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Interannual variability of tropical climate in NorESM-1M Historical simulations: preliminary analysis

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Abstract:

Preliminary assessments of the NorESM1-M historical ensemble members over the tropical region to understand the Indian Summer Monsoon features and monsoon-ENSO teleconnections have been carried out in this paper. It was found that the NorESM model better represents the interannual variability of EIMR index though the variance is less in model compared to observations. The relationship between ENSO-monsoon is assessed with the help of spatial correlation of austral and boreal summer monsoon rainfall with the winter anomalies of Nino3.4 SST, and the results show that the model is able to capture the major features of the ENSO-monsoon relationship in tropics similar to observations. Thus, we suggest that the overall performance of the NorESM model is better over the tropical region and can be used for further assessments of spatial and temporal scales of tropical climate and also to understand the tropical-extra tropical interactions.

1. Introduction

Monsoons are the most energetic parts of the tropical climate and prediction or understanding of the monsoon variabilities in the climate system models or earth system models are essential for the model assessment. The interannual variability of the monsoon and their interactions with the seasonal processes and teleconnection processes in tropics form an important task for the CMIP5 and Climate modeling community (Meehl et al 2012, Cook et al 2012, Lee et al 2012, and Li et al 2012). The fundamental mechanism of the Asian monsoon is the land-sea thermal contrast (Webster 1987). In 1900s the linkages of Asian monsoon with Himalayan and Eurasian snow cover and strong links with ElNino Southern Oscillation (ENSO) have been identified. The monsoon-ENSO relationships have been addressed by many researchers (Annamalai 2005, Braco et al 2007, Greshunov et al 2001, Ju et al 1995, Krishnamurthy and Goswami 2000, Krishnamurthy et al 2003, Slingo and Annamalai 2000, Sperber and Palmer 1996, Webster and Yang 1992, Wu and Kirtman 2004, and many more from IPCC 2007 report). ENSO is closely related to the Asian monsoon on interannual timescales through influencing the east-west displacement of large-scale heat sources in the tropics (Walker 1924; Rasmusson and Carpenter 1983). Thus, understanding the ENSO behaviour in coupled models and their links to the monsoon system over different parts of the tropics is essential. Monsoon is a global in nature, and occurs over many regions of the tropics. The understanding of the Asian monsoon system in this regard is essential due to its influence on the agricultural production and hence the economy for within the Asian countries and outside. In the present paper, a preliminary analysis of NorESM1-M historical ensemble simulations have been carried out to study the monsoon variability over the Indian region and ENSO-monsoon relation as depicted by these simulations.

2. Model description and Simulations:

The Norwegian Earth System Model (NorESM; Bentsen et al. 2012, Iversen et al. 2012) is one out of ~20 climate models that has produced output for the CMIP5 (http://cmip-pcmdi.llnl.gov/cmip5). The CMIP5 project provides a framework for coordinated climate change experiments for the next five years and includes simulations that will be used in the upcoming Fifth Assessment Report of the IPCC (http://www.ipcc.ch), due 2013/14. The development of the NorESM started under the now finalized research project NorClim (http://www.norclim.no) and is continued as part of the ongoing EarthClim project (http://gfi.uib.no/EarthClim). EarthClim has ten partners: Uni Research AS (coordinator); Bjerknes Centre at the University of Bergen; CICERO Center for Intern Climate and Environmental Research; Norwegian Meteorological Institute; Department of Geosciences, University of Oslo; Norwegian Computing Center; Norwegian Institute for Air Research; and Norwegian Polar Institute, of which the Norwegian Meteorological Institute and the Bjerknes Centre have the main responsibility for the model development. The organizational framework for NorESM is the virtual Norwegian Climate Centre (NCC) consisting of nine of the ten institutions participating in EarthClim.

NorESM consists of the four main components: atmosphere, land, ocean and sea ice. These components can be understood as individual models that run in parallel and communicate with the help of a model coupler tool. The coupler exchanges fields between the atmosphere, land and sea ice components every 30 minutes of integration (model time), and with the ocean component every day of integration. The main components contain a series of subcomponents that are tightly integrated in the code of the main components. The subcomponents share data variables with the main components and use the same grid spacing. The schematic shown in Fig. 1 illustrates the communication of NorESM's main components and the integration of selected subcomponents. In the following, the individual components are presented in more detail. NorESM is built upon the Community Earth System Model version 1 (CESM1; see http://www.cesm.ucar.edu; Gent et al., 2011) developed at the National Center for Atmospheric Research (NCAR) and share substantial parts of model components and supporting framework.

