CAFE
Climate Advanced Forecasting of sub-seasonal Extremes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 813844

Sub-seasonal predictions and verification: part 2

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Part I:

- Sub-seasonal predictions: bridging the gap between weather and climate
- Introduction to the chaotic nature of weather and climate systems
- Chaos and representation of uncertainties
- Ensemble predictions
- Predictability and skill

Part II:

- Standard verification methods
- What's a reliable probabilistic forecast
- Resolution and sharpness of a probabilistic forecast
- Current skill of sub-seasonal predictions
- Conditional skill

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How we evaluate our predictions ?

- comparing the model statistics (mean climate, variability associated with MJO, ENSO etc..) with the real world statistics → model evaluation (diagnostics)
- assessing to what extent predictions follows the time evolution of past climate or past weather events → verification
- For both evaluation and verification we need some data that describe the true →verification sample

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Representation of the "true" Data for verification

Verification data is affected by uncertainties:
Instrument errors
Inconsistencies in time and location
Different method of assimilation

- Analysis
- Reanalysis
- Other observations on GTS (WMO exchange network for observations)
- National and regional networks
- Processed observation products (e.g. OSTIA SST, GPCP)

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Evaluation of biases based on 30-year period: 2-metre temp.

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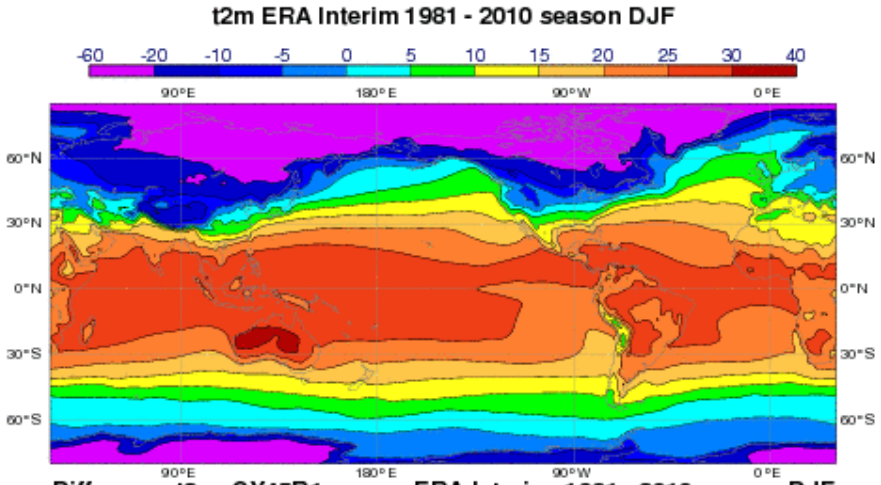
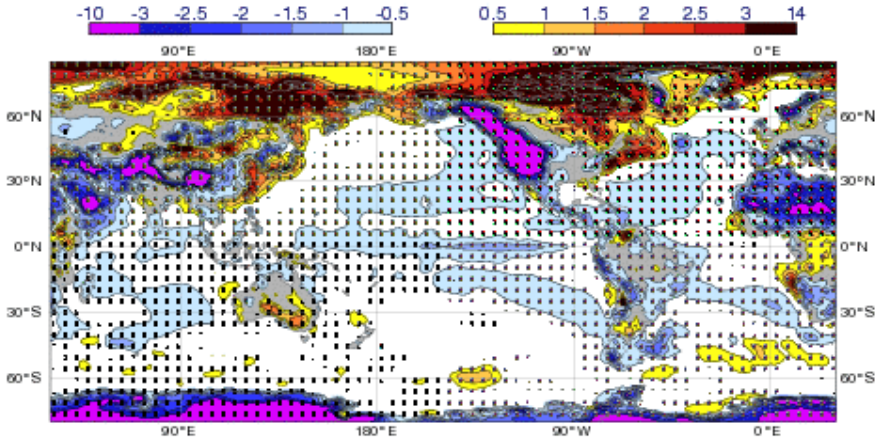
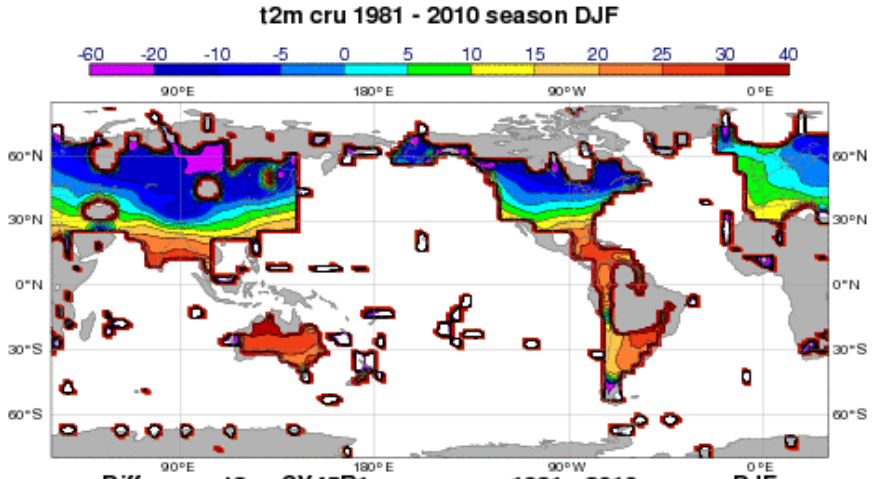
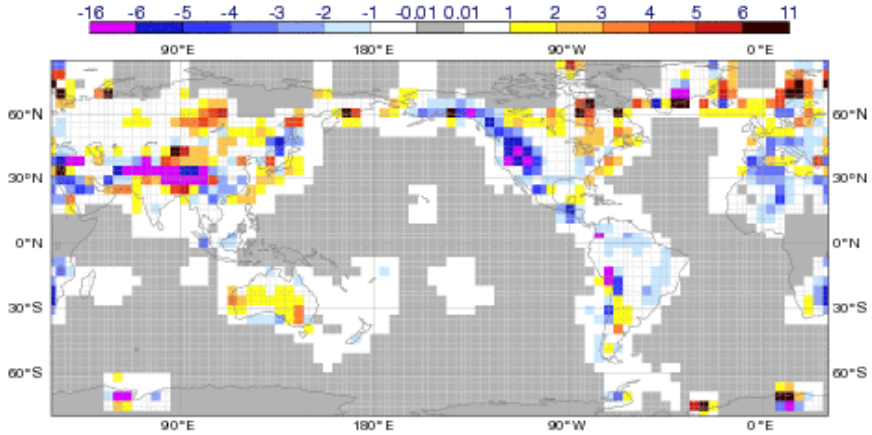
Against ERA-Interim





Against CRU (gridded land data)





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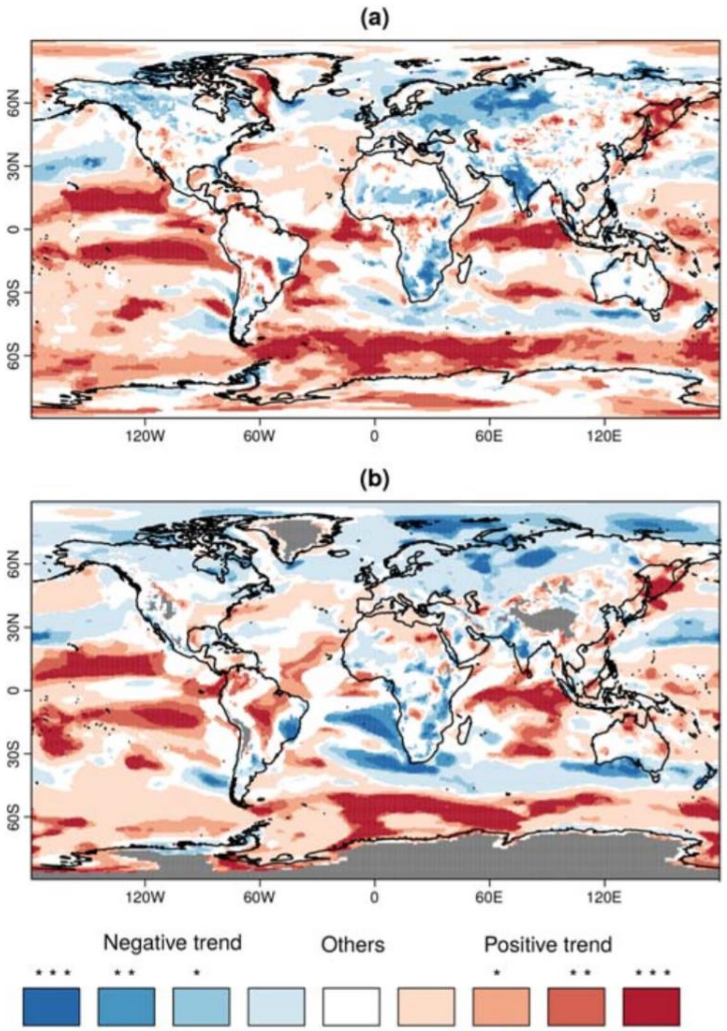

Figure 4. Comparison of the (*a*) 10 m and (*b*) 850 hPa wind speed trends produced by ERA-I, JRA-55 and MERRA-2. Blues (Reds) indicate agreement between the three reanalyses about the negative (positive) trends of 10 m wind speed for December–January–February in the period of 1980–2015. Asterisk indicates that the trends are significant at the 95% confidence level: no asterisk indicates that the trends are not significant, (∗) indicates that only one of the reanalysis has significant trends, (∗∗) informs that two reanalyses have significant trends, and (∗∗∗) indicates that the three reanalyses have significant trends. Grey areas indicate where the surface level is higher than the 850 hPa level.

Verónica Torralba et al 2017
Environ. Res. Lett. 12 114019

What is a reanalysis?

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(e.g. ERA-Interim, ERA-5, MERRA2, JRA-55, NOAA 20C, ...)

- Use similar data assimilation system as the operational forecasts
- Reprocess historical observations
- Re-run the data assimilation over a long period with a fixed assimilation system

Key Strengths: (from https://climatedataguide.ucar.edu/climate-data/atmospheric-reanalysis-overview-comparison-tables)

- Global data sets, consistent spatial and temporal resolution over 3 or more decades, hundreds of variables available; model resolution and biases have steadily improved
- Reanalyses incorporate millions of observations into a stable data assimilation system that would be nearly impossible for an individual to collect and analyze separately, enabling a number of climate processes to be studied
- Reanalysis data sets are relatively straightforward to handle from a processing standpoint (although file sizes can be very large)

Key Limitations:

- Observational constraints, and therefore reanalysis reliability, can considerably vary depending on the location, time period, and variable considered
- The changing mix of observations, and biases in observations and models, can introduce spurious variability and trends into reanalysis output
- Diagnostic variables relating to the hydrological cycle, such as precipitation and evaporation, should be used with extreme caution

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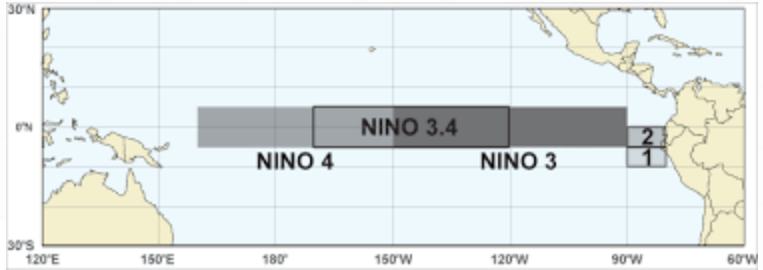
Deterministic Verification:

It works for a single forecast (e.g. the ensemble mean)

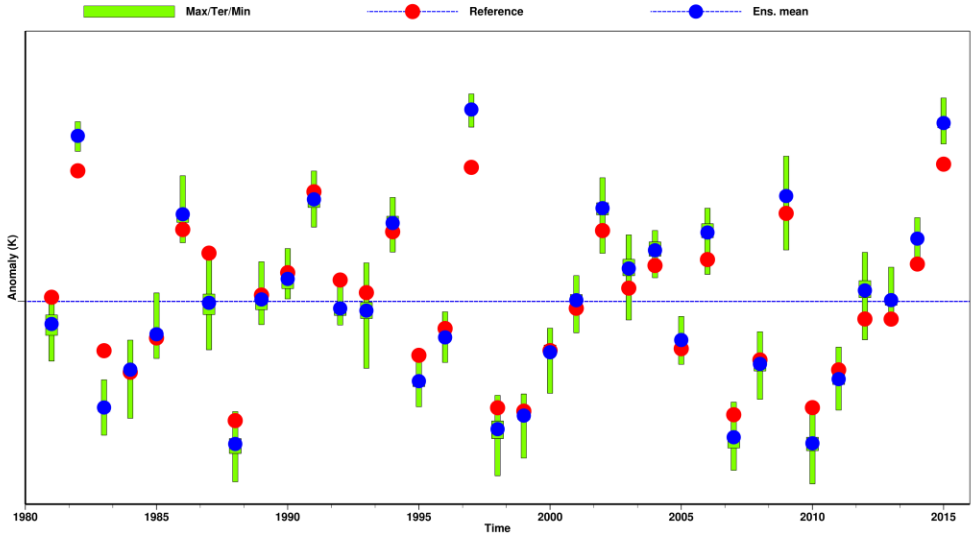
metrics: anomaly correlation, Root-mean-square error (RMSE), Mean error (bias), Anomaly standard deviation

NINO3.4



Nino3.4 SST (ocean only)
ORecmfEX0001SY04M1 with 25 ensemble members
Hindcast period 1981-2015
Start date November and fcst. time 2 to 4

ACC (ens. Mean) =0.97



The definition of the root-mean-square forecast error, *RMSE*, in terms of the values of the forecast, f, and the analysis, a, is:

$$RMSE^2 = \overline{(f-a)^2} = \overline{(f-c)^2} + \overline{(a-c)^2} - 2\overline{(f-c)}\,\overline{(a-c)} \quad \text{(A1)}$$

The definition of the un-centred ACC (*Wilks*, 2006) is:

$$ACC = \frac{\overline{(f-c)(a-c)}}{\sqrt{\overline{(f-c)^2}\,\overline{(a-c)^2}}} \quad \text{(A2)}$$

Here the overbar indicates a regional or global average and $(f-c)^2$ and $(a-c)^2$ are the squared standard deviations of the forecast anomalies and analysis anomalies from the climate, c,

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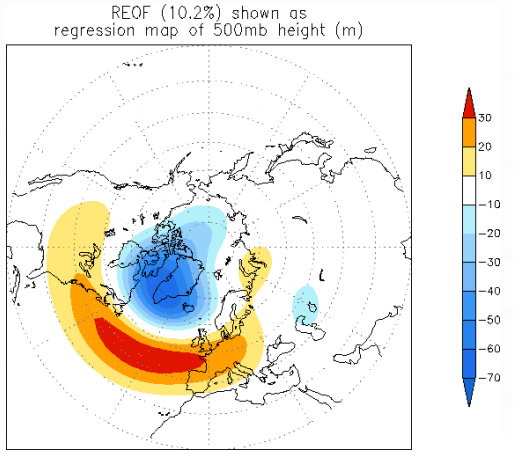

NINO3.4

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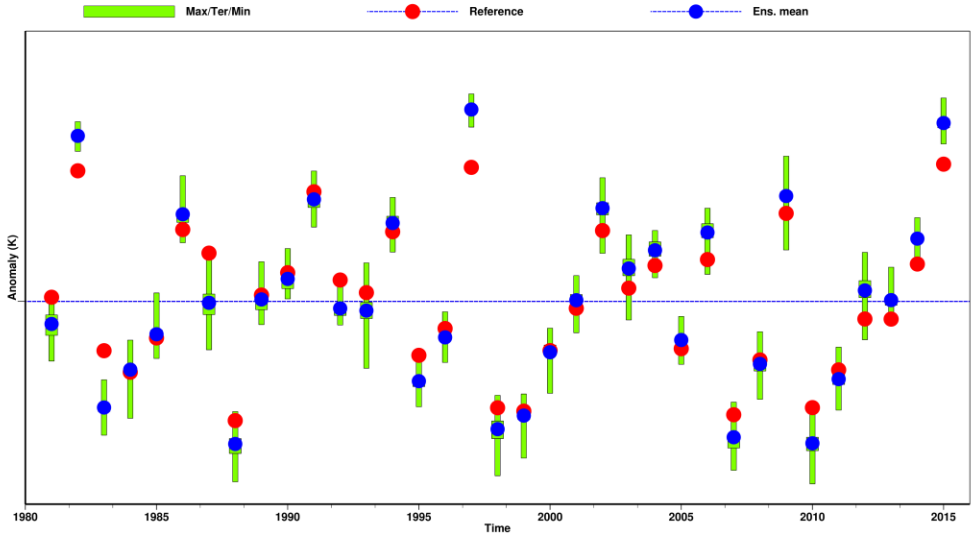
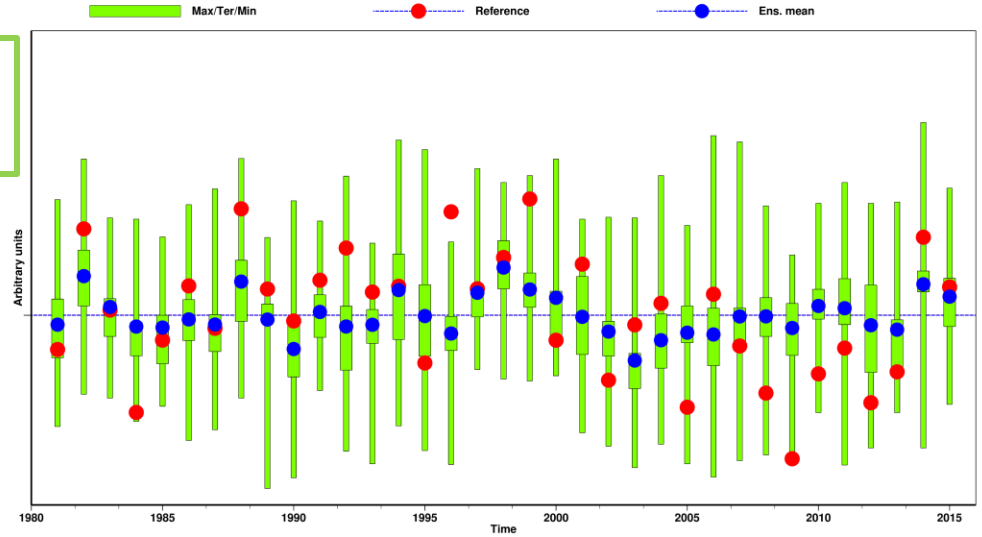


Ensemble spread is very different !!

