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APCC TECHNICAL REPORT 2012-01

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PREFACE

It is our pleasure to present to you the APEC Climate Center (APCC)'s Technical Report 2012, which reports the core outcomes of our research activities from the past year.

Since 2005, APCC, as a hub of climate information in the Asia-Pacific region, has strived to share our analysis and prediction of abnormal climate and to apply this information to regional development. The Center has established the most extensive Multi-Model Ensemble (MME) system for seasonal prediction in the world through its international science network and has provided value-added products to various stakeholders. Recently, APCC has expanded its mandate to include enhancing the capacity of APEC member economies to respond effectively to climate change and variability through better application of climate information.

In 2012, APCC continued to make an effort to improve the quality and quantity of our short-term climate forecasts and our online climate information systems, as information dissemination tools. Additionally, APCC began its endeavor to produce more applicable climate information through interdisciplinary research among various sectors, such as agriculture and hydrology. The following technical report provides more information about our research outcomes from 2012.

In 2013, following APCC's goal to enhance socioeconomic well-being through better utilization of climate information, APCC will continue to improve the quality and accuracy of its climate information, recognizing that the utility of this information is only as good as its quality. We would like to make the best use of our research outcomes in various scientific and application areas. We welcome any feedback on this report or on our services.

My best and warmest regards to all of you.

Dr. Chin-Seung Chung
Director/APEC Climate Center

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Dr. Prabodha Kumar Pradhan

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Assessment of EL Nino and Indian Summer Monsoon Rainfall Relationship using Coupled GCMs and MME Approach

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ABSTRACT

The warm phase of El Niño Southern Oscillation (El Niño) and Indian Summer Monsoon rainfall (ISMR) relationship is explored through seven fully coupled global climate models (CGCMs), which are semi-operational at APEC Climate Center (APCC). The 23-year (1983-2005) of hindcast datasets of individual model ensembles derived from May initial conditions for southwest monsoon season (JJAS) utilized to find out the simultaneous influence of El Niño -ISMR relationship in 1990s, which is observed to be weaker than present decades. The hindcast of ISMR climatology derived from seven individual models viz. APCC, NCEP, POAMA, SINT, SUT1, PNU and UHT1 appears to be not reasonably well, in particular above 50% departure as shown in CGCMs. In addition, four of six El Niño years during aforementioned period, are well depicts in most of the CGCMs, while the year 1994 and 1997 fails to be well represent by any of these models. The warm SST anomaly aligned with surplus precipitation over tropical equatorial Pacific through five models such as APCC, NCEP, POAMA, SINT and SUT1 are relatively better close toward observation. The El Niño-ISMR teleconnection skills both in monthly to seasonal scale are very poor in PNU as well UHT1 and their RMSE 3.84 and 3.77 less than APCC, NCEP, POAMA, SINT and SUT1 models. The authors show two types of approach Multi-Model Ensemble (MME) by simple composites of ensembles forecast from seven models (APCC, NCEP, POAMA, SINT, SUT1, PNU and UHT1) referred as MME1 and MME2 includes five (APCC, NCEP, POAMA, SINT and SUT1) best performing models. Importantly, anomaly correlation coefficient (ACC) shows the one-month lead MME2 prediction reasonably good for the El Niño and its adverse influence on ISMR than MME1. However, there are some limitations in capturing SST forcing over Indian Oceanic region in both types of MMEs.

1. INTRODUCTION

The Asian monsoon climate is significantly dominated by Indian summer monsoon rainfall (ISMR). Every year more than 80 % of annual rainfall is received over only the Indian land grid points so called all India summer monsoon rainfall index (hereafter AISMR) followed by *Parthsarathy et al.* (1994). Within a short span of four months starting from June through September (JJAS), AISMR plays a vibrant role on agriculture, economy and living status of the people. It appears to be year to year fluctuation is most prominent variation on the interannual scale is between the so called good (poor) with above-average (deficient) rainfall strongly related with food productivity, even though modest decrease of 10% of long term mean rainfall leads to significant decrease in rice production over India (Swaminathan, 1987; Gadgil, 1995; Webster et al., 1998). In addition, the inter-annual variability of AISMR shows larger impact on gross domestic product (GDP) and agricultural production of the country in the coming years (Abrol and Gadgil, 1999). Therefore, the prediction of AISMR is very essential for GDP. It has been recognized that deficient/surplus of AISMR is associated with the individual influence of warm/cooling phase of El Niño Southern Oscillation (ENSO) in seasonal to inter-annual scales (Sikka 1980; Mooley and Pathasarathy, 1984; Kripalini and Kulkarni, 1999; Krishna Kumar et al, 1999). The numerous works by *Walker and Bliss* (1932), documented that the inter-annual variability of ISMR has teleconnection characteristic with ENSO since 180 years ago. Therefore, this relationship has been analyzed and discussed (Rasmussion and Carpenter 1983; Barnett, 1984; Krishna Kumar et al. 1995; Webster et al. 1998; Slingo et al, 1999; Annamalai et al. 1999; Behera et al. 1999; Krishnamurthy and Goswami, 2000; Goswami and Jayavelu, 2001; Krishnan, et al. 2000; Gadgil et al, 2004). A critical analysis of Kripalani and Kulkarni (1999) documented that droughts over India caused by El Niño forcing are much more severe than non-El Niño episodes. Thus, El Niño response with ISM has been given more importance since three decades ago.

Recent finding by Rajeevan and Pai (2006) suggested that using the SST anomaly (SSTA) over the Niño 3.4 region (Trenberth, 1997) in central Pacific might be a better indicator for the association than the combined index derived from Niño 3 and Trans Niño Index (TNI). Therefore, the reliable long records of AISMR are obtained from the Indian Institute of Tropical Meteorology (IITM) rainfall datasets with Niño3.4 index. The details of rainfall datasets are discussed in www.tropmet.res.in. The normalized AISMR and Niño3.4 indexes during 150 years, starting from the period of 1861to 2011 from the observations are analyzed in terms of 30 years interval are discussed in Table 1. The correlation coefficients (CC) between the Pacific warming over two different regions (Niño 3 and Niño3.4) with AISMR is found to be around -0.15, -0.67, -0.71, -0.62 and -0.47 respectively. However, the CC between both of these Pacific warming with AISMR shows weak relationships as compared to 30 years ago. The recent three decades, starting from 1980-2011 has considered in this study. While model hindcast data sets are available at APCC for 1983-2005 and ENSO monsoon relationships are represented for same period as shown in Figure

1. The results are shown as highlighted by vertical gray color bars; the majority of deficient (excess) monsoon rainfalls have been associated with El Niño (La Niña) events.

The teleconnection characteristic between AISMR with Niño3.4 index became weak approximately 15 % as compared to immediate tri-decades (1950-1980). Similarly, this weakening relationship is also documented in several studies (Krishna Kumar et al. 1999, 2006; Gershunov et al. 2001; Ashok et al. 2001, 2004; Kinter et al. 2002; Annamalai et al. 2007; Kucharski et al. 2007, 2008; Xavier et al. 2007; Boschat et al. 2011). This is an important question since our ability to forecast ENSO up to one year in advance has shown increasing skill in recent years (e.g., Latif et al. 1998). If the monsoon– ENSO relationship remains reasonably constant rather than weak in the future, then interannual fluctuations of the monsoon might be difficult to predict. Otherwise, if this relationship fails, then the prominent indicator of year-to-year monsoon variability remains precarious (Annamalai et al. 2007). However, that would make it difficult to produce monsoon epochs in interannual time scales. The prime objective of this paper will provide the recent fidelity of individual coupled GCMs on prediction of AISMR in weak ENSO conditions.

