Forecasting Extreme Events

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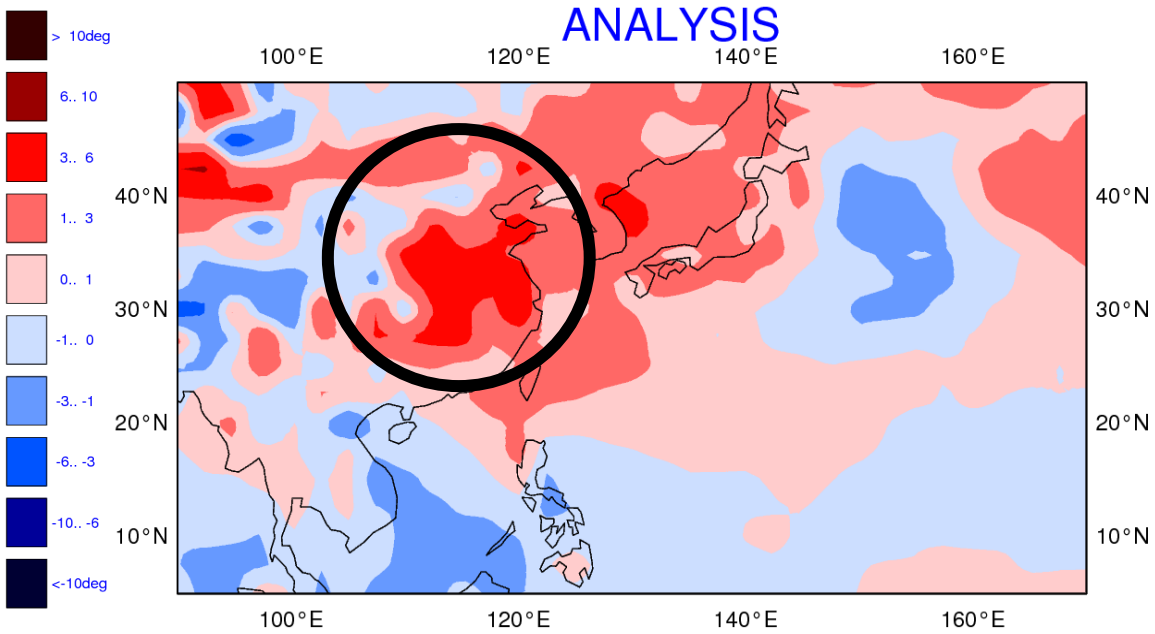
Outline

- Introduction
- How can we define what is extreme?
  - Model climate (M-climate);
- The Extreme Forecast Index (EFI)
- Use and interpretation of the EFI – severe weather cases in the tropics and extra-tropics

A heat wave, China, summer 2013

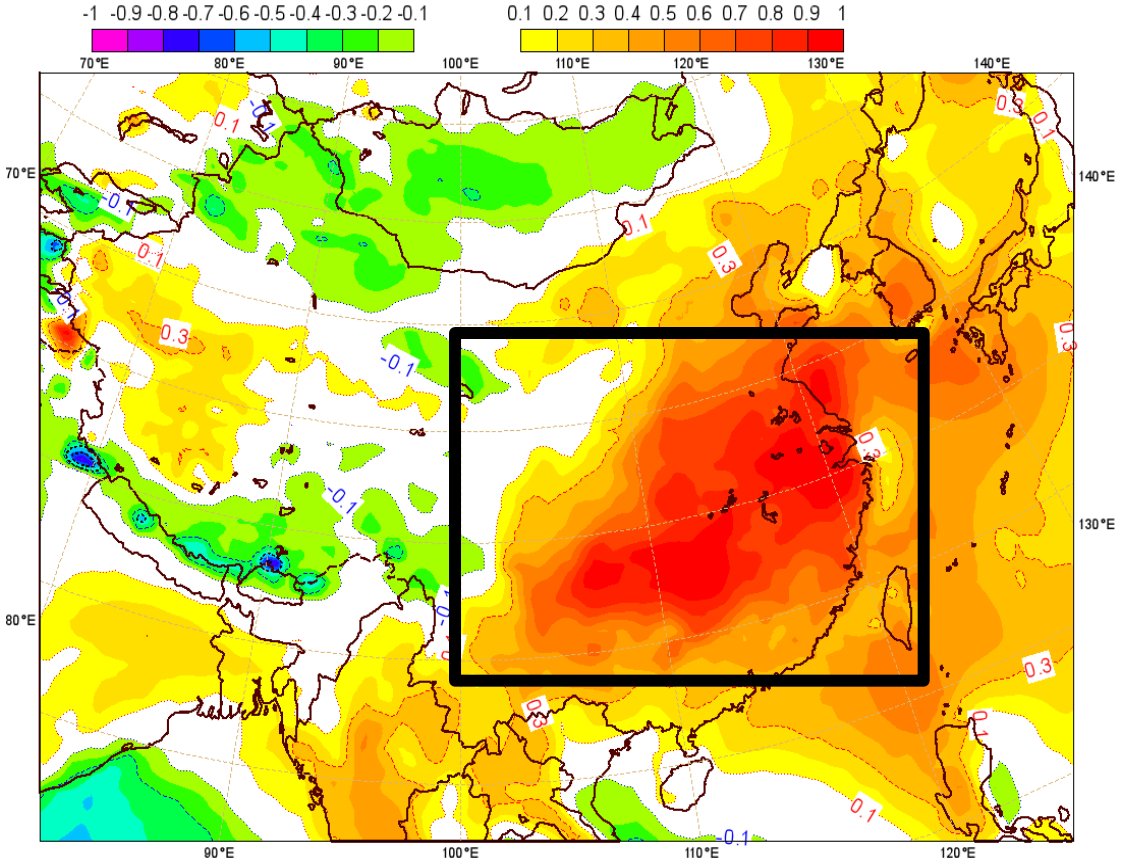
05-11.08.2013



A stationary subtropical high caused a persistent heat wave with record-breaking temperatures in China at the end of July and beginning of August 2013. Shanghai's meteorological bureau recorded a new record-breaking temperature of 40.8 C on 7th August.

A heat wave, China, summer 2013

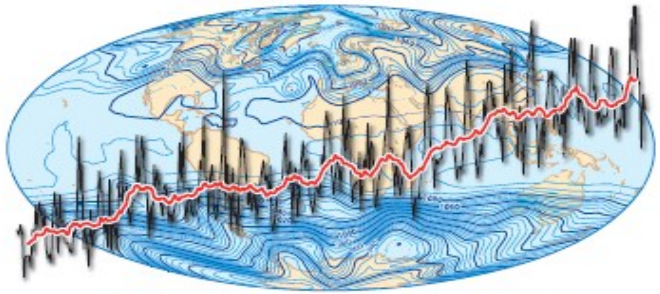
26/07/2013 00 UTC; Extreme Forecast Index (EFI) for 2-metre mean temperature
T+240-360h forecast valid from 05/08/2013 00UTC to 10/08/2013 00UTC



- **An unusually strong signal (EFI ~ 1) of extremely hot weather 10-days in advance**

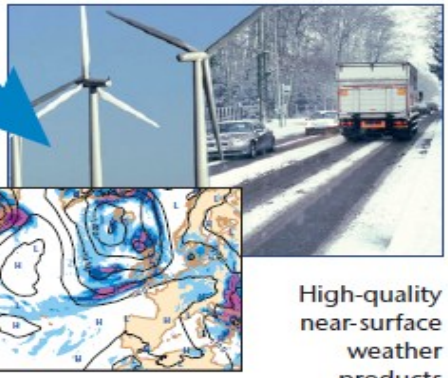
ECMWF

The ECMWF Strategy 2011–2020

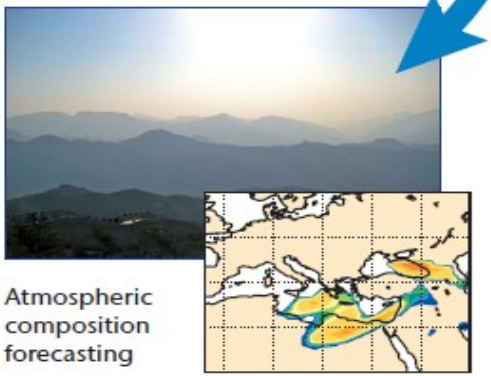


Developing the core forecasting systems

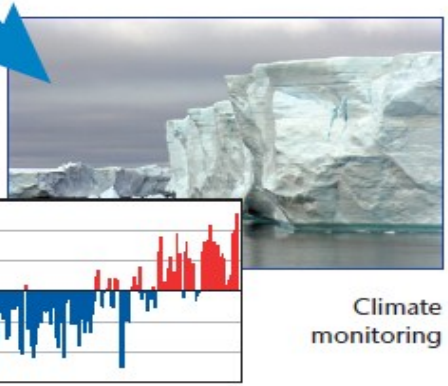
Reliable forecasts of severe weather



High-quality near-surface weather products



Atmospheric composition forecasting



Climate monitoring

How can we define what is extreme?

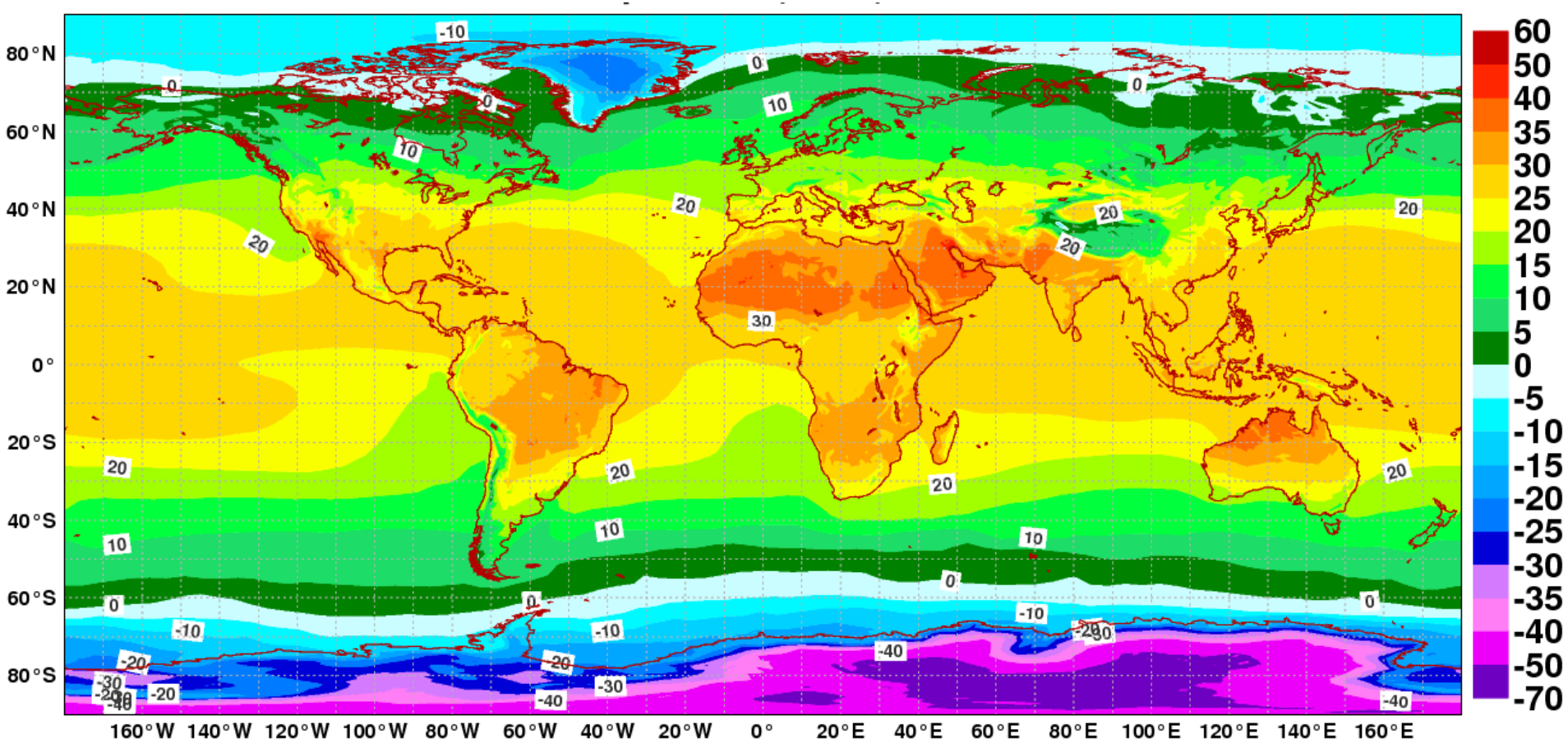
- Definition of extreme weather is highly climate dependent, it varies in space and time.
- In summer, temperatures of 35 °C are extreme in the UK but in the Sahara Desert they are not.
- Snowfall is normal in Central Europe in January but not in May.

What can be used to define 'extreme' across the globe?

- Particular Thresholds? NO
- Return Periods? YES
- We need reference threshold levels, for each weather parameter of interest, everywhere across the globe
- Return Periods from observational data are not available everywhere. However global model forecasts provide output everywhere.
- Therefore global model forecasts can be used to provide the climatology from which to extract Return-Period-type information
- Re-forecasts are performed each time a model is upgraded, to provide the relevant climatology.

Model Climate

M-climate median of 2-metre maximum temperature at the beginning of October



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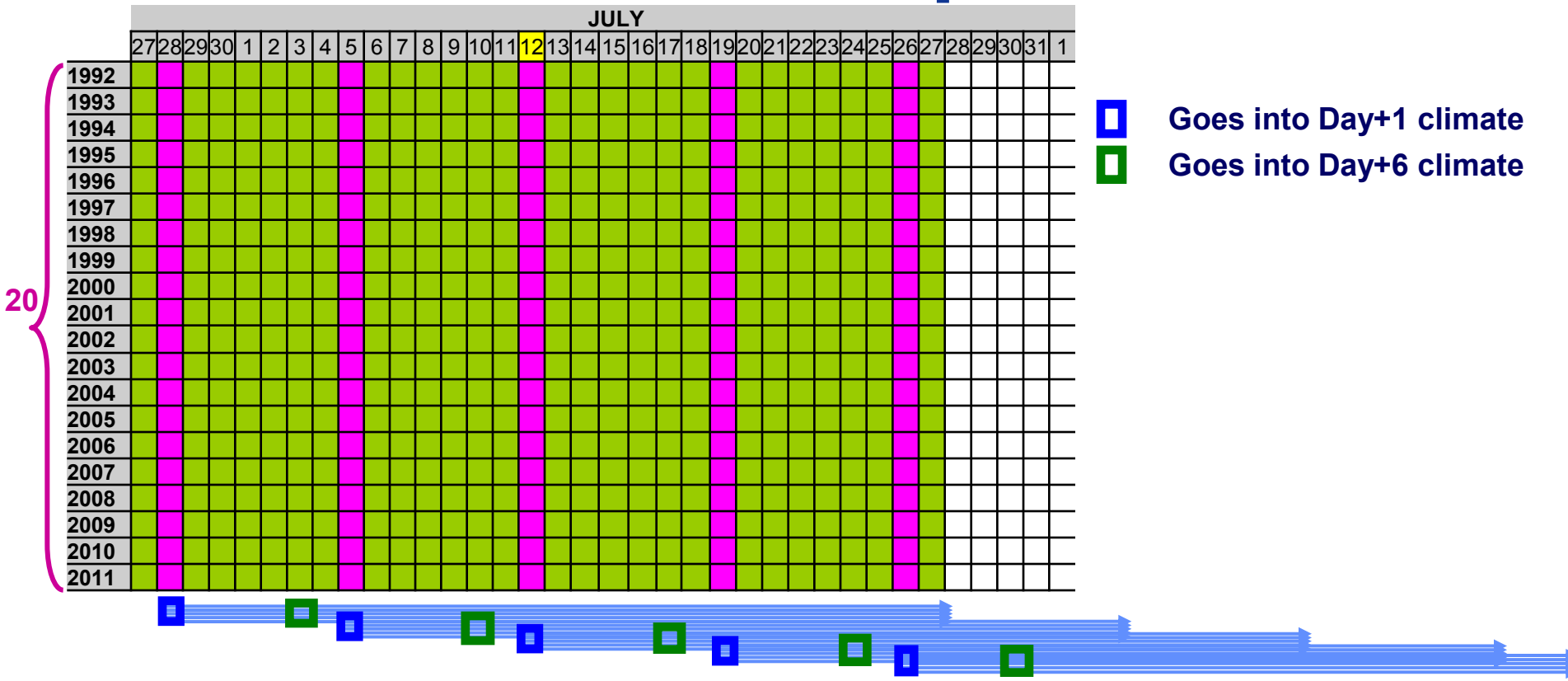
The Model Climate (M-Climate)

- 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 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 EFI and other model climate related products to any upgrade of ENS

M-Climate – schematic representation



- To provide a more 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 climate sample size is: 20 years * 5 members * 5 weekly runs = 500 re-forecast fields
- As the M-climate consists of 500 realisations, the M-climate extrema correspond, approximately, to 16-year return periods (for a month-long time windows)

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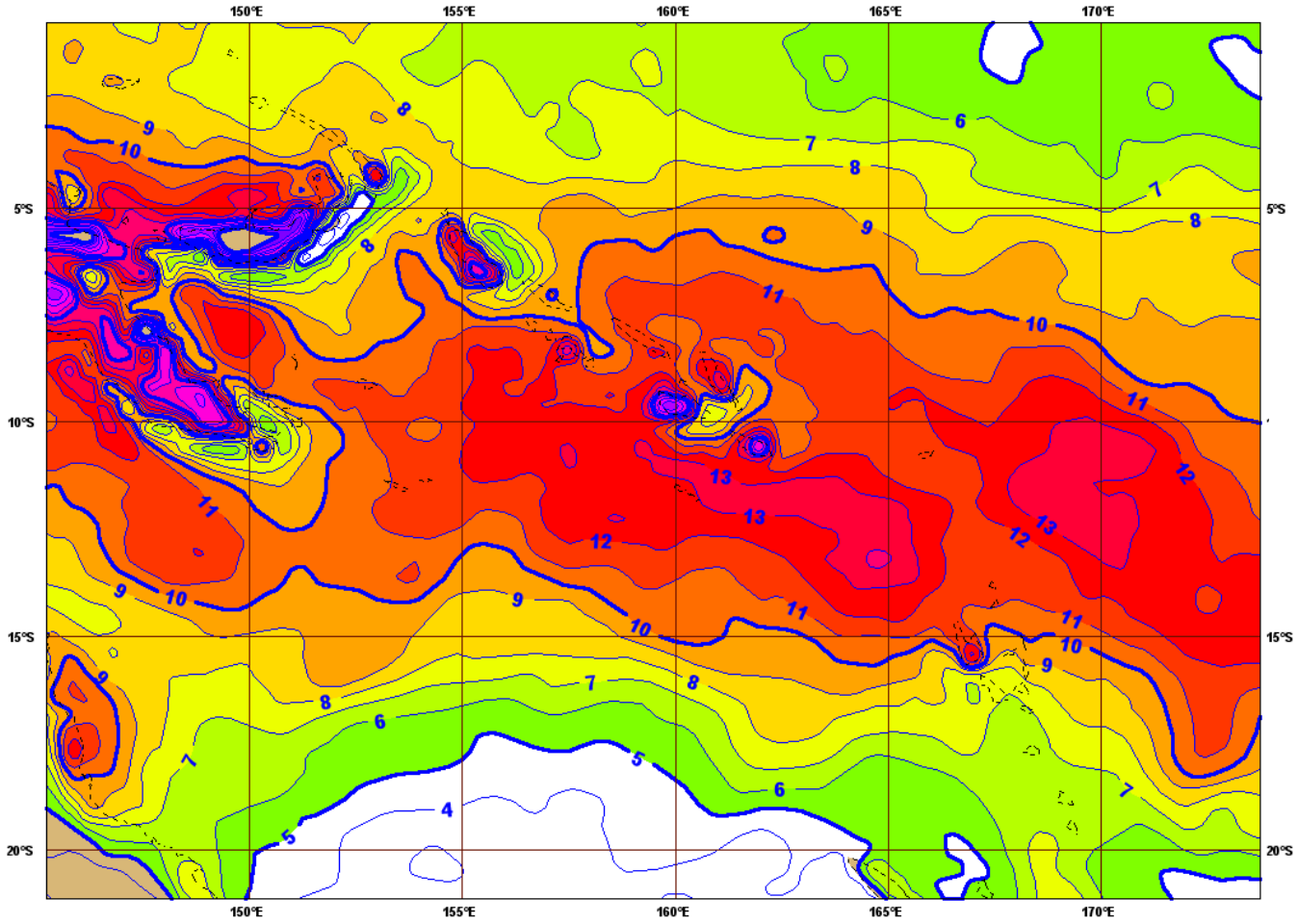
M-climate

- **M-Climate** is a function of 3 factors:
  - ➔ Location
  - ➔ Time of year, to take account of seasonal variations
  - ➔ Forecast lead time

But why forecast lead time?

