

Fizyka Procesów Klimatycznych

Wykład 6

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Wykorzystano slajdy dr Aleksandry Kardaś

Co obejmuje kriosfera?



Lodowce



Thomson Glacier,
Kanada

Gross Aletschgletscher,
Szwajcaria





SHAPE



CONSISTENCY AND DENSITY

Snowflakes , 90% air, $<0.1 \text{ g/cm}^3$

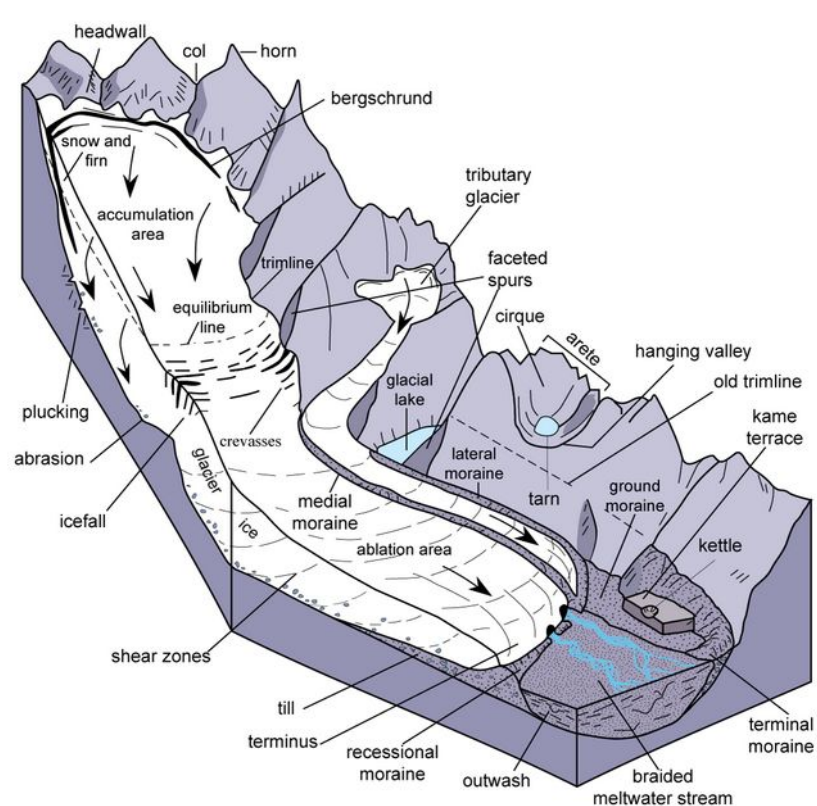
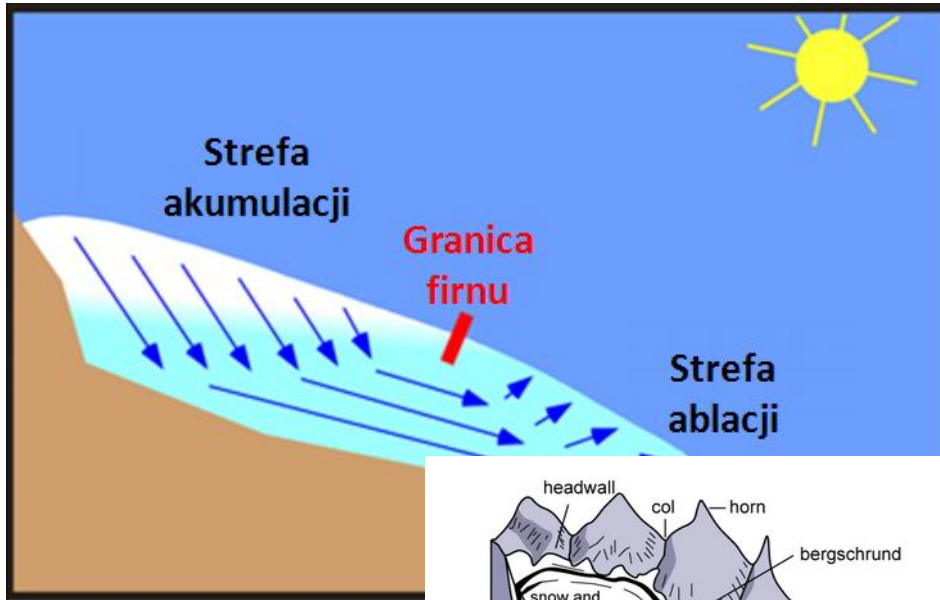
Ice granules, 50% air, $\sim 0.3 \text{ to } 0.5 \text{ g/cm}^3$

Firn, 30% air, $\sim 0.5 \text{ to } 0.7 \text{ g/cm}^3$

Ice, 20% air as bubbles, $>0.7 \text{ g/cm}^3$



O co chodzi z ruchem?

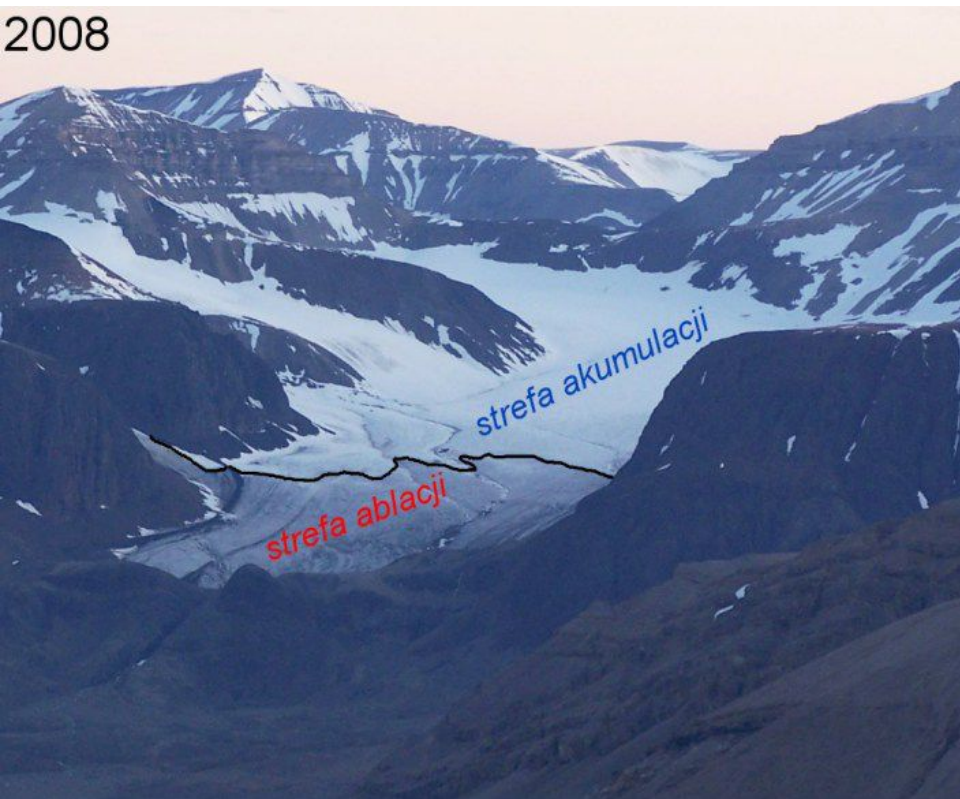


O co chodzi z ruchem?

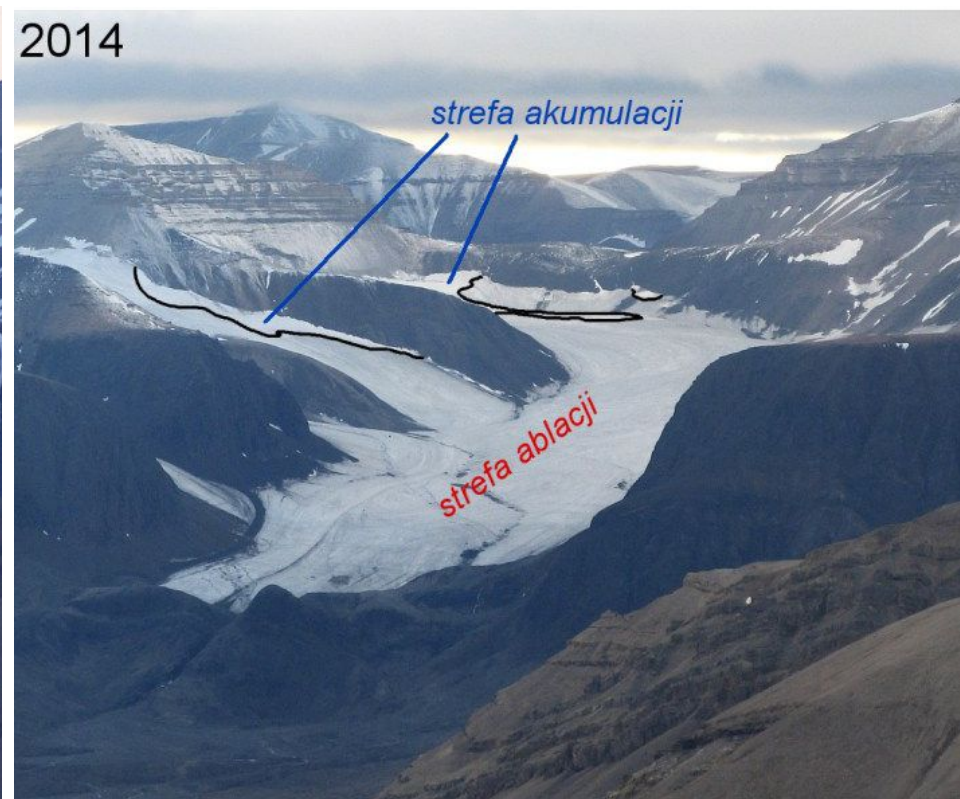


Akumulacija i ablacija

2008

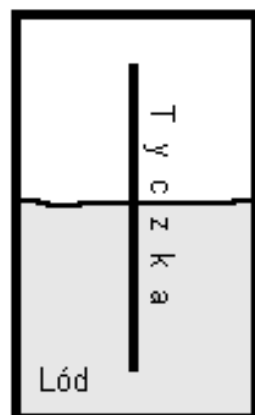


2014

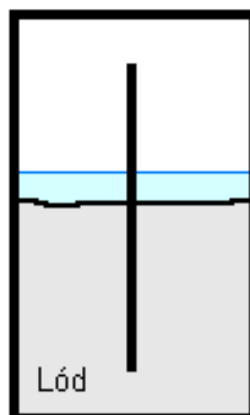


Bilans masy lodowca w strefie ablacji

Koniec lata/jesień



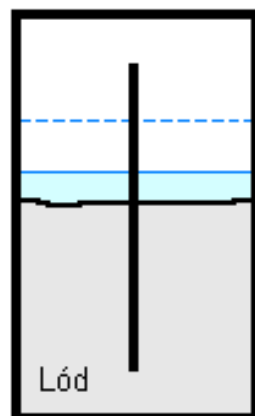
Wczesna zima



Koniec zimy



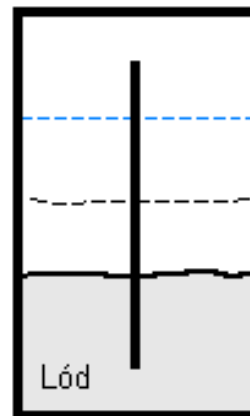
Wiosna



Wczesne lato



Koniec lata/jesień



Bilans zimowy
Bilans letni
Bilans netto

Pomiar bilansu masy lodowca



Narciarska wyprawa naukowa do
AMUPS 2015.

Pomiar bilansu masy lodowca



Foto:
Magdalena
Puczko

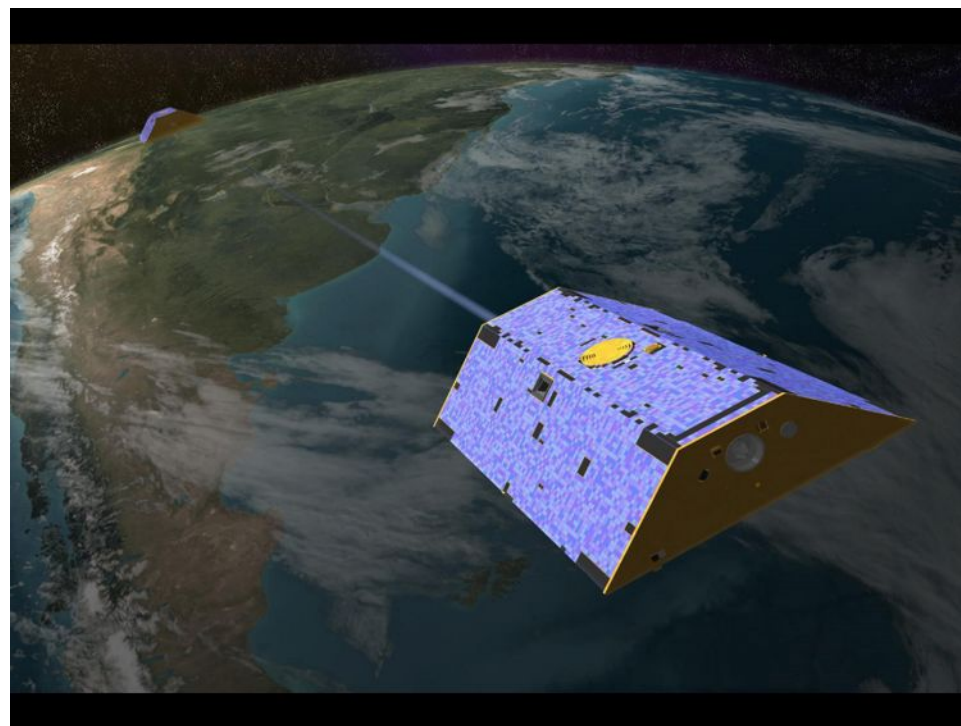
Pomiar bilansu masy lodowca

Svenbreen, Svalbard

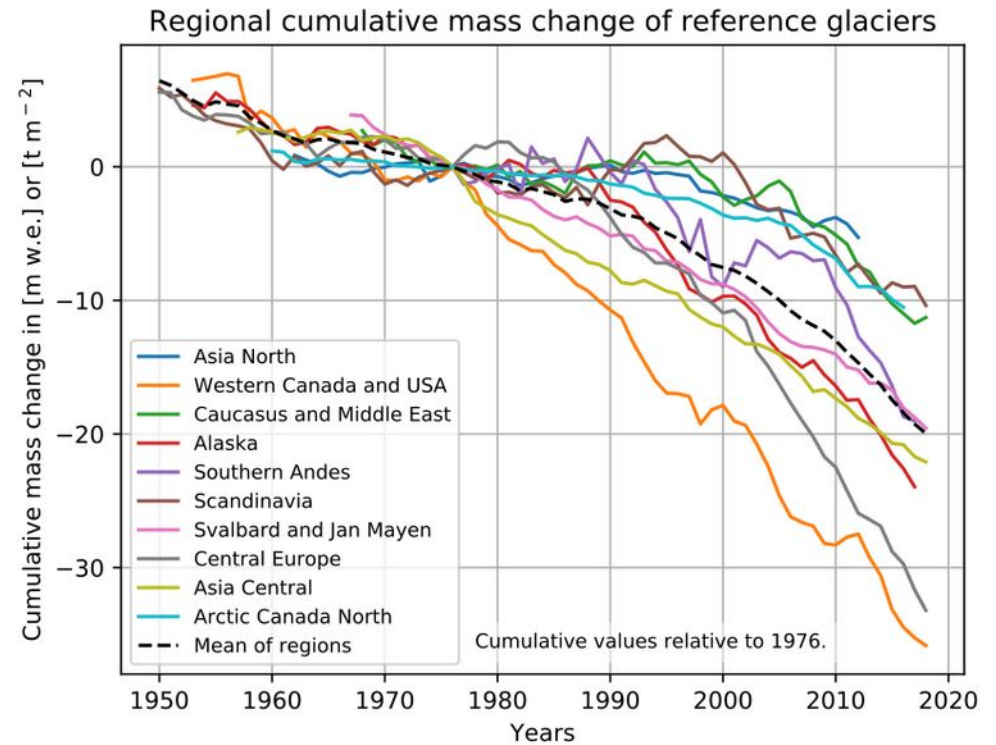
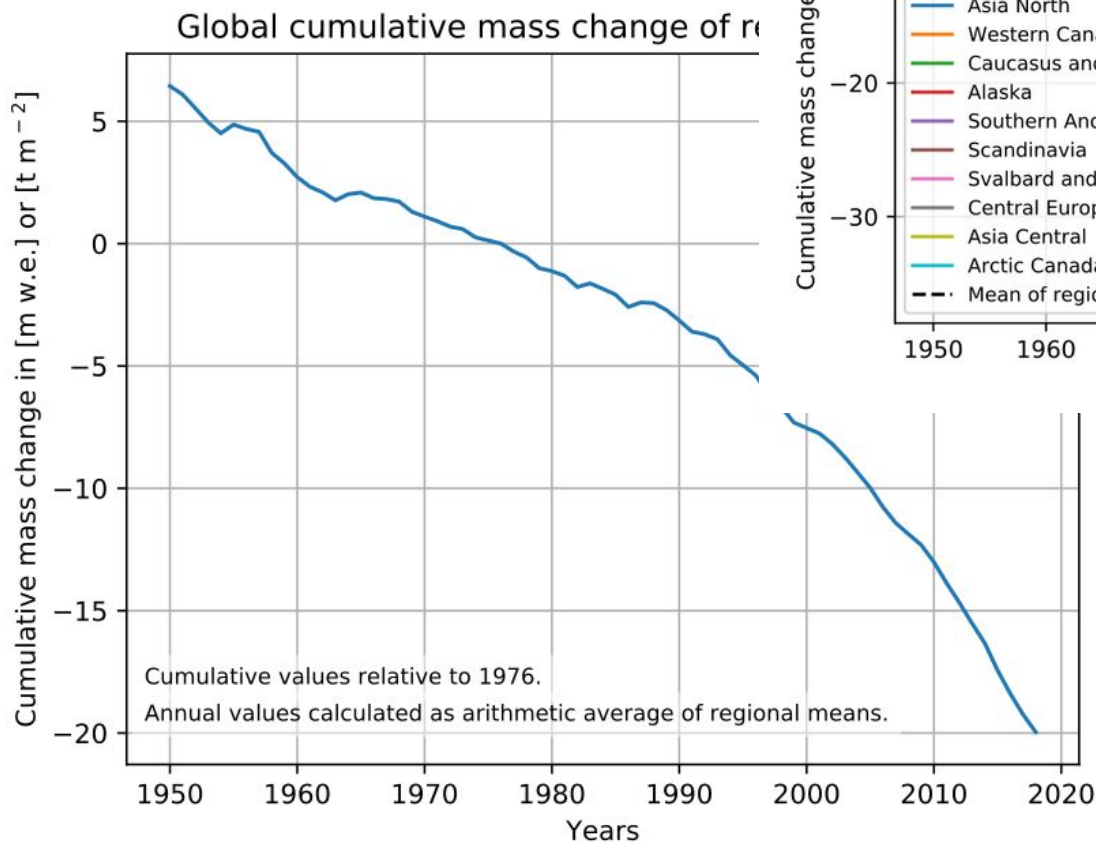