The ISMR prediction skills through statistical (Rajeevan et al. 2004; 2007) and atmospheric global model (AGCM) are discussed (Gadgil and Sajini, 1998, Kang et al, 2002; Wang et al. 2004; Rajeevan and Nanjundiah 2009). The recent study by *Gadgil et al*. (2005) addresses the deficiency of these models; even the India Meteorological Department's (IMD) current operational statistical model is incompetent to predict major drought conditions such as 2002, 2004 and 2009 respectively. When the seasonal prediction of ISMR is concern, it is expected that the performance and reliable prediction could be only possible through coupled global climate model (CGCM) instead of AGCM and statistical models. Thus, an assessment of AGCM and CGCMs was carried by Ministry of Earth Sciences (MoES) for seasonal prediction of Indian Monsoon (SPIM), which concluded that CGCM prediction skills for the extremes condition of ENSO, IOD and EQUNOO (Janakiraman al. 2011; Gadgil and Srinivasan, 2011) is better than AGCM. After this, CGCMs became reliable tools for dynamical seasonal prediction and currently most of operational climate prediction centers are providing their real time forecast in 3 to 6 month in advance (Barnston et al. 2011). However, in dynamical model, significant improvement has been made through the improvement of the model physics and dynamics in last few years, but present day AGCM are unable to simulate mean and interannual variability of Indian summer monsoon very successfully (Kang et al., 2002). It is also found that the skill of the AGCM is poorer in simulating Indian monsoon; probably this is due to lack of proper representation of realistic sea surface temperature (Shukla et al. 1996) and the forecast errors in the seasonal prediction can be reduced through the combinations of the ensemble members forecast (Brankovic et al., 1990; Brankovic and Palmer, 1997). Therefore, the focus is now mainly on multi-model ensemble and super ensemble forecast (Krishnamurti et al., 1999; Wu et al., 2002; Wang et al., 2004; Chakraborty and Krishnamurti, 2006; Rajeevan et al 2011; Acharya et al. 2011) for the seasonal and interannual prediction of monsoon.

One approach is to generate the multi model ensemble (MME) forecast based on combination of individual model with perturbed initial conditions (Lorenz, 1969), which would provide better prediction for ISM. However, the skill of MME depends on the fidelity of individual models thus, evaluation of CGCMs is very essential. The prediction skills of seven CGCMs are discussed here and the study is divided into five sections. The observational and CGCMs datasets are introduced in section 2. In section 3, the mean monsoon rainfall climatology and biases are investigated. In addition, the anomalous features of El Niño composites discussed in section 3. The skill of AISMR and ENSO teleconnection is represented in section 4. In weak ENSO conditions, the purpose of MME and prediction of AISMR are compared with individual CGCMs are discussed in 5 and section 6 contain the discussion and conclusion respectively.

2. Data and methodology

The hindcast datasets are derived from seven fully coupled global climate models (CGCMs) for 6 month lead MME forecast using May initial condition which has been semi-operational since 2009 at Asian Pacific Economic Cooperation (APEC) Climate Center, Busan, used for the present study. The detail descriptions regarding the aforementioned models are represented in Table 2. These CGCMs viz. APCC, NCEP, PNU, POAMA, SINT, SUT1 and UHT1, outputs have been obtained through CliPAS[4] project, which has planned for utilization of climate prediction (Wang et al. 2009; Ham and Kang 2010; Lee et al. 2010) APEC region. The detail, information regarding these models and respective initial conditions are discussed in *Joeng et al*. (2012).

The extended reconstructed monthly sea surface temperature (ERSSTV3, which includes satellite data) from National Ocean Atmosphere Administration (NOAA) of 2^o x 2^o resolutions available in http://www.ncdc.noaa.gov/ersst (Smith et al. 2005), the gridded precipitation data from the Global Precipitation Climatology Project version (GPCP v2) with 2.5^o x 2.5^o resolution (Adler et al. 2003) is obtained. These datasets are linearly interpolated as per the model resolution. The atmospheric variables such as wind field obtained from National Center for Environmental Prediction, Department of Energy (NCEP/DOE-II) reanalysis data (Kanamitsu et al. 2002). We have examined the composite precipitation and SST anomaly over the Asian monsoon region from MME and compared with the observations. The AISMR index anomaly calculated from the monthly mean subdivisional rainfall dataset available from IITM for the period of 1831-2011 are used in this study. To recognize the 150 years of teleconnection characteristics with ENSO-monsoon relationship, the correlation coefficients among the AISMR index and Niño 3.4 SST anomaly (area average of 5^oS-5^oN; 170^oE-60^oW) from ERSST V3 have been evaluated.

In order to examine the CGCMs fidelity, 1-month lead seasonal prediction for JJAS period of 1983-2005 climatology and bias has been calculated. To identify the dominant features during aforementioned period, the seasonal anomaly also calculated. However, for each model the ensemble mean anomalies are calculated based on the monthly ensemble mean climatology for each lead-time. Some additional calculations such as composites analysis, temporal and spatial correlation coefficient have been employed to investigate the relationship between observation and individual CGCMs. Using the best models among the seven GCMS, the MME forecast for AISMR-ENSO relationship are also discussed herewith.

3. Hindcast skills for El Niño and Indian summer monsoon relationship

3.1 Climatology and Bias

In order to understand the prediction skill of the individual CGCMs mean ensembles products available in APCC, the precipitation over the ISM region during JJAS are investigated on the basis of climatology, bias and their map-to-map correlation coefficients (CC). The 23 years (1983-2005) of spatial distribution of precipitation over the ISM derived from GPCP v2 and CGCMs are represented in Figure 2. The spatial distribution of maximum precipitation over the head Bay of Bengal (BOB) and along the west coast of India recorded in GPCP v2. However, another maximum precipitation area is also seen in southeast Indian Ocean besides to Indonesian region and minimum precipitation recorded over the northwest as well southwest part of India in Figure 2(a).

The ensemble mean monsoon rainfall climatology with respect to their bias for the same period for the seven models is presented in Fig. 2(b-h). In general, the spatial distributions of mean precipitation patterns appear to be reasonably well and close towards observation (Figure 2a). However, there are significant differences between the predicted rainfall by different ensemble members of each model (results not shown here), indicating that the monsoon rainfall could be very sensitive to initial conditions. The models behave differently for most part of the country with an underestimation of rainfall by some models while an overestimation of rainfall noticed in the same region by a different model, particularly over central India. The model-to-model variability in simulating rainfall is also large over the Indian Ocean region. Most of CGCMs have shown an underestimation of rainfall over heavy rainfall regions like west coast of India, over northeast India and the equatorial regions as shown in Figure 2 (b-h).

3.2 Inter-annual variability

The Figure 3 shows the percentage departure of monsoonal mean rainfall (mm/season) over land grid points are obtained from two different types of observations viz. IITM rain gauge stations (Parthasarthy et al. 1995) and GPCP v2 compared with CGCMs during hindcast period to investigate inter-annual variability. It has been recognize that, model quality could be evaluated through the retrospective predictions of AISMR to quantify all models, showing significant fluctuation and diverse nature of the model and their dependency with the initial conditions. Although there is large spread of predicted AISMR among these models, the prediction with NCEP, POAMA, SINT and SUT1 are relatively better than APCC, PNU and UHT1 models.