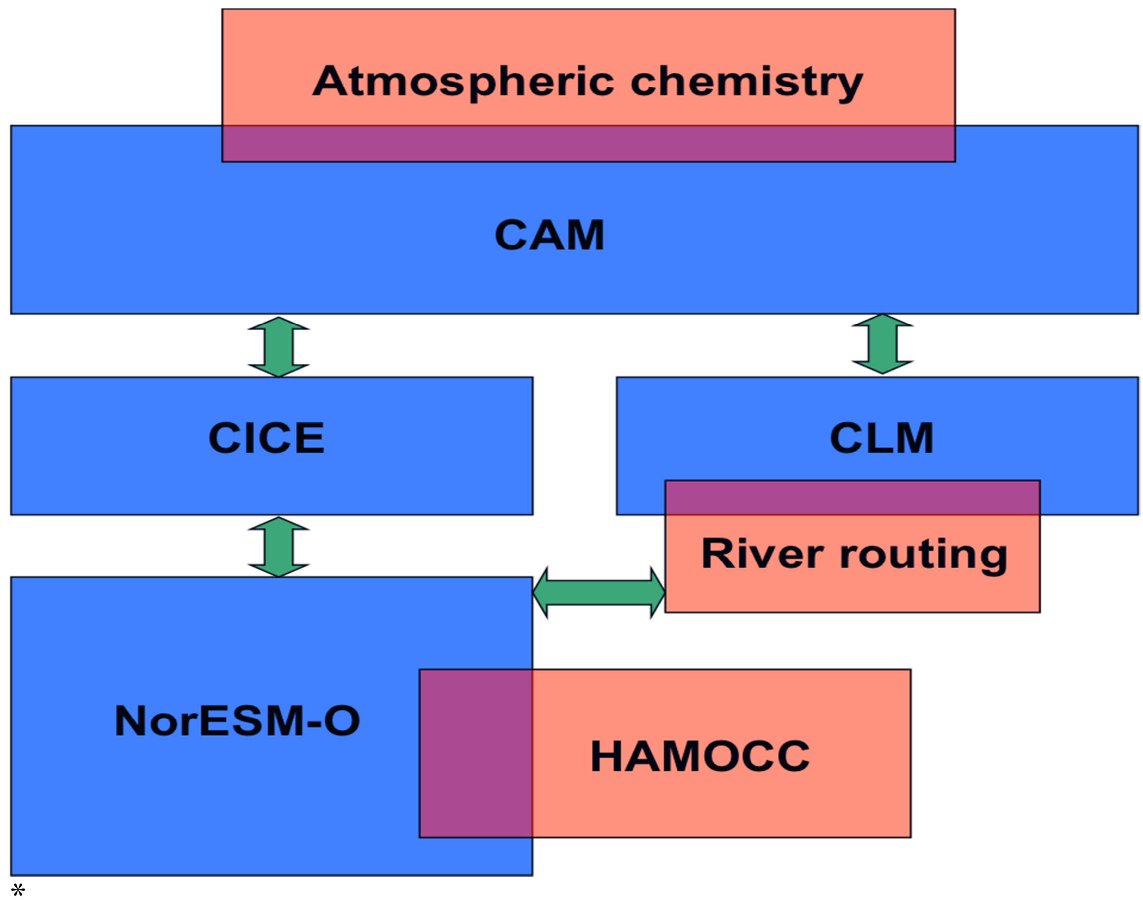

Fig. 1: Schematic of NorESM. Blue boxes denote the main model components. Green arrows indicate exchange of information between the components through the model coupler. Red boxes denote selected subcomponents that are embedded in the main components.

In order to understand the sensitivity of the climate system to different GHG concentration and to the newly developed Representative Concentration Pathways (RCPs) scenarios, a series of experiments have been carried out at the BCCR institute which is also submitted to the CMIP5 set of experiments (Fig 2). A spin-up of the NorESM model has been carried out for every horizontal resolution to ascertain that the coupled processes are stable and there is no climate drift, the historical simulations of NorESM1-M model is then carried out for three ensemble members and extensions of these simulations from historical to the CMIP5 based experiments are carried forward.

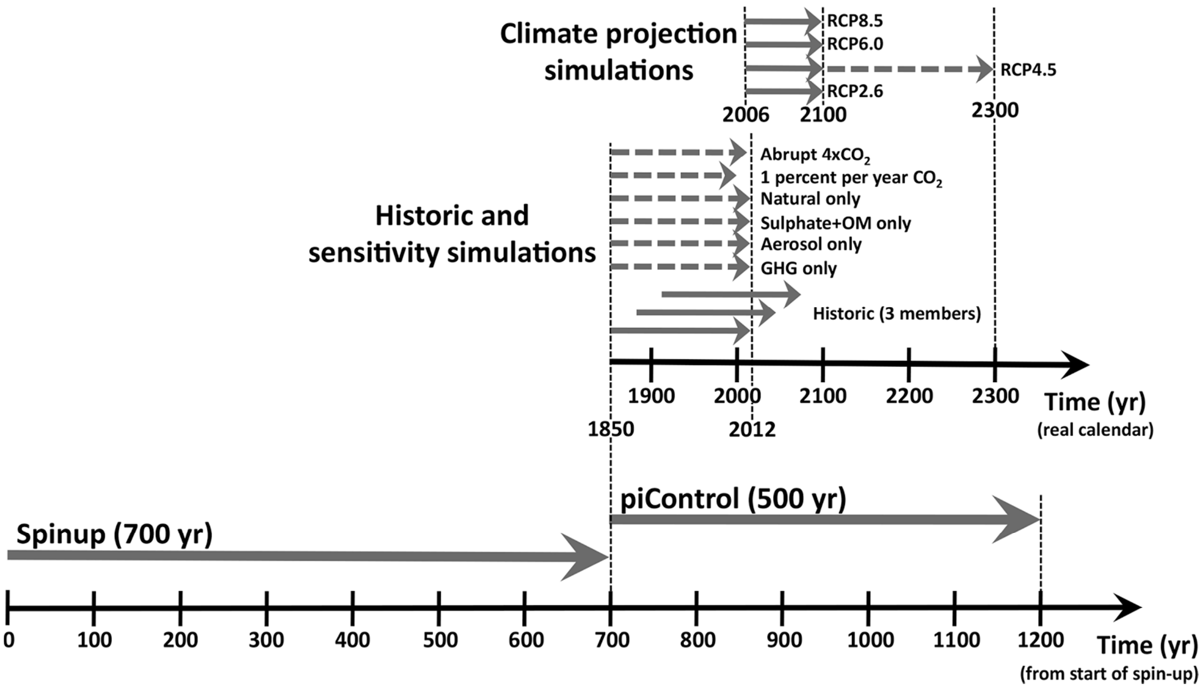

Fig. 2 Schematic of the pre-industrial spinup and CMIP5 experiments carried out with NorESM1-M.

In the present paper the historical ensemble members of NorESM1-M (without carbon cycle) for the period 1950-2005 has been considered for analysis. In order to compare the datasets with observations, we have considered IMD gridded monthly dataset (1979-2005) of rainfall, MERRA reanalysis (Modern ERa Retrospective analysis for Research Applications[1]) at 50kmx50km horizontal resolution for rainfall, zonal wind at 850mb for the period 1979-2005. Also, for the analysis of ENSO, NOAA extended reconstructed SST dataset has been considered from the NOAA, PSD website[2].

