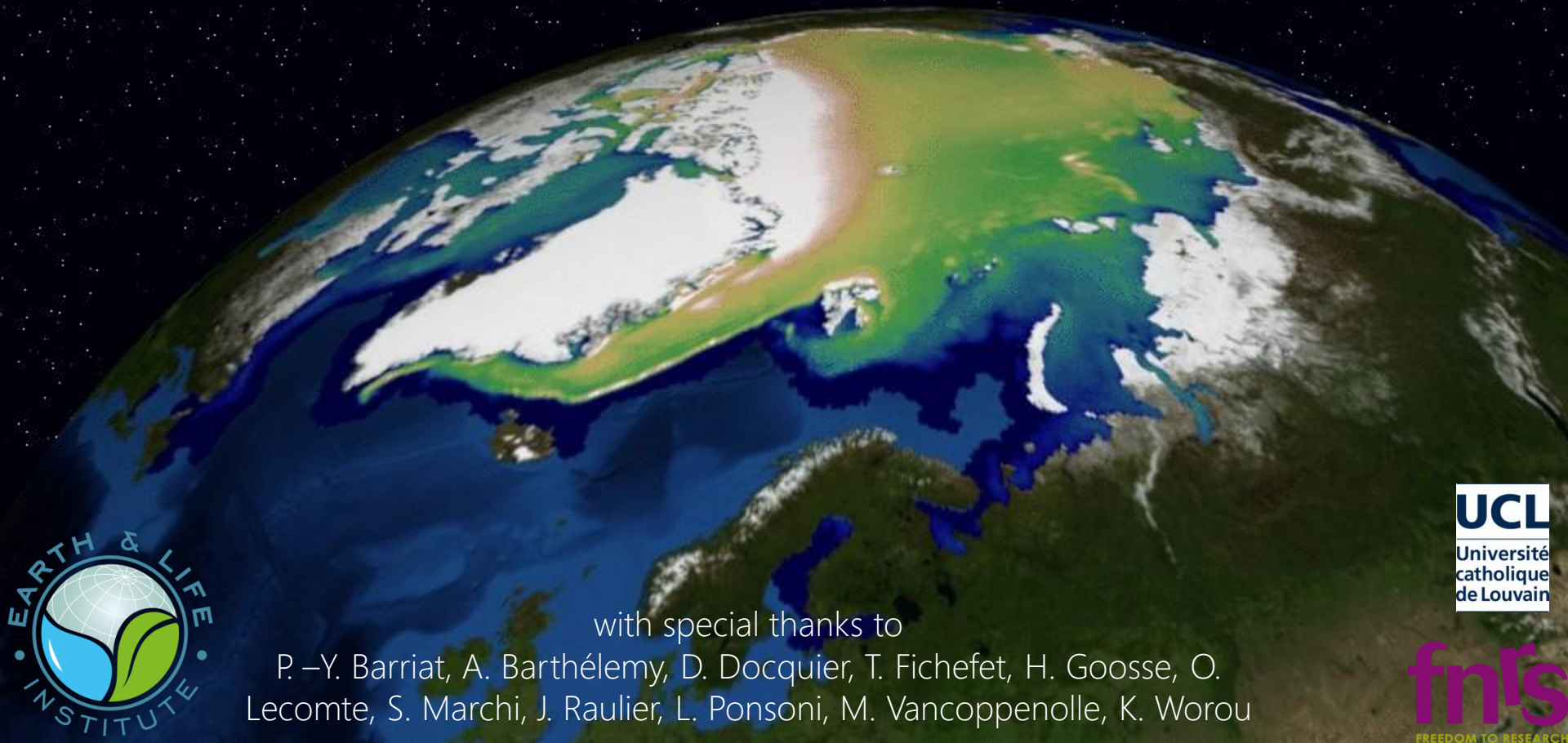


Royal Meteorological Institute
May 12th 2017

Past and future sea-ice variability

François Massonnet

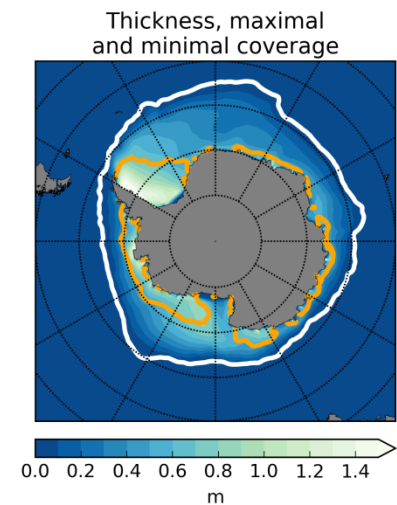
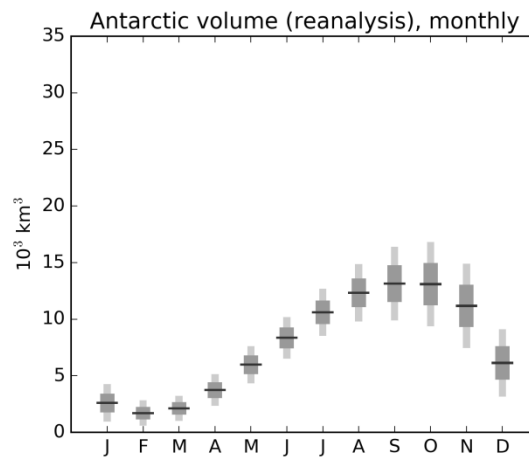
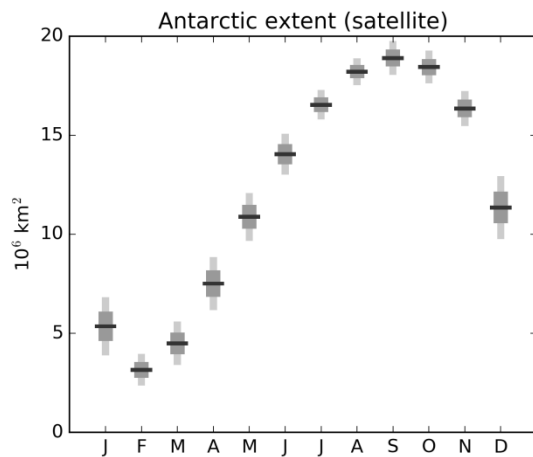
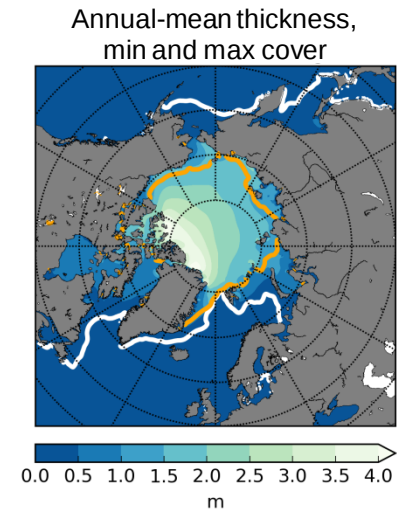
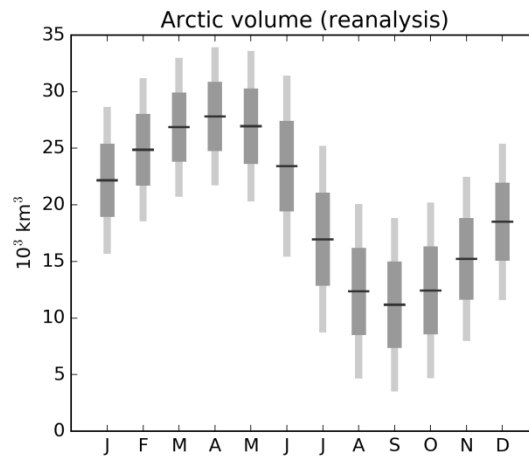
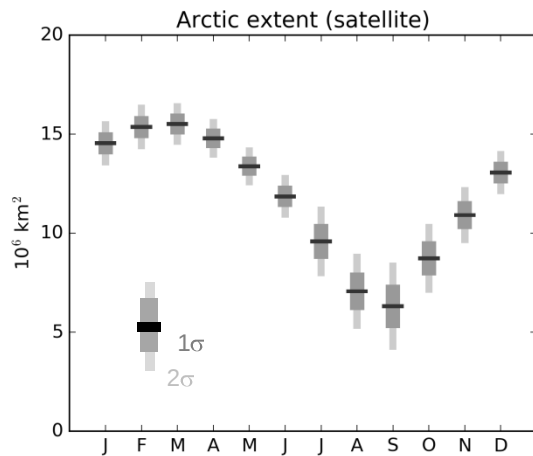


with special thanks to

P. -Y. Barriat, A. Barthélemy, D. Docquier, T. Fichefet, H. Goosse, O. Lecomte, S. Marchi, J. Raulier, L. Ponsoni, M. Vancoppenolle, K. Worou



Sea-ice mean state (1979-2016)



Extent data: NSIDC sea ice index. NH volume: PIOMAS. SH volume: ORAP5.

