Investigating the 2016 record Antarctic sea ice spring retreat

C. Pelletier H. Goosse F. Klein

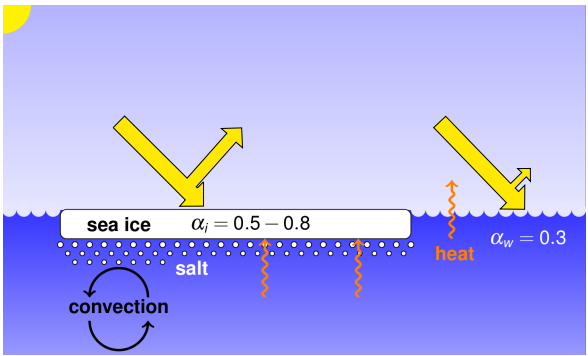
ELI/TECLIM, UCLouvain

Polar oceans facing change
Liège, May 8^{th} 2019

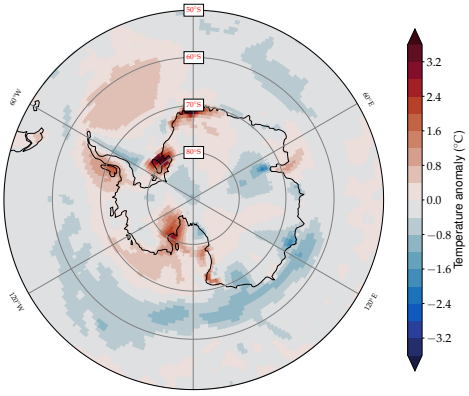
UCLouvain

Role of sea ice on climate system

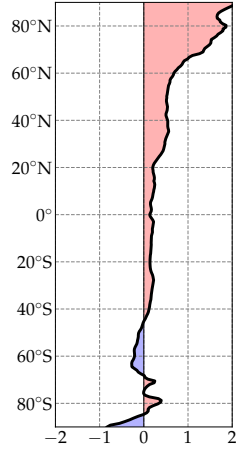
- Acts as a **lid** between the ocean and atmosphere;
- Enhanced/damped **air - sea fluxes** upon melting/freezing;
- **Low albedo** compared to open water (positive feedback upon melting);
- Driving **freshwater fluxes** at the surface (brine rejection or freshwater release).



Antarctica in a changing climate

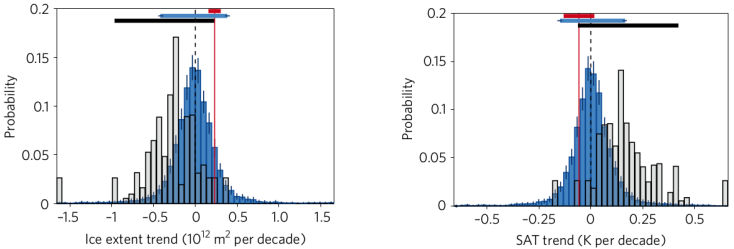


- Climate change **amplification** in polar oceans.
- Last decades: Antarctica is getting **colder**.
- **Heterogeneous** space pattern.



Map: mean 2m temperature anomalies between 1979-1997 and 1998-2017 from the ERA-Interim reanalysis in Antarctica. Plot: same, zonally averaged and at all latitudes.

Climate model representations of recent Antarctic climate changes



Bar diagrams: Antarctic sea ice extent and surface air temperature trends in CMIP5 pre-industrial (pre-1850 emissions, blue) and historical runs (1979 - 2015, grey); horizontal bars represent 5 - 95% range of simulations. Observations in red (horizontal red bars represent 90% confidence interval). *Jones et al. 2016*

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

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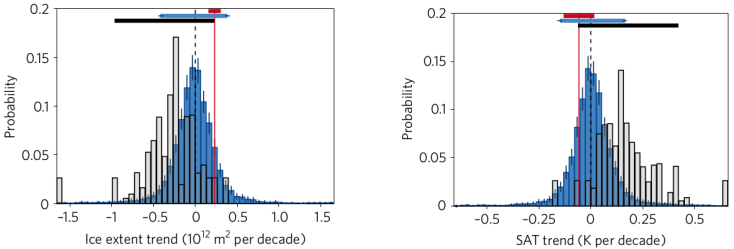

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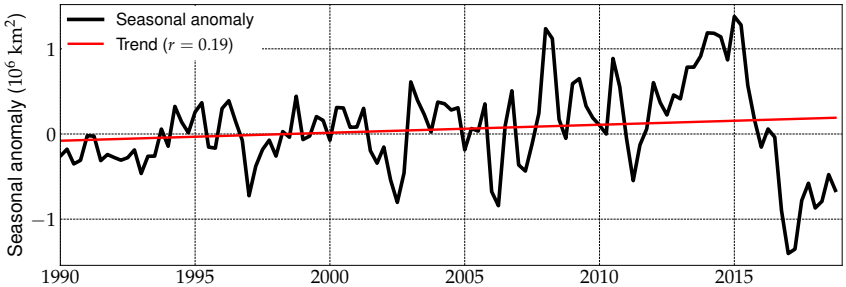
- Sparse **observational data**;
- Unrepresented complex climate sub-component **feedback**;
- **Freshwater input** from continental ice not well constrained.

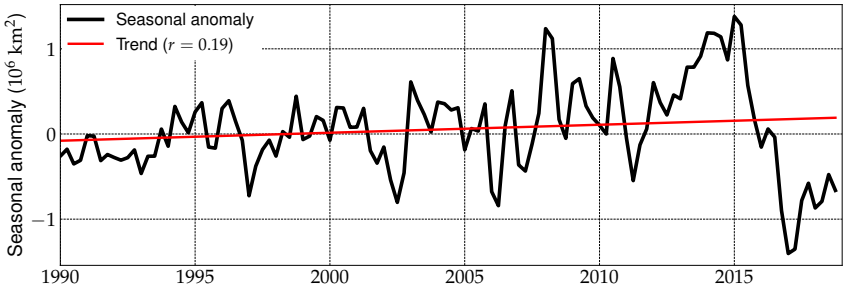
Outline

Sea ice extent evolution



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

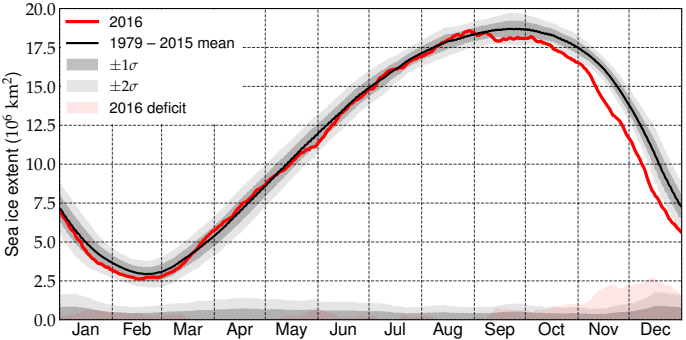
Sea ice extent evolution

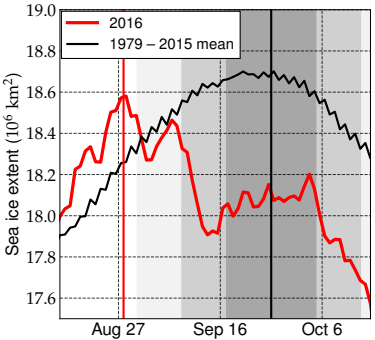


Sea ice extent seasonal anomalies from satellite observations (NSIDC).

