

Understand the Role of Ocean in Global Warming

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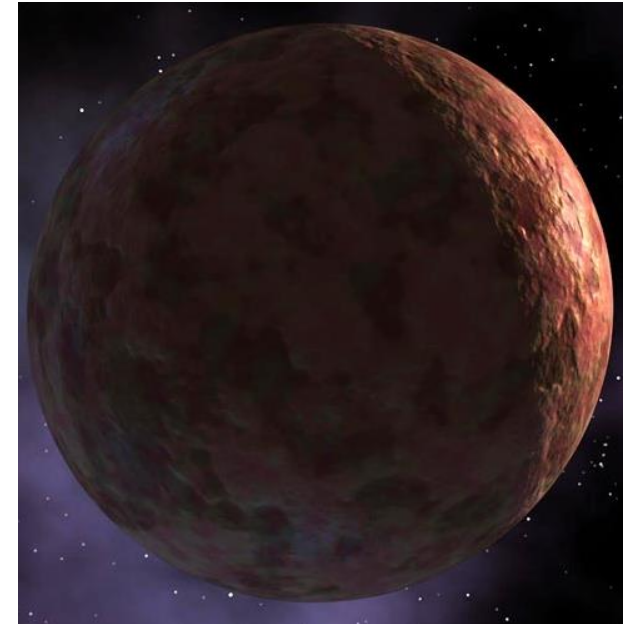
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Atmosphere + Ocean = Habitable Earth

