Forecasting Extreme Events

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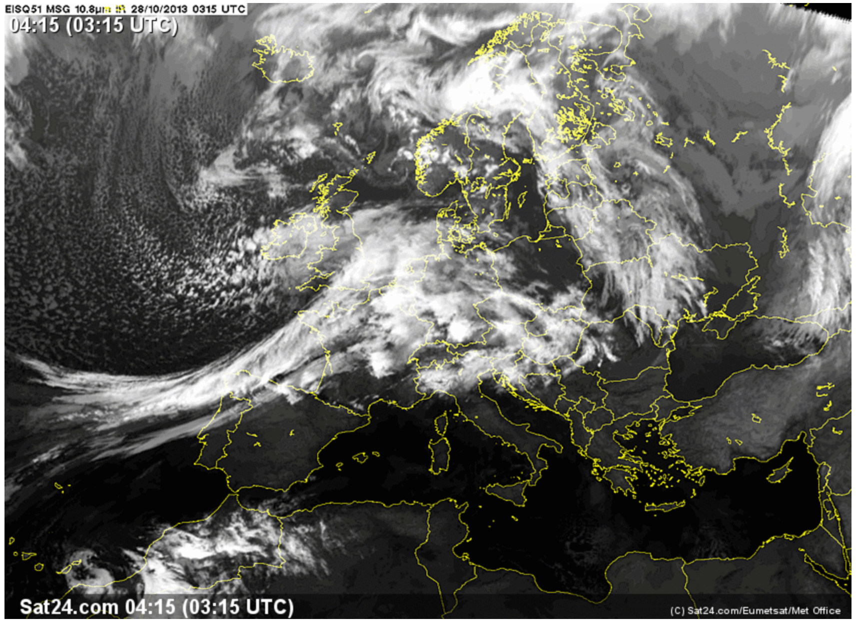
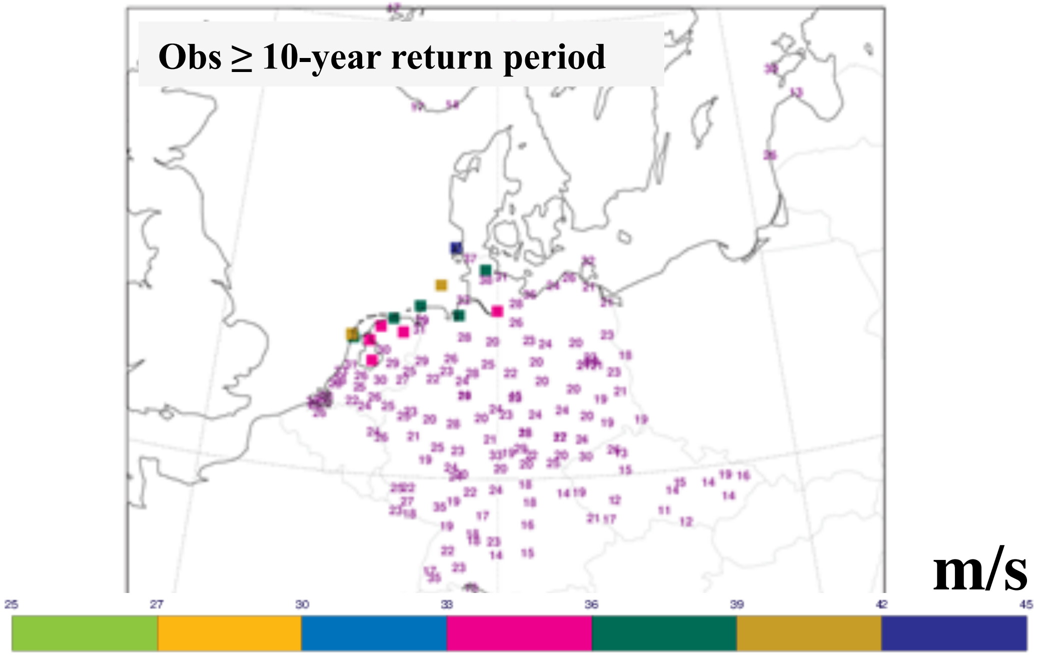
Outline

- Example of severe weather – St. Jude Storm
- Extreme Forecast Index (EFI) and the Model climate (M-climate)
- Shift Of Tails (SOT) – an index to complement EFI
- Operational products and verification
- Case studies:
    - US cold snap, early January 2014
    - Central European floods, beginning of June 2013
- Return-period probabilities
- EFI for CAPE?

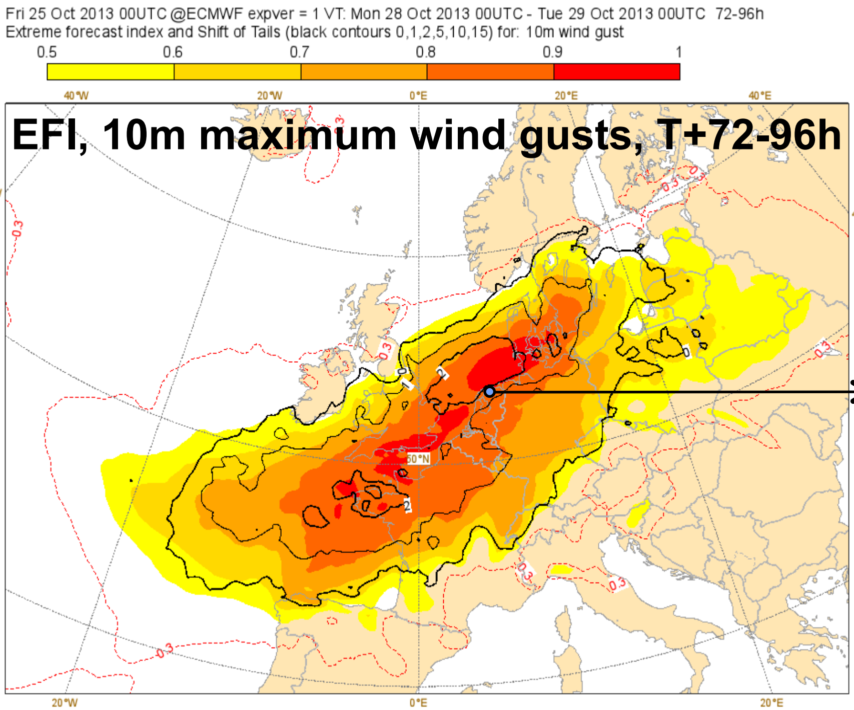
St Jude Storm, 27-28 Oct 2013

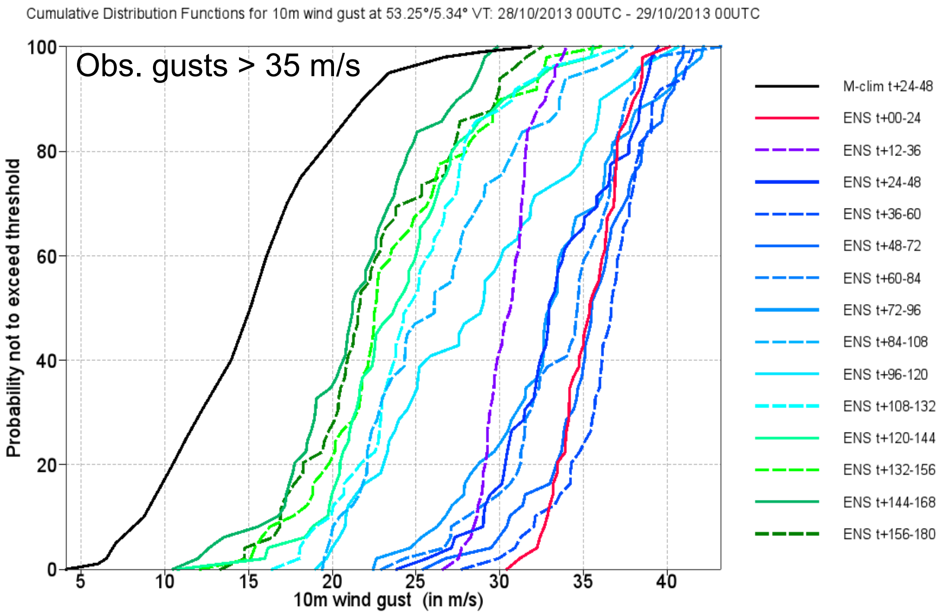




Daily maximum wind gust observations (m/s) exceeding the 10-year return period. Return values associated with the return periods are computed using the Extreme Value Theory for the base period 1991-2010 (from European Climate Assessment & Dataset, ECA&D project). Square symbols (▪) represent the stations where the values exceeded the return values. Stations which not exceeded the return values are in numbers.

St Jude Storm, 27-28 Oct 2013





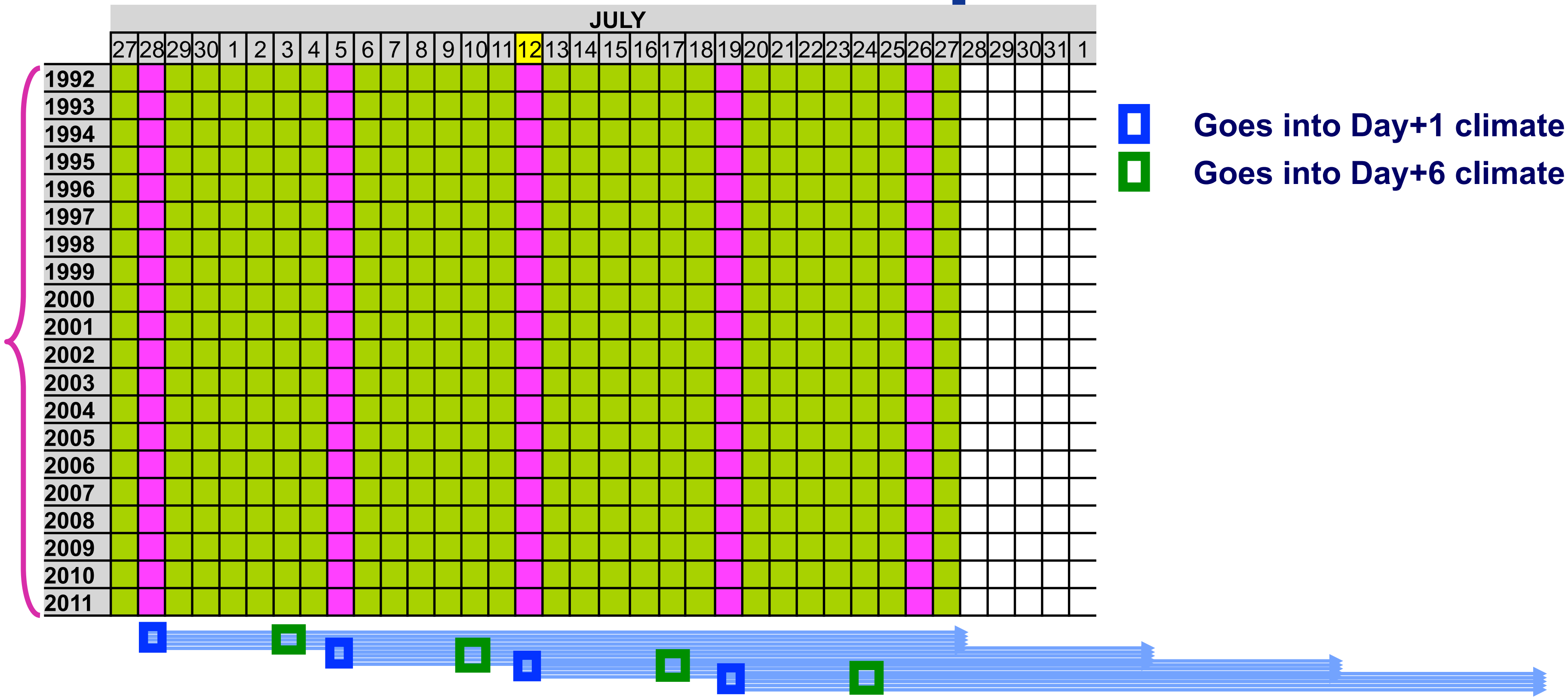
- EFI indicated a risk of windstorm in the medium range. Positive SOT (black contours) showed that an exceptionally strong windstorm was likely.
- There was a sign of windier-than-normal conditions 7 days in advance with the last 7 runs predicting extreme wind (see CDF).

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 (eg. > 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)

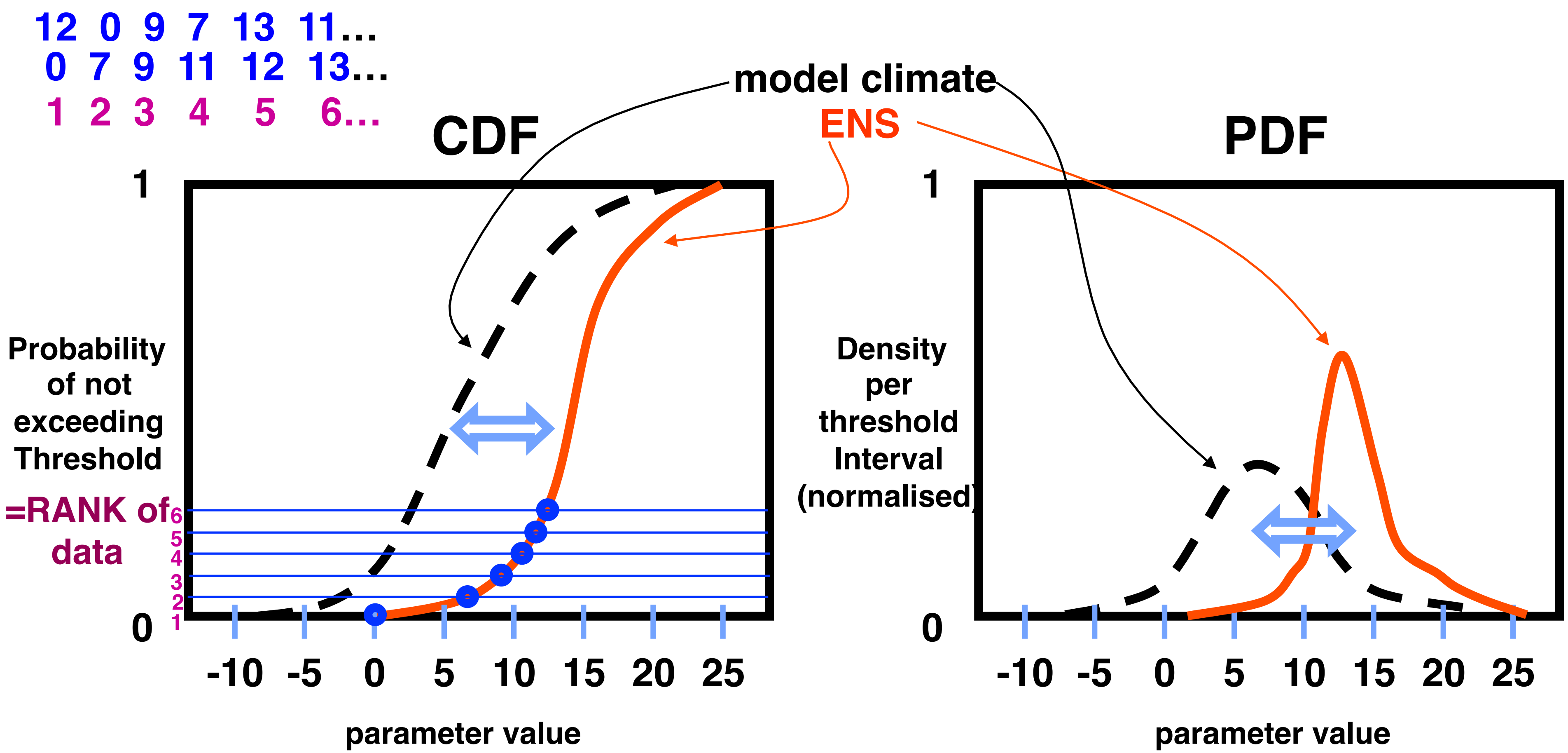
M-Climate – schematic representation



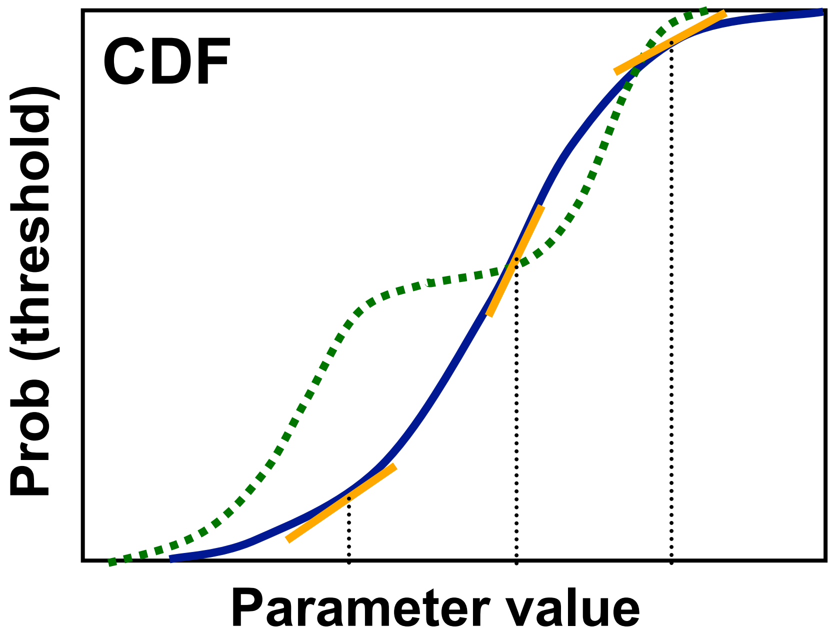
- To provide a robust, less noisy M-Climate, we don't use just one set of re-forecasts, but five sets centred on the week in question (increasing the sample size by a factor of 5)...
- The M-climate sample size is: 20 years * 5 ensemble members * 5 weekly runs = 500 re-forecast fields
- As the M-climate consists of 500 realisations, the M-climate extreme values correspond, approximately, to 16-year return periods (for month-long time windows)

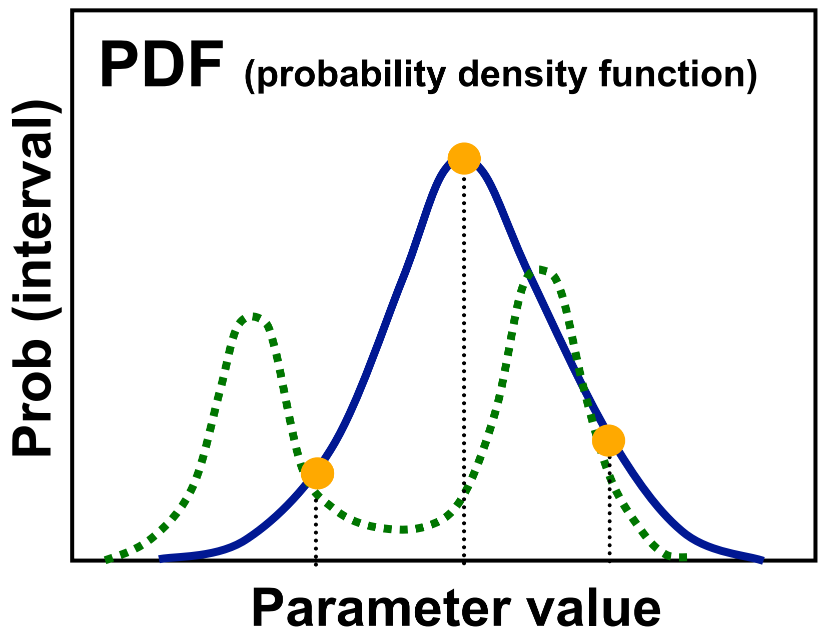
Extreme Forecast Index (EFI)

- 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?



