Impacts of Southern Ocean circulation on climate and sea level

Highlighting GFDL and Princeton/SOCCOM collaborations

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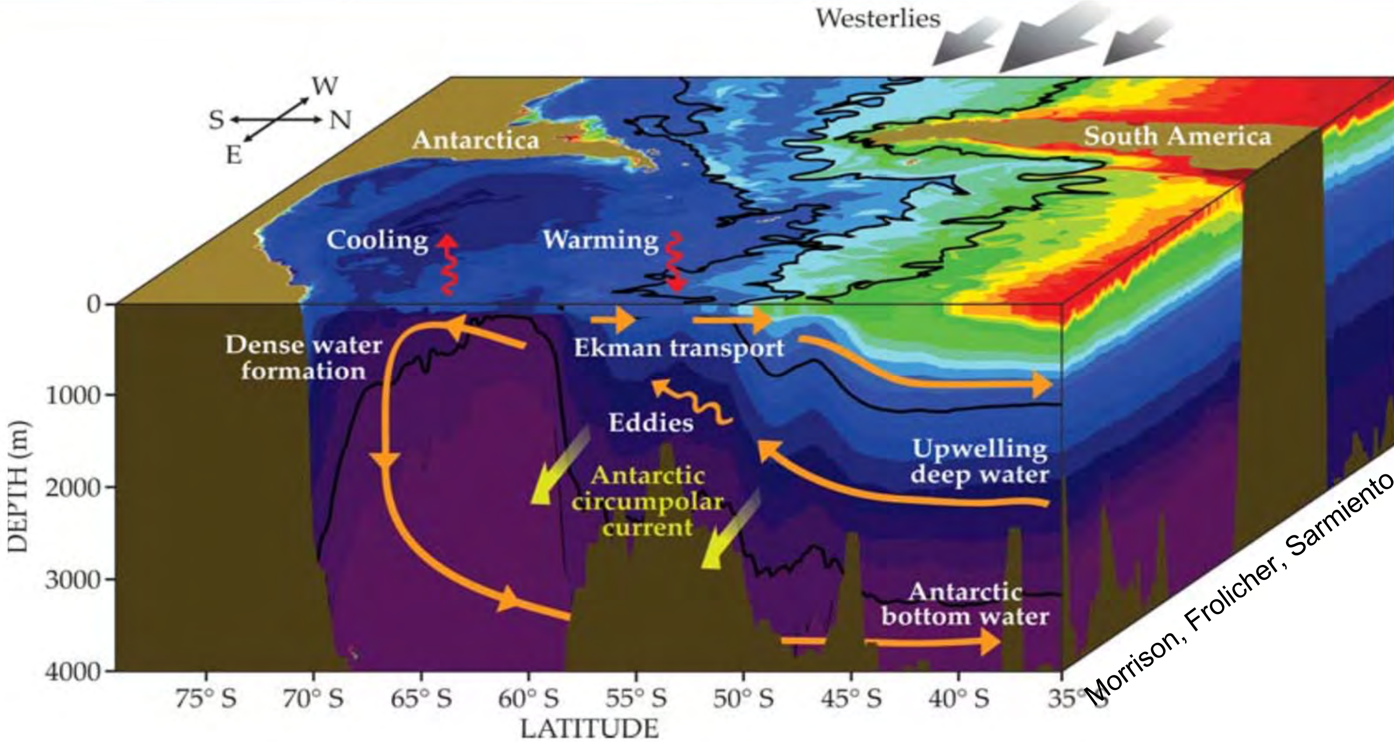
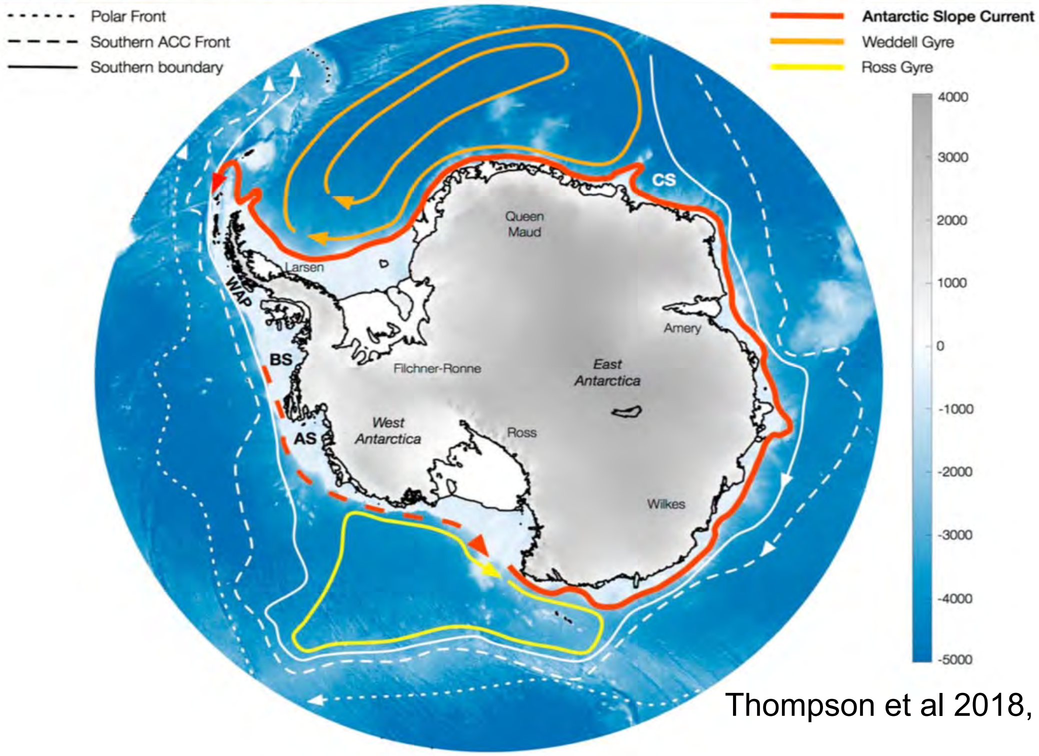
Topic A: ACC + SOMOC



