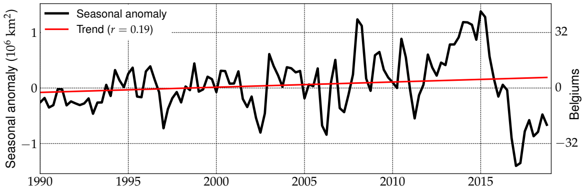
Investigating the role of the ocean heat content variability in the 2016 Antarctic sea ice event

C. Pelletier H. Goosse F. Klein

ELI/TECLIM, UCLouvain (Belgium)

IGS Sea Ice Symposium
Winnipeg, August 22^{nd} 2019

Recent Antarctic sea ice evolution



Antarctic Sea ice extent seasonal anomalies from observations (NSIDC).

- Late 20^{th} - early 21^{st} century up to 2016: **positive trend** in Antarctic sea ice extent;

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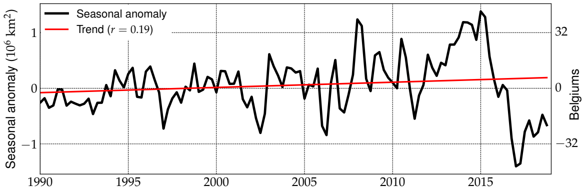

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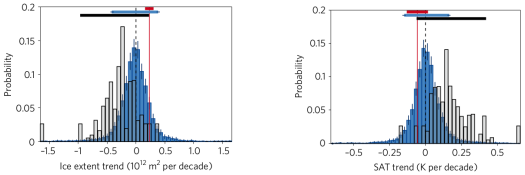

Only a few CMIP5 ensemble members represent positive (negative) trend in sea ice extent (surface air temperature).

- Late 20$^{\text{th}}$ - early 21$^{\text{st}}$ century up to 2016: **positive trend** in Antarctic sea ice extent;
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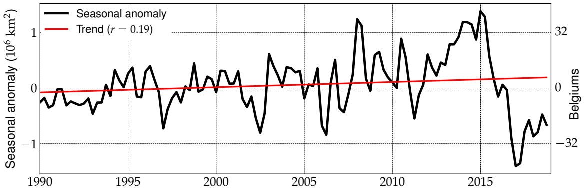

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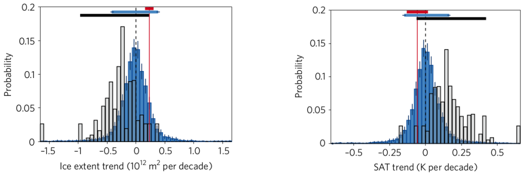

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- **Poorly caught** by CMIP models (sparse observational data, ice shelf representations, high natural variability...)
- Suddent drop post-2016;

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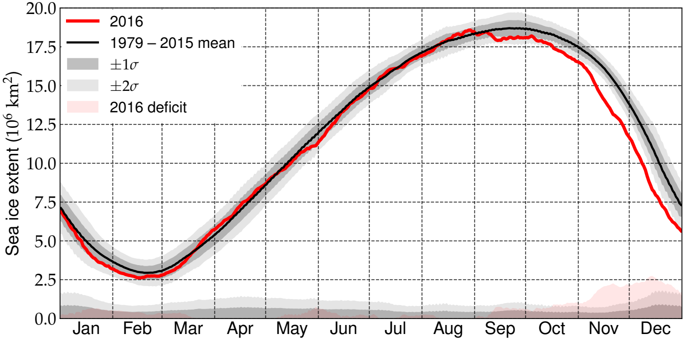
Observations of sea ice extent in 2016



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- Below average **minimum** in February

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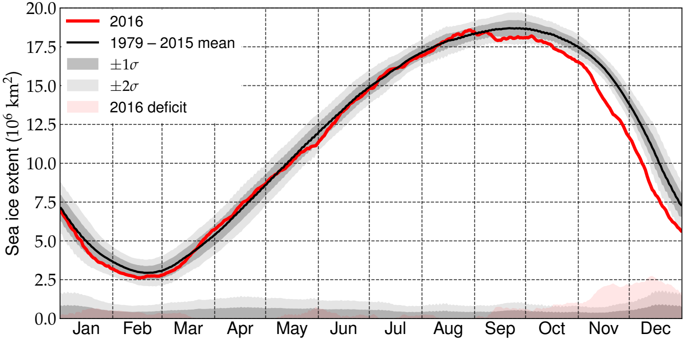
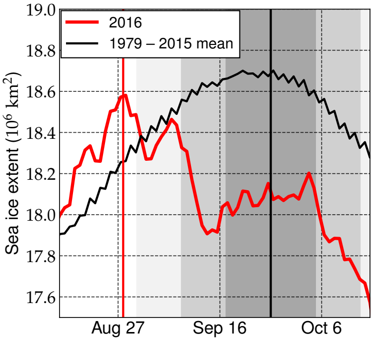
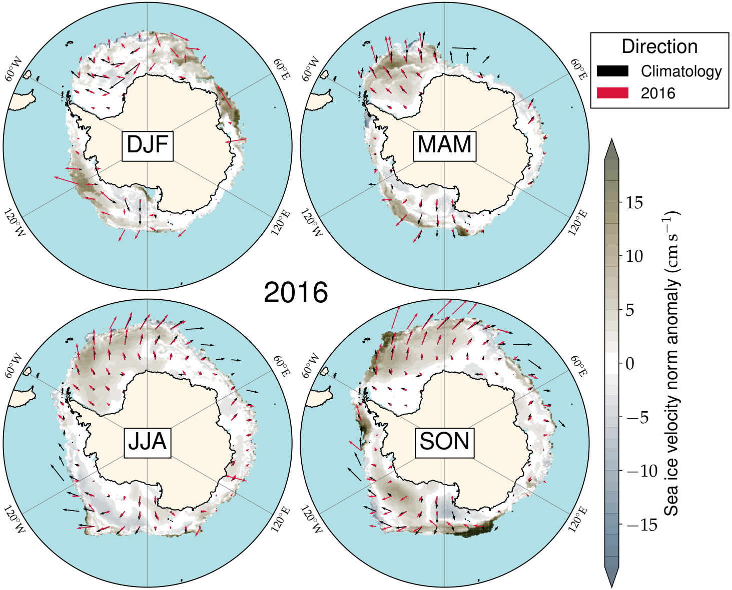




- 2016: regular year up to winter.
- Below average **minimum** in February
- **Early and low maximum** in August 2016
- Record **springtime retreat** in 2016

Data: NSIDC (obs.)

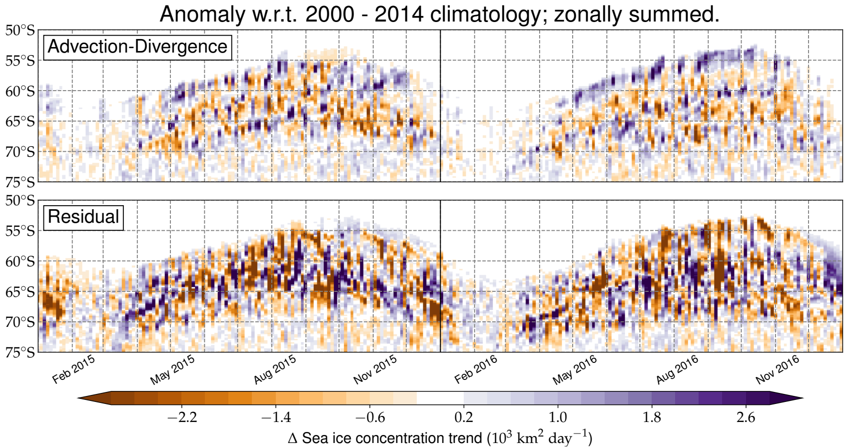
Sea ice velocity anomalies in 2016



Sea ice velocity norm (colormap) and direction (arrows) anomalies. Observational data taken from NSIDC-0116.

- Sea ice dynamics globally more intense than usual in 2016;
- Sustained northwards advection in the Weddell sea from the freezing season on;
- Less intense but still significant in the Ross sea.

Advective and thermodynamical trends in 2015/2016



Advection-divergence and residual sea ice concentration evolution from NSIDC-G0220 and NSIDC-0116. Method taken from Holland et al. *(2011).*

- 2016 freeze season: northwards advection.
- No perceivable differences on thermo-dynamics.

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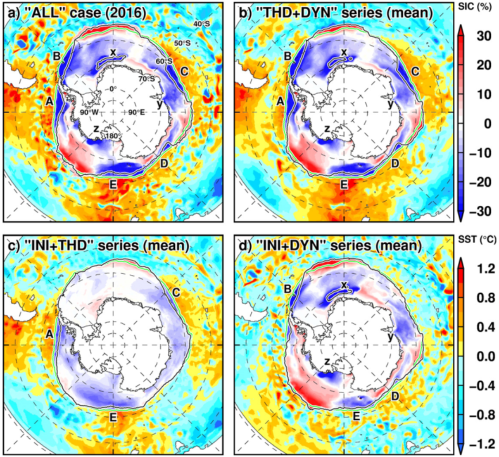
Separating different contributions leading to the 2016 events

Kusahara et al. (*Environ. Res. Lett.*, 2018)

Ensemble re-runs of 2016 aiming at separating contributions from:

1. Thermodynamical surface forcings (heat fluxes)
2. Dynamical surface forcings (wind stress)
3. Oceanic conditions



2016 sea ice concentration and SST anomalies for the regular year (a), and ensemble perturbations on: (b) initial Jan. 2016 ocean conditions; (c) wind forcings; (d) thermodynamical forcings.