www.Glacjoblogia.wordpress.com

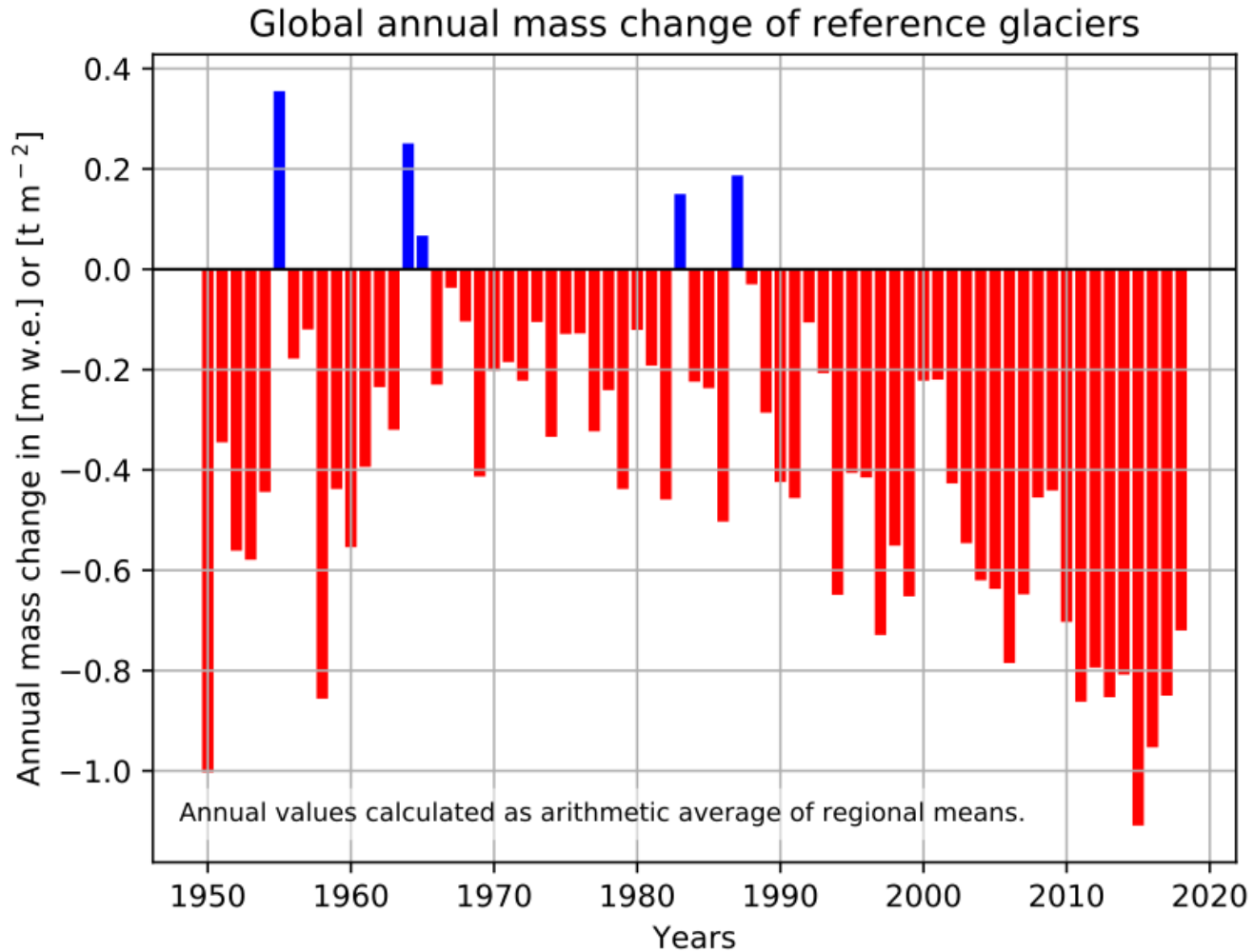
<https://grace.jpl.nasa.gov/data/data-analysis-tool/>



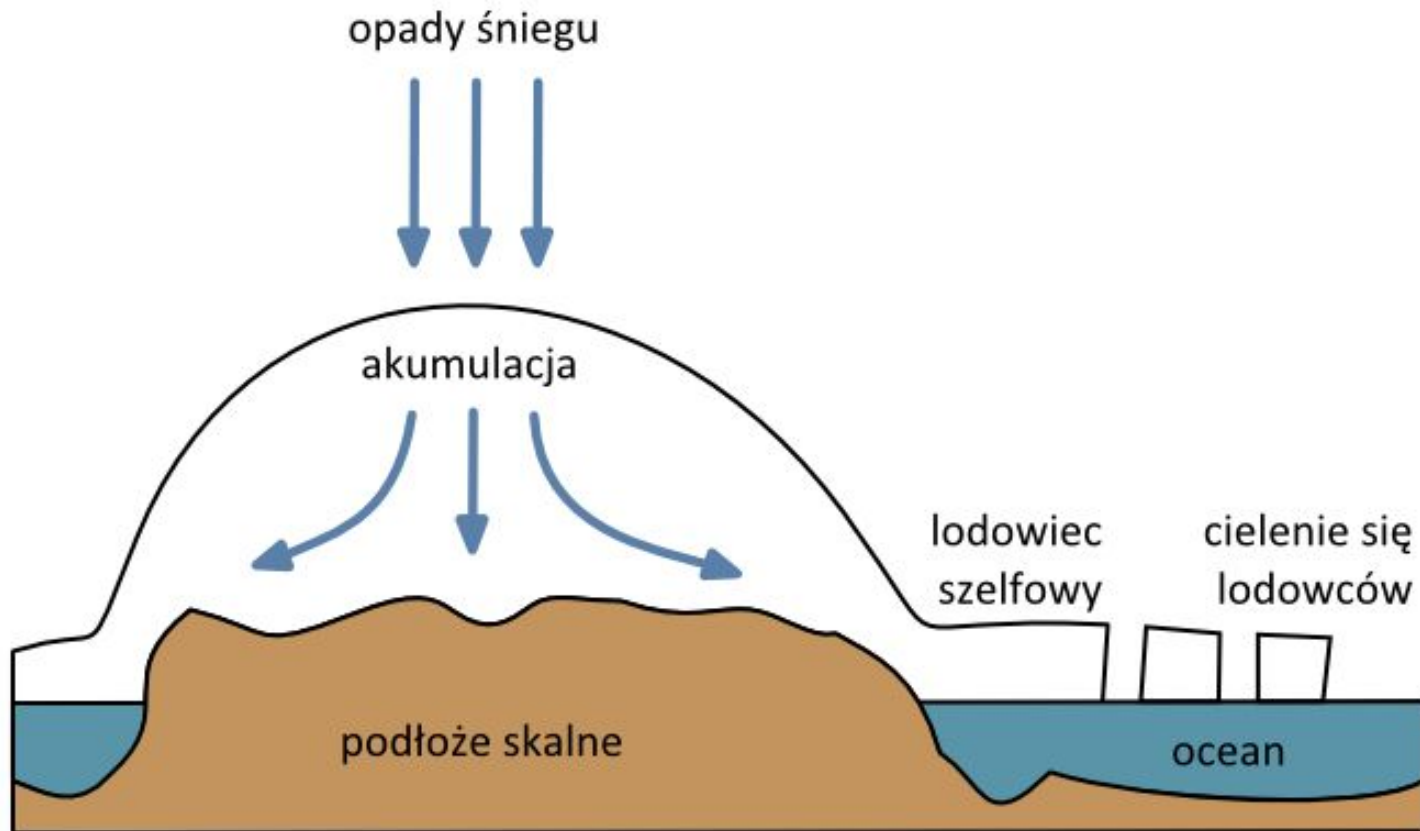
Światowy bilans masy lodowców



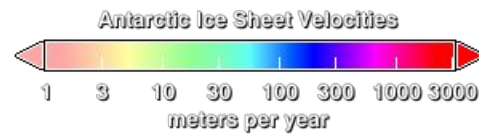
Światowy bilans masy lodowców



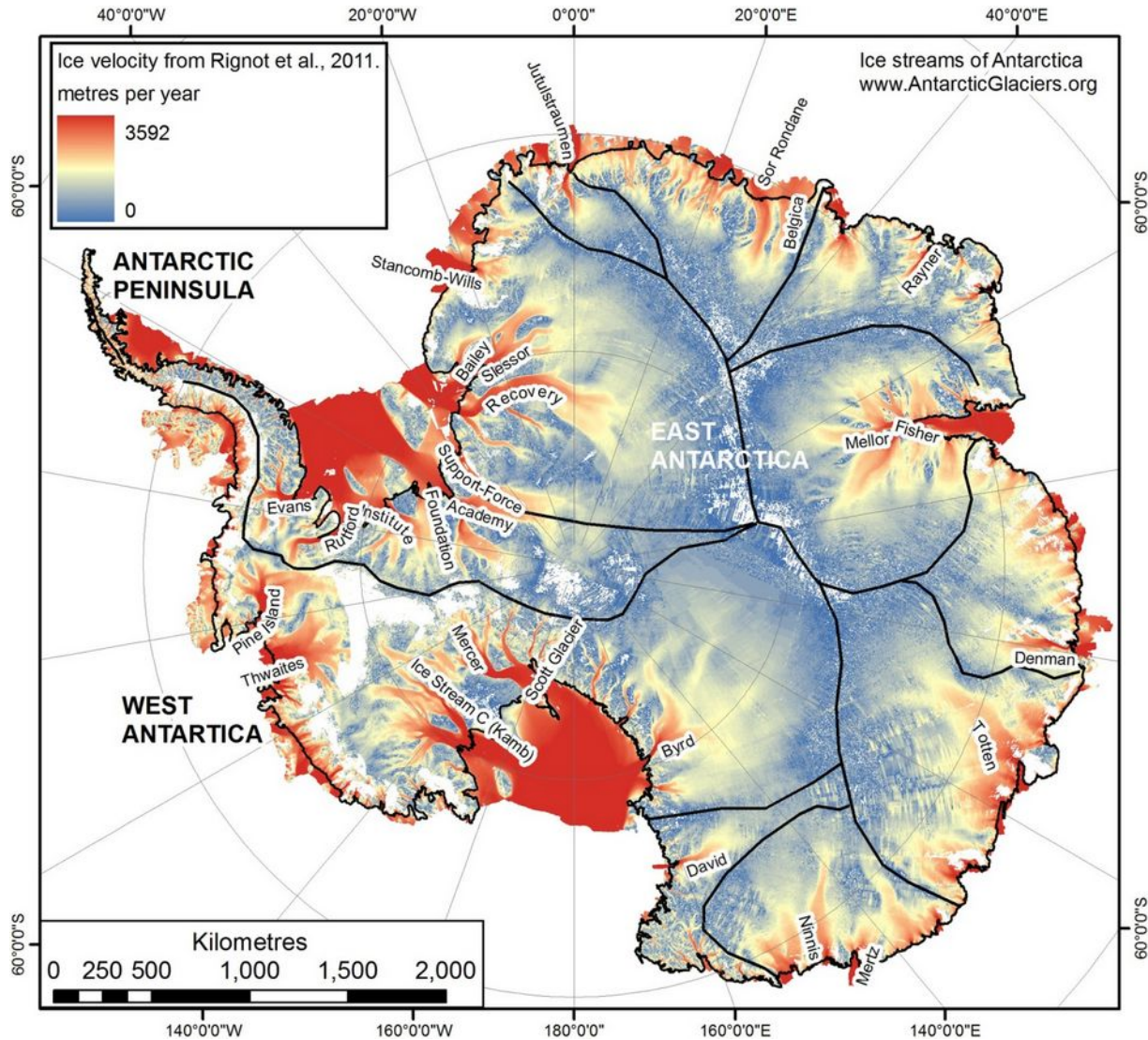
Lądolód



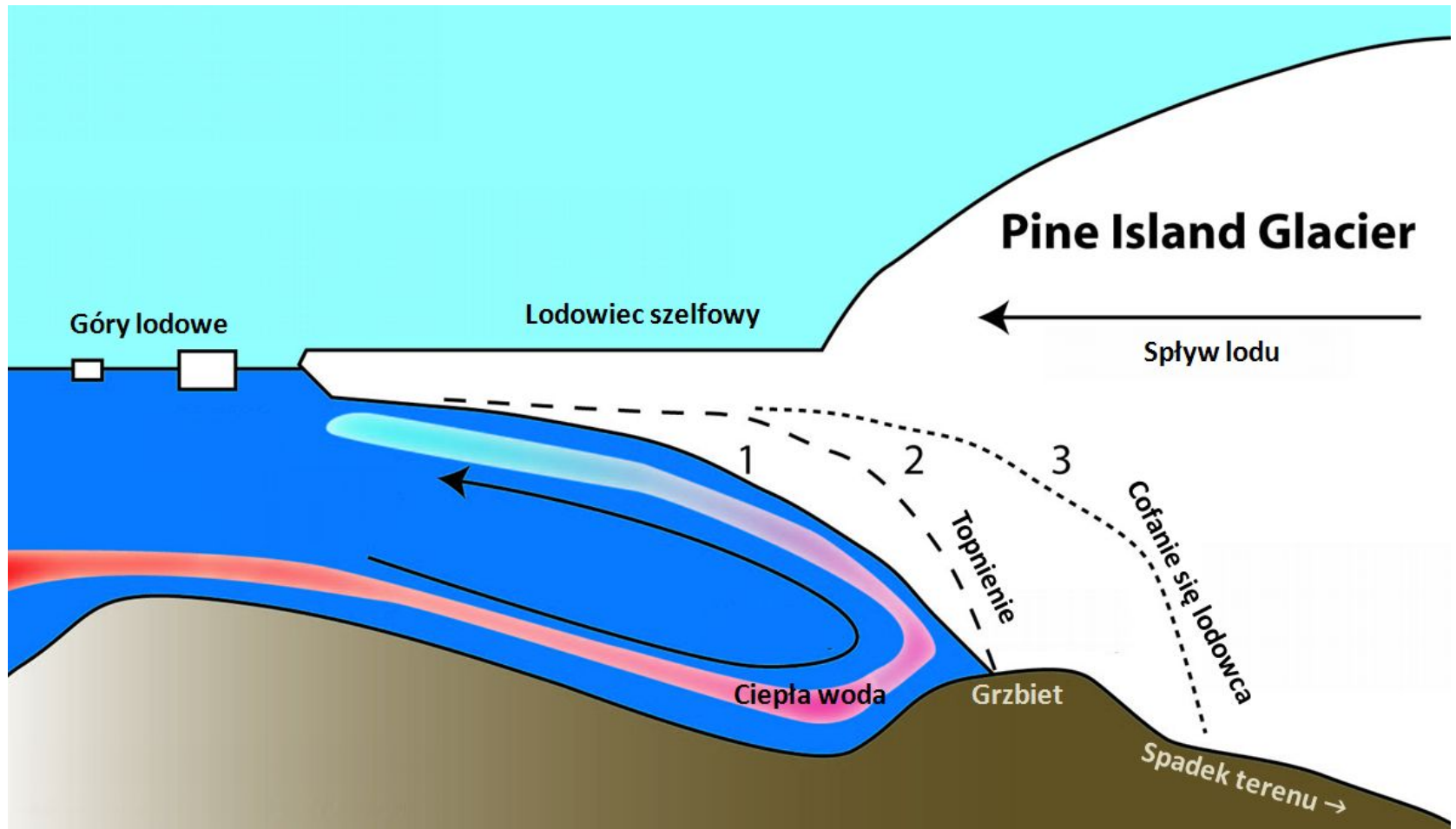
Antarktyda też płynie



Antarktyda też płynie



Jak znika lód Antarktydy?



