Probabilistic Weather Forecasting and the EPS at ECMWF

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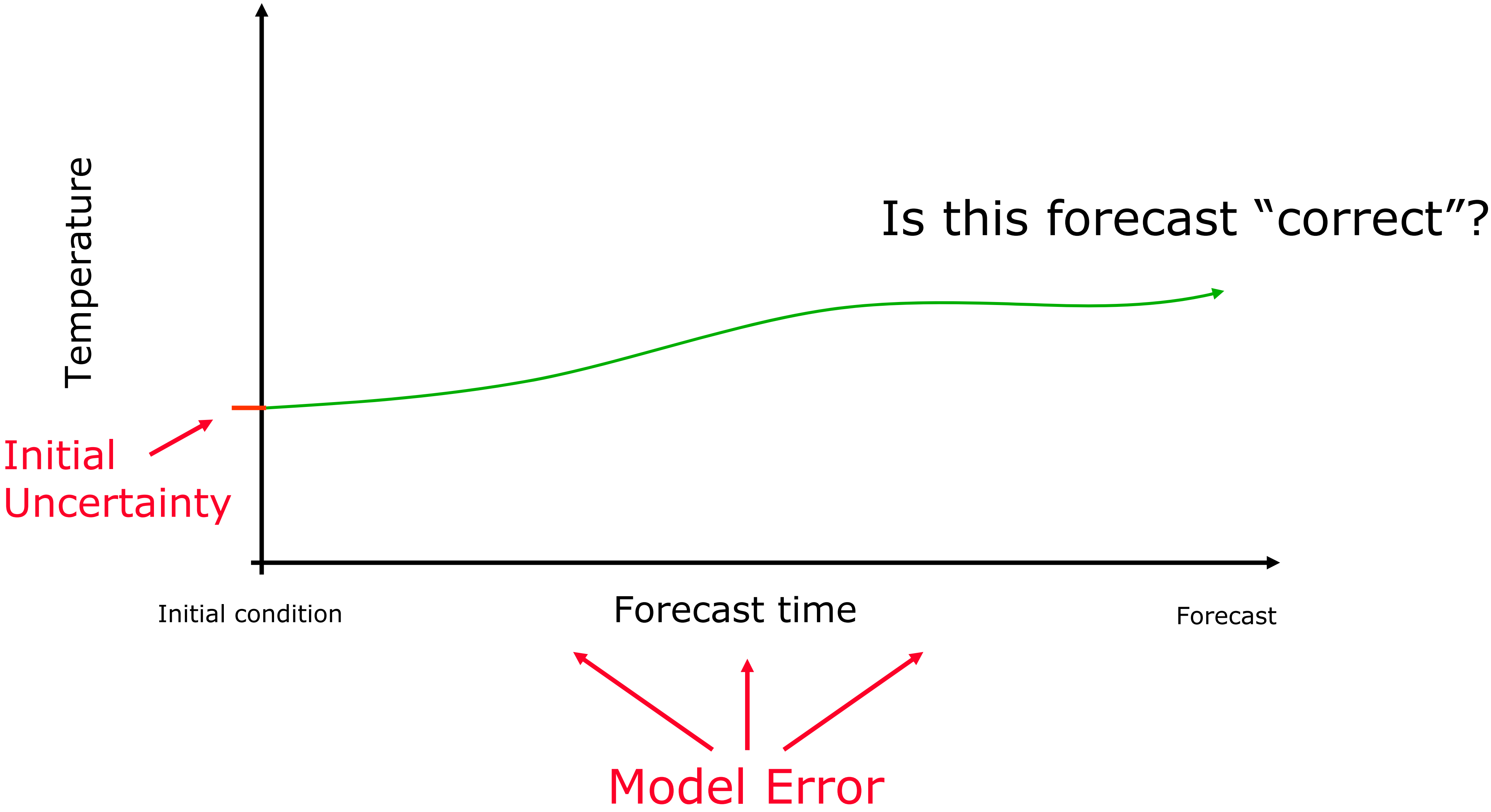
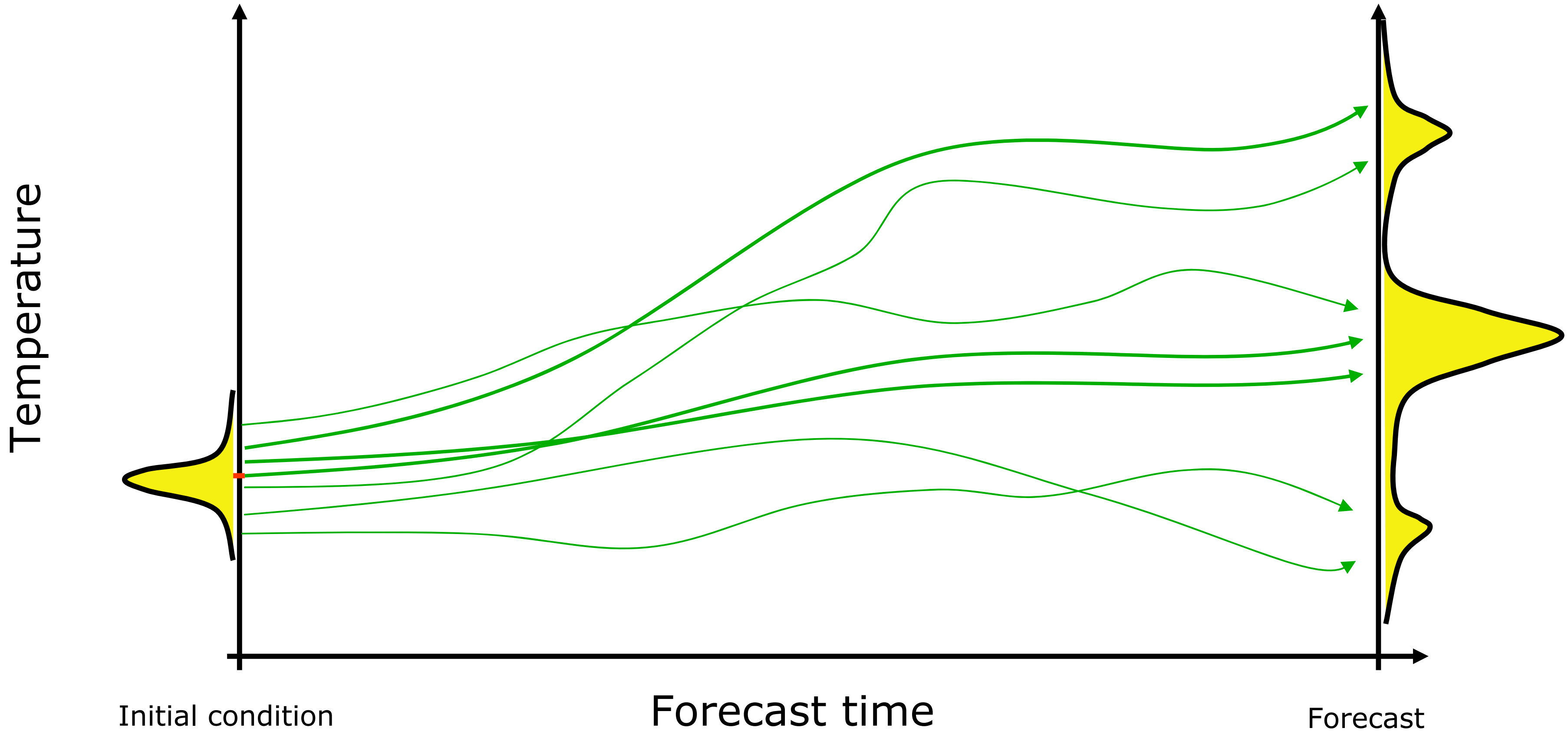
Questions

- What is an Ensemble Prediction System (EPS)?
  - multiple forecasts from slightly different initial conditions
  - enables probabilistic forecasts
- Why do we need an EPS and probabilistic forecasts?
  - to account for uncertainties in initial conditions and model error
  - to support user specific decision-making processes
- How do we use probabilistic forecasts?
  - products (stamp maps, probability maps, EFI, EPSgrams)
  - important verification aspects

Deterministic Forecasting



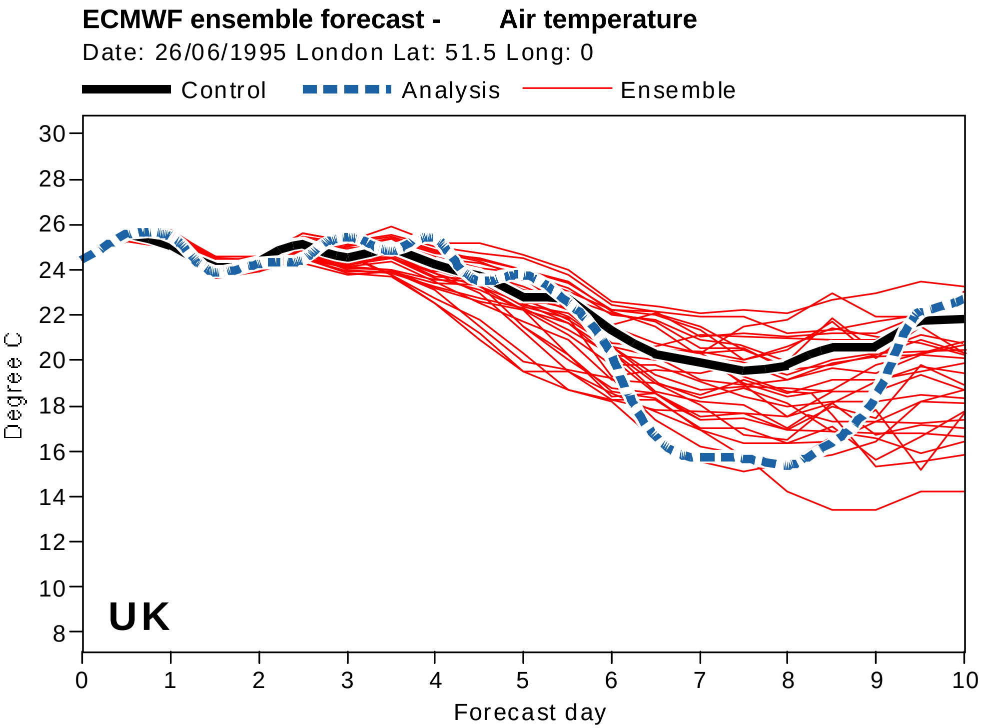
Ensemble Forecasting



Complete description of weather prediction in terms of a Probability Density Function (PDF)

