NOAA Ocean Color Coordinating Group
NOCCG Seminar
October 11th 2023

Remote Sensing of Sea Surface Glacial Meltwater on the Antarctic Peninsula Shelf

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Jet Propulsion Laboratory
California Institute of Technology

Background

B. Jack Pan

- UC Irvine (2013)

B.S. in Earth & Environmental Sciences
Undergrad Advisors: Keith Moore, Eric Rignot

- DEVELOP @ JPL (2013, 2014)

"The SAR *Sargassum* Project"
"The Wastewater Project" part III
Advisors: Michelle Gierach, Ben Holt

- Scripps Institution of Oceanography (2020)

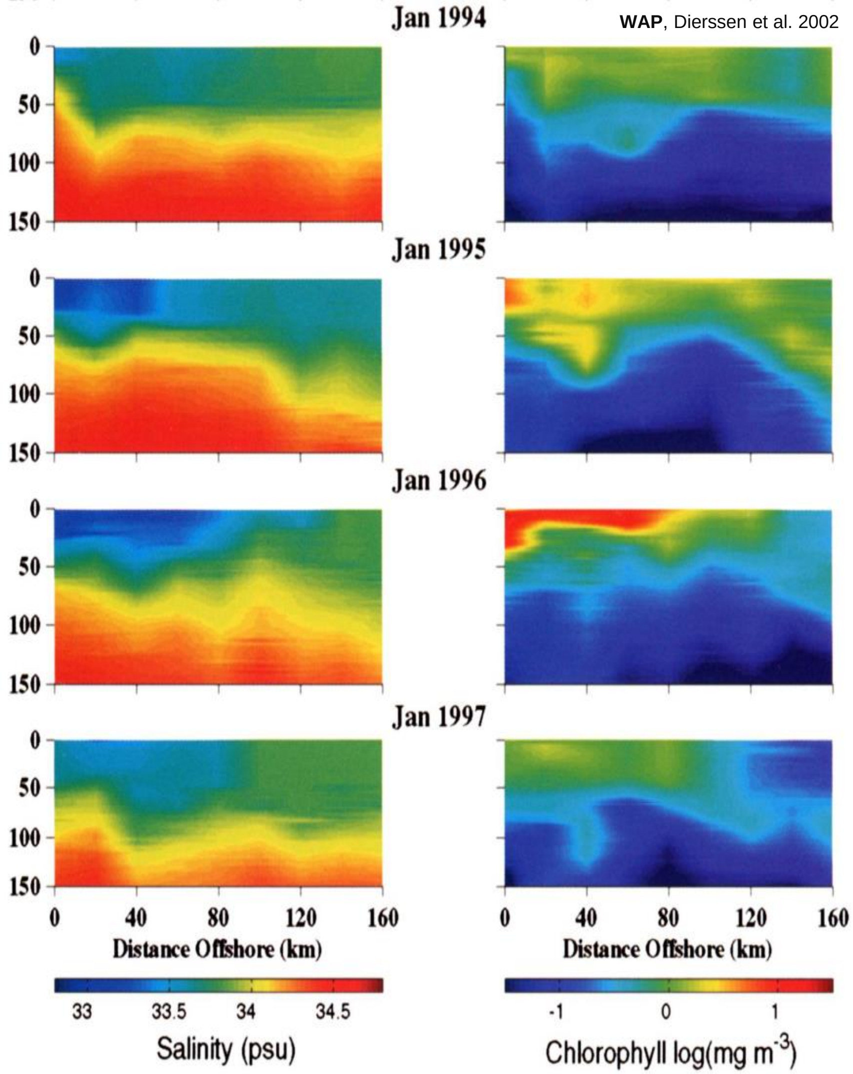
Masters in Marine Biology | Ph.D. in Oceanography
Dissertation: "The Impact of Seasonal Environmental Variables on Phytoplankton Ecology at the Antarctic Ice-Ocean Boundary"
Advisor: Maria Vernet

- NASA Jet Propulsion Laboratory (2021 - present)

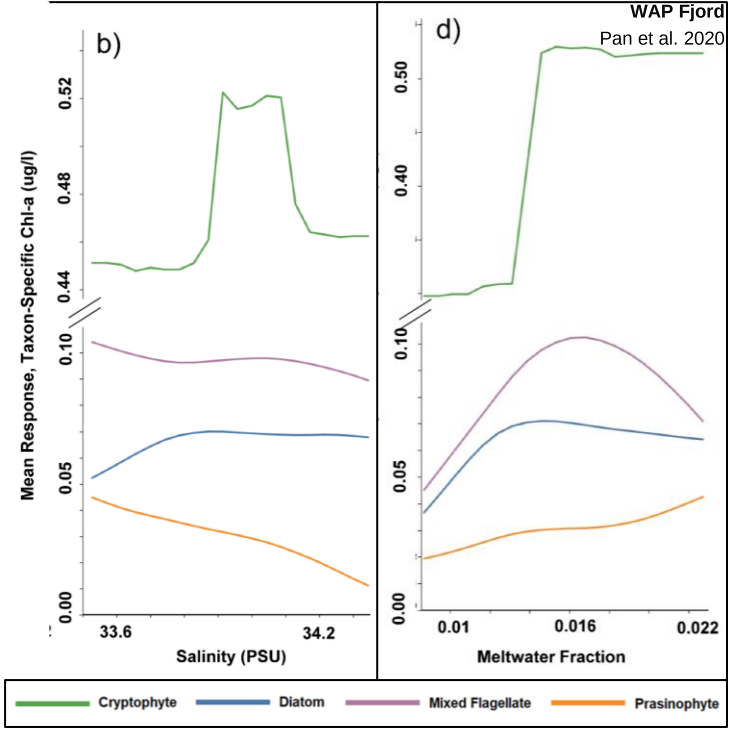
NPP / JPL Postdoctoral Fellow
Water & Ecosystems Group
Advisor: Michelle Gierach

