# High-resolution modeling clarifies future changes of the Indonesian Throughflow

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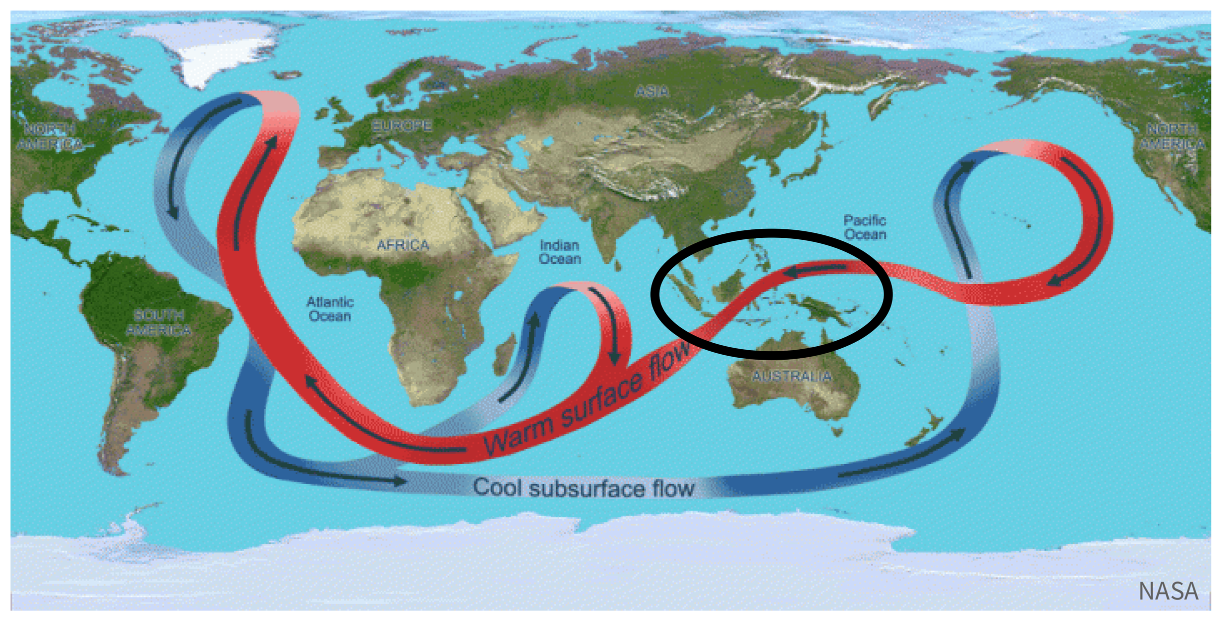
## Introduction

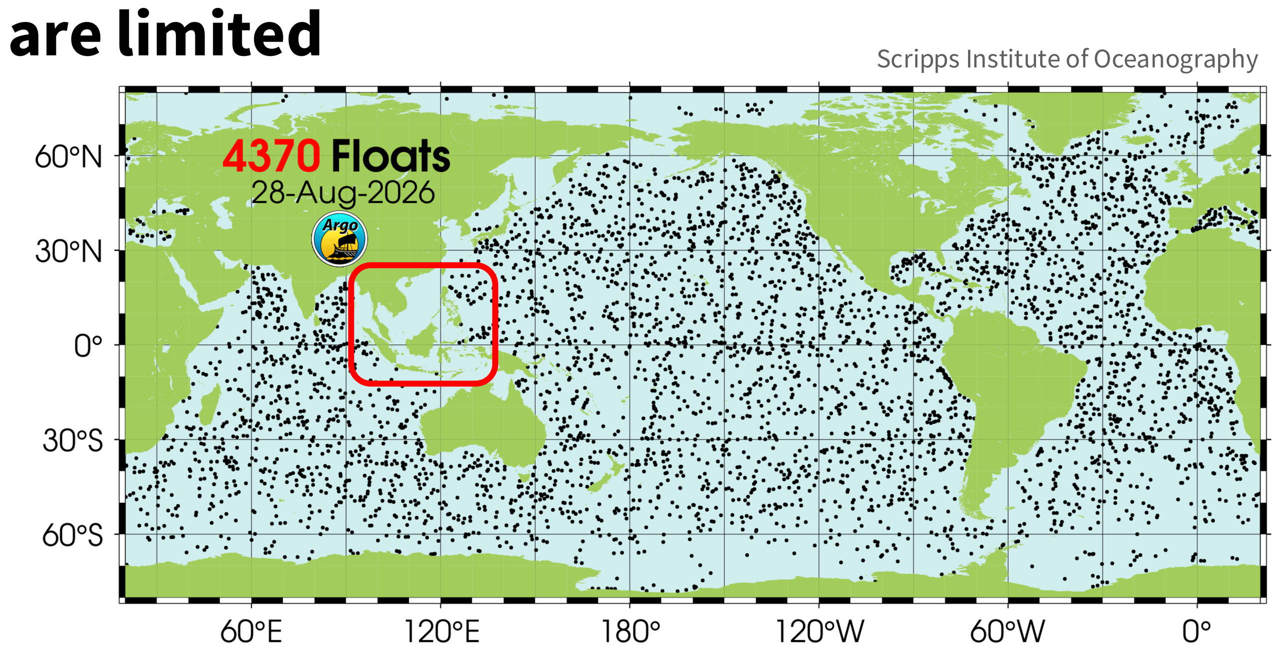
### The Indonesian Throughflow (ITF) is a key component of the global overturning circulation




