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Predictability: Seasonal to decadal climate prediction over the Mediterranean area

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Seasonal Prediction for the Mediterranean area

F. J. Doblas-Reyes, IC3

Contents

- Long-range forecasting
- Long-range forecasting with one coupled GCM
- Operational seasonal forecast system: ECMWF System 3
- Systematic errors
- Multi-model forecasting

Sources of seasonal predictability

- Important:
  - ENSO - biggest single signal
  - Other tropical ocean SST - difficult
  - Climate change - important in mid-latitudes
  - Local land surface conditions - soil moisture, snow
  - Atmospheric composition - difficult

- Other factors:
  - Volcanic eruptions - important for large events
  - Mid-latitude ocean temperatures - still somewhat controversial
  - Remote soil moisture/snow cover - not well established
  - Sea-ice anomalies - at least local effects
  - Stratospheric influences - various possibilities
  - Remote tropical atmospheric teleconnections

- Unknown or Unexpected

Methods of seasonal forecasting

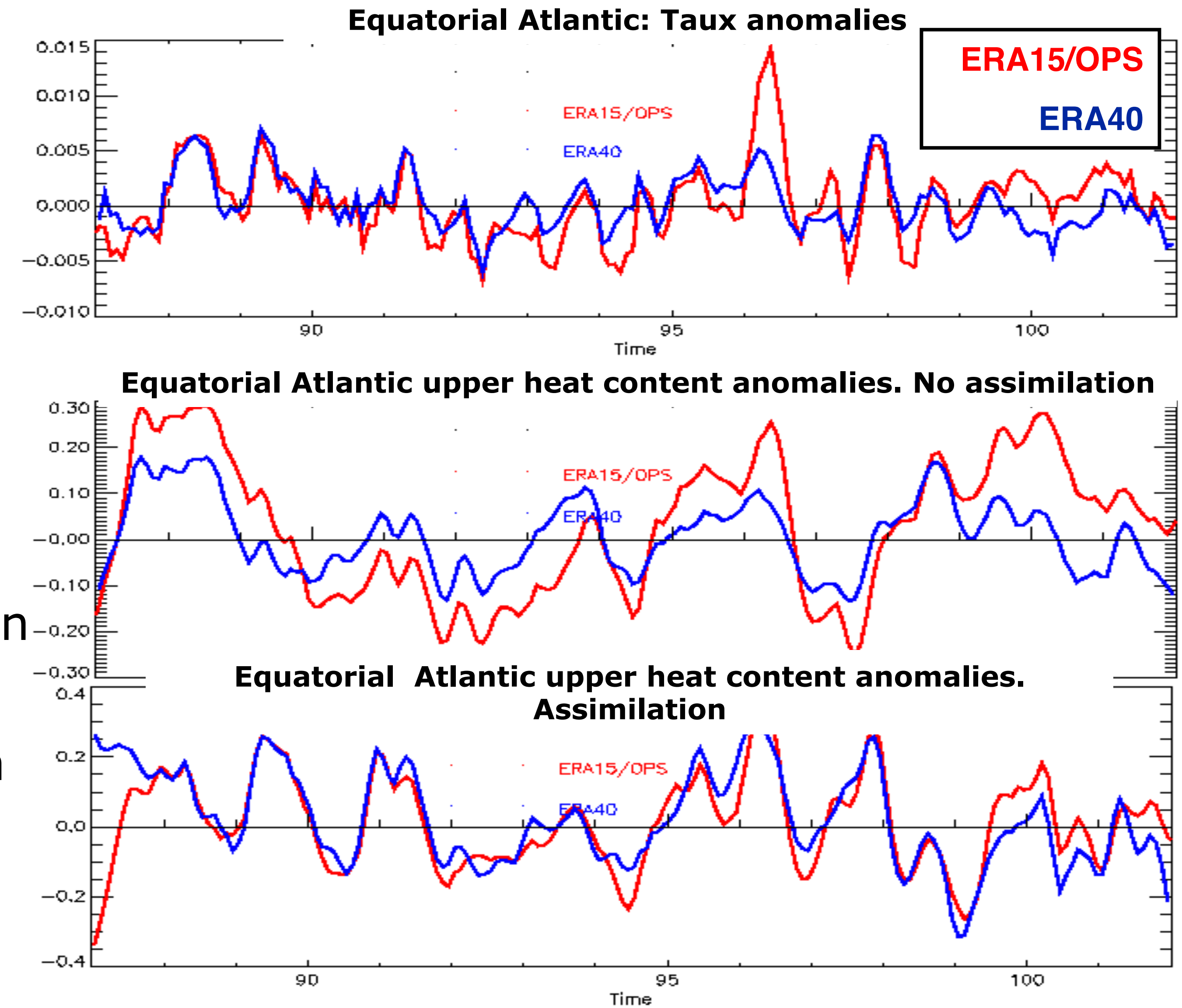
- Empirical forecasting
  - Use past observational record and statistical methods
  - Works with reality instead of error-prone numerical models
  - Limited number of past cases
  - A non-stationary climate is problematic
  - Can be used as a benchmark
- Two-tier forecast systems
  - First predict SST anomalies (ENSO or global; dynamical or statistical)
  - Use ensemble of atmosphere GCMs to predict global response
  - Systematic model error is an issue
- Single-tier GCM forecasts
  - Include comprehensive range of sources of predictability
  - Predict joint evolution of ocean and atmosphere flow
  - Includes a large range of physical processes
  - Includes uncertainty sources, important for prob. Forecasts
  - Systematic model error is an issue!

To produce dynamical forecasts

- Build a coupled model
- Prepare initial conditions
- Initialize coupled system
  - o The aim is to start the system close to reality. Accurate SST is particularly important, plus ocean sub-surface. Usually, worry about "imbalances" a posteriori.
- Run an ensemble forecast
  - o Explicitly generate an ensemble on the e.g. 1st of each month, with perturbations to represent the uncertainty *in the initial conditions*; run forecasts for several months.
- Produce probability forecasts from the ensemble
- Apply calibration and combination if significant improvement is found

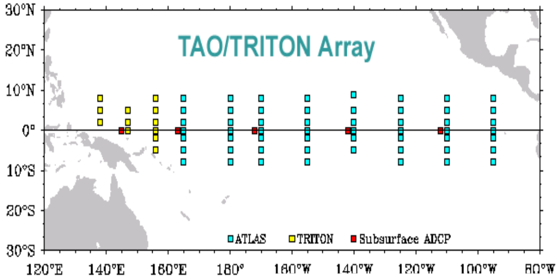
Need for ocean data assimilation

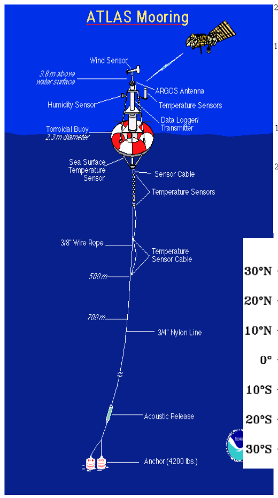
- Large uncertainty in wind products lead to large uncertainty in ocean subsurface.
- Possibility to use additional information from ocean data
- Assimilation of ocean data:
  - ➢ constrain the ocean state
  - ➢ improve the ocean estimate
  - ➢ improve the seasonal forecasts

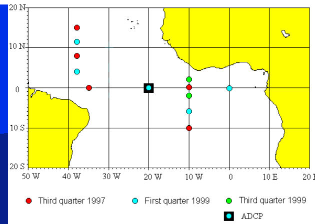


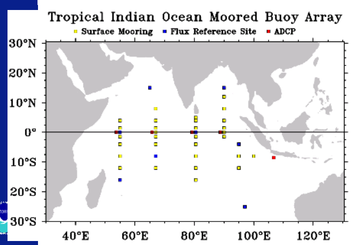
Real-time ocean observations

Moorings

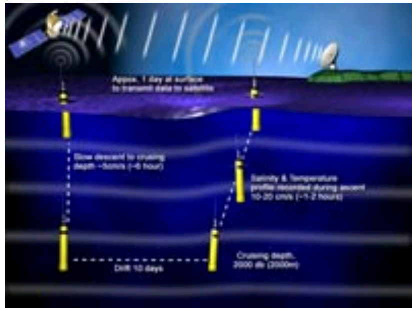


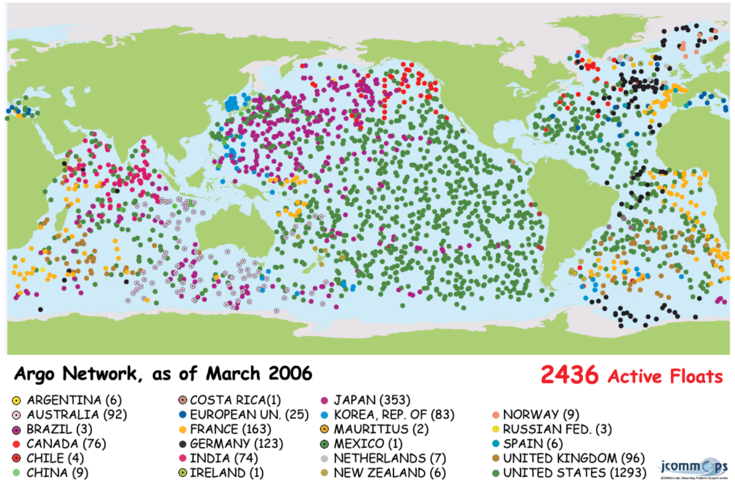






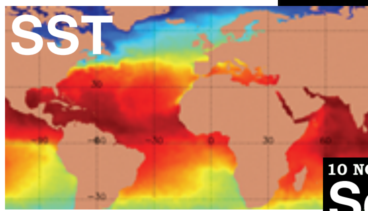
ARGO floats

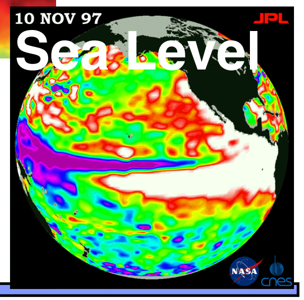




XBT (eXpendable BathiThermograph)

Satellite



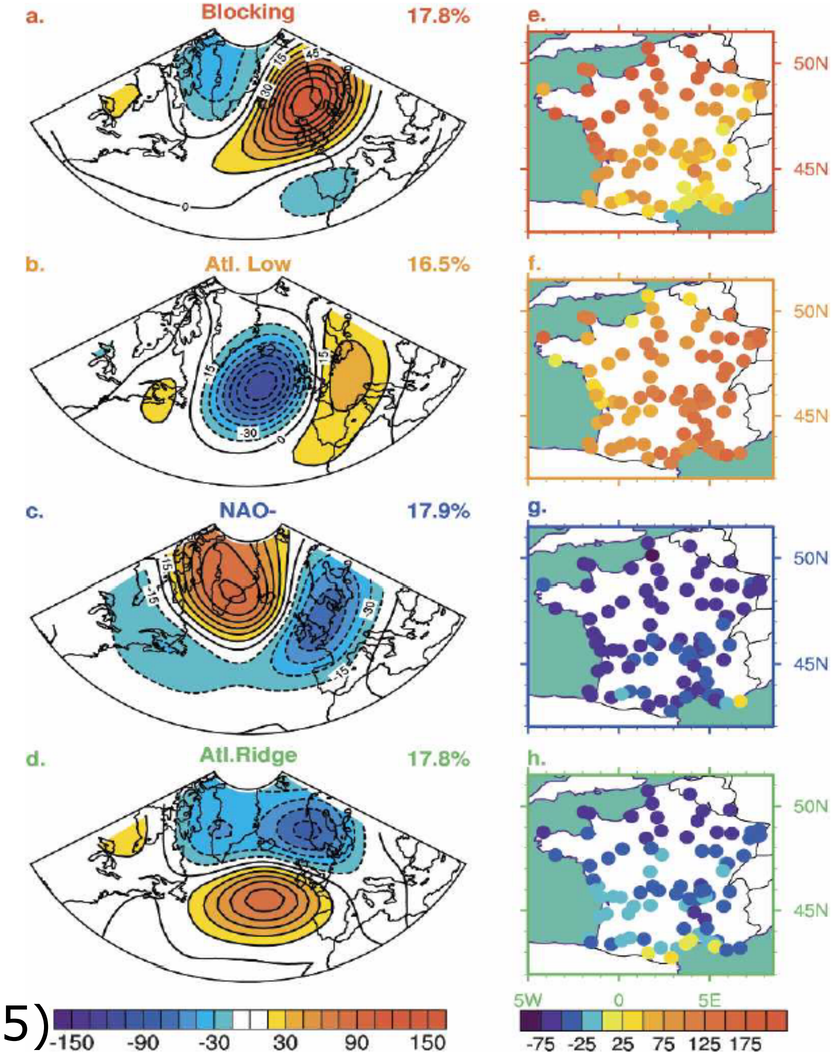


Start with dynamical forecasts

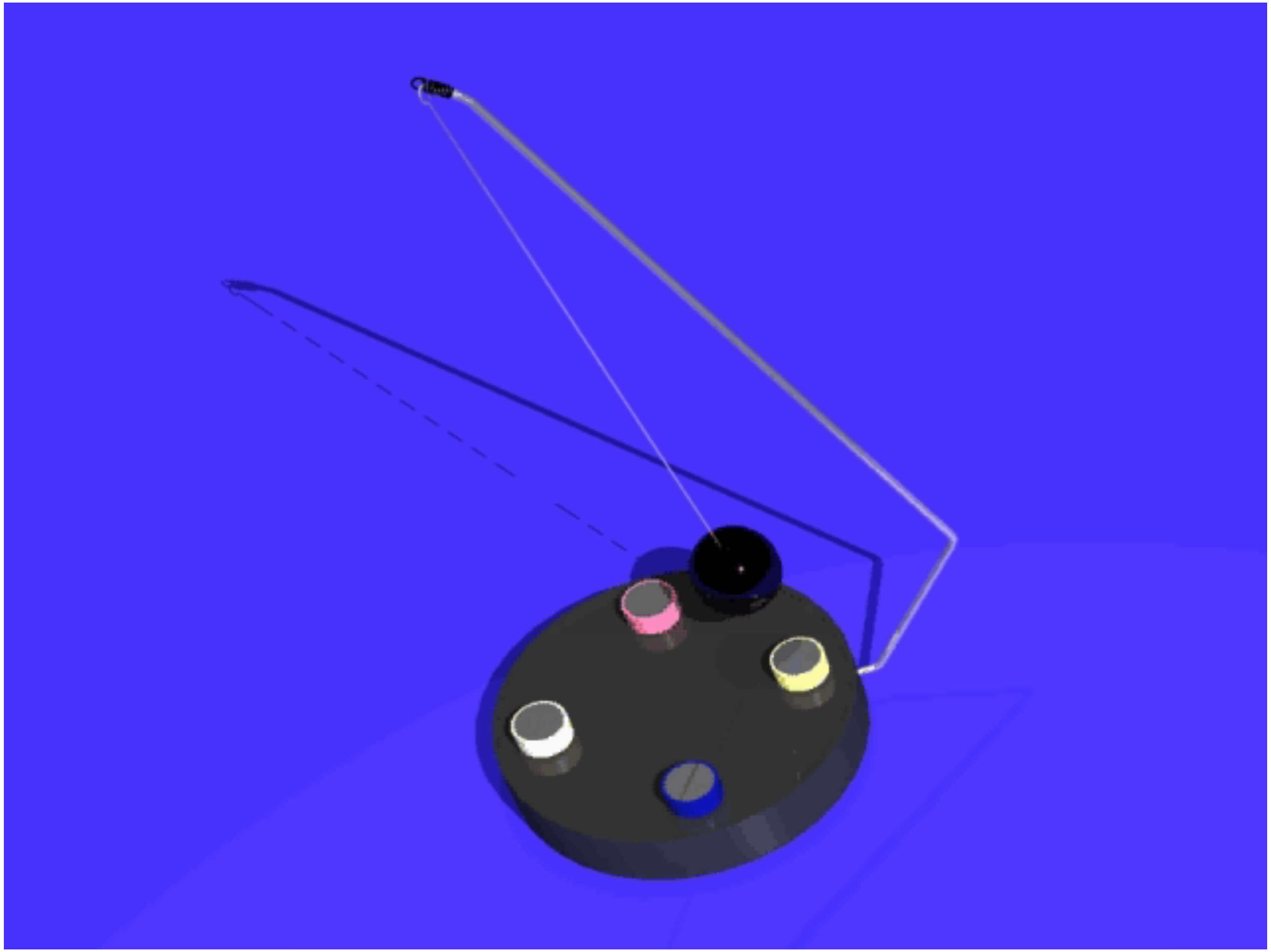
- Build a coupled model
- Prepare initial conditions
- Initialize coupled system
  - The aim is to start system close to reality. Accurate SST is particularly important, plus ocean sub-surface. Don't worry too much about "imbalances".
- Run an ensemble forecast
  - Explicitly generate an ensemble on the e.g. 1st of each month, with perturbations to represent the uncertainty *in the initial conditions*; run forecasts for 7 months (seasonal) or 10 years (decadal).
- Worry about model error later and produce probabilities from the ensemble ….

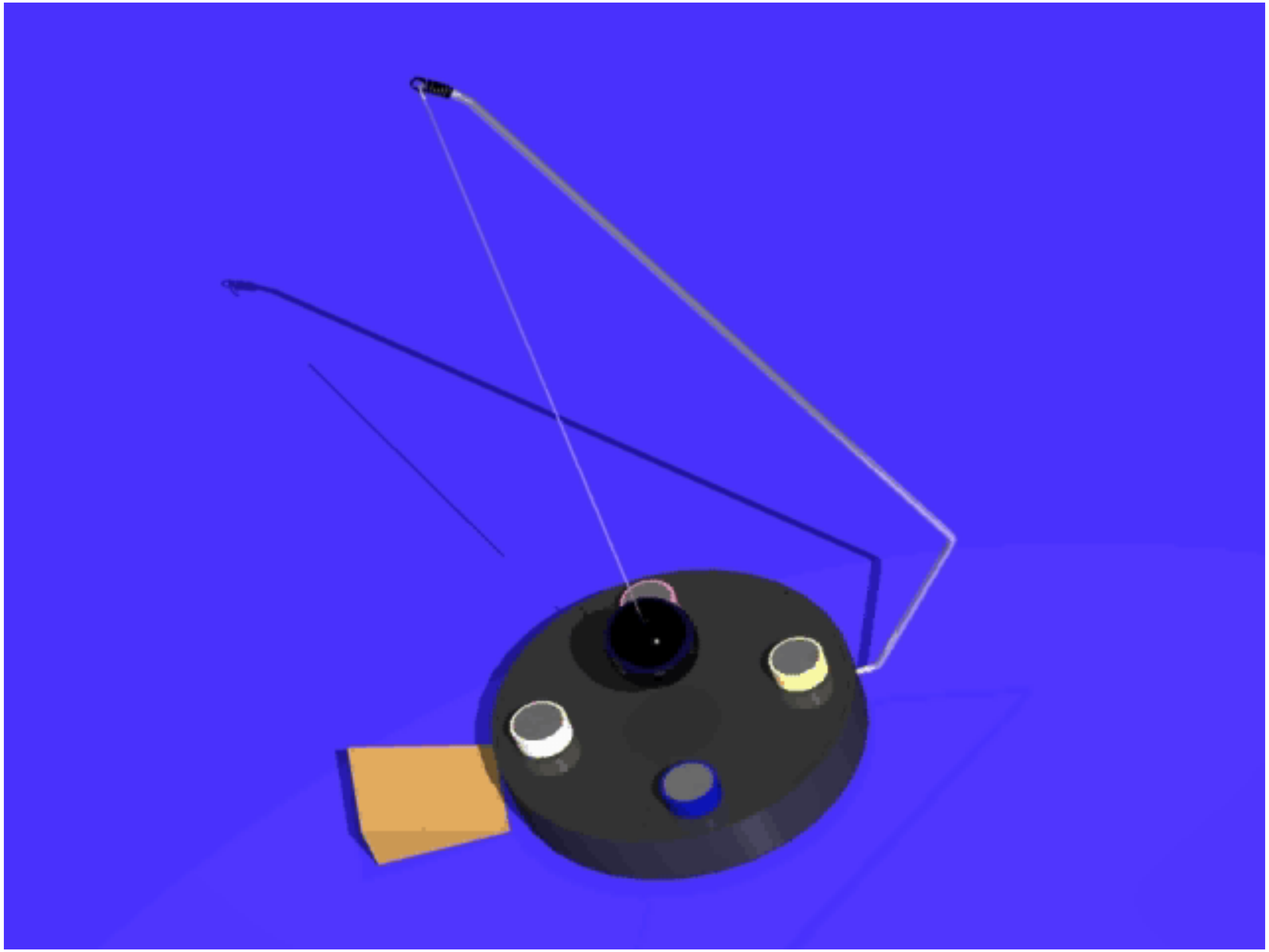
Weather types

Z500 summer weather types and frequency change (%) of warm days

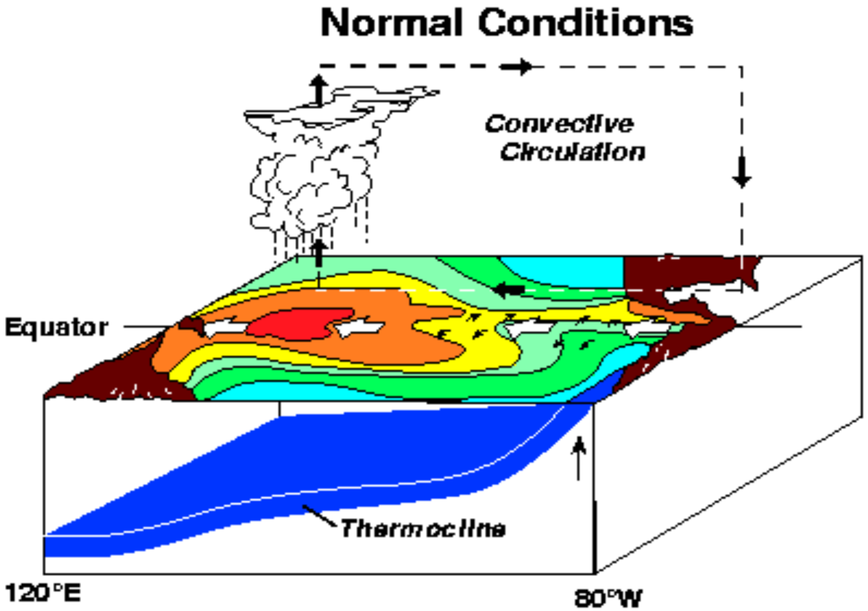


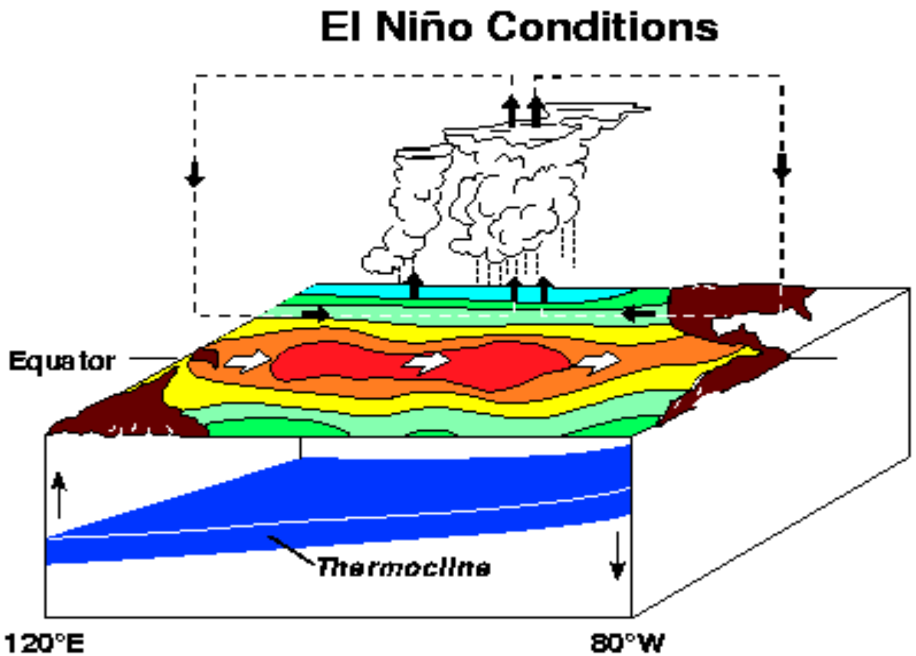
From Cassou et al. (2005)