Neko Harbor, December 2015

Context

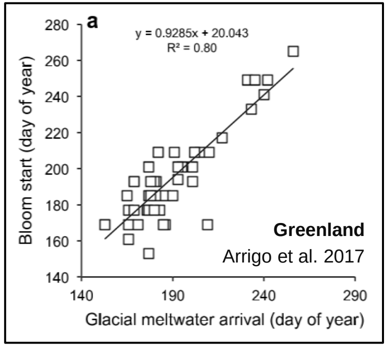


WAP, Dierssen et al. 2002



WAP Fjord

Pan et al. 2020



Greenland

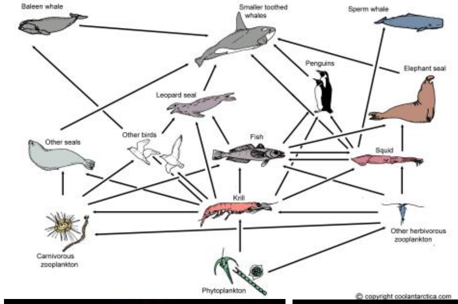
Arrigo et al. 2017

Why Monitor Meltwater?

for Antarctic ecology and more!

- Relatively short food chain in Antarctica
- Phytoplankton (mostly diatom) → Krill (prefer diatoms) → whales, seals, penguins, and fishery species

- “Omega krill oil,” “Chilian sea bass”
- Tourism
- Antarctic marine living resources depend on marine phytoplankton



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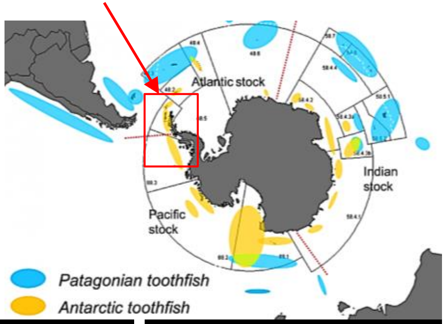
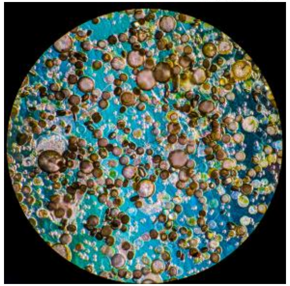
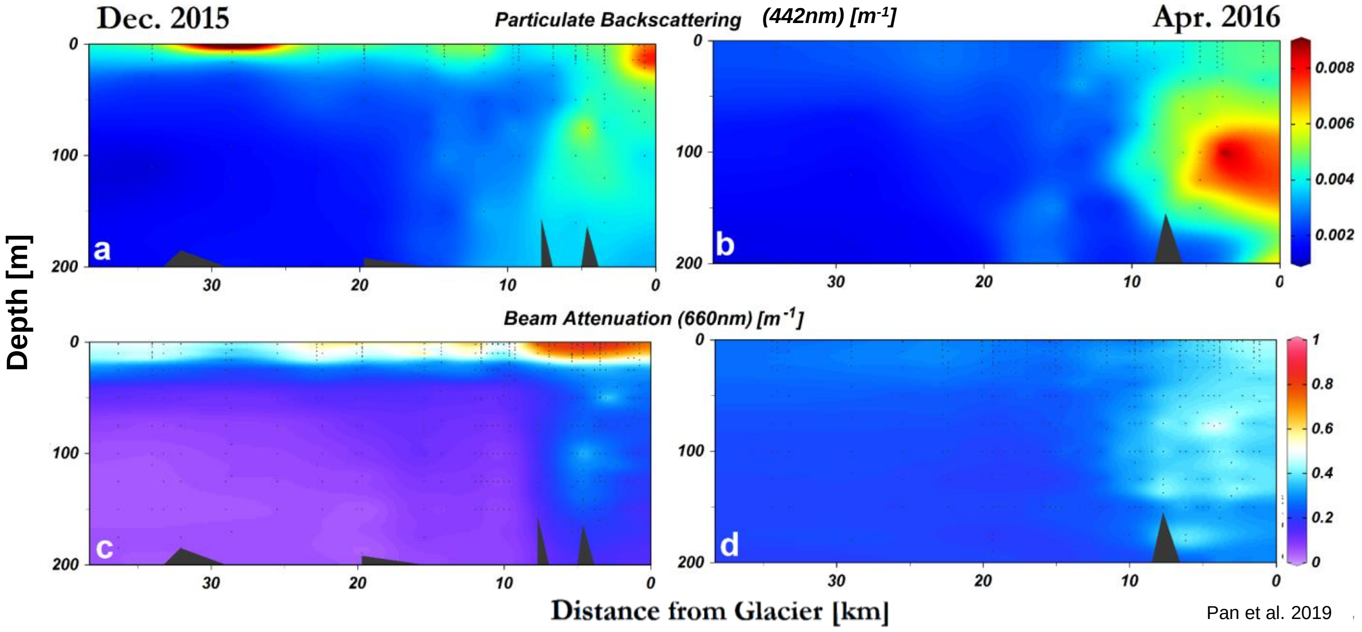
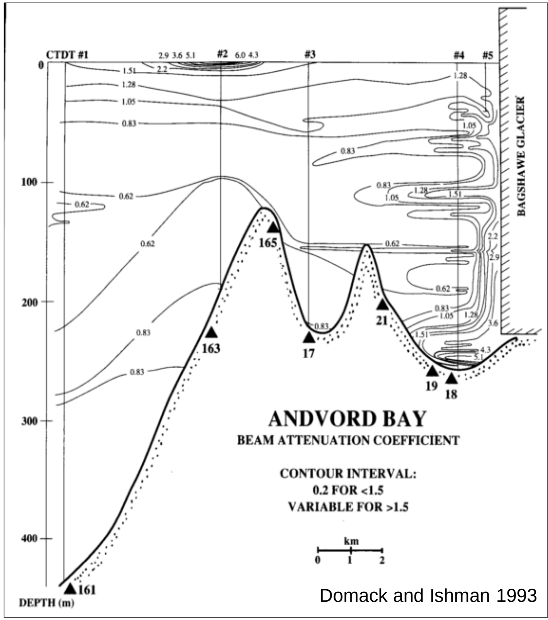