- Large interannual and decadal **variability**
- Statistically significative **positive trend** over last few decades
- Suddent and sustained **drop** post-2016

Observations of sea ice extent in 2016

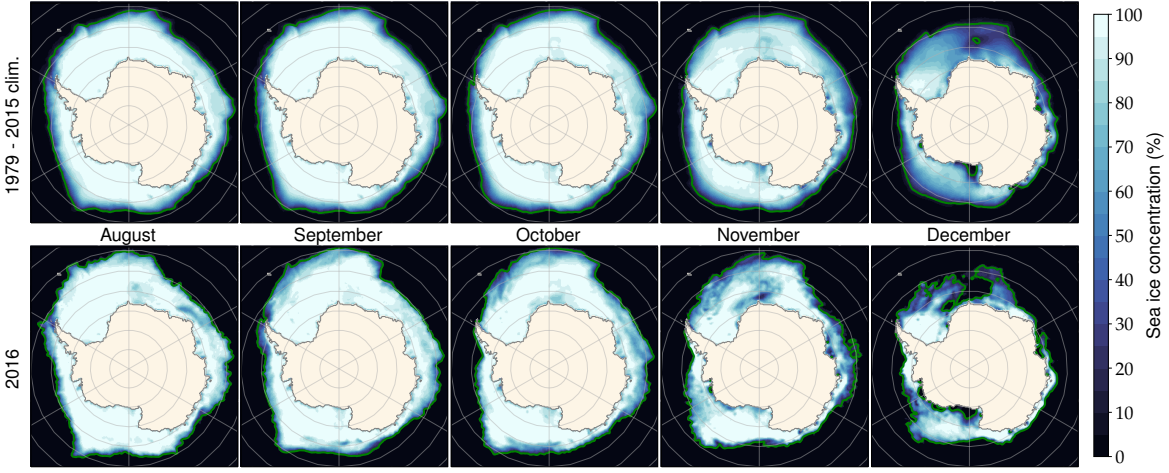




- 2016: regular year up to winter.
- Below average **minimum** in February
- Exceptionally **early maximum** in August 2016
- Record **springtime retreat** in 2016

Data: NSIDC (obs.)

2016 spatial sea ice evolution



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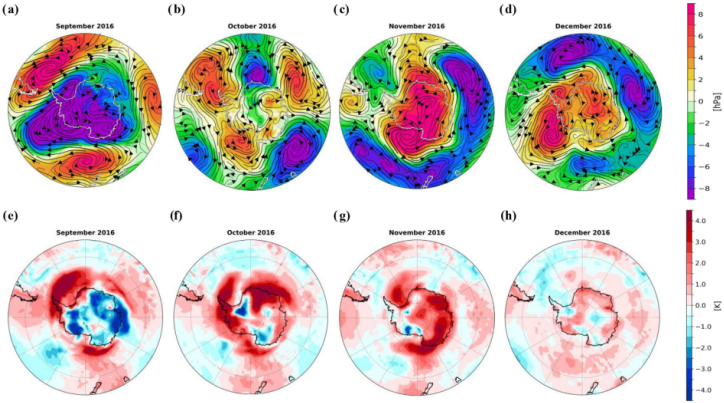
Outline

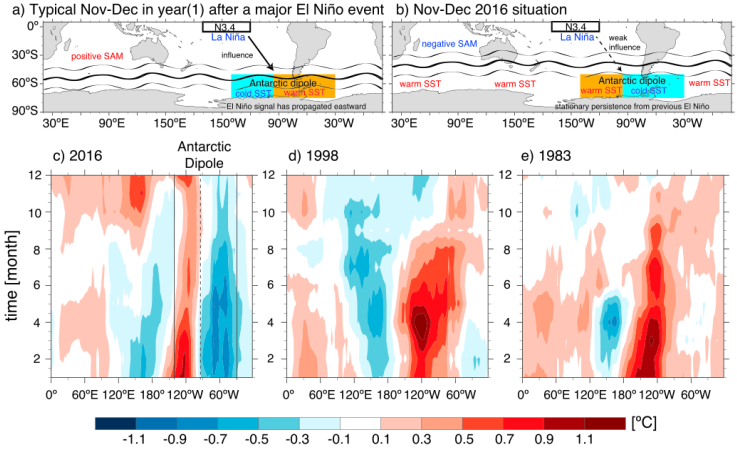
Warm, moist air advection in the spring of 2016



Sea level pressure and near-surface temperature 2016 anomalies (ref. 1979 – 2010). *Ionita et al. 2018*

- September: 3 SLP anomalies advecting warm air southwards
- November: Antarctic continent SLP anomaly
- Full peri-Antarctic ocean surface exceptionally warm

Tropical teleconnection



Top left (right): typical (2016) strong El Nino event effect of near-Antarctic peninsula SSTs. Bottom: Hovmöller diagram for the temporal evolution of meridionnally ($50^\circ\mathrm{S} - 70^\circ\mathrm{S}$) averaged SSTs on 3 strong El Nino years.
Stuecker et al. 2017

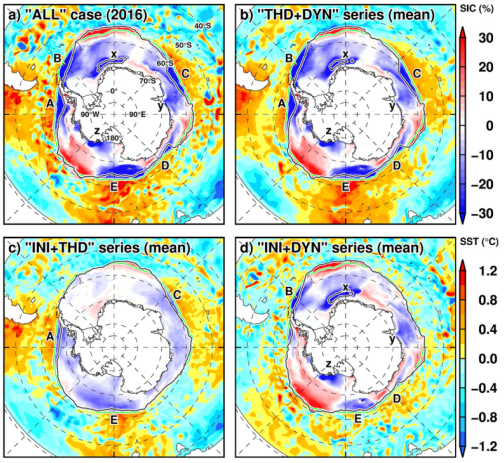
- 2015/2016 extreme El Niño $\Rightarrow$ anomalously warm SSTs in eastern Ross & Amundsen seas;
- Persisted all throughout 2016 (relatively weak La Niña?);
- Negative (-1σ) SAM in mid to late 2016 further emphasizing melt.

