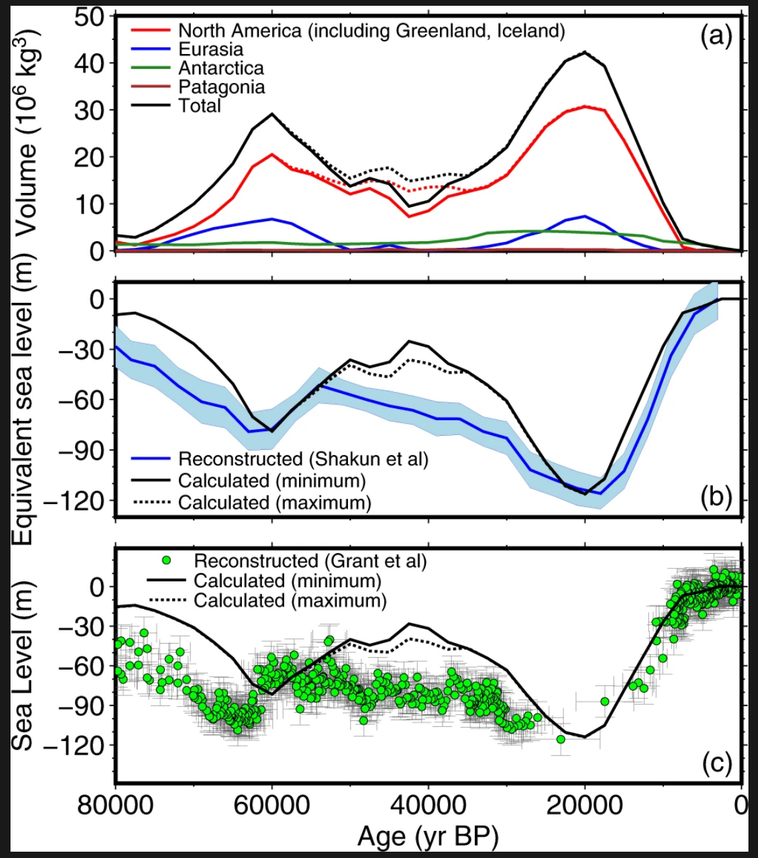
A Tango between Ice and Sea level

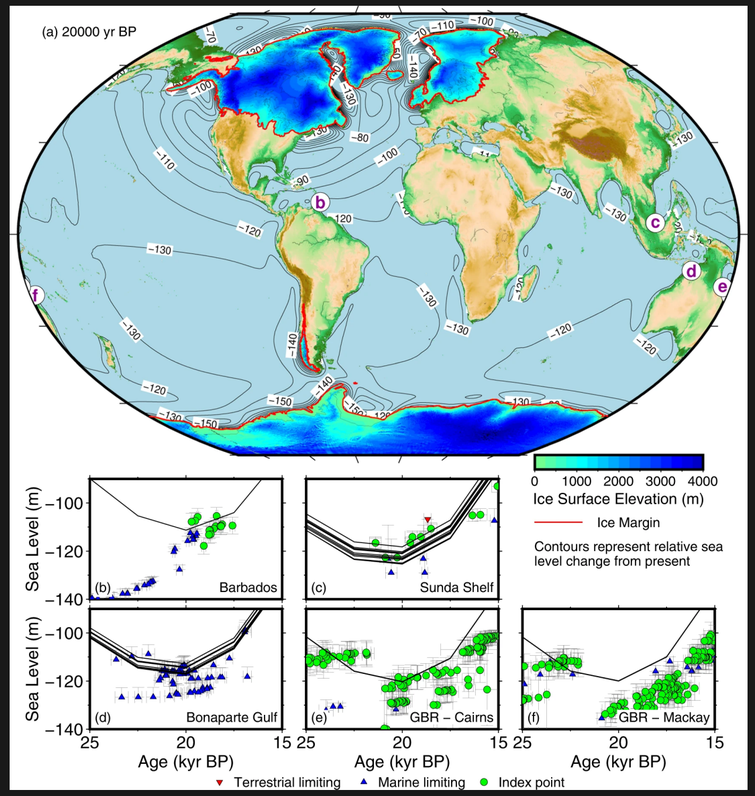
Roelof Rietbroek, with contributions from Ingo Sasgen, Thomas Frederikse, Andreas Groh, Riccardo Riva

Relevant ICCC joint working groups:

- JWG C.3: Geodesy for the Cryosphere: advancing the use of geodetic data in polar climate modelling
- JWG C.4: Sea level and vertical land motion

They've been dancing since the last Quaternary (~2.6 Million yrs bp)





Evan Gowan et al. 2021

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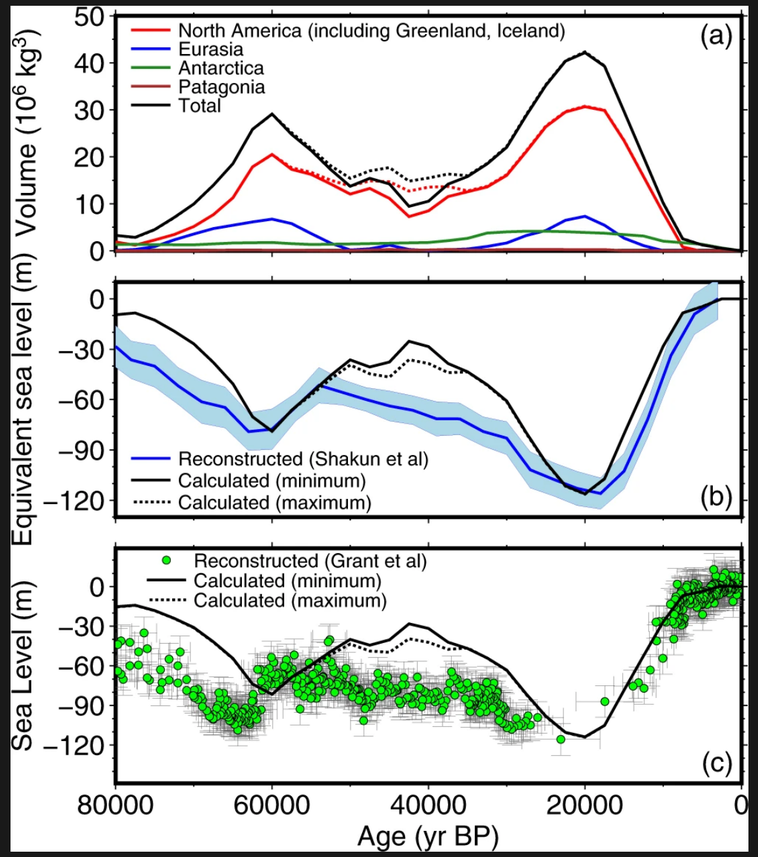

