Extreme Forecast Index (EFI)

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Extreme Forecast Index (EFI)

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

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

⟺

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

The Model climate (M-climate)

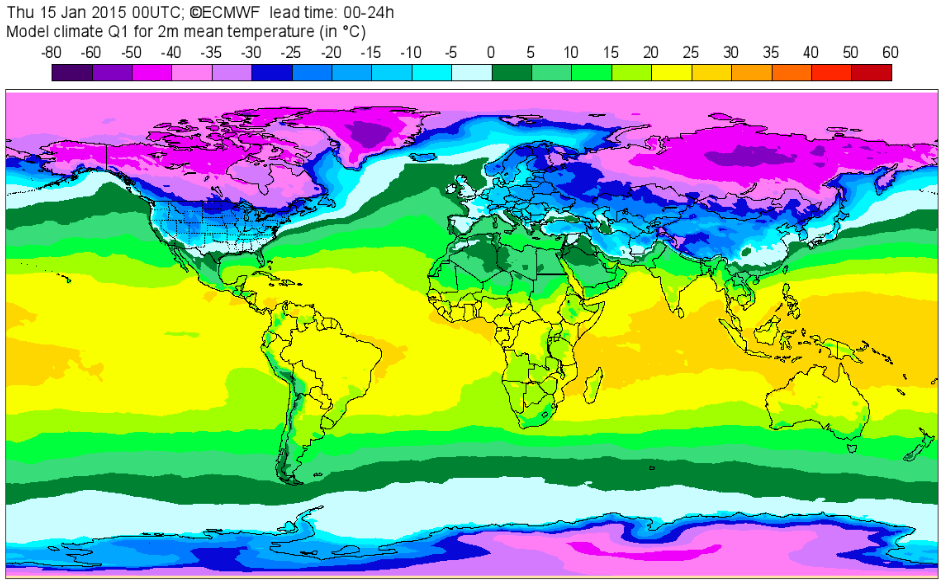
For climate related products like the EFI a reliable model climate is essential.

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

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

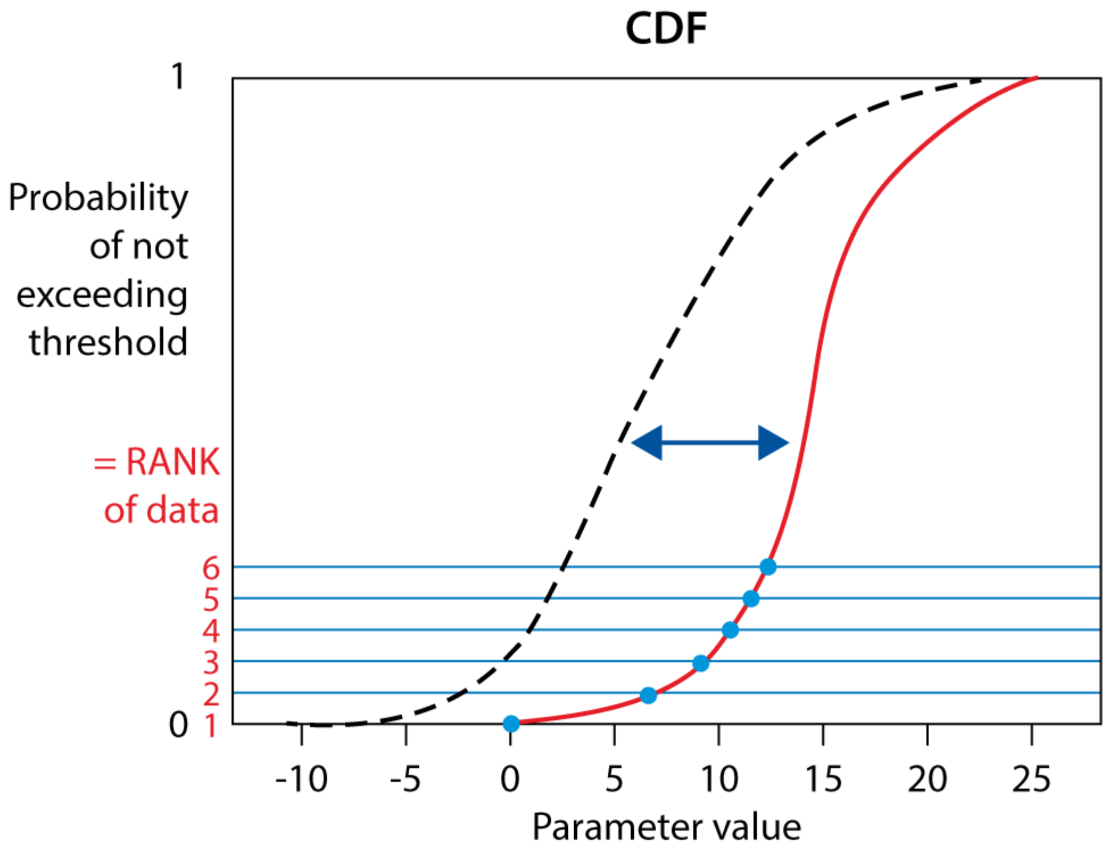
- Running an ensemble re-forecast suite with 10 perturbed ensemble members and the Control **(was 4 perturbed member + Control)**
- Always for the most recent 20 years with initial conditions taken from the ECMWF global atmospheric reanalysis ERA-Interim
- Re-forecast runs every Monday and every Thursday. Therefore climate files from the closest preceding run are taken. **(only Thursday runs before)**
- Model run for 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

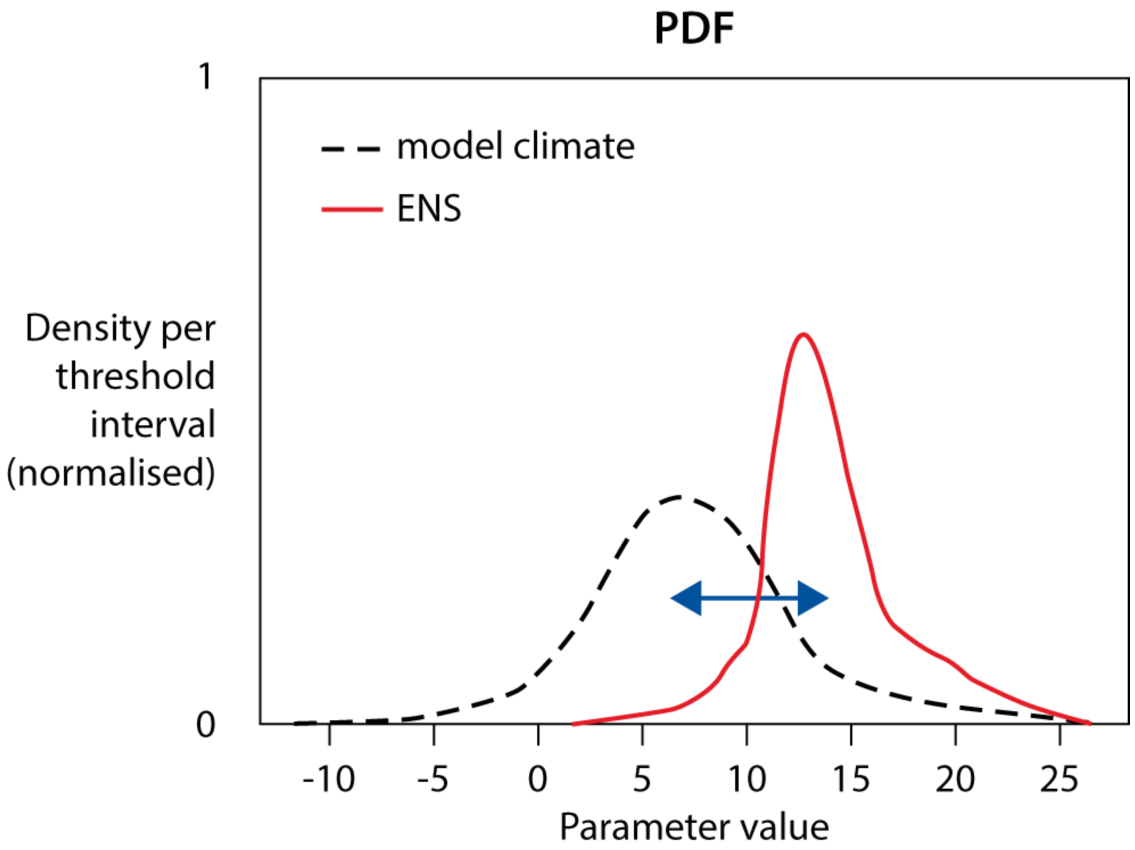
Model climate (M-climate)



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

How do CDFs and PDFs relate?

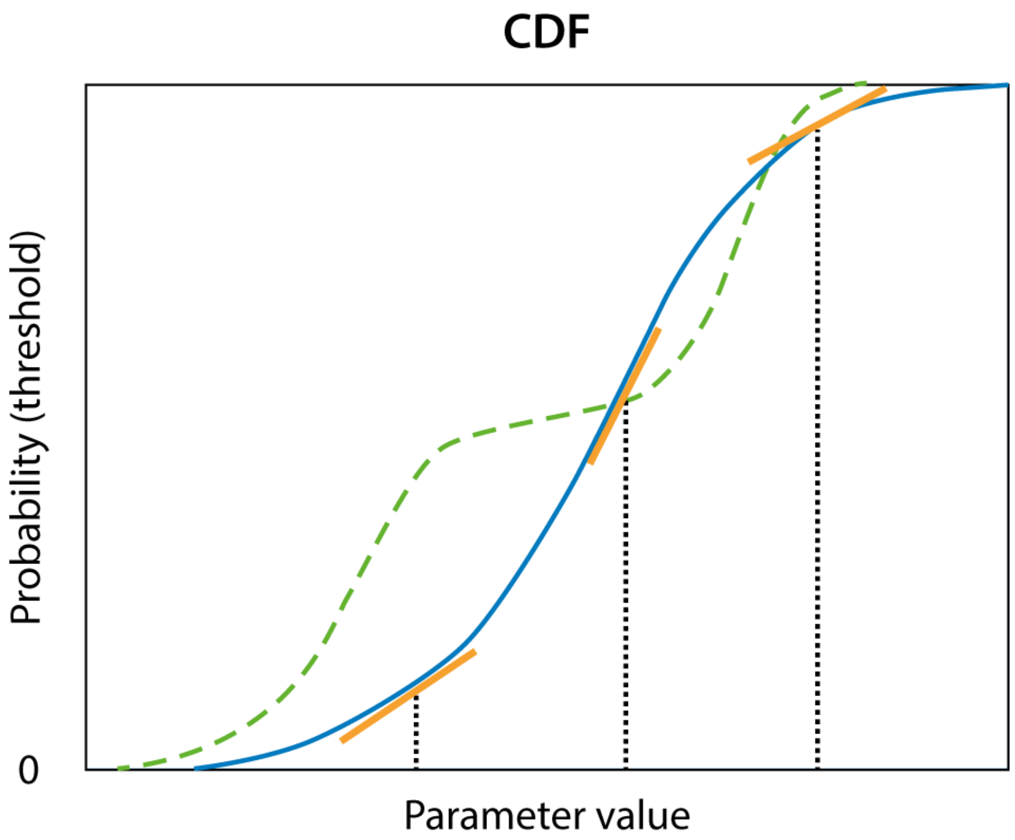


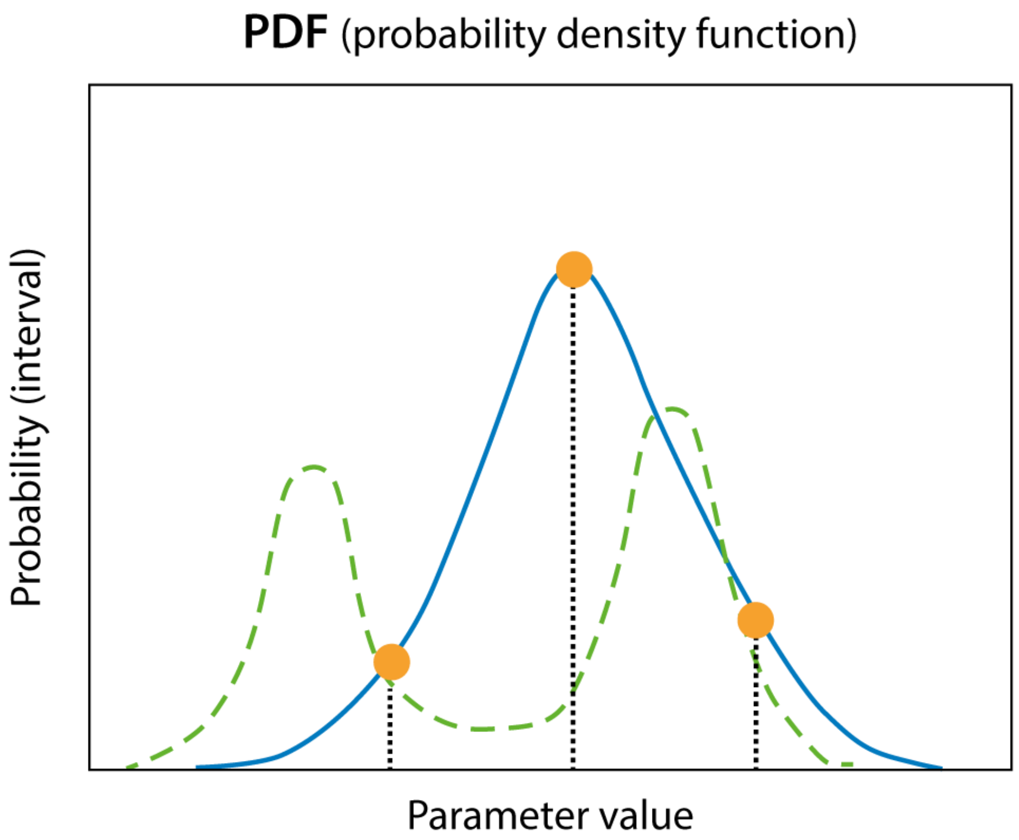


- CDF displays the values of a given (meteorological) parameter of interest on the x-axis versus the probability of not exceeding those values on the y-axis.

