OCCI report

The ENSO-Monsoon Relationship: The Role of the Indonesian Throughflow

Annalisa Bracco
Department of Physical Oceanography

The Indian Monsoon-El-Nino Southern oscillation (ENSO) relationship, according to which a drier than normal monsoon season precedes El Nino conditions, weakened significantly during the last two decades of the 20th century (see for example Kumar et al., Science 1999). No satisfactory explanation has been put forward so far. In this work an ensemble of integrations of an Atmospherical General Circulation Model (AGCM) regionally coupled to an Ocean model (OGCM) is used to investigate the causes of such a weakening.

A first hypothesis tested is that the relationship between the South Asia monsoon and the tropical Pacific implies, together with the atmospherical teleconnection, an oceanic bridge, modulated by the variability of the thermocline in the West Pacific and at the Indonesian Throughflow. Using a high resolution general circulation ocean model (MICOM, version 2.9) coupled to the AGCM in the tropical Indian and Pacific Ocean I investigated if and how thermocline anomalies associated with ENSO can precondition the ocean subsurface in the eastern Indian Ocean, favoring the co-occurrence of the same phase of ENSO and of the Indian Ocean Zonal Mode (IOZM), discovered in 1999 (Saji et al., 1999; Webster et al., 1999). The second half of the XX century has been characterized by a shift in the basic state of ENSO from the so-called S- (or surface) mode to the T- or Thermocline mode, according to the definitions used by Fedorov and Philander (2000, 2001). In the S-mode state ENSO is characterized by a 2-3 years periodicity, with SST anomalies determined by advection and entrainment across the thermocline, by a pronounced thermocline gradient, and by westward propagation of SST anomalies. In the T-mode ENSO periodicity is between 5 and 7 years, SST anomalies are generated by thermocline movements, the thermocline gradient is smaller and SST anomalies propagate eastward across the equatorial Pacific. Guilyardi (2006) visualized such a shift in terms of lag correlation of the Trans-Nino index (defined as the difference between the Nino.1+2 and Nino4 indices) with the Nino3 index (see Trenberth and Stepaniak, 2001 for more details).

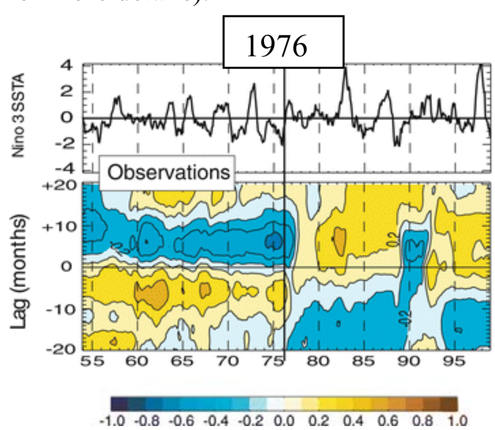

Fig. 1 Normalized Nino3 SST anomalies (top) and lag-correlation of the Trans Nino index (TNI) with the normalized Nino3 SSTA (bottom) in the HadISST dataset. A positive correlation for positive lag, as in the 1977-1999 period, indicates equatorial SST anomalies propagating west to east, which is indicative of ENSO with T-mode properties, while the westward propagation of SST anomalies recorded between 1950 and 1976 interval is suggestive of S-mode ENSO dynamics . Diagnostics done using a 12 year running window. **From Guilyardi, Climate Dynamics, 2006.**

The model set-up is as follows:

- ICTP AGCM, 8-layers, T30 resolution (Molteni, 2003; Bracco et al., 2005; Kucharski et al., 2006 ; Bracco et al., 2006)
- MICOM (Miami Isopycnic Coordinate Ocean Model) 2.9, 1*1 resolution in a regional configuration
- Los Alamos coupler adapted by KNMI (Hazeleger et al., 2004)

An SST correction is imposed according to

$$SSTA = SSTcl + \alpha [SSTO - <SSTO>]$$

with α varying between 0 and 1 over a training period, then set to 1 for the further spin-up and production phases. The length of the training period sets the SST climatology of the ocean model and influences the characteristics of the modeled ENSO.

Two runs have been performed:

1. T-like ensemble: 2 member ensembles, each 150 years long, with the ocean model coupled in the Tropical Pacific and Indian Ocean (35S-30N) and monthly climatological SSTs forcing the AGCM elsewhere. The training period is 20 years.

2. S-like ensemble: as above but with a training period of 10 years.

The analysis performed on the model outputs and the comparison with reanalysis data-sets (NCAR-NCEP data, Hadley Center SST reanalysis – HadISST -, CMAP precipitation data) allows concluding that

- ENSO and the IOZM are connected via the atmospheric bridge and through the ocean subsurface as well. The baroclinic component of the Indonesian Throughflow (ITF) is responsible for the oceanic bridge. Whenever ENSO is in a T-mode state, its greater persistency reinforces this connection. During the 1977-2000 period a shallower than average thermocline in the west Pacific and at the ITF, due to persistent eastward zonal wind anomalies in those regions, allowed for a better transfer of the thermocline anomalies associated with ENSO to the eastern Indian Ocean, thus favoring the co-occurrence of positive IOZM events and El-Ninos (as, for example, in 1997).
- T-mode El Nino events are on average of large amplitude and cause significant reduction in the monsoon precipitations over the Indian peninsula. Such a reduction is greater than during (weaker) S-mode El-Ninos.
- The IOZM exerts a limited influence on the interannual variability of the Indian monsoon rainfall over the June-to-September season in the model. It is however important over Indonesia, for the countries facing the South Cina Sea and for China and Japan.
- The co-occurrence of positive ENSO and IOZM events does not result in a weakening of the ENSO-monsoon relationship. In the limit of the model results, the working hypothesis has to be rejected.