To quantify the models' fidelity in reproducing spatial pattern of rainfall climatology, pattern correlation coefficient (PCC) between the rainfall simulated by the models and GPCP v2 are computed. The PCC in terms of interannual variability of precipitation over two different domains, over the Indian summer monsoon region (ISMR: 20^{o}S-40^{o}N; 40^{o} E-140^{o} E) which includes both land and oceanic grid points and other over an area bounded by (AISMR: 8^{o}-35^{o} N; 68^{o}- 98^{o} E) only land grids are calculated shown in Table 3. The CGCMs shows the highest skill in predicting the spatial pattern of JJAS precipitation over the ISMR and mean PCC of these models varies from 0.68 to 0.84 uniform characteristics, which is very difficult to quantify the individual models. In order to know the prediction skills of AISMR, the mean PCC varies in the range of 0.06 to 0.64, which indicates large variation in the model fidelity as compared to ISMR. Similar types of results for DEMETER coupled models and CFS is discussed in details (Preethi et al. 2010; Gadgil et al. 2011; Acharya et al. 2011). Interestingly, the AISMR has shown larger variability in terms of seasonal to intra-annual time scale (Parthsarathy et al, 1994, Krishna Kumar et al, 1995).The year-to-year model fidelity in terms of PCC as discussed in Table 3, shows models particularly APCC, SINT, SUT1, POAMA and NCEP has better PCC as compared to PNU and UHT1 models. However, the PCC is reproduced consistently well in neutral and La Niña years rather than the El Niño years. Further investigation carried out in this study; to evaluate the coupled GCMs predictability based on ocean-atmosphere interaction over the Pacific Ocean have been examined for the El Niño years rather than La Niña events. The source of the deficient rainfall during JJAS period over Indian region arises due to warming phase of SST anomaly over the equatorial tropical Pacific, which has adverse impact of Indian economy (Gadgil el al., 2005). Therefore, the El Niño teleconnection with AISMR has been explored.

3.3 Anomalous features of El Niño composites and its influence on Indian summer monsoon

(a) SST and Precipitation

The six El Niño events occurred during JJAS period of 23 years (1983-2005) and these events are characterized through warm SSTA over Niño 3.4 region ≥ 0.45 °C its standard deviation followed by *Trenberth,* (1997). The composites of SST (°C) and precipitation (mmday $^{-1}$) anomaly are analyzed through observation as well with CGCMs and are represented in Figure 4 and 5 (a-h). Importantly, the seasonal anomaly has calculated based on 1983-2005 climatology, and the El Niño years are identified through Niño 3.4 index. The SST anomaly (SSTA) obtained from ERSST shown in Figure 4 (a), warm SSTA more than 1.0 ° C in central Tropical Pacific region that extended towards east equatorial Pacific. The Figure 5 shows, maximum surplus precipitation anomaly also notice over the equatorial central Pacific and its west to northwest part. However, positive precipitation anomalies also seen over the Myanmar, Thailand, Laos, Vietnam and South China Sea (SCS) and adjoining region which coincides with the warm SSTA. The warming over Niño 3.4 region significantly tightly aligned with the monsoonal precipitation over the tropical region, particularly in between 10.0°N-10.0°S; 160.0° E-180.0°E. Similarly, strong negative precipitation anomaly is observed over the Indonesian region. However, moderate to deficient precipitation is seen over Indian peninsula through the Bay of Bengal (BOB) and adjoining Indian seas. The aforementioned precipitation and SSTA predicted by all models shows that the model variability over the Pacific is less than Indian Ocean. The surplus negative precipitation anomaly distributions over the maritime continent region particularly Indonesian region well predicted by two models such as NCEP and POAMA as shows in Figure 5(c) and (e) agreeing with GPCP v2 observation. However, moderate to poor represent by other five models such as SINT, SUT1, PNU, APCC and UTH1 respectively. The warm phase of ENSO is associated with a weakening of the Indian monsoon on overall reduction of precipitation is well represented by four models PNU, POAMA, SINT, & UHT1. In addition, the La Niña signature is well reproduced by APCC model whereas, NCEP unable to reproduce adverse influence of El Niño with AISMR and the same features are shifted to the west coast of India particularly in Arabian Sea.

(b) Wind 850 hPa

Based on the results discussed above, it is possible to deduce the dynamics associated with the enhancement of convective anomalies over NW Pacific during warm phase of ENSO conditions. Composite wind at 850hPa level during JJAS period of El Niños are represented from observation and CGCMs in order to evaluate the dynamical linkage of cyclonic and anti-cyclonic features significantly associated with NWP convection, that triggers due the warming over the east to central part of equatorial Pacific. The earlier studies by *Hoskins and Karoly (1981); Nitta (1987)* have shown that, interactions between the tropical convection and the wind anomalies can generate and maintain large-scale anomaly patterns of alternating highs and lows which extend meridionally from the equatorial region into the subtropics and mid-latitudes through Rossby wave dispersion (Mujumdar et al., 2006). Furthermore, the meridional dispersion of Rossby waves is well known to be strongly enhanced in a belt of westerlies located over the region of anomalous convection (*Hoskins and Karoly 1981; Lau and Lim 1984; Chang and Webster 1990*) thus, we examined the wind composites of six El Niño events at 850 hPa derived from NCEP/DOE-II reanalysis. The observation (Figure 6a) shows, at low-level strong southwesterly wind anomalies that originated from the Maritime continent region in between 120^{o} E to 150^{o} W. In addition to that anti-cyclonic circulation also observed along Japan coast which causes the reduction of convection over the same region (Figure 4a). However, an elongated structure of cyclonic circulation tilted towards the northeast direction and its vicinity persisted in between 170^{o} E, 35.0^{o} N, which could be attributed to suppressed convection over east-west Pacific rim and illustrated in the schematic, in Figure 6 (a). Note that the meridional circulation pattern is characterized by an intensified cyclonic anomaly over the NW Pacific region. In fact, coupled GCM prediction provide support indicating that the enrichment of low-level westerlies and eastlies over Indo-Pacific rim favored enhanced convection in the region agreeing with the observations. However, among these CGCMs in particular NCEP, POAMA, SINT, SUT1 and APCC exhibits the best capability of the anomalous features such as cyclonic and anti-cyclonic patterns attributed with warming through SSTA shown in Figure (4 b-h), but the location of the cyclonic and anti-cyclonic features contrary to the observation. Thus, the enhanced precipitation over NW Pacific was sustained due to cyclonic activity (Kumar and Krishnan 2005; Pradhan et al., 2011and Kim, et al., 2011) by the intensified low and increased cyclonic activity over the region. In turn, the strong ascending motions over NW Pacific forced subsidence and rainfall reduction over the Indian subcontinent through anomalous east–west circulation in between 10^{o} N and 20^{o} N (Fig. 5 b). Thus, the convection variability over NW Pacific can be served, as an important component, which arbitrates the ENSO-monsoon teleconnection dynamics (Mazumdar et al. 2007; Ashok et al. 2012).

(c) 3.3 Evolution SST and Precipitation over Indo-Pacific rim during El Niño's

Prior to evaluating the monsoon–ENSO relationship, we need to evaluate the amplitude of ENSO behavior in these models, in particular the space–time evolution of SST and associated precipitation anomalies along the equatorial Pacific, and thus circulation anomalies are linked with tropical Pacific up to Indian monsoon domain. The spatial evolution of tropical Pacific SST and precipitation anomalies over ENSO is a crucial element for determining the fidelity of a model [Annamalai et al. 2007]. Figure (7a) represents the composite evolution of Niño-3.4 SST anomalies in monthly scale starting from June to September of all El Niño events in the observation compared with seven coupled GCMs mean ensembles. It is clearly shown that in observation, maximum warming was found in 1987 as well 1997 rather than other El Niño years and are well represented by all models but, APCC and SUT could not predict the same. The eastward movements of the warmest SSTs are accompanied by an eastward migration of convection into the central Pacific and cooling SSTs associated with suppression of convection over the Maritime Continent during El Niño years, noticed in observation (Fig 8a). This is one of the important features of El Niño events unable capture through the coupled GCMs clearly. The warming SSTA over the equatorial Pacific in between 160^o W and 90^o W clearly represented by NCEP, SINT, POAMA and SUT1. However, the location of cooling over the Indian Oceanic region represented by the models does not agreeing with observation during JJAS of years 1987, 1994 and 1997, which might may be the reason all models fails to predict the India summer monsoon in the year of 1994 and 1997 respectively. For the comparison of precipitation anomaly within observation and all models during the El Niño events, NCEP and POAMA show better results than other models resembles with SST anomaly (Fig 6a).