- The EFI is defined on the basis of the Cumulative Distribution Functions (CDF). The position and the shape of CDFs of the real-time ENS and M-climate determine the abnormality level in the forecast.

How do CDFs and PDFs relate?



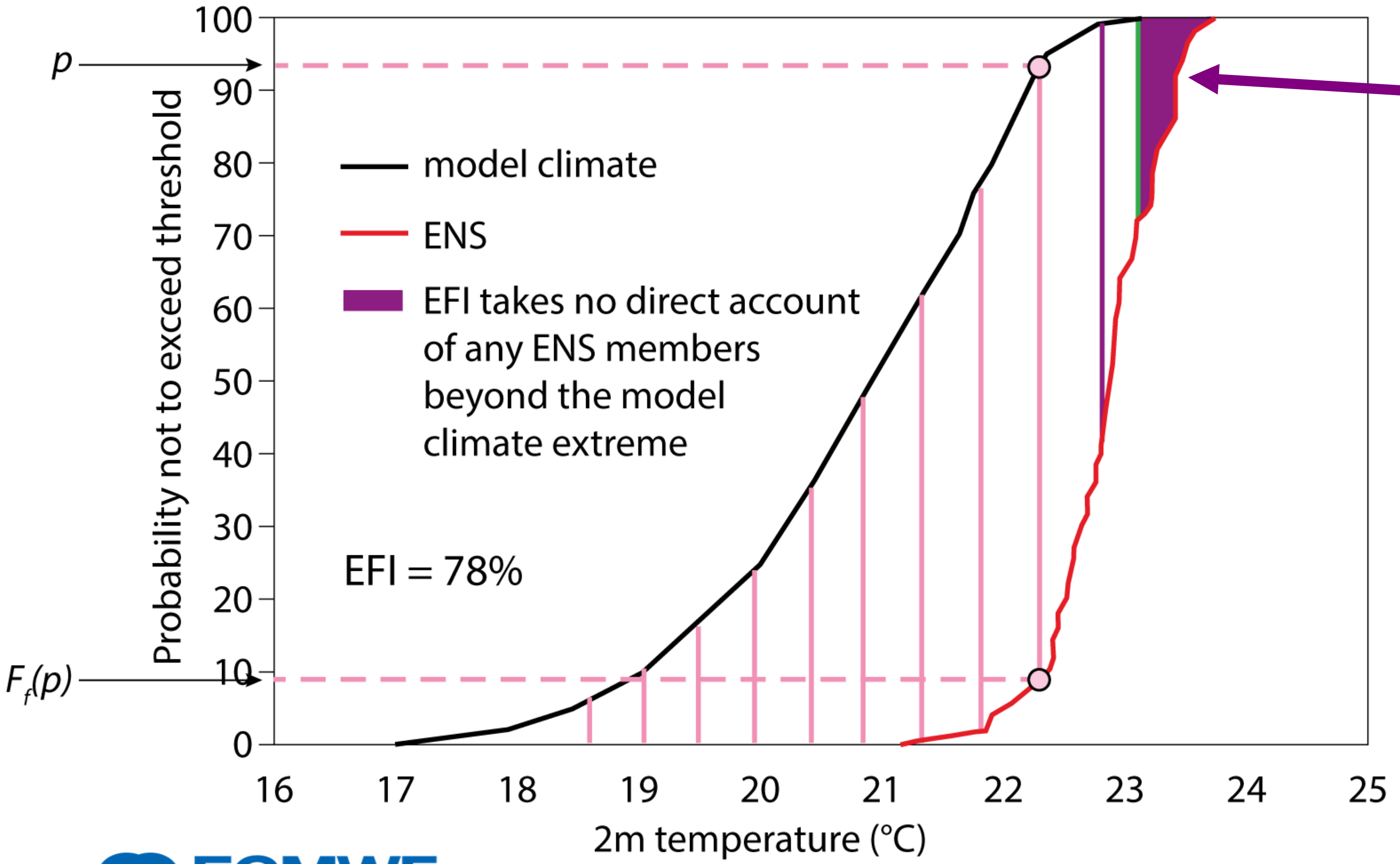


- The PDF (y-axis) value equals the slope of the CDF
- **Steeper** CDF = **narrower** PDF = higher confidence in the forecast
- A step in the CDF means a bimodal PDF

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

Represented by pink lines below

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

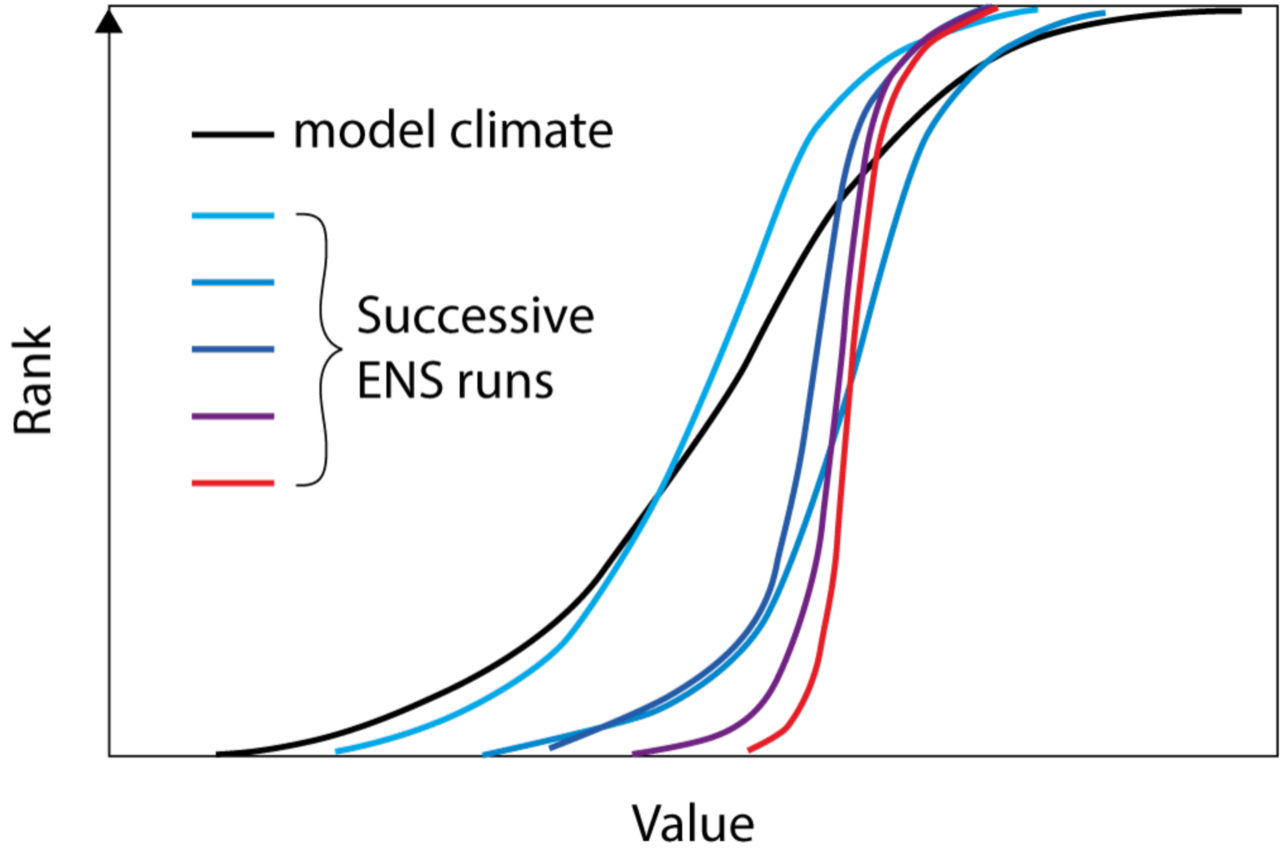


EFI takes no direct account of any ENS members beyond the M-climate extremes

$-1 \leq EFI \leq 1$

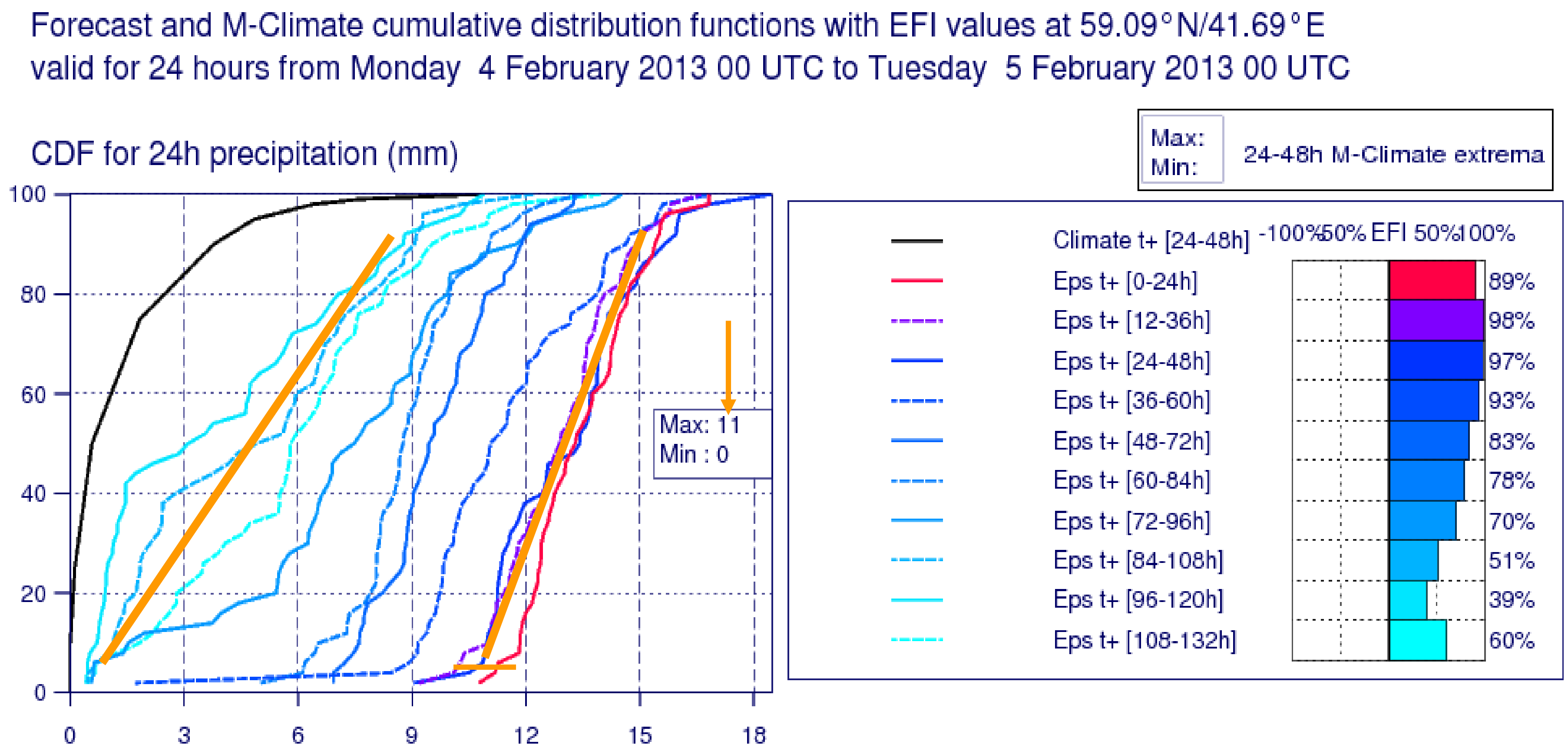
$-100\% \leq EFI \leq 100\%$

How ‘should’ CDFs behave in successive ENS runs?



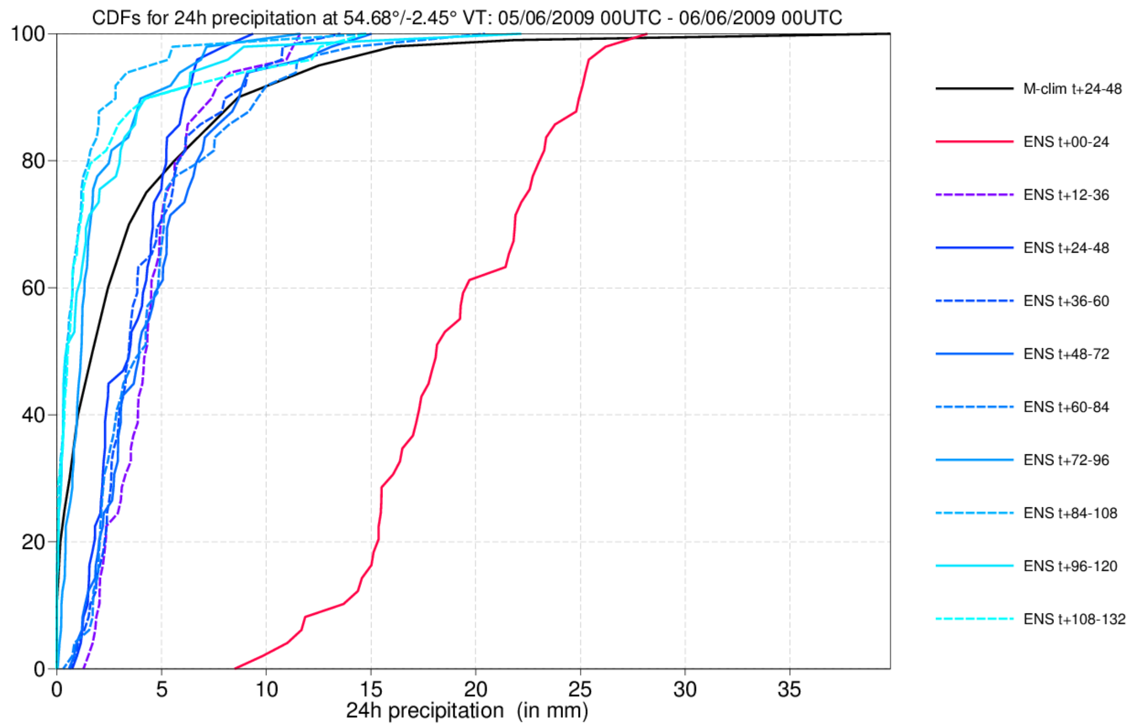
- At long lead times forecast CDF may be similar to the M-climate.
- Lateral variations in CDF position between successive runs should, mostly, become less (with time).
- CDF will tend to become steeper (with time), implying higher confidence.