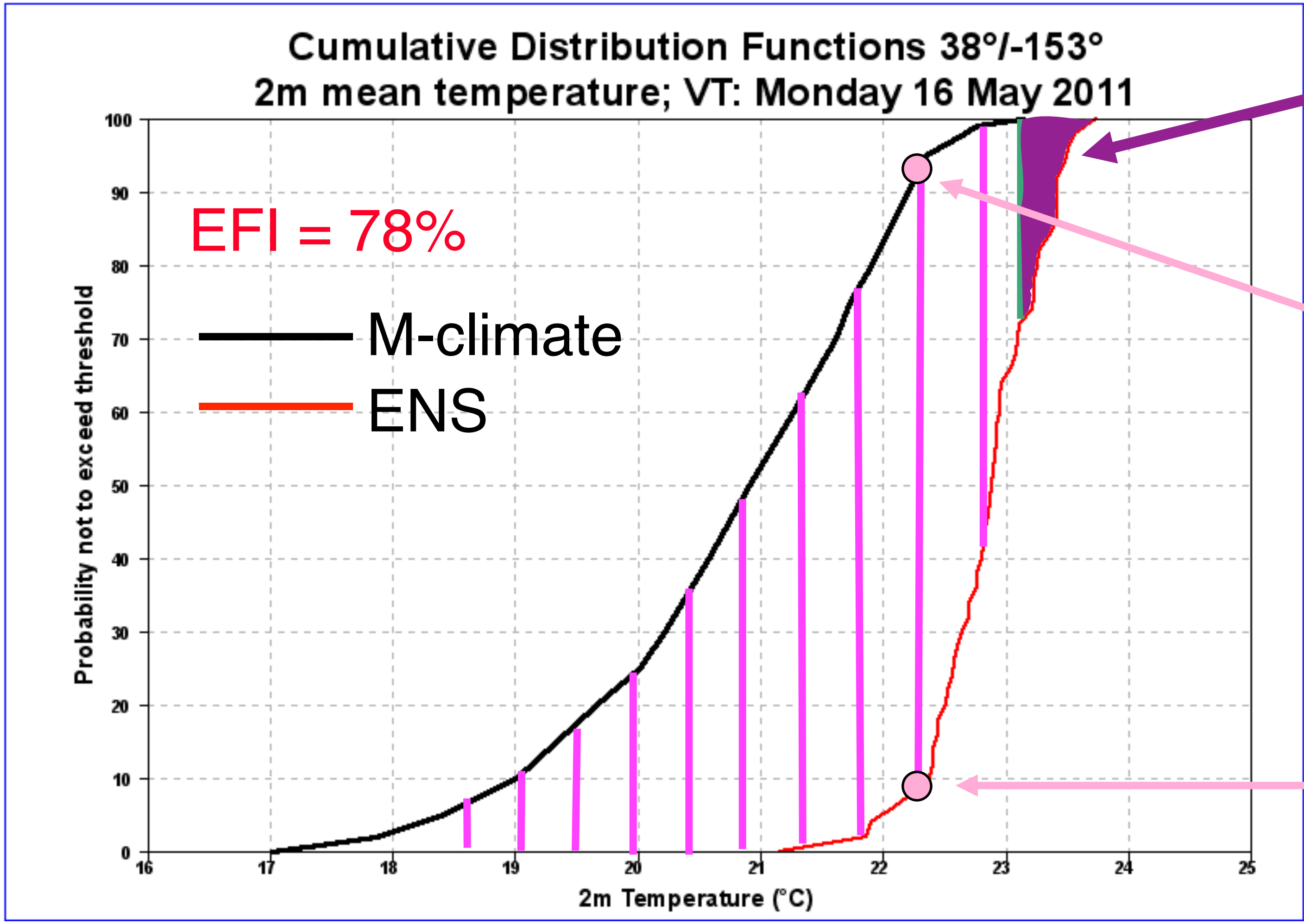


- The PDF (y-axis) value equals the slope of the CDF
- Steeper CDF = narrower PDF = higher confidence in the forecast
- A step in the CDF means a bimodal PDF

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

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

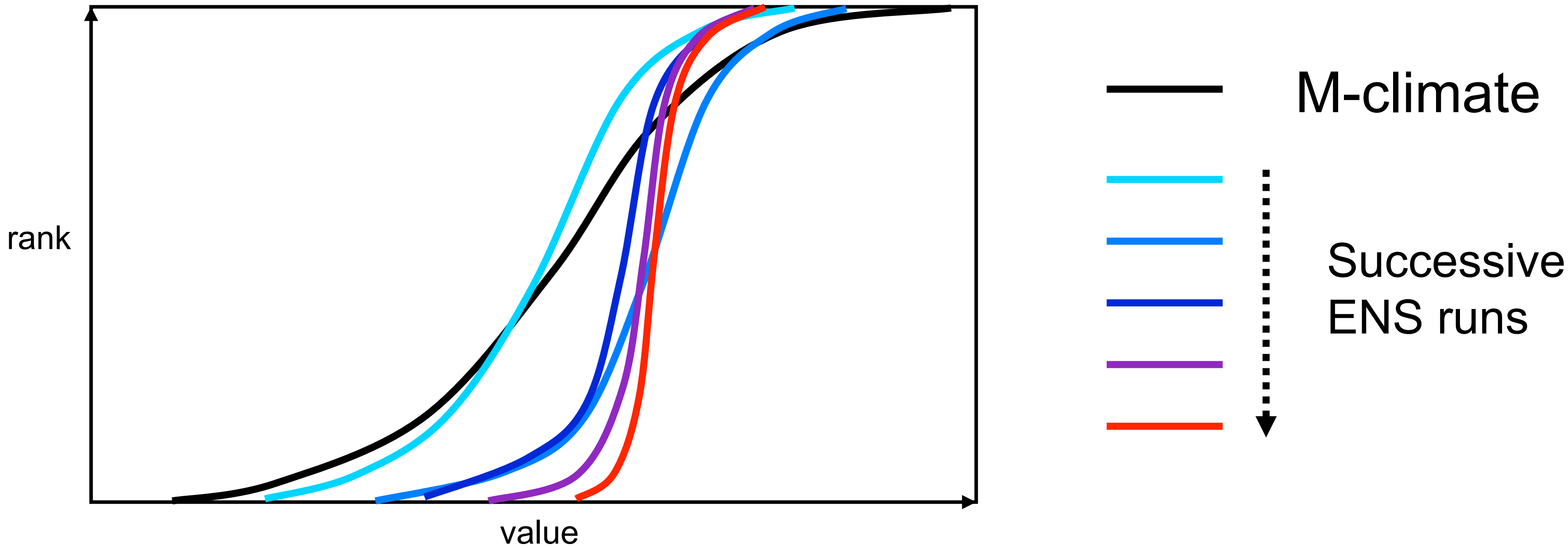
p

$F_f(p)$

-1 ≤ EFI ≤ 1

-100% ≤ EFI ≤ 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.

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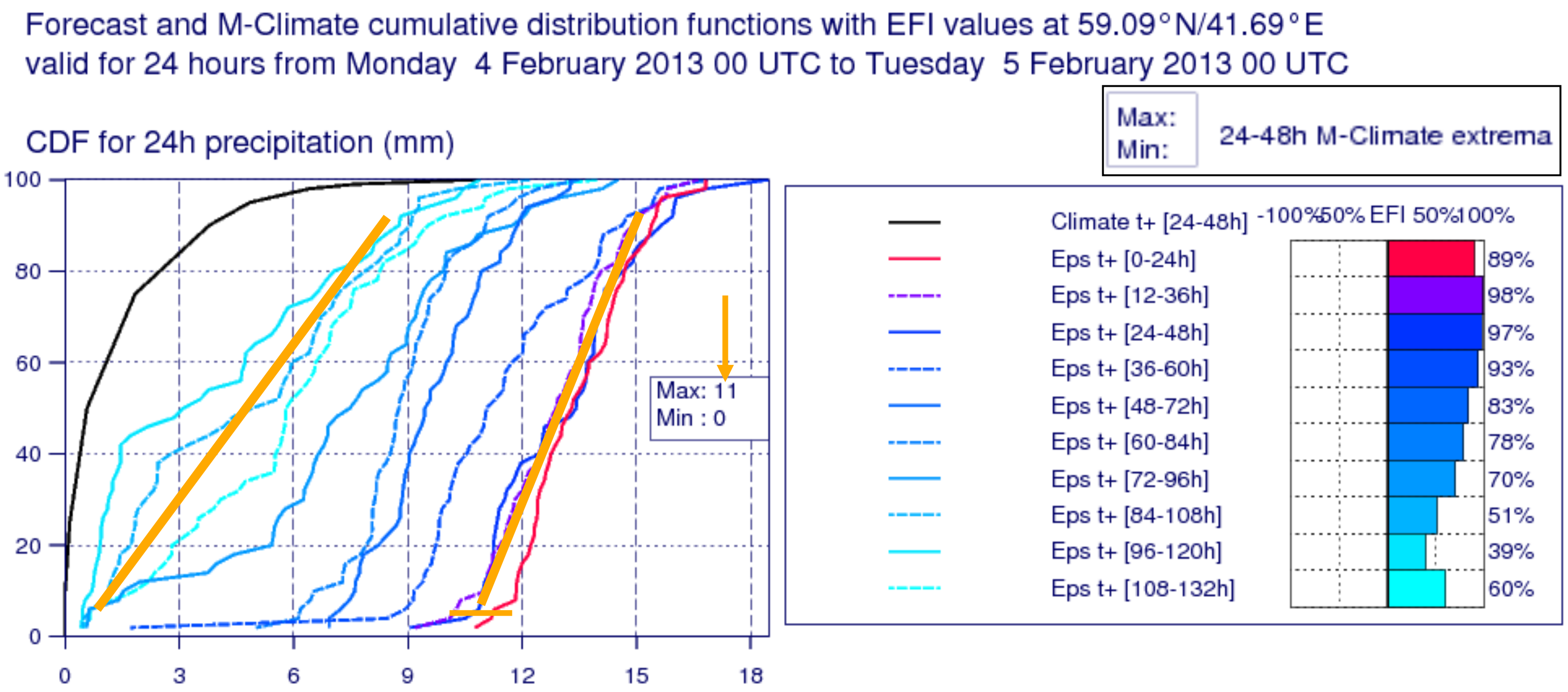
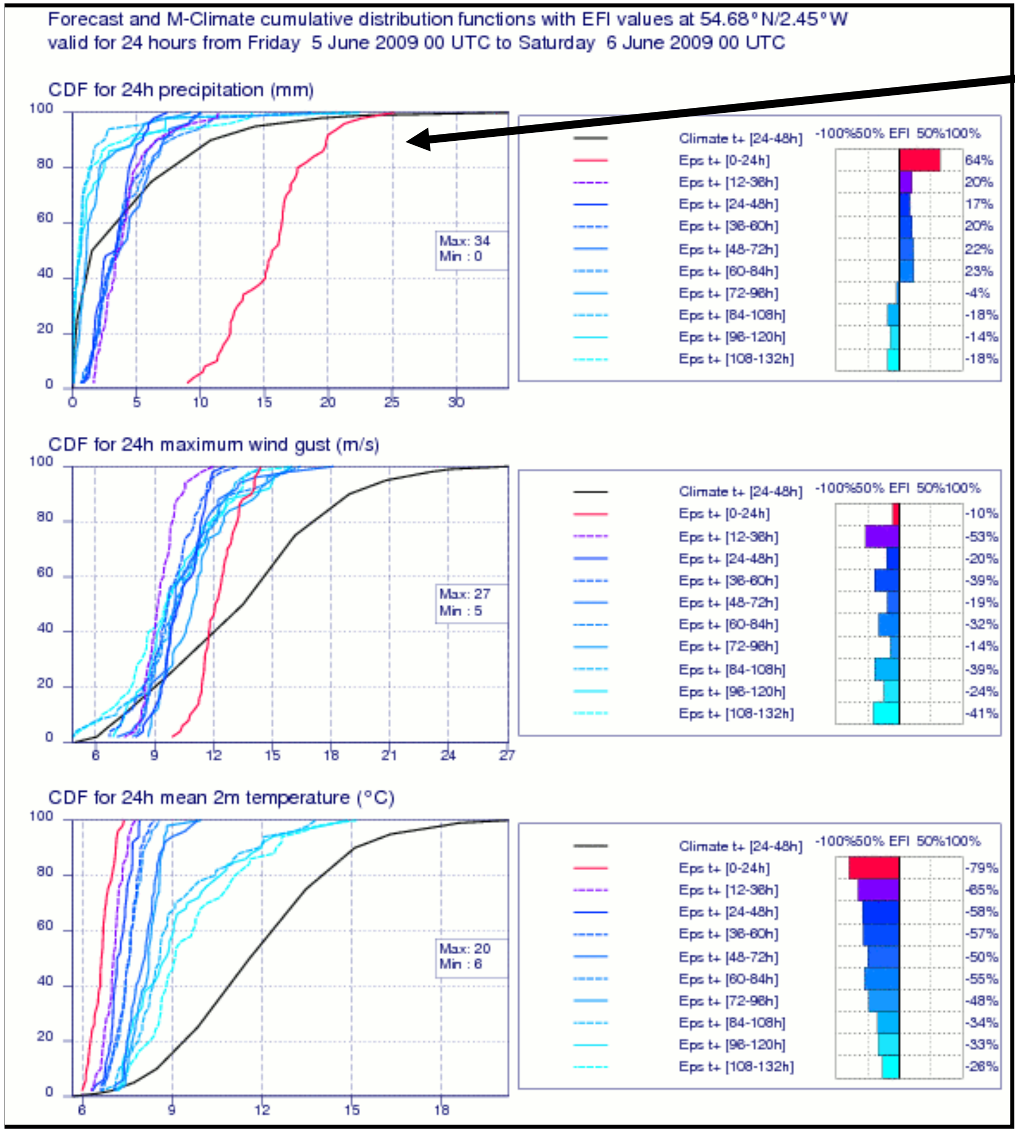
Example



- 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



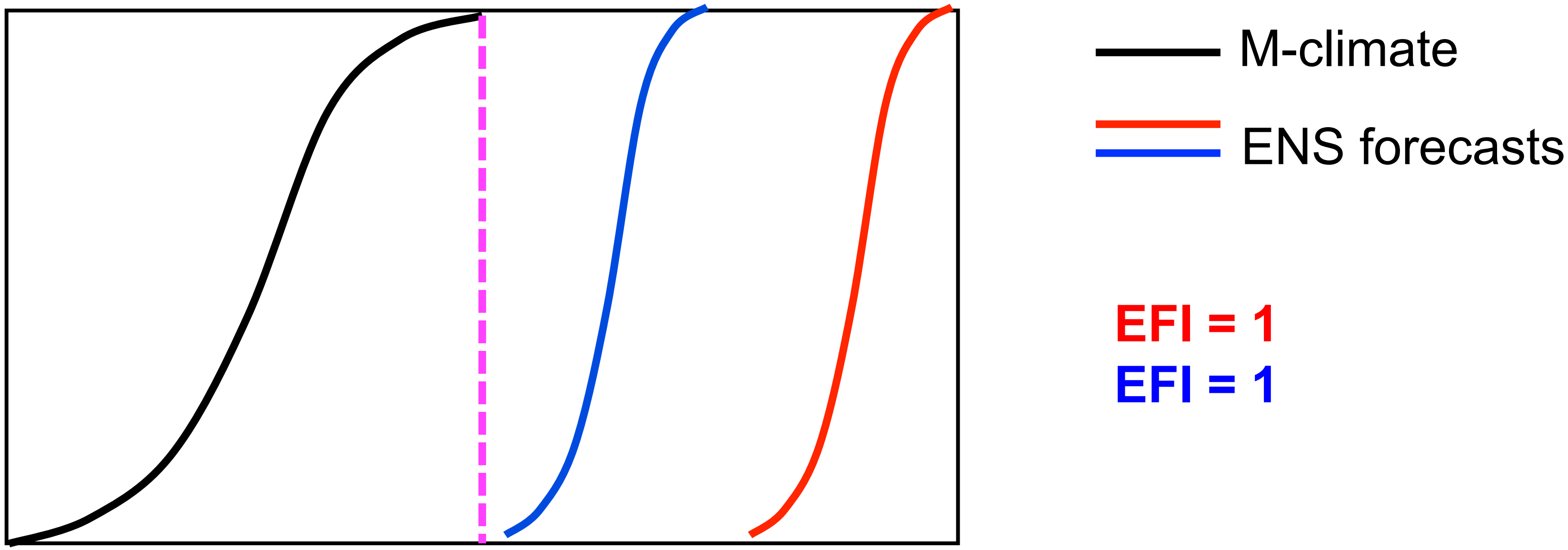
- N England rain – June ’09 - low prob alternative became likely at short range. If rare this is OK.

ECMWF

Some limitations

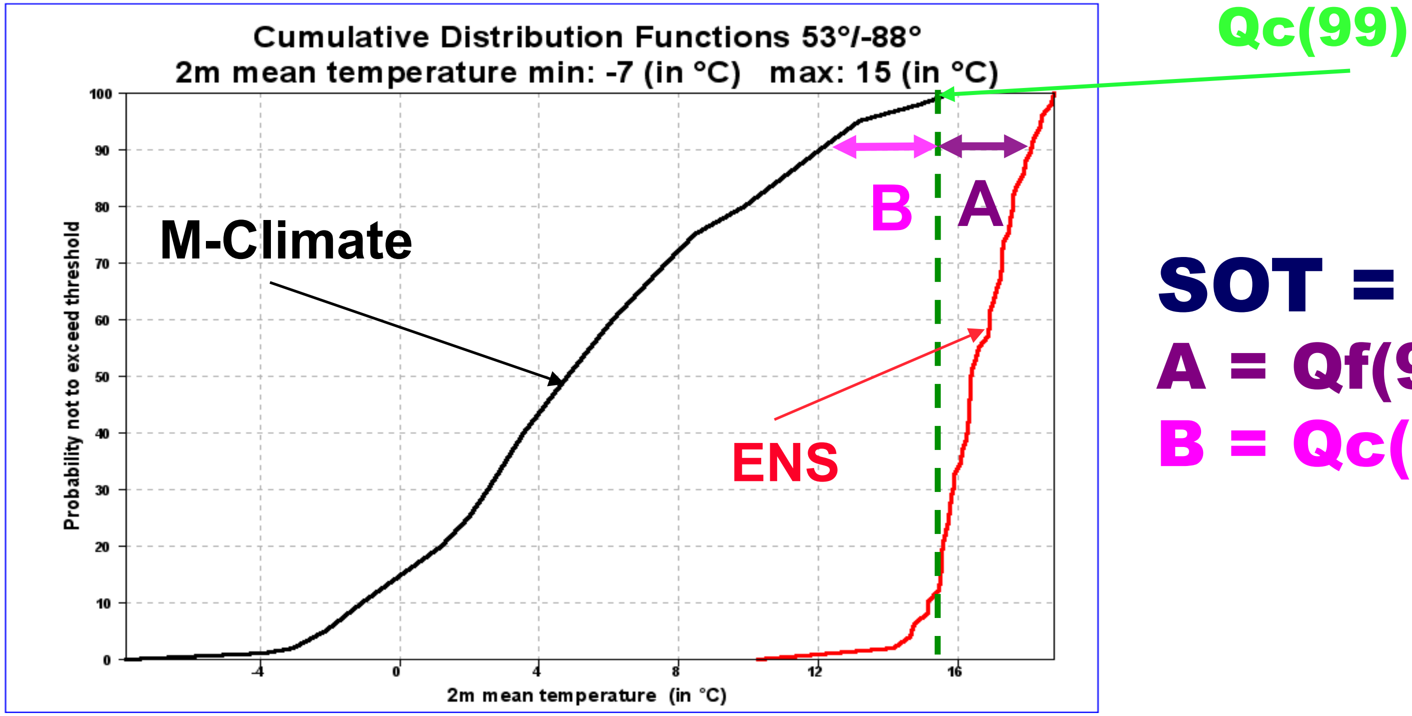
- Extreme does not *necessarily* mean high impact (eg 2mm rain in the desert)
- Past history also important but not directly accounted for (eg heavy rain when ground saturated)
- Windstorm impact can depend on whether trees are in leaf, whether ground is saturated…
- Products are only as good as the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

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 introduced 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 (upper tail) and 10th (lower tail for temperature only) M-climate percentiles
- SOT > 0 → extreme event is likely

