Biology dominates seasonal carbon uptake at high latitudes in Antarctic coastal waters

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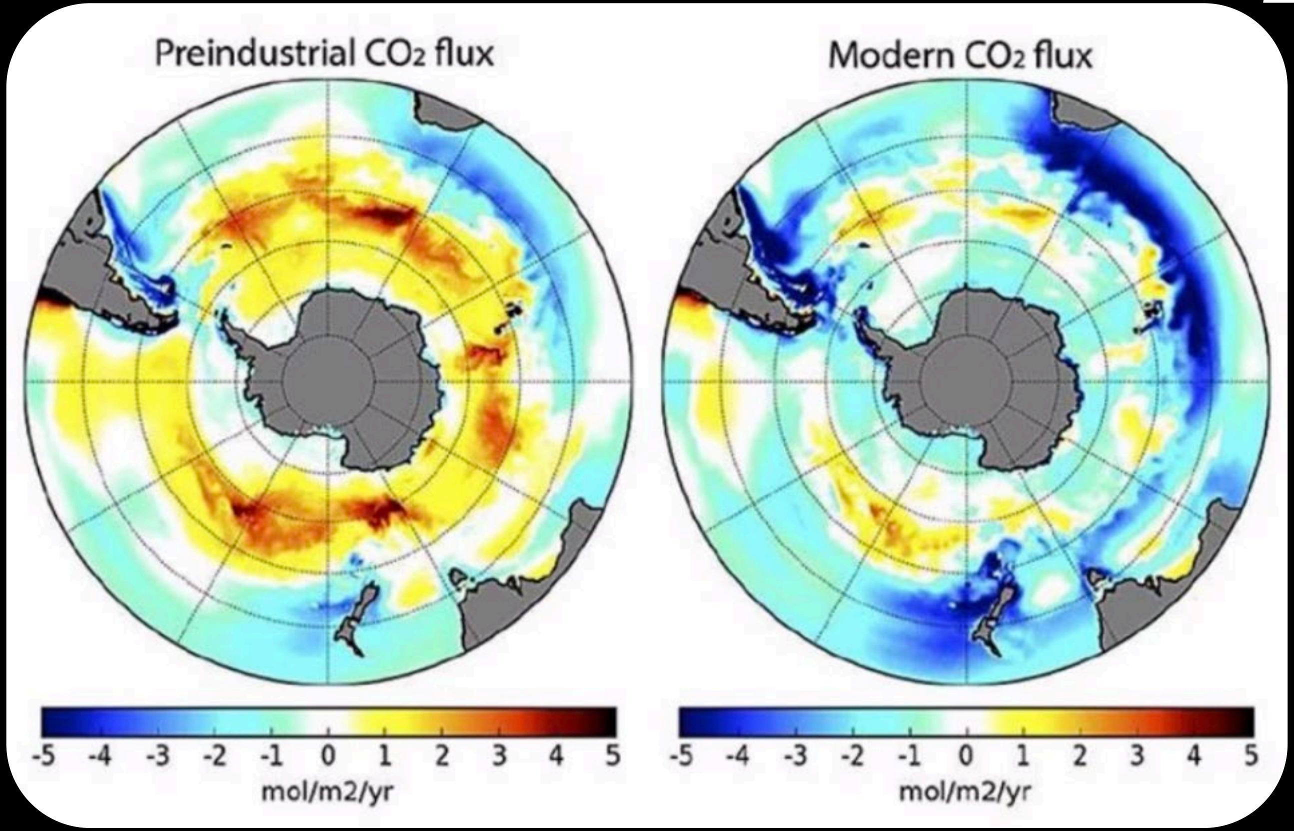
Ocean Carbon from Space Workshop
Tuesday, November 24, 2025

Is the Southern Ocean a CO_2 Sink?

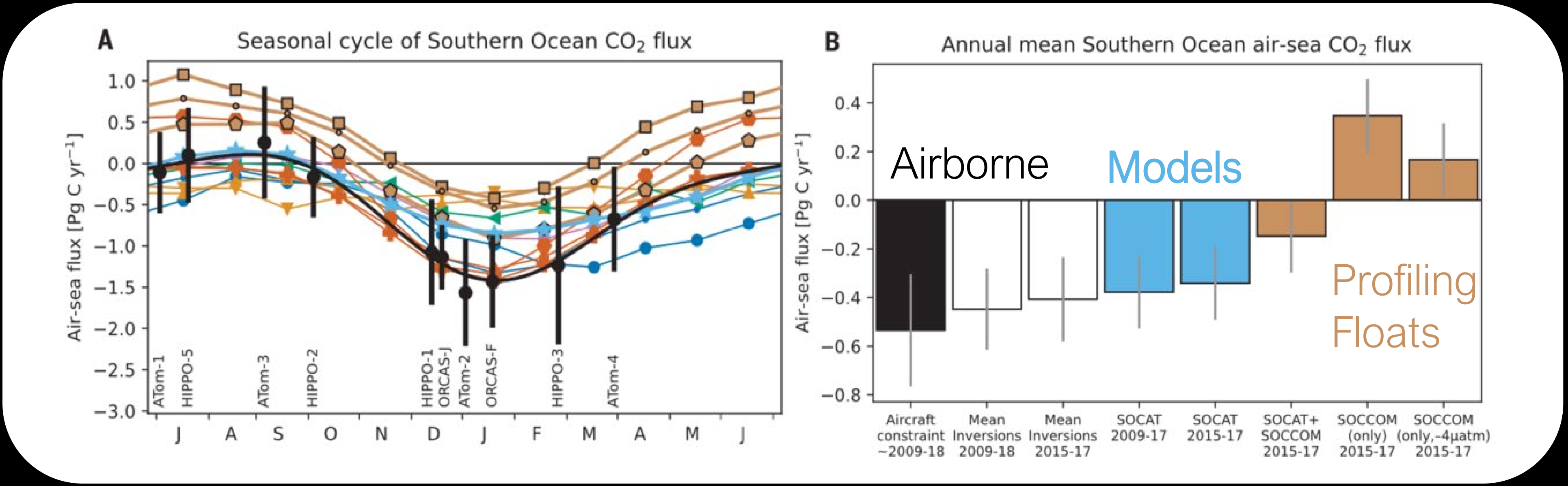


13th Carbon Mitigation Initiative Annnual Report
https://cmi.princeton.edu/annual-meetings/annual-reports/year-2013/quantifying-the-ocean-carbon-sink/

Southern Ocean thought to be one of the largest sinks of anthropogenic CO_2 in the global ocean…

Is the Southern Ocean a CO_2 Sink?

- How much CO_2 does the Southern Ocean really take up?
- Even the *sign* is uncertain:

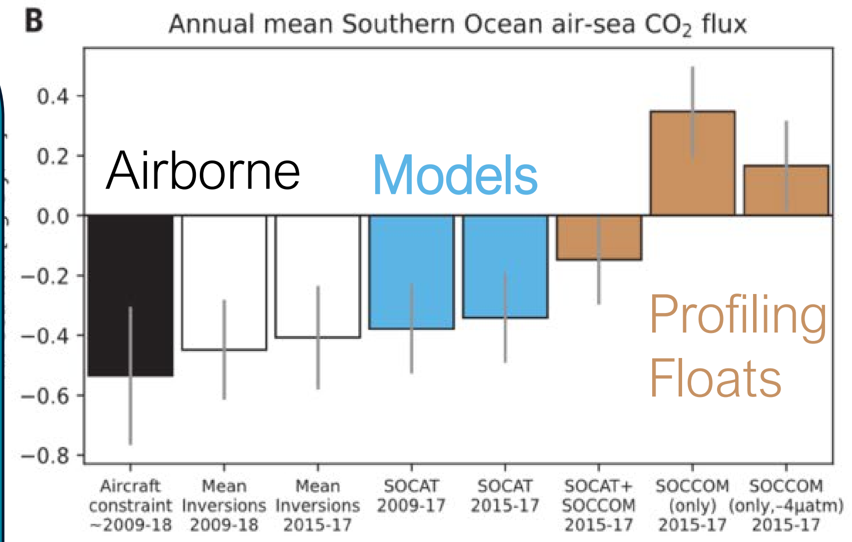


(Long et al. 2021, Science)

Is the Southern Ocean a CO_2 Sink?

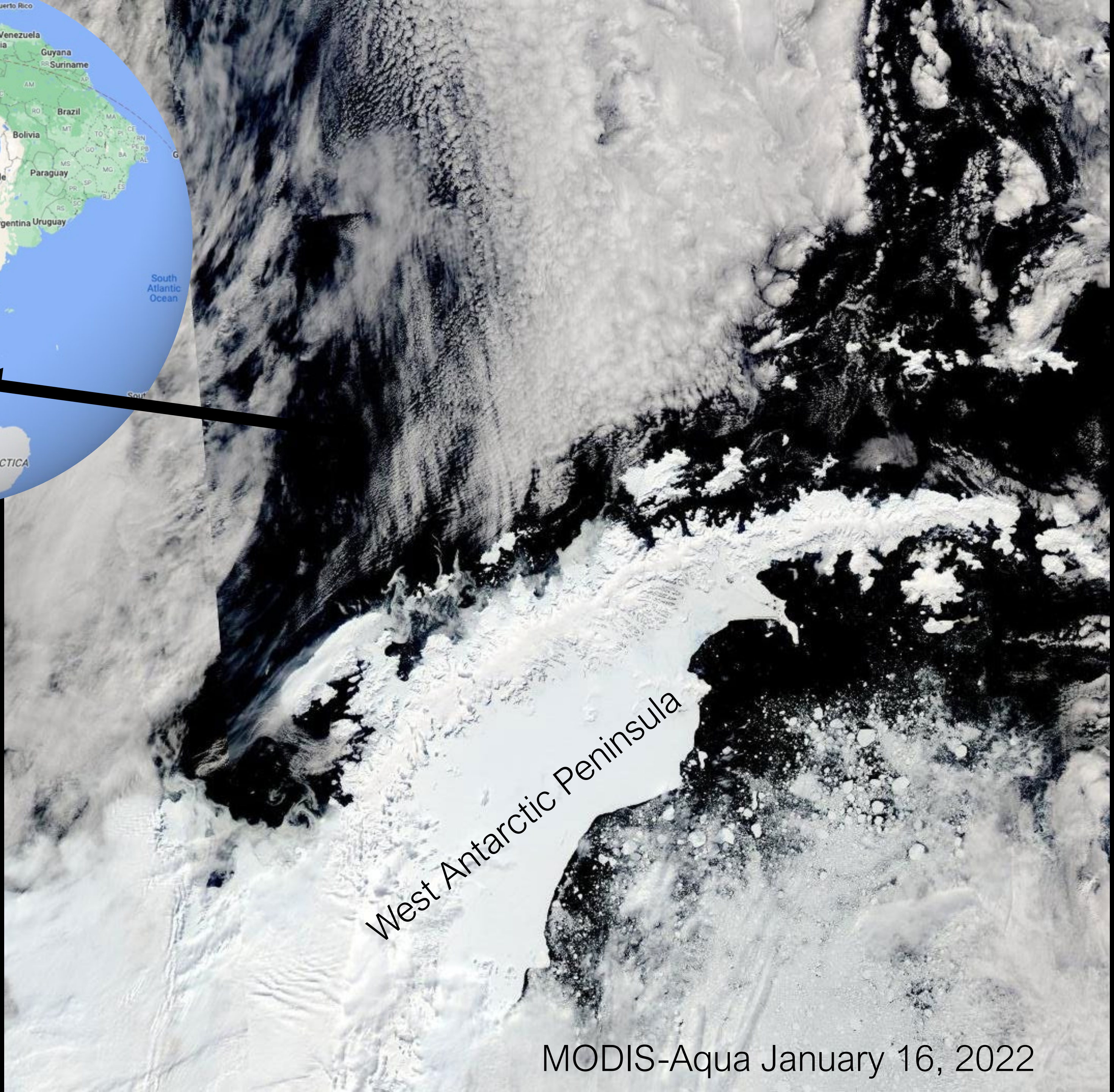
- How much CO_2 does the Southern Ocean really take up?
- Even the *sign* is uncertain:

- What about specific regions?
- Varies with latitude?
- Role of biology?
- Seasonality / Phenology?
- Can satellite ocean color data help us answer these questions?



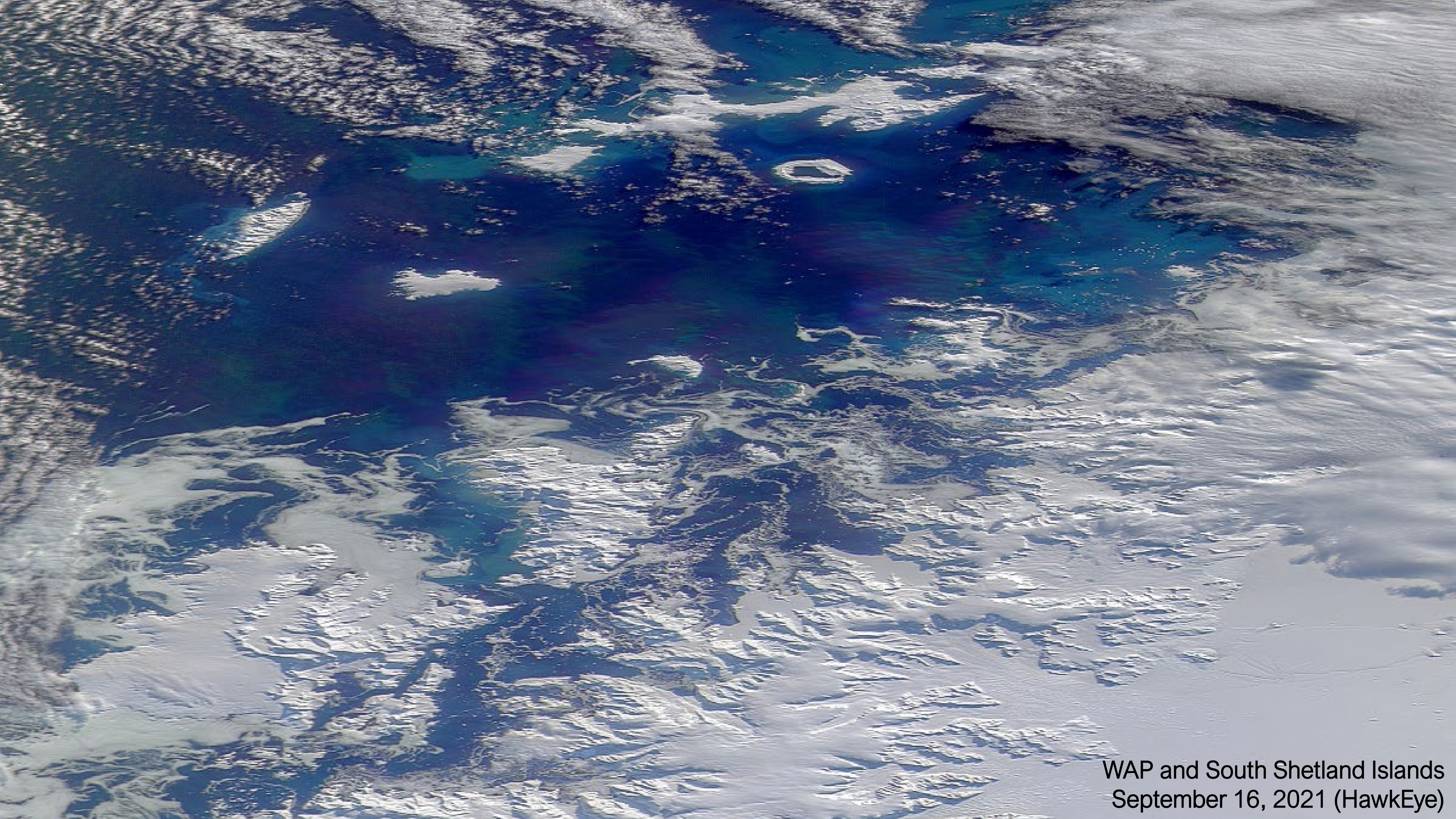
(Long et al. 2021, Science)