A naked Rock

	Real	Estimated
◇ Mars	−53°C	−56°C
◇ Earth	+15°C	−18°C
◇ Venus	+430°C	+41°C



Atmosphere + Ocean = Habitable Earth

A Rock with still Air

	Real	Estimated
◆ Earth	+15°C	+67°C



Atmosphere + Ocean = Habitable Earth

A Rock with moving Air

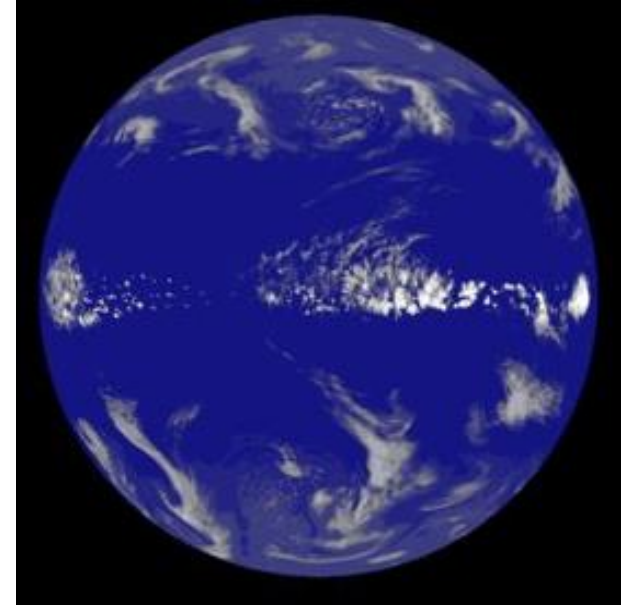
	Real	Estimated
◆ Earth	+15°C	<<67°C



Atmosphere + Ocean = Habitable Earth

A Rock with Air + Ocean

	Real	Estimated
◆ Earth	+15°C	~15°C



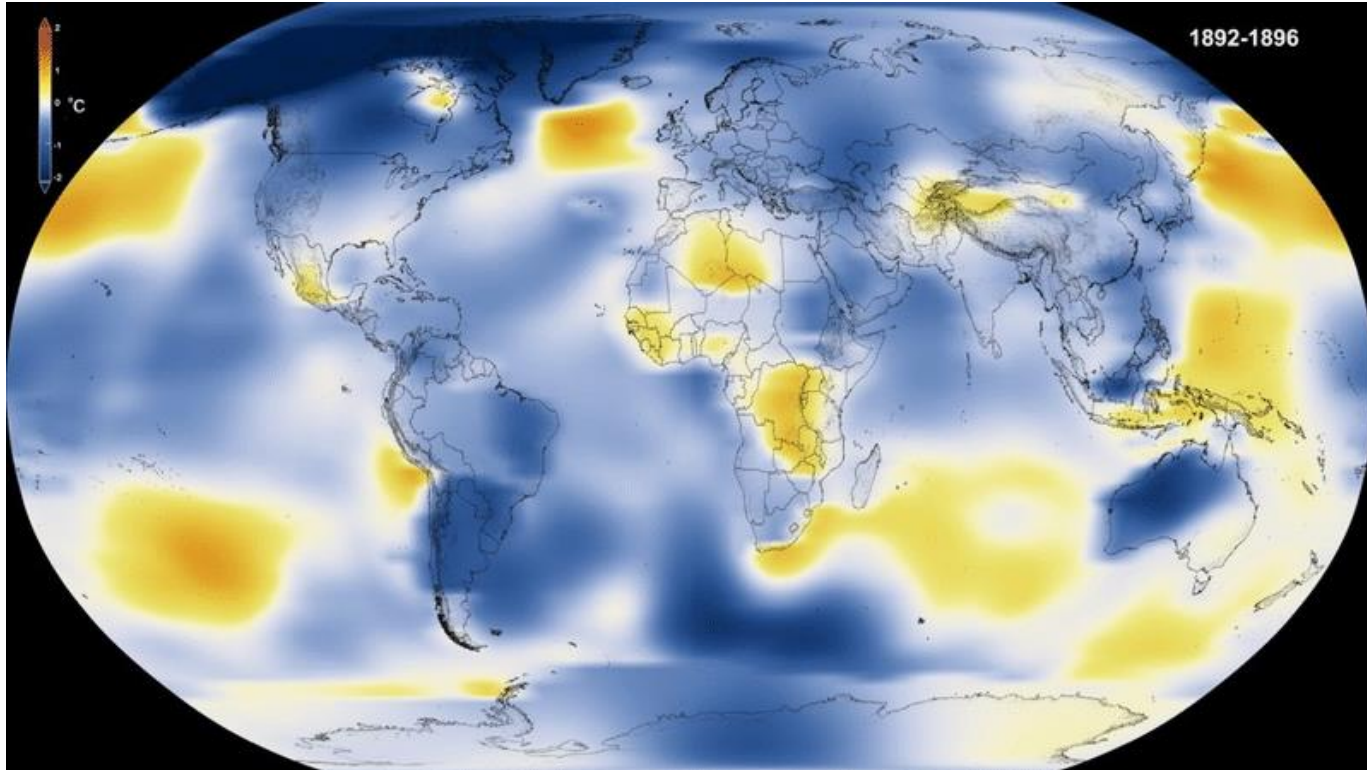
Atmosphere + Ocean = Habitable Earth

A Rock with Air + Ocean + Land

	Real	Estimated
◆ Earth	+15°C	+15°C



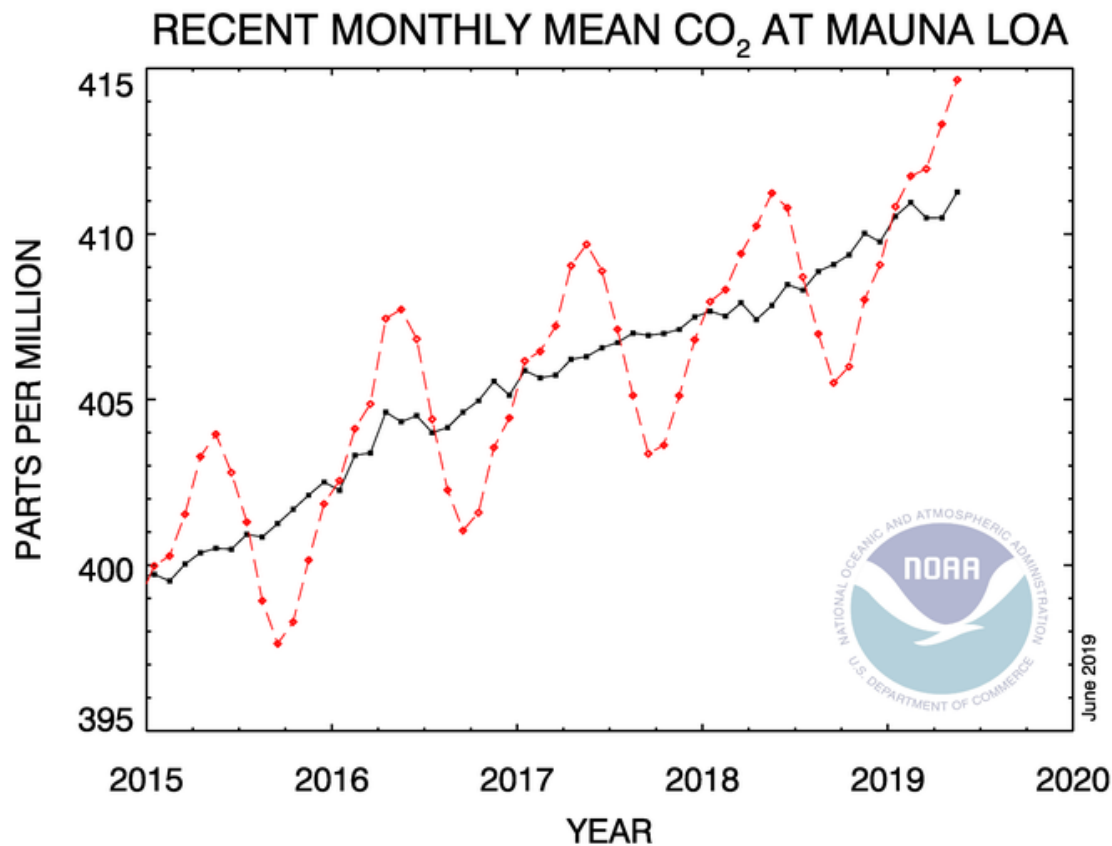
A Warming Climate



NASA/GSFC/Scientific Visualization Studio

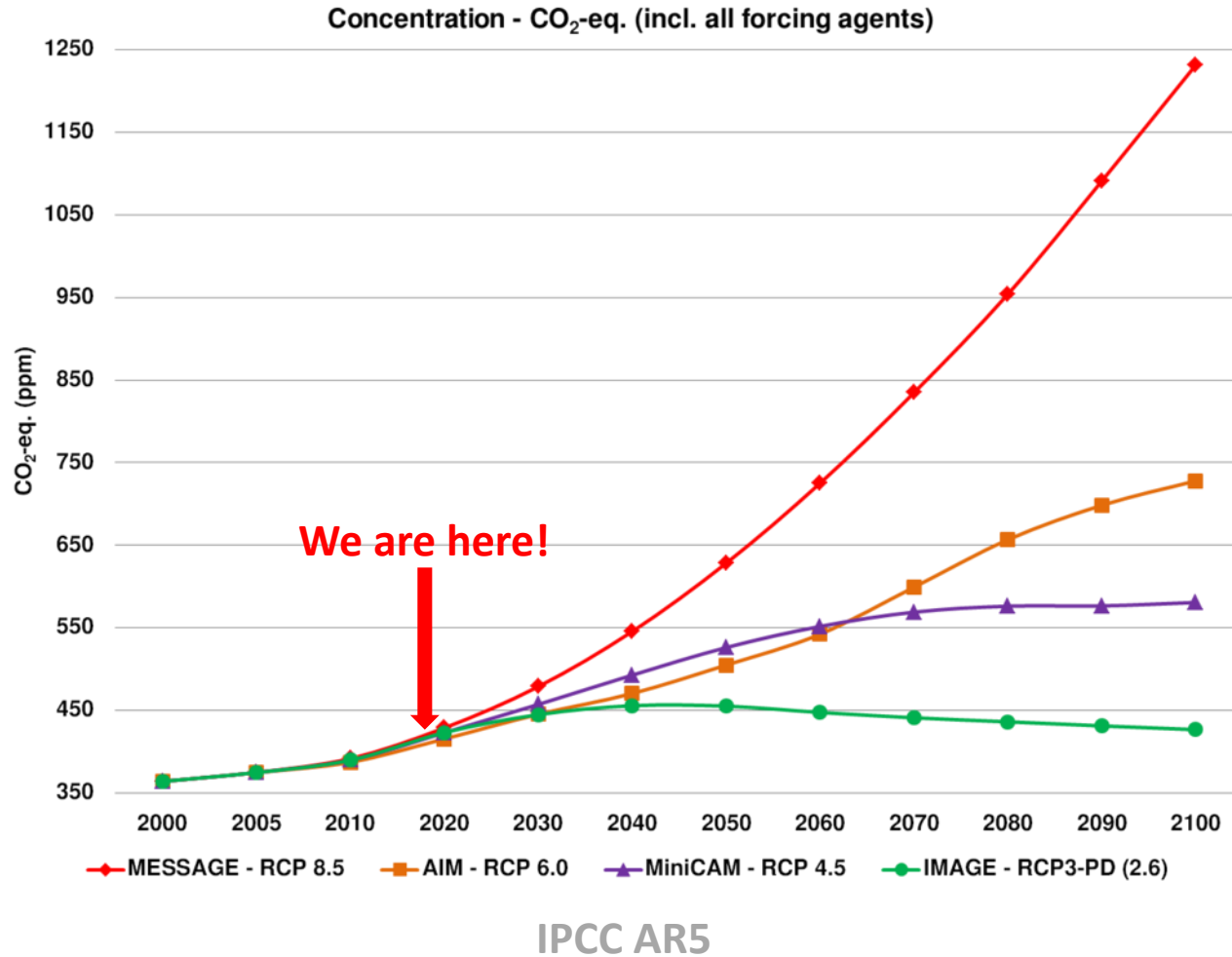
<https://www.giss.nasa.gov/research/news/20170118/2016gistempupdateblack.gif>

A Rapid Rising CO₂



<https://www.esrl.noaa.gov/gmd/ccgg/trends/gr.html>

An Awful Future Projection ?



