# Forecasting Extreme Events

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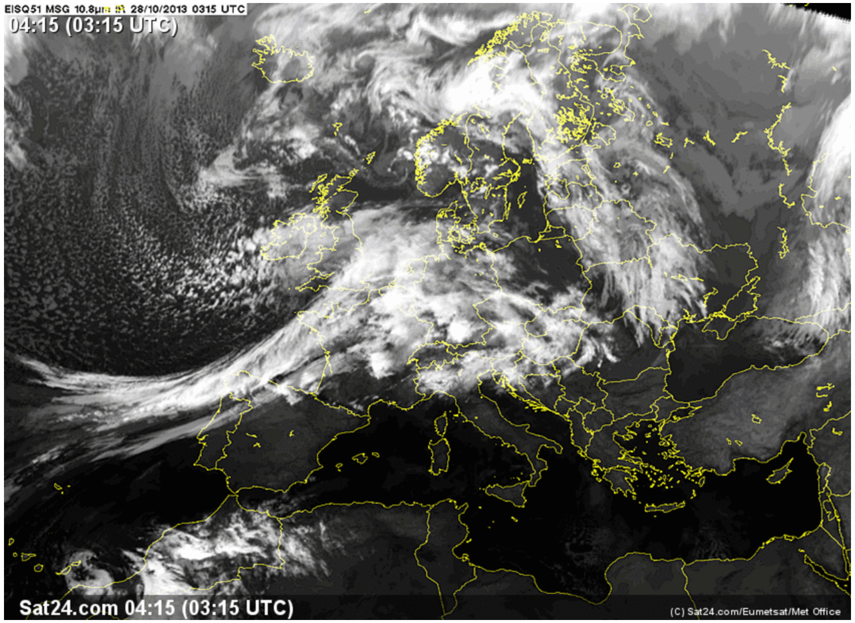
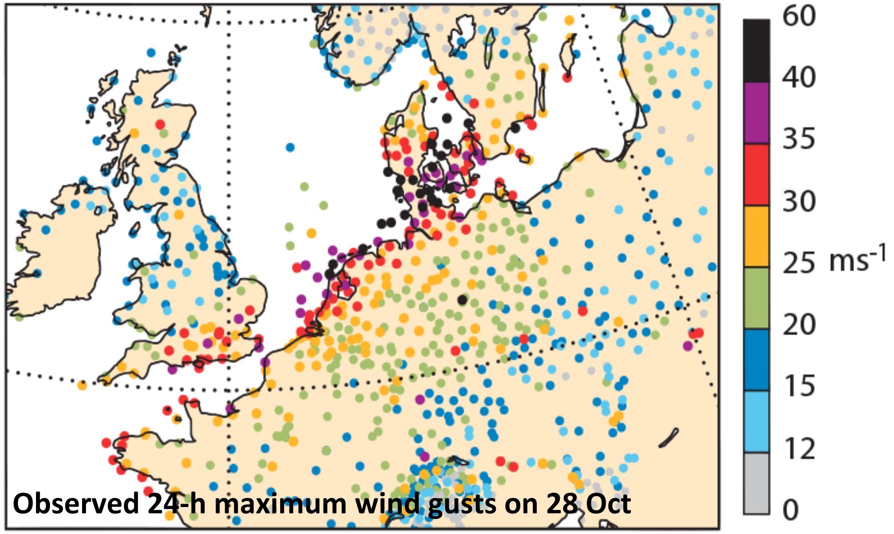
# Outline

- An 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
- A case study: extreme cold, US
- Operational products and verification
- Forthcoming changes
- Recent development - EFI for convection

# St Jude Storm, 27-28 Oct 2013

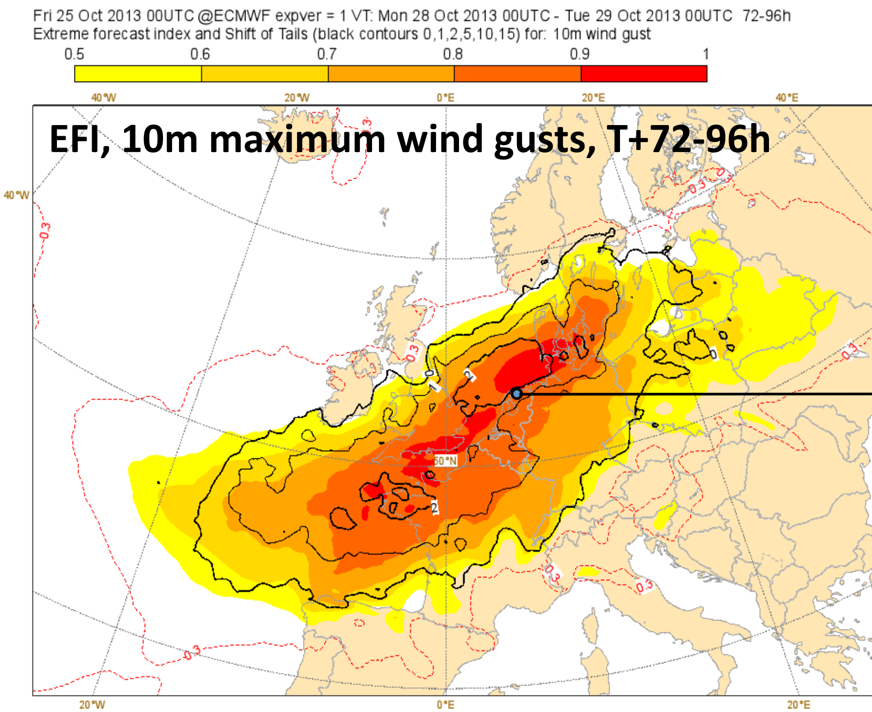



Areas exceeding the 5-year return period of 24-hour maximum wind gust diagnosed using the ERA-Interim reanalysis as a proxy for observations

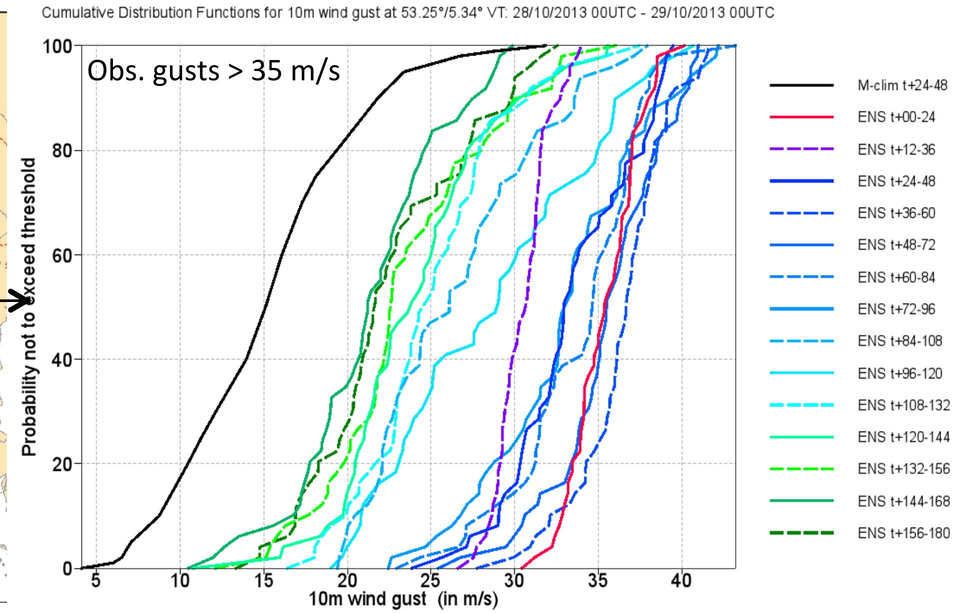




Observed 24-h maximum wind gusts on 28 Oct

# 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 (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) |

# The Model Climate (M-Climate)

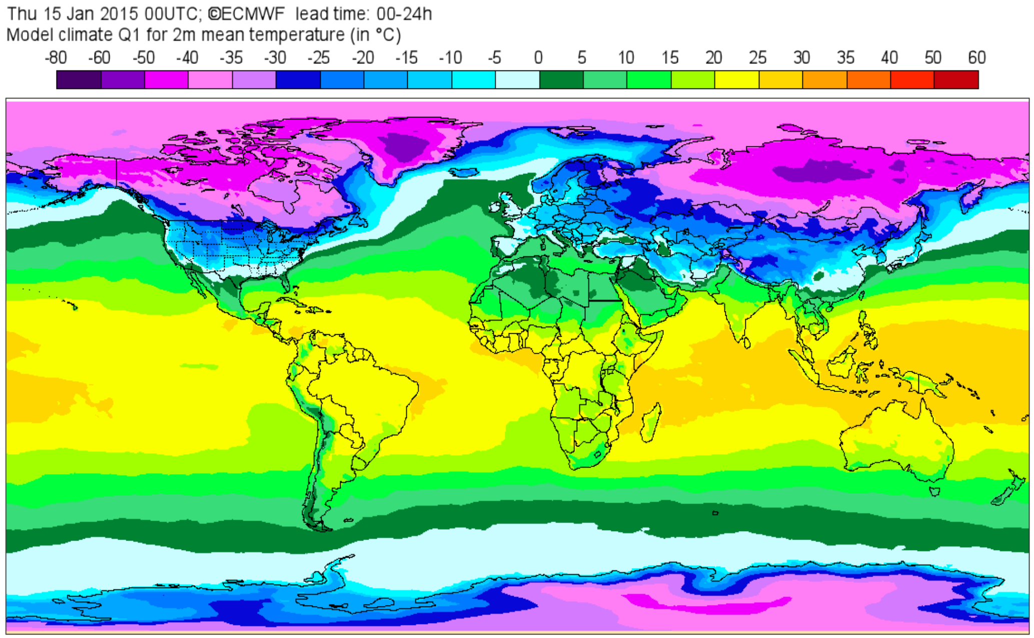
For climate related products like the EFI a reliable model climate is essential.

*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 in use:

- Running an ensemble re-forecast suite with 4 perturbed ensemble members and the Control
- Always for the most recent 20 years with initial conditions taken from the ECMWF global atmospheric reanalysis ERA-Interim
- Currently runs every Thursday (therefore climate files are available only for Thursdays. For days in between Thursdays the closest preceding Thursday's files are taken)
- 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

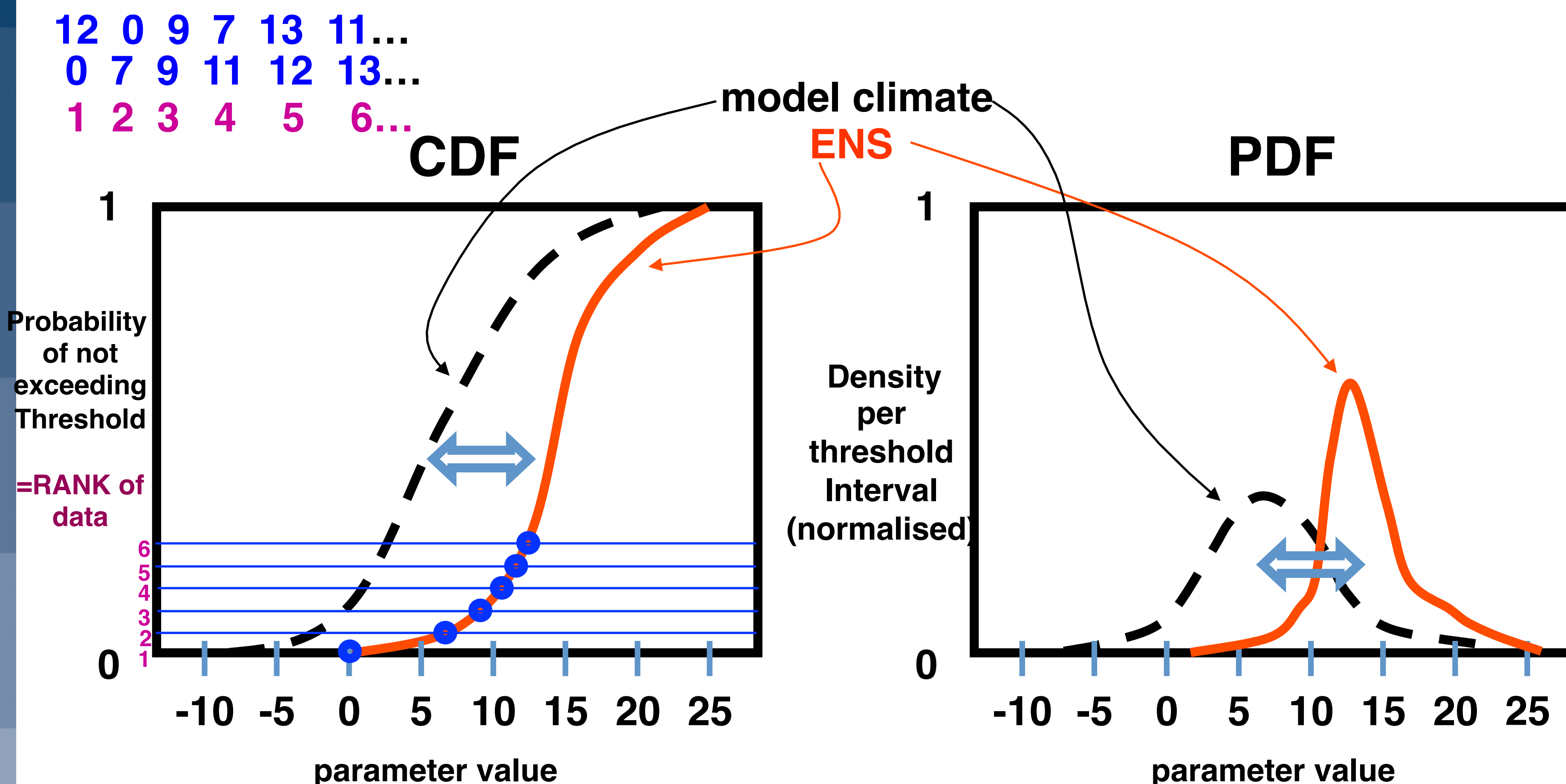
# Model climate (M-climate)



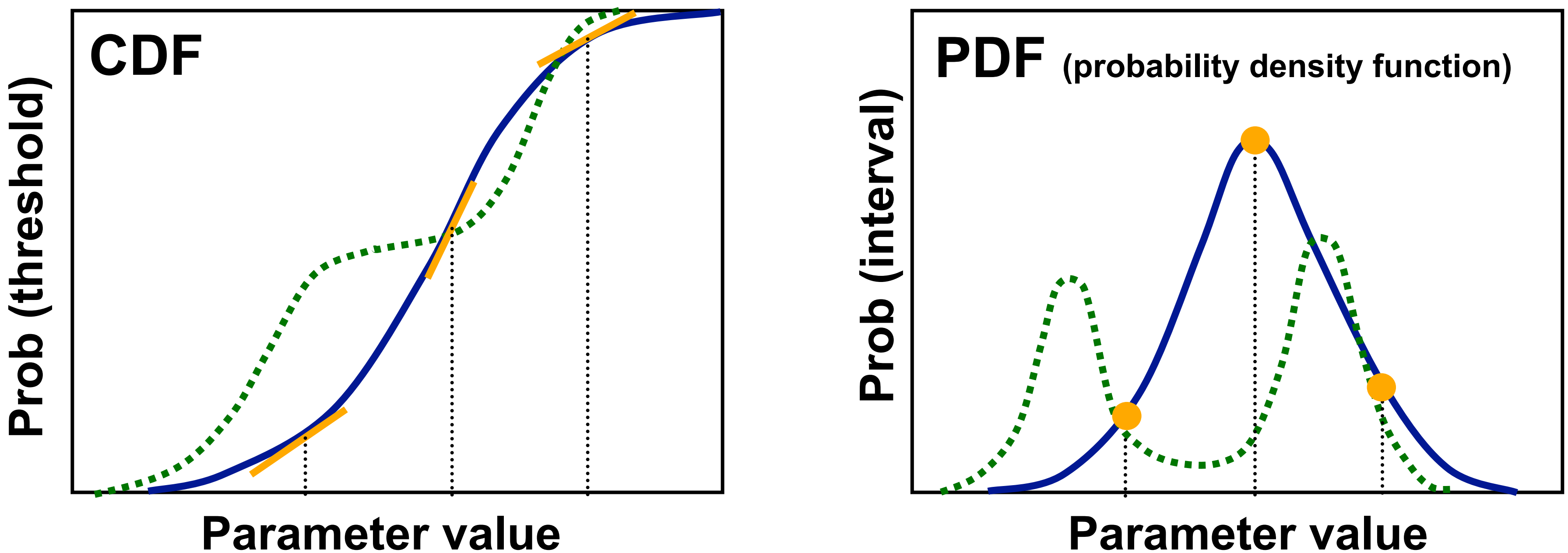

- To provide a robust, less noisy M-Climate, we do not use just one set of re-forecasts, but five sets centred on the week in question (increasing the sample size by a factor of 5)...
- M-climate sample size is: 20 years * 5 ensemble members * 5 weekly runs = 500 re-forecast fields
- As the M-climate 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?

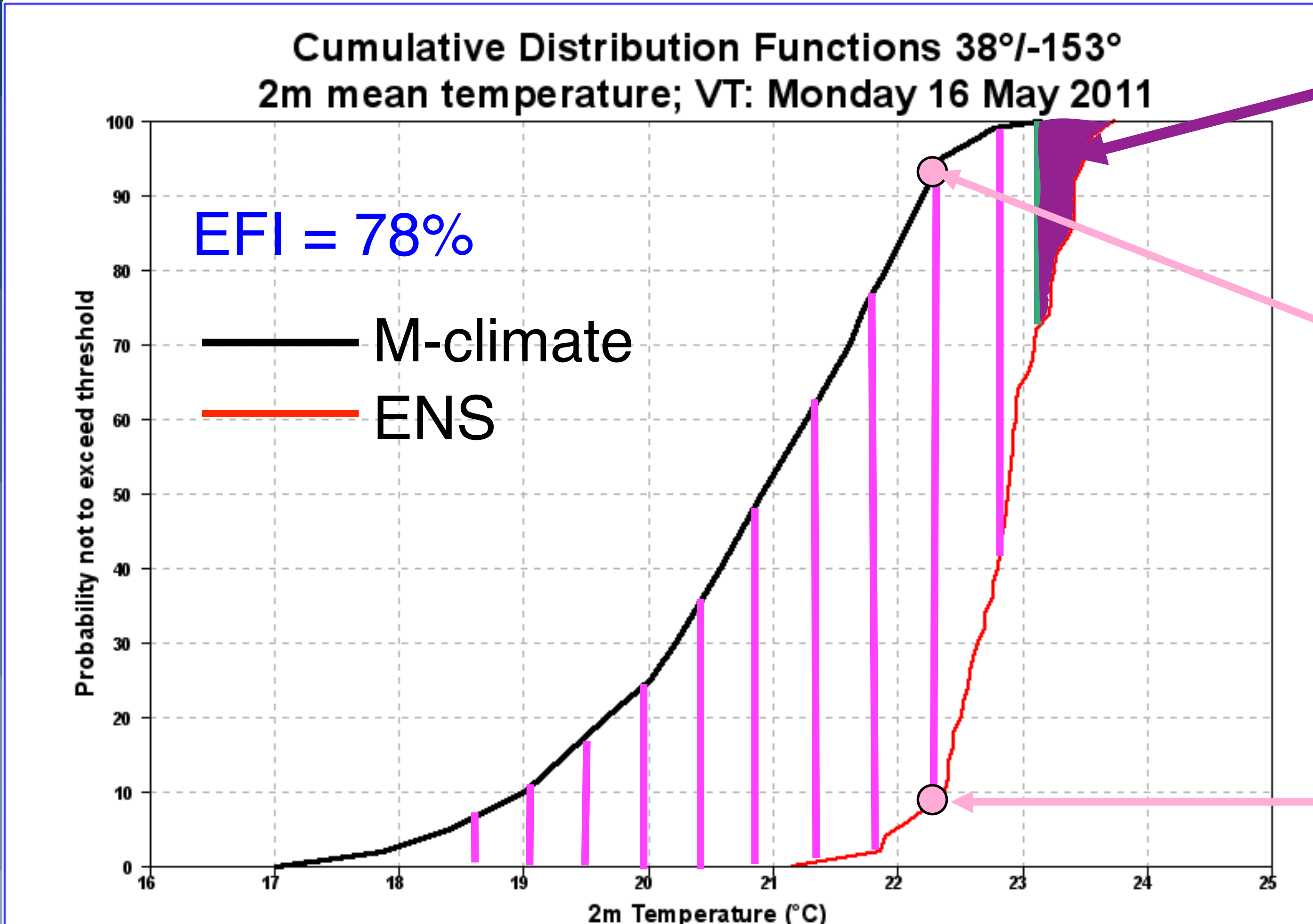



- The PDF (y-axis) value equals the slope of the CDF
- **Steeper** CDF = **narrower** PDF = higher confidence in the forecast
- A step in the CDF means a bimodal PDF

