Decadal climate predictions with the ECMWF coupled system

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In this study we present results of decadal climate hindcasts over the period 1960–2000 carried out with the ECMWF coupled system IFS/Nemo in which both atmosphere and ocean are initialised to bring the state of the coupled model close to the observed state. The ocean conditions have been produced with NEMOVAR, a multivariate 3D-Var data assimilation method. The atmosphere and land surface initialization was from the ERA-40 and ERA-Interim reanalysis. The skill of the model in reproducing the observed coupled teleconnection patterns and the leading modes of interannual variability in the atmosphere is evaluated. An assessment of the extent to which near-surface air temperature is are skilfully predicted in the forecast range from one to ten years is shown as well.

EXPERIMENTAL SET-UP

Model

The atmospheric model is the IFS with a horizontal truncation of TL159 and 91 vertical levels. The ocean model is NEMO V3.0 in the ORCA1 configuration (approximately 1x1 degree lat/lon resolution with an equatorial refinement and 42 levels in the vertical (*Madec et al.* 2008)). The coupler OASIS3 is used to interpolate the fields exchanged once per day between the ocean and atmospheric grids.

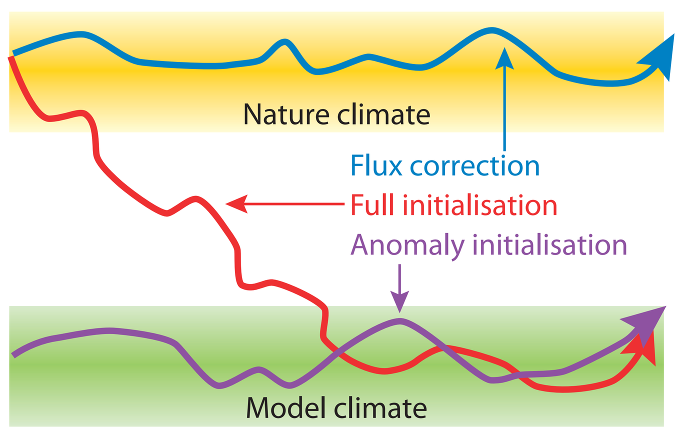
The atmosphere and land surface initialization was from the ERA-40 reanalysis (*Uppala et al.*, 2005) for the period 1960 to 1985, from ERA-interim for the remaining starting dates.

The ocean initial conditions have been produced with NEMOVAR, a multivariate 3D-var data assimilation method for the NEMO ocean model.

In the experiments described below, two different NEMOVAR based systems method have been used: NEMOVAR-COMBINE and NEMOVAR-ORAS4. NEMOVAR-ORAS4 is the operational analysis system for the new Seasonal forecast system (System4) at ECMWF. The main differences with NEMOVAR-COMBINE reside in the improved treatment of observations near the coast, vertical thinning of observations, the latitudinal dependence of the bias terms, and the assimilation of altimeter data (both anomalies and global trends).

Model climate and Nature climate

Model inadequacy causes forecasts starting from an observed state to drift away from the nature climate towards a different model climate. In order to avoid this drift different initialisation and integration strategies can be adopted. One possibility consists in assimilating observed anomalies into the model climate (see for example *Smith et al.* 2007). This method, called "Anomaly Initialisation", is expected to reduce the model drift by translating the observed anomalous state into a model anomalous state. Model drift, and more in general model systematic errors, might be partially compensated during the integration by applying "flux correction" in the coupling between atmosphere and ocean.



Here we show results from hindcasts in which these three methodologies (i.e. full initialisation, anomaly initialisation and flux correction) have been applied.

Experiments

All the hindcasts were started once every five years over the period 1960 to 2005, i.e. in 1960, 1965, and so on. Each simulation started at 00GMT on the 1st of November of each year and run for 120 months.

All the integrations have been carried out at the same model resolution, but two different configurations of the ECMWF coupled system have been used:

EXP 1 IFS Cycle 36R1 / NEMO – ERA40-ERAInterim atmospheric reanalysis – NEMOVAR-COMBINE ocean reanalysis – No Ice Model (sampled Sea Ice from the five years preceding the integration).

