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NCEI- Silver Spring
Sep 26, 2016

Sea ice retreat & ocean surface warming in the Arctic Seas

Michael Steele

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Steele, M., S. Dickinson, J. Zhang, & R. Lindsay, "**Seasonal ice loss in the Beaufort Sea: Toward synchrony & prediction**," *JGR*, 2015.

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(i) Intro

(ii) Steele, M., S. Dickinson, J. Zhang, & R. Lindsay, "**Seasonal ice loss in the Beaufort Sea: Toward synchrony & prediction**," *JGR*, 2015.

(iii) Steele, M. & W. Ermold, "**Loitering of the retreating sea ice edge in the Arctic Seas**," *JGR*, 2015.

(iv) Steele, M & S. Dickinson, "**The phenology of Arctic Ocean surface warming**," *JGR*, 2016.

(v) …and something about SST in the MIZ

Ice Retreat & Ocean Warming

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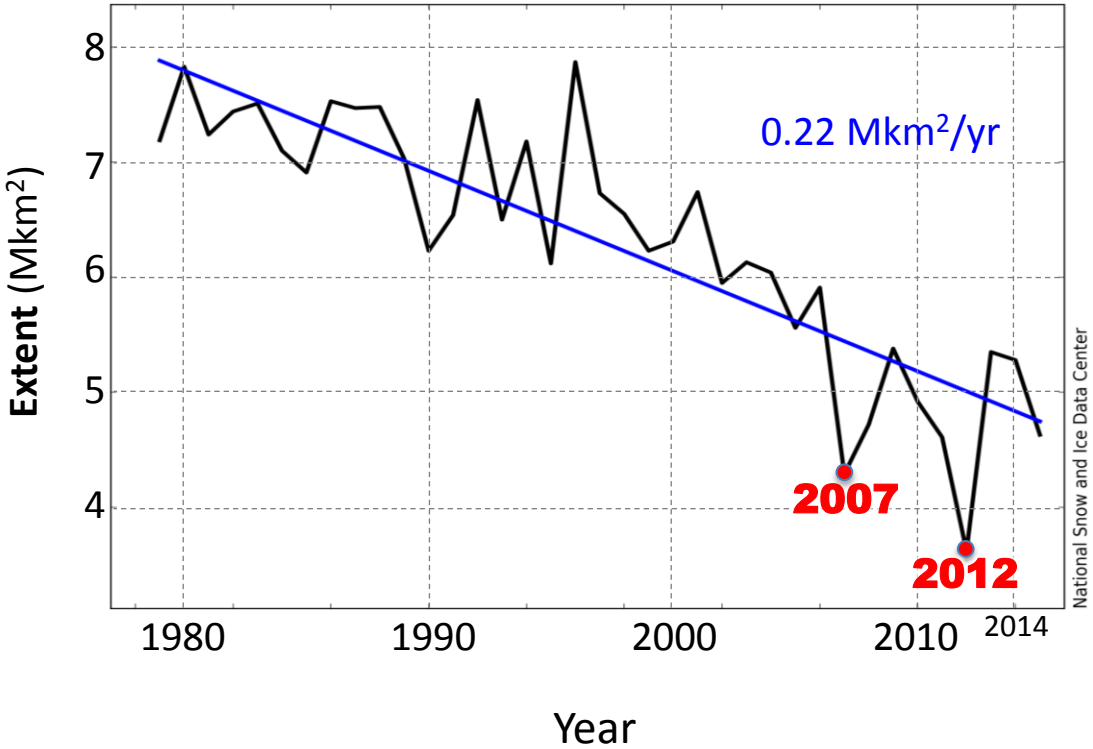
In the beginning, there was…

Sea Ice Decline

September Arctic Sea Ice Extent

1979 - 2015



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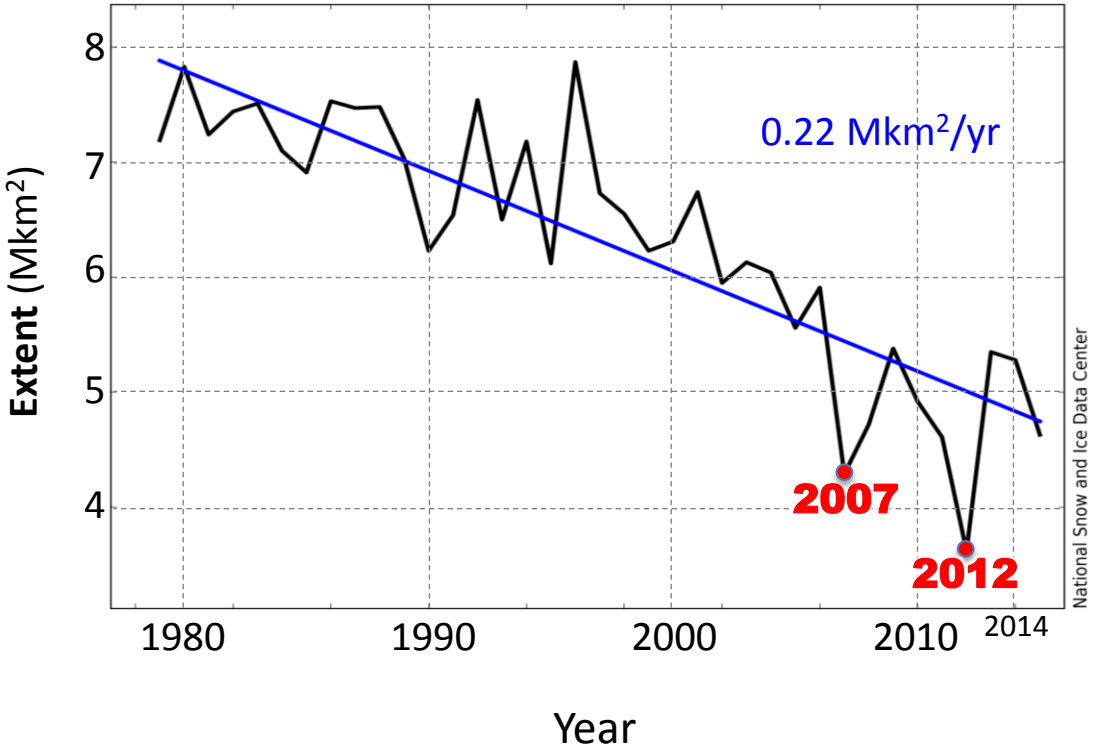

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In the beginning, there was…

Sea Ice Decline

NSIDC *(March, 2016): "Another record low for Arctic sea ice max.* ***winter*** *extent"*

September Arctic Sea Ice Extent

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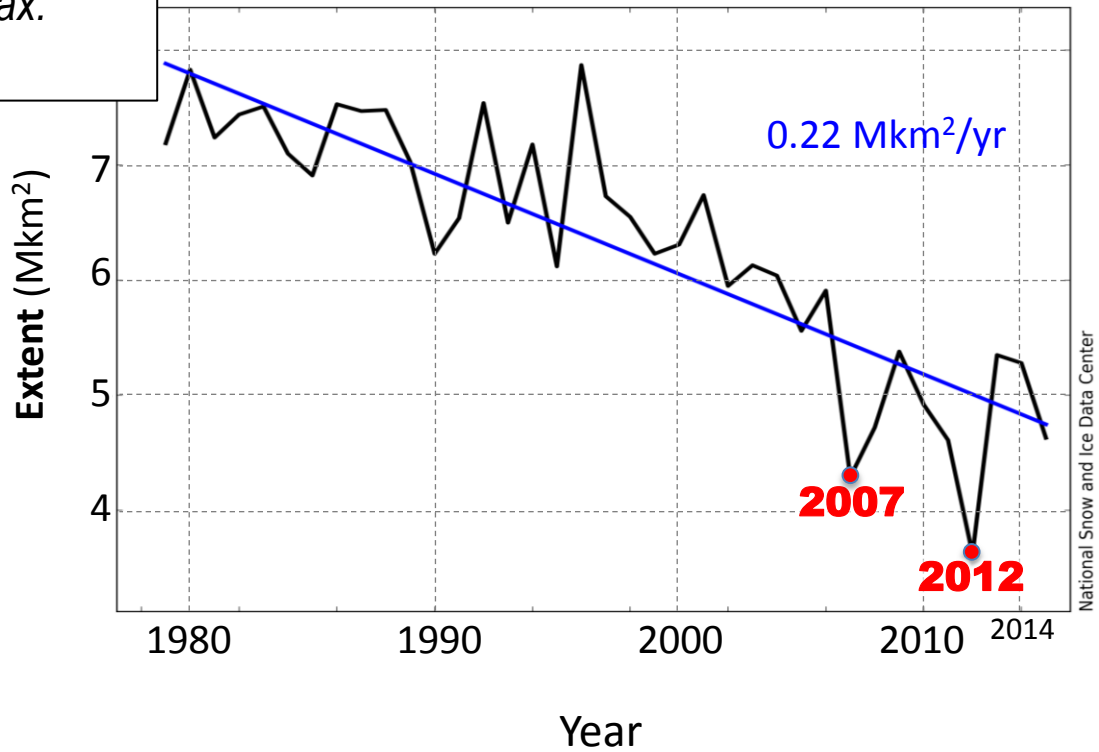

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University of Washin

Ice Retreat ➔ Ocean Warming

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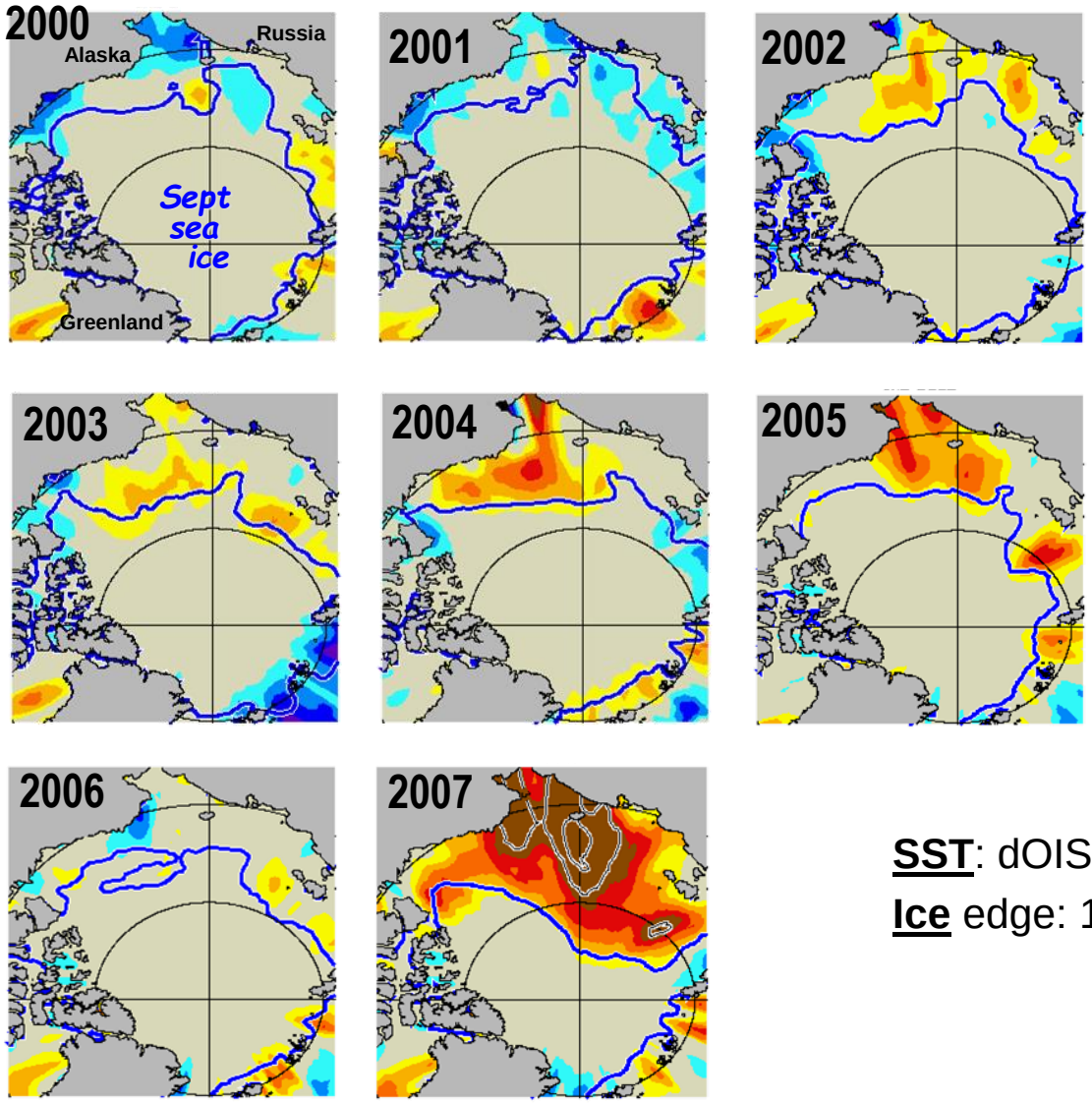
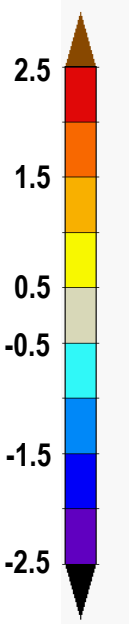
Steele et al. (GRL, 2008)





Anomaly of Summer ≡ JAS
Sea Surface Temperature (°C)
(relative to 1982-2007 mean)

SST: dOISST (AVHRR only)
Ice edge: 15% concentration (NASA Team1)

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Ice Retreat ➔ Ocean Warming

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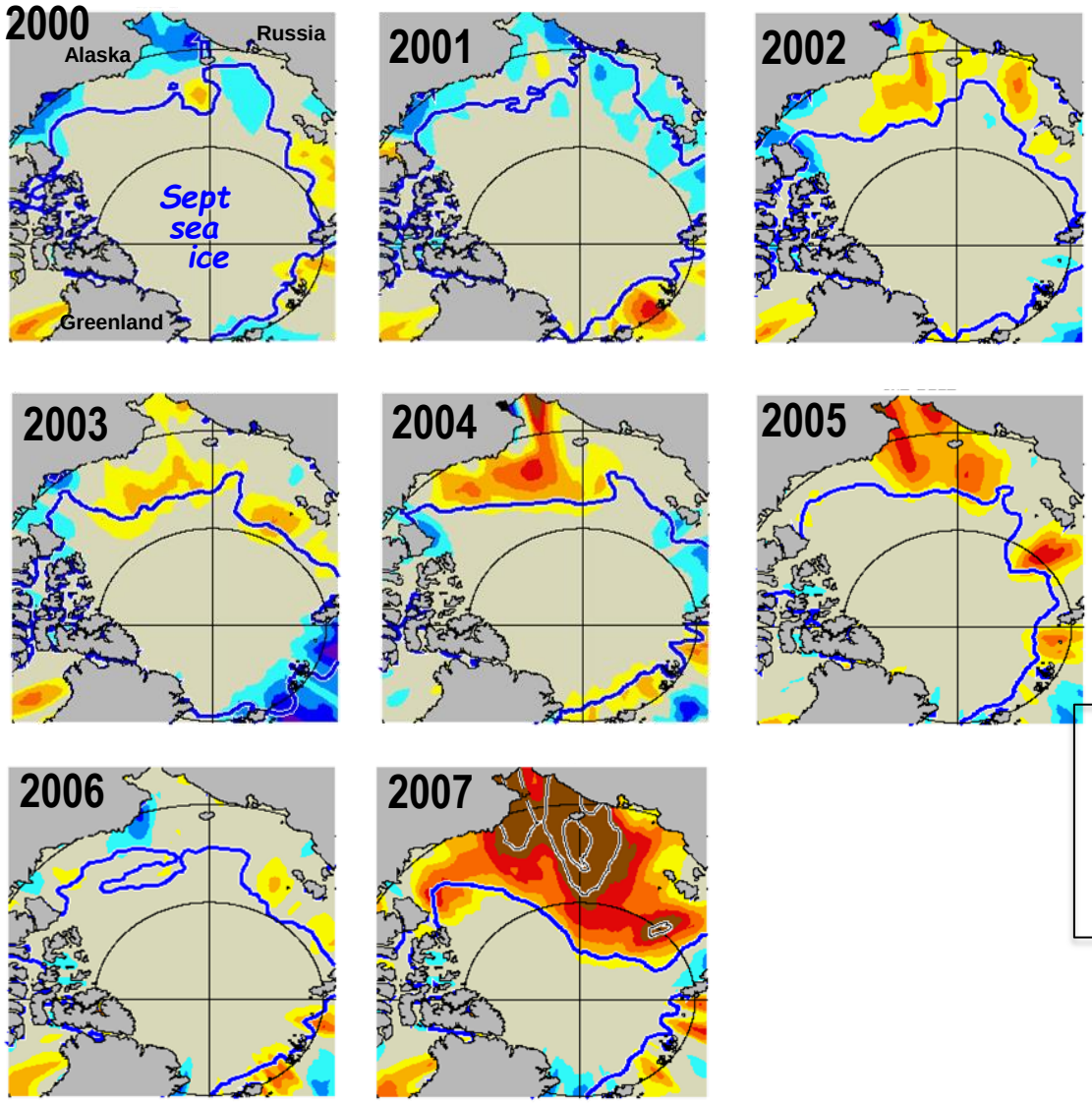

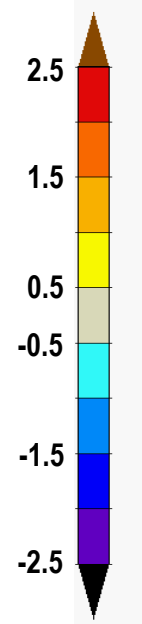

Anomaly of Summer ≡ JAS
Sea Surface Temperature (°C)
(relative to 1982-2007 mean)

Most of this is **local solar input**

Steele et al. JGR (2010)

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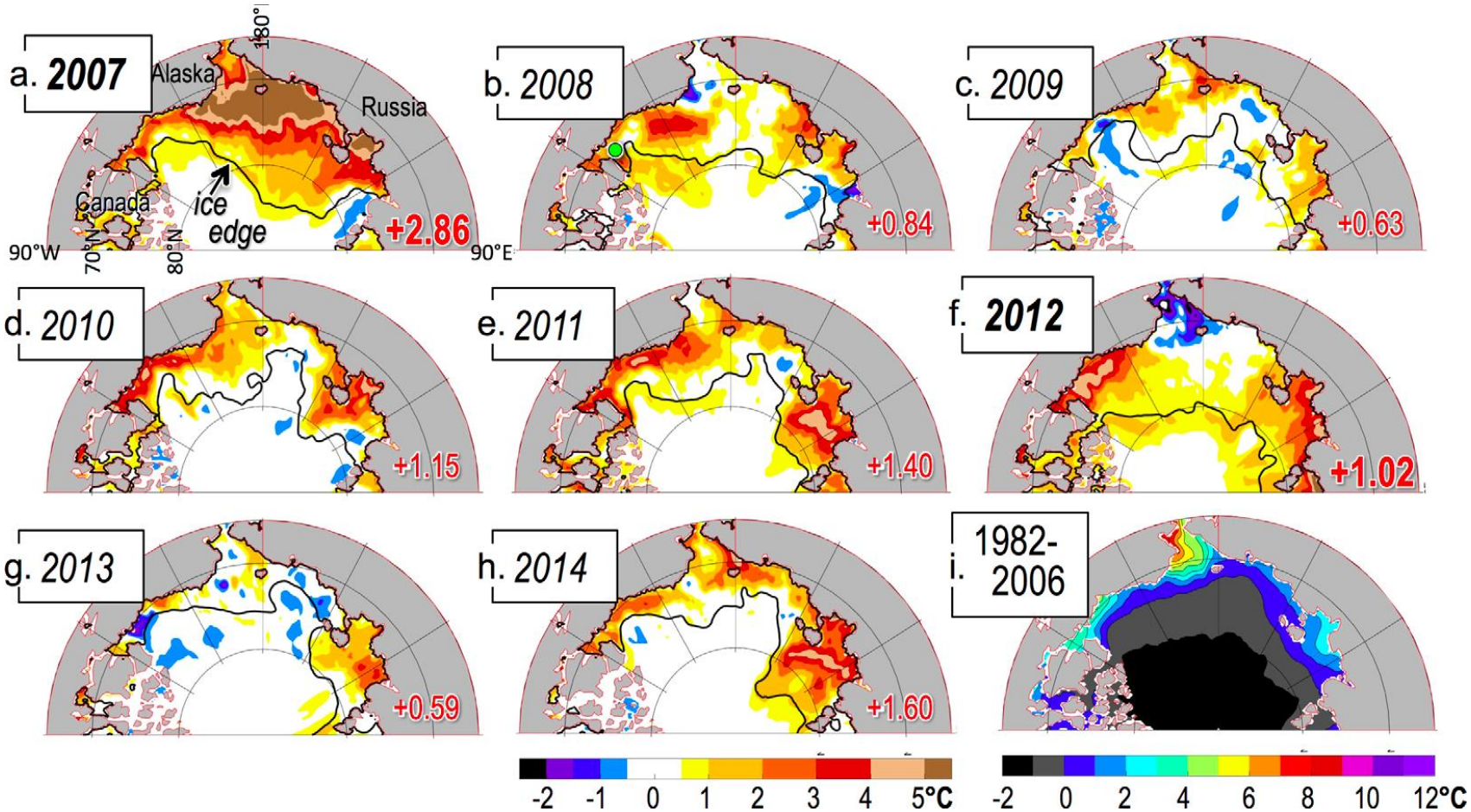
Update

NCEI- Silver Spring
Sep 26, 2016

Aug/Sep SST anomalies

Steele & Dickinson (JGR, 2016)



SST: dOISST (AVHRR only)

Ice edge: 15% concentration (NASA Team1)

Mostly warm

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Update

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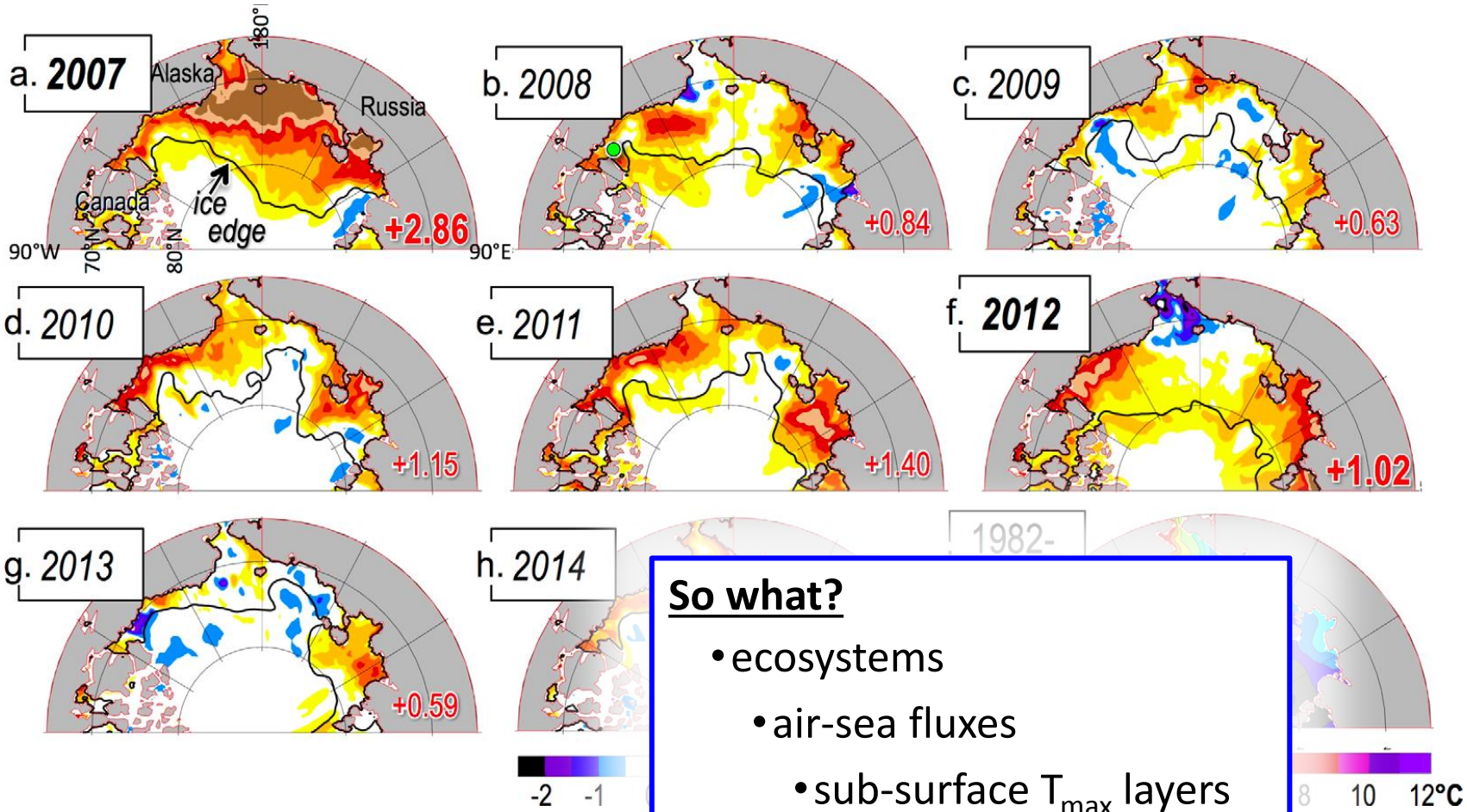

So what?