Illustrate the need for this with an example…

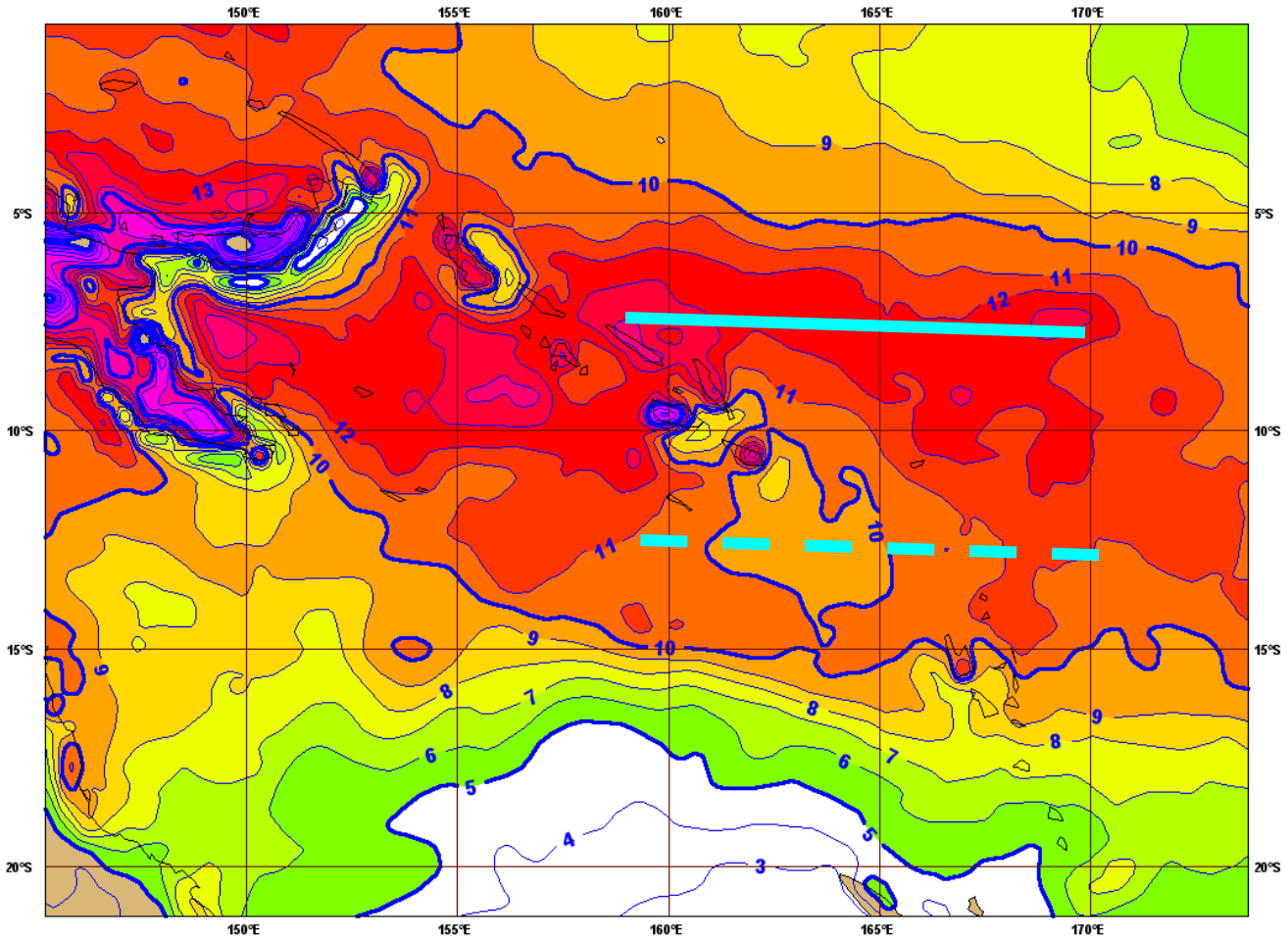
M-Climate e.g. Mean Daily Rainfall - SW Pacific – end of Jan



Day 2

ECMWF

M-Climate e.g. Mean Daily Rainfall - SW Pacific – end of Jan



Day 4

ECMWF

Model drift

- The drift in rainfall in the SW Pacific is quite an extreme example

  → This relates to the difficulties the model has with handling tropical convection

- In other parts of the world such as Europe drift is generally much less. But it is still not zero.

- Anyway, the EFI needs to account for any drift, to see how extreme a particular set of forecasts are relative to what the forecast would 'ordinarily' produce at such lead times.

Extreme Forecast Index

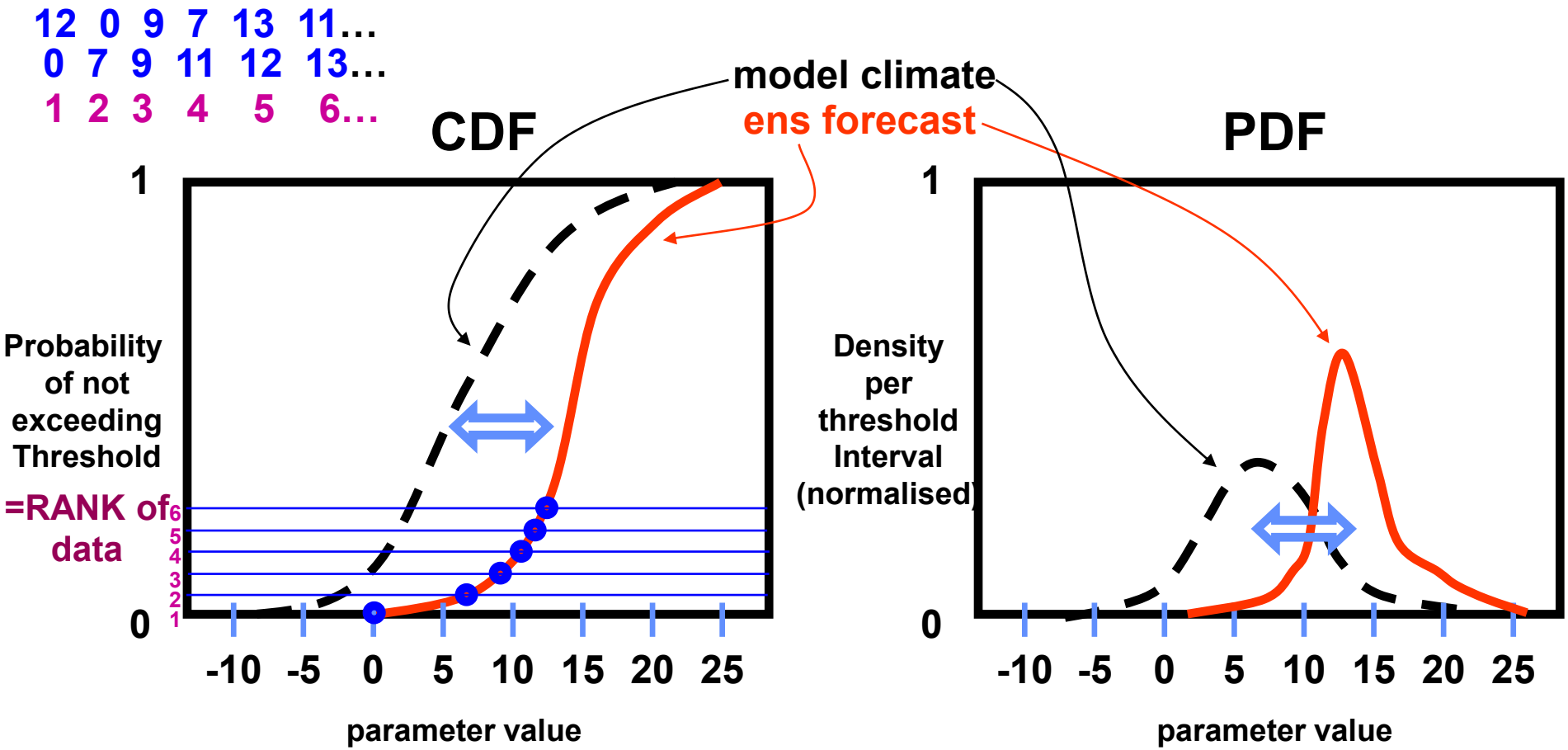
Extreme Forecast Index (EFI)

- **Extreme Forecast Index (EFI)** is designed to measure the extremity of the ensemble forecast.
- EFI is a measure of the difference between the ensemble distribution and a model climate (M-climate) distribution.
- 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. T > 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)

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.



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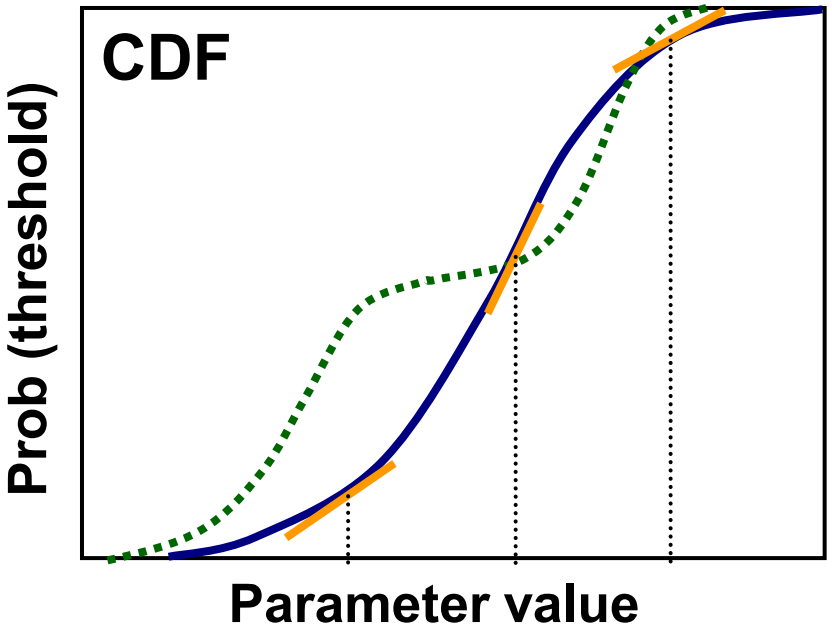
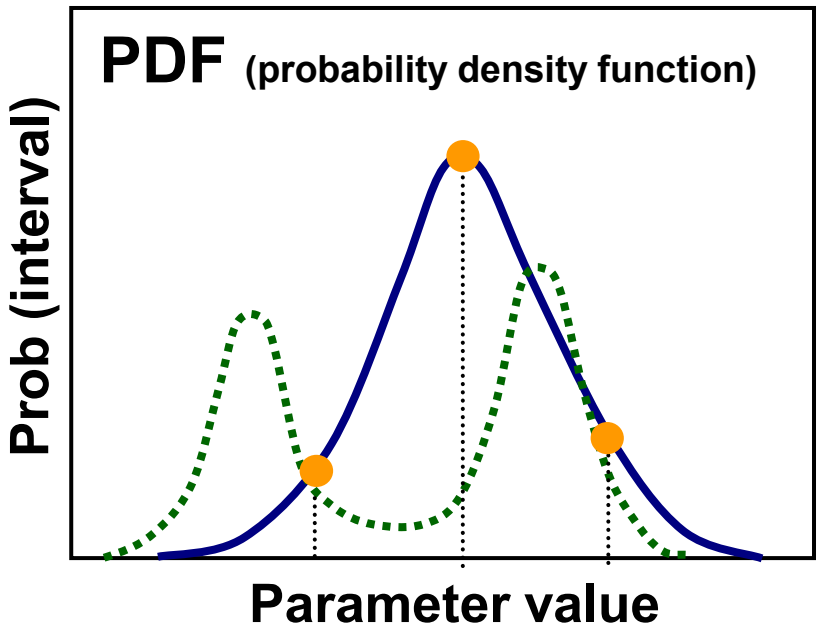
How do CDFs and PDFs relate?





- 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

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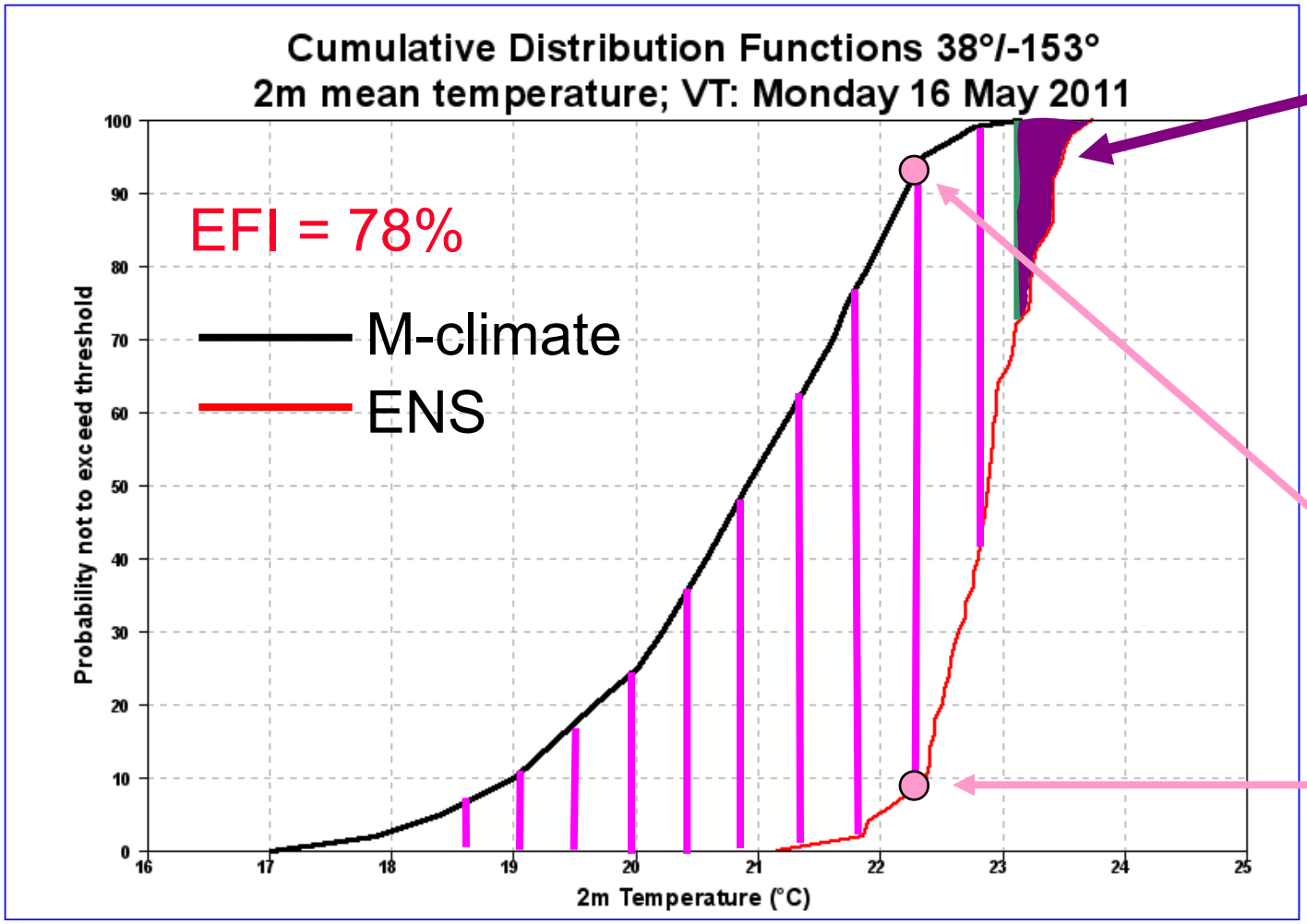
$$EFI = \frac{2}{\pi}\int_0^1 \left(\frac{p - F_f(p)}{\sqrt{p(1-p)}}\right) dp$$