- Glacial meltwater is fresh and buoyant, can help stabilize the surface ocean, create optimal light conditions for phytoplankton
- Buoyance-driven upwelling of nitrate- & iron-rich deep waters
- Glacial meltwater itself is also a source of iron supply for phytoplankton via subglacial + submarine melting



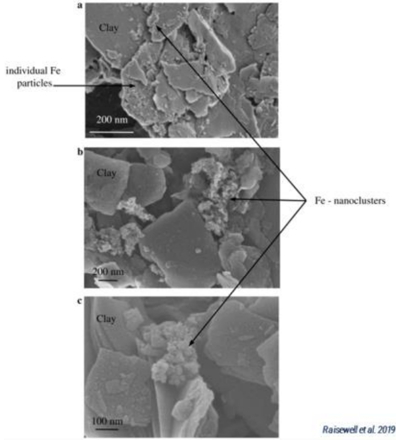


Pan et al. 2019



Domack and Ishman 1993

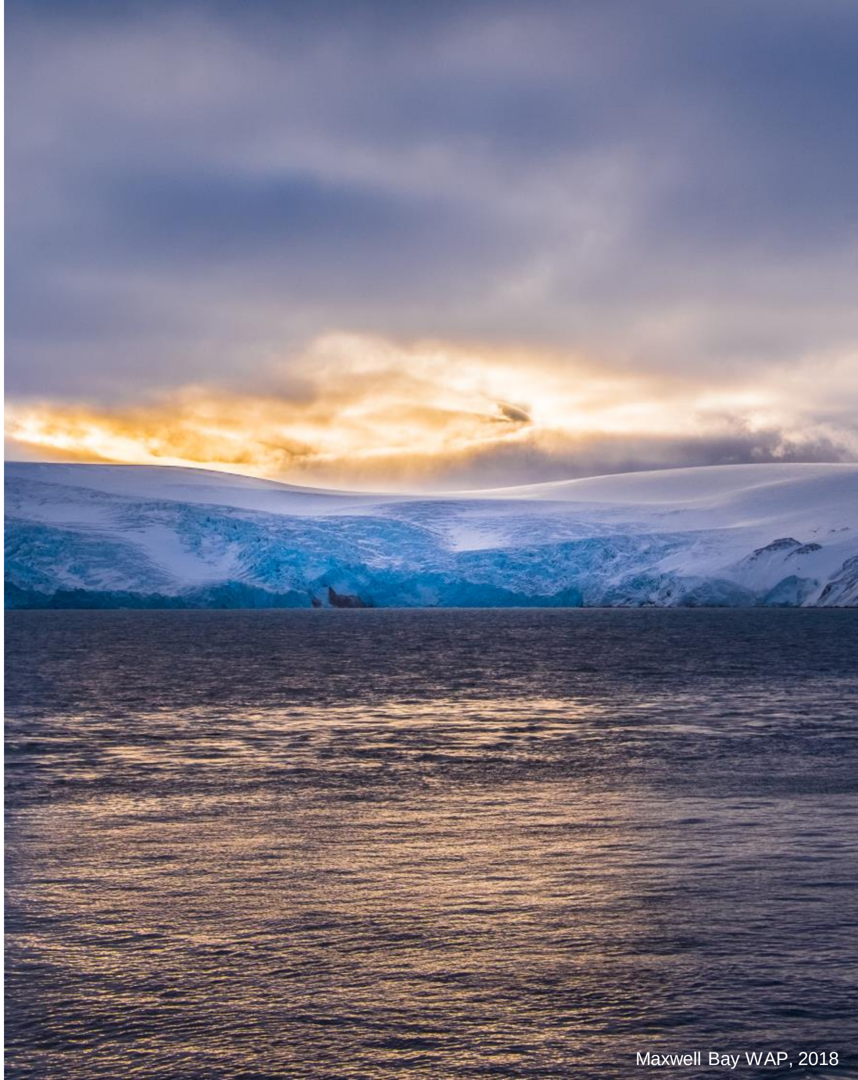
- Particulate backscattering coefficient and beam attenuation coefficient are significantly higher in the inner basin of a WAP fjord, close to the glaciers, during both December and April (Pan et al. 2019)
- Prior study conducted in the early 1990’s found similar optical features at this location (Domack and Ishman 1993)
- These optical signals are attributed to meltwater due to entrained glacial nanoparticles (Hawkings et al. 2018) (Raiswell 2008)
- These findings offer a potential for remote detection of glacial meltwater with ocean color data



Raiswell et al. 2019

Goals

- We present the initial development of a Gen-1 model to map sea surface glacial meltwater (SSGM)
- We describe the machine learning methodology used to develop this experimental SSGM model using MODIS-Aqua data
- Confirmation with existing field data from diverse field campaigns at the WAP covering a range of spatial and temporal scales
- Applying the model to visualize SSGM fraction in the broader WAP region