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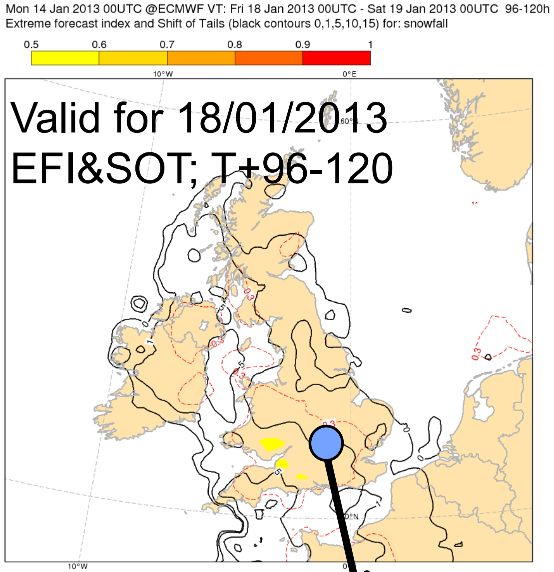
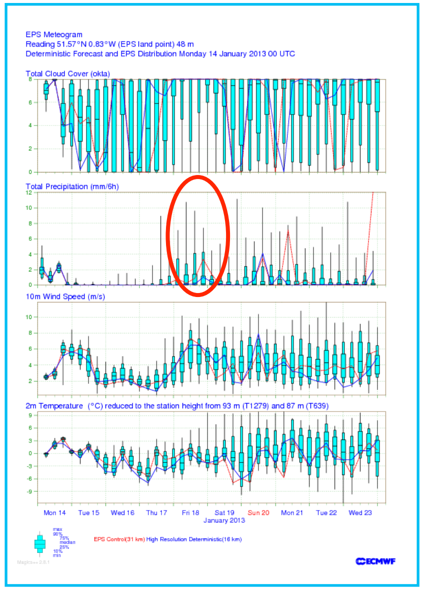
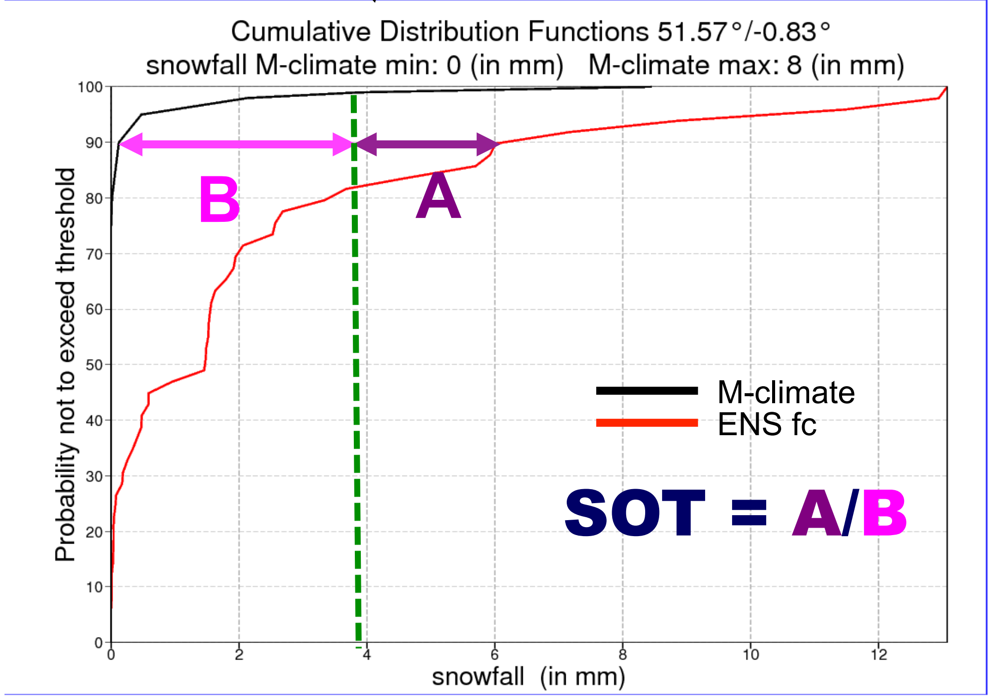


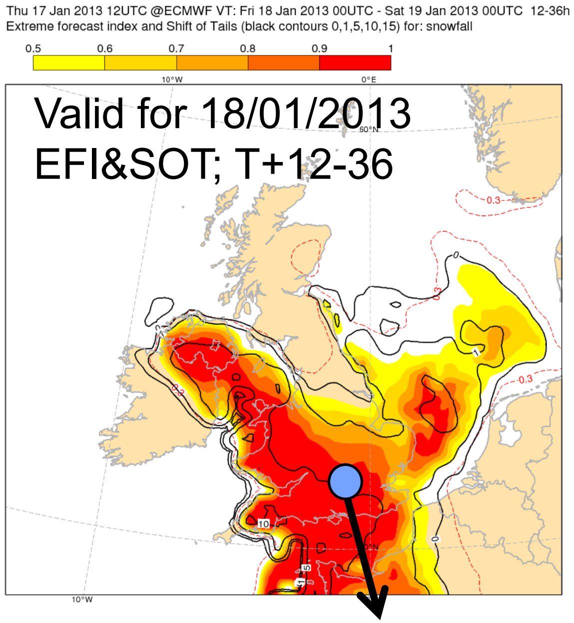


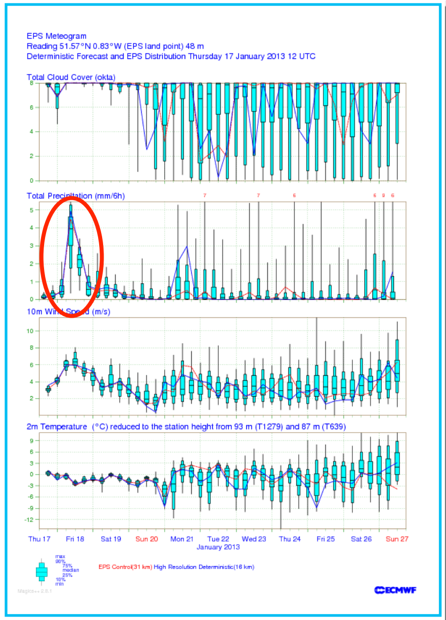


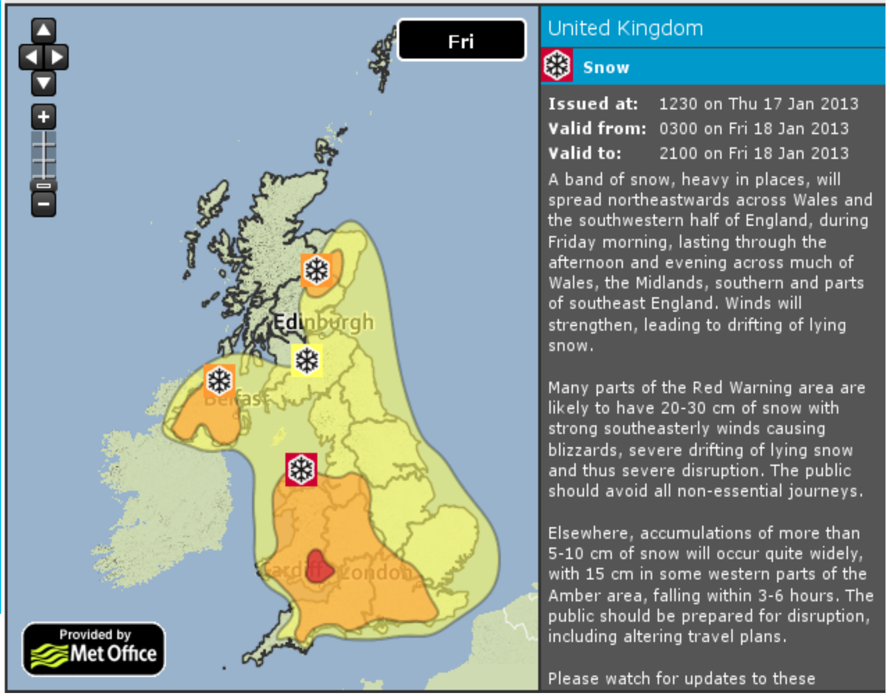
- **SOT > 0 → at least 10% of the ensemble members are above the 99th percentile M-climate**
- **The higher the SOT value is, the further this top 10% of the ensemble forecast is beyond Q99 of the M-climate.**
- **In the example (Reading):**
  - **EFI = 0.36**
  - **SOT = 0.8**

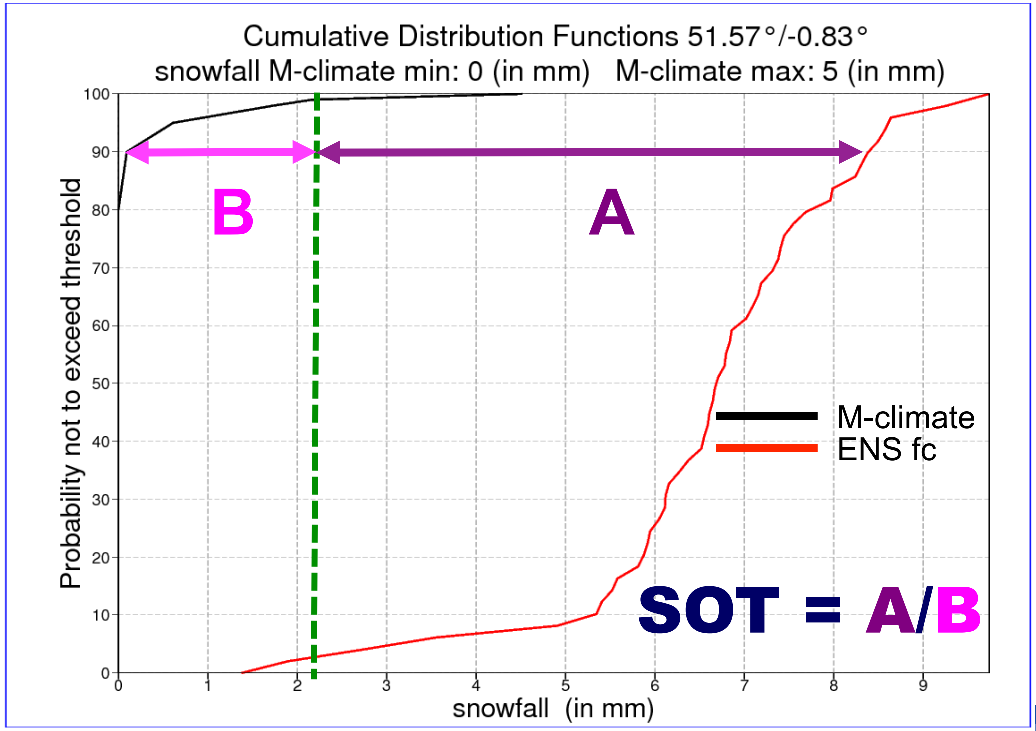
– **EFI positive → forecast suggests some snow**

– **SOT >0 → there are ENS members predicting extreme snowfall but the forecast is still uncertain (low EFI)**









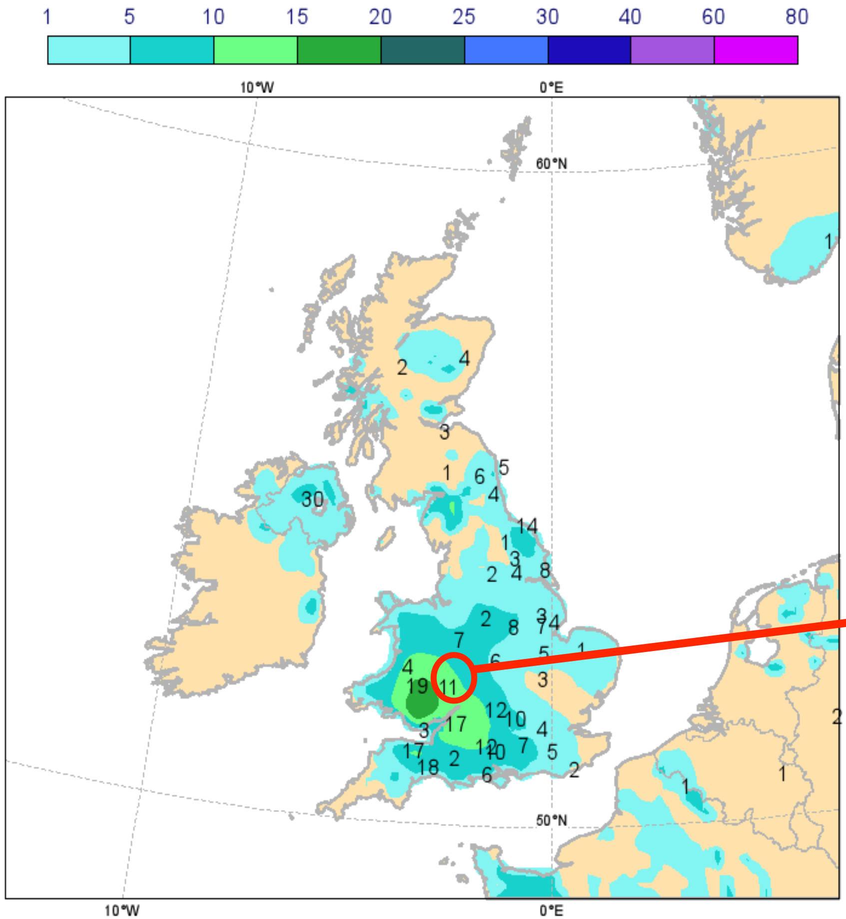
Reading:

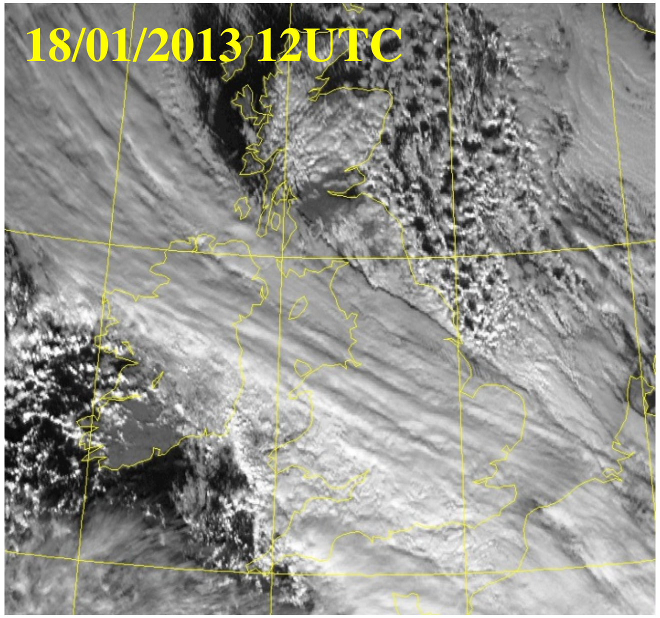
- ➢ **EFI = 0.96**
- ➢ **SOT = 3.5**

- **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)**

What happened

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

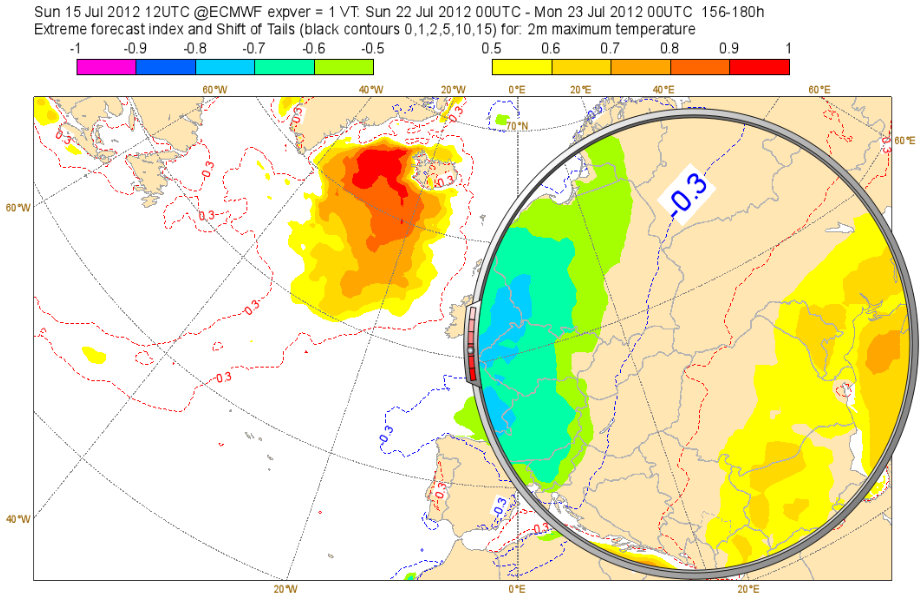


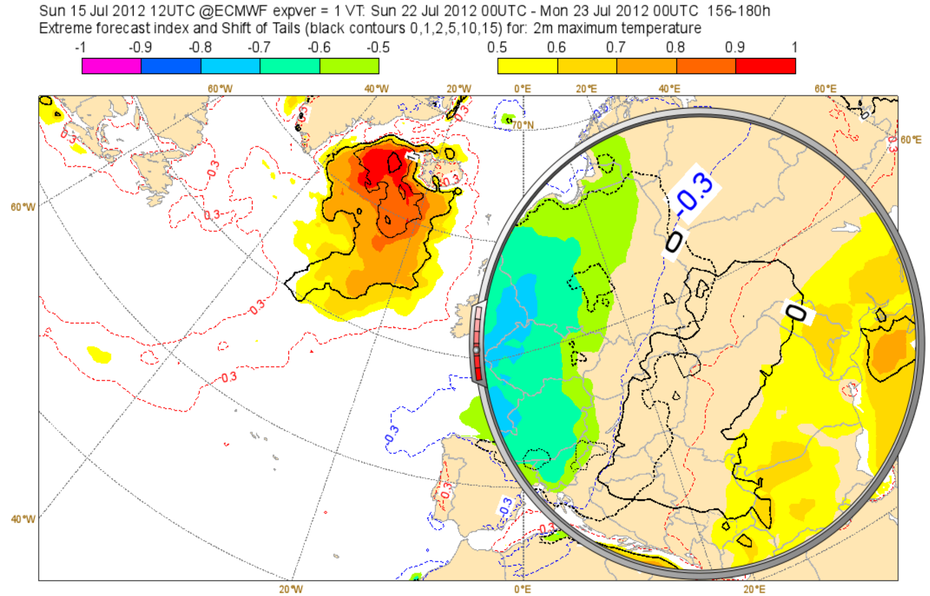


Bromsgrove, near Birmingham, UK

A beer garden in Bromsgrove. Credit: Sue Eden

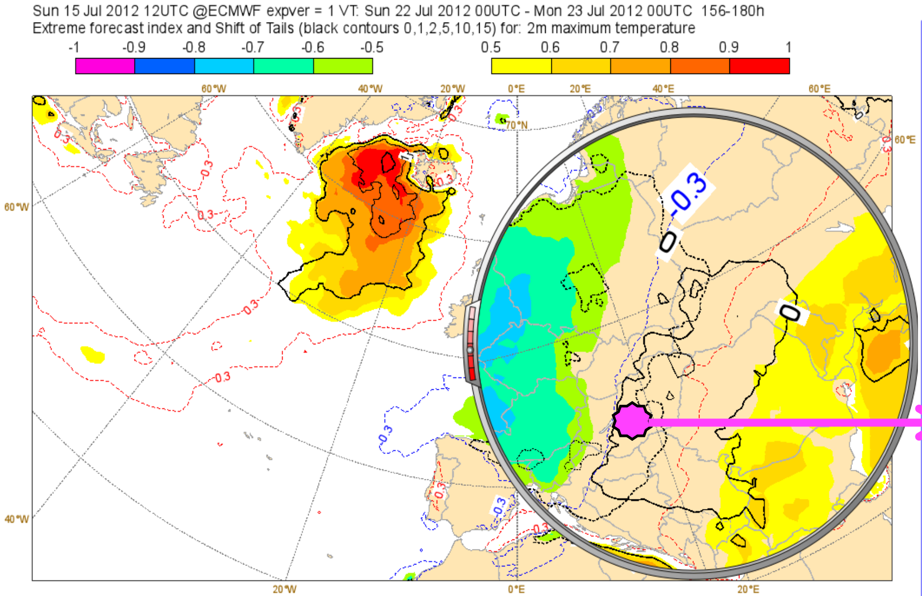
A case of large uncertainty

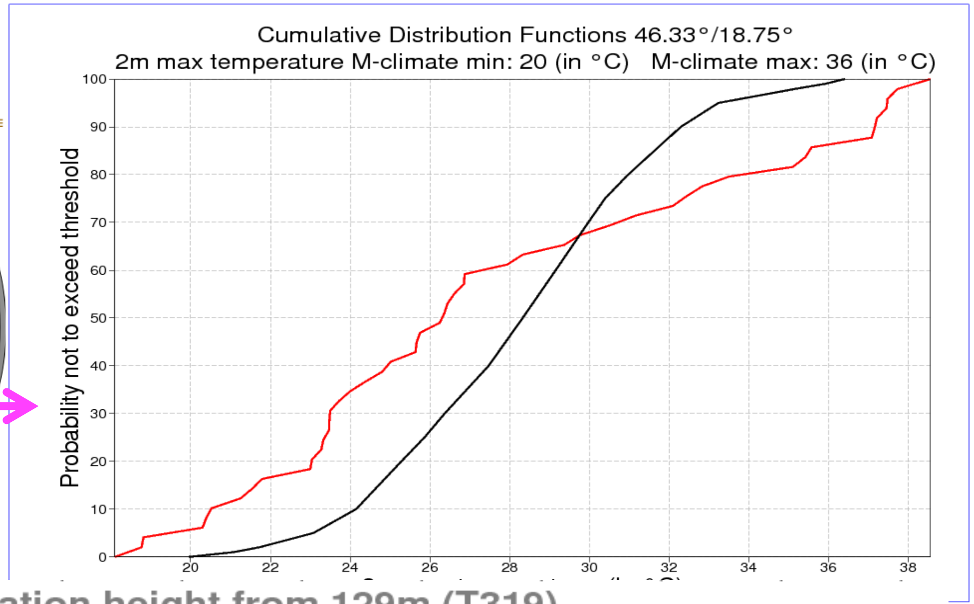


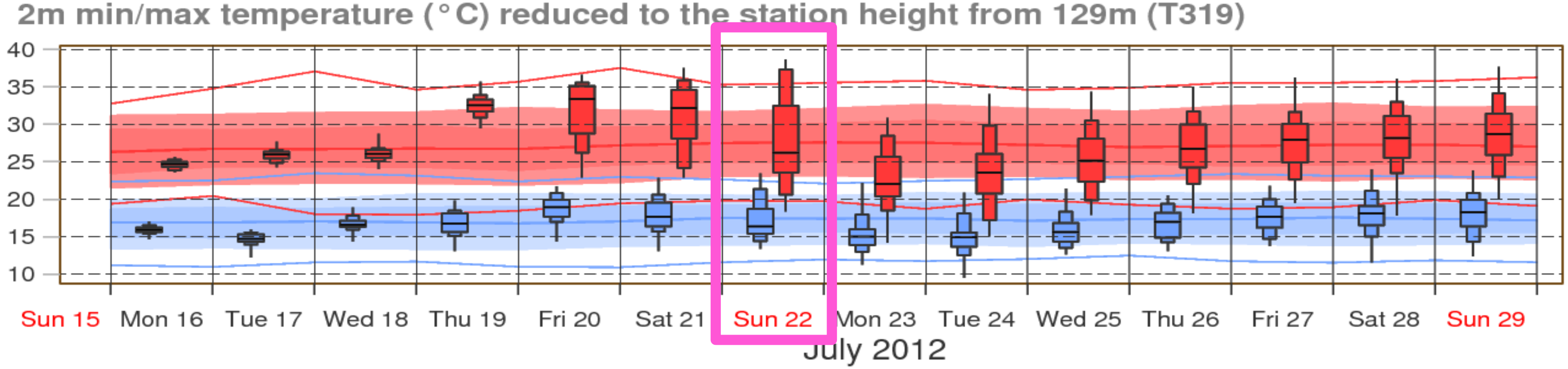


- EFI forecast shows cold conditions over Central Europe and hot weather to the east over the Balkans.
- SOT gives additional information. In the area between the cold and hot weather SOTs overlap. This is a signal of very uncertain forecast – over that area extremely low and extremely high temperatures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