The wedge: ENSO in the tropical Pacific

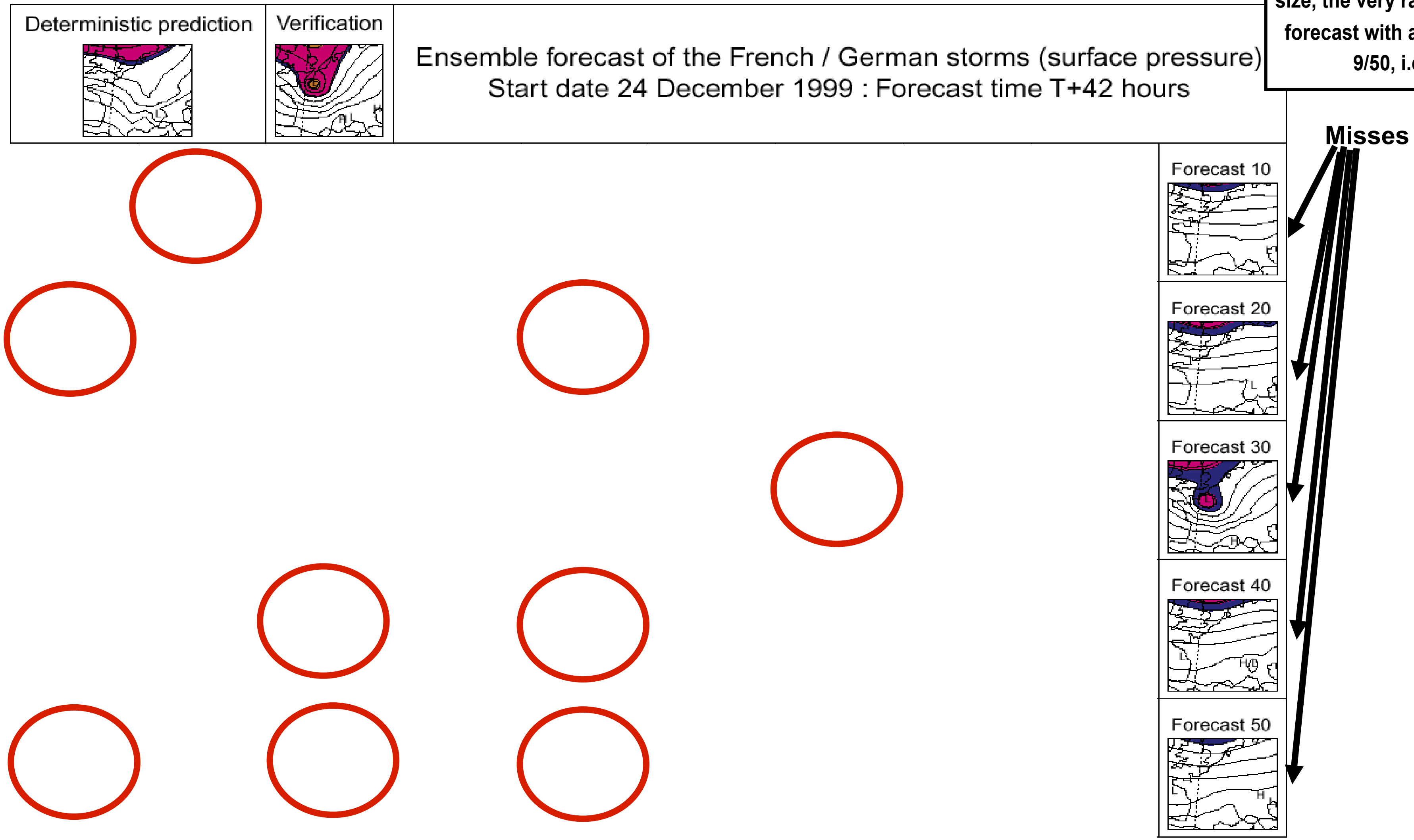




How many members: ensemble size

ECMWF forecasts (D+42) for the storm Lothar

With a large enough ensemble size, the very rare event can be forecast with a probability of 9/50, i.e. ~20%



Creating the ensemble: the ECMWF way

- Wind perturbations
  - Perfect wind would give a good ocean analysis, but uncertainties are significant. We represent these by adding perturbations to the wind used in the ocean analysis system.
  - BUT only have 5 member ensemble, and no representation of other sources of uncertainty in ocean analysis (obs error, E-P, ..).
- SST perturbations
  - SST uncertainty is not negligible.
  - SST perturbations added to each ensemble member at start of forecast.
  - BUT perturbations based on analyses that use the same input data.
- Atmospheric unpredictability
  - Atmospheric 'noise' soon becomes the dominant source of spread in an ensemble forecast. This sets a fundamental limit to forecast quality.
  - To ensure that noise grows rapidly enough in the first few days, we activate 'stochastic physics' and use atmospheric singular vectors.

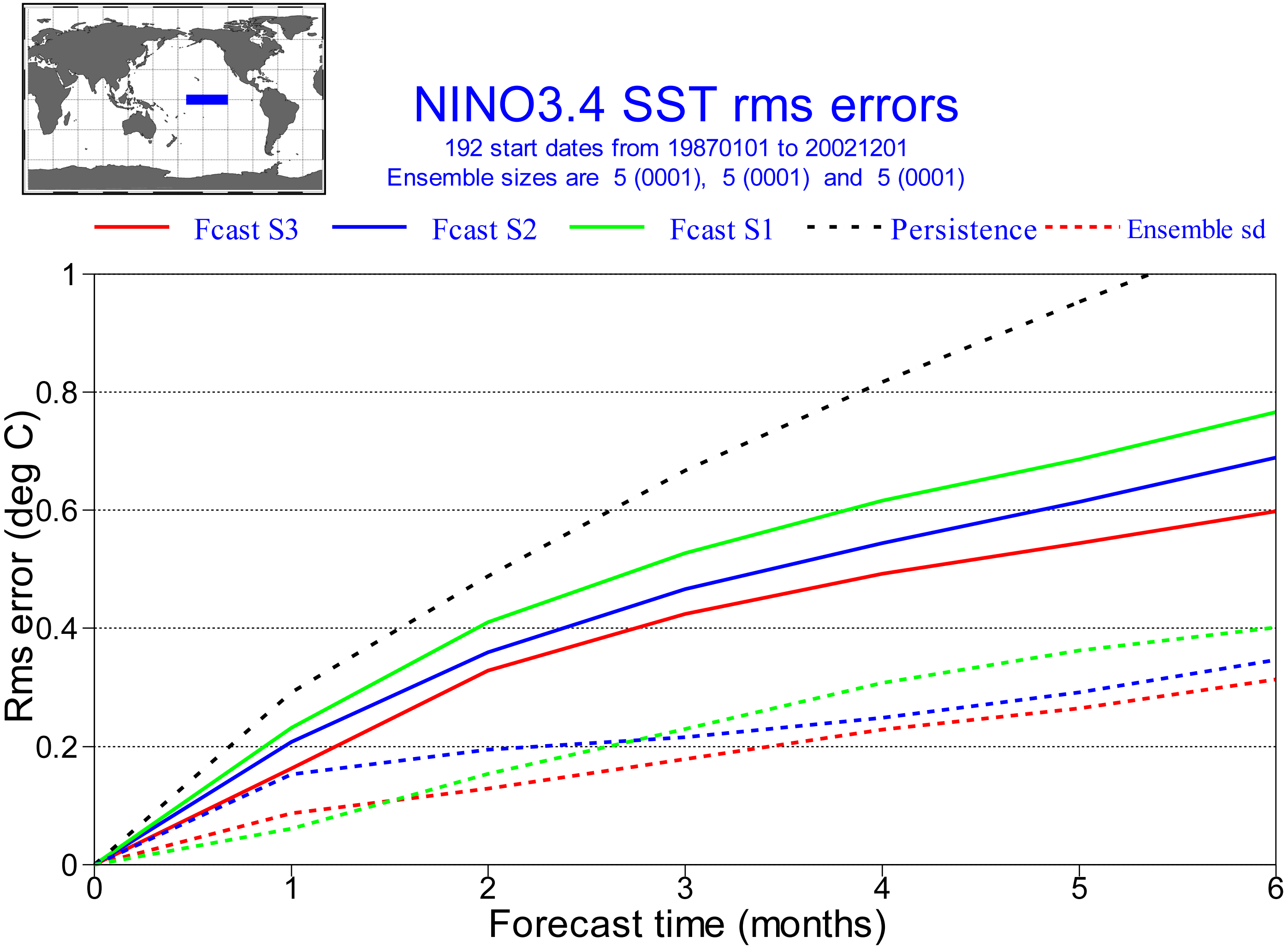
ECMWF's System 3 configuration

- Real time forecasts:
  - 41-member ensemble forecast to 7 months
  - SST and atmos. perturbations added to each member

  - 11 member ensemble forecast to 13 months
  - Designed to give an 'outlook' for ENSO
  - Only once per quarter (Feb, May, Aug and Nov starts)
  - November starts are actually 14 months (to year end)

- Back integrations from 1981-2005 (25 years)
  - 11-member ensemble every month
  - 5 members to 13 months once per quarter

Ensemble spread in different systems



Rms error of forecasts has been systematically reduced (solid lines)

… but ensemble spread (dashed lines) is still substantially less than actual forecast error.

Substantial amounts of forecast error are not from the initial conditions.

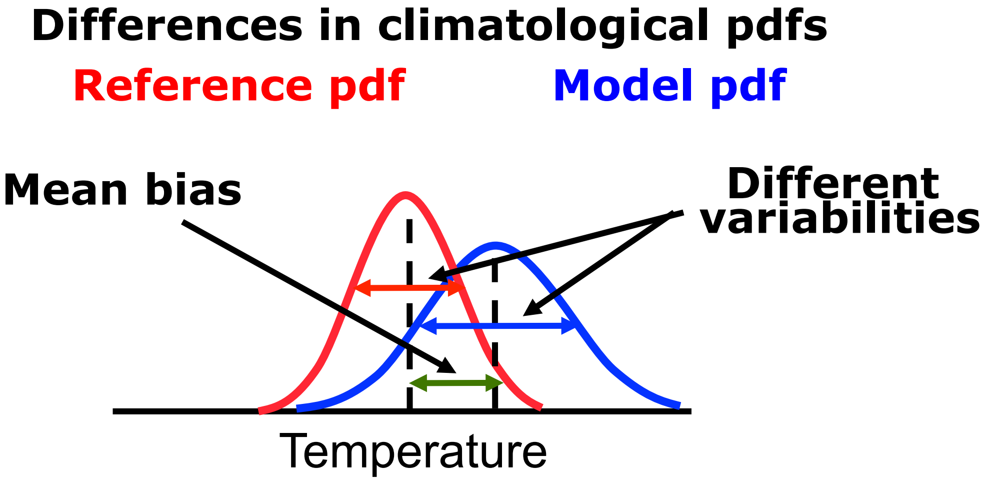
And there are systematic errors

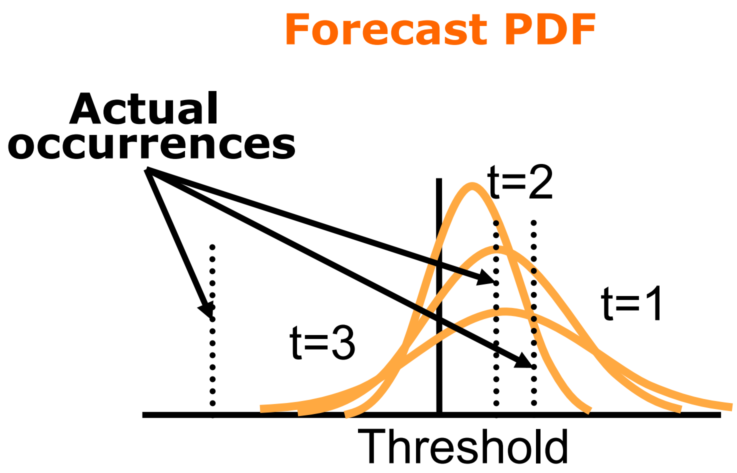
- Model drift is typically comparable to signal
  - Both SST and atmosphere fields
- Forecasts are made *relative* to past model integrations
  - Model climate estimated from 25 years of forecasts (1981-2005), all of which use a 11 member ensemble. Thus the climate has 275 members.
  - Model climate has both a mean and a distribution, allowing us to estimate eg tercile boundaries.
  - Model climate is a function of start date and forecast lead time.
- Implicit assumption of linearity
  - We implicitly assume that a shift in the model forecast relative to the model climate corresponds to the expected shift in a true forecast relative to the true climate, despite differences between model and true climate.
  - Most of the time, the assumption seems to work pretty well. But not always.

Systematic errors in ensemble forecasts

Main systematic errors in dynamical climate forecasts:

- Differences between the model climatological pdf (computed for a lead time from all start dates and ensemble members) and the reference climatological pdf (for the corresponding times of the reference dataset): systematic errors in mean and variability.
- Conditional biases in the forecast pdf: errors in conditional probabilities implying that probability forecasts are not trustworthy. This type of systematic error is best assessed using the reliability diagram.

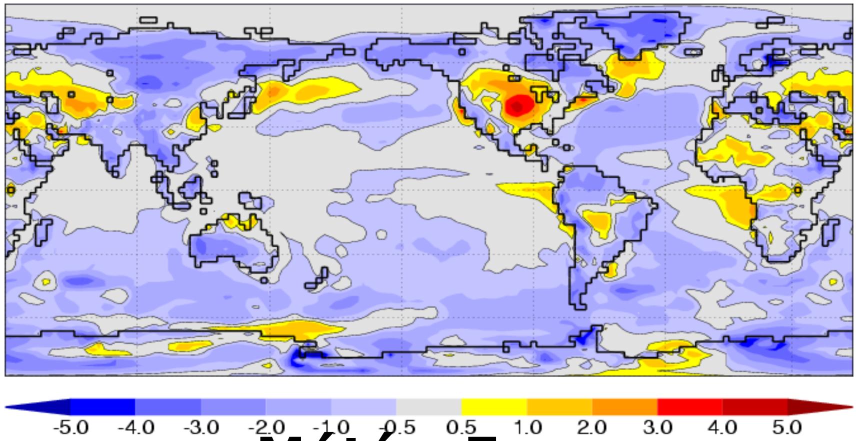




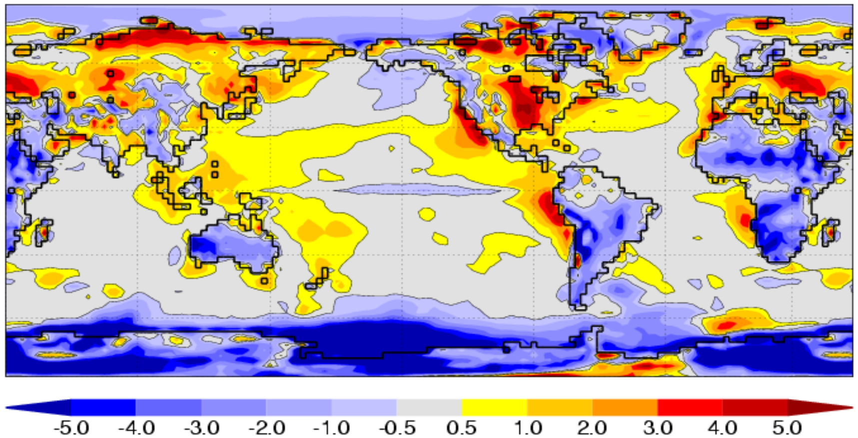
Mean error

Mean biases (JJA 2mT over 1993-2005) are often comparable in magnitude to the anomalies which we seek to predict

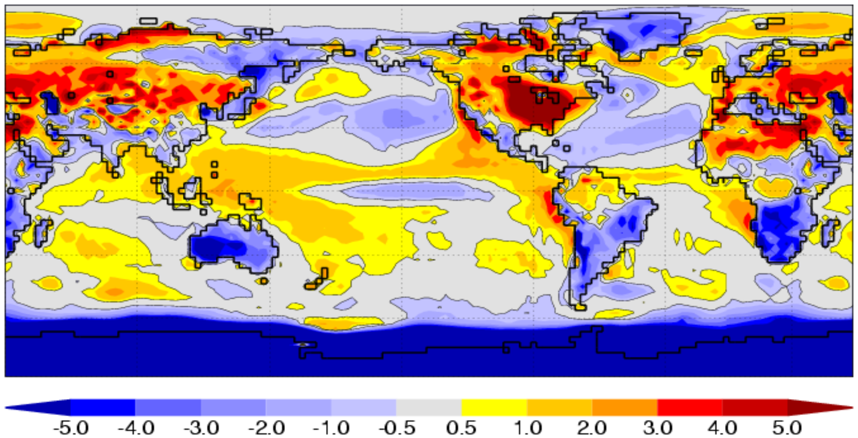
ECMWF



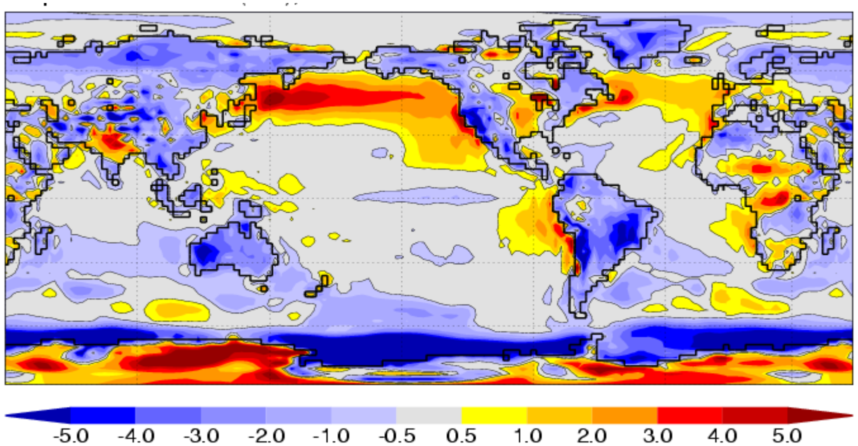
Met Office



Météo-France

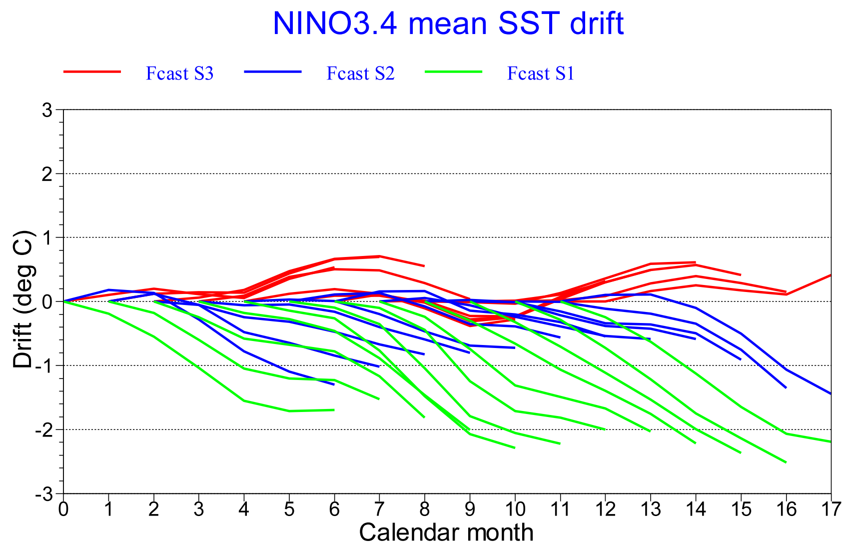


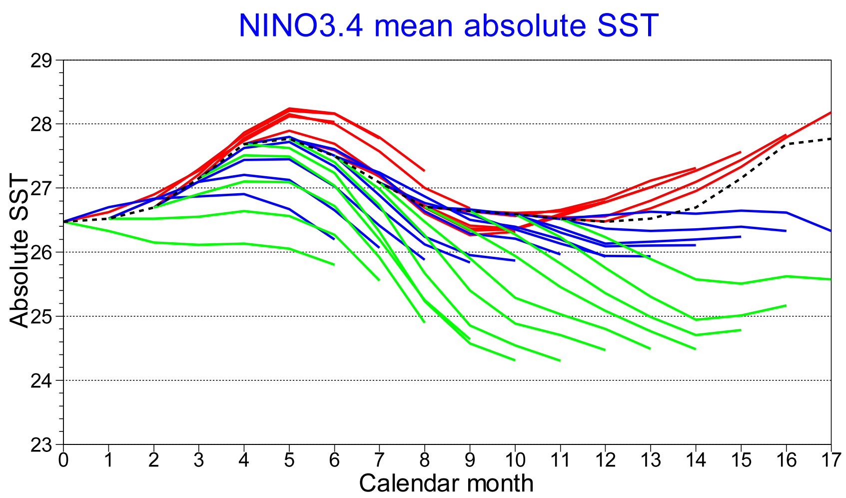
CFS



Mean error

Mean SST bias for System 3 (1981-2005) Bias is a function of lead time and season. More recent systems have less bias, but it is still large enough to require correcting for.