Morrison, Frolicher, Sarmiento, Physics Today (2015)

- Southern Ocean is ~20% of ocean area yet accounts for ~40% of ocean carbon uptake and absorbs ~75% of total anthropogenically generated heat.
- Zonal circulation (ACC) & Southern Ocean meridional overturning circulation (SOMOC) are intimately woven together to create the large-scale S.O. flow.
- **GFDL Research/Development Goal**: Accurately simulate and understand physical and biogeochemical processes affecting Southern Ocean circulation features and their roles in climate and climate change.

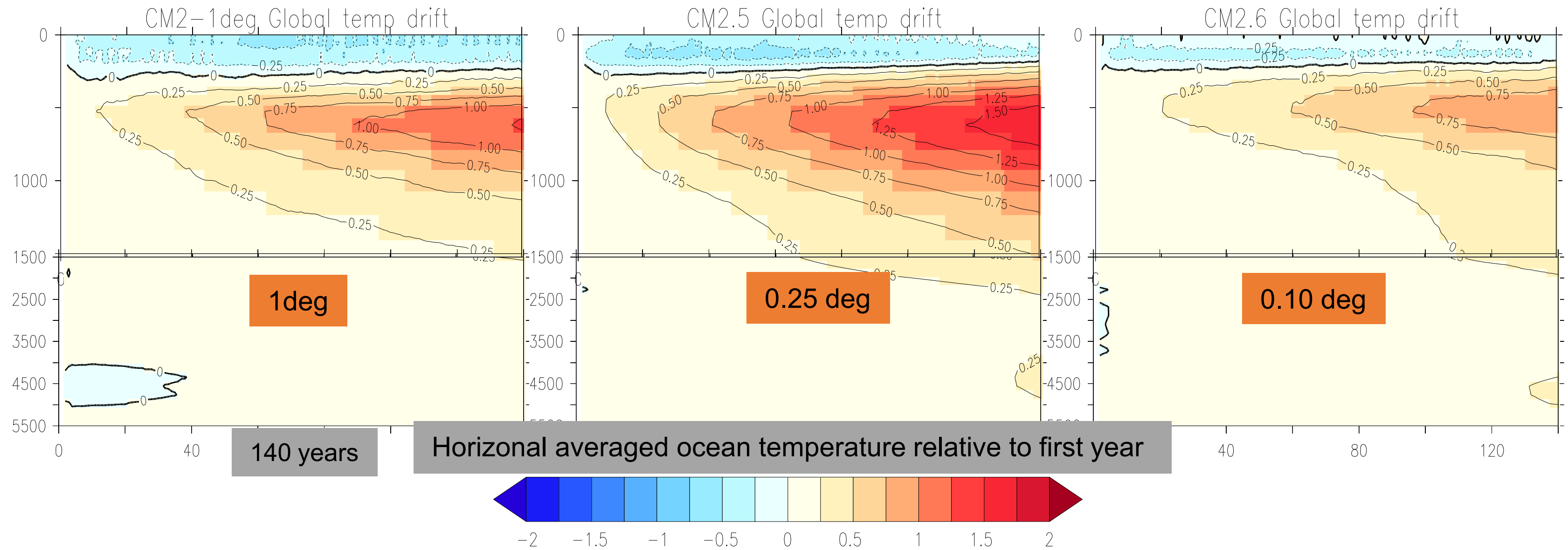
Topic B: Antarctic Slope Current (ASC) & ocean/ice-shelf interactions