Separating different contributions

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

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

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



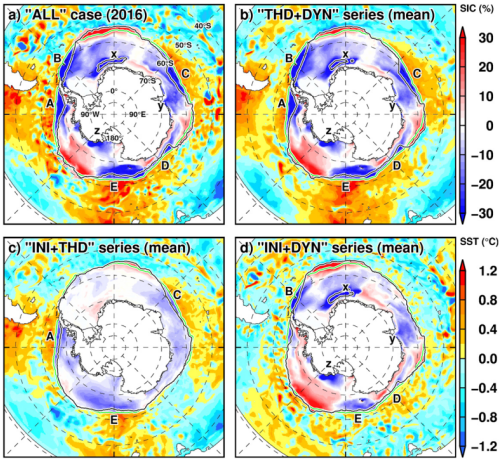
2016 sea ice concentration and SST anomalies for the regular year (a), and ensemble perturbations on: (b) initial Jan. 2016 ocean conditions; (c) wind forcings; (d) thermodynamical forcings.

Separating different contributions

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

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

1. Oceanic conditions **13%**
2. Dynamical surface forcings (wind stress) **34%**
3. Thermodynamical surface forcings (heat fluxes) **53%**



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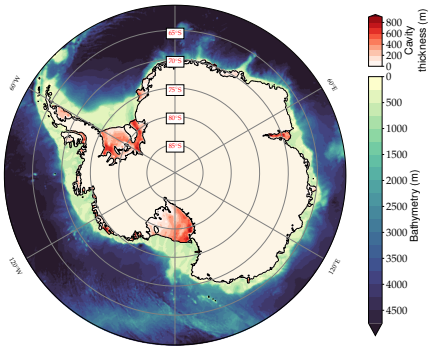
Configuration description

SO025: new **NEMO-LIM** configuration

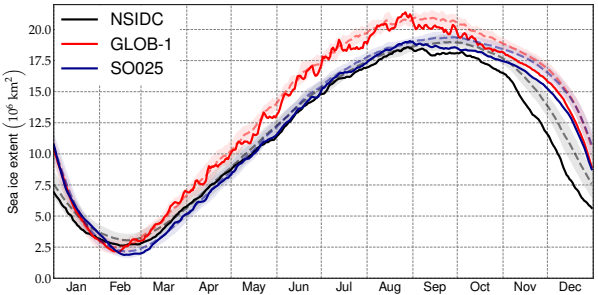
- eORCA025 grid ($1/4^\circ$, 75 levels) cut at 30°S ;
- Ice shelf cavity including;
- JRA-55 reanalysis as atmosphere forcings;
- WOA18 based climatology;
- GLORYS2V4 reanalyses on lateral boundaries;
- BedMachine2 & ETOPO1 bathymetry.



Configuration bathymetry and ice shelf cavities around the Antarctic continent

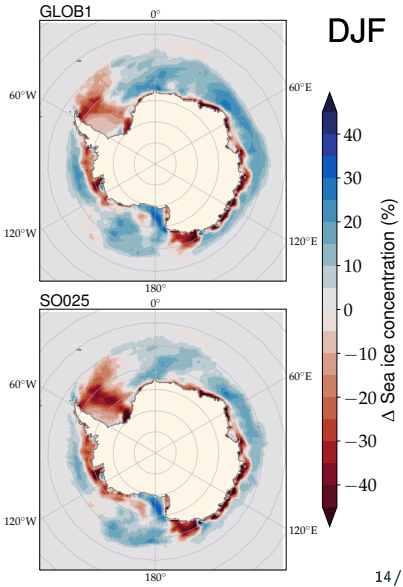
Within the context of the Belgian **PARAMOUR** project (decadal predictability in 5-component coupled models). Still under development

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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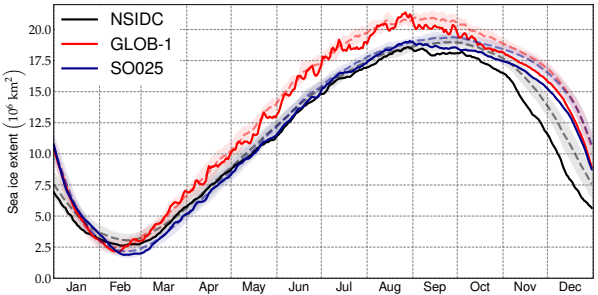

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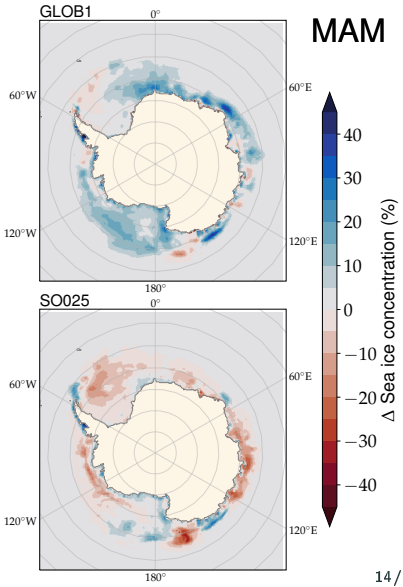

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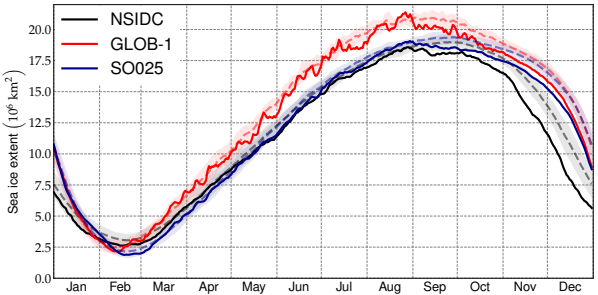

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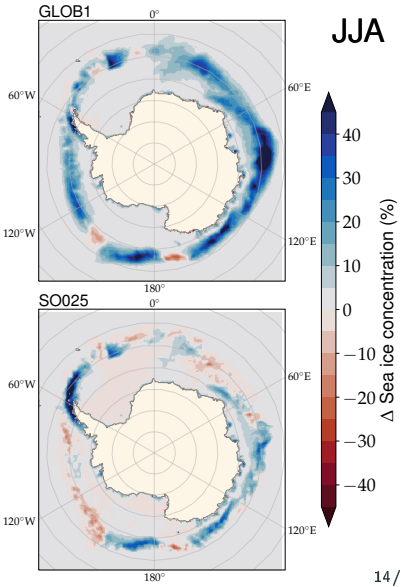