3. Results and Discussion:

Fig 3 shows the comparison of annual mean rainfall simulated from NorESM with the TRMM 3B43 dataset, it was found that the double-ITCZ phenomena is still predominant in the equatorial Pacific region for the model. The variance assessment over the tropics (Fig 3 c-d) shows that over the Indian and Asian region the variance of the model is similar to the observational TRMM dataset, with magnitude being higher in the NorESM model especially in the Indian ocean region, Arabian Sea and Western Ghats and in the Himalayan region (Bentsen et al 2012).

[1] http://gmao.gsfc.nasa.gov/merra/
[2] http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html

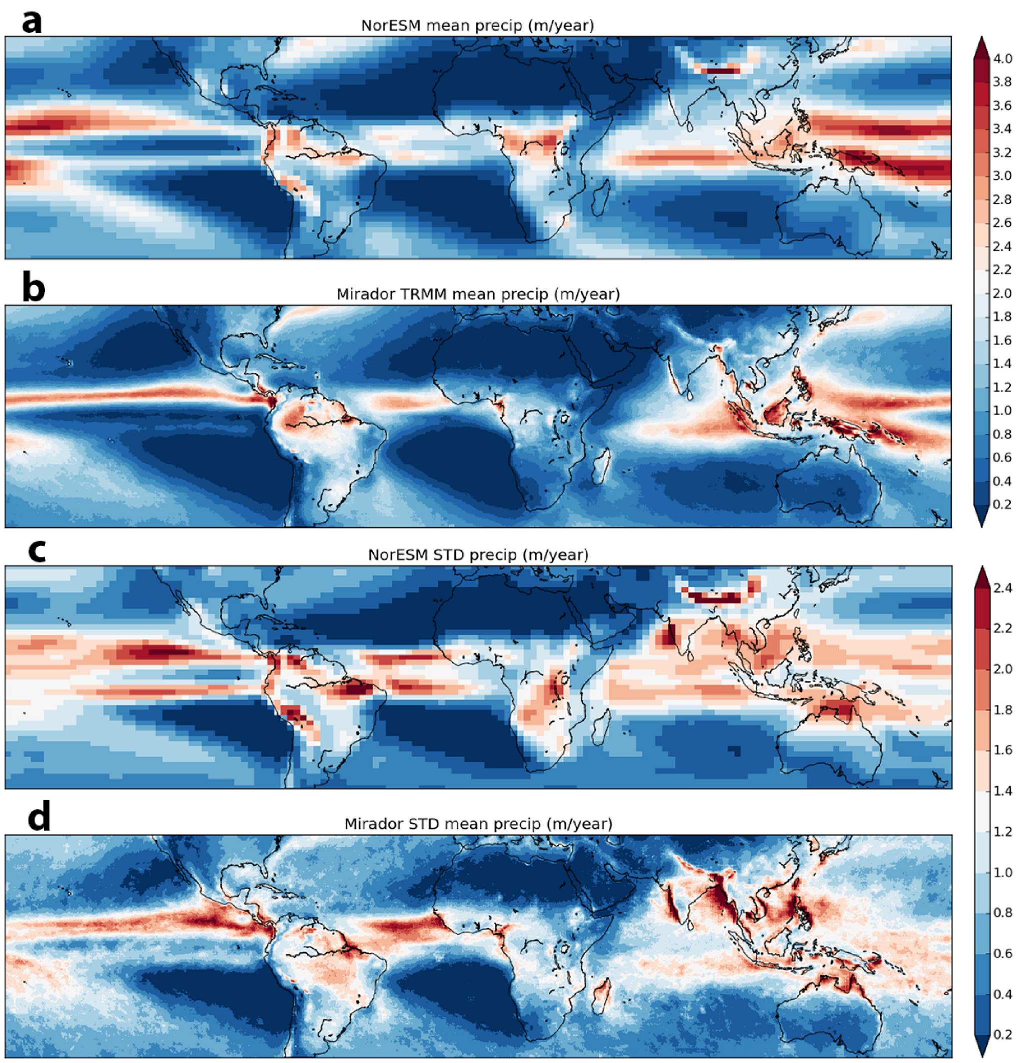

Fig 3: (a) Simulated and (b) observation-based annual mean precipitation (m yr-1). In (a), mean value of year 1976-2005 from Historical1 is shown, whereas (b) is based on Mirador 4 TRMM version 3B43 for the period 1998-2011 (Huffman et al., 2007). Panels (c) and (d) show the monthly mean standard deviation of the fields in (a) and (b), respectively. The fields are shown on their native horizontal resolution.(Courtesy: Bentsen et al 2012).

NorESM1-M assessments carried out by Bentsen et al 2012, suggest that the model underestimates the global mean near surface air temperature, the SST biases are smaller in terms of global mean SST. Another distinct feature of the NorESM is that the ITCZ related bias is more confined to the Northern Hemisphere while the bias in CCSM4 is more symmetric about the equator (Bentsen et al 2012, Iversen et al 2012). This difference may be due to the aerosol direct and indirect effects in NorESM being different from CCSM4 (see Iversen et al 2012 for further details).

