Southern Hemisphere pathways to Indian Summer Monsoon

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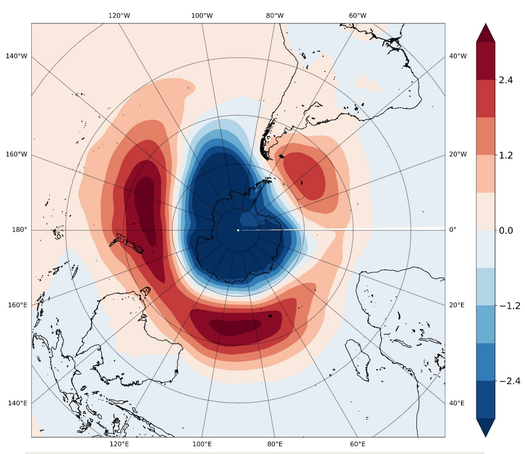
Background/ Motivation

Indian Summer Monsoon (ISM) is linked to many of the climate modes El Nino Southern Oscillation, North Atlantic Oscillation, Indian Ocean Dipole, etc. (e.g., Gadgil et al., 2004; Goswami et al., 2006; Krishnamurthy and Krishnamurthi, 2014)

The monsoon circulation originates in the oceanic region of the Southern Hemisphere. (Nithin and Mohankumar, 2013)



MSLP anomalies during positive phase of SAM

Southern Annular Mode (SAM) is a leading mode of variability in the Southern Hemisphere

The study on SAM modulating Tropical Indian Ocean circulation is a prerequisite

The SAM and ISM teleconnection through Indian Ocean pathways not much explored

Datasets used

Sl no.	Ocean reanalysis data	Period
1	SODA v2.2.4	1871-2010
3	ORAS4	1959-2017
4	CFSR	1980-2011
5	GECCO2	1948-2016

Sl no.	Atmospheric reanalysis data	Period
1	ERA-20C	1901-1978
3	ERA5	1979-2018

Temperature profiles obtained from EN4 and Ishi datasets during the period 1959-2010

The ISMR index from the Indian Institute of Tropical Meteorology (IITM) for the period 1901 to 2018 is used

Methodology

SAM index (SAMI) is estimated as the difference of zonal mean sea level pressure between 40°S and 65°S.

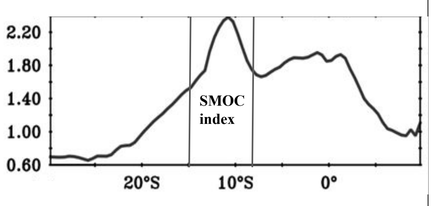
$$SAMI = MSLP_{40oS} - MSLP_{65oS}$$

The strength of transport associated with SMOC is estimated from meridional overturning stream function Ψ(y, z, t).

$$\Psi(y,z) = \int_{z}^{\eta}\int_{x_w}^{x_e} v\,dx\,dz,$$

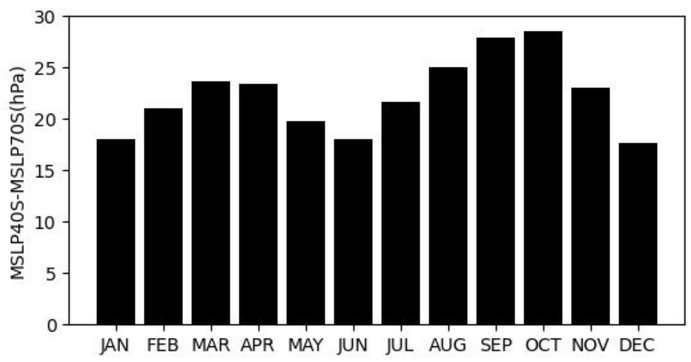
where, z - Vertical coordinate
v - Meridional current
x_e, x_w - Eastward and westward boundaries, respectively.

SMOC index is estimated as the detrended anomaly of stream function at upper 60m averaged between 8.5°S to 15°S (Pai et al., 2022)



The SIOD index is computed as the difference between area averaged SST anomalies over the southwestern box (50°E-85°E, 40°S-27°S) of subtropical Indian Ocean and the northeastern box (80°E-115°E, 25°S-10°S).