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

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

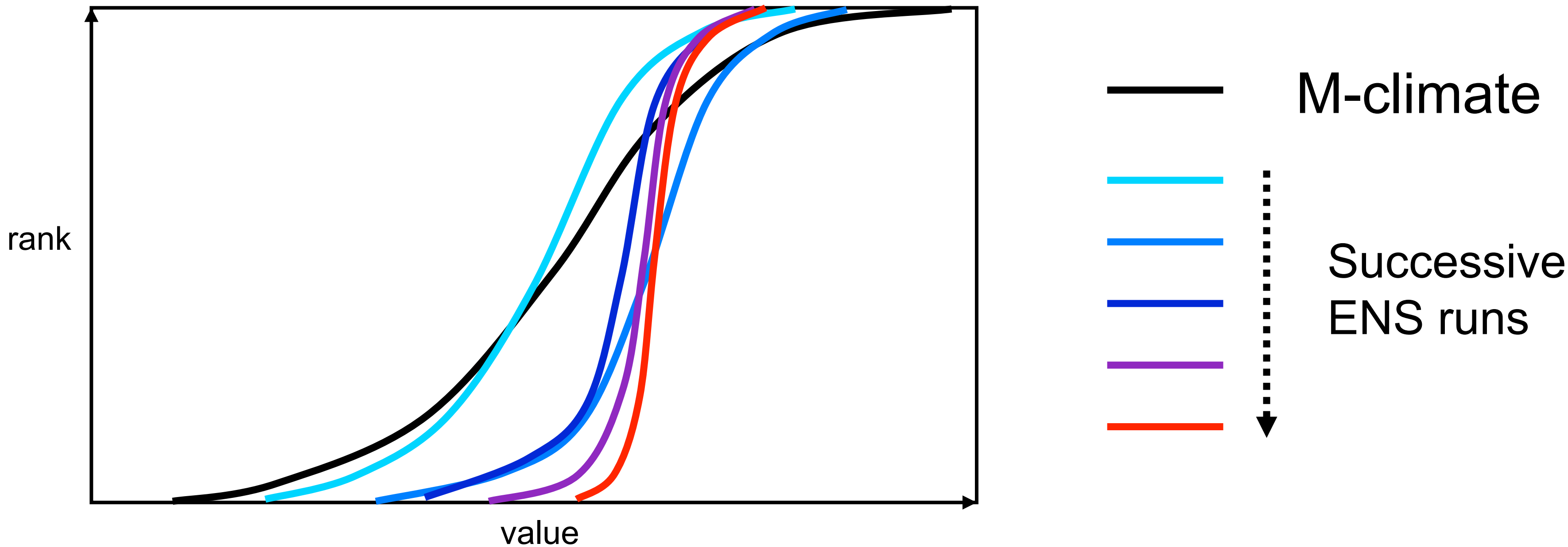
$p$

$-1 \leq EFI \leq 1$

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

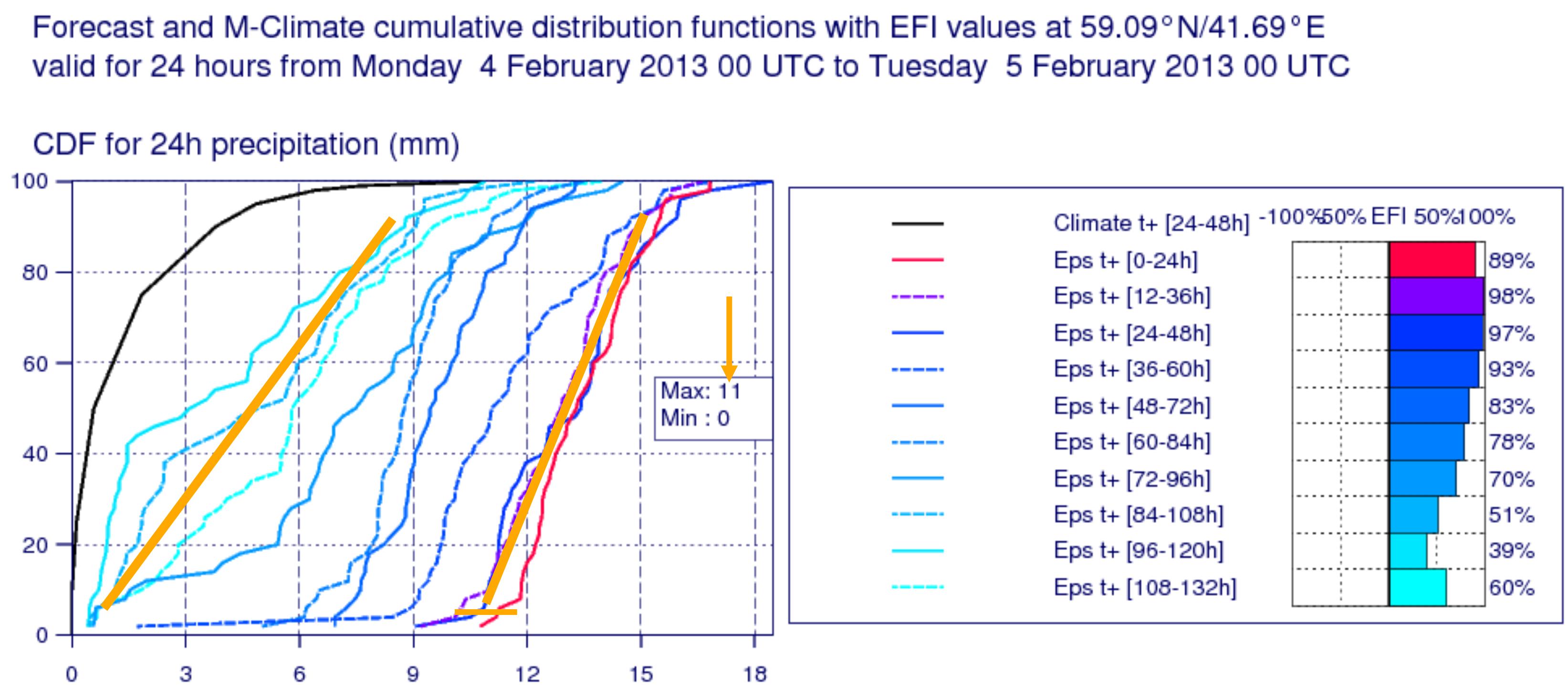
$F_f(p)$

# How ‘should’ CDFs behave in successive ENS runs?



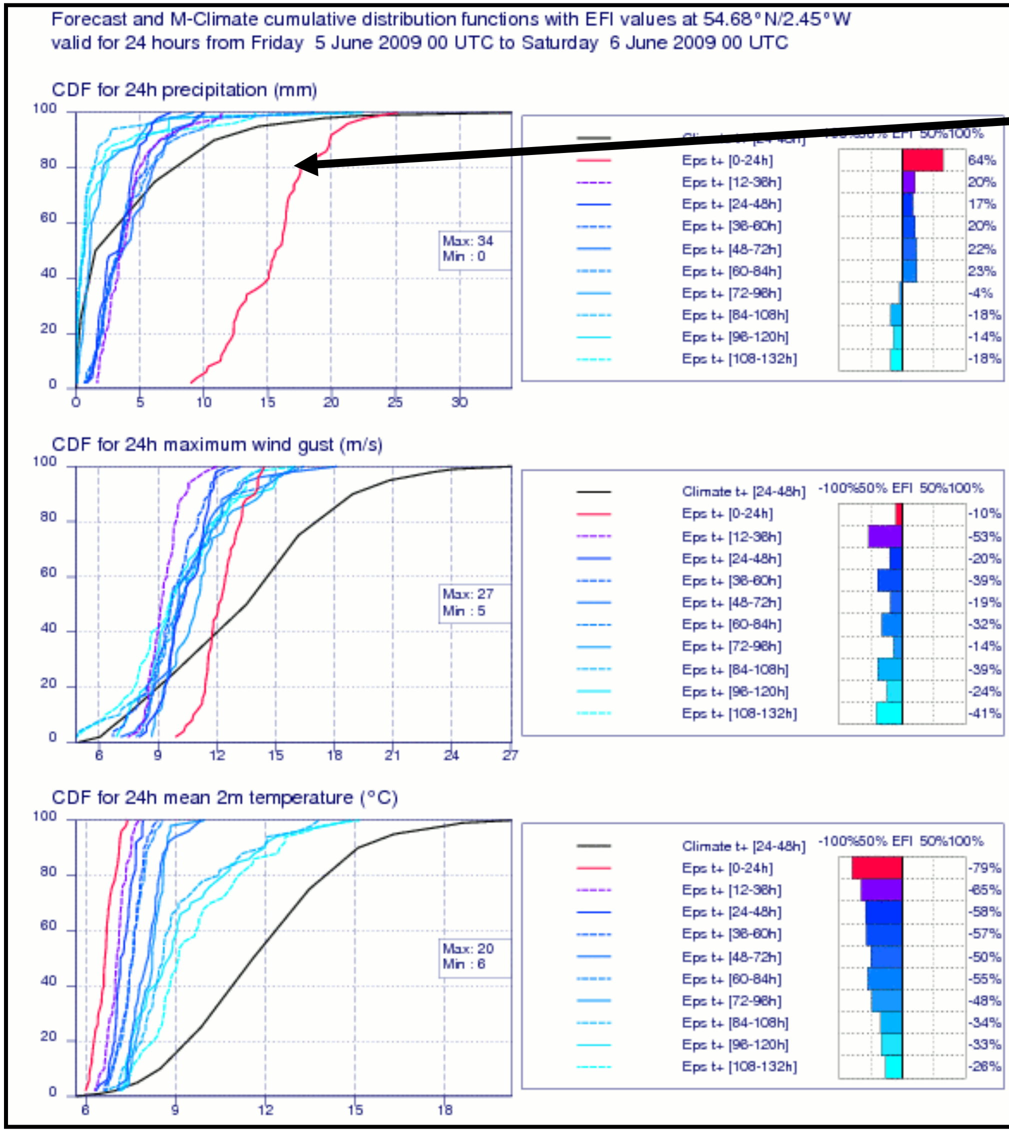

- At long lead times forecast CDF may be similar to the M-climate.
- Lateral variations in CDF position between successive runs should, mostly, become less (with time).
- CDF will tend to become steeper (with time), implying higher confidence.

# An example




- 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

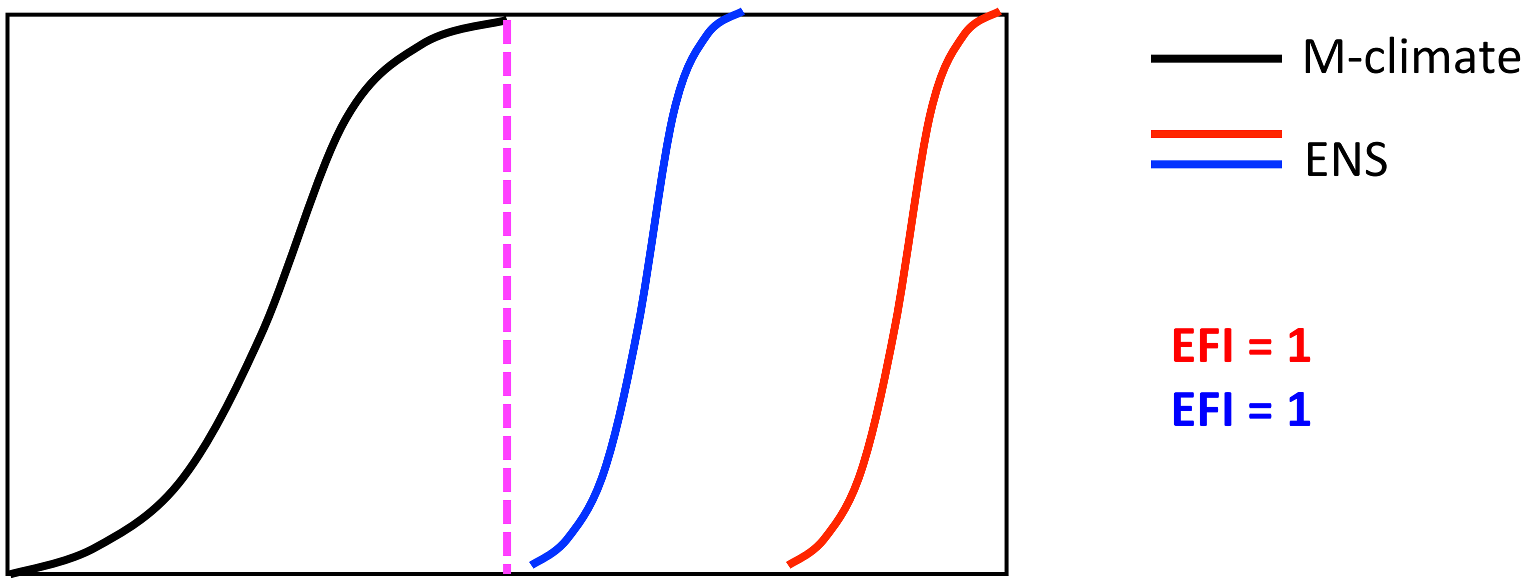



- N England rain – June' 09 - low prob alternative became likely at short range.

# Some limitations

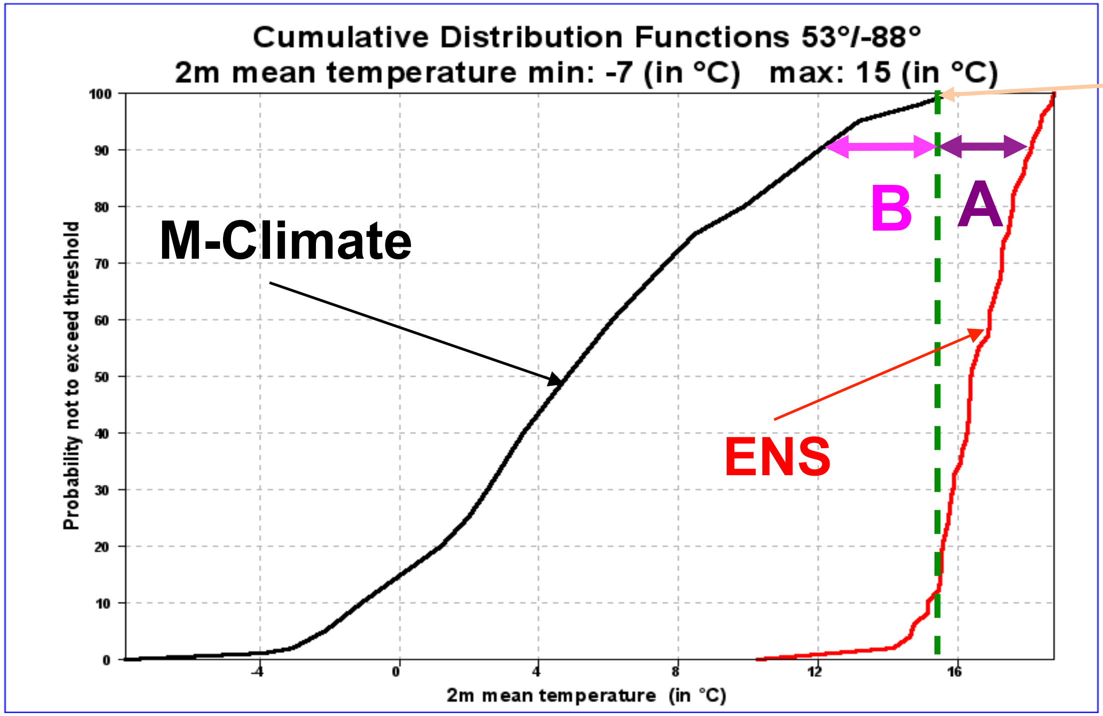
- **Extreme does not *necessarily* mean high impact (eg 2mm rain in the desert)**
- **Past history also important but not directly accounted for (eg heavy rain when ground saturated)**
- **Windstorm impact can depend on whether trees are in leaf, whether ground is saturated…**
- **Products are only as 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 introduced since 19 June 2012 to complement EFI by providing information about how extreme an extreme event might be.

# Shift Of Tails (SOT)

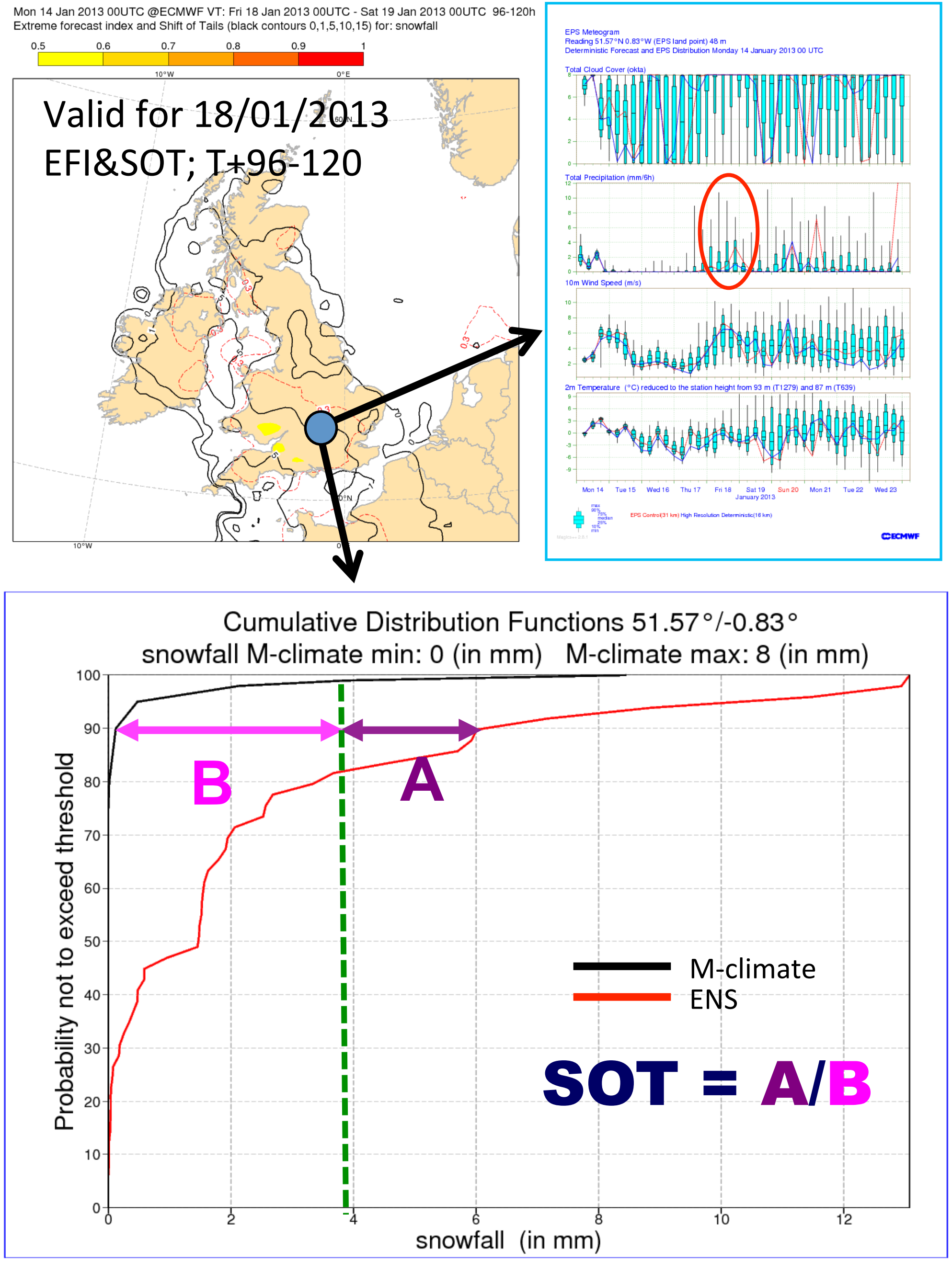



**SOT = A/B**

**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**



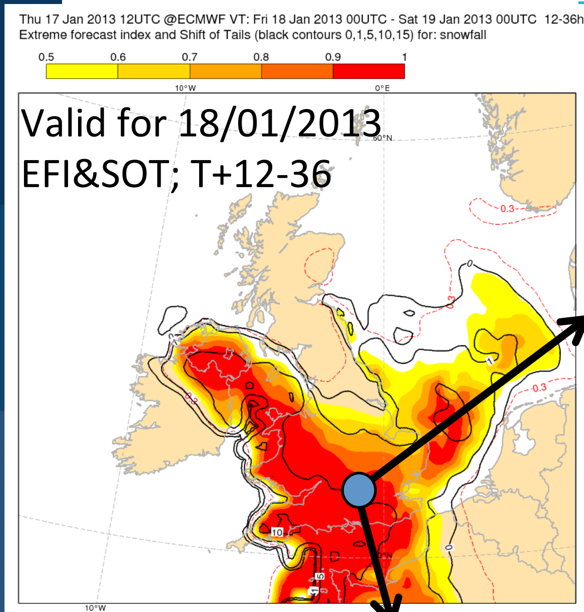

- SOT > 0 → at least 10% of the ensemble members are above the 99th percentile M-climate
- The higher the SOT value is, the further this top 10% of the ensemble forecast is beyond Q99 of the M-climate.