A Hope from the Ocean



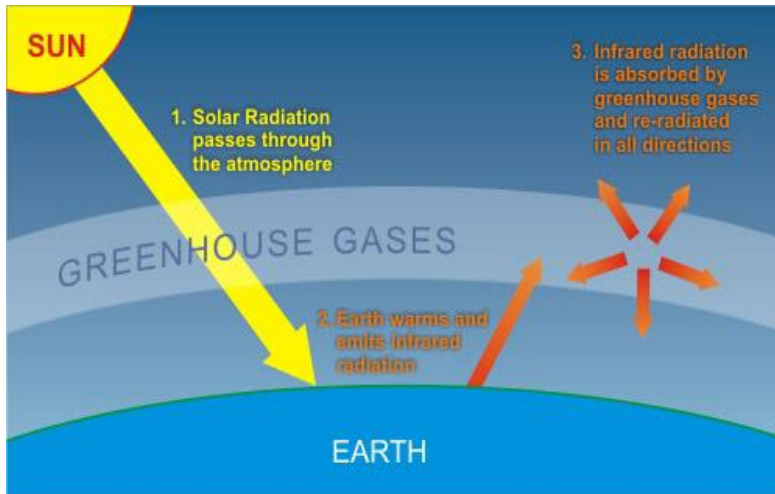
Aqua-Planet: 71% covered by ocean

Ocean: Buffering the Global Warming

Resulted from

Heating

Hosing



Decoding **Hosing** and **Heating** Roles in a **Warming** Climate

Water Role – A Fundamental

Lapse Rate



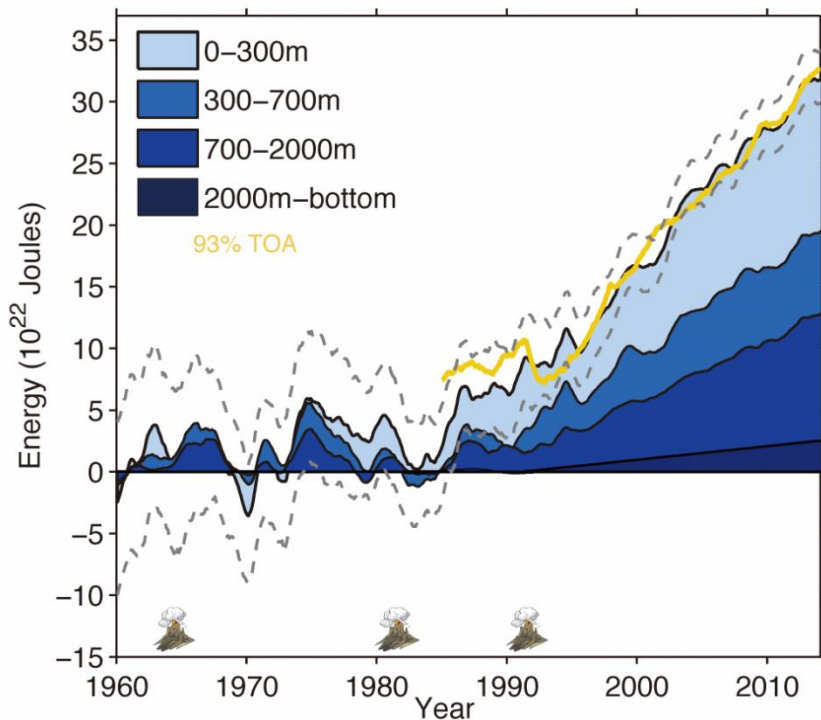
Dry Air: $\Gamma_d = g/c_p = 9.8$ °C/km

Wet Air: $\Gamma_w = \dots\dots = 6-7$ °C/km

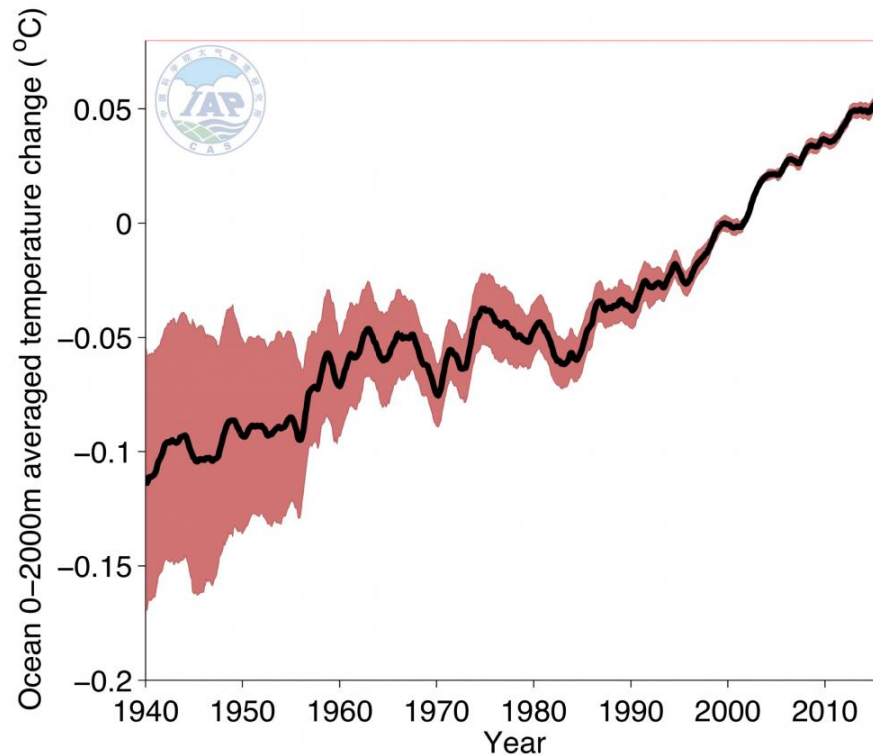
30%

Latent Heat: Solid $\xrightarrow{334\text{J/g}}$ Liquid $\xrightarrow{2260\text{J/g}}$ Gas

Ocean Heat Content Change

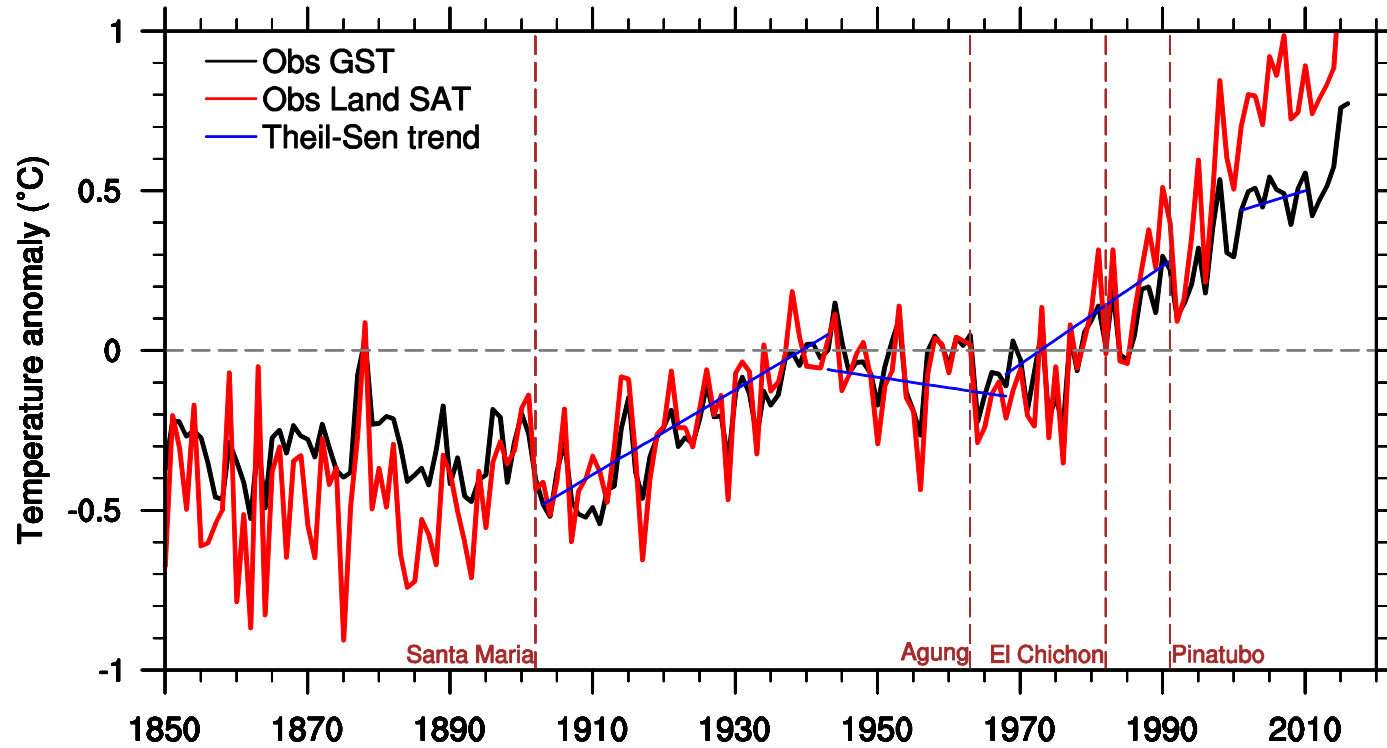


Ocean energy budget based on IAP ocean temperature analysis. The 93% of the energy imbalance observed from the top of atmosphere is shown in yellow. OHC change below 2000m is from Purkey and Johnson 2010. (contributed by L Cheng)

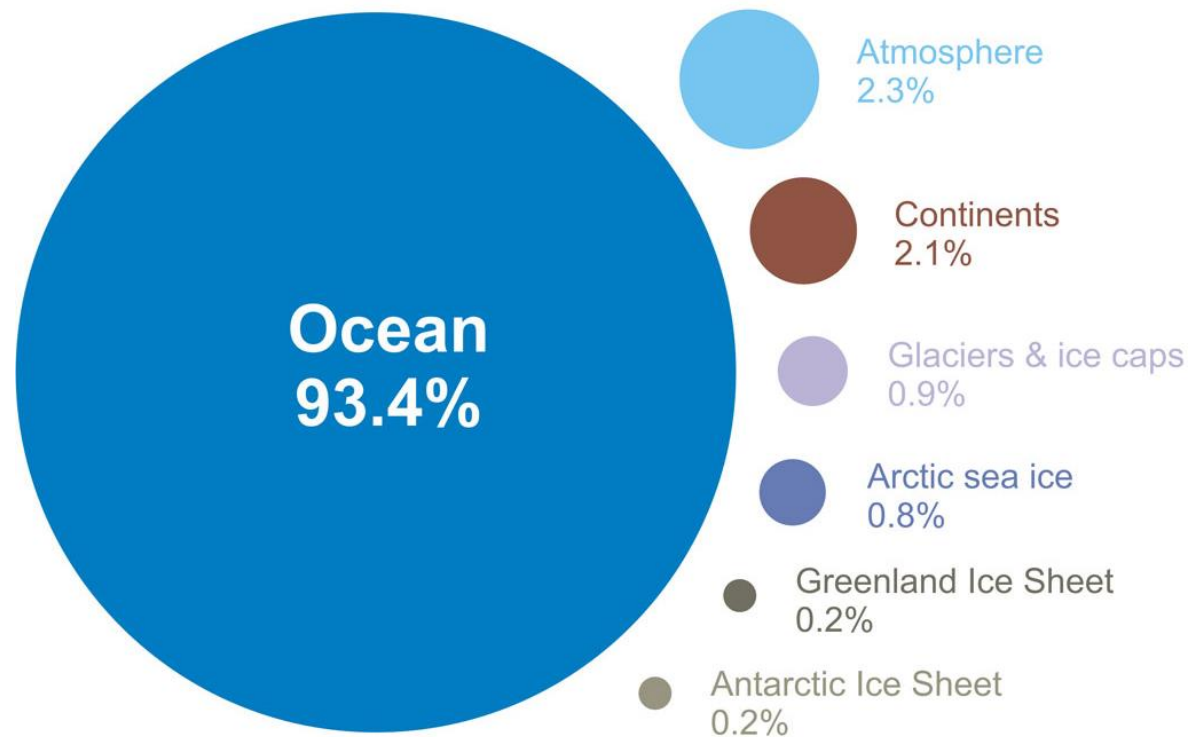


0-2000m averaged temperature change since 1940/01 to 2016/12 along with uncertainty estimates (95% confidence interval). (contributed by L Cheng)