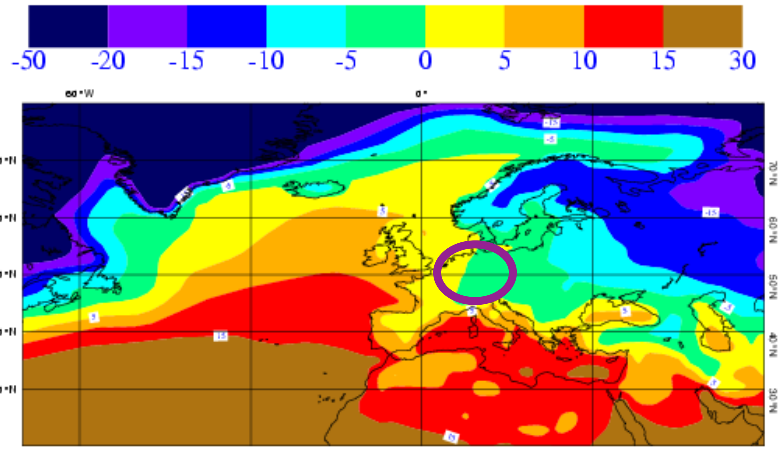


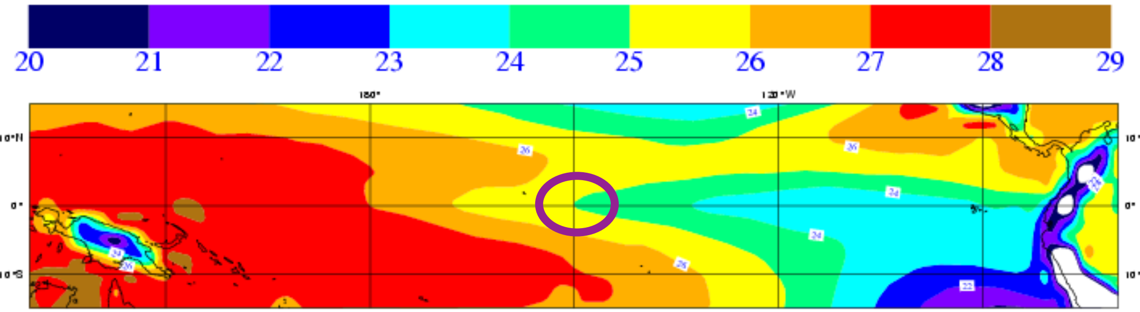


Systematic error: variability

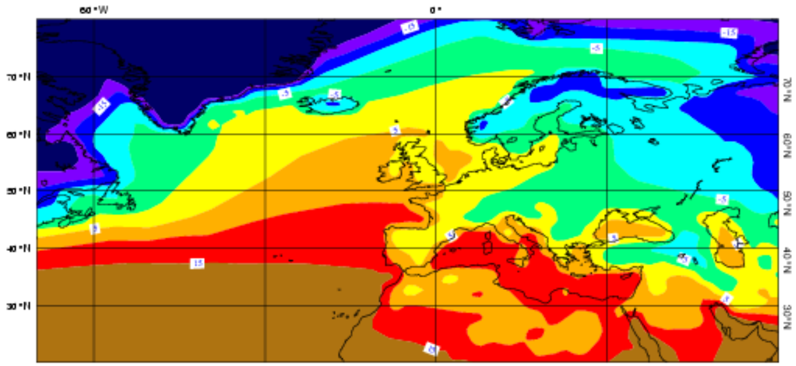
Lower quintile of DJF T2m for ERA-40/OPS (top row) and ECMWF System 3 1st November (bottom row) in 1960-2005 (°C)

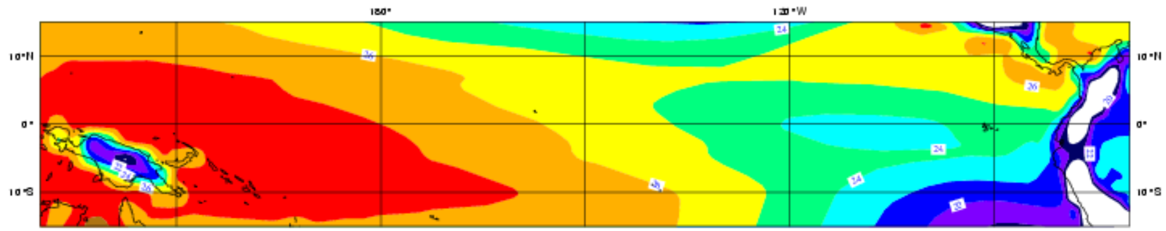
ERA/OPS





ECMWF System 3





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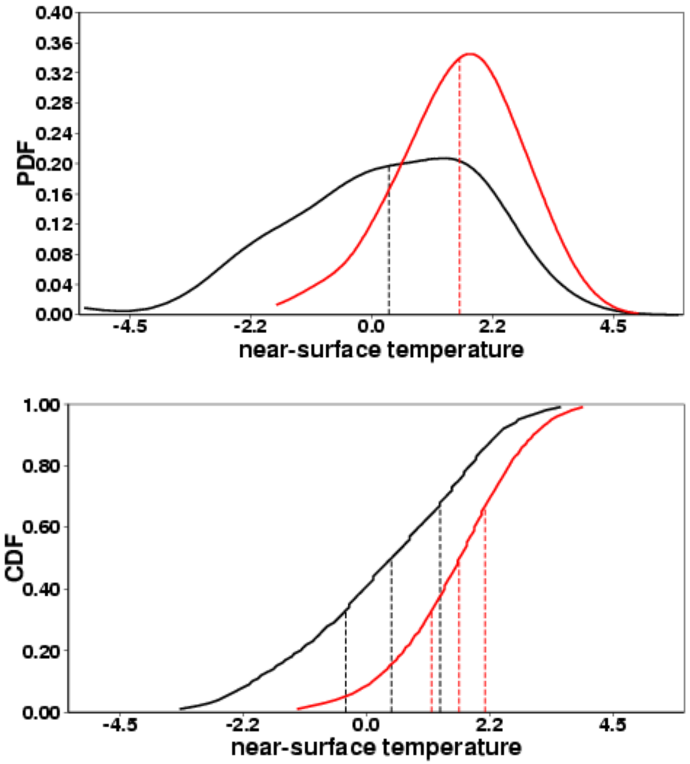
Systematic error: climatological pdf

Climatological PDF of DJF T2m (°C) for ERA-40/OPS and ECMWF System 3 computed over the period 1960-2005

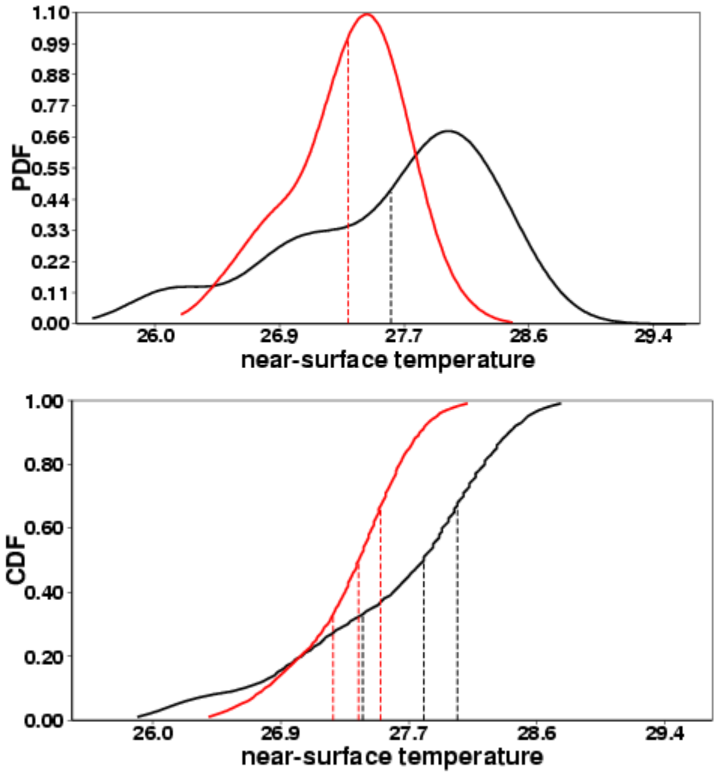
For deterministic forecasts, compute anomalies with respect to the corresponding mean

For probabilistic forecasts, compute probabilities with respect to hindcast and reference thresholds (terciles)

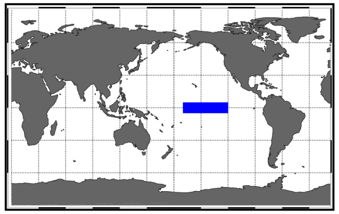
Central Europe (50°N, 10°E)

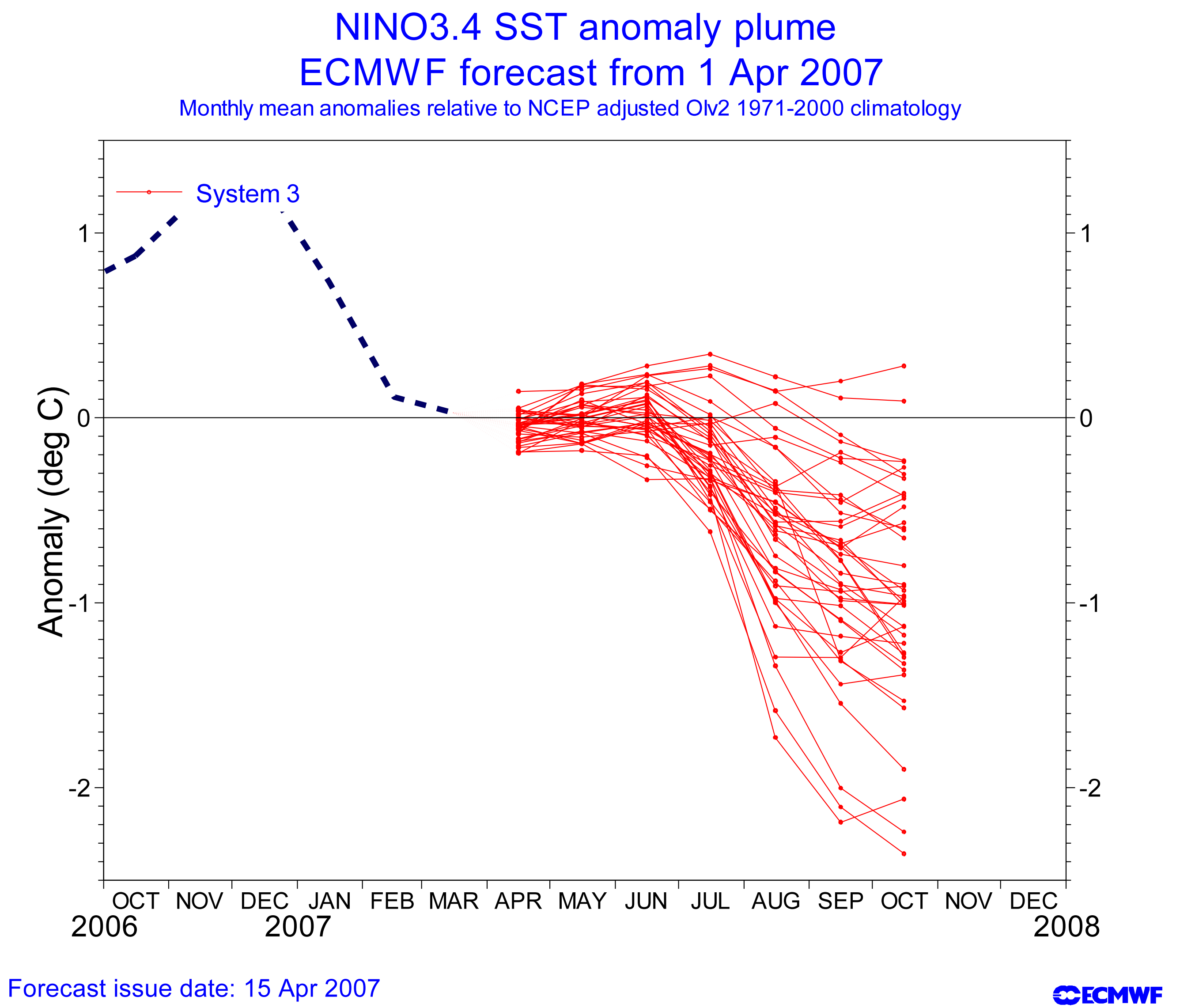


Equatorial Pacific (0, 180°)

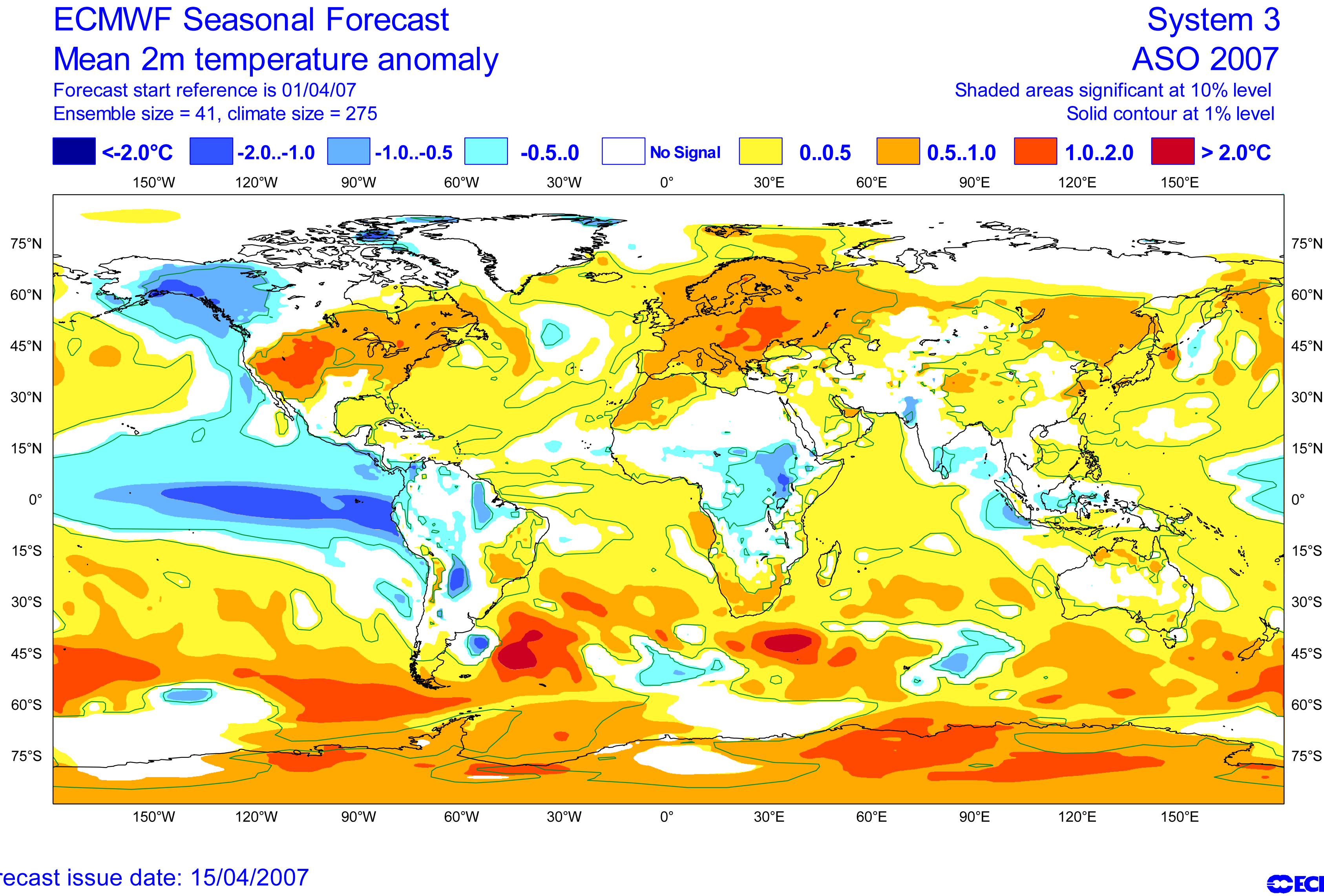


ENSO ensemble predictions





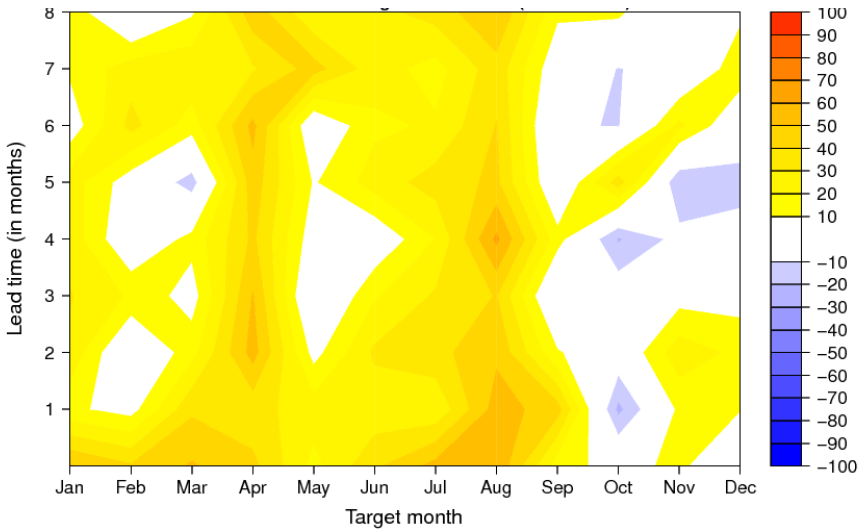
Ensemble-mean prediction



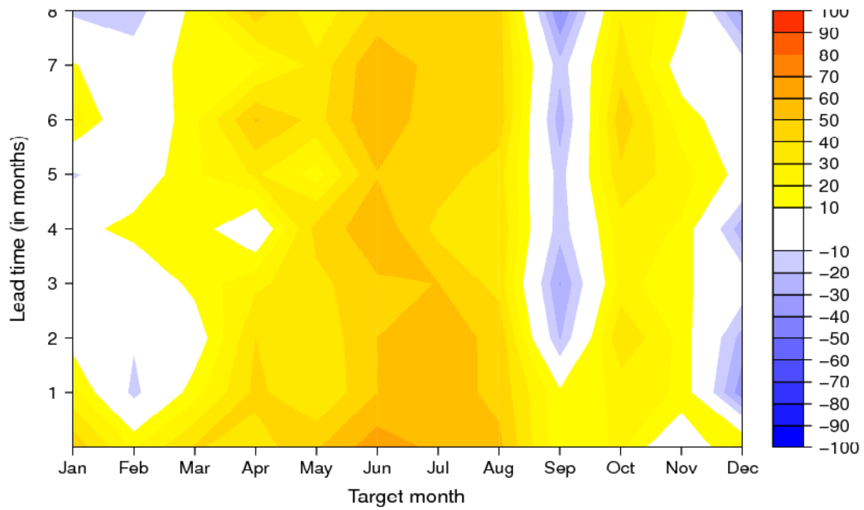
Simple empirical model: persistence

Correlation of a persistence model based on linear regression with GHCN temperature over 1981-2005, with the first regression model using data for 1952-1980.