Regional case study: West Antarctic Peninsula

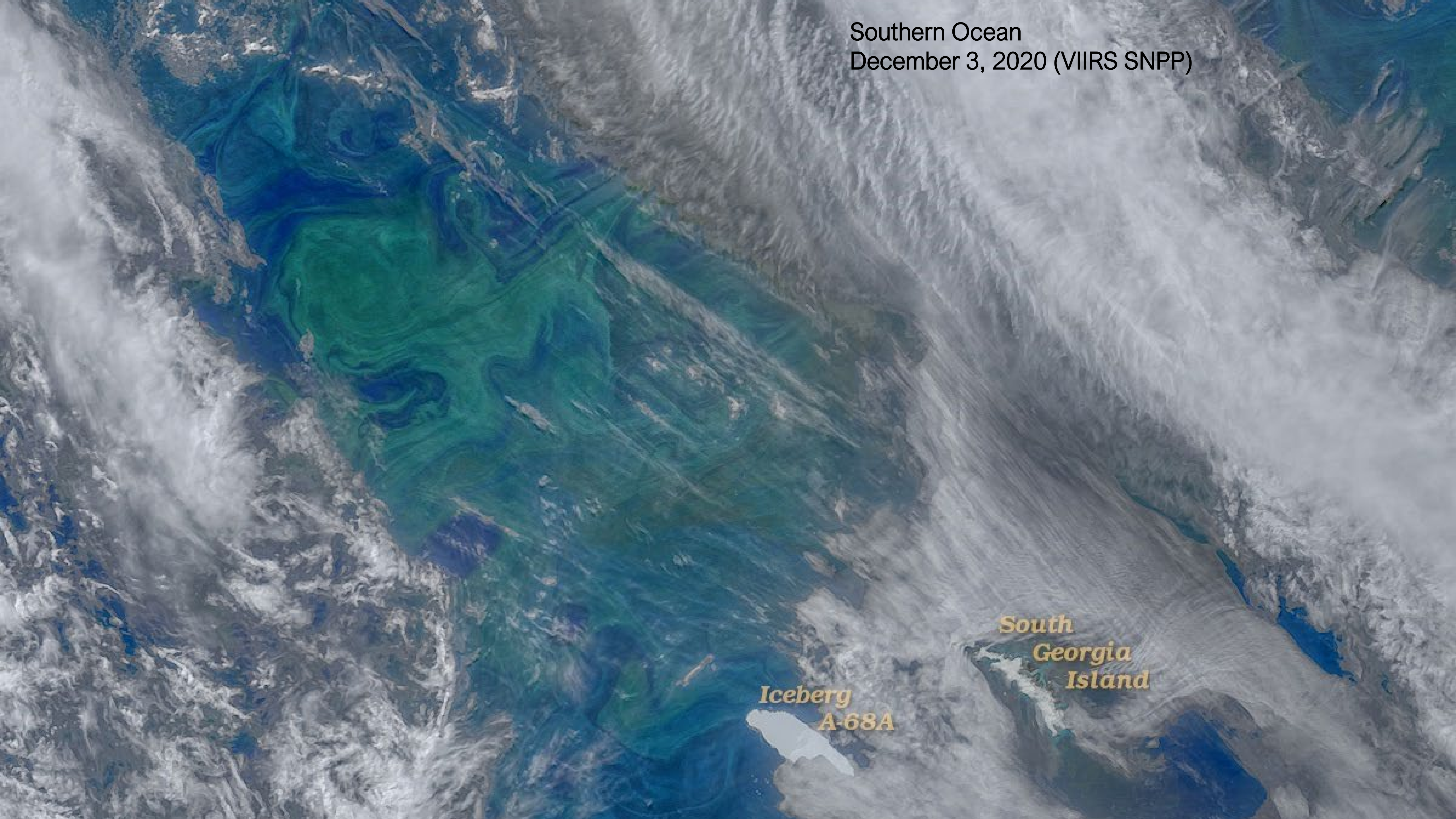


Regional case study: West Antarctic Peninsula

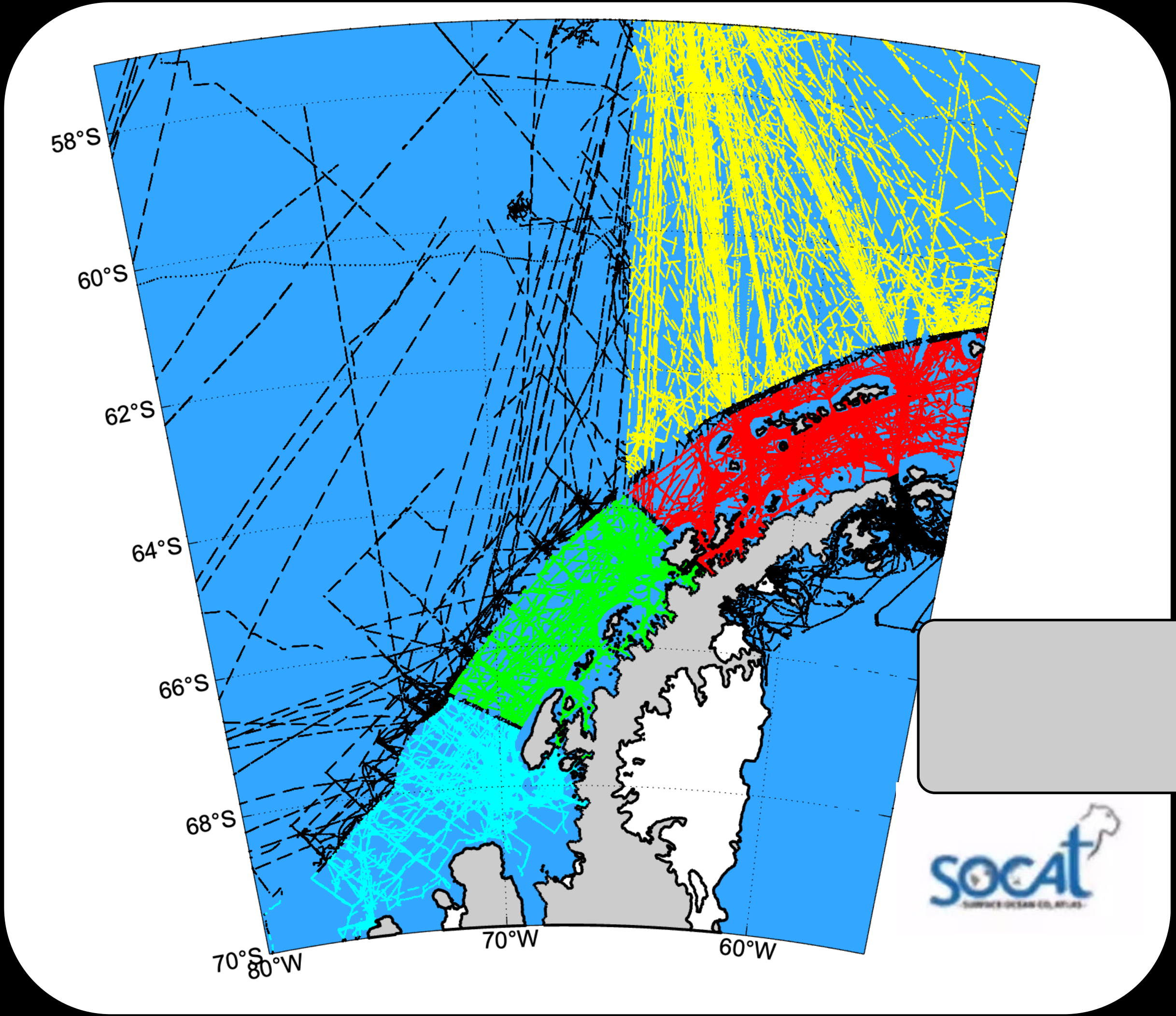
- Legacy of in situ observations LTER 1990-2024
- Rapidly warming
- Sea ice decline
- Glacial retreat
- Substantial amount of ship-based pCO_2 measurements (ship tracks)
- Dynamic ecosystem



WAP and South Shetland Islands
September 16, 2021 (HawkEye)


Southern Ocean
December 3, 2020 (VIIRS SNPP)
South
Georgia
Island
Iceberg
A-68A

Data sources



20 years of ship-track in situ pCO_2 data

(2000-2020, binned to monthly data)

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Data sources

Chlorophyll-a from Ocean Colour Climate Change Initiative (OC-CCI)

(monthly data)

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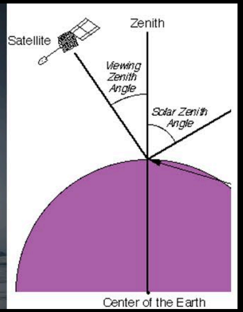
Data sources

Satellite data in the Antarctic:

- Challenges

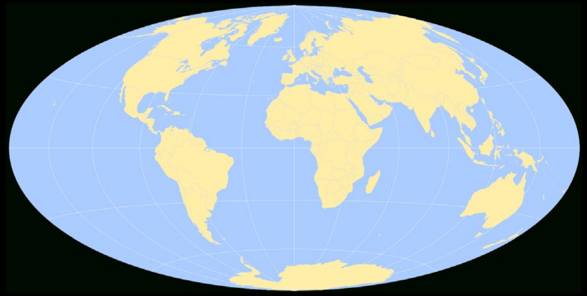


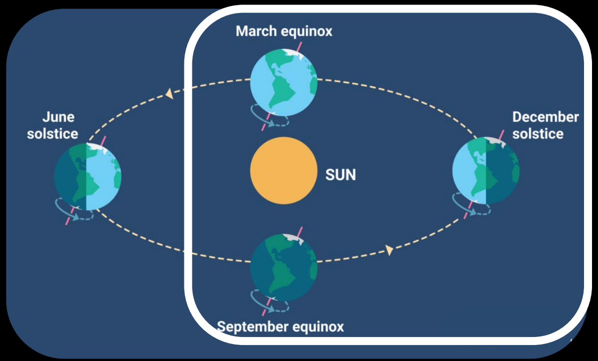
Afonso Ferreira

Sea ice   Clouds   Solar zenith angle

- Opportunities

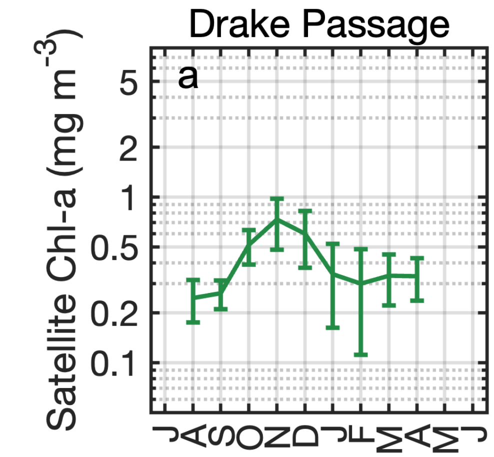


Expand spatial coverage

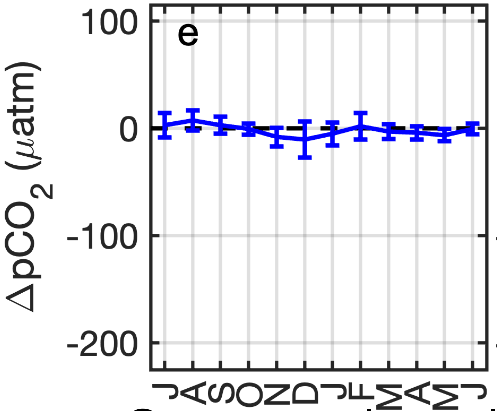


Expand seasonal cycle

Results



Chlorophyll-a from satellite



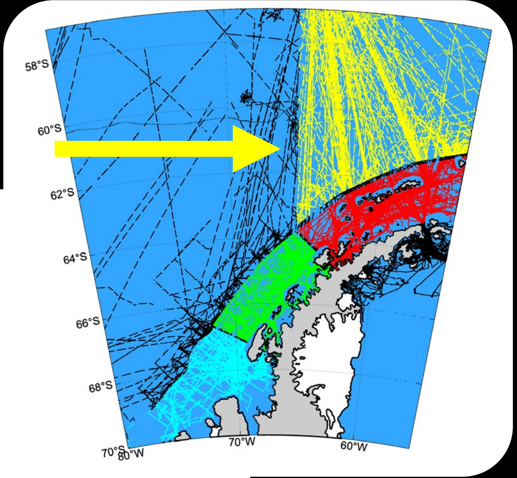
Outgassing - positive

Delta pCO_2 from research vessels

Uptake - negative

Seasonal cycle

Spring – Summer – Fall



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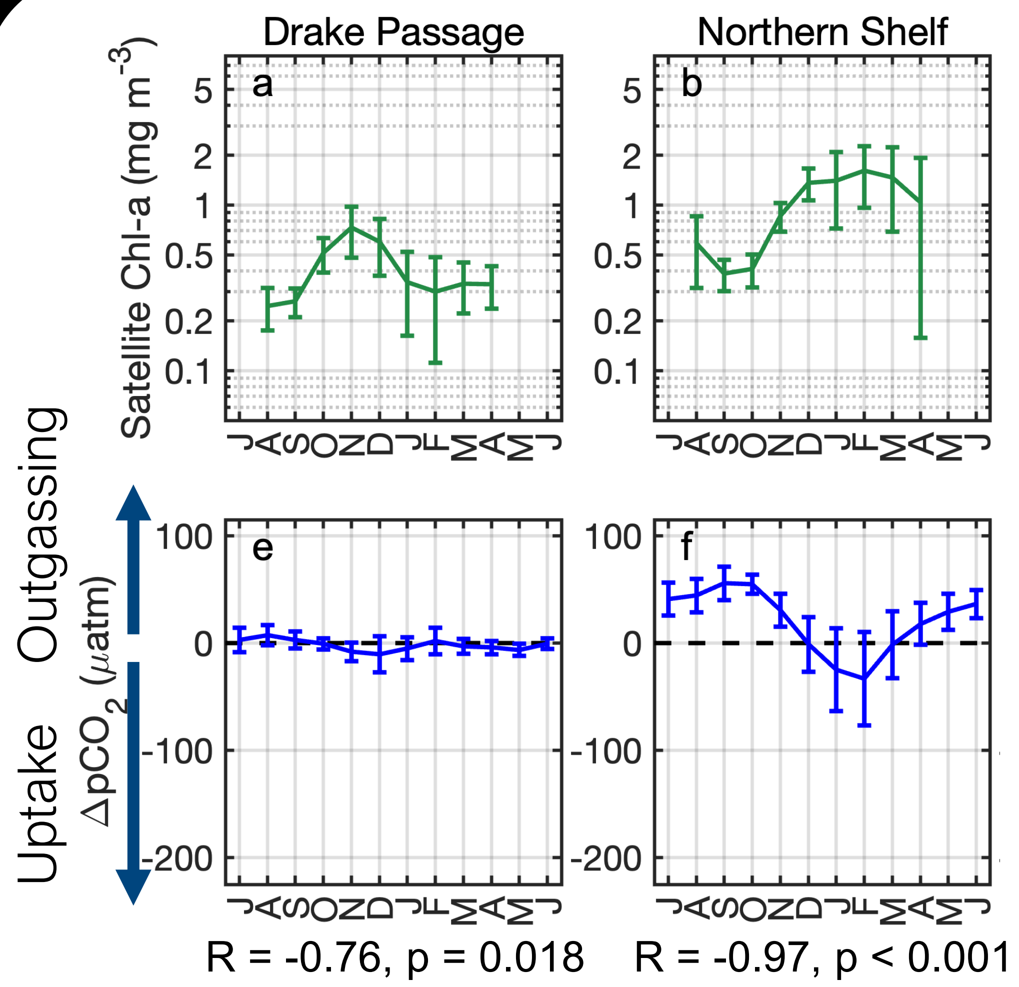
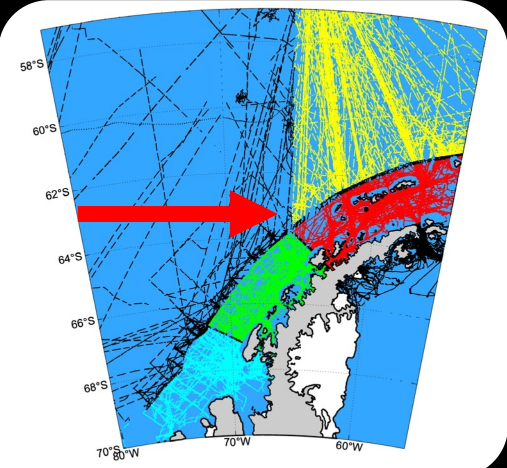
Results





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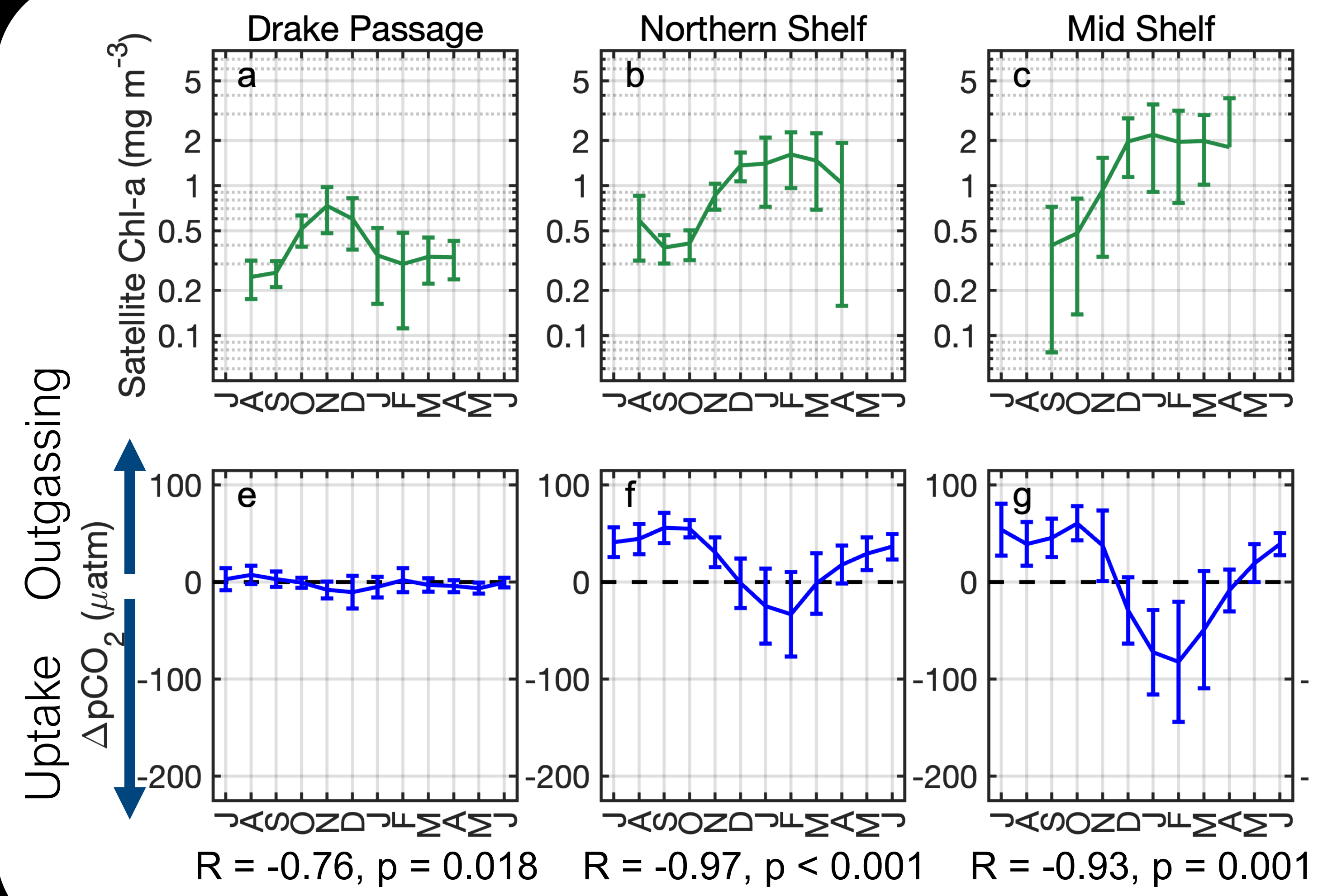
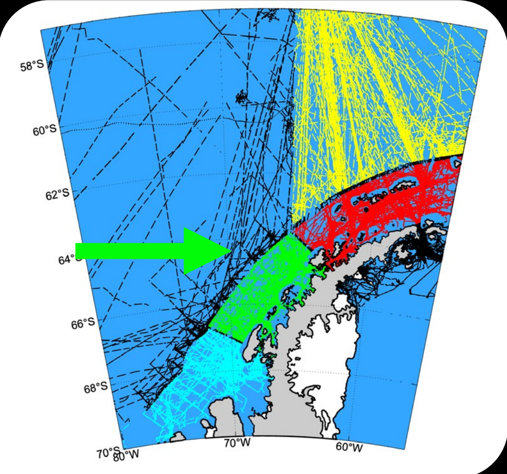
Results





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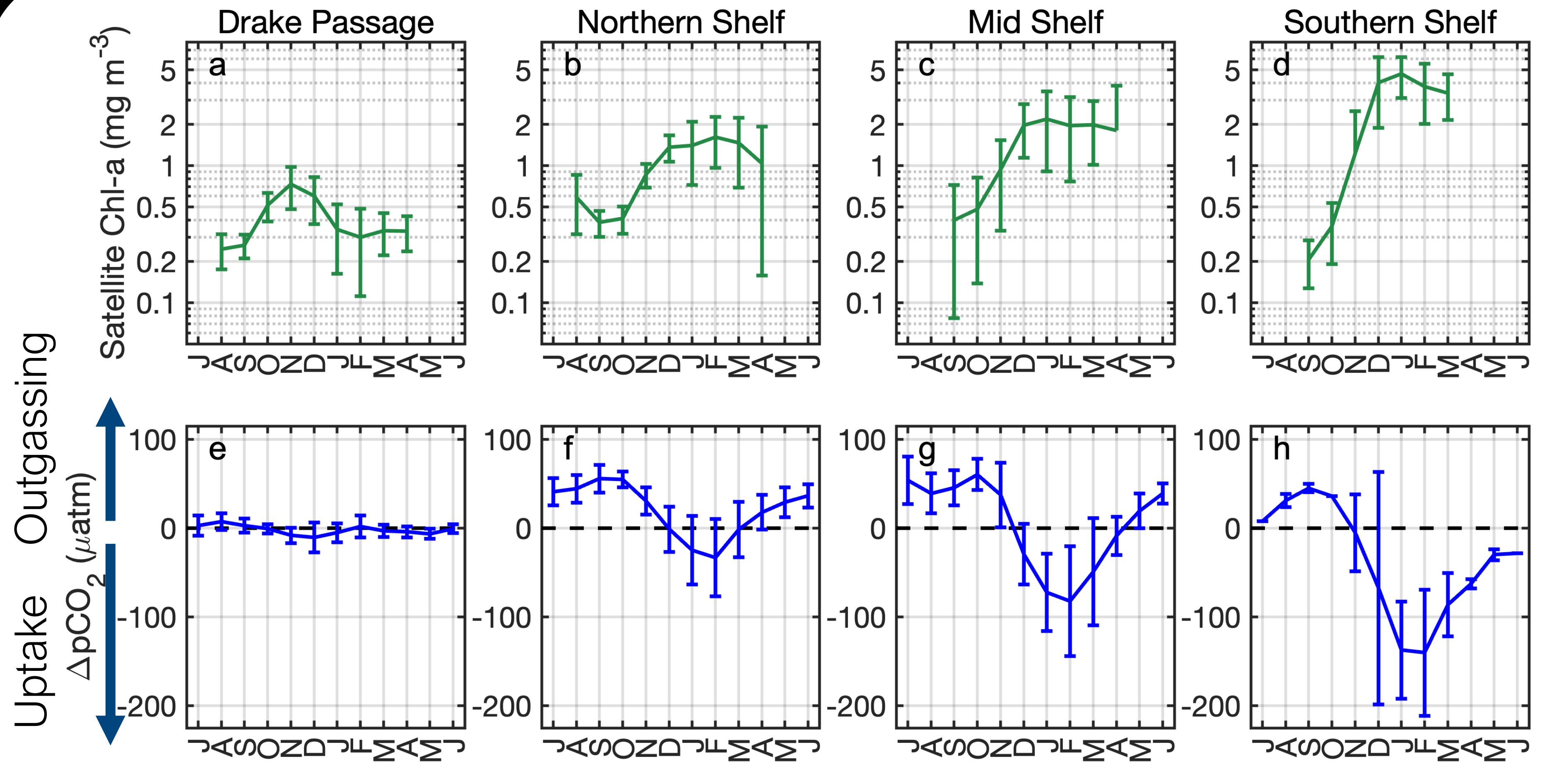
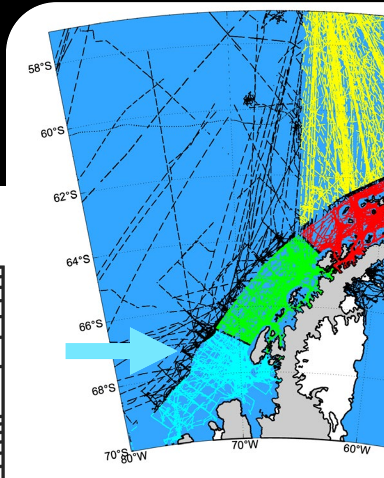
Results



R = -0.76, p = 0.018 R = -0.97, p < 0.001 R = -0.93, p = 0.001, R = -0.95 p = 0.001



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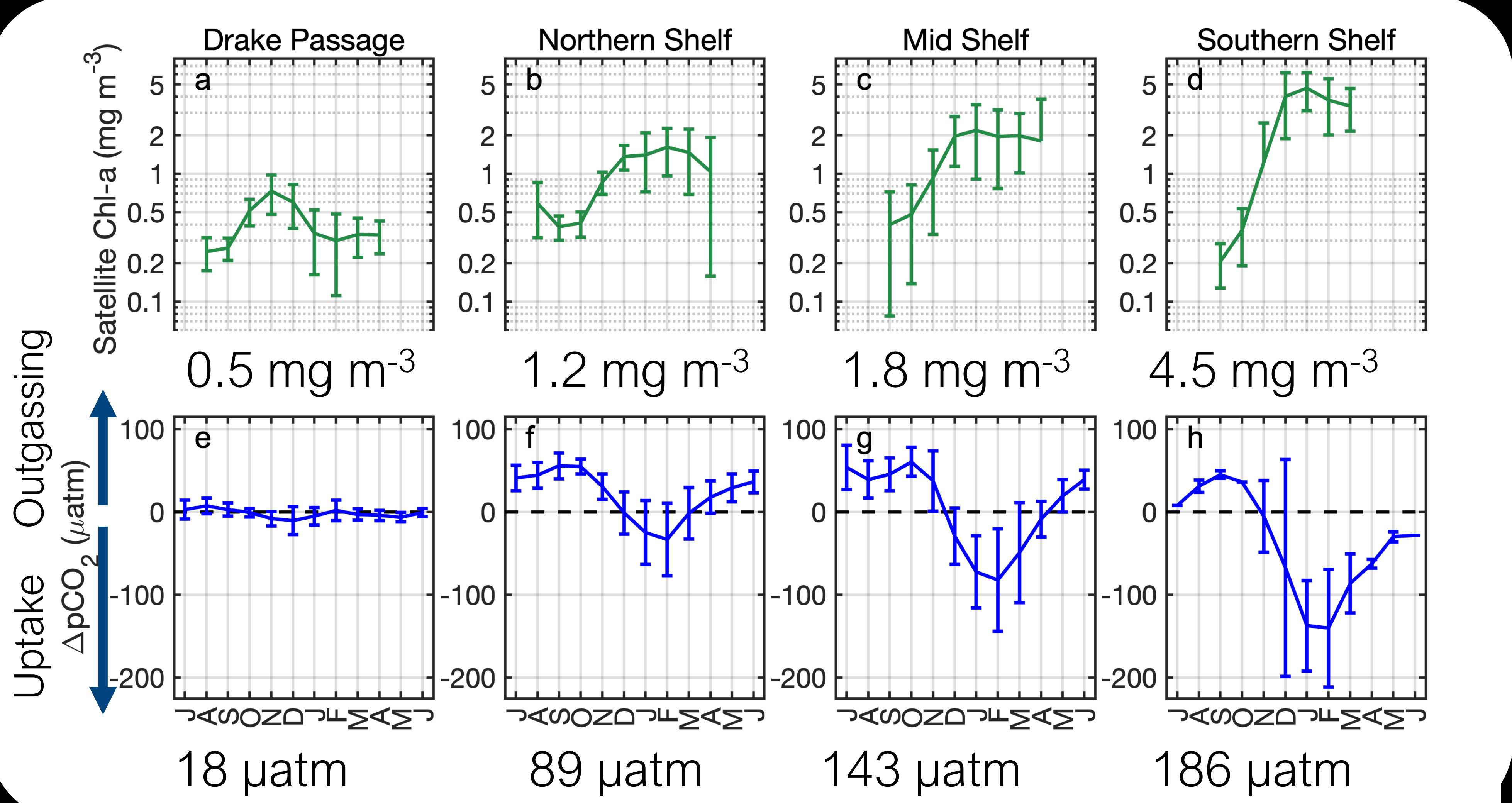
Results – Amplitudes of Seasonal Cycles



