STSM report

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ABSTRACT

The response of the tropical Pacific to the 11-yr solar cycle is under debate because past studies suggested either an El Niño-/La Niña-like warming/cooling in solar maxima. The Short Term Scientific Mission, held from 18 March till 7 April at University of Oxford, aimed at the tropical Pacific response to the 11-yr solar cycle forcing in ensemble simulations with the "high-top" HadGEM2-CC model. Filtering with the Multichannel Singular Spectrum Analysis showed a statistical synchronization of the decadal oscillations to the 11-yr solar cycle forcing. A basin-wide warming is simulated in the tropical Pacific during periods of enhanced solar activity, with stronger warming up to 0.4 K in the eastern sector. The response lags the solar cycle forcing by 1-2 years, in a fashion similar to unpublished simulations with the middle atmosphere version of ECHAM5/MPIOM. This suggests that similar mechanisms may act in both models.

Purpose of the STSM

The observed increase of the total solar irradiance (TSI) in the course of the nominal 11-yr solar cycle is weak (~0.1%) and straightforward calculations with radiative balance models estimate small global responses (Gray et al., 2010). Yet, various analyses of observations have isolated substantially stronger signals in the troposphere and at the surface. In the tropical Pacific Ocean, in particular, past analyses demonstrated either anomalous positive or negative sea surface temperature (SST) anomalies with much stronger amplitudes than expected. Filtering of observations identified positive SST anomalies with El Niño-like spatial characteristics, oscillating almost in phase with the 11-yr solar cycle (White et al., 1997). In contrast, the composite analysis of van Loon et al. (2007) detected a La Niña–like cooling in peak years of sunspot numbers.

Simulations with comprehensive coupled atmosphere-ocean global circulation models (GCMs) have given an equally complicated picture because they showed either warm or cool conditions over the tropical Pacific in solar maxima. Recently, Misios and Schmidt (2012) carried out a large ensemble of simulations with the middle atmosphere version of ECHAM5 coupled to the MPI ocean model and found a weak warming oscillating almost in phase with the observed solar cycle from 1955-2006. Unpublished simulations with the same GCM but forced with an idealized sinusoidal solar cycle showed a statistical synchronization of natural modes of Pacific decadal variability to the 11-yr solar cycle. In solar cycle forced ensemble simulations, the Tropical Pacific Quasi-Decadal Oscillation (TPQDO) is modulated by the imposed external forcing and its positive phase lags the positive phase of the solar cycle by 1 to 2 years.

The main focus this Short Term Scientific Mission (STSM) was to assess the tropical Pacific response to the 11-yr solar cycle forcing in ensemble simulations with the "high-top" version MetOffice Hadley Centre HadGEM2 (HadGEM2-CC). In the following, some important results are described briefly.

Preliminary analysis of the HadGEM2-CC simulations

A large number of simulations with different combination of historical forcings have been carried out within the Coupled Model Intercomparison Project Phase 5 (CMIP5). To facilitate detection

of the 11-yr solar cycle signatures, an ensemble of 4 simulations with the HadGEM2-CC forced only with the observed solar spectral and total irradiance variability (as recommended by IPCC / SPARC) from 1860 to 2009 has been conducted. All other external forcings (e.g. volcanoes, greenhouse gases) were kept constant. These runs focus on the effects of the 11-yr solar cycle variability only as the secular trend has been deliberately filtered out.
The unforced tropical Pacific variability on interannual and decadal time scales is evaluated from a 240-yr control integration of HadGEM2-CC. The monthly Nino3.4 index exhibits two well separated spectral peaks at about 6-7 years and 17 years, respectively, associated with the El Niño- and decadal-type variability (Figure 1, right). Although the standard deviation of monthly Nino3.4 compares well with observations (0.68 K in HadGEM2-CC vs 0.7K in ERSST), the reoccurring period of the El Niño episodes is unrealistically slow with average period of 6-7 years. Nevertheless, the spatial signature of El Niño on SSTs is well captured in HadGEM2-CC. More work is needed to describe the nature of the very pronounced decadal oscillation.

