Ice - Climate - Solid Earth Interactions: Key Challenges & Future Priorities

Tim Naish – Antarctic Research Centre, Victoria University of Wellington

Co-chief Officer SCAR INSTANT; Joint Scientific Committee Member of the WCRP

World Climate Research Programme

Climate and Cryosphere

MUR CSNA

Consiglio Nazionale delle Ricerche

ENEA Agenzia nazionale per le nuove tecnologie,

OGS Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

VICTORIA UNIVERSITY OF WELLINGTON TE HERENGA WAKA

SCAR Scientific Committee on Antarctic Research – International Science Council

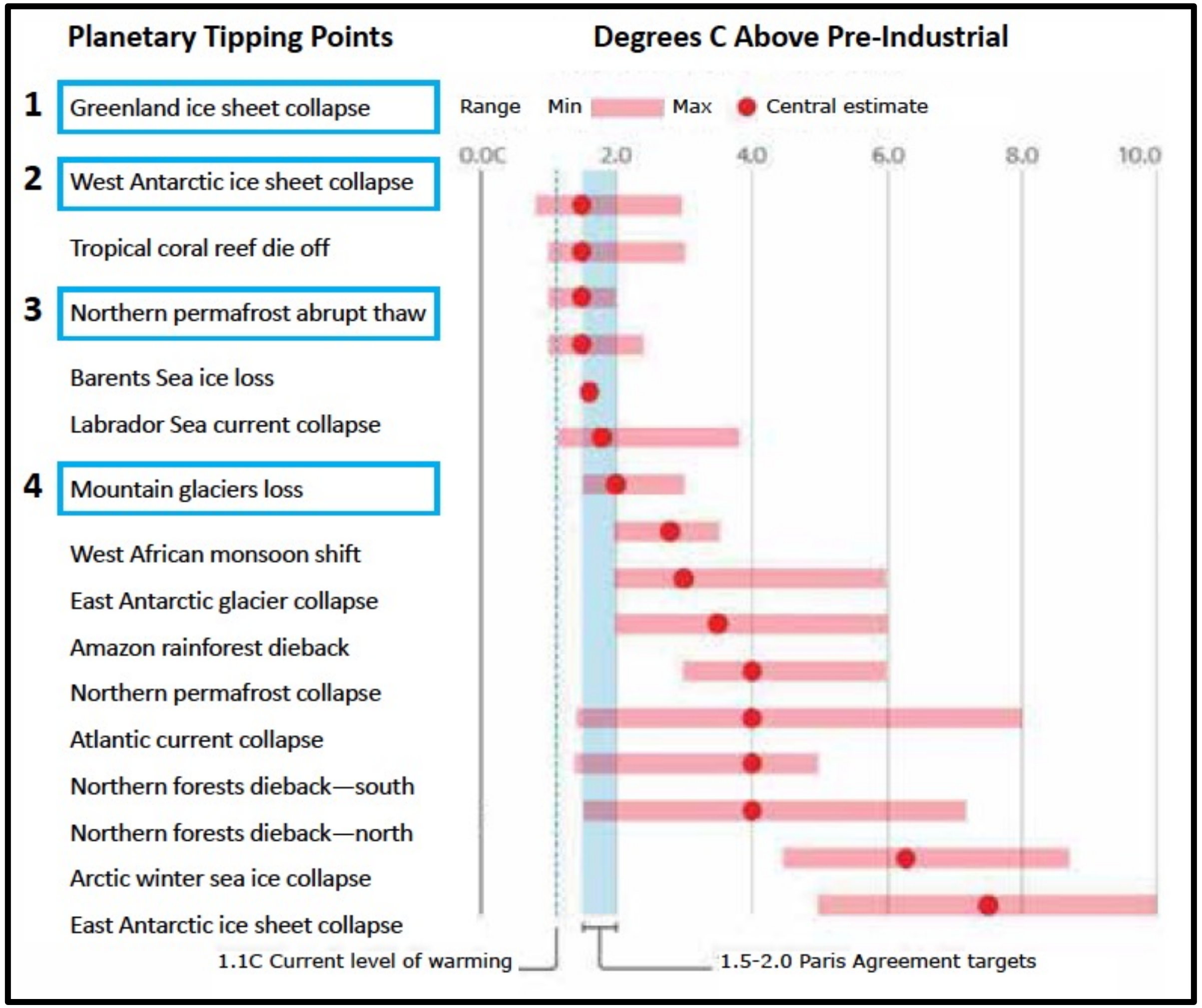
INSTANT Instabilities & Thresholds in Antarctica

AntClimNow

The international imperative

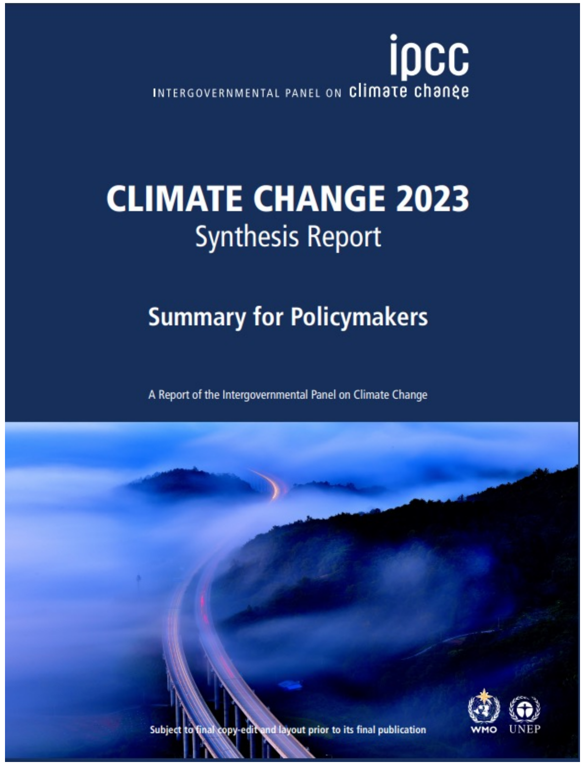
- UNFCCC – COP 28 – net carbon zero by 2050
- The ATCM Helsinki Declaration on Climate Change and Antarctica
- The WCRP-WMO Kigali Declaration on actionable science required for the Paris Target
- The **cryosphere is in crisis** and approaching multiple tipping points at 1.5-2°C of global warming:

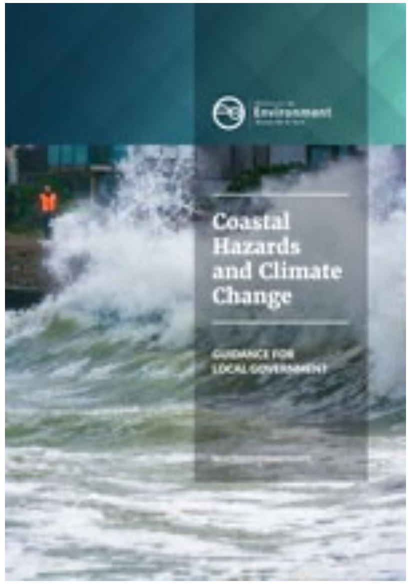
    - *Irreversible polar ice sheet meltdown and commitment to multi-metre sea-level rise impacting 2B people*
    - *Irreversible loss of glaciers in high mountain regions (Himalaya-Hindu Kush, Andes, Alps) impacting 2B people*
    - *Localised and widespread methane and CO_2 release from Artic permafrost enhancing global heating*
    - *Irreversible loss of sea-ice and AABW leading to slowdown or shutdown of meridional overturning circulation*

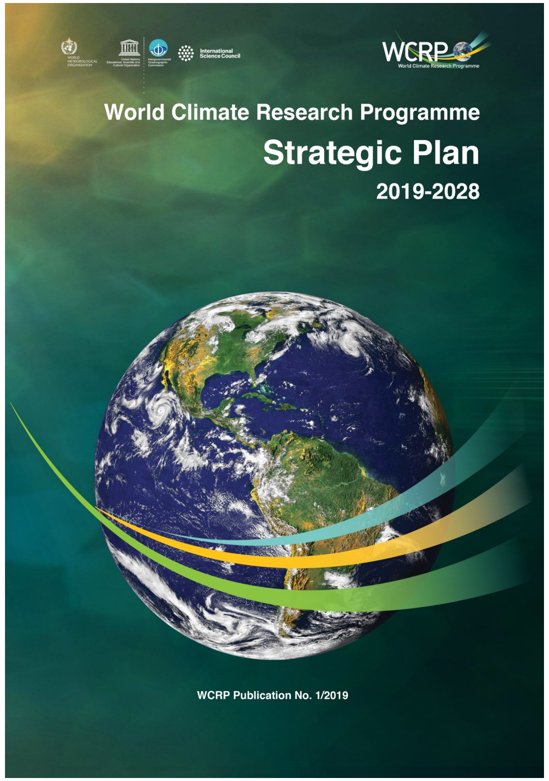


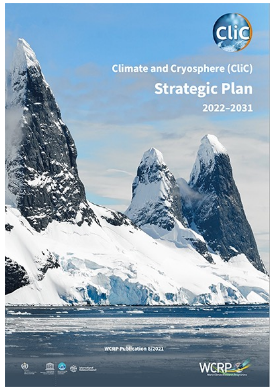
Strategic Research Priorities

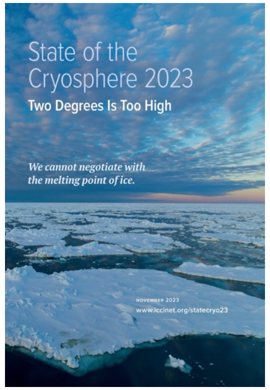
- IPCC AR6
- SCAR Strategic Plan
- SCAR ACCE Decadal Synopsis & Recommendations
- SCAR Horizon Scan
- WCRP Strategic Plan
- WCRP-CLiC Strategic Plan
- State of the Cryosphere 2023











The grand challenges in Antarctic science

1. Improve understanding of the rates of **ice mass loss** and quantify its **contribution to sea-level rise.**
   - Delivery of heat to the Antarctic margin via ocean and atmospheric processes, timing and process of ice shelf loss, role of instabilities in marine based ice sheet dynamics
   - Incorporate key processes and physics into ice-sheet models used for sea-level projections – reduce deep uncertainty.

2. Improve understanding of the controlling processes of **sea-ice variability and retreat** and improve predictability, including longer term changes in sea-ice state.
   - Better predictability of geochemical cycles, carbon and heat budgets, and their consequences for the Earth System, including impacts on ecosystems and climate.

3. Improve understanding of **oceanic and atmospheric teleconnections to low latitudes**
   - Better predictability of southern ocean circulation and influences on global THC
   - Improved predictability of climate extremes, heat waves, atmospheric rivers, floods, droughts and wildfires
   - Improved understanding and predictability of climate inter-decadal/decadal variability ENSO, SAM, PDO relationships

Deep uncertainty in future sea-level rise is an Antarctic problem

Eos

The Uncertain Future of Antarctica's Melting Ice

A new multidisciplinary, international research program aims to tackle one of the grand challenges in climate science: resolving the Antarctic Ice Sheet's contribution to future sea level rise.

