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A brief description of early warning products for extreme weather events

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TIGGE

THORPEX

A World Weather Research Programme

Introduction

This is a short guide on how to use the ensemble-based early warnings products for extreme weather events displayed on the two website:

http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_extreme_prob.html

http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_warning.html

These early warning products are based on operational ensemble forecasts from four of the leading global NWP centres: ECMWF, JMA, UK Met Office and NCEP. The forecast data have been extracted from the TIGGE database (see http://tigge.ecmwf.int); these TIGGE data are available with a 2-day delay as part of the THORPEX research programme.

Whether you are an operational forecaster or anyone else interested in predicting extreme weather, we would appreciate your comments on these prototype products. Depending on feedback received, they could form the basis for future real-time products for use in forecast demonstration projects and operational forecasting.

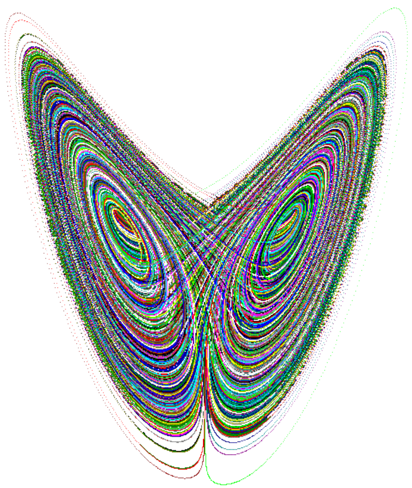
Introduction

This guide assumes that you are familiar with ensemble prediction systems (EPS) and the use of probabilistic forecasting products. For more information about ensemble forecasting, we recommend the following:

- "Guidelines on Ensemble Prediction Systems and Forecasting"
  http://www.wmo.int/pages/prog/www/Documents/1091_en.pdf
  is published by the WMO expert team on EPS;

- The ECMWF User Guide
  http://www.ecmwf.int/products/forecasts/guide/
  provides comprehensive guidance on the use of ECMWF systems including detailed advice on the use of EPS;

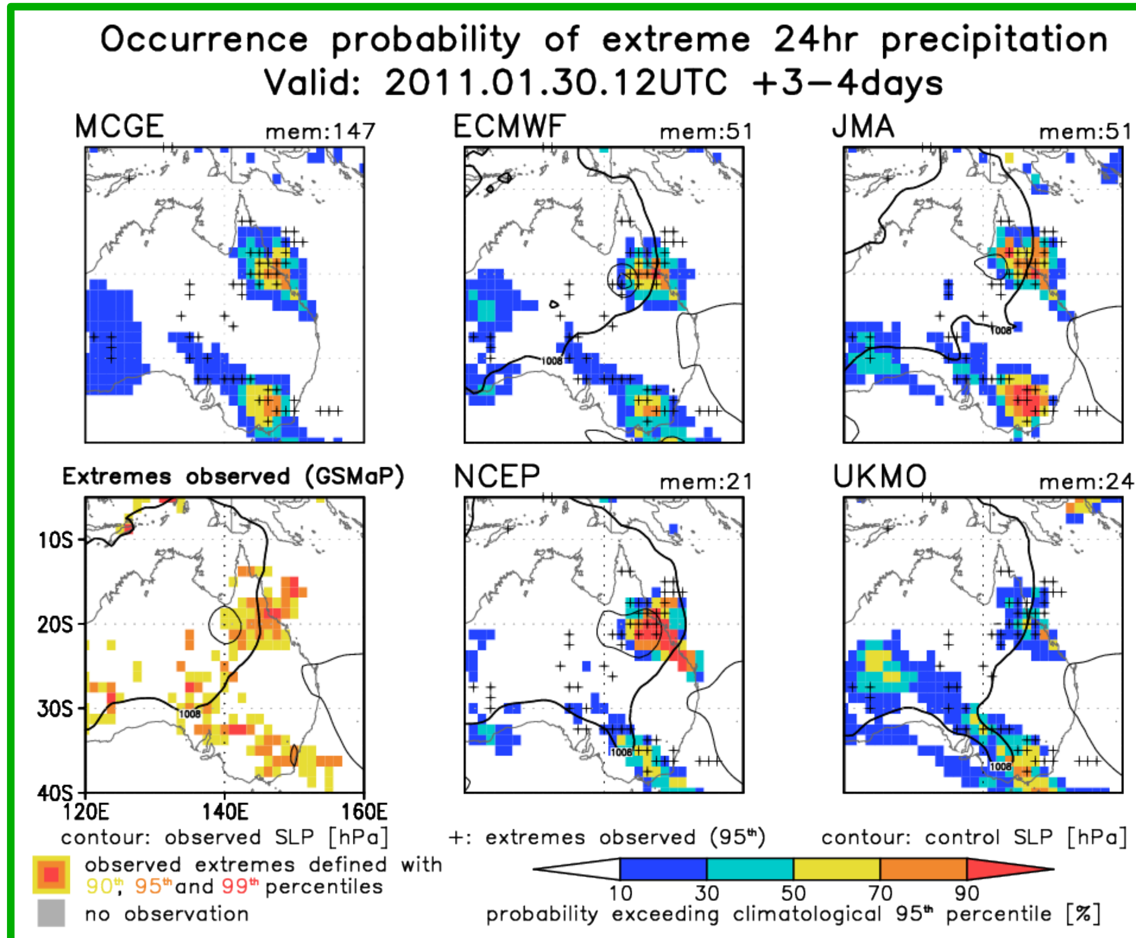
- The COMET training materials
  https://www.meted.ucar.edu/training_detail.php
  provide training on the use of EPS.



Ensemble-based early warning products

The first type of product highlights the probability of occurrence of extreme weather. Four versions of this product are available, to highlight the risks of

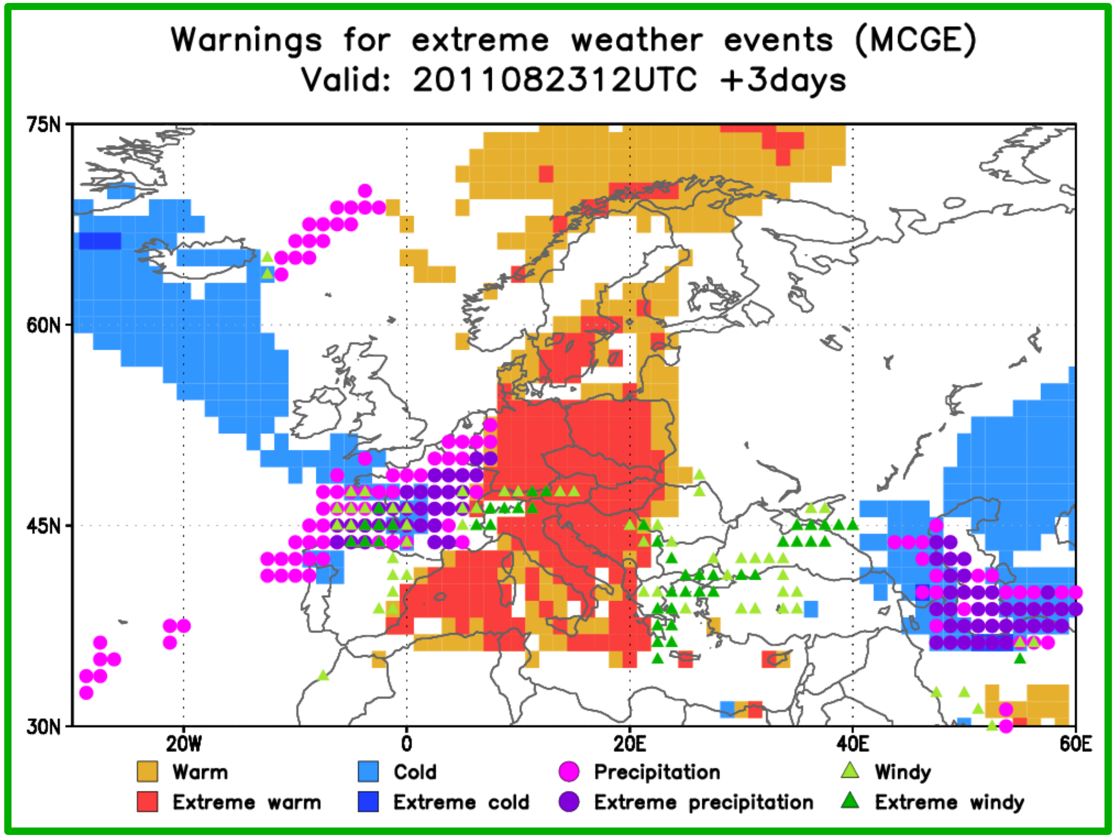
- heavy rain
- strong winds
- high temperatures
- low temperatures.



In each case, the extreme weather is identified by comparing the actual model forecast values with the model forecast climatology.

Ensemble-based early warning products

The second type of product summarises the same four types of extreme weather, by plotting colours and symbols on a single map. The probabilities are calculated both from both each individual ensemble and the Multi-Centre Grand Ensemble – a large ensemble including all the members from each of the four NWP centres.



The following sections of the guide given more details on how these products are calculated, and how they should be interpreted:

1. How the probability of occurrence of extreme events is calculated from TIGGE data
2. How climatological probability density function s (PDFs) are estimated from TIGGE forecasts
3. How to use the early warning products
4. An example of early warning products for an extreme weather event

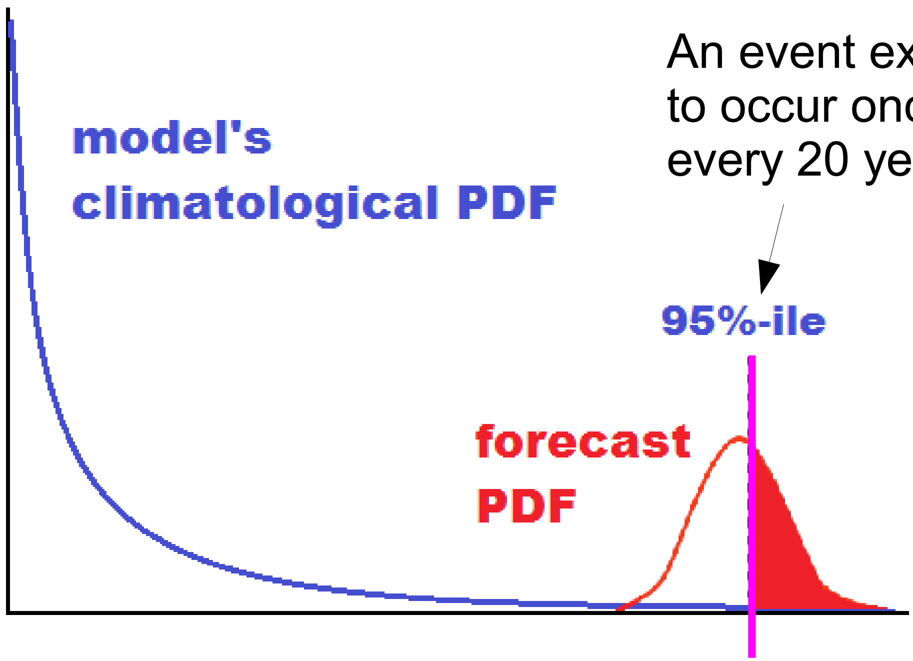
Occurrence probability of an extreme event

Occurrence probability of an extreme event is measured by

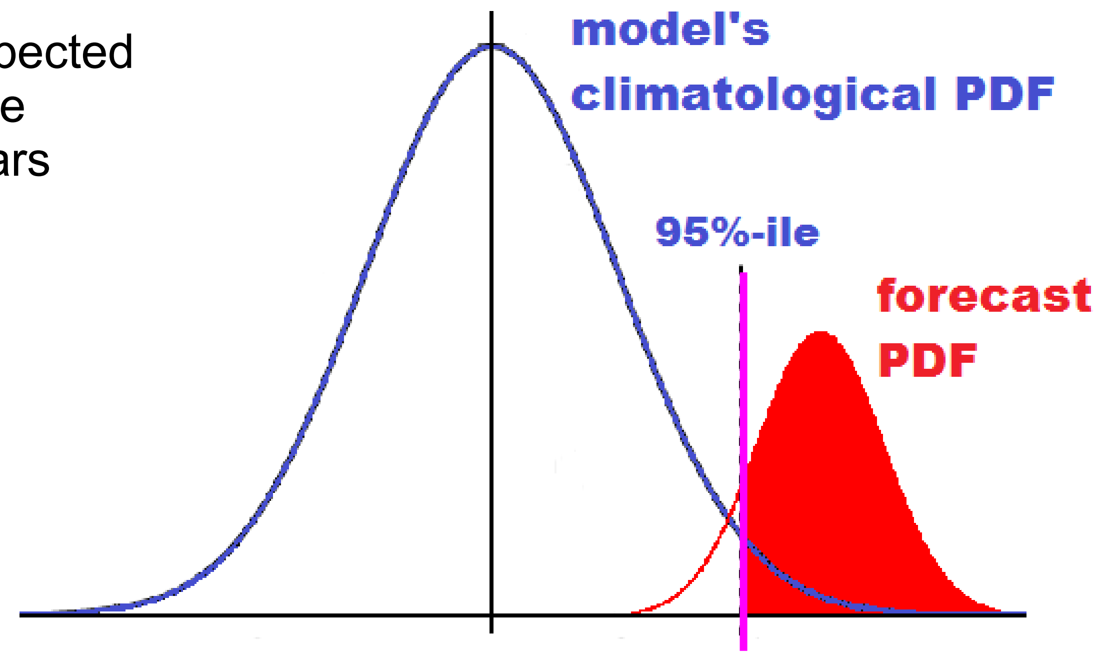
the fraction of ensemble members that predict a higher or lower values than the specified “climatological” percentile (e.g. 95^{th} percentile) to ensemble size.

The occurrence probability is defined at each grid point.

Precipitation



Surface temperature



90^{th}, 95^{th} and 99^{th} percentiles are used to indicate when rainfall, wind or temperatures exceed the values expected on 10%, 5% or 1% of occasions. Similarly, 10^{th}, 5^{th} and 1^{st} percentiles are used for extreme cold temperatures.

Occurrence probability of an extreme event (single-centre ensemble)

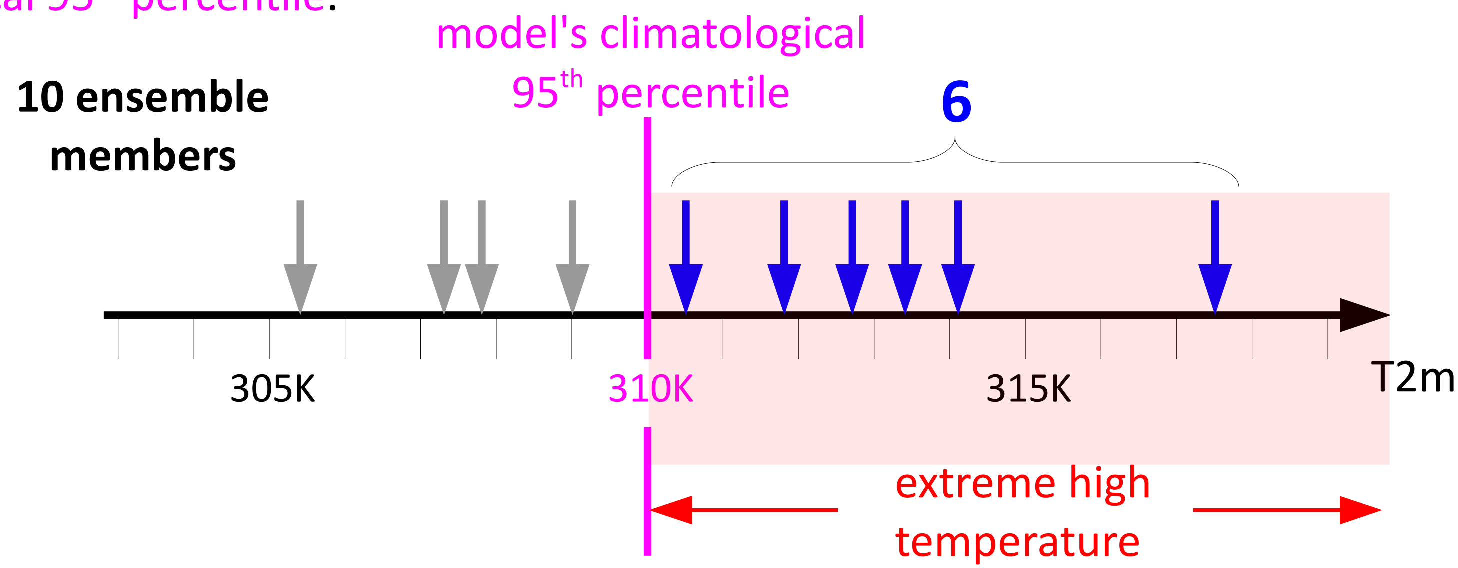
Occurrence probability of an extreme event is measured by

the fraction of ensemble members that predict a higher or lower values than the specified "climatological" percentile (e.g. 95th percentile) to ensemble size.

The occurrence probability is defined at each grid point.

Example: 10-member ensemble forecast of surface temperature at Oxford

Here, extreme high temperature is defined as temperature exceeding the model's climatological 95th percentile.

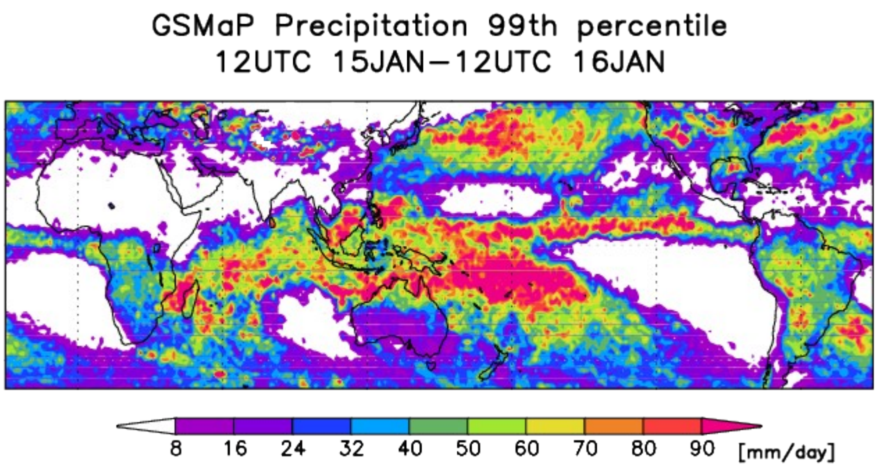


6 members predict a higher value than the climatological 95th percentile (310K): extreme high temperature. Then, occurrence probability of extreme high temperature is defined as **60%**.

How climatological PDFs are estimated from the TIGGE data

A climatological PDF (probability density function) from observed data differs from that from forecast data (e.g. 10mm/hr in a model is not equal to 10mm/hr in observation). We have to prepare a climatological PDF in "a model world" for forecasts. However, a climatological PDF is strongly sensitive to model or the model version (e.g. 10mm/hr in a ECMWF model is not equal to 10mm/hr in a JMA model). Also, operational models are frequently upgraded!