Sea-ice variability

Observed?

Sea-ice variability

Observed?



Unusual?

Sea-ice variability

Observed?



Unusual?



Attributable?

Sea-ice variability

Observed?



Unusual?



Attributable?



Predictable?

Sea-ice variability

Observed?



Unusual?



Attributable?



Predictable?



Important at all?

Sea-ice variability

Observed?

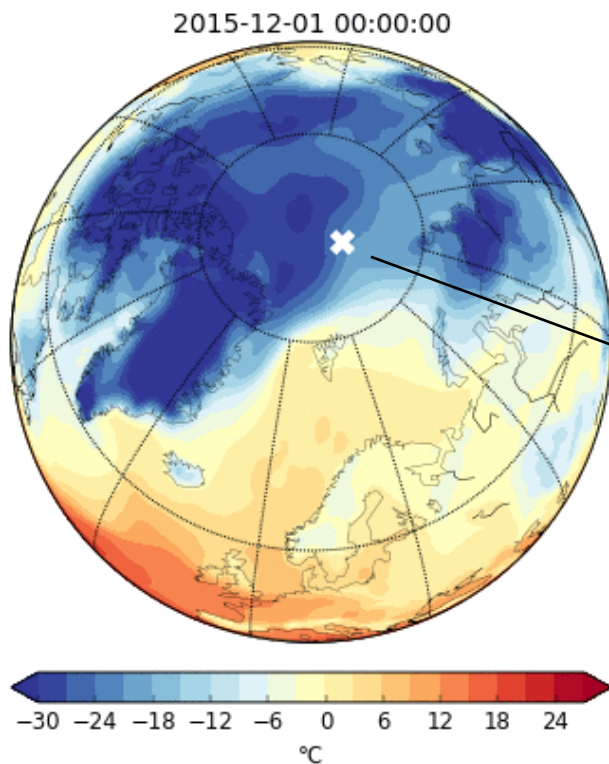
Unusual?

Attributable?

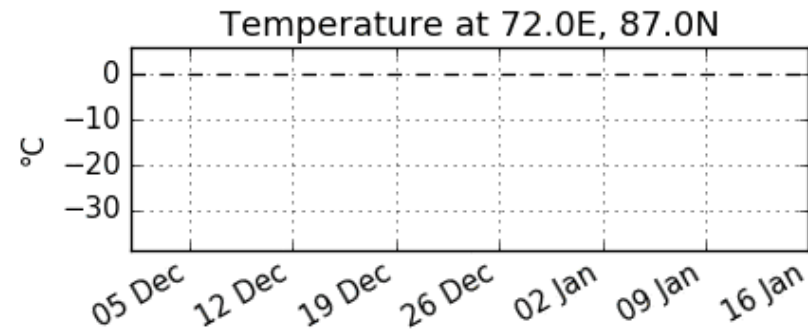
Predictable?

Important at all?

Recent warm air pulses during Arctic winters



Data: 2-m air temperature
ERA-Interim Reanalysis

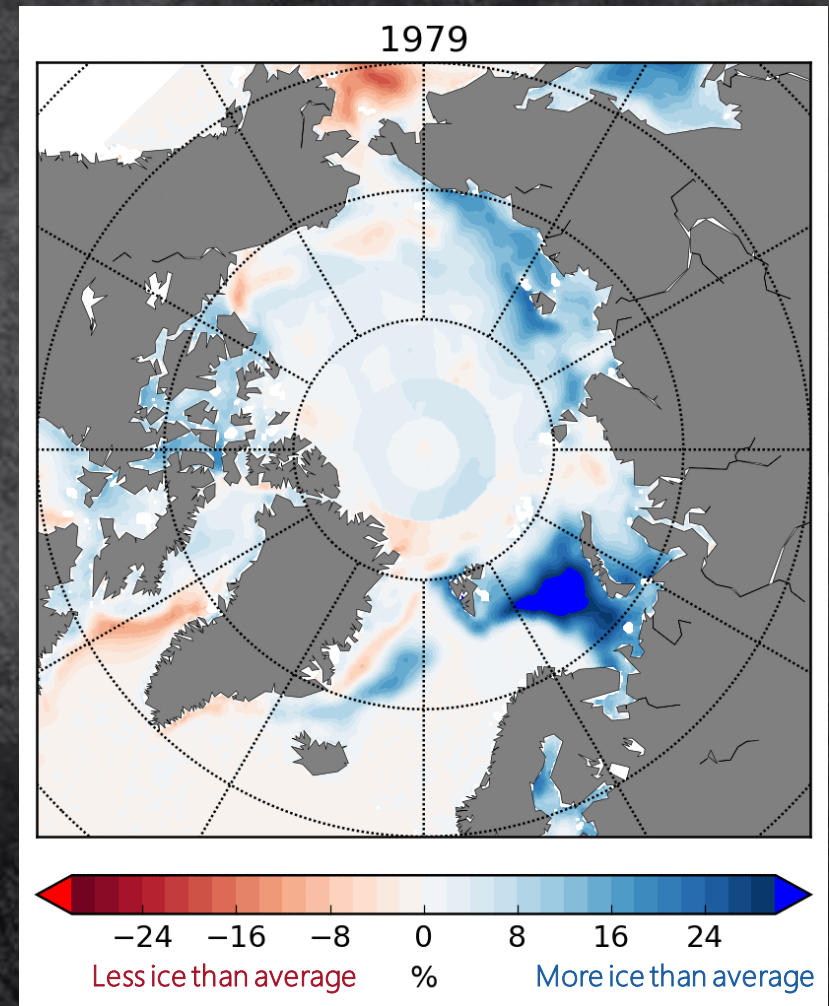


Recent changes in Arctic sea ice

Arctic sea ice has become...

- Less extensive and compact

Anomalies of annual-mean
concentration from 1979-2015 average

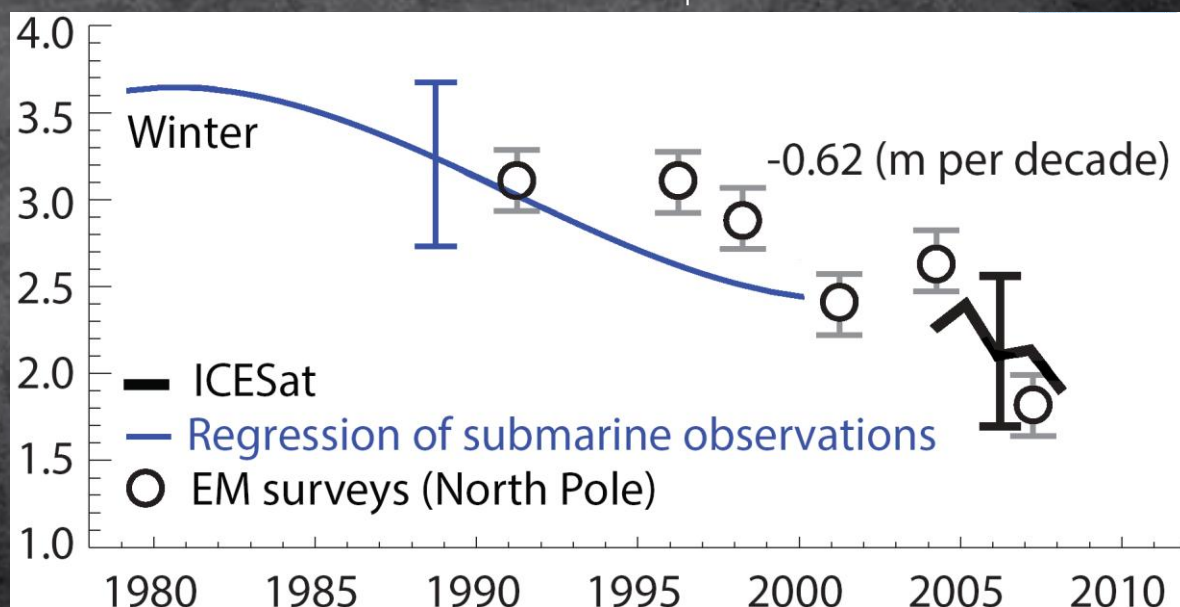


Recent changes in Arctic sea ice

Arctic sea ice has become...