By Florence Colleoni, Tim Naish, Robert DeConto, Laura De Santis, and Pippa L. Whitehouse
10 January 2022

ISMASS ICE SHEET MASS BALANCE AND SEA LEVEL

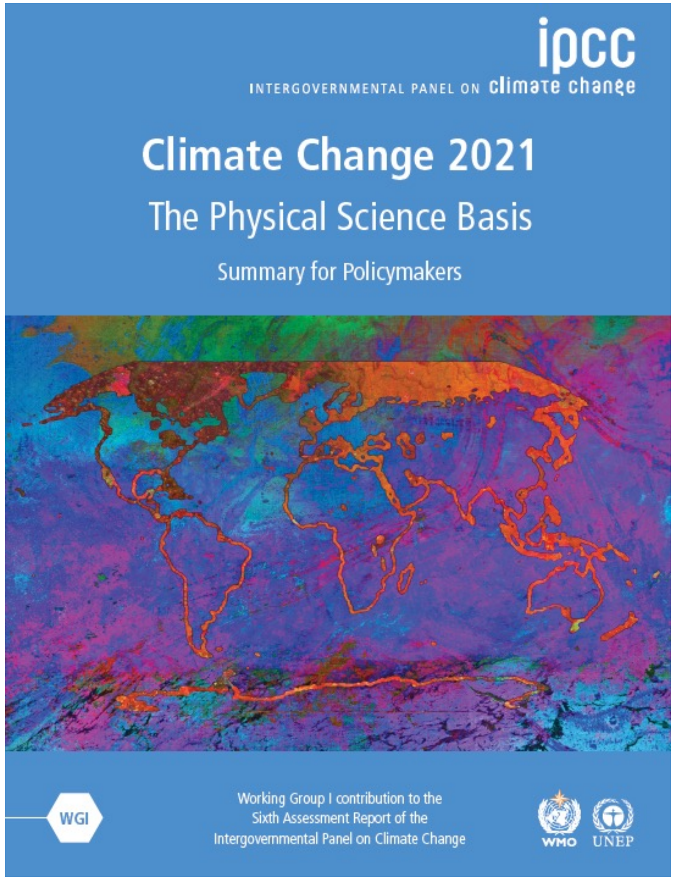
CliC Climate and Cryosphere

WCRP World Climate Research Programme

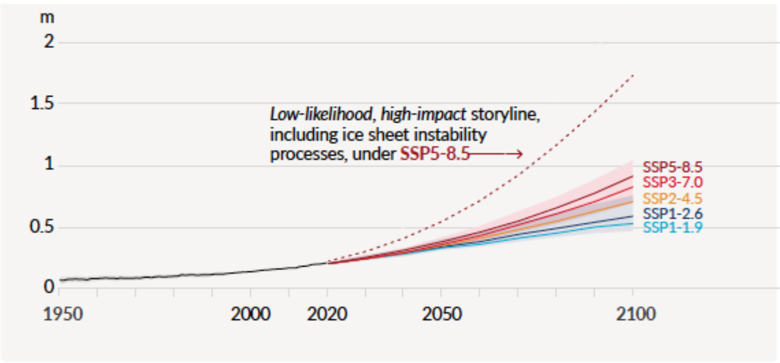
ISMIP6 Ice Sheet Model Intercomparison Project for CMIP6

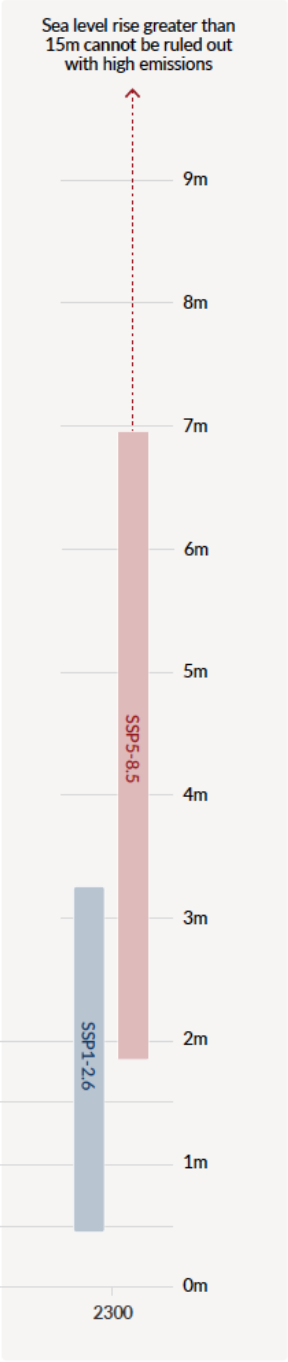
SCAR Scientific Committee on Antarctic Research

INSTANT INSTABILITIES & THRESHOLDS IN ANTARCTICA



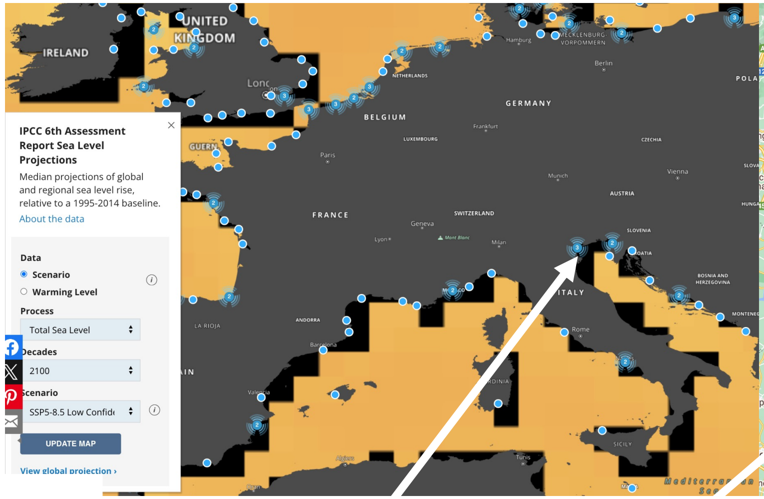
"Global mean sea level rise above the likely range – approaching ***2 m by 2100 & 5 m by 2150 and 15m by 2300*** *under a very high GHG emissions scenario (SSP5-8.5) (low confidence) – cannot be ruled out due to deep uncertainty in ice sheet processes"…IPCC AR5 WG1 SPM*

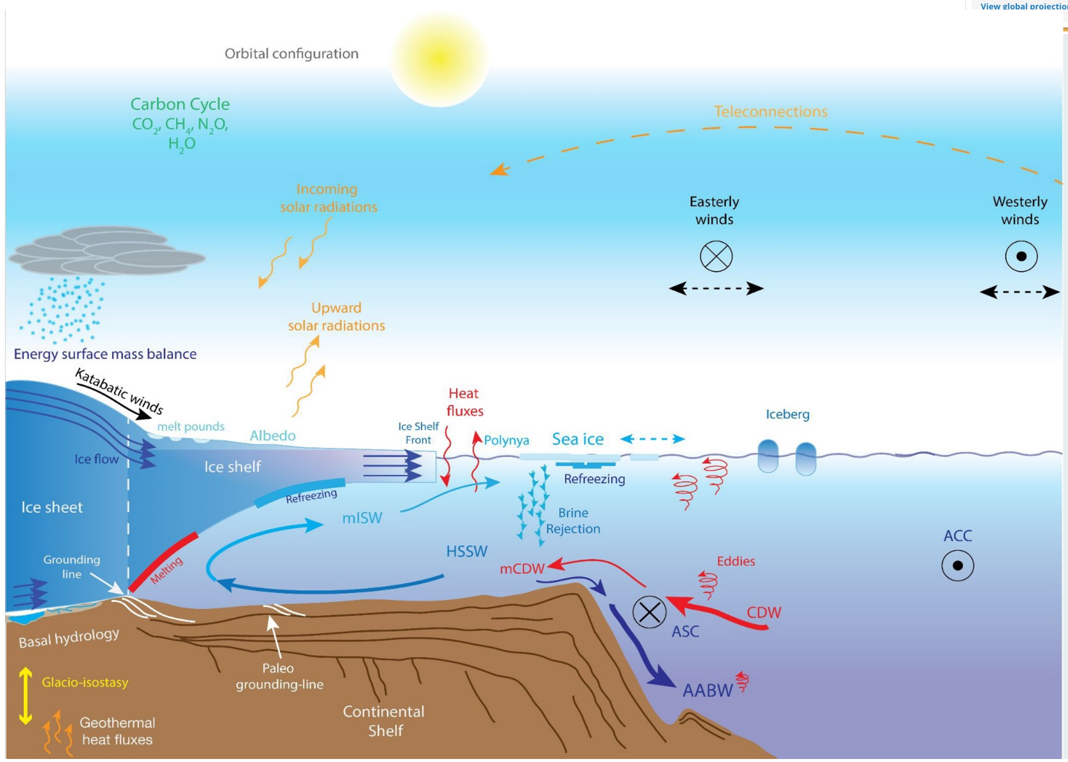




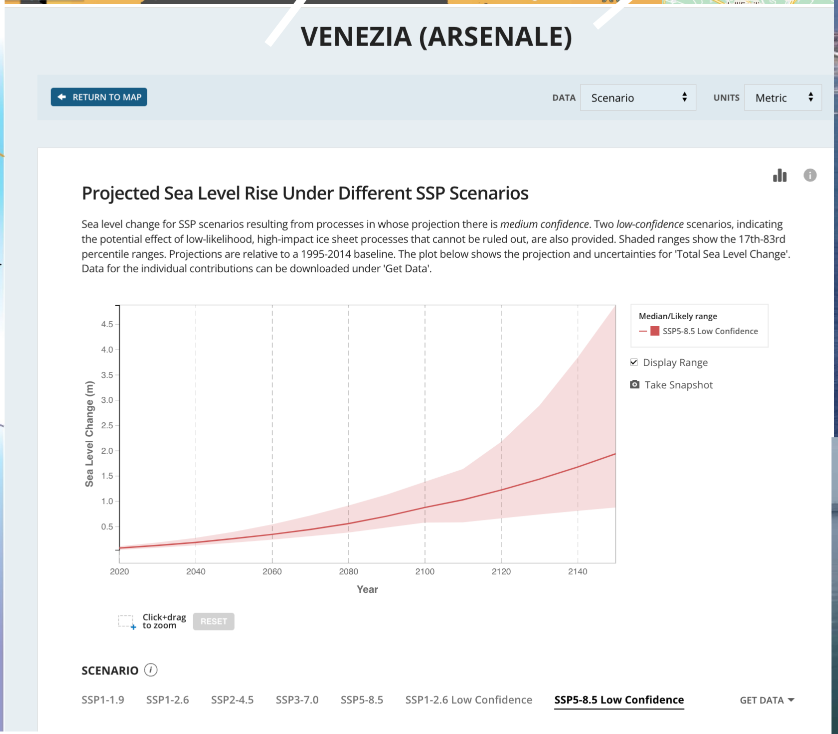
1. Understanding Antarctica's contribution to sea-level change

…is the challenge of SCAR'S INSTANT (Instabilities and Thresholds in Antarctica) Programme!

