

Out of Equilibrium in a Warming World: Glaciers and Sea Level Rise



Credit: Frank Paul

Alex S. Gardner



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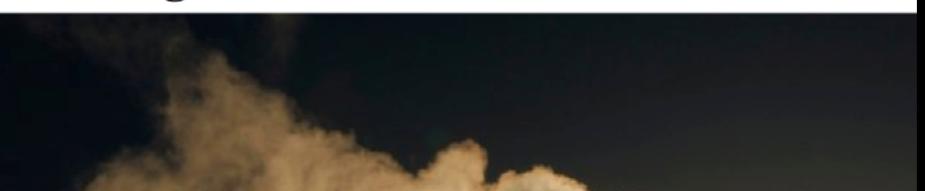


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By Karl Ritter | ASSOCIATED PRESS SEPTEMBER 27, 2013

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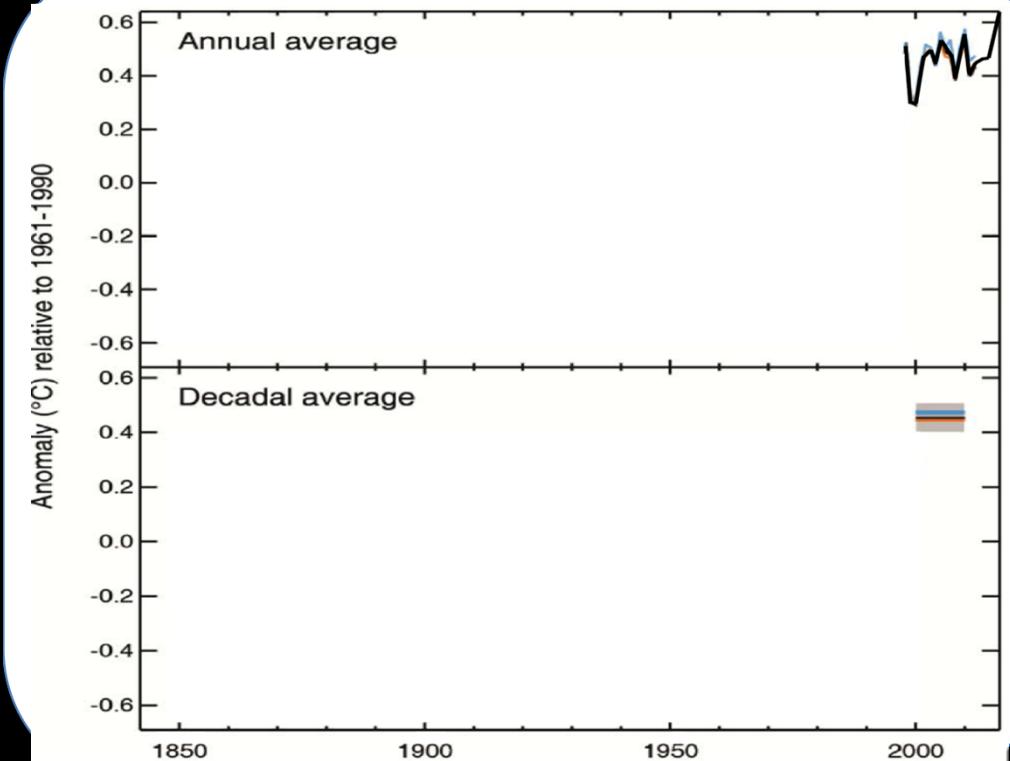
Global warming 'extremely likely' to be man-made, UN panel says

Recent slowdown in warming unlikely to last

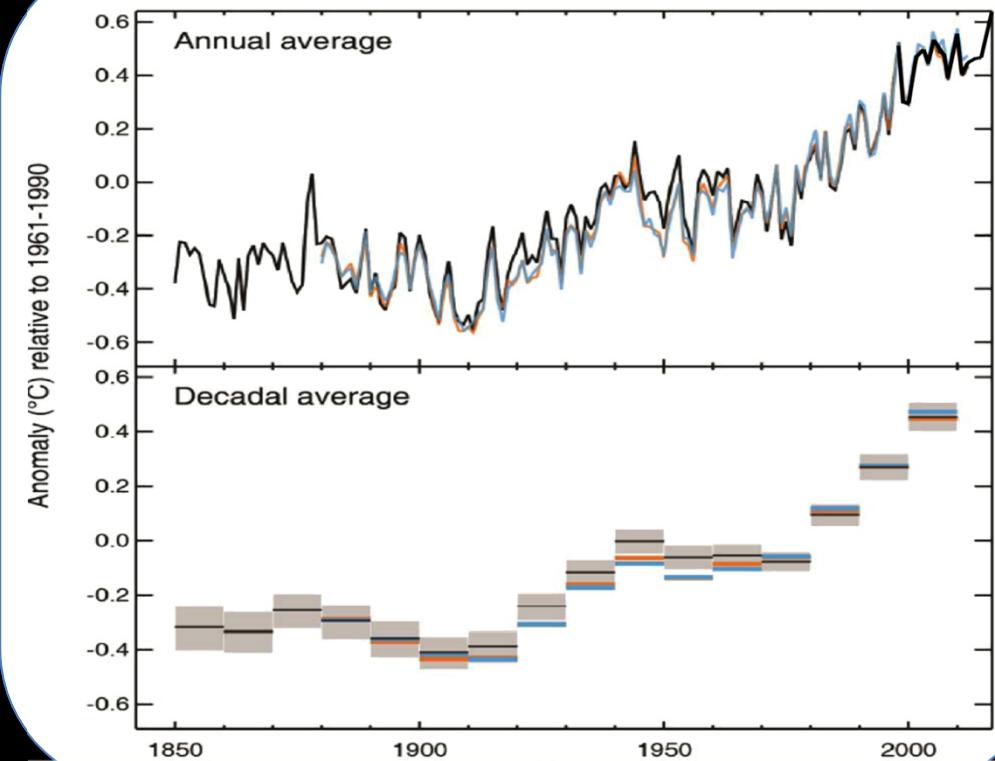
The Associated Press Posted: Sep 27, 2013 3:16 AM ET | Last Updated: Sep 27, 2013 10:52 AM ET



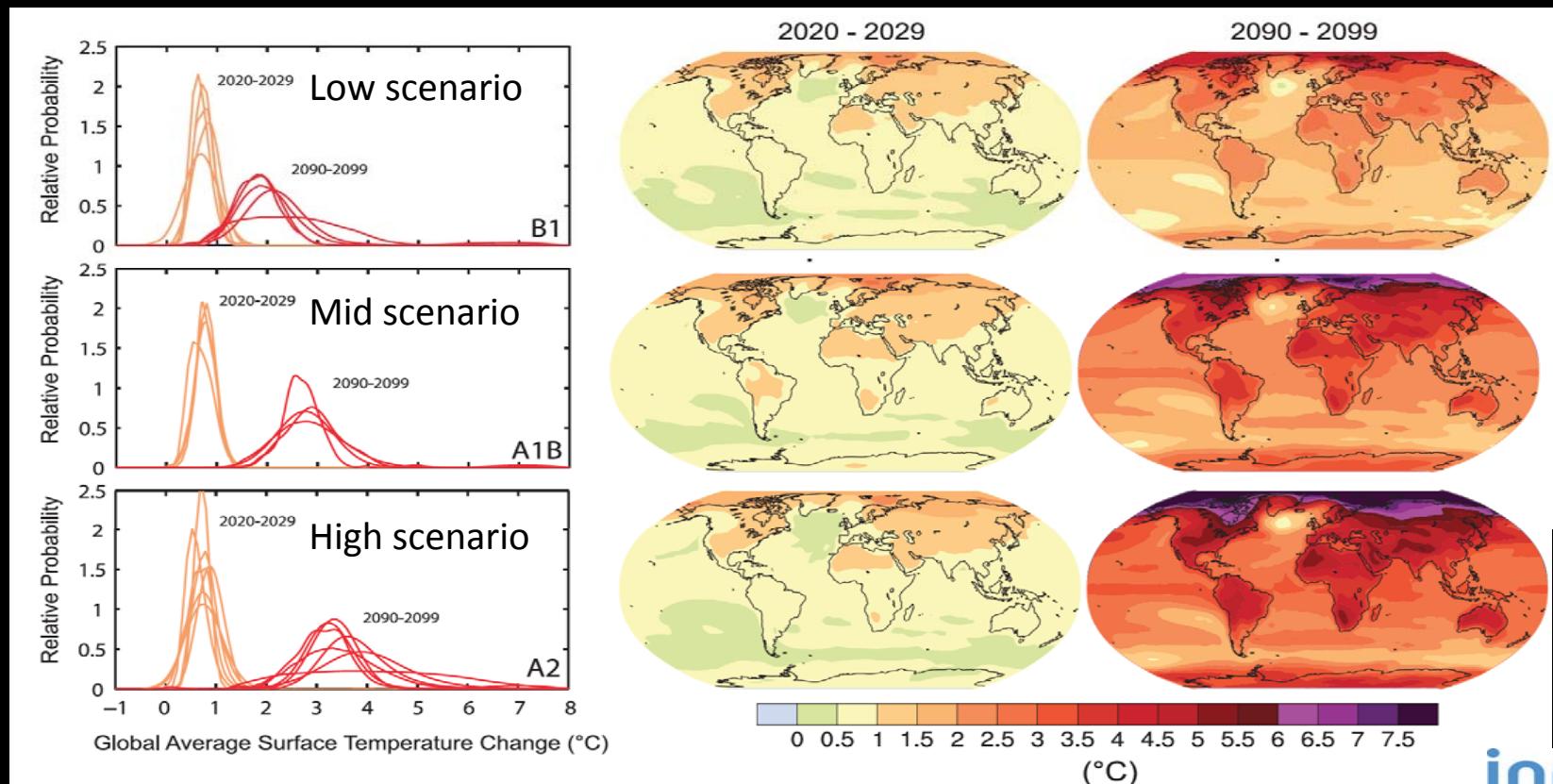
Global mean land + ocean surface temperature: 1999-2015