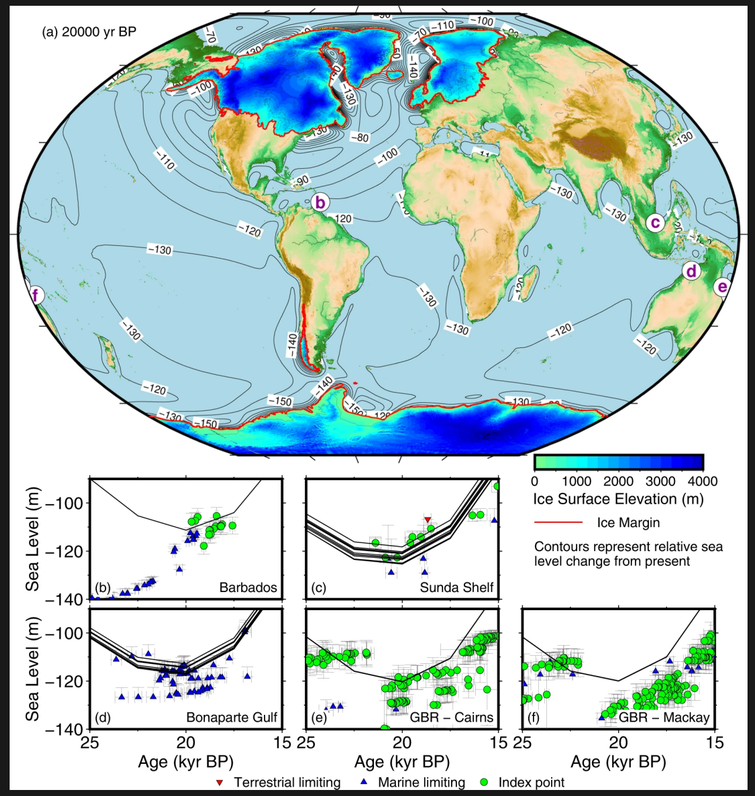

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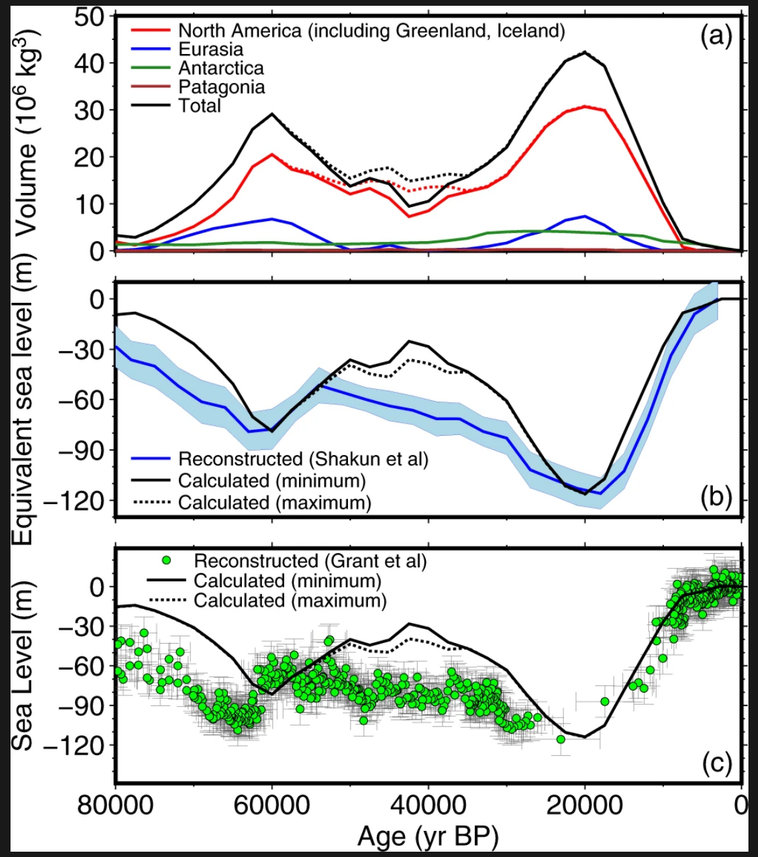

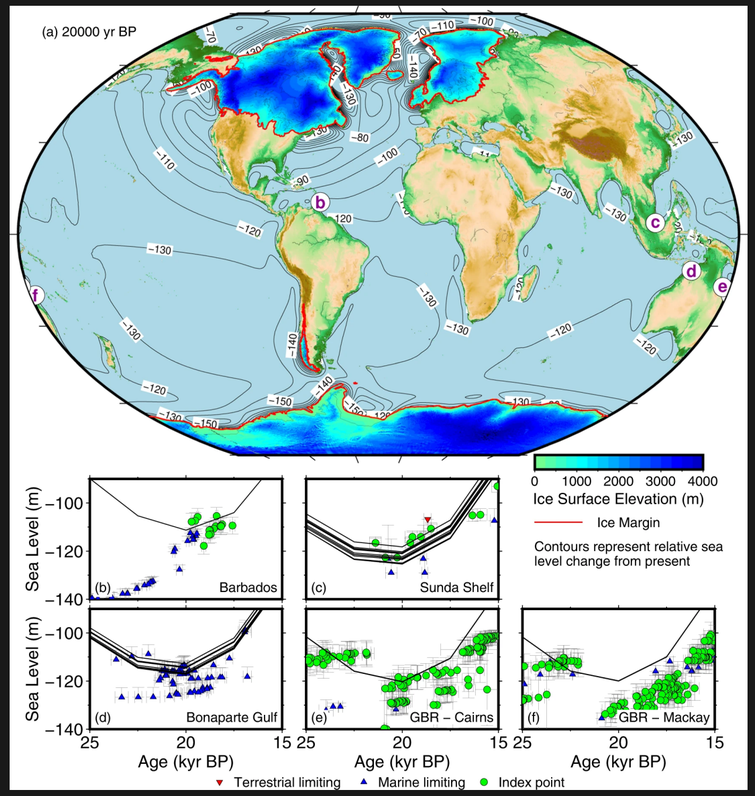

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- How do we know? sea level indicators and proxies: corals, oxygen isotopes,..

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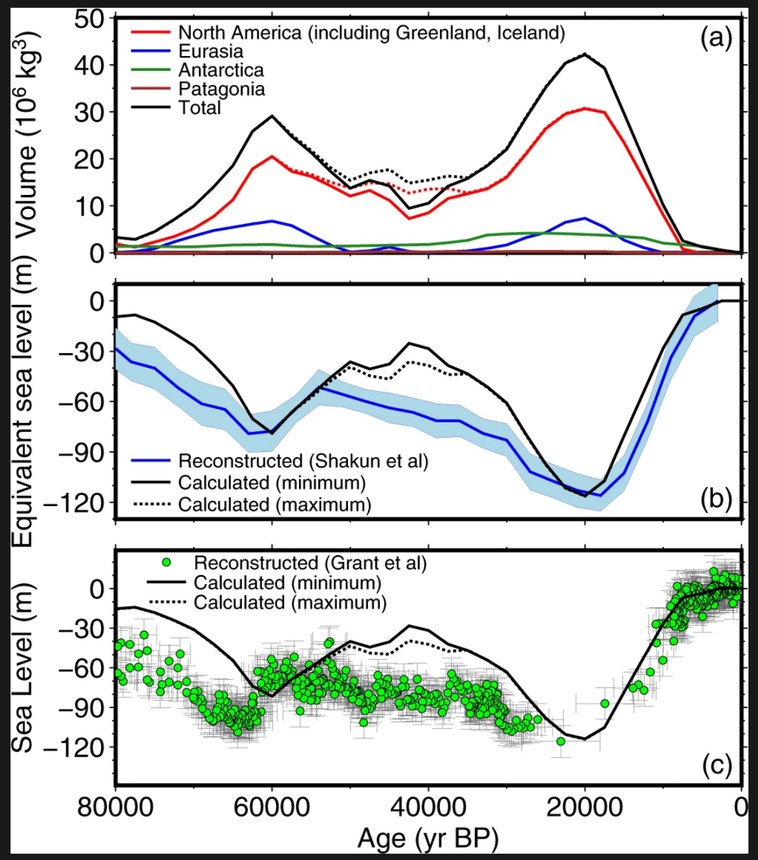

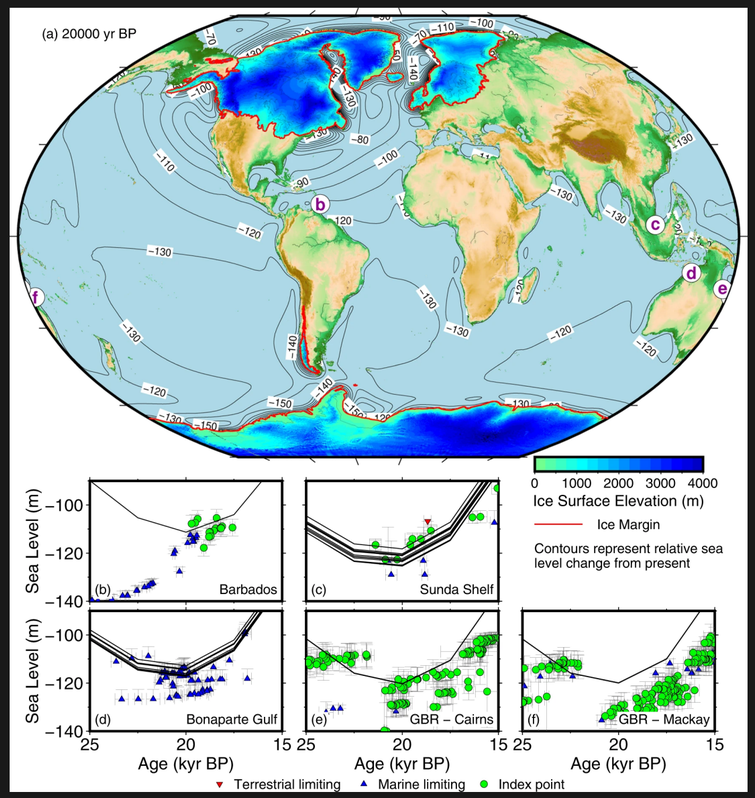

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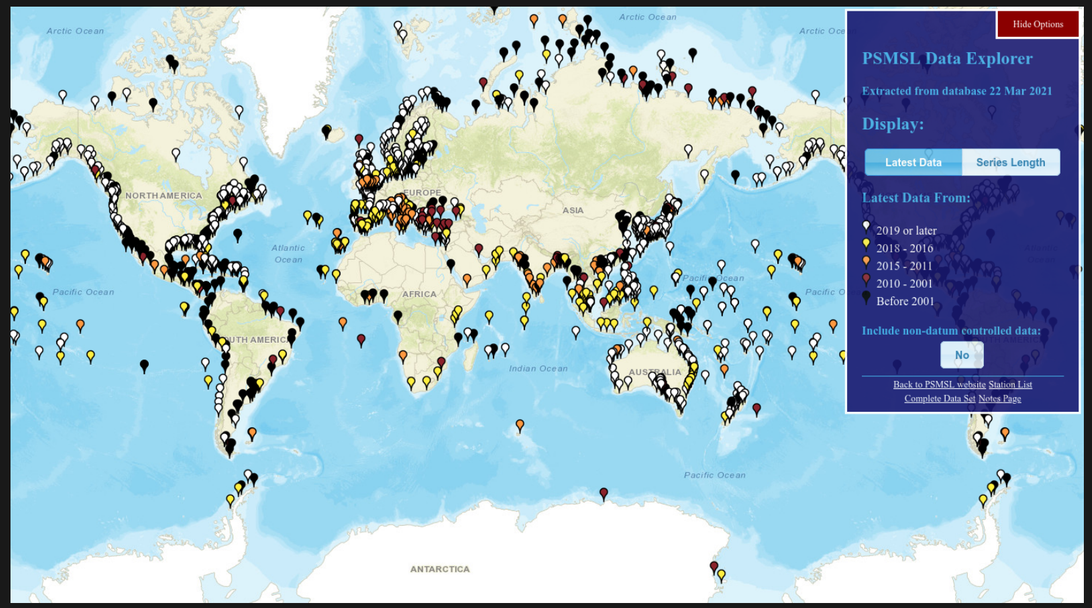
- Sealevel 🕺 <-> 🕺▦ ice volume
- How do we know? sea level indicators and proxies: corals, oxygen isotopes,..
- Challenge is to reconcile sea level indicators with physics of glacial isostatic adjustment