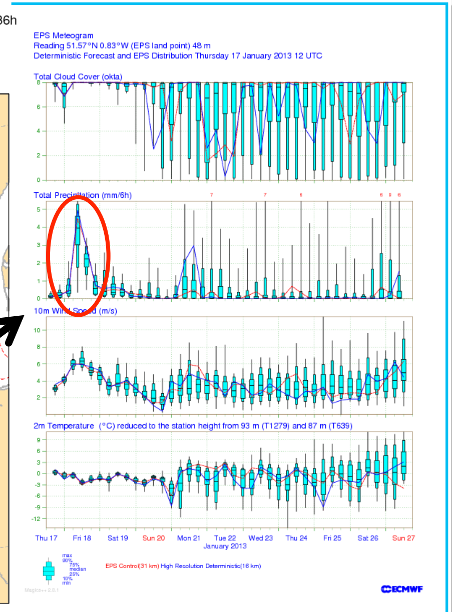
In the example (Reading):

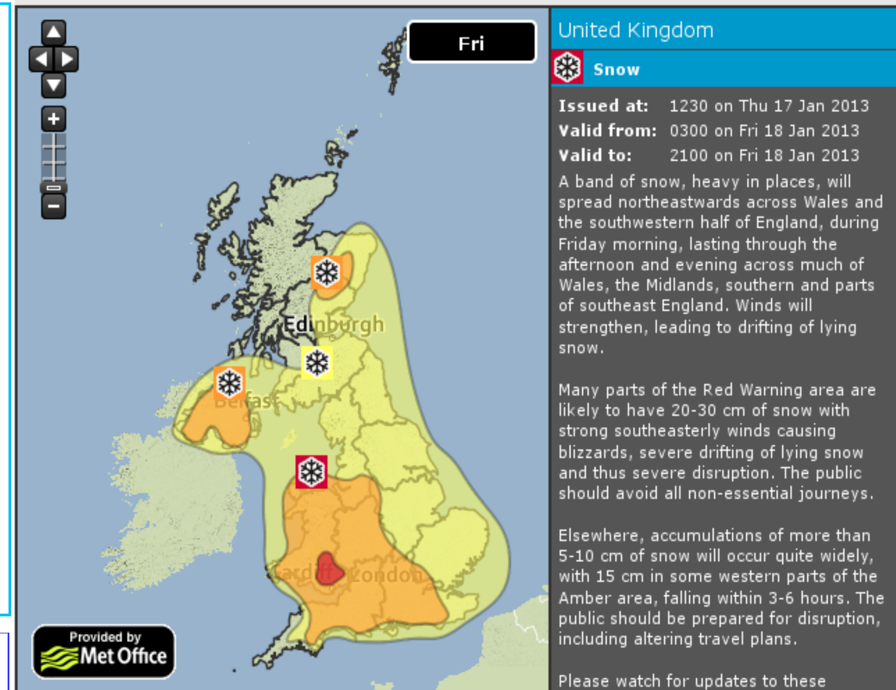
- ✓ EFI = 0.36
- ✓ SOT = 0.8

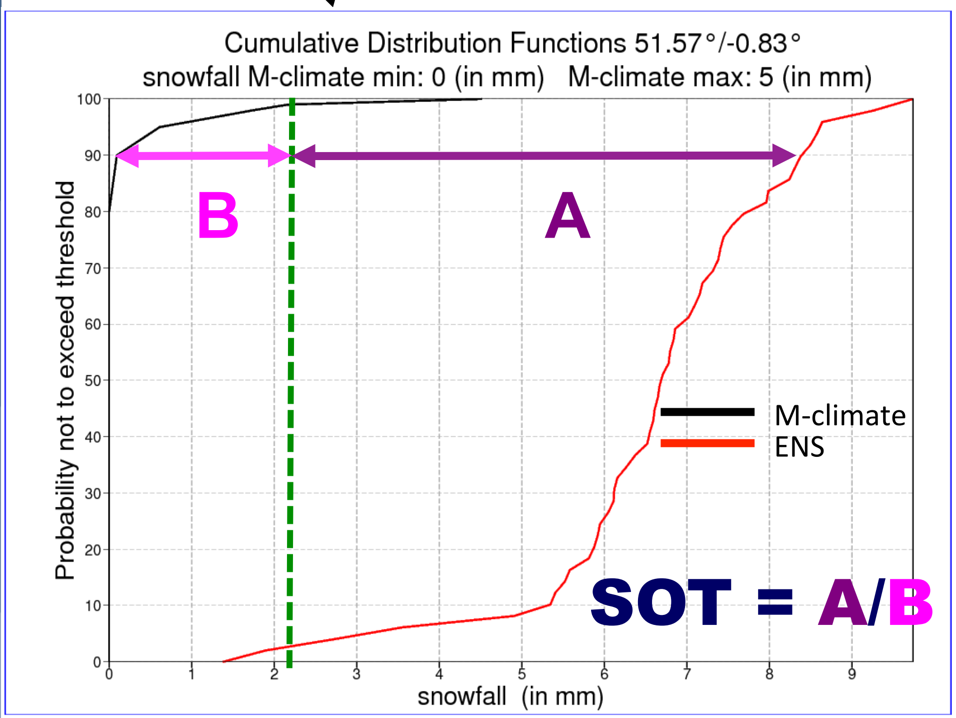
EFI positive → forecast suggests some snow

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




Reading:

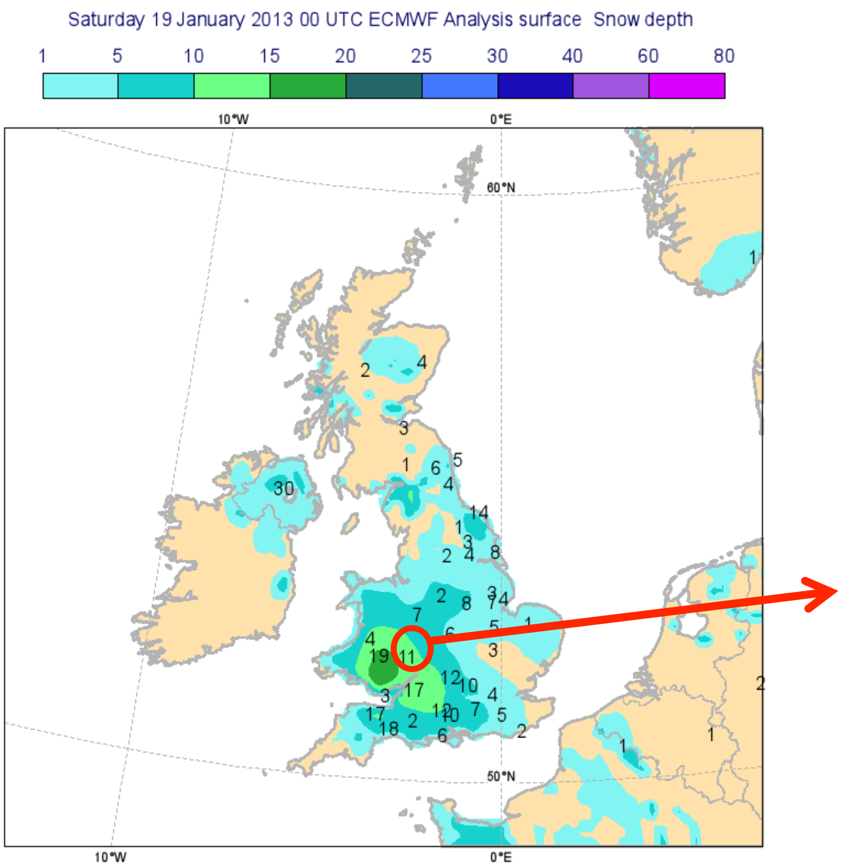
- EFI = 0.96
- SOT = 3.5

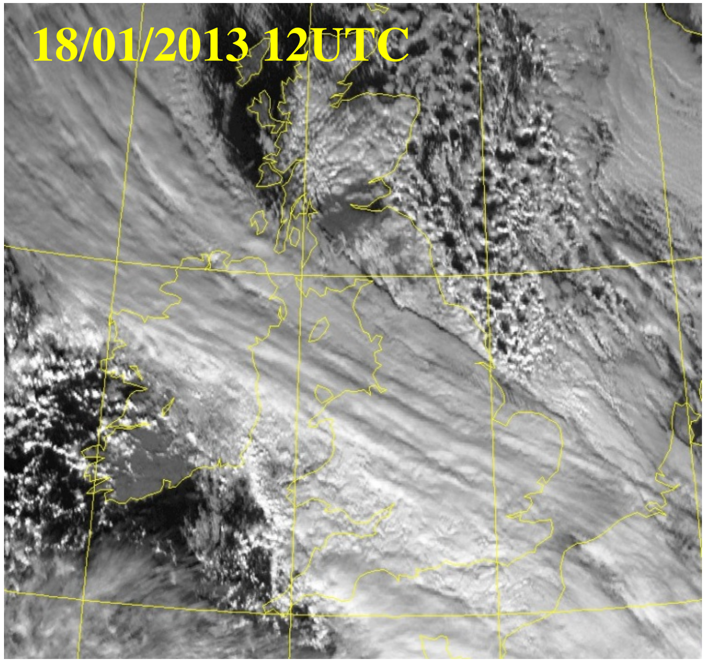
✓ High values of the EFI imply high confidence that extreme snowfall may happen.

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

# 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

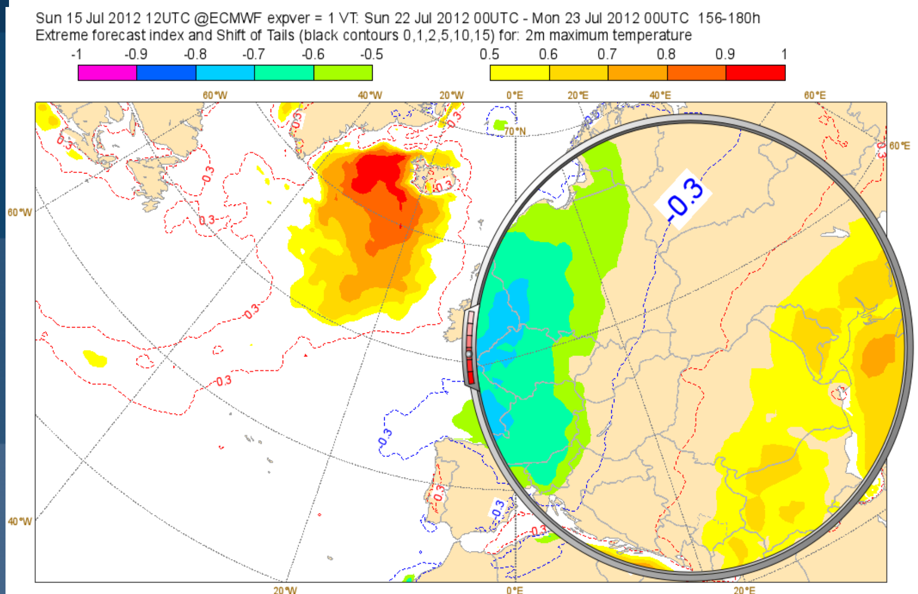


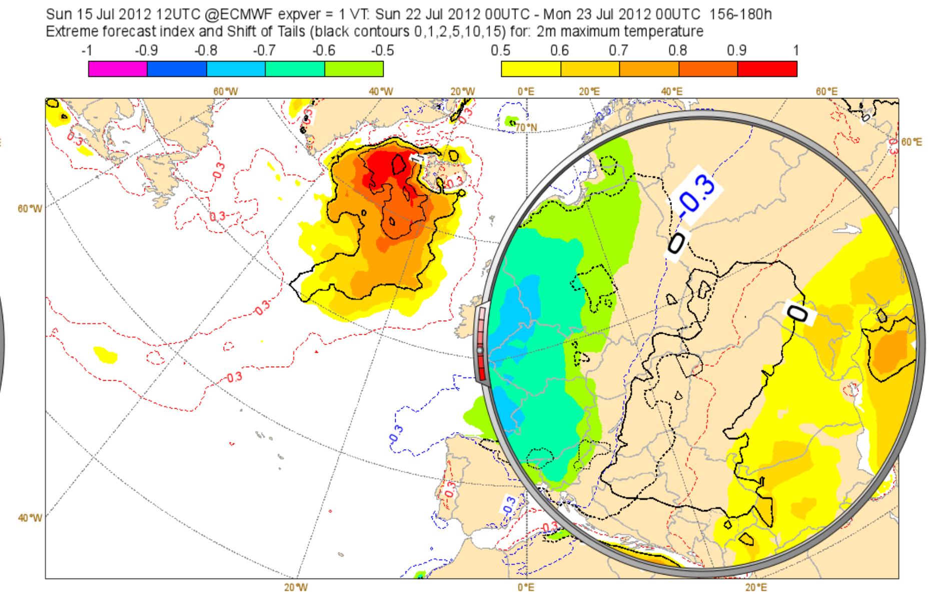





A beer garden in Bromsgrove. Credit: Sue Eden

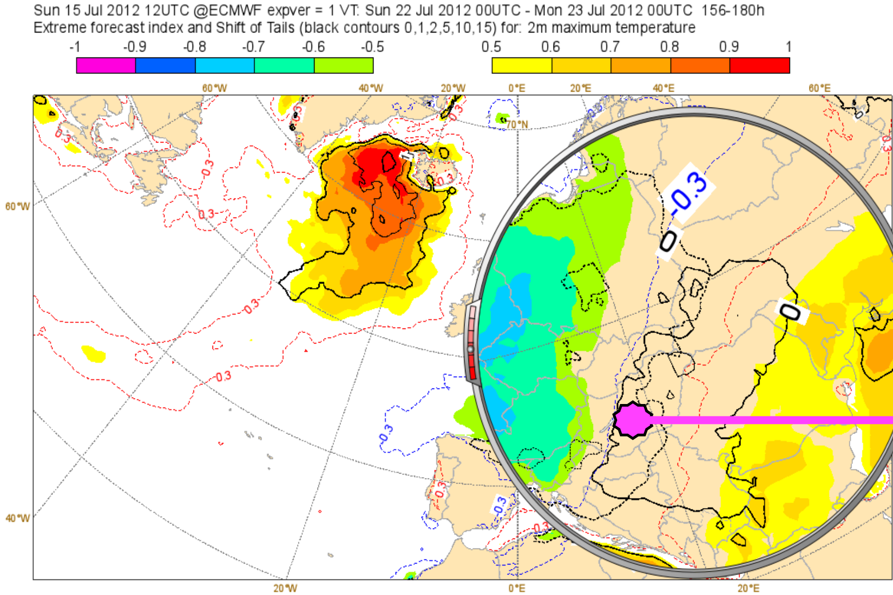
# A case of large uncertainty

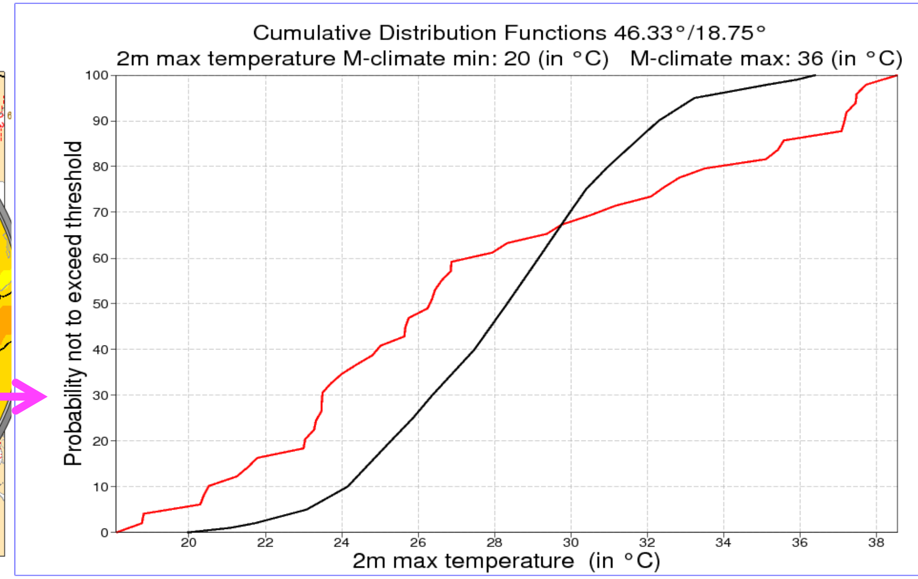


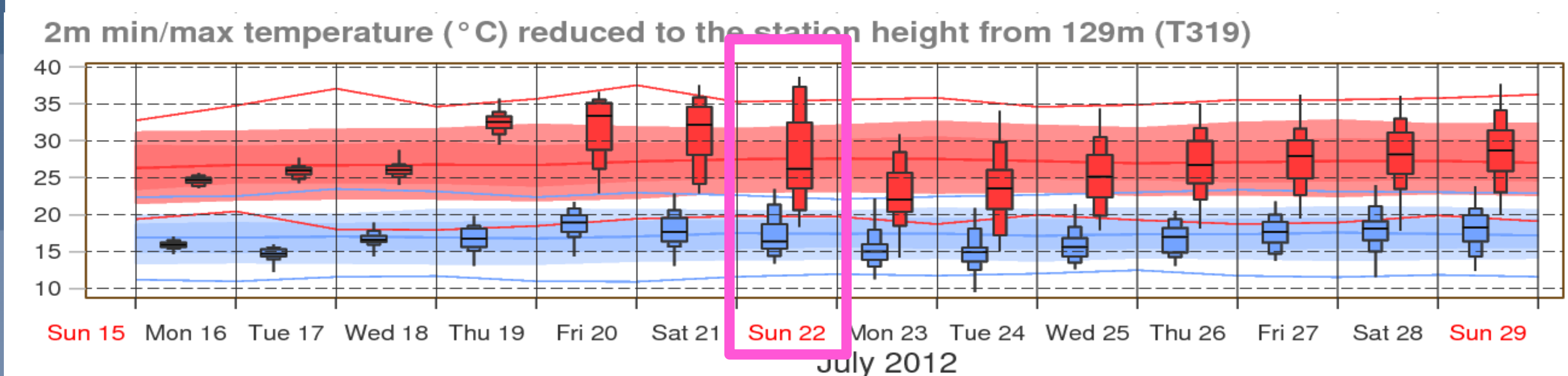




- EFI forecast shows cold conditions over Central Europe and hot weather to the east over the Balkans.
- SOT gives additional information. In the area between the cold and hot weather SOTs overlap. This is a signal of very uncertain forecast – over that area extremely low and extremely high temperatures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

# A case of large uncertainty



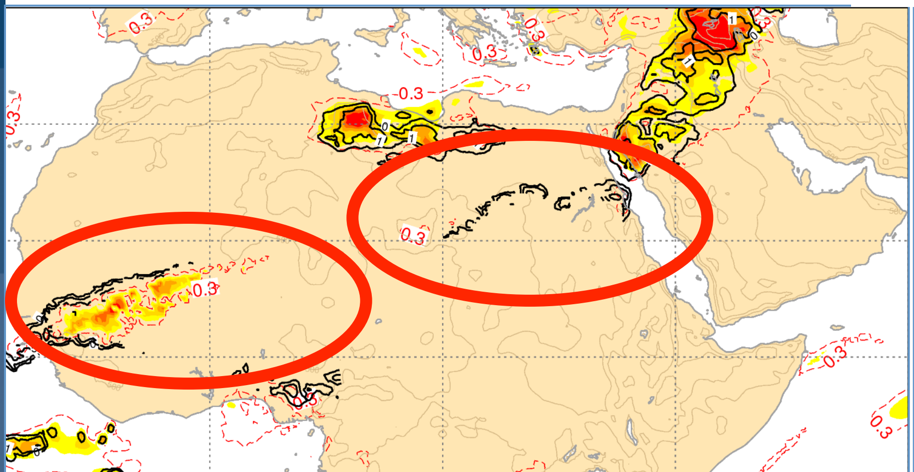



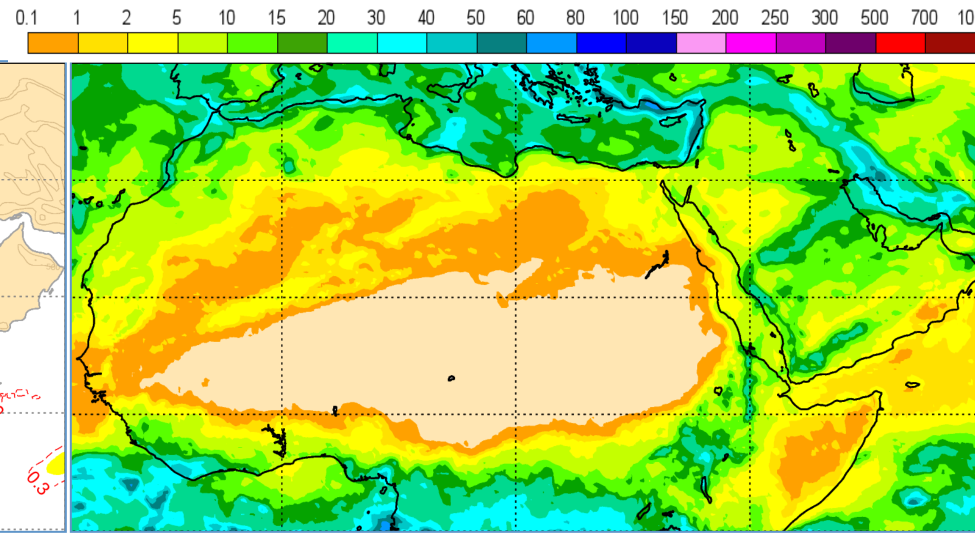

Some ENS members predict maximum temperature below the M-climate minimum, but some – above the M-climate maximum!