Global mean land + ocean surface temperature: 1850-2015

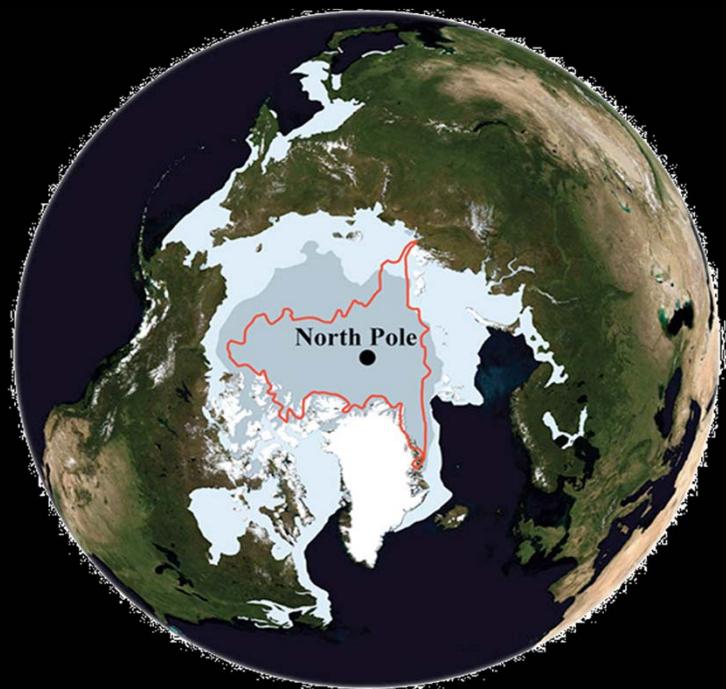


A much warmer Arctic

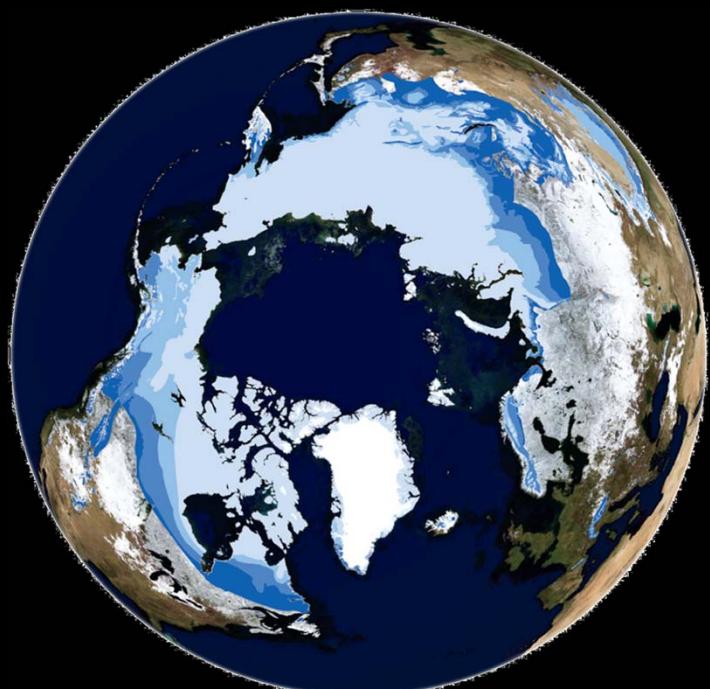


New equilibrium for a frozen landscape

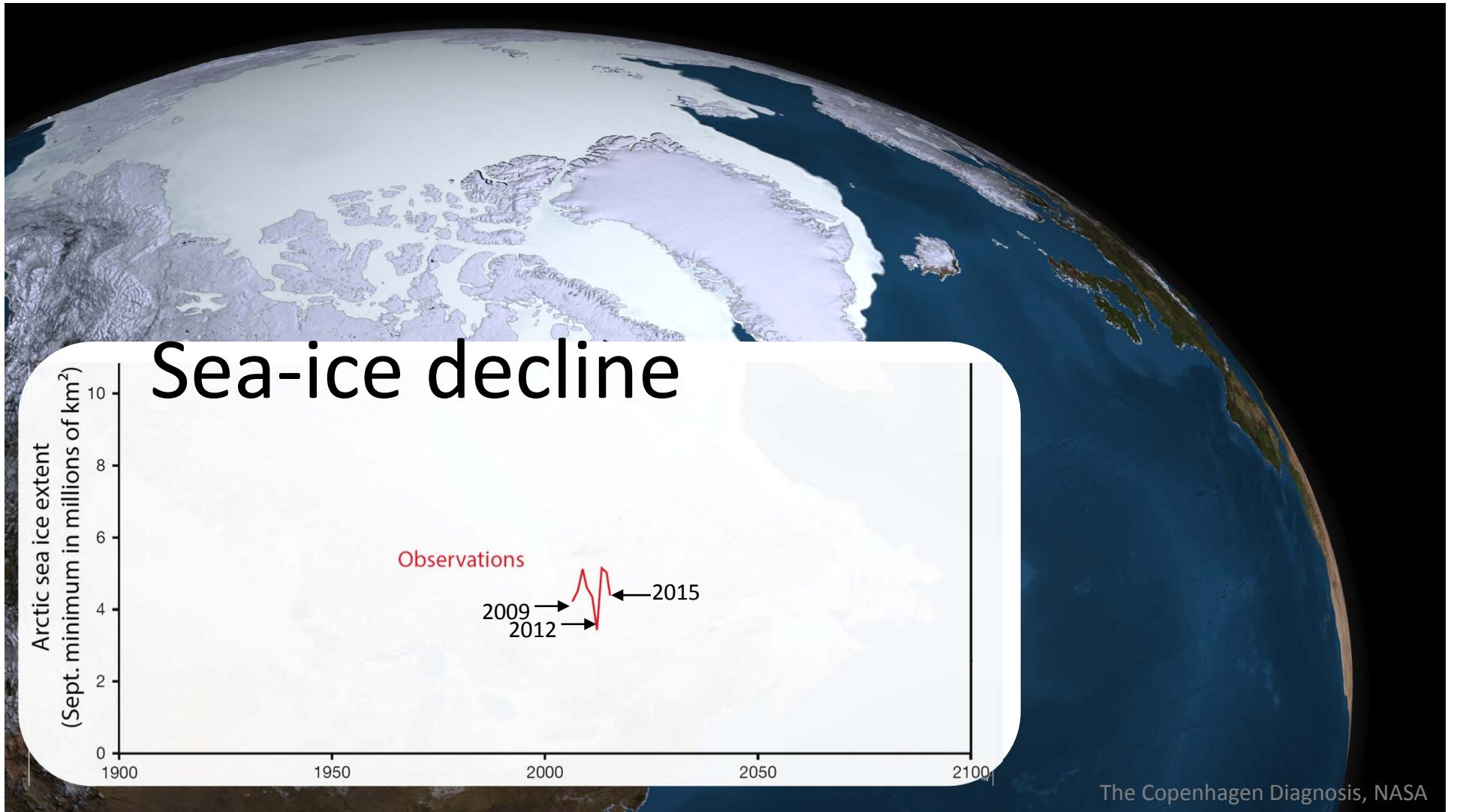
Sea Ice

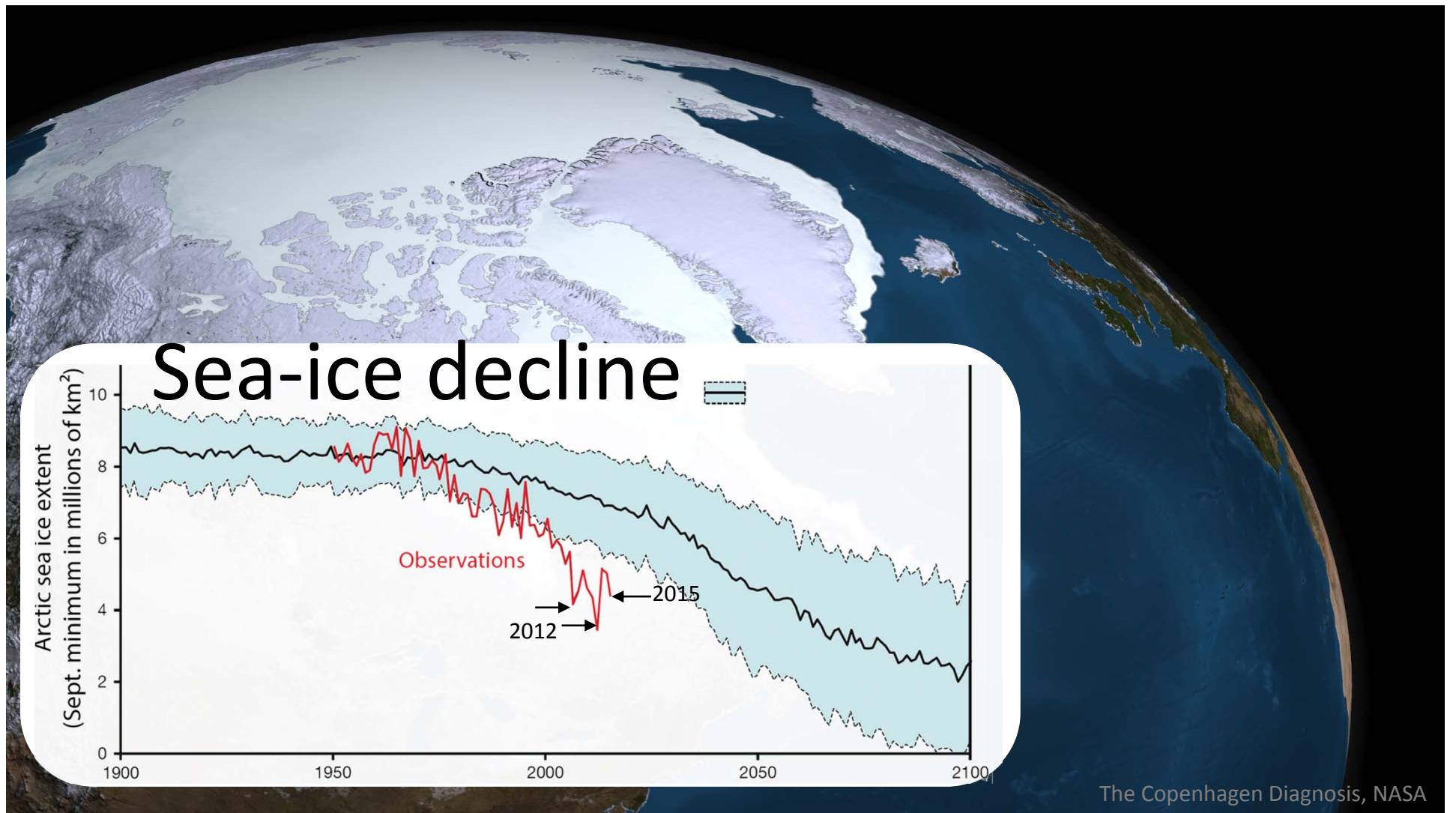


Land Ice



State of the Earth's cryosphere at the beginning of the 21st century—Glaciers



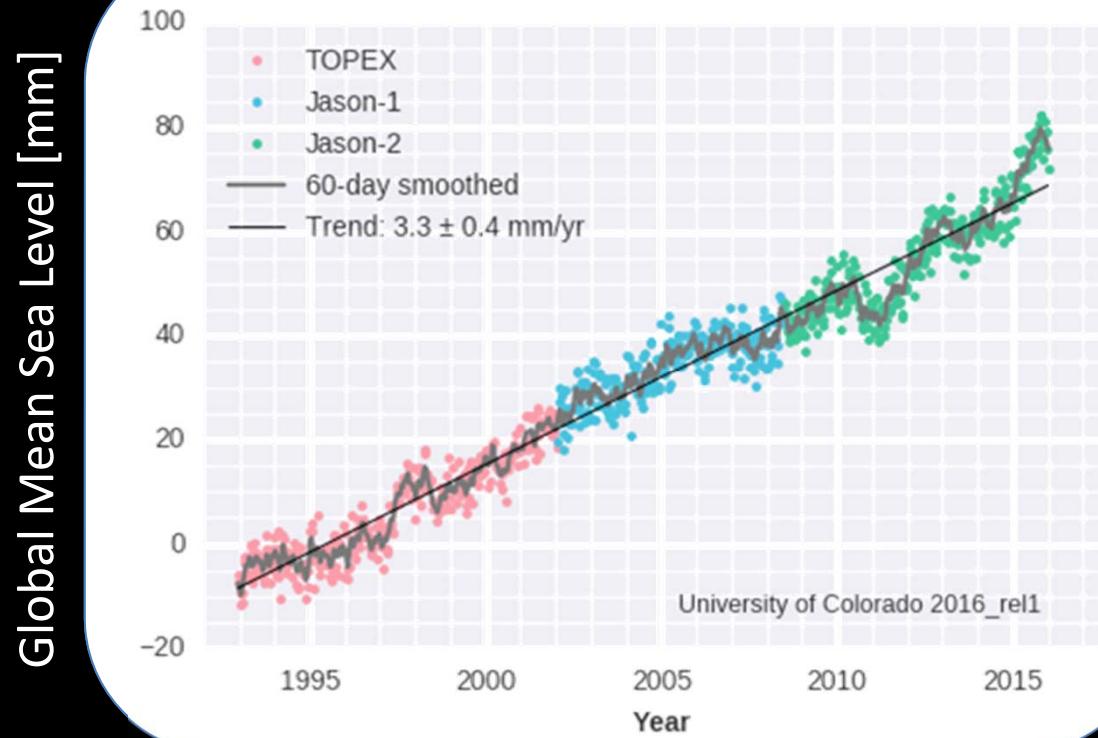


Glacier Mass Loss (losses > gains)