- ecosystems
  - air-sea fluxes
    - sub-surface T_{max} layers
      - ice edge "loitering"
        - ice-albedo fdbk

SST: dOISST (AVHRR only)

Ice edge: 15% concentration (NAS

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University of Washington

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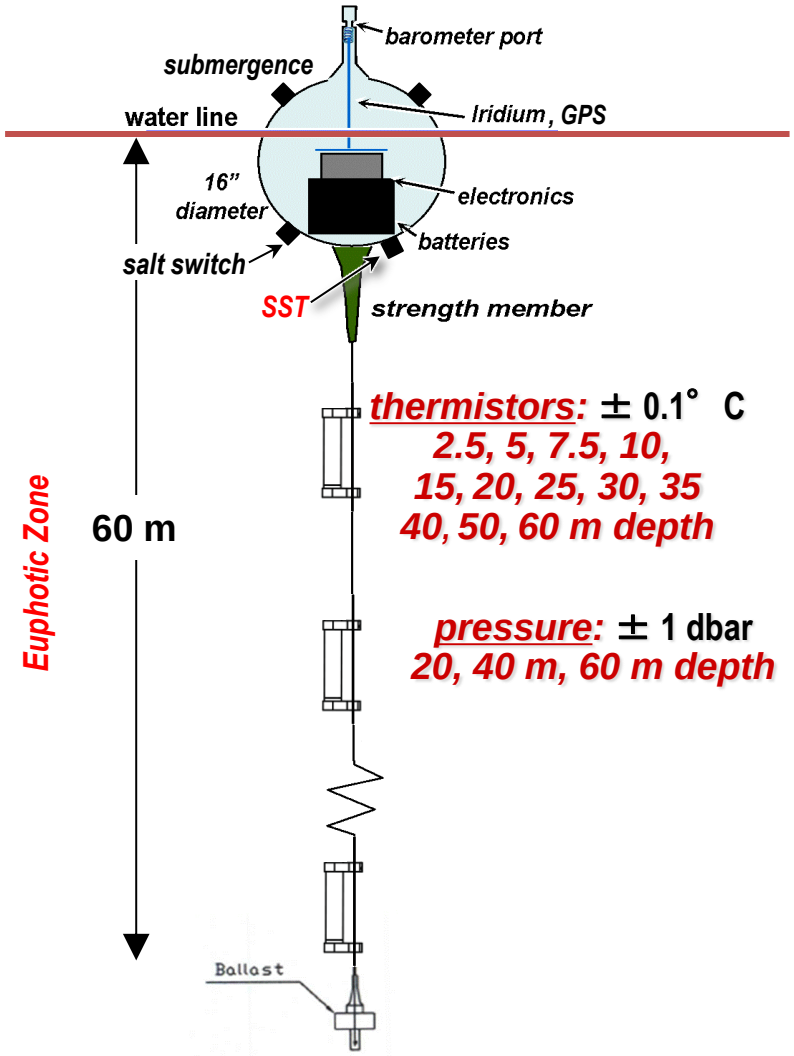
Sep 26, 2016

The UpTempO buoy

Upper Temperature of the polar Oceans



- Surface: SLP, **SST**, GPS, Iridium …*[anemometer]*
- Cable: 12-16 x **T** *(± 0.1° C)*, 3 x **P** *(± 1 dbar)* …*[S*
- 60 m (basin) or 25 m (shelves)

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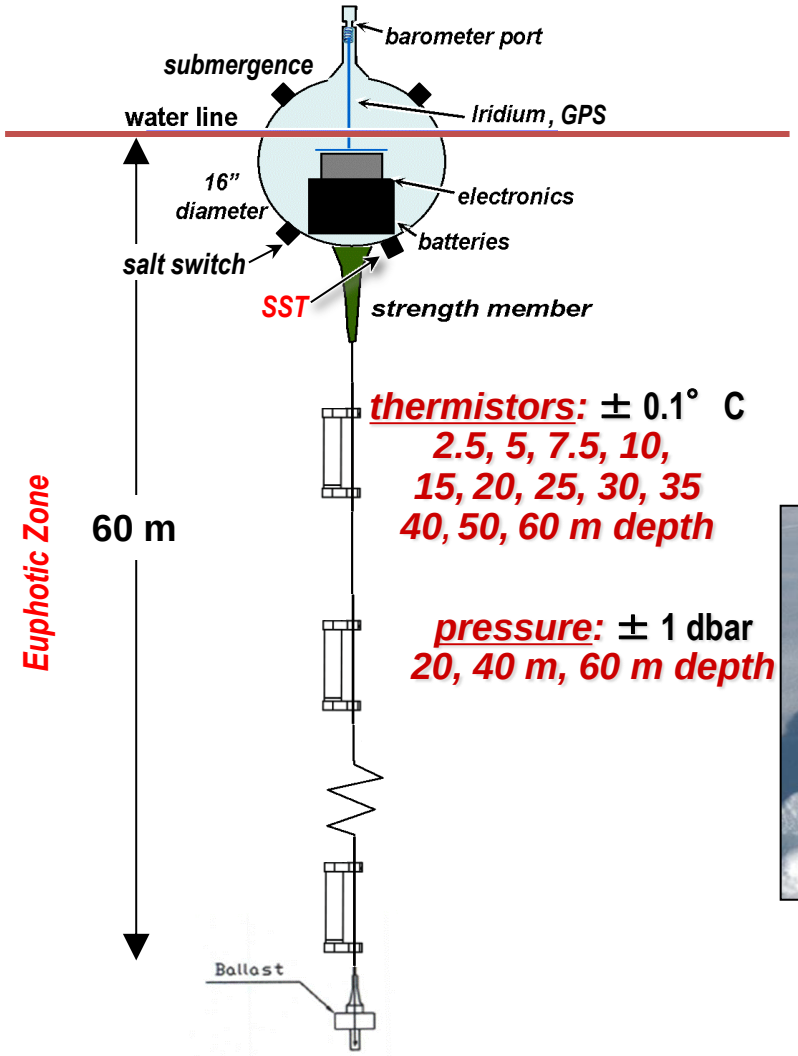

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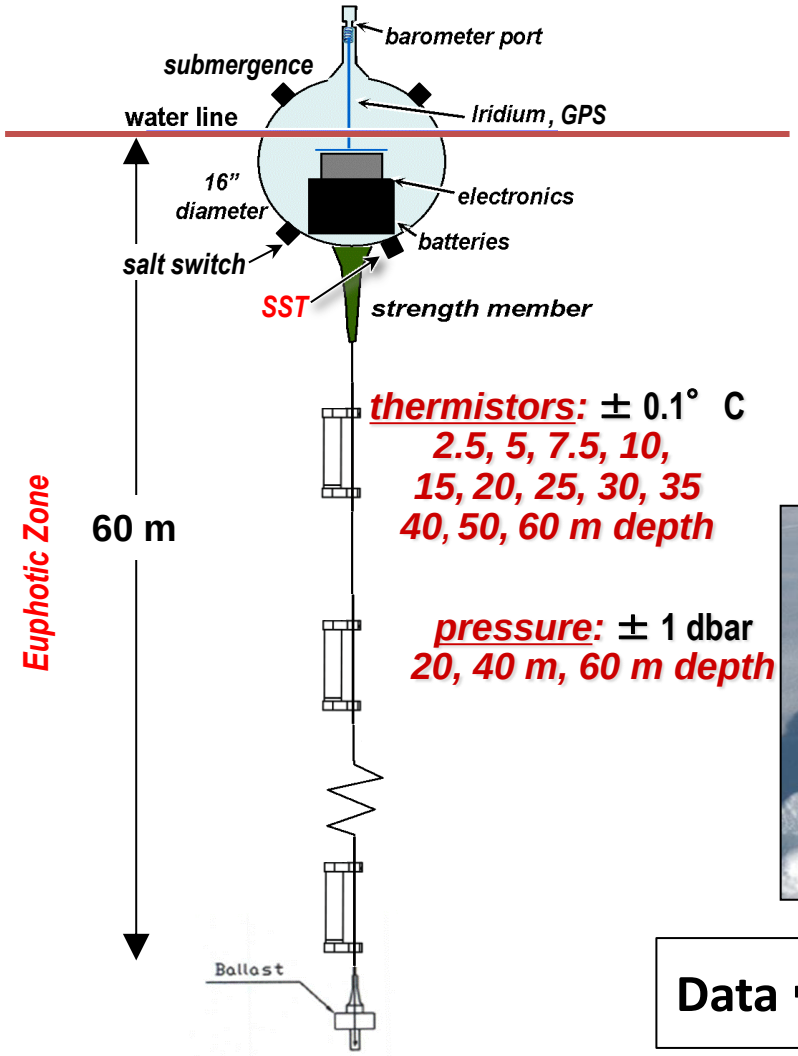

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Data → GTS

NSF, ONR

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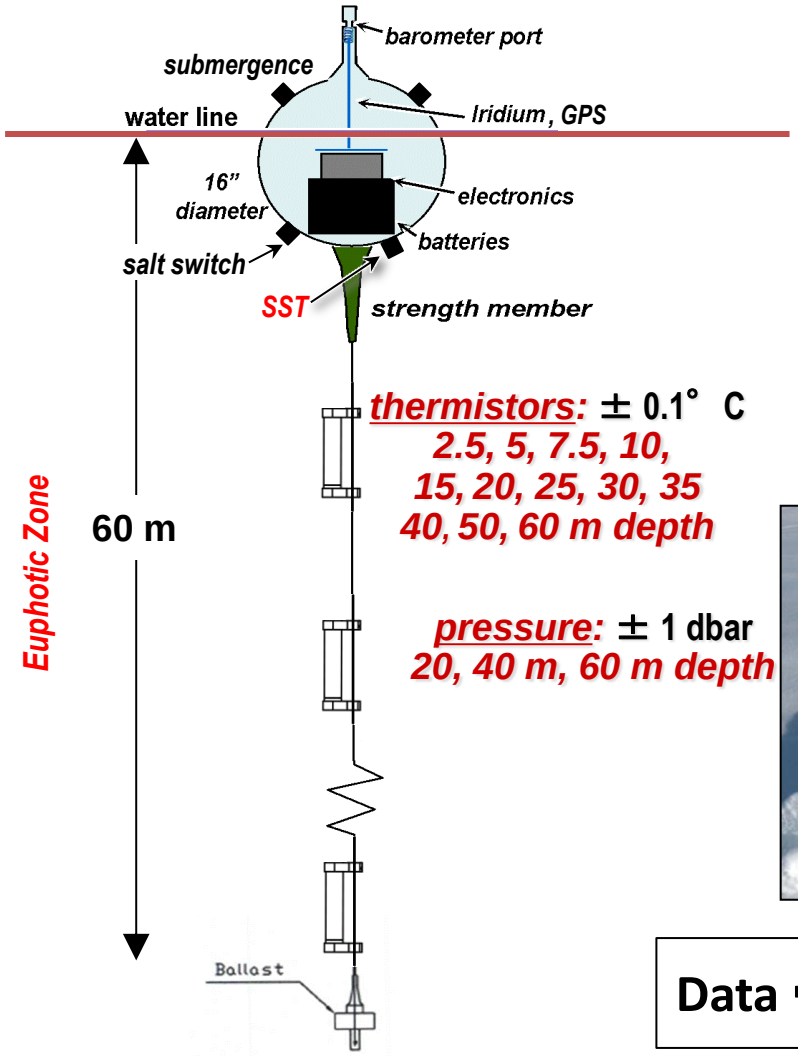

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NSF, ONR …NOAA? ☺

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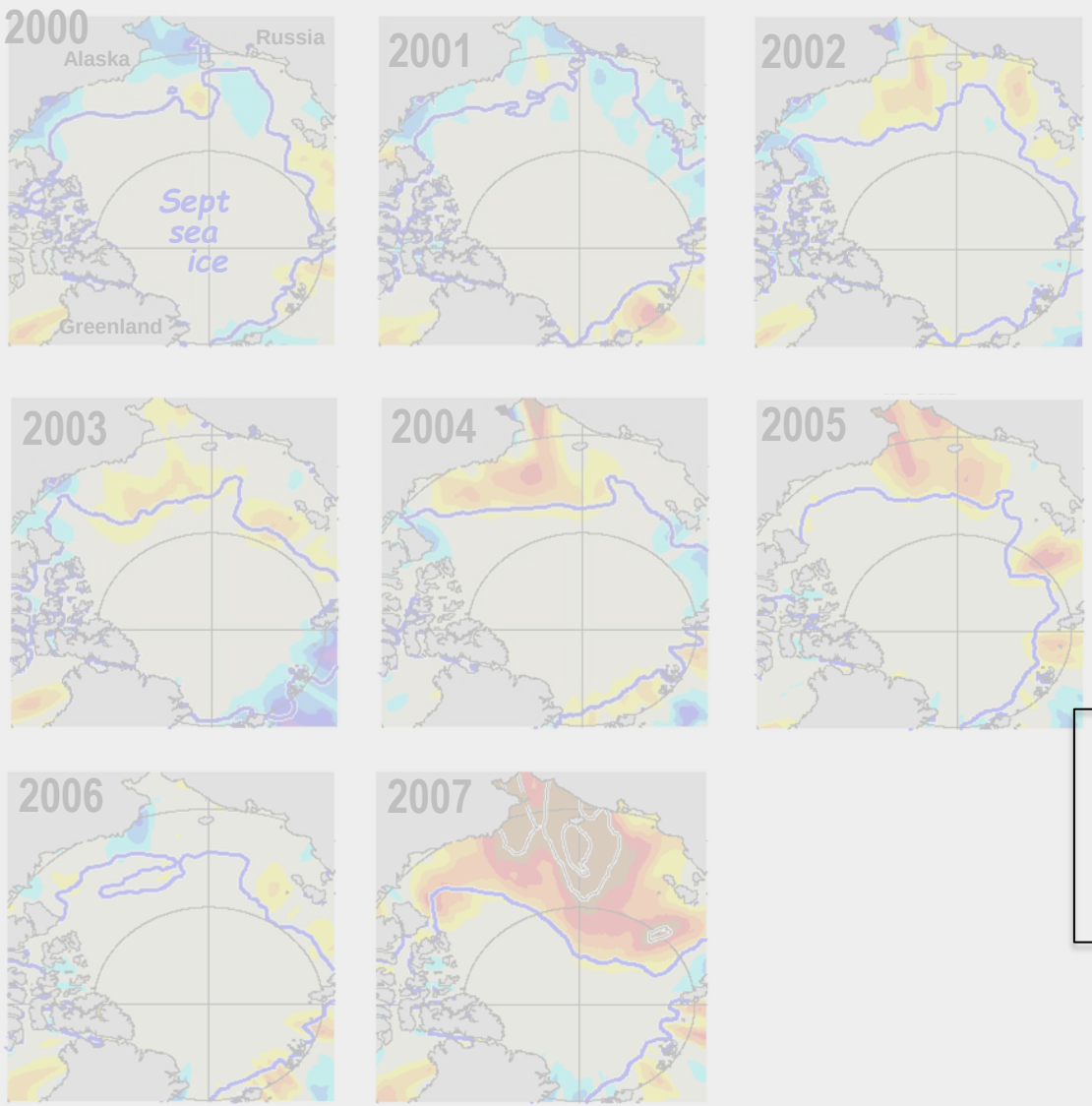

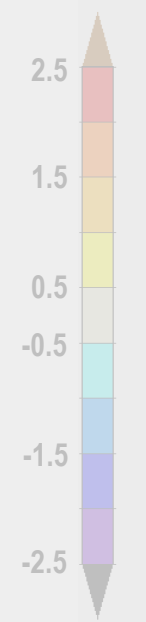

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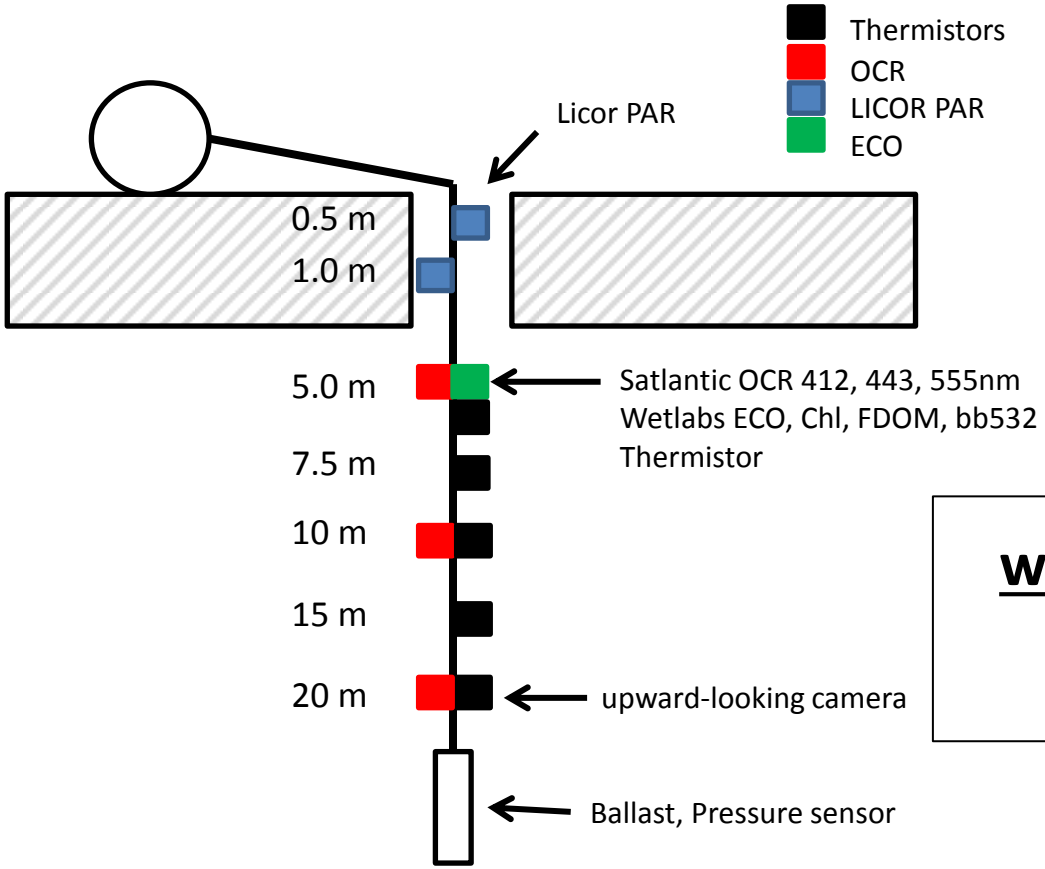
UpTempO + Optics: The "WARM" buoy

WArming &
ir**R**adiance **M**easurements

V. Hill, *B. Light, M. Steele*



warming ~ solar + advection

T ~ PAR + residual

…& some to 50 m

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Zeroing in:
Beaufort Sea ice retreat

"synchrony" & prediction

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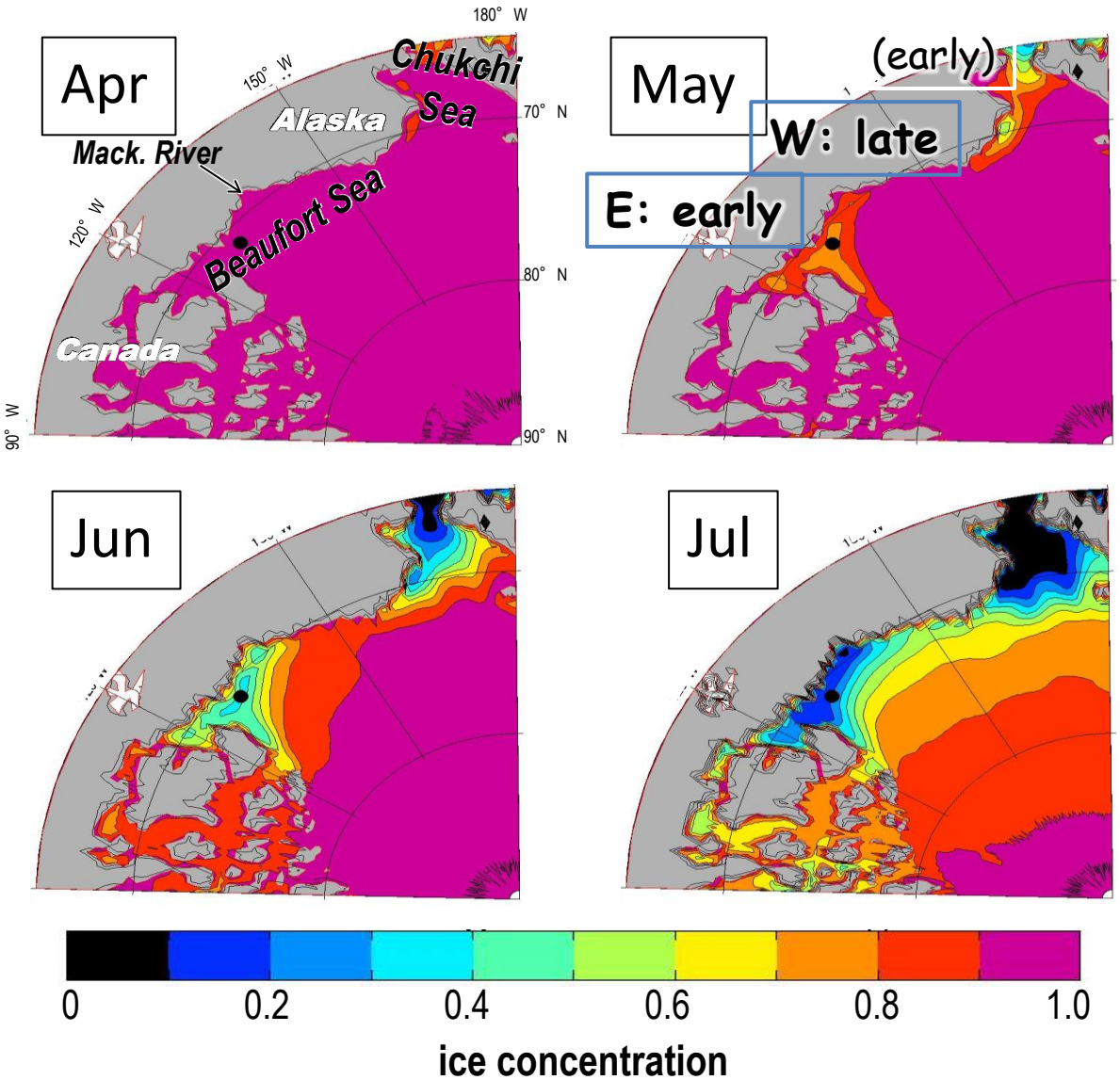
University of Washington

Now let's consider:

Ice retreat in the Beaufort Sea

Monthly mean
ice concentration
1979-2012

(passive µwave, NASA Team / NSIDC)



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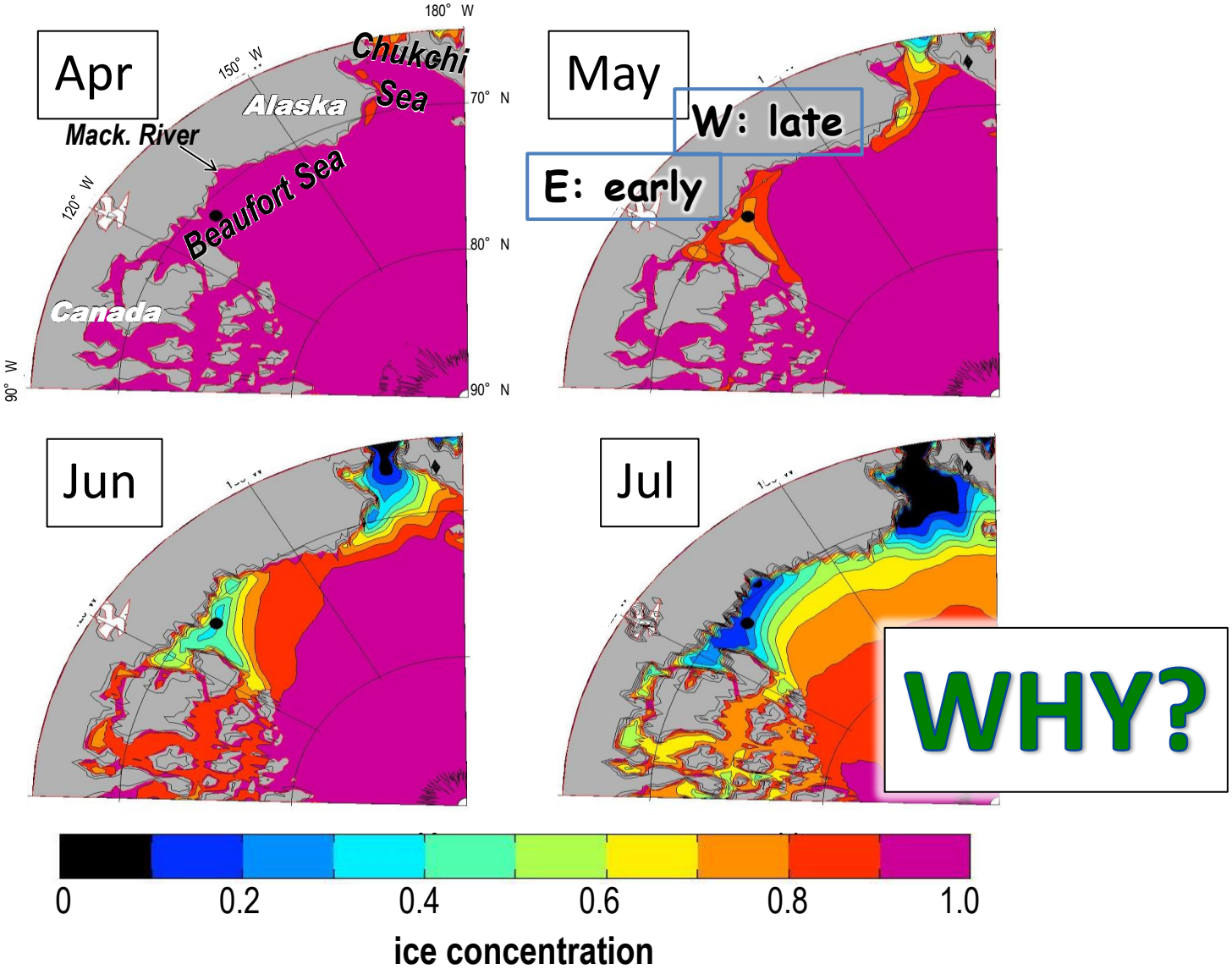

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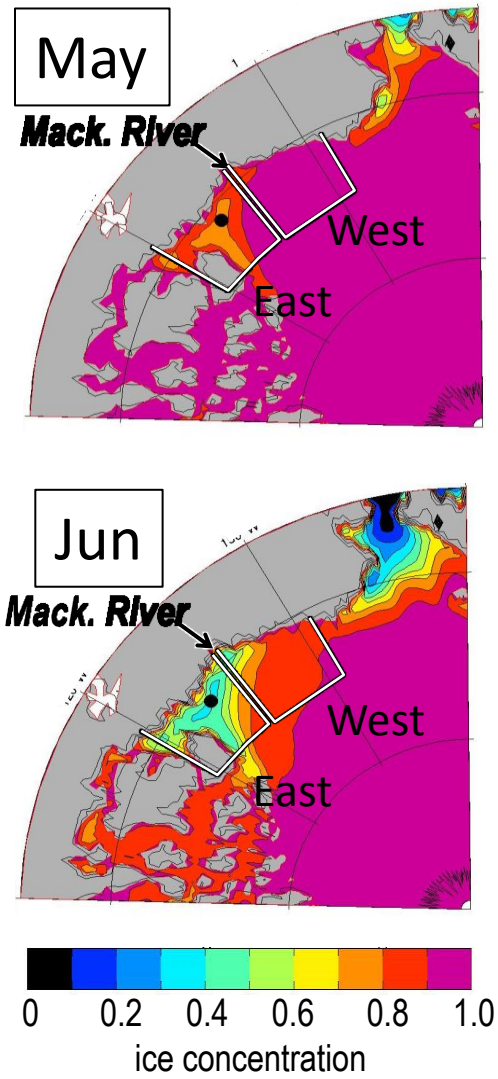
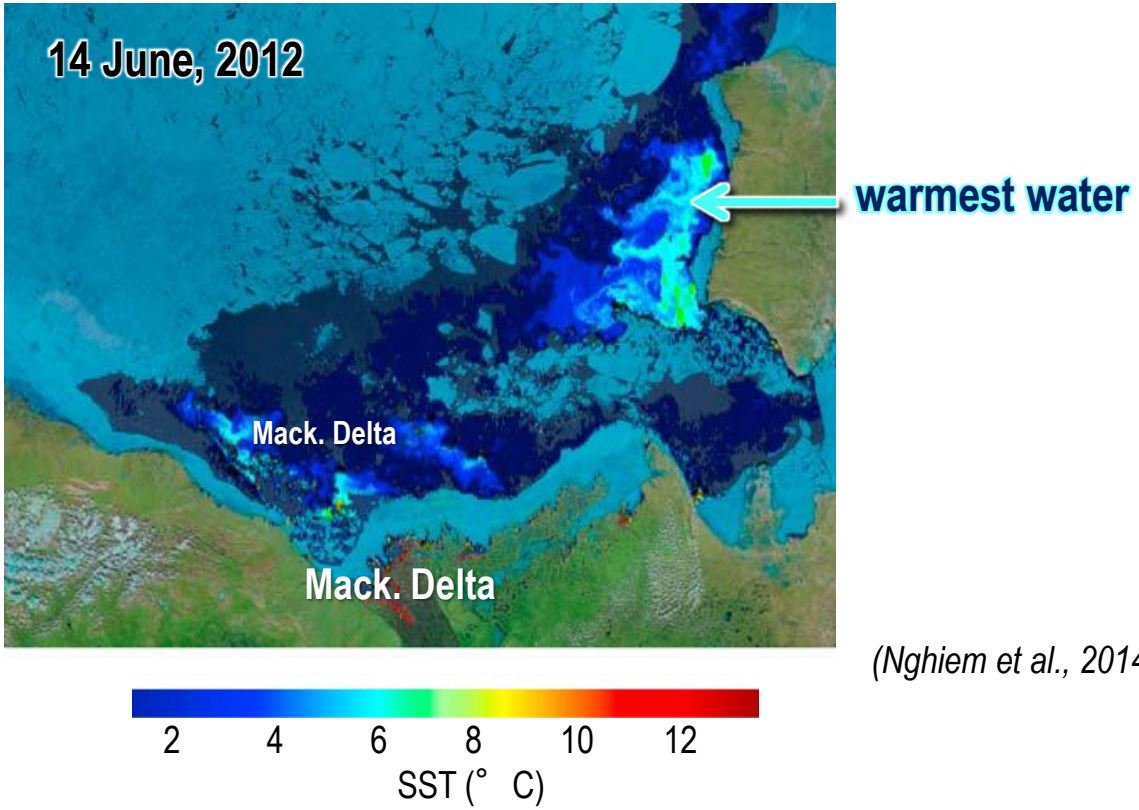
Is it the Mackenzie River?





