Michael Steele
Polar Science Center / APL
University of Washington

Arctic Upper Ocean **warming**: The role of the atmosphere

Michael Steele *& real meteorologists*
Polar Science Center, Applied Physics Lab, University of Washington
Seattle, WA USA

Zhe Li
UCSB, Santa Barbara, CA

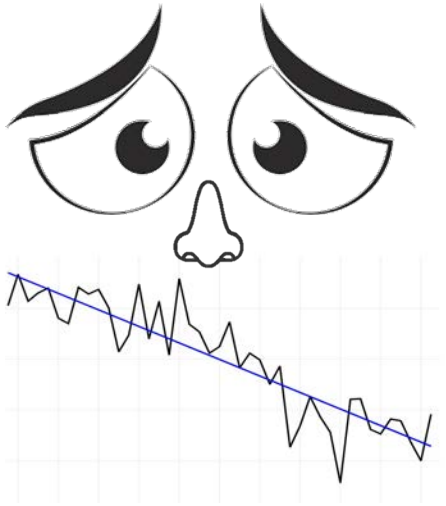
& Q. Ding (UCSB), A. Schweiger (UW)

Anne Sledd
NOAA/CIRES, Boulder, CO

& J. Kay (CU), T. L'Ecuyer (UWisc)

Michael Steele
Polar Science Center / APL
University of Washington

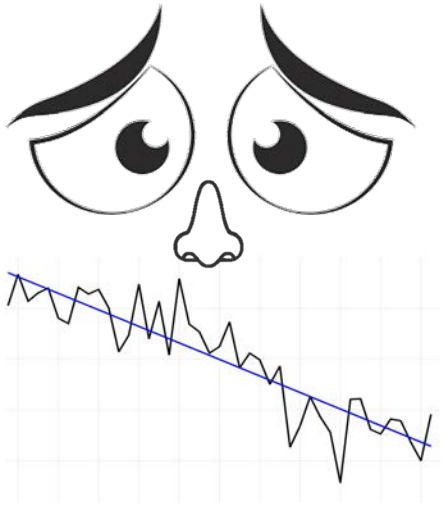
Ice Retreat



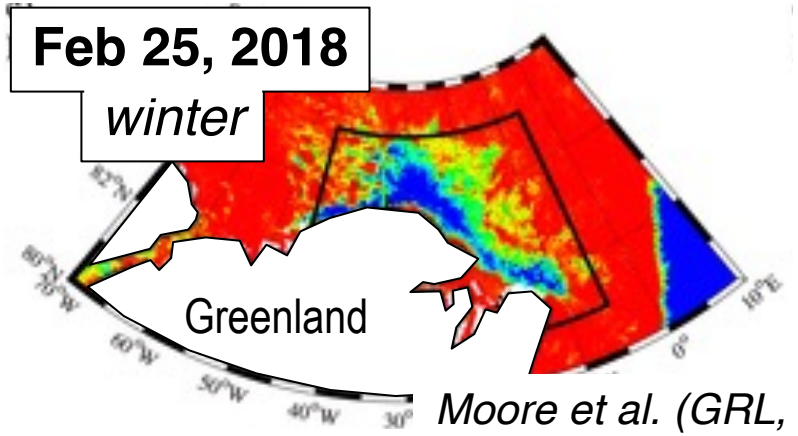
Sept. Arctic Sea Ice Extent
(1979-2021, NSIDC)

Michael Steele
Polar Science Center / APL
University of Washington

Ice Retreat



Sept. Arctic Sea Ice Extent
(1979-2021, NSIDC)



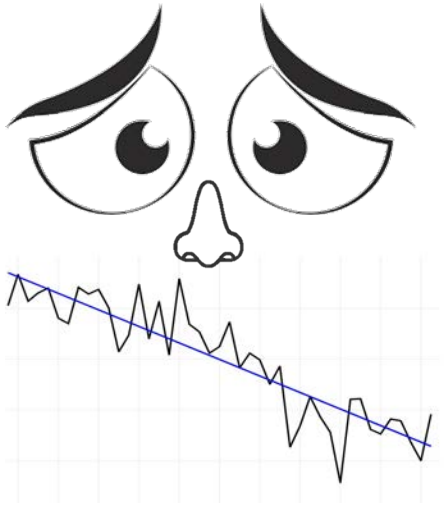
Moore et al. (GRL, 2018)

Ice loss even north of Greenland!

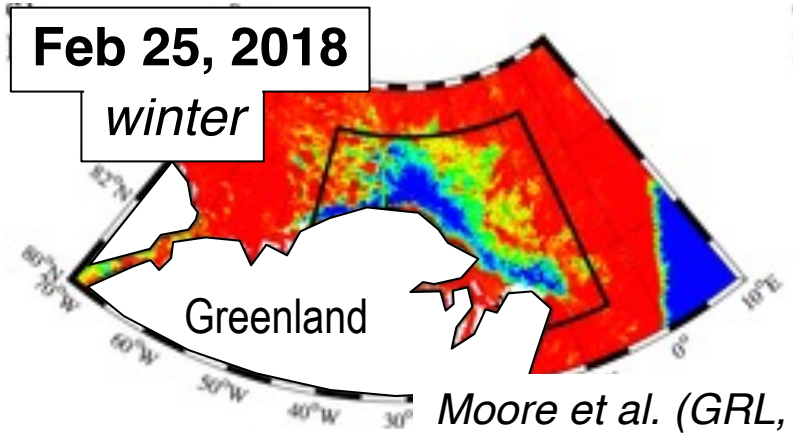
"Wandel Sea"

Michael Steele
Polar Science Center / APL
University of Washington

Ice Retreat



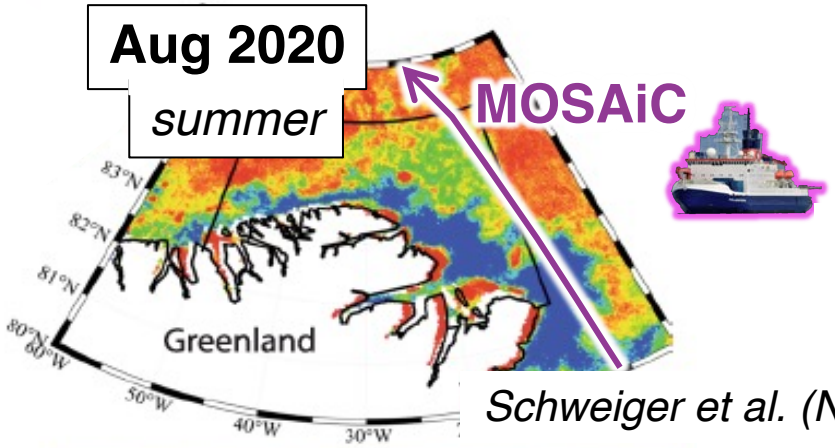
Sept. Arctic Sea Ice Extent
(1979-2021, NSIDC)



Moore et al. (GRL, 2018)

Ice loss even north of Greenland!

"Wandel Sea"

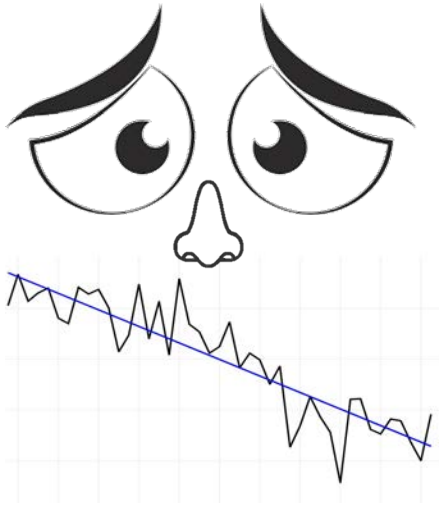


NSTM & ice-α feedback

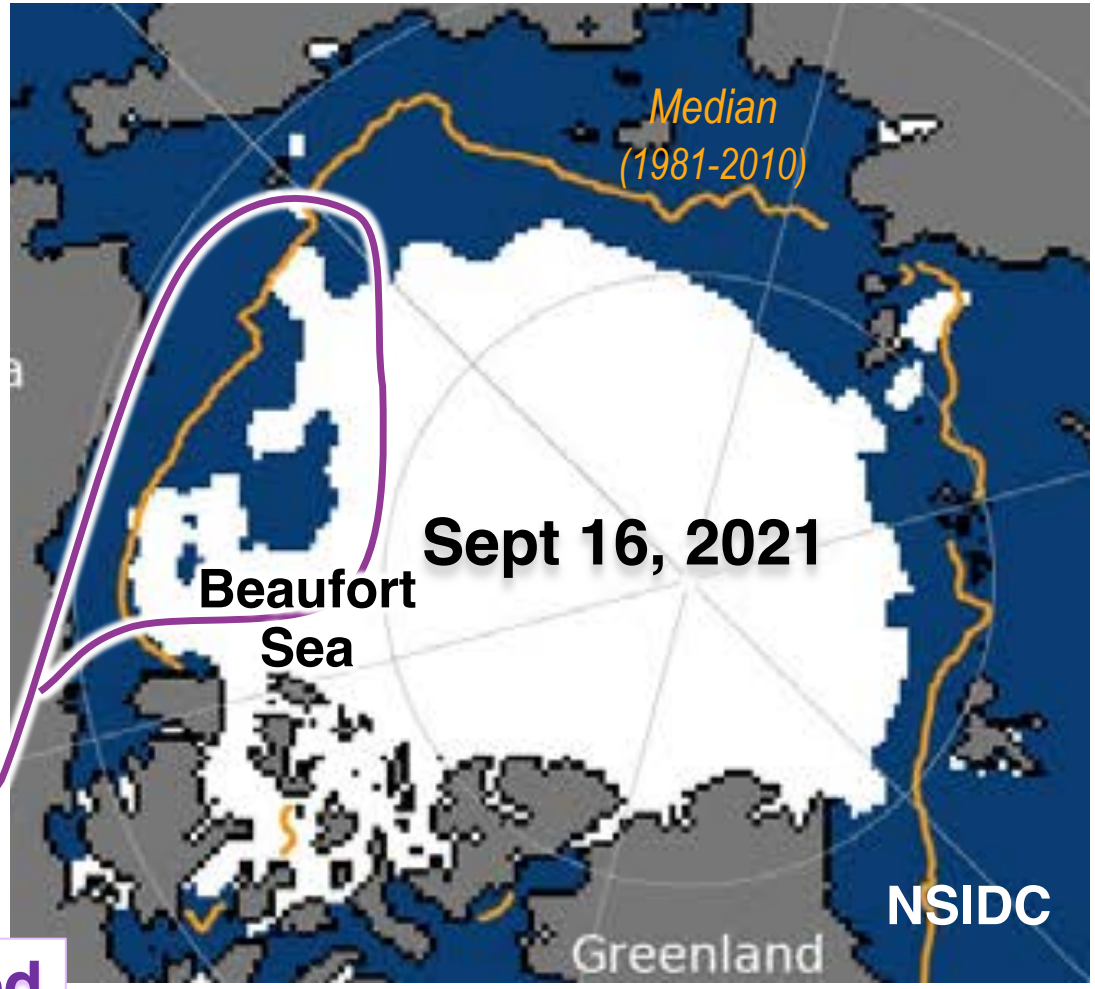
Schweiger et al. (Nature CE&E, 2021)

Michael Steele
Polar Science Center / APL
University of Washington

Ice Retreat



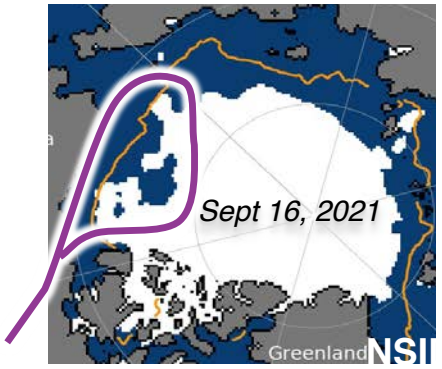
Sept. Arctic Sea Ice Extent
(1979-2021, NSIDC)



Complicated 2D geometry

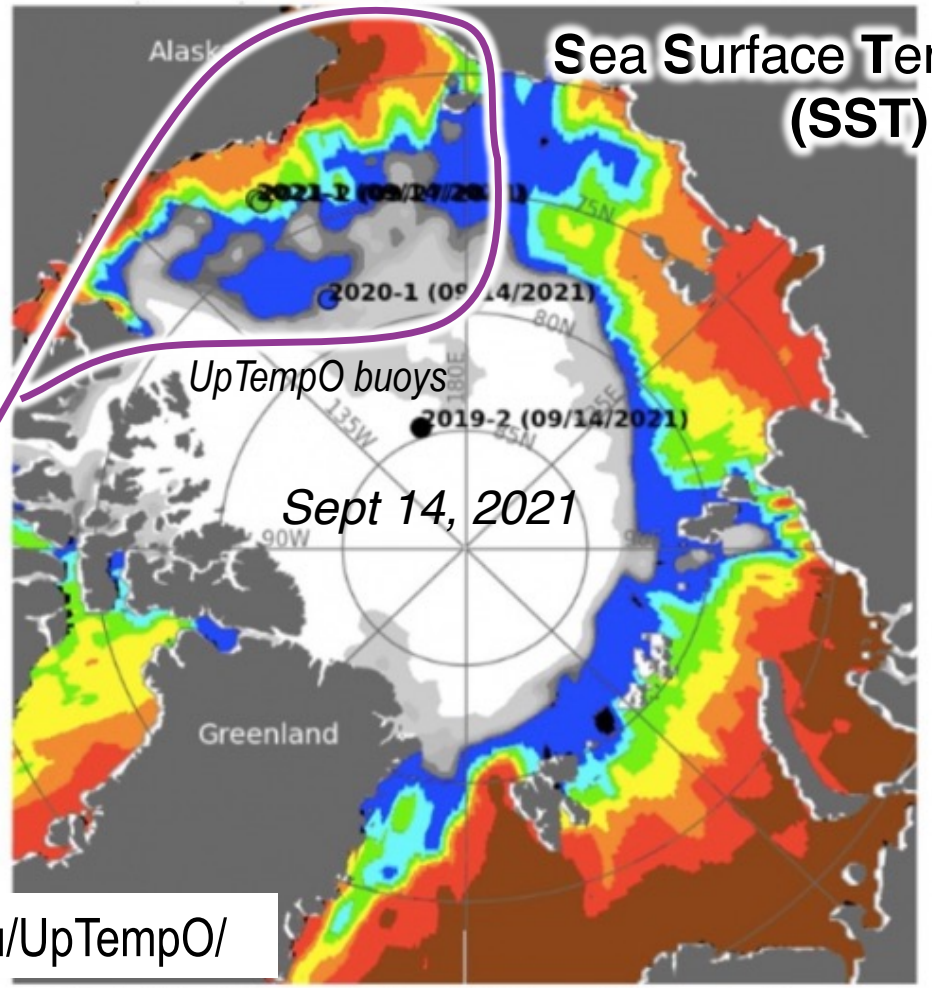
Michael Steele
Polar Science Center / APL
University of Washington

Ocean surface warming

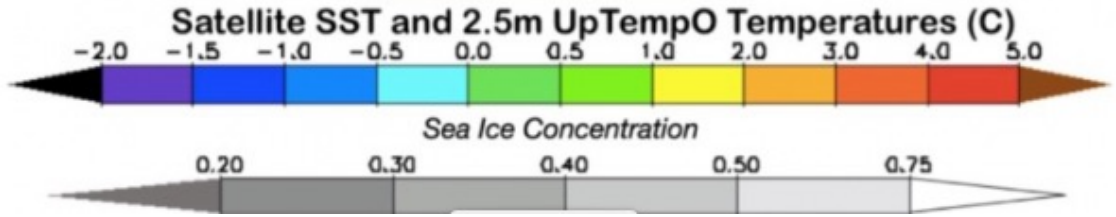


Complicated geometry

Complicated SST!