NAO

Projection onto the NAO (Z500)
ORecmfEXgl82SY04M1 with 25 ensemble members
Hindcast period 1981-2015
Start date November and fcst. time 2 to 4

ACC (ens. mean) =0.46



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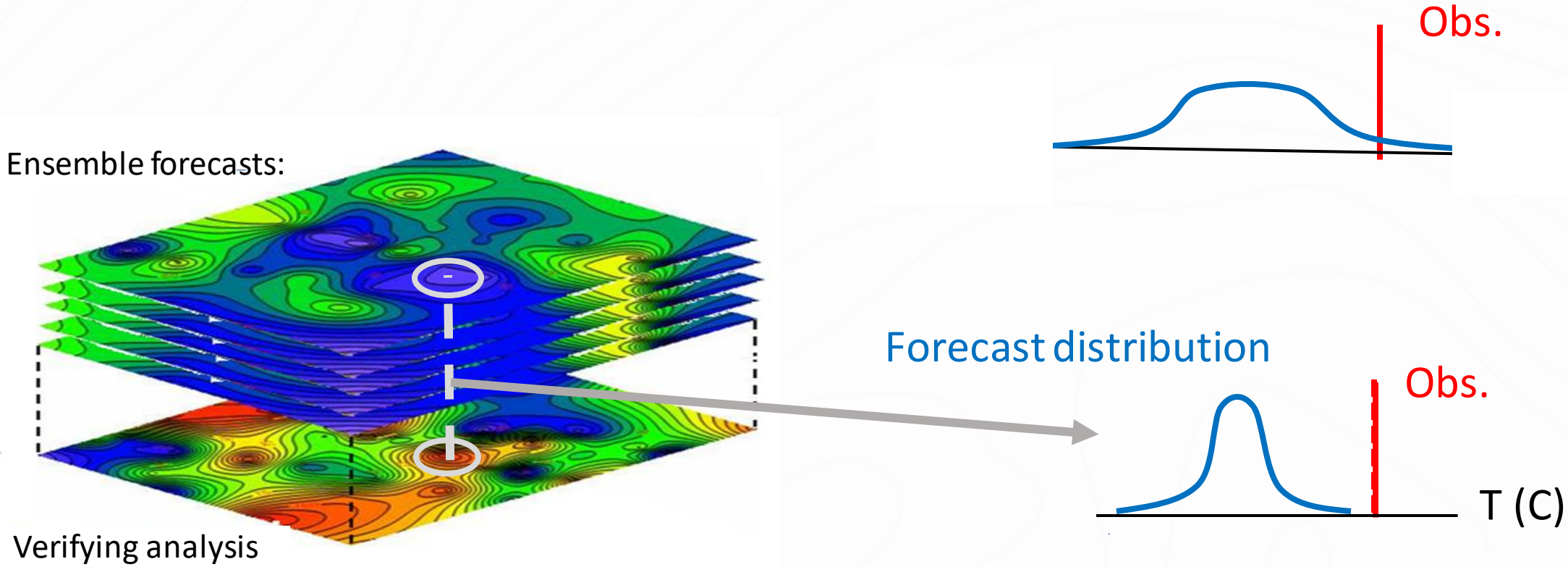
Probabilistic Verification:



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Attributes of forecast quality:

The accuracy, level of agreement between forecast and observation, can be divided into:

Reliability → Forecast distribution represents distribution of observations – unbiased probabilities
Reliability can be improved by calibration – a reliable forecast might have no skill.

Can I trust probabilities?

Discrimination and resolution → the forecast ability to represent the sample events into subsets with different frequency distribution.

Sharpness → is an attribute of the forecast alone and refers to the tendency to forecast extreme values. Sharp forecasts are "useful" BUT don't want sharp forecasts if not reliable. Implies unrealistic confidence.

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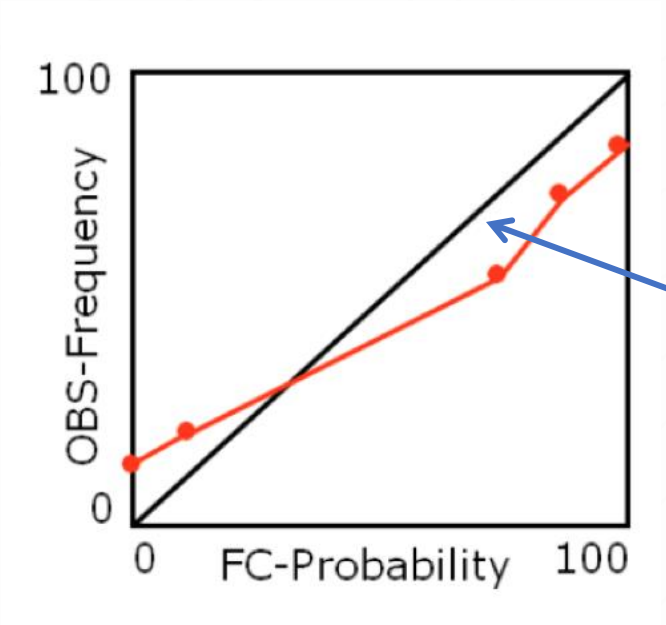
Reliability Diagram

How often was the event (T >25◦ C) predicted with probability p? and how often such event was observed.

Joint distribution of forecast and obs.

how often (as a percentage) a forecast probability actually occurred.



Perfect reliability

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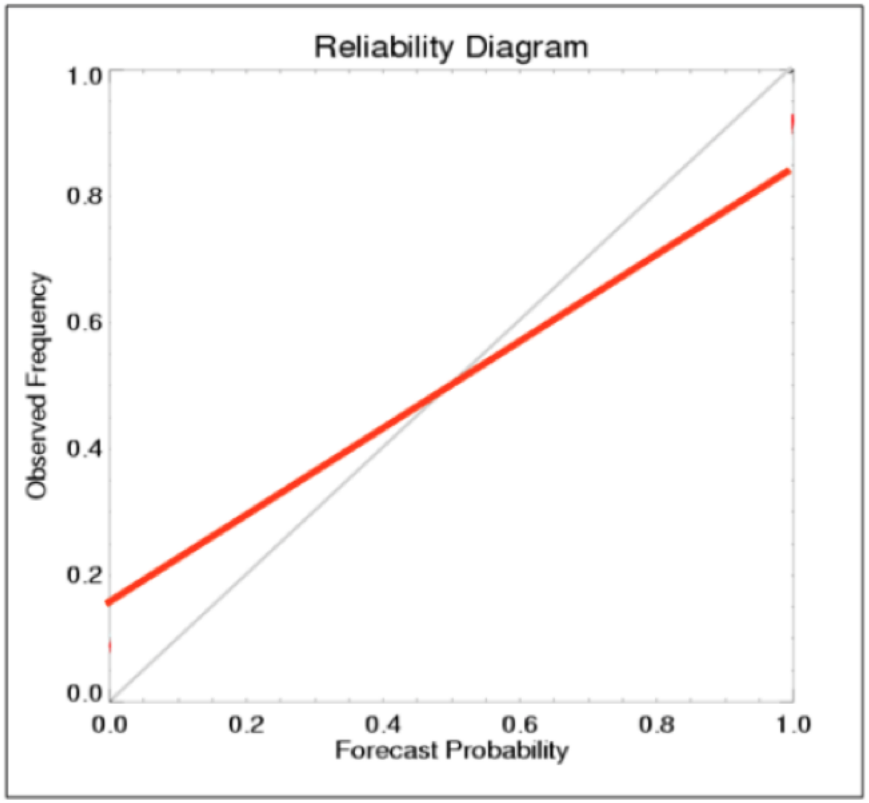
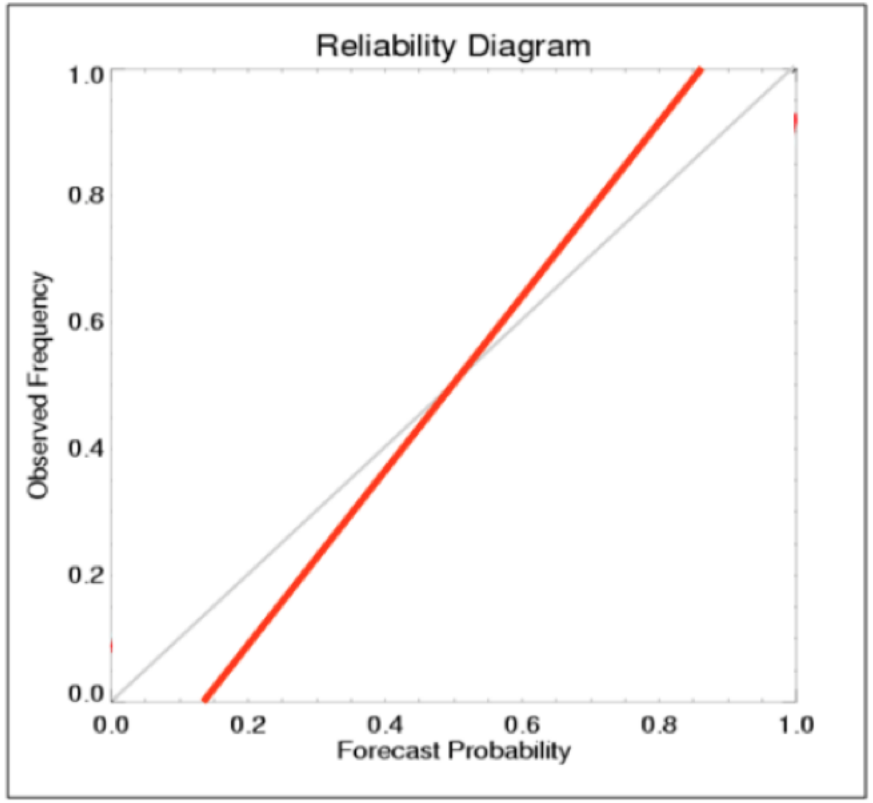
Over- and under- confidence reliability diagram

over-confident model



under-confident model



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ROC and Discrimination:

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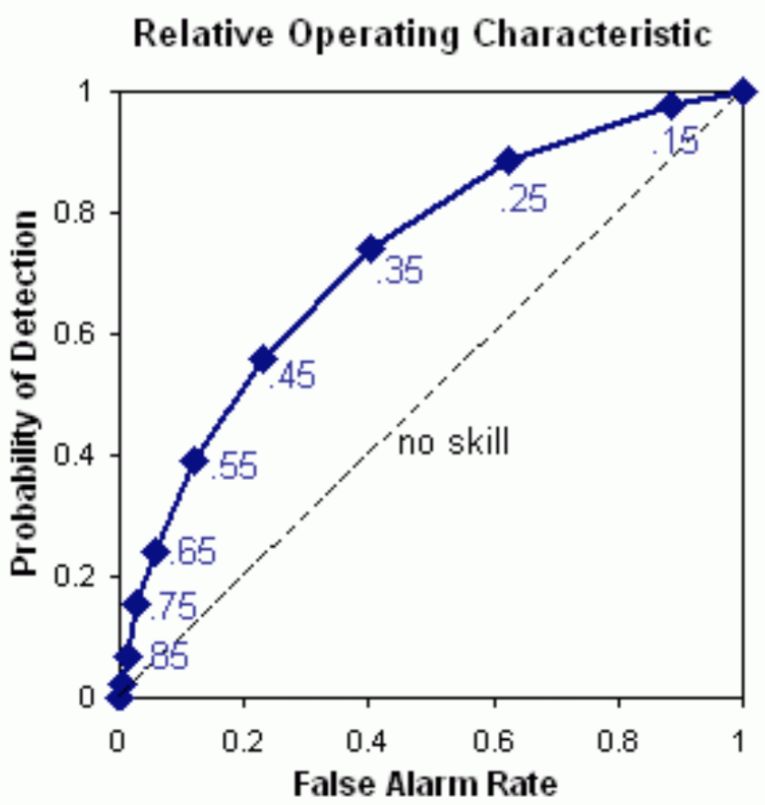
To measure the ability of a forecast system to discriminate between occurrence and non-occurrence of an event, one has to ask:

What distributions of probabilities have been predicted when the event occurred and when it did not occur?

The relative operating characteristic (ROC, also referred to as receiver operating characteristic) shows Hit rate versus False alarm rate for all probability thresholds.

Close to upper left corner good discrimination
Below diagonal poor discrimination
The area under the ROC curve is a useful summary measure.

