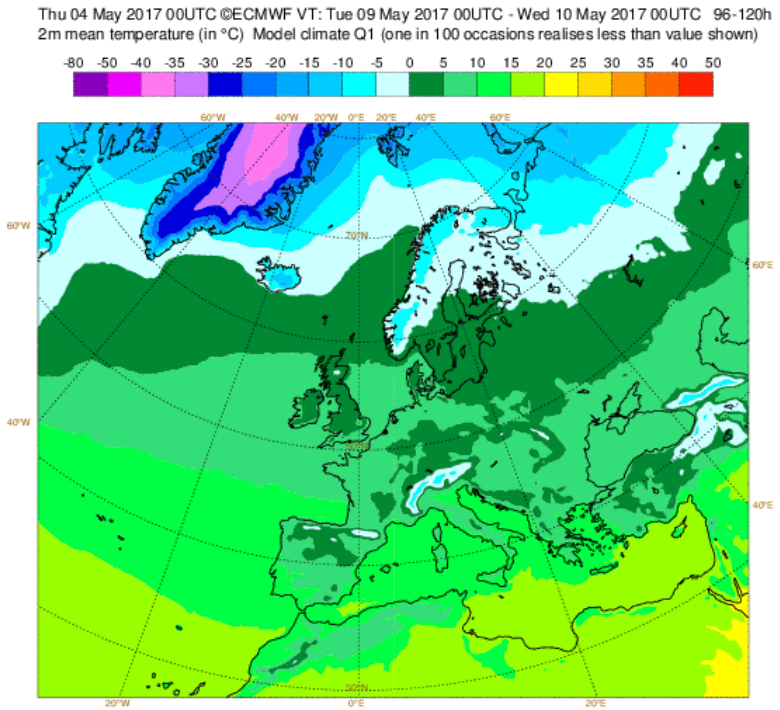


M-climate is not perfect. It is affected by model biases and therefore it depends on the lead time:

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

Seasonal trend issue





On the animation, the EFI valid for the same date is becoming less extreme although the forecasts are similar because the M-climate is becoming colder for shorter lead times. Suddenly the EFI jumps to m extreme values again after the update of the M-climate because the model climatology appears warm after that update as we add one warm week and remove another cold week. The effect will be opposit for a case in autumn.