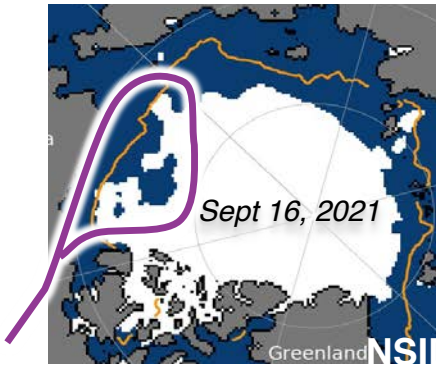


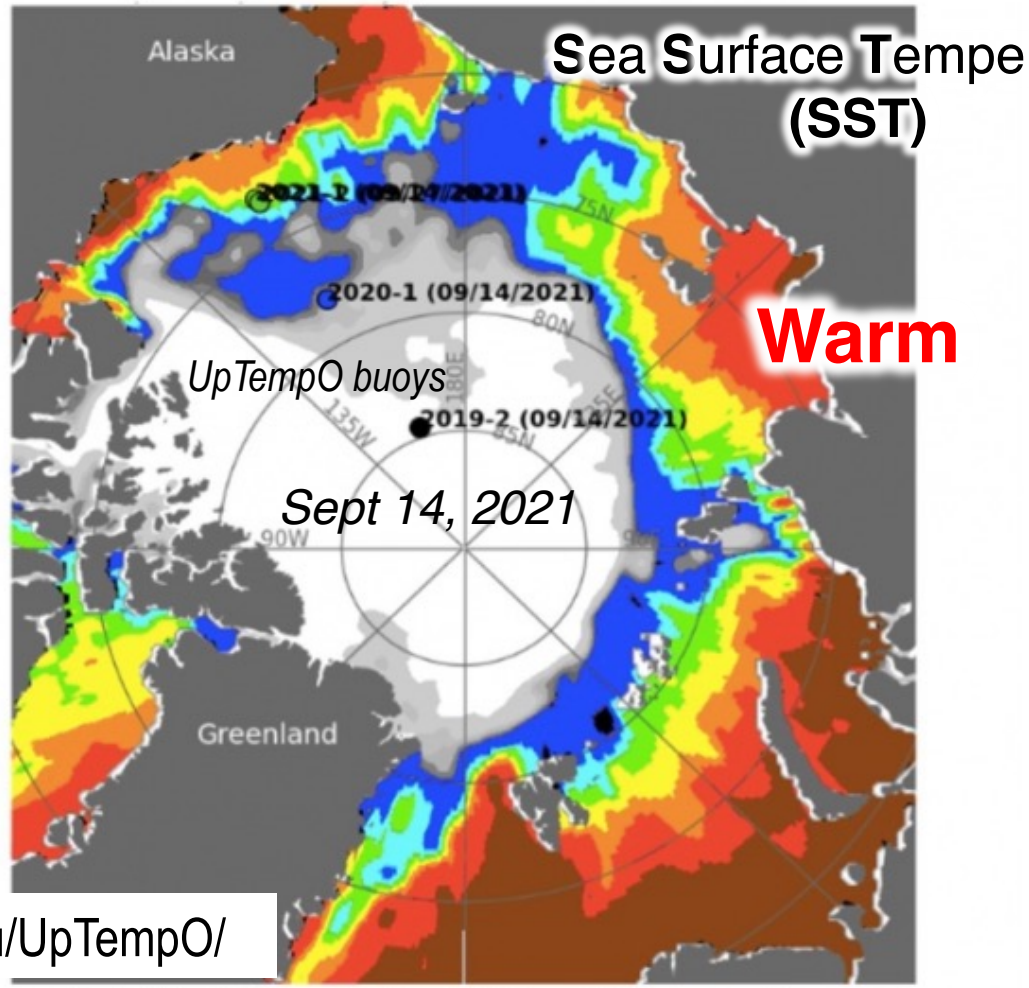
http://psc.apl.washington.edu/UpTempO/



Michael Steele
Polar Science Center / APL
University of Washington

Ocean surface warming



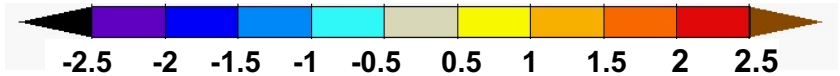


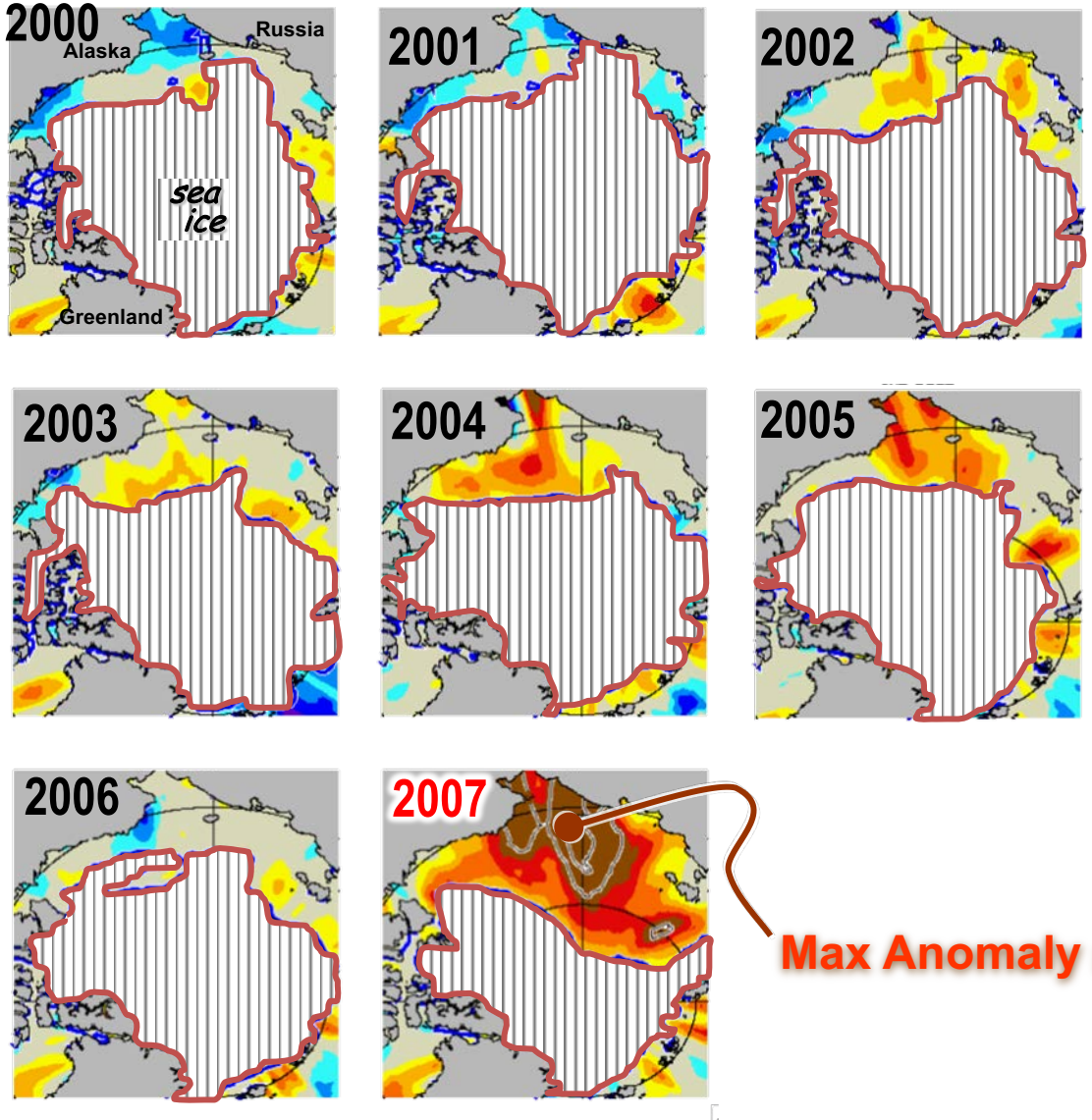
http://psc.apl.washington.edu/UpTempO/

Michael Steele
Polar Science Center / APL
Ur

Summer (*JAS*) SST anomalies *(rel. to 2000-2007)* (°C)

(NOAA/OISST aka "Reynolds")



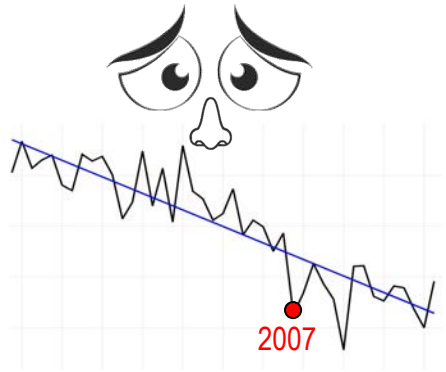


Where it all started

Arctic Ocean surface warming trends over the past 100 years

M. Steele, W. Ermold, J. Zhang

(GRL, 2008)

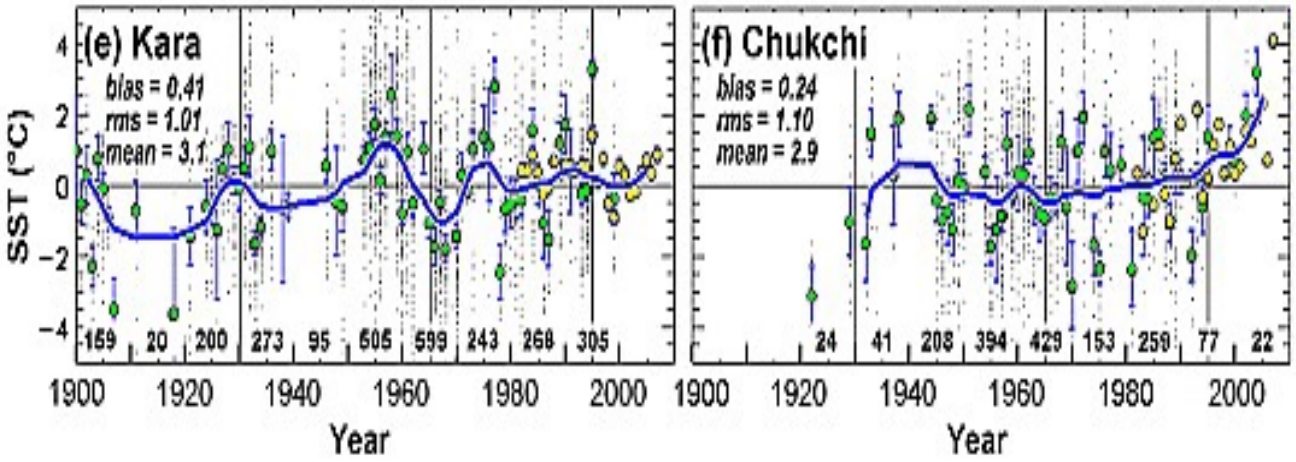


Sept. Arctic Sea Ice Extent

(1979-2021, NSIDC)

Michael Steele
Polar Science Center / APL
University of Washington

Where it all started



- **in situ** *(World Ocean Database)*
- **satellite** *(OISST)*

Arctic Ocean surface warming trends over the past 100 years

M. Steele, W. Ermold, J. Zhang

(GRL, 2008)

AGU talk Dec. 2007

Michael Steele
Polar Science Center / APL
University of Washington

My Climate Crank

Subject: Global Warming
Dates: Dec 2007 – July 2008

The San Francisco Chronicle printed "New Alarm is Raised Over Melting Polar Ice." I quote, "Michael Steele, an oceanographer at the Polar Science Center, said his group's measurements ...have shown a **warming trend for the past 100 years**".

Since the Polar Science Center has only been in operation since 1978, how is that possible? It makes one wonder how many other articles written by such **"scientists"** are **more political** than scientifically factual.

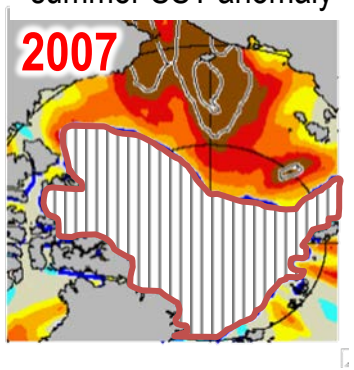
I have also sent a letter to the Dean of the school asking for **disciplinary action** against you, Mr. Steele, for your obvious deception.

Mr. Steele's comments will be brought to the attention of **Fox News Network**. Maybe Bill O'Reilly or Sean Hannity can sort it out with Mr. Steele.

Robert A. Casper, SR
64 Wallace Way
San Rafael, CA 94903

Michael Steele
Polar Science Center / APL
University of Washington

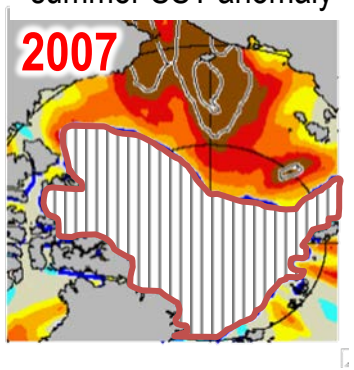
summer SST anomaly

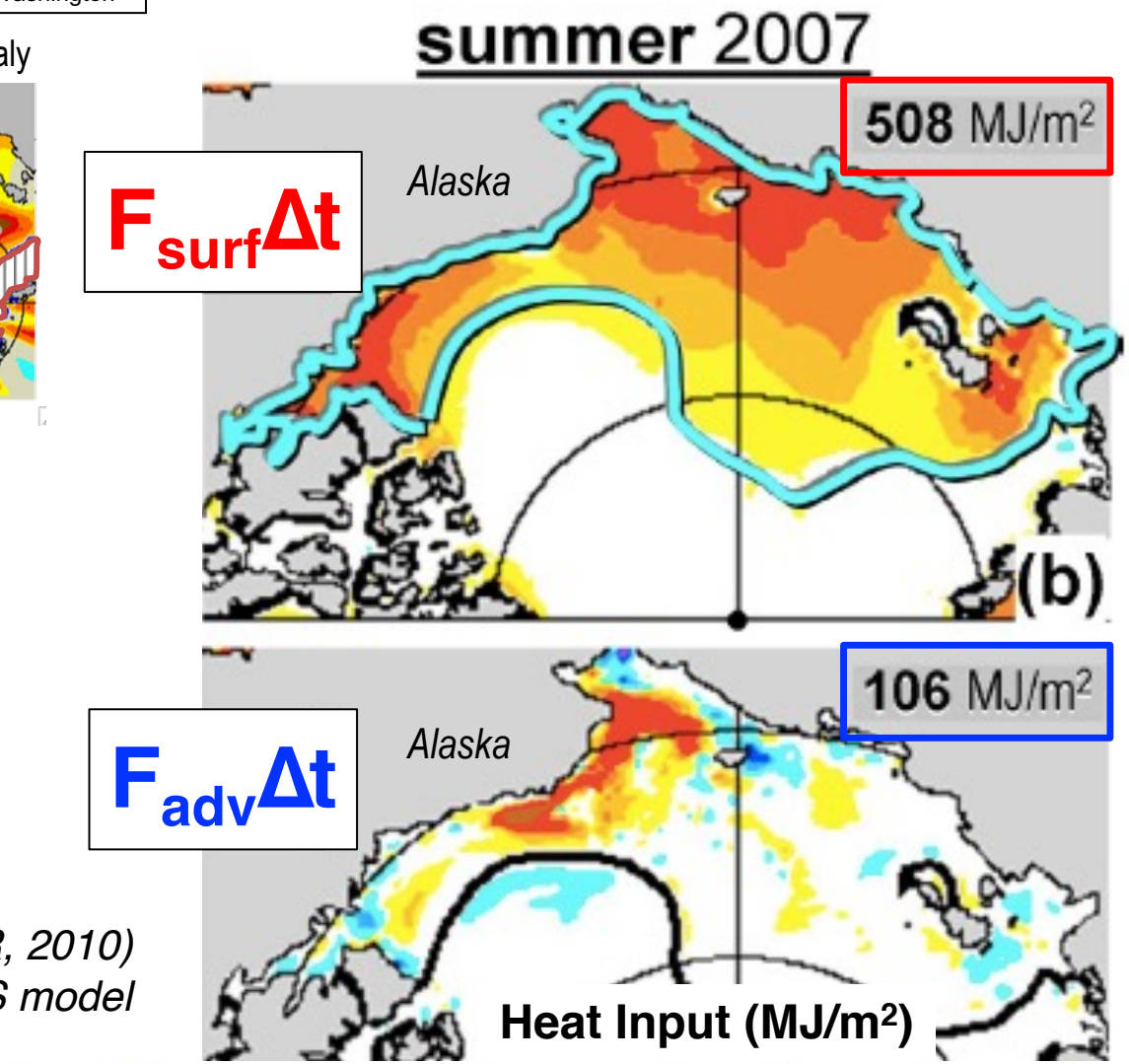


Physics?

Michael Steele
Polar Science Center / APL
University of Washington

summer SST anomaly





Atmos heating ~ 5 x

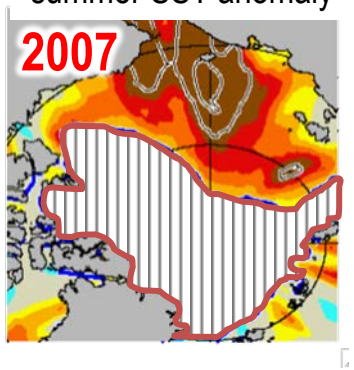
Lateral ocean heat flux convergence

Steele et al. (JGR, 2010)

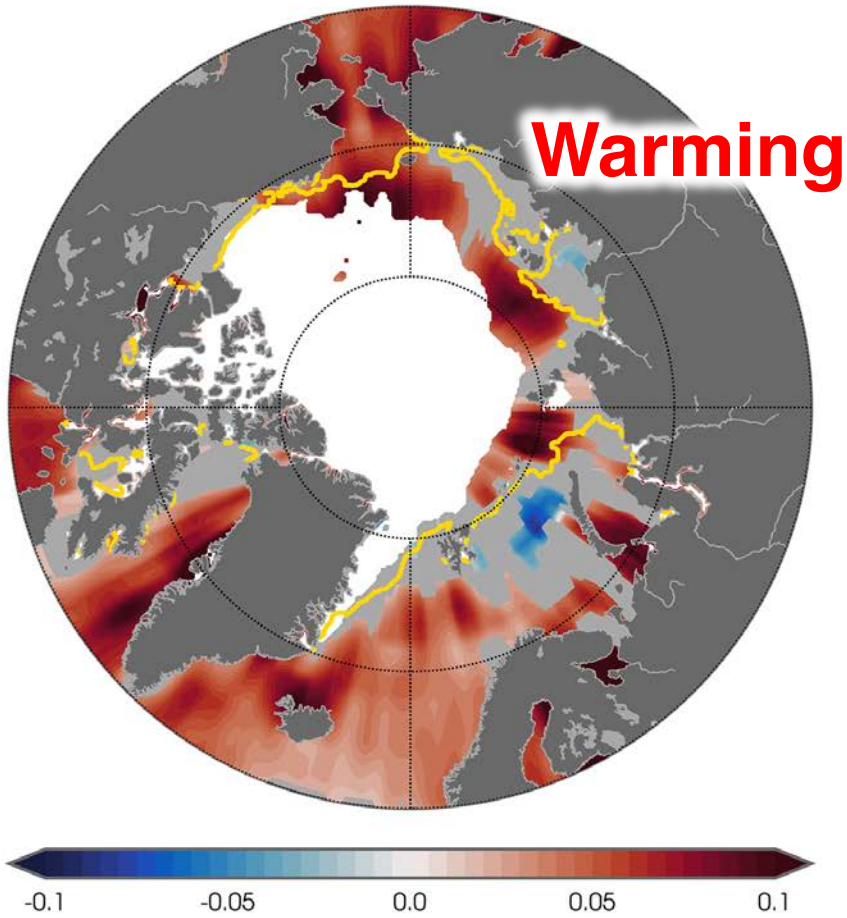
- *using PIOMAS model*

Michael Steele
Polar Science Center / APL
University of Washington

summer SST anomaly



Recently?



