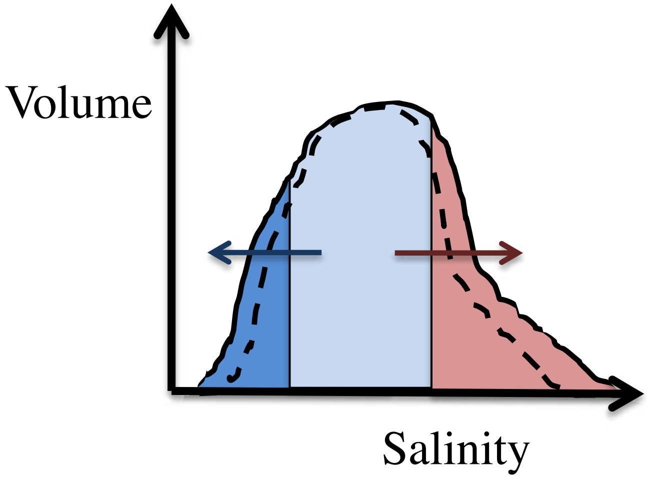
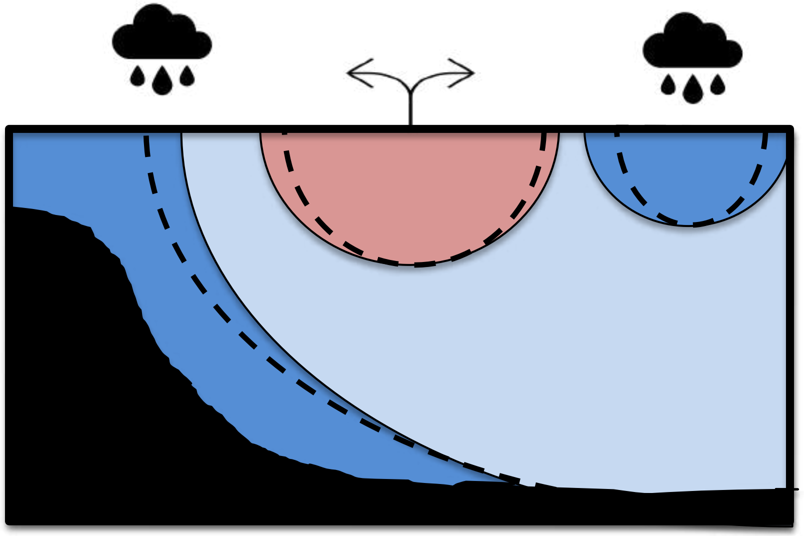
Pattern of water cycle amplification evident from ocean water masses changes

Jan Zika and Taimoor Sohail





Inferring water cycle change using:

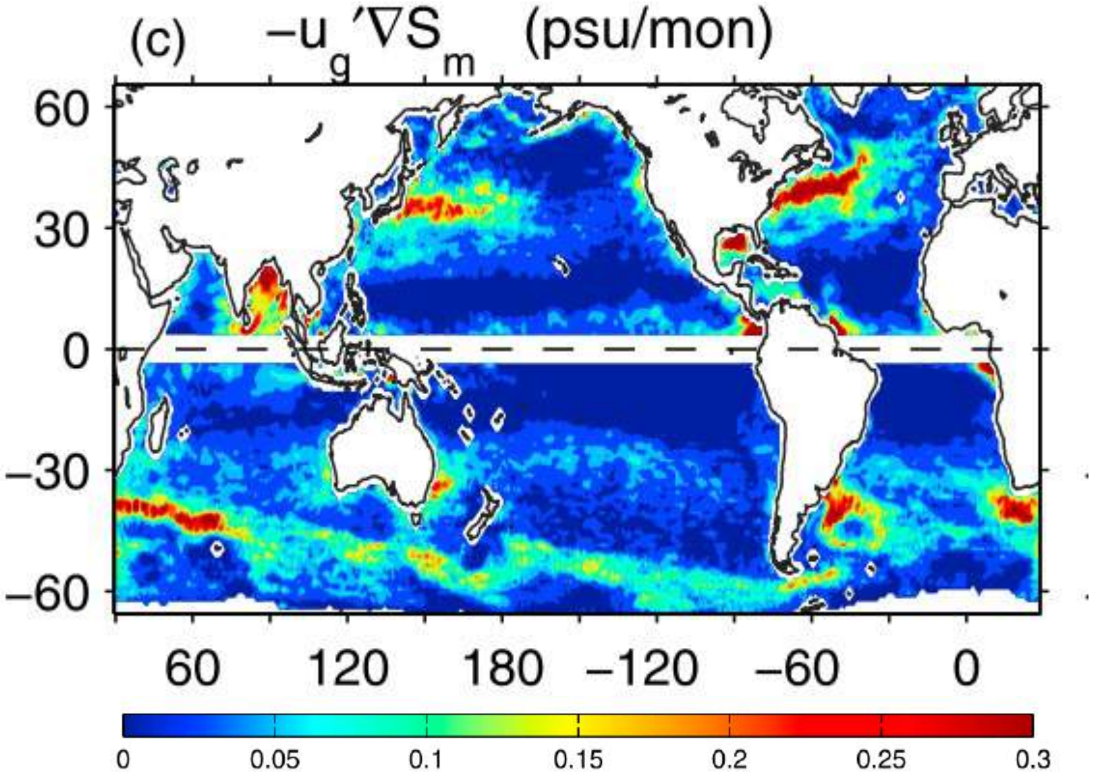
1. The sea surface salinity pattern;

2. Full depth global salinity distribution;

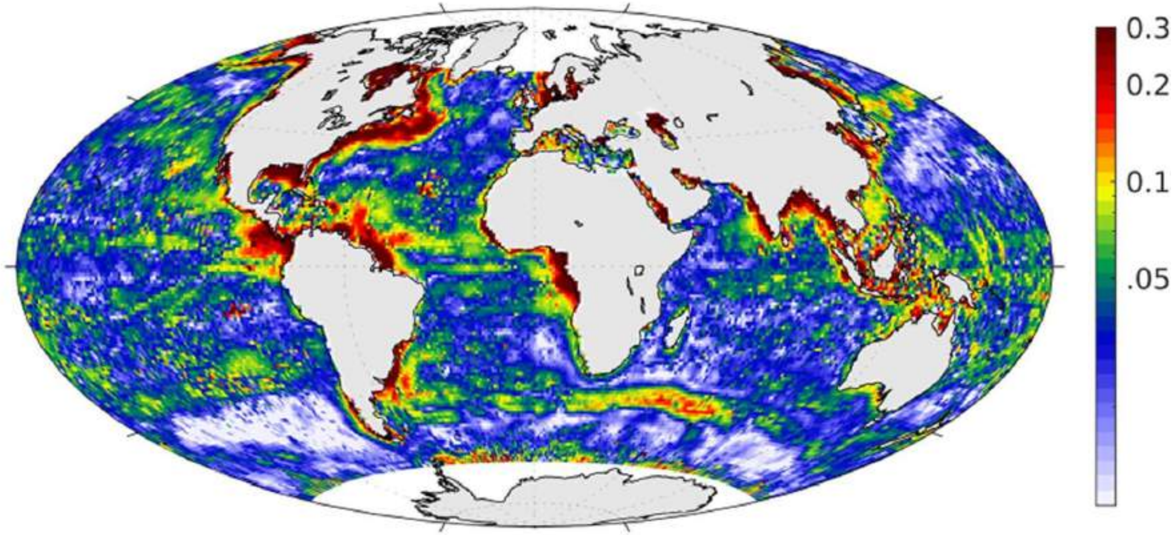
3. The global temperature-salinity (*T-S*) curve;