ROC area >0.5 useful fct.
ROC area =0.5 climatology



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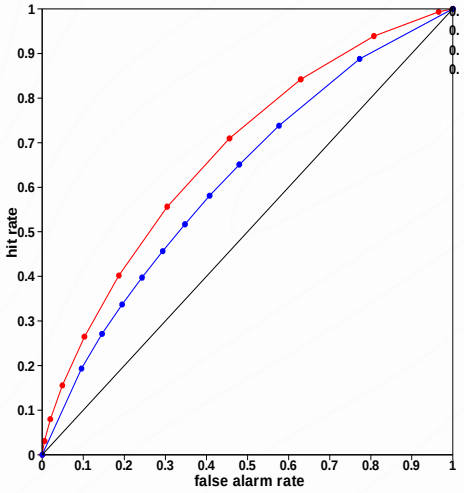
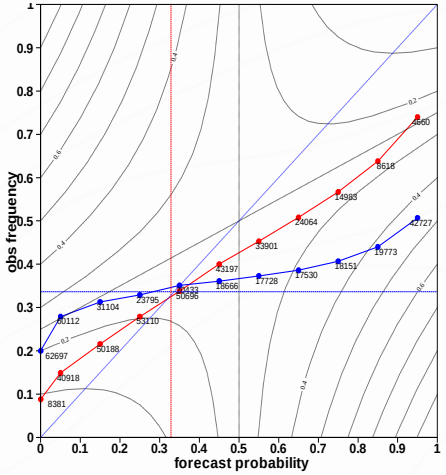
2-meter temperature in upper tercile - Day 12-18

ROC score Reliability diagram

Day 12-18

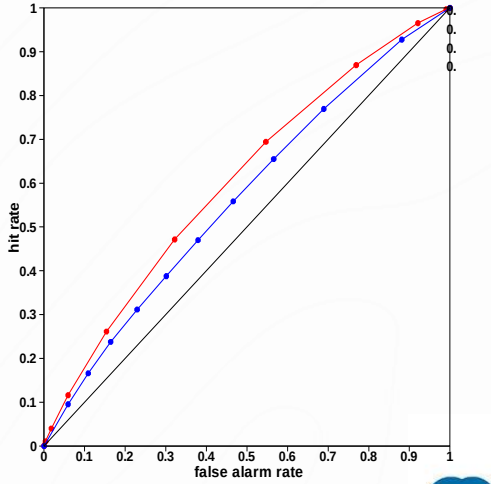


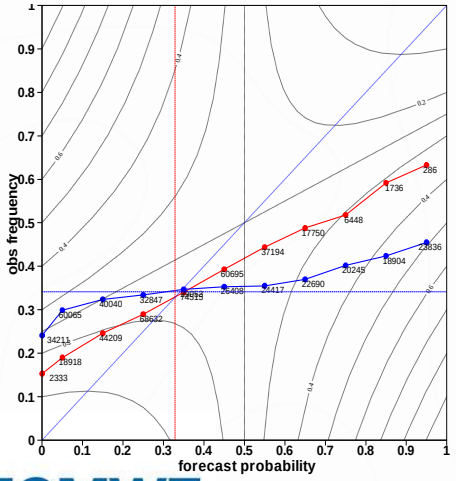


Persistence of day 5-11

subseasonal forecast day 12-18

Day 19-25





Persistence of day 5-18

subseasonal forecast day 19-32

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ROC for 2mt in the upper tercile

since Oct 2004

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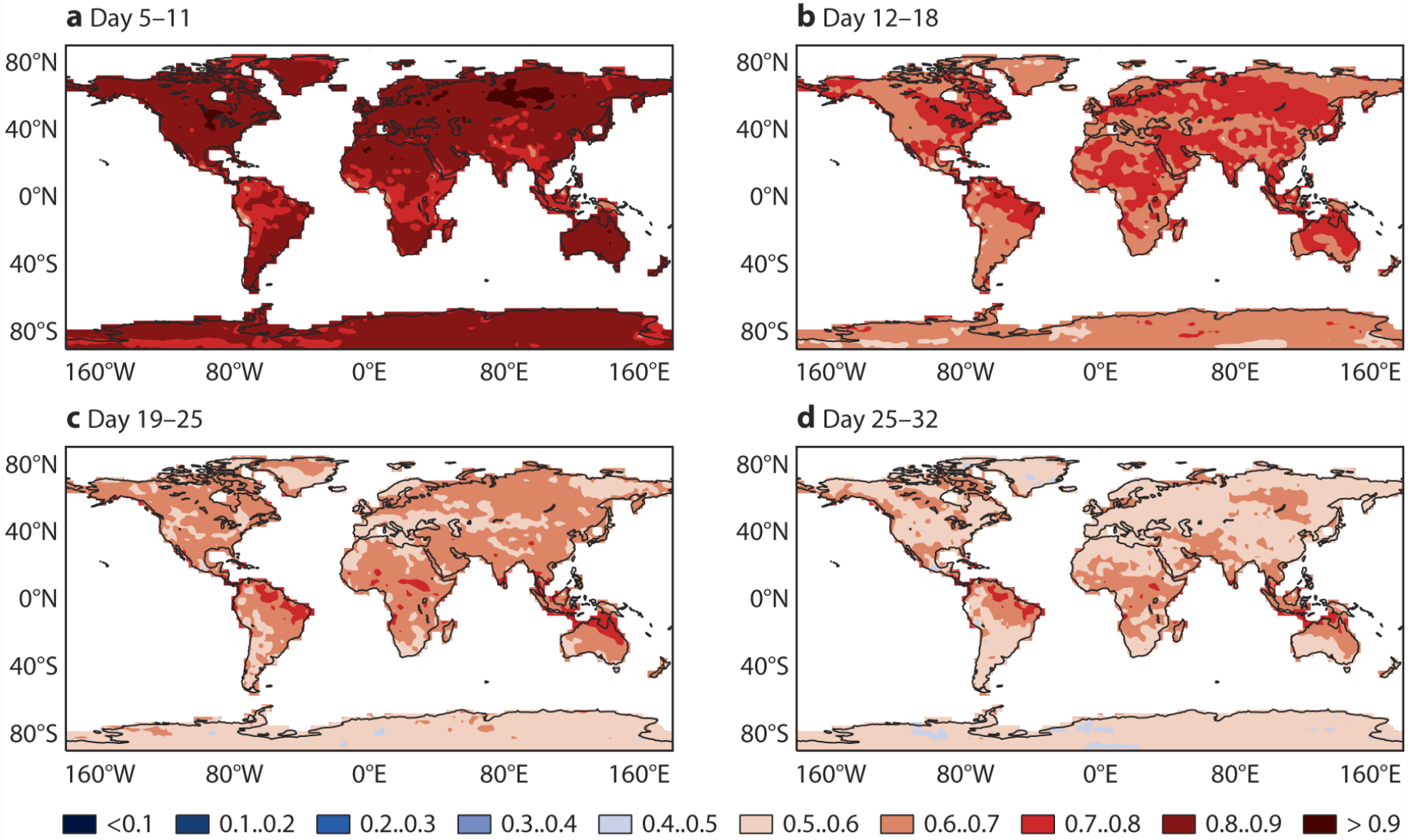

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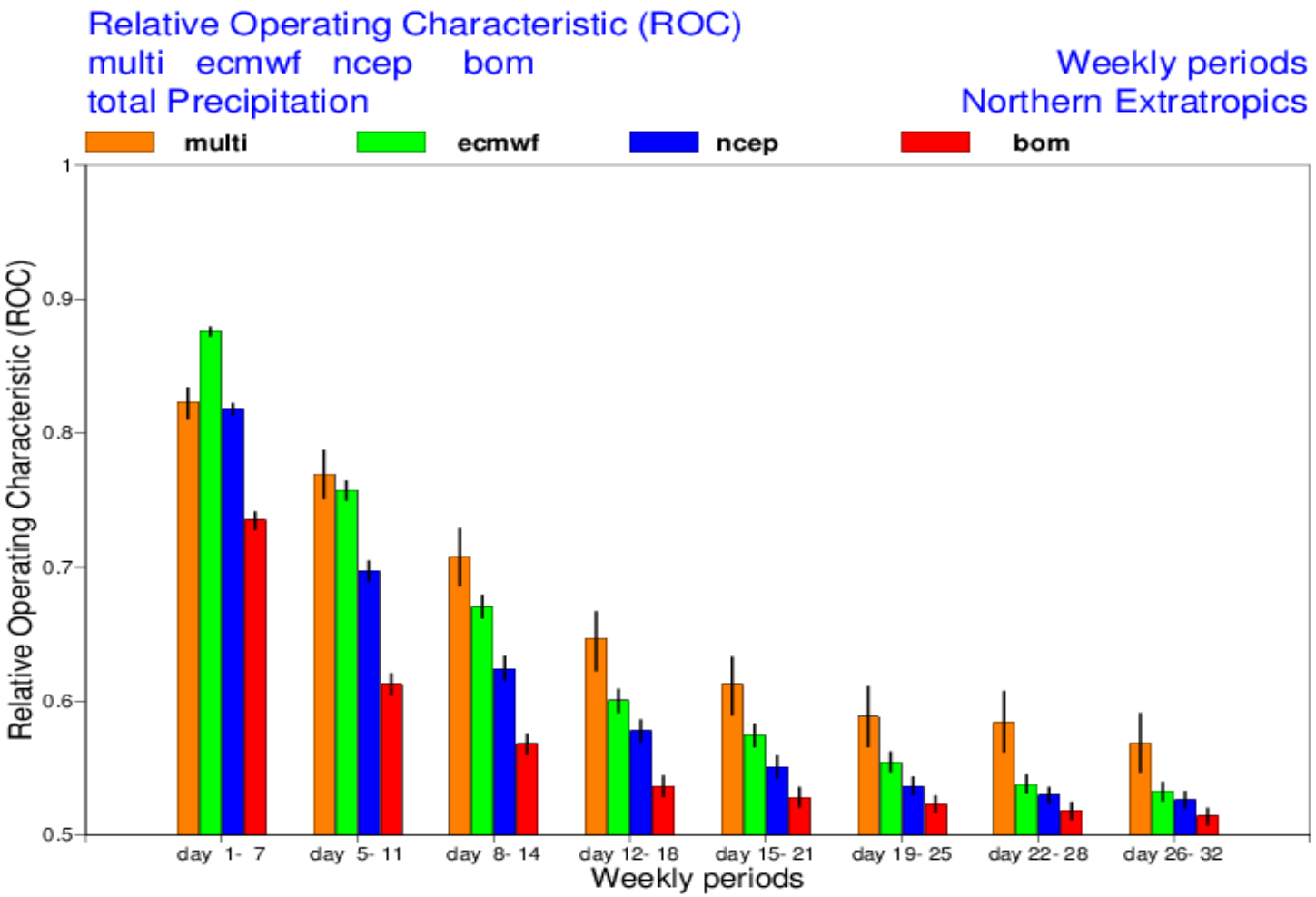
2015/2016 Real-time Forecast verification



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Skill Scores (SS):

Is a comparative measure of the skill (using any metric) and tell us if a set of forecasts is better than a reference set.

Reference (ref) set can be persistence, climatology, or any other forecast

SS=[score (fct)-score(ref)]/ [score(perfect fct)-score(ref)]

For example for RMSE metric SS= 1-RMSE(fct)/RMSE(ref)

SS→ 1 (perfect forecast)

SS→ 0 (fct = ref)

Predicting skill associated with the Euro-Atlantic Regimes

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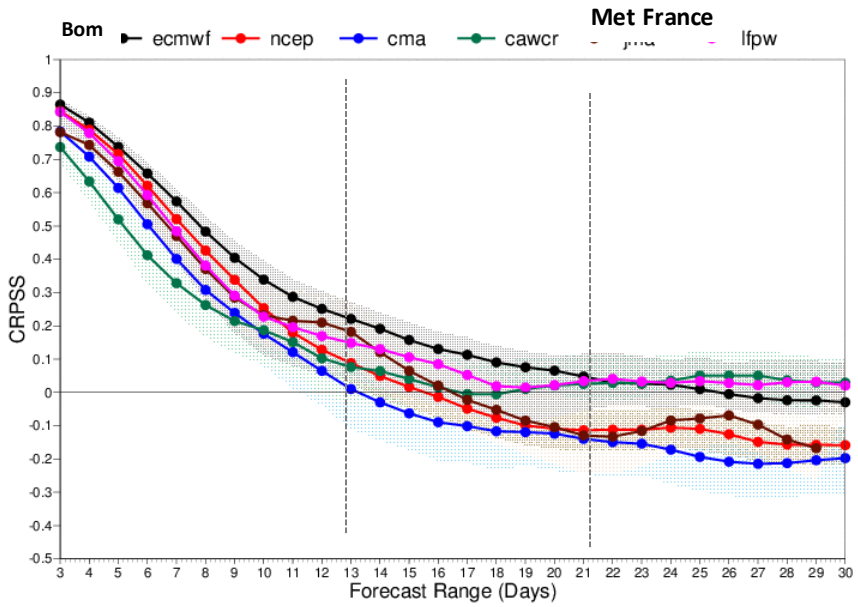
CRPS measure the mean error in probability space:

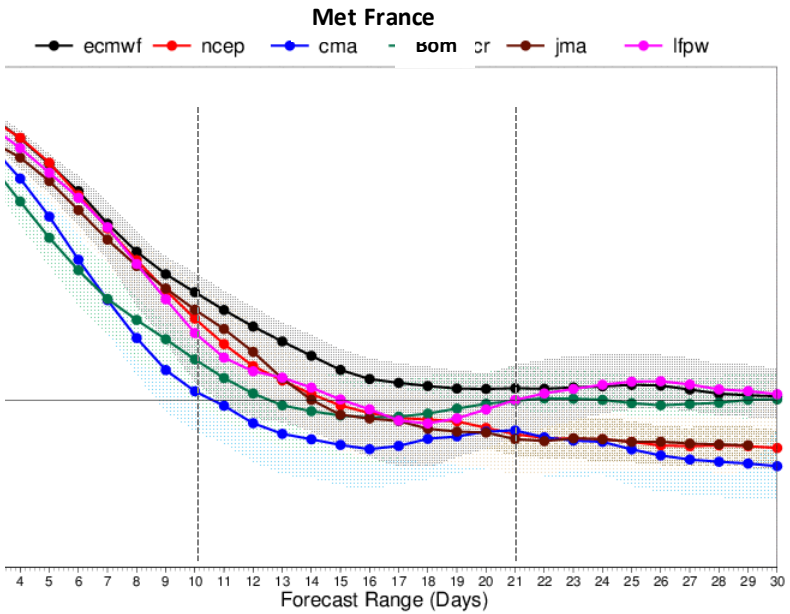
More details on how compute CRPS see Hersbach 2000