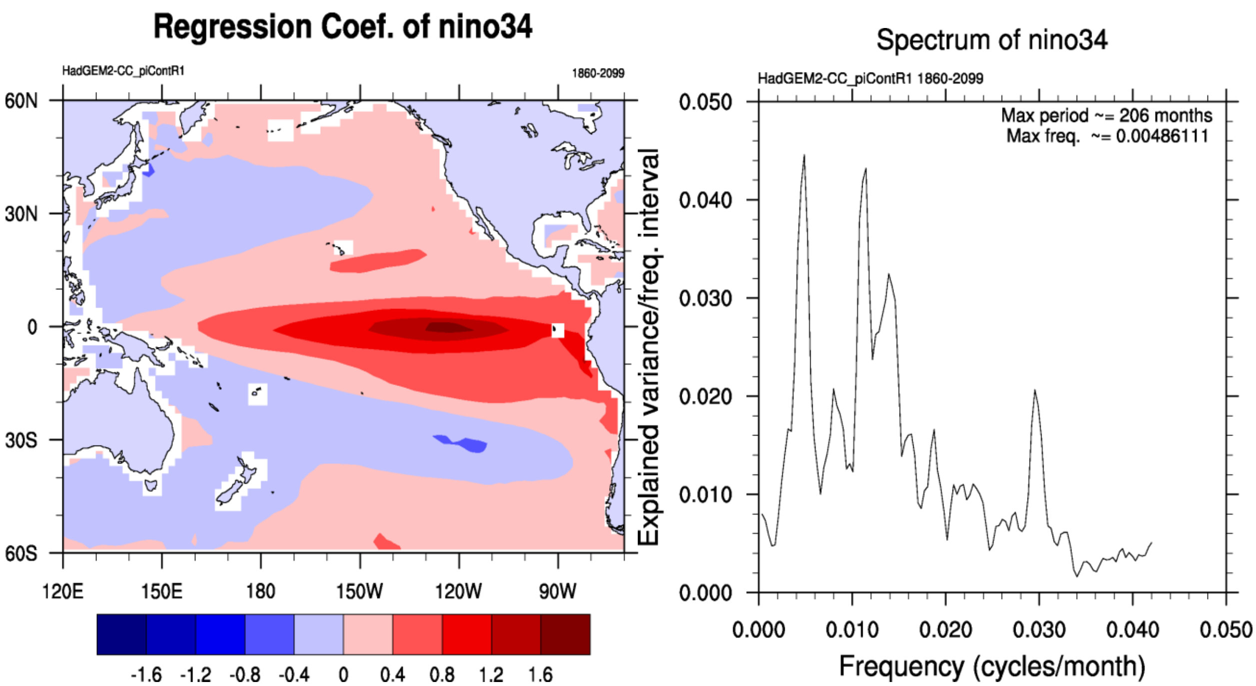

Figure 1 (left) Regression coefficients of monthly SST anomalies from the control run of HadGEM2-CC onto the Nino3.4 index (K/std). **(right)** Spectrum of the Nino3.4 index from the control run.

The tropical Pacific variability in the solar forced runs is evaluated by employing a Multichannel Singular Spectrum Analysis (MSSA) on the tropical (20°S-20°N, 120W-290W) annual SST anomalies over the period 1860-2009. MSSA has been extensively utilized in the past to isolate quasi-periodic phenomena (Ghil et al., 2002). MSSA detects pairs of oscillatory modes in the annual SST anomalies that describe pronounced semi-periodic variability such as the ENSO phenomenon. Obviously, the focus here is on quasi-decadal time scales, where a solar cycle related variability, if does exist, should be detected. Interestingly, two individual members of the ensemble (number 3 and 4) do show a very pronounced spectral peaks at about 10.8 years. This is very close to the average period of the 11-yr solar cycle from 1860 to 2009. The other two ensemble members show pronounced SST variability on 23-yr (ensemble number 1) and 12.3-yr (ensemble number 2), respectively.
In order to investigate a possible physical link between the 11-yr solar cycle and the quasi-

decadal oscillatory modes detected in the ensemble members 3 and 4, we calculated the ensemble mean annual SST anomalies over the tropical Pacific considering only these two model runs. The annual MSSA-filtered SST anomalies are then reconstructed by selecting the two oscillatory modes that refer to the 10.8 yr period. This reconstructed quasi-periodic oscillation will be referred to as the TPQDO and the area averaging of the MSSA-reconstructed SSTs over the shaded box in Figure 2 defines the TPQDO index.

Figure 2 shows scaled regression coefficients of the ensemble mean SSTs onto the TPQDO index. The scaling (normalization of regression coefficients in every grid point to the mean value over the noted area) yields weighting factors that being multiplied with the TPQDO index (red line) return the true amplitude of the TPQDO.

