IGAD ICPAC

CR4D Climate Research for Development in Africa

CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS

United Nations Economic Commission for Africa

The Eastern and Southern African Climate Variability: Physical Mechanisms and Predictability

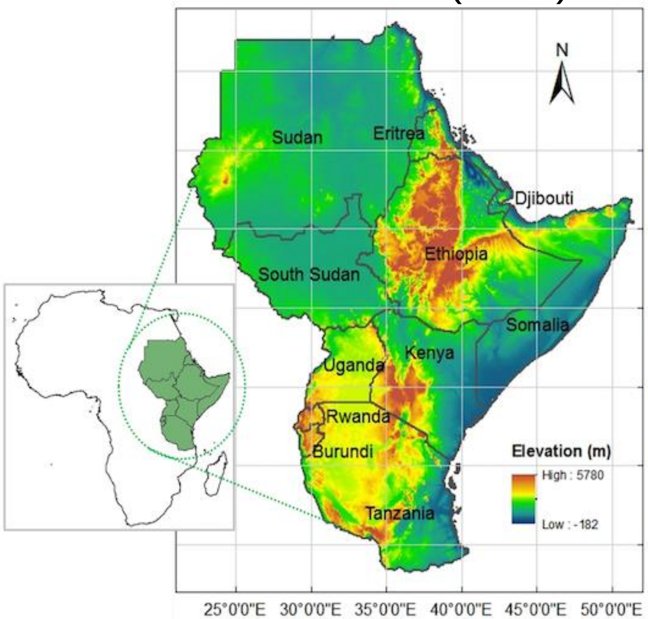
Titike K. Bahaga

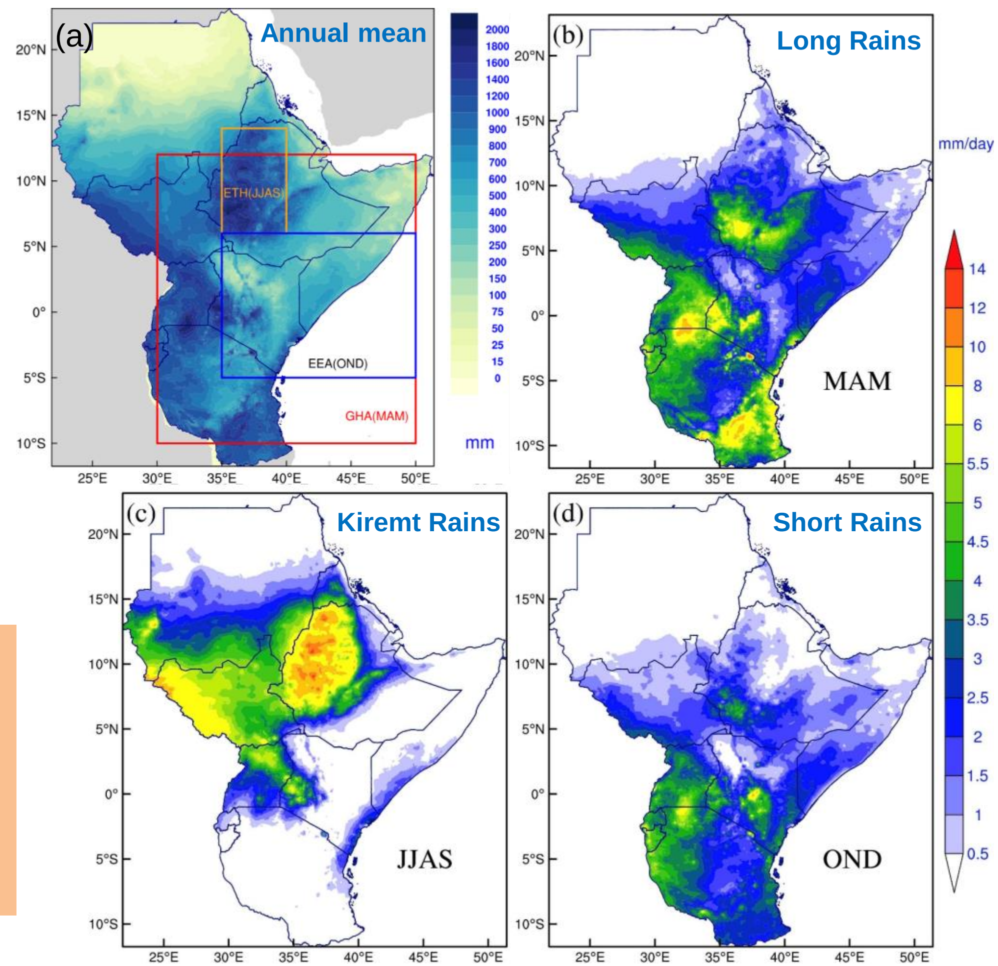
Workshops on Objective Climate Forecasts for Agriculture and Food Security Sector in Eastern and Southern Africa

Topography and Seasonality of Climatological Rainfall

Mean climate patterns linked to regional factors (ITCZ=bimodal).

Greater Horn of Africa (**GHA**)



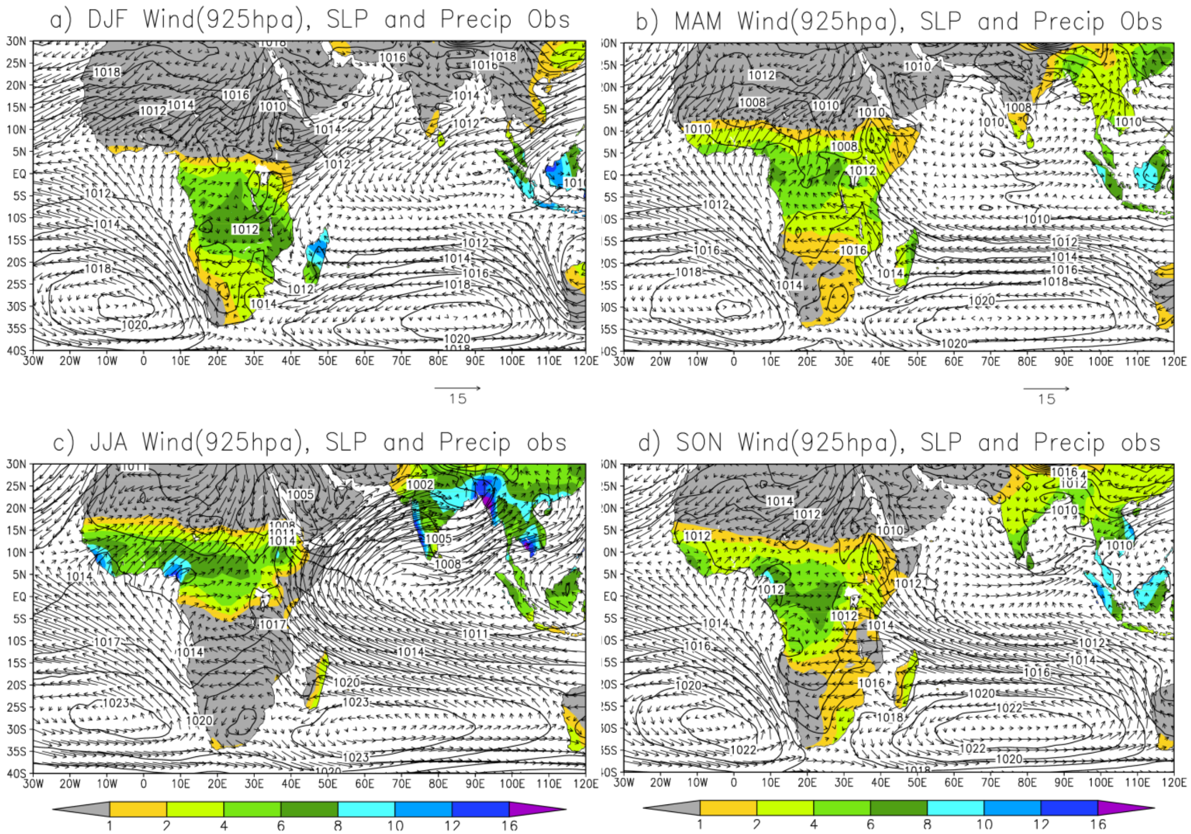


- Inhomogeneity of annual mean rainfall ranges ≈200—2000 mm.
- Bimodal rainfall pattern experienced over many parts during: Long Rains (MAM) and Short Rains (OND).

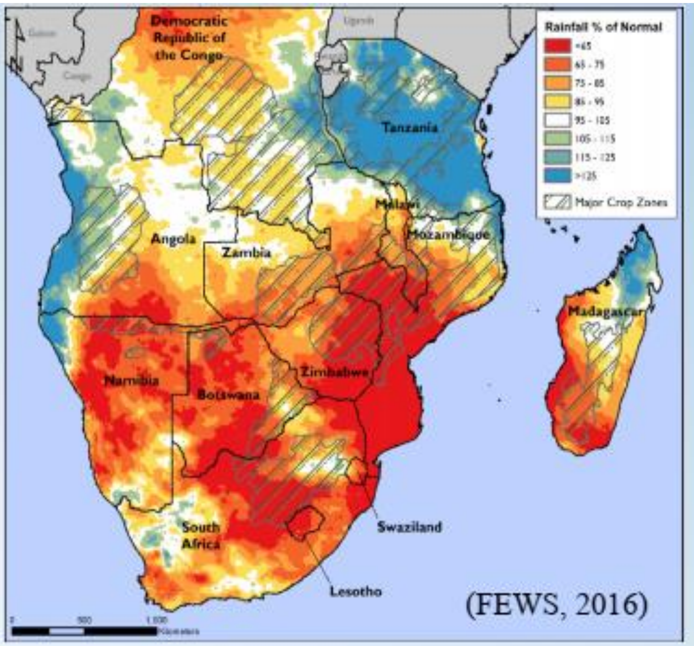
Dynamics of African Climate

The dynamics of climate at any location is determined by the space-time characteristics of the GC; which controlled by complex interaction between ecosystem, land, oceanic & atmospheric process.

- Complex topography
- Atlantic and IO monsoons, ITCZ
- OA (SST) and LA interaction (SM)
- Tropical Waves/Oscillations
- Tropical-Extratropical interactions
- TC and Subtropical Anticyclones
- Jet streams
- Congo air boundary.



Impacts of Drought in Southern Africa



(FEWS, 2016)

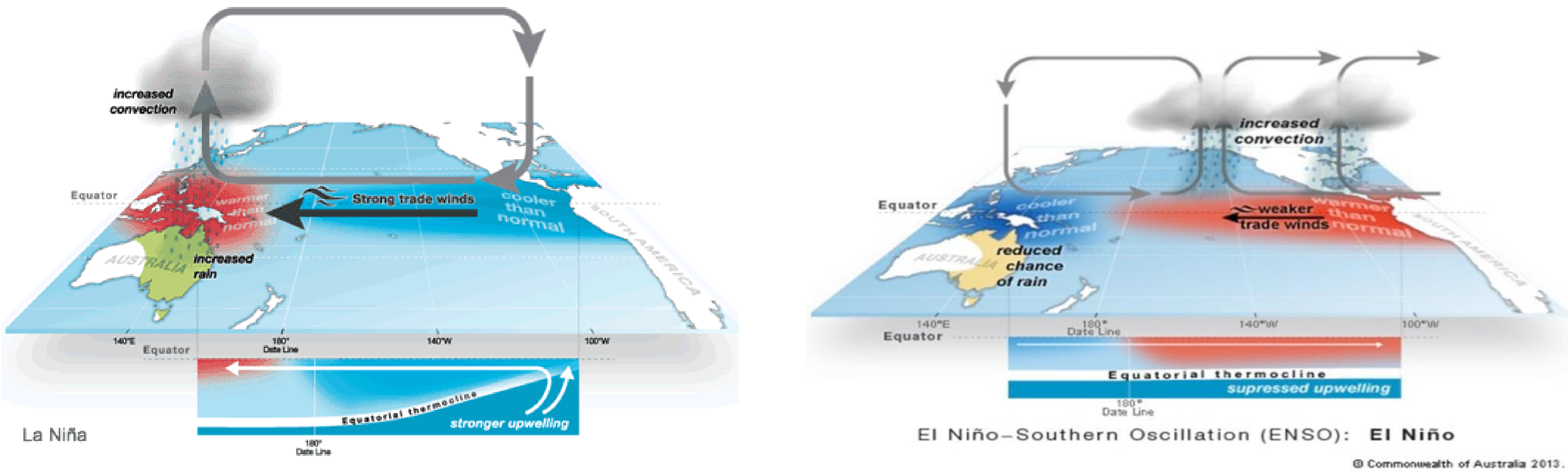
- Crop failures and livestock losses
- High economic and agricultural losses
- Food shortages
- Socio-economic impacts
- Water scarcity for human and animal consumption
- Waterborne diseases

During 2015, SST in the central tropical Pacific was warmer than normal. By December 2015, the anomaly in the Niño-3.4 area reached +2.9 °C, which indicated about the strongest event of the past 36 years.

