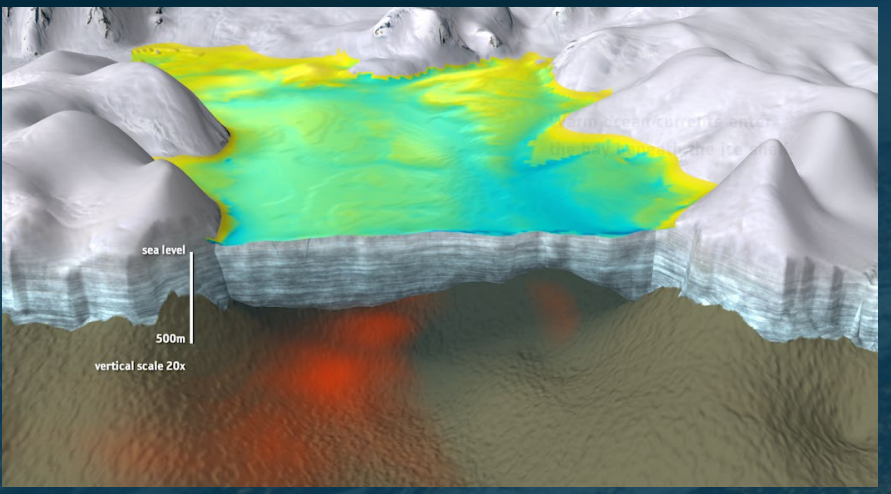
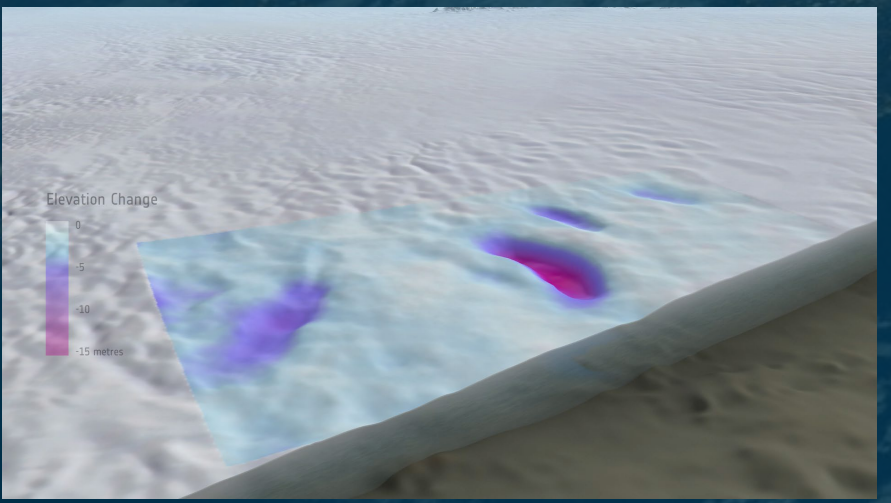
ESA Polar Science Cluster – Workshop Report

Some Statements and Points for Discussion



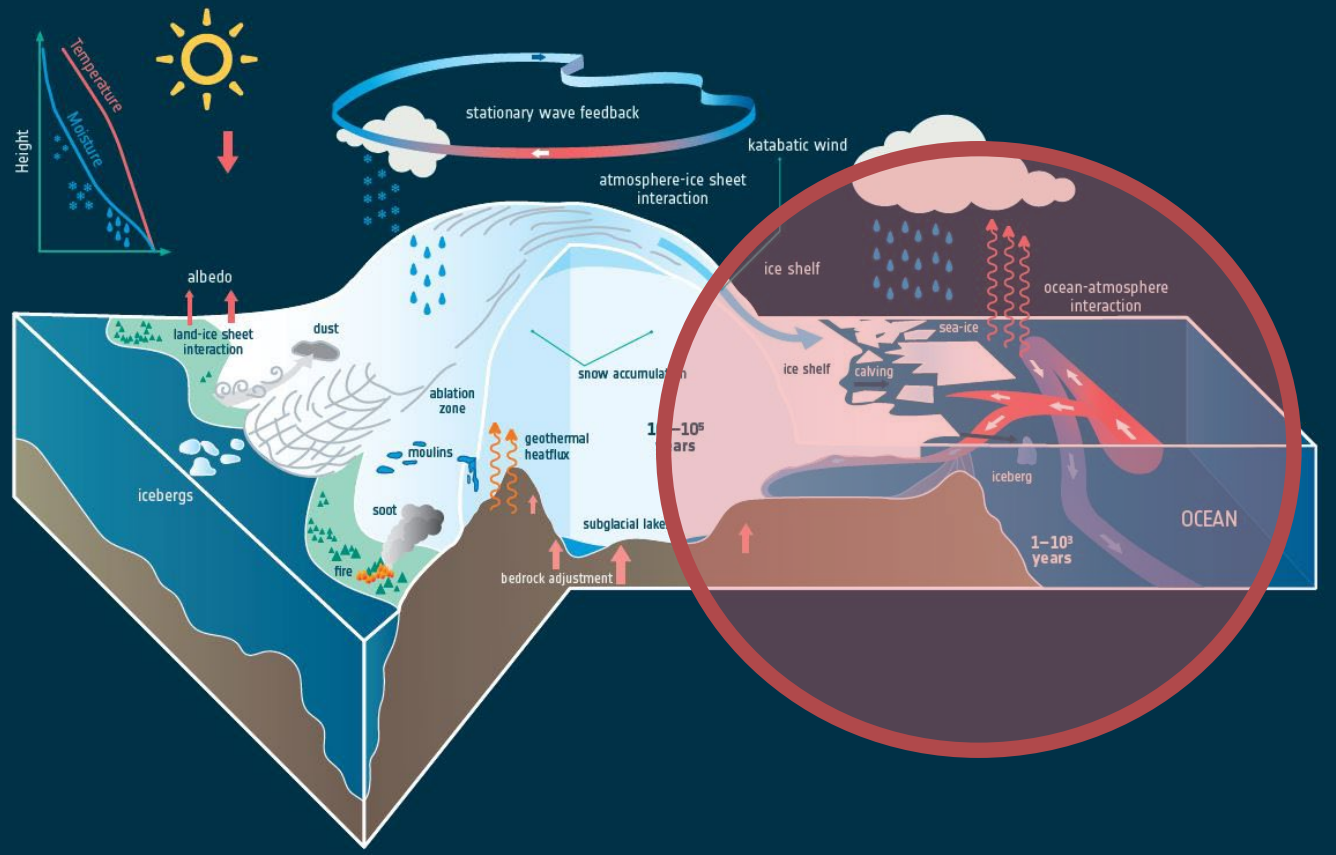


- **Ocean forcing of marine terminating glaciers.** 40% of global ice losses are due to ocean forcing, mainly in Antarctica. The signals of imbalance are in grounding line retreat, ice thinning, and ice speedup; the forcing is in ocean circulation and temperature change. All can be determined from EO. **A effort focussed on assessing the forcing and imbalance from EO and integrating with modelling makes a lot of sense.**

- We need to **investigate the role of subglacial environment on ice sheet loss (e.g. role in mass balance budget, impact on grounding line and ice shelf melt rates) and its impacts on the ocean**, on ocean circulation and bio-chemistry (e.g. iron supply, primary productivity). This involves EO and simulation of ice sheet, subglacial, ocean, ad bio-chemistry systems.

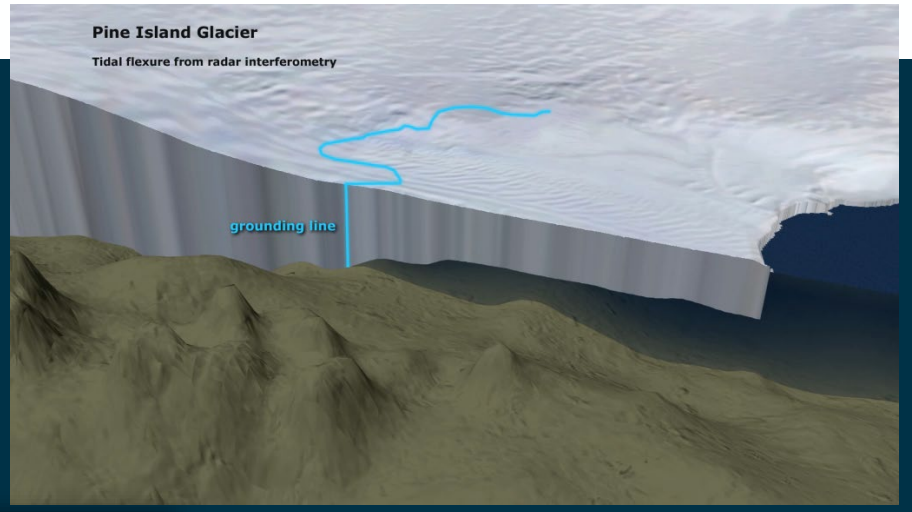
- The major scientific gap is our capacity to observe and **understand the Southern Ocean under ice** - particularly adjacent to the Antarctic margins / continental shelf break and near the ice-ocean interface, where some of the most globally-important climatic changes are unfolding. Need to explore all new opportunities to tackle this gap by synergistic use of emerging advances in remote sensing and (in situ) autonomous robotic / distributed sensing technologies?

