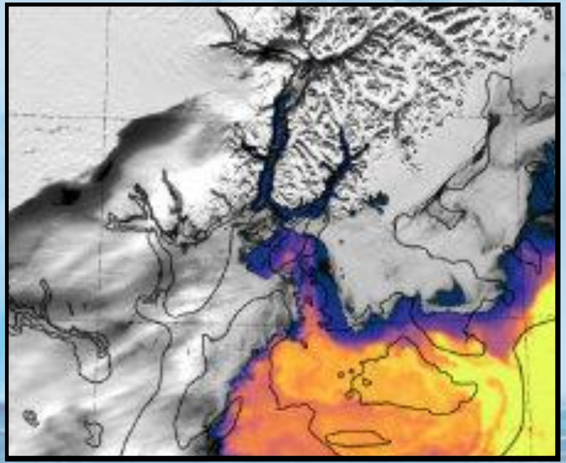
Pairing eyes in the sky with instruments in the deep: new applications of thermal infrared imagery in Antarctic glacier-ocean systems using open cloud-computing workflows

Tasha Snow
Colorado School of Mines

New ice-ocean tools and applications

Background on ice-ocean interactions in Antarctica

New thermal remote sensing techniques and more comprehensive/collaborative ways of applying them



Collaborators

Colorado School of Mines
- Matthew Siegfried
- Elena Savidge
- Michael Field
- Eojin Lee

CIRES
- Waleed Abdalati
- Ted Scambos

University of St. Andrews
- Lars Boehme
- Gui Bortolotto

University of Göthenburg
- Anna Wåhlin
- Bastien Queste
- Aleksandra Mazur

University of East Anglia
- Yixi Zheng
- Karen Heywood
- Tiago Dotto
- Rob Hall

Scripps Institute of Oceanography
- Fiamma Straneo
- James Holte

MIT/Woods Hole Institute of Oceanography
- Gordon Zhang

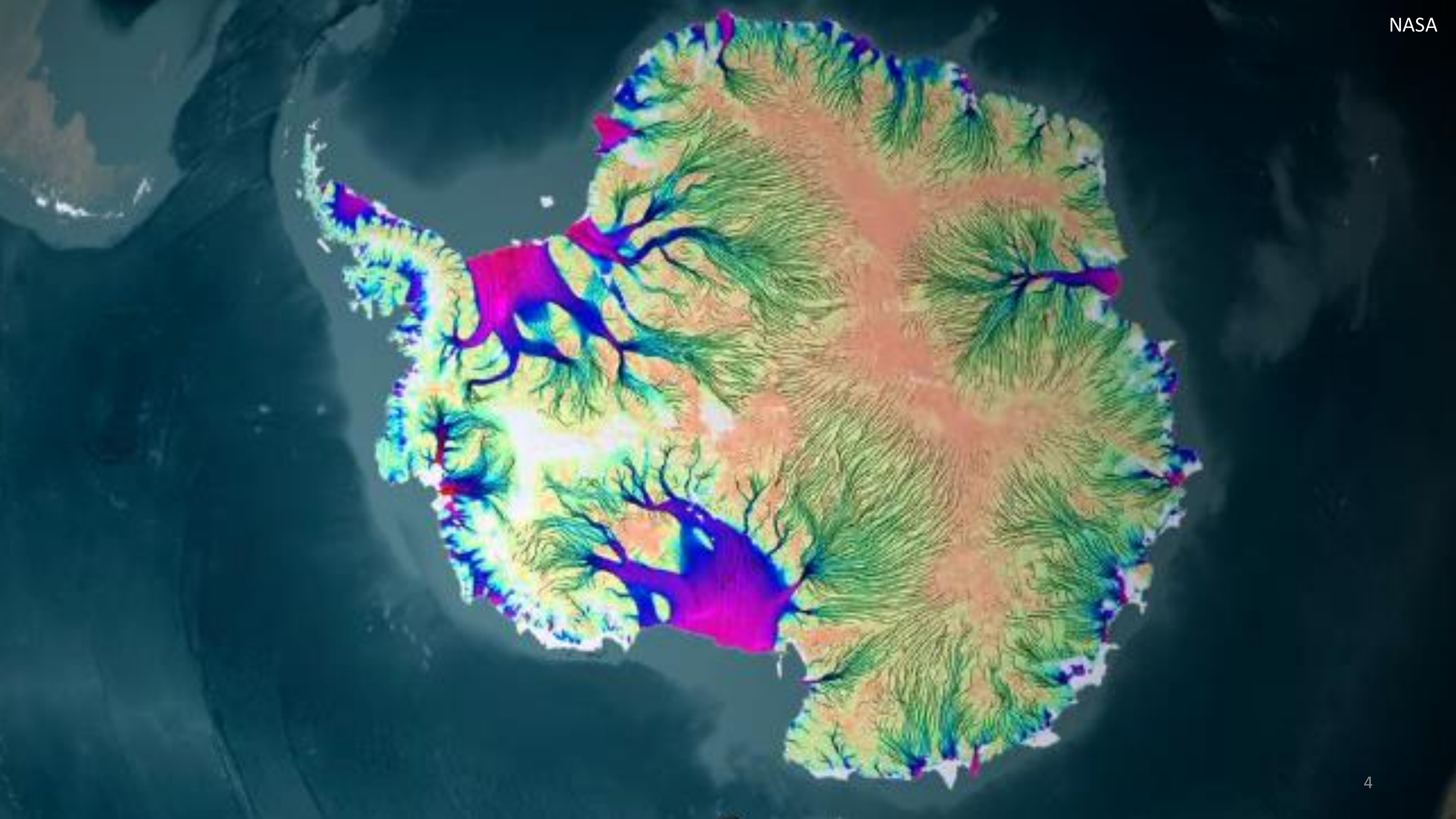
Stanford University
- Jonathan Taylor

University of Manitoba
- Karen Alley

NASA Goddard
- Shane Grigsby

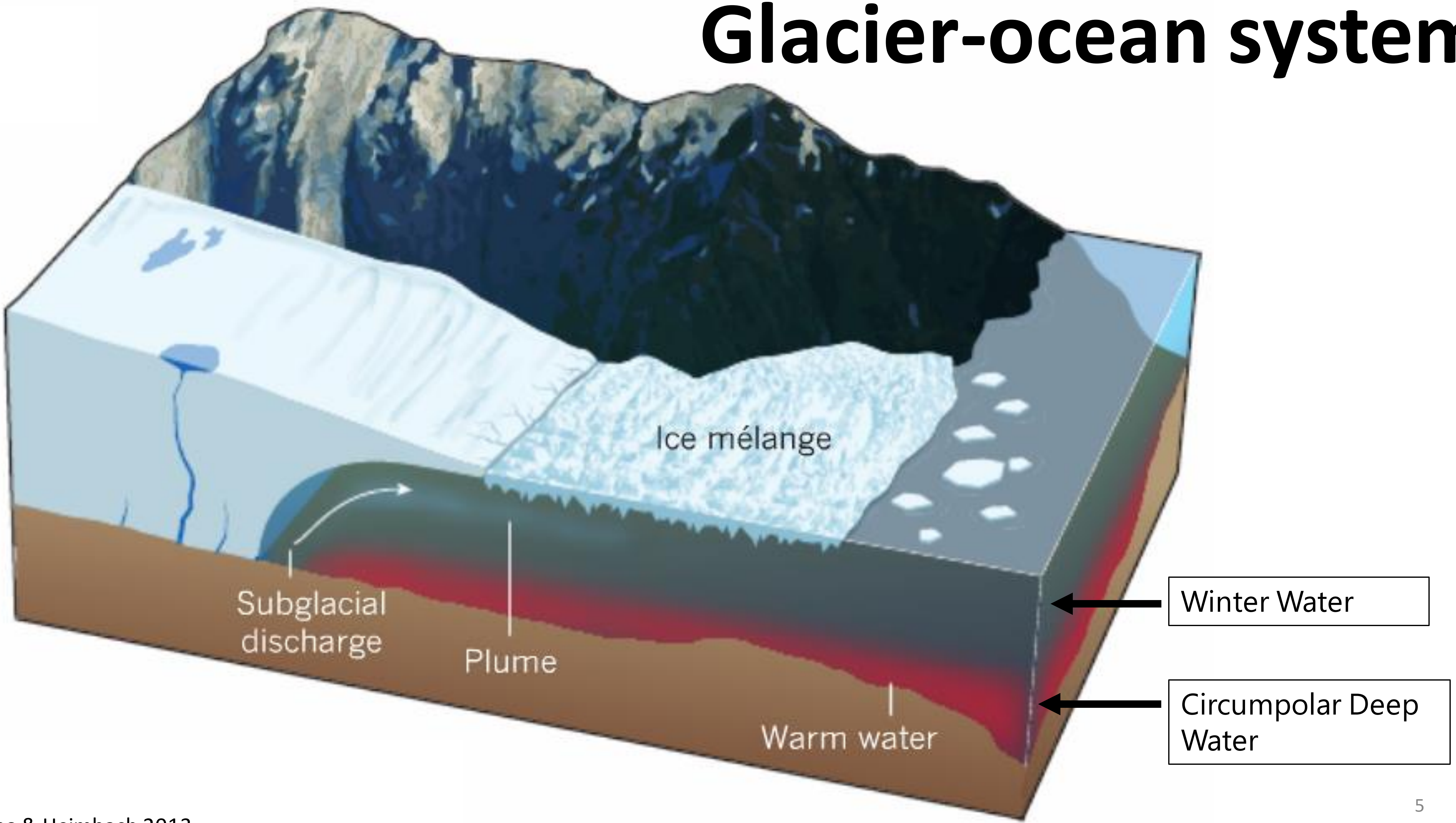
TARSAN and NBP1902 Team

University of California Berkeley
- Fernando Pérez
- Facu Sapienza
- Whyjay Zheng
- Ellie Abrahams



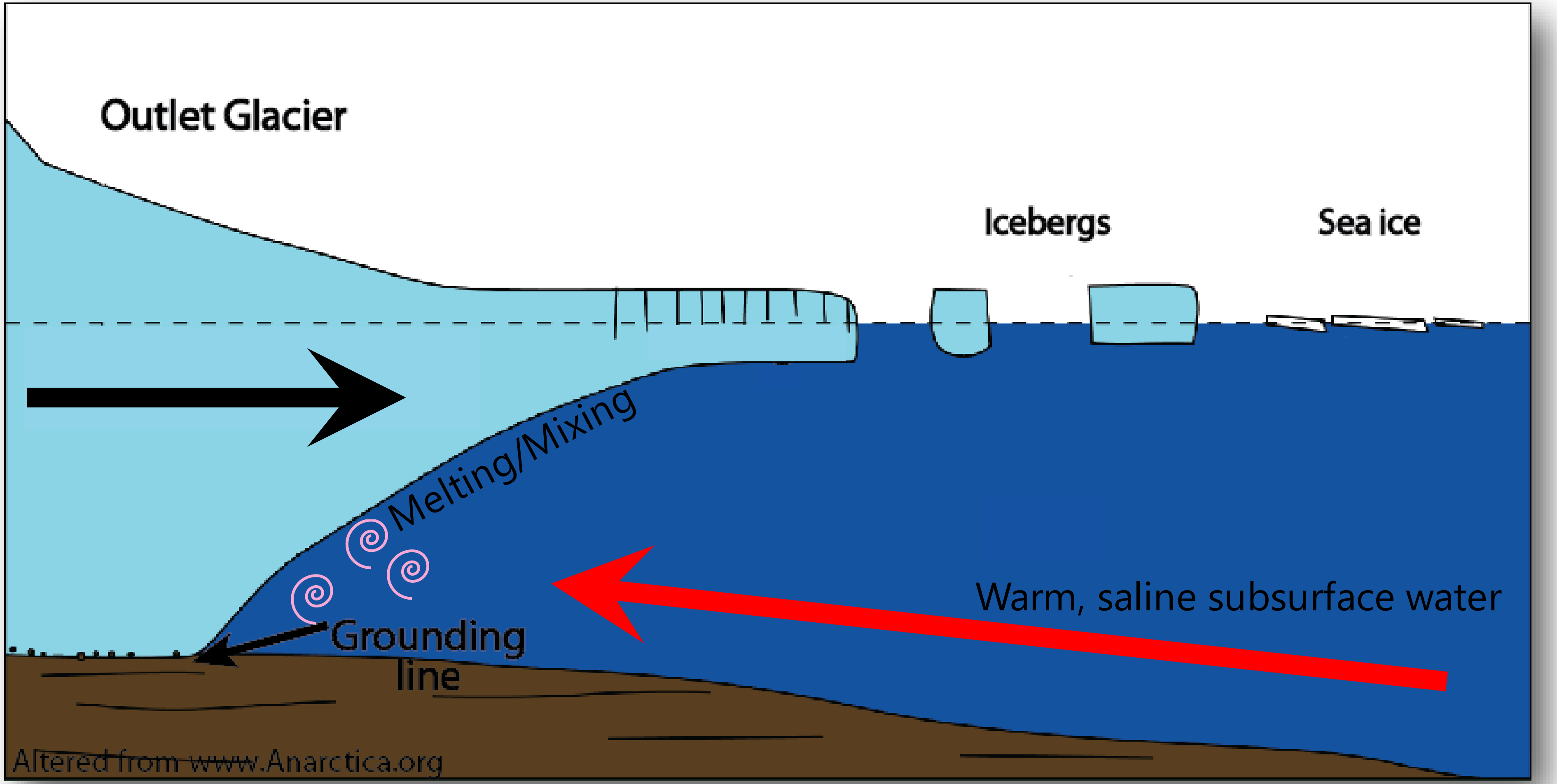
NASA

Glacier-ocean system



Straneo & Heimbach 2013

Ocean heat transport to a glacier:



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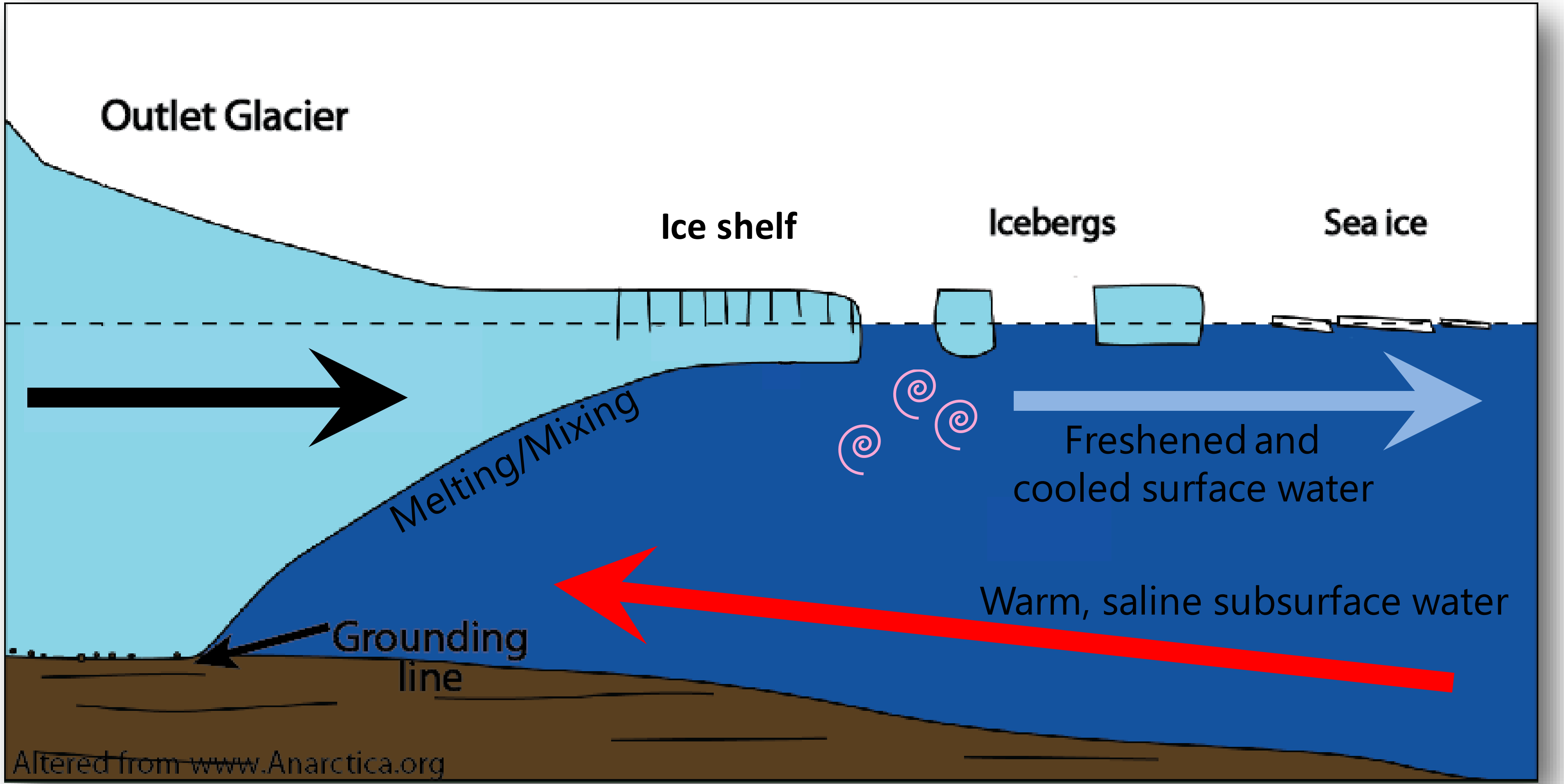


Our understanding of ice-ocean interactions in Antarctica

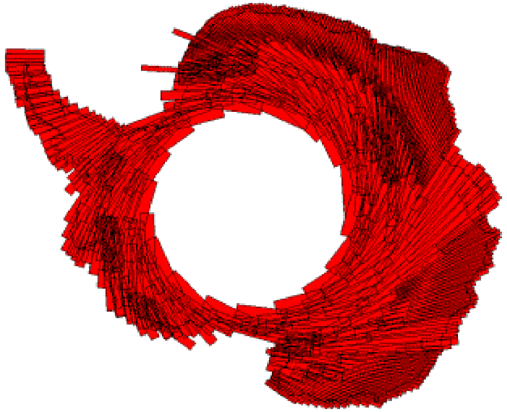
1978 **West Antarctic ice sheet and CO_2 greenhouse effect: a threat of disaster** J. H. Mercer

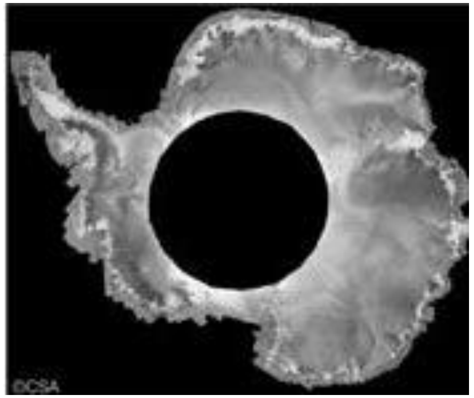
1981 **The weak underbelly of the West Antarctic ice sheet**
T.J. Hughes

Radarsat Antarctic Mapping Mission

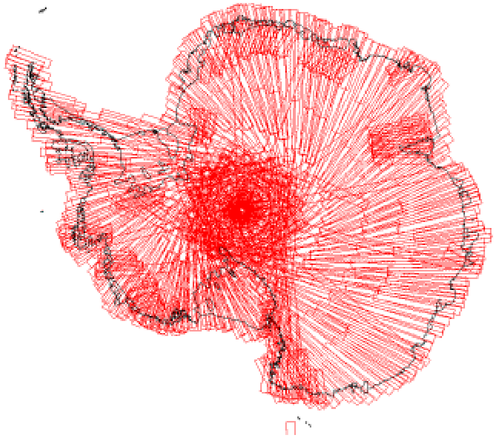
- September 9 – October 20th 1997
- First detailed mapping of this part of the world
- 180 degree yaw of Radarsat spacecraft to map south polar region of Antarctica

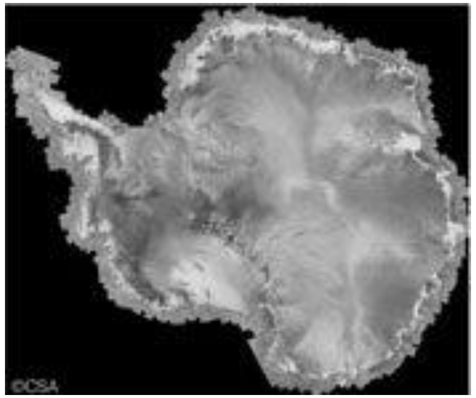
1997 mosaic





2000 mosaic





ASF

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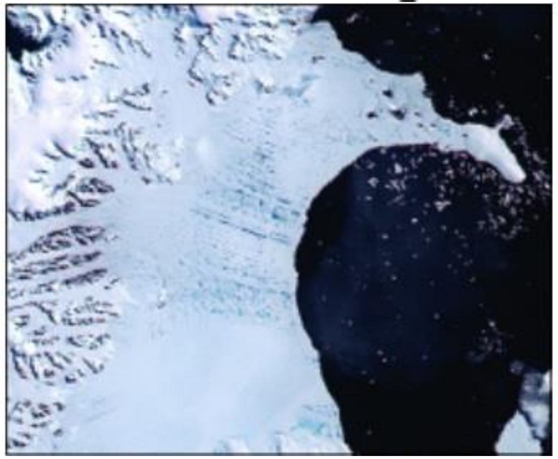
1981 **The weak underbelly of the West Antarctic ice sheet**
T.J. Hughes

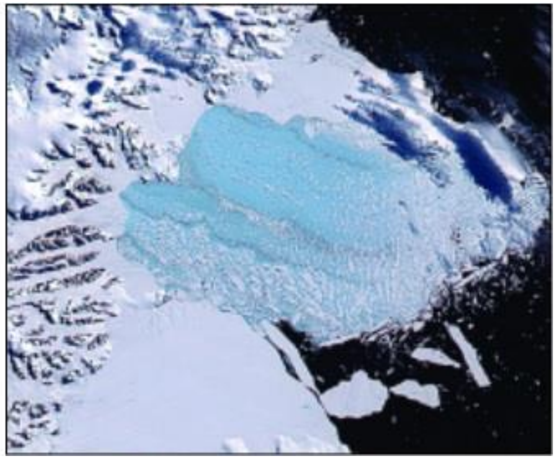
2002 **Rapid Bottom Melting Widespread near Antarctic Ice Sheet Grounding Lines**

2004 Glacier acceleration and thinning after ice shelf collapse in the Larsen B embayment, Antarctica

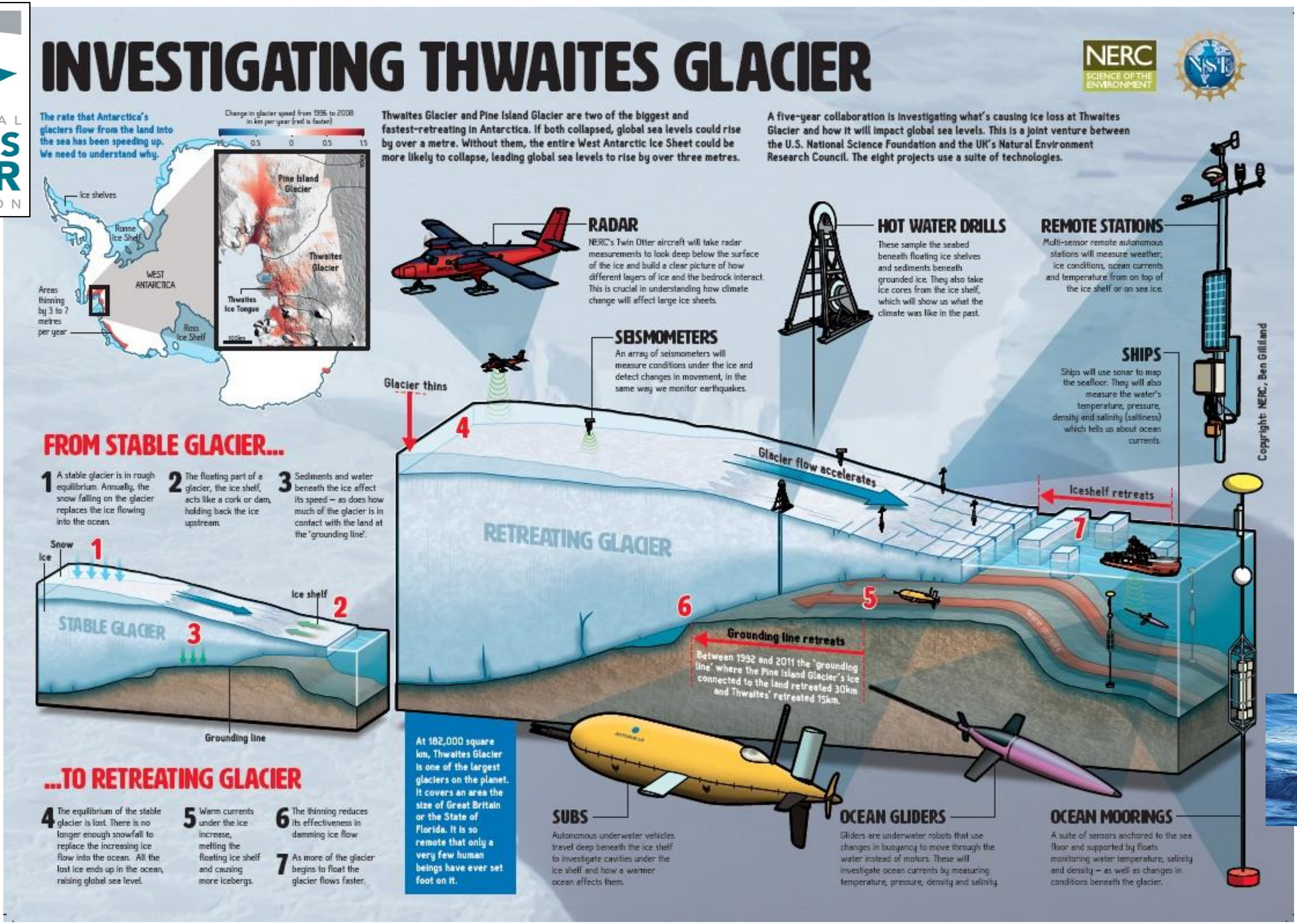
Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf

2014 **Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica**

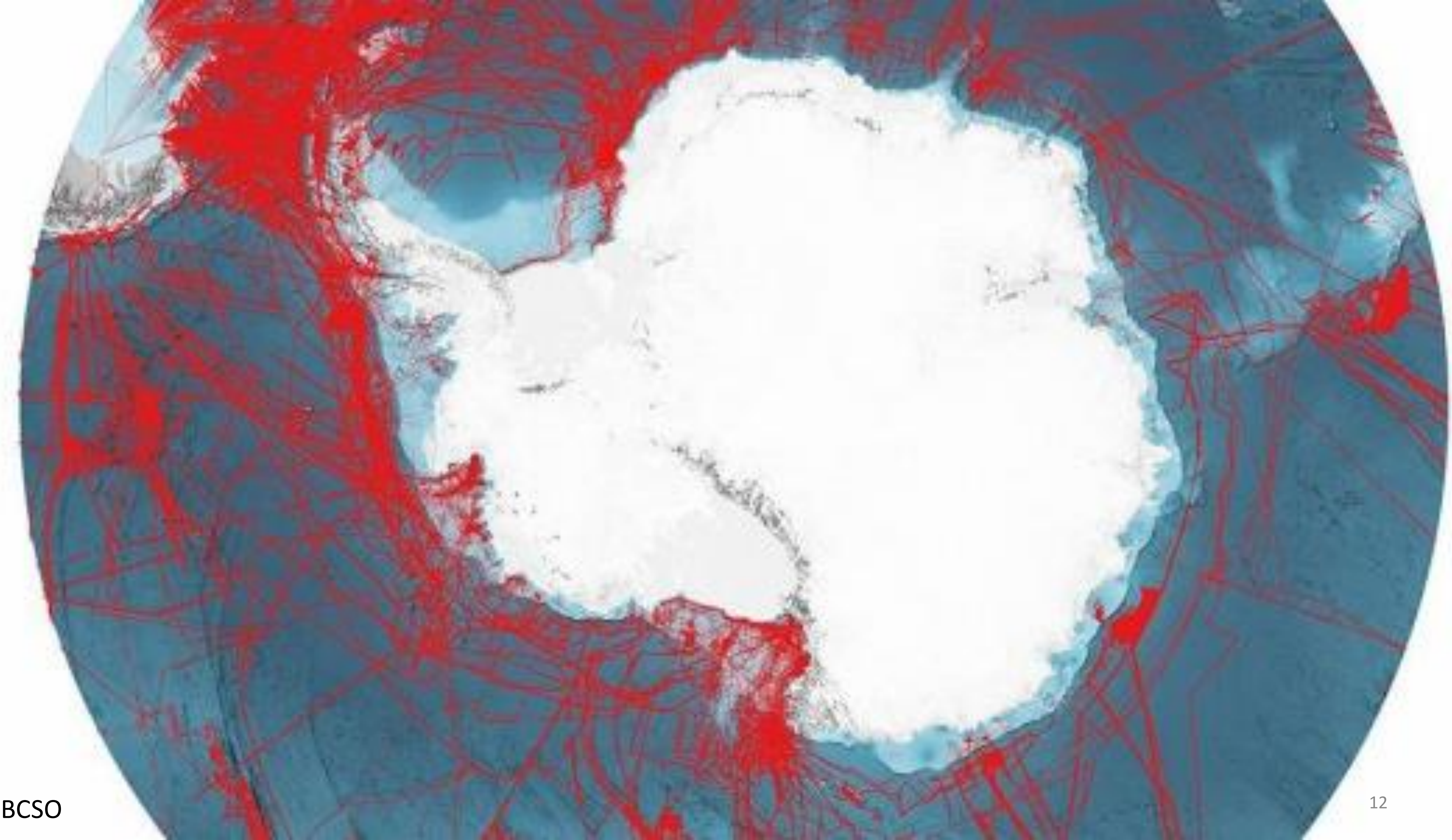




INTERNATIONAL THWAITES GLACIER COLLABORATION



Gilliland, NERC

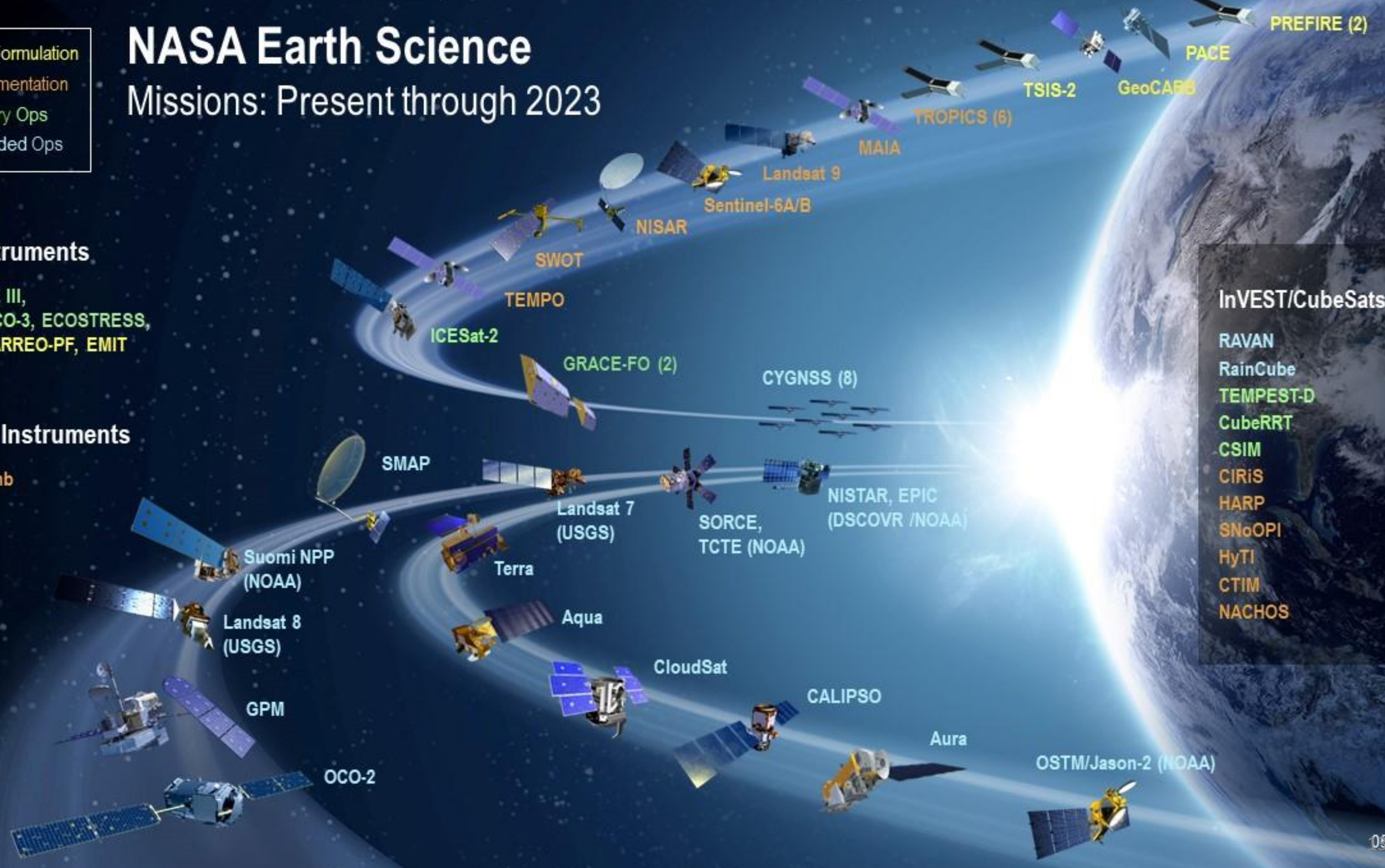


IBCSO

NASA Earth Science

Missions: Present through 2023

- (Pre)Formulation
- Implementation
- Primary Ops
- Extended Ops



ISS Instruments

LIS, SAGE III,
TSIS-1, OCO-3, ECOSTRESS,
GEDI, CLARREO-PF, EMIT

JPSS-2 Instruments

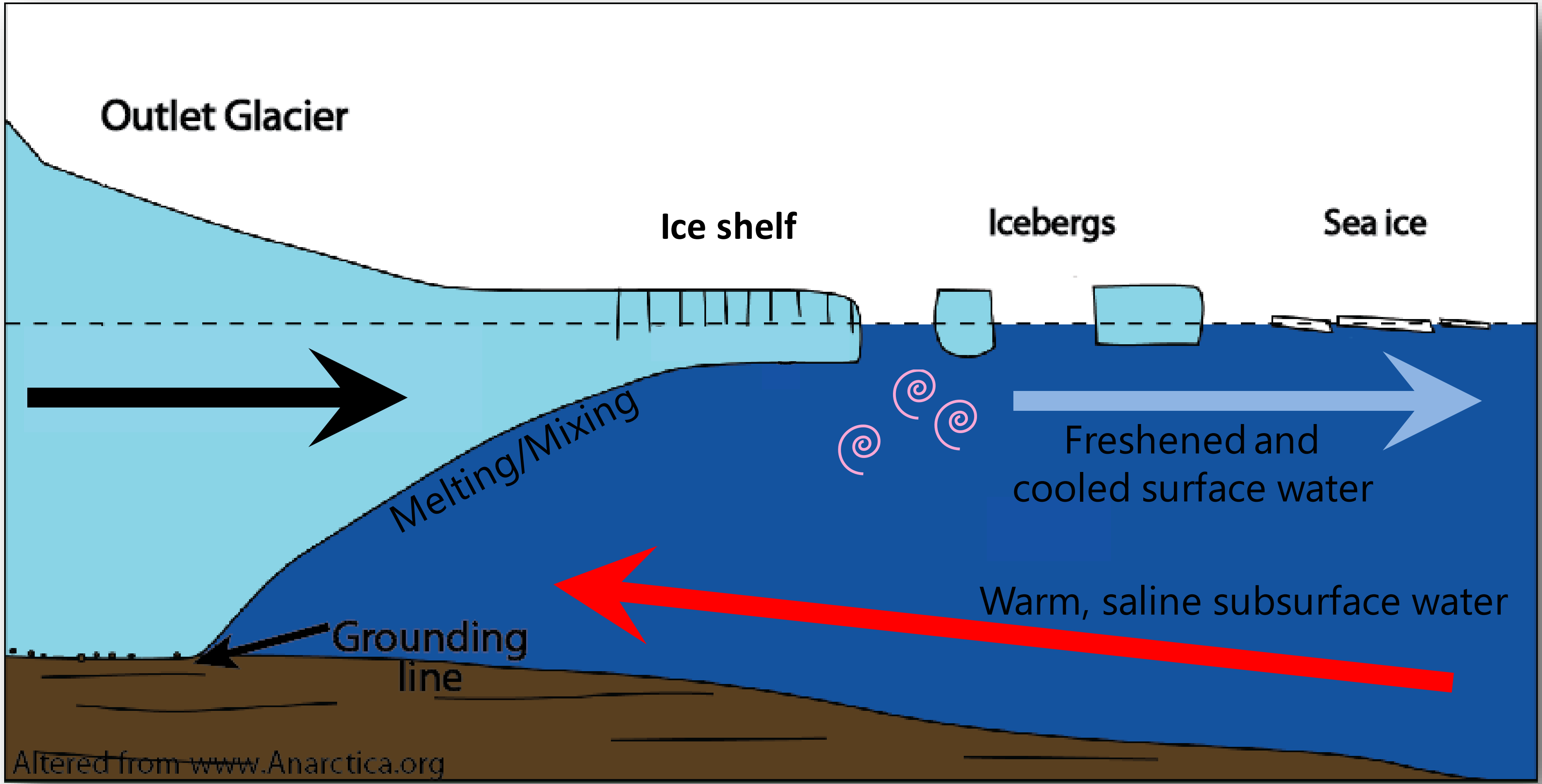
OMPS-Limb

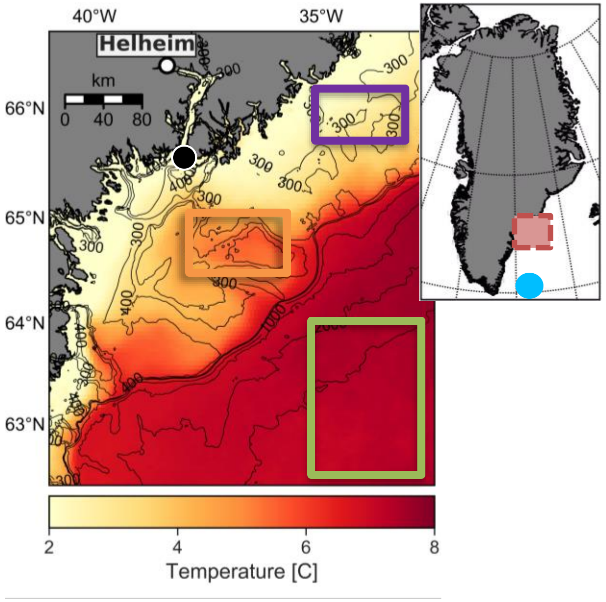
InVEST/CubeSats

RAVAN
RainCube
TEMPEST-D
CubeRRT
CSIM
CIRiS
HARP
SNoOPI
HyTI
CTIM
NACHOS

05.23.19

Detect ocean heat transport to the ice using remote sensing?

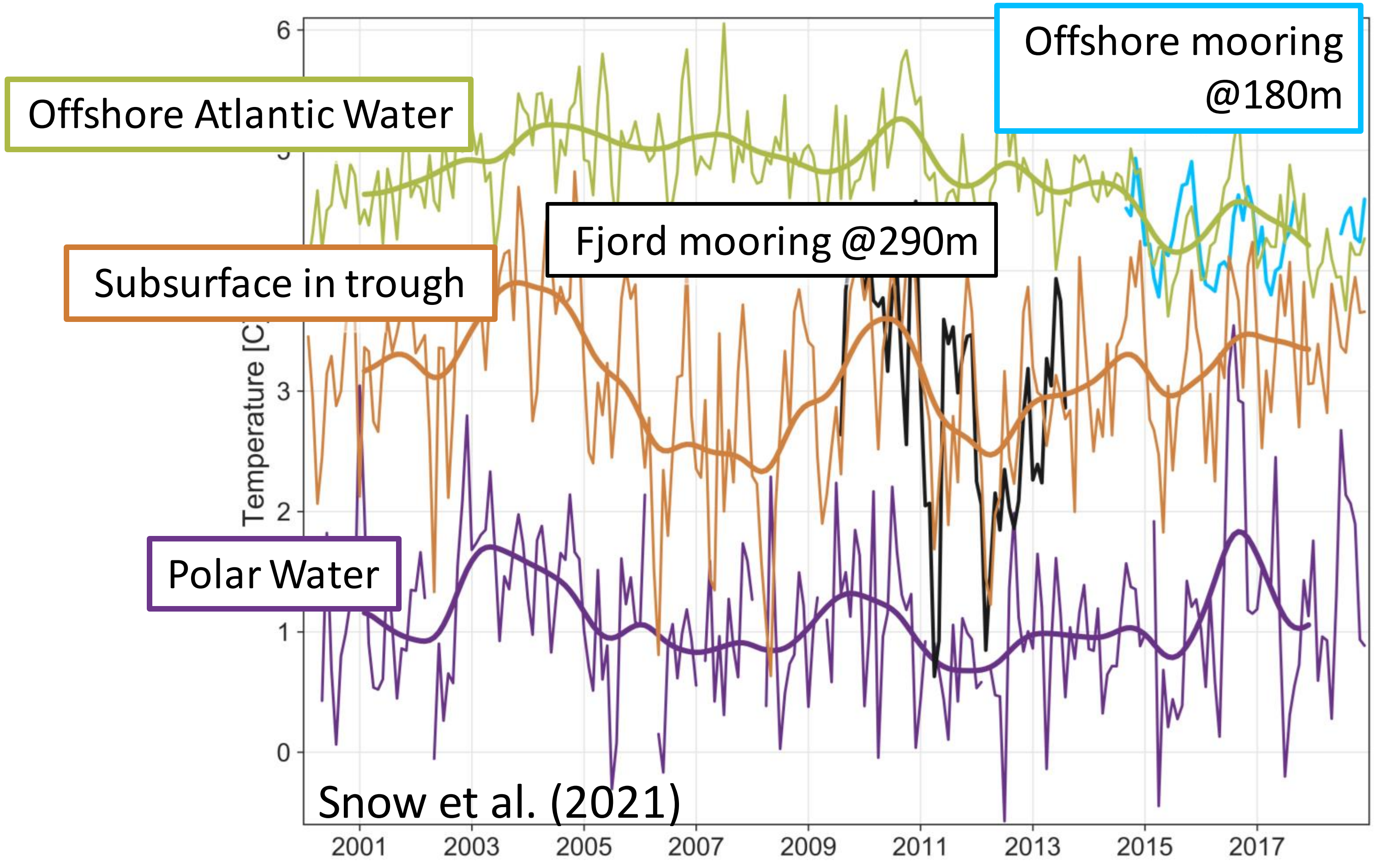




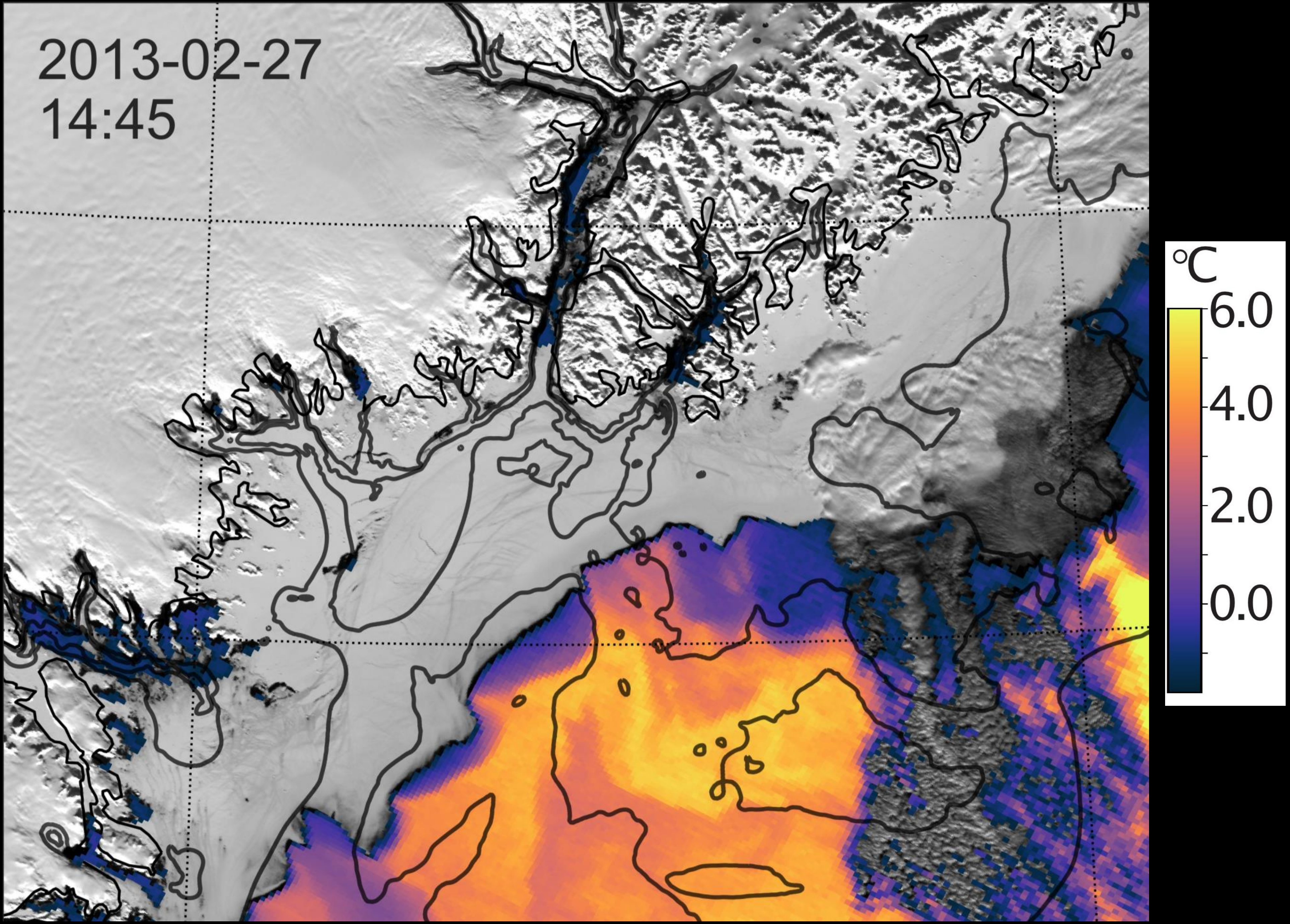
JGR Oceans

Research Article | Open Access

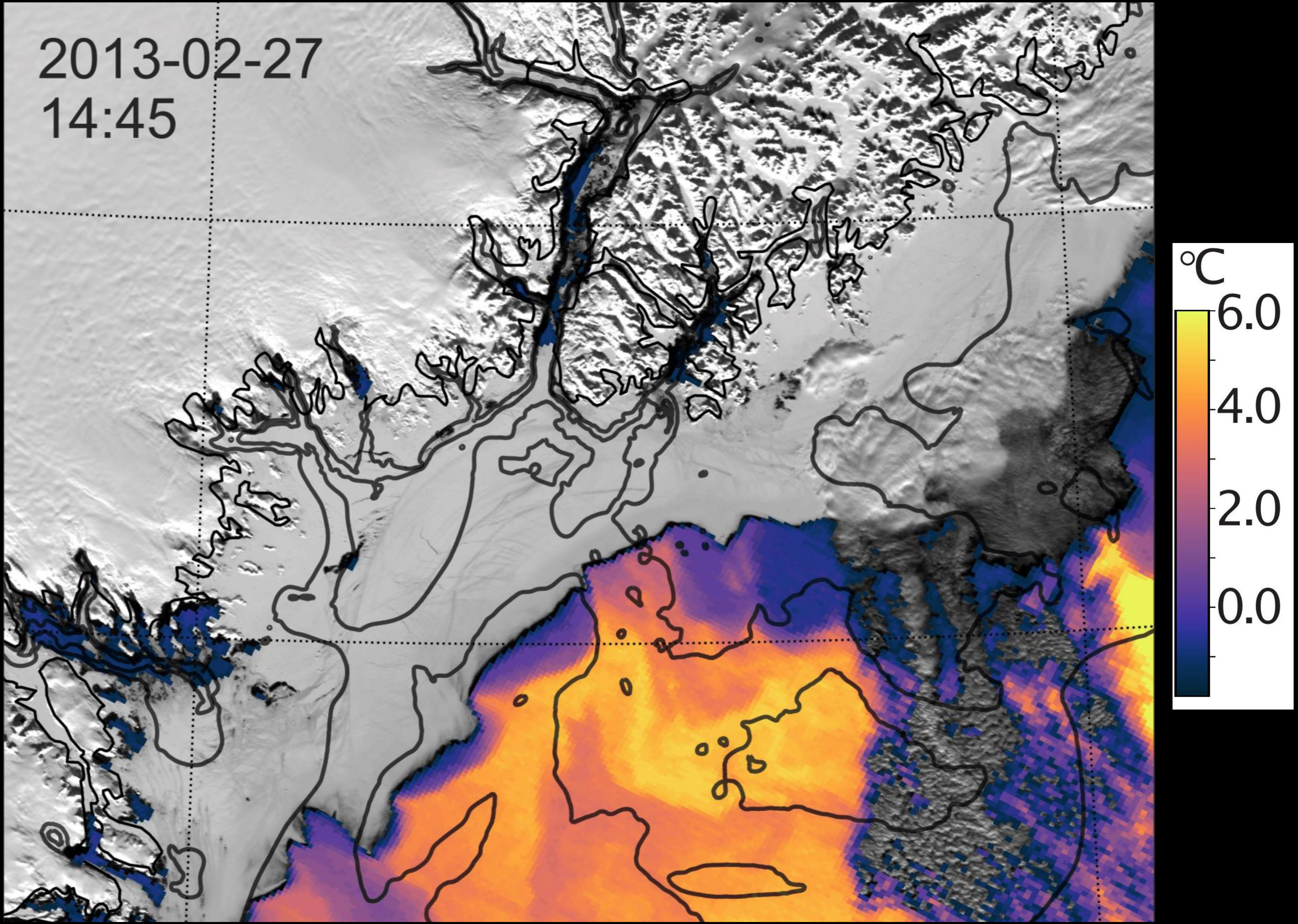
More than Skin Deep: Sea Surface Temperature as a Means of Inferring Atlantic Water Variability on the Southeast Greenland Continental Shelf Near Helheim Glacier



SST provides proxy for surface and subsurface water temperatures in southeast Greenland

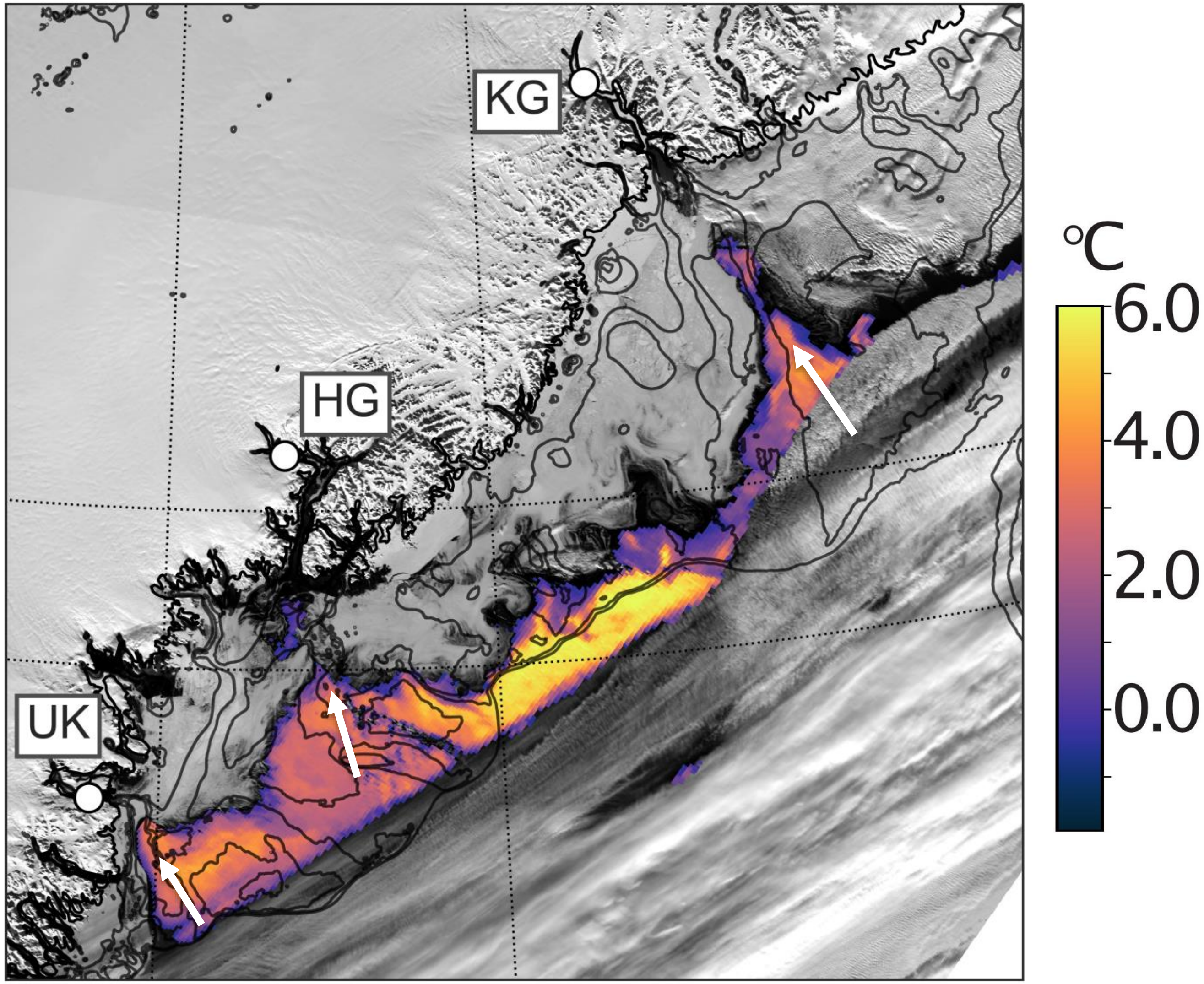


Snow et al.
(in review)

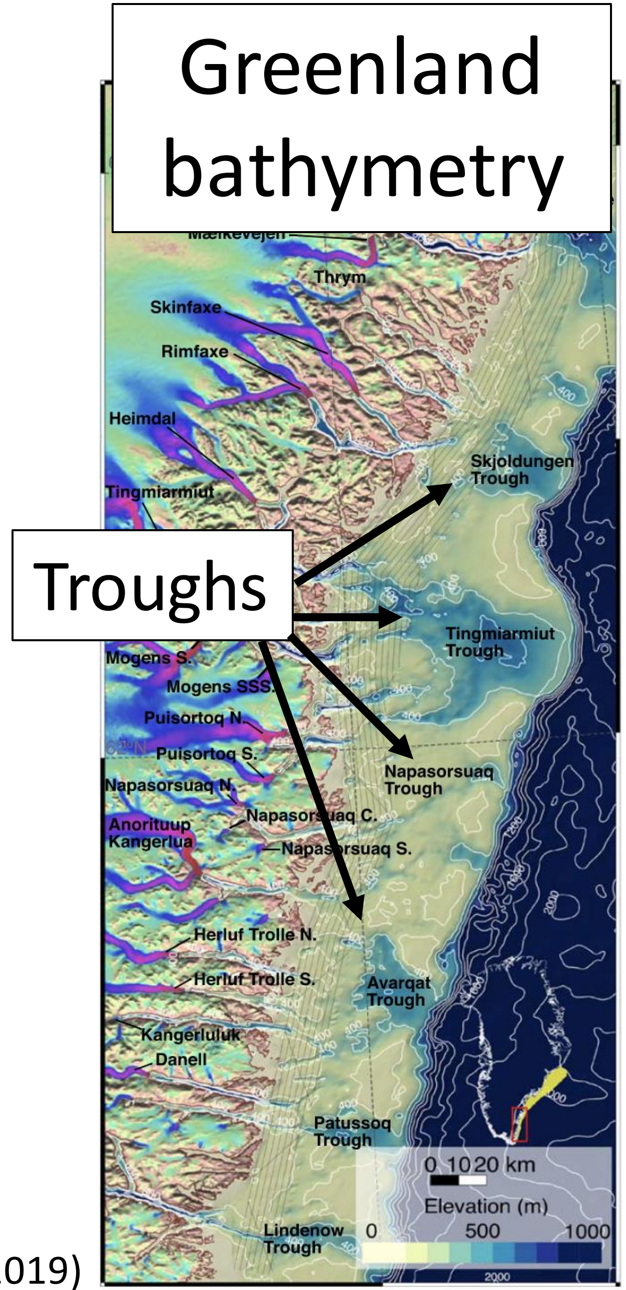


Snow et al.
(in review)

Intrusions drive warm Atlantic Water inshore and warm the subsurface waters at troughs



Snow et al. (in review)



Lu An et al. (2019)

New ice-ocean tools and applications

Detection of the Antarctic Coastal Current in an integrated thermal remote sensing and field observation data set

Thermal detection of ice features and warm plumes at the ice-ocean interface in Antarctica with the aid of machine learning

Where we are going next – big data ice-ocean analyses in the cloud using open science principles

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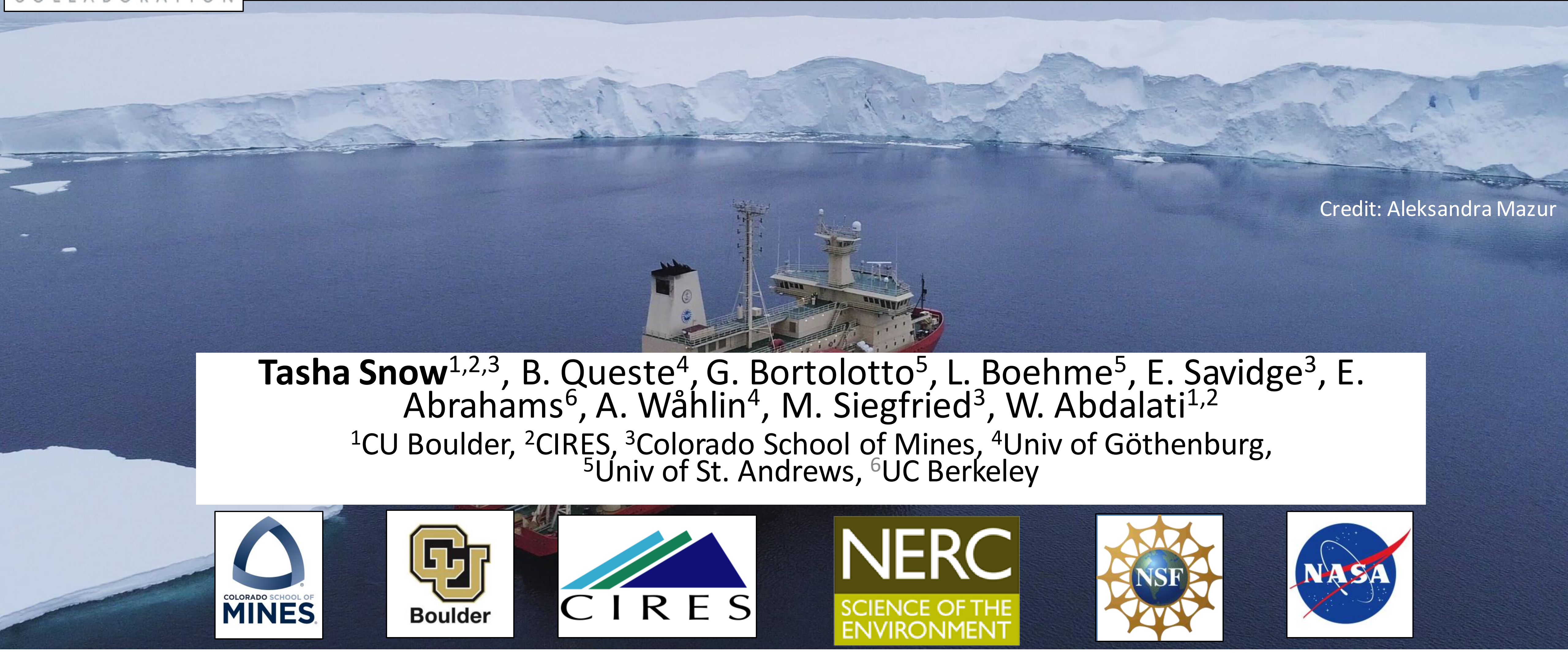
Seasonal and interannual variability of the Antarctic Coastal Current in the eastern Amundsen Sea