3.1 Monsoon Assessment over Indian region

Monsoon variability is a response of the coupled ocean-atmosphere-land system to the annual march of the solar forcing. Monsoon systems are global in nature and are related to atmospheric overturning of circulations that is dependent on the seasons. Changes in the regional scale monsoon feature can be better understood if the global monsoons are assessed. In climate change perspective, the regional monsoon variability is essential in order to understand the model performance and its usefulness for further downscaling the global models to regional areas of interest. The Indian summer monsoon rainfall (ISMR) has received utmost importance due to its impact on agricultural production and hence on the economy of the country, the relationship between ISMR and Gross Domestic Product (GDP) of the country has revealed that the impact of severe droughts on GDP is between 2 and 5%. Gadgil et al (2006) found that there exists an asymmetry in the response of monsoon variability with its impact on magnitude of food grain production (IFGP) and GDP, it was found that the low-response of food grain production to average and above average monsoon rainfall post-1980 is due to the strategies that would allow farmers to reap benefits of the good rainfall years. Thus, understanding the ISMR variability in regional scales plays an important role, the ISMR variability on interannual scales have been address by many researchers (Parthasarathy et al 1992, Ihara et al 2007, Krishnakumar et al 1995, Krishnamurthy and Bhalme 1976, Webster and Yang 1992, Wang and Fan 1999, Fasullo 2004, Trenberth 2001, Goswami et al 1999, and Wang et al 2001).

The number of indices developed to understand the ISMR variability has been many, out of them most useful indicators which are used are All Indian Summer Monsoon Mean Rainfall called as AIMR. However importance to develop a dynamical monsoon index has been recognized for a long time, Goswami et al 1999 and Wang and Fan 1999 developed two different indices which consider the meridonal wind shear as important and determinant factor (former) and westerly wind shear is important to describe the monsoon variability (latter). Both these studies show that, the relationship with Extended Indian Monsoon Rainfall and the corresponding indices of wind shear have shown significant importance in understanding the monsoon variability. Wang et al 2001, readdressed the indices found that the monsoon variabilities in Asia could be better understood with the help of understanding not only the Indian monsoon but also the West North Pacific (WNP) monsoon. The distinct features between these two monsoon systems are, in case of Indian monsoon, the meridional land –sea thermal contrasts and thermal effects of elevated. Tibetan Plateau reinforce the interhemispheric thermal contrast which is inturn resulting due to differential solar heating, whereas in case of East Asian Monsoon it is more of east-west land-sea contrast which dominates. The ISM and WNP are driven by two major convective heat sources located at Bay of Bengal and Phillipine Sea. The changes in the intensity of the two convection regions have fundamental impacts on the variability of the two monsoon subsystems. Also, the advection of SST anomaly in WNP influences the EASM more predominantly, and hence also the ISM system. Thus, understanding of ISMR could be linked to WNP monsoon variability and ENSO.

In order to understand the monsoon variability and the teleconnections of Indian monsoon variability with ENSO as represented in NorESM model, we consider the most commonly used indices for rainfall, which is called EIMR (Extended Indian Monsoon Rainfall index) defined as the rainfall averaged over (70^{o}E-110^{o}E, 10^{o}N-30^{o}N), the dynamical indian monsoon index (IMI) developed by

Wang et al (2001) which is defined as difference of the 850-hPa zonal winds between a southern region of (5°–15°N, 40°E-80°E) and a northern region of (20°N–30°N, 70°E–90°E)[3].

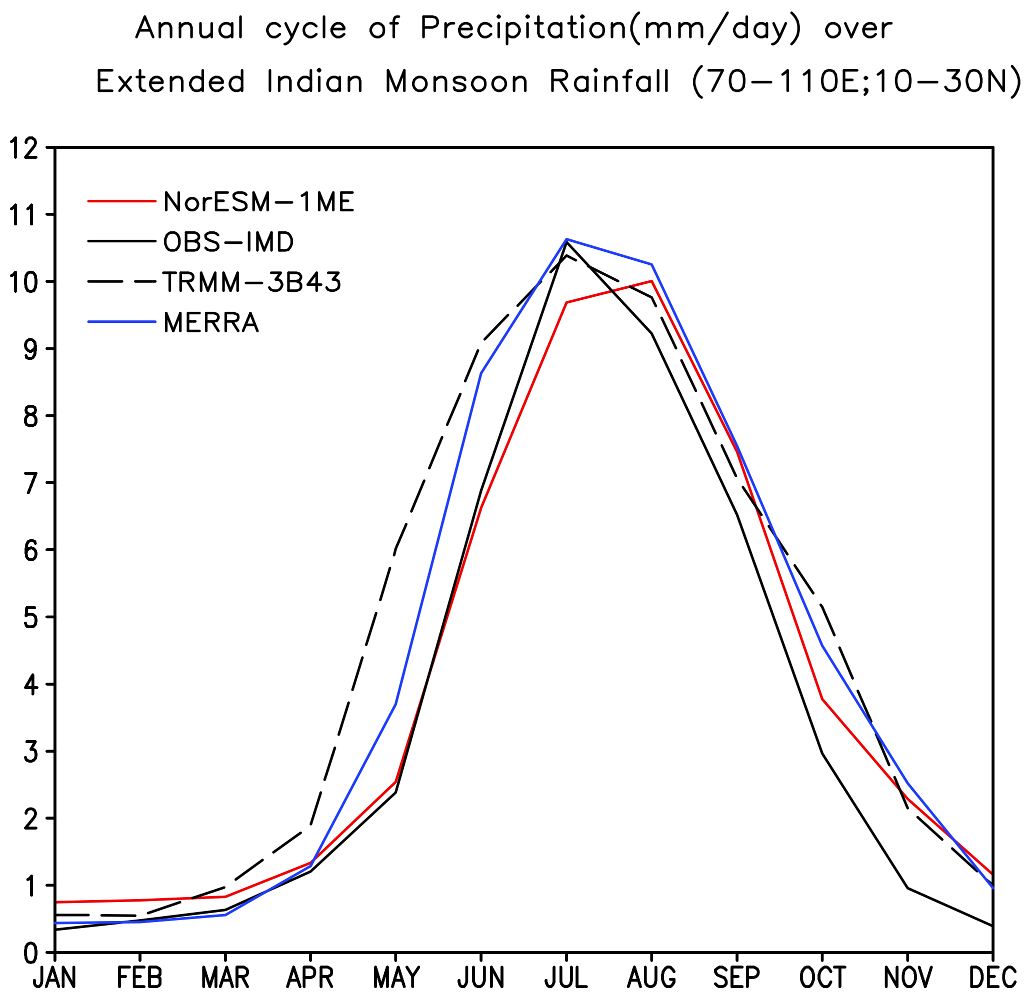

Figure 4: Climatological mean cycle of Precipitation (in mm/day) index (EIMR) averaged over (70°E-110°E, 10°N-30°N), for ISMR-IMD dataset (black thick), TRMM 3B43 (Mirador dataset) (black dashed), MERRA reanalysis (blue thick) and NorESM-1M historical ensemble mean (red thick), for the period of 1979 -2005.