The best way to estimate climatological PDFs for each model is to run many forecasts for past cases, using the current versions of each model (often referred to as hindcasts or reforecasts). But reforecast data is not available from all the NWP centres. Instead, we have to estimate climatological PDFs from the TIGGE forecast data.



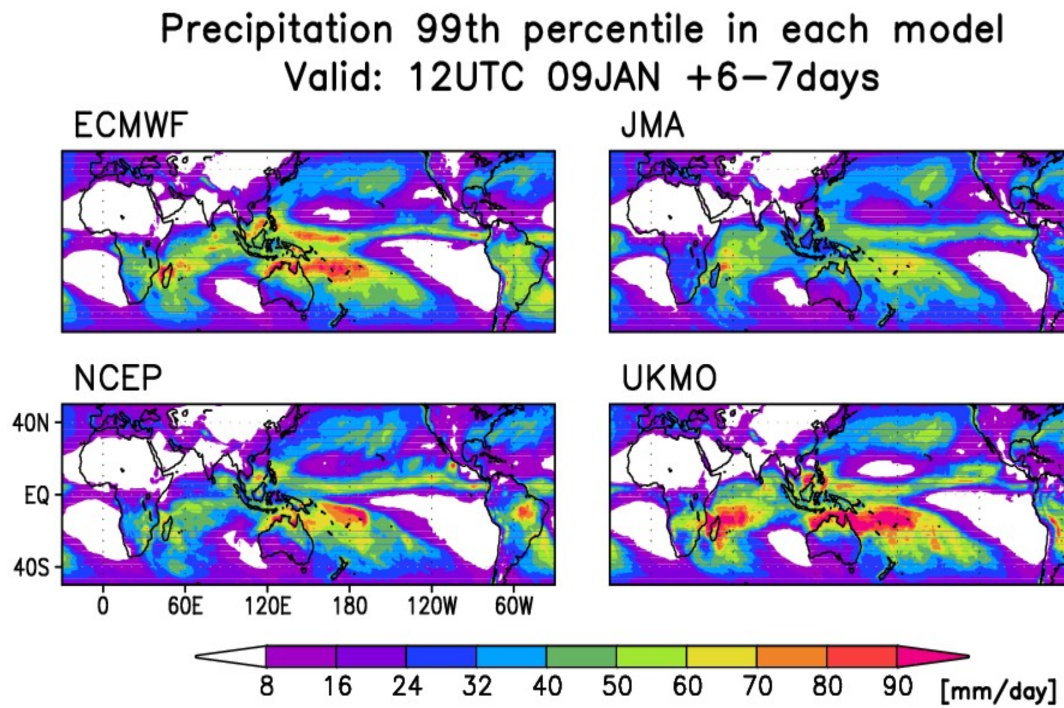


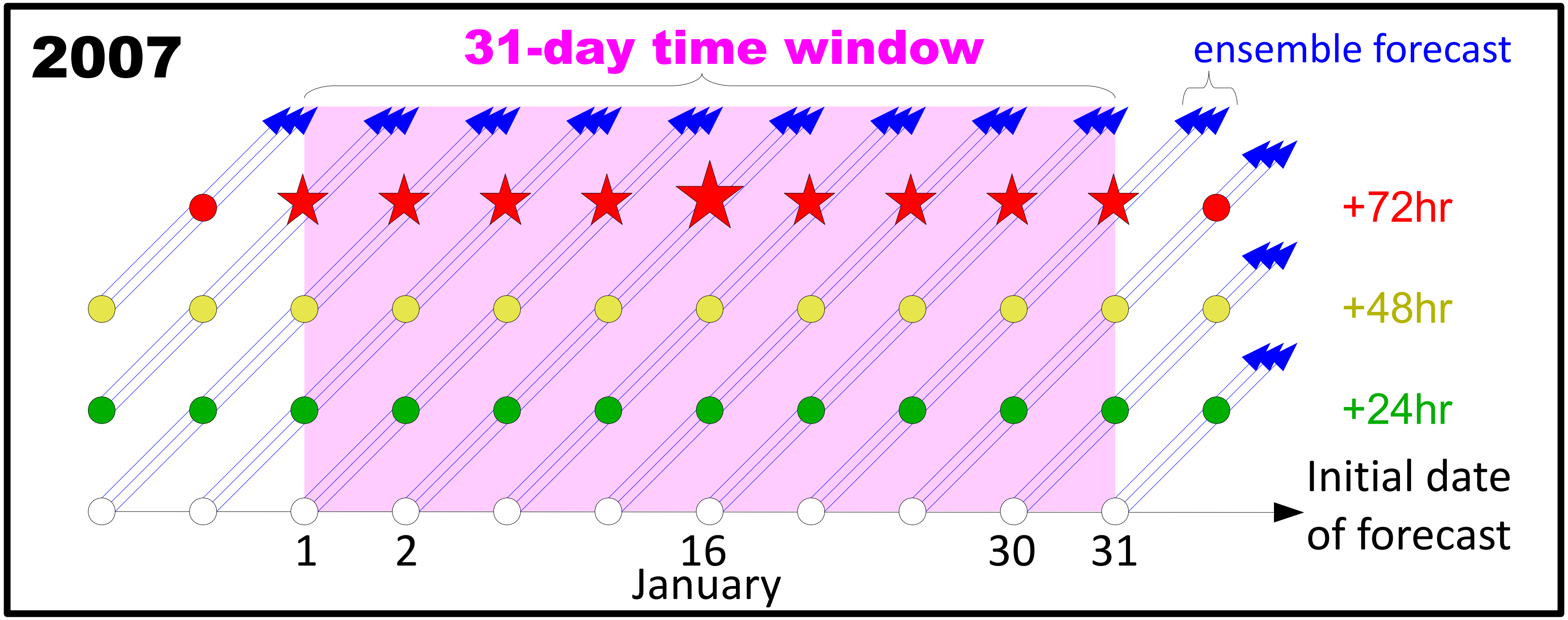
Figure: Climatological 99th percentiles of precipitation for GSMaP (left panel) and NWP models (four right panels).

How climatological PDFs are estimated from the TIGGE data

A climatological PDF used here is:

- calculated for each EPS using TIGGE data (all members in each EPS) during October 2006 to January 2011
- defined at each grid point for each calender day in each forecast lead time with the 31-day time window.

Example: A climatological pdf for 72-hr ECMWF ensemble forecast verified on 16th January is made from all the 72-hr ECMWF forecasts (members) verified on 1st - 31st January in 2007 to 2011.



No bias correction.

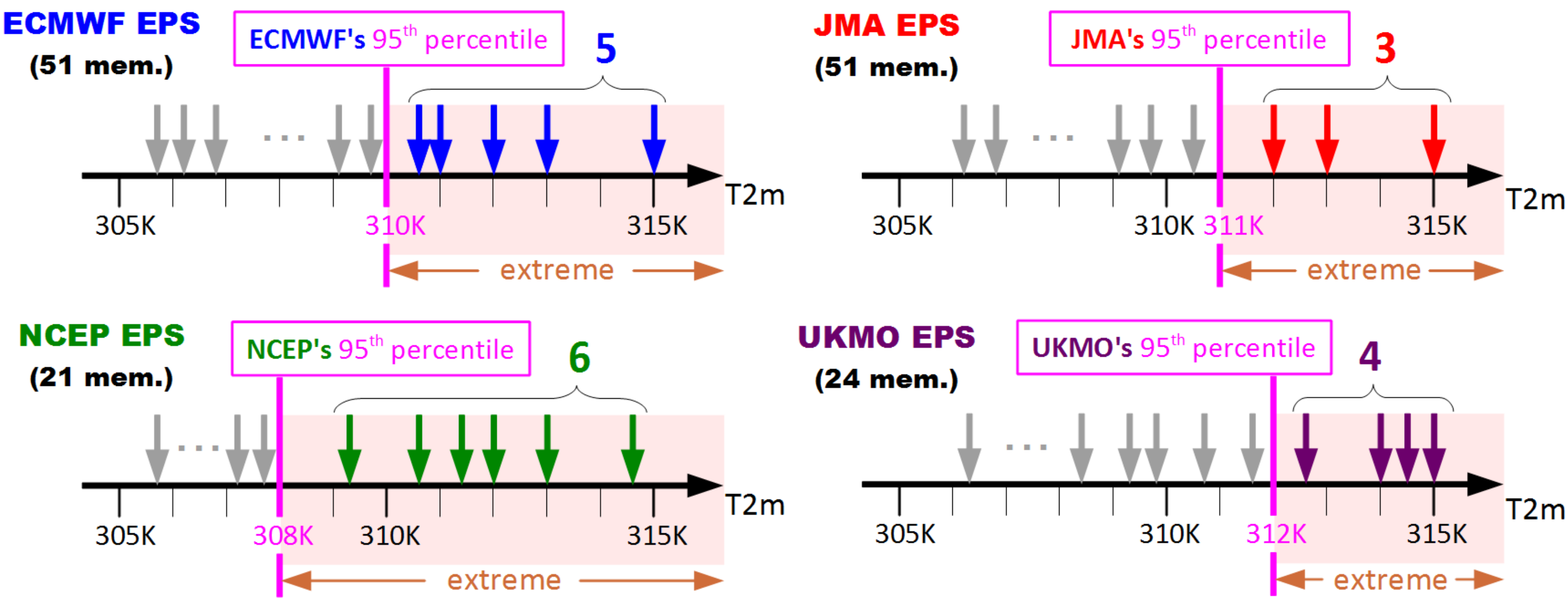
x 5 years

Total number of samples (★) for ECMWF: 31days x 5yrs x 51mems = 7905

Occurrence probability of an extreme event (grand ensemble)

Climatological percentiles derived from NWP models differ from each other. Each model's climatological percentile value is used for a definition of extreme event.

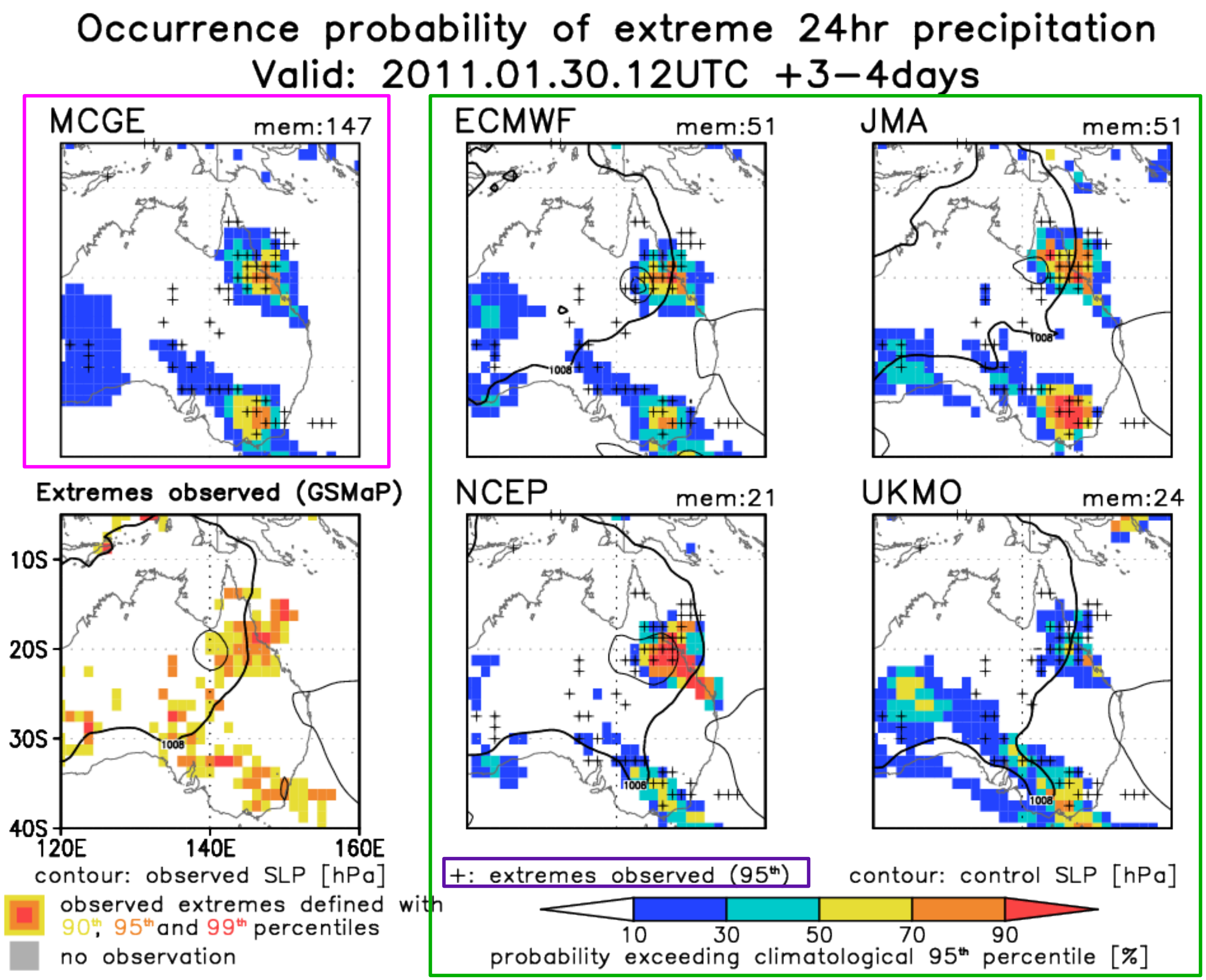
Example: forecast probability of surface temperature at Oxford



18 (=5+3+6+4) members predict a higher value than each model's climatological 95%-iles (310, 311, 308, and 312K). Then, occurrence probability of extreme high temperature is defined as 12.2% **(=18/(51+51+21+24))**.

How to use the early warning products (precipitation)

URL: http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_extreme_prob.html



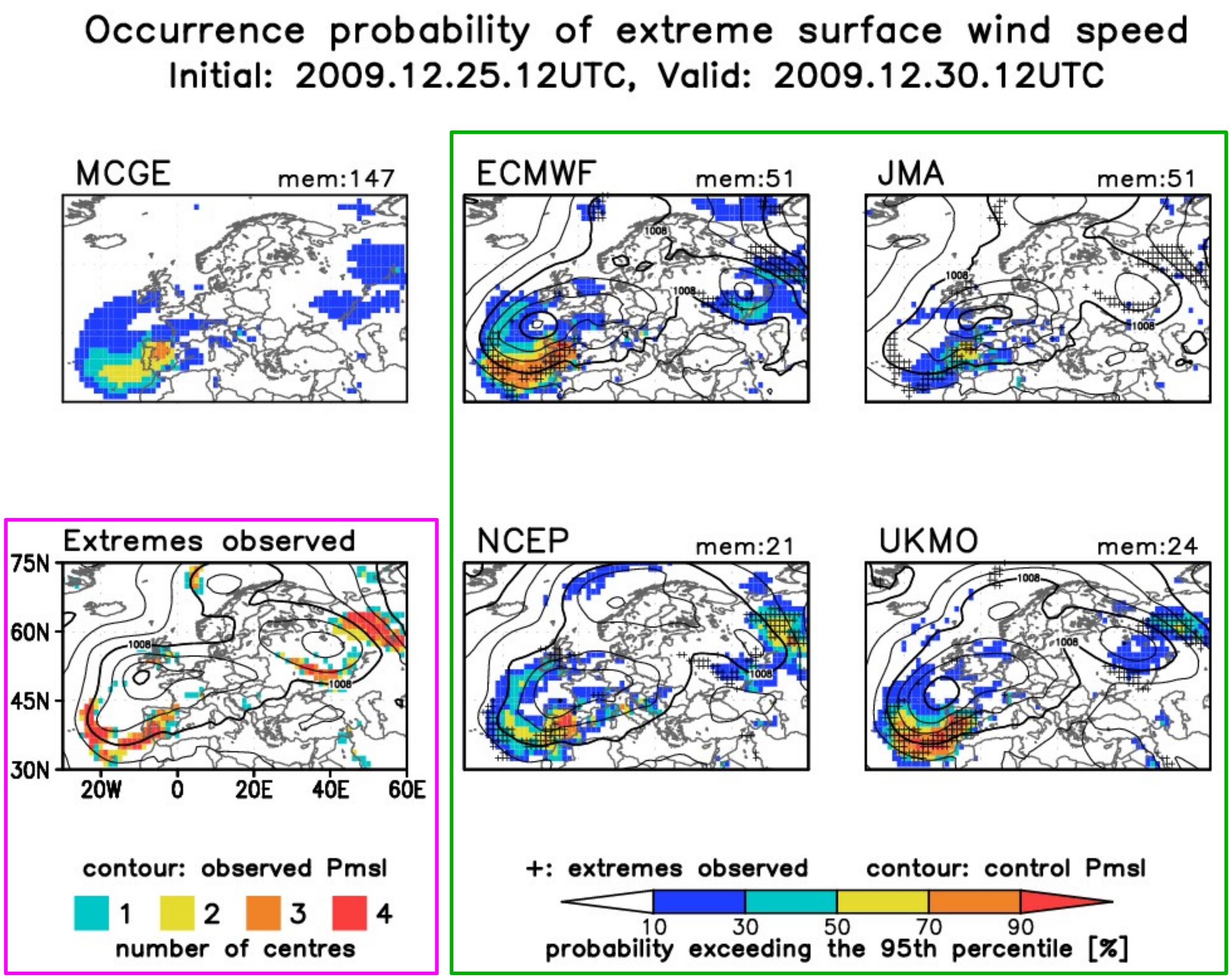
This is occurrence probabilities of extreme precipitation estimated by ensemble forecasts. Here, the 95th percentile of each model's climatological PDF is used as a threshold for a detection of extreme weather events.

Four right panels show predicted occurrence probabilities by ECMWF, JMA, NCEP, and UKMO (shading) and observed extreme precipitation ("+", also shown as shadings in the lower left panel). The upper left panel shows predicted an occurrence probability by Multi-Centre Grand Ensemble(MCGE) consisting of ECMWF, JMA, NCEP, and UKMO, based on each model's climatological PDF.

All these products are available for the 90th and 99th percentile, as well as the 95th percentile. The products are available for past forecast cases, during the period covered by TIGGE (from October 2006).