Maxwell Bay WAP, 2018

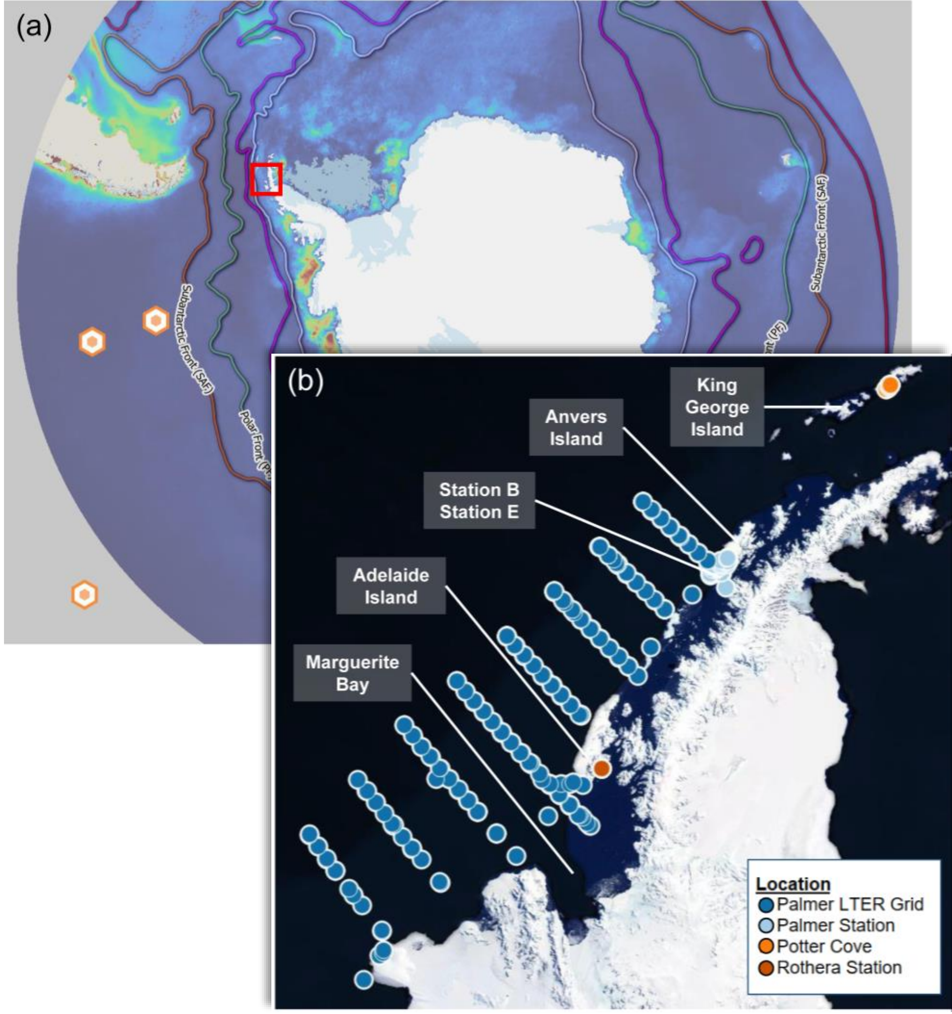
In-situ Data

- Discrete stable oxygen isotope samples ($\delta^{18}O$)
- One of the most effective field methods for measuring glacial meltwater
- Compiling surface data (shallowest ≤ 5m) from Palmer LTER grid (Meredith et al., 2017), Palmer Station on Anvers Island (Meredith et al., 2021), Potter Cove (Meredith et al., 2018), and Rothera Point on Adelaide Island (Meredith et al., 2010)
- Deriving meteoric water fraction by mass balance equations

