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# Decadal climate predictions with the CMCC-CM coupled OAGCM initialized with ocean analyses

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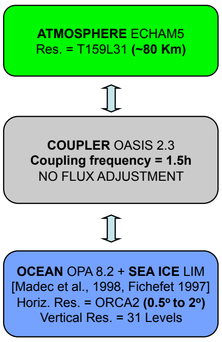
## INTRODUCTION

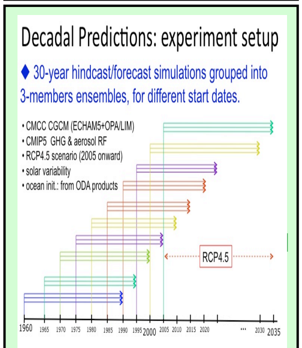
The effects of realistic oceanic initial conditions on a set of decadal climate predictions performed with a state-of-the-art coupled ocean-atmosphere general circulation model (OAGCM) are investigated. The decadal predictions are performed in both retrospective (hindcast) and forecast mode. The full set of predictions consists of 3-members ensembles of 30-years simulations, starting at 5-years intervals from 1960 to 2005, using CMIP5 historical radiative forcing conditions (including greenhouse gases, aerosols and solar irradiance variability) for the 1960-2005 period, followed by RCP4.5 scenario settings for the 2005-2035 period. The ocean initial state is provided by ocean syntheses differing by assimilation methodologies and assimilated data. The use of alternative ocean analyses yields the required perturbation of the full three-dimensional ocean state aimed at generating the ensemble members spread. A full-value initialization technique is adopted. The predictive skill of the system is analysed at both global and regional scale as well as the processes underlying the enhanced predictability exhibited over specific regions. SST predictive skill, particularly for the long decadal term, is mainly driven by the external radiative forcing trend. However, after detrending, residual skill is evident, particularly in the Atlantic region. This is consistent with predictability found for the Atlantic Dipole and AMO indices (2-5 yrs) and Atlantic MOC (3-4 yrs).

## The CMCC-CM Coupled Model

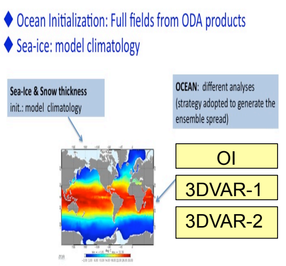



The CMCC-CM Coupled Model

## Experiment Setup




## Initialization & Perturbation




**Perturbation of ocean initial conditions using different ocean reanalyses**

**CMCC OI** (Bellucci et al.2007): Assimilating in-situ T,S observations (ENSEMBLES EN3 dataset) using an Optimal Interpolator assimilation system.
**CMCC 3DVAR** (Storto et al., 2011): Assimilating EN3 in-situ T,S data (as OI) + along-track sea-level anomaly observations using a three-dimensional variational data assimilation system (two different implementations).

## Global SST

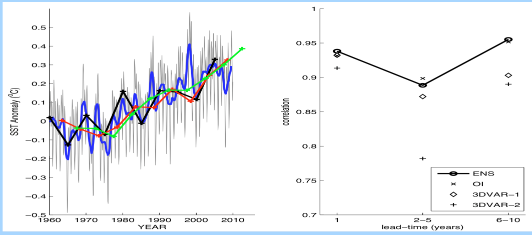
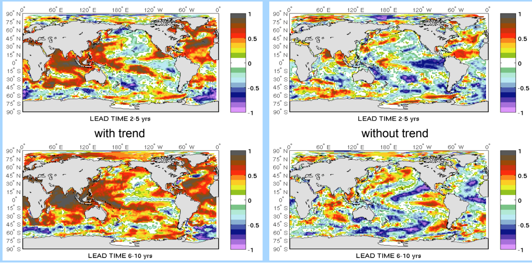



**Fig. 1 (left) shows the time series of global mean SST anomalies (w.r.t. 1960-1990 baseline) in observations (grey and blue) and ensemble mean predictions, with the latter averaged over lead times 1 (black), 2-5 (red) and 6-10 (green) yrs. The effect of initialization is clearly reflected in the 1-yr lead time hindcasts (right panel), while slightly lower skill in the 2-5 years range emerges in contrast with the larger score revealed for the 6-10 years range. To large extent, ensemble averaged SSTs show a better skill with respect to single enesemble members, confirming a well known result from seasonal prediction studies.**