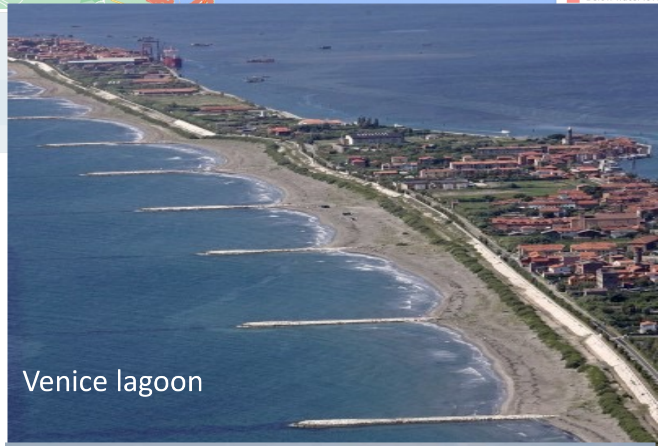




Colleoni et al., 2019, 2022



NASA sea-level tool



INSTANT: Aims & approach

- Quantify the Antarctic ice sheet contribution to **past and future sea-level change**,

- Improve understanding of **atmosphere, ocean and solid Earth interactions, feedbacks**, and **rate-determing processes (e.g. instabilities & thresholds)**

- Improve **skill and performance of Antarctic ice sheet models** and **reduce uncertianty in the Antarctic ice mass** contribution to **future sea-level rise**

- To better **anticipate** and assess **the risk** in order to **manage and adapt** to sea-level rise and evaluate mitigation pathways – what are the **safe landing climates for the Antarctic Ice Sheet?**

- **Integrated Earth Systems approach involving biology, geology, glaciology, oceanography, climatology, numerical modelling, social science, end users, and partners**

Research priorities from the Trieste SCAR INSTANT Conference, 2023

Climate & ice sheet interactions

1. Focus on processes, feedbacks and physics to reduce ”deep uncertainty” in ice sheet mass and sea-level projections.
2. What are the key rate-determining processes. Understand the processes and timing of ice shelf collapse
3. Identify sign-posts such as state change in sea-ice retreat, amplified surface warming, CDW intrusions
4. Understand ice shelf cavity circulation and processes at the grounding zone of marine-based ice sheets.
5. Does MICI matter?
6. Improve coupling of dynamic ice sheet and ocean circulation models
7. Improved understanding of Antarctic surface mass balance

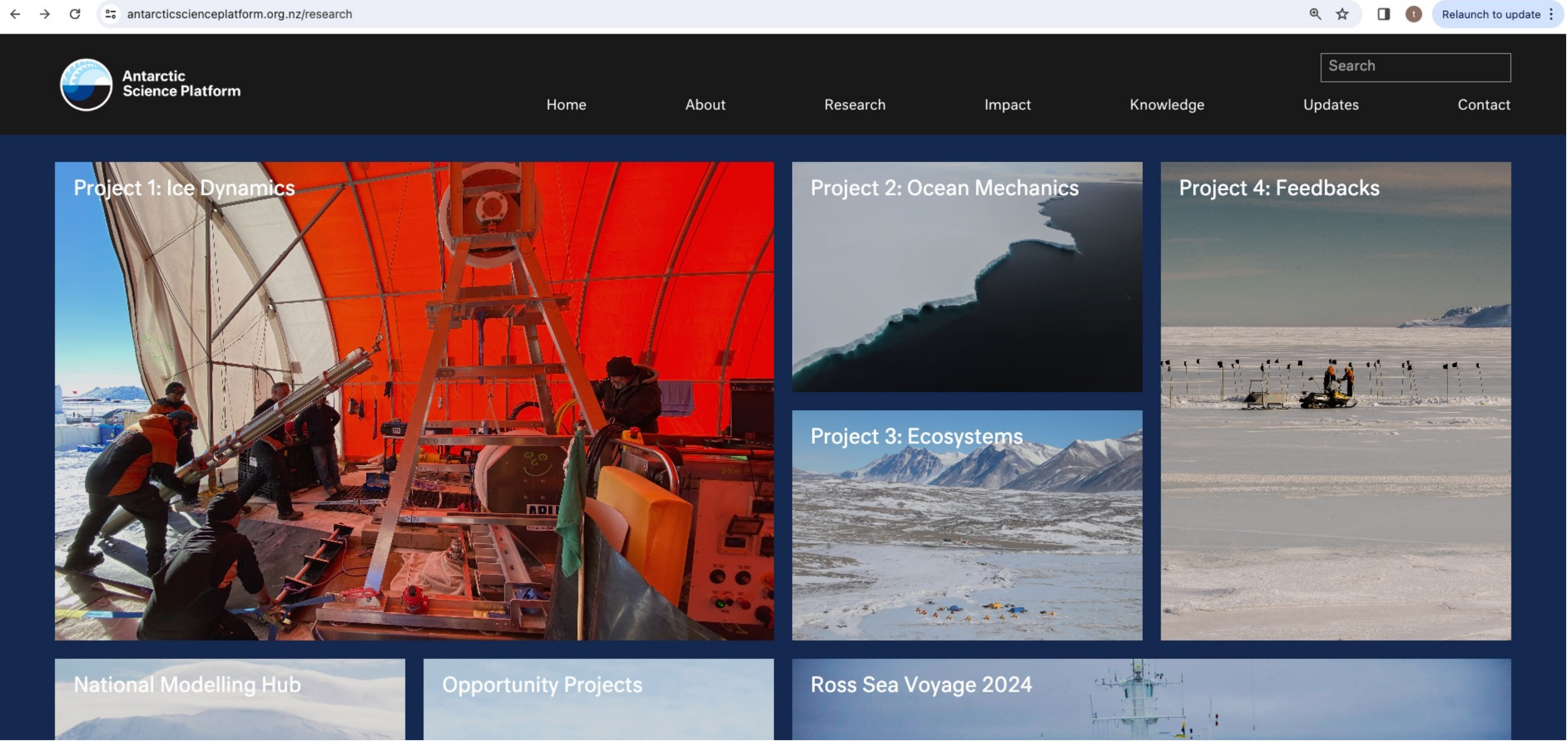
Solid Earth & ice sheet interactions

1. Improve coupling between solid Earth (GIA) and dynamic ice sheet models to understand feedbacks on mass loss rates
2. Improved understanding of geothermal heat flux. Heat flow and glaciology communities need to work together
3. Improved understanding of subglacial hydrology and sediments on basal flow and dynamics
4. Improve subglacial topography and continental shelf bathymetry (boundary conditions)

Improved sea-level projections

1. Engage with needs of user communities and groups. ISMIP, IPCC, SL Projections, Practitioners, Planners, Decision Makers, NAPs, COMNAP, CEP.
2. ISMIP/IPCC and other modelling communities need to work together on how to reduce deep uncertainty in low confidence processes e.g ice shelf hydrofracture/collapse/MICI/MISI
3. Provide actionable science information for decision-making

NZ has designed $10M project to align with the SCAR INSTANT



2. Improved understanding of sea-ice variability, retreat & implications

1. When will we see a state change in Antarctic sea-ice?
2. When will we see amplified surface warming?
3. What are the freshwater feedbacks and their implications?

Freshening by glacial meltwater enhances melting of ice shelves and reduces formation of Antarctic Bottom Water

Alessandro Silvano,[1,2,3]* Stephen Rich Rintoul,[2,3,4] Beatriz Peña-Molino,[2,3,4] William Richard Hobbs,[3,5] Esmee van Wijk,[2,3] Shigeru Aoki,[6] Takeshi Tamura,[3,7,8] Guy Darvall Williams[1,3,5]

communications earth & environment

ARTICLE

https://doi.org/10.1038/s43247-023-00961-9 OPEN

Check for updates

Record low Antarctic sea ice coverage indicates a new sea ice state

Ariaan Purich[1✉] & Edward W. Doddridge[2]

nature climate change

Article https://doi.org/10.1038/s41558-023-01791-5

The quandary of detecting the signature of climate change in Antarctica

Received: 24 October 2022

Accepted: 2 August 2023

Mathieu Casado[1✉], Raphaël Hébert[2], Davide Faranda[1,3,4] & Amaelle Landais[1]

Article

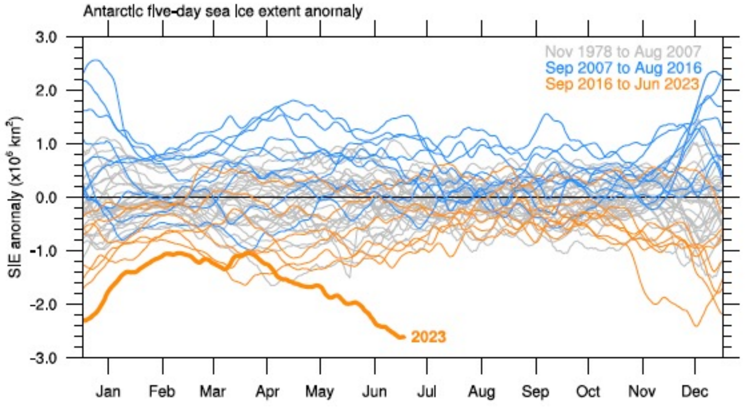
Abyssal ocean overturning slowdown and warming driven by Antarctic meltwater

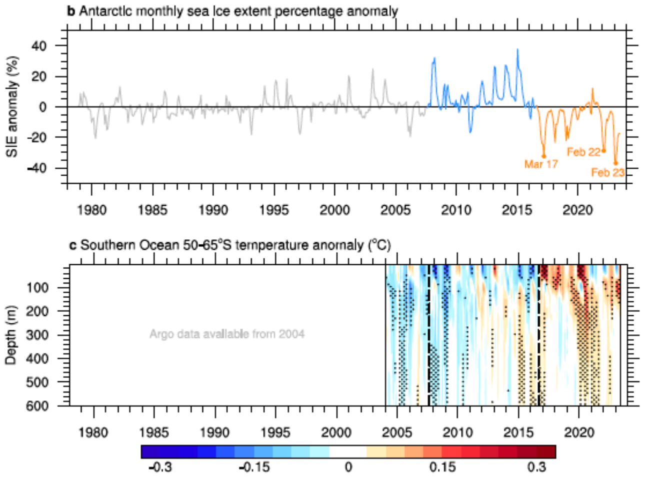
https://doi.org/10.1038/s41586-023-05762-w

