Supplementary Material

Potential of Equatorial Atlantic Variability to Enhance El Niño Prediction

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1. Model and experiments

Model: All experiments were performed with the ECHAM5/MPI-OM coupled general circulation model (GCM) from Max-Planck Institute for Meteorology in its IPCC AR4 configuration [*Jungclaus et al.*, 2006]. The atmospheric component, ECHAM5 [*Roeckner et al.*, 2003], is a spectral model. It is run at T63 (~1.8°) horizontal resolution, and with 31 vertical levels, extending to 10hPa (~30km). The oceanic component, MPI-OM [*Marsland et al.*, 2003], solves the primitive equations for a hydrostatic Boussinesq fluid on a curvilinear grid with a 1.5° average horizontal resolution and 40 vertical levels; a sea-ice model is embedded in MPI-OM. The two components are coupled with the OASIS3 software [*Valcke*, 2006]. No flux adjustment is applied.

Experiments: The impact of Atlantic SST on seasonal prediction skill in the Indo-Pacific Sector is assessed with six different experiments. The first five are seasonal prediction experiments differing only in their treatment of SST over the Atlantic. They are initiated each year on the 1st of February and end December 31st (i.e., 11-months long), cover the period 1980-2005, and unless indicated otherwise, consist of nine ensemble members:

1. *Standard* prediction is the reference for the other experiments, as global SST evolves freely, and in common with other prediction systems [*Stockdale et al.*, 2006], skill in predicting boreal summer equatorial Atlantic SST is poor (Fig. S1).

2. *Observed Atlantic SST* assesses the impact of near-perfect knowledge of Atlantic SST on prediction skill. Model SST are relaxed to observations over the Atlantic in this experiment, which otherwise is as Standard. The relaxation constant is strong (0.25 day^{-1}) between 30°S-30°N, and decreases linearly to zero between 30-60°S and between 30-60°N. Poleward of 60°S and 60°N and outside the Atlantic the model is fully coupled.

3. *Observed Equatorial Atlantic SST* isolates the impact of equatorial Atlantic variability. It is as Observed Atlantic SST, except that model SST are relaxed to observations only over the equatorial Atlantic (20°S-10°N). The relaxation constant is 0.25 days^{-1} between 15°S-5°N, and decreases linearly to zero between 15-20°S and between 5-10°N. Outside the equatorial Atlantic (10N-20S) the model is fully coupled.

4. *Observed Atlantic climatological SST* assesses the impact of improving the model Atlantic climatology. It is as Observed Atlantic SST, except that model SST are relaxed to the observed (1980-2005) monthly climatology.

5. *Observed Atlantic SST till May* is as the Observed Atlantic SST experiment, except that from June-December model SST is restored to observed climatological SST rather than interannual varying SST. From Feb 1st to May 30th both experiments are identical. This experiment consists of only five ensembles members. It is used to assess the impact of observed SST variations from June to December, verses those in boreal spring.

6. *Observed Atlantic SST 20C* estimates predictive skill arising solely from Atlantic SST variability. It is a partial-coupled experiment with SST relaxed to observations only over the Atlantic, as in the Observed Atlantic SST forecasts. The experiment begins in 1950 and ends in 2005, and consists of five ensemble members that differ only in their initial conditions. This experiment has been used to investigate the Zonal Mode's influence on ENSO [*Ding et al.*, 2011].

Forecast initialisation: the initial conditions for the prediction experiments were obtained from three coupled integrations covering the period 1950-2005 in which model SST were relaxed to observations, as in previous studies [*Keenlyside et al.*, 2005; *Keenlyside et al.*, 2008]. The relaxation constant varies in latitude as in Observed Atlantic SST, but extends to the other oceans. This simple method has skill in simulating upper ocean heat content anomalies in the Tropical Pacific, due to strong ocean-atmosphere coupling [*Keenlyside et al.*, 2005]. The observed SST used in all experiments is the NCEP/NCAR reanalysis [*Kalnay et al.*, 1996] daily skin temperature. The three initialisation simulations and the Observed Atlantic SST 20C experiments were started from year 1950 of three different 20th century simulations. Other studies with different relaxation constants achieve similarly skilful predictions [*Luo et al.*, 2005; *Luo et al.*, 2010]

