Intra-Decadal Variability of the Indian Ocean Shallow Meridional Overturning Circulation during Boreal Winter

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Background/ Motivation

The wind driven Shallow Meridional Overturning Circulation (SMOC) confined at upper 500m have a great influence on the exchange of heat between tropics and subtropical Indian Ocean.

Previous studies have reported that the SMOC displays variability from seasonal to decadal timescales.

However, the association of SMOC variability with climate variability is not well understood.

Century long ocean reanalysis data provides an opportunity to study the variability of SMOC during the last century.

Studying the SMOC variability may be also helpful in understanding its impact on thermal structure of Indian Ocean.

Objectives

- To study the variability of the Indian Ocean SMOC and its association with the climate variability during last century
- To examine the impact of SMOC variability on the thermal structure of the Indian Ocean

Datasets used

Windstress, temperature, Sea surface height and ocean currents obtained from Simple Ocean Data Assimilation (SODA) 2.2.4 during the period 1871-2010

To confirm robustness in the results ocean reanalysis from different agencies available over different periods (see the table on the right)

Data	Period
ORAS4	1959-2017
CFSR	1980-2011
GECCO2	1948-2016

Profiles of temperature obtained from EN4.2.1 and Ishi datasets during the period 1959-2010.

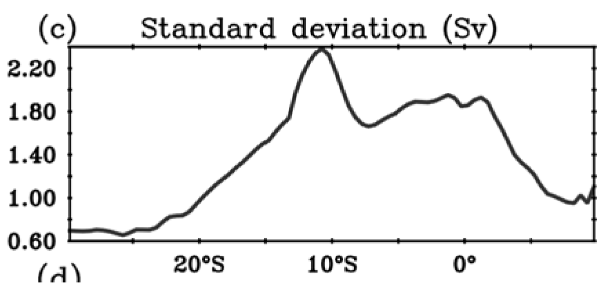
Methodology

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

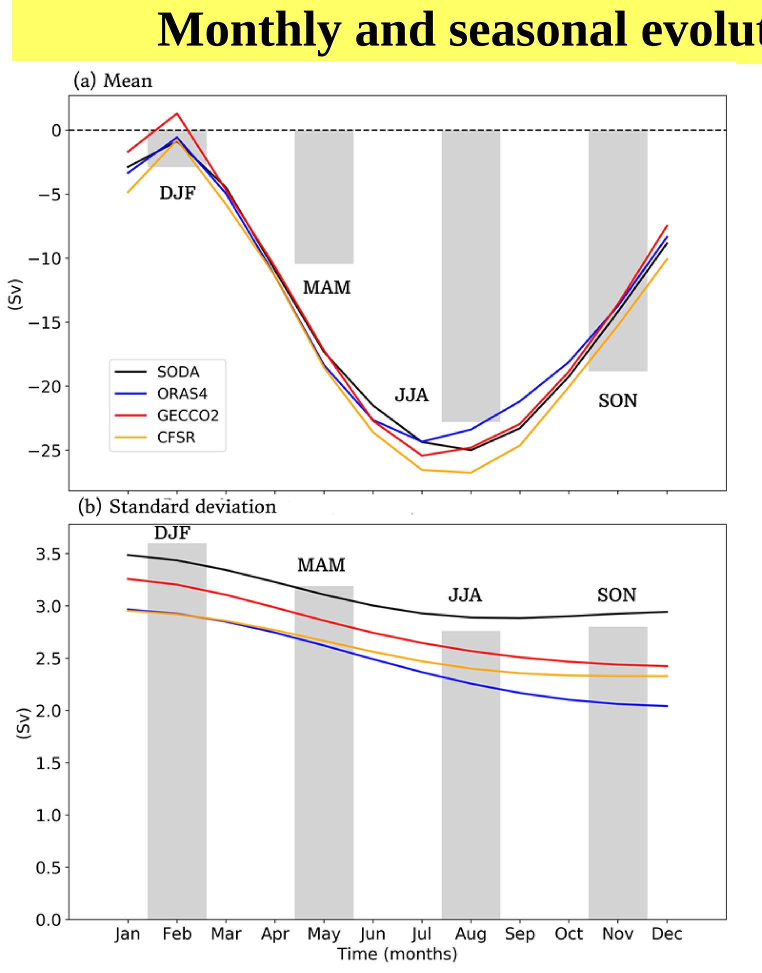
$$\Psi(y,z) = \int_z^{\eta} \int_{x_w}^{x_e} v \, dx \, dz,$$

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

SMOC index is defined as the detrended anomaly of stream function at upper 80m averaged between 8.5°S to 15°S (region of maximum standard deviation)



Monthly and seasonal evolution of SMOC index



The seasonal evolution of the SMOC index indicates that variability is maximum during the winter DJF compared to other seasons

The result is consistent among different products.

