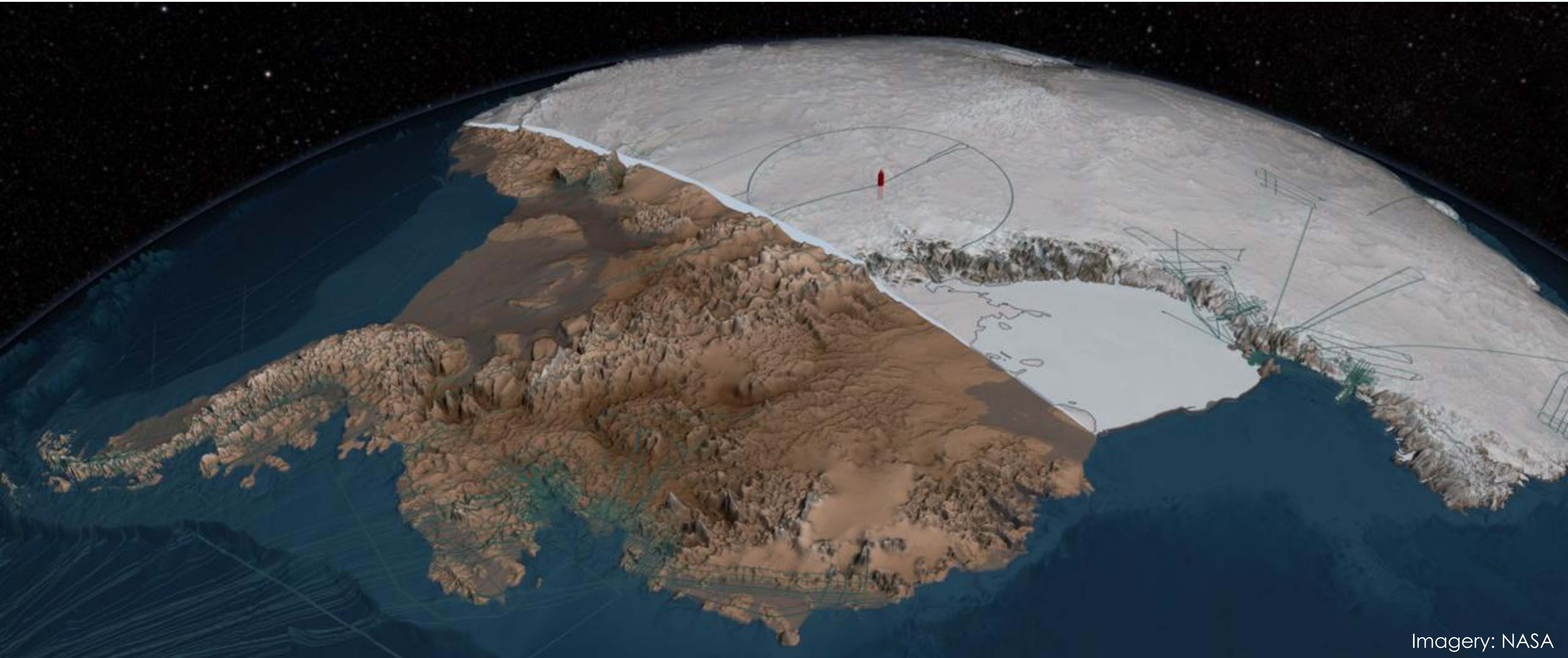
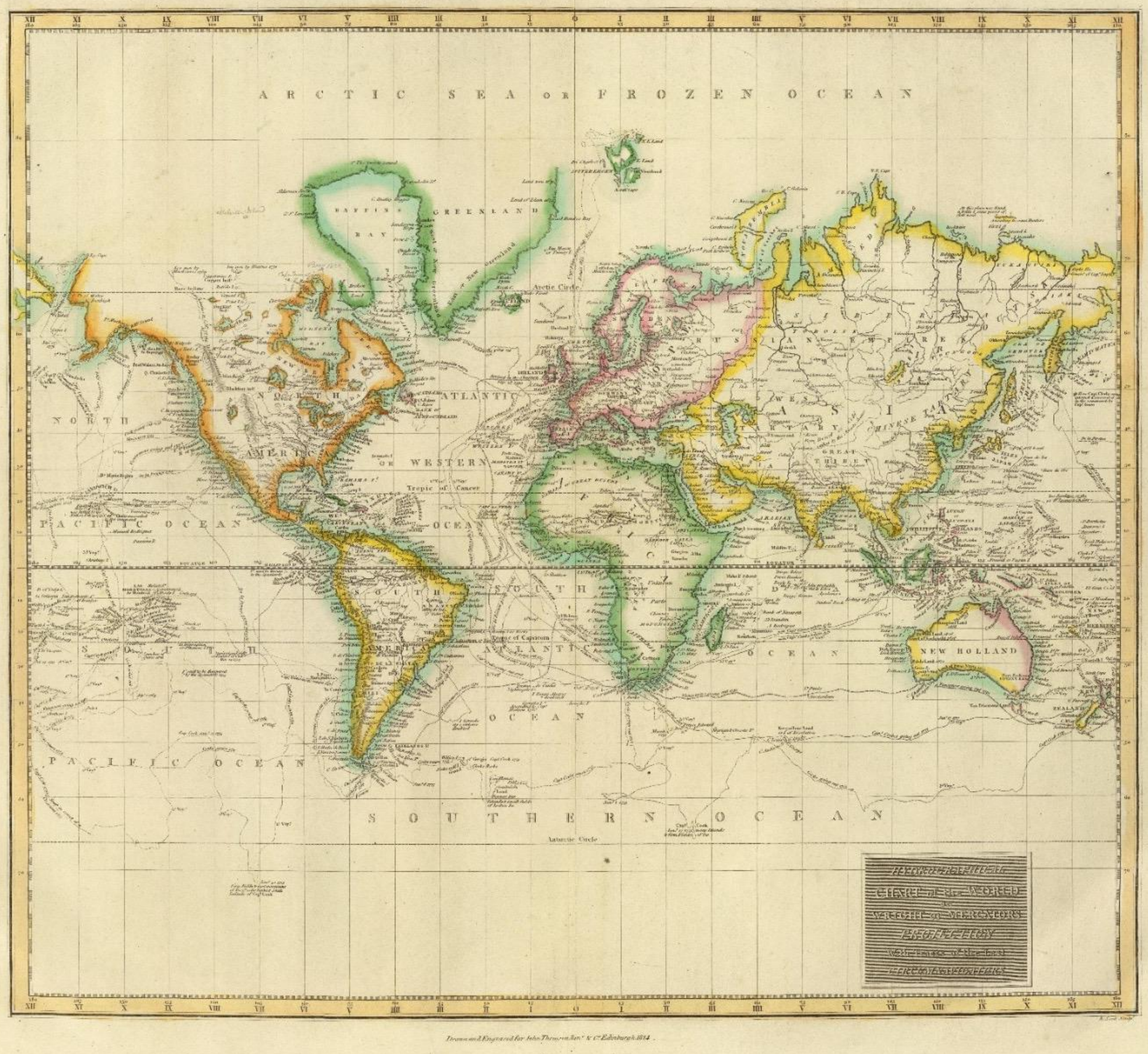
Satellite-based science and the changing nature of what it means to "explore" Antarctica

Presenter: Heather J. Lynch

May 29 – June 8, 2023
Helsinki ~ Finland
XLV
ANTARCTIC TREATY CONSULTATIVE MEETING



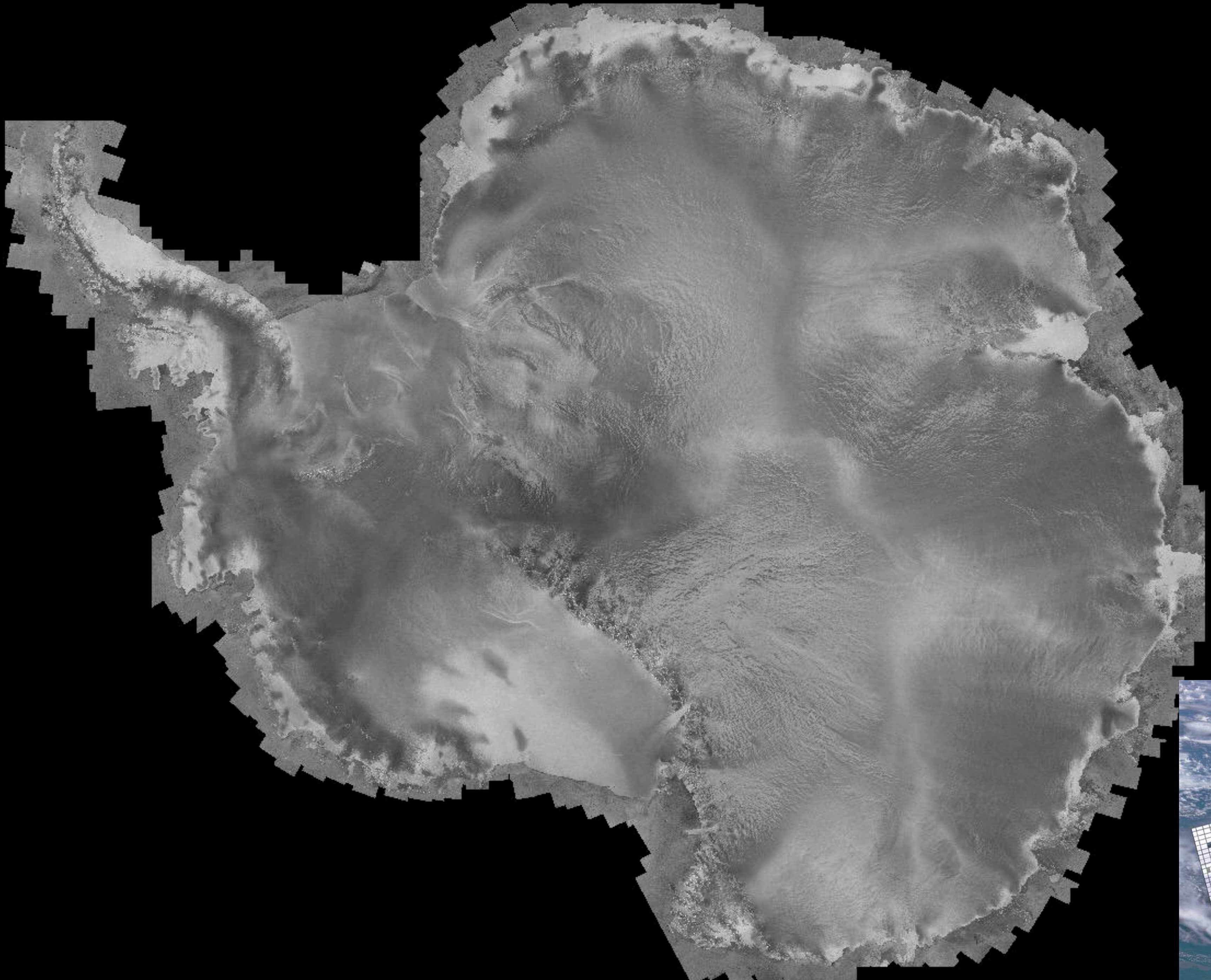
Imagery: NASA



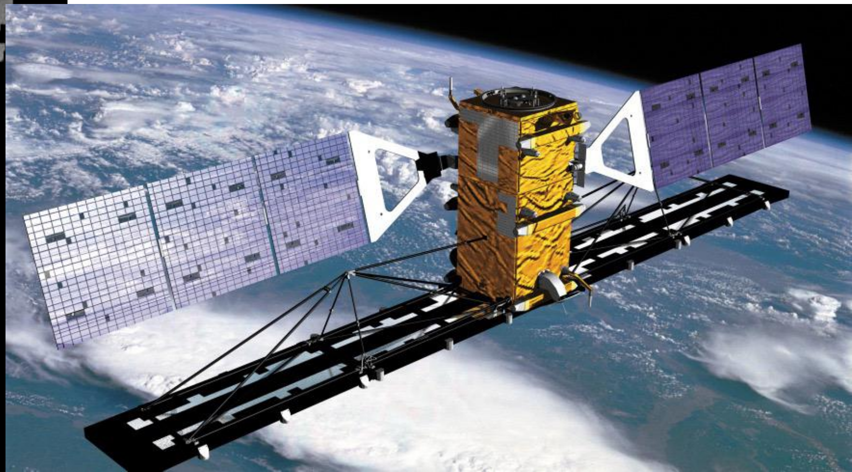
Hydrographical chart of the World (1817)

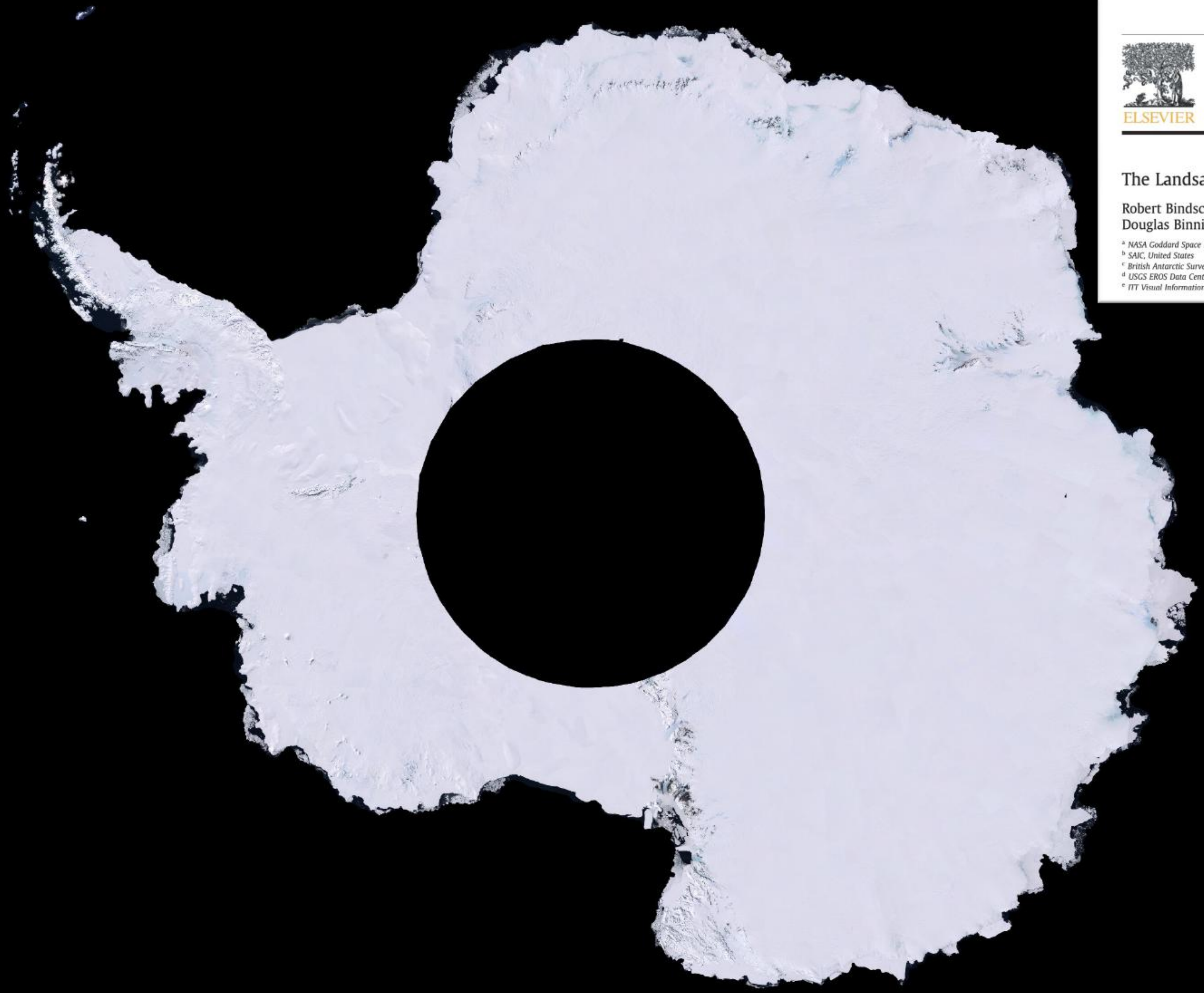
Source: Rumsey Collection


BRITISH ANTARCTIC
EXPEDITION
1910-13.
TRACK CHART OF
MAIN SOUTHERN JOURNEY
Outward Journey
Inward
Statute Miles.
Heights in feet above Sea Level.
ROSS SEA
ROSS BARRIER
SURFACE
SOUTH
VICTORIA
LAND
The Great Ice Barrier Edge
Mean Height 150 Feet
Bay of Whales
Mt. Evans
McMurdo Sound
C. Bird
Mt. Erebus 13,350
Mt. Terror 10,750
ROSS ISLAND
Crozier
C. Evans
Hut Pt.
C. Armitage
Nov. 5 Corner Camp
Taylor Glacier
Ferrar Glacier
Mt. Discovery
Minna Bluff
Mt. Morning
WORCESTER RANGE
Moore Bay
Bluff Depôt
Skelton Inlet
Mulock Inlet
One Ton Depôt
Tent
Mar. 19
C. Murray
Mt. Hughes 7890
Oates
BRITANNIA RANGE
Barne Inlet
C. Selborne
Mar. 9-10
Mt. Hooper
Mt. Hamilton 7,400
C. Parr
Day's Party ret'd.
Mt. Albert Markham 10,469
Mid Barrier Depôt
C. May
C. Wilson
Shackleton Inlet
C. Lyttelton
C. Goldie
Dec. 1 S. Barrier Depôt
Mts. Markham
QUEEN ALEXANDRA RANGE
Socks Glacier
Alice Glacier
Meares & dog teams ret'd.
Mt. Kyffin
Lieut. Evans found to be suffering from Scurvey on return journey
The Cloudmaker 9977
Bingley Glacier
Mid Glacier Depôt
Keltie Glacier
Buckley Island
Mt. Darwin
Upper Glacier Depôt
Atkinson's party ret'd.
Mill Glacier
King Edward VII.
Plateau
Feb. 1
Three Degree Depôt
Jan. 1st. 1912
Lt. Evans' Party ret'd.
Degree Depôt
Last Depôt
Jan. 18th
Jan. 18th 1912
SOUTH POLE