Given that the co-occurrence of IOZM and ENSO events is not (in the model) of fundamental importance for interpreting the interannual variability of the Indian Summer Monsoon, one more ensemble has been performed. 10 members have been integrated with the ocean model domain limited to the Indian Ocean basin (35S-30N, 20E-140E) and HadISST reanalysis data forcing the AGCM elsewhere. The observed ENSO variability during the period 1950-1999 is now forcing the modeled atmospherical circulation. This third ensemble is able to realistically reproduce the observed interdecadal variability of the ENSO-monsoon relationship (Fig. 2).

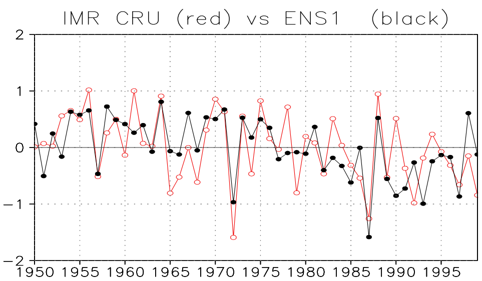

Fig. 2 Time series of observed (CRU; red) vs modeled (black) ensemble mean Indian JJAS rain anomalies (averaged over land points of the region 70E-95E and 10N-30N). The units are mm/day.

A detailed analysis of the model output reveals that a dominant portion of the variability is associated to changes in the Tropical Atlantic SSTs in boreal summer. In correspondence to ENSO, the Tropical Atlantic SSTs display negative anomalies south of the Equator in the last quarter of the 20^{th} century and weakly positive anomalies in the previous period. Those anomalies in turn produce heating anomalies which excite a Rossby wave response in the Indian Ocean in both the model and reanalysis data, impacting the time-mean monsoon circulation. The proposed mechanism of remote response of the Indian rainfall to the tropical Atlantic SST anomalies is further tested using a set-up identical to the one used in the third ensemble, but with monthly climatological SSTs in the Tropical Atlantic region forcing the atmospherical circulation. In this fourth ensemble, the observed interannual variability of the ENSO-monsoon relationship is indeed not reproduced. Results are summarized in the table below.

cor. coef.	1950-1999	1950-1974	1975-1999	1975 to 1999 – 1950 to 1974
CRU, nino3 (observations)	-0.59	-0.69	-0.45	**0.24**
IO ENSave, nino3	-0.63	-0.79	-0.51	**0.28**
IO-noATL ENSave, nino3	-0.51	-0.49	-0.52	**-0.03!!**

In summary, in the model adopted in this study the Tropical Atlantic is the key player in determining the strength of the ENSO-monsoon teleconnection. Whenever the South tropical Atlantic is cooler than ‘normal’ a Rossby wave response to the SST anomalies projects onto the mean stream-function and enhances the monsoon circulation.

This work will result in two papers. One manuscript is currently under revision for publication in Journal of Climate. The second manuscript will be submitted to Climate Dynamics.

Bibliography:

Bracco, A., F. Kucharski, R. Kallummal, and F. Molteni, 2004: Internal variability, external forcing and climate trends in multi-decadal AGCM ensembles. *Climate Dynamics*, **23,** 659-678.

Bracco, A., F. Kucharski, F. Molteni, W. Hazeleger, and C. Severijns, 2005a: Internal and forced modes of variability in the Indian Ocean. *Geophysical Research Letters*, **32**.

Fedorov, A. V. and S. G. Philander, 2000: Is El Nino changing? *Science*, **288,** 1997-2002.

——, 2001: A stability analysis of tropical ocean-atmosphere interactions: Bridging measurements and theory for El Nino. *Journal of Climate*, **14,** 3086-3101.

Guilyardi, E., 2006: El Nino-mean state-seasonal cycle interactions in a multi-model ensemble. *Climate Dynamics***,** published on-line. DOI: 10.1007/s00382-005-0084-6.

Hazeleger, W., F. Molteni, C. Severijns, R. Haarsma, A. Bracco and F. Kucharski, 2003: SPEEDO: A flexible coupled model for climate studies. *CLIVAR Exchanges* **N. 28** – Coupled Modeling.

Kumar, K. K., B. Rajagopalan, and M. A. Cane, 1999: On the weakening relationship between the Indian monsoon and ENSO. *Science*, **284,** 2156-2159.

Trenberth, K. E. and D. P. Stepaniak, 2001: Indices of El Nino evolution. *Journal Of Climate*, **14,** 1697-1701.

Saji, N. H., B. N. Goswami, P. N. Vinayachandran, and T. Yamagata, 1999: A dipole mode in the tropical Indian Ocean. *Nature*, **401,** 360-363.

Webster, P. J., A. M. Moore, J. P. Loschnigg, and R. R. Leben, 1999: Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-98. *Nature*, **401,** 356-360.