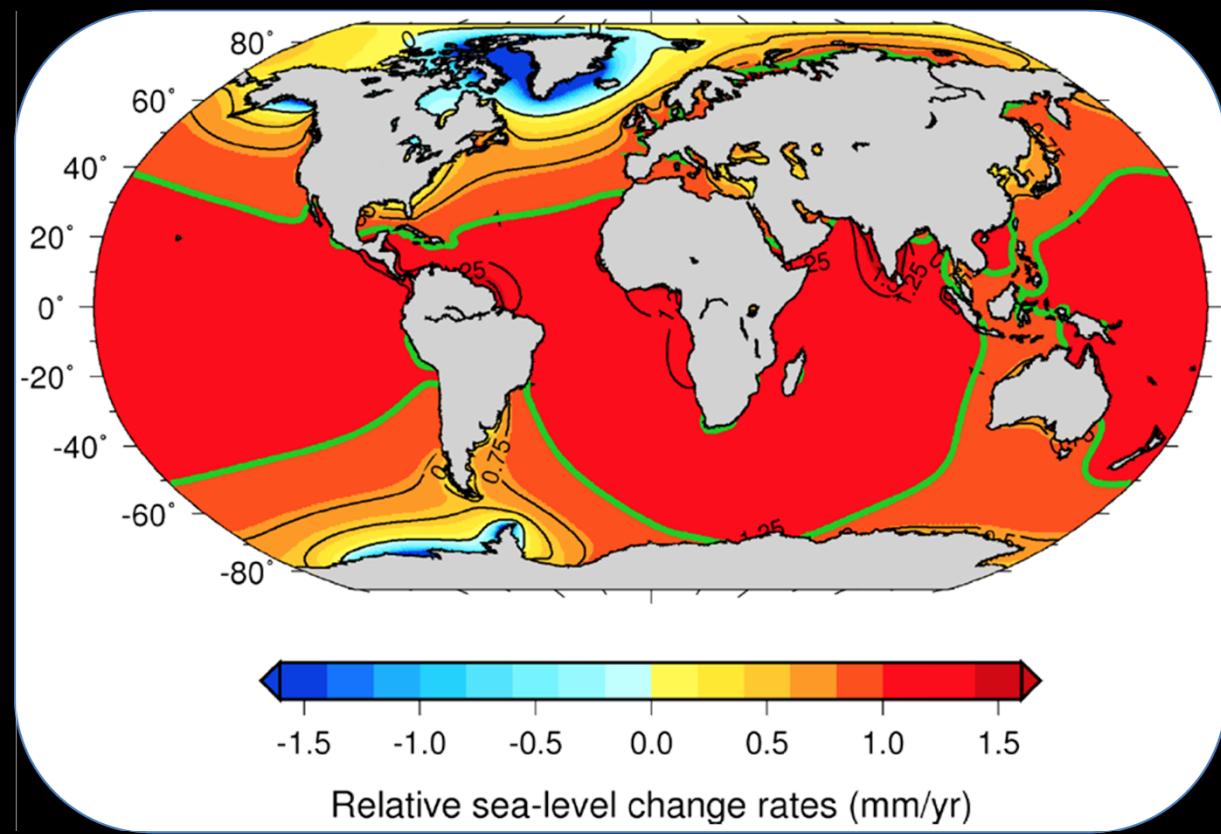


W. Tad Pfeffer

Sea level rise

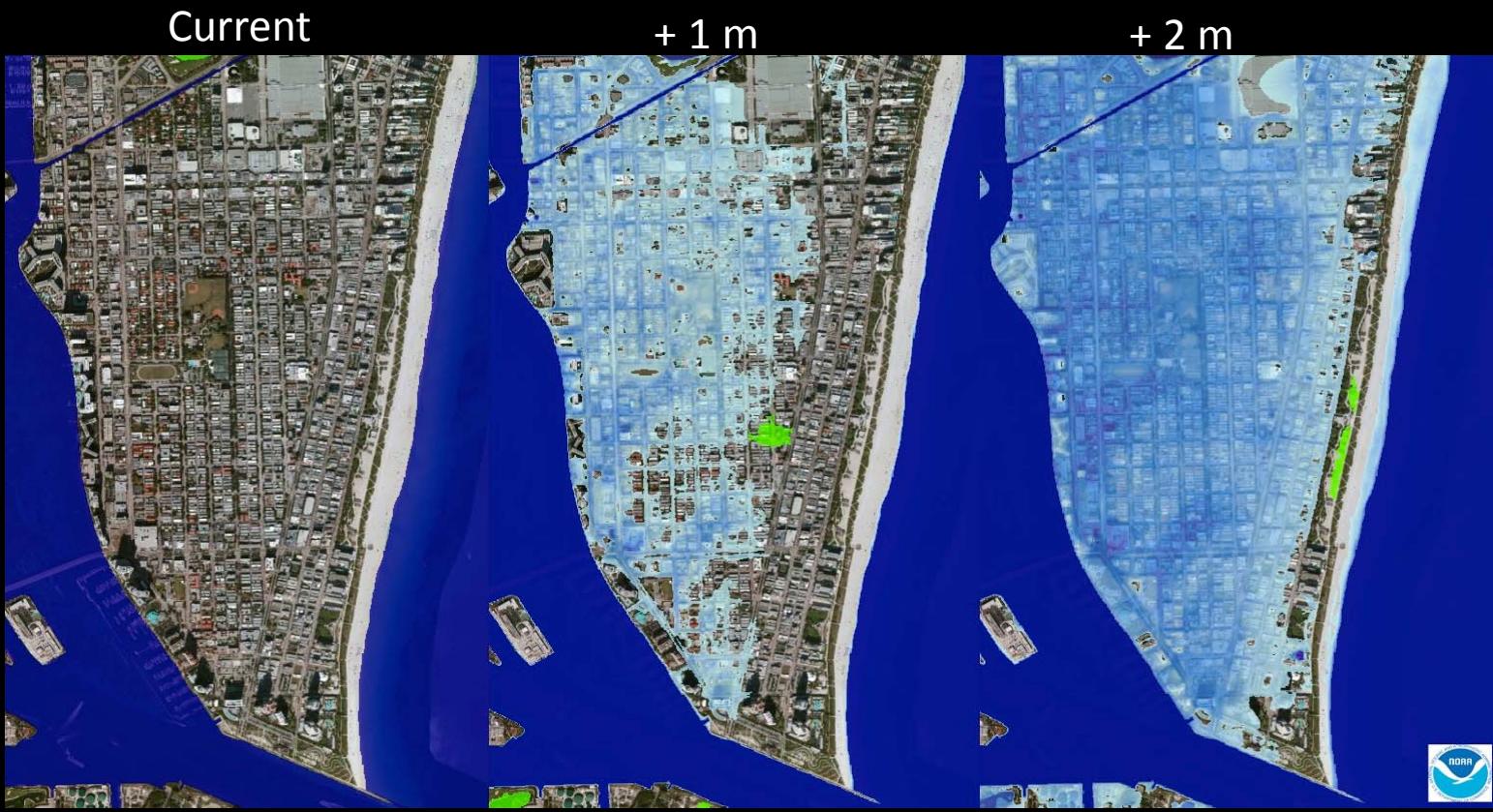


Sea level change “fingerprint”



Riva, et al., 2010

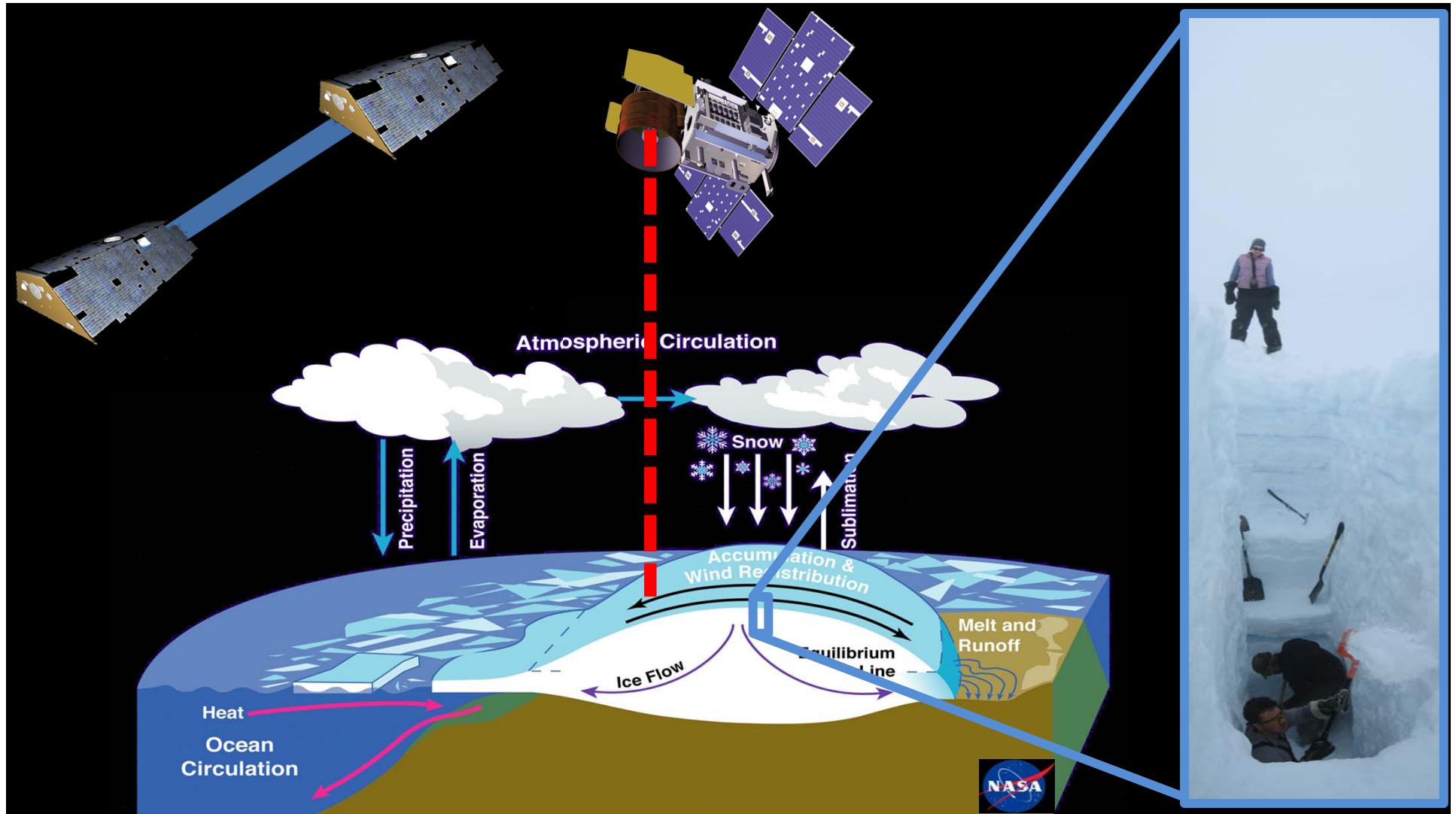
Millimeters matter





How do we determine
how much changes in
land ice contribute to
sea level rise?

E. Berthier



The Ice Sheets

Greenland
Ice Sheet

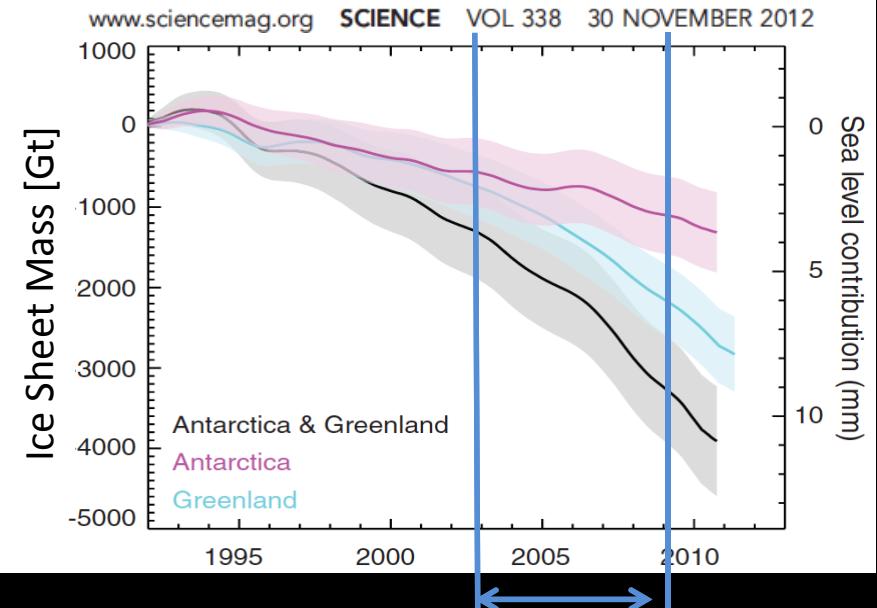
Antarctic
Ice Sheet

Gardner et al., 2013

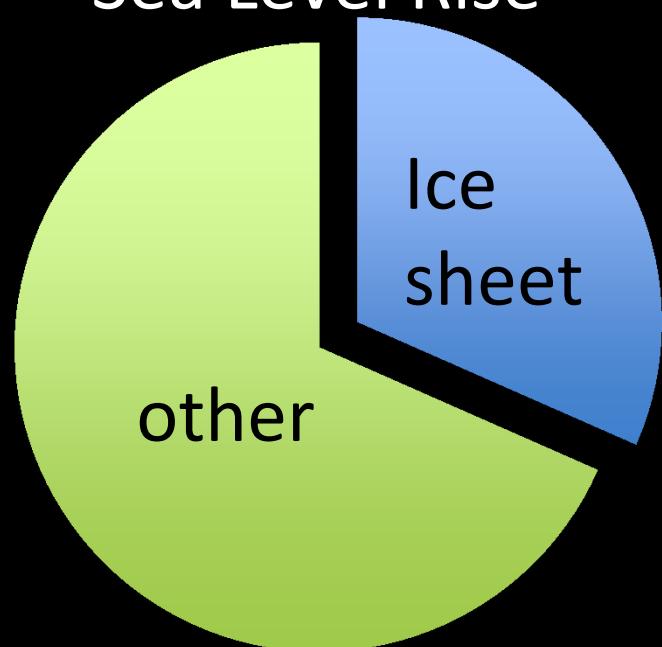
The Ice Sheets

A Reconciled Estimate of Ice-Sheet Mass Balance

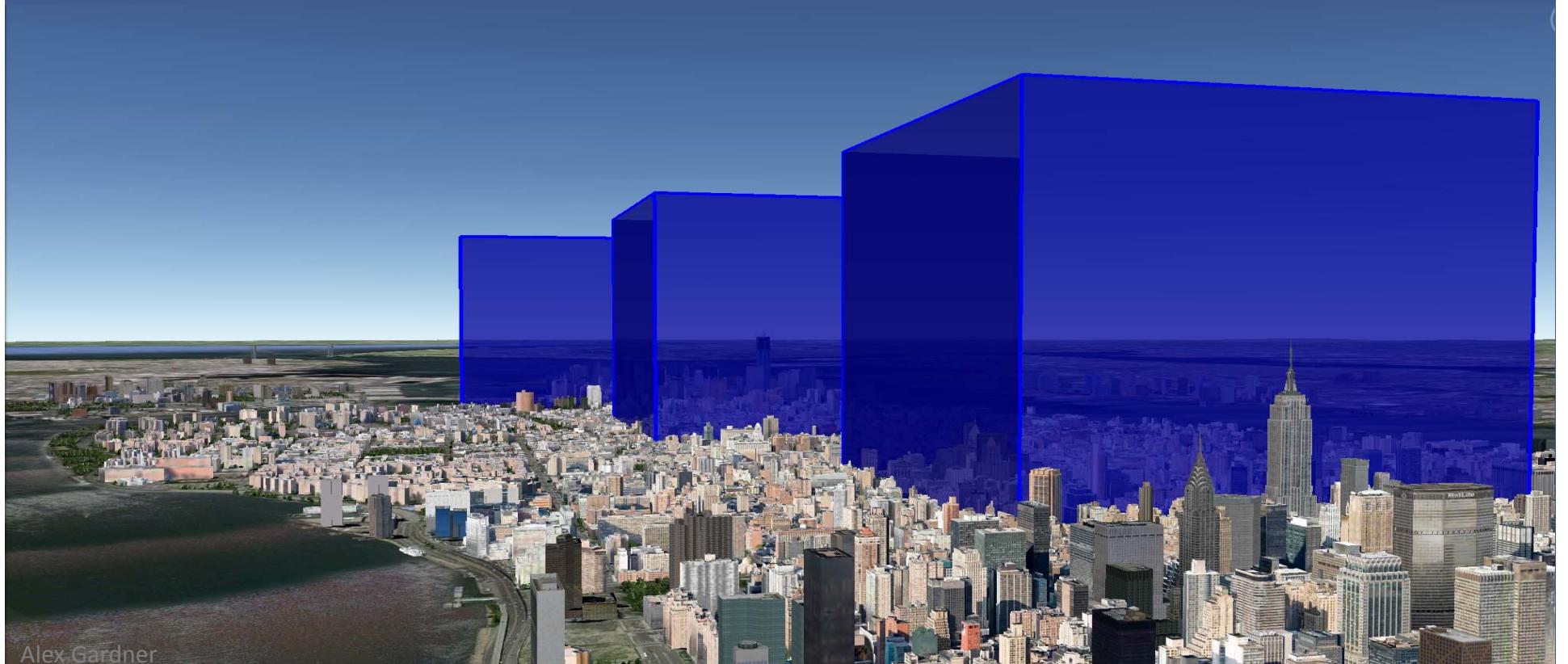
Andrew Shepherd,^{1,*} Erik R. Ivins,^{2,*} Geruo A.,³ Valentina R. Barletta,⁴ Mike J. Bentley,⁵
And many others