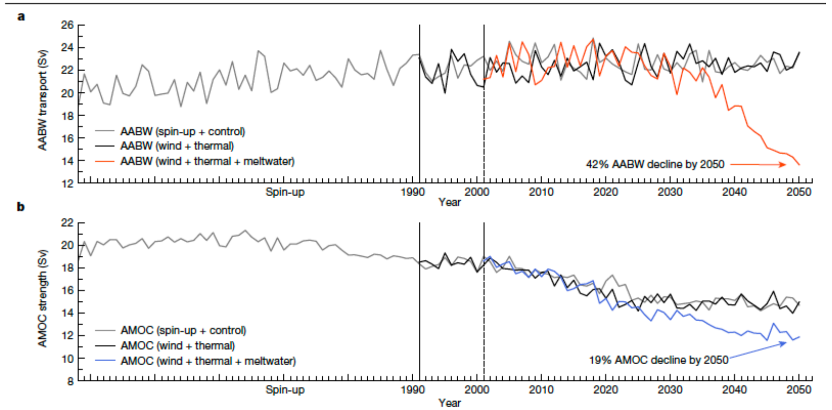
Received: 20 March 2022

Accepted: 25 January 2023

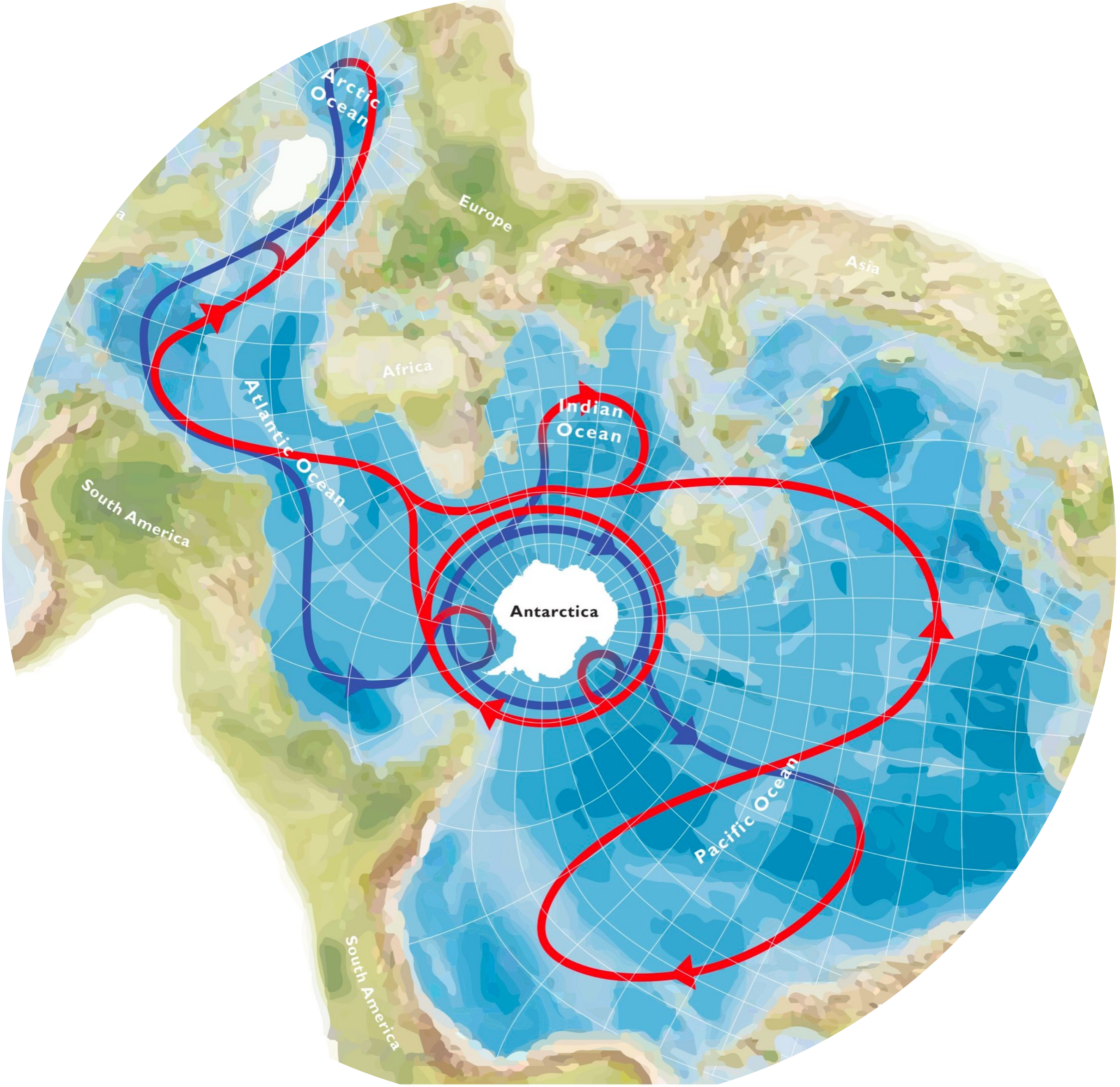
Qian Li[1], Matthew H. England[2✉], Andrew McC. Hogg[3], Stephen R. Rintoul[4,5] & Adele K. Morrison[6]







The Antarctic sea ice trigger



Is the recent sharp decline in Antarctic sea ice extent still within natural variability of the climate system?

Will it return?

This is a critical question facing the climate science community?

The permanent reduction of summer sea-ice will be an important "sign-post" indicating rapid change is now imminent. As the white, frozen ocean around Antarctica recedes:

- heat absorption accelerates surface warming,
- ice shelves collapse,
- leading to rapid and potentially unstoppable loss of up to one third of Antarctica's ice sheets - equivalent to19m of global sea-level rise
- the vigor of Antarctic bottom water production and global ocean circulation decreases impacting global heat distribution,
- Southern ocean carbon storage reduces,
- Southern ocean nutrient supplies that currently support 75% of global ocean production are reduced

3. Improve understanding of oceanic and atmospheric teleconnections

1. Atmospheric rivers transport large amounts of moisture from mid- to high-latitudes, and are a primary driver of extreme snowfall events and surface melting in Antarctica (Maclennan et al., 2023, Laing 2023, Wille et al., 2022).

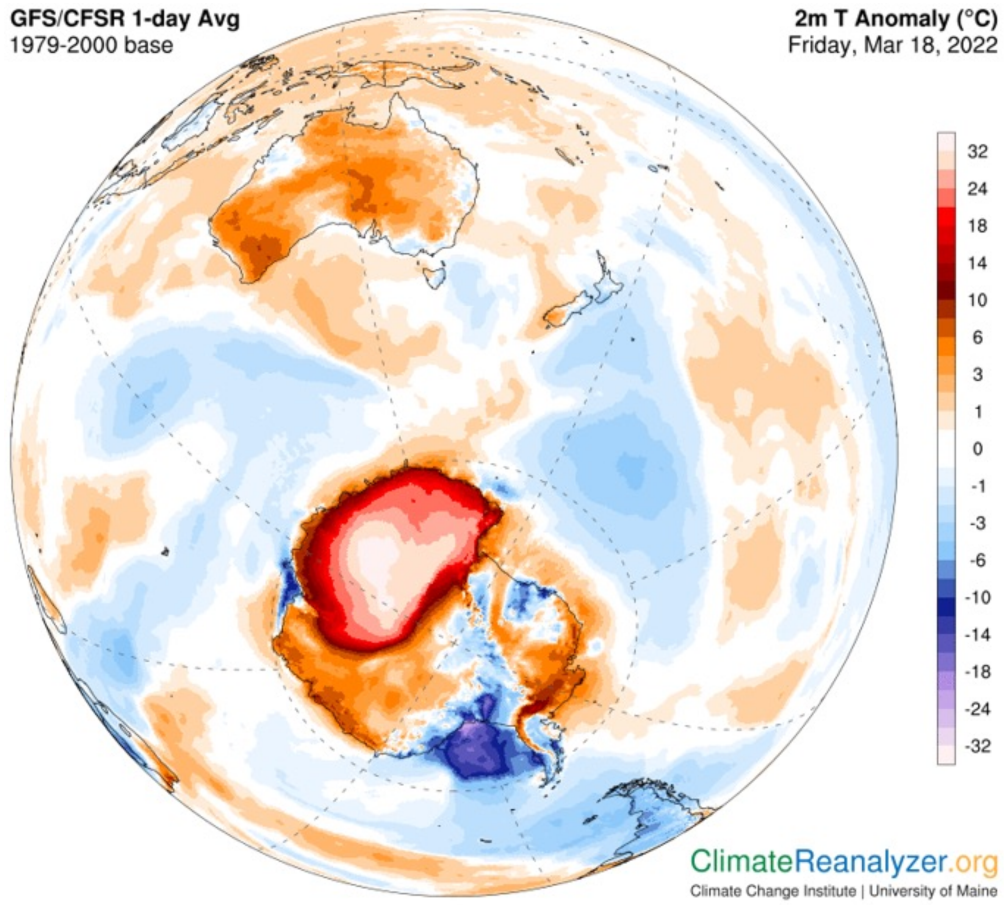
2. An unprecedented heat wave occurred over East Antarctica in March 2022, peaking at 39°C above climatological average - the largest temperature anomaly ever recorded globally. (Blanchard-Wrigglesworth et al., 2023).

3. Future heatwaves over the warmer, lower elevation West Antarctic Ice Sheet to trigger widespread surface melting and collapse of ice shelves (Maclennan et al., 2023)

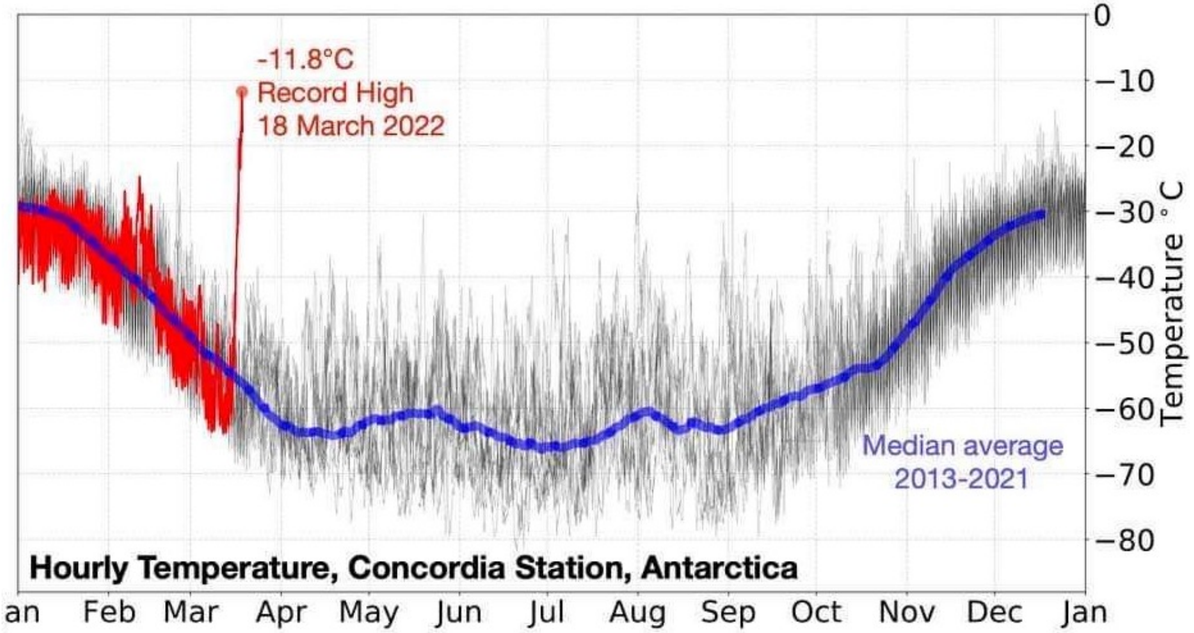
4. High latitude low pressure systems cause “bomb” cyclones and extreme weather at lower latitudes (floods) (Linn et al., 2022).