Radiative forcing in the initialisation and Observed Atlantic SST 20C experiments, as well as the three 20th century simulations used to initialise both, follows observations (greenhouse gas and sulphate aerosol concentrations, solar cycle variations, and major volcanic eruptions) prior to 2000, and the IPCC A1B scenario post 2000 [*Keenlyside et al.*, 2008]. Radiative forcing in the seasonal predictions is identical, except that solar cycle variations are repeated from the previous eleven years, and major volcanic eruptions that occurred during a forecast are not included, but the impact of any that occurred prior to the forecast is reduced with a one-year e-folding time.

2. Supporting figures

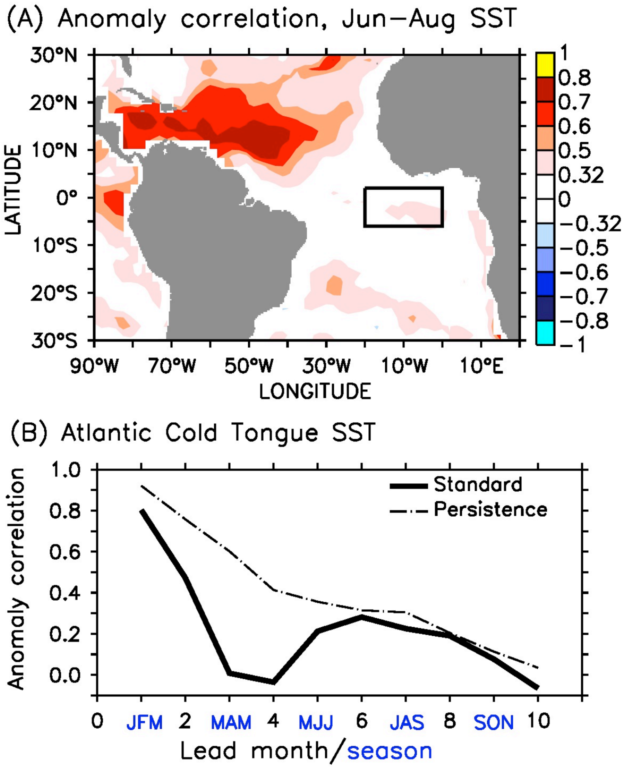


Figure S1. Skill of the standard predictions for Equatorial Atlantic SST (A) summer (JJA) and (B) averaged over the Equatorial Atlantic cold tongue (20°-0°W,6°S-2°N; box in A) as a function of forecast lead time. Predictions were started February 1st. Skill in (B) is computed for centered seasonal three-month averages, and skill for persistence forecast is also shown. Values greater than 0.32 are significant at the 5% level according to a 1-sided Student's t-test.