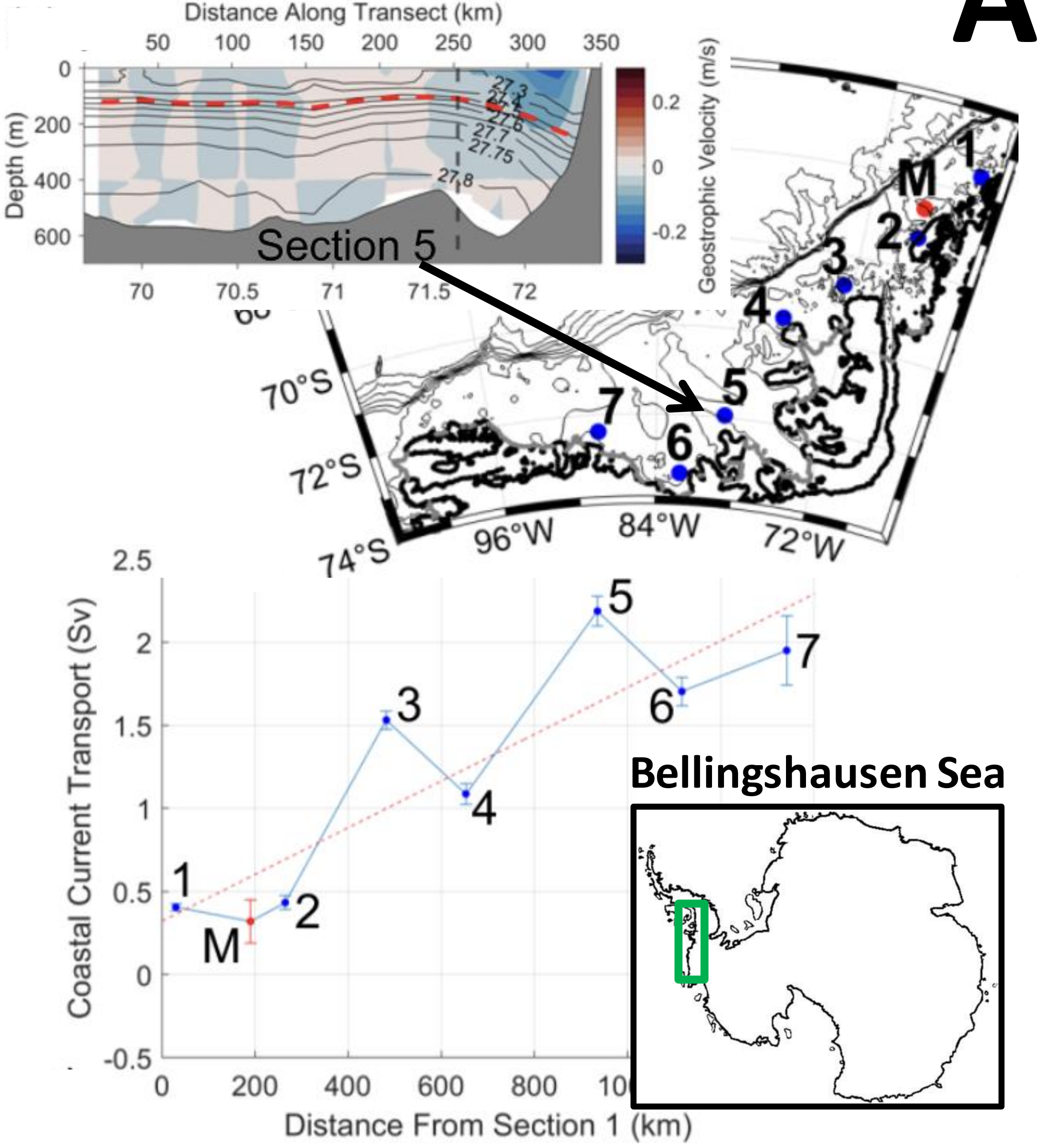
Credit: Aleksandra Mazur

Tasha Snow[1,2,3], B. Queste[4], G. Bortolotto[5], L. Boehme[5], E. Savidge[3], E. Abrahams[6], A. Wåhlin[4], M. Siegfried[3], W. Abdalati[1,2]

[1]CU Boulder, [2]CIRES, [3]Colorado School of Mines, [4]Univ of Göthenburg, [5]Univ of St. Andrews, [6]UC Berkeley

Antarctic Coastal Current (AACC) in the Amundsen Sea: Largely unknown

Schubert et al. (2021)



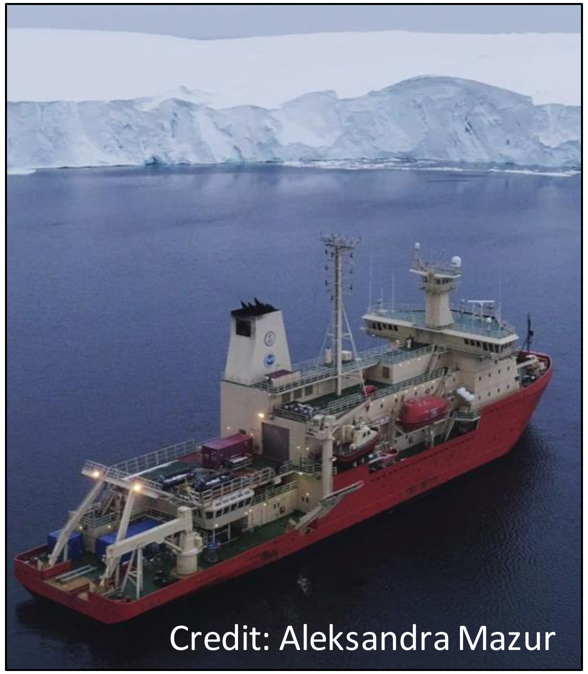
South of Antarctic Circumpolar Current often along coastline

Fast and shallow westward flow

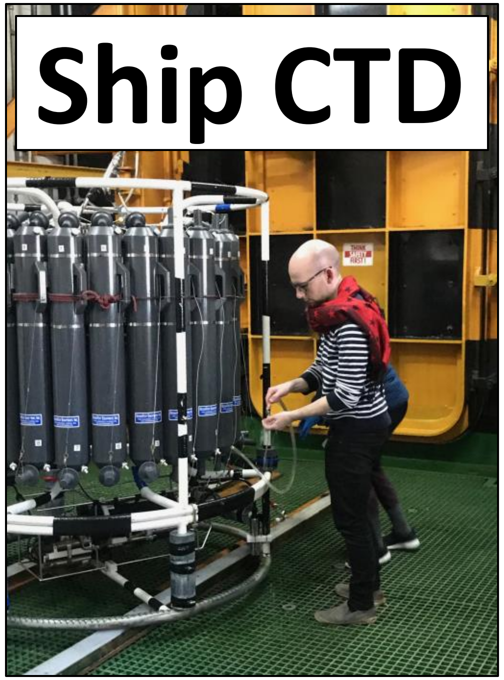
Meltwater concentration increases as flows west (Schubert et al., 2021)

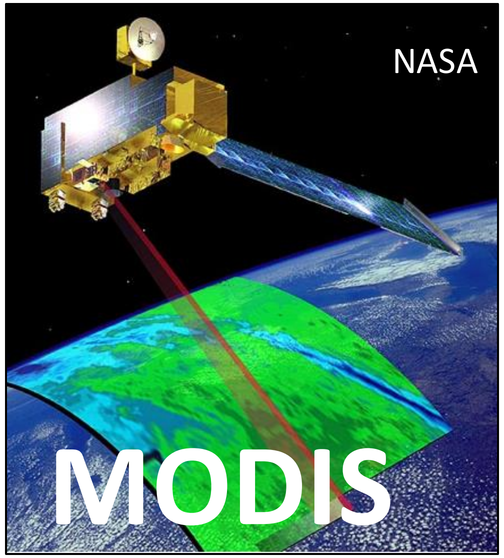
AACC variability affects heat transport to ice shelves (Hellmer et al., 2012)

Many data sources



Conductivity (salinity), Temperature, Depth





SST spatial resolution:

4 km

100 m

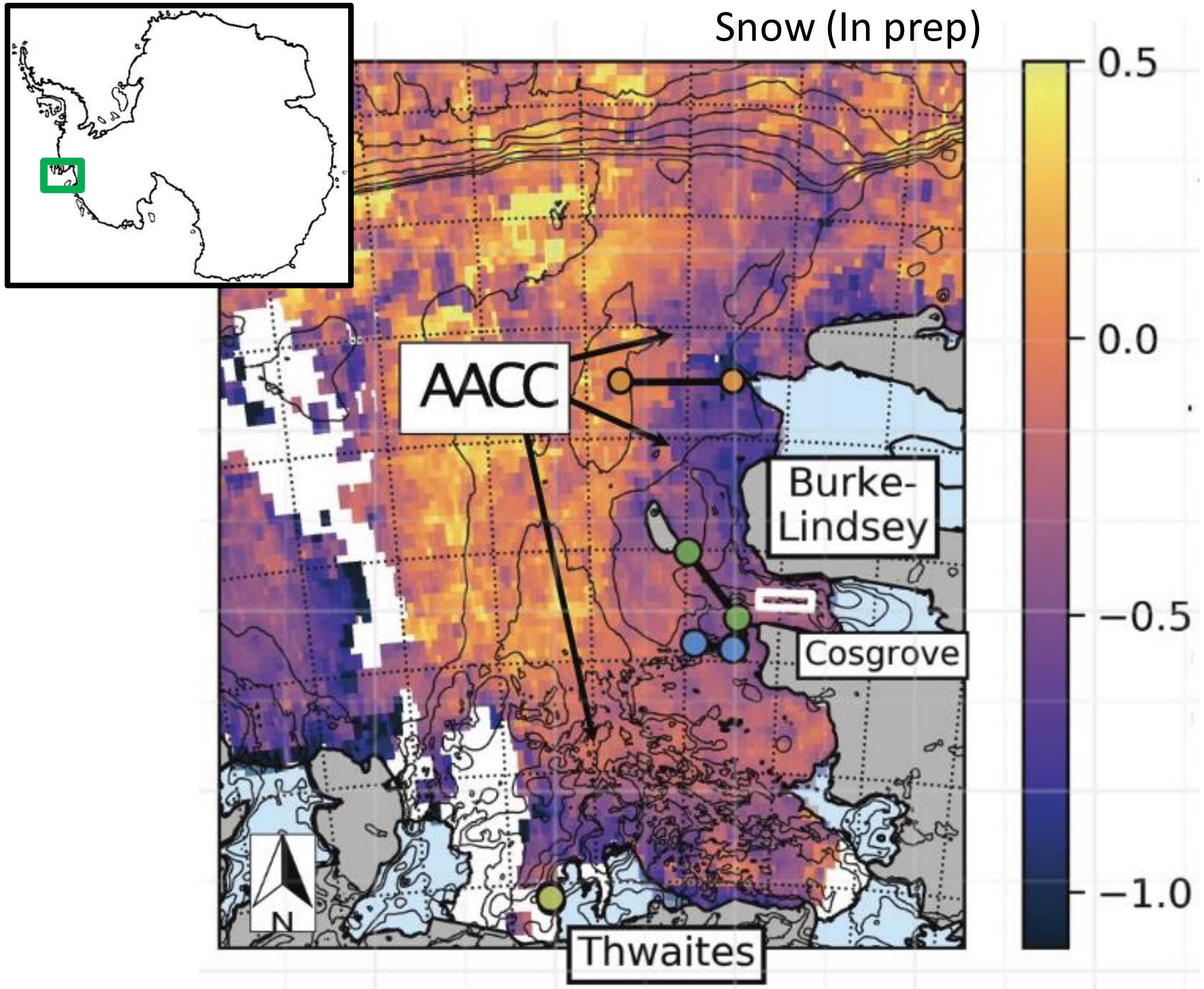
Permit#UK29/2018

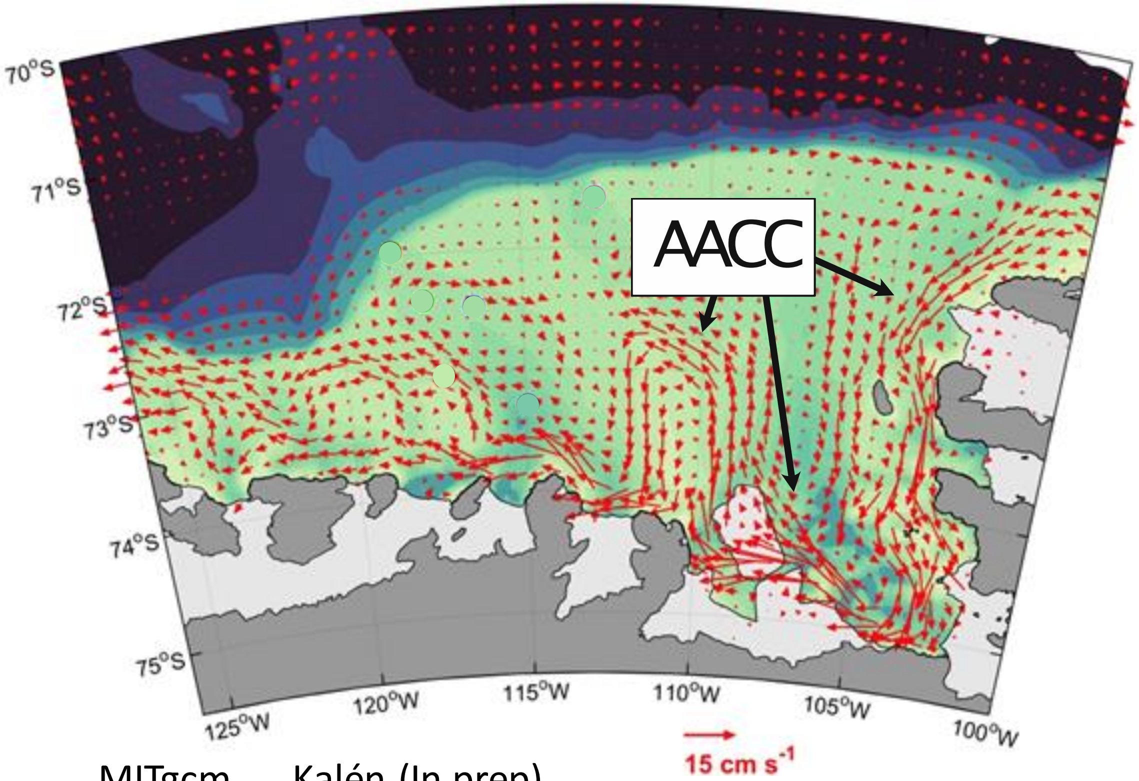
ADCP

Acoustic Doppler Current Profiler (water velocity)

Cool sea surface temperatures often correspond to AACC

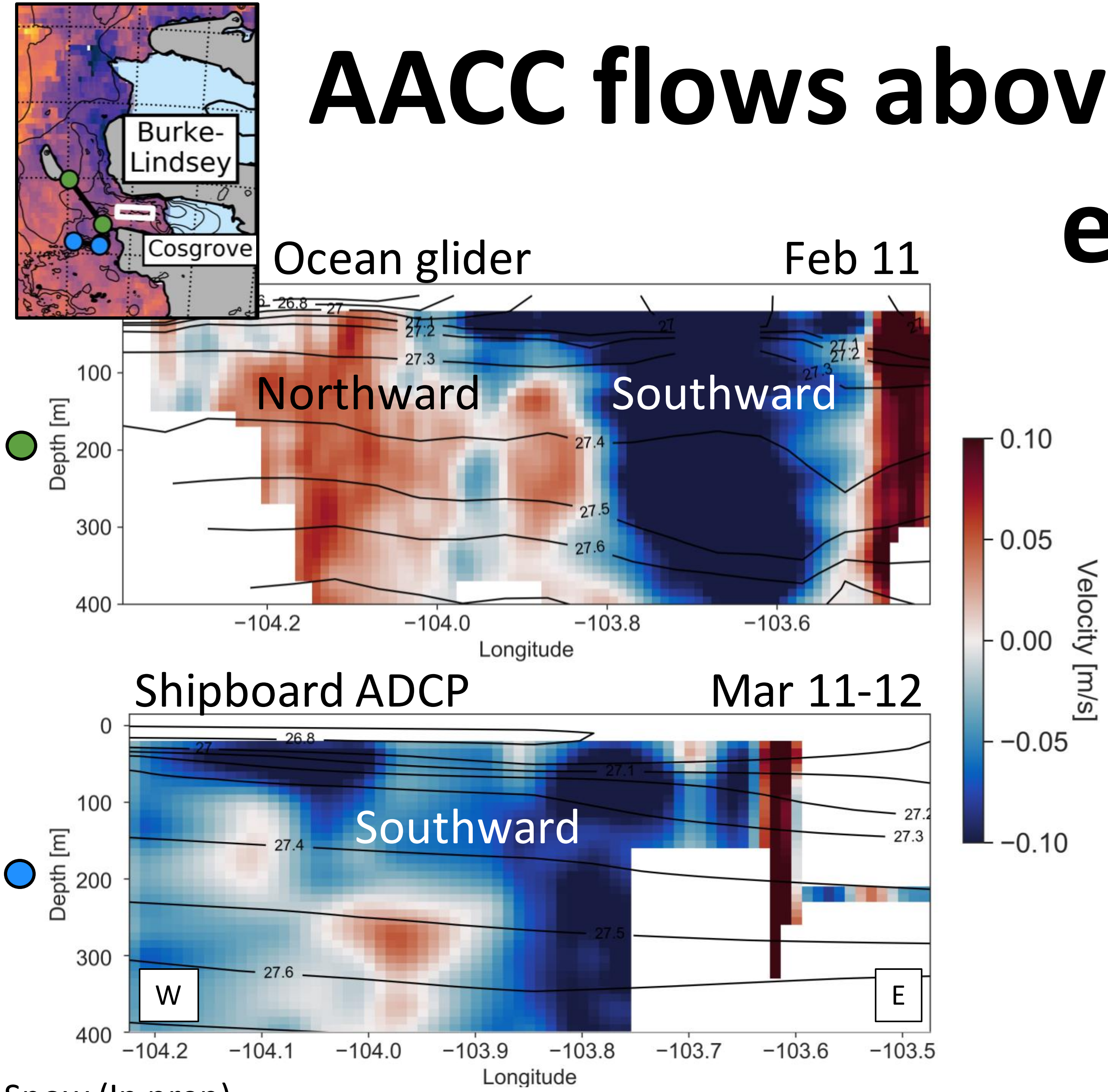
Snow (In prep)





MITgcm Kalén (In prep)

AACC flows above 50-100 m deep in east Amundsen Sea



Snow (In prep)

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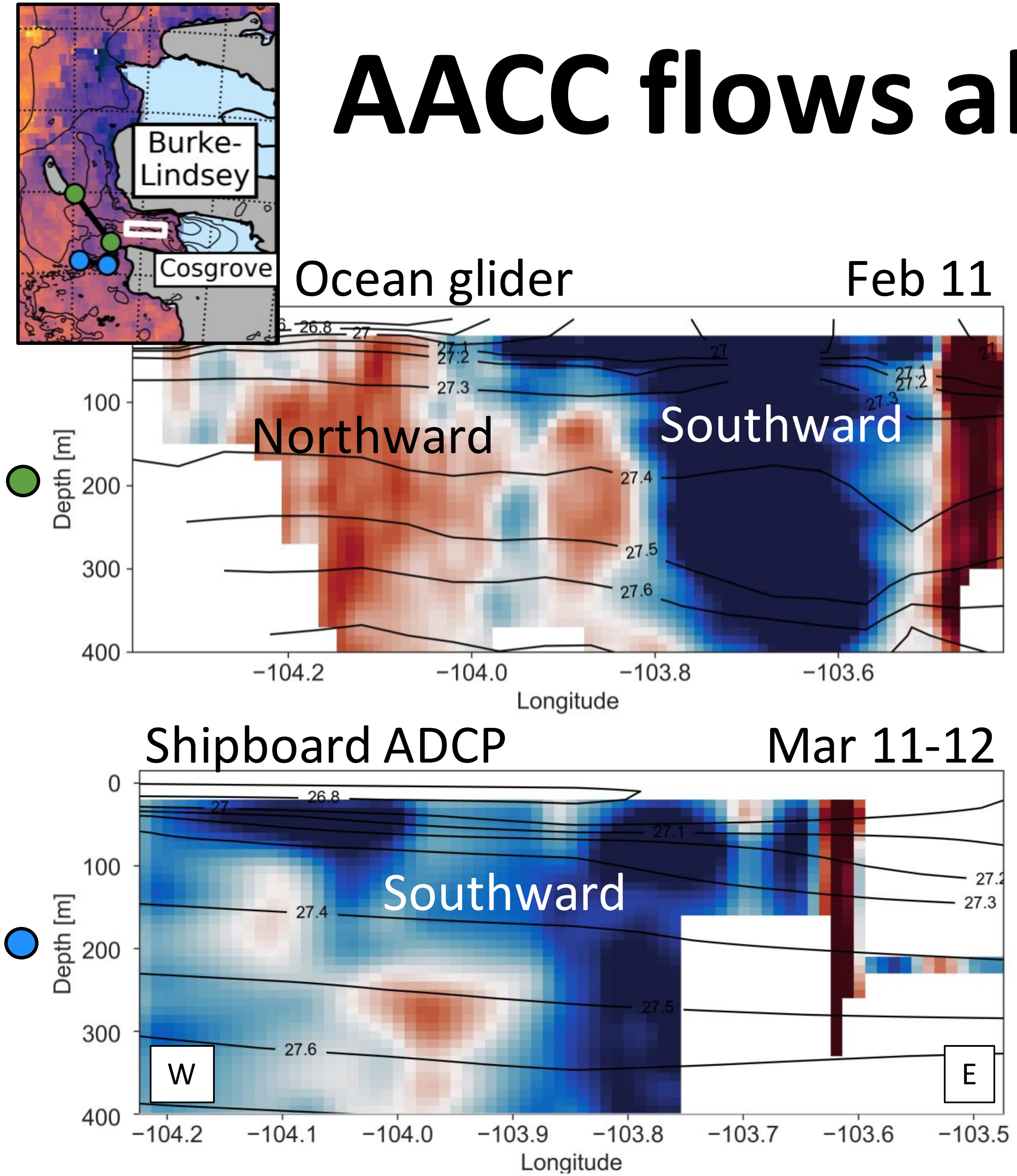
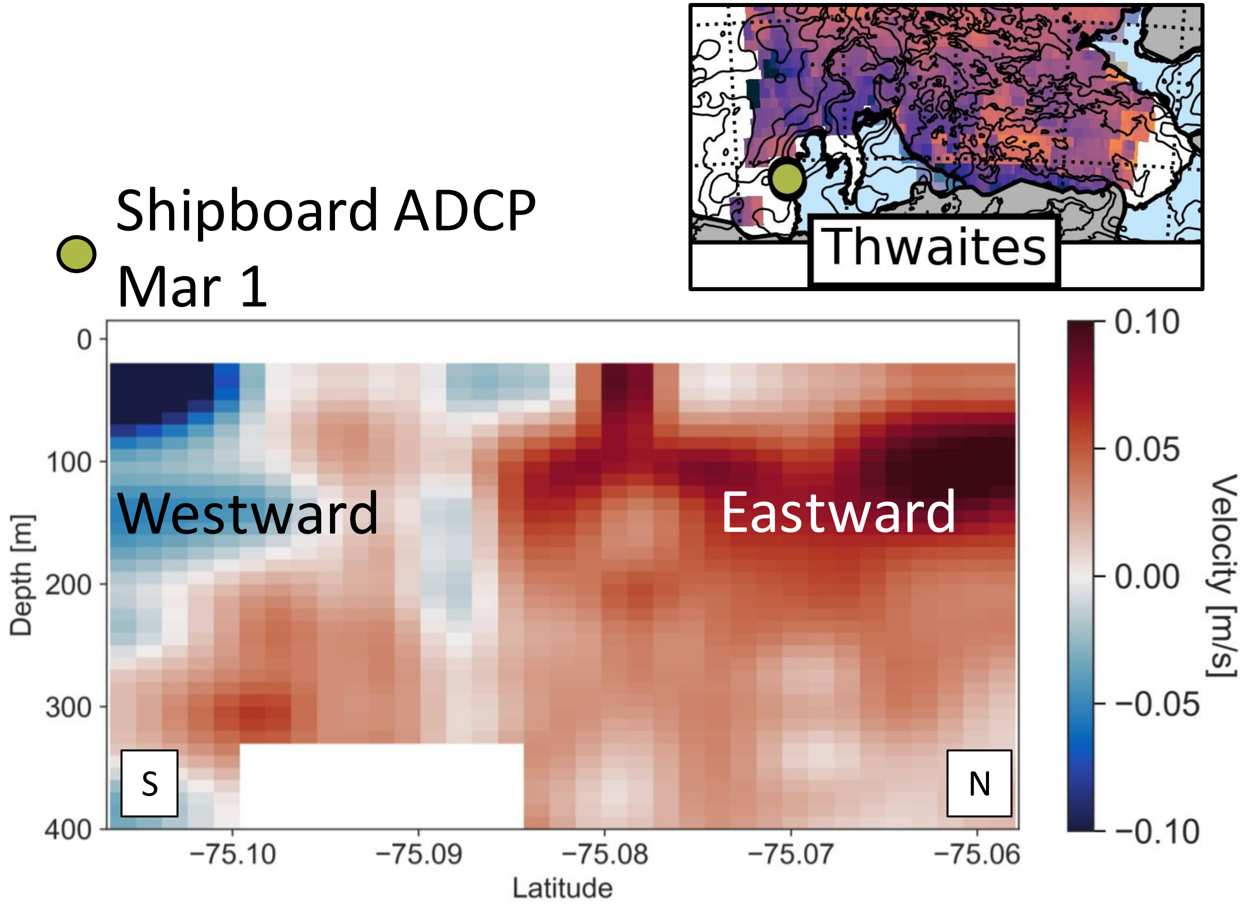
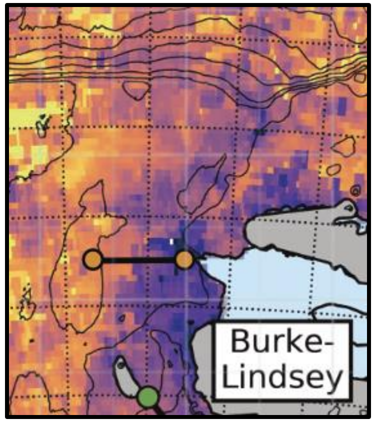
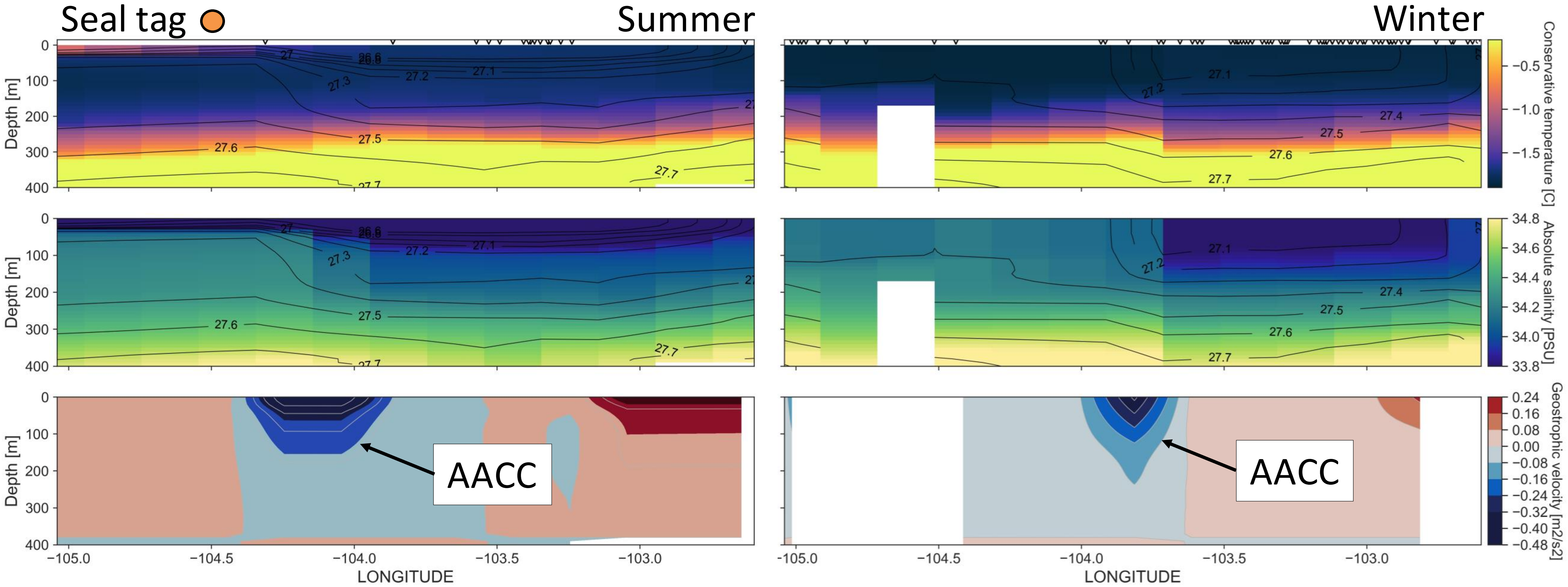