How to use the early warning products (continued)

URL: http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_extreme_prob.html



As well as highlighting the risks of extreme rainfall, products are also available for

- Strong wind (as illustrated),
- Surface temperature (both extreme cold and hot),

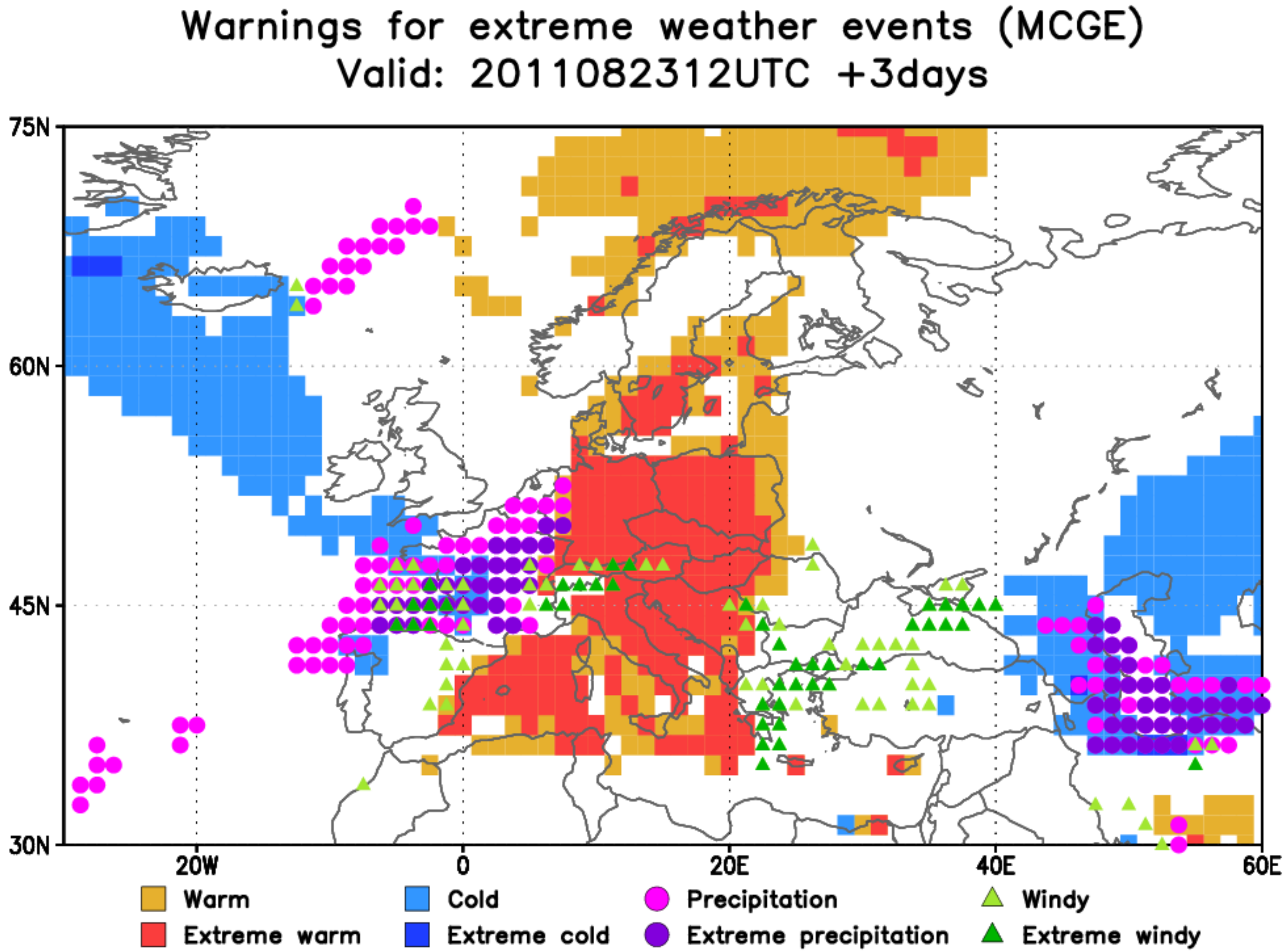
all in a similar format to the precipitation product.

The observation (analysis) for each NWP centre is defined as the control run at the initial time of the forecast. Observed extremes are detected based on the 95th percentile of each analysis's climatological PDF.

All these products are available for the 90th and 99th percentile, as well as the 95th percentile. The products are available for past forecast cases, during the period covered by TIGGE (from October 2006).

How to use the early warning products (extreme weather summary)

URL: http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_warning.html



Early warnings by Multi-Centre Grand Ensemble (MCGE):
ECMWF(51), JMA(51), NCEP(21), UKMO(24)

Early warnings by each NWP centre are also available.

This product is only provided for recent forecasts, in quasi-real time, and not for past forecasts.

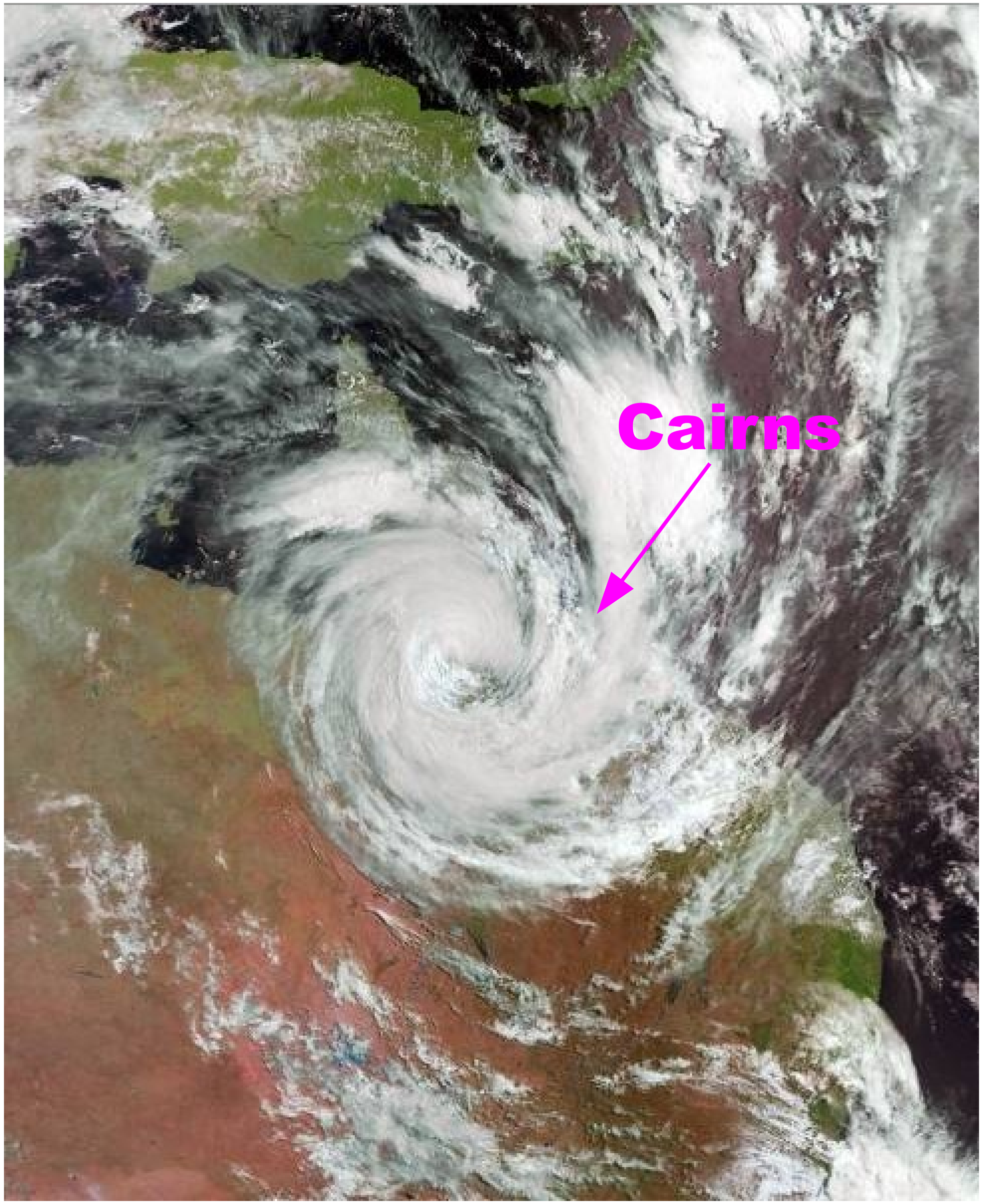
There are two extreme levels for surface warm and cold temperature, precipitation, and surface wind (e.g. "warm" and "extreme warm"). If over 50% of members in MCGE exceed the each model's 90^{th} (95^{th}) percentile, the "warm" ("extreme warm") alert is given.

Examples of early warning for extreme weather events

- heavy rainfall from tropical cyclone Yasi (February 2011)
- flash floods/snow in South Africa (June 2011)
- Russian heatwave (JJA 2010)
- Pakistan floods (July 2010)
- Hurricane Irene (August 2011)
- Hurricane Sandy (October 2012)

Tropical cyclone Yasi (February 2011)

3rd February, 2011



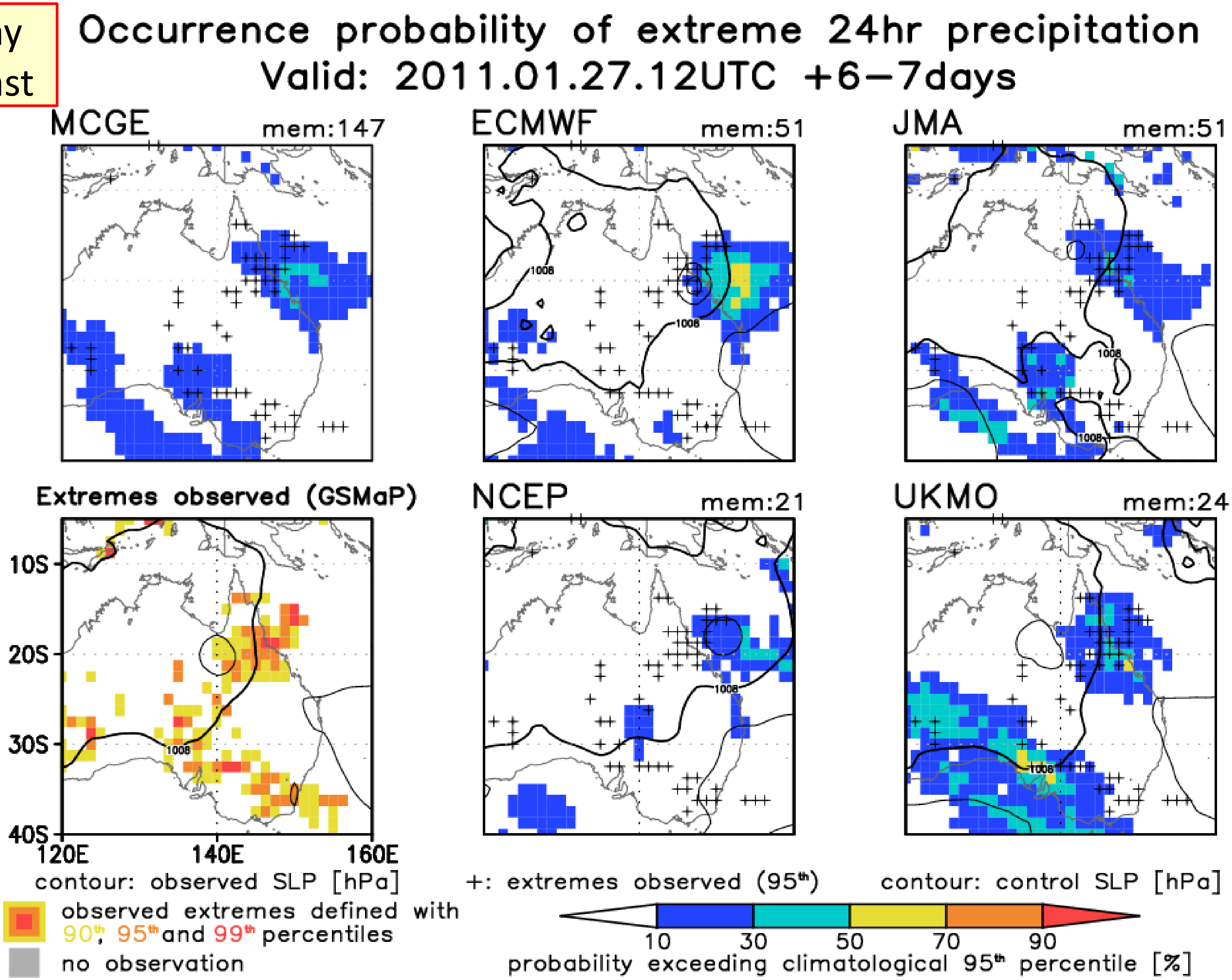
Yasi struck Cairns with a wind speed of 79m/s

Tully, Queensland, Australia

Innisfail, Queensland, Australia

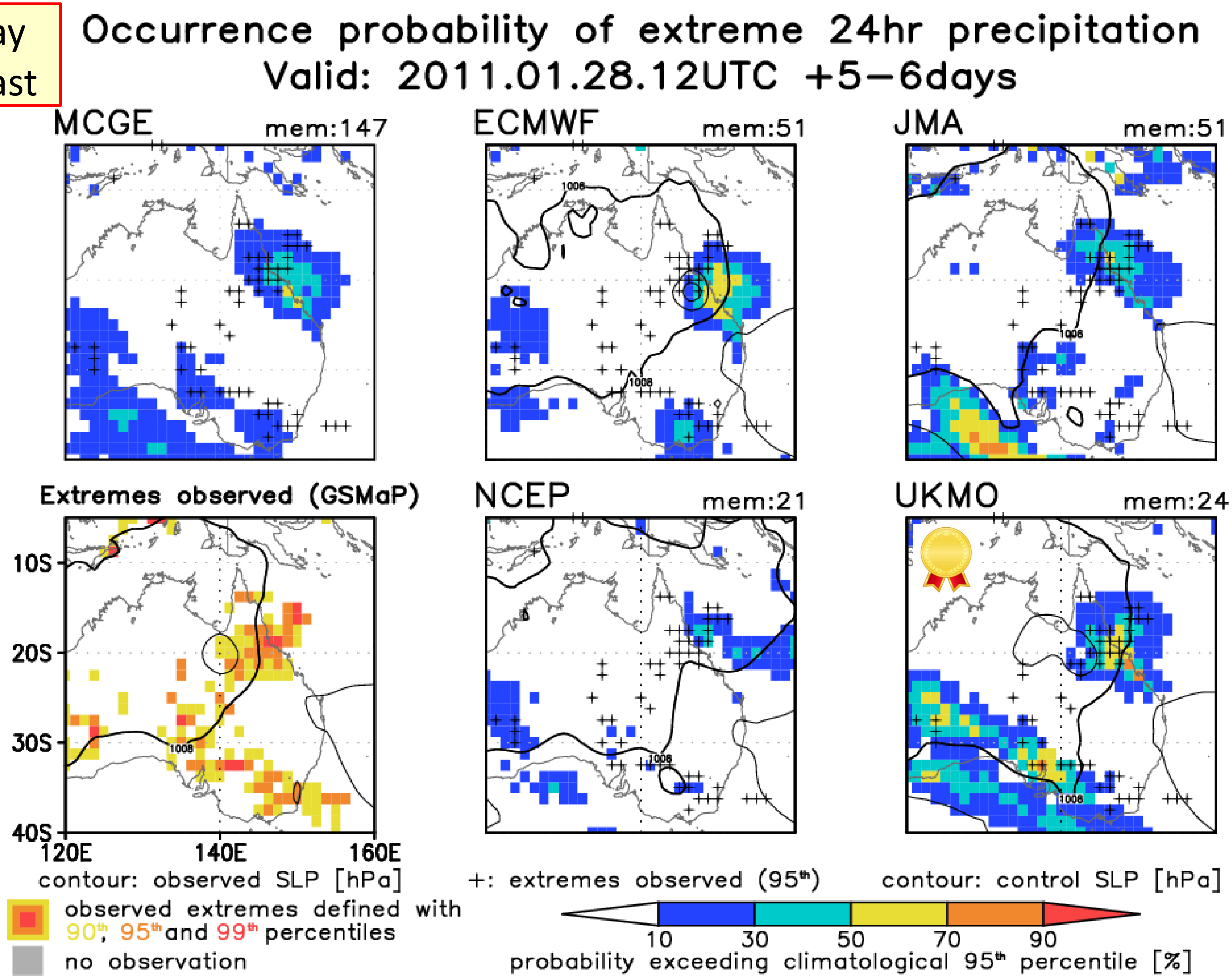
Tropical cyclone Yasi (February 2011)

+ 7-day forecast



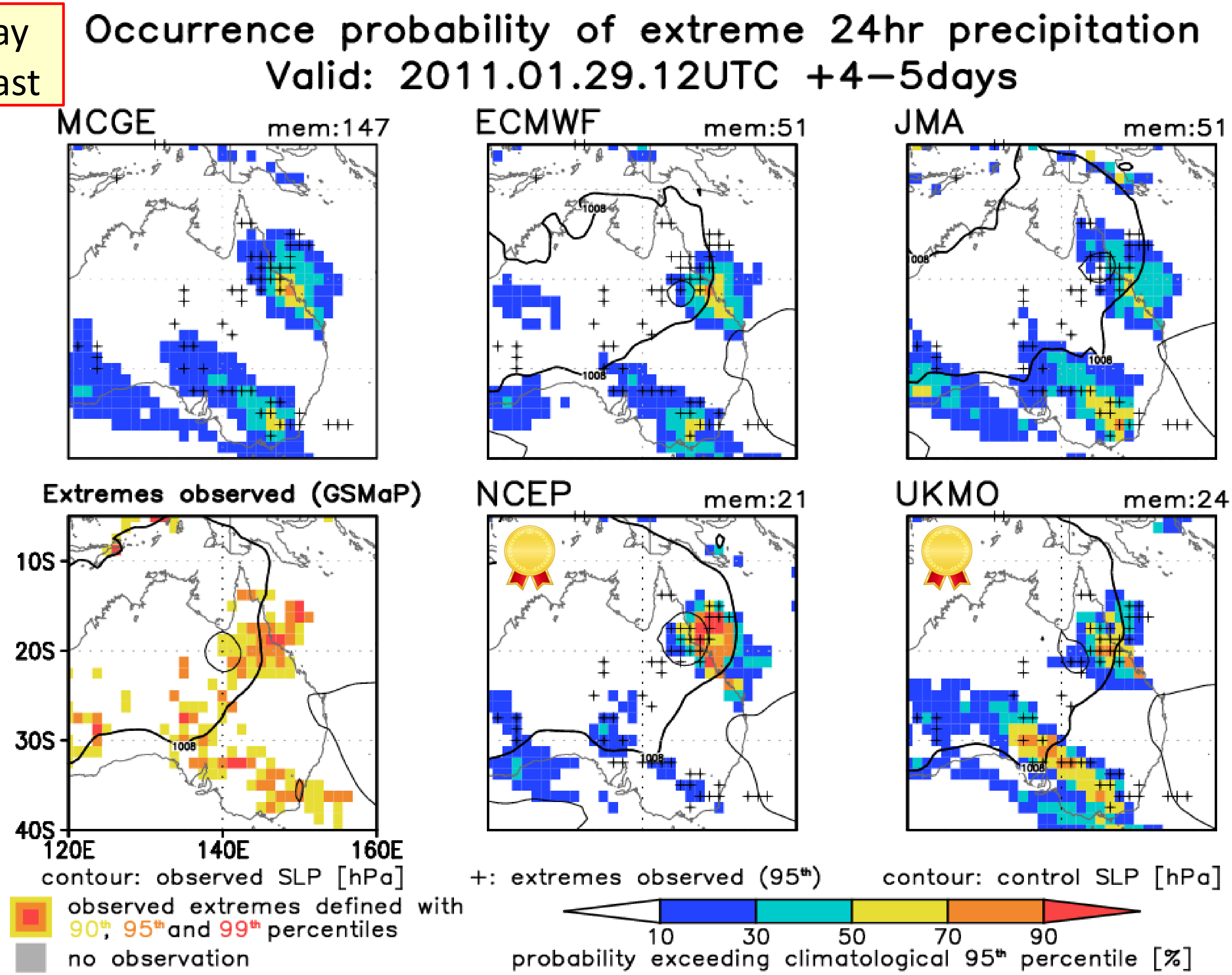
Tropical cyclone Yasi (February 2011)