Warm, fresh waters in the western tropical Pacific are transported into the Indian Ocean by the Indonesian Throughflow (ITF).

ITF transport is driven by an **inter-basin pressure gradient** that is maintained by the prevailing trade winds which generate a steric height difference.

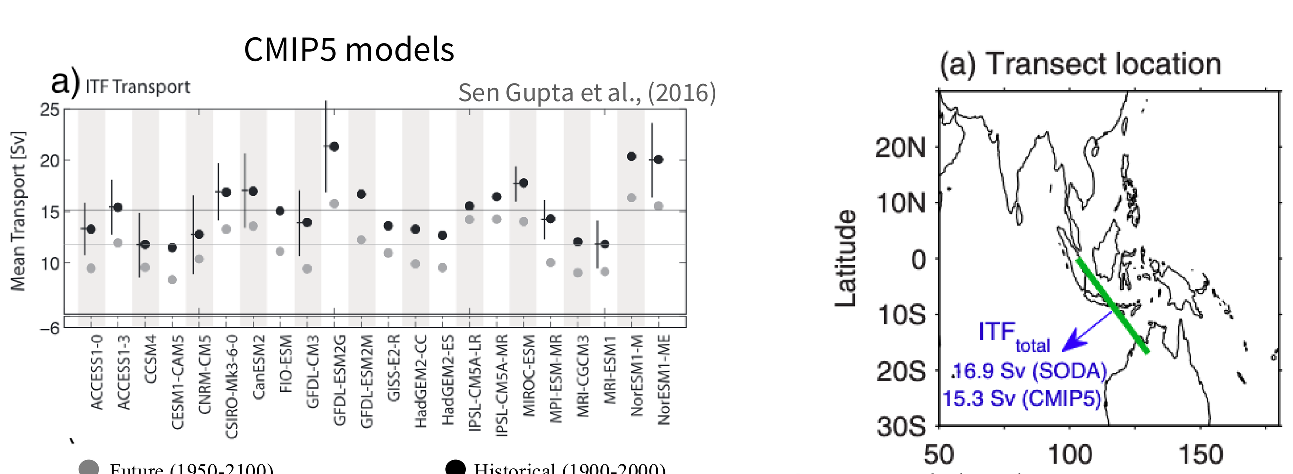
### Direct subsurface measurements in the ITF are limited




Argo floats are rarely deployed in the Indonesian Seas due to the complex topography and strong tidal signals.

In-situ hydrographic measurements primarily come from the few long-term moorings within the Indonesian Seas (INSTANT, MITF, WPOC). These moorings provide **less than 25 years of continuous in-situ data**, which limit their utility for understanding long-term change.