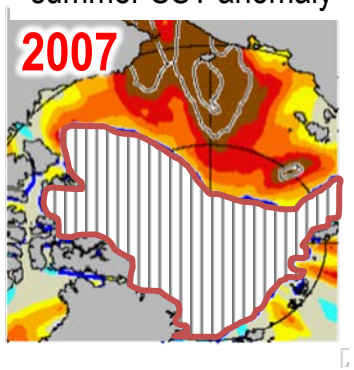
1982-2020 August linear SST trend (°C/yr)

Timmermans & Labe (NOAA, 2020)

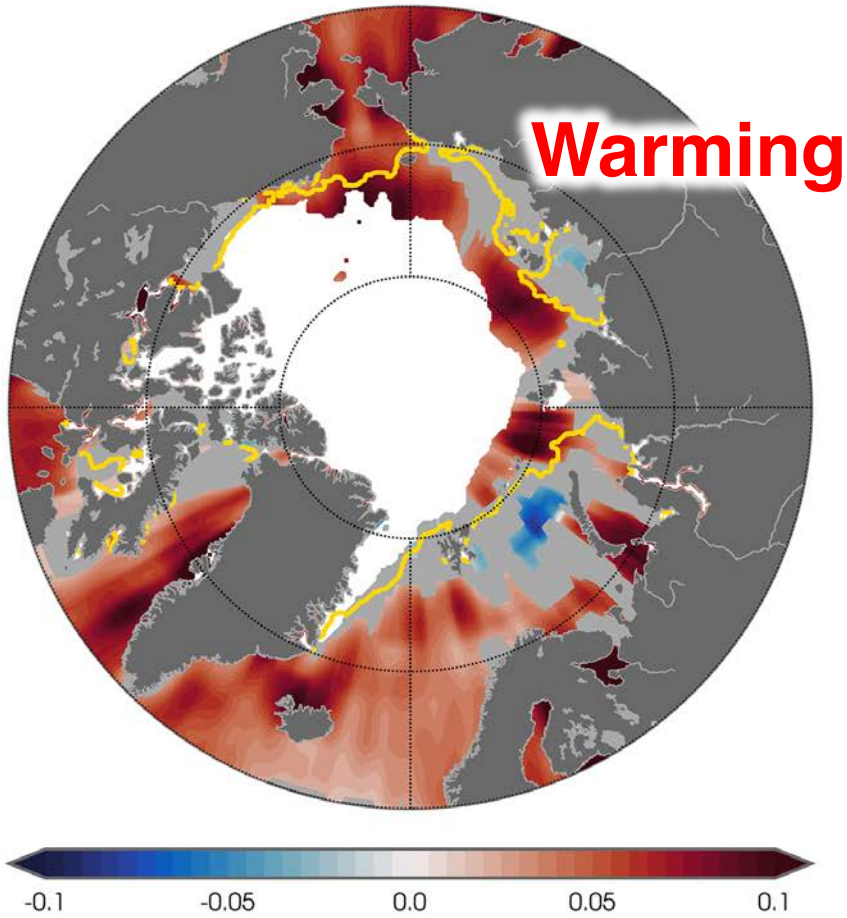
40 years x 0.05-0.1°C/yr
=
2-4°C

Michael Steele
Polar Science Center / APL
University of Washington

summer SST anomaly



Recently?



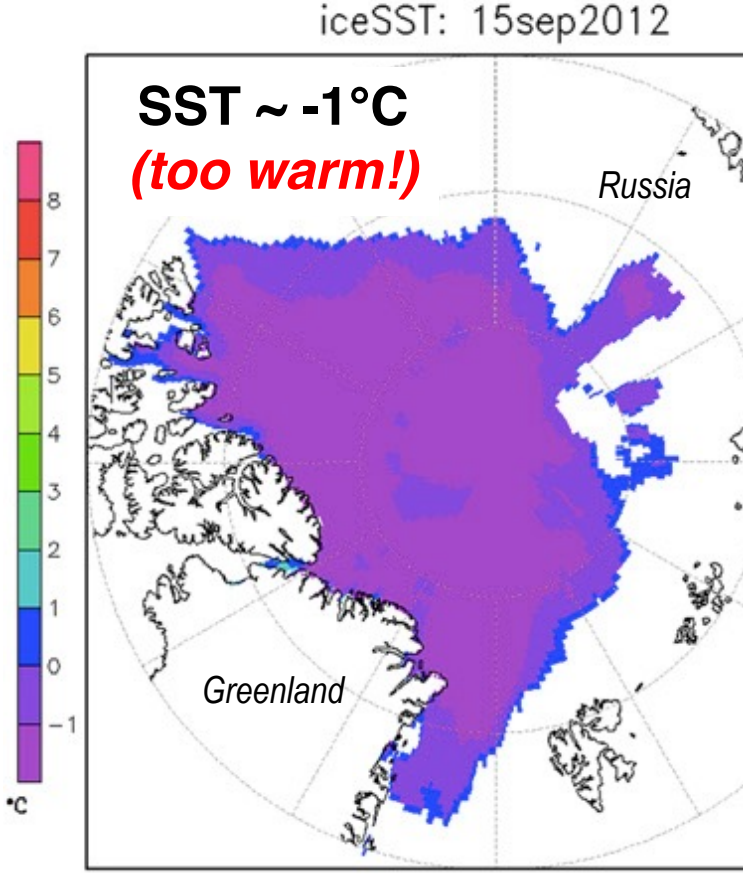
*Timmermans & Labe (**NOAA**, 2020)*

40 years x 0.05-0.1°C/yr
=
2-4°C

Michael Steele
Polar Science Center / APL
University of Washington

(NOAA/**OISST** ~~aka "Reynolds"~~)

25 km global, gridded SST 1981-present

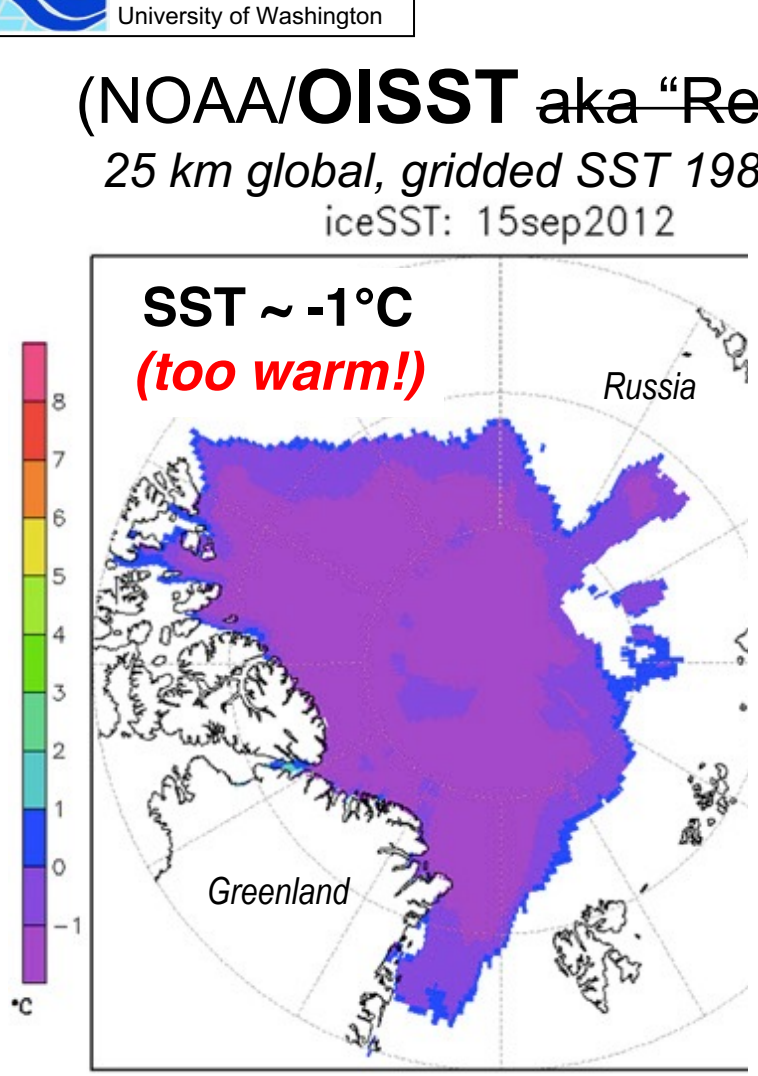


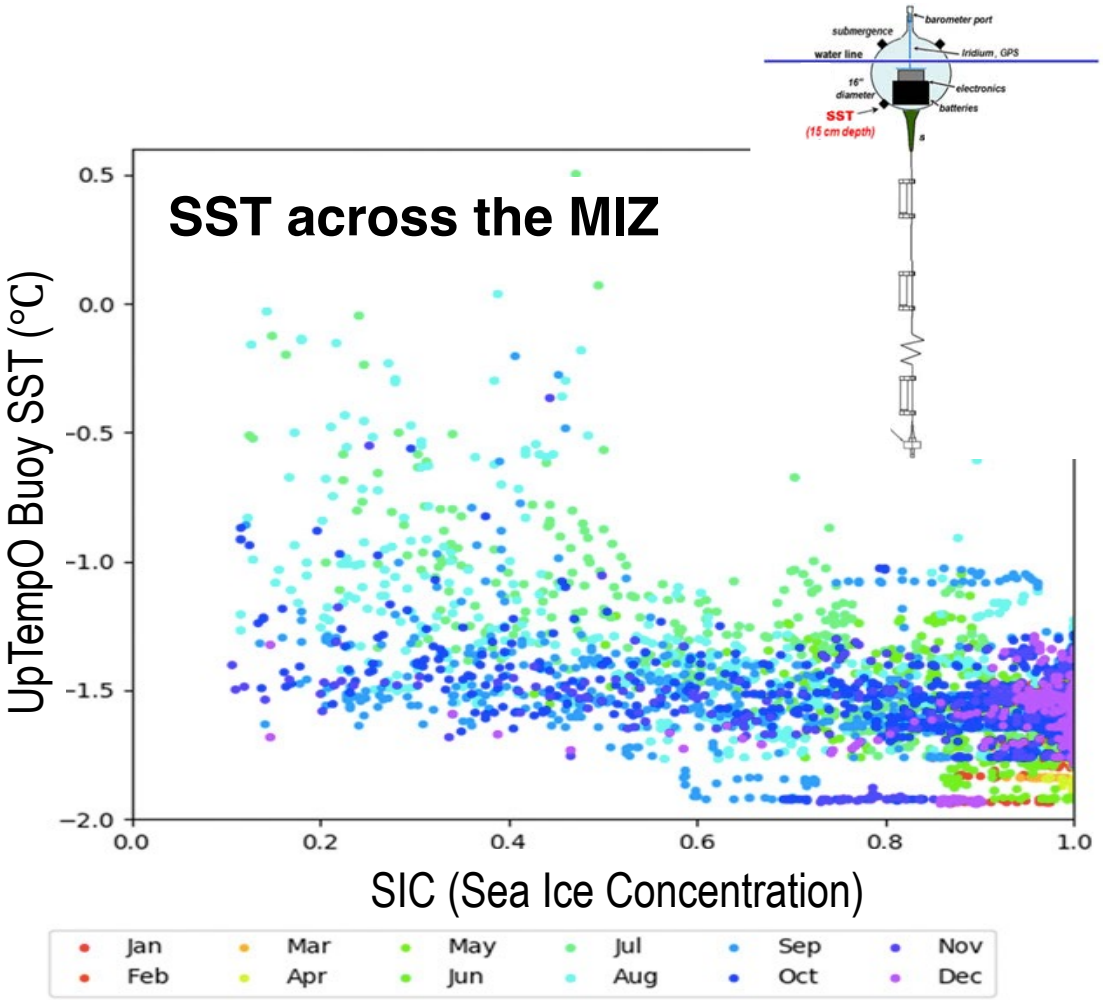
Banzon et al. (J Tech, 2020)
Huang et al. (J Climate, 2021)

Michael Steele
Polar Science Center / APL
University of Washington

(NOAA/**OISST** ~~aka "Reynolds"~~)

25 km global, gridded SST 1981-present



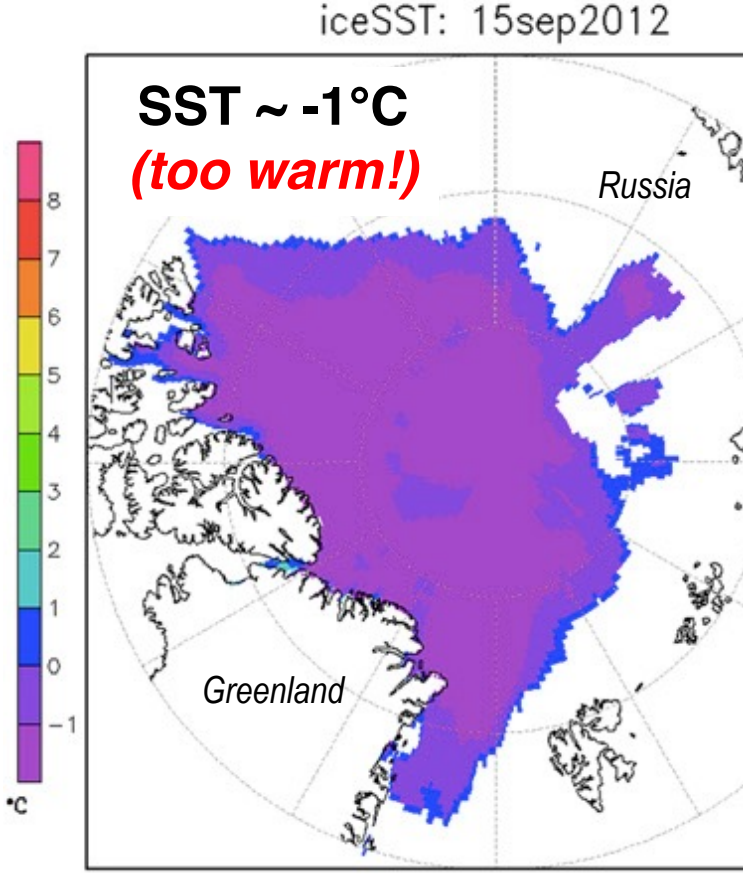


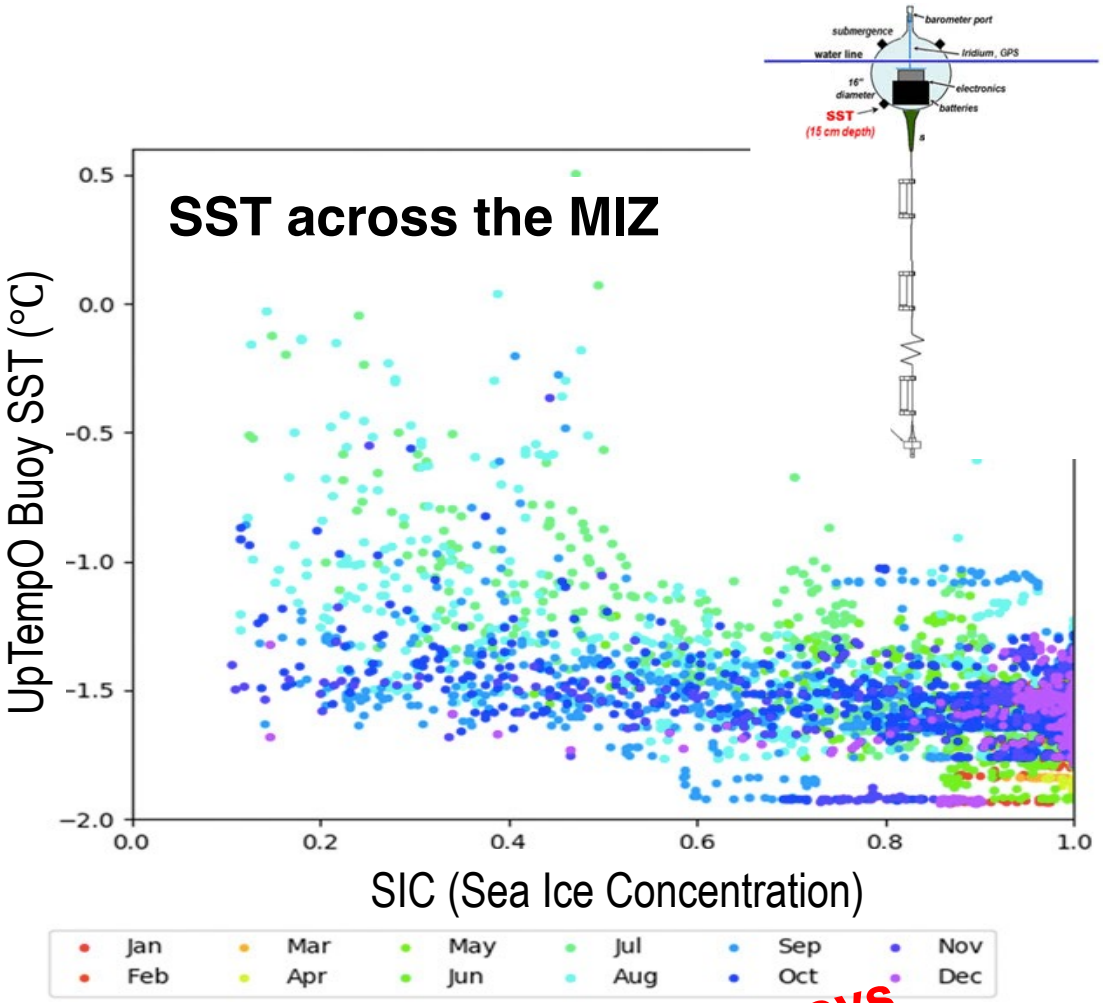
Banzon et al. (J Tech, 2020)
Huang et al. (J Climate, 2021)

Michael Steele
Polar Science Center / APL
University of Washington

(NOAA/**OISST** ~~aka "Reynolds"~~)

25 km global, gridded SST 1981-present





UpTempO buoys

OISST**v2.1**:

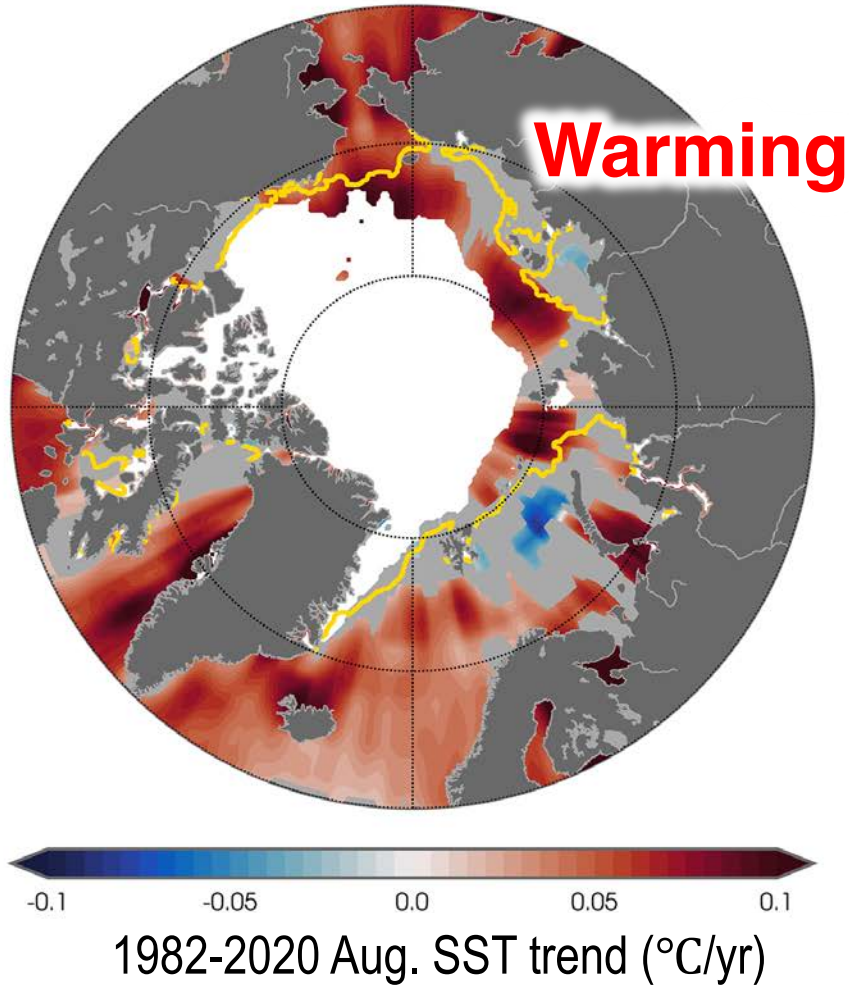
- SST = T_f + **c***SIC
- T_f (climo SSS)

Banzon et al. (J Tech, 2020)
Huang et al. (J Climate, 2021)

Michael Steele
Polar Science Center / APL
University of Washington

How much of this is due to:

- **Global warming vs.**
- **Internal climate variability?**



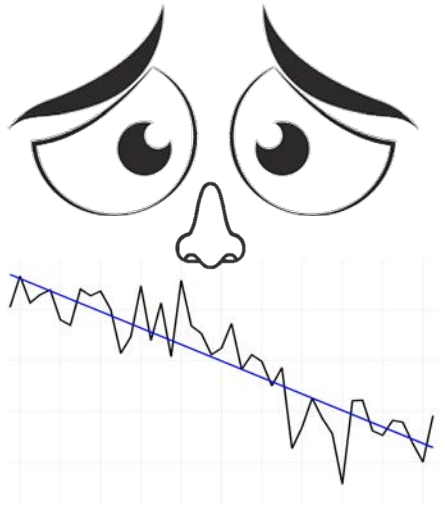
Michael Steele
Polar Science Center / APL
University of Washington

Background Question:

How much **Arctic sea ice loss** is due to:

Global warming vs. internal climate variability?