+ 6-day forecast



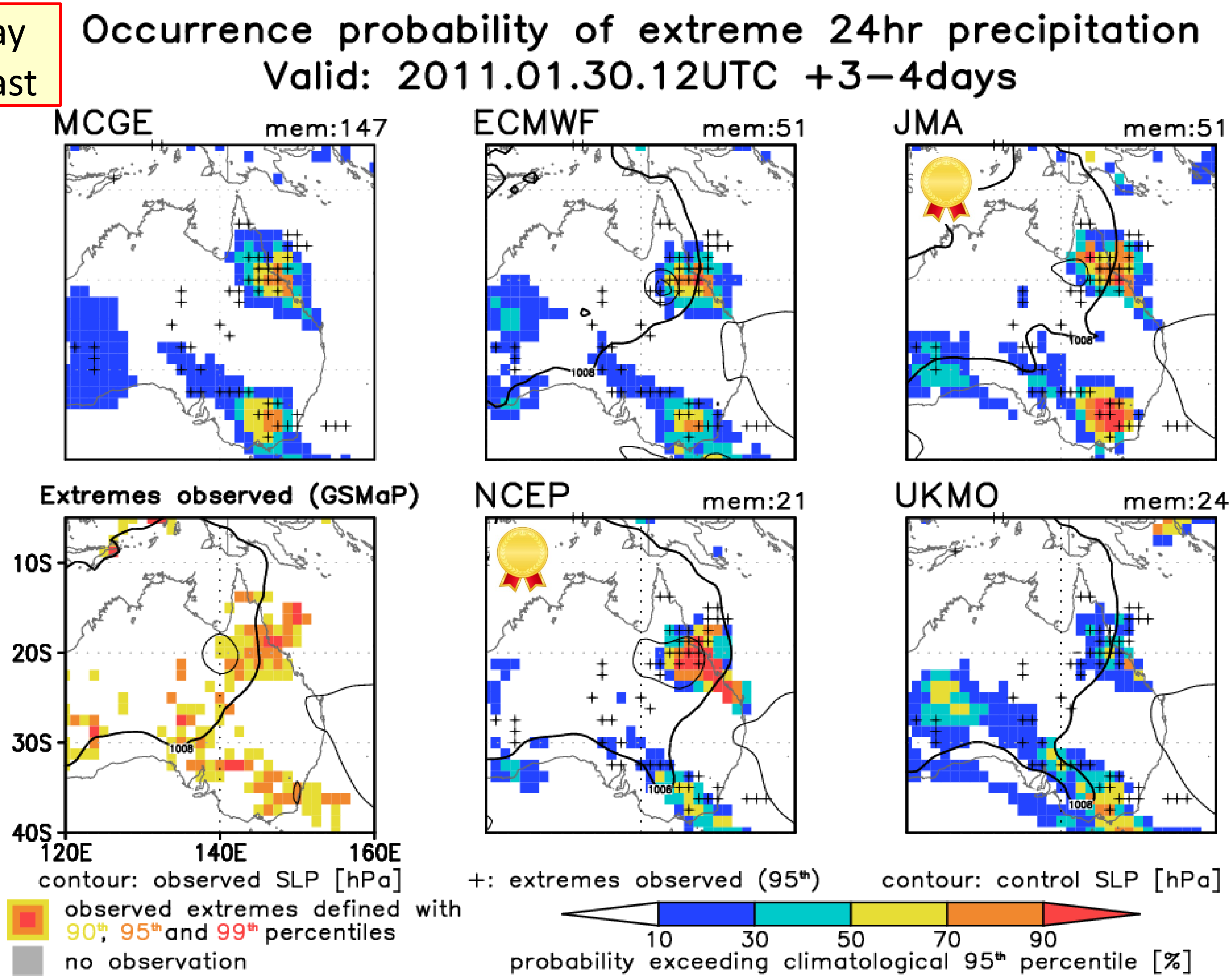
Tropical cyclone Yasi (February 2011)

+ 5-day forecast



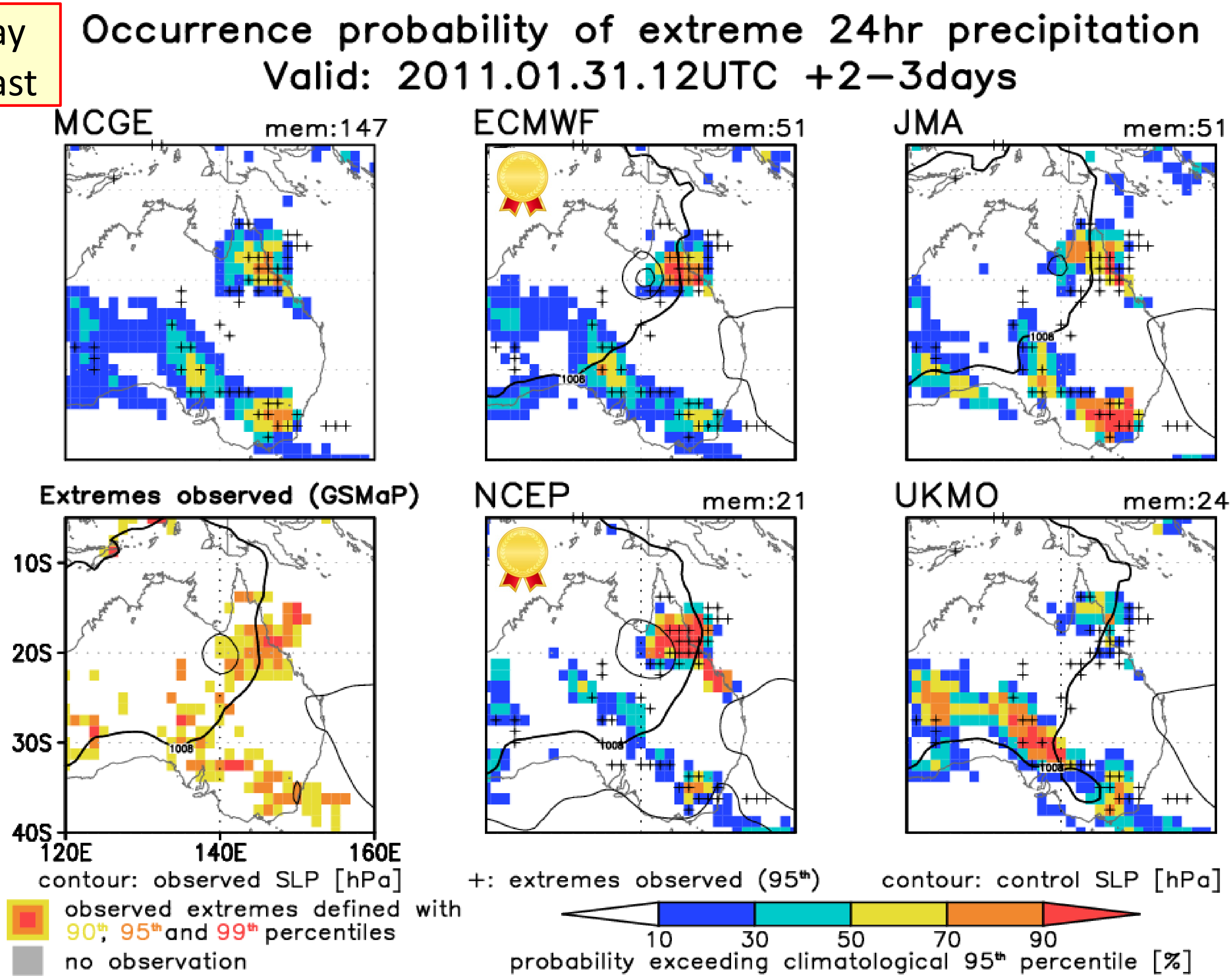
Tropical cyclone Yasi (February 2011)

+ 4-day forecast



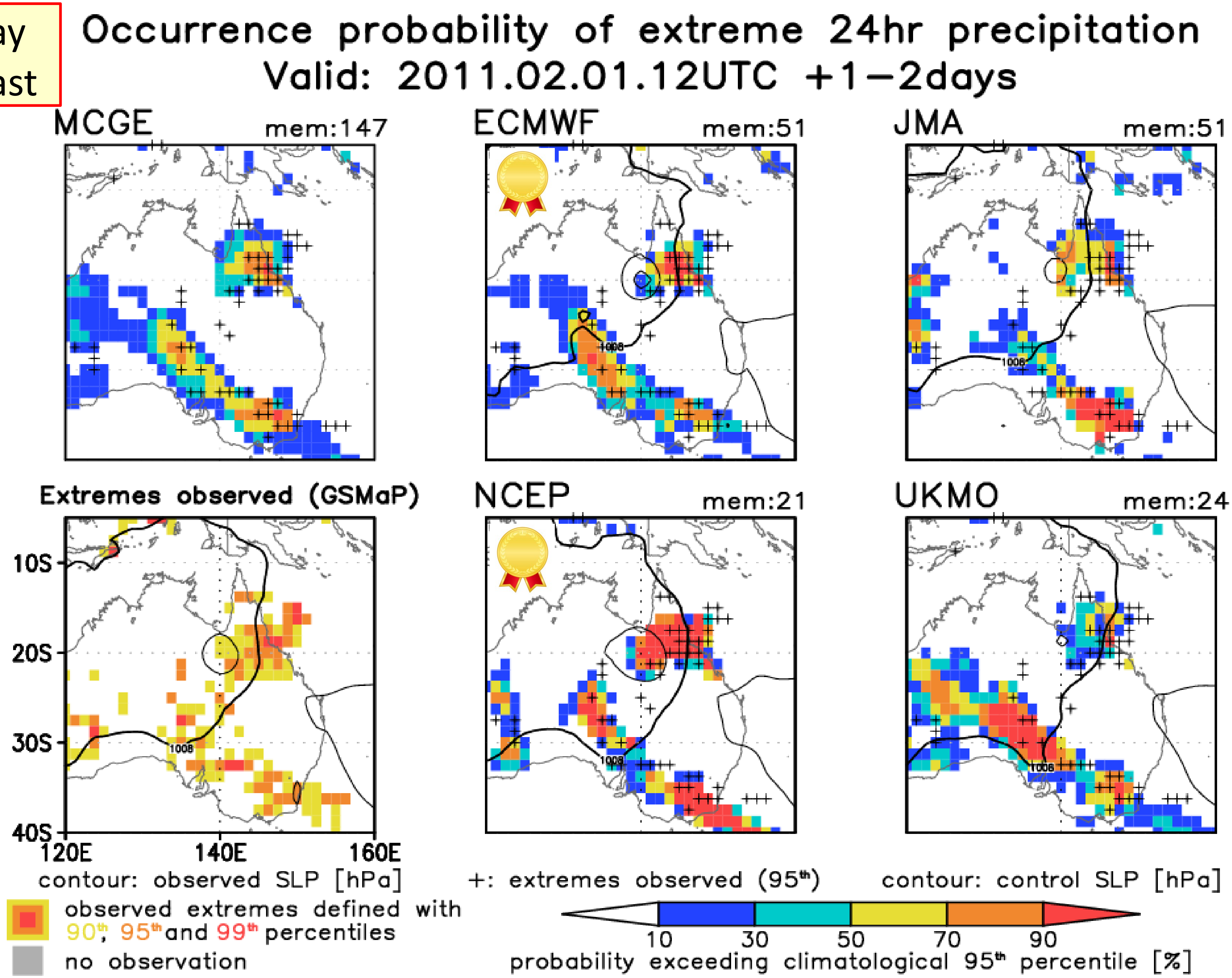
Tropical cyclone Yasi (February 2011)

+ 3-day forecast



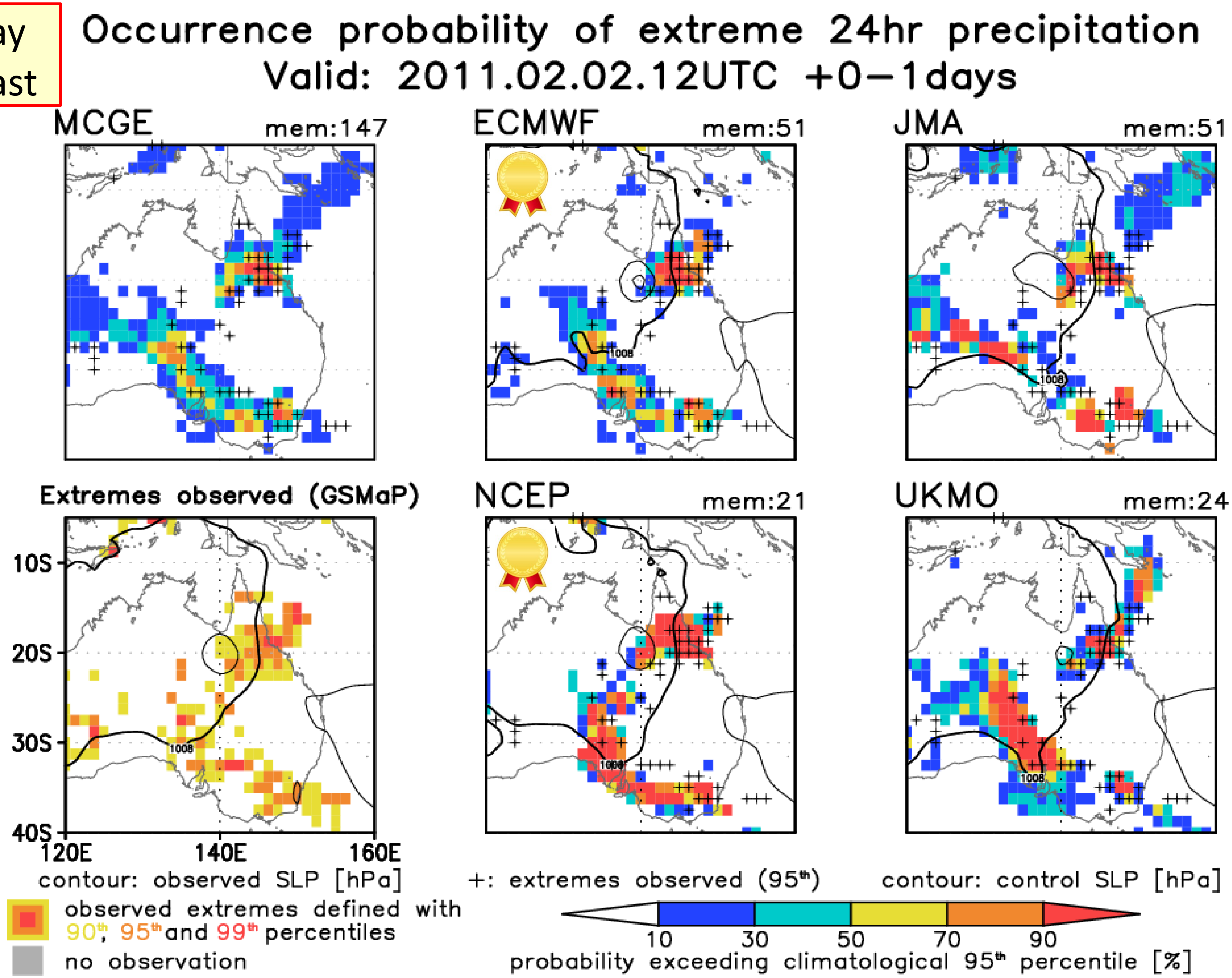
Tropical cyclone Yasi (February 2011)

+ 2-day forecast

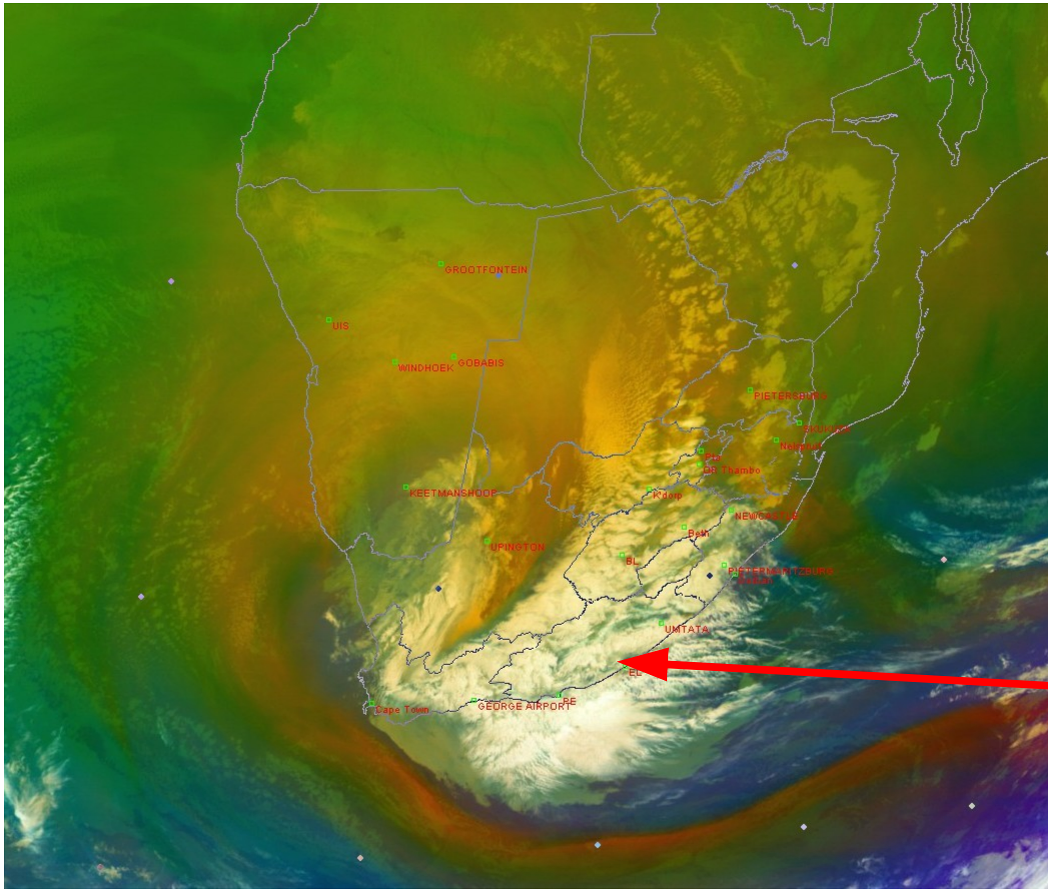


Tropical cyclone Yasi (February 2011)