Direct observations of sea level: Tide Gauges

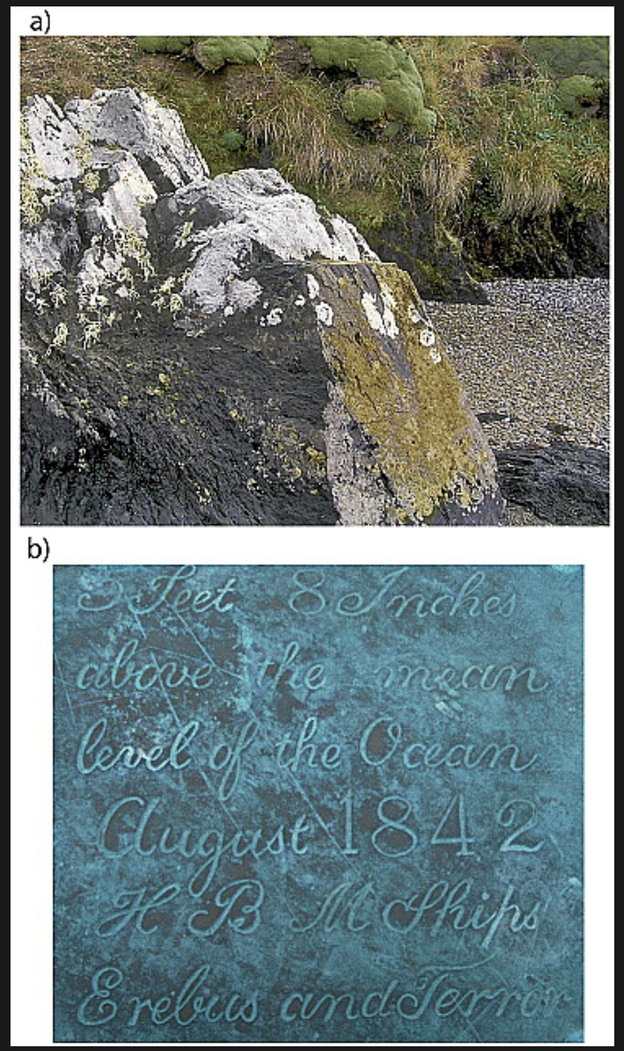


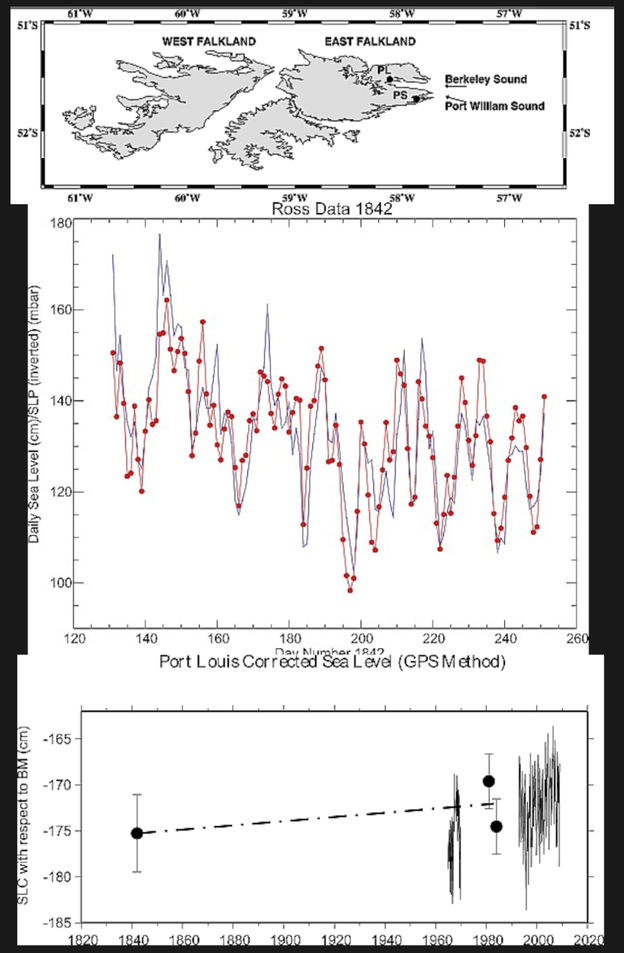
Tide gauge locations from the Permanent Service of Mean Sea level (PSMSL)

Inspection of a Greenland TG, 1926, Credit: NOAA

- Some tide gauge records go back to the 18-19th century!
- Useful for charting tides, but also **relative sea level** rise
- 'Asymmetrical' coverage (space and time)

James Clark Ross' voyage of research and discovery in the Southern Ocean (1839-1843)



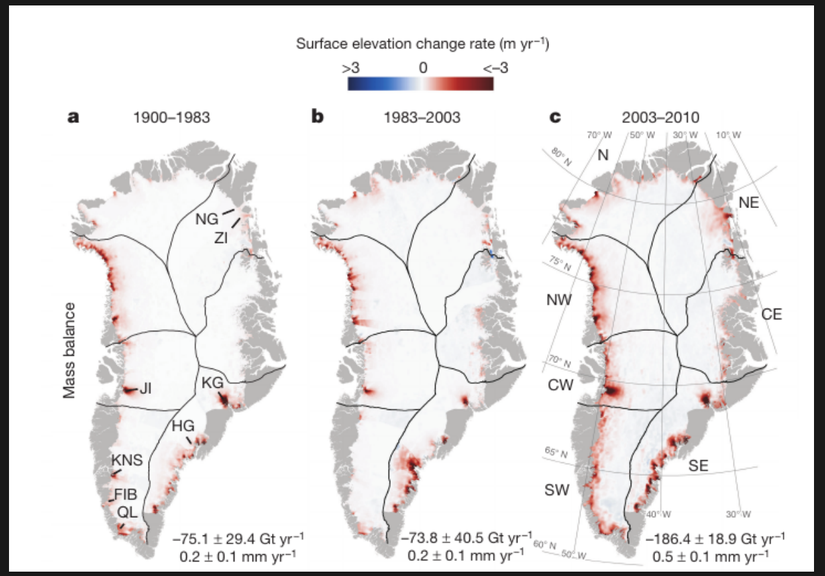


Woodworth et al. 2010

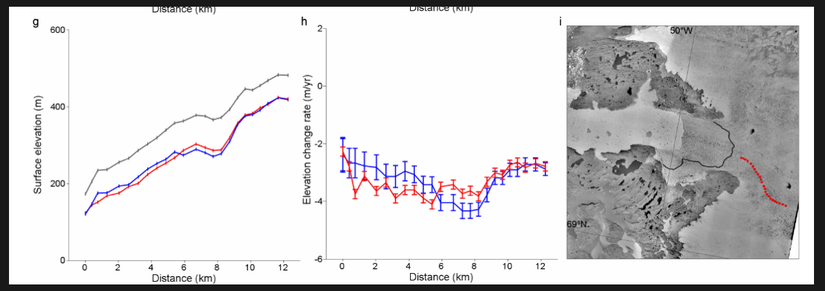
- Take home message: Make benchmarks as indestructible as possible
- 19th century sea level observations (~1 year) in the Falklands (Port Louis)
- Corrections needed: air pressure (IB), Glacial Isostatic Adjustment
- Connecting the history series to more recent records yields a trend estimate of 1.23 ± 0.22 mm/yr (Woodworth et al. 2010)

Using areal photography of Greenland to estimate glacier changes (Kjeldsen et al. 2015)

- Areal photography from the 80's provide early snapshots of the glaciers
- Use geometric relationship to map front locations to glacier mass change
- Identify ice fronts and lateral moraines in DEM to estimate the ice extent in 1900
- Shows and accelerated mass balance from -75+/-29 Gt/yr (1900-1983) to -186+/-19 Gt/yr (2003-2010)