4. Skill of ENSO and AISMR teleconnection

The spatial patterns of temporal correlation coefficient (TCC) between observed Niño 3.4 indexes obtained from NOAA SST with GPCP v2 precipitation for JJAS period during 1983-2005 has been illustrated in Figure (9a). The TCC of observation shows the strongest to moderate negative scores over the Maritime Continents and Indian region, however positive TCC is noticed around Myanmar, Burma, Cambodia and adjoining southern part of China region. In addition, the strong positive TCC scores over the equatorial Pacific, particularly maximum at 180^o E, 2.5^o N is shown by the observations. The representation of simultaneous impact of SSTA over the Niño 3.4 region of tropical Pacific and their influence on precipitation indicates the adverse influence for AISMR, which is one of the important characteristic of El Niño showing the natural sensitivity of India's monsoon epoch's (Kumar et al. 2010).

The teleconnection characteristics between ENSO and Indian summer monsoon rainfall has been well known (Goswami and Xavier, 2005; Krishnamurthy and Goswami, 2000; Krishna Kumar et al, 1999;2006) and studies through coupled GCMs are well documented (Webster et al,1991; AchutaRao, K., and K. R. Sperber, 2002; Annamalai et al., 2007; Preethi et al., 2010; Choudhari et al., 2012; Joseph et al., 2012; Rajeevan et al., 2011). To evaluate the prediction skill of the CGCMs, it is necessarily important to quantify the SSTA over the Niño 3.4 region in the Pacific Ocean. Thus, for quantitatively measure the forecast skill, temporal correlation coefficient (TCC) calculated at each grid points are considered here. The spatial patterns of TCC between observed Niño 3.4 obtained from ERSST with GPCP v2 precipitation during 1983-2005 has been illustrated in Figure (9a). In similarly fashion, the TCC predicted between Niño3.4 index and global precipitation from seven coupled GCMs also represented in Figure 9(b-h) for comparison with observation. The TCC of observation shows the strong and moderate negative scores over the Maritime Continents and Indian region, however positive TCC is seen around Myanmar, Burma, Cambodia and adjoining southern part of China region. In addition, the strong positive TCC scores over the equatorial Pacific, particularly maximum at 180^o E, 2.5^o N is represented by the observations. This representation of SSTA over the Niño 3.4 region of tropical pacific and precipitation indicates the reverse relationship for Indian summer monsoon and thus, causes weakening of AISMR. The Figure 9 also indicates TCC score from the CGCMs, that shows the negative TCC scores over the maritime continent, particularly Philippines Sea and adjoining region as represented by observation. The prediction skills over the Philippines Sea through CGCMs particularly NCEP, POAMA, SINT, UHT1 agreeing well with observation, whereas as poorly represented by APCC, PNU and SUT1 models. The main significant features of the negative and positive TCC over the East Indian and West Indian Ocean are depicted in observations, which are clearly reflected in NCEP as well POAMA models. However, there is no TCC signal captured by NCEP over peninsular India (Karnataka) region whereas POAMA over estimated over the northwest (Gujarat) and northeast (Assam) part of India.

5. Propose of MME suite for AISMR prediction

As discussed in previous sections, the individual CGCMs performance has been evaluated through climatology and their bias, composite analysis and monthly evolution of the anomalous SST and precipitation over the equatorial Indo-Pacific rim with conclusion APCC, NCEP, POAMA, SINT and SUT1 show better skills. Thus, keeping that in mind, we propose two kinds of MME of these CGCMs based on using simple composite method (SCM). Firstly, we consider seven CGCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1 and UHT1) to construct a MME referred as MME1 and similarly MME2 including five CGCMs (APCC, NCEP, POAMA, SINT and SUT1) respectively. However, their performance of remotely climate influence such as ENSO and ISMR has evaluated. The analysis derived from MME1, MME2 shows TCC of Niño3.4 index with precipitation, and subsequently AISMR with global SST relatively appears to be close towards observation. The significant improvements in negative TCC skills are shown in MME1 and MME2 as compared individual CGCMs. The positive (negative) scores of TCC over the northwest pacific (adjoining Japan) region became weak in MME2 than MME1, while this asymmetric condition is incorporated with cyclonic and anti-cyclonic features (Figure not shown). In addition, the negative TCC skill over Indian peninsula has reduced by around 15% through MME2 than MME1 and better skill seems to be over the North East Indian region. However, TCC score of MME2 is relatively close to the observation better than MME1 as well individual CGCMs.

The standardized anomaly of predicted Niño3.4 SST and AISMR anomaly from the seven coupled models for the retrospective 23 year period shows, major ENSO conditions like 1987/1988, 1997/1998 and 2002/2003 are well agreeing with observation indicates, the coupled of models has credibility to representing the climate indices over the tropical Pacific region shown in Table 4. The CC of CGCMs with observation is highly statistically significant above 90.0 % level except PNU model. However, the warm phase of ENSO condition during 1987 and 2002 fails to predict by UHT1 and same feature could be captured by all CGCMs. In addition to that, PNU and UHT1 could not capture the La Niña phase during 1998 as well. The MME1 and MME2 is better than individual CGCMs and their spatial CC is relatively higher than observation (-0.48), in fact the ENSO and ISM teleconnection MME2 is -0.62 whereas MME1 shows -0.76 respectively. In addition, the 23 years hindcast prediction through MME1 and MME2 of AISMR particularly and their comparison with IITM observation summarized that the CC of MME2 shows better prediction skill than MME1 and their CC is around 0.51 and 0.35 respectively.

The anomaly correlation coefficients (ACC) between GPCP and seven individual ensemble forecast of AISMR has been calculated followed by (Kar et al. 2011) as shown in Figure 11. The figure shows that four models viz. NCEP, POAMA, SINT, SUT1 and their ACC varies range in between 0.35 to 0.88. However, 0.35 to 0.7 ACC are obtained by APCC, PNU and UHT1. Thus, we prepared the MME mean prediction of AISMR from all CGCMs and five best CGCMs. The results are encouraging and predictive skills of both MME1 and MME2 are better than individual models. Interestingly, 1994 and 1997 was El Niño year but AISMR recorded moderate to normal rainfall, ACC relatively better represented in MME2 than MME1 as well as individual CGCMs. In addition, Figure 12 summarized that, the skill of seasonal prediction of AISMR during El Niño years could not captured well through MME1 and MME2 as we expected but, precipitation in MME2 shows significantly better skills than MME1 and relatively close towards observation.

6. Discussion and conclusions

The prime objective of this work is to evaluate the prediction skill of ISMR through the seven-CGCMs, which are currently semi-operational at APCC since 2009. The strength of ISMR represented by AISMR index and its interannual variability associated with the characteristics of SSTA over the central-eastern Pacific such as Niño 3.4 region. Therefore, the amplitude of ENSO and variability of AISMR derived from the observed and retrospective prediction of coupled GCMs such as APCC, NCEP, PNU, POAMA, SINT, SUT1 and UHT1 during JJAS period starting from 1983 to 2005 with May initial condition in other words ahead of 1-month lead, has been documented in this work.

The southwest monsoon precipitation derived from ensemble mean of the individual coupled GCMs results show systematic biases in the representation of mean monsoon seasonal precipitation over the Indian region. The spatial distribution precipitation over the northeast and west coast of India through 5 models such as APCC, NCEP, POAMA, SINT and SUT1 are better and the prediction skill is around 48%. The biases in most of the coupled GCMs are common and the correction of the inherent bias in the mean state is critical for improving in one-month lead-time. Interestingly, the remote forcing over the Pacific such as warm phase of ENSO and its coupling with Indian summer monsoon prediction is robust with coupled GCMs. However, the SSTA over the tropical Indian Oceanic region preserve dipole modes are associated by ENSO (Ashok et al.2004), also influences AISMR thus their predictions and skills relatively poor as compared to the ENSO. The ENSO amplitudes analyzed through the Niño 3.4 index and the standardized anomaly correlation coefficient with observation and coupled GCMs particularly APCC and UHT1 show poor performance than other models. Among these seven CGCMs, two CGCMs show poorer skill than the remaining. The poor performance also affects the MME technics. To quantify this issue, we tested two types of MME schemes viz. MME1 and MME2 with and without two CGCMs. The ACC shows that MME2 is better than MME1. We plan to further extended this present study has to be further extended using different MME schemes.