A case of large uncertainty



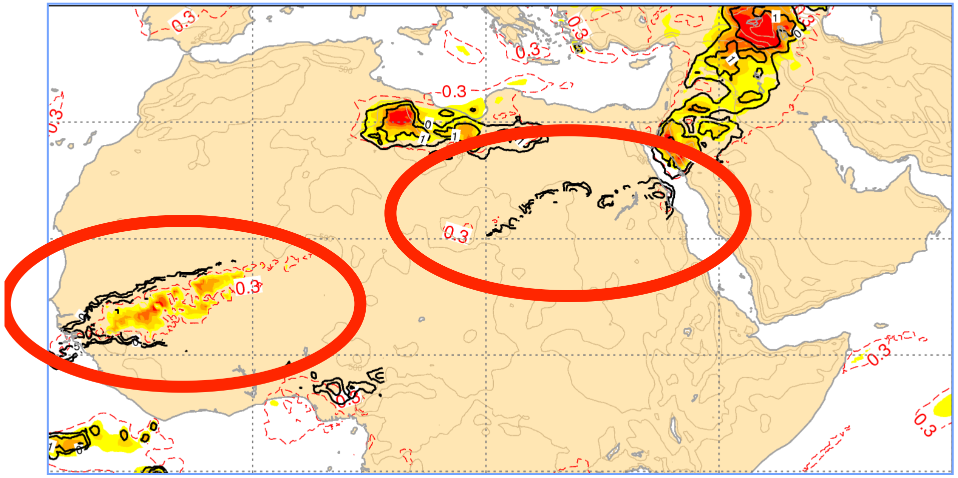




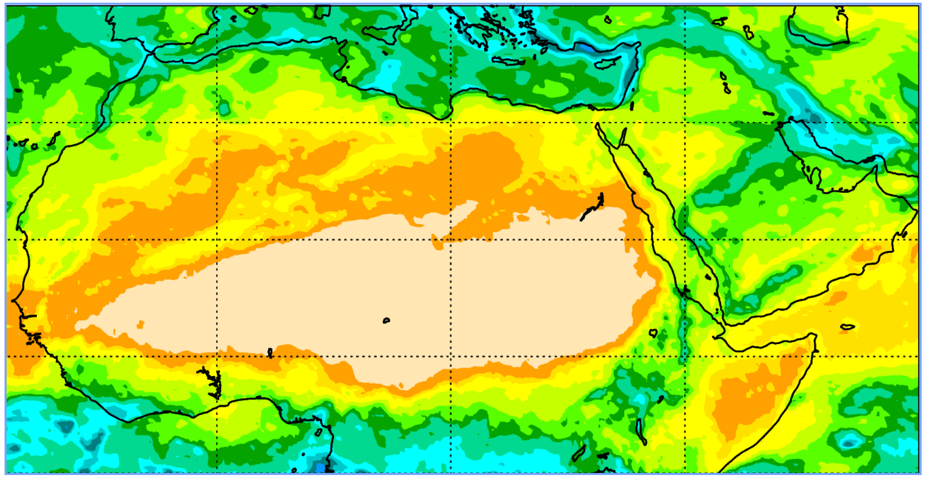
- **Some ENS members predict maximum temperature below the M-climate minimum, but some – above the M-climate maximum!**

Some limitations

EFI &SOT; precipitation

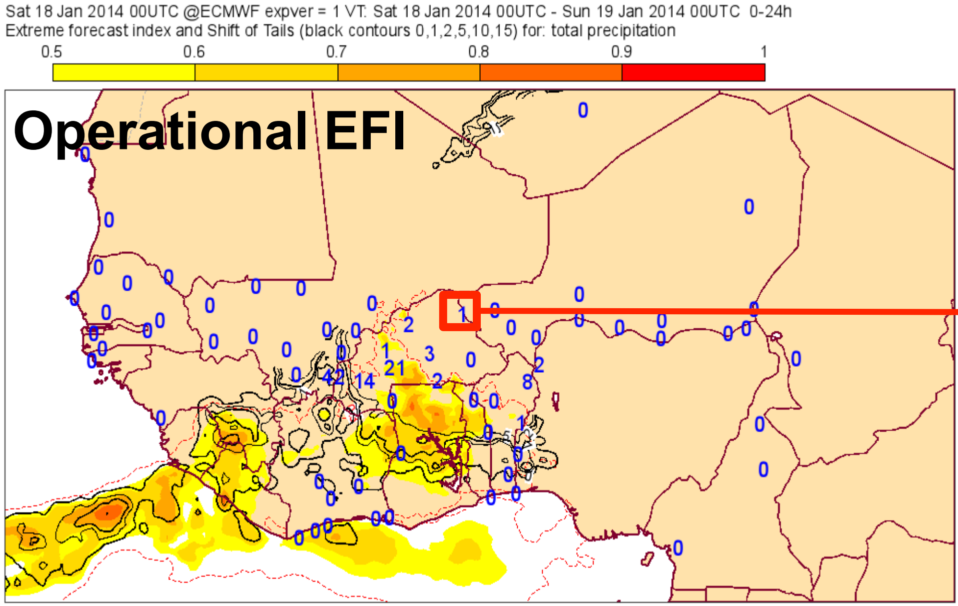


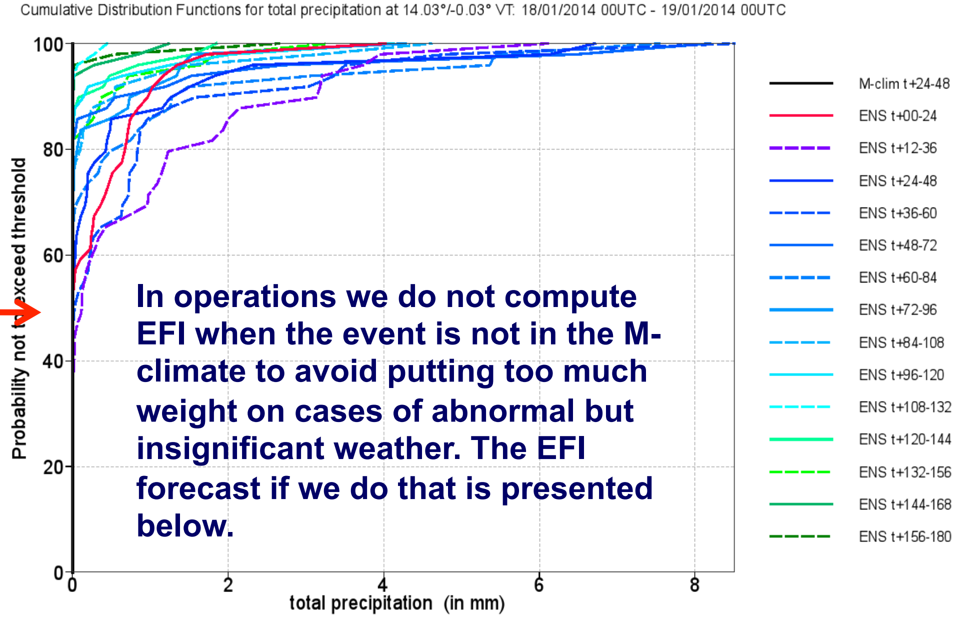
M-climate Q99



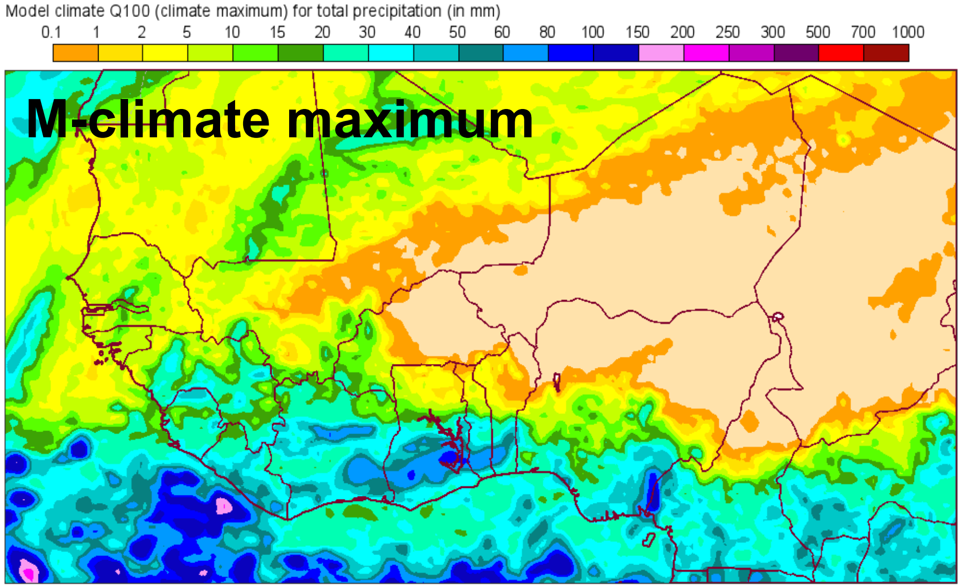
- **SOT is not defined when M-climate Qc(90)= Qc(99) (division by 0). This leads to some noise on plots. To avoid this and to close SOT contours for snowfall, SOT is artificially set to -1 where not defined only for plotting purposes.**

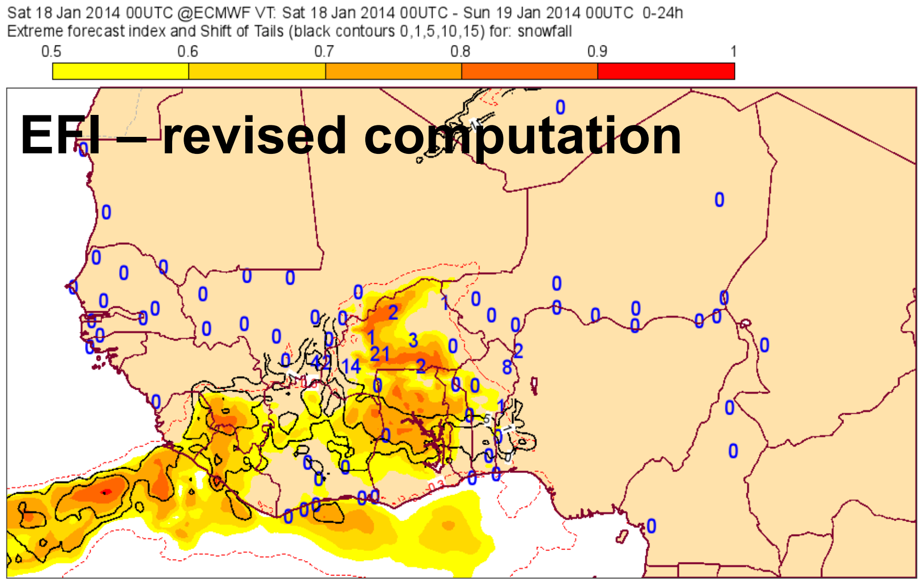
Some limitations – a case of very rare rainfall





In operations we do not compute EFI when the event is not in the M-climate to avoid putting too much weight on cases of abnormal but insignificant weather. The EFI forecast if we do that is presented below.





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

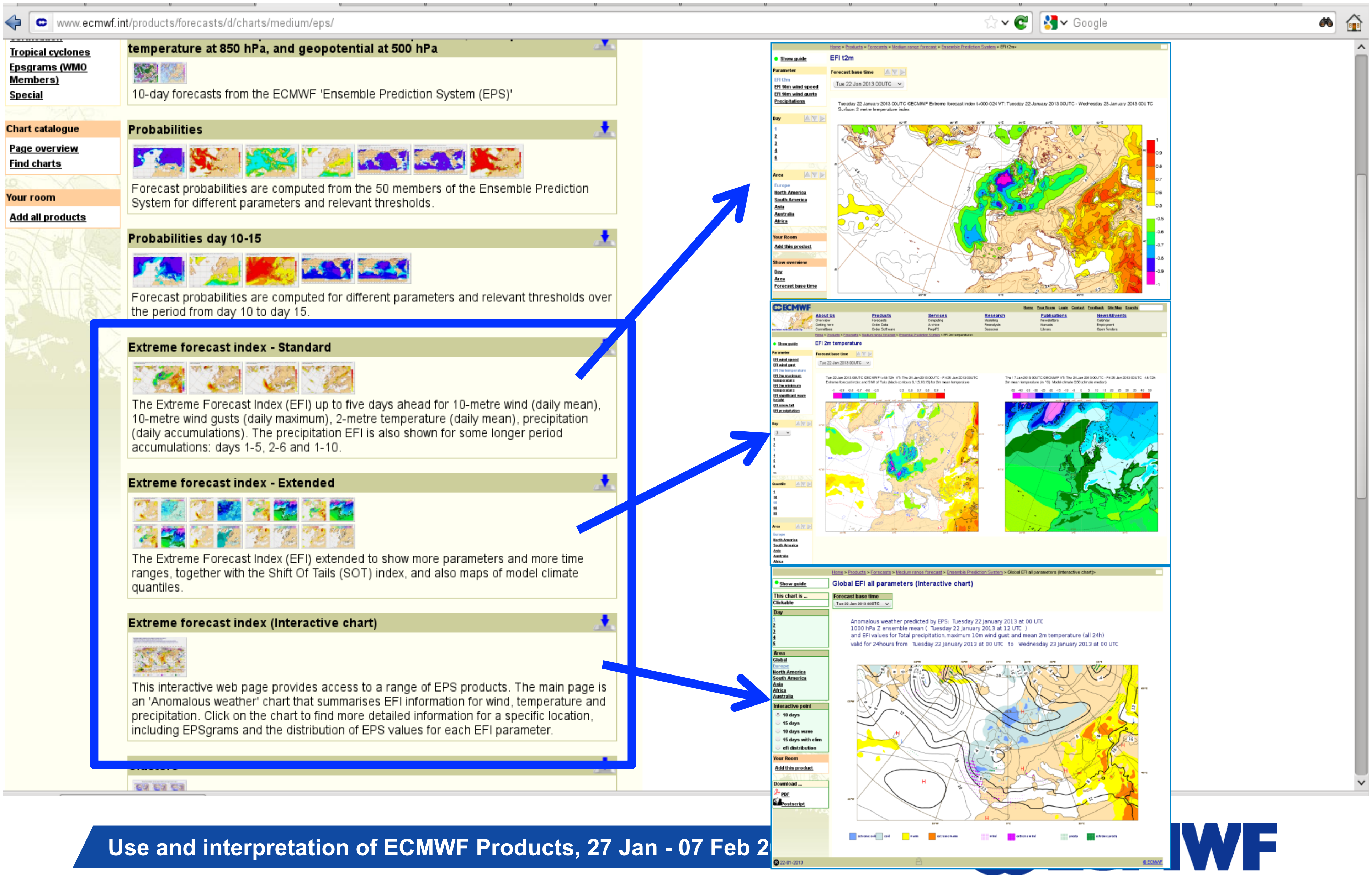
- EFI and SOT parameters:
  - 2-metre mean temperature index (2ti)
  - total precipitation index (tpi)
  - 10-metre mean wind speed index (10wsi)
  - 10-metre maximum wind gusts index (10fgi)
  - 2-metre minimum temperature index (mn2ti)
  - 2-metre maximum temperature index (mx2ti)
  - total snowfall index (sfi)
  - maximum significant wave height index (maxswhi)

* Parameters in red available since 19th June 2012

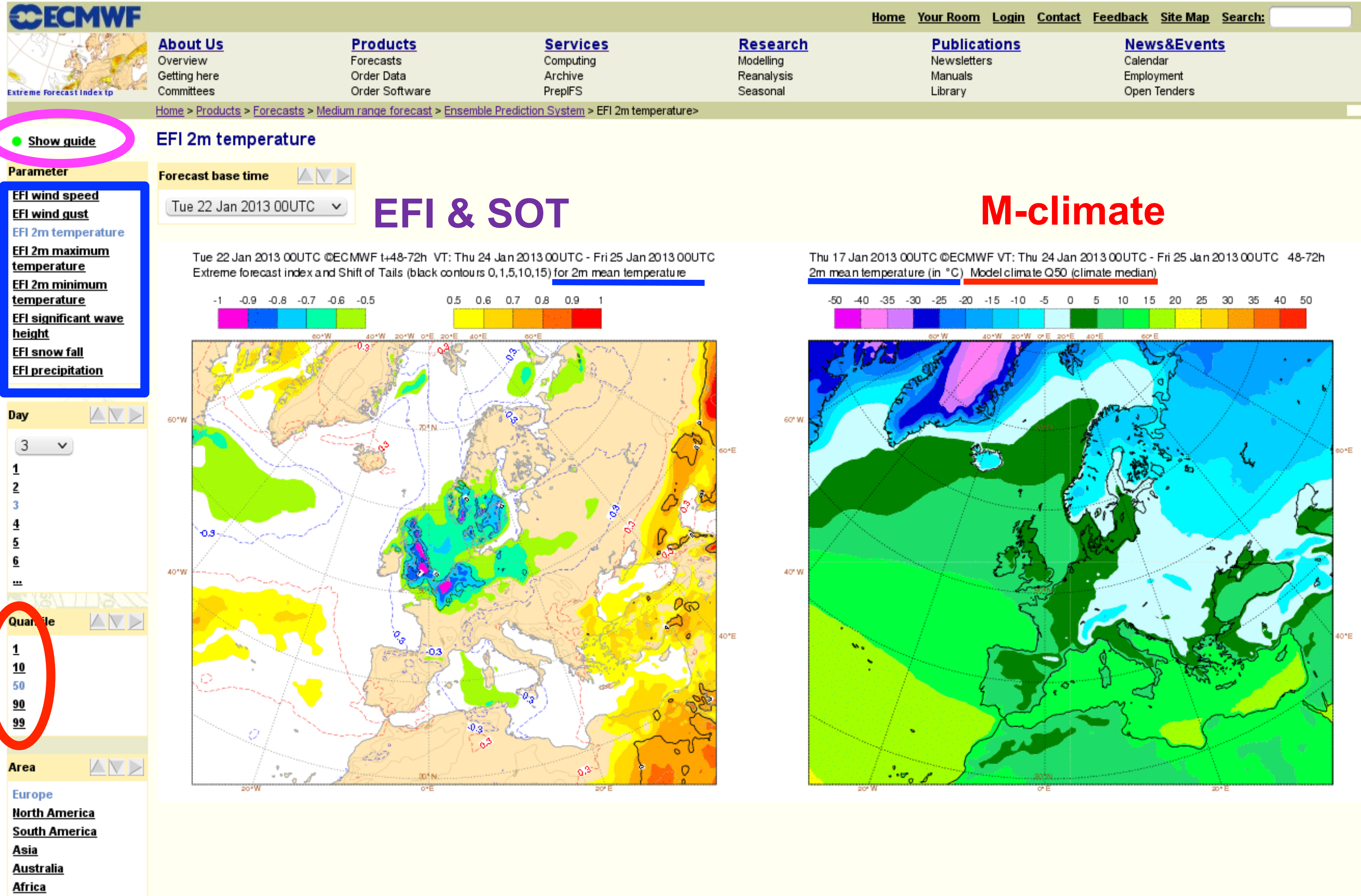
Operationally available EFI fields

- **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 (only for tpi before), 24-144 (only for tpi before), 48-168, 72-192, 96-216
  - 12UTC: 12-132, 36-156, 60-180, 84-204, 108-228
- **240h interval: parameters 2ti, tpi, 10swi**
  - 00UTC: 000-240 (only for tpi before)
  - 12UTC: 000-240 (only for tpi before)