### Standard resolution climate models project a long-term ITF weakening

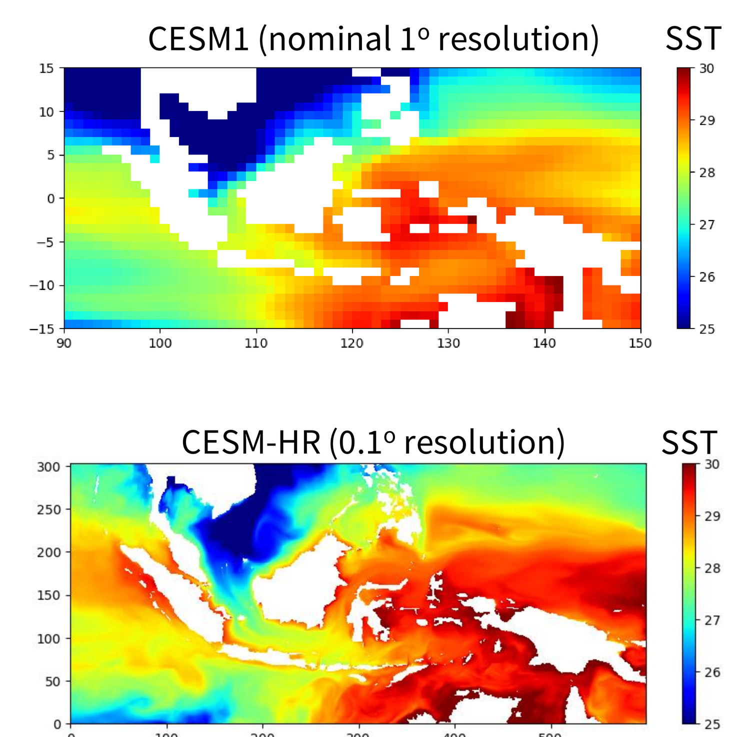



CMIP5 and CMIP6 models project **an overall ITF transport decline** in response to 21st century anthropogenic forcings. However, these coarse models (~1° resolution) **fail to accurately represent individual ITF passageways**.

## Questions and Approach

- **How do individual ITF pathways change under future warming?**
- **What mechanisms drive these changes?**

### High-resolution modeling of the Indonesian Seas

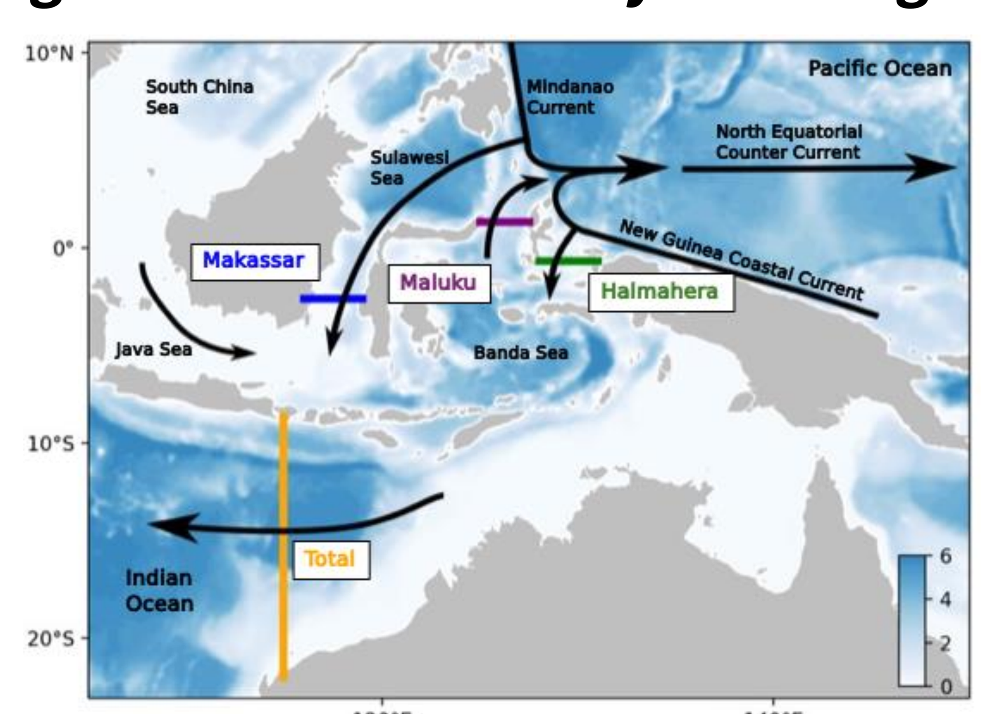



Here we analyze the **CESH-HR (MESACLIP) simulations** to explore how the velocity structure of individual ITF pathways will evolve under a high-emission scenario (RCP8.5).

CESM-HR uses the CESM1.3 model configured at **1/10° resolution in ocean/sea-ice and 1/4° atmosphere/land**.