Ocean Buffering the Surface Warming



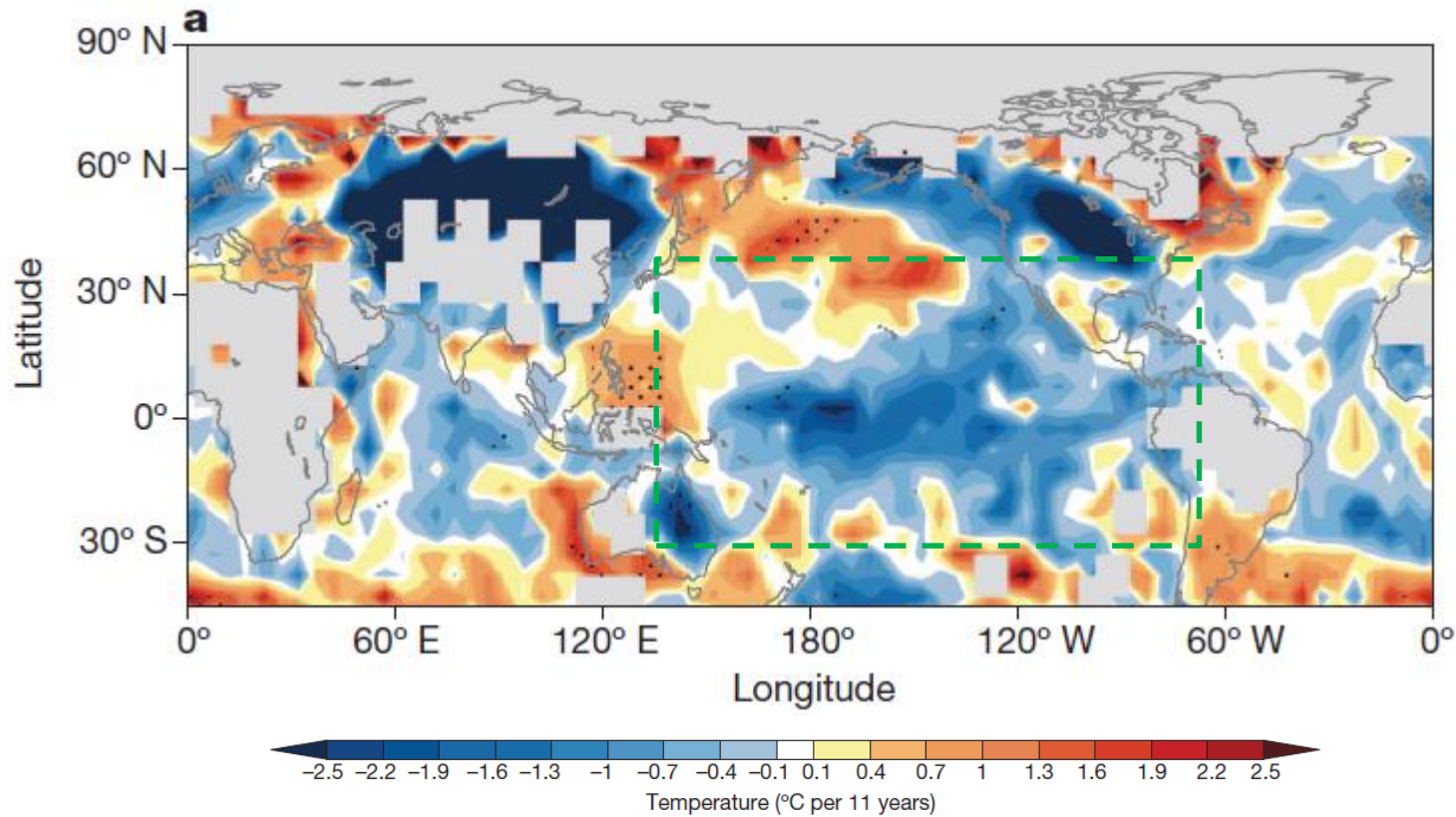
Where is Global Warming Going?



S. Levitus, J. I. Antonov, T. P. Boyer, O. K. Baranova, H. E. Garcia, R. A. Locarnini, A. V. Mishonov, J. R. Reagan, D. Seidov, E. S. Yarosh, and M. M. Zweng | published 17 May 2012

Where is Global Warming Going?

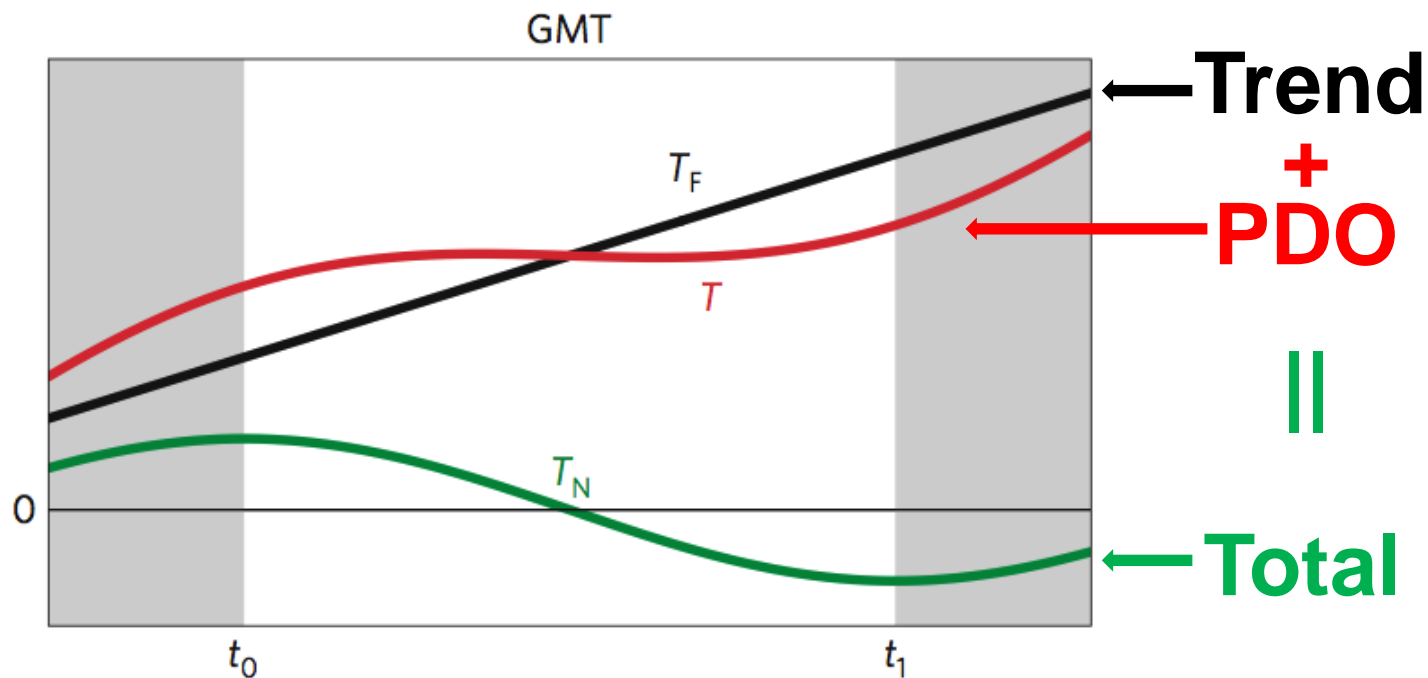
Pacific ?



Kosaka and Xie (2013); Xie et al. (2015); Meehl et al. (2011) ; Liu et al. (2016); etc..