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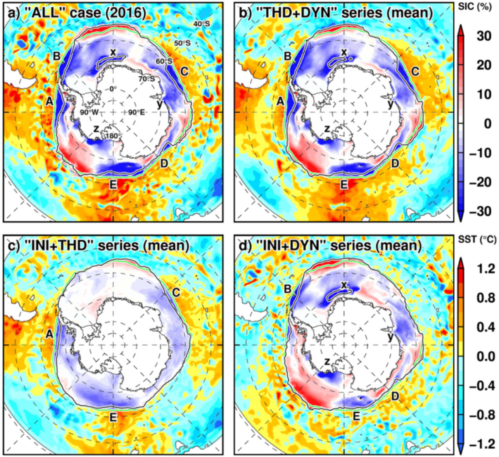

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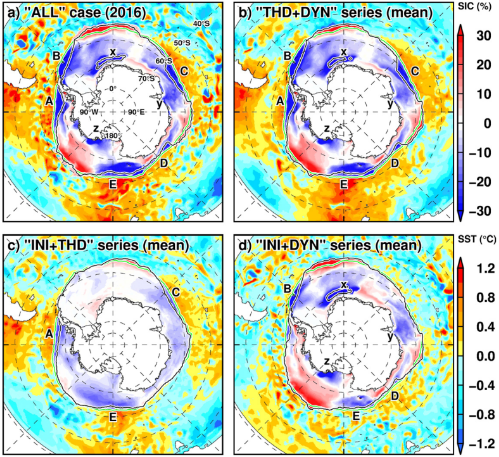
Investigate the potentially more predictable **ocean pre-conditioning**'s role in the 2016 events.



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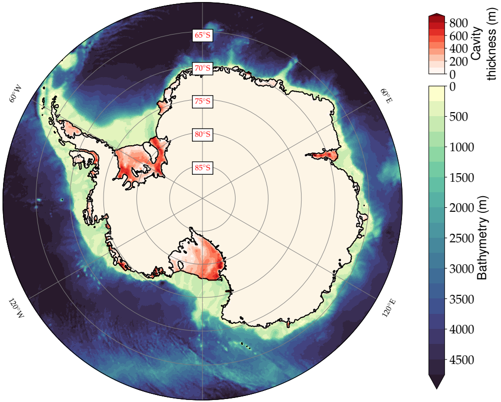
Configuration description

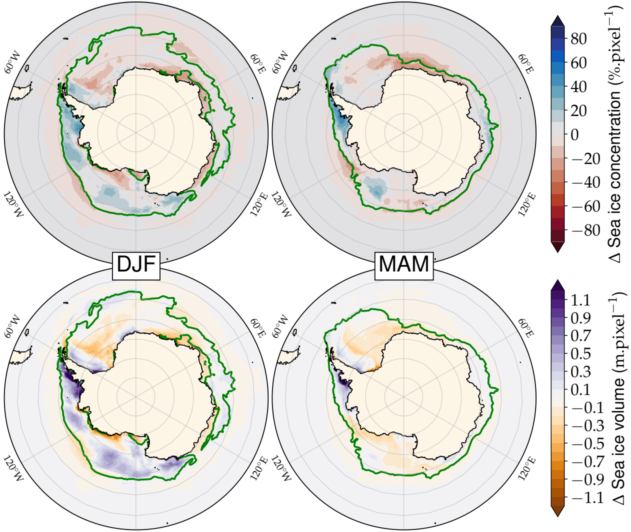
SO025: new **NEMO-LIM3** configuration

- eORCA025 grid ($1/4°$, 75 levels) cut at $30°S$;
- Ice shelf cavity open to ocean circulation and dynamical melt;
- ERA-Int. reanalysis as atmosphere forcings;
- BedMachine2 & ETOPO1 bathymetry.
- Within the context of the Belgian **PARAMOUR** project (decadal predictability in 5-component coupled models). Still under development



Configuration bathymetry and ice shelf cavities around the Antarctic continent.

Comparing spatial sea ice concentration and volume 2016 anomalies



SO025 simulated seasonal sea ice concentration and volume 2016 anomalies (extent in green contour).

Regular summer and autumn.

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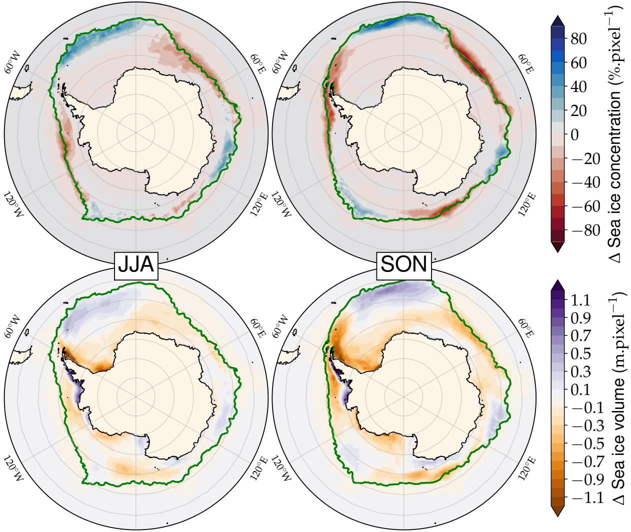

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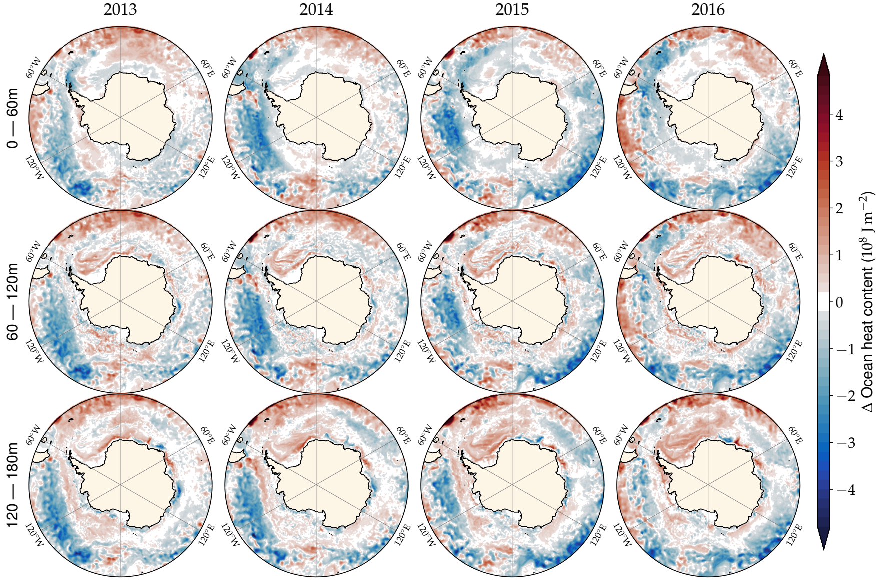
Regular summer and autumn.

Winter and spring:

- Matching concentration/volume patterns in the MIZ;
- Increased melt in the vicinity of the **Antarctic peninsula**;
- Strong **volume anomaly** in the Weddell sea without noticeable concentration anomaly.

Ocean heat content anomaly spatial distribution



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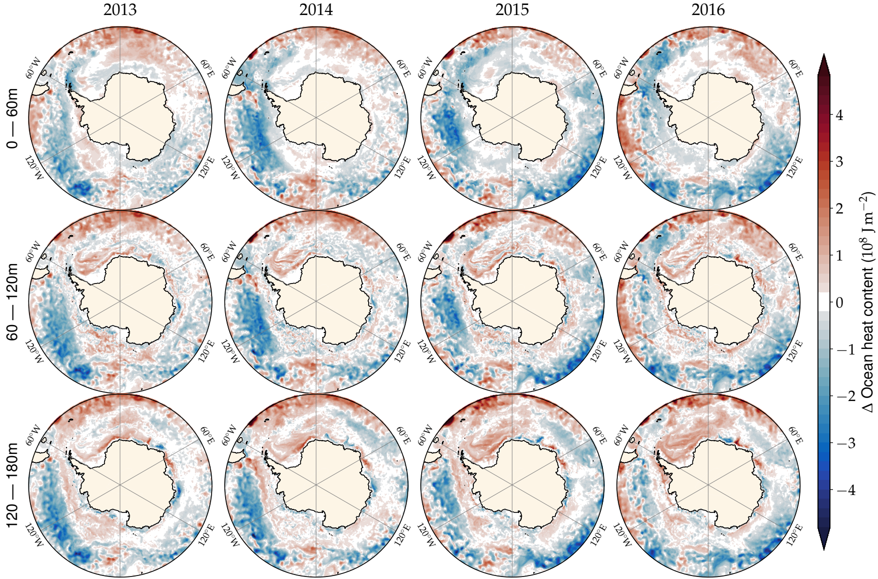
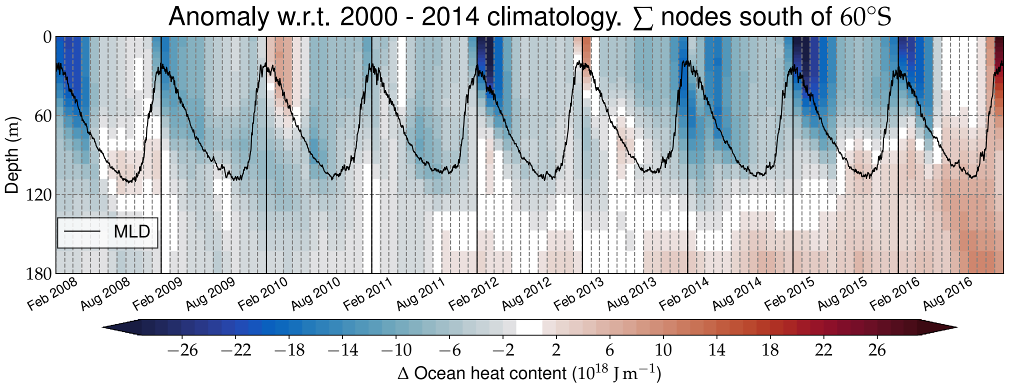