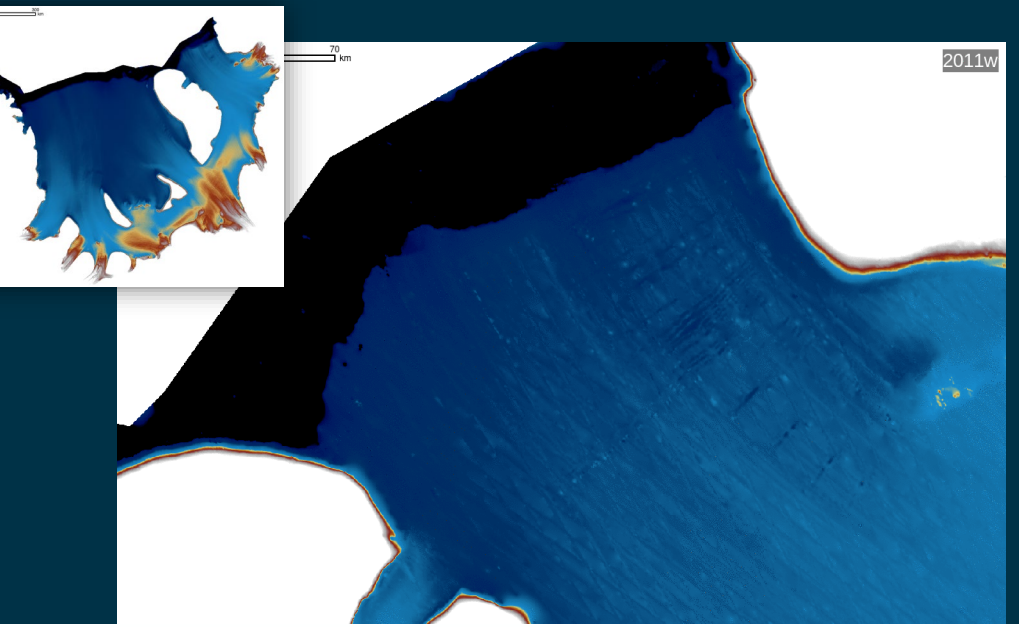
Statement from report



The key science challenge over the Southern Ocean is to better understand how the ocean circulation is coupled with high latitude cryosphere. For that, it appears fundamental to observe and quantify the main mechanisms governing interactions between the Ocean (sea level change, freshwater fluxes) and the Cryosphere (ice shelf, land ice, sea ice) and assess their respective impacts on both regional and global scales. **This can only be achieved by considering the Southern Ocean as a truly coupled system with cryosphere...**

Monitoring change, stability, breaking points…





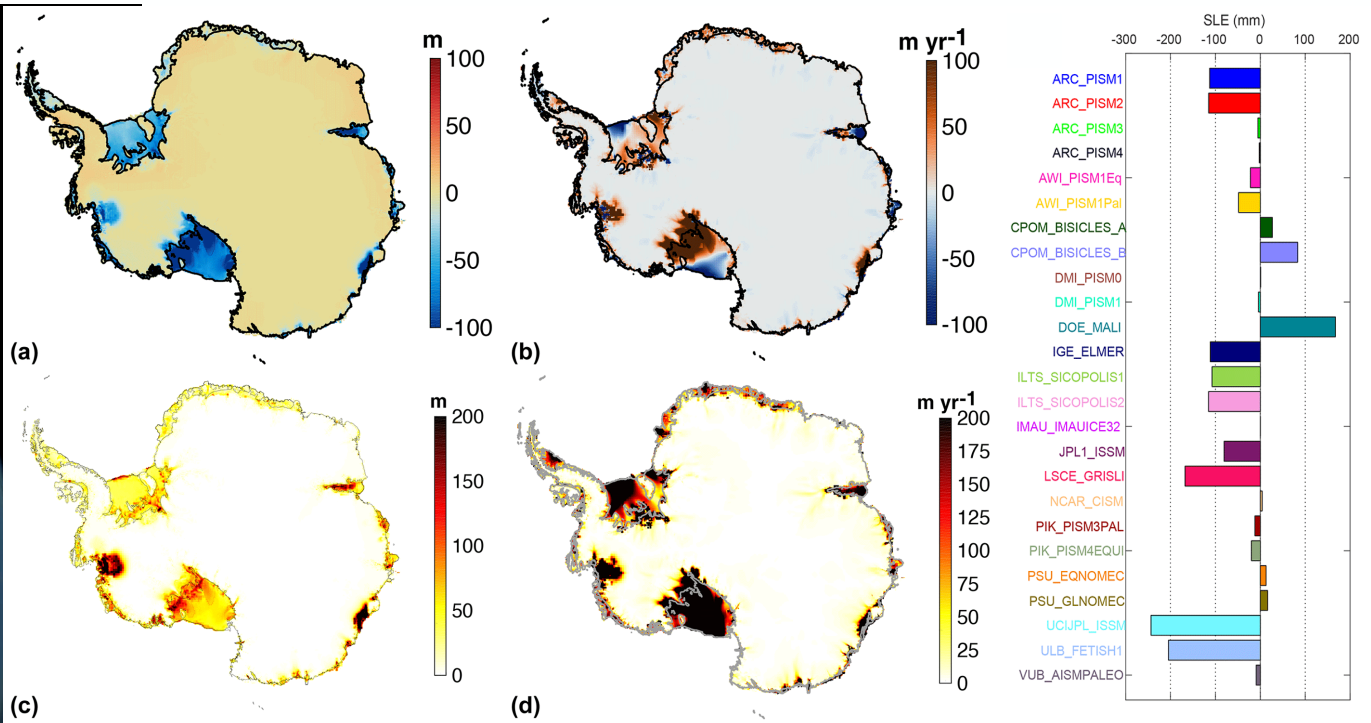
Assessing Antarctica stability… Detecting Antarctic tipping points. This is long overdue; most (if not all) work on tipping points is from a theoretical, model, or palaeo- perspective. **What is needed is an EO capability to detect change and then contrast that to the model/theory/palaeo work to establish whether change is sufficient to equal a tipping point**. Includes marine ice sheet instability (ie grounding line retreat, glacier speedup, etc), marine ice cliff instability (ie glacier calving front retreat), and ice shelf collapse (ie tracking crevasse fracture).

Develop Methods for detecting first signs and for monitoring the evolution ice shelf fracturing, calving and disintegration
Action: Monitor stress pattern and detection of cracking, calving
Assess and monitor the role of surface melt intensity and duration for the formation and spreading of fractures
Determine the role of ocean currents and pre-frontal sea ice on crack propagation

We need an R&D + systematic comprehensive set of observations geared towards detecting onset and magnitude of change -> as signal of change of state, of **potential tipping points**

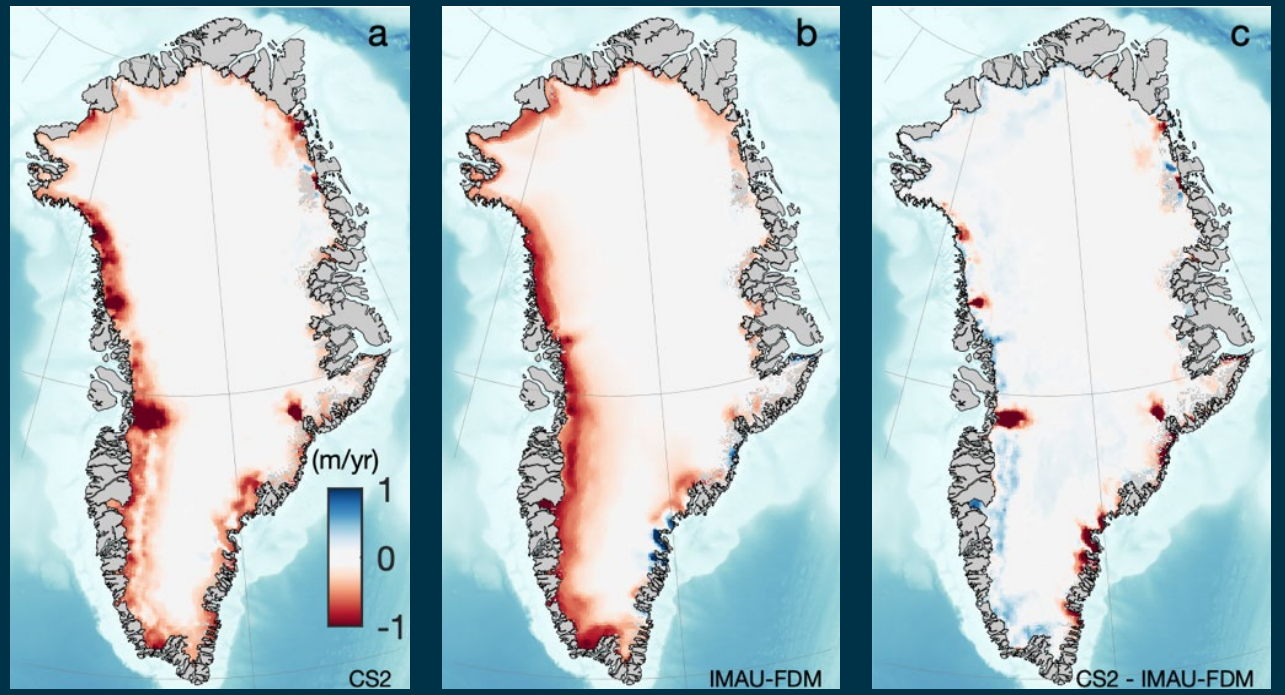
Mass imbalance and SL predictions

- **Ice sheets models present major differences:** Standard deviations among models are greater than the signals. Strong variability particularly in most unstable areas (poor characterization of ice shelve–ocean interactions).



Seroussi, 2019 & 2020

Some Statements and Points for Discussion



Mass imbalance - Attribution of ice sheet and glaciers ice imbalance to Oceanic and Atmospheric forcing. Ice imbalance needs to be quantified and partitioned between SMB and Dynamics; then related to forcings from ocean and atmospheric change; needs to consider e.g. stress balance, buttressing. Output can be some form of parametrisation that can be used e.g. by simulation for future ice sheet projections.

Some Statements and Points for Discussion

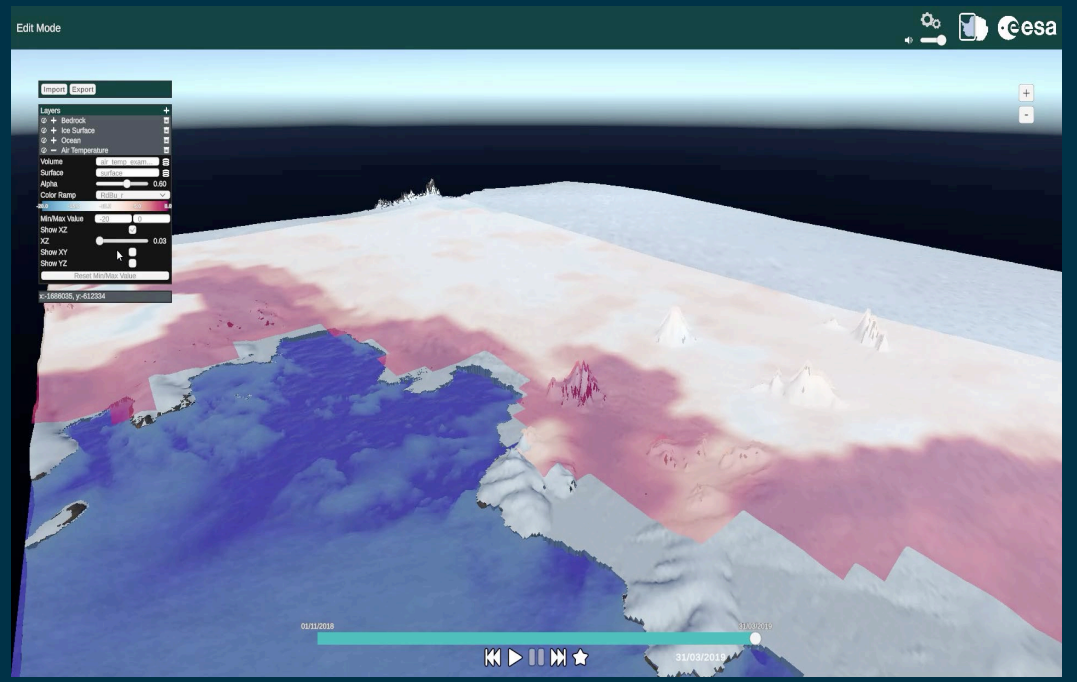
Observe mass discharge and balance on regional scale and individual ice streams of Antarctica with monthly to seasonal frequency as a contribution to sea level rise.