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Table 1 The 150 years correlation co-efficient between the SST anomaly over Niño 3 and Niño 3.4 region (Predictor) with all India summer monsoon rainfall (AISMR) index anomalies during the JJAS period of 1861-2011

Time period	CC AISMR with SST Anomaly over the tropical Pacific Ocean	
	Niño 3 Index	Niño 3.4 Index
*1861-2011	-0.53	-0.52
1861-1890	-0.20	-0.15
1891-1920	-0.68	-0.67
1921-1950	-0.72	-0.71
1951-1980	-0.67	-0.62
1981-2011	-0.34	-0.47
1983-2005	-0.35	-0.48

Table 2 Combination of ocean and atmospheric models used for coupled GCMs at APCC/CliPAS Programme

Sl. No	Name of the Model	Host Organization	AGCM horizontal/vertical resolution	OGCM horizontal/vertical resolution	Ensemble member	Forecast period	Reference
1	CCSM3	APCC	CAM3T85 L26	POP1.3 gxlv3 L40	5	1983-2008	Jeong et al. (2008)
2	CFS	NCEP	GFS T62/L64	MOM2.2 1/3 Lat x 1lon L40	15	1981-2006	Saha et al. (2006)
3	PNU	PNU	CCM3 T42L18	MOM3~0.7 (low lat) ~1.4 (mid lat) and ~2.8 (high lat) L29	10	1979-2008	Sun, J. Q., and J. B. Ahn, 2011
4	POAMA	BOM	BAM 3.0d T47/L17	ACOM2 0.5-1.5lat x 2lon L31	10	1981-2006	Zhao and Hendon (2009)
5	SINT	FRCGC	ECHAM4 T106/L19	OPA 8.2 2 cos (lat) x 2 lon L31	9	1981-2009	Luo et al. (2005)
6	SUT1	SNU	SNU T42/L21	MOM2.2 1/3lat x 1lon L32	6	1981-2009	Ham and Kang (2010)
7	UHT1	UH	ECHAM4 T31/L19	UH Ocean 1latx2lon L2	10	1982-2005	Fu and Wang (2004)

Table 3 The root mean square error (RMSE) and spatial co-relation coefficient of JJAS precipitation climatology between GPCP v2 and CGCMs ensemble mean over the ISRM and AISMR grid points.

MODEL	RMSE between GPCP v2 and individual CGCMs		Pattern Correction Coefficients (PCC) between GPCP v2 and individual CGCM	
Region	ISMR(20S-40N;40-140E)	AISMR(8-35N;68-98 E)	ISMR(20S-40N;40-140E)	AISMR(8-35N;68-98 E)
APCC	2.24	2.80	0.7	0.37
NCEP	2.71	3.37	0.81	0.43
PNU	3.39	3.84	0.68	0.15
POAMA	3.1	3.61	0.75	0.48
SINT	1.8	1.98	0.84	0.64
SUT1	2.8	3.04	0.78	0.49
UHT1	3.69	3.77	0.73	0.06

Table 4 Same as Table 1 but values are obtained from individual CGCMs as well two different MMEs.

Models	1-month lead forecast of ENSO and AISMR relationships
APCC	-0.24
NCEP	-0.60
PNU	-0.57
POAMA	-0.66
SINT	-0.64
SUT1	-0.60
UHT1	-0.78
MME1	-0.76
MME2	-0.62

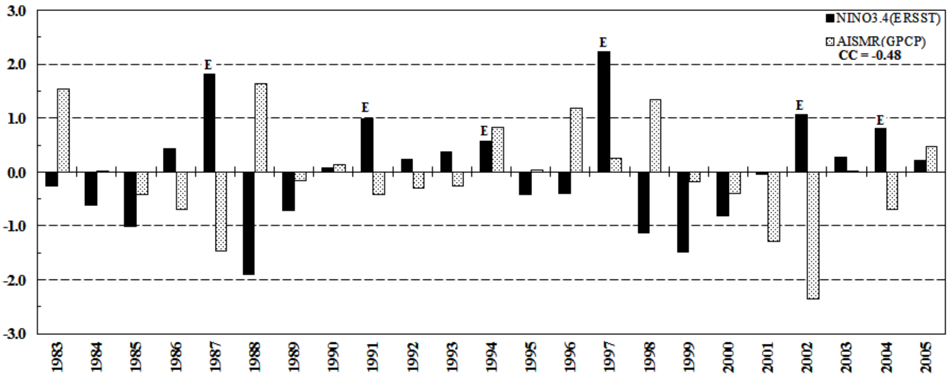

Figure 1 The year to year variability of normalized all Indian summer monsoon rainfall anomaly (AISMR) and Niño 3.4 index (black shaded) anomaly for the period of 1983 to 2005.

