Importance of the Antarctic Slope Current (ASC) in the Southern Ocean response to Ice Sheet Melt and Wind Stress Change.


Currently in-revision in Journal of Geophysical Research: Oceans
Two major changes are occurring in the Southern Ocean and projected to strengthen throughout the 21st century.

1. Increased melting of the Antarctic Ice Sheet (AIS)

Mass loss from Antarctica (2003 to 2019)
Two major changes are occurring in the Southern Ocean and projected to strengthen throughout the 21st century:

1. **Increased melting of the Antarctic Ice Sheet (AIS)**
   - Mass loss from Antarctica (2003 to 2019)
   - Smith et al. 2020

2. **Strengthened and poleward shifted westerlies**
   - Goyal et al. 2021
Why do we care?

A. Both winds and meltwater impact ocean ventilation & thus oceanic carbon and heat fluxes and storage
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B. Both winds and meltwater influence the properties of water on the Antarctic shelf that directly interact with ice shelves & thus may lead to feedbacks that control the future stability of the Antarctic ice sheet
Why do we care?

A. Both winds and meltwater impact ocean ventilation & thus oceanic carbon and heat fluxes and storage

B. Both winds and meltwater influence the properties of water on the Antarctic shelf that directly interact with ice shelves & thus may lead to feedbacks that control the future stability of the Antarctic ice sheet
What insight have we gained from modeling studies on how the Antarctic shelf responds to wind and meltwater perturbations?
Poleward and intensified westerlies warm the Antarctic shelf by increasing access of warm CDW

Spence et al. 2014 (MOM025; 0.25°)
Poleward and intensified westerlies warm the Antarctic shelf by increasing access of warm CDW

Spence et al. 2014 (MOM025; 0.25°)

Robust across model resolutions
Bronselaer et al. 2020
Purich and England 2021
Antarctic meltwater ............
Antarctic meltwater ...........

Warms the shelf waters?

Bronselaer et al. 2018; GFDL-ESM2M, 1º
Antarctic meltwater ...........

Warms the shelf waters?

Cools the shelf waters in some regions and warms in others?

Bronslaer et al. 2018; GFDL-ESM2M, 1º

Moorman et al. 2020; ACCESS-OM2-01 (MOM5.1); 0.1º

Cools the shelf waters in some regions and warms in others?
Coarse ocean horizontal grid spacing ($\geq 1^\circ$)

Warming of Antarctic shelf

Fine ocean horizontal grid spacing ($\leq 0.25^\circ$)

Inhomogeneous response
Coarse ocean horizontal grid spacing ($\geq 1^\circ$) → Warming of Antarctic shelf

Fine ocean horizontal grid spacing ($\leq 0.25^\circ$) → Inhomogeneous response

Bronselaer et al. 2018

Moorman et al. 2020
Coarse ocean horizontal grid spacing ($\geq 1^\circ$)

- Warming of Antarctic shelf

- Implies positive feedback that would accelerate melt along shelf

Fine ocean horizontal grid spacing ($\leq 0.25^\circ$)

- Inhomogeneous response

- Implies negative feedback that would decrease melt in West Antarctica
Ensemble of experiments performed using GFDL’s CM4 and ESM4 coupled models where meltwater and wind stress perturbations of magnitudes expected near mid-21st century were imposed in preindustrial control (piControl) simulations.
### Stress
Faf-stress perturbation in the surface zonal and meridional momentum flux (i.e., wind stress).

### Antwater
A temporally-uniform freshwater flux applied in regions of observed ice shelf melting around the Antarctic coast, scaled to a total of 0.1 Sv.

### AntwaterStress
Stress + Antwater
1. **Stress**
   Faf-stress perturbation in the surface zonal and meridional momentum flux (i.e., wind stress).

2. **Antwater**
   A temporally-uniform freshwater flux applied in regions of observed ice shelf melting around the Antarctic coast, scaled to a total of 0.1 Sv.

3. **AntwaterStress**
   Stress + Antwater
CM4 and ESM4 disagree in subsurface shelf response

**Strong subsurface cooling in West Antarctic**

**Strong subsurface warming in West Antarctic**

Depth-averaged response from 200 to 1,000 meters
CM4 and ESM4 disagree in subsurface shelf response

Strong subsurface cooling in West Antarctic

Strong subsurface warming in West Antarctic

Moorman et al. 2020

Depth-averaged response from 200 to 1,000 meters
CM4 and ESM4 disagree in subsurface shelf response

Strong freshening homogenized and trapped on shelf

Not the case in ESM4

Depth-averaged response from 200 to 1,000 meters
The key component that explains the discrepancy in the shelf response to freshwater forcing between CM4 and ESM4 is its ability to represent the Antarctic Slope Current (ASC)
Stronger & more defined ASC in CM4