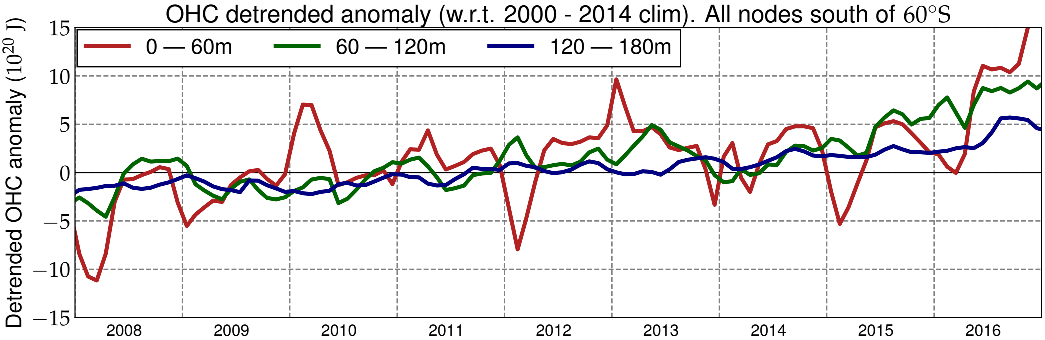
- The sea ice cover constrains heat storage in upper layers;
- No clear signal above 60m;
- 120 — 180m: significant heat anomaly in the Weddell sea.

Ocean heat content vertical distribution



- Shift between negative and positive surface anomaly in 2016;
- Pluri-annual, persistent ocean heat content anomaly developing below the winter MLD from 2013.

Is it model drift?



Simulated detrended ocean heat content anomaly (ref. 2000 - 2014) south of 60°S.

- Longer-term, deeper trend is **not** 1st-order model drift;
- Lower layer anomaly significant in terms of **standard deviation**;
- **Uninterrupted** positive bias from 2013 on at 120 – 180m;
- 2016: **generalized** heating in mean above 180m.

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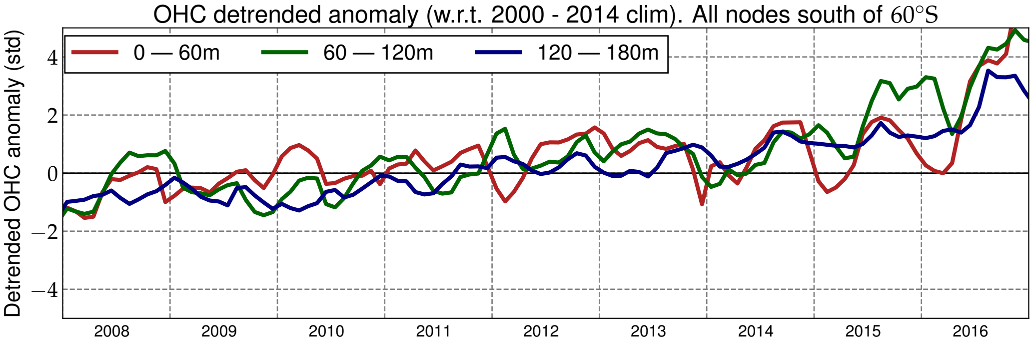

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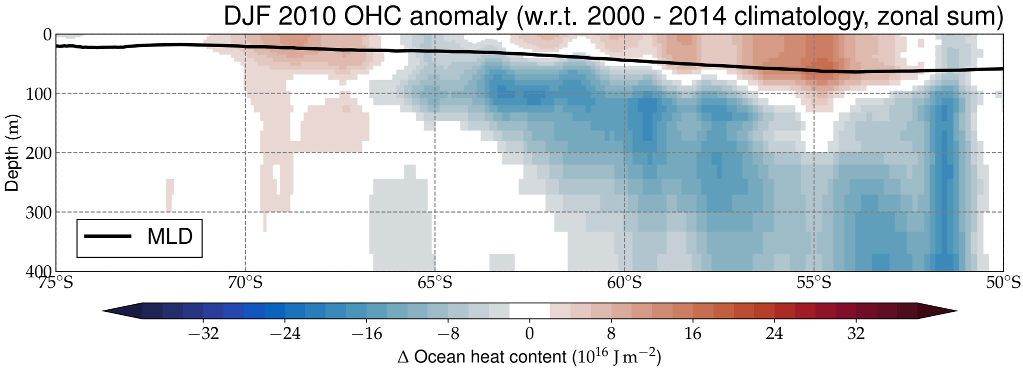

Simulated zonally-summed ocean heat content anomaly (ref. 2000 - 2014).

- Anomaly is located **above the continental shelf**;
- Regularly reaches **MLD level** from 2010 on; progressively diffused upwards, reaching the surface in 2016;
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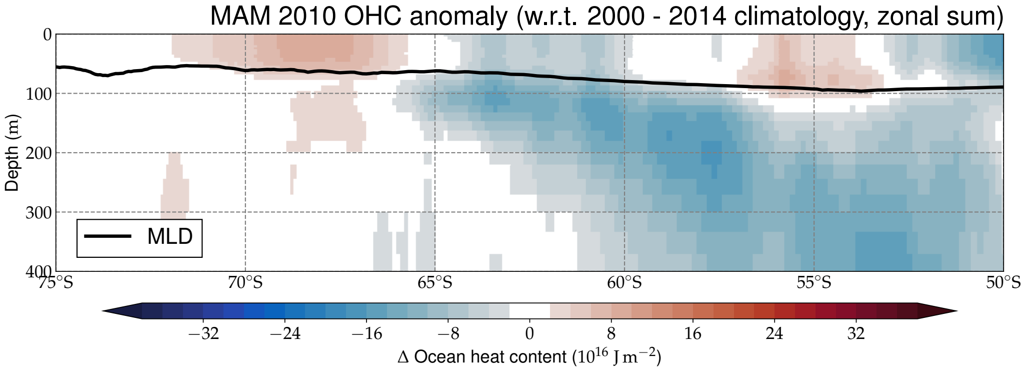

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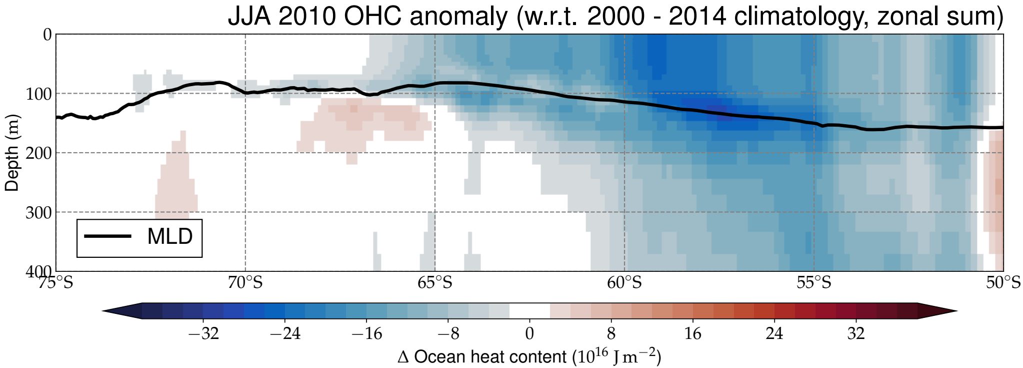