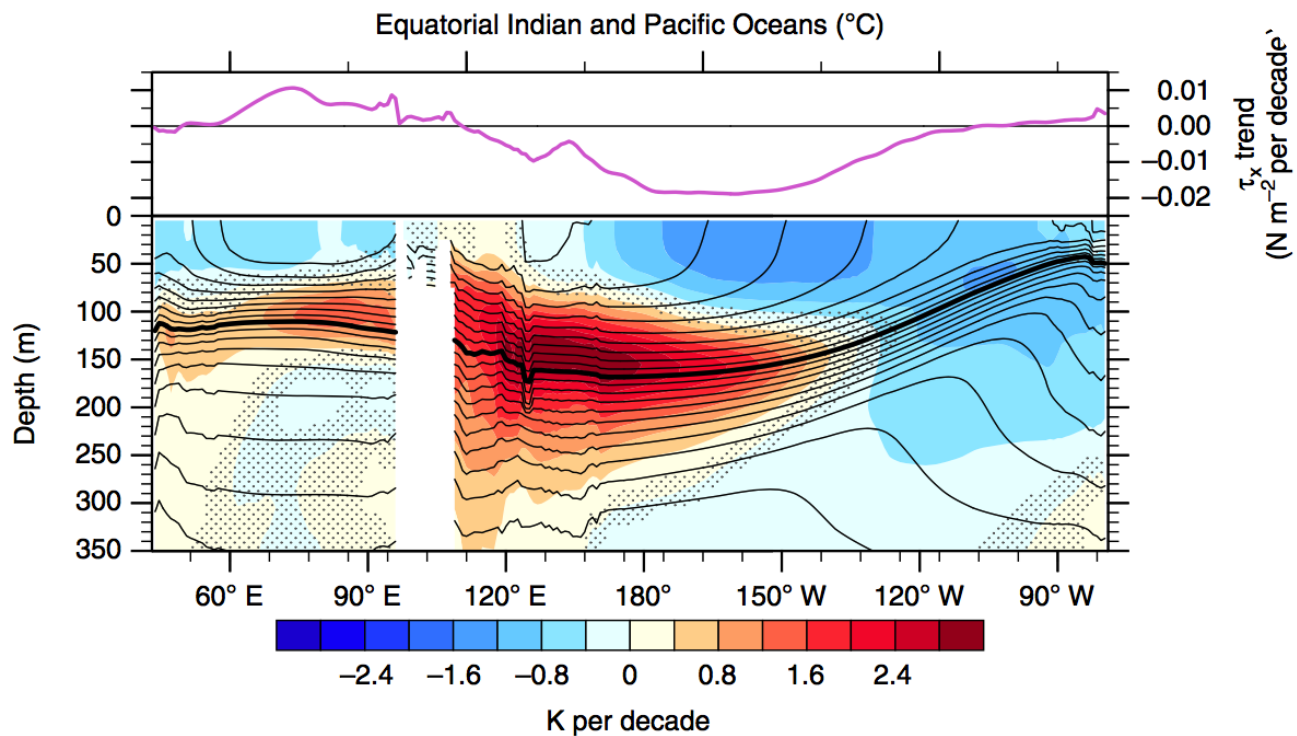
Where is Global Warming Going?

Why ?



Xie et al. (2015)

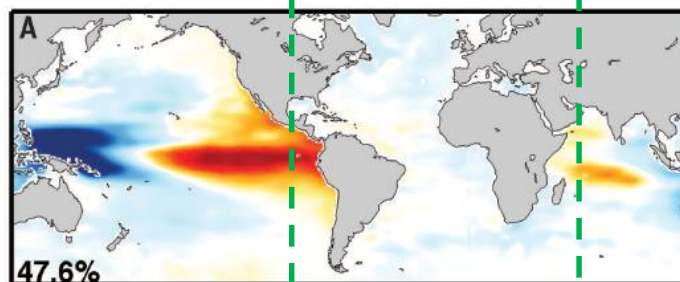
Where is Global Warming Going?



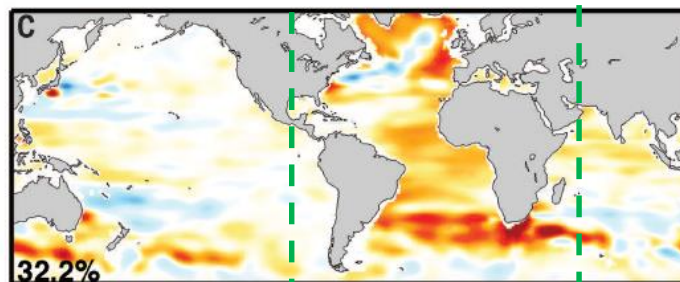
Liu et al. (2016)

Where is Global Warming Going?

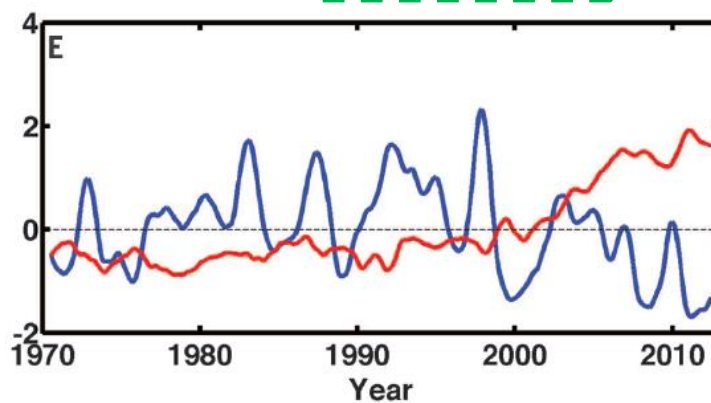
Atlantic?



Surface



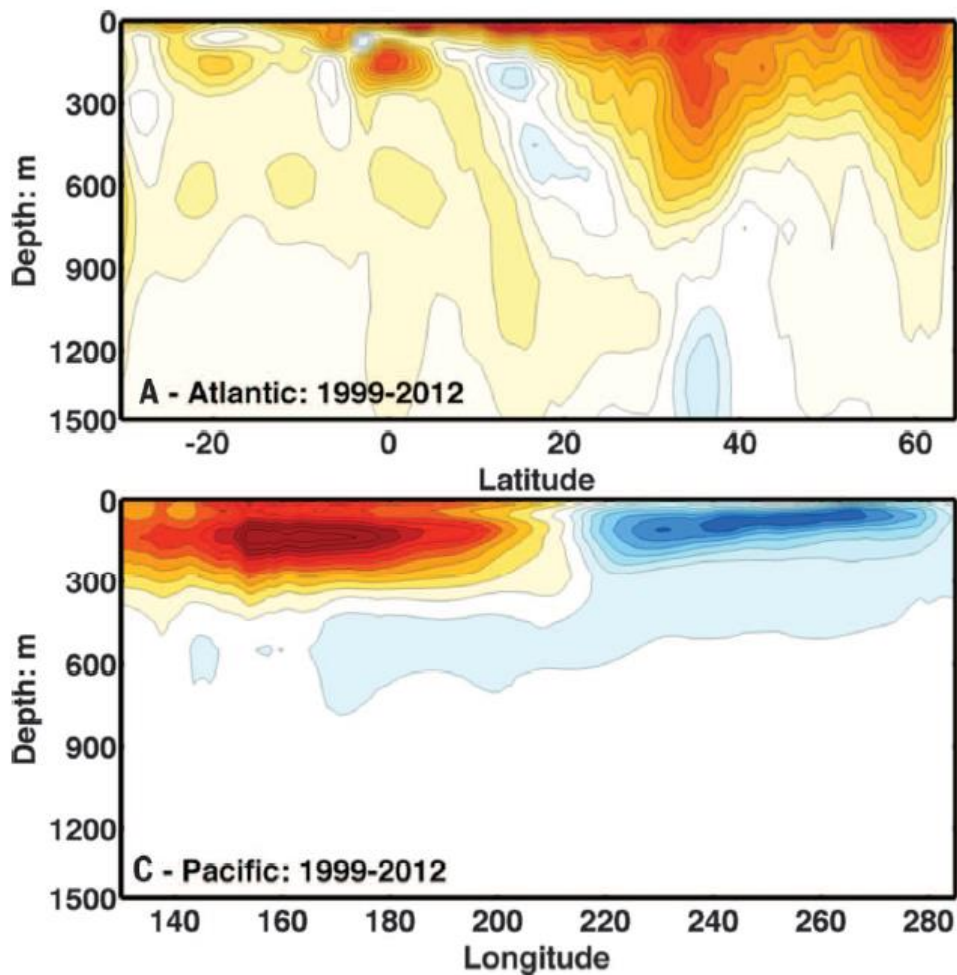
0-300m



Chen et al. (2014)

Where is Global Warming Going?

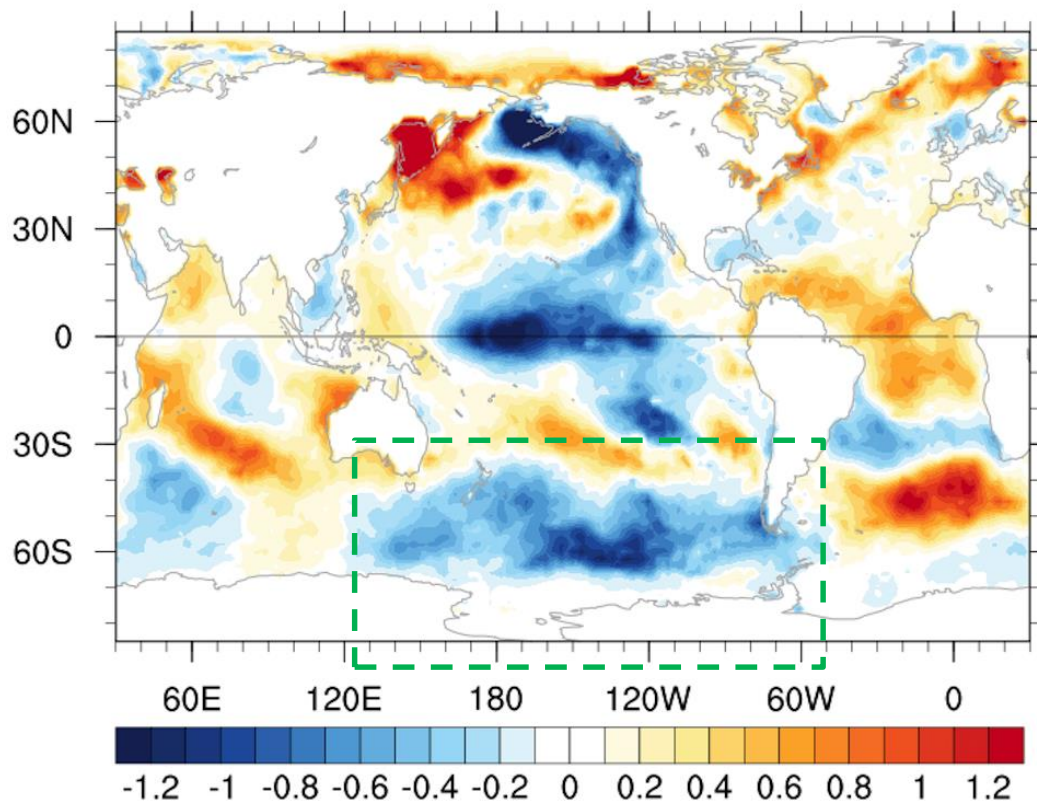
Atlantic?