$$F_{sim} + F_{met} + F_{ow} = 1$$

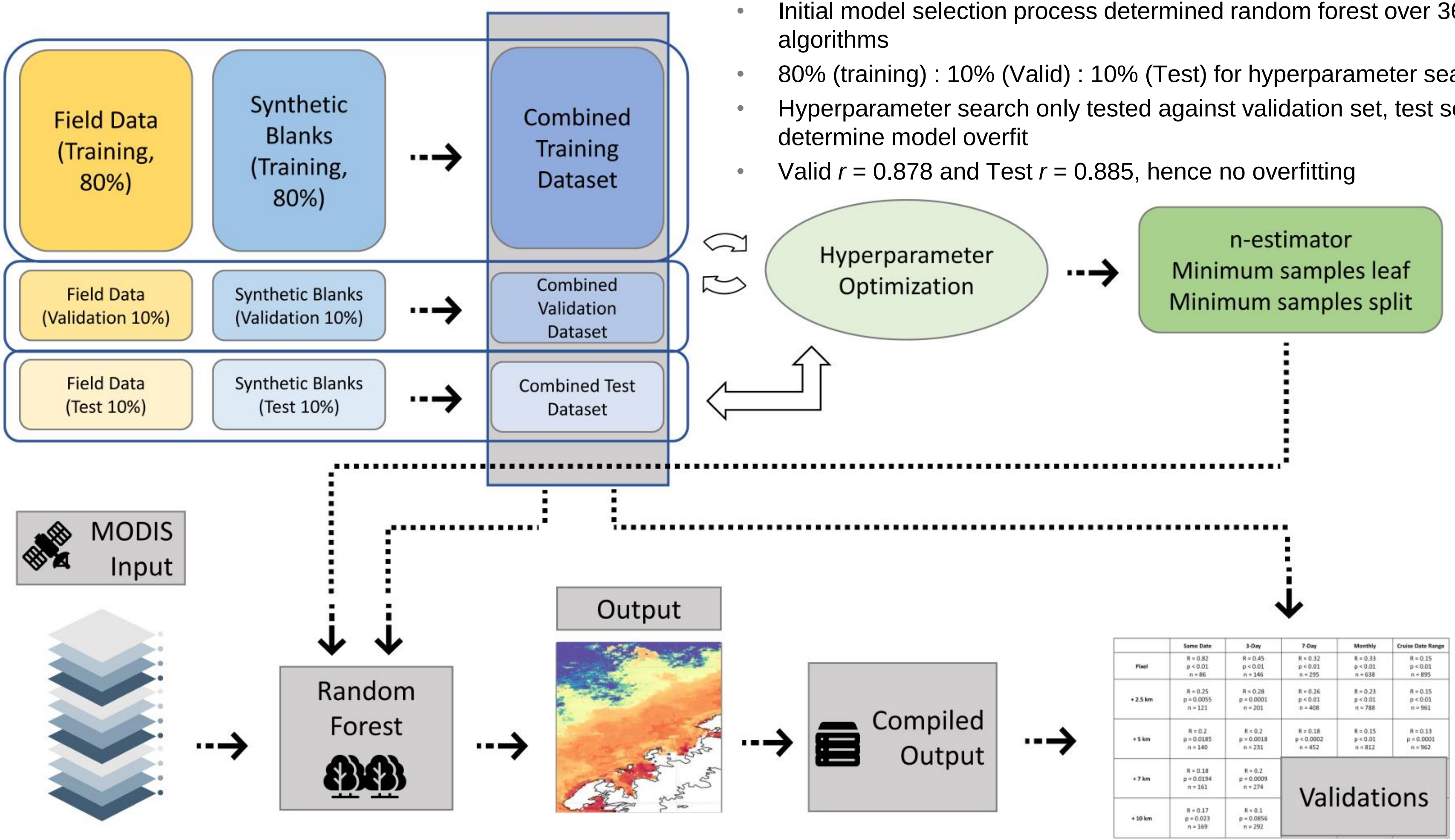
$$S_{sim} \cdot F_{sim} + S_{met} \cdot F_{met} + S_{ow} \cdot F_{ow} = S_{total}$$

$$\delta^{18}O_{sim} \cdot F_{sim} + \ \delta^{18}O_{met} \cdot F_{met} + \ \delta^{18}O_{ow} \cdot F_{ow} = \ \delta^{18}O_{total}$$



Model Training

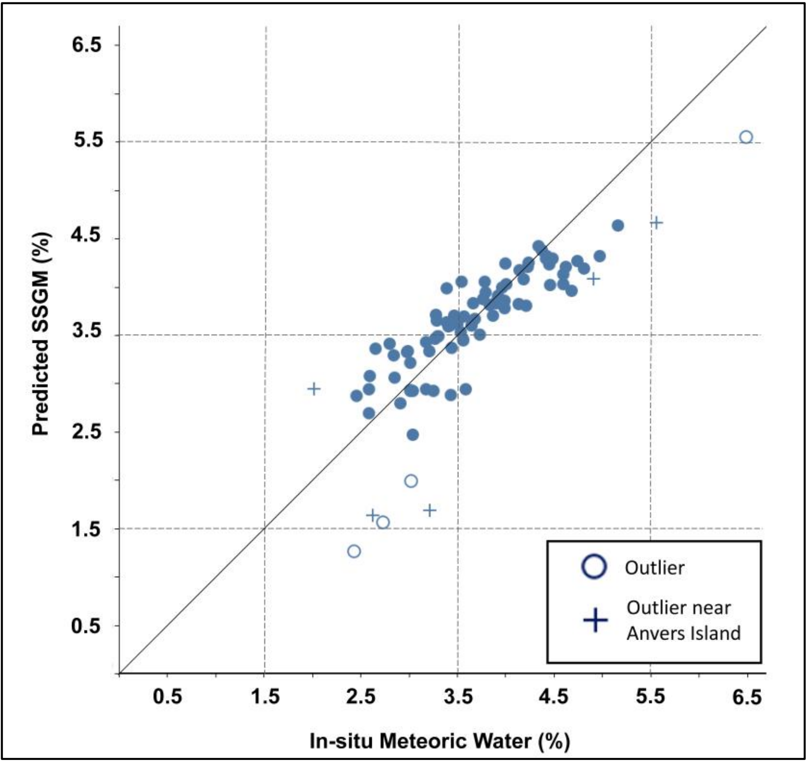
- Initial model selection process determined random forest over 36 algorithms
- 80% (training) : 10% (Valid) : 10% (Test) for hyperparameter search
- Hyperparameter search only tested against validation set, test set used to determine model overfit
- Valid $r = 0.878$ and Test $r = 0.885$, hence no overfitting