Represented by pink lines below

More weight to the extremes of M-climate



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

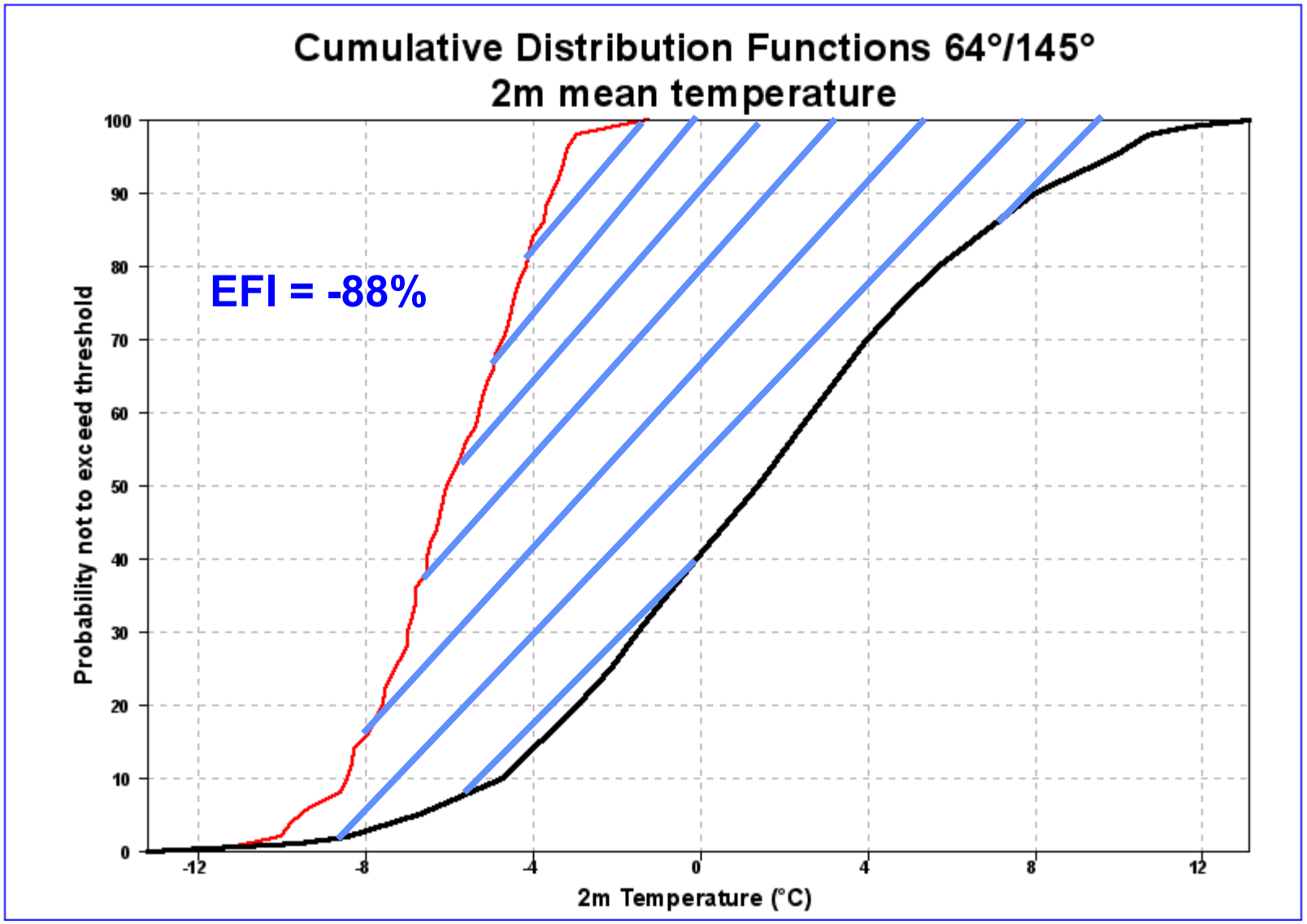
$-1 \le EFI \le 1$

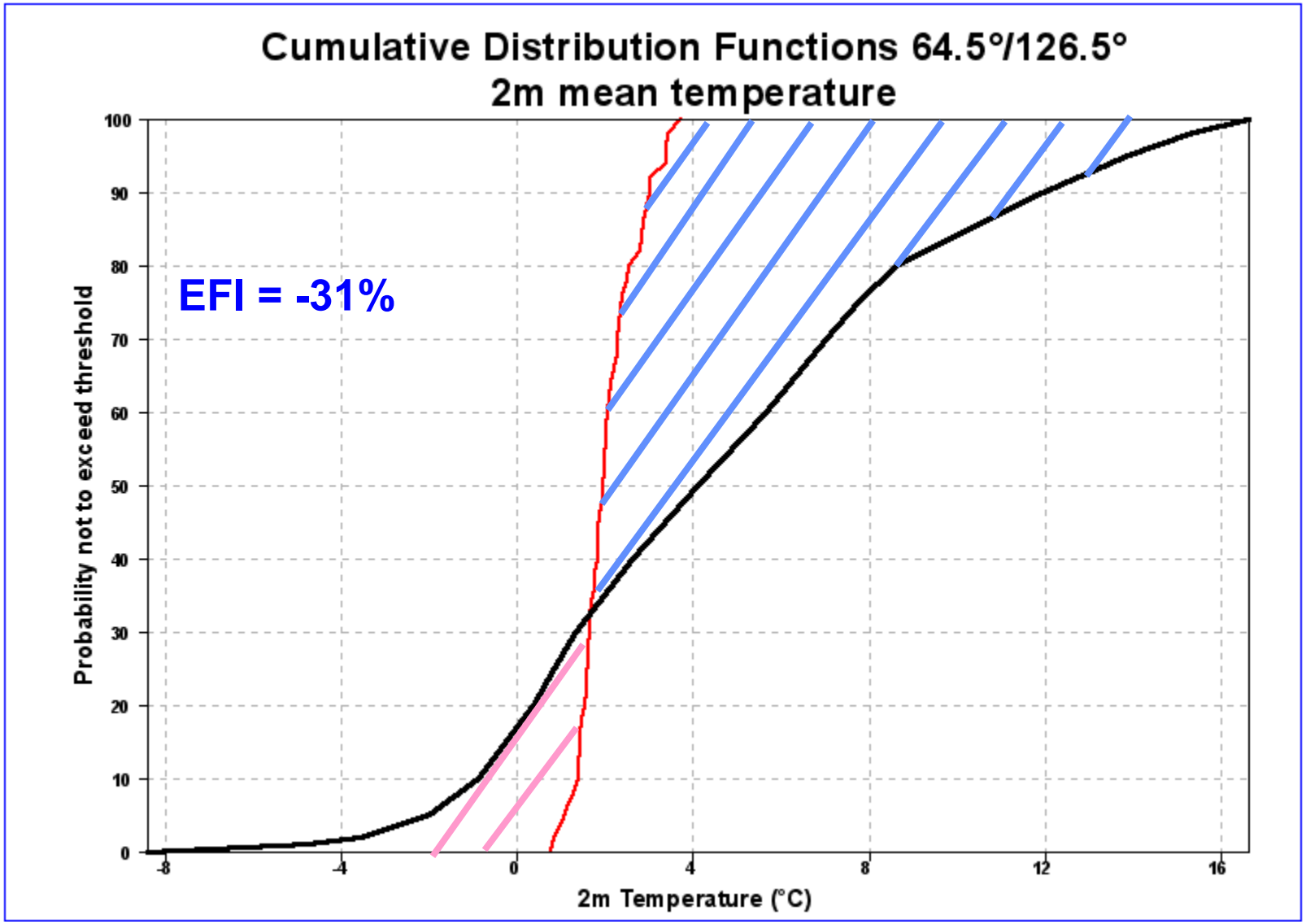
$-100\% \le EFI \le 100\%$

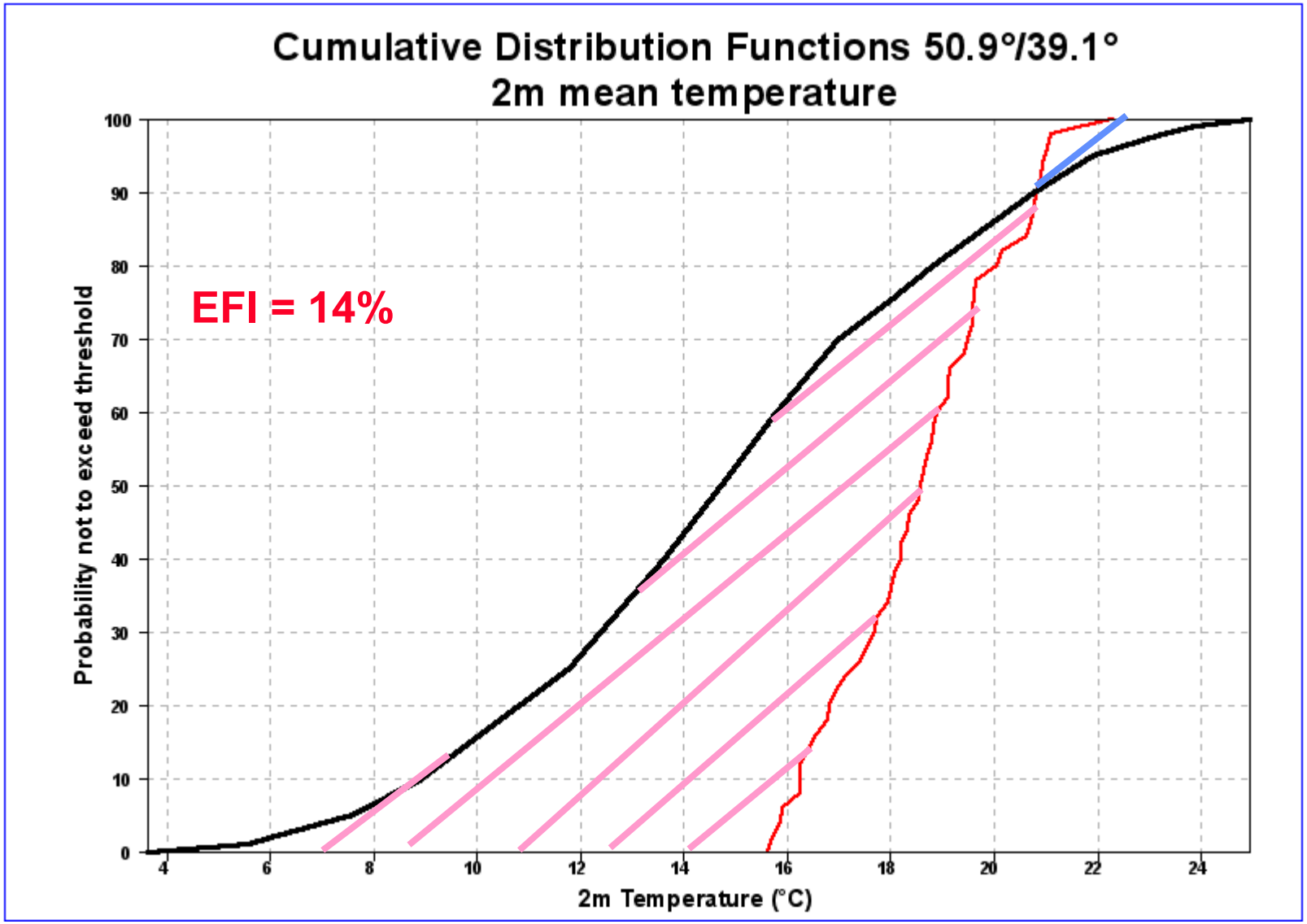
p

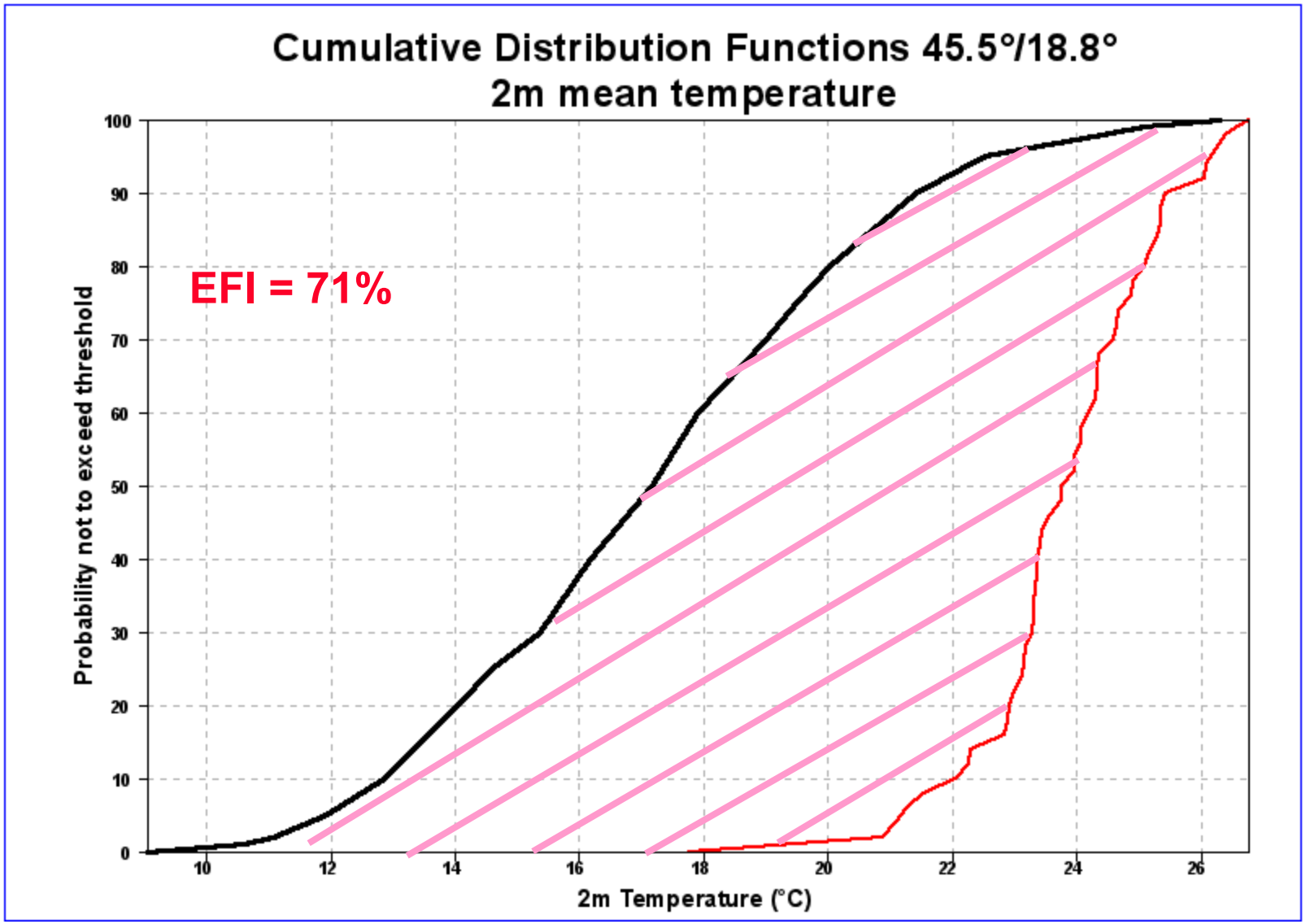
$F_f(p)$

ECMWF

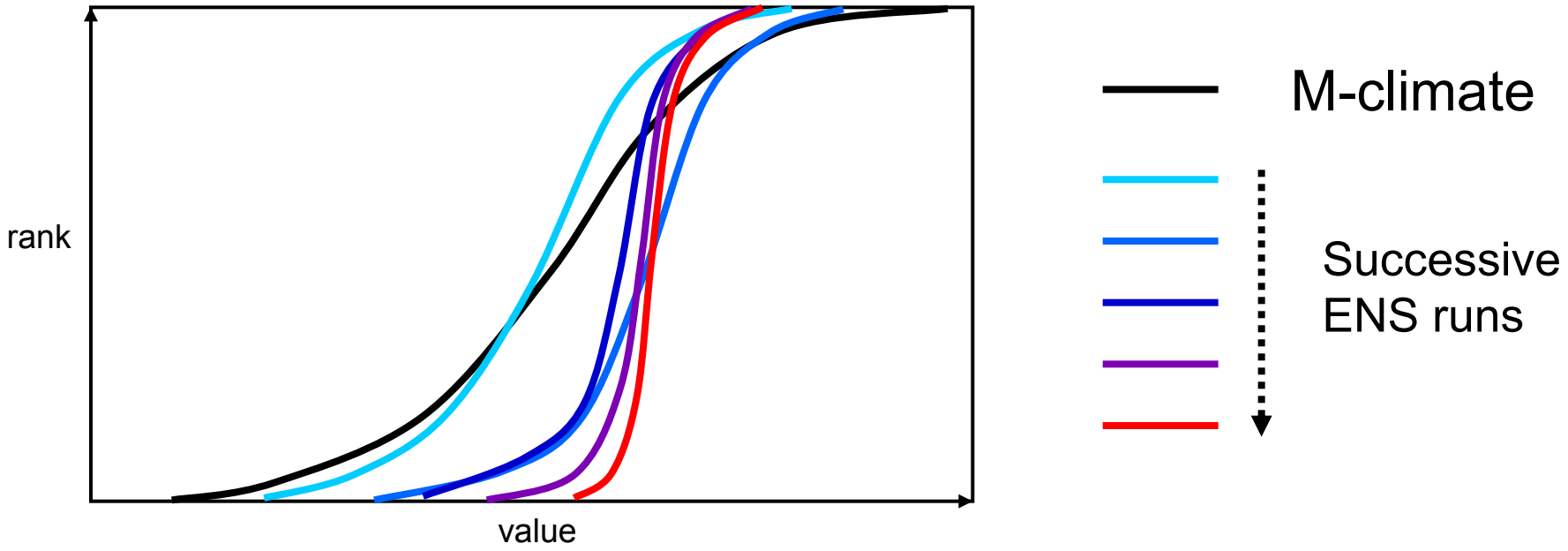

Cumulative Distribution Functions 64°/145°
2m mean temperature
EFI = -88%
Probability not to exceed threshold
100
90
80
70
60
50
40
30
20
10
0
-12
-8
-4
0
4
8
12
2m Temperature (°C)


Cumulative Distribution Functions 64.5°/126.5°
2m mean temperature
EFI = -31%
Probability not to exceed threshold
100
90
80
70
60
50
40
30
20
10
0
-8
-4
0
4
8
12
16
2m Temperature (°C)


Cumulative Distribution Functions 50.9°/39.1°
2m mean temperature
EFI = 14%
Probability not to exceed threshold
100
90
80
70
60
50
40
30
20
10
0
4
6
8
10
12
14
16
18
20
22
24
2m Temperature (°C)

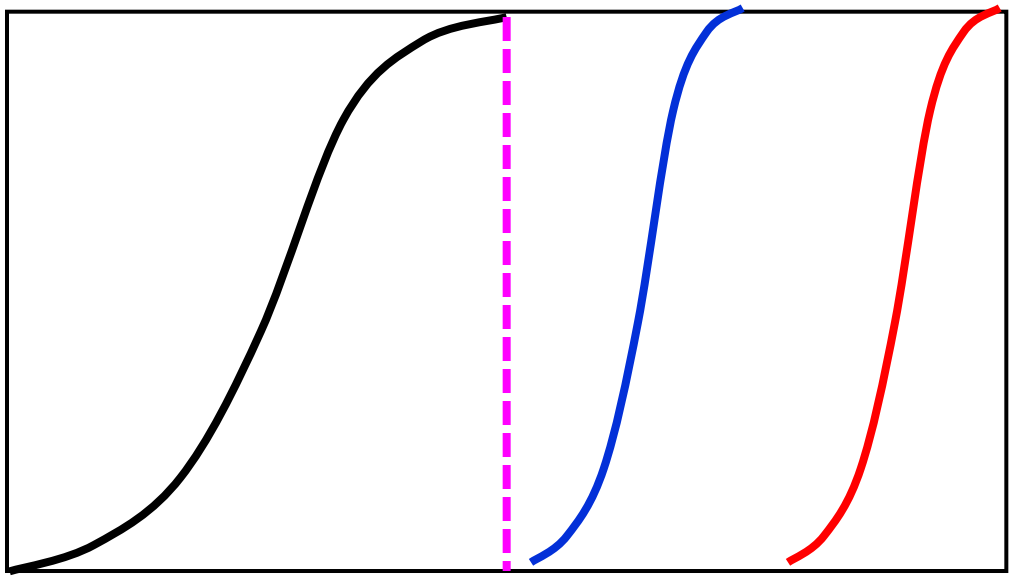

Cumulative Distribution Functions 45.5°/18.8°
2m mean temperature
EFI = 71%
Probability not to exceed threshold
0
10
20
30
40
50
60
70
80
90
100
10
12
14
16
18
20
22
24
26
2m Temperature (°C)

How ‘should’ CDFs behave in successive ensemble runs?



- At long lead times 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.