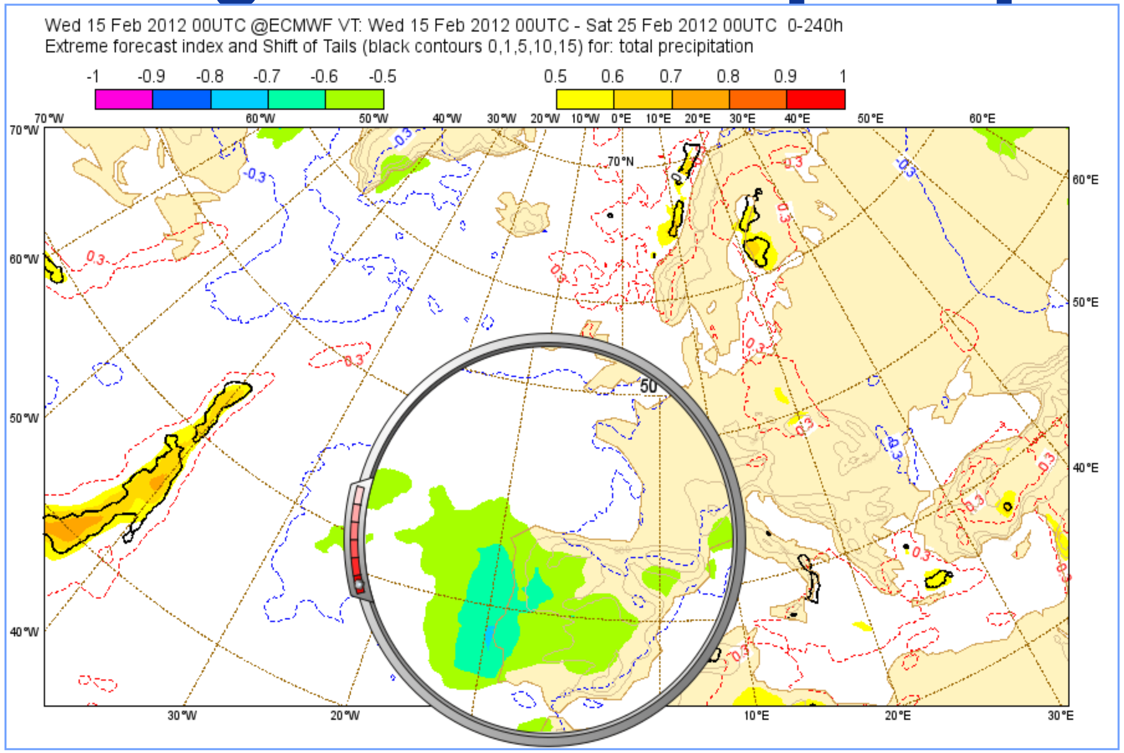
http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/



New web plots – available for all member states



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 likelihood of dry weather.**

EFI fields available for all WMO members

Home > Products > Forecasts > Medium range forecast > Ensemble Prediction System > EFI t2m>

Show guide

Parameter

EFI t2m
EFI 10m wind speed
EFI 10m wind gusts
Precipitations

Day

1
2
3
4
5

Area

Europe
North America
South America
Asia
Australia
Africa

Your Room

Add this product

Show overview

Day
Area
Forecast base time

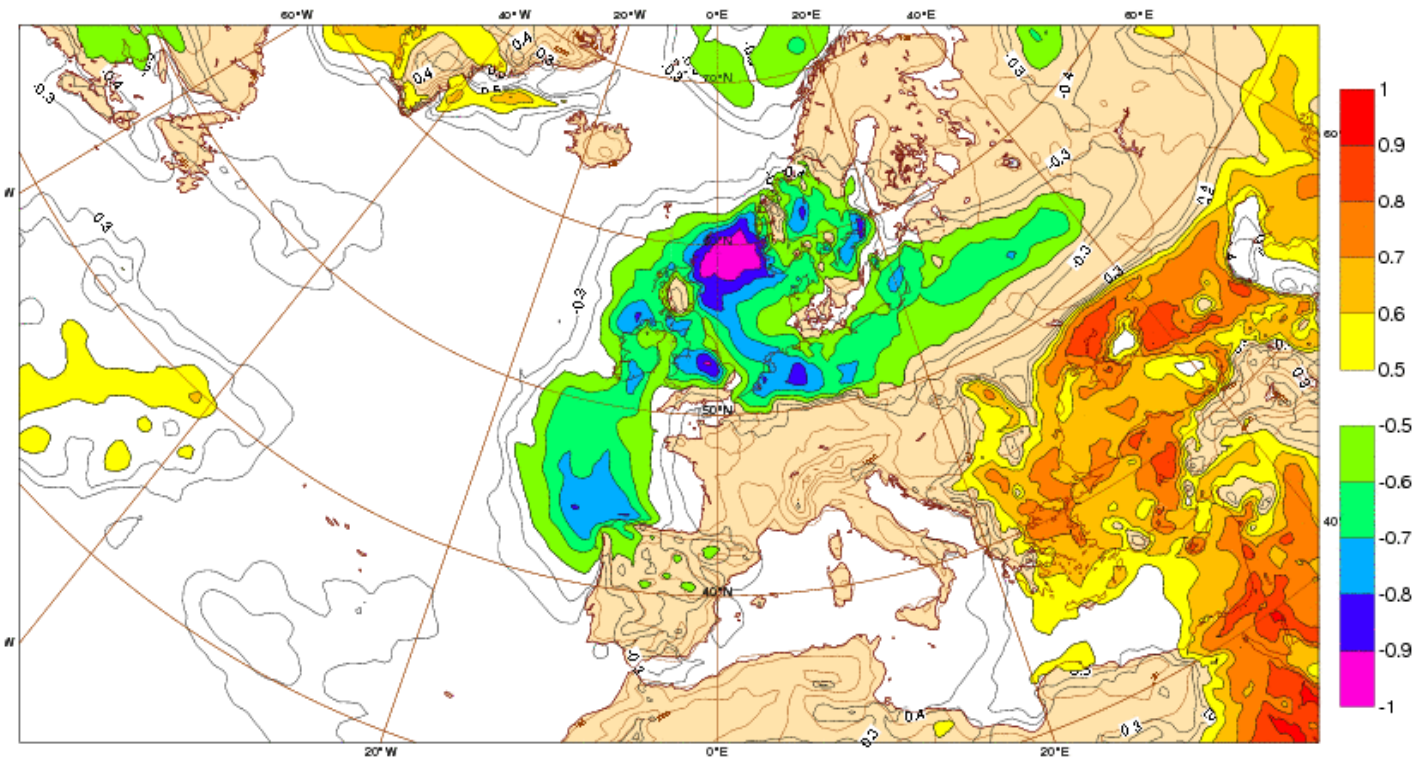
EFI t2m

Forecast base time

Tue 22 Jan 2013 00UTC

Selected parameters and time ranges

Tuesday 22 January 2013 00UTC ©ECMWF Extreme forecast index t+000-024 VT: Tuesday 22 January 2013 00UTC - Wednesday 23 January 2013 00UTC
Surface: 2 metre temperature index



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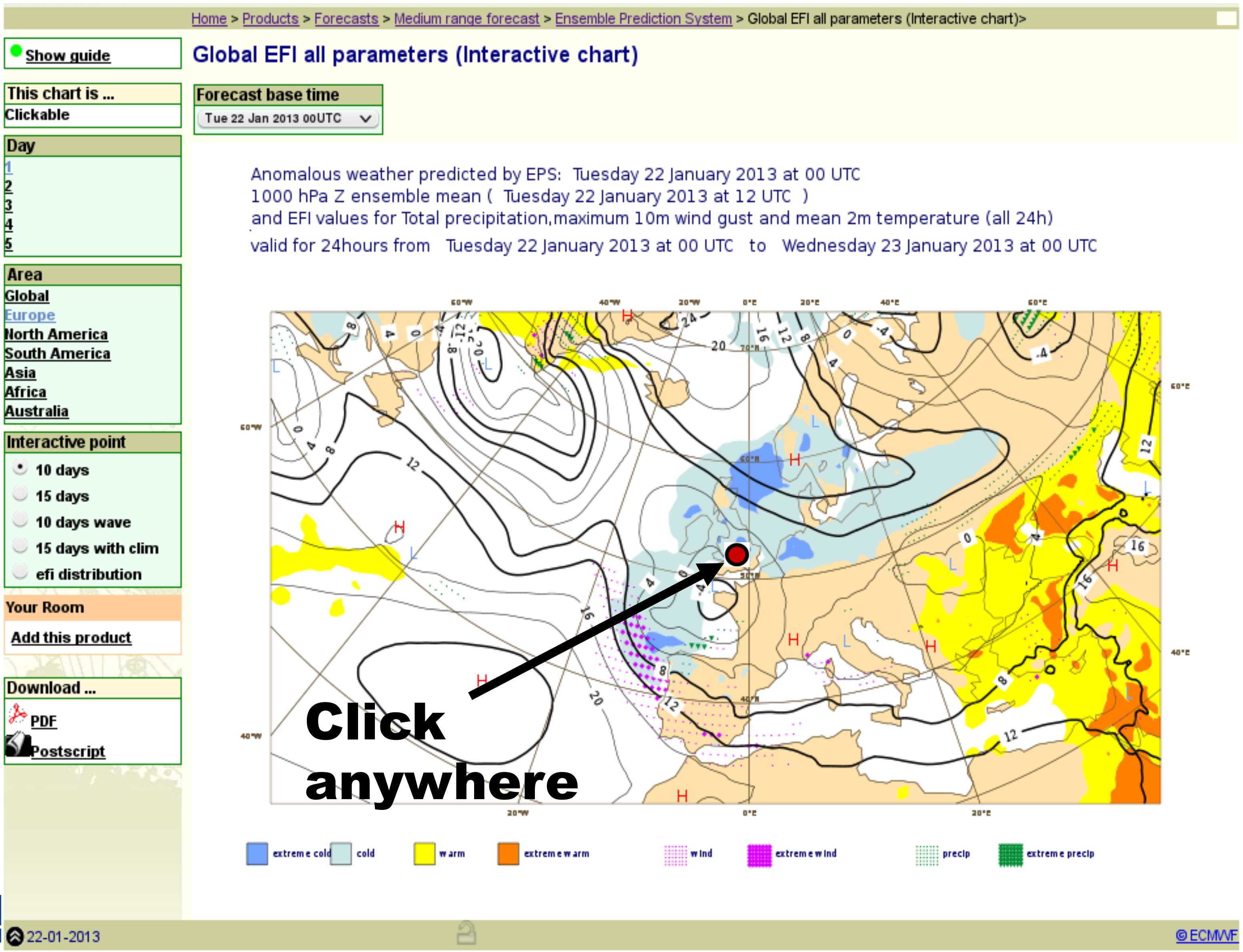
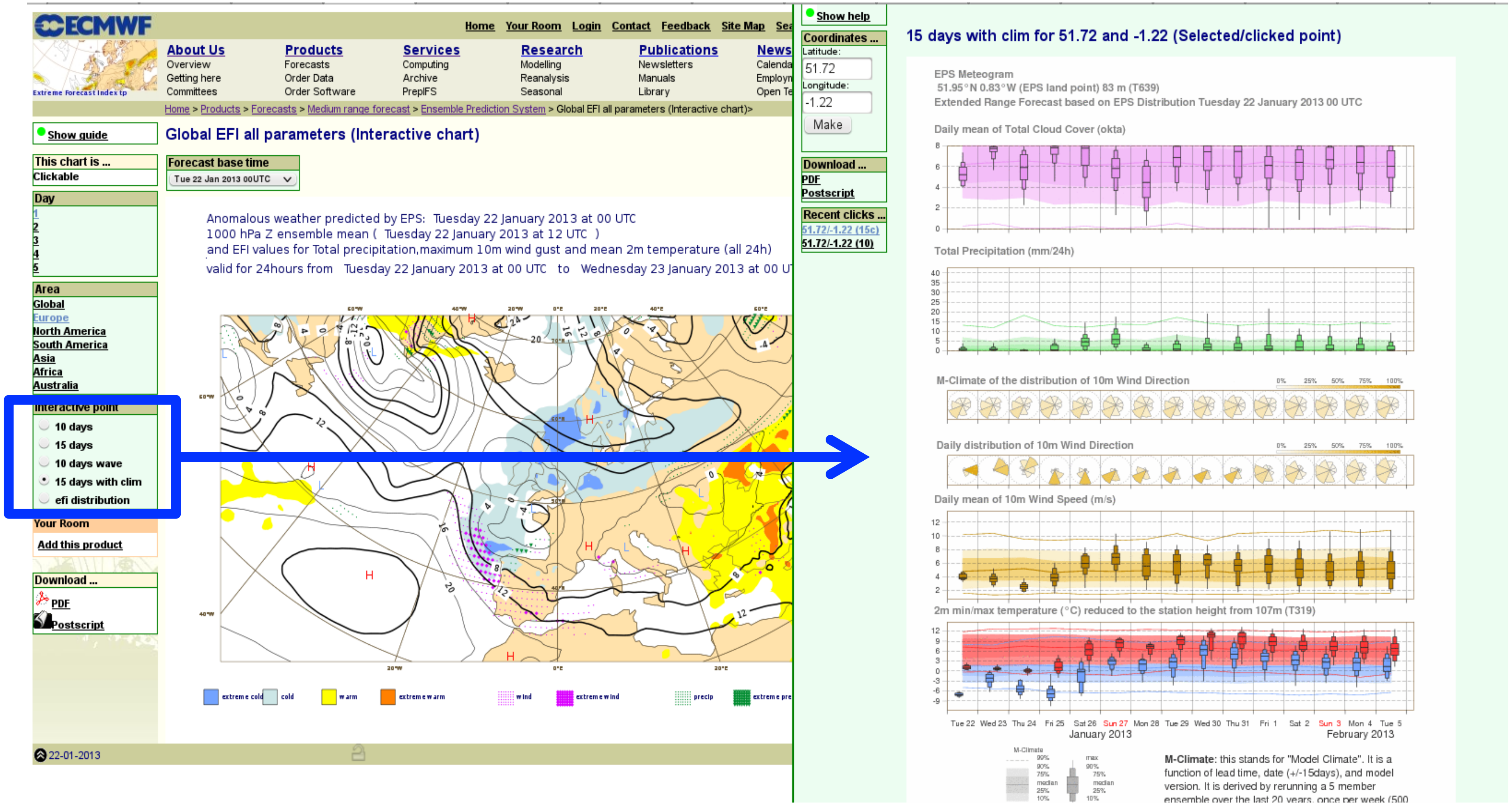
“Anomalous weather” map



“Anomalous weather” map



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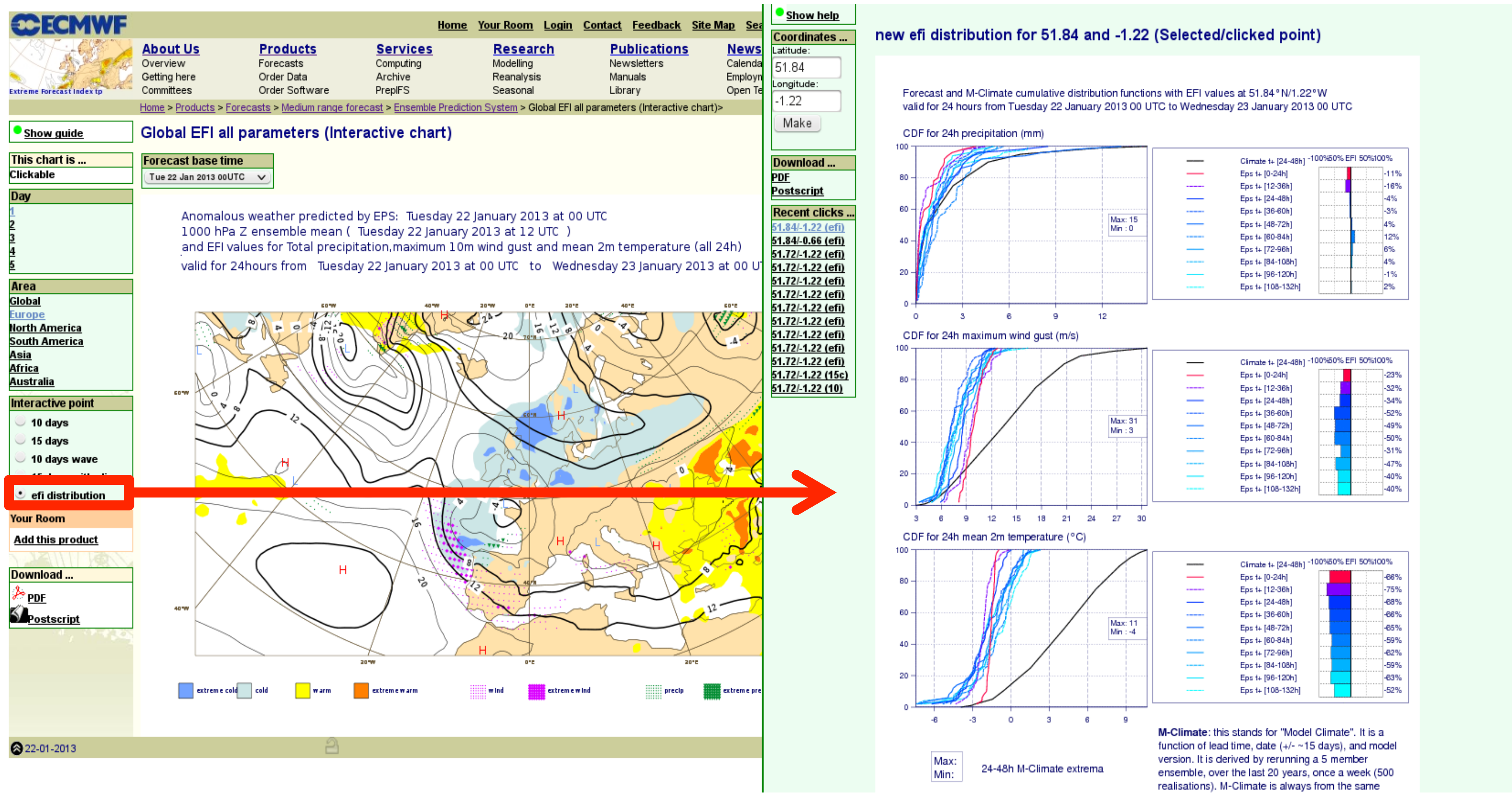
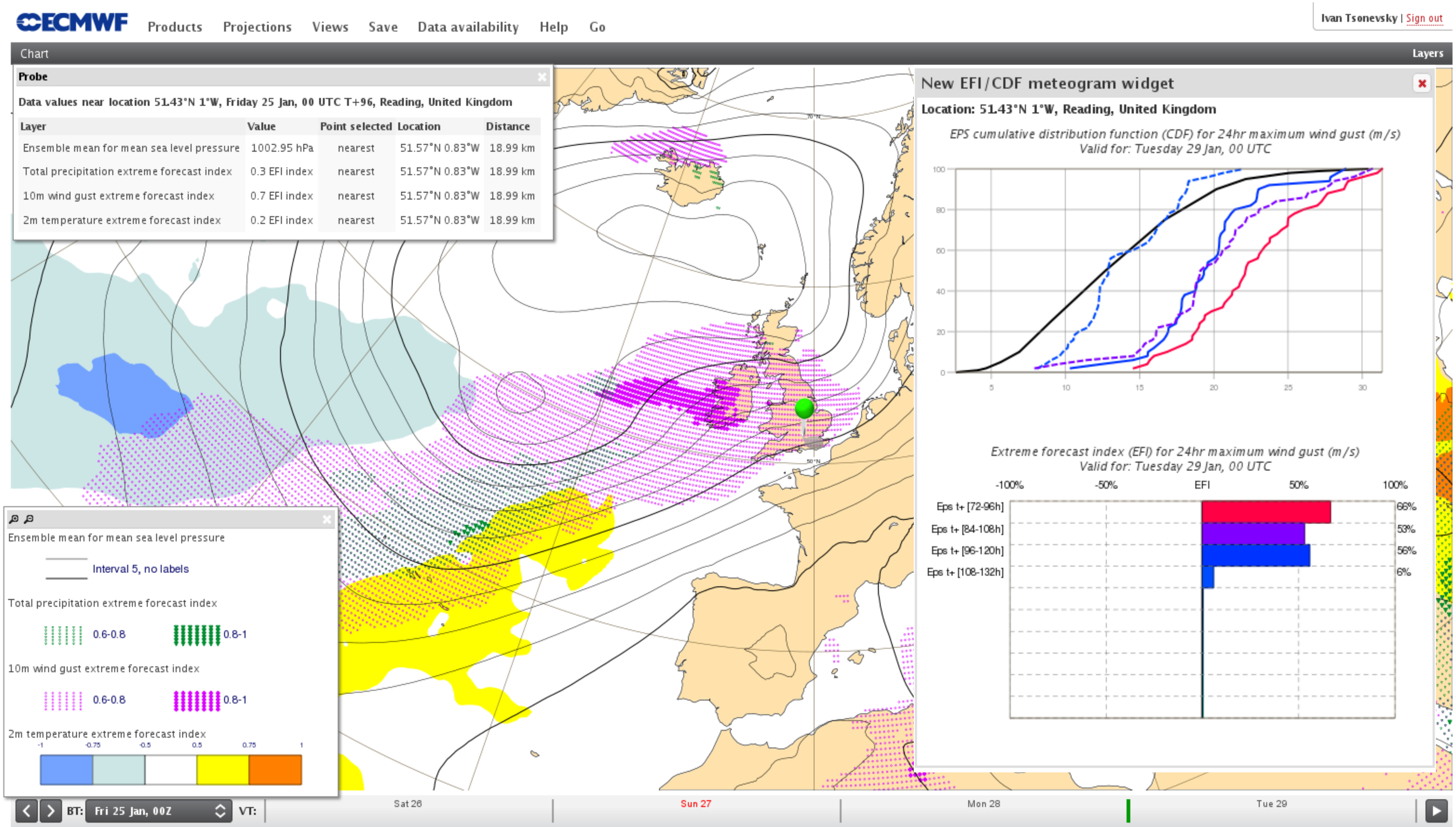
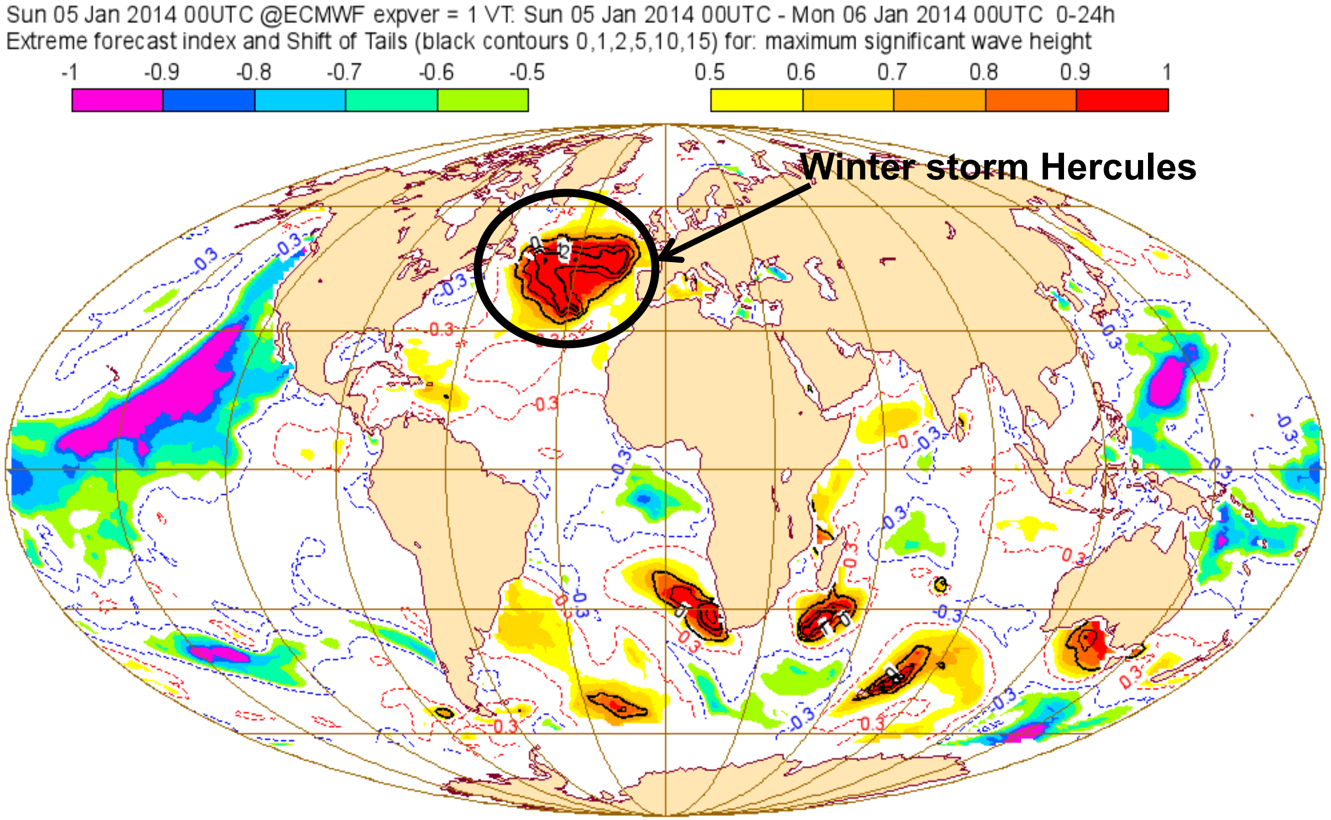
“Anomalous weather” map