Flow dependence of forecast errors

<u>26th June 1995</u>



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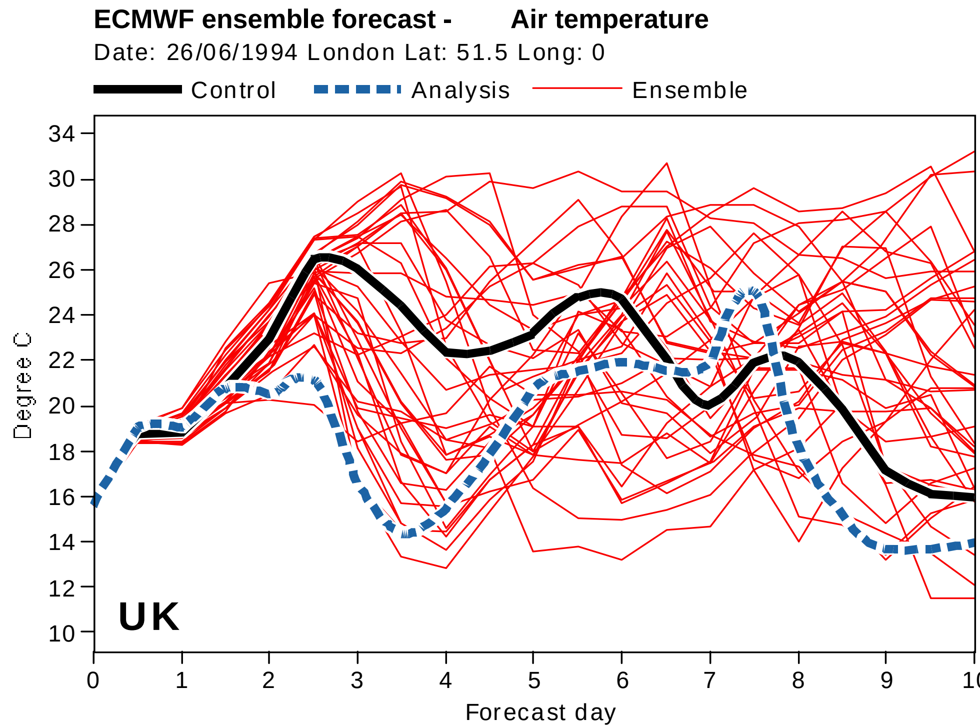
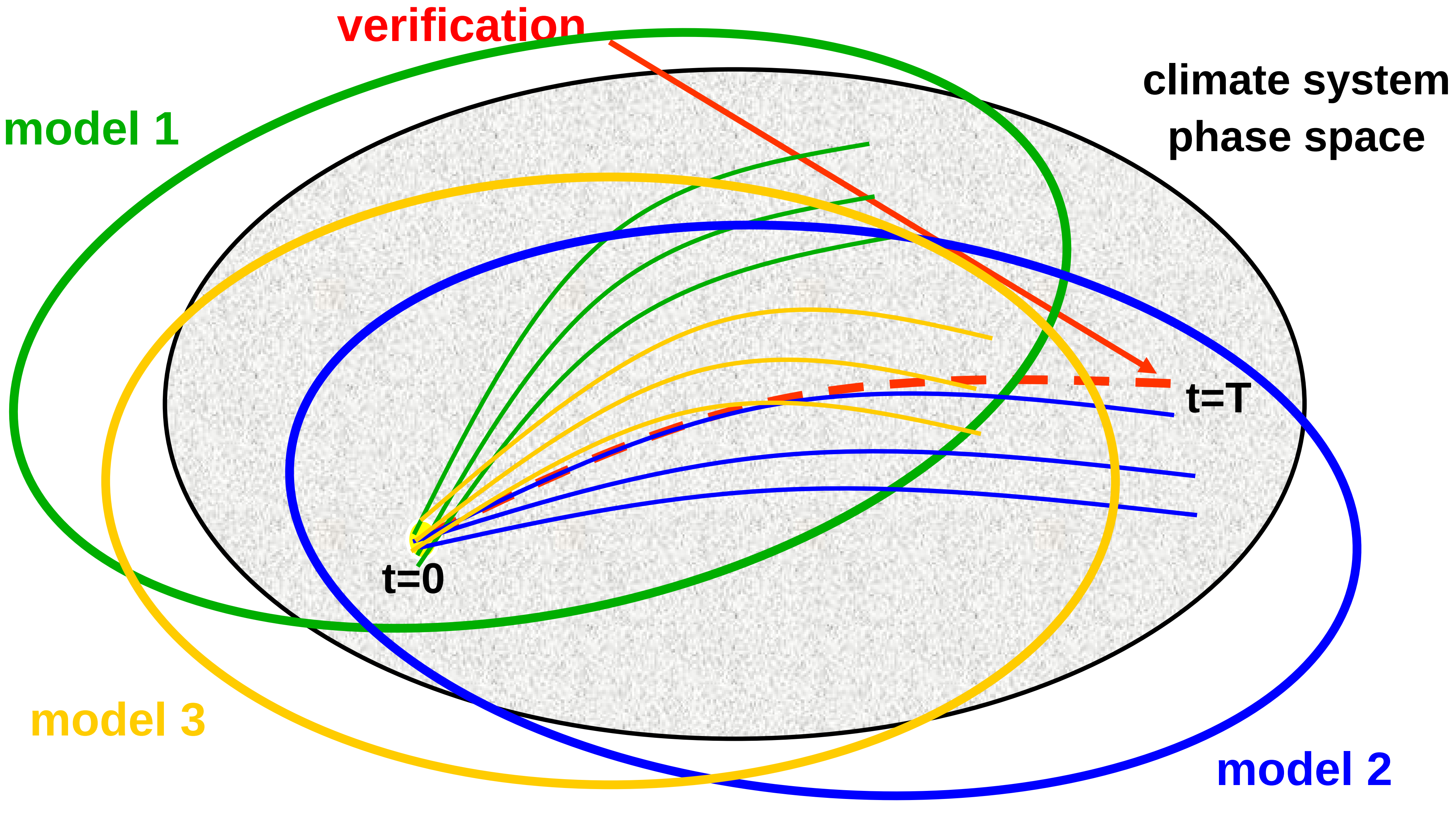


If the forecasts are coherent (small spread) the atmosphere is in a more predictable state than if the forecasts diverge (large spread)

Multi-Model Ensemble Forecasting



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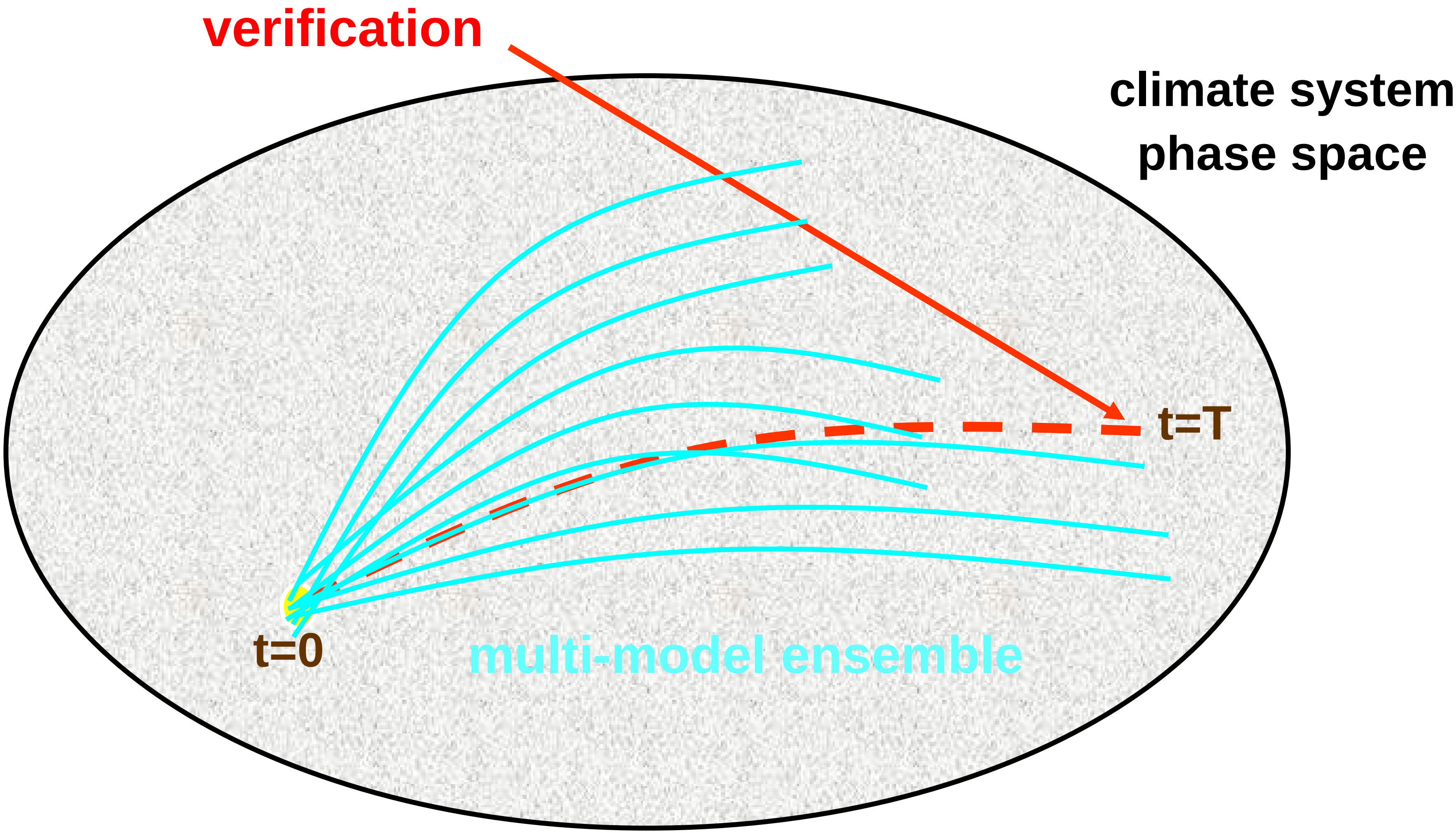