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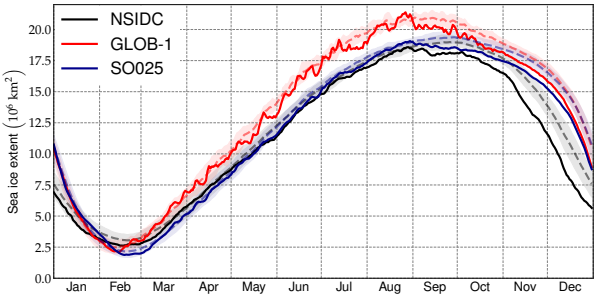

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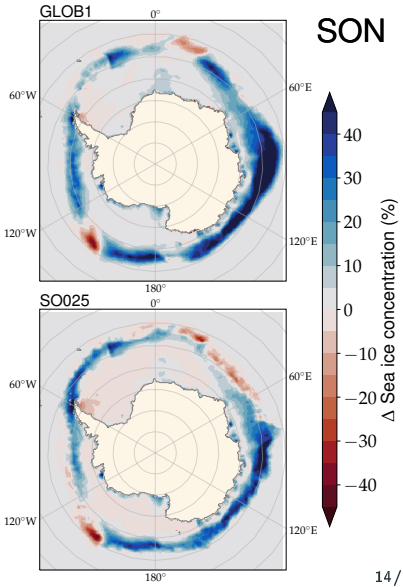
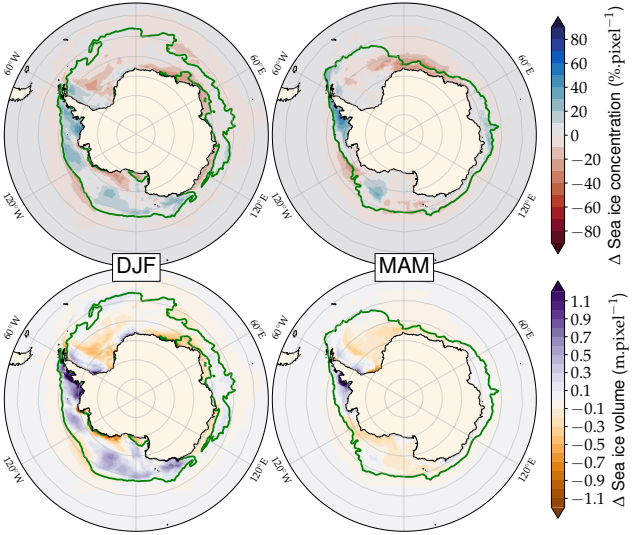


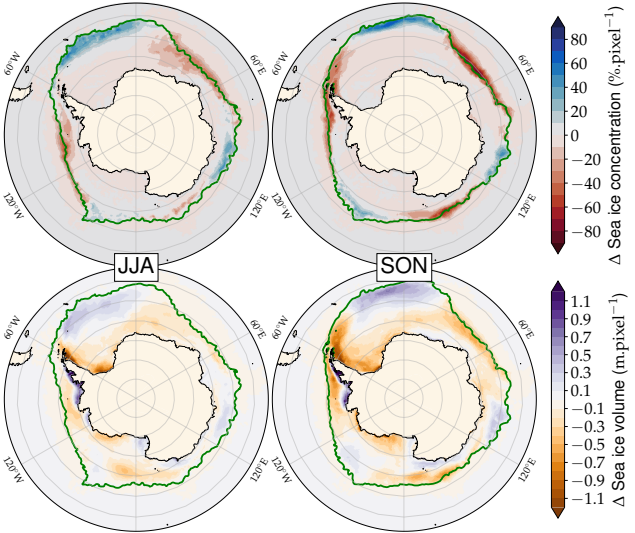
Comparing spatial sea ice concentration and volume 2016 anomalies



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

Regular summer and autumn.

Comparing spatial sea ice concentration and volume 2016 anomalies



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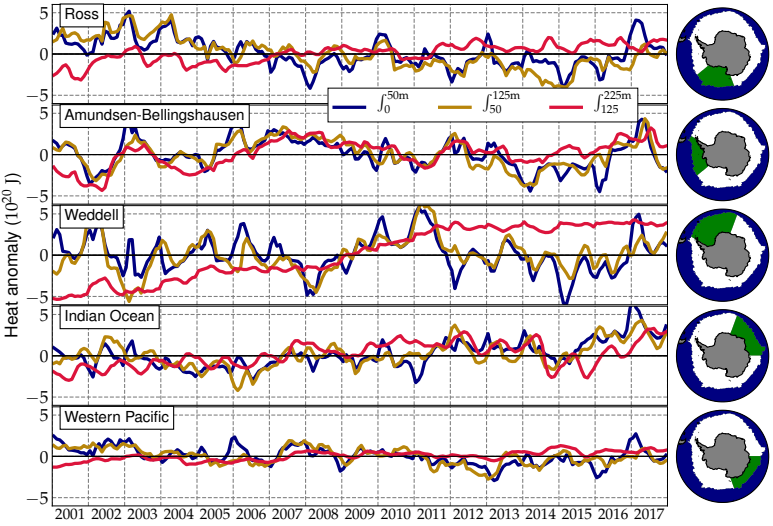
Regular summer and autumn.

Winter and spring:

- Matching concentration/volume patterns along extent line (advection of sea ice).
- **Dipole** across the Antarctic peninsula.
- Strong **volume anomaly** in the Weddell sea without noticeable concentration anomaly.

Regional heat anomalies



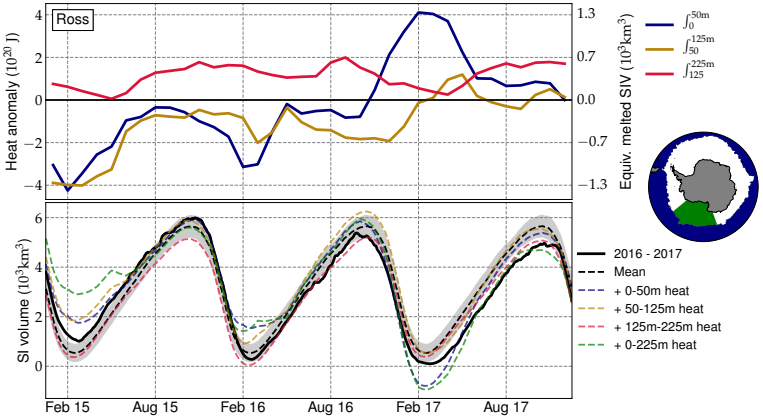
Simulated heat anomalies in zonally-averaged distinct areas, meridionally-averaged under maximum sea ice extent.

$$\iint_{z,A} \rho_{sw} c_p^{sw} \left(T(t,z,A) - \overline{T^{2001;2016}}(t,z,A) \right) \mathrm{d}z\mathrm{d}A$$

Expected **seasonal variability** in shallow waters.

Mid-depth anomalies developing in Ross, Amund.-Bell. and **Weddell**.