EFI products on ecCharts

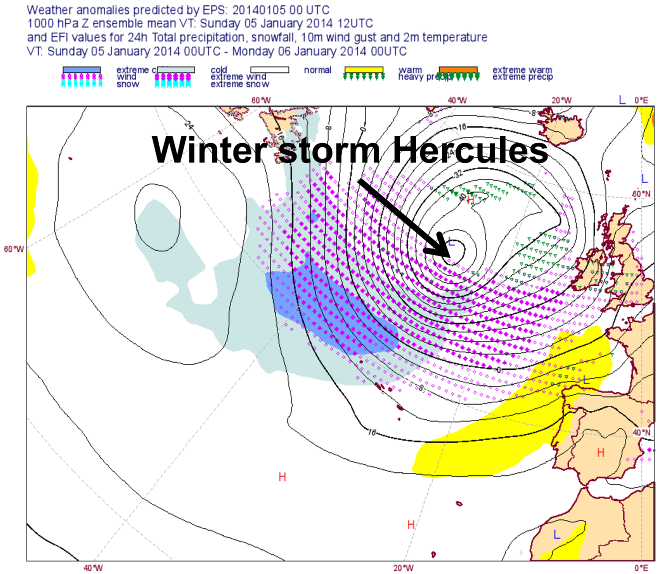


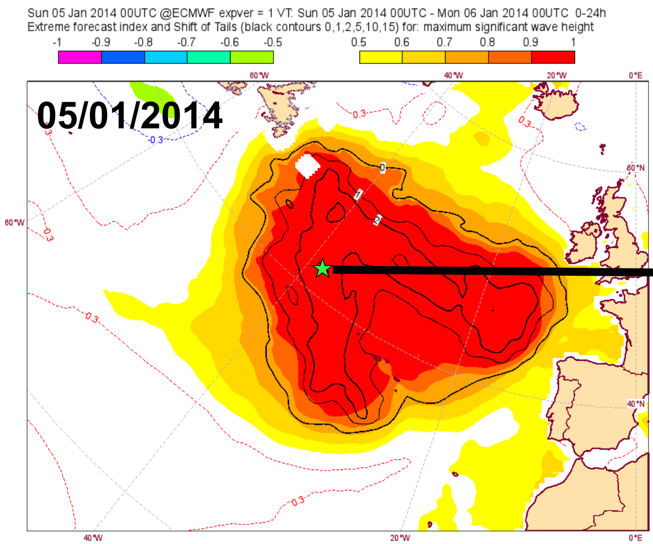
EFI for waves

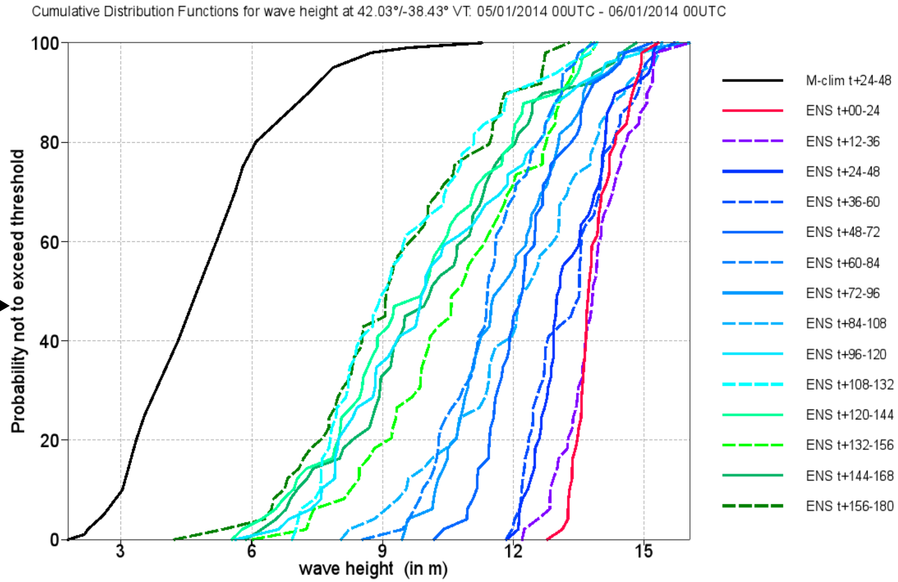


- Negative EFI (calm sea) also plotted on the web.
- The winter storm Hercules generated waves up to 20 m in height on 5 and 6 January 2014.

Historic swell – Storm Hercules







EFI Verification

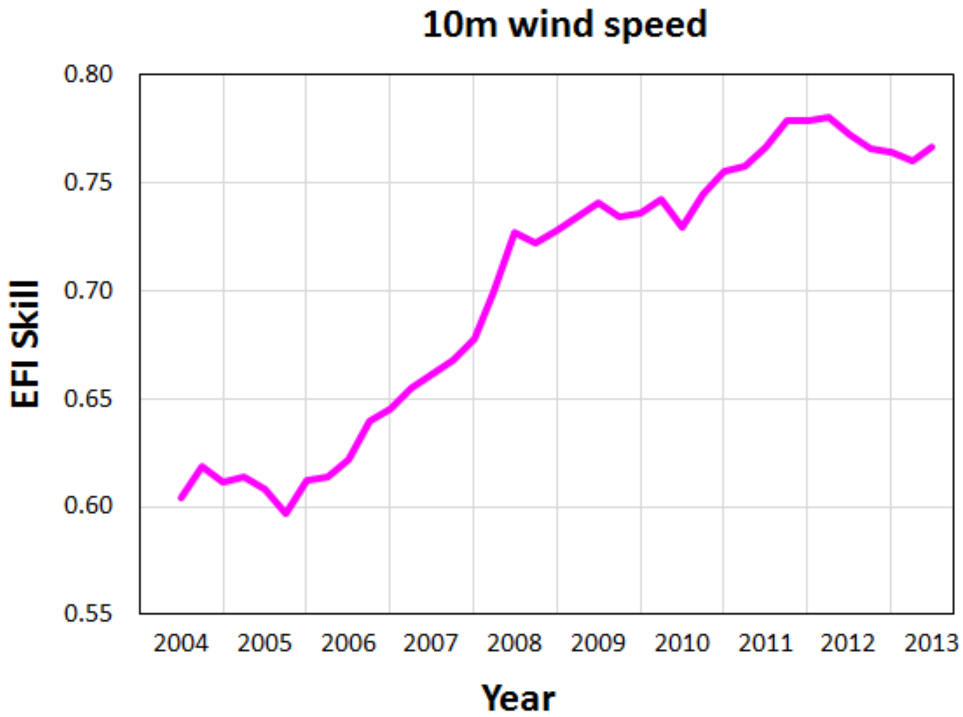
- Verification of the EFI has been done using synoptic observations over Europe available on the GTS.
- An extreme event is taken as occurring if the observation exceeds the 95th percentile of the observed climate for that station (calculated from a 15-year sample).
- The ability of the EFI to detect extreme events is assessed using the Relative Operating Characteristic area (ROCA).
- EFI Skill = 2ROCA-1;

    0 → no skill, 1 → perfect score

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

ECMWF

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 curve shows a four-season running mean.**

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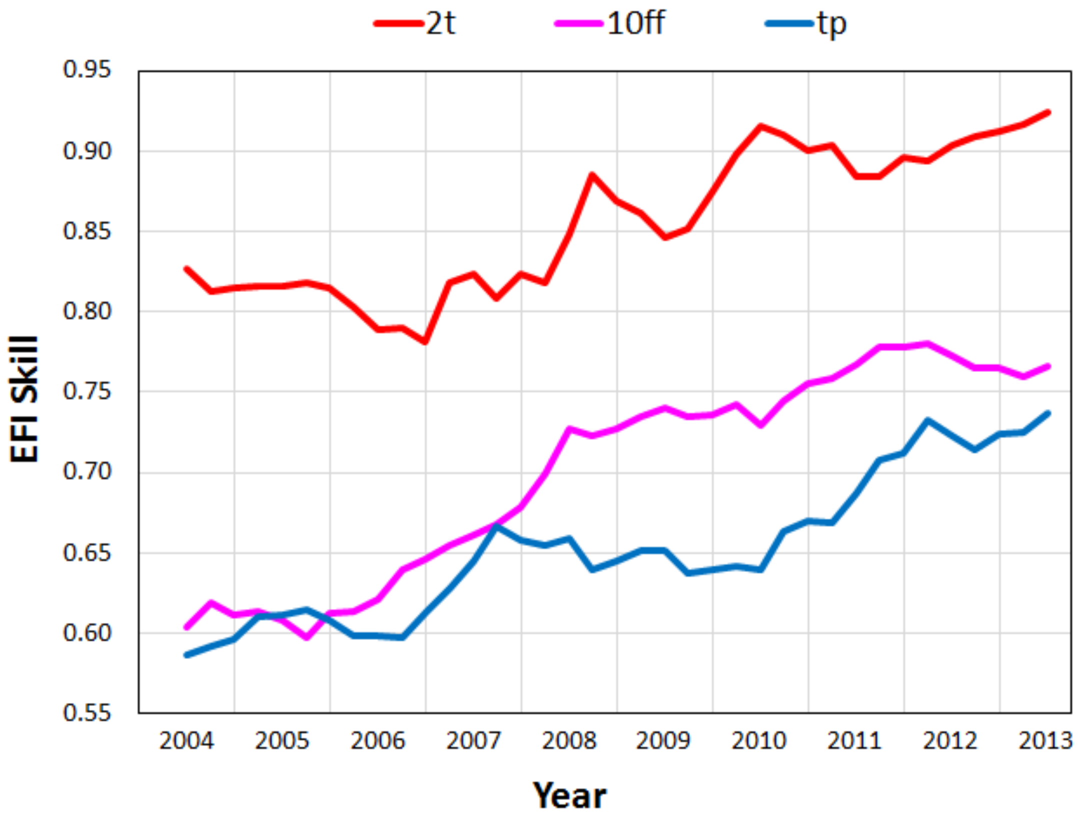
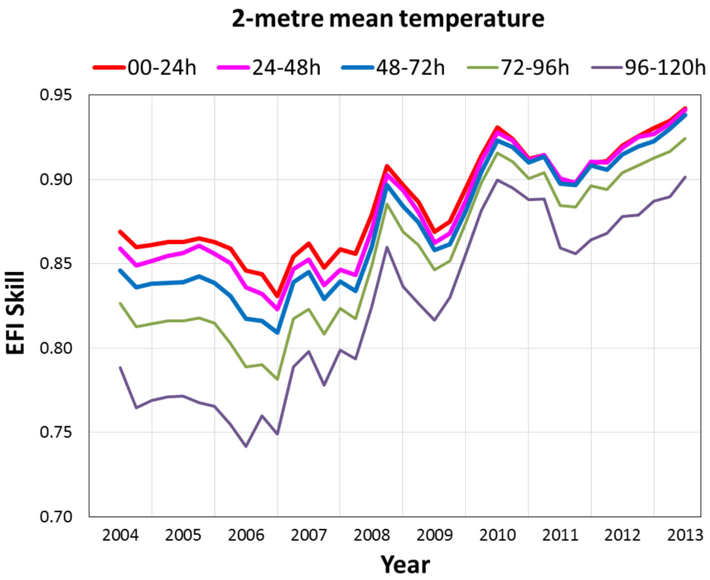
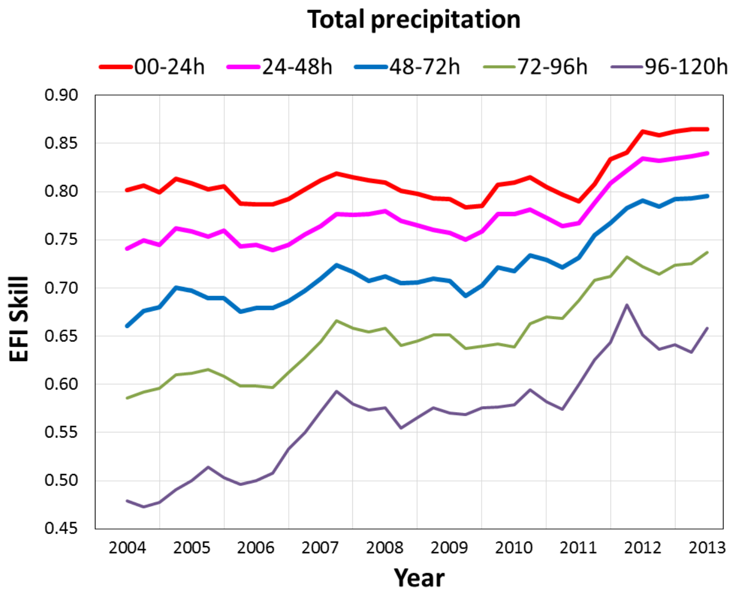
EFI Verification

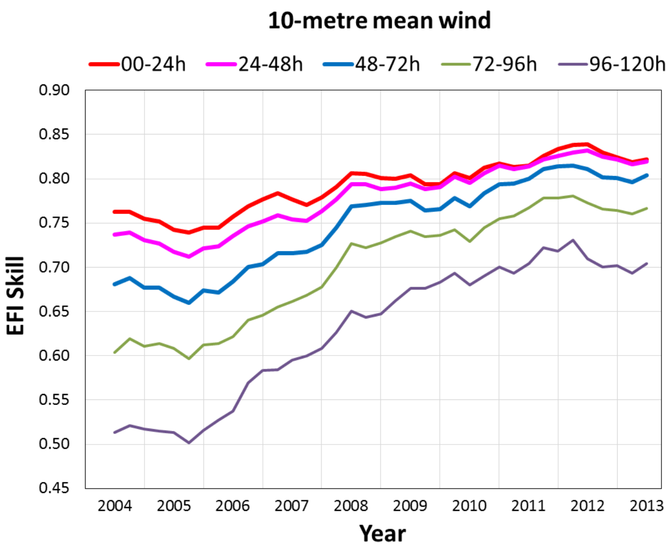


- Curves show a four-season running mean of the EFI skill score for 2m mean temperature (2t), 10 metre mean wind speed (10ff) and total precipitation (tp).
- The EFI for 2m temperature is more skilful than EFI for the other two parameters.