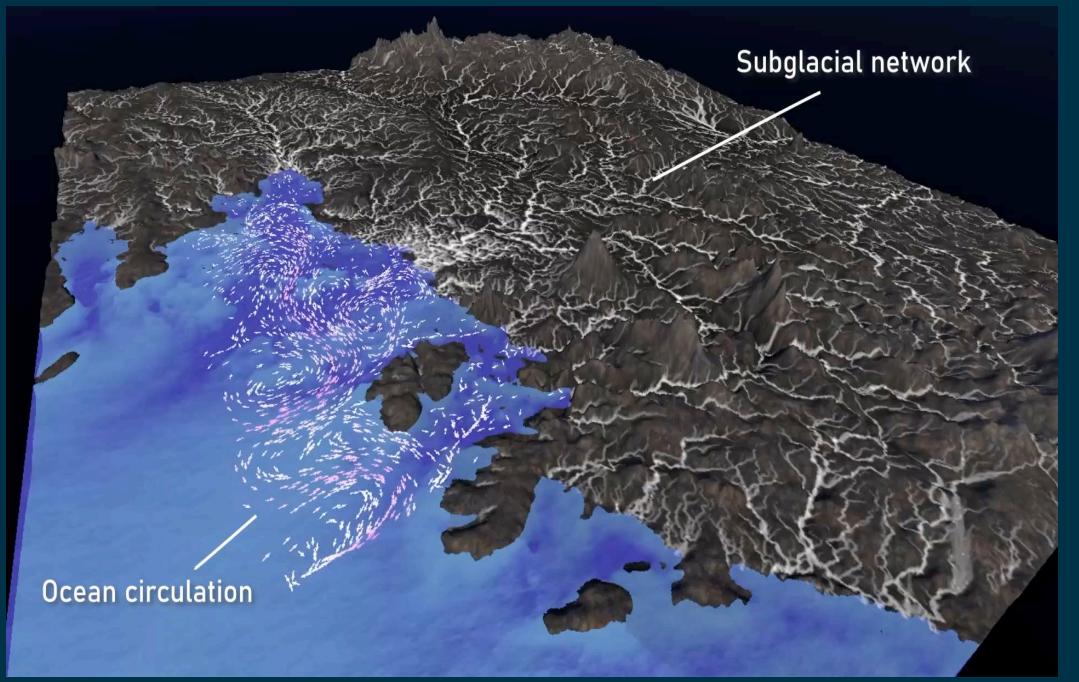
- *Action: study oceanic forcing on flow dynamics and ice export of outlet glaciers*
- *Action: Determine the role of prefrontal sea ice production for flow dynamics and mass balance of ice shelves and calving glaciers*
- *Action: Develop synergistic methods for improved ice discharge estimation by combining SAR, Altimeter and other data*
- *Action: Identify and fill gaps on ice thickness data at grounding zone using airborne acquisitions in synergy with altimetric data, including the temporal evolution*
- *Action: Evaluate potential of deriving surface elevation / mass/ volume changes for ice streams and outlet glaciers in complex terrain by combining Altimeter data and Single pass interferometry (preparing for upcoming ESA and Copernicus missions: Harmony, Cristal)*
- *Action: Study suitability of ice velocity retrieval combing C- and L-band SAR data (S1, ROSE-L) of crossing orbits applying InSAR and OT in synergy*

Making more reliable estimates of mass loss by the input-output method, by getting the missing outlet glacier depths around the "gates", especially in East Antarctica. The IMBIE results are not really independent (a lot of interpolation and assumptions). This require coordinated international flight campaigns with radar, gravity (for hard-to-sound deep glaciers) and general geophysics (magnetics) for understanding rapid changes. SCAR has just approved an action group to make plans for this at the last SCAR National Delegates Meeting (Read: "SCAR RINGS" for summary)

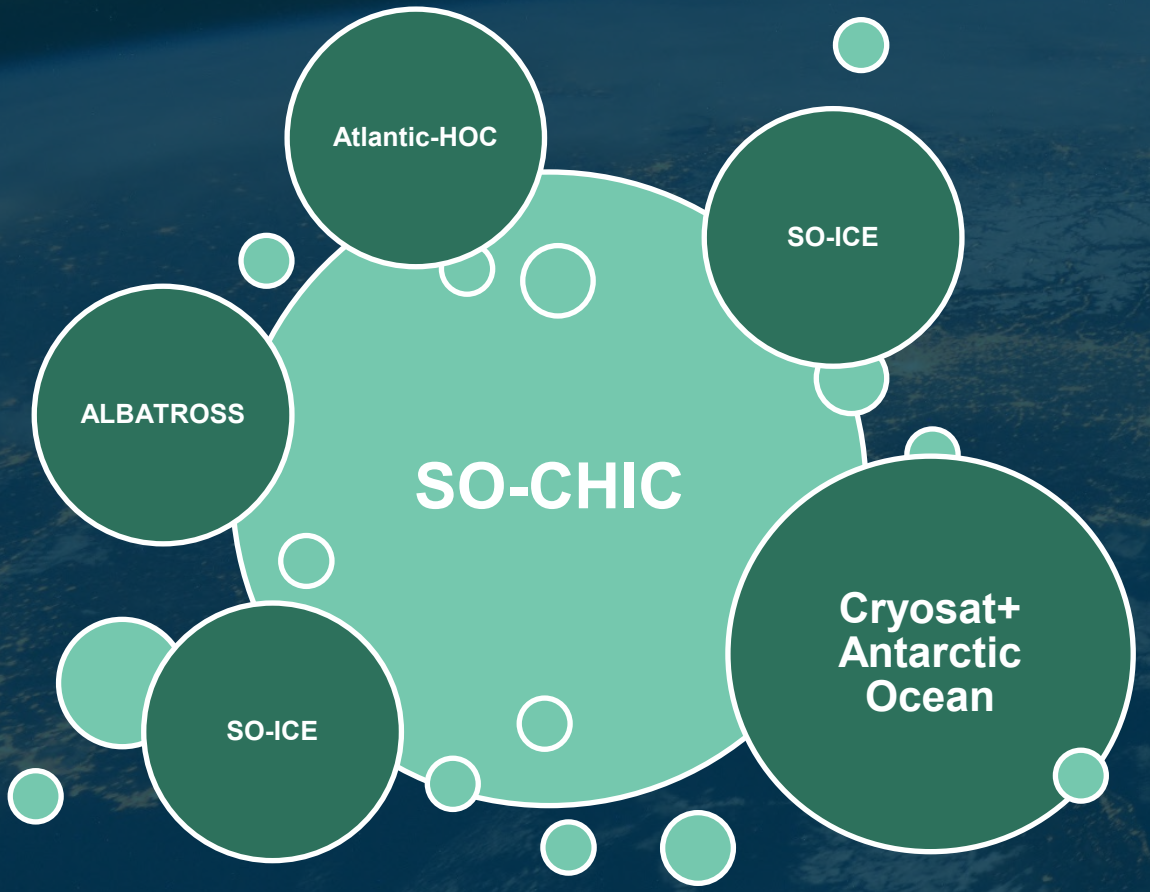
Some Statements and Points for Discussion

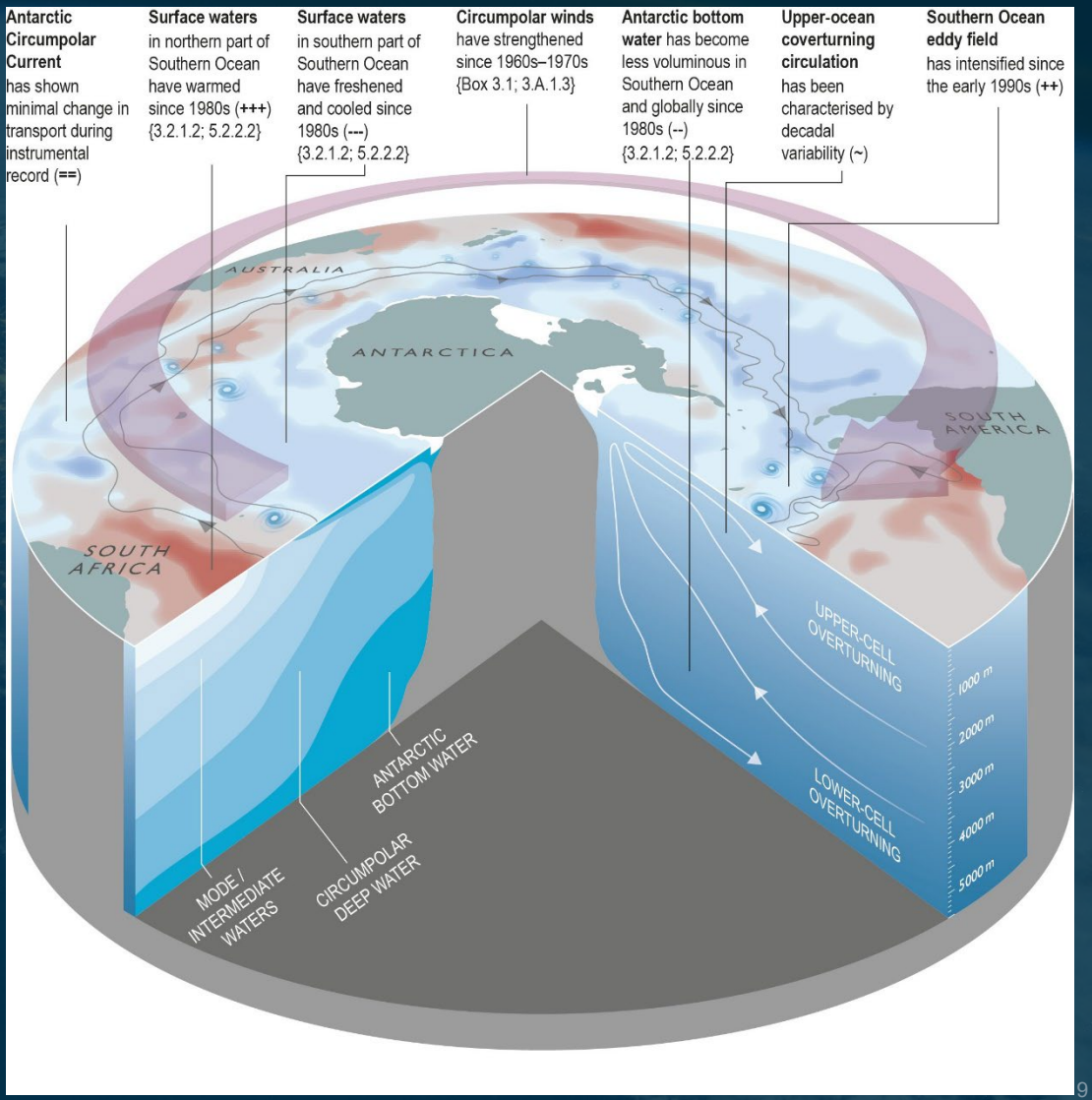
We need a digital copy of Antarctica, linking up the ice sheet, subglacial, ocean, atmosphere, biosphere, built from EO, simulation and in-situ products and algorithms. This would facilitate all of the above.