4. Changes in the volumetric *T-S* distribution.

Regionally, SSS is highly variable and uncertain



Spread mean salinity among climatologies (5m)

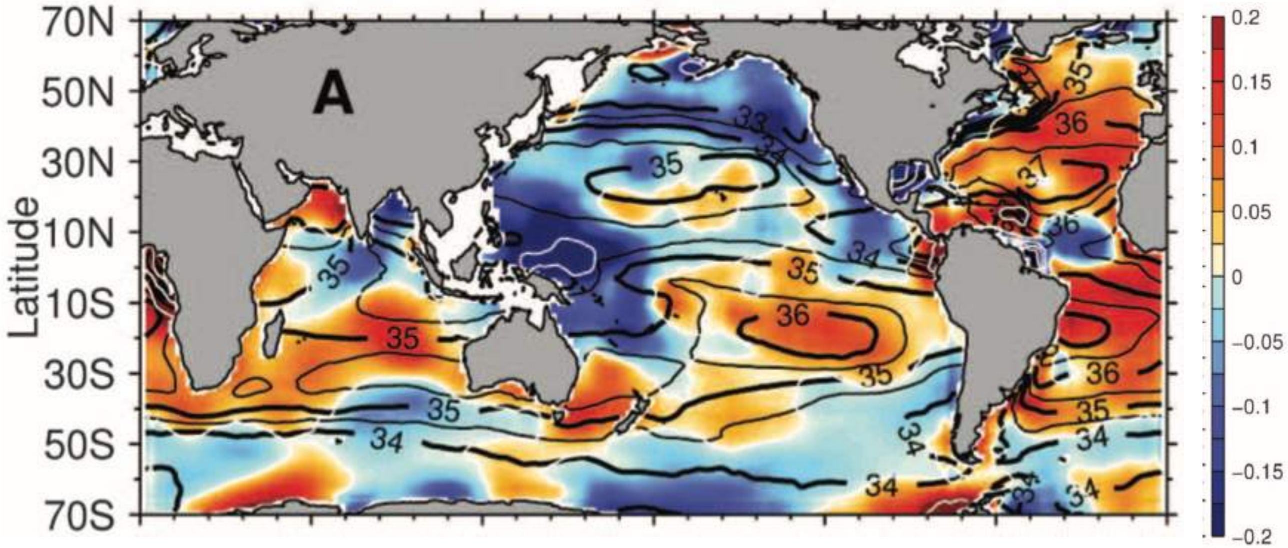


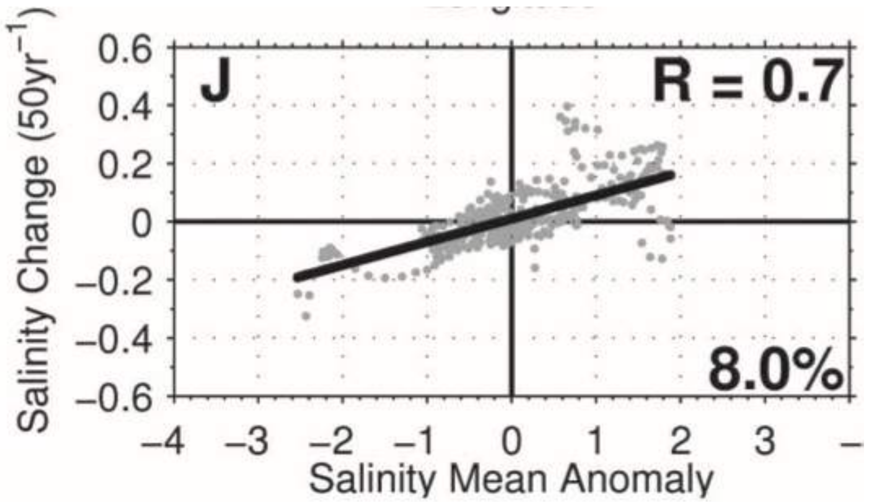
Yu, L. (2011), A global relationship between the ocean water cycle and near-surface salinity, J. Geophys. Res., 116, C10025, doi:10.1029/2010JC006937.

D. Stammer, M. Sena Martins, J. Köhler, A. Köhl: How well do we know ocean salinity and its changes? Progress in Oceanography, 190, 2021, doi.org/10.1016/j.pocean.2020.102478.