Radarsat Antarctic Mapping Project 1997





Remote Sensing of Environment 112 (2008) 4214–4226

Contents lists available at ScienceDirect

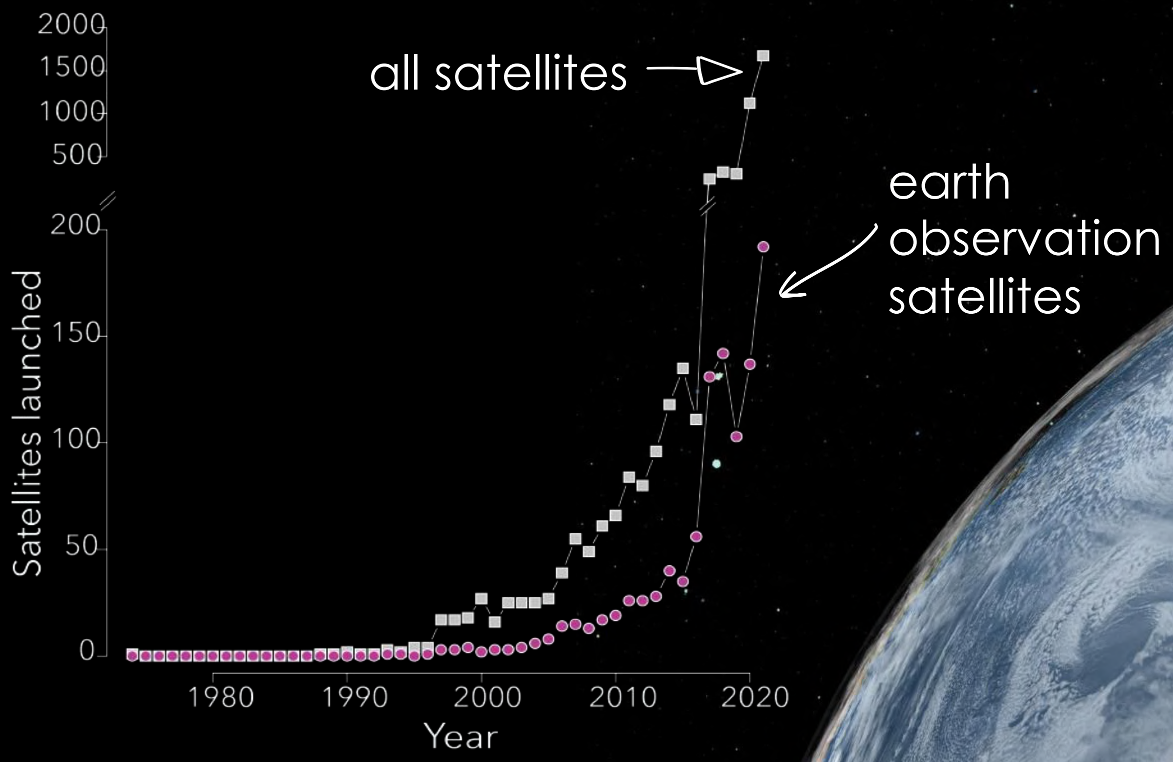
Remote Sensing of Environment

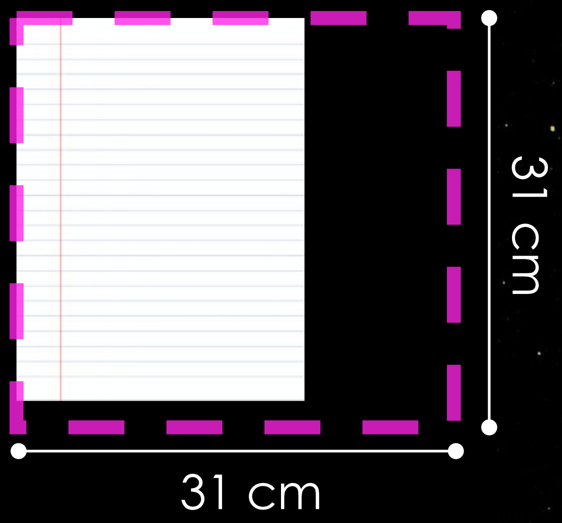
journal homepage: www.elsevier.com/locate/rse

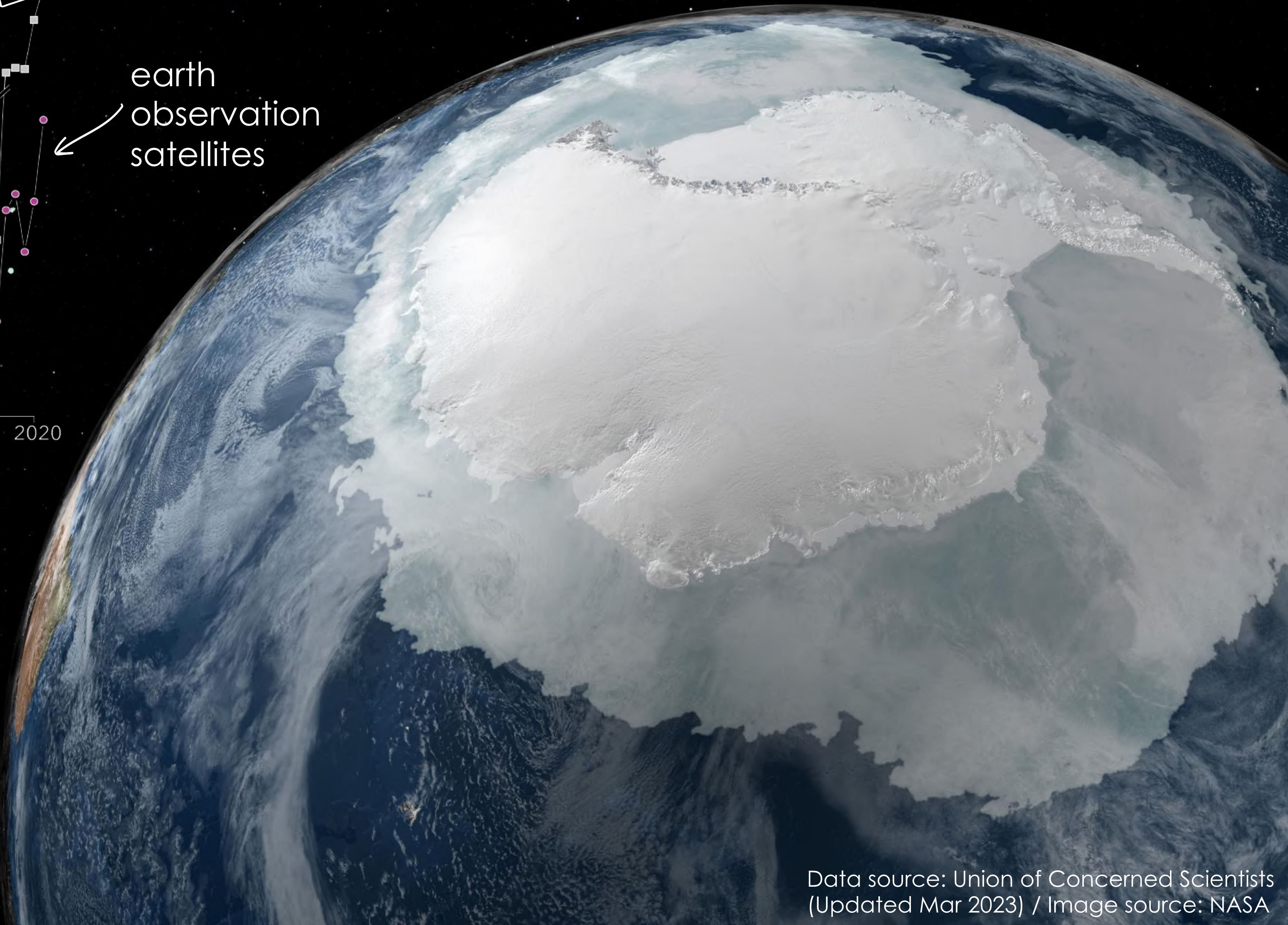
The Landsat Image Mosaic of Antarctica

Robert Bindschadler [a,*], Patricia Vornberger [b], Andrew Fleming [c], Adrian Fox [c], Jerry Mullins [d], Douglas Binnie [d], Sara Jean Paulsen [d], Brian Granneman [d], David Gorodetzky [e]

[a] NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States
[b] SAIC, United States
[c] British Antarctic Survey, United Kingdom
[d] USGS EROS Data Center, United States
[e] ITT Visual Information Systems, United States

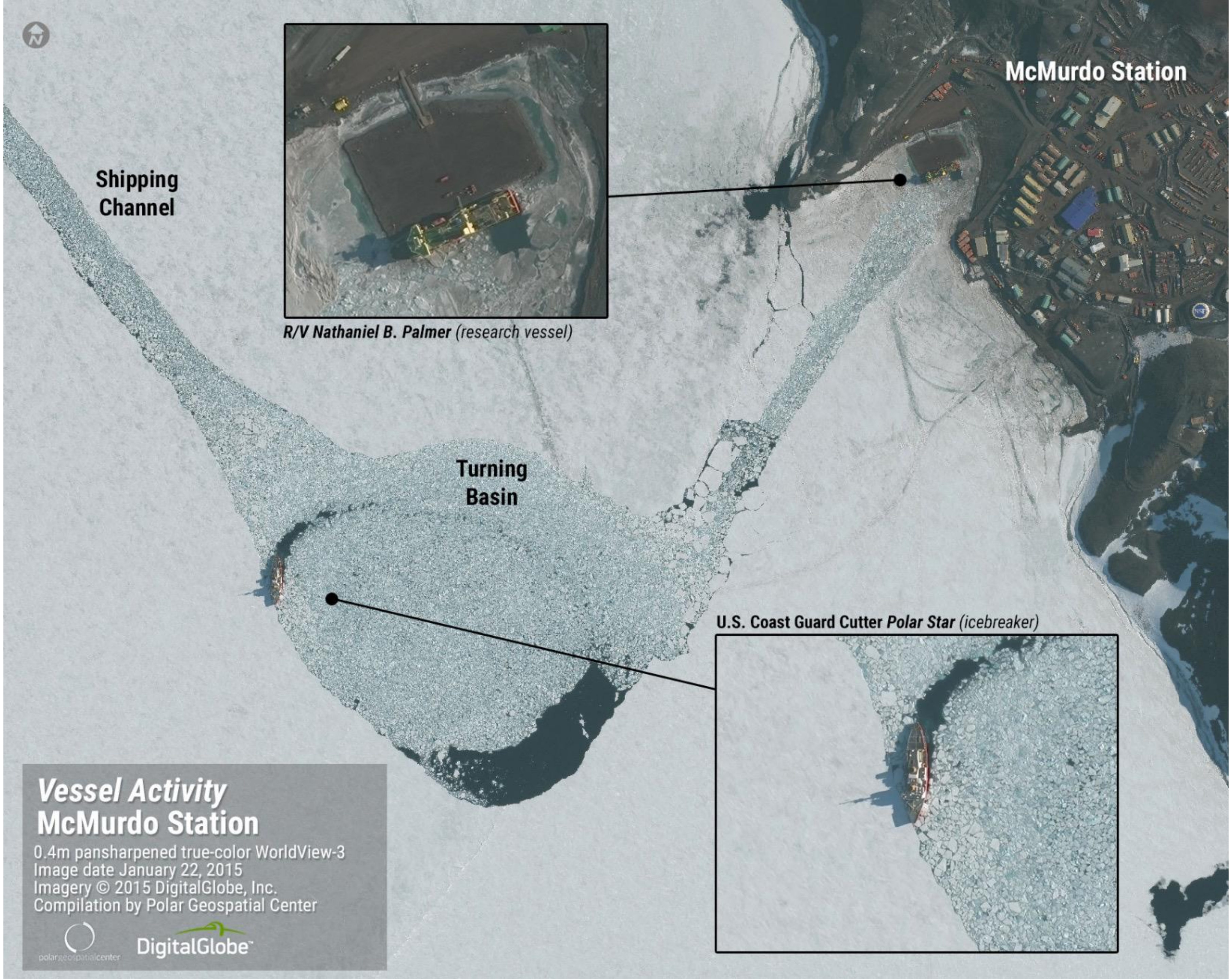






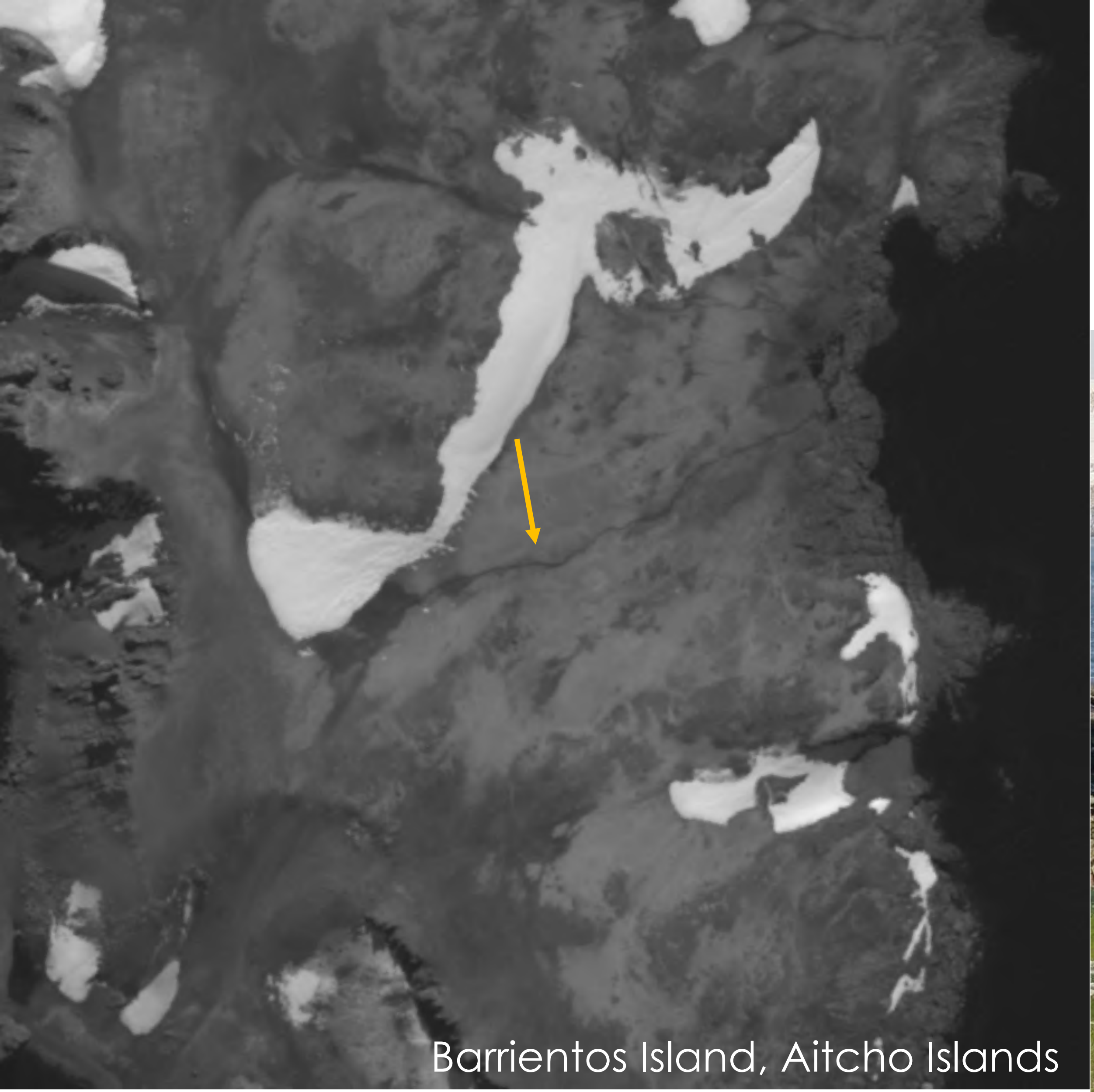
Data source: Union of Concerned Scientists (Updated Mar 2023) / Image source: NASA


We can now see every detail of
the human footprint in Antarctica
NSF
Imagery courtesy of Maxar