See Q. Ding's poster

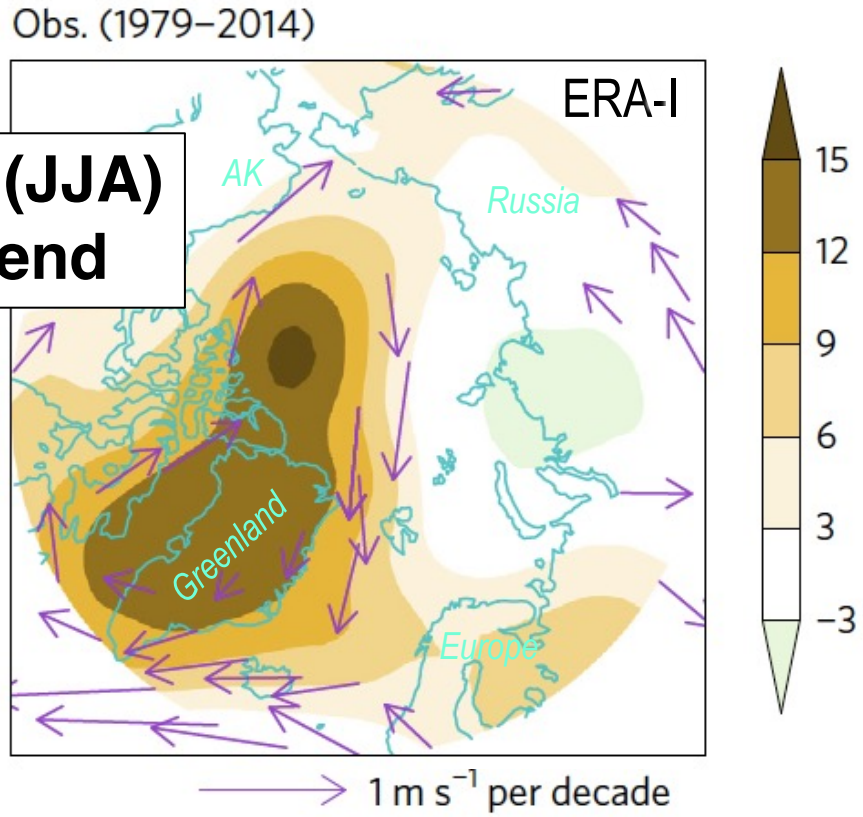


Sept. Arctic Sea Ice Extent
(1979-2021, NSIDC)

Michael Steele
Polar Science Center / APL
University of Washington

Atmos trends

Summer (JJA)
Z700 trend



☞ **Incr. high pressure & AC winds** ☜

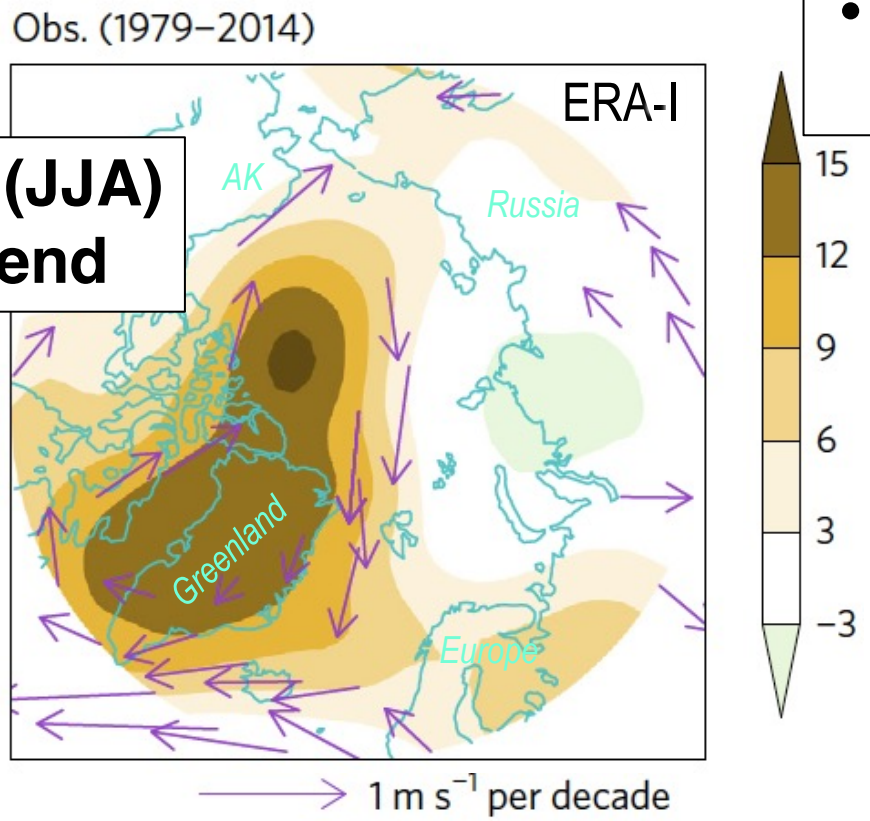
Michael Steele
Polar Science Center / APL
University of Washington

Ding et al. (Nature CC, 2017)

CLIVAR Arctic Oean
Seattle, WA

Atmos trends

Summer (JJA)
Z700 trend



Atmos is:

- **Warmer** *(subsidence)*
- *Wetter/cloudier @ surface*
  (incr. LW down)

☞ **Incr. high pressure & AC winds** ☜

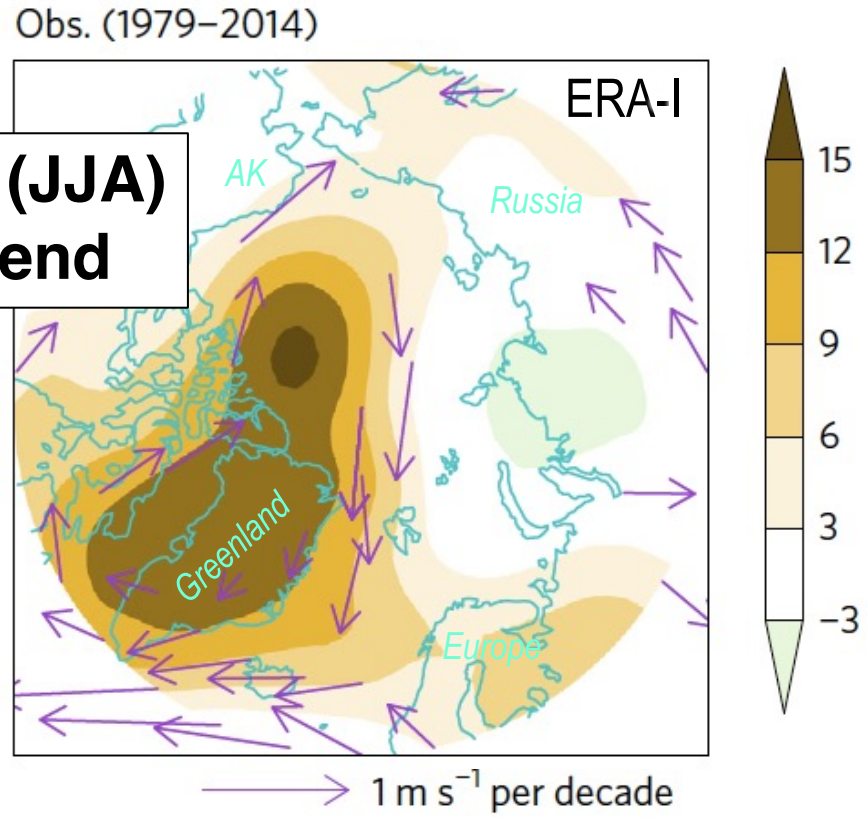
Michael Steele
Polar Science Center / APL
University of Washington

Ding et al. (Nature CC, 2017)

Atmos trends

Internal climate variability
+
global warming

Summer (JJA)
Z700 trend

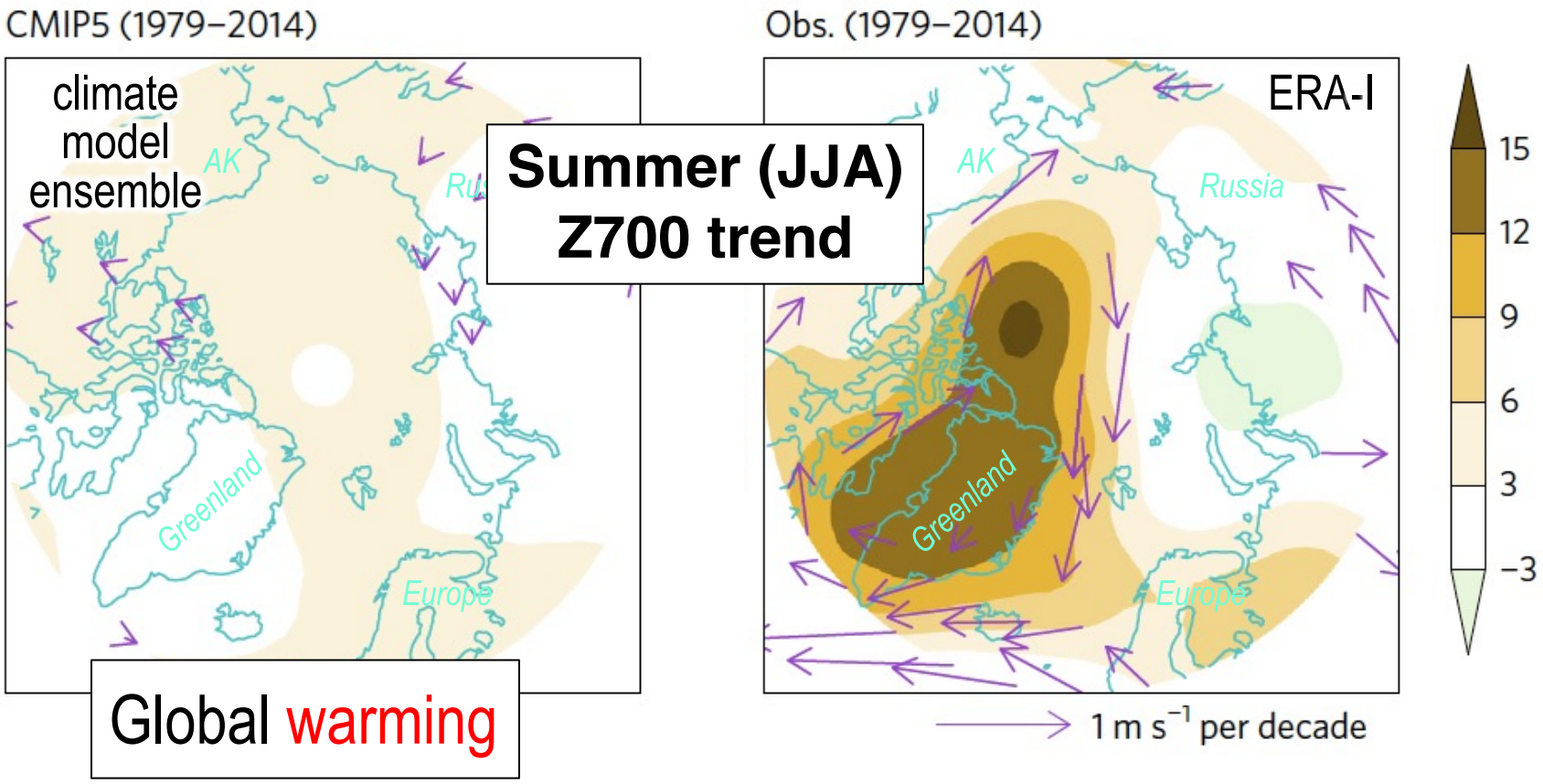


☞ **Incr. high pressure & AC winds** ☜

Michael Steele
Polar Science Center / APL
University of Washington

Ding et al. (Nature CC, 2017)

Atmos trends



Summer (JJA) Z700 trend

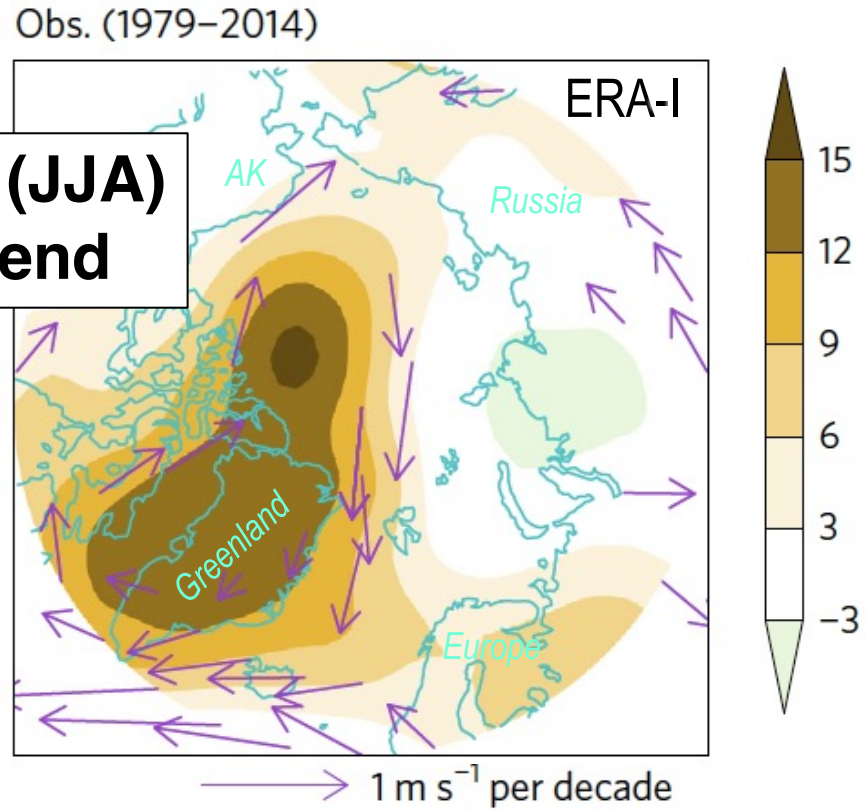
Global warming

☞ **Incr. high pressure & AC winds** ☜

Michael Steele
Polar Science Center / APL
University of Washington

Ding et al. (Nature CC, 2017)

Summer (JJA)
Z700 trend



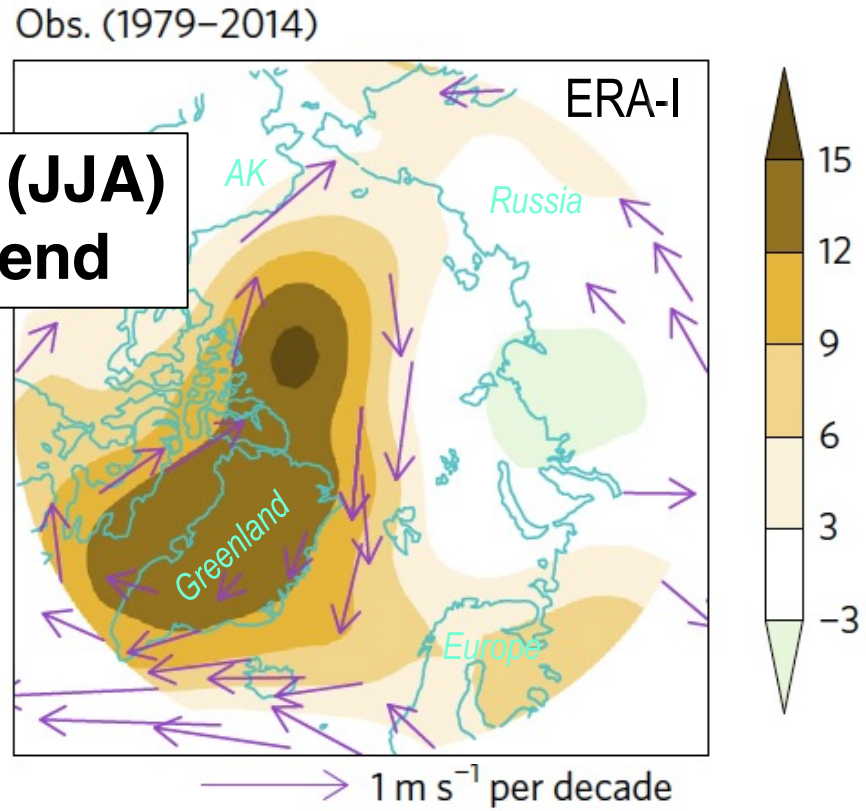
~ 40% of sea ice loss is from internal climate variability

☞ **Incr. high pressure & AC winds** ☜

Michael Steele
Polar Science Center / APL
University of Washington

Ding et al. (Nature CC, 2017)

Summer (JJA)
Z700 trend



~ 40% of sea ice loss
is from internal climate variability

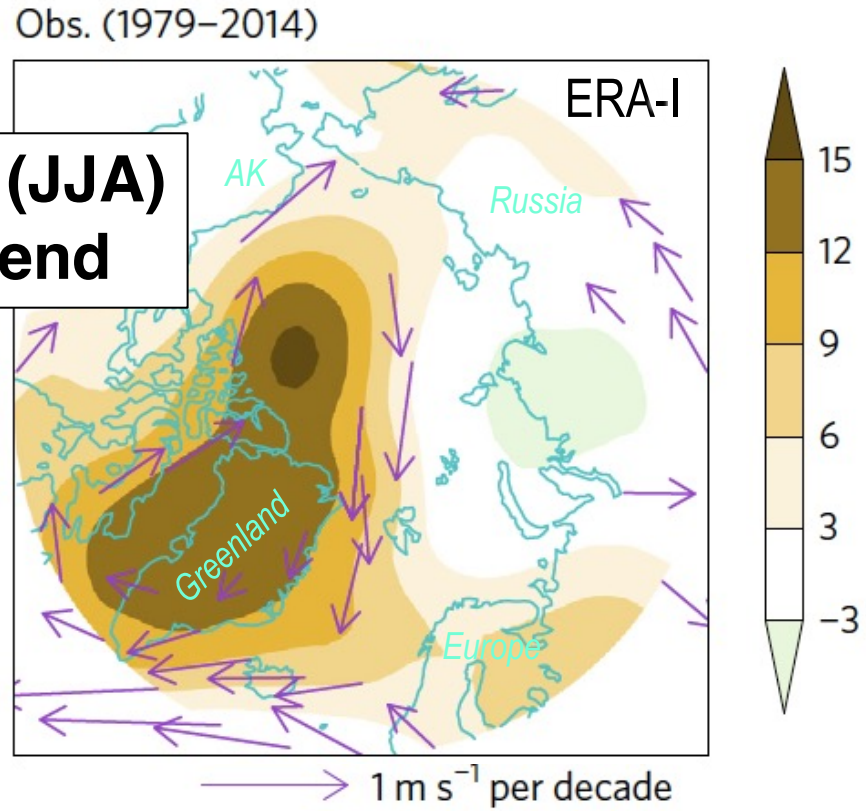
…ultimately forced by the tropical Pacific!