(Nghiem et al., 2014)

Not at first…

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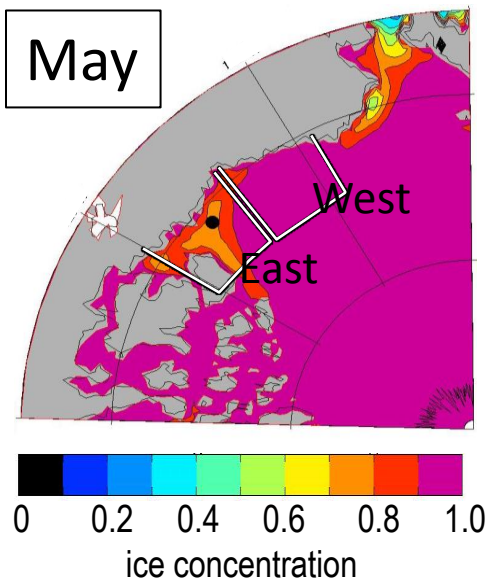
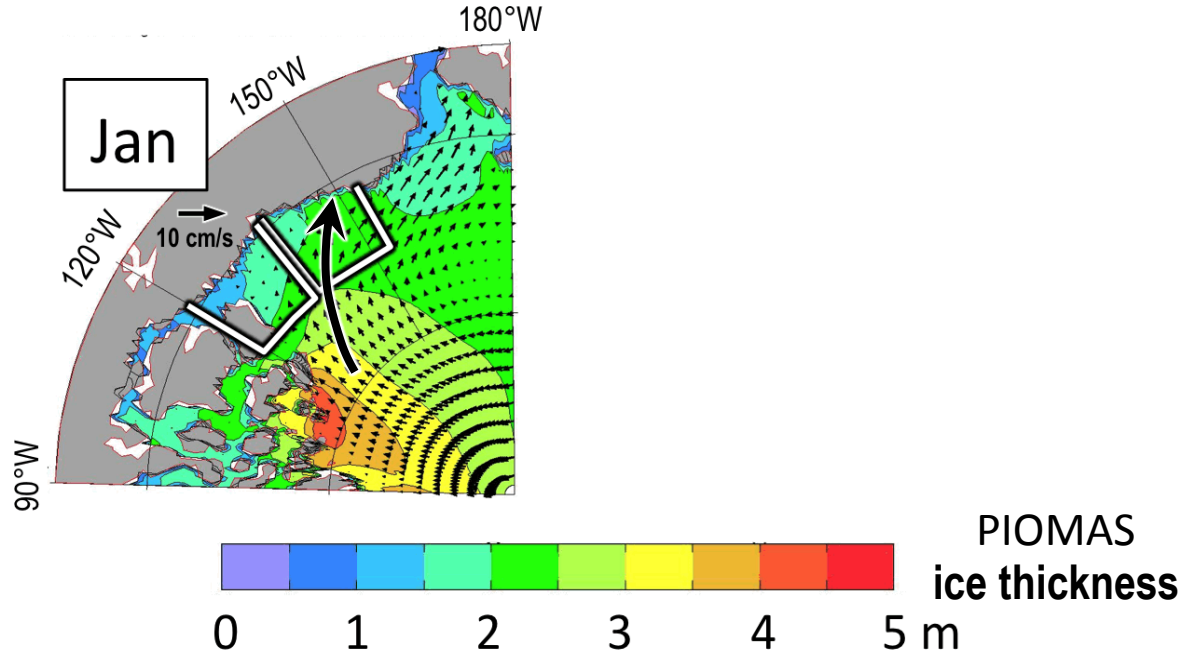
Asynchrony

"not happening at the same time"



thick* ice advection into the *West



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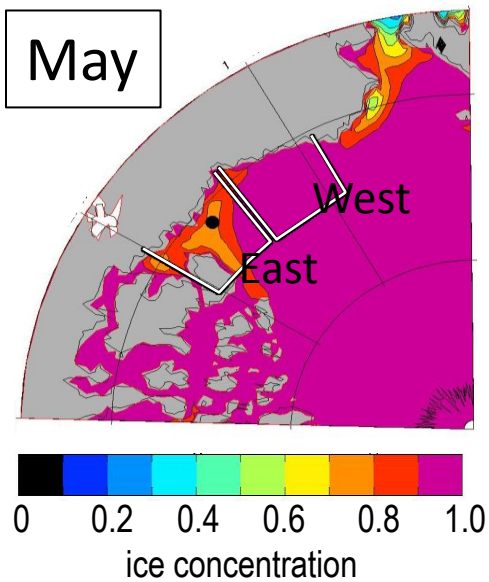
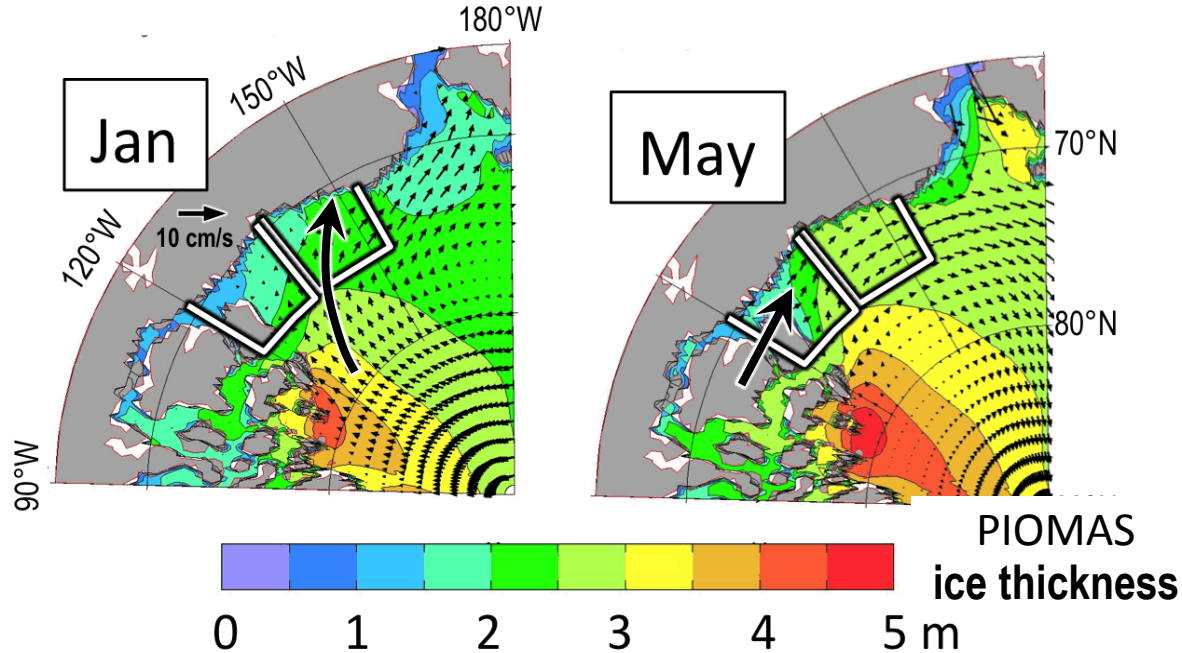


thick* ice advection into the *West

easterly winds* ➔ *thin* ice in *East



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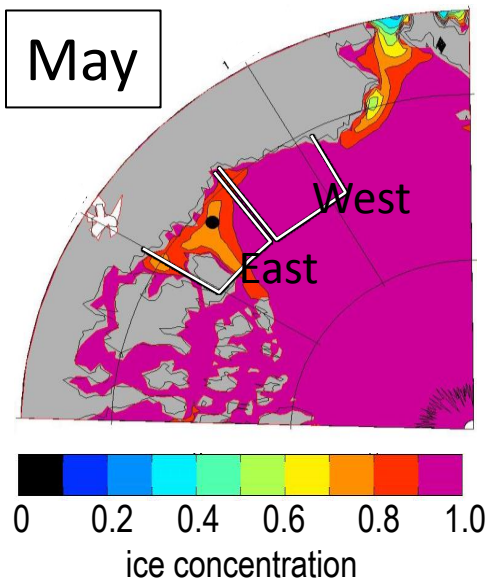

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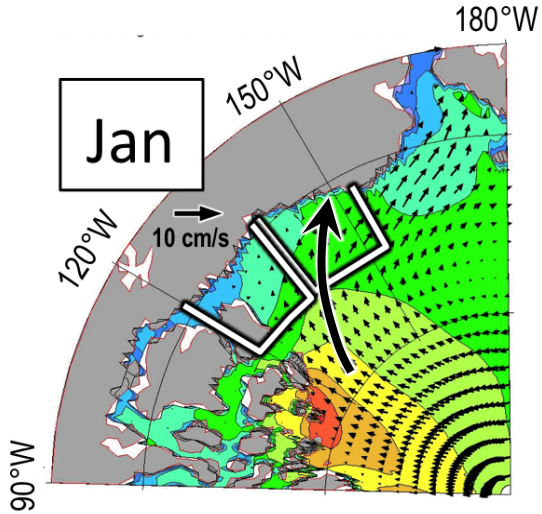

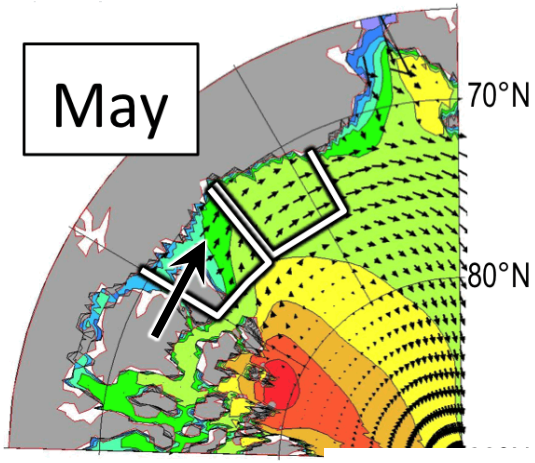

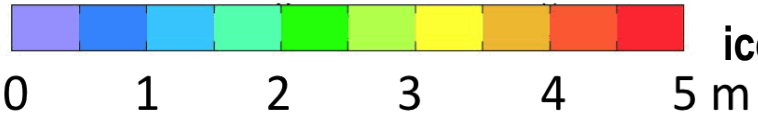

PIOMAS
ice thickness

later melt in W

earlier melt in E

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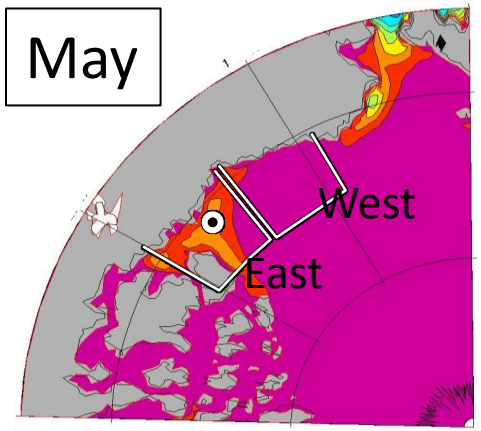
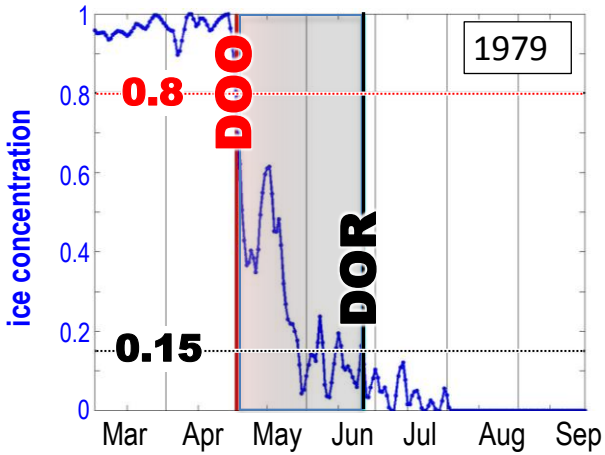
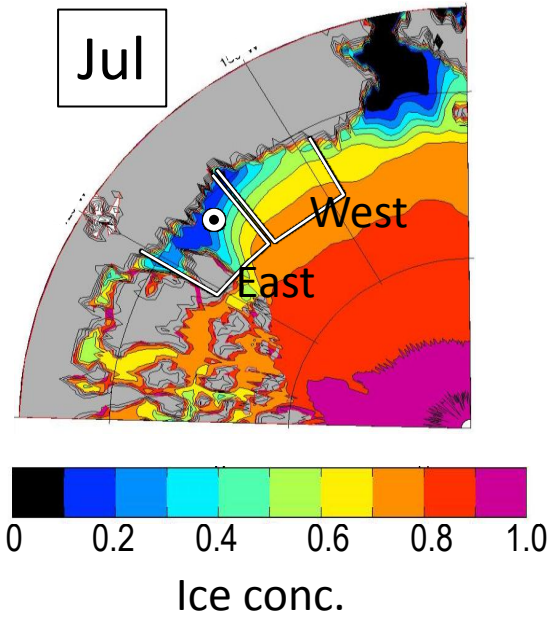
University of Washingtc

Two stages of early season sea ice loss







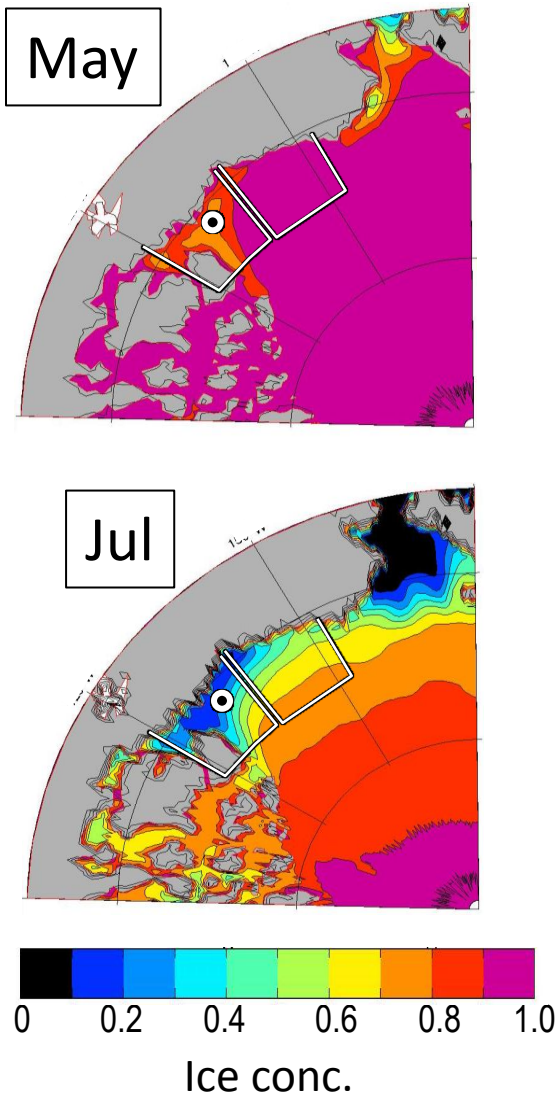
DOO = **D**ate **o**f **O**pening (*initial stage of ice loss*)

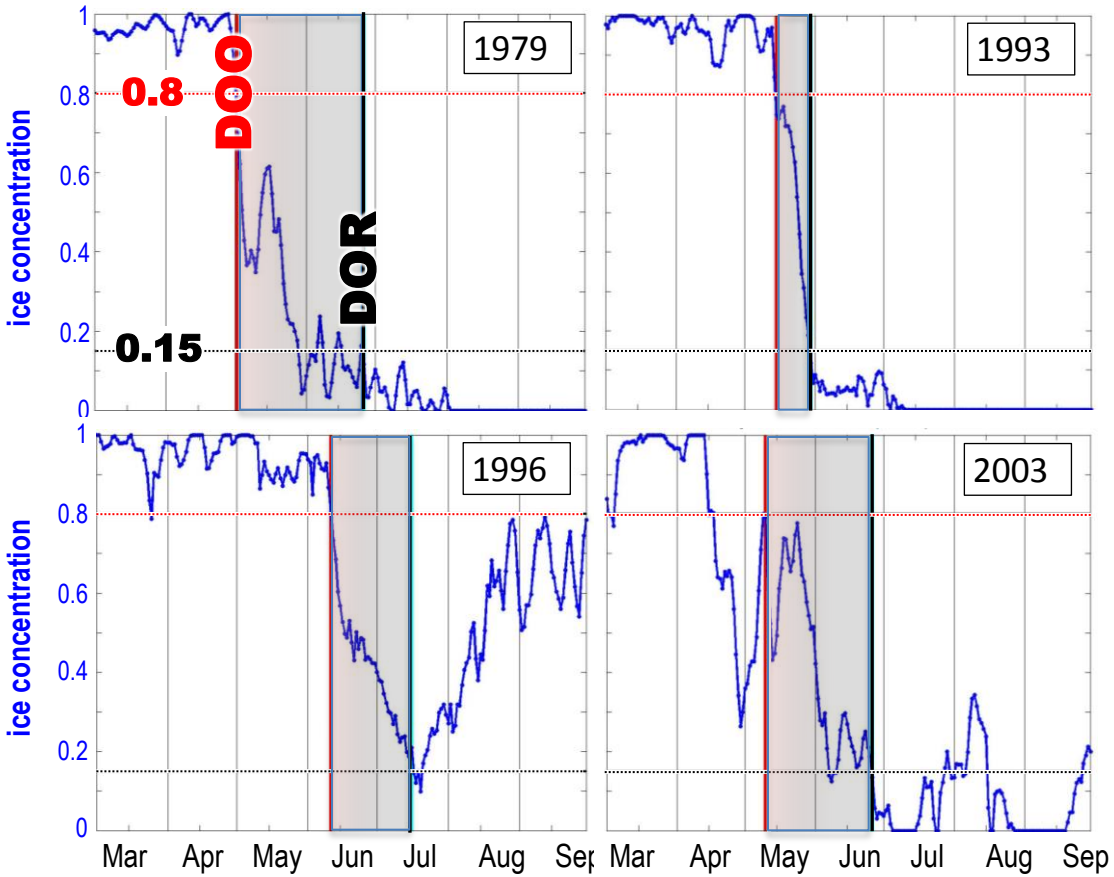
*... last day when conc ➔ < **0.8** before summer min.*

DOR = **D**ate **o**f **R**etreat (*final stage of ice loss*)

*... last day when conc ➔ < **0.15** before summer min.*

Two stages of early season sea ice loss





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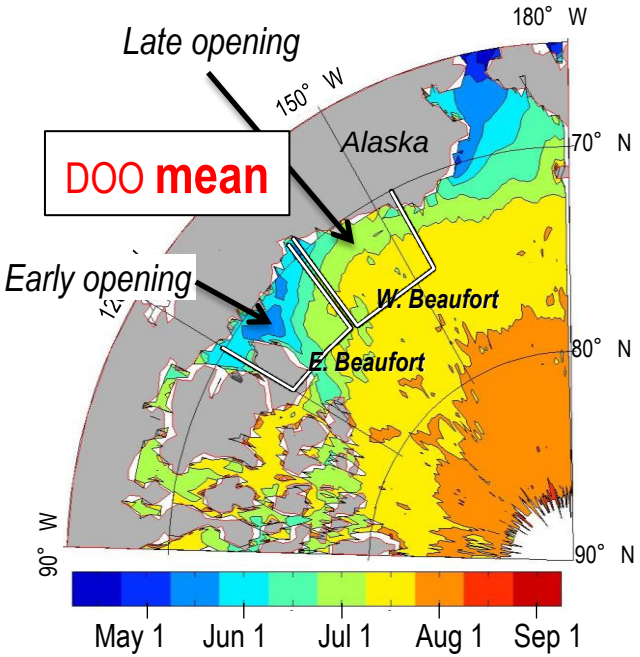
Toward synchrony

"happening at the same time"

Date of Opening: 1979-2012



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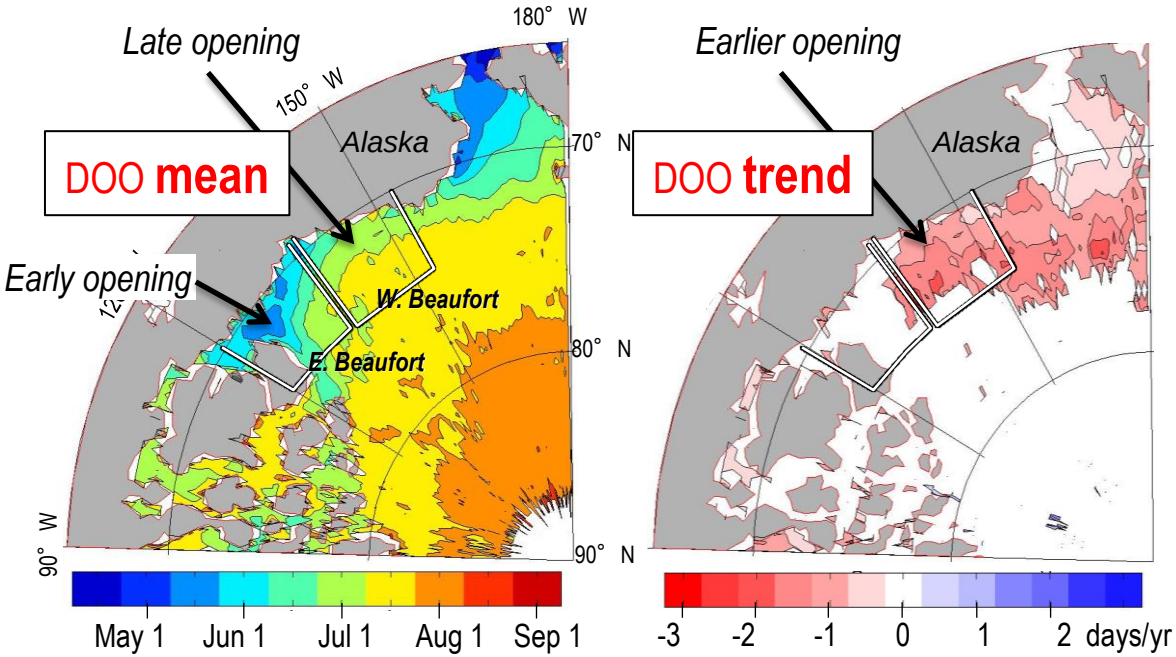

East*: *early staying ***early***

West*: *late getting ***earlier***

➔ increasing synchrony!

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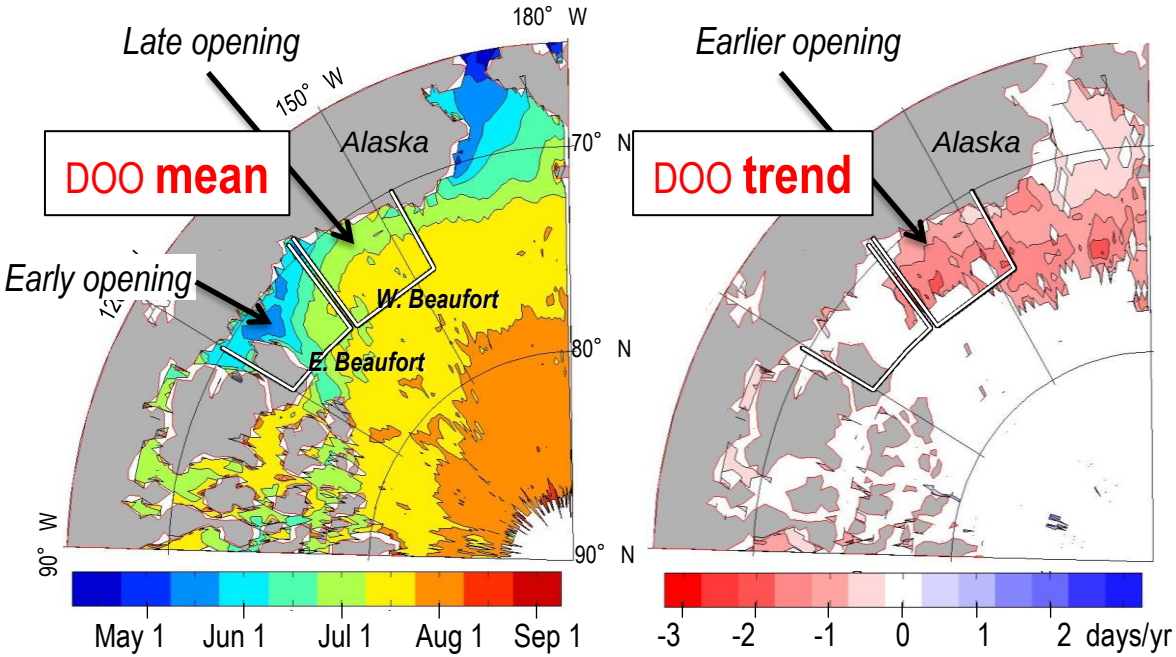
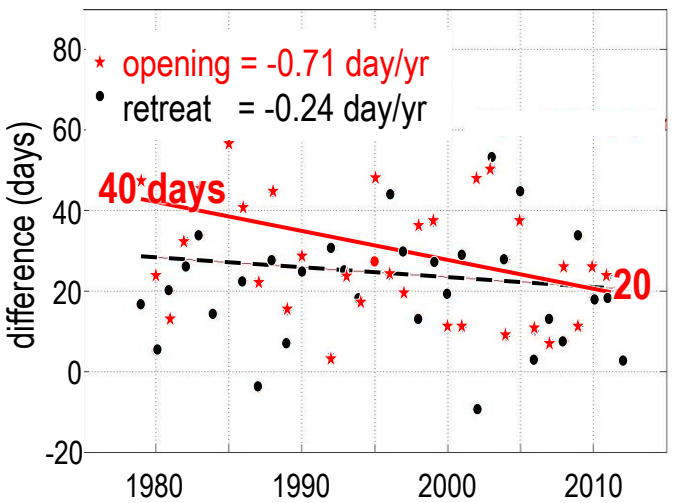


W – E Beaufort dates



East*: *early* staying *early

West*: *late* getting *earlier

➔ increasing synchrony!

ΔDOO: 40 ➔ 20 days

ΔDOO & **ΔDOR** both now ~ 20 days

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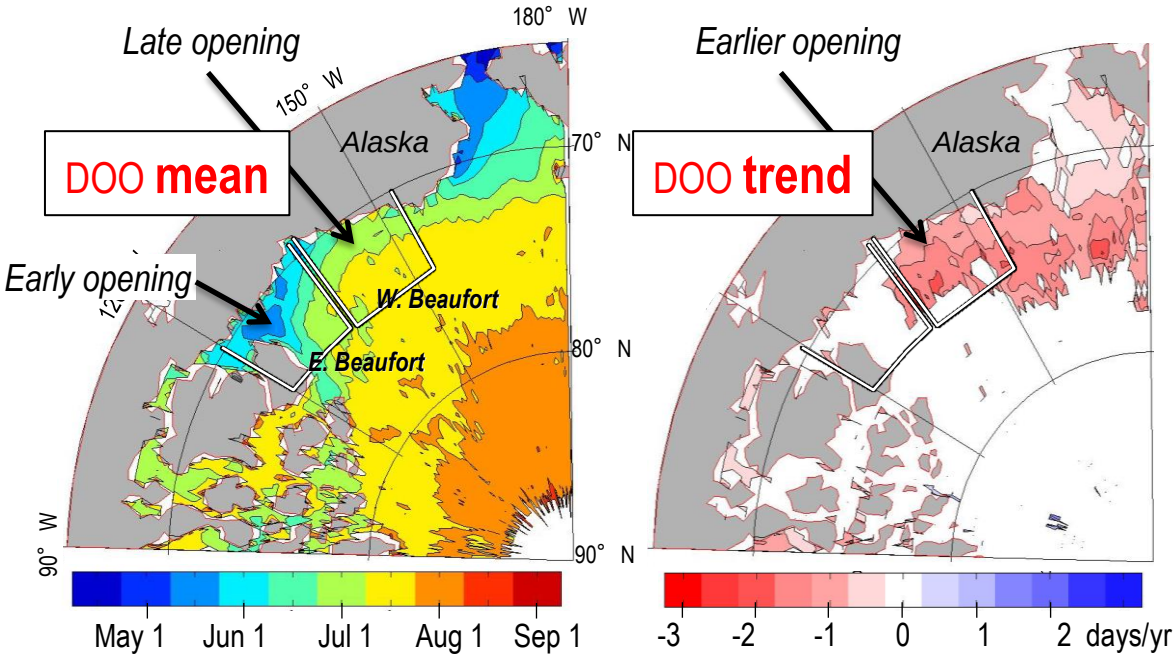

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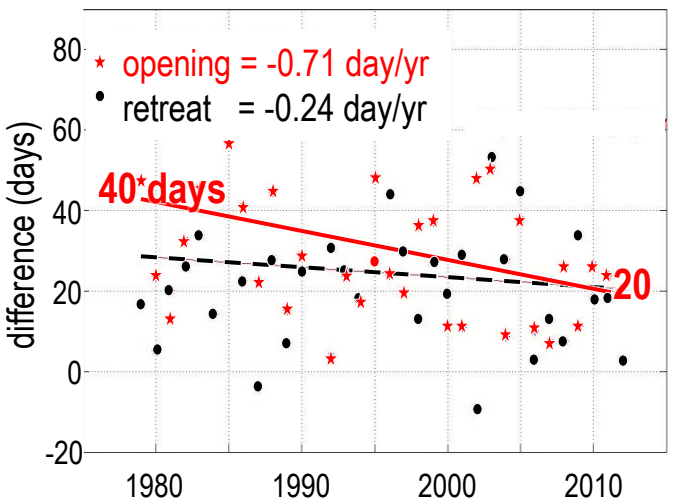

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➔ increasing synchrony!

ΔDOO: 40 ➔ 20 days

ΔDOO & **ΔDOR** both now ~ 20 days

shipping, marine mammals, etc.

➔ The Northwest Passage!

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University of Washington

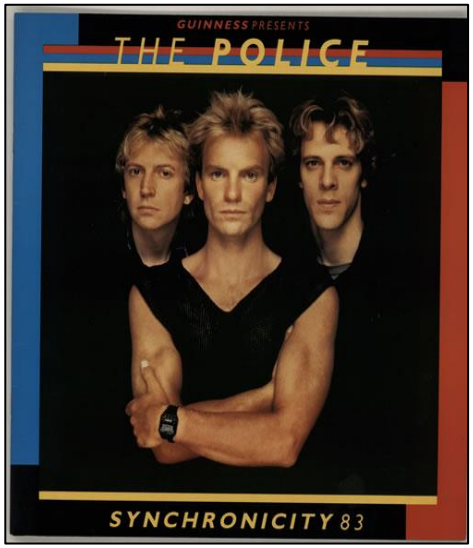
Toward synchrony

"happening at the same time"

...formerly: "Toward ***synchronicity***"

Reviewer #1: Synchronicity = "a meaningful coincidence"

Carl Jung, 1920s



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Prediction

Detrended interannual variability:

For each
1 m/s increase in spring easterly wind speed,

DOR is
1-2 weeks earlier in summer,

with a
2-3 month lead time.

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1-2 weeks earlier in summer,

with a
2-3 month lead time.

Works well in past few years!