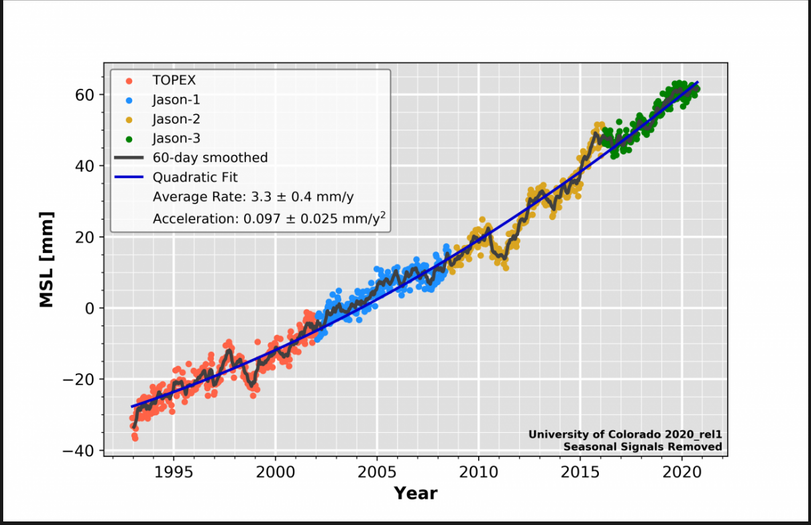
Kjeldsen et al. 2015, Greenland mass change since 1900



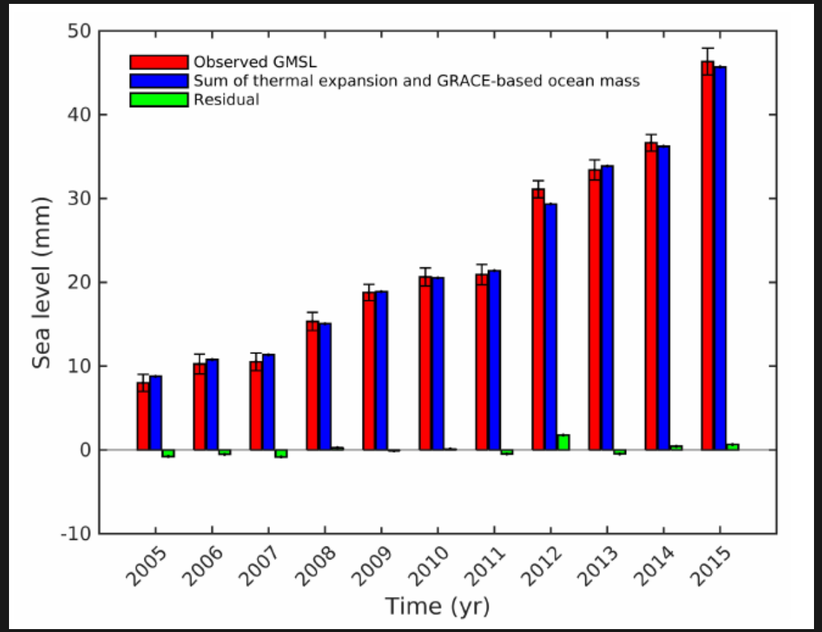
Kjeldsen et al. 2015, Photogrammetic DEM from (1978-1987) overlaid with ice surface elevation from the Nasa Airborne Topographic Mapper (2003)

Observing global mean sea level

- Radar altimetry enabled global observations of sea level
- Global mean sea level is a good metric for the state of the climate (mass and energy accumulation)
- Sea level budget closure over the altimetry era within ~0.3mm/yr (Cazenave et al. 2018)

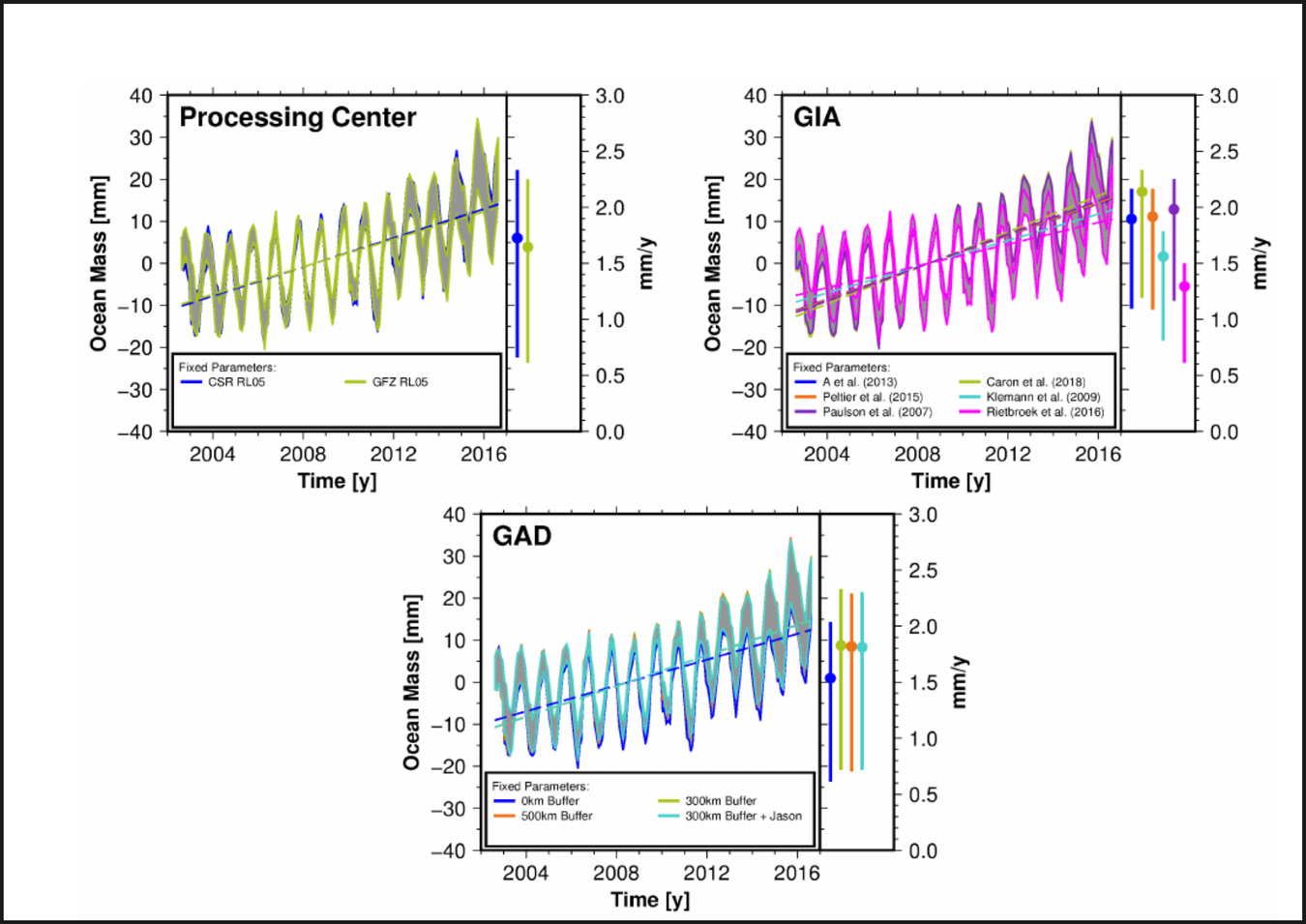


Global mean sea level from altimetry



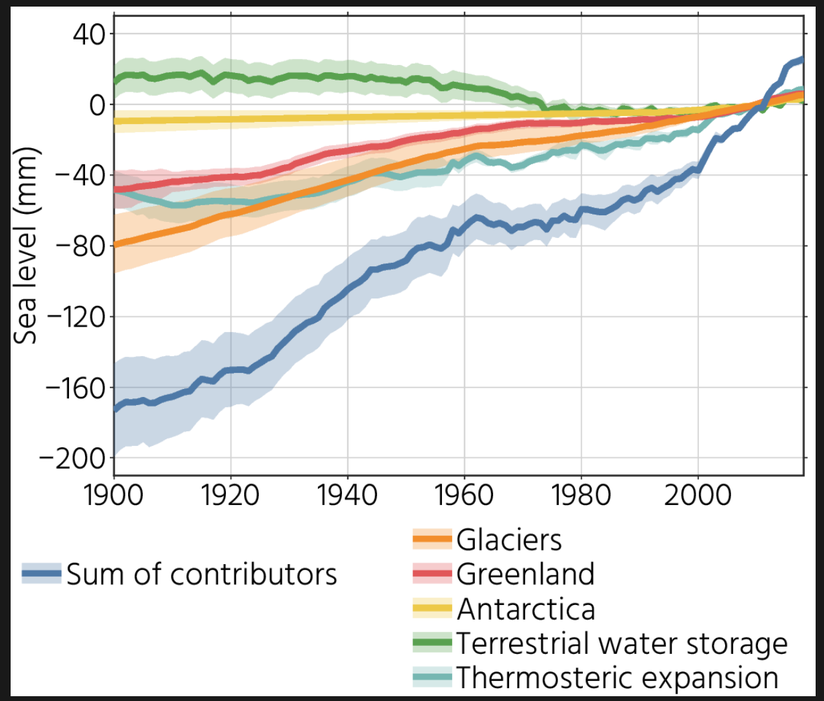
Sea level budget closure from Cazenave et al. 2018