1. The sea surface salinity pattern;

Characterizing the change as a ‘pattern amplification’ (PA) can help

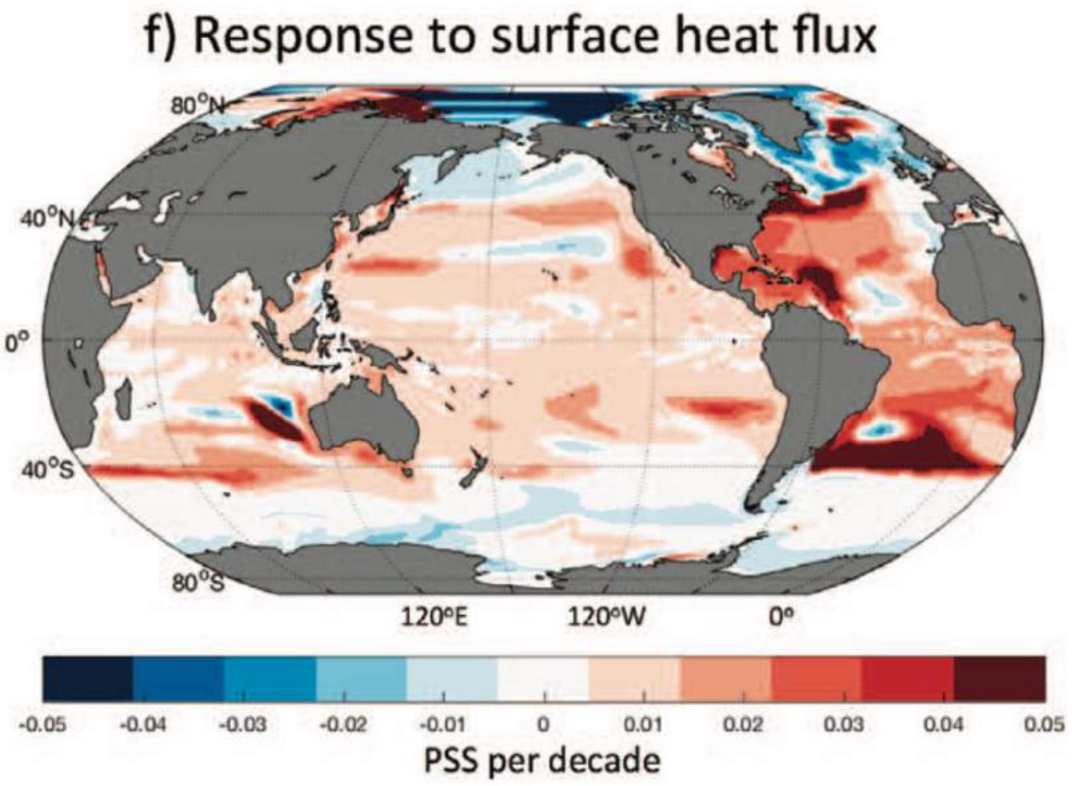




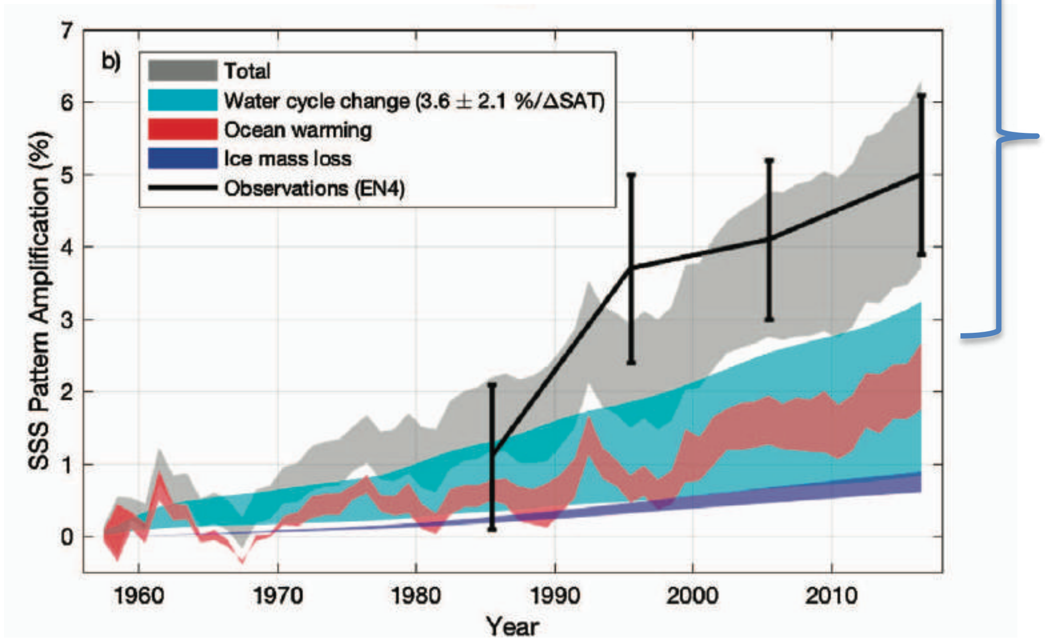
1. The sea surface salinity pattern;

Paul J. Durack *et al.* (2012: Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000. *Science* 336, 455.
DOI: 10.1126/science.1212222

But, half the PA is due to warming (mixing suppression)…



Durack et al. (2012) ~ 8%



11.6%/K Water Cycle change implied

Zika, J. D., N. Skliris, A. Blaker, R. Marsh, N. G. Nurser, S. Josey, 2018: Improved estimates of water cycle change from ocean salinity: the key role of ocean warming. 13 74036, Environmental Research Letters.

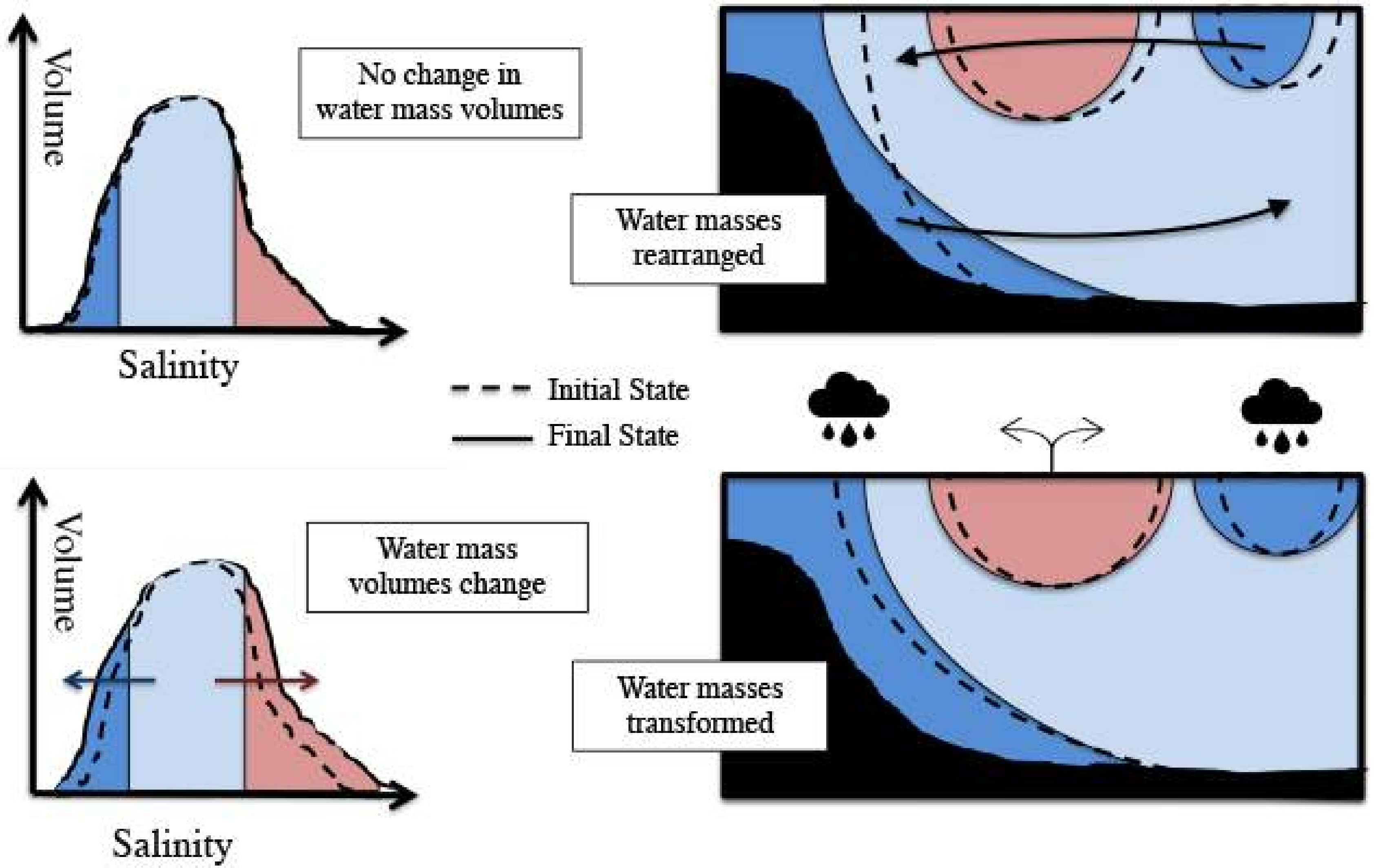
…and estimates of PA vary a lot.

1. The sea surface salinity pattern;

Using the full depth salinity distribution

Circulation doesn't (directly) change water masses.