EFI Verification





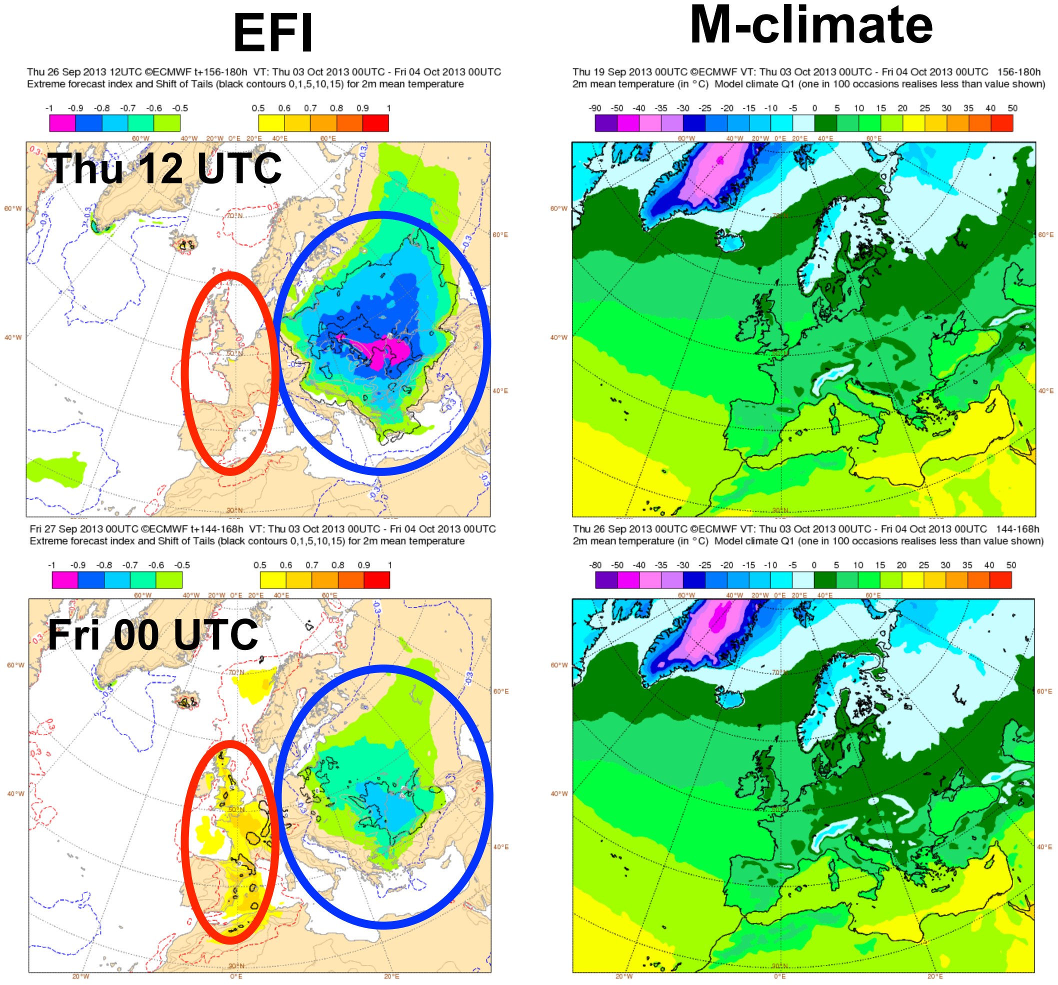


- **EFI skill as a function of the lead time**

Known issues

- Re-forecast sample size is still not sufficient for providing robust climate:
  - Noise, especially in the tails of the climate distribution
  - Jumpiness in the EFI and especially in Shift Of Tails (SOT)
- M-climate is computed only once a week (every Thursday):
  - Sudden jumps in the EFI forecasts when changing the M-climate on Fridays due to the seasonal trend
- M-climate is not perfect. It may be affected by model biases:
  - Jumpiness in the M-climate for different lead times

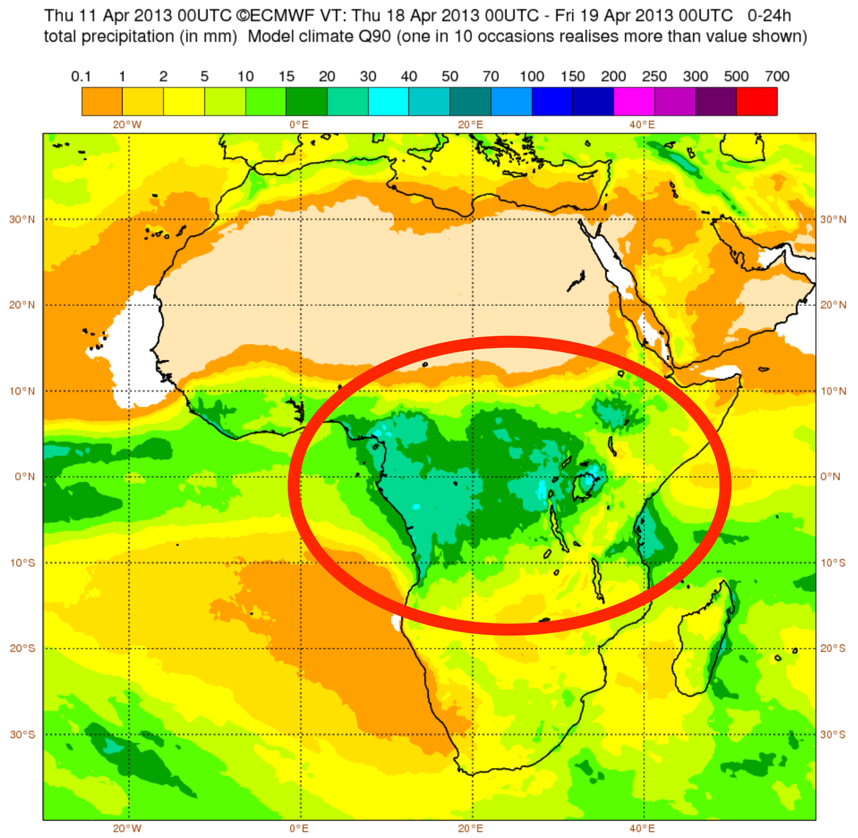
Known issues – example of a cold wave, Europe, beginning of October 2013

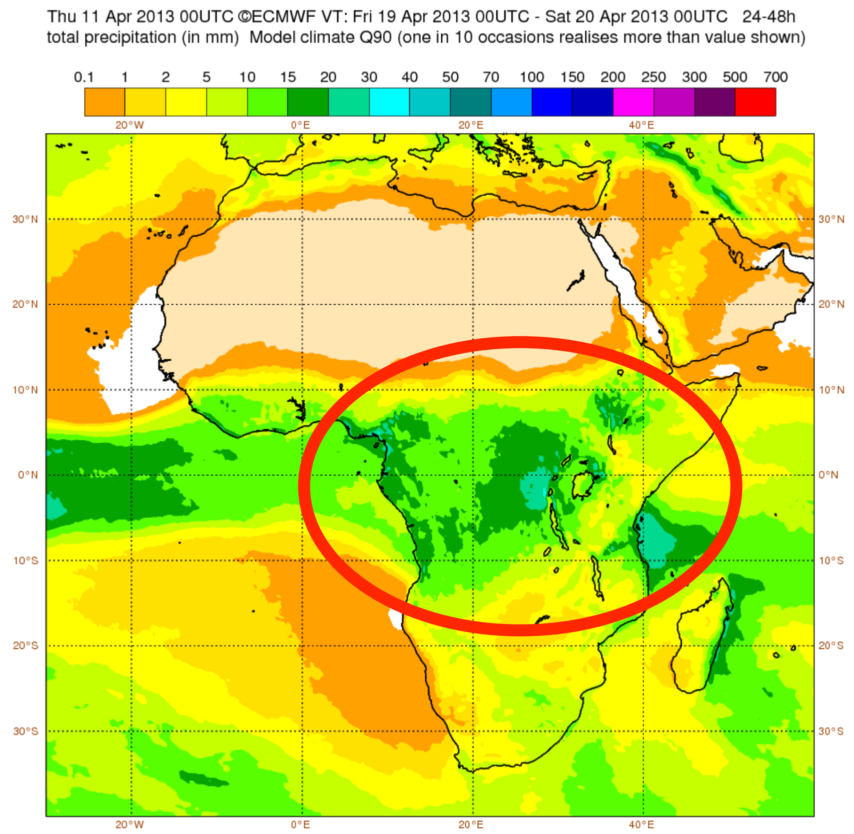


- **M-climate is computed only once a week (every Thursday):**
  - **Sudden jumps in the EFI forecasts when changing the M-climate on Fridays due to the seasonal trend**

Example: two consecutive forecast runs. The signal of extremely cold weather is less prominent in the Friday's run because of the different climate though the forecasts are similar.

Known issues – example tropical Africa





The striking difference between t+00-24h and t+24-48h climate is noticeable on these charts which represent 90th model climate percentile. Precipitation amounts corresponding to Q90 for 00-24h are much bigger than those for 24-48h.

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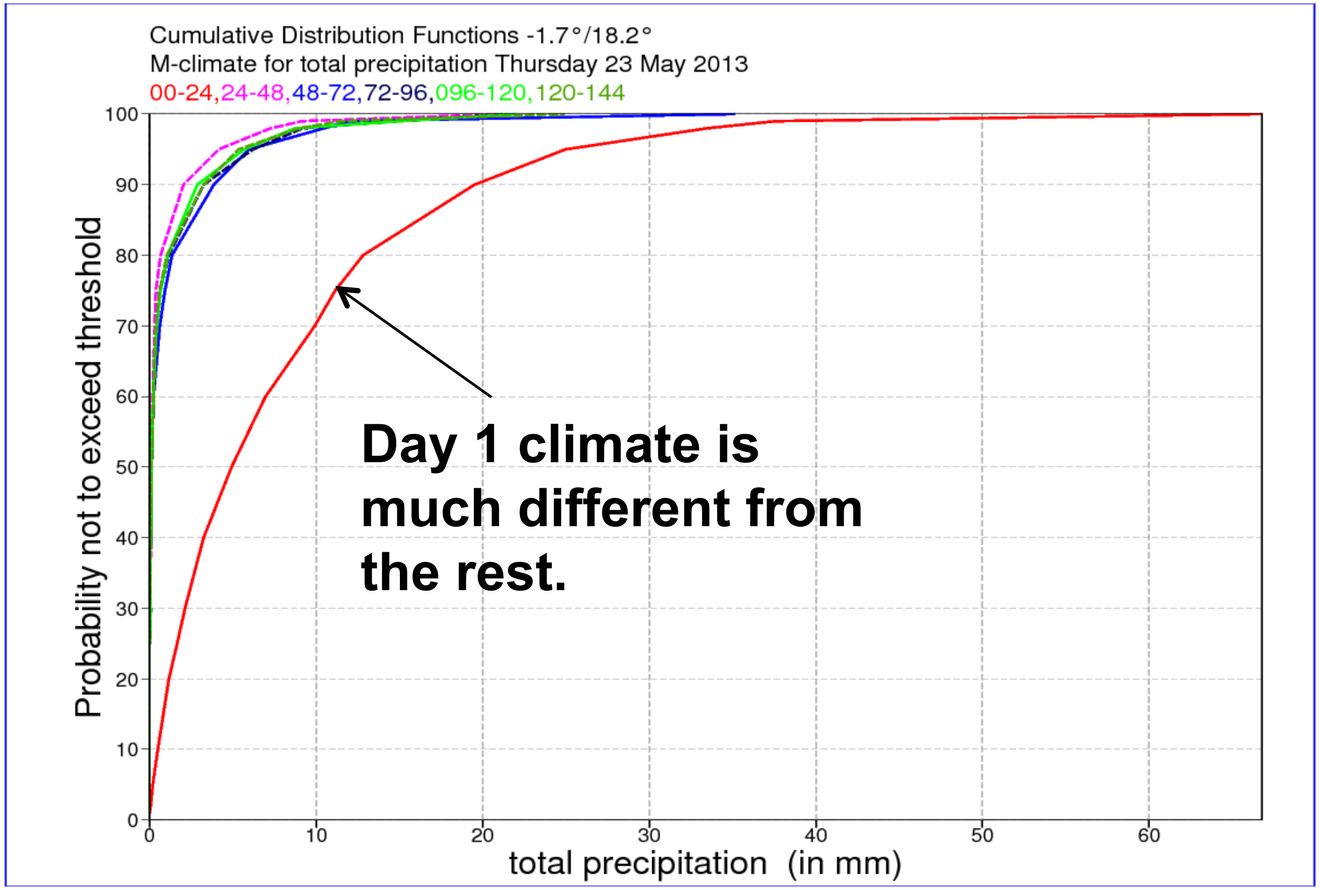
Known issues – example tropical Africa

- M-climate is not perfect. It may be affected by model biases:
  - Jumpiness in the M-climate for different lead times



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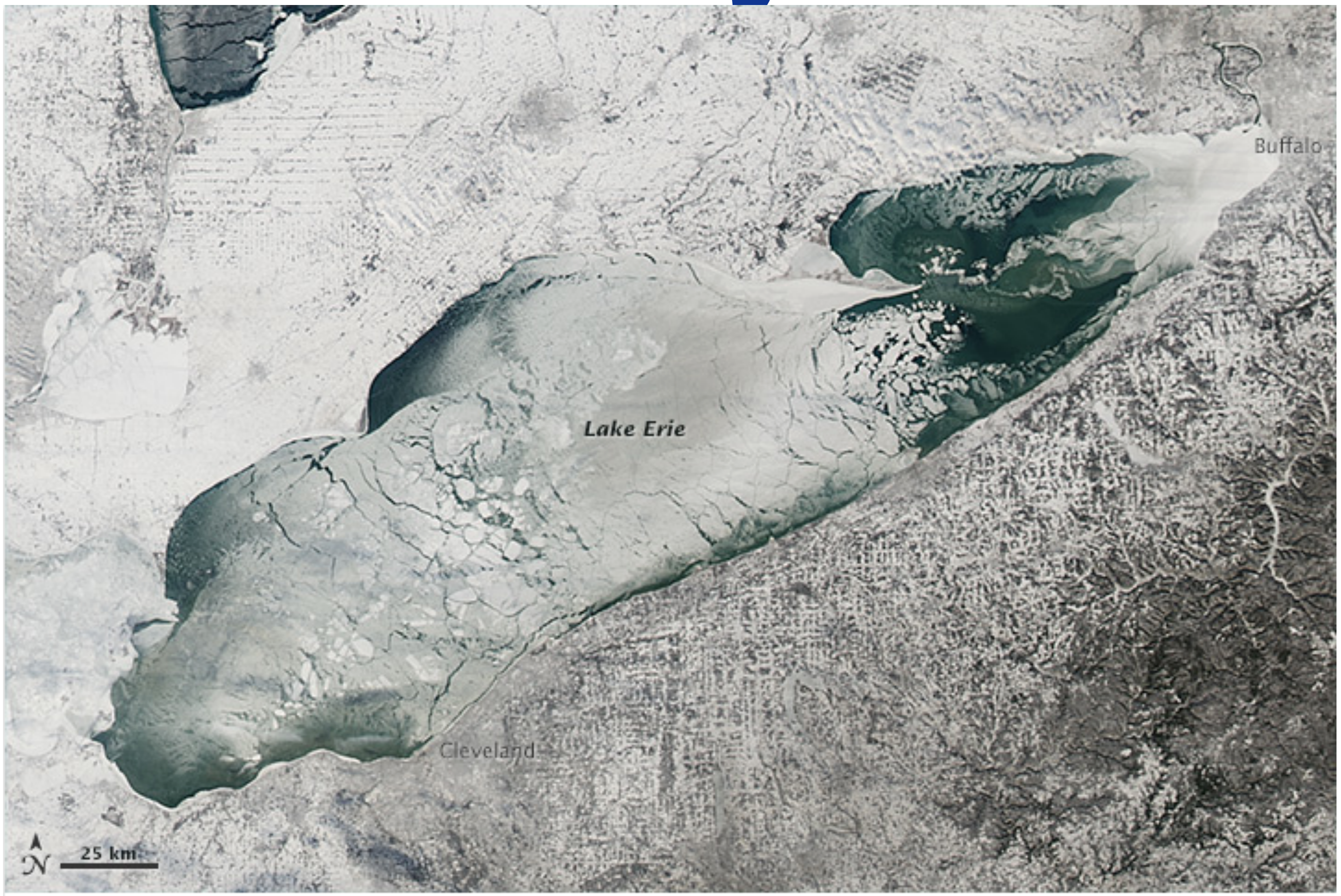
Proposed changes in the M-climate

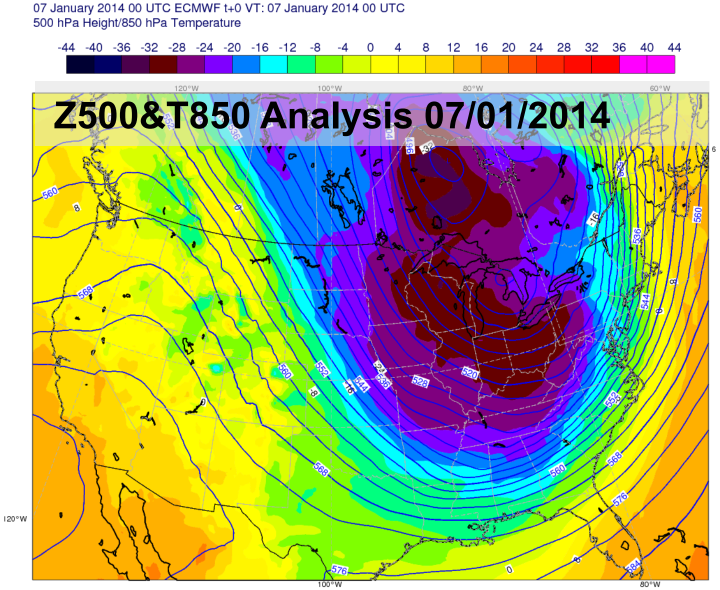
- To increase the number of the ensemble members in the re-forecasts from 5 (now) to 11:
  - The sample size will considerably increase from 500 to 11*5*20=1100
  - Still not enough in the first 2 days of the forecast as the ensemble spread is not big enough to cover the whole range of the possible outcomes
- To run re-forecast suite twice a week (every Monday and Thursday) instead of being run once a week (Thursdays)
  - It will better account for the seasonal trend, hence less jumpy forecasts due to the seasonal trend when the M-climate changes