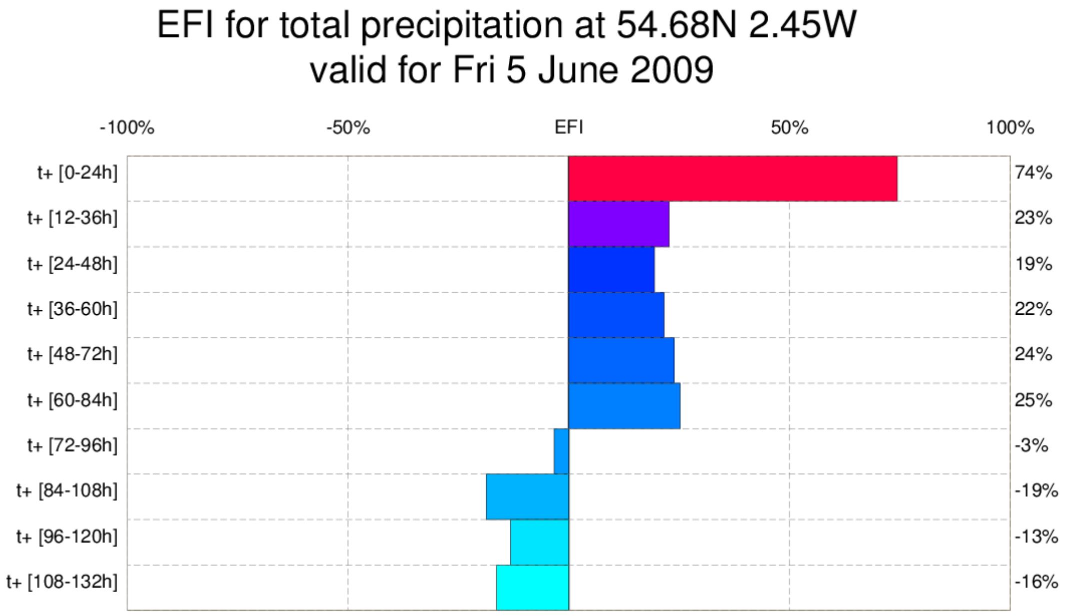
An example



- 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

Counterexample





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

Some limitations of EFI

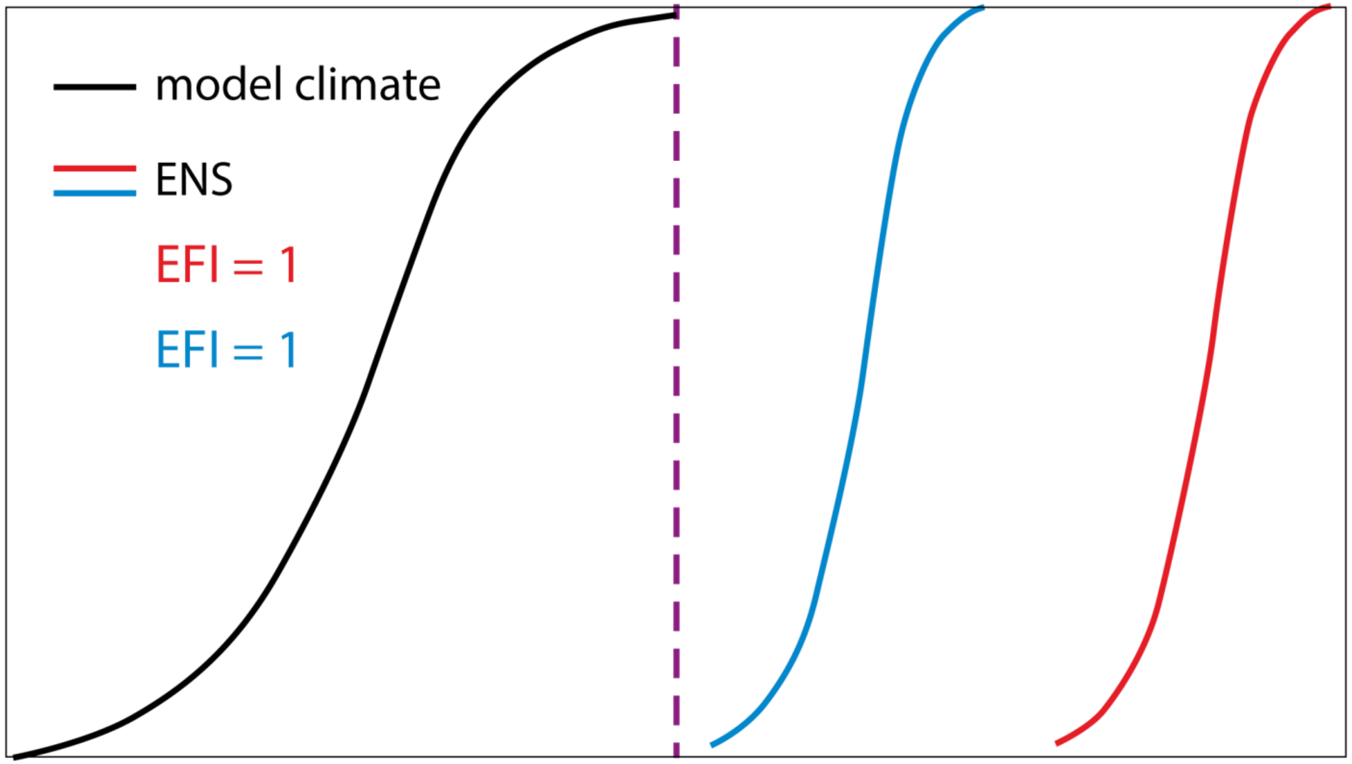
- Extreme does not *necessarily* mean high impact (eg 2mm rain in the desert)
- Past history also important but not directly accounted for (eg heavy rain when ground saturated)
- Windstorm impact can depend on whether trees are in leaf, whether ground is saturated…
- Products are only as good as the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

TEST 1

For a given location the ensemble members forecast daily mean temperatures which are all less than the lowest daily mean temperature of the M-climate. What will be the EFI value?

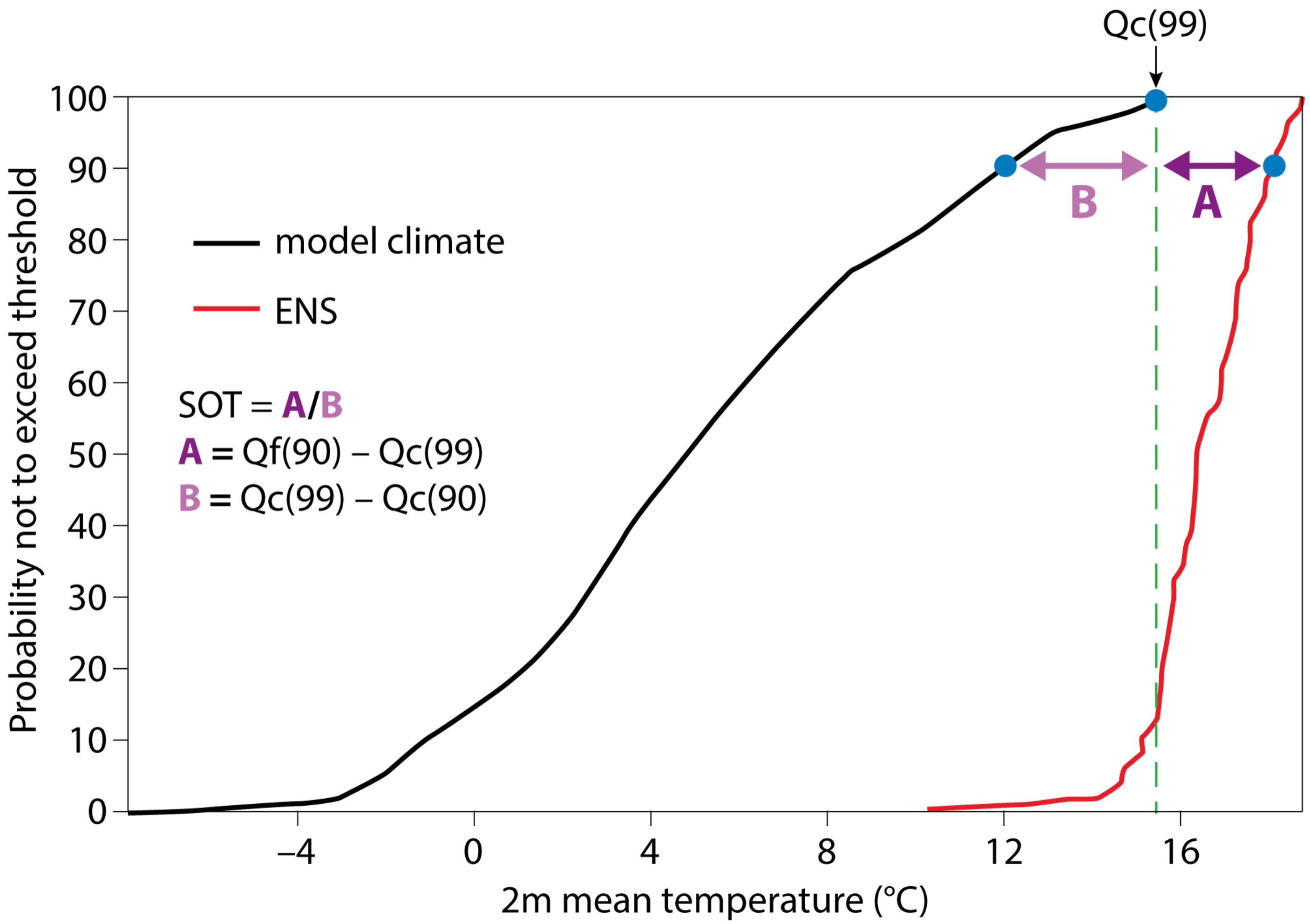
a. 0
b. 1
c. -1
d. -1.5

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

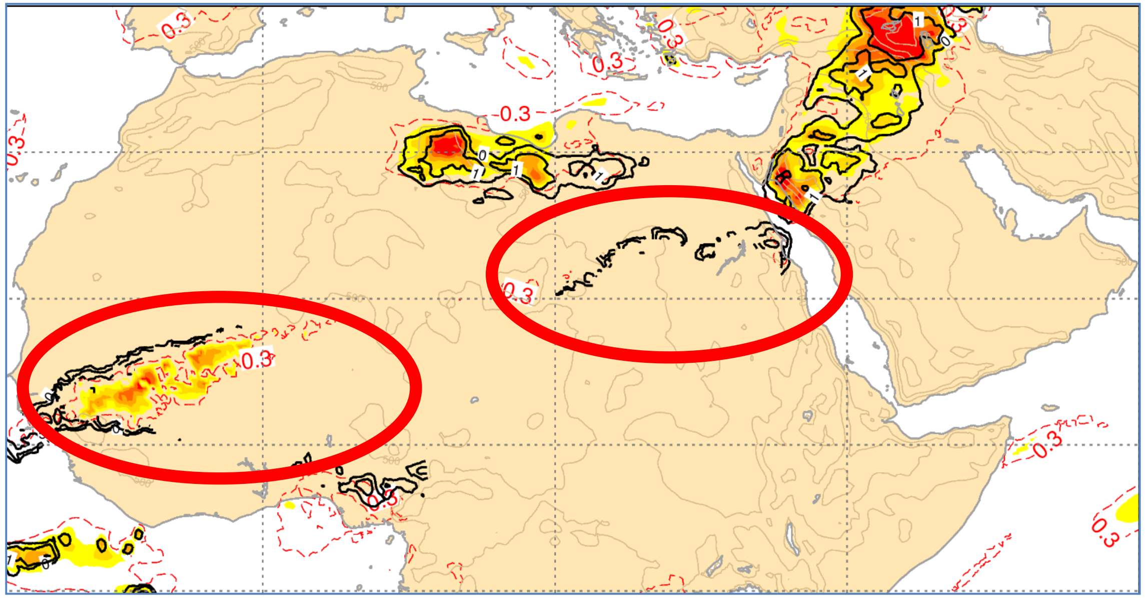
TEST 2

The total precipitation EFI value is 30% and SOT is +2. What does this mean?

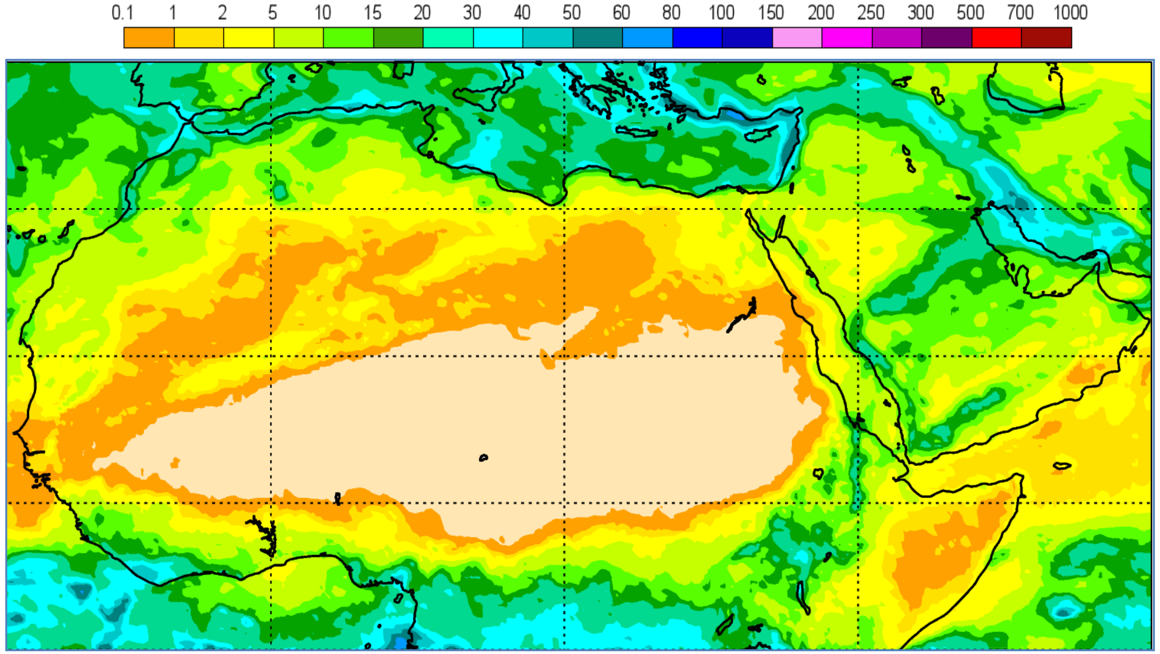
a. The probability of extreme rainfall is 30%.
b. The probability of extreme rainfall is 70%.
c. The probability of extreme rainfall is very high.
d. Extreme rainfall is possible but forecast uncertainty is large.