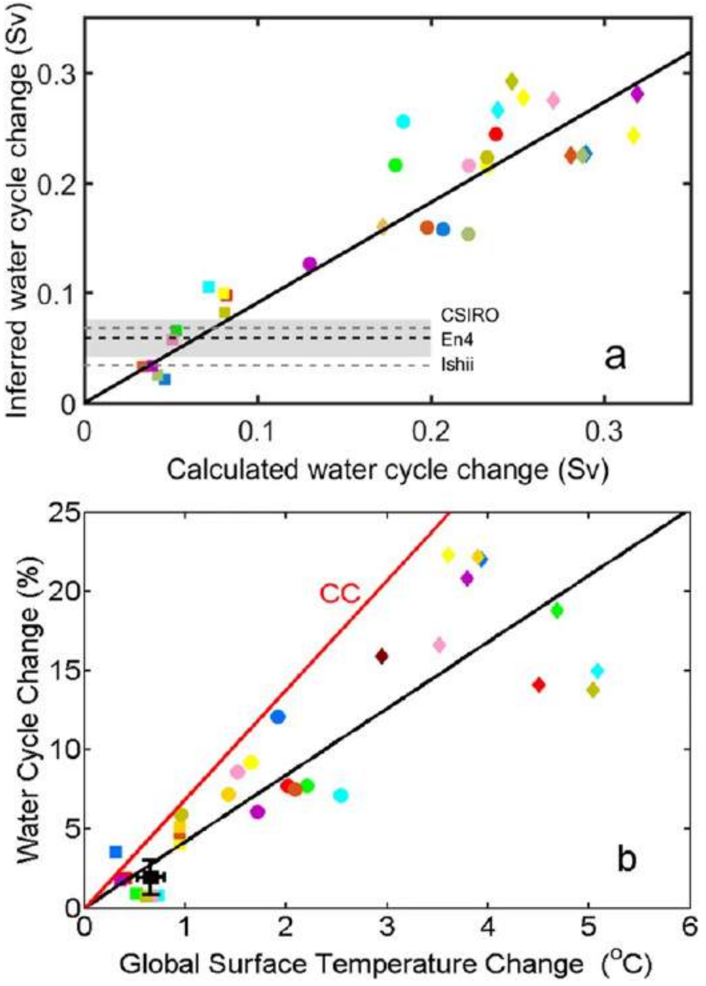
Water cycle change does.

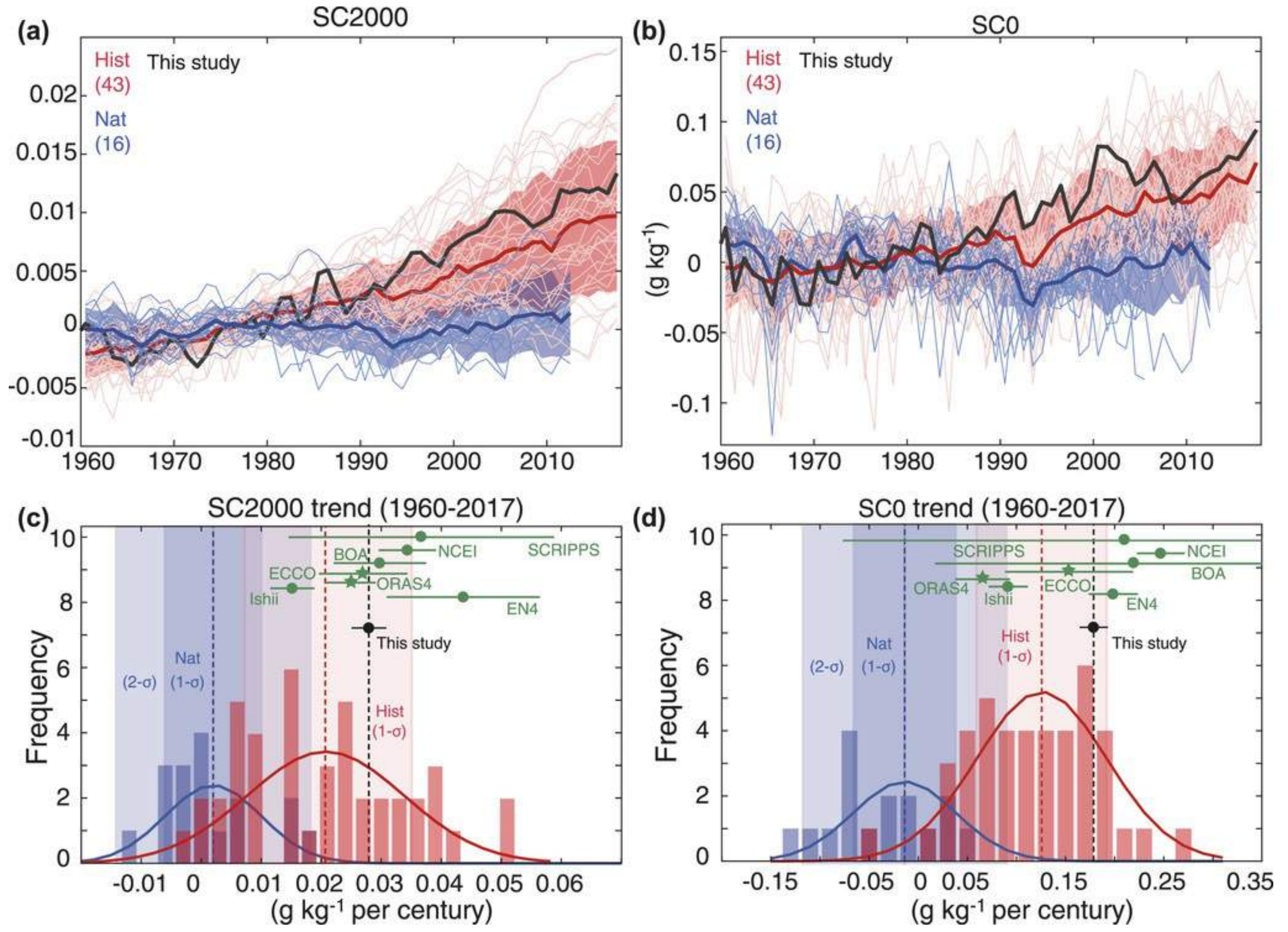


2. Full depth salinity distribution;

Zika, J. D et al. 2015: Maintenance and broadening of the ocean's salinity distribution by the water cycle. Journal of Climate. 28, 9550-9560.

Demonstrates robust water cycle amplification



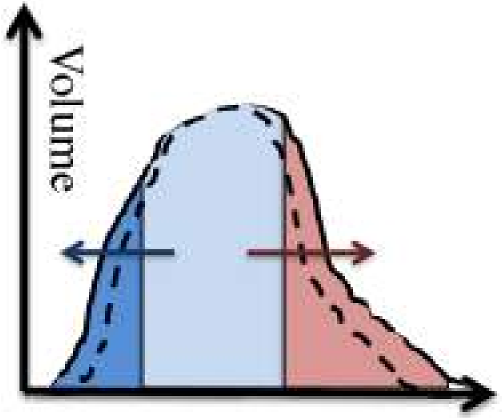


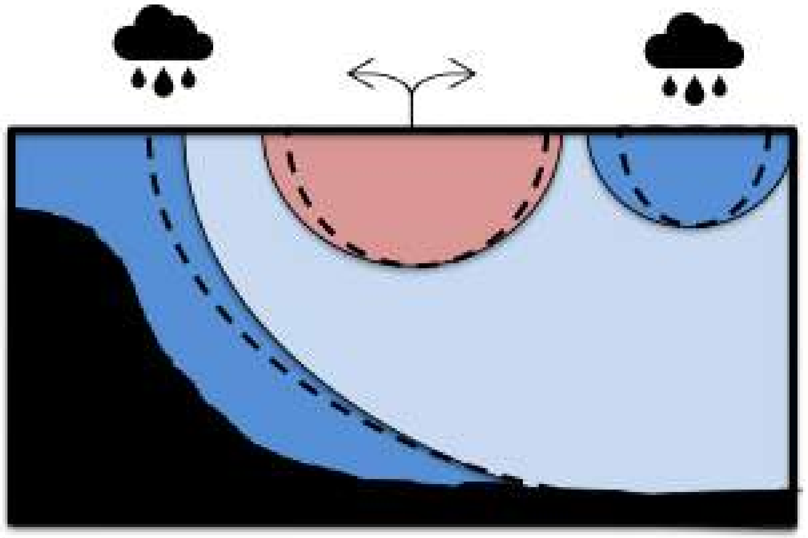
Skliris, N, J. D. Zika, N. G. Nurser, S. Josey, R. Marsh, 2016: Global water cycle amplifying at less than the Clausius-Clapeyron rate. Nature Scientific Reports. 6, 38752.