*(This year: need to consider **meridional** wind)*

Michael Steele
Polar Science Cente
University of Washi

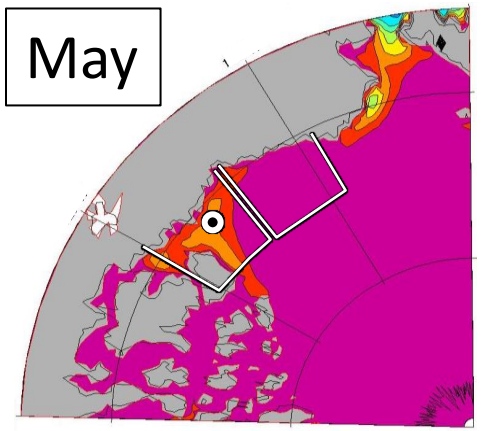
Focus on:
Daily ice retreat

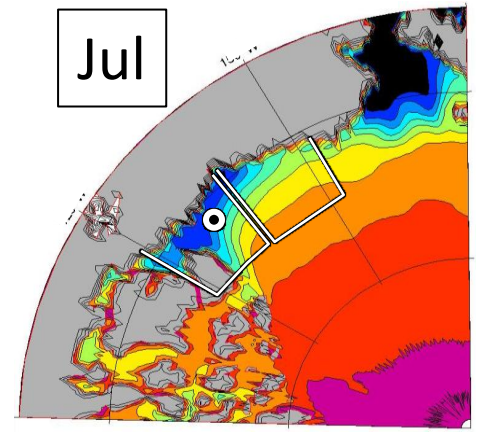
"loitering"

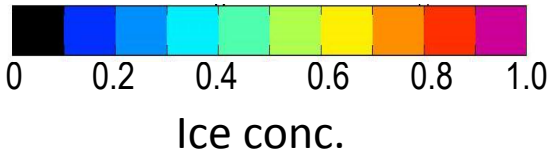
Michael Ste
Polar Scienc
University of

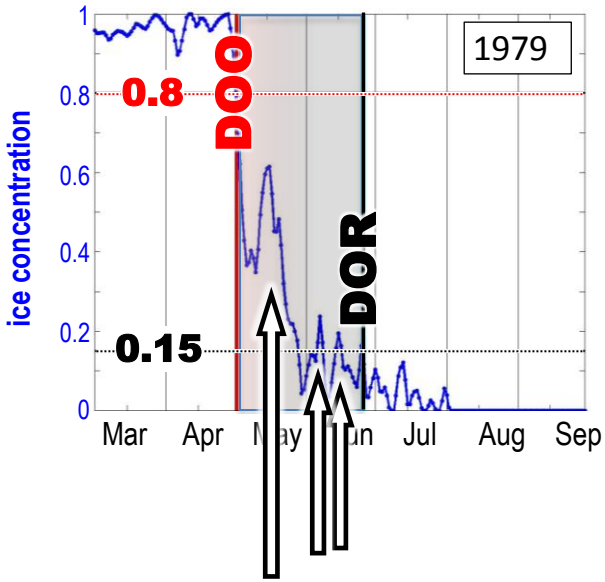
Hey…ice retreat is *not steady*!

NCEI- Silver Spring
Sep 26, 2016









DOO = **D**ate **o**f **O**pening (*initial stage of ice loss*)

DOR = **D**ate **o**f **R**etreat (*final stage of ice loss*)

Michael Steele
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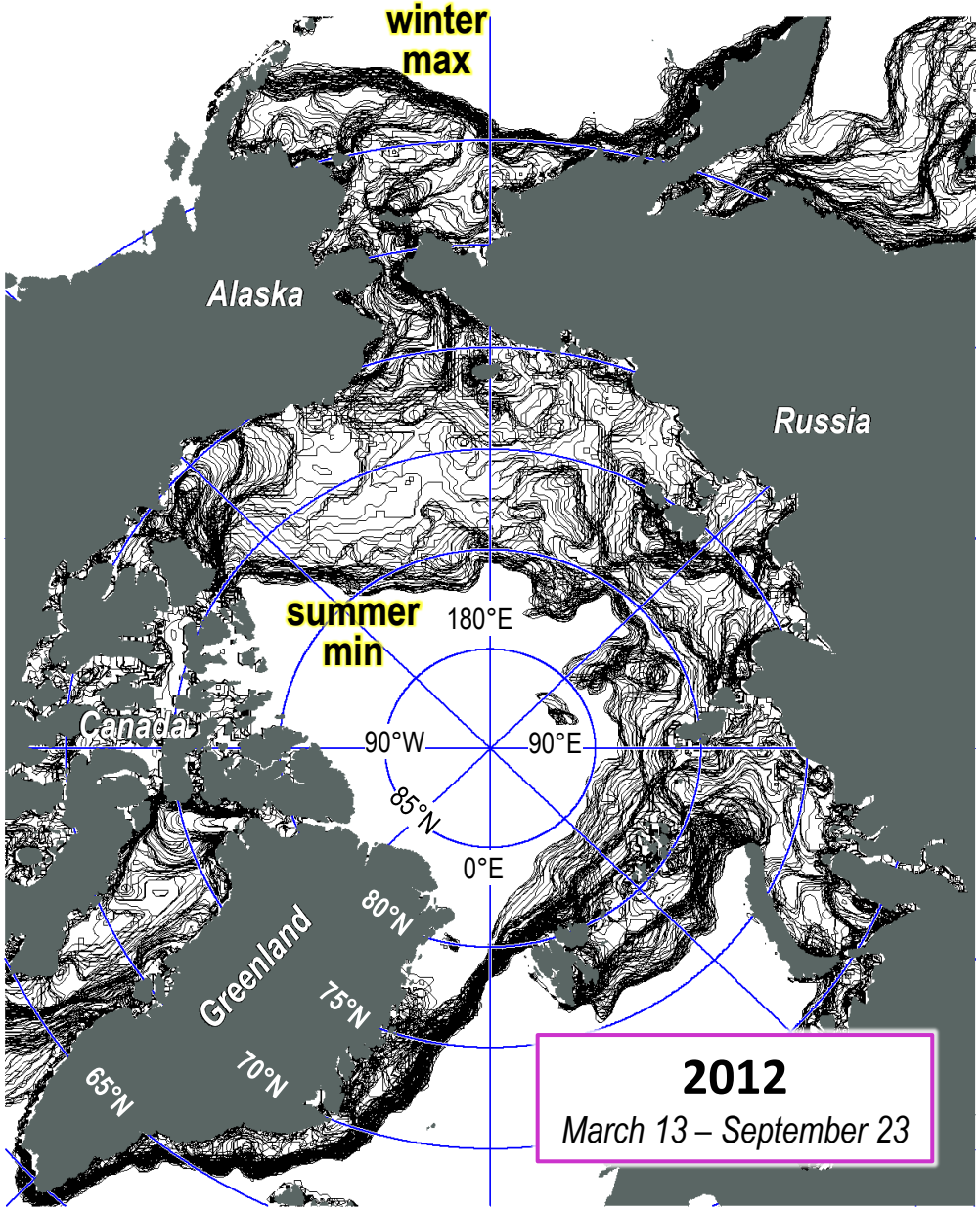
University of Washington

Daily ice retreat



Daily 15% ice concentration contour = "ice edge"

SSM/I-SSMIS (NASA Team algorithm)

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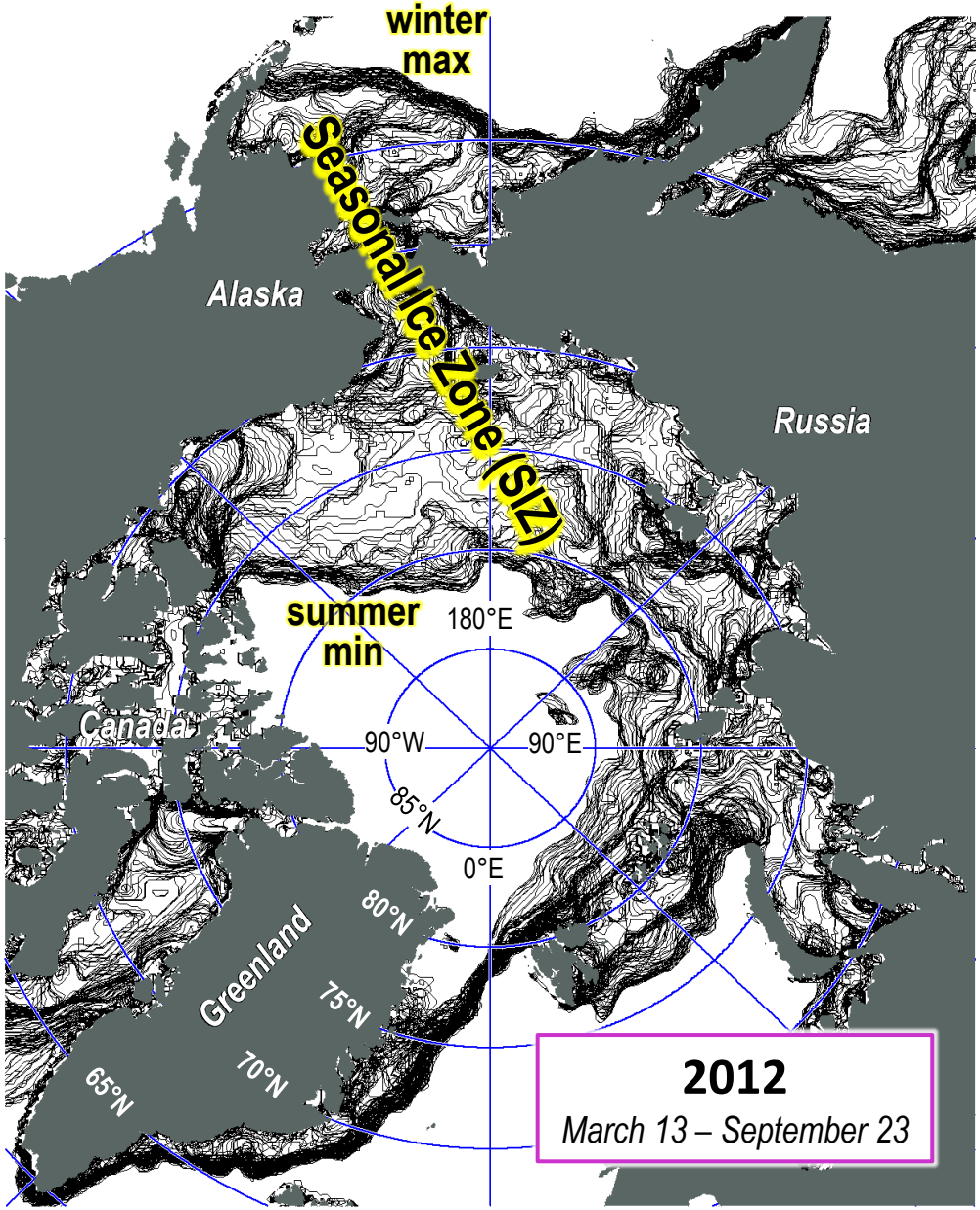
University of Washington

Daily ice retreat



Daily 15% ice concentration contour = "ice edge"
SSM/I-SSMIS (NASA Team algorithm)

The "**SIZ**"
= **S**easonal **I**ce **Z**one
= winter max to summer min

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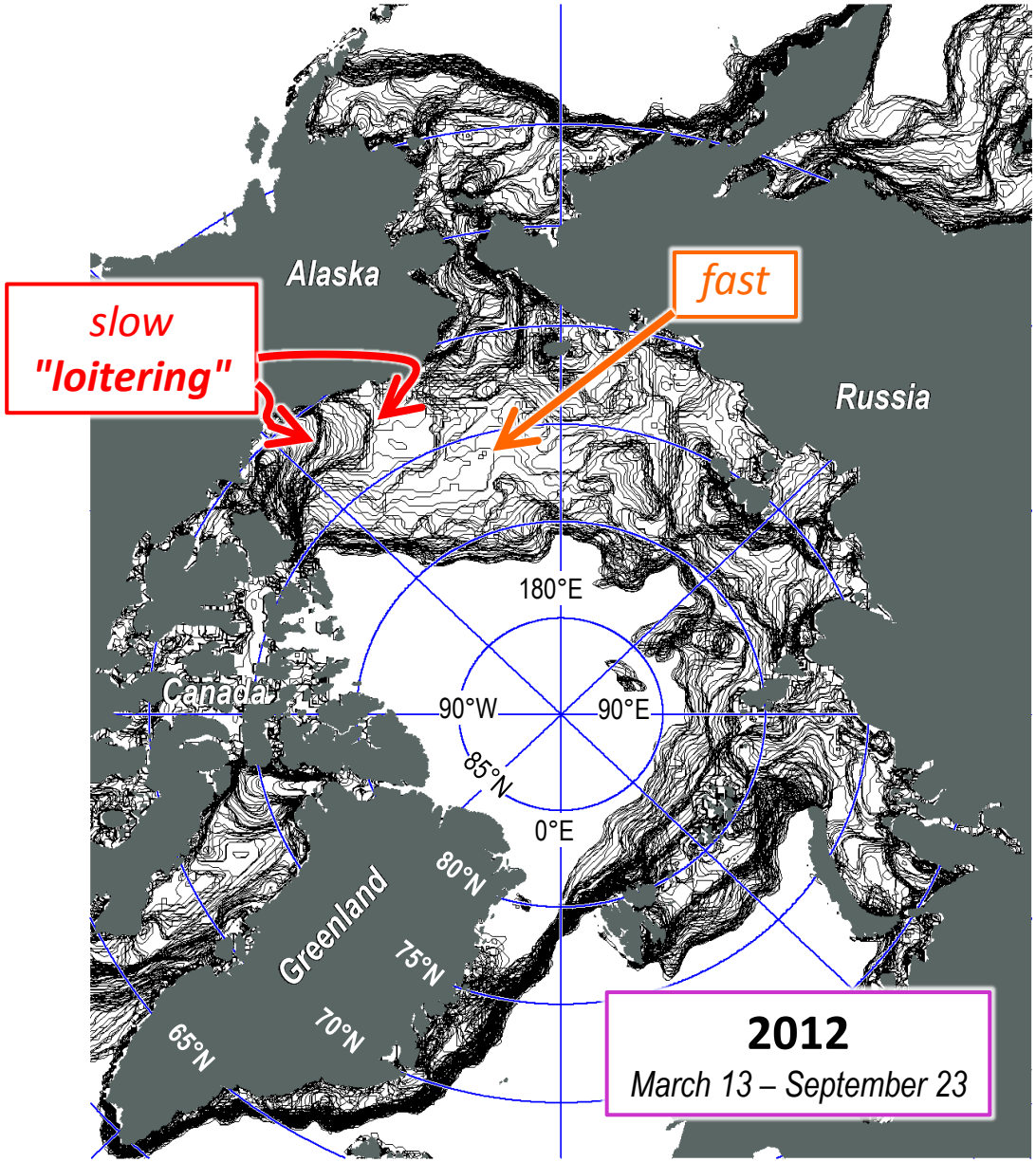
Daily ice retreat



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SSM/I-SSMIS (NASA Team algorithm)

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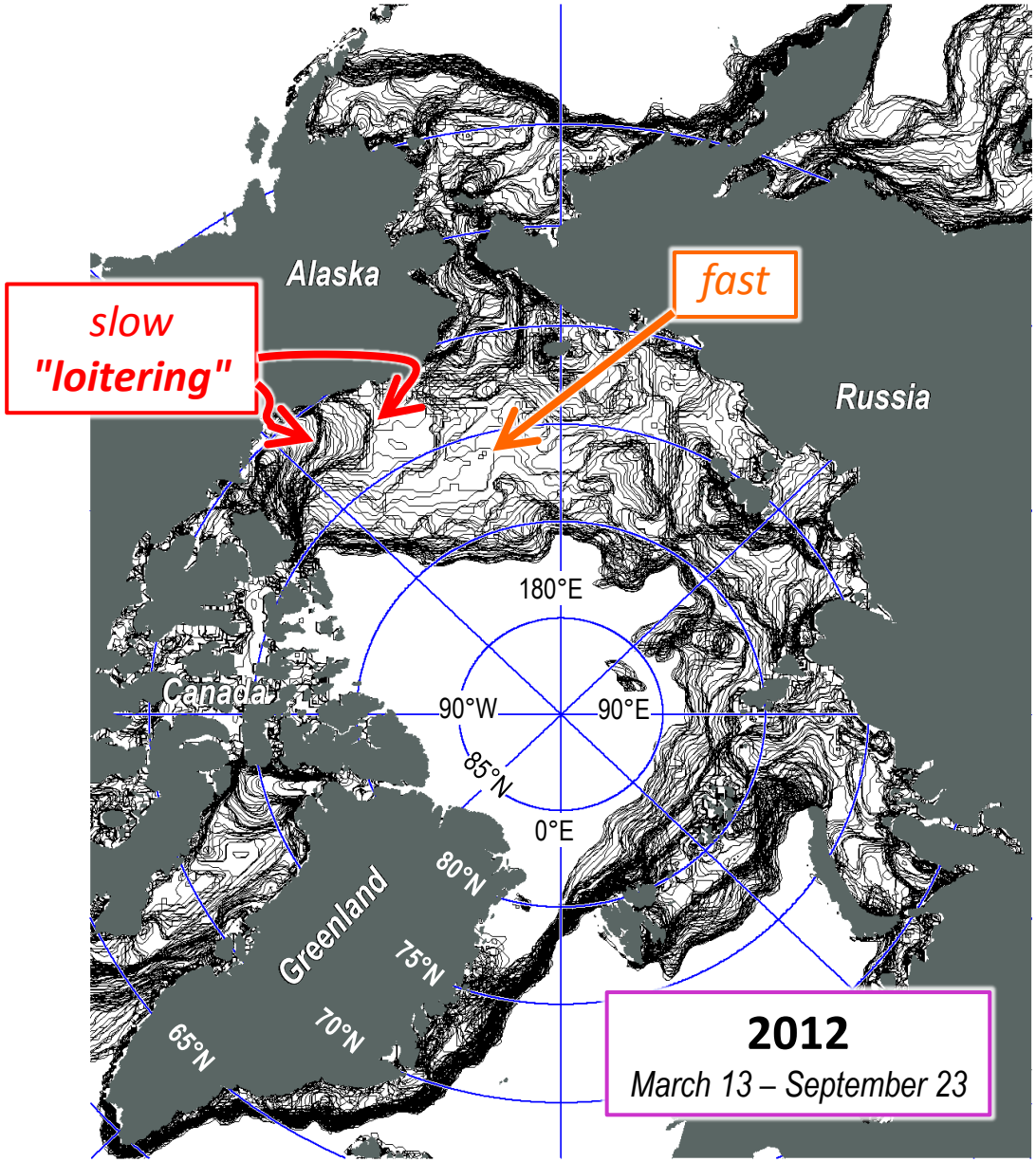
Daily ice retreat



Daily 15% ice concentration contour = "ice edge"

SSM/I-SSMIS (NASA Team algorithm)

Other data sets:

- **AMSR2** (*3.25 km PMW*)
- **MASIE** (*NSIDC multi-sensor*)
- **PIOMAS model** (*no assimilation*)

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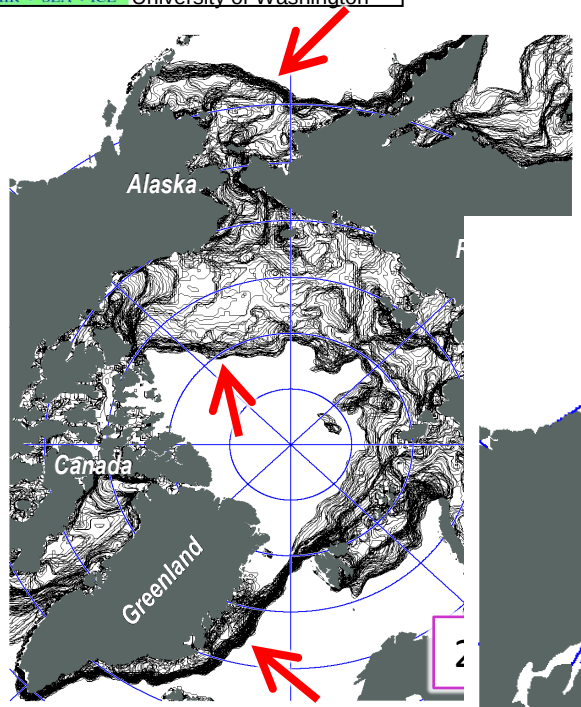
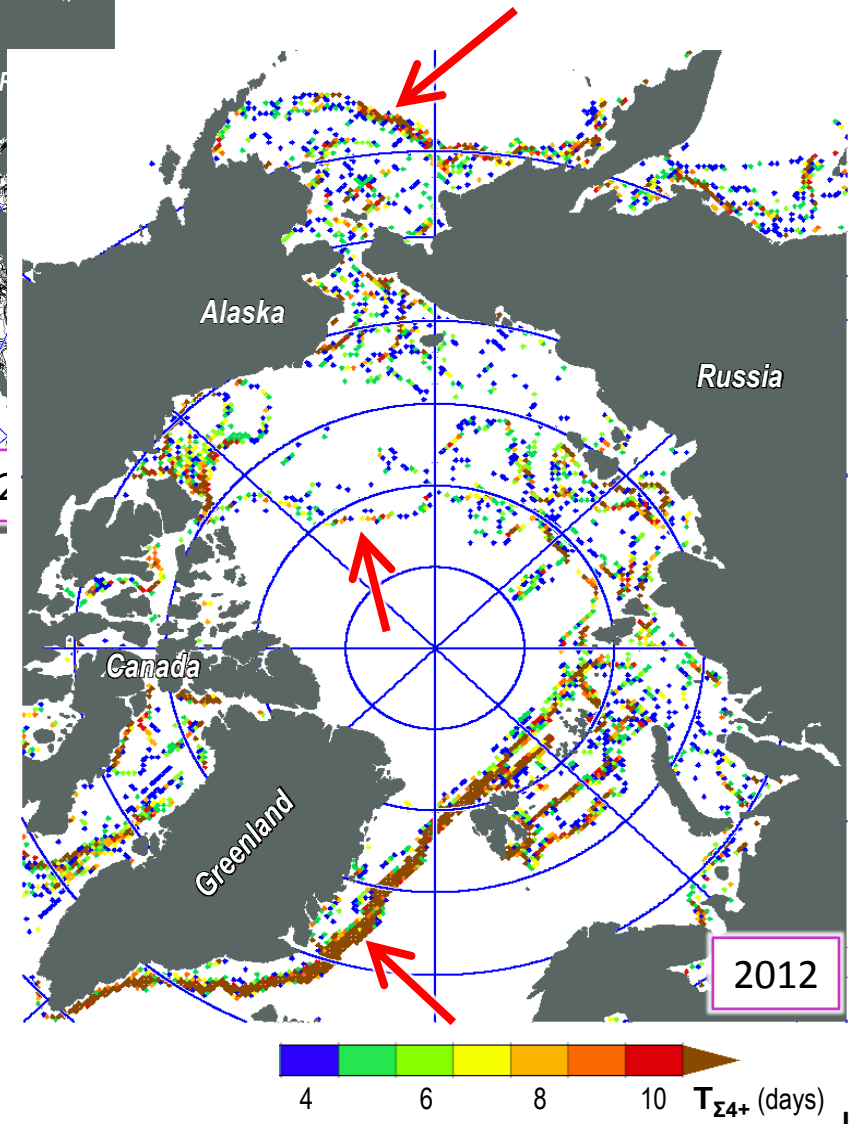
Quantitative analysis

...on the 25 km grid





# of days
the ice edge
loitered in a pixel

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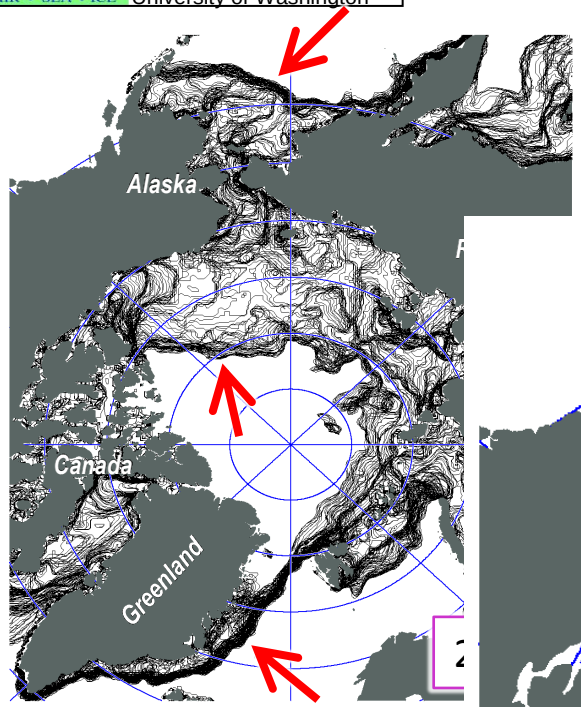
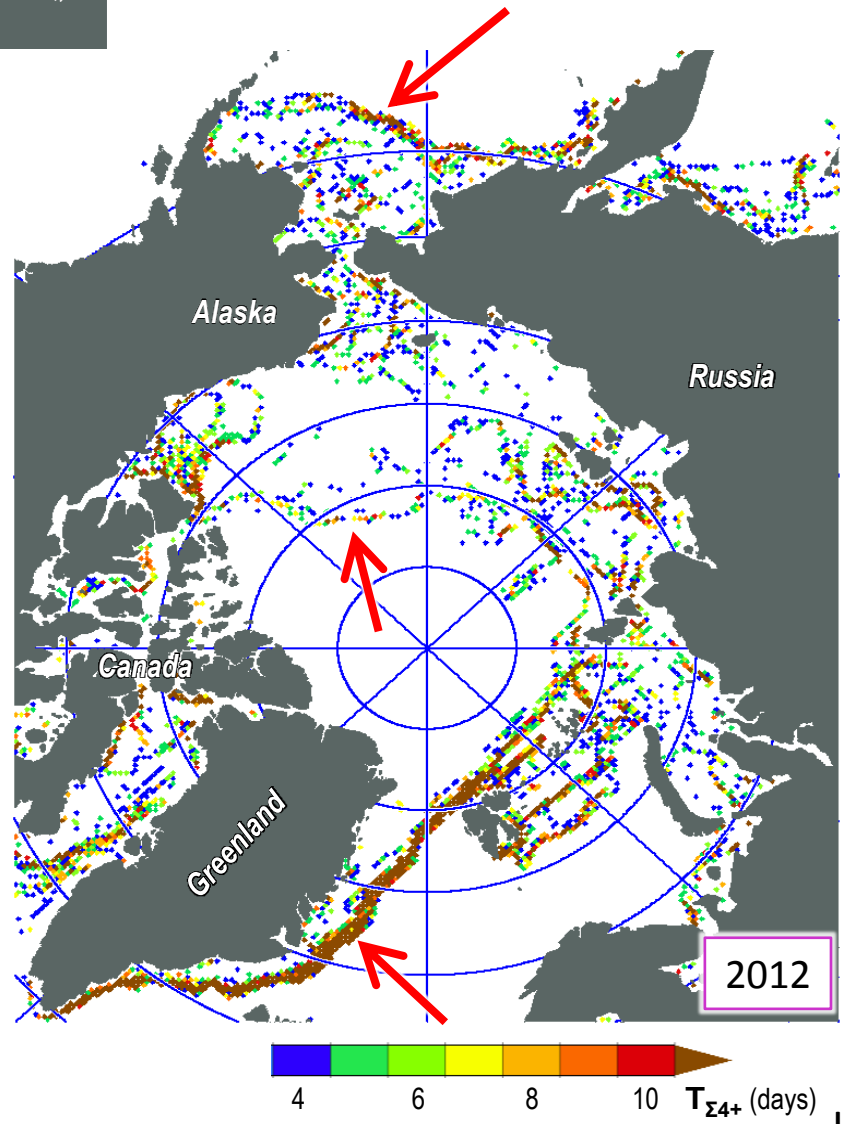
Quantitative analysis

...on the 25 km grid





Loitering ice edge:

≤ 8 km/day*

≥ 4 days in a 25 km pixel

***Ave ice speed 8-12 km/day**

Spreen et al. *(GRL, 2011)*
Olason & Notz *(JGR, 2014)*

# of days
the ice edge
loitered in a pixel

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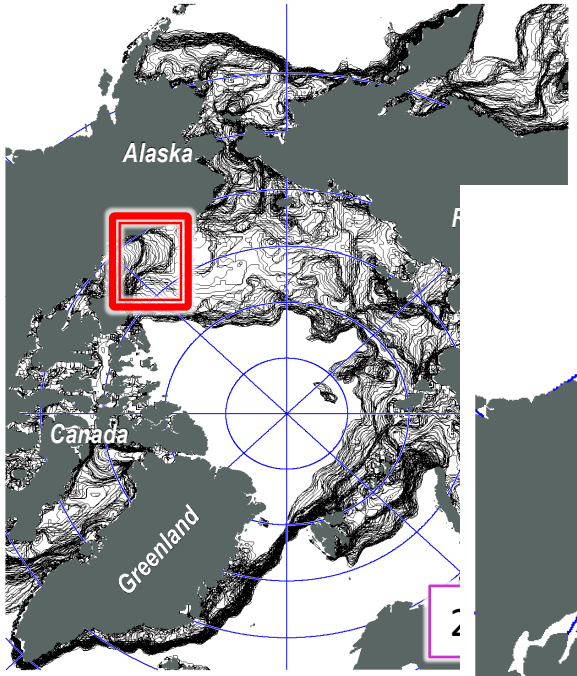
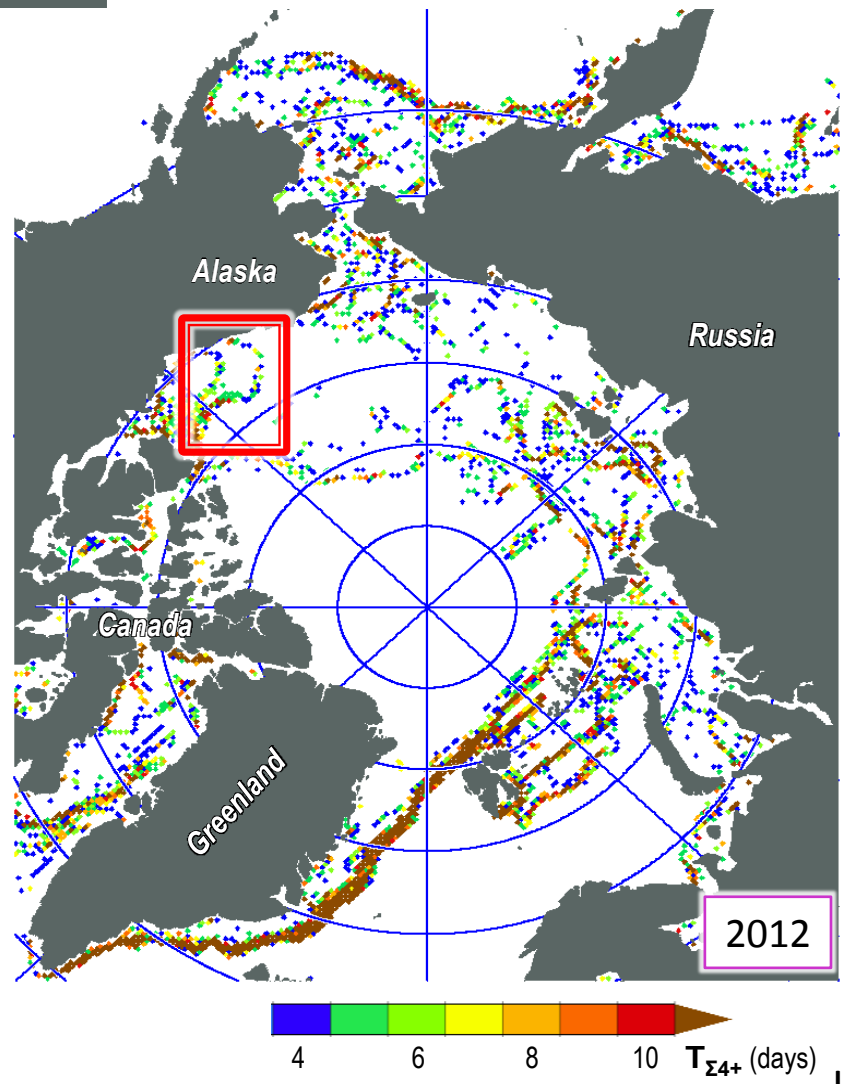
Quantitative analysis

...on the 25 km grid





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Spreen et al. *(GRL, 2011)*
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# of days
the ice edge
loitered in a pixel

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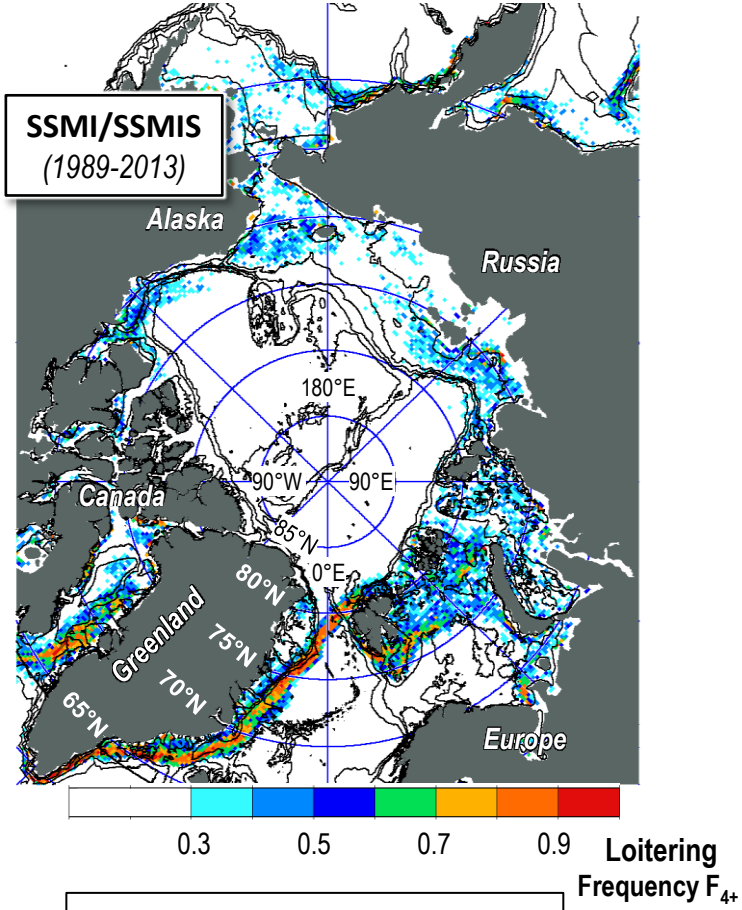
Space & Time Scales

1989-2013
SSMI/SSMIS



Loitering covers

20-25% of the SIZ

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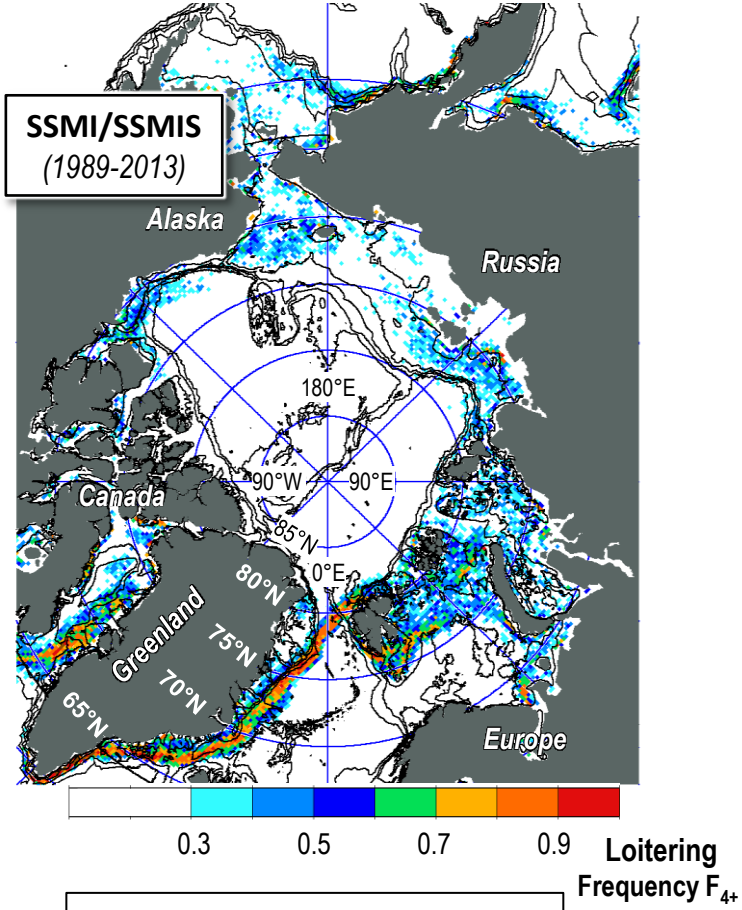
Space & Time Scales

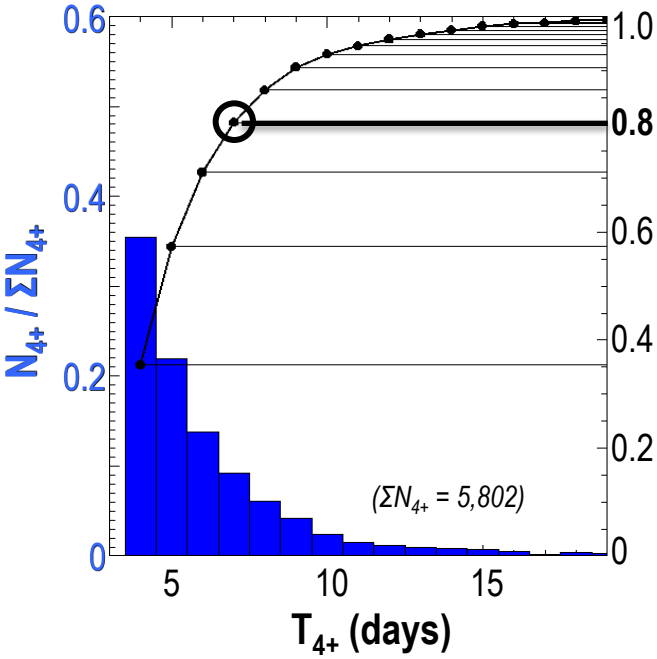


Loitering covers

20-25% of the SIZ

1989-2013

SSMI/SSMIS



80% of loitering

events last 4-7 days

...synoptic storms...

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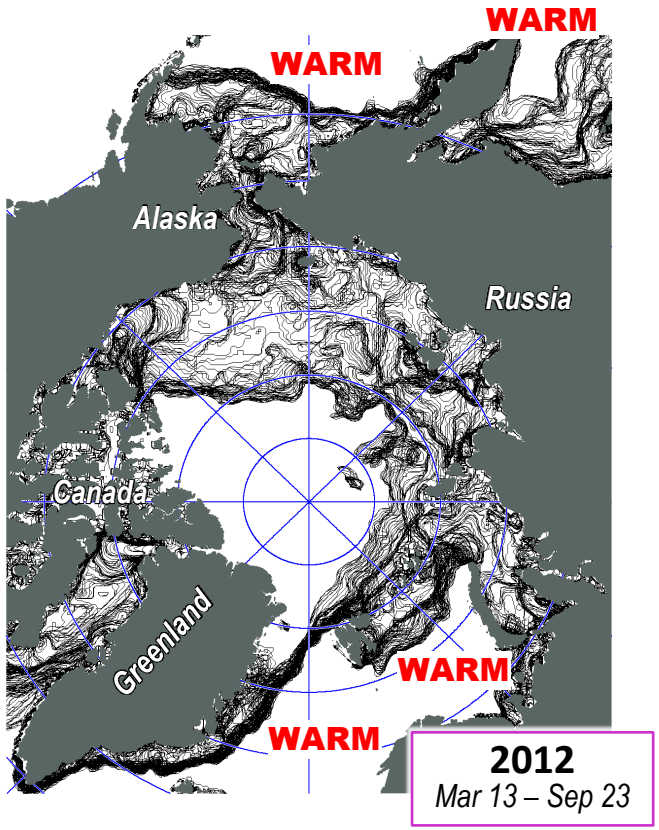
Where does it loiter?

Winter ice max
@ warm SST fronts



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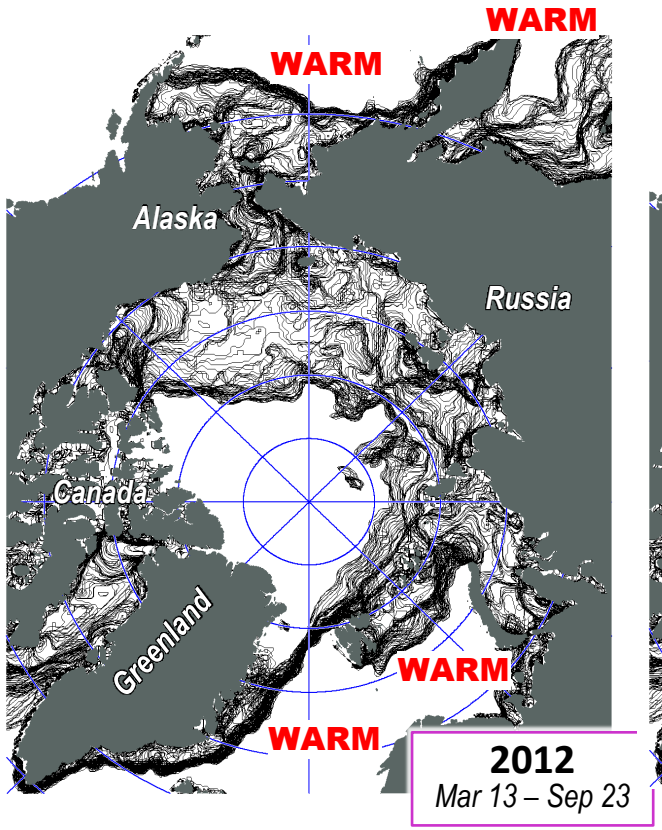
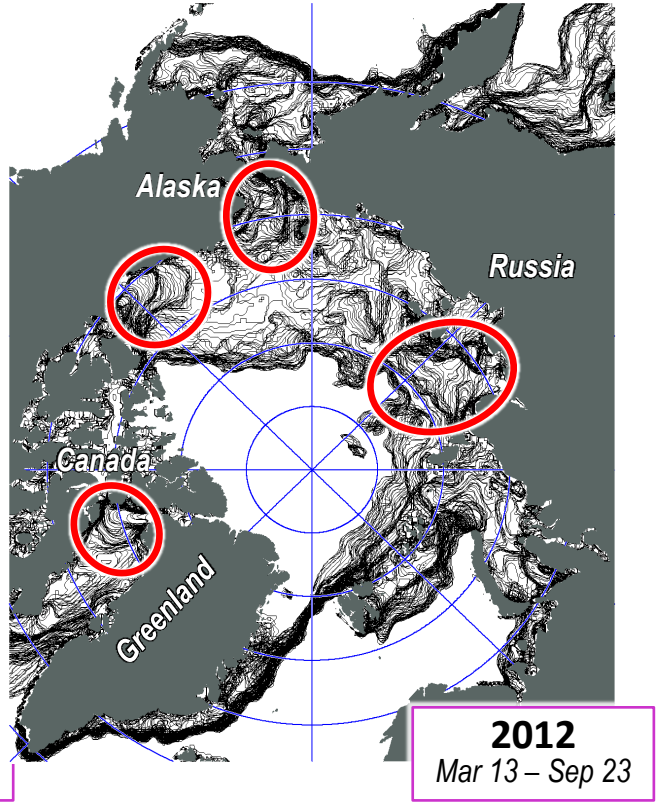
Where does it loiter?

Winter ice max
@ warm SST fronts



Within the SIZ
in some places...***why***?



N. Baffin, E. Beaufort,
N. Chukchi, Laptev...

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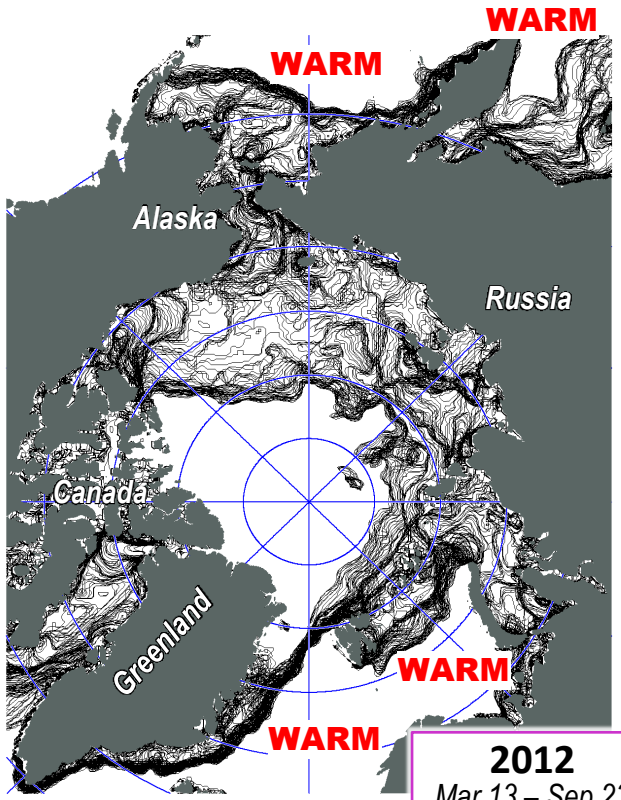
Why does it loiter?

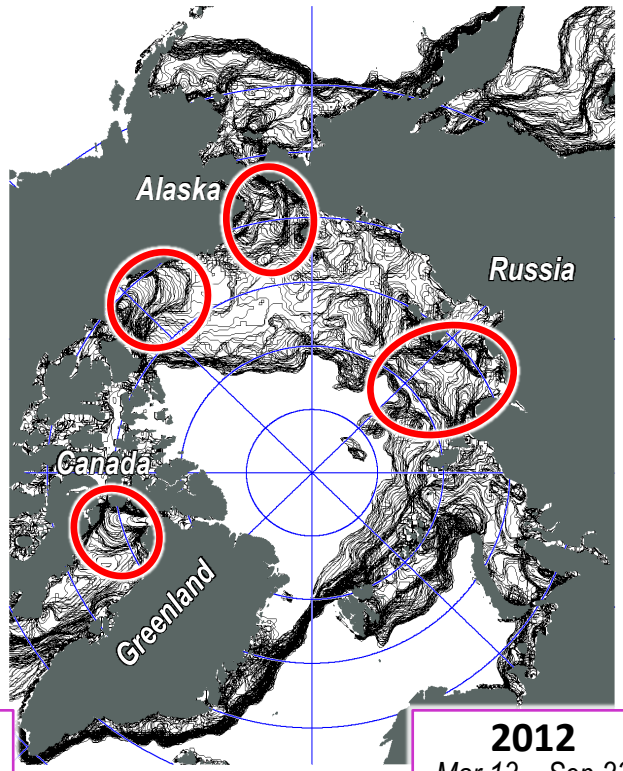
Winter ice max
@ warm SST fronts

Within the SIZ
in some places...***why***?

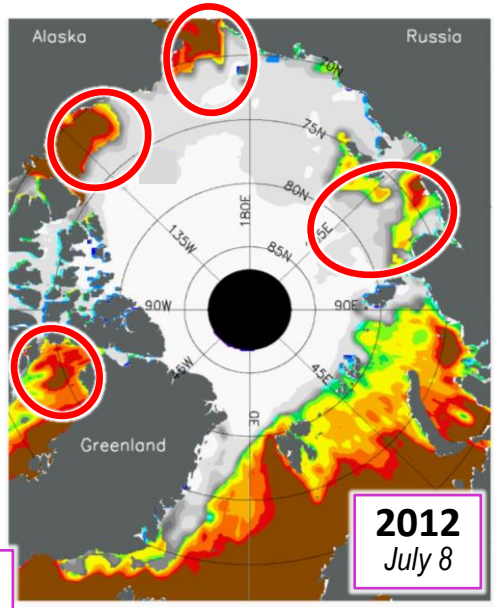
Early ice retreat
↓
early SST warming
↓
loitering



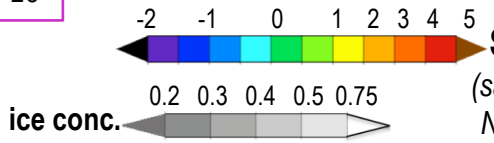
2012
Mar 13 – Sep 23



2012
Mar 13 – Sep 23



2012
July 8



(satellite data: NOAA OI.v2 AVHRR)

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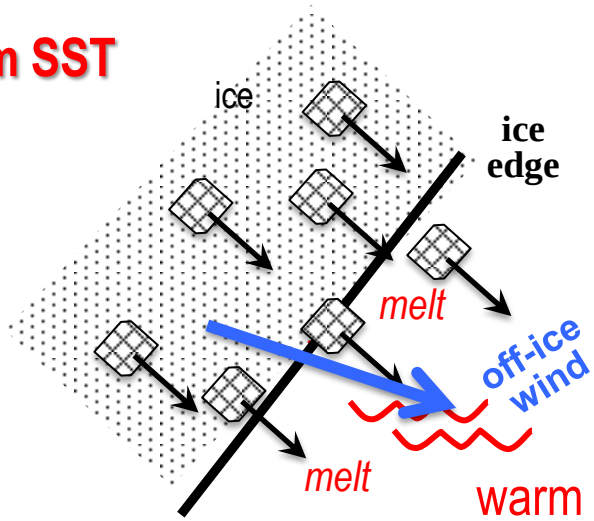
Why does it loiter?

Loitering:

wind + warm SST



Warm SST = 2.5°C above freezing
can melt ~ 35 cm/day

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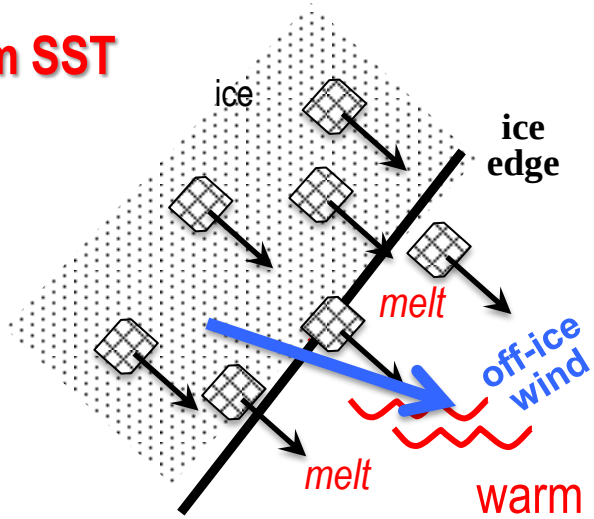
Why does it loiter?

Loitering:

wind + warm SST



Warm SST = 2.5°C above freezing
can melt ~ 35 cm/day

The retreat season

- ***Retreat***
  On-ice winds
- ***Loitering***
  Off-ice winds + warm SST
- ***Advance***
  Off-ice winds + cold SST

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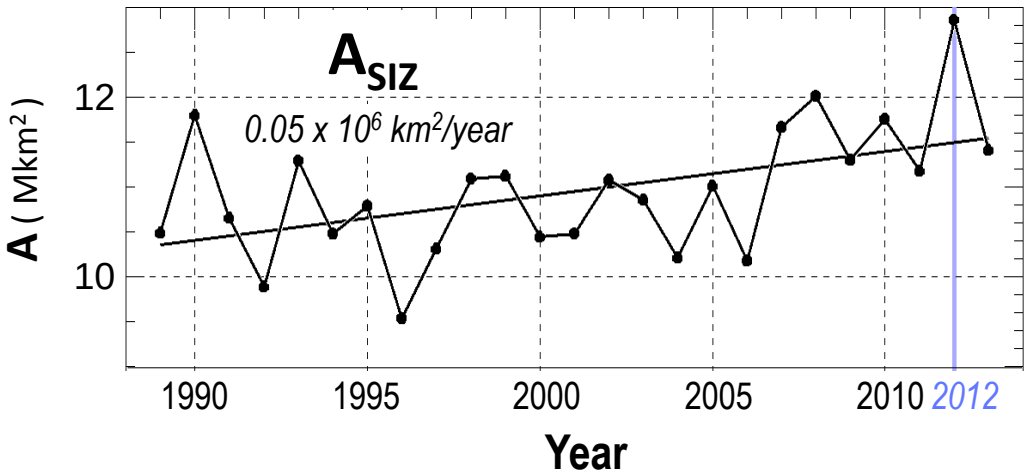
Trends



The area of the **SIZ** $\mathbf{A_{SIZ}}$ is increasing.

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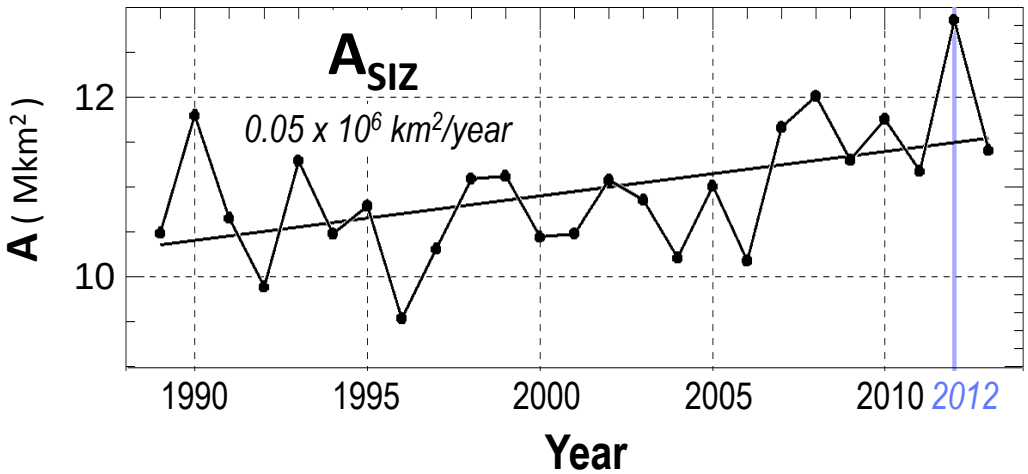
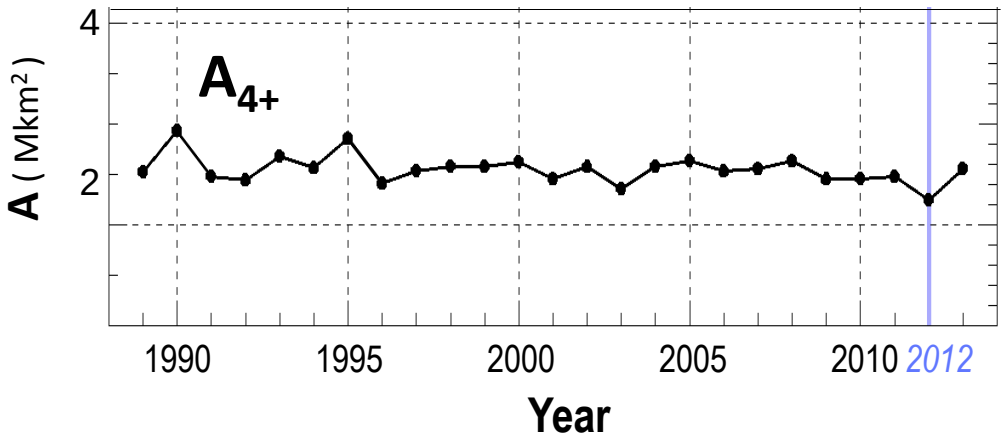
Trends



The area of the **SIZ** $\mathbf{A_{SIZ}}$ is increasing.



...but the area of **loitering** $\mathbf{A_{4+}}$ is not!

