THE THERMOHALINE STREAM FUNCTION IN A CHANGING CLIMATE

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THE THERMOHALINE STREAM FUNCTION

REVEALING DIFFERENCES OF THE GLOBAL OCEAN CIRCULATION IN A CHANGING CLIMATE AT A GLANCE

Stockholm University

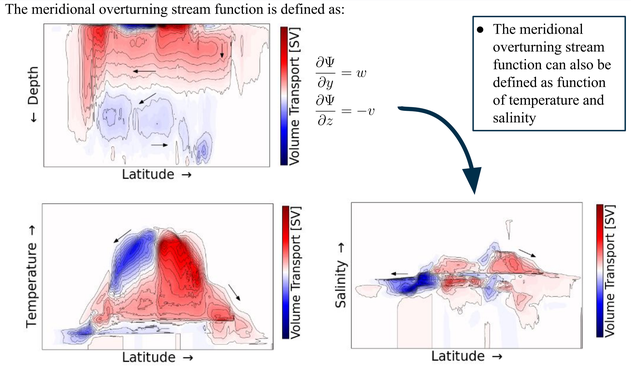
Bolin Centre for Climate Research

WATER MASS TRANSFORMATION (WMT) - FROM PHYSICAL SPACE TO TEMPERATURE - SALINITY SPACE

I INTRODUCTION - STREAM FUNCTIONS

- The meridional overturning stream function is defined as:

$$\frac{\partial \Psi}{\partial y} = w \qquad \frac{\partial \Psi}{\partial z} = -v$$



- The meridional overturning stream function can also be defined as function of temperature and salinity

- The **thermohaline stream function** can be used to study **water mass transformation** of the global ocean.

$$\frac{\partial \Psi}{\partial \theta} = -F^S \qquad \frac{\partial \Psi}{\partial S} = F^\theta$$

- Going from physical coordinates to temperature and salinity coordinates

MATHEMATICAL FORMULATION OF THE THERMOHALINE STREAM FUNCTION

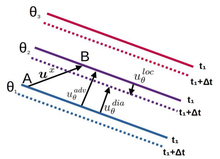
The thermohaline stream function is defined for a divergence-free vector field as:

$$\Psi(S', \theta') = \frac{1}{\Delta t} \int_{t_0}^{t_0+\Delta t} \int_V \delta\left[(S' - S)(\vec{x}, t)\right] \mu\left[\theta' - \theta(\vec{x}, t)\right] F^S d\vec{x} dt$$

with δ as the Dirac delta function to consider only fluxes where the salinity is equal to S' and μ as the Heaviside step function to integrate over all fluxes where the temperature is smaller than θ'. The absolute tendencies of salinity and temperature are defined as:

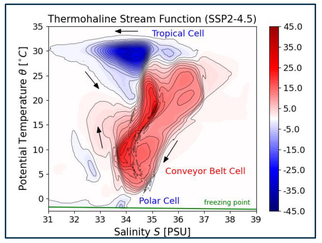
$$F^S = \frac{DS}{Dt} = \frac{\partial S}{\partial t} + \boldsymbol{u}\nabla S = u_S^{loc} + u_S^{adv} = u_S^{dia}$$

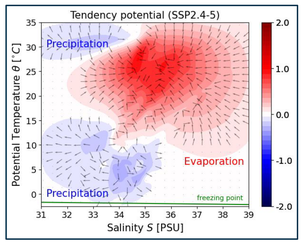
$$F^\theta = \frac{D\theta}{Dt} = \frac{\partial \theta}{\partial t} + \boldsymbol{u}\nabla\theta = u_\theta^{loc} + u_\theta^{adv} = u_\theta^{dia}$$



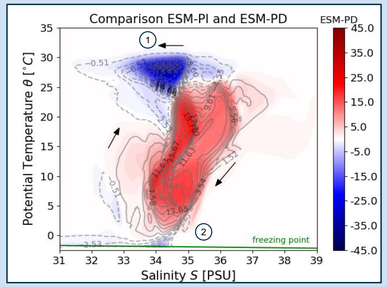
HELMHOLTZ DECOMPOSITION

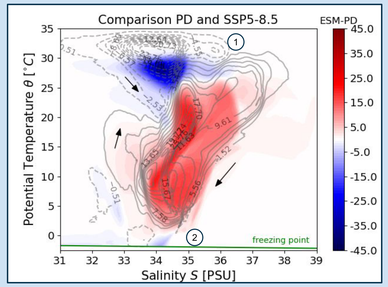
The vector field $\vec{F} = (F^S, F^\theta)$ is separated into a rotational (Stream function) and a divergent part (tendency potential) to ensure non-divergence for the stream function: $\vec{F} = \vec{F}_{rot} + \vec{F}_{div}$





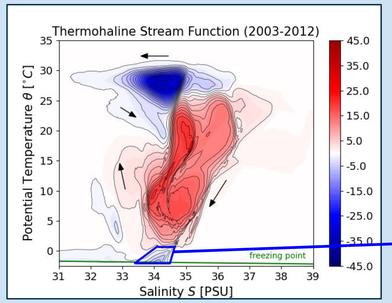
II CLIMATE SCENARIOS - EARTH SYSTEM MODEL (ESM)