What drives the EA and SA Rainfall Variability

El Niño Southern Oscillation (ENSO)

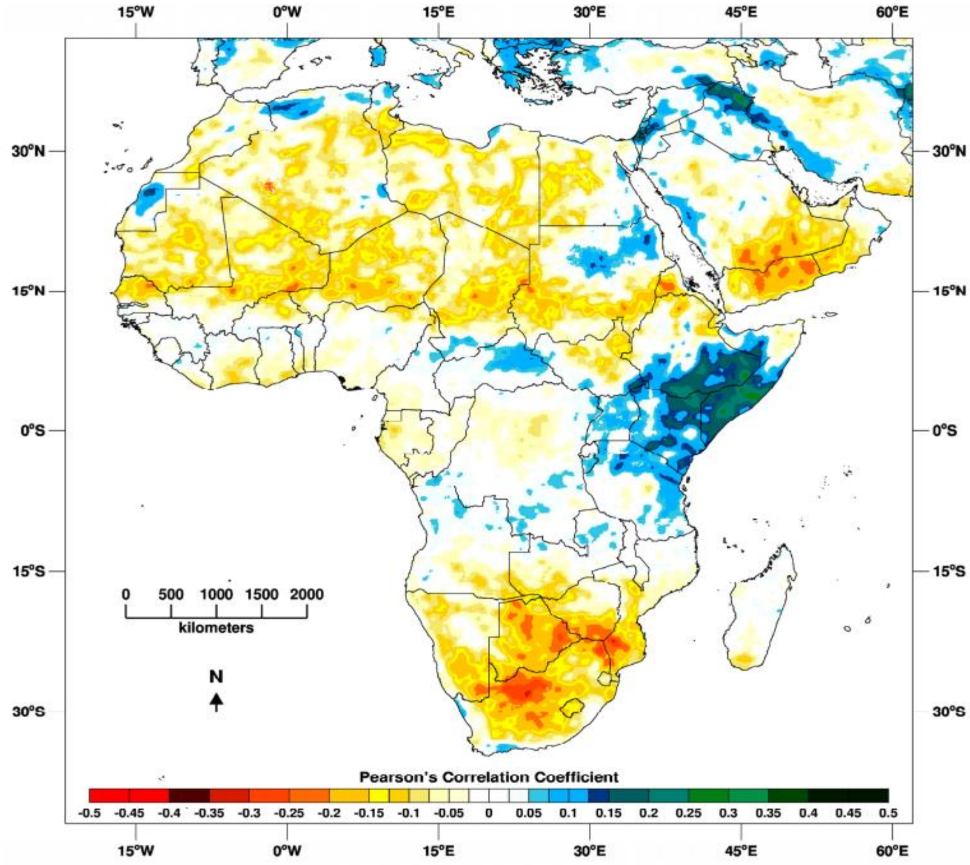
- ENSO is a coupled oceanic and atmospheric phenomenon that occurs at irregular intervals of two to seven years in the equatorial PO.
- A warm event, or an El Niño, is associated with Warm SST anomalies in the eastern equatorial PO, cold SST anomalies in the western equatorial PO, and weak westerly trade winds.



- The dramatic change in ocean temperature disrupts atmospheric dynamics in this region and has downstream effects on global circulation patterns influencing temperature, winds and precipitation in various regions via teleconnection signals

ENSO Impact on Vegetation Response Patterns

Correlation of N34 index with monthly anomalies of AVHRR NDVI data from 1981 to 2017.

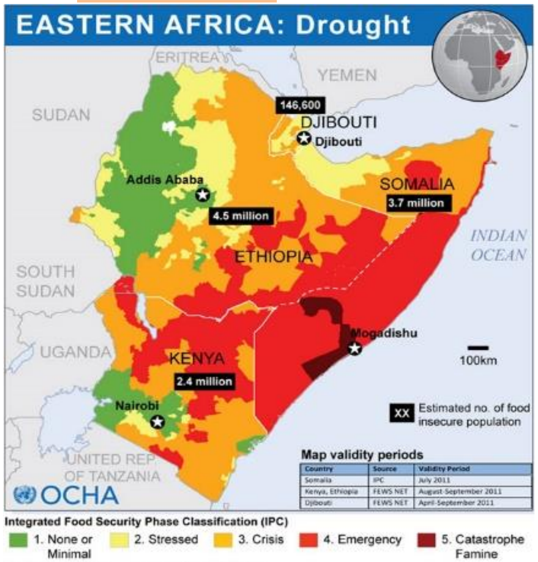


- EA and SA regions experience strong but opposite effects; during El Niño events SA is typically warm and dry and EA is typically cool and wet. The effects are largely reversed during La Niña events. Peak Vegetation impacts lag peak ENSO anomalies by 1-month.

Impacts of Drought and Flood in Eastern Africa

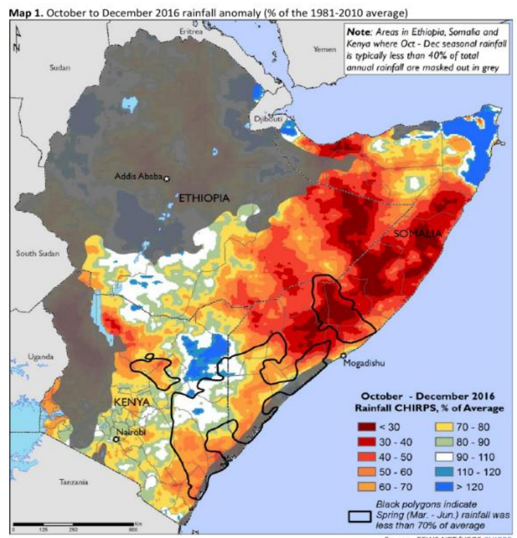
GHA countries are facing recurrent extreme climate events with extensive economic and social consequences.

OCHA (2011)



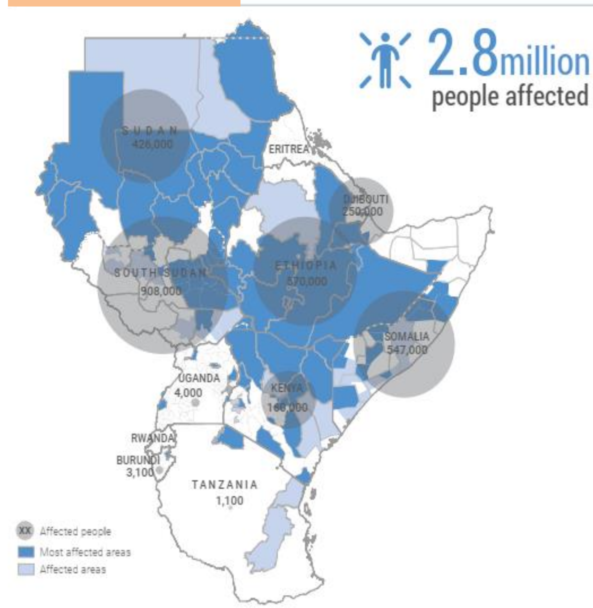
In 2010/11 drought caused the worst humanitarian crises in 60 years.

The "Long" and "Short Rains" in 2016 almost totally failed in parts of Kenya and Somalia.



www.fews.net

OCHA (2019)



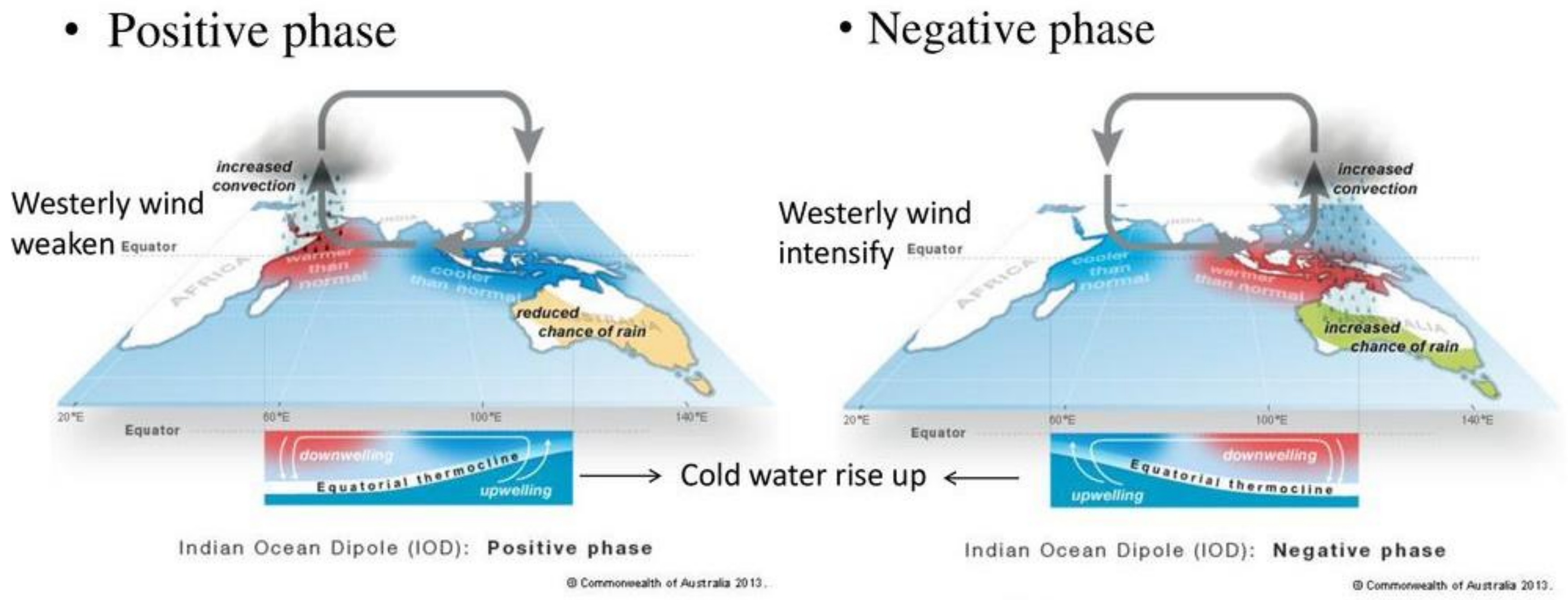
The region threatened by +IOD induced unusual heavy "Short Rains" in 2019 and almost 2.8M affected.