5. Changing atmospheric and ocean circulation patterns on Antarctic sea ice and westerly winds, shows a strong connection with atmospheric dynamics at lower latitudes involving climate modes such as ENSO, PDO and SAM (Hartmann, 2022). Ozone hole - SAM – ENSO teleconnection

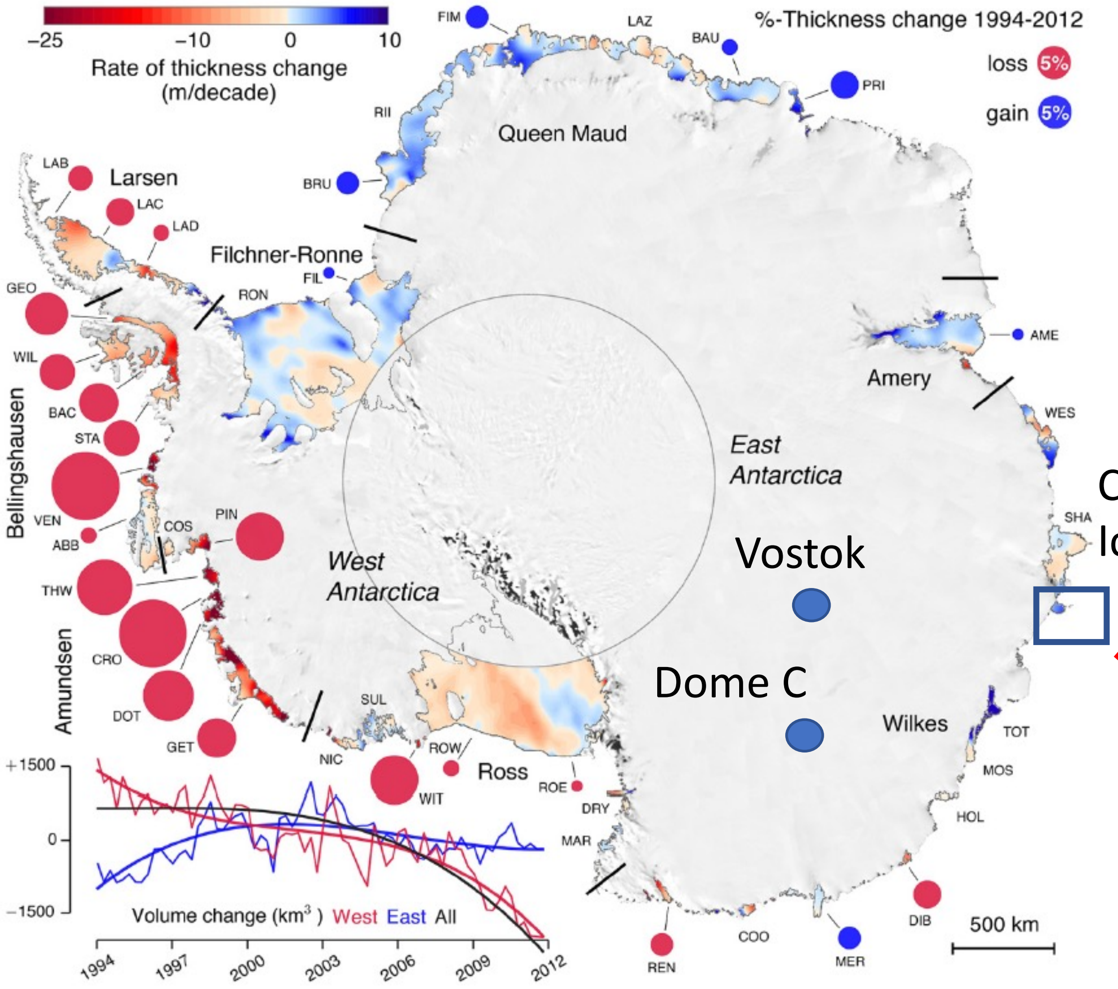
Antarctica is experiencing extreme weather – heat waves and atmospheric rivers



- *March 18, 2022 heatwave over east Antarctica*
- *Record temperatures recorded at Vostok and Dome C, 38℃ above usual but still -11.8C.*

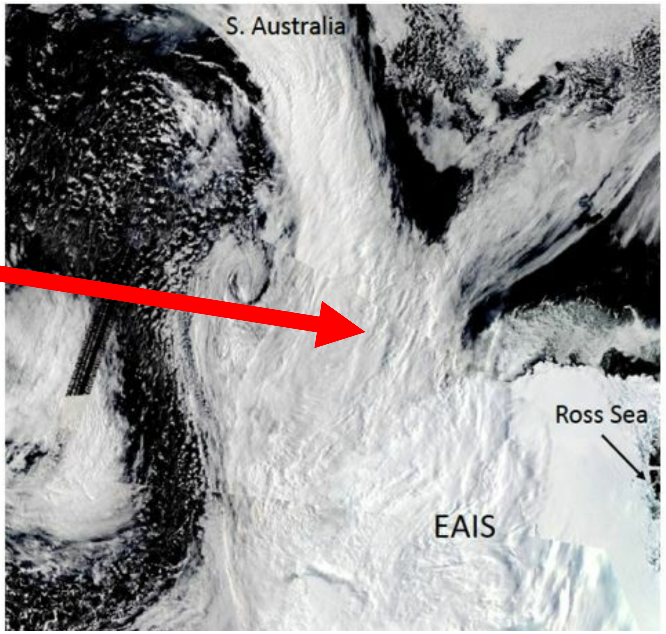


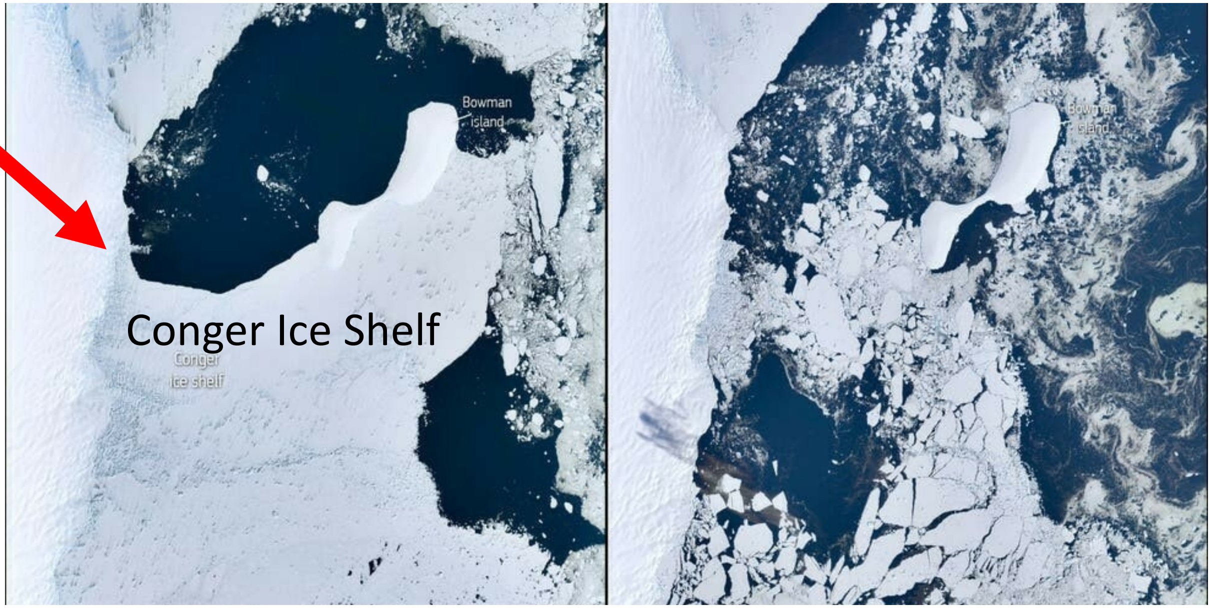
Ice shelf collapses in response



Conger Ice Shelf

The “atmospheric river”

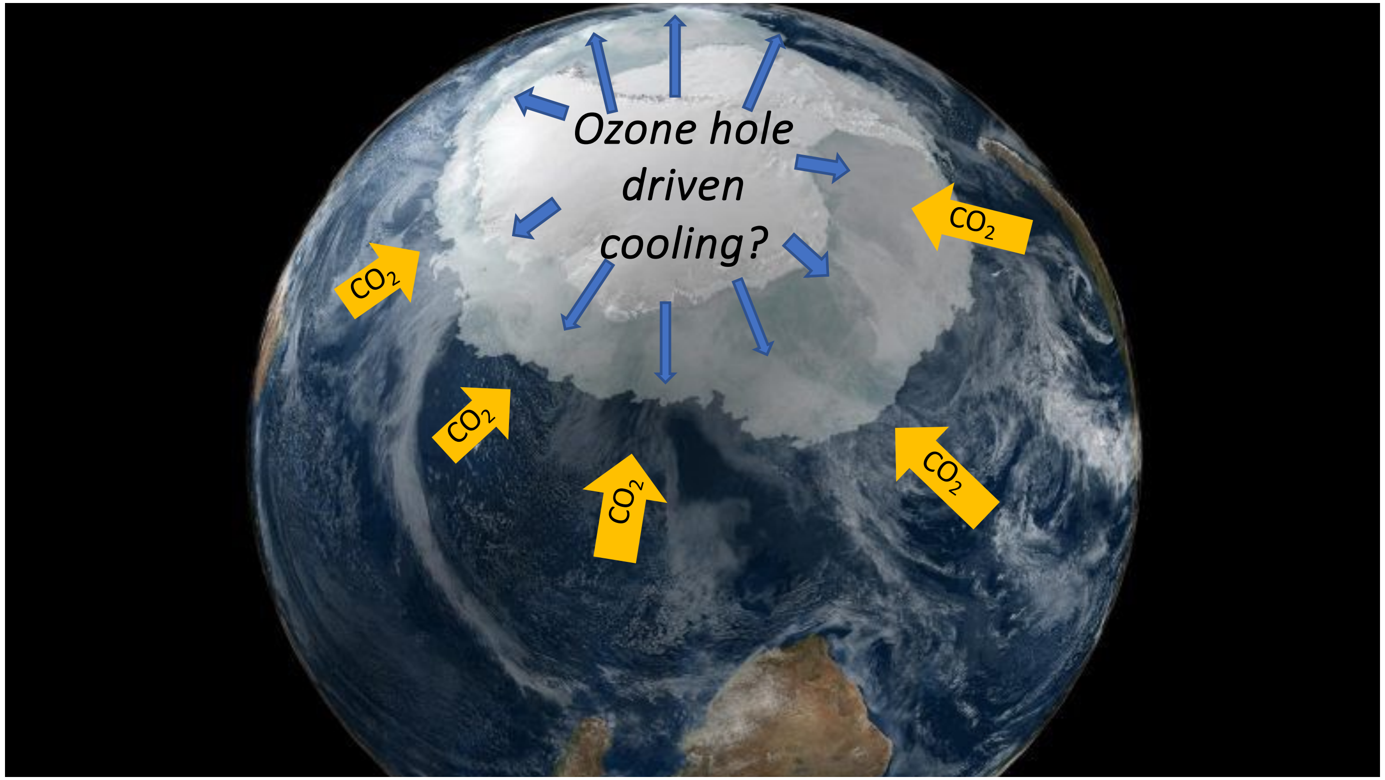




18th March 2022. 21st March 2022

- *March 18, 2022 heatwave over east Antarctica*
- *Record temperatures recorded at Vostok and Dome C, 38℃ above usual but still -11.8C.*