Fraction of total
Sea Level Rise

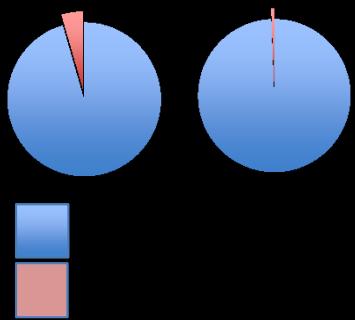


What's a Gigaton?



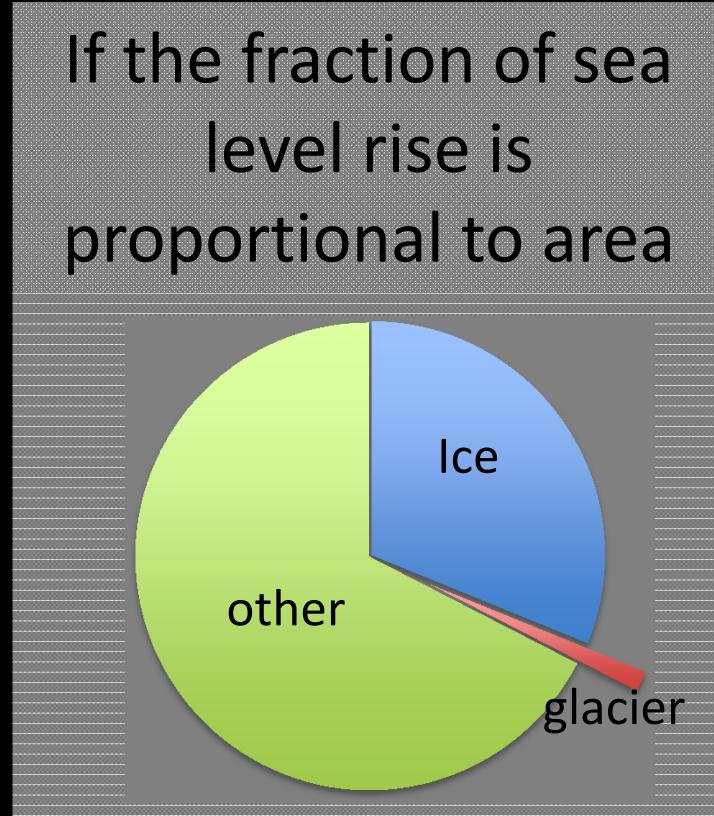
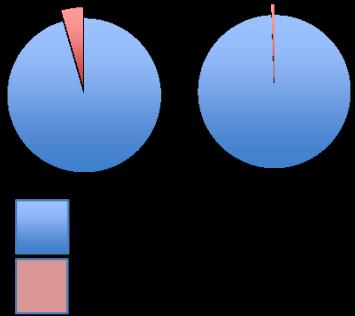
Alex Gardner

What's going on with the other 1% of glacier ice?



Gardner et al., 2013

What's going on with the other 1% of glacier ice?

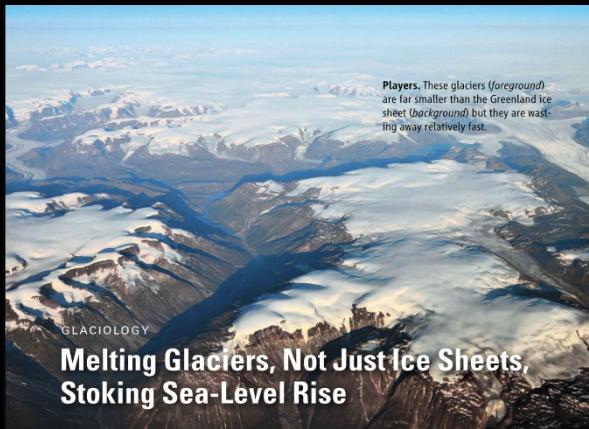


Gardner et al., 2013

A reconciled estimate: 2003 to 2009

A Reconciled Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009

Alex S. Gardner,^{1,2,*} Geir Moholdt,³ C. Graham Cogley,⁴ Bert Wolters,^{5,6} Anthony A. Arendt,⁷ John Wahr,^{5,8} Etienne Berthier,⁹ Regine Hock,^{7,10} W. Tao Pfeffer,¹¹ Georg Kaser,¹² Stefan R. M. Lütkenberg,¹³ Tobias Bolch,^{14,15} Martin J. Sharp,¹⁶ Jon Ove Hagen,¹⁷ Michiel R. van den Broeke,¹³ Frank Paul¹⁴

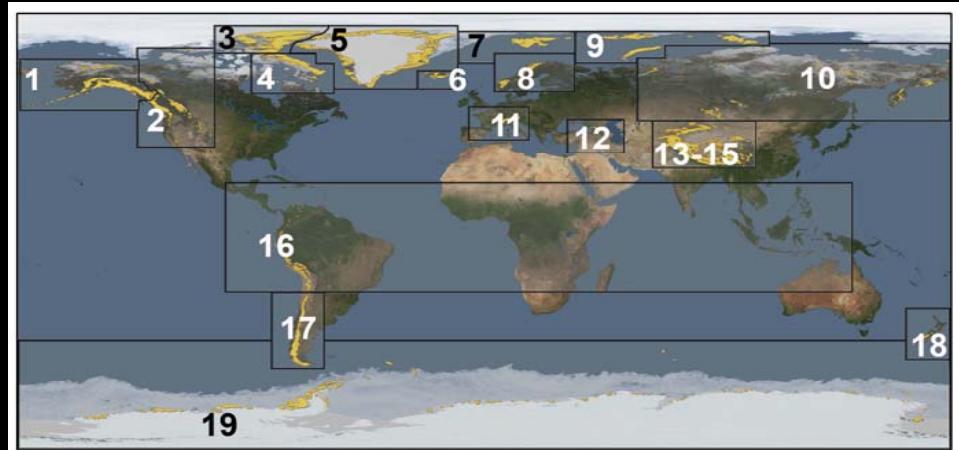


losing ice or might even be gaining a bit, but all 19 glacierized regions lost ice between 2003 and 2009 at a global rate of 259 billion plus or minus 28 billion tonnes per year. That's enough water to raise sea level around the world about 0.7 millimeters per year, an amount roughly equal to the contribution from the shrinking Greenland and Antarctic ice sheets.

"We think this is a very strong result confirmed by three independent methods," Gardner says. The study also showed that field geologists had gotten the shrinkage right for the glaciers they had monitored but that the other glaciers in the same regions were not losing ice as fast.

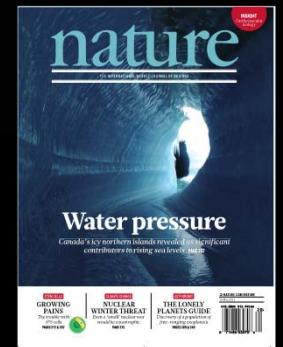
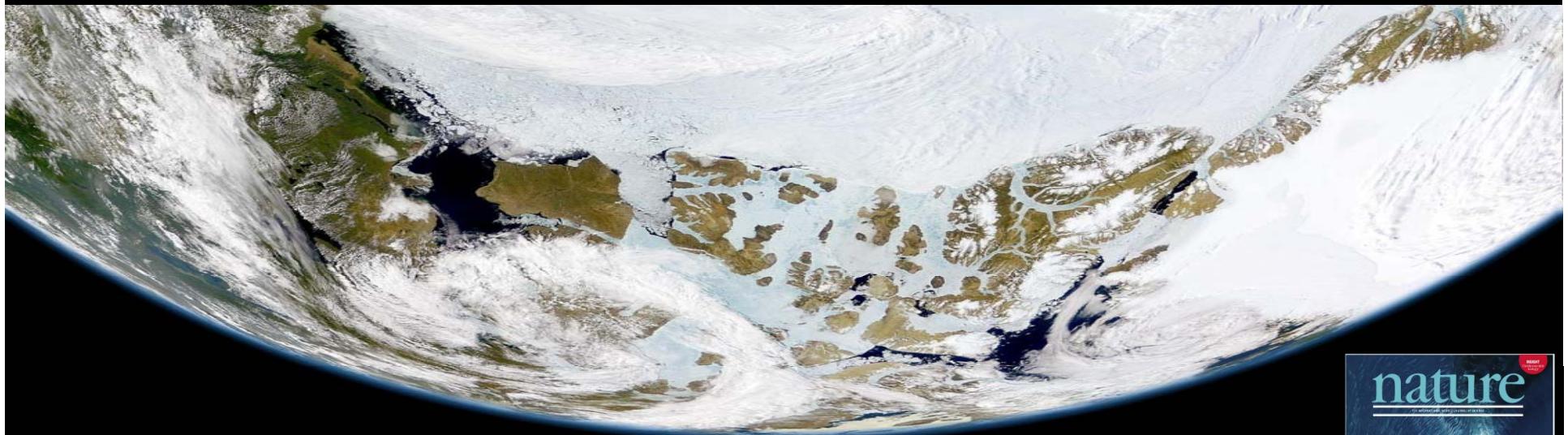
Space-based geophysicist Erik Ivins of NASA's Jet Propulsion Laboratory in Pasadena, California, says it's "remarkable" that the multidisciplinary team