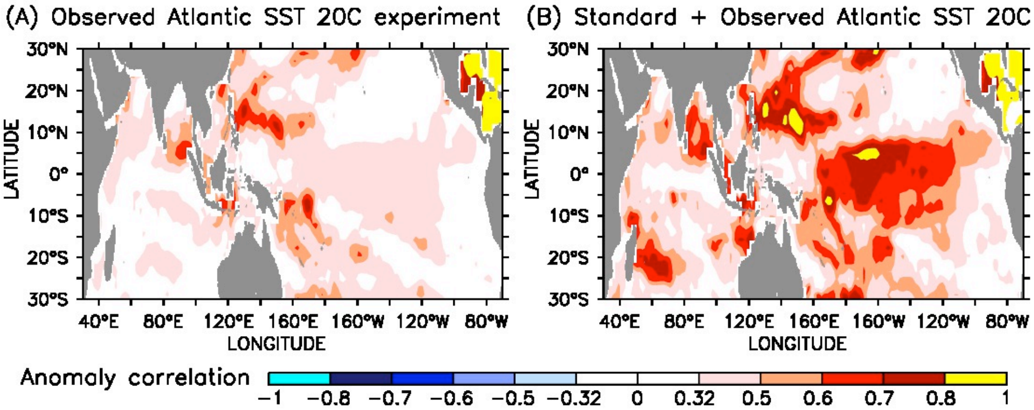


Figure S2. Anomaly correlation skill for October-December average SST for (A) coupled model experiments with model SST relaxed to observations over the entire Atlantic (60°S-60°N) and radiative forcing following observations. (B) Correlation due to the summed contributions of prediction skill from variability internal to the Pacific and forced from the Atlantic, as estimated as the square root of summed variances of Standard and Observed Atlantic SST 20C experiments. Shaded positive values are significantly different from zero at 5% level according to a 1-sided Student's t-test.

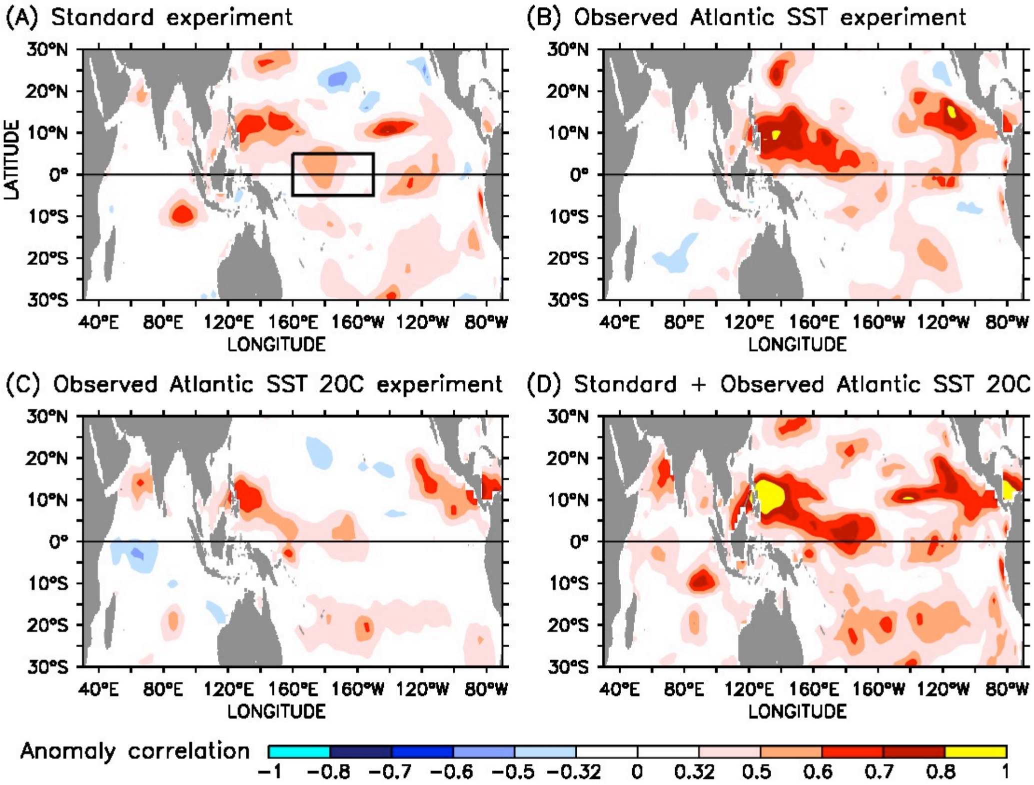


Figure S3. Anomaly correlation skill for June-August average zonal wind stress for prediction experiments started Feb 1st in which (A) Atlantic SST are predicted by the model and (B) model SST are relaxed to observations over the entire Atlantic (60°S-60°N). (C) Skill of 20th century experiments with model SST relaxed observations over the entire Atlantic. (D) Correlation due to the summed contributions of prediction skill from variability internal to the Pacific and forced from the Atlantic, as estimated as the square root of summed variances of (A) Standard and (C) Observed Atlantic SST 20C experiments. Box in (A) delineates the Niño4 (160°E-150°W, 5°S-5N) region.