The "tug of war" in the atmosphere between the equator and the pole. The tropics are expanding, the Antarctic influence will contract



PNAS RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES

The Antarctic ozone hole and the pattern effect on climate sensitivity

Dennis L. Hartmann[a,1]

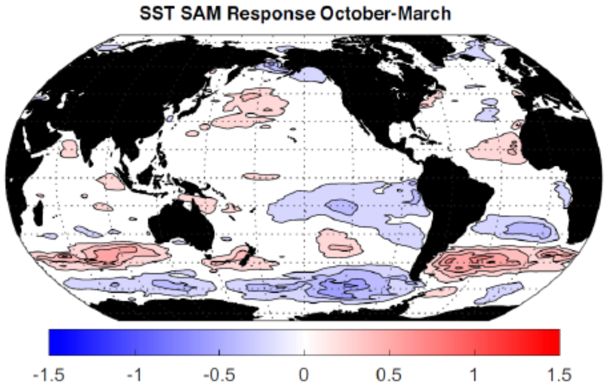


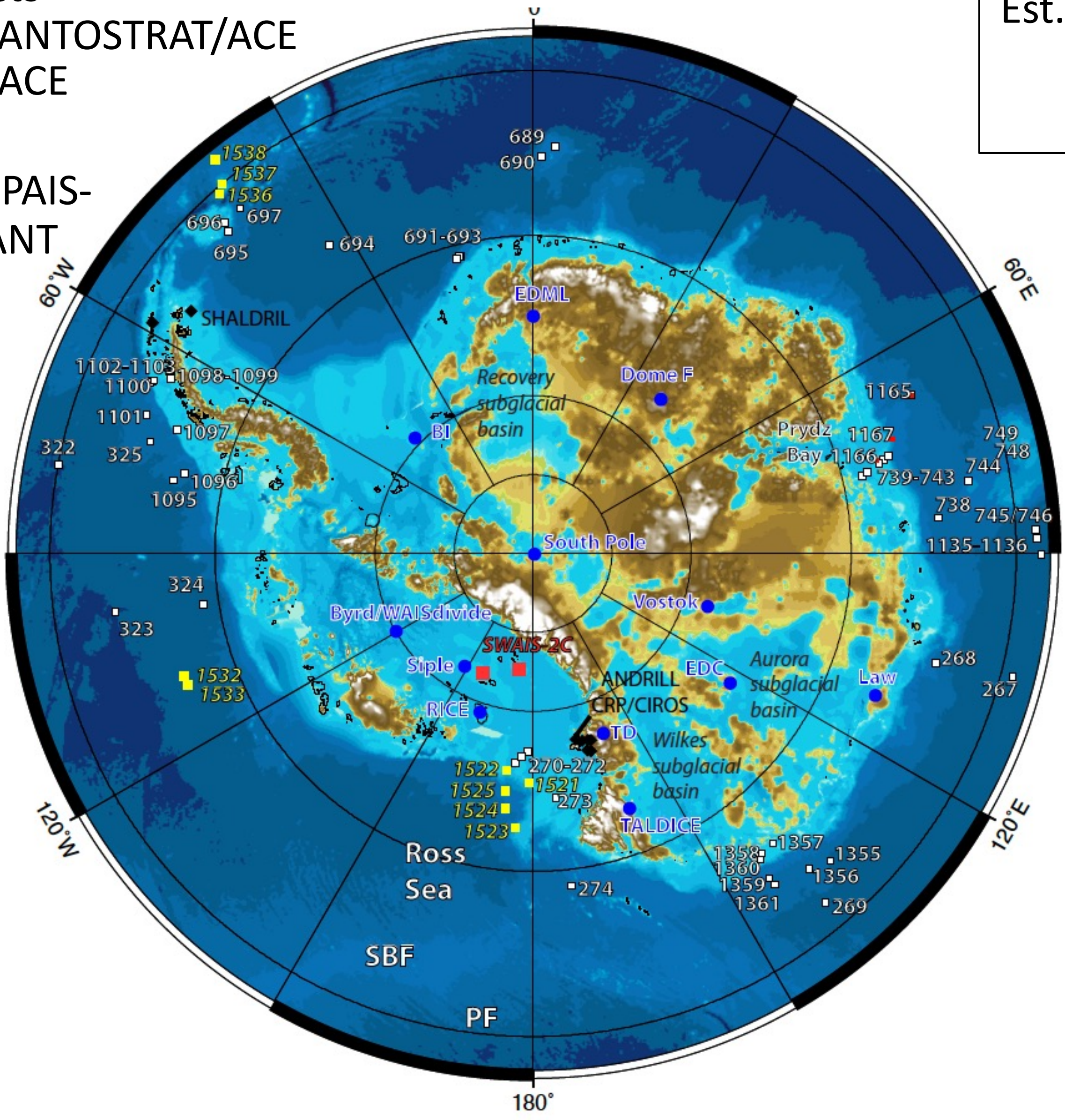
Fig. 3. Response of October–March monthly SST to the monthly SAM index, based on ERA-5 data (38). Contour interval is 0.15 K; zero contour is not plotted.

Characteristics of a successful Antarctic research programme

1. Focus resources on the key questions guided by national and international strategic directions, not the discipline – break down silos. These questions may be stakeholder driven (e.g. NAP, government, local government, IPCC/UNFCC, CEP/ATCM, CAMMLR) or more ”fundamental basic science”
2. Interdisciplinary approach (numerical modellers, observationalists, paleoclimatologists, glaciologists, oceanographers, climate dynamicists, geologists, biologists)
3. Co-design project science and logistical operations within the interdisciplinary team to utilise syngeries and efficiencies.
4. MORE data acquisition and observations of critical processes and boundary conditions (ships, aircraft, satellites, ocean, ice surface, ice shelf and sub-ice bed observations, and reconstructions from ice and sediment drill cores) for IMPROVING model design and performance, to reduce uncertainties.
5. Need to build and maintain network of instruments and observatories for long term monitoring (e.g. GNSS, moorings, satellite missions)
6. Large-scale data acquisition requires co-ordination and international collaboration between scientists, government research funders and NAPs (e.g. SCAR RINGS, SOOS, ISMIP, PALSEA, SCAR INSTANT, IODP).
7. Timely data availability and sharing, trust rather than compete.
8. Need to strengthen numerical modelling capacity (people and infrastructure).
9. Balance between disciplinary and integrated science. Think about a small number of flagship projects.
10. Development and maintenance of capability (science and operational) and capacity – opportunities for ECMRs.
11. For research directly related to the climate crisis, time is short, Antarctica and Southern ocean are big, and we need to act at pace and scale.
12. $$$$$, Euros!!

What does success look like? Drilling to understand past & future ice sheet dynamics

- Ice core Projects (blue circle)
- IODP drilling - ANTOSTRAT/ACE (open square)
- SHALLDRILL - ACE (black diamond)
- ANDRILL - ACE (black square)
- IODP drilling – PAIS- (yellow square)
- SWAIS2C INSTANT (red square)



Est. total co-mingled funding =
~ USD $300 million
(sediment drilling only)

- Community co-ordination
- Planning
- Site survey
- Technology development
- Logistics
- Science
- Funding
- Consortia

SCAR
SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH
INTERNATIONAL SCIENCE COUNCIL

The SWAIS 2C Project – Sensitivity of the West Antarctic Ice Sheet to 2°C (Paris target)

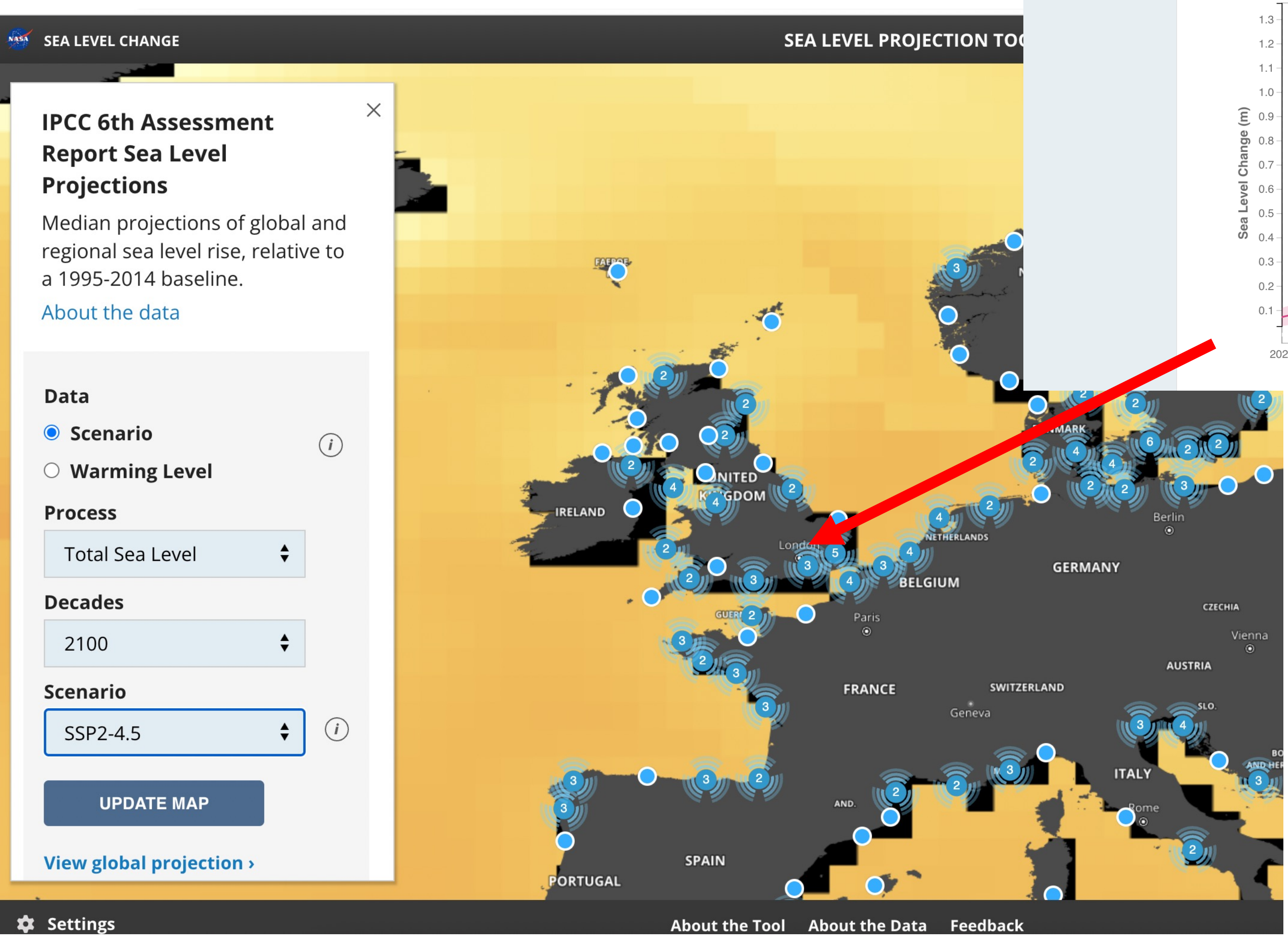
Antarctic Science Platform
Antarctica New Zealand
AuScope
NSF
KOPRI 극지연구소
BGR
AWI
INGV
icdp
UKRI
Natural Environment Research Council
NiPR National Institute of Polar Research