THORPEX Interactive Grand Global Ensemble

TIGGE

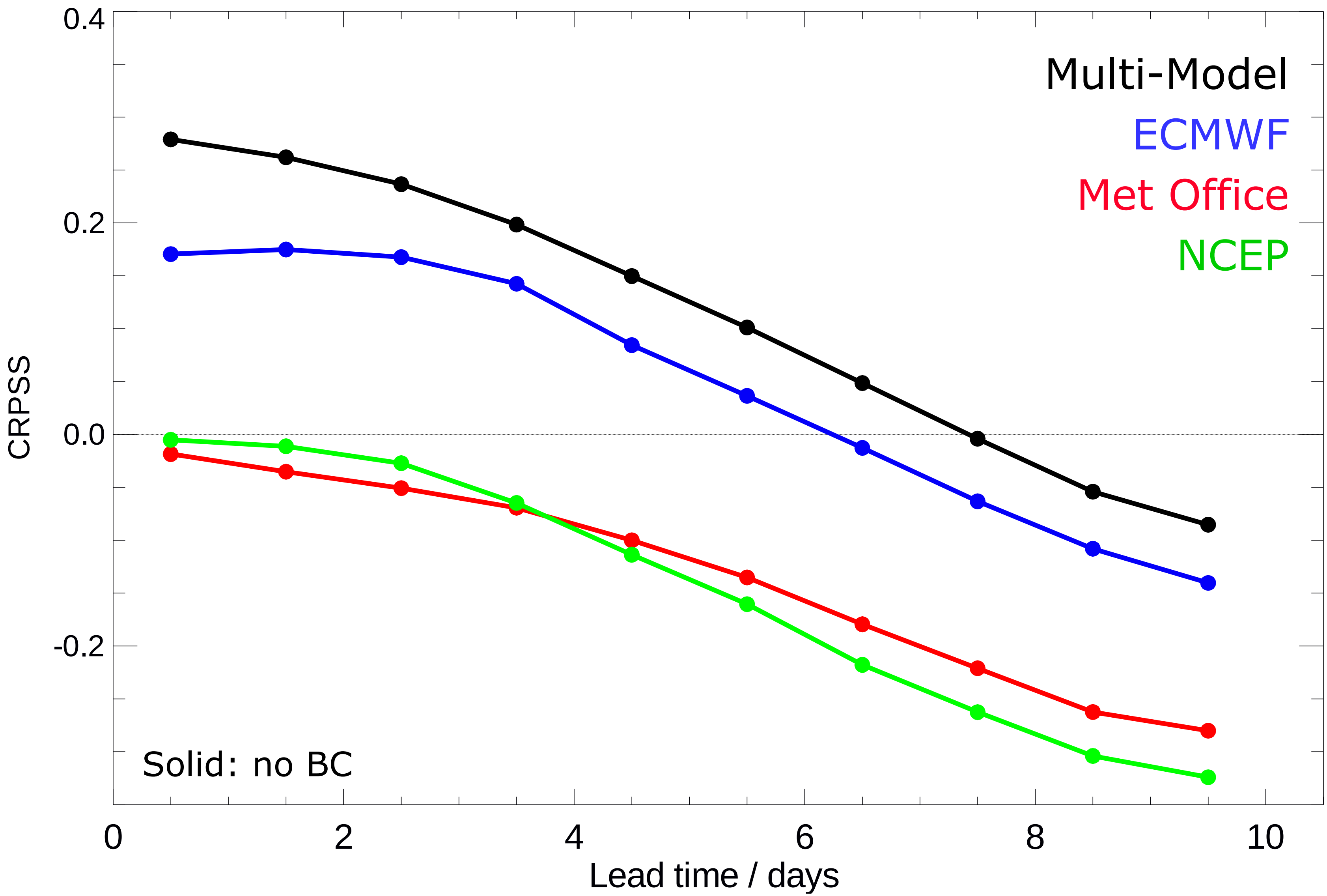
- A key component of THORPEX (to accelerate the improvements in the 1-day to 2-week high-impact weather forecasts for the benefit of humanity)
  - Enhance international collaboration on ensemble prediction for severe weather
  - Develop theory and practice of multi-model ensembles
  - Develop the concept of a Global Interactive Forecasting System (GIFS), responding dynamically to changing uncertainty
- TIGGE archive:
  - Global operational ensemble forecasts from 10 centres:

    BMRC (Australia), CMA (China), CPTEC (Brazil), ECMWF (Europe), JMA (Japan),

    KMA (Korea), Météo-France (France), Met Office (UK), MSC (Canada), NCEP (USA)

SM vs. MM results

T-2m, 250 European stations
2008060100 – 2008073000 (60 cases)



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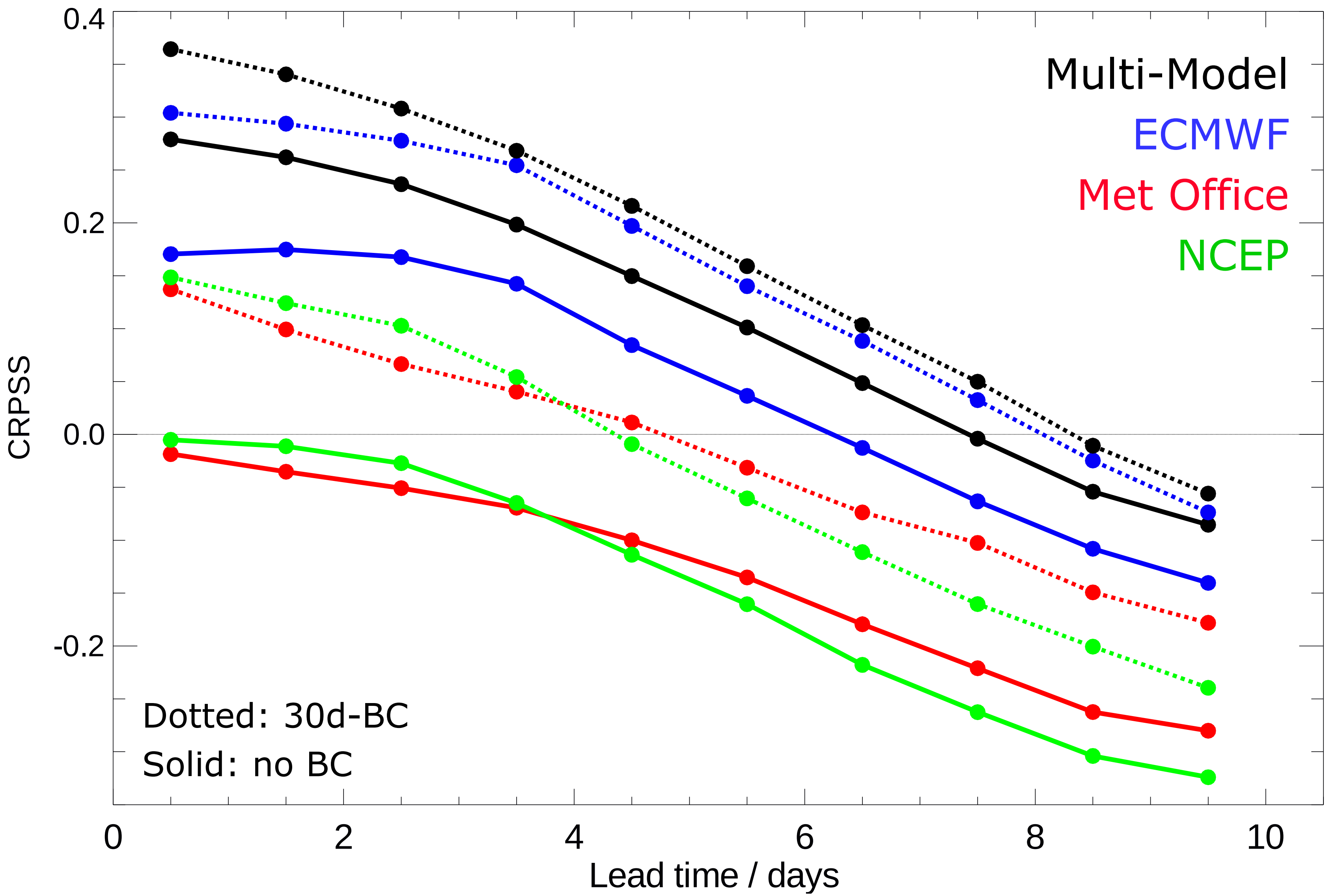