☞ **Incr. high pressure & AC winds** ☜

Michael Steele
Polar Science Center / APL
University of Washington

Ding et al. (Nature CC, 2017)

Summer (JJA)
Z700 trend



~ 40% of sea ice loss
is from internal climate variability

…ultimately forced by the tropical Pacific!

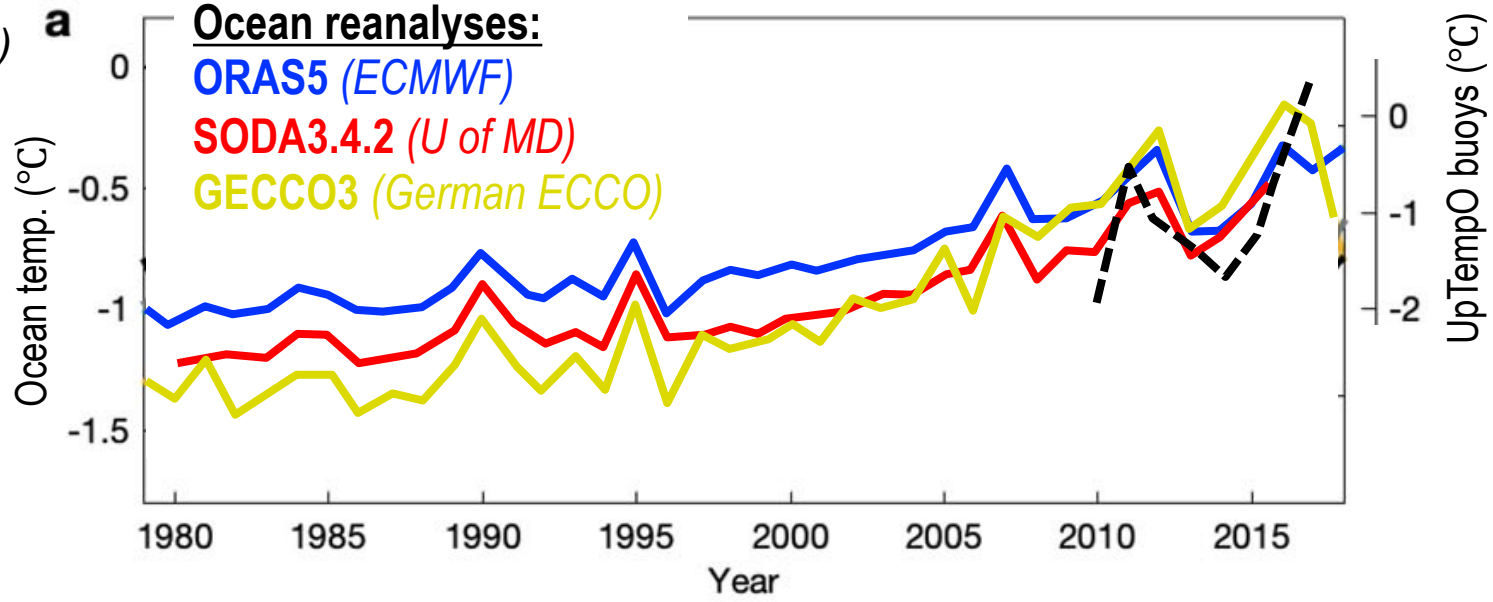
➜ OK SO WHAT ABOUT SST?

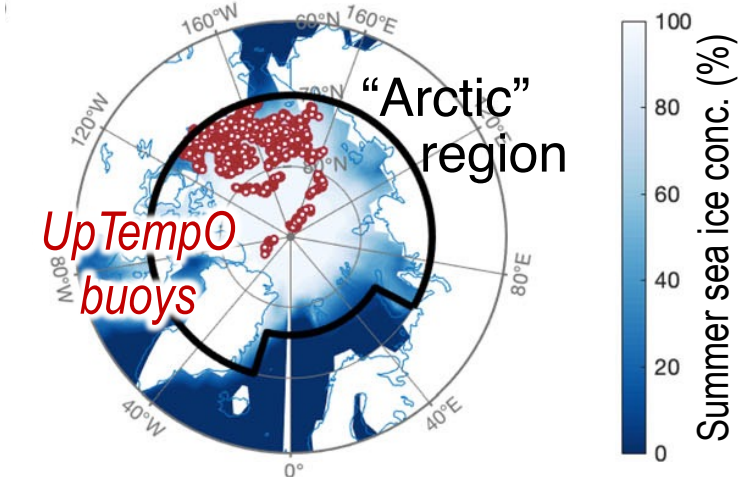
☞ **Incr. high pressure & AC winds** ☜

Michael Steele
Polar Science Center / APL
University of Washington

Upper Arctic Ocean warming (*0-50 m depth*)

Li et al.
(Nature Comm, 2017)

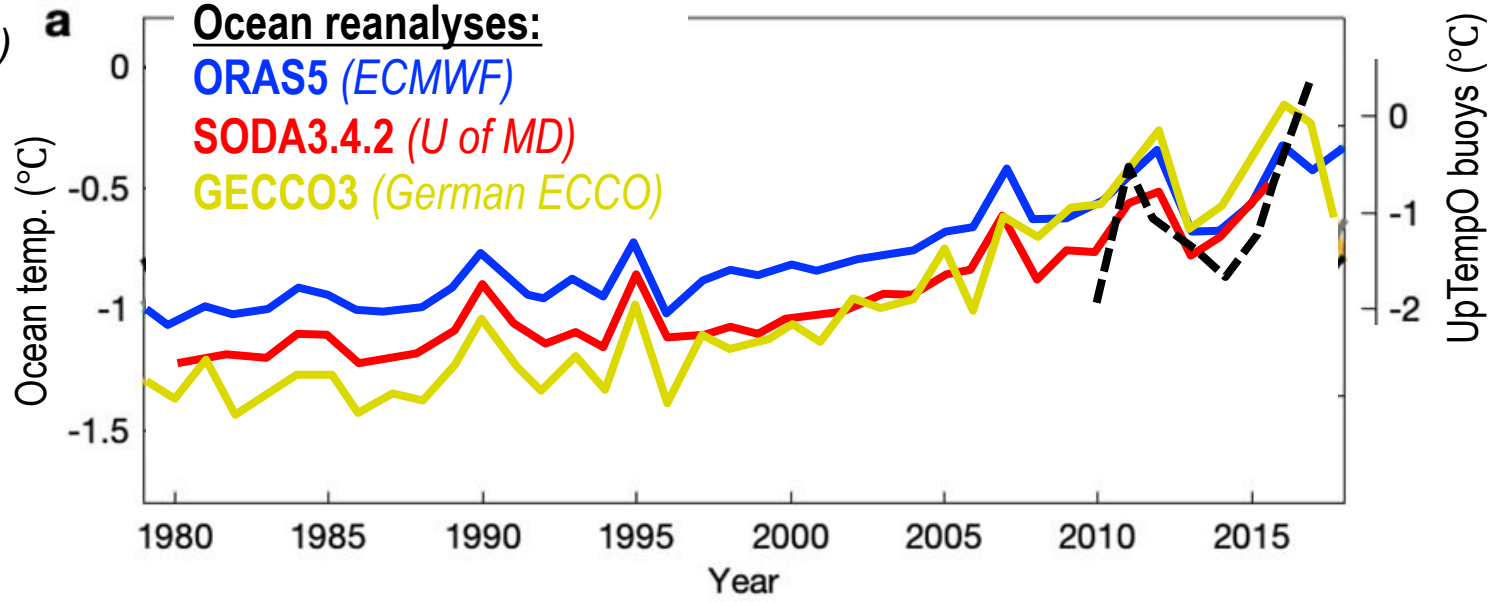


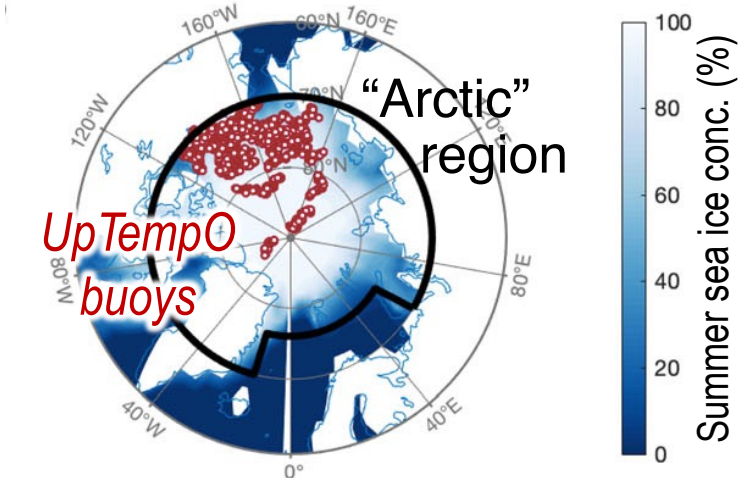


Michael Steele
Polar Science Center / APL
University of Washington

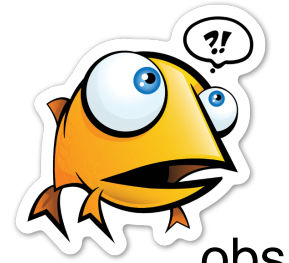
Upper Arctic Ocean warming (*0-50 m depth*)

Li et al.
(Nature Comm, 2017)





Meteorologists using **ocean reanalyses as "truth!"**



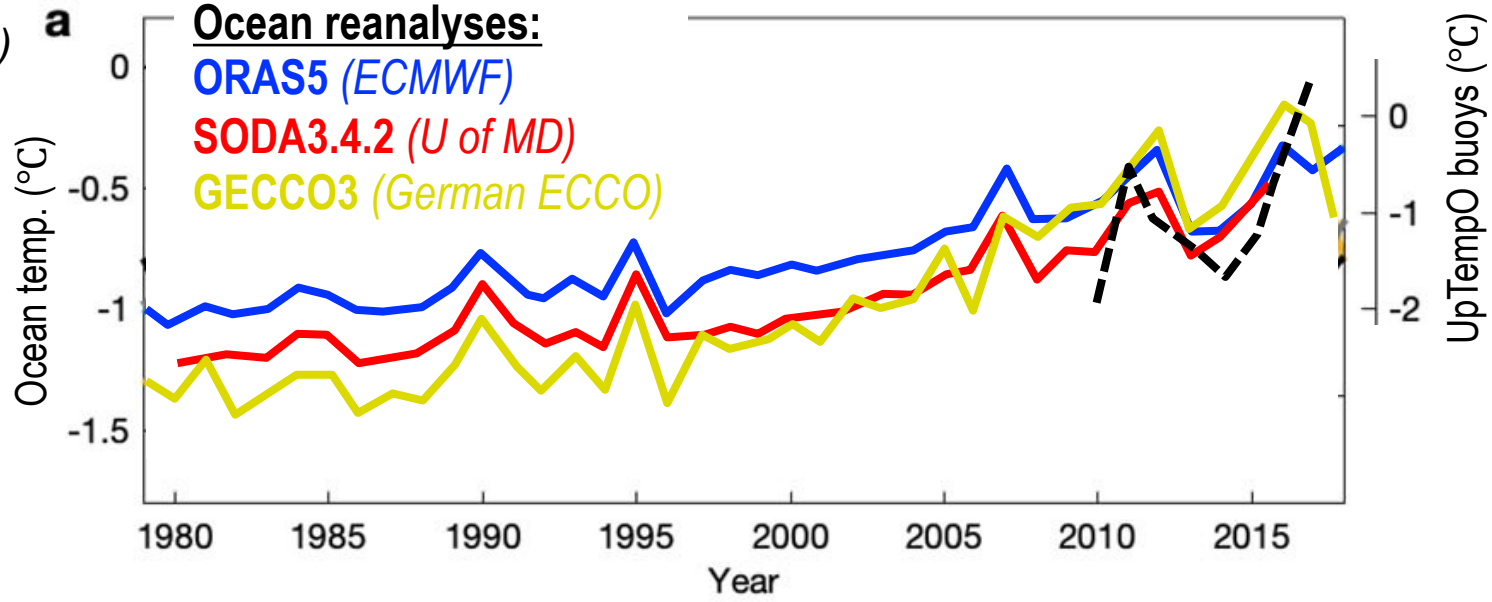
obs. oceanographer

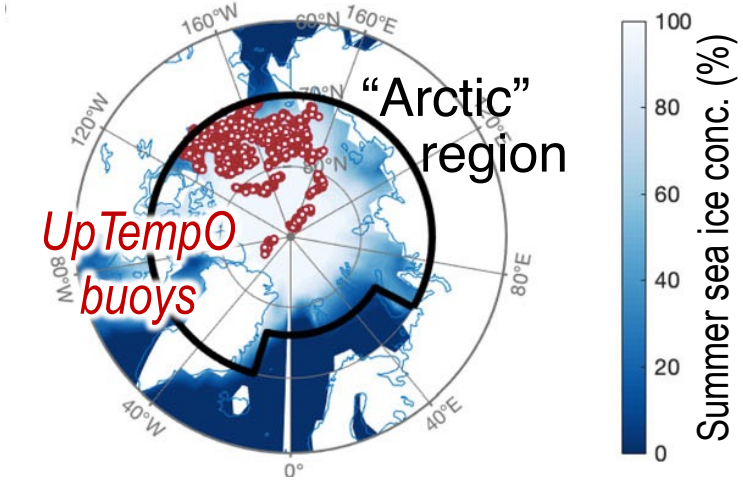
Is this even bad?!

Michael Steele
Polar Science Center / APL
University of Washington

Upper Arctic Ocean warming (*0-50 m depth*)

Li et al.
(Nature Comm, 2017)





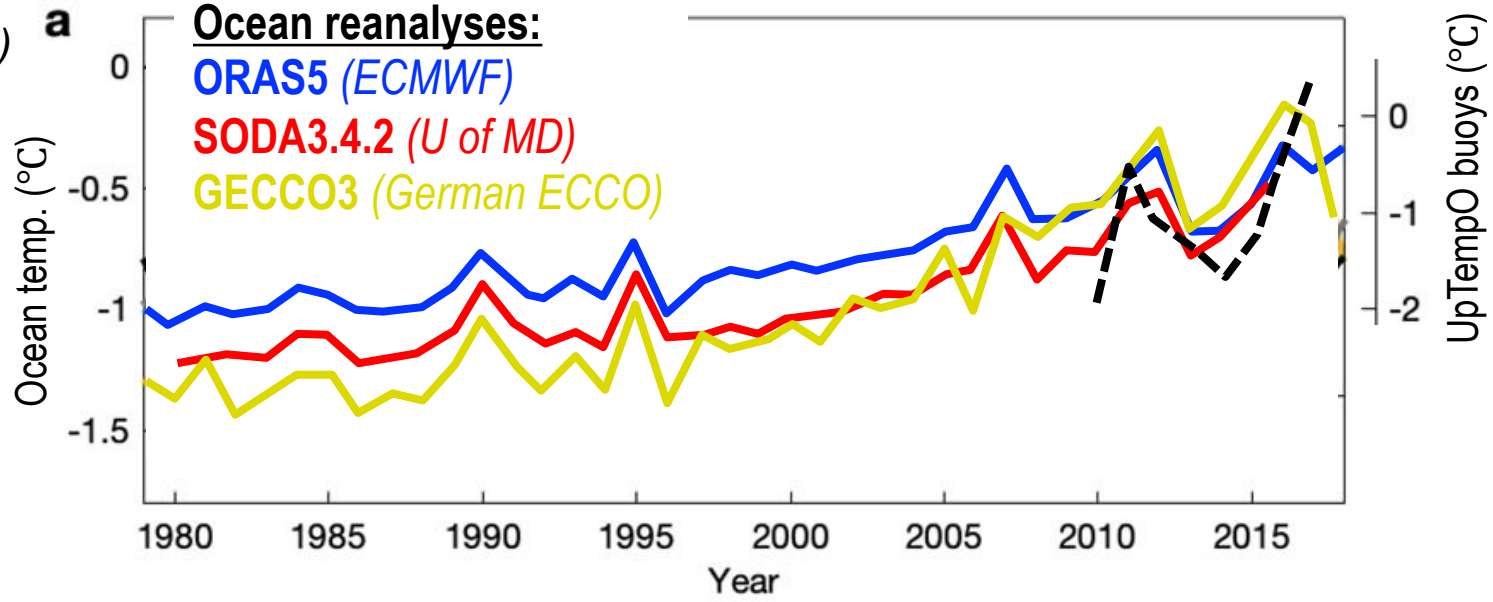
Sound familiar?!