Ukształtowanie podłoża Antarktydy

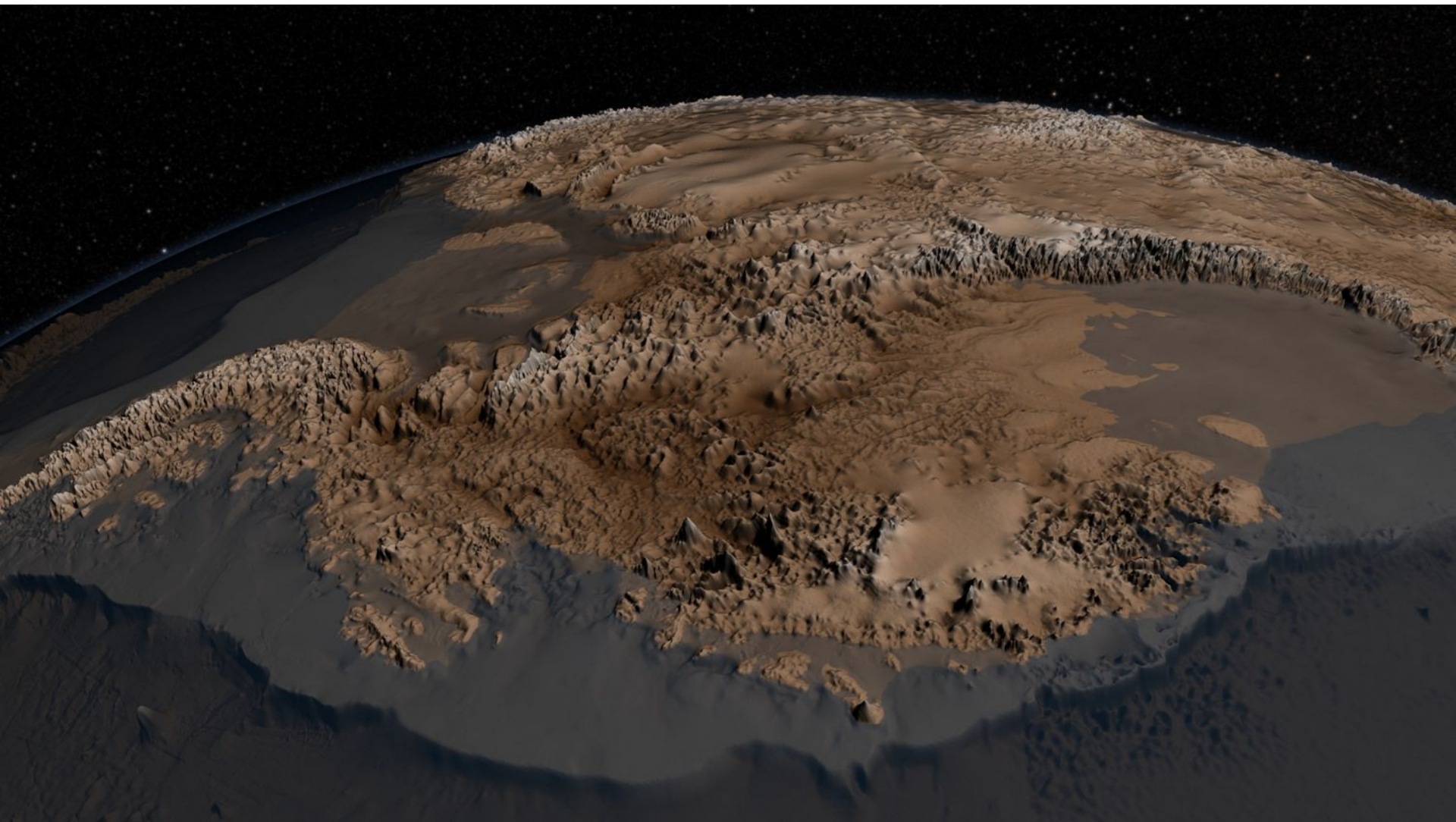
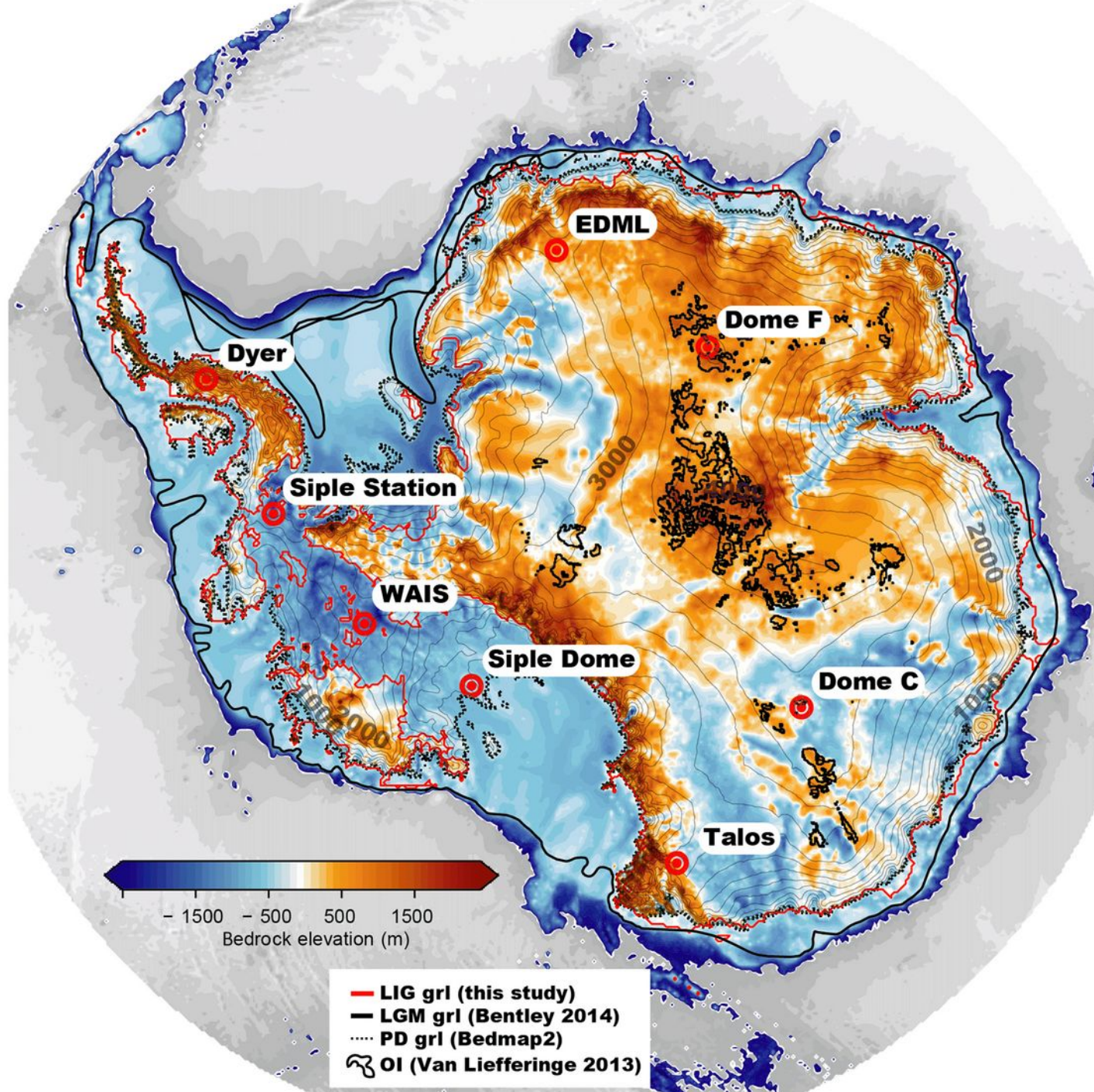


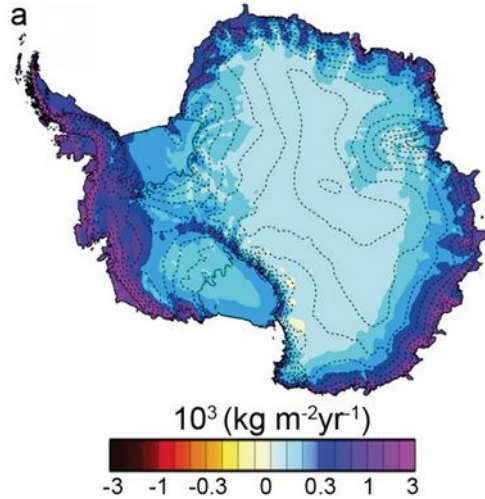
Figure 1. Antarctic bedrock topography overlain by surface contours (grey lines). The present-day (PD) grounding line (grl) from BEDMAP2 (Fretwell et al., 2013) depicted by the dashed black line. The Last Glacial Maximum (LGM) grounding line reconstruction from Bentley et al. (2014) (thick black lines) is compared to simulated grounding line retreat in one of the ensemble members for the Last Interglacial (LIG, red line). Regions previously identified as potentially viable sites for Oldest Ice (Van Liefferinge and Pattyn, 2013) are outlined by thick black lines. Eight ice core locations are highlighted, which are used as tuning targets with respect to ice core thickness and analysed in Figs. 9 (West Antarctica) and 10 (East Antarctica), respectively.



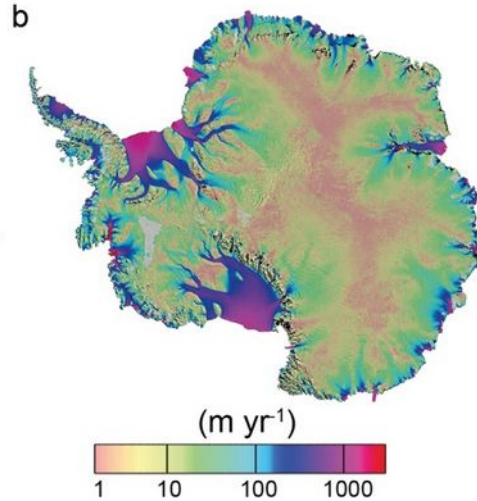
Sutter, J., Fischer, H., Grosfeld, K., Karlsson, N. B., Kleiner, T., Van Liefferinge, B., and Eisen, O.: Modelling the Antarctic Ice Sheet across the mid-Pleistocene transition – implications for Oldest Ice, *The Cryosphere*, 13, 2023–2041, <https://doi.org/10.5194/tc-13-2023-2019>, 2019

Jak znika lód Antarktydy?

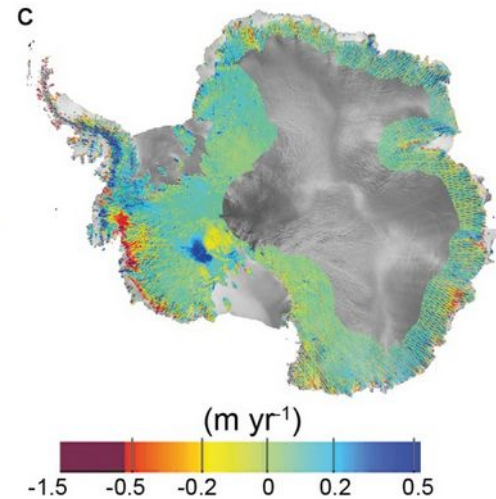
Bilans masy
1989-2004



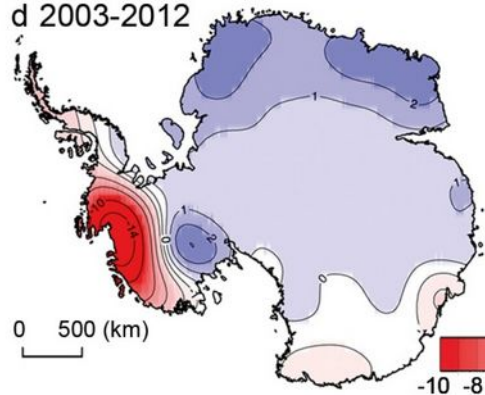
Prędkość
2007-2009



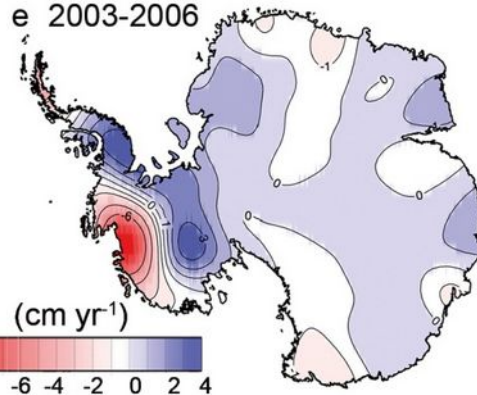
Zmiany wysokości
2003-2008



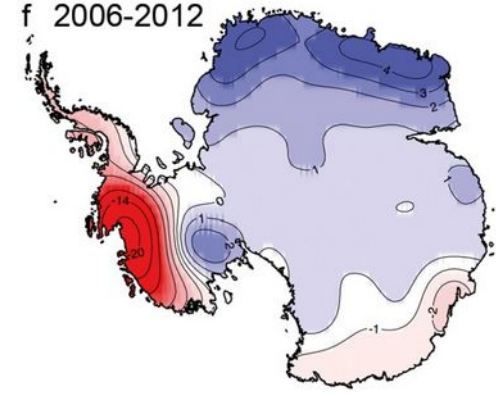
d 2003-2012



e 2003-2006

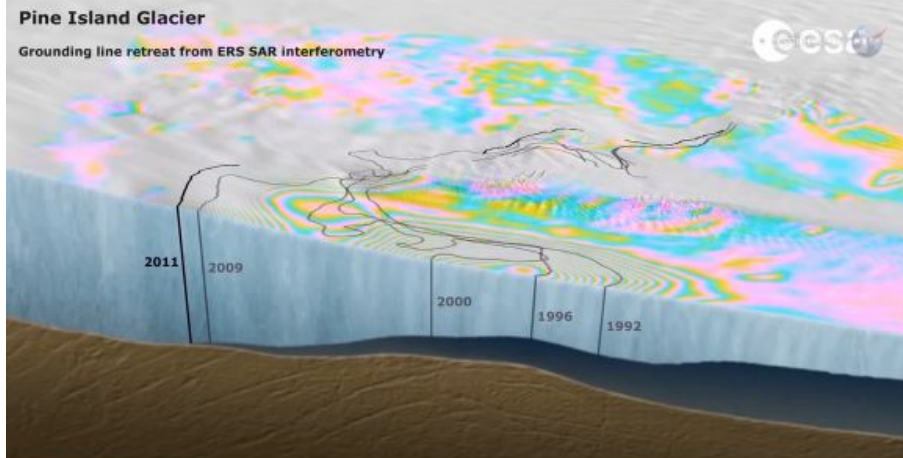
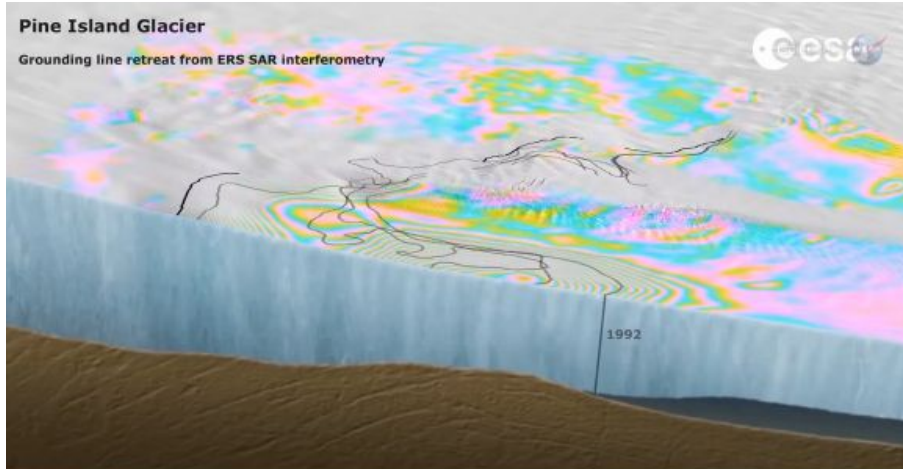


f 2006-2012

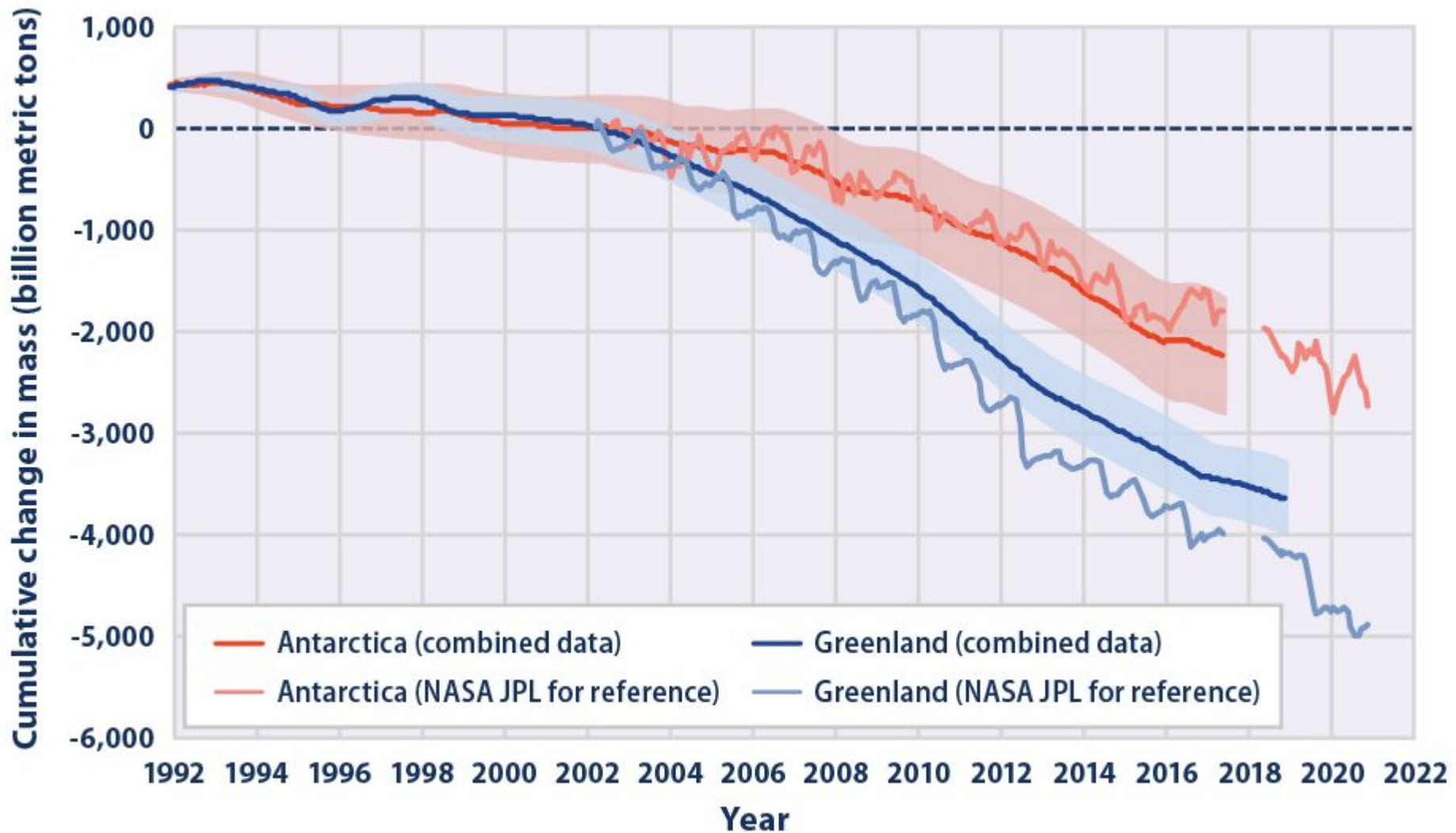


Straty lodu w ekwiwalencji wodnym

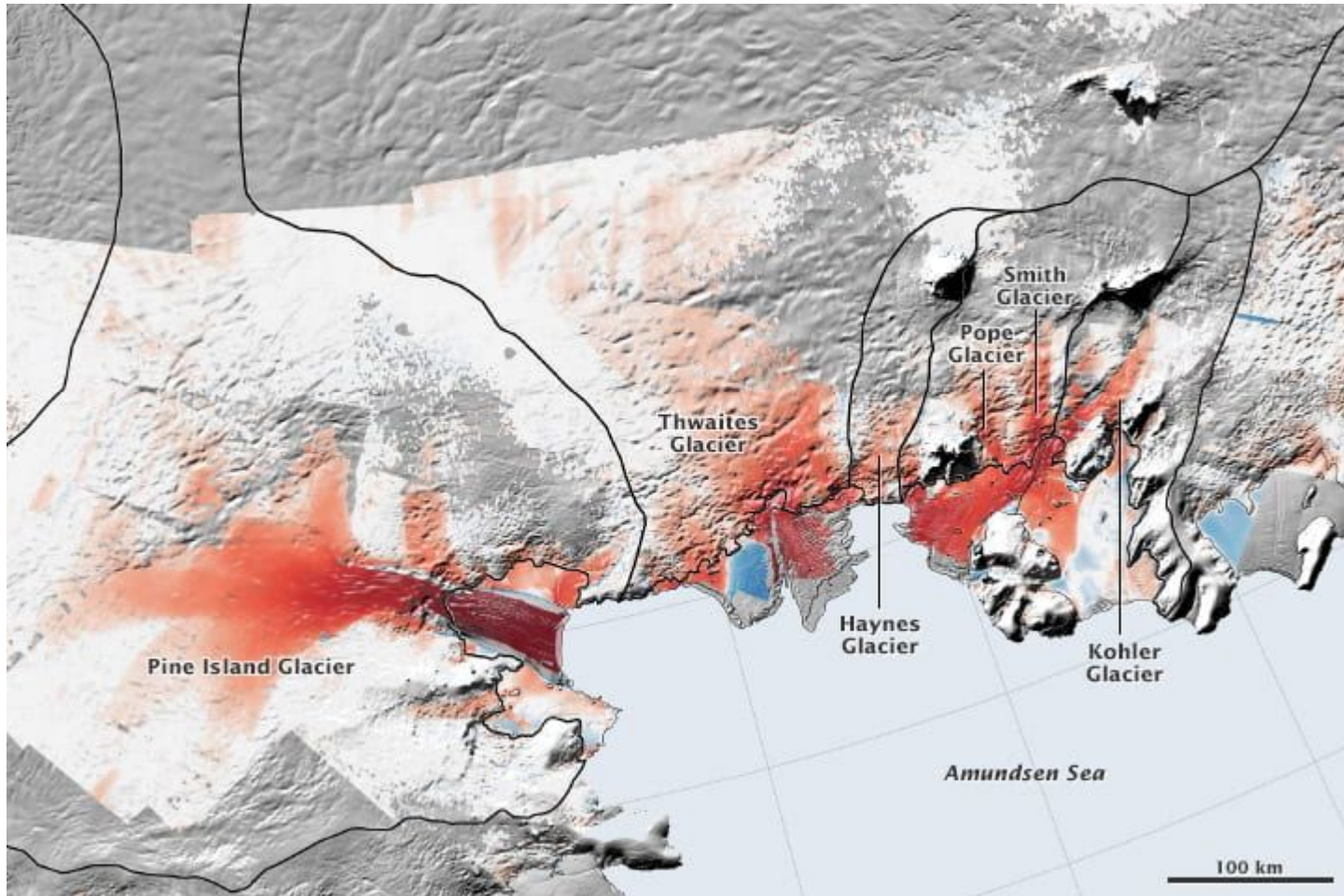
Jak znika lód Antarktydy?