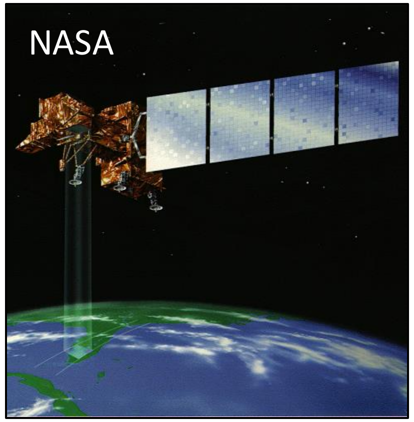




NE Amundsen: AACC larger, faster, and further offshore in summer



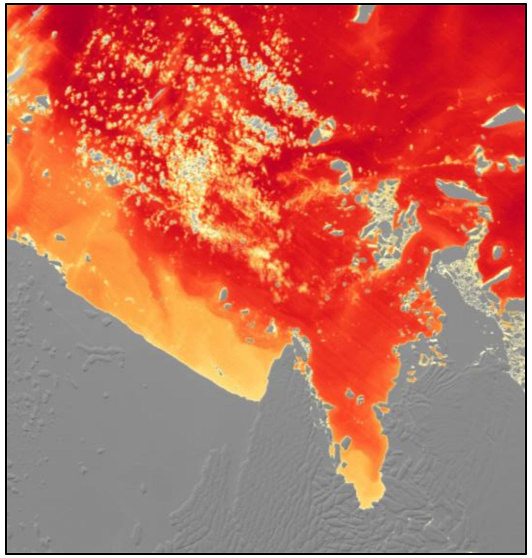
Landsat thermal processing pipeline



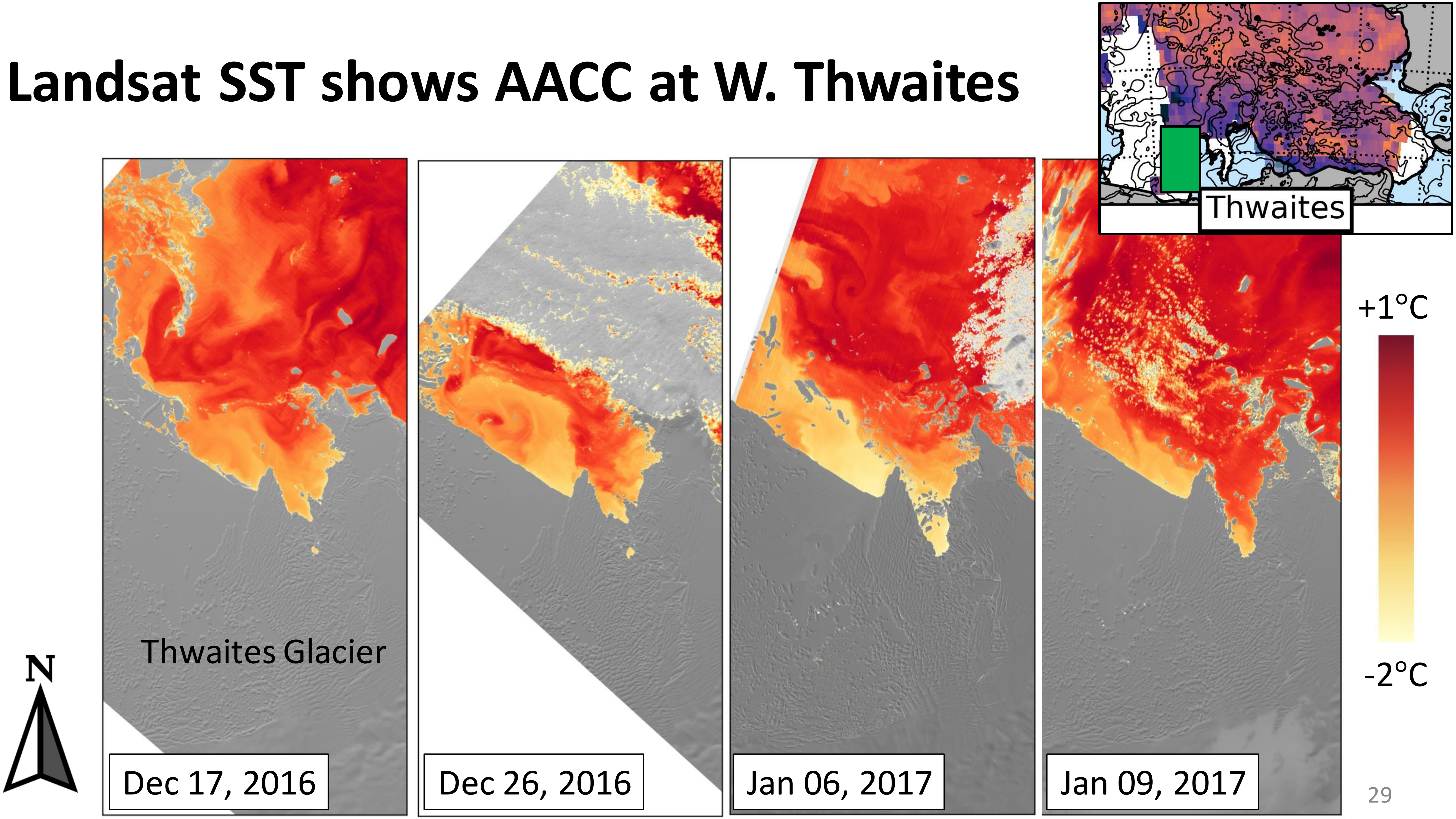
Build land mask from non-thermal bands

→ Produce scene specific ice and cloud masks

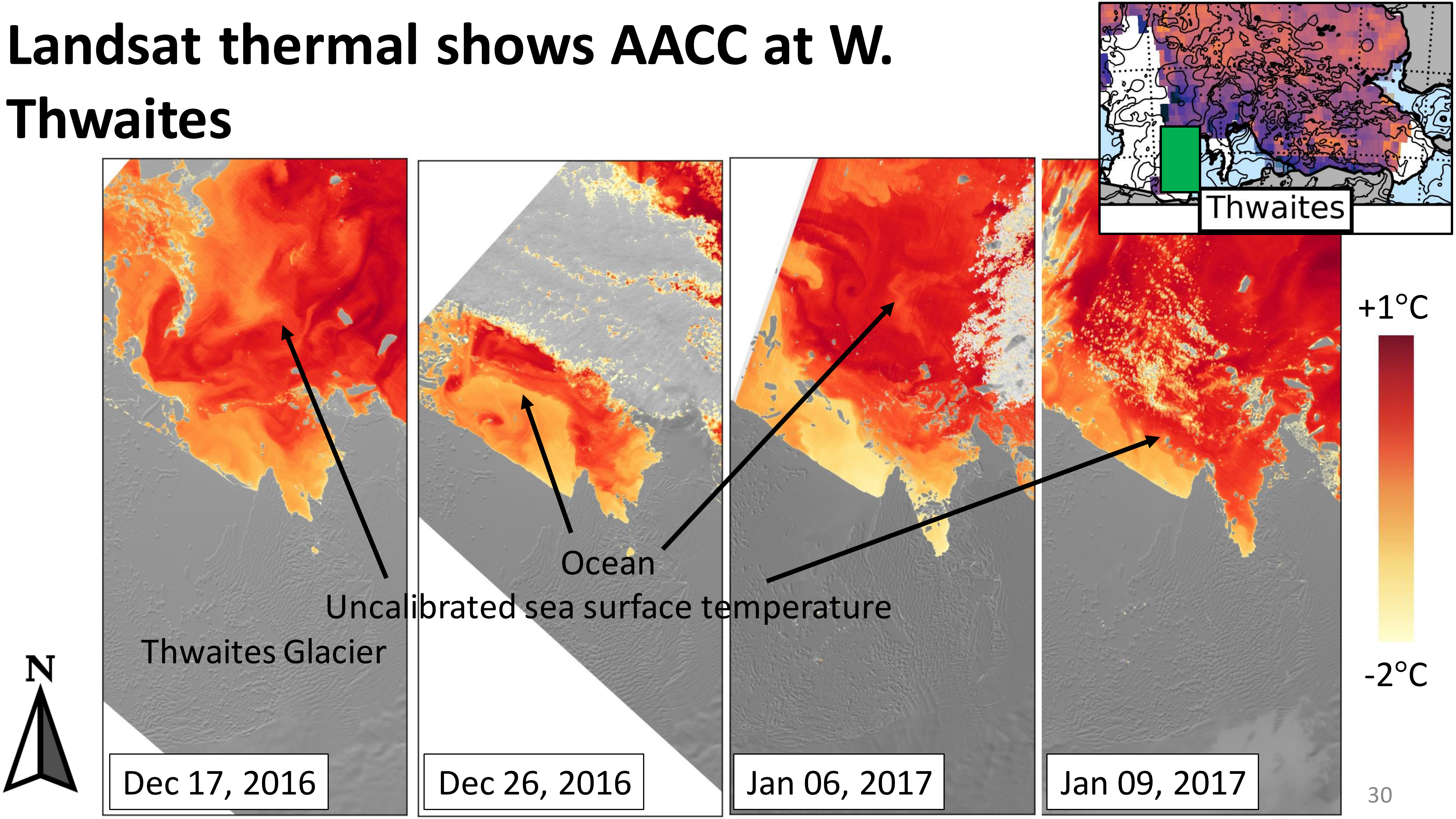
→ Extract ocean surface pixels from thermal band (Band 10)



Landsat SST shows AACC at W. Thwaites



Landsat thermal shows AACC at W. Thwaites



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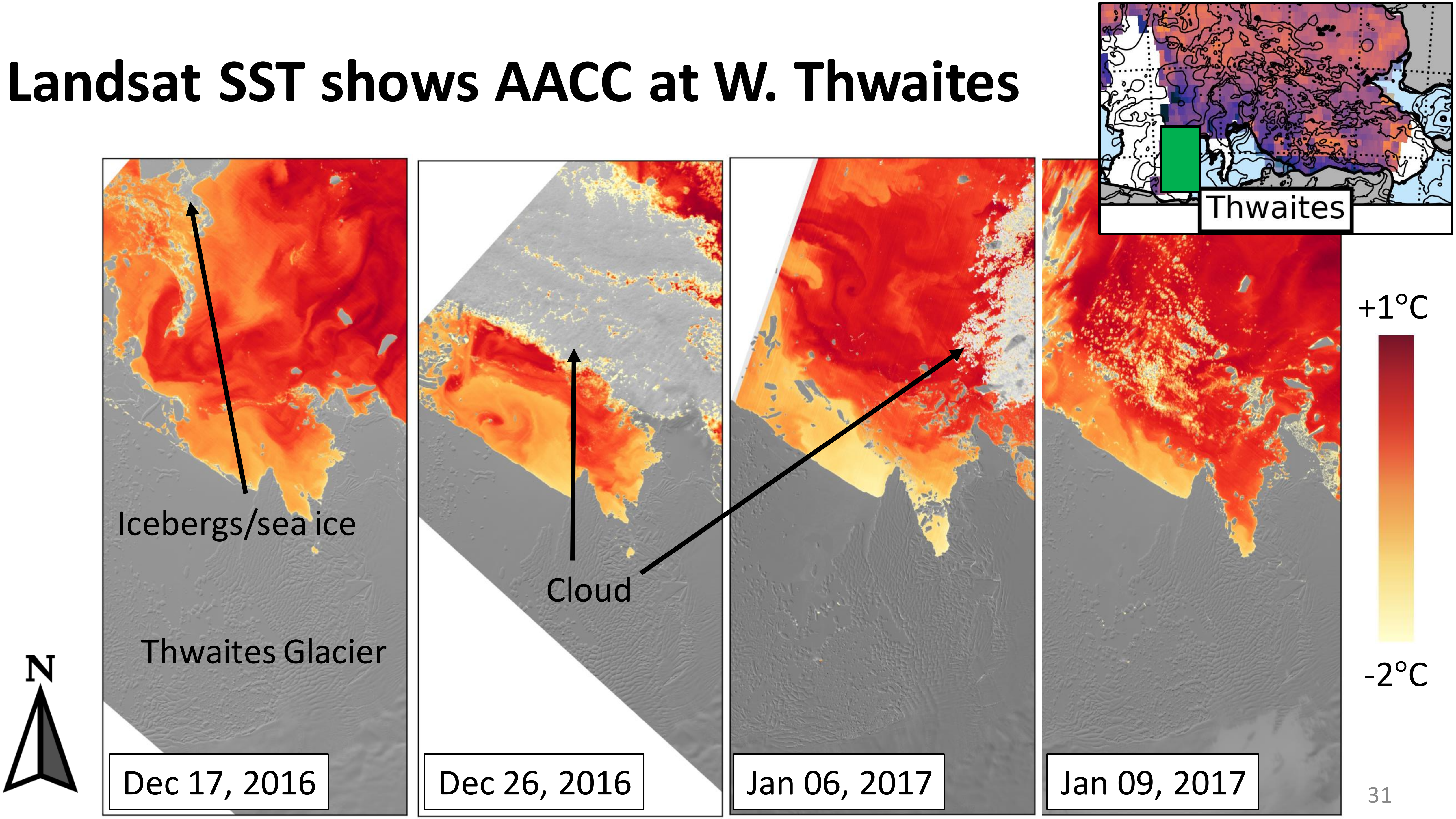

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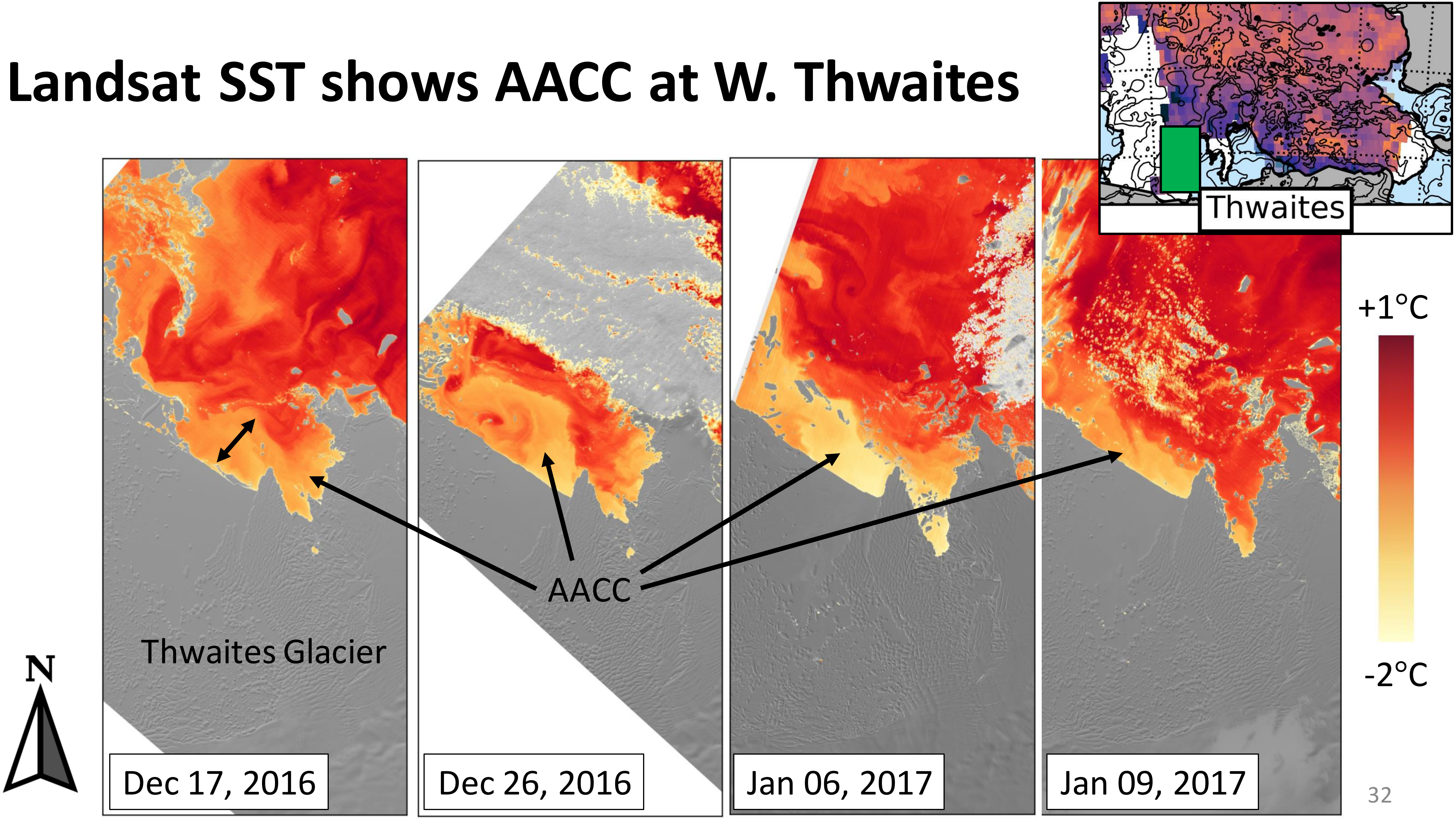
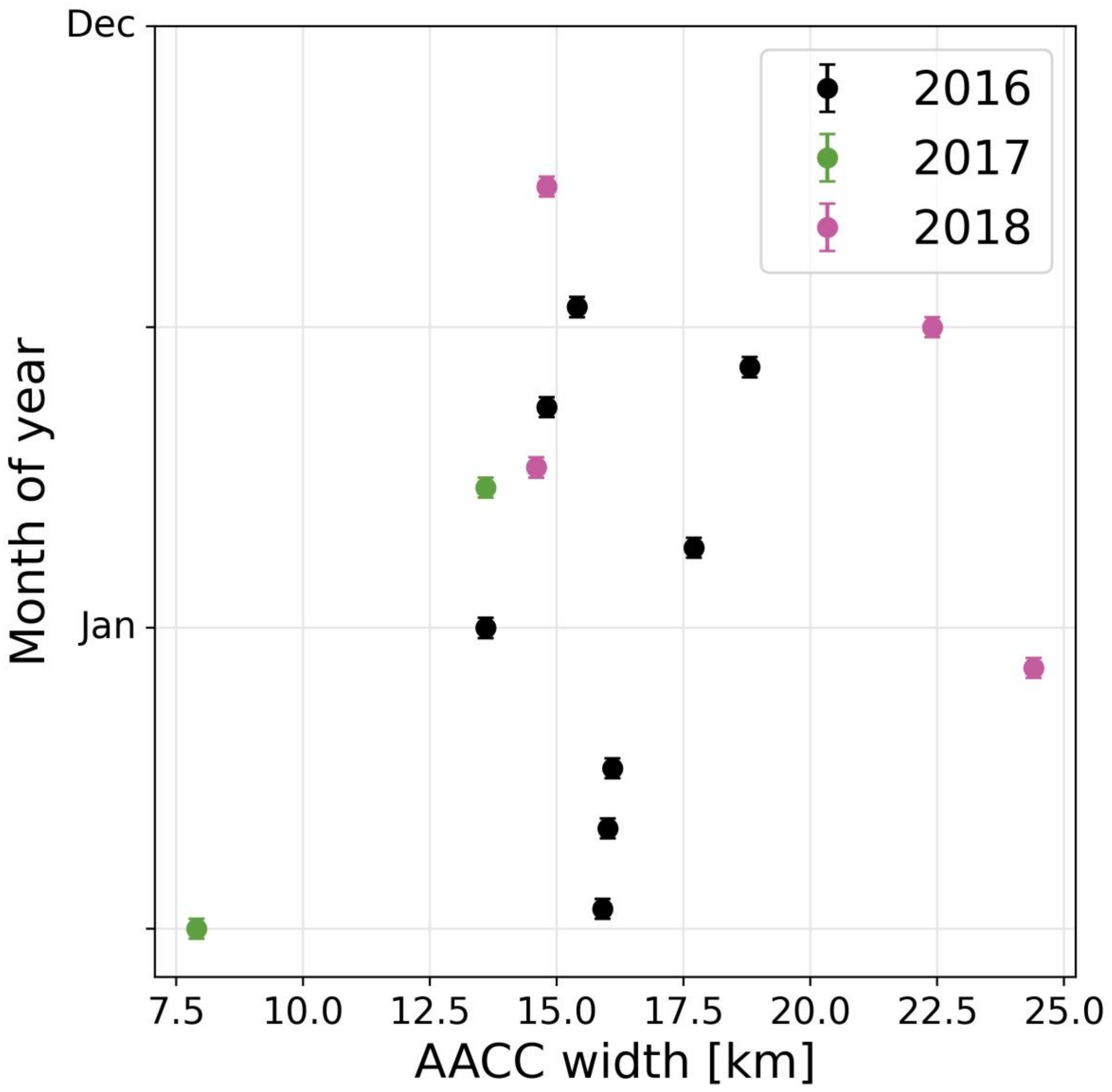


AACC typically ~15 km wide with some large deviations

Physical explanations for variability:
- Changes to influx of meltwater
- AACC diversion away from ice front
- Widening/narrowing with storms

Potential errors in technique for capturing AACC width



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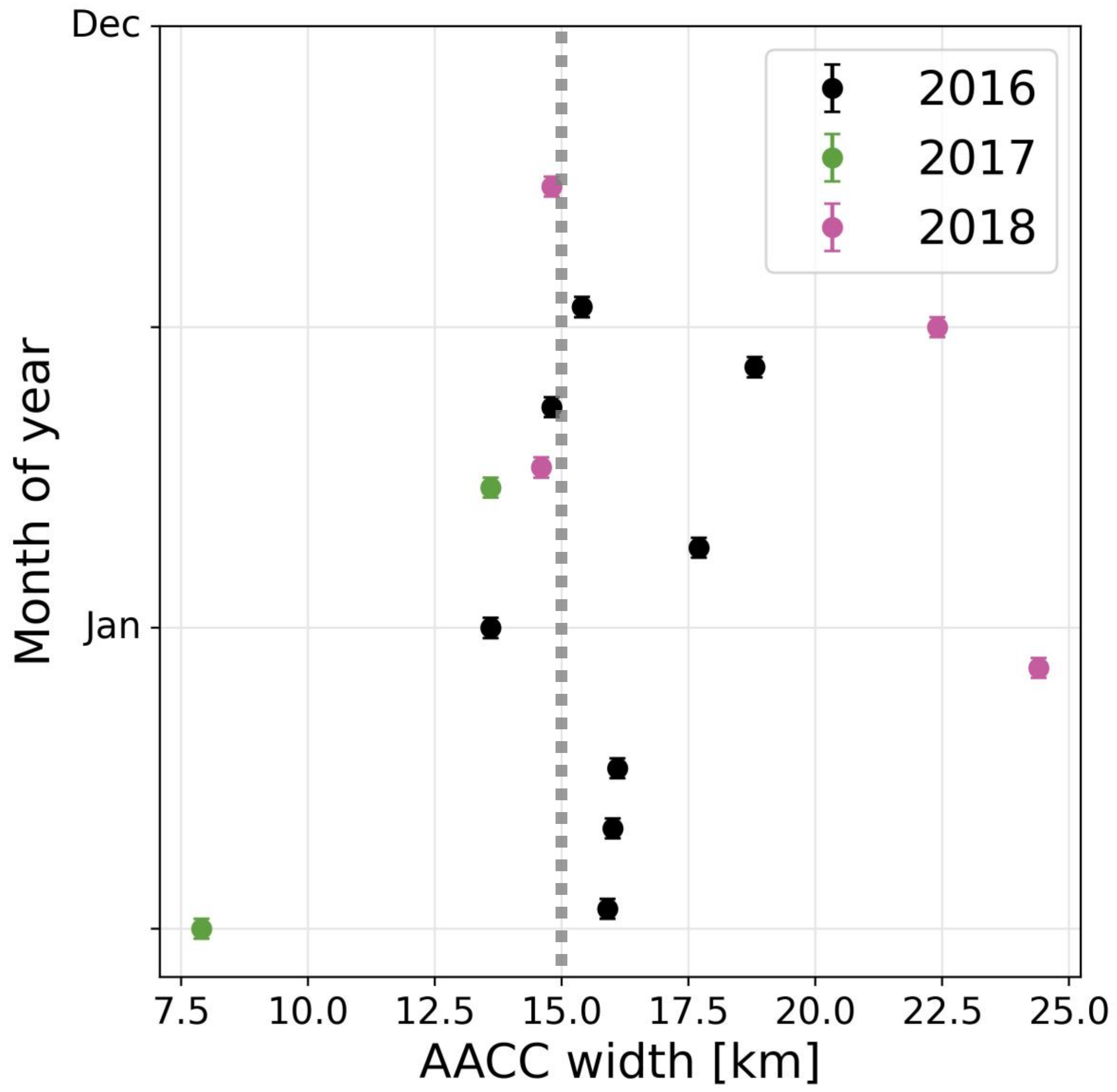
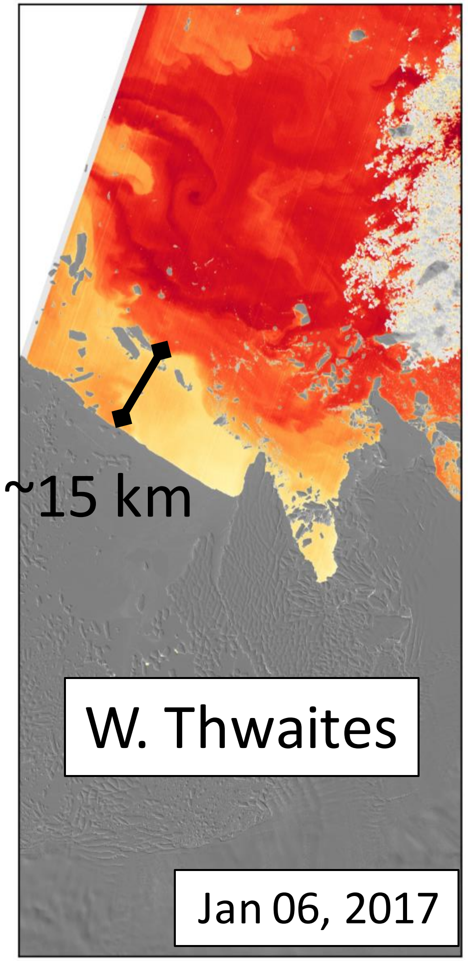


Conclusions

Combining satellite thermal measurements with field-based observations provides a more robust understanding of the AACC

AACC flows above 100 m deep, generally westward along coastline, and varies seasonally and interannually

AACC variability may modify heat transport to ice fronts, especially as ice fronts retreat



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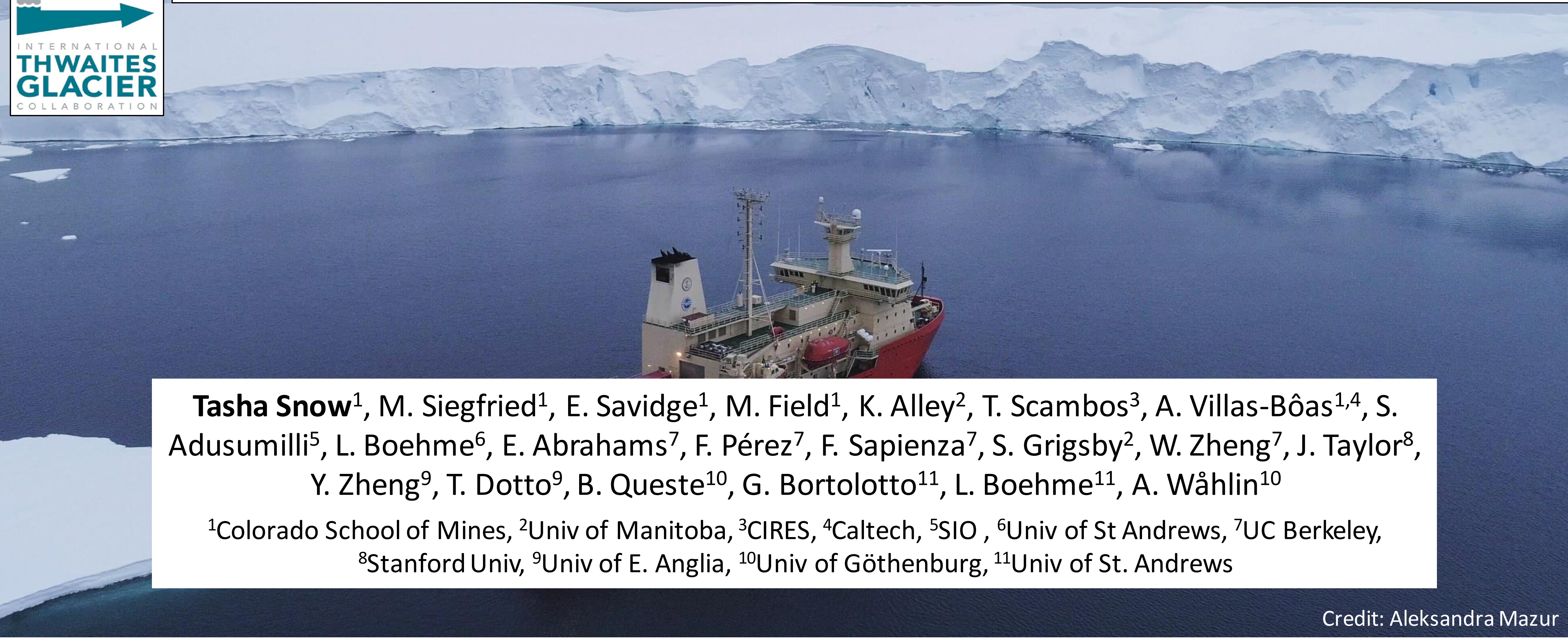
Investigating the impact of Antarctic basal channel and persistent polynya co-evolution on ice shelf stability

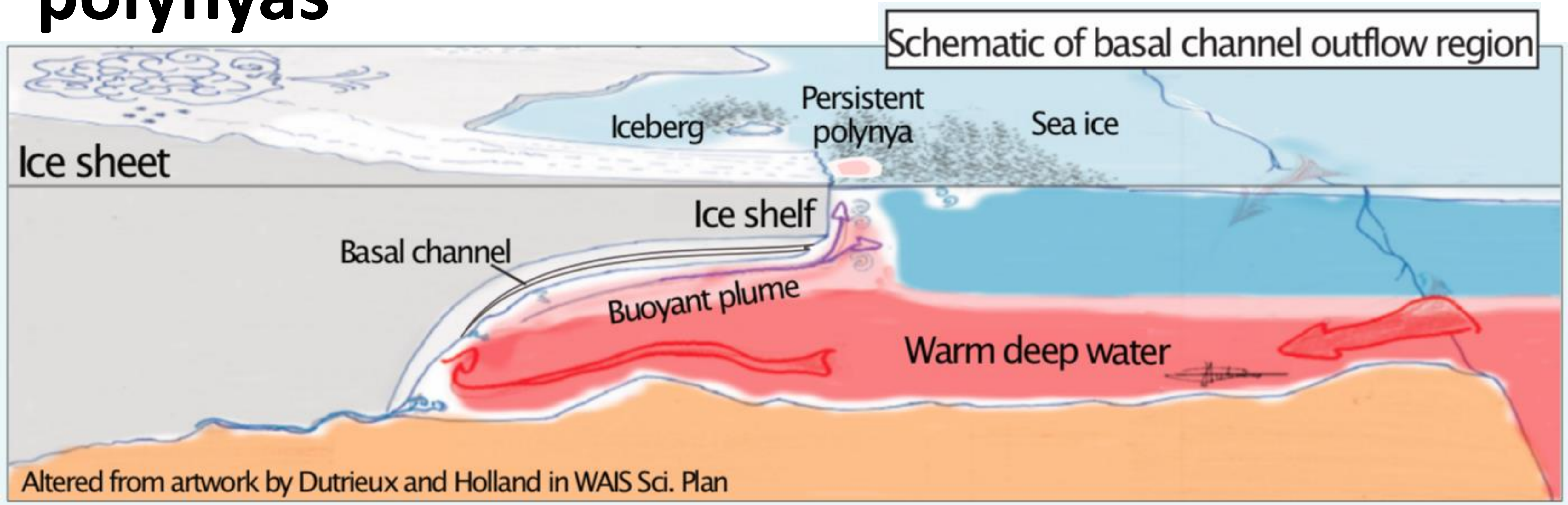


Tasha Snow[1], M. Siegfried[1], E. Savidge[1], M. Field[1], K. Alley[2], T. Scambos[3], A. Villas-Bôas[1,4], S. Adusumilli[5], L. Boehme[6], E. Abrahams[7], F. Pérez[7], F. Sapienza[7], S. Grigsby[2], W. Zheng[7], J. Taylor[8], Y. Zheng[9], T. Dotto[9], B. Queste[10], G. Bortolotto[11], L. Boehme[11], A. Wåhlin[10]

[1]Colorado School of Mines, [2]Univ of Manitoba, [3]CIRES, [4]Caltech, [5]SIO , [6]Univ of St Andrews, [7]UC Berkeley, [8]Stanford Univ, [9]Univ of E. Anglia, [10]Univ of Göthenburg, [11]Univ of St. Andrews