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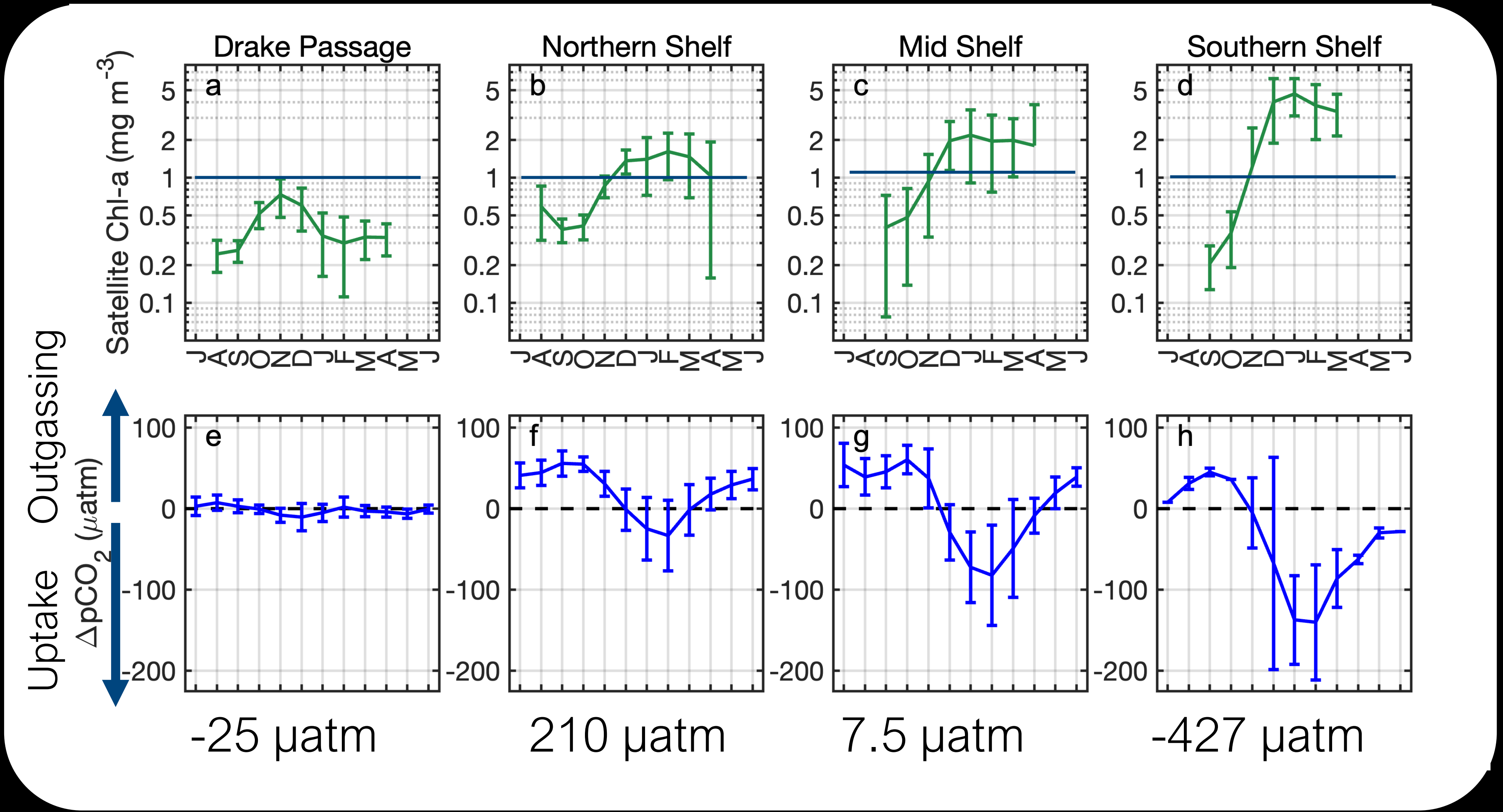
Results – Annual Mean Air-Sea Flux



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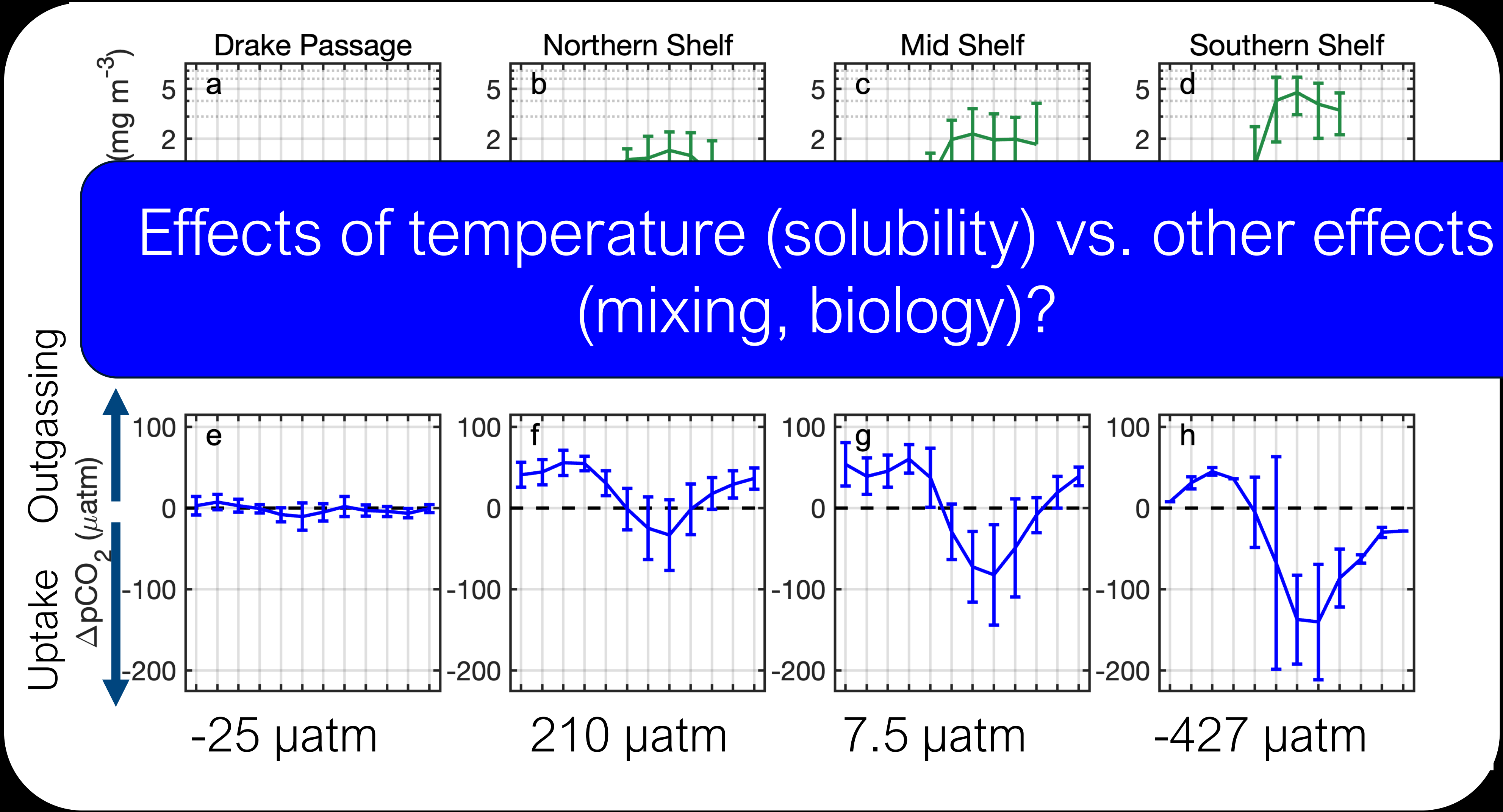

Effects of temperature (solubility) vs. other effects (mixing, biology)?

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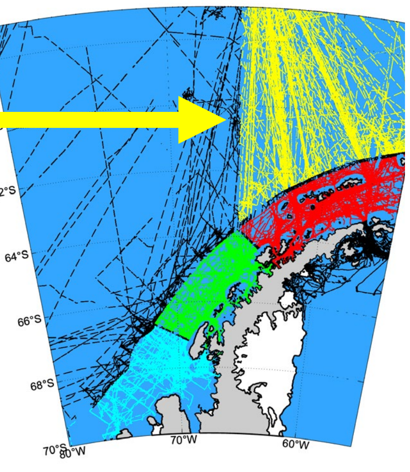
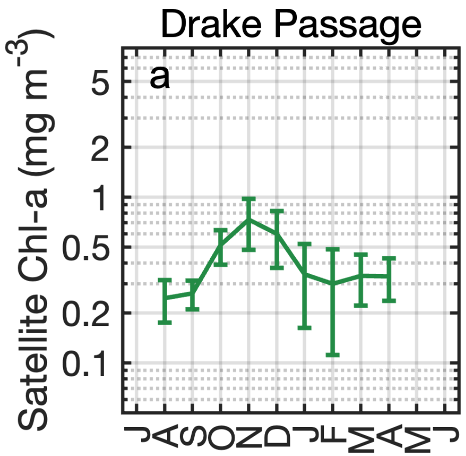
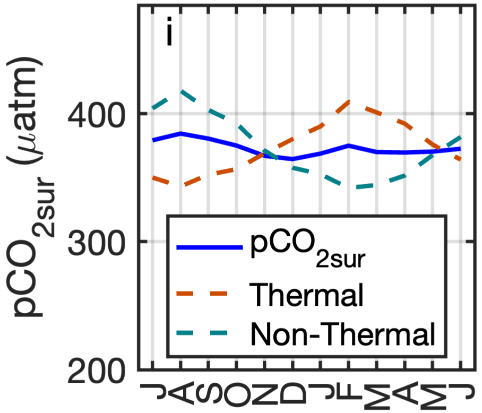
Results – T vs. non-T components





Chlorophyll-a from satellite



Seasonal cycle

Spring – Summer – Fall

pCO_{2sur} from research vessels

Decomposed into T and non-T components via Takahashi et al. (1993) w/ equations from Wanninkhof et al. (2022).

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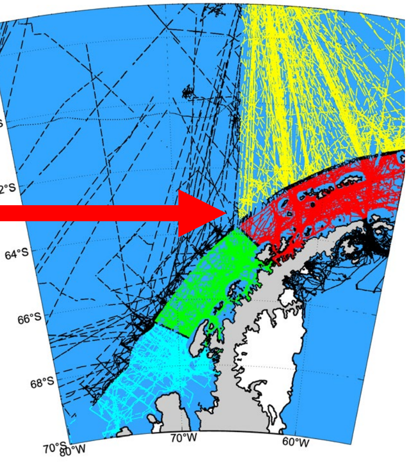
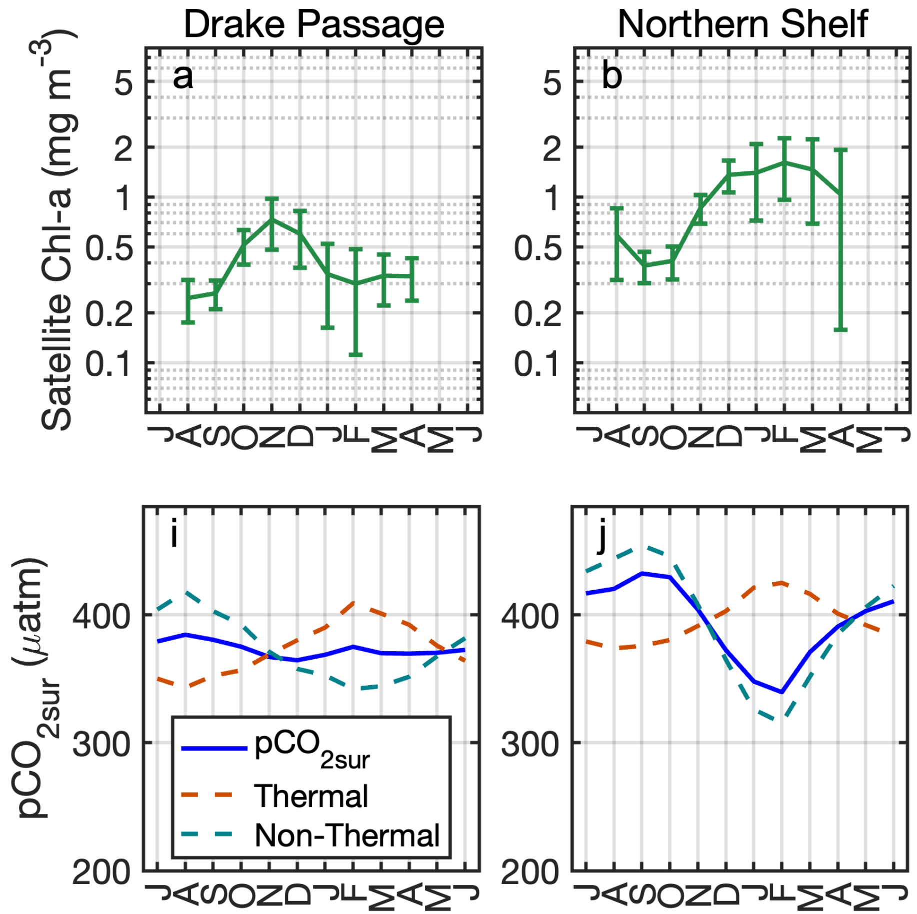
Results – T vs. non-T components