Some limitations

EFI &SOT for precipitation



M-climate Q99



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

Operationally available EFI fields

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

Operationally available EFI fields

EFI and SOT parameters:

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

* Parameters in red available since 19th June 2012

* Parameters in blue available since summer 2015

Operationally available EFI fields

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

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

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

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

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

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

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

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

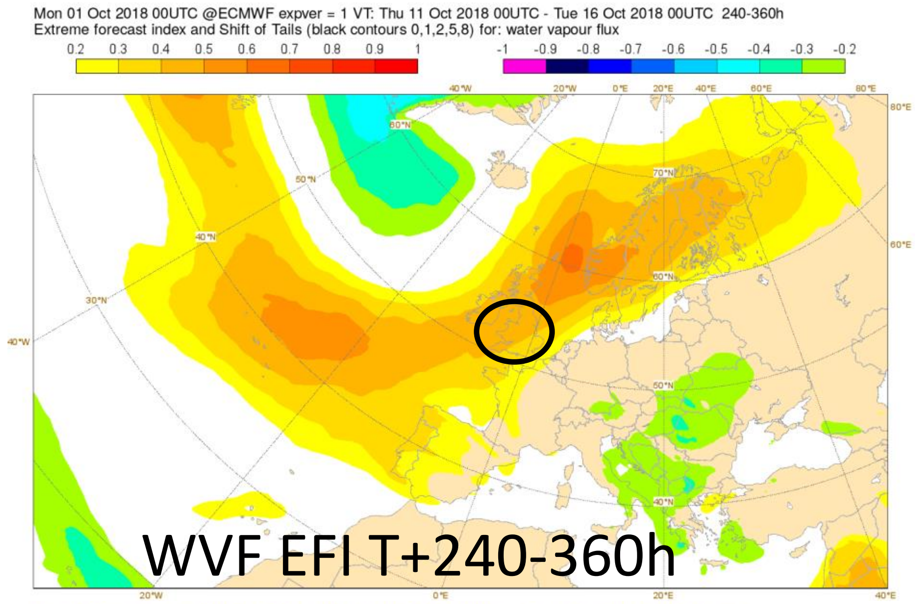
360h interval: parameters 2ti, tpi, 10swi

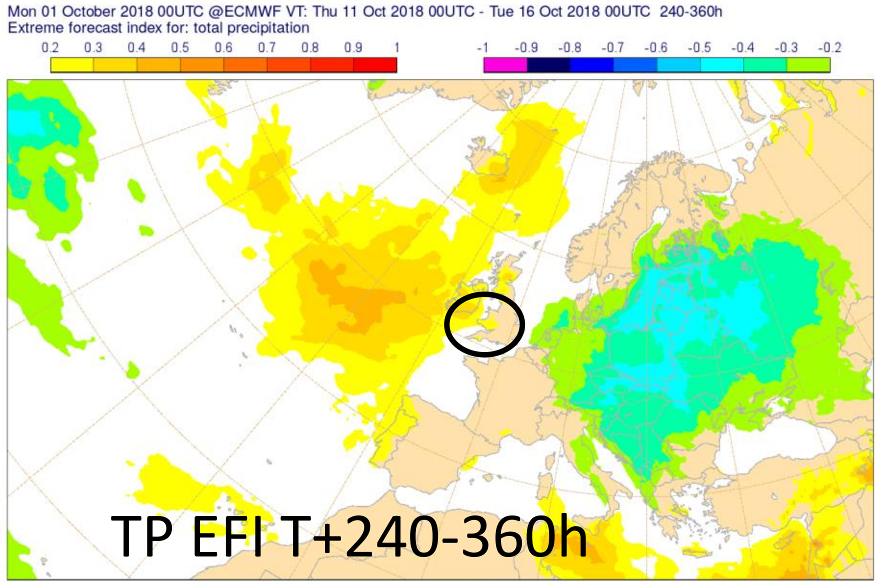
- 00UTC: 000-360

* available since 19th June 2012

** available since 12th May 2015

EFI for water vapour flux (coming soon)





Water vapour flux [$kgm^{-1}s^{-1}$] - magnitude of the combined vertical integrals of the eastward and northward water vapour flux components:

$$wvf = \sqrt{viwve^2 + viwvn^2},$$

where

$$viwve = \int_{l=1}^{nlev} \frac{q_l u_l}{g} dl$$

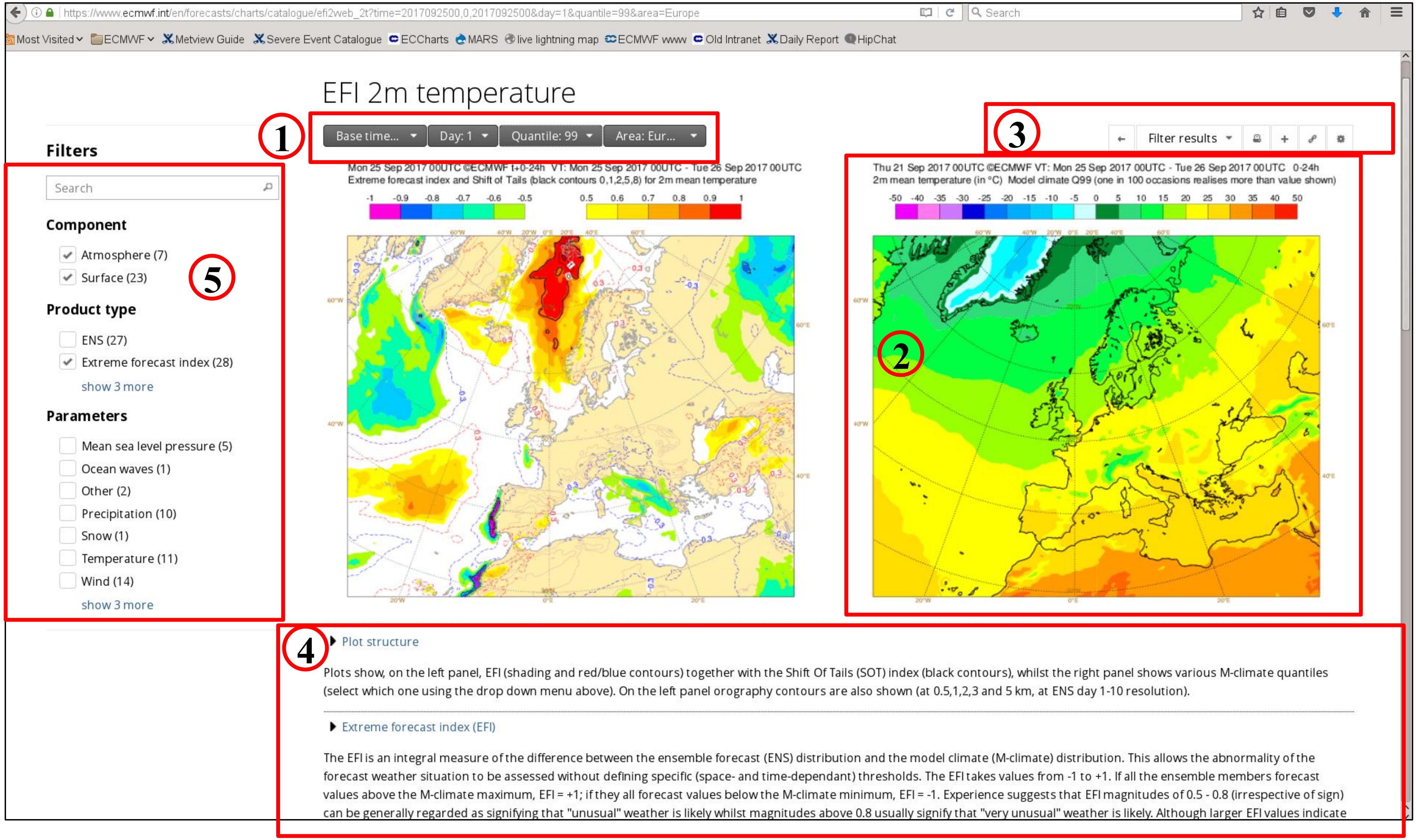
$$viwvn = \int_{l=1}^{nlev} \frac{q_l v_l}{g} dl$$

are vertical integrals of eastward water vapour flux and northward water vapor flux respectively. Here, q_l is specific humidity at model level *l*, u_l and v_l are the zonal and meridional components of the wind at level *l* and *g* is the acceleration of gravity.

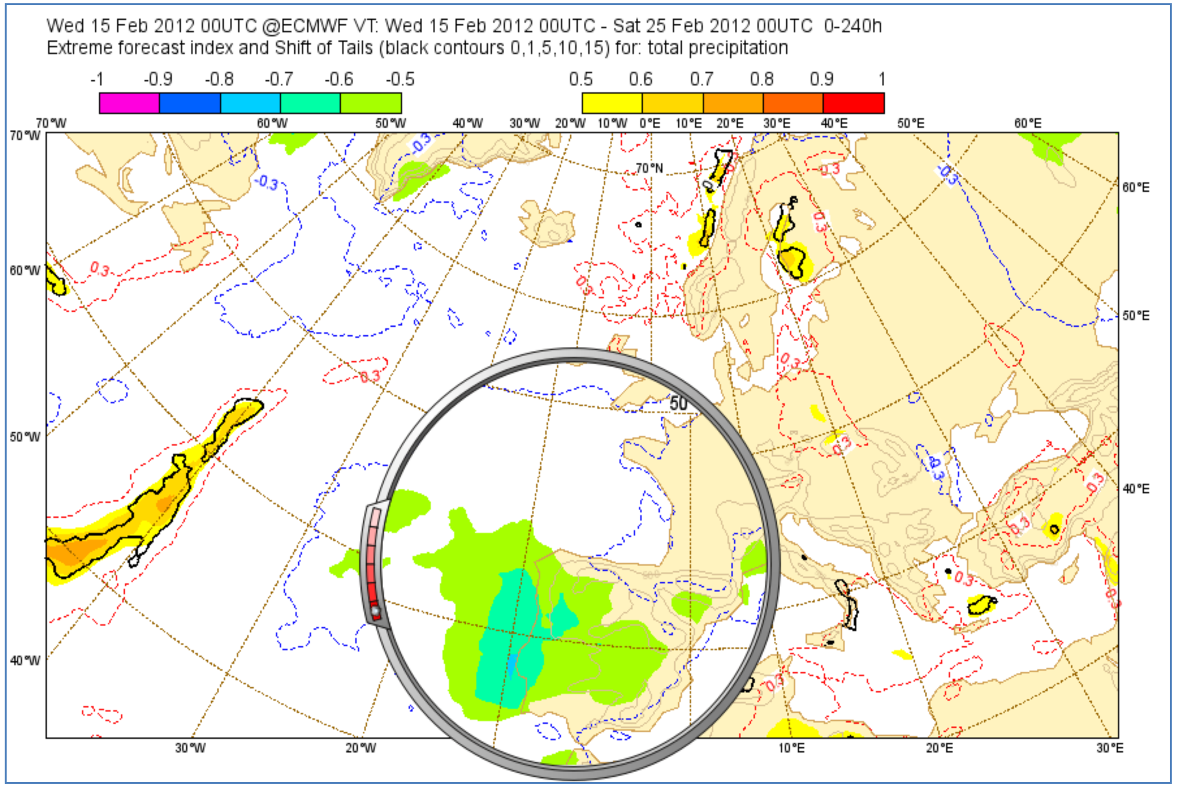
- The example shows the storm Callum which caused floods in Wales