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

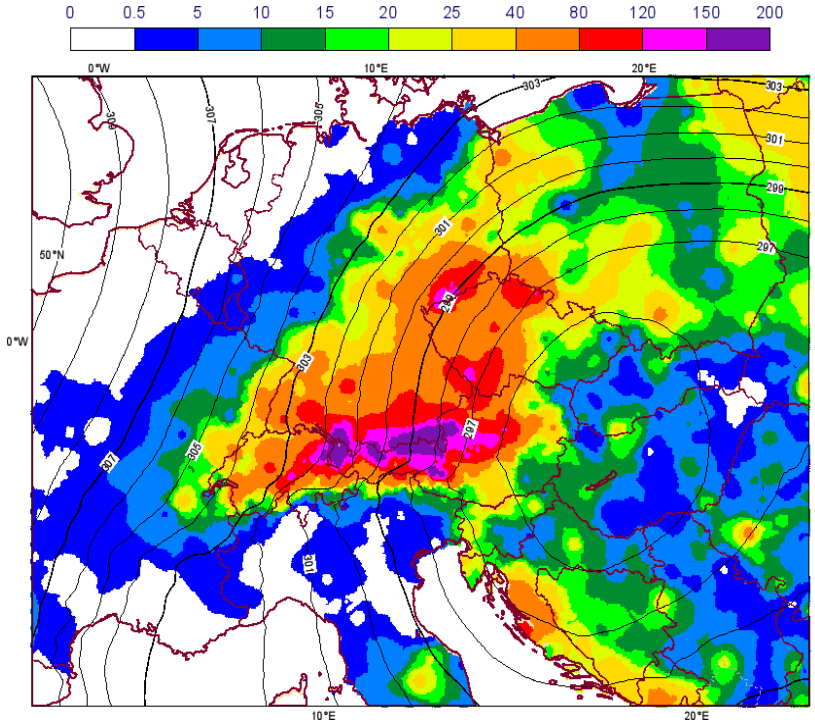
Forecast and Research Departments

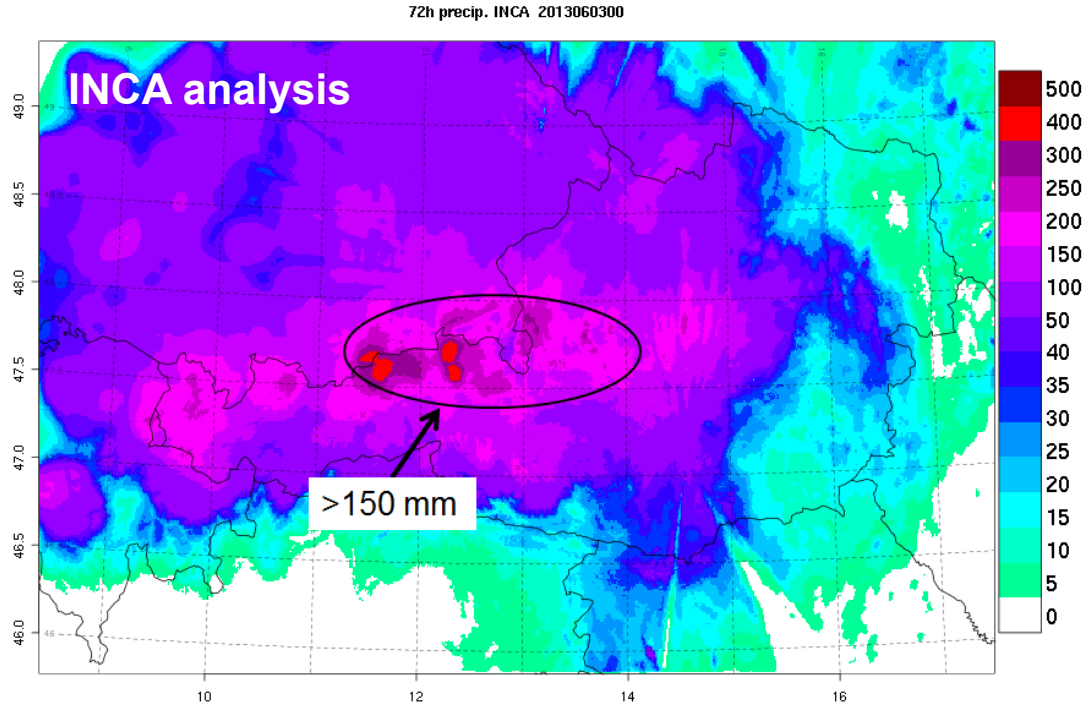
June 2014

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

Analysis

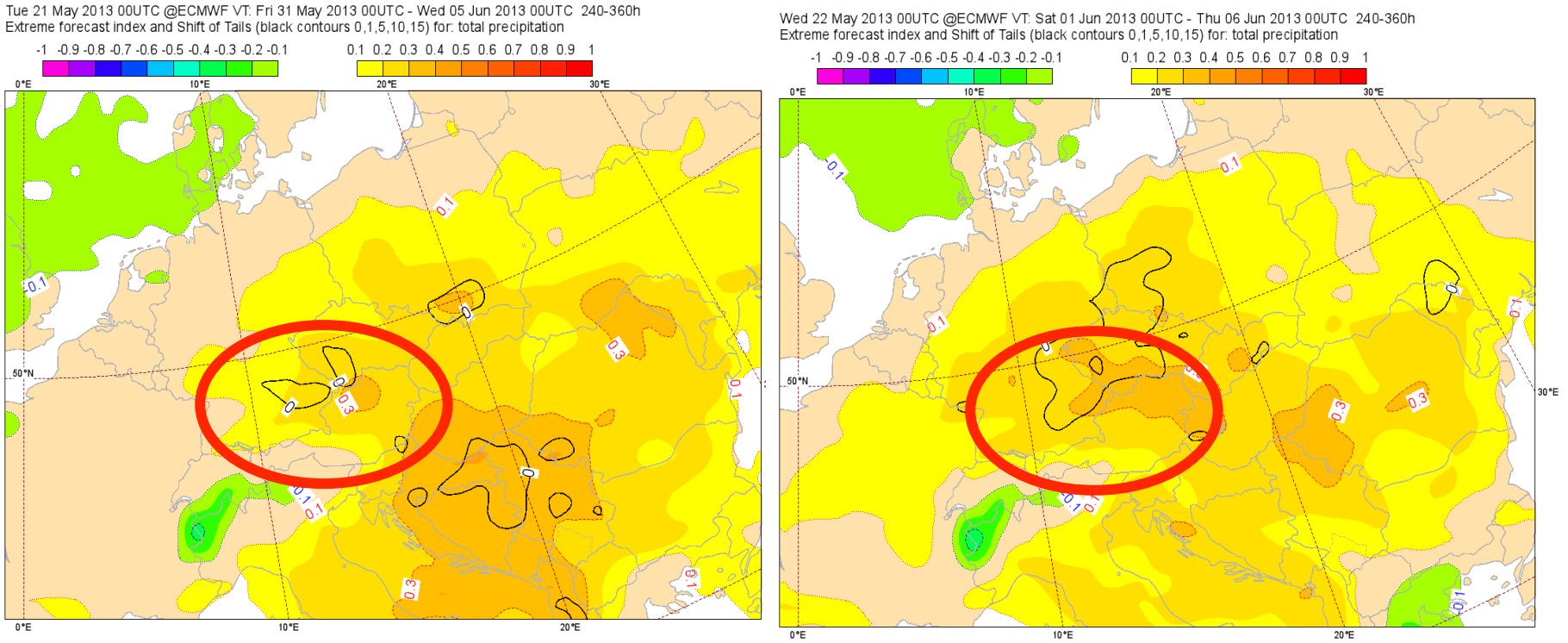
Observed rainfall interpolated on a grid and Z700
(mean over the period) ECMWF analysis
VT: 31/05/2013 06 UTC – 03/06/2013 06UTC





- 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 for this long lead time.
- Positive SOT values mark the areas where the forecast system predicts exceptionally heavy rain.

EFI/SOT for forecasting severe convection

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

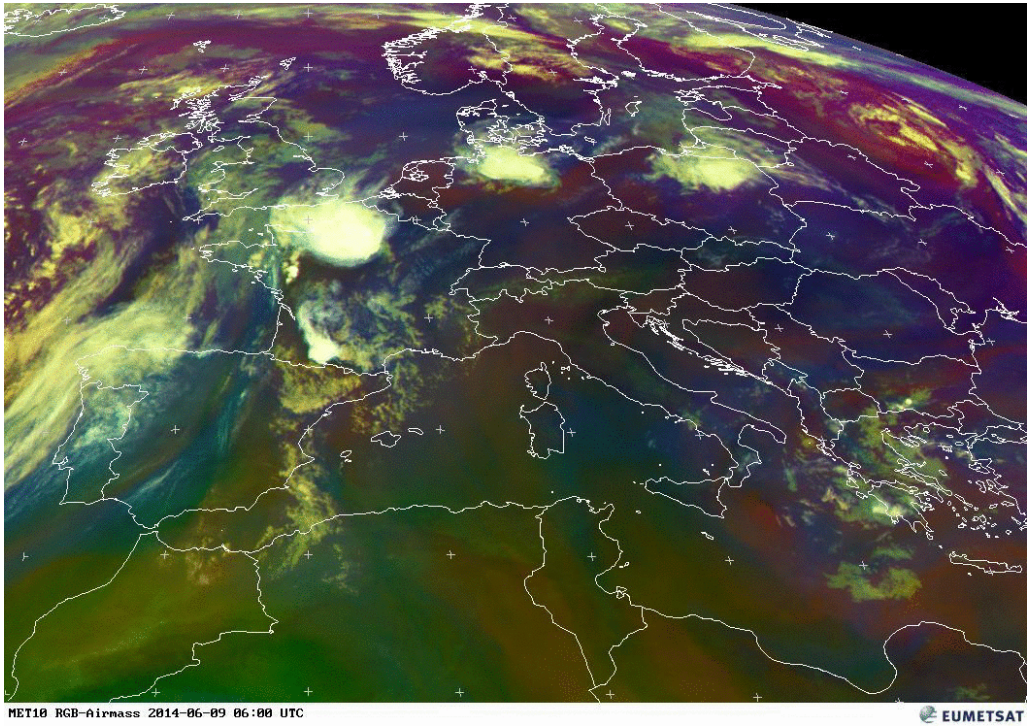
$$CAPE = \int_{z_{LFC}}^{Z_{EL}} g\left(\theta_{e,up} - \theta_{e,sat}\right) / \theta_{e,sat} \; dz$$