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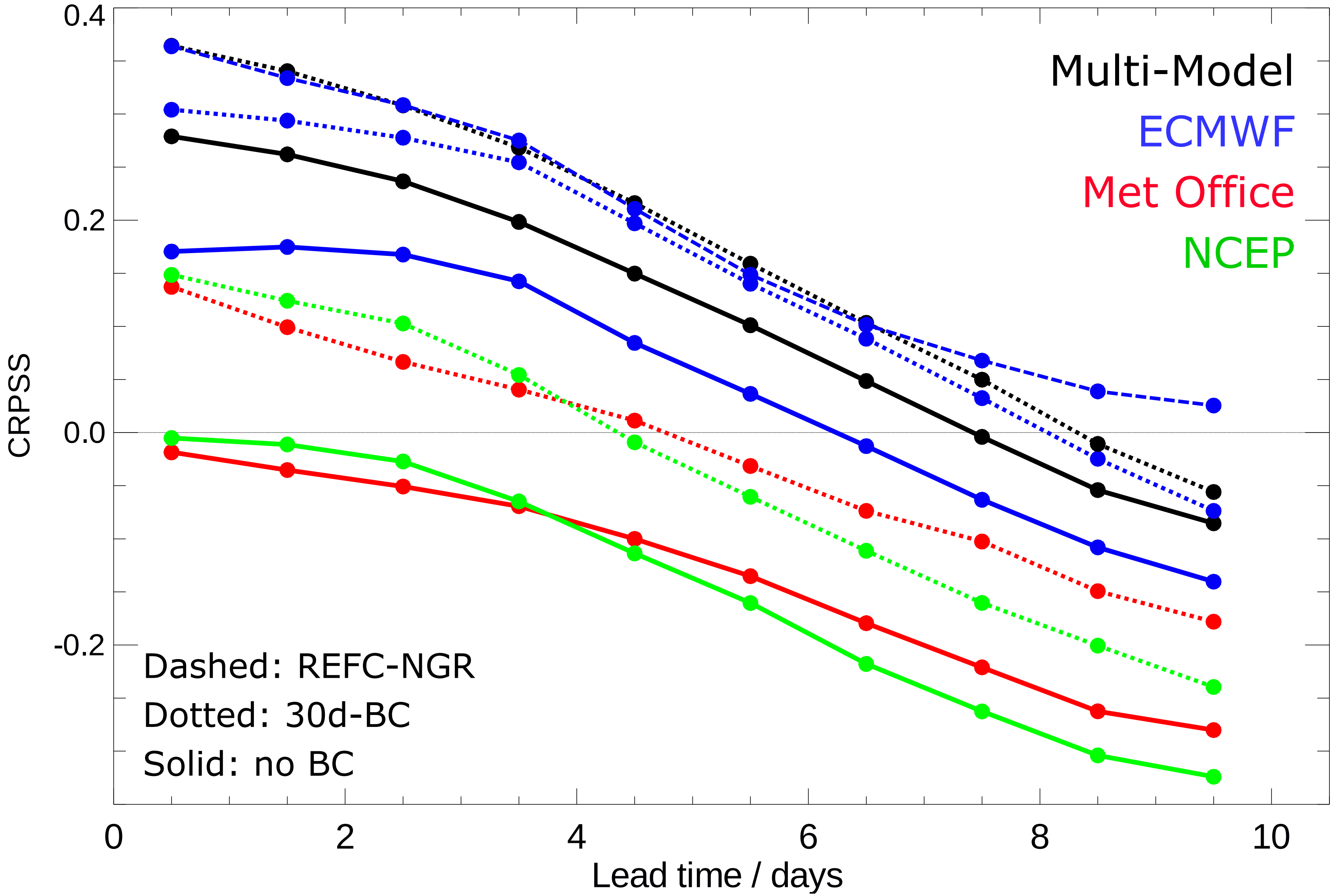

Goal of Ensemble Prediction

- Represent uncertainty of prediction
  - ➢ Ensemble Spread should
    - o capture "truth" (spread ~ RMS error)
    - o indicate range of uncertainty
- Move from deterministic to probabilistic forecast

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Why Probabilities?

- Energy contract scenario:
  - penalty for non-delivery: 100€ (if ff>25m/s), buying in energy: 20€
  - weather forecast: 30% probability for ff>25m/s
  - what would you do?

- Test the system for 100 cases of forecasts predicting 30% probability for the event "ff>25m/s" to occur

  Note: statistically, 30 times the event should occur, 70 times not occur

  - buy extra energy in these 100 cases -> 100 x 20 = 2000
  - do not buy extra energy in these 100 cases -> 30 x 100 = 3000

- Buying in extra energy beforehand (spending 20€) is beneficial when probability for ff>25m/s is greater 20%
- The higher/lower the cost loss ratio, the higher/lower probabilities are needed in order to benefit from action on forecast

Defining the cost-loss ratio

- Defining the specific costs and losses associated to your application
  - Can prove to be a non-trivial problem
  - Should be done in consultation with economic experts
  - Examples for research and applications in this area exist, e.g.:

    http://www.iiasa.ac.at/Research/RAV/Projects/gov-fair.html?sb=4

The **Decisions and Governance** theme investigates how the presence of risk and uncertainty influences the design of successful policies in the areas of environmental management and climate change.

In Europe, the group has identified successful ways of involving citizens in the design of programmes to reduce flood risk, and is now applying these lessons to similar efforts in China and Japan…

Ensemble Prediction System

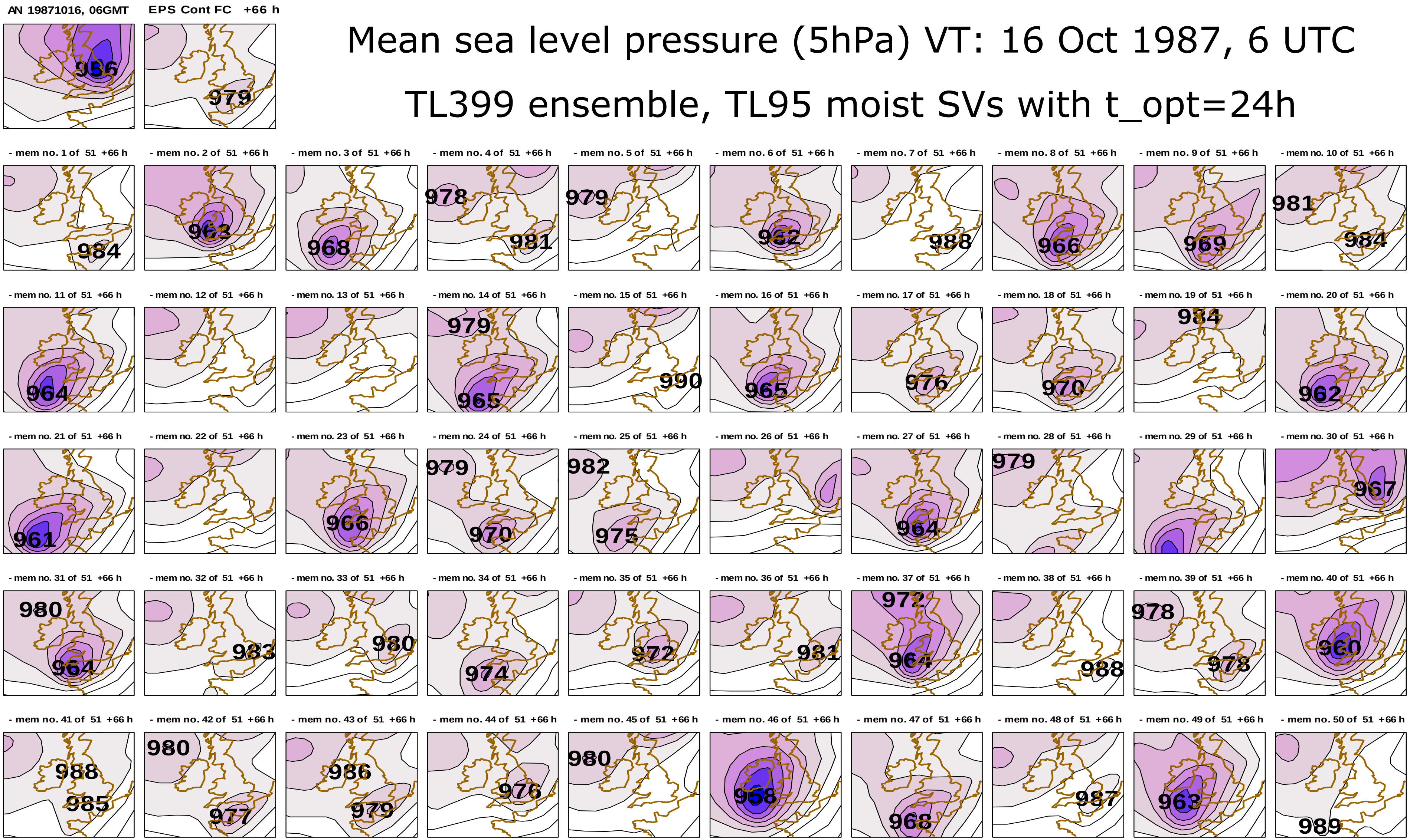
- 1 control run + 50 perturbed runs (T_L399 L62)
  - added dimension of ensemble members
  - f(x,y,z,t,e)
- How do we deal with added dimension when
  - interpreting, verifying and diagnosing EPS output?

