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# How well do IPCC-AR4 models simulate Australian rainfall teleconnections during two-consecutive positive Indian Ocean dipole events?

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**Abstract:** It has been hypothesised that in a warmer world, positive Indian Ocean Dipole (pIOD) events, which refer to a phase with low sea surface temperature (SST) anomalies in the eastern Indian Ocean (IO) and warm anomalies in the west, may become more frequent or more intense, resulting in more drought-like conditions across much of Australia. Indeed, in 2006-2007 two consecutive pIOD events occurred in conjunction with a 2007 La Niña event causing wide-spread drought across eastern Australia. Significant improvements have been achieved in the simulation of Indo-Pacific variability, such as the IOD and the El Niño-Southern Oscillation (ENSO) by climate models used in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC-AR4). In this paper, we discuss the dynamics behind Australian seasonal rainfall teleconnections associated with two-consecutive pIOD events and with one occurring in a La Niña year, using outputs from IPCC-AR4 climate models. The results show that only six out of 24 models produce at least one such combinations during the latter part of their 20th Century simulation, and that the associated evolution of rainfall anomalies are reasonably simulated.

***Keywords:*** *IPCC-AR4, Indo-Pacific variability, rainfall teleconnections, Indian Ocean Dipole*

## 1. INTRODUCTION

A positive Indian Ocean Dipole (pIOD) event refers to a phase with low sea surface temperature (SST) anomalies in the eastern Indian Ocean (IO) and warm anomalies in the west. During 2006-2008, the IO experienced a rare occurrence of three consecutive pIOD events [*Cai et al. 2009a*]. Furthermore, the 2007 pIOD event occurred in a La Niña year, which has El Niño-Southern Oscillation (ENSO)-induced anomalies unfavourable for the development of pIOD events, and was preceded by a pIOD in 2006 in conjunction with an El Niño. Such pIOD events cause droughts in East Asia, Australia, the Arabian Peninsula, and flooding to parts of India and East Africa through its rainfall teleconnection in austral winter and spring [*e.g., Saji et al. 1999, Yamagata et al. 2004, Ashok et al. 2003*]. The 2006-2008 consecutive pIODs have further extended the recent drought in south eastern Australia, making it the most severe drought (during 2001-2007) in over 100 years, surpassing the previous record dry during 1939-1946. According to the classification of IODs found in *Meyers et al. [2007]*, the only precedence in the instrumental record for a consecutive triple pIOD series occurred during 1944-1946, when the Pacific was in a neutral condition. This makes the pIOD-La Niña combination in 2007 unique, although according to *Behera et al. [2008]* using a different criterion, a pIOD and La Niña combination occurred in 1967. However, these events are certainly rare.

How rare is it for a pIOD event to occur in a La Niña year? How is the evolution of rainfall anomalies simulated? We examine 20$^{th}$ century experiments from all available IPCC models to provide the statistics.

## 2. MODEL DATA, IOD DEFINITION, AND MODEL SELECTION

We take a 50-year (1950-1999) sample from one experiment each of the 24 models to provide a large inter-model space of multi-century realizations for the second half of the 20th century climate. Details of these models are summarised in Table 1 of *Cai et al. [2009b]*. The outputs are interpolated onto a common grid (0.8°×1.9°), detrended and then stratified into four seasons. We focus on the September, October, November (SON) season, when an IOD matures. To benchmark model performance we use an updated version of the observed Global Sea Ice and Sea Surface Temperature [*Rayner et al. 2003*].

In our study, the IOD was represented by the leading component of an Empirical Orthogonal Function (EOF) analysis of the anomalous 20°C isotherm depth in an IO domain of 20°S to 20°N. We apply EOF analysis to SON SST anomalies for all 24 models and the observed in the tropical IO domain, 40°E-120°E, 25°S-25°N, in which the variance is expressed in the EOF vector pattern, and the associated time series, taken as our IOD index [*e.g., Cadet. 1985, Klien et al. 1999*].. This is then scaled so that the standard deviation is one. We refer to an IOD event when the amplitude reaches or exceeds one-standard deviation value. Likewise, we refer to an ENSO event when the normalised SON Niño3.4 index reaches one standard deviation.