Southern Ocean… dedicate Ocean Challenges??

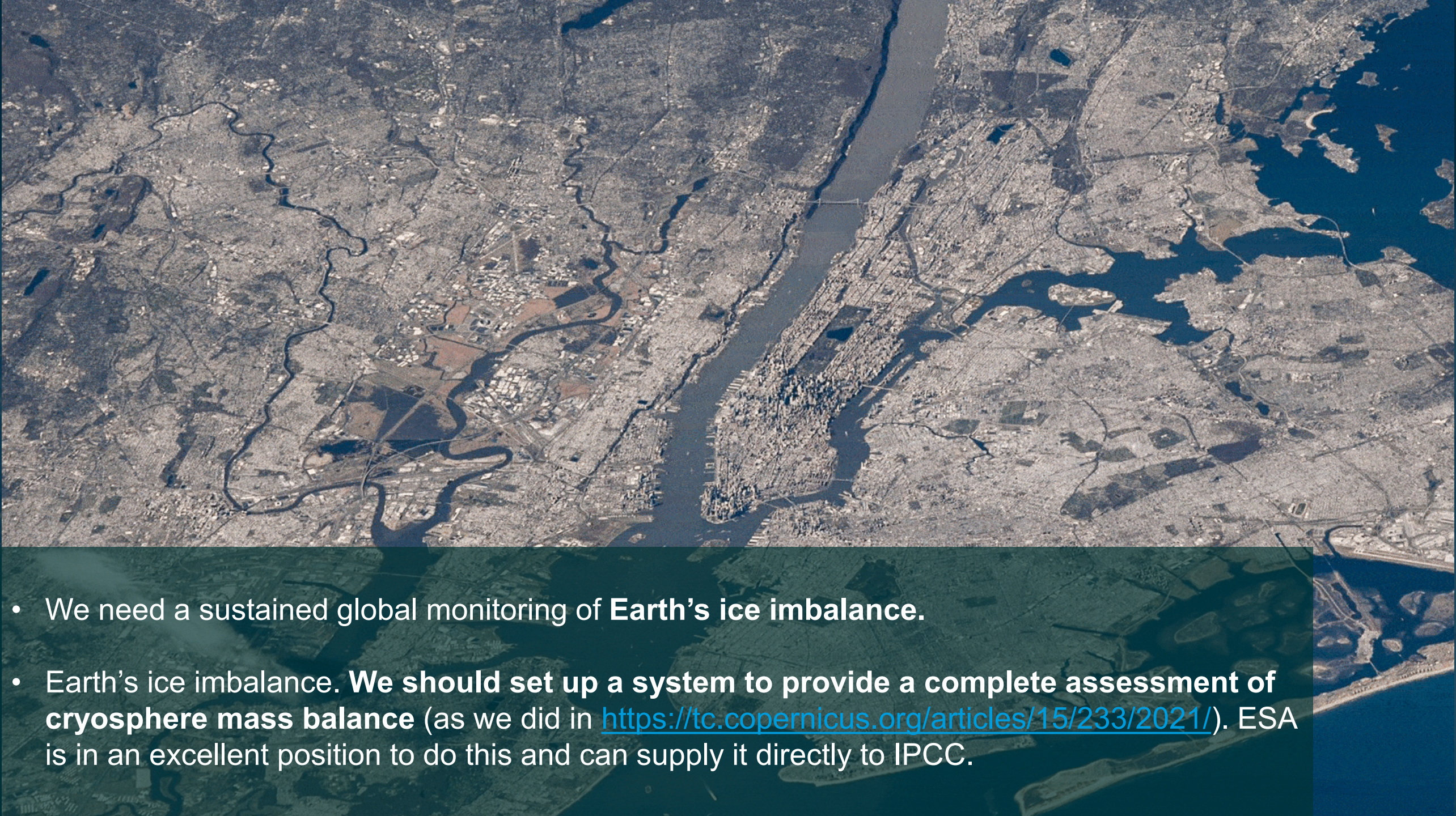




Some Statements and Points for Discussion

- **Other datasets – observations. Wind/snow interactions.** Blowing snow is prominent in Antarctica and has a very uncertain impact on SMB. Surface roughness (resulting from wind/snow interactions) has an impact on SEB and on the interpretation of radar data (altim, SAR, ...). The investigations in this domain with EO are lagging w/r to other ECV to my opinion. Original use of satellite data and probably original sensors will be needed in the future.

- **In-situ data collection** is still extremely scarce in Antarctica and may become scarcer due to economical and environmental issues. Nothing to compare with the Arctic. This limits the new usages of satellite data. This has been quite invisible in the last two decades, because satellite techno and availability (e.g. thanks to Copernicus) have sharply increased, leading to significant progresses. However on a long run, this disconnection between the in-situ observers and the algo/model developers is going to be a limitation. Given the timescales in this domain, this problem needs to be tackle now.



- We need a sustained global monitoring of **Earth's ice imbalance.**
- Earth's ice imbalance. **We should set up a system to provide a complete assessment of cryosphere mass balance** (as we did in https://tc.copernicus.org/articles/15/233/2021/). ESA is in an excellent position to do this and can supply it directly to IPCC.