Oceanographers using **atmos reanalyses as "truth!"**

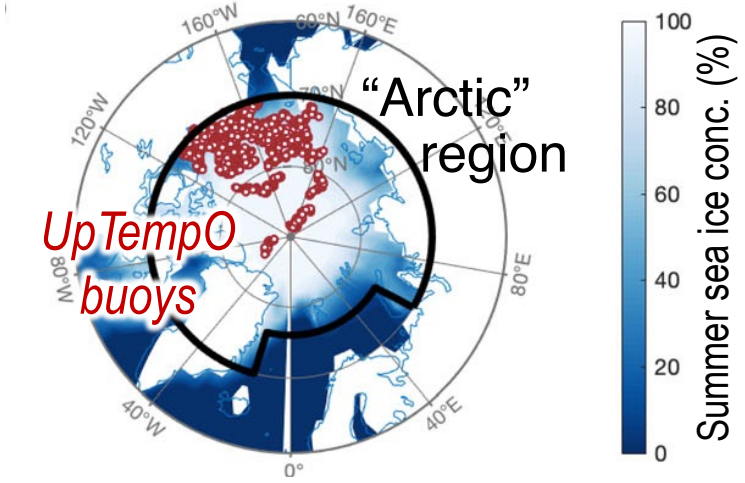
Michael Steele
Polar Science Center / APL
University of Washington

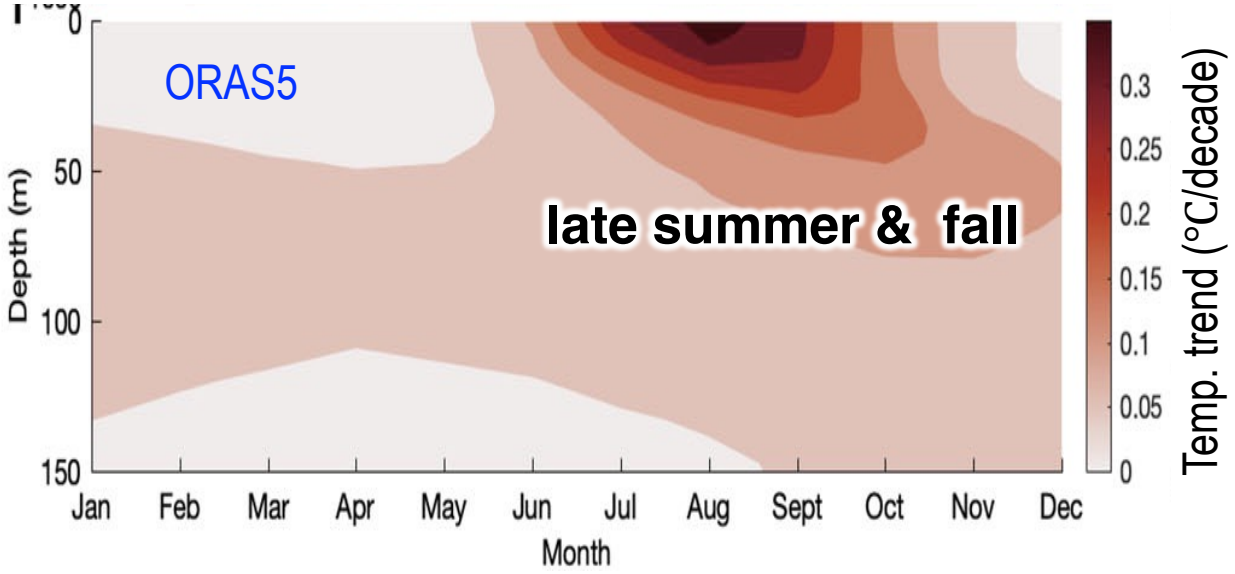
Upper Arctic Ocean warming (*0-50 m depth*)

Li et al.
(Nature Comm, 2017)



➢ fall (SON)

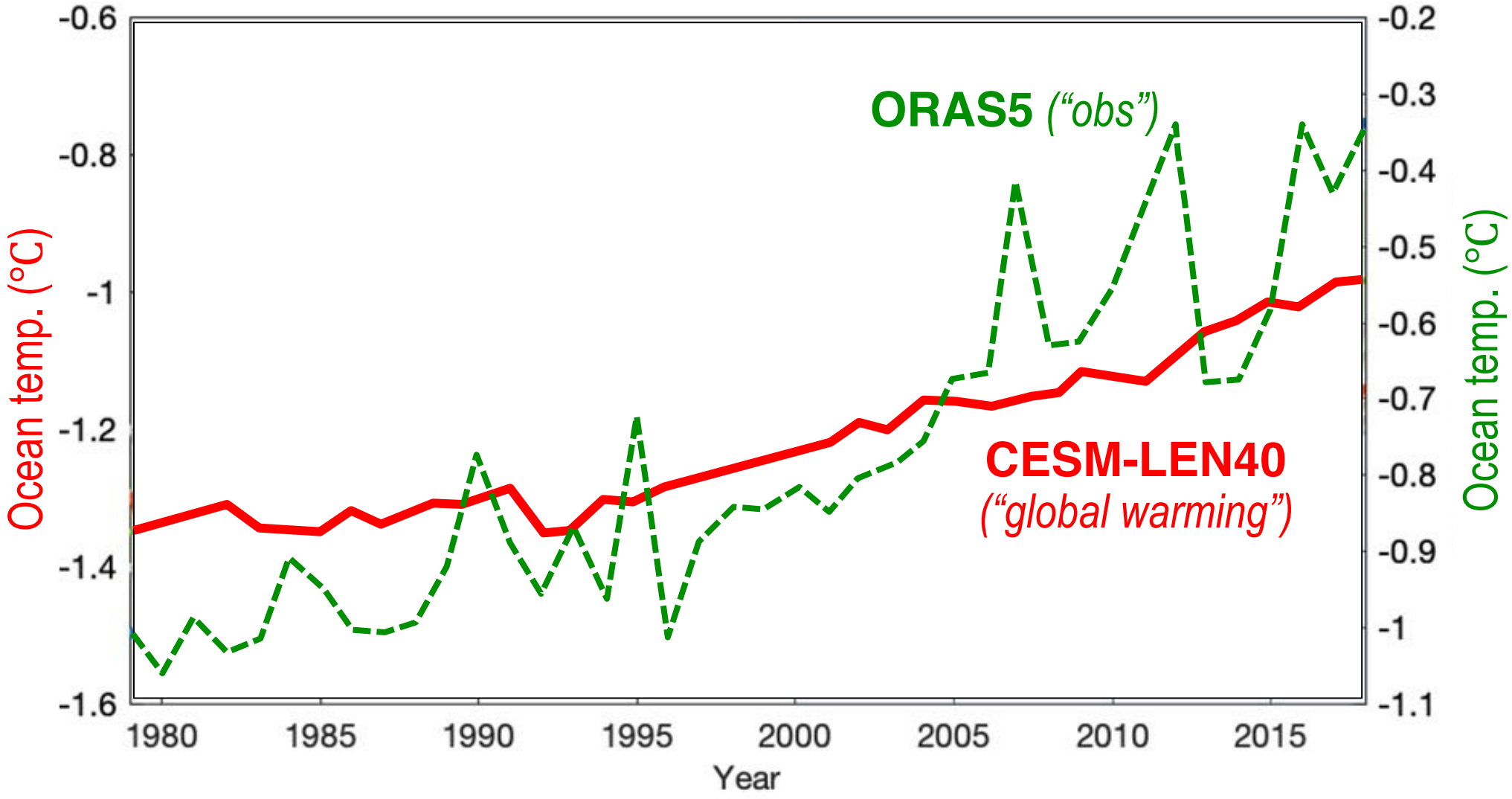




Michael Steele
Polar Science Center / APL
University of Washington

The role of global **warming** *(incr. CO_2)*

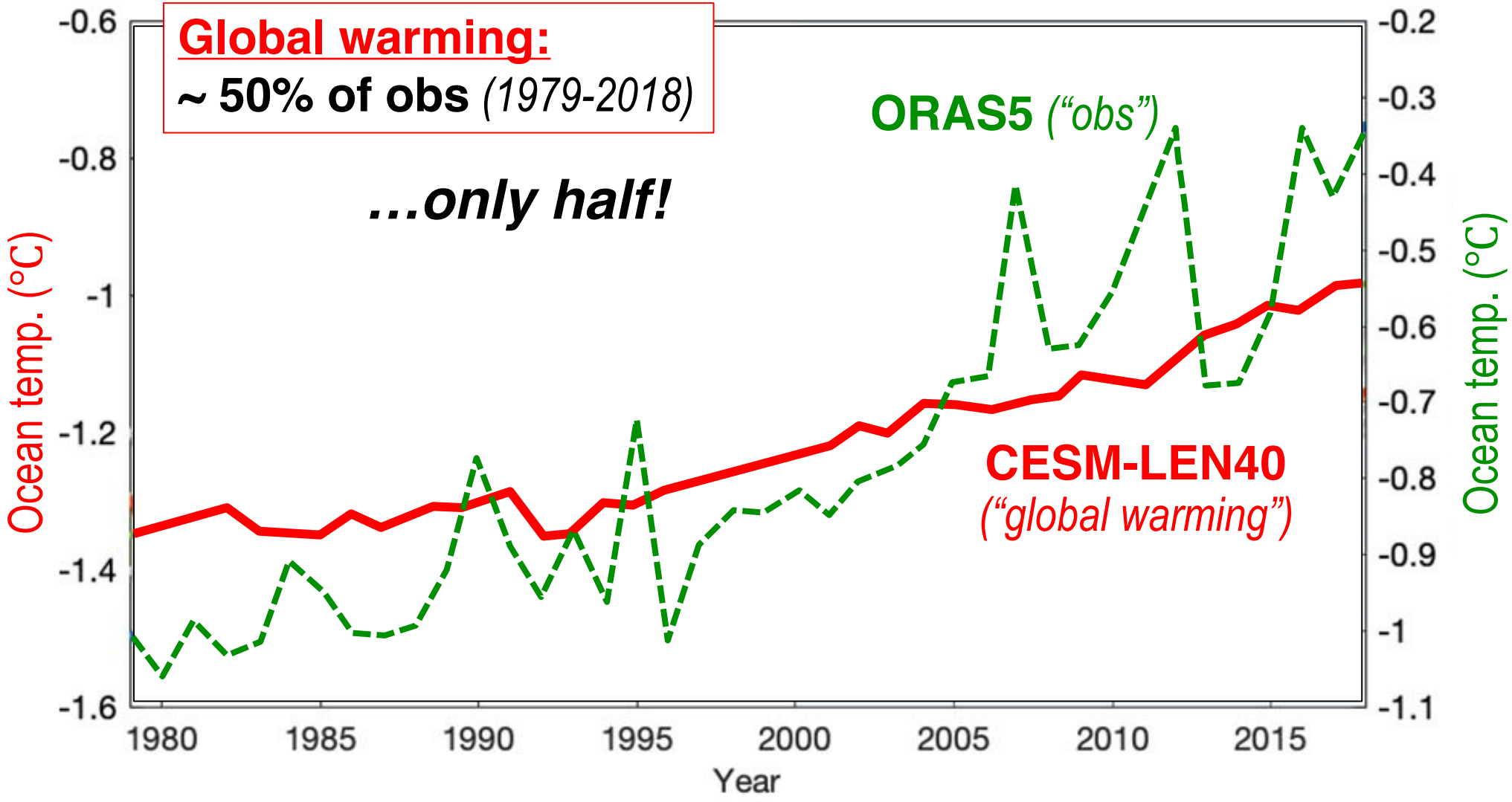
Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

The role of global **warming** *(incr. CO_2)*

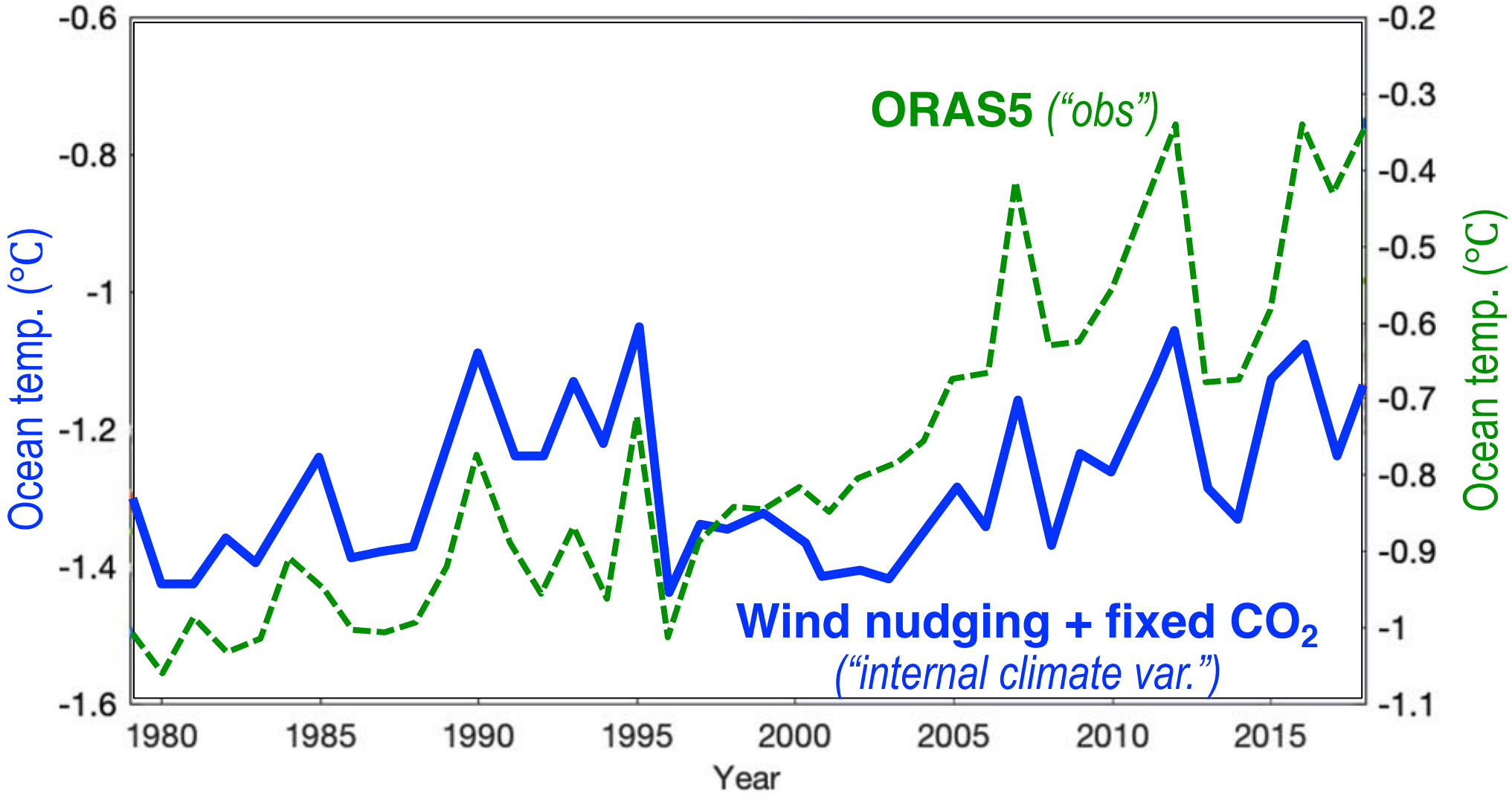
Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

The role of internal climate **variability**

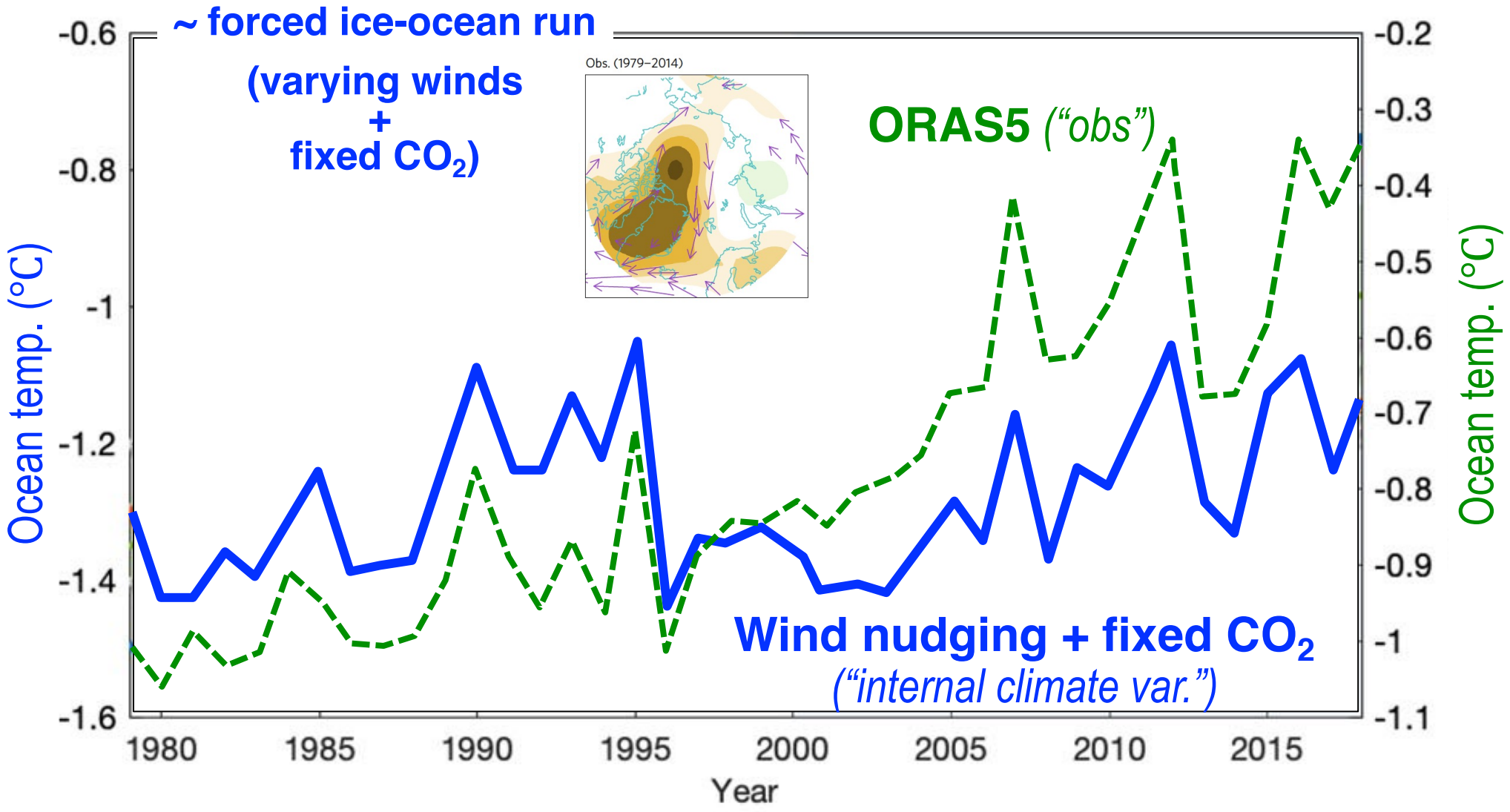
Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