Chl-a vs. pCO_{2sur}-T: R = -0.07, p = 0.85 R = 0.96, p<0.001

Chl-a vs. pCO_{2sur}-non-T: R = -0.13, p = 0.74 R = -0.98, p<0.001

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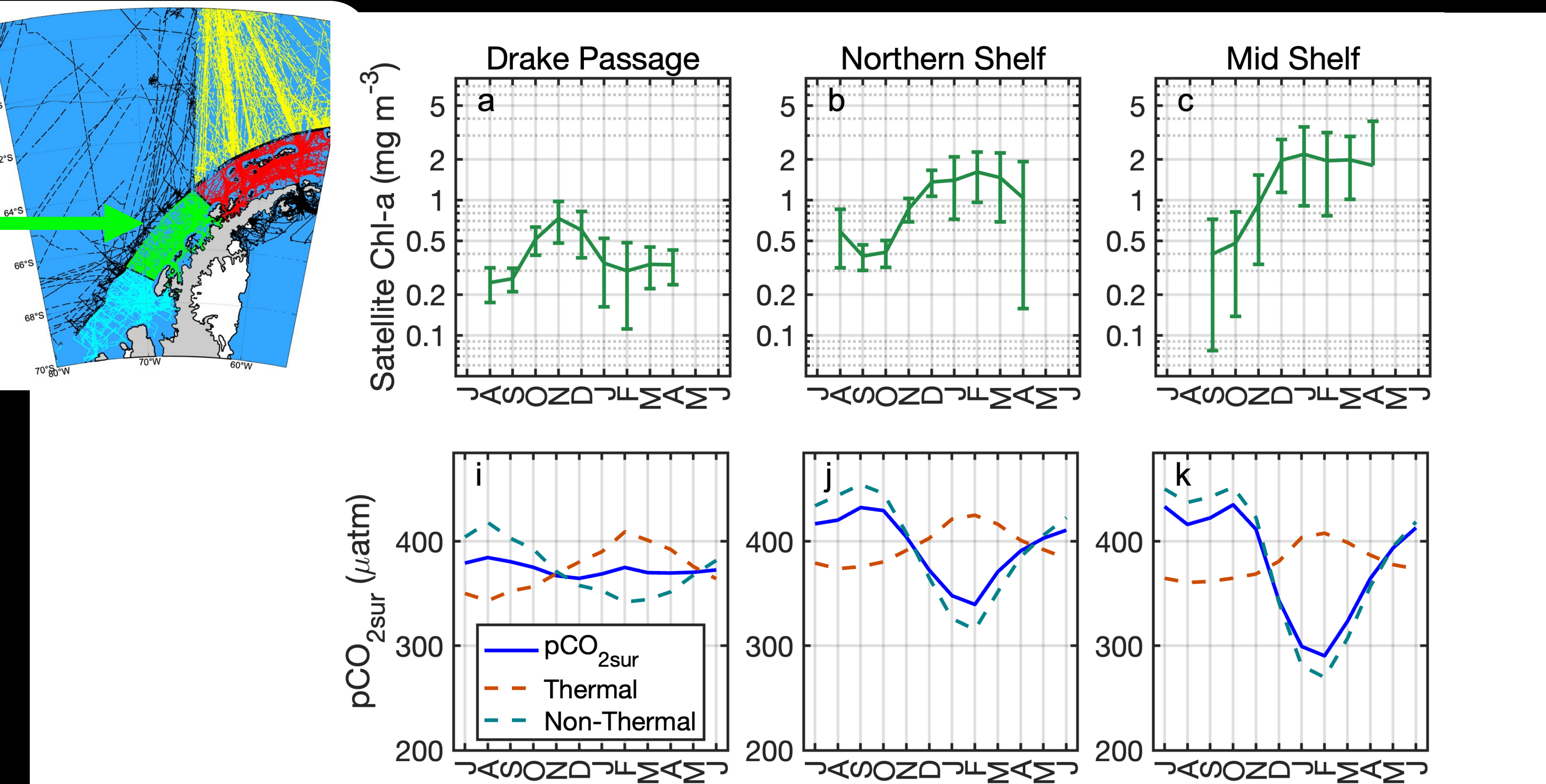
Results – T vs. non-T components



Chl-a vs. pCO_{2sur}-T: R = -0.07, p = 0.85 | R = 0.96, p<0.001 | R = 0.9, p=0.002

Chl-a vs. pCO_{2sur}-non-T: R = -0.13, p = 0.74 | R = -0.98, p<0.001 | R = -0.94, p<0.001

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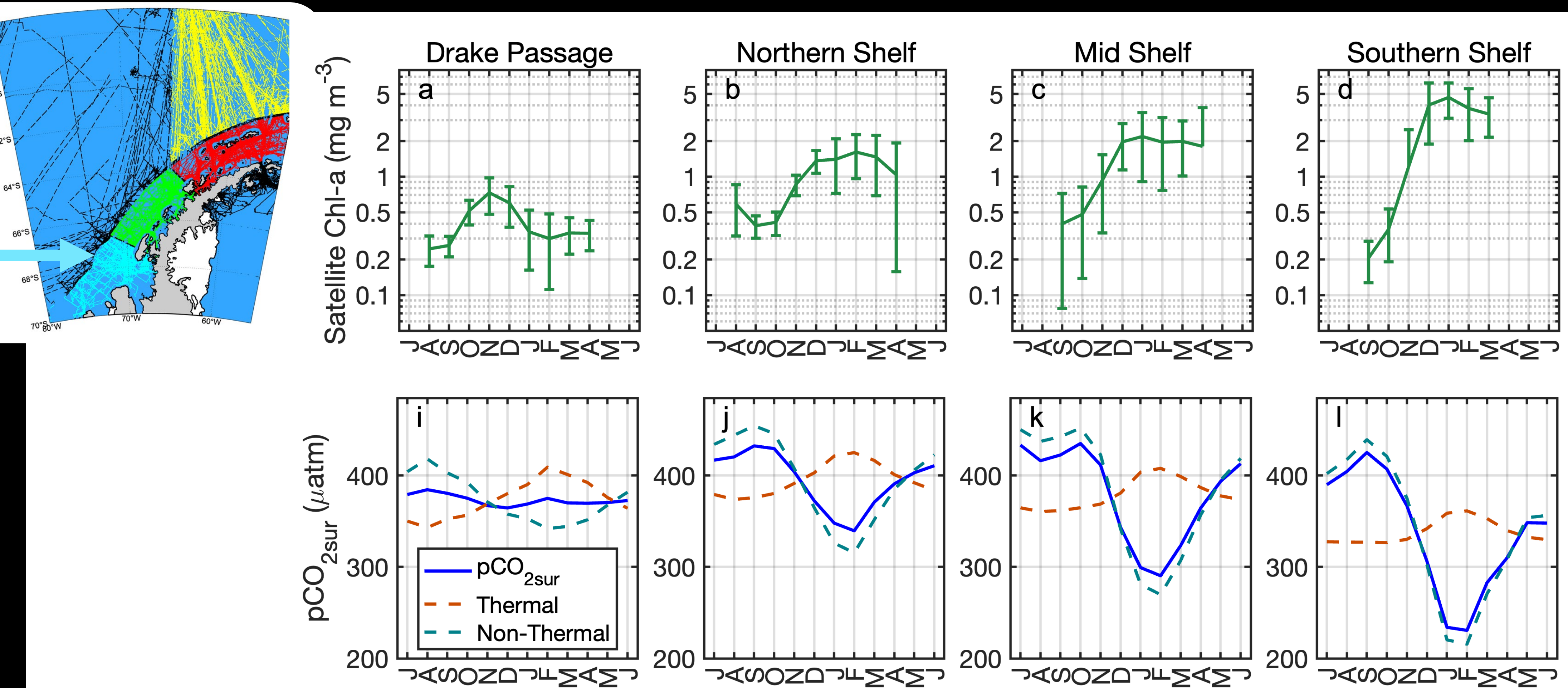
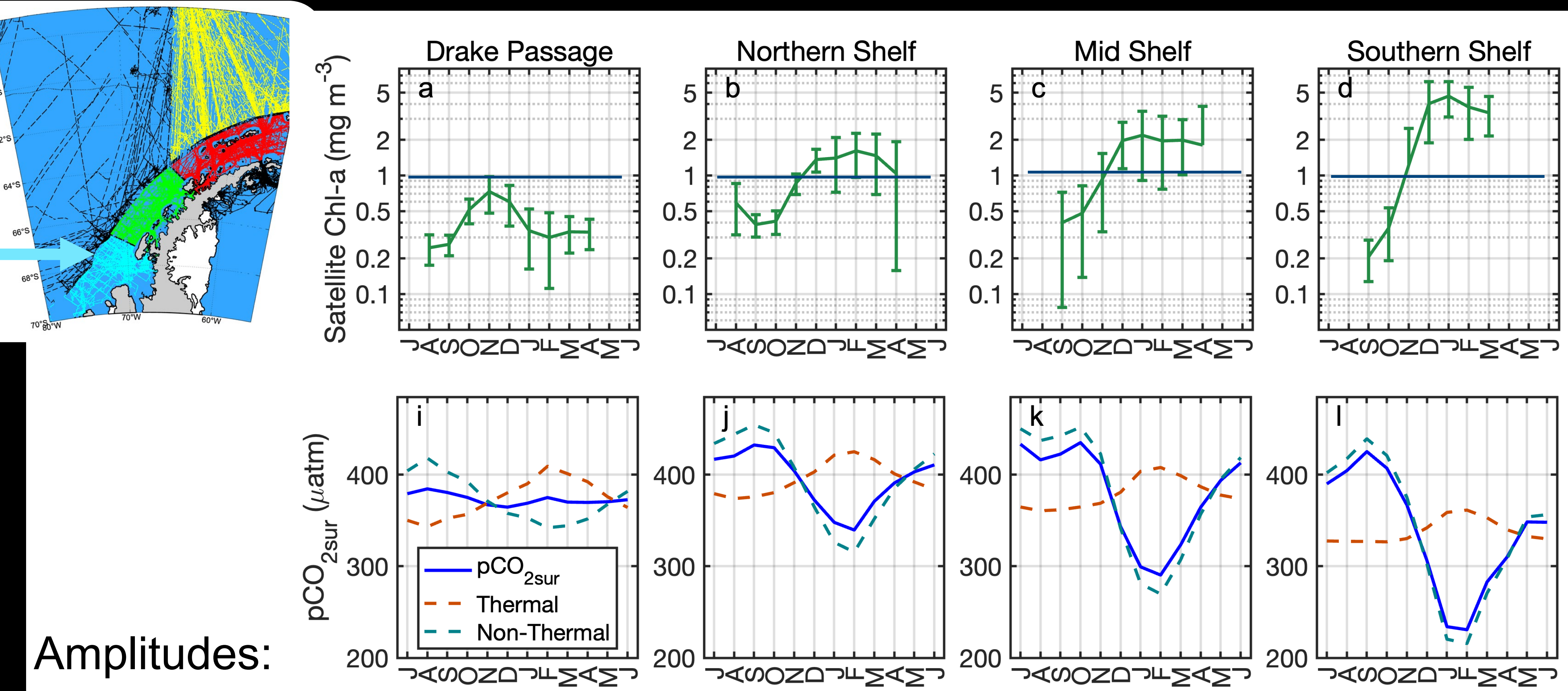
Results – T vs. non-T components



Chl-a vs. pCO_{2sur}-T: R = -0.07, p = 0.85 R = 0.96, p<0.001 R = 0.9, p=0.002 R = 0.9, p=0.006

Chl-a vs. pCO_{2sur}-non-T: R = -0.13, p = 0.74 R = -0.98, p<0.001 R = -0.94, p<0.001 R = -0.95, p=0.001

Results – T vs. non-T components



Amplitudes:

Chl-a vs. pCO_{2sur}-T:	66 µatm	51 µatm	47 µatm	35 µatm
Chl-a vs. pCO_{2sur}-non-T:	76 µatm	139 µatm	182 µatm	224 µatm

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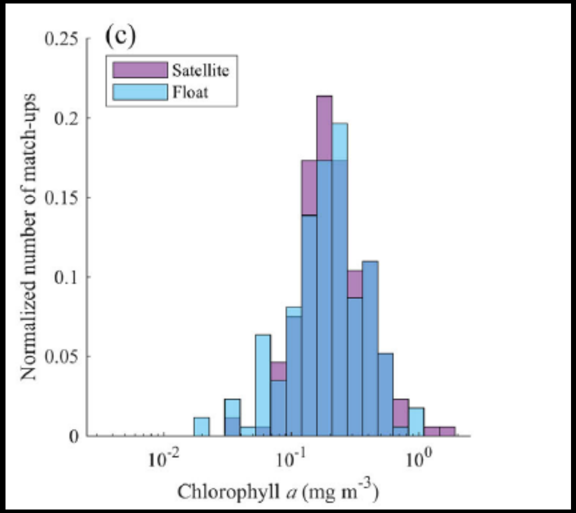
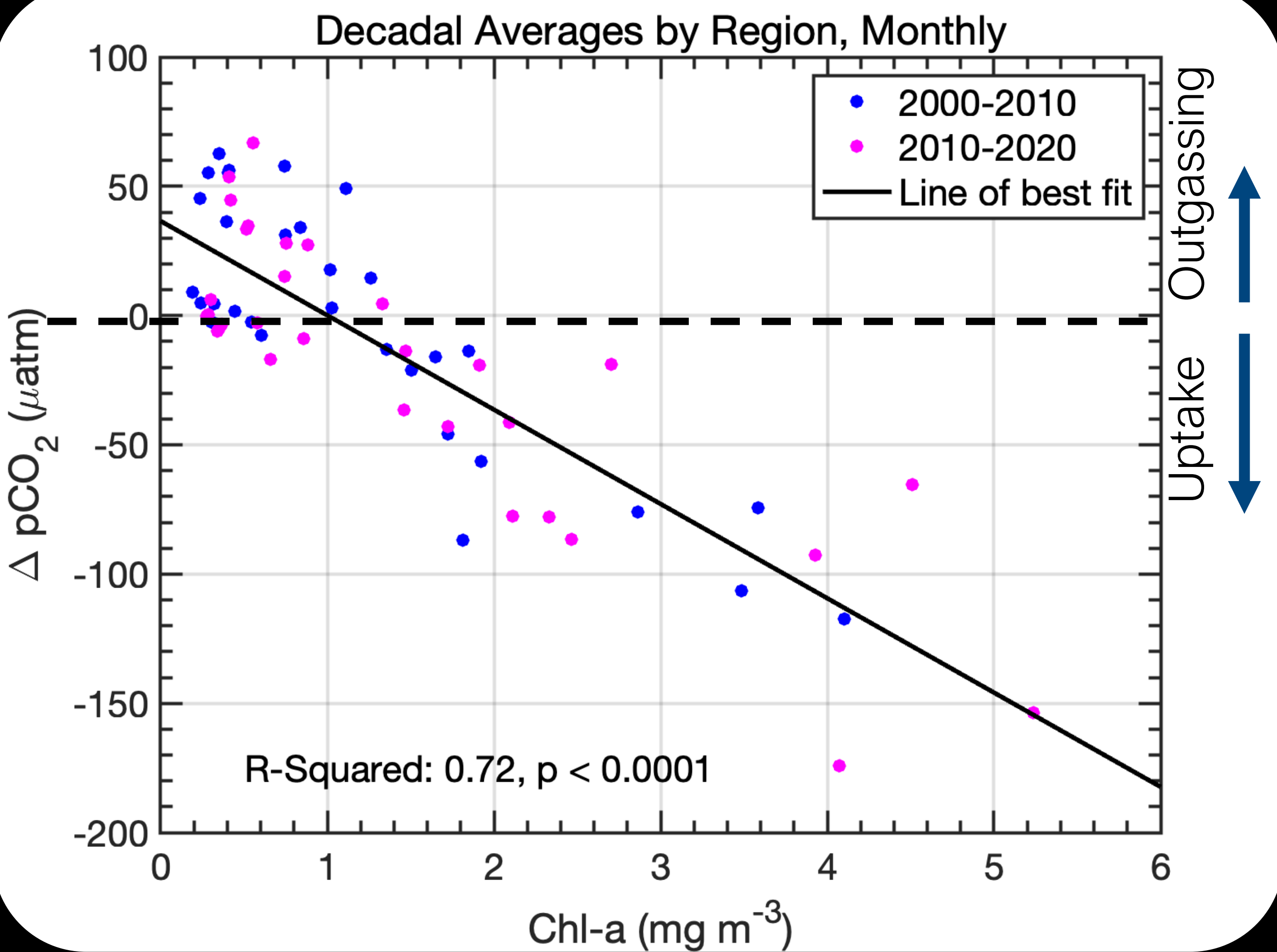
Biology dominates Thermal in the Coastal Zone!