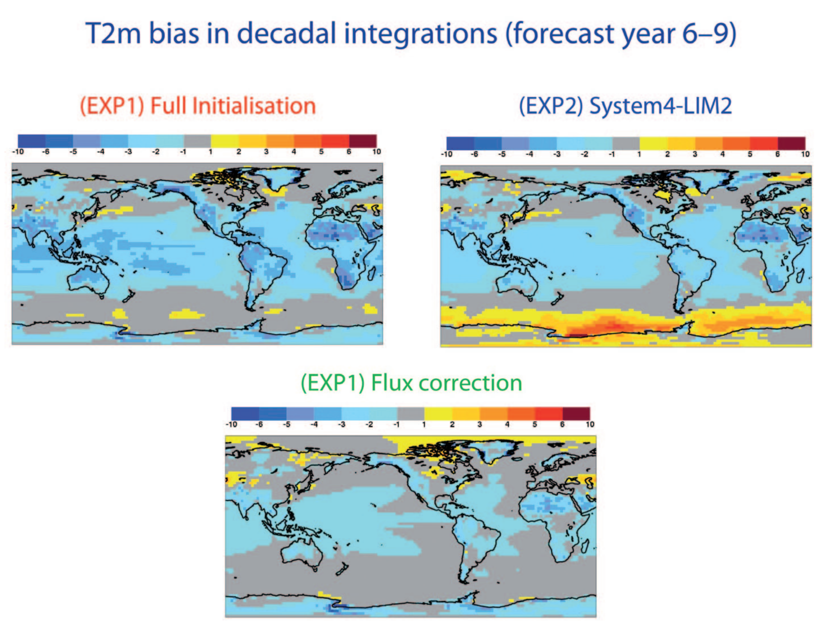
EXP 2 IFS Cycle 36R4 / NEMO [ECMWF System4] - ERA40-ERAInterim atmospheric reanalysis – NEMOVAR-ORAS4 ocean reanalysis – Sea-Ice model LIM2.

Table 1 – Summary of experiments

Model	Ensemble Members	Atmospheric Analysis	Ocean Analysis	Initialisation	Forcing fields	Flux Correction	Volcanic eruptions	Sea Ice Model
IFS36R1/NEMO3 T159L91/1x1	7	ERA	NEMOVAR/ COMBINE	Full Initialisation	Varying GHG & anthropogenic aerosols	No	No	Sampled observed Sea Ice
IFS36R1/NEMO3 T159L91/1x1	7	ERA	NEMOVAR/ COMBINE	Full Initialisation	Varying GHG & anthropogenic aerosols	Heat & Momentum	No	Sampled observed Sea Ice
IFS36R1/NEMO3 T159L91/1x1	7	ERA	NEMOVAR/ COMBINE	Anomaly Initialisation	Varying GHG & anthropogenic aerosols	No	No	Sampled observed Sea Ice
IFS36R1/NEMO3 T159L91/1x1	3	ERA	NEMOVAR/ COMBINE	Full Initialisation	Varying GHG & anthropogenic aerosols	No	Yes	Sampled observed Sea Ice
IFS36R1/NEMO3 T159L91/1x1	3	ERA	NEMOVAR/ COMBINE	Full Initialisation	Varying GHG & anthropogenic aerosols	Heat & Momentum	Yes	Sampled observed Sea Ice
IFS36R4/NEMO3 T159L91/1x1	5	ERA	NEMOVAR/ ORAS4	Full Initialisation	CMIP5	No	Yes	LIM2

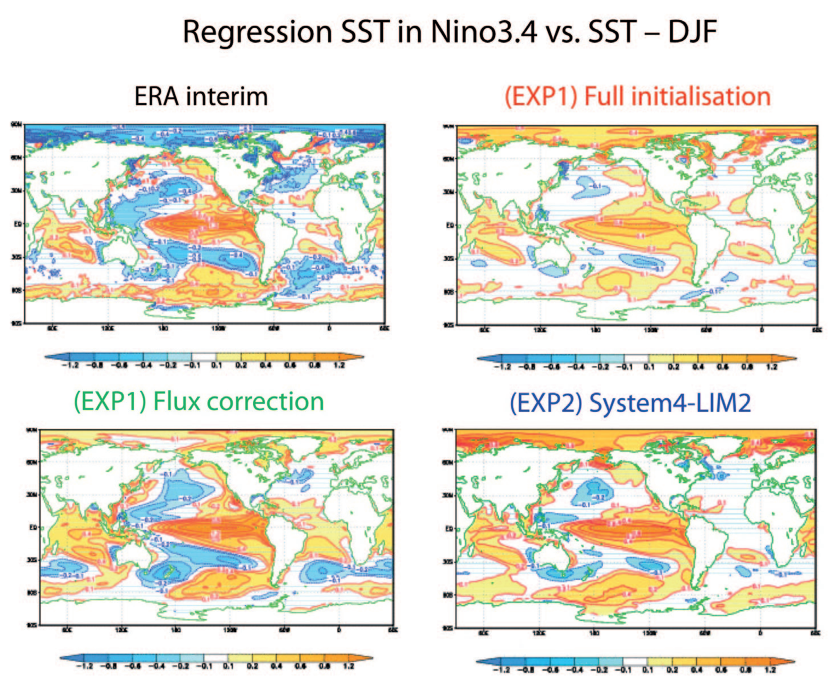
BIAS & EL NINO – SST TELECONNECTIONS

T2m bias in decadal integrations (forecast year 6–9)