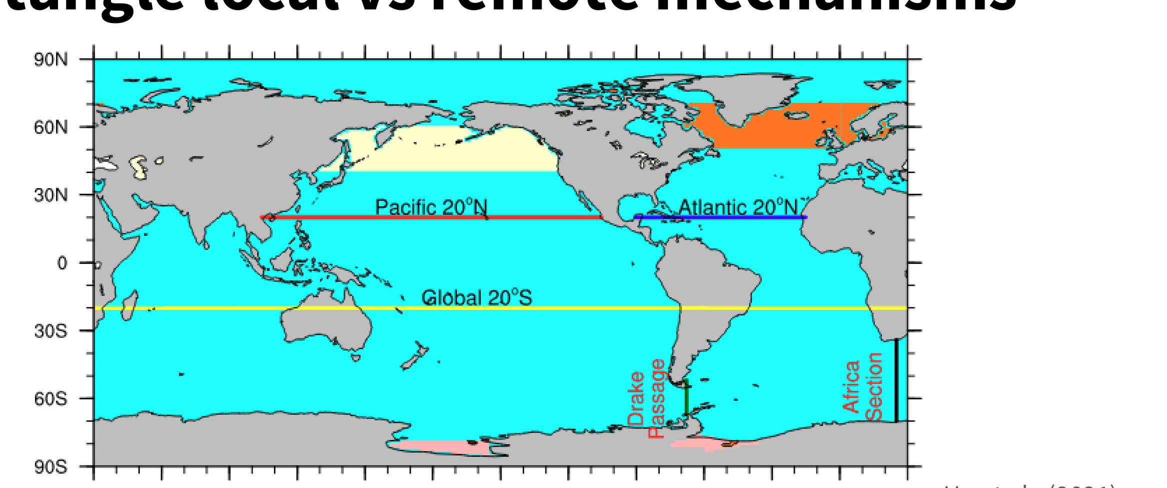
CESM-HR faithfully captures key ITF features including a dominant Makassar Strait and an intermediate WBC through the Maluku Sea (Yuan et al., 2022).

### How do the three ITF inflow passageways change under 21st century warming?




We focus on understanding changes in the three main ITF inflow pathways that comprise ~98% of total volume transport: the Makassar Strait, Maluku Strait, and Halmahera Strait.

### Idealized AMOC collapse experiment to disentangle local vs remote mechanisms



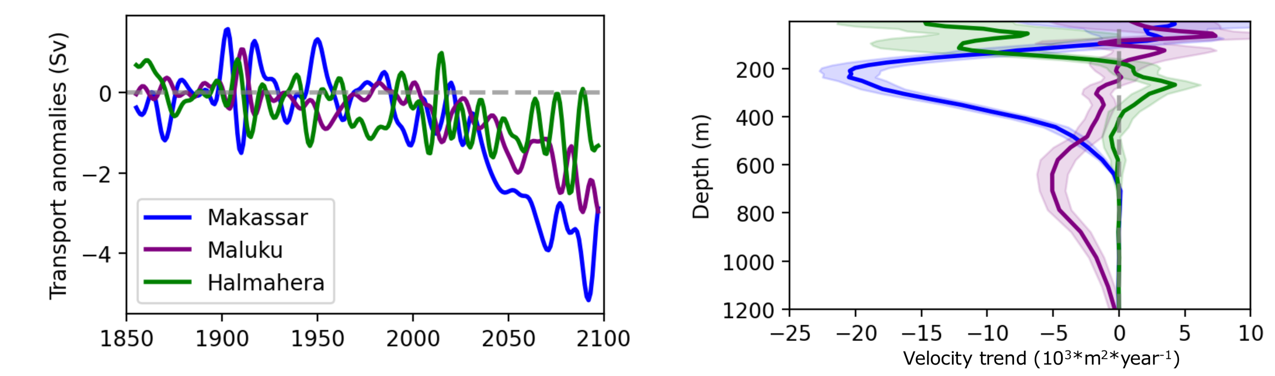

To disentangle changes associated with local surface forcings versus remote influences associated with a weakening AMOC, we also utilize a **CESM1 (standard resolution) simulation where AMOC is weakened** through North Atlantic freshwater input (Hu et al., 2021). No anthropogenic emissions are imposed in this experiment.