+ 1-day forecast



Flash floods/snow in South Africa (June 2011)

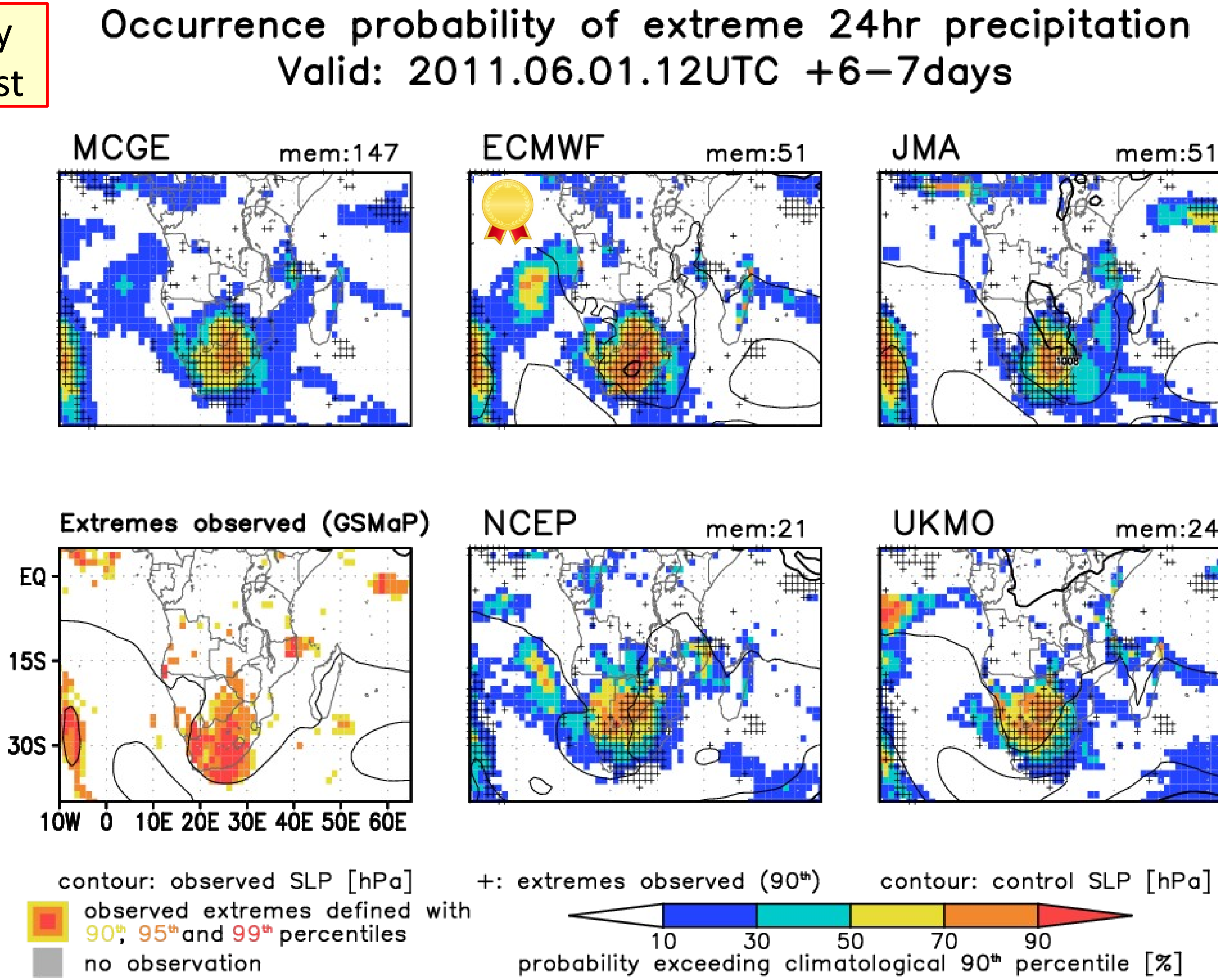


00UTC 08 June, 2011

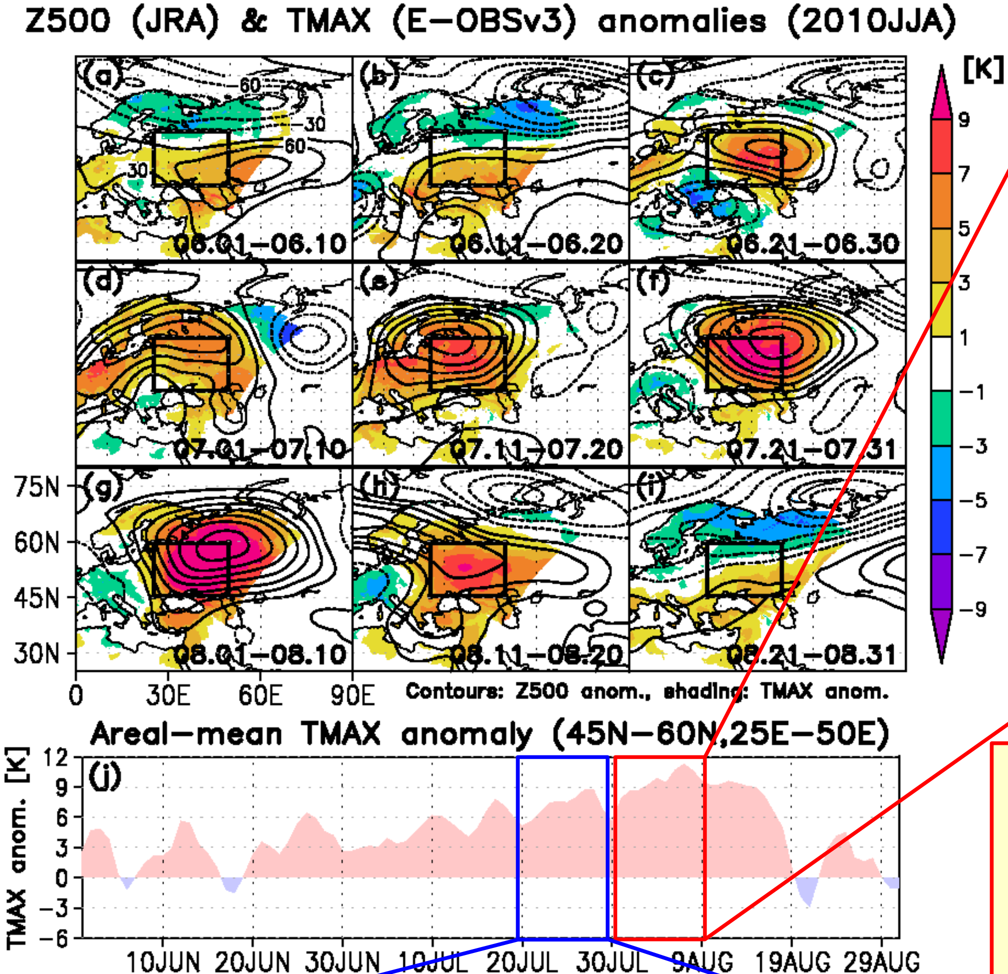
East London, South Africa

Flash floods/snow in South Africa (June 2011)

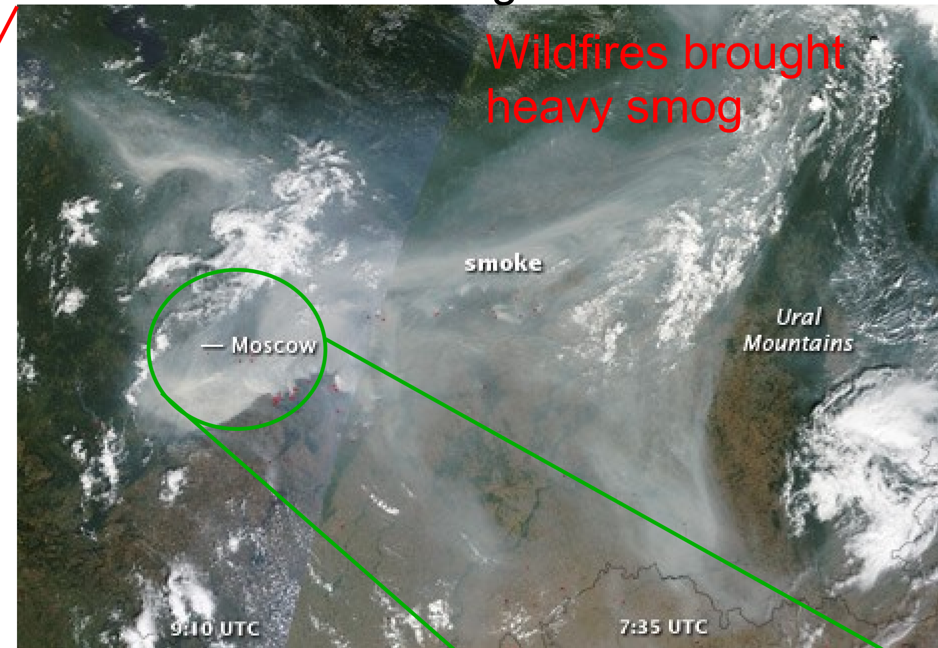
+ 7-day forecast



Russian heatwave (JJA 2010)



4th August



The heatwave killed at least 15,000 people, and brought wildfires, smog-induced health injury, and huge economic loss.

Moscow

New maximum record of 39℃!

1,600 drowning deaths!

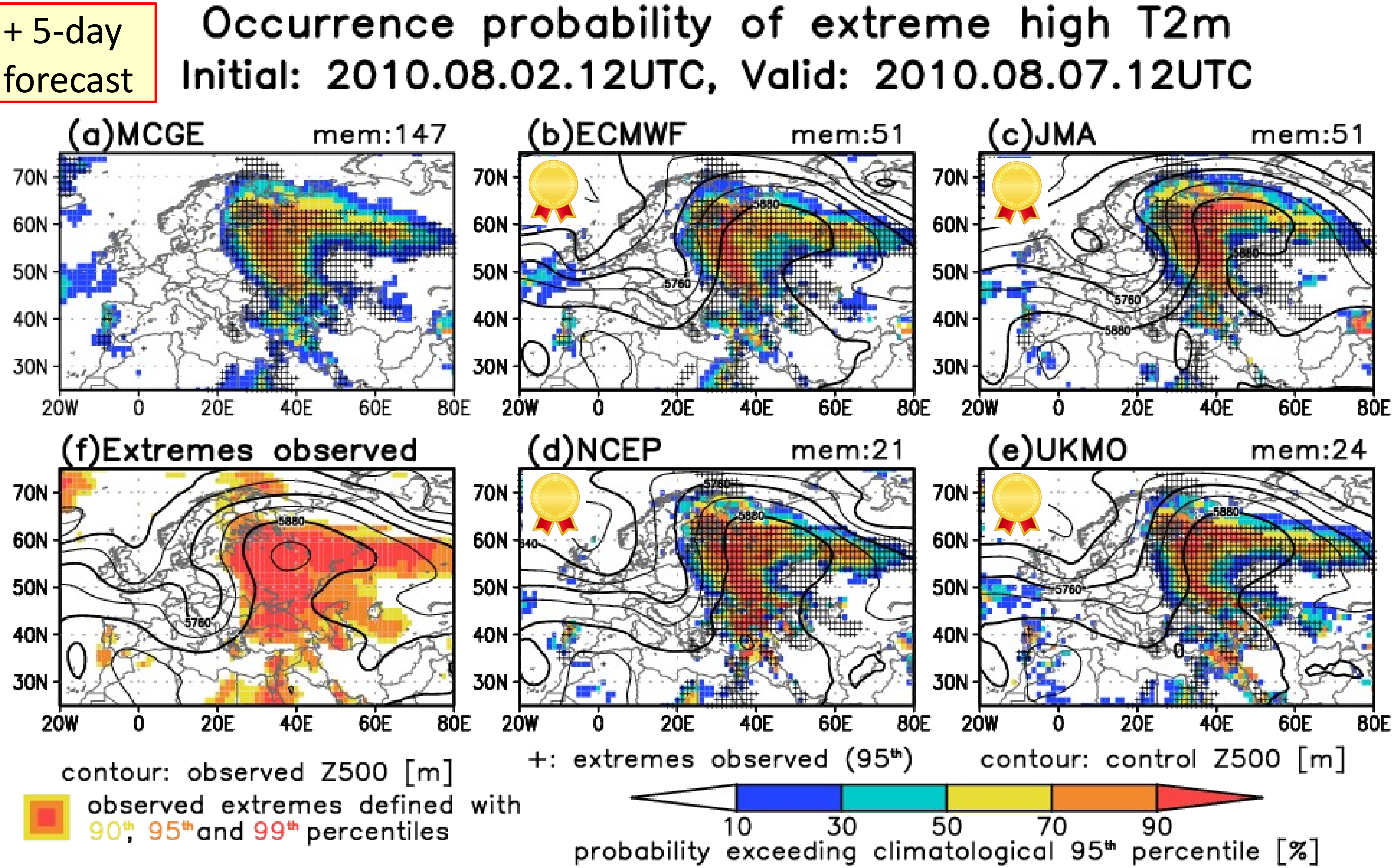
Moscow

China!?

Not flu!

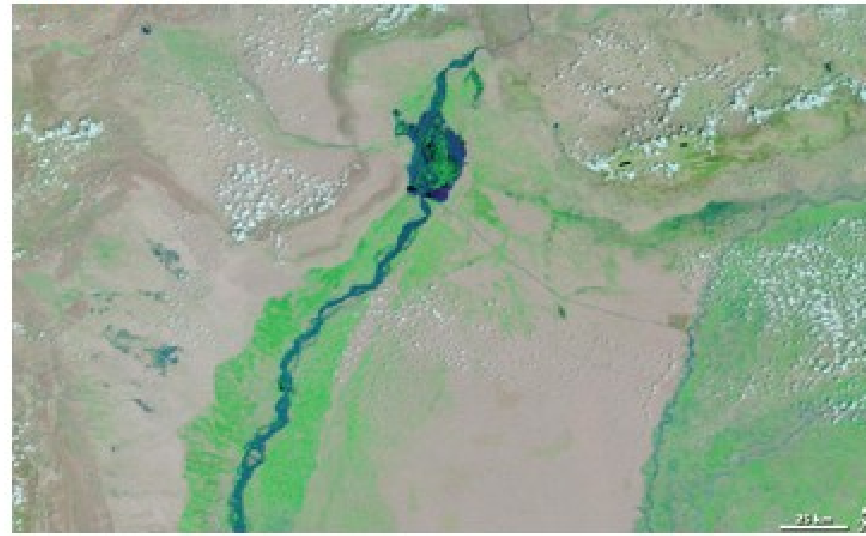
Russian heatwave (JJA 2010)

+ 5-day forecast



Pakistan floods (July 2010)

a August 2009



b August 2010

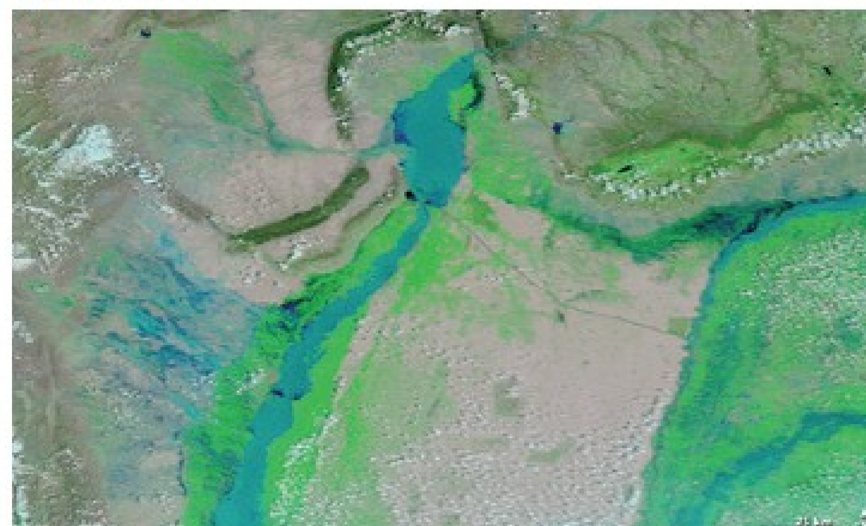
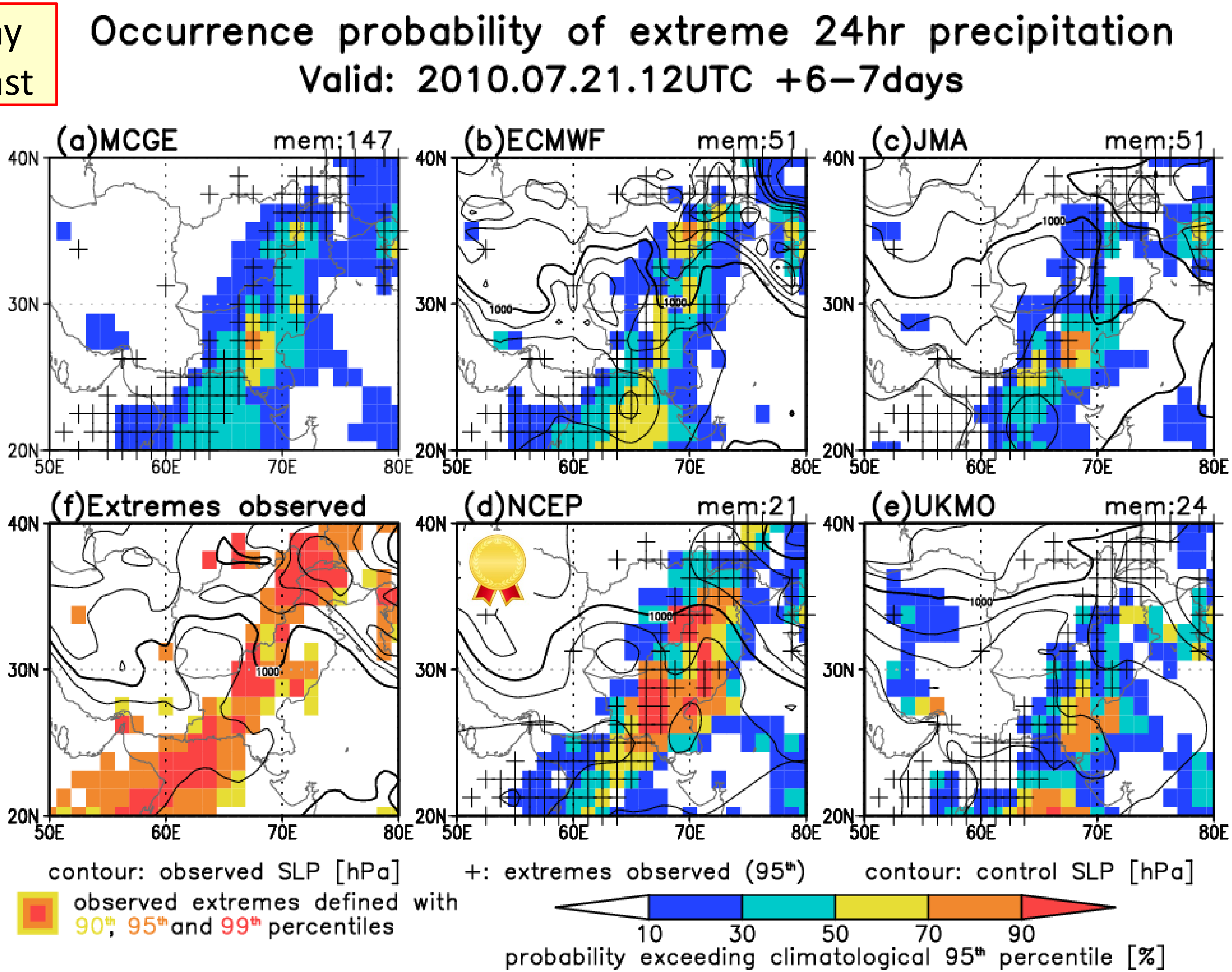


Figure 7 Satellite images of the catchment of the river Indus for (a) August 2009 and (b) August 2010.