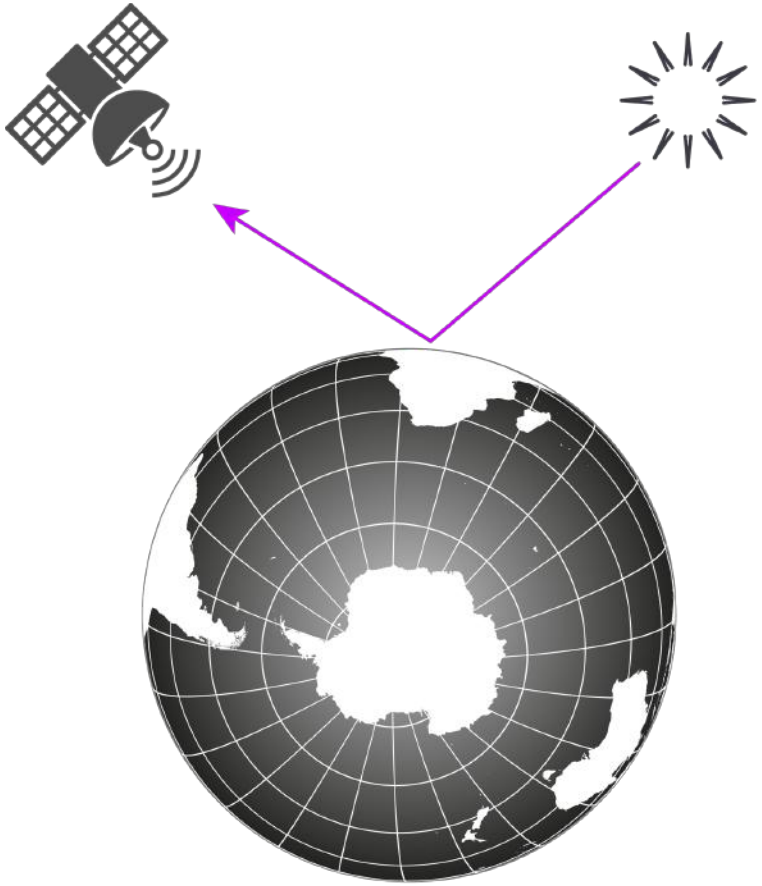
Imagery courtesy of Maxar


WAIS Divide
Imagery courtesy of Maxar

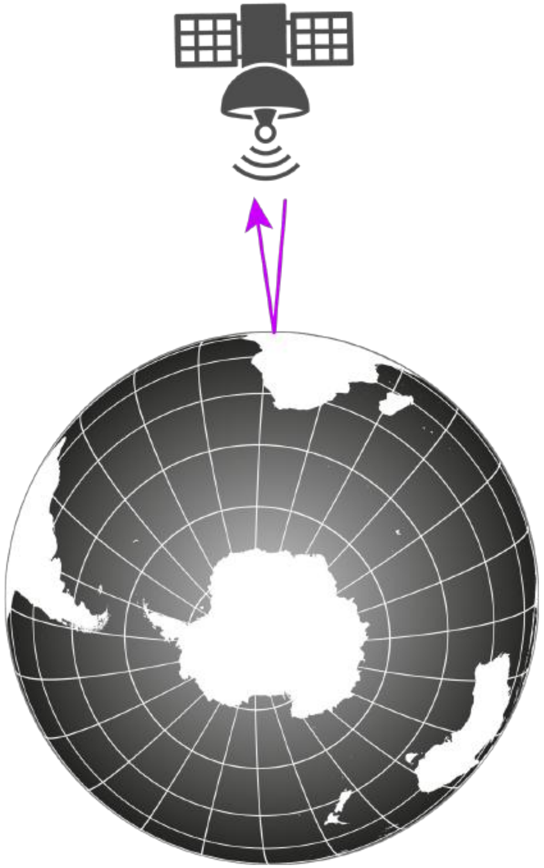

Barrientos Island, Aitcho Islands

WP18 & 41


…and even human trails through ancient moss beds…



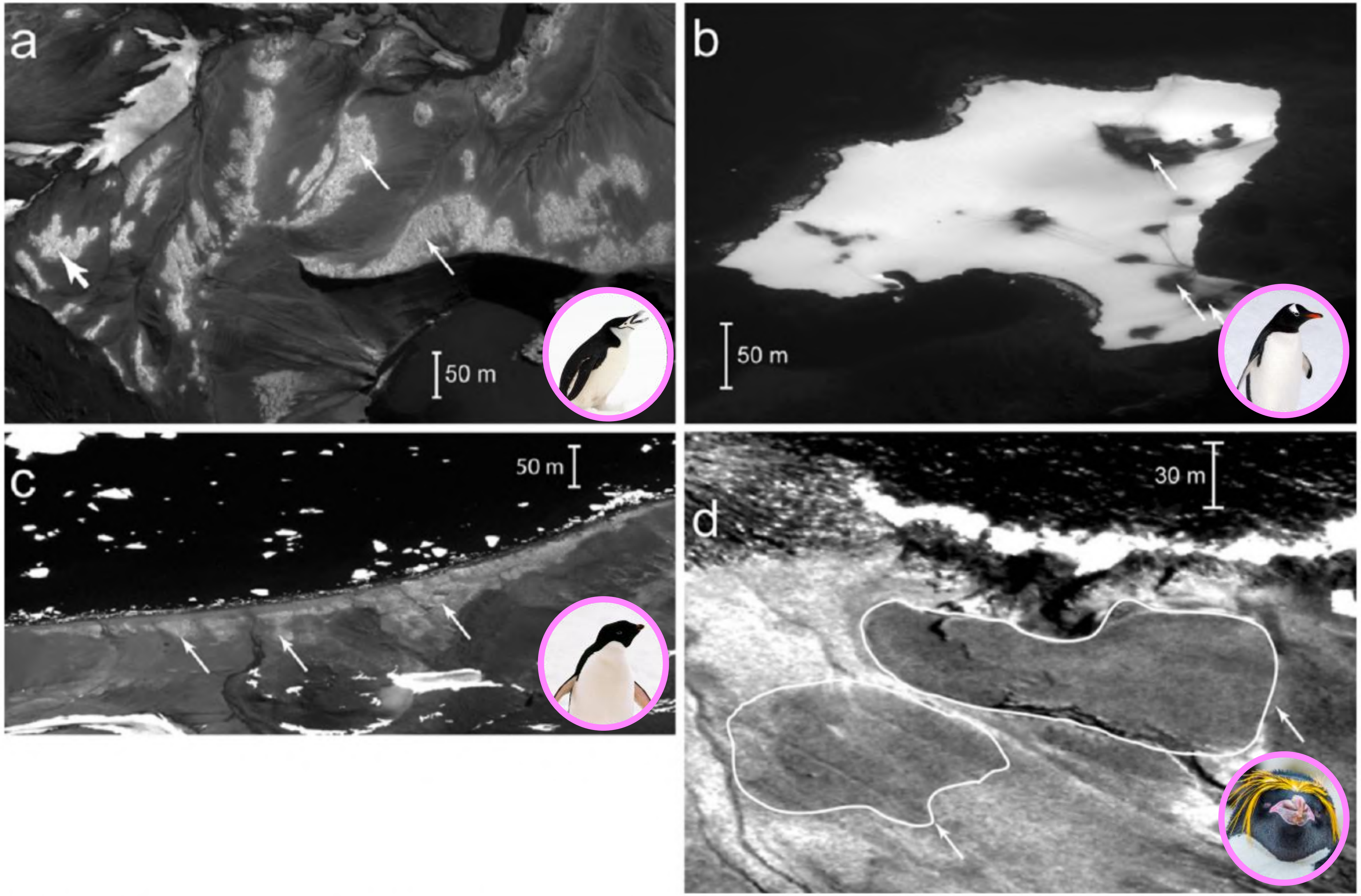
Passive
(e.g., optical imagery)

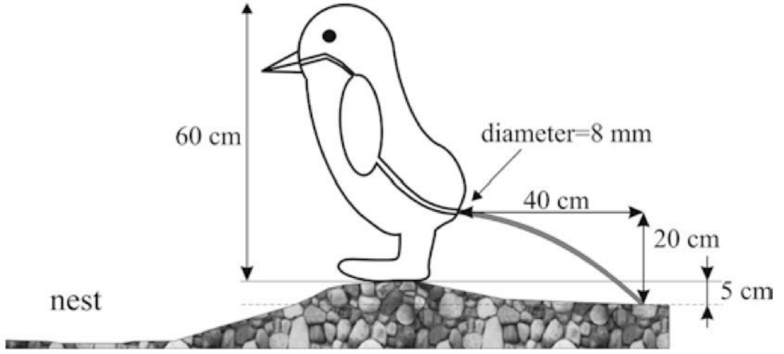


Active
(e.g., radar, LiDAR)

RADARSAT Constellation

TERRASAR-X





Meyer-Rochow and Gal (2003)

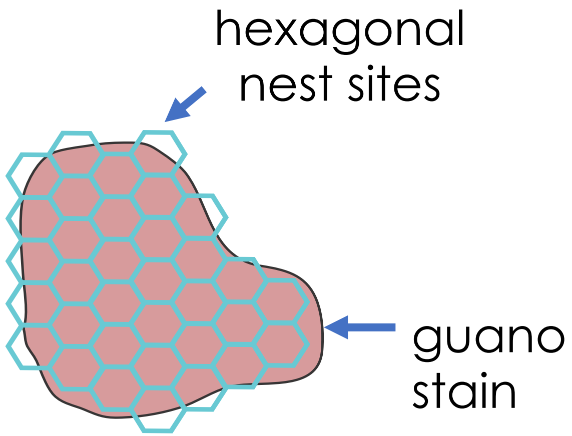
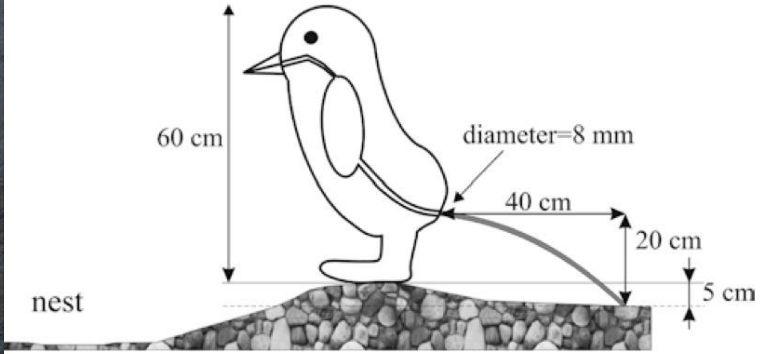


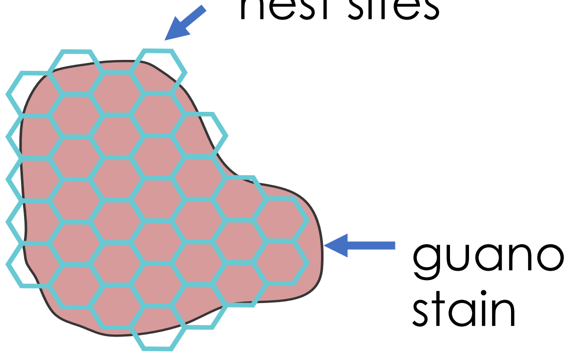
Fig. 1 Penguin colonies (indicated by *white arrows*) as they appear in panchromatic satellite imagery. Note that *arrows* indicate a representative sample of penguin colonies at this site; visually similar areas also represent penguin colonies. Imagery provided through the NGA Commercial Imagery program. **a** Chinstrap penguin colonies at Baily Head, Deception Island on January 21, 2003. Imagery copyright (2003) by DigitalGlobe, Inc. **b** Gentoo penguin colonies at Bombay Island, Mikkelsen Harbor, on December 3, 2010. Imagery copyright (2010) by DigitalGlobe, Inc. **c** Adélie penguin colonies at Devil Island on December 15, 2010. Imagery copyright (2010) by DigitalGlobe, Inc. **d** Macaroni penguin colonies (white polygons) lying within a larger chinstrap penguin colony at Acrid Point, Zavodovski Island (SSI) on January 8, 2011. Imagery copyright (2011) by DigitalGlobe, Inc

Lynch et al. 2012

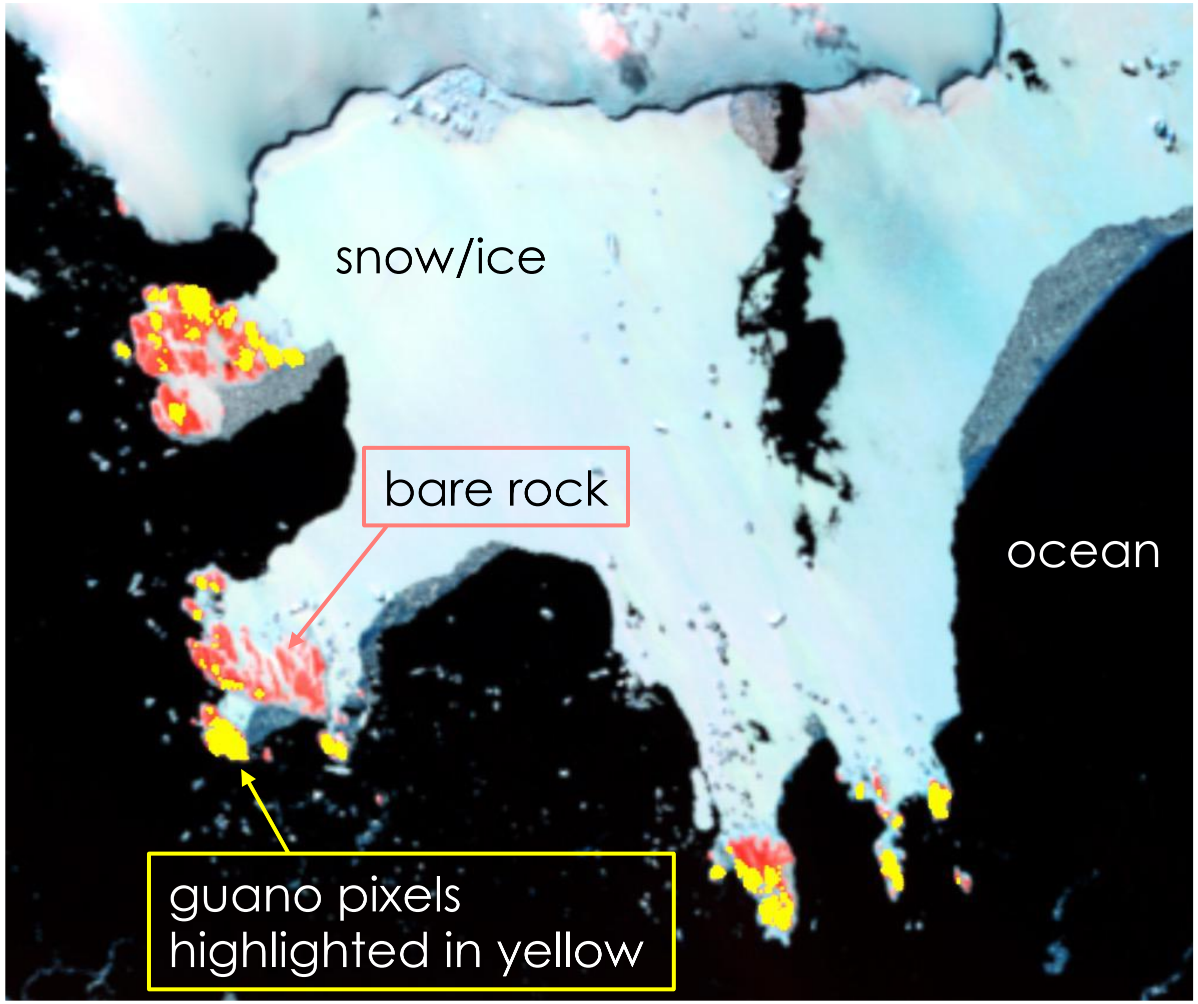
Lynch et al. 2012



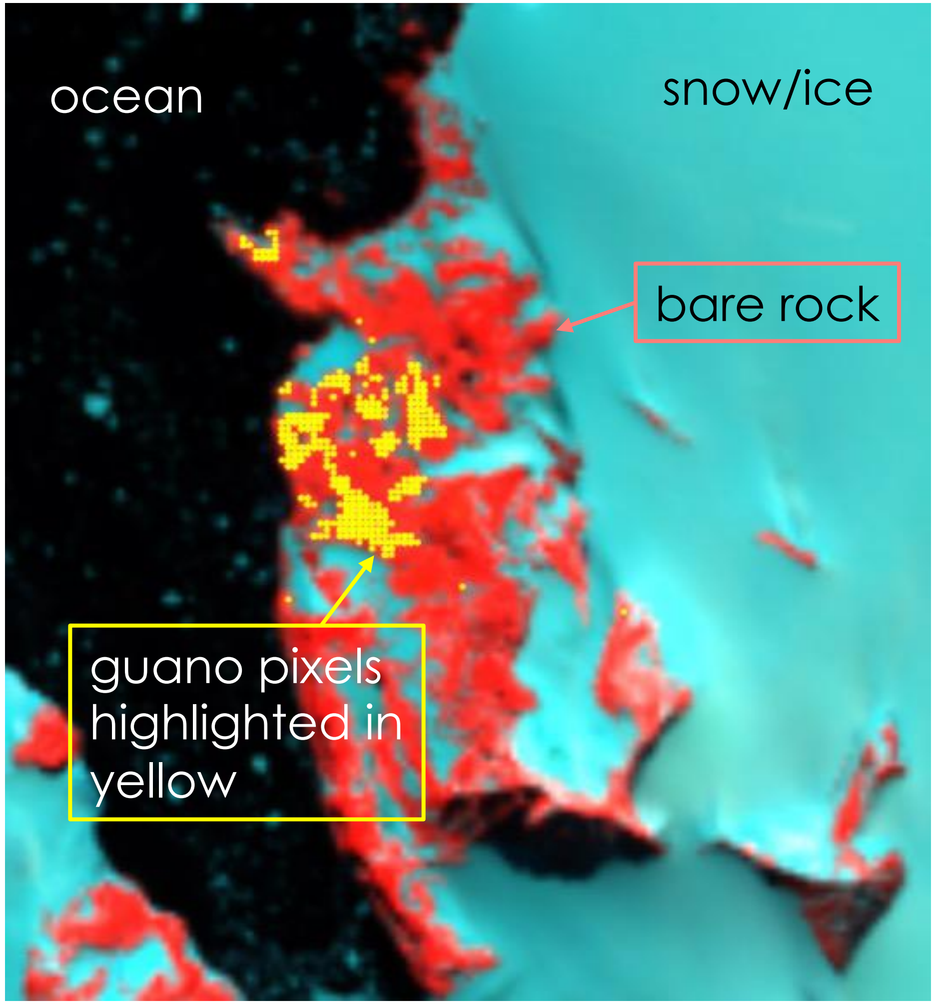
Meyer-Rochow and Gal (2003)