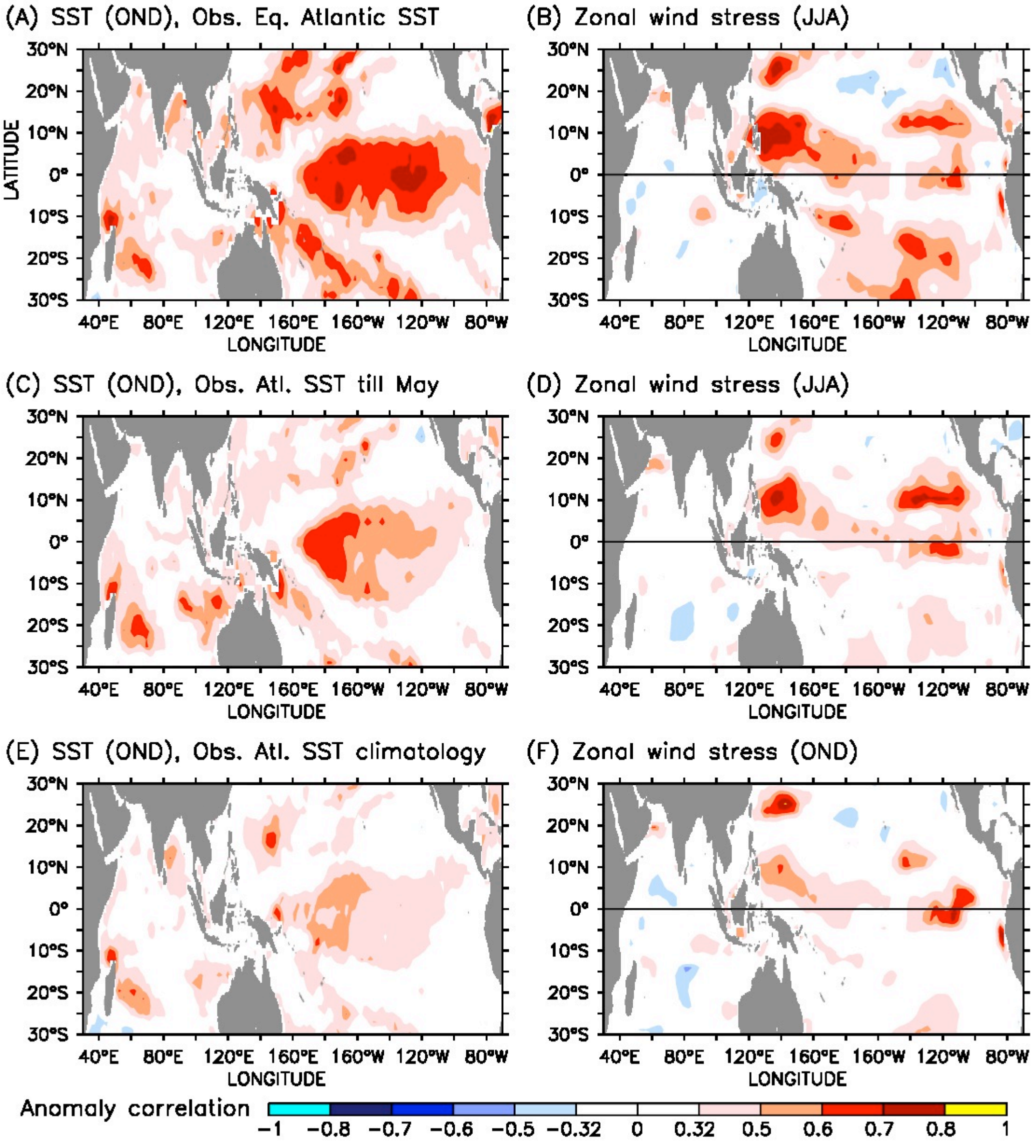


Figure S4: Anomaly correlation skill for (A,C,E) October-December average SST and (B,D,F) June-August average zonal wind stress from additional sensitivity experiments: For prediction experiments in which model SST are (A,B) relaxed to observations only in the equatorial Atlantic (10°N-20°S); (C,D) relaxed over the Atlantic (60°N-60°S) to observations during February to May and to the observed climatology from June to December; and (E,F) relaxed over the Atlantic (60°N-60°S) to observed climatology.