Some limitations



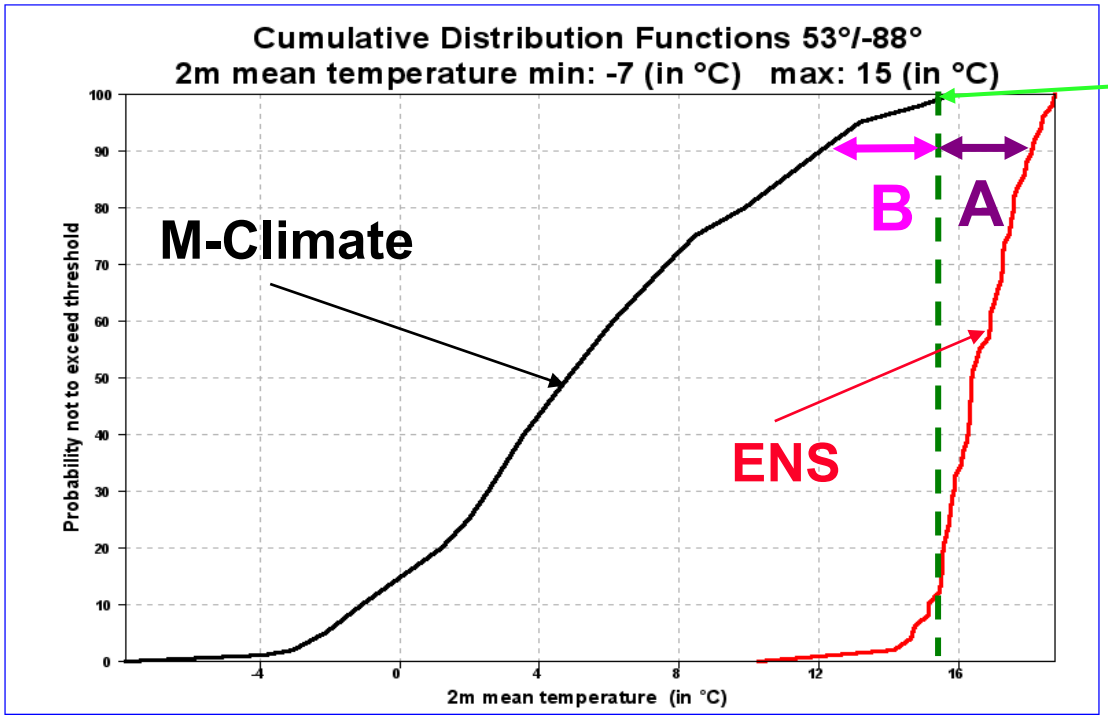
M-climate

ENS forecasts

EFI = 1
EFI = 1

- 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 operationally 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 → unusual event is likely; SOT = 0 → 10 % of ENS members are beyond the M-climate (Q99)

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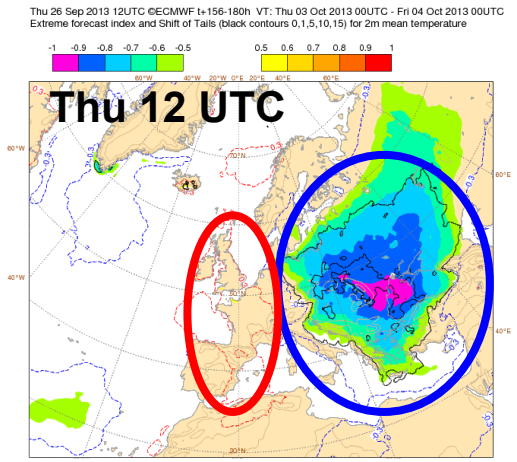
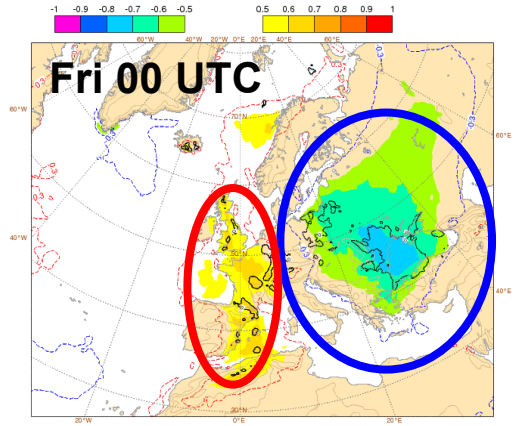
Known issues

- **Re-forecast sample size is still not sufficient for providing stable 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 files on Fridays**
- **M-climate is not perfect. It may be affected by model biases:**
  - **Jumpiness in the M-climate for different lead times**

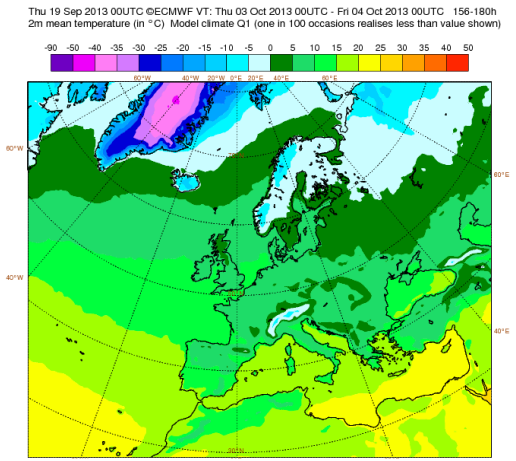
Known issues – example of a cold wave Europe, beginning of October 2013

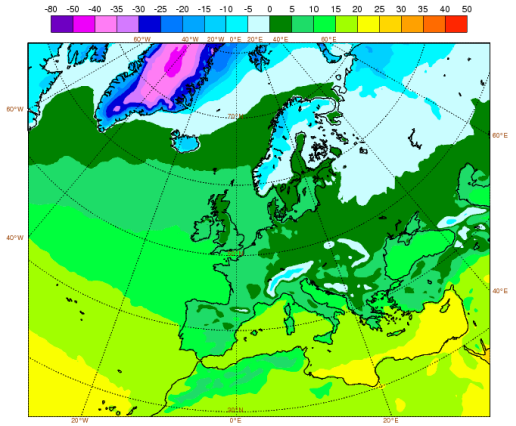
EFI





M-climate



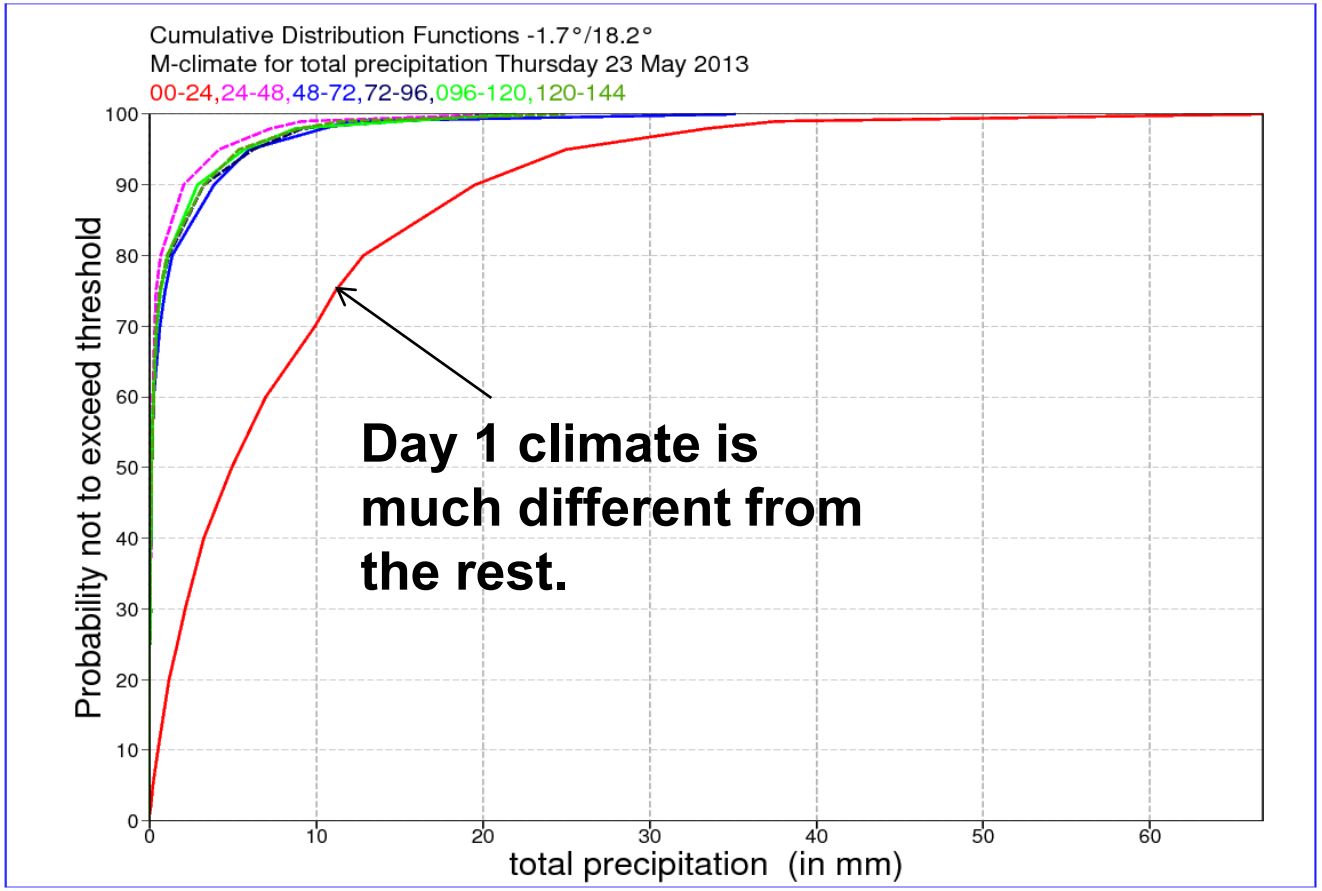


- **M-climate is computed only once a week (every Thursday):**
  - **Sudden jumps in the EFI forecasts when changing the M-climate on Fridays**

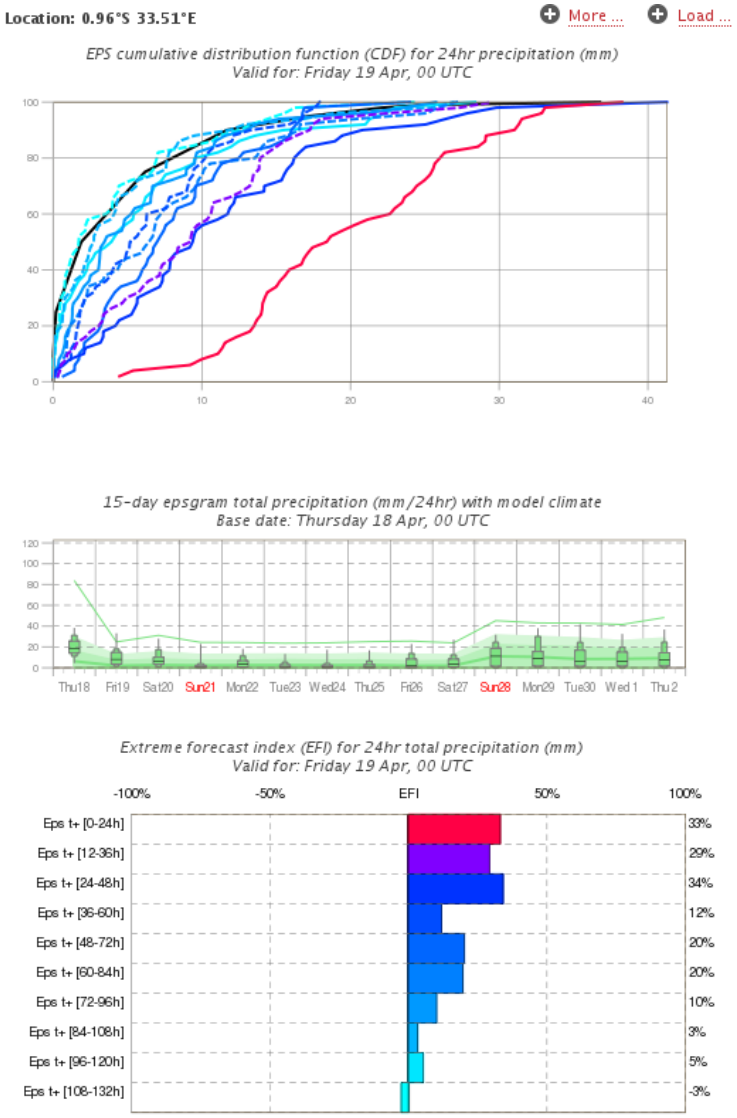
Example: two consecutive forecast runs. The signal of extremely cold weather is less prominent in the Friday's run because of the different climate though the forecasts are similar.

Known issues – example tropical Africa

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



Known issues – example tropical Africa



The forecast in red (T+0-24h) is much wetter than the others valid for the same time but from longer lead times. EFI, however, doesn't change much because M-climate is shifted in the same direction. This is an example of a model bias.

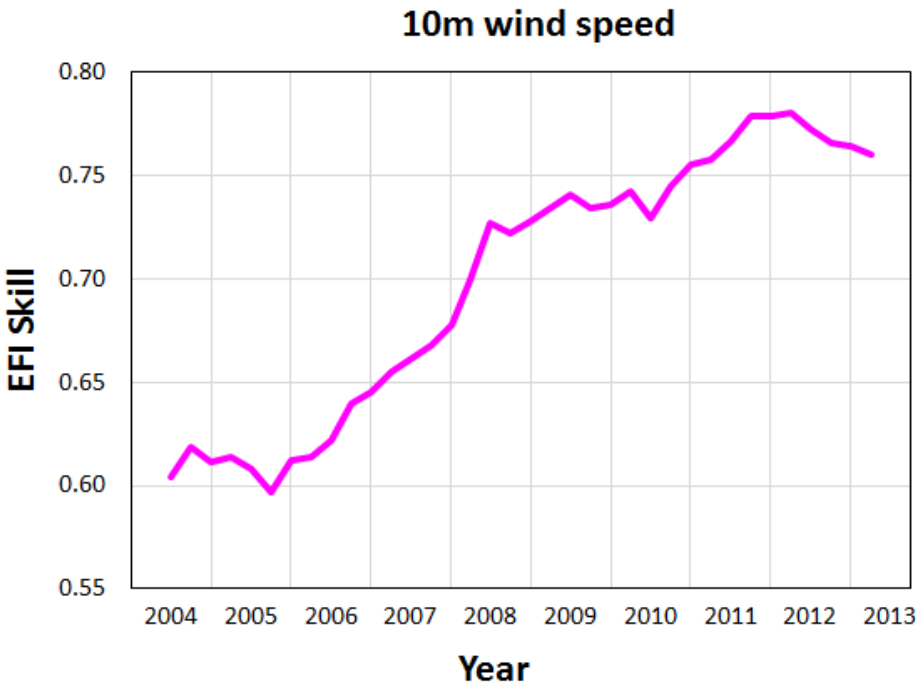
✓Should be taken into account when using probabilities.
✓Action: improve the model

EFI Verification

- Verification of the EFI has been carried out 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 (ROC).
- $$EFI\_skill = \frac{ROCA_f - ROCA_{ref}}{ROCA_{perf} - ROCA_{ref}} = \frac{ROCA_f - 0.5}{1 - 0.5} = 2 \times ROCA_f - 1$$

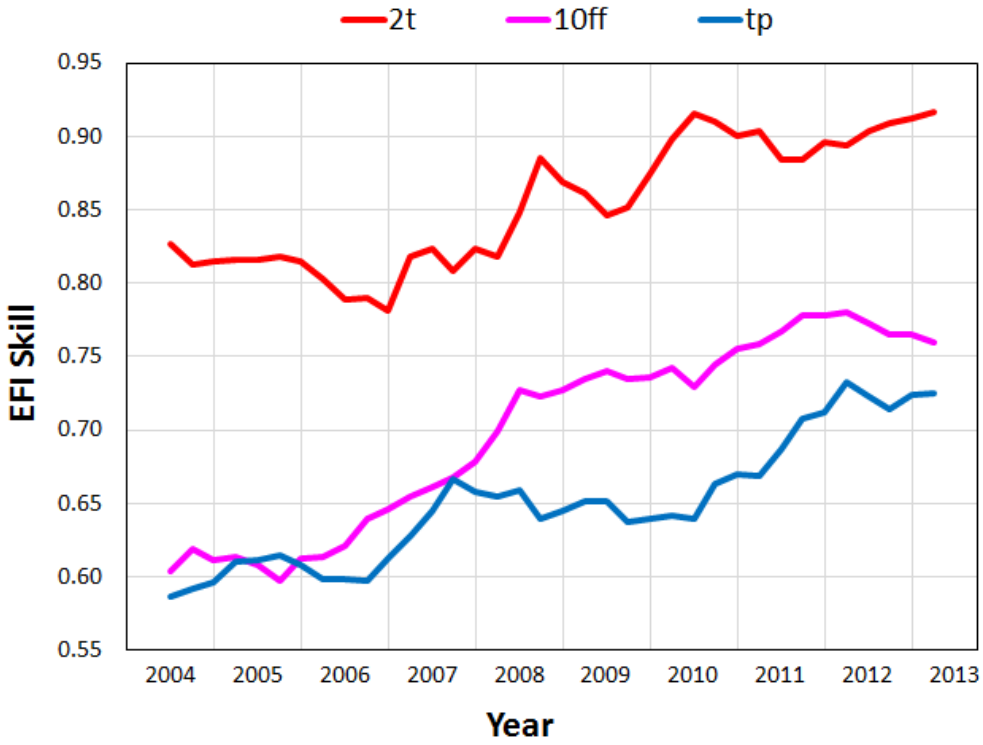
  0 → no skill, 1 → perfect score
- The verification is done for 3 parameters: 2m mean temperature, 10m mean wind speed and total precipitation

EFI Verification



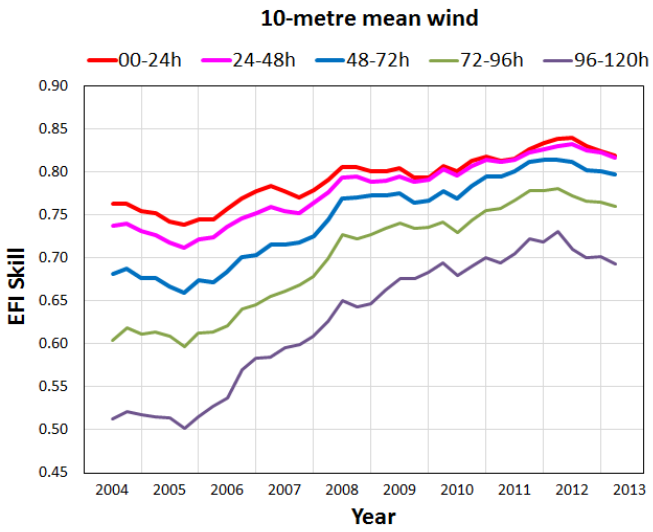
- **The plot shows the skill of the EFI for 10-metre wind speed** (a supplementary headline score adopted by the ECMWF Council) **at forecast day 4** (t+72-96h)**.**