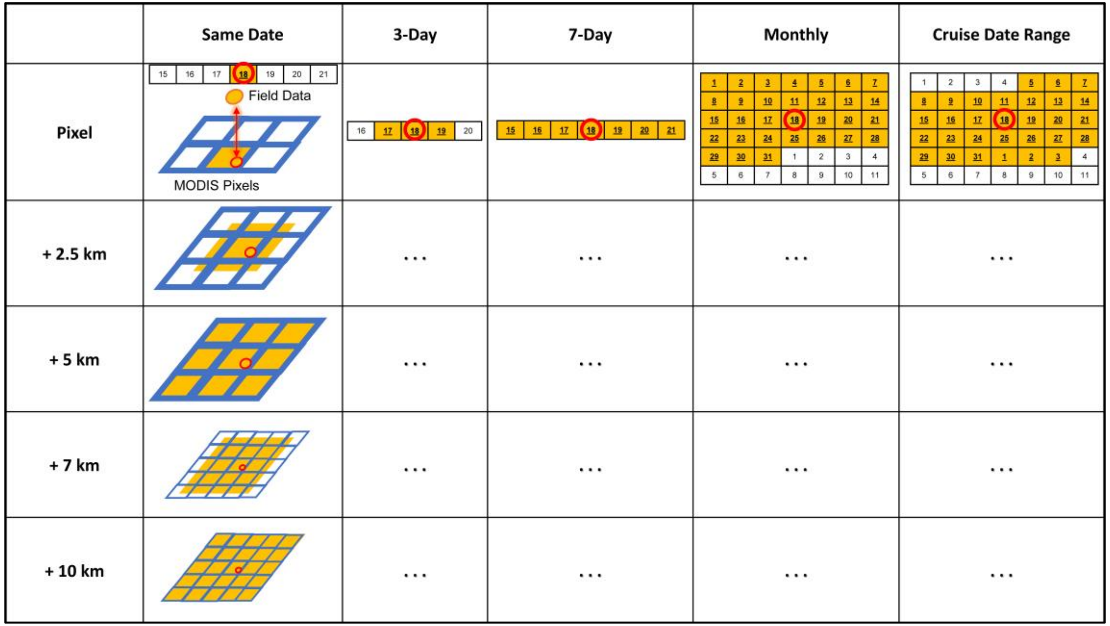


	Same Date	3-Day	7-Day	Monthly	Cruise Date Range
Pixel	R = 0.82 p < 0.01 n = 86	R = 0.45 p < 0.01 n = 146	R = 0.32 p < 0.01 n = 295	R = 0.33 p < 0.01 n = 638	R = 0.15 p < 0.01 n = 895
+ 2.5 km	R = 0.25 p = 0.0055 n = 121	R = 0.28 p = 0.0001 n = 201	R = 0.26 p < 0.01 n = 408	R = 0.23 p < 0.01 n = 788	R = 0.15 p < 0.01 n = 961
+ 5 km	R = 0.2 p = 0.0185 n = 140	R = 0.2 p = 0.0018 n = 231	R = 0.18 p < 0.0002 n = 452	R = 0.15 p < 0.01 n = 812	R = 0.13 p = 0.0001 n = 962
+ 7 km	R = 0.18 p = 0.0194 n = 161	R = 0.2 p = 0.0009 n = 274			
+ 10 km	R = 0.17 p = 0.023 n = 169	R = 0.1 p = 0.0856 n = 292			