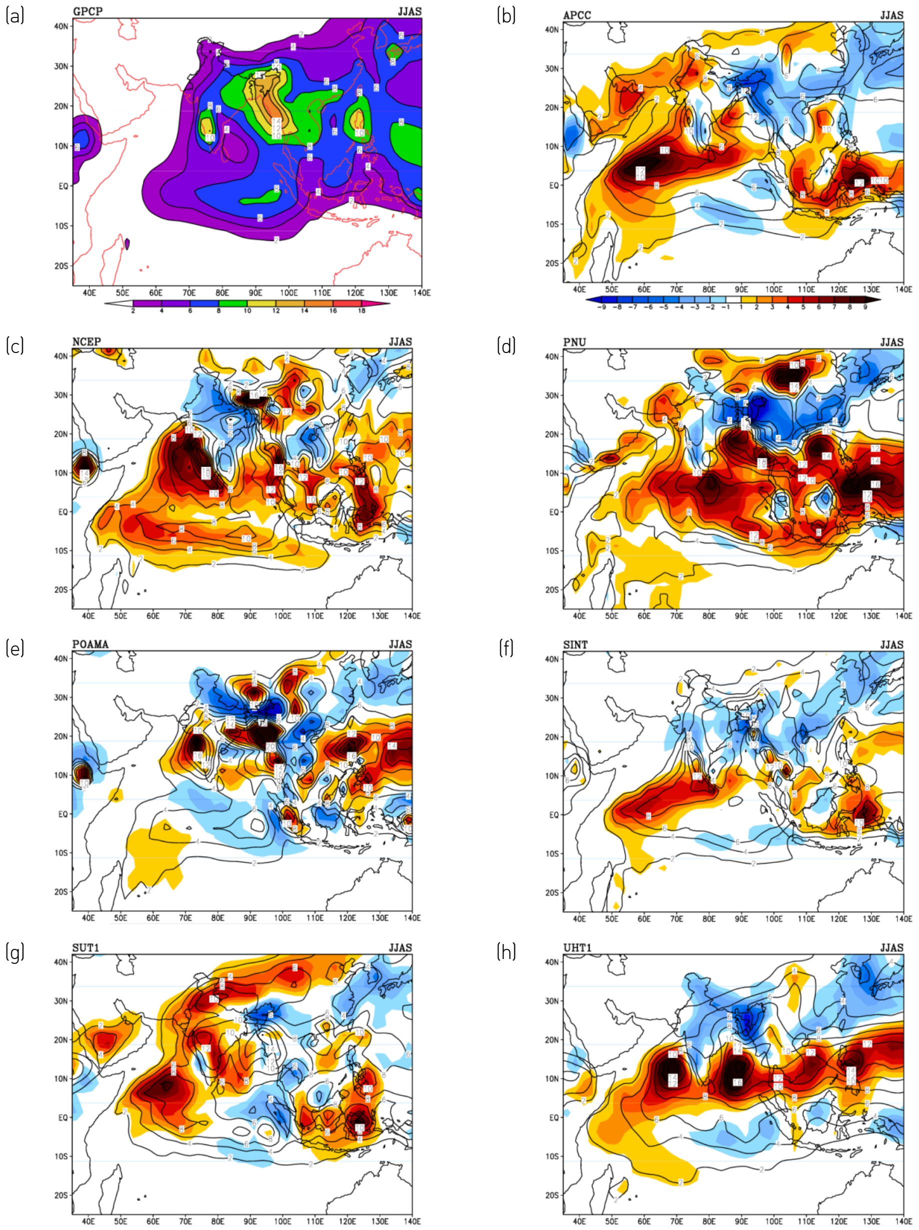

Figure 2 (a-h) Spatial distribution of southwest monsoon precipitation (mm/day) climatology (1983-2005) derived from observation (a) GPCP v2 ; (b-h) Ensemble mean climatology (counter) and their bias (shaded) of seven CGCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1, and UHT1) respectively.

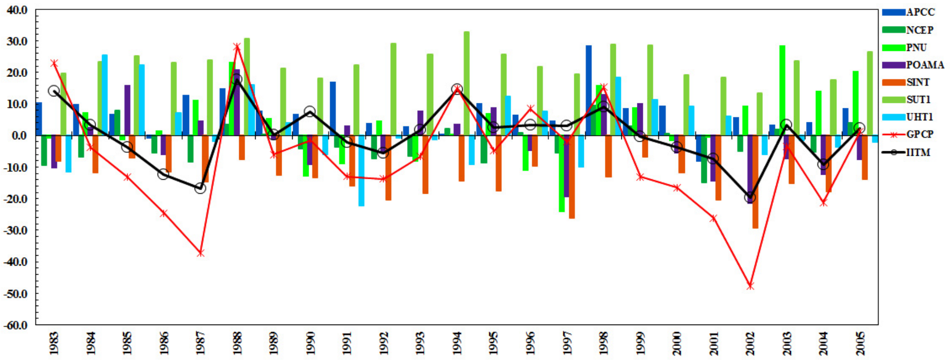

Figure 3 Comparison of monsoonal precipitation percent departure over Indian land grid point region derived from IITM as well GPCP v2 observations and seven CGCMs ensemble mean such as (APCC, NCEP, PNU, POAMA, SINT, SUT1, and UHT1 respectively.

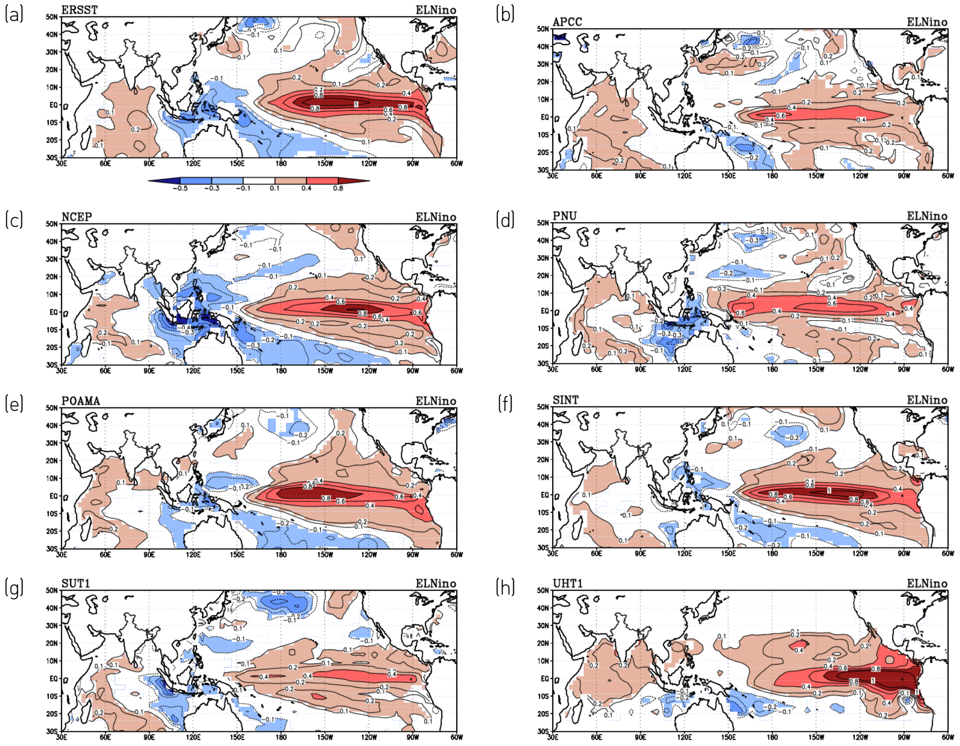

Figure 4(a) Compotes of JJAS SST (°C) anomaly for El Niño years (1987, 1991, 1994, 1997, 2002 and 2004); Figures (b-h) same as (a) but from 7 coupled GCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1 and UHT1). Significant values at 70, 80 and 90 % confidence level are shown in shadings.

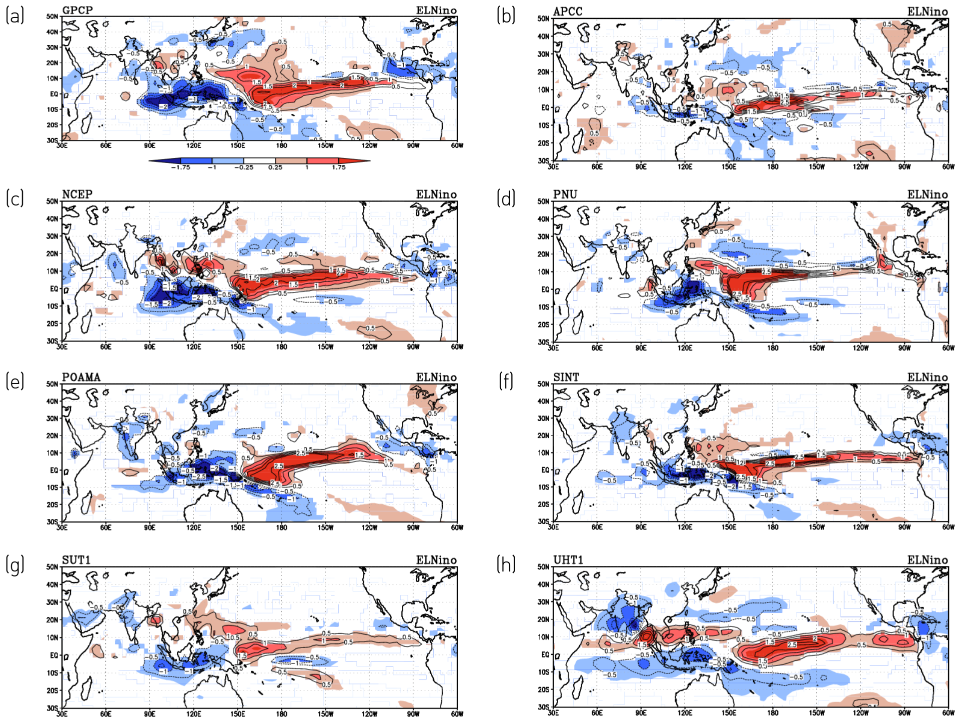

Figure 5 (a) Same as Fig. 4 (a-h), but for JJAS precipitation (mmday^{-1}). Significant values at 70, 80 and 90 % confidence level are shown in shadings.