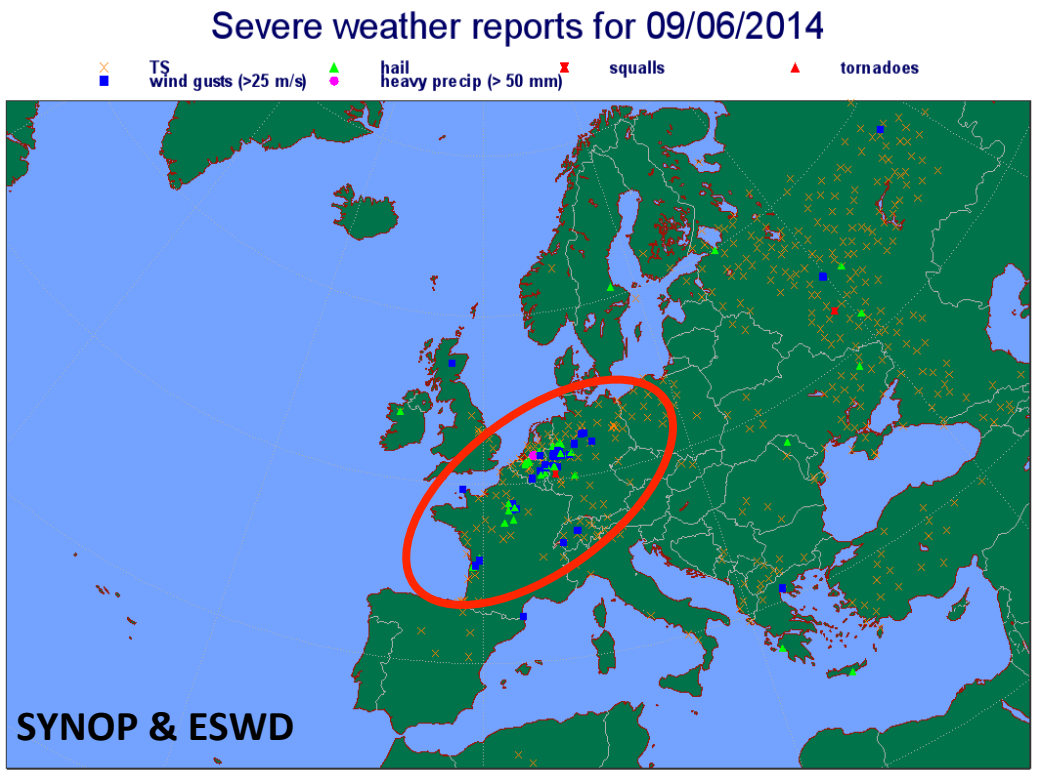
- CAPESHEAR Parameter (CSP):

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

  - $WS_{l_1 l_2}$ - bulk wind 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.

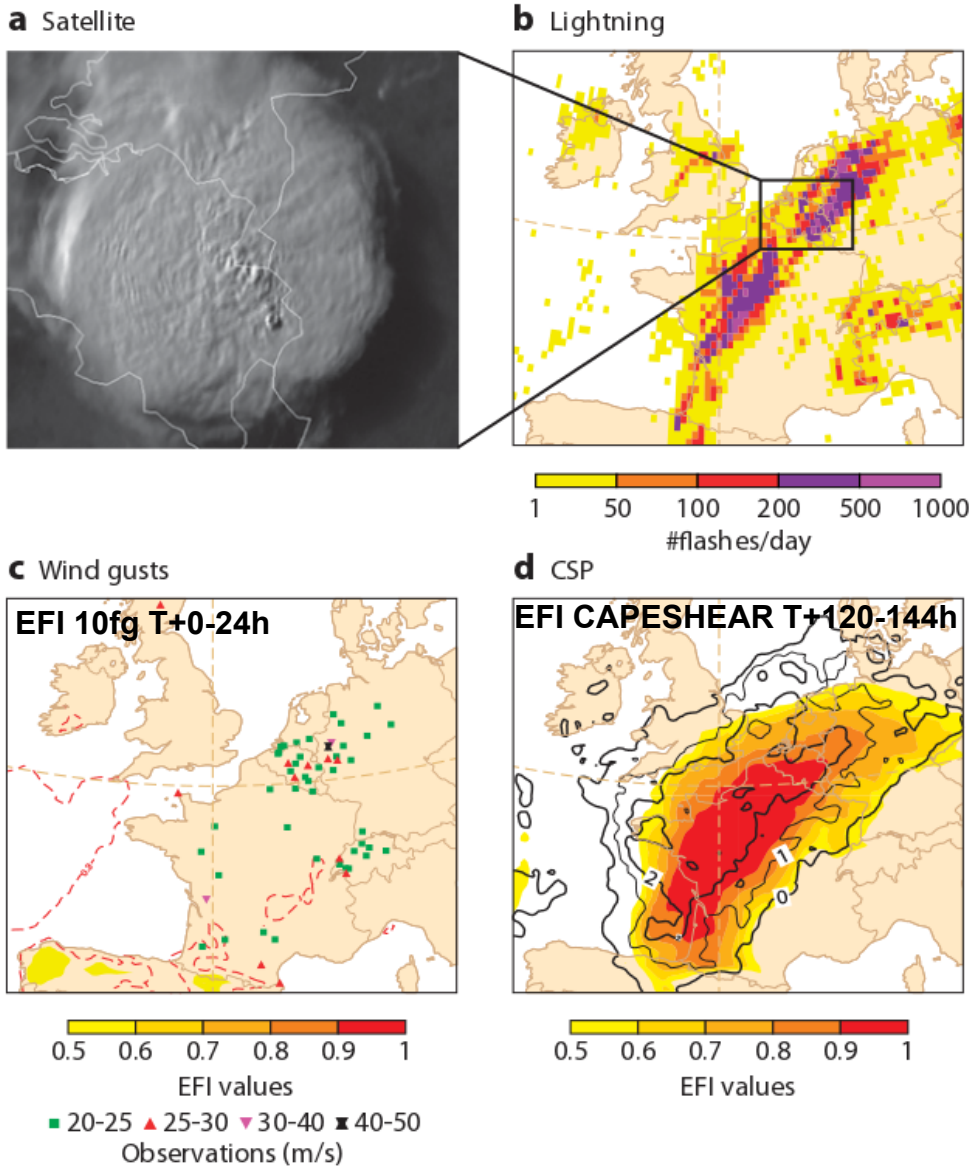
Severe convection, 9 June 2014





- 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 in the European Severe Weather Database (ESWD).