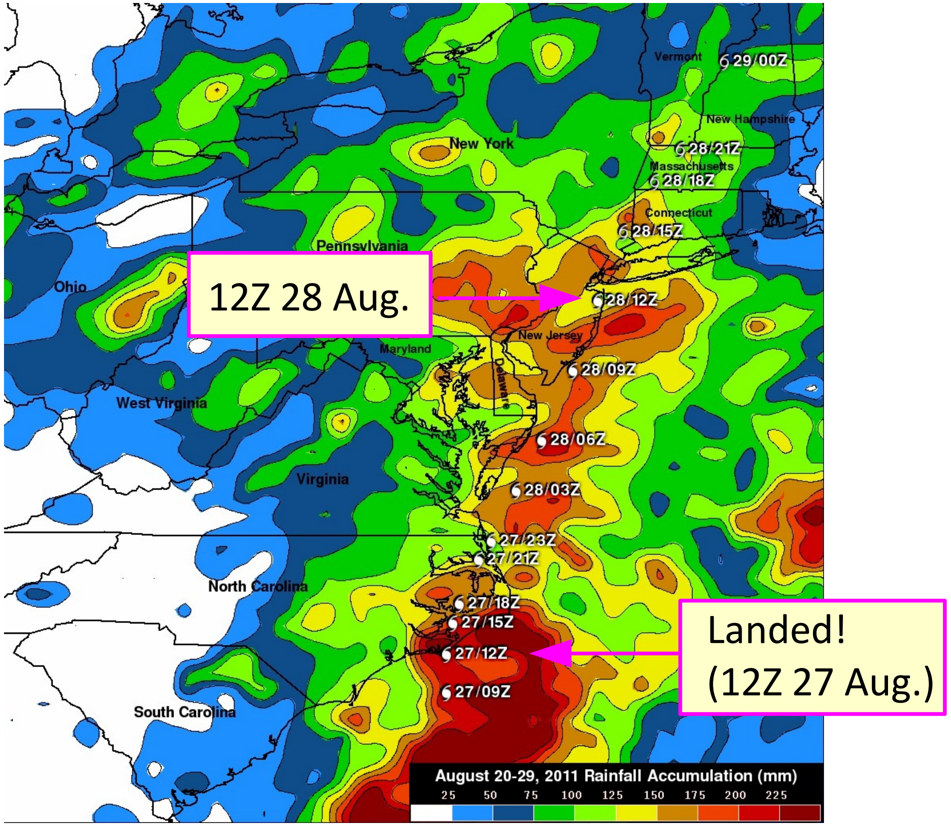
ECMWF Newsletter (No. 125, 2010)

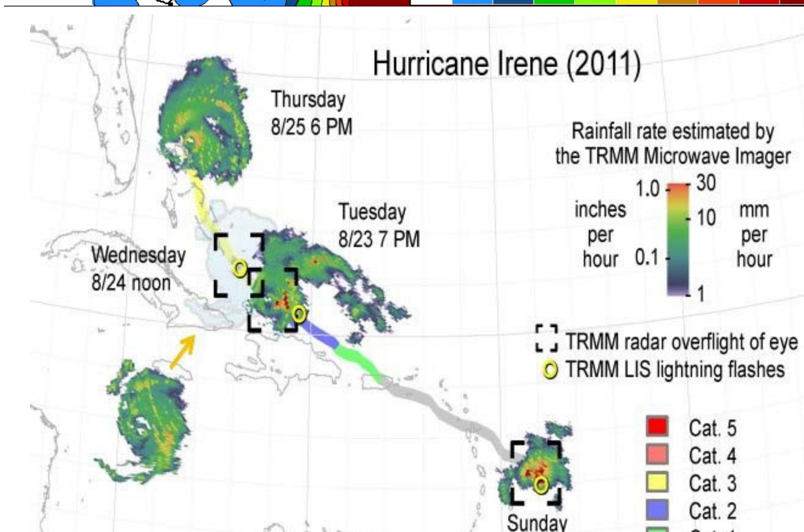
Pakistan floods (July 2010)

+ 7-day forecast



Hurricane Irene (August 2011)



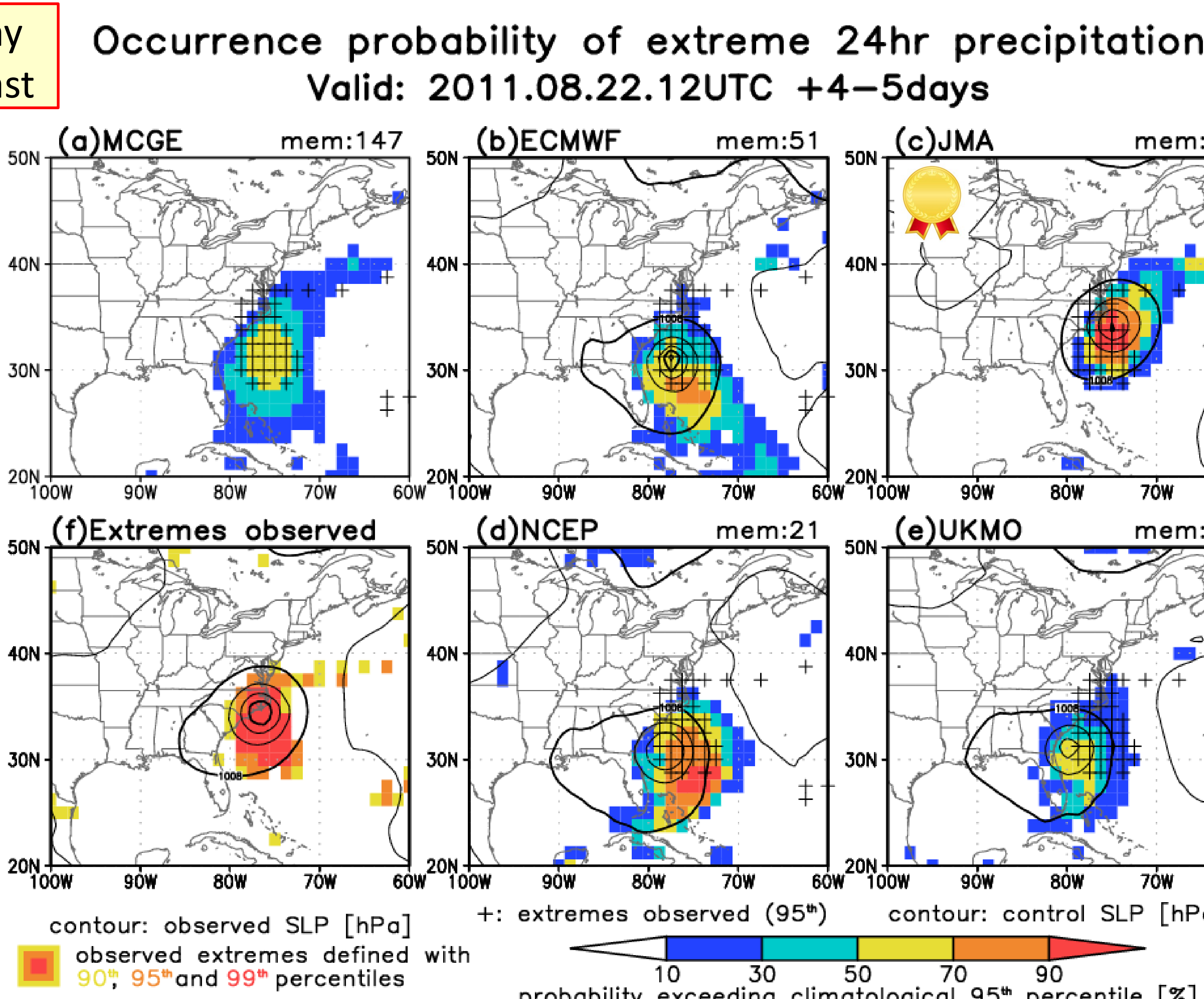


From NASA's web

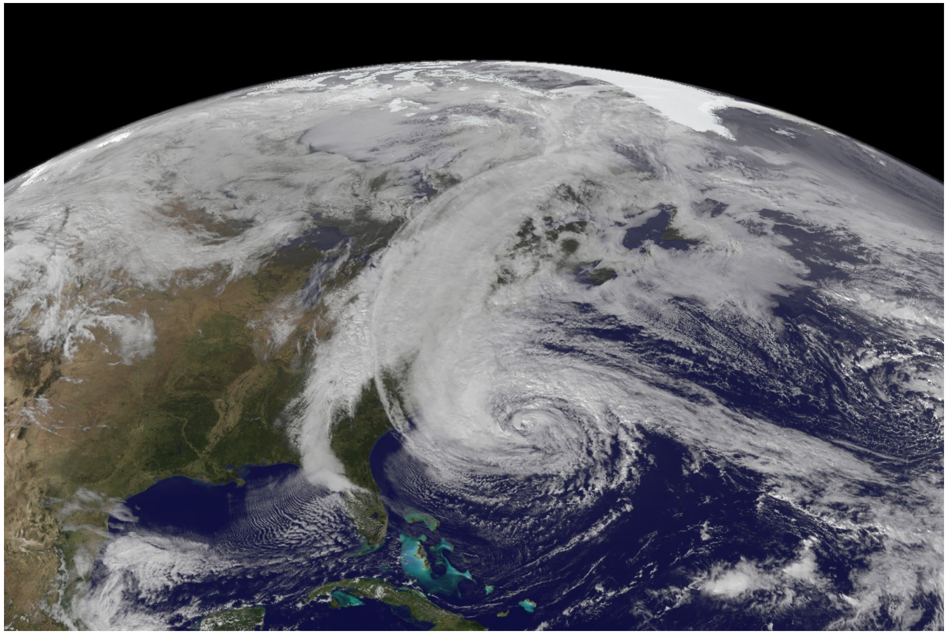
Kill Devil Hills, North Carolina, USA
(25 August, 2011)

Hurricane Irene (August 2011)

+ 5-day forecast



Hurricane Sandy (October 2012)



Hurricane Sandy (28 October, 2012)

Early warning (28 October, 2012)

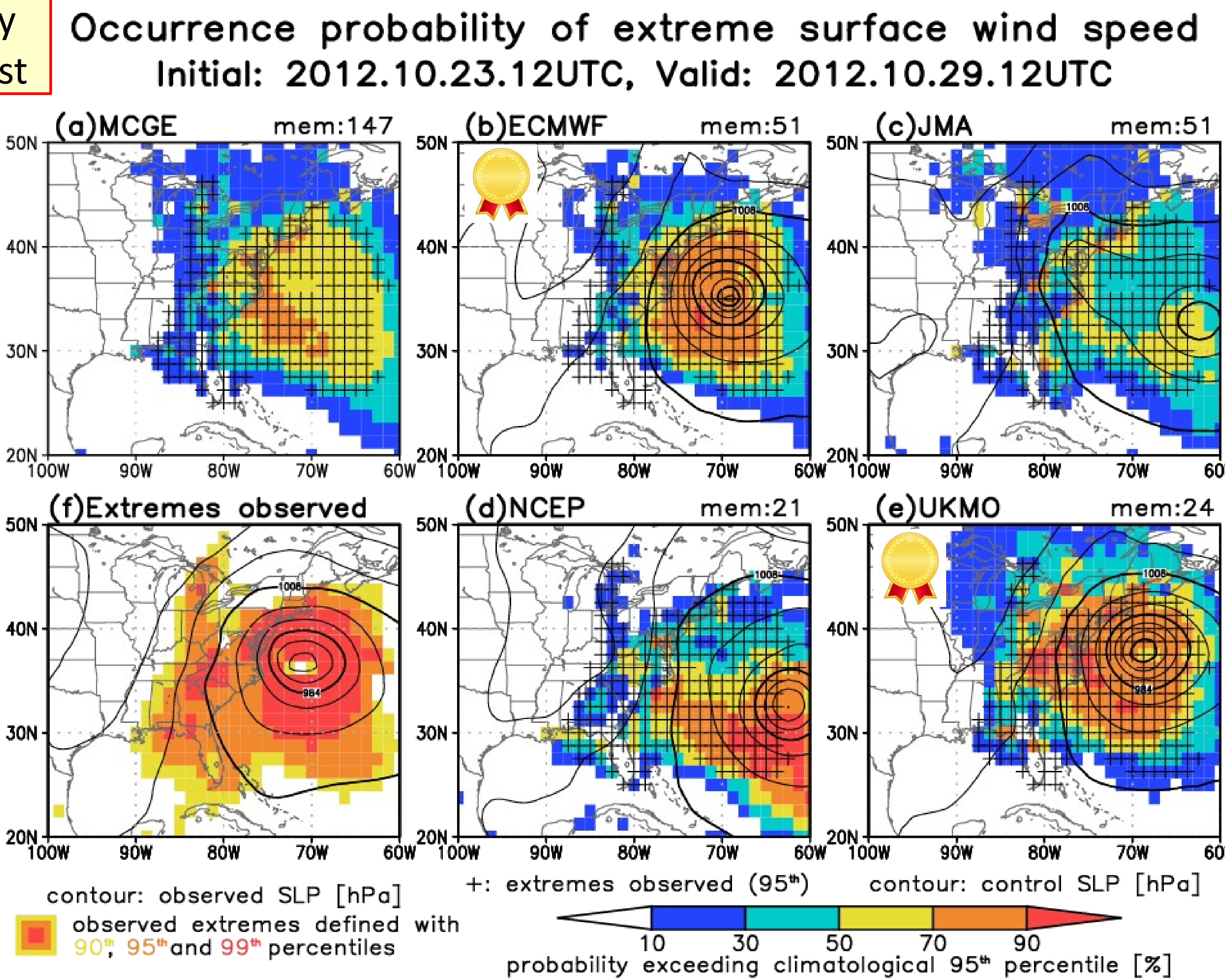
New England, USA
(30 October, 2012)

Queens, New York City, USA
(30 October, 2012)

Staten Island, New York City, USA
(1 November, 2012)

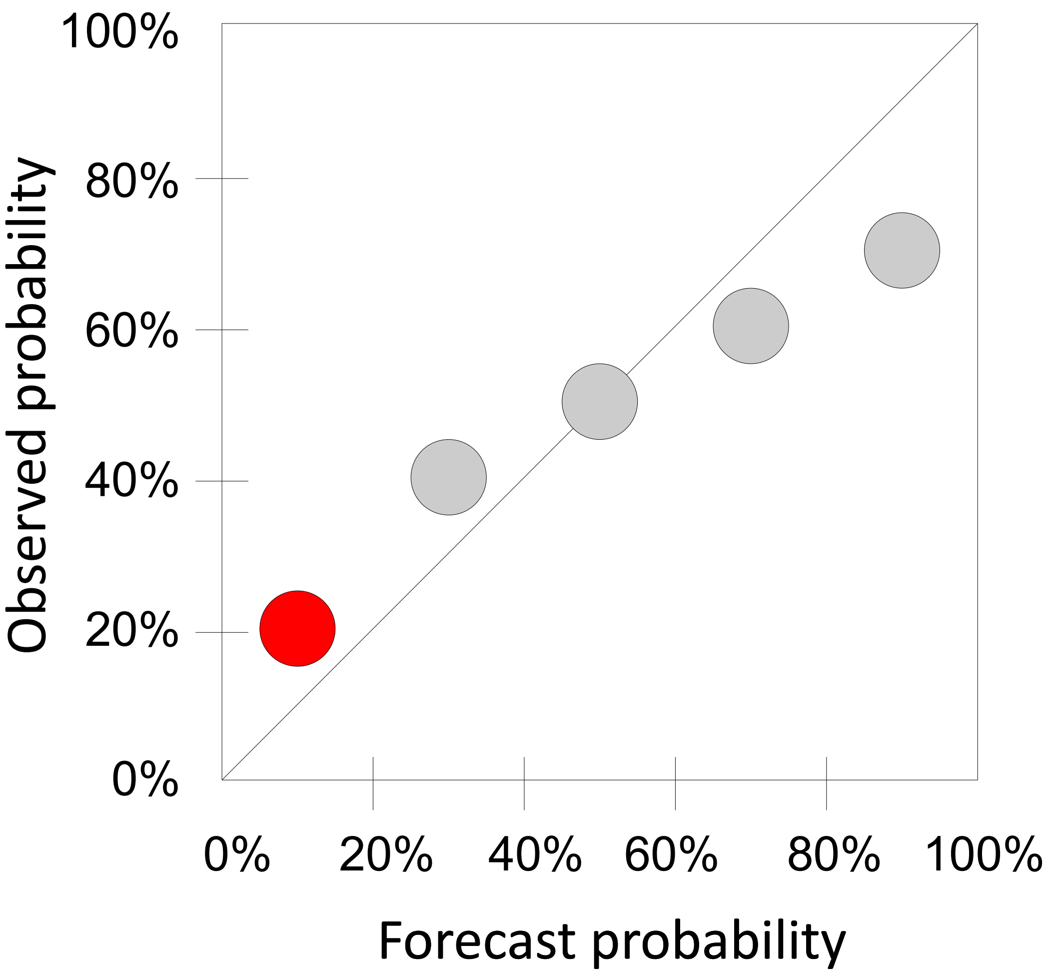
Hurricane Sandy (October 2012)

+ 6-day forecast



Verification of probabilistic forecast

Reliability diagram



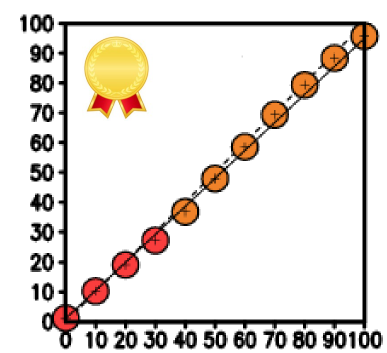
In a reliability diagram, the forecast probability is plotted against the frequency of occurrence.

fcst. prob.	**10%**	30%	50%	70%	90%
# of fcst.	30	20	10	20	30
# of obs.	6	8	5	12	21

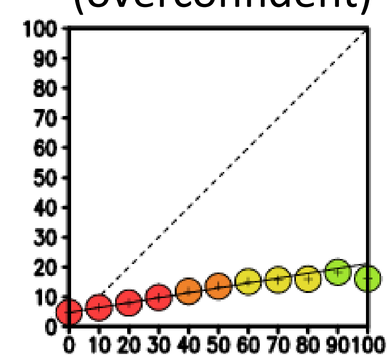
10% was issued 30 times.
Event occurred 6 times.
(observed frequency = 6/30 = **0.2**)

The distribution should lie along the 45° diagonal for a reliable probabilistic forecast.