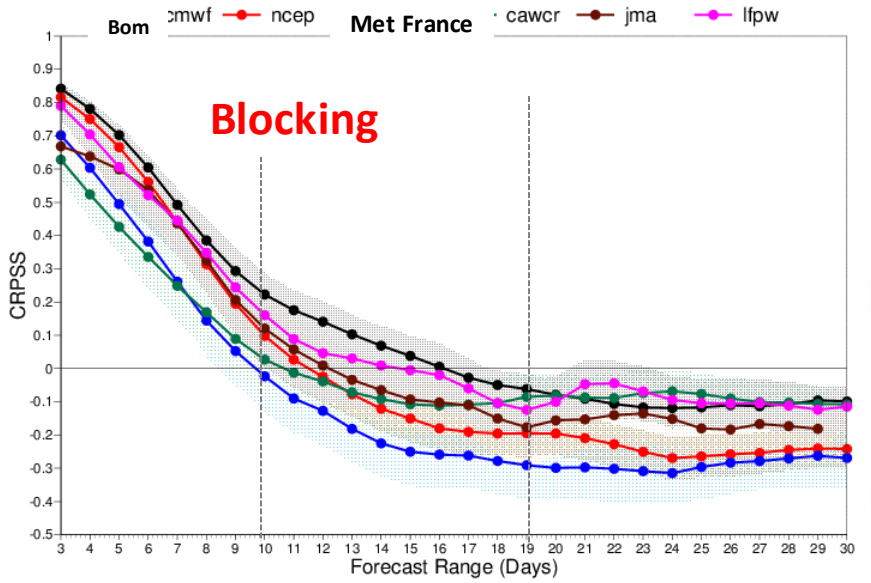
CRPSS=1-CRPS(fct)/CRPS(ref)CRP

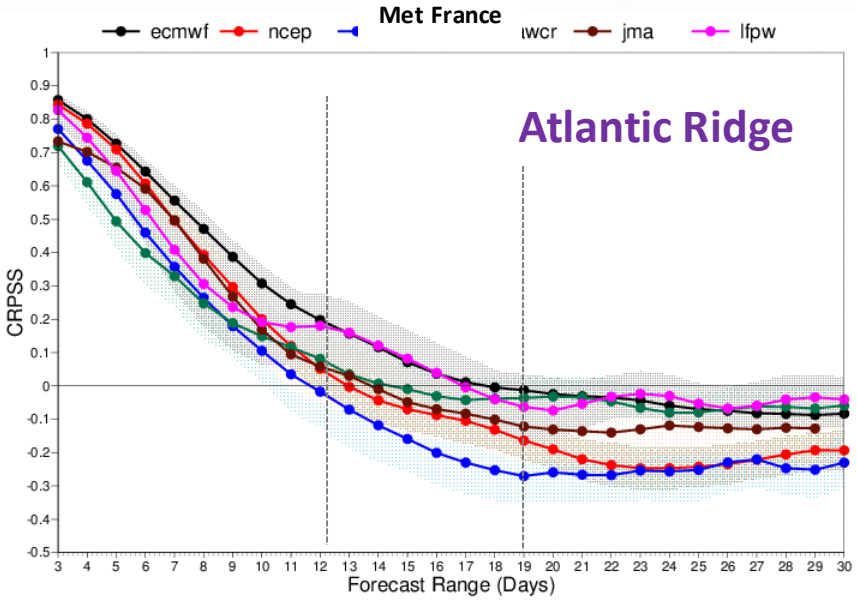
NAO +



NAO -







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Brier score

$$BS = \frac{1}{N}\sum_{t=1}^{N}(f_t - o_t)^2$$

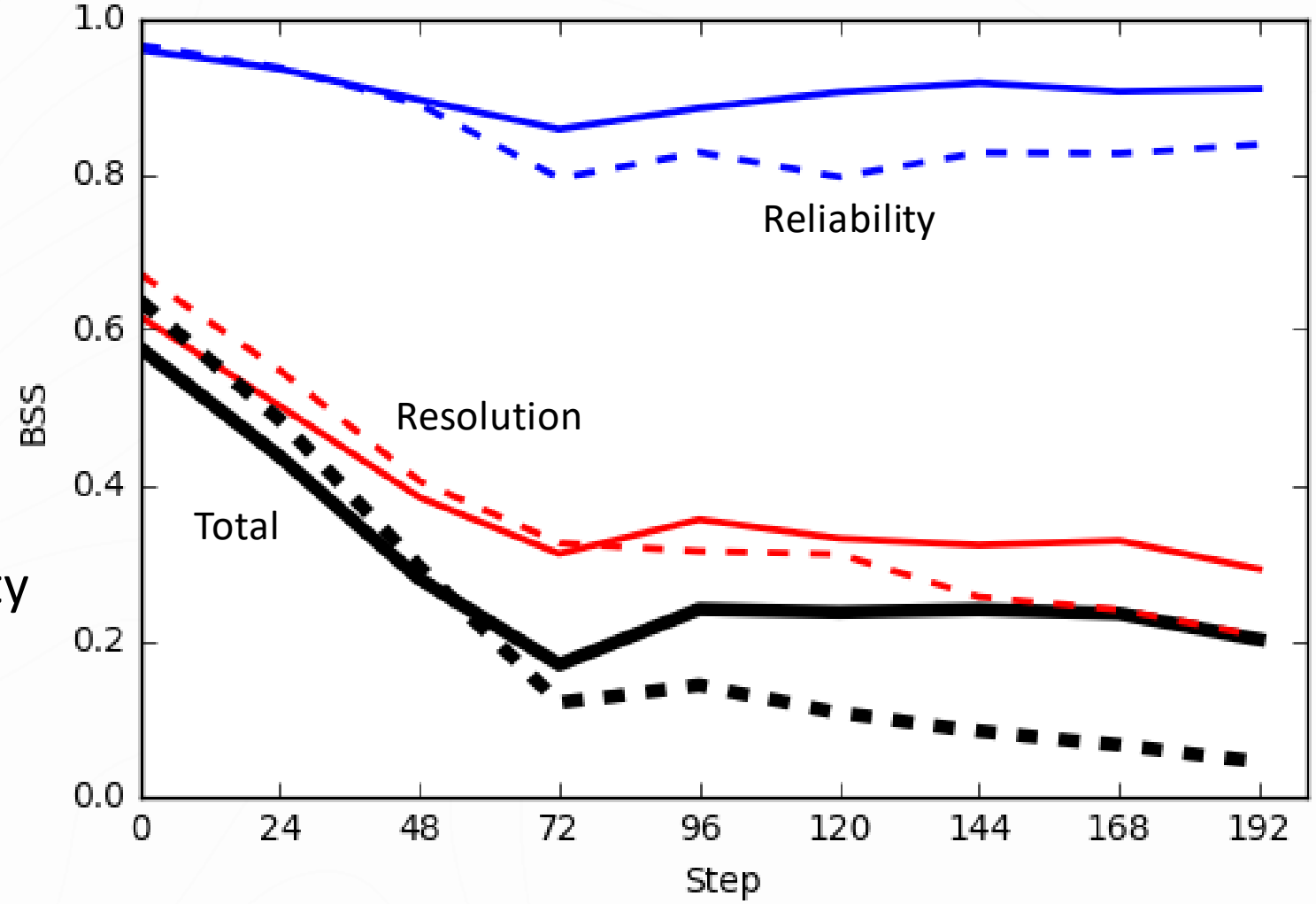
F = predicted probability for an event, O – outcome (0 or 1)

It measured the mean squared probability error

BS = Reliability – Resolution + Uncertainty (Murphy 1973)

BSS= 1 – BS/BS_{CLIM}

<980hPa All (solid), north of 20N (dashed)



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Verification of extremes :

Single probabilistic forecasts for life-threating events cannot be verified!

- The true probability distribution function is not known – only the single outcome
- Life-threating events usually rare – return periods often >20 years – too small sample to do a probabilistic verification
- Life-threating events are usually a composite of sub-events and unique in horizontal and temporal scale.

What can we do:

- Statistical verification of less extreme events
- Evaluate model climate of extremes
- Learn about important aspects from case studies

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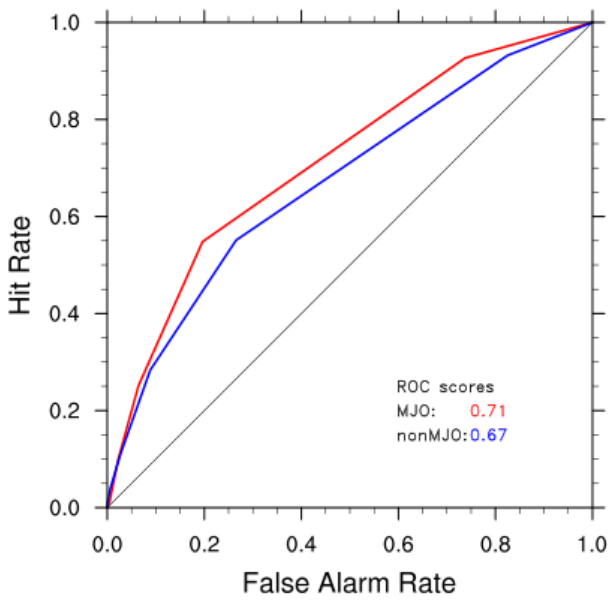
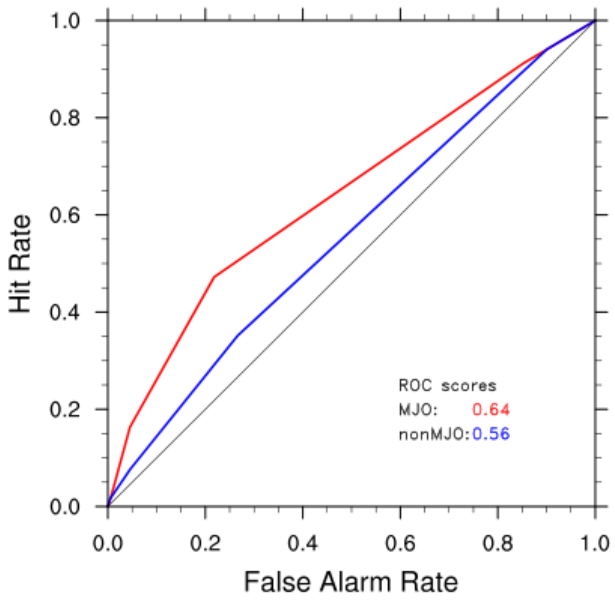
Skill for severe cold events

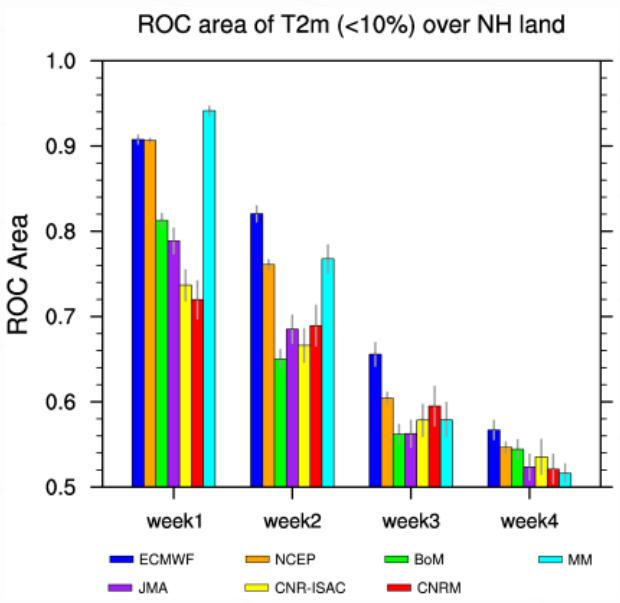
2m temperature weekly averages (below the 10% of the model climate)

Week 3



Week 4





Regional average ROC for EC over Europe during the period NDJFMA of 2008-2017.
The red forecasts with an MJO in the IC, blue forecasts with no MJO

From Xiaoyun Liang et al. report 2019

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Conditional skill

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Verification results vary with region, season, climate drivers (MJO, ENSO …..)

Pooling samples can mask variations in forecast performance this is particularly important for subseasonal and seasonal predictions

Stratify data into sub-samples (forecast with MJO active etc..) help to quantify the effect of climate drivers on the skill.

BUT must have enough samples to give robust statistics!

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Probabilistic skill scores – NDJFMA 1989-2008

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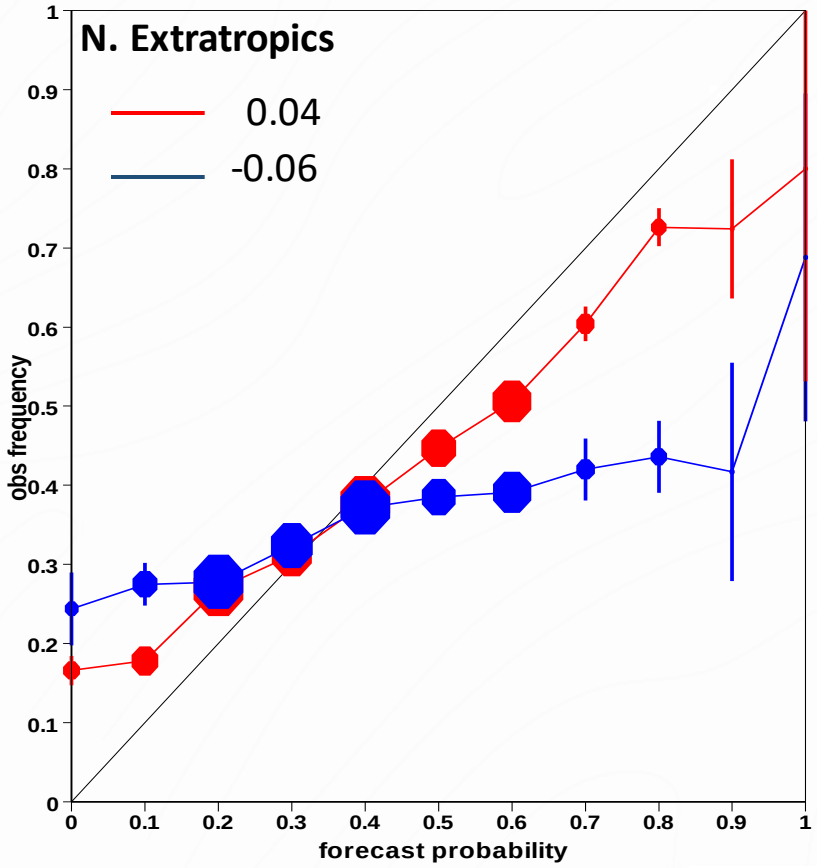
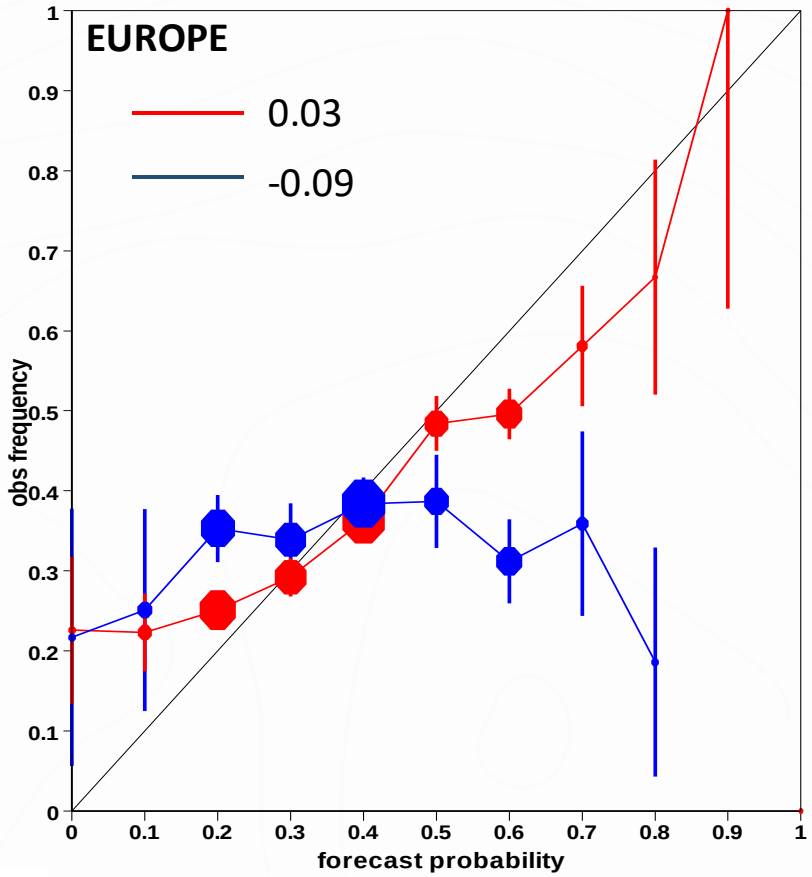
Reliability Diagram
Probability of 2-m temperature in the upper tercile
Day 19-25





MJO in IC

NO MJO in IC

MJO impact on probabilistic scores:

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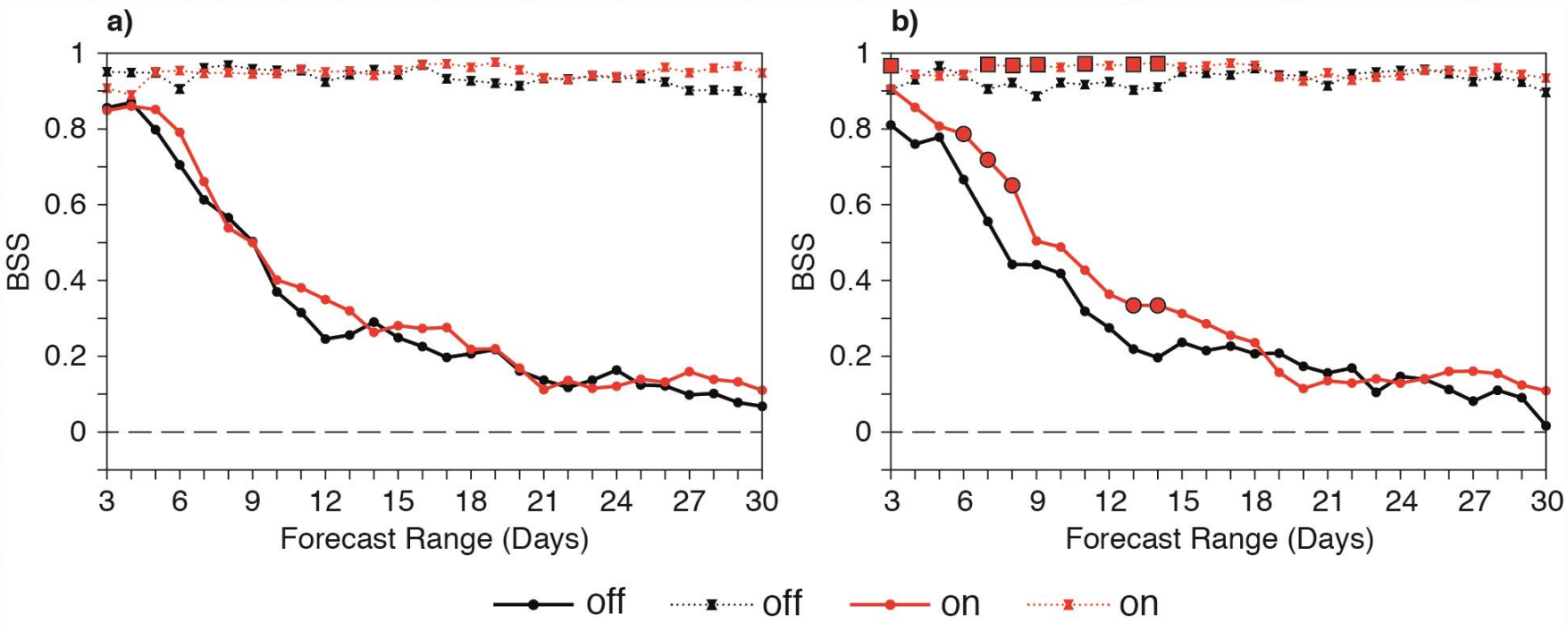
NAO+

NAO-



Small impact for NAO+ predictions
Significantly higher skill for NAO- forecasts with and MJO in the i.c.

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Key considerations:

Are the forecasts significantly better than a reference forecast? Does ensemble A perform significantly better than ensemble B?

- Take into account sampling variability
- Significance levels and/or confidence intervals
- Non-parametric resampling methods (Monte Carlo, bootstrap)

Effects of observation errors

- Adds uncertainty to verification results
- True forecast skill unknown
- Extra dispersion of observed PDF

- Active area of research

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Communicating probabilistic verification can be challenging:

Jolliffe and Beth Ebert

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References :

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Murphy, A. and R. L. Winkler, 1987: A general framework for forecast verification. Mon. Wea. Rev., 115, 1330-1338.