Seasonal evolution of SAM

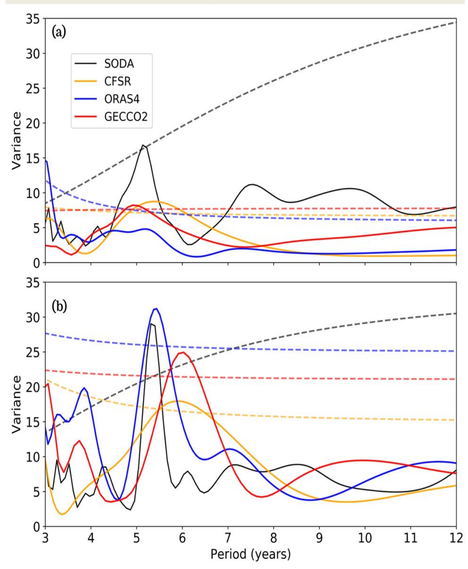


SAM peaks during August-October months with a secondary peak during February-April.

SAM positively influences the SLP over Mascarene high region.

SAM teleconnection to Tropical Indian Ocean Circulation

Power spectrum of SMOC index during (a) JJAS and (b) DJF



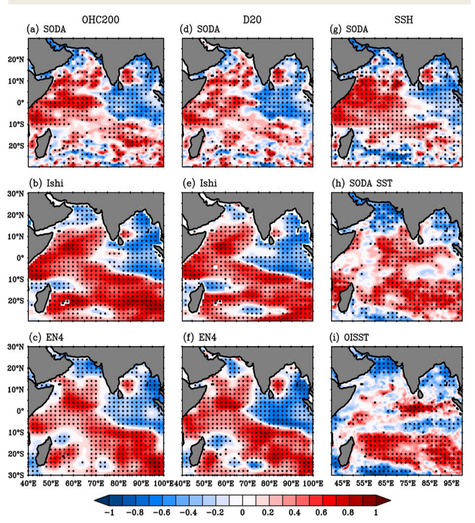
The power spectrum of the SMOC index reveals that the winter SMOC display variability with periodicity of 5 to 7 year (intra-decadal) with 95% confidence level.

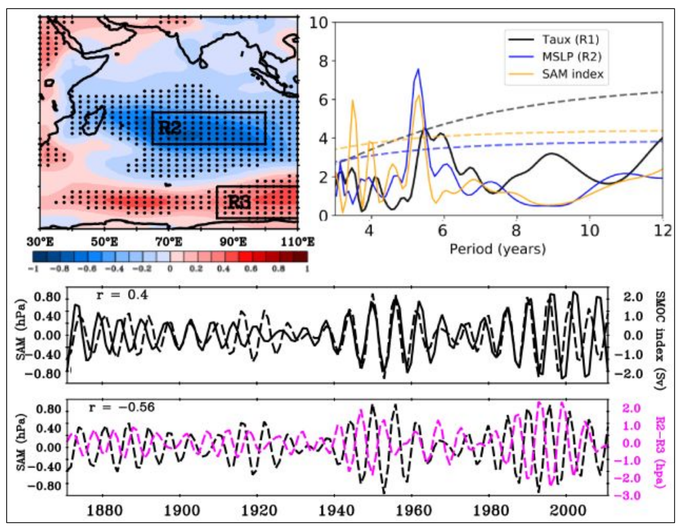
The robustness in the signal is confirmed among different ocean reanalysis datasets covering different period of time.

The band pass filtered upper ocean heat content (OHCA200), Sea level, thermocline depth and SST anomalies at south of equator display strong coherency with SMOC index at 95% confidence level.

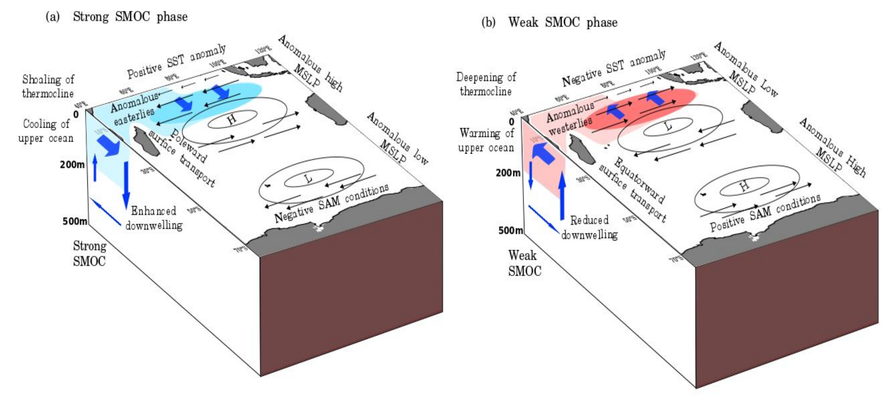
This indicates that the strong (weak) SMOC leads to a reduction (increase) in the OHCA200, D20, Sea level, and SST over south of 10°S.