Northern Europe (40-75°N,10°W-40°E)

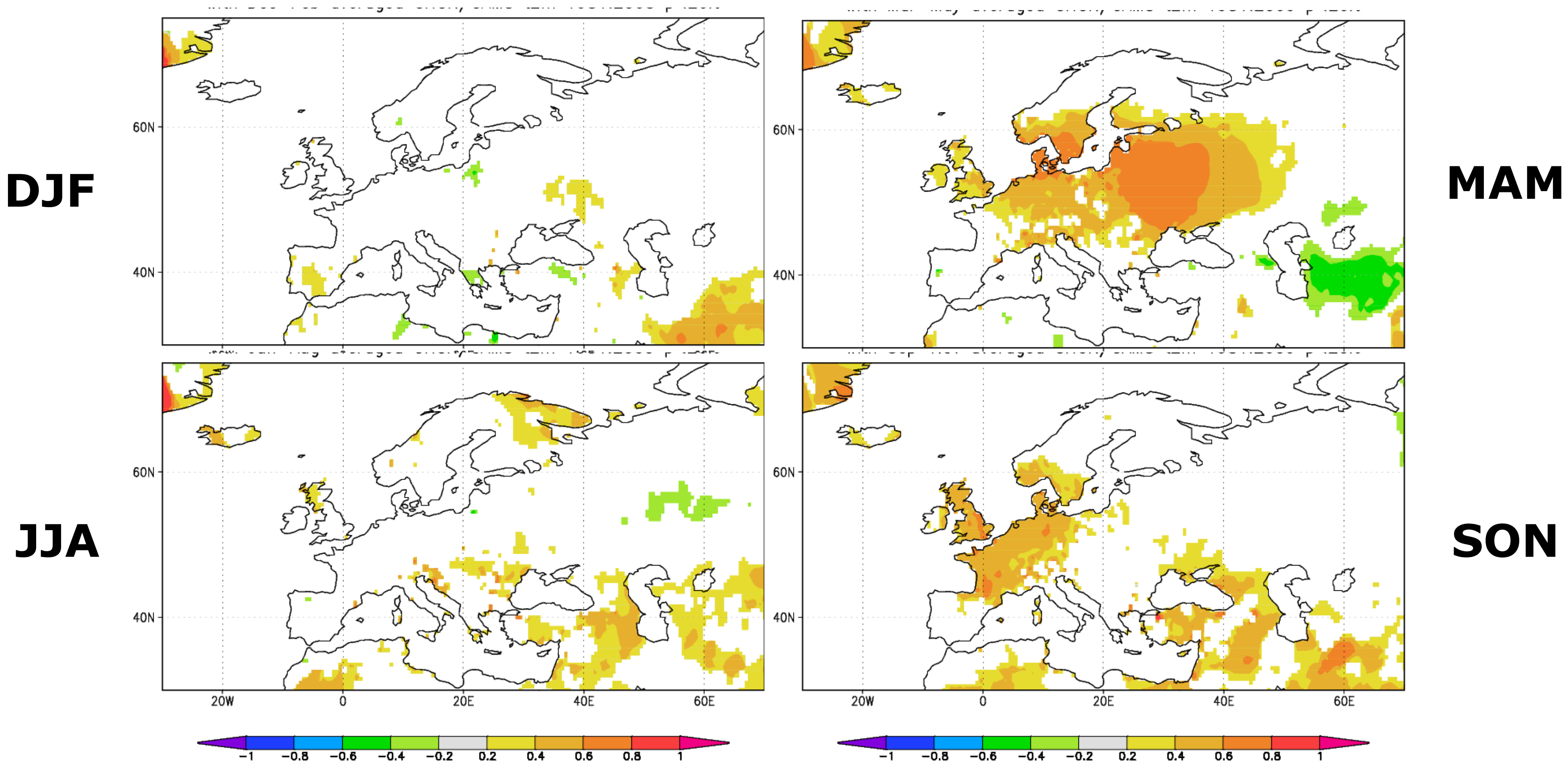


Southern Europe (35-45°N,5°W-30°E)



Temperature skill: persistence

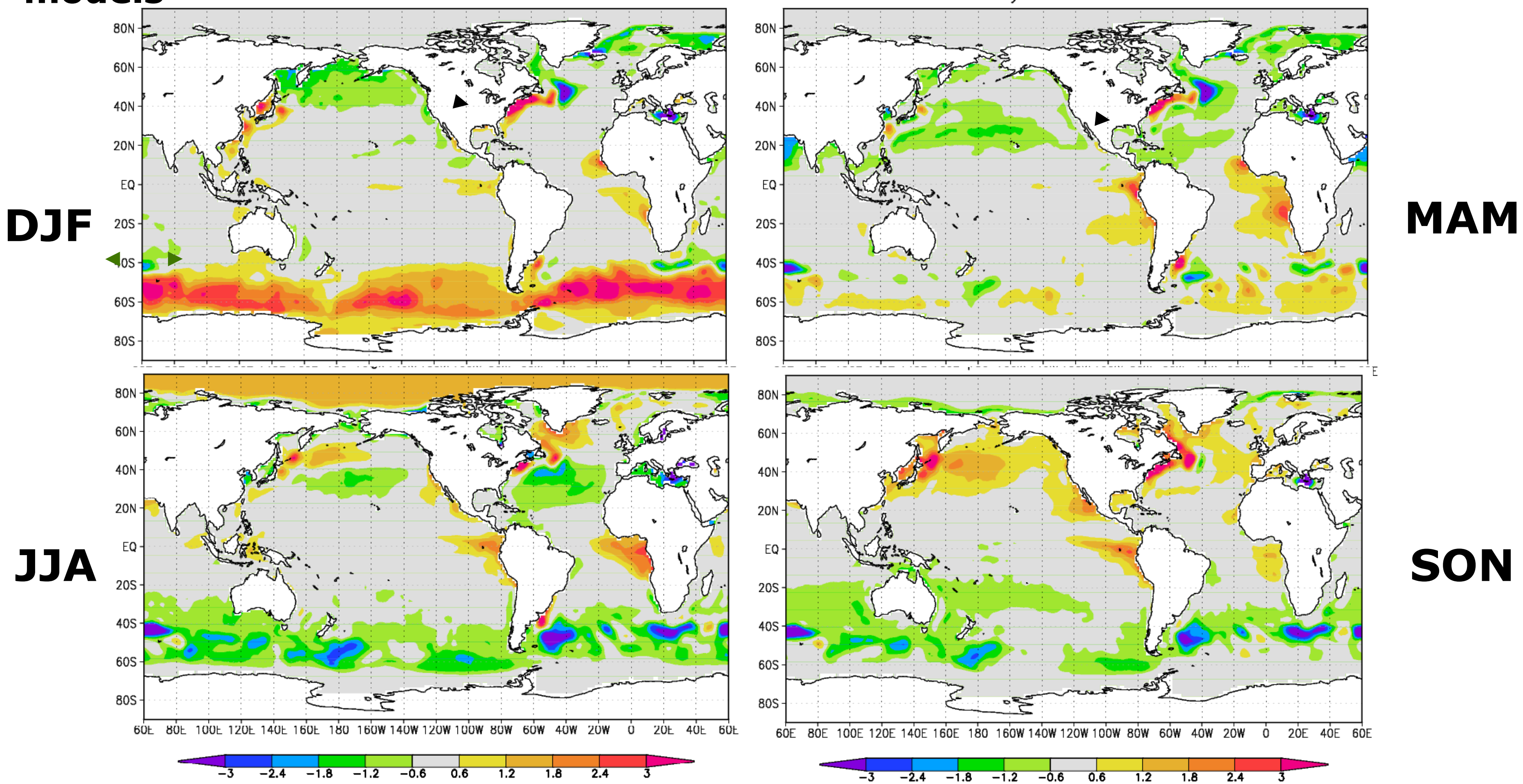
Correlation of GHCN temperature of one-month lead anomaly persistence over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Mean error: SSTs

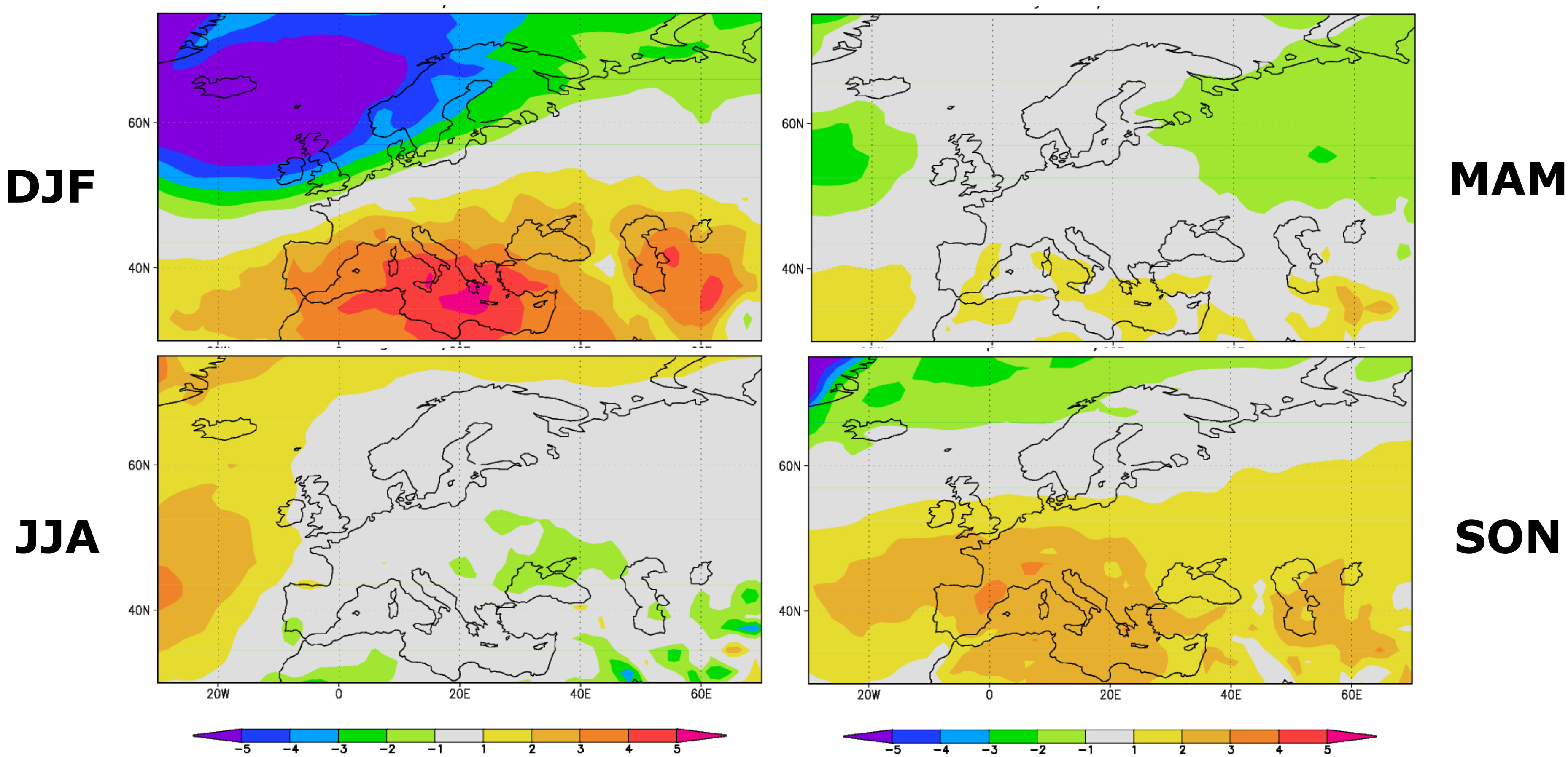
System 3 one-month lead SST (K) bias wrt HadISST1 over 1981-2005.

Typical of CMIP3 models



Mean error: MSLP

System 3 one-month lead mean sea level pressure (hPa) bias wrt NCEP/NCAR R1 over 1981-2005.



Mean error: T2m

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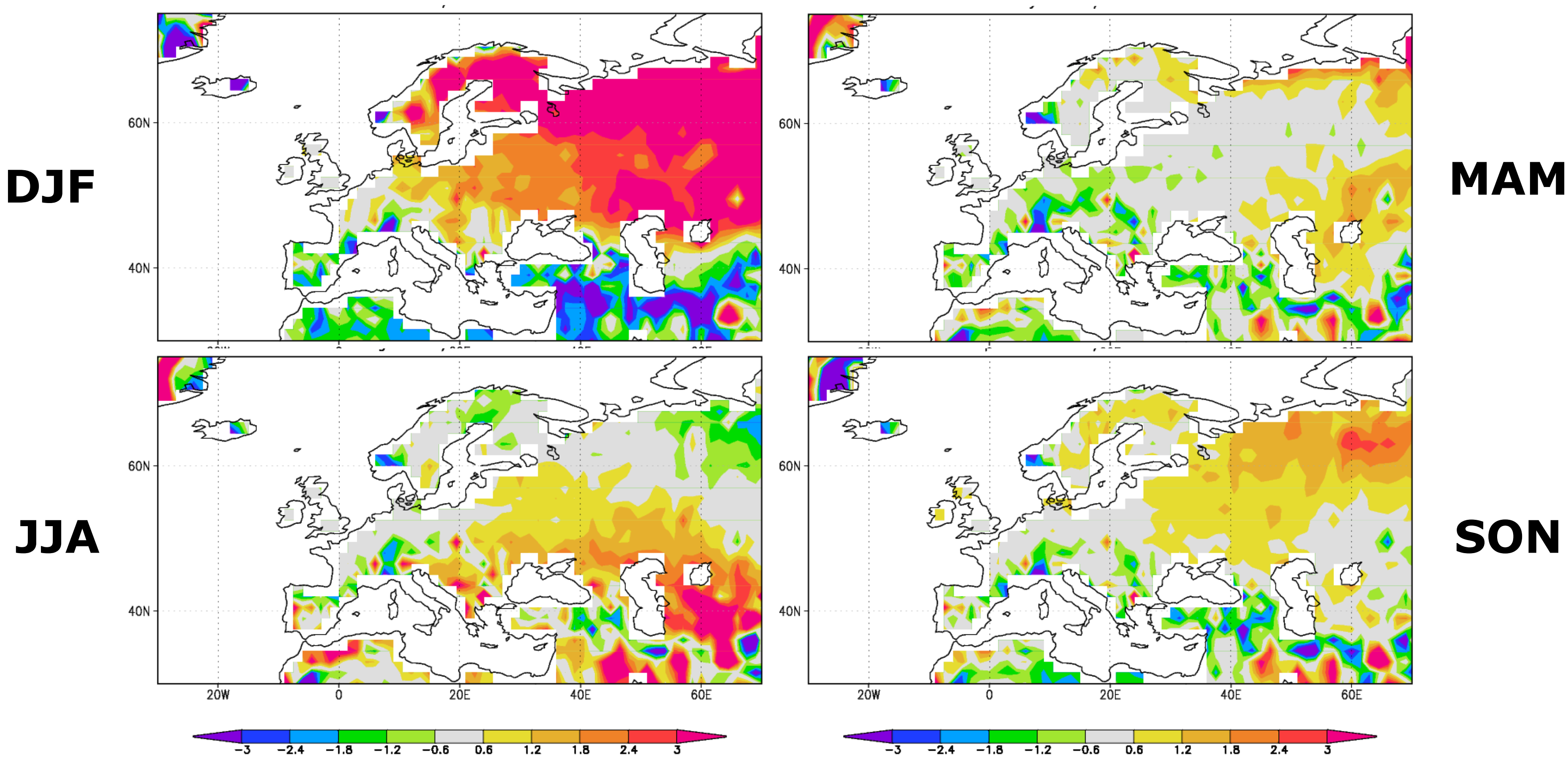
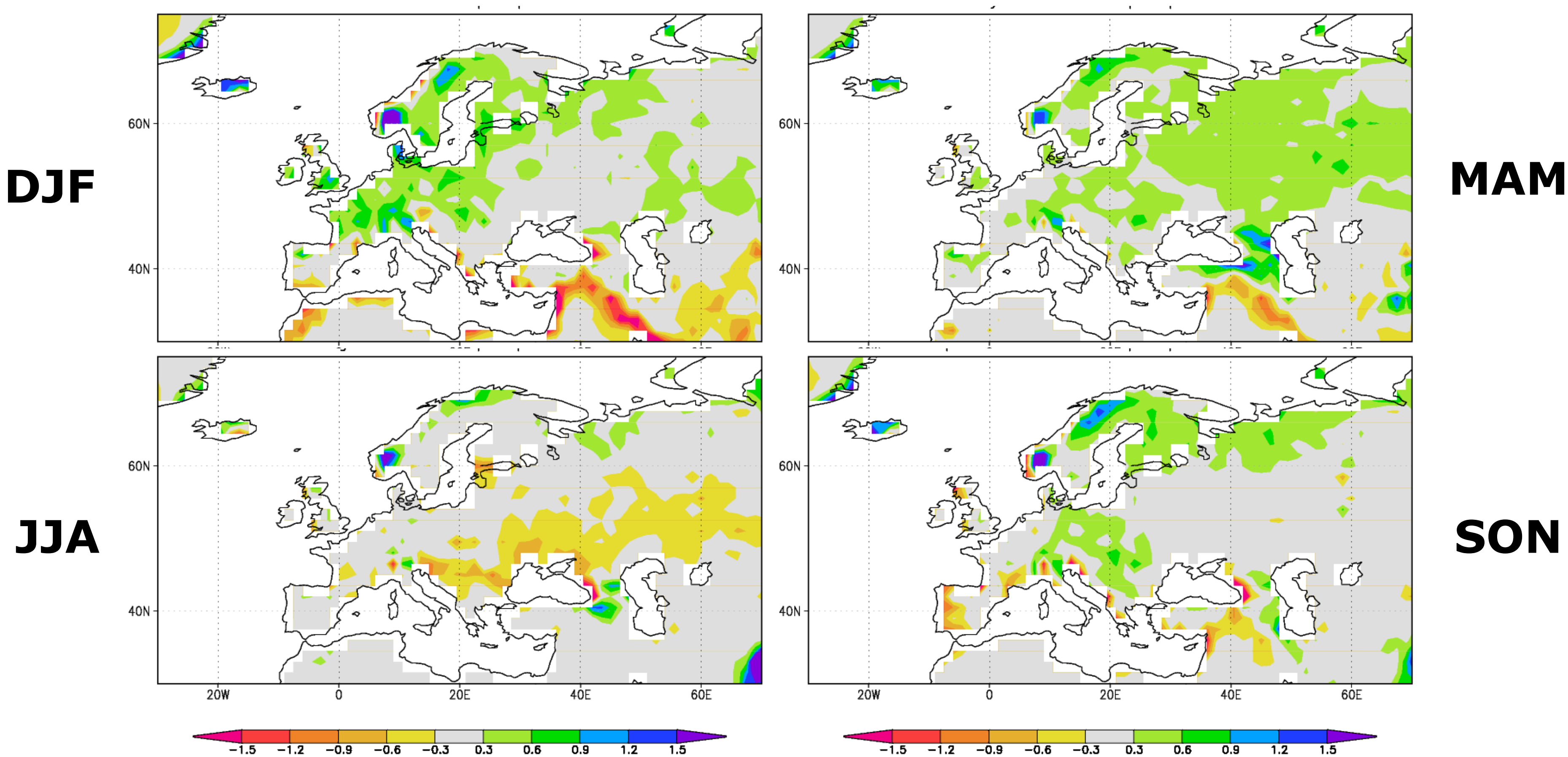
System 3 one-month lead near-surface air temperature (K) bias wrt GHCN over 1981-2005.



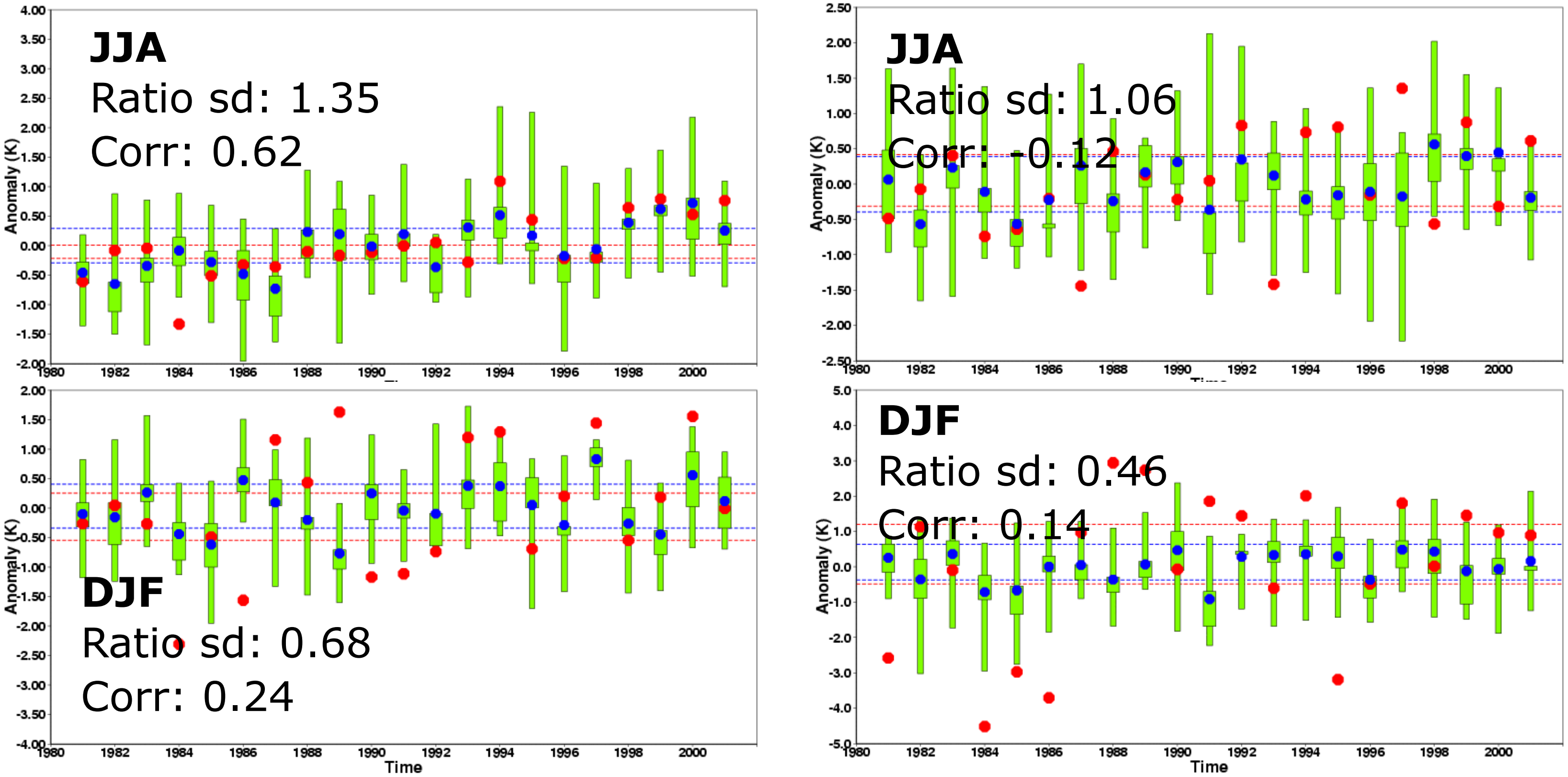
Mean error: precipitation

System 3 one-month lead precipitation (mm/day) bias wrt GPCC over 1981-2005.