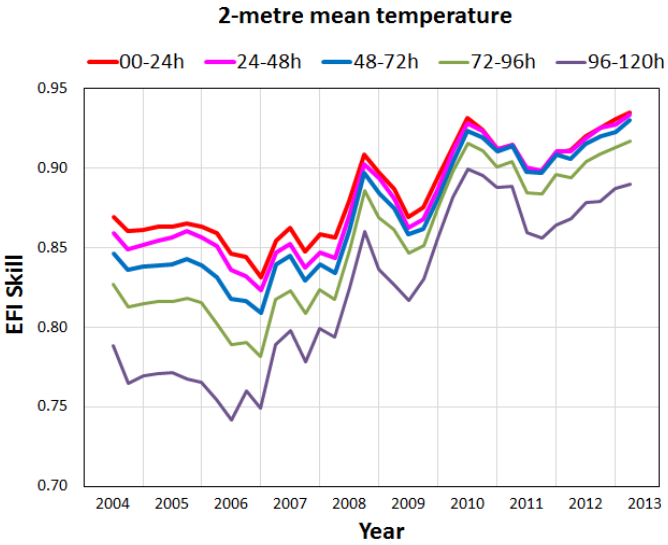
EFI Verification

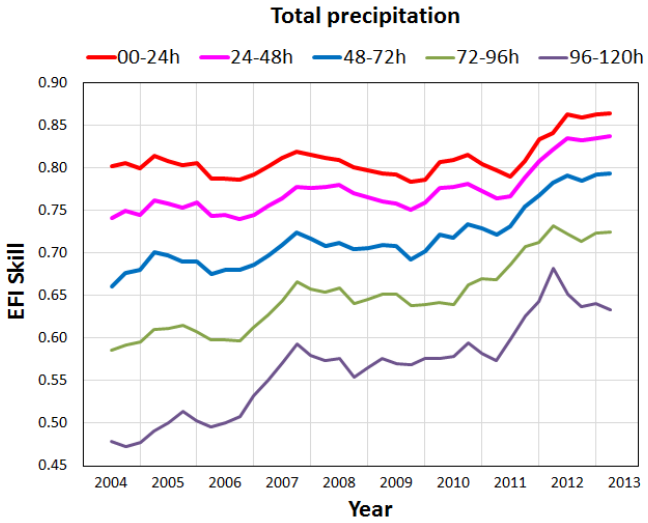


- **The plot shows the skill of the EFI for 10-metre wind speed (10ff), 2-metre mean temperature (2t) and total precipitation (tp) at forecast day 4** (t+72-96h)**.**
- **The highest skill is for 2t. Improvements over the years are bigger for 10ff.**

EFI Verification





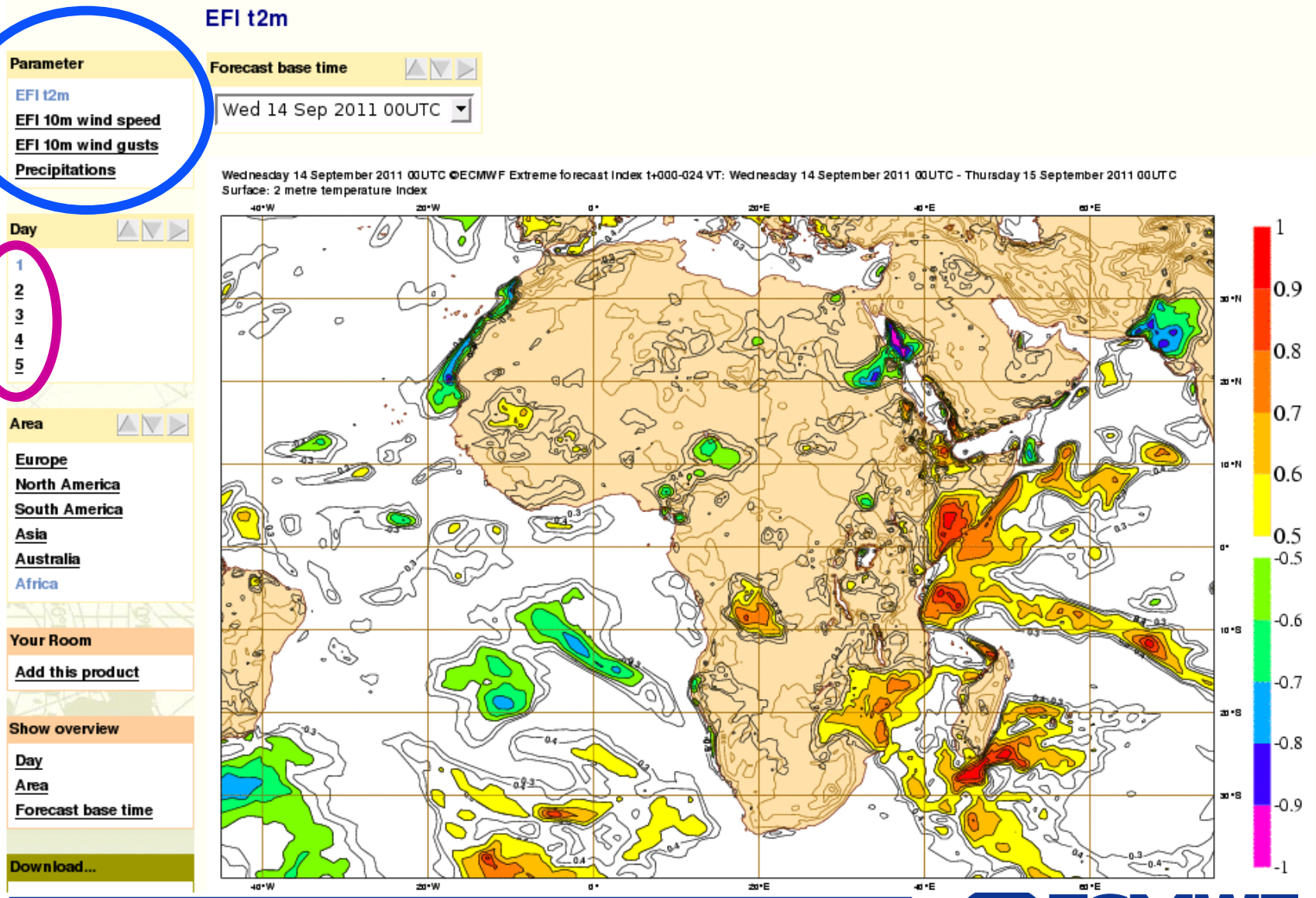


EFI skill for different lead times

EFI fields available for all WMO members

- 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).

EFI fields available for all WMO members



ECMWF

EFI fields available for all WMO members

Precipitations

Parameter

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

Forecast base time

Wed 14 Sep 2011 00UTC

Day

- 1
- 2
- 3
- 4
- 5
- 1-5
- 2-6
- 1-10

Area

- Europe
- North America
- South America
- Asia
- Australia
- Africa

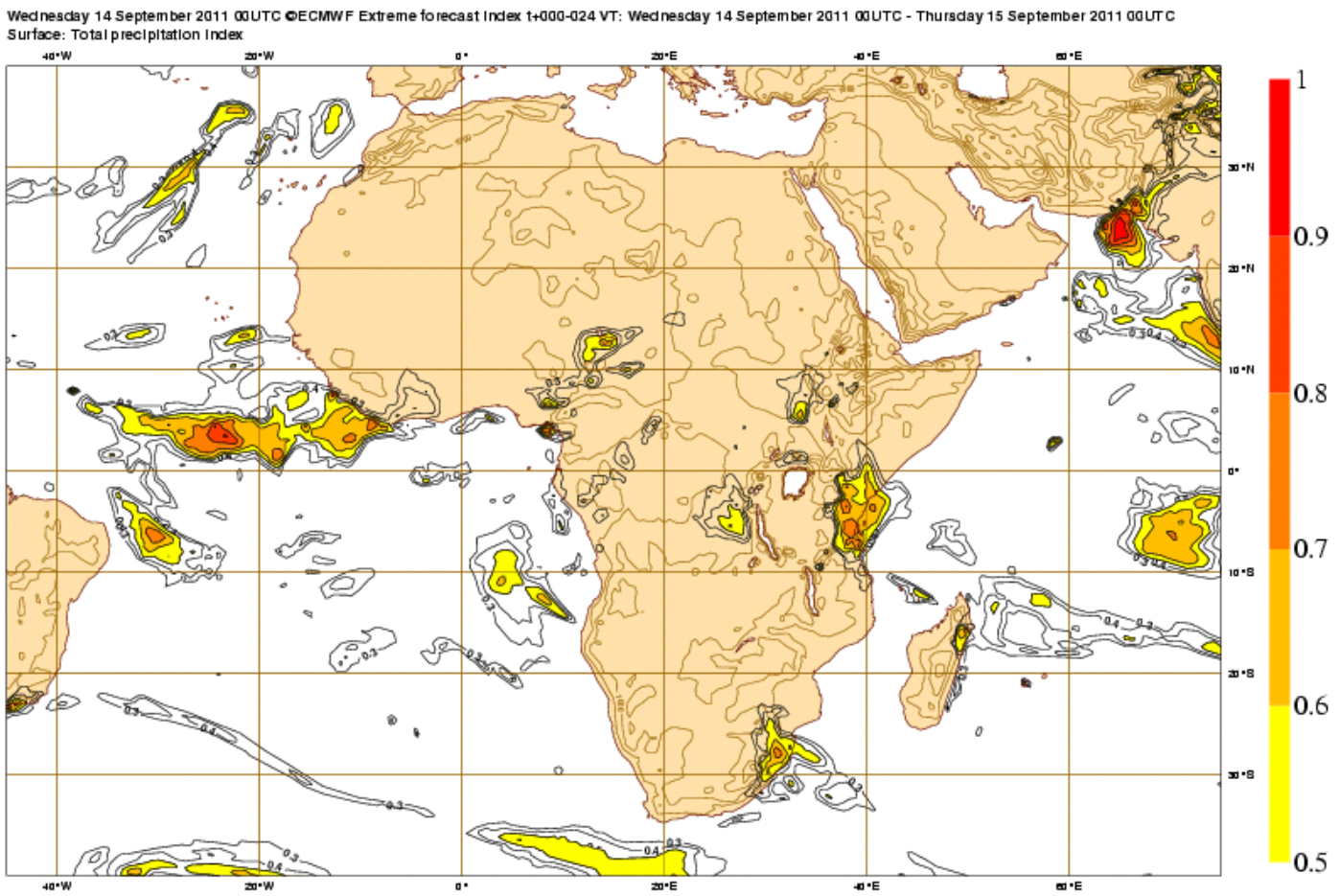
Your Room

- Add this product

Show overview

- Day
- Area
- Forecast base time

2



ECMWF

EFI products with restricted access

Show guide

EFI 2m temperature

Parameter

EFI wind speed
EFI wind gust
EFI 2m temperature
EFI 2m maximum temperature
EFI 2m minimum temperature
EFI significant wave height
EFI snow fall
EFI precipitation

Forecast base time

Thu 3 Oct 2013 00UTC

Day

1
1
2
3
4
5
6
...