Transition from deterministic (yes/no) to probabilistic

EPS products: stamp maps

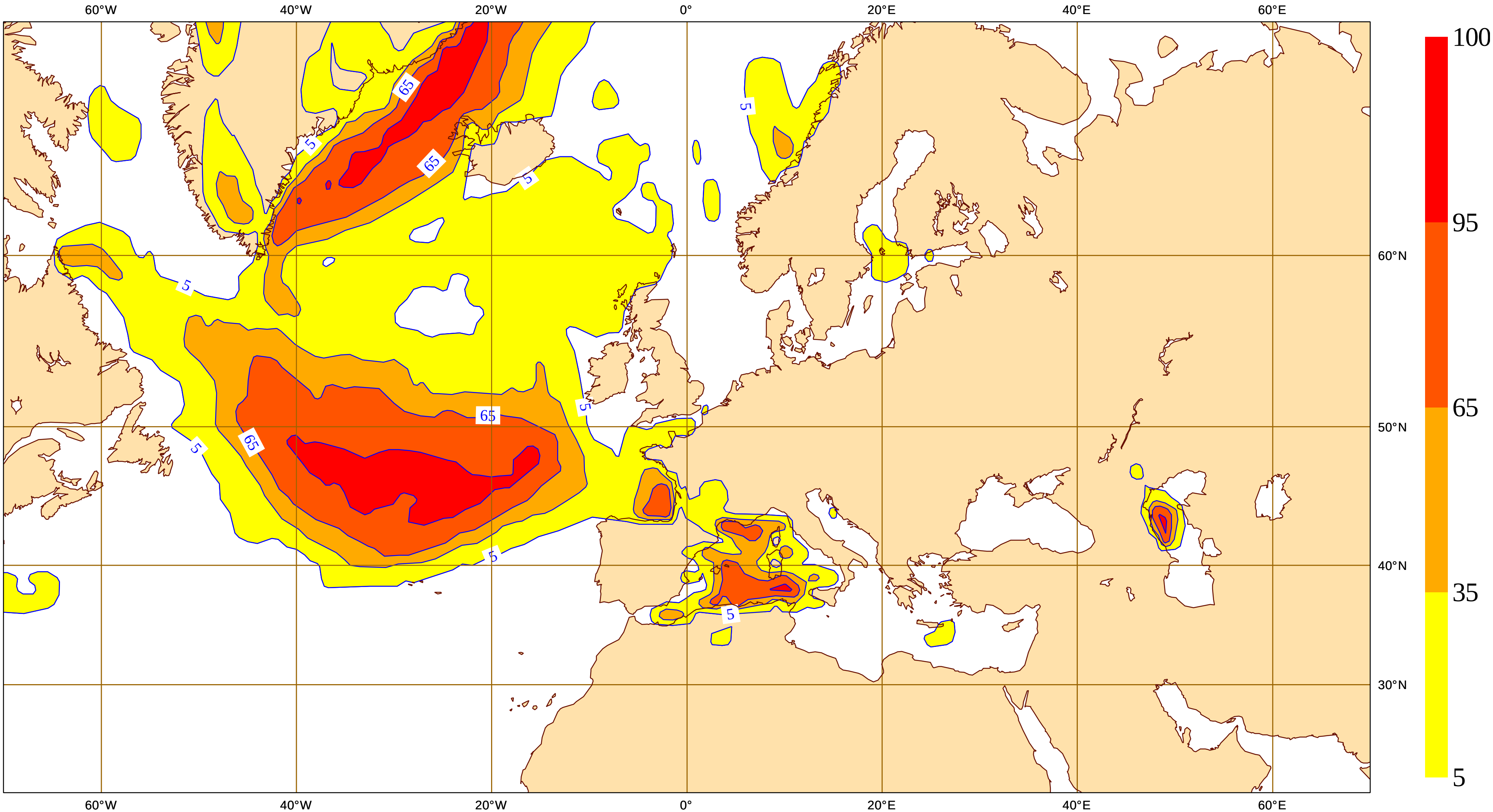
Mean sea level pressure (5hPa) VT: 16 Oct 1987, 6 UTC

TL399 ensemble, TL95 moist SVs with t_opt=24h



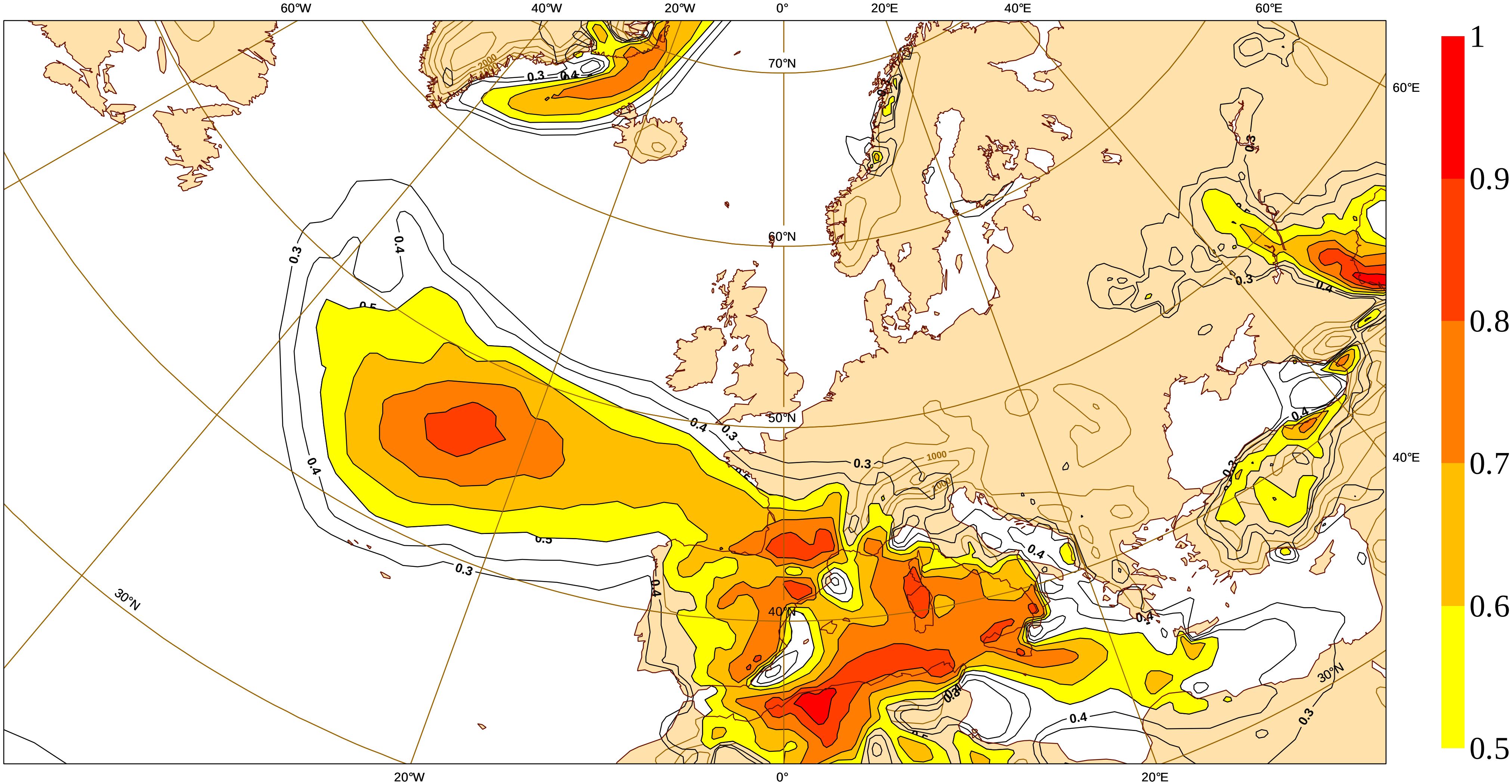
Probability of 10m windspeed ≥ 15 m/s

Wednesday 21 January 2009 00UTC ©ECMWF Forecast probability t+084 VT: Saturday 24 January 2009 12UTC
Surface: 10 metre Wind speed of at least 15 m/s