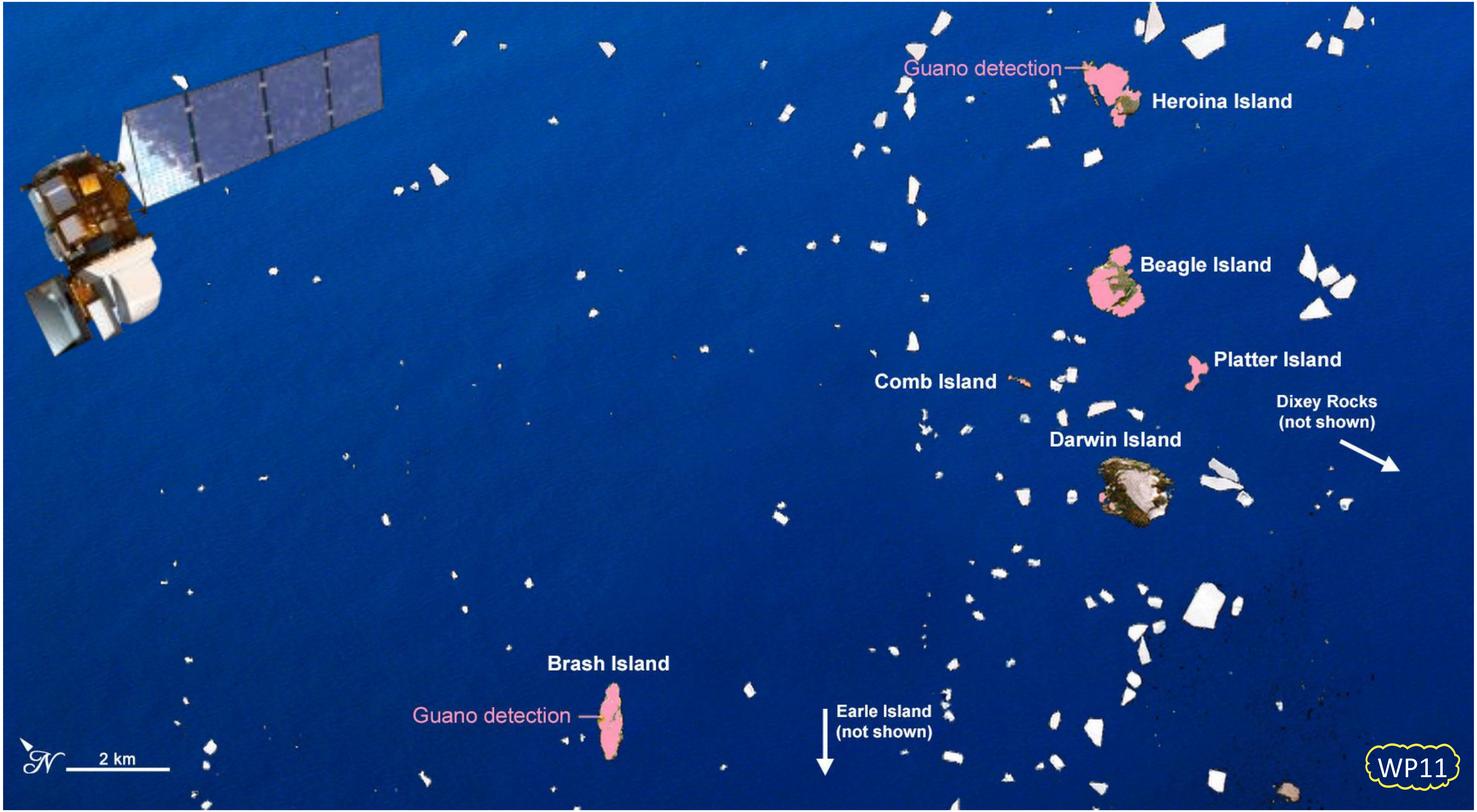
Landsat satellite images reveal penguin guano clustered on bare rock outcrops

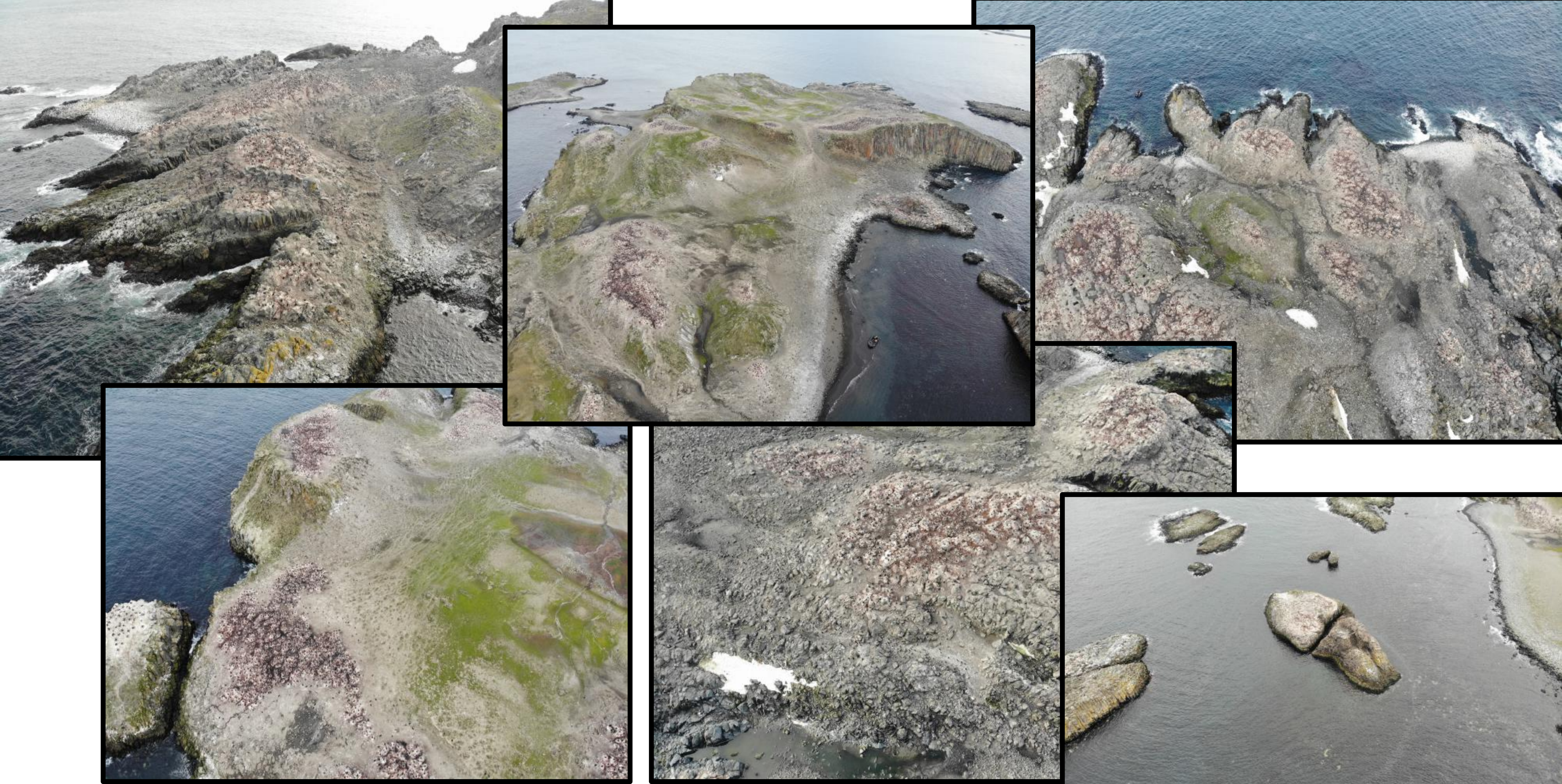


Lindsay Islands



Hope Bay


Guano detection
Heroina Island
Beagle Island
Platter Island
Comb Island
Dixey Rocks
(not shown)
Darwin Island
Brash Island
Guano detection
Earle Island
(not shown)
N
2 km
WP11



~20,000 chinstrap penguins discovered right around the corner from a popular tourist landing site


> 1 million penguins discovered by satellite imagery

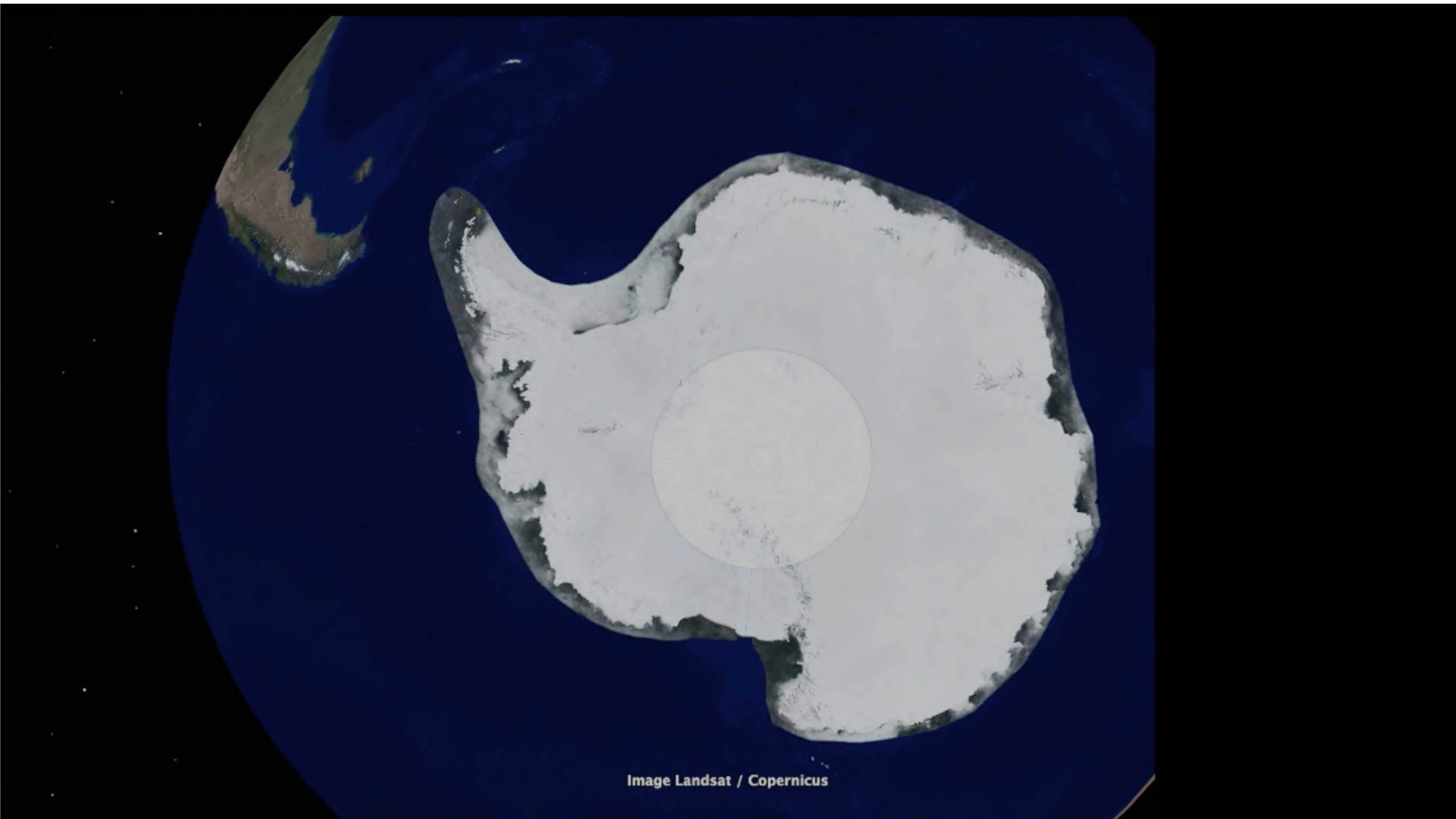


Image Landsat / Copernicus

Emperor penguin colonies far more dynamic than previously believed

An Emperor Penguin Population Estimate: The First Global, Synoptic Survey of a Species from Space

Peter T. Fretwell[1]*, Michelle A. LaRue[2], Paul Morin[2], Gerald L. Kooyman[3], Barbara Wienecke[4], Norman Ratcliffe[1], Adrian J. Fox[1], Andrew H. Fleming[1], Claire Porter[2], Phil N. Trathan[1]

1 British Antarctic Survey, Cambridge, United Kingdom, 2 Polar Geospatial Center, University in Minnesota, Minneapolis, Minnesota, United States of America, 3 Scripps Institution of Oceanography, University of California San Diego, La Jolla, California, United States of America, 4 Australian Antarctic Division, Hobart, Tasmania, Australia

Research

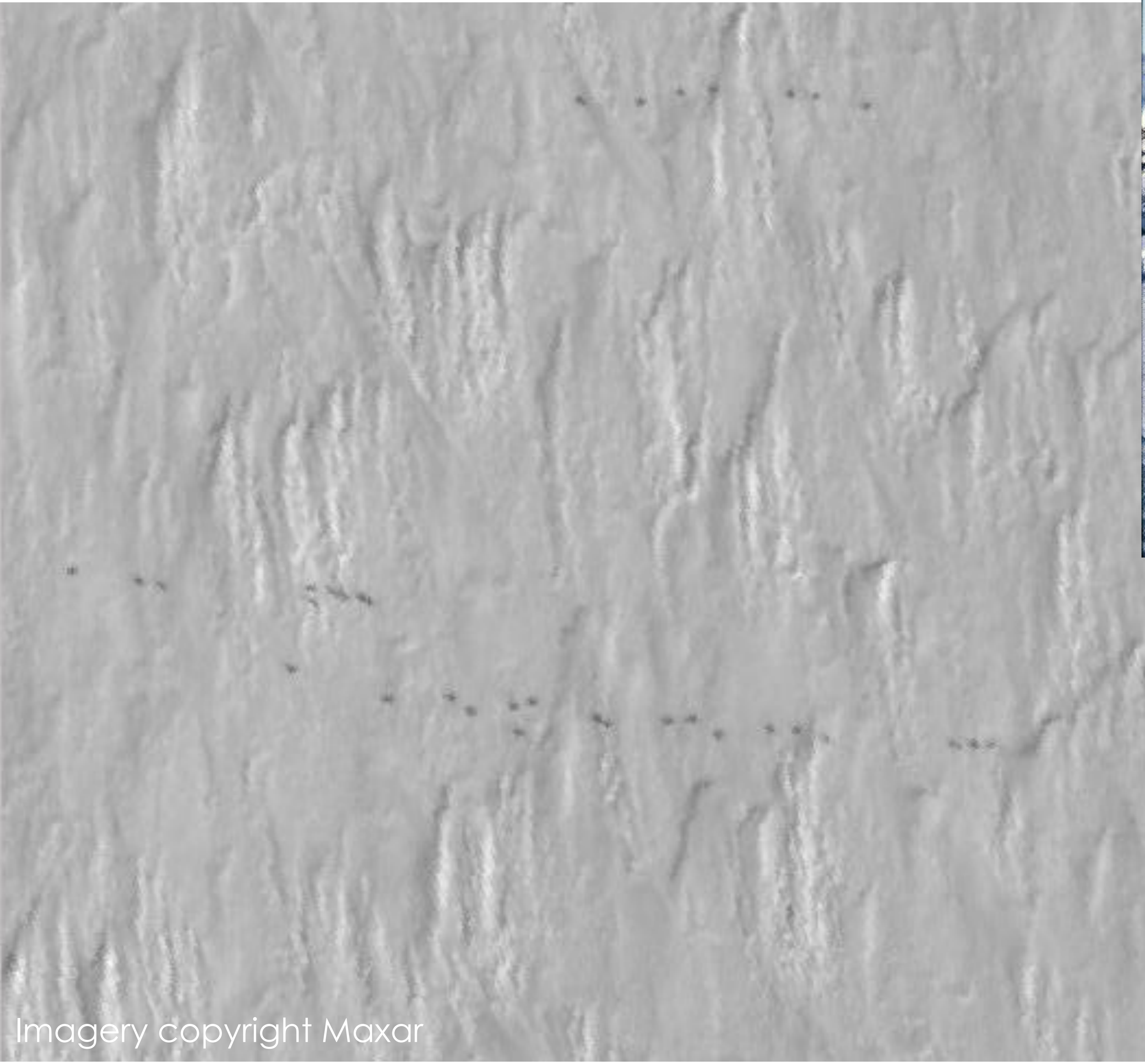
Ecography 38: 114–120, 2015
doi: 10.1111/ecog.00990