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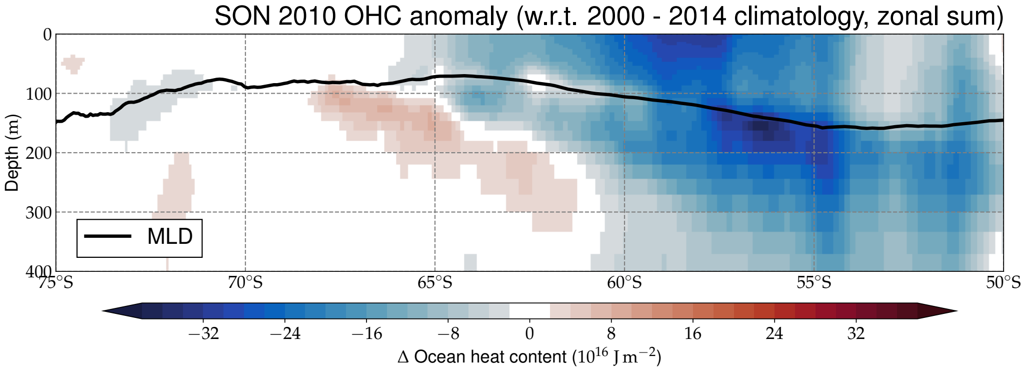

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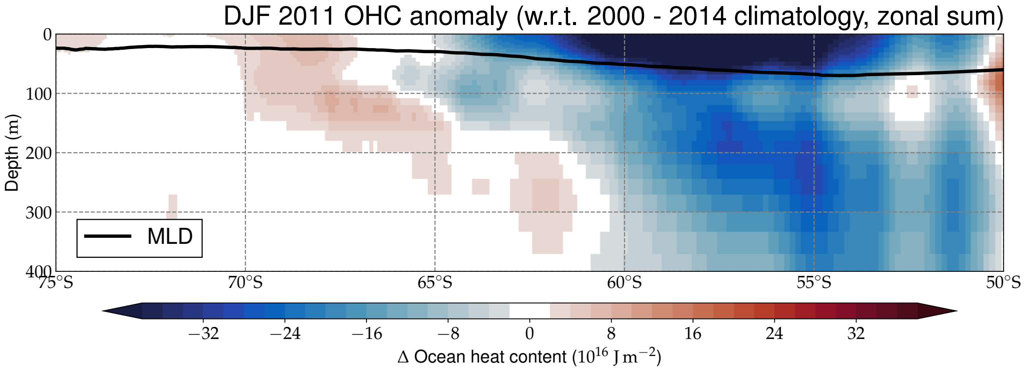

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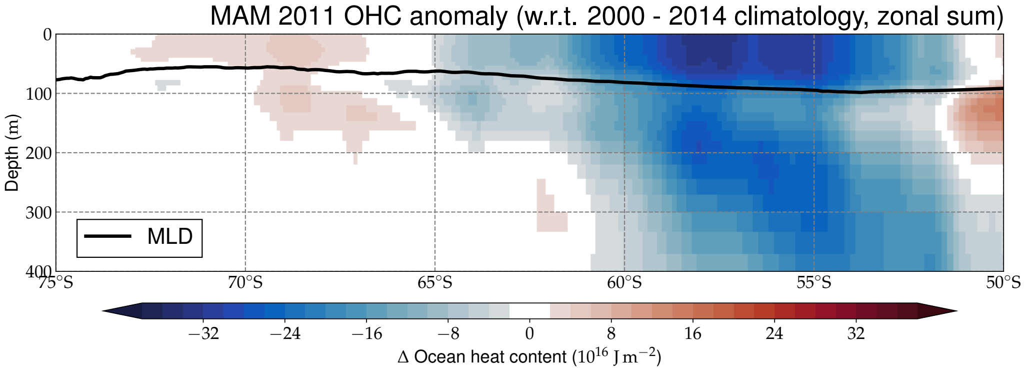

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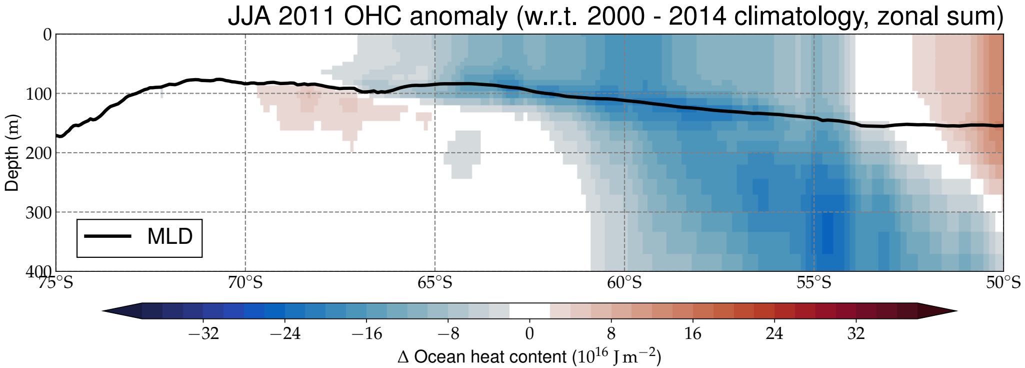

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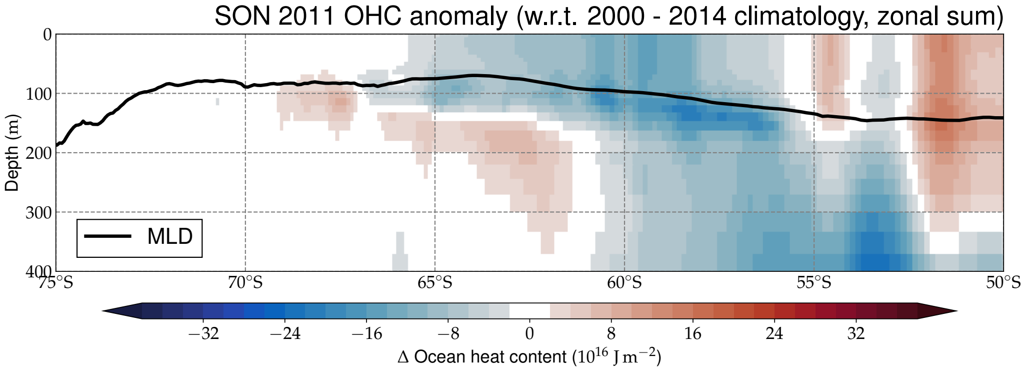

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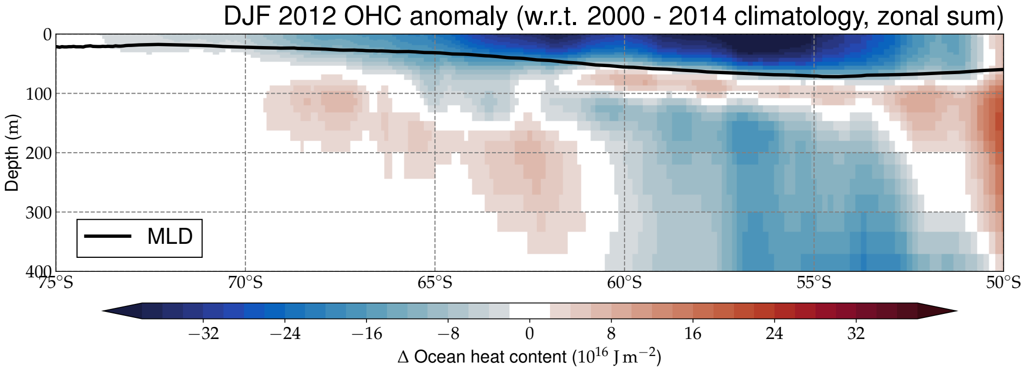

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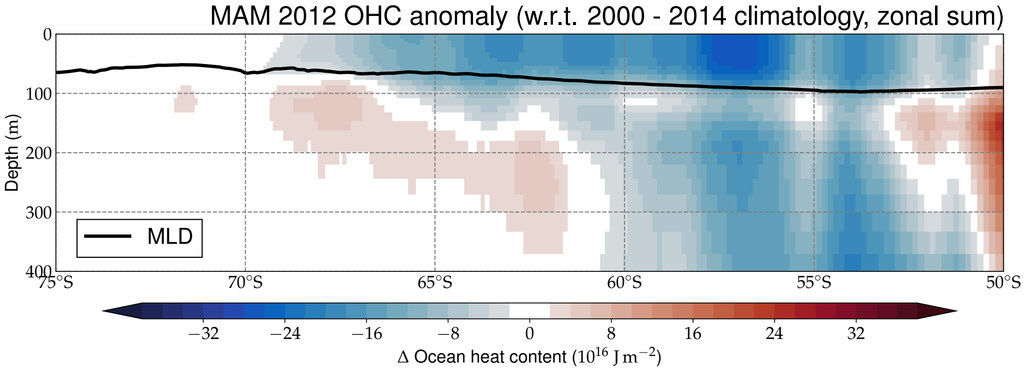

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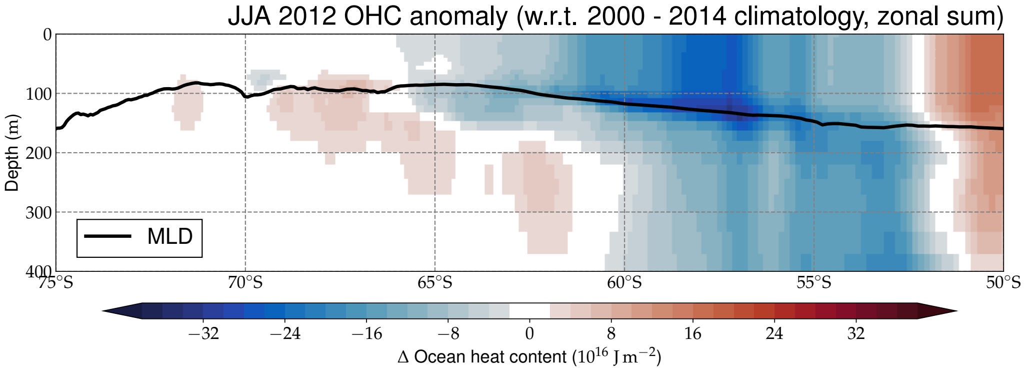