Thompson et al 2018, Review of Geophysics

- Ocean heat can melt ice shelves & allow downslope flow of ice sheets, thus leading to an increase in sea level.
- Antarctic Slope Current (ASC) provides a barrier (in places) to cross-shelf heat transport. What dynamical processes set the strength of that barrier?
- **GFDL Research/Development Goal**: Accurately simulate & understand physical processes contributing to Southern Ocean gyre & coastal circulations, along with their interactions with the ACC to the north and ice-shelves to the south.

CM2-O-suite: ocean resolution (1,0.25,0.10) hierarchy of coupled models → role of ocean mesoscale in climate

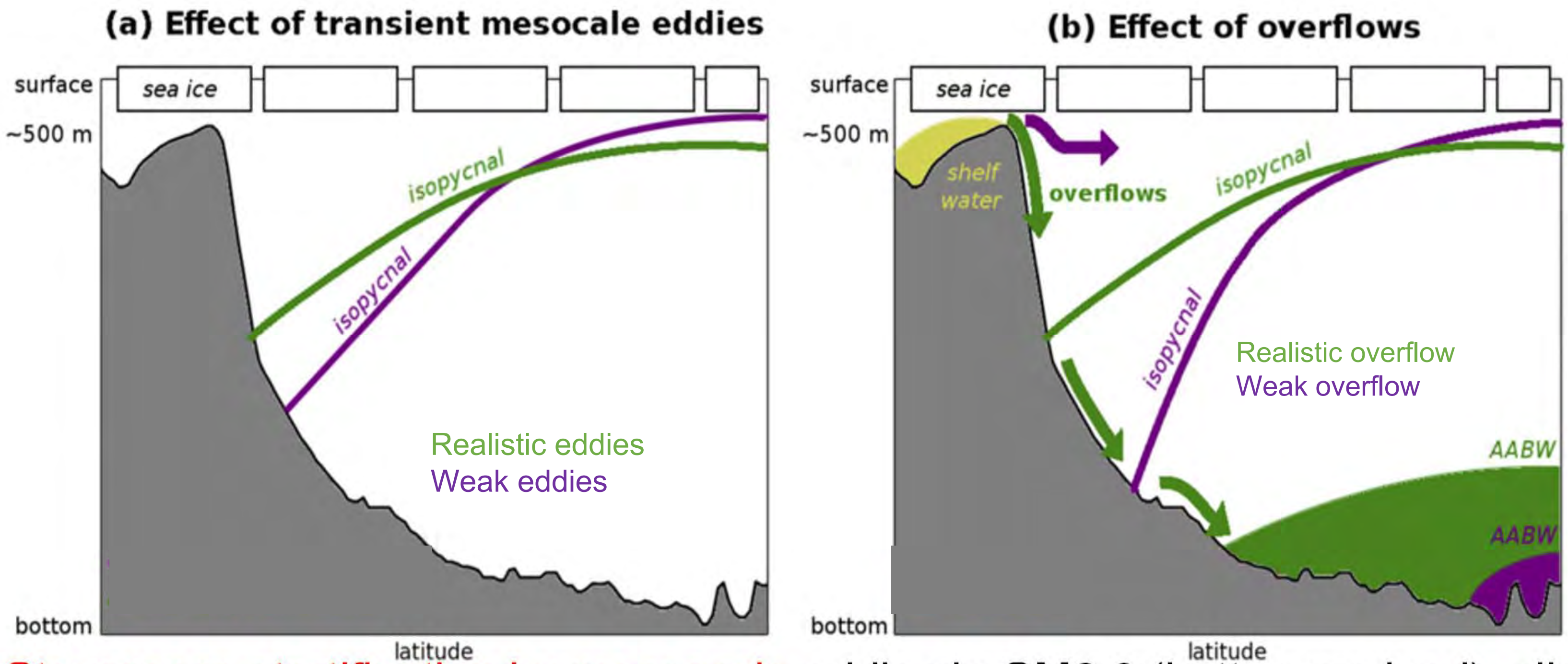


- Griffies et al (2015): vertical transport by mesoscale eddies for ocean heat uptake & climate model drift.
- CM2-O suite exemplifies the value of model resolution hierarchies for probing the role of ocean processes in global climate.