Severe convection, 9 June 2014



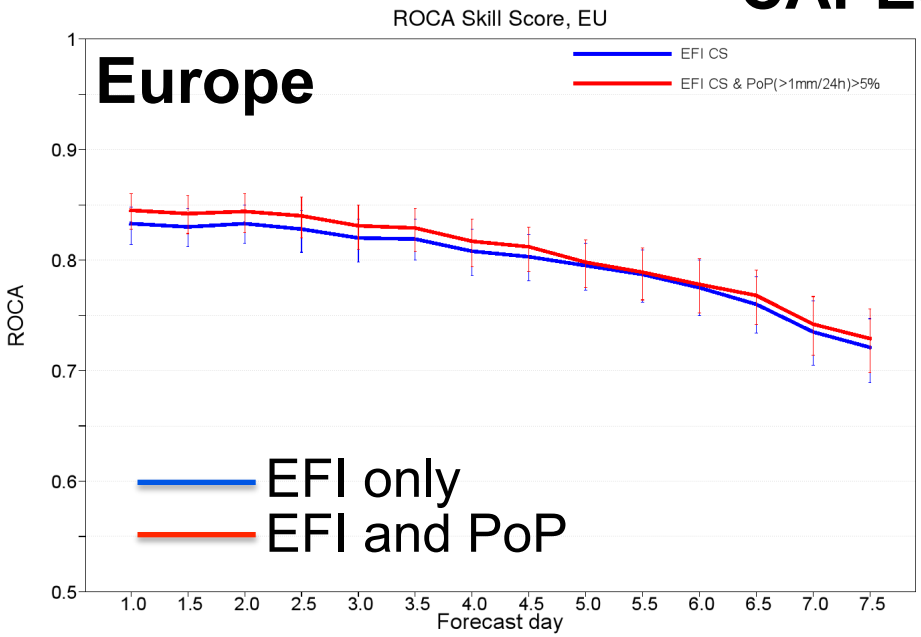
- Strong wind gusts were reported in France, Belgium, the Netherland an Germany.
- The maximum wind gust at Düsseld airport was 42 m/s.
- The EFI gave no indication of sever wind gusts even in the short range (
- The EFI for CAPESHEAR reached values close to 1 six days in advanc (**d**).

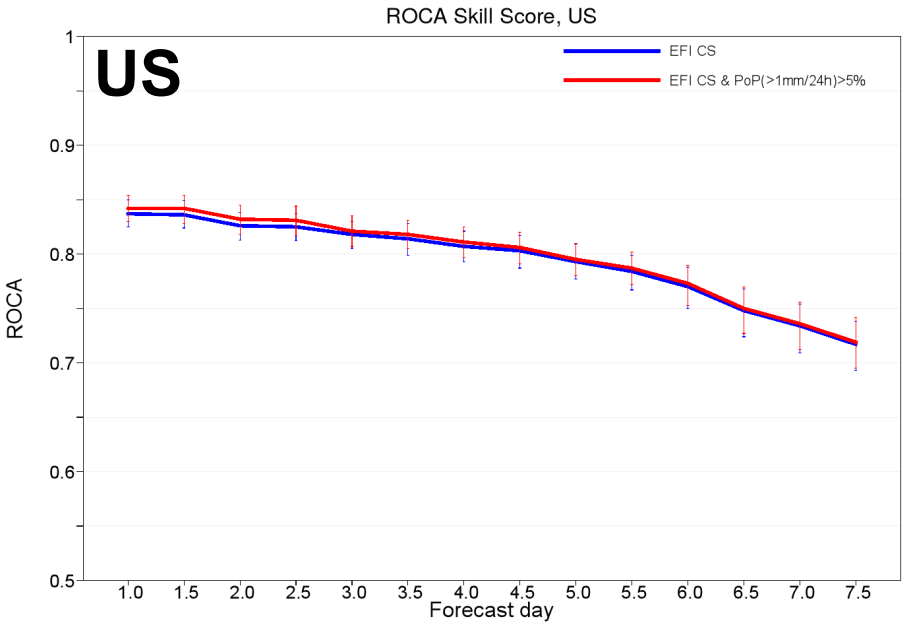
Verification

- 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
  - ✓ European Severe Weather Database (ESWD) operated by ESSL
  - ✓ 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)
- Verification is performed just for land points

Verification

CAPESHEAR





- Verification period is 1 April – 30 September 2016
- For Europe ESWD reports for tornadoes, severe wind and large hail used only
- EFI v. EFI and PoP (>1mm/day) > 5%
- Similar results for Europe and the US
- High skill well in the medium range.

Some considerations and future plans

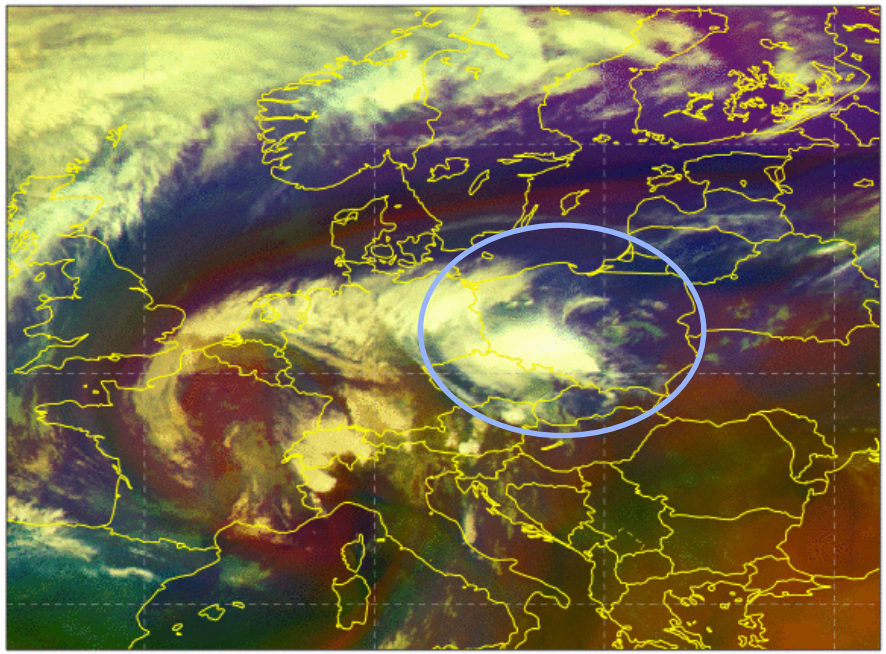
- The EFI provides signals of anomalous weather relative to the model climatology.
  - ✓ very low CAPE values (<10 J/kg) are filtered out to avoid insignificant signals in the areas of low CAPE values in the M-climate (e.g. Arctic in winter)
  - ✓ severe convection unlikely when climatological values 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).