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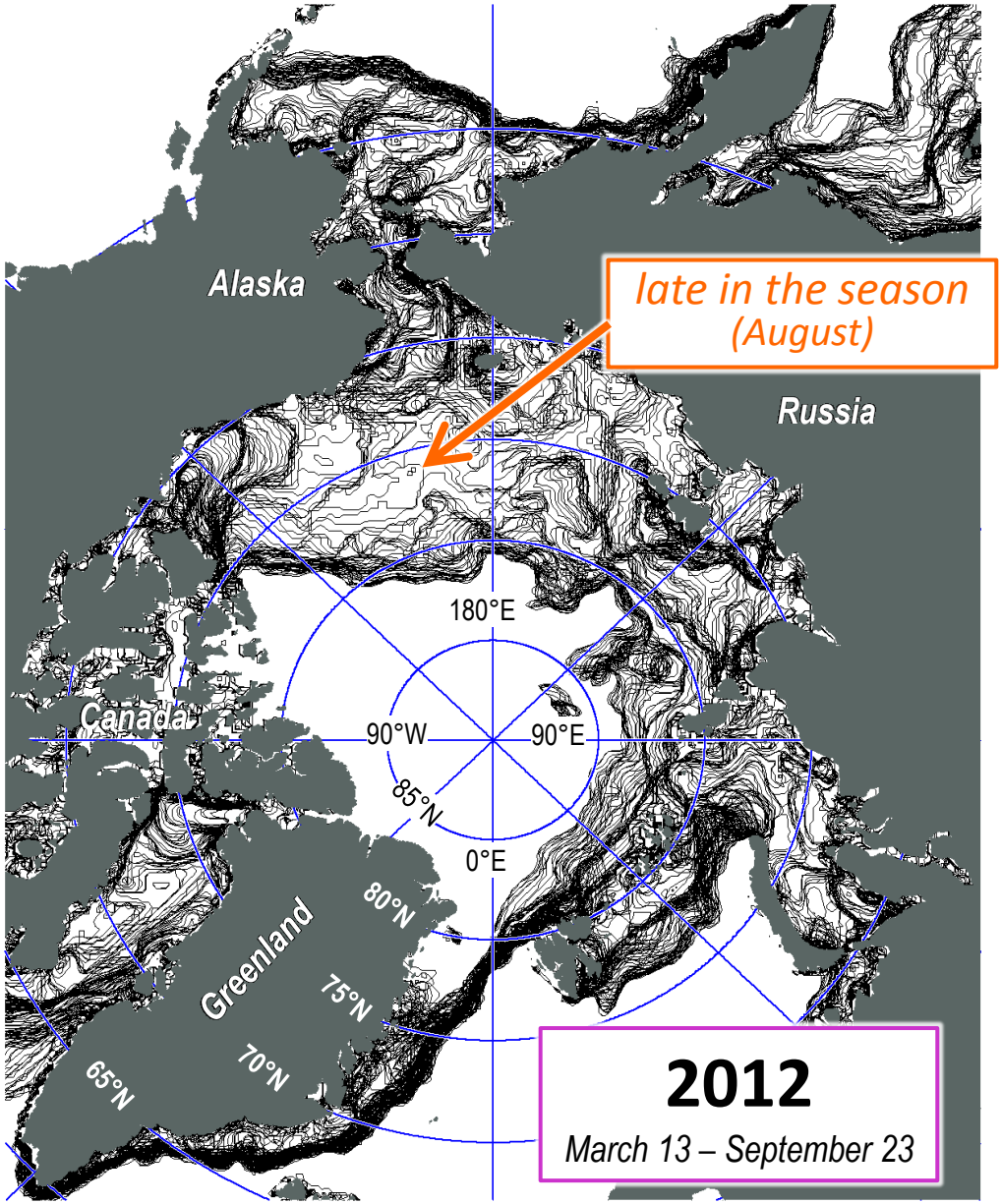
Why isn't A_{4+} increasing?



rapid retreat,

cold SST,

off-ice winds ➔ *advance*,

not *loitering*

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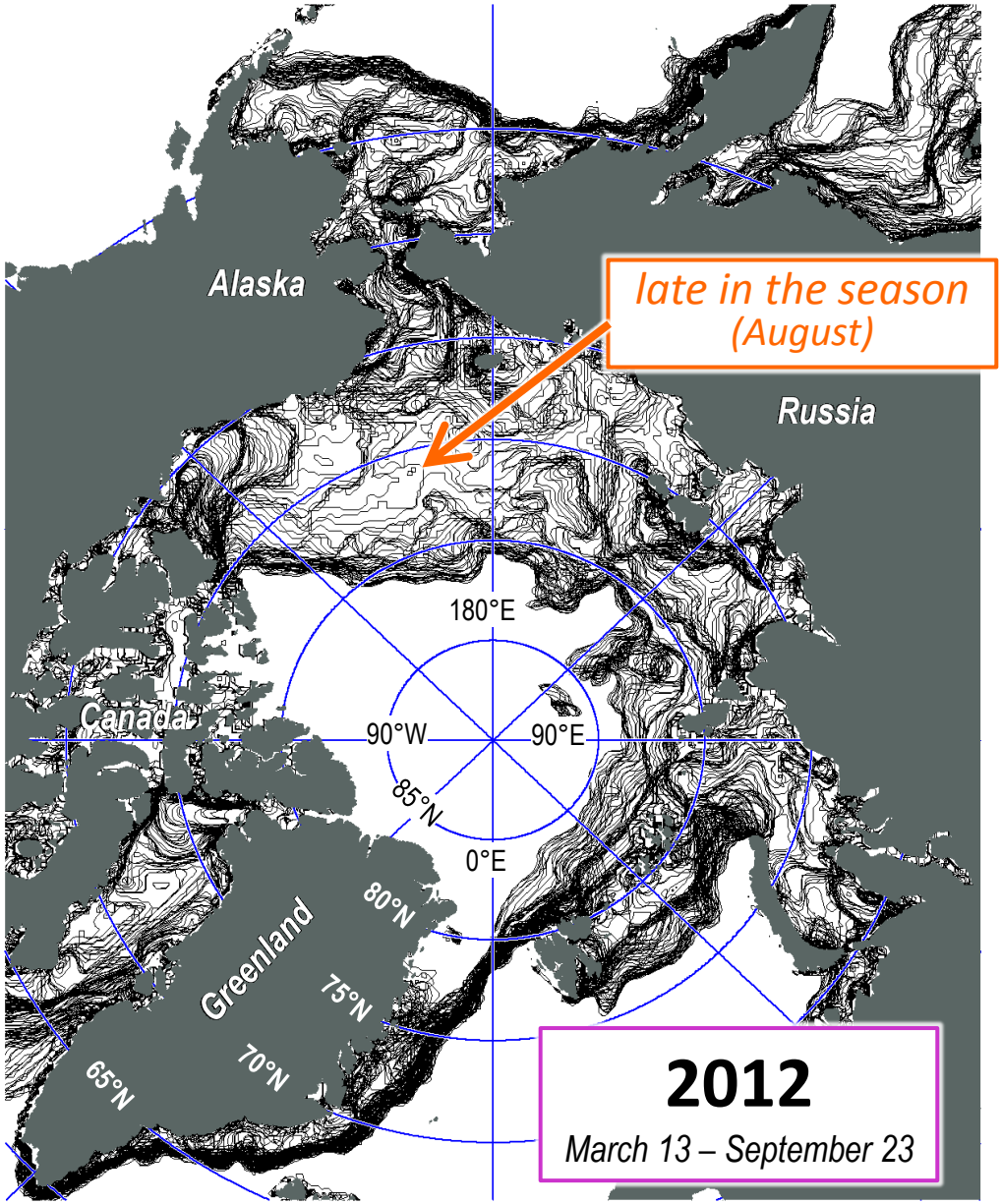
University of Washington

Why isn't A_{4+} increasing?



rapid retreat,

cold SST,

off-ice winds ➔ *advance*,

not *loitering*

Hmmm… maybe we should look into this!

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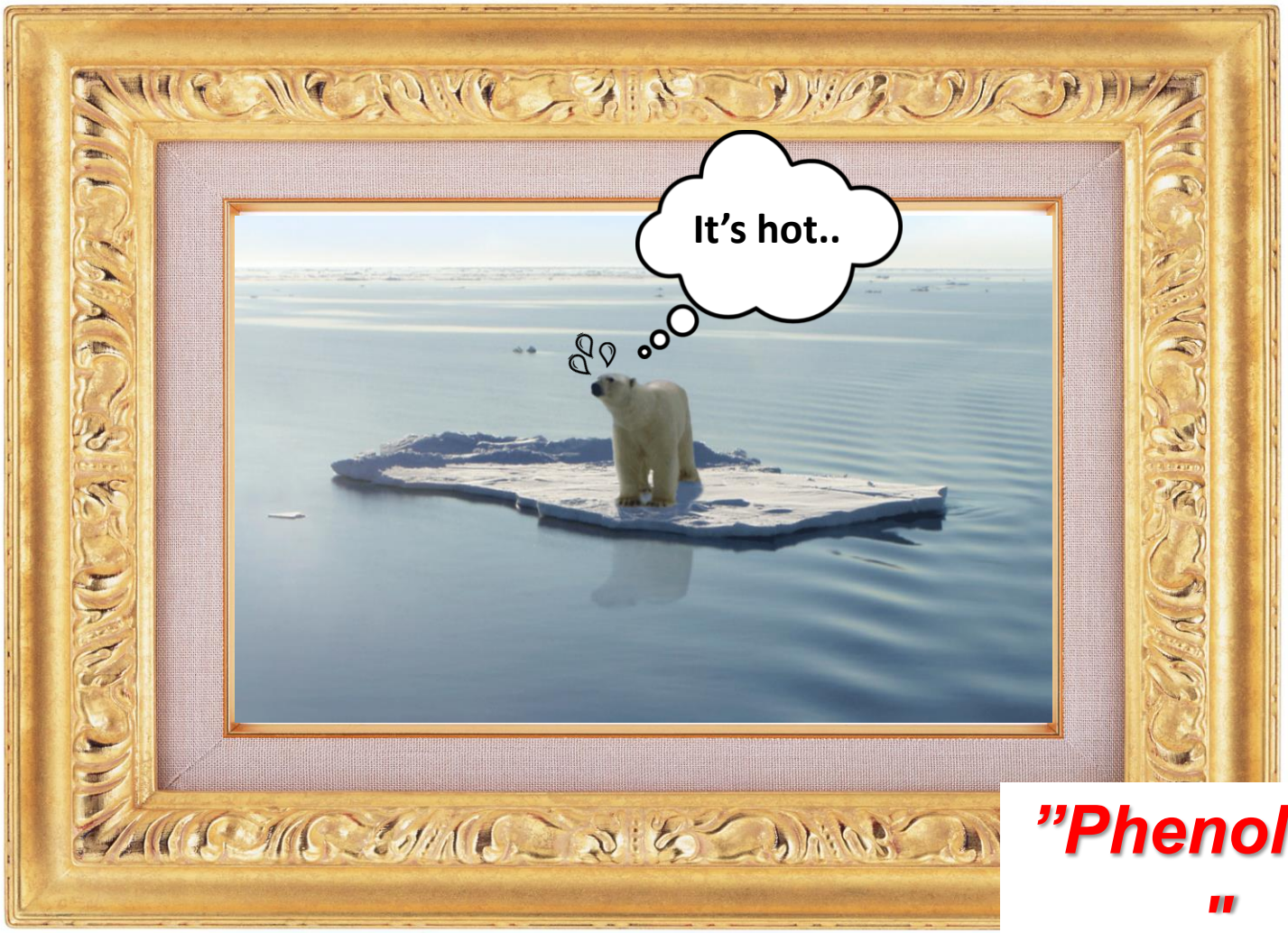
Polar Science Cente
University of Washi

SST year-to-year



"Phenology"

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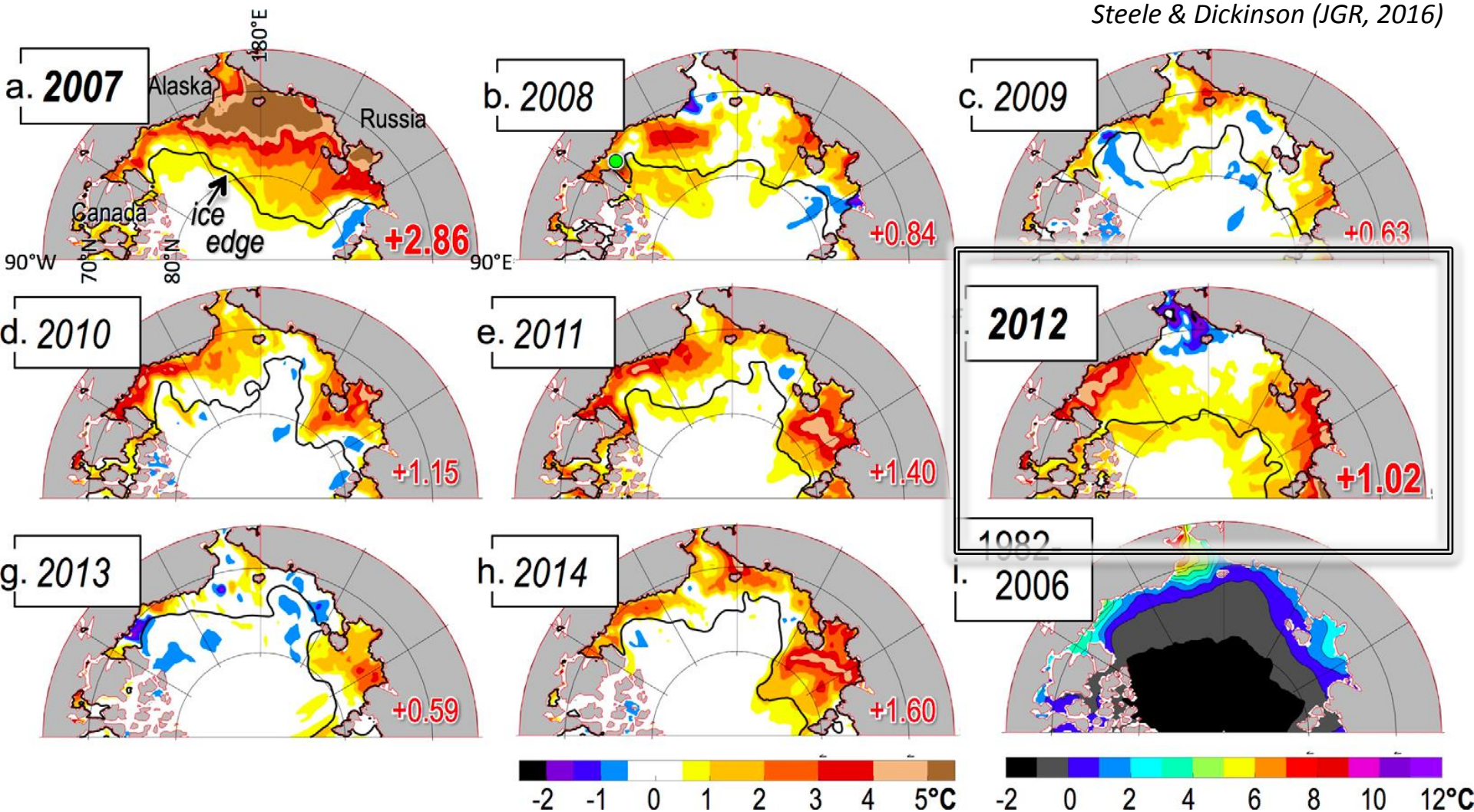
2012: Why were SSTs not so warm?

NCEI- Silver Spring
Sep 26, 2016

Steele & Dickinson (JGR, 2016)



SST: dOISST (AVHRR only)

Ice edge: 15% concentration (NASA Team1)

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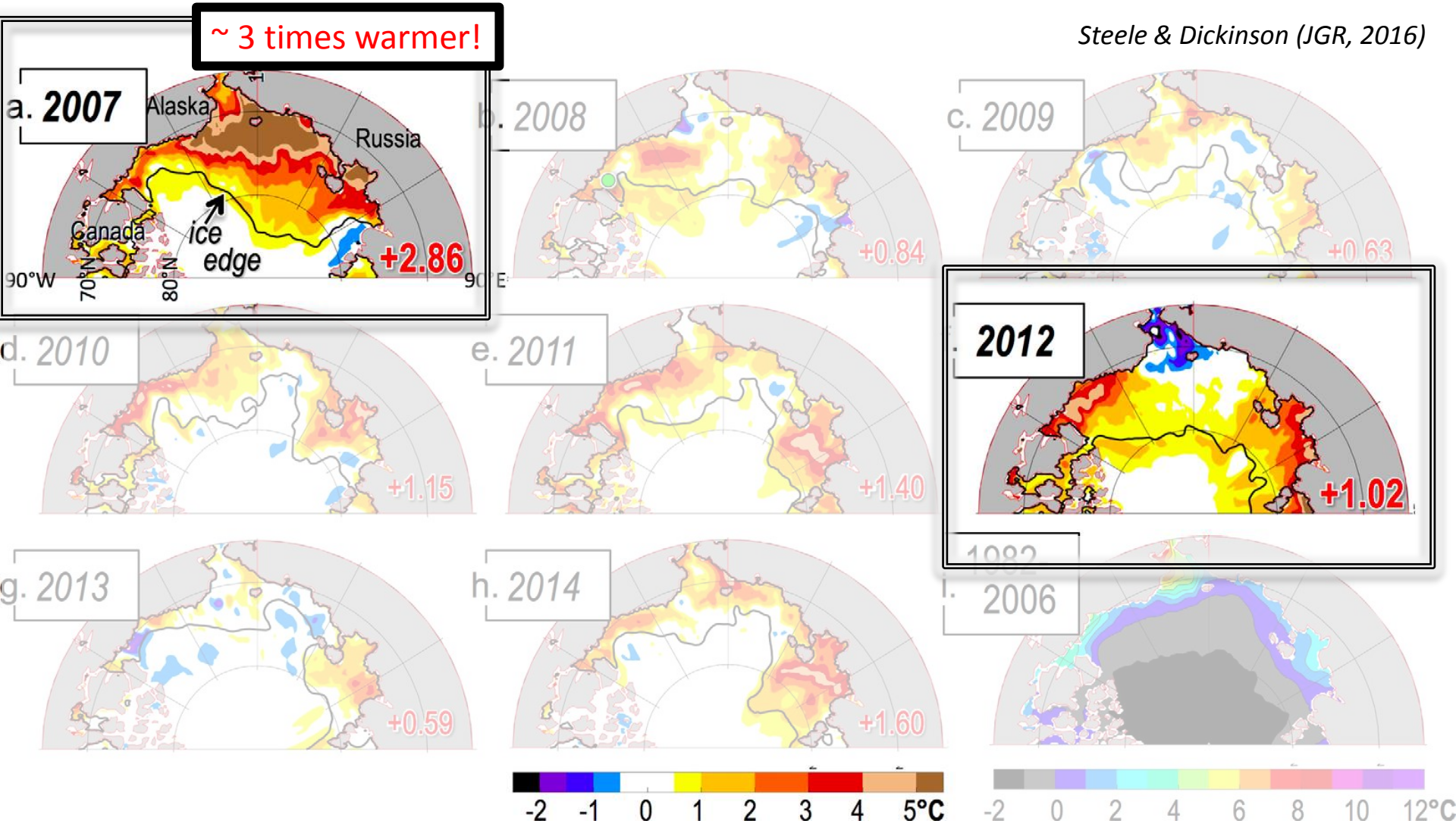
Seasonal **SST** warming

NCEI- Silver Spring
Sep 26, 2016

*Aug/Sept SST = **S**ea **S**urface **T**emperature anomalies*

Steele & Dickinson (JGR, 2016)



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NCEI- Silver Spring
Sep 26, 2016

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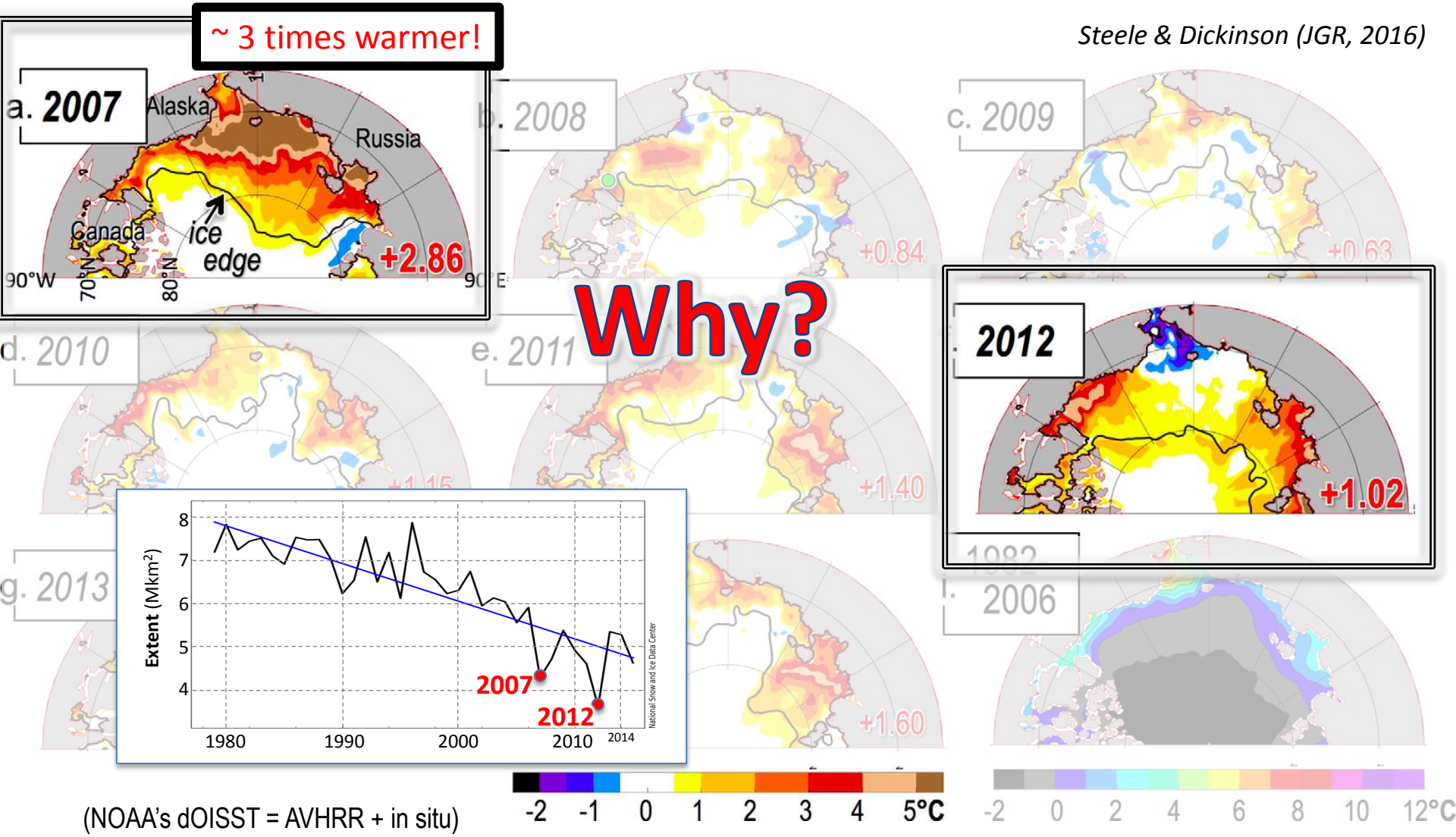

(NOAA's dOISST = AVHRR + in situ)

SST: dOISST (AVHRR only)

Ice edge: 15% concentration (NASA Team1)

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The "phenology" of SST warming

NCEI- Silver Spring
Sep 26, 2016

Steele & Dickinson (JGR, 2016)

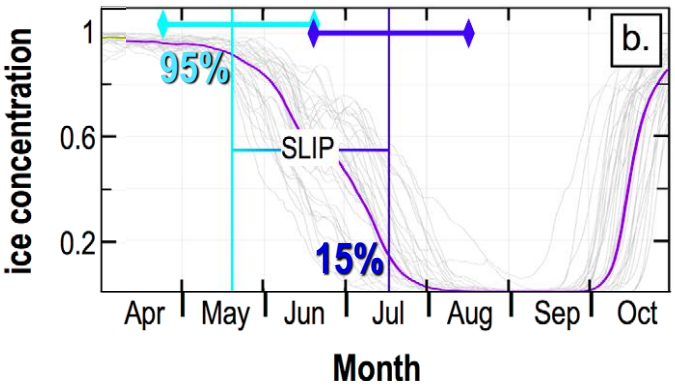
(NASA Team PMW 25 km) **ICE**

Date of Opening

Date of Retreat

1982-2014

E. Beaufort + Laptev



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The "phenology" of SST warming

NCEI- Silver Spring
Sep 26, 2016

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(NASA Team PMW 25 km) **ICE**

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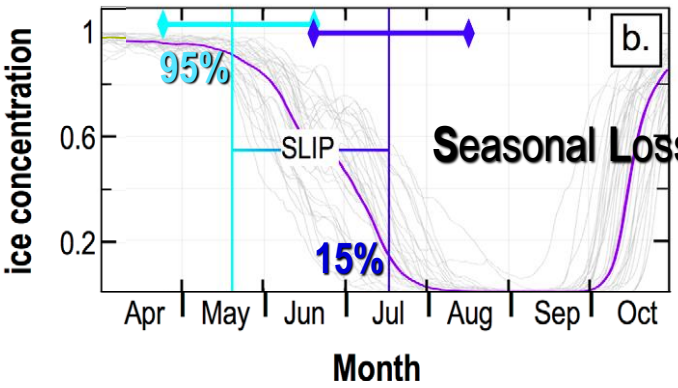

Seasonal Loss of Ice Period: *7 weeks!*

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The "phenology" of SST warming

NCEI- Silver Spring
Sep 26, 2016

Steele & Dickinson (JGR, 2016)

1982-2014

E. Beaufort + Laptev

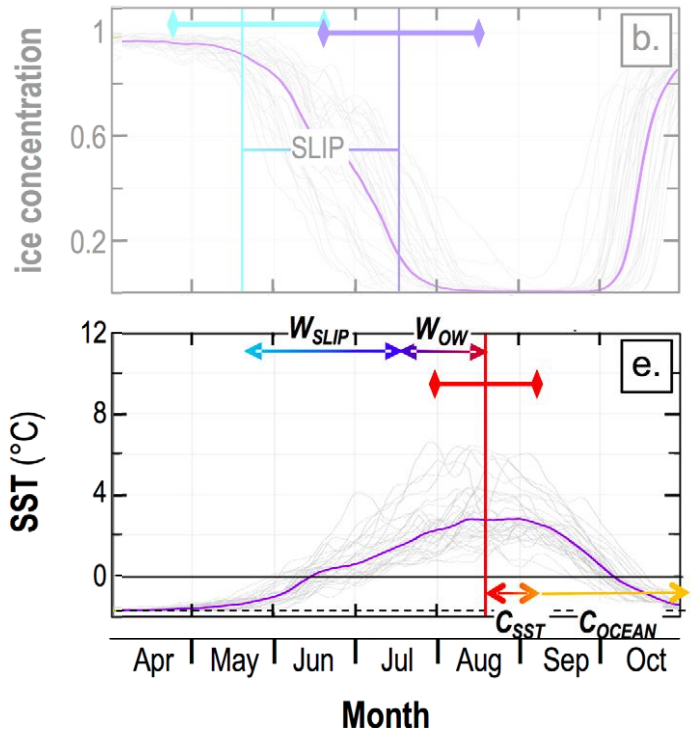
ICE

Date of Opening

Date of Retreat

(dOISST AVHRR 0.25°) **SST**

Date of T_{max}



T_{max} ~ mid-late August

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The "phenology" of SST warming

NCEI- Silver Spring
Sep 26, 2016

1982-2014

Steele & Dickinson (JGR, 2016)

E. Beaufort + Laptev

ICE

Date of Opening

Date of Retreat

SST

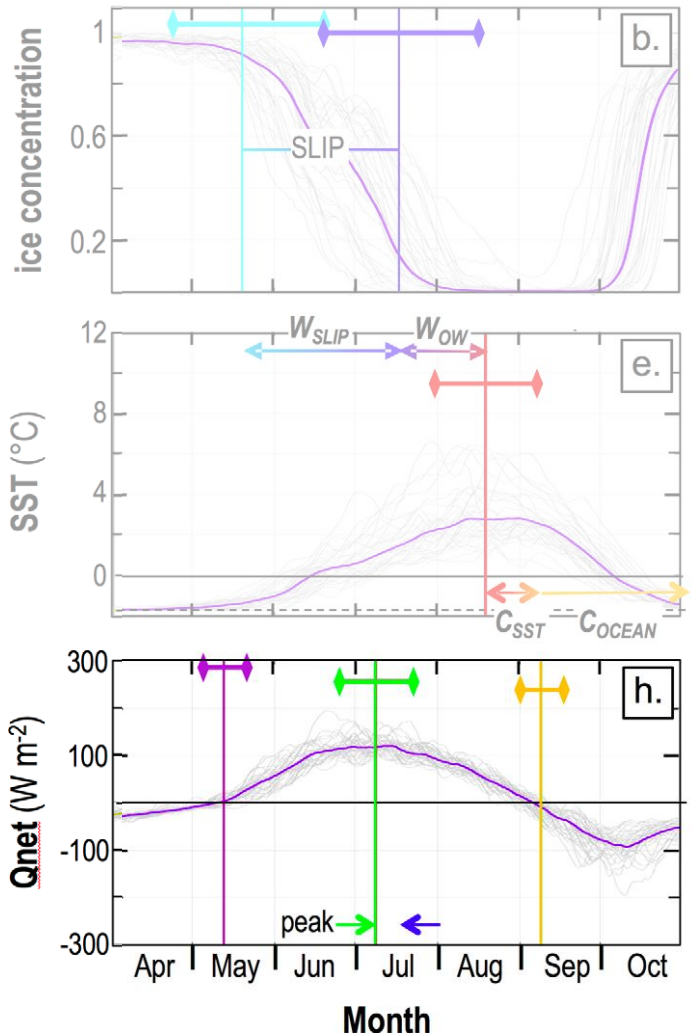
Date of T_{max}

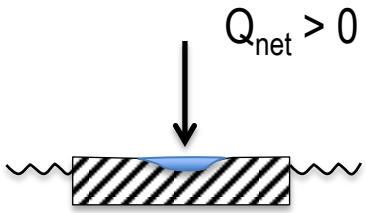
(MERRA1) **Q_{net}**

Date of $Q_{net} > 0$

Date of max Q_{net}

Date of $Q_{net} < 0$





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University of Washington

The "phenology" of SST warming

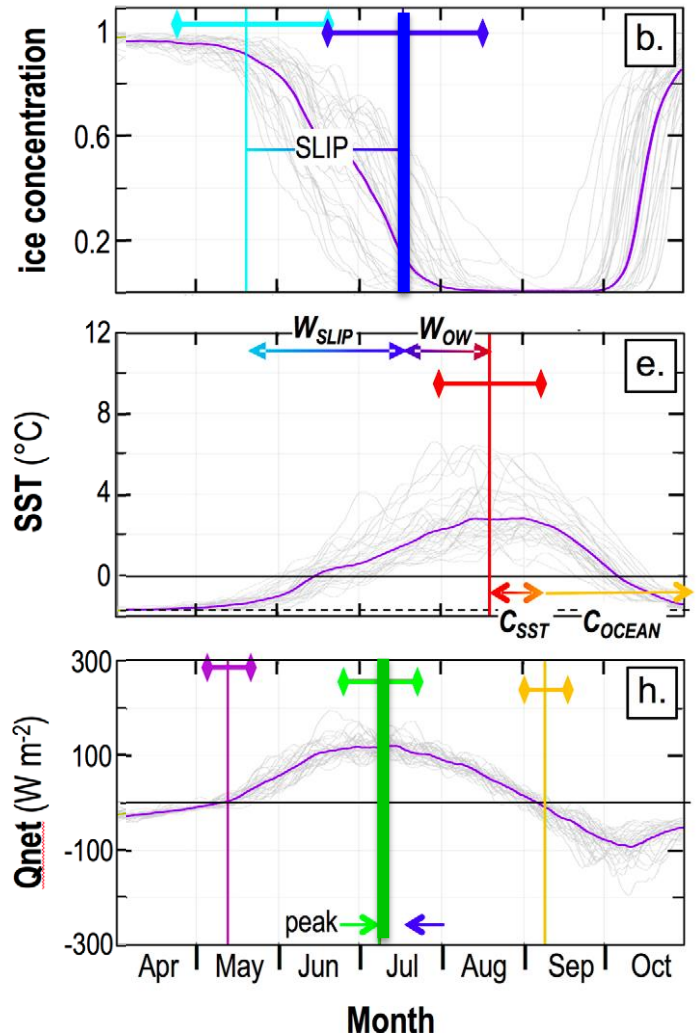
NCEI- Silver Spring
Sep 26, 2016

1982-2014

E. Beaufort + Laptev

Date of Retreat

Date of max Q_{net}



DOR > **DOQ**

☞ Open water appears only **after** Q_{net} has started to decline!