Pan et al. 2023

Results



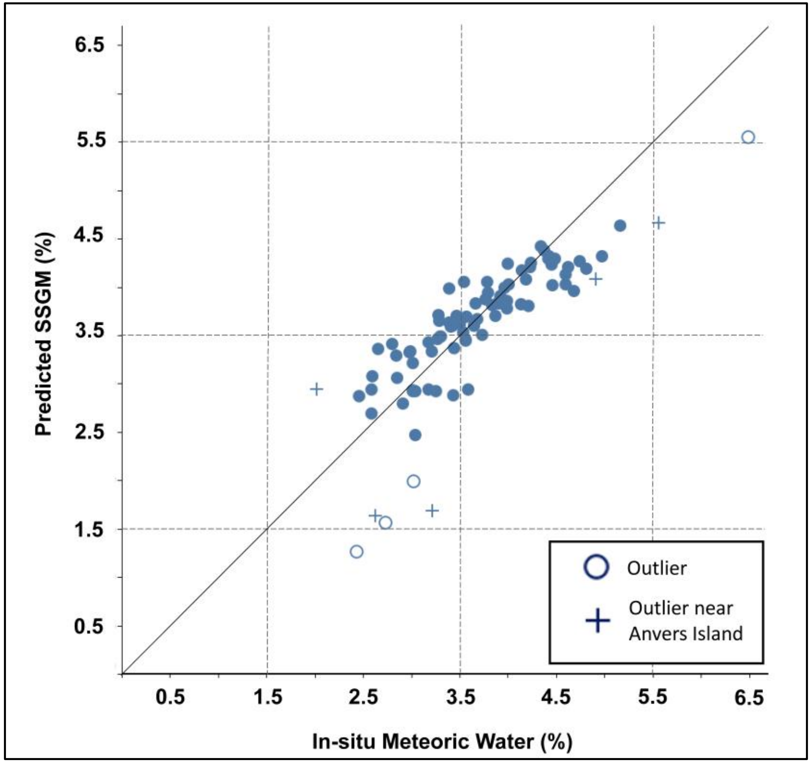


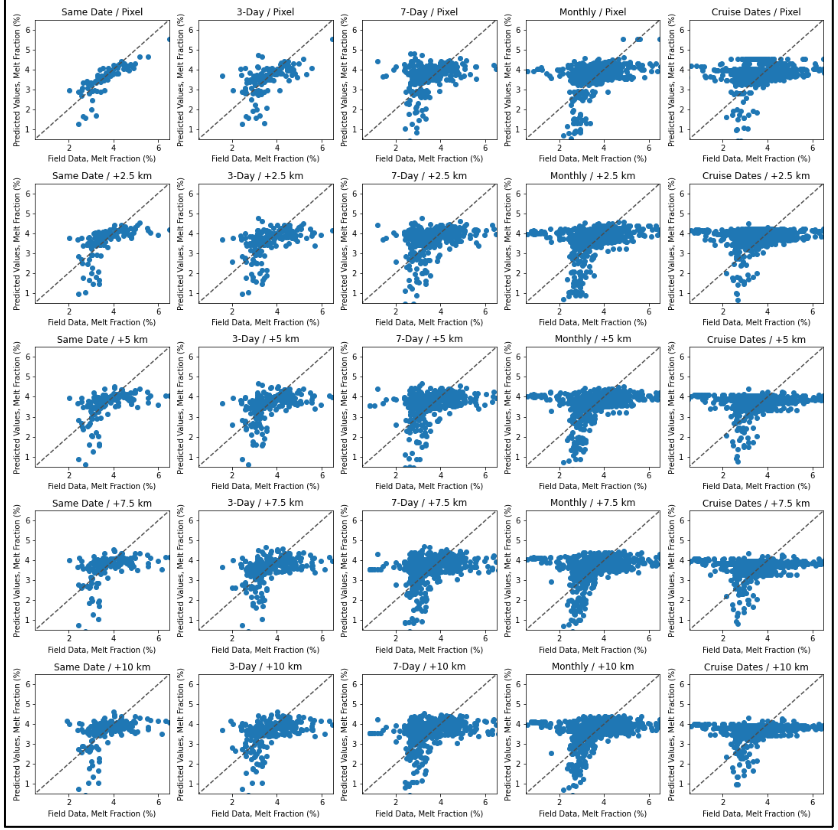
	Same Date	3-Day	7-Day	Monthly	Cruise Date Range
Pixel					
+ 2.5 km		…	…	…	…
+ 5 km		…	…	…	…
+ 7 km		…	…	…	…
+ 10 km		…	…	…	…

- Final model 1:1 validation: $r = 0.82$, $p < 0.01$
- Also compared discrete daily in-situ data with spatially and temporally averaged derived values

Pan et al. 2023

Results & Discussion

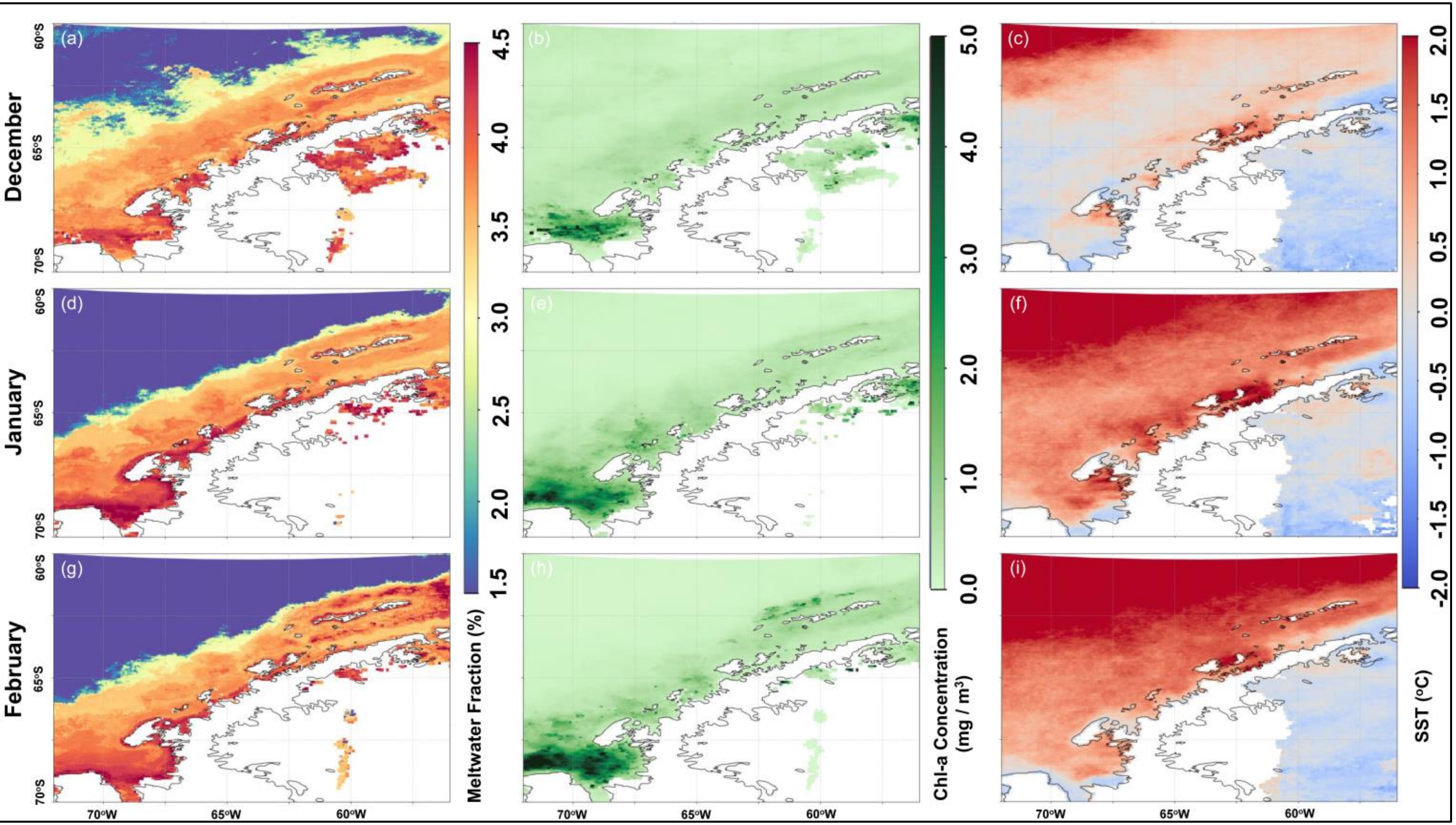




- Distinct “thresholds” formed when averaging derived glacial meltwater >3 days and > 5 km
- Provides some insights on potential residence time and spatial resolution needed to resolve surface glacial meltwater features (Kohut et al., 2018, Hudson et al., 2021) to support future field campaigns and remote sensing missions (Cawse-Nicholson et al., 2021)