Regional heat anomalies: equivalent sea ice volume melt



Simulated heat anomalies and equivalent melted sea ice volume in zonally-averaged distinct areas, meridionally-averaged under maximum sea ice extent.

Heat anomalies **highly correlated** to sea ice volume.

Indian Ocean: 2016 summer **full melt** → late summer + mixing & autumn **heat storage** → winter **weaker ice production** → spring **record melt**.

Exceptional 2016 retreat → summer 2016/2017 peak in heat → **persistence** of SIE anomaly in 2017.

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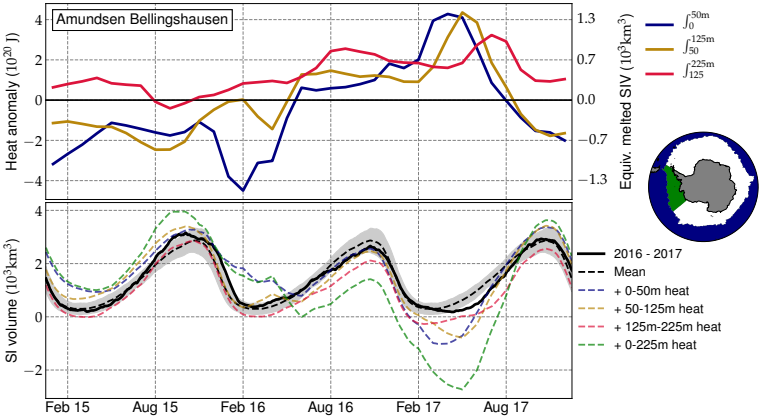

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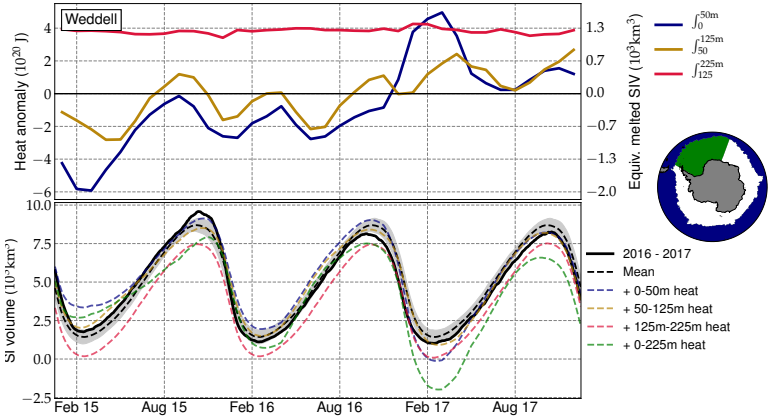

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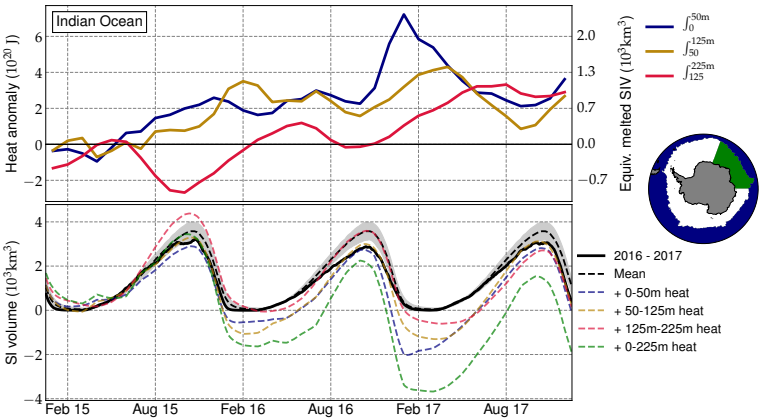

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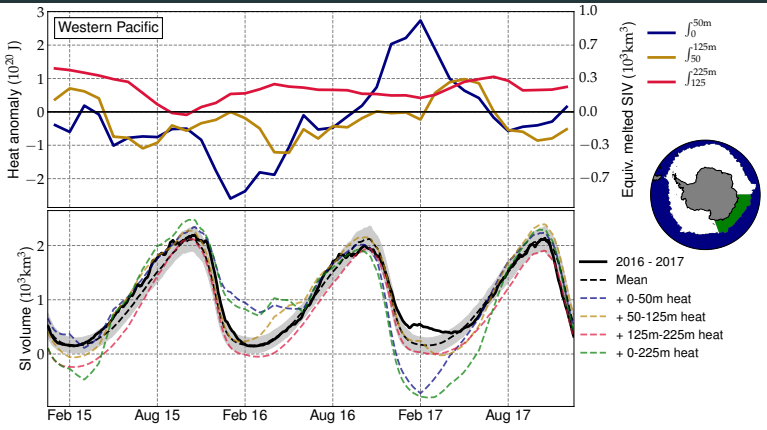

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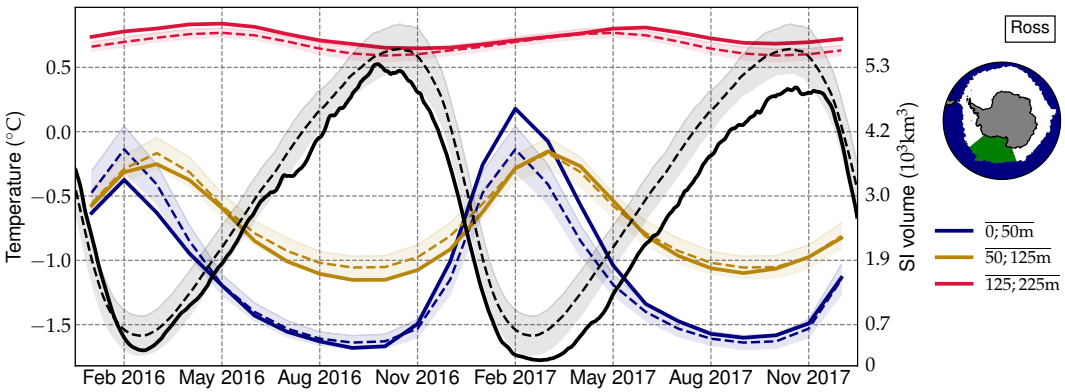
Conclusions

- **Wind and thermodynamic forcings** are indeed predominant (sea ice advection & surface melt).
- **Pluriannual heating** seen in simulations which enhanced melting. Heat stored in depths during lower sea ice summers, which could explain **persistence** of low winter sea ice post-2016.
- **Sea ice volume** diagnoses and measurements are important for getting the full picture.
- Configuration still under development: focus on **ice shelf** melt and cavity circulation which suffer from large biases degrading the vertical stratification.