The climatological cycle of EIMR rainfall (Fig 4) shows that the EIMR rainfall is well captured by both MERRA, TRMM 3B43 and NorESM-1M historical ensemble mean simulations. Fig 4 shows that the seasonal cycle of rainfall especially during the summer monsoon months is better understood and in agreement with TRMM-3B43 and MERRA reanalysis. It can also be seen that the ISMR variability is represented well by both observation and reanalysis and correlation of EIMR index with ISMR is greater than 0.5 (Goswami et al 1999). The important point to be noticed is the pre-monsoon months rainfall of EIMR is similar to ISMR, which is essential in the long term for impact studies.

[3] Here the vorticity is not considered since the meridional wind shear has a weaker correlation with the rainfall and the zonal wind part dominates the vorticity. (Wang et al 2001).

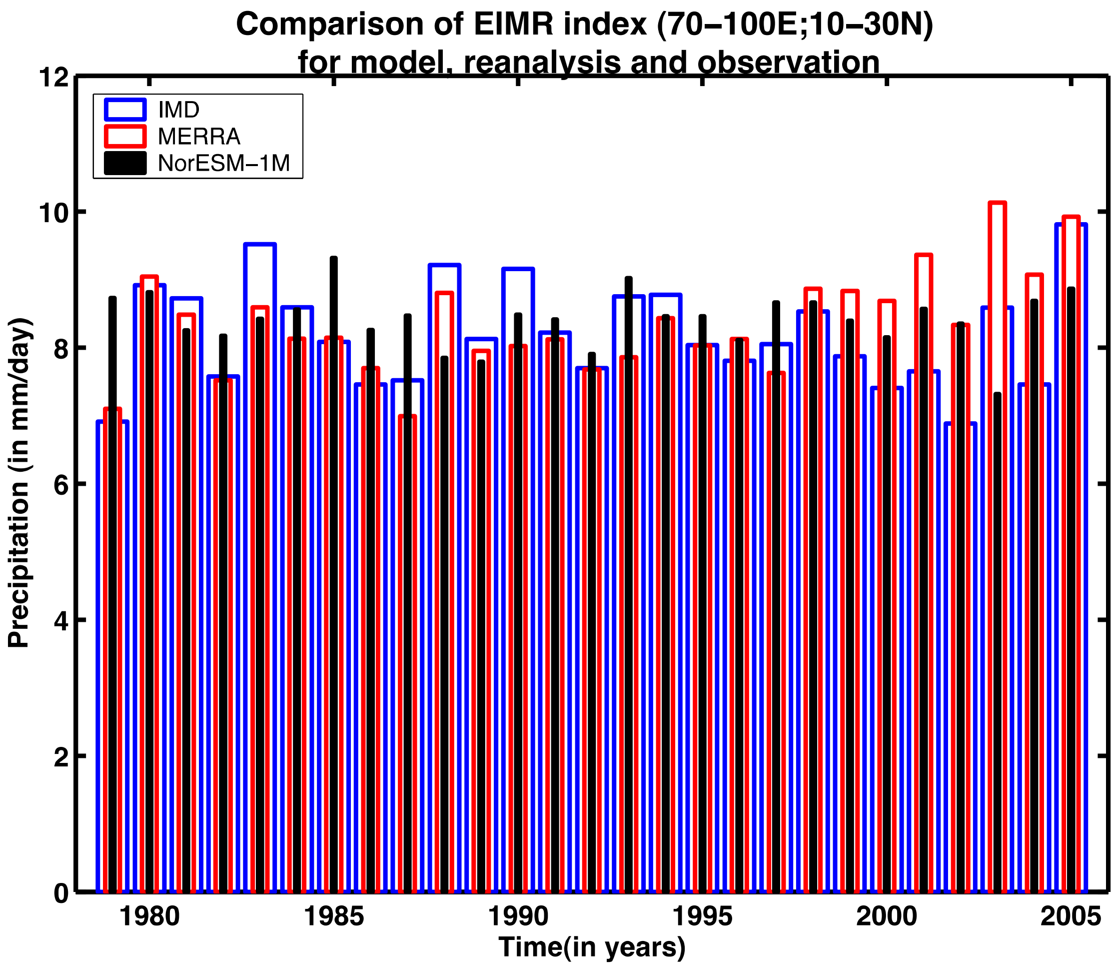

Figure 5: JJAS mean EIMR index variability for IMD (ISMR- blue bar), MERRA (red bar) and NorESM1-M historical ensemble mean (black thick line). The standard deviation of EIMR index for IMD and MERRA is around 0.75 and for NorESM1-M ensemble mean is around 0.45.

The interannual variability of EIMR with MERRA and IMD also shows that the NorESM model (Fig 5) is able to simulate the magnitude and variability to a better extent over this region. Though the variance is less in NorESM-1M model it is able to capture the magnitude of summer monsoon rainfall to a better extent. In order to understand the dynamical monsoon index which triggers the monsoon, the dynamical monsoon index calculation have been carried out and its comparison to the EIMR anomaly performed shows that the correlation coefficient between IMI and EIMR in MERRA was around 0.95 and for NorESM1-M is around 0.97. The spectral analysis of IMI index from MERRA and NorESM-1M shows that the low frequency variability in both time series is below the red-noise spectra (Fig 6) and the maximum power in MERRA is found during 24-32 months whereas in NorESM-1M the spectral peak was predominant around 30-45 months. The relationship between ISMR and Nino3.4 SST anomaly from the NorESM1-M model analysis shows that in most of the years the inverse relationship between ISMR and ENSO is found in the model (Figure 7). Figure 6 and Figure 7 analysis indicates that the spectral power in IMI is around 42 months which is similar to ENSO periods in East Pacific. The teleconnection assessment between ISMR and ENSO thus needs to be further understood.