**Anomaly Correlation (AC) patterns for ens. mean SST evaluated against HadISST data, are shown in figure 2 for lead-time 2-5 yrs (top) and 6-10 yrs (bottom), with (left) and without (right) linear trend. Residual skill after removing the trend emerges over wide areas of the North Atlantic over lead-times 2-5 yrs. Statistical significance at 90% is r=0.47 (one-sided t-test 9 pts)**

## Atlantic Multidecadal Variability

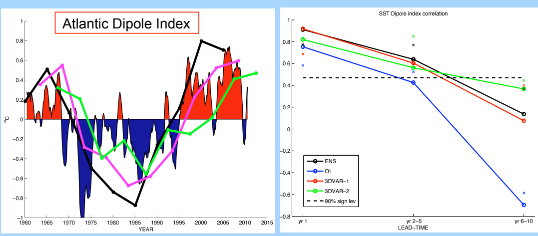



**Fig.3 [Left] Time series of an SST index defined as the area-averaged SST in the [40-60N; 60W-10W] minus [10-40S;30W-10E] region for observations and ensemble mean predictions for yr 1 (black), yrs 2-5 (magenta) and yrs 6-10 (green). [Right] Significant predictability with the observed record is found up to 2-5 years. Predictions initialized with 3DVAR reanalyses show a better skill compared to OI. The same statistics but for the detrended AMO index (Trenberth and Shea, 2006) is also shown (crosses ; right panel), revealing qualitatively similar results.**

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## Atlantic Meridional Overturning Circulation

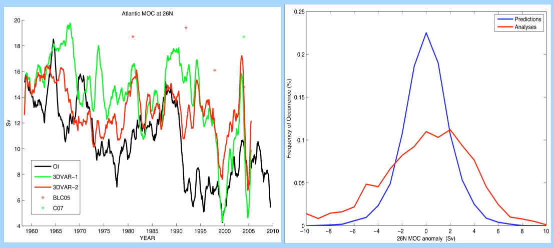


**Fig.4[Left] Time series of the maximum Atlantic MOC (AMOC, Sv; 1 Sv=$10^6$ $m^3s^{-1}$) at 26°N from CMCC ocean reanalyses (used to initialize decadal predictions) using OI and 3DVAR data assimilation schemes. Two different parameterizations for the background error covariance are used in 3DVAR-1 and -2. 3DVAR reanalyses display a closer agreement with existing estimates (Bryden et al. 2005; Cunningham et al. 2007), wrt OI. The large AMOC spread highlights the large perturbations imposed to the initial state of the MOC for different ensemble members. [Right] PDF of AMOC anomalies at 26N from ocean reanalyses and predictions (obtained by removing average forecast from each raw forecast). Predicted AMOC span a much narrower range of values, wrt reanalyses, revealing a systematic underestimation of MOC variance.**

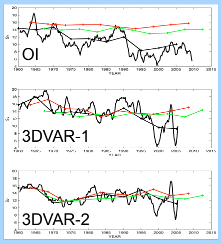


**Fig.5 the AMOC at 26N for each initialization reanalysis (black) and the corresponding predictions averaged over lead-times 1 (black-dot), 2-5 (red) and 6-10 (green) yrs are shown. The comparison highlights the large sensitivity of predicted MOC to the specific ocean initialization data set. In particular, OI-initialized hindcasts exhibit a systematic upward drift in the 2-5 years transient after initialization, which is virtually absent in the 3DVAR-initialized predictions.**

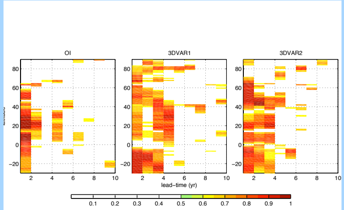


**Fig.6 shows the AC for the Atlantic MOC in the 2D latitude-lead time domain for different initialization reanalyses. Compared to OI, the 3DVAR-initialized predictions display a longer term predictability (3-4 yrs against 1-2 years in OI) for a wide range of latitudes. MOC and Atlantic Dipole Index show a consistent level of predictability both showing predictive skill in the 2-5 yrs range.**

## CONCLUSIONS

- **SST predictive skill, particularly for the long decadal term, is mainly driven by the external radiative forcing trend. However, after detrending, residual skill is evident, particularly in the Atlantic region.**
- **Unforced variability associated with Atlantic Dipole and (detrended) AMO index are skillfully predicted up to the 2-5 yrs range.**
- **Atlantic MOC is very sensitive to assimilation methodology and data used to produce the initial conditions. MOC shows predictability up to 3-4 yrs.**
- **3DVAR-initialized predictions exhibit a better performance wrt to OI.**

### References

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