Jak znika lód Antarktydy?

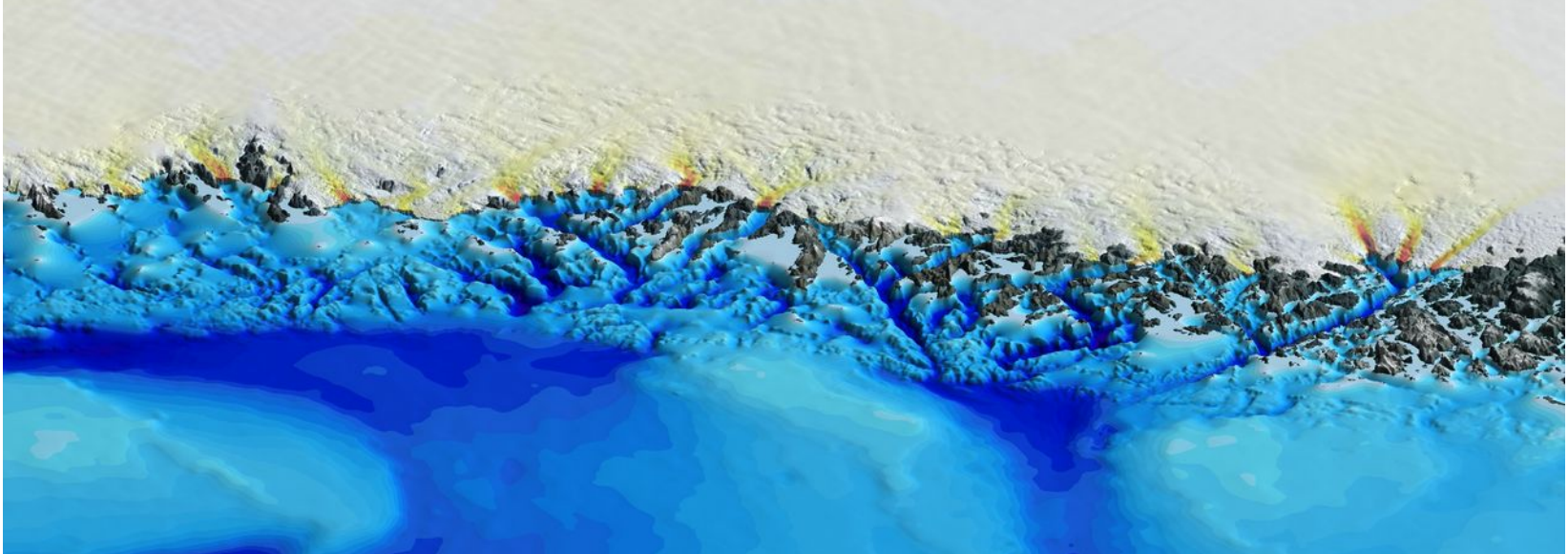
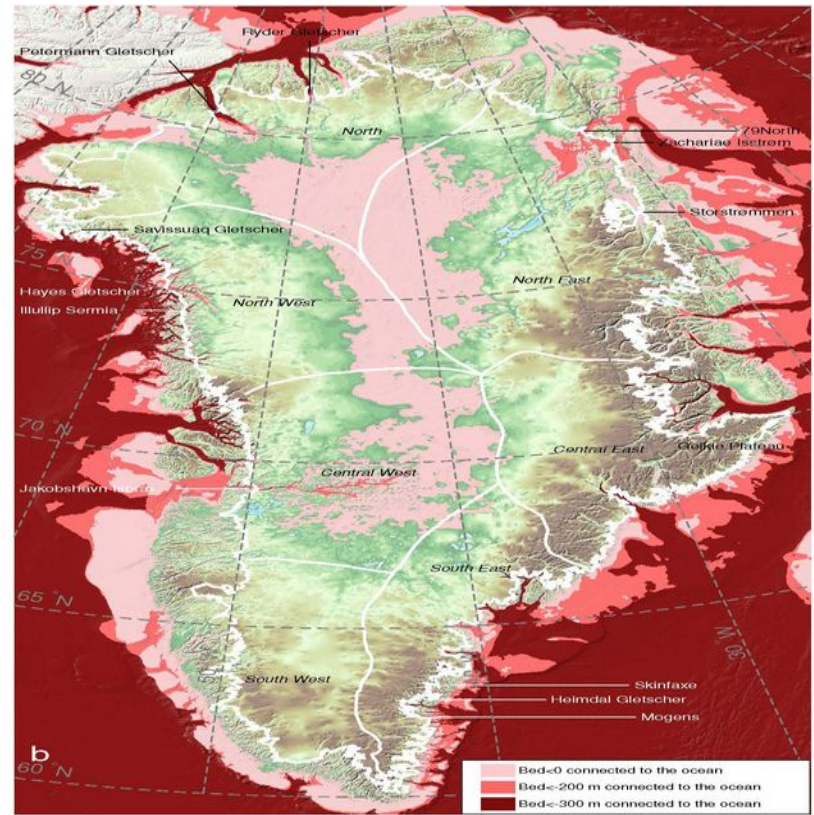
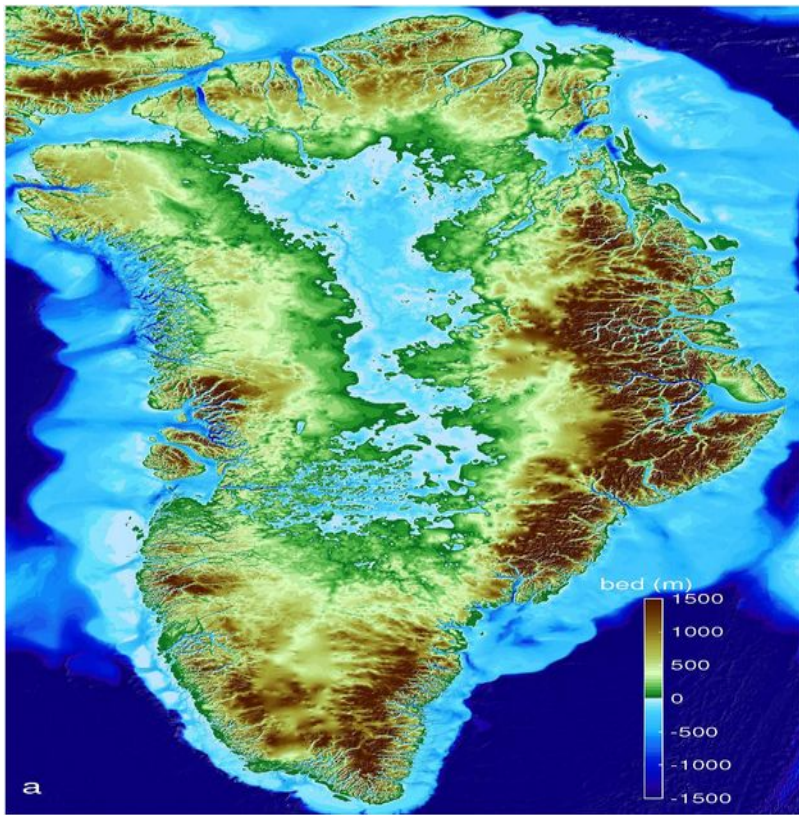


„Doomsday glaciers”

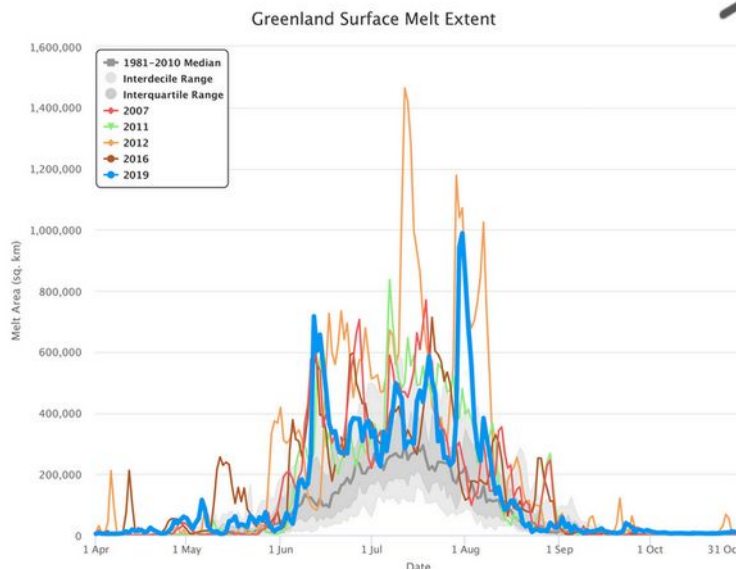
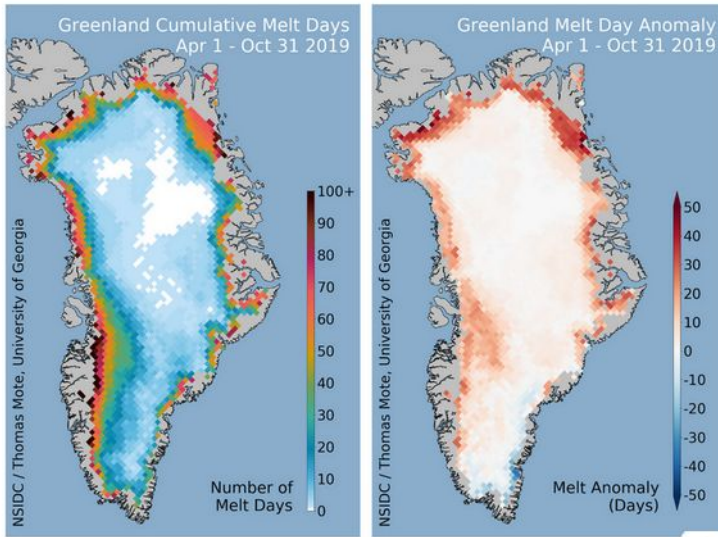


Grenlandia też płynie





Topnienie powierzchniowe



Czarny śnieg

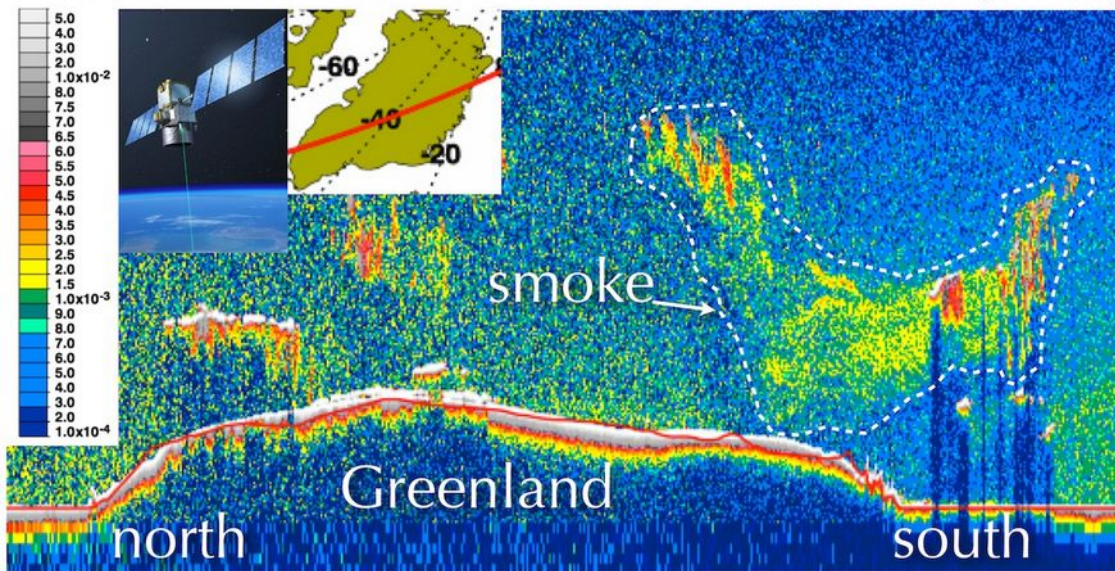


Jason Box, Dark Snow Project



Czarny śnieg - sadza

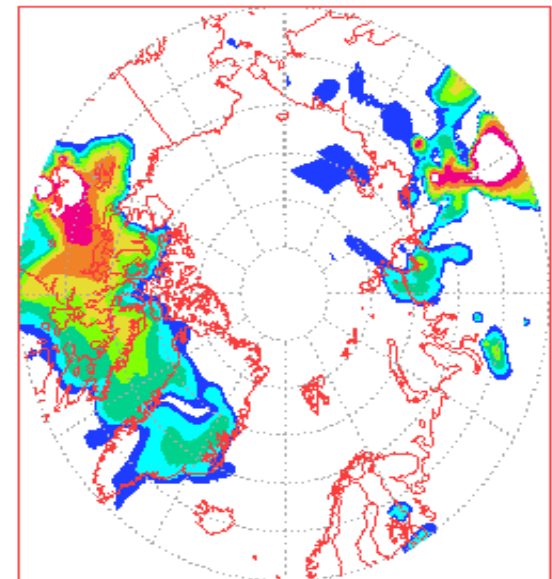
NASA Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)



532 nm total attenuated backscatter, $\text{km}^{-1} \text{sr}^{-1}$

17 June 2012 0518z

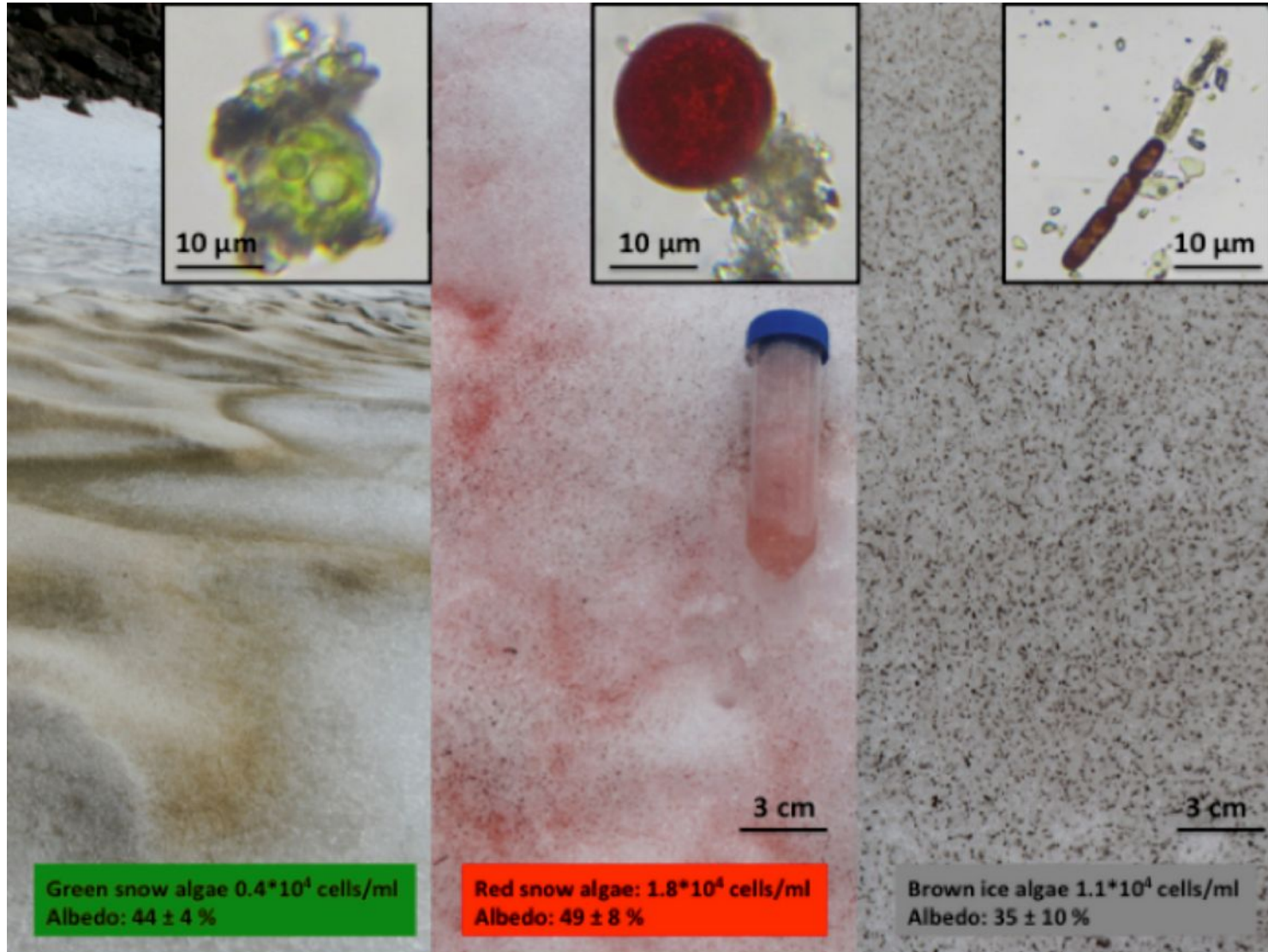
Smoke Surface Concentration ($\mu\text{g}/\text{m}^3$) for 2014072800