Towards a common goal

esa

Snow grain size

Snow Albedo

Supraglacial lakes

Snow melting processes

Sea state

Ocean salinity

Surface elevation

Glacier velocity

Calving Fronts

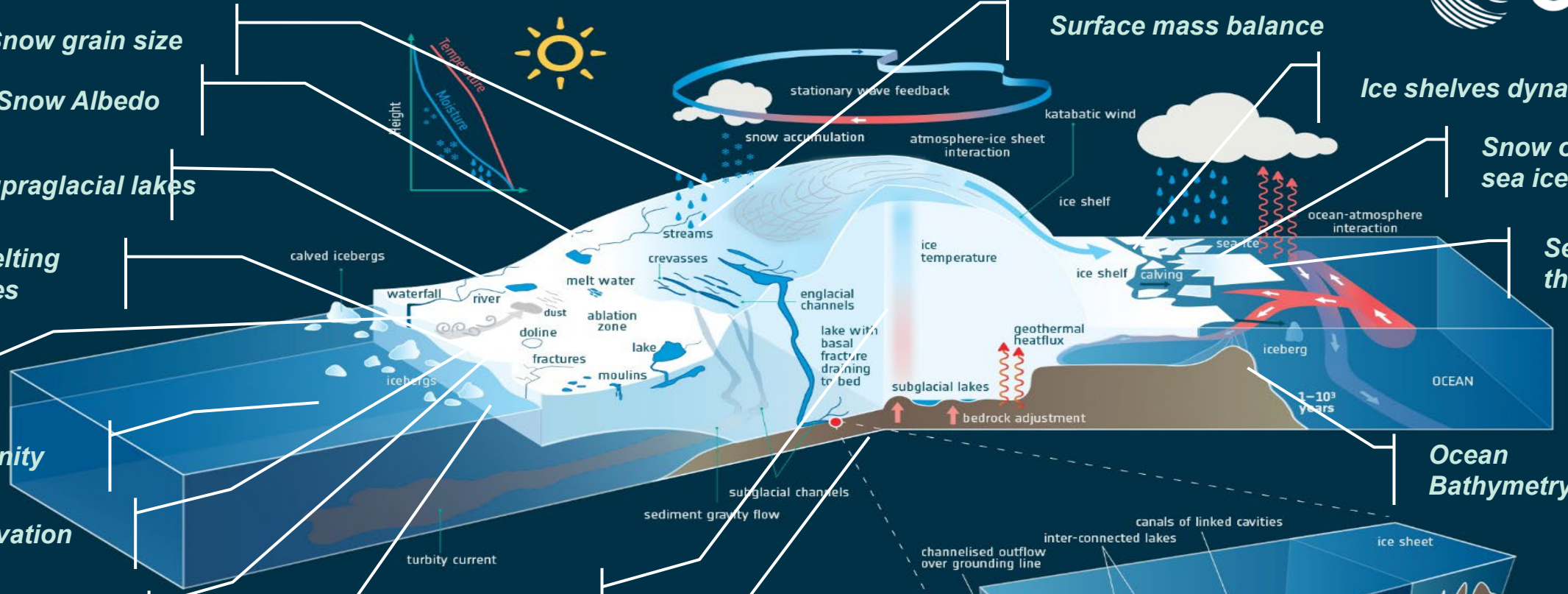
Surface mass balance

Ice shelves dynamics

Snow on sea ice

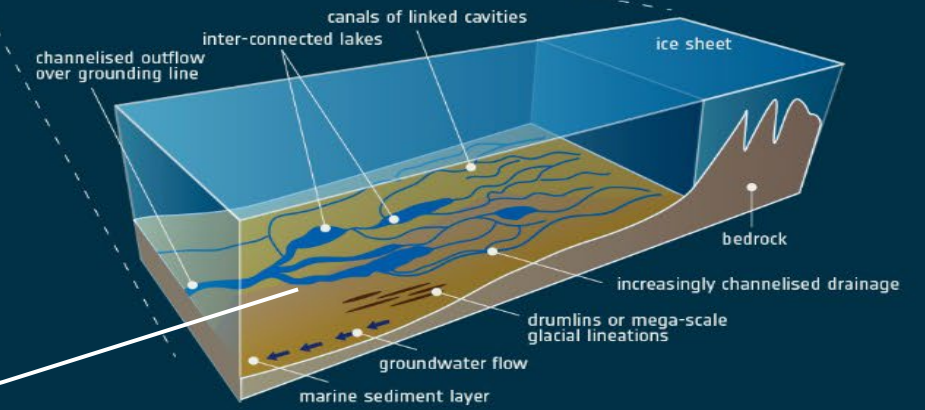
Sea ice thickness

Ocean Bathymetry



Ice sheets T

Lithosphere Modelling



Subglacial environment

Greenland and the Arctic

Diego Fernandez

14/09/2021

Overview


NORTH PACIFIC OCEAN
Bering Sea
Petropavlovsk Kamchatsky
Sakhalin
Sea of Okhotsk
Gulf of Alaska
Bering Strait
Anadyr
Magadan
Anchorage
Nome
Vancouver
JUNEAU
Fairbanks
RUSSIA
Chukchi Sea
ALASKA
Barrow
Wrangel Island
East Siberian Sea
Yakutsk
CANADA
Prudhoe Bay
ARCTIC CIRCLE
Beaufort Sea
Yellowknife
Laptev Sea
Cambridge Bay
Melville Island
Somerset Island
Churchill
Devon Island
Resolute
NORTH POLE
Repulse Bay
Kara Sea
Franz Josef Land
Kuujjuaq
Qaanaaq/ Thule
Baffin Bay
Iqaluit
GREENLAND
Disko Bay
Ilulissat/ Jakobshavn
Longyearbyen
Greenland Sea
Barents Sea
Sisimiut/ Holsteinsborg
NUUK
Ittoqqortoormiit
RUSSIA
Alta
Murmansk
Archangel
Jan Mayen
Scoresby Sund
Labrador Sea
Denmark Strait
Kiruna
FINLAND
REYKJAVIK
Akureyri
NORTH ATLANTIC OCEAN
ICELAND
SWEDEN
HELSINKI
MOSCOW
NORWAY
OSLO
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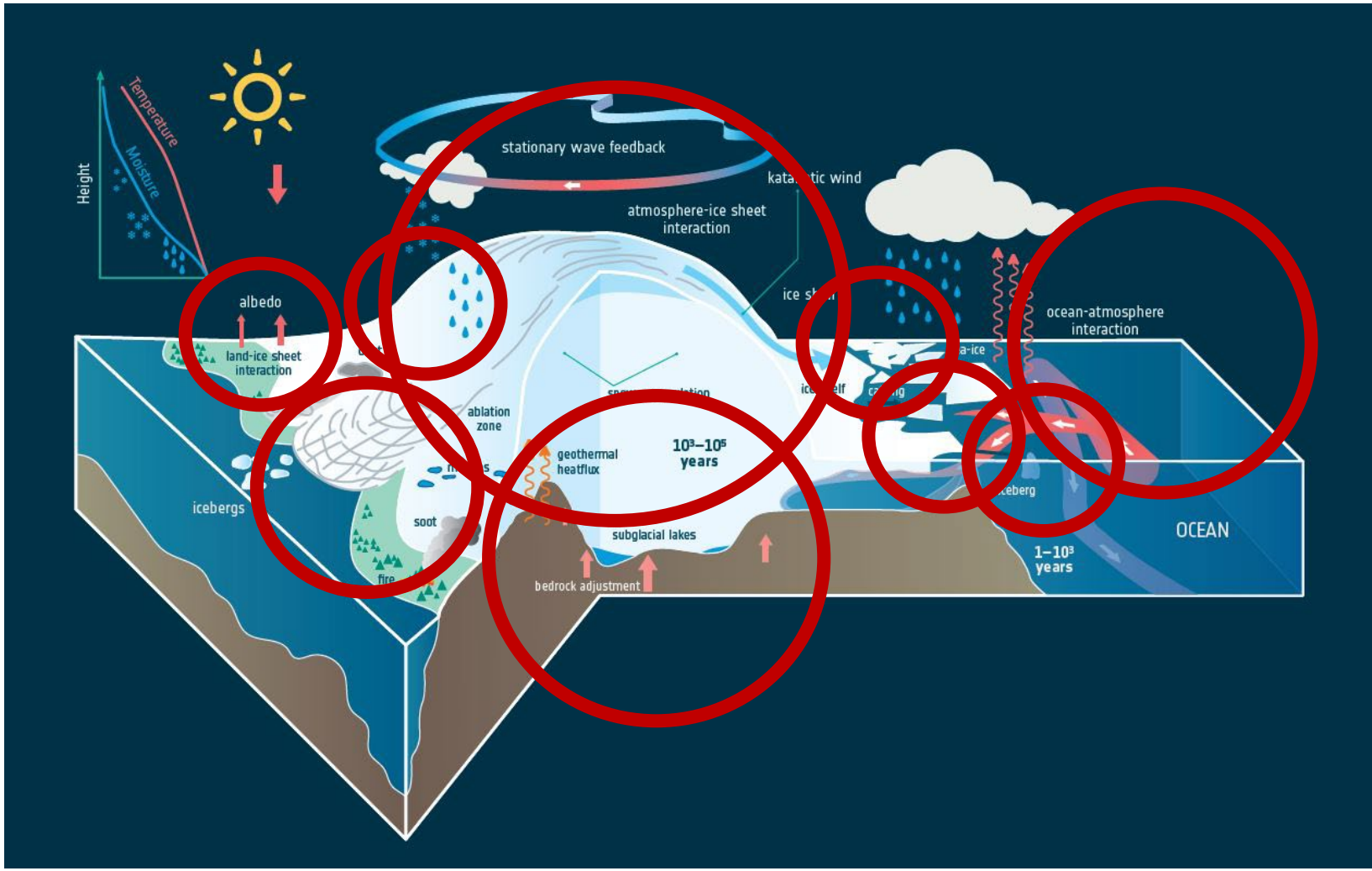

Height
Temperature
Moisture
stationary wave feedback
atmosphere-ice sheet interaction
albedo
land-ice sheet interaction
ablation zone
geothermal heatflux
10^3–10^5 years
ocean-atmosphere interaction
icebergs
soot
subglacial lakes
bedrock adjustment
OCEAN
1–10^3 years

Greenland ice sheets.

Most of the discussions we had on the Antarctic ice sheets and the importance to betters characterise and systematically observe the atmosphere-ice-sheet-ocean interactions applies to Greenland and the Arctic..

But we have a quite a different situation in Greenland with more land terminated glaciers (limited ice shelf coverage), more interconnected hydrology and may be more influenced by CC (Greenland mass lost acceleration, Arctic Amplification)…

Likely the needs and priories are similar but with some different…. The need for **monitoring and assessment of "stability issues" or observing and explaining (attribution) acceleration of mass loss** is priority in Greenland? Driving processes are different… key driver in Antarctica may be the ocean… Atmosphere forcing may be the key driver or change in Greenland?

Technical comments: For the Greenland ice sheet there is a challenge to unify radar and laser measurements (i.e. CryoSat and IceSat) for elevation changes. There is a need to combine multi-frequency altimetry (e.g. L-band, Ku-band, and Ka-band) with real-time met models to get reliable models for the real surface elevation changes, and the associated conversion to mass loss. Improved SAR ice velocities, by combined L-band and S-1 interferometry, could also help understanding radar penetration issues.

Freshwater flux into the Arctic ocean & North Atlantic.

The set of activities currently undergoing will add to our understanding and quantification of the freshwater flux from Greenland to the Arctic Ocean. It would be obvious in future work **to join forces with other scientific communities (river discharge, sea ice, modellers) to investigate the freshwater budget of the Arctic Ocean.** Such a goal requires a large and diverse partner consortium. Potential for really ground breaking results.

Freshwater flux into the North Atlantic and how this affects AMOC and NW Europe weather. Would involve sea ice, snow, ice sheet & glacier discharge, ice sheet & glacier runoff. The solution is mostly EO, with some modelling (e.g. of snowmelt into river runoff). Then there is work to make use of the observations which presumably the EU would be interested to fund.

Global warming and Arctic

Global warming and Arctic amplification occur across a wide range of spatial and temporal scales, encompassing numerous multi-variable interactions and feedback mechanisms that are still difficult to characterize and quantify. It is therefore highly opportune and important to accelerate a more multi-disciplinary approach to: (i) combine model outputs with statistical analysis to jointly exploit multi-resolution model outputs and observations; (ii) fully capitalize on the wealth of present multi-modal observations (in situ, satellite) with advances in deep (machine) learning strategies; and (iii) contribute to the design and implementation of future performant observation networks along with numerical models. It is therefore recommended to execute:

Systematic multi-modal data driven exploration and joint co-variability analyses of multi-disciplinary satellite data of atmosphere - sea ice - ocean interaction and mutual feedback mechanisms for advances in understanding of coupled thermodynamics and mesoscale processes in the upper ocean and atmospheric boundary layer and their impact and role for sea ice motion, damage and thickness variability and change.

Design and implementation of dedicated multidisciplinary experiments and field campaigns for advances in: (i) validation of existing and new satellite data; (ii) process understanding and dominant interactions and feedback mechanisms; (iii) model validation; (iv) model parameterization, initialization and predictions.

Other issues…

Need for more technical work on key aspects: e.g., Optical and microwave modelling of cryosphere objects. Such developments have been ongoing for ~4 decades, but progresses are still needed (esp. in altimetry, polarimetry) and surprisingly are still possible despite the mass of work already done. New theories and models are being developed and really move forwards the boundaries. I would not qualify this as a challenge, since progresses are there and I don't see risks for this domain, but this is definitely a domain that needs support.

Need for more exploratory studies: It is important to **ensure future funding for exploratory studies** and not just product-oriented projects. E.g., right small exploratory study on the possibilities of mapping subglacial lake activity in Greenland, which shows exciting results.

Towards a systematic production: Several data products from different projects shows great potential to be implemented in a systematic manner.

Summary and final recomendations

Diego Fernandez

14/09/2021

A summary: New and unprecedented set of observation and science results

SMOS very thin sea ice below 0.5 m
SMOS + Cryosat sea ice thickness
Snow on sea ice
Sea ice with dynamic snow accumulation
Daily multi-mission radar freeboard
Dedicated Antarctic sea ice thickness products Antarctic SSH, MDT

Cryosat Swath elevation and elevation change over ice sheets
Cryosat Swath elevation and elevation change over mountain glaciers and ice caps
Cryosat Swath based sub-glacial lakes
Active sub-glacial lakes volume discharge
Glaciers an ice cap mass change and attribution
Ice Sheet Basal melting Run-off

Ice shelves thickness
Ice shelves surface and basal melting
Ice shelves fractures
Calving fronts

3D Surface velocities
S1 TOP based velocities
Combined INSAR + Offset tracking velocities
Grounding line

Ice thickness temperature profiles

Snow extend
Snow albedo
Snow grain size
Snow melting/wet

Supra-glacial lakes coverage
Supra-glacial lakes volume

SMB

Sea Surface Salinity Arctic
Sea Surface salinity Antarctica
Bathymetric and tides Arctic
Bathymetry and tides Antarctica

Antarctic lithosphere model
Arctic/Greenland lithosphere model
Arctic heat-flux and GIA
Antarctica heat-flux and GIA

Greenland integrated hydrology assessment
Antarctica integrated hydrology assessment
Artic ocean process studies
Antarctic ocean ice shelves interact
Antarctic ocean sea ice

Cryo

CH4 high latitude observations
Permafrost land related observations

Campaigns

70+ papers

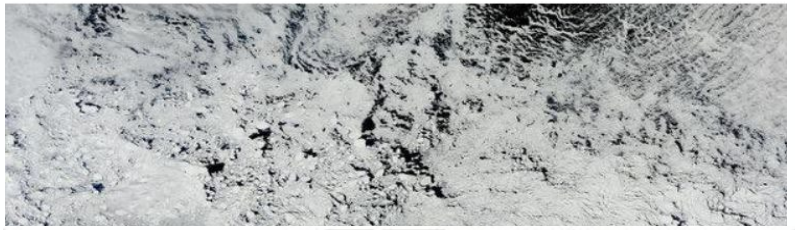
ESA Polar Cluster in the Media

The New York Times

TRILOBITES

Beneath Antarctica's Ice Is a Graveyard of Dead Continents

Data from a European satellite has revealed the tectonic underworld below the frozen southernmost continent.