Seasonal cycle in heat storage



Simulated mean temperature anomalies at varying depth intervals (left y-axis, color plots) and sea ice volume (right y-axis, black) in zonally-averaged distinct areas, meridionally-averaged under maximum sea ice extent for years 2016/2017 (full lines) and 2001 - 2015 means (dashed lines). Shades represent one STD.

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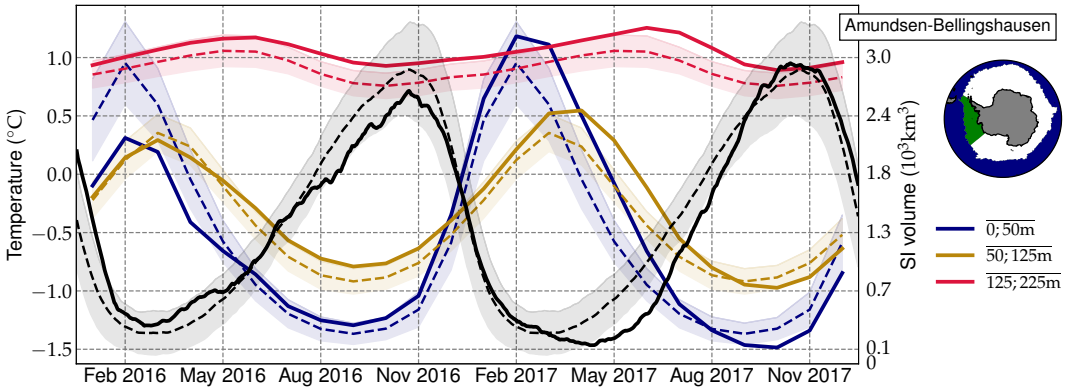

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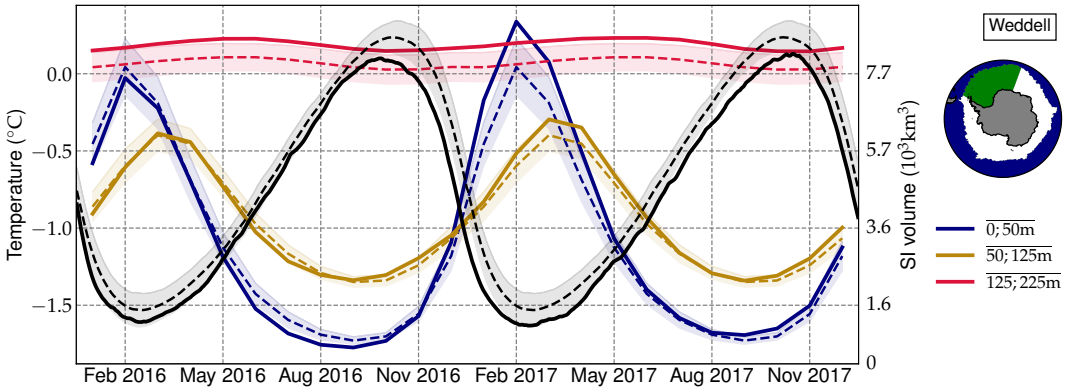

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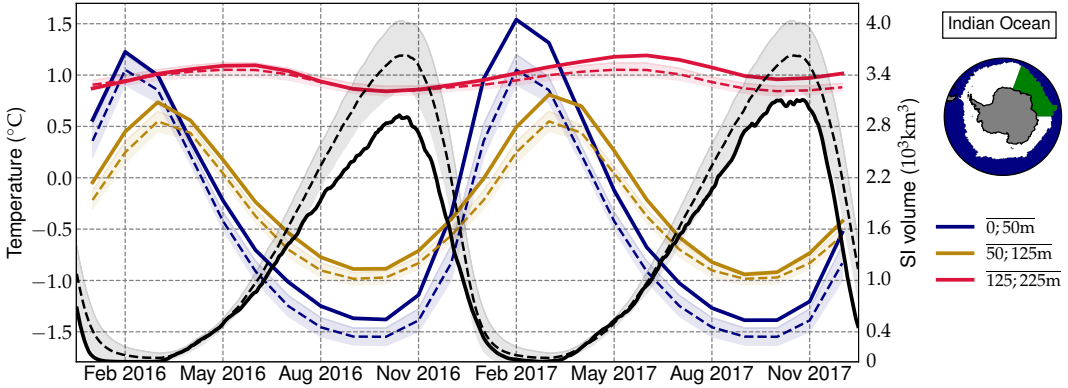

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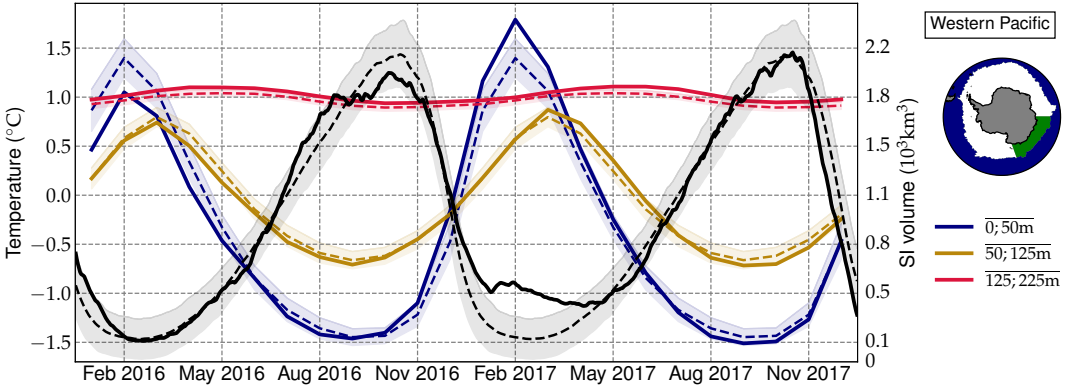

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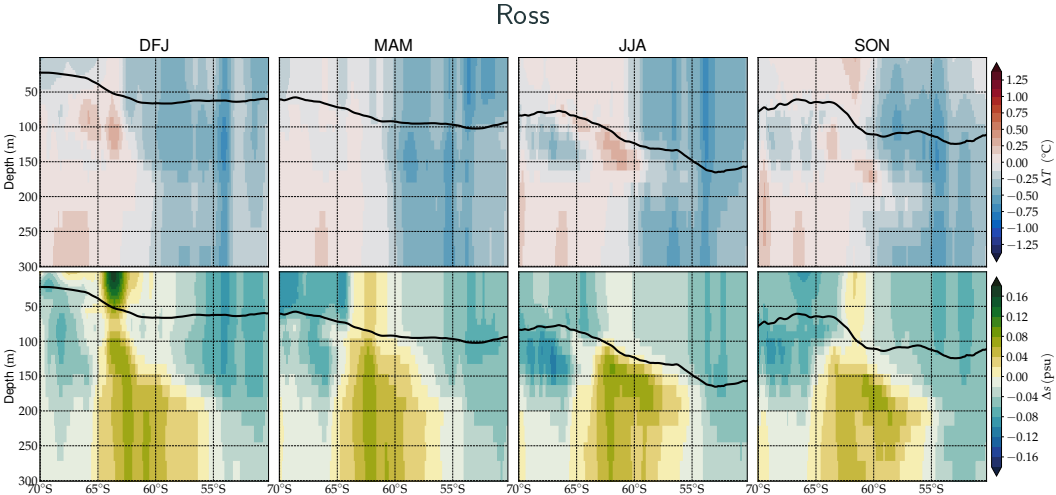
Vertical anomalies in 2016



Simulated vertical temperature and salinity anomalies in zonally-averaged distinct areas.

