Long-term changes of the Indonesian Throughflow's Vertical Structure and the Impact on Heat and Salinity Transports

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Highlights

- **Projected 21st century weakening of Makassar Strait transport (100-400m depth) in a CESM high-resolution run under RCP8.5 forcing**
- **Makassar Strait flow shows two distinct layers with differing variability and trends**
- **Freshwater transport exhibits increasing trend which is driven by local and remote precipitation induced salinity changes**
- **Reduction of deep-water export from Southern Ocean explains substantial weakening of the Indonesian Throughflow**

Data

- iHESP's CESM high resolution, fully-coupled climate simulations [Chang et al. 2020; Zhang et al. 2020]
- 0.1° ocean resolution
- 0.25° atmosphere resolution
- Historical forcing 1850-2005
- RCP 8.5 forcing 2006-2102

Methods

- time-series are smoothed with 2-year lowpass Butterworth filter
- Heat Transport:
- Freshwater Transport: , with and [Fang et al. 2010]
- Break points are identified by segmented linear regression for two segments

Motivation

The Indonesian Throughflow, a low-latitude passage of the global conveyor belt, transfers water from the tropical Pacific to the Indian Ocean, modulating the properties of both oceans. Long-term changes in this region play a pivotal role in the global heat and freshwater transports. The primary inflow passage is the Makassar Strait which represents nearly 80% of the total ITF transport. We address long term changes in the Makassar Strait and the vertical structure under global warming and possible drivers. Therefore, transient runs of high resolution CESM are used to assess the forced changes under a high-emissions future scenario, namely RCP8.5 forcing.

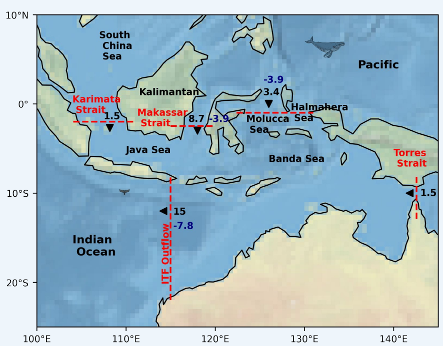

Fig1 Map of the Indonesian Seas with major basins in black and transport sections in red; black numbers indicate mean volume transport through a section under historical forcing (1850:2005) and numbers in blue represent linear transport change for the period 1850:2102 in Sv for CESM HR.

Lack of long observational time series of the ITF → Transient runs of HR CESM → Address long-term changes of the ITF and its vertical structure

Results

Makassar Strait Transport

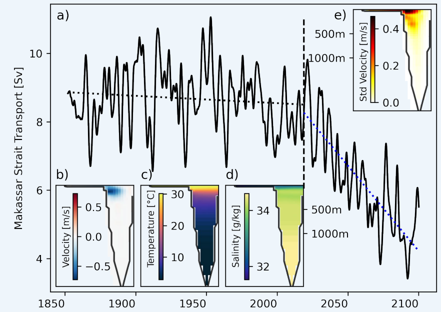

Fig2 Makassar strait volume transport timeseries and cross sections (2.5°S, 116:119°E); a) shows volume transport time series in black, break point as vertical dashed black line, linear trends before and after break point as black and blue dotted lines. Mean cross sections at 2.5°S for b) meridional northward velocity, c) potential temperature, d) salinity and e) standard deviation of meridional velocity (1850:2102).

- Mean Makassar Strait volume transport of 8.7 Sv before 2018
- 2018 break point in linear trend
   After 2018 rapid increase in weakening trend from 0.02 to 0.50 Sv/decade
- Highest variability and mean transport occur shallower than 400m

Where in the water column does this strong weakening signal occur?

Vertical Structure

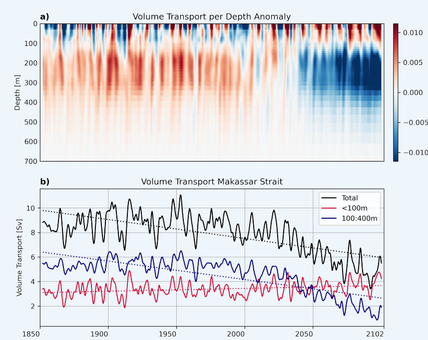

Fig3 Vertical structure of southward Makassar strait volume transport with a) volume transport per depth anomaly (mean subtracted for each depth) integrated along 2.5°S and b) timeseries of total transport in black, surface transport (<100m) in red and subsurface transport (100:400m) in blue.