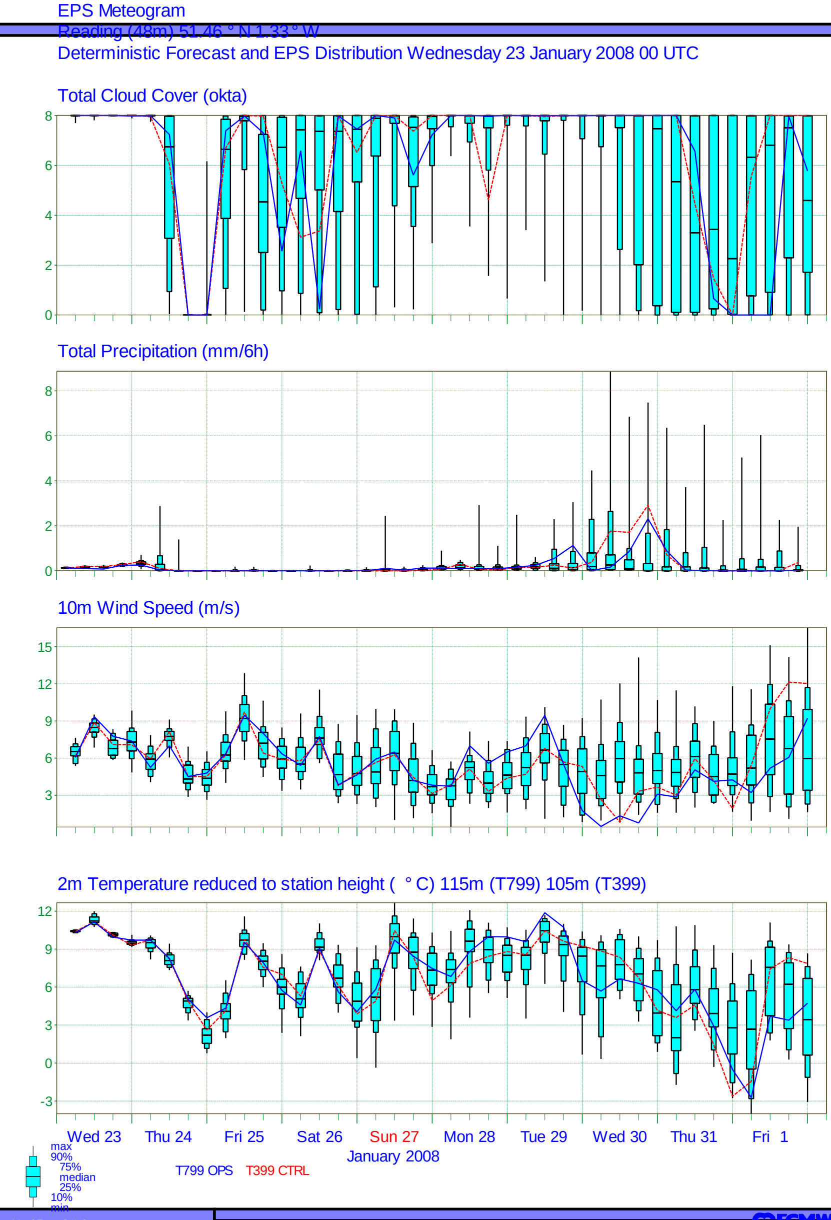


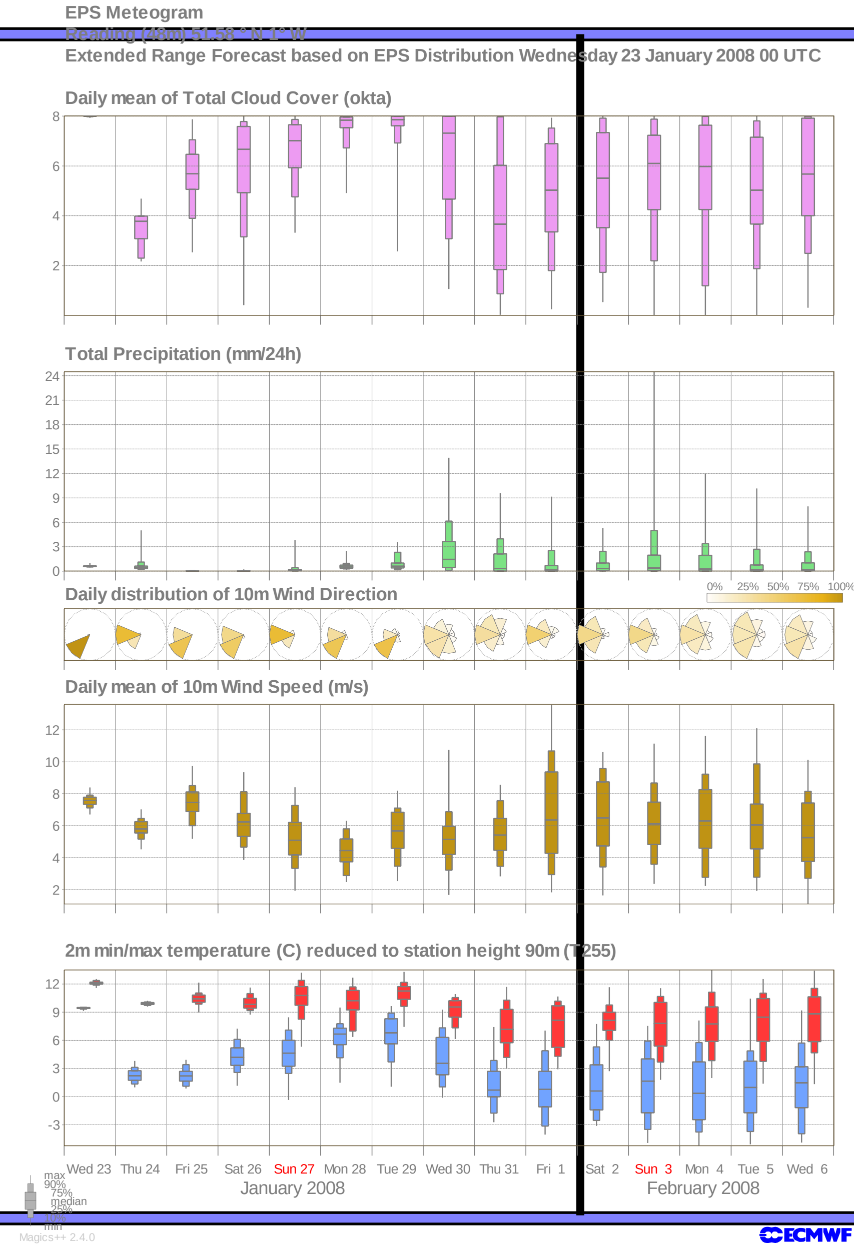
Extreme Forecast Index

Wednesday 21 January 2009 00UTC ©ECMWF Extreme forecast index t+072-096 VT: Saturday 24 January 2009 00UTC - Sunday 25 January 2009 00UTC
Surface: 10 metre speed index



EPS products: EPSgram





Assessing the quality of a forecast

- The forecast indicated 10% probability for rain
- It did rain on the day
- Was it a good forecast?
  - □ Yes
  - □ No
  - □ I don't know
- Single probabilistic forecasts are never completely wrong or right (unless they give 0% or 100% probabilities)
- To evaluate a forecast system we need to look at a (large) number of forecast–observation pairs

Assessing the quality of a forecast system

- Characteristics of a forecast system:
  - **Consistency***: Do the observations statistically belong to the distributions of the forecast ensembles? (consistent degree of ensemble dispersion)
  - **Reliability**: Can I trust the probabilities to mean what they say?
  - **Sharpness**: How much do the forecasts differ from the climatological mean probabilities of the event?
  - **Resolution**: How much do the forecasts differ from the climatological mean probabilities of the event, and the systems gets it right?
  - **Skill**: Are the forecasts better than my reference system (chance, climatology, persistence,…)?

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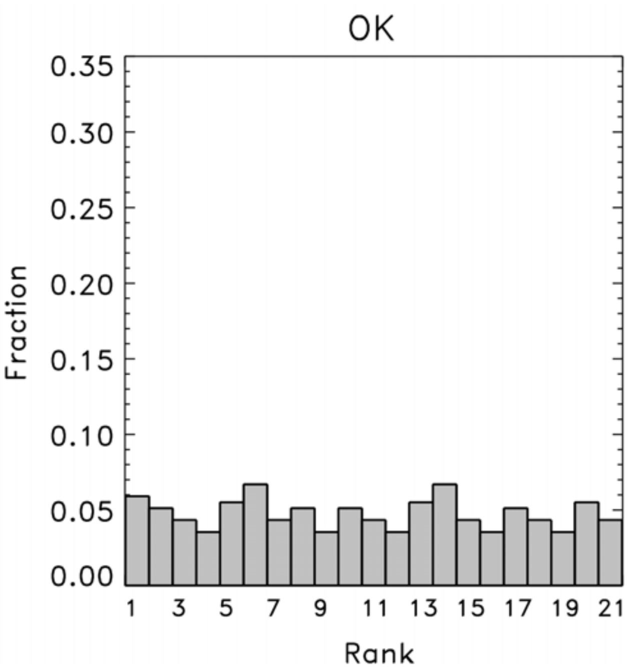
* Note that terms like consistency, reliability etc. are not always well defined in verification theory and can be used with different meanings in other contexts

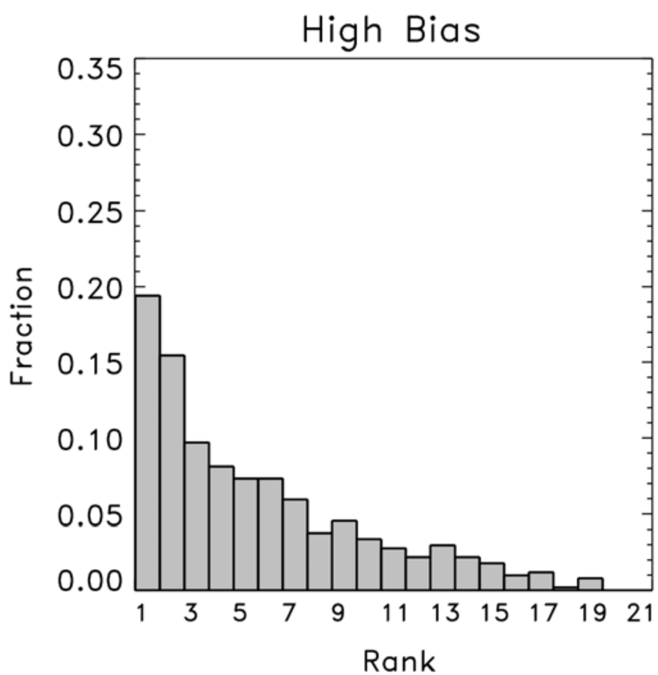
Rank Histogram

- Rank Histograms asses whether the ensemble spread is consistent with the assumption that the observations are statistically just another member of the forecast distribution
  - Check whether observations are equally distributed amongst predicted ensemble
  - Sort ensemble members in increasing order and determine where the observation lies with respect to the ensemble members