- 40 peer-review papers using CM2.6 for a wide variety of projects: physics, biogeochemistry, ecosystems, fisheries (many led by post-docs and students). Two studies highlighted in next slides.
- See also Vince Saba's fisheries talk and John Krasting's sea level talk in Theme 3.

Griffies et al (2015, Journal of Climate)

Study of Weddell Sea Polynyas

Polynyas in CM2.6 (1/10th degree) but none in CM2.5 (1/4th degree). Why?



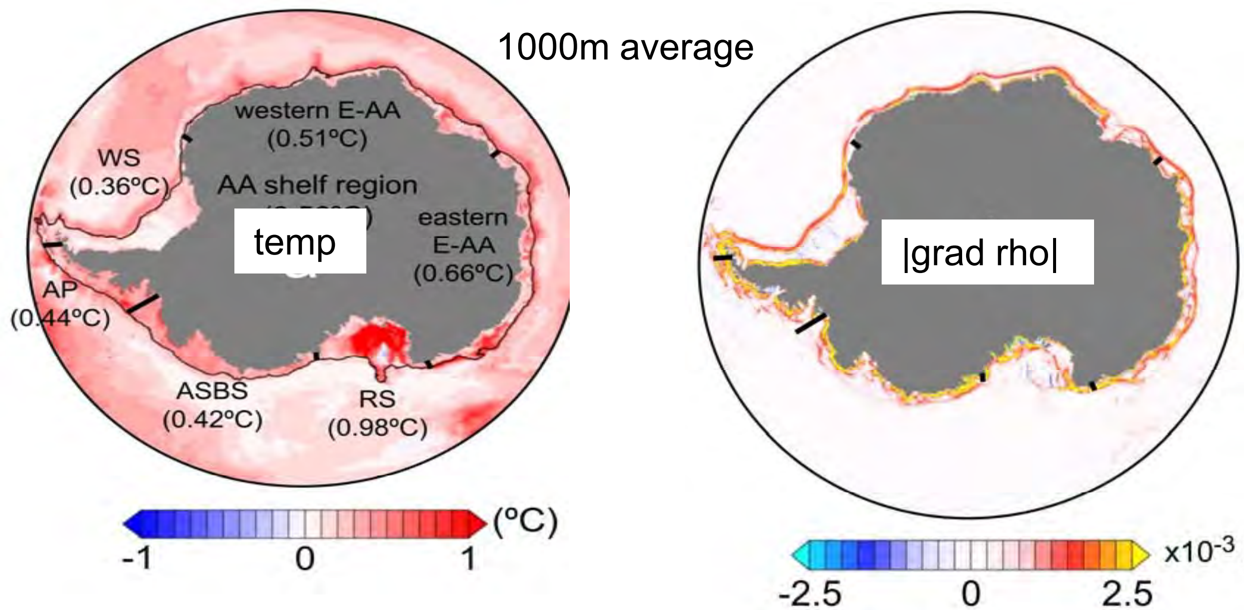
- Stronger re-stratification by mesoscale eddies in CM2.6 (better resolved), allowing for heat to build-up at depth rather than continually released via steady convection in CM2.5.
- Better overflow representation in CM2.6 thus supporting deep stratification.

- See Zhang et al (2019) for analysis of polynyas in the SPEAR (L. Zhang talk in Theme 3).
- See Princeton PhD work Zanowski et al (2015, JPO) on polynyas in ESM2G.