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

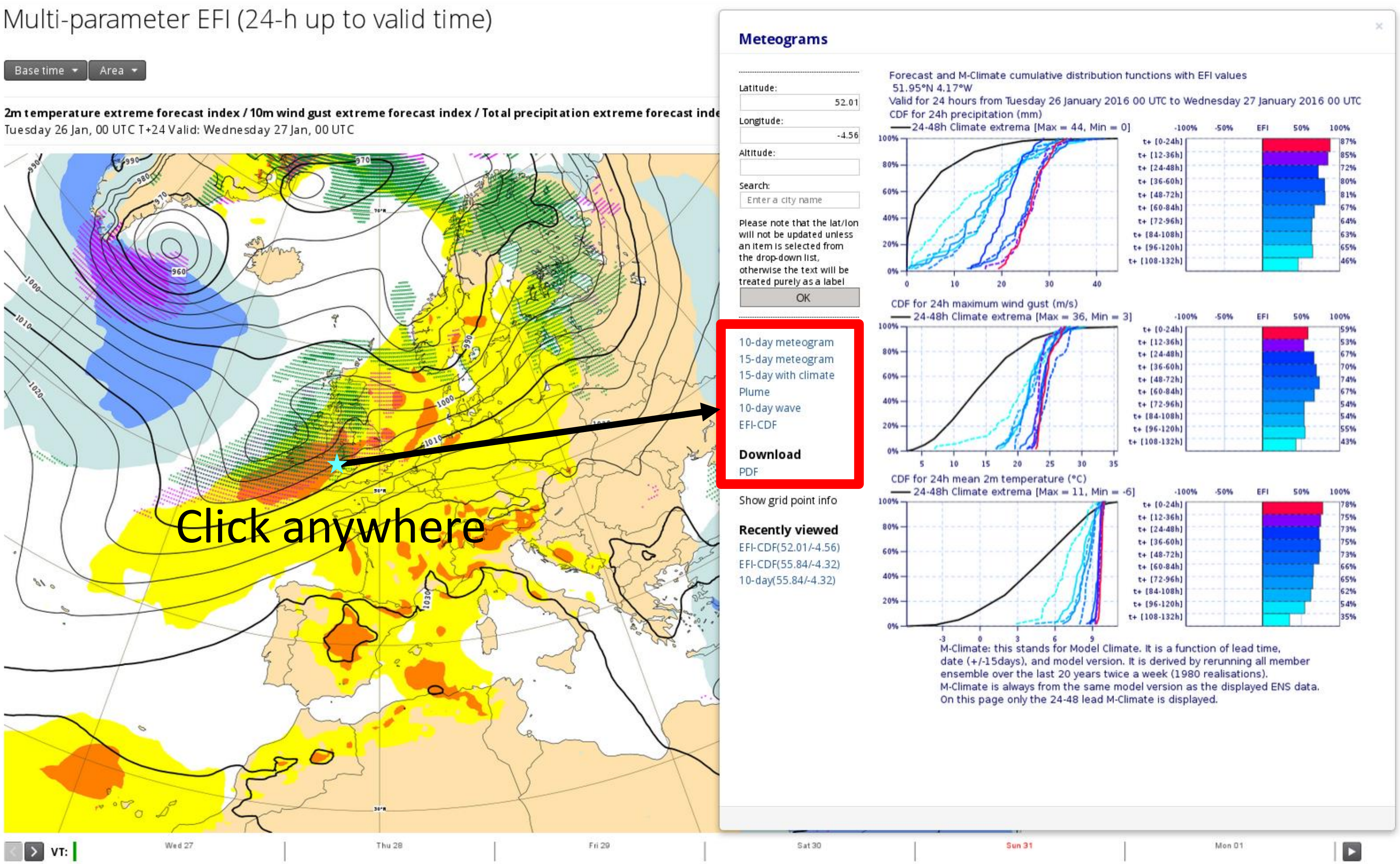


A case of severe drought in Portugal in 2011-2012

- For 24-hour accumulations negative EFI for precipitation does not make sense because precipitation 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 weather for a relatively prolonged period of time, e.g. 10 or 15 days.

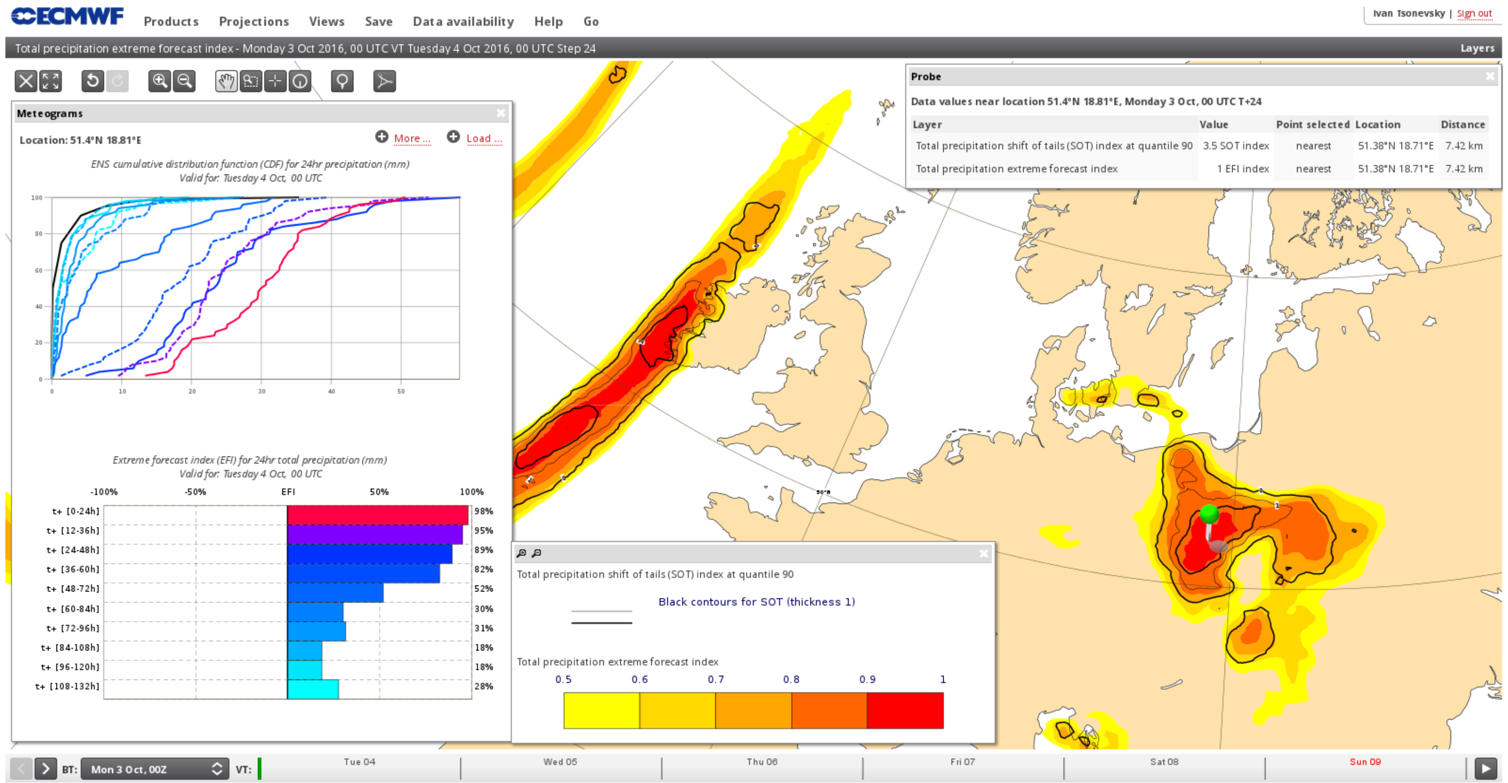
Clickable charts

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



ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

EFI on the ecCharts



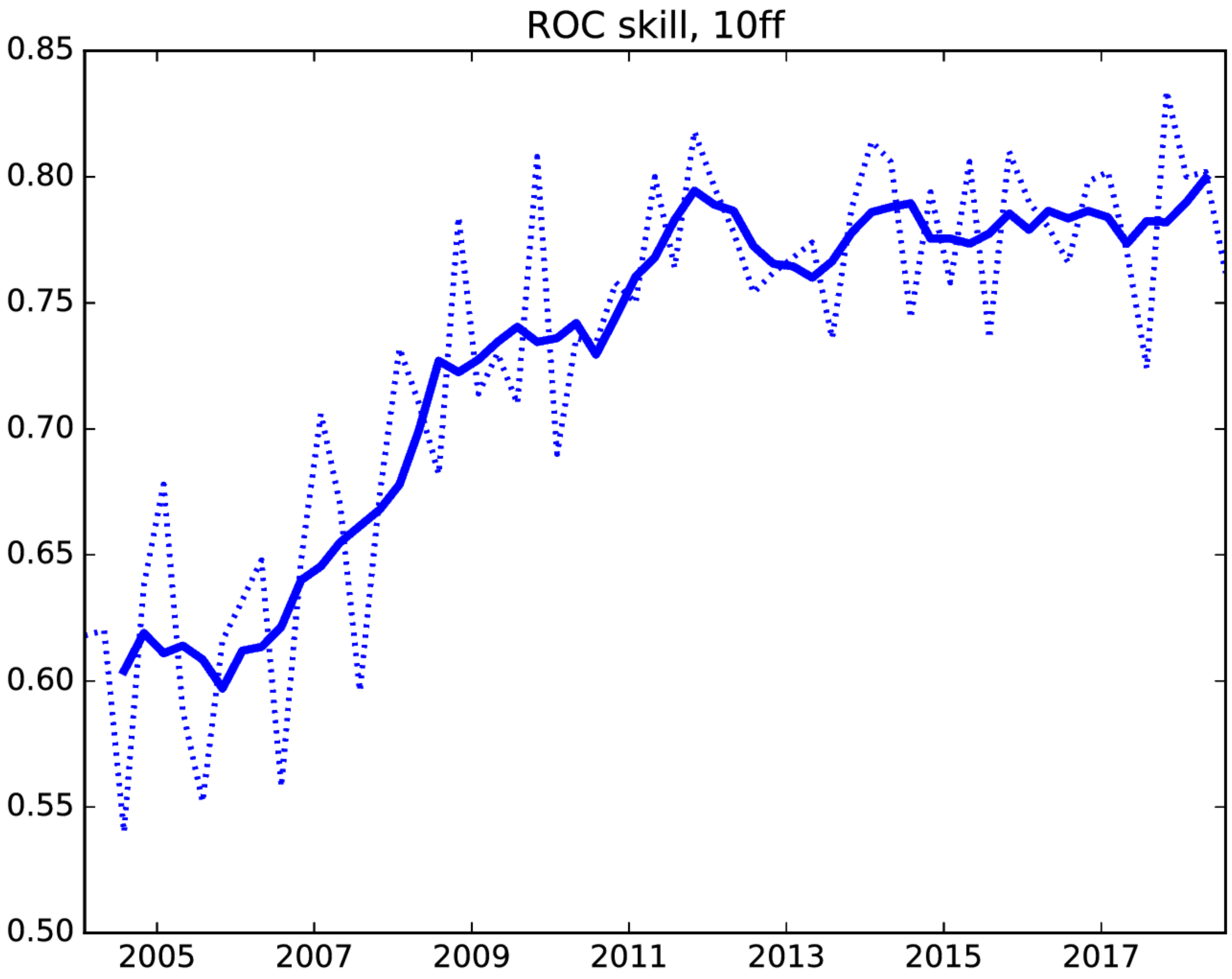
- EFI & SOT can be accessed via ecCharts at http://wrep.ecmwf.int/forecaster/.
- CDFs and EFI bar plot for a given location can be displayed as well, just for (2t, 2tmin, 2tmax,10fg, tp) at the moment. More will be added soon.
- M-climate is available as well.

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.
- $EFI\ skill\ score = \frac{score_{forecast} - score_{reference}}{score_{perfect\ forecast} - score_{reference}} = \frac{ROCA_f - 0.5}{1 - 0.5} = 2ROCA_f - 1$

  0 → no skill, 1 → perfect score
- The verification is done for 3 parameters: 2m mean temperature, 10m mean wind speed and total precipitation