Credit: Aleksandra Mazur

Warm water melting the ice shelf base creates buoyant plumes and persistent polynyas



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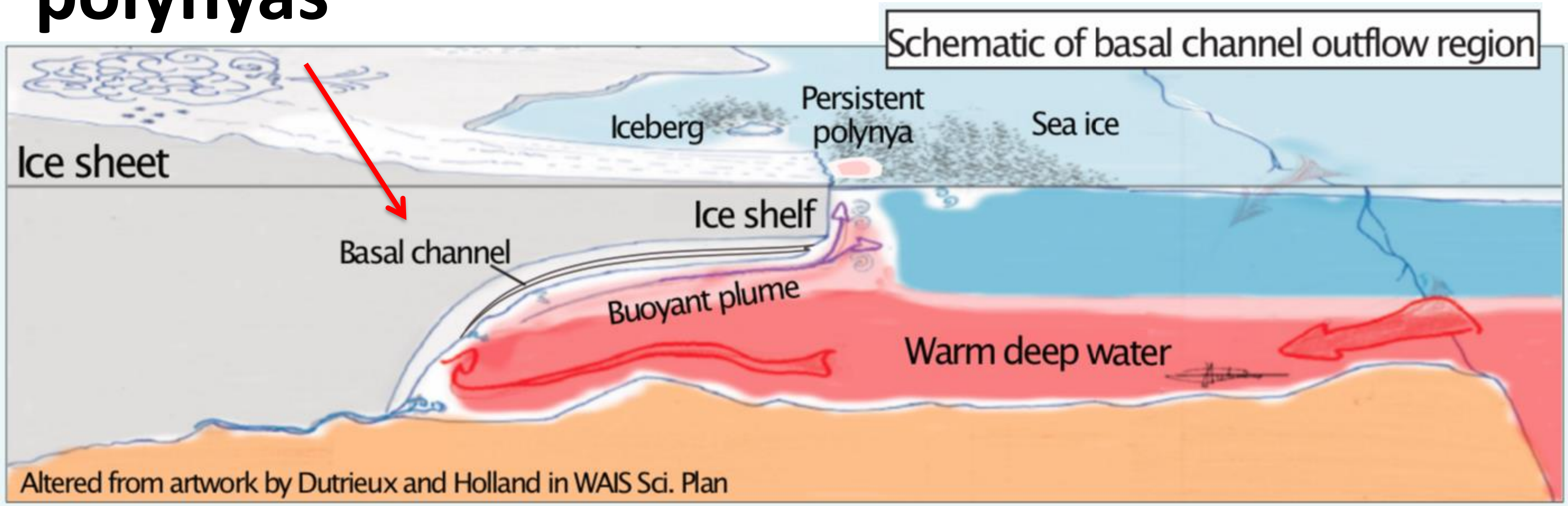

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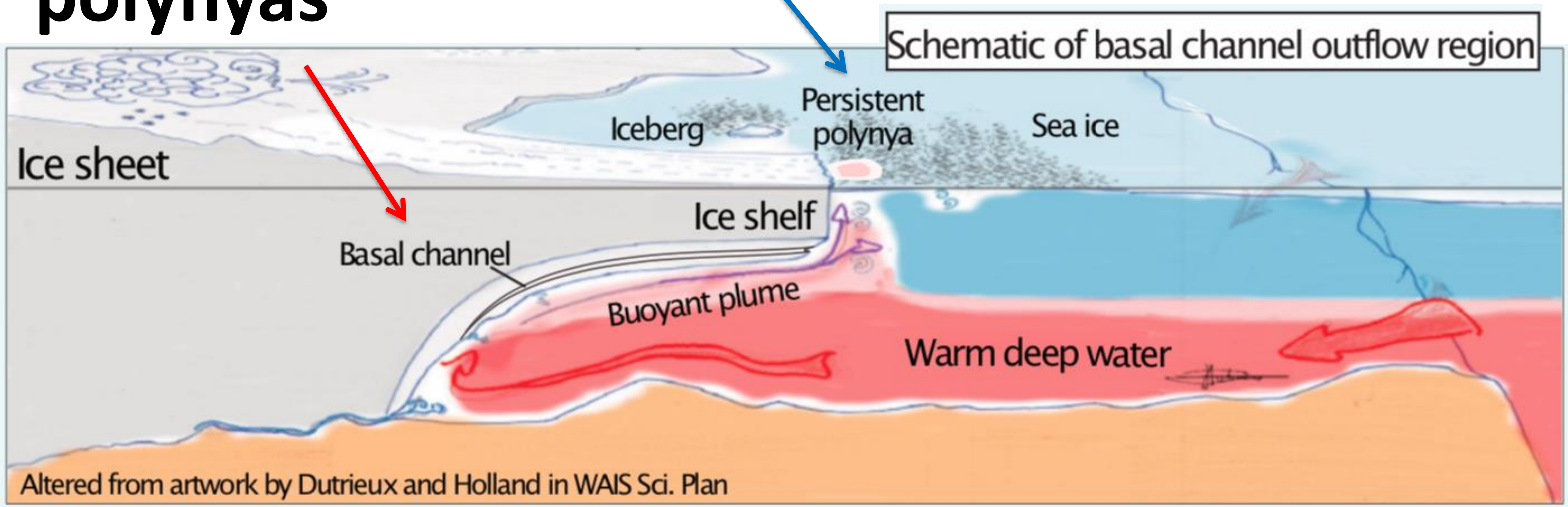
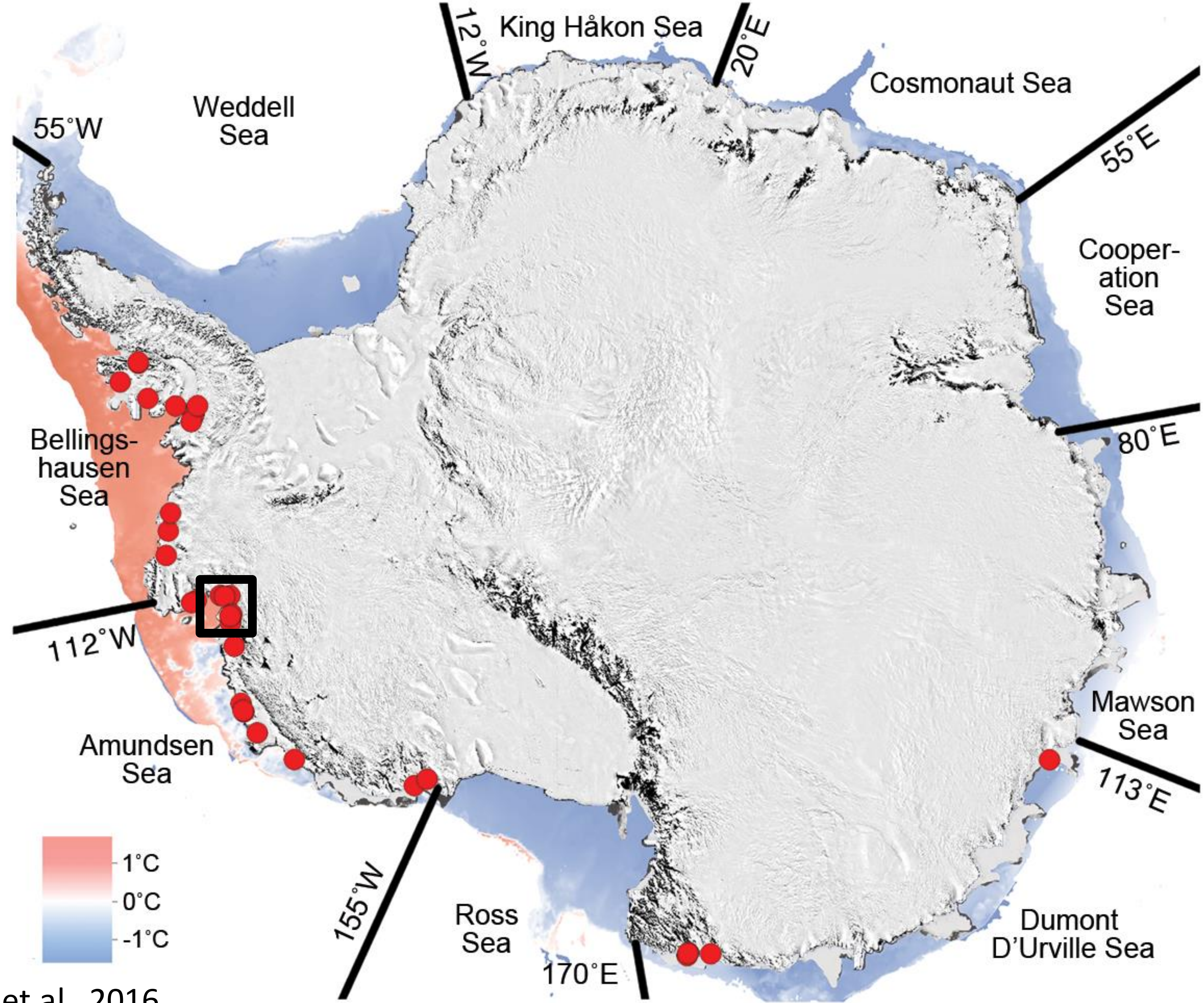


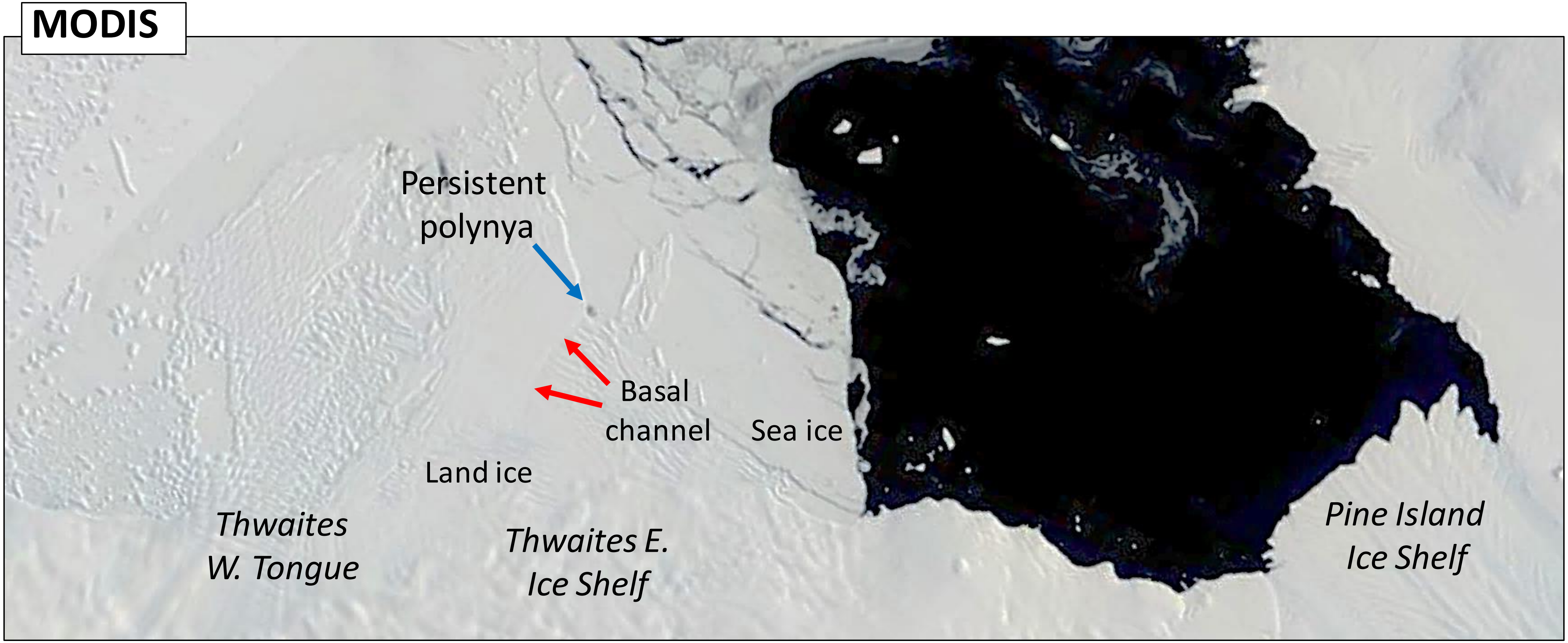
Plumes entrain warm water as they rise → may melt hole in sea ice at the ice shelf front (persistent polynya)

Seasonally open, multiple years in a row in the same location



Adjusted from Alley et al., 2016

Goal: Investigate persistent polynya variability and mechanisms driving that variability



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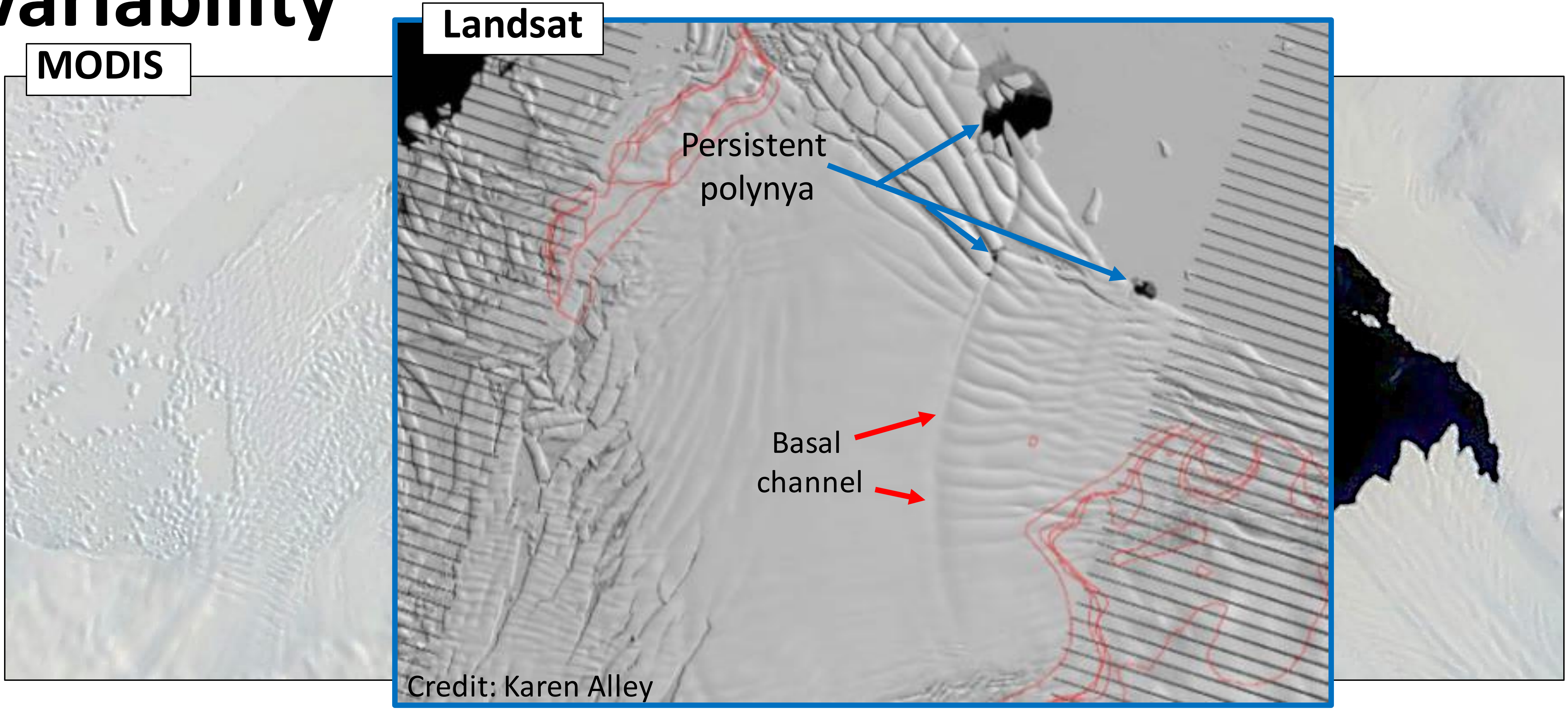
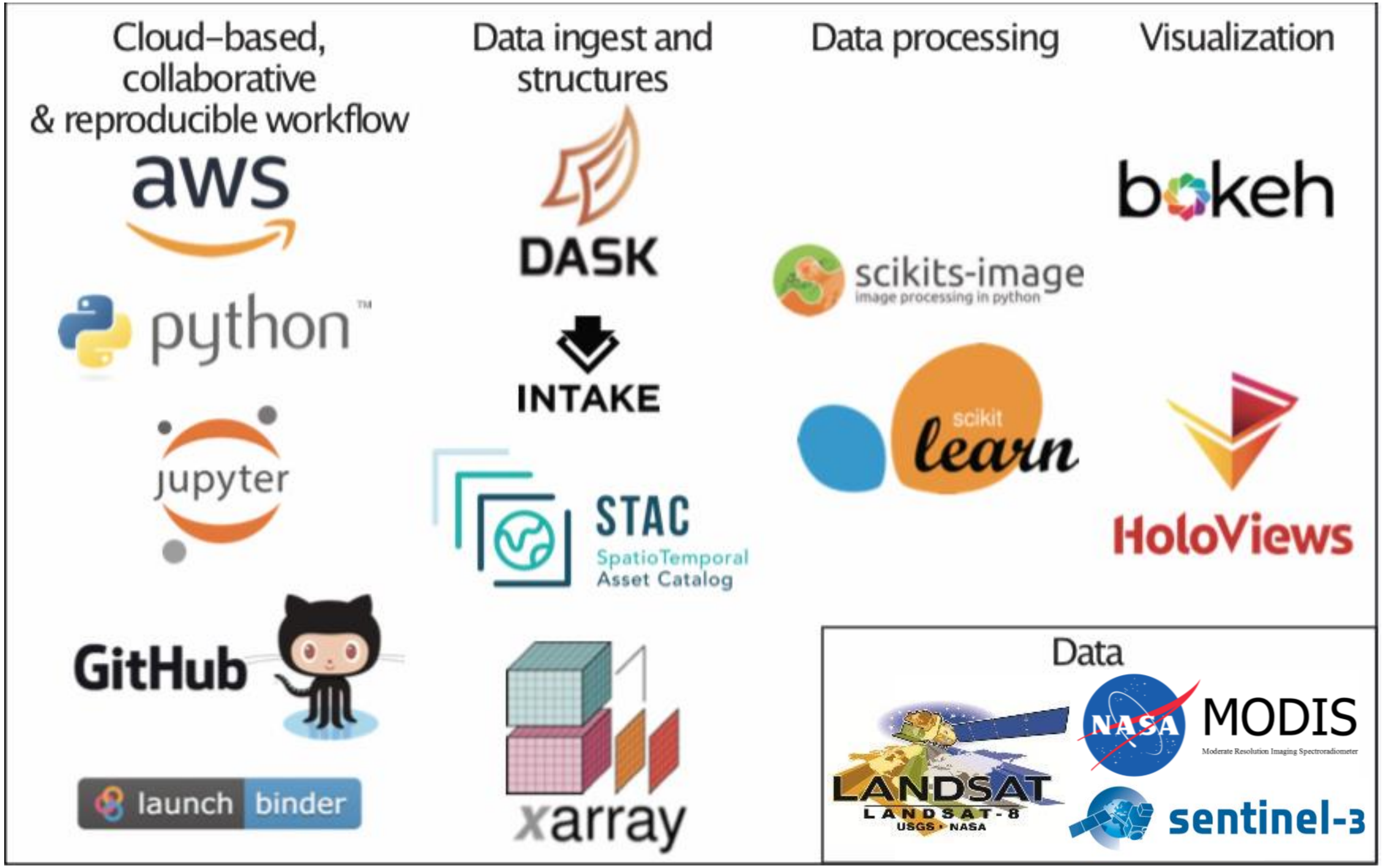
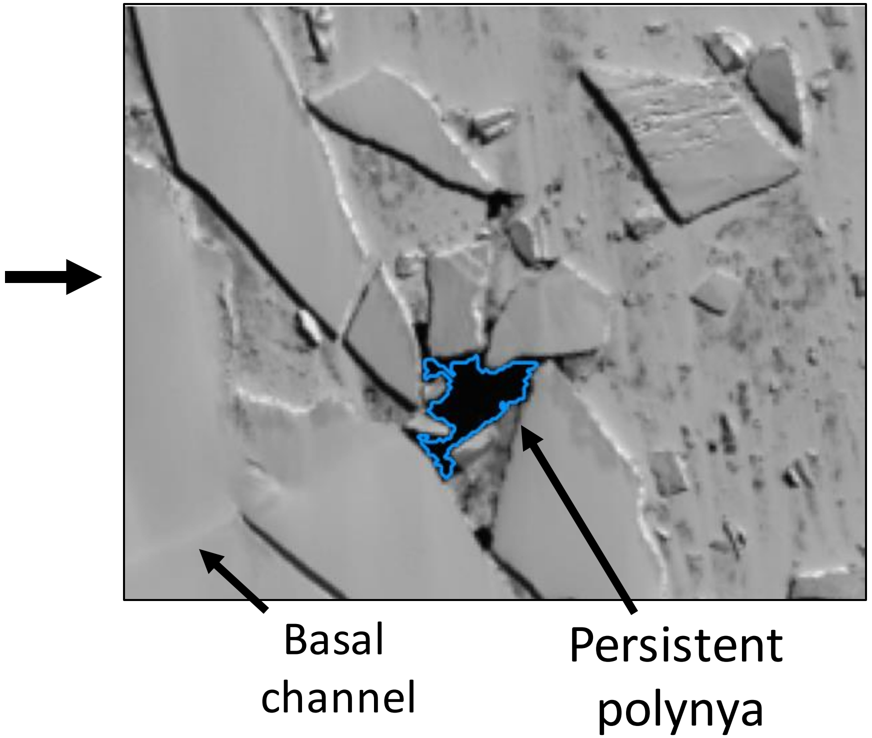


Automated persistent polynya detection in a cloud-based workflow





Snow et al. (in prep)

Automated persistent polynya detection in a cloud-based workflow

Cloud-based, collaborative & reproducible workflow

aws
python
jupyter
GitHub
launch binder

Data ingest and structures

DASK
INTAKE
STAC SpatioTemporal Asset Catalog
xarray

Data processing

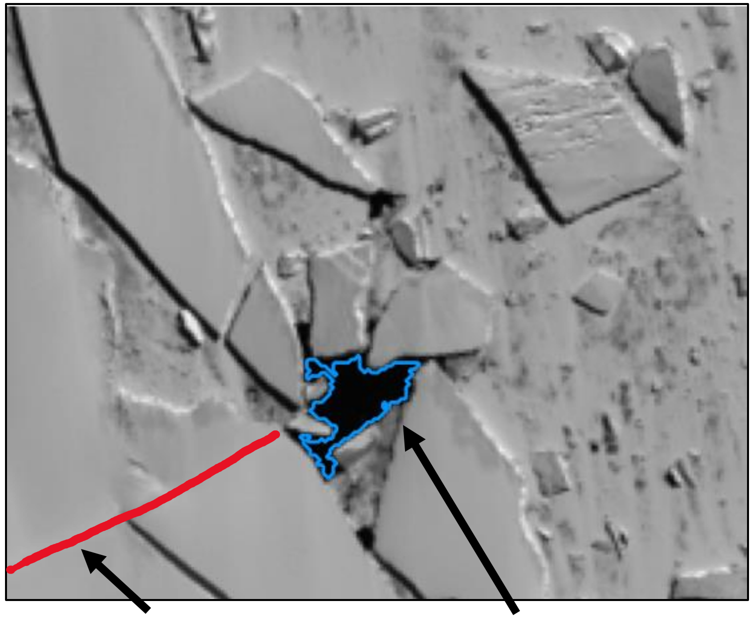
scikits-image image processing in python
scikit learn

Visualization

bokeh
HoloViews

Data

LANDSAT LANDSAT-8 USGS · NASA
NASA MODIS Moderate Resolution Imaging Spectroradiometer
sentinel-3



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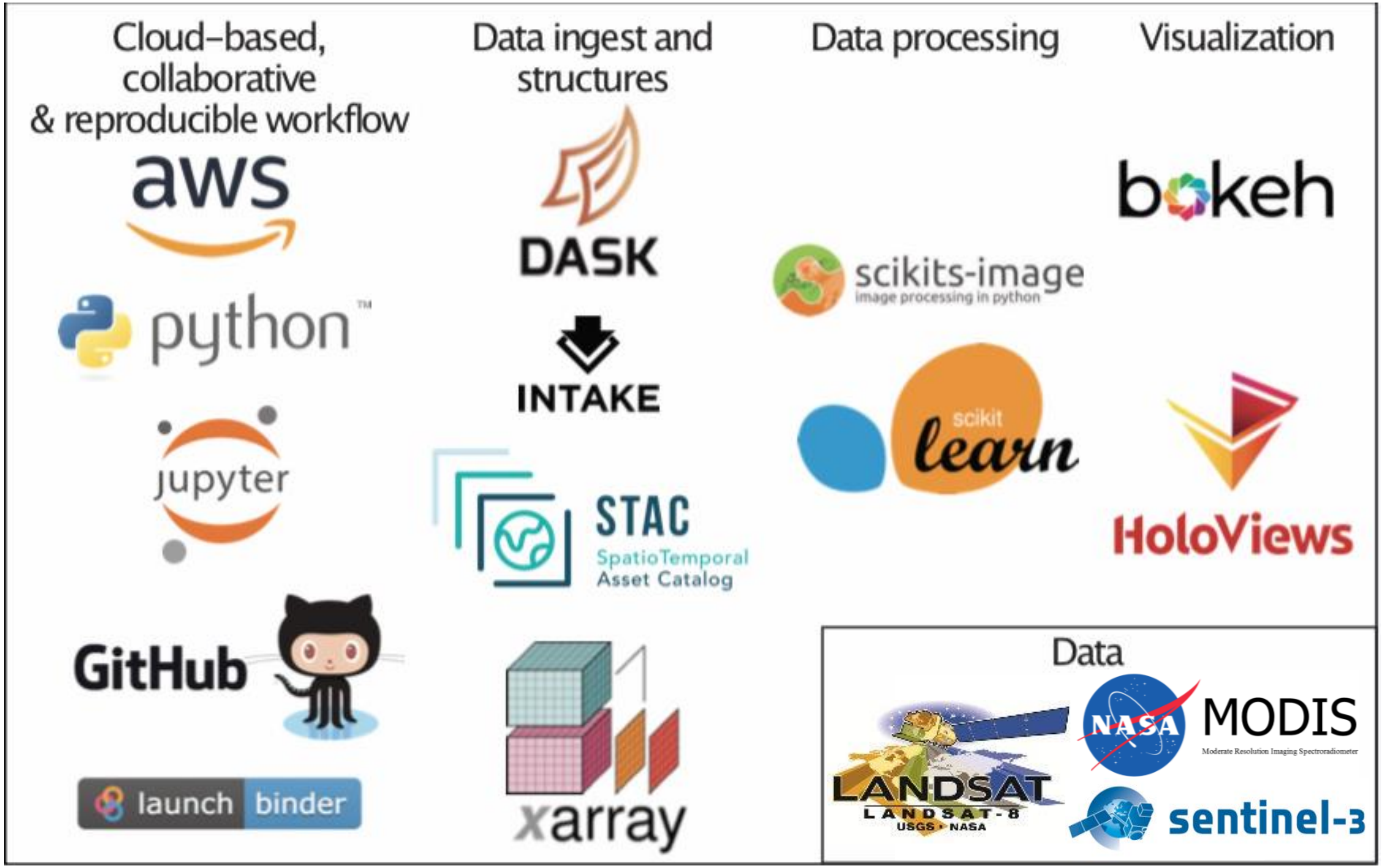
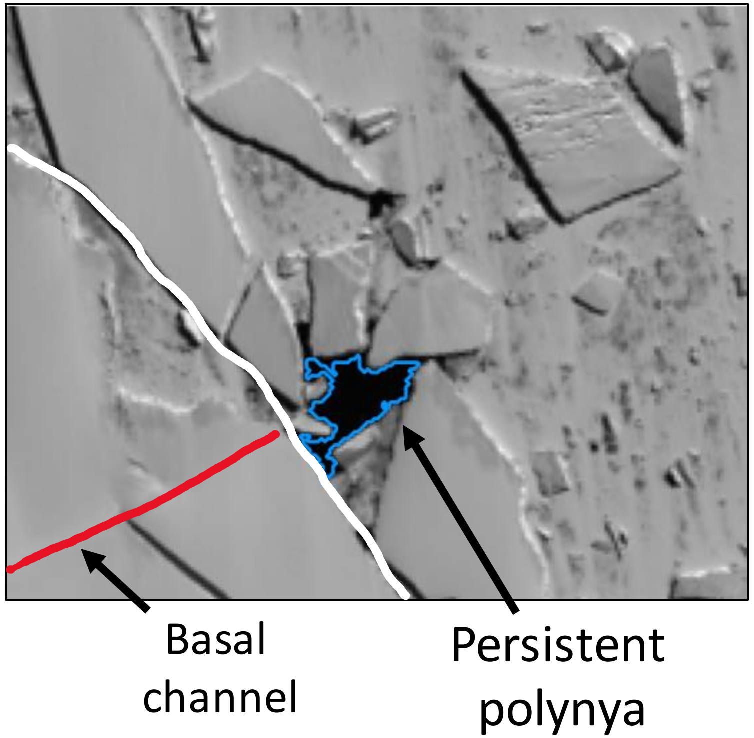
Automated persistent polynya detection in a cloud-based workflow