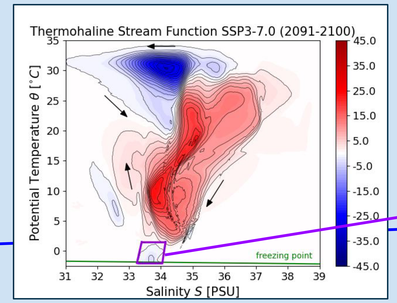




- Larger shift towards higher temperatures between present-day (PD) and SSP5-8.5 compared to the pre-industrial (PI) and present-day simulation. (1)
- This shift is larger at warmer compared to colder temperatures. (2)
- Water mass transformation orruces at a larger range of salinity in SSP5-8.5.

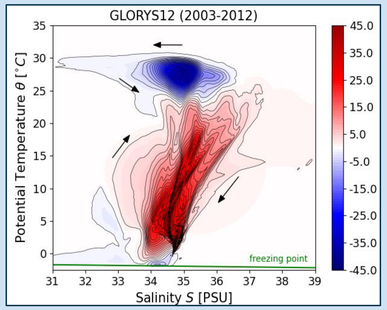
IV INVESTIGATING THE POLAR CELL IN ESM SIMULATIONS

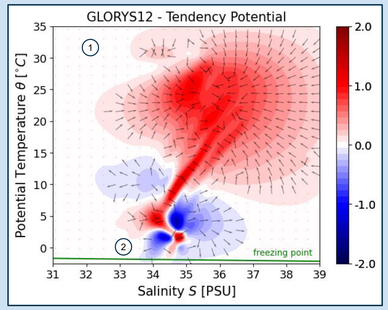




- Polar Cell is reduced in its magnitude and its salinity range in SSP3-7.0.
- Appearance of the Polar Cell at smaller salinities in SSP3-7.0.
- The extension of the Polar Cell reaches warmer temperatures in SSP3-7.0.

VI REANALYSIS DATA (GLORYS12)



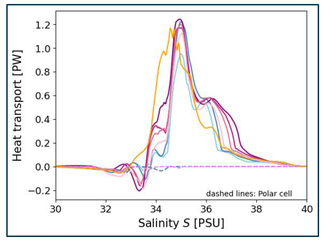


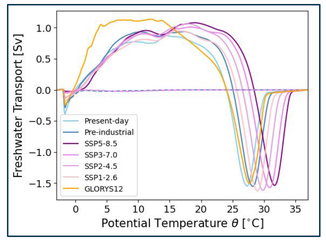
- Missing precipitation at fresh and warm water masses in GLORYS12. (1)
- Pronounced convergence and divergence at cold temperatures. (2)
- The magnitude of the thermohaline stream function is larger compared to the ESM simulations and is more structured.

CODE AVAILABILITY

The code for the thermohaline stream function computation is provided soon. →

III HEAT AND FRESHWATER TRANSPORT

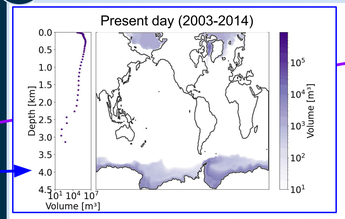


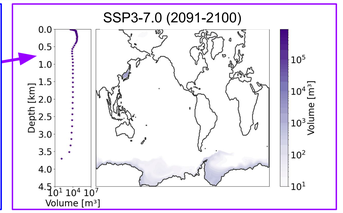


- Larger change of maximum between pre-industrial and present-day simulation than between present-day and scenarios.
- Heat transport in larger salinity range with increasing scenarios.
- Magnitude of heat transport in GLORYS12 comparable to ESM but at smaller salinities.

- Shift of fresh water transport towards higher temperatures in scenarios and decline in amplitude.
- Less fresh water transport in GLORYS12 compared to ESM simulations at high temperatures but more at low temperatures.

V DECOMPOSITION AND REMAPPING OF THE POLAR CELL





- Water masses of the polar cell are reduced in their geographical extension.
- Volume of water masses corresponding to the polar cell properties is reduced.
- Future work: More detailed analyses.

VII OPEN QUESTIONS AND FUTURE WORK

- Which role does melting and freezing processes play for the polar cell and its changes in climate scenarios?
- Why is the Potential of the ocean reanalysis data so different from the ESM?

DATA DESCRIPTION

This study uses the following data sets:

- CMIP6 Earth System Model (ESM) using EC-Earth-3 for pre-industrial (PI) (1851-1860), present-day (PD) (2003-2012) and the climate scenarios SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5 (2091-2100) on a 1° horizontal resolution Arakawa C-grid, 75 vertical z-coordinate levels.
- Ocean reanalysis data (MOI GLORYS12) on a 1/12° horizontal resolution Arakawa C-grid and 50 vertical z-coordinate levels containing data assimilation.

Analysed data needs to have global 3-D fields of velocities (or fluxes), cell thicknesses and information about the bathymetrie and a grid description.

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