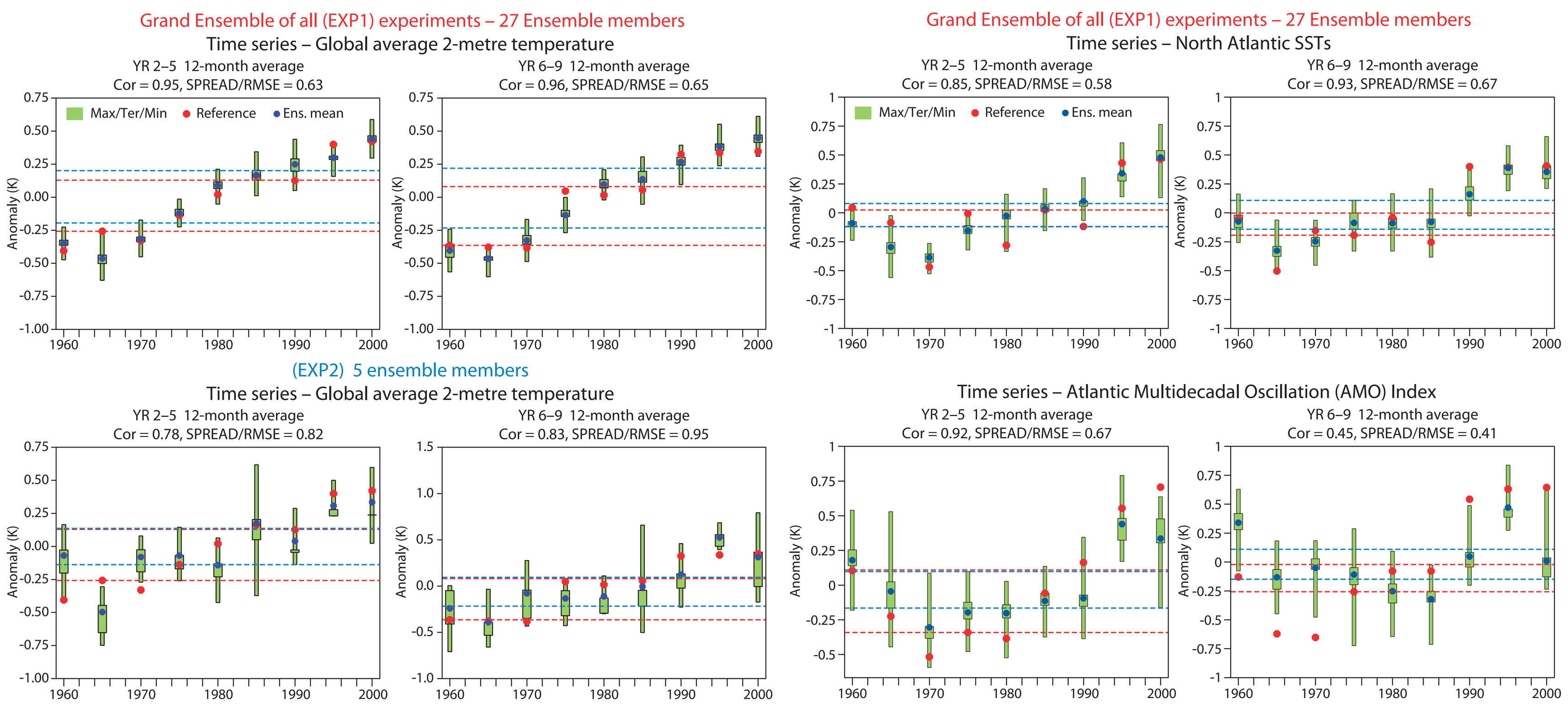
Near Surface Temperature Bias in EXP1 and EXP2 – Average over forecast year 6-9.

Regression SST in Nino3.4 vs. SST – DJF



Regressions patterns of Nino3.4 Index vs. SSTs in DJF. Comparison between model integrations and ERA-Interim.