Cheng, L., Trenberth, K. E., Gruber, N., Abraham, J. P., Fasullo, J. T., Li, G., Mann, M. E., Zhao, X., & Zhu, J. (2020). Improved Estimates of Changes in Upper Ocean Salinity and the Hydrological Cycle, *Journal of Climate*, *33*(23), 10357-10381. Retrieved May 27, 2022, from https://journals.ametsoc.org/view/journals/clim/33/23/jcliD200366.xml

2. Full depth salinity distribution;

But where is the water cycle changing?



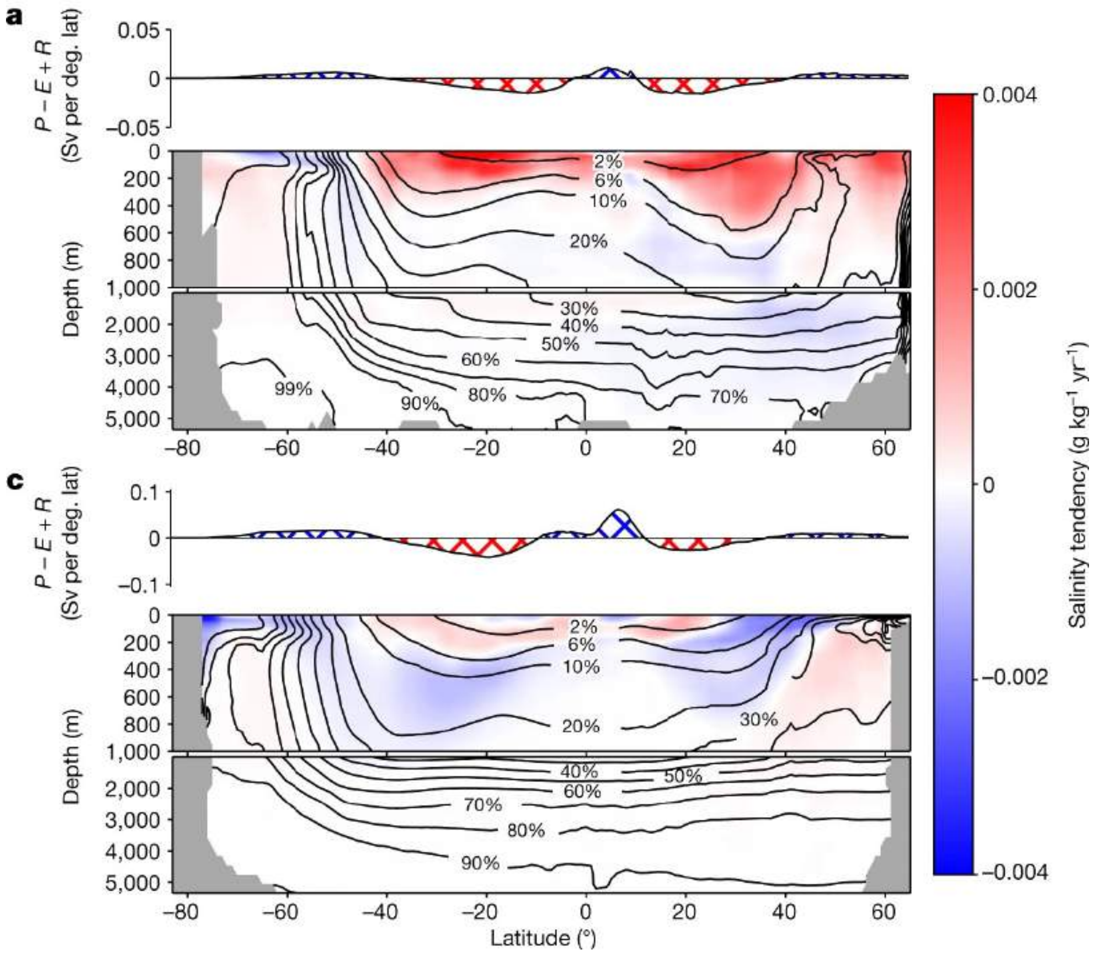


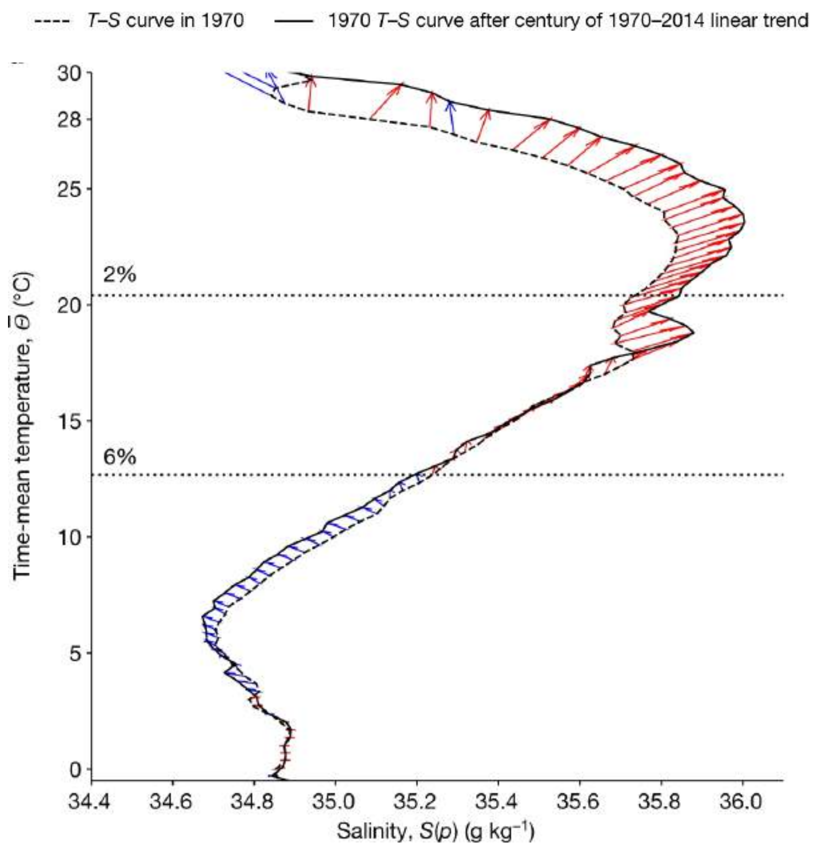
2. Full depth salinity distribution;