Devil is in the detail: ocean mass from GRACE



Processing choices affect ocean mass estimates Uebbing et al. 2019. GIA correction in Antarctica remains a large error source

Global sea level contributions (Frederikse et al. 2020)



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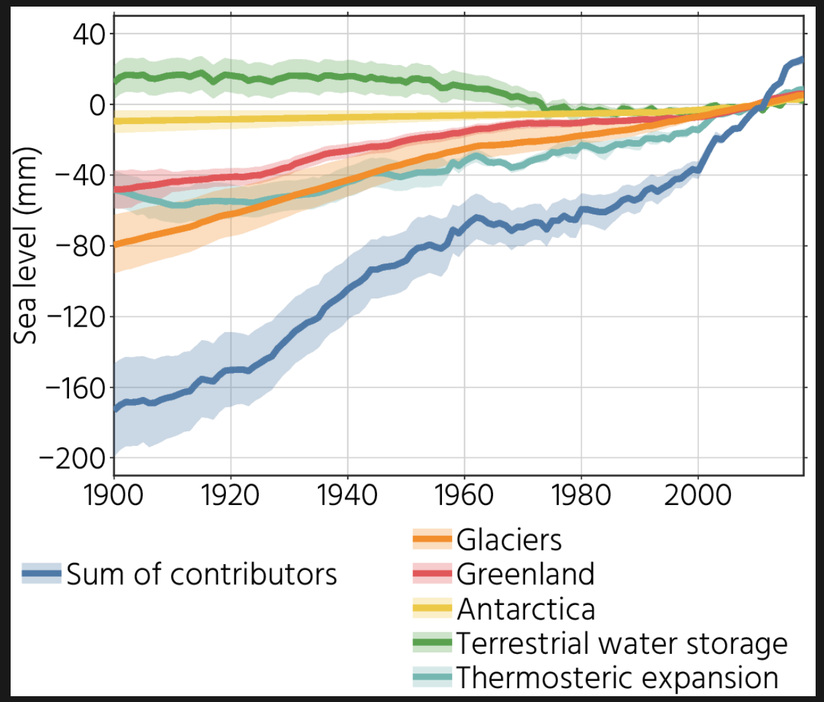
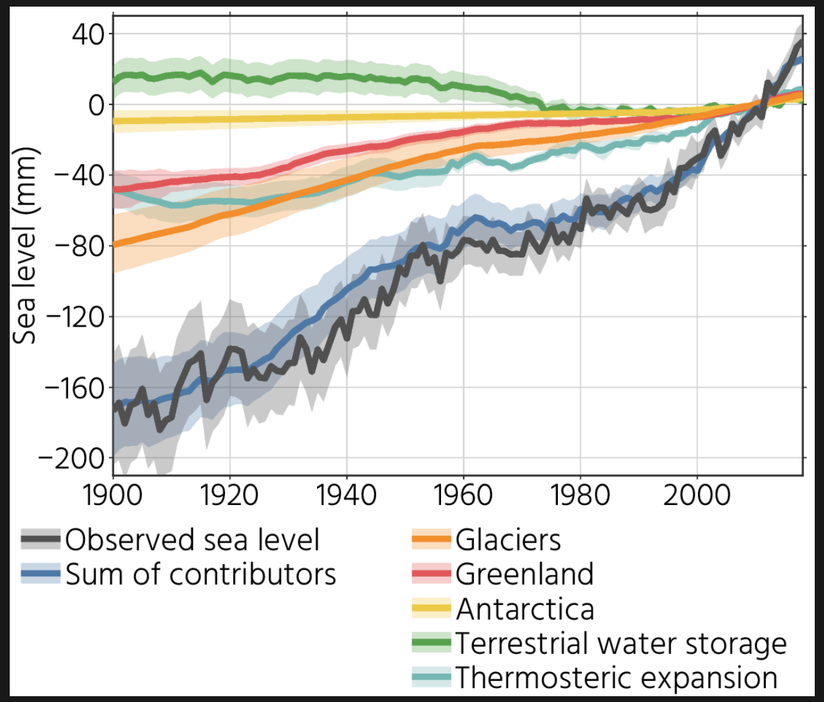
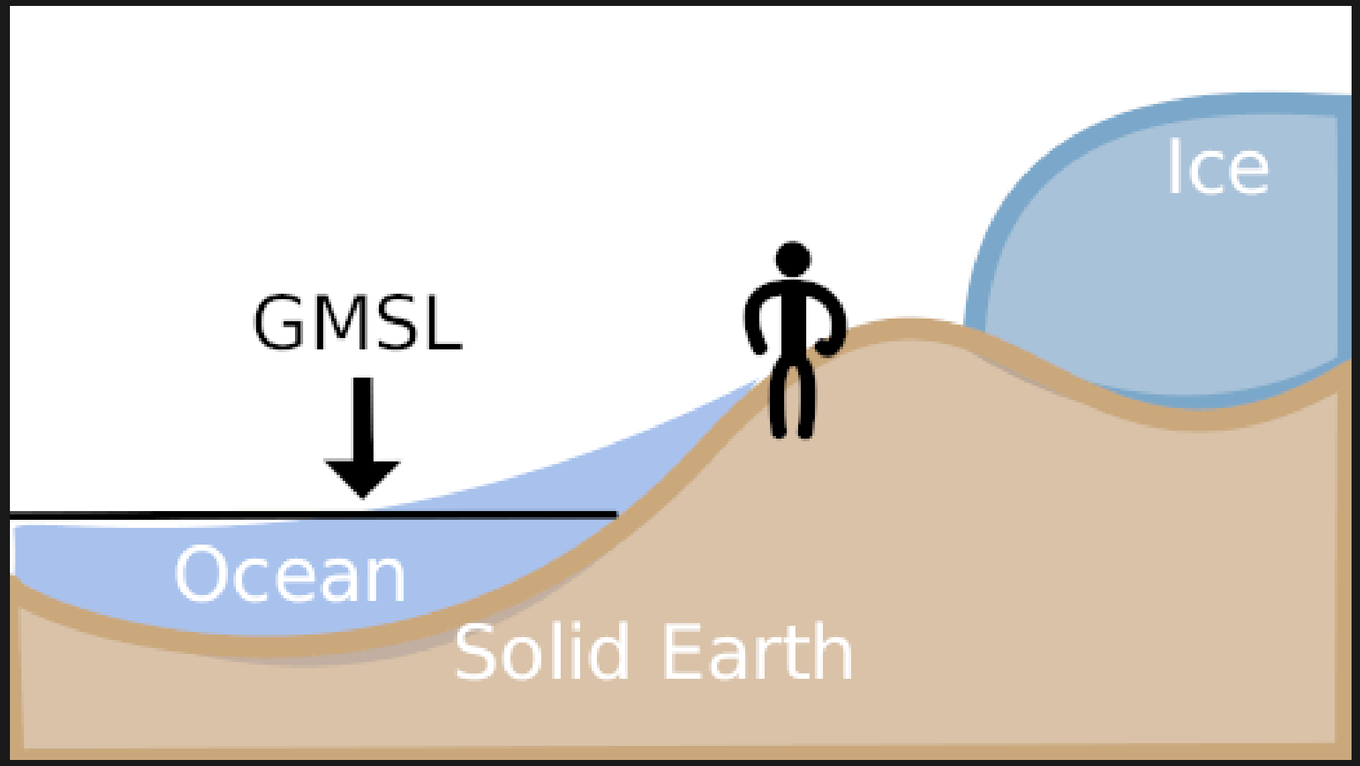