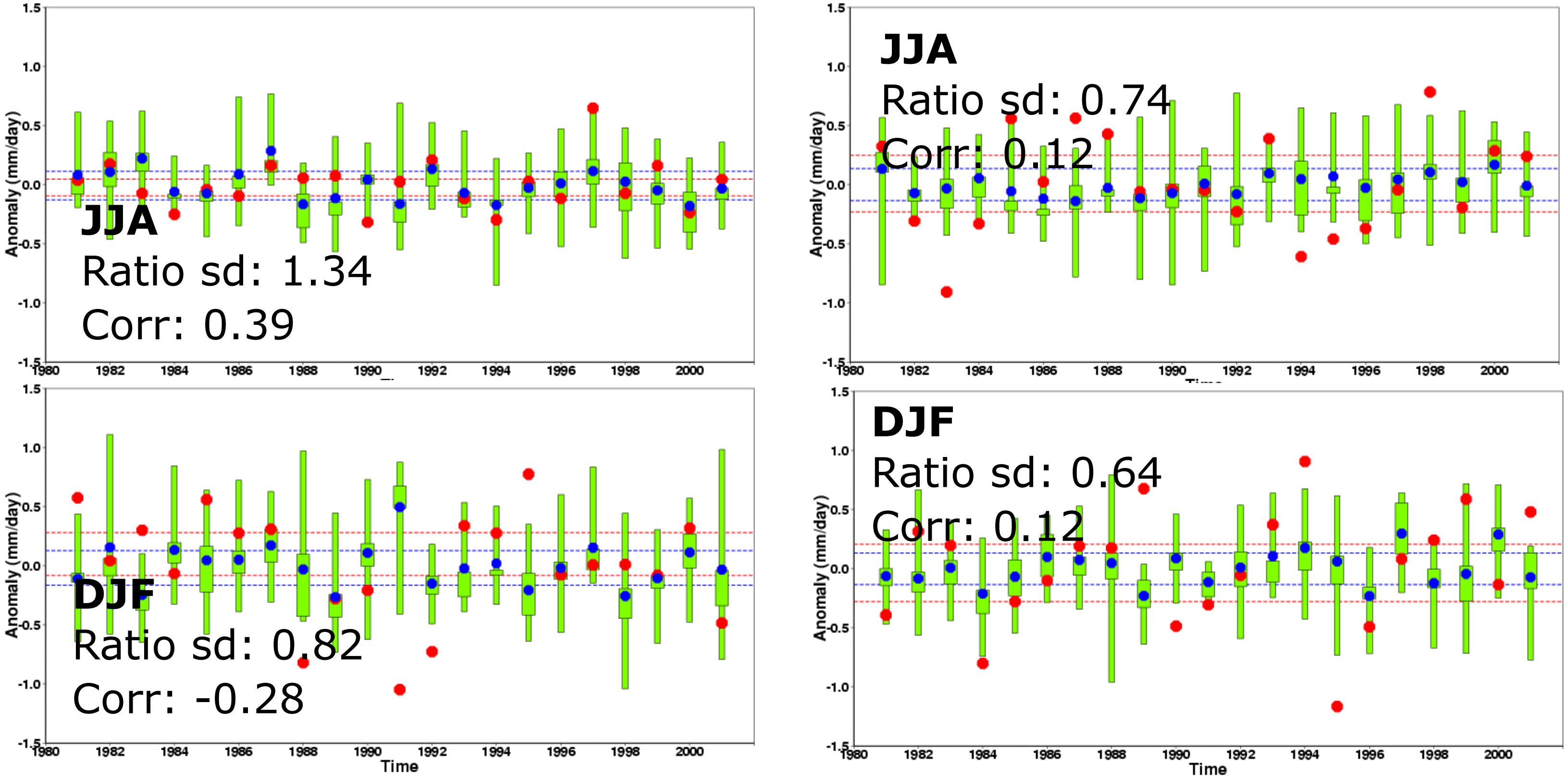
Seasonal re-forecasts for Europe

System 3 temperature re-forecasts for Southern (left) and Northern Europe (right) over 1981-2005. The green box-and-whisker show the ensemble range, the blue dot the ensemble mean and the red dot the ERA40/ERAInt value.



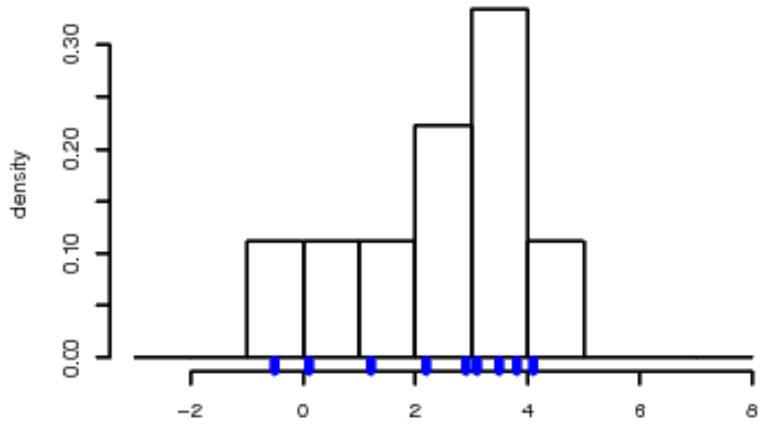
Seasonal re-forecasts for Europe

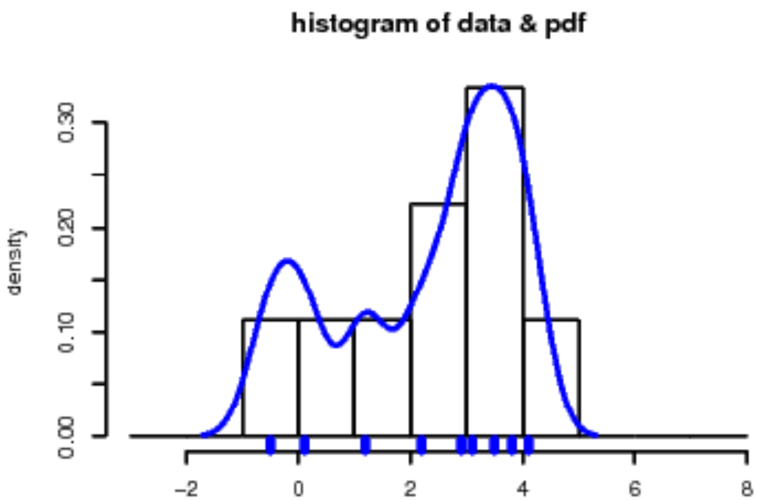
System 3 precipitation re-forecasts for Southern (left) and Northern Europe (right) over 1981-2005. The green box-and-whisker show the ensemble range, the blue dot the ensemble mean and the red dot the GPCP value.

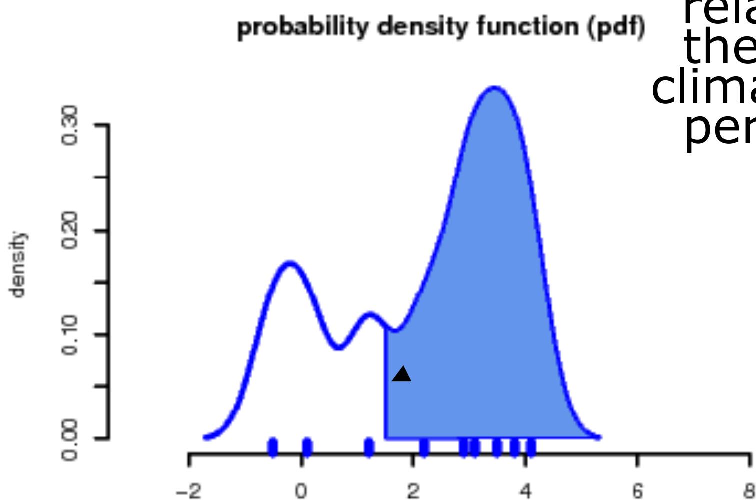


From ensembles to probability forecasts

Constructing a probability forecast from a nine-member ensemble



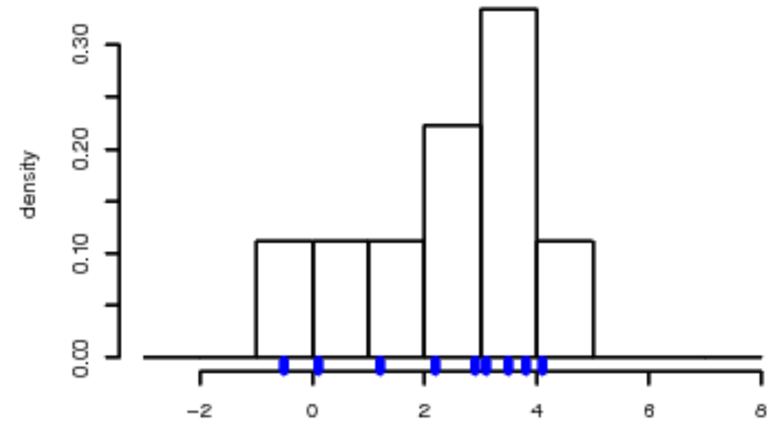


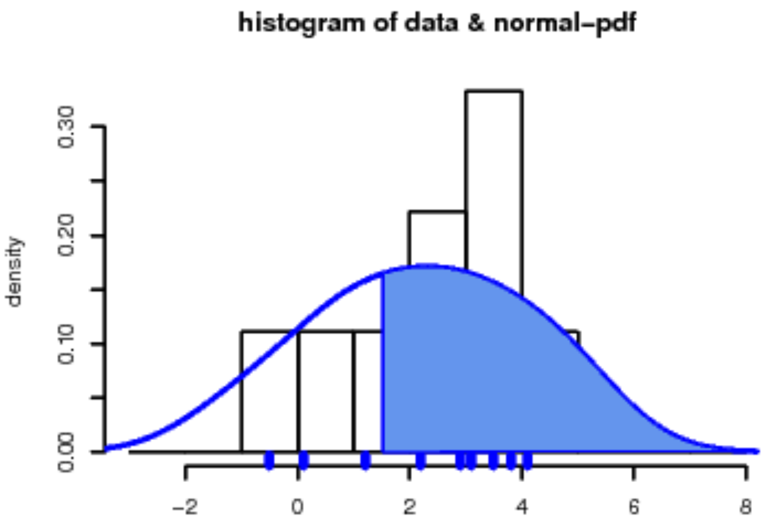


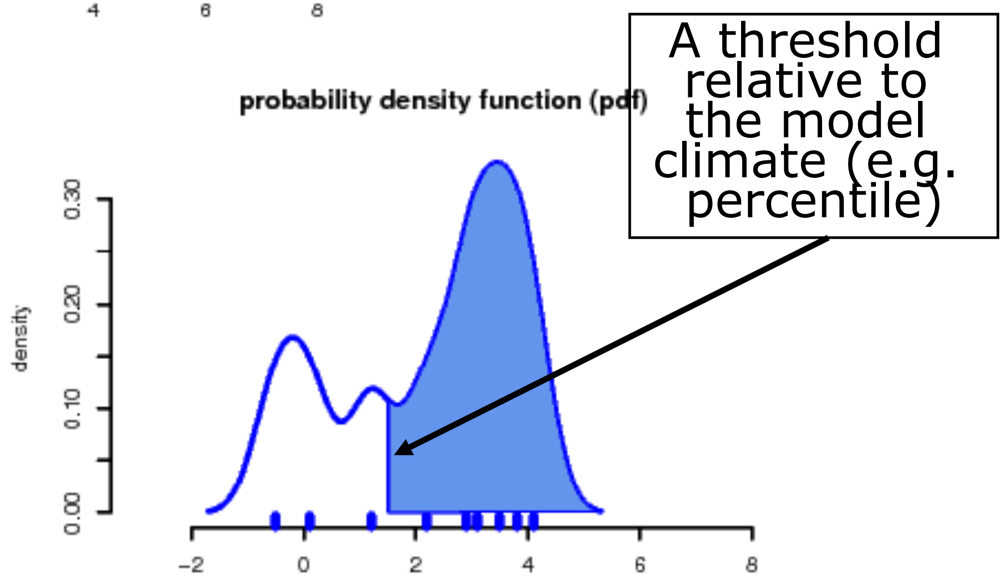
A threshold relative to the model climate (e.g. percentile)