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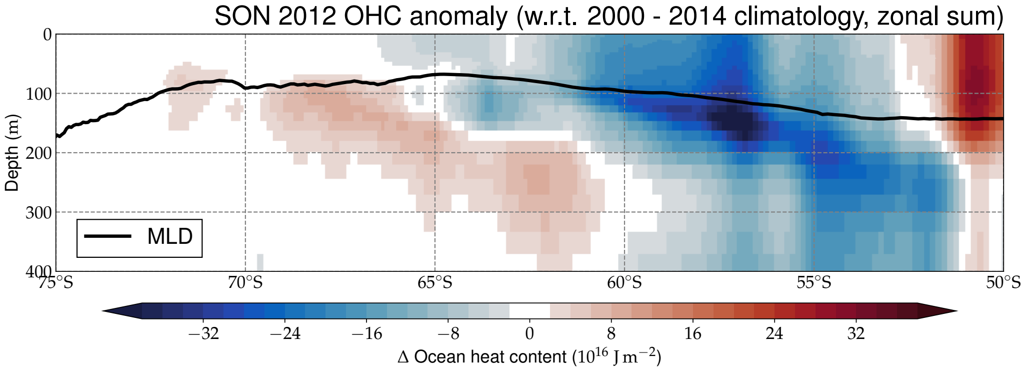

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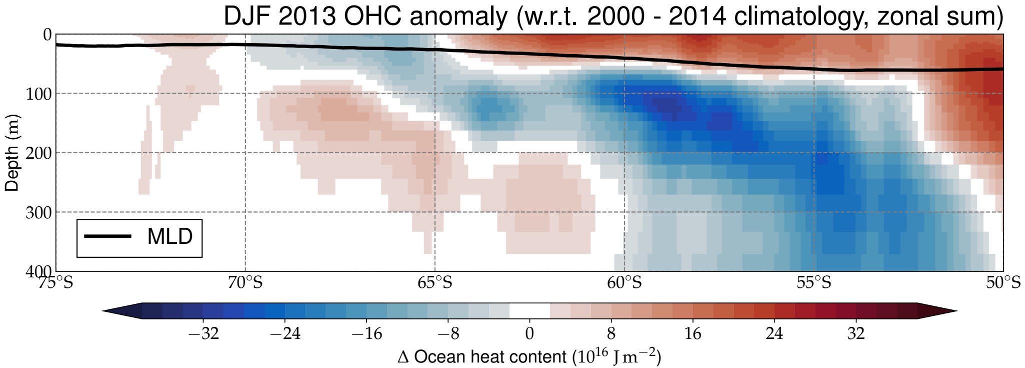

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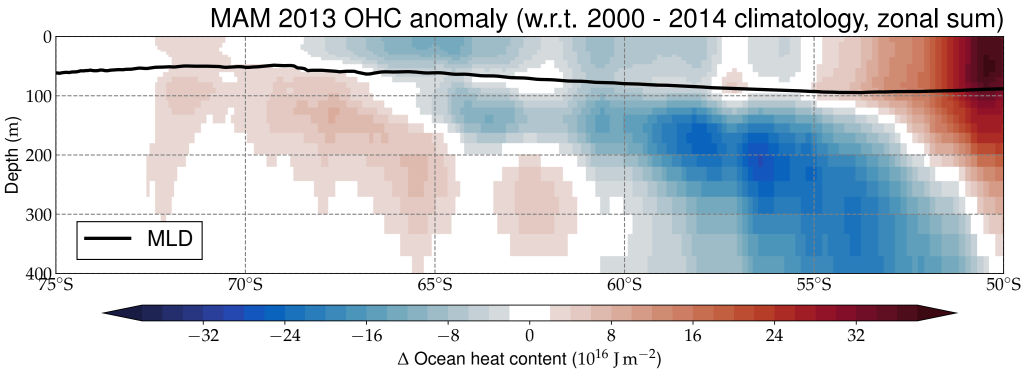

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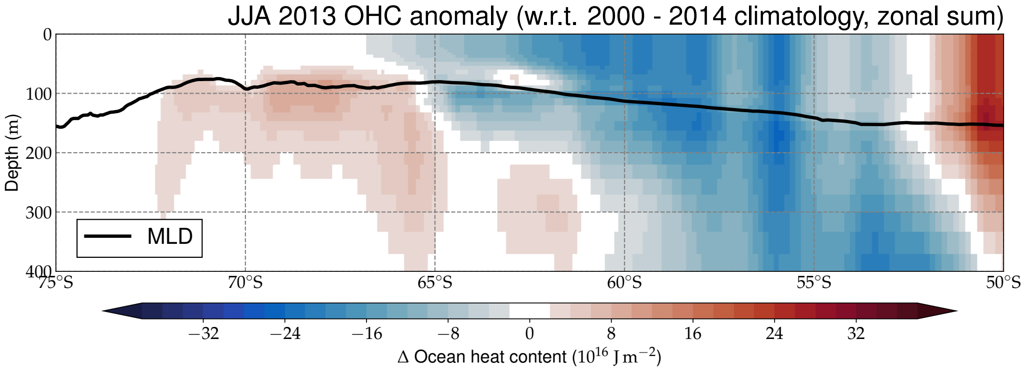

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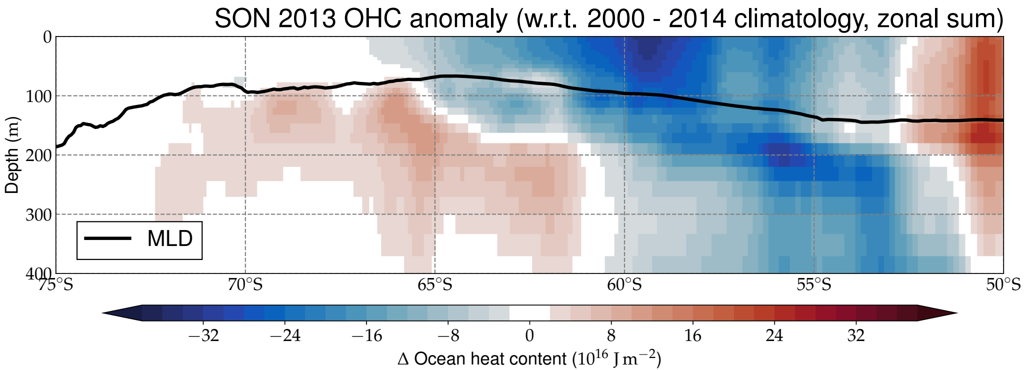

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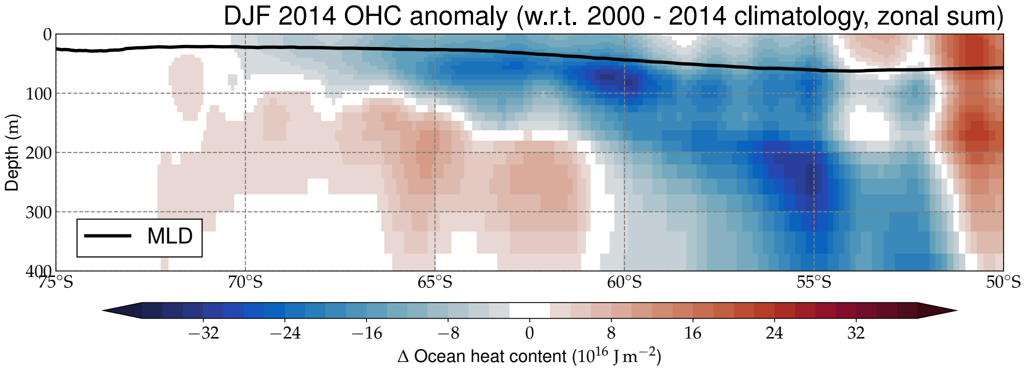

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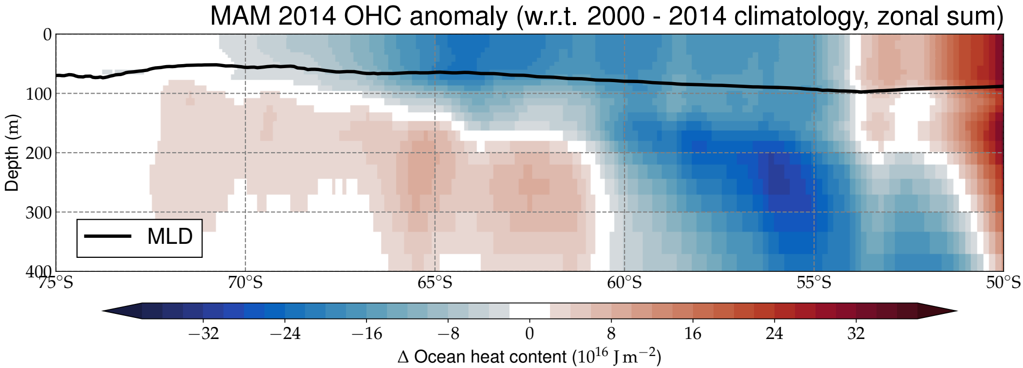