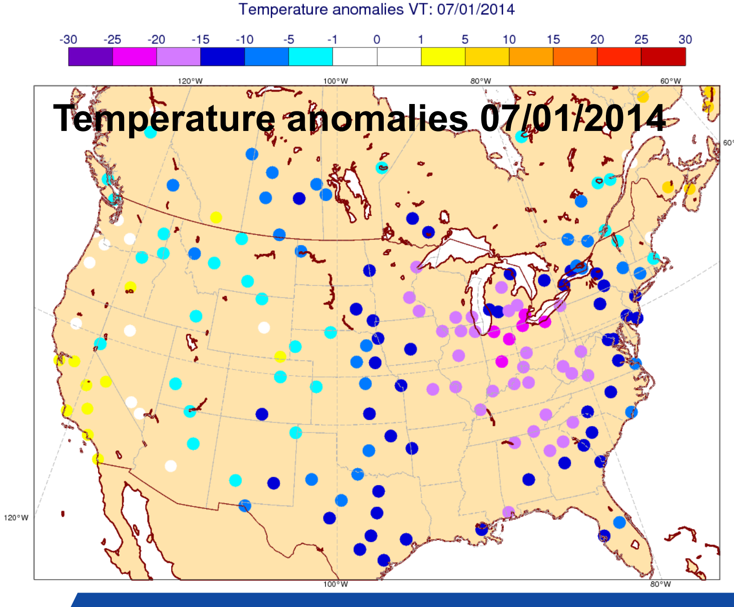
US cold snap
January 2014



Great Lakes frozen

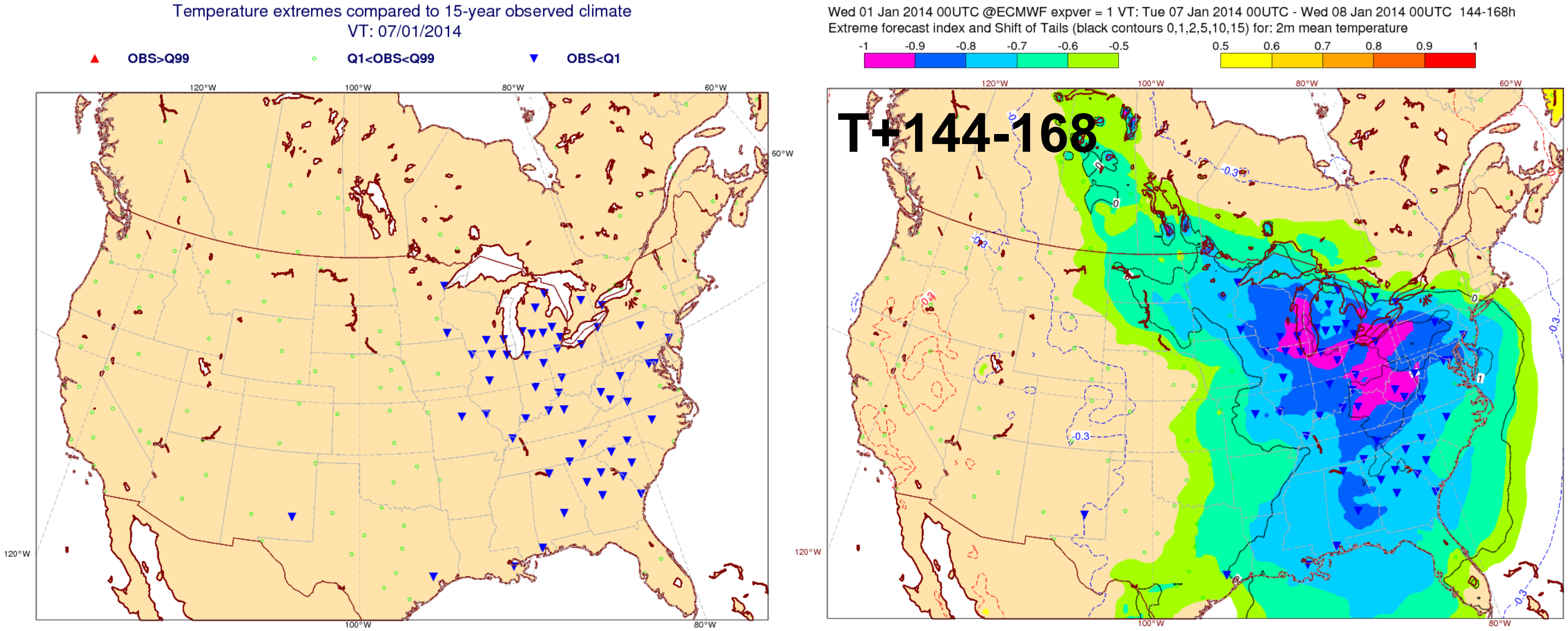
US cold snap, January 2014





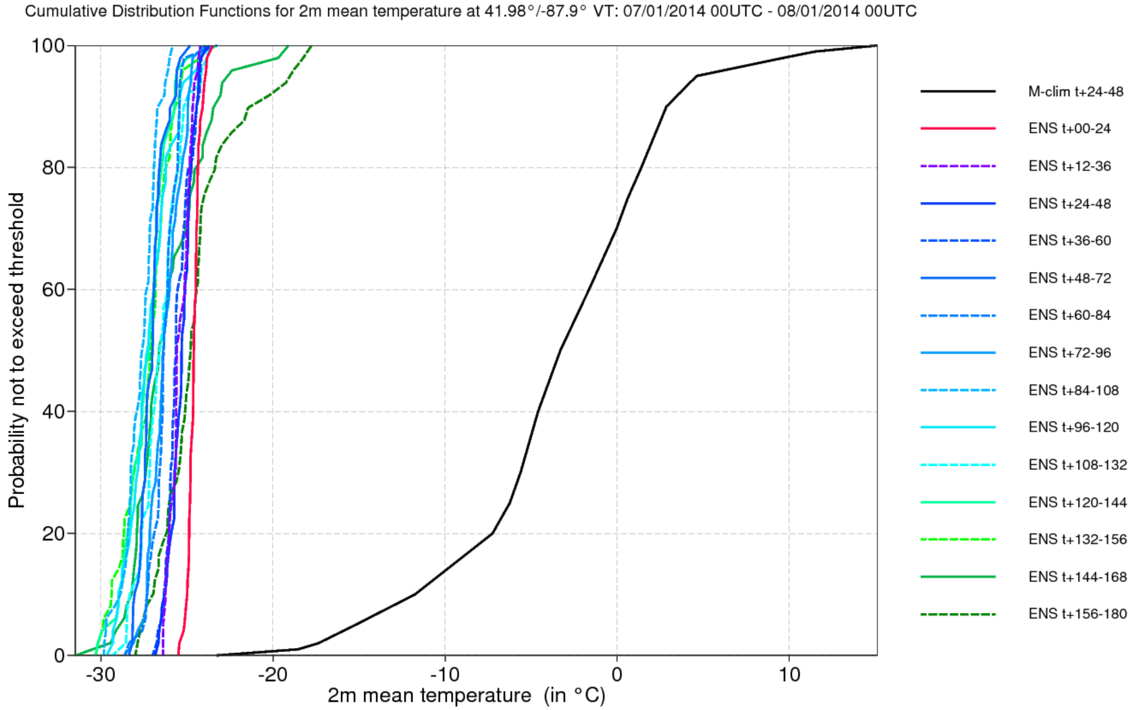
- An extremely cold airmass from the Arctic region dropped the temperatures in the US January 5-7, 2014.
- Record freezing temperatures (15 to 22C below normal) brought many cities to a standstill. Over a dozen deaths were attributed to the cold wave.
- It was the coldest weather since early February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

US cold snap, January 2014

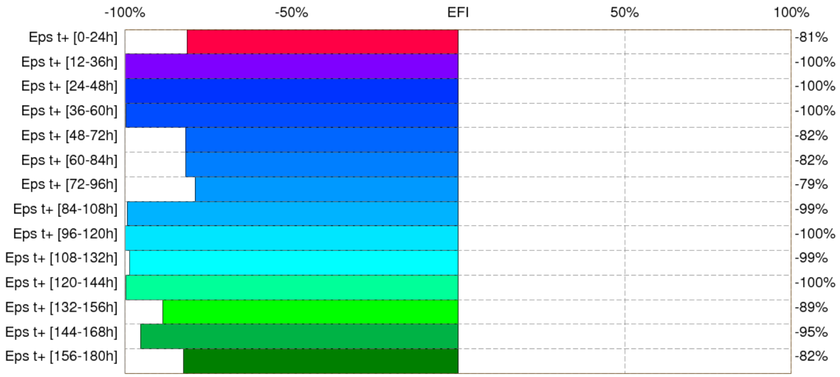


- Blue triangles denote extremely low temperatures below 1st percentile of the 15-year climatology from observations.
- Positive SOT (black contours) and high negative EFI match very well the areas of extremely low temperatures even 7 days in advance.

US cold snap, January 2014



Extreme Forecast Index for 2m mean temperature at 41.98N -87.9W
Tuesday 7 January 2014



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

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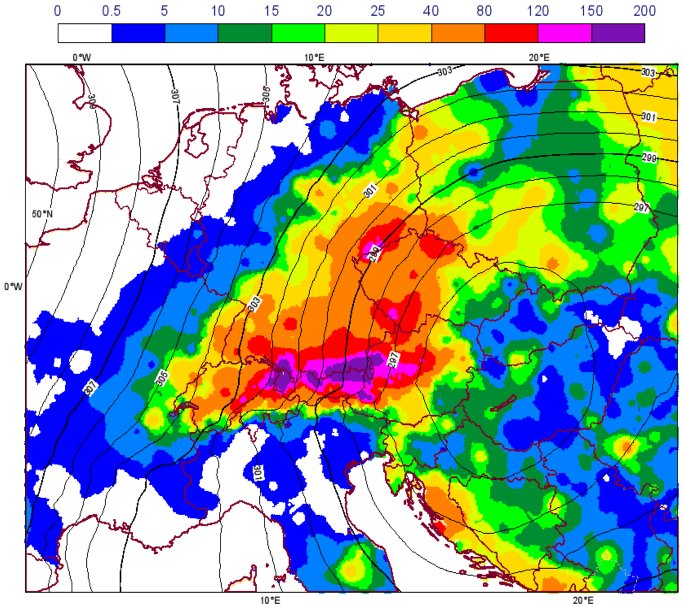
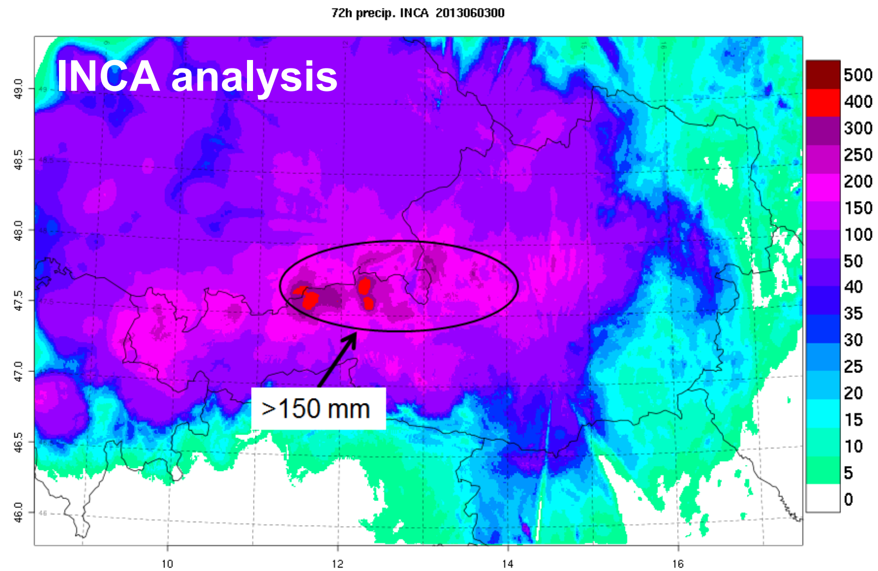
Floods in Central Europe

June 2013

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 Alps played an important role.

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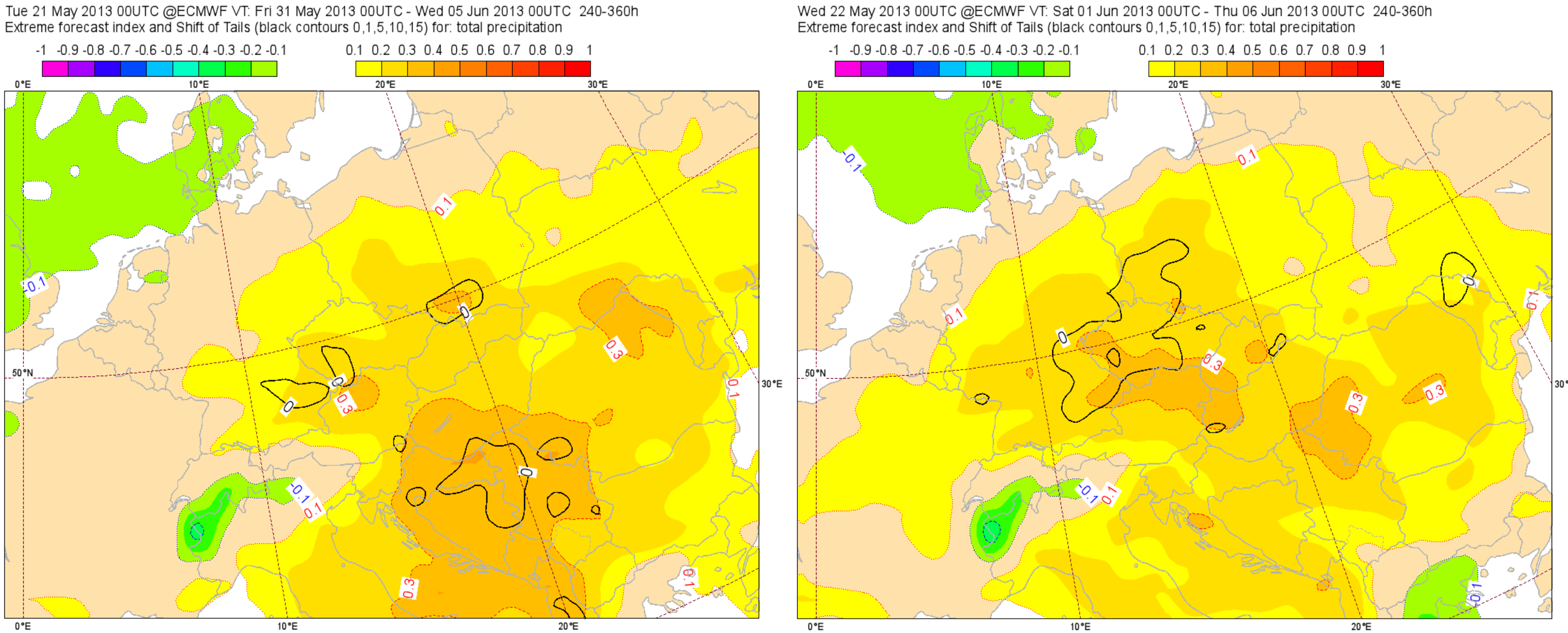
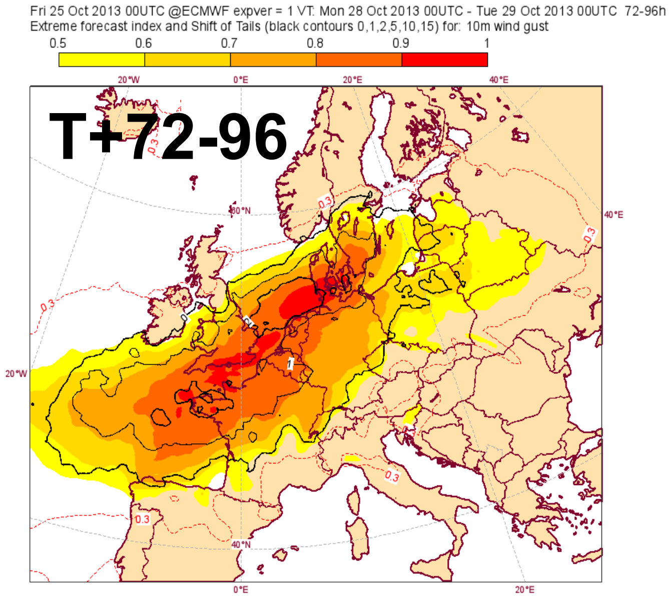
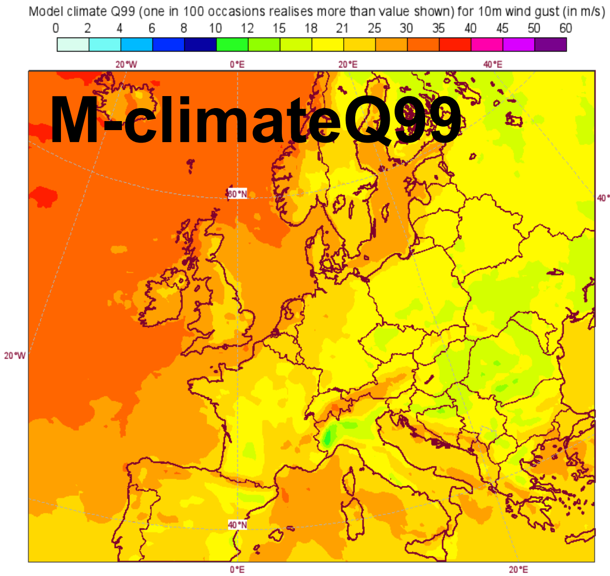
EFI & SOT, total precipitation, T+240-360

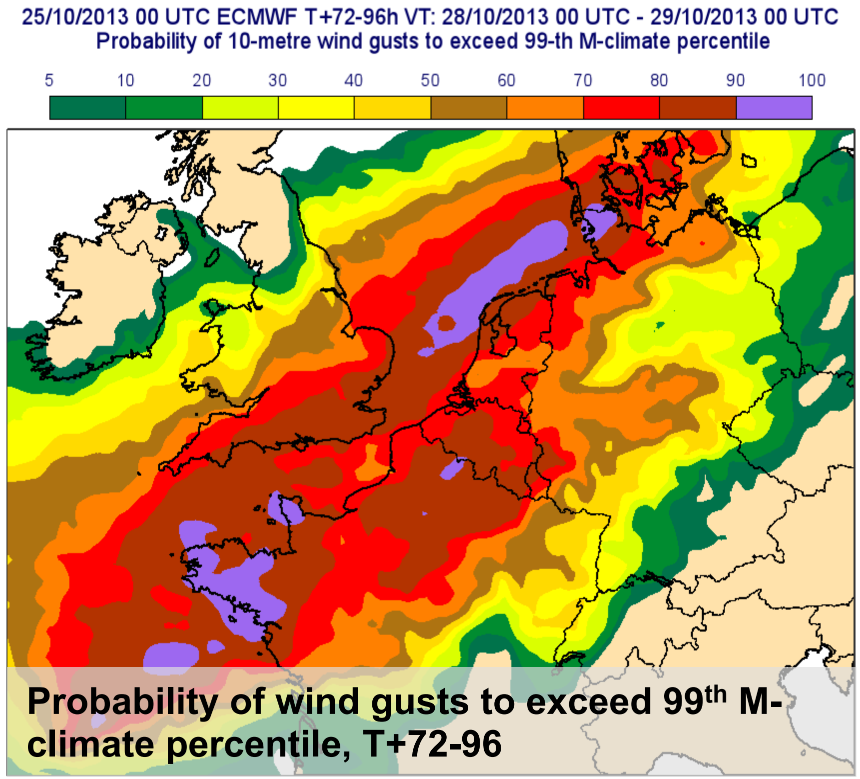


- A remarkably strong signal in the EFI.
- Positive SOT marks the areas where the forecast system predicts exceptionally heavy rain.

St. Jude storm case







Probability of wind gusts to exceed 99th M-climate percentile, T+72-96

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

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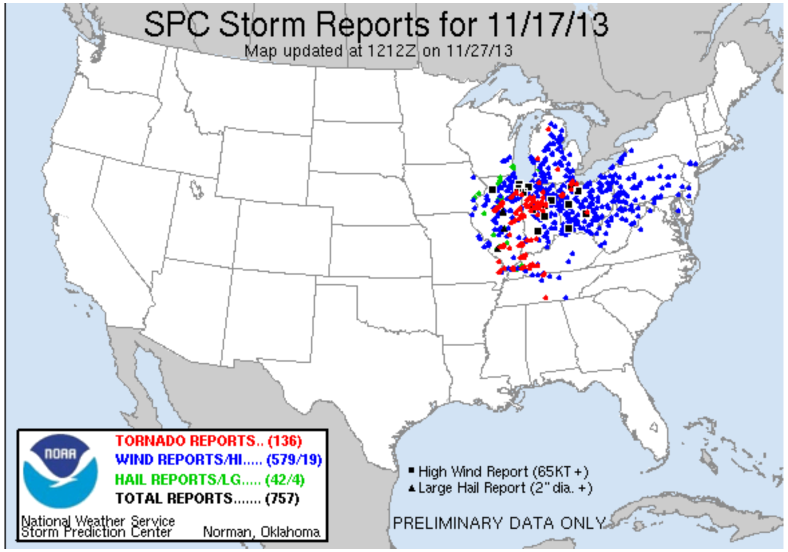
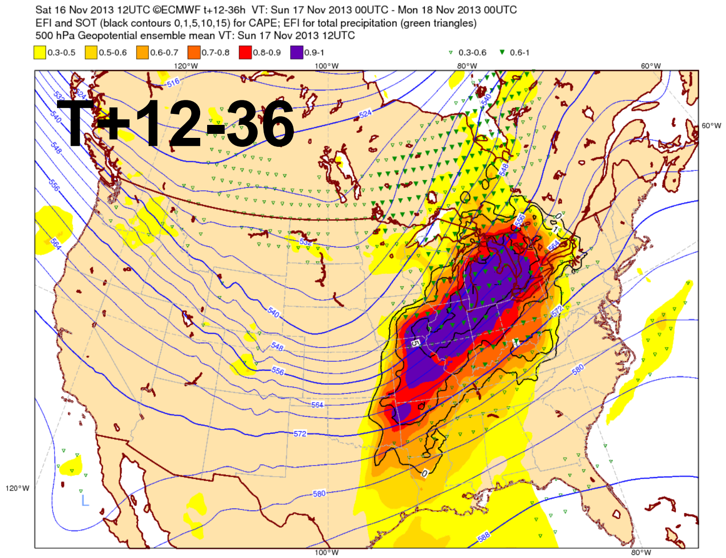
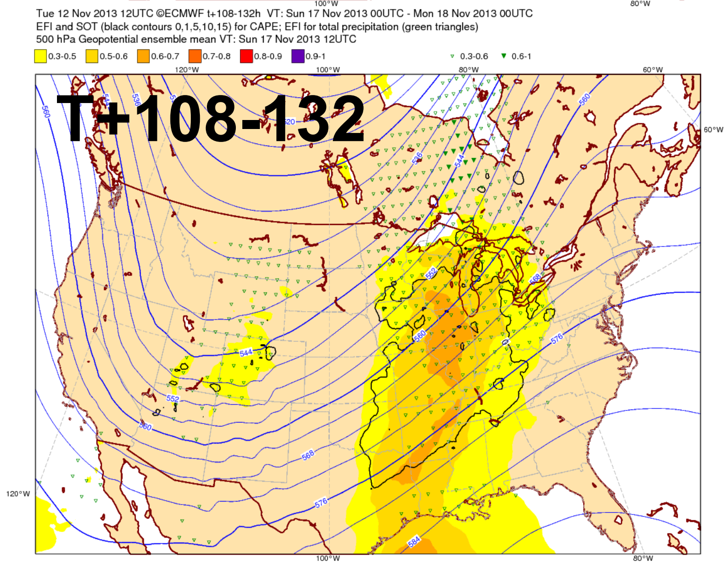
EFI and SOT for CAPE (experimental)







- Several sates in Midwest of the USA were affected by severe convection and tornadoes that killed at least six people on the 17th Nov 2013.
- EFI warned of abnormally high values of CAPE several days in advance.

Further Reading:

- “Application of the new EFI products to a case of early snowfall in Central Europe”, *ECMWF Newsletter* No. 133 – Autumn 2012, p. 4
- “Early warnings for severe weather” at http://www.ecmwf.int/newsevents/meetings/forecast_products_user/Presentations2012/