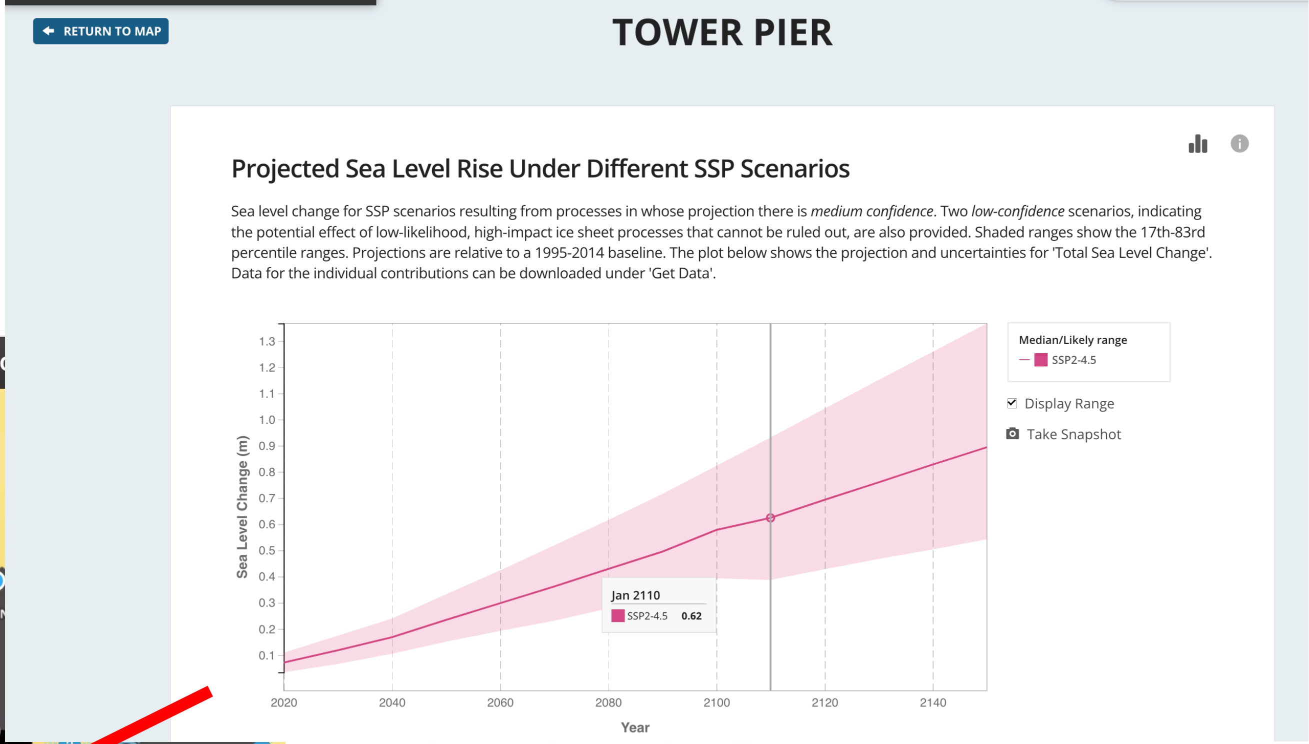
8 countries contributing USD $5.4M

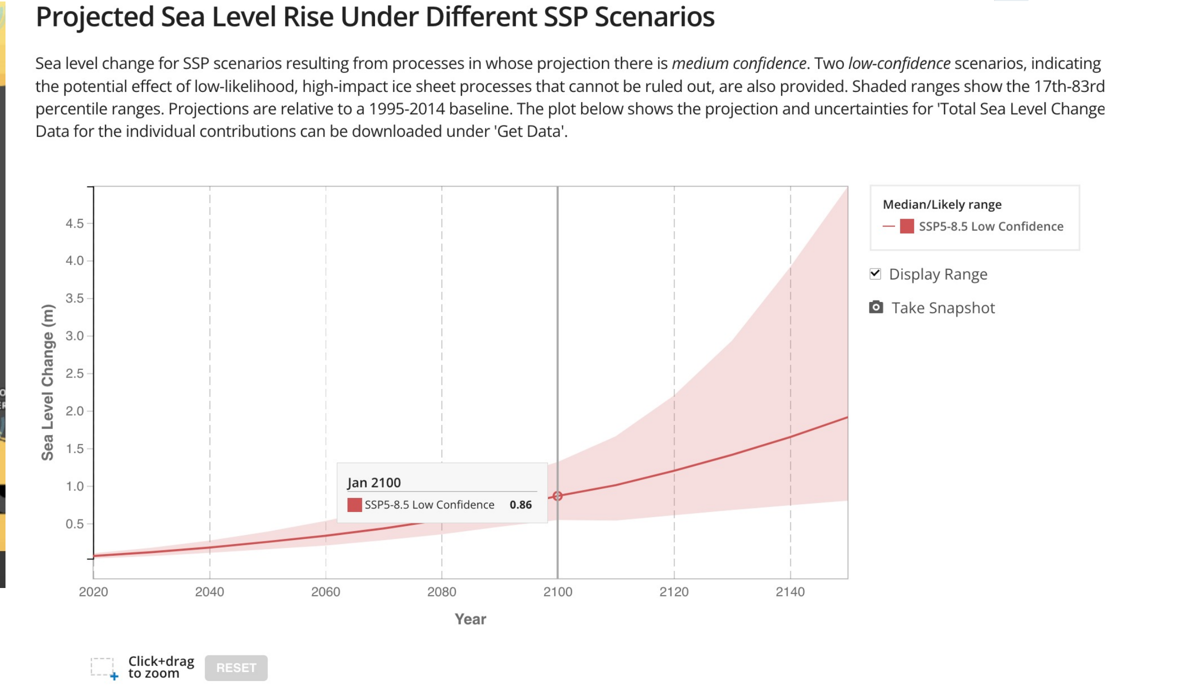
Scientific Drilling
Open Access

Patterson, Levy, et al. (2021)

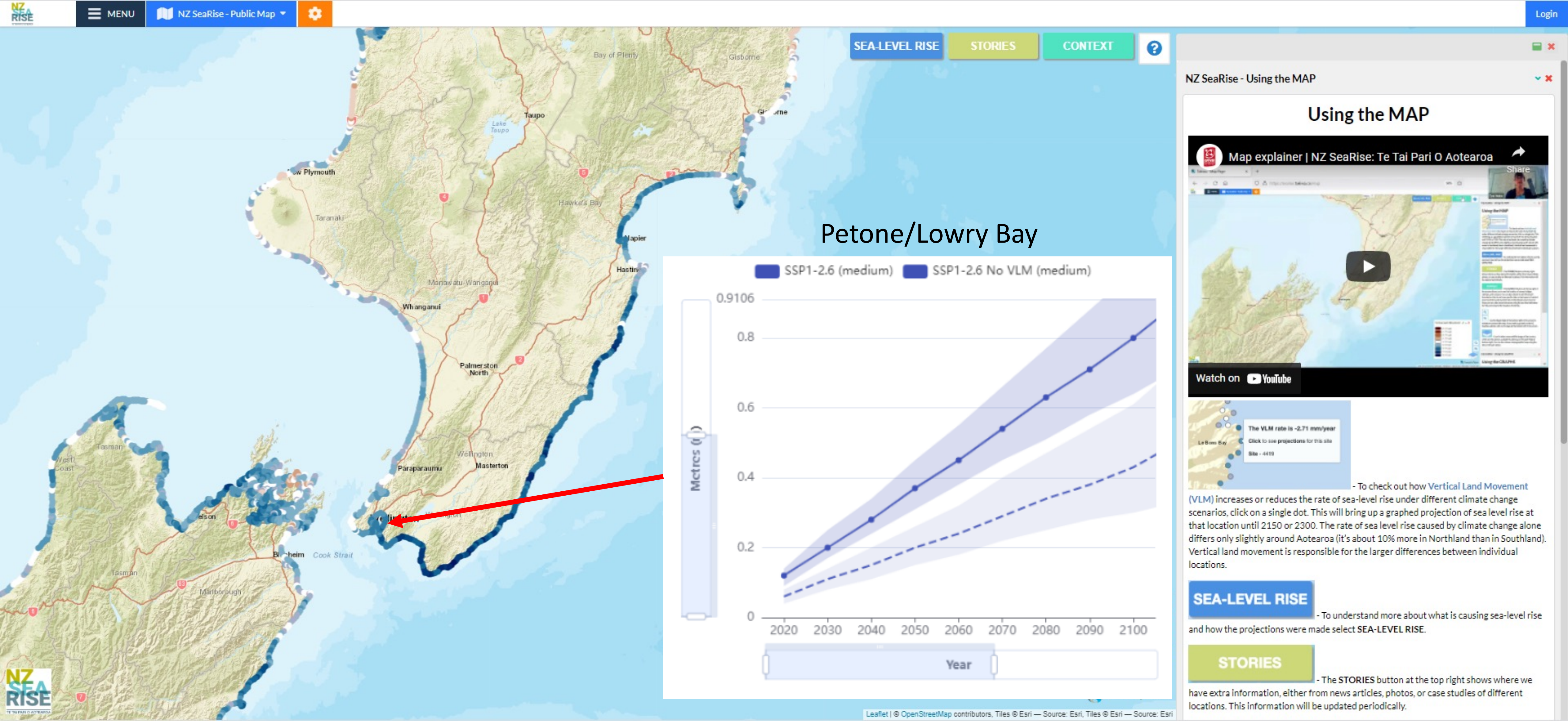
Building tools for improved sea-level projections and coastal hazard risk assessment







https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool



NZ SEA RISE
TE TAI PARI O AOTEAROA

Check out the new online sea-level tool projections at www.searise.nz/maps

Takiwā

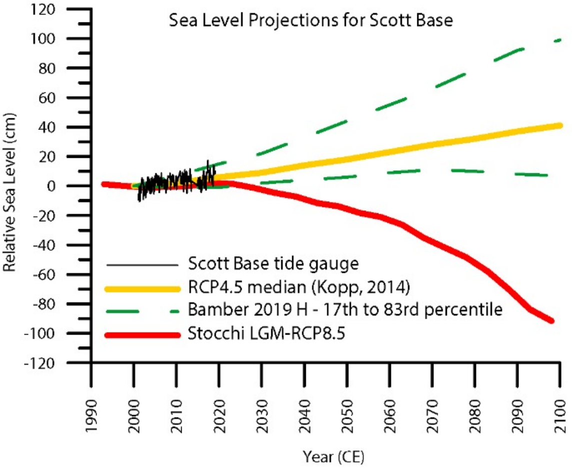
Sea level projections for all Antarctic coastal stations, heritage sites, infrastructure, protected areas and bio-regions

