Multi-decadal Changes in Water Mass Properties of the South Indian Ocean

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The three main watermasses in the Southern Indian Ocean changes during 1963-2019

- The **Subtropical Water (STW)** is getting saltier and warmer due to shallowing of isopycnal depth; this watermass shows cooling on depth levels.
- The **Subantarctic Mode Water (SAMW)** shows constant cooling and freshening on both depth and density levels.
- The **Antarctic Intermediate Water (AAIW)** shows increasing temperature and salinity from the voyage observations but shows a cooling and freshening linear trend from the ORAS5 long–term time series.

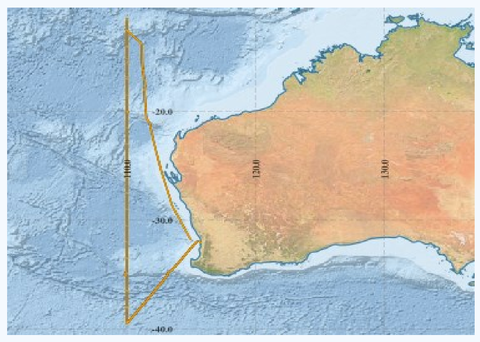


Figure 1:IN2019v03 voyage plan

- **Voyage Observations:** A line along 110°E in the Southeast Indian Ocean was measured twice during the first and second International Indian Ocean Expeditions (IIOE; Figure 1) in **May 1963** and **May-June 2019**.
- **Ocean Reanalysis: ORAS5** provides gridded data including temperature and salinity from 1958 to the present.

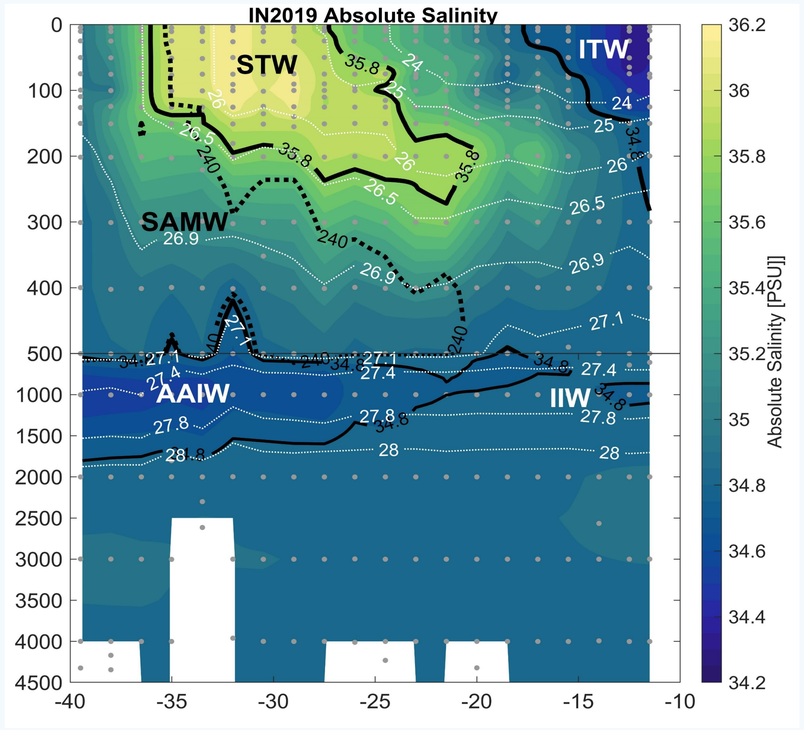


Figure 2: Illustration of Indian Ocean Watermasses (Phillips et al. (2022)).