SOCCOM matchups (Haentjens et al. 2017)

Floats: mostly Chl-a < 1 mg m^{-3}



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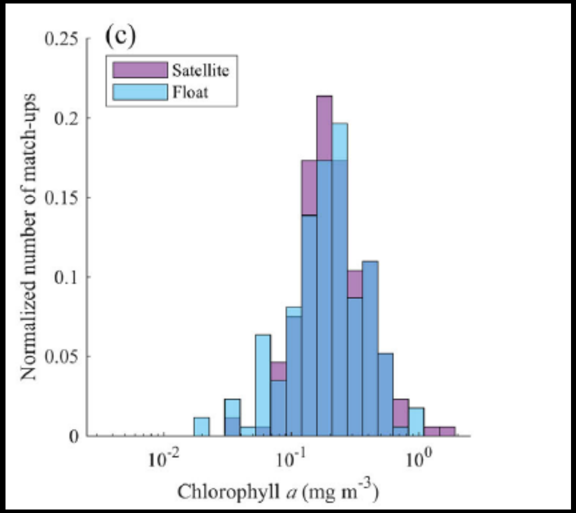

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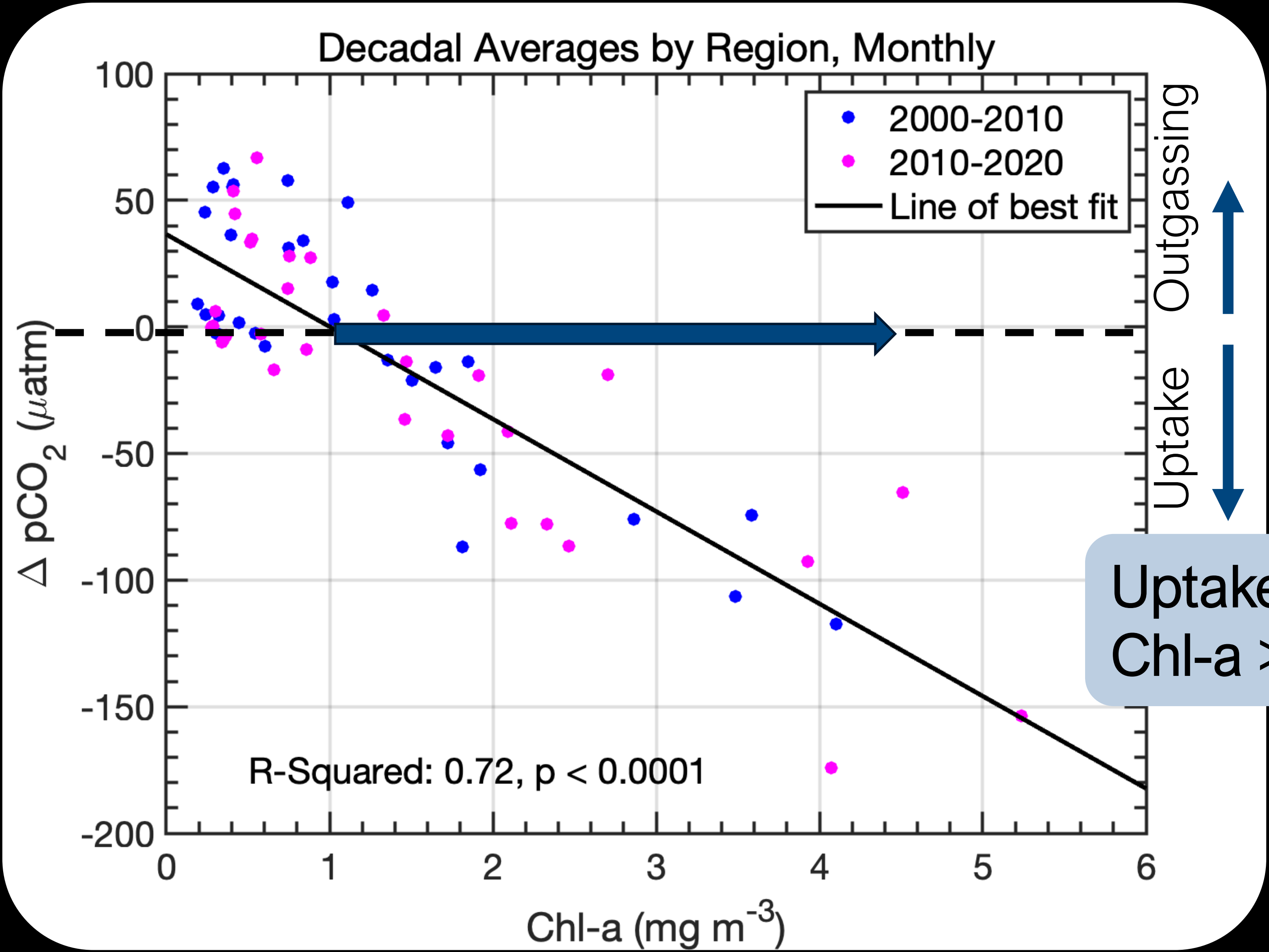

Uptake generally when Chl-a > 1 mg m^{-3}

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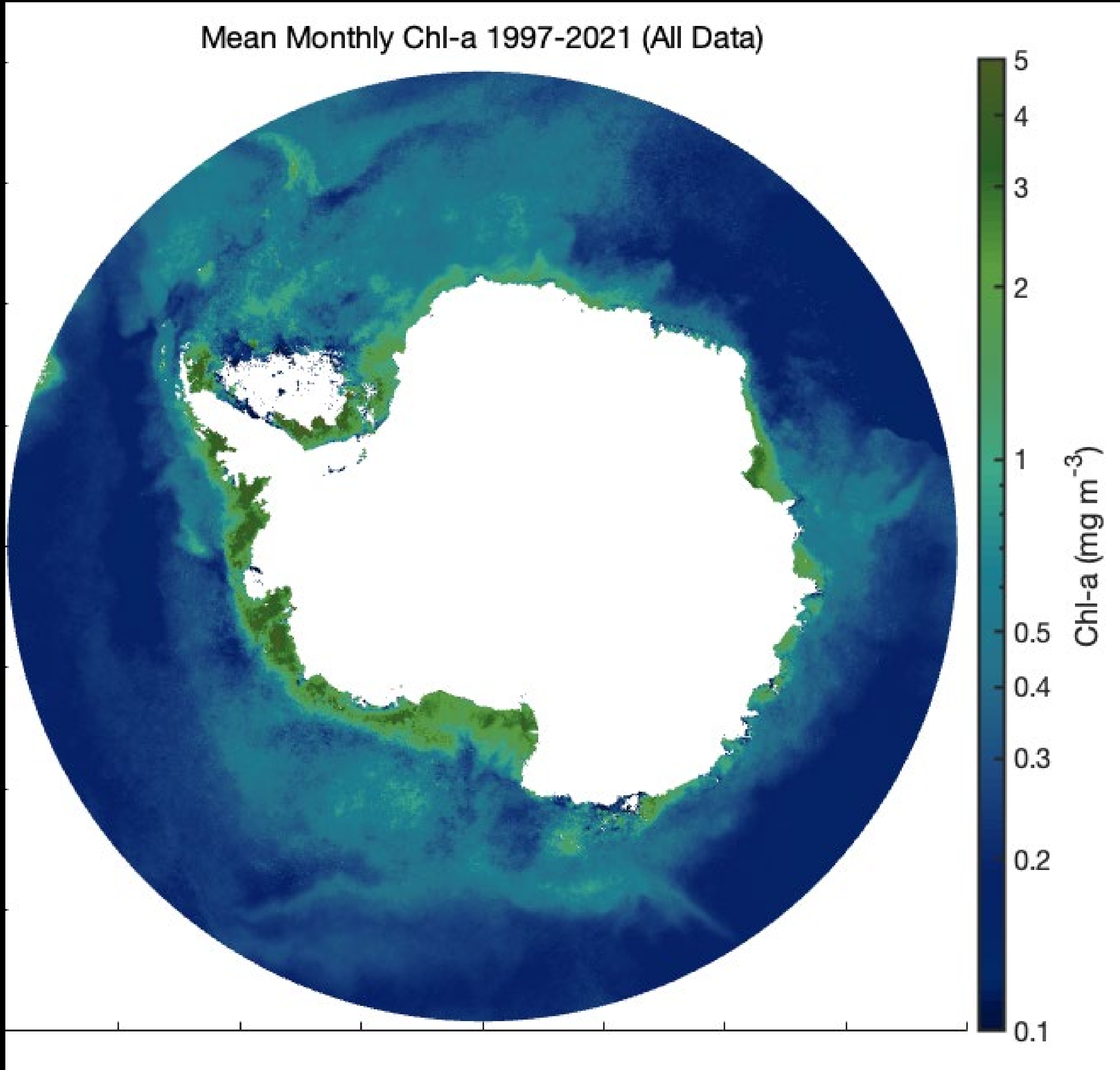
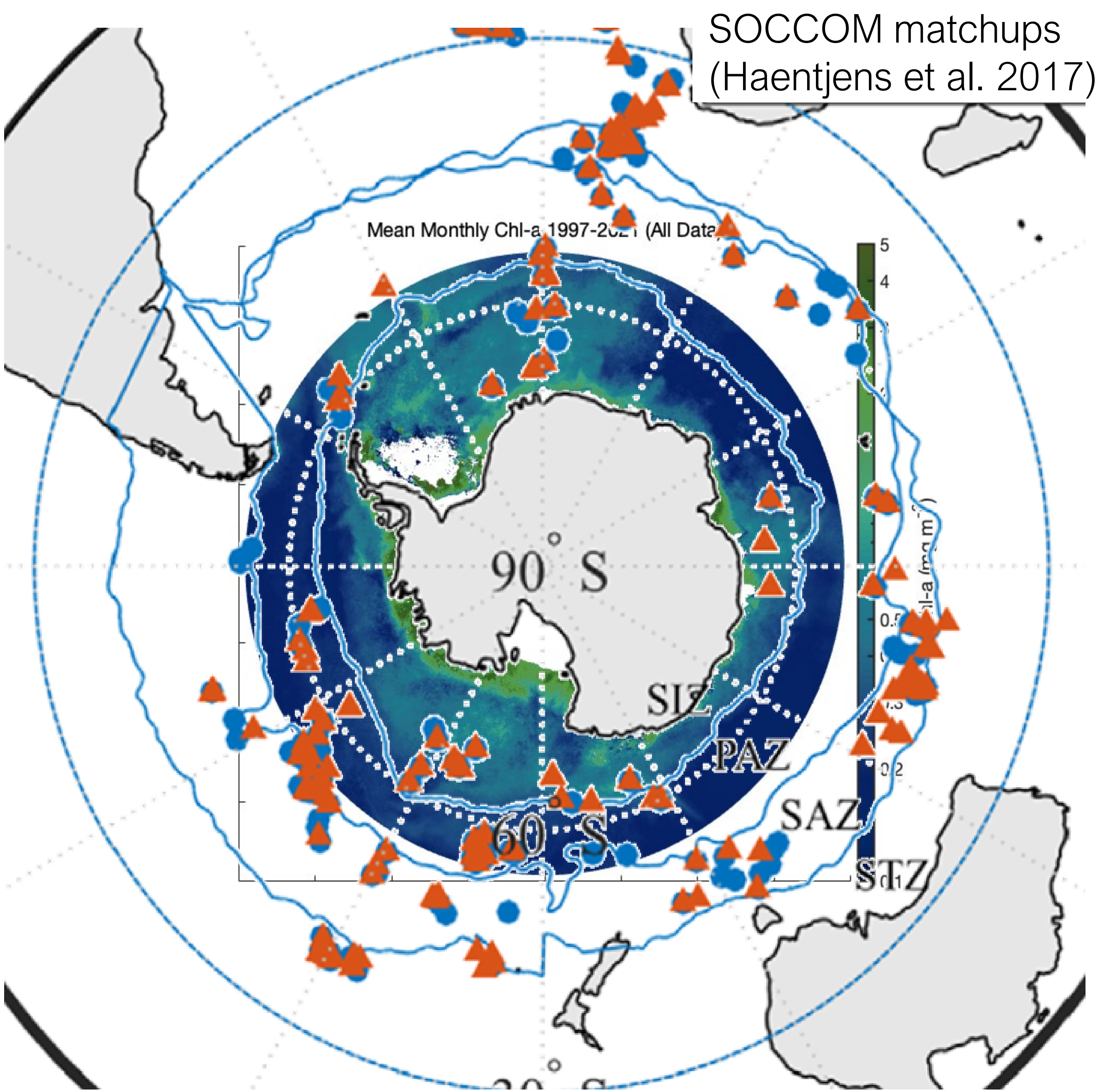
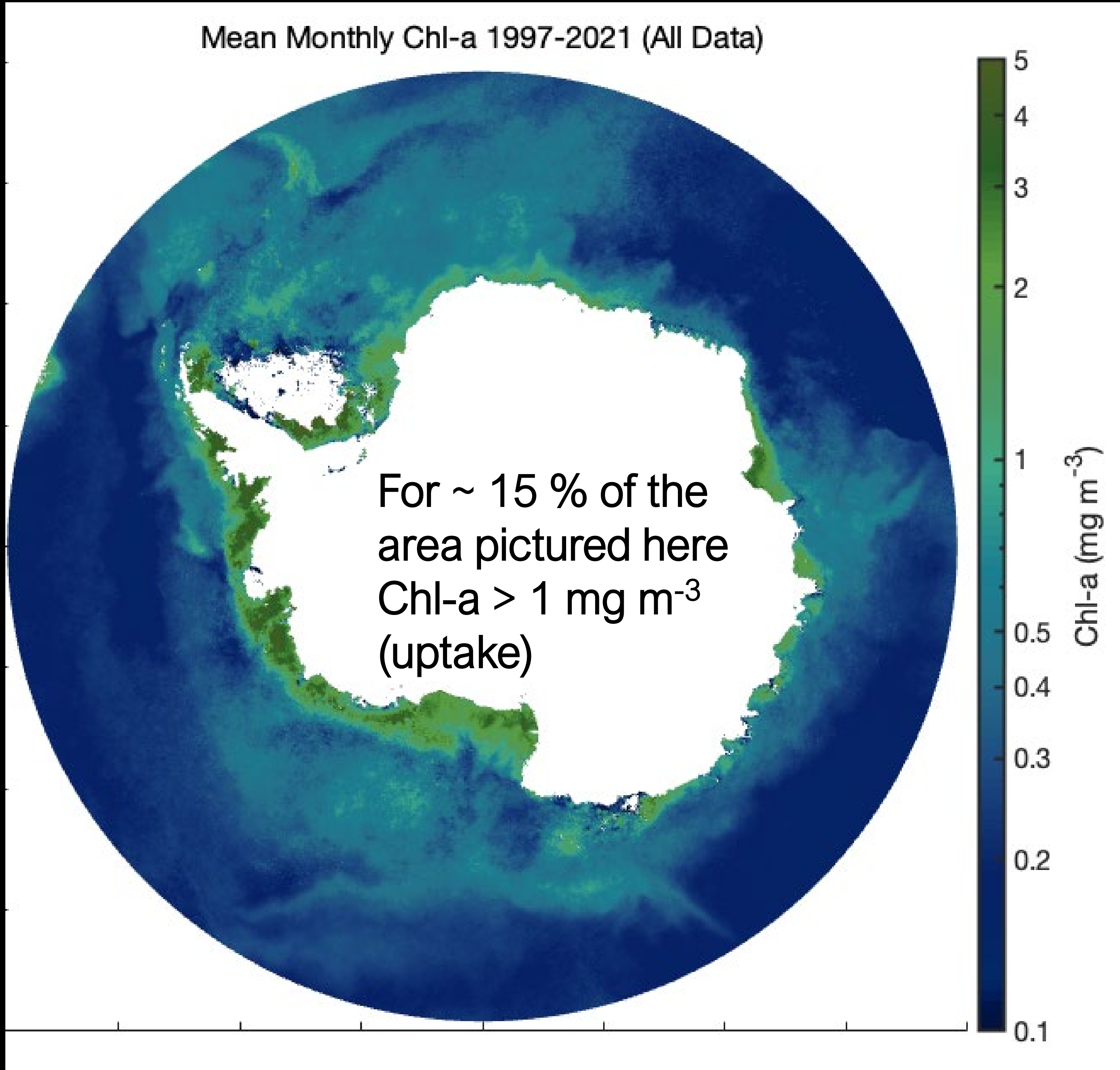


Coastal Zone of the Southern Ocean

We are working on using the imagery and these relationships to estimate “average” carbon uptake across different zones in the Antarctic



Are SOCCOM floats - in general - missing patterns from the Coastal Zone?