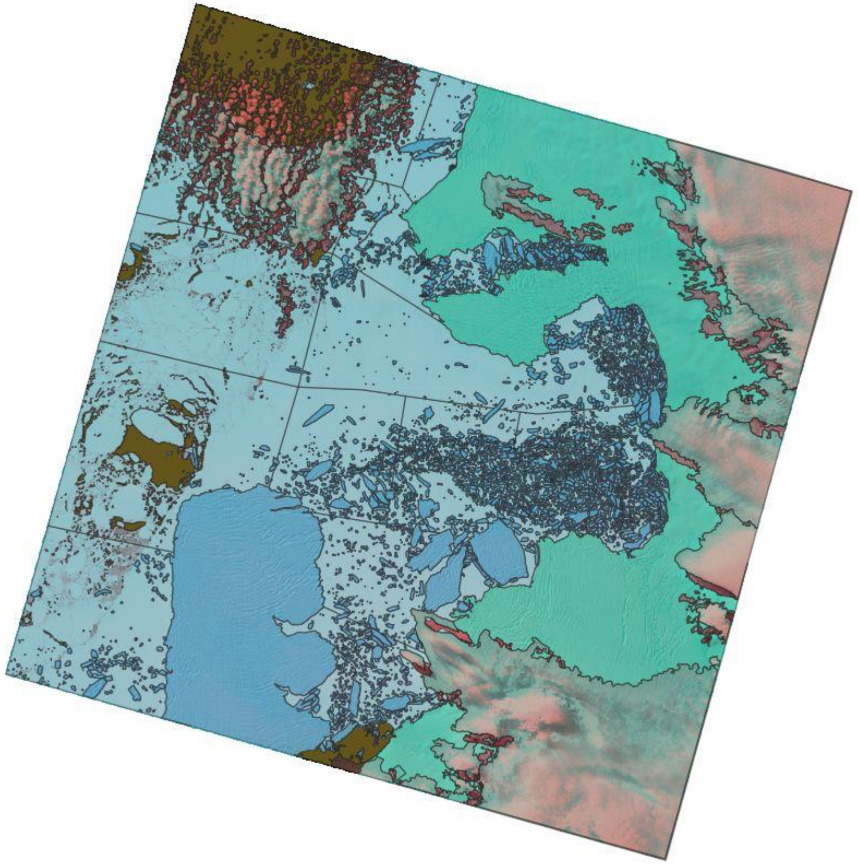


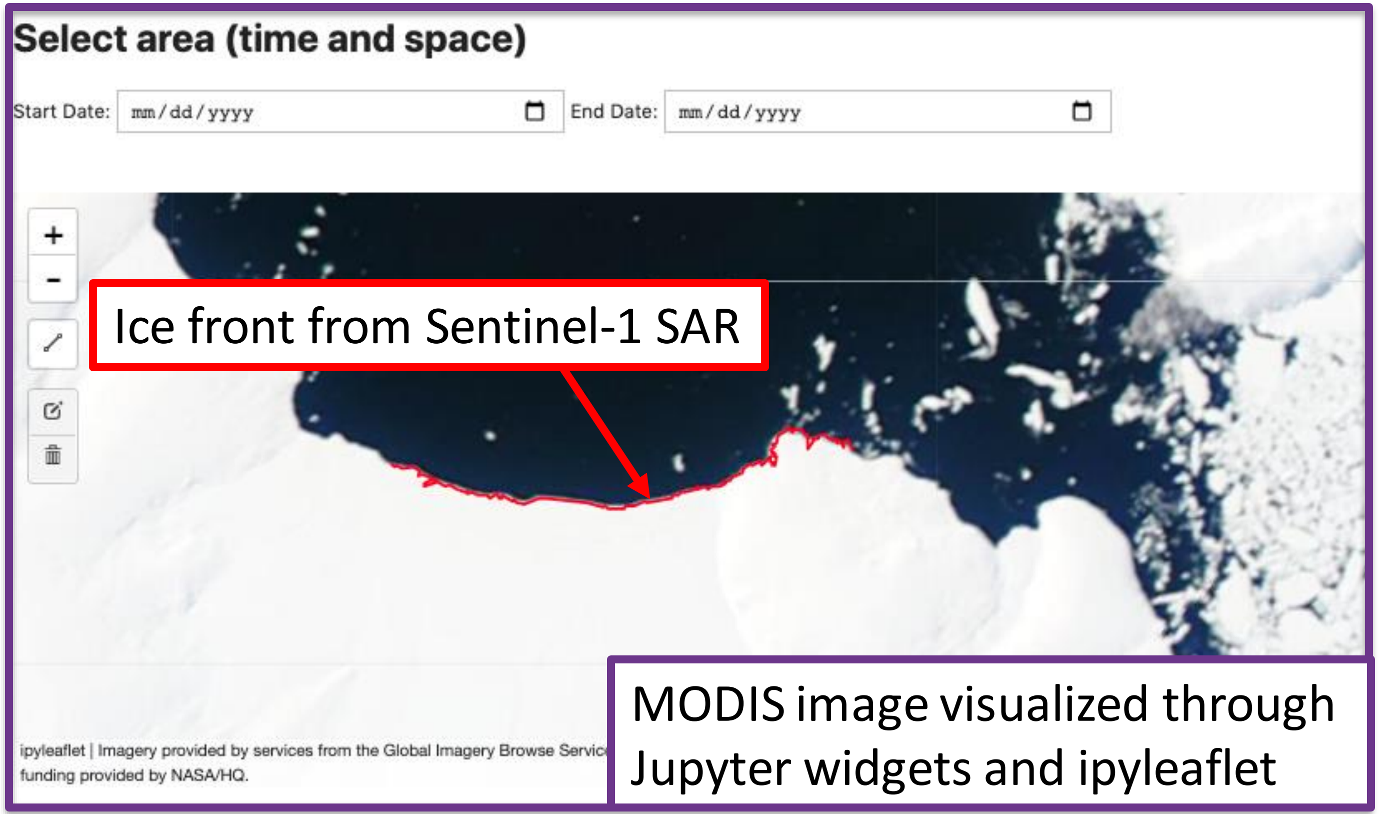
Snow et al. (in prep)

Ice front hand-labeling and detection using neural nets on imagery

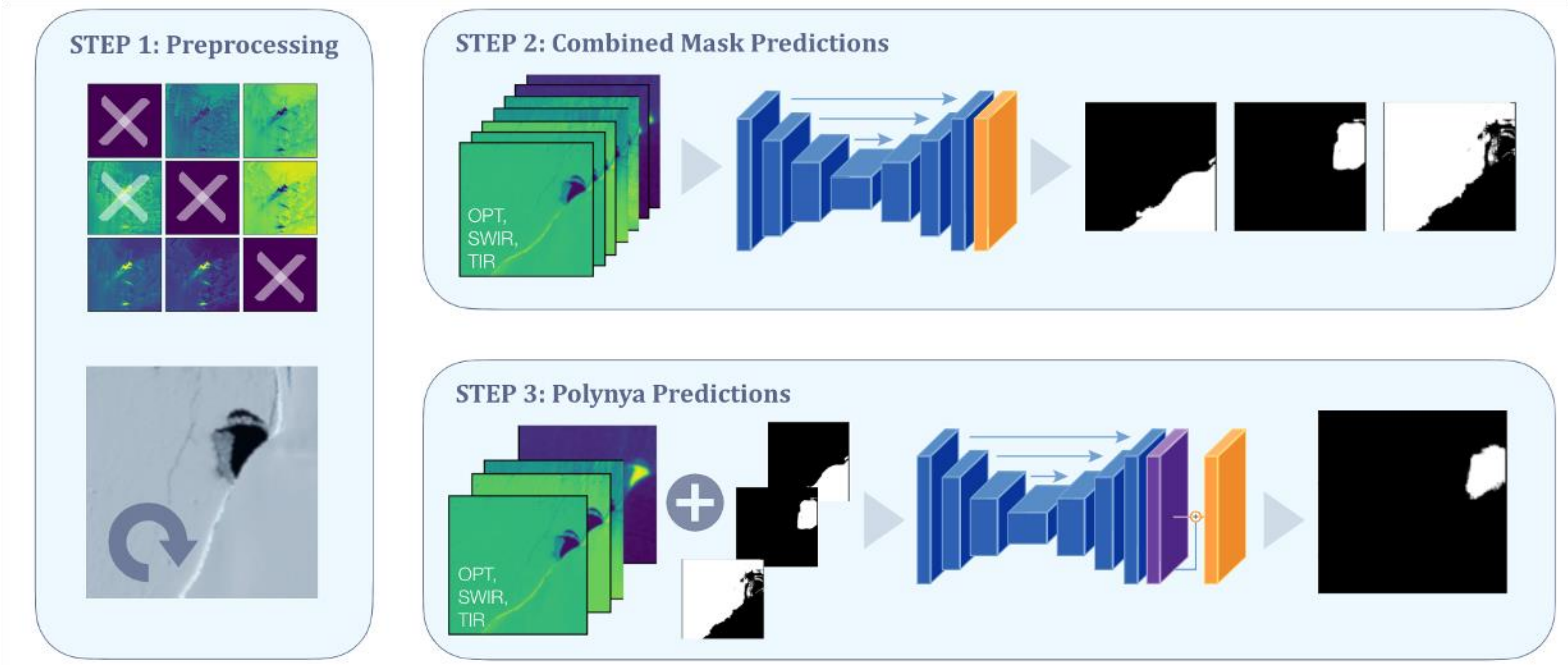
Eojin Lee

Michael Field





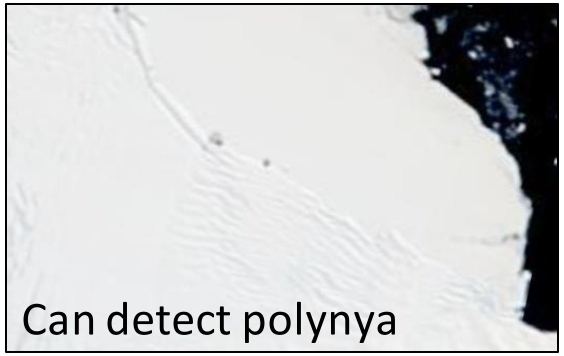
Physics-featurized segmentation to detect persistent polynyas

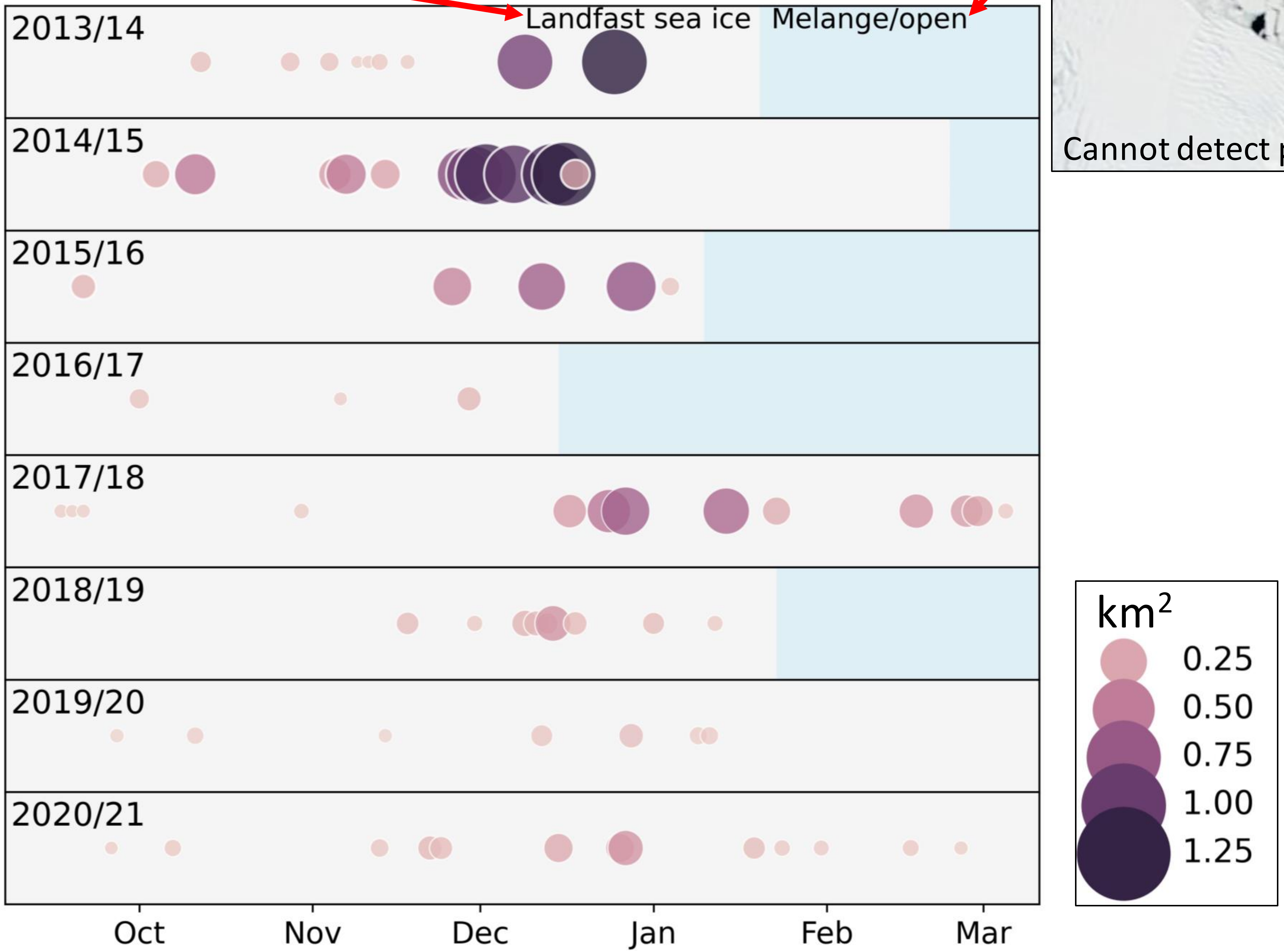


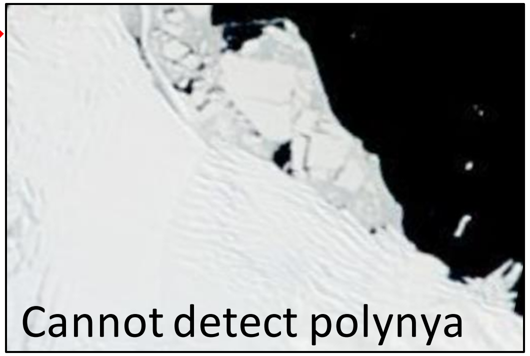
Ellie Abrahams

Berkeley
UNIVERSITY OF CALIFORNIA

Abrahams (in prep)







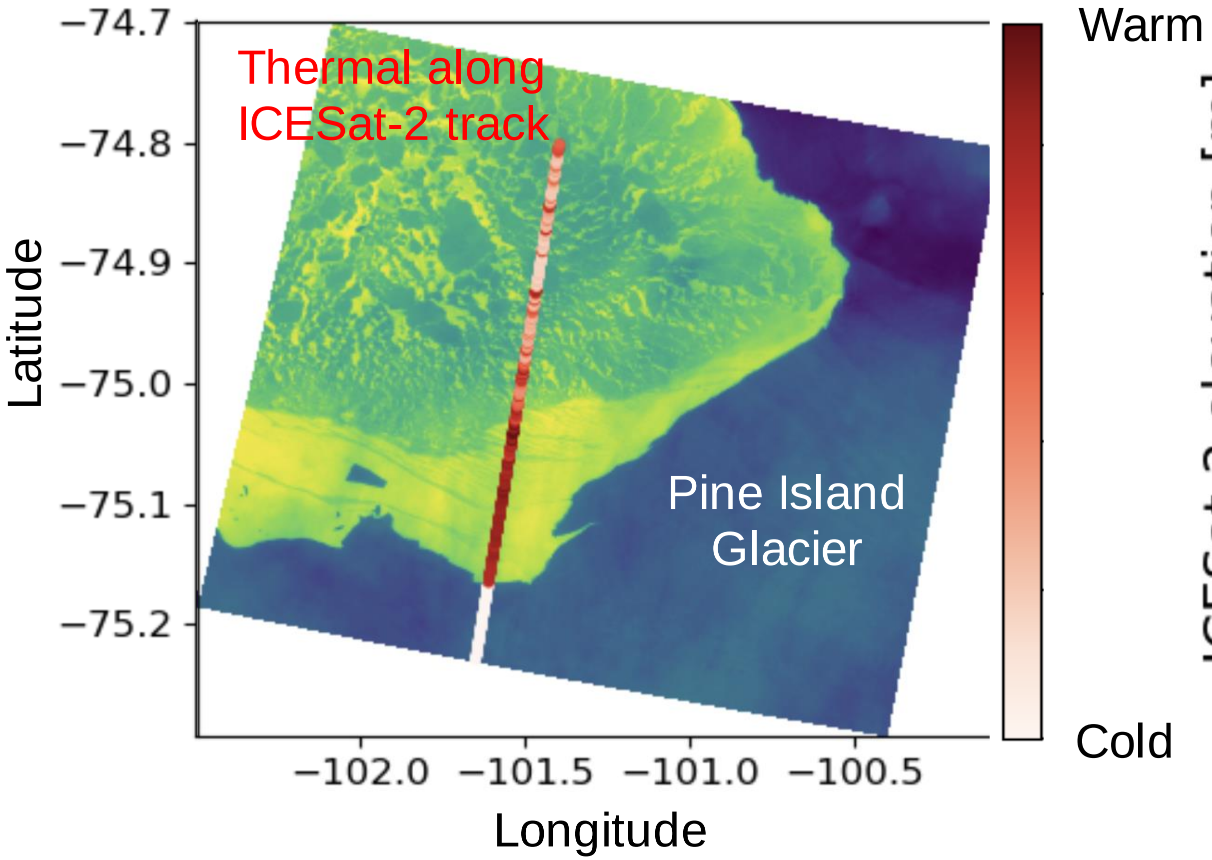
Seasonal and interannual polynya variability related to basal melt

Snow (in prep)

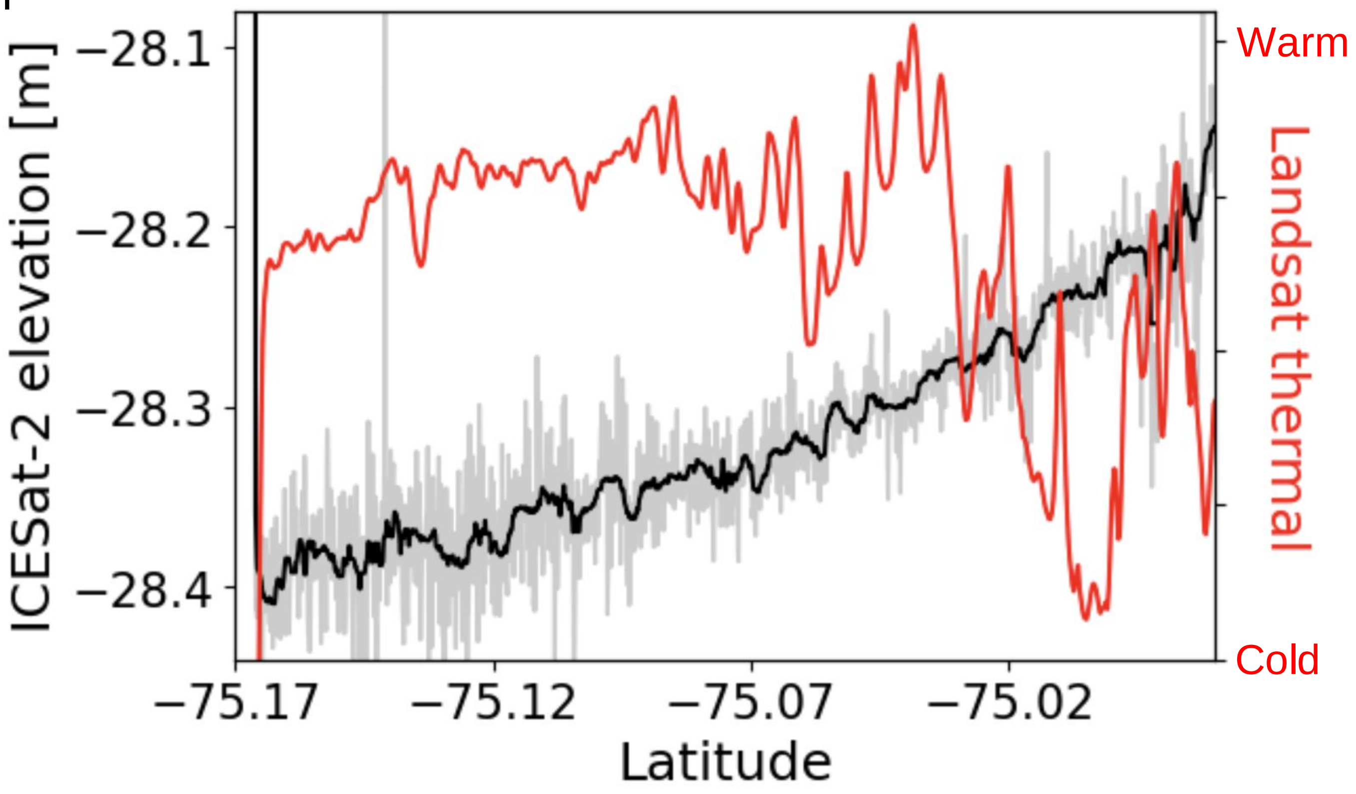
Thin sea ice and warmer ice temperatures associated with polynya

ICESat-2 Hackweek Team: Mengnan Zhao, Maria Lozano, Loïc Bachelot, Ann-Sofie Zinck, Wilson Sauthoff, Tasha Snow

Landsat thermal



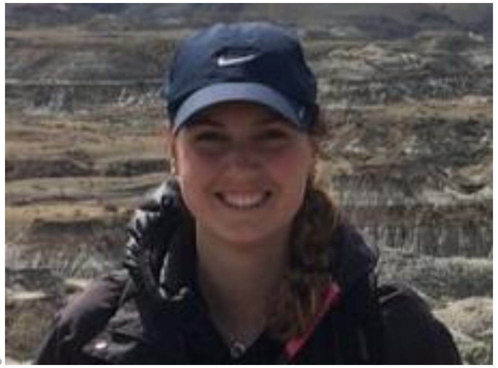
Surface elevation & thermal



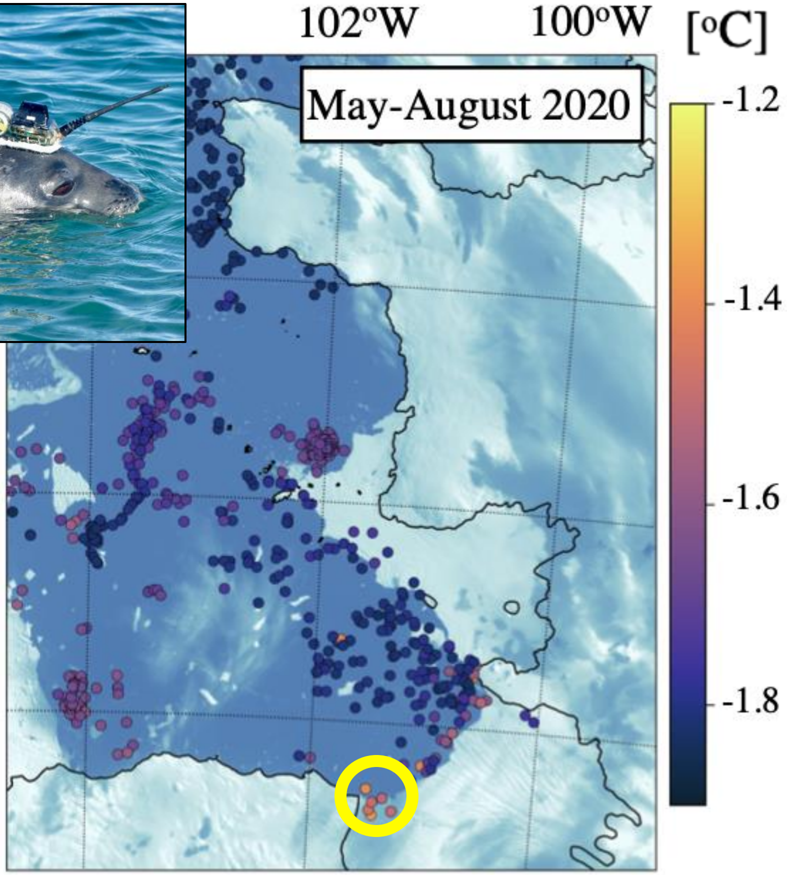
Snow (in prep)

Winter seal-tag ocean measurements correspond to warm thermal anomalies at polynyas

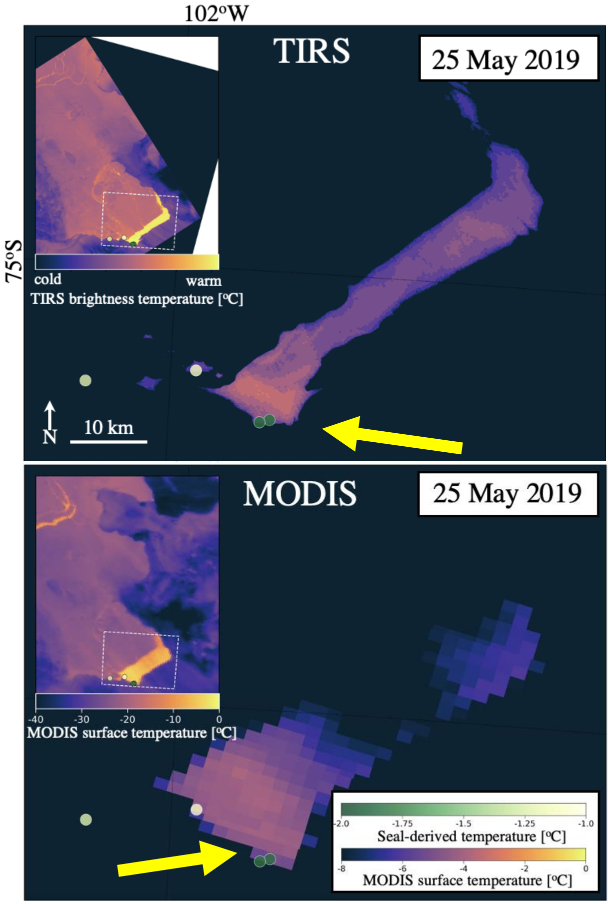
Requires Landsat thermal to be collected in polar winter



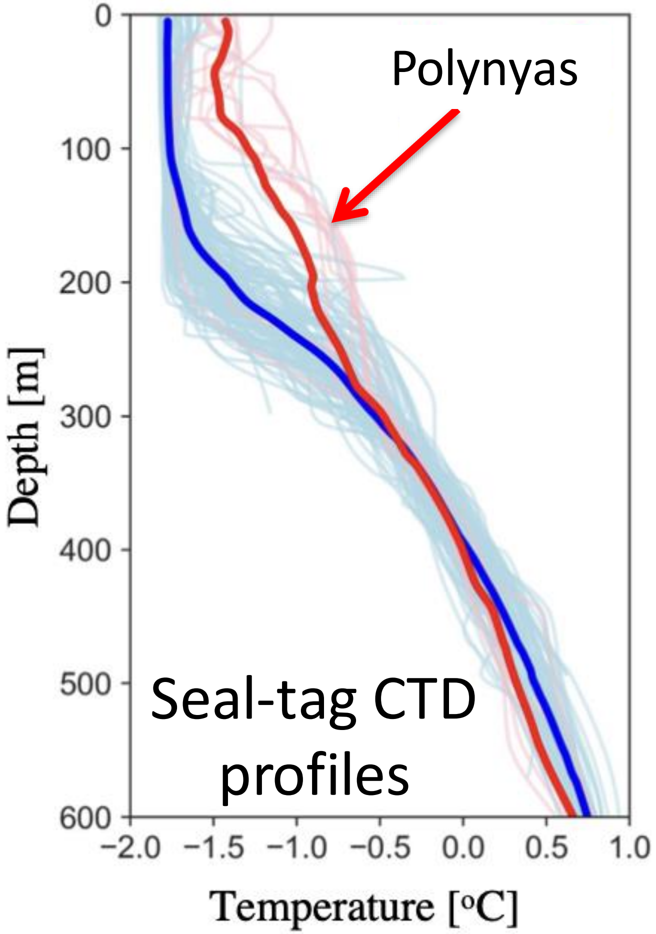
Elena Savidge



Seal-tag surface temperatures



Satellite thermal

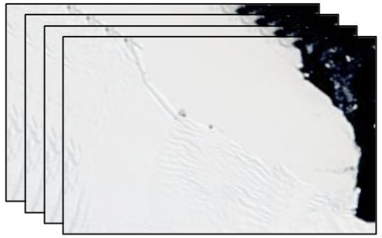


Savidge et al. (accepted)

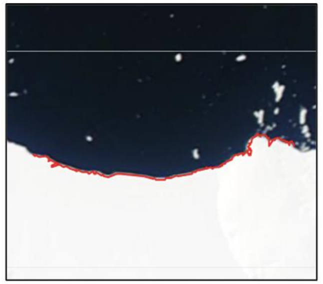
Persistent polynya detection and characterization in a cloud-based workflow

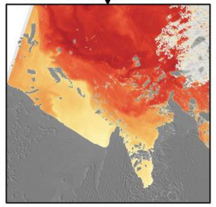
Seal-tag CTDs

Landsat/MODIS/Sentinel imagery

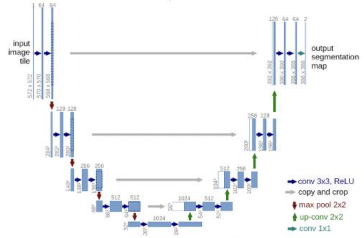


Neural net-derived ice fronts

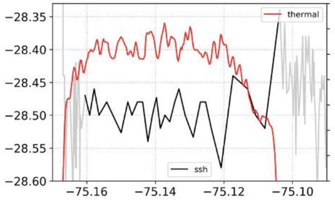




Sea surface temperature

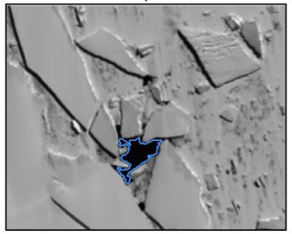


Physics-featurized segmenter



ICESat-2 polynya characterization

2i2c
the international interactive computing collaboration
jupyterhub
aws



Persistent polynya variability

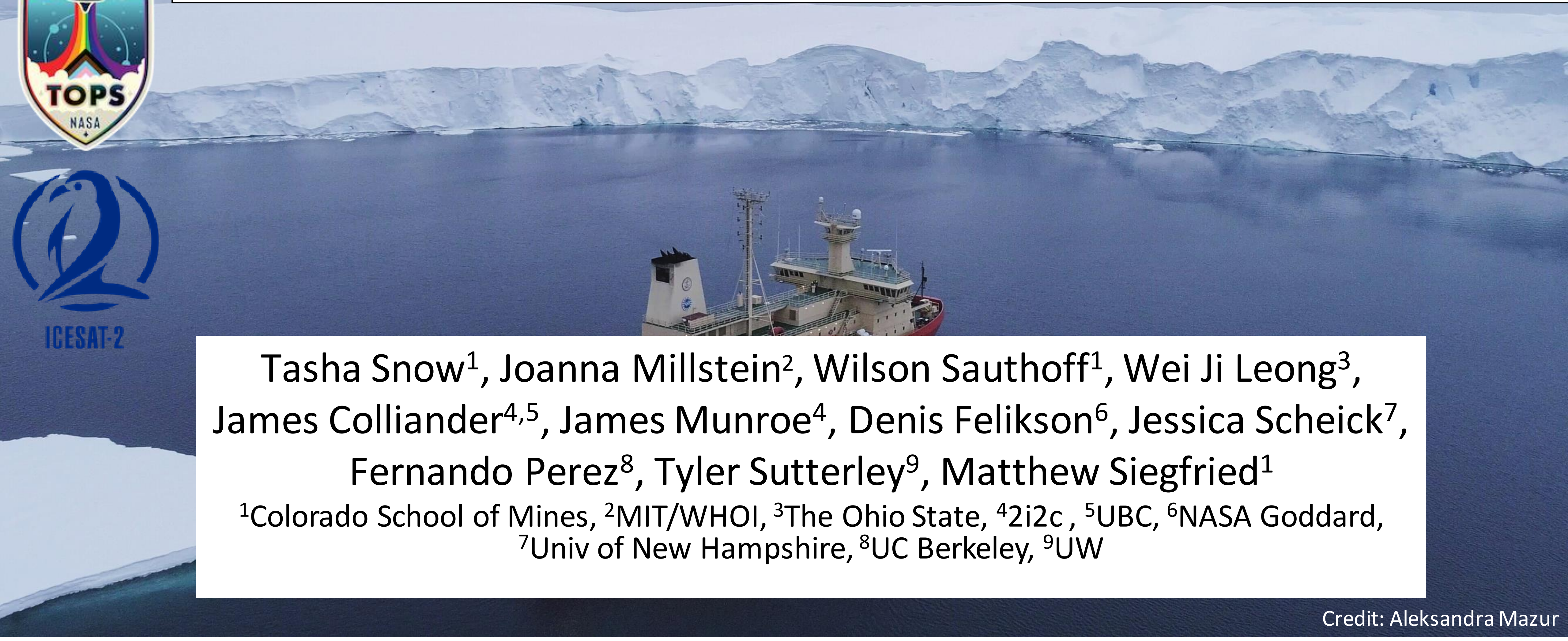
New ice-ocean tools and applications

Detection of the Antarctic Coastal Current in an integrated thermal remote sensing and field observation data set

Thermal detection of ice features and warm plumes at the ice-ocean interface in Antarctica with the aid of machine learning

Where we are going next – big data ice-ocean analyses in the cloud using open science principles

CryoCloud: Accelerating discovery for Cryosphere communities with open-cloud infrastructure



Tasha Snow[1], Joanna Millstein[2], Wilson Sauthoff[1], Wei Ji Leong[3], James Colliander[4,5], James Munroe[4], Denis Felikson[6], Jessica Scheick[7], Fernando Perez[8], Tyler Sutterley[9], Matthew Siegfried[1]

[1]Colorado School of Mines, [2]MIT/WHOI, [3]The Ohio State, [4]2i2c , [5]UBC, [6]NASA Goddard, [7]Univ of New Hampshire, [8]UC Berkeley, [9]UW

Credit: Aleksandra Mazur

Science done in a fundamentally more open way is the future

Open science is a collaborative culture enabled by technology that empowers the open sharing of data, information, and knowledge within the scientific community and the public to accelerate scientific research and understanding

Open-source science at the forefront

OPEN-SOURCE SCIENCE INITIATIVE

Overview Why Do Open Science? Transform to Open Science (TOPS)

Open-Source Science Initiative

NASA is making a long-term commitment to building an inclusive open science community over the next decade. Open-source science is a commitment to the open sharing of software, data, and knowledge (algorithms, papers, documents, ancillary information) as early as possible in the scientific process. The principles of open-source science are to make publicly funded scientific research transparent, inclusive, accessible, and reproducible. Advances in technology, including collaborative tools and cloud computing, help enable open-source science, but technology alone is insufficient. ***Open-source science requires a culture shift to a more inclusive, transparent, and collaborative scientific process, which will increase the pace and quality of scientific progress.***

To help build a culture of open science, **NASA is championing a new initiative: the Open-Source Science Initiative (OSSI).** OSSI is a comprehensive program of activities to enable and support moving science towards openness, including policy adjustments, supporting open-source software, and enabling cyberinfrastructure. OSSI aims to implement NASA's Strategy for Data Management and Computing for Groundbreaking Science 2019-2024, which was developed through community input.