Drought are becoming more **frequent** and more **intense**. Therefore, Understanding of the mechanisms that produce inter-annual to decadal variability and climate information is urgently needed.

What drives the SR Variability over GHA?

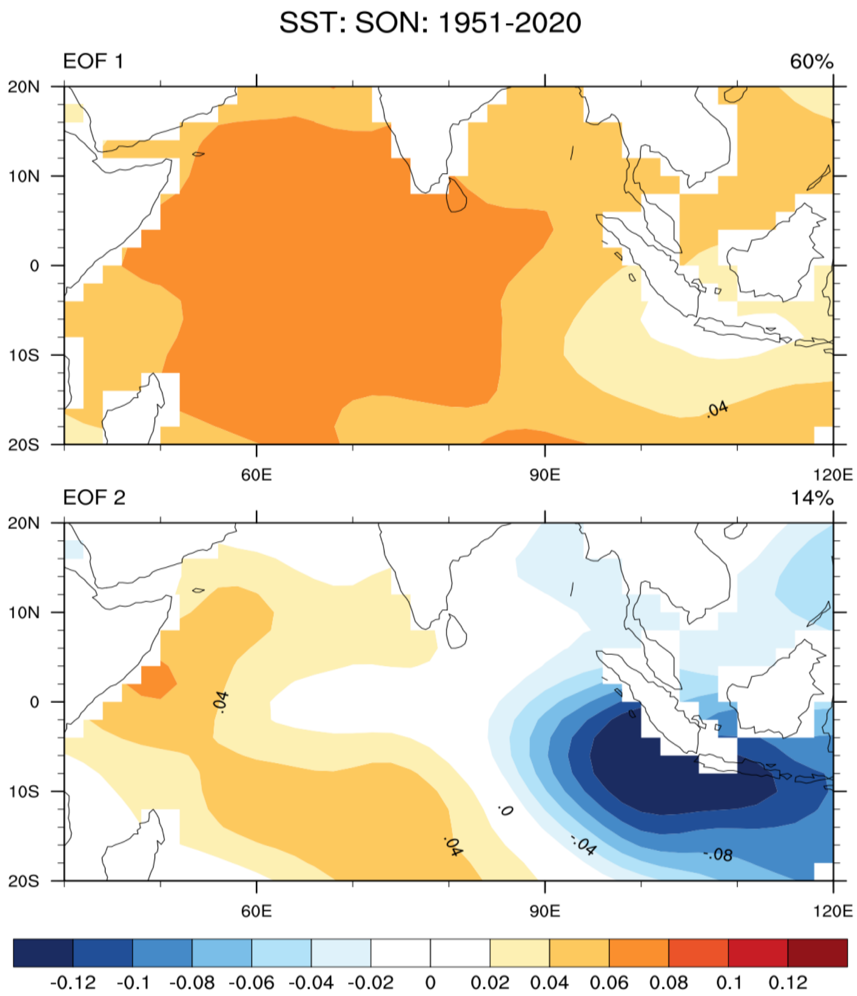
IOD (Indian Ocean Dipole)

- It is an inherently coupled ocean-atmosphere phenomenon in the IO and distinct from ENSO
- +IOD is a pattern of internal variability and anomalously warm/cold SST over WTIO/ETIO.

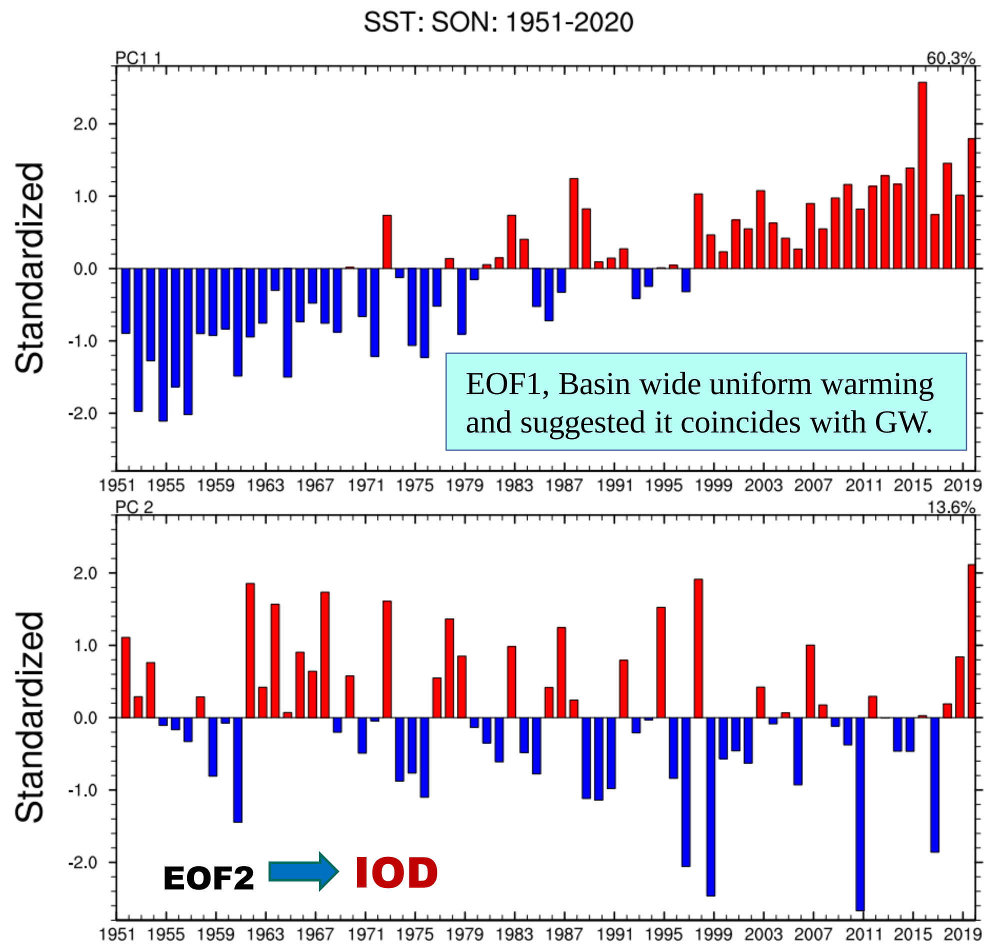


- We cannot control the Oceans, but we can inform and make communities more resilient.
- A **better understanding** of the TO Variability and its impact on African climate events will enable **improved climate service.** Support to better anticipate and prepare for extremes, up to six months in advance of the event.

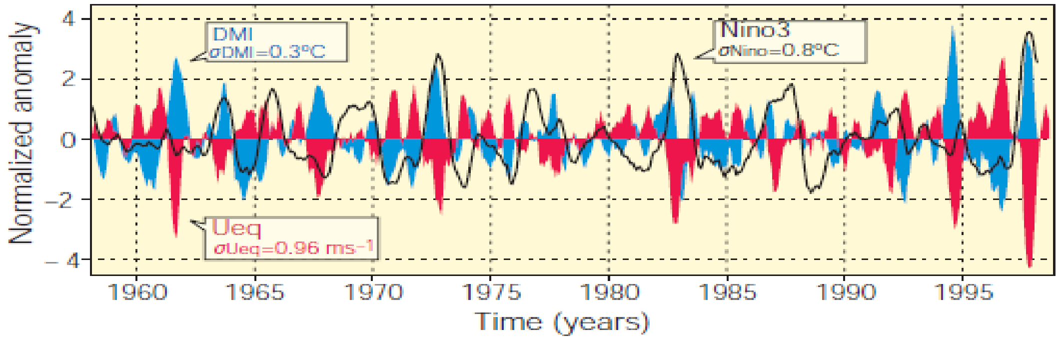
First and Second Modes of SST variability in the IO



The aim of EOF/PCA is to find the linear combination of all the variables, i.e. grid points, that explains maximum variance



The IOD event appears as a major signal in some years. This statistically lower position is due to less frequent occurrence of the events compared to ENSO events.



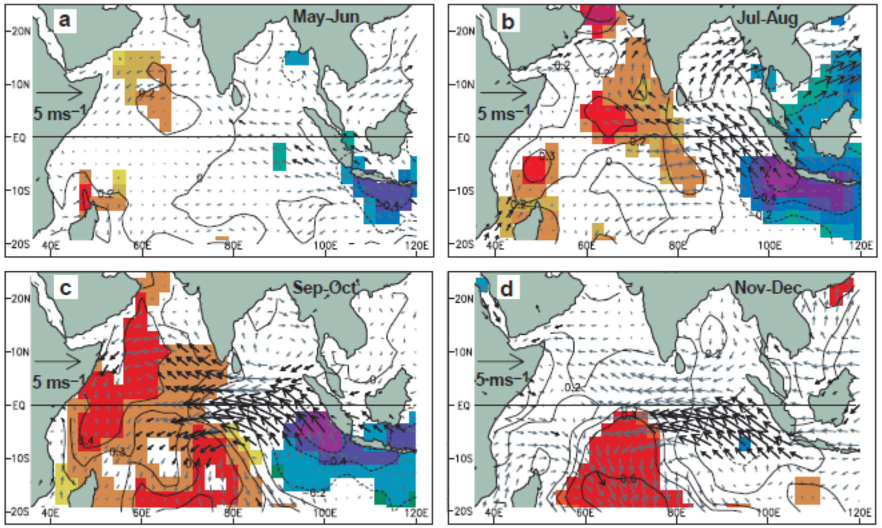
Saij et al. 1999

- The dipole mode event is independent of the ENSO in the Pacific Ocean. Note the significant dipole mode events of 1961, 1967 and 1994 coinciding with no ENSO, a La Nina and a weak El Nino, respectively.

- There are years in which dipole mode events coincide with strong ENSO events as in 1972 or1997.

- Seasonal phase locking is an important characteristic of the DMI time series

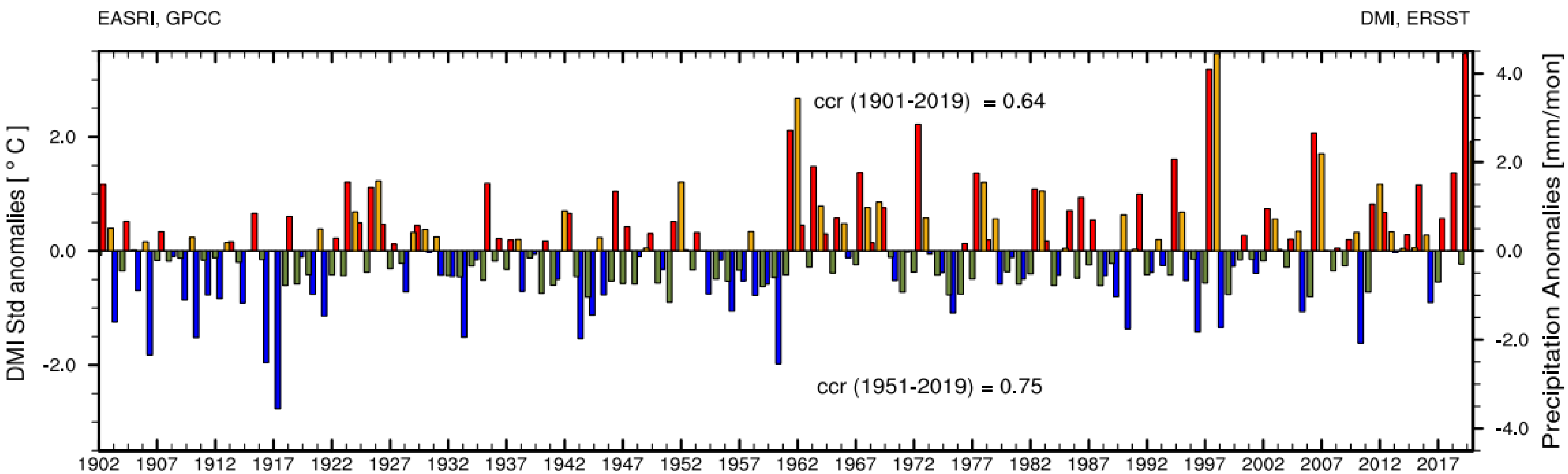
- Significant anomalies appear around June intensifies and peak in October