Impact of intra-decadal SMOC variability on thermal structure of Indian Ocean





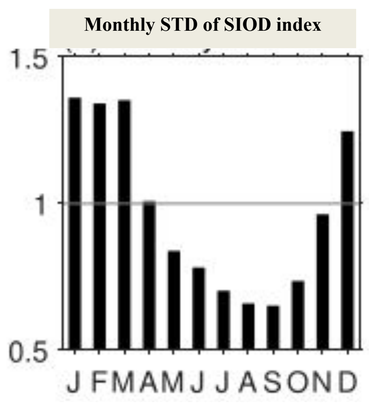
(a) Correlation of intra-decadal SMOC index and MSLP anomaly. (b) power spectrum of zonal wind stress anomaly at SIO, MSLP at R2, and SAM index. Time series of 5 to 7 year bandpass filtered SAM index with SMOC inex and difference in MSLP at R2 and R3 (R2-R3)



A detailed analysis revealed that the intra-decadal SMOC variability is driven by zonal wind variations south of 10°S modulated by the meridional pressure gradient between tropics and high latitude associated with the SAM (*Pai et al., 2022*).

SAM teleconnection to Indian Summer Monsoon

Monthly STD of SIOD index

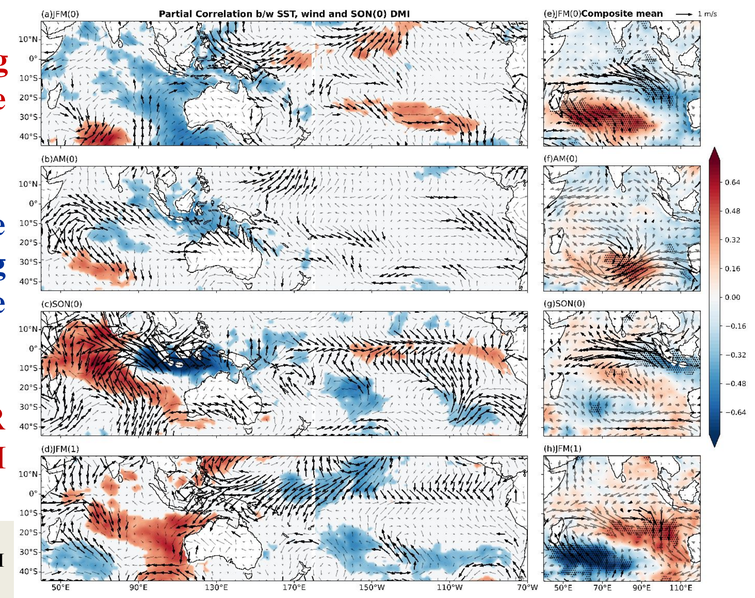


The Subtropical Indian Ocean Dipole (SIOD), second mode of subtropical Indian Ocean SST variability, is developed by the wind circulation over the Mascarene high region (Behera and Yamagata, 2001).

SIOD peaks during JFM months.

SAM influences SIOD by affecting the SLP and surface wind over the subtropical Indian Ocean region.

Seasonal evolution of SIOD related surface wind and SST anomalies



SIOD SST anomalies and associated anticyclonic surface wind sustained and shifted northwards in the following seasons, causing development of easterly winds over the equatorial Indian Ocean during JJA months.

The positive relation of the equatorial easterlies with ISMR can be the Indian Ocean pathway which connects FM SAM and ISMR.

Correlation between (a) bimonthly SAM index and ISMR for different periods, (b) Monthly SAM index and June-July and August-September rainfall

SIOD related mechanism during JFM and following AM months

Summary and conclusion

The teleconnection of SAM with Indian Ocean circulation and Indian Summer monsoon is studied.

Robust signal of Intra-decadal variability of Indian Ocean SMOC during boreal winter is identified.

The SMOC is forced by the zonal wind variation due to local meridional pressure gradient in SIO associated with the SAM and it modulates the upper Indian Ocean heat content, thermocline depth and sea level at intra-decadal scale during boreal winter.

The SAM positively influences SIOD by modulating Mascarene high. The SST and anticyclonic wind anomalies associated with positive SIOD shifted equatorward in the following seasons and induce equatorial easterlies during June-July months.

Thus origin of equatorial wind variability is traced. Previous studies suggested that the equatorial easterlies positively related to ISMR (Gadgil et al., 2004)

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