Subject Editor: Cagan Sekercioglu. Accepted 5 June 2014

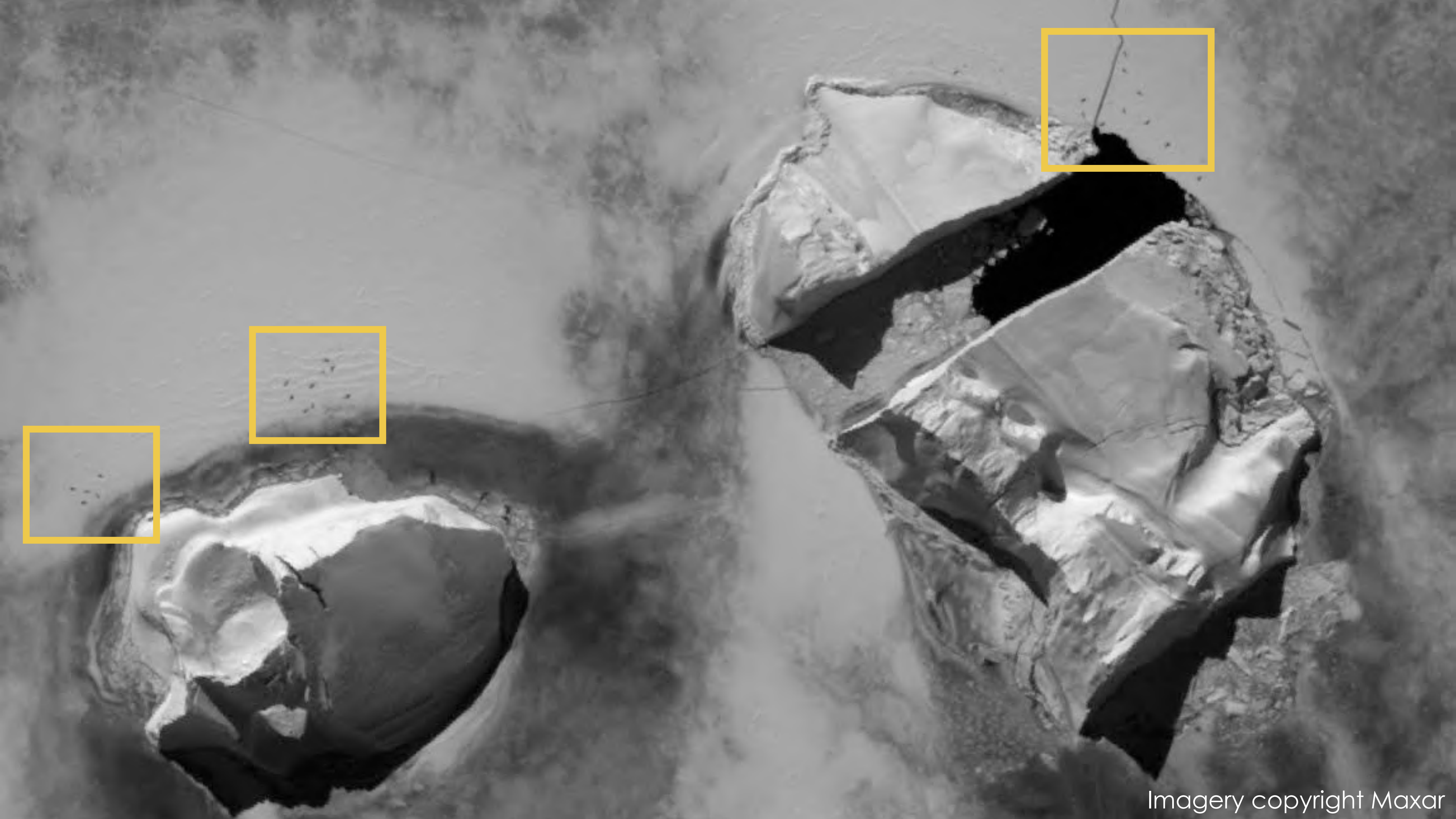
Emigration in emperor penguins: implications for interpretation of long-term studies

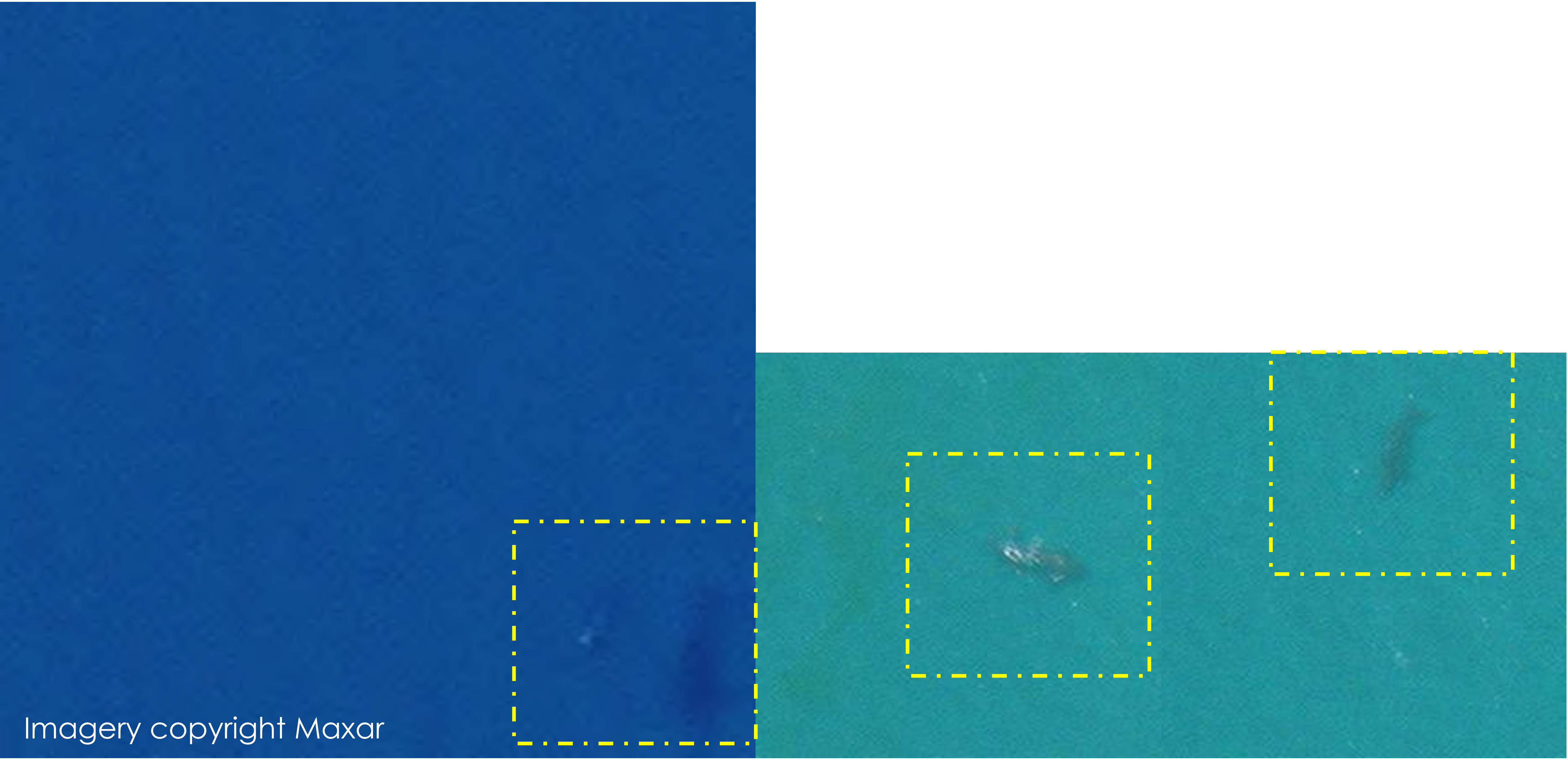
Michelle A. LaRue, Gerald Kooyman, Heather J. Lynch and Peter Fretwell

WP9 & 52

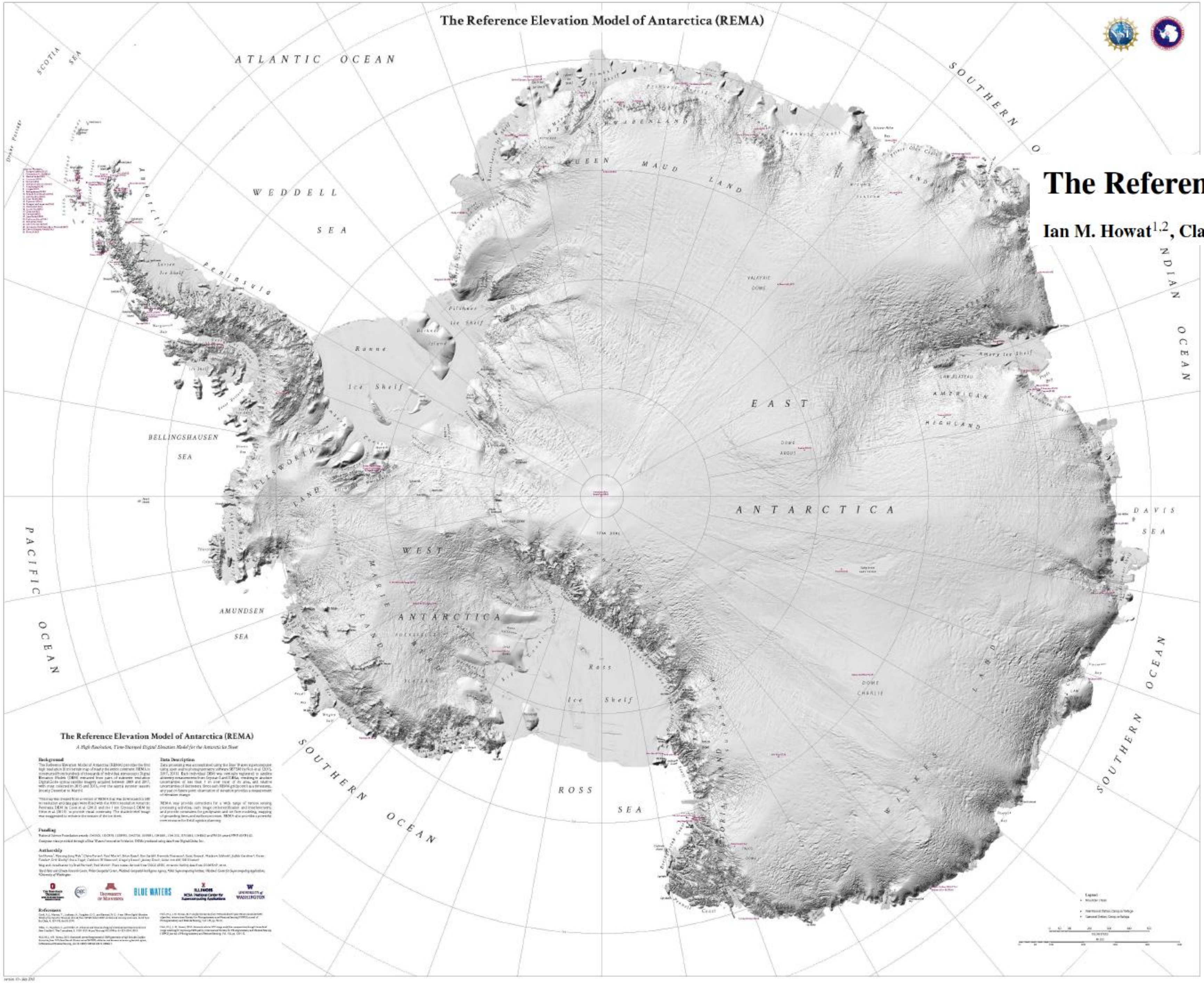


WP9 & 52





Borowicz et al. (2020)



The Cryosphere, 13, 665–674, 2019
https://doi.org/10.5194/tc-13-665-2019

The Cryosphere

The Reference Elevation Model of Antarctica

Ian M. Howat[1,2], Claire Porter[3], Benjamin E. Smith[4], Myoung-Jong Noh[1], and Paul Morin[3]

pan-Antarctic elevation model

2 m spatial resolution

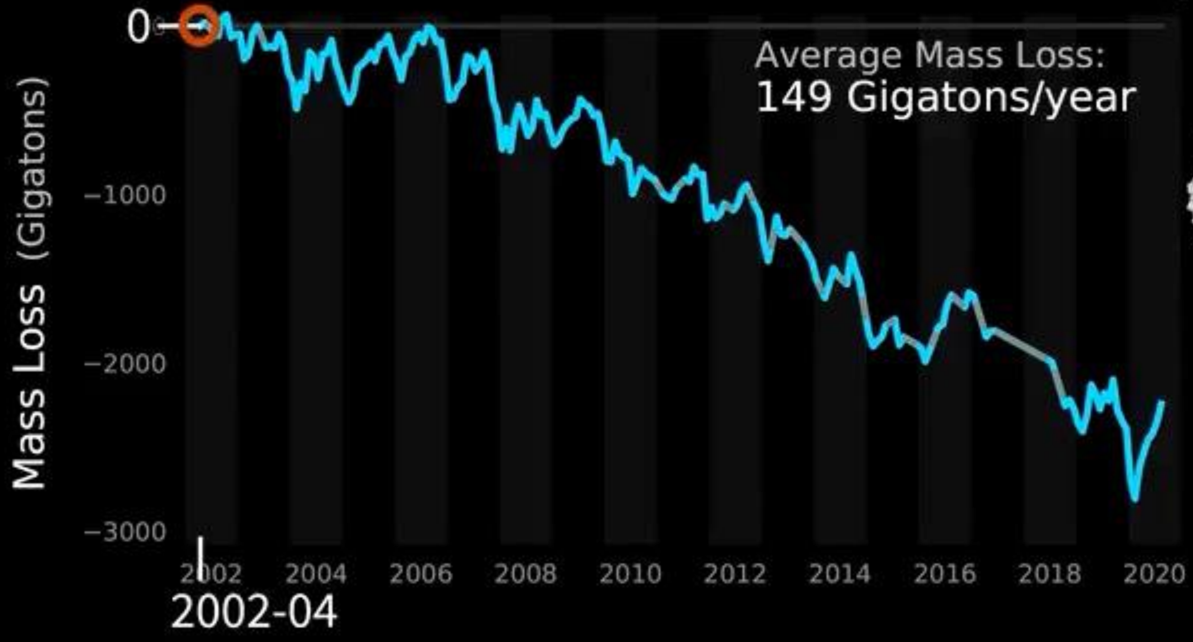
typical vertical errors < 1 m

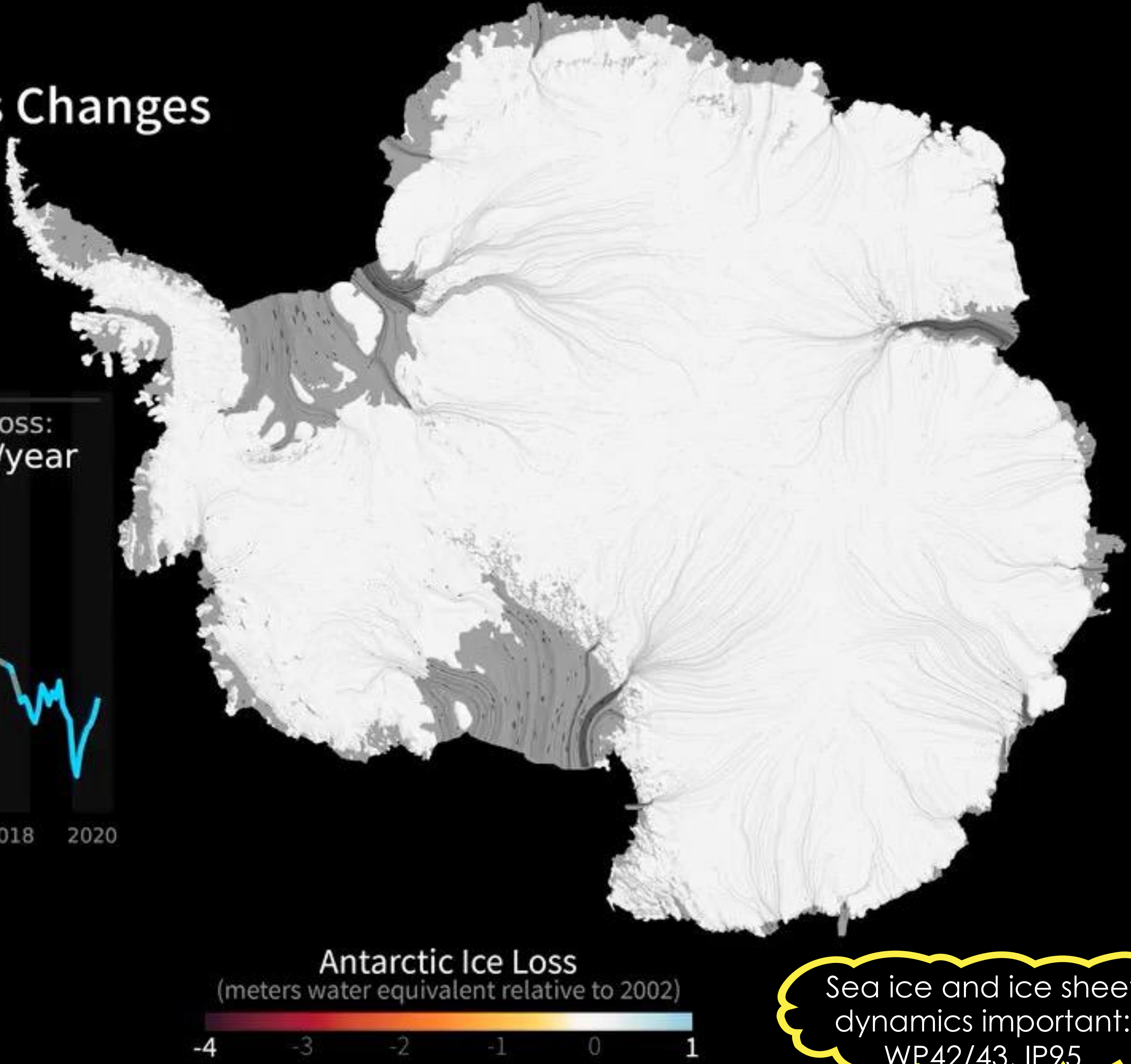
Gravity Recovery and Climate Experiment (GRACE)