Severe convection, Poland, 11/08/17

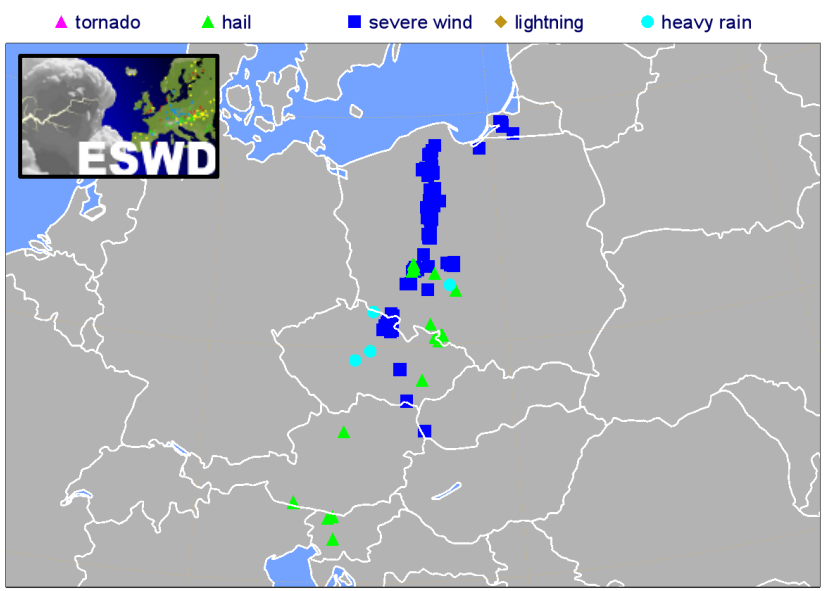
- 5 people killed during an outbreak of severe thunderstorms on Friday, 11 August 2017

Analysis

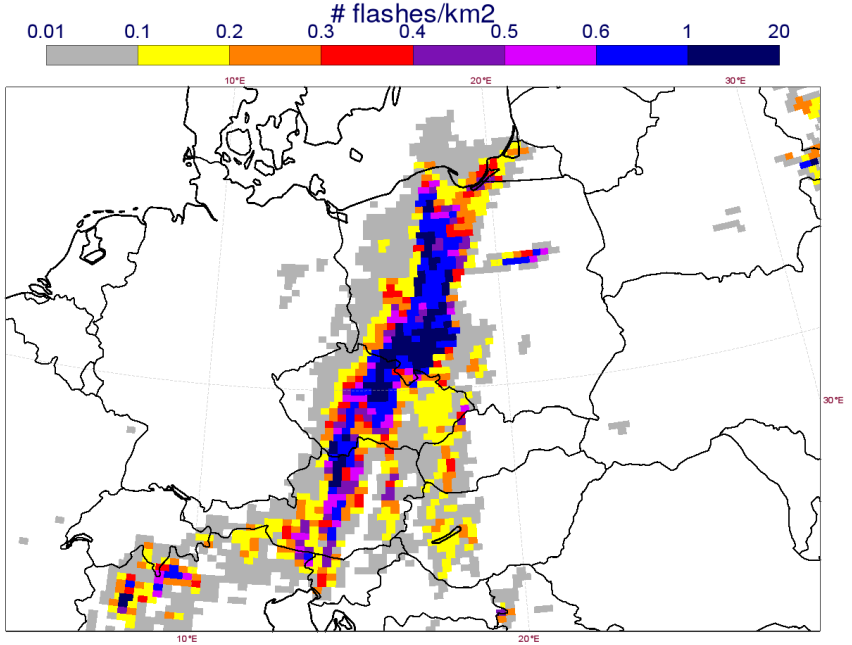
11 August 2017 00:00Z



Severe weather reports for Friday 11 Aug 2017

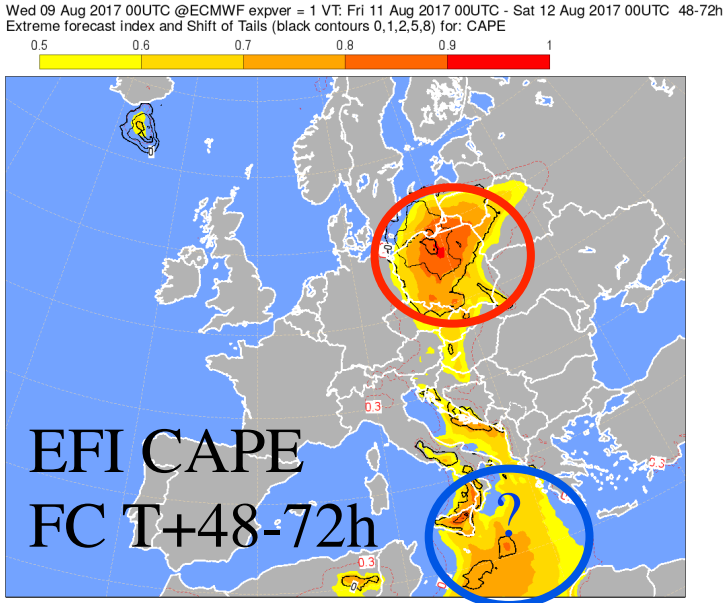


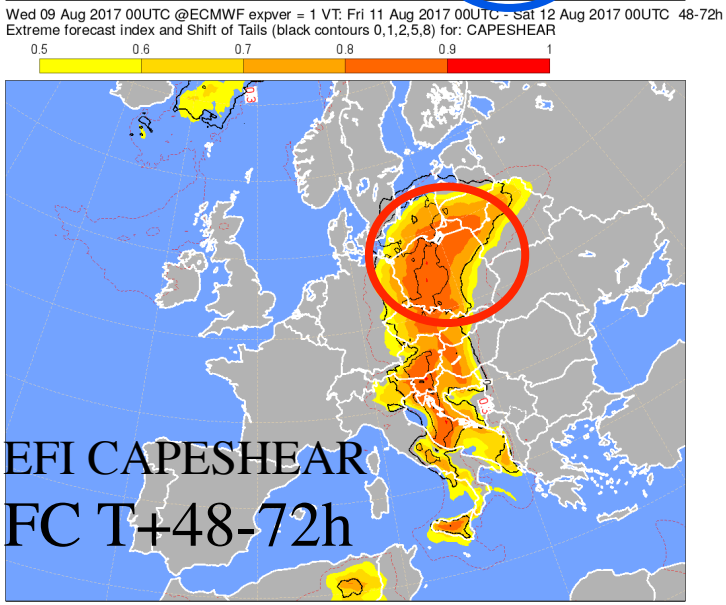
ATDnet Lightning density for Friday 11 August 2017
flashes/km2