- Less extensive and compact
- Thinner

Annual-mean Arctic sea ice
thickness from composite sources



Recent changes in Arctic sea ice

Arctic sea ice has become...

- Less extensive
- Thinner

But also,

- Sea ice has become younger
- Ice drift has increased
- Snow thickness has dropped
- Melt pond fraction has increased



<http://blogs.agu.org/geospace/files/2012/09/meltponds-3.jpg>

Recent changes in Arctic sea ice

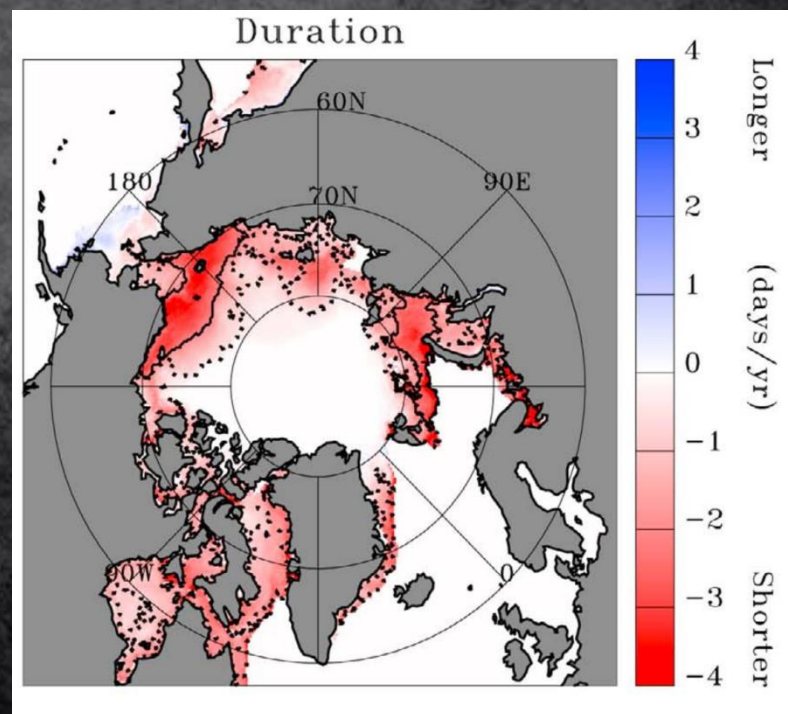
Arctic sea ice has become...

- Less extensive
- Thinner

But also,

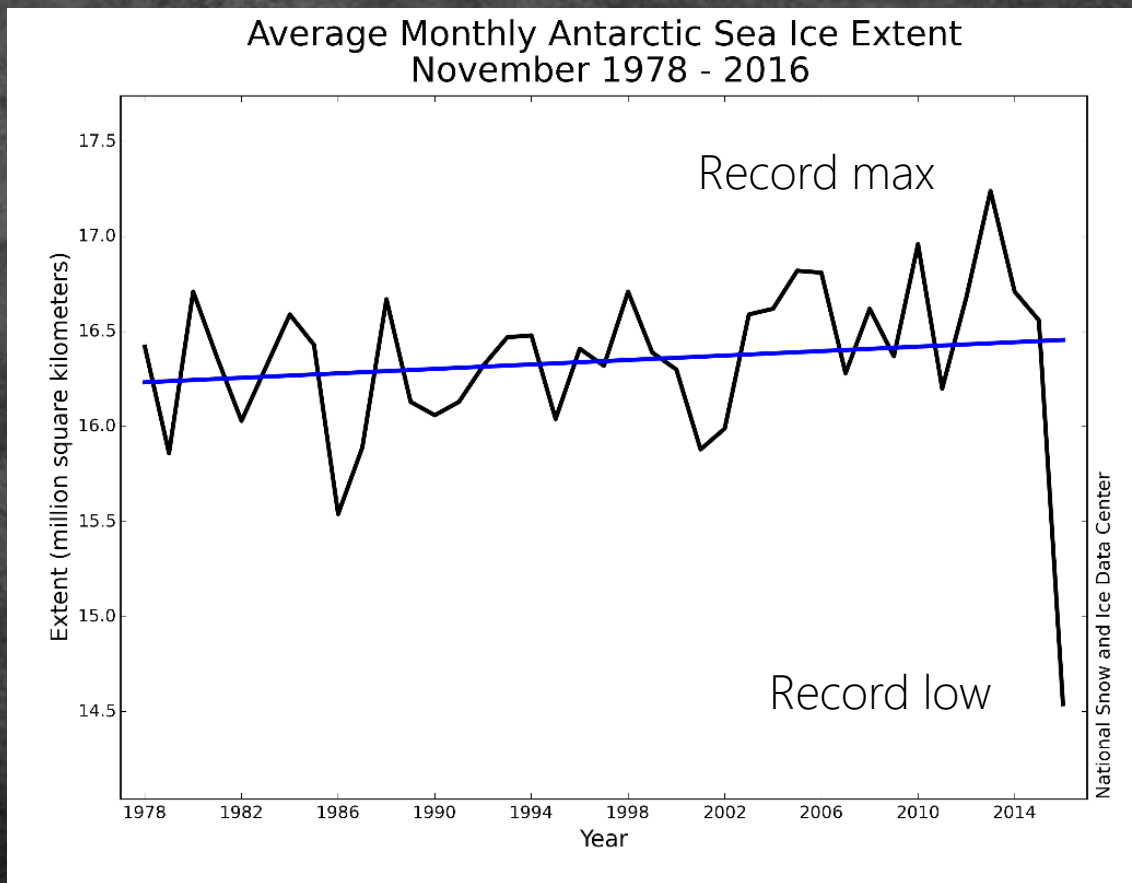
- Sea ice has become younger
- Ice drift has increased
- Snow thickness has dropped
- Melt pond fraction has increased
- Ice season has become shorter

Trend in ice season length (1979-2010)



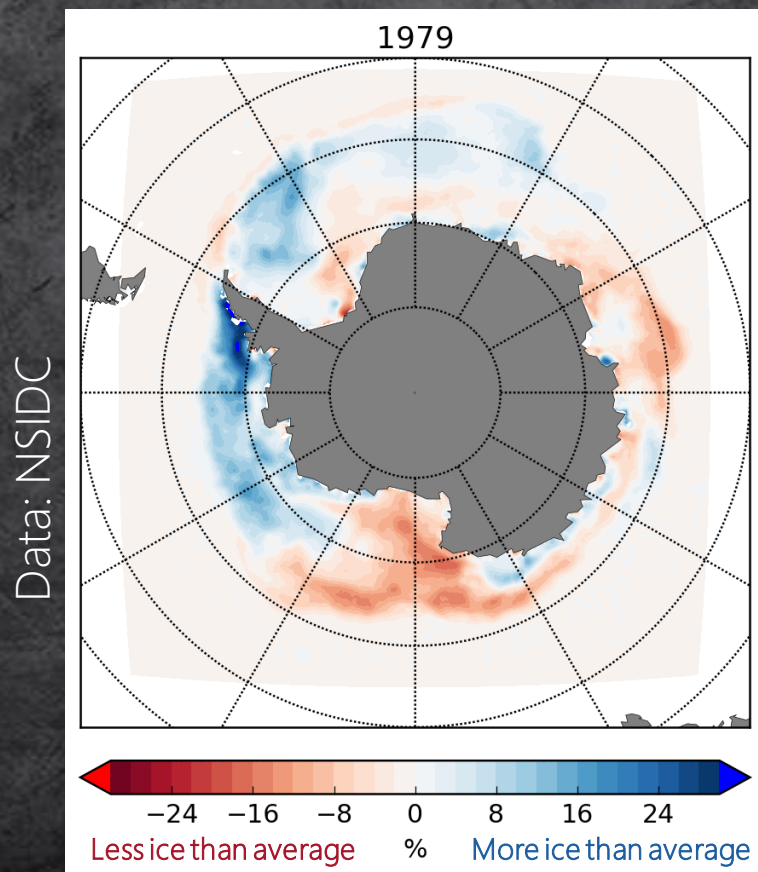
[Stammerjohn et al., GRL, 2012]