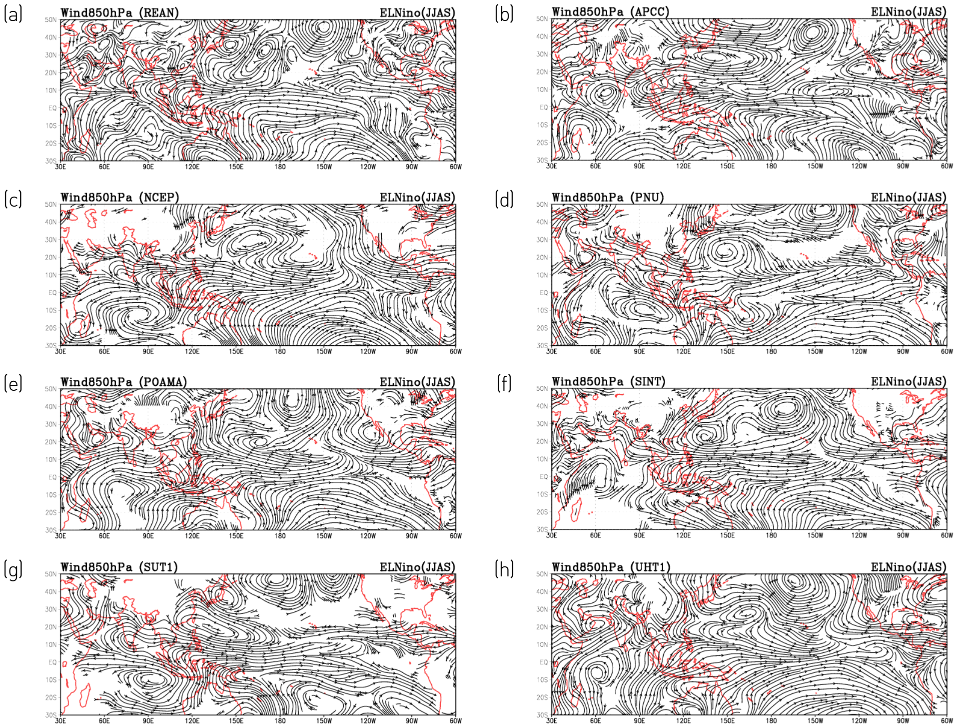

Figure 6 (a) Composites of JJAS wind at 850 hPa (m/sec) anomaly for El Niño years (1987, 1991, 1994, 1997, 2002 and 2004); Figures (b-h) same as (a) but from seven CGCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1 and UHT1).

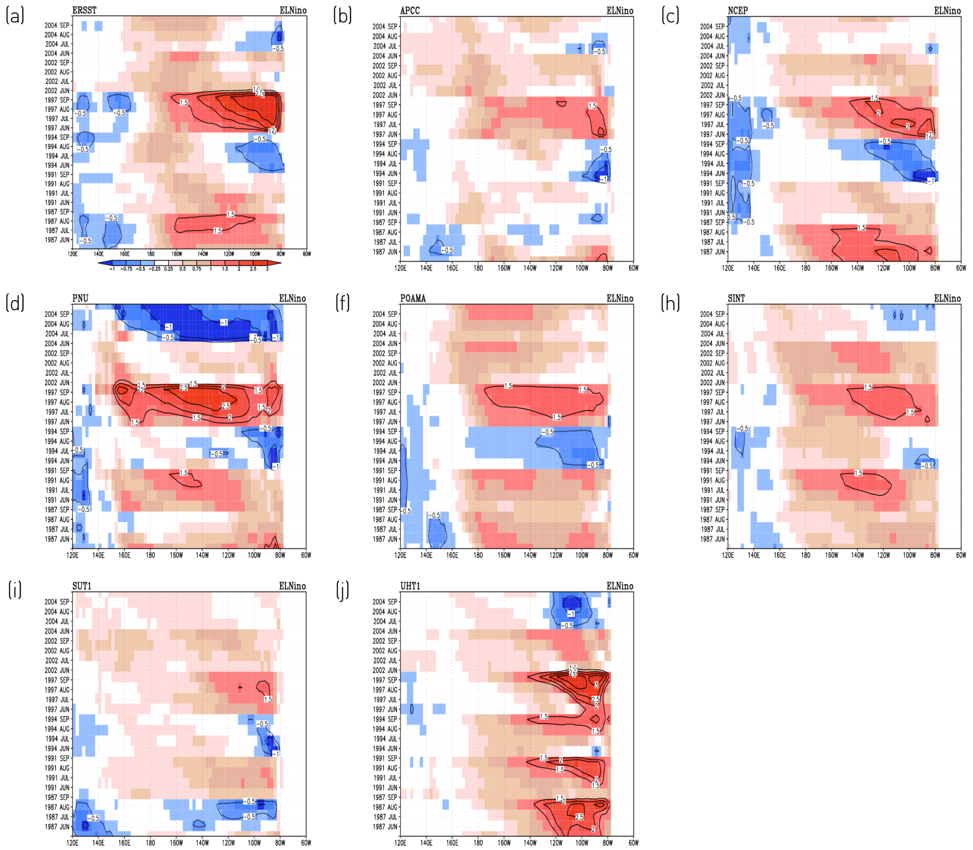

Figure 7 Evolution of SST anomaly (oC) through June to September over the Indio-Pacific region [area average of (5o S-5o N)] during 6 El Niño events (1987, 1991, 1994, 1997, 2002 and 2004) (a) observation; (b-h) from coupled GCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1, and UHT1).

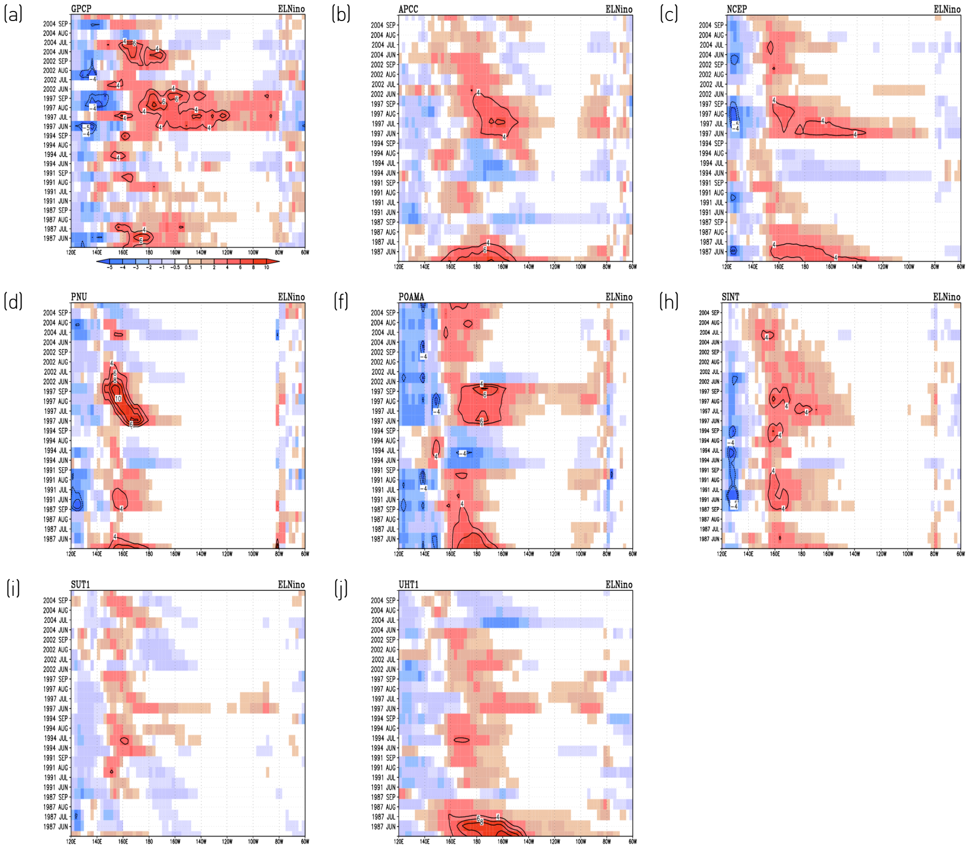

Figure 8 Evolution of precipitation anomaly (mm/day) through June to September over the Indio-Pacific region [area average of (5o S-5o N)] during 6 El Niño events (1987, 1991, 1994, 1997, 2002 and 2004) (a) observation; (b-h) from coupled GCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1, and UHT1).