For all 17 glacier regions





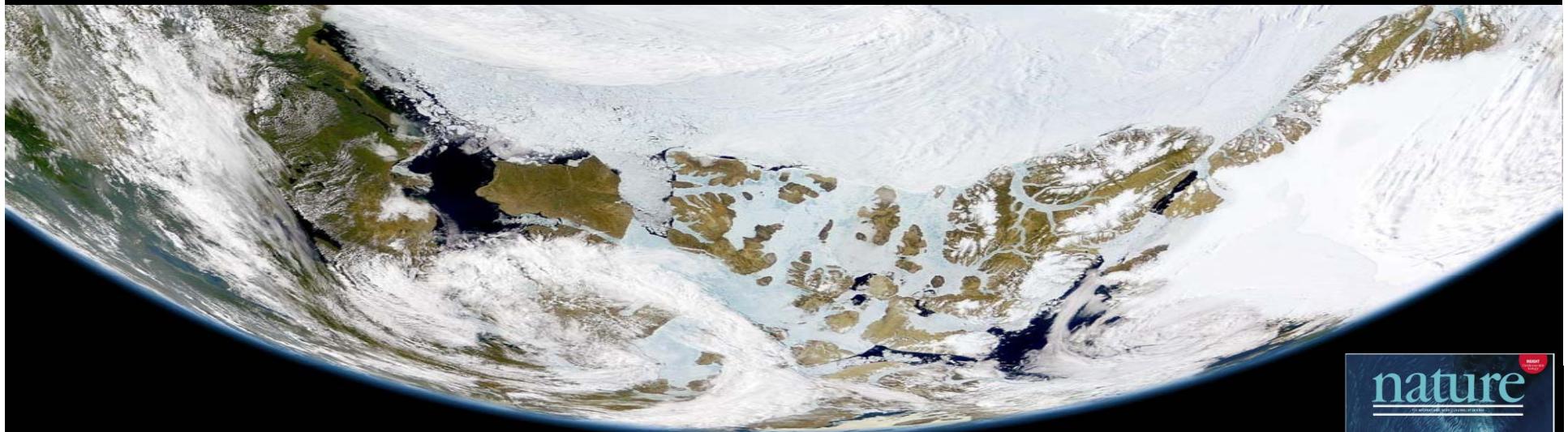
The Canadian Arctic



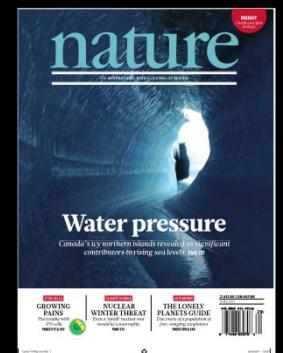
Gardner et al., 2011



The Canadian Arctic



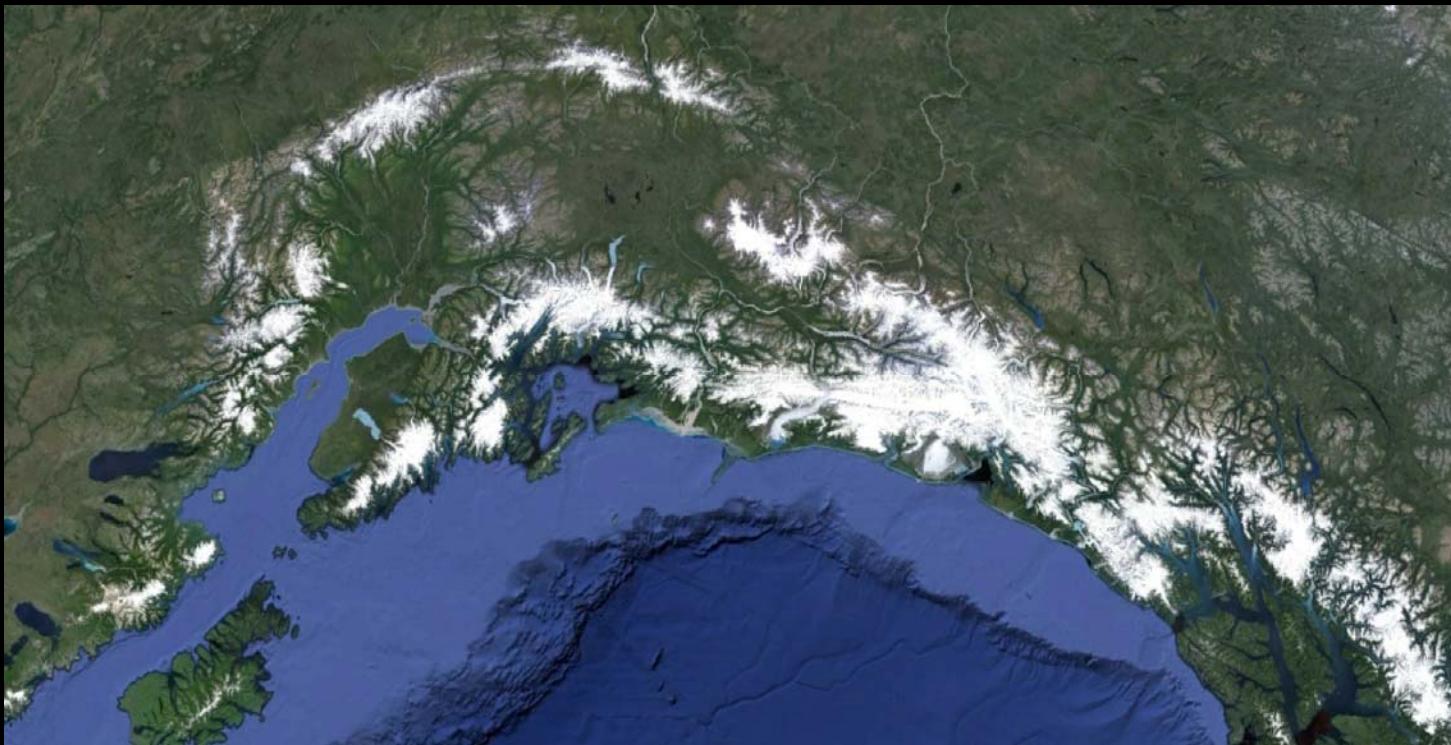
$-60 \pm 8 \text{ Gt yr}^{-1}$



Gardner et al., 2011



Alaska



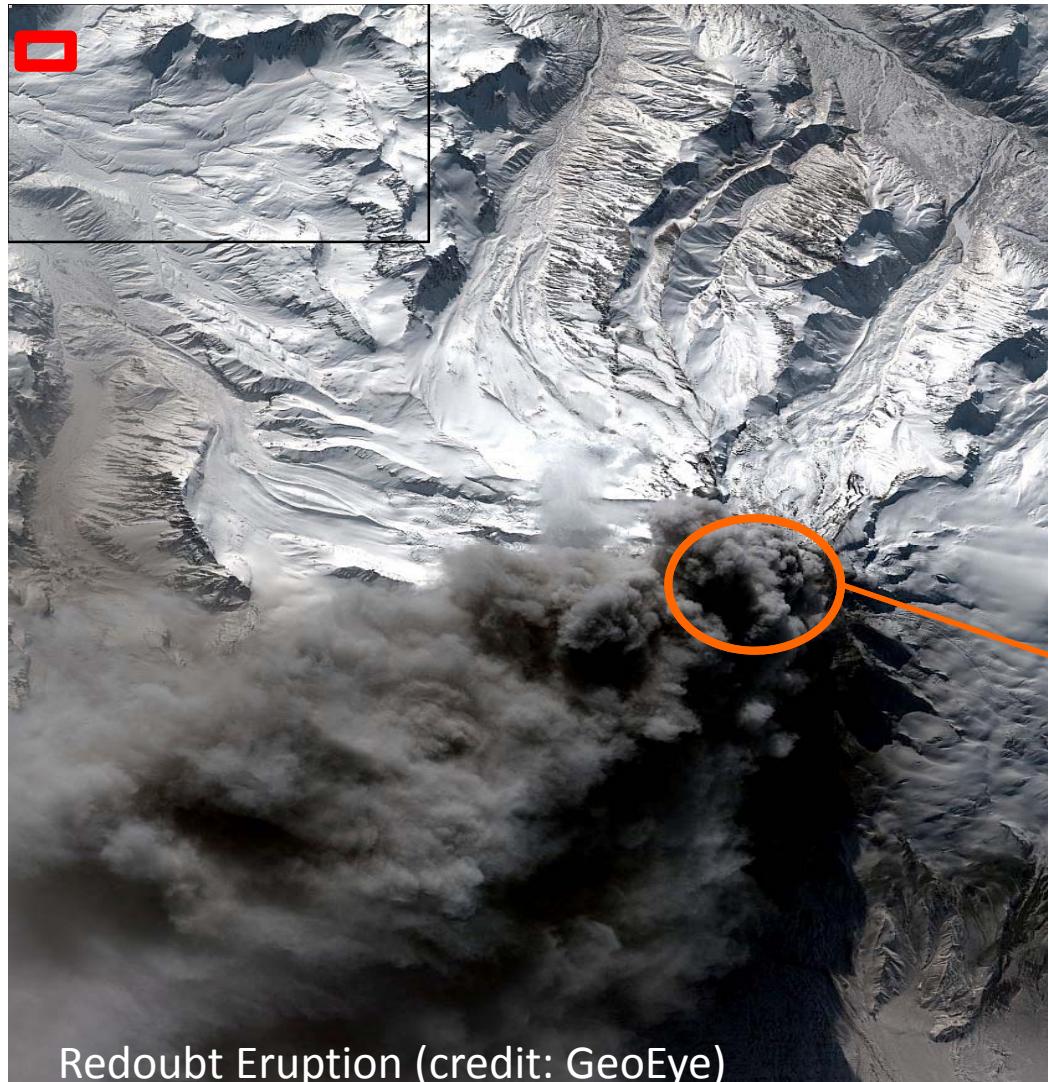
Arendt et al., 2013



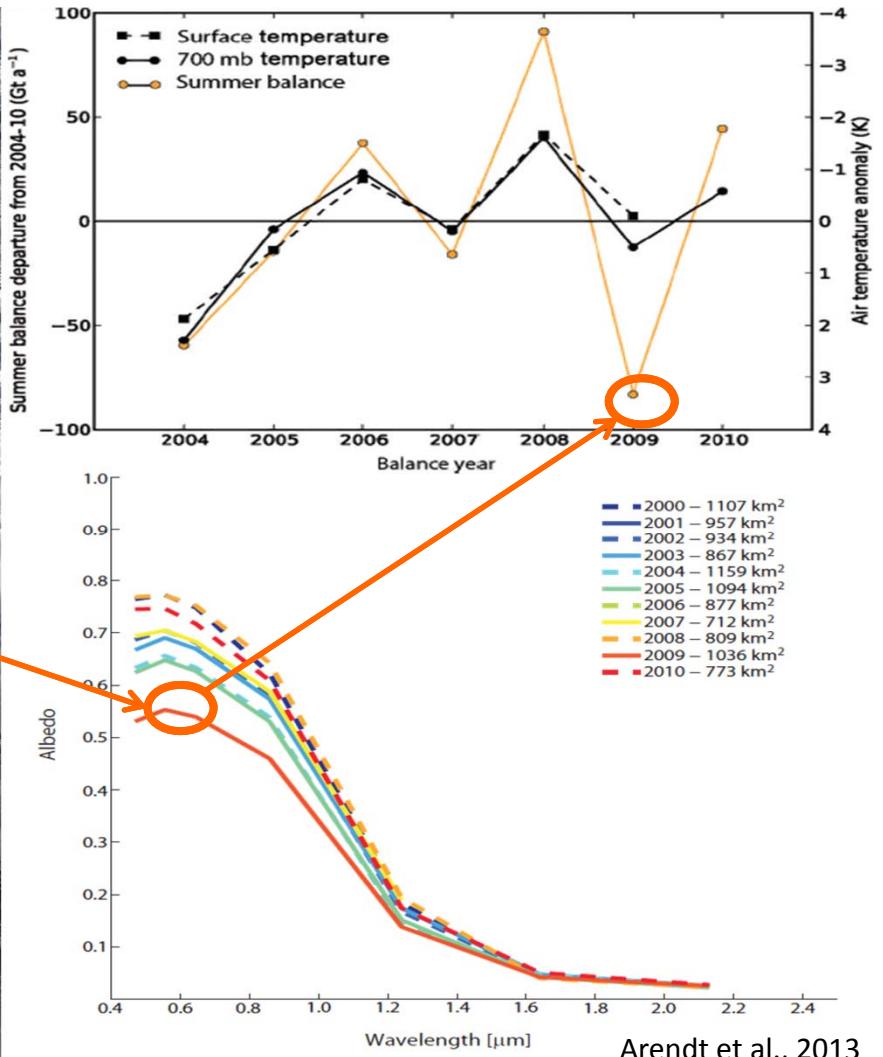
Alaska



Arendt et al., 2013



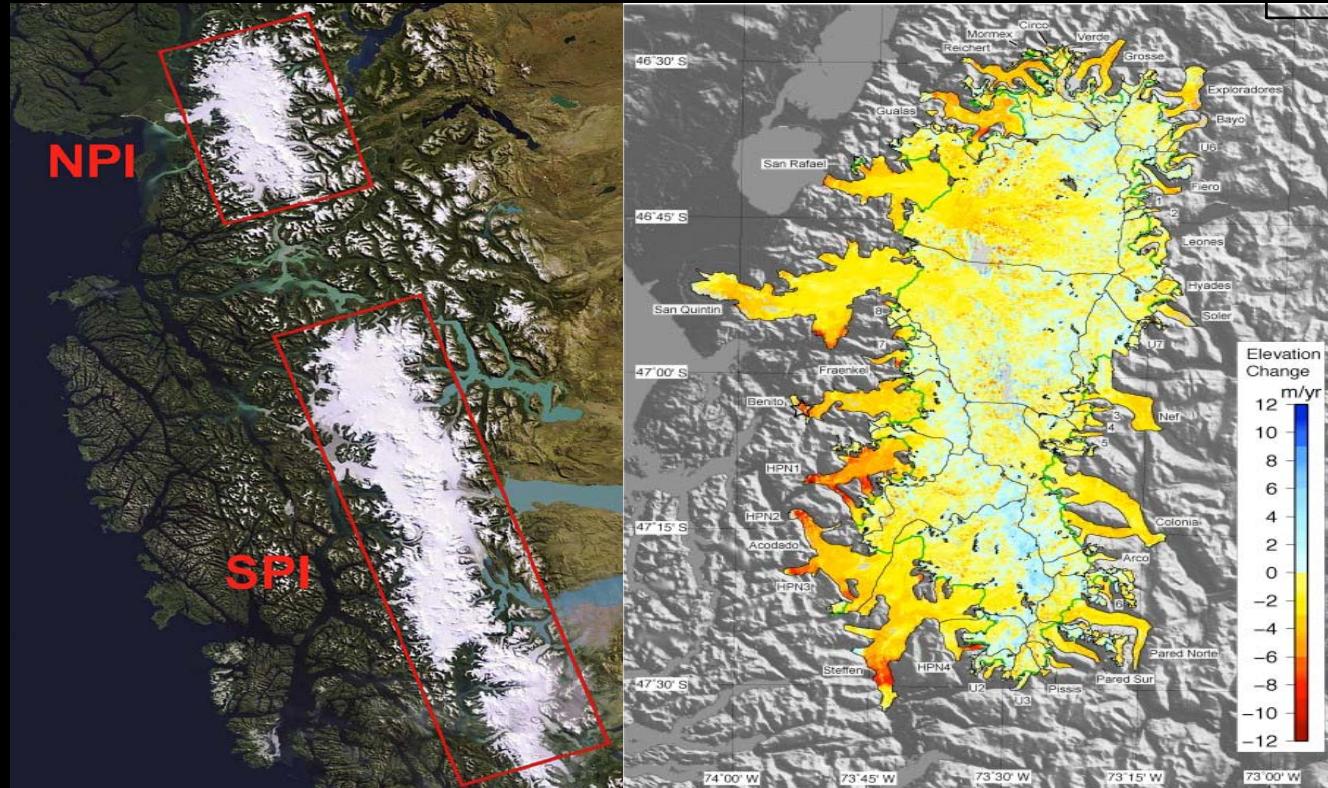
Redoubt Eruption (credit: GeoEye)