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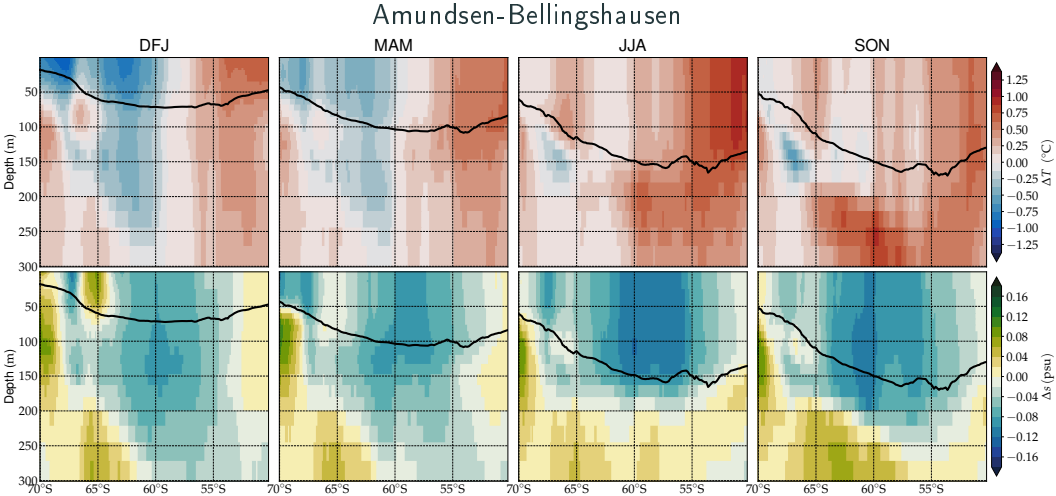
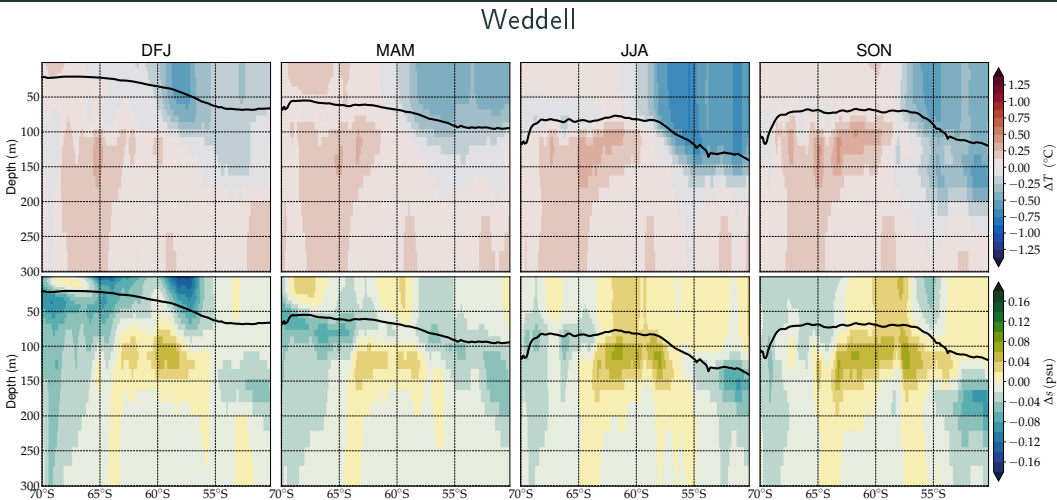


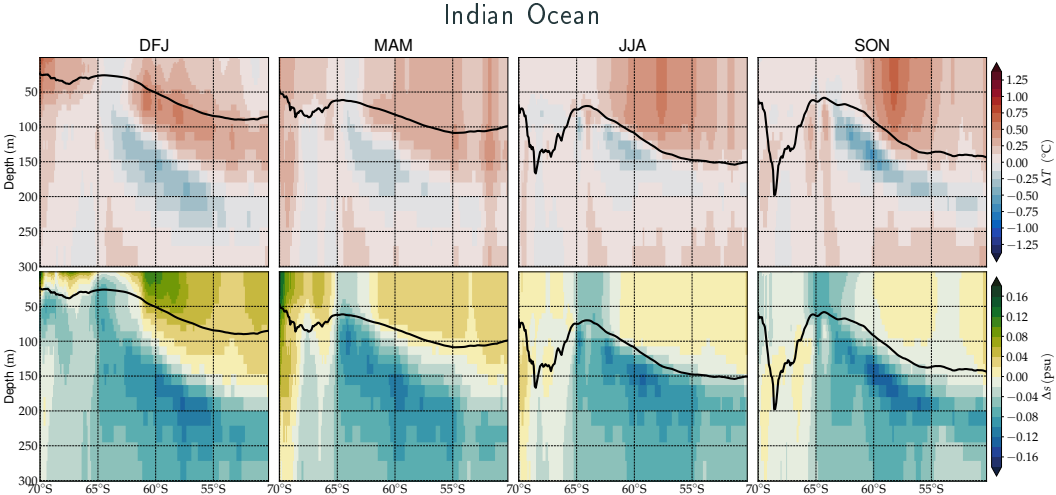
Simulated vertical temperature and salinity anomalies in zonally-averaged distinct areas.