1 2 4 6 10 32 64 128

Ciemny śnieg - glony

Dark snow project

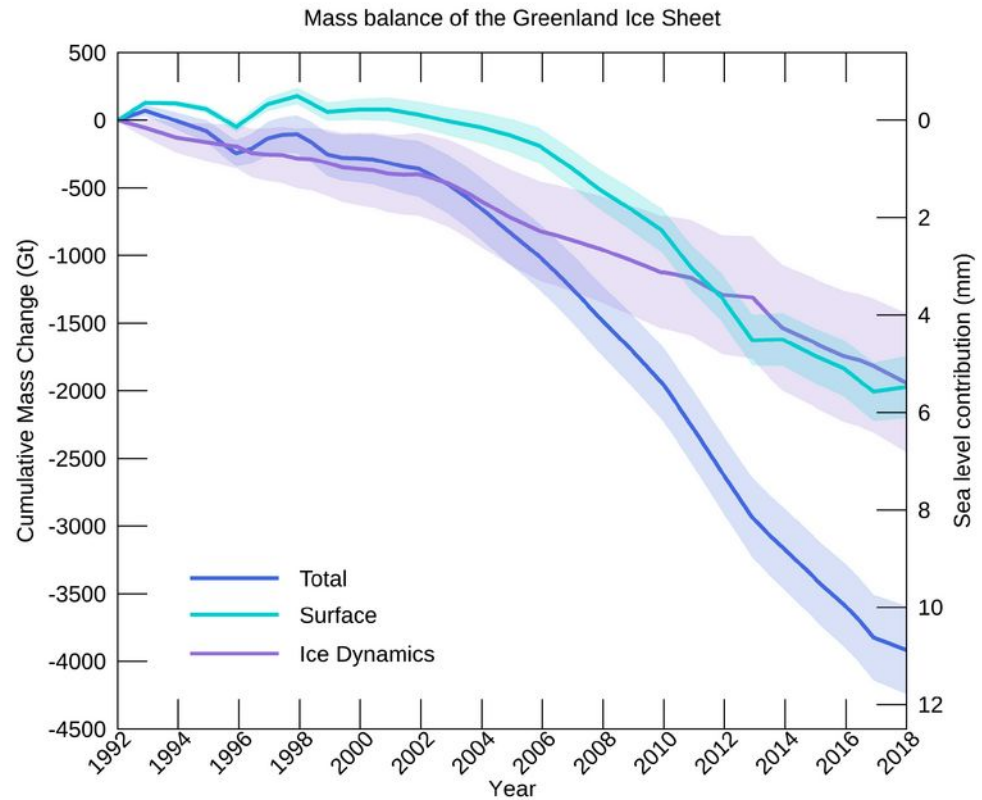
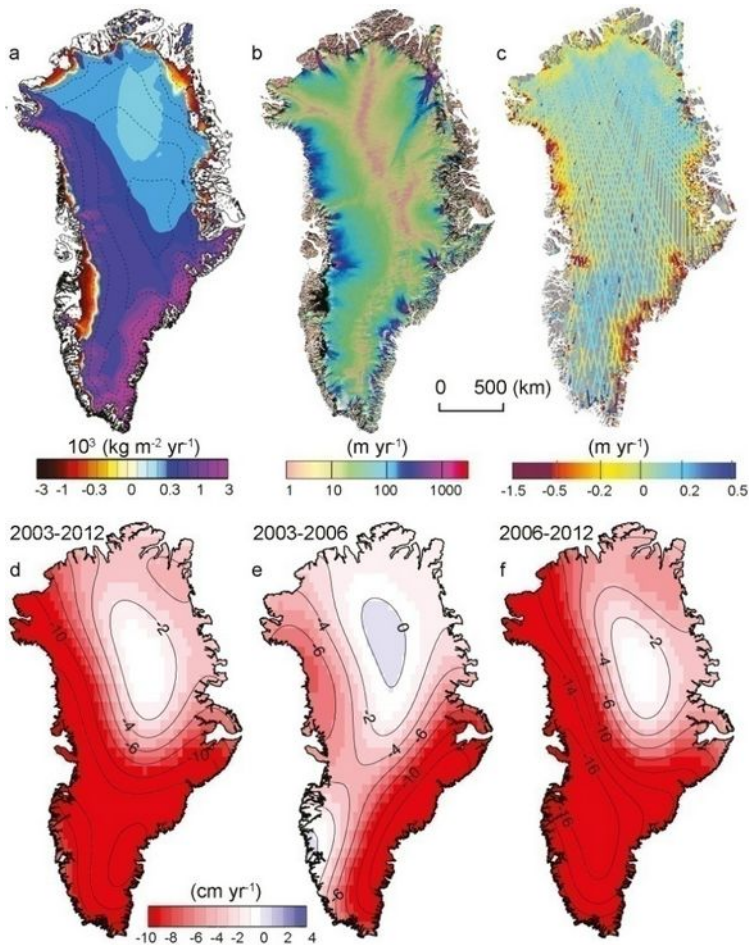


Jak znika lód Grenlandii?

Bilans masy
1989-2004

Prędkość
2007-2009

Zmiany wysokości
2003-2008

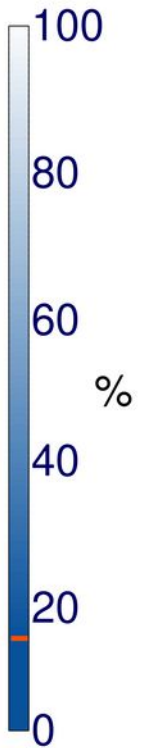
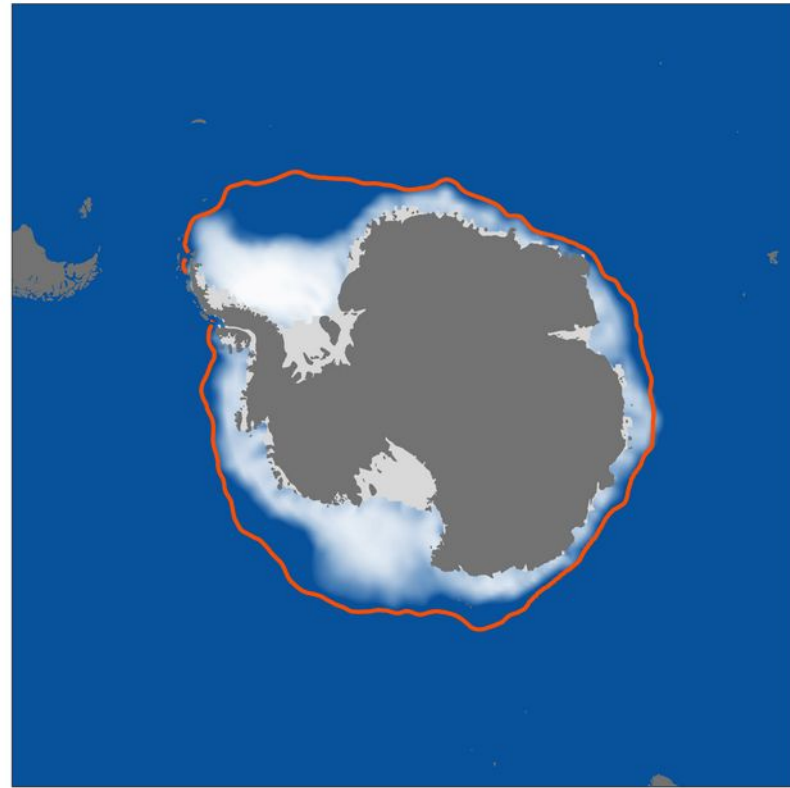
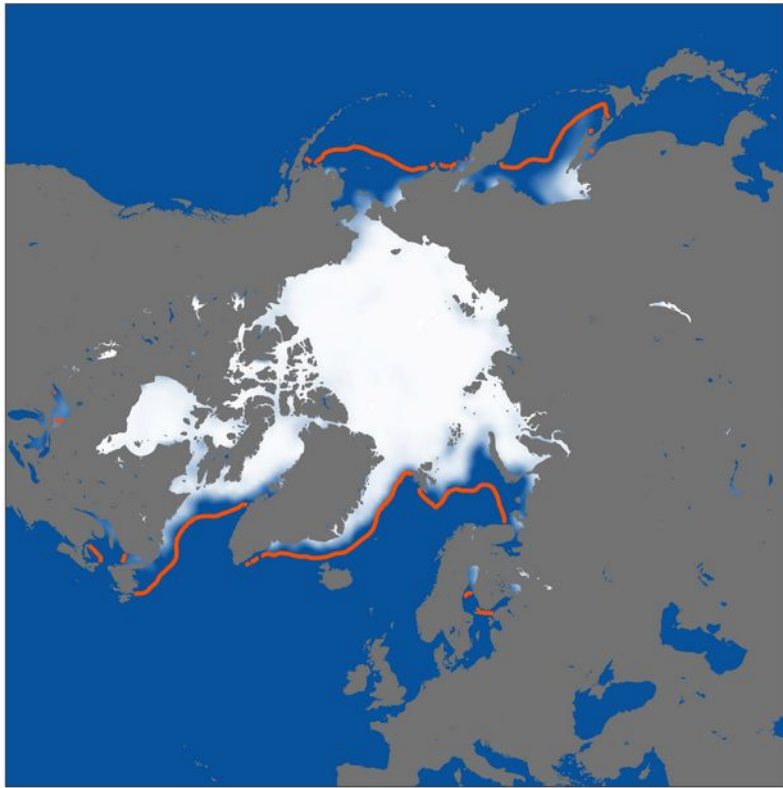