Recent changes in Antarctic sea ice

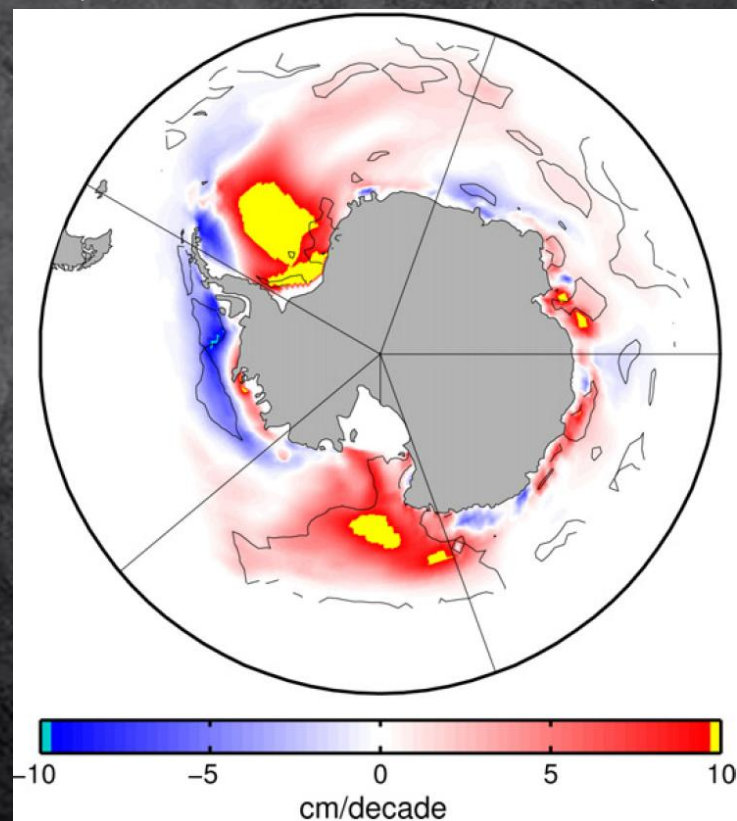


Recent changes in Antarctic sea ice

Anomalies of annual-mean
concentration from 1979-2015 average



Linear trend in sea ice thickness
(model with data assimilation)



[Massonnet et al., Ocean Mod., 2013]

« Antarctic sea ice is increasing »

- Strong regional patterns: individual analyses are required
- Strong seasonality
- Pronounced interannual variability
- Recent puzzling events

Sea-ice variability

Observed?

Unusual?

Attributable?

Predictable?

Important at all?

Sea-ice variability

Observed?

Unusual?

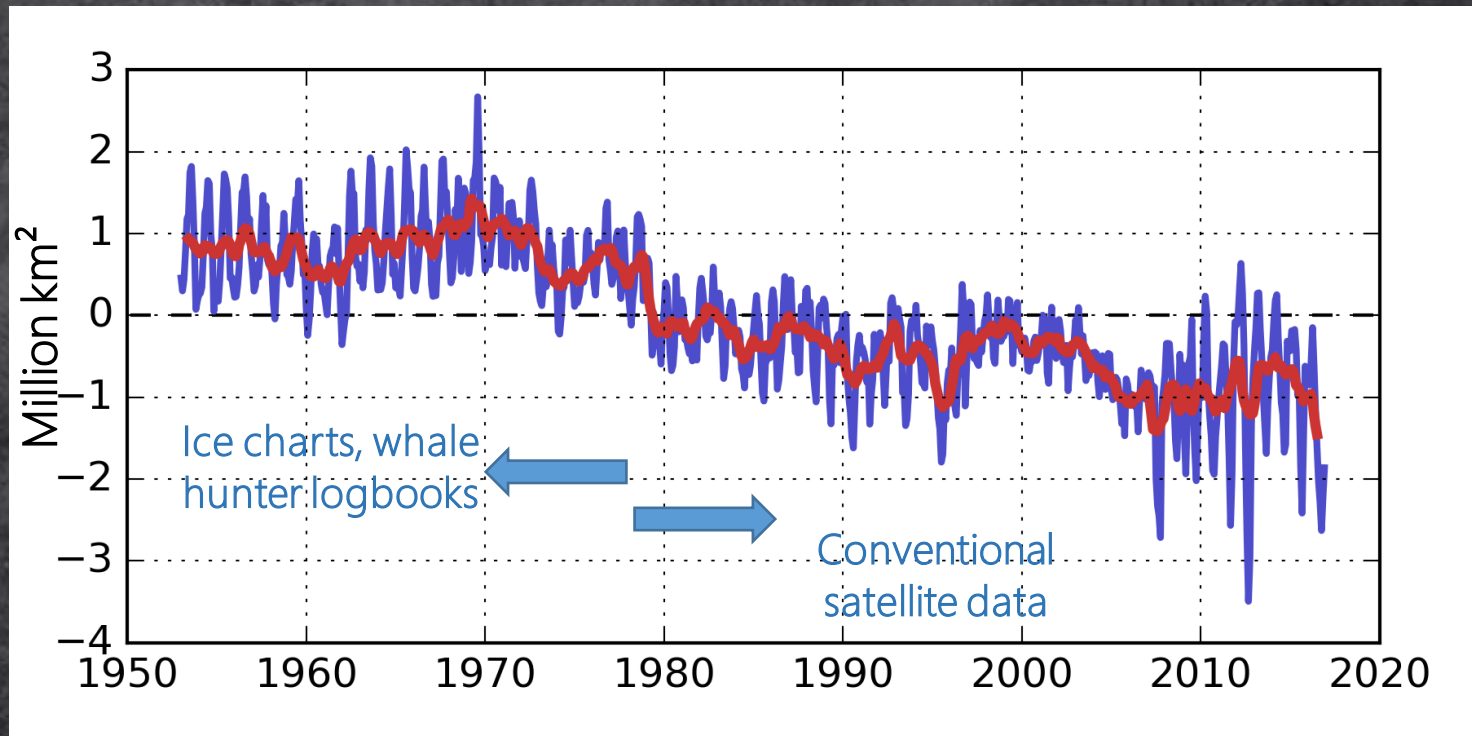
Attributable?

Predictable?

Important at all?