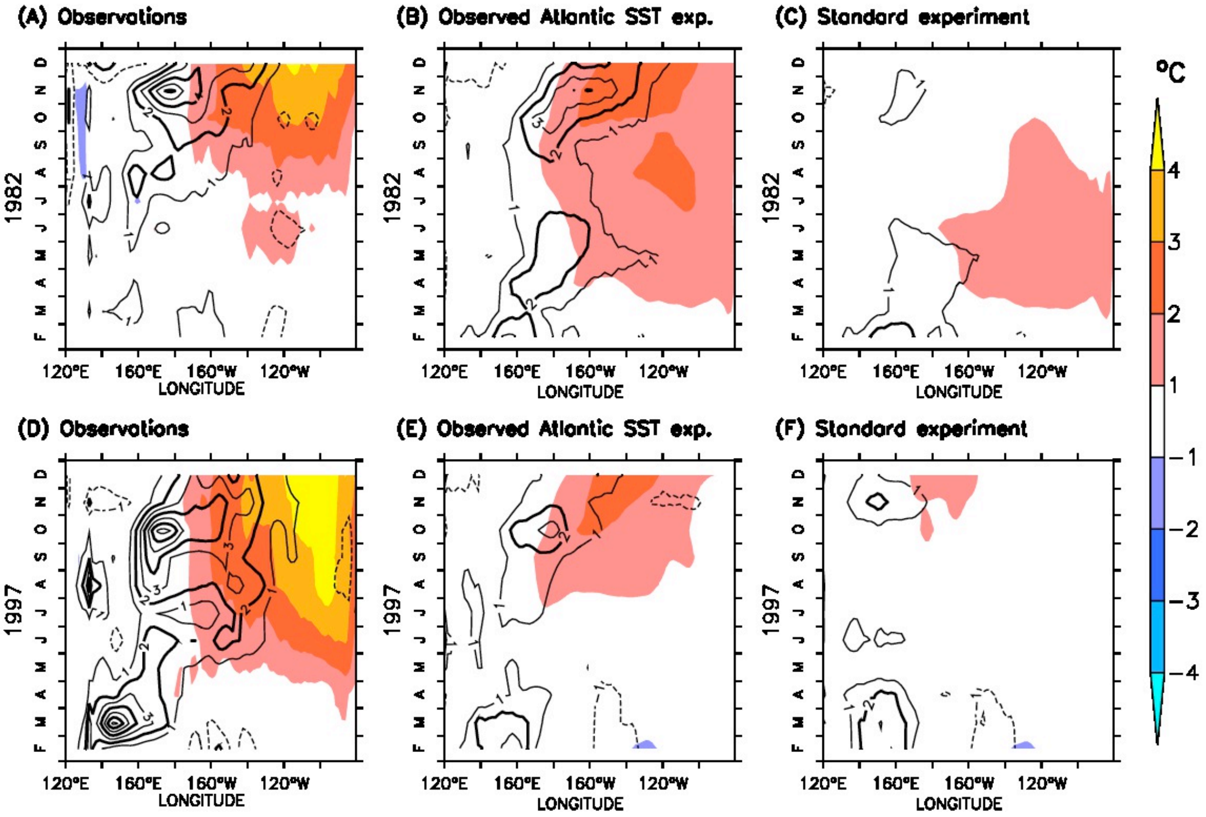
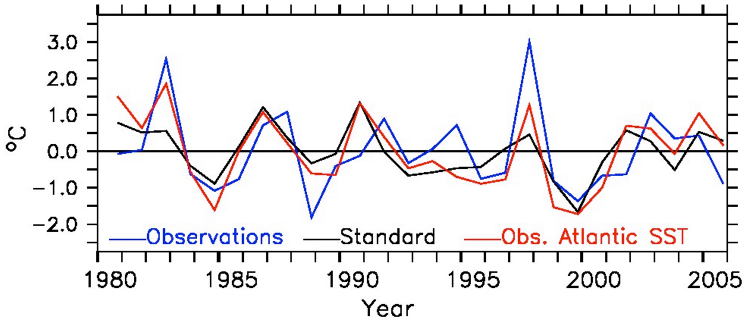
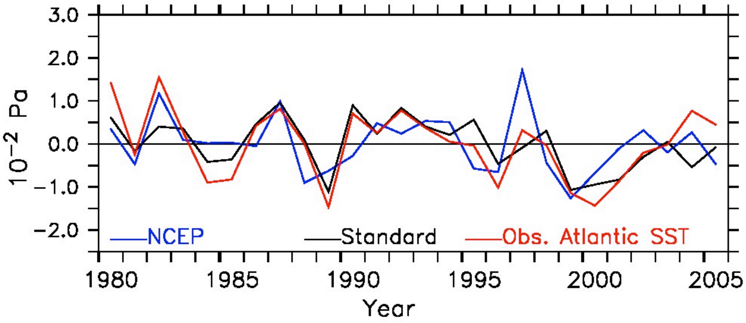