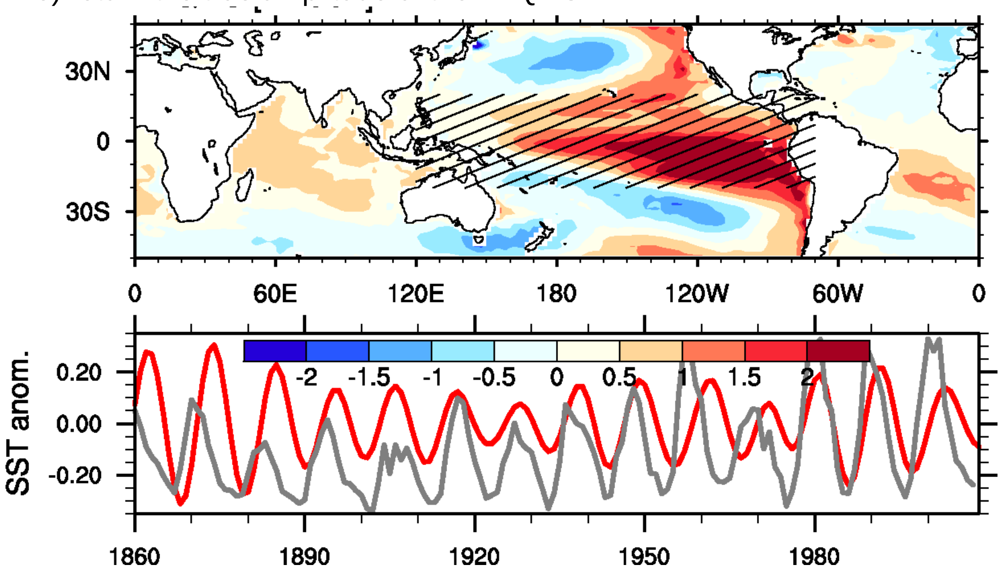

Figure 2 Spatial pattern (top) of the TPQDO and time sequence (down) of the TPQDO index simulated with the HadGEM2-CC. The spatial pattern is the regression coefficients of the ensemble mean SST anomalies onto the TPQDO index, normalized to the sum over the noted area (slashed box). The solar forcing (grey) used in the HadGEM2-CC runs is superposed for reference.

A basin-wide warming is simulated in the tropical Pacific during periods of enhanced solar activity, with stronger warming up to 0.4 K in the eastern sector. Positive temperature anomalies of much weaker amplitudes are seen over the Indian and Atlantic oceans, implying a dynamical amplification in the Pacific. This is consistent with the work of Misios and Schmidt (2012) but further work is required to verify the mechanisms at action. Obviously, the “bottom-up” mechanism of Meehl et al. (2008), which relates direct heating at the ocean surface in solar maxima with more water vapour, enhanced precipitation, stronger meridional (Hadley) circulation and enhanced upwelling of cold water in the eastern Pacific, cannot explain the simulated warming in solar maxima.

Interestingly, the temperature response lags the solar forcing by 1-2 years. The lagged correlation coefficients between the TPQDO index and the 11-yr solar cycle are 0.37, 0.58, 0.59 for lags 0 to 2 years, respectively. When all four ensemble members are considered the correlation weakens considerably (0, 0.15, and 0.28), as expected from the reduced sensitivity of the tropical Pacific to the solar cycle forcing in the first two ensemble members. It must be noted that similar lags between TPQDO and the solar forcing has been simulated in an ensemble of idealized simulations with the MAECHAM5/MPIOM (Misios et al., 2013 in preparation). The obvious next step is to compare the atmospheric and subsurface responses between the two models and to identify amplification mechanism acting in both models.

Summary and Future plans

The short term mission facilitated the analysis of ensemble simulations with the HadGEM2-CC carried out within the CMIP5 initiative. Unforced quasi-periodic oscillations in the coupled system of the tropical Pacific were identified and briefly described. A complete understanding of the underling mechanism is a future goal. Furthermore, we also isolated oscillations in the tropical Pacific related to the solar cycle forcing. Similar to the MAECHAM5/MPIOM results, the tropical Pacific warms during solar maxima and the peak warming lags solar forcing by about 1-2 years. This quasi decadal oscillation is detected in two out of four ensemble members suggesting a statistical relationship. In other words, the otherwise natural modes of decadal variability of the tropical Pacific system seem to synchronize to the 11-yr solar cycle in a statistical way. The same could be happening is reality. Future analysis will explore a physical mechanism to explain that apparent synchronization.

I believe that the short term mission should be characterised successful with respect to the scientific goals. Furthermore, it was important for organizing future plans such as the forthcoming coordinated analysis of the CMIP5 historical and future experiments. It is obvious that all scientific questions cannot be addressed in great details within a 3 weeks visit but results presenting in this report are very promising and guarantee for further collaboration. I would like to thank Prof. Lesley Gray for hosting my visit to University of Oxford and Dr. Dann Mitchell for providing data from the HadGEM2-CC simulations. I would also like to thank the COST-TOSCA project for funding my visit to Oxford.

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