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Scientists have identified a way in which the effects of Antarctic melting can be enhanced.

Their new satellite observations of the Dotson Ice Shelf show its losses, far from being even, are actually focused on a long, narrow sector.

In places, this has cut an inverted canyon through more than half the thickness of the shelf structure.

If the melting continued unabated, it would break Dotson in 40-50 years, not the 200 years currently projected.

"That is unlikely to happen because the ice will respond in some way to the

EL PAÍS

EL PERIÓDICO GLOBAL

El ritmo del deshielo de la Antártida se triplica en 30 años

El continente ha perdido tres billones de toneladas de hielo desde el año 1992, según alerta un estudio de medio centenar de organizaciones científicas internacionales

IRENE MOLLÁ

13 JUN 2018 - 19:02 CEST

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Actualité › Sciences & Environnement

Fonte accélérée des glaces de l'Antarctique

Mail Online

Science

Antarctica are revealed by satellite images after scientists track 200 million years of tectonic plate shifts

- Images reveal a timeline of the ancient landmasses buried beneath Antarctica
- They were taken by the long-dead Gravity field and Ocean Circulation Explorer
- The ESA satellite collected data on Earth's gravitational pull

By HARRY PETTIT FOR MAILONLINE

PUBLISHED: 11:33 GMT, 9 November 2018 | **UPDATED:** 14:17 GMT, 9 November 2018

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The Washington Post

Democracy Dies in Darkness

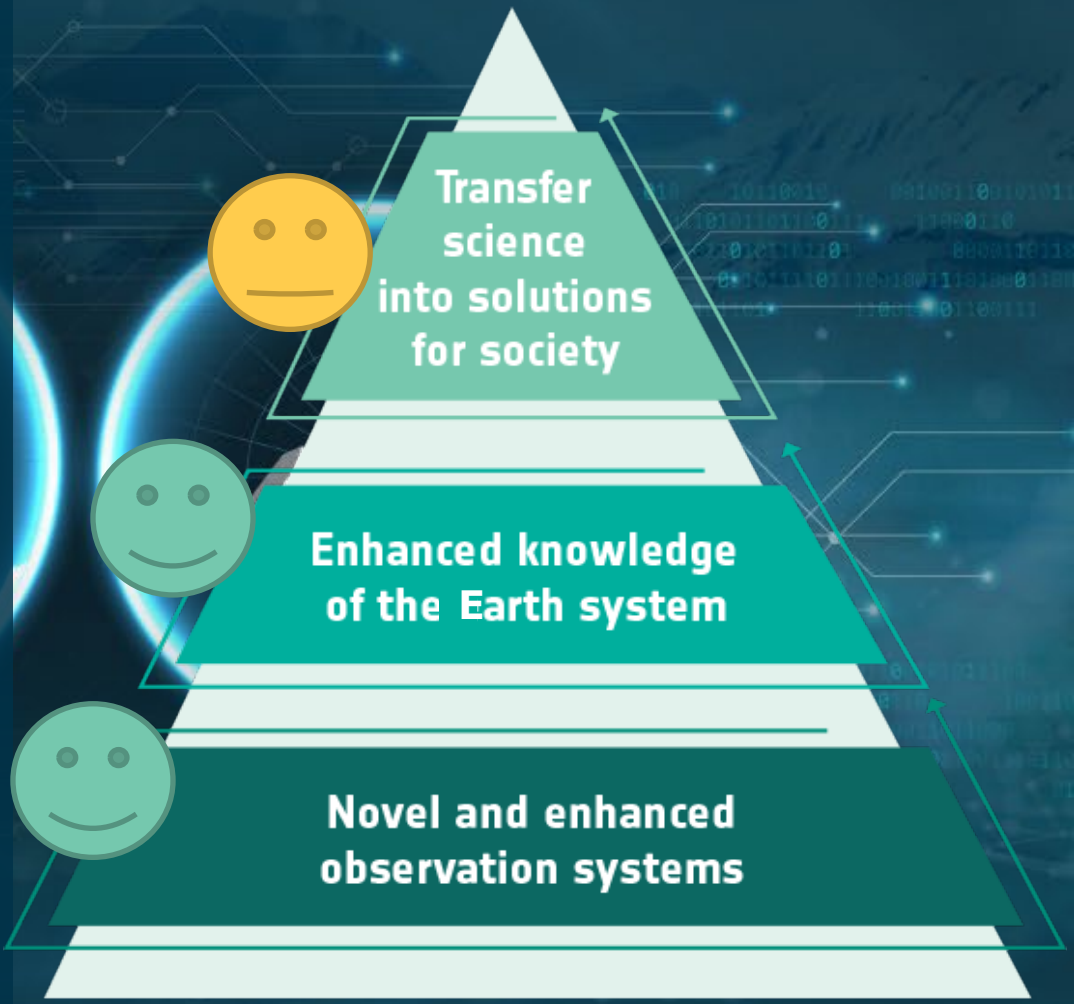
Energy and Environment

Worrying new research finds that the ocean is cutting through a key Antarctic ice shelf

By Chris Mooney October 11

ESA Polar Science Cluster - Objectives

- *We have developed an unique dataset providing an advanced and comprehensive view of major Polar processes across all domains.. (and more coming)*
- *We have used those new datasets to generated a significant number of scientific results providing new evidence of change, unknown processes and potential evolution of the system… (more in preparation)*
- *We have also started to exploit ITC capability to bring together data (satellite, in-situ…) with cloud computing and processing capabilities to offer an integrated and collaborative research environment … More to be done..*
- *More work needed to ensure these results have an impact beyond science and may have a direct impact on society, specially local populations…*



Some points on more urgent “pragmatic aspects”

Urgent need for ensuring a systematic generation of novel “successful” datasets

Urgent need to bring all datasets together in an advance open science platform

Urgent need to bring together results into a synthesis “paper” and outreach effort beyond the EO community

Huge opportunities for synergistic process studies across teams (ESA, EC,..)

LPS22

Monitoring change

- In 2011–2020 annual average Arctic sea ice area reached its lowest level since at least 1850 (*high confidence*). Late summer Arctic sea ice area was smaller than at any time in at least the past 1000 years (*medium confidence*).
- There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large internal variability.
- The global pattern of glacier retreat, with almost all of the world's glaciers retreating synchronously, since the 1950s is unprecedented in at least the last 2000 years (*medium confidence*).
- Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.
- Permafrost temperatures have increased to record high levels (1980s–present) (very high confidence) including the recent increase by 0.29ºC ± 0.12ºC from 2007 to 2016 averaged across polar and high mountain regions globally. Arctic and boreal permafrost contain 1400–1600 Gt organic carbon, almost twice the carbon in the atmosphere (medium confidence).
- There is medium evidence with low agreement whether northern permafrost regions are currently releasing additional methane and CO2 due to thaw. Permafrost thaw and glacier retreat have decreased the stability of high mountain slopes (high confidence).

Attribution:

- Human influence is *very likely* the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019 (about 40% in September and about 10% in March).
- Human influence *very likely* contributed to the decrease in Northern Hemisphere spring snow cover since 1950.
- It is *very likely* that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades, but there is only *limited evidence*, with *medium agreement*, of human influence on the Antarctic Ice Sheet mass loss.

Predictions:

- It is *virtually certain* that the Arctic will continue to warm more than global surface temperature, with *high confidence* above two times the rate of global warming.
- The Arctic is projected to experience the highest increase in the temperature of the coldest days, at about 3 times the rate of global warming (*high confidence*). With additional global warming, the frequency of marine heatwaves will continue to increase (*high confidence*), particularly in the tropical ocean and the Arctic (*medium confidence*).
- Additional warming is projected to further amplify permafrost thaw and loss of seasonal snow cover, of land ice and of Arctic sea ice (*high confidence*).
- The Arctic is *likely* to be practically sea ice free in September at least once before 2050 under the five illustrative scenarios presented in this report, with more frequent occurrences for higher warming levels. There is *low confidence* in the projected decrease of Antarctic sea ice.
- Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*).
- Loss of permafrost carbon following permafrost thaw is irreversible at centennial timescales (*high confidence*).
- Continued ice loss over the 21st century is *virtually certain* for the Greenland Ice Sheet and *likely* for the Antarctic Ice Sheet. There is *high confidence* that total ice loss from the Greenland Ice Sheet will increase with cumulative emissions.
- There is *limited evidence* for low-likelihood, high-impact outcomes (resulting from ice sheet instability processes characterized by deep uncertainty and in some cases involving tipping points) that would strongly increase ice loss from the Antarctic Ice Sheet for centuries under high GHG emissions scenarios
- The probability of low-likelihood, high impact outcomes increases with higher global warming levels (*high confidence*). Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice sheet melt and forest dieback, cannot be ruled out (*high confidence*).