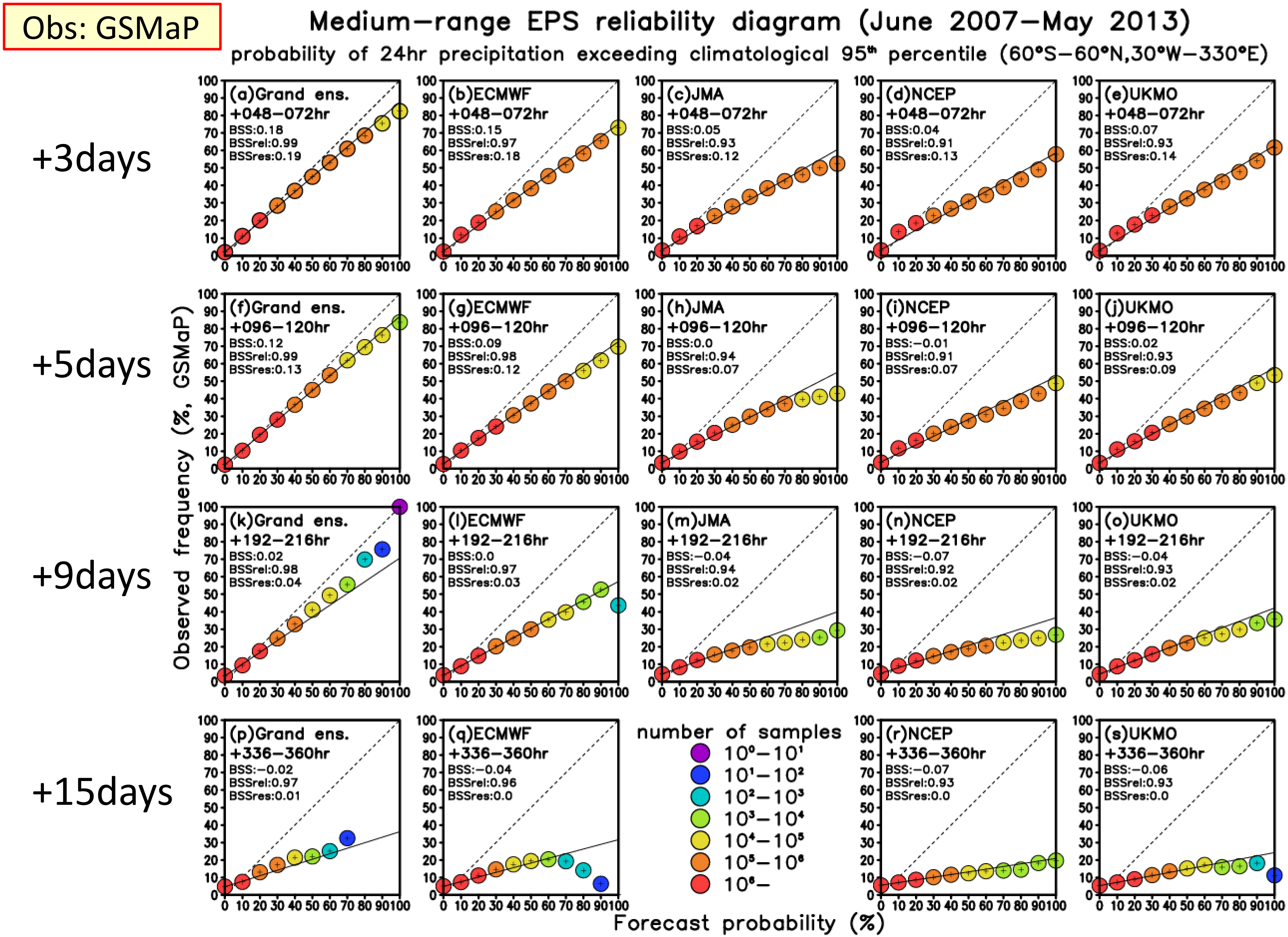
perfect reliability



poor reliability
(overconfident)

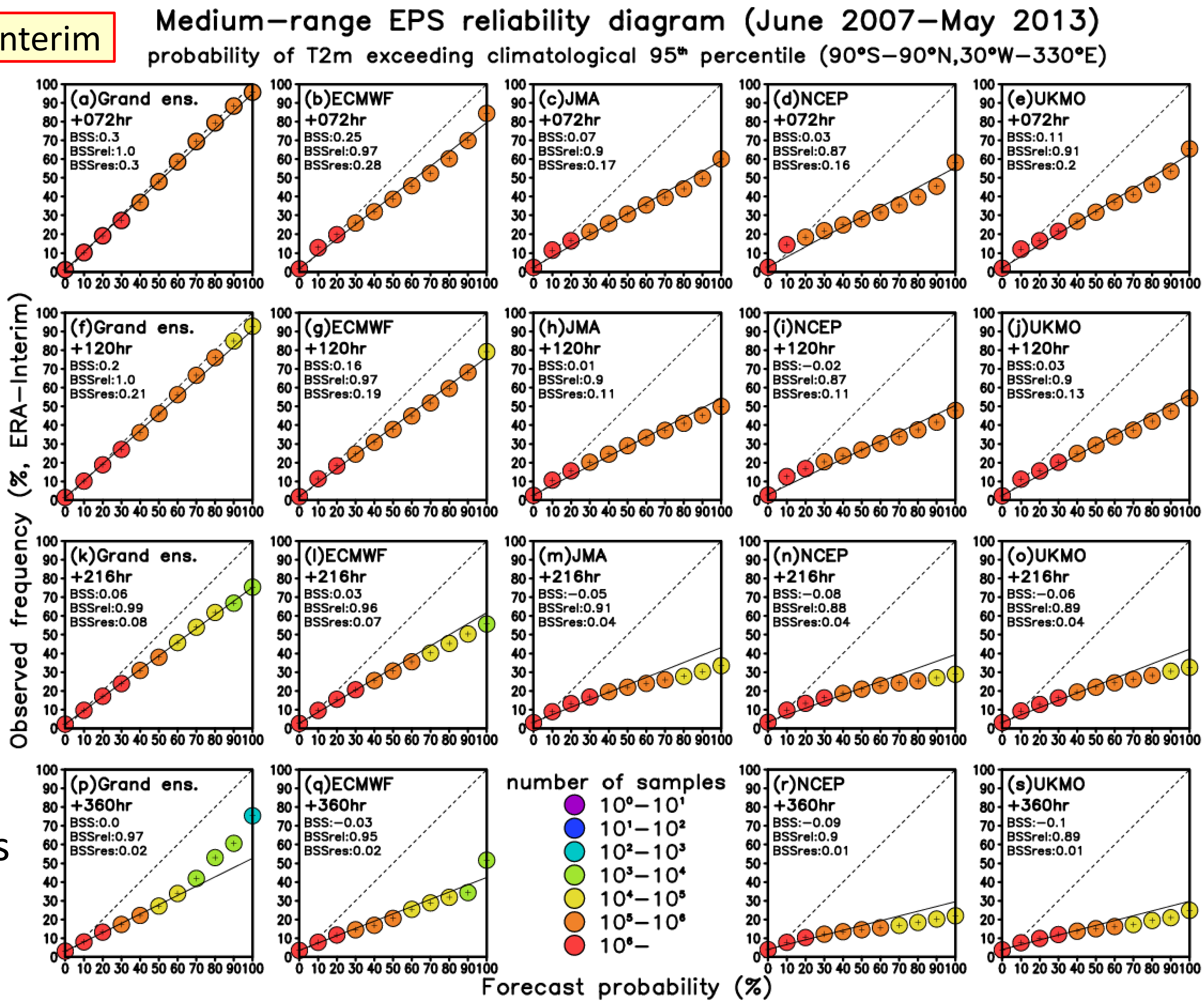


Verification — reliability diagram for extreme precipitation —



Verification — reliability diagram for extreme high temperature —

Obs: ERA-Interim



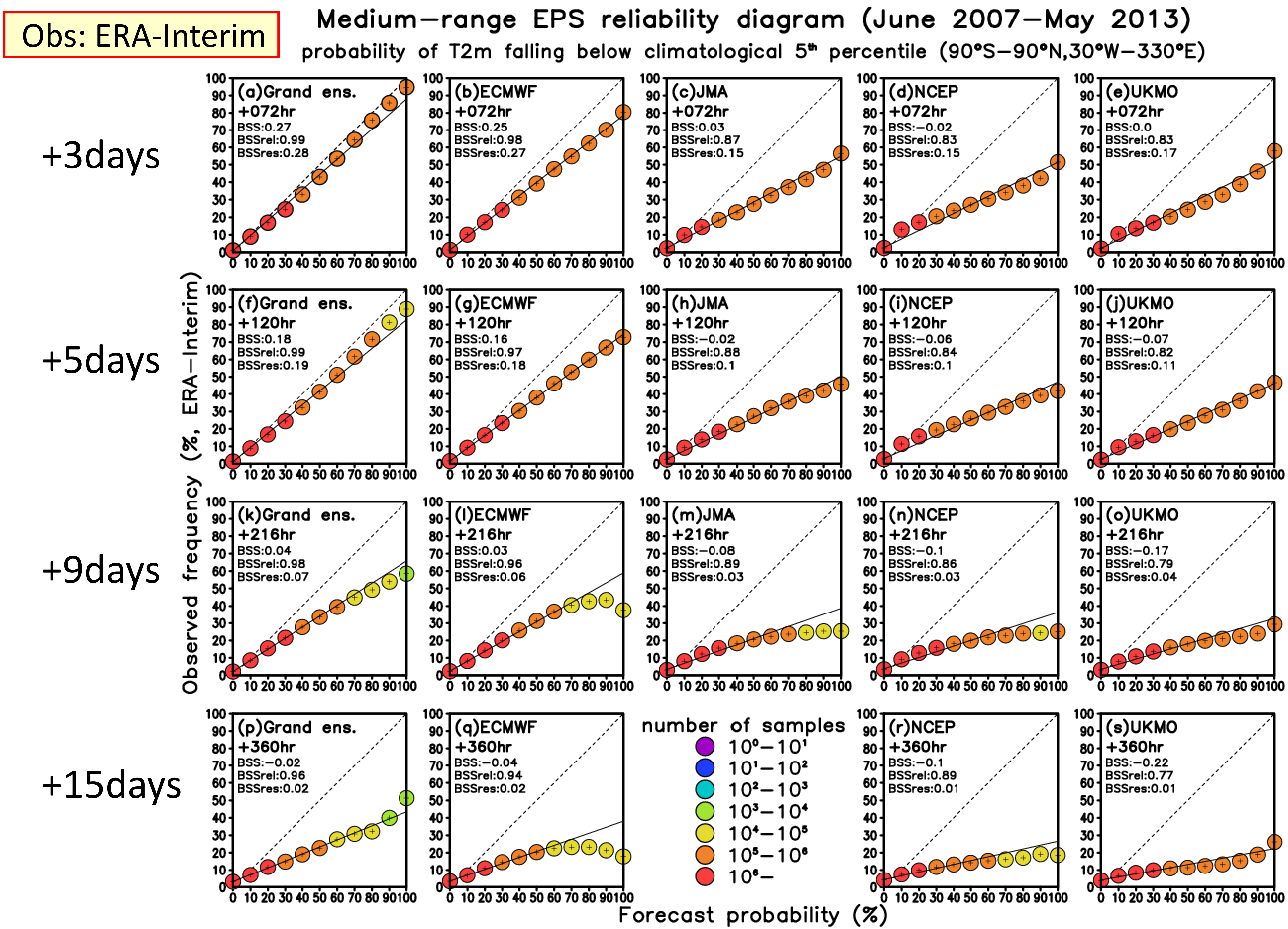
+3days

+5days

+9days

+15days

Verification — reliability diagram for extreme low temperature —



Verification — reliability diagram for high wind speeds —

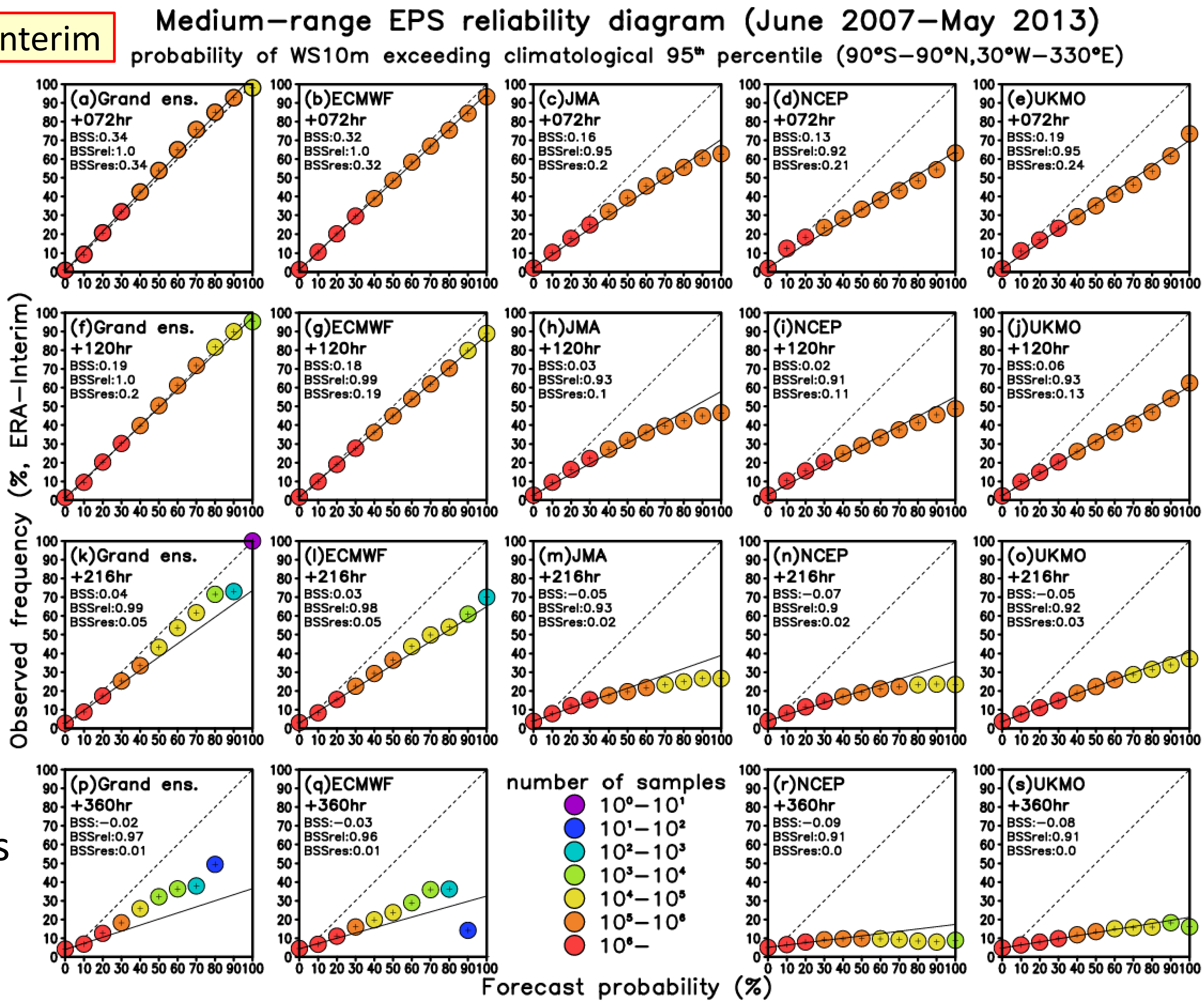
Obs: ERA-Interim

+3days

+5days

+9days

+15days



Verification of probabilistic forecast

fcst. prob.	10%	30%	50%	70%	90%
# of fcst.	30	20	10	20	30
# of obs.	6	8	5	12	21

Brier Score (BS, Brier 1950)

The most common verification score for probabilistic forecasts.

$$BS = \frac{1}{N}\sum_{i}^{N}(p_i - o_i)^2$$

p_i : forecast prob. of an event (0 - 1)

o_i : observed prob. of an event (0 or 1)

N : Number of forecasts

BS measures the difference between the forecast probability of an event (p) and its occurrence (o). BS = 0 for a perfect forecast. The lower, the "better". The Brier score is closely related to the reliability diagram.

Brier Skill Score (BSS)

$$BSS = 1 - \frac{BS_{fcst}}{BS_{ref}}$$

BSS = 1: a perfect skill ($BS_{fcst} = 0$)

BSS = 0: a comparable skill to a reference forecast

BSS < 0: a poorer skill than a ref. forecast (no skill)

BSS is conventionally defined as the relative probability score compared with the probability score of a reference forecast. Here, a climatological forecast is considered as a reference forecast. BSS = 1 for a perfect forecast.

Verification of probabilistic forecast

Brier Score and its decomposition

B-3.1 The Brier score - the MSE of probability forecasts
The most common verification method for probabilistic forecasts, the Brier score (BS), has a mathematical structure similar to the MSE

$$BS = \overline{(p-o)^2}$$

BS measures the difference between the forecast probability of an event (p) and its occurrence (o), expressed as 0 or 1, depending on whether the event has occurred or not. As with RMSE, the BS is negatively orientated, i.e. the lower, the "better".

B-3.2 Decomposition of the Brier score
Similarly to the MSE the BS can be decomposed into three terms, the most often quoted was suggested by Allan Murphy (1973, 1986) who used "binned" probabilities:

$$BS = \overline{n_k(p_k-\overline{o})^2} - \overline{n_k(\overline{o}-o_k)^2} + \overline{o}(1-\overline{o})$$

where n_k is the number of forecasts of the same probability category k. The first term on the right hand side measures how much the forecast probabilities can be taken at face value, their *reliability*. On the reliability diagram this is the n_k weighted sum of the distance (vertical or horizontal) between each point and the 45° diagonal (see Figure 87).

The second term measures how much the predicted probabilities differ from a climatological average and therefore contribute information, the *resolution*. On the reliability diagram this is the weighted sum of the distances to a horizontal line defined by the climatological probability reference.