Dufour et al (2017, Journal of Climate)

Study of warming on the Antarctic shelf

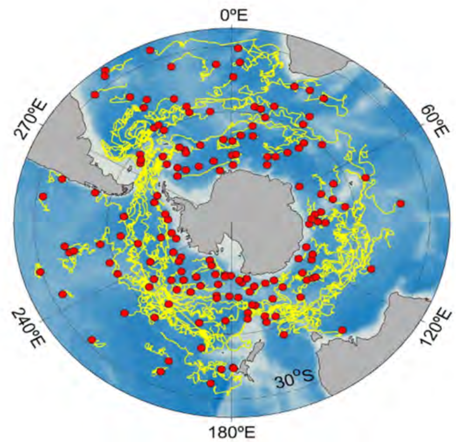
Mechanisms for cross-shelf exchange & on-shelf warming in CM2.6 2xCO_2 vs control?



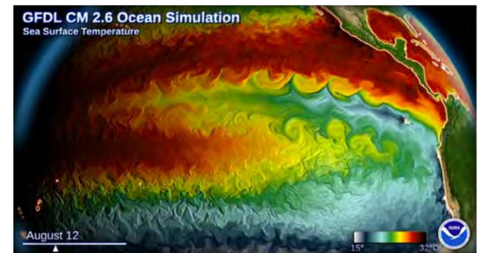
- Also affected by stratification changes (ice melt + increased precipitation).
- Detailed heat budget reveals importance of stratification changes on vertical mixing.
- Selected regions of weak baroclinicity see warming penetrate deeply on shelf (e.g., Ross Sea).
- See Bronselear et al (2019) for suggestions that SOCCOM floats might be detecting some of this coastal warming.
- Shelf warming in CM2.6 is induced by wind changes (Ekman; Spence et al 2014, 2017).
- See also the sea level talk from John Krasting in Theme 3.

Goddard et al (2017, JGR-Oceans)

The SOCCOM Project



SOCCOM
Southern Ocean Carbon and Climate Observations and Modeling



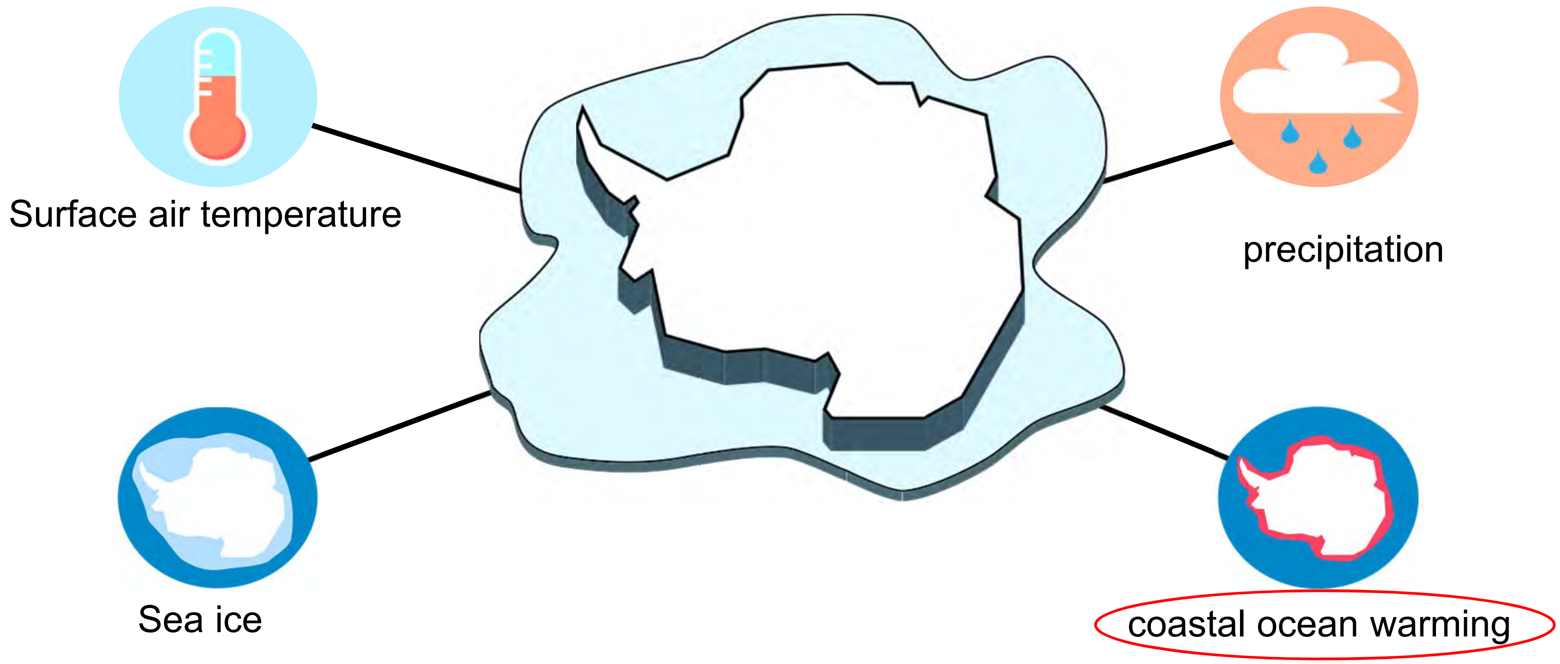
- Six year (2014-2019), $21 million NSF project to transform understanding of the Southern Ocean, a major sink of carbon and heat.
- Extensive NOAA support via US Argo program, GFDL, PMEL, and AOML.
- SOCCOM is headquartered at Princeton Univ (PI Jorge Sarmiento); involves over 80 participants at 13 partner institutions (including NOAA/GFDL)
- Deploying ~200 floats that measure pH, nitrate, oxygen, chlorophyll, particles
- High-resolution modeling (CM2.6, CM4/OM4) & state estimates (SOSE)
- GFDL is involved as collaborators/mentors along with model datasets.