Need for an observation effort and advanced systematic observations of onset and magnitude of change

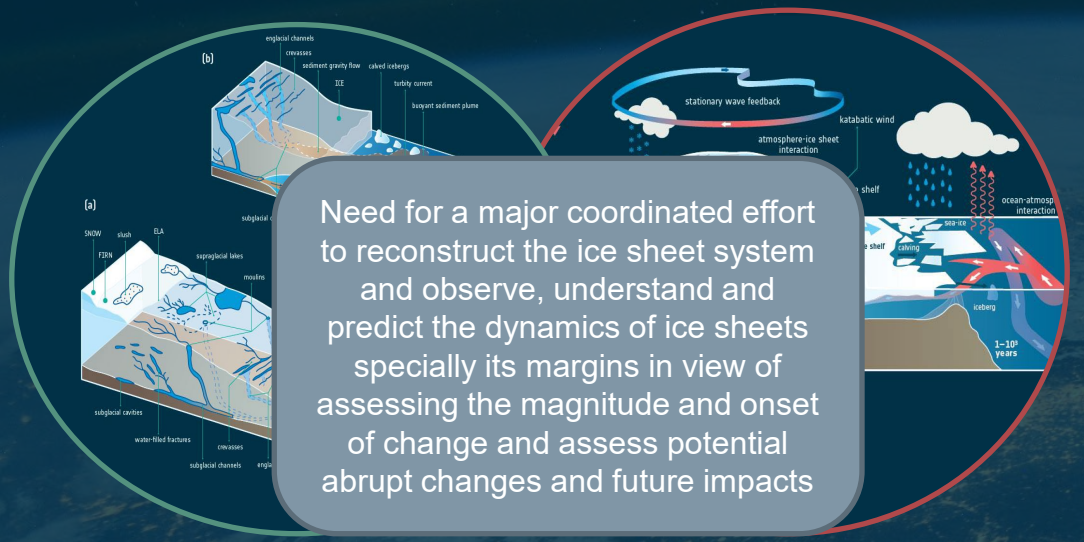
Need for an advanced capacity to early identification of abrupt responses

Need for a better understanding of drivers of change both natural and anthropogenic

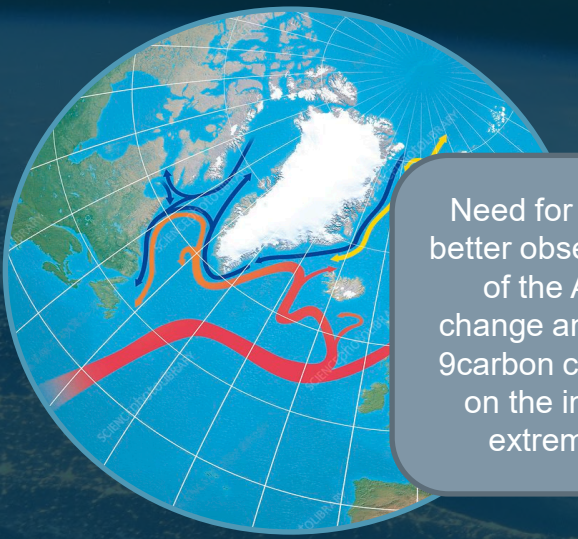
Need for an enhanced capacity to asses and predict the impacts

Need for an enhanced understanding of portly known processes and transfer to models

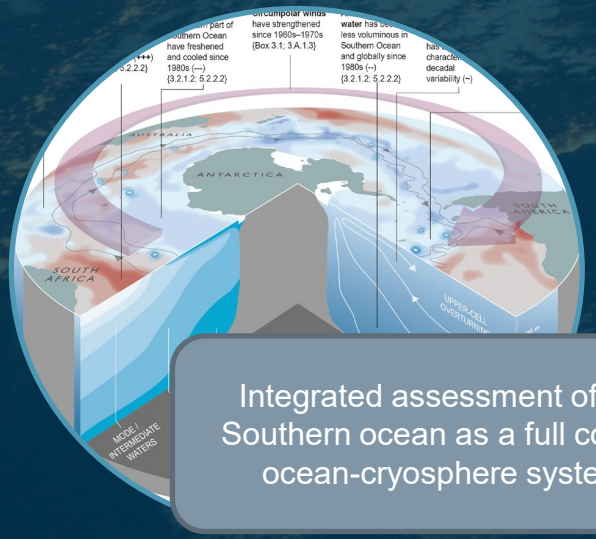
Huge Challenges for the future



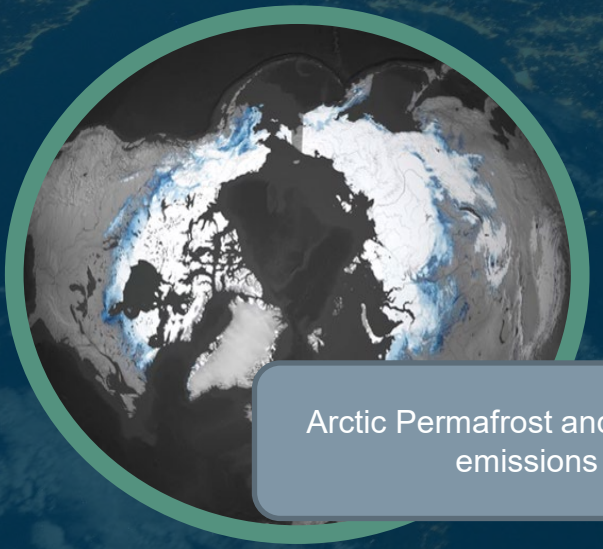
Need for a major coordinated effort to reconstruct the ice sheet system and observe, understand and predict the dynamics of ice sheets specially its margins in view of assessing the magnitude and onset of change and assess potential abrupt changes and future impacts



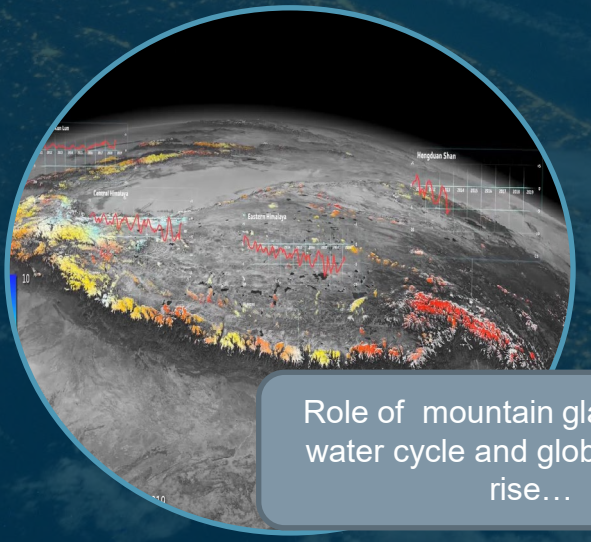
Need for a major coordinated effort to better observe and understand evolution of the Arctic ocean under climate change and its role in the Earth system 9carbon cycle, water cycles) with focus on the impacts of Arctic application, extremes, and freshwater fluxes



Integrated assessment of the Southern ocean as a full couple ocean-cryosphere system

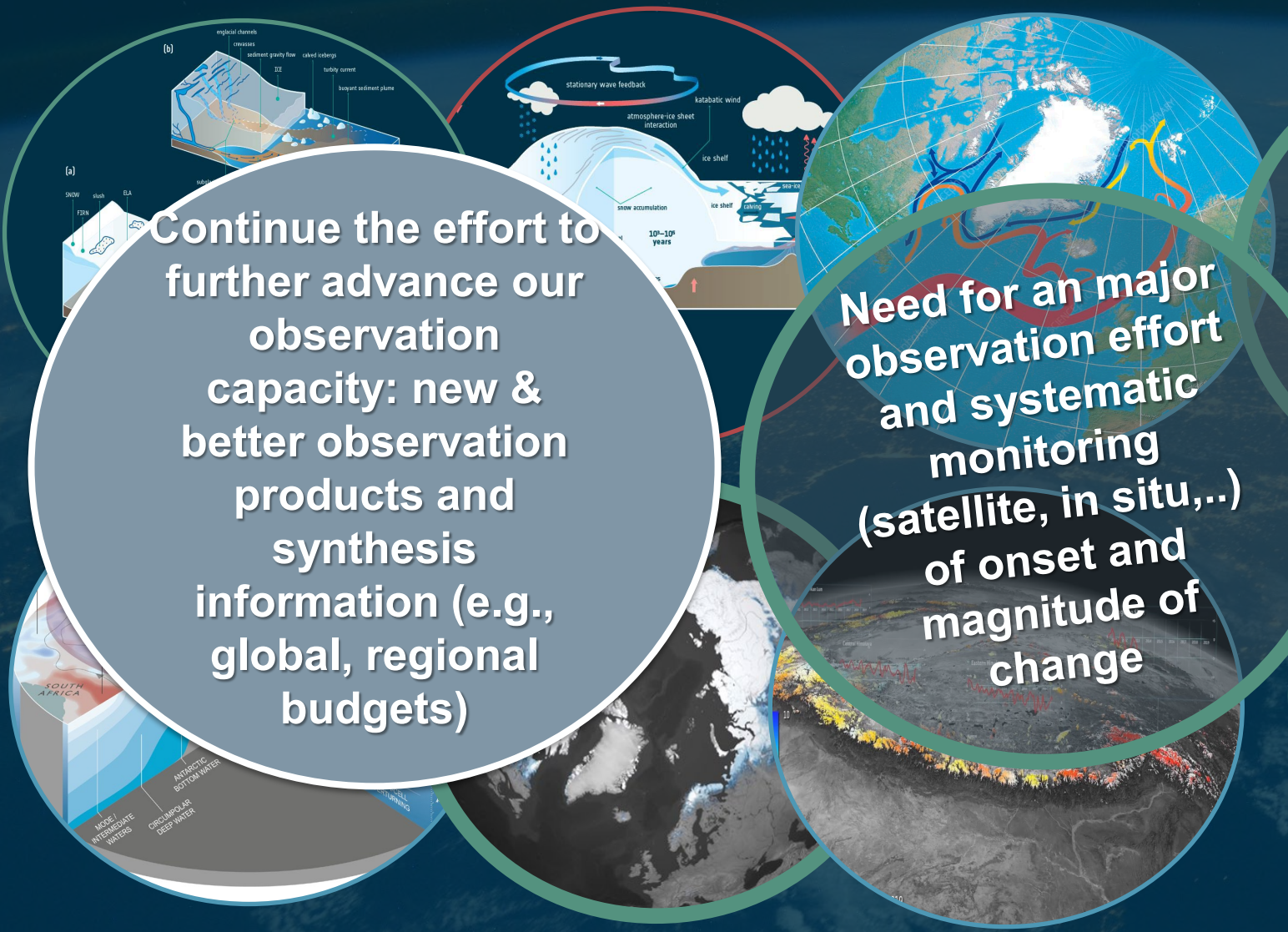


Arctic Permafrost and methane emissions



Role of mountain glaciers in the water cycle and global sea level rise…

Huge Challenges but also an unique opportunity



Continue the effort to further advance our observation capacity: new & better observation products and synthesis information (e.g., global, regional budgets)

Need for an major observation effort and systematic monitoring (satellite, in situ,..) of onset and magnitude of change