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http://www.cawcr.gov.au/projects/verification/

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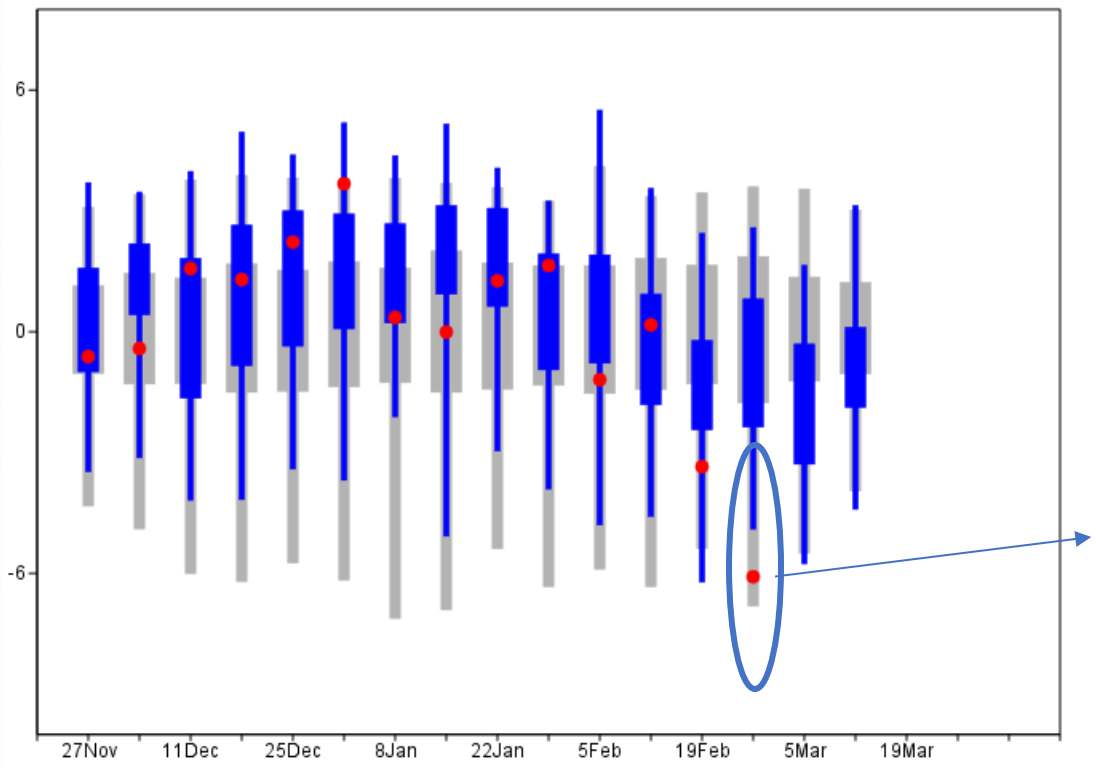
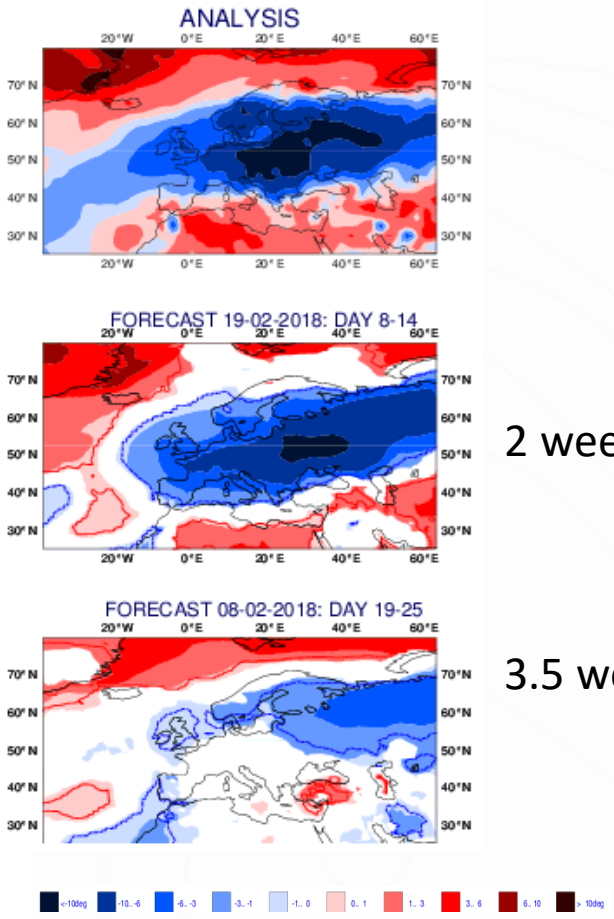
Severe cold spell end of February 2018:

2mt over Europe weekly means anomalies at 19-25 days (3.5weeks)



26/2-4/3 2018



2 weeks

3.5 weeks

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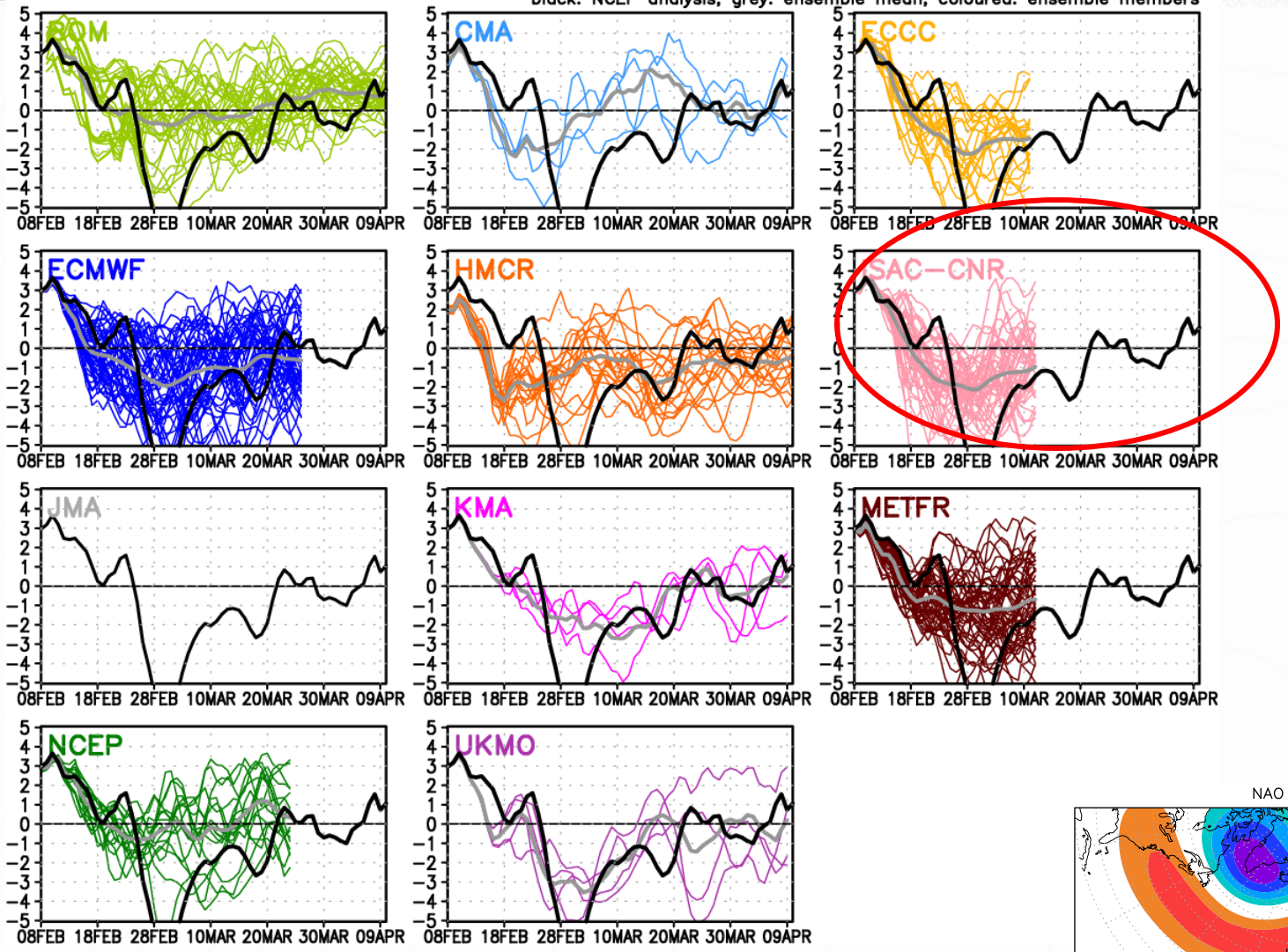
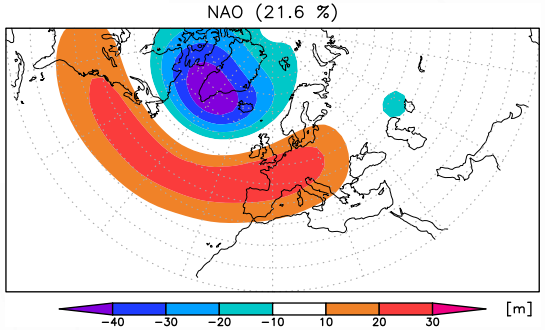
S2S NAO index forecasts (initial: 2018.02.08, Thu)

black: NCEP analysis, grey: ensemble mean, coloured: ensemble members





http://gpvjma.ccs.hpcc.jp/S2S/

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Questions:

- What is a chaotic system?
- What is ensemble weather/climate predictions?
- Is uncertainty in a forecast due to a lack of knowledge?
- What are the advantages of ensemble predictions?

Example of variability diagnostics: Blocking index

Tribaldi and Molteni (1990)

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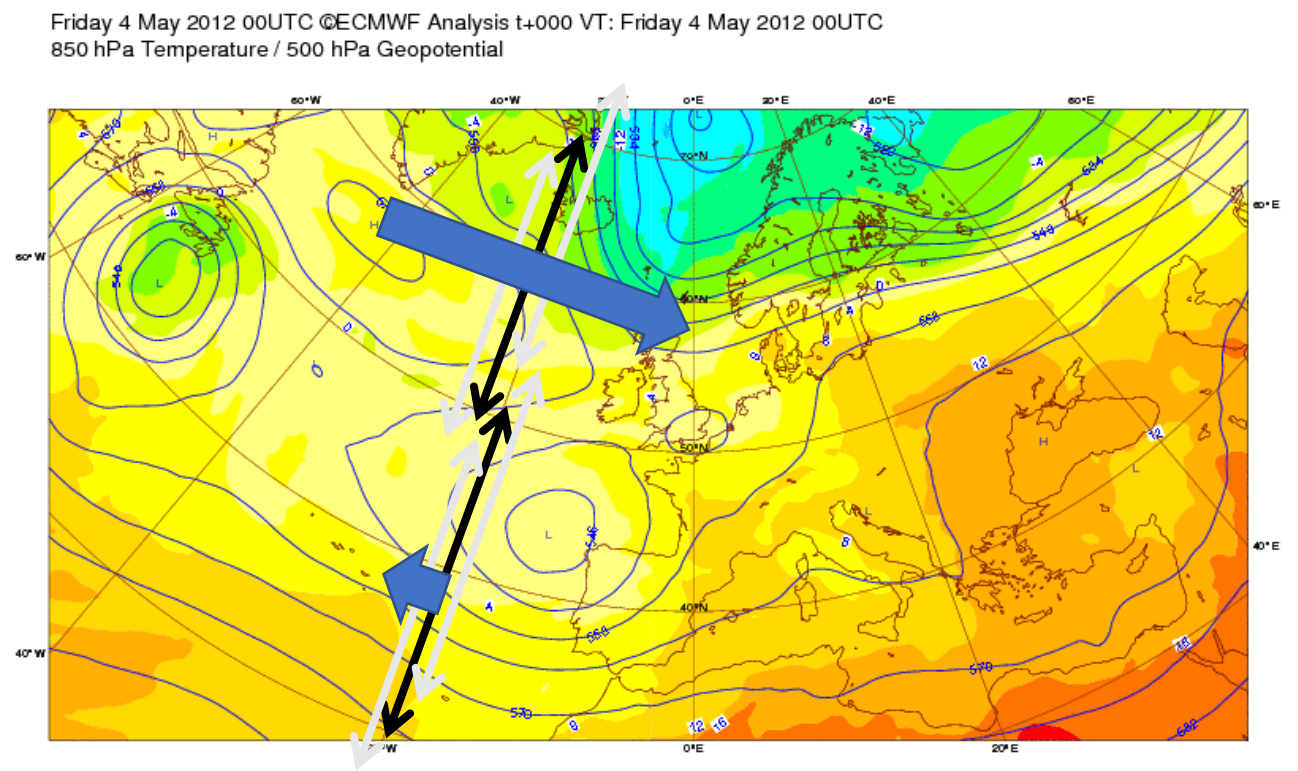

dz/dlat< -5 (North)

dz/dlat > 0 (South)

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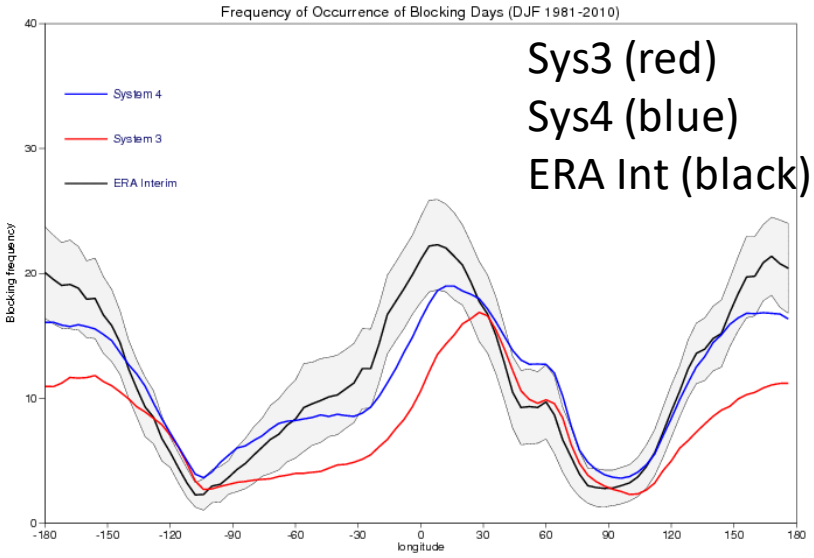
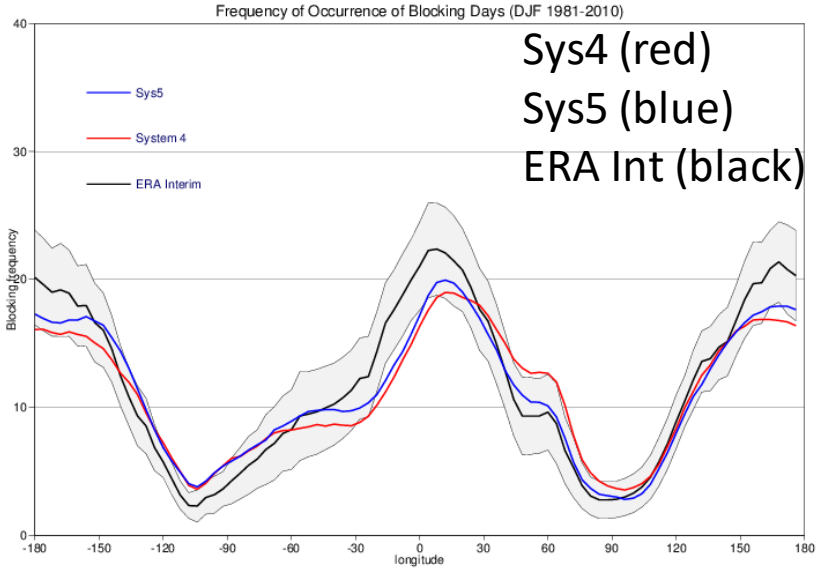
Blocking cont.