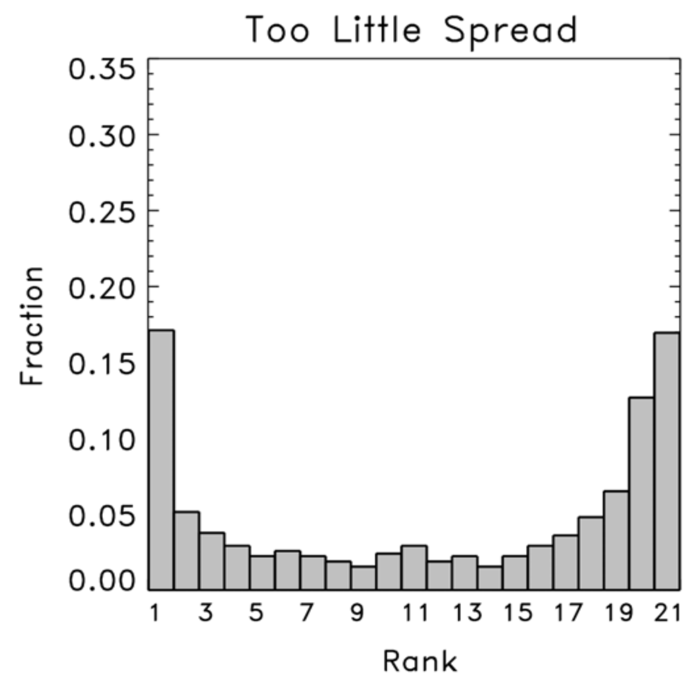
Rank Histograms



OBS is indistinguishable from any other ensemble member



OBS is too often below the ensemble members (biased forecast)

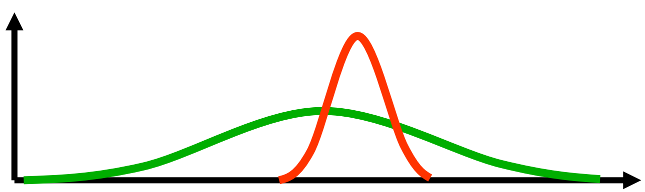


OBS is too often outside the ensemble spread

A uniform rank histogram is a necessary but not sufficient criterion for determining that the ensemble is reliable (see also: T. Hamill, 2001, MWR)

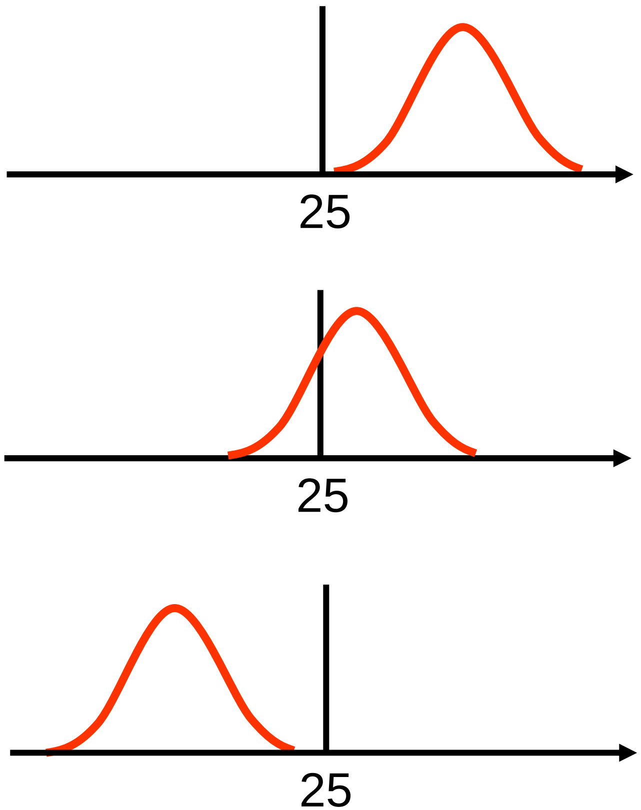
Reliability

- A forecast system is reliable if:
  - statistically the predicted probabilities agree with the observed frequencies, i.e.
  - taking all cases in which the event is predicted to occur with a probability of x%, that event should occur exactly in x% of these cases; not more and not less.
- A reliability diagram displays whether a forecast system is reliable (unbiased) or produces over-confident / under-confident probability forecasts
- A reliability diagram also gives information on the resolution (and sharpness) of a forecast system



Reliability Diagram

Take a sample of probabilistic forecasts:
e.g. 30 days x 2200 GP = 66000 forecasts
How often was event (T > 25) forecasted with X probability?



FC Prob.	# FC	"perfect FC" OBS-Freq.	"real" OBS-Freq.
100%	8000	8000 (100%)	7200 (90%)
90%	5000	4500 (90%)	4000 (80%)
80%	4500	3600 (80%)	3000 (66%)
....	....	....	....
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10%	5500	550 (10%)	800 (15%)
0%	7000	0 (0%)	700 (10%)

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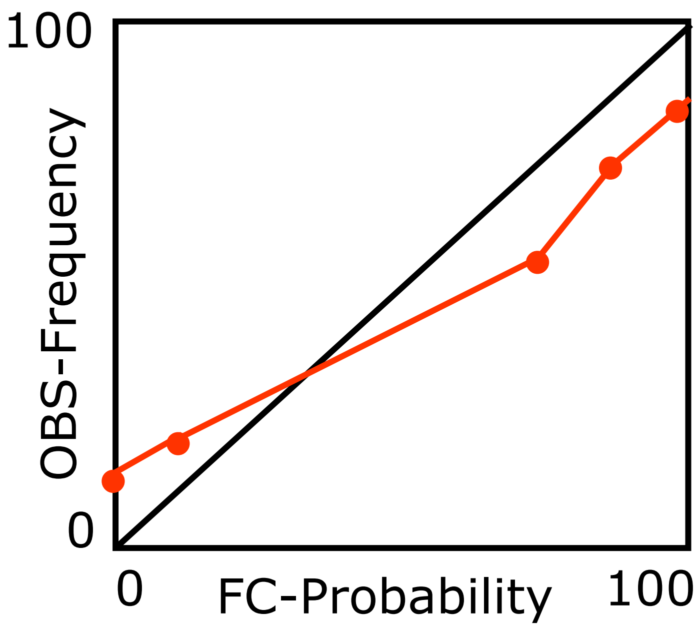