Chen et al. (2014)

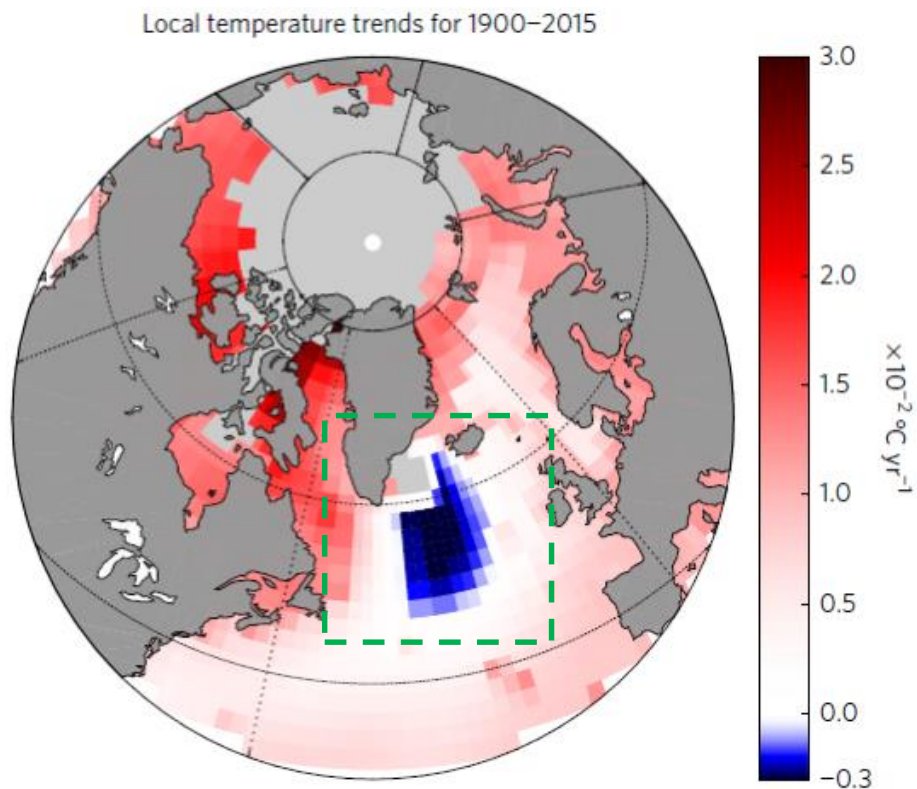
Where is Global Warming Going?

Southern Ocean?



Where is Global Warming Going?

Melting Polar Ice

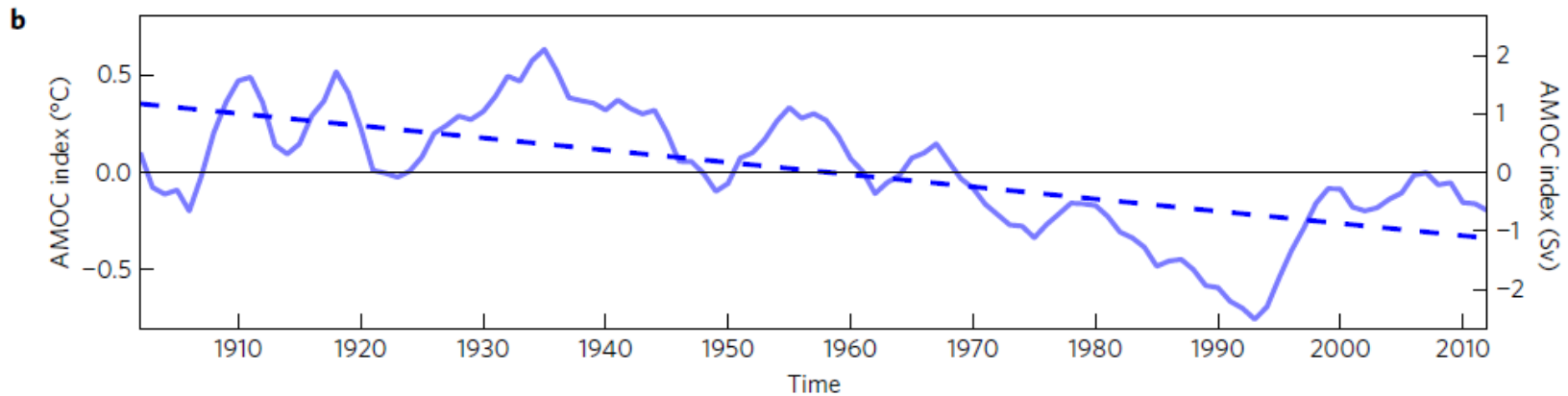
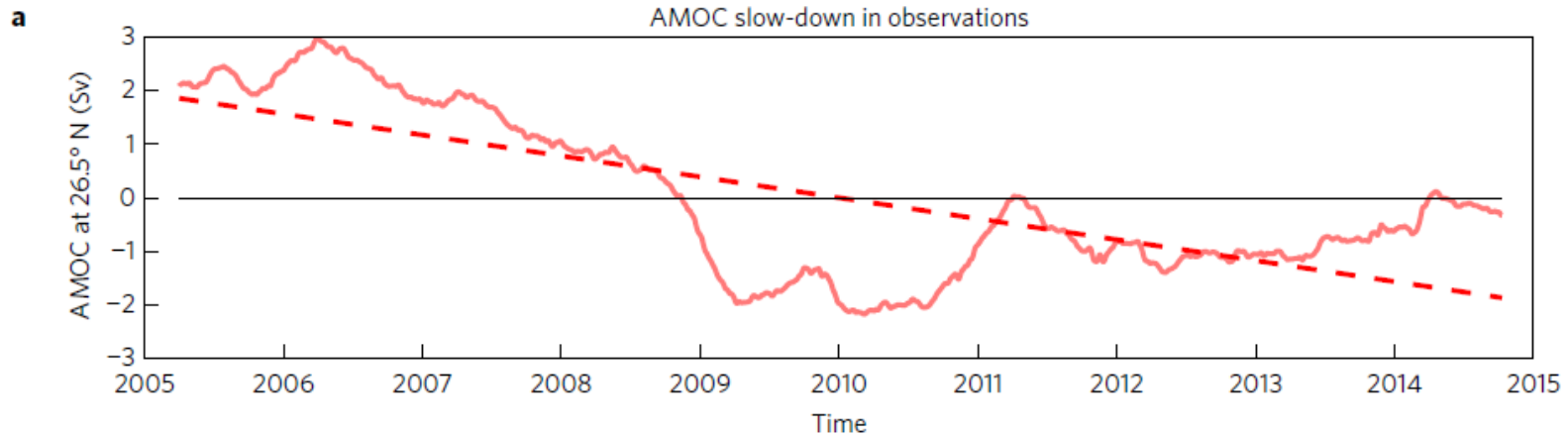


A Warming Hole

Sevellec et al. (2017)