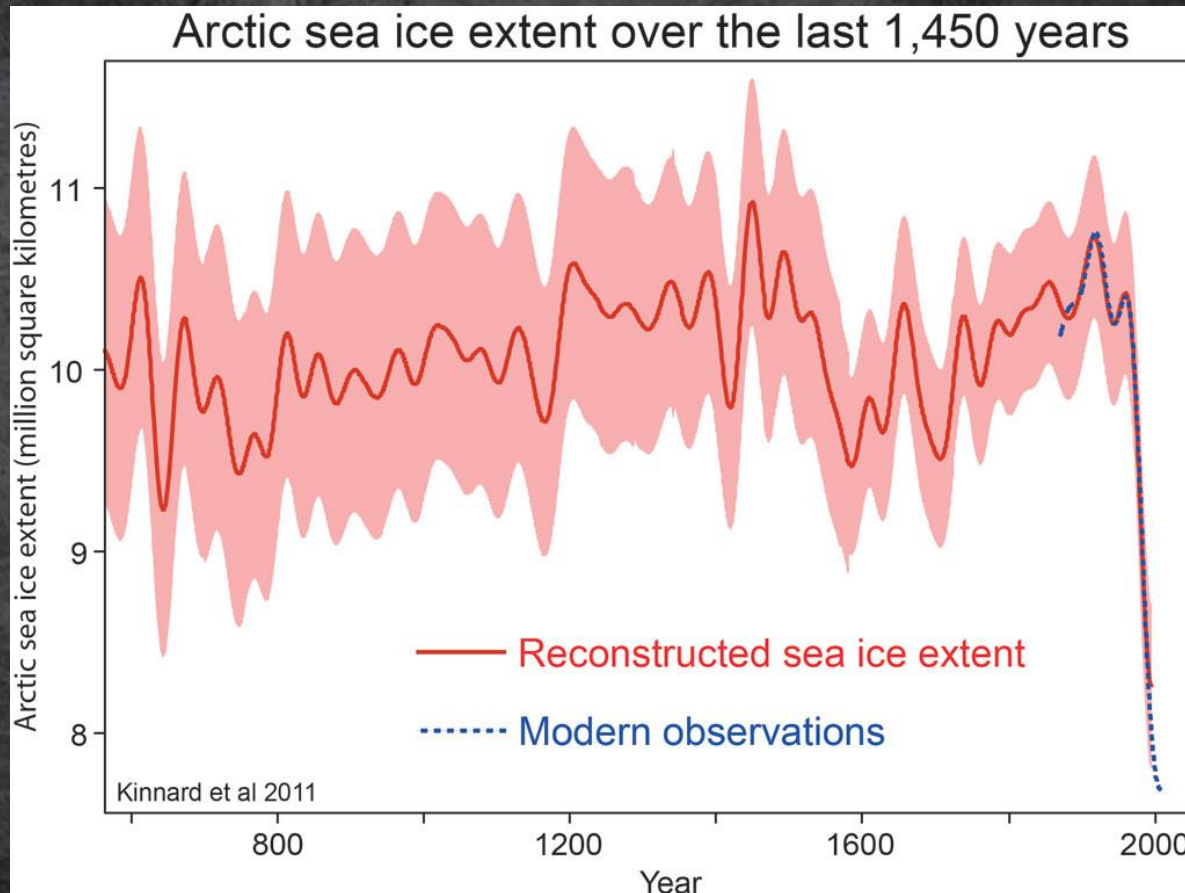
Arctic sea ice is pushed well outside its comfort zone

Anomalies of sea ice extent



Data: HadISST [Rayner et al., JGR, 2003]

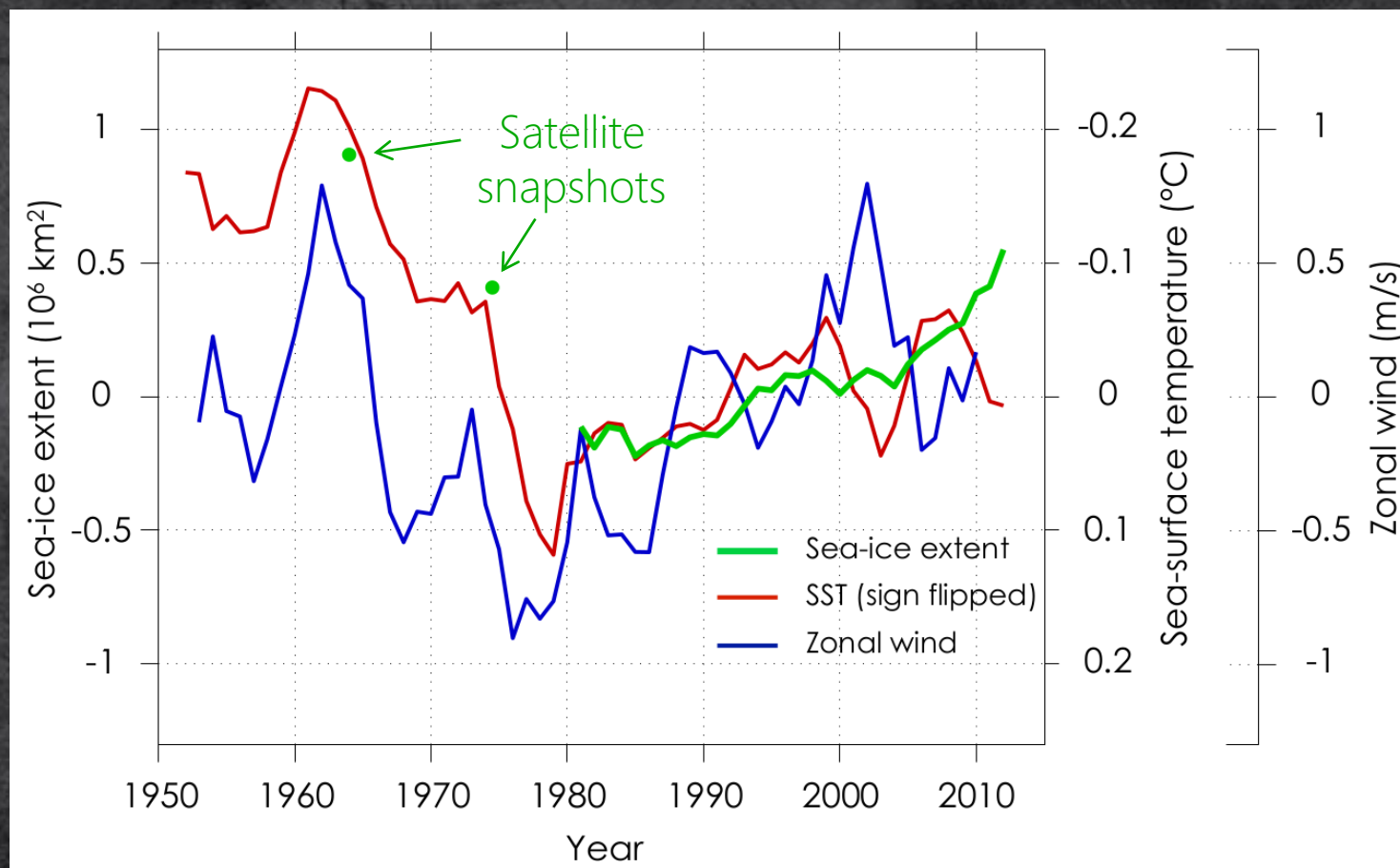
Arctic sea ice is pushed well outside its comfort zone



[Kinnard et al., Nature, 2011]

Recent Antarctic sea ice variability is not inconsistent with natural multi-decadal fluctuations