GRACE-Follow On

Image source: NASA/JPL-Caltech

GRACE AND GRACE-FO
Observations OF Antarctic Ice Mass Changes





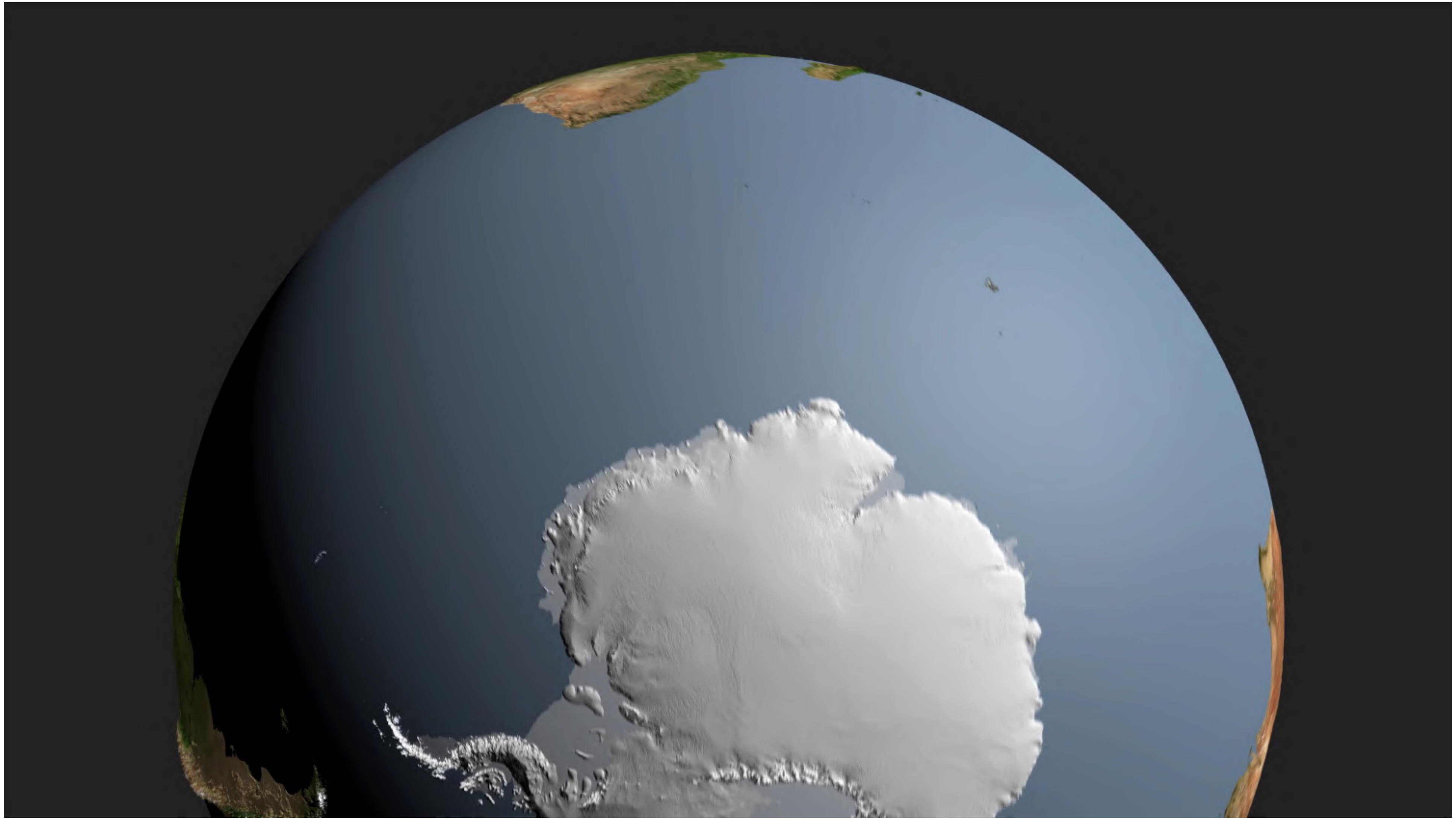
Source: NASA/JPL-Caltech

Sea ice and ice sheet dynamics important: WP42/43, IP95

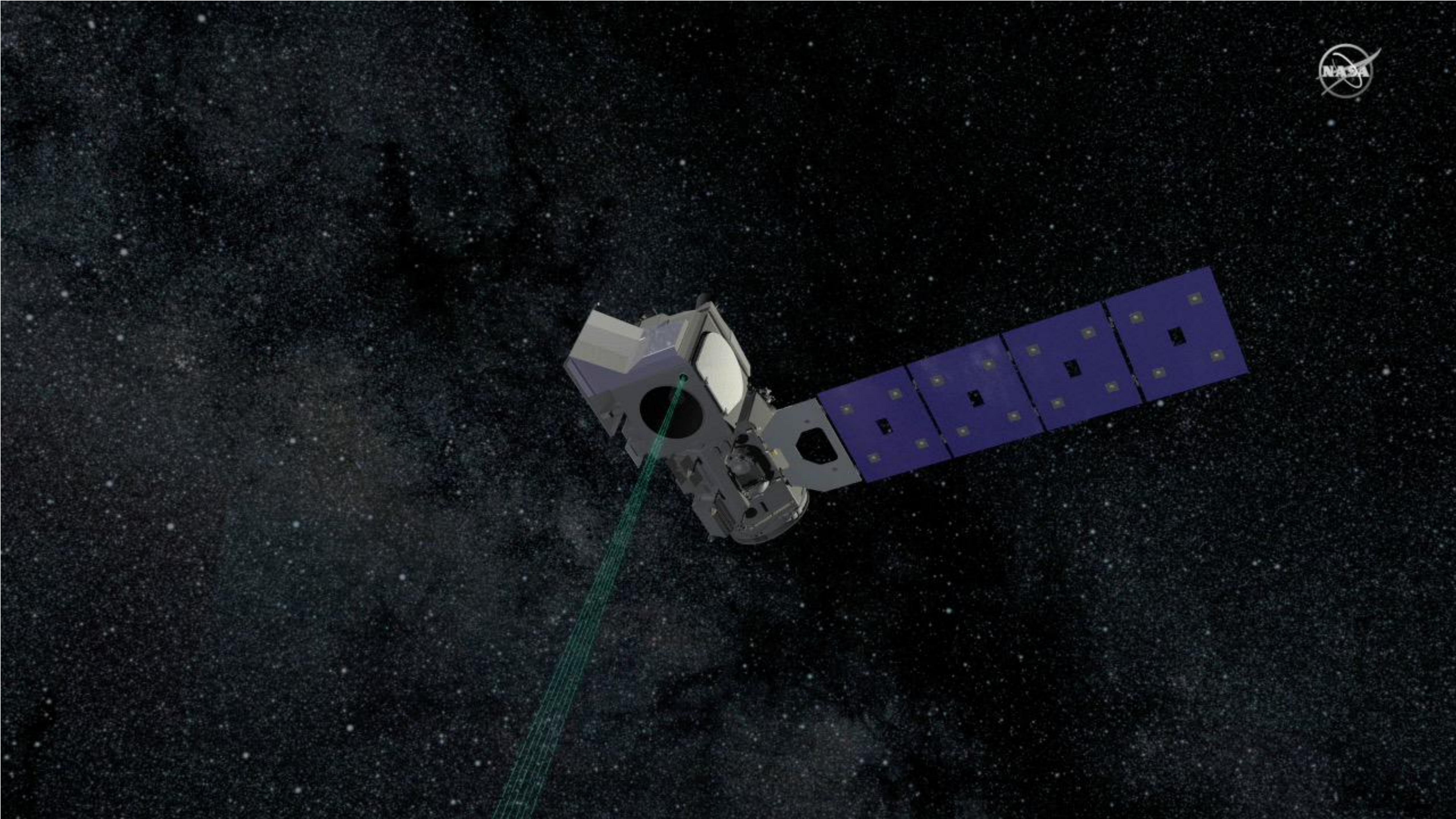
ARTICLES
https://doi.org/10.1038/s41561-019-0510-8
nature geoscience

Deep glacial troughs and stabilizing ridges unveiled beneath the margins of the Antarctic ice sheet

Mathieu Morlighem[1*], Eric Rignot[1,2], Tobias Binder[3], Donald Blankenship[4], Reinhard Drews[3,5], Graeme Eagles[3], Olaf Eisen[3,6], Fausto Ferraccioli[7], René Forsberg[8], Peter Fretwell[7], Vikram Goel[9], Jamin S. Greenbaum[4], Hilmar Gudmundsson[10], Jingxue Guo[11], Veit Helm[3], Coen Hofstede[3], Ian Howat[12], Angelika Humbert[3,6], Wilfried Jokat[3], Nanna B. Karlsson[3,13], Won Sang Lee[14], Kenichi Matsuoka[15], Romain Millan[1], Jeremie Mouginot[1,16], John Paden[17], Frank Pattyn[18], Jason Roberts[19,20,21], Sebastian Rosier[10], Antonia Ruppel[22], Helene Seroussi[2], Emma C. Smith[3], Daniel Steinhage[3], Bo Sun[11], Michiel R. van den Broeke[23], Tas D. van Ommen[19,20,21], Melchior van Wessem[23] and Duncan A. Young[4]



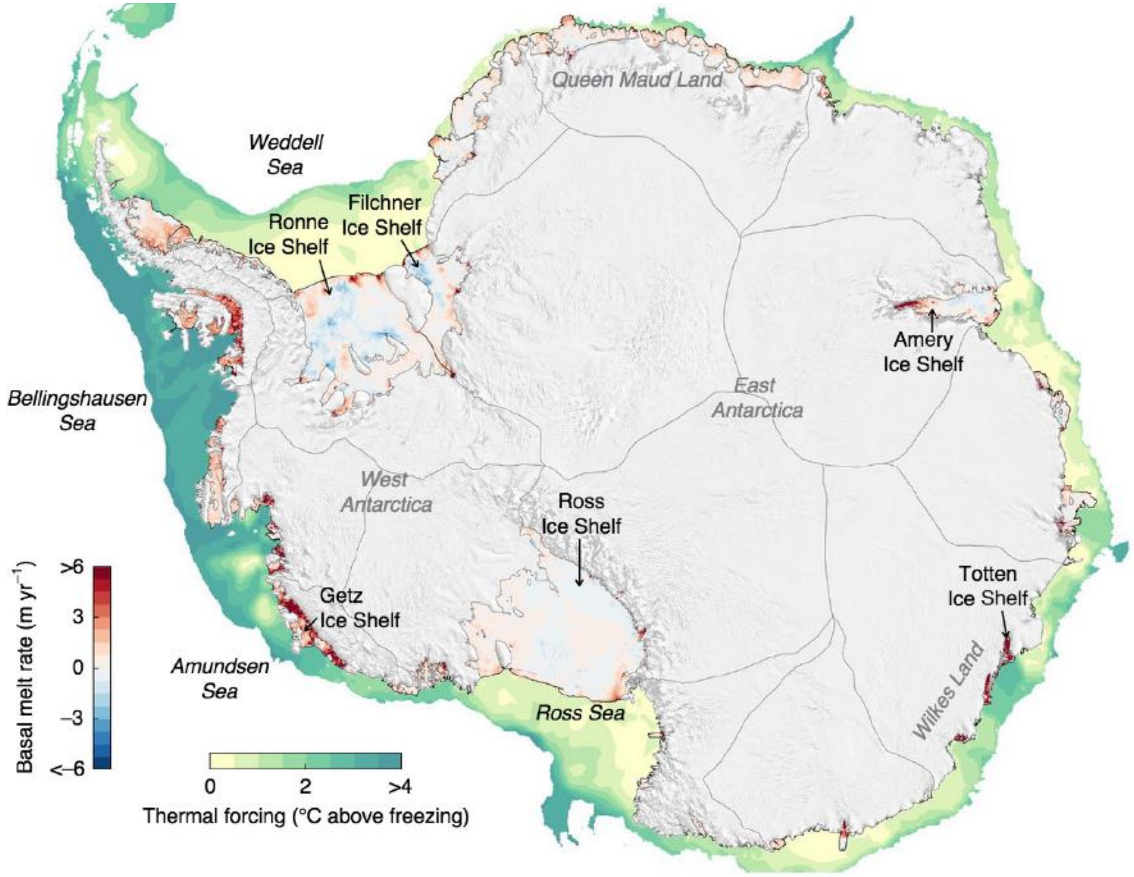
Video courtesy of Mathieu Morlighem



ARTICLES
https://doi.org/10.1038/s41561-020-0616-z
nature geoscience

Interannual variations in meltwater input to the Southern Ocean from Antarctic ice shelves

Susheel Adusumilli[1], Helen Amanda Fricker[1], Brooke Medley[2], Laurie Padman[3] and Matthew R. Siegfried[4]



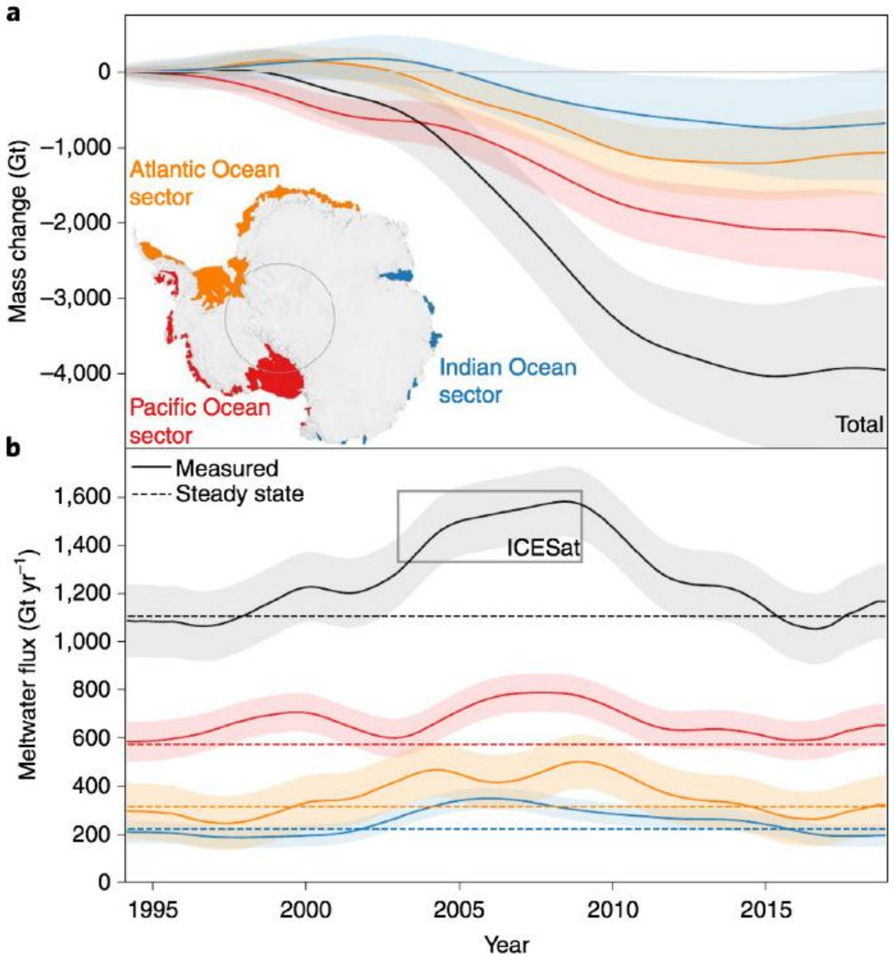


Fig. 3 | Variations in Antarctic ice-shelf mass between 1994 and 2018.

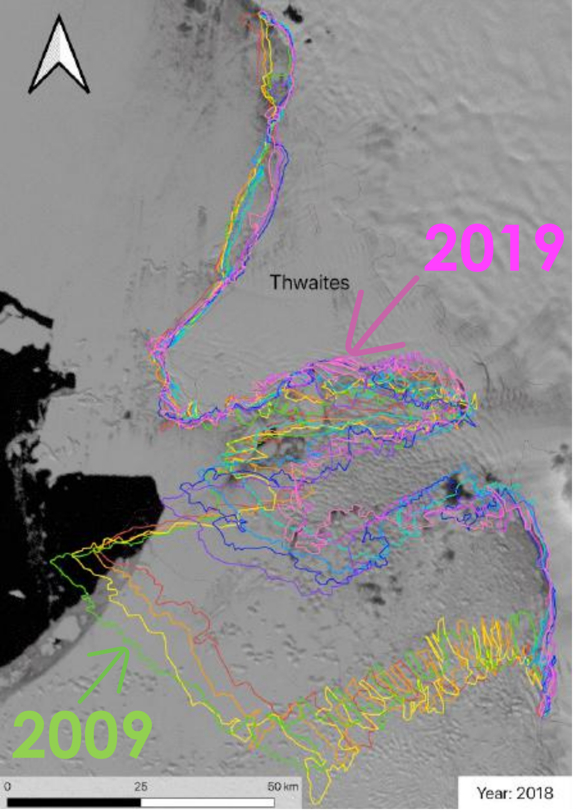
Sea ice and ice sheet dynamics important:WP42/43, IP95

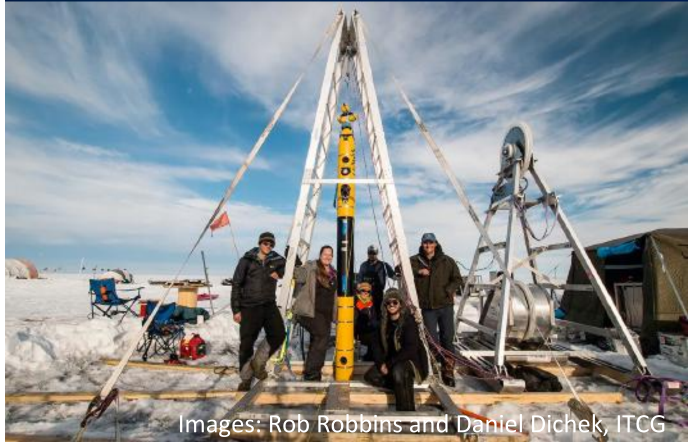
The Antarctic sea ice extent has reached a record low

Guardian graphic. Source: National Snow and Ice Data Center

On February 13, 2023,
Antarctic sea ice extent set a new record low.