Fig 1: (a) Monthly mean (lines) of SMOC index and its (b) standard deviation among different datasets. The bar denotes the seasonal evolution of SMOC index from SODA.

Variability in SMOC during annual, summer and winter

Data	Annual	Summer	Winter
SODA	2.0	1.86	2.21
ORAS4	1.44 (0.4)	1.80 (0.54)	2.2 (0.78)
GECCO2	1.03 (0.50)	1.71 (0.6)	2.46 (0.79)
CFSR	0.93 (0.54)	1.28 (0.4)	2.1 (0.78)

Standard deviation of detrended SMOC index for annual, summer and winter from all datasets during the respective available periods. The correlation of the SMOC index with respect to SODA is also provided in brackets

Winter display high correlation between detrended SMOC index from SODA to that estimated from other datasets used (Table 2)

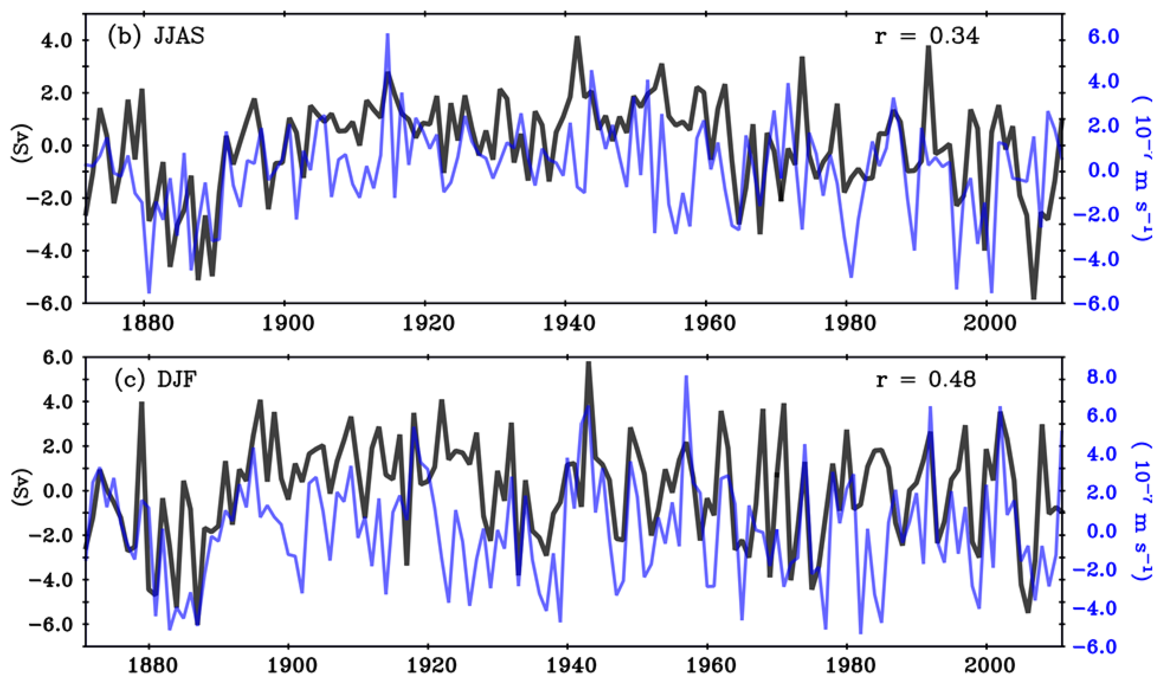


Fig 2: Variability of SMOC index over the study region (black, Sv) and vertical current anomaly over south Indian Ocean subduction zone (blue, 10^{-7} m s^{-1}) estimated for (b) summer (JJA), and (c) boreal winter (DJF) from SODA during the period 1871-2010.

The stronger SMOC variability leads to strong downward velocity variability in the subduction zone, and vice versa.