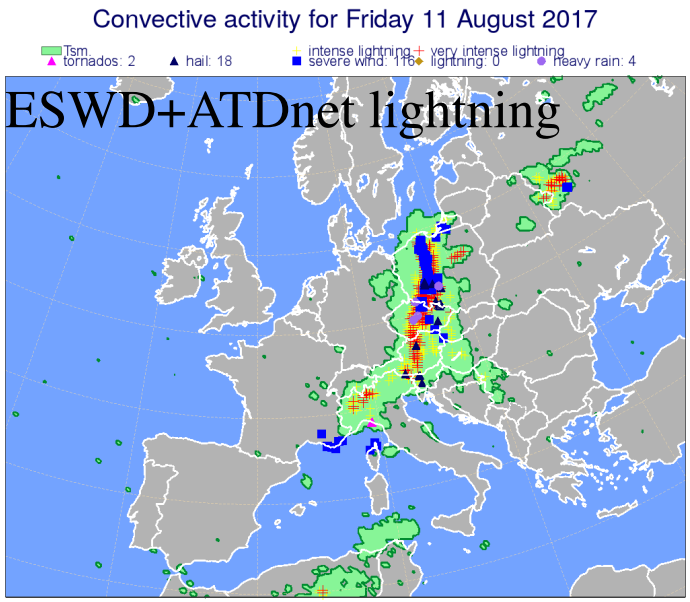


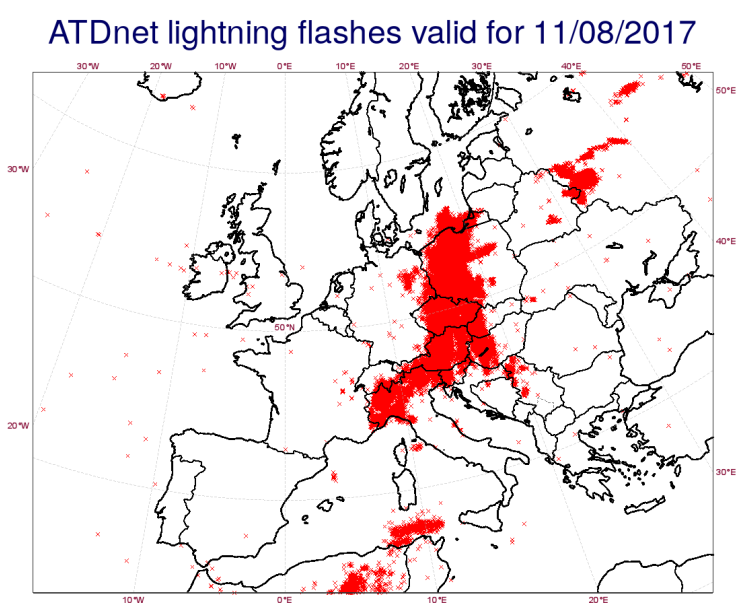
- On the eastern flank of upper low over Poland, a combination of very moist air in the boundary layer and EML with lapse rates > 7 °C/km
- Favourable synoptic-scale conditions