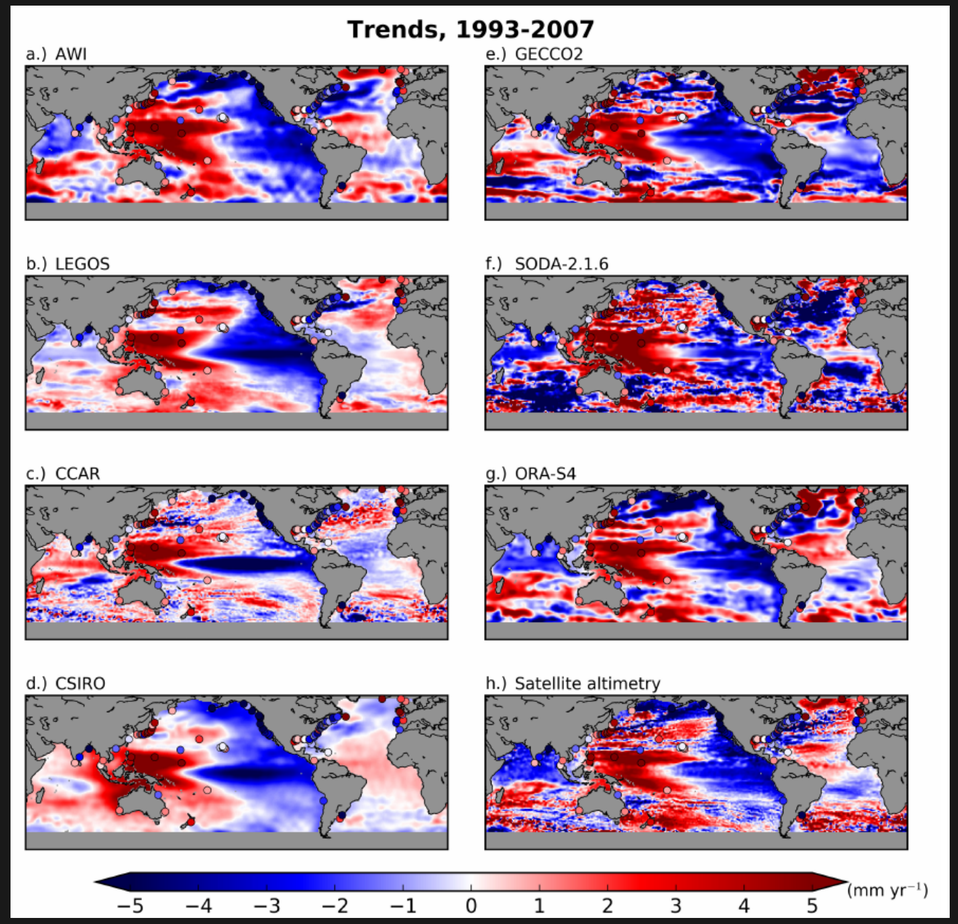


The Bathtub Fallacy

- An oversimplification of the concept of sea level
  - Particularly important when we talk about regional sea level change

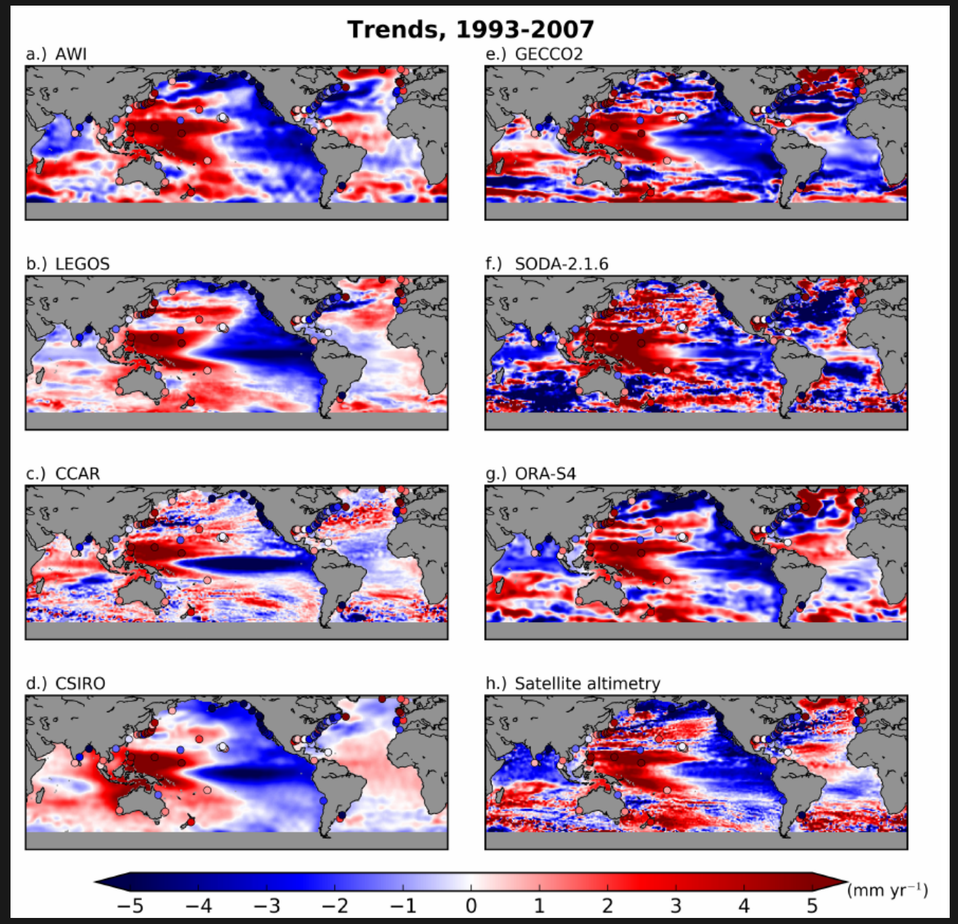


The challenge of regional Sea level



From Carson et al. 2017

The challenge of regional Sea level



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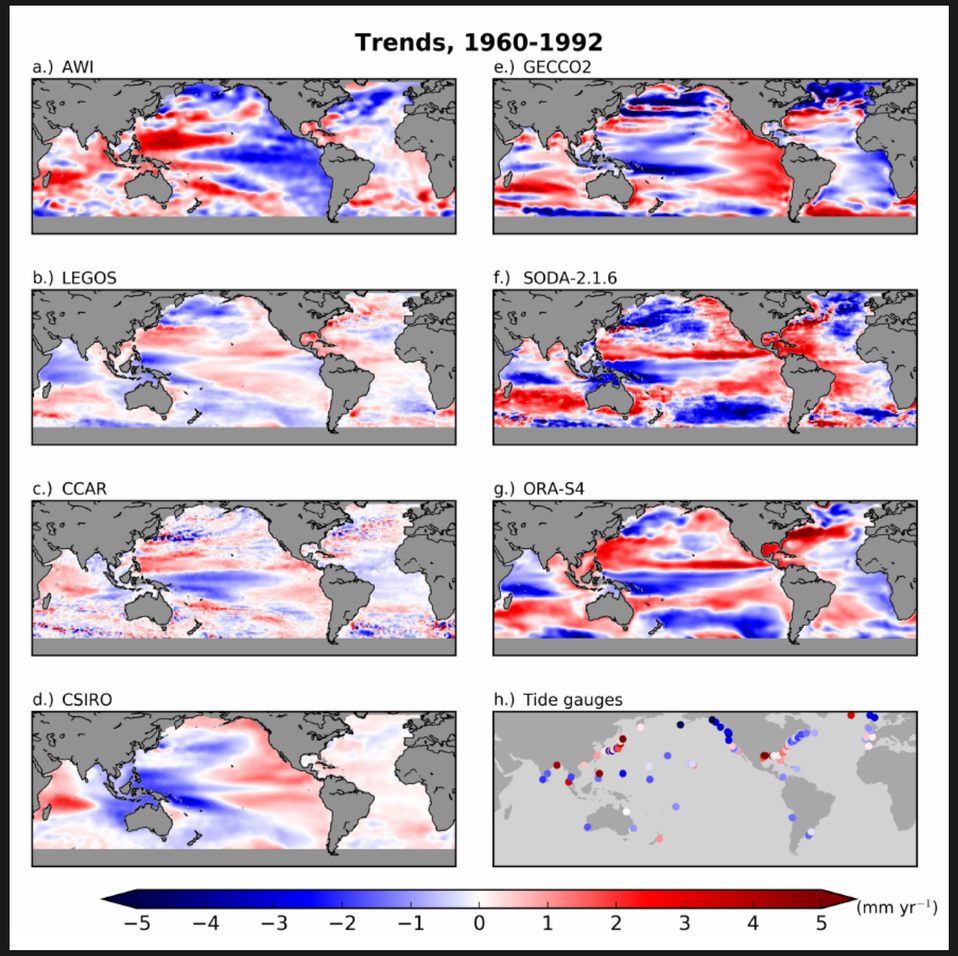
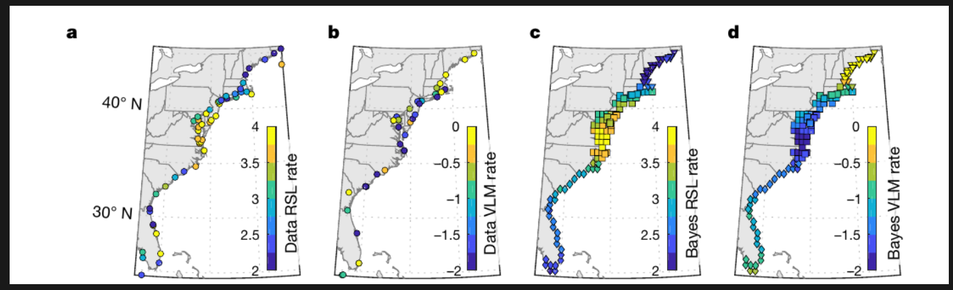


From Carson et al. 2017

Separation of vertical land motion and relative sea level (Piecuch et al. 2018)

- Use of GPS, Tide gauge and proxy RSL records, and GIA ensemble
- Separate GIA-VLM contributions from local/regional VLM effects with Bayesian framework