Intra-decadal variability of SMOC during boreal winter

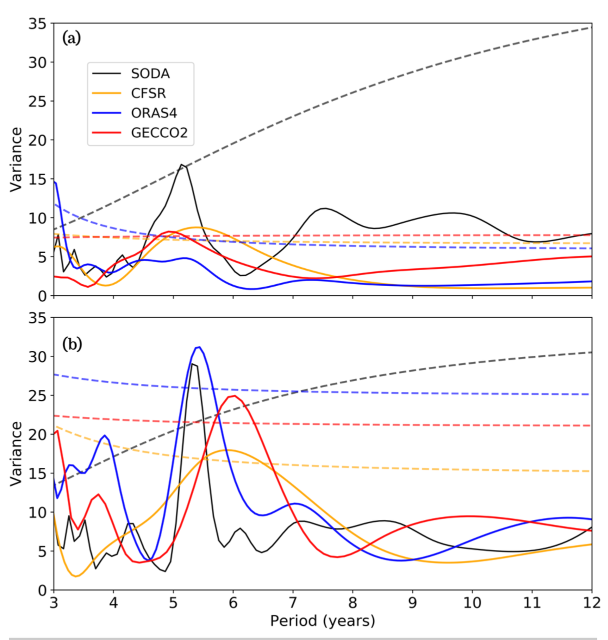


Fig 3: Spectrum of SMOC index for (a) summer (JJAS) and (b) Winter (DJF) from SODA (black), CFSR (cyan), GECCO2 (blue) and ORAS4 (red) during the period 1871-2010, 1979-2010, 1948-2010, 1958-2010, respectively. The dashed lines represent the 95% confidence levels of the spectrum.

The spectrum of the SMOC index reveals that the summer and winter SMOC display highest peak between 5 - 7 years (Intra-decadal timescale) with 95% confidence level

The variance of the signal during winter is double than that during summer.

Further analysis focuses on the SMOC variability during DJF

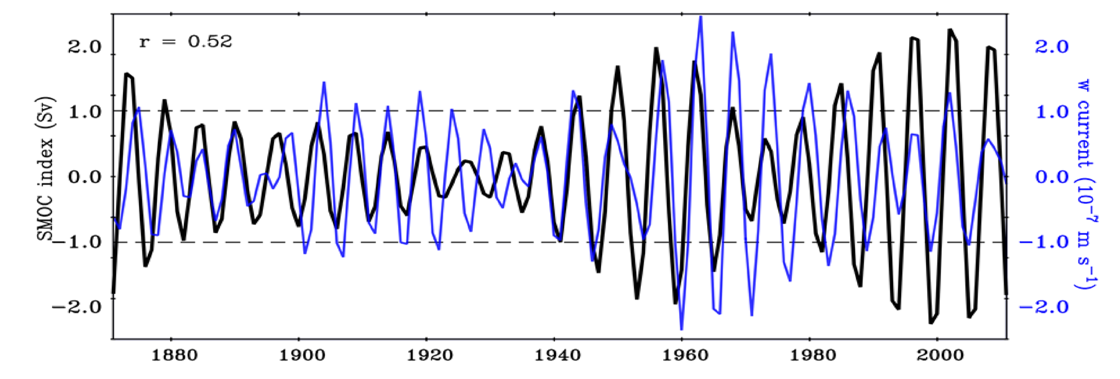
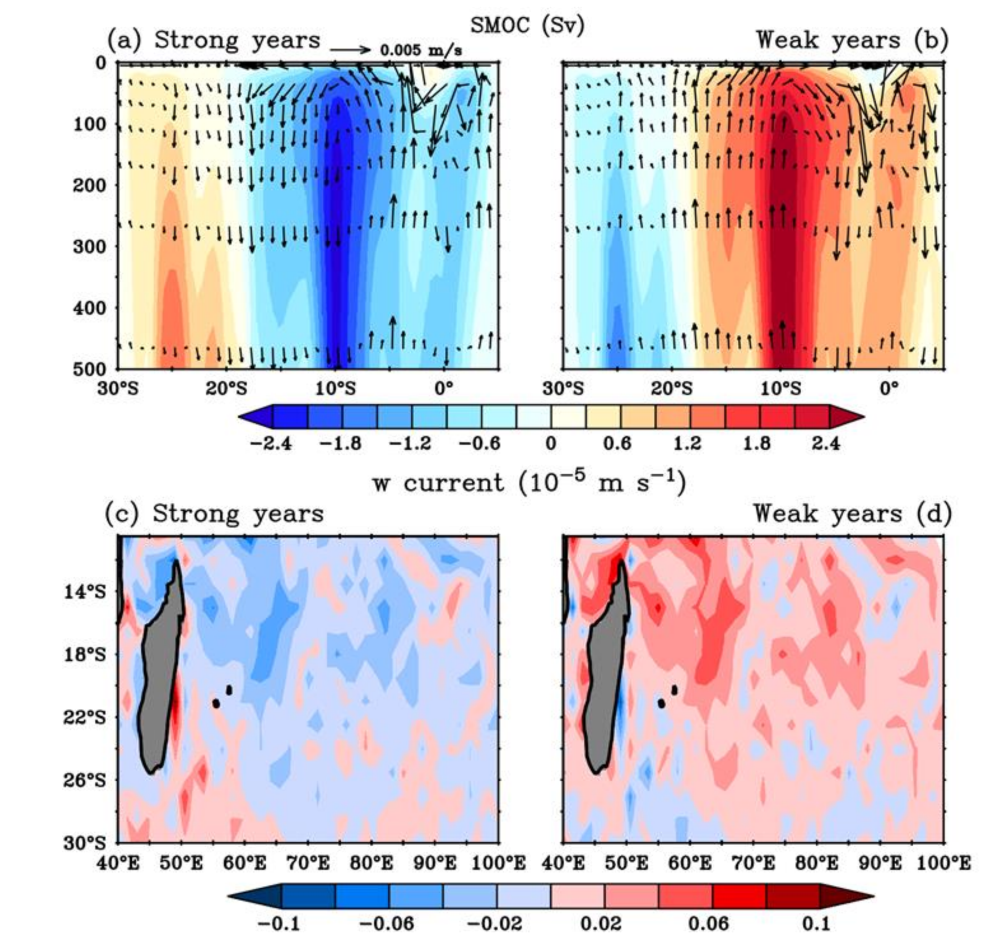