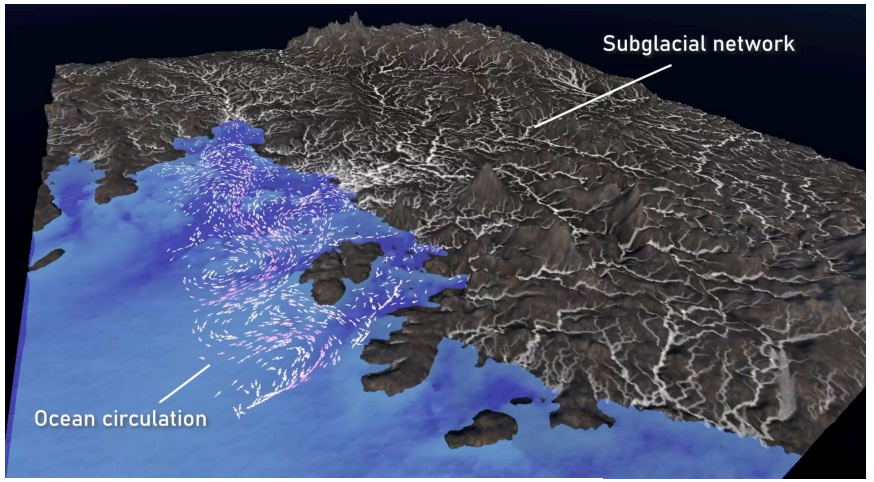
Need for an advanced capacity to early identification of abrupt responses

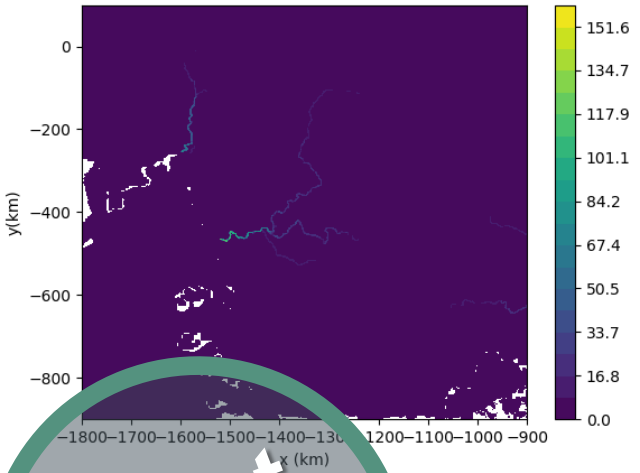
Need for a better understanding of drivers of change both natural and anthropogenic

Need for an enhanced capacity to asses and predict the impacts on society

Need for an enhanced understanding of portly known processes and transfer to models

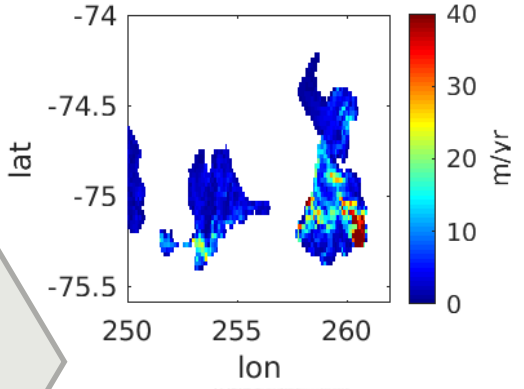
Connecting dots: data, models, what if scenarios

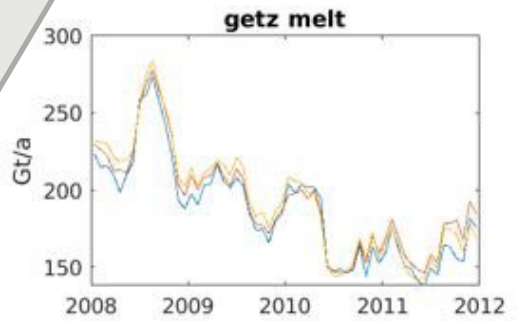


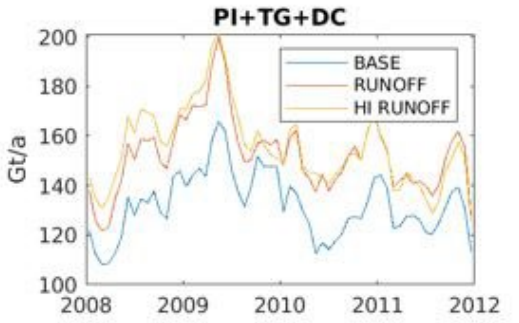


Assessment: Subglacial flux (run-off) calculated from basal inversion of satellite based velocities and heat-flux

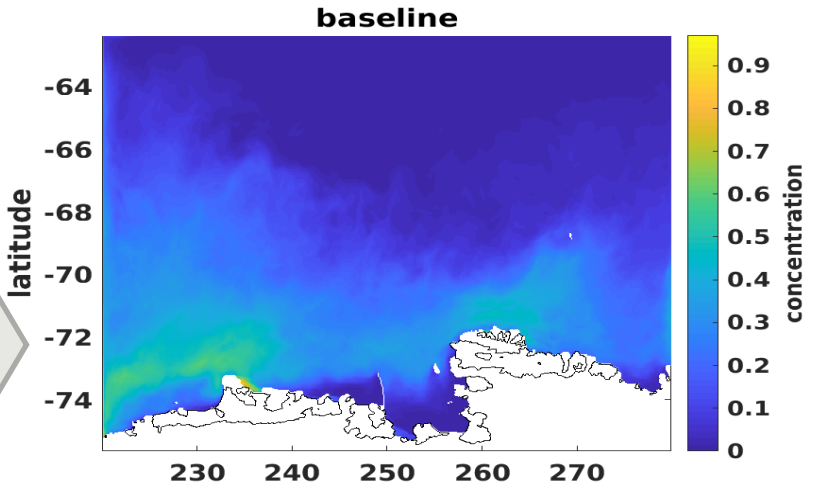
What-if: Doubled basal dissipation simulating a high run-off.

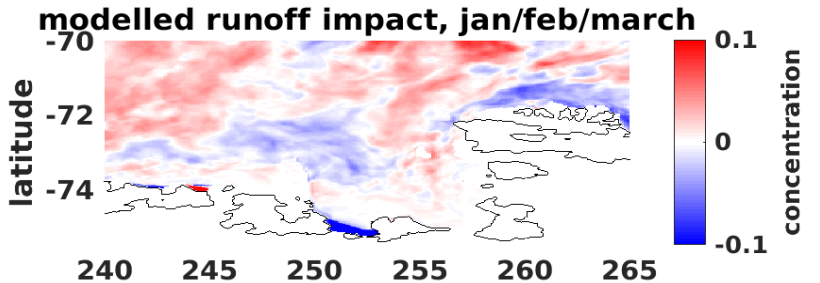


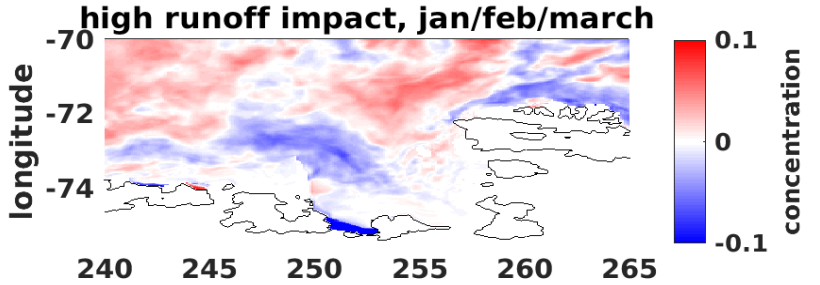




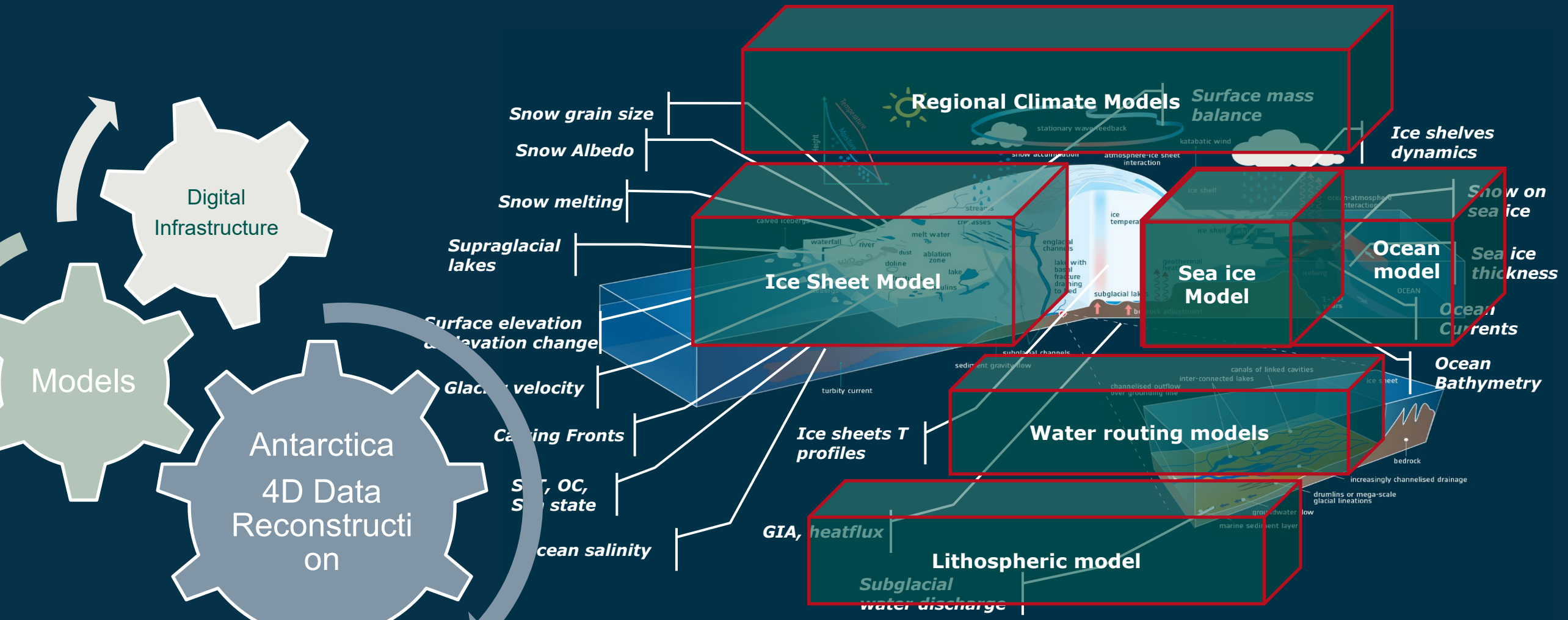
Time series of melt under major ice shelves







Need for an integrated reconstruction of the Ice Sheets



An example: Digital Twin Antarctica (prototype)