Episodes lasting >1 day





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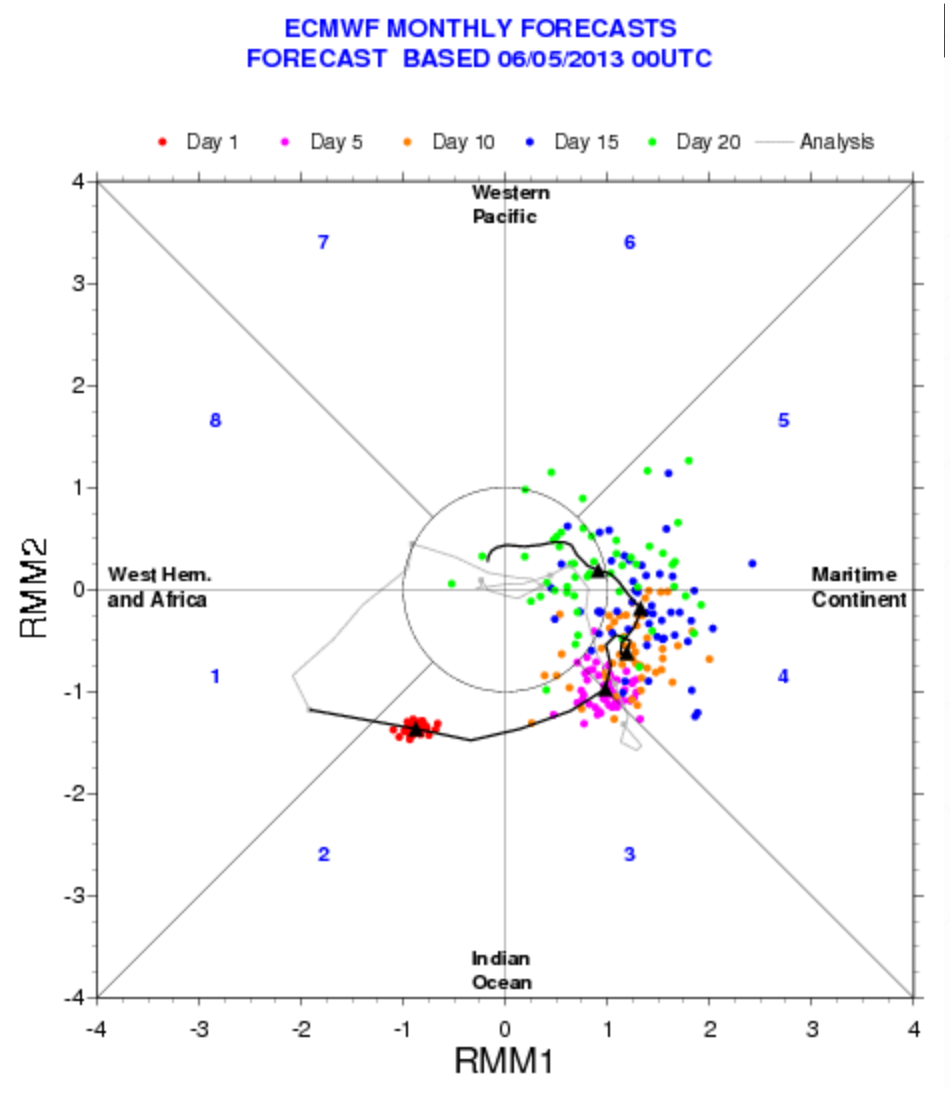
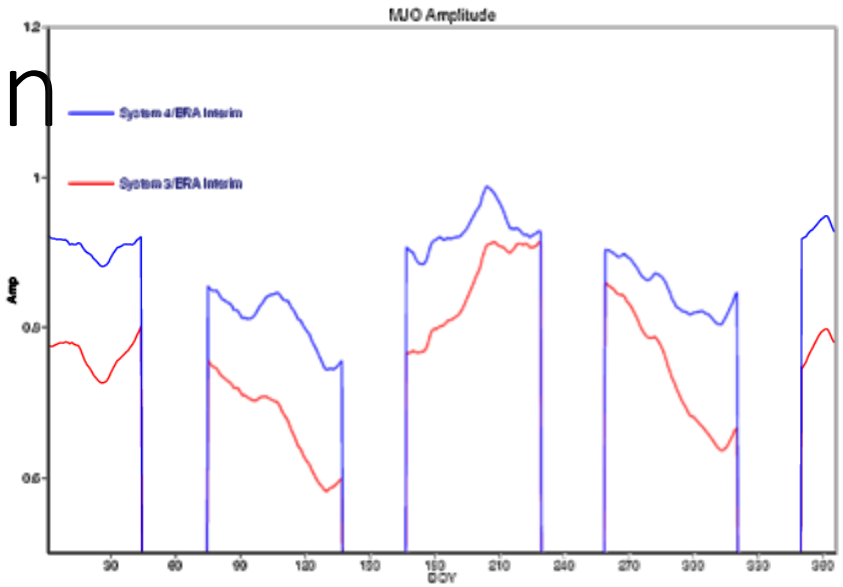
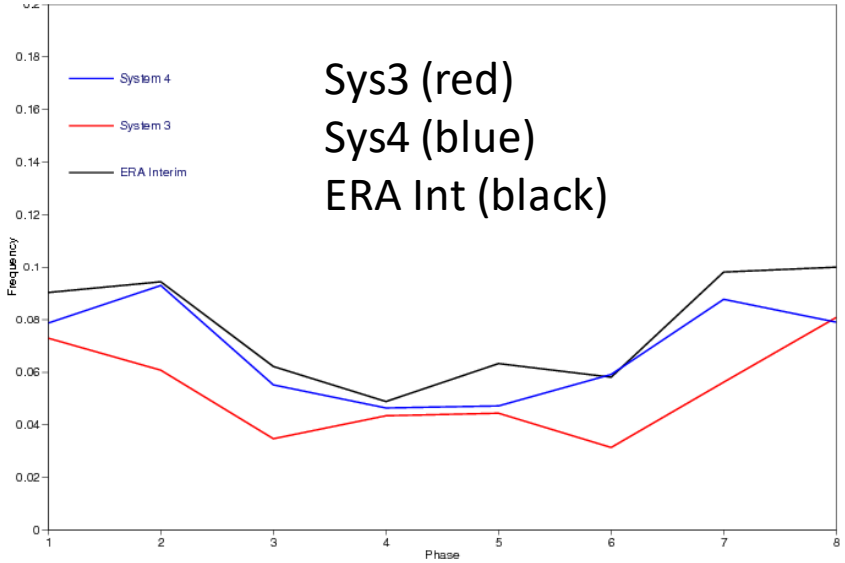
Ma ion

Statistics for Seasonal reforecasts







Sys3 (red)
Sys4 (blue)
ERA Int (black)

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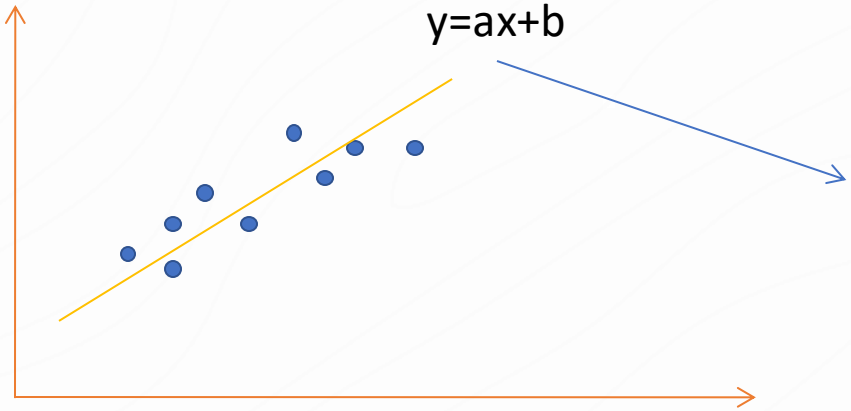
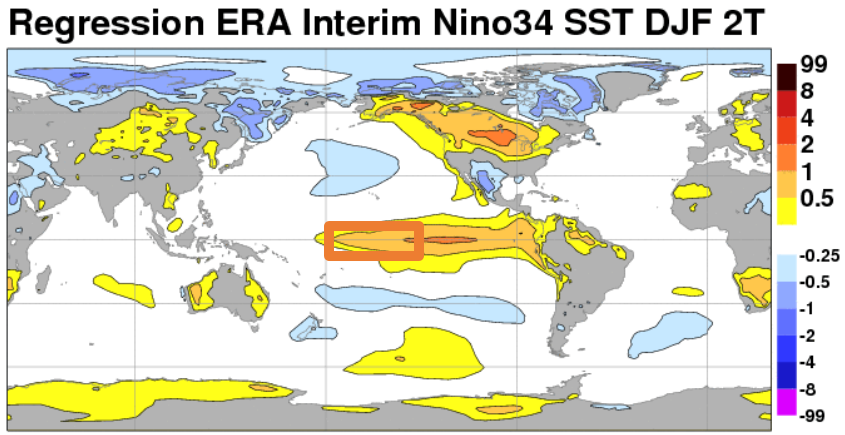
Teleconnections – linear regression

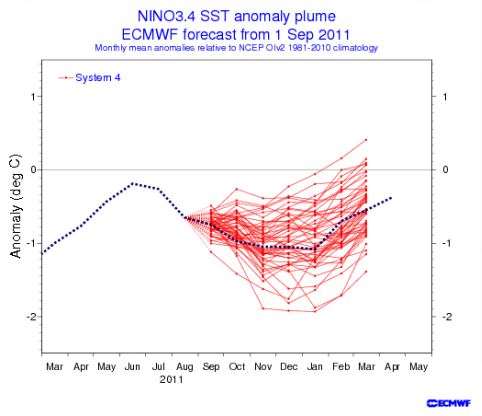
T2m in a grid point



Nino3.4 SST
(190E-240E,10N-10S)



(logarithmic scale)



Example for seasonal for Nino3.4

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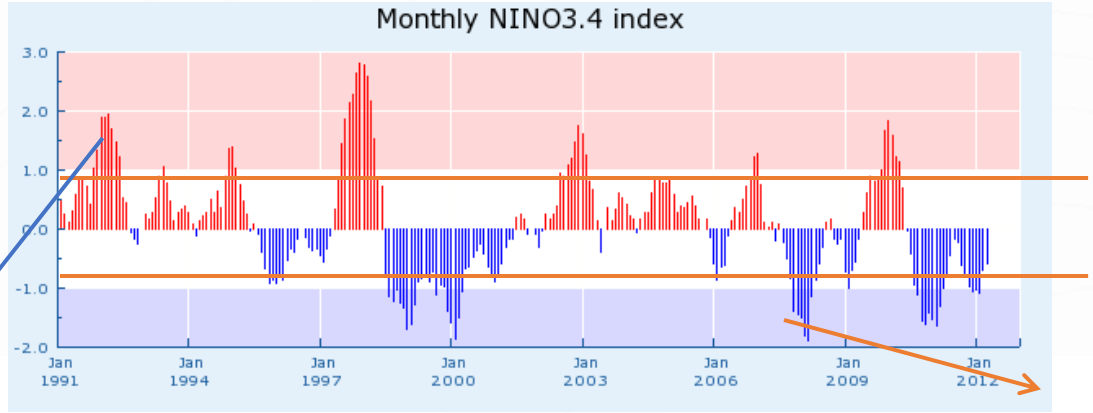
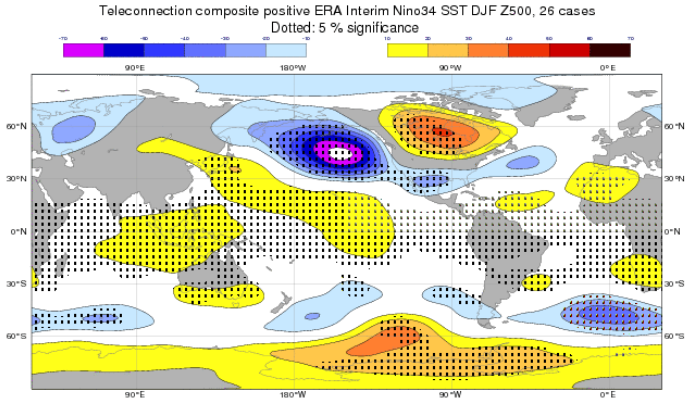
Teleconnections - composites

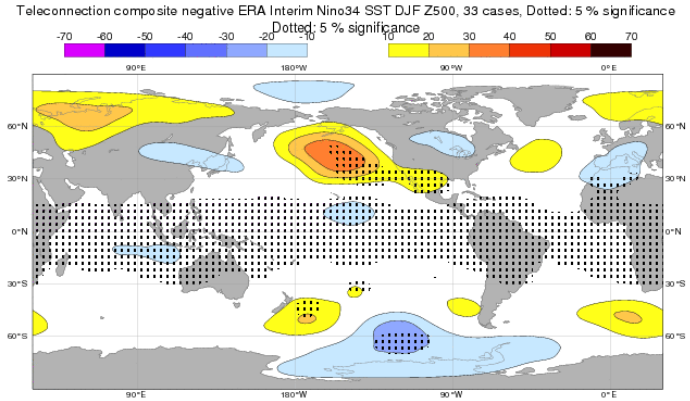


+/- 0.5 stdev

Positive composite

Negative composite





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Group exercise

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- List the type of verification data sets your are using
- List the problems you have experienced
- How did you overcome the problems?

m-R

What are driving the predictability on different scales?

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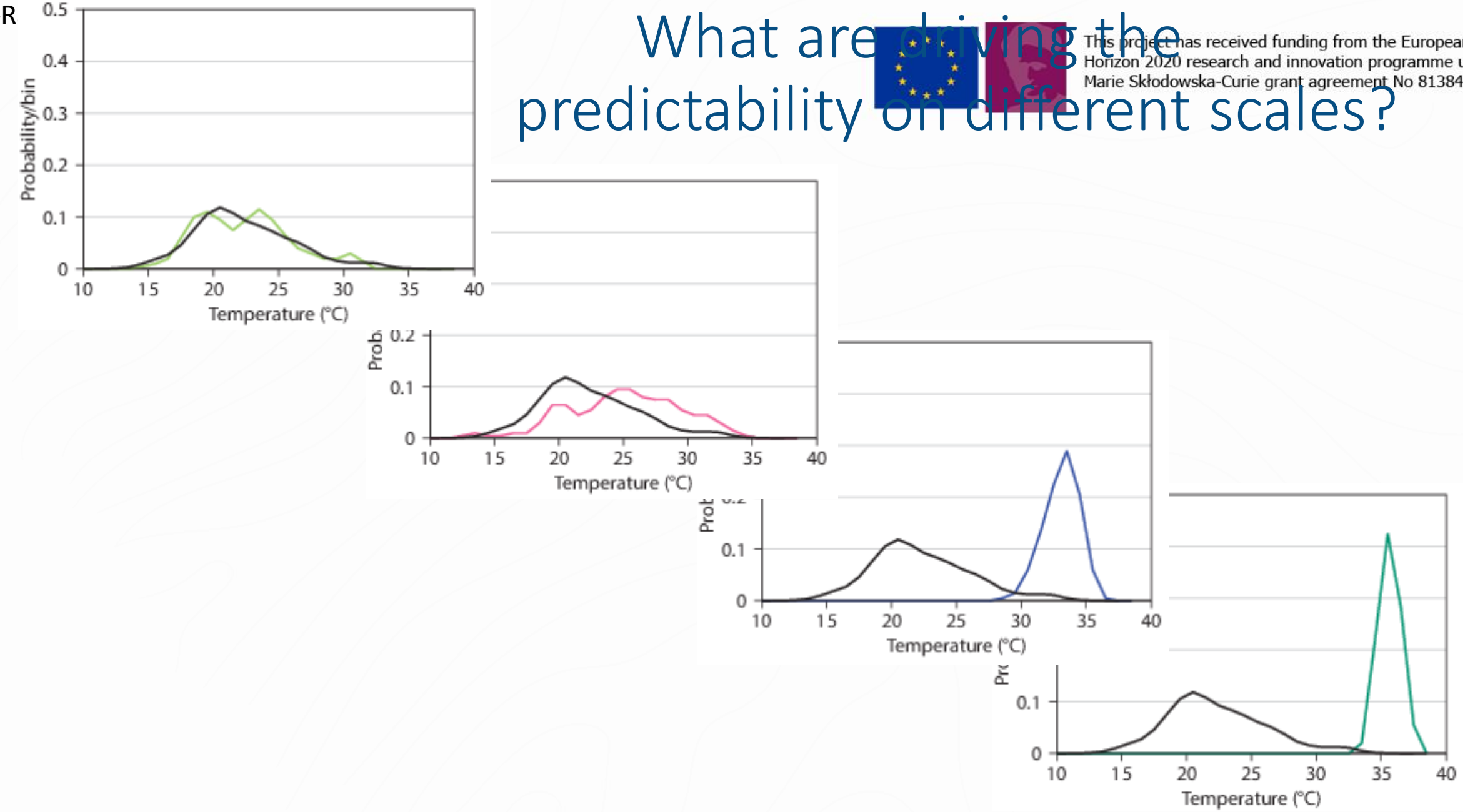

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Teleconnections to large-scale forcing patterns for extremes