There are two fresh regions: warm and cold

Atlantic

Indian + Pacific



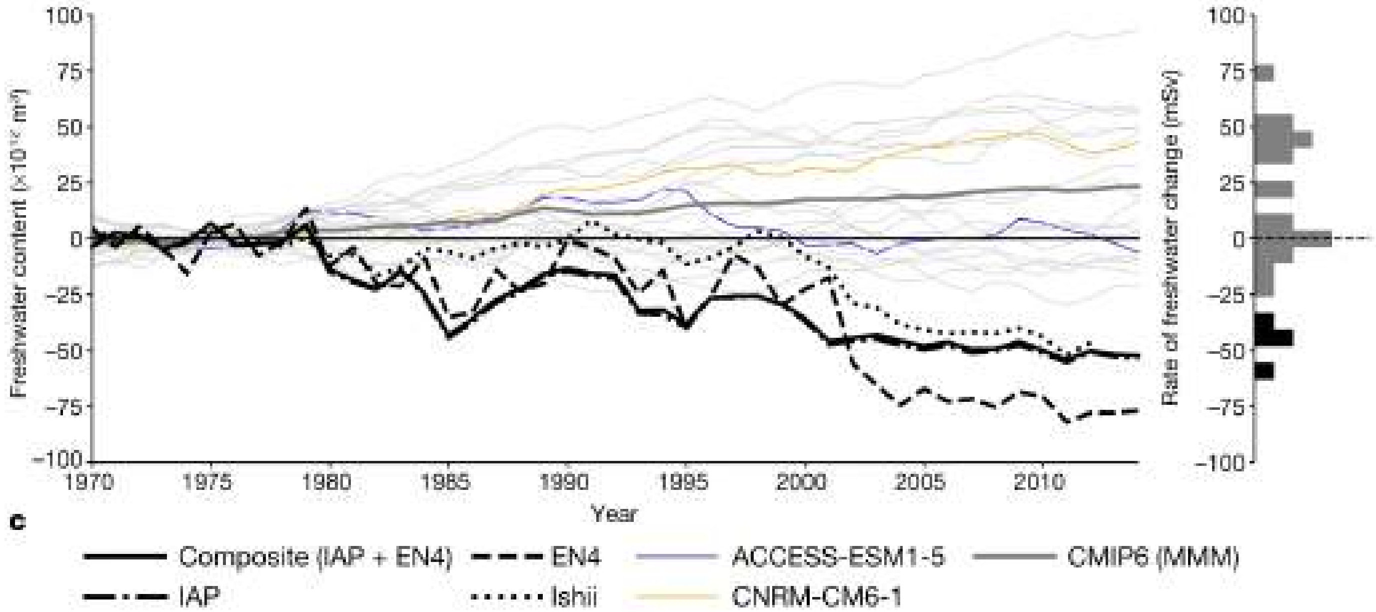


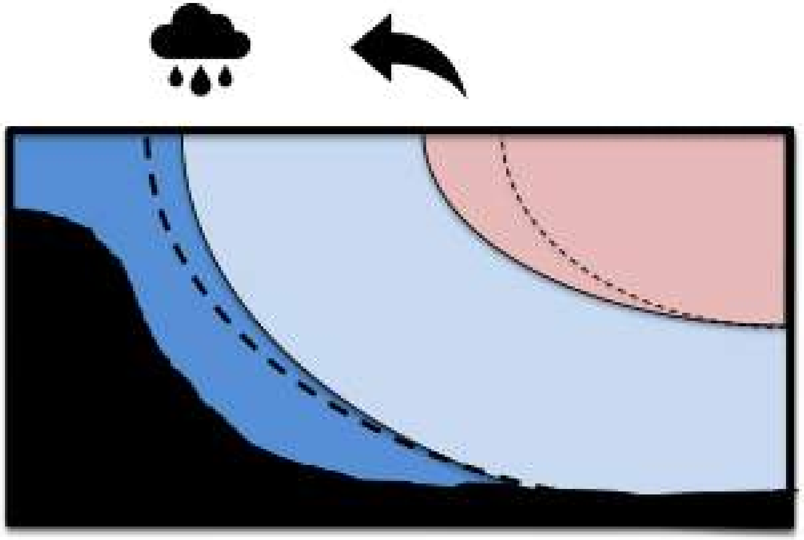
3. The global temperature-salinity (*T-S*) curve;

Sohail, T., Zika, J.D., Irving, D.B. *et al.* Observed poleward freshwater transport since 1970. *Nature* **602,** 617–622 (2022). https://doi.org/10.1038/s41586-021-04370-w (See Taimoor Sohail's poster!!!!)

Poleward fresh-water transport is amplifying dramatically, more than any CMIP6 model

Change in freshwater content of the warmest 6% of the ocean



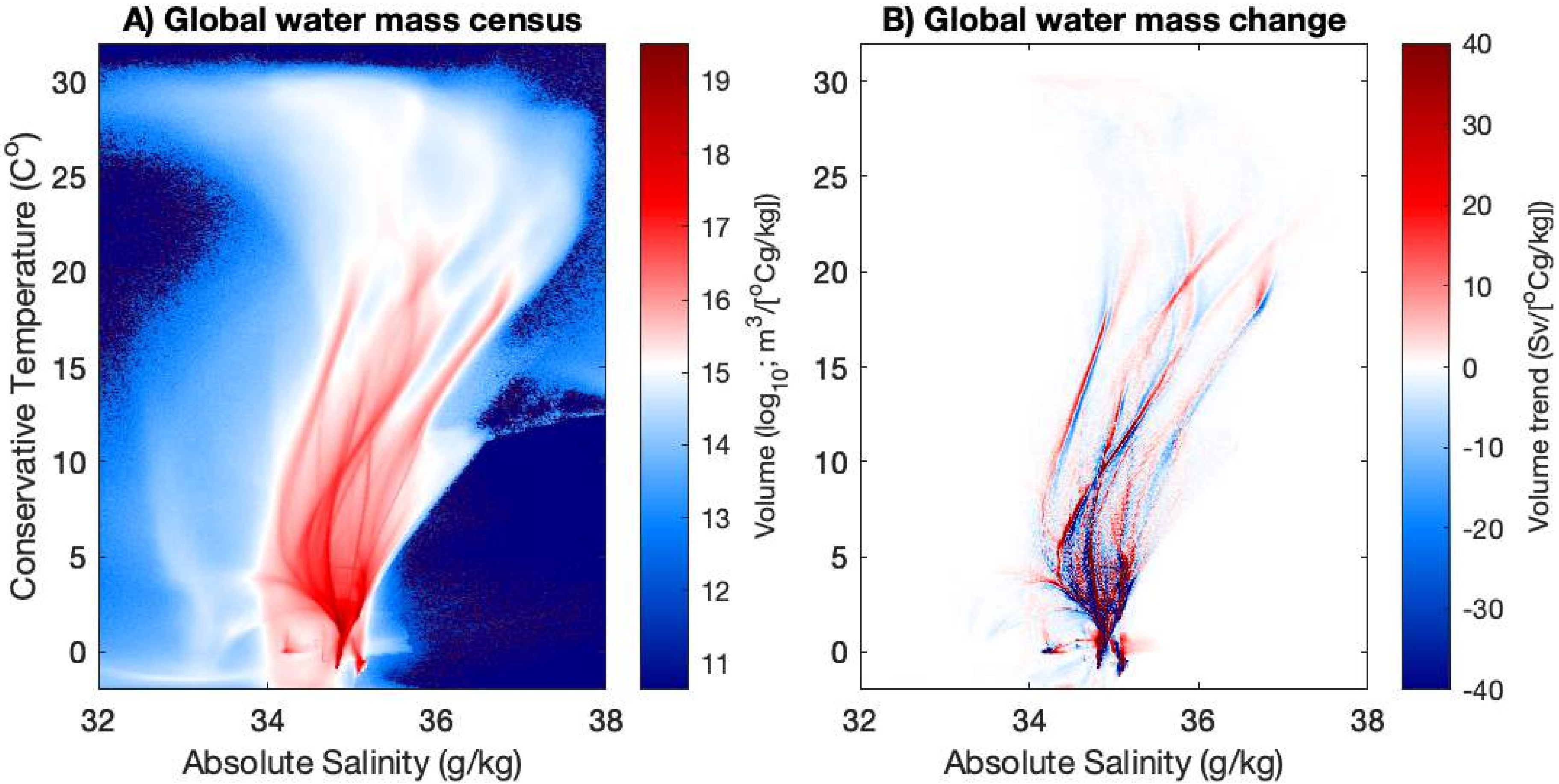


Sohail, T., Zika, J.D., Irving, D.B. *et al.* Observed poleward freshwater transport since 1970. *Nature* **602,** 617–622 (2022). https://doi.org/10.1038/s41586-021-04370-w (See poster!!!!)