## Results

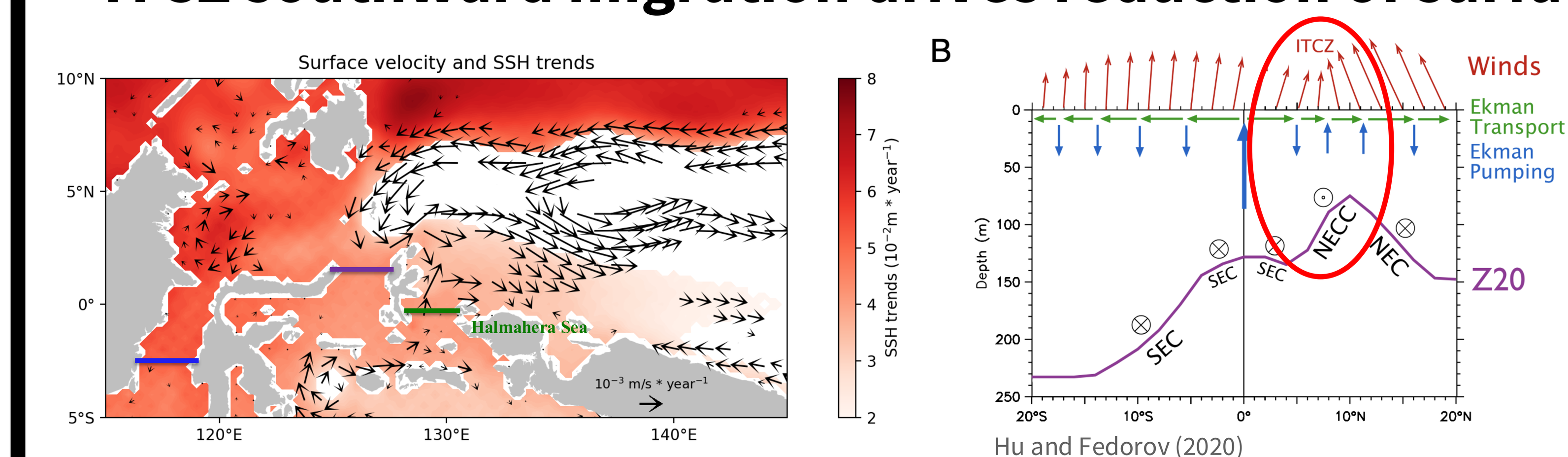
### Projected transport decline across all three passageways

In CESM-HR, volume transport is projected to **decline across all main pathways**.

However, the vertical structure of velocity changes are distinct, suggesting potentially different mechanisms of change.