Data Source: IMBIE, Credit: IMBIE/ESA/NASA

Straty lodu w ekwiwalencji wodnym

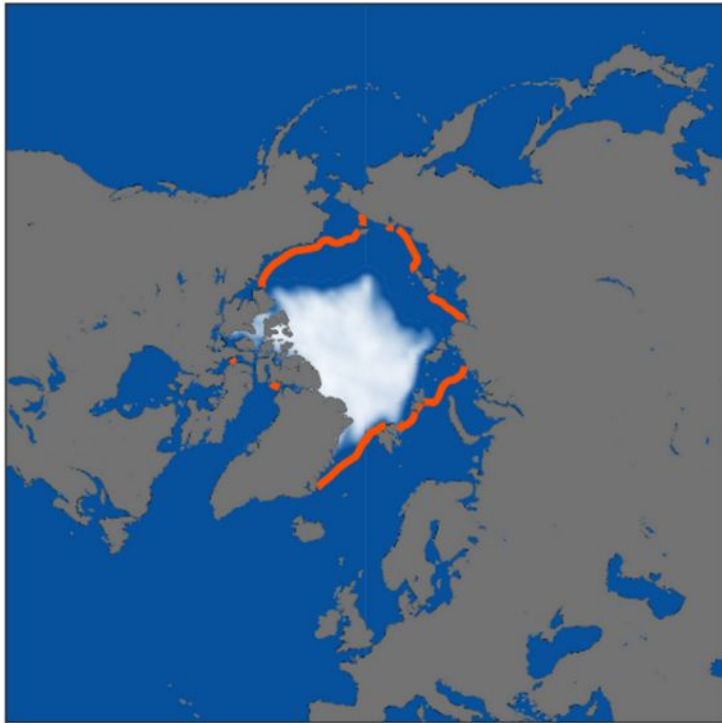
Lód morski

Sea-ice cover for April 2019



Arctic sea-ice concentration for September 2019

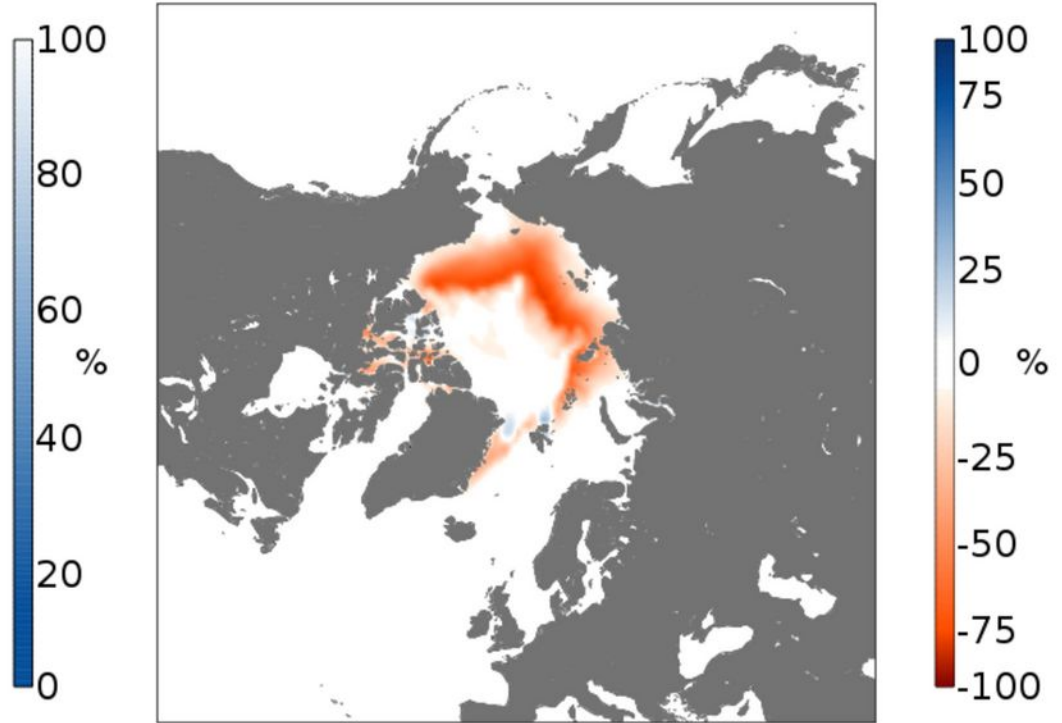
Average concentration



— Average ice edge September 1981-2010

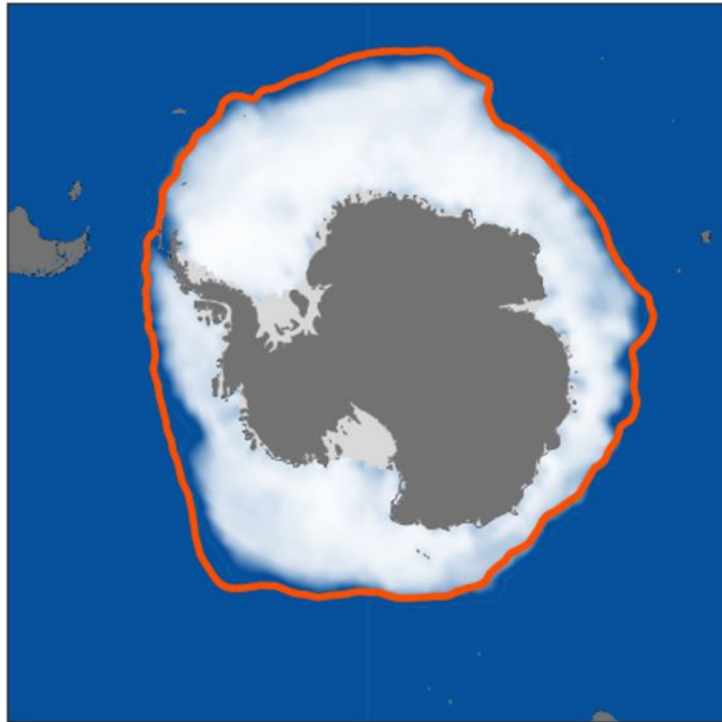
Data: ERA5

Anomaly relative to 1981-2010



Antarctic sea-ice concentration for September 2019

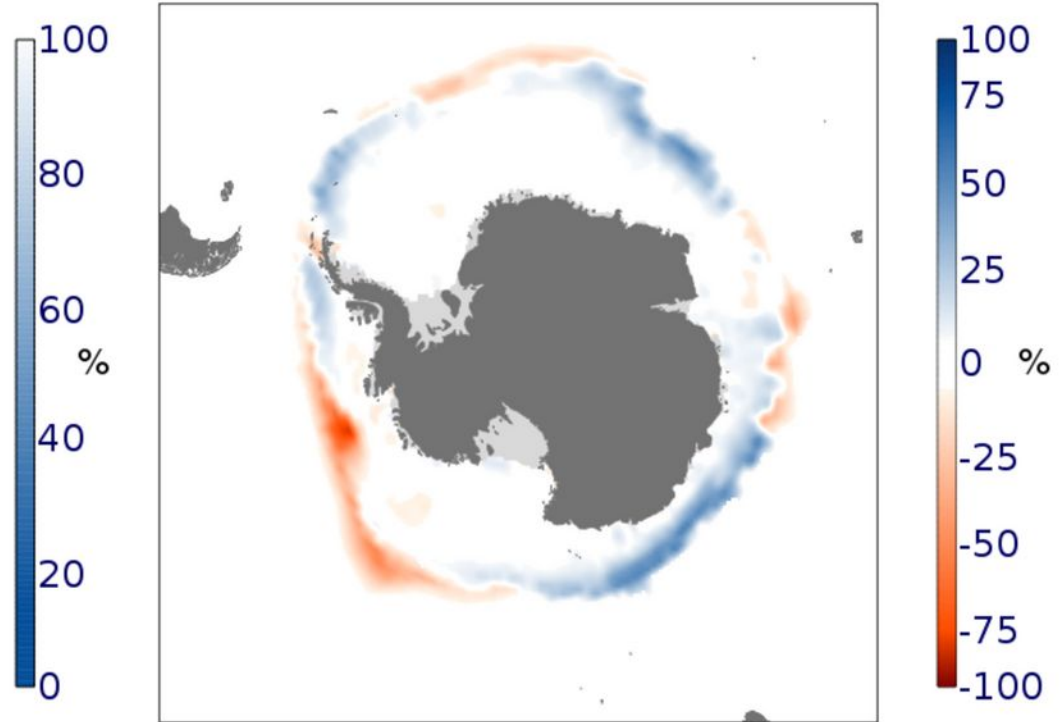
Average concentration



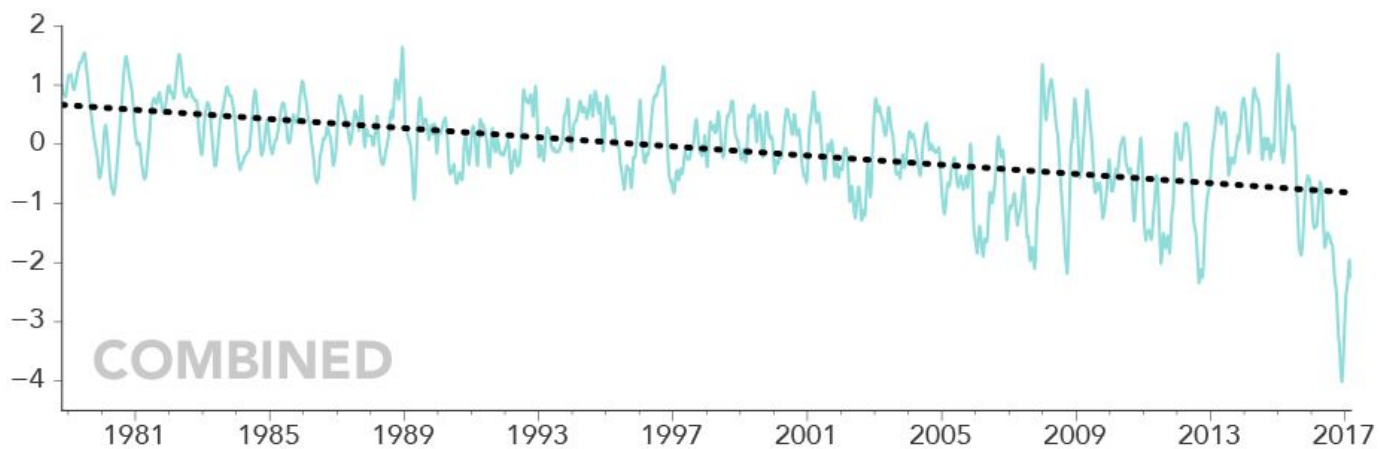
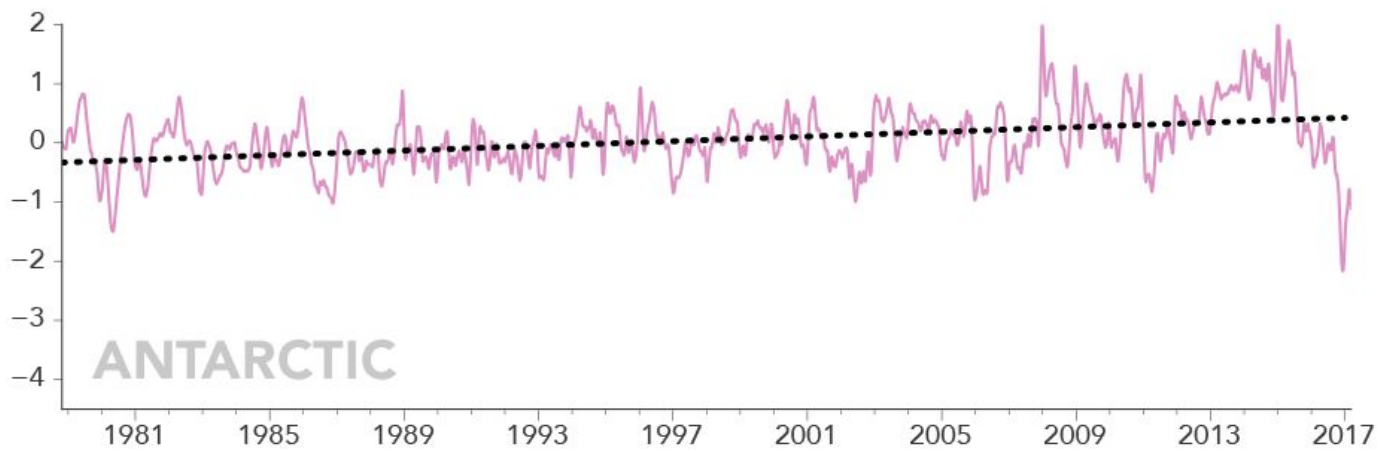
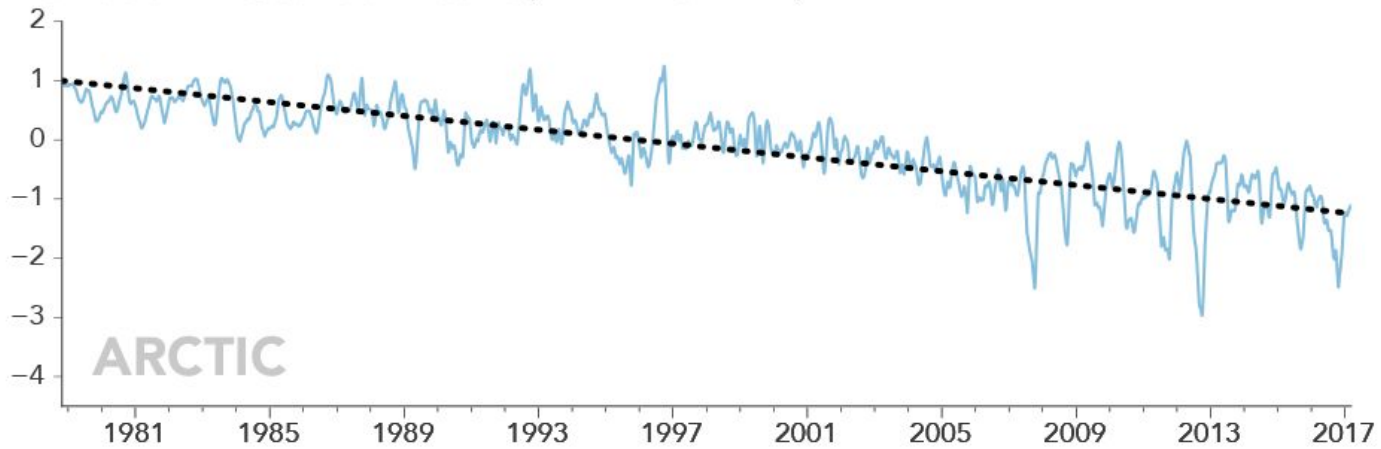
— Average ice edge September 1981-2010

Data: ERA5

Anomaly relative to 1981-2010

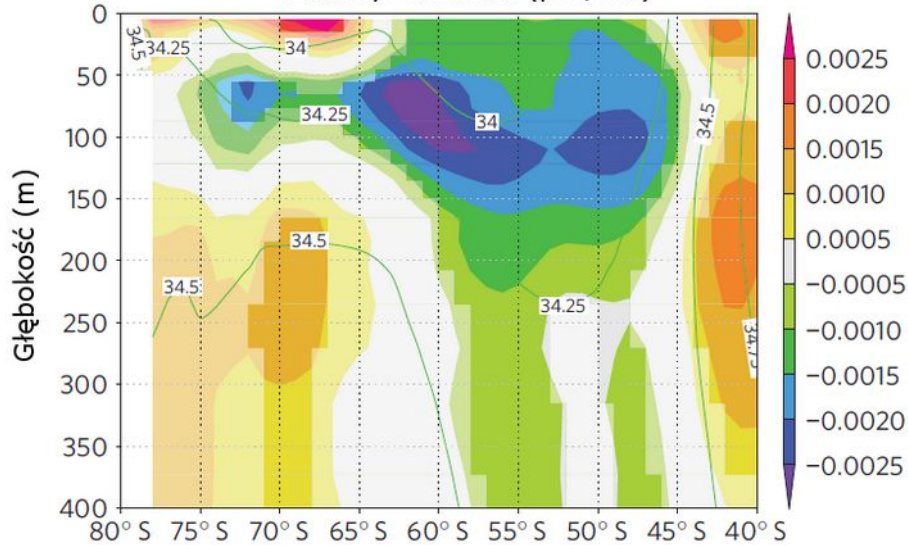


Deviation in Sea Ice Extent (x 1 million km²)

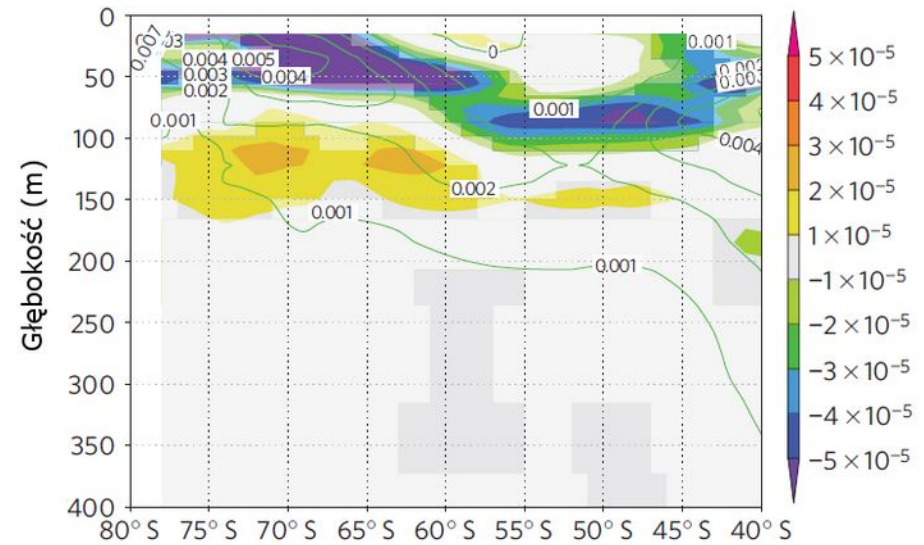


Czemu lód w Antarktyce przyrastał?

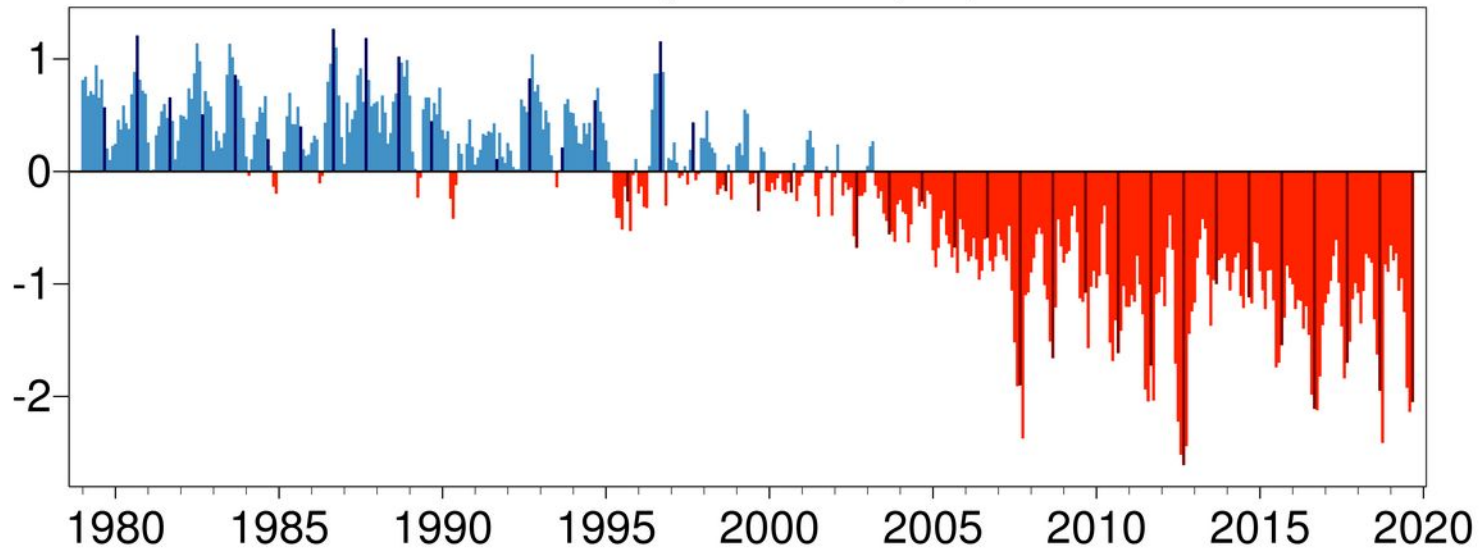
Zmiany zasolenia (psu/rok)



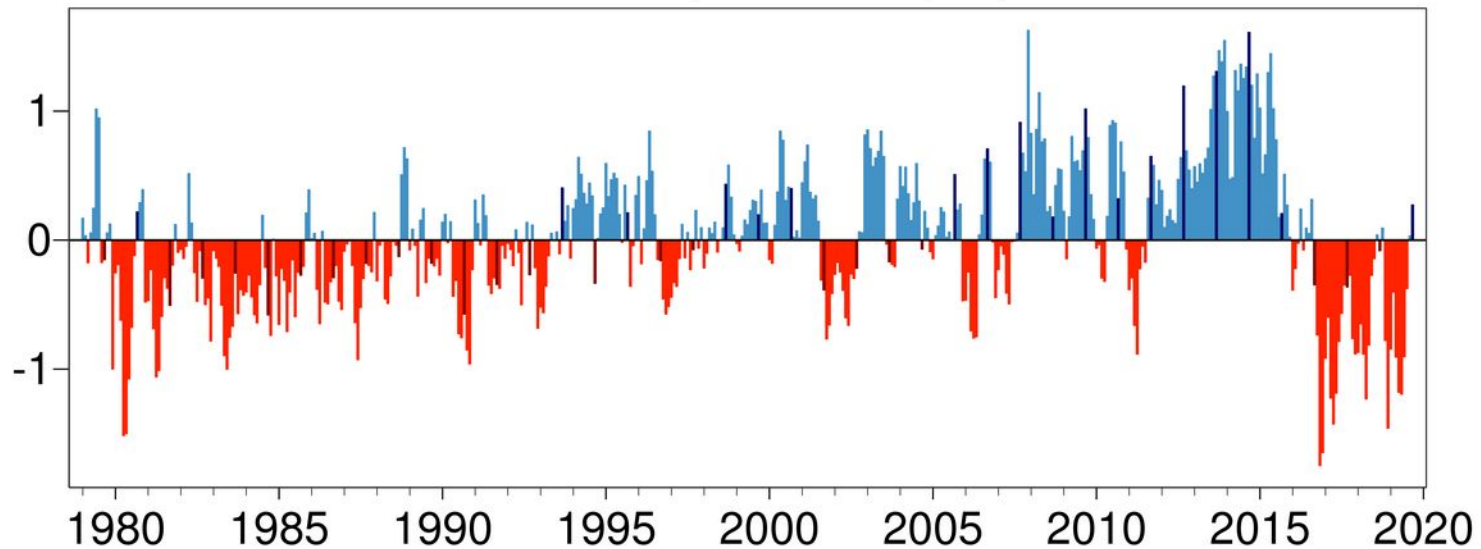
Zmiany pionowego gradientu gęstości ($\text{kg/m}^4/\text{rok}$)



Arctic sea ice area anomalies (millions of sq km) relative to 1981-2010



Antarctic sea ice area anomalies (millions of sq km) relative to 1981-2010



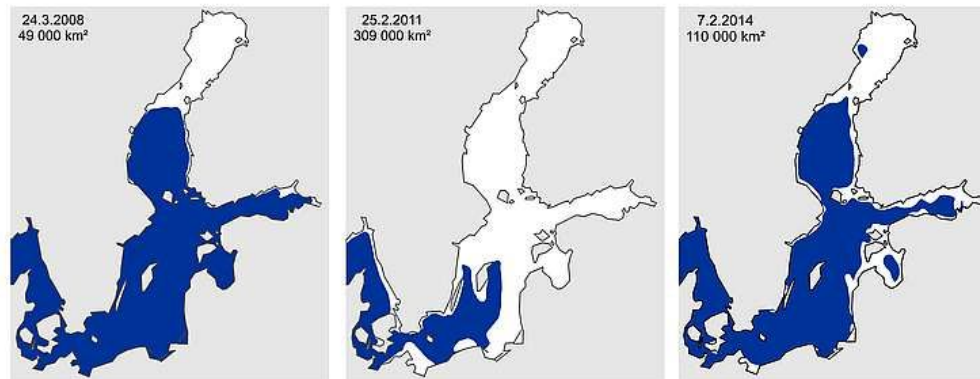
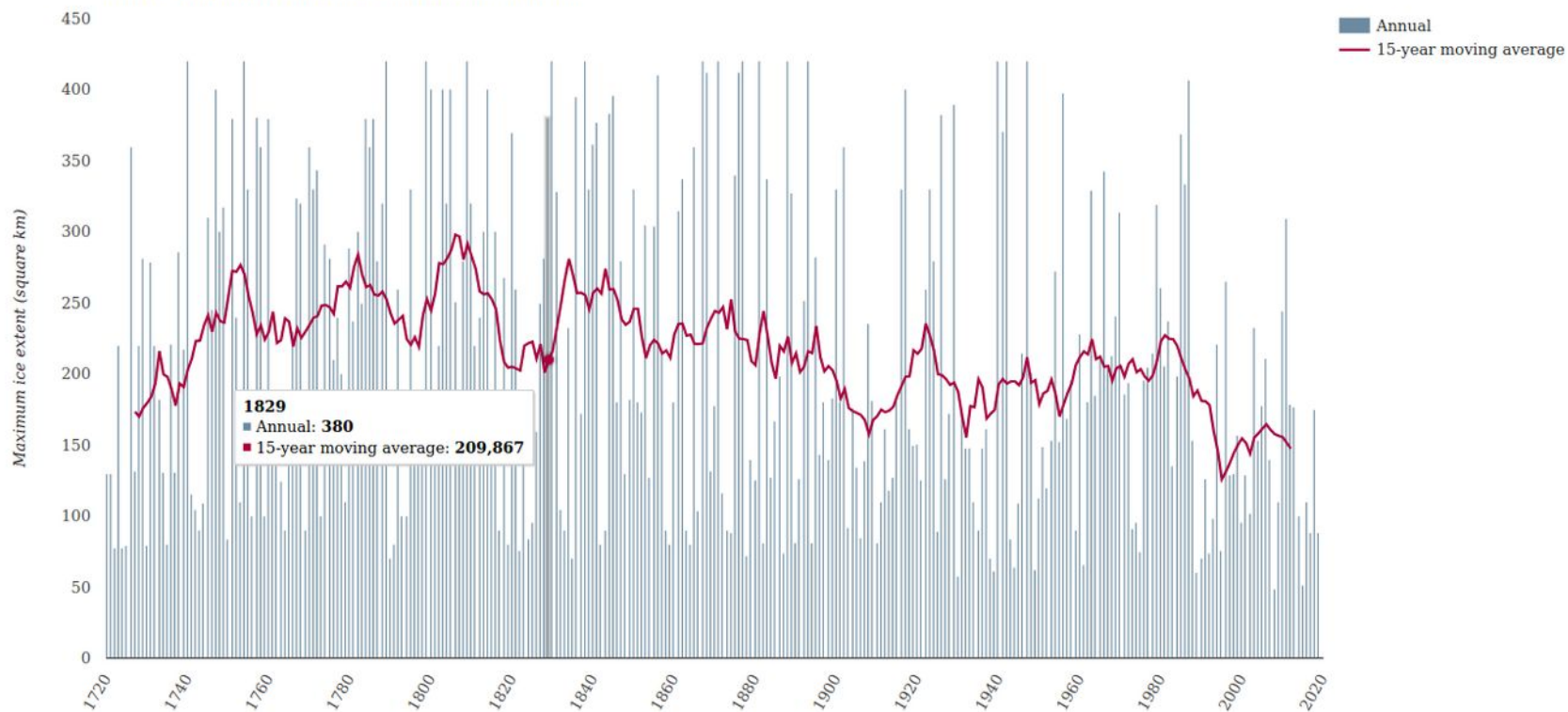