Arendt et al., 2013

Patagonia

0

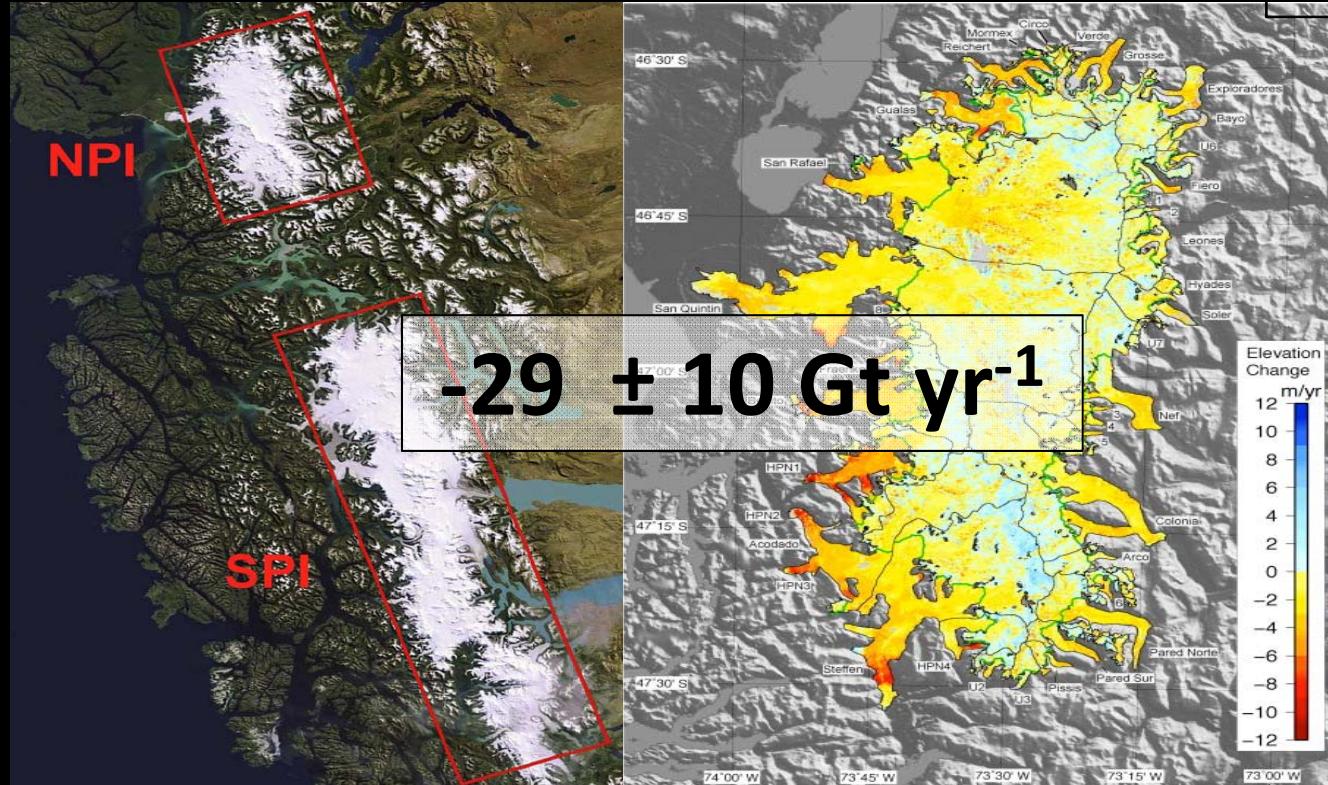


Elevation Change

Willis, et al. 2012

Patagonia

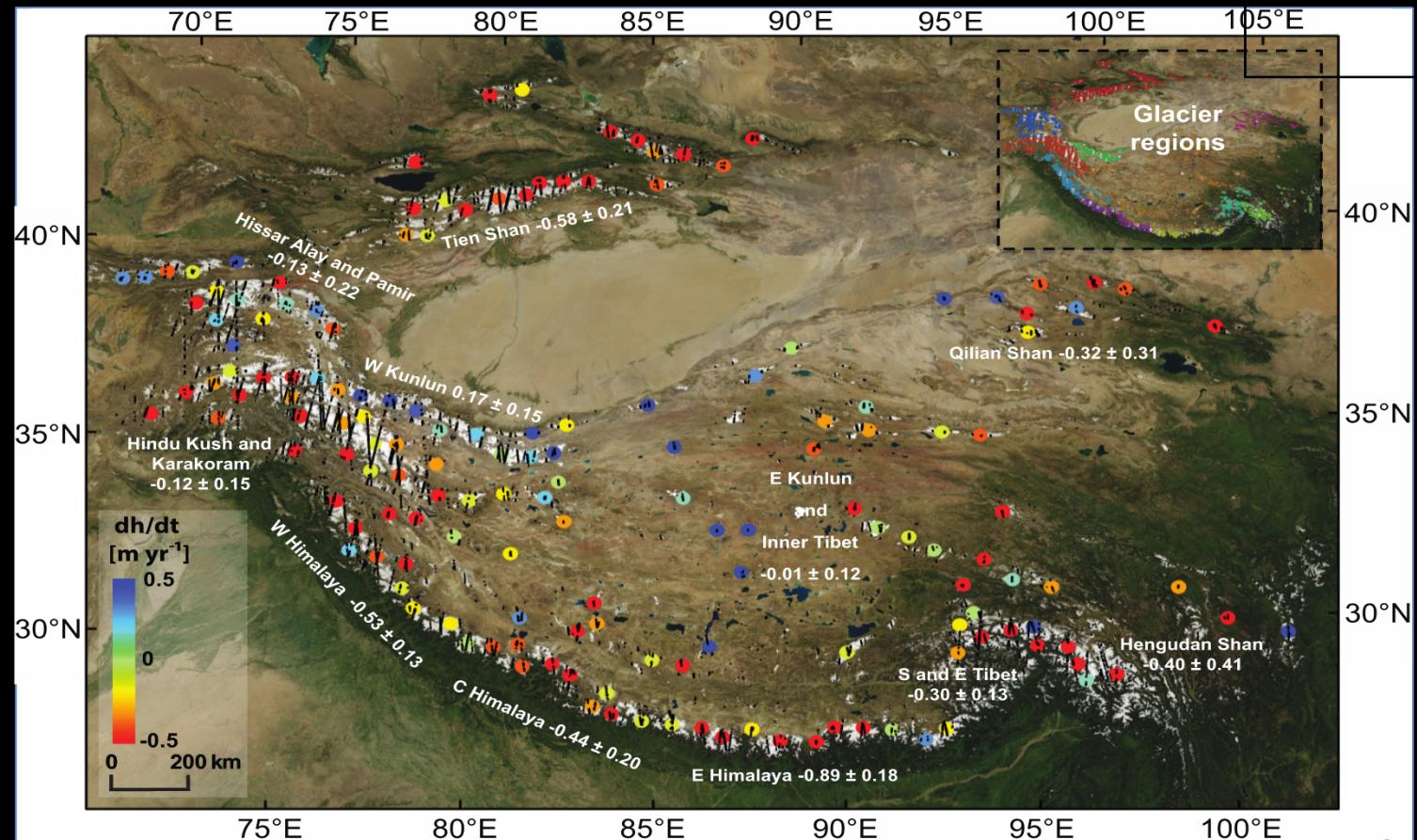
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Elevation Change