Figure S5. Atlantic variability enhances prediction of the two strongest El Niño events in recent decades. Evolution of SST (shaded) and zonal wind stress (contours, 10^{-2}Pa) for the (A-C) 1982/83 and (D-F) 1997/98 El Niño events as (A,D) observed, and in prediction experiments with Atlantic SST (B,D) relaxed to observations, and (C,D) predicted by the model.

(A) Oct–Dec Nino3 SST anomalies



(B) Jun–Aug Nino4 zonal wind stress anomalies



(C) Impact of summer Atlantic SST on Pacific

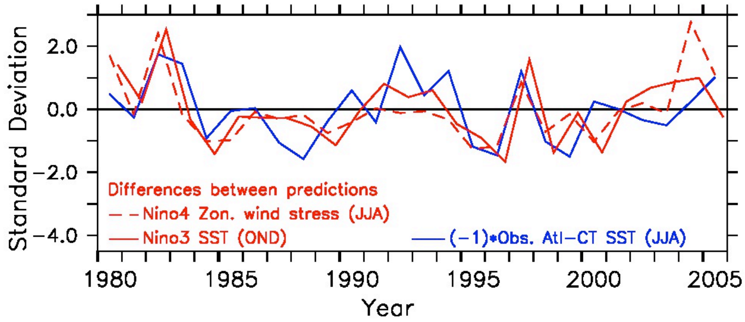


Figure S6. Time series showing that Equatorial Atlantic SST modulates ENSO variability, through influencing western Equatorial Pacific wind stress. (A) Niño3 SST anomalies averaged over October to December for observations and in prediction experiments with Atlantic SST relaxed to observations (Observed Atlantic SST), and predicted by the model (Standard). (B) As in (A), except for Niño4 zonal wind stress averaged over June to August. Comparison of predictions in (A) and (B) indicates that Atlantic SST restoring acts mainly to modulate the Pacific SST and zonal wind stress variations. (C) Difference between Observed Atlantic SST and Standard prediction experiments for JJA Niño4 zonal wind stress and OND Niño3 SST, and JJA inverted Equatorial Atlantic cold tongue SST from observations; time series are normalized. The correlation between the observed Atlantic cold tongue SST and Equatorial Pacific SST (zonal wind stress) indices is 0.5 (-0.5), both significant at the 5% level (r=0.4). The relation among these indices is consistent with the Atlantic Zonal Mode modulating ENSO variability.

3. References

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