- Vertical structure shows two layers behaving distinctly in the interannual, decadal variability and the long-term trend
- Strong weakening signal occurs between 100m and 400m while the surface layer even shows a slight strengthening

Where does the strong Makassar Strait Transport and ITF weakening come from? →

Heat and Freshwater Transport

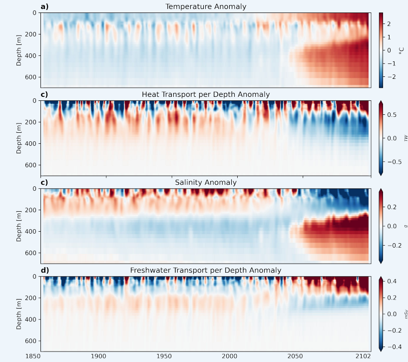

Fig4 Vertical structure of the Makassar Strait's a) temperature, b) heat transport per depth, c) salinity and d) freshwater transport per depth anomaly (mean subtracted for each depth) integrated along 2.5°.

- **Heat transport weakening between 100 and 400m** (-133 TW) is mostly driven by the volume transport weakening
- **Long-term strengthening trend (103 TW) of surface heat transport (<100 m)** is roughly 43% due to warming and 57% due to strengthening of the volume transport
   results in total heat transport weakening of about -45 TW (residual -14 TW below 400 m)
- **Strong decrease in salinity in the upper 200m**
- The strong increase in freshwater transport (67 mSv) occurs in the surface layer (81mSv) where the volume transport strengthens as well and acts on the fresh surface water
- **Strong increase in total freshwater transport** despite the total weakening of volume transport suggests predominant role of salinity changes and therefore advection or precipitation

Does local or remote precipitation play a major role?

Precipitation Effects on Freshwater Transport

- Precipitation trend for the whole period shows increase in precipitation over the Pacific and decrease towards the Indian Ocean highlighting influence of the upstream precipitation for freshening in the Makassar Strait
- However, both local and upstream precipitation exhibit rapid changes and increase after 2000

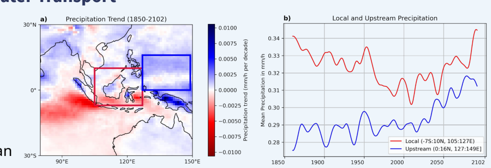

Fig5 Local and upstream precipitation of the Makassar Strait region. In a) the precipitation trend in the Indo-Pacific warm-pool region and the local box in red and upstream boxes in blue and b) timeseries (10-year lowpass Butterworth filter) of local (-7:10N, 105:127E) in red and upstream (0:16N, 127:149E) in blue mean precipitation.

Role of the Southern Ocean

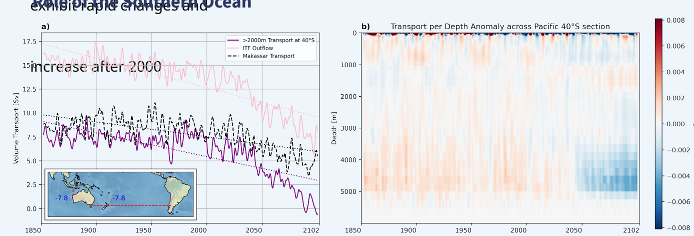

Fig6 Vertical structure of northward volume transport from the Southern Ocean into Pacific (40°S, 145°E:70°W) with a) timeseries of northward deep water transport (>2000m) at 40°S in purple, ITF Outflow in pink, Makassar transport in dashed black and corresponding dotted linear trends in the respective colour and b) volume transport per depth anomaly (mean subtracted for each depth) integrated along 40°S; c) map with Pacific 40°S section (40 °S, 145°E:70°W) and ITF-Outflow sections in dashed red lines and in blue numbers linear transport change for whole period (1850:2102)

- ITF weakening of 7.8 Sv is associated with a similar weakening in the export from Southern Ocean into Pacific
- About 80% of the weakening occurs in the deep-waters below 2000m and 50% in the bottom water depth below 4000m associated with basin wide reduction in upwelling in the Pacific north of 40°S
- About 75 % of the weakening is along the eastern flank of New Zealand (175°E:155°W)
- Makassar Strait transport weakening is only about 50% of the 40°S northward transport and ITF-Outflow weakening as the passage through the Molucca and Halmahera Seas undergoes a weakening of another 50%
- Weakening of Southern Ocean deep-water export may be associated with melting along Antarctica [Li et al. 2023]

References & Acknowledgements

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We gratefully acknowledge support by the U.S. National Science Foundation under OCE-2303515 (to DWO and CCU), and the German Foreign Exchange Service (DAAD) through a RISE fellowship (to DW). We gratefully acknowledge use of model output from CESM-HR simulations as part of iHESP conducted by Texas A&M and QNLM.

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