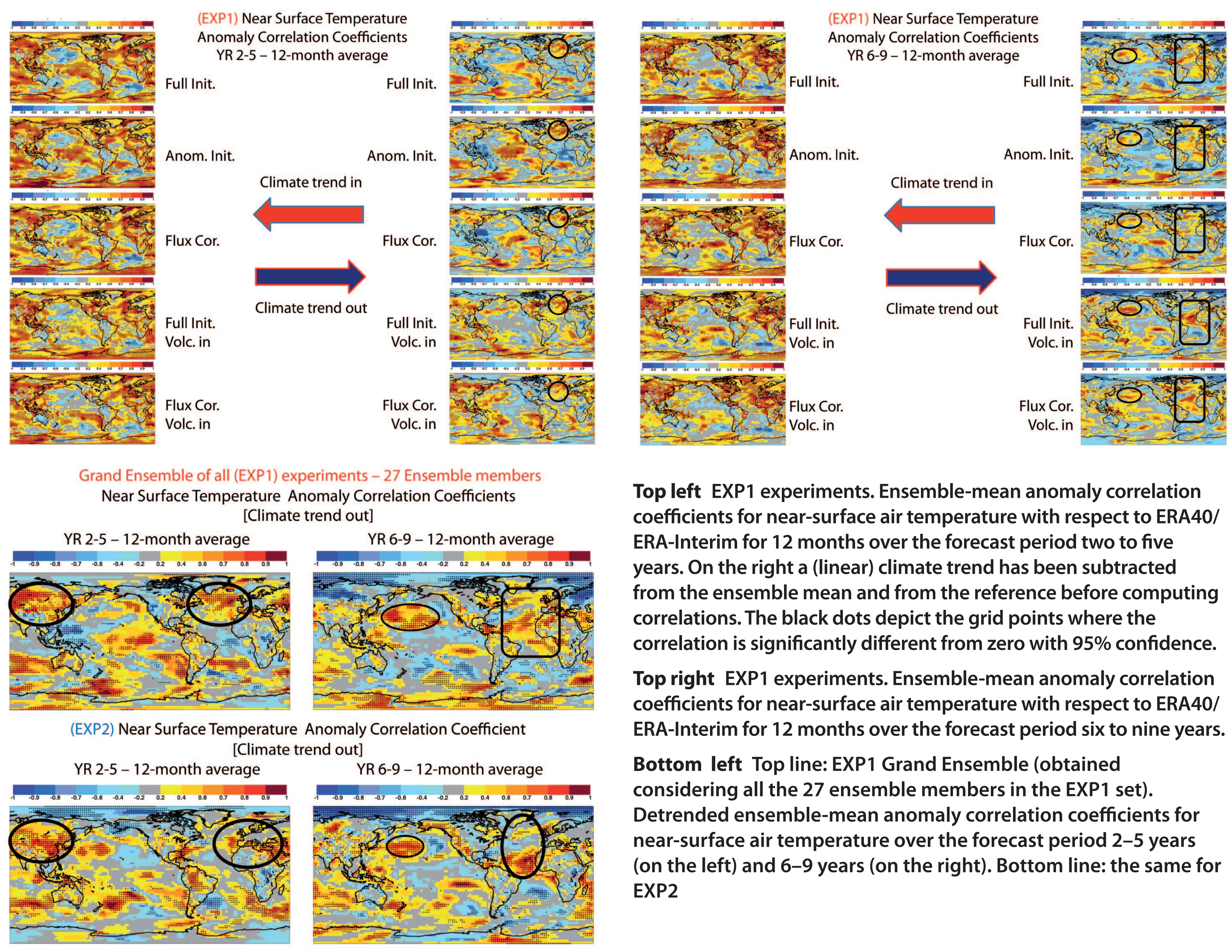
DETERMINISTIC SCORES – TIME SERIES



Time Series of Global average near-surface temperature for EXP1 and EXP2 and for the periods 2-5 years and 6-9 years. The red dots represent the reference, the blue dot the ensemble mean. The green rectangle defines the tercile boundaries and the whiskers are the maximum and the minimum of the ensemble distribution. The dashed lines represent the tercile boundaries over the all period.

Time Series of North Atlantic SSTs and Atlantic Multidecadal Oscillation (AMO) index for EXP1 for the periods 2–5 years and 6–9 years.