Main Watermasses & Their Identification

Southern watermasses are identified by their property extrema

- **STW** –salinity maximum (**Smax**) with density between 25-26.5
- ITW – Indonesian Throughflow Water
- **SAMW** – high dissolved oxygen (**Omax**) water with density between 26.5-27.1
- **AAIW** –salinity minimum (**Smin**) with density between 27.1-27.8
- IIW – Indonesian Intermediate Water

IIOE changes: 2019-1963 along 110°E

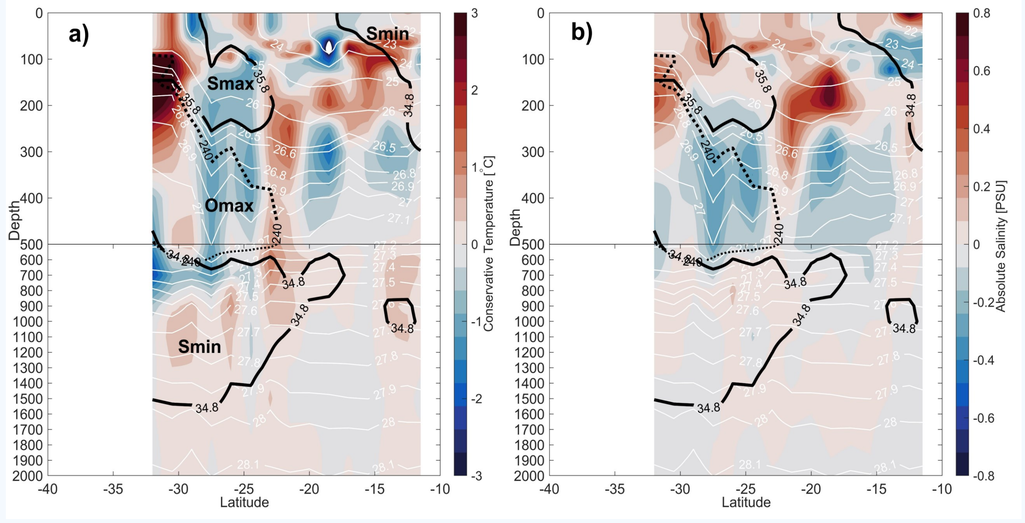


Figure 3: Difference (2019-1963) in conservative temperature (a) and absolute salinity (b) along 110°E on depth levels. White lines mark the mean neutral density from the two voyages.

Table 1: Change in watermass properties from 1963 to 2019

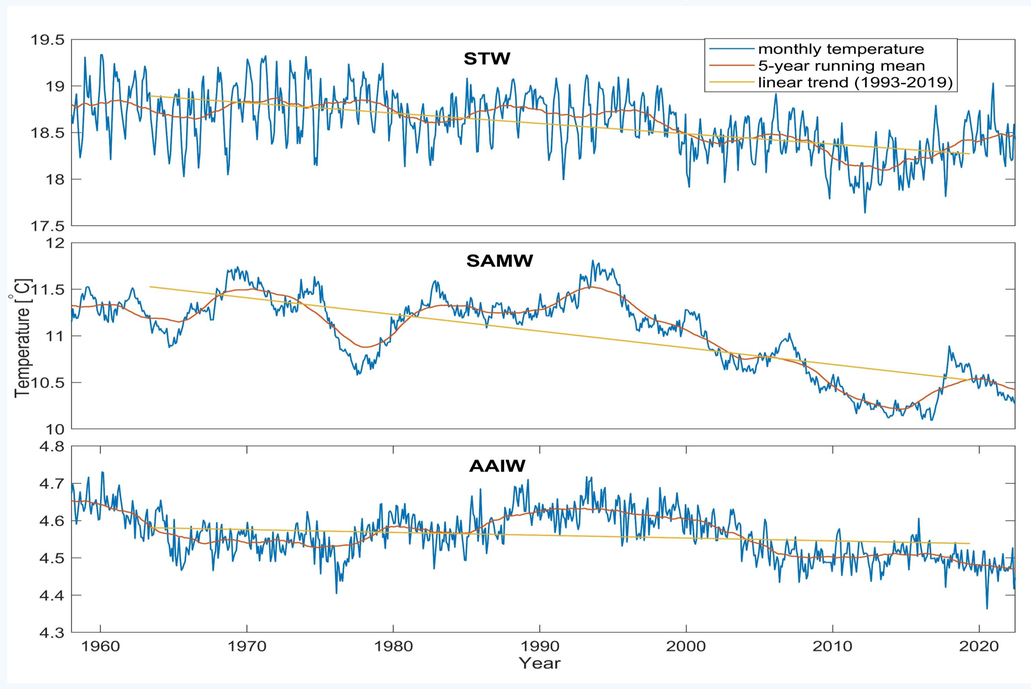
	CT	SA	Isopycnal depth	DO	Nitrate	PO4
STW	↓	↑	**shallower**	↑(upper) ↓(lower)	↓(upper) ↑ (lower)	↓
SAMW	↓	↓	**deeper**	↓	↑	↑
AAIW	↑	↑	**Shallower in top** **Deeper in bottom**	↓	↑	↑