…even more in later DOR areas

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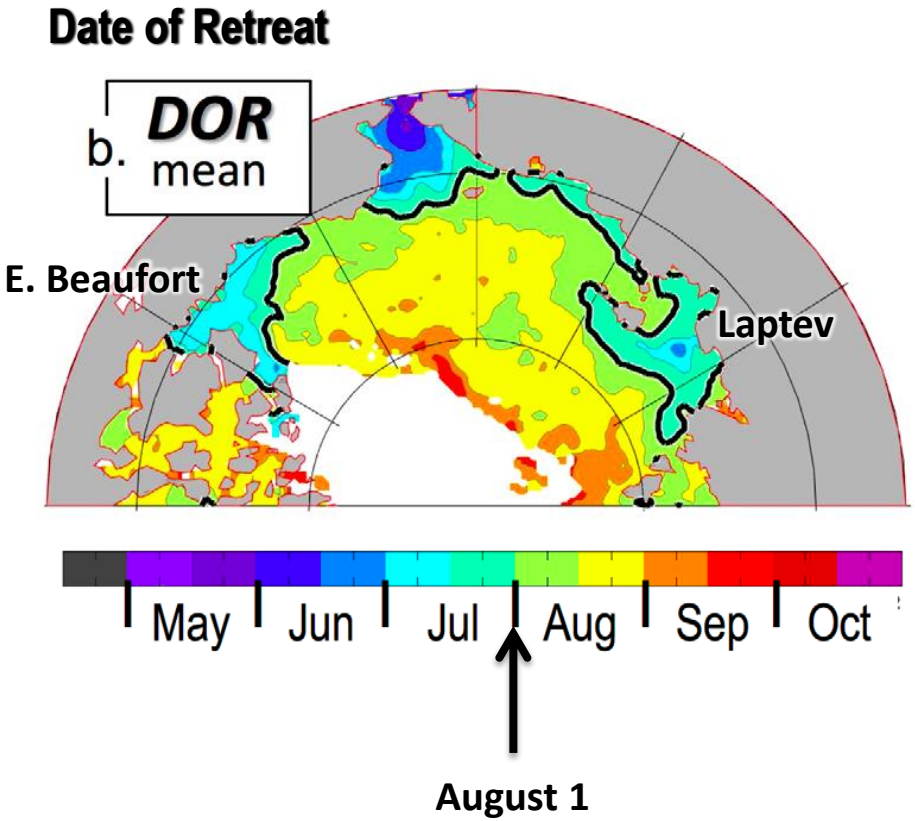
University of Washington

DOR vs. **SSTmax**

1982-2014



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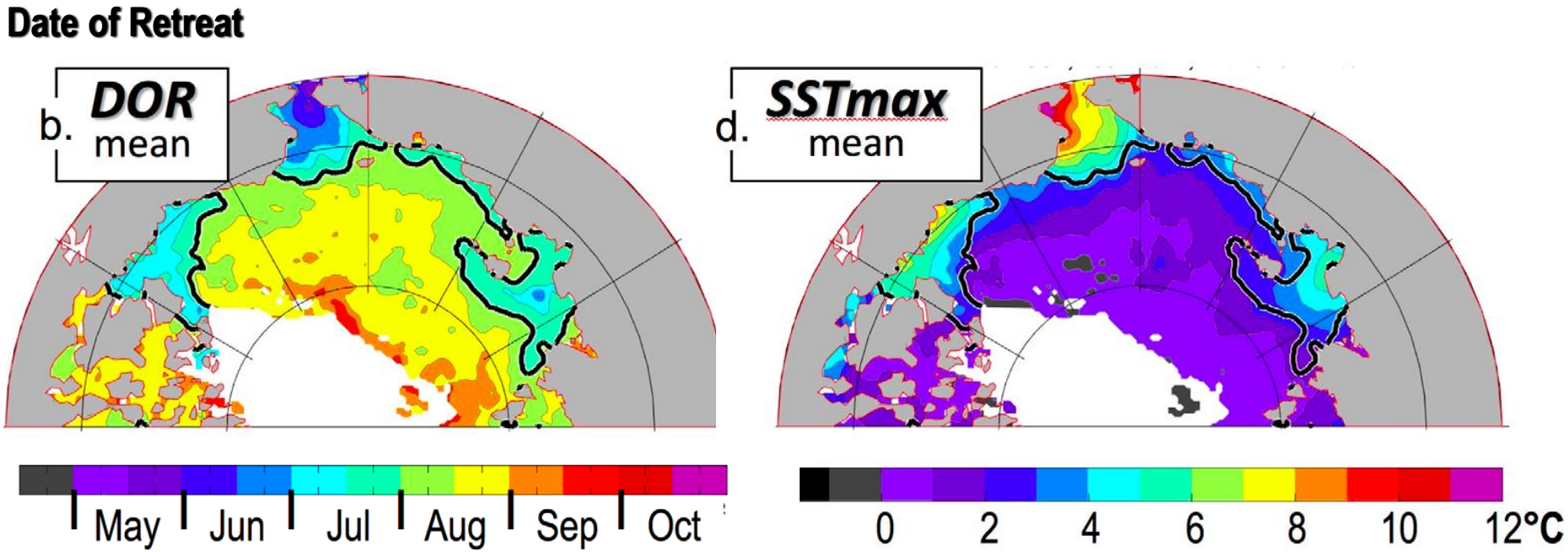
University of Washington

DOR vs. **SSTmax**

1982-2014



Early retreat ➔ warmer SSTmax

Also: variance, correlation

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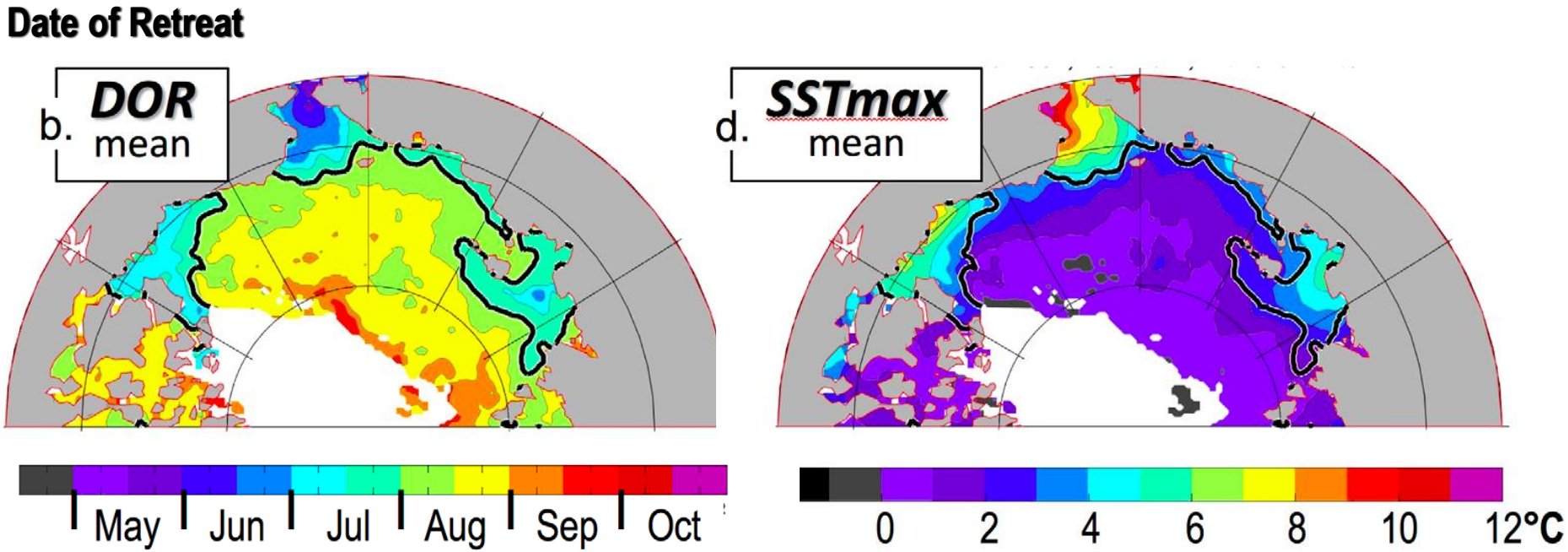
University of Washington

DOR vs. SSTmax

1982-2014



Early retreat ➔ warmer SSTmax

…but ONLY when DOR is near DOQ!!!

Date of max Q_{net}

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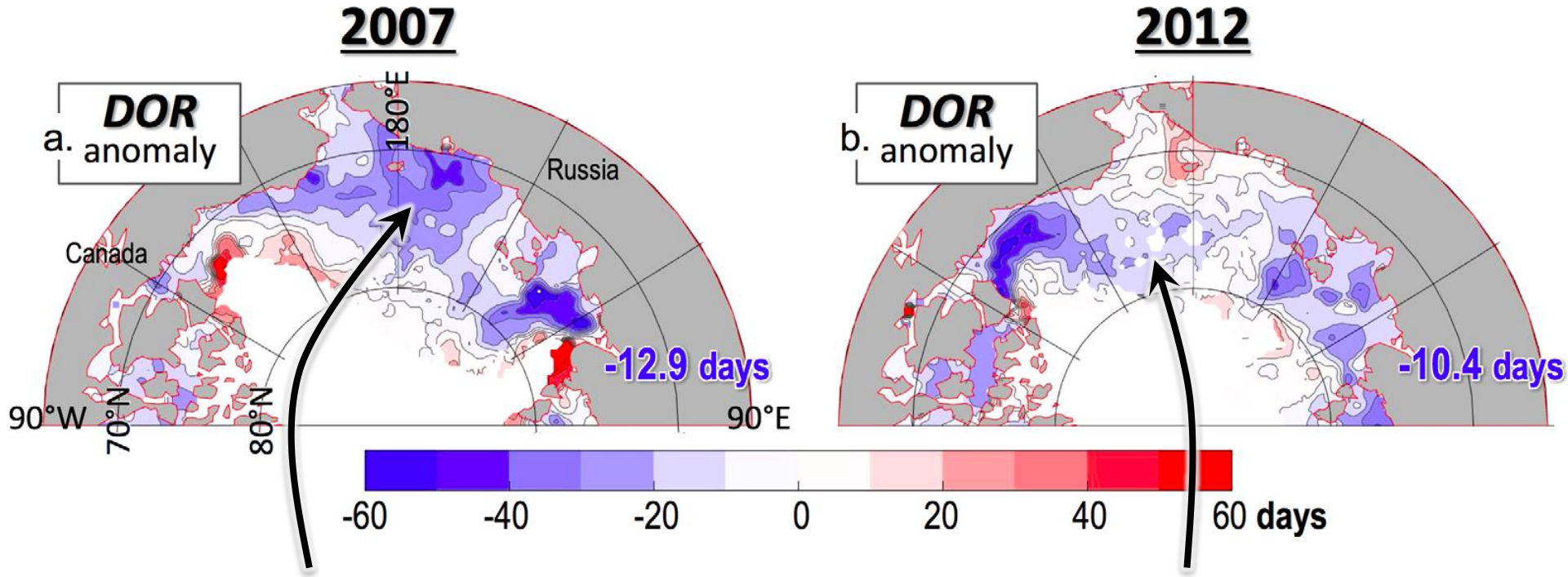
University of Washington

It's about the ***timing*** of ice retreat



Early retreat

DOR ~ DOQ

(June/July)

Warm SSTs

"Early" retreat…but

DOR >> DOQ

(Aug/Sep)

Cold SSTs

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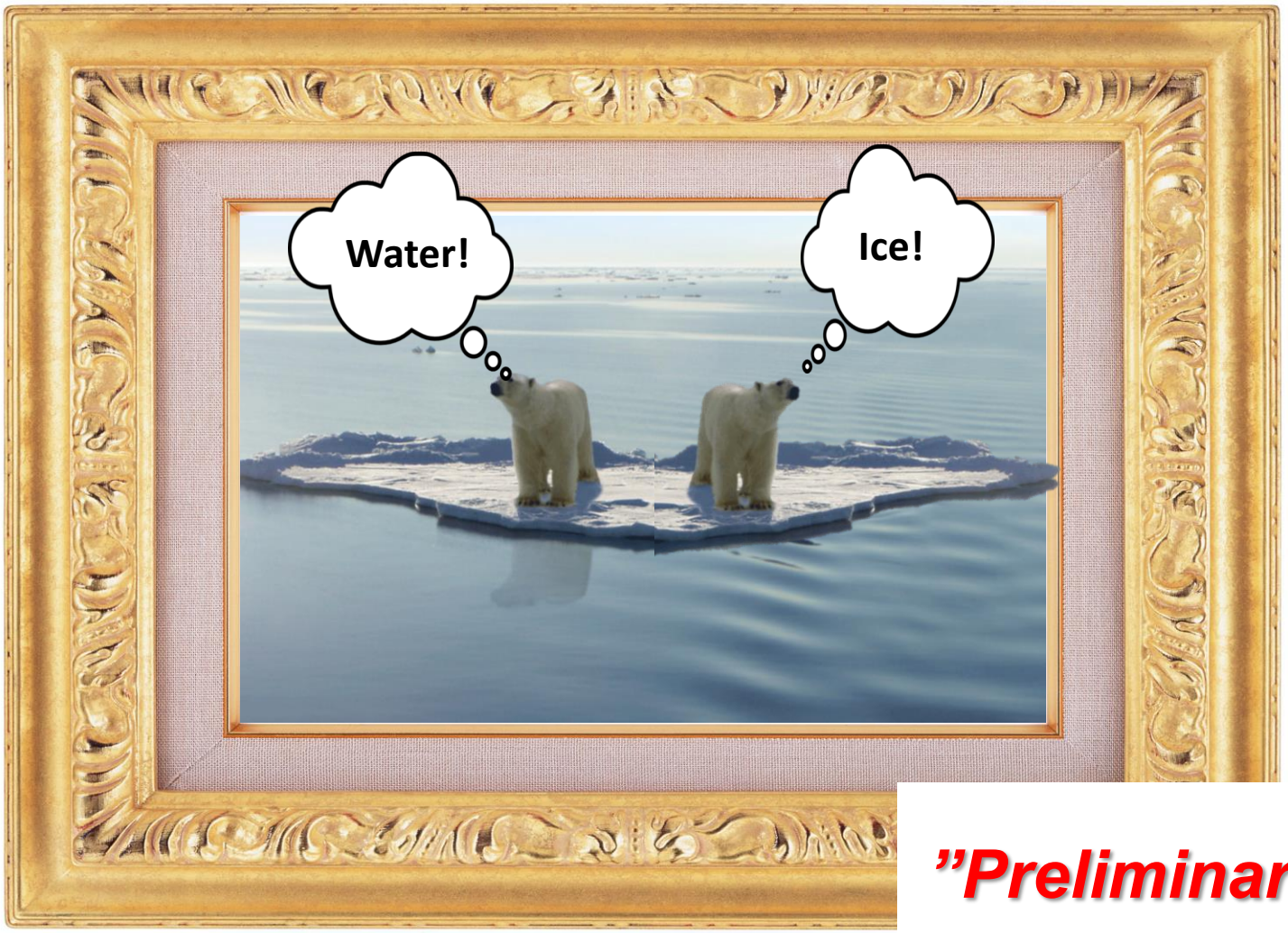
University of Washi

SST across the MIZ



"Preliminary!!"

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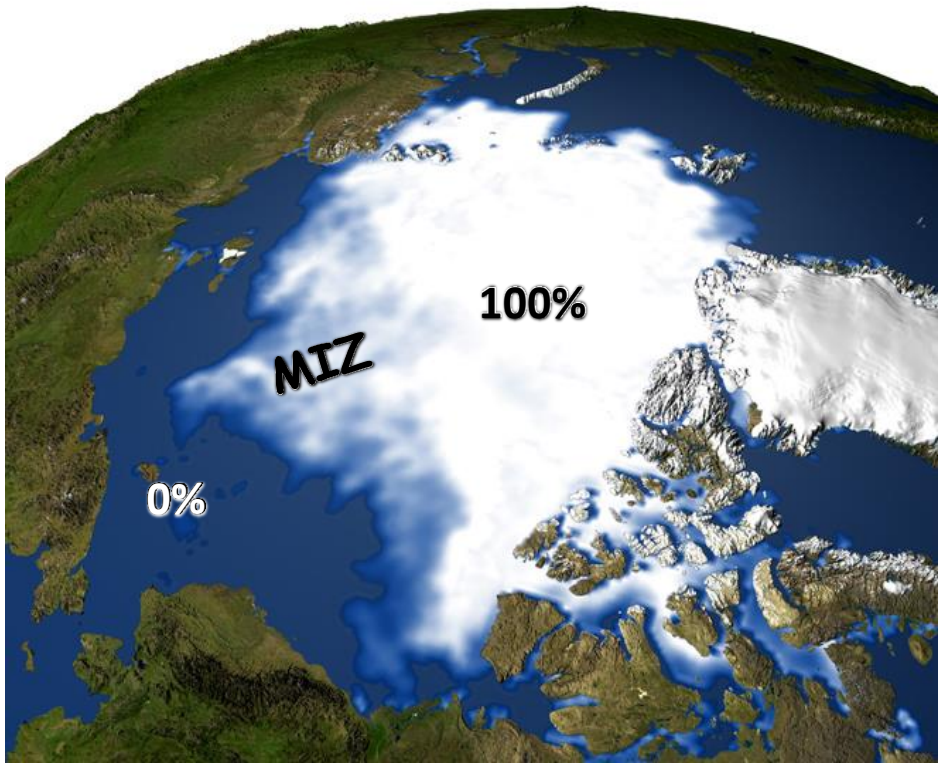
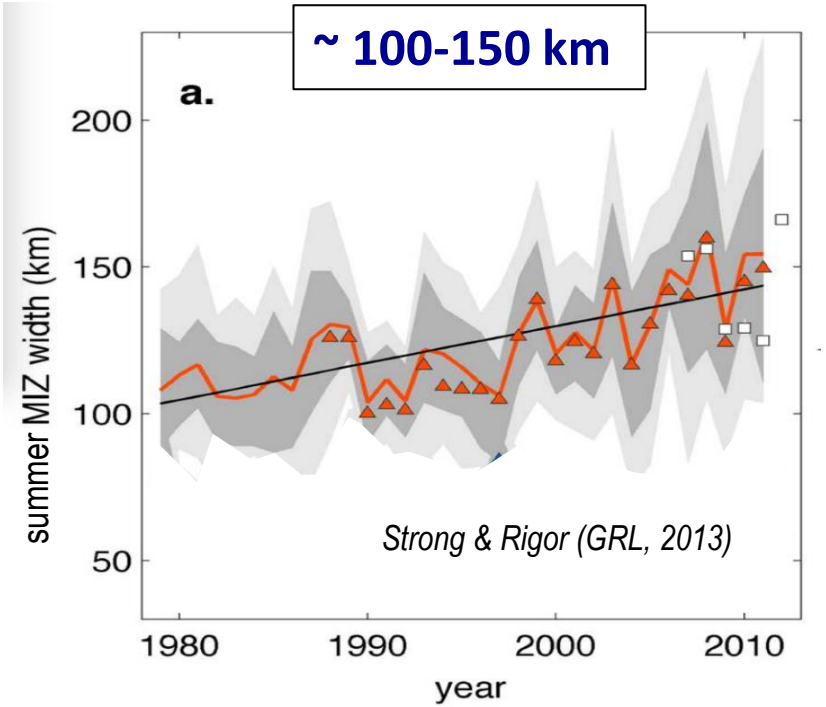
The **M**arginal **I**ce **Z**one (**MIZ**)





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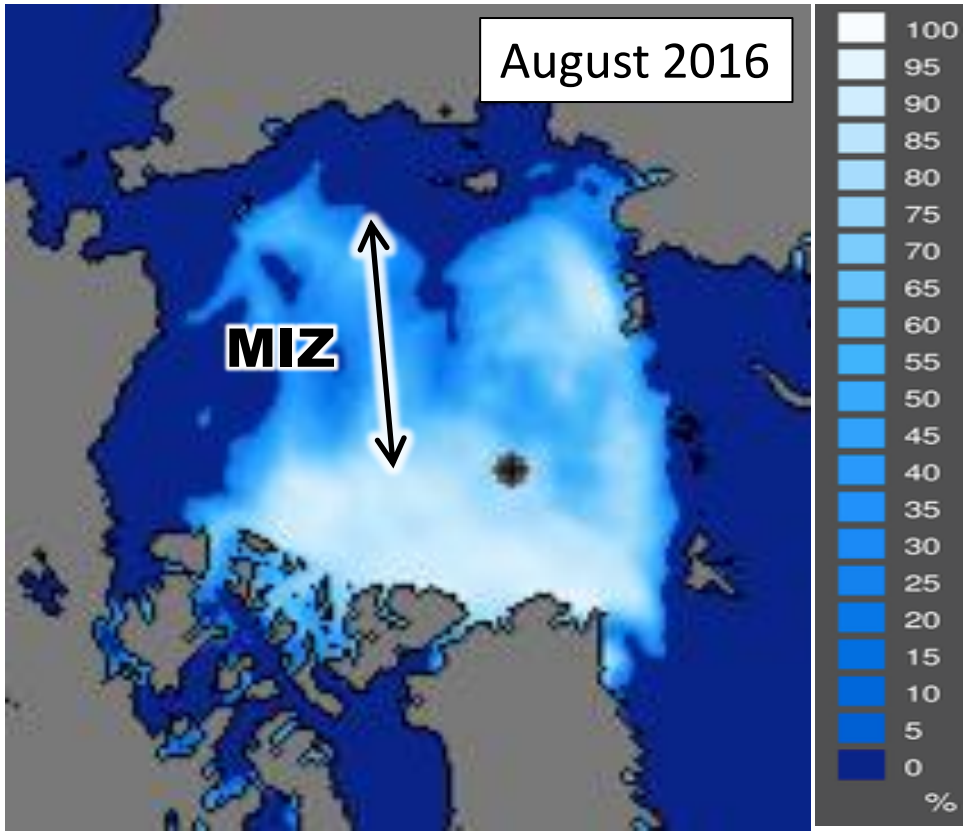
MIZ ~ Arctic Ocean!



ice conc.

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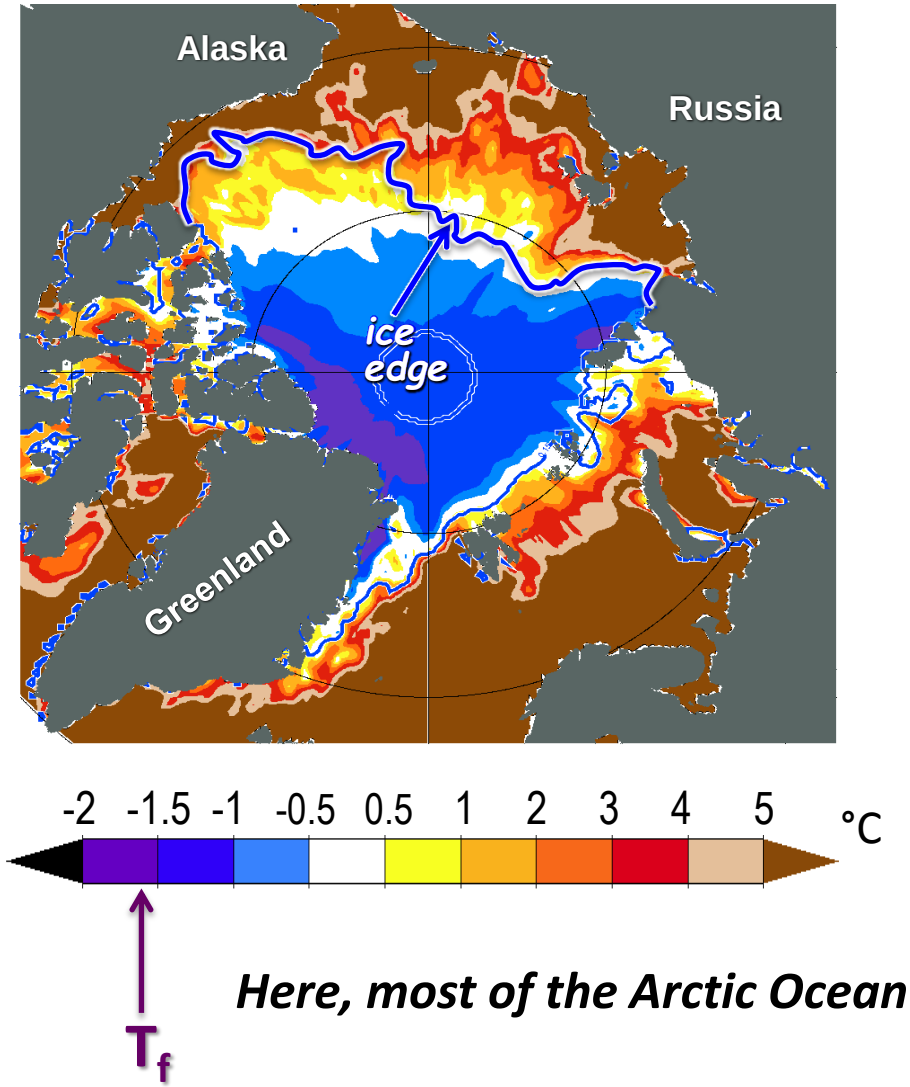
Polar Science Cente
University of Washin

SST within the ice pack?

SST: August 15, 2007 ***dOISST***



Here, most of the Arctic Ocean SST > T_f

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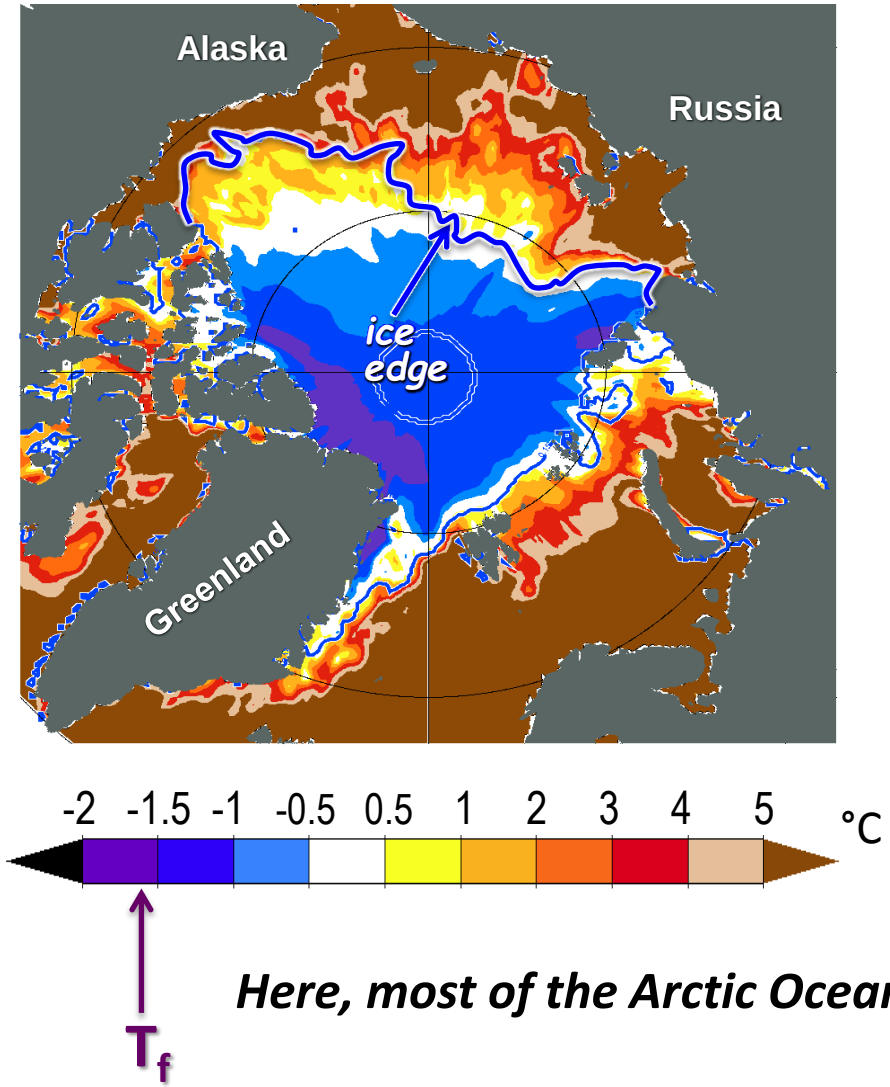
University of Washin

Warm SST under the ice?!

SST: August 15, 2007 ***dOISST***



This is built into *(most)* **L4 SSTs**

...but how realistic is it?