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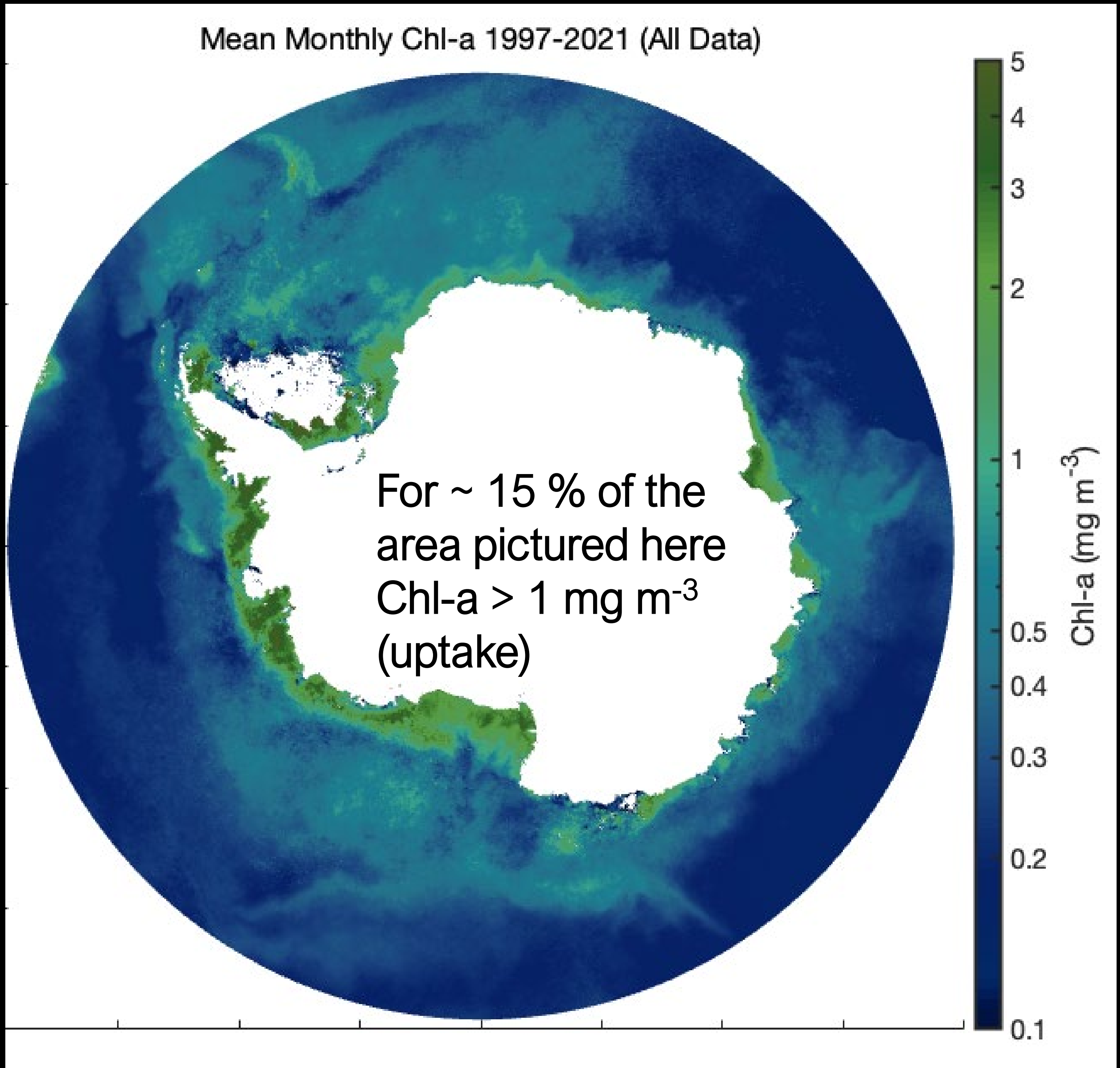


Summary:

- Biology dominates air-sea CO_2 flux in the coastal zone of the West Antarctic Peninsula
- Satellite ocean color data helps in areas where floats commonly undersample

Knowledge gaps and priorities for next steps

- 1 year
  - "average" spatial patterns in delta-pCO_2 estimated from ocean color (a first-try)
- 5 years
  - With depth: Incorporate optics on BGC-Argo floats that stay on the shelf, obtain depth profiles
  - Winter: full seasonal cycle including under-ice
- 10 years – How will this change as:
  - Areas previously covered in sea ice open up for more of the season?
  - Ice-associated waters become open water for longer with higher wind speed?

Acknowledgements

NSF NASA UCONN UNIVERSITY OF CONNECTICUT

Collaborators on Antarctica work:

- Heidi Dierssen, Uconn
- Michael Cappola, UDel
- Sharon Stammerjohn, CU Boulder
- Oscar Schofield, Rutgers
- Dave Munro, CU Boulder
- Heather Kim, WHOI
- Maria Kavanaugh, OSU
- Hilde Oliver, WHOI
- Amanda Fay, Columbia/Lamont-Doherty

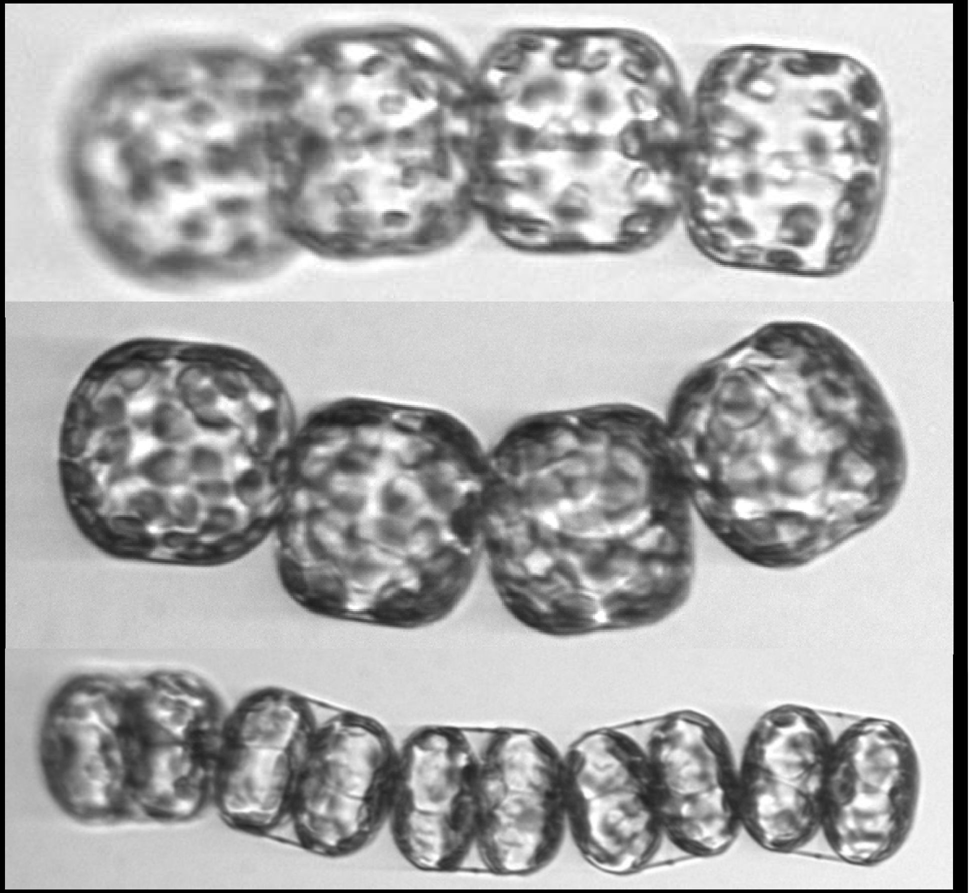
Western Antarctic Peninsula and South Shetland Islands, September 16, 2021 (HawkEye)

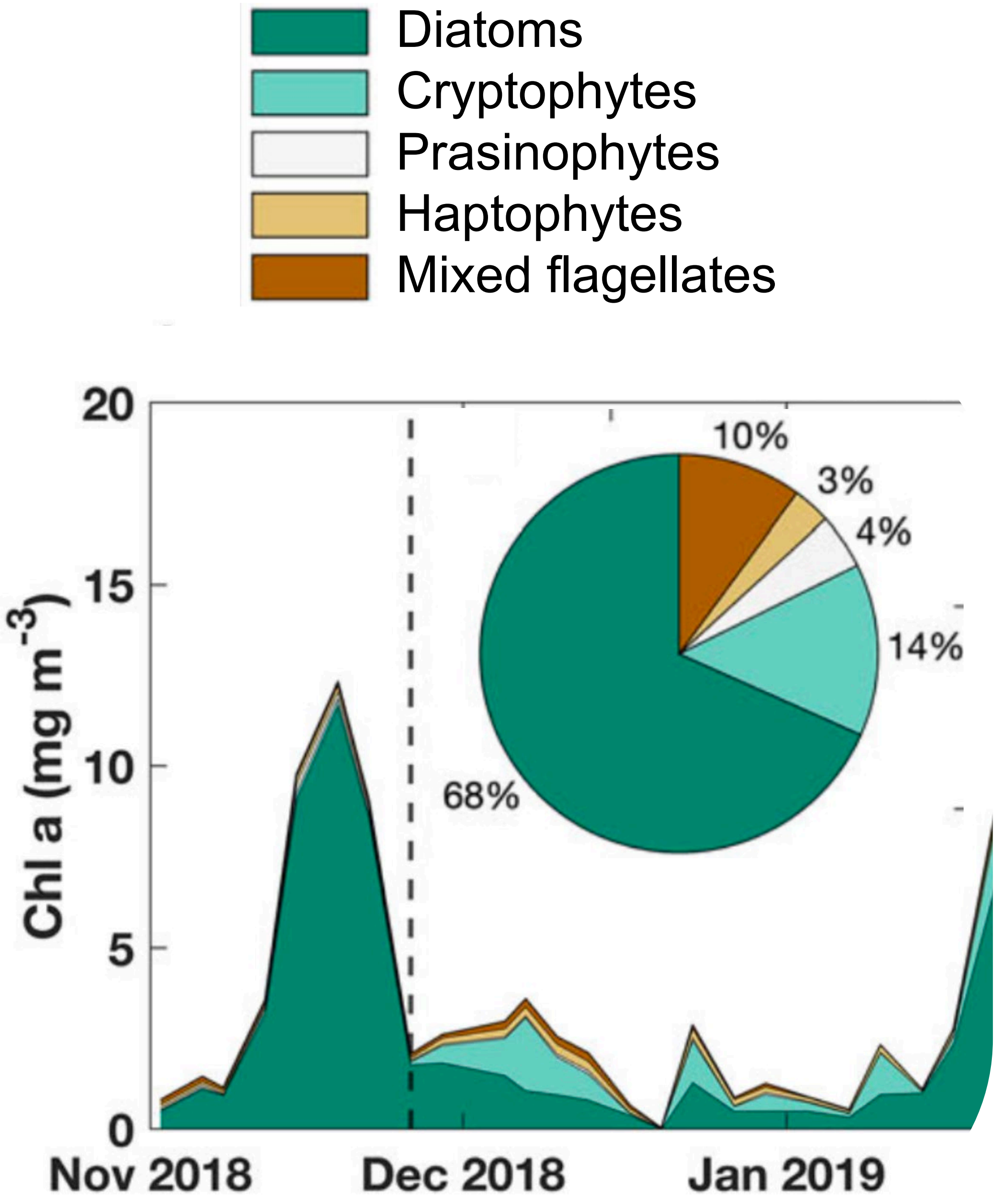
Questions?