### ITCZ southward migration drives reduction of surface flow

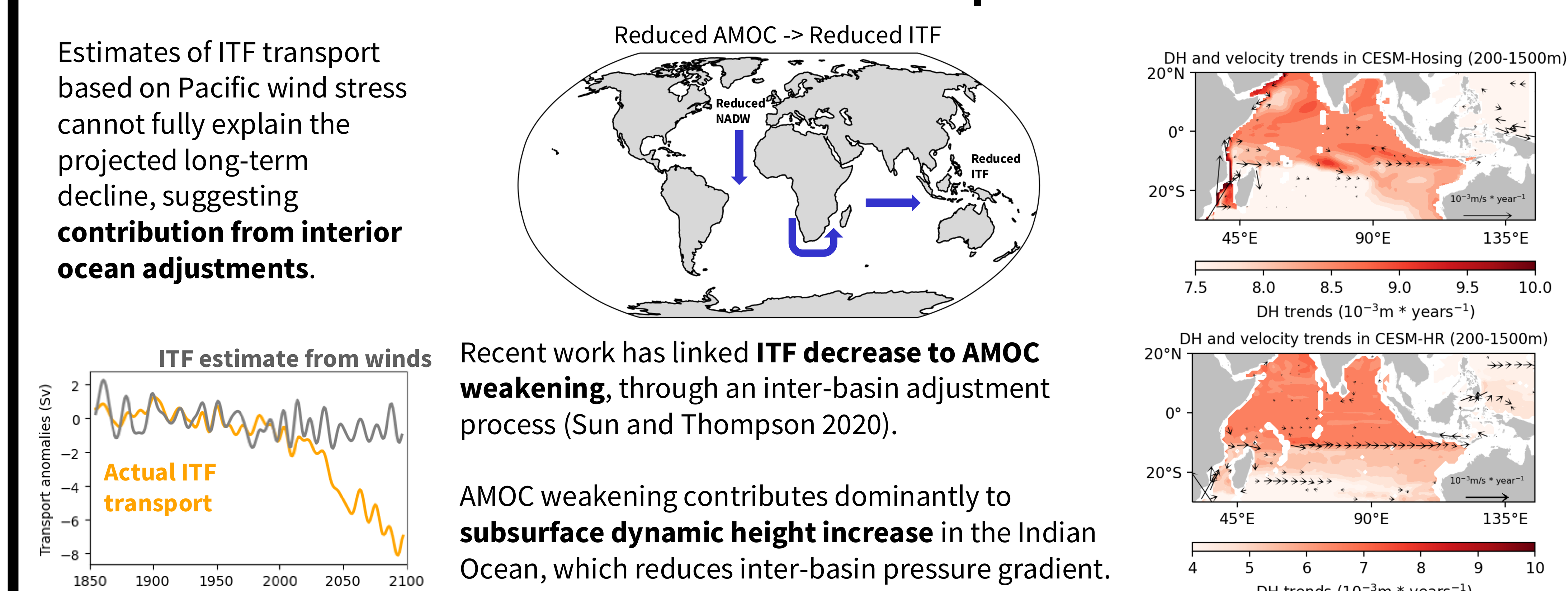



Surface ITF decline (through Halmahera) is linked to the **southward shift of the NECC**.

The NECC latitude is governed by Pacific wind-stress curl and ITCZ position. Thus, **ITCZ southward migration also modulates NECC**.

### AMOC decline weakens ITF subsurface transport

Estimates of ITF transport based on Pacific wind stress cannot fully explain the projected long-term decline, suggesting **contribution from interior ocean adjustments**.




Recent work has linked **ITF decrease to AMOC weakening**, through an inter-basin adjustment process (Sun and Thompson 2020).

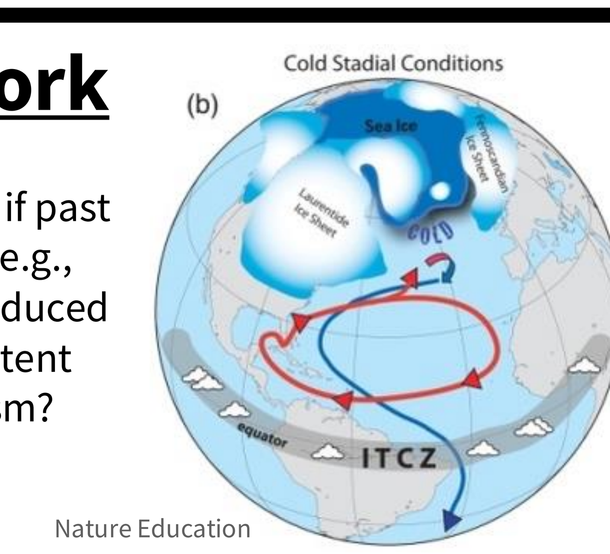
AMOC weakening contributes dominantly to **subsurface dynamic height increase** in the Indian Ocean, which reduces inter-basin pressure gradient.

## Conclusions

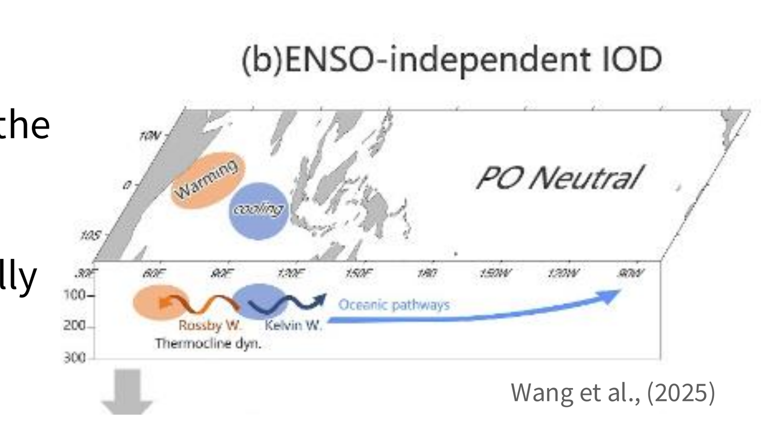
1. Using high-resolution climate models, we find that all major ITF pathways are projected to weaken under 21st century forcings.
2. The surface transport decrease is due to a southward migration of the ITCZ, which reduces NECC contributions to the Halmahera Sea.
3. The subsurface decline is linked to a weakened AMOC which excites an inter-basin adjustment.

## Future work

Could we evaluate if past AMOC weakening (e.g., Heinrich events) induced ITF changes consistent with this mechanism?




How does higher resolution ITF affect the representation of tropical basin interactions, especially ENSO-IOD coupling?

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