Vertical anomalies in 2016



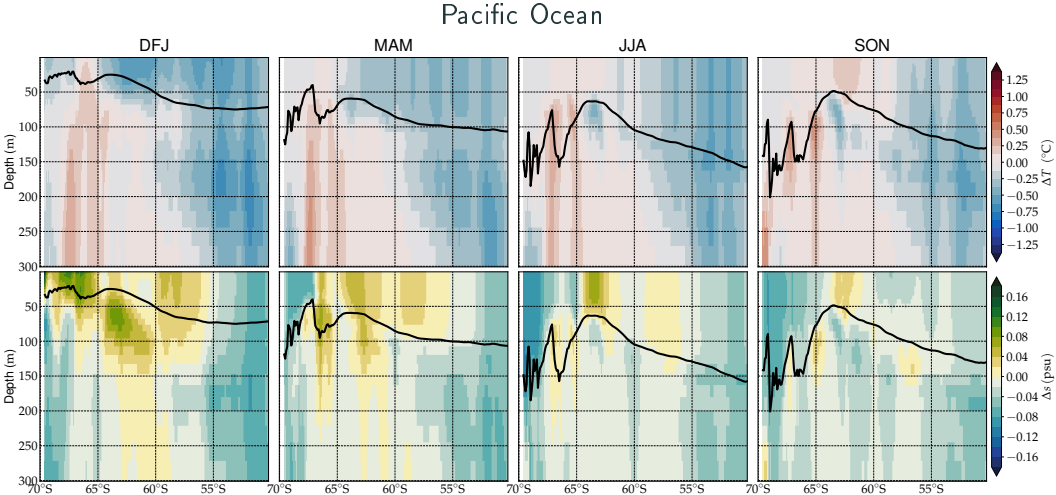
Simulated vertical temperature and salinity anomalies in zonally-averaged distinct areas.

Vertical anomalies in 2016



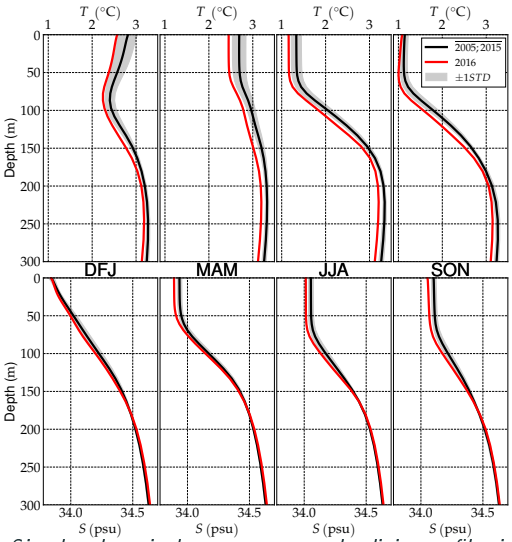
Simulated vertical temperature and salinity anomalies in zonally-averaged distinct areas.

Vertical anomalies in 2016



Simulated vertical temperature and salinity anomalies in zonally-averaged distinct areas.

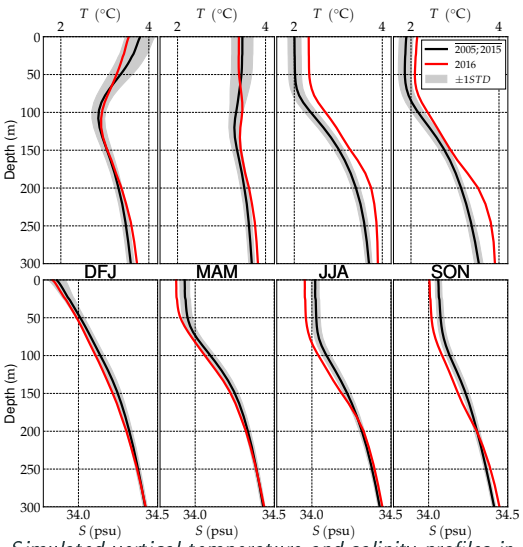
Vertical anomalies in 2016



Simulated vertical temperature and salinity profiles in zonally and meridionally averaged distinct areas.

Ross

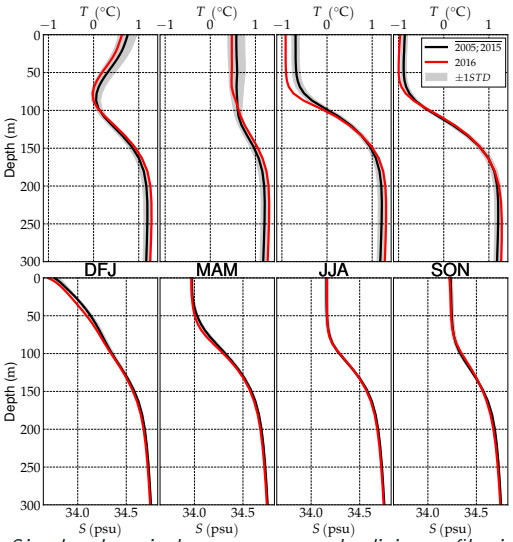
Vertical anomalies in 2016



Simulated vertical temperature and salinity profiles in zonally and meridionally averaged distinct areas.

Amundsen-Bellingshausen

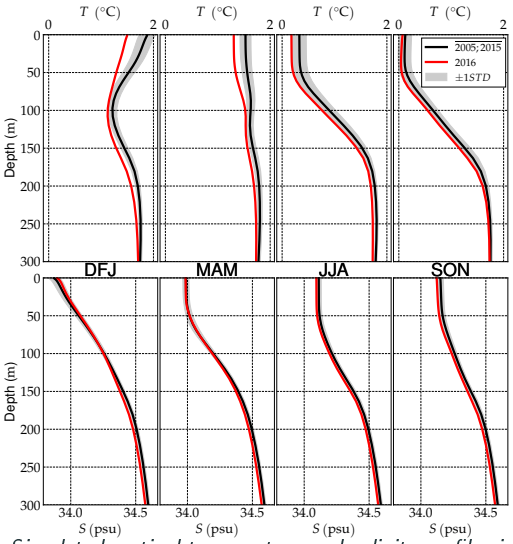
Vertical anomalies in 2016



Simulated vertical temperature and salinity profiles in zonally and meridionally averaged distinct areas.

Weddell

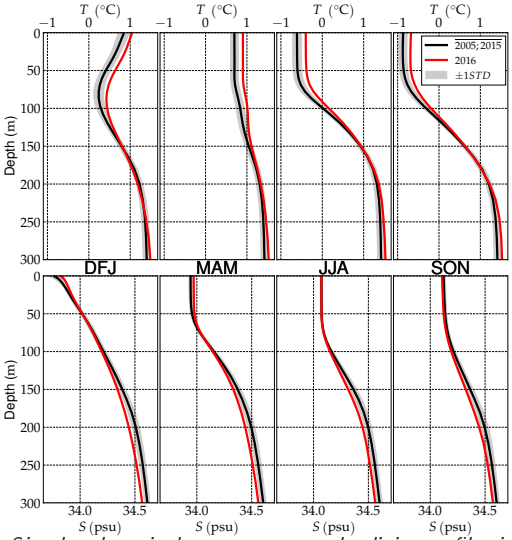
Vertical anomalies in 2016



Simulated vertical temperature and salinity profiles in zonally and meridionally averaged distinct areas.

Indian Ocean

Vertical anomalies in 2016



Simulated vertical temperature and salinity profiles in zonally and meridionally averaged distinct areas.

Pacific Ocean