OPEN **(TRANSPARENT)** SCIENCE
scientific process and results should be visible, accessible, and understandable

OPEN **(ACCESSIBLE)** SCIENCE
data, tools, software, documentation, and publications should be accessible to all (FAIR)

OPEN **(INCLUSIVE)** SCIENCE
process and participants should welcome participation by and collaboration with diverse people and organizations

OPEN **(REPRODUCIBLE)** SCIENCE
scientific process and results should be open such that they are reproducible by members of the community

Transform to Open Science (TOPS)

From 2022 to 2027, TOPS will accelerate the engagement of the scientific community in open science practices through events and activities aimed at:

- Lowering barriers to entry for historically excluded communities
- Better understanding how people use NASA data and code to take advantage of our big data collections
- Increasing opportunities for collaboration while promoting scientific innovation, transparency, and reproducibility.

The TOPS mission is aligned with recommendations from NASA's Strategy for Data Management and Computing for Groundbreaking Science 2019-2024, the National Academies reports on open science, reproducibility, and scientific software, and the 2021 UNESCO draft Recommendation on Open Science synthesis report.

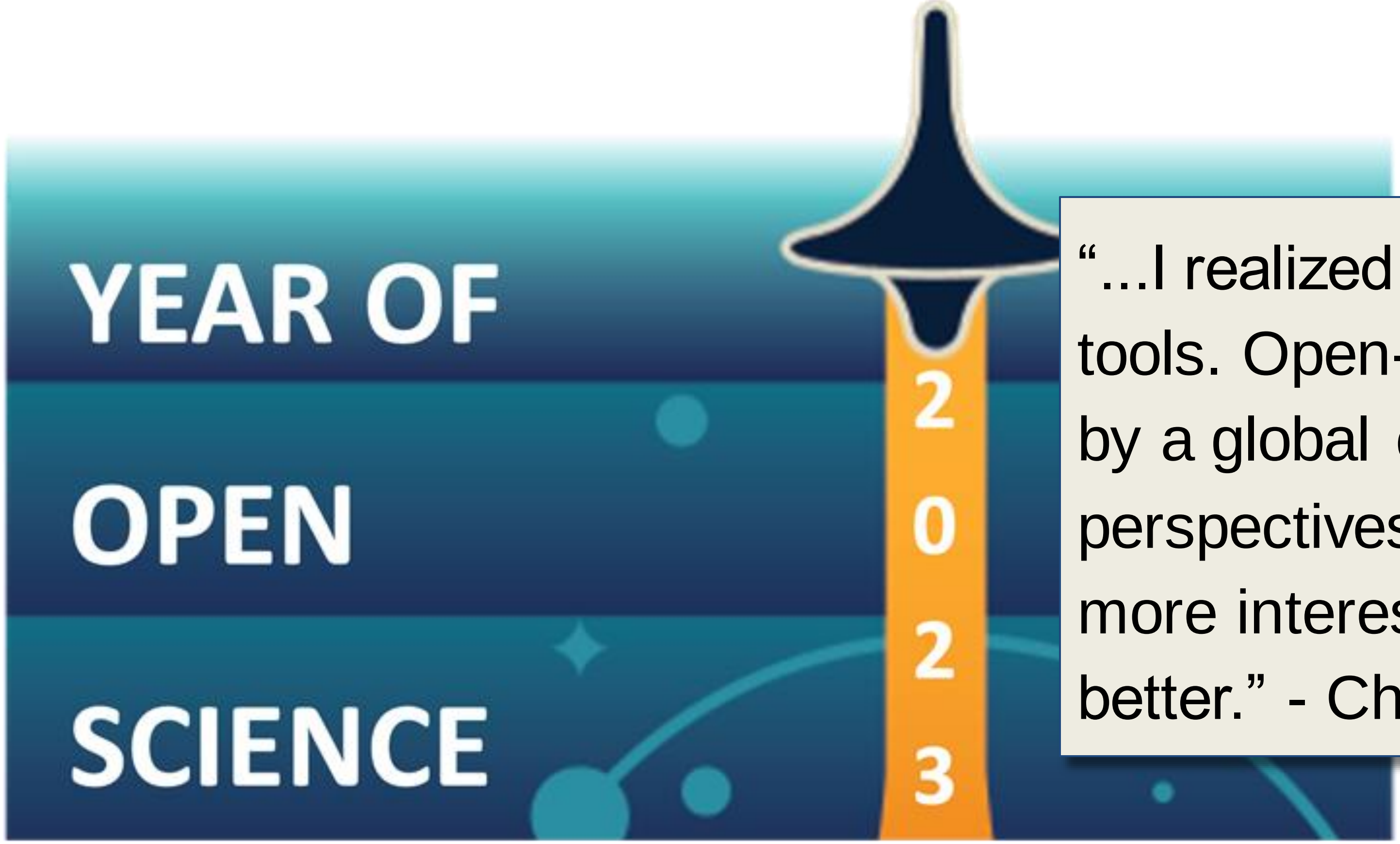
Engage in the open science community on the Transform to Open Science (TOPS) GitHub

TOPS
TRANSFORM to OPEN SCIENCE

Open Science Curricula: *OpenCore*

github.com/learnopenscience

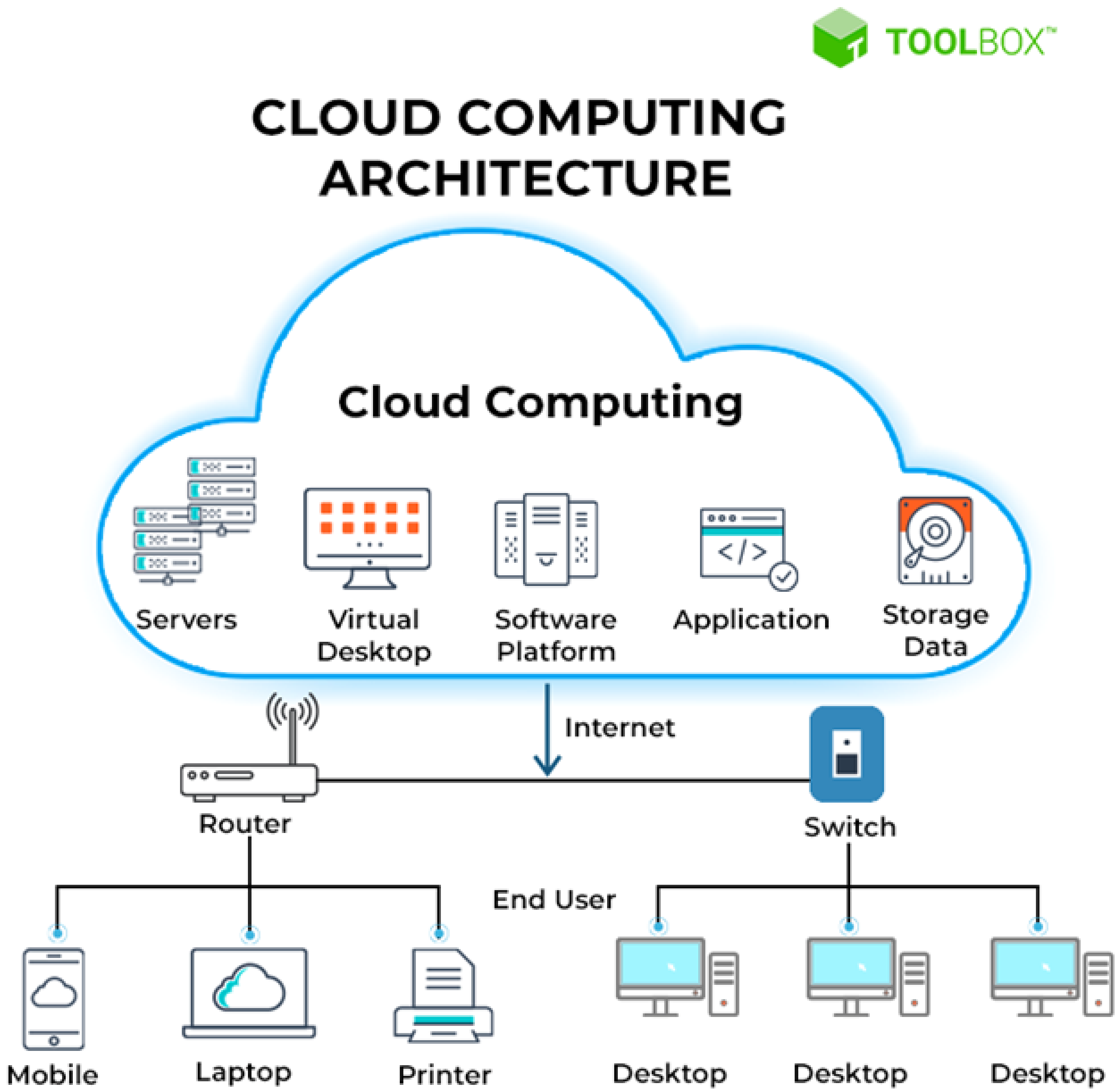
NASA (and US+): 2023 the Year of Open Science



“...I realized that open science isn’t just about tools. Open-science innovation is being driven by a global community with diverse perspectives. The scientific questions are more interesting and nuanced, the solutions better.” - Chelle Gentemann

open.science.gov

What is the cloud?



The Digital Watering Hole (in the cloud)

Image: diana_robinson

An opportunity shaped by:

- Open, FAIR and CARE Data
- Scalable computation next to the data
- Modular tools for exploration/narrative

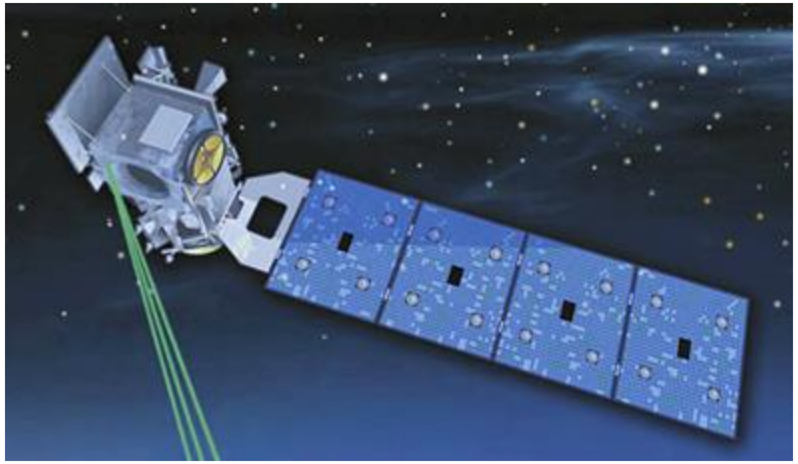
To tackle challenges that

- go beyond disciplinary silos…
- require analysis of *really* big data
- integration of disparate data…
- *participation* of disparate, diverse communities…
- to ultimately connect with society and impact critical decision making.

Cloud computing and ICESat-2 science

Cloud computing and open science concerns from the May 2022 ICESat-2 Science Team Meeting

- Non-intuitive pricing structures, documentation, computing options, infrastructure
- Costly to use
- Time to transition workflows
- Worries around intellectual theft
- Not obviously more collaborative or faster



This didn't ring true to our experience in the cloud!

CryoCloud: A cloud-computing platform with *bumpers*

Goal: Simple and cost effective managed cloud environment for training new users and transitioning to cloud workflows

Built and developed for cryosphere scientists by software professionals at **2i2c** to make it possible to:

- Process data faster
- Democratize science

CryoCloud: A cloud-computing platform with *bumpers*

- Persistent for (at least) three years
- Small instances for all users with option to bring in your own AWS credits
- New tool development
  - Personal cost-monitoring tool to understand your usage
  - Improved intra- and inter-hub collaboration tools
- Helping 2i2c scale with community surveys, feedback, and guidance

CryoCloud community building

cryointhecloud.com

CryoCloud Github:
github.com/cryointhecloud

CryoCloud JupyterBook

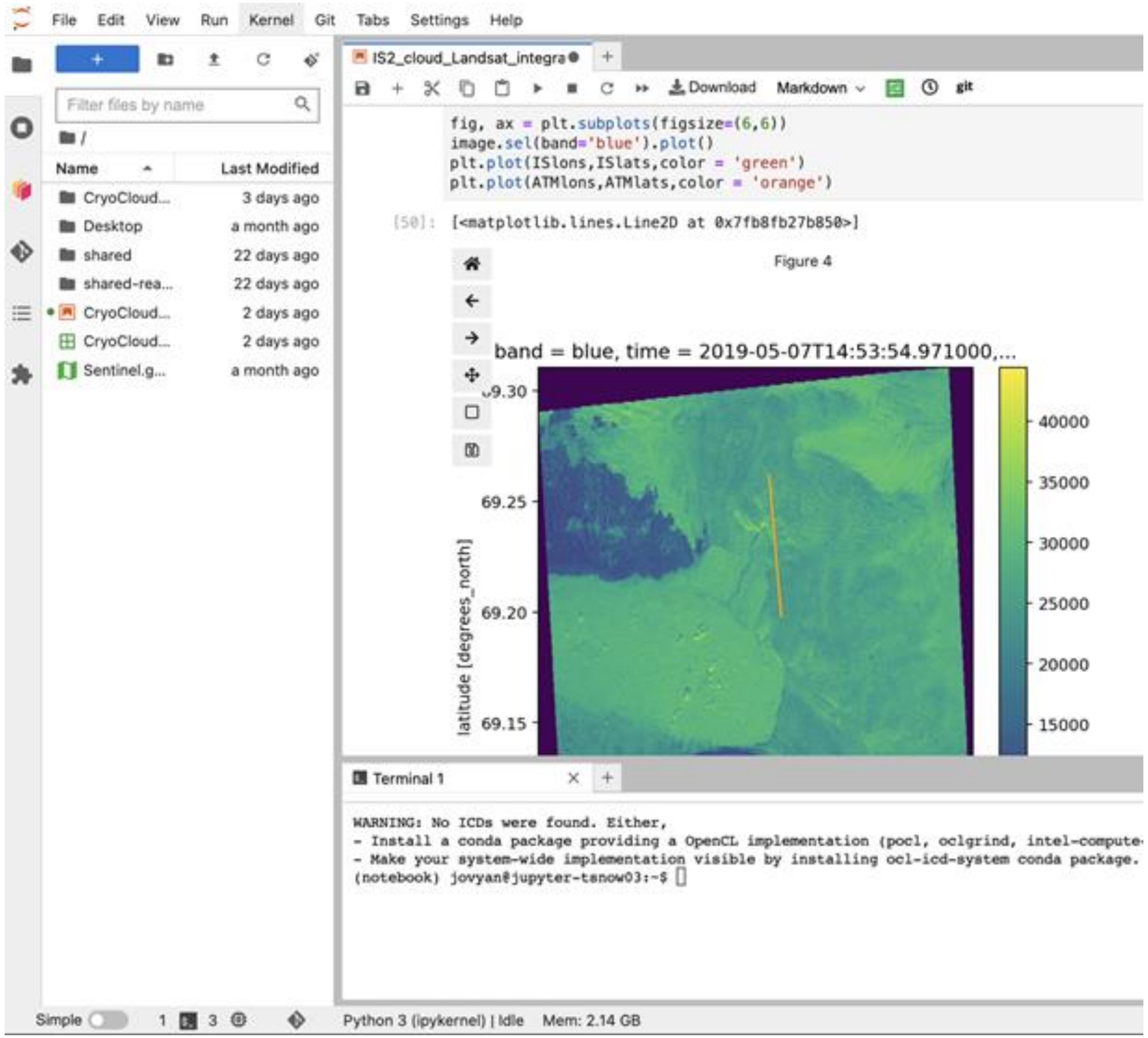
All the content! More about us, resources, training, and tutorials all found here!

CryoCloud JupyterHub

Get onto the cloud. Our shared cloud platform for NASA Cryosphere communities.

- New Hub tools
- CryoCloud Slack
- Community office hours
- Training, tutorials, and resources
- Bringing in related Cryosphere communities and sharing in infrastructure ideation and construction

Different kinds of users in one place to accelerate feedback and collaboration



Tools and Developers

xarray

icepyx

earthaccess

A Python Library for NASA Earthdata

Datasets

ICESat-2

ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

NASA

MODIS

Moderate Resolution Imaging Spectroradiometer

LANDSAT

LANDSAT-8

USGS • NASA

Open science values

open.science.gov

Intellectual generosity

Intellectual humility

Right to participate in science

Everyone deserves to be treated with dignity and respect

Intellectual generosity

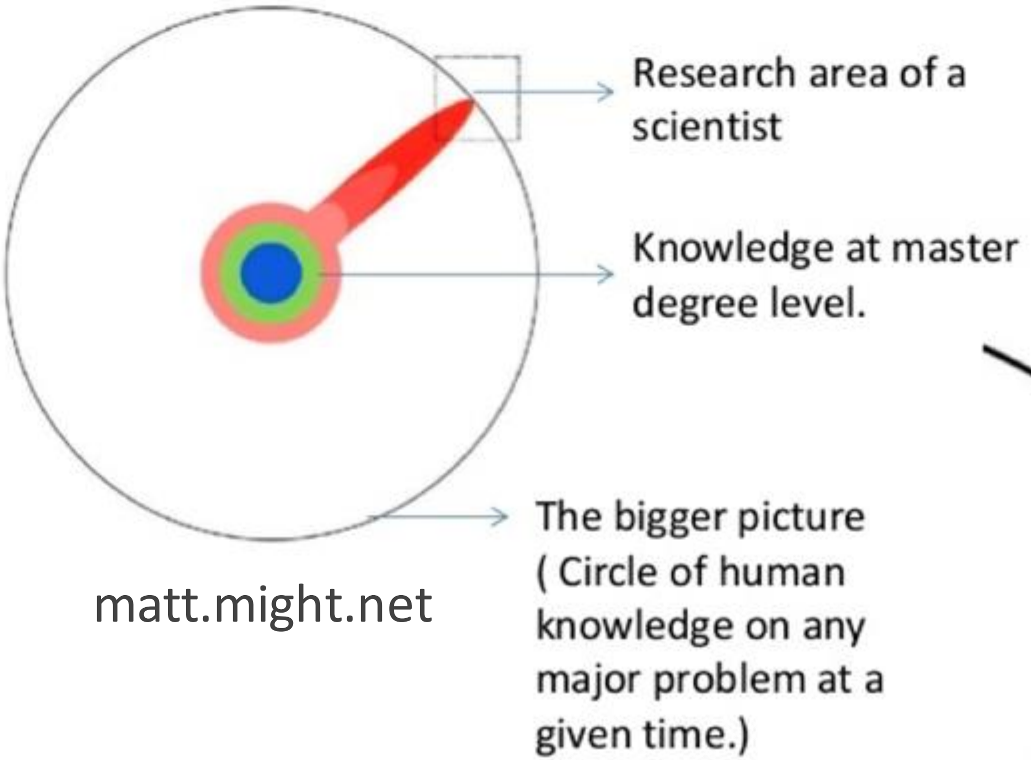
Sharing ideas, advancing other’s understanding

Reduce competition and enhance collaboration

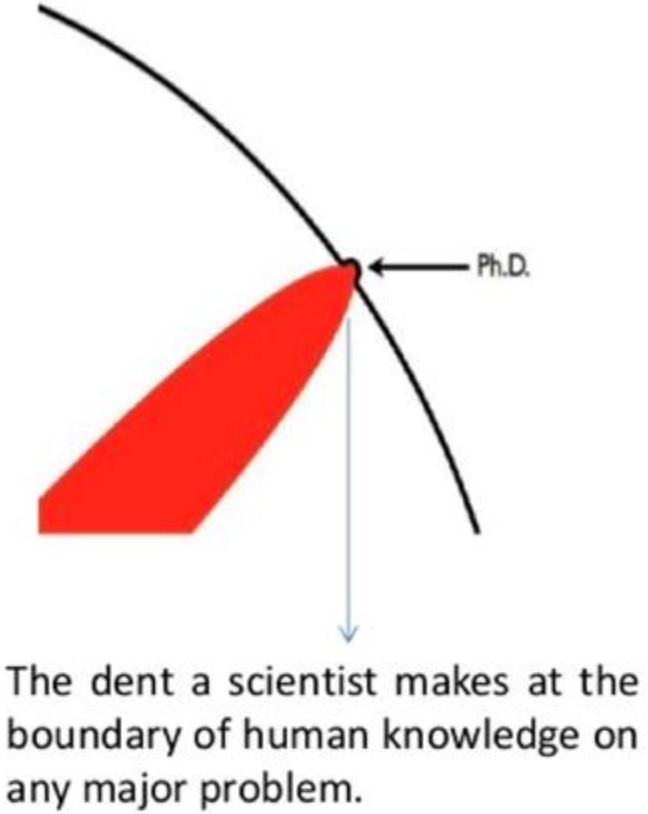
LinkedIn

Intellectual humility

Our contributions are small relative to the body of knowledge



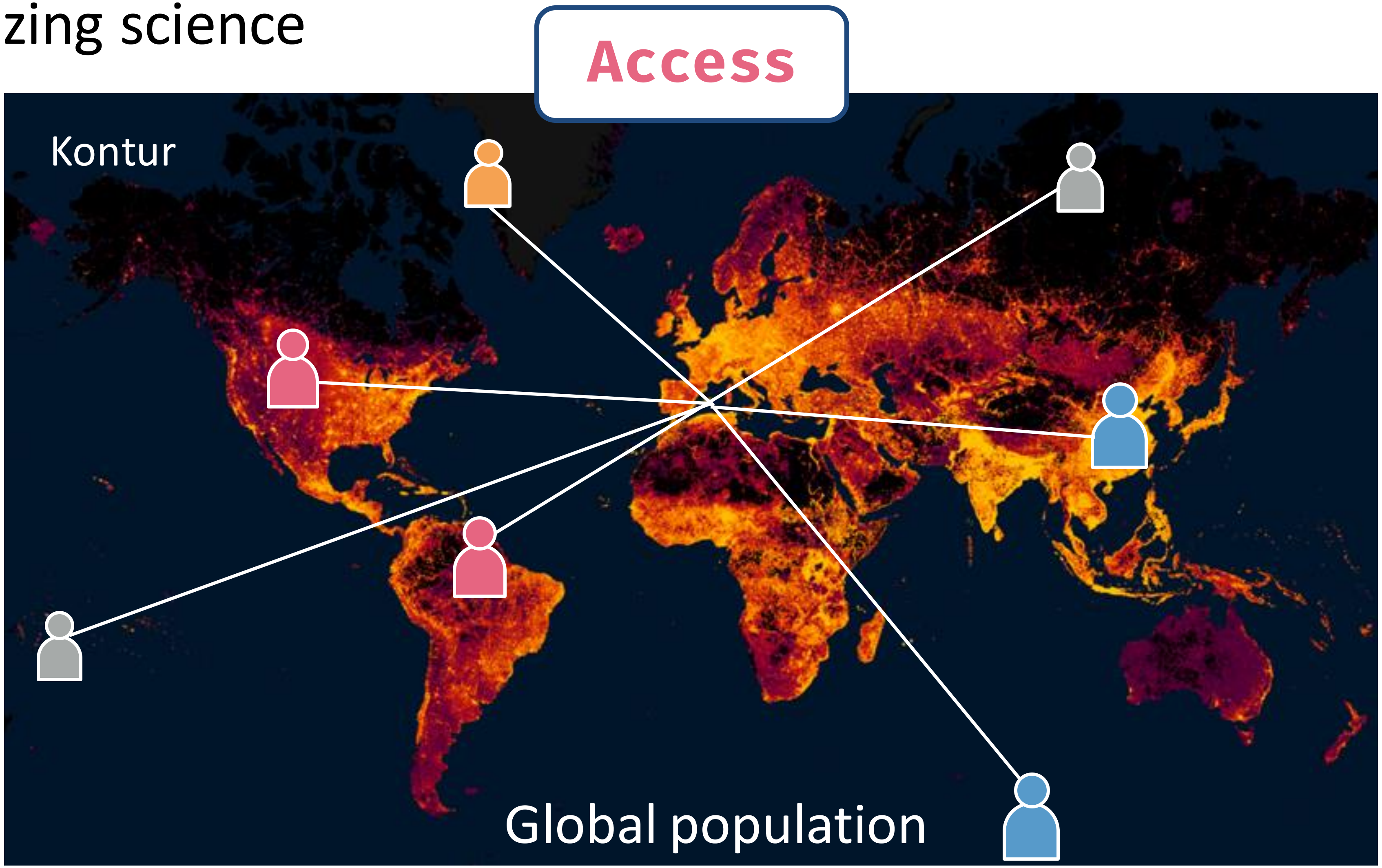
matt.might.net



Give and receive criticism with grace

Right to participate in science

Democratizing science



Everyone deserves to be treated with dignity and respect

Objective and constructive discourse

Open science values

open.science.gov

Intellectual generosity

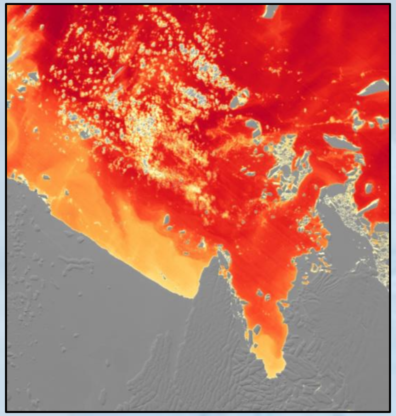
Intellectual humility

Right to participate in science

Everyone deserves to be treated with dignity and respect

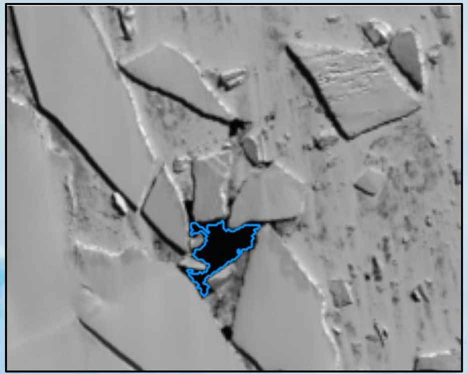
Open science as a process, not a product

New ice-ocean tools and applications



Combining satellite thermal measurements with field-based observations provides a more robust understanding of Antarctic ocean circulation

Integration of machine learning through interdisciplinary collaborations provides unprecedented opportunities



cryointhecloud.com

CryoCloud

Ice-ocean research in the cloud using open science principles will accelerate science to meet the global need