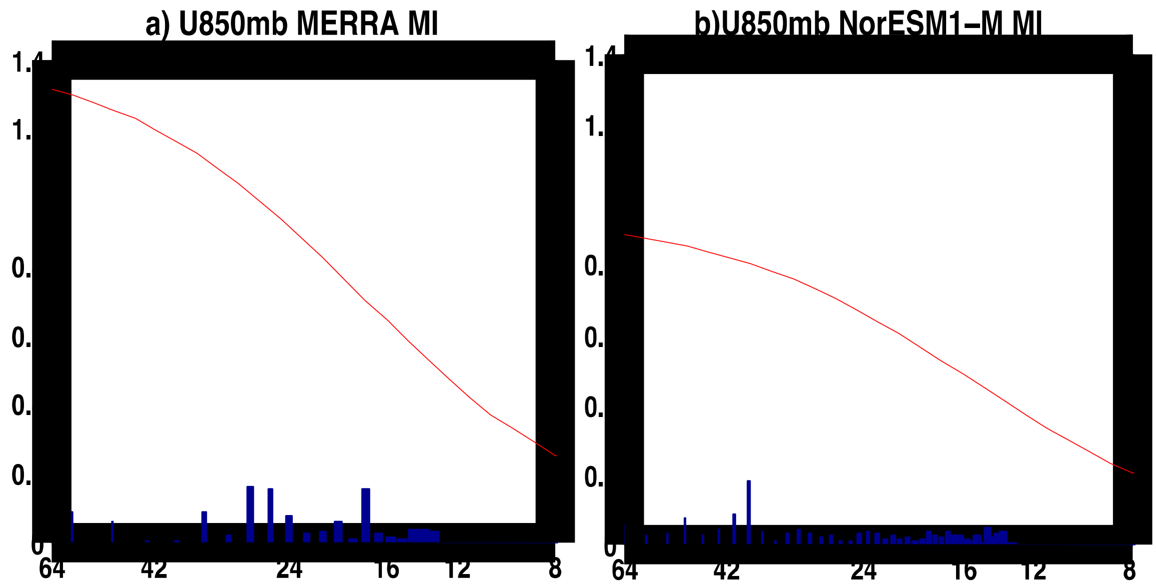

Figure 6: Spectral analysis of IMI index (a) for MERRA reanalysis (1979-2005) and (b) NorESM-1M historical ensemble mean values (1950-2005). The red line denotes the rednoise spectra calculated for the time series.

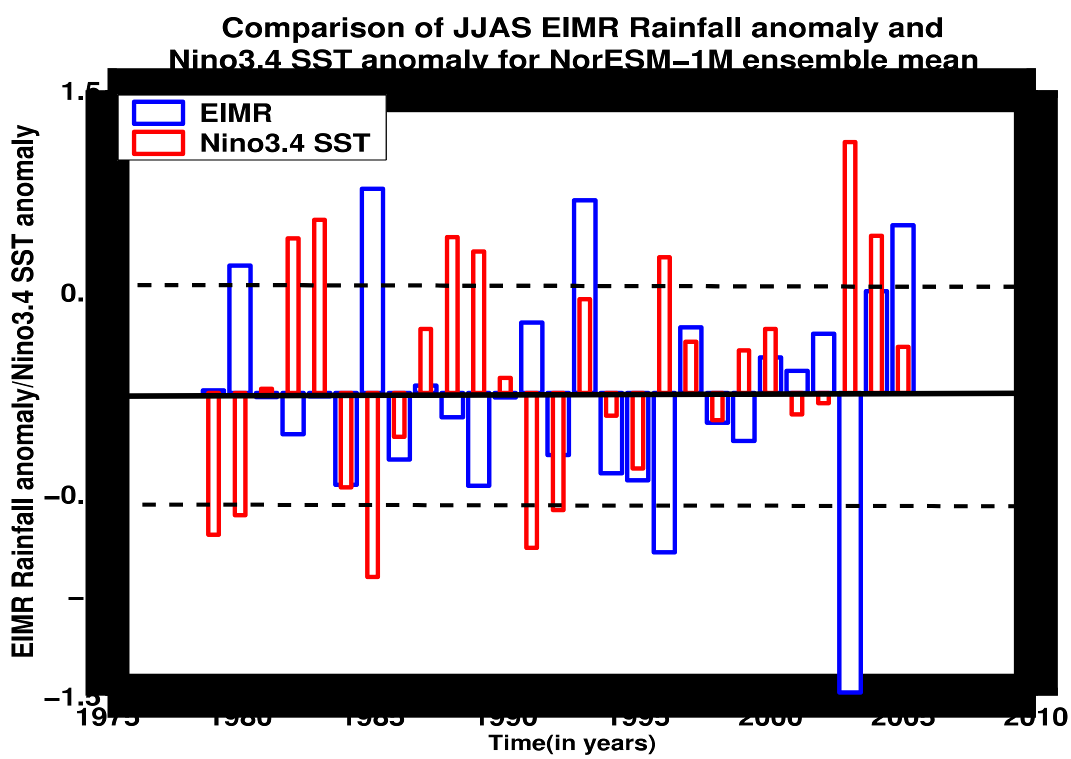

Figure 7: Comparison of JJAS EIMR Rainfall anomaly with Nino3.4 SST anomaly for NorESM1-M historical model simulation. The black dashed lines indicate the ± σ standard deviation values for both rainfall and SST; the value for rainfall is around 0.53 and for SST around 0.56.