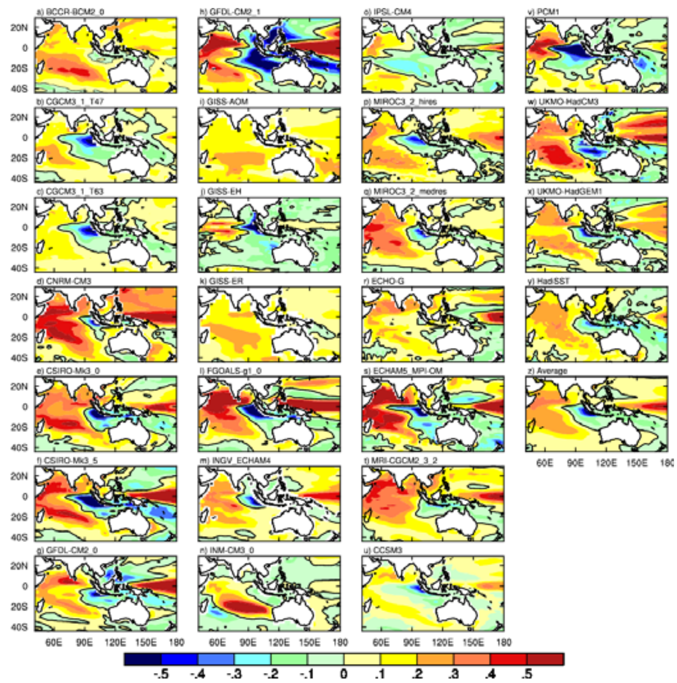

**Figure 1.** Inter-model IOD pattern. The pattern is obtained by regressing grid-point global SST anomalies onto EOF1 time series of IO domain.

An examination identifies five models in which the IOD pattern (Figure 1) is rather unrealistic. These models are ECHO-G, IPSL, GISS_AOM, GISS_ER, and INM-CM3_0. Their patterns are characterized by weak but scattered anomalies, very dissimilar to the observed (Figure 1y). Before those models are finally excluded, we conduct another experiment based on the global anomaly pattern associated with normalised SON eastern IO SST anomalies (90°E-110°E, 10°S-10°S) through a simple regression. Figure 2 plots the inter-model variations in the standard deviation of the regression coefficient in the tropical IO domain versus the inter-model variations in the pattern correlation between the all-model average global pattern and that for each individual model. The pattern/coefficient is obtained by regressing detrended grid-point global SST anomalies onto an EOF time series of the eastern IO. In the five models, the associated pattern in the IO domain and beyond shows either considerably too low or, too negative correlation from the all-model average. These models produce a pan-IO response to the model Pacific ENSO that is typical in the December, January and February (DJF) season, with La Niña-induced westerly anomalies generating a pan-IO cooling (including the eastern IO) through an atmospheric teleconnection [*e.g., Liu and Alexander 2007*]. We exclude these five models in our subsequent analysis reducing our model sample size to 19, providing a 950-year realization.

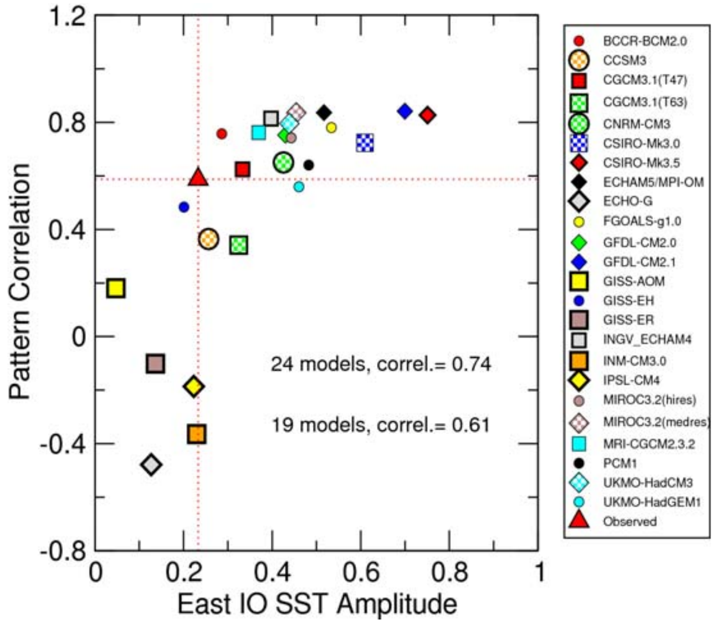


**Figure 2.** Inter-model variations in the standard deviation of the regression coefficient over the eastern IO domain (90°E-110°E, 5°S-15°S) versus inter-model variations in the pattern correlation between the all-model average global pattern and that for each individual model. The pattern/coefficient is obtained by regressing detrended grid-point global SST anomalies onto an EOF time series of the eastern IO.