EFI Verification



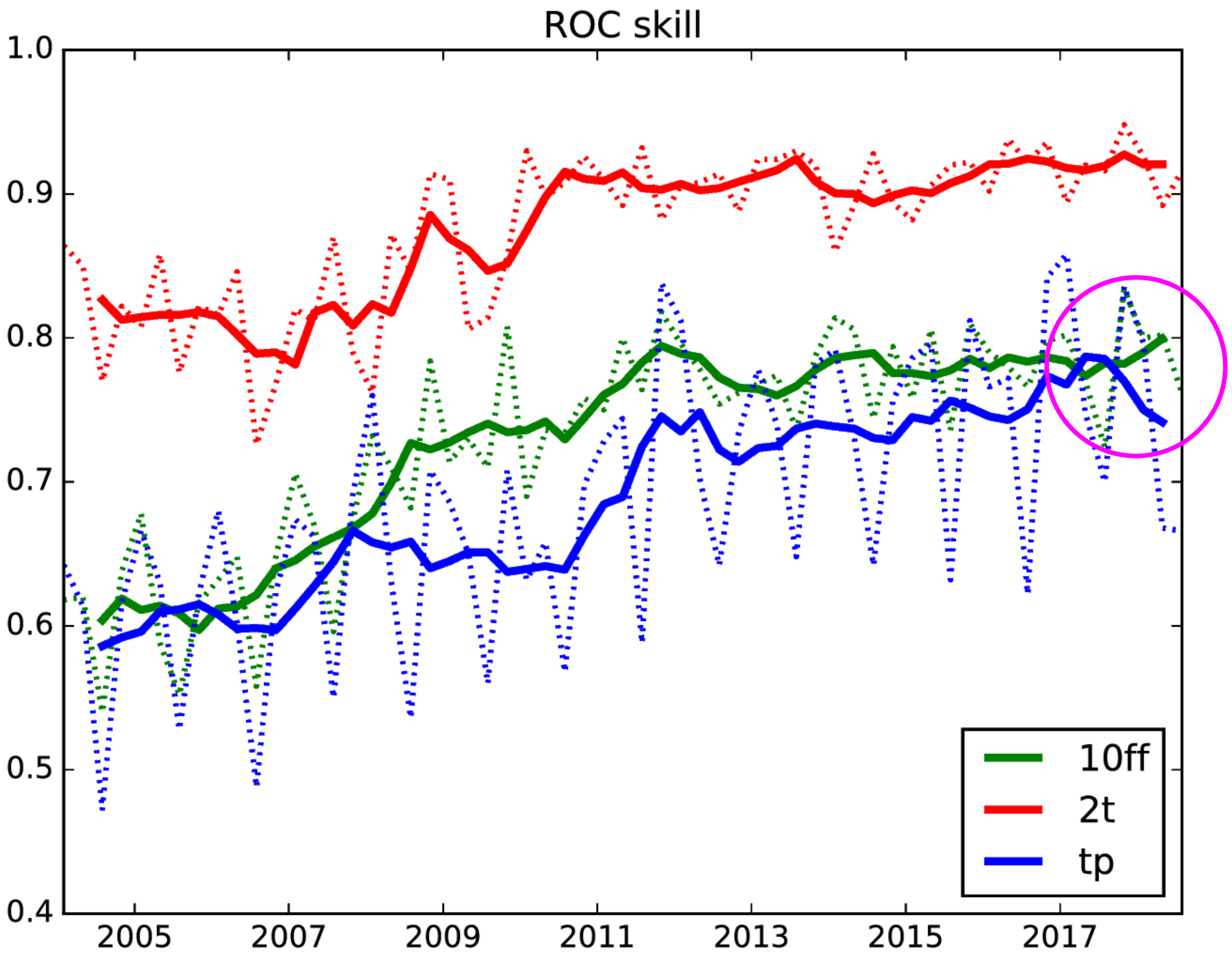
EFI Skill = 2*ROCA-1

EFI Skill = 0 no skill

EFI Skill = 1 perfect score

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

EFI Verification

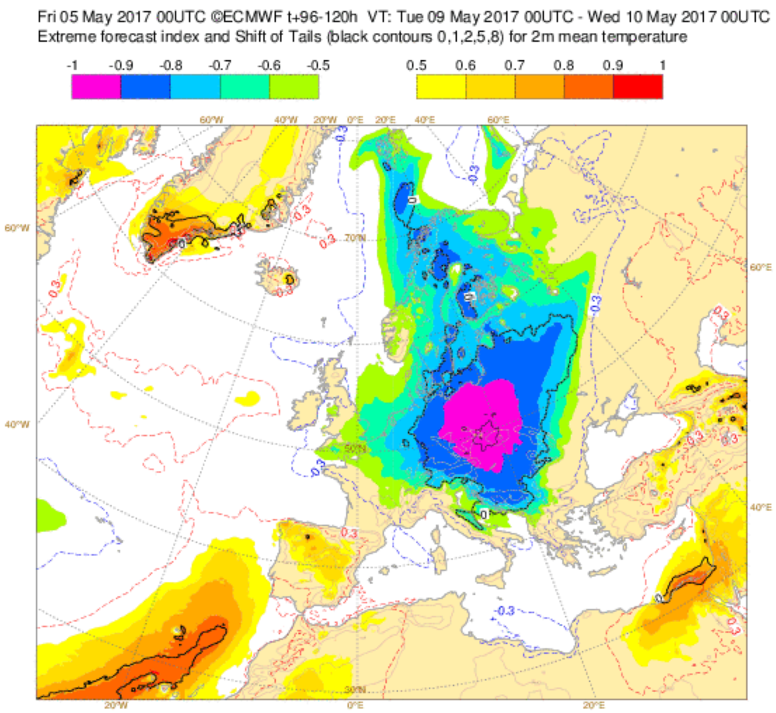


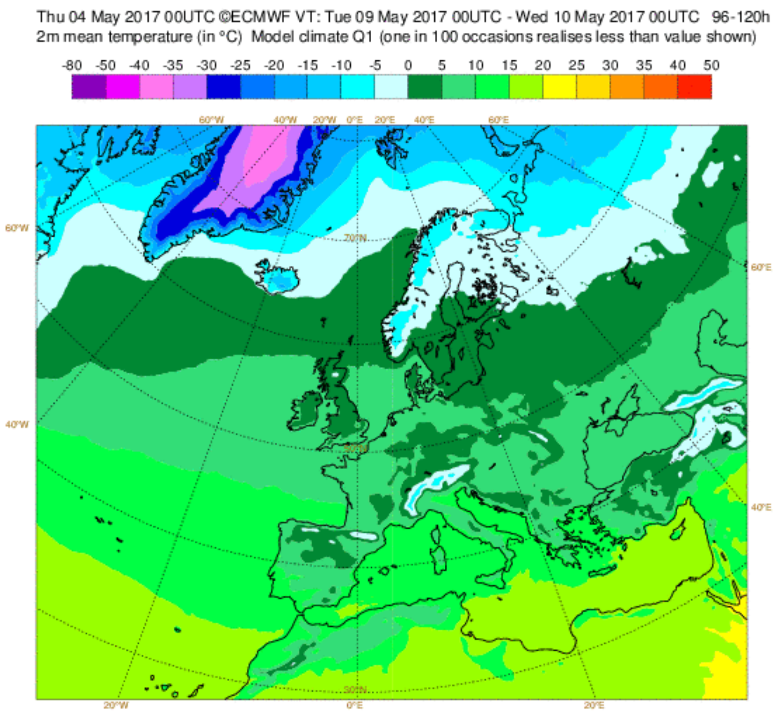
- Solid curves show a four-season running mean and dashed curves show seasonal EFI skill scores for 2m mean temperature (2t), 10 metre mean wind speed (10ff) and total precipitation (tp) for day 4 (t+72-96h for 00UTC).
- The EFI for 2m temperature is more skilful than EFI for the other two parameters.
- Total precipitation EFI skill has dropped recently due to low predictability following a period of very high predictability.

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**.**

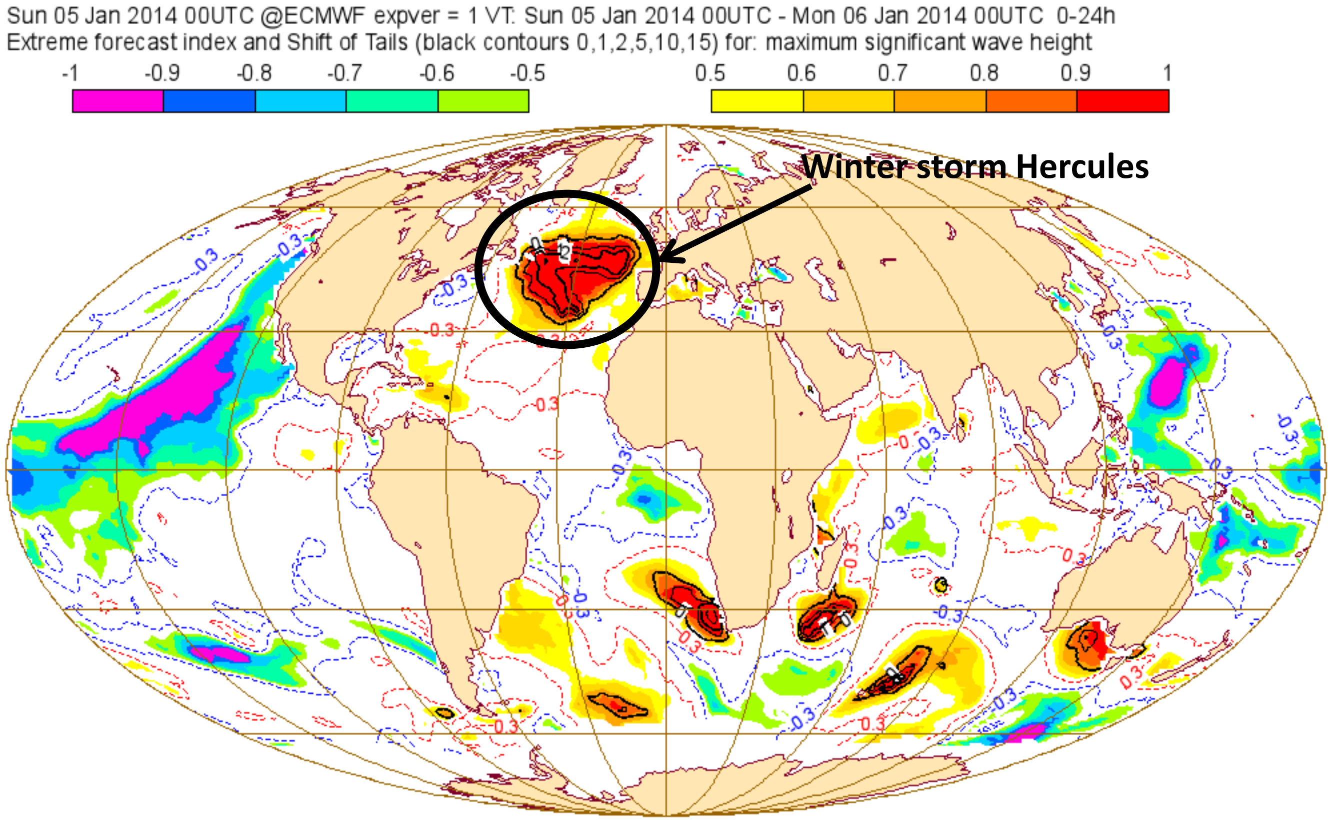
Seasonal trend issue





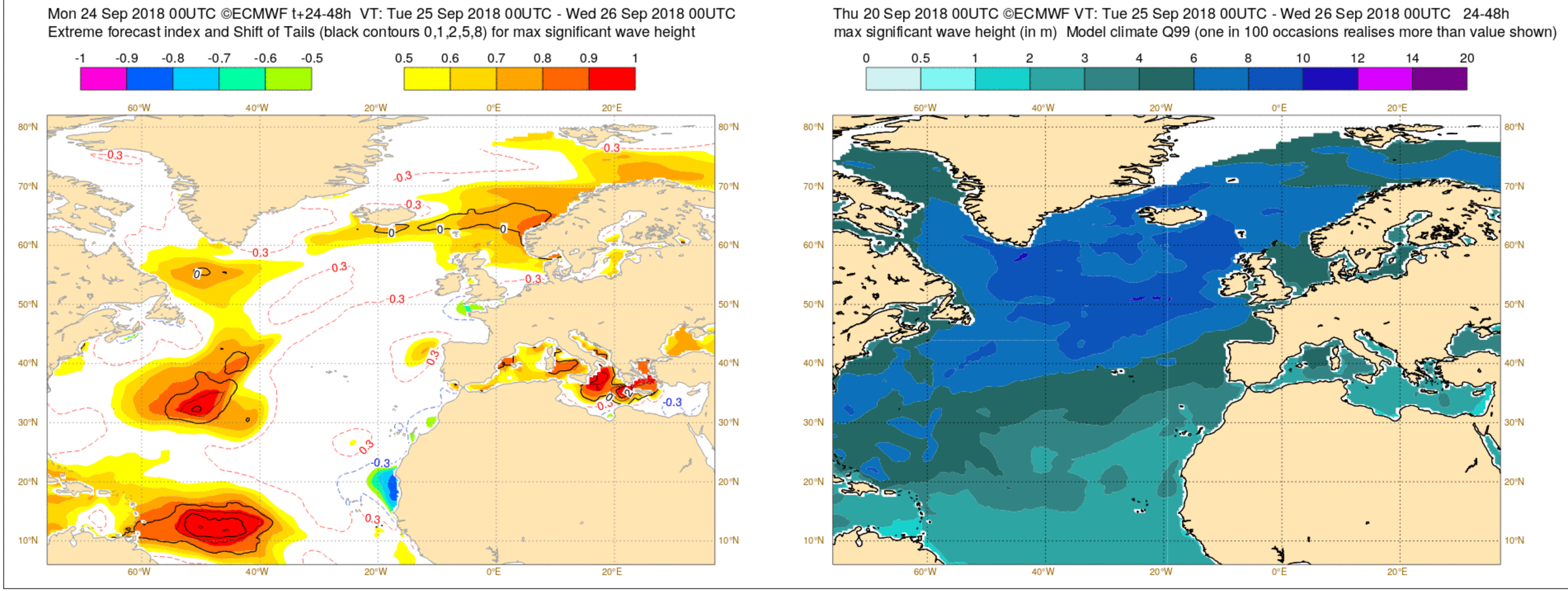
On the animation, the EFI valid for the same date is becoming less extreme although the forecasts are similar because the M-climate is becoming colder for shorter lead times. Suddenly the EFI jumps to more extreme values again after the update of the M-climate because the model climatology appears warmer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

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.

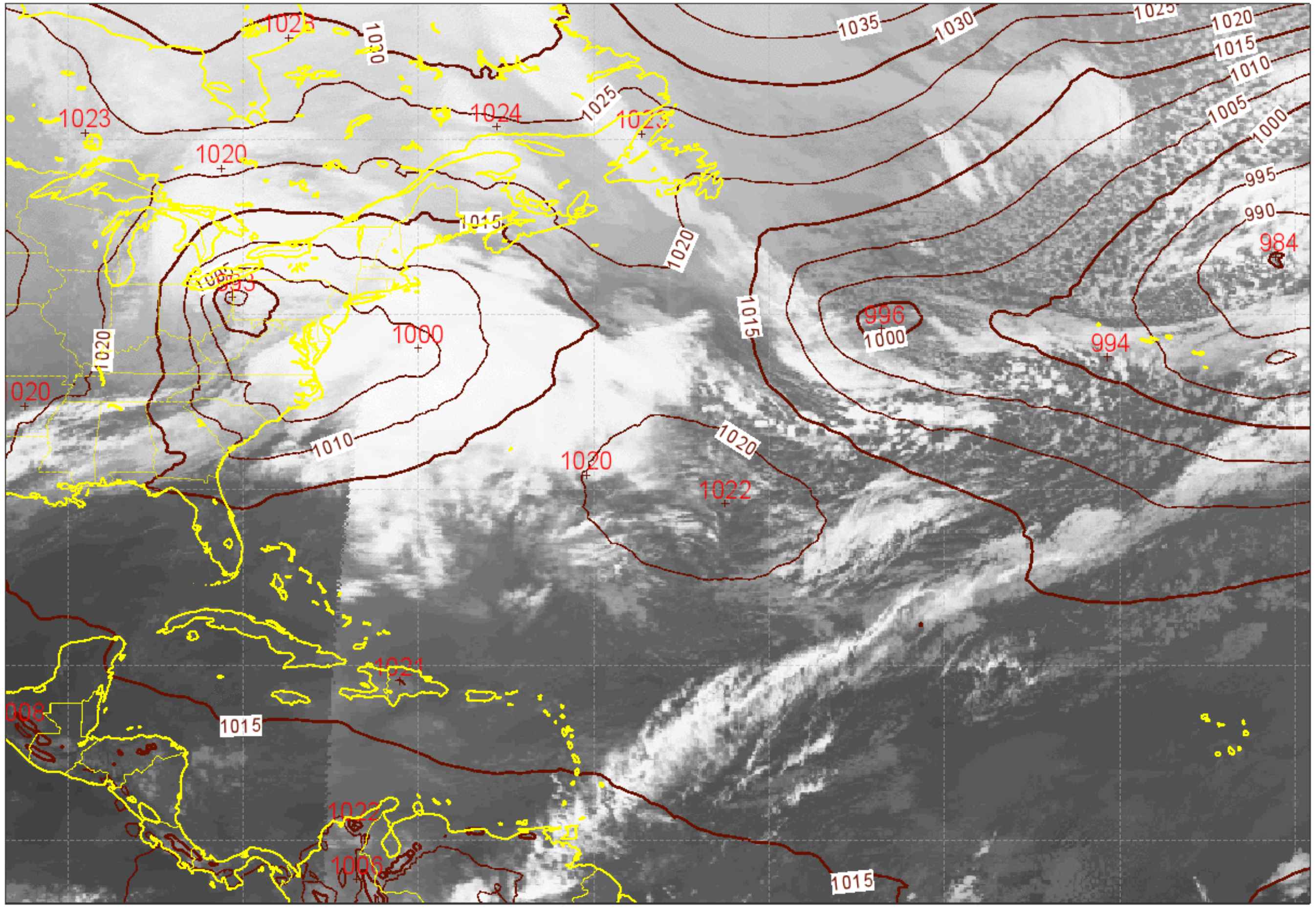
EFI for waves



- High values of the EFI and SOT over the North Atlantic are related to two tropical storms:
  - Tropical Storm Leslie to the north and
  - Tropical storm Kirk heading to the Caribbean