What about a detailed regional picture?...

3. The global temperature-salinity (*T-S*) curve;

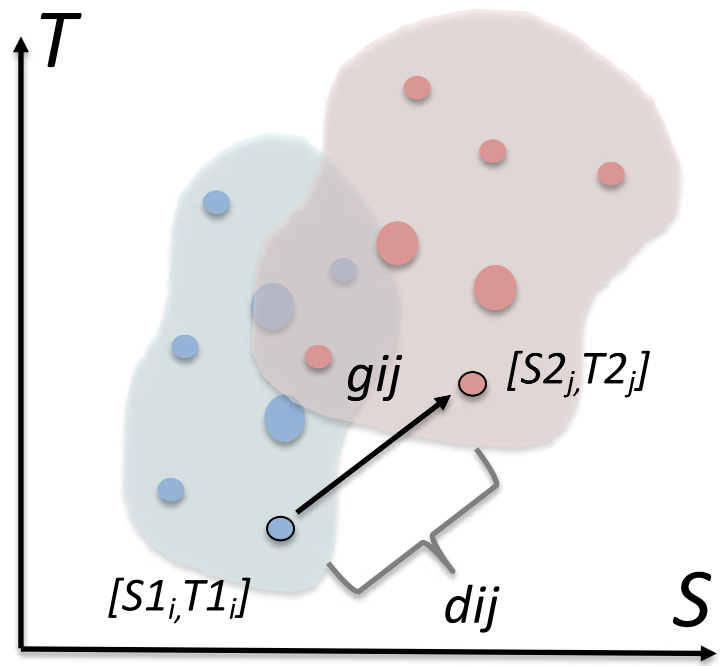
How much of observed *T-S* change *can* be explained by mixing and circulation change?



4. Changes in the volumetric *T-S* distribution.

Zika, J. D., J. M. Gregory, E. L. McDonagh, A. Marzocchi, L. Clement, 2021: Recent water mass changes reveal mechanisms of ocean warming. Journal of Climate. 34 (9), 3461-3479.

To find the 'minimum transformation' I have been using an Earth Mover's Distance algorithm.



This is an established problem in 'optimal transportation theory' where the water mass volumes are conserved such that

$$V1_i = \sum_{j=1}^{M} g_{ij} \text{ and } V2_j = \sum_{i=1}^{N} g_{ij}.$$

And we minimise

$$\sum_{j=1}^{M}\sum_{i=1}^{N} g_{ij}\, d_{ij}$$

where

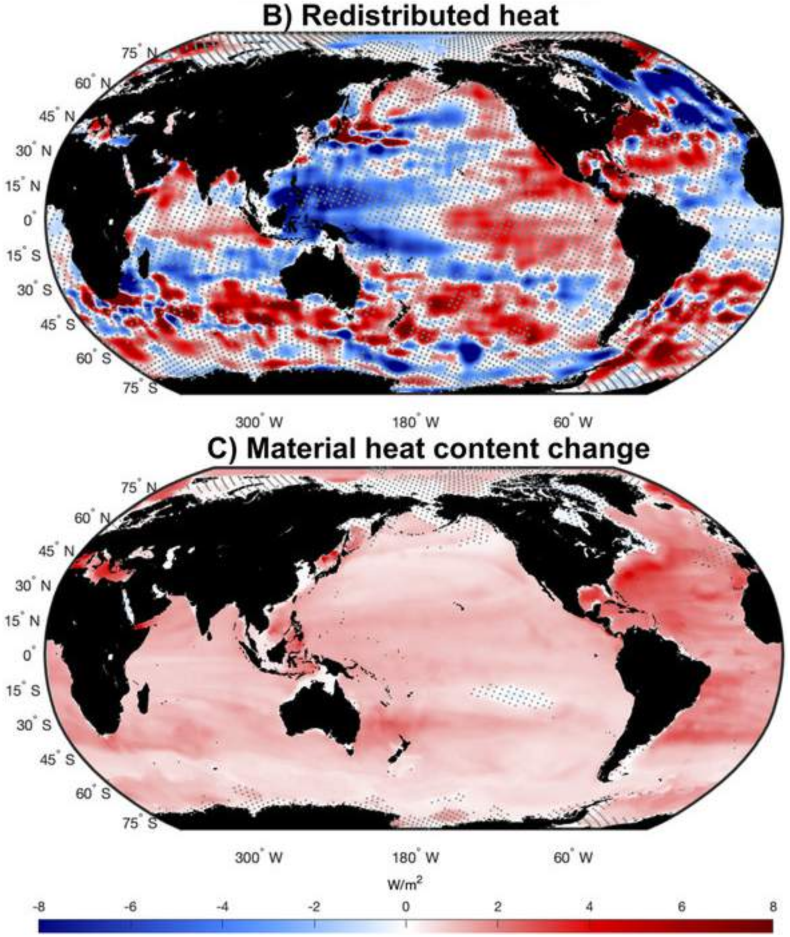
$$d_{ij} = (T2_j - T1_i)^2 + \left(a\left(S2_j - S1_i\right)\right)^2$$

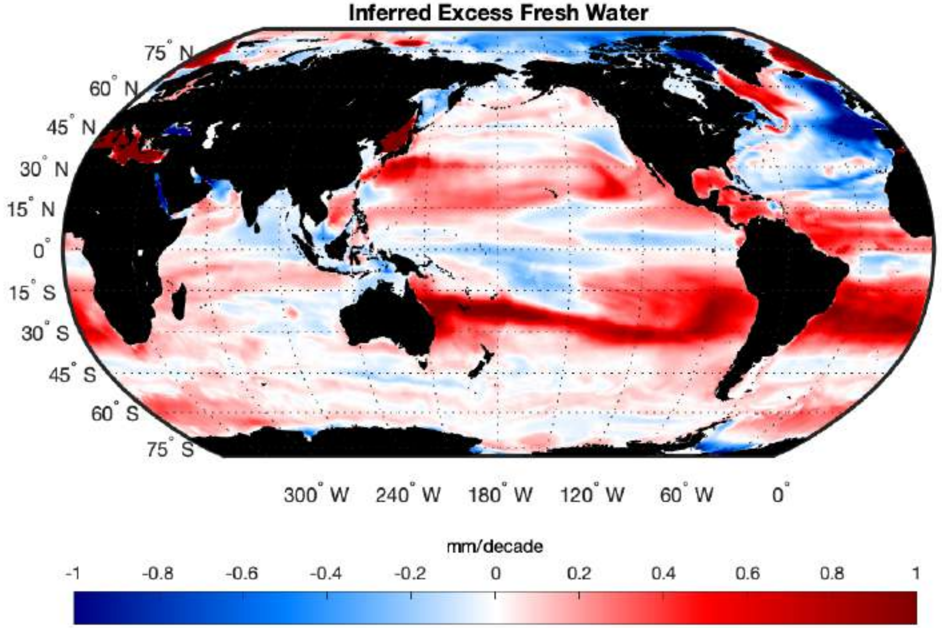
with a arbitrary.