## 3. RAINFALL EVOLUTION DURING POSITIVE IOD-LA NIÑA EVENTS

### 3.1. Frequency of occurrences

In order to examine the frequency of pIOD-La Niña occurrences, an assessment of the ENSO-IOD relationship is in order. *Saji et al. [2006]* showed that there is no systematic relationship between the IOD and ENSO. *Cai et al. [2009c]* also showed that inter-model relationship, based on the 19 models, with a correlation of 0.39, is not statistically significant at the 95% confidence level. More models generate an ENSO-IOD coherence lower than the observed, supporting the notion that the Indian Ocean has the ability to generate independent variability, and that ENSO is not the only trigger of the IOD [*Cai et al. 2009d]*. Moreover, the lower ENSO-IOD coherence should be favourable for the generation of pIOD-La Niña occurrences. Thus, any rarity of the

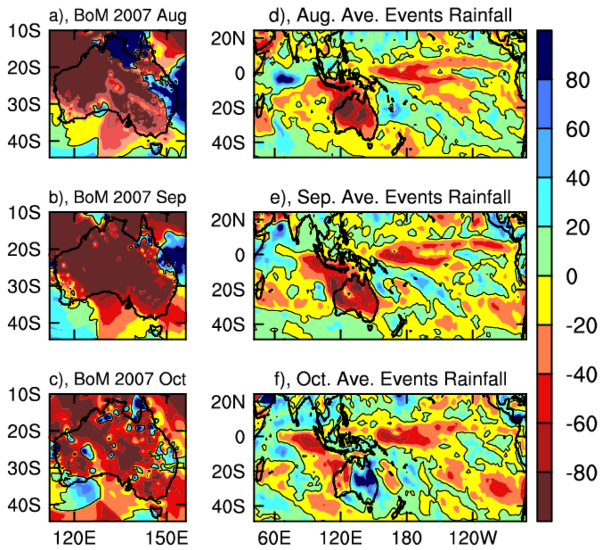


**Figure 3.** Maps of rainfall anomalies in terms of percentage of climatology (a) August, (b) September, and (c) October. Panels (d)-(f), the same as (a)-(c), but six pIOD-La Niña events ensemble average from six IPCC-AR4 models.

pIOD-La Niña pair is not attributable to an overly strong control of ENSO over the IOD, and it was found that only six out of 19 models selected produce at least one such combination during the latter part of their 20$^{th}$ Century simulation.

### 3.2. Rainfall anomalies during pIOD-La Niña events

How well are the model rainfall anomalies compared with observations during such events? Figure 3 shows the evolution of rainfall anomalies during the pIOD-La Niña in terms of percentage of climatology from the observed (Figure 3a-3c) and averaged over six model pIOD-La Niña events (Figure 3d-3f). The percentage maps show how rainfall is distributed throughout the IOD-prevalent months. In August and September the model teleconnection are generally reasonable, matching to the observation, but too wet in October from the model simulation over eastern Australia

## 4. DISCUSSION AND CONCLUSIONS

During 2006-2007, the IO experiences a rare occurrence of two consecutive positive pIODs. In addition, the 2007 event takes place in a La Niña year, which usually provides unfavourable atmospheric anomalies for pIOD development. How rare are such consecutive occurrences and are they well-reproduced by climate models? We first identified 19 IPCC AR4 models which produce reasonable IOD-like patterns, defined as the first EOF of austral spring SST anomalies, providing a 950-year realization. Along with our definition of a La Niña event we find that there are only six models producing a total of six pIOD-La Niña occurrences, of which coincide with two-consecutive pIODs. The model rarity is not due to an overly strong ENSO control over IO variability; because most models produce ENSO-IOD coherence lower than the observed. Averaged over the six occurrences, the evolution of rainfall anomalies compares reasonably well with the observed. As it has been hypothesised that in a warmer world, positive Indian Ocean Dipole (pIOD) events will become more frequent or more intense, further model projection work needs to be undertaken looking at the potential impact on Australian rainfall.

## ACKNOWLEDGMENTS

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