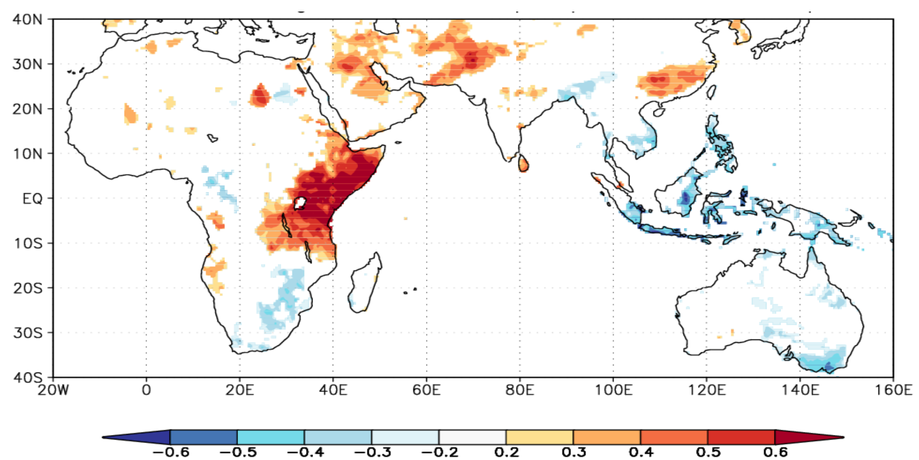


Composite of extresmes1961, 1967, 1972, 1982, 1994 and 1997

What are the Mechanisms that IOD Impacts SR Variability?

SR Potential Predictability and Non-Stationary Teleconnections

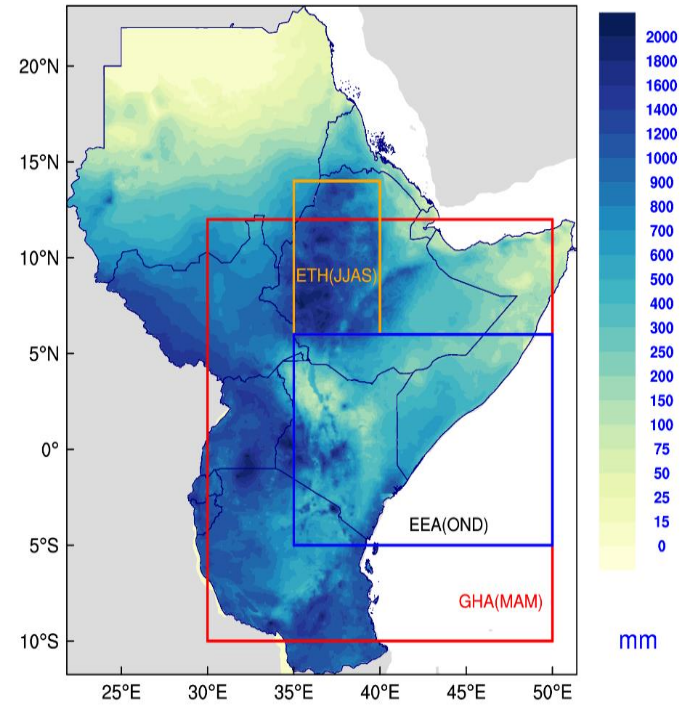




Dataset and Methods

Data:

- Gridded Precipitation: GPCC, CenTrends/GHA, CHIRPS 2.0
- Sea Surface Temperature (SST): ERSSTv4 and HadISST
- ERA-Interim reanalysis from ECWMF
- Various well-known climate state indices
- Simple and complicated CM



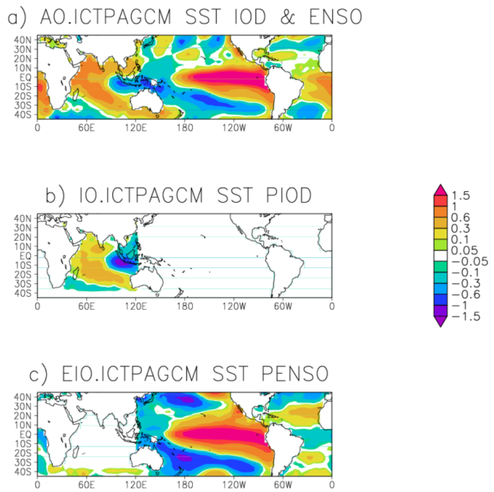
Predictands:

1. Greater Horn of Africa Long Rains SPI (**GHA-LR-SPI**): (10°S–12°N, 30°–52°E) March-May (MAM)
2. EThiopian Highland Kiremt Rains SPI (**ETH-KR-SPI**): (6°–14°N, 35°–40°E), June-September (JJAS)
3. Equatorial East Africa Short Rains SPI (**EEA-SR-SPI**): (5°S–5°N, 35°–50°E), October–December (OND)

Methods:

- Standardized Precipitation Index (SPI) (McKee et al.1993)
- Pearson's **linear correlations** in triangle representations (as in **Diatta and Fink, 2014**) using **detrended** raw, high- and low-pass filtered time series (Butterworth filter, cut-off 8 years)
- **Partial correlation**
- Linear **Regression**, **Composite**, and **EOF** analysis
- **Significance test** of **non-stationarity** in linear correlations of sliding windows (van Oldenborgh & Burgers 2005)

AGCM Experimental Set Up to Understand IOD Impact on EA SR.



ICTPAGCM

AO

10 ensemble simulation forcing global Ocean with observed time varying SST.

- Provide best estimate for Mutual influence ENSO & IOD
- Assess potential predictability
- Validate model climatology

IO

10 ensemble simulation, forcing in the IO basin with time-varying observed SSTs While the rest ocean prescribed with annual cycle of SSTs

- Investigate the role IO anomalies in deriving EEASR anomalies
- Physical mechanism

EIO

10 ensemble simulation prescribing annual cycle of SSTs over IO and the rest of global ocean forced with observed SSTs

- Evaluate the response by removing the IO anomalous forcing.
- Understand the extent of influence coming from other ocean

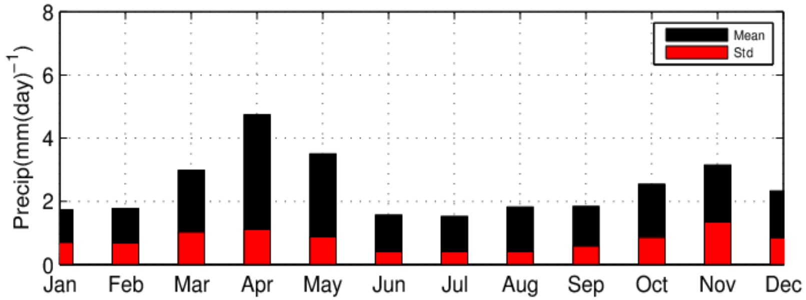
- Runs are initiated on January 1st 1919 and run up to December 31st 2010.
- Different ensemble members have been constructed by small perturbations in the initial conditions and year-1 considered as spin-up period.

Seasonal cycle and model climatology

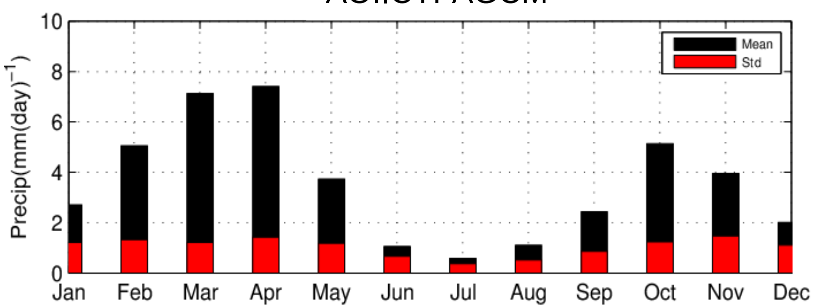
1948 - 2002

The seasonal characteristics of low level wind and rainfall distribution reasonable well reproduced

CRU pre

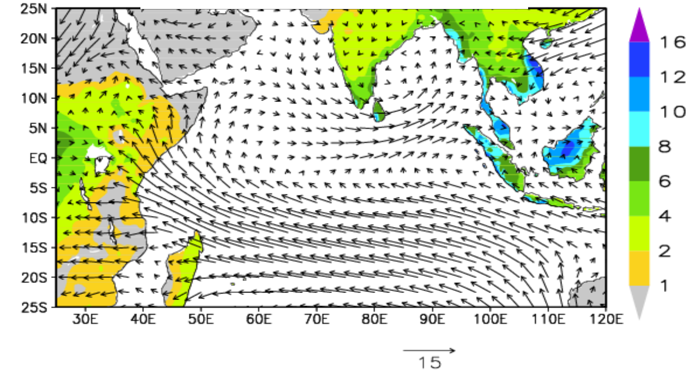


AO.ICTPAGCM

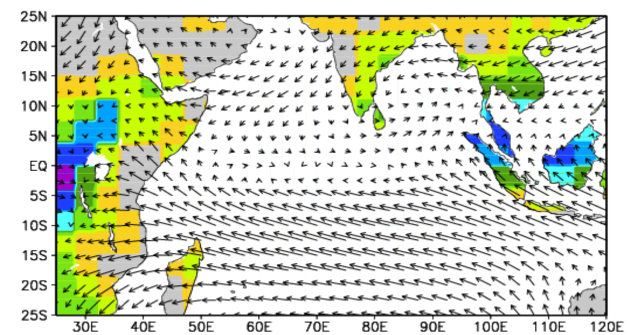


EEARI (5S-5N, 30-40E)

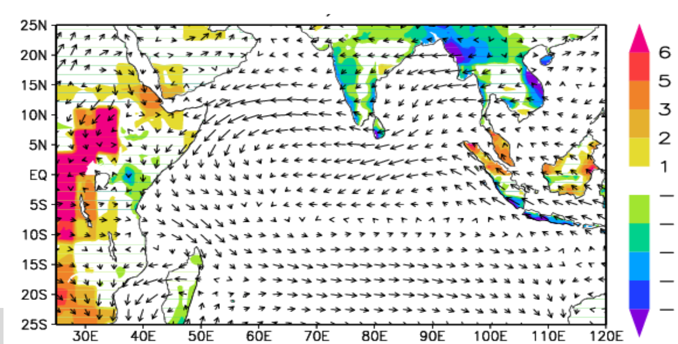
CRU pre & NCEP wind



AO.ICTPAGCM



Bias



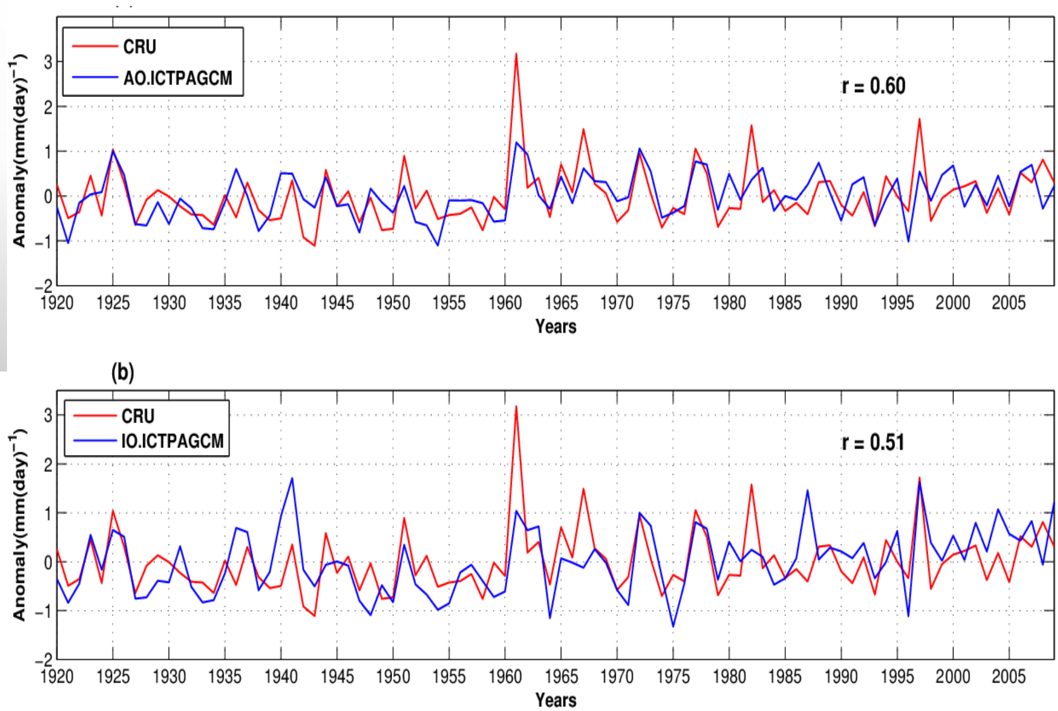
we have verified the our result is robust with respect to small variation in size & position of the index