Analogy:

N mounds of dirt and M holes. What set of movements of wheelbarrows moving the dirt from mounds to holes requires the least mass weighted distance to be travelled.

T-S changes suggest patterns of 'material' temperature and salinity change



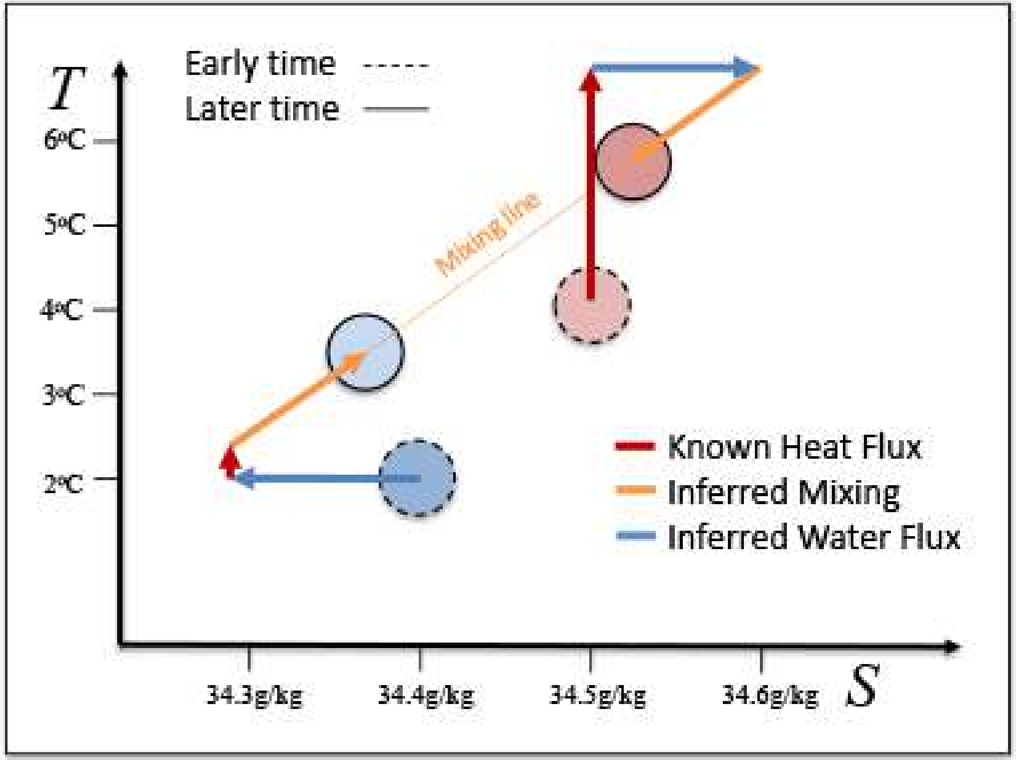


We are working on a method to to directly infer E-P change necessary to change T-S distribution.

Zika, J. D., J. M. Gregory, E. L. McDonagh, A. Marzocchi, L. Clement, 2021: Recent water mass changes reveal mechanisms of ocean warming. Journal of Climate. 34 (9), 3461-3479.

4. Changes in the volumetric *T-S* distribution.

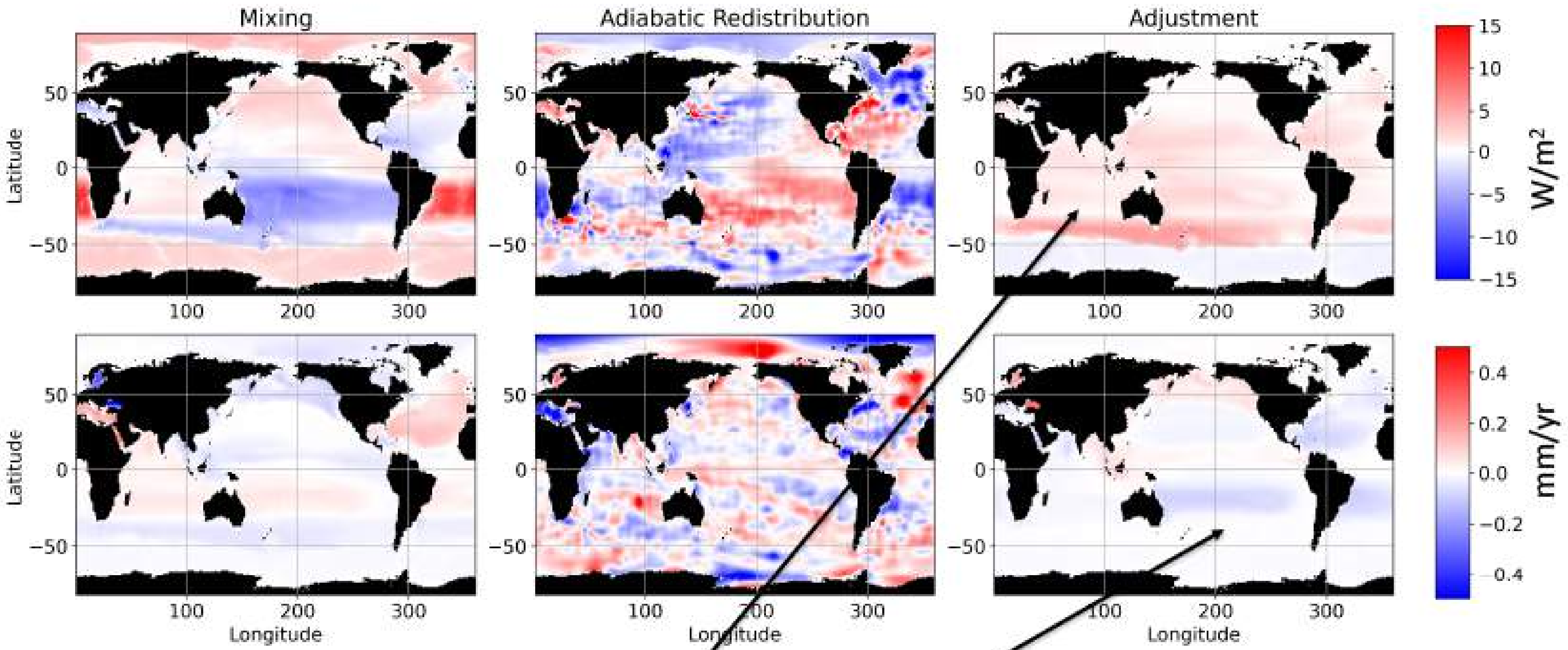
In *T-S* space, changes are constrained



If we know the changes in T and S and one flux, all remaining terms can be inferred.

This requires a (new?) type of 'transportation problem'
Instead of the Earth Mover's Distance we'd minimise the difference between the final state and mixtures of initial states. (Work in progress)

(Very) preliminary results using EN4 (2006-2017)



Smallest (rms) air sea flux that can plausibly explain change in water masses.

4. Changes in the volumetric T-S distribution.

Summary

1. Surface salinity pattern amplification-based estimates of water cycle change are influenced by warming and vary substantially.
2. Changes in the volumetric (*S*) distribution are robust and linked to water cycle change but do not give regional information.
3. The cold ocean is getting fresher and warm ocean is getting saltier suggesting a dramatic change in the poleward branch of the water cycle exceeding all CMIP6 models. (See Taimoor Sohail's poster!)
4. New optimal transport approaches may allow for the pattern of water cycle change to be inferred directly from changes in the volumetric *T-S* distribution regionally.