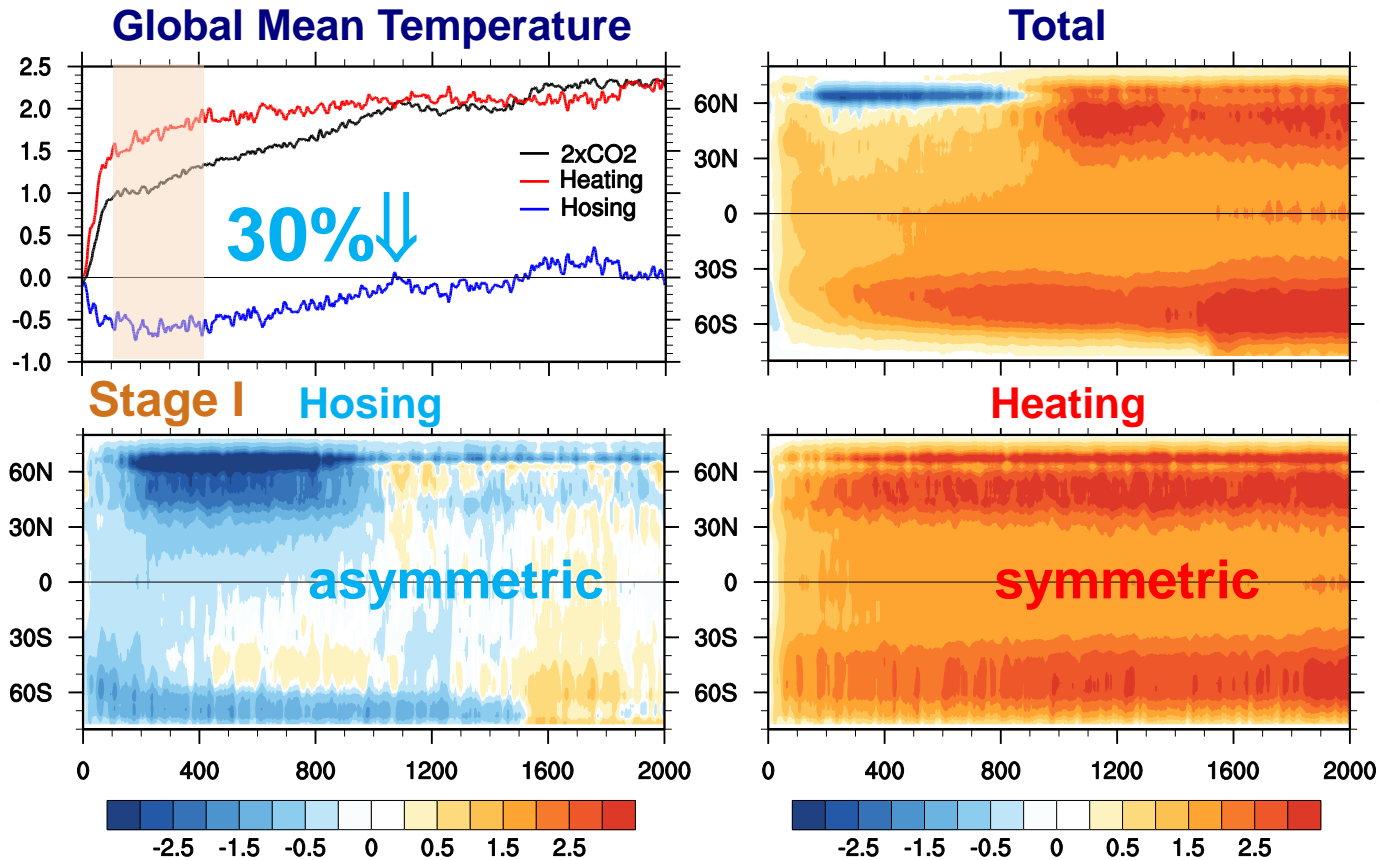
Where is Global Warming Going?

Weakening AMOC



Sevellec et al. (2017)