Fig 4: The time series of 5 to 7 year bandpass filtered SMOC index (black, Sv) and vertical current anomaly at 75m averaged over the subduction region (blue, 10^{-7} m s^{-1}) from SODA during the DJF. The dashed line denotes the standard deviation of the SMOC index for SODA (1.1 Sv). The correlation of the SMOC index and the vertical current anomaly is also provided.

The strong and weak SMOC years are identified based on the 5 to 7 year band pass filtered SMOC index (Fig 4).

Strong SMOC years	1870,1875,1876,1940,1945,1946,1952,1953,1958,1959,1964, 1981,1986,1987,1992,1993,1998,1999,2004,2005,2010
Weak SMOC years	1872,1873,1878,1943,1949,1955,1956,1961,1962,1967,1983, 1984,1989,1990,1995,1996,2001,2002,2007,2008



During strong (weak) SMOC years, the composite analysis of transport displayed more (less) southward (northward) transport centered at 10°S

The vertical velocity showed excess (less) subduction over the South Indian Ocean.

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

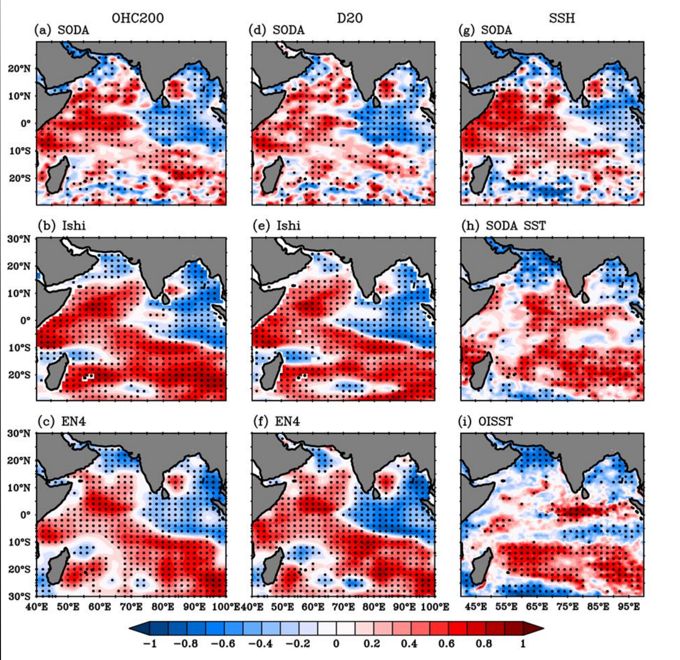


Fig 6: Correlation of 5 to 7-year bandpass filtered OHC200 anomaly (a-c), D20 anomaly (d-f), Sea level anomaly (g) with SMOC index during winter from SODA, Ishi, and EN4 during the common period 1959-2010. The correlation of 5-7year bandpass filtered SST anomaly from (h) SODA and (i) OISST with the SMOC index is also provided. The dots denote the region where the correlation is 95% significant