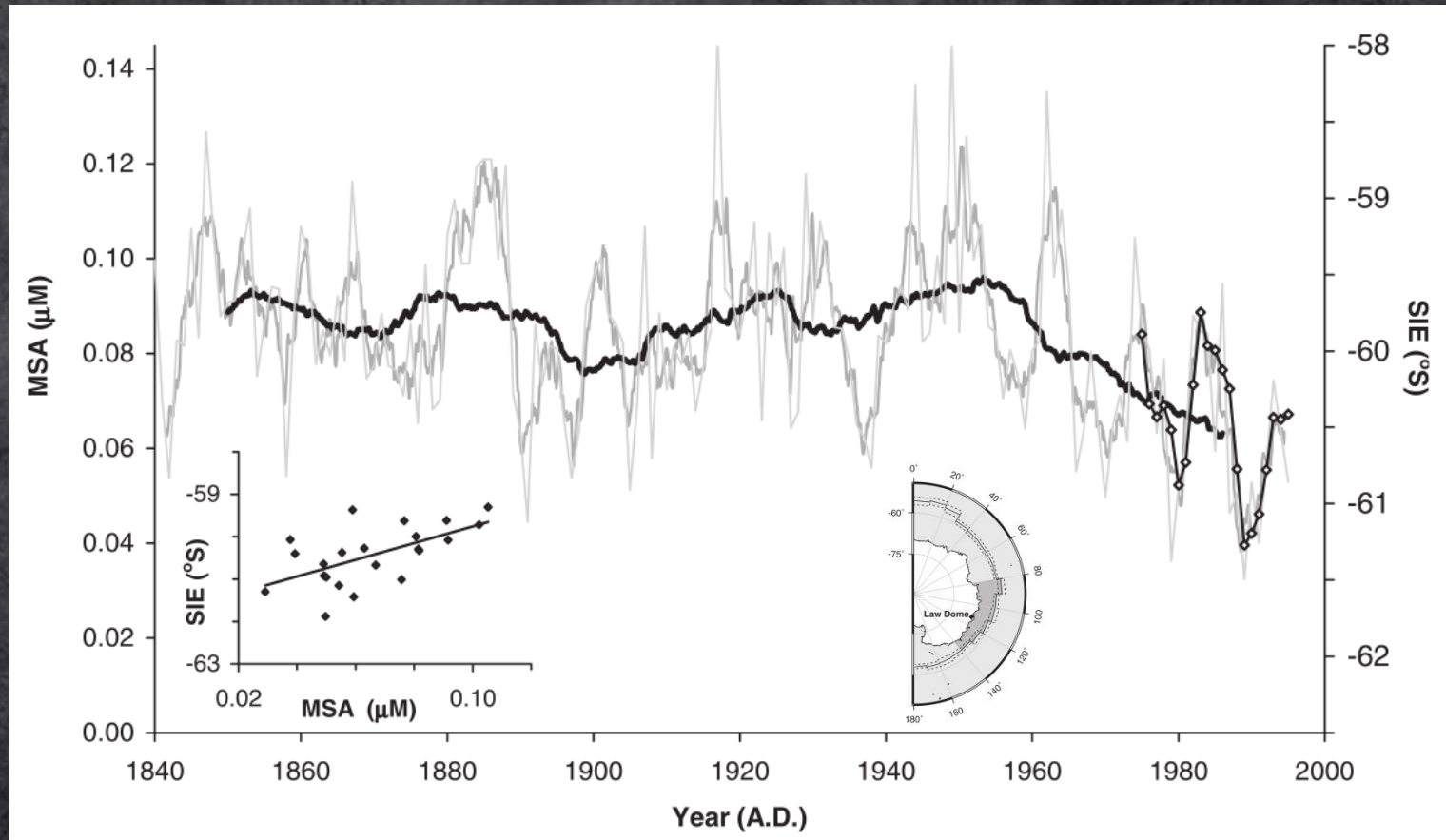
Anomalies of sea ice extent, SST and winds



[Armour and Bitz, US Clivar Variations, 2015]

Recent Antarctic sea ice variability is not inconsistent with natural multi-decadal fluctuations

Reconstructed maximal sea ice edge latitude



[Curran et al., Science, 2003]

Sea-ice variability

Observed?

Unusual?

Attributable?

Predictable?

Important at all?

Sea-ice variability

Observed?

Unusual?

Attributable?

Predictable?

Important at all?

Sea-ice variability

Observed?

Unusual?

Well modelled?

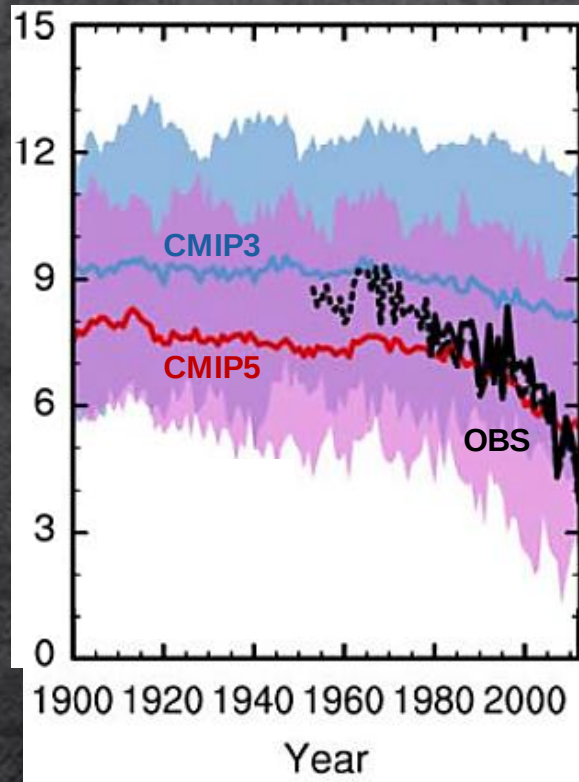
Attributable?

Predictable?

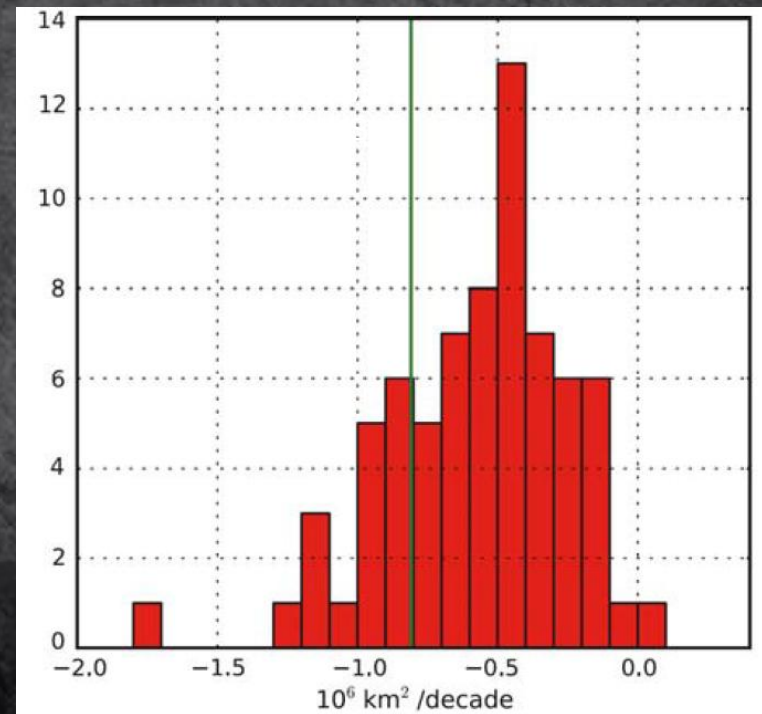
Important at all?

Summer sea-ice trends better represented...

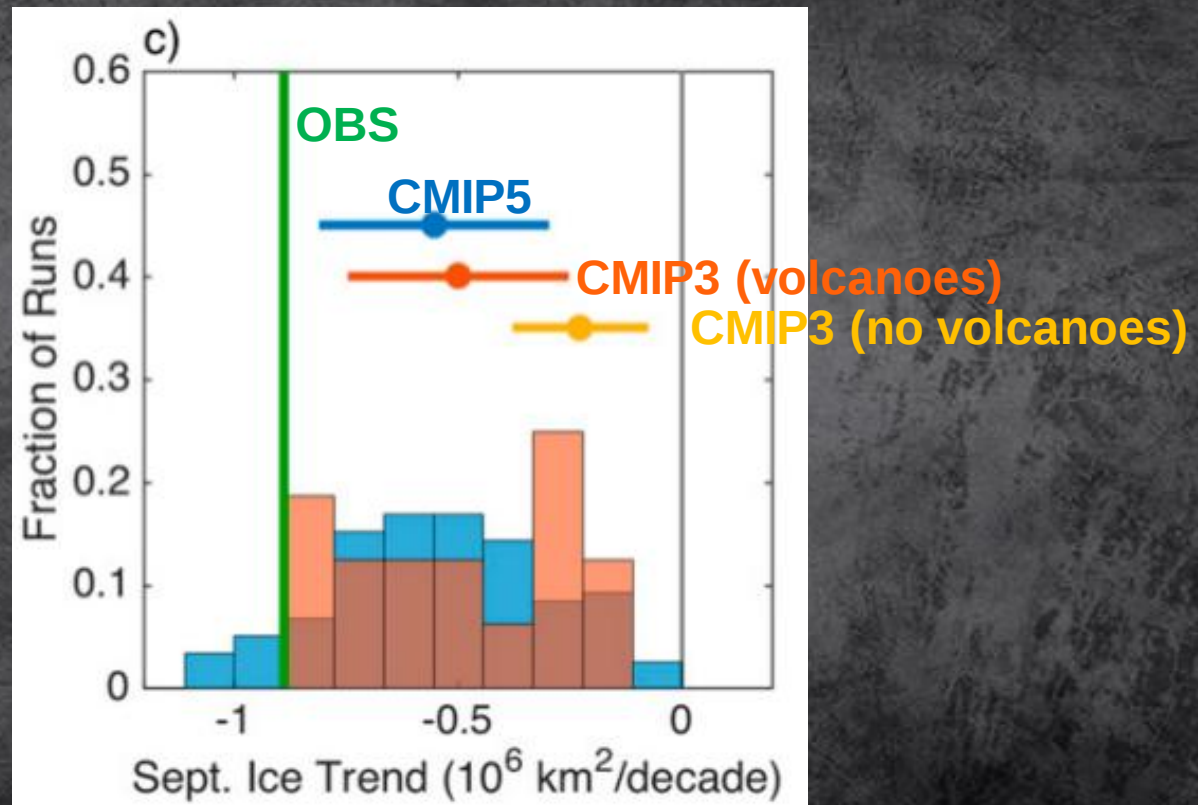
September Arctic sea ice extent



Distribution of CMIP5 September Arctic sea ice extent **trends** (1979-2010, 66 realisations)