Forecast v. observations



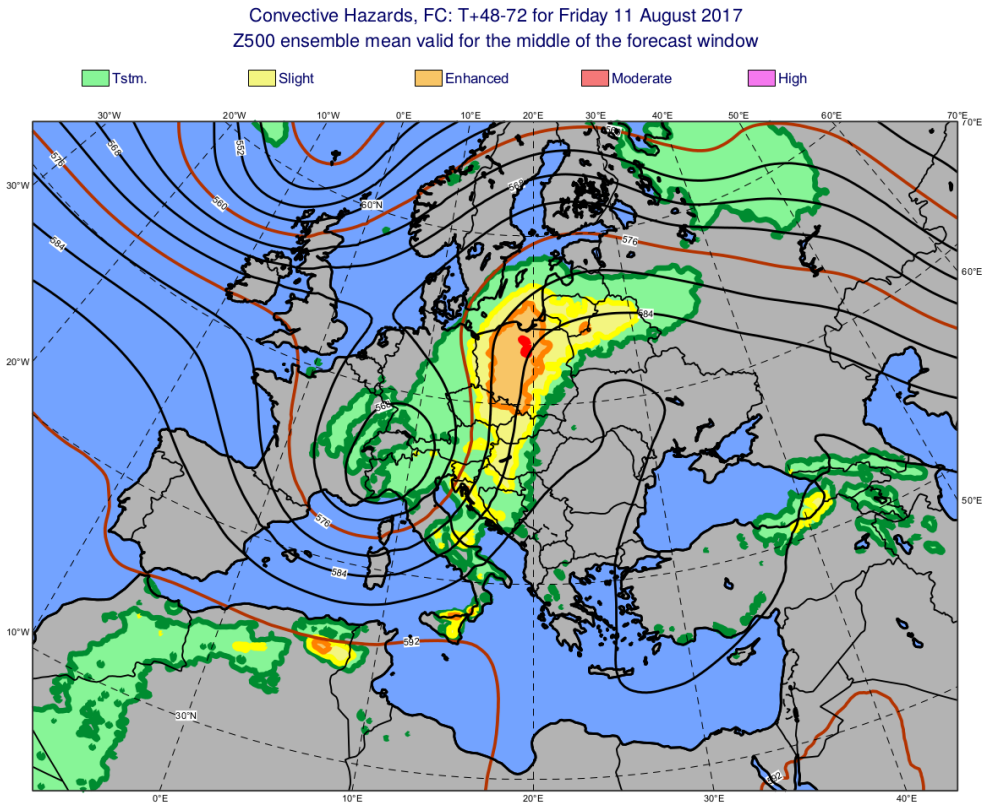




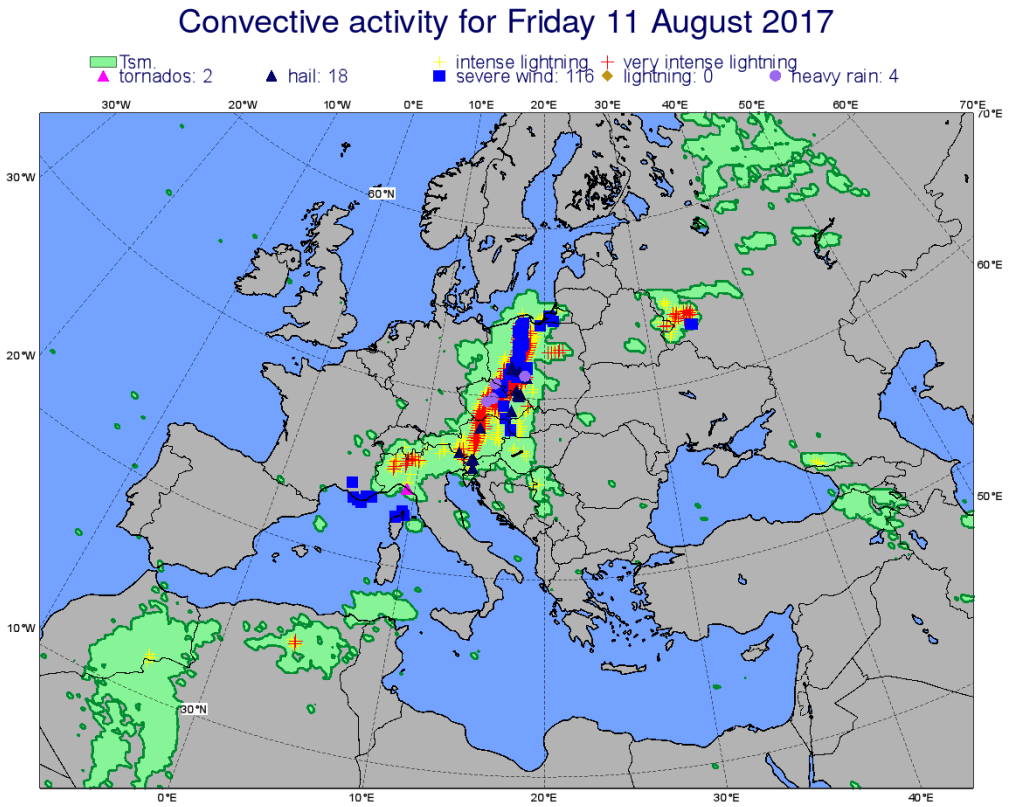


Convective hazards product

FC T+48-72h

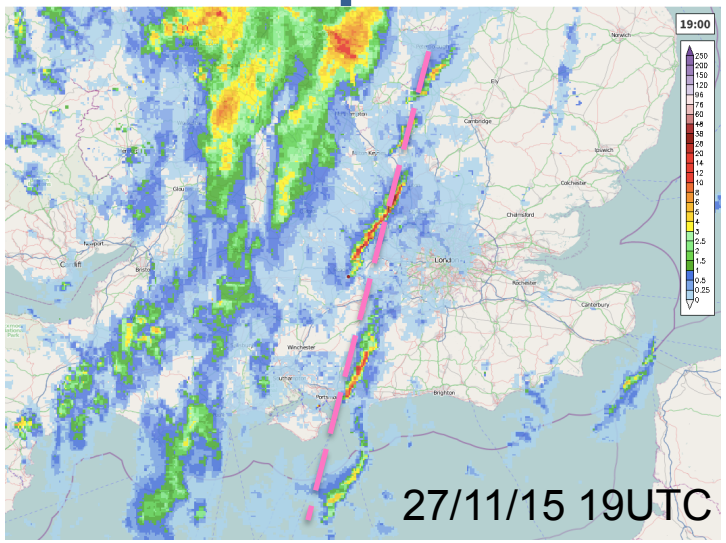


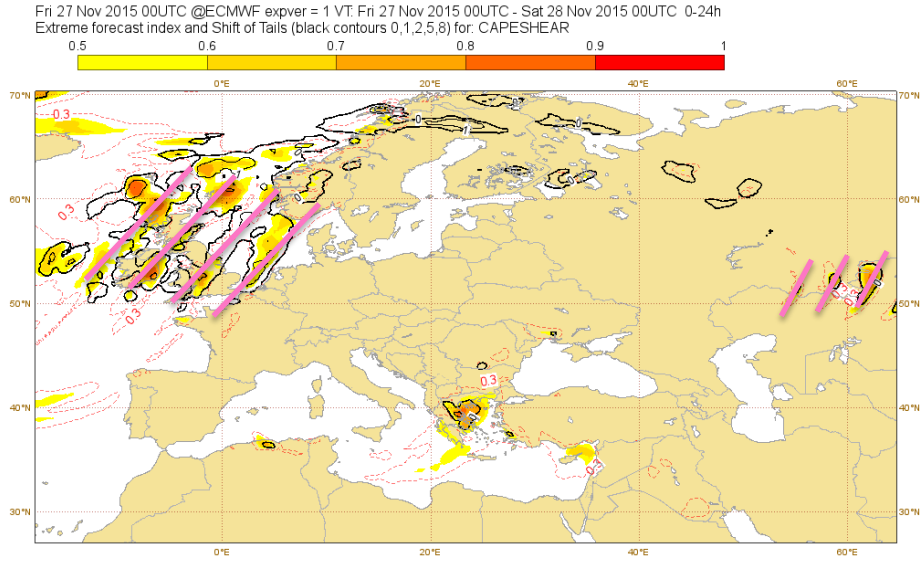
OBS

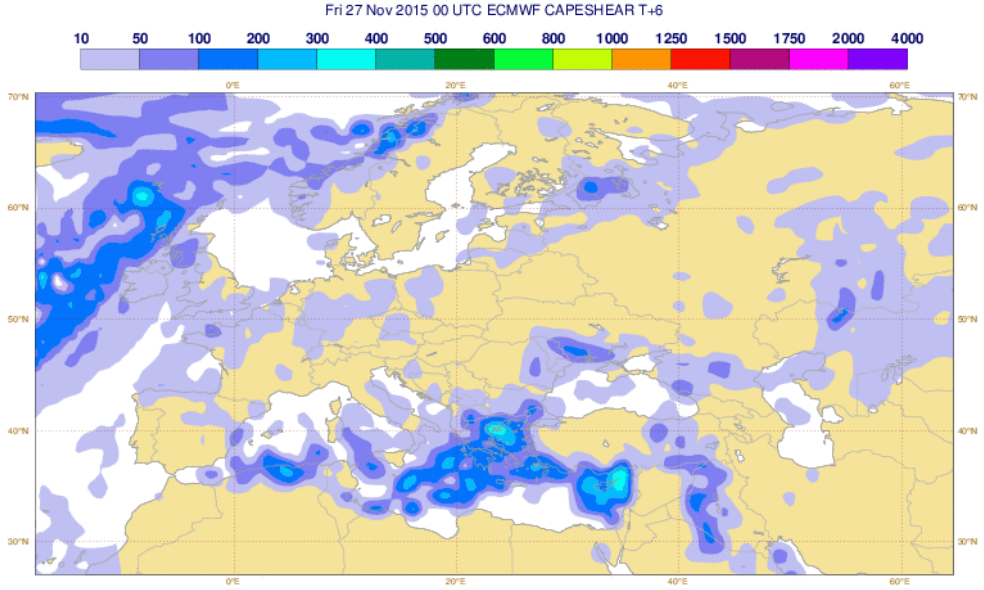


- Enhanced risk (orange): an area of organised storms with varying level of intensity
- Moderate risk (red) - widespread severe thunderstorms some of them intense; risk of super producing tornadoes and/or large hail (5+ cm dia.) or risk of an intense squall line with widespread damaging winds