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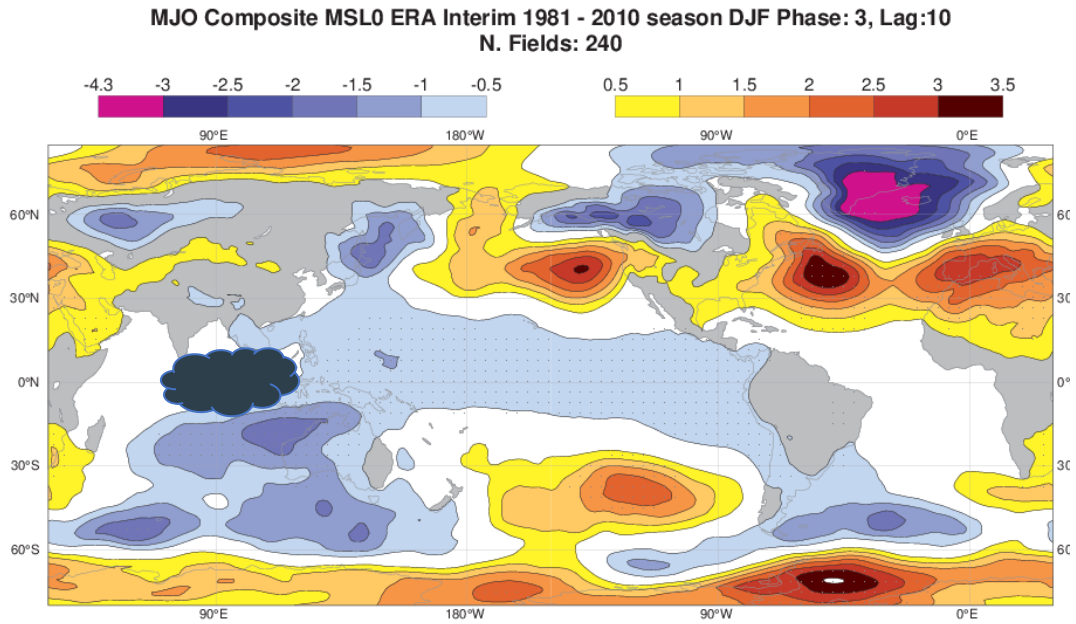
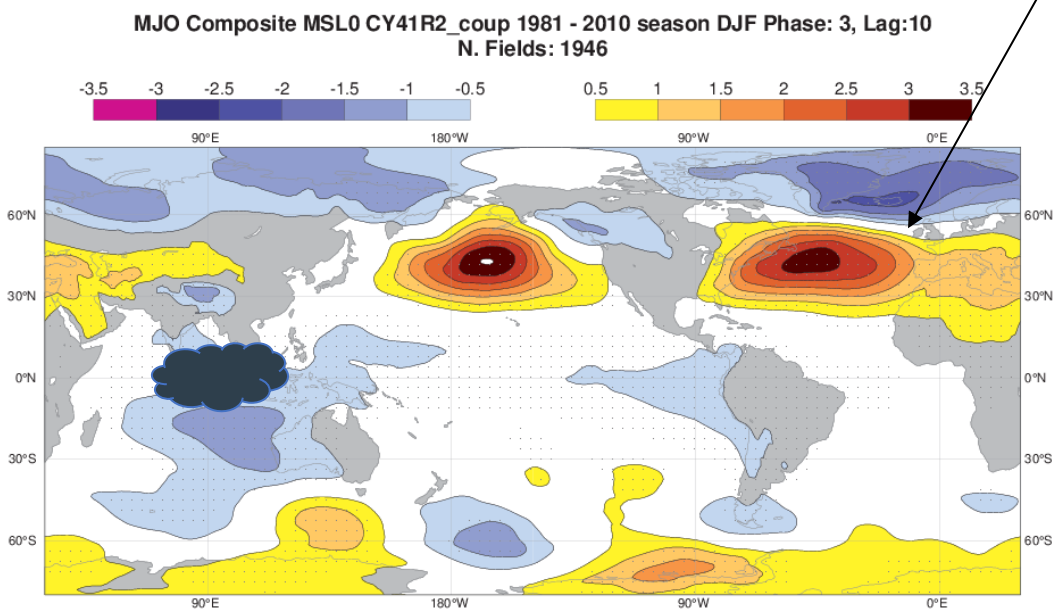
Composites of MSLP 10 days after MJO in phase 3

Reanalysis



Model

Windstorms more likely!



See e.g Cassou, 2008

Extended range: 19 November

m-Range Weather Forecasts

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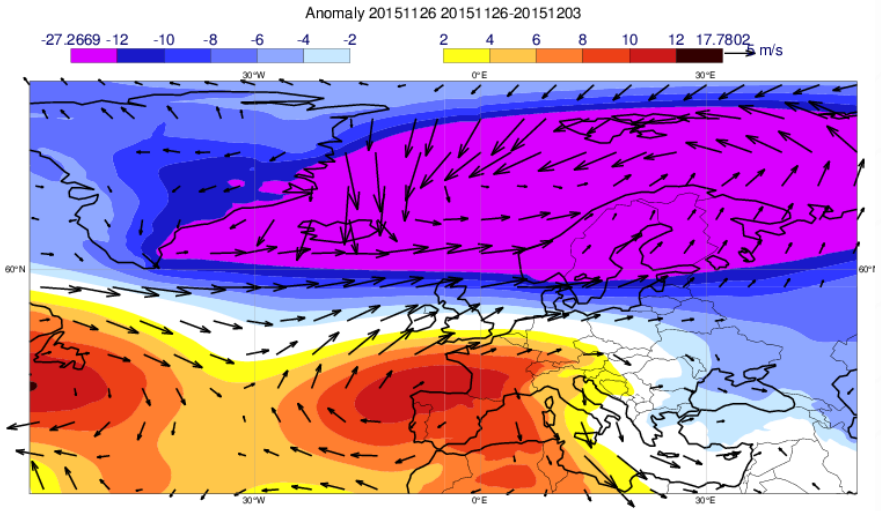
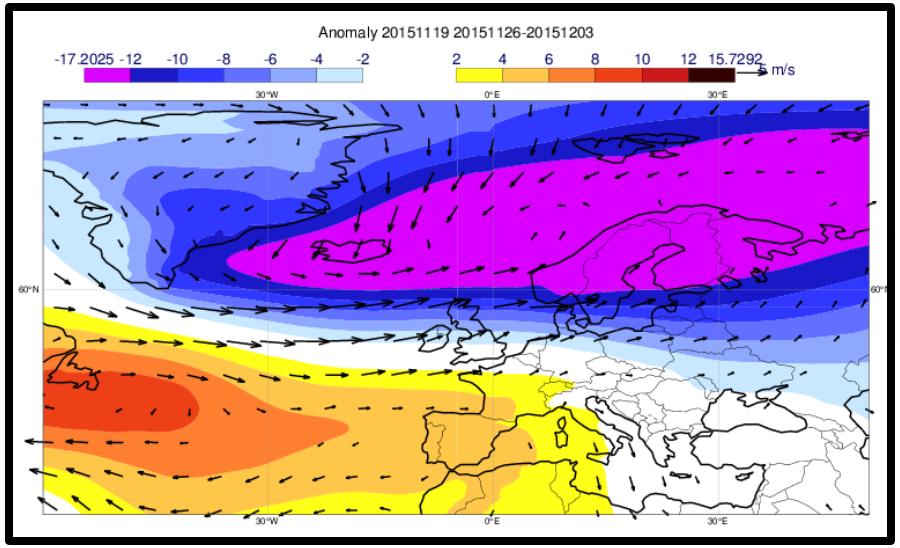
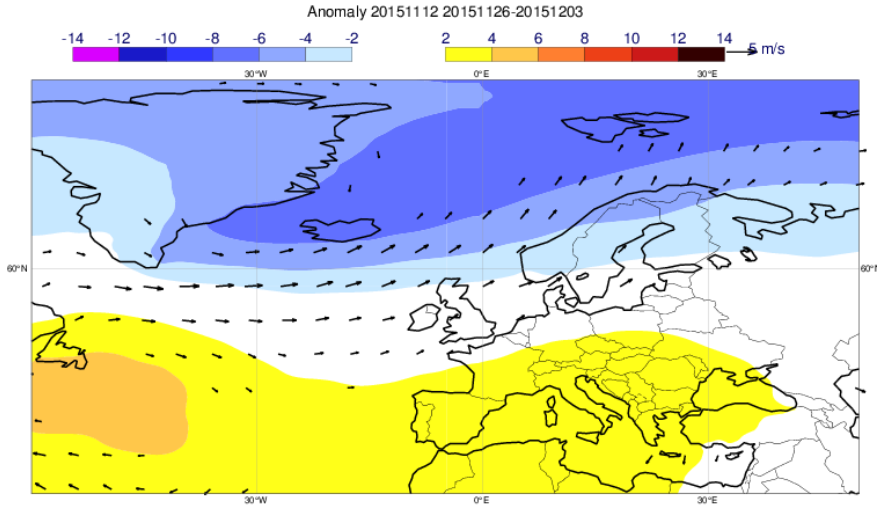
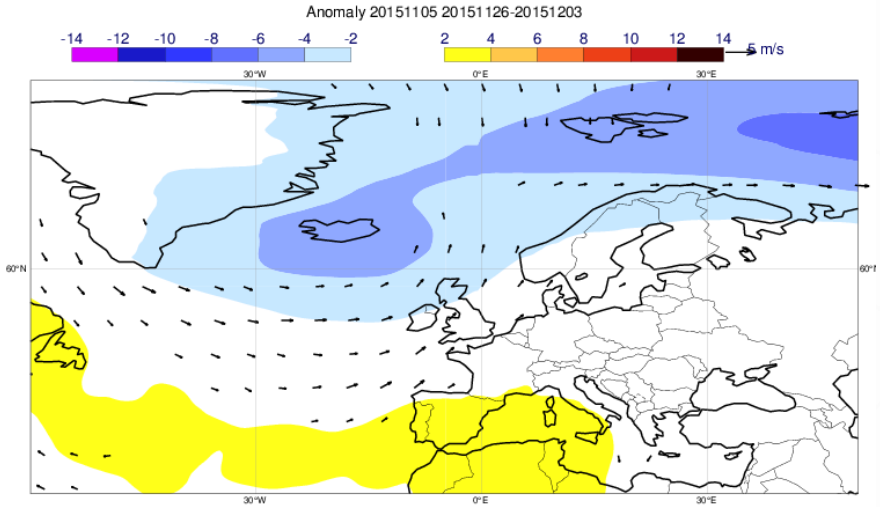
This proj
Horizon
Marie Sk

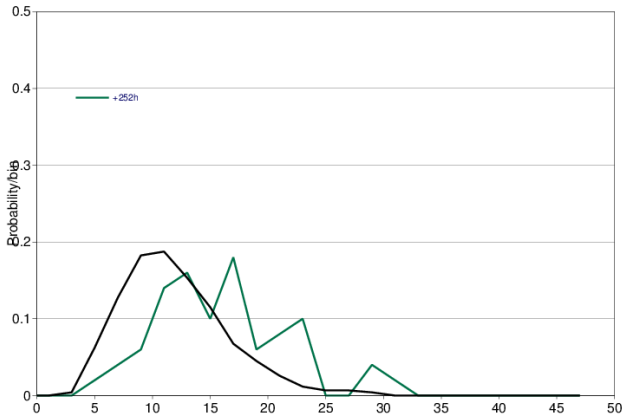
MSLP and wind anomaly 26 November – 3 December

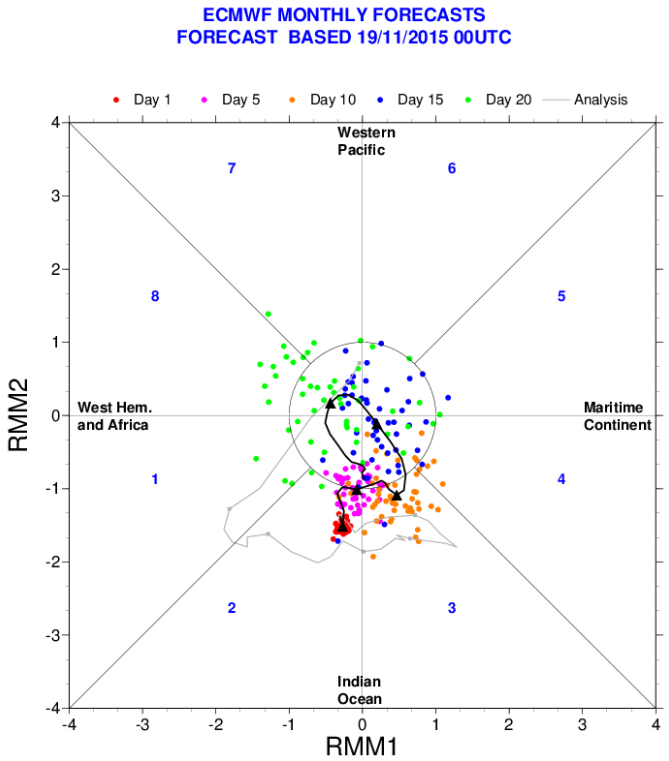












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Verification of monthly forecasts (sorry for bad map projection)

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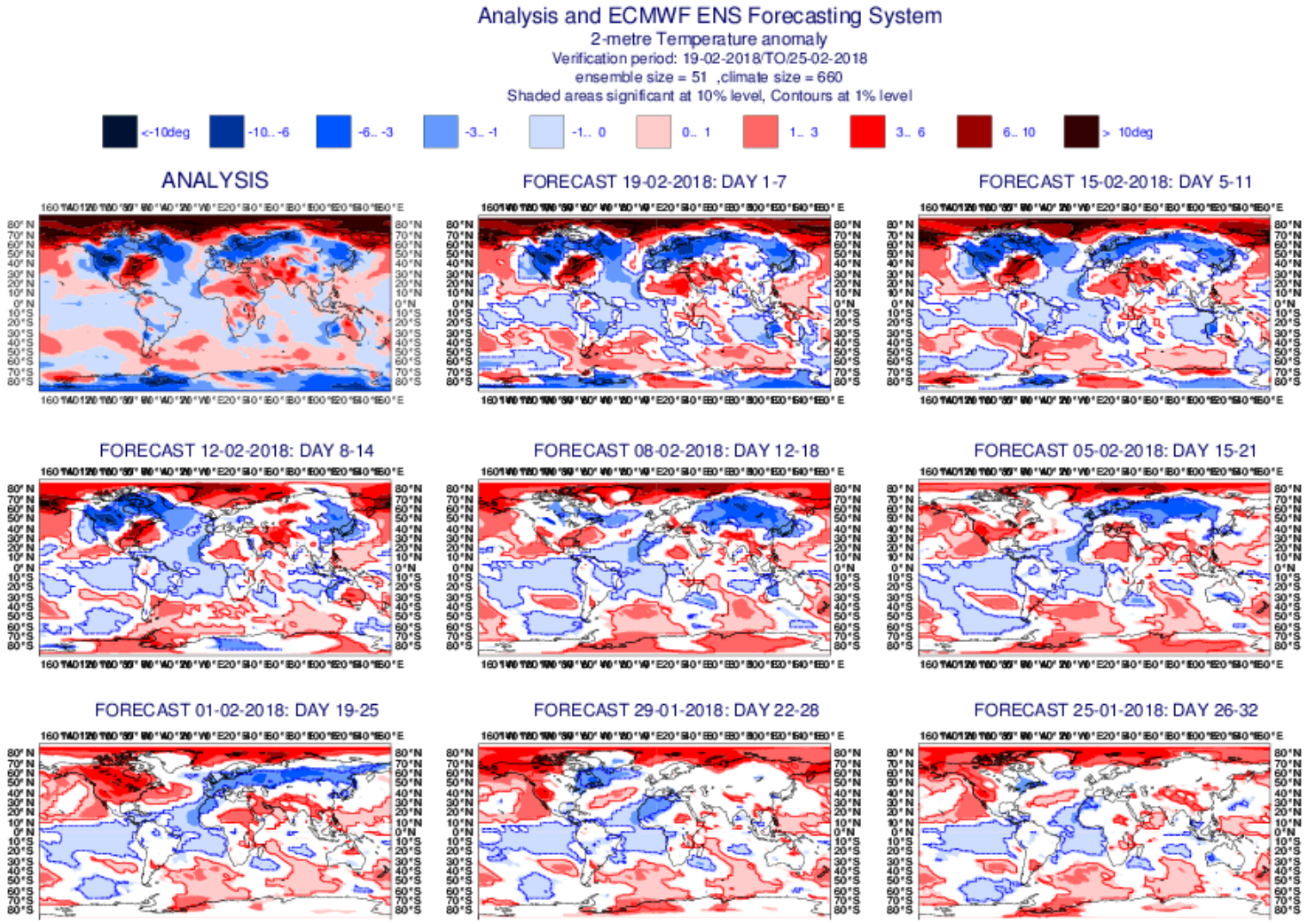

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2500 anomaly verification from monthly forecasts