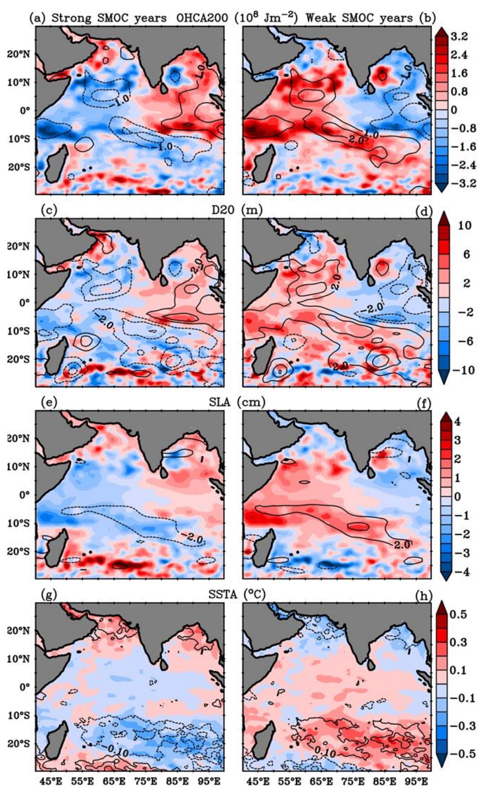
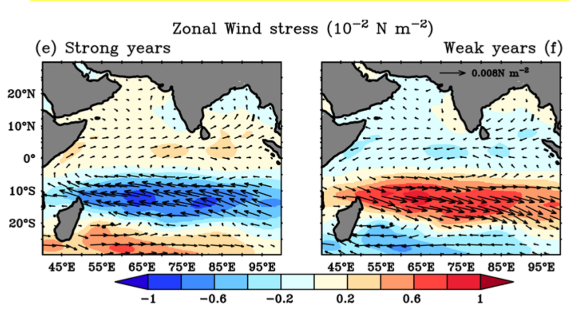


Fig 5: Composite of 5-7year filtered upper 200m Ocean Heat content anomaly (10^8 Jm^{-2}) and depth of 20° isotherm anomaly during DJF for (a,c) strong and (b,d) weak SMOC years from SODA (shaded) and EN4 (contour), respectively. The composite of 5 to 7 year filtered sea level anomaly during winter for (e) strong and (f) weak SMOC years from SODA (shaded) and AVISO (contour). The 5-7year filtered composites of winter mean SST anomalies from SODA (shaded) and OISST (contour) for (g) strong and (h) weak SMOC years is also provided.

The band pass filtered OHCA200, Sea level, D20 and SST anomalies at south of equator display strong coherency with SMOC index at 95% confidence level.

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

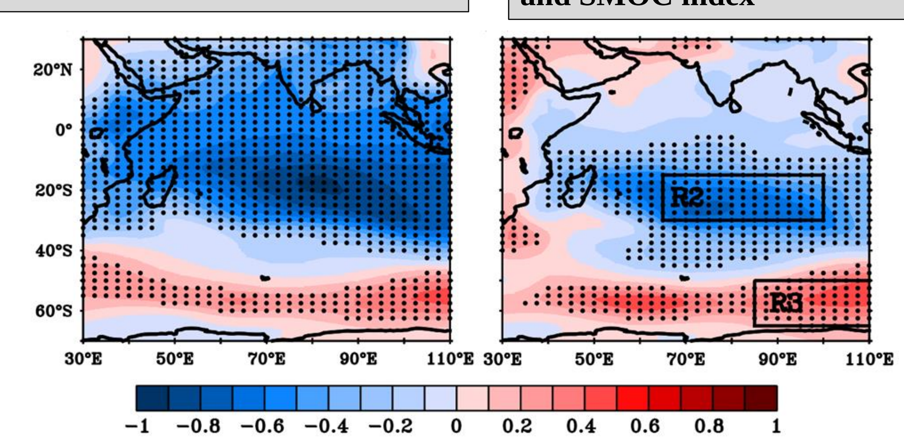
Causes of Intra-decadal SMOC variability