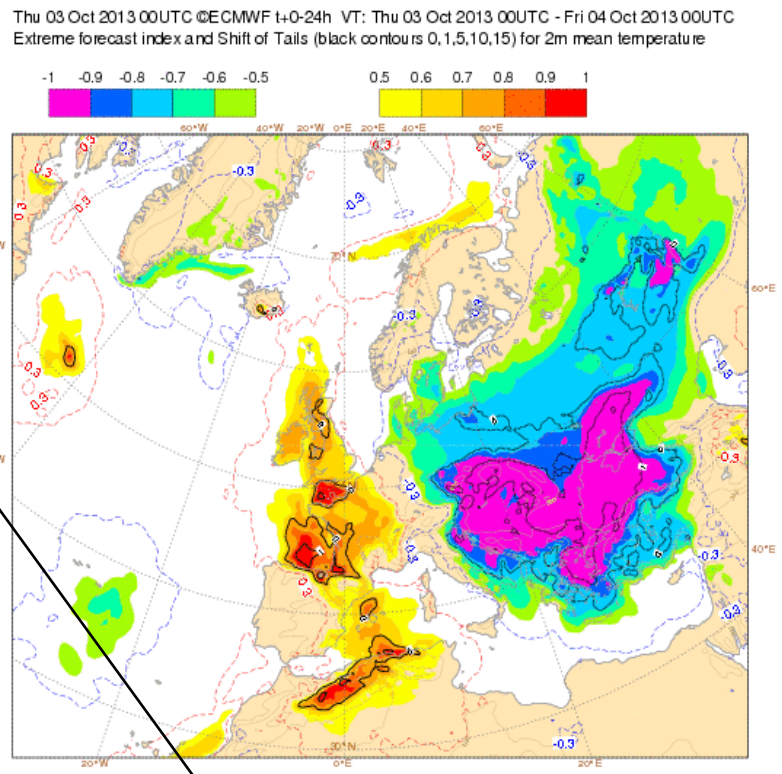
Quantile

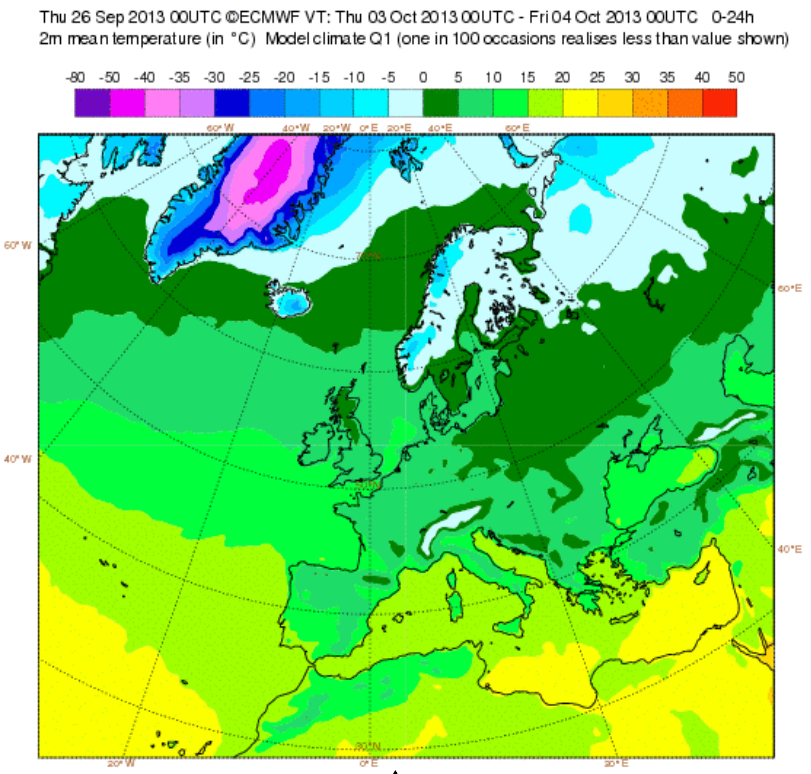
1
10
50
90
99

Area

Europe
North America
South America
Asia
Australia
Africa

More parameters





More time ranges

M-climate

ECMWF

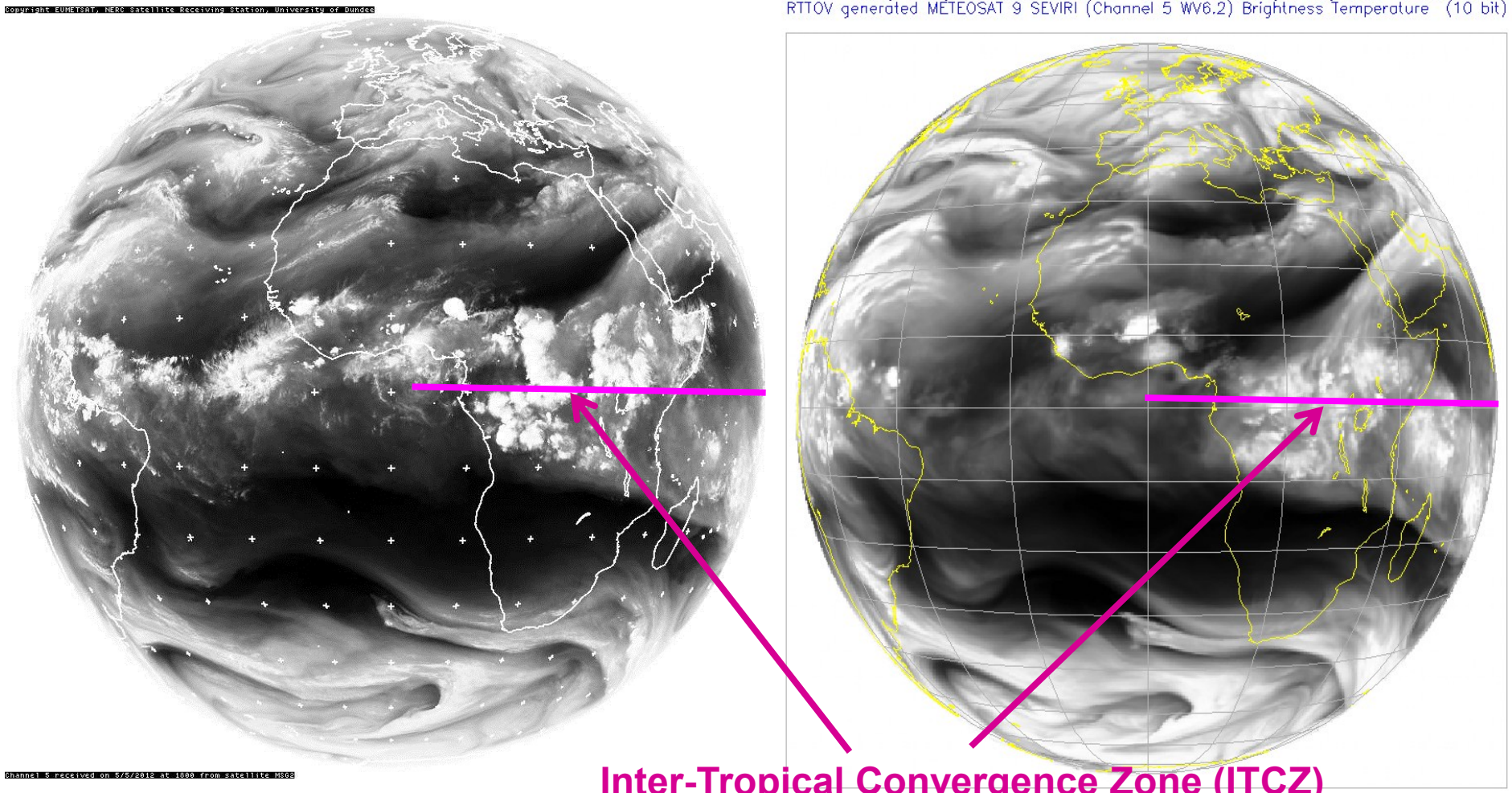
Severe weather
in the Tropics

Real satellite imagery, WV6.2

5th May 2012 18UTC

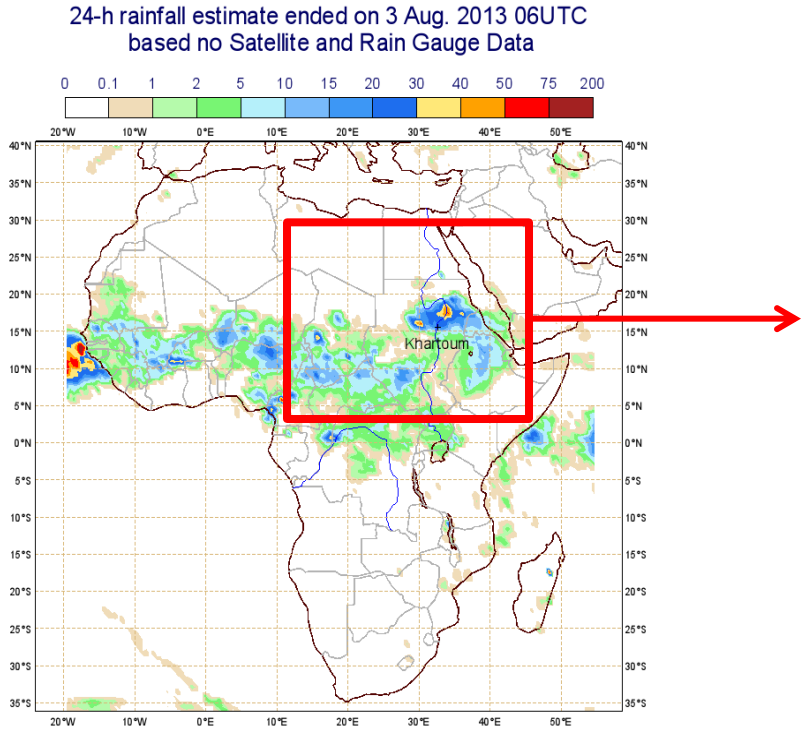
Simulated satellite imagery, WV6.2

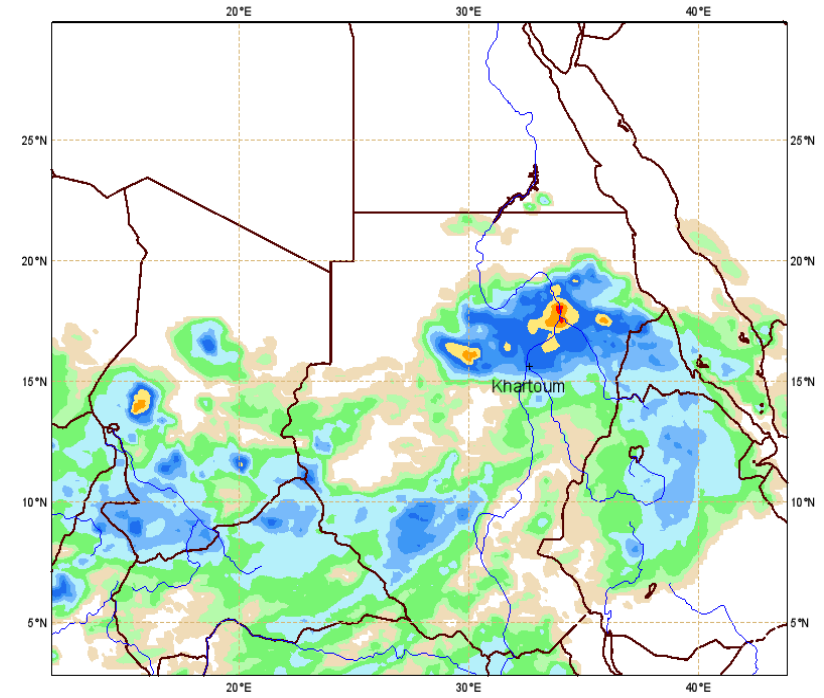
Forecast t+42 VT: 5th May 2012 18UTC



ECMWF

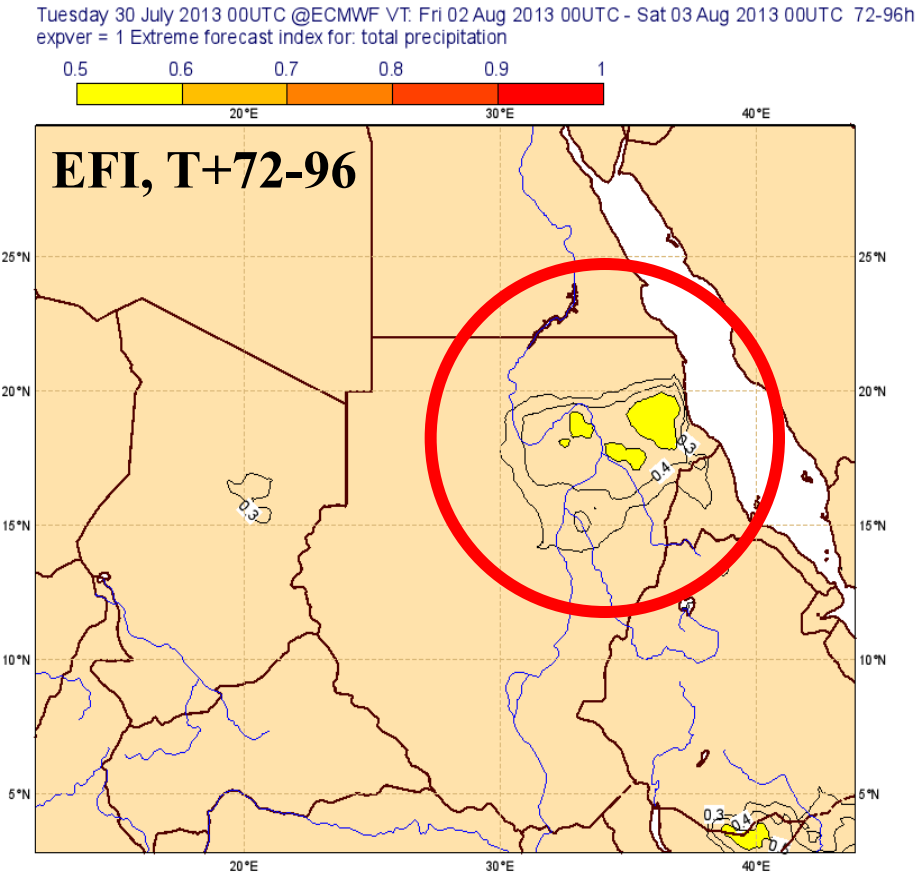
Heavy rain in Sudan, August 2013

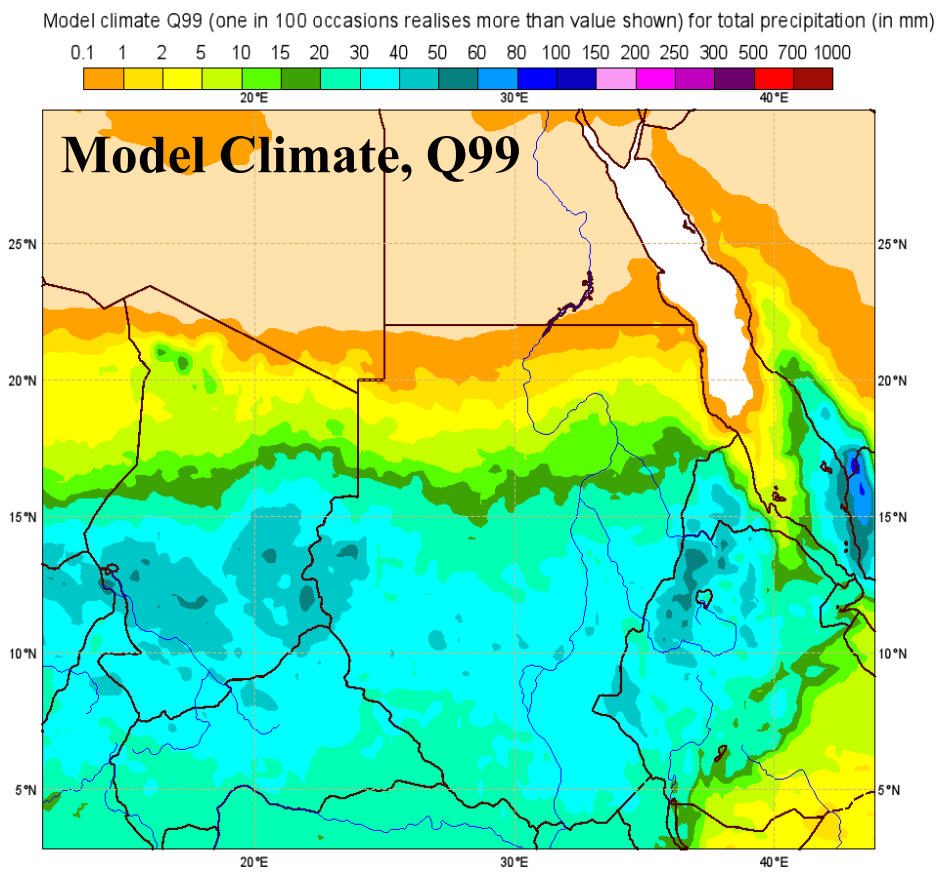




Sudan was affected by devastating floods in August 2013. The capital Khartoum was particularly badly hit. The charts show a heavy rain event at the beginning of August.

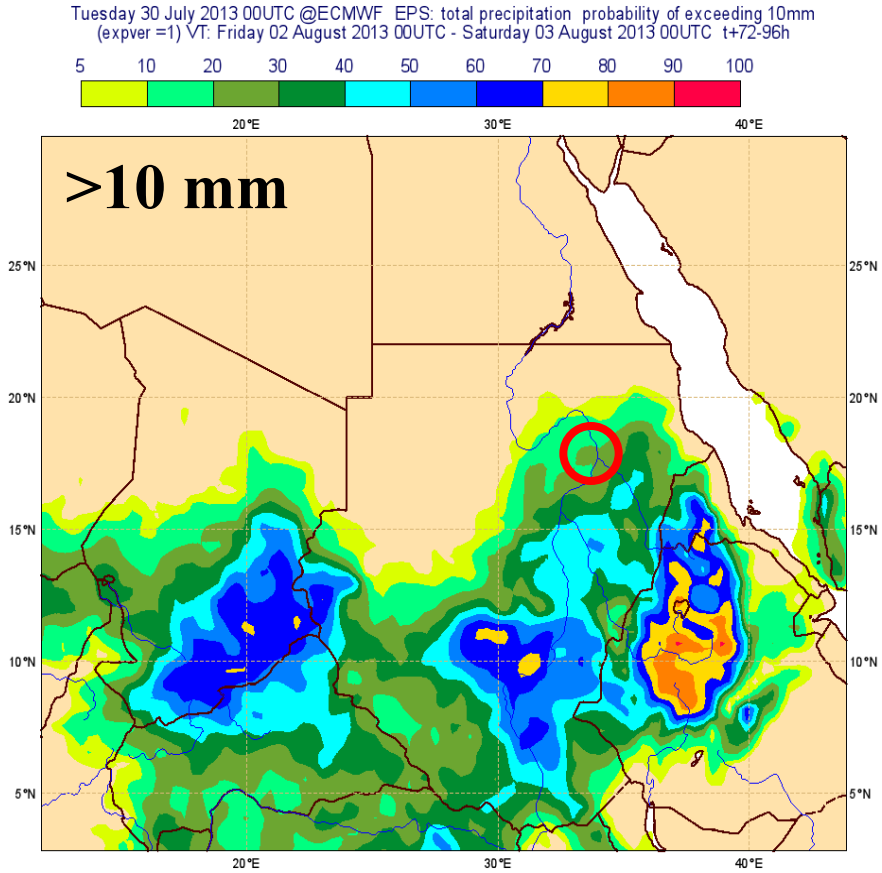
Heavy rain in Sudan, August 2013

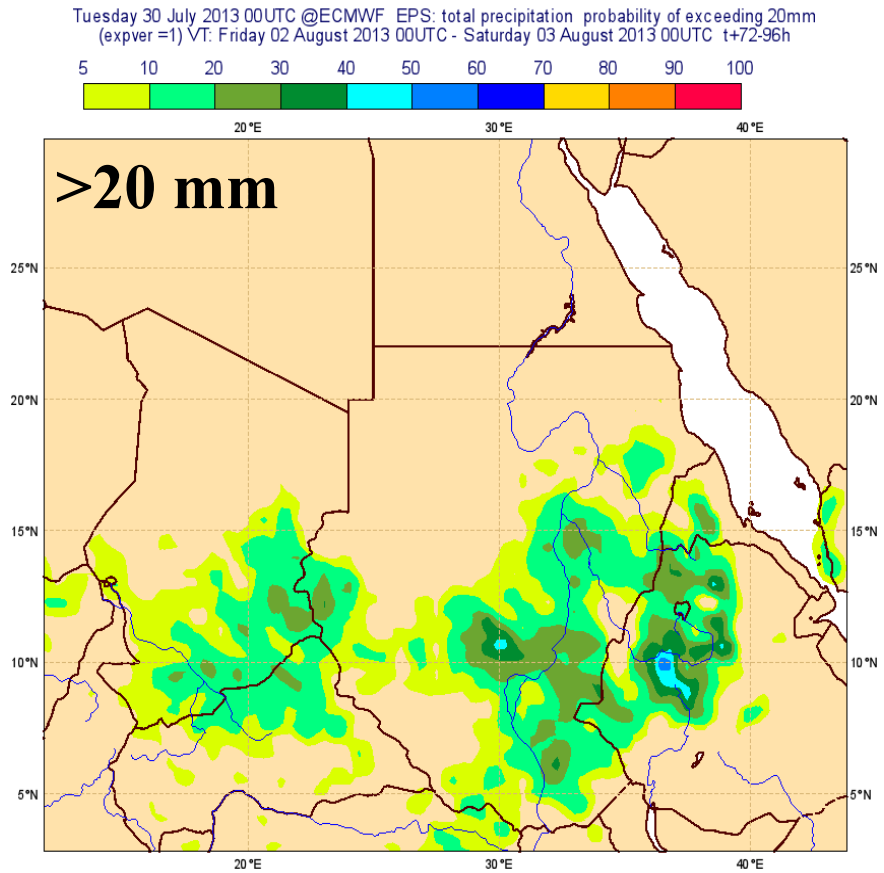




- EFI gives a signal of heavy rain – positive values
- Model climate (right plot) shows what is extreme according to the model. The area of interest is relatively dry.

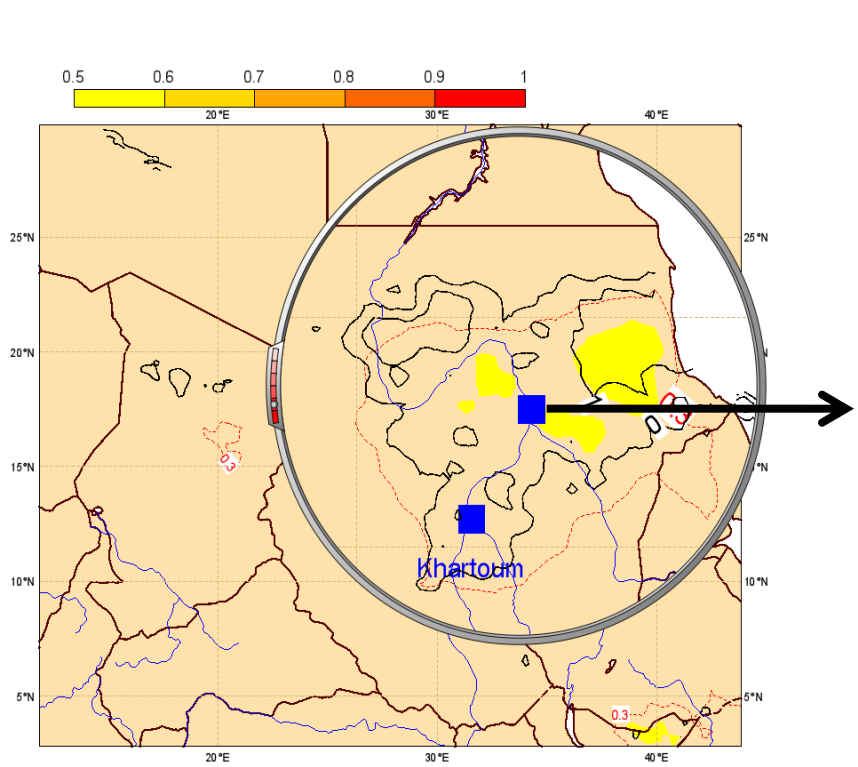
Heavy rain in Sudan, August 2013

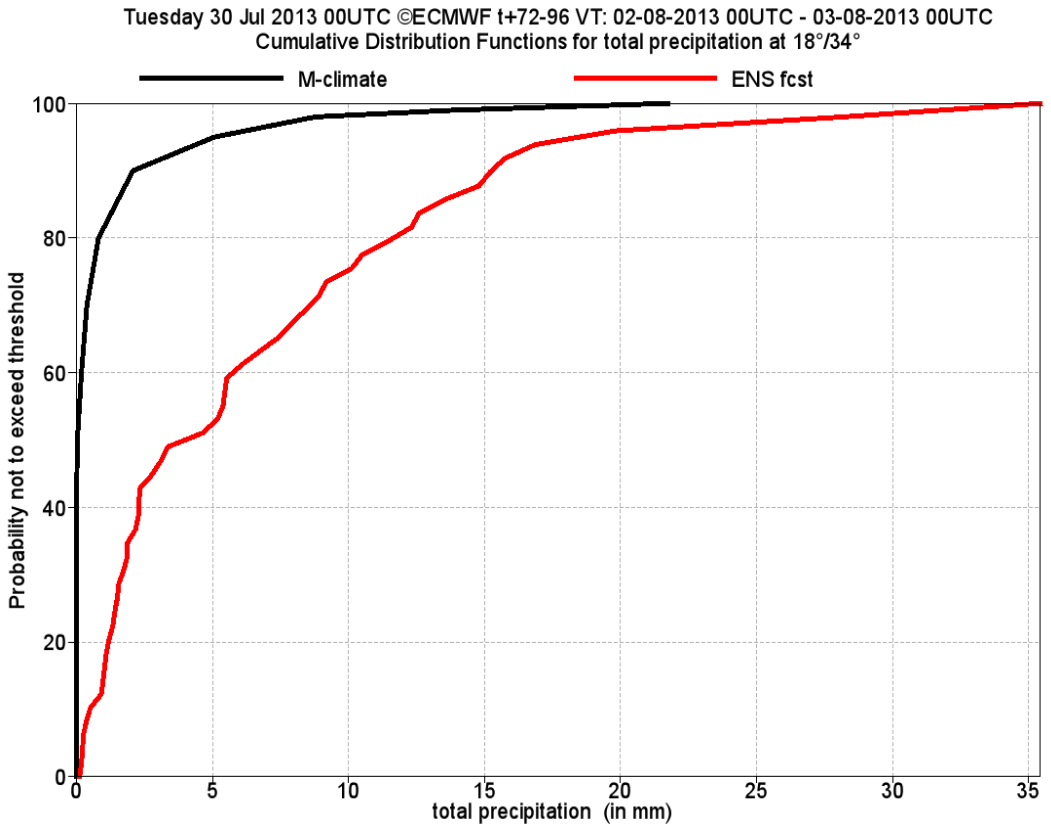




- **Climatological probability of rain to exceed 10mm/24h is about 2% in the area inside the red circle. Prob. > 10mm/24h from the forecast shown is above 20%, hence, much higher than climatology.**

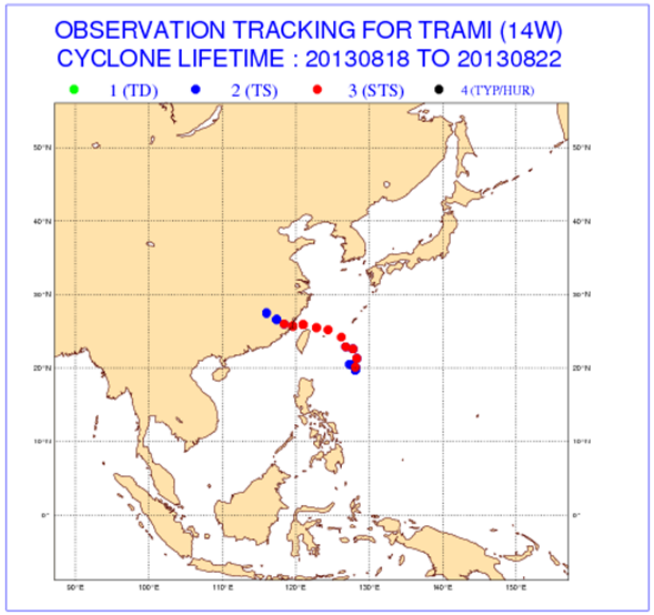
Heavy rain in Sudan, August 2013

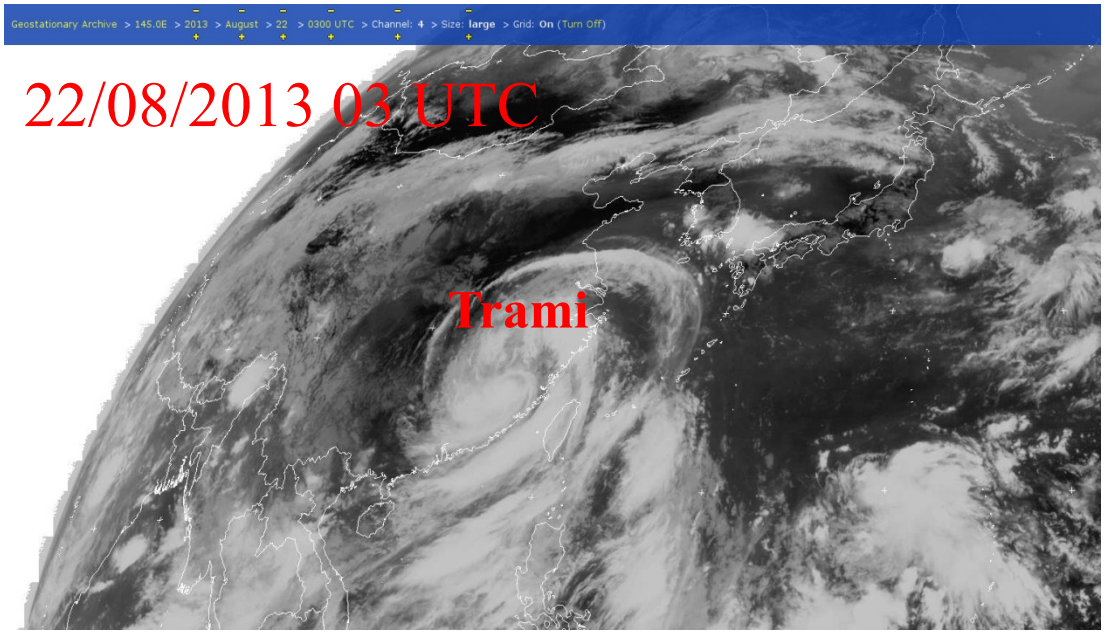




- Forecast of wet weather though quite uncertain forecast in terms of rainfall amounts
- The tail of the forecast distribution is much wetter than climatology – positive SOT (black contours on the left plot).