3.2 Monsoon-ENSO teleconnections:

Understanding the ENSO-monsoon teleconnections in the tropical region plays an important role in the predictability of interannual variability of tropical climate. ENSO is a coupled ocean-atmosphere phenomena and affects the Walker cycle (Walker 1924, Rasmusson and Carpenter 1983) and therefore the amount of rainfall received during monsoon cycle in different areas and temperature anomalies over the regions (Trenberth et al 1998, Alexander et al 2002). Coupled Ocean Atmosphere Models are used to understand the phenomena of ENSO and its teleconnections to different regions in the world, the model predictions of ENSO has been improved consistently during the past few decades (IPCC 2007, Meehl et al 2007, Guilyardi et al 2010 and Wang et al 2012). Guilyardi et al 2012 showed the performance of ENSO in the CMIP5 models is better than CMIP3 with their preliminary analysis. Recent studies of Kim and Yu 2012 suggest that the CMIP5 models are able to simulate the East Pacific type ENSO better than the Central Pacific (CP) based ENSO, and these models indicate that the intensities of CP ENSO is increasing from pre-industrial to historical and then to RCP4.5 based scenarios. The preliminary assessment of NorESM1-M historical simulations by Bentsen et al 2012 showed that the NorESM1-M models provides a spectral power of 2-4 years in the Nino3.4 SST anomaly when compared to 3-7 years of the Observed HadISST. The spatial correlation of Nino3.4 SST anomalies with global SST shares many features with observations, although the model produces too narrow correlation pattern in the tropical Pacific.

In this section we will address the spatial correlation of Nino3.4 SST anomaly with JJAS Rainfall over the tropical region to observe if the model also represents the features represented in observations. From the previous section, we found that the EIMR anomaly is negatively correlated with Nino3.4 SST anomaly. In order to understand the spatial representation of correlation coefficient between Nino3.4 SST anomaly for NDJF (November-December-January-February) with rainfall anomaly of JJA (June-July-August) over the whole tropics is calculated (Fig 8). Fig 8 shows the spatial correlation coefficients between Nino3.4 SST anomaly from NOAA Extended Reconstructed SST with GPCC precipitation anomaly over the tropics for the period 1979-2005 (Fig 8a) and Fig 8b shows the spatial correlation coefficient of Nino3.4 SST anomaly from NorESM1-M historical runs with JJA Rainfall. For these analysis ensemble mean of both the models are considered, individual ensemble member calculation has also been performed to check for consistency and they follow similar pattern as the Ensemble mean (figure not shown). It can be found from Fig 8a and b that the regions with positive correlations exist in the Central Pacific region for both observations and model and also the negative relation between the Nino3.4 SST anomaly and ISMR region is quite similar as observations. Also, note that in the East Asian region both the observations and models have positive correlation with Nino3.4 SST anomaly. Thus, to a large extent we can say that the monsoon-ENSO features in NorESM1-M historical ensemble simulations is better represented.

Similar analysis for austral summer monsoon region assessments have been carried out (Fig 9a and b), and the assessments show that the austral summer monsoon regions in Australia, South America and few regions of South Africa have excessive rainfall during the years of ENSO, hence ENSO and its relation to austral monsoon regions in models also follow similar to observations. In order to understand the power associated with the Nino3.4 SST anomaly from observations and models, a one-dimensional wavelet assessment following Torrence and Compo (1998) has been carried out.

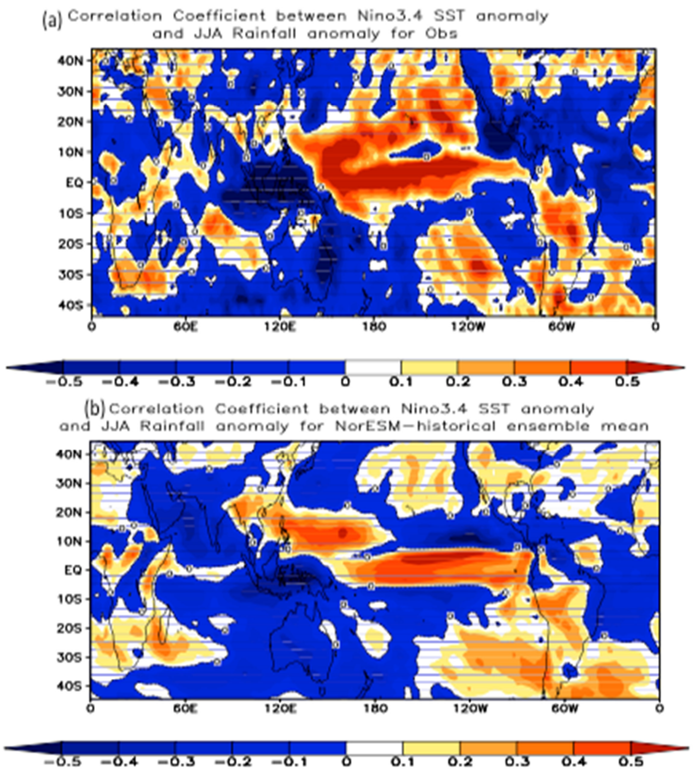

Figure 8: Correlation coefficient between Nino3.4 SST anomaly (190^{o}E-240^{o}E,5^{o}S-5^{o}N), and JJA rainfall at all grids over tropics. (a) Observations with NOAA SST and GPCC rainfall, (b) for NorESM1-M historical ensemble mean values. Red values show positive correlations and blue values vice-versa.