# Some limitations

**EFI &SOT for 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 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)

* 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

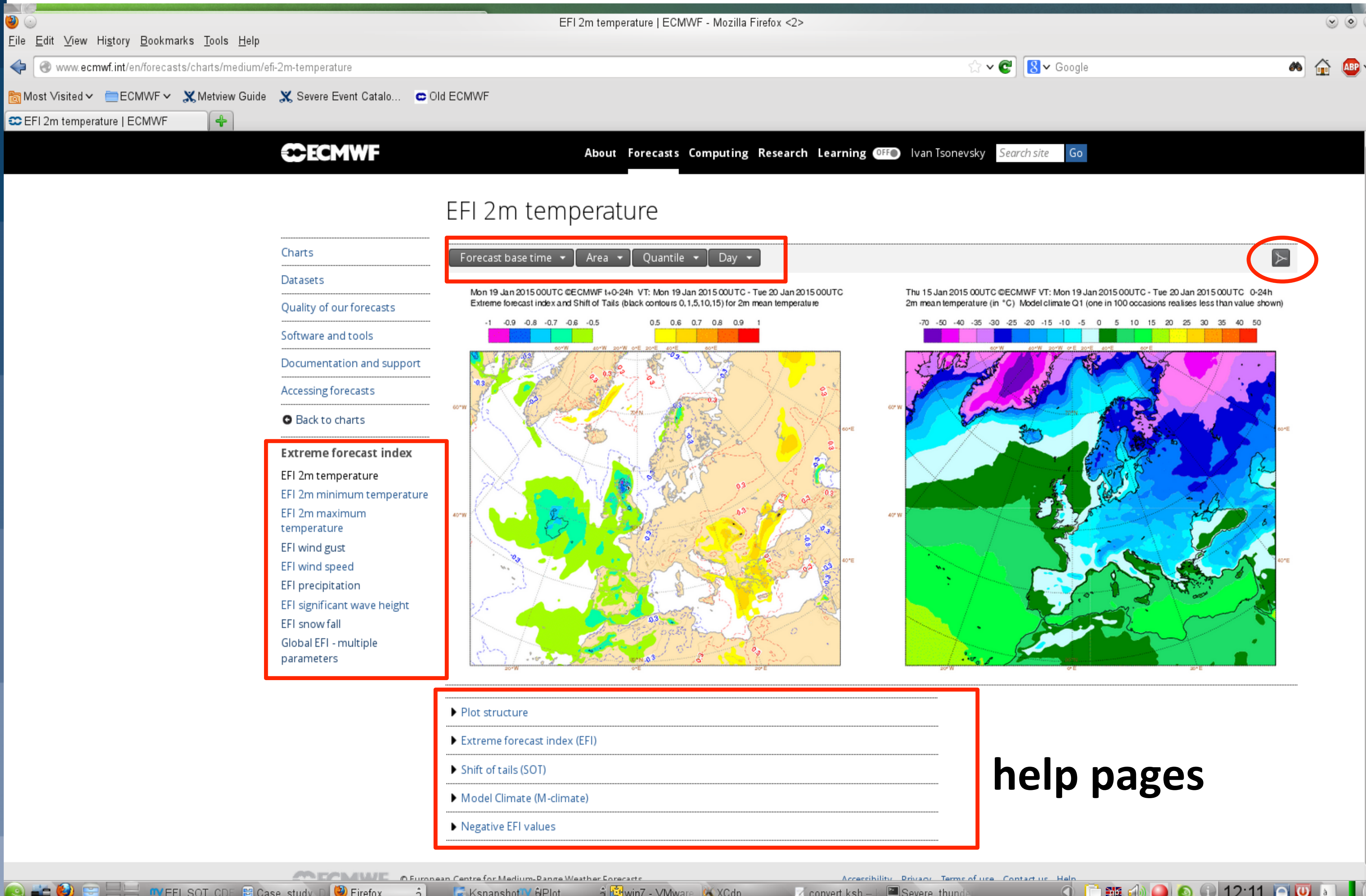
## 120h interval: parameters 2ti, tpi, 10swi

- 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

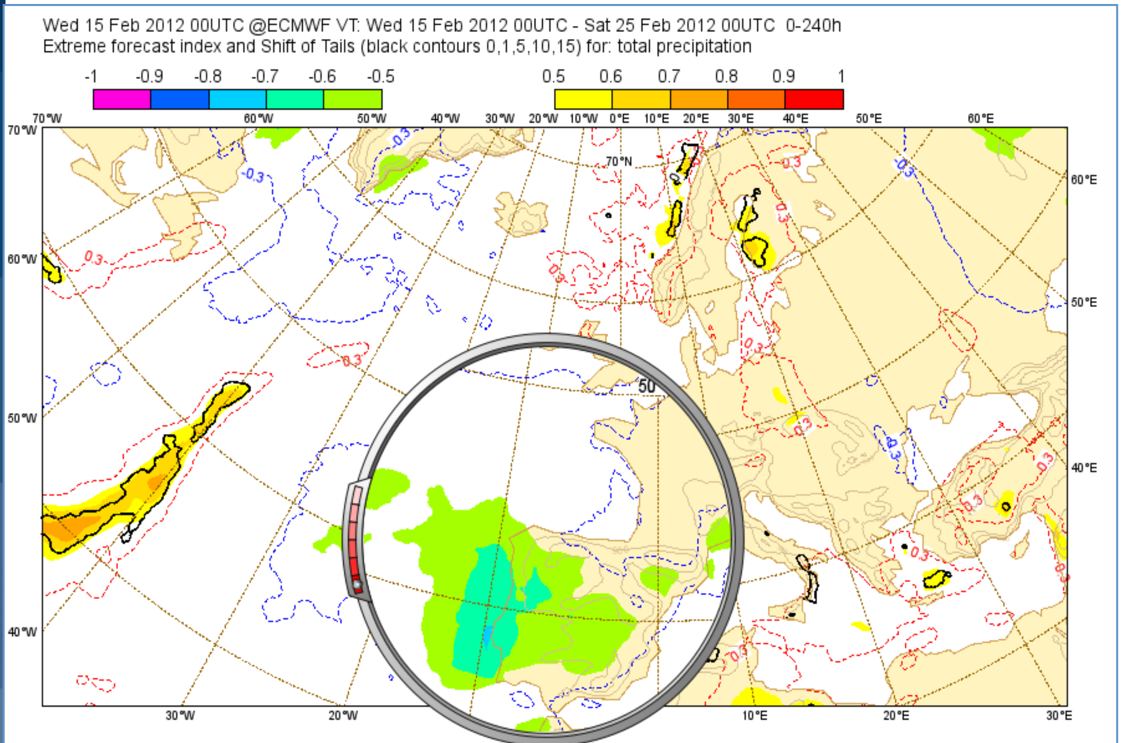
## 240h interval: parameters 2ti, tpi, 10swi

- 00UTC: 000-240 (only for tpi before)
- 12UTC: 000-240 (only for tpi before)

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



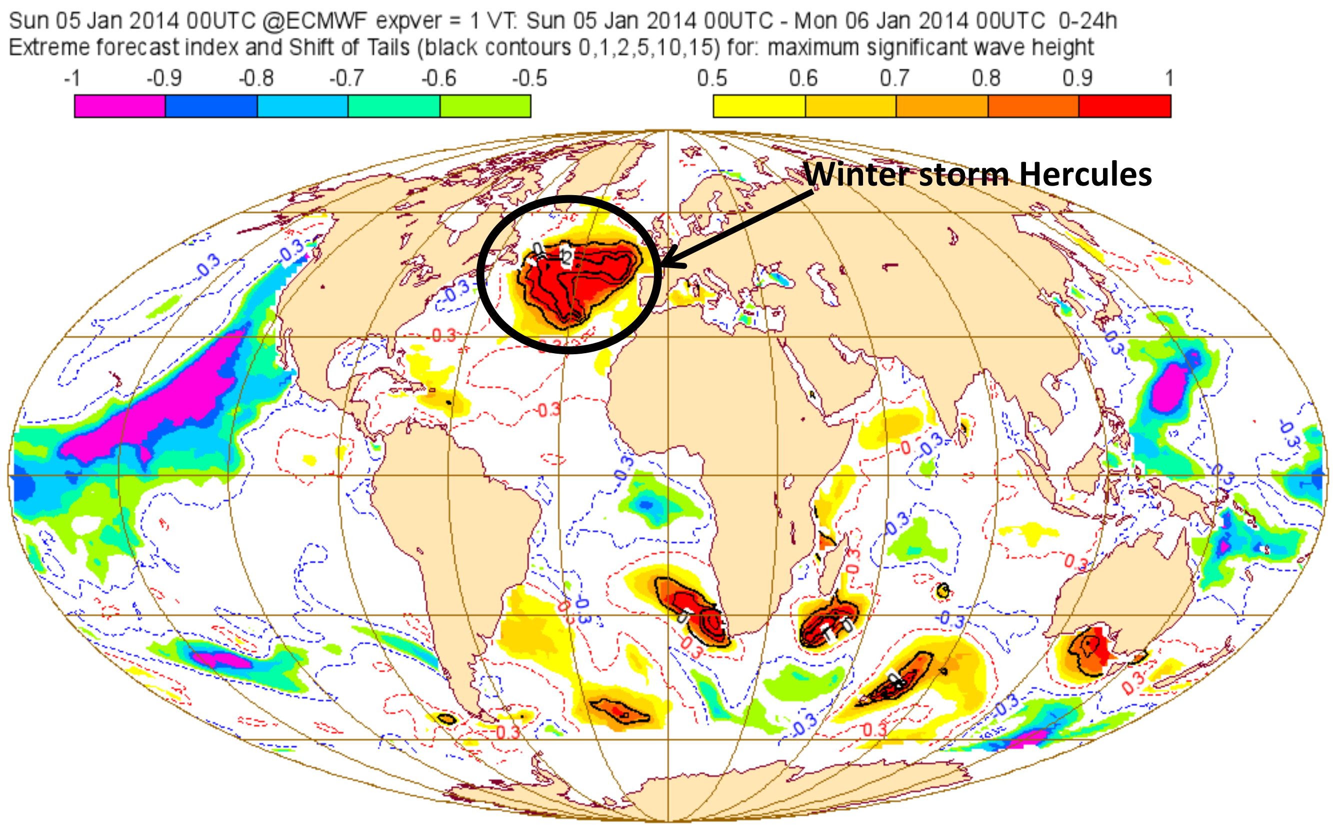
# Negative EFI for precipitation




**Severe drought in Portugal**

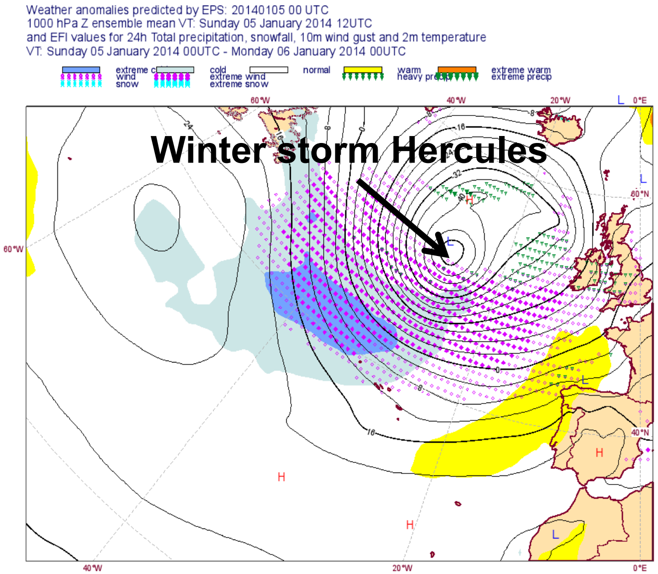
- For 24-hour accumulations negative EFI for precipitation does not make sense because precipitation is bounded by 0.
- For accumulations over longer periods negative EFI does make sense. It shows the risk of dry weather.

# EFI for waves

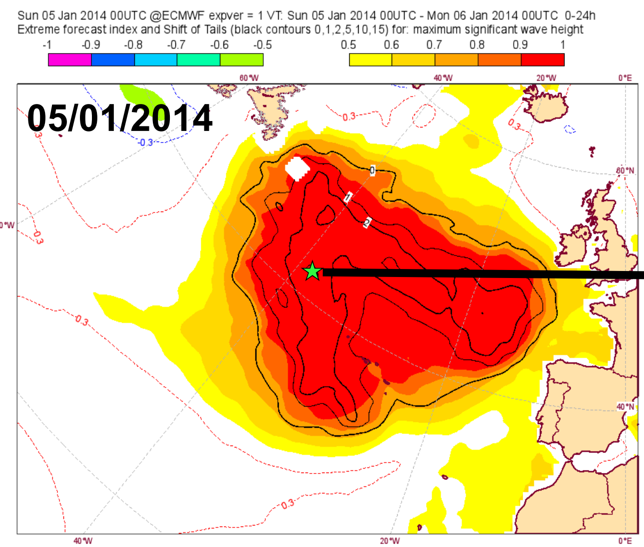


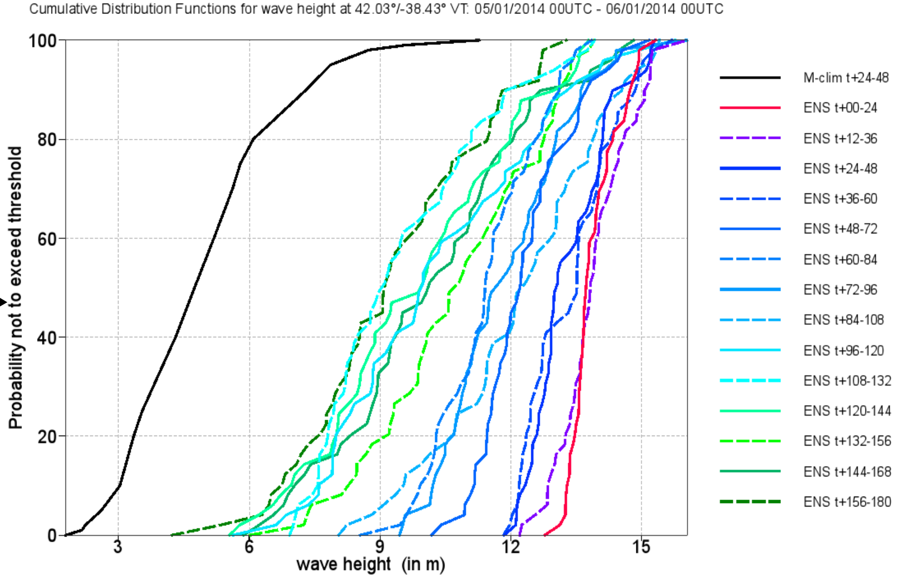

- Negative EFI (calm sea) also plotted on the web.
- The winter storm Hercules generated waves up to 20 m in height on 5 and 6 January 2014.