The role of internal climate **variability**

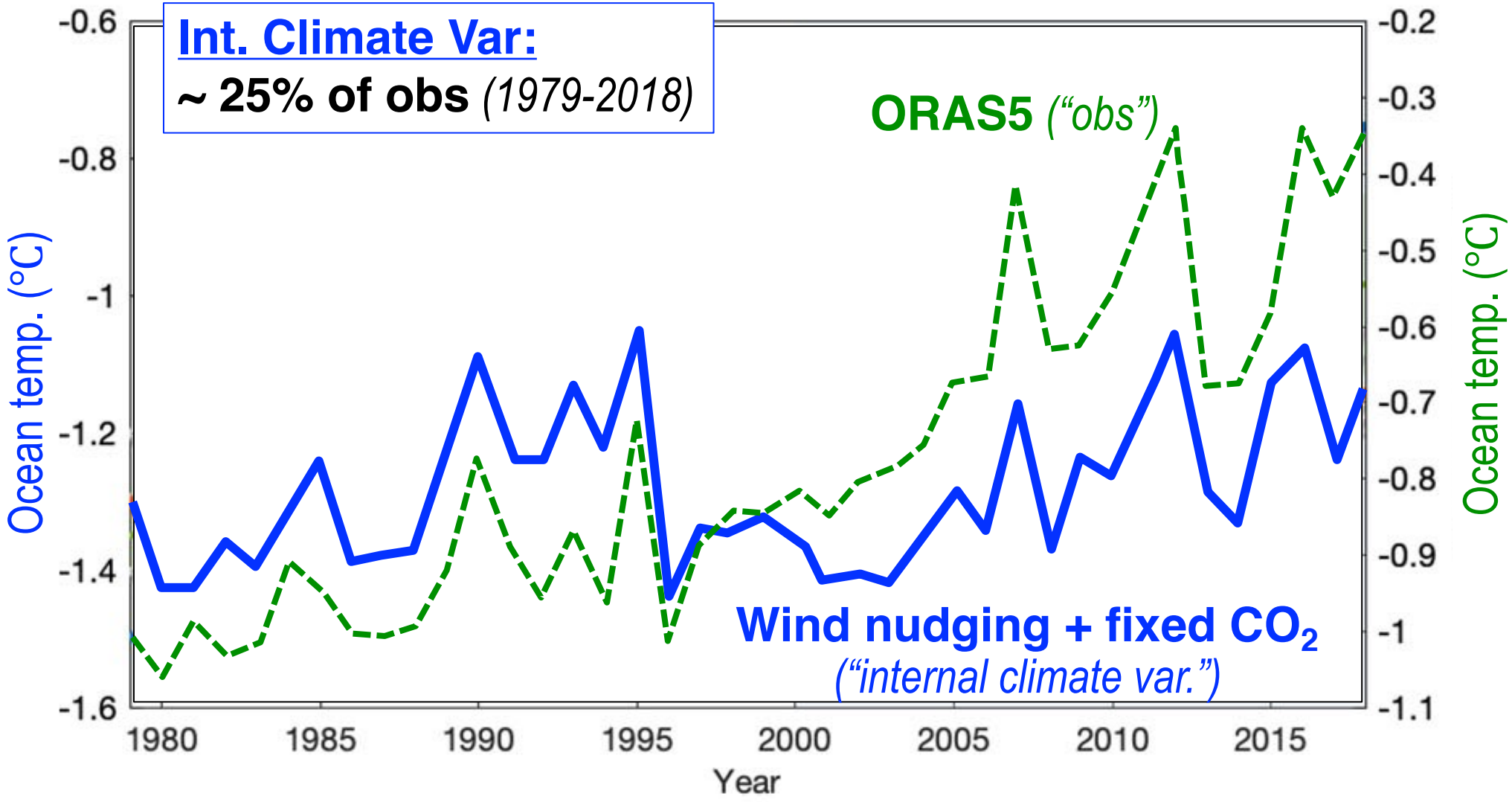
Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

The role of internal climate **variability**

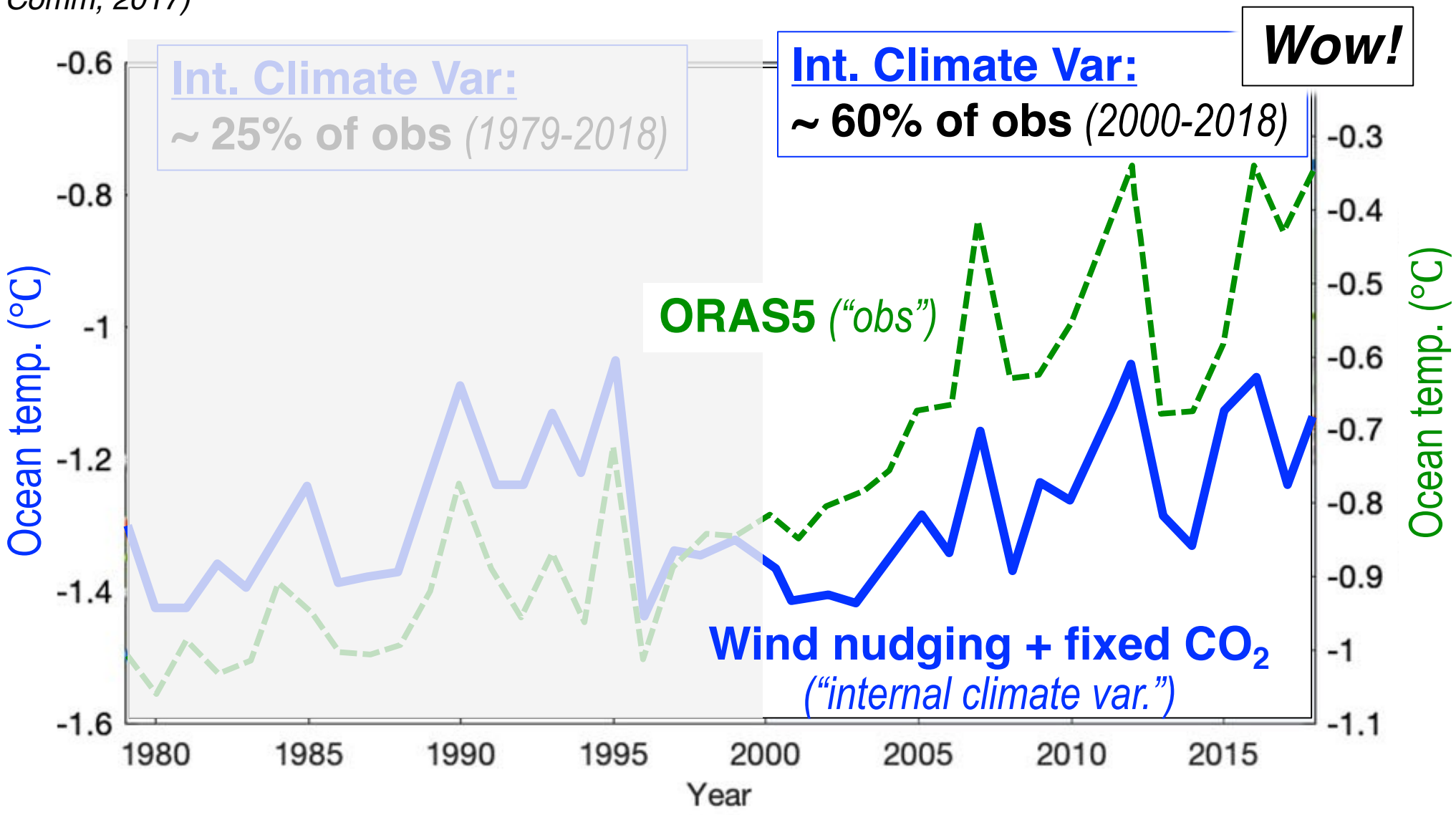
Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

The role of internal climate **variability**

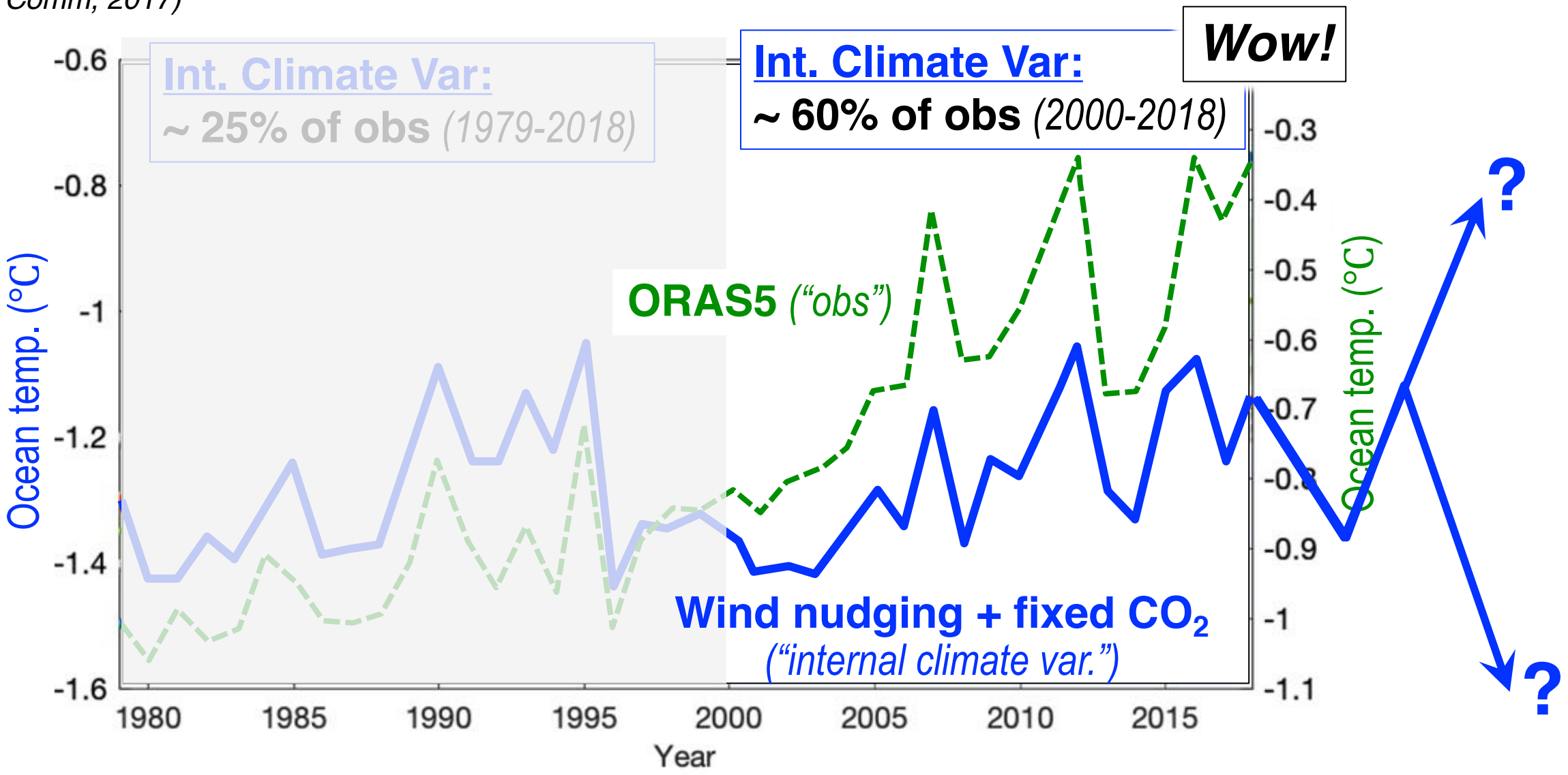
Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

The role of internal climate **variability**

Li et al.
(Nature Comm, 2017)



Michael Steele
Polar Science Center / APL
University of Washington

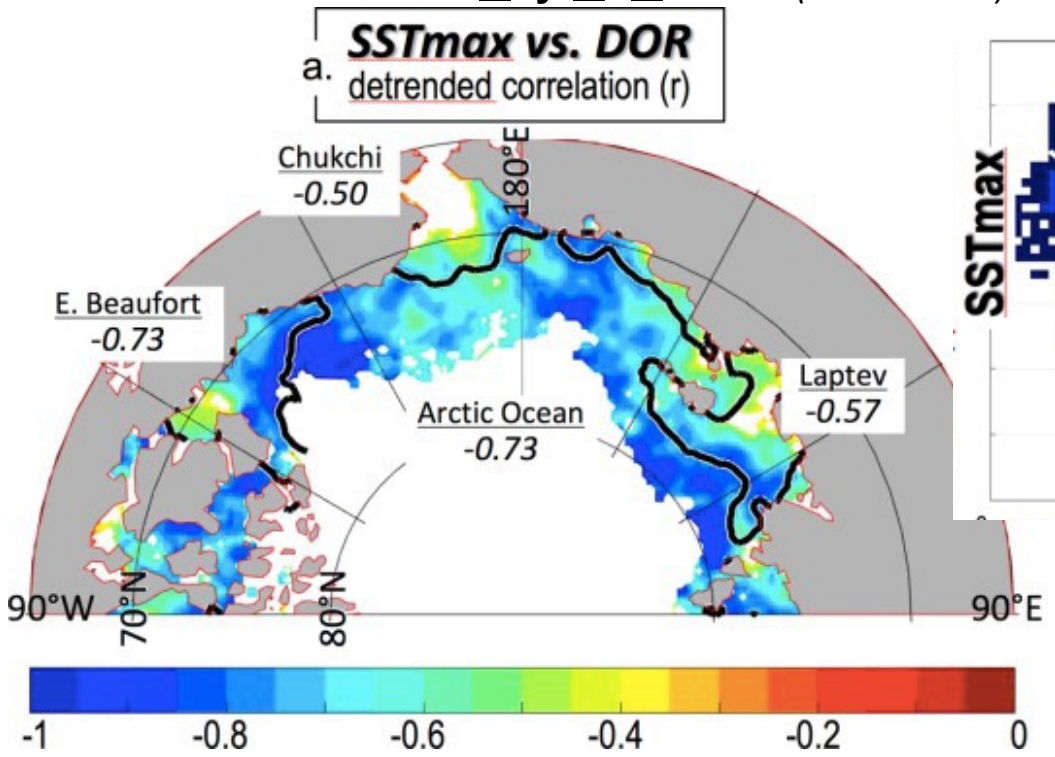
Multi-year ➜ ***seasonal*** Arctic Ocean SST warming

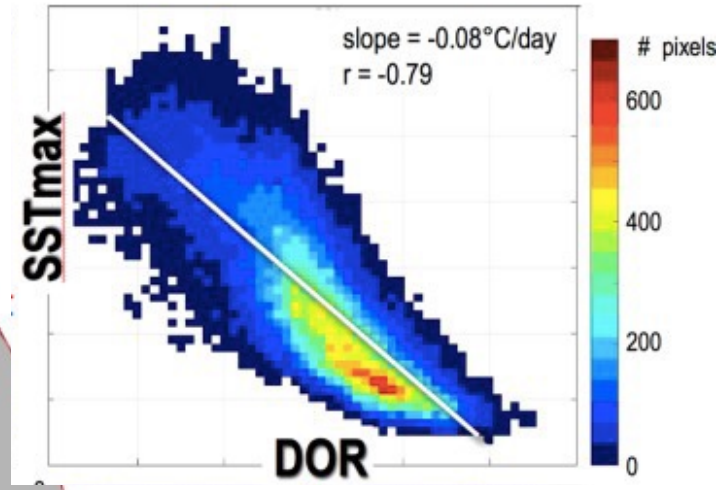
Michael Steele
Polar Science Center / APL
University of Washington

The seasonal SST_{max}: What controls it?