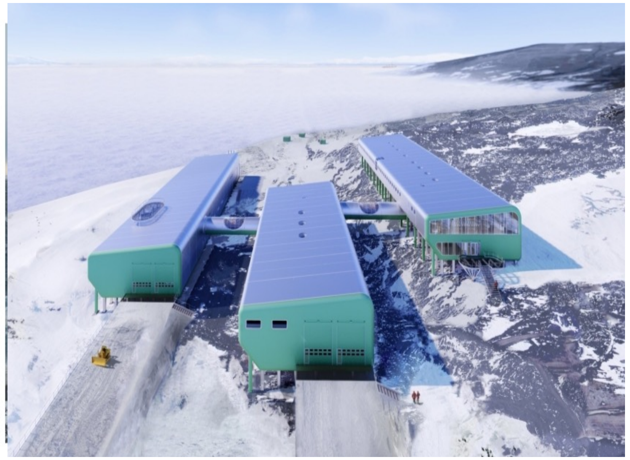
IP 95

29.5.–8.6.2023
Helsinki ~ Finland
XLV ANTARCTIC TREATY CONSULTATIVE MEETING

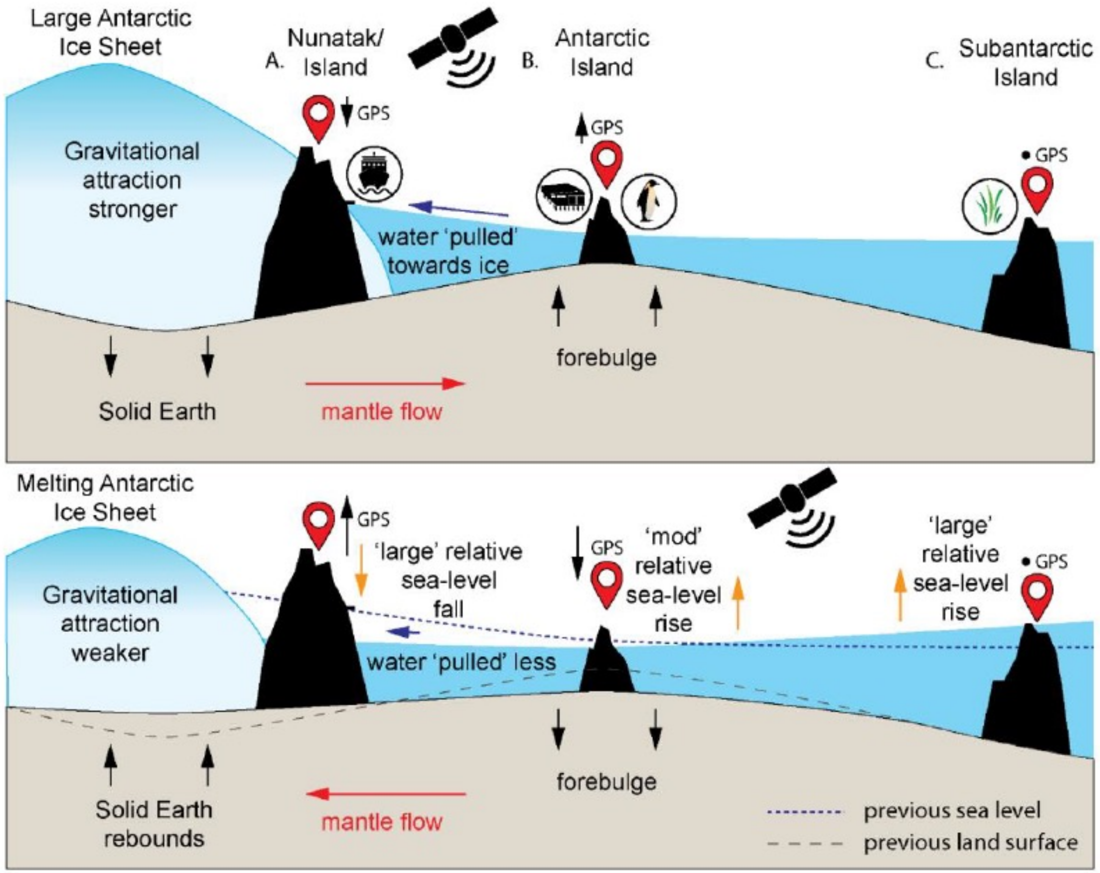
Understanding Future Sea-level Change Around Antarctica

Information Paper submitted by SCAR and COMNAP



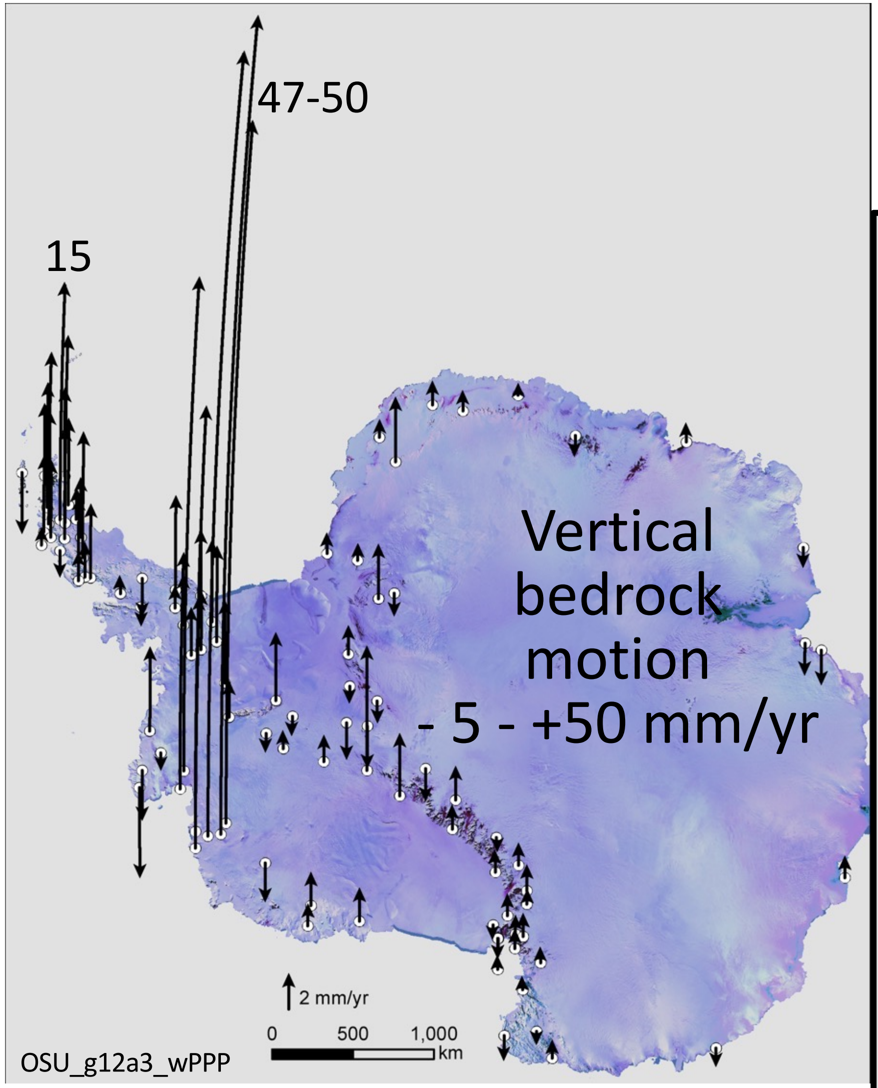


Levy et al., *GNS Science Report*, 2020

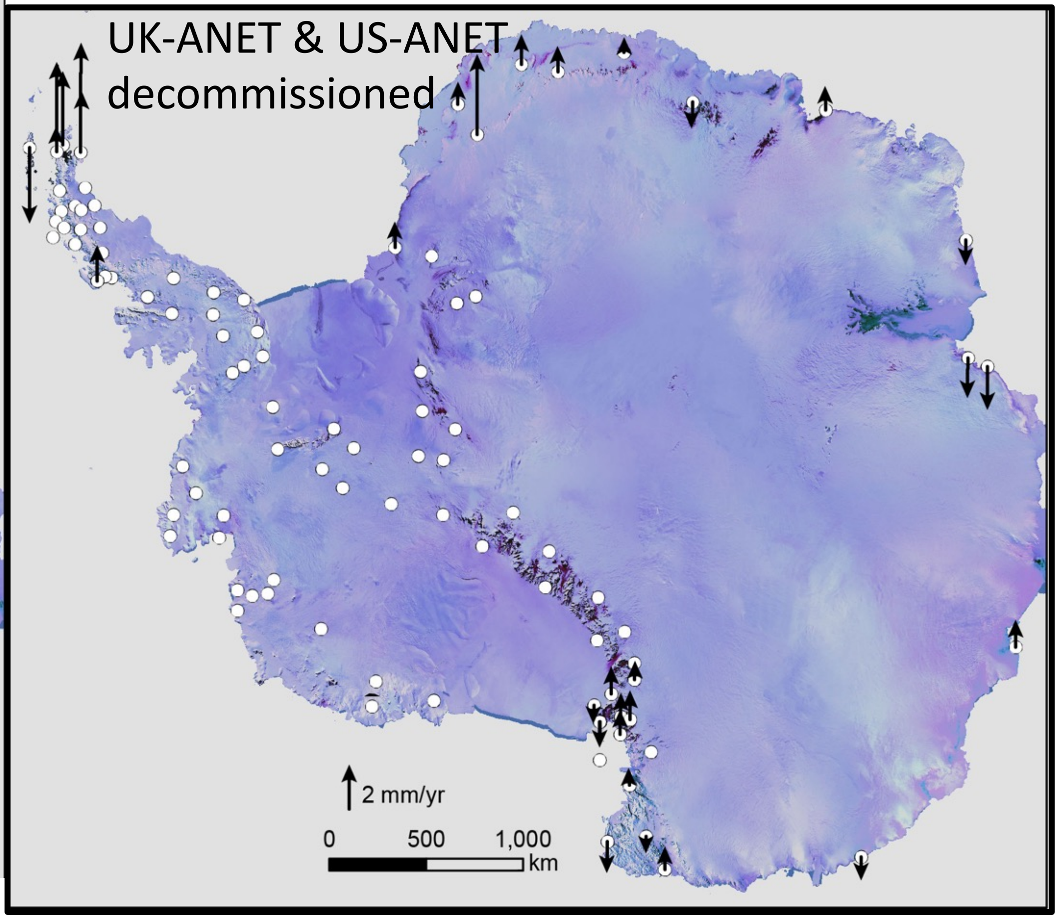


An Information paper to ATCM 45, results of full study for next ATCM

But how do we maintain critical observations and capability?



Need multinational collaboration!



Critical for estimating near field vertical land movements & estimating glacio-isostatic adjustment (e.g. GRACE)

There are many future opportunities to address the "big" issues from international collaboration in the Ross Sea - Wilkes Land region.

THANK YOU