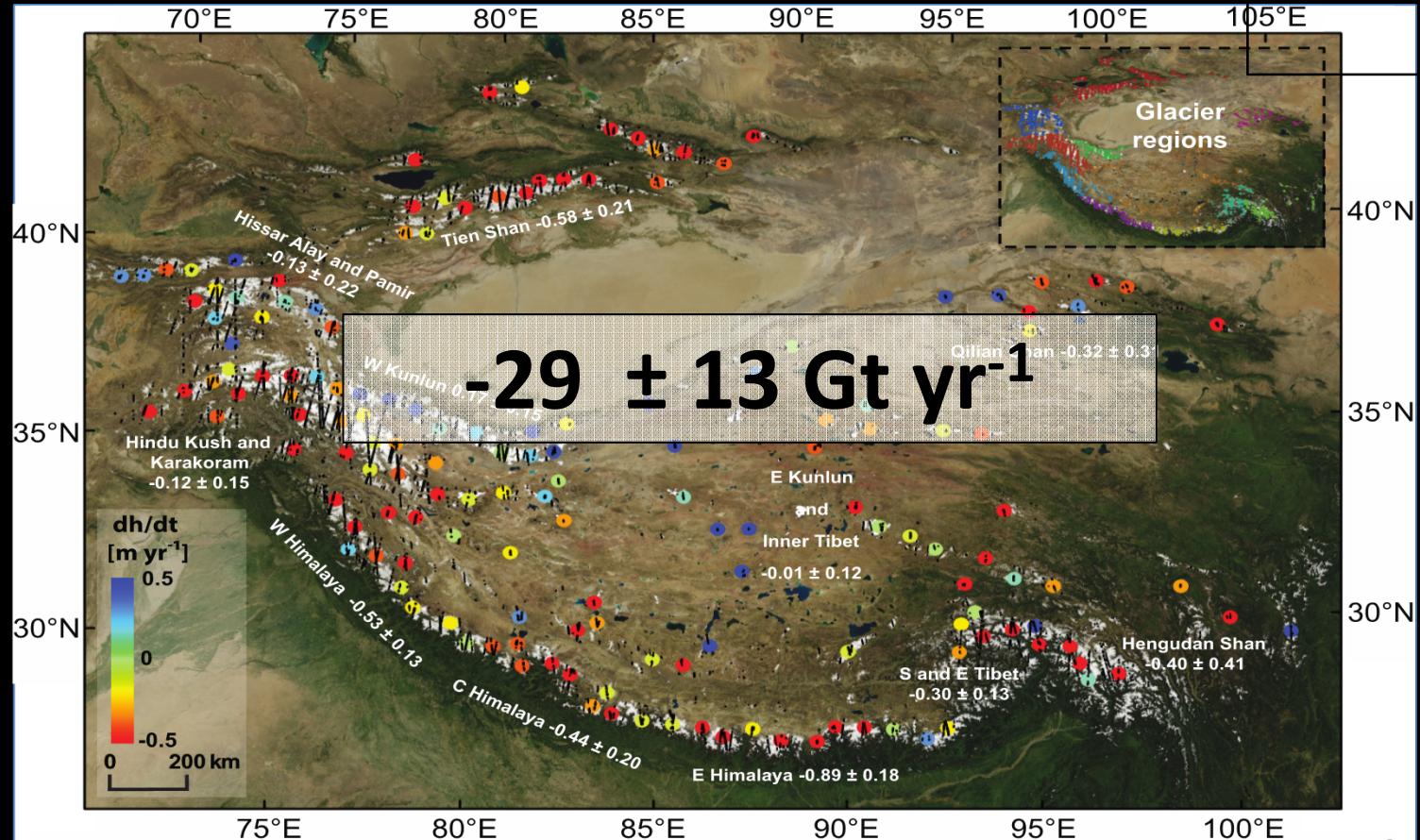
Willis, et al. 2012

High Mountain Asia



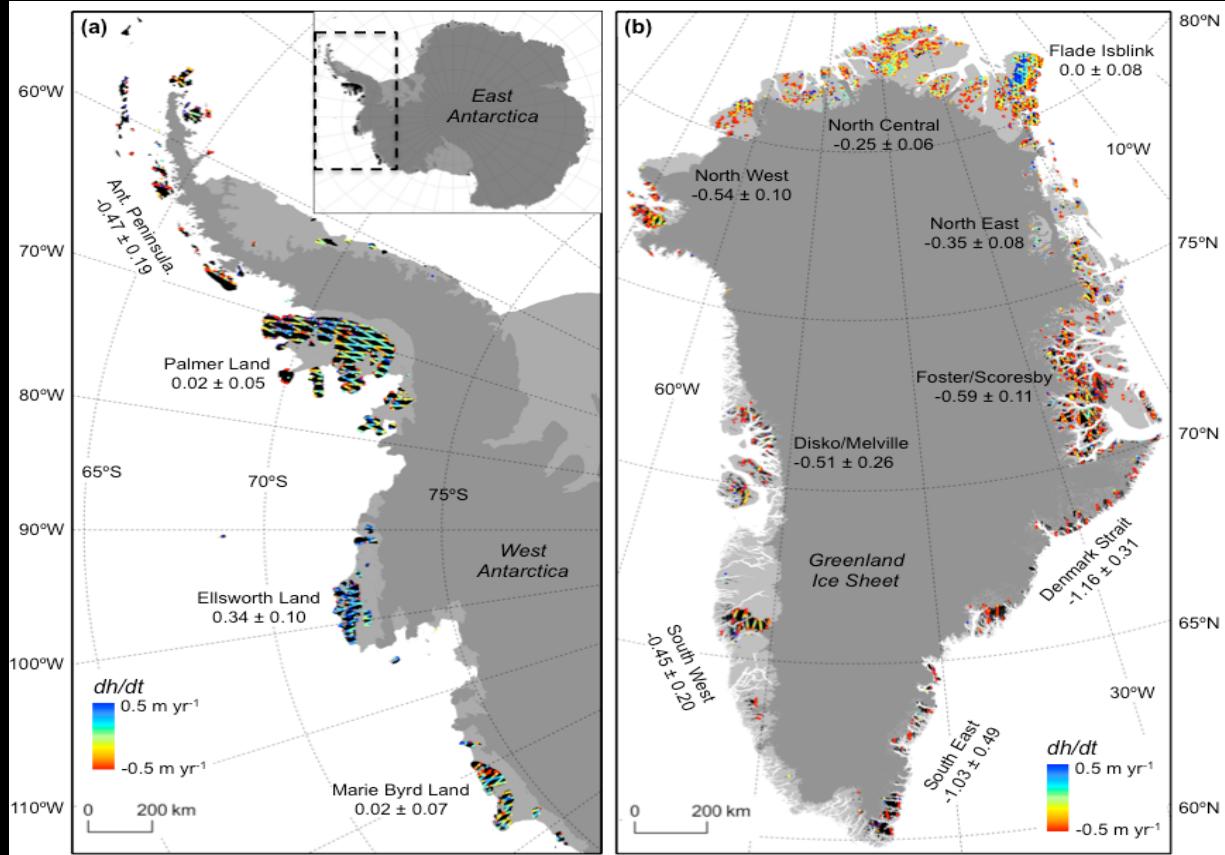
Gardner et al., 2013

High Mountain Asia



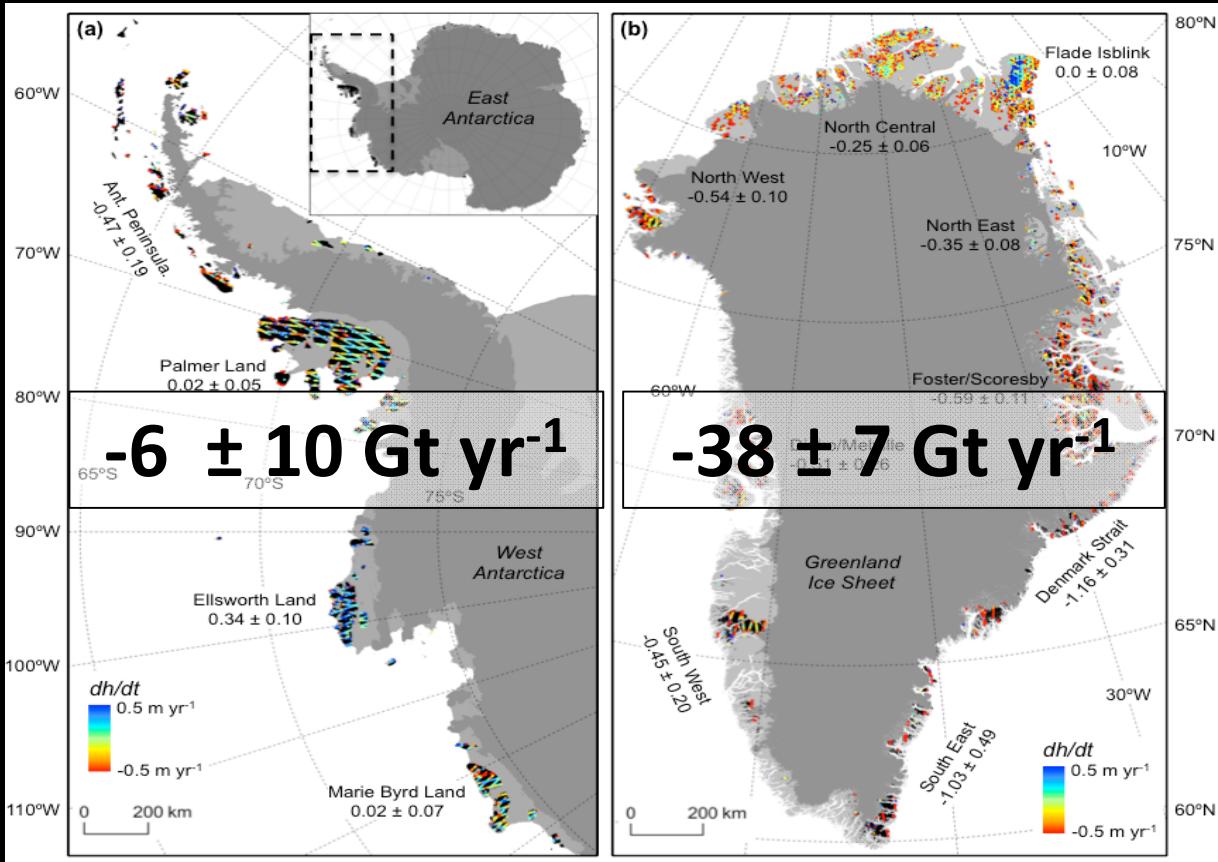


Peripheral Glaciers



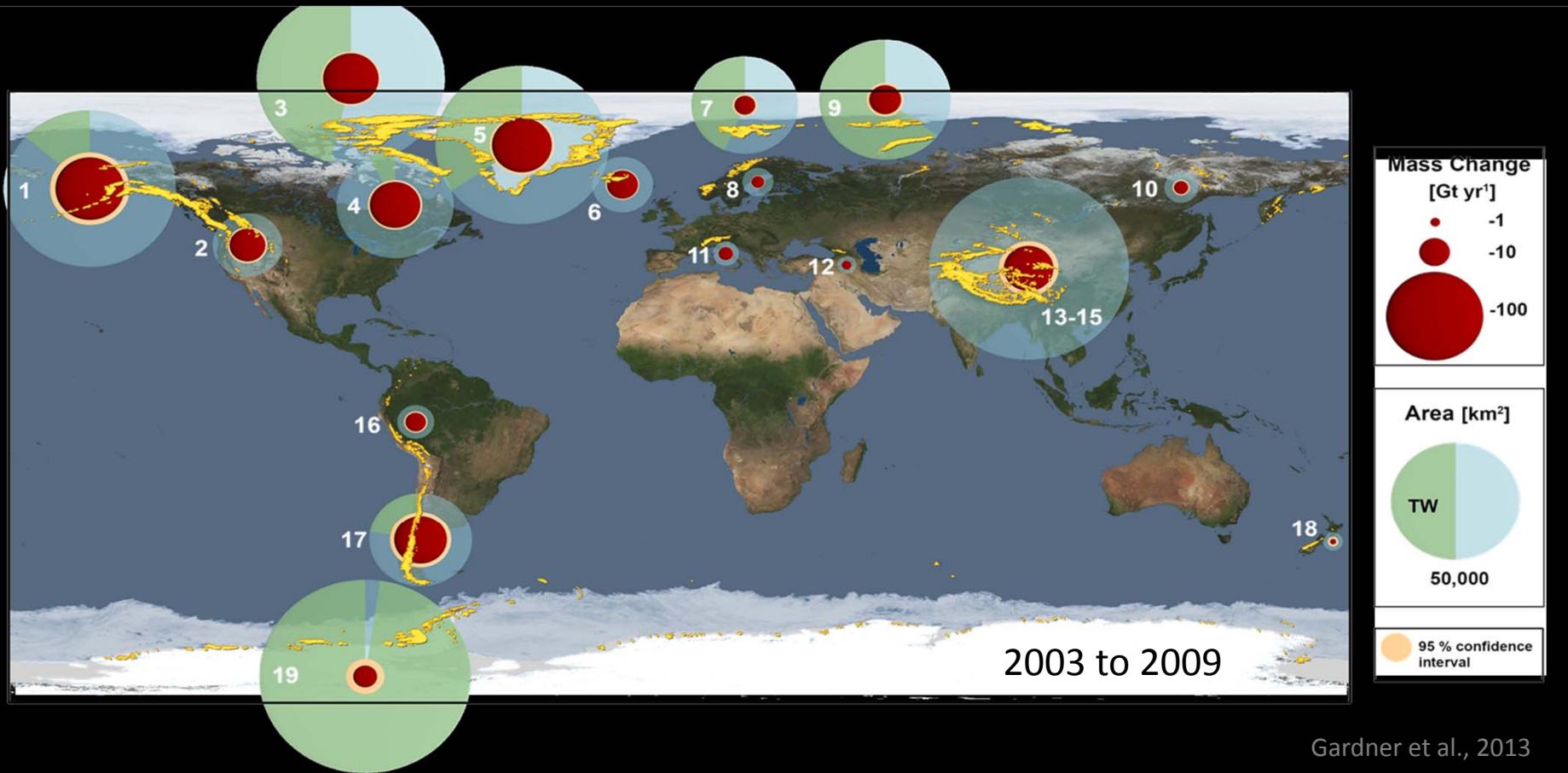
Gardner et al., 2013

Peripheral Glaciers

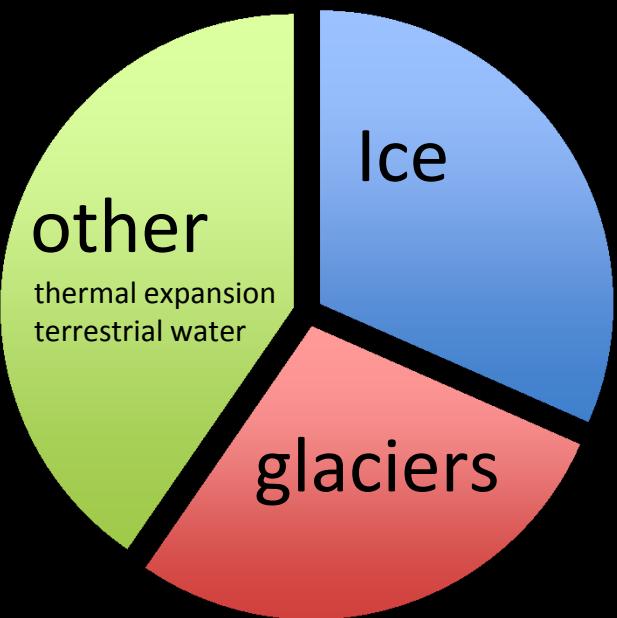


Gardner et al., 2013

Global glacier loss: $-259 \pm 28 \text{ Gt yr}^{-1}$



Global Sea Level Rise

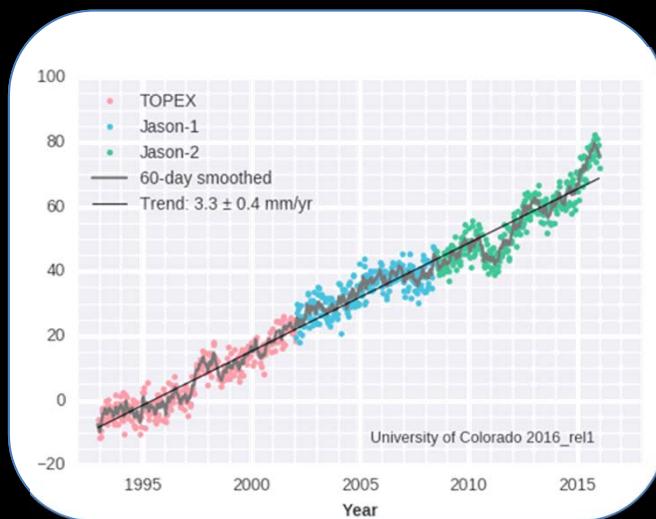


Glacier + ice sheet losses accounted for **two thirds** of the observed sea level rise between 2003 and 2009

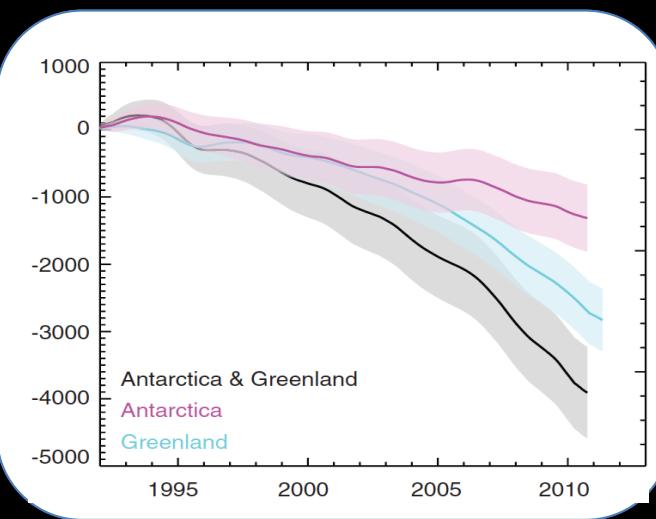
Gardner et al., 2013

But if ice loss is accelerating... way
haven't we observed an acceleration
in sea level rise?