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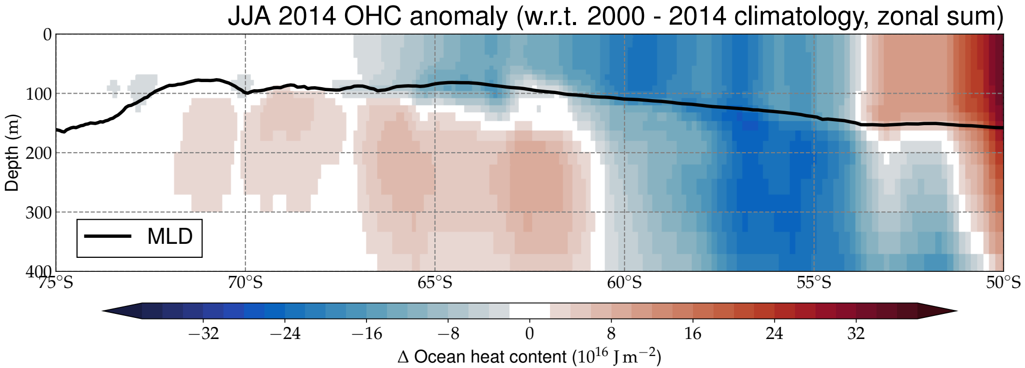

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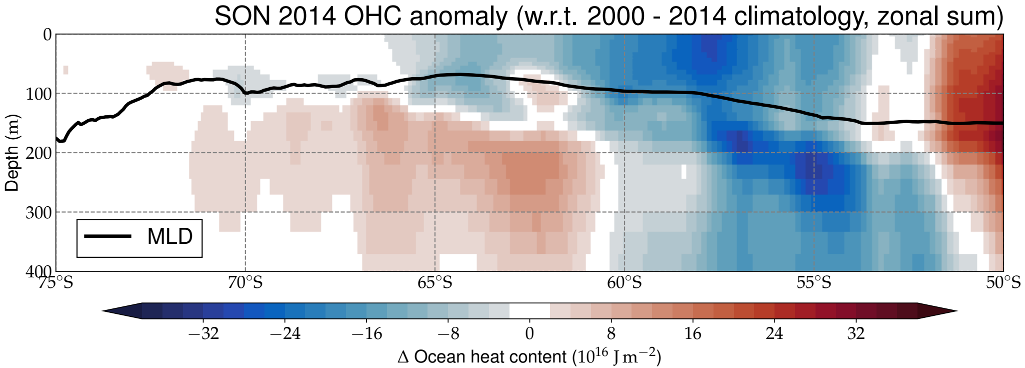

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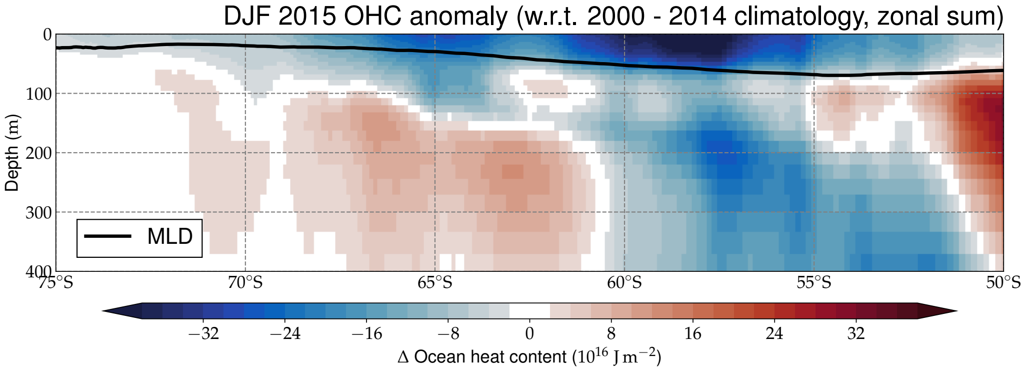

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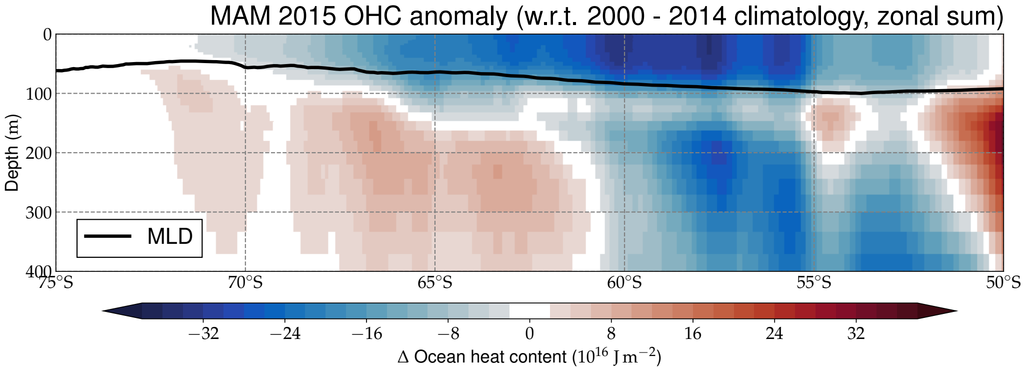

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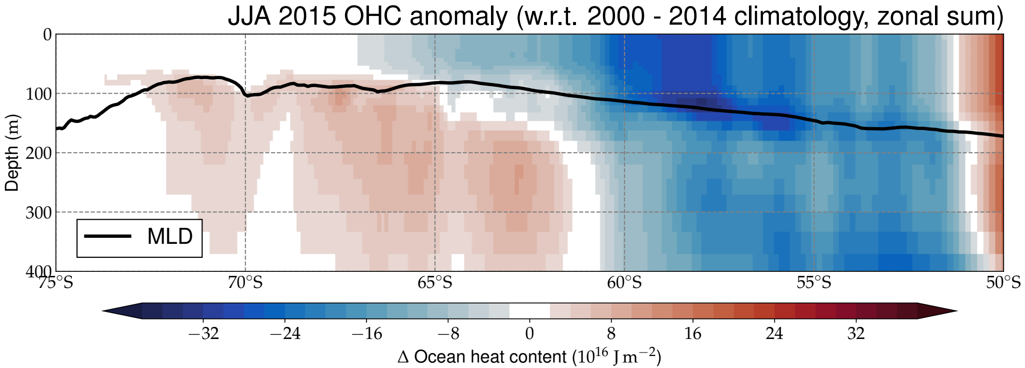

Simulated zonally-summed ocean heat content anomaly (ref. 2000 - 2014).

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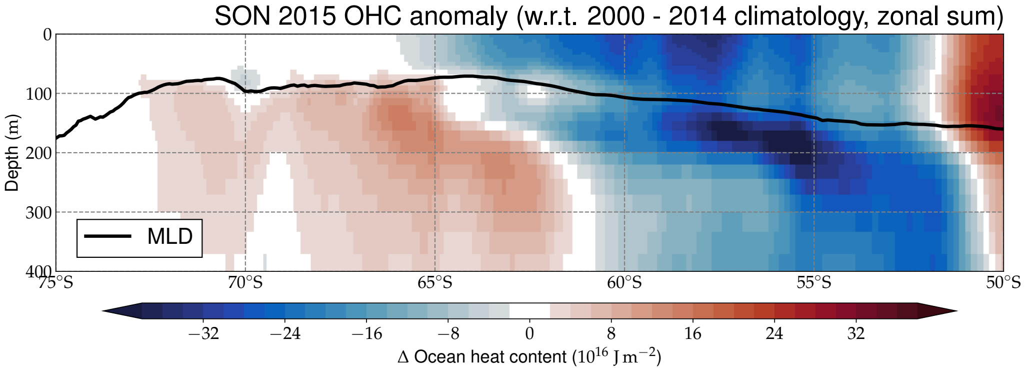

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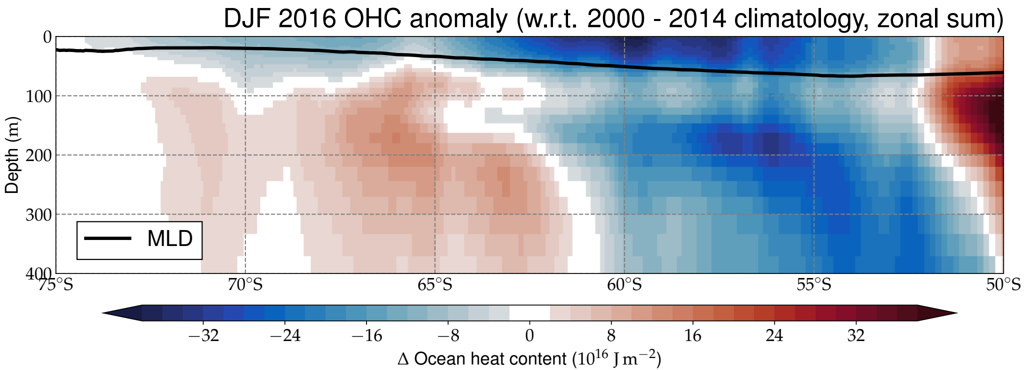