# Historic swell – Storm Hercules

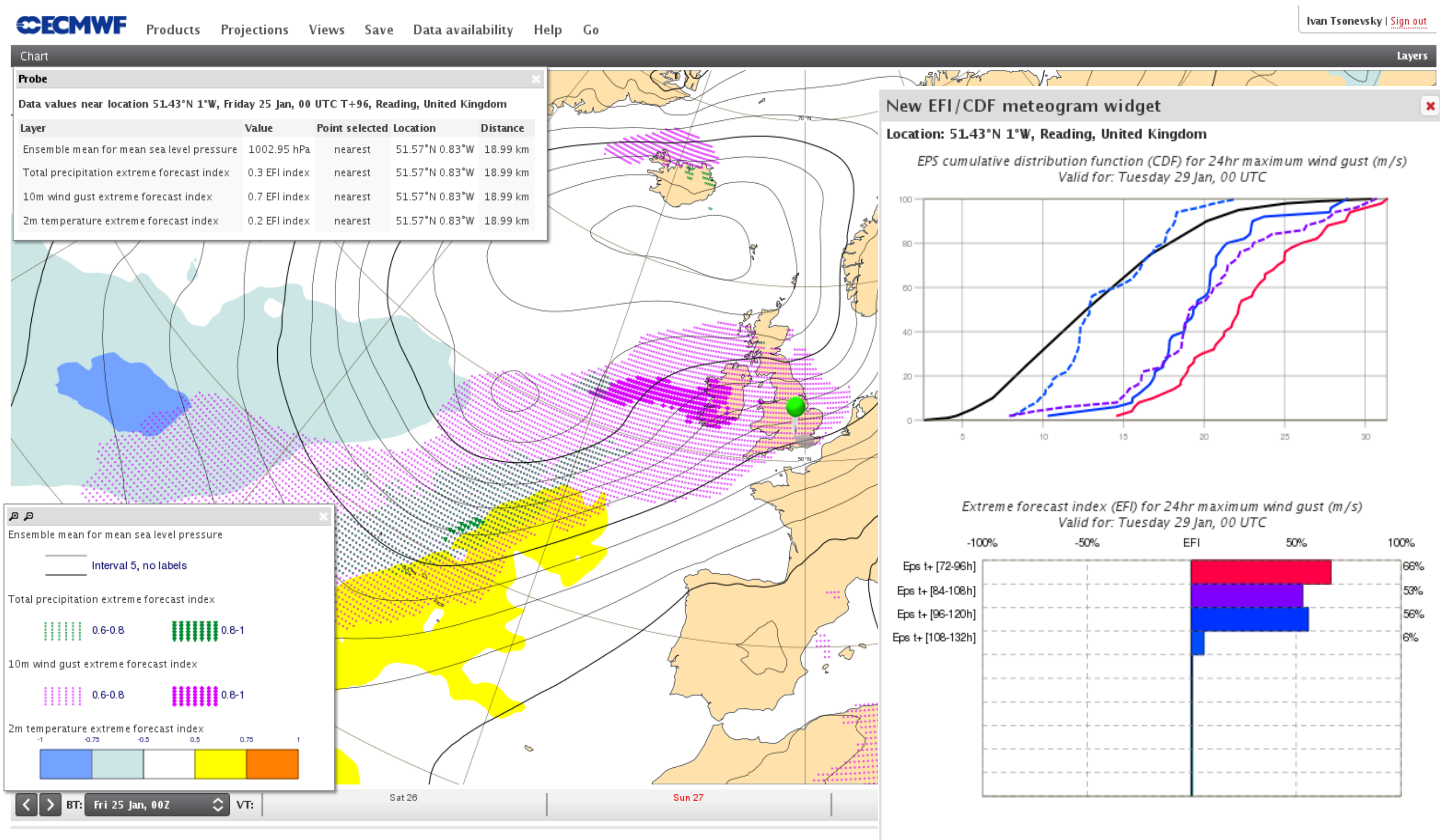




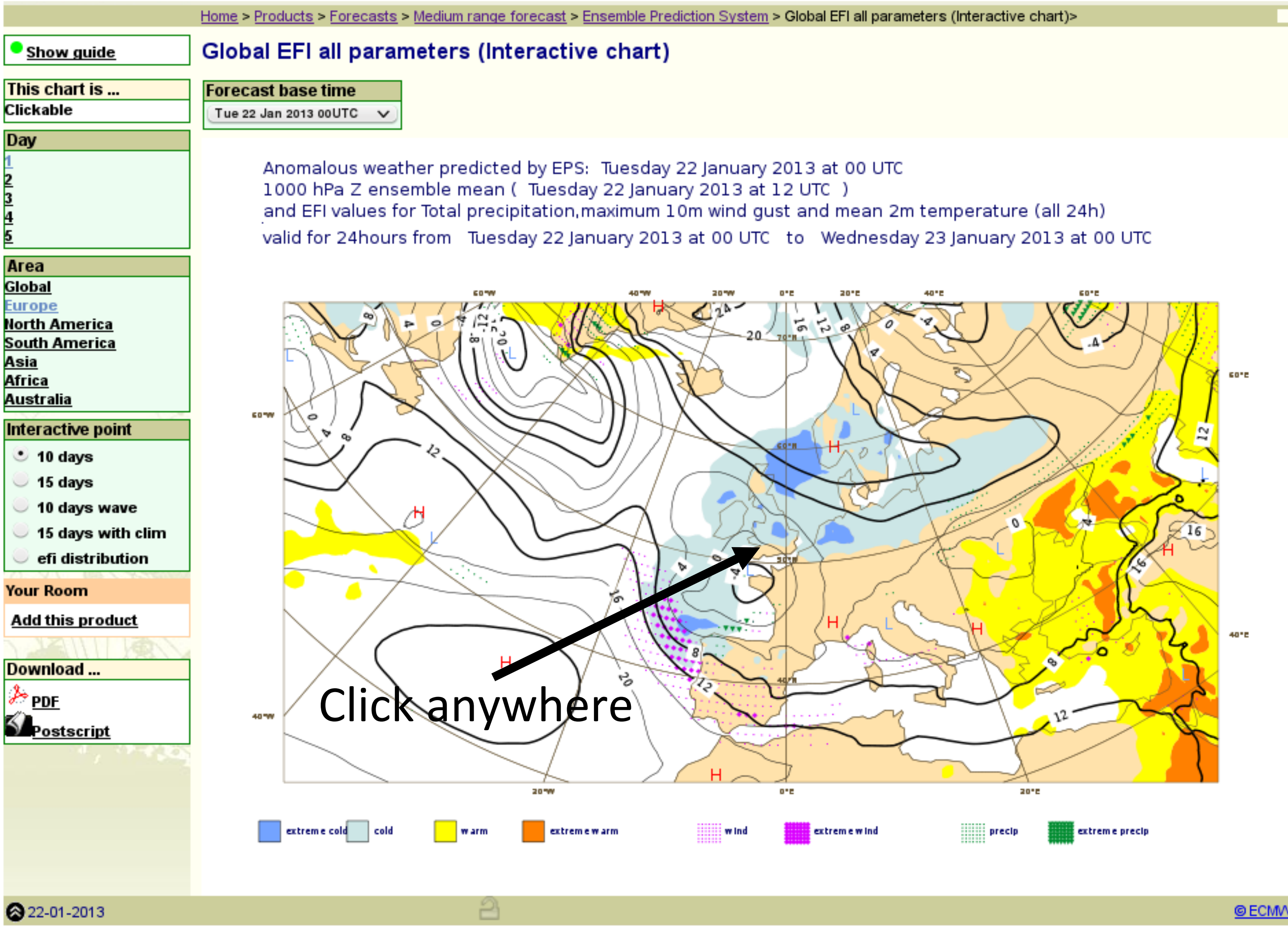


# EFI on the ecCharts



# "Anomalous weather" map (old web)



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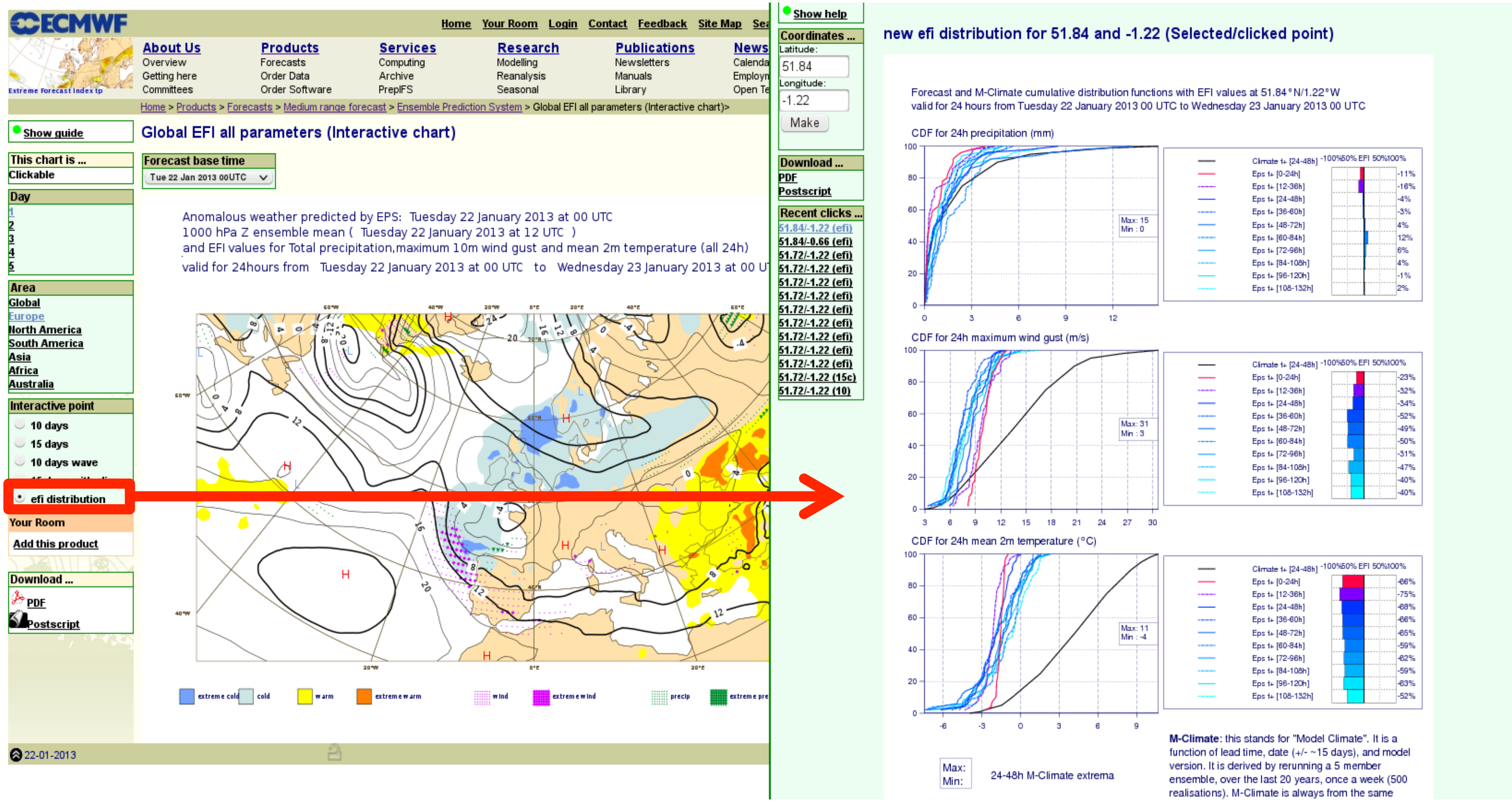
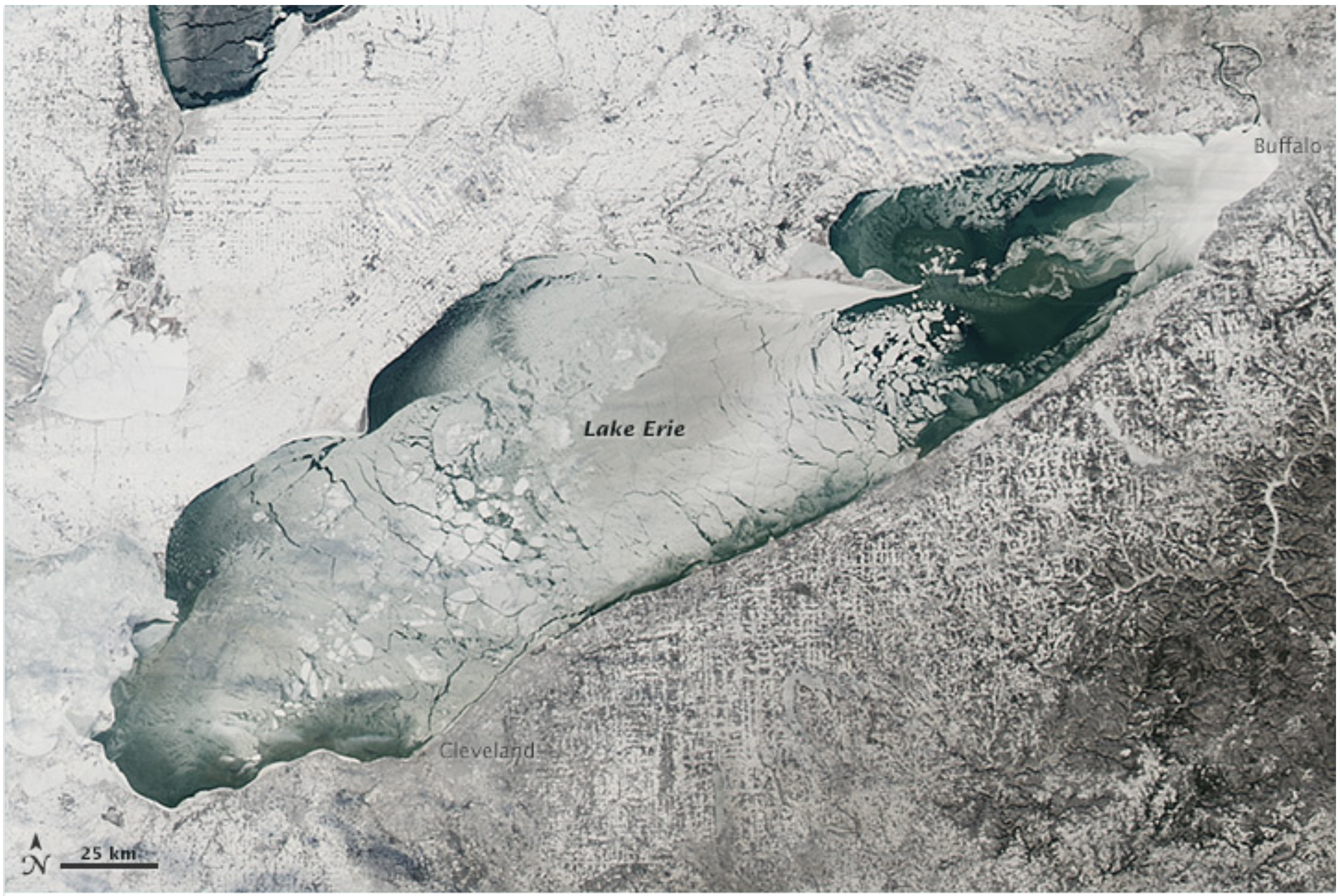
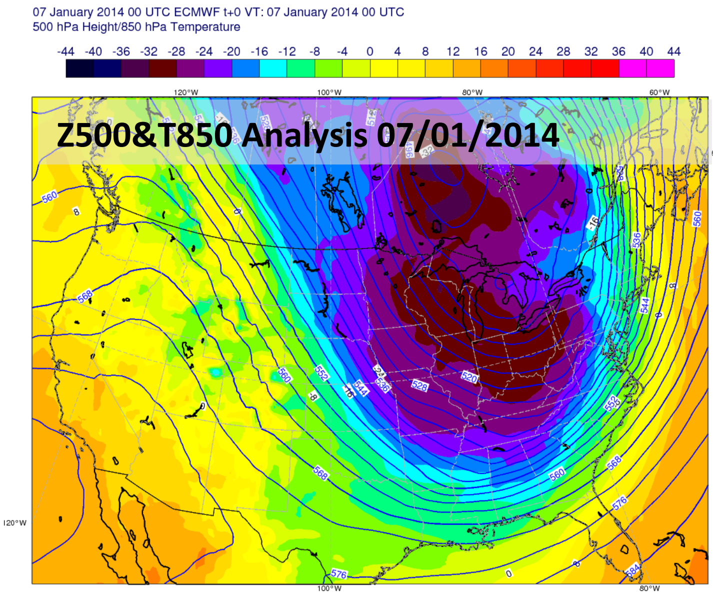


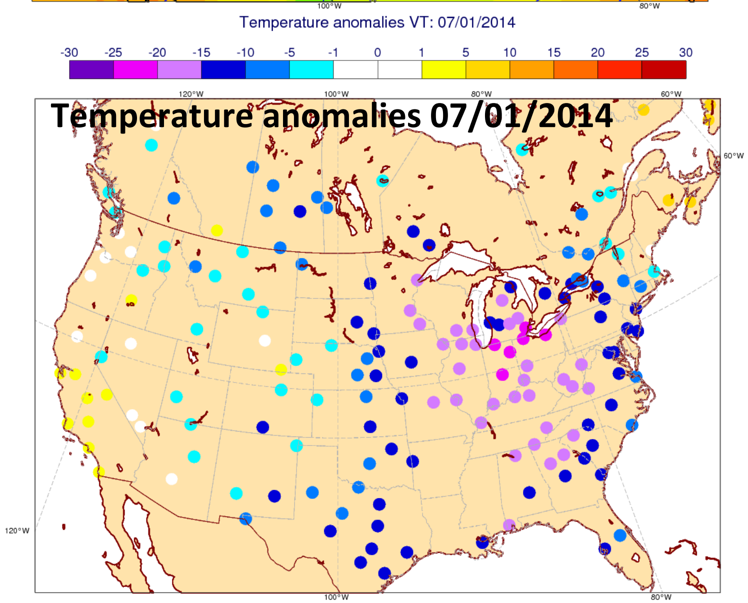
# US cold snap January 2014




Great Lakes frozen

# US cold snap, January 2014

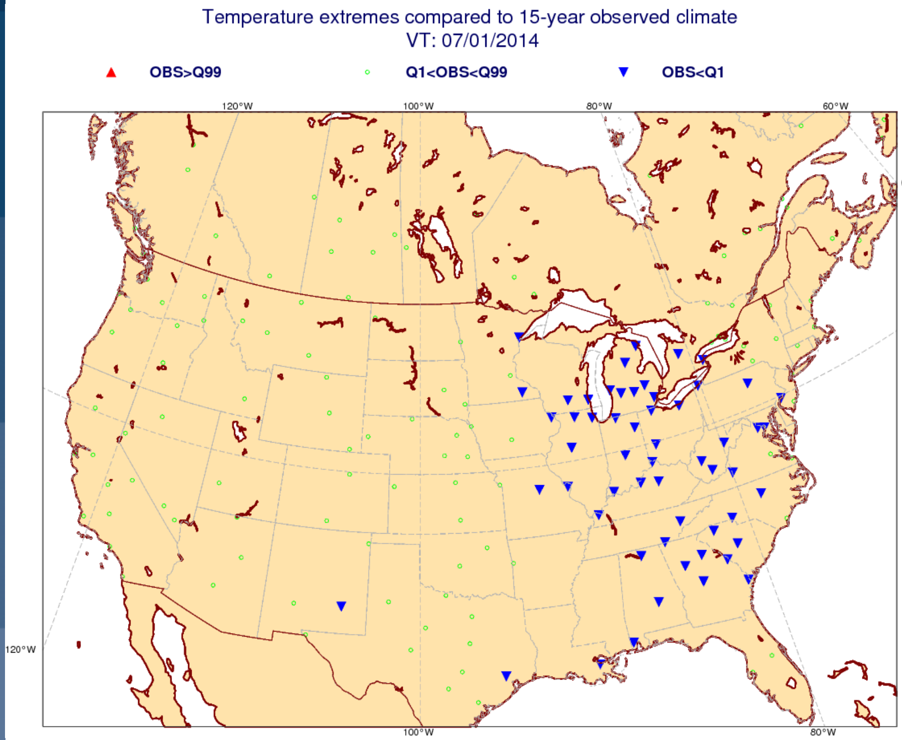


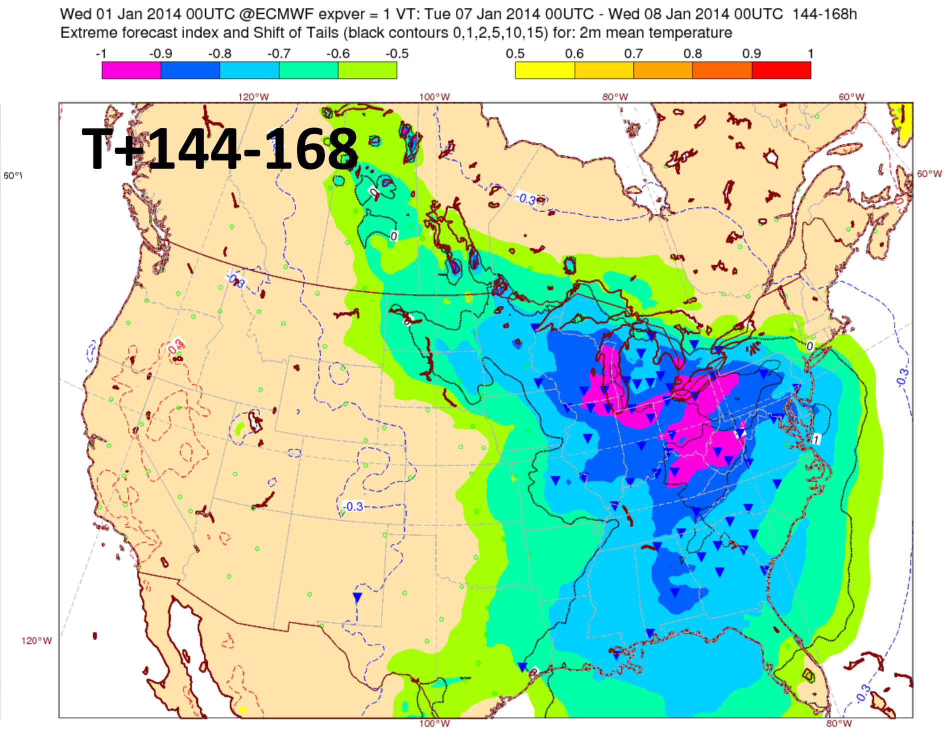





- An extremely cold airmass from the Arctic region dropped the temperatures in the US January 5-7, 2014.
- Record freezing temperatures (15 to 22C below normal) brought many cities to a standstill. Over a dozen deaths were attributed to the cold wave.
- It was the coldest weather since early February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

# US cold snap, January 2014

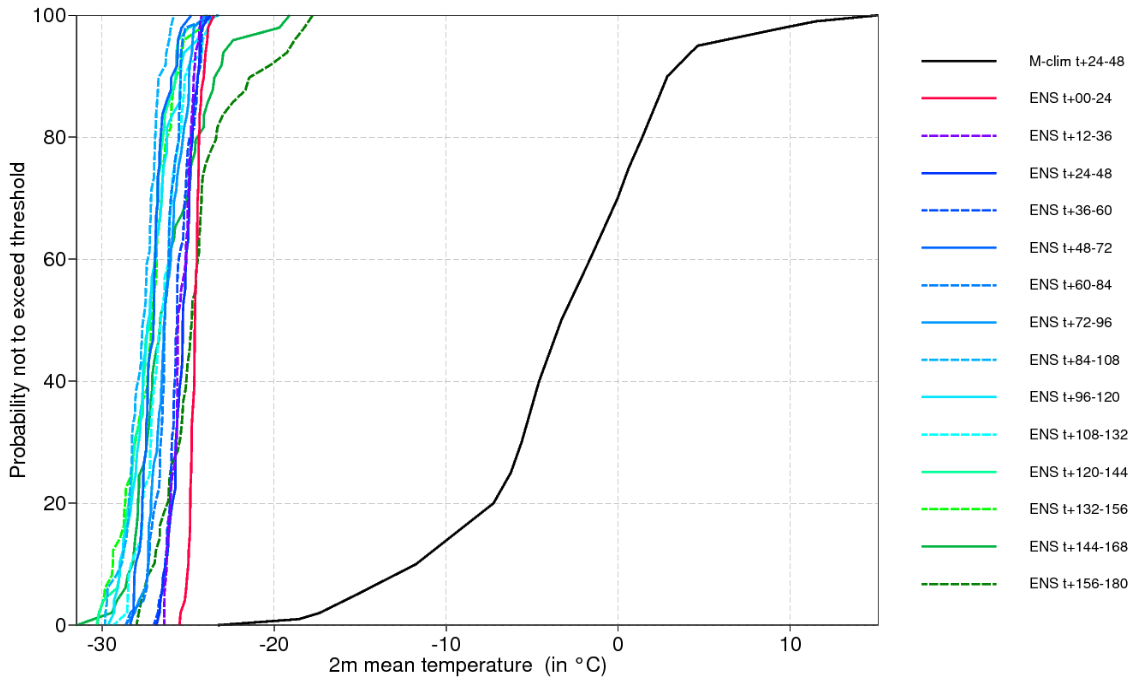


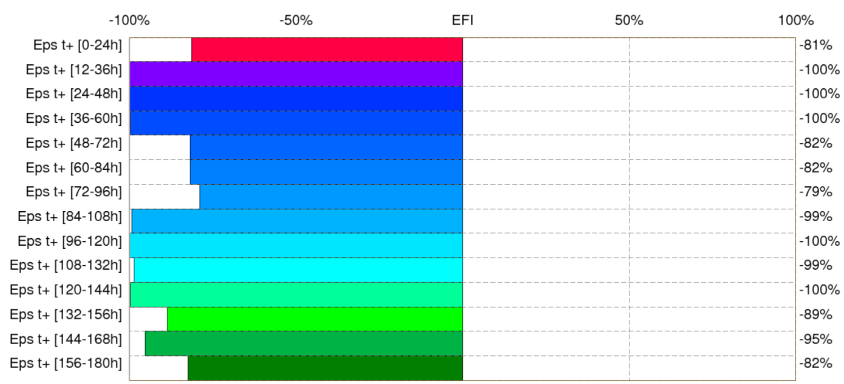

- Blue triangles denote extremely low temperatures below 1st percentile of the 15-year climatology from observations.
- Positive SOT (black contours) and high negative EFI match very well the areas of extremely low temperatures even 7 days in advance.

# US cold snap, January 2014

Cumulative Distribution Functions for 2m mean temperature at 41.98°/-87.9° VT: 07/01/2014 00UTC - 08/01/2014 00UTC




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



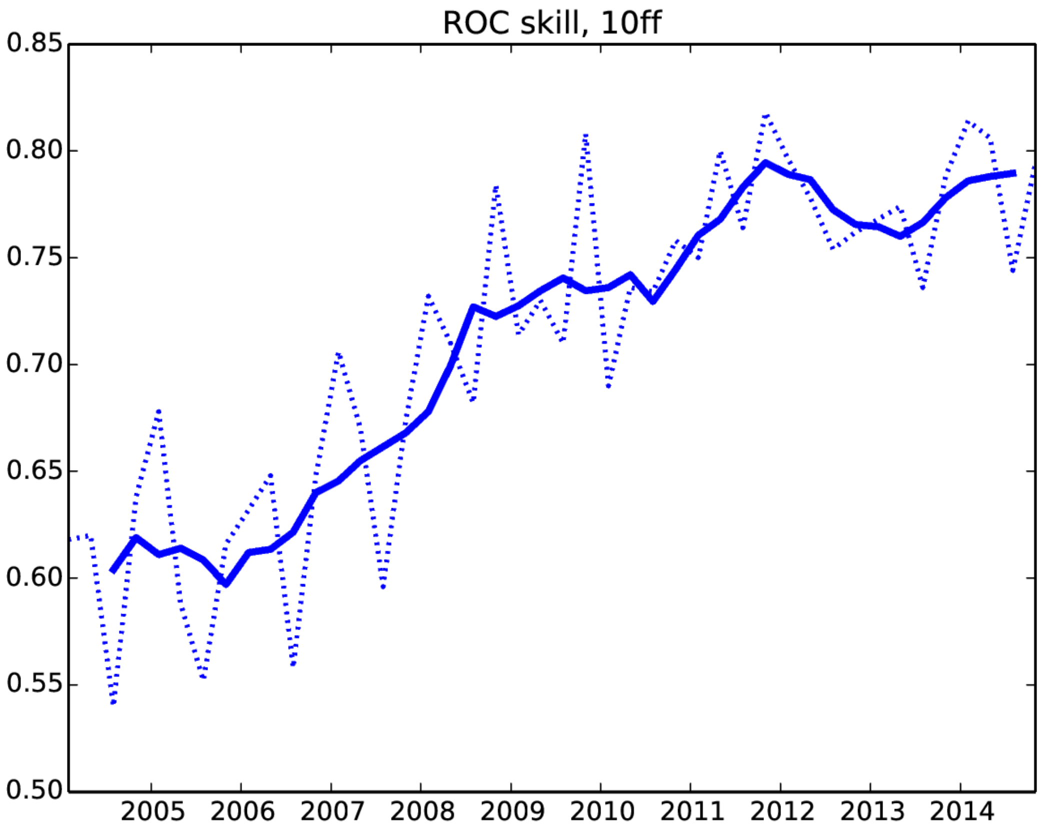

- CDFs and EFI forecast for Chicago
- All the forecast CDFs are closely packed.
- Near vertical CDFs imply high confidence in the forecast.