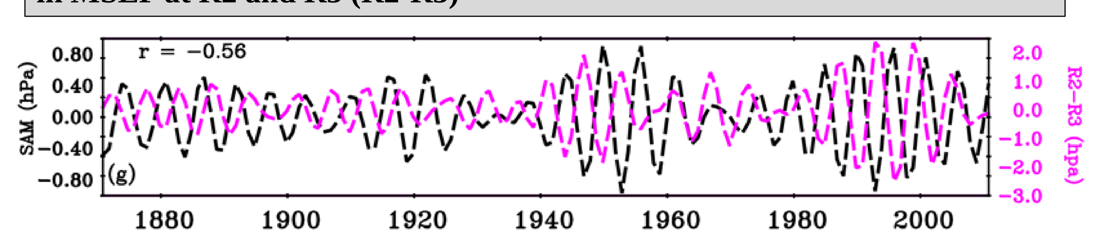
The Intra-decadal variability of SMOC is associated with the zonal wind variation between 10°S and 20°S (Correlation is 0.85)

Correlation between 5 to 7year bandpass filtered MSLP anomaly and Zonal winds between 10 ° -20°S

Correlation between 5 to 7year bandpass filtered MSLP anomaly and SMOC index



Time series of 5 to 7 year bandpass filtered SAM index Vs. and difference in MSLP at R2 and R3 (R2-R3)

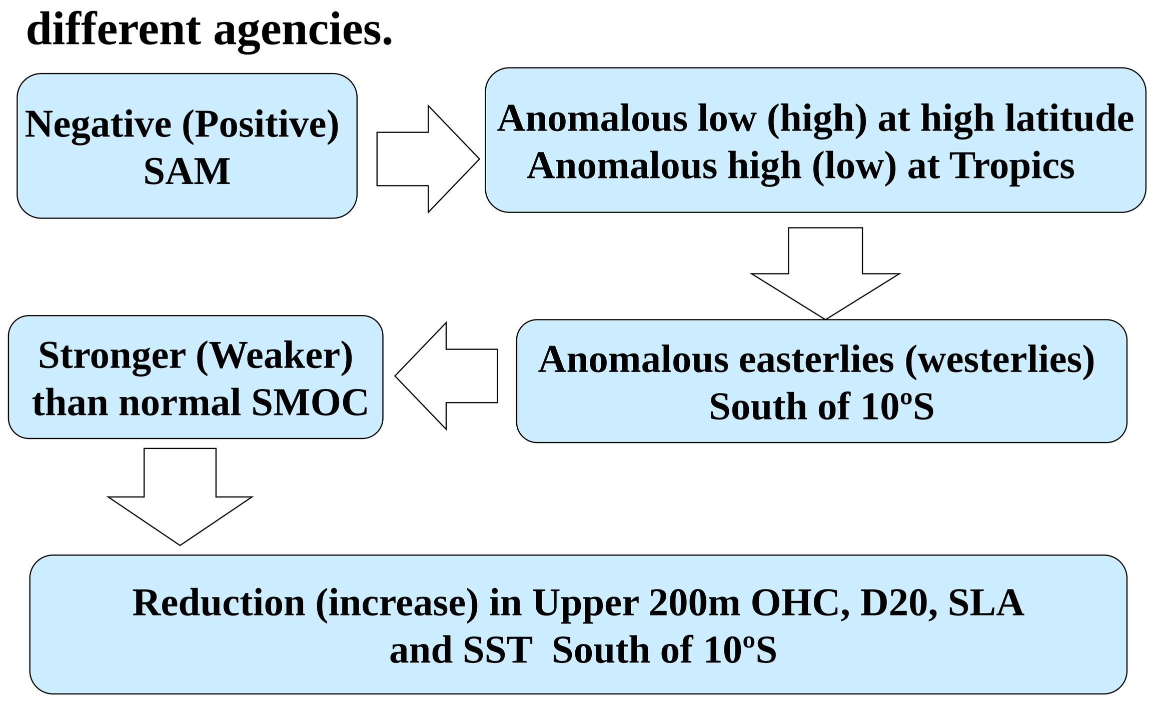


The variability of zonal wind is driven by the meridional pressure gradient between tropics and high latitude associated with the southern annular mode (SAM)

Summary and conclusion

Intra-decadal variability of Indian Ocean SMOC during boreal winter for last century is studied using century long ocean reanalysis dataset.

The robustness of the intra-decadal signal is confirmed between ocean reanalysis datasets from different agencies.



Acknowledgment

- The Director, IITM, Pune
- We acknowledge AMW 2021 and team for providing an opportunity for participating in the workshop