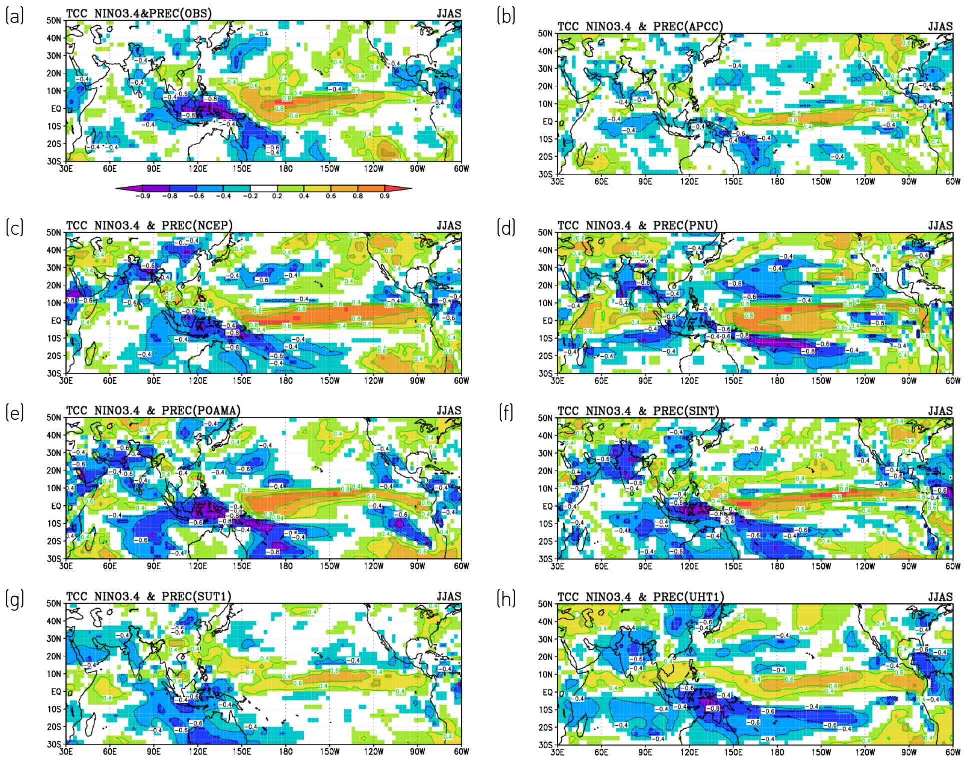

Figure 9 Temporal correlation coefficients (TCC) between Niño 3.4 index and global precipitation anomaly during JJAS period derived from coupled GCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1, and UHT1).

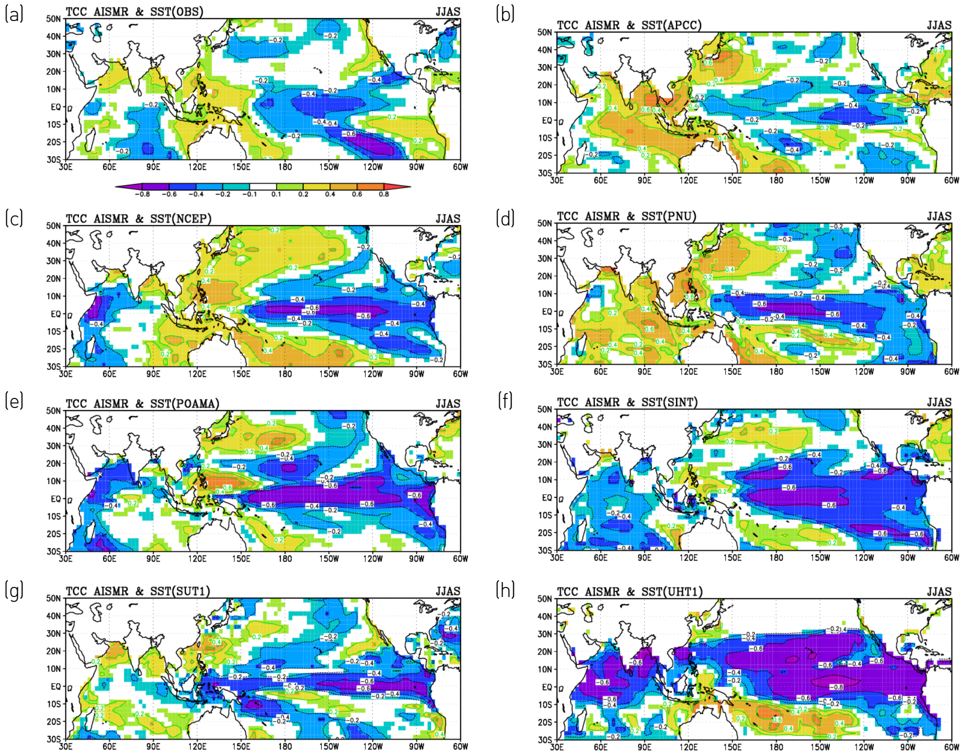

Figure 10 Temporal correlation coefficients (TCC) between AISMR and global SST anomaly during JJAS period derived from coupled GCMs (APCC, NCEP, PNU, POAMA, SINT, SUT1, and UHT1).

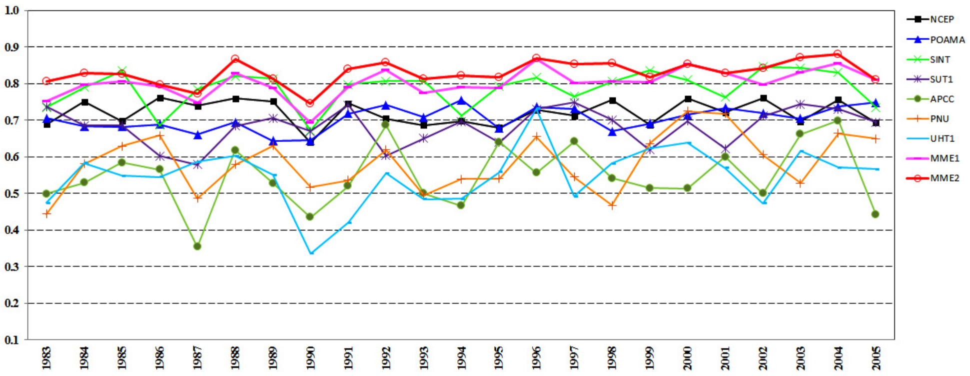

Figure 11 Anomaly Co-relation Coefficients (ACC) of AISMR between GPCP v2 observation with individual CGCMs as well as MME1 (APCC, NCEP, PNU, POAMA, SINT, SUT1, UHT1) and MME2 (APCC, NCEP, POAMA, SINT, and SUT1)

APCC TECHNICAL REPORT 2012-01

- Application of Bayesian Model Averaging on Multi-Model Ensemble Seasonal Prediction
- Decadal Change of Variability and Predictability of Two Types of ENSO
- Assessment of Relationship between EL Nino and Indian Summer Monsoon Rainfall
- Long-lead MME Extreme Drought Prediction
- Assessment of APCC Multi-Model Ensemble Predictions

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