From ensembles to probability forecasts

Constructing a probability forecast from a nine-member ensemble

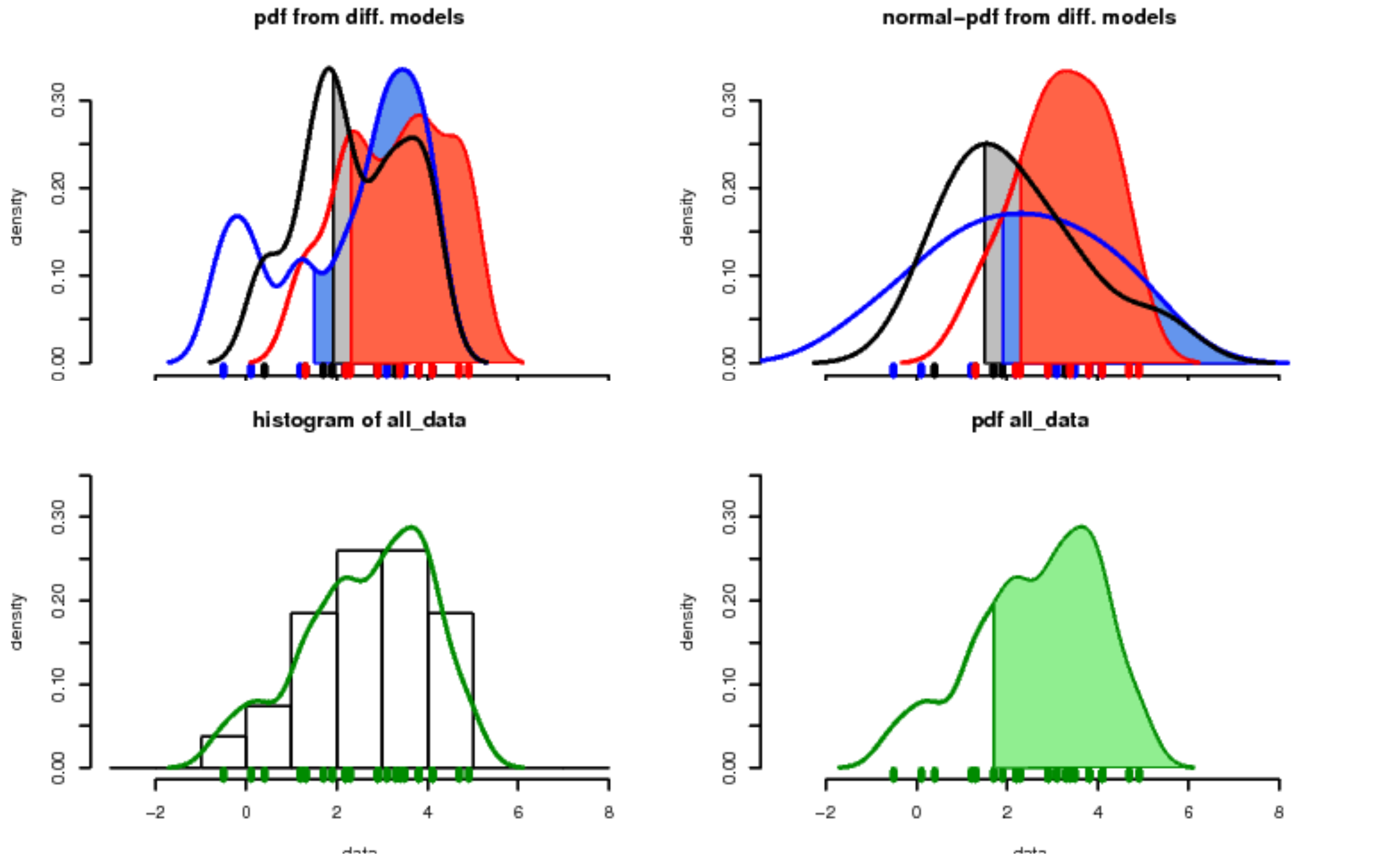






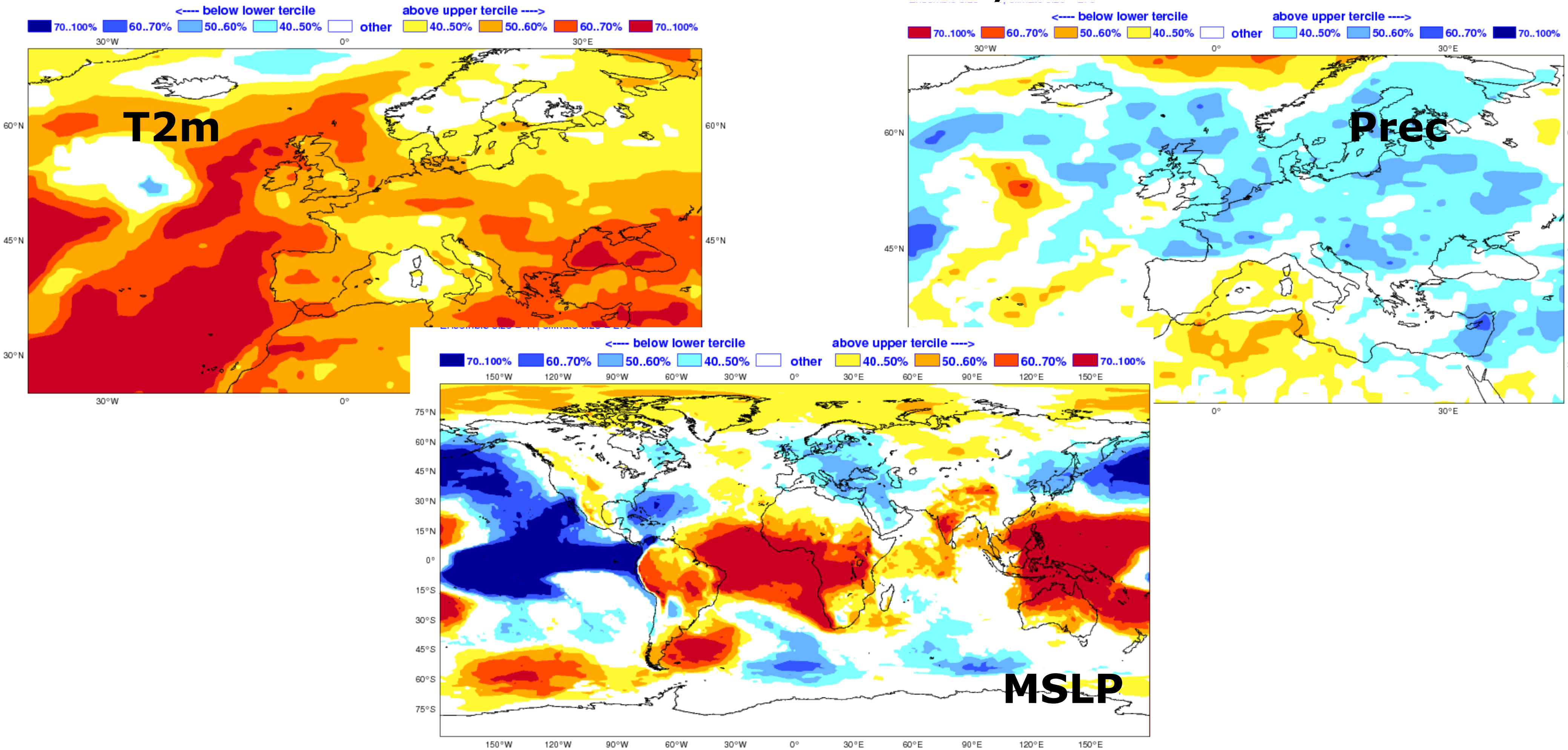
From ensembles to probability forecasts

Constructing a probability forecast from a multi-model ensemble



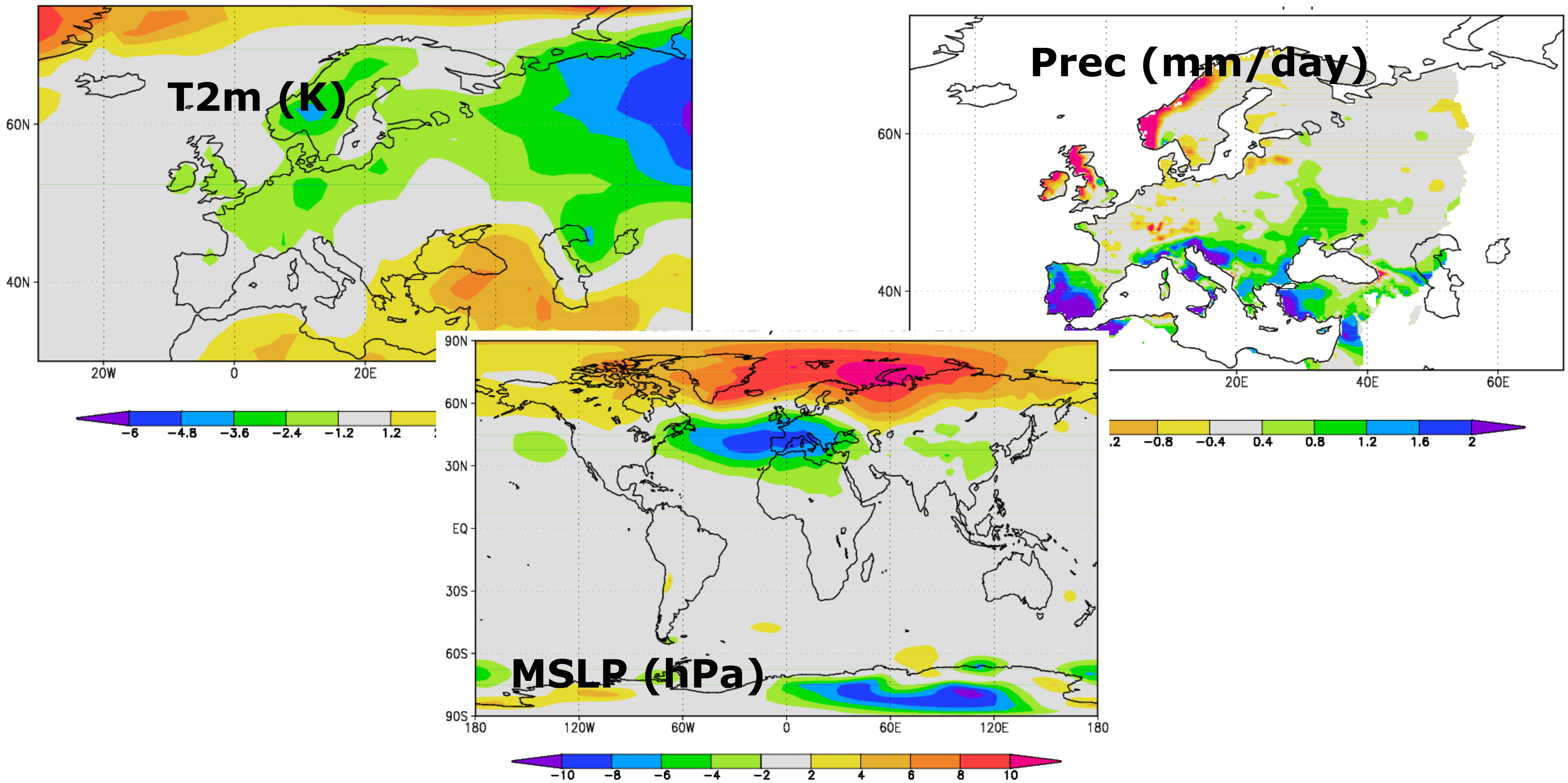
Probabilistic prediction

One-month lead DJF 2009-10 System 3 seasonal forecasts: tercile summary



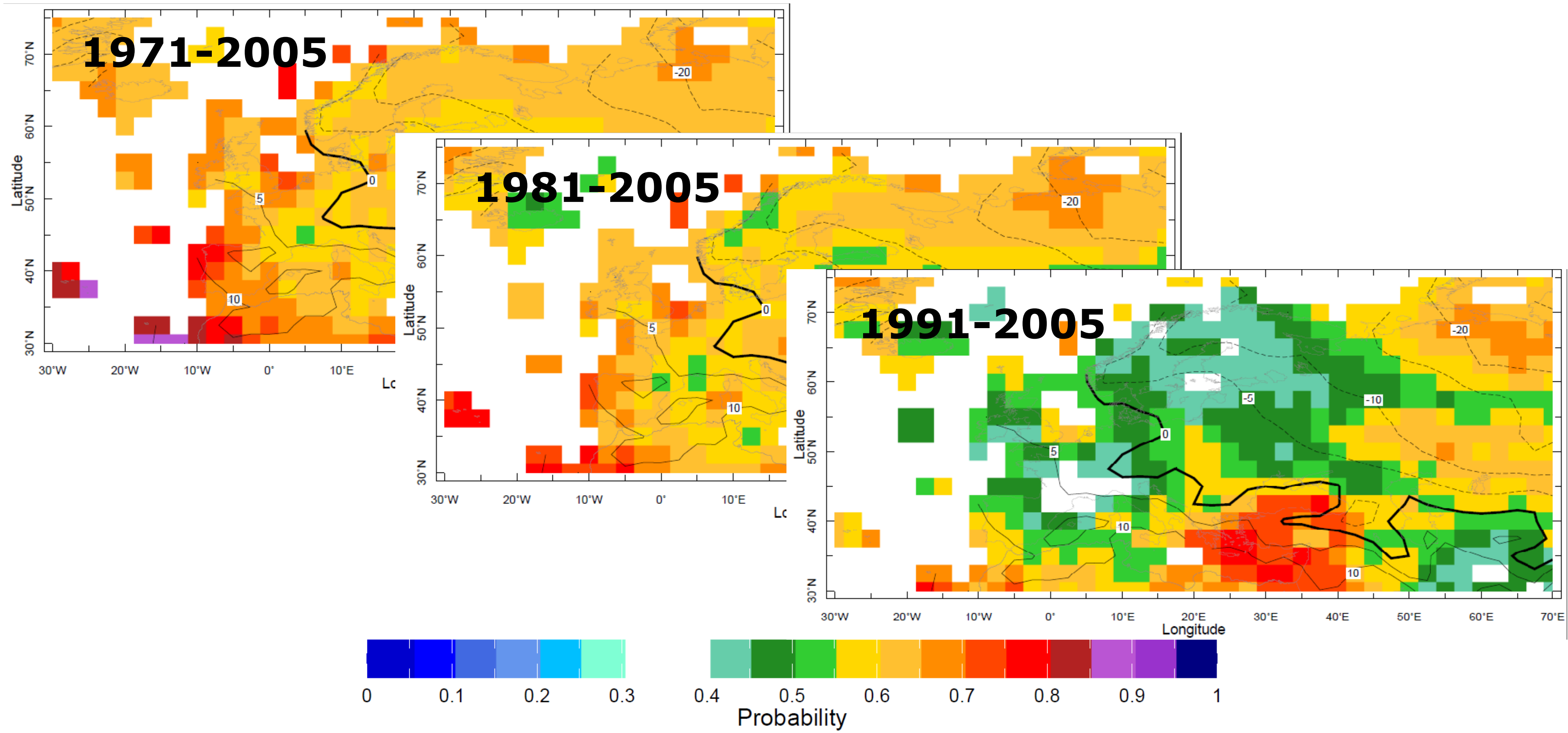
References: what actually happened

DJF 2009-10 seasonal anomalies wrt 1981-2005.



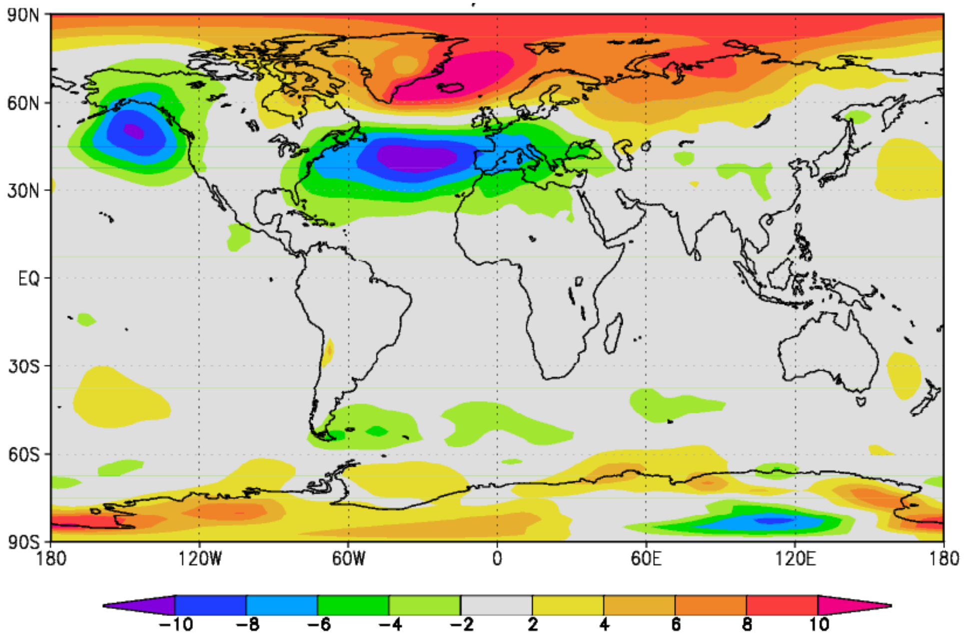
Probabilistic prediction

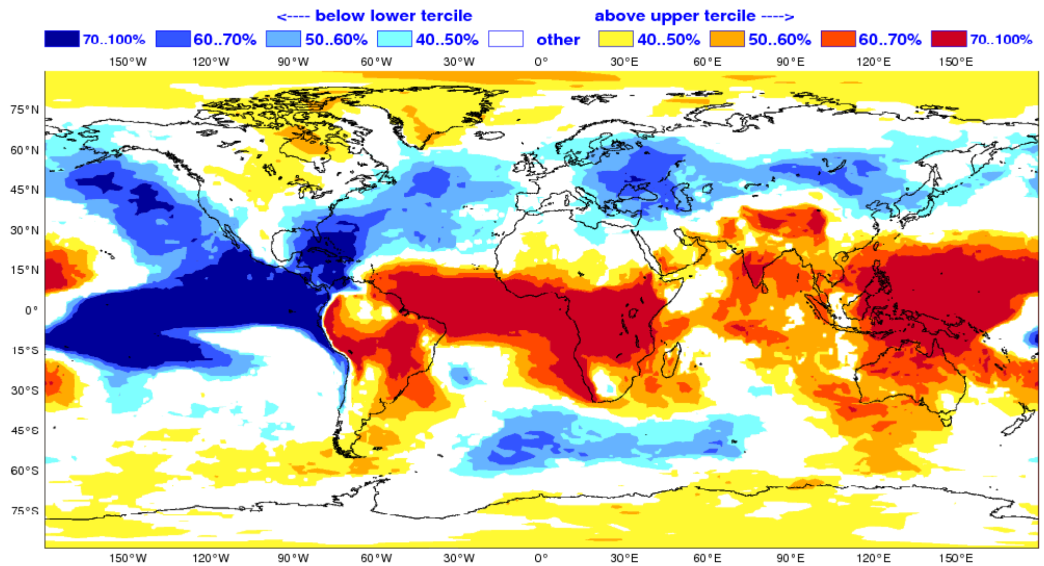
One-month lead DJF 2009-10 IRI (flexible format) temperature forecasts for anom. above the upper tercile



December start date forecasts: JFM

JFM 2010 mean sea level pressure seasonal anomalies for (left) NCEP/NCAR R1 (hPa) and (right) tercile summary for the one-month lead System 3 forecasts wrt 1981-2005.





Temperature skill: System 3

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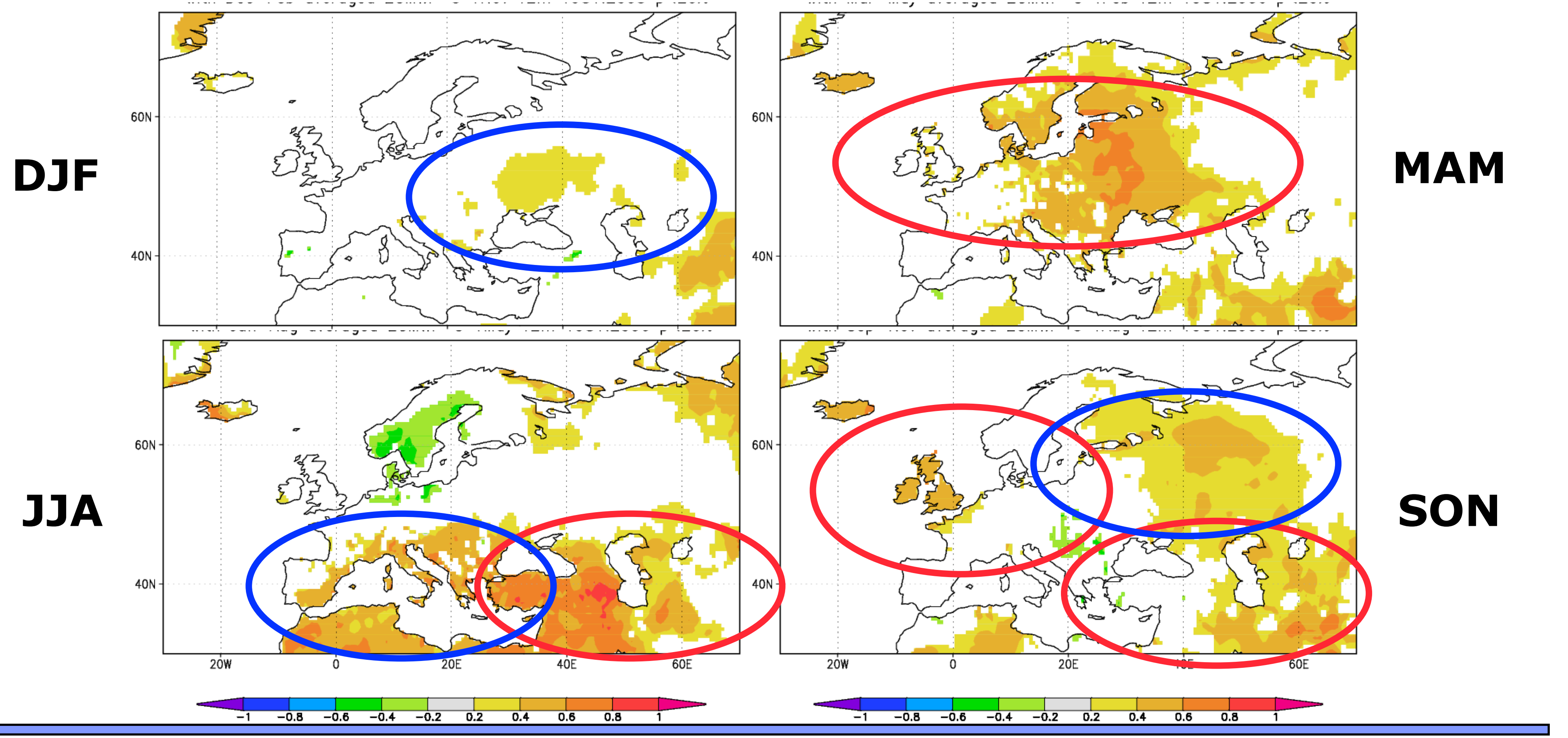
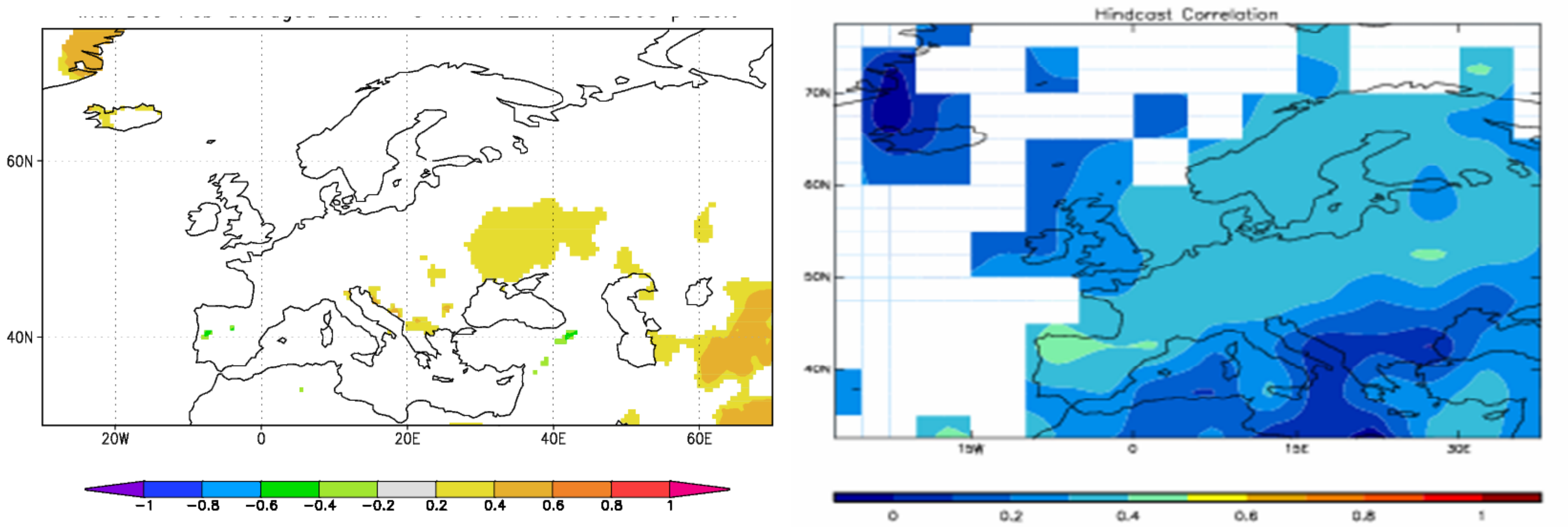
Correlation of System 3 seasonal forecasts of temperature wrt GHCN over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Temperature skill: Potential predictability

(Left) Correlation of System 3 DJF seasonal forecasts of temperature wrt GHCN over 1981-2005. (Right) Potential predictability of DJF seasonal predictions using Folland et al. (2010) statistical model.



Precipitation skill: System 3

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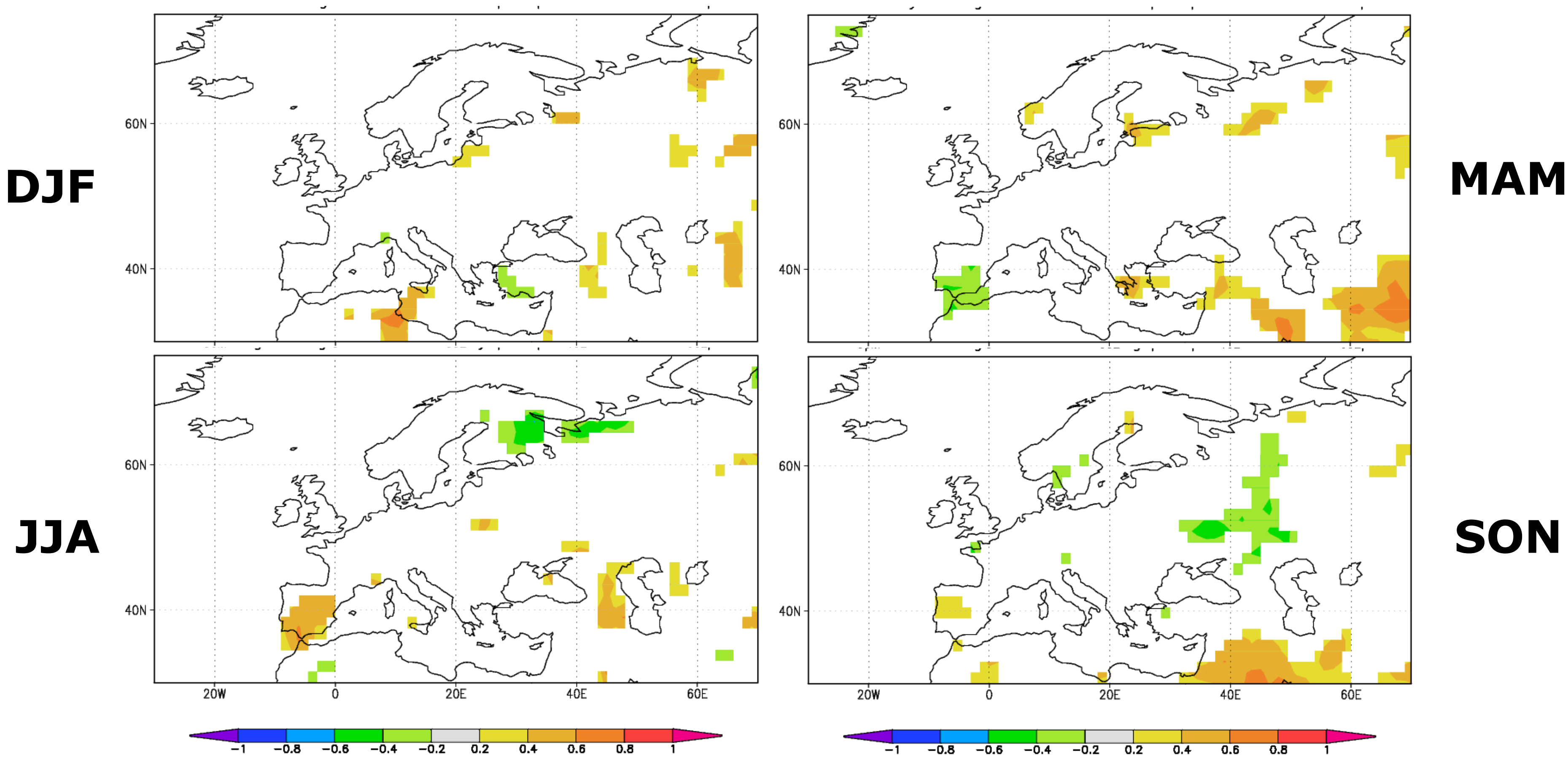
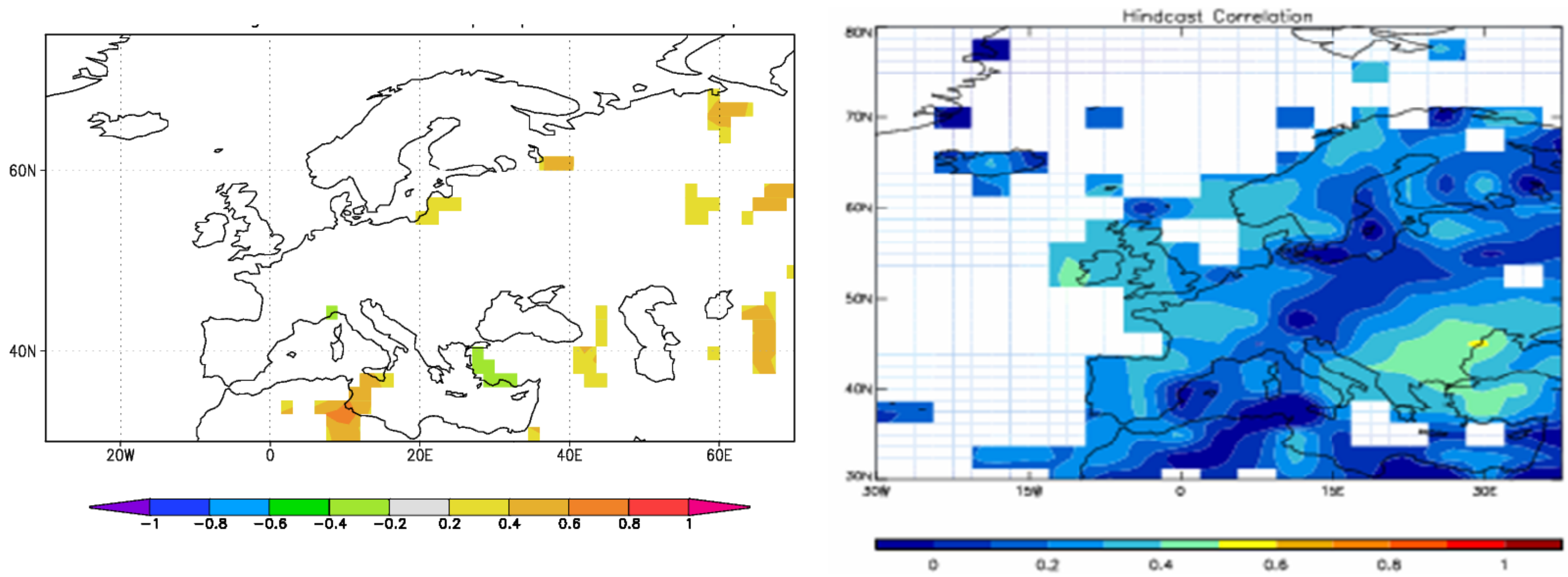
Correlation of System 3 seasonal forecasts of precipitation wrt GPCC over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Precipitation skill: System 3

(Left) Correlation of System 3 DJF seasonal forecasts of precipitation wrt GPCC over 1981-2005. (Right) Potential predictability of DJF seasonal predictions using Folland et al. (2010) statistical model.