# 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

# EFI Verification



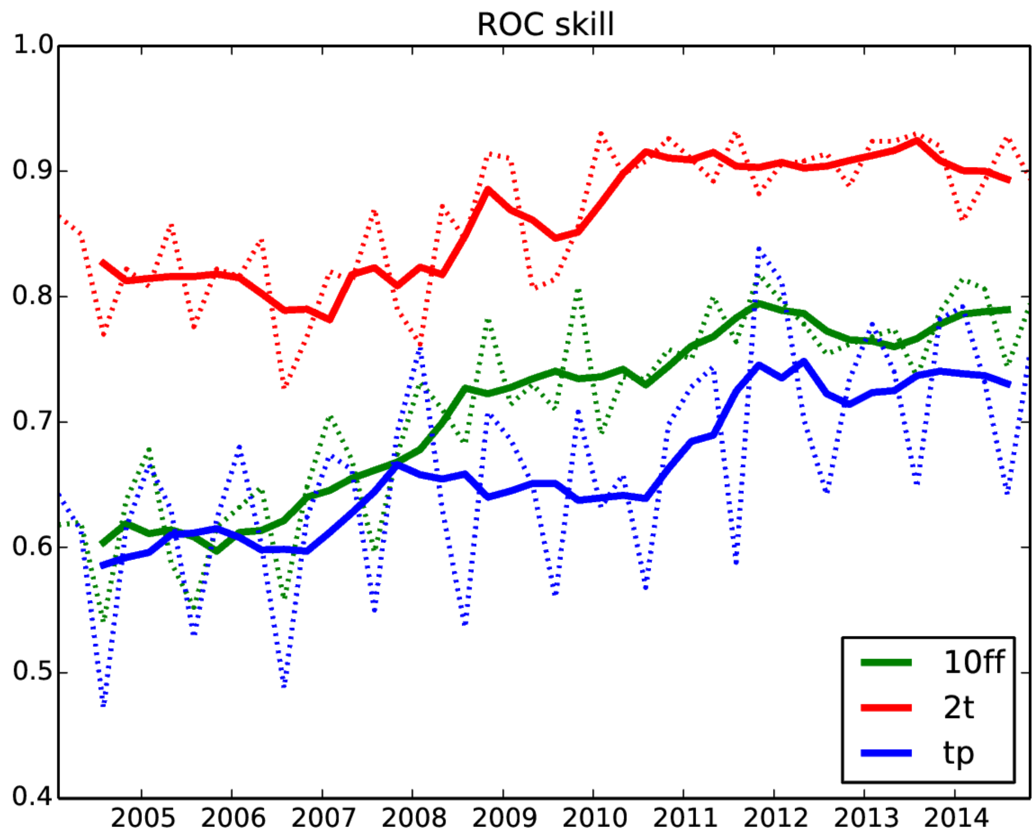

**EFI Skill = 2*ROCA-1**

**EFI Skill = 0 no skill**

**EFI Skill = 1 perfect score**

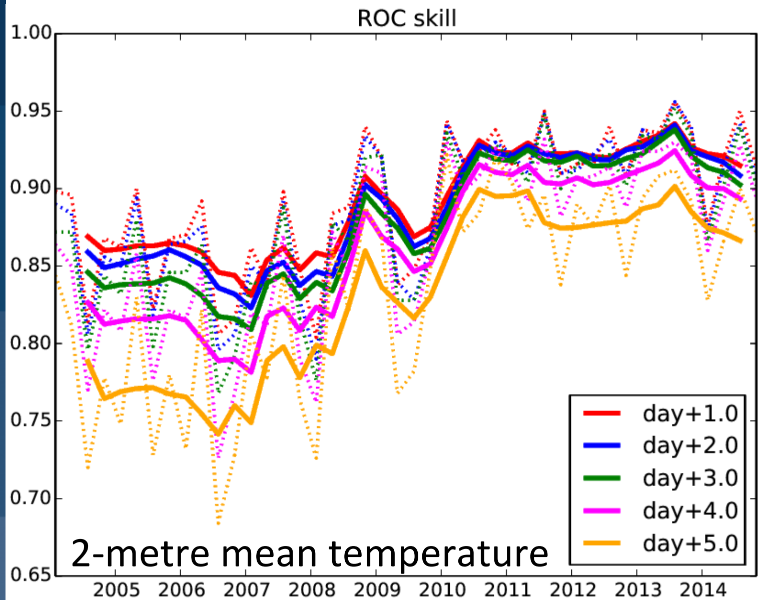
- **The plot shows the skill of the EFI for 10-metre wind speed** (a supplementary headline score adopted by the ECMWF Council) **at forecast day 4** (t+72-96h for 00UTC).
- **The solid curve shows a four-season running mean.**

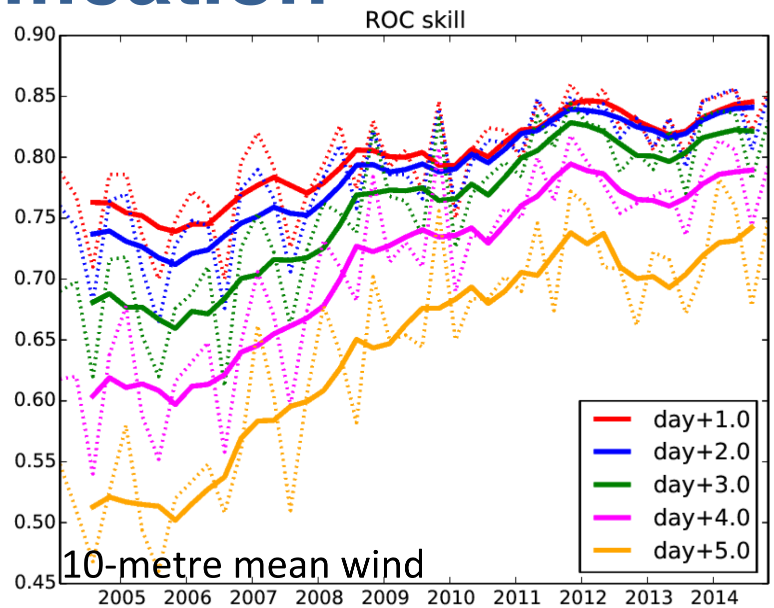
# EFI Verification

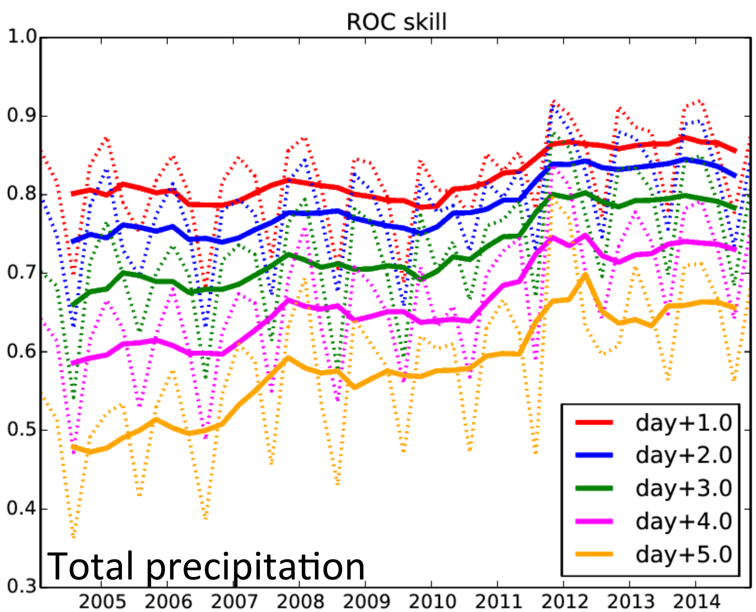



- Curves show a four-season running mean of the EFI skill score for 2m mean temperature (2t), 10 metre mean wind speed (10ff) and total precipitation (tp) for day 4 (t+72-96h for 00UTC).
- The EFI for 2m temperature is more skilful than EFI for the other two parameters.

# EFI Verification



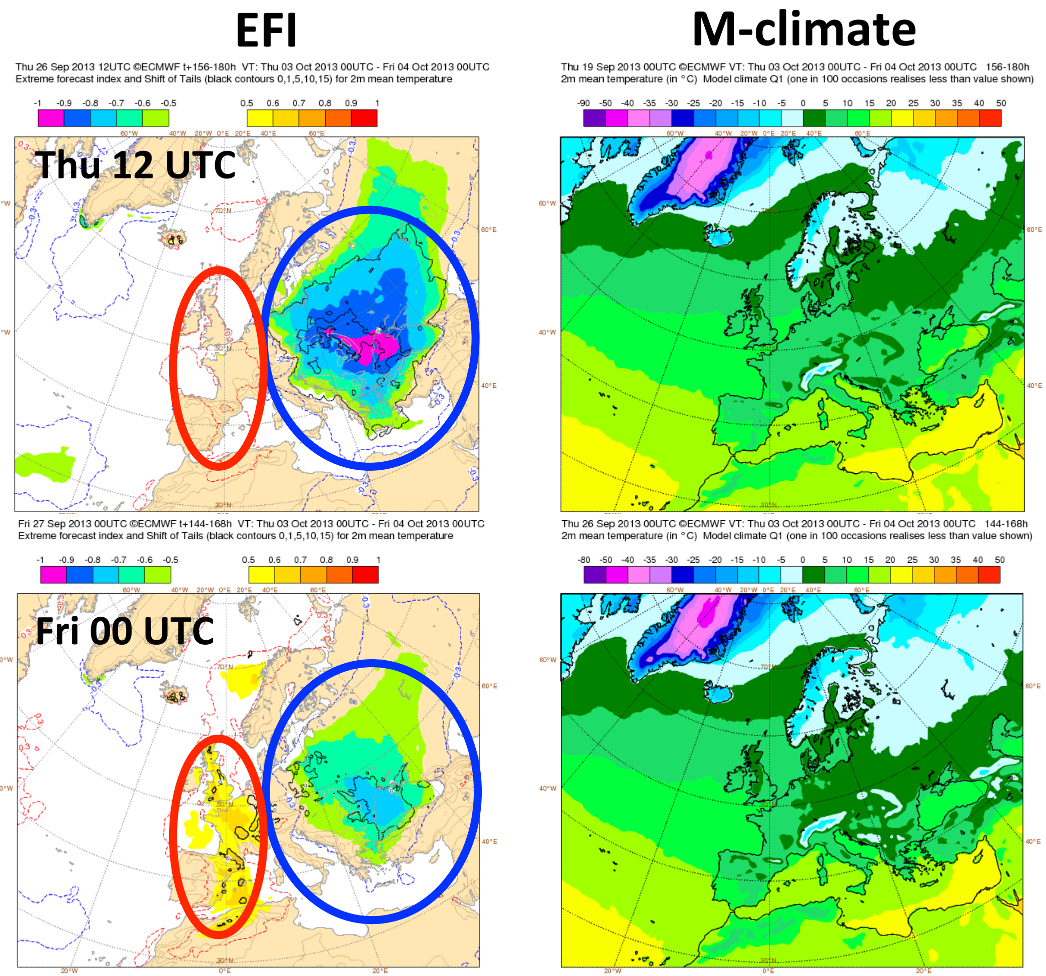




- EFI skill as a function of the lead time

# Known issues

- **Re-forecast sample size is 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 a strong seasonal trend
- **M-climate is affected by model biases:**
  - ✓ Jumpiness in the M-climate for different lead times
  - ✓ This does not affect the EFI/SOT

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

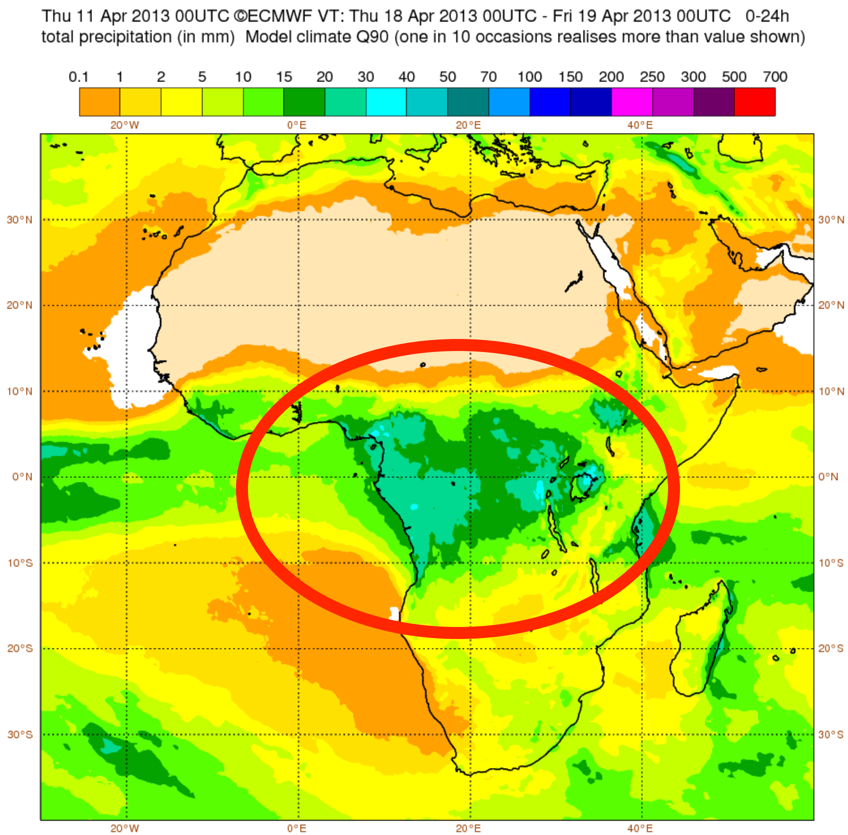


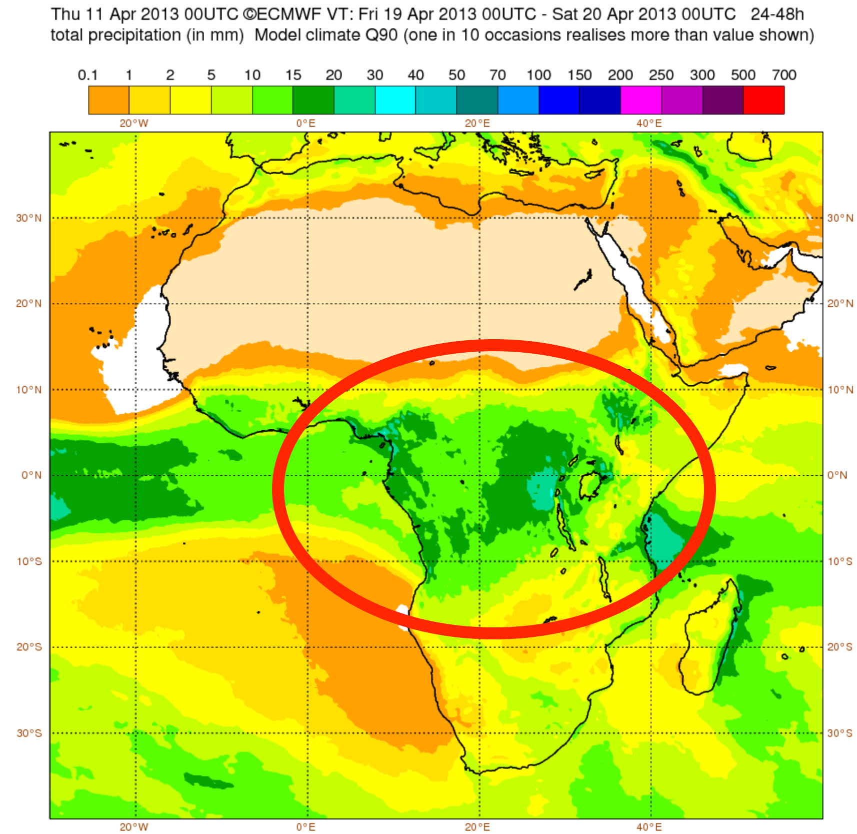

M-climate is computed only once a week (every Thursday):

- 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.

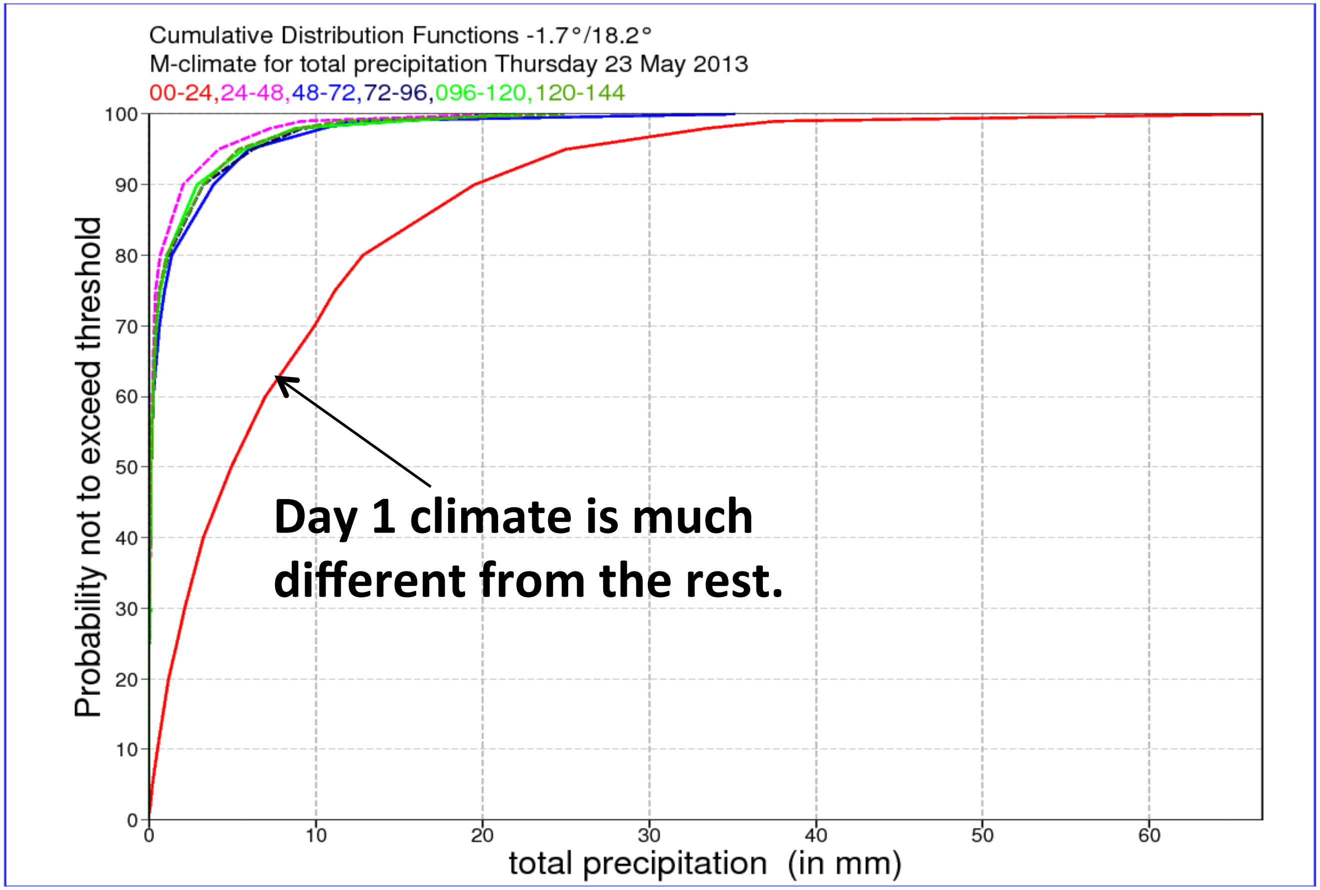
# Known issues – an example, tropical Africa




- 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.

# 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

# Forthcoming changes in the M-climate
## (next model cycle)

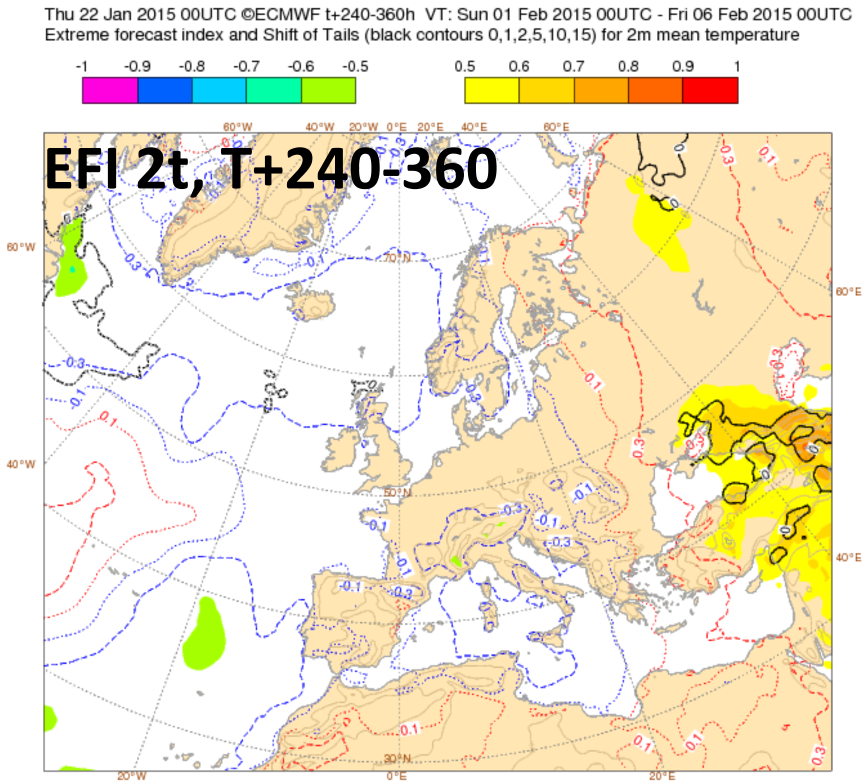
- ➢ Increase in the number of the ensemble members in the re-forecasts from 5 (now) to 11.
- ➢ Re-forecast suite will run twice a week (every Monday and Thursday) instead of once a week (Thursdays).