A squall line along a cold front

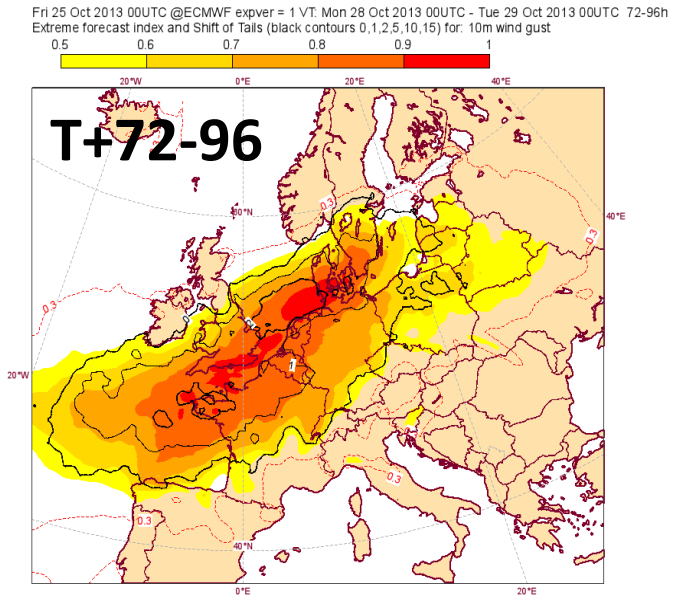


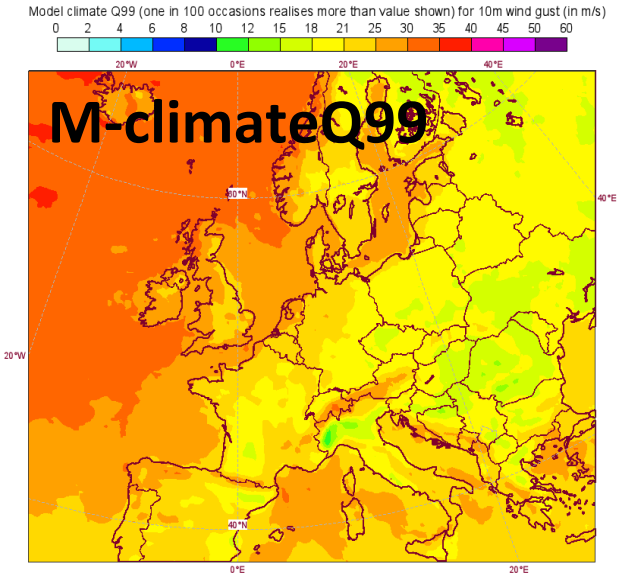


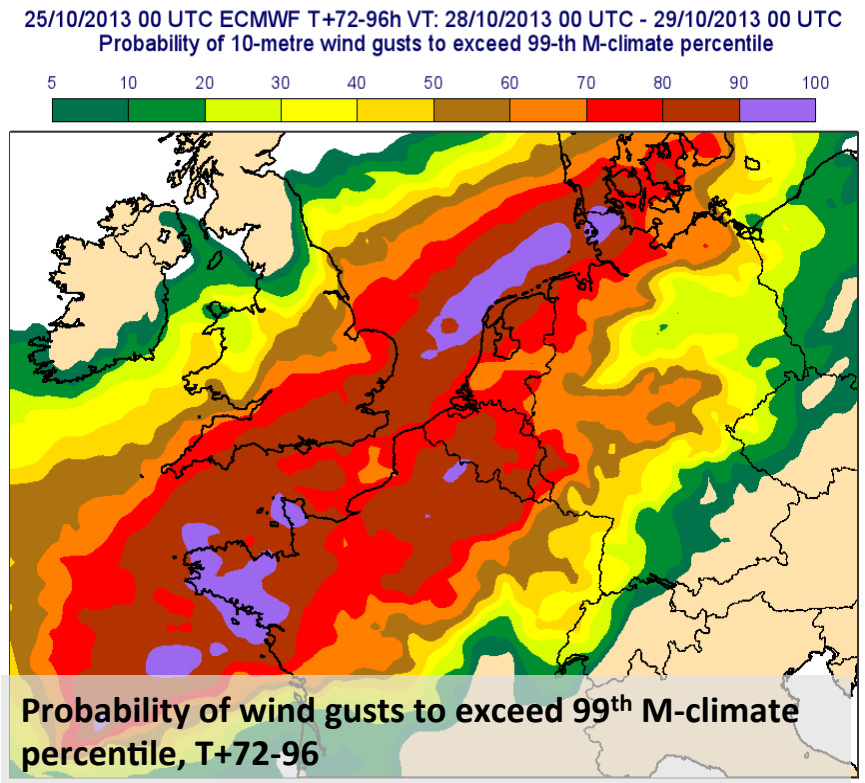


- The stripy structure is due to the combination of a fast moving front and 6-hourly discretization used for the computation
- This feature will disappear once maximum values start to be used instead of the instantaneous values

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