Fig. 2: Maximum extent of ice cover in the Baltic Sea

Chart

Chart — Maximum extent of ice cover in the Baltic Sea



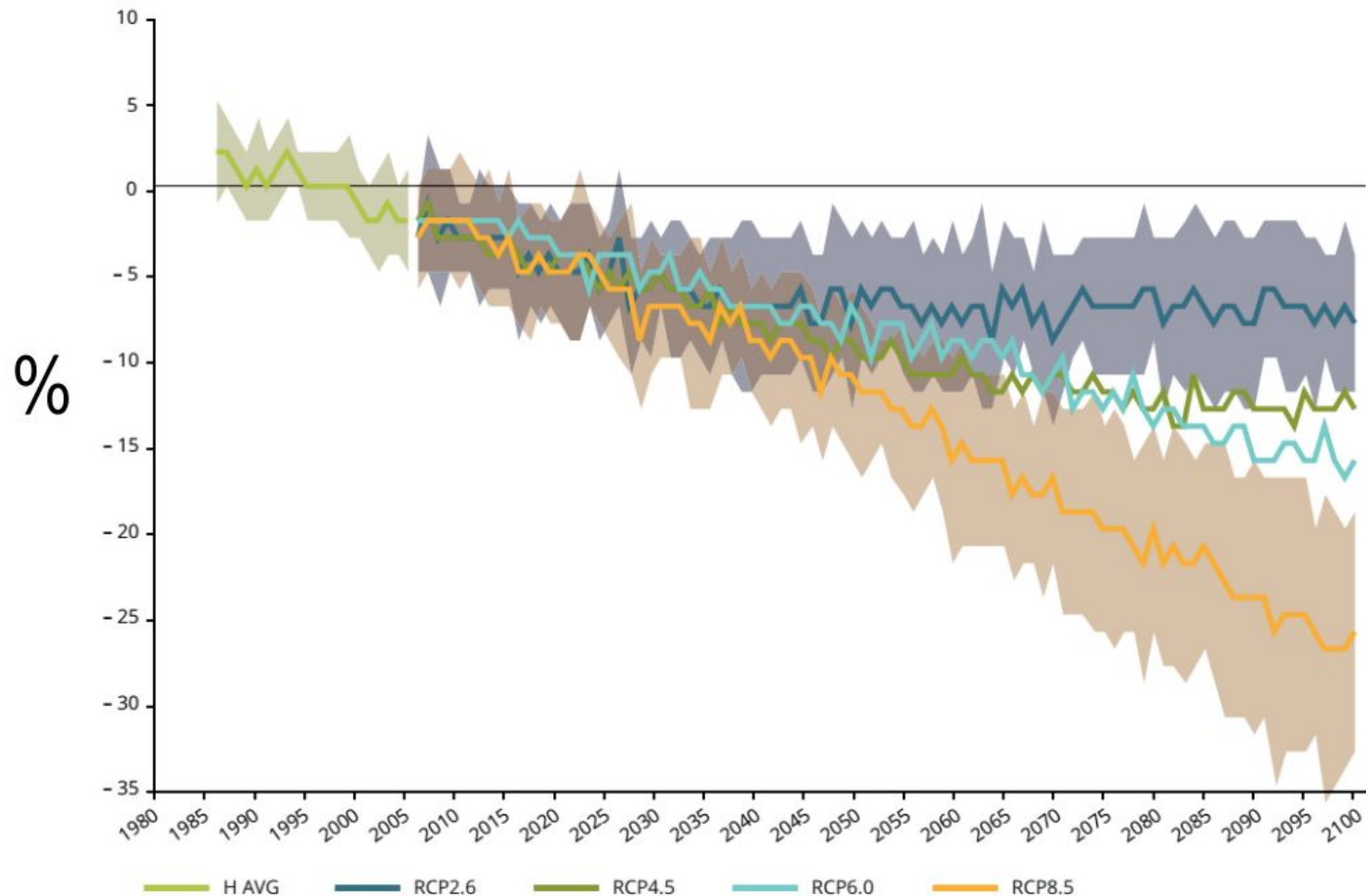
Note:
Maximum extent of ice cover in the Baltic Sea in winter in the period from 1719/1720 to 2018/2019 (blue bars) and 15-year moving average (red line).

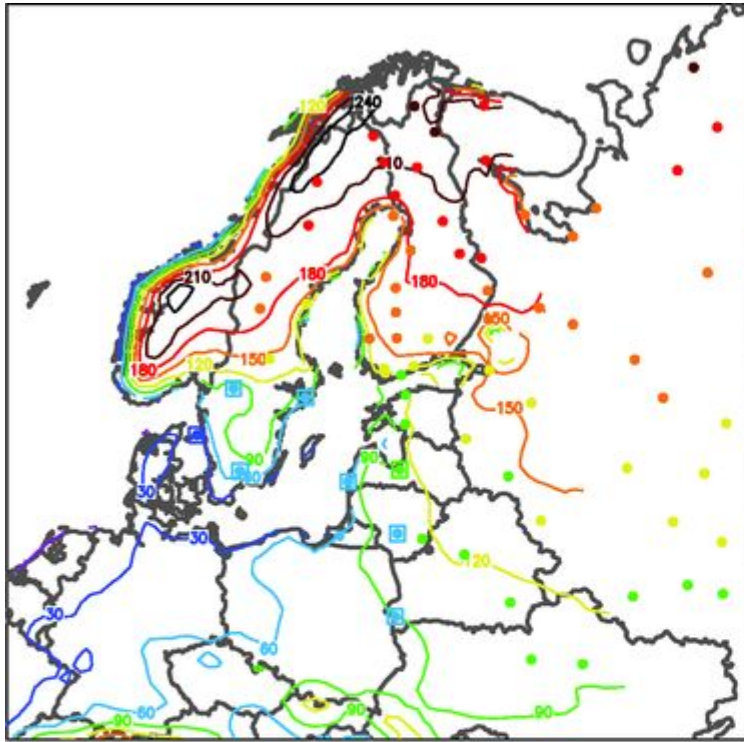
Pokrywa śnieżna



ZMIANY POKRYWY ŚNIEŻNEJ WIOSNĄ

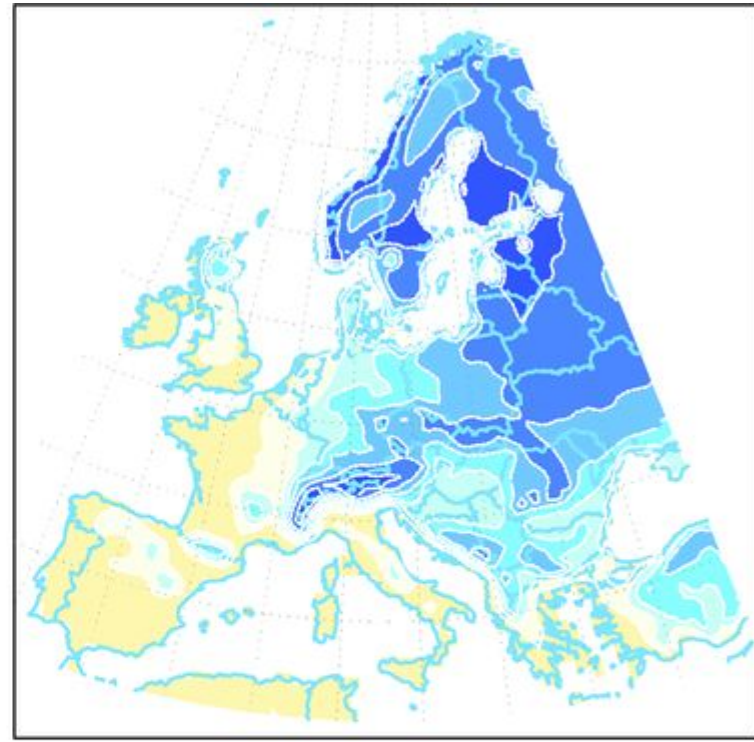
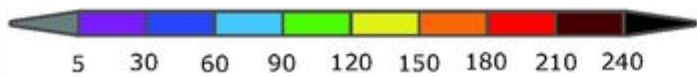
marzec - kwiecień, półkula północna





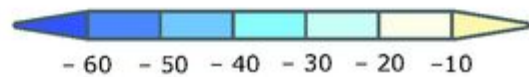
Annual number of days with snow cover

Observed means in northern Europe, 1961-1990 (coloured dots) and modelled means for Europe, 1961-1990

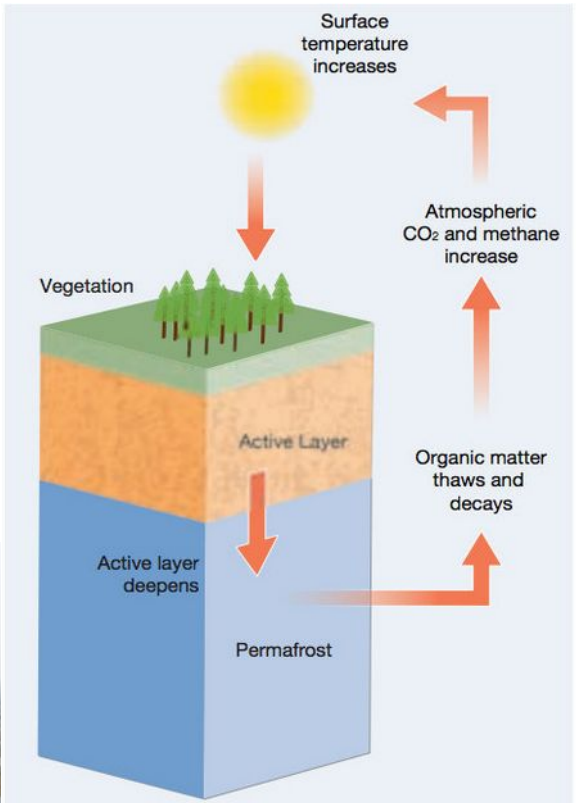


Projected change of annual number of days with snow cover

Projected multi-model mean changes for the period 2071-2100, relative to 1961-1990