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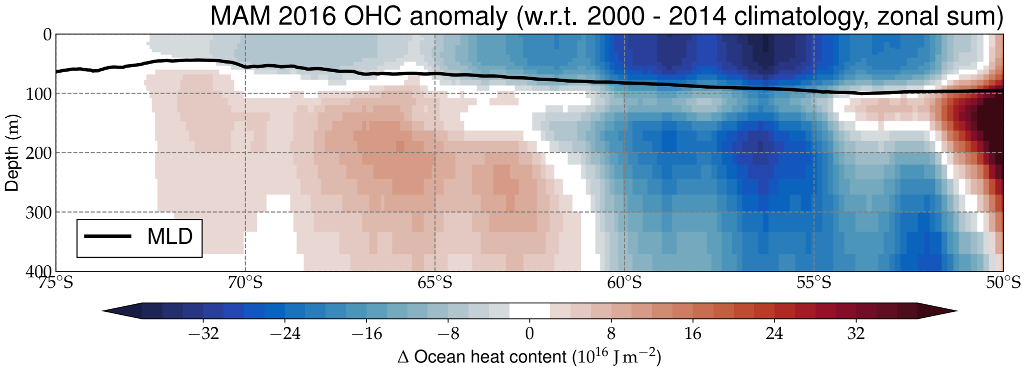

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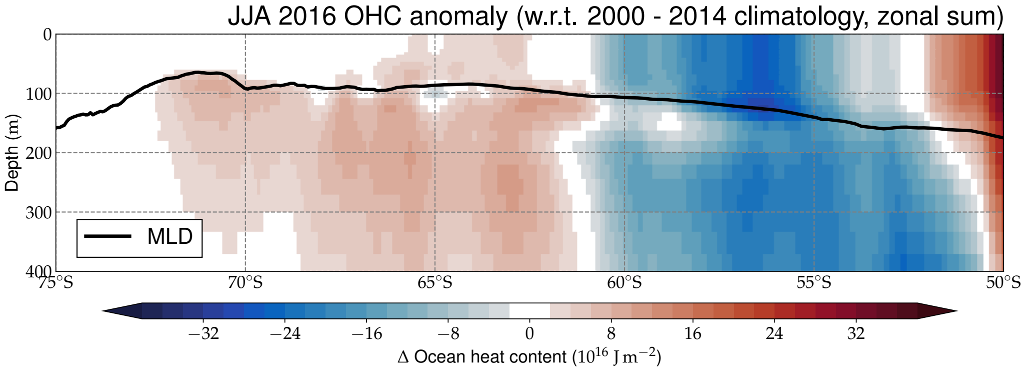

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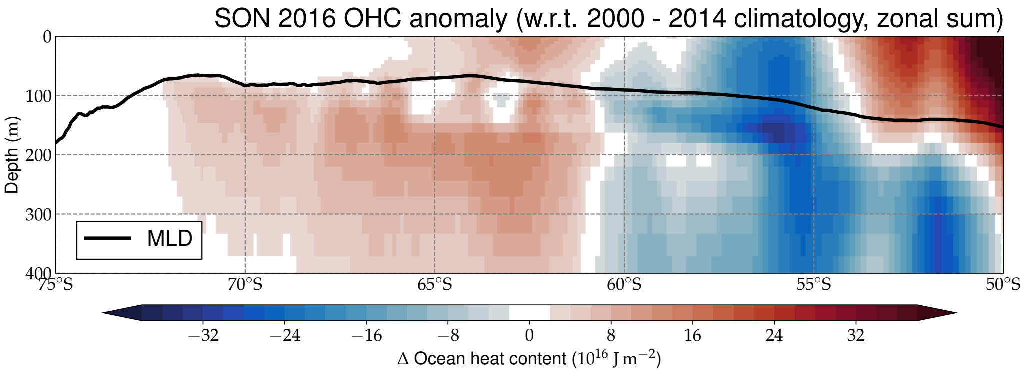

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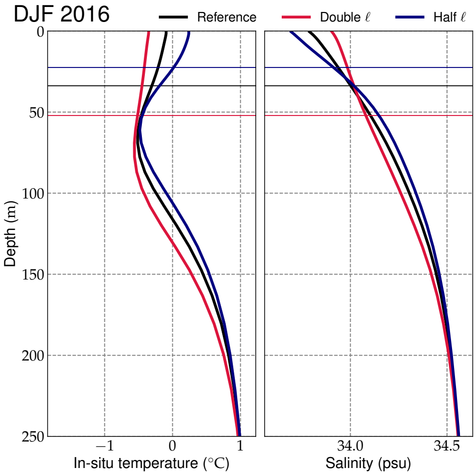

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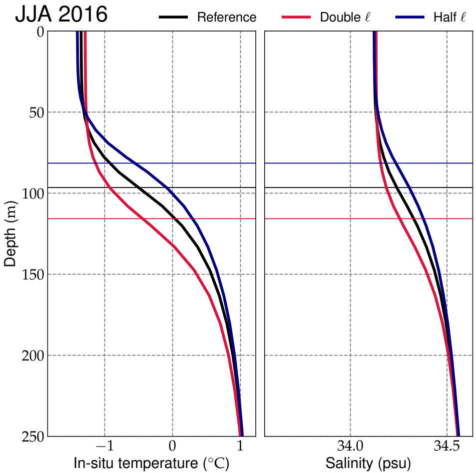

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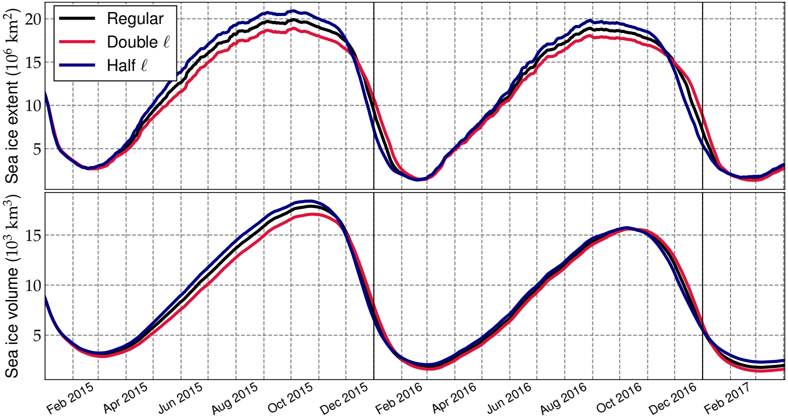
Late-freezing season: small yet perceivable bias on surface temperature.

Perturbated mixing almost immediately yields ***strong & persistent below-MLD biases****.*

Seasonal impact of perturbated mixing on sea ice



2015-2016 Antarctic sea ice extent and total volume for reference and perturbated simulations.

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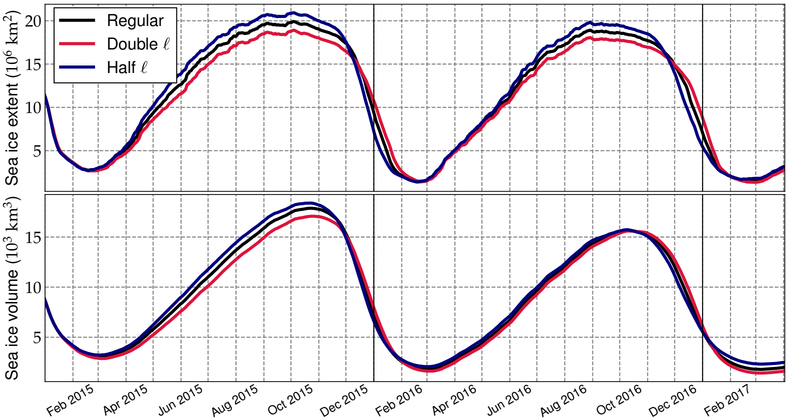


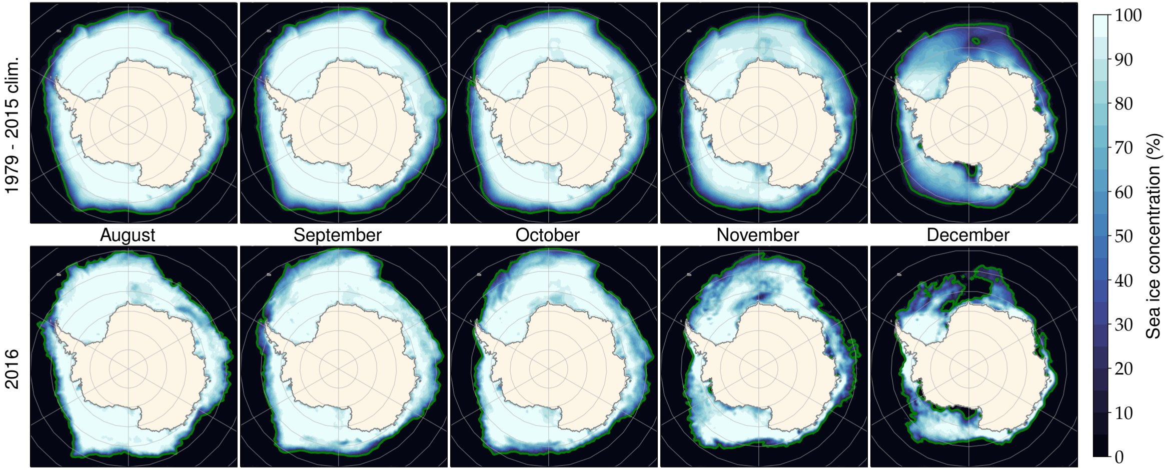
2015-2016 Antarctic sea ice extent and total volume for reference and perturbated simulations.