- Low level wind captured fairly well compared to NCEP reanalysis, although with under estimation southeasterly flow
- The model simulate the seasonal rain and their variability well despite wet bias in peak months
- **In general the model performance is comparable to typical the state of art CMIP5.**

Influence conti ……

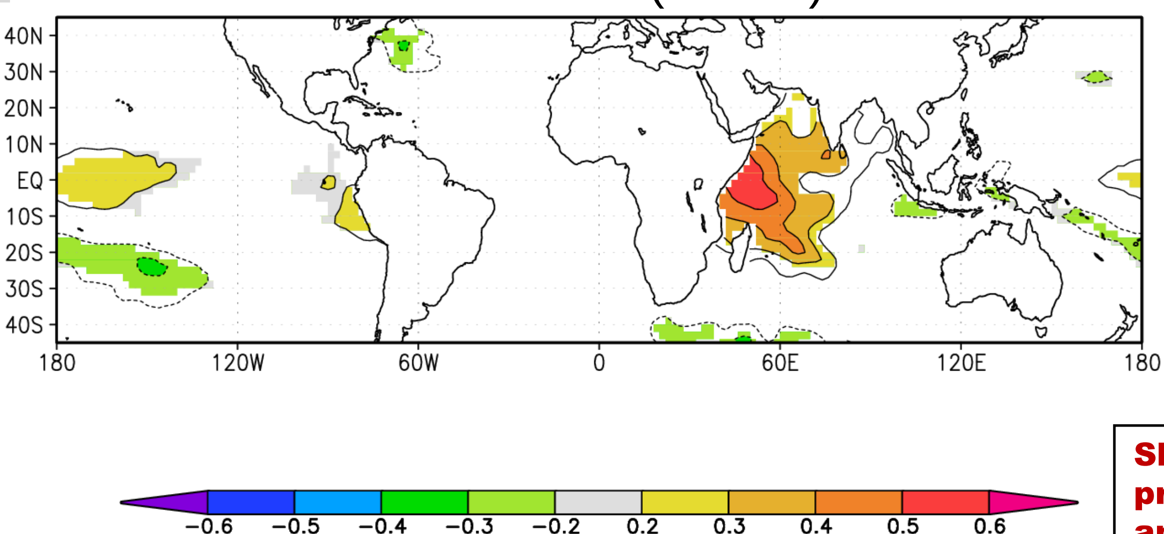
EEARI time series from observed and modeled rainfall are statistically significantly correlated at 99.9% confidence level.

EIO.ICTPAGCM Experiment (not shown), on the other hand, is slightly negative correlated with observed counterpart EEARI.



There is substantial skill in reproducing the EA short rains variability given the SSTs are known.

AO.ICTPAGCM (EEARI)

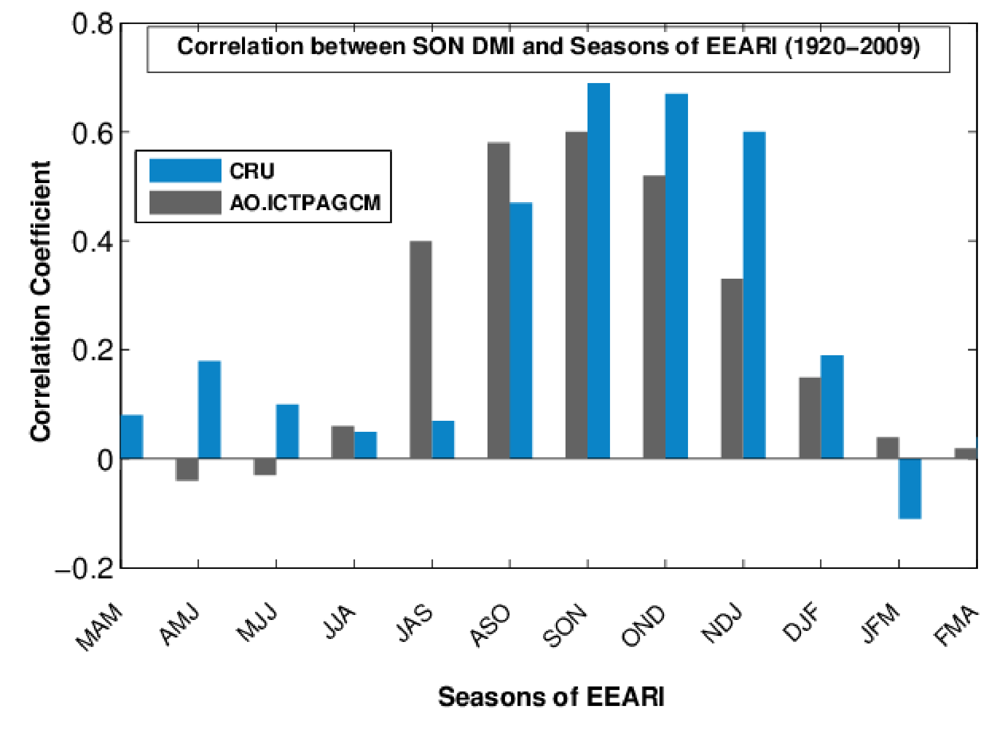


- Large correlation exceeding 0.5 in the WIO
- Significant at 95% confidence level, but small correlations in the EIO.

Short rains anomalies in EA are driven predominantly by the local warm SST anomalies in WIO, while EIO has lesser importance

IOD, ENSO and combined influence

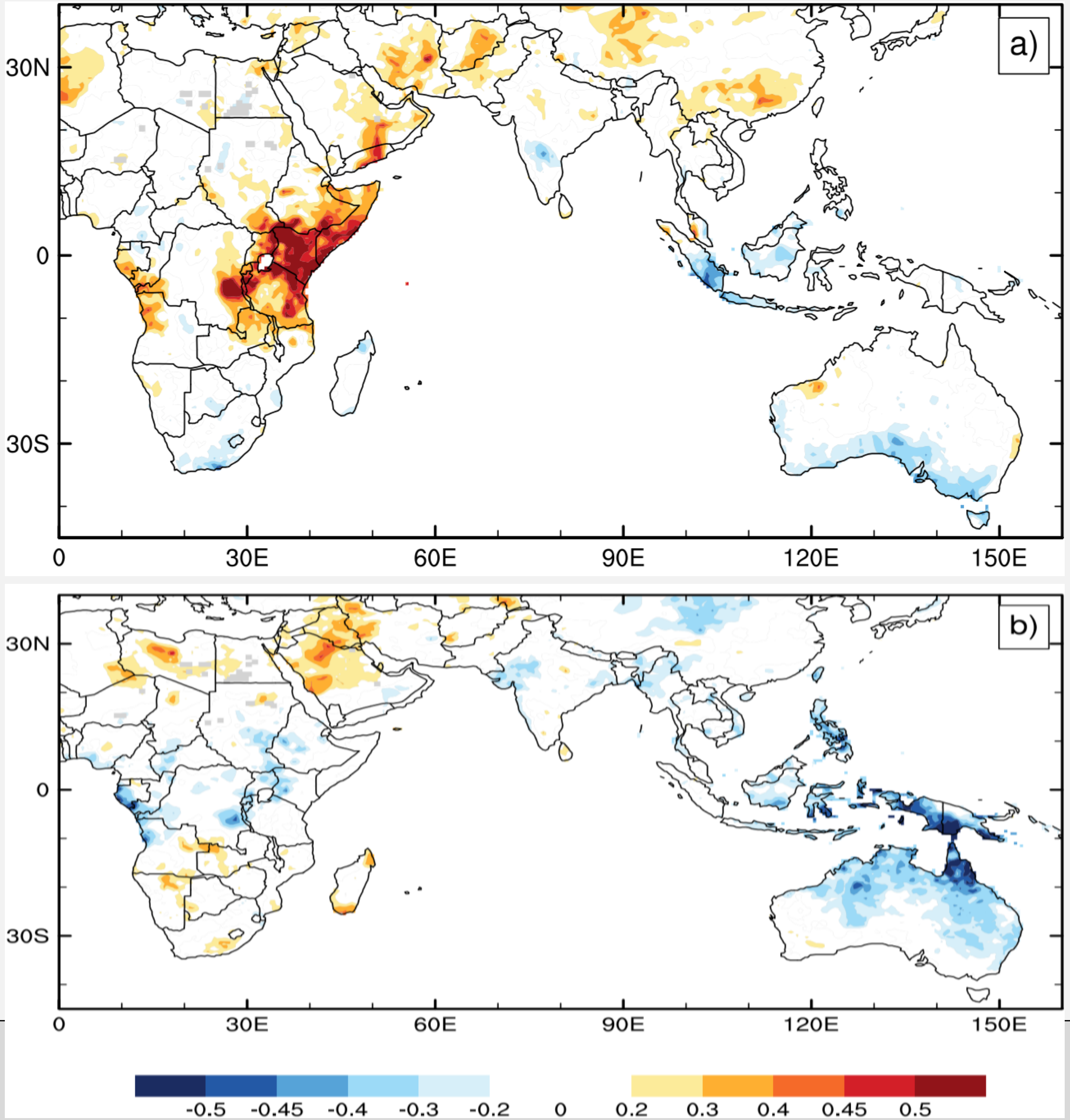
The short rain season considered is SON which is also climatologically important and peak season in the involution of IOD. However, there could be a delay between the IOD and the atmospheric response.



- Clearly, the SON DMI shows the largest correlation with SON EEARI in the CRU &AO.ICTPAGCM
- SON season shows statistically significant and relatively high correlation with SST anomalies in IO.
- However, long rain Is hardly relate to anomalies of the climate system and hence difficult to predict

IOD, ENSO and combined influence

The analysis is further supported by The partial correlation between the Short Rains index and DMI anomalies after partialing out the Niño-3.4 influence (a).



In order to further analyze the SST forcing of East African short rains, we use composite analysis.