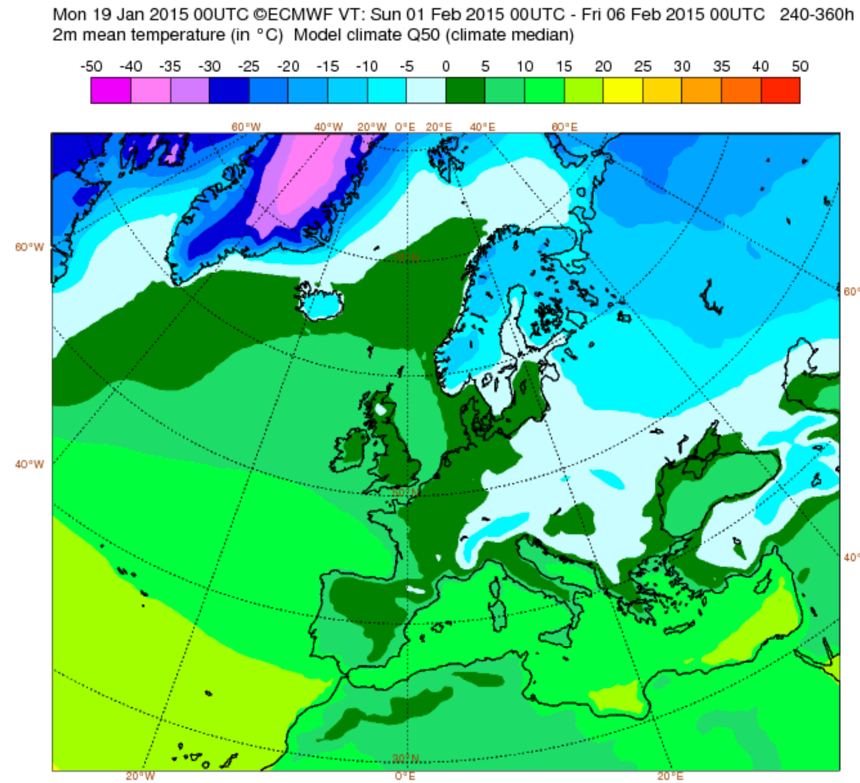
- ➢ M-climate will still use 5 weeks but it will be updated twice a week, every Monday and Thursday.
- ➢ M-climate will use all the runs in the 5-week period, e.g. the M-climate on a given Thursday will consist of all Thursday's runs in a 5-week period (2 weeks before and 2 weeks after the Thursday of interest) and all Monday's runs in between, in total 9 re-forecast runs.
- ➢ Climate sample size will increase considerably from 500 values to 11 members X 20 years X 9 runs = 1980 values.

- ➢ These changes will:
- ✓ Decrease of the noise in the tails of the M-climate distribution and will increase considerably the consistency of SOT;
- ✓ Decrease of the jumpiness due to the seasonal trend.

# Forthcoming changes in the EFI/SOT
## (next model cycle)

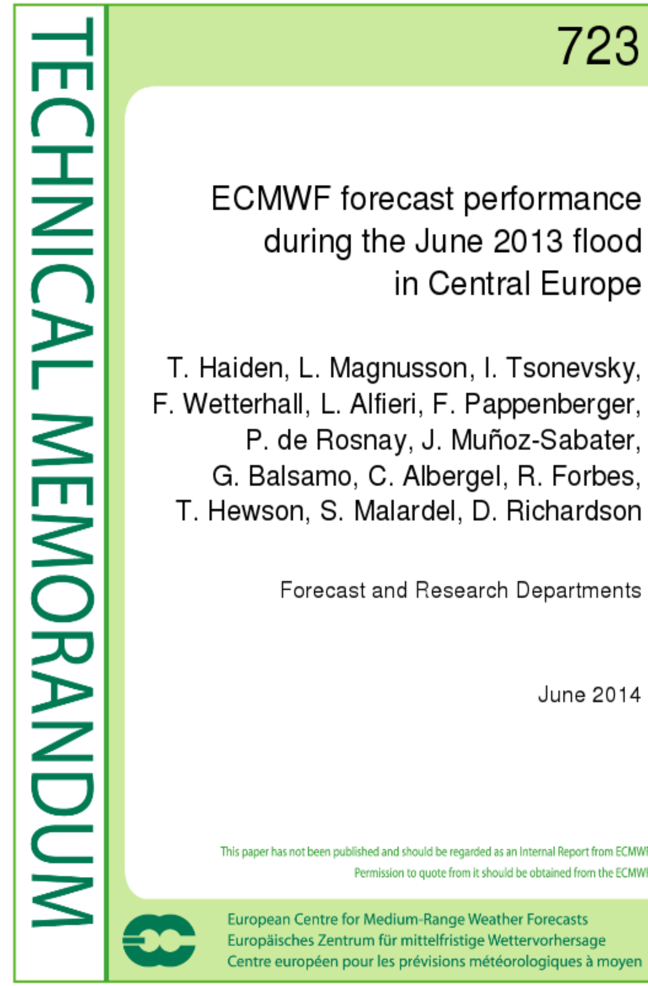
- Two new time ranges will be added to EFI/SOT for 2t, 10fg and tp: **T+000-360h** and **T+240-360h**
- The EFI computational code will be replaced with a new more robust code. This won't change the EFI significantly.



# 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

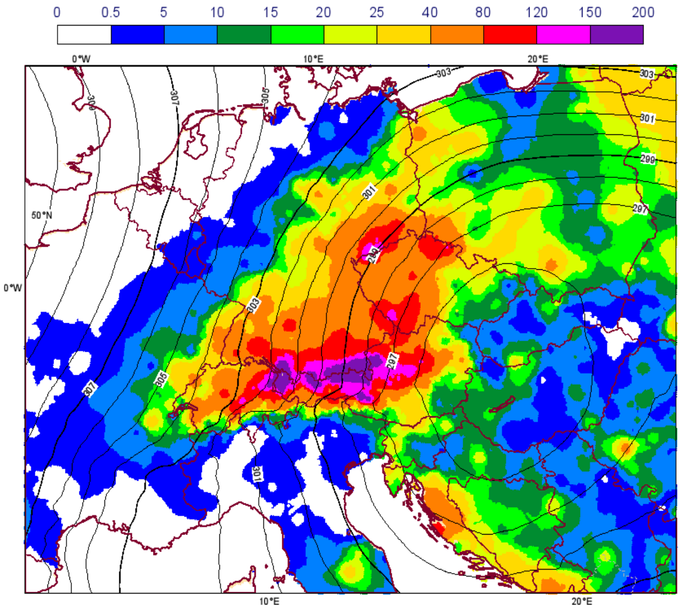
June 2014

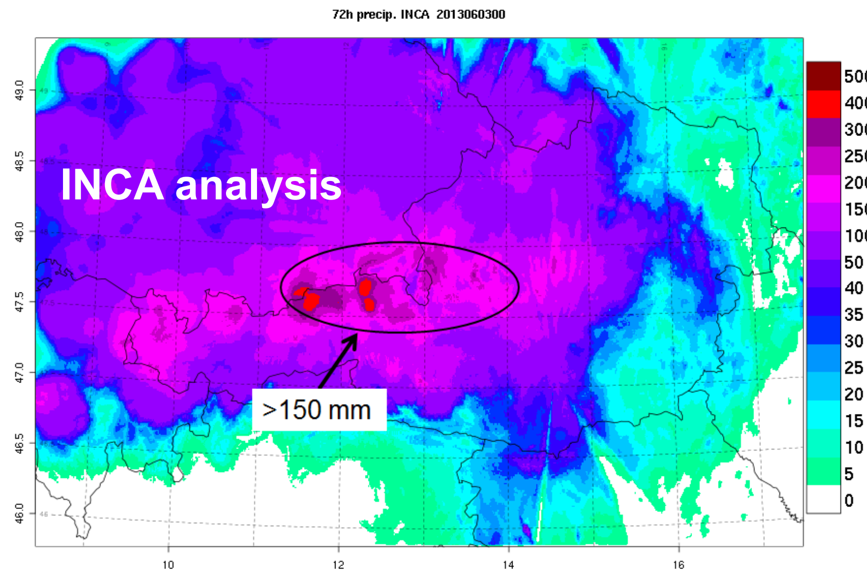
This paper has not been published and should be regarded as an Internal Report from ECMWF. Permission to quote from it should be obtained from the ECMWF.

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

# Analysis

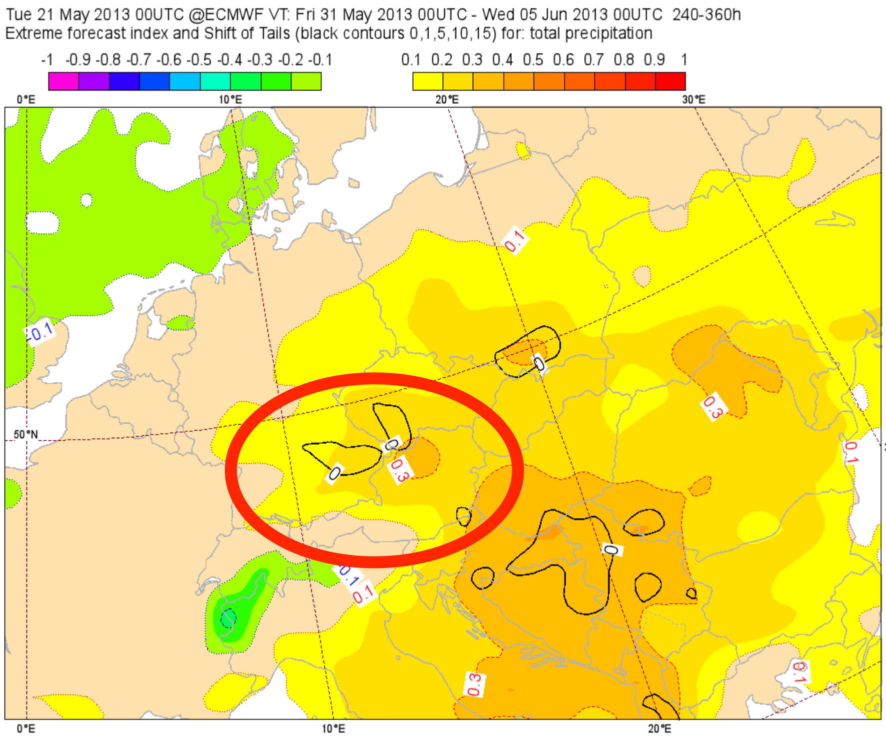
Observed rainfall interpolated on a grid and Z700 (mean over the period) ECMWF analysis
VT: 31/05/2013 06 UTC – 03/06/2013 06UTC

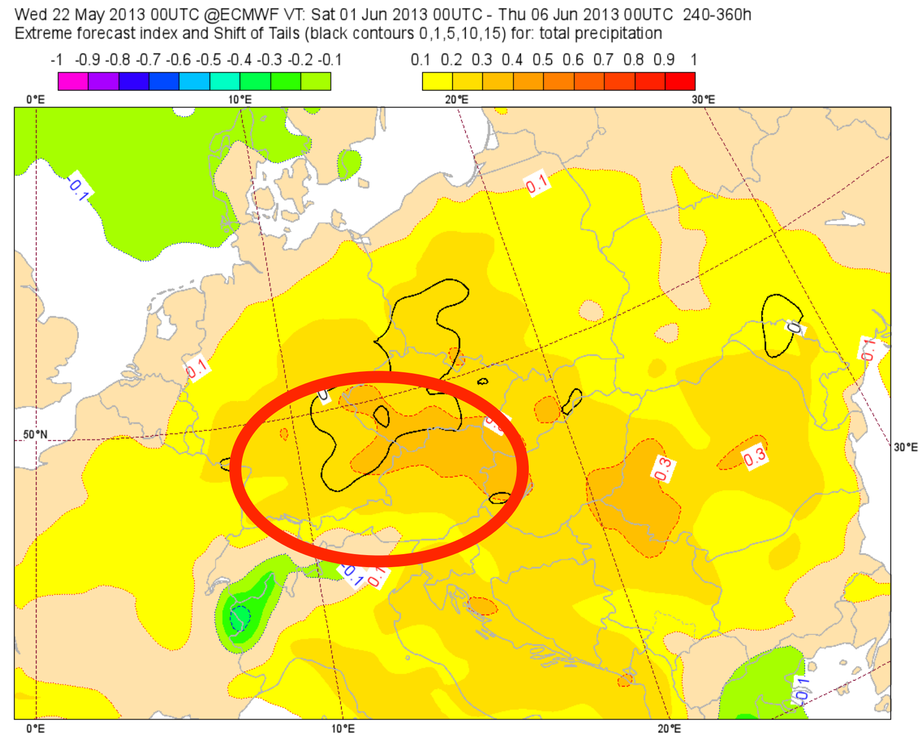



- A quasi-stationary low pressure system brought moist, warm air from the east and northeast into Central Europe causing massive amounts of rain in southern Germany and western Austria.
- Orographic enhancement of precipitation along the northern side Alps played an important role.

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



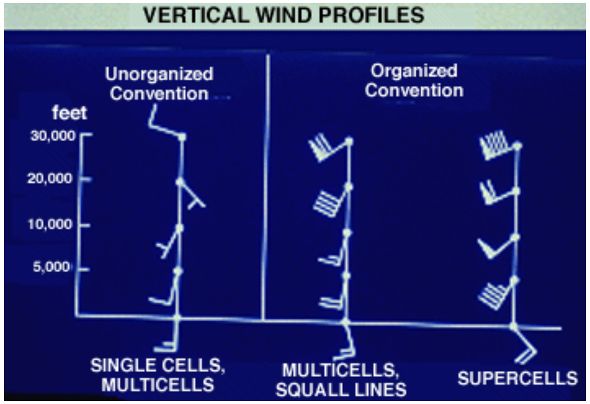




- A remarkably strong signal in the EFI.
- Positive SOT marks the areas where the forecast system predicts exceptionally heavy rain.

# EFI/SOT for convection (summer 2015?)

Motivation:

- A substantial number of severe weather events are related to deep convection, especially in the warm season.
- EFI/SOT does not cover convection so far and EFI/SOT for precipitation and wind gusts are less skilful in case of severe convection; moreover, deep convection is not just heavy rain/snow and strong wind gusts but also large hail, damaging lightning, etc.
- Significant improvements of convection in the model recently (see *ECMWF Newsletter No. 136 – Summer 2013*)
- Many and continuing user requests for guidance about forecasting severe convection.



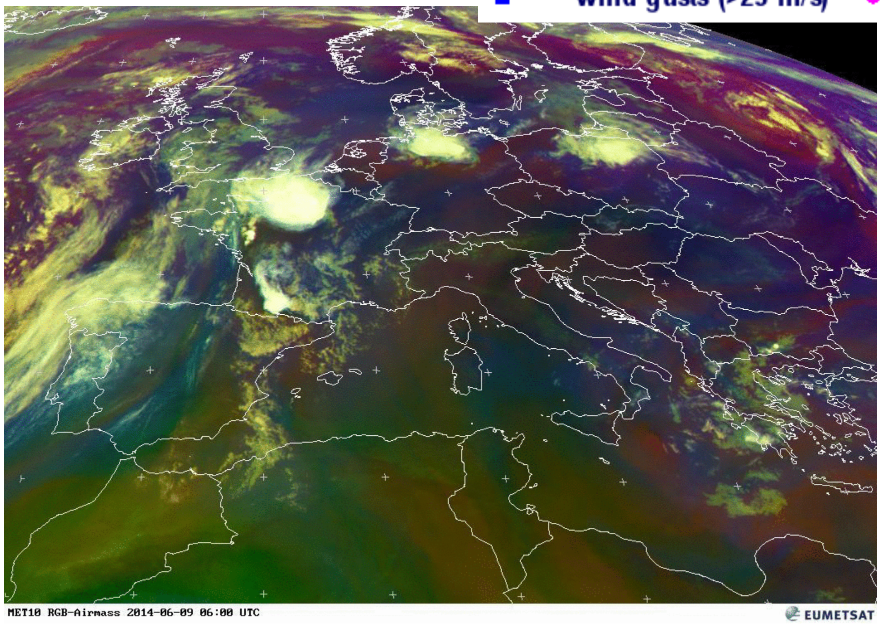

**CAPESHEAR** parameter used to highlight the possibility of extreme convection:

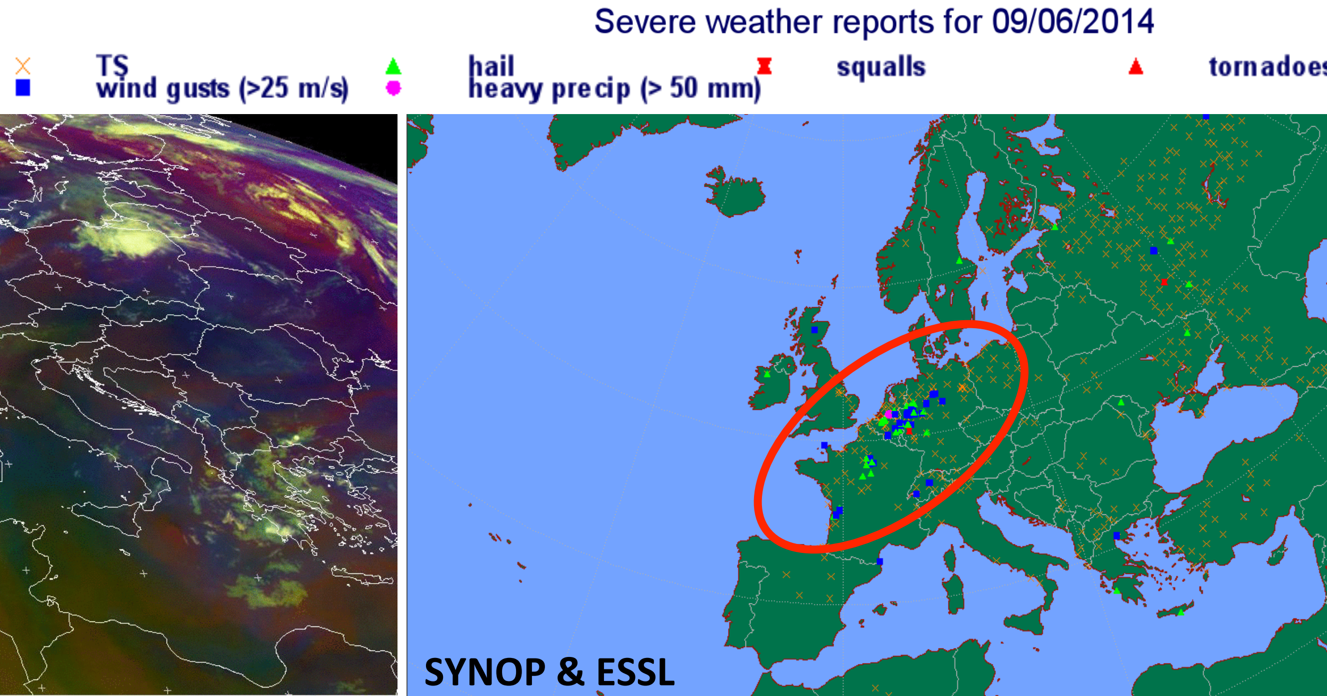
$$CAPESHEAR = [WS]_{L1}^{L2} * \sqrt{CAPE}$$

where WS is the wind shear between levels L1 and L2. The dimension of CAPESHEAR is $m^2s^{-2}$ (energy).

- CAPE is a key ingredient of deep moist convection.
- Large vertical wind shear favours the organised convection.
- Supercells occur where strong shear is combined with large instability
- The EFI was computed using the maximum value for CAPESHEAR out of every four values during a 24-hour period (the standard output from the ensemble model is every 6 hours so there are 4 values every 24 hours).
- CAPE values of less than 10 J/kg are filtered out to emphasise convection rather than anomalous but insignificant CAPESHEAR.
- **Limitations:** CIN not taken into account.

# Severe convection, 9 June 2014

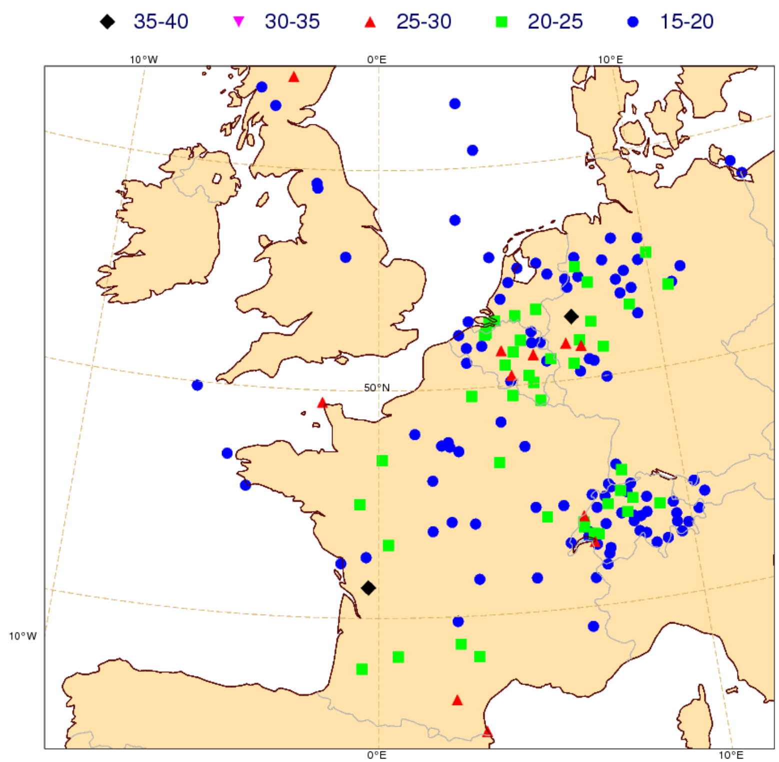


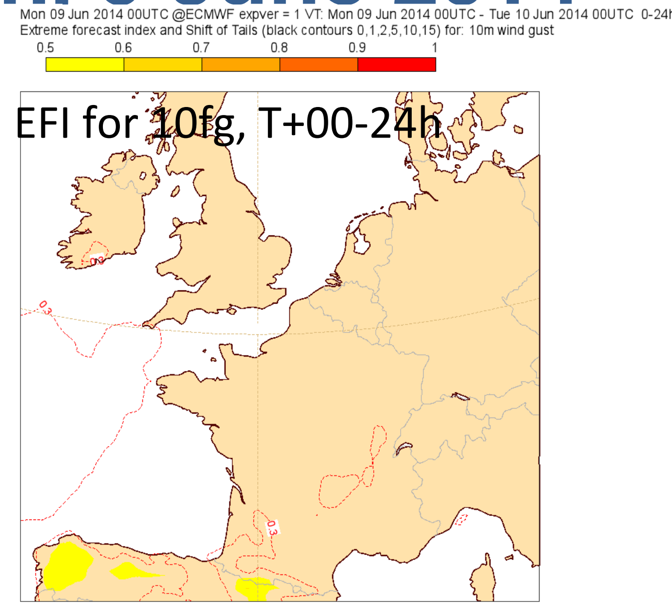



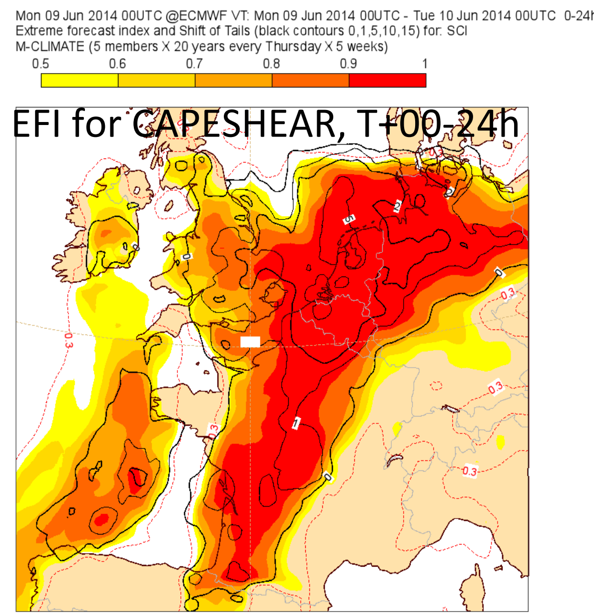

- Severe convection affected Western Europe on 9 June 2014.
- Deep moist convection developed along the western fringe of a hot air mass.
- Many weather reports of severe wind gusts and large hail.