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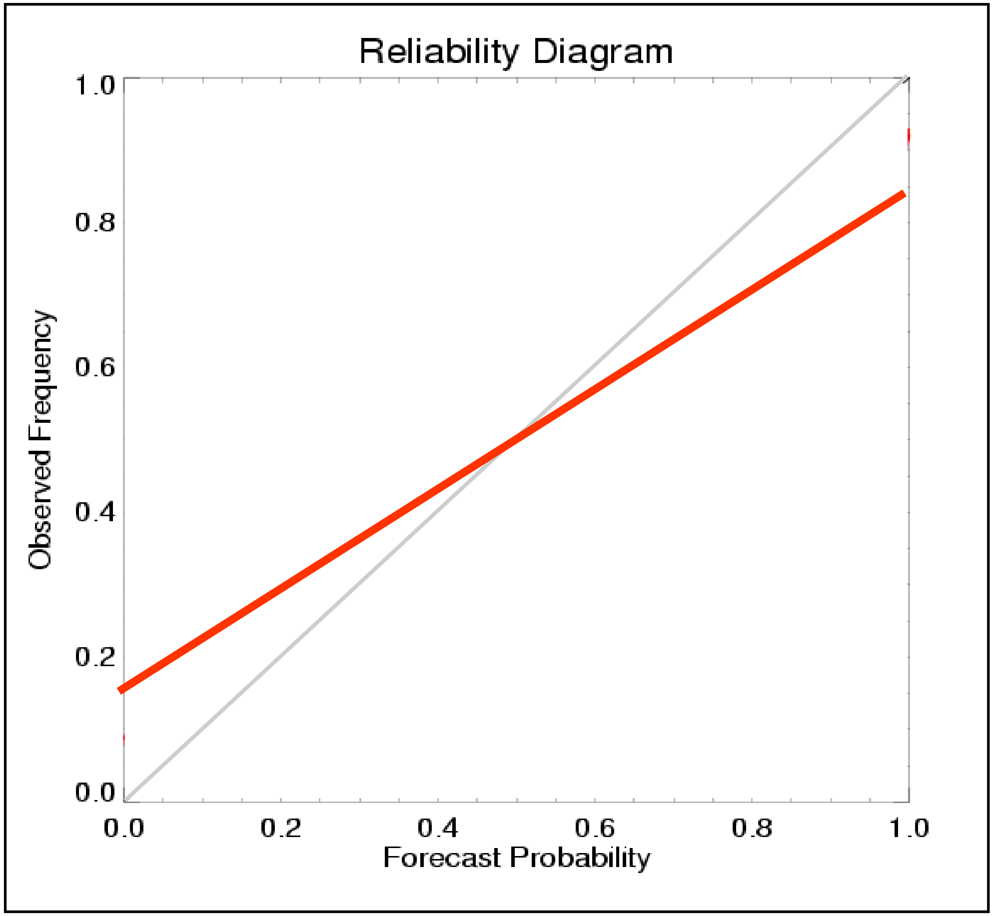
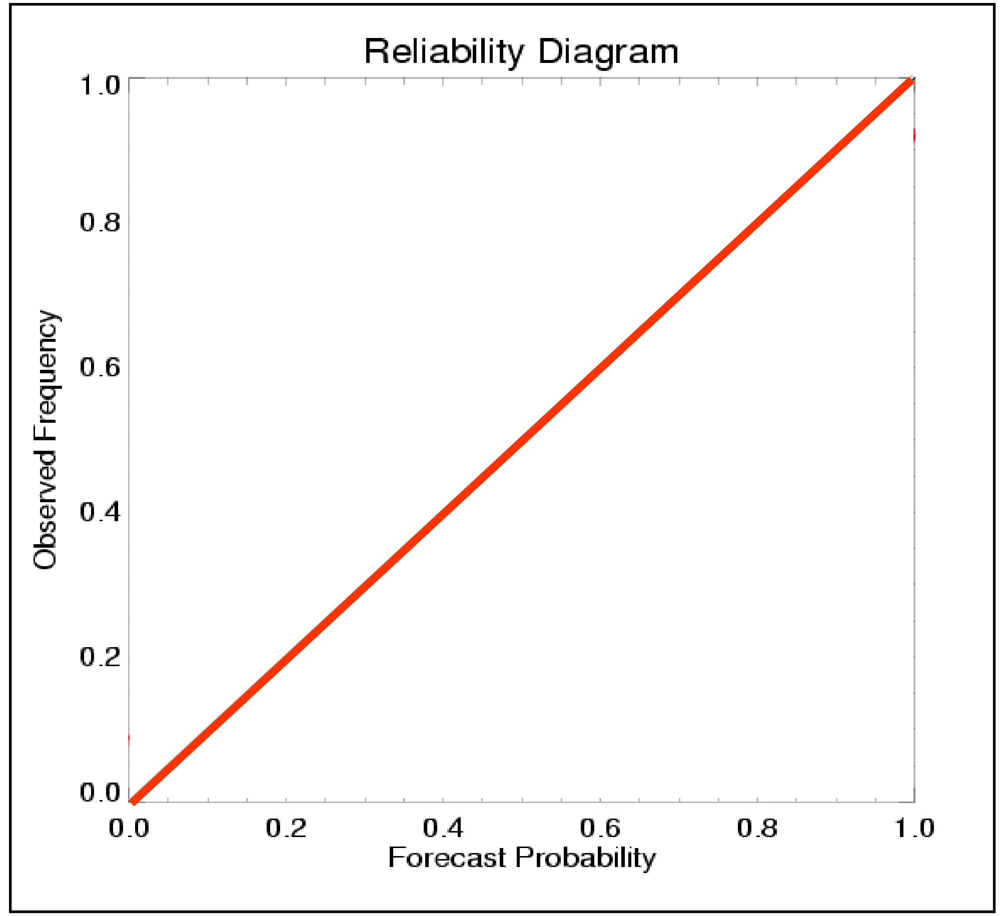
over-confident model



perfect model



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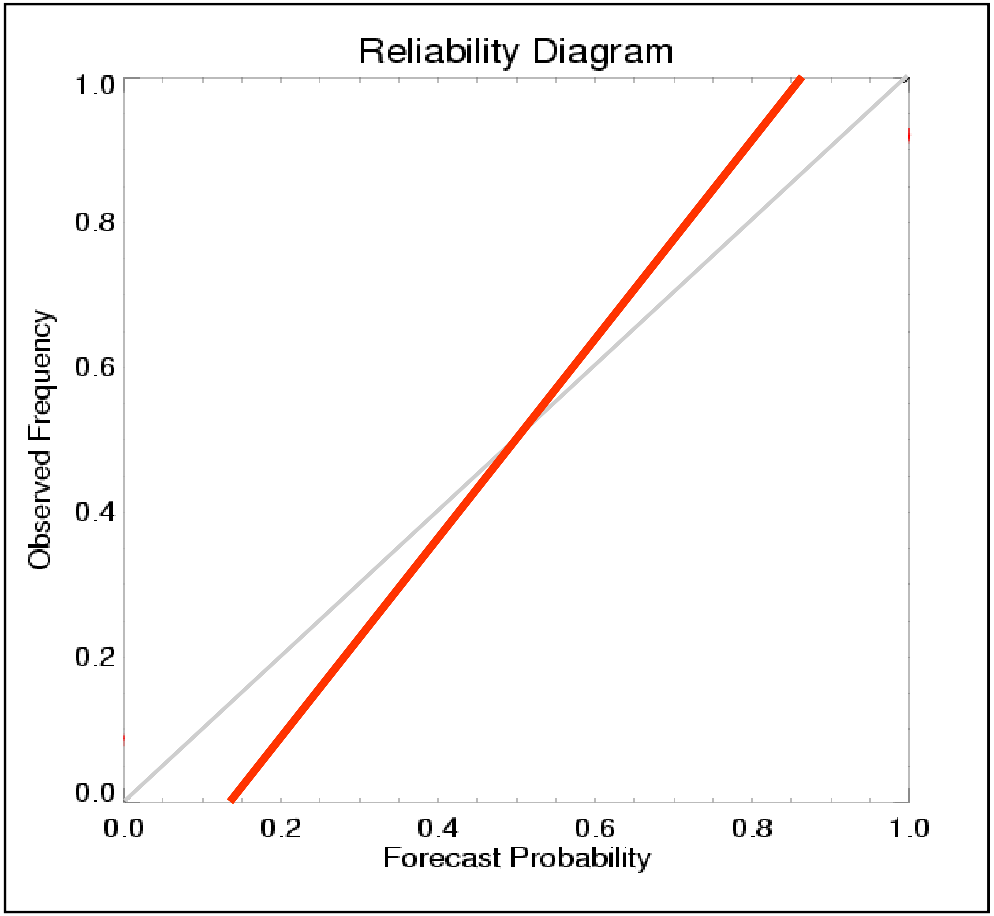
under-confident model



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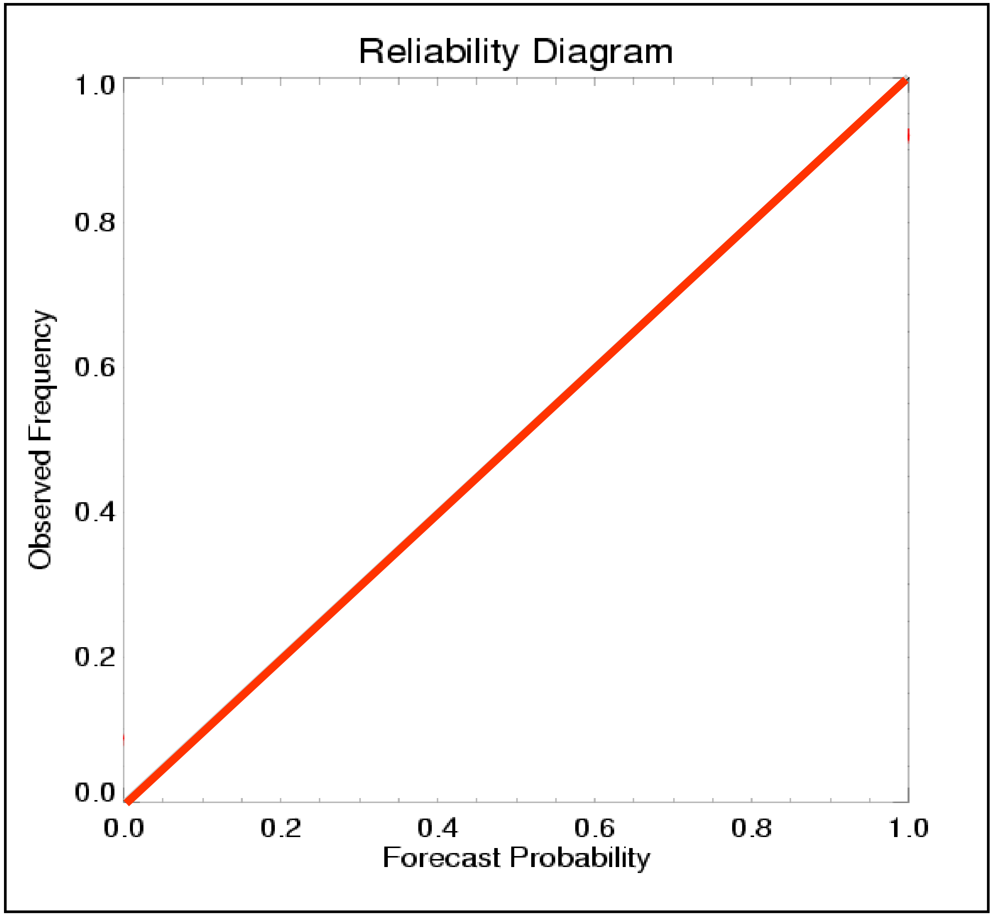

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