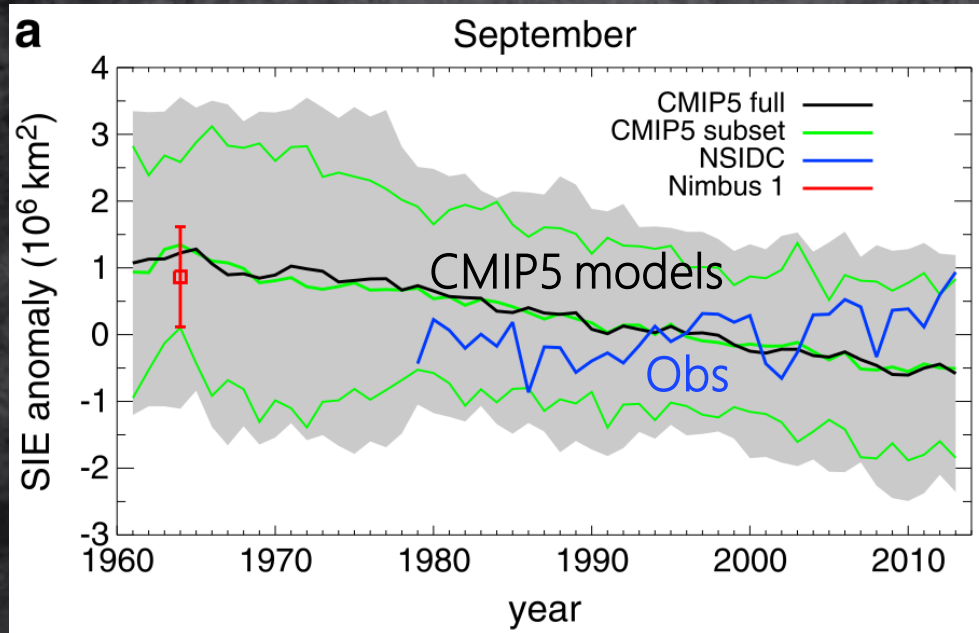
... probably for the wrong reasons



[Rosenblum and Eisenman, J. Clim., 2016]

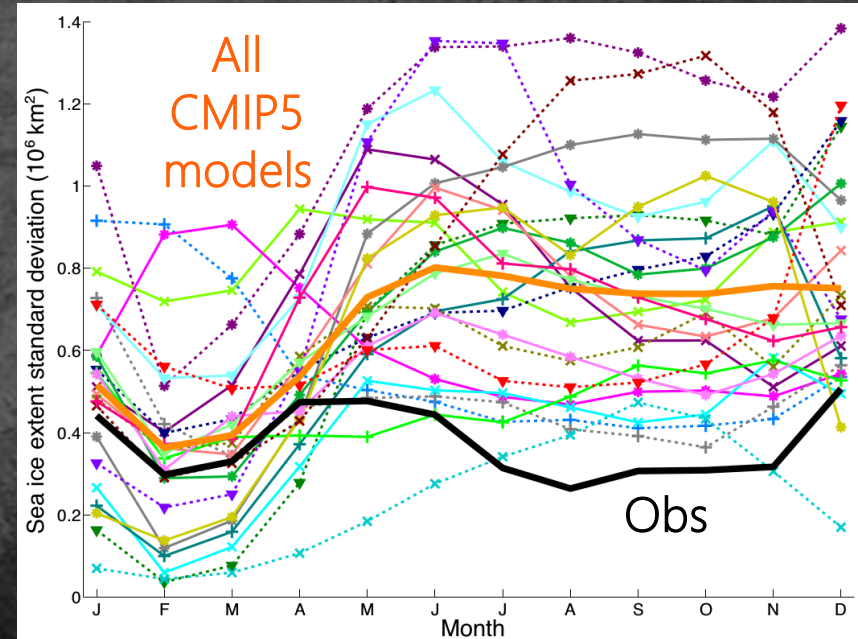
Systematic deficiencies in simulated Antarctic sea ice variability

Winter sea ice extent



[Gagné et al., GRL, 2015]

Standard deviation of
1979-2005 sea ice extent



[Zunz et al., The Cryosphere; 2013]

Sea-ice variability

Observed?

Unusual?

Well modelled?

Attributable?

Predictable?

Important at all?

Sea-ice variability

Observed?

Unusual?

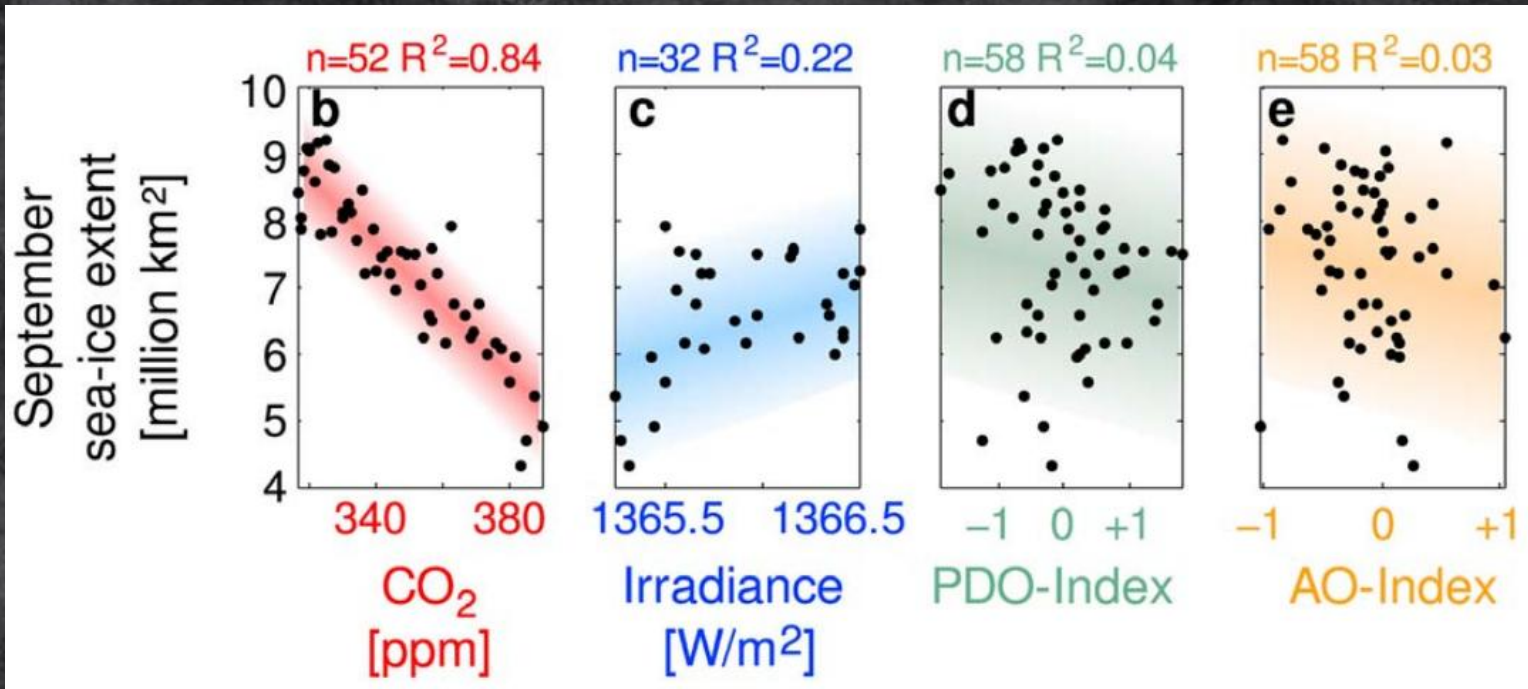
Well modelled?