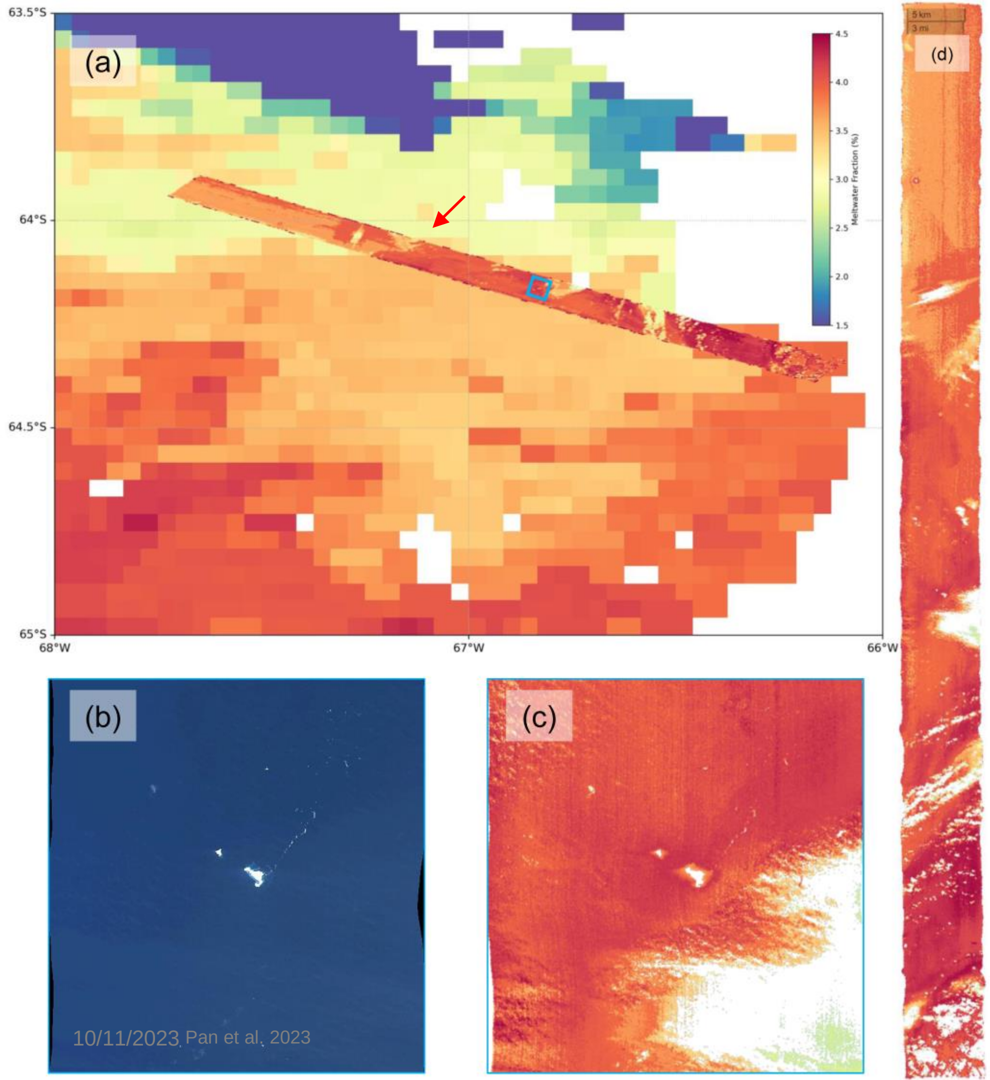
Pan et al. 2023

Results & Discussion



- **Climatology of the Austral summer months from 2010 to 2020**: a, d, g: surface glacial meltwater fraction; b, e, h: chl; c, f, i: SST
- Accumulation of meltwater (Pan et al. 2019) in Marguerite Bay due to the southward flow of the Antarctic Peninsula Coastal Current + glacial drainage near Alexander Island (Moffat et al., 2008, Meredith et al., 2010, Savidge and Amft, 2009, Stein, 1992)
- High meltwater content coincides with high chl-a concentration, but spatially different (Dierssen et al. 2002, Pan et al. 2020)
- Nearshore high meltwater content associated with cold and fresh water masses (Domack and Williams, 1990, Lundesgaard et al., 2020,)

Pan et al. 2023



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Results & Discussion

- **NASA PRISM airborne data (prm20160125t181722) overlaying MODIS-derived surface glacial meltwater fraction from January 25th, 2016** (prm20160125t181722)
- PRISM data have finer spatial resolution
- A distinct front can be observed in both datasets immediately south of 64 ^{o}S (a)
- An iceberg with a trail of bergy bits can be observed in both enhanced RGB (b) and derived glacial meltwater images (c)
- The entire scene has an average of 3.94% meltwater fraction, while it reaches 6.49% near the icebergs
- Demonstrating this model is applicable across different ocean color platforms
- Highlighting the benefit of supplementing existing multispectral spaceborne datasets with hyperspectral airborne data to achieve better detection and monitoring of glacial meltwater

Conclusions

- A novel method for quantifying glacial meltwater in the Western Antarctic Peninsula
- Results are robust in comparison with a comprehensive in-situ dataset
- Results further supported by prior studies and environmental analyses
- The model can be applied across remote sensing platforms
- Implication to enhance understanding of polar ecosystem dynamics and biogeochemistry

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Prince Gustav Channel, 2018

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