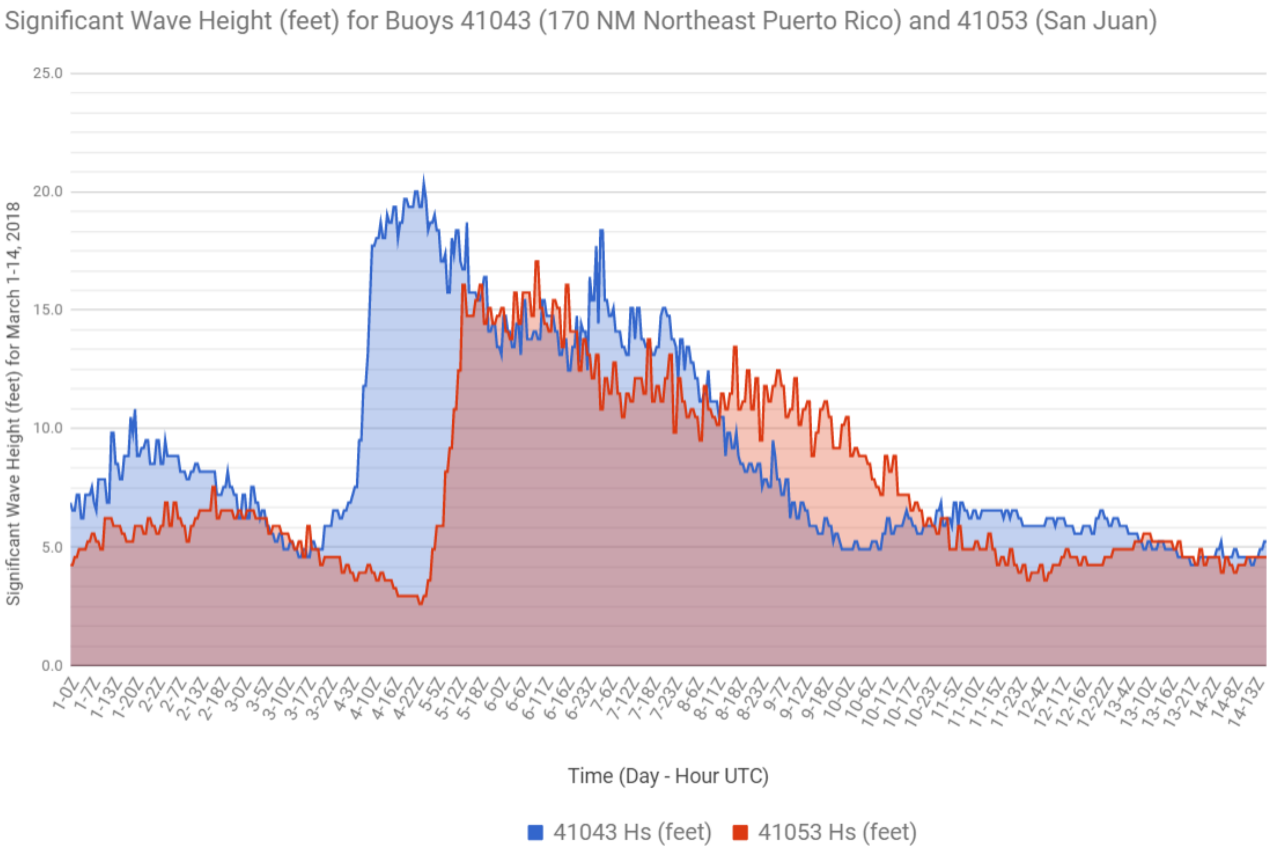
Historical Swell Event - March 4-7, 2018

Satellite IR and MSLP AN 02/03/2018 00 UTC



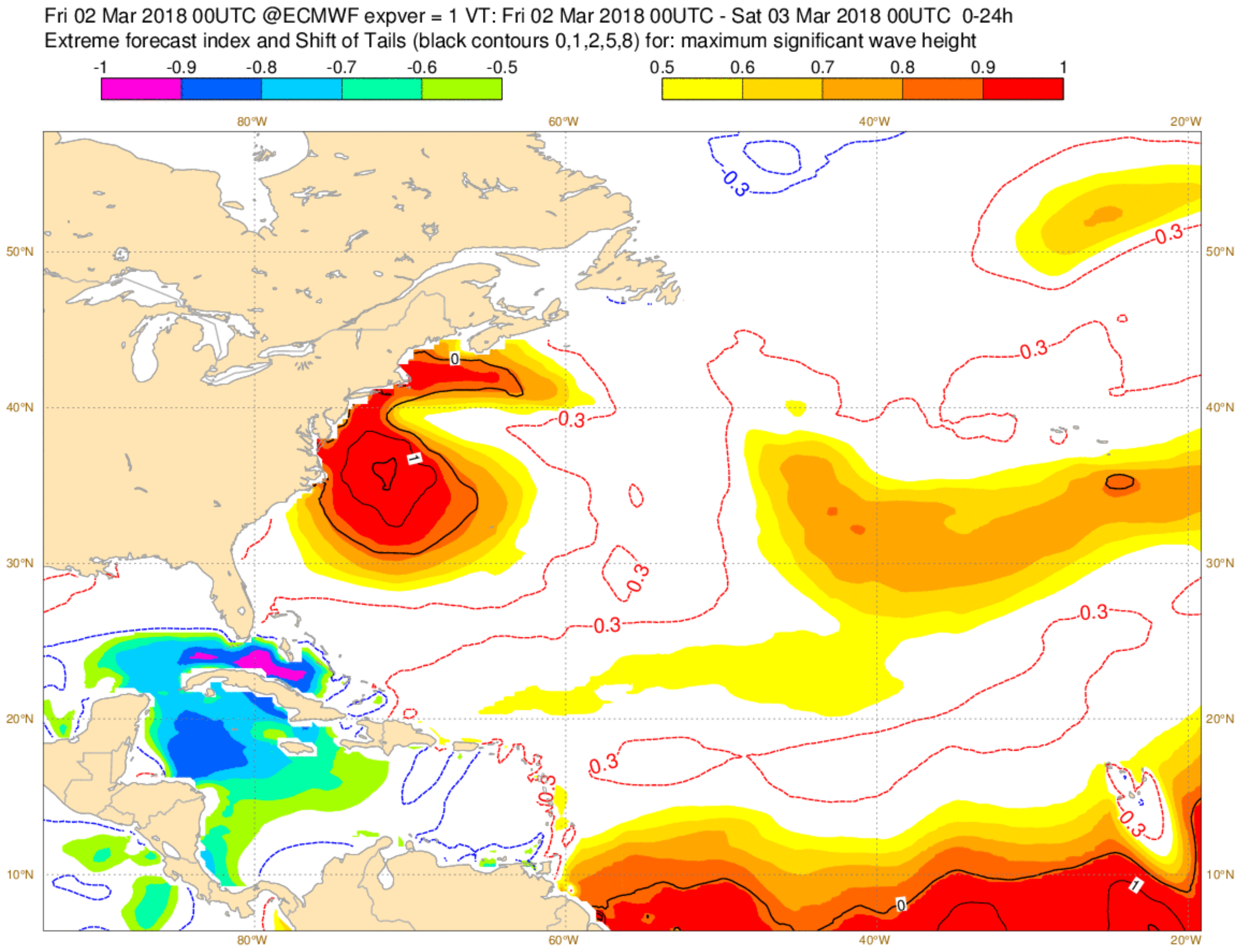
- A potent Nor’easter moved over the Northeast Coast of the US on March 2, 2018, rapidly intensifying into a 973 hPa low. This low pressure system then moved over the northwest Atlantic Ocean during the following days.
- Hurricane force winds generated waves over 12 m. Large swells travelled across much of the north Atlantic basin for several days. These large and very long period swells propagated towards the south-southeast across the basin affecting the Bahamas, Greater and Lesser Antilles.

Historical Swell Event - March 4-7, 2018



- ➢ Coastal flooding and beach erosion in parts of the Caribbean, for example Puerto Rico

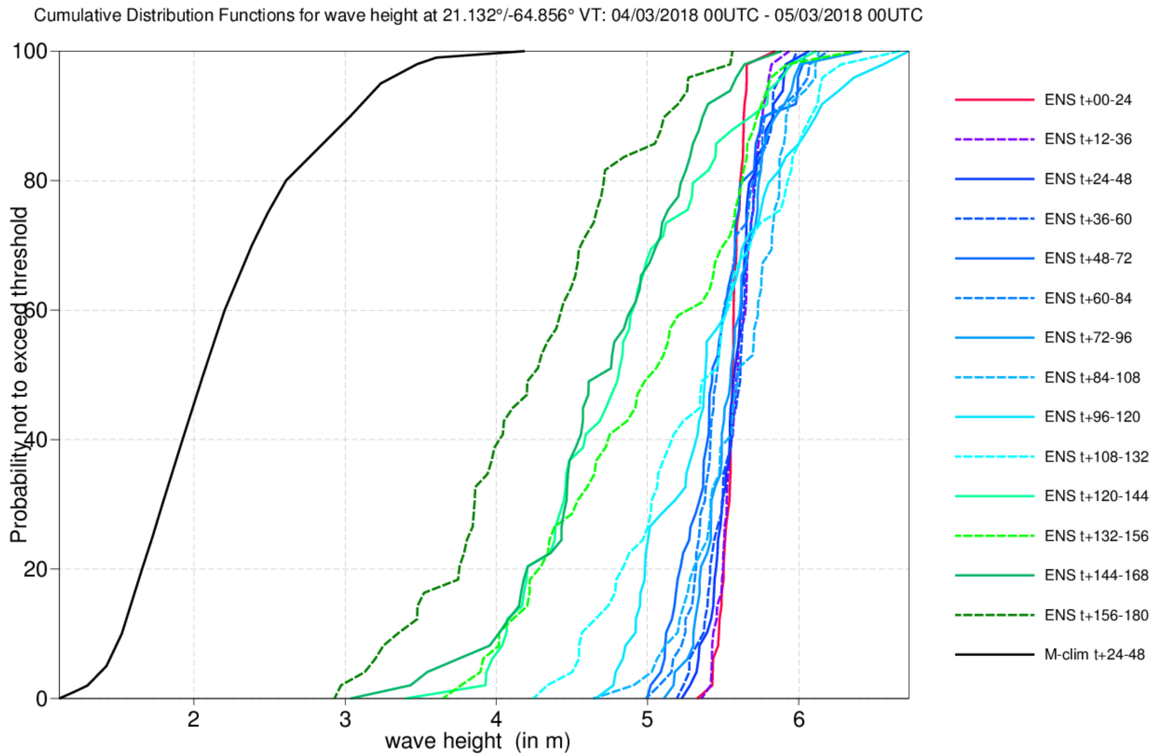
EFI for significant wave height

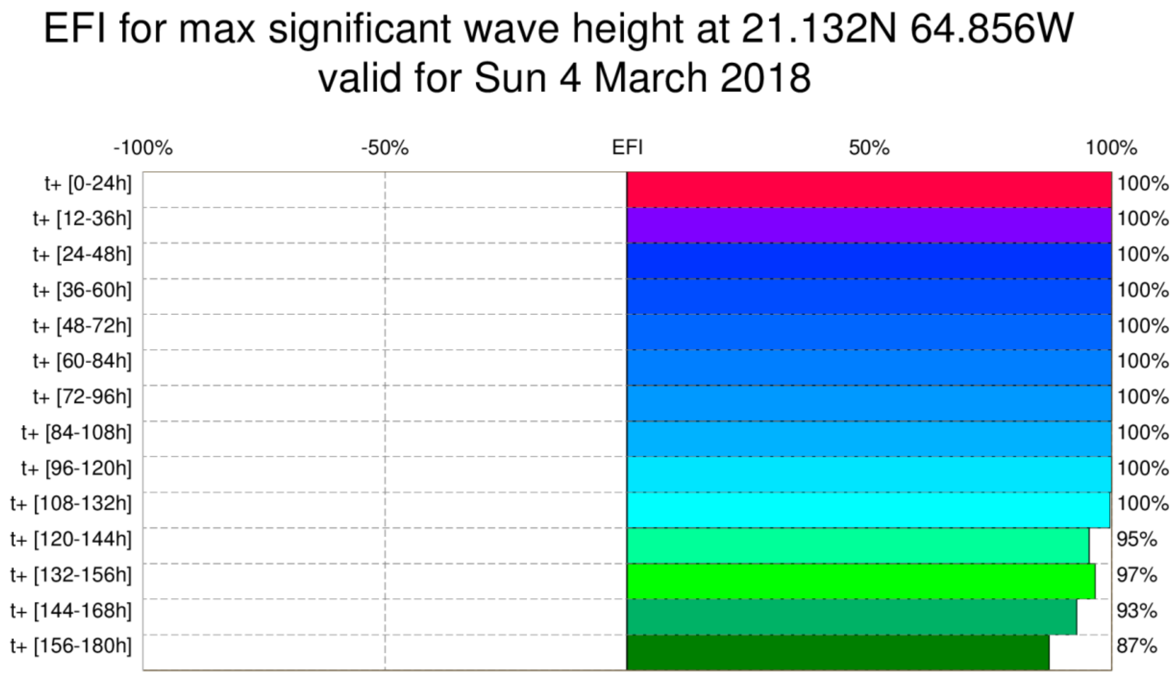


- The forecast is from 00 UTC on March, 2.
- Very high EFI values (close to 1) propagate from the east US coast in S-SE direction towards the eastern Caribbean islands.
- Large positive SOT – an indication of a possible very extreme event.