Here, most of the Arctic Ocean SST > T_f

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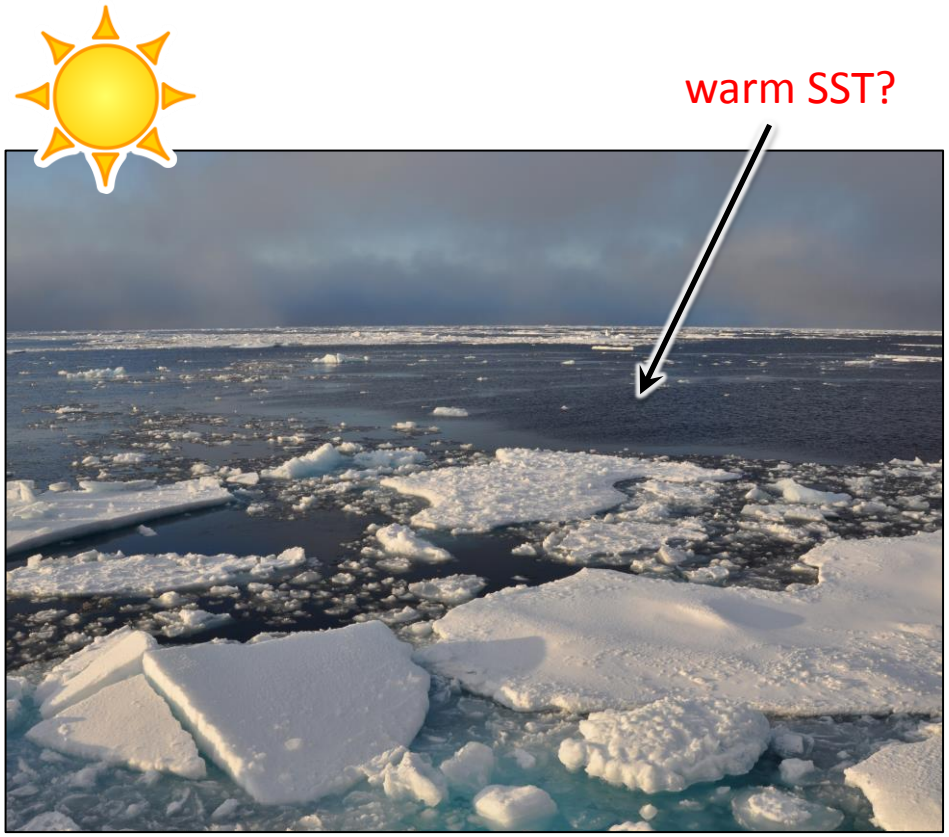
SST in the MIZ *(summer)*



0 < ice concentration < 100%

- How **warm**?
- How **deep**?
- **Wind**, **solar** forcing?

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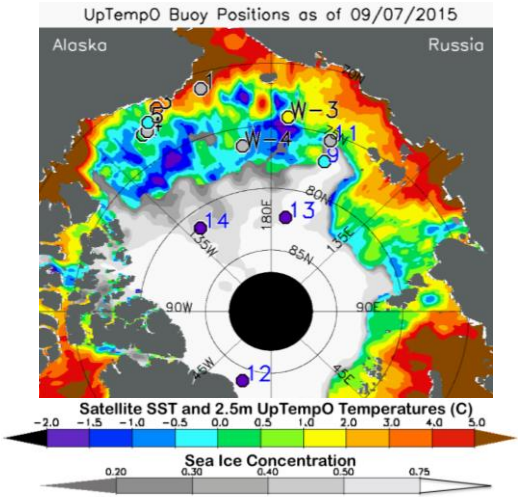
NCEI- Silver Spring
Sep 26, 2016

MIZ SST obs



"UpTempO" buoy project

ship + aircraft deployments

2012 – present

Steele et al., JTech 2016 in prep.

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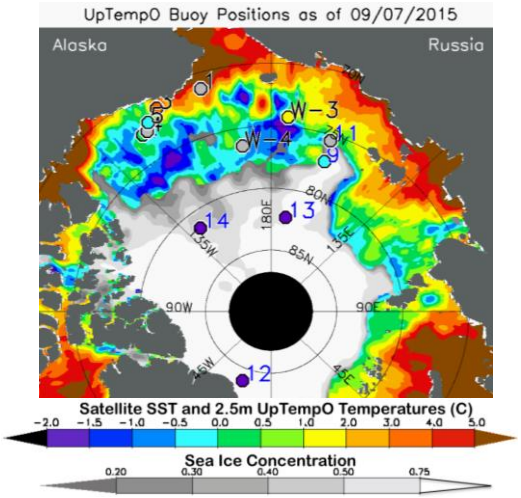

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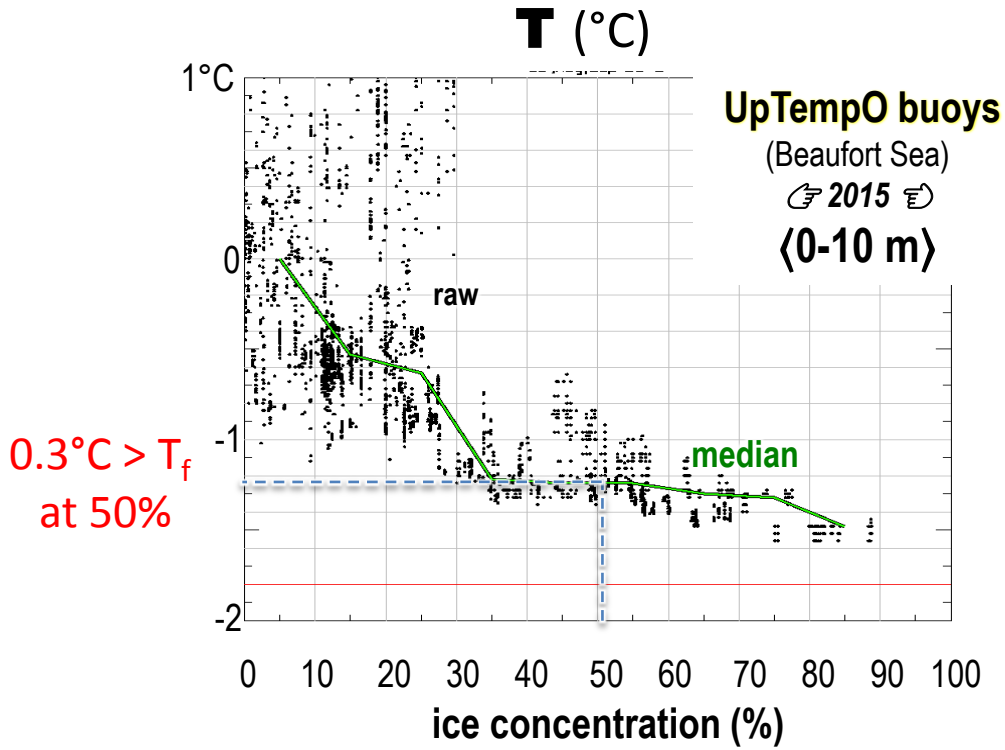

NASA Team (SSMI/SSMIS 25 km passive μwave)

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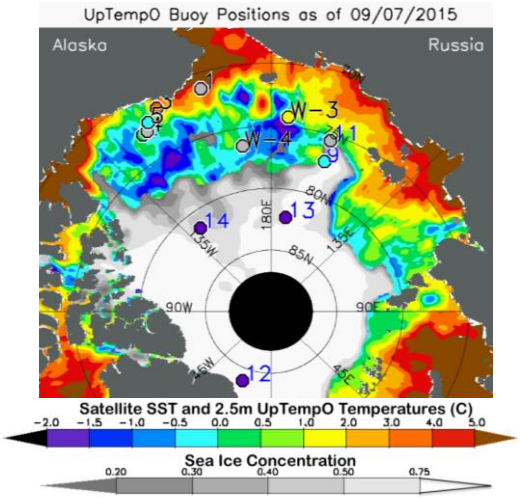
MIZ SST obs



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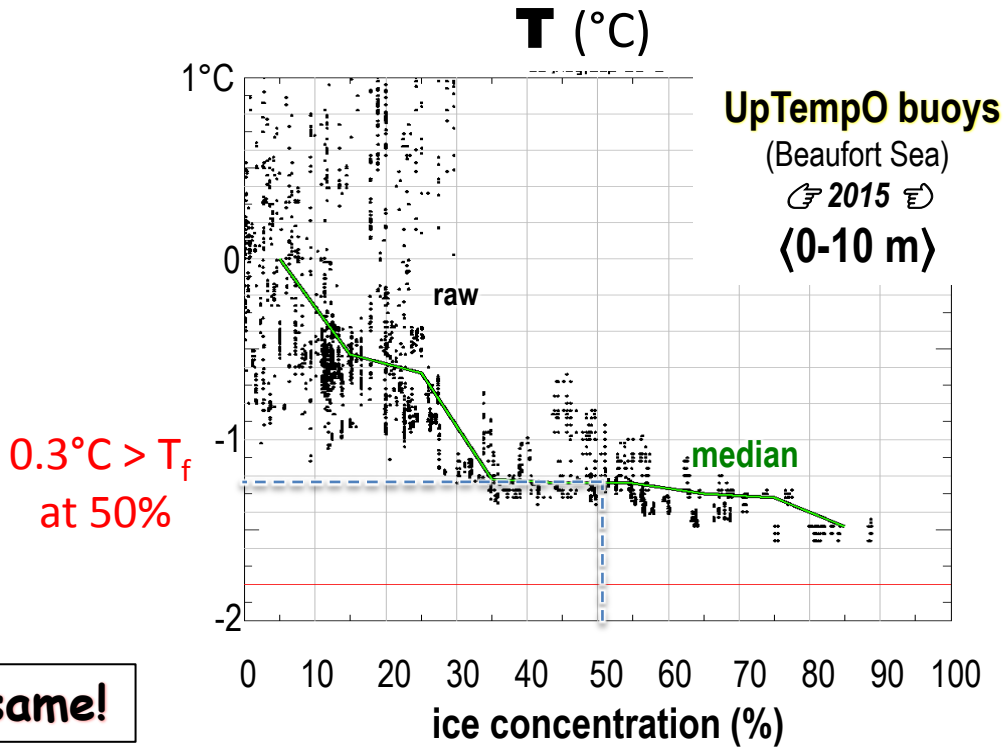
⟨0-5 m⟩, ⟨0-1 m⟩ ~ same!



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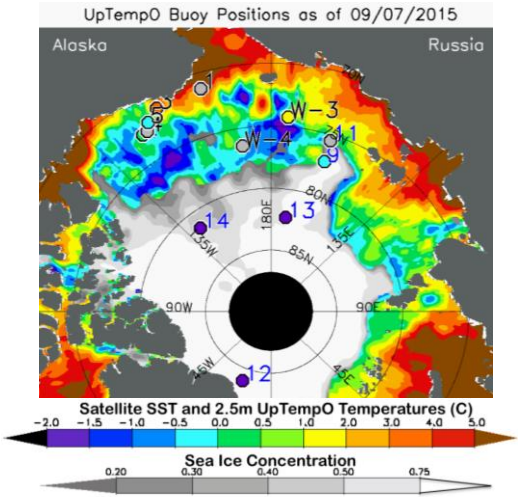

"UpTempO" buoy project

ship + aircraft deployments

2012 – present

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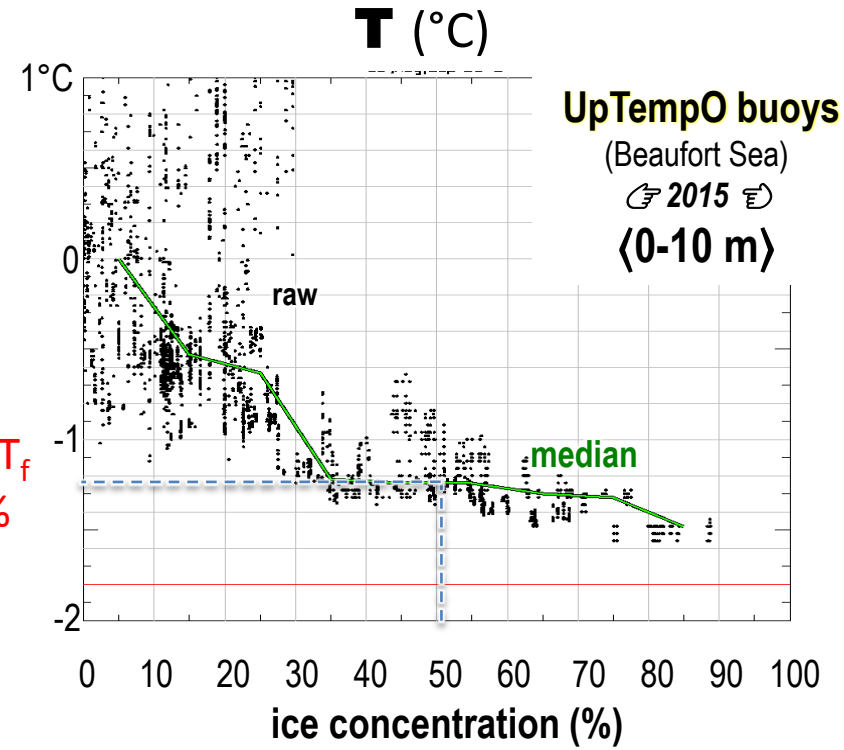
⟨0-5 m⟩, ⟨0-1 m⟩ ~ same!

0.3°C > T_f
at 50%



NASA Team (SSMI/SSMIS 25 km passive μwave)

- Similar for: **ship CTD, AxCTD**
- To do: **gliders**

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MIZ SST dOISST

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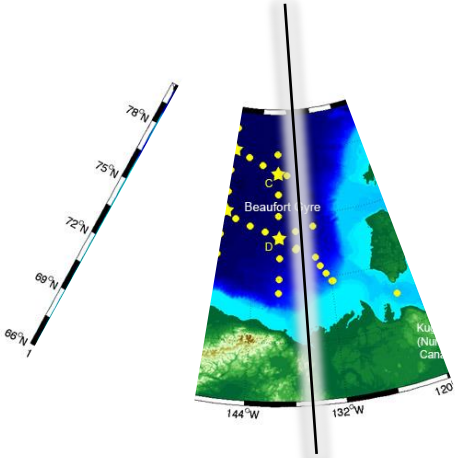
MIZ SST dOISST

August 2012

65-90°N, 120-150°W



135°W

Ice Concentration

"simulated" SST = b' IC + c'

for IC > 50%

SST(IC=100%) = -1.8°C

b', c' from regressions

("historical AVHRR + in situ obs")

30° longitude bands, monthly mean

Reynolds et al., J. Clim. 2007

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MIZ SST dOISST

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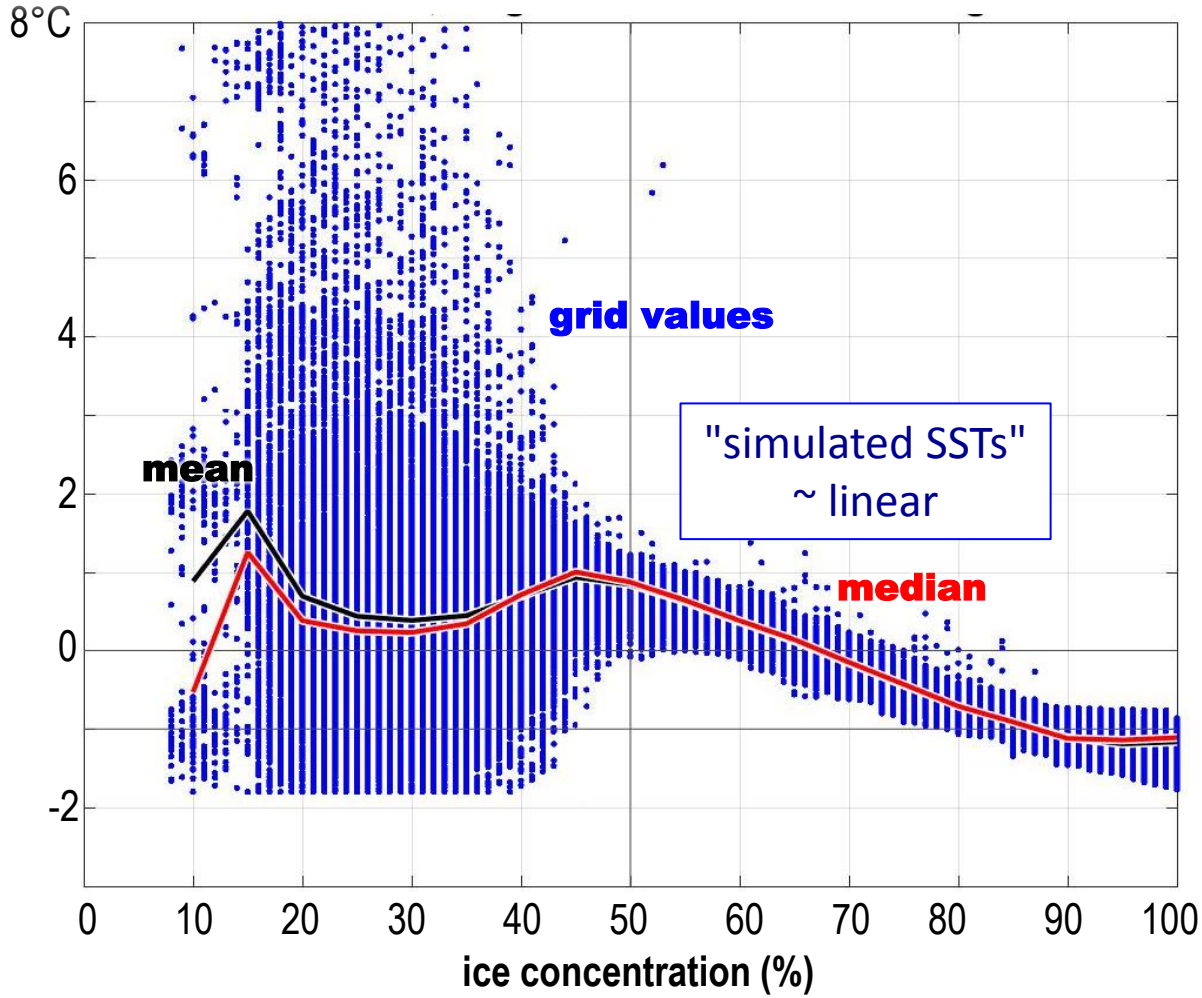

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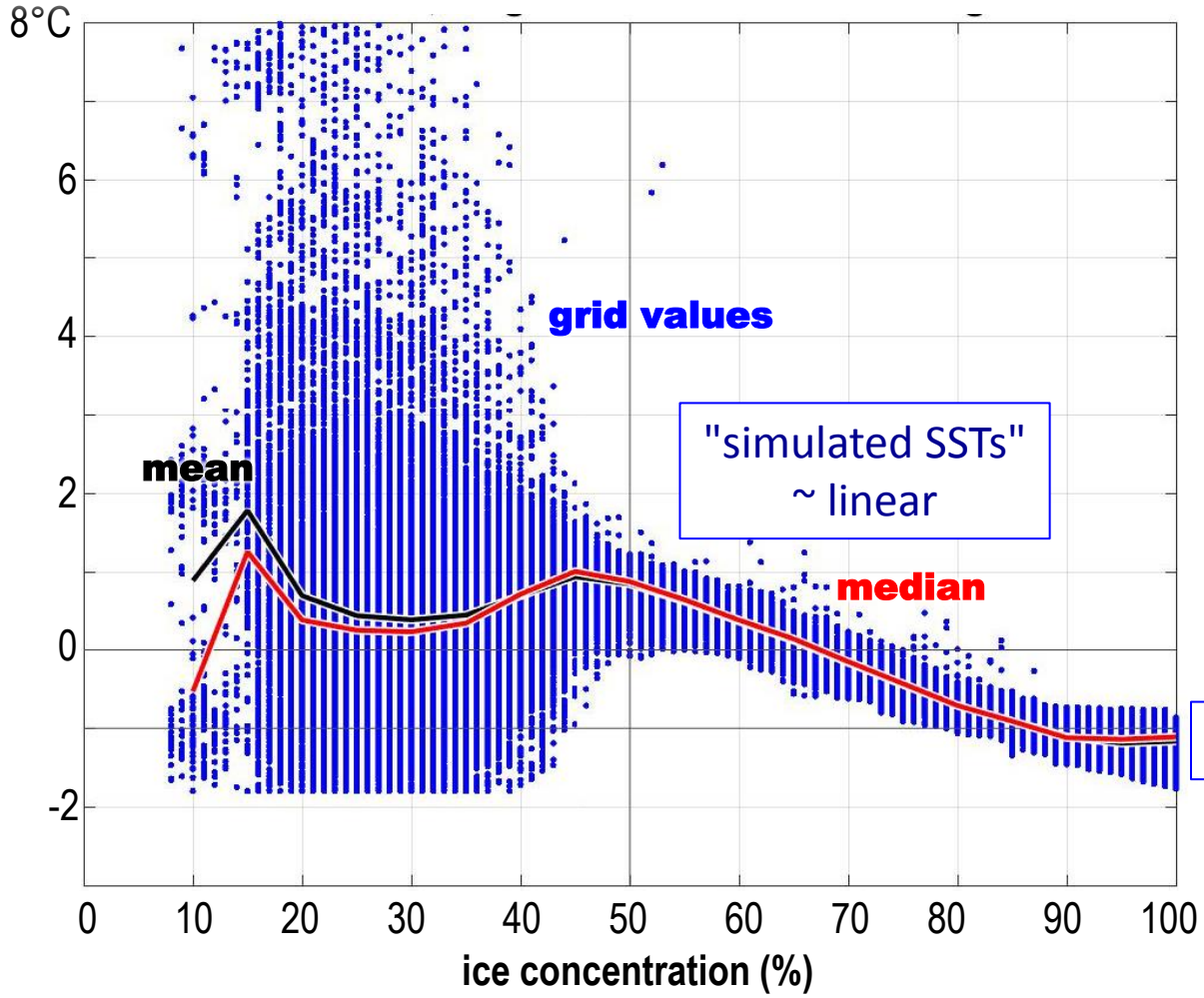

Too warm T_f?

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MIZ SST dOISST

August 2012

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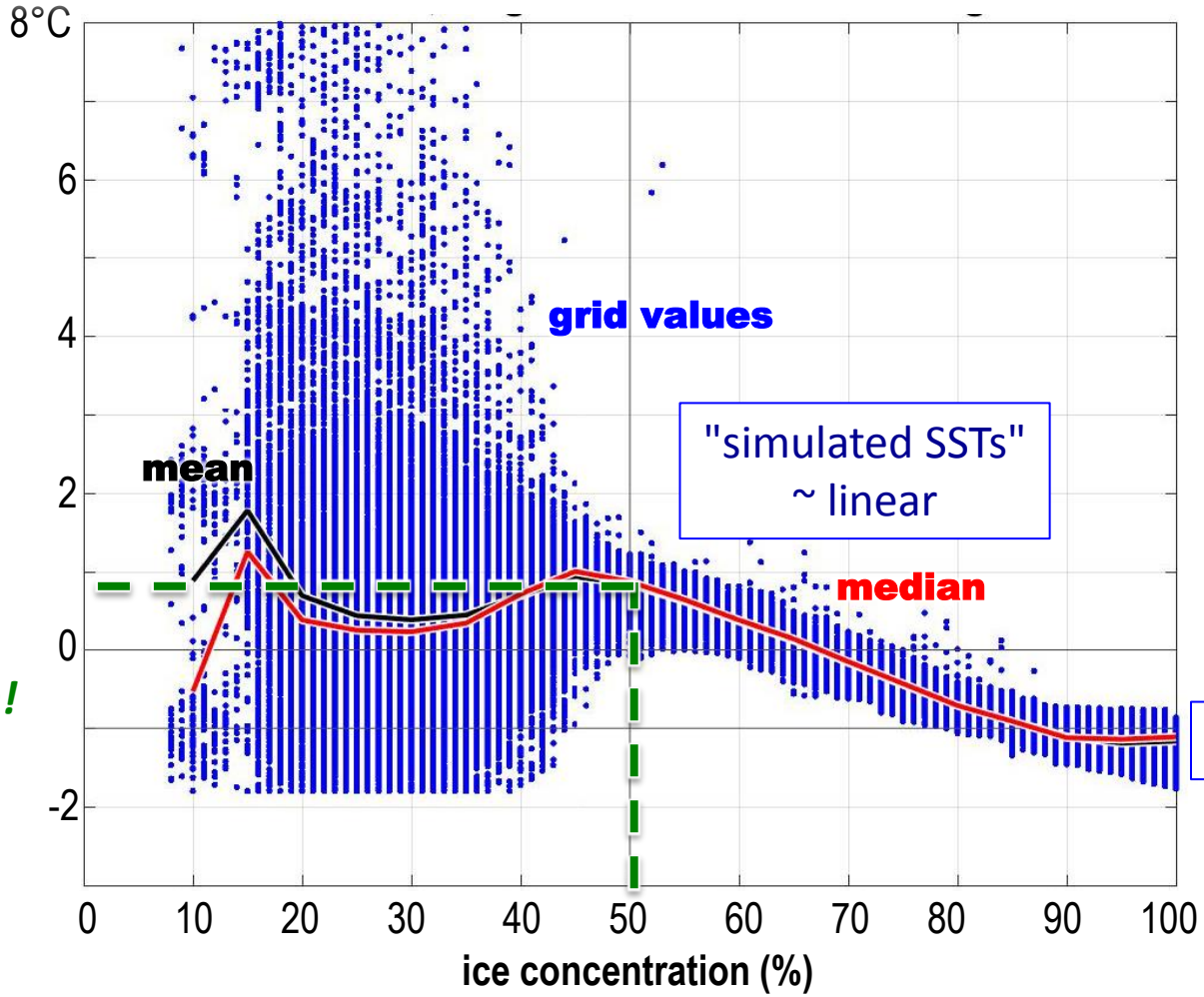
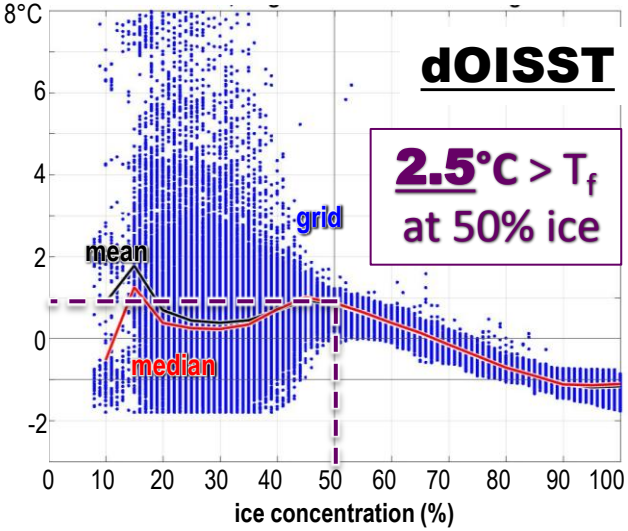


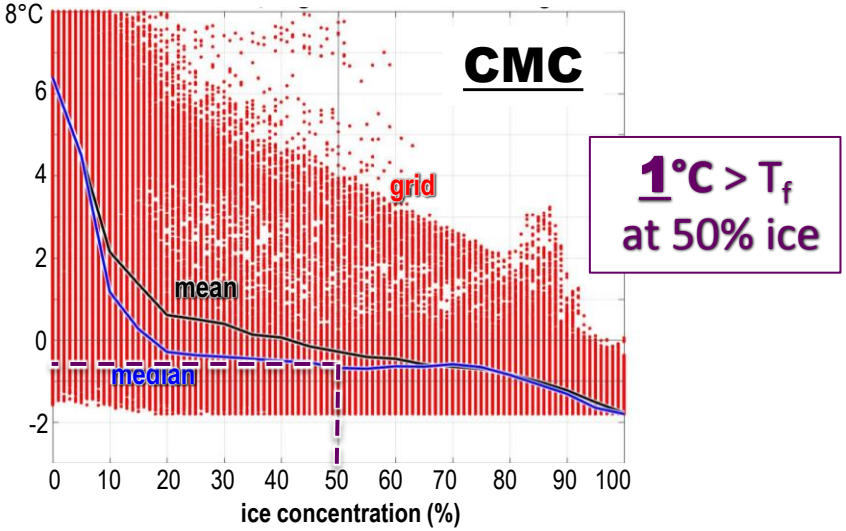
2.5°C > T_f
at 50%

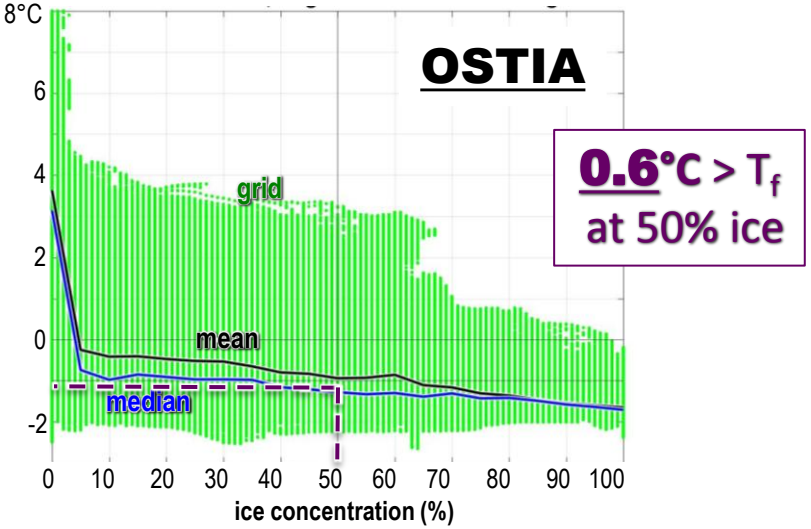
...too warm!

L4 **SST** vs **IC** intercomparison

August 2012
65-90°N, 120-150°W







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Summary

- *The Arctic* ➔ one big **S**easonal **I**ce **Z**one!

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- *The Arctic* ➔ one big **S**easonal **I**ce **Z**one!
- *End of summer 2016*: It was one big **M**arginal **I**ce **Z**one!

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Summary

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- *It's about the 3 P's:*
  - **P**roperties, **p**rocesses, & **p**rediction

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Thank you