Upper 500 m speed

Velocity

20°E

-18.38 Sv

20°E

-14 ± 6.8 Sv

20°E

-7.0 ± 4.1 Sv
Stronger ASC in CM4 & acceleration with shelf freshening

80°W

Upper 500 m speed

CM4

ESM4

Upper 500 m speed
Stronger ASC in CM4 & acceleration with shelf freshening
Stronger ASC in CM4 & acceleration with shelf freshening

80°W

Flow reversal in West Antarctic & acceleration of coastal currents

Not the case in ESM4
Development of westward flow along West Antarctic shelf break causes an isolation of West Antarctic shelf waters from warm circumpolar deep water (CDW) located off-shore.
Isopycnal shoaling induced from wind stress change acts as important control on magnitude of warming / cooling in West Antarctic.

Wind & meltwater reinforce each other, enhancing the subsurface warming anomaly.

Wind and meltwater forcing counteract each other, reducing subsurface cooling anomaly.
Putting the pieces together ......
a tale of two feedbacks
AntwaterStress

More meltwater moves off the shelf and is incorporated into the open ocean.

Weak, not well defined ASC
AntwaterStress

More meltwater moves off the shelf and is incorporated into the open ocean.

Reduced upward vertical transport of heat from increased stratification coupled with a depression of isopycnals toward coast directing more warm offshore to shelf, warms subsurface.

Weak, not well defined ASC

warm anomaly cold anomaly accelerating coastal current

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AntwaterStress

More meltwater moves off the shelf and is incorporated into the open ocean

Reduced upward vertical transport of heat from increased stratification coupled with a depression of isopycnals toward coast directing more warm offshore to shelf, warms subsurface.

Weak eastward flowing ACC off shelf

Slightly accelerated coastal current

Weak, not well defined ASC

warm anomaly cold anomaly accelerating coastal current

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Positive feedback: increased meltwater leads to subsurface warming which would act to accelerate further melt.

AntwaterStress

Reduced upward vertical transport of heat from increased stratification coupled with a depression of isopycnals toward coast directing more warm offshore to shelf, warms subsurface.

Weakened eastward flowing ACC off shelf

More meltwater moves off the shelf and is incorporated into the open ocean

Warm anomaly | Cold anomaly | Accelerating coastal current

Weak, not well defined ASC
Positive feedback: increased meltwater leads to subsurface warming which would act to accelerate further melt.

- **Strong, well defined ASC**: Freshwater trapping by strong and accelerating ASC.
- **Weak, not well defined ASC**: More meltwater moves off the shelf and is incorporated into the open ocean.

Diagram with labeled areas:
- **Melt Location**: Warm shelf, Cold shelf.
- **Currents**: ACC, ASC.
- **Heat Transport**: Reduced upward vertical transport of heat from increased stratification coupled with a depression of isopycnals toward coast directing more warm offshore to shelf, warms subsurface.
- **Flowing ACC**: CM4 0.25°, ESM4 0.50°.
Positive feedback: increased meltwater leads to subsurface warming which would act to accelerate further melt.
Positive feedback: increased meltwater leads to subsurface warming which would act to accelerate further melt.

Negative feedback: increased meltwater leads to subsurface cooling which would act to limit further melt.

Freshwater trapping by strong and accelerating ASC

More meltwater moves off the shelf and is incorporated into the open ocean

Reduced upward vertical transport of heat from increased stratification coupled with a depression of isopycnals toward coast directing more warm offshore to shelf, warms subsurface.

Westward flowing slope current develops

Accelerated coastal current

Weakly accelerated coastal current

Strong, well defined ASC

Weak, not well defined ASC

0.50°

0.25°
**Positive feedback:** increased meltwater leads to subsurface warming which would act to accelerate further melt

**Negative feedback:** increased meltwater leads to subsurface cooling which would act to limit further melt

Freshwater trapping by strong and accelerating ASC

More meltwater moves off the shelf and is incorporated into the open ocean

Reduced upward vertical transport of heat from increased stratification coupled with a depression of isopycnals toward coast directing more warm offshore to shelf, warms subsurface.

Westward flowing slope current develops

Consistent with results using fine resolution models

Consistent with results using coarse resolution models
Key Point

Models with sufficient horizontal resolution to resolve an ASC respond differently to meltwater perturbations compared to coarse resolution models that have a less well-defined ASC or no ASC at all.

Weak ASC (ESM4)

Strong subsurface shelf warming

Positive feedback that would act to enhance melting of AIS

Strong ASC (CM4)

Strong subsurface shelf cooling

Negative feedback that would act to reduce melting of AIS
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