Relatively consistent changes are observed within each watermass. A summary of the changes on depth levels observed from the voyage is shown in Table 1.

Temporal variability 1963-2019 from ORAS5

- The **long-term trend** between the voyages is examined from the time series from ORAS5 (Zuo et al., 2019, Figure 3).
- From 1963 to 2019, the ORAS5 shows a **cooling and freshening** trend in all three watermass layers in density levels overlaid on interannual to decadal variability.

ORAS5 Conservative Temperature Time Series Averaged over -33° to -23° S



ORAS5 Absolute Salinity Time Series Averaged over -33° to -23° S

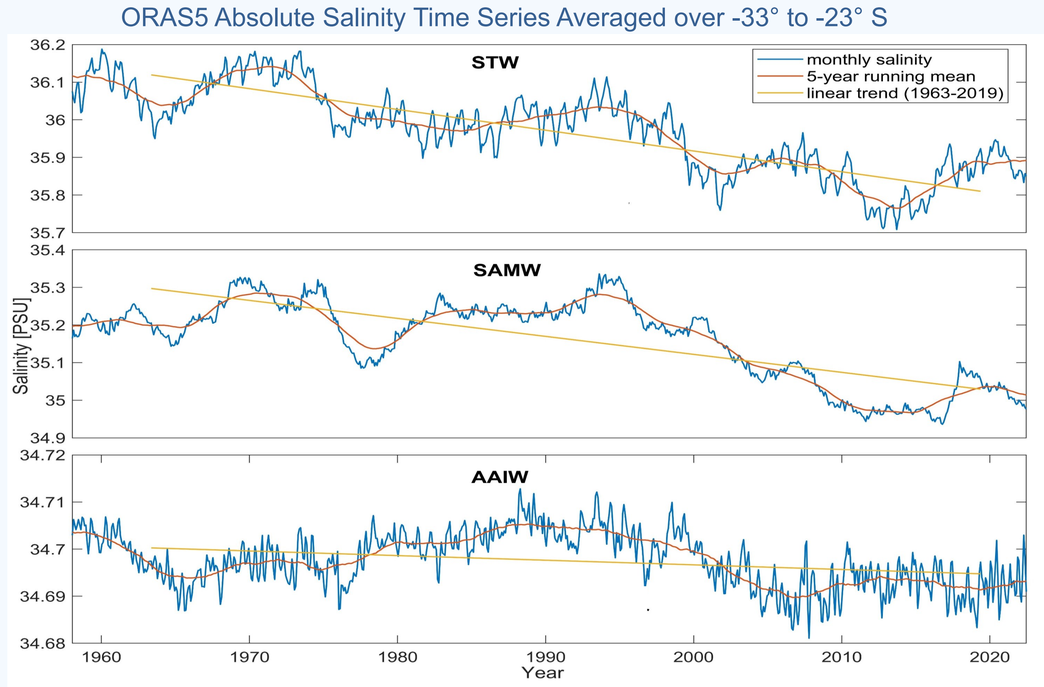


Figure 4: Time series and trends of conservative temperature and absolute salinity along 110°E from ORAS5, averaged over 33°S to 23°S where all 3 watermasses are present.

References:

Phillips, HE et al. 2022, 'Watermass characteristics and circulation near 110°E in the southeast Indian Ocean', *Deep Sea Research Part II: Topical Studies in Oceanography*, vol. 202, p. 105149.

Zuo, H et al. 2019, 'The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: A description of the system and assessment', *Ocean Science*, vol. 15, no. 3.

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