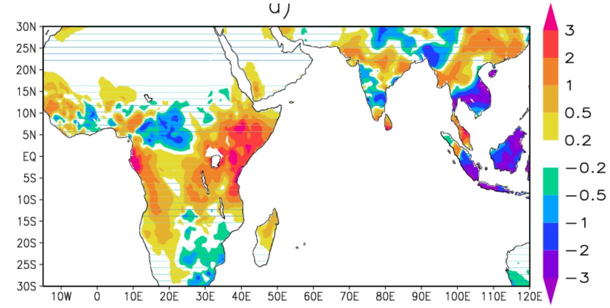
We applied the definition of IOD used by Saji and Yamagata (2003) & for ENSO adopted from Trenberth (1997)

A pure positive (negative) IOD episodes is identified as events when El Nino (La Nina) does not exist

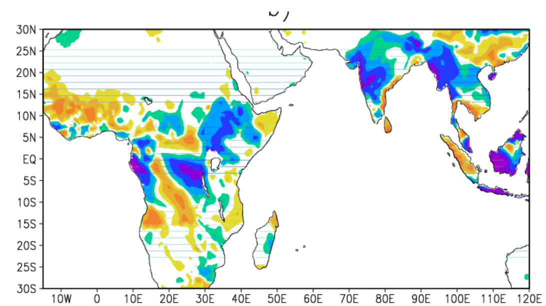
PIOD	NIOD	ElNino	LaNina
1961*	1958*	**1963**	**1964**
1963	1960*	1965*	1967*
1967*	**1964**	1969*	**1970**
1972	**1970**	**1972**	1971*
1977*	1989*	1976*	1973*
1982	1992*	**1982**	1975*
1994*	1996*	1986*	1988*
1997	-	1991*	-
-	-	**1997**	-

- Pure IOD has a strong influence on the variability of short rains.
- The EA region receives above (below) normal rainfall during positive (negative) IOD events.
- For the pure ENSO composite, the response is rather noisy, but with a tendency for reduced rainfall over parts of EA specially north of the equator.
- The joint response is similar to the pure IOD

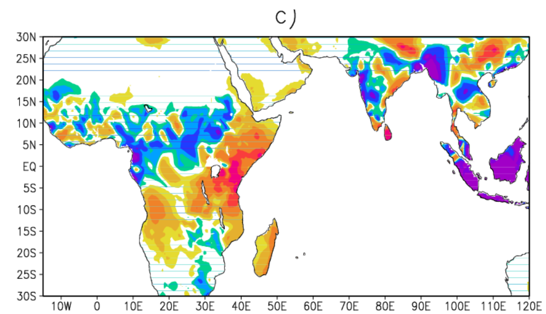
Pure IOD



Pure ENSO



Joint

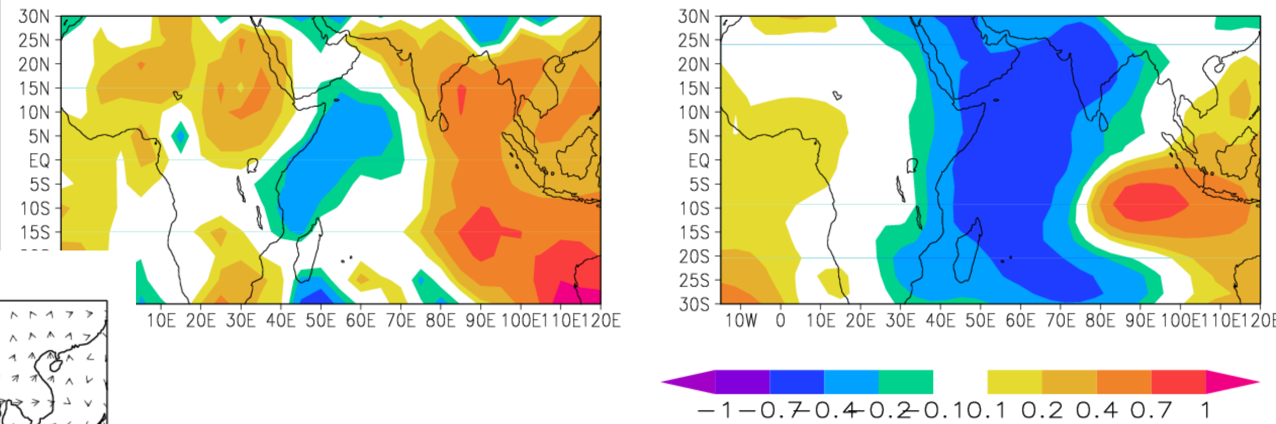


CRU precipitation

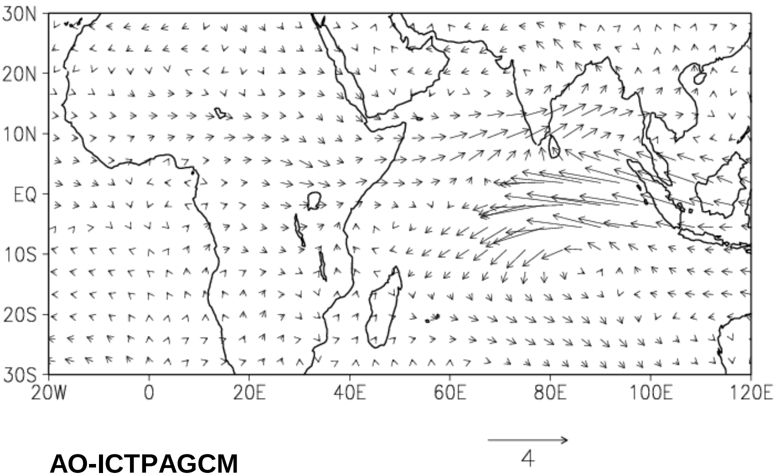
Physical Mechanisms for IOD Influence

pure IOD events shows an extensive area negative pressure anomalies in the west and positive in the east.

HadSLP AO-ICTPAGCM

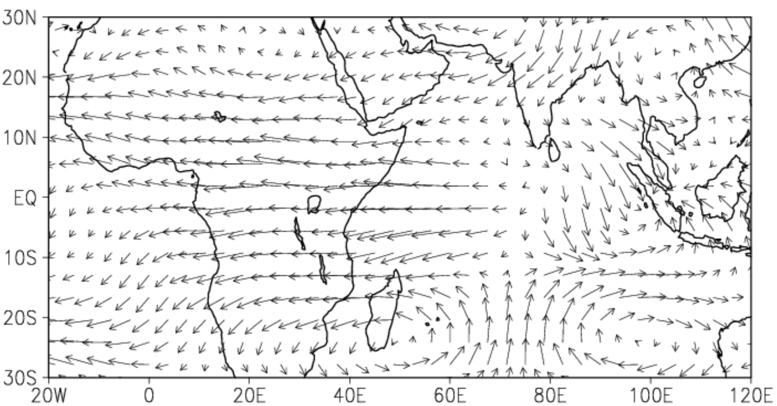


Wind (850hPa)



AO-ICTPAGCM

Wind (200hPa)



The low-pressure anomaly over the western IO is a response induced by the warm pole of the pure IOD events.

From Bahaga et al. (2016)

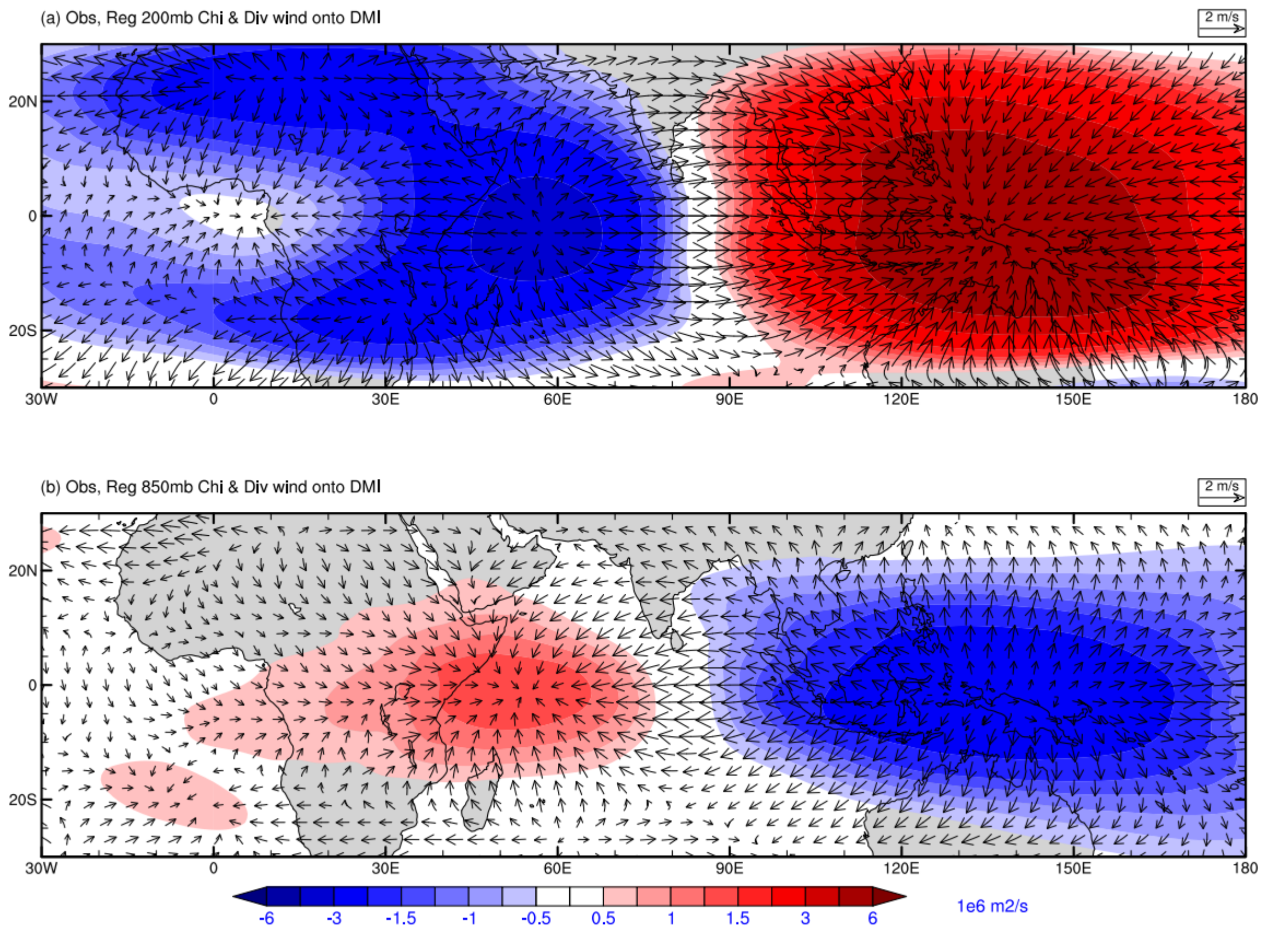
Consistent with the sp response there are easterly 850 hPa wind anomalies to the East and westerly anomalies to the west of the low pressure in the western IO.

- The modulation of the Walker circulation up to the tropopause height during the dipole events.

- **In general, such a response is consistent with a Gill-type response to the western IO SST anomalies.**

The spatial distribution OND velocity potential and divergence wind at 850 and 200 hPa regressed on to standardized DMI in ERAIn

The interpretation is further supported by the regression analysis of 850 and 200 hPa velocity potential derived from Obs.