Tropical cyclones



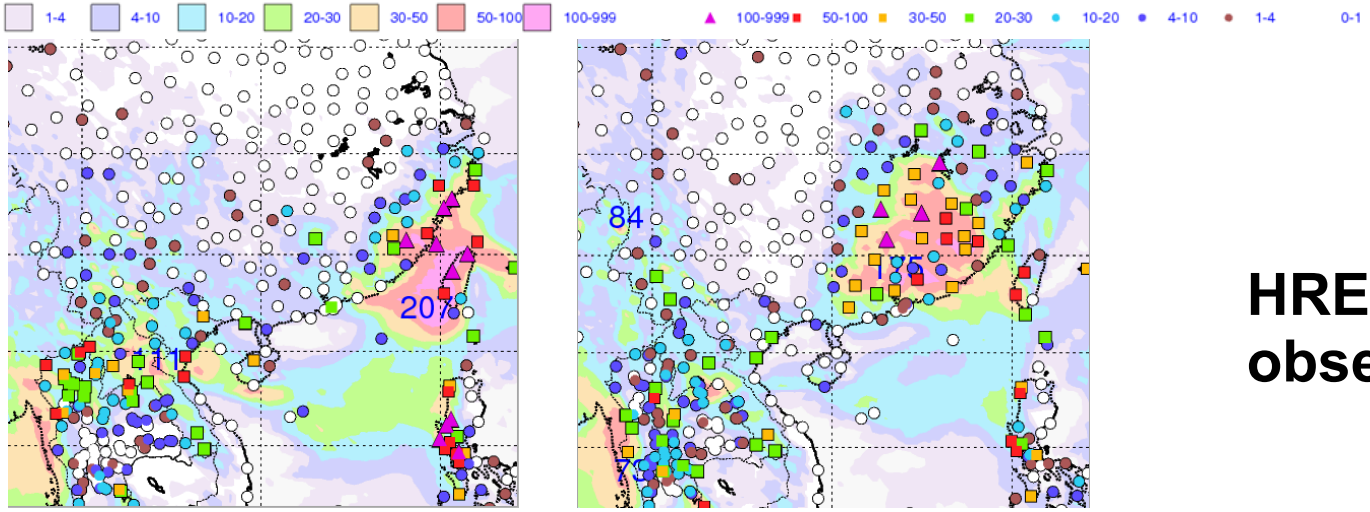


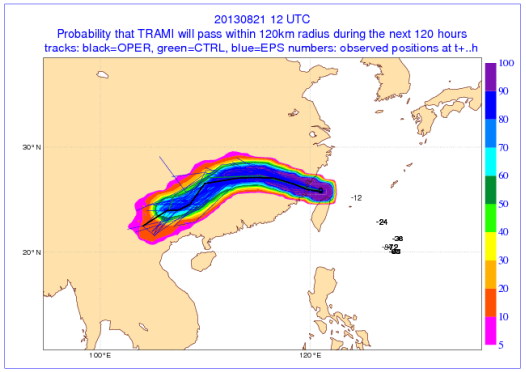
- **Typhoon Trami hit China in late August, bringing rainstorms that caused floods, huge economic losses and affected millions of people.**

Tropical cyclones

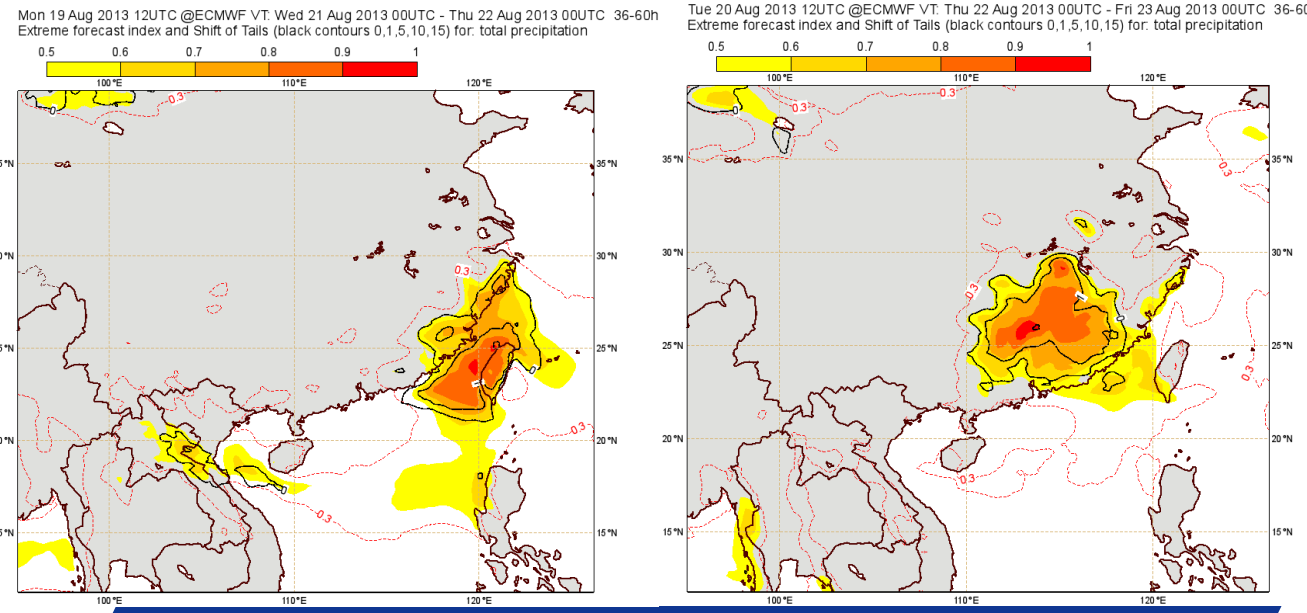
21/08/2013

22/08/2013





HRES T+36-60h & observations

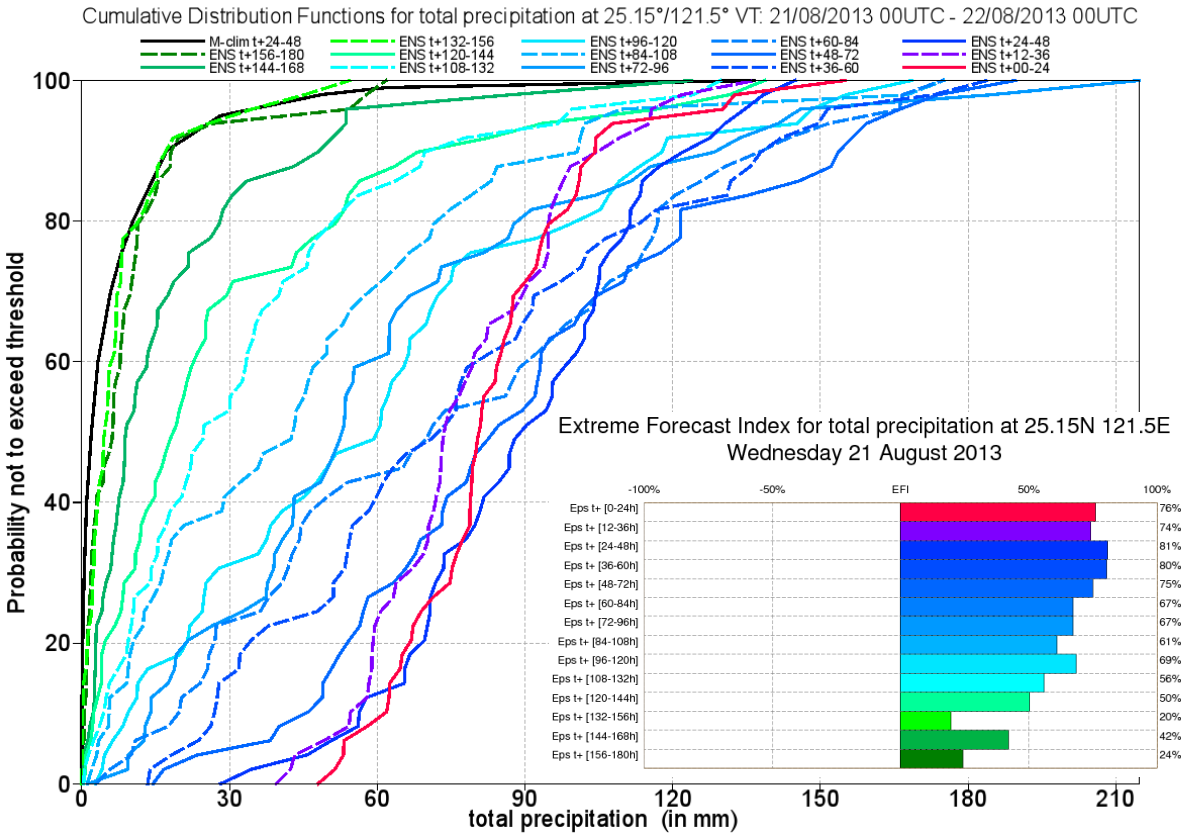


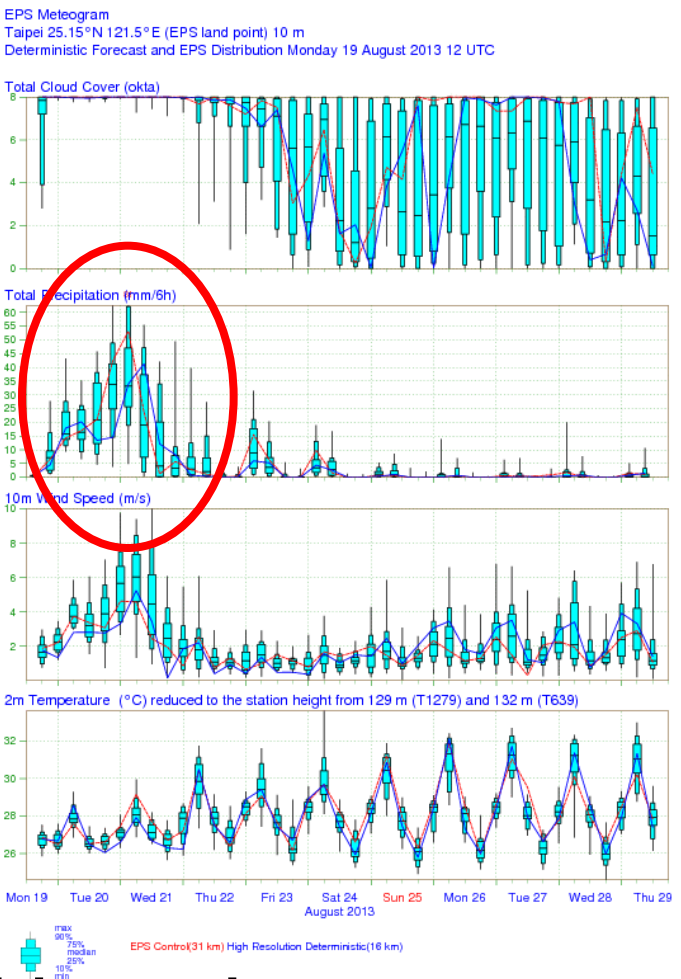
EFI & SOT for total precipitation

T+36-60h

ECMWF

Forecast for Taipei

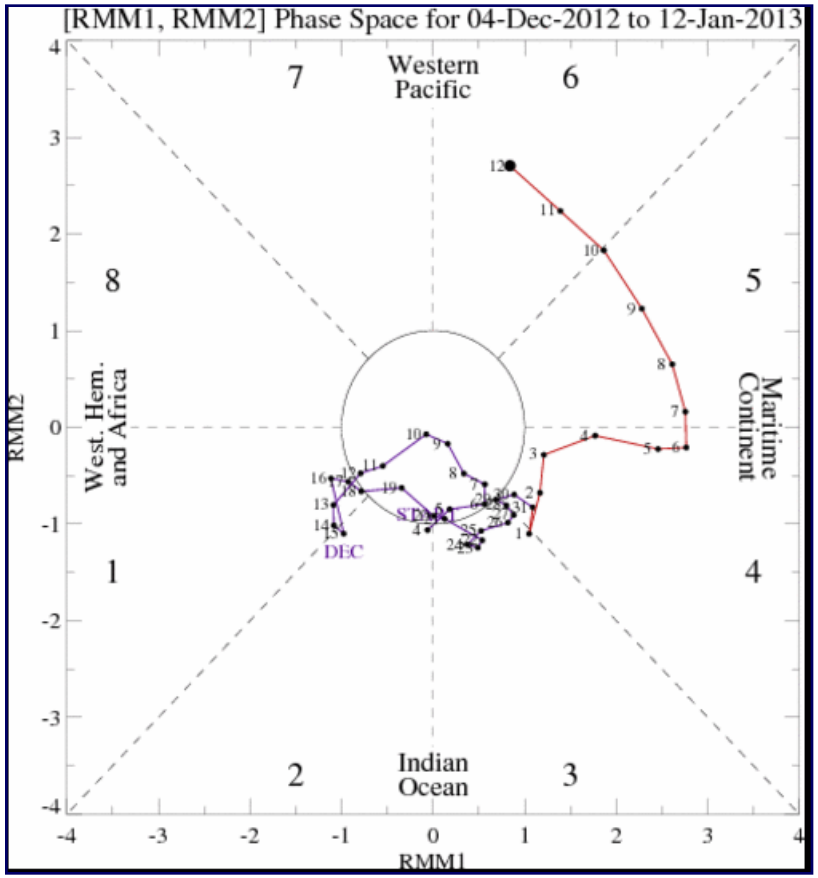


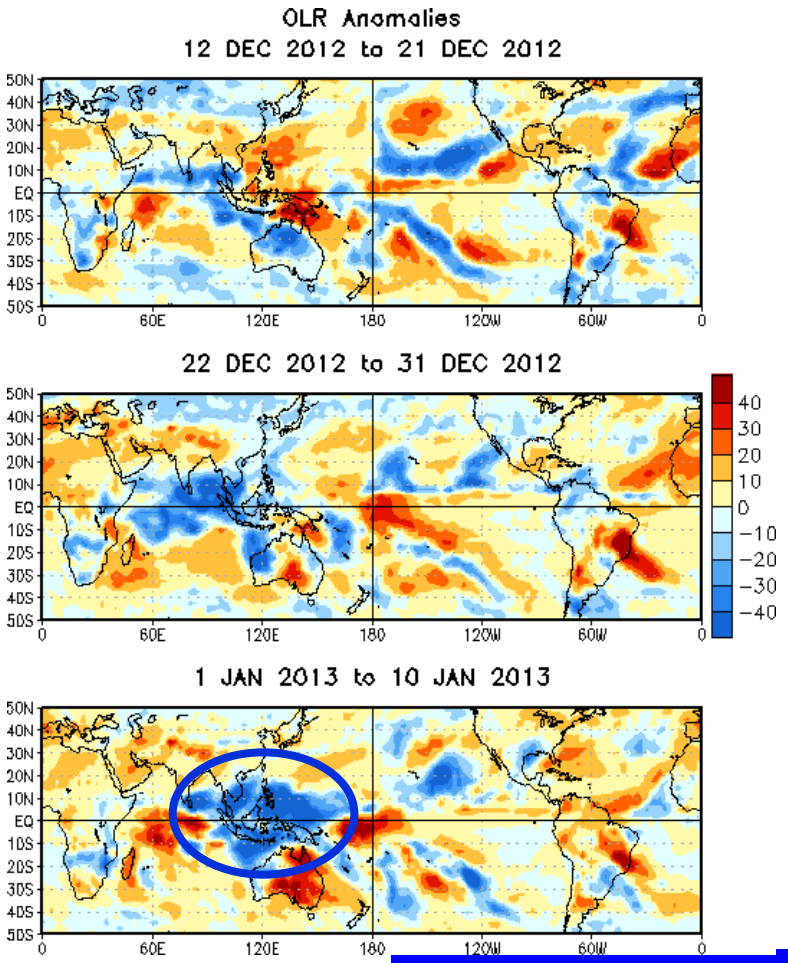


- **Typhoon Trami caused havoc across Taiwan where numerous locations were flooded after over 200 mm of rain fell including in Taipei.**

Madden-Julian Oscillation (MJO)

MJO index, Analysis, NCEP



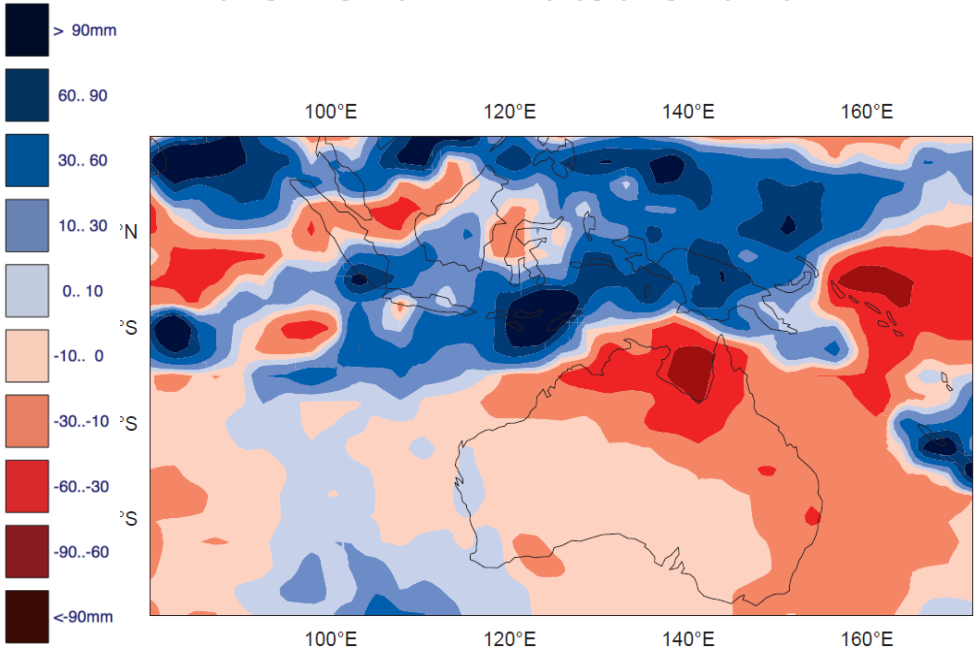


In early January 2013, the MJO contributed to enhanced convection across the Maritime Continent.