Funding recently awarded for 4 additional years (30 floats/yr)

Climate impacts from Antarctic melt

What impact does freshwater from ice sheet melt have on climate?

SOCCOM/GFDL study with an ensemble of ESM2M (1deg climate model) freshwater perturbation expts.
Examined changes in air temp, sea ice, precip, & coastal warming.



Enhanced subsurface ocean warming

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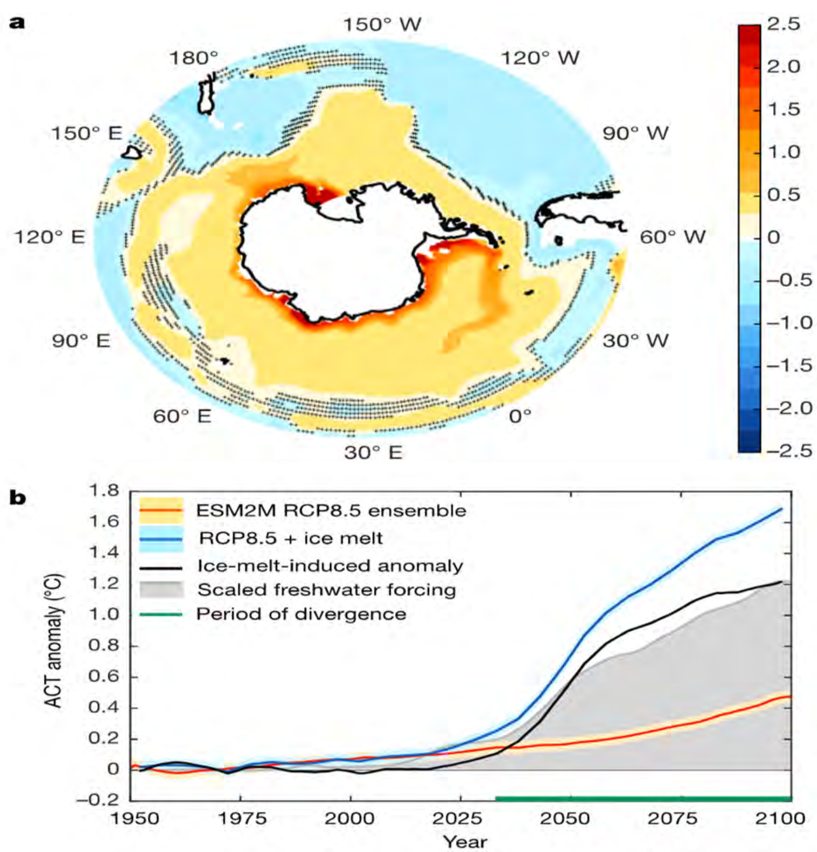
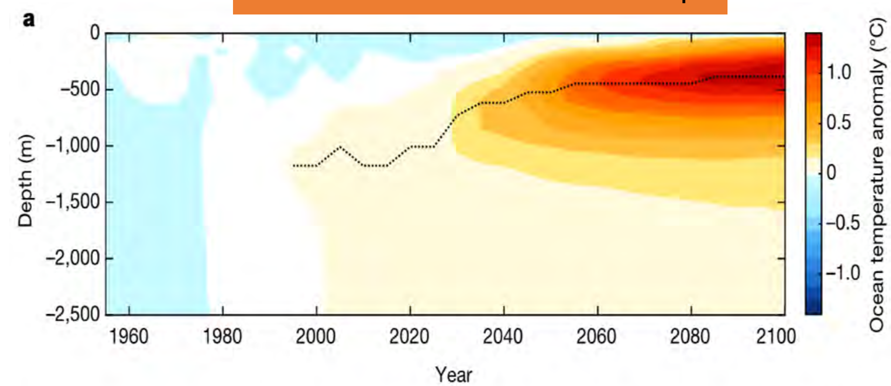
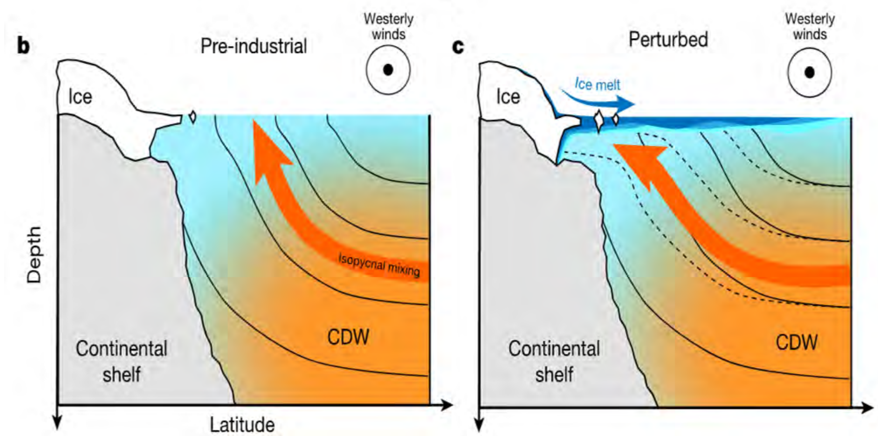