Global Mean Sea Level [mm]



Ice Sheet Mass [Gt]





NASA Study Concludes Global Warming Is Actually Slowing Sea Level Rise



MICHAEL BASTASCH

1:39 PM 02/12/2016



MICHAEL S. SCH

1:39 PM 02/12/2016

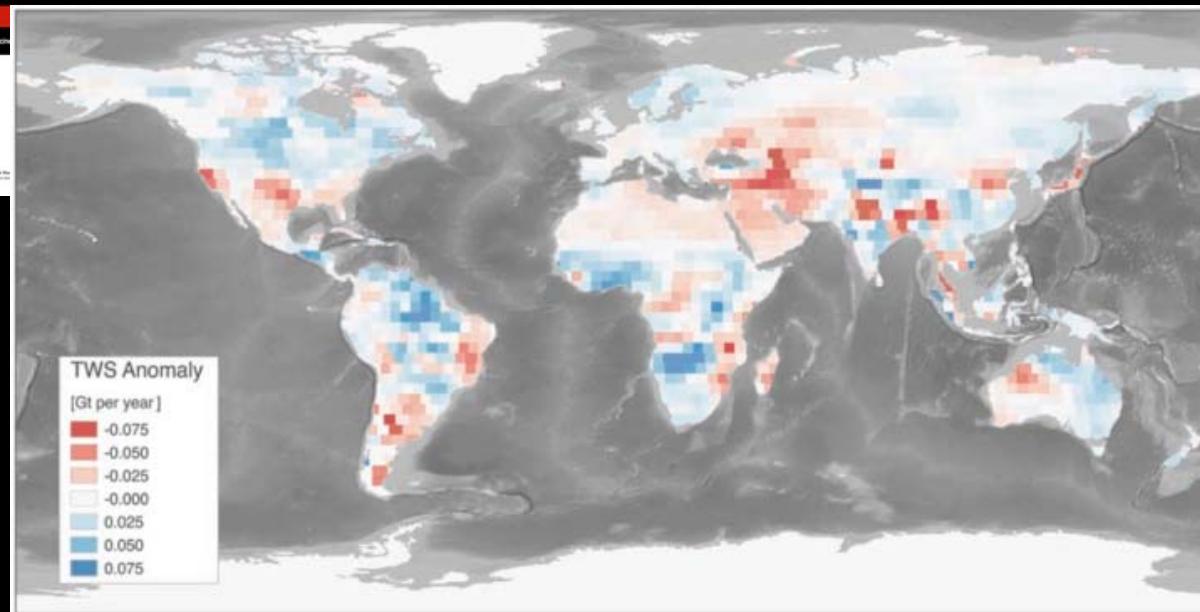
Short-term increase in terrestrial water storage

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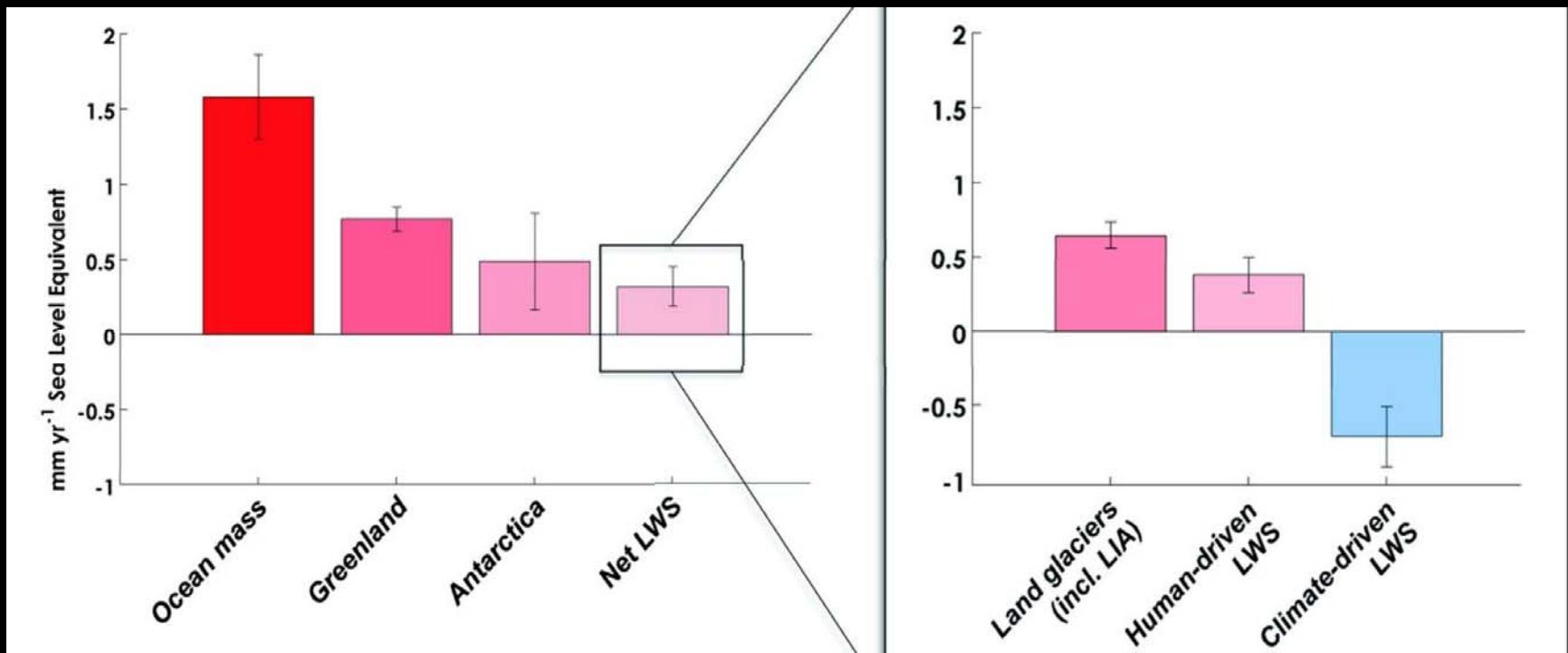
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A decade of sea level rise slowed by climate-driven hydrology
J. T. Reager^{1,2*}, A. S. Gardner¹, J. S. Famiglietti^{1,2}, D. N. Wiers³, A. Elsner³, M.-H. Lo²
+ Author Affiliations
*Corresponding author. E-mail: john.reager@gsfc.nasa.gov
Journal: 12 Feb 2016; 351(6273):699–703
DOI: 10.1126/science.aad390

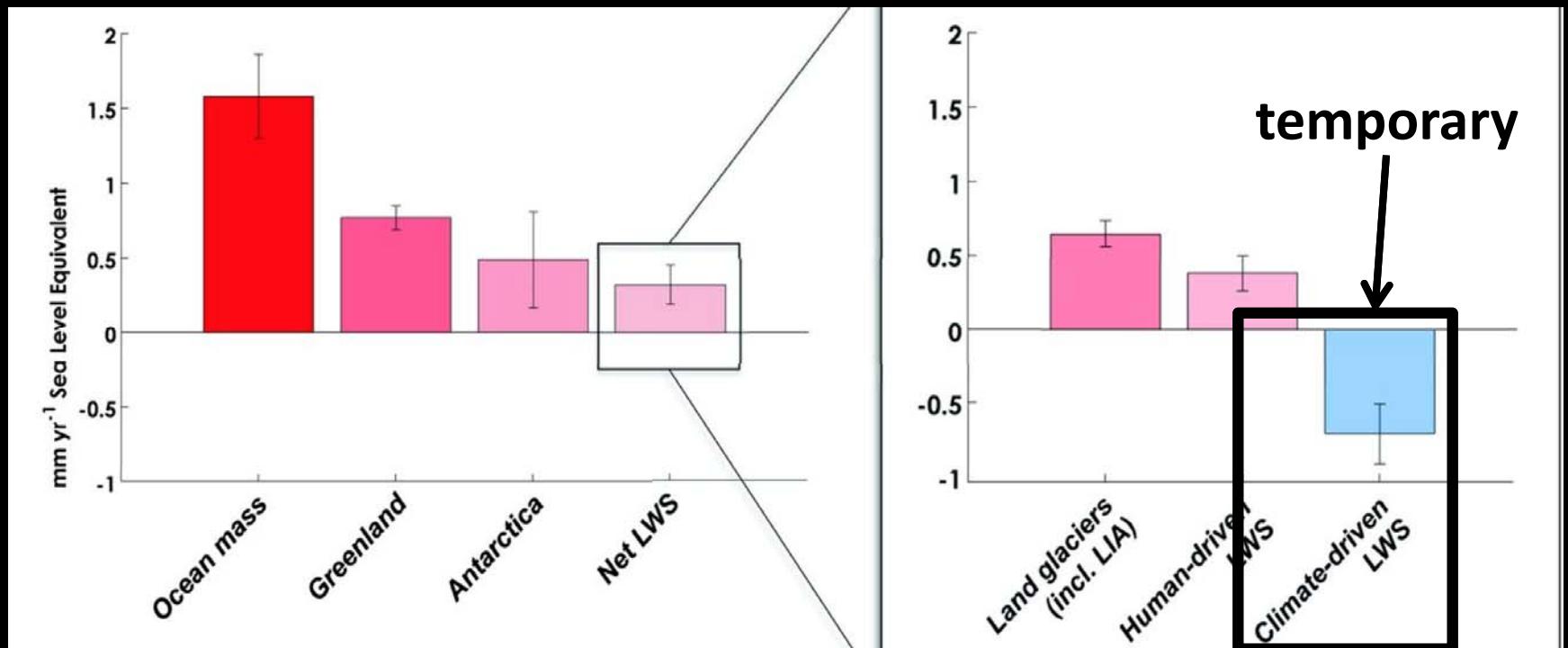


Terrestrial water storage anomaly [Gt/yr]

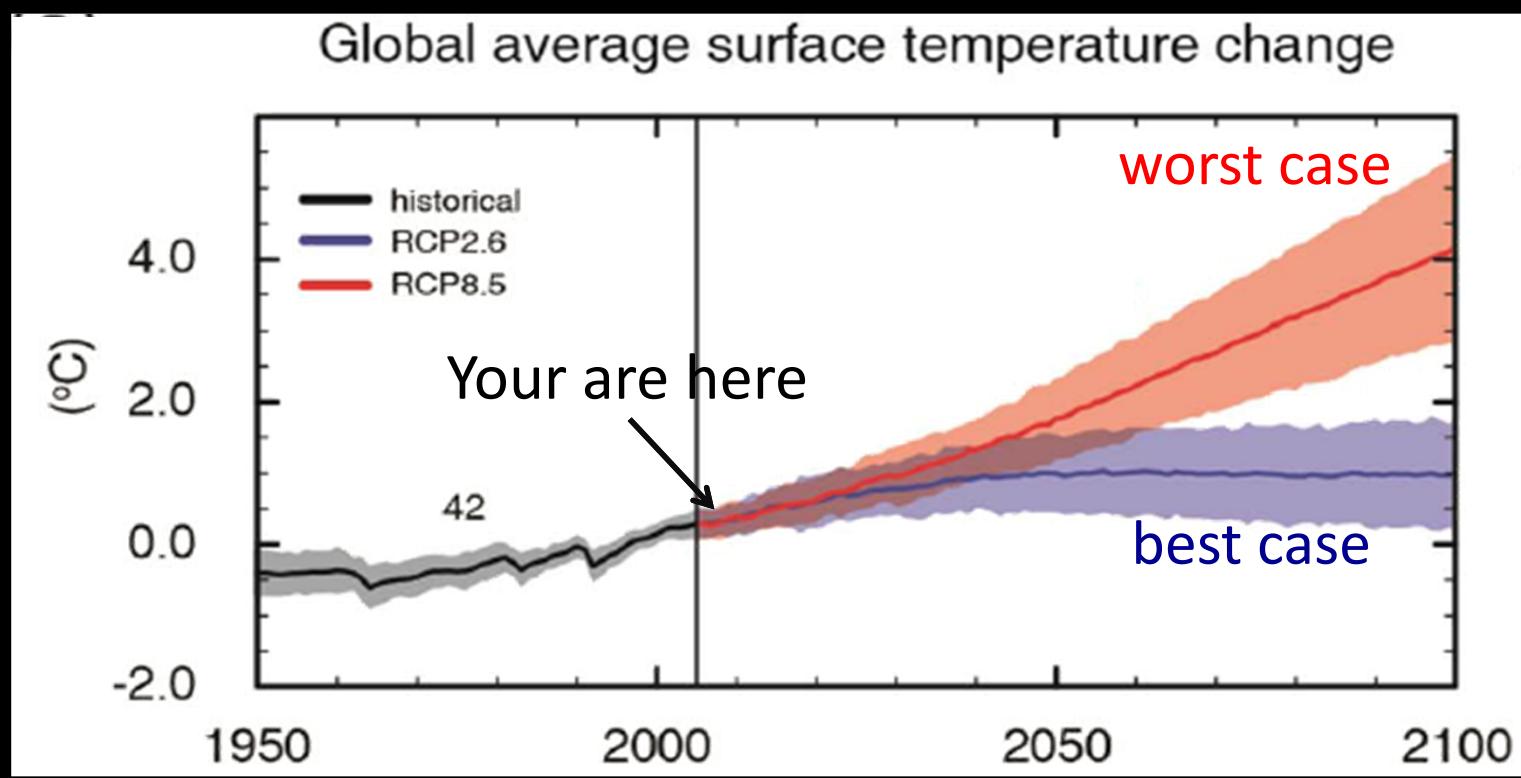
Sea Level Budget: 2002-2014



Sea Level Budget: 2002-2014



What to expect going forward?



What to expect going forward?

- Losses from glacier and ice sheets will accelerate as the atmosphere and ocean warm over the next century and beyond
- The big unknown is how much and how quickly

Thank you