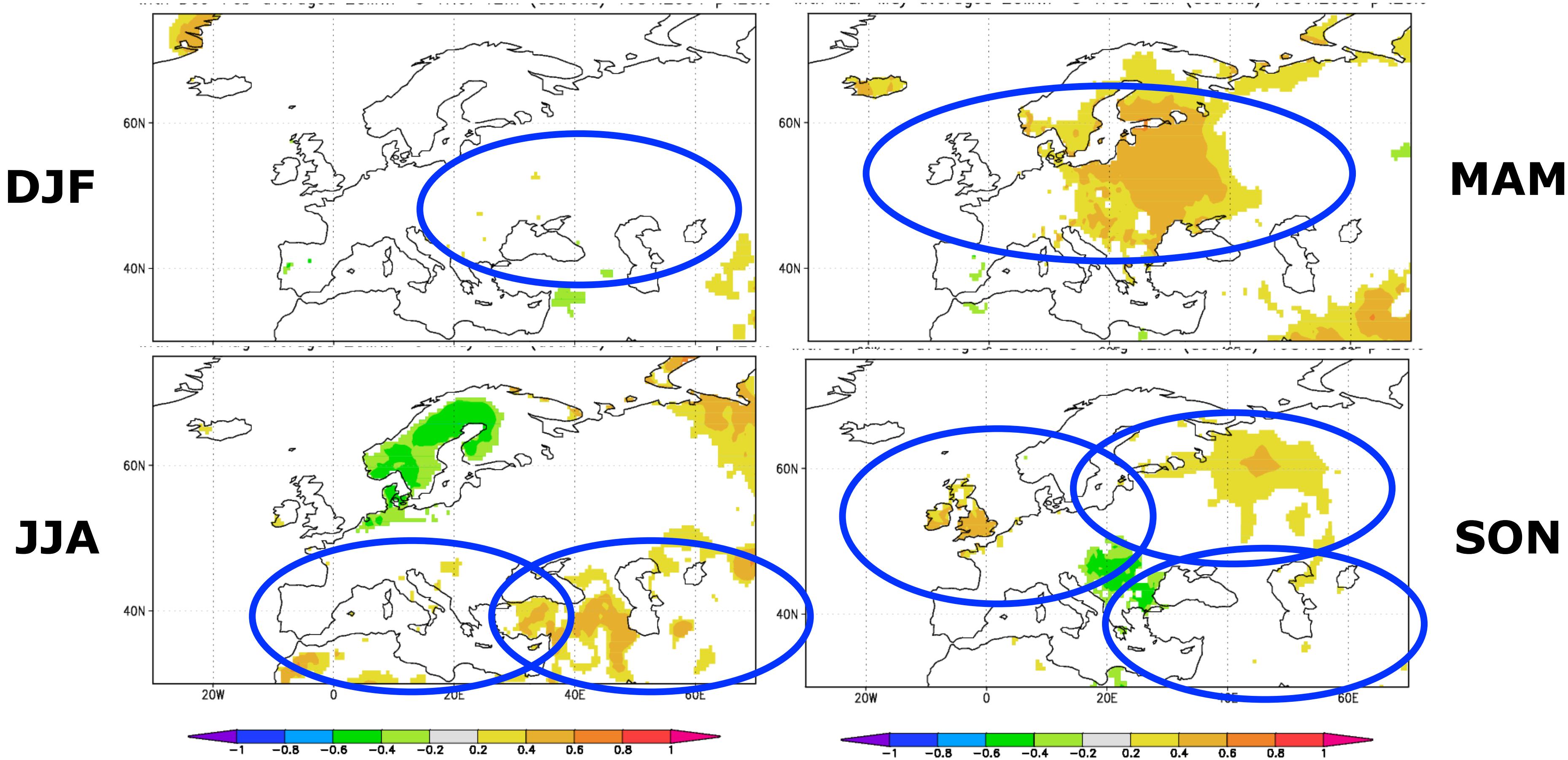


Sources of predictability and error

- ENSO and tropical Atlantic
- Extratropical SSTs
- Trends and anthropogenic warming
- Model inadequacy
- Model improvement
- Soil moisture
- Snow
- Stratospheric processes
- Volcanic aerosol

Impact of the trend: temperature

Correlation of System 3 seasonal forecasts of detrended temperature wrt GHCN over 1981-2005. Only values statistically significant with 80% confidence are plotted.

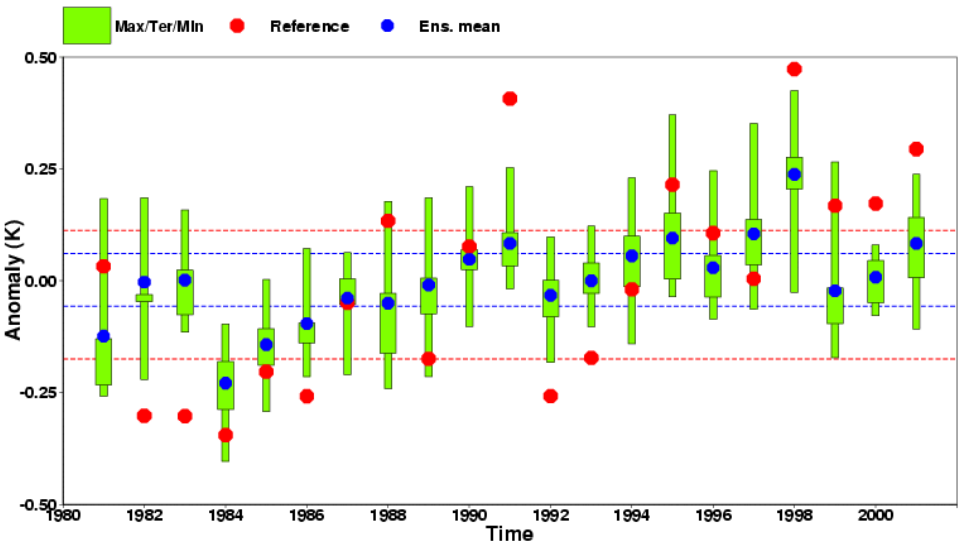


Temperature: global trend

Global-mean near-surface air temperature for System 3. The green box-and-whisker plots show the ensemble range, the blue dot the ensemble mean and the red dot the ERA40/ ERAInt value.

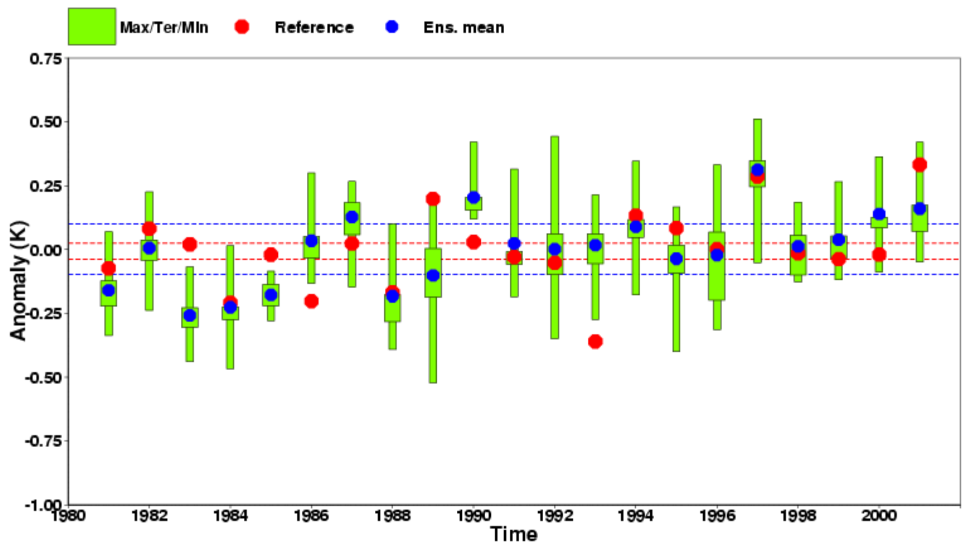
JJA

Ratio sd: 0.59
Corr: 0.69



DJF

Ratio sd: 1.26
Corr: 0.44



Temperature: impact of the trend

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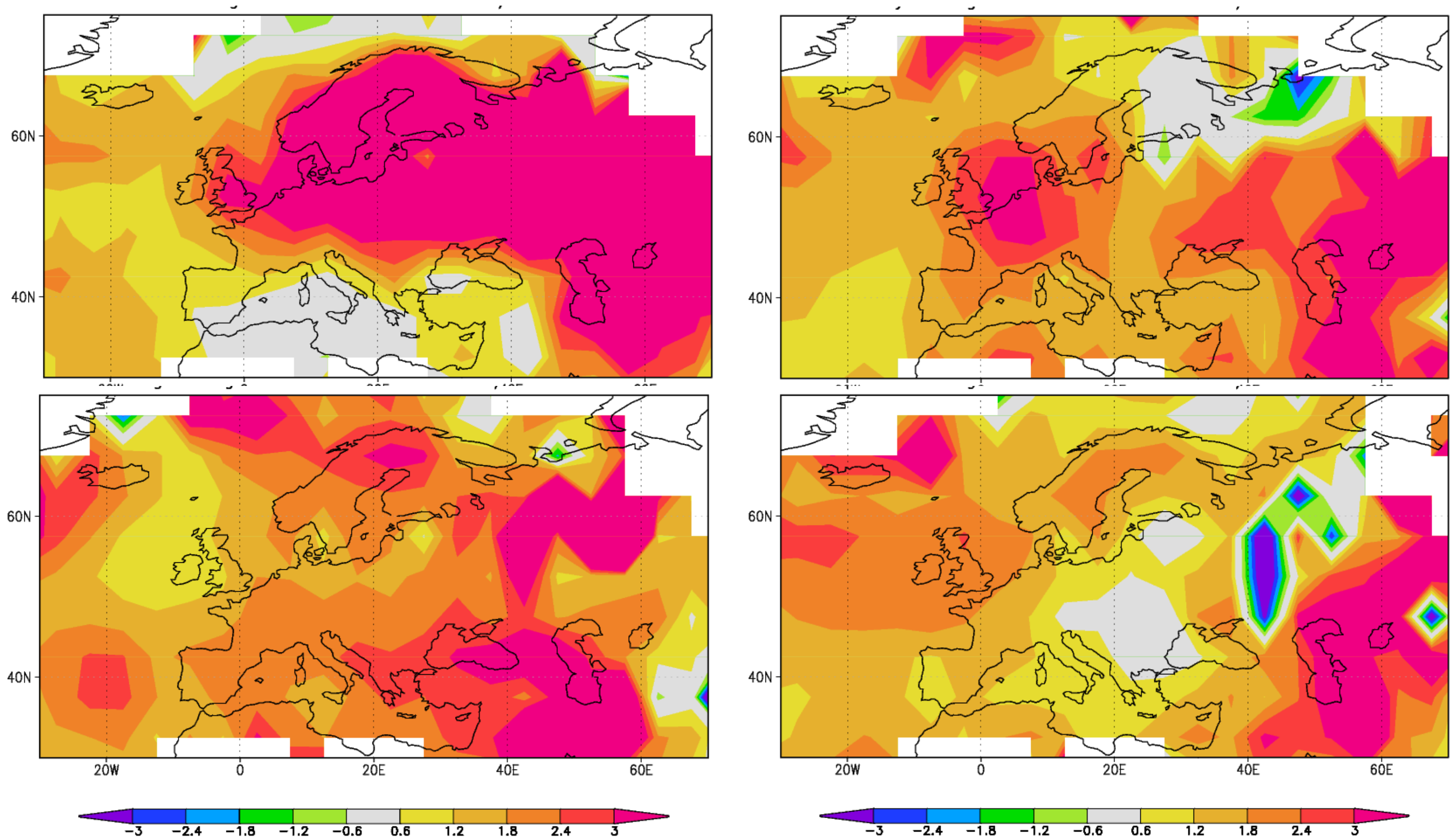
Regression of CRUTEM3/HadSST2 temperature with the HadCRUT3 global-mean temperature over 1981-2005.

DJF

MAM

JJA

SON



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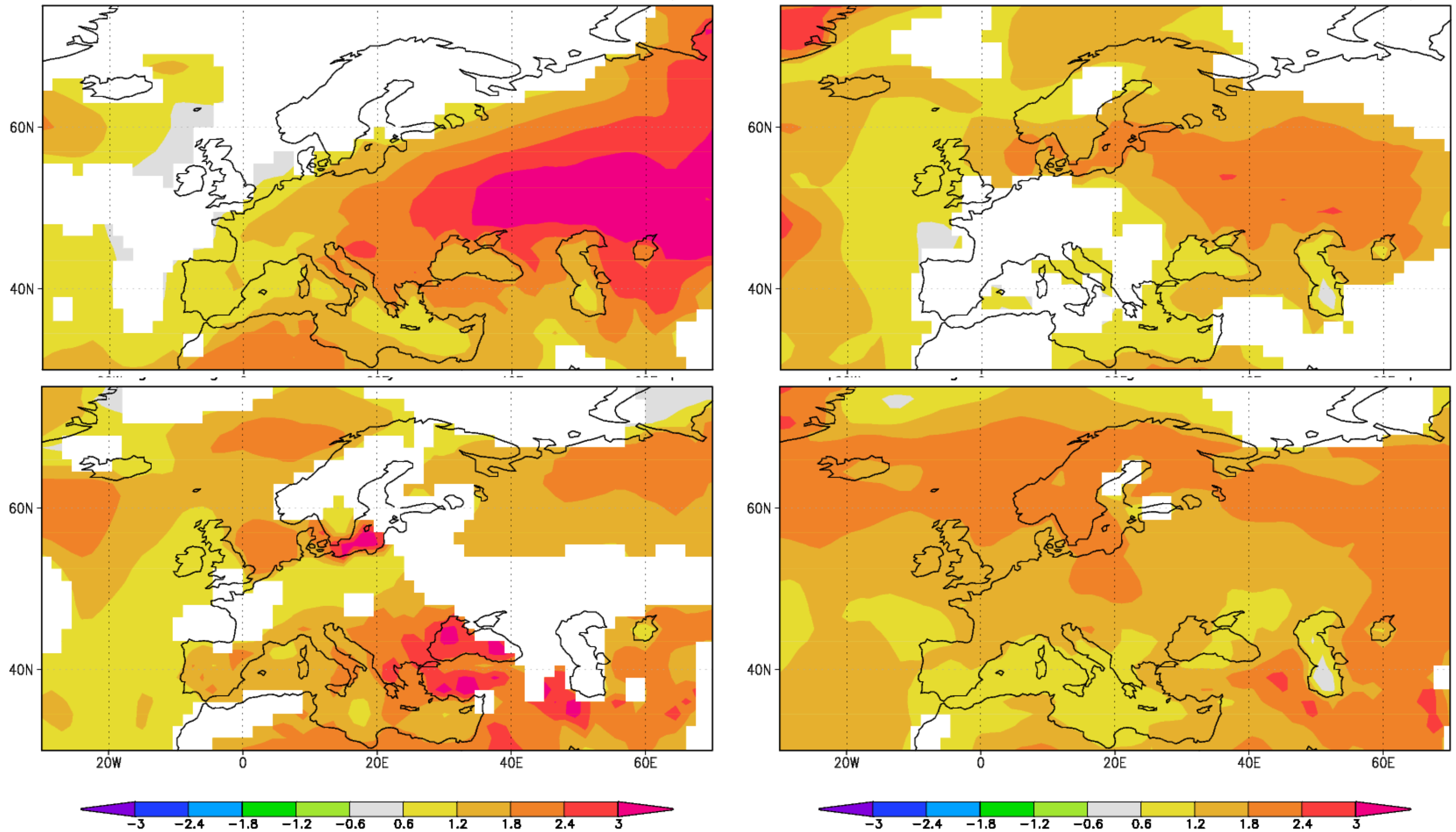
Temperature: impact of the trend

Regression of System 3 temperature seasonal forecasts on the global-mean temperature over 1981-2005. Only values statistically significant with 80% confidence are plotted.