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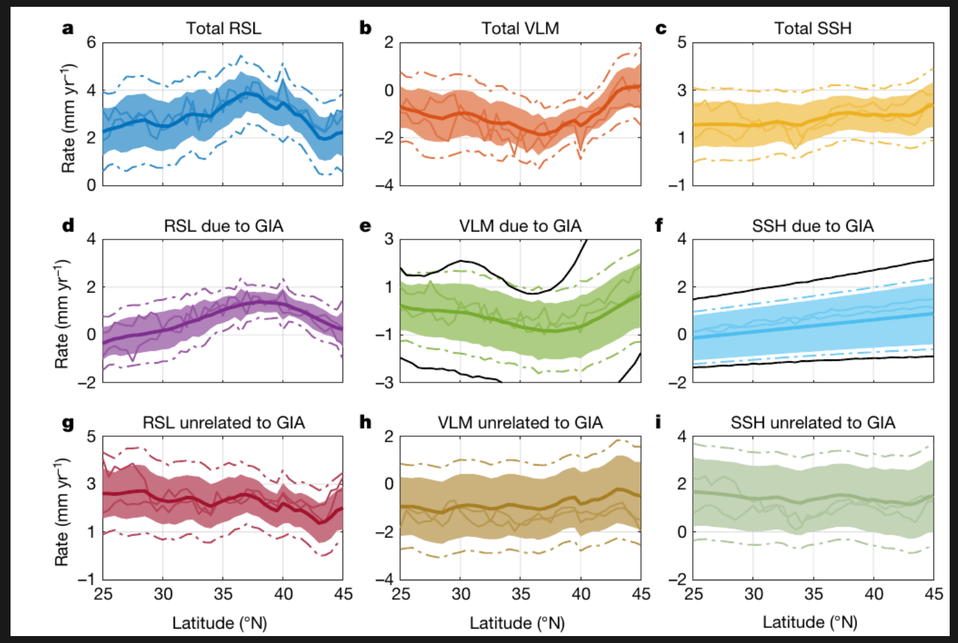
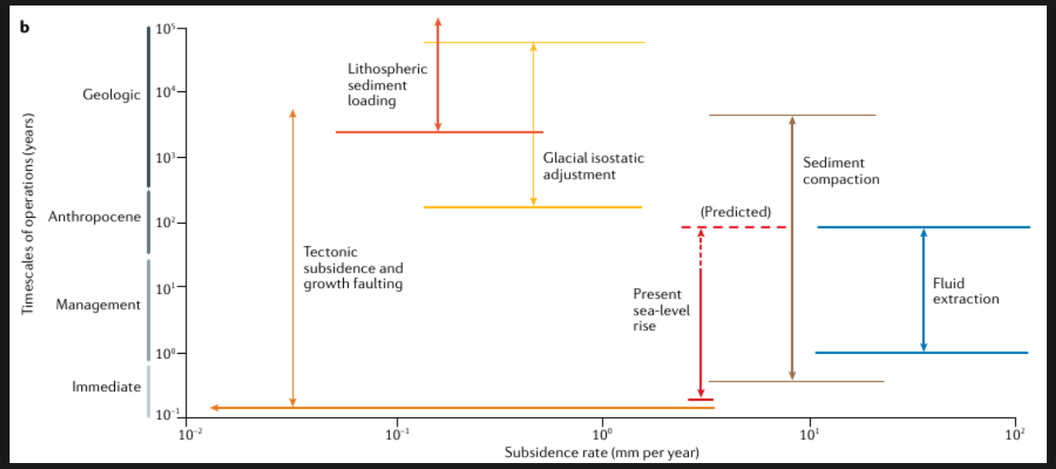


From Piecuch et al. 2018

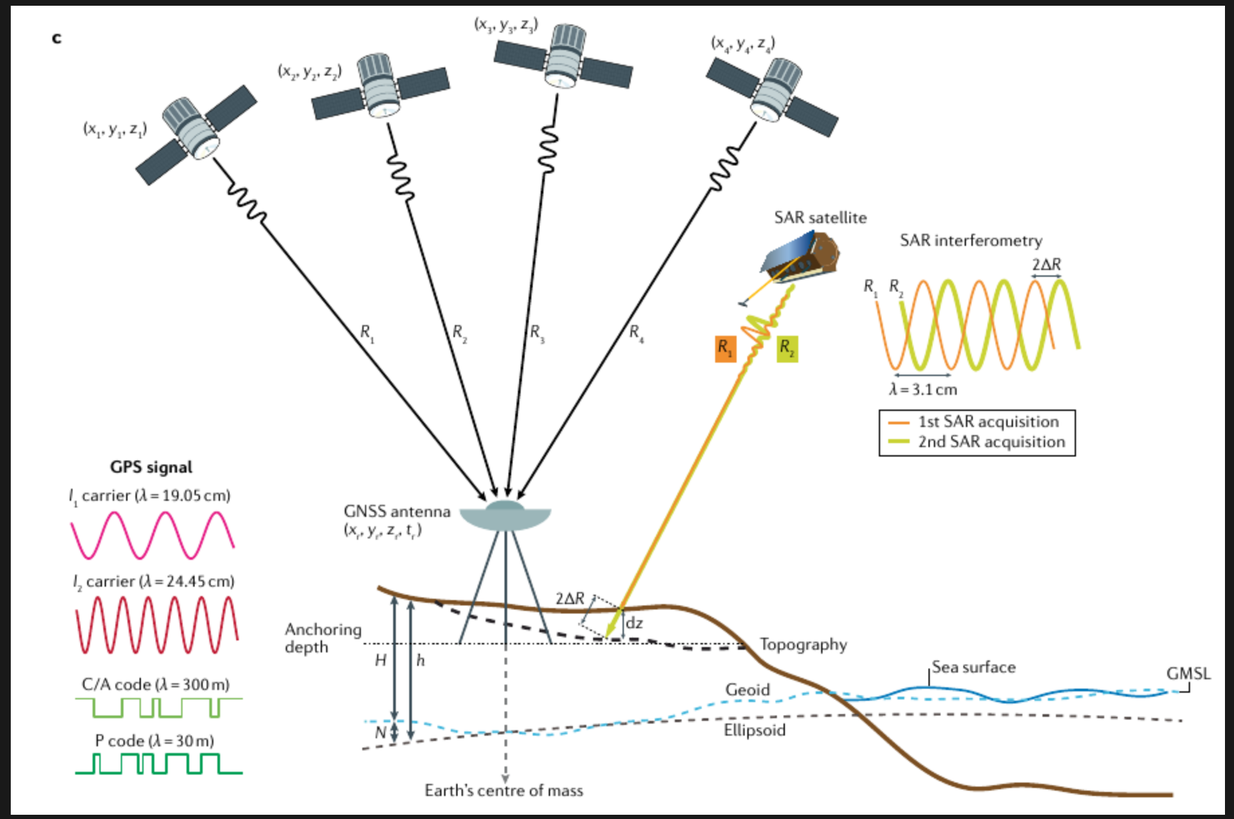
The importance of Vertical Land Motion

Land subsidence in Semarang Indonesia, pic by Lisa Bott, SPP1889 TRANSOCAP, Uni Köln



Shirzaei et al. 2021

Opportunities for combining Sar interferometry and GNSS?



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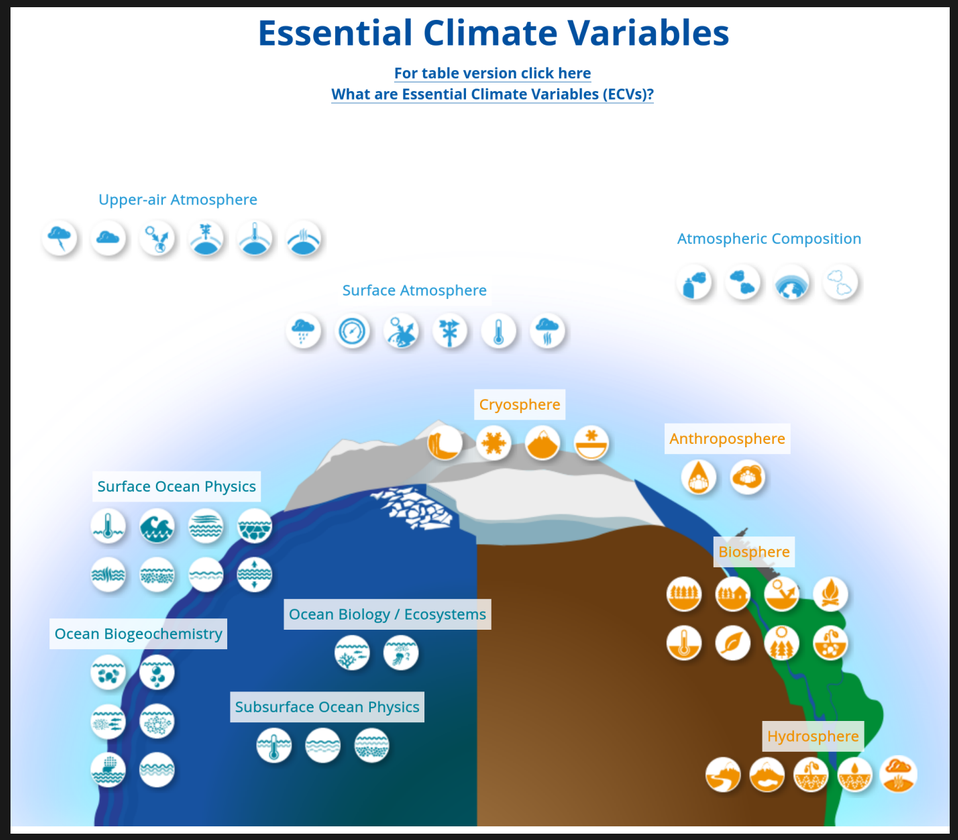
Recap so far