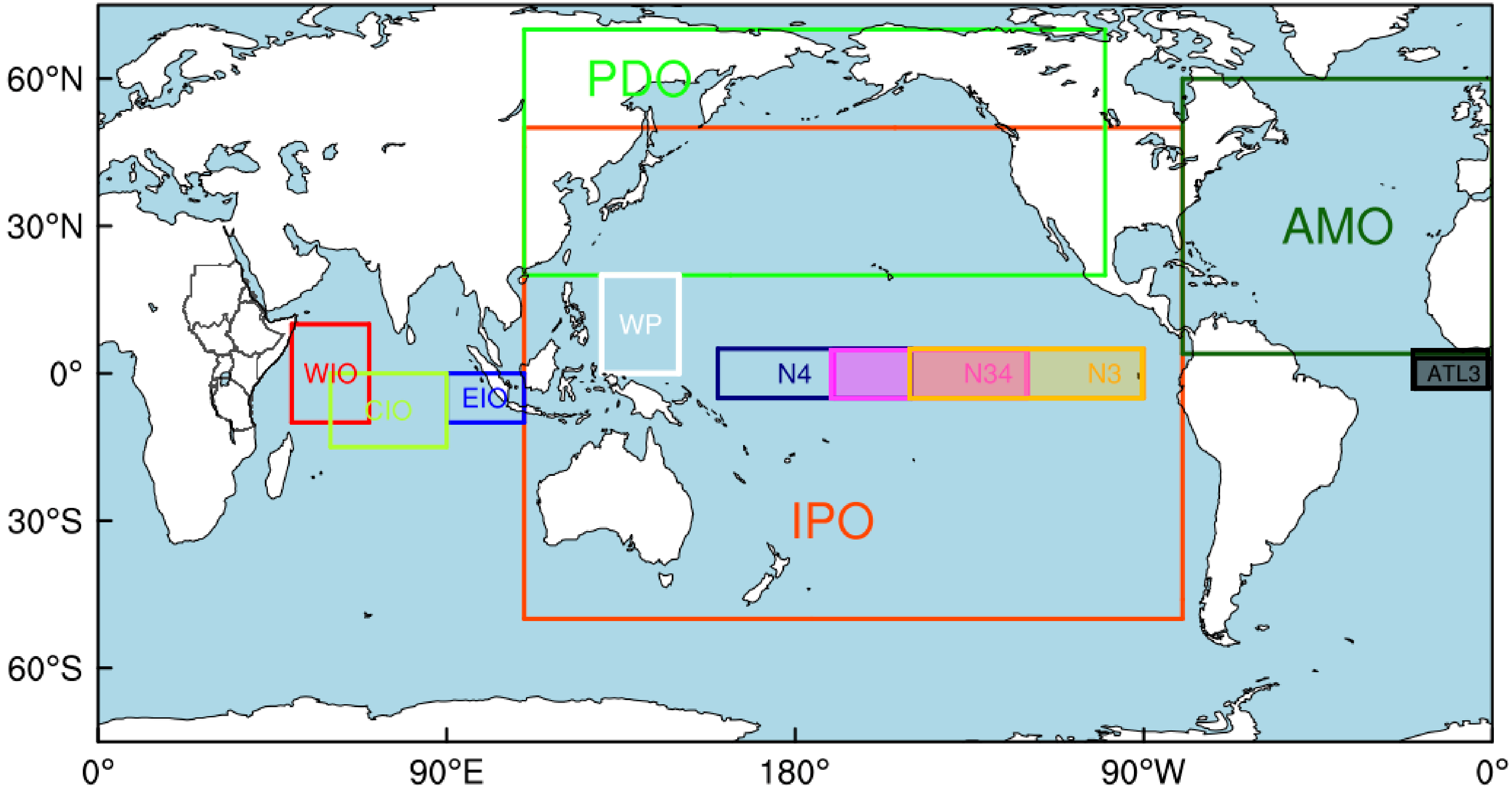


IOD events counteract the easterly climatological MF in the African region and shifts the convergence zone to the east. This leads to an increased MF convergence in the EEA region (not shown).

Non-Stationary Teleconnections

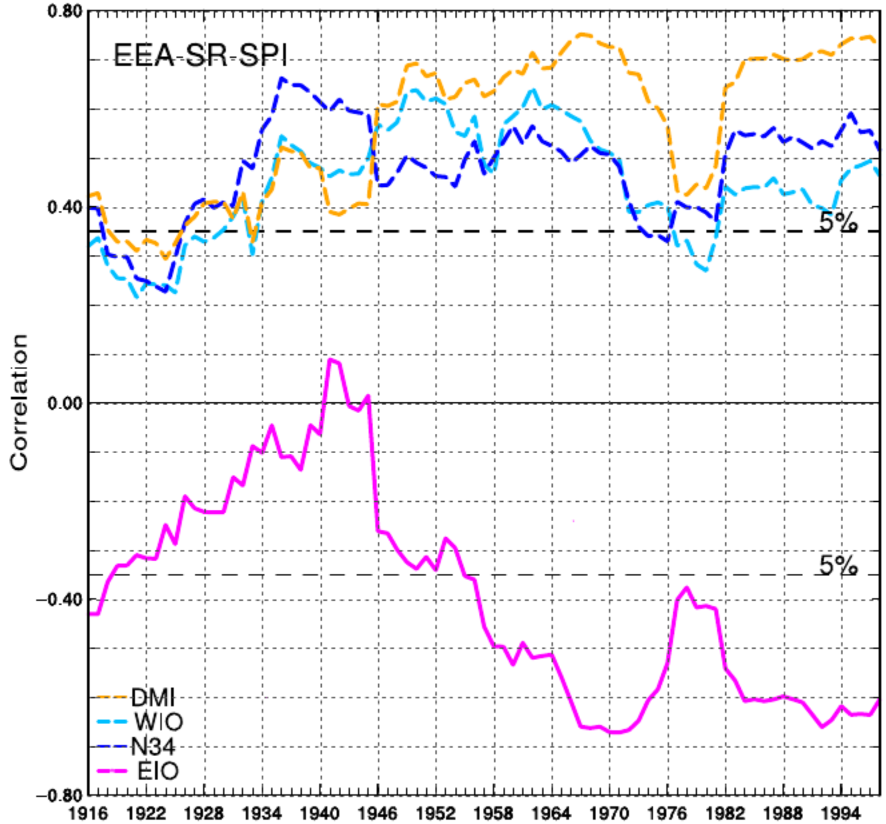
From Bahaga et al. (2019)

Location of utilized indices of remote climate anomalies



Multidecadal changes in Short Rains teleconnections

Time evolution of linear correlation to **Short Rains** over **31-year moving window**, **OND**, 1901—2013.



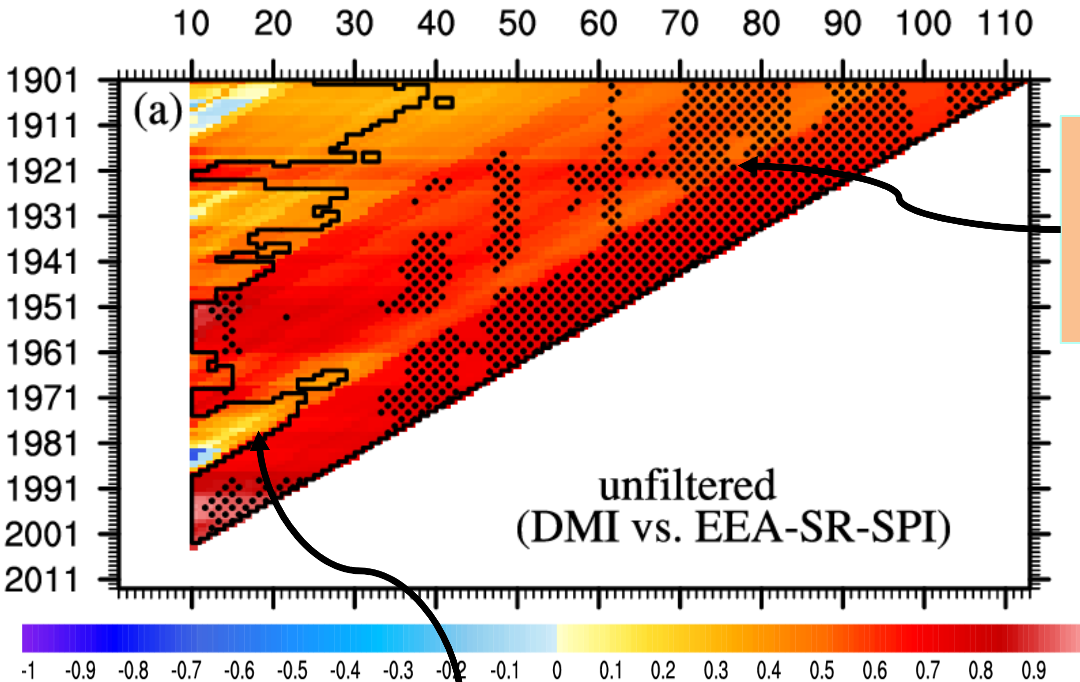
Solid curve: significant
Non-stationarity

- Short rains dominantly influenced by the SST anomalies in the Indian ocean, IOD
- EIO index shows significant non-stationary correlations (interpretation needed)
- Partial correlation analysis reveals that El Niño influence is largely due to its correlation with DMI (not shown).

How to interpret triangle correlation plots?

Increasing time series length at a fixed start year on Y-axis.

Increasing starting years for a fixed length window (on X-axis) across 1901-2013 period.



Stippling: 5% significance with reduced degree of freedom

Contour: 5% significance with standard degree of freedom

Short Rains prediction: APCC-MME

From Bahaga et al. (2017)

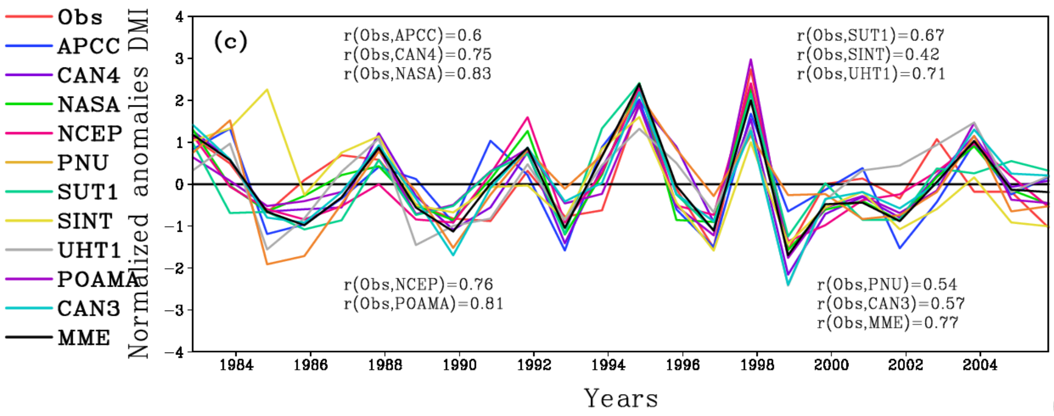
Assessment on short rain prediction (MME)