CDFs and EFI


SWH over 5-6 m
SWH over 5 m
Turks and Caicos Islands
Haiti
Port-au-Prince
Dominican Republic
Santo Domingo
Puerto Rico
British Virgin Islands
US Virgin Islands
Anguilla
St Kitts & Nevis
Antigua and Barbuda
Montserrat
Guadeloupe


Cumulative Distribution Functions for wave height at 21.132°/-64.856° VT: 04/03/2018 00UTC - 05/03/2018 00UTC
Probability not to exceed threshold
wave height (in m)
ENS t+00-24
ENS t+12-36
ENS t+24-48
ENS t+36-60
ENS t+48-72
ENS t+60-84
ENS t+72-96
ENS t+84-108
ENS t+96-120
ENS t+108-132
ENS t+120-144
ENS t+132-156
ENS t+144-168
ENS t+156-180
M-clim t+24-48


EFI for max significant wave height at 21.132N 64.856W
valid for Sun 4 March 2018
-100%
-50%
EFI
50%
100%
t+ [0-24h] 100%
t+ [12-36h] 100%
t+ [24-48h] 100%
t+ [36-60h] 100%
t+ [48-72h] 100%
t+ [60-84h] 100%
t+ [72-96h] 100%
t+ [84-108h] 100%
t+ [96-120h] 100%
t+ [108-132h] 100%
t+ [120-144h] 95%
t+ [132-156h] 97%
t+ [144-168h] 93%
t+ [156-180h] 87%

EFI/SOT for forecasting severe convection

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

$$CAPE = \int_{z_{LFC}}^{z_{EL}} g\left(\frac{\theta_{e,up} - \bar{\theta}_{e,sat}}{\bar{\theta}_{e,sat}}\right) dz$$

- CAPE-shear Parameter (CAPES):

$$CAPES = WS_{l_1}^{l_2}\sqrt{CAPE}$$

  - $WS_{l_1}^{l_2}$ - bulk wind shear between l_1=925 hPa and l_2=500 hPa;
  - $w_{max} = \sqrt{2CAPE}$ 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.

Some considerations and future plans

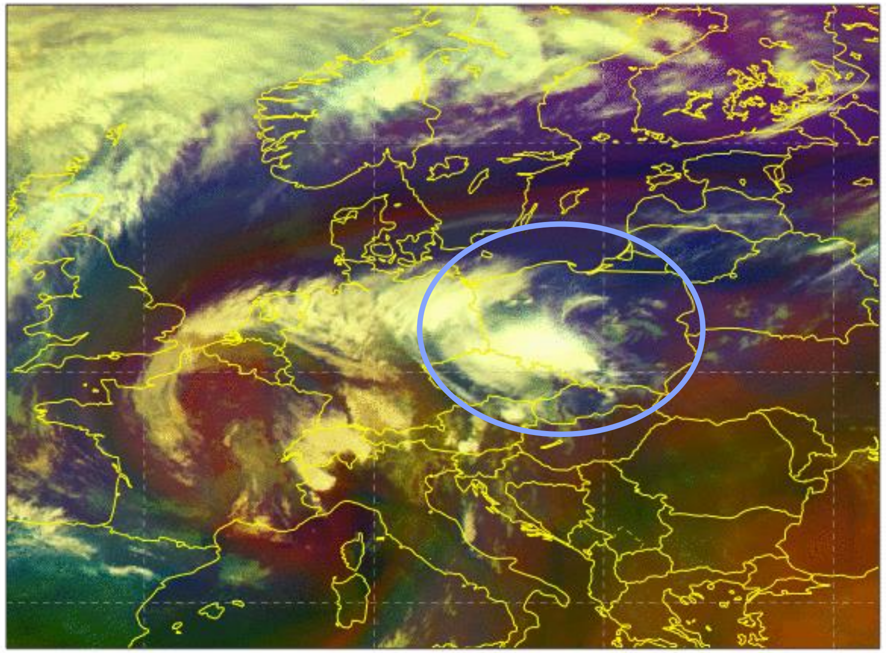
- The EFI provides signals of anomalous weather relative to the model climatology.
    - ✓ very low CAPE values (<10 J/kg) are filtered out to avoid insignificant signals in the areas of low CAPE values in the M-climate (e.g. Arctic in winter)
    - ✓ severe convection unlikely when climatological values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

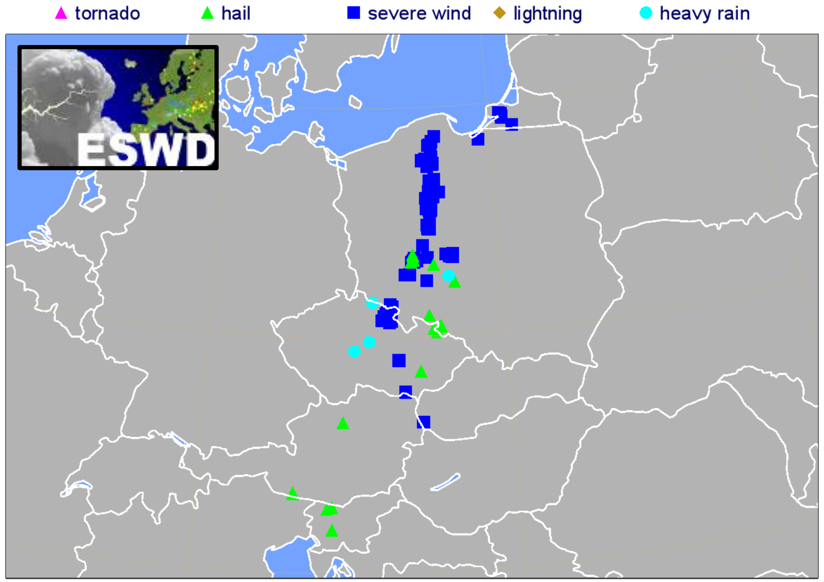
- 5 people killed during an outbreak of severe thunderstorms on Friday, 11 August 2017

Analysis

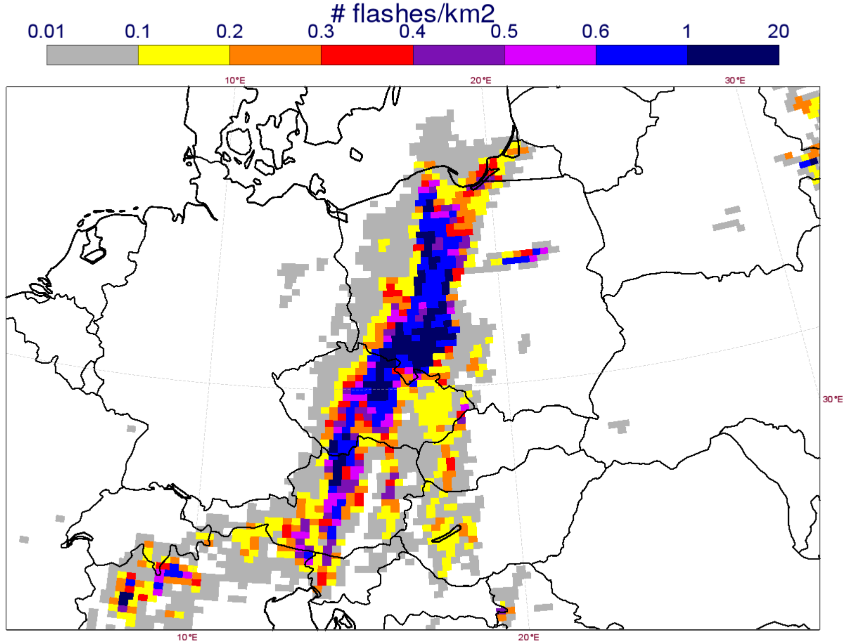
11 August 2017 00:00Z



Severe weather reports for Friday 11 Aug 2017

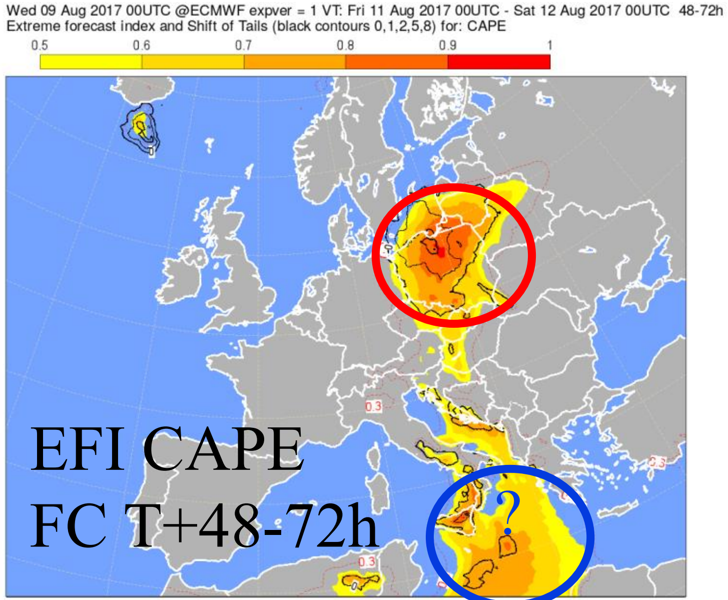


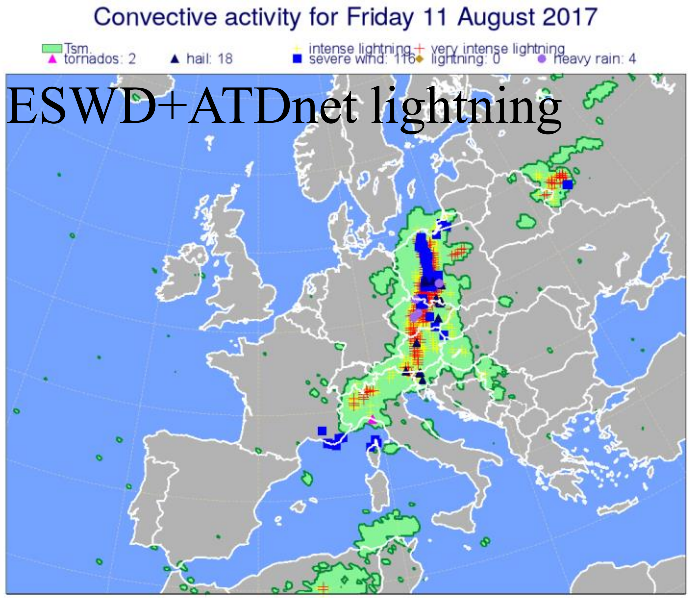
ATDnet Lightning density for Friday 11 August 2017

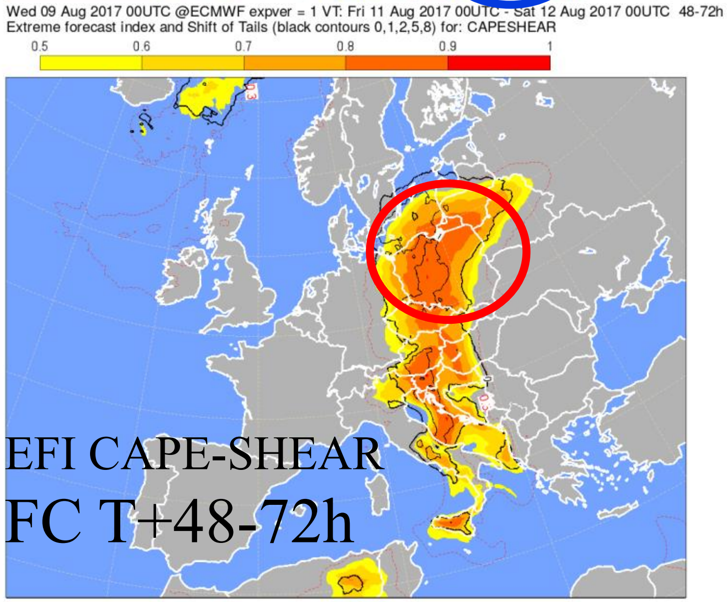


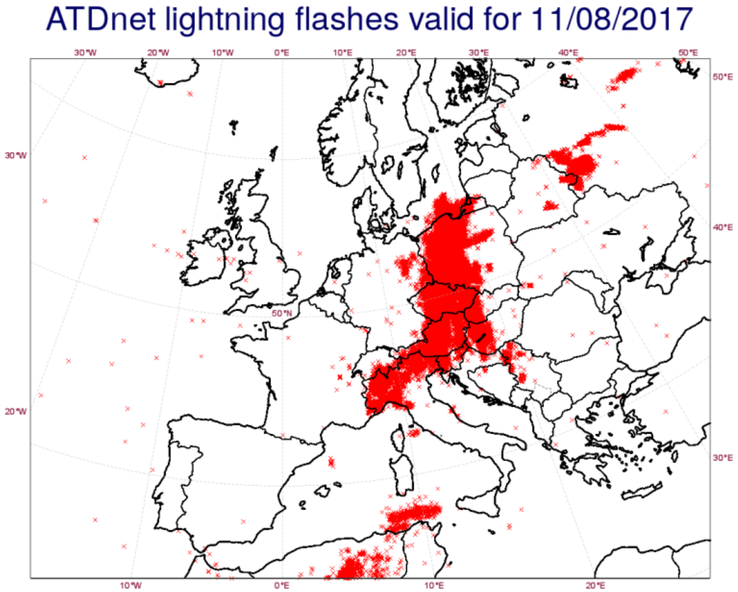
- On the eastern flank of upper low over Poland, a combination of very moist air in the boundary layer and EML with lapse rates > 7 °C/km
- Favourable synoptic-scale conditions

Forecast v. observations









Further Reading:

- ✓ User Guide to ECMWF forecast products: https://confluence.ecmwf.int/display/FUG/Forecast+User+Guide
- ✓ **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.
- ✓ **Tsonevsky, I.,** C. A. Doswell III, H. E. Brooks, 2018: Early Warnings of Severe Convection Using the ECMWF Extreme Forecast Index, *Wea. Forecasting,* **33,** 857-871. (Open Access)

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

https://journals.ametsoc.org/doi/pdf/10.1175/WAF-D-18-0030.1