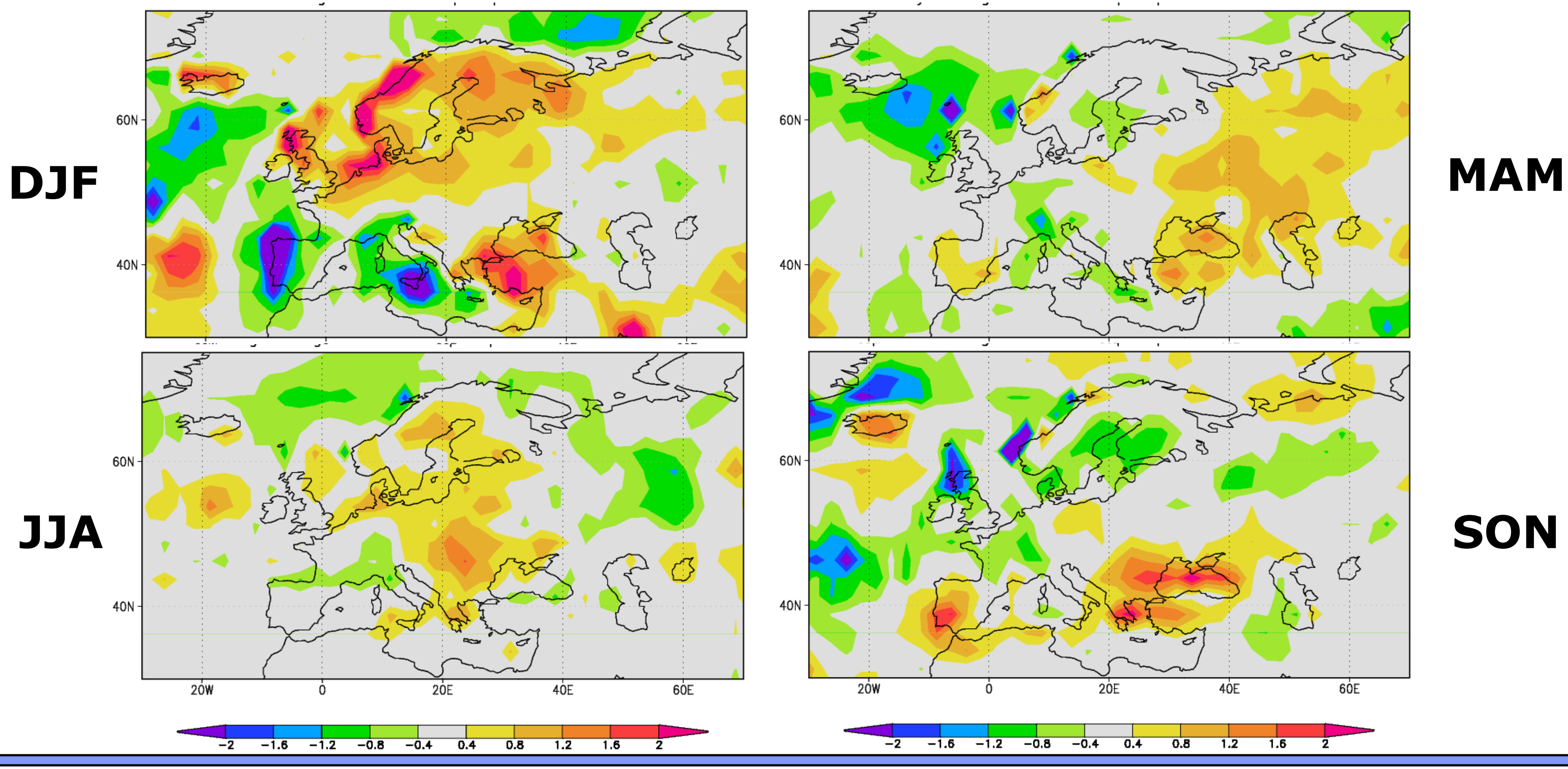
DJF **MAM**

JJA **SON**



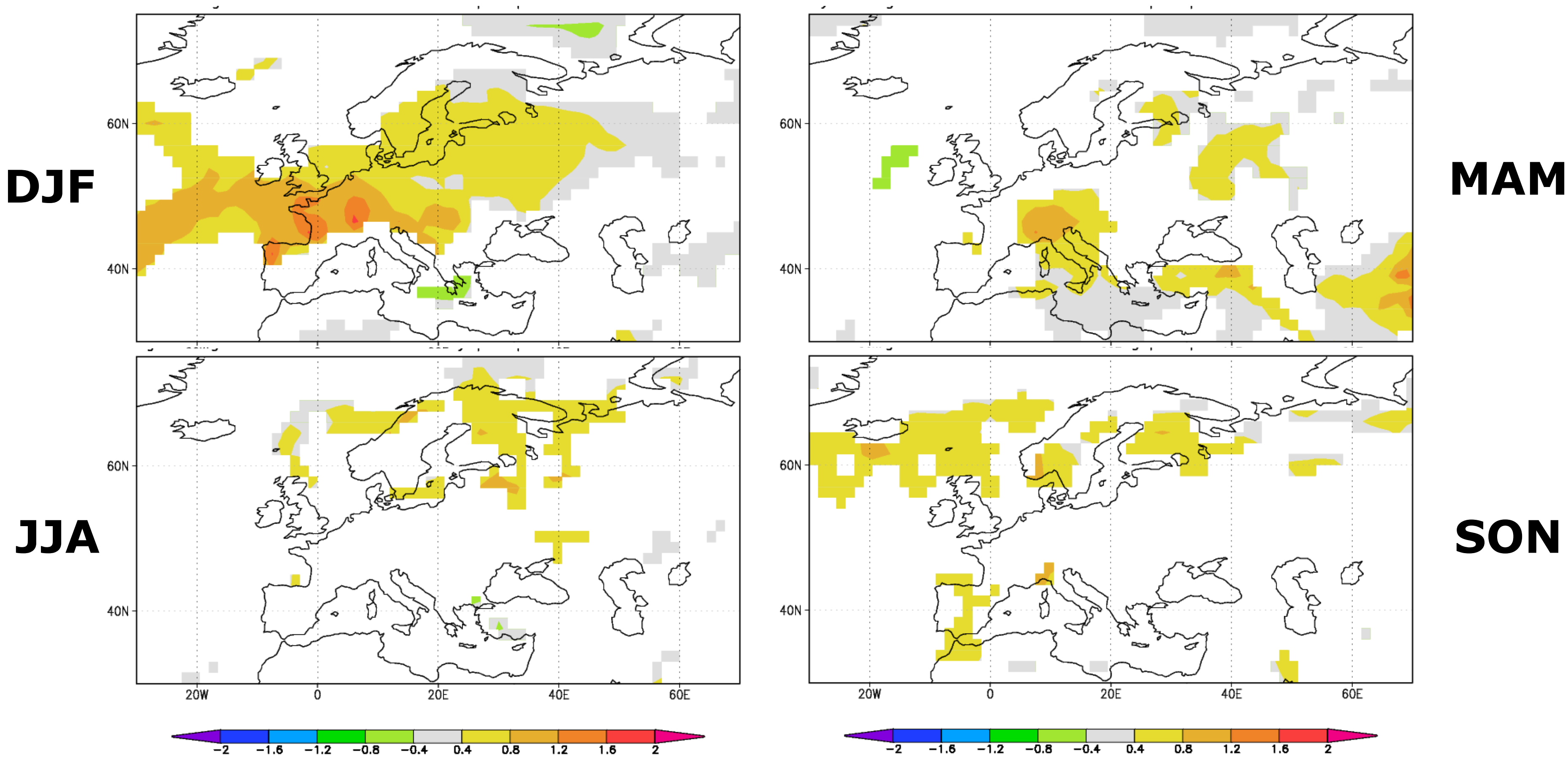
Precipitation: impact of the trend

Regression of GPCP precipitation with the HadCRUT3 global-mean temperature over 1981-2005.



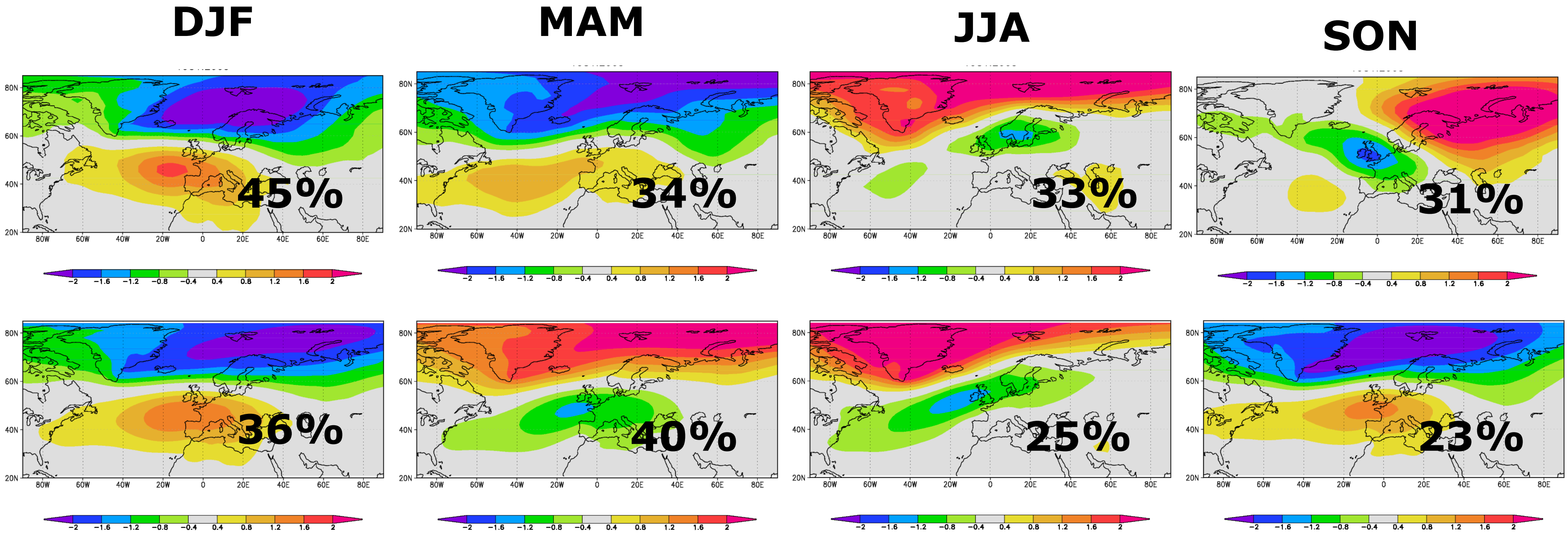
Precipitation: impact of the trend

Regression of System 3 seasonal forecasts precipitation on the global-mean temperature over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Modes of variability: NAO

Leading EOF of SLP over the region 20°-85°N,90°W-90°E for NCEP/NCAR R1 (top row) and one-month lead System 3 re-forecasts (bottom row). Variance percentage in brackets.



Modes of variability: NAO

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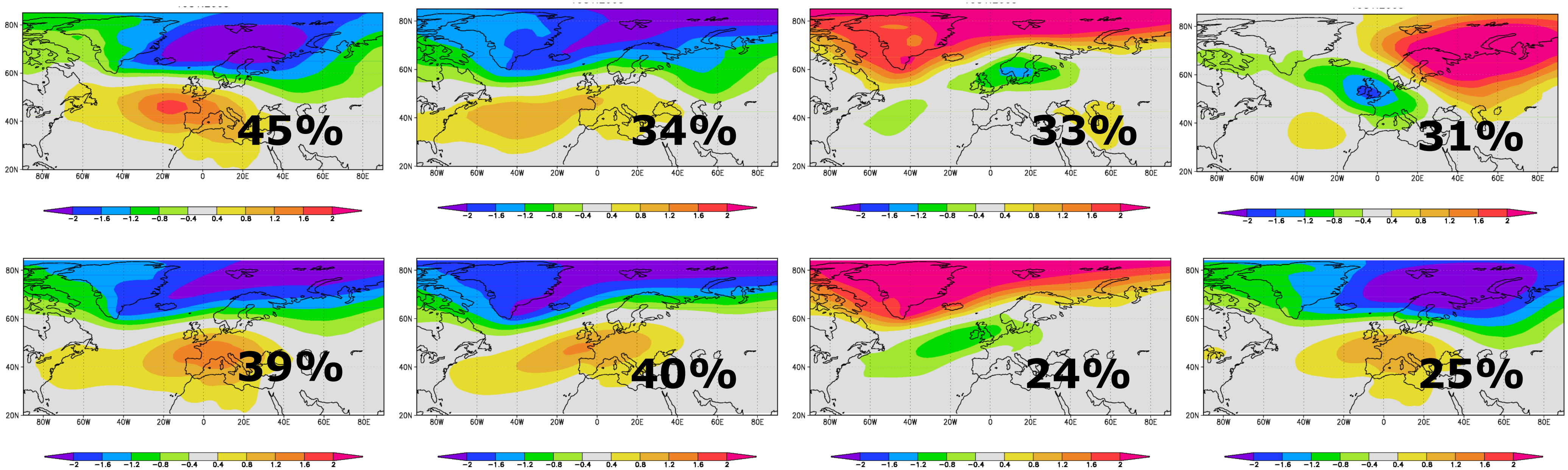
Leading EOF of SLP over the region 20°-85°N,90°W-90°E for NCEP/NCAR R1 (top row) and three-month lead System 3 re-forecasts (bottom row). Variance percentage in brackets.

DJF **MAM** **JJA** **SON**



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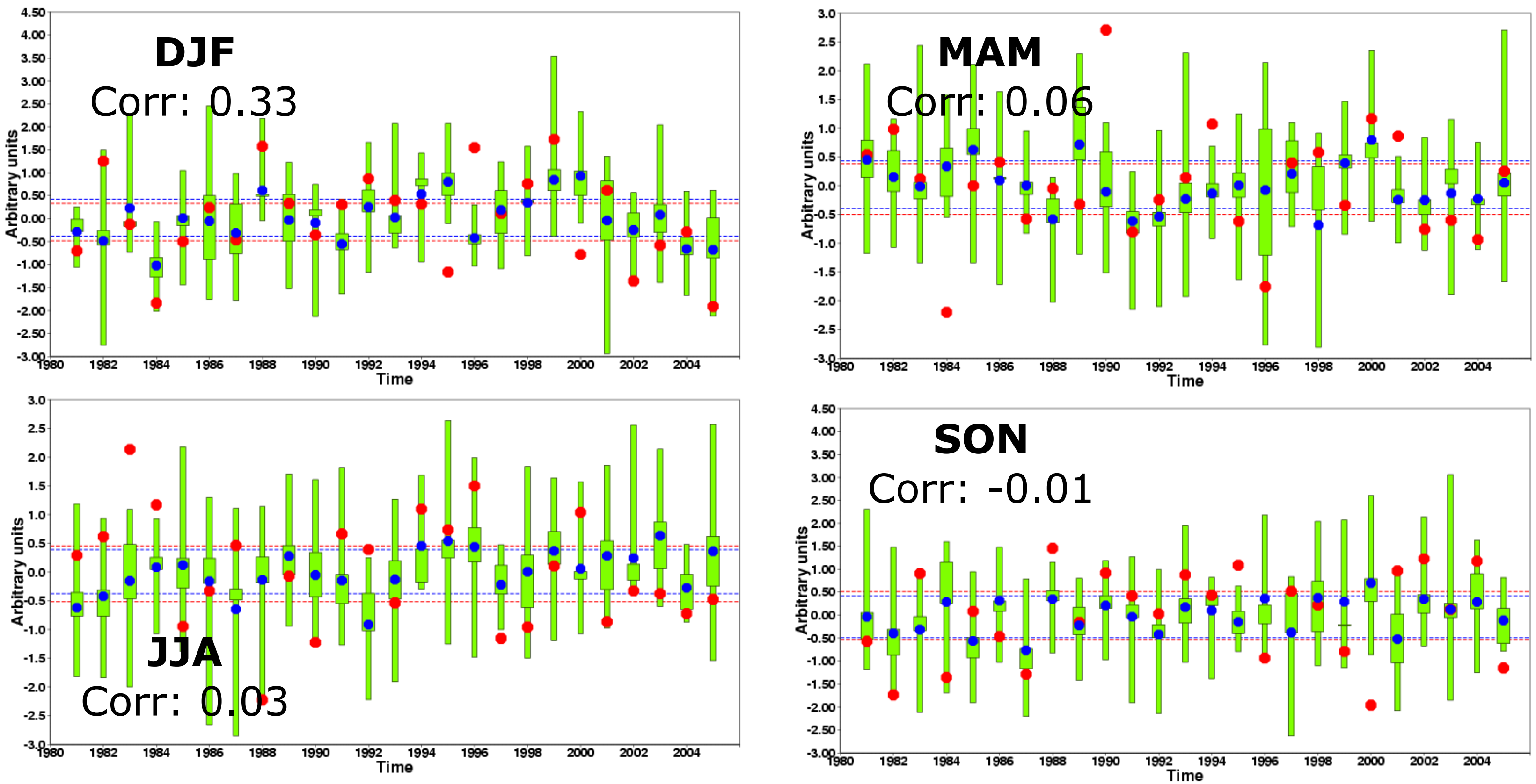
Modes of variability: NAO

System 3 NAO predictions over 1981-2005. The green box-and-whisker show the ensemble range, the blue dot the ensemble mean and the red dot the ERA40/ERAInt value.



Prediction of extreme NAO

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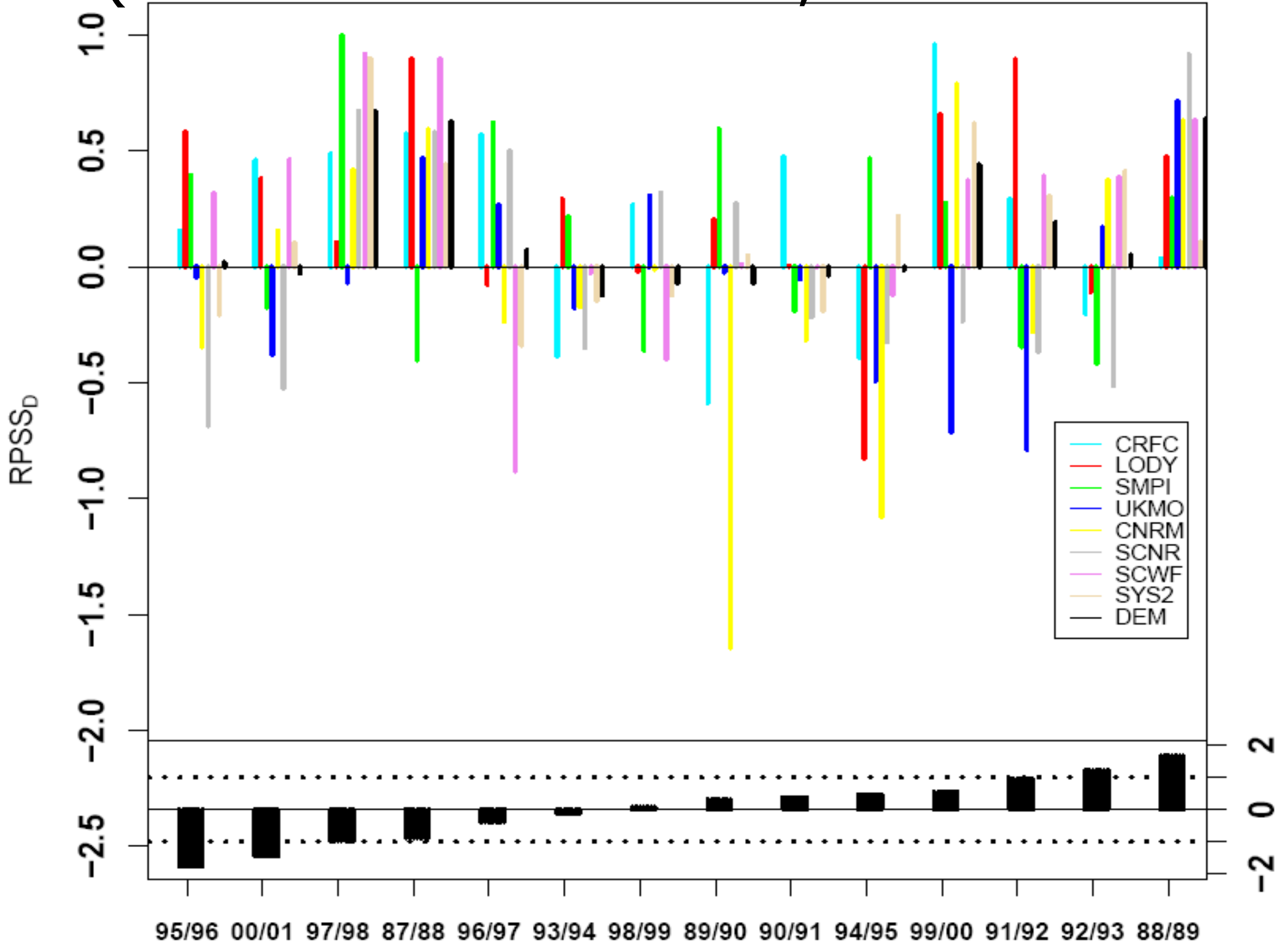
ECMWF System 2 and DEMETER NAO DJF forecasts (November start date, 1-month lead, 1987-2001).



$RPSS_D$ for tercile categories

Observed NAO

Müller et al. (2005)

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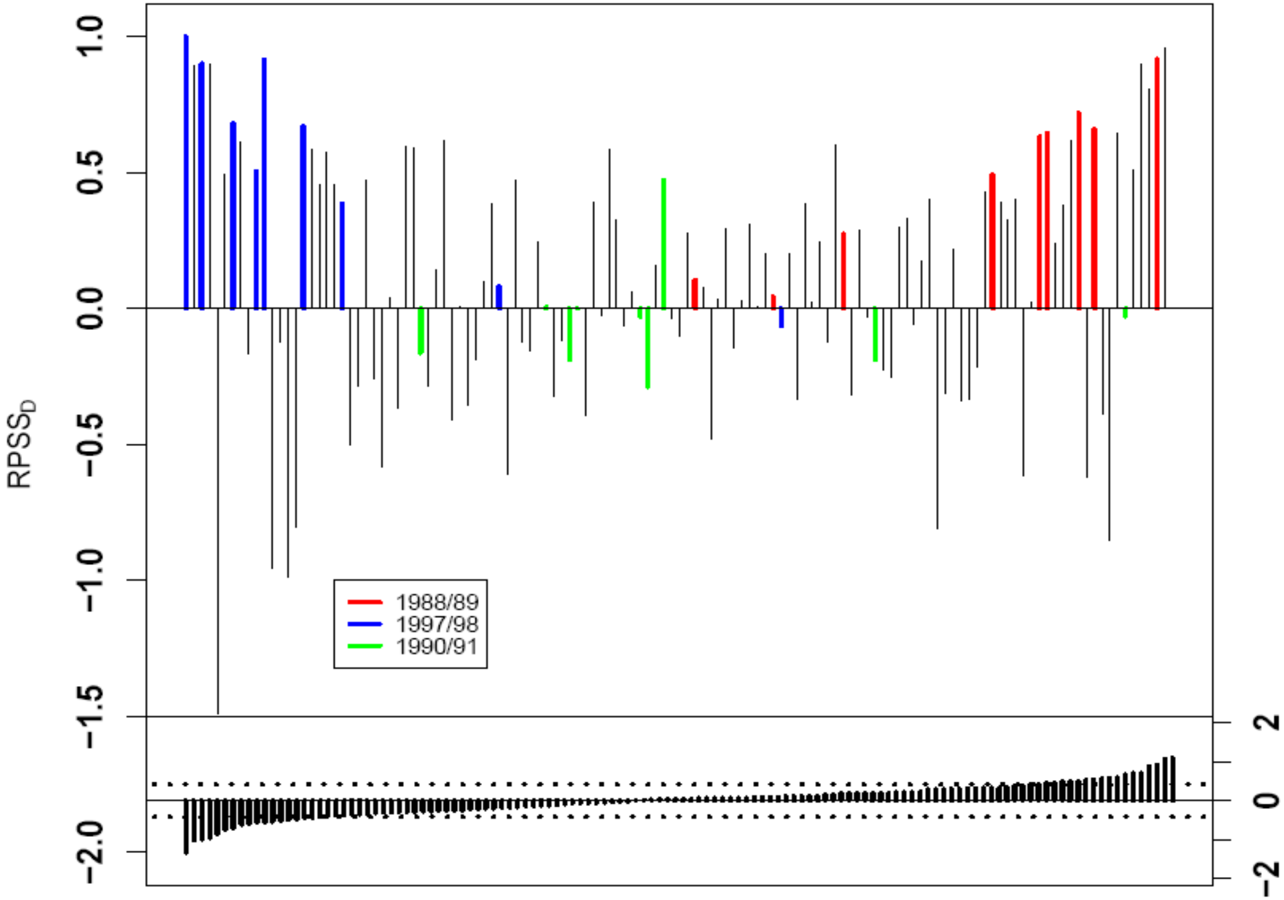
NAO predictions

ECMWF System 2 and DEMETER NAO DJF forecasts (November start date, 1-month lead, 1987-2001).



RPSS$_D$ for tercile categories

Predicted NAO

Müller et al. (2005)

Summary

- Substantial systematic error, including lack of reliability, is still a fundamental problem in dynamical forecasting and forces *a posteriori* corrections to obtain useful predictions. Don't take model probabilities as true probabilities.
- Initial conditions are still a very important issue.
- Estimating robust forecast quality is difficult, but there are windows of opportunity for reliable skilful predictions, and there is always the anthropogenic warming.
- There is a potential coming from methods that deal with model inadequacy (e.g. multi-model ensembles).
- Many more processes to be analyzed: sea ice, anthropogenic aerosols, …

Some final thoughts

- In the end we need trustworthy models, but model development is a slow process.
- Timescale for improvements
  - Optimist: in 10 years, we'll have much better models, pretty reliable forecasts, confidence in our ability to handle climate variations
  - Pessimist: in 10 years, modelling will still be a hard problem, and progress will largely be down to improved calibration Users will require calibration and can provide feedback on the presentation of forecast information.
- Seasonal forecasting over Europe would benefit from a coordinated effort to improve the forecast systems and to combine climate information from different sources.