Sea ice and ice sheet dynamics
important:WP42/43, IP95





Article | Open Access | Published: 15 February 2023

Suppressed basal melting in the eastern Thwaites Glacier grounding zone

Peter E. D. Davis, Keith W. Nicholls, David M. Holland, Britney E. Schmidt, Peter Washam, Kiya L. Riverman, Robert J. Arthern, Irena Vaňková, Clare Eayrs, James A. Smith, Paul G. D. Anker, Andrew D. Mullen, Daniel Dichek, Justin D. Lawrence, Matthew M. Meister, Elisabeth Clyne, Aurora Basinski-Ferris, Eric Rignot, Bastien Y. Queste, Lars Boehme, Karen J. Heywood, Sridhar Anandakrishnan & Keith Makinson

Nature **614**, 479–485 (2023) | Cite this article

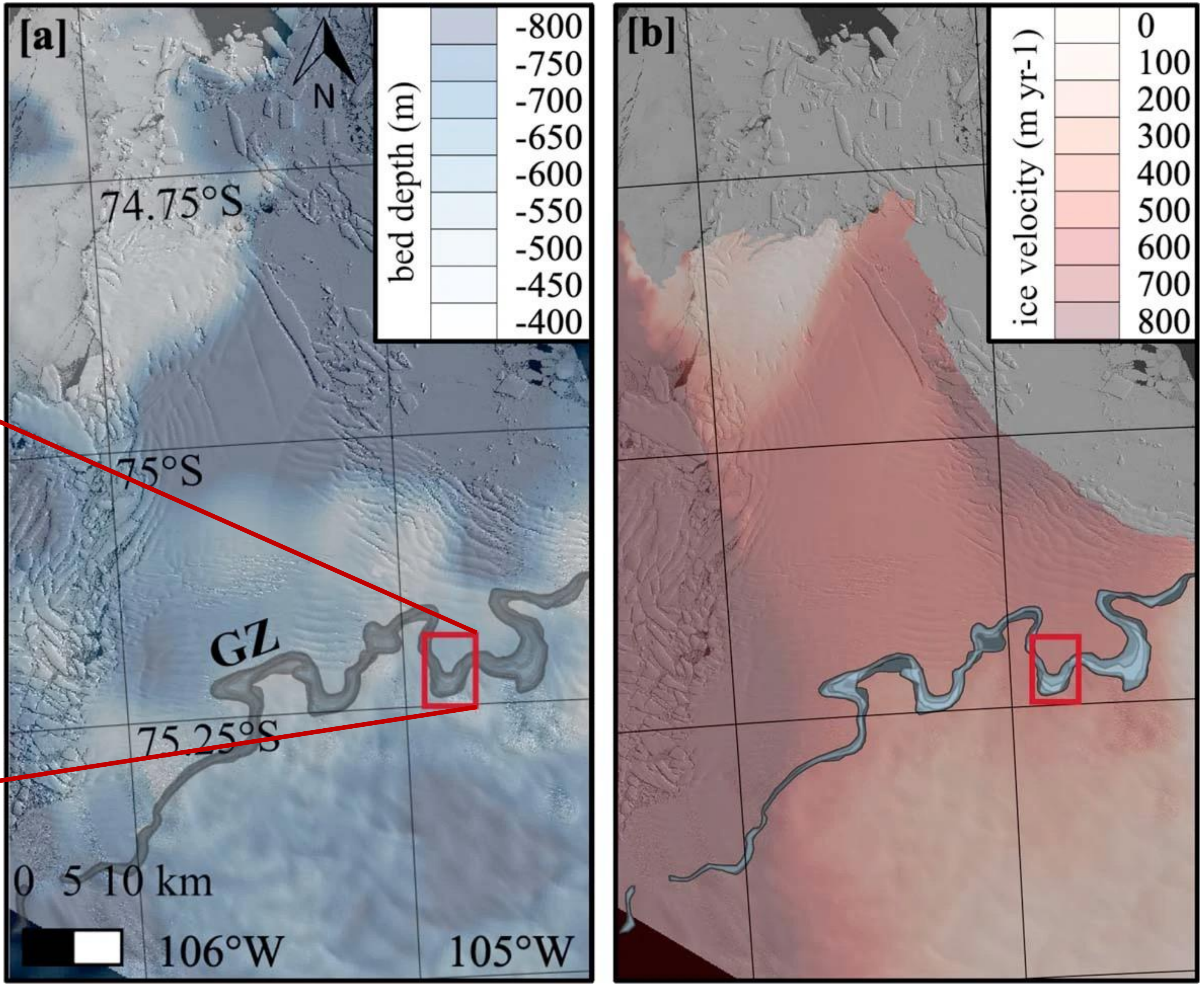
Article | Open Access | Published: 15 February 2023

Heterogeneous melting near the Thwaites Glacier grounding line

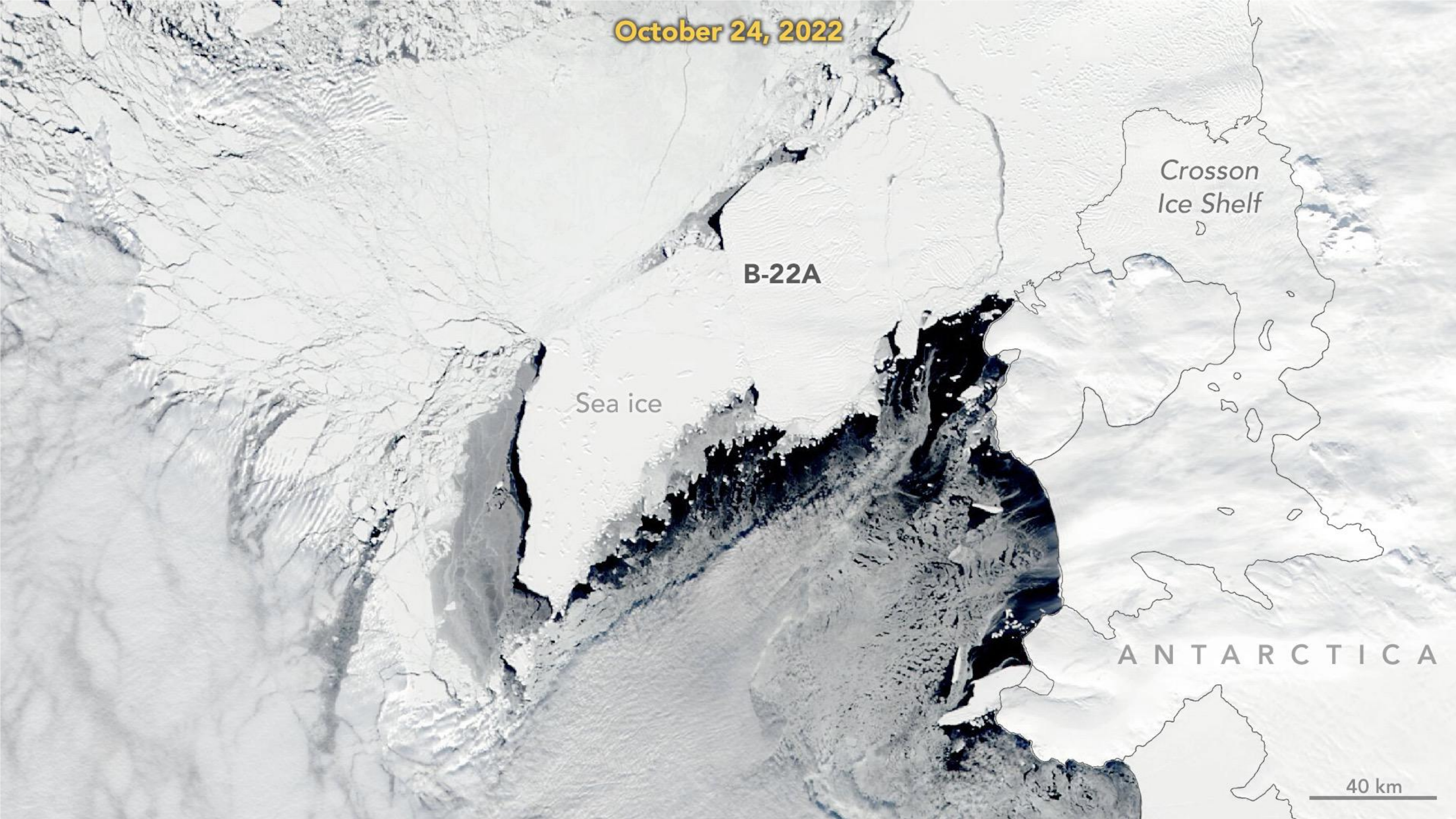
B. E. Schmidt, P. Washam, P. E. D. Davis, K. W. Nicholls, D. M. Holland, J. D. Lawrence, K. L. Riverman, J. A. Smith, A. Spears, D. J. G. Dichek, A. D. Mullen, E. Clyne, B. Yeager, P. Anker, M. R. Meister, B. C. Hurwitz, E. S. Quartini, F. E. Bryson, A. Basinski-Ferris, C. Thomas, J. Wake, D. G. Vaughan, S. Anandakrishnan, E. Rignot, ... K. Makinson + Show authors

Nature **614**, 471–478 (2023) | Cite this article

Colorized image from BedMachine overlaid on a Landsat 8 satellite image from Schmidt et al. (2023)



Bed topography is critical: IP73


October 24, 2022
Crosson
Ice Shelf
B-22A
Sea ice
ANTARCTICA
40 km

Article

https://doi.org/10.1038/s41561-023-01131-4

Widespread seasonal speed-up of west Antarctic Peninsula glaciers from 2014 to 2021

Received: 15 March 2022

Accepted: 24 January 2023

Benjamin J. Wallis [1], Anna E. Hogg [1], J. Melchior van Wessem [2], Benjamin J. Davison [1] & Michiel R. van den Broeke [2]

Melting glaciers have enormous ‘downstream’ impacts

Article

A large West Antarctic Ice Sheet explains early Neogene sea-level amplitude

https://doi.org/10.1038/s41586-021-04148-0
Received: 20 January 2021
Accepted: 14 October 2021
Published online: 15 December 2021
Check for updates

J. W. Marschalek[1✉], L. Zurli[2], F. Talarico[2,42], T. van de Flierdt[1], P. Vermeesch[3], A. Carter[4], F. Beny[5], V. Bout-Roumazeilles[5], F. Sangiorgi[6], S. R. Hemming[7], L. F. Pérez[8,9], F. Colleoni[10], J. G. Prebble[11], T. E. van Peer[3,12], M. Perotti[2], A. E. Shevenell[13], I. Browne[13], D. K. Kulhanek[14,15], R. Levy[11,16], D. Harwood[17], N. B. Sullivan[18], S. R. Meyers[18], E. M. Griffith[19], C.-D. Hillenbrand[8], E. Gasson[20], M. J. Siegert[1,21], B. Keisling[7], K. J. Licht[22], G. Kuhn[23], J. P. Dodd[24], C. Boshuis[6], L. De Santis[10], R. M. McKay[16] & IODP Expedition 374*

Article

Antarctic calving loss rivals ice-shelf thinning

https://doi.org/10.1038/s41586-022-05037-w
Chad A. Greene[1✉], Alex S. Gardner[1], Nicole-Jeanne Schlegel[1] & Alexander D. Fraser[2]
Received: 21 January 2022

Article

Antarctic ice dynamics amplified by Northern Hemisphere sea-level forcing

https://doi.org/10.1038/s41586-020-2916-2
Received: 20 September 2019
Accepted: 16 September 2020
Published online: 25 November 2020
Check for updates

Natalya Gomez[1✉], Michael E. Weber[2], Peter U. Clark[3,4], Jerry X. Mitrovica[5] & Holly K. Han[1]

Sea-level rise due to ice loss in the Northern Hemisphere in response to insolation and greenhouse gas forcing is thought to have caused grounding-line retreat of marine-based sectors of the Antarctic Ice Sheet (AIS)[1–3]. Such interhemispheric sea-level forcing may explain the synchronous evolution of global ice sheets over ice-age cycles. Recent studies that indicate that the AIS experienced substantial

Article

Ice front blocking of ocean heat transport to an Antarctic ice shelf

https://doi.org/10.1038/s41586-020-2014-5
Received: 11 March 2019
Accepted: 3 December 2019
Published online: 26 February 2020
Check for updates

A. K. Wåhlin[1✉], N. Steiger[2,3], E. Darelius[2,3], K. M. Assmann[1,12], M. S. Glessmer[4], H. K. Ha[5], L. Herraiz-Borreguero[6,7], C. Heuzé[8], A. Jenkins[9,13], T. W. Kim[10], A. K. Mazur[1], J. Sommeria[11] & S. Viboud[11]

Mass loss from the Antarctic Ice Sheet to the ocean has increased in rec… largely because the thinning of its floating ice shelves has allowed the o…

Article

Ice retreat in Wilkes Basin of East Antarctica during a warm interglacial

https://doi.org/10.1038/s41586-020-2484-5
Received: 19 November 2019
Accepted: 21 May 2020
Published online: 22 July 2020
Che…

T. Blackburn[1✉], G. H. Edwards[1], S. Tulaczyk[1], M. Scudder[1], G. Piccione[1], B. Hallet[2], N. McLean[3], J. C. Zachos[1], B. Cheney[1] & J. T. Babbe[1]

Efforts to improve sea level forecasting on a warming planet have focused on determining the temperature, sea level and ext… …olar ice sheets during Earth… About 4… …during the intergla…

ICE SHEETS

A dynamic saline groundwater system mapped beneath an Antarctic ice stream

Chloe D. Gustafson[1,2]*, Kerry Key[1], Matthew R. Siegfried[3], J. Paul Winberry[4], Helen A. Fricker[2], Ryan A. Venturelli[5], Alexander B. Michaud[6]

67%

Article

Vulnerability of Antarctica's ice shelves to meltwater-driven fracture

https://doi.org/10.1038/s41586-020-2627-8
Received: 28 August 2019
Accepted: 29 June 2020
Published online: 26 August 2020
Check for updates

Ching-Yao Lai[1✉], Jonathan Kingslake[1,2], Martin G. Wearing[3], Po-Hsuan Cameron Chen[4], Pierre Gentine[5], Harold Li[6], Julian J. Spergel[1,2] & J. Melchior van Wessem[7]

Atmospheric warming threatens to accelerate the retreat of the Antarctic Ice Sheet by increasing surface melting and facilitating 'hydrofracturing'[1–7], where meltwater flows into and enlarges fractures, potentially triggering ice-shelf collapse[3–5,8–10]. The collapse

Article

Mas… ce of th… Gree… Ice Sheet fro… 992 … 201…

https://doi.org/10.1038/s41586-019-1855-2
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Accepted: 25 November 2019
Published online: 10 December 2019
Check for updates

The IMBIE Team*

The Greenland Ice Sheet has been a major contributor to global sea-level rise in recent decades[1,2], and it is expected to continue to be so[3]. Although increases in glacier flow[4–6] and surface melting[7–9] have been driven by oceanic[10–12] and atmospheric[13,14] warming, the magnitude and trajectory of the ice sheet's mass imbalance remain uncertain. Here

Article

Accelerated global glacier mass loss in the early twenty-first century

https://doi.org/10.1038/s41586-021-03436-z
Received: 3 July 2020
Accepted: 9 March 2021

Romain Hugonnet[1,2,3✉], Robert McNabb[4,5], Etienne Berthier[1], Brian Menounos[6,7], Christopher Nuth[5,8], Luc Girod[5], Daniel Farinotti[2,3], Matthias Huss[2,3,9], Ines Dussaillant[1,10], Fanny Brun[11] & Andreas Kääb[5]

REVIEW

The Southern Ocean and its interaction with the Antarctic Ice Sheet

David M. Holland[1,2]*, Keith W. Nicholls[3], Aurora Basinski[1,2]

Article

Antarctica's wilderness fails to capture continent's biodiversity

https://doi.org/10.1038/s41586-020-2506-3
Received: 21 January 2019
Accepted: 3 May 2020
Published online: 15 July 2020
Check for updates

Rachel I. Leihy[1], Bernard W. T. Coetzee[2,3], Fraser Morgan[4,5], Ben Raymond[6,7], Justine D. Shaw[8], Aleks Terauds[6], Kees Bastmeijer[9] & Steven L. Chown[1✉]

Recent assessments of Earth's dwindling wilderness have emphasized that Antarctica is a crucial wilderness in need of protection[1,2]. Yet human impacts on the continent are widespread[3–5], the extent of its wilderness unquantified[2] and the importance thereof

Article

The hysteresis of the Antarctic Ice Sheet

https://doi.org/10.1038/s41586-020-2727-5
Received: 5 April 2019
Accepted: 11 August 2020
Published online: 23 September 2020
Check for updates

Julius Garbe[1,2], Torsten Albrecht[1], Anders Levermann[1,2,3], Jonathan F. Donges[1,4] & Ricarda Winkelmann[1,2✉]

More than half of Earth's freshwater resources are held by the Antarctic Ice Sheet, which thus represents by far the largest potential source for global sea-level rise under future warming conditions[1]. Its long-term stability determines the fate of our coastal

Key advantages to satellite-based research

- possible to collect data at the pan-Antarctic scale

IP37

- more accessible to smaller programs or to early-career researchers
- less prone to disruption of time series (e.g., Covid-19, lapses in funding)
- highly cost effective (conditional on having the satellites in orbit already)
- no disturbance to wildlife or the surrounding environment
- lower carbon footprint

... but field research remains not only the best, but often *the only* method of collecting data for certain research questions

Satellites can help us do field work more efficiently and more safely.