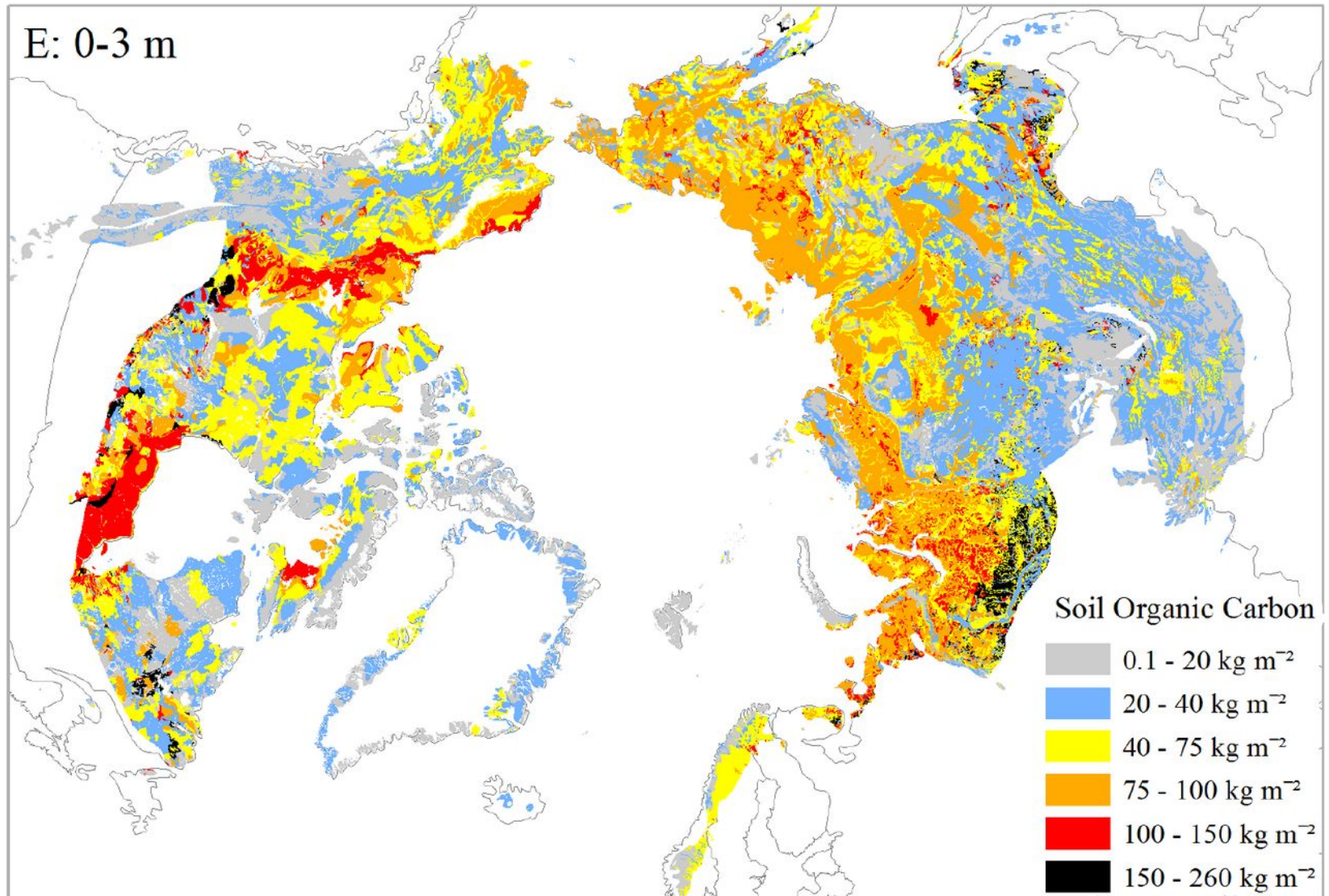


Wieloletnia zmarzlina

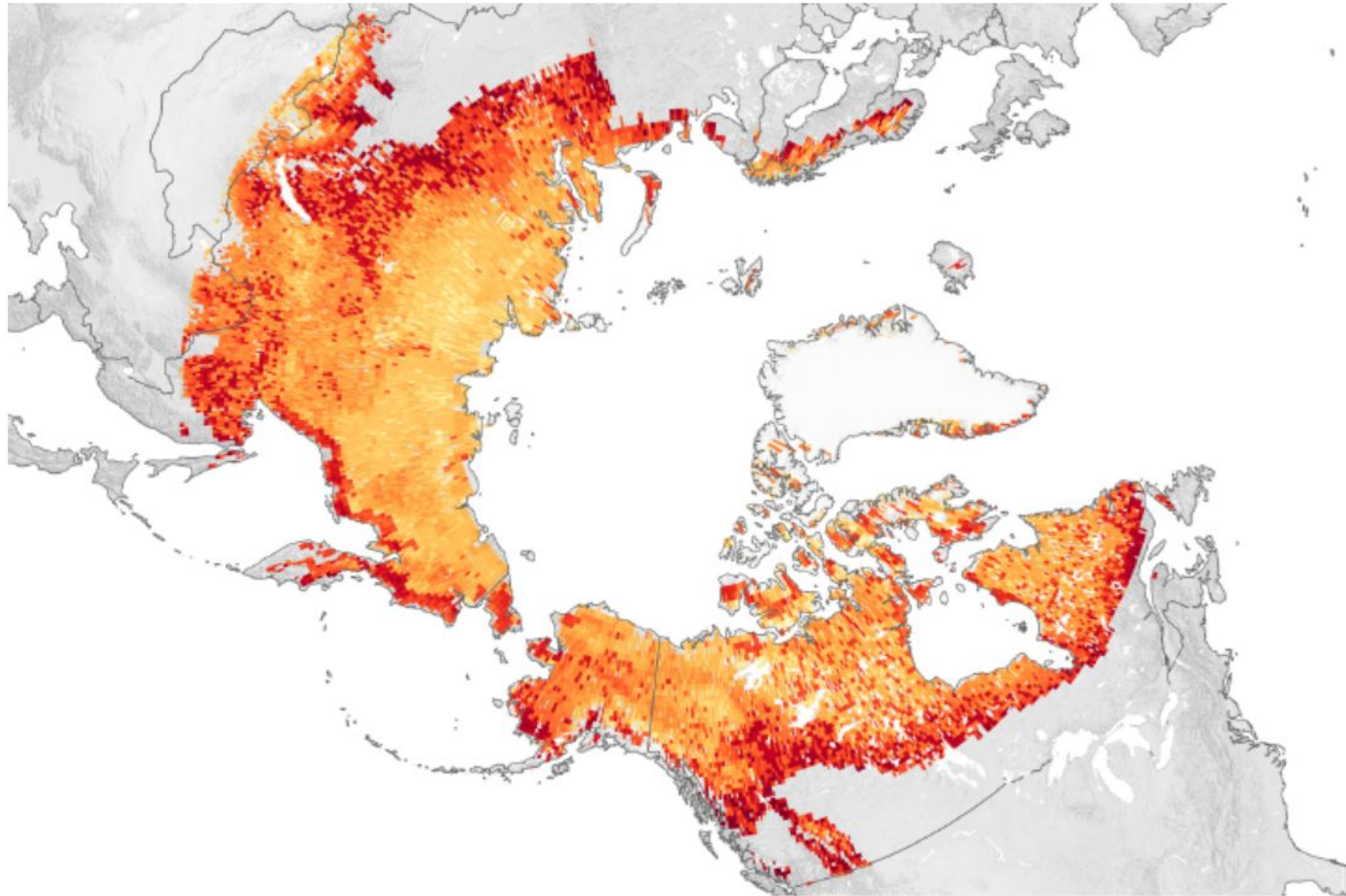


Delta Leny, lipiec 2012, Volkmar Kochan/rbb

Wieloletnia zmarzlina - węgiel organiczny



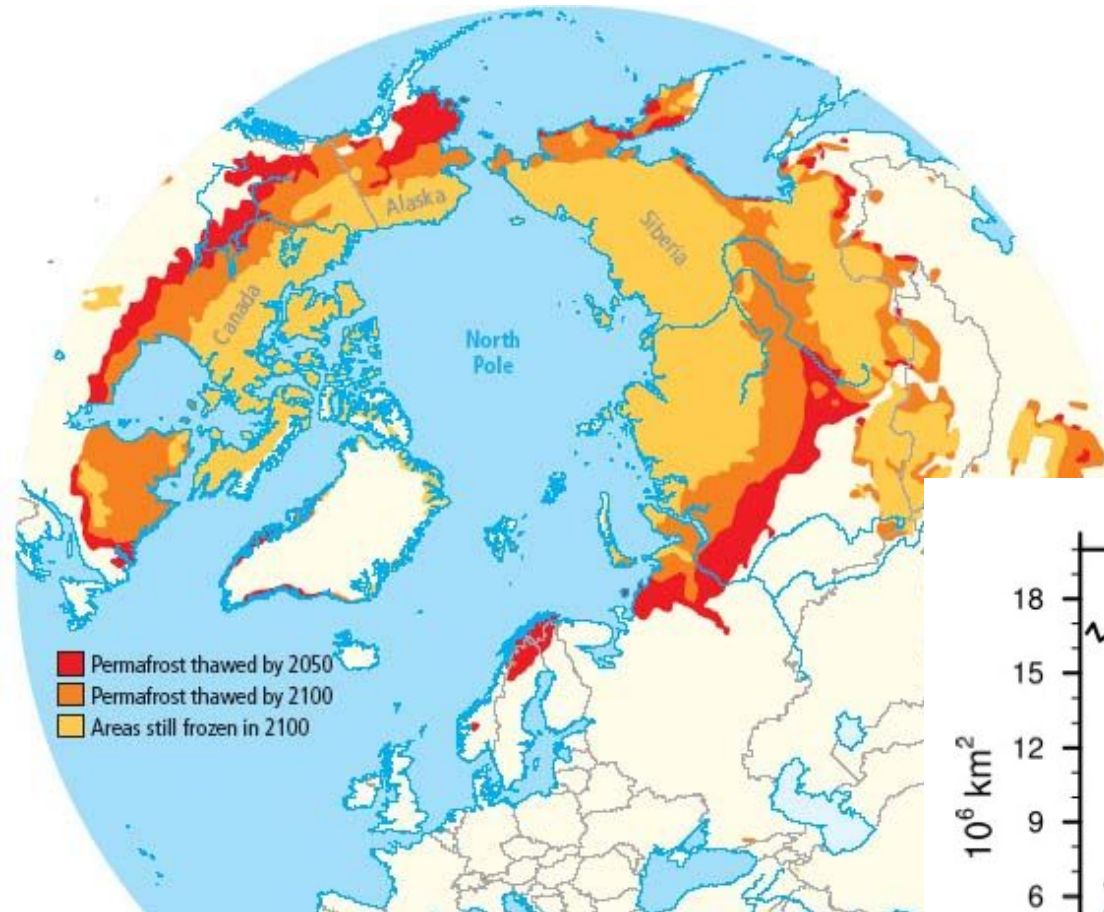
Natali, S.M., Watts, J.D., Rogers, B.M. et al. Large loss of CO₂ in winter observed across the northern permafrost region. *Nat. Clim. Chang.* 9, 852–857 (2019).
<https://doi.org/10.1038/s41558-019-0592-8>



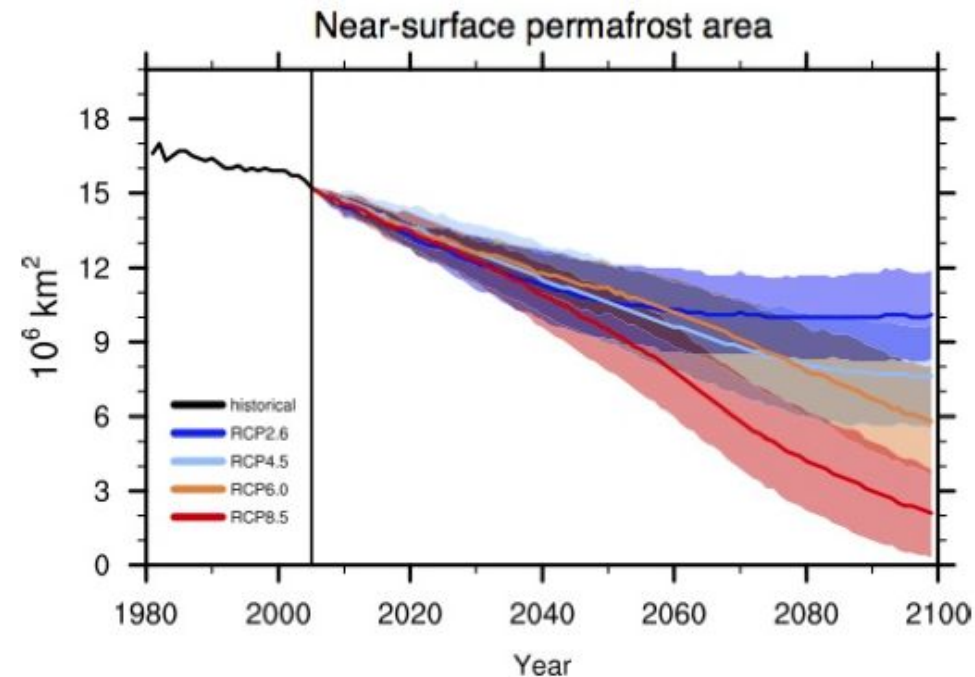
Winter CO₂ Emissions (g/m²/year, 2003-2017)

≤20	50	80	110	140	170	≥200
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Wieloletnia zmarzlina



Vladimir Romanovsky, 2009



WZROST POZIOMU MORZA 1993-2010



■ rozszerzalność cieplna
1,1 mm/r

■ lodowce 0,76 mm/r

■ Grenlandia 0,33 mm/r

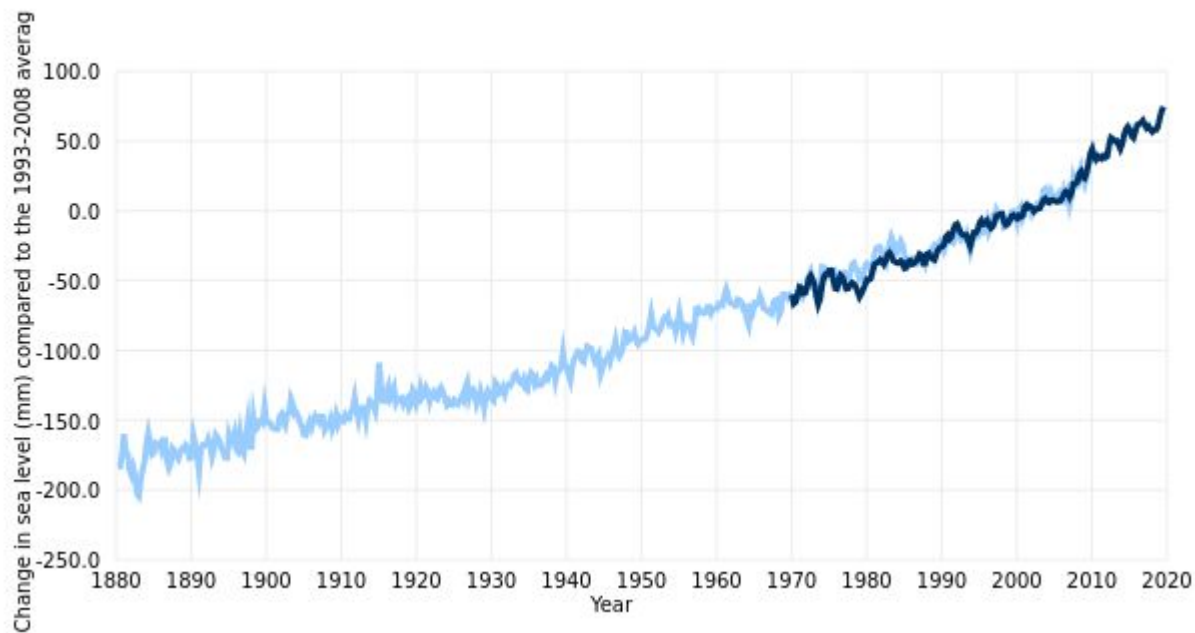
■ Antarktyda 0,27 mm/r

■ sptyw z lądów 0,38 mm/r

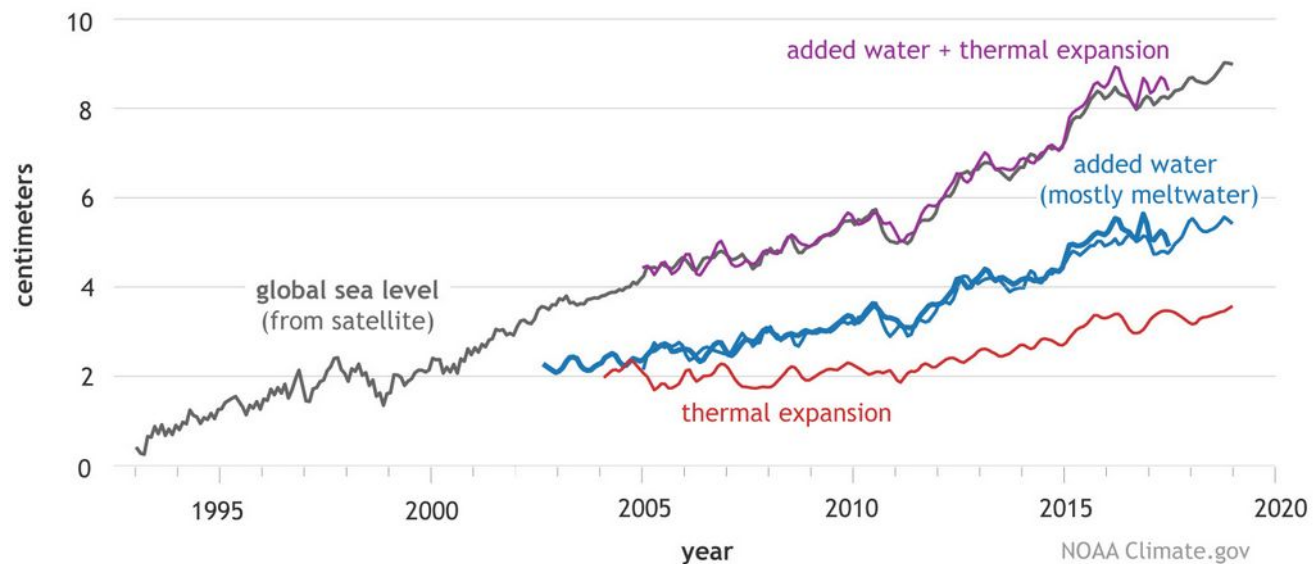
Źródło: V raport IPCC, www.climatechange2013.org

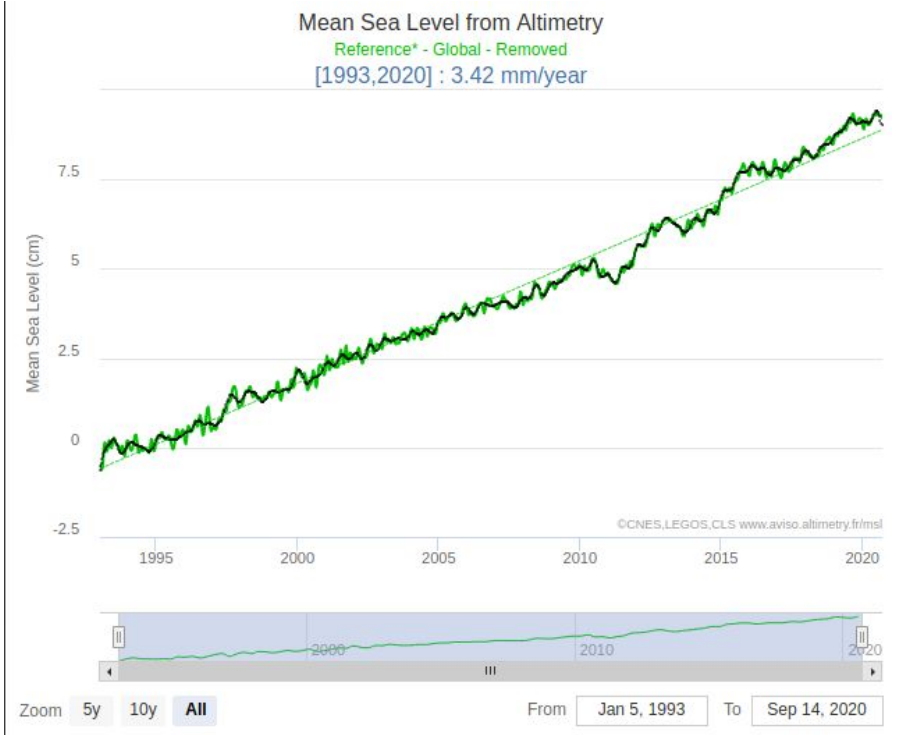
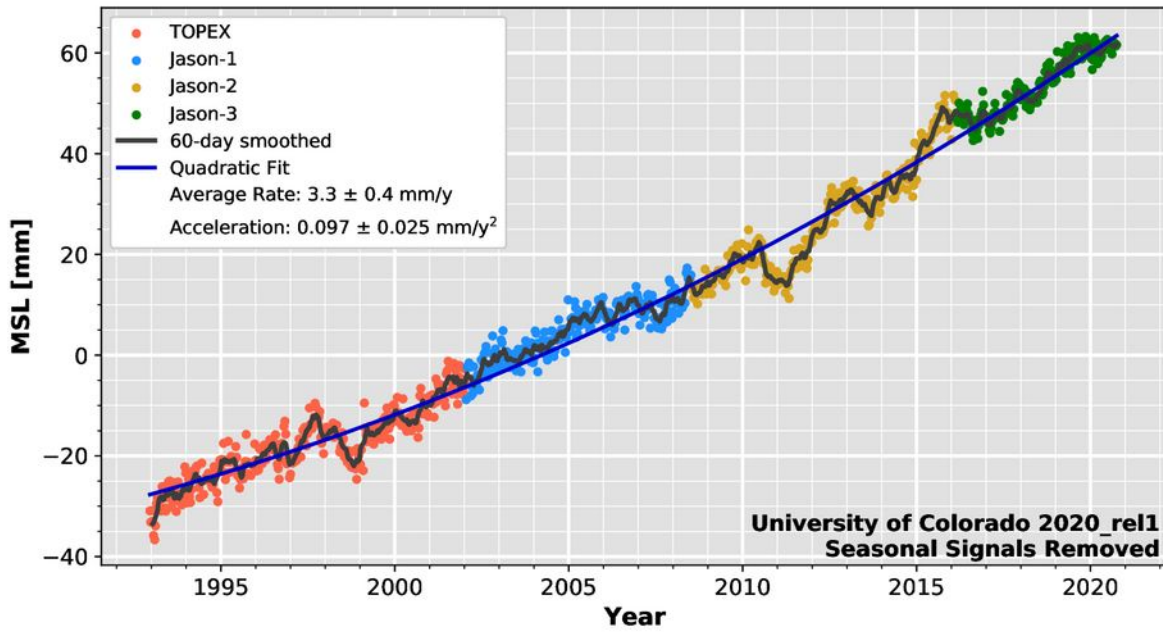
Wzrost poziomu morza

Sea level since 1880

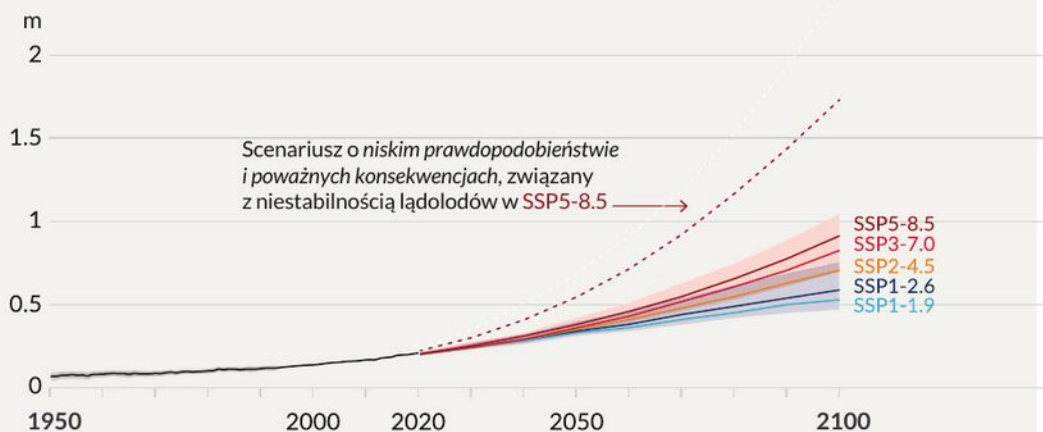


Contributors to global sea level rise (1993-2018)

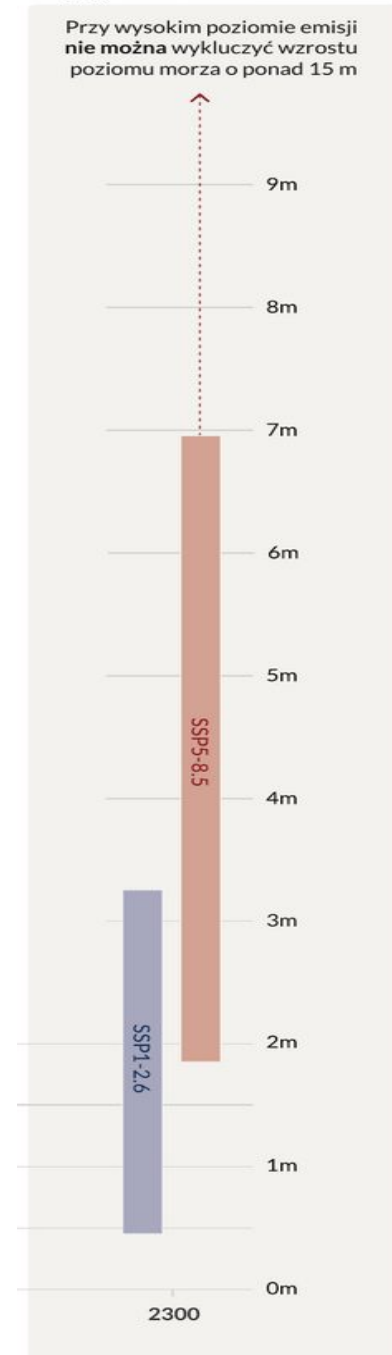




d) Zmiana średniego globalnego poziomu morza w stosunku do roku 1900



e) Zmiana średniego globalnego poziomu morza w 2300 r. względem 1900 r.



Rola kriosfery w systemie klimatycznym

- wpływa na bilans energii (wysokie albedo śniegu i lodu)
- wpływa na poziom światowego oceanu
- wpływa na cyrkulację oceaniczną w wysokich szerokościach geograficznych i nie tylko
- bierze udział w szeregu sprzężeń zwrotnych w systemie klimatycznym