- **Maximum sea ice cover**: more mixing $\Rightarrow$ warmer surface water during freezing months;
- **Springtime retreat speed** acts as a "regulator", bringing back sea ice extent to atmosphere forcing-induced minimum.

Summary and conclusions

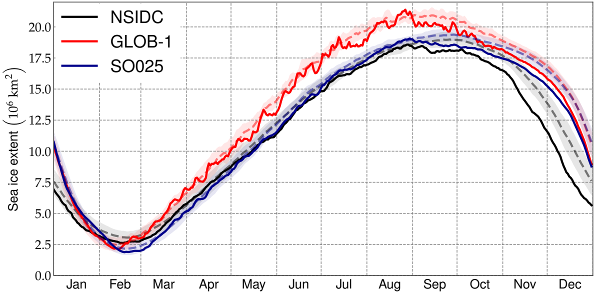
- **Anomalous winds** and atmosphere heat fluxes have played a crucial role in **triggering** and **scaling the amplitude** of the 2016 events, through sea ice advection & surface melt;
- However, **pluriannual mid-depth heating** brought up to the surface during winter may have impacted the freezing season, leading to the low August maximum;
- Heat anomaly most probably sustained by surface anomalies progressively **stored** at winter mid layer depths through **mixing**;
- **Sea ice volume** diagnoses and measurements are important and could lead to seasonal predictability (e.g. Weddell sea in 2016);
- Strongest anomalies located in the Weddell sea, which harbor several **large ice shelves**.

2016 spatial sea ice evolution

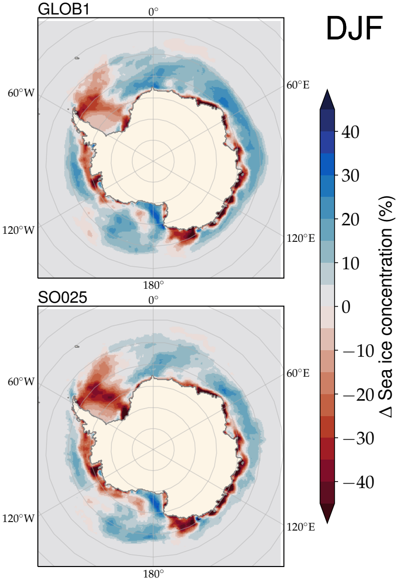


Data: NSIDC-G02202 (obs.)

Sea ice extent evaluation



2016 (full lines), mean (dashed lines) and ±1STD (shades) of the SIE on observations (NSIDC), a previous low-res (GLOB-1) and our higher-res (SO025) simulations.



- Slight SO025 improvement compared with GLOB1
- Less spurious variability
- Better catch of the 2016 maximum
- Still too much amplitude and melt biases

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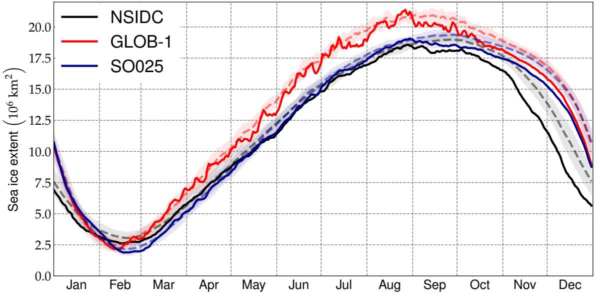

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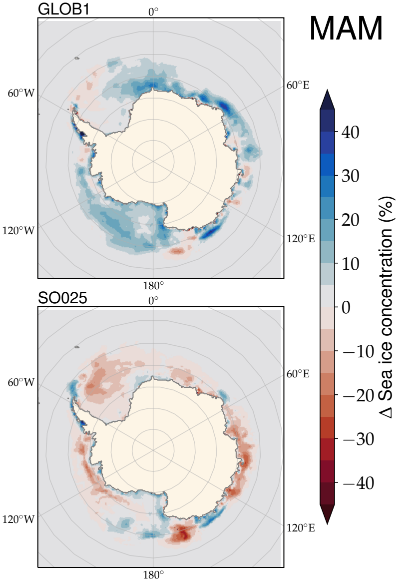

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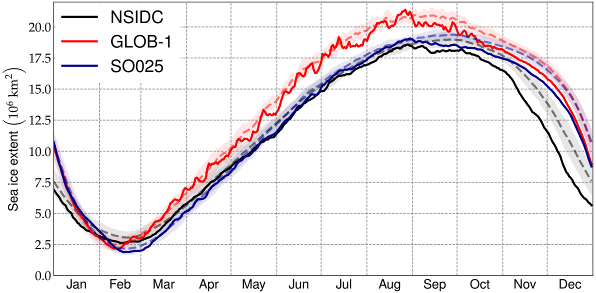

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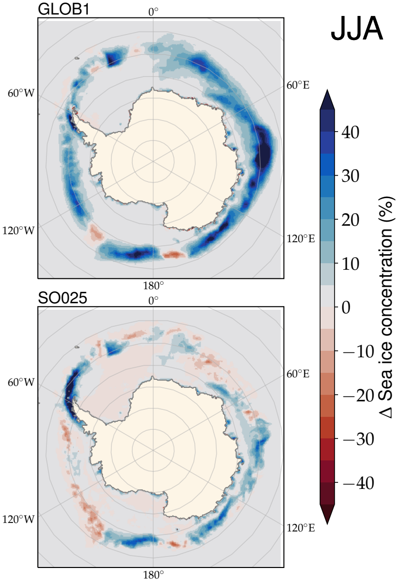

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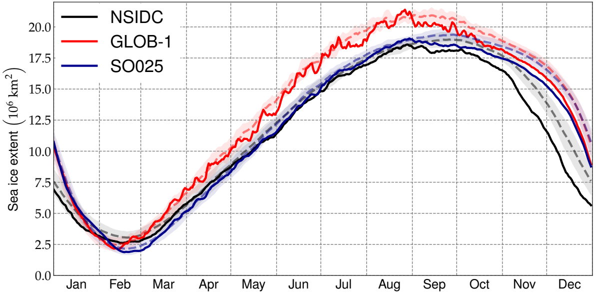

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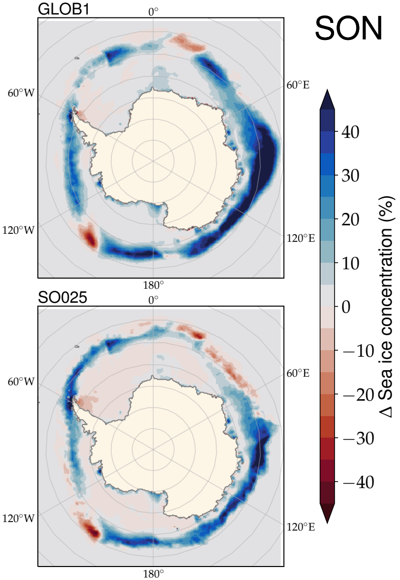
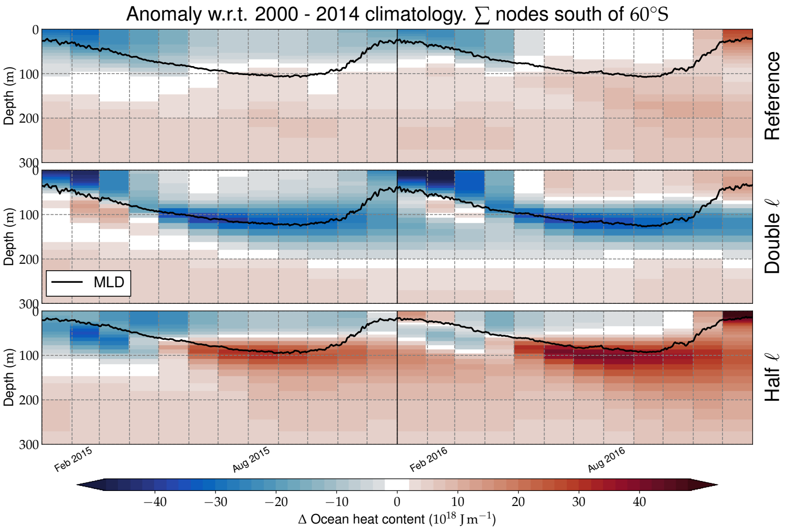


Ocean heat content response to perturbated turbulent mixing



2015 - 2016 ocean heat content anomaly vertical distribution south of 60°S for the reference and perturbated simulations.

- Mixing
-