- Thanks to paleo, historic and satellite measurements, we have handles on changes in the ice sheets and sea level
    - Recent accelerations are telling a consistent story of ice mass loss and sea level rise acceleration
    - We have a good idea of the underlying contributors of global mean sea level
- Regional sea level is more challenging
    - Non stationary over time
    - Separation of local from regional vertical land motion
    - But there's considerable progress in "fusion" of geodetic data and separation of different contributors by various inversion methods

Sea level and ice sheets as Essential Climate Variables

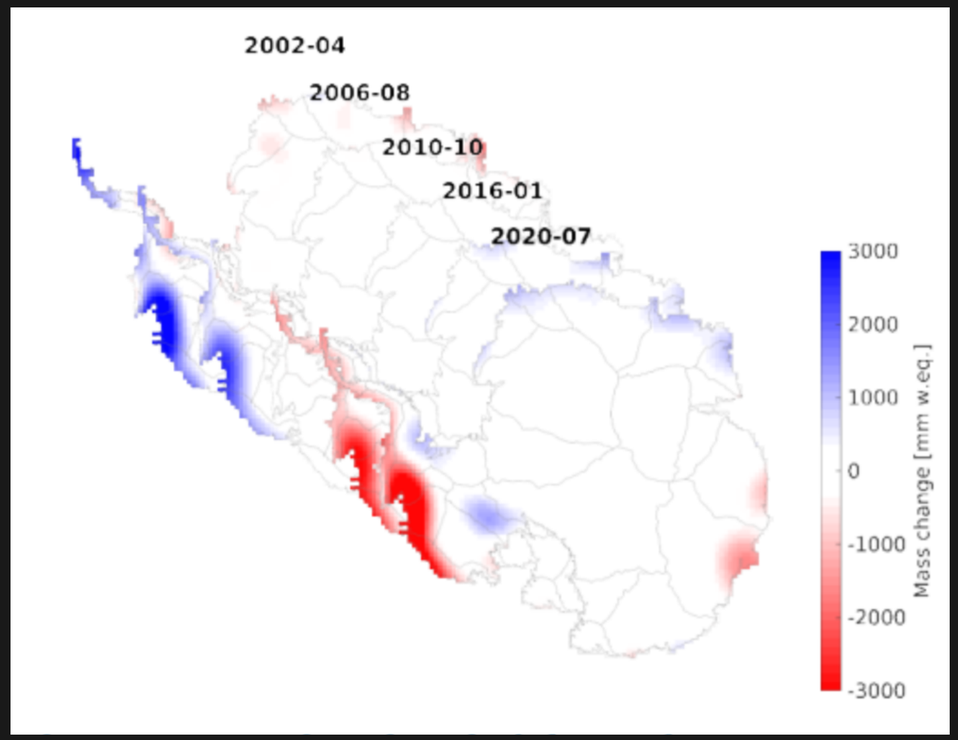


GCOS ECV's

- Not just for scientific purposes, but monitoring ECV's inform policy on mitigation and adaptation decisions
- More inviting for **operational** use (e.g. assimilation)
- **Ice sheets and Ice shelves**
  - Surface elevation
  - Ice velocity
  - Ice mass change
  - Grounding lines and thickness
- **Sea level**
  - global mean sea level
  - regional sea level
  - but missing: vertical land motion...

Example: Antarctic Ice mass changes from the Climate Change Initiative

- Products based on GRACE/GRACE-FO solutions of release CSR RL06
- Download and visualize https://data1.geo.tu-dresden.de/ais_gmb



Courtesy Andreas Groh TU Dresden, gridded product

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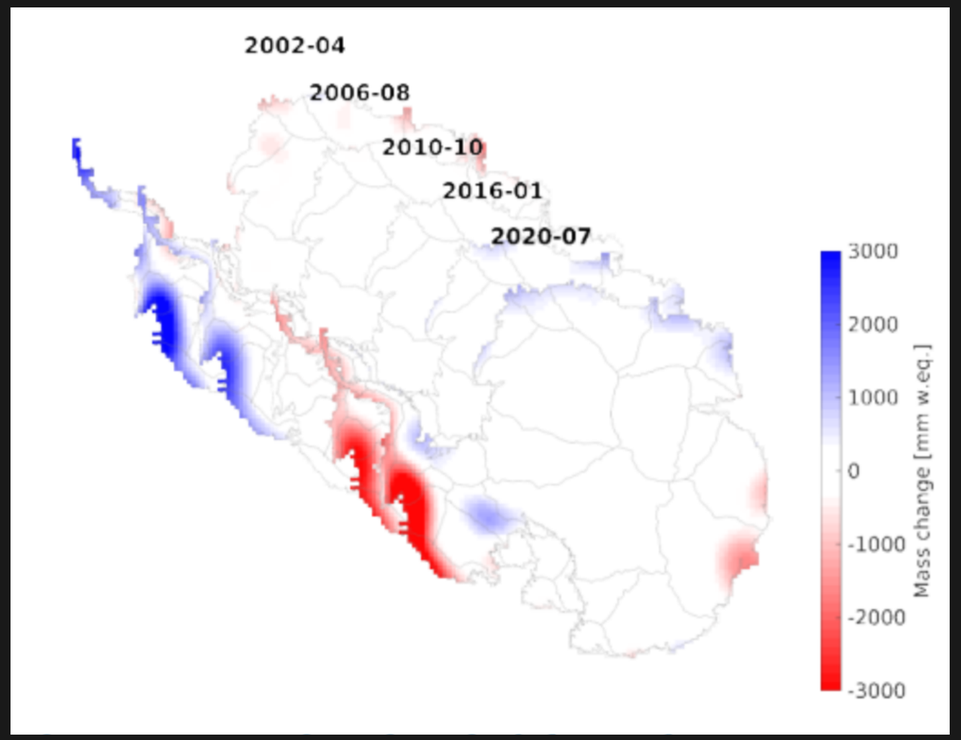

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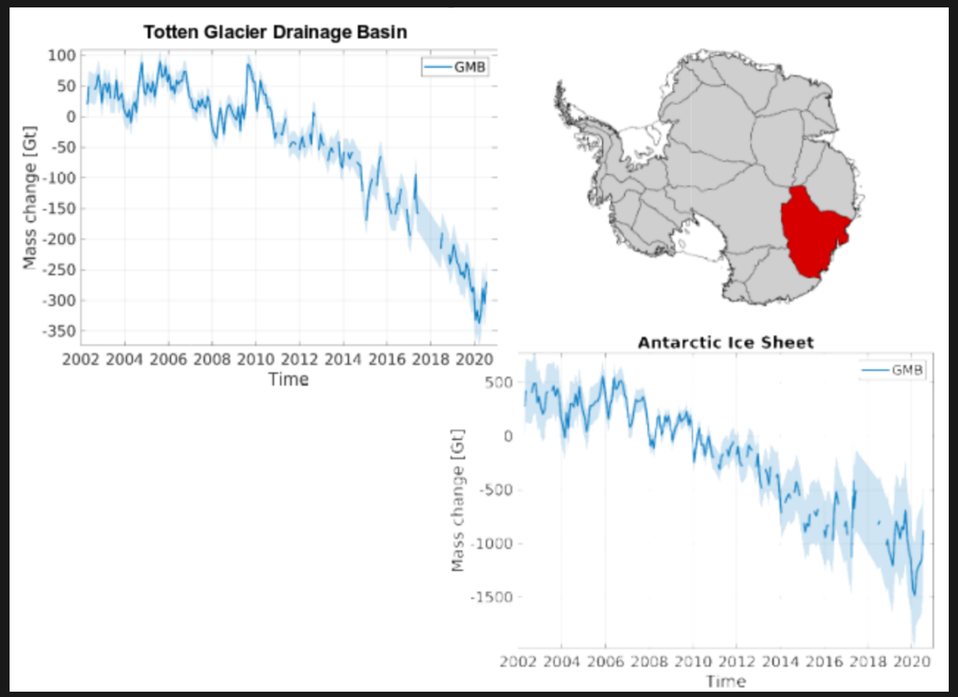

Basin product

Are we dancing for the right audience?

"*If it measures the Earth it's probably geodesy*": Rene Forsberg, during the IAG 2017 Workshop in Bonn

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