Thank you

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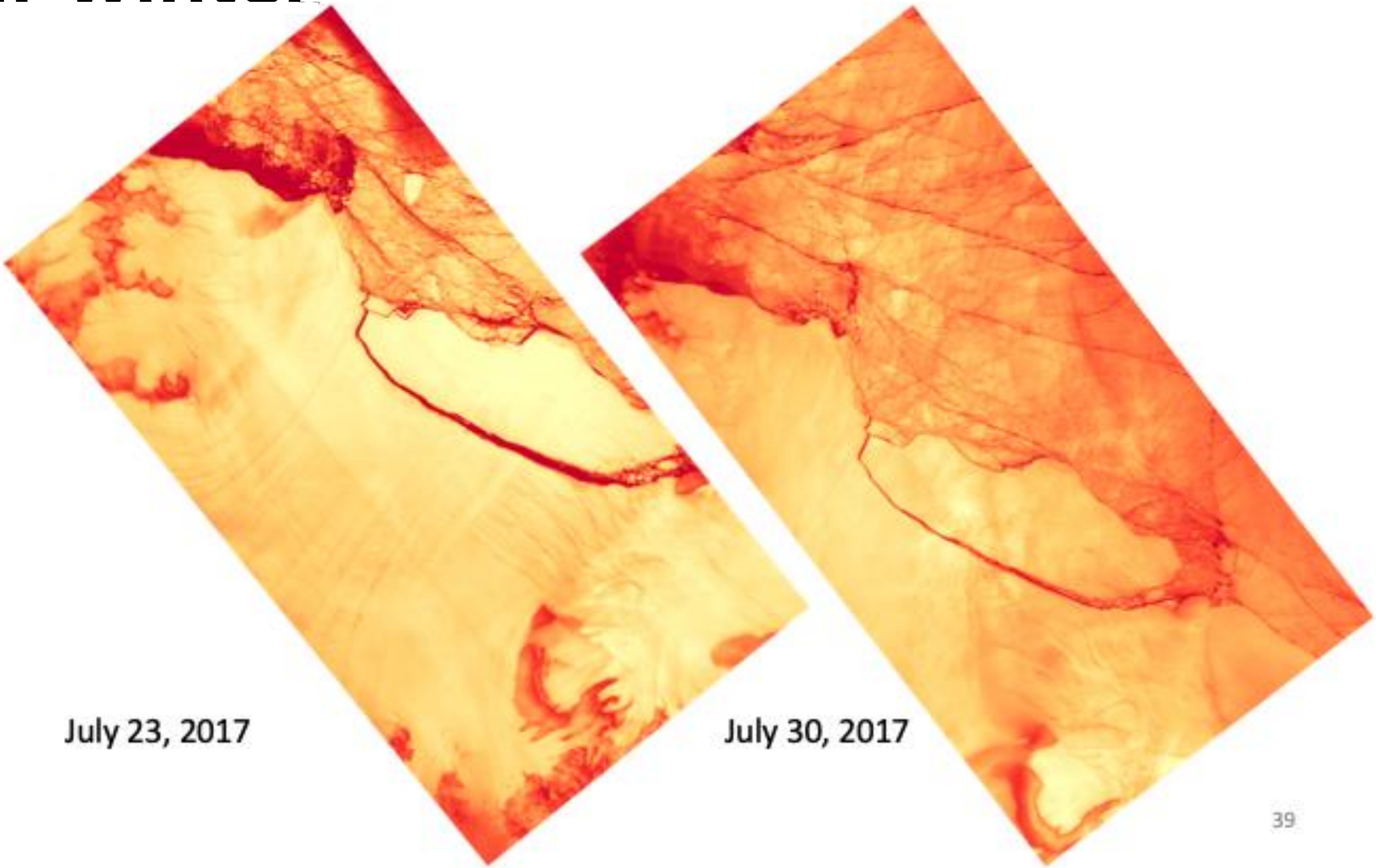
tsnow03.github.io
@tsnow03
@TashaMSnow
tsnow@mines.edu

Funding sources:

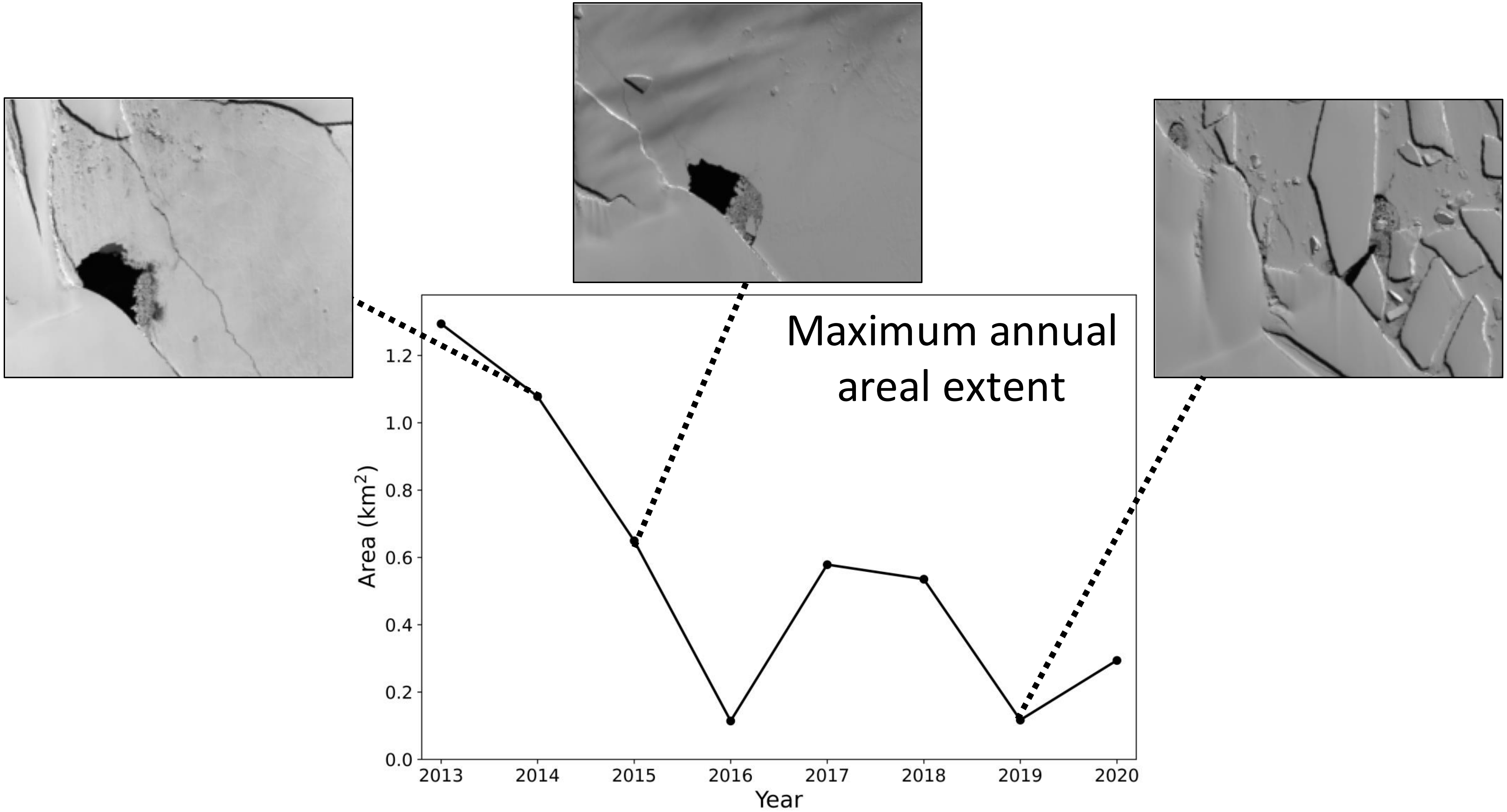
NASA Transform to Open Science Program (80NSSC23K0002)
NASA ROSES Cryosphere Program (80NSSC22K0385, 80NSSC22K1877)
NSF Earth Cube Program (1928406, 1928374)
NSF Graduate Research Fellowship Program (DGE1650115)
NASA Earth and Space Science Fellowship Program (NNX16AO33H)
Colorado School of Mines
Cooperative Institute for Research in Environmental Sciences
International Thwaites Glacier Collaboration (NERC/NSF)
Amazon Web Services Research Grant

COLORADO SCHOOL OF MINES | CIRES | NERC SCIENCE OF THE ENVIRONMENT | NSF | NASA | CU Boulder

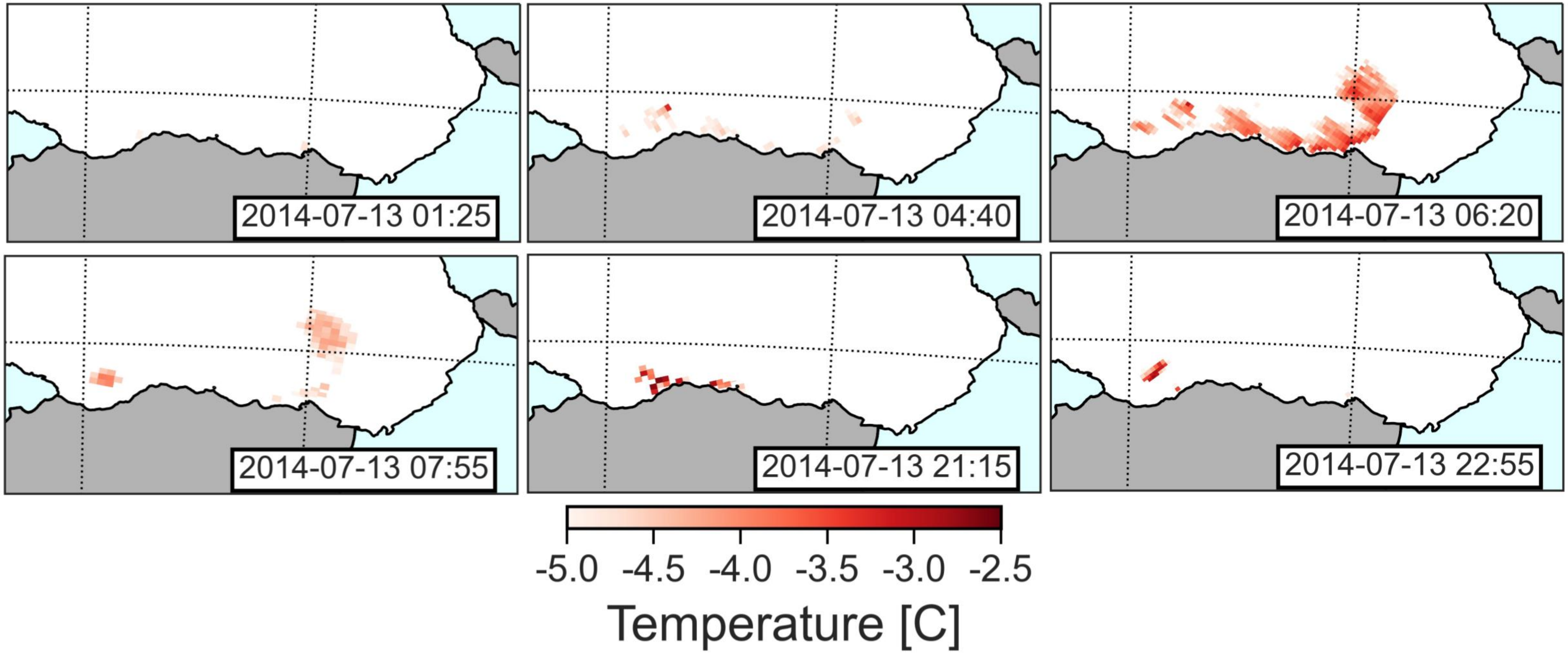
Iceberg calving at Larsen C ice shelf in polar winter



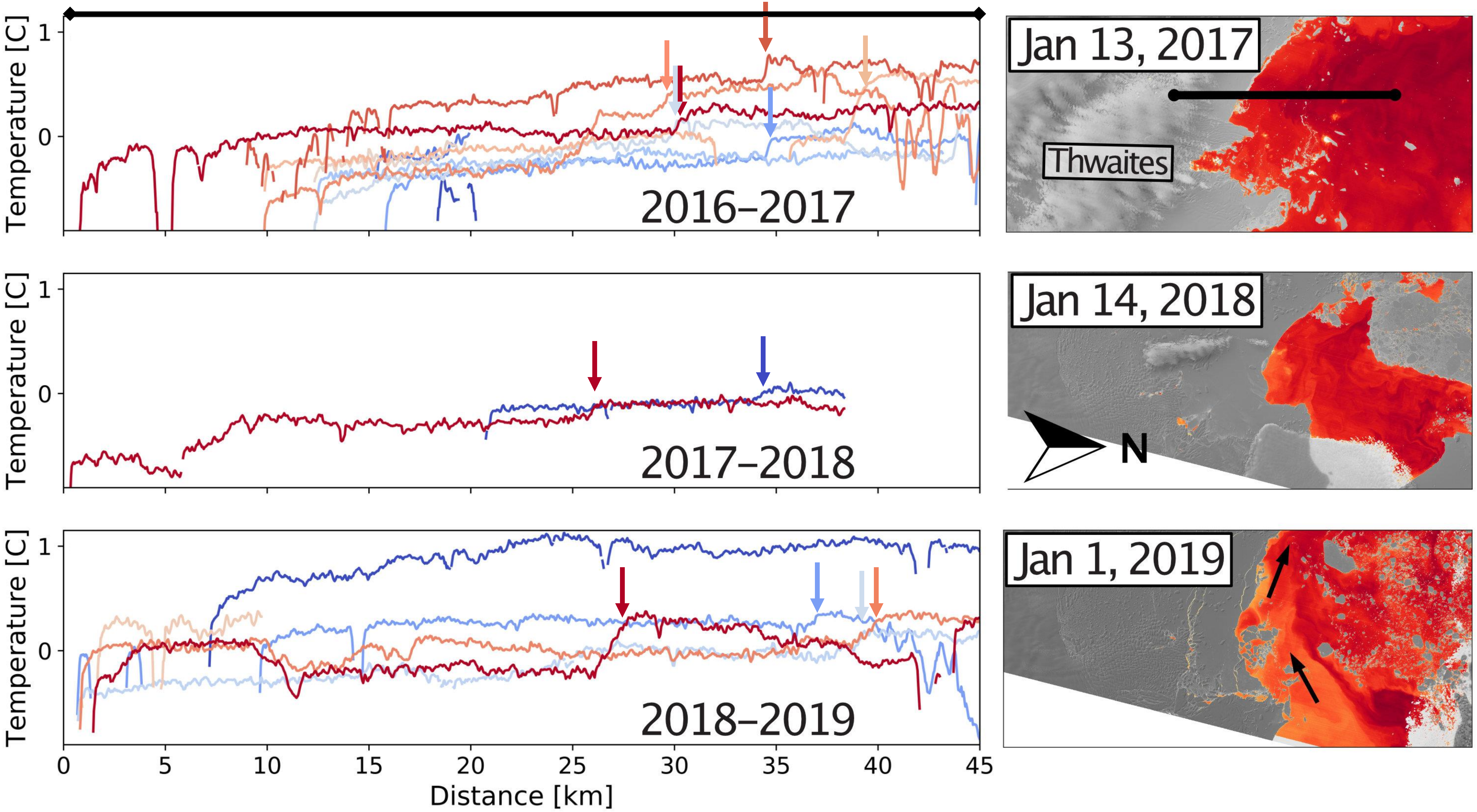
Maximum annual extent varied by an order of magnitude, potentially indicating fluctuations in ice shelf basal melt rates



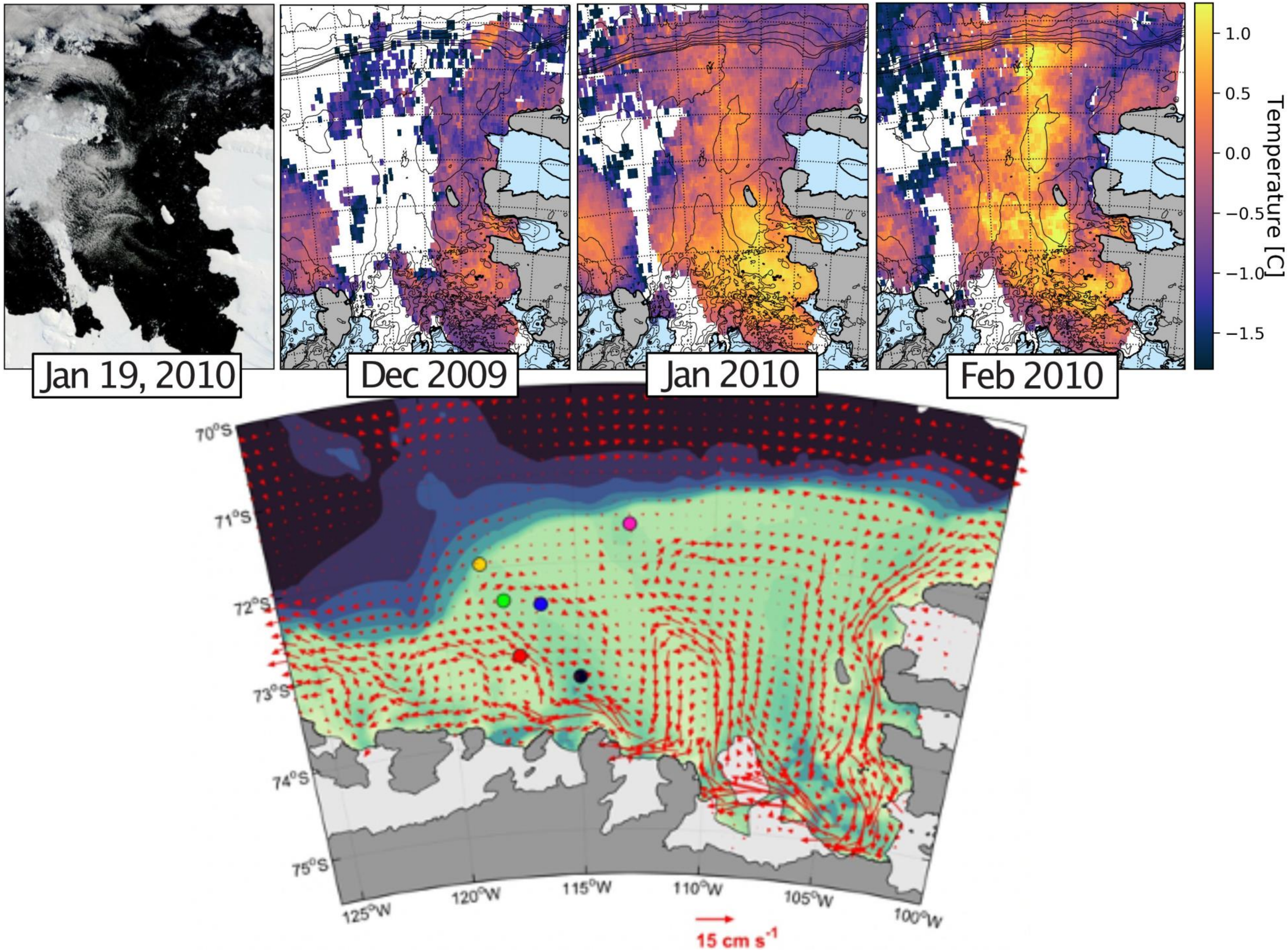
SST or thermal records can provide insight into sub-daily changes in polynyas during winter



AACC between 9 and 40 km wide near Thwaites Glacier



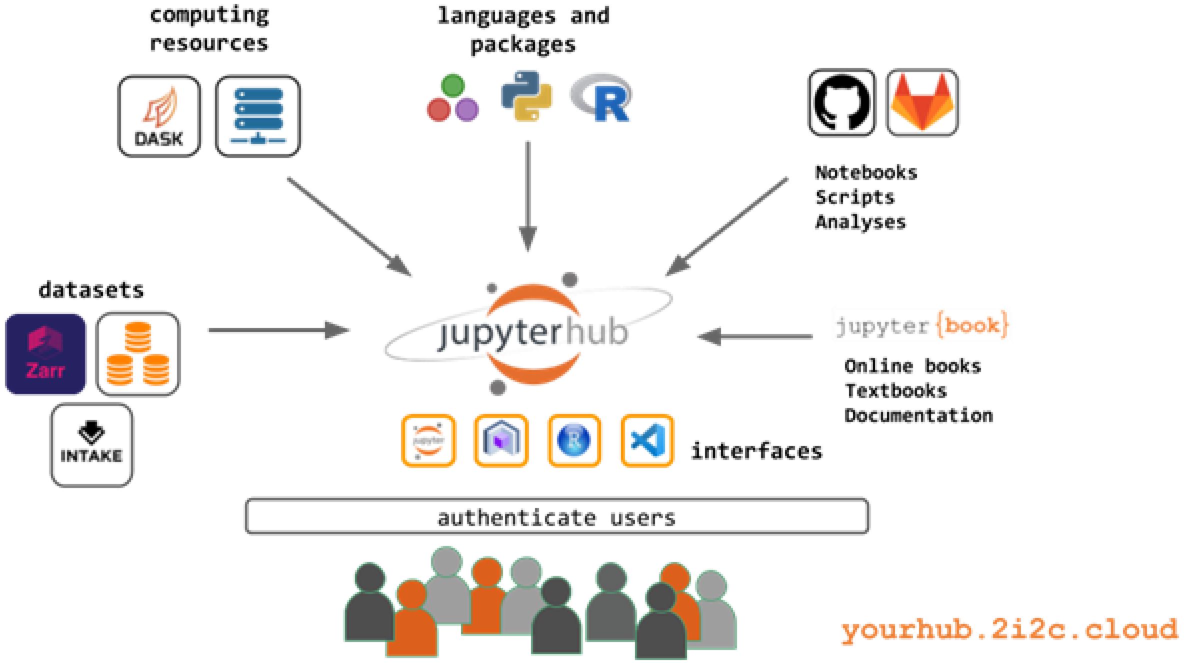
MODIS cool tempsagree wi MITgcm



2i2c.org

The International Interactive Computing Collaboration

- **Non-profit.**
- **Service provider** for interactive computing infrastructure.
- An R&D team that **contributes back to open source** communities.



Berkeley Computing, Data Science, and Society

jupyter

binder

PANGEO

Callysto

SYZYGY.CA

Funding
(Open Science Program)

No vendor lock-in + community empowerment

Customers have the right to replicate their infrastructure in its entirety elsewhere, with or without 2i2c.

A shared responsibility model empowers the community to learn cloud development skills and aid in maintaining the infrastructure.

`2i2c.org/right-to-replicate`

2i2c is committed to running its own infrastructure on open-source tools and vendor-agnostic infrastructure, though it does not *force* users to use only open-source tools in their own environments, code, and data. Below is a table describing how the Right to Replicate fits into 2i2c hub technology.

(Definitions of `MUST`, `MUST NOT`, `SHOULD`, `MAY`, etc are defined in RFC 2119)

User Code and Data	**May** be Open Source	We encourage adopting and producing open source code and data, but this is up to the user. e.g., licenses for user content/code
User Environment	**Should** be Open Source	Strong preference for open source tools only, although in some cases user needs may override this. e.g., Python, R, PyData stack.
2i2c Infrastructure	**Must** be Open Source	Strong commitment to using only open source software. e.g., JupyterHub, Kubernetes, Postgresql
Cloud Provider Infrastructure	**Must** be Portable	See this blog post for more information.

Cloud service collaboration model

Collaborate via…
Communicate change requests and issues
Co-create content to guide users
Discuss potential cloud / OSS improvements

Community Leadership Team

Experts in community goals, needs, and dynamics.
Usually **members of a community**.

Community Guidance Team

Experts in service design and community guidance.
Usually **2i2c staff**.

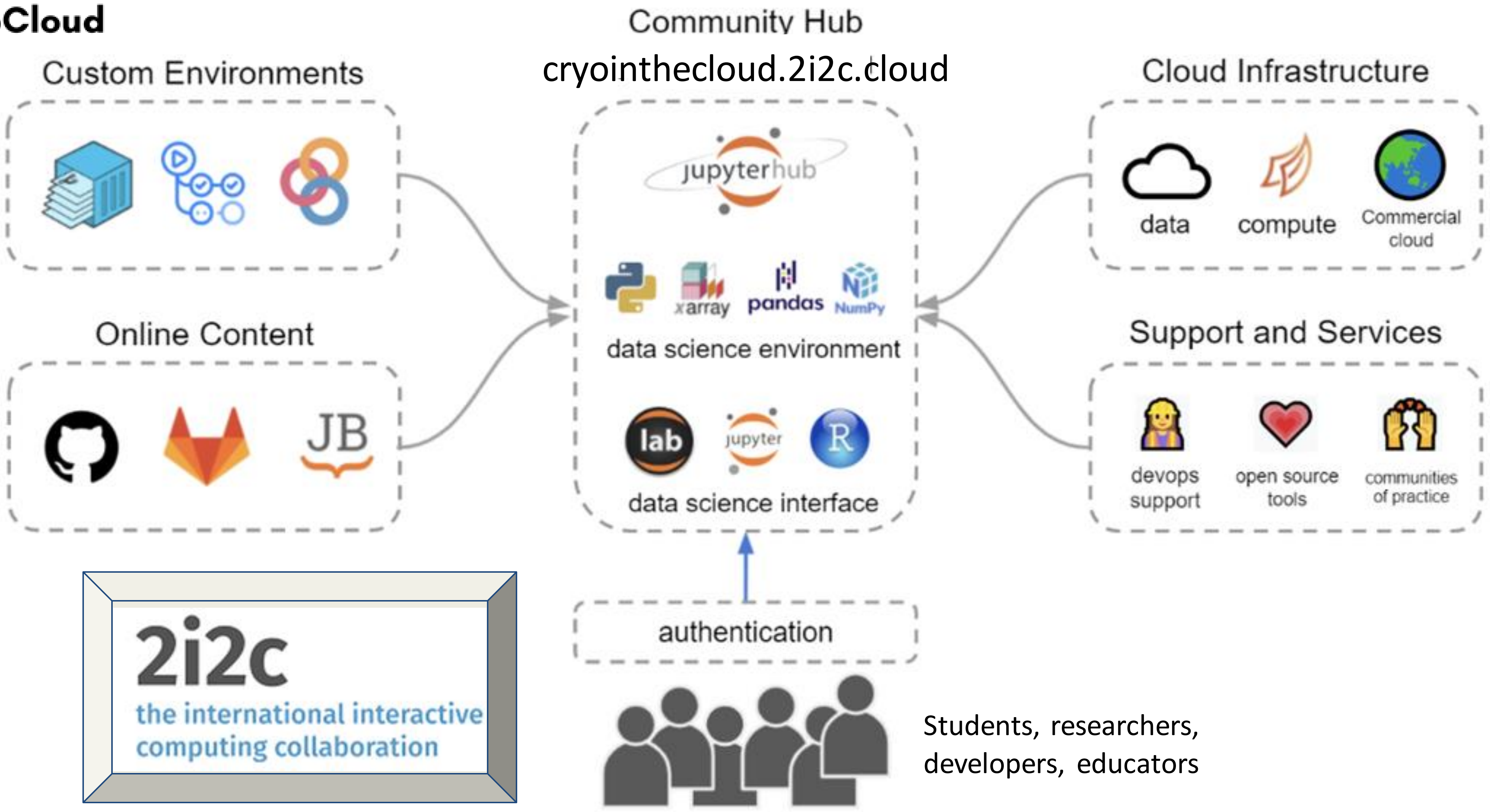
Collaborate via…
Communicate around hub deployment and incidents
Co-develop Open Source Software
Share infrastructure management skills (if desired)

Collaborate via…
Refine and discuss issues to improve service
Align on direction of service and tools
Prioritize and plan development efforts

Cloud Engineering Team

Experts in Cloud Infrastructure and Open Source Development
Usually **2i2c staff**.

CryoCloud: accelerate discovery and enhance collaboration

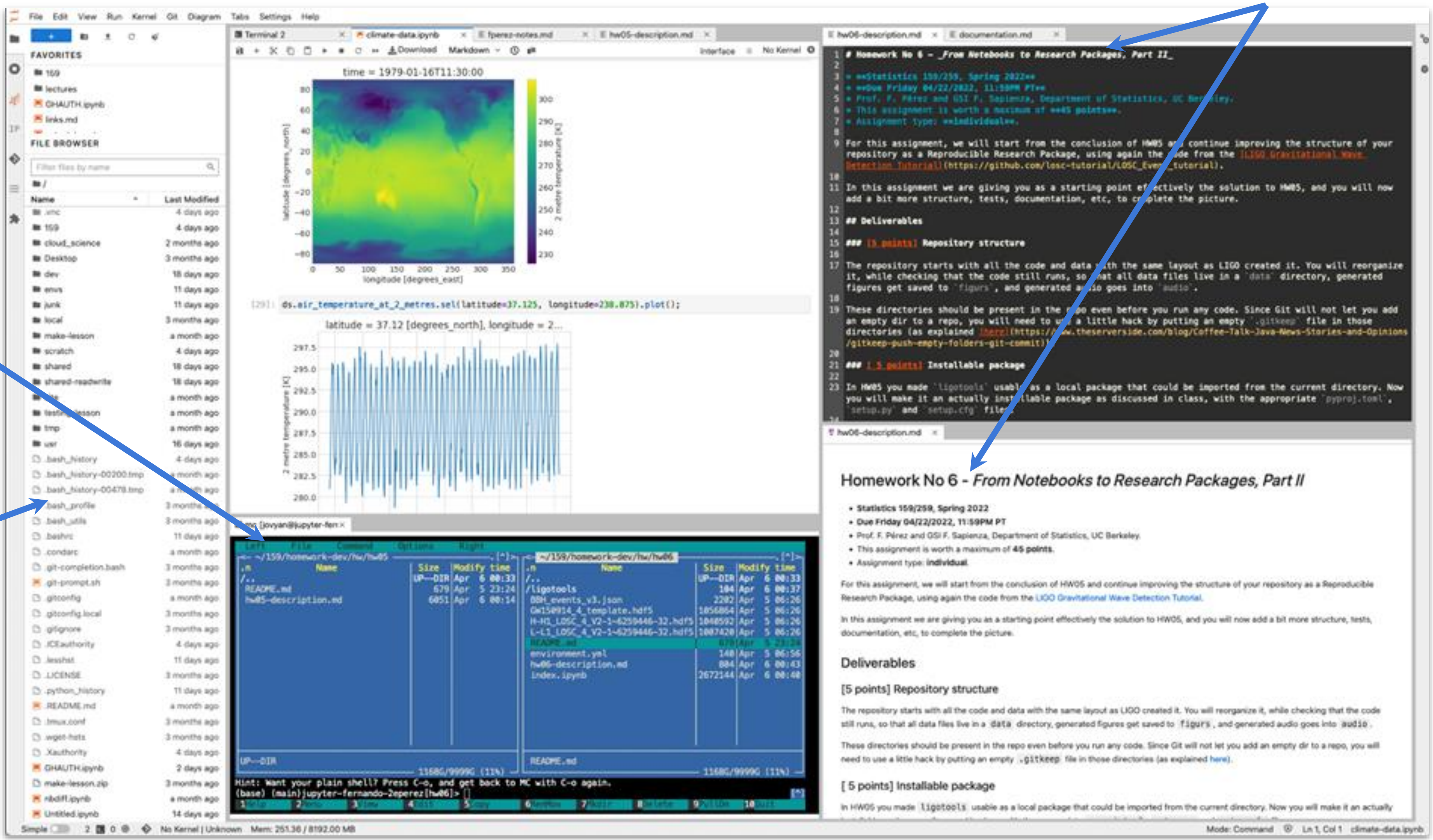


JupyterHub: a rich workbench

Markdown w/preview editing (or Python, R, Latex, Bash, C++, …)

Full terminal workflow

File management



Building collaborative and transferable community standards and infrastructure