# Severe convection. 9 June 2014

Observed maximum wind gusts on 09 June 2014



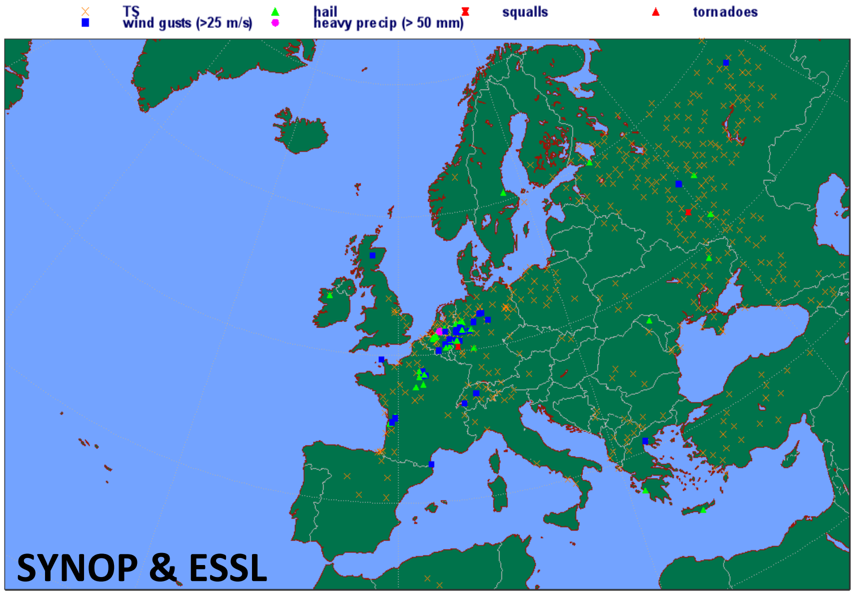



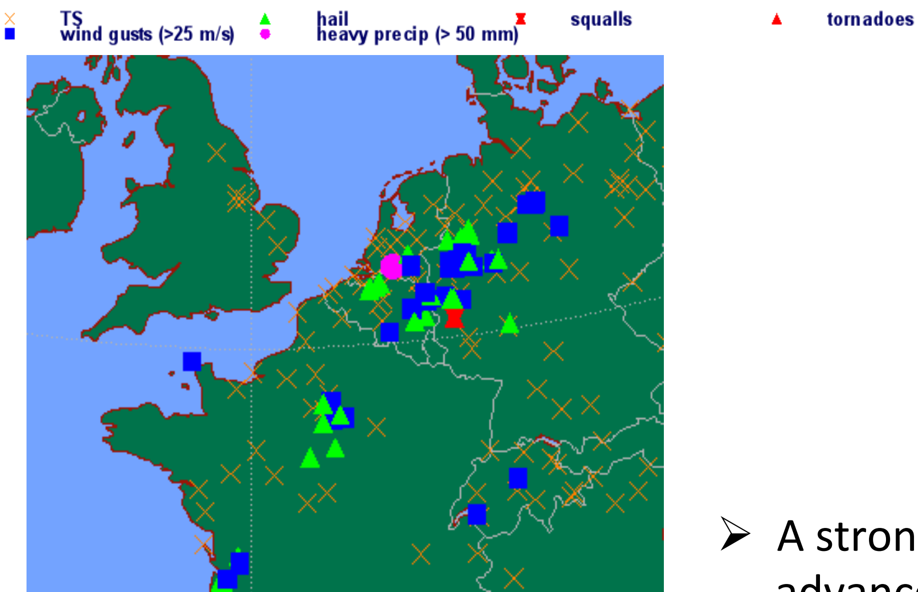



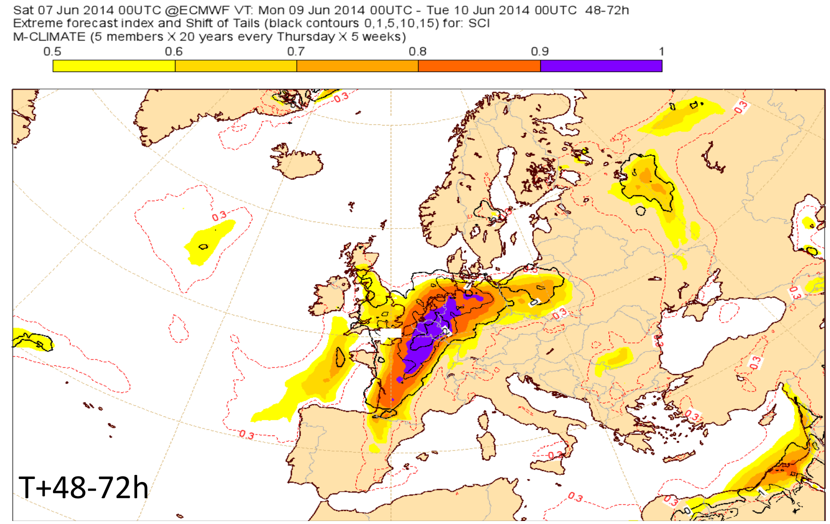

- Strong wind gusts were reported in France, Belgium, the Netherland and Germany.
- The maximum wind gust at Dűsseldorf airport was 42 m/s.

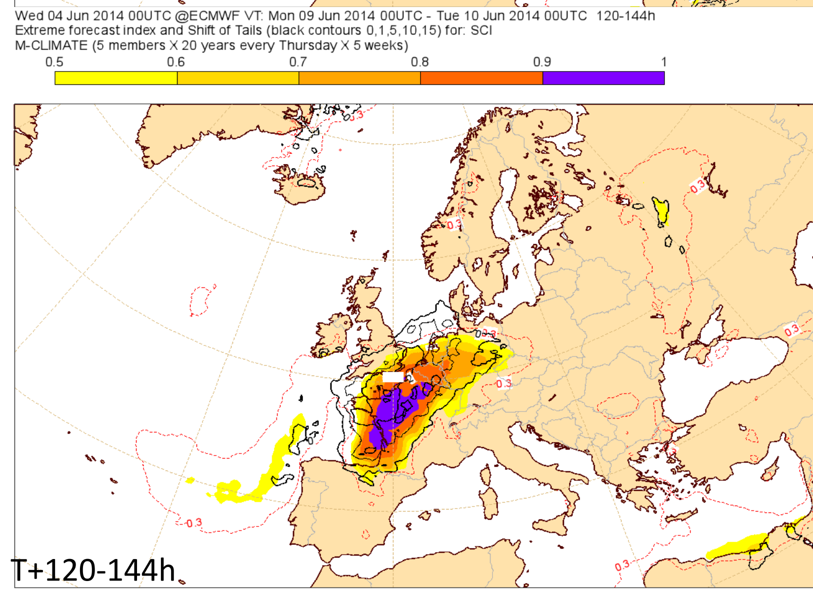
# EFI for CAPESHEAR

Severe weather reports for 09/06/2014



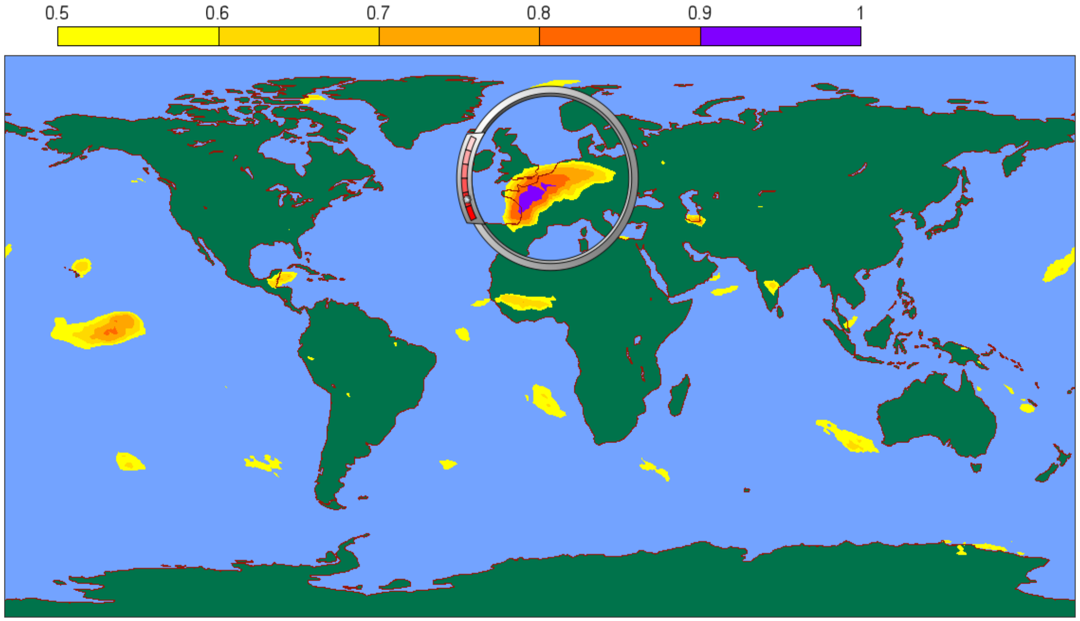



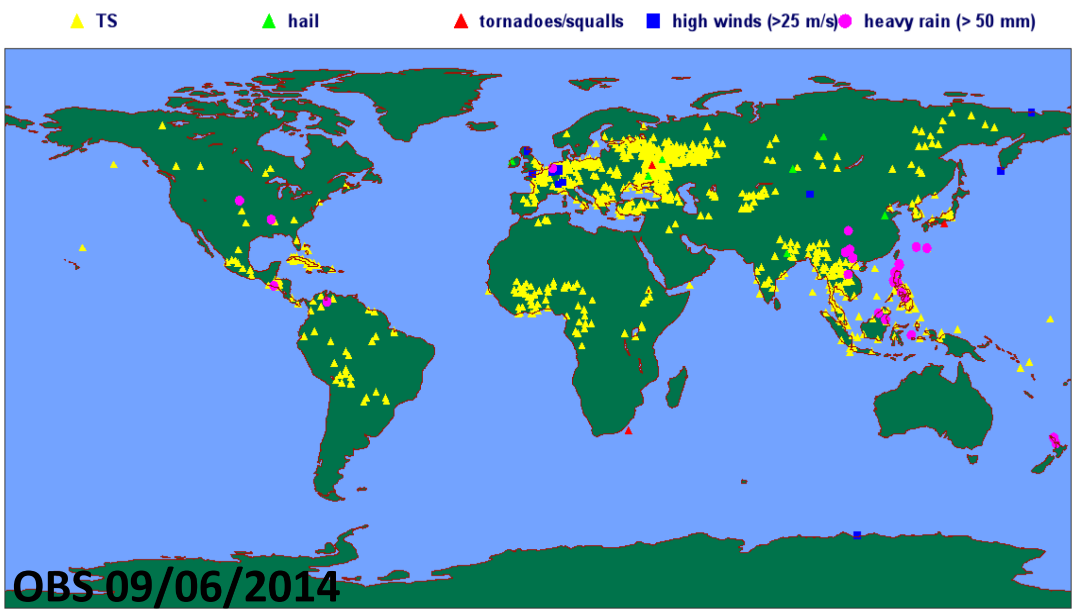




- A strong signal of anomalous weather 5 days in advance.

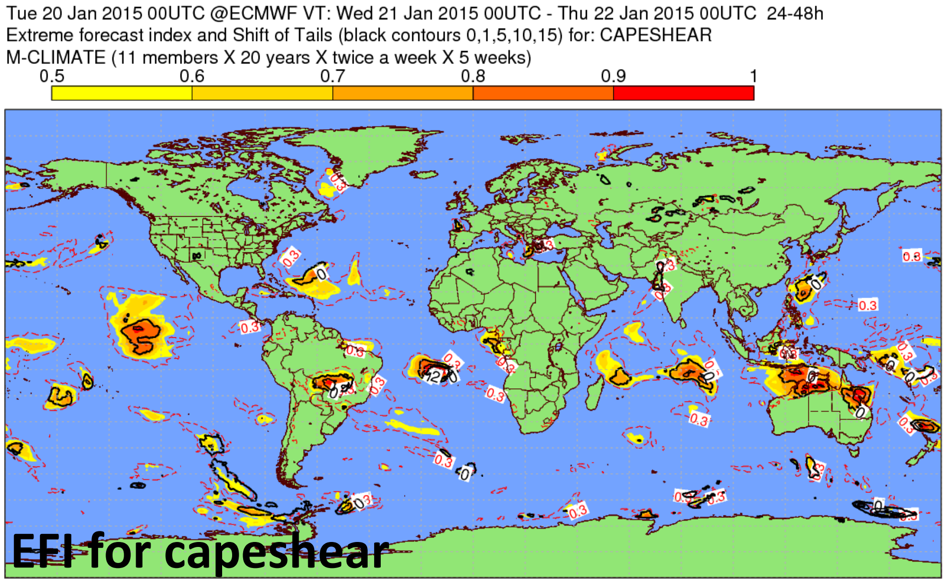
# EFI for CAPESHEAR, T+120-144 VT: 09/06/2014

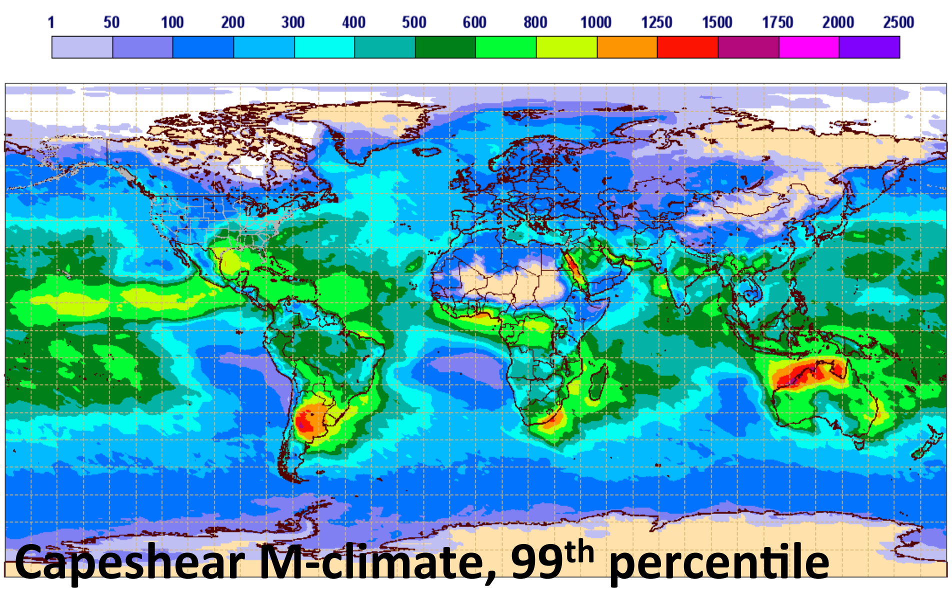



- ➢ The strongest signal of anomalous CAPESHEAR over Western Europe.

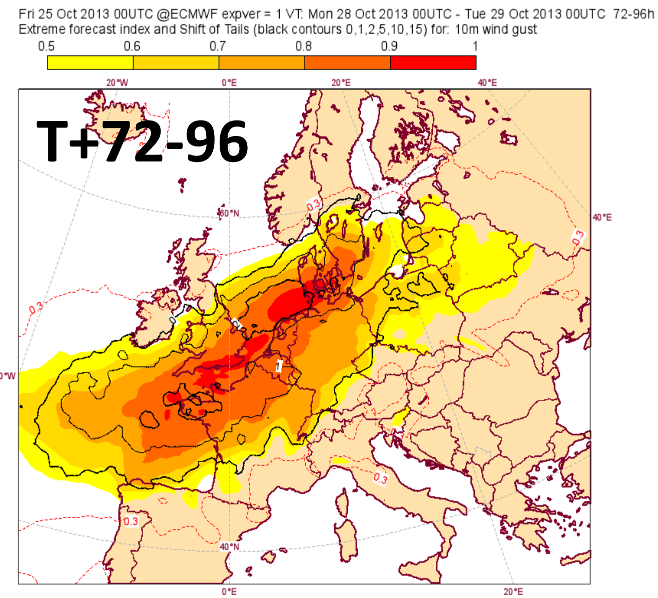
# EFI for capeshear and M-climate

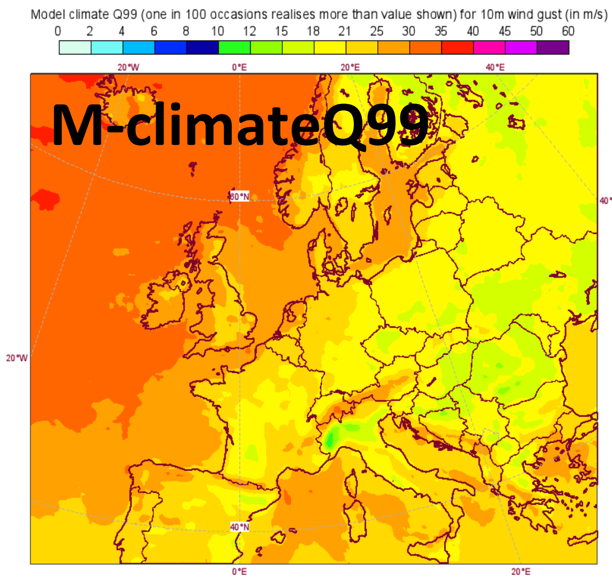


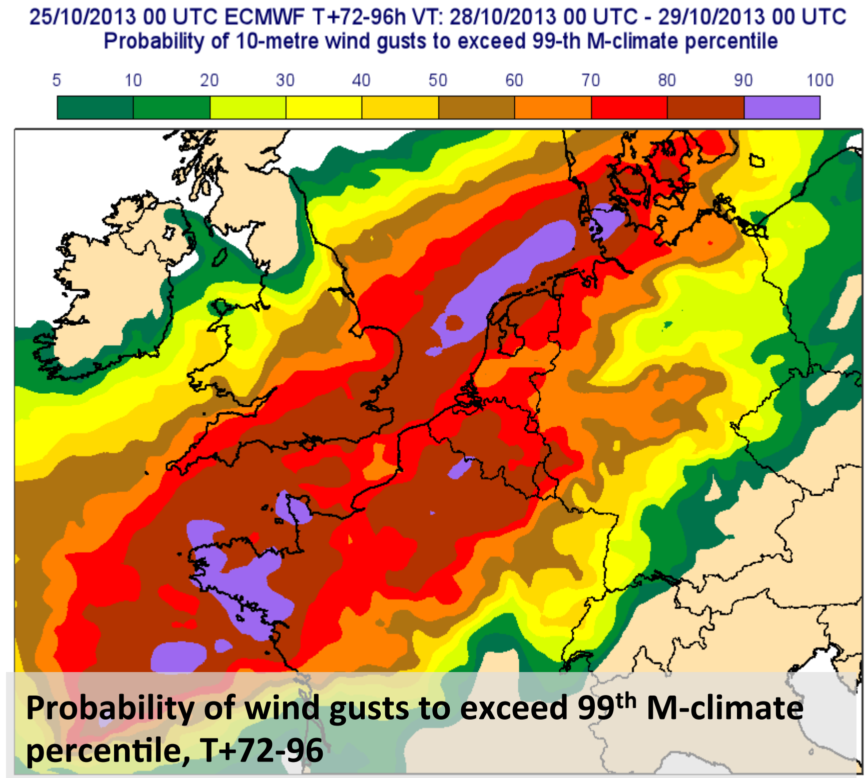




- M-climate helps to assess the significance of the anomalous capeshear index.

# 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://old.ecmwf.int/products/forecasts/guide/user_guide.pdf

✓"Application of the new EFI products to a case of early snowfall in Central Europe", *ECMWF Newsletter* No. 133 – Autumn 2012, 4