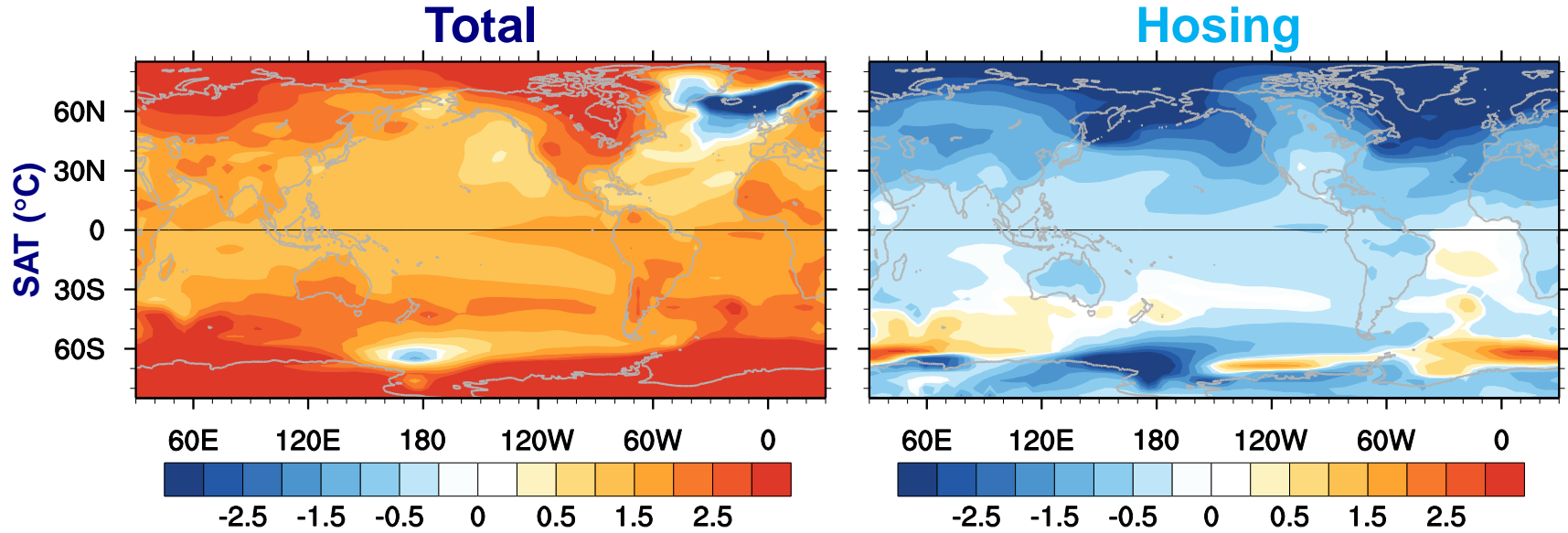
Global *Temperature* Evolution



Earlier stages in Global Warming

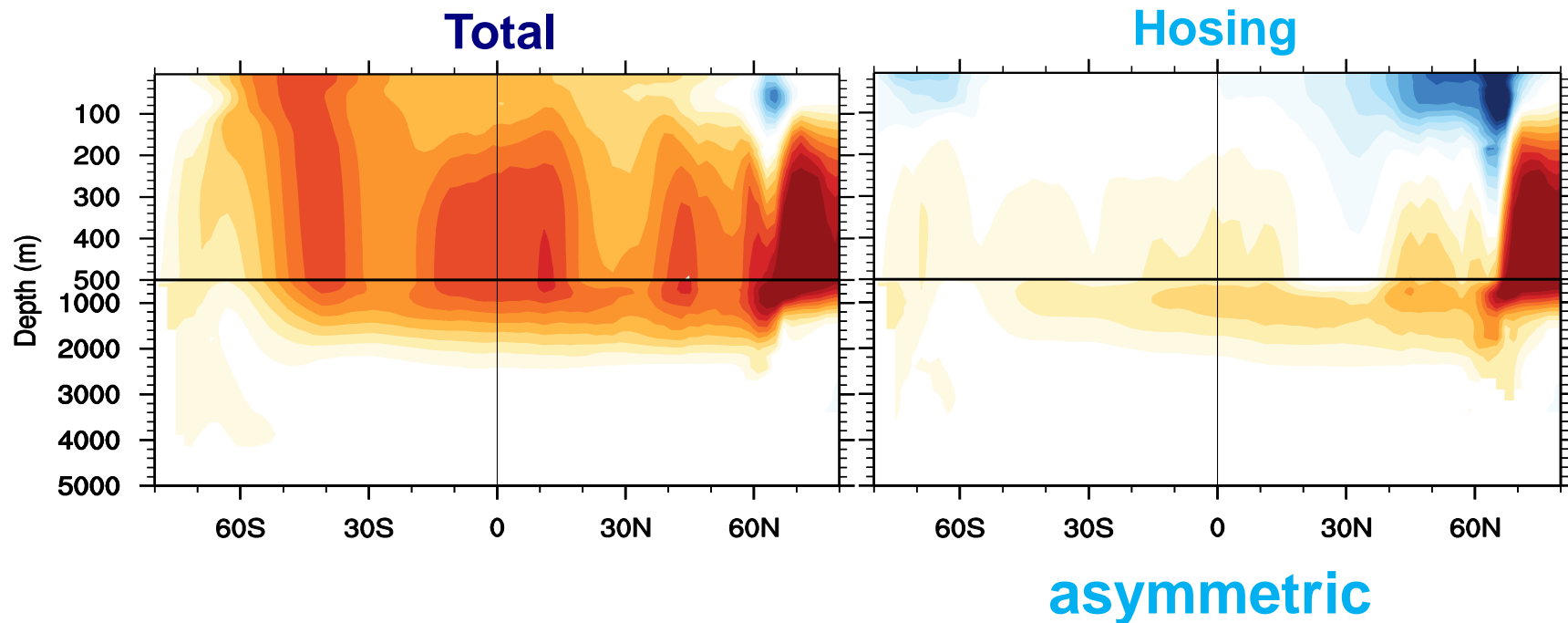
Most relevant to that **We** are

Surface Changes



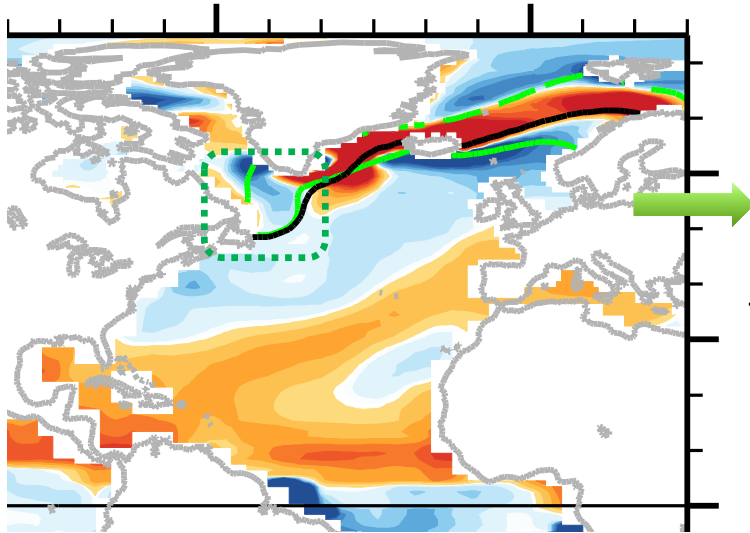
**Freshwater results in cooling and freshening,
asymmetric change**

Ocean Changes

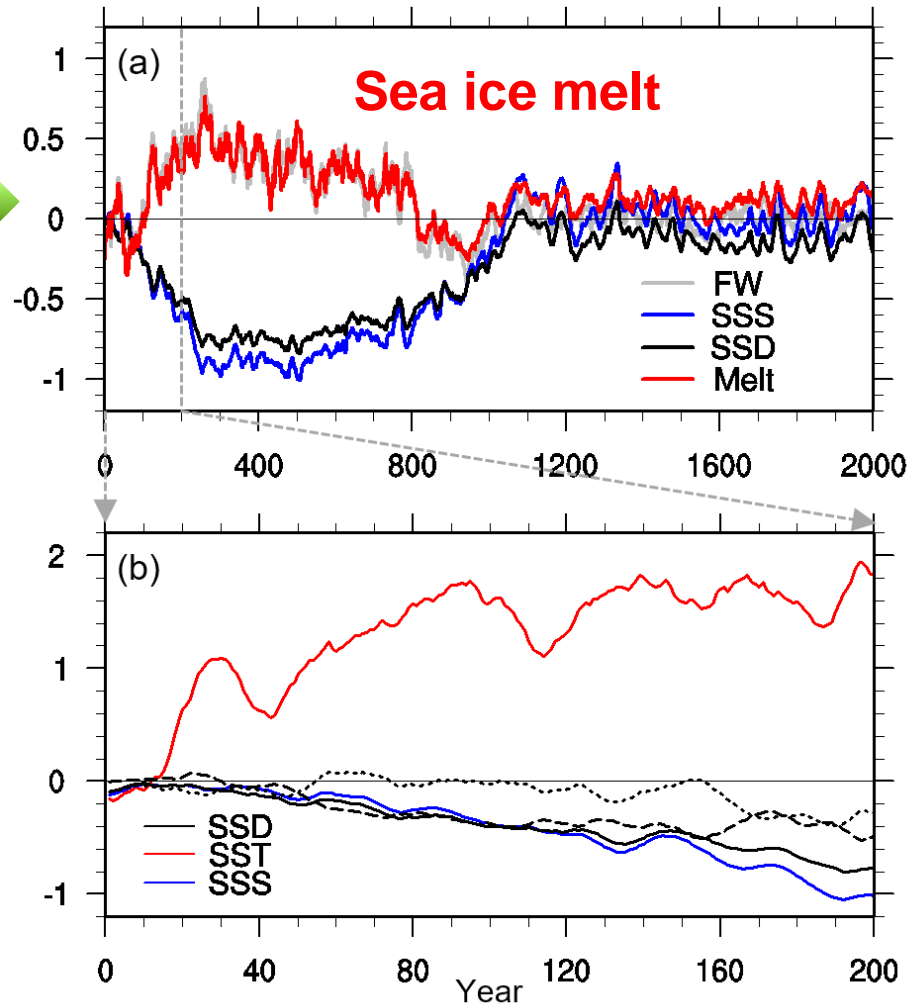


Freshwater Change in N. Atlantic

Total

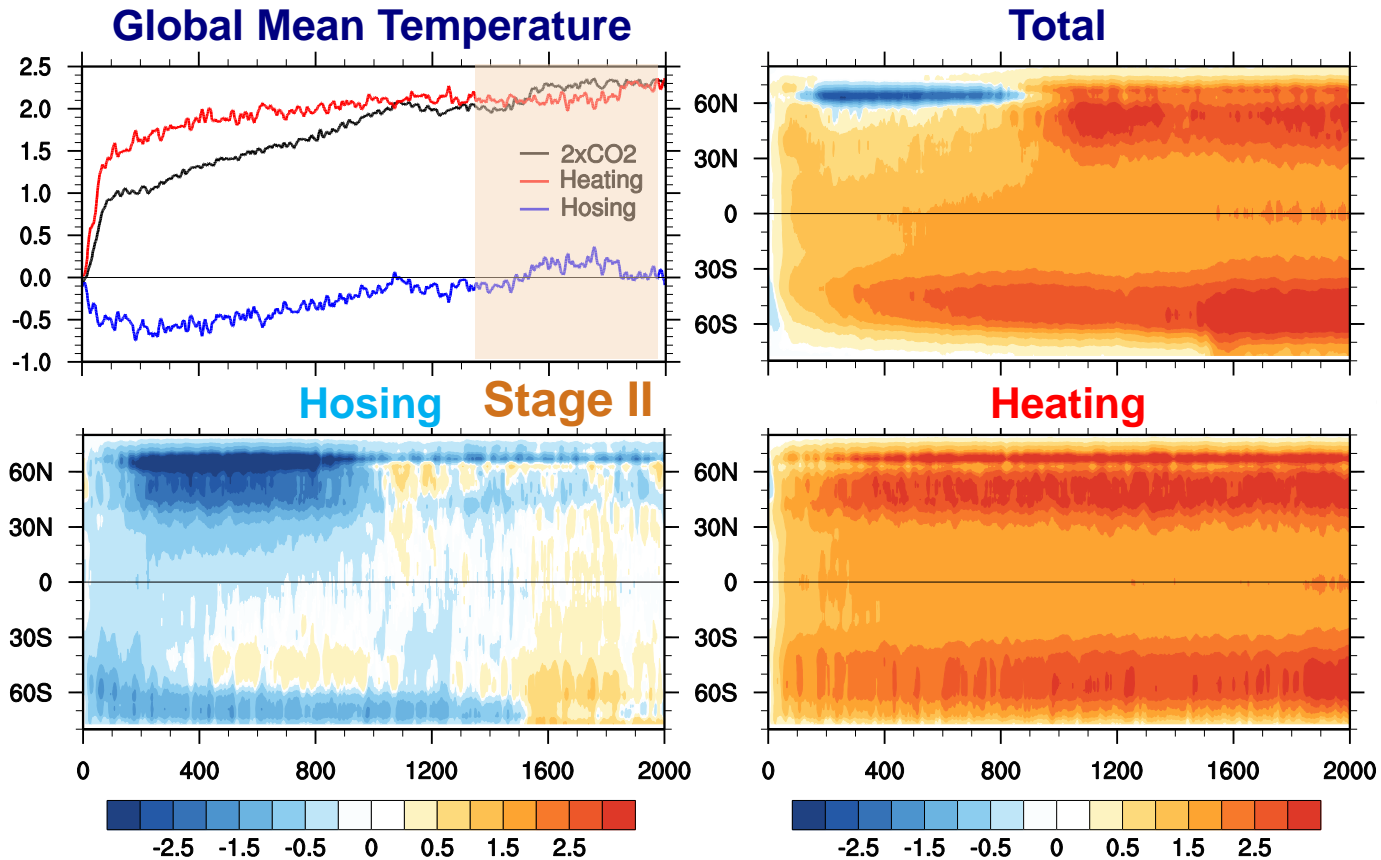


More Freshwater due
to **sea-ice melting**



Later stages in Global Warming ...

Global *Temperature* Evolution



Summary and Discussion

Earlier stage:

- ◇ Ocean: **30%** cooling
 - ◇ Downward heat transport
 - ◇ Sea-Land ice melting

Later stage:

- ◇ Accelerate surface heating
 - ◇ No ice buffering effect
 - ◇ Deeper ocean heat release

No land surface processes considered!



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Thanks