DETERMINISTIC SCORES – ANOMALY CORRELATION COEFFICIENTS

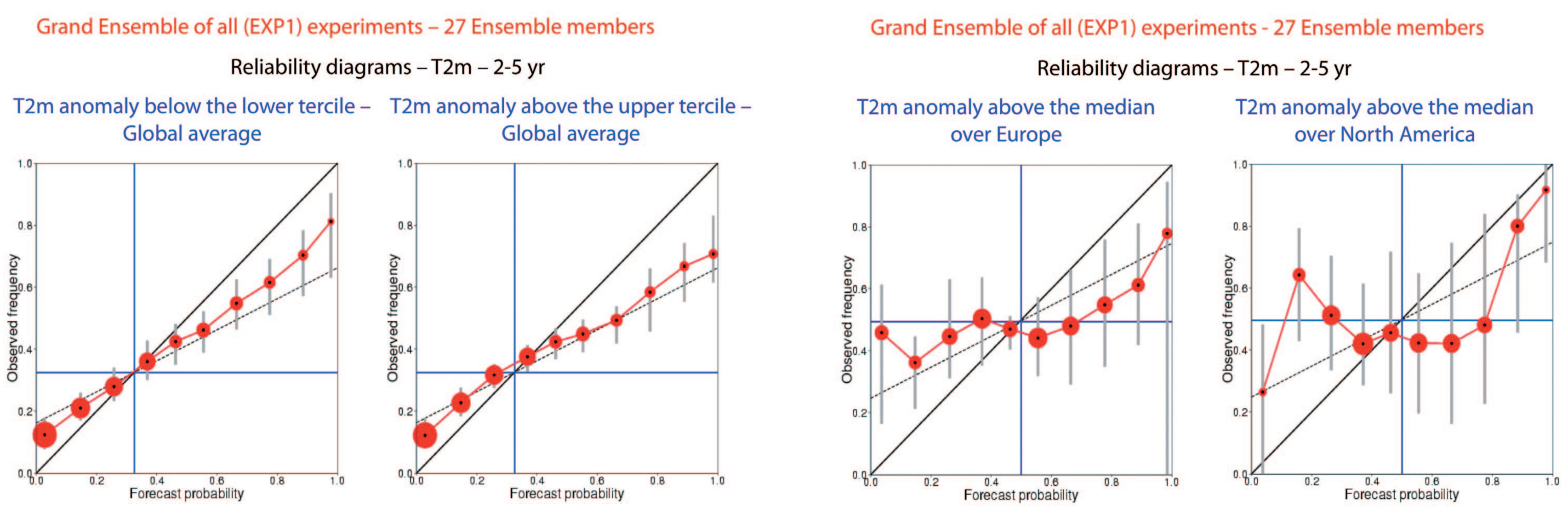


Top left EXP1 experiments. Ensemble-mean anomaly correlation coefficients for near-surface air temperature with respect to ERA40/ ERA-Interim for 12 months over the forecast period two to five years. On the right a (linear) climate trend has been subtracted from the ensemble mean and from the reference before computing correlations. The black dots depict the grid points where the correlation is significantly different from zero with 95% confidence.

Top right EXP1 experiments. Ensemble-mean anomaly correlation coefficients for near-surface air temperature with respect to ERA40/ ERA-Interim for 12 months over the forecast period six to nine years.

Bottom left Top line: EXP1 Grand Ensemble (obtained considering all the 27 ensemble members in the EXP1 set). Detrended ensemble-mean anomaly correlation coefficients for near-surface air temperature over the forecast period 2–5 years (on the left) and 6–9 years (on the right). Bottom line: the same for EXP2

PROBABILISTIC SCORES – RELIABILITY DIAGRAMS



EXP1 Reliability diagrams for the global near-surface temperature anomalies below and above the upper tercile for the period 2–5 years. The size of the bullets represents number of forecasts in probability category (sharpness).

EXP1 Reliability diagrams for the near-surface temperature anomalies blow and above the median over Europe and North-America for the period 2-5 years.

- The IFS36R1/NEMO coupled model is affected by an overall cold bias, which is partially reduced in the new 36r4/NEMO (System4) coupled system. The flux correction improves the ENSO mean state, its variability and the ENSO related teleconnections.
- In spite of model drift and the fact that several climate processes, such as those related to sea-ice formation, export and melting, are not represented in the model, the decadal prediction experiments labelled EXP1 show a positive forecast quality that can be statistically significant over several areas.
- Some regions (common to all the experiments carried out) of more pronounced predictability have been identified.
- Reliability diagrams show encouraging results when applied to global means.

REFERENCES

Madec, G., 2008: NEMO ocean engine. *Note du Pôle de Modélisation, Institut Pierre-Simon Laplace (IPSL)*, **No 27**.

Smith D. M, S. Cusack, A. W. Colman, C. K. Folland, G. R. Harris, and **J. M. Murphy** (2007), Improved surface temperature prediction for the coming decade from a global climate model, *684 Science*, **317**, 796–799

Uppala, S. M. and 45 others, 2005. The ERA-40 reanalysis. *Q. J. R. Meteorol. Soc.*, **131**, 2961-3012.