Steele & Dickinson (JGR, 2016)

Day Of Retreat *(SIC < 15%)*





Satellite & atmos reanalysis

Earlier ice retreat ➜ warmer SST_{max}

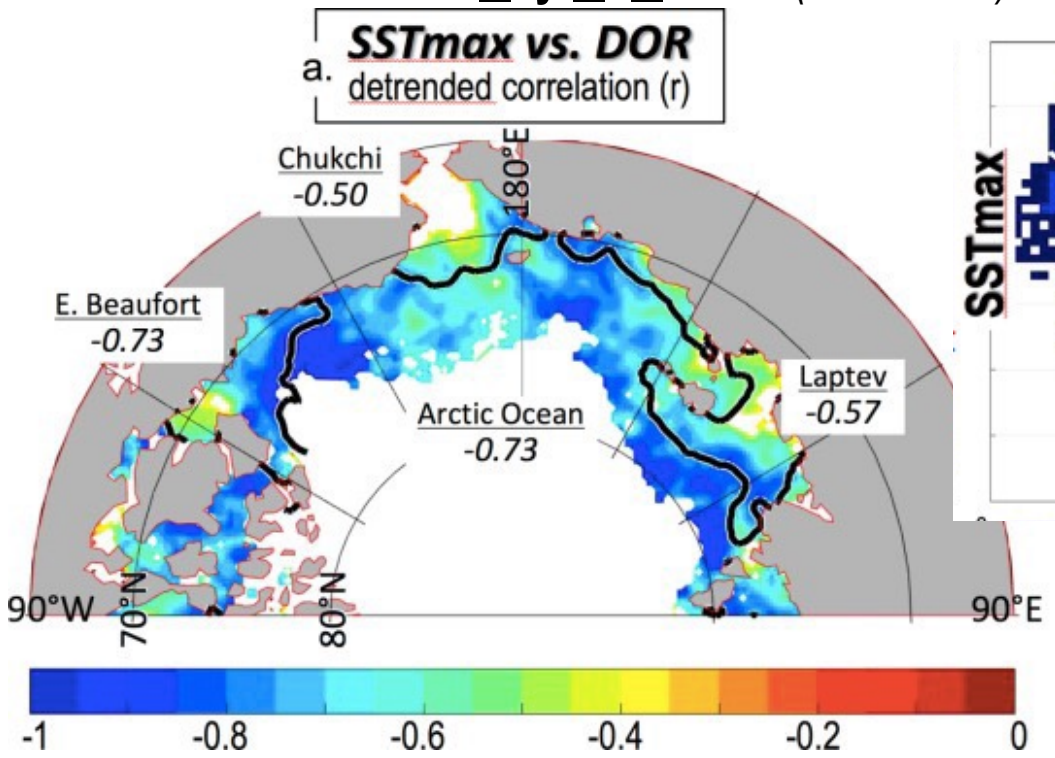
Michael Steele
Polar Science Center / APL
University of Washington

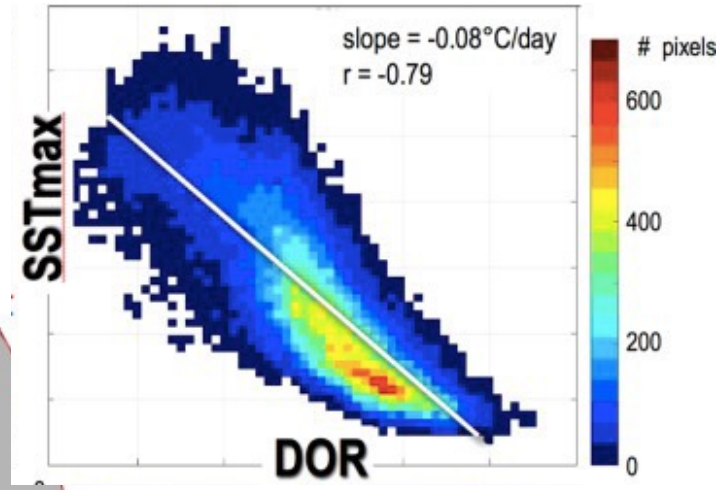
CLIVAR Arctic Oean
Seattle, WA

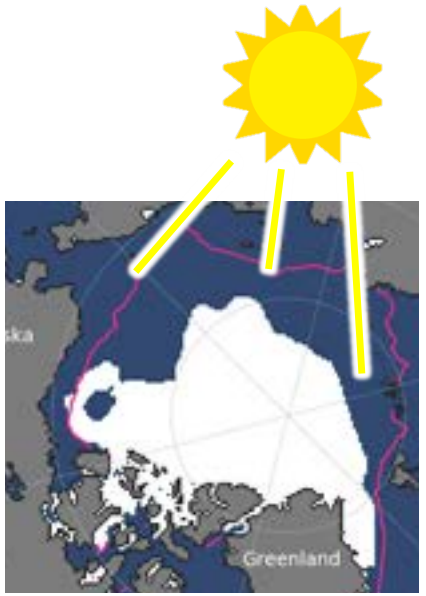
The seasonal SST_{max}: What controls it?

Steele & Dickinson (JGR, 2016)

Day Of Retreat *(SIC < 15%)*





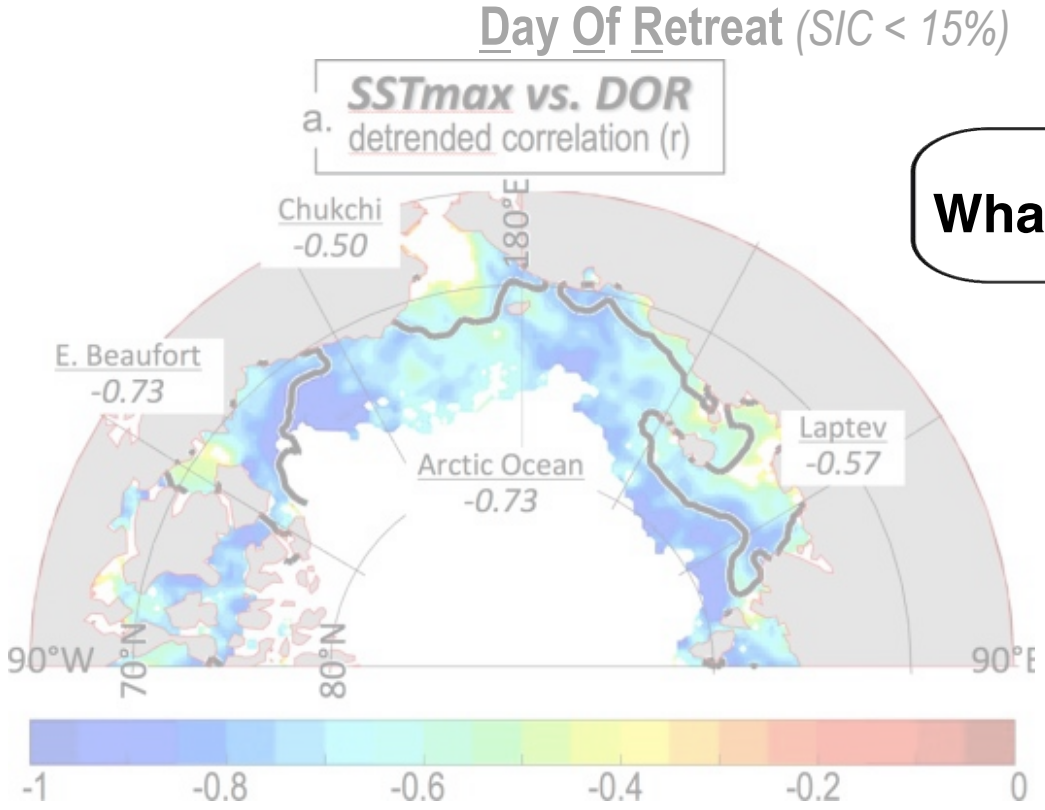


Earlier ice retreat ➜ warmer SST_{max}

Michael Steele
Polar Science Center / APL
University of Washington

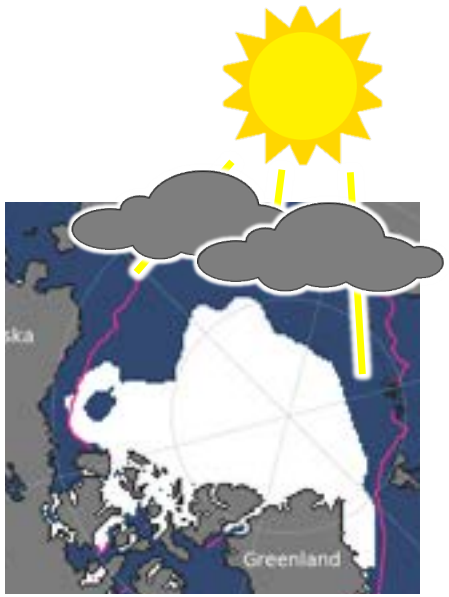
The seasonal SST_{max}: What controls it?

Steele & Dickinson (JGR, 2016)



What about clouds?

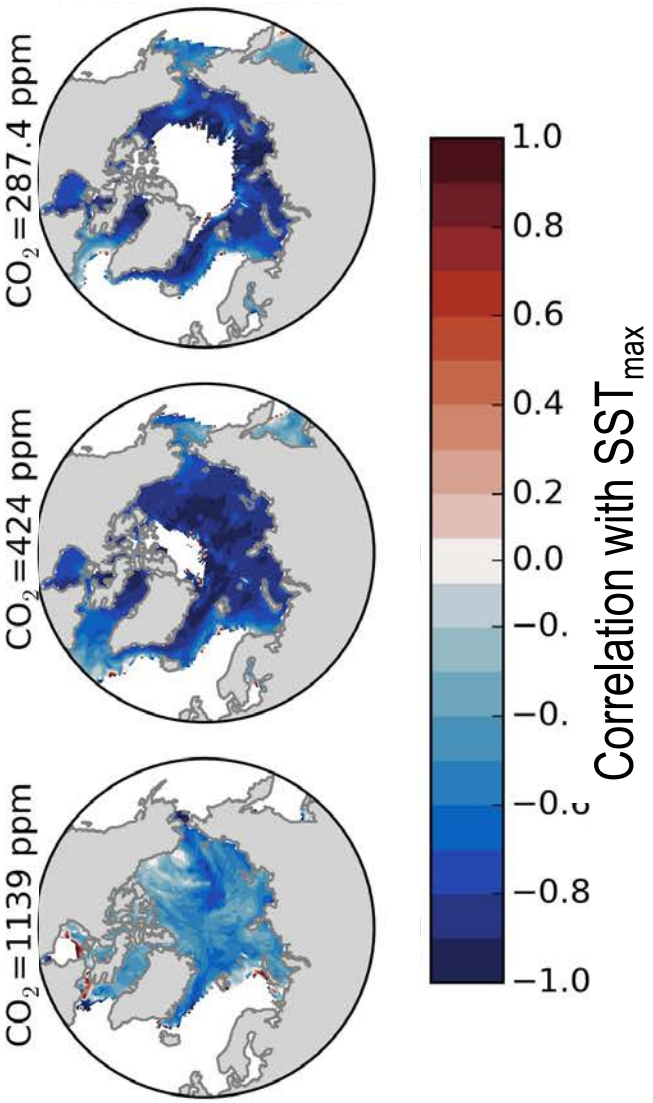
Jen Kay



Earlier ice retreat ➜ warmer SST_{max}

The seasonal SST_{max}: *The effect of DOR*

Day of Retreat
SIC < 15%



Sledd et al.
(GRL, 2022, in prep.)

CESM model runs

"pre-industrial CO_2"

"present-day CO_2"

Day of Retreat controls SST_{max} especially in the north

"4 x CO_2"
(seasonal ice pack)

Weaker control with earlier DOR

Michael Steele
Polar Science Center / APL
University of Washington

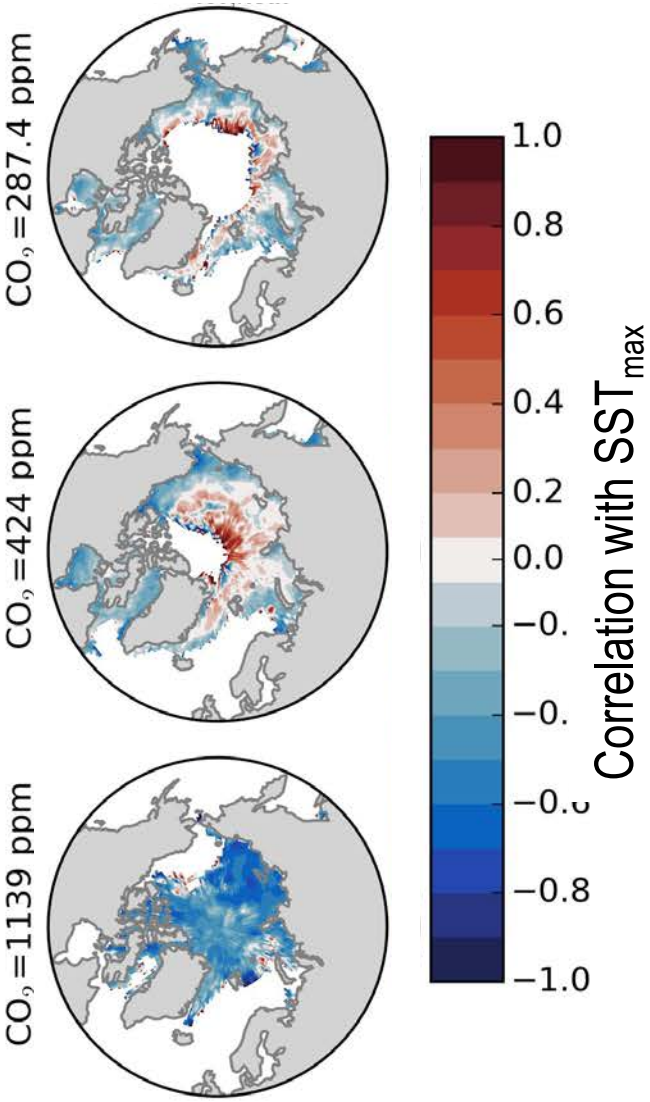
CLIVAR Arctic Oean
Seattle, WA

The seasonal SST_{max}: *The effect of clouds*

Cloud Fraction

Sledd et al.
(GRL, 2022, in prep.)

CESM model runs



"pre-industrial CO_2"

"present-day CO_2"

Cloud Fraction influence is weak/moderate

cools in the south

warms in the north

"4 x CO_2"

(seasonal ice pack)

Cloud Fraction influence is strong

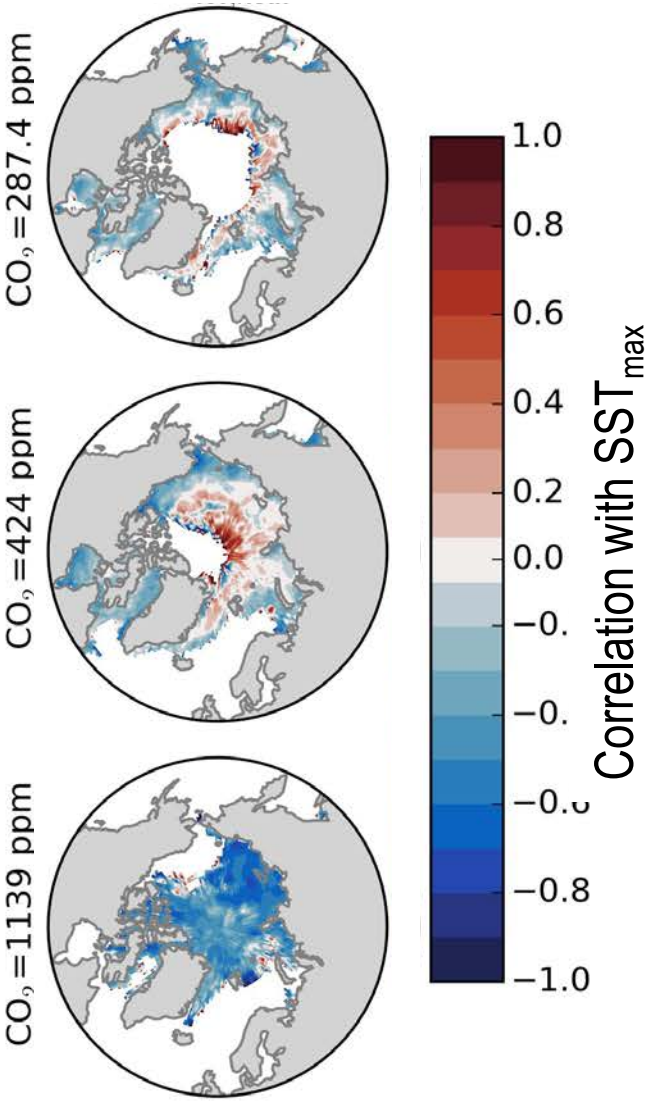
cools everywhere

Michael Steele
Polar Science Center / APL
University of Washington

CLIVAR Arctic Oean
Seattle, WA

The seasonal SST_{max}: *The effect of clouds*

Cloud Fraction



Sledd et al.
(GRL, 2022, in prep.)

CESM model runs

"pre-industrial CO_2"

"present-day CO_2"

Cloud Fraction influence is weak/moderate

cools in the south

warms in the north

"4 x CO_2"

(seasonal ice pack)

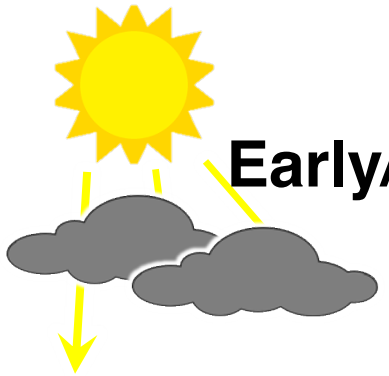
Cloud Fraction influence is strong

cools everywhere

As ice retreats earlier, clouds play a bigger role

Michael Steele
Polar Science Center / APL
University of Washington

Summary: **Clouds** & Arctic **SST**



Early/mid summer: cooling

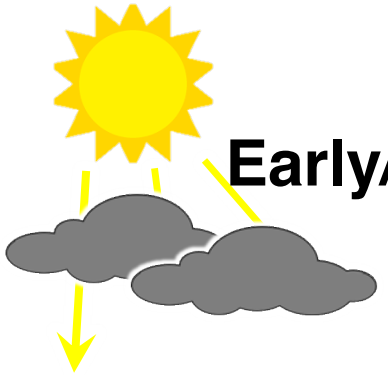
decr SW down

The future: Early sea ice retreat

➜ a boring, “regular” ocean!

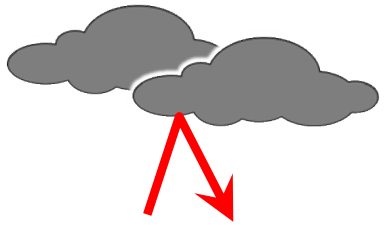
Michael Steele
Polar Science Center / APL
University of Washington

Summary: **Clouds** & Arctic **SST**



Early/mid summer: cooling

decr SW down



Late summer / fall: warming

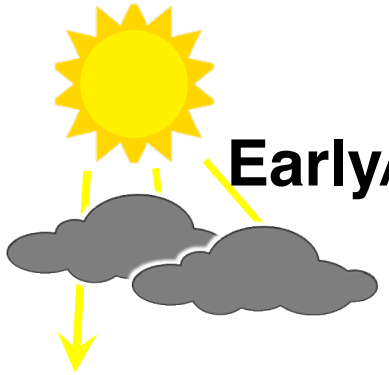
incr LW down

The future: Early sea ice retreat
➜ a boring, “regular” ocean!

Now & always: Arctic SST strongly influenced by the tropical Pacific!

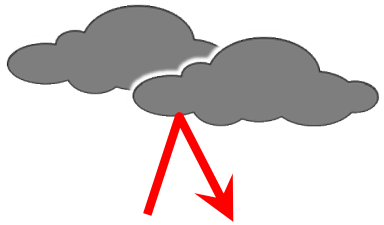
Michael Steele
Polar Science Center / APL
University of Washington

Summary: **Clouds** & Arctic **SST**



Early/mid summer: cooling

decr SW down



Late summer / fall: warming

incr LW down

The future: Early sea ice retreat
➜ a boring, “regular” ocean!

Now: Arctic SST strongly influenced by the tropical Pacific!

Thank you