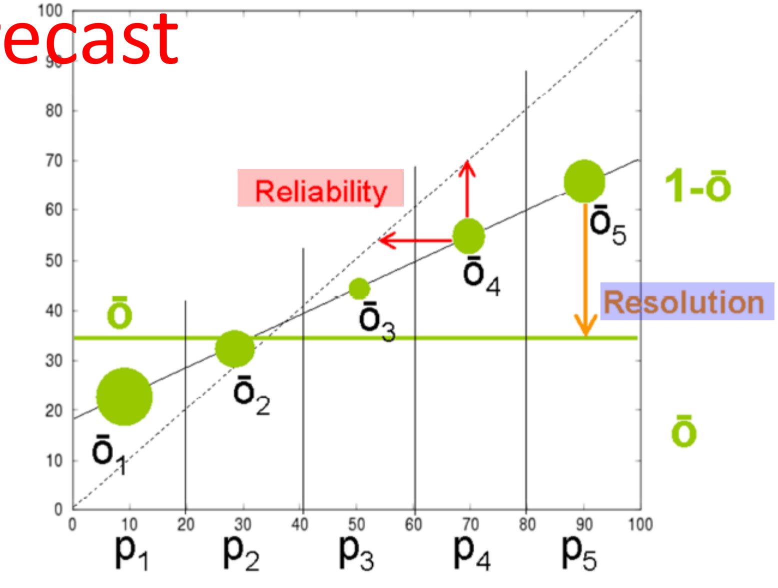


Figure 87: Summary of Allan Murphy's reliability and resolution terms

Resolution, the degree to which the forecasts can discriminate between more or less probable events, should not be confused with sharpness, the tendency to have predictions close to 0% and 100%. They are also independent of one another.

The final term in the decomposition, called *uncertainty*, is the variance of the observations. It takes its highest, most "uncertain", value when $\overline{o}$=0.5 (see Figure 88).

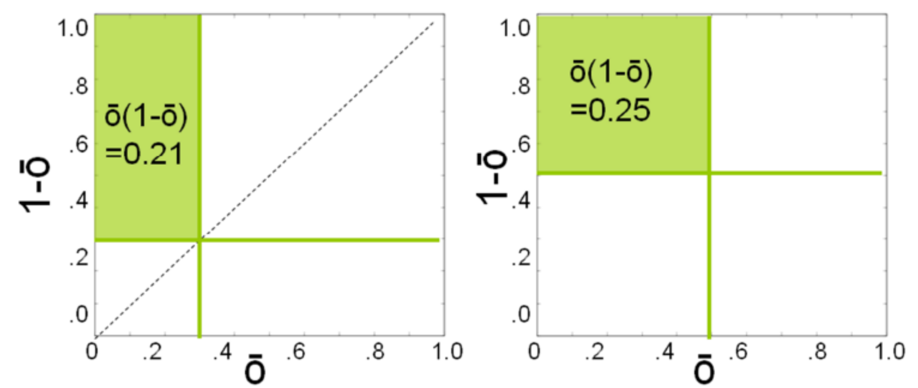
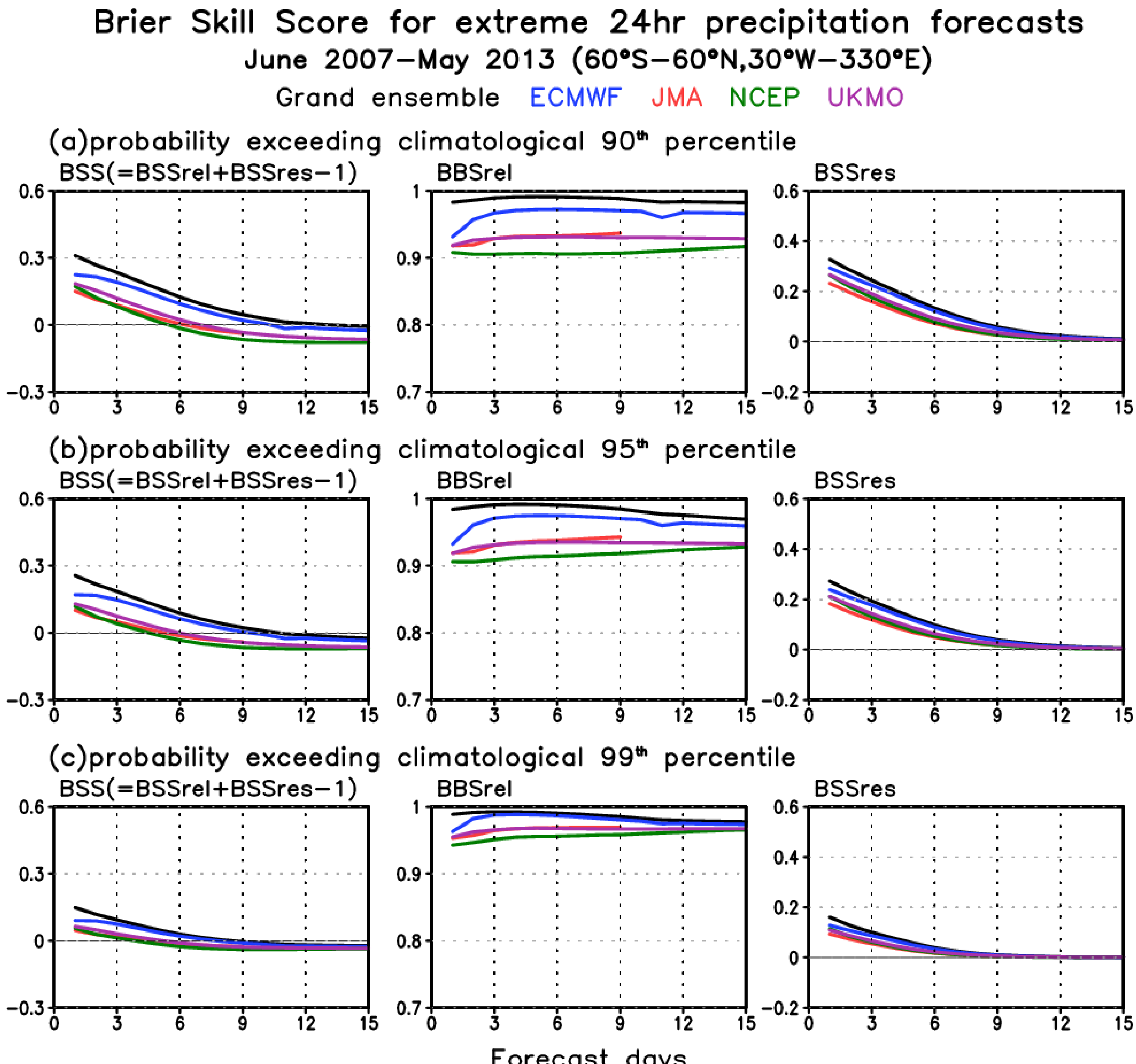


Figure 88: Uncertainty is at its maximum for a climatological observed probability average of 50%.

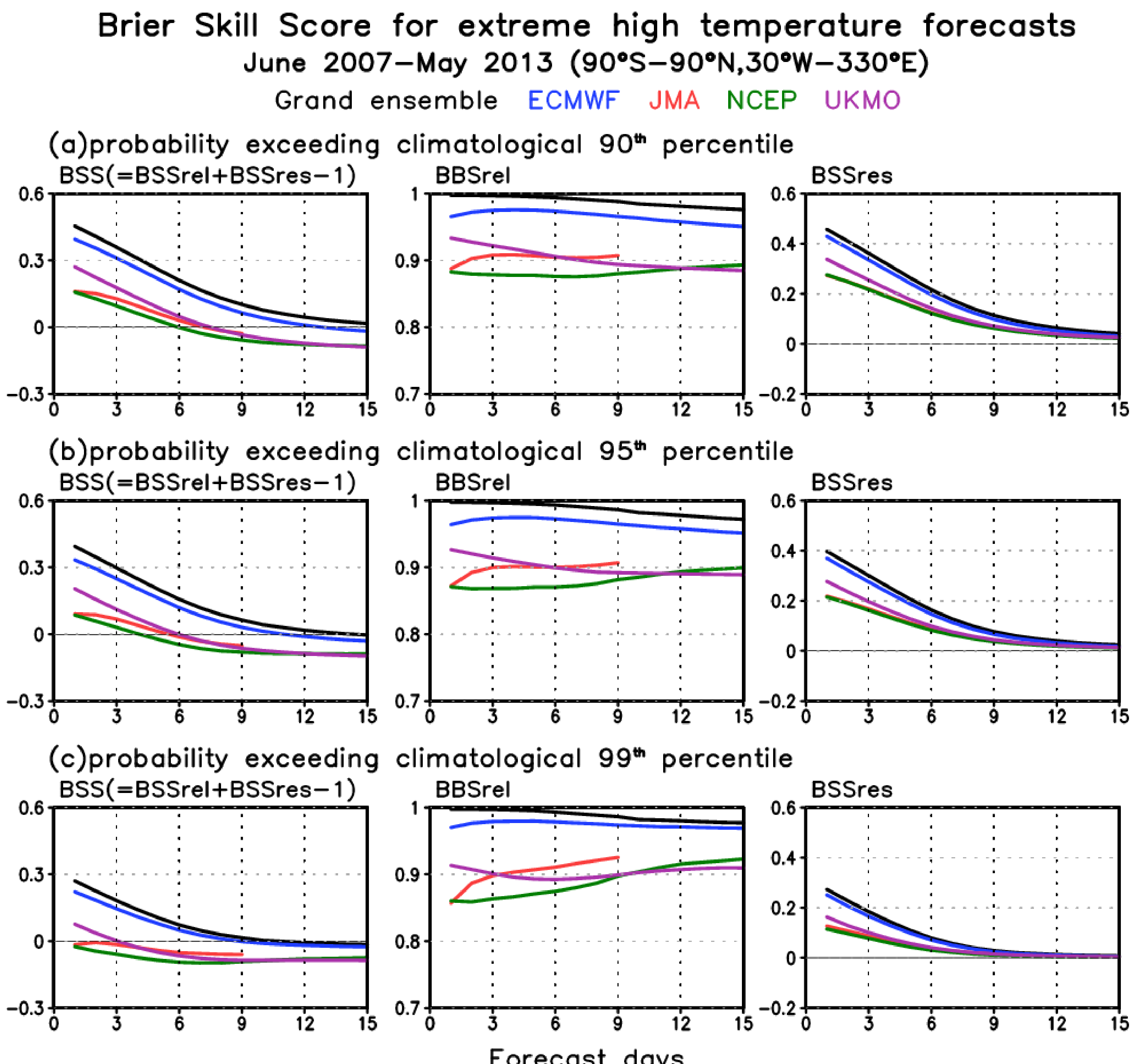
The name "uncertainty" can be understood from the familiar fact that it is easier to predict the outcome of tossing a coin if it is heavily biased. In the same way, if it rains frequently in a region and rarely stays dry, forecasting can be said to be "easier" than if rain and dry events occur equally often.

(from "User guide to ECMWF forecast products")

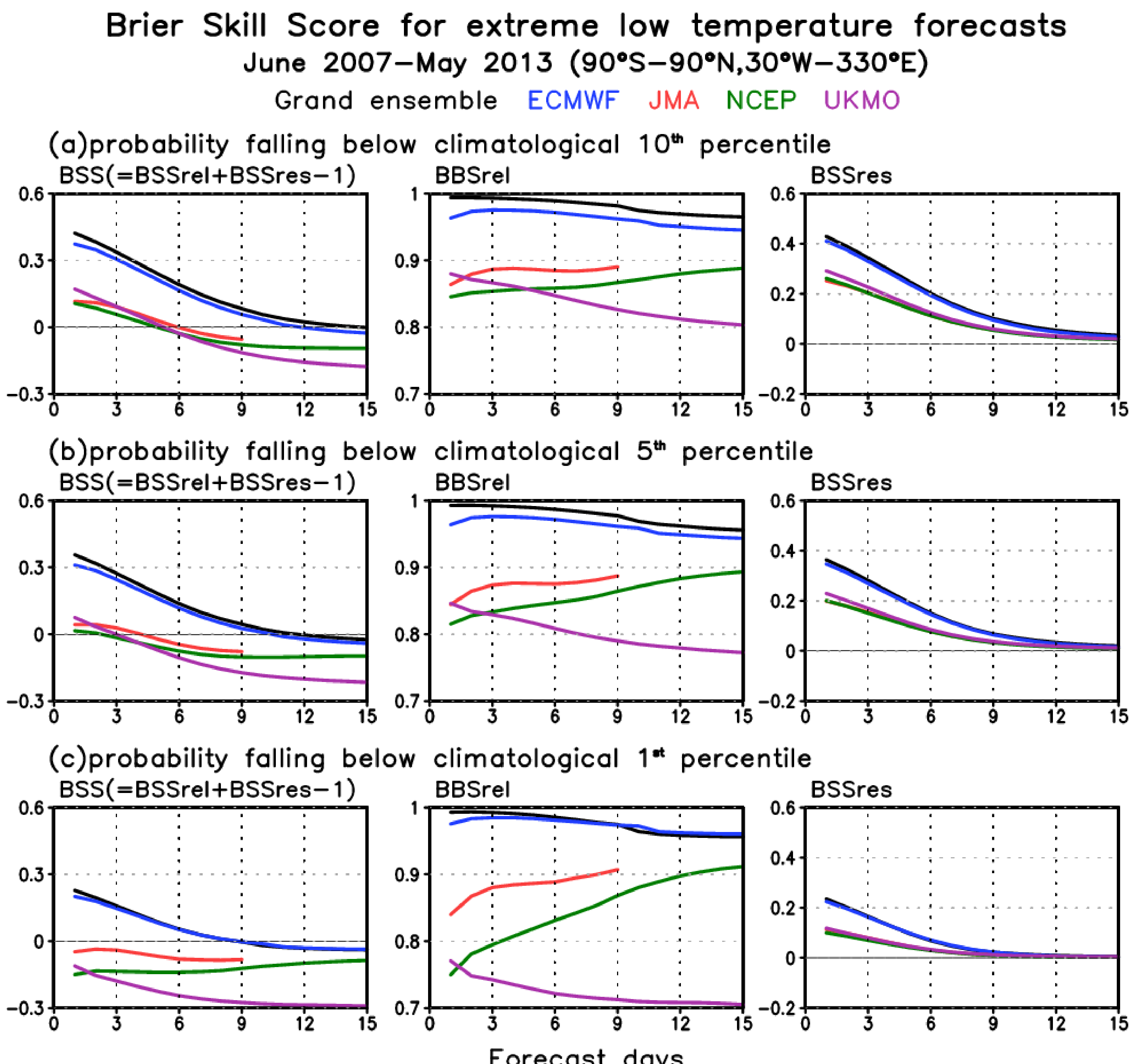
Verification — Brier Skill Score for extreme precipitation —



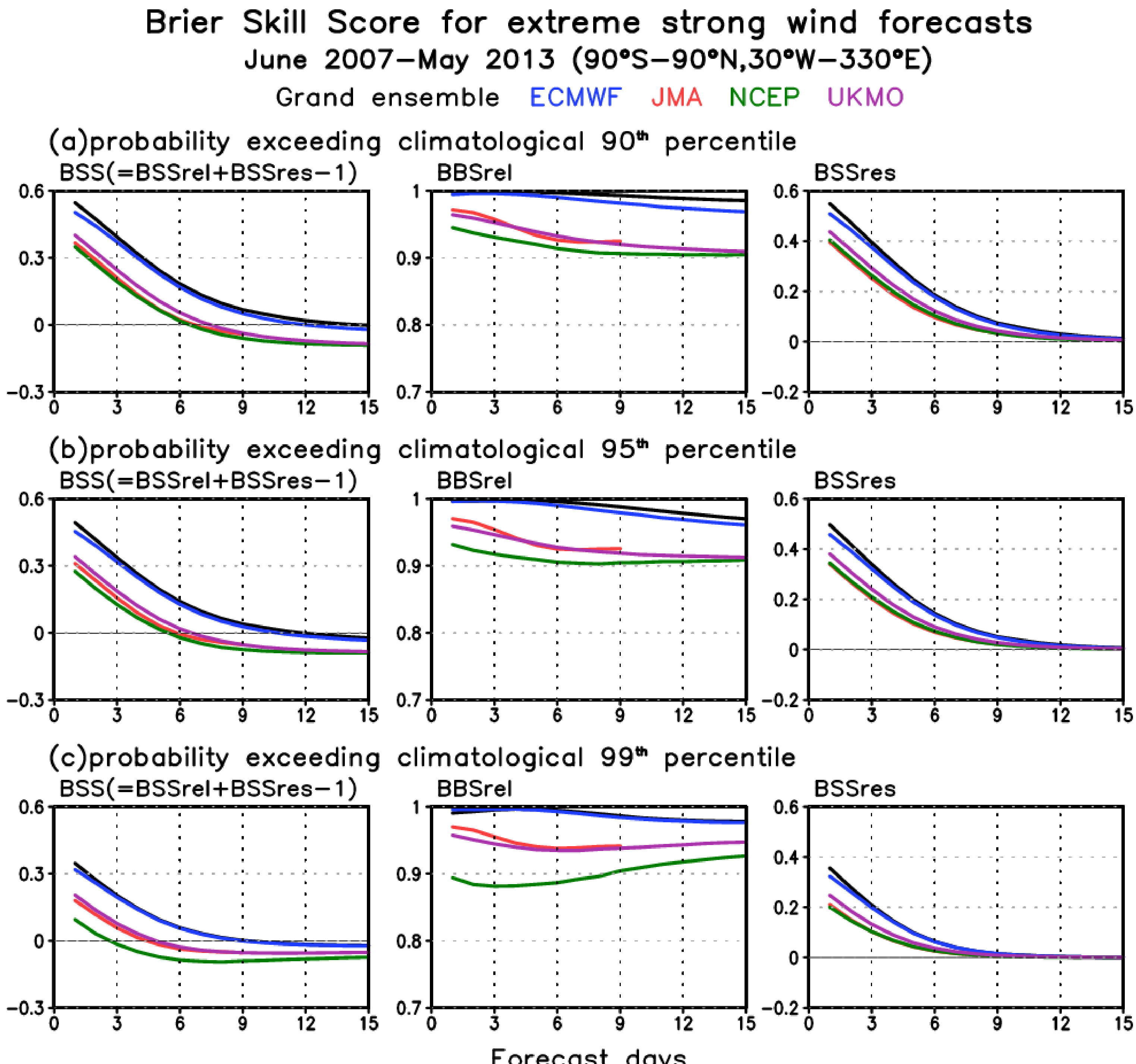
Verification — Brier Skill Score for extreme high temperature —



Verification — Brier Skill Score for extreme low temperature —



Verification — Brier Skill Score for high wind speeds —



Summary

We have introduced the ensemble-based early-warning products for extreme weather events, including heavy rainfall, strong surface winds and extreme high/low surface temperatures. The early warning products are based on operational medium-range ensemble forecasts from four of the leading global NWP centres: ECMWF, JMA, NCEP, and UKMO.

The construction of a grand ensemble by combining four single-centre ensembles can improve the forecast reliability regarding probabilistic forecasts of extreme events, up to a lead time of + 360 hr. The grand ensemble can provide more reliable forecasts than single-centre ensembles. This results from a fact that the best performing ensemble is case dependant.

Thus, the products may aid the reliable detection of extreme weather events far enough in advance to help mitigate the associated catastrophic damage, especially in developing countries.

The other products using TIGGE data (e.g. daily weather chart, MJO and blocking forecasts, verifications of forecast skills) are also available at

The TIGGE Museum:
http://gpvjma.ccs.hpcc.jp/TIGGE/index.html. (Google: “TIGGE museum”)