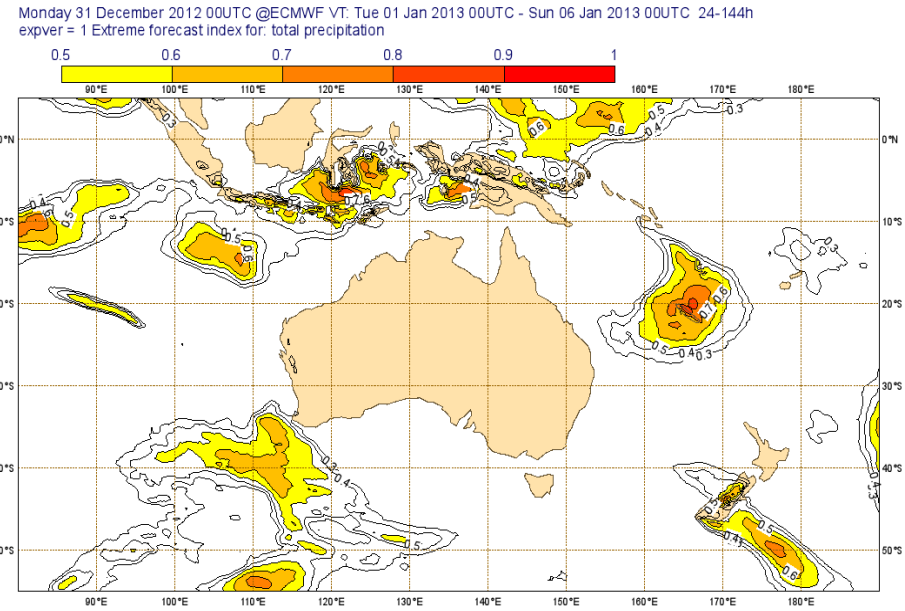
Drier-than-normal conditions, positive OLR anomalies (yellow/red shading) ; Wetter-than-normal conditions, negative OLR anomalies (blue shading)

MJO

Rainfall anomalies, ECMWF analysis
VT: 31/12/2012 – 06/01/2013



EFI T+24-144
VT: 01-05/06/2013

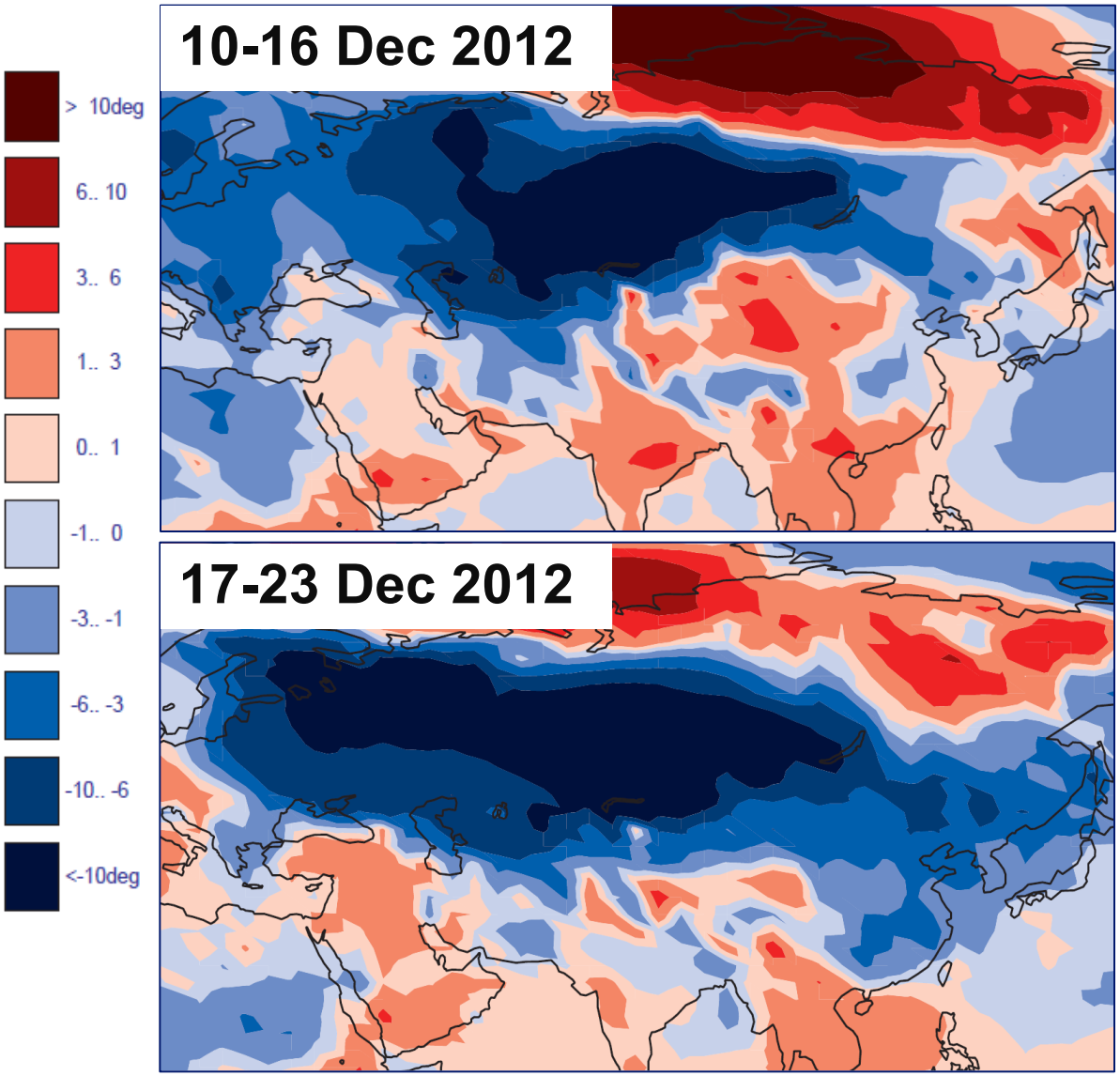


- Signals of extreme rain (EFI) and analysed rainfall anomalies in the maritime continent match pretty well and they both are in accordance with the observed strong MJO.

Severe weather case in the extra-tropics

A cold snap over Central Asia mid December 2012

Cold weather in Central Asia - mid December 2012

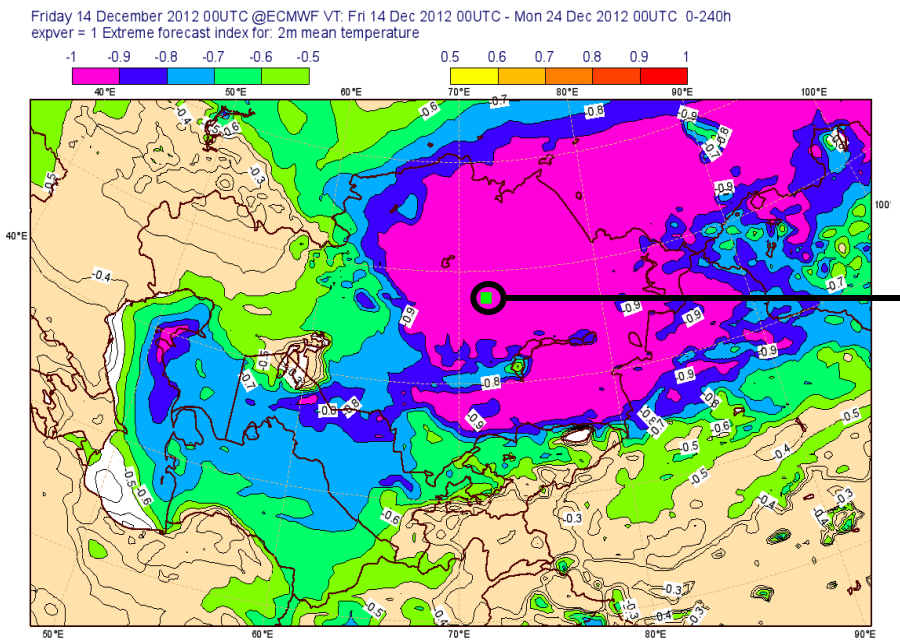


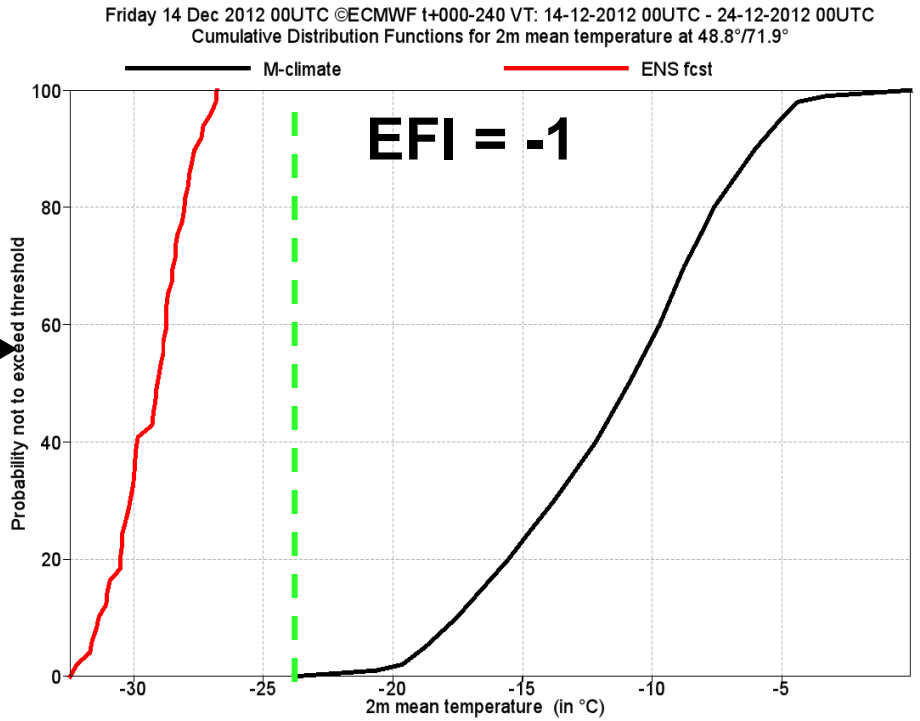
ECMWF analysis of 2-metre mean temperature anomalies

ECMWF

Cold weather in Central Asia - mid December 2012

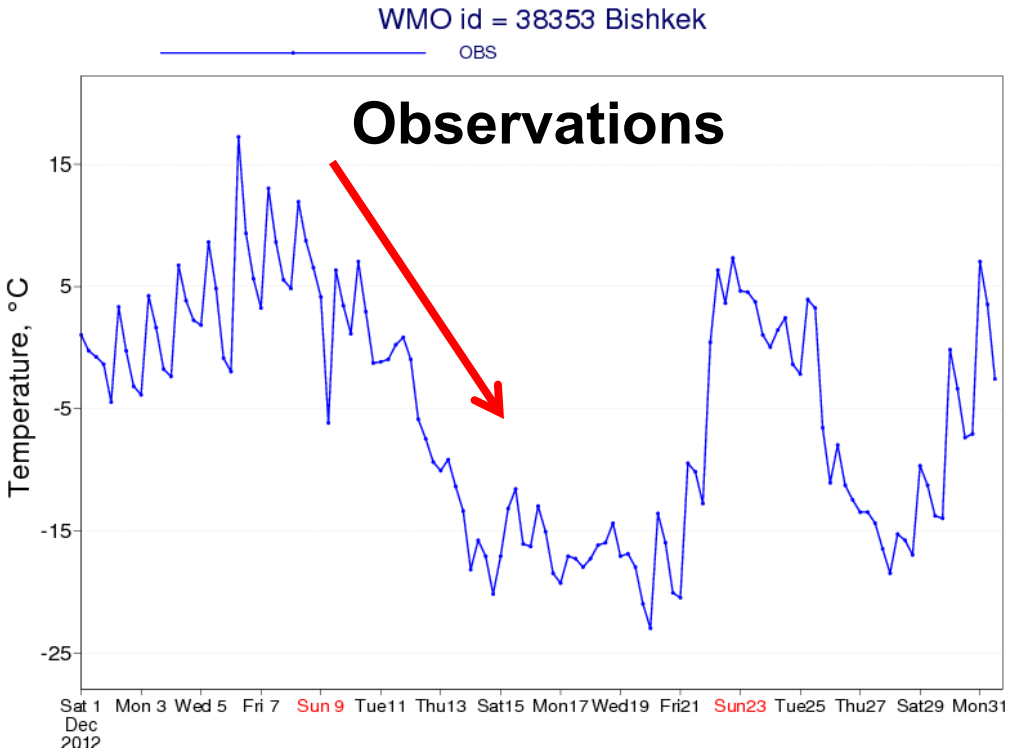
EFI, BT: 14/12/2012, T+0-240h

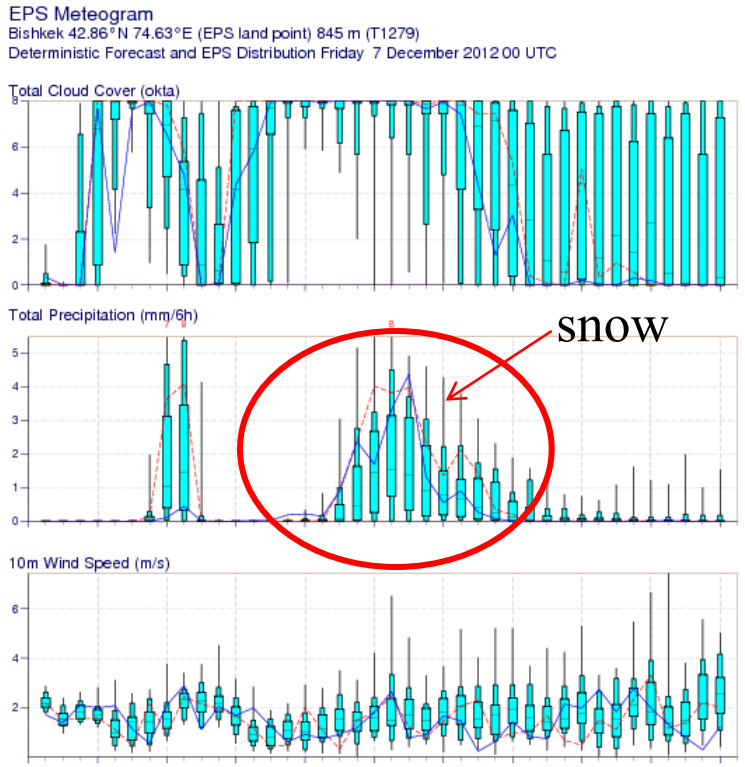




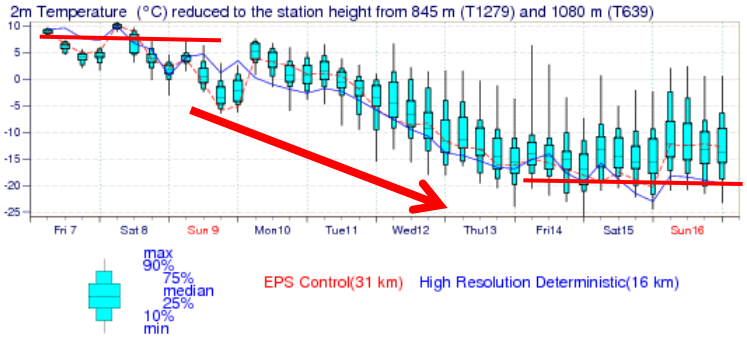
- **EFI for 2-metre mean temperature over a 10-day period reached -1 which signifies abnormally cold weather in the following 10-days. CDF plot reveals that mean temperature at that location in Kazakhstan is expected to be below the M-climate minimum.**

Cold weather in Central Asia - mid December 2012





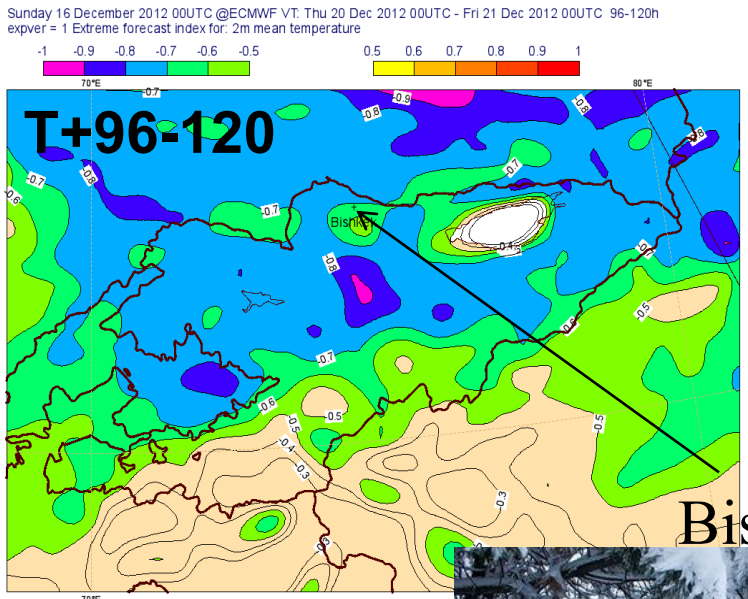
- **Temperatures in Bishkek, the capital of Kyrgyzstan, dropped below -20° C leaving many homes without gas and electricity.**

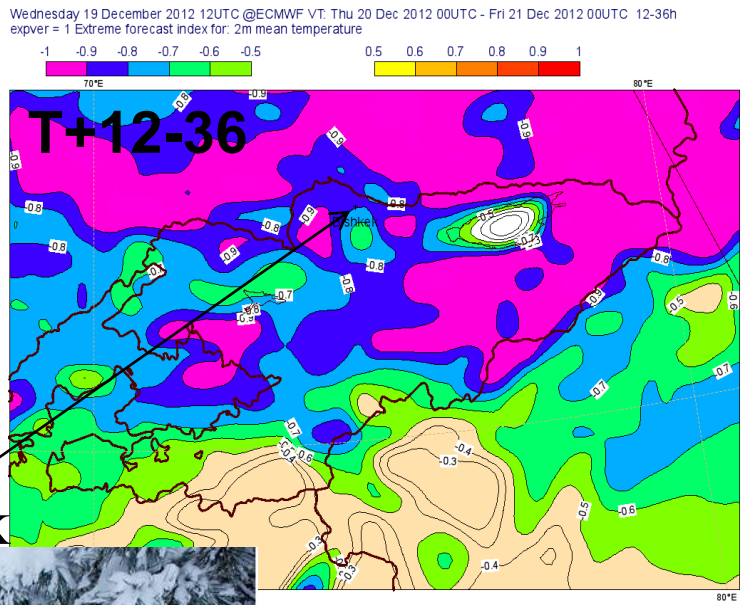


ECMWF

Cold weather in Central Asia - mid December 2012

EFI for 2m temperature valid for 20th Dec 2012





Bishkek

Photo: Southern Gate
Victory Park, Bishkek

ECMWF

Further Reading:

User Guide to ECMWF Forecast Products (new edition), available online at *http://www.ecmwf.int/products/forecasts/d/charts*