Contact: jturners@odu.edu

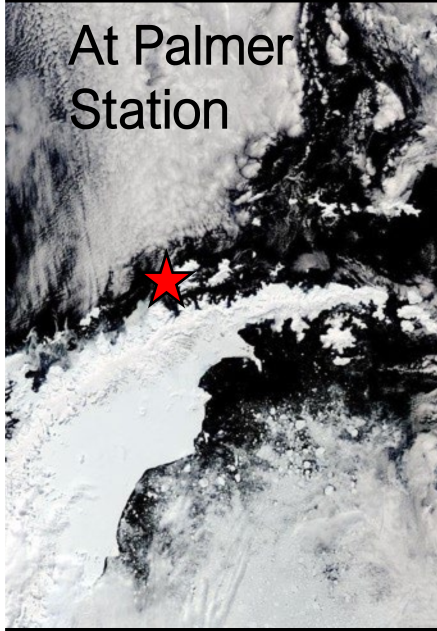
Extra Slides

- Nearshore, 1st bloom of the season mostly diatoms

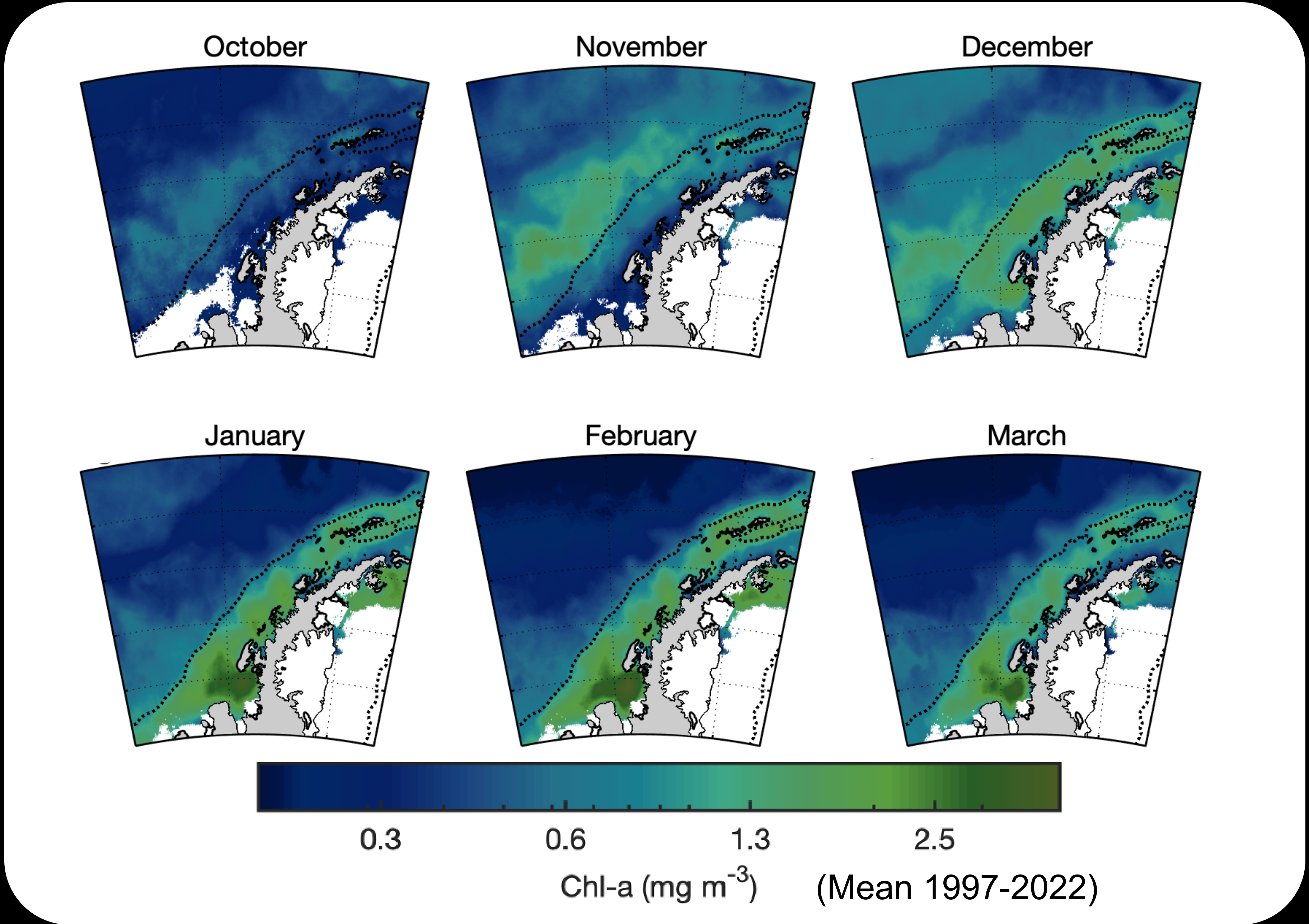




Nardelli et al. 2023

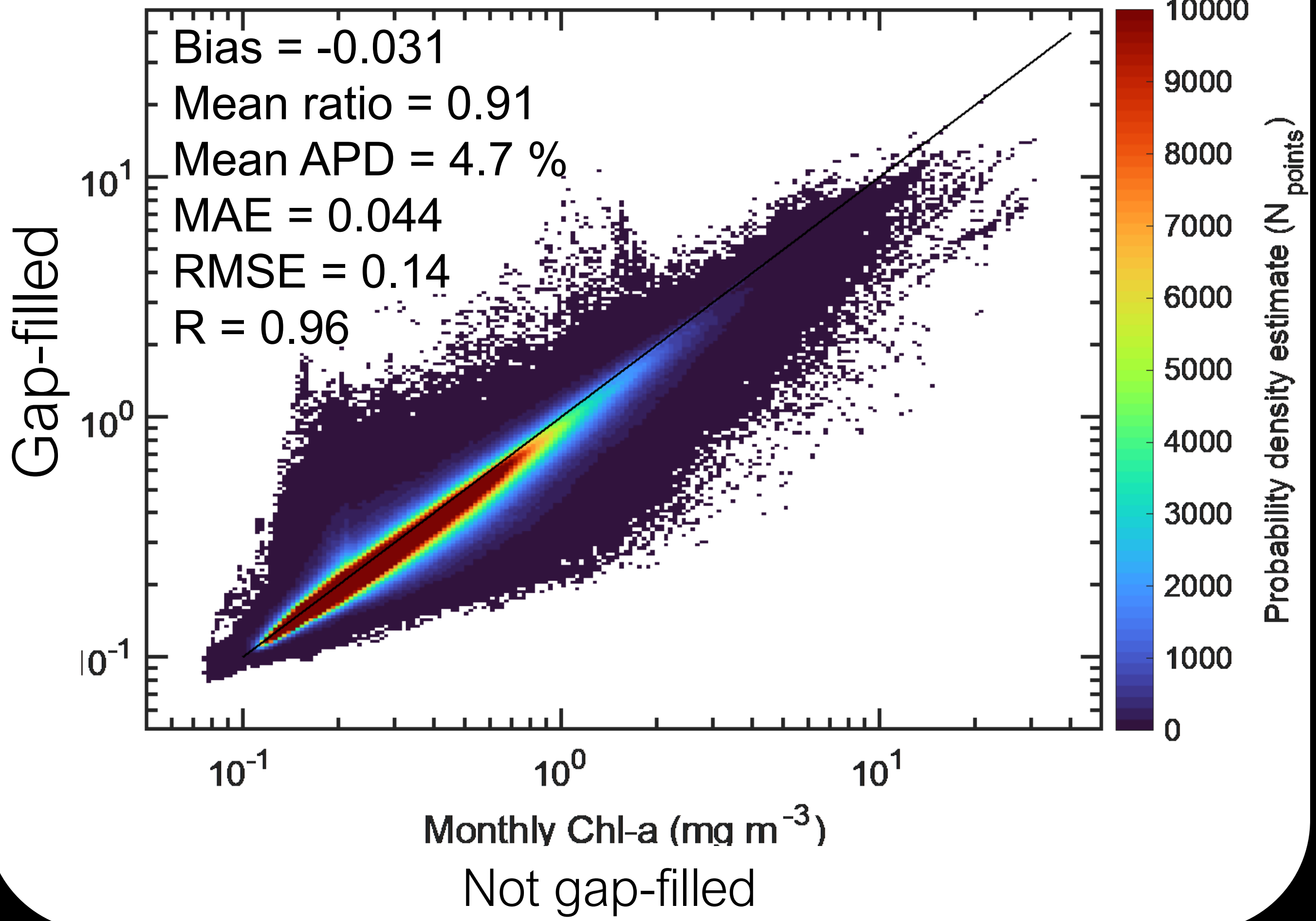


Seasonal Climatologies



1. Changing Phenology

- Satellite-derived Chl-a
- CMEMS GlobColour Level-4 gap-filled global Chl-a (Garnesson et al. 2019, Hu et al. 2012, Gohin et al. 2002)



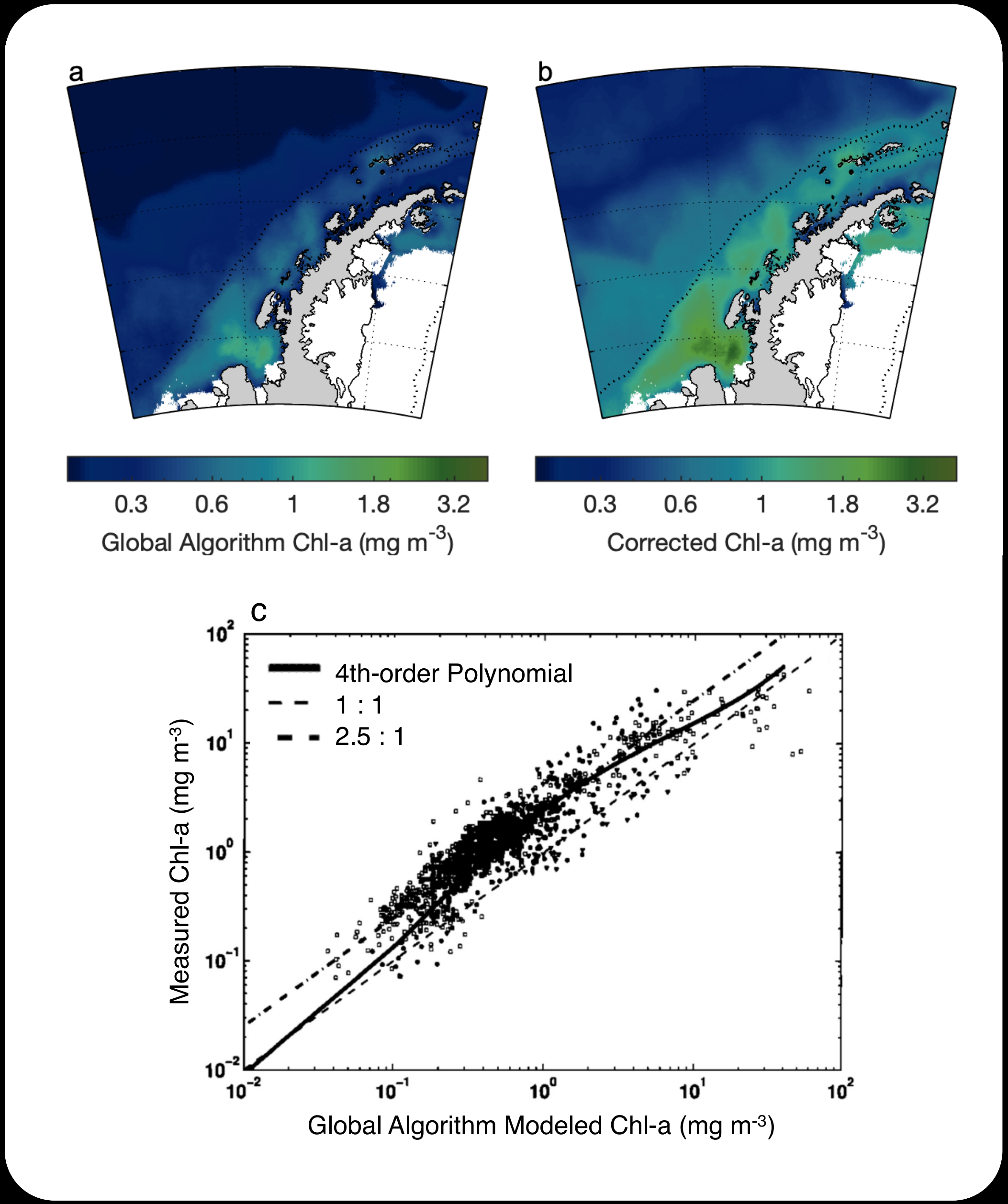
1. Changing Phenology

- Global algorithm not accurate for West Antarctic Peninsula (ongoing mystery!)
- "Factor of 2" underestimation of in situ Chl-a by satellites

Unique optical properties

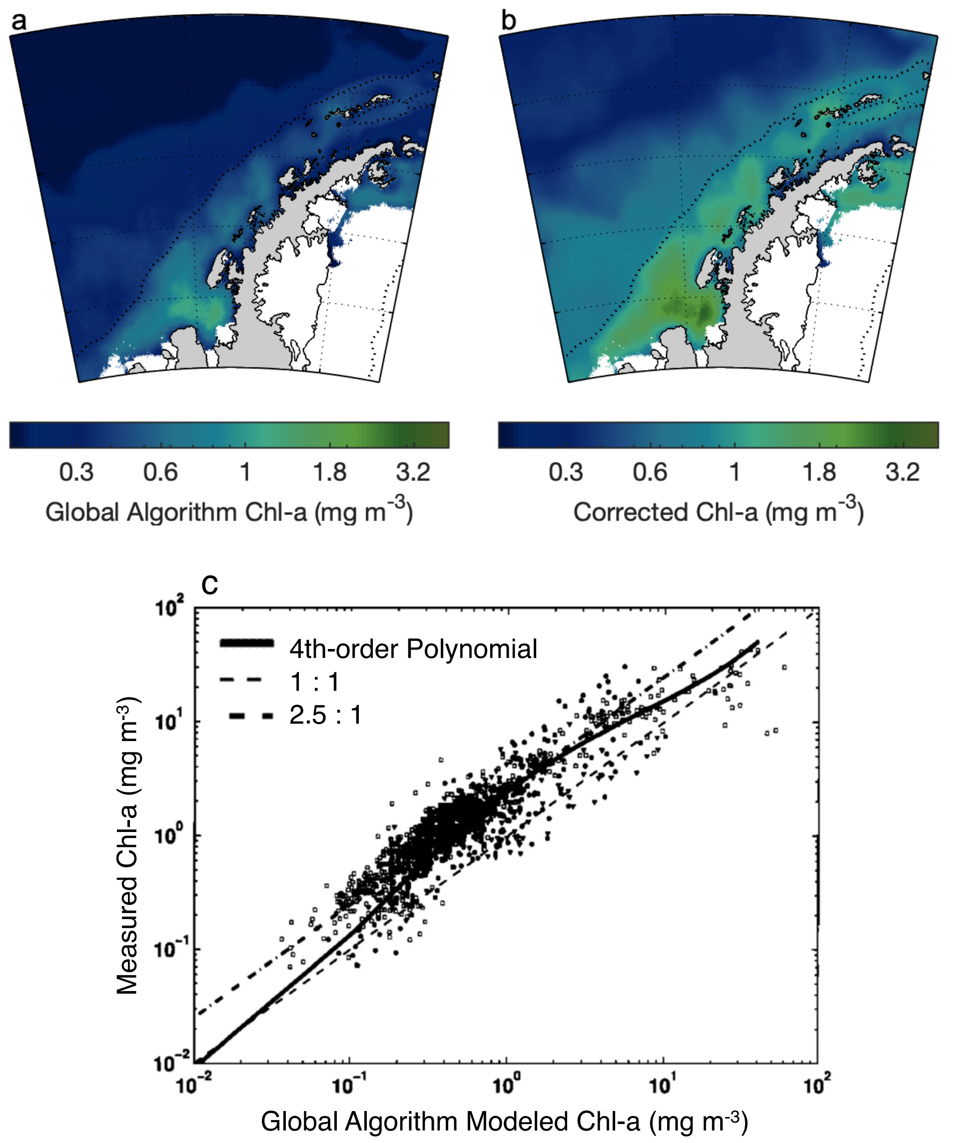
- *Pigment packaging*
- *High RuBisCO*
- *Relatively low CDOM, detritus, bacteria*

Future work…



1. Changing Phenology

- Global algorithm not accurate for West Antarctic Peninsula (ongoing mystery!)
- "Factor of 2" underestimation of in situ Chl-a by satellites
- Corrected global Chl-a to match field data with 4th-order polynomial (Dierssen & Smith 2000)



$$X = \log(Chl_{global})$$

$$Chl_{corrected} = 10^{(0.3914 + 1.0176X - 0.3114X^2 + 0.0186X^3 + 0.0610X^4)}$$