Description of APCC coupled Model Hindcast

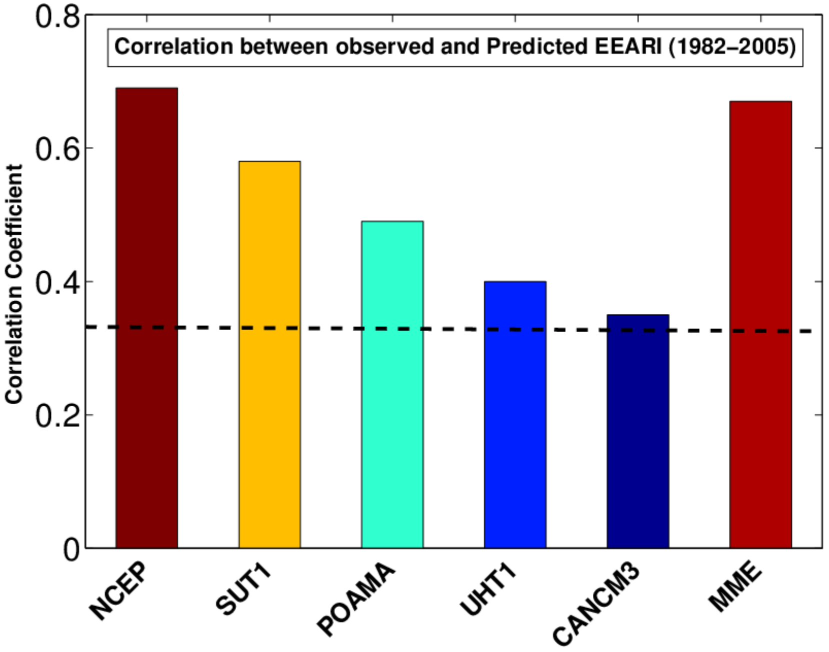
Institute	*Model*	*AGCM*	*Resolution*	*OGCM*	*Resolution*	*Ensemble*	*Reference*
APCC	CCSM3	CAM3	T85L26	POP1.3	gxlv3L40	5	Jeong et al. (2008)
NCEP	CFS	GFS	T62 L64	GFS	1/3°ltX5/8°lnL27	15	Saha et al. (2006)
SNU	SNU	SNU	T42 L21	MOM2.2	1/3°ltX1°lnL32	6	Ham and Kang (2010)
NASA	NASA	NSIPP1	2°ltx2.5°lnL34	PoseidonV4	1/3°lt5/8°lnL27	8	Vintzileos et al.(2003)
UHT1	UHT1	ECHAM4	T31L19	UH Ocean	1°ltx2°lnL2	10	Fuand Wang (2004)
FRCGC	SINTEX-F	ECHAM4	T106 L19	OPA8.2	2°cos(lt)x2°lnL31	9	Luo et al. (2005)
BMRC	POAMA1.5	BAM 3.0d	T47 L17	ACOM2	0.5-1.5°ltx2°lnL31	10	Zhong et al. (2005)
PNU	PNU	CCM3	T42L18	MOM3	2.8125°L29	5	Sun, J. Q. et al. (2011)
MSC	CanCM4	AGCM4	T63L35	OGCM4	1.41x0.94,L40	10	Scinocca et al.(2008)
MSC	CanCM3	AGCM3	T63L31	OGCM4	1.41x0.94,L40	10	Farlane et al.(2005

- APCC couple models have Different Hindcast period
- 1 to 6 month-lead forecast
- 4 times per year: initialized on 1st of February, May, August , and November
- In this study we have considered only August initial condition only
- Our analysis is based on common period 1982 – 2005
- Models resolution are different but interpolated onto common 2.5X2.5 grid prior to analysis

Do D-Models have skill to predict IOD and SR?



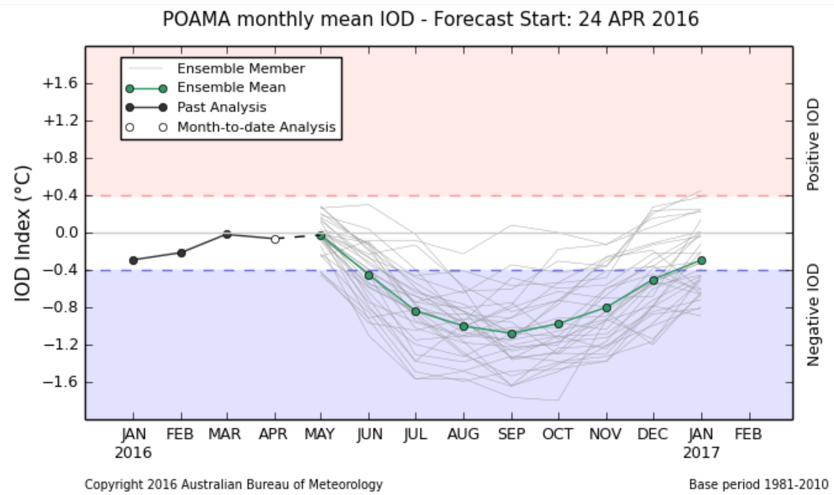
- **Forecast skill for DMI in CM & MME statistically significant at 99% Confidence level**
- **Five CM predict equatorial East Africa short rain with 90% confidence level.**
- **NCEP prediction giving the strongest correlation of all and SUT1, UHT, POAMA and CANCM3 also show significant skill.**
- **Model selection improves the skill of MME from 0.44 (95%) for all models to 0.67 (99.9%)**



❖ **Dynamical models extract predictive information from August initial conditions.**

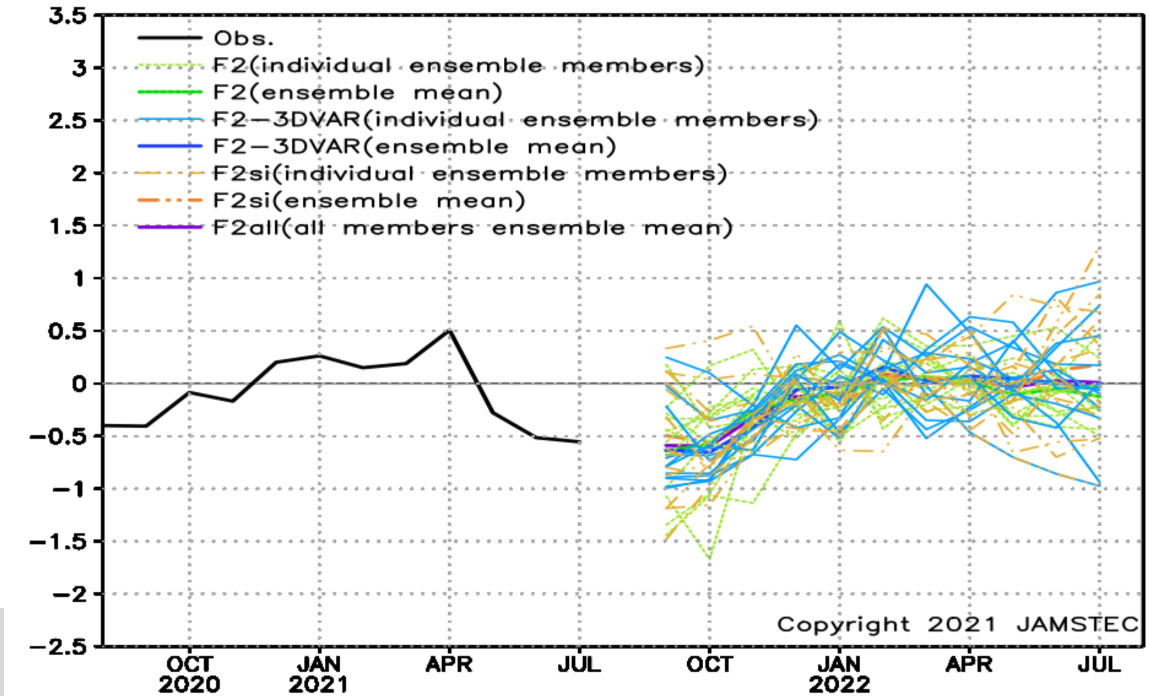
❖ **The skill of the dynamical models arises from the significant relation between EEARI and SON SSTs anomalies over TIO and the fact that CM can predict SST with high skill.**

The possibility of Using Readily Available S2D Predictions

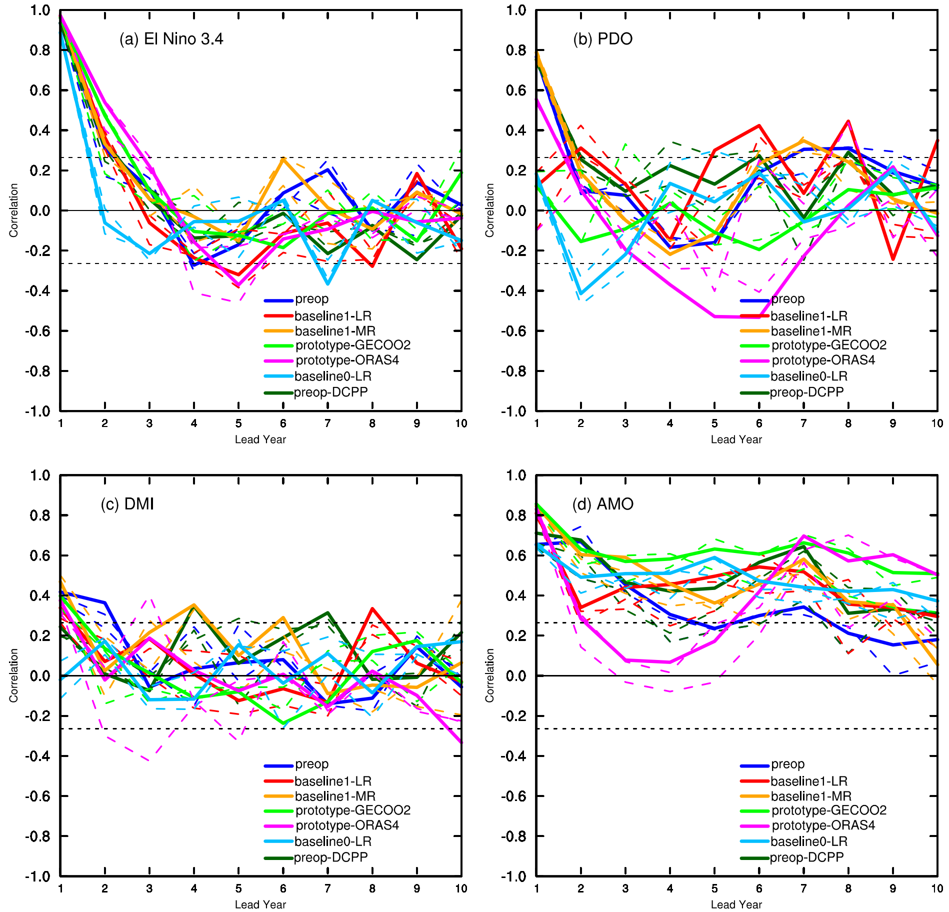


By March and April 2016, models were suggesting the development of a negative IOD event.

Forecast issued 1 Aug



Predictability of climate drivers at seasonal to decadal time-scale



- JFM N34 index has considerable prediction skill (r > 0.85), but JJAS (not shown) skill substantially reduced.

In general, the prediction skill for SST is weaker over most parts of the tropical regions.

Conclusions

- Composites of observed and modeled rainfall for pure **IOD events enhance** (reduce) precipitation over EA (Indonesia), on the other hand pure ENSO composites show a mixed signal with **non coherent reduction** of short rains over parts of EA.

- We found that the main driver of EA short rains is the IOD, and ENSO provides only a minor contribution that opposes the IOD forced signal.

- The **physical mechanism** for the IOD influence on EA short rains in our model is that the warm pole of a positive **IOD leads to a Gill-type response** that causes westerly wind anomalies over Africa, moving the moisture flux convergence zone towards EA.

- There is a **substantial potential predictability** associated with an East African short rains index (EEARI), given that Indian Ocean SSTs are known or predicted.

- **Low frequency variations of the prediction skill** are mostly related to SSTs outside the IO region and likely due to an increased interference of ENSO with the IO influence on EA short rains after the mid-70s climate shift.

- Abrupt shifts in correlation with DMI are observed for short time window, suggesting that the shift in IOD and short rains relation is reinforced by IPO.

- CM produce **Significant skill in forecasting (SSTAs)** over the western and eastern parts of the equatorial IO, giving significant correlation at 99% confidence level for DMI.

- The skill of couple models is attributed to the fact that slowly evolving **SST primary source of predictability**, and to the fact that climate models produce more skillful predictions of SON SST anomalies over Indian Ocean.