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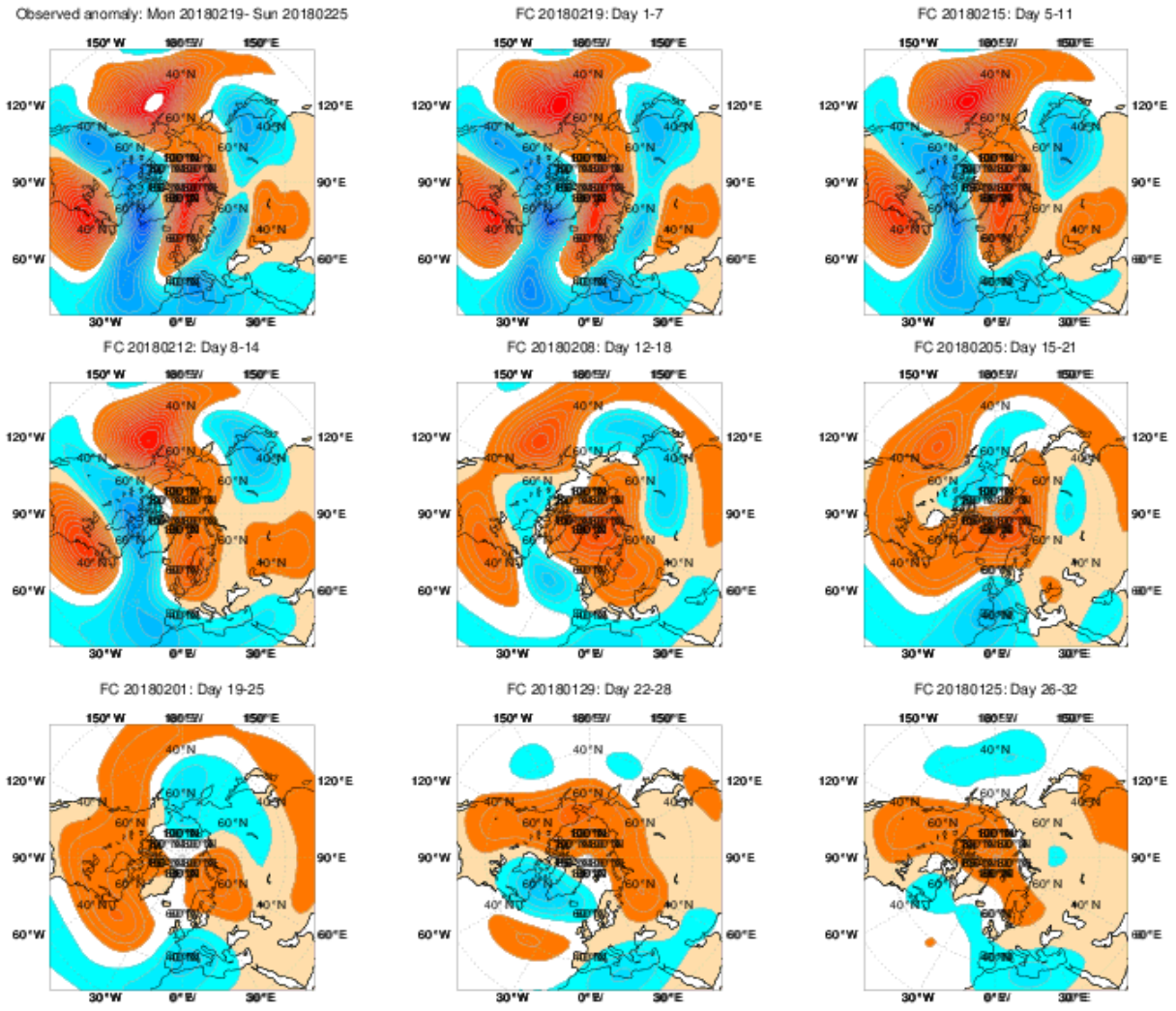

Euro-Atlantic regimes

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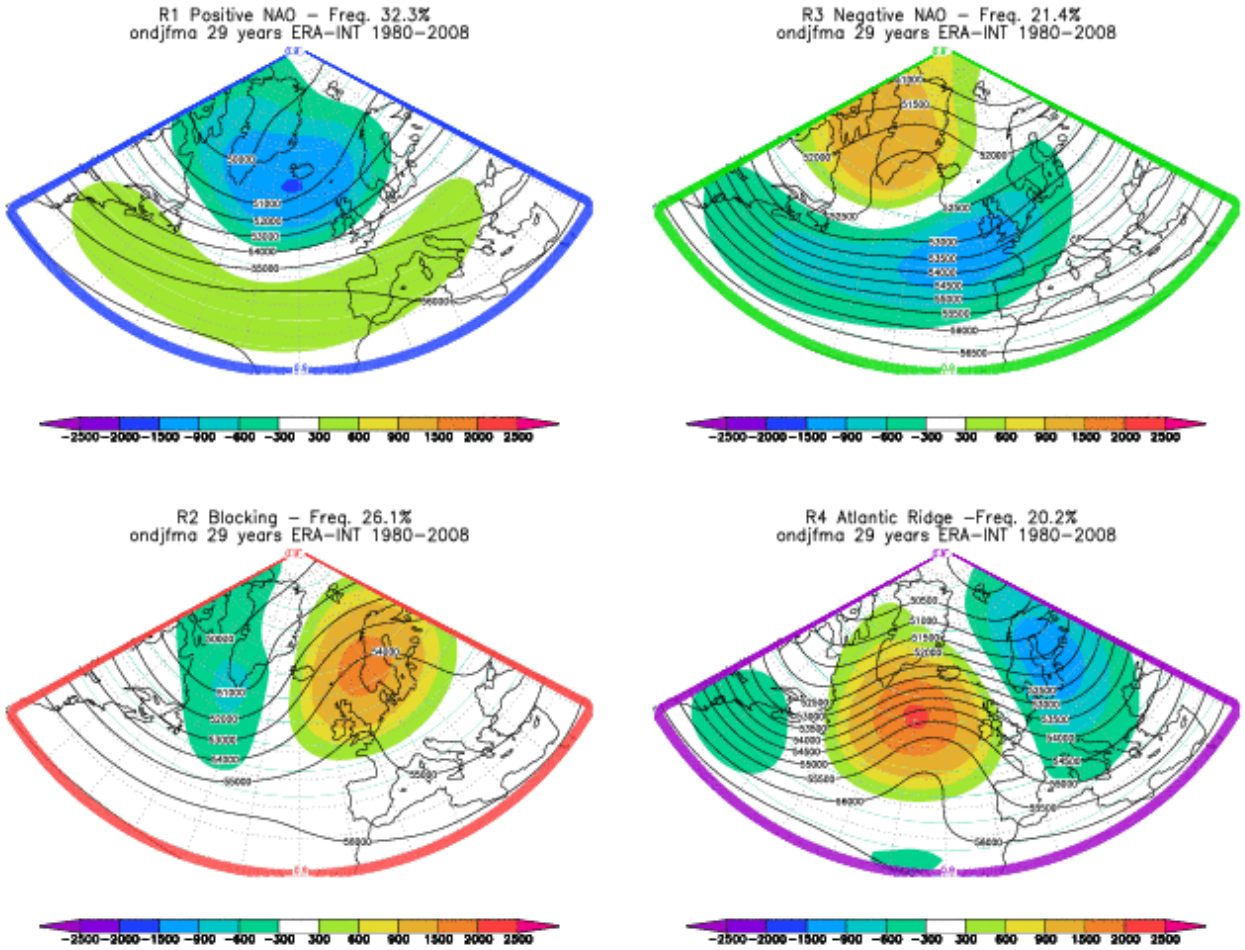

Regime verification for real time forecasts (51 members)

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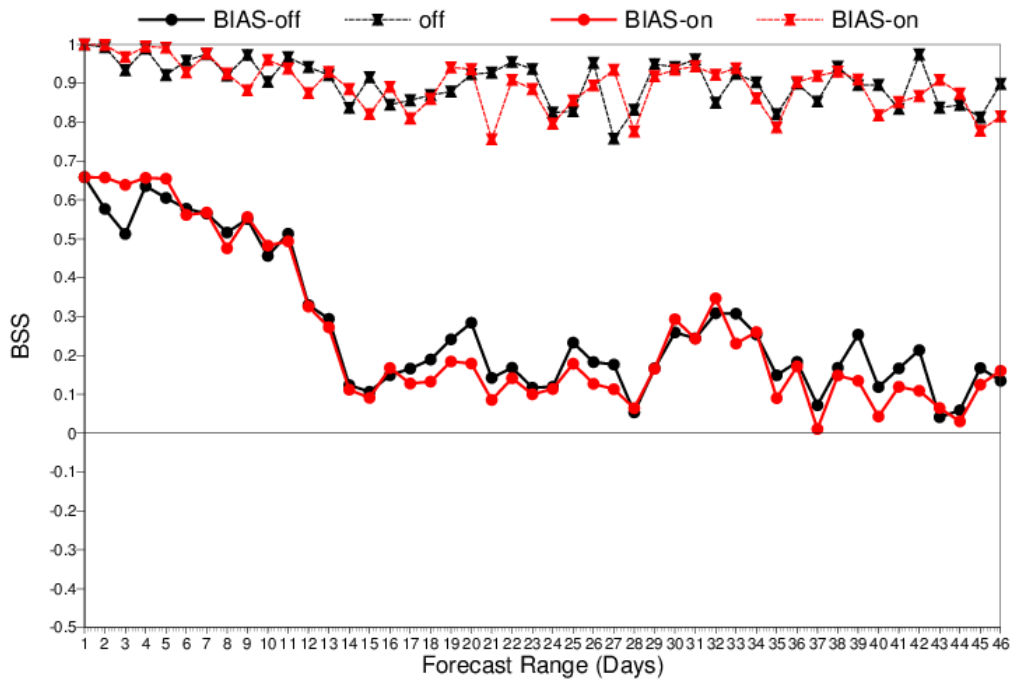
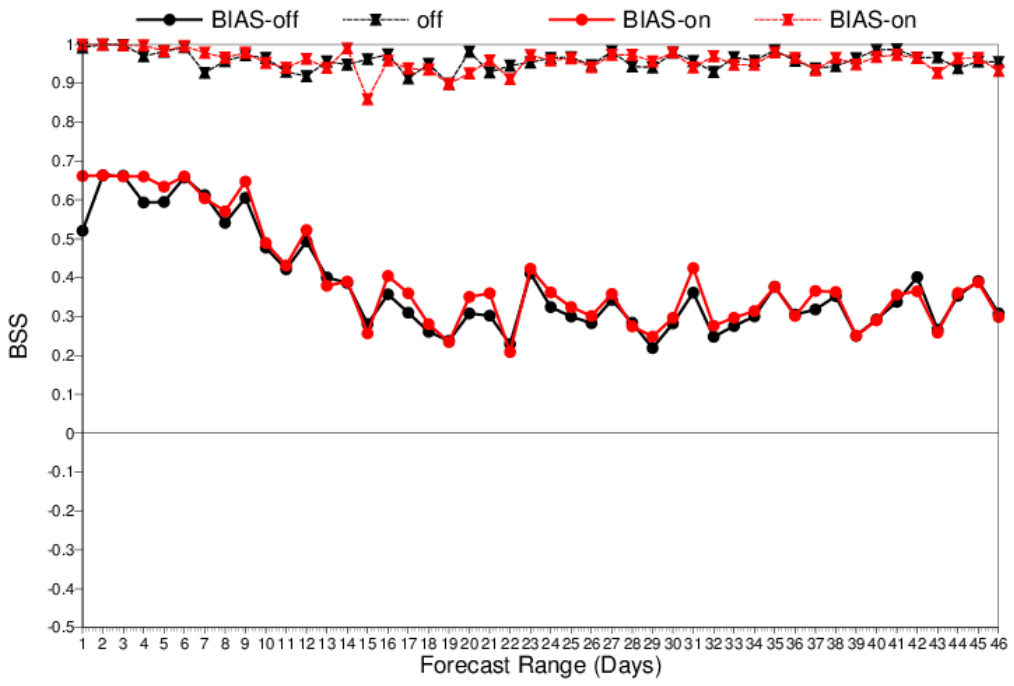
Sensitivity to the mean bias is relatively small even at the extended range

● Brier Skill scores ✖ Reliability Skill scores

BLOCKING



Atlantic Ridge



ECMWF

Regime verification for real time forecasts (51 members)

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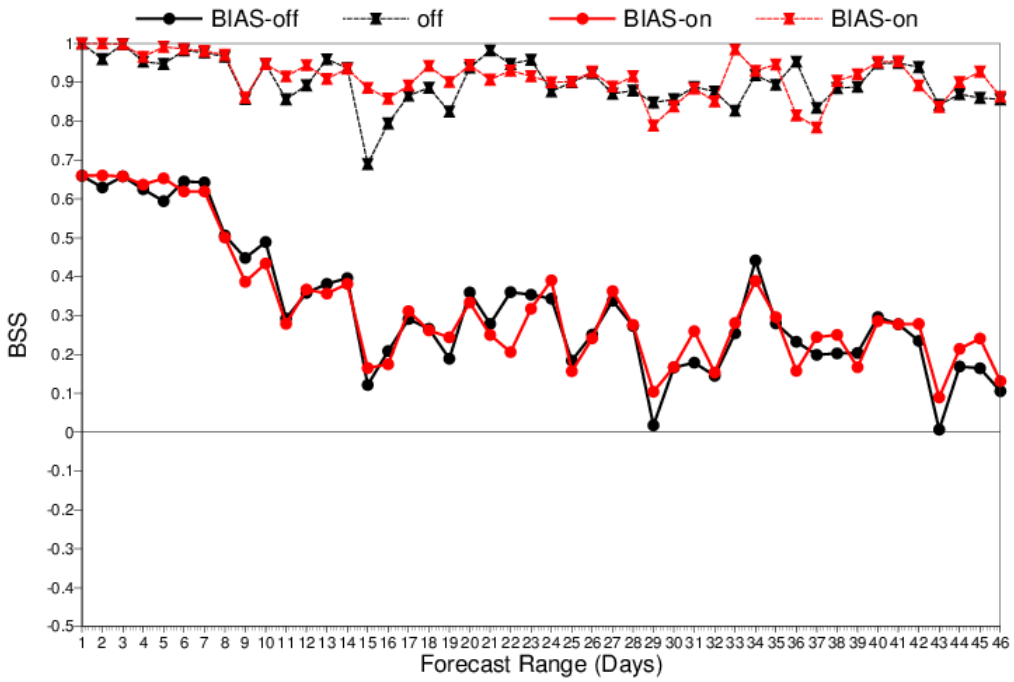
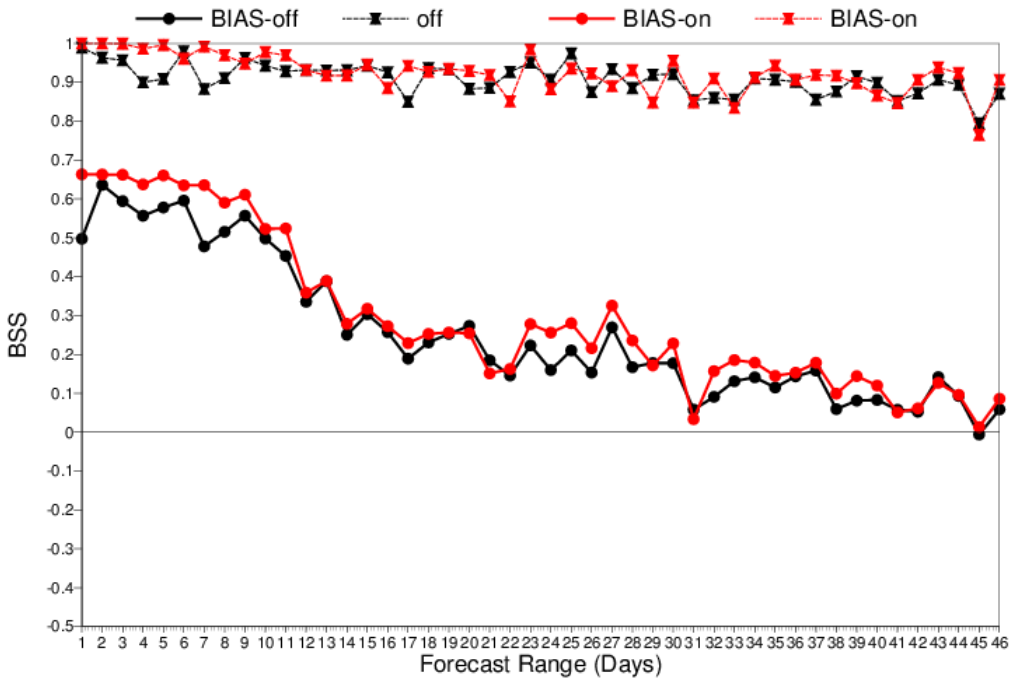
Sensitivity to the mean bias is relatively small even at the extended range

● Brier Skill scores ✖ Reliability Skill scores

NAO +



NAO-



ECMWF