Time series of subsurface temp





Eddy mechanism for subsurface warming

- Positive feedback: more subsurface warming → more melt → more warming.
- Potentially significant contribution to ice sheet melt and corresponding sea level rise.
- Exemplifies interactions of open ocean & coastal processes in the Southern Ocean.

Bronselear et al (2018, Nature)

Future Plans & Challenges

- Merge elements of deep ocean (ACC and SOMOC) with shelves (ASC):
  - Tools: resolution hierarchy MOM6/SIS2: 0.5, 0.25, 0.125 forced w/ JRA55-do atmospheric state (CMIP6/OMIP), Griffies et al 2016, Tsujino et al 2018) & coupled climate (CM4 with hierarchy of ocean resolutions).
  - Science: study fine scale flows impacting coastal and shelf region.
  - Evaluate: compare to SOCCOM data (physics and BGC).
- Address the sea level question: model tools, theory, processes, and measurements (e.g., SOCCOM):
  - Couple ocean/sea-ice models to interactive ice sheets (Olga Sergienko talk).
- Engage with Princeton/SOCCOM students/post-docs to address basic understanding and nurture next generation.
  - Mesoscale/submesoscale eddies & jets & fronts; ACC/ASC interactions; topography influences; surface ventilation of heat and BGC, etc.

Summary of visions/aspirations

- Circulation/sea level: GFDL + Princeton are strategically placed to address Southern Ocean circulation questions & impacts of coastal warming on ice-sheets & sea level.
- Cross-scale interactions: Cutting edge Southern Ocean questions involve interactions across scales.
  - Mixing scales: gravity waves, sub-mesoscale, mesoscales
  - Spanning flow regimes: open ocean ACC/SOMOC to shelf processes and Antarctic Slope Current (ASC).
- Synergies: The GFDL, Princeton University AOS Program, and SOCCOM collaboration supports NOAA science.
  - We do so by engaging smart & energetic students/postdocs on climate relevant questions of fundamental importance related to understanding the role of the Southern Ocean, from the Antarctic coast to global ocean.

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