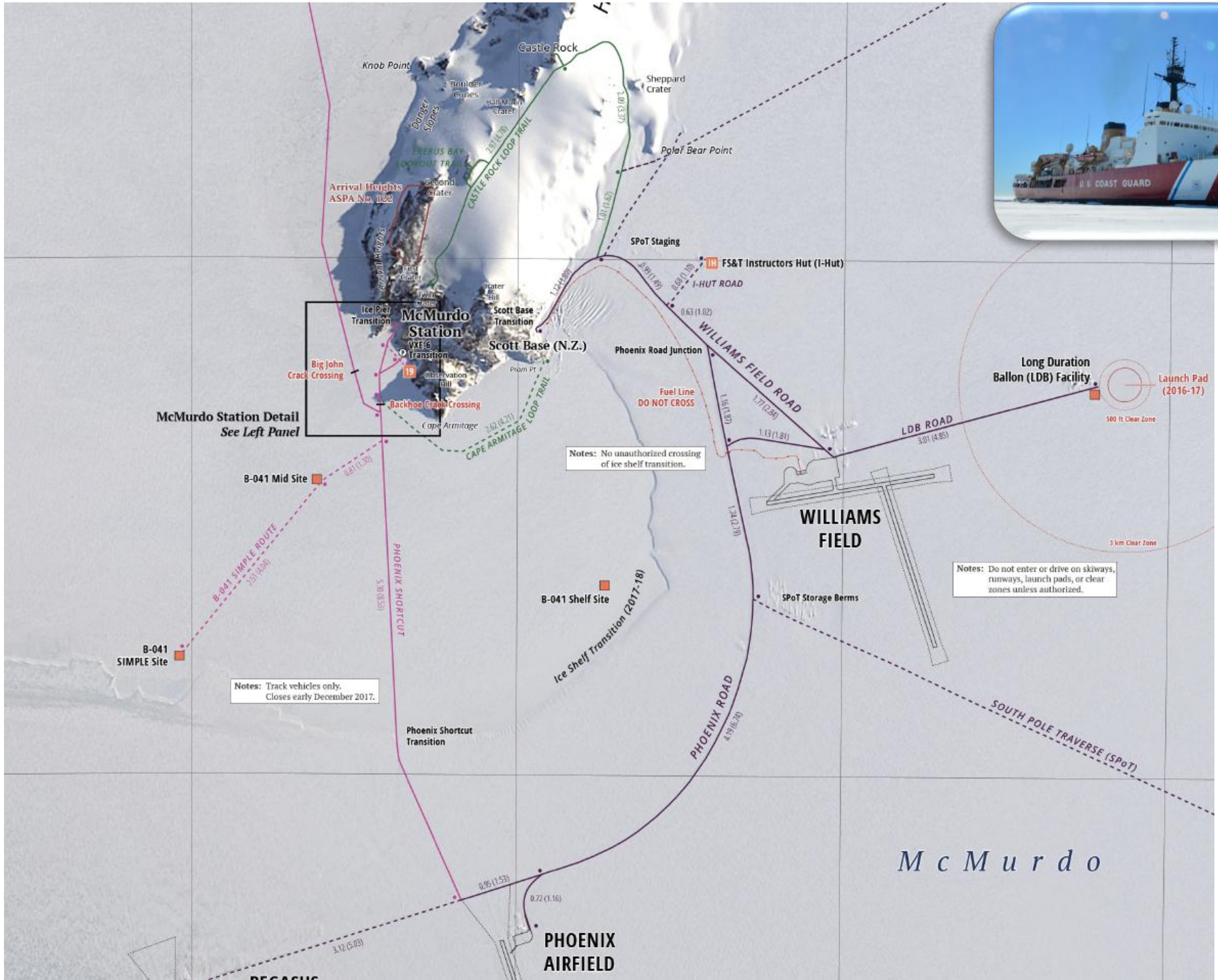
Photo credit: Tim Gee

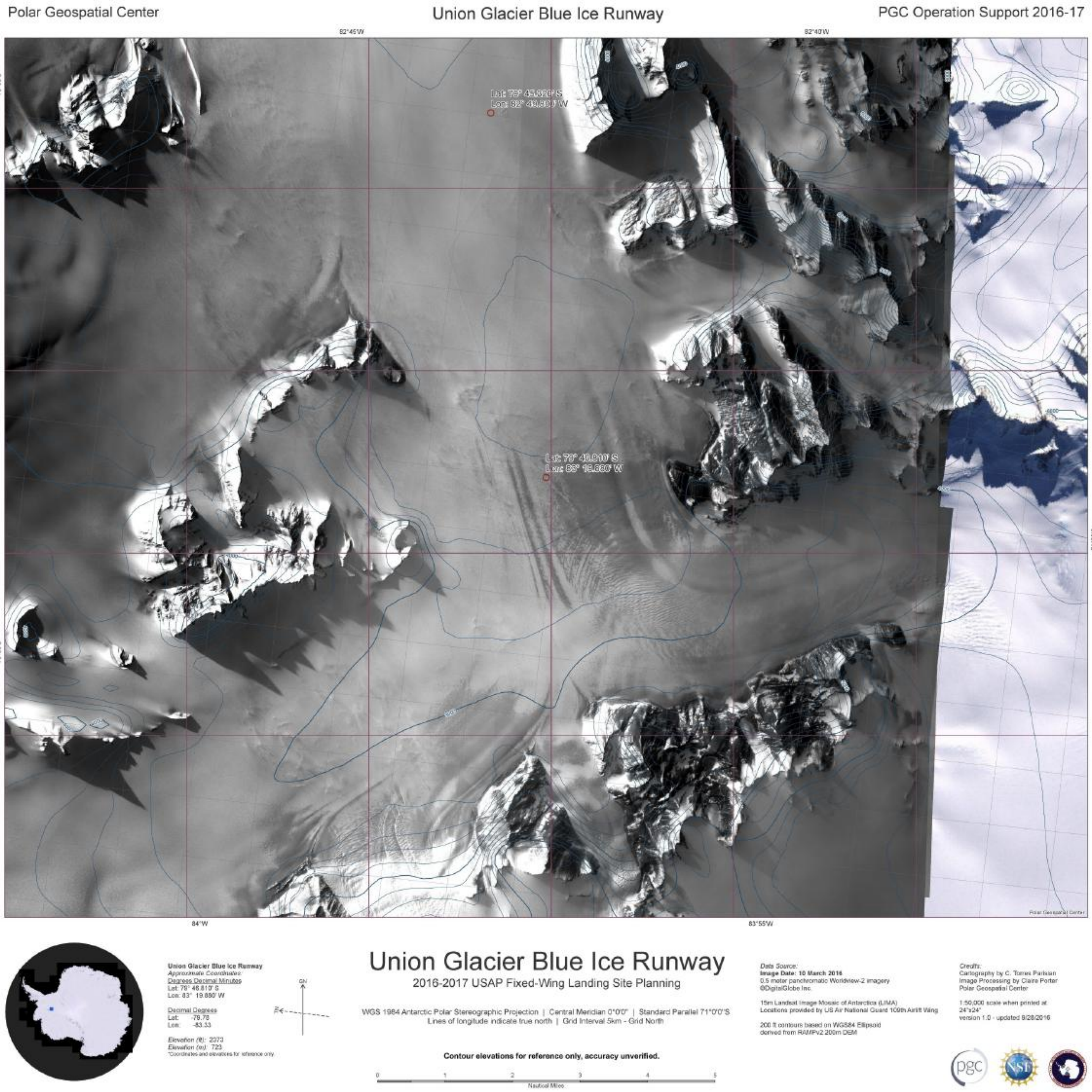
McMurdo Station Sea Ice Routes 2017-18

McMurdo Station to Cape Royds

Map Information:
Map by Brad Herried
Polar Geospatial Center (PGC)

PGC Reference ID: ANT NAV-OS2011-007
October 2017
version 1.0 - revised 10/18/2017





Satellite imagery facilitates the selection of safe landing sites in the deep field, without the expense and risk of additional reconnaissance flights...

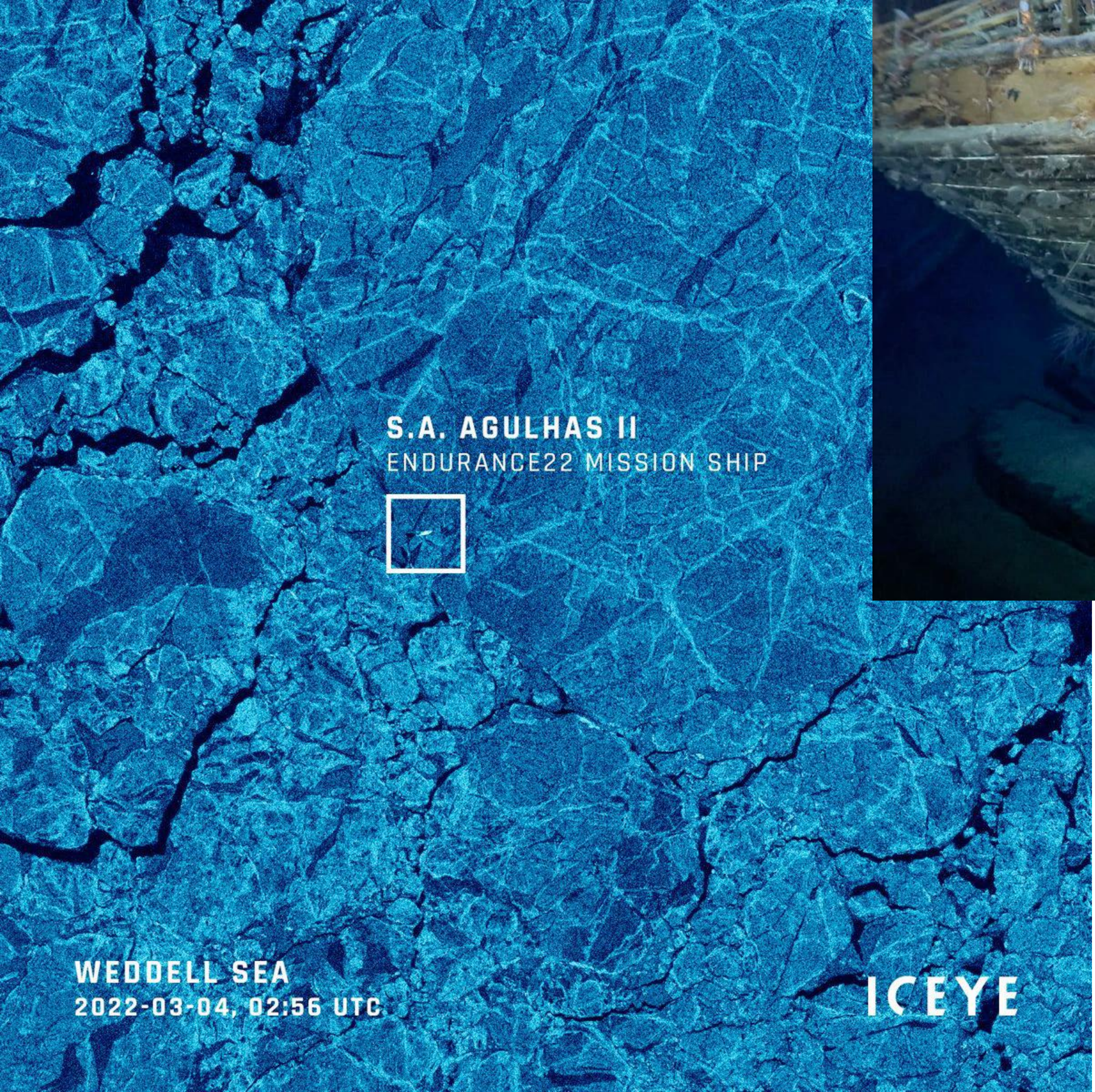


Image: National Geographic

planet.

Source: Tom Hart/PenguinWatch

CEP's Climate Change Response Work Programme

Satellite imagery will have a significant impact on our ability to address 26 (of 40) of gaps/needs identified in the CEP XXIV Report

Examples of gaps/needs or action/tasks supported by satellite-based imagery:

- Use remote sensing techniques to monitor changes in vegetation within ASPAs and more widely, to inform the further development of the Antarctic protected areas system
- Synthesize knowledge of Antarctic biodiversity, biogeography and bioregionalisation and undertake baseline studies to establish which native species are present
- Monitor emperor penguin colonies, including using remote sensing and complementary techniques, to identify trends in populations and potential climate change refugia
- Monitor bird populations to inform future management actions
- Collection and submission of spatially explicit biodiversity data
- Long-term monitoring and sustained observations of environmental change
- Long-term monitoring of biological values in ASPAs
- Long-term monitoring to verify or detect environmental impacts associated with human activities
- Monitoring to assess the status of values at ASPA 107 Emperor Island
- Regular population counts and research to understand the status and trends in the southern giant petrel population

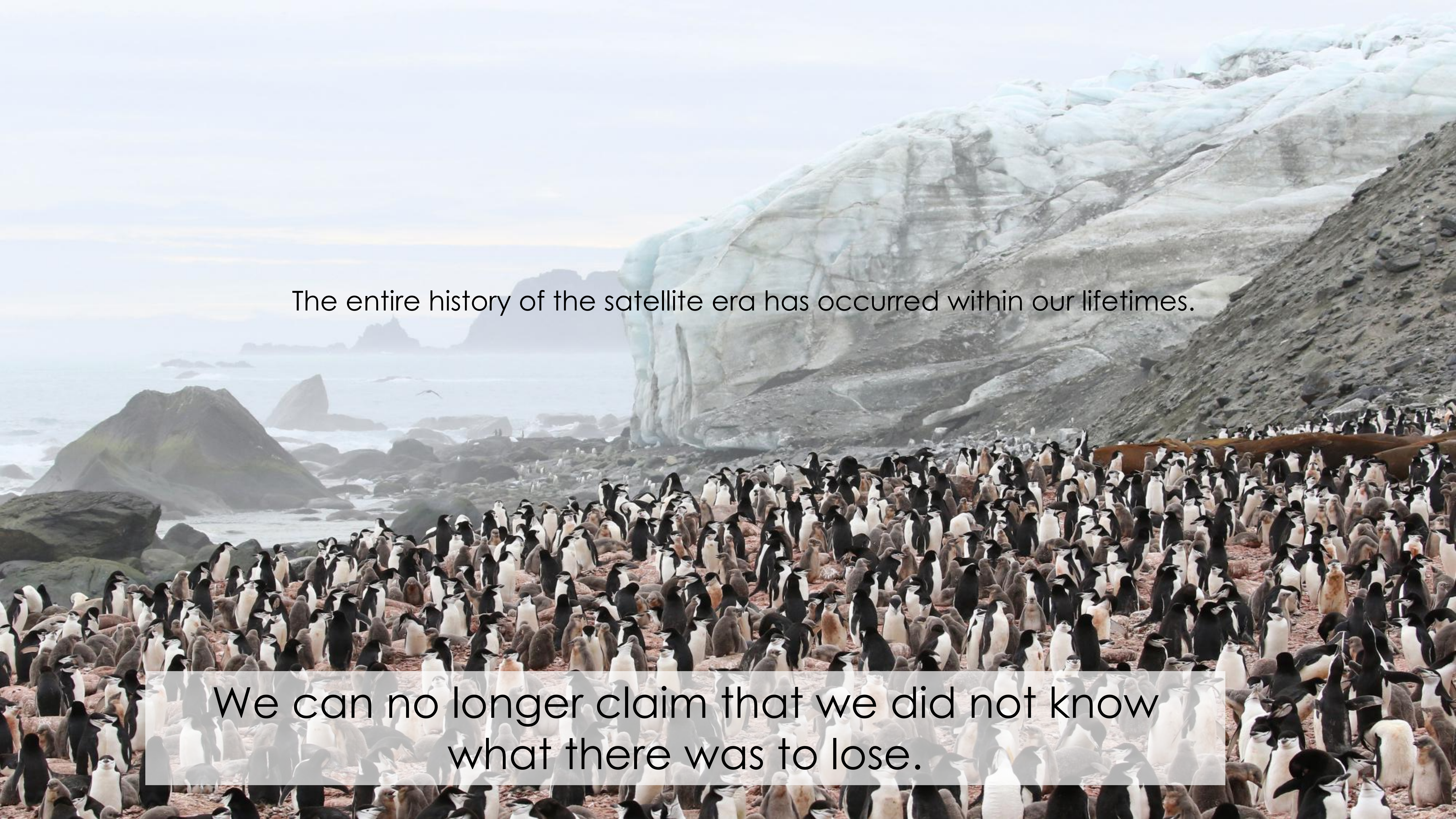
New SCAR Scientific Research Programs (SRPs)

AntClimNow – Near-term Variability and Prediction of the Antarctic Climate System

INSTANT – Instabilities & Thresholds in Antarctica

Ant-ICON – Integrated Science to Inform Antarctic and Southern Ocean Conservation

SCAR Earth Observation Action Group


The entire history of the satellite era has occurred within our lifetimes.
We can no longer claim that we did not know what there was to lose.