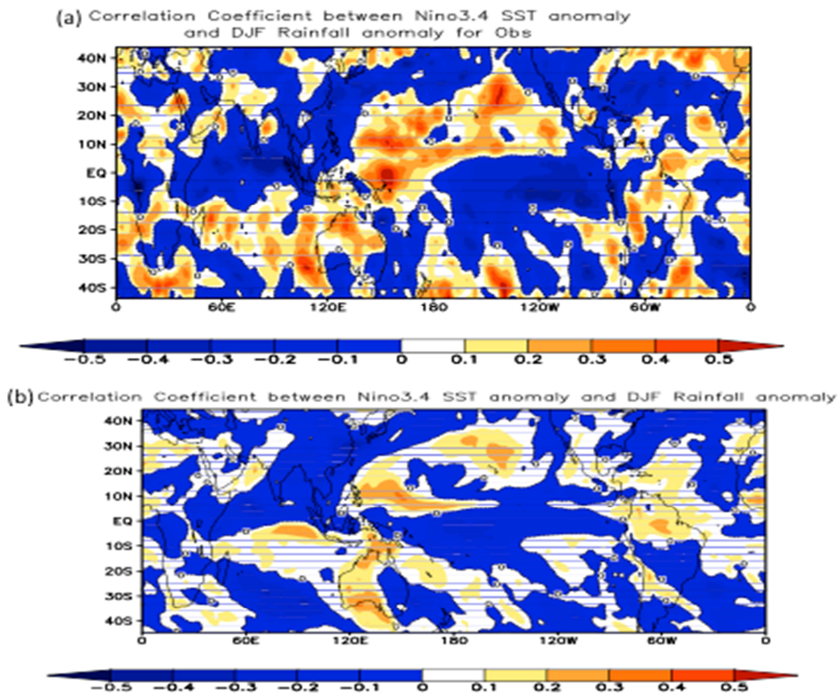

Figure 9: Similar to Figure 8 for DJF.

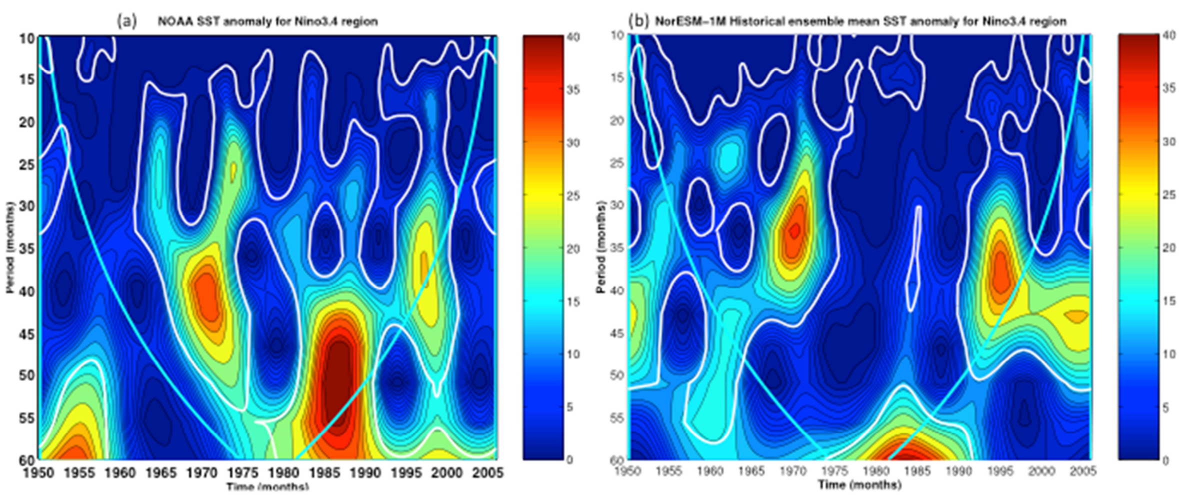

Figure 10: Wavelet analysis of Nino3.4 SST anomaly (190^{o}E-240^{o}E; 5^{o}S-5^{o}N), for (a) Observations (left) and (b) NorESM1-M (right). The cyan represents the cone of influence and the white thick lines represents significant 95% confidence level using chi-square method.

The wavelet analysis of Nino3.4 SST anomaly for observations and models suggest that in case of observation a significant power exists in 40-60 months, whereas the NorESM1-M (ensemble mean values) show a significant power in and around 30-45 months. On average, the ENSO power is predominant around 3-7 years and NorESM1-M model seems to be representing the power in ENSO and the evolution of ENSO anomaly similar to observations.

4. Summary:

The monsoon and ENSO teleconnections assessment for NorESM1-M historical simulations have been carried out in this paper. The preliminary assessment of the monsoon variability showed that the Extended Indian Monsoon Region (EIMR) rainfall is well represented by the NorESM1-M models and follows similar pattern as observations. The interannual variability of EIMR with dynamical monsoon index following westerly shear as developed by Wang et al 2001 shows that the correlation coefficient between EIMR and IMI index is 0.97 which is almost similar to what is found in MERRA reanalysis. Also, the spectral analysis of IMI index showed that the model has lower frequency compared to MERRA. The inverse relationship between EIMR and Nino3.4 SST anomaly suggests that the ENSO-monsoon relationship might be better represented in this model. Thus we can fairly say that to a large extent monsoon variability is better represented in NorESM1-M.

To understand the monsoon-ENSO teleconnection, an assessment has been carried out to find out the spatial correlations between summer/winter monsoon rainfall in boreal and austral regions with respect to winter Nino3.4 SST anomalies. The analysis suggests that the NorESM1-M model shows similar relationship between Nino3.4 and other monsoon regions as observations, and this is also shown for austral summer regions. Thus, our preliminary assessment of the monsoon-ENSO teleconnection assessment in NorESM1-M shows that NorESM1-M might be a better Earth System Model to study in-depth assessment of Monsoon variabilities over the region and also might be useful for better impact assessment.

5. Future work

We plan to assess the monsoon variabilities not only over India but in other monsoon regimes and also to assess the carbon cycle based model and its performance over the regions for historical, and RCP scenarios. It is also required to understand not only the interannual variability but the intraseasonal, diurnal variabilities as represented in NorESM models and how it might improve understanding of the Indian monsoon system as a whole. In future, it is also essential to understand the interdecadal variability and the relationship of ISMR with extra-tropical or polar teleconnections.

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