Attributable?

Predictable?

Important at all?

Arctic sea ice follows radiative forcing (at first order)



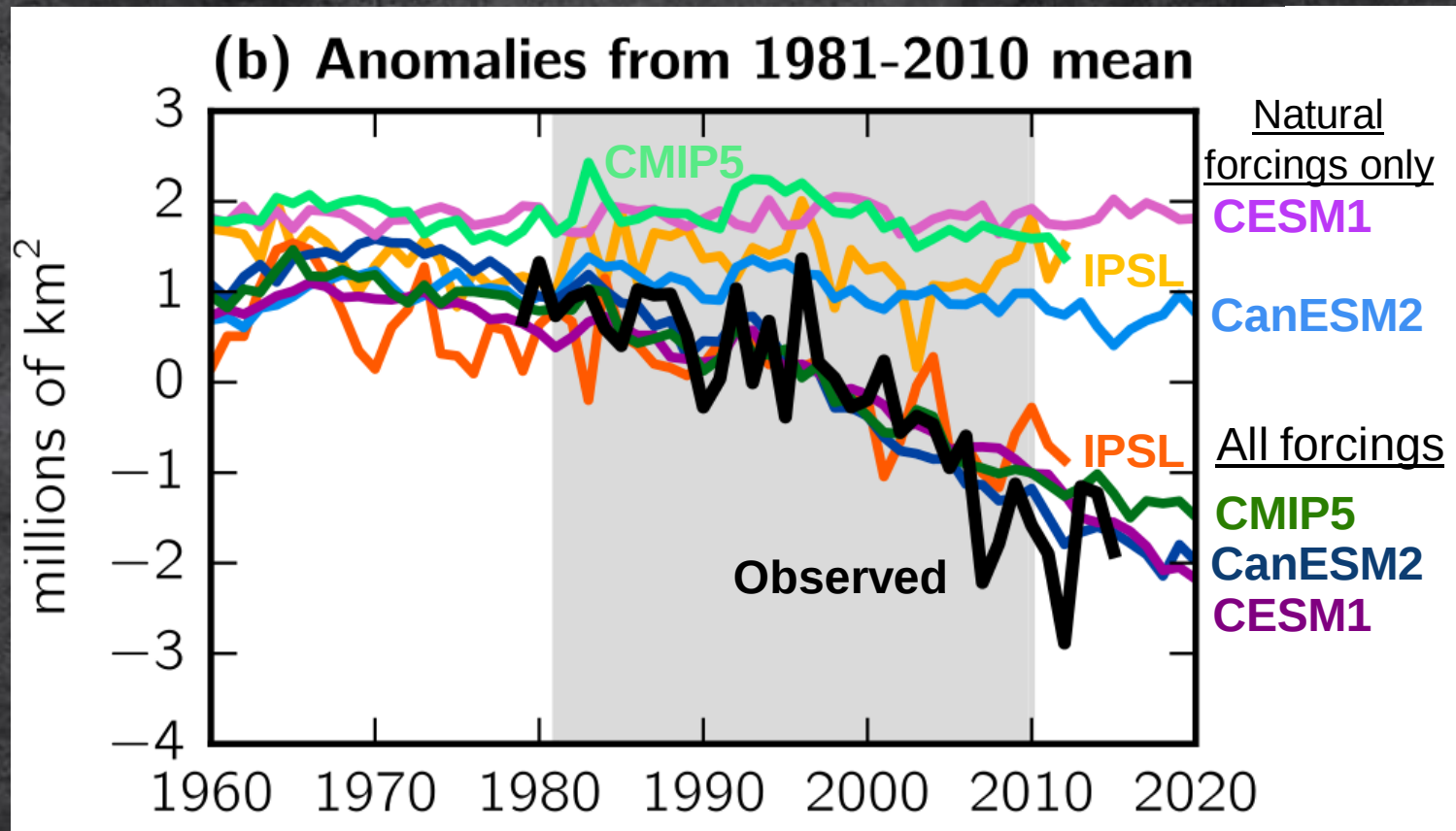
[Notz and Marotzke, GRL, 2012]

See also:

[Mahlstein and Knutti, JGR, 2012]

[Notz and Stroeve, Science, 2016]

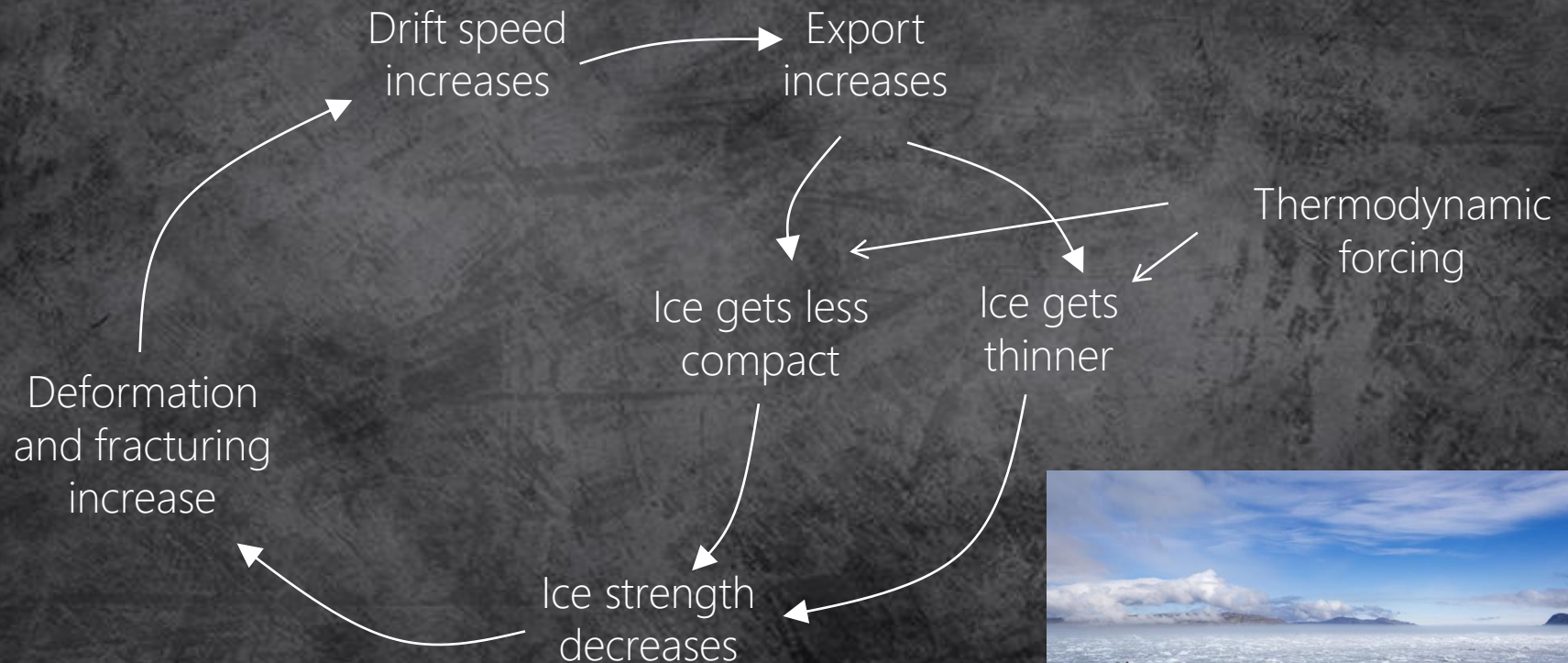
Anthropogenic influence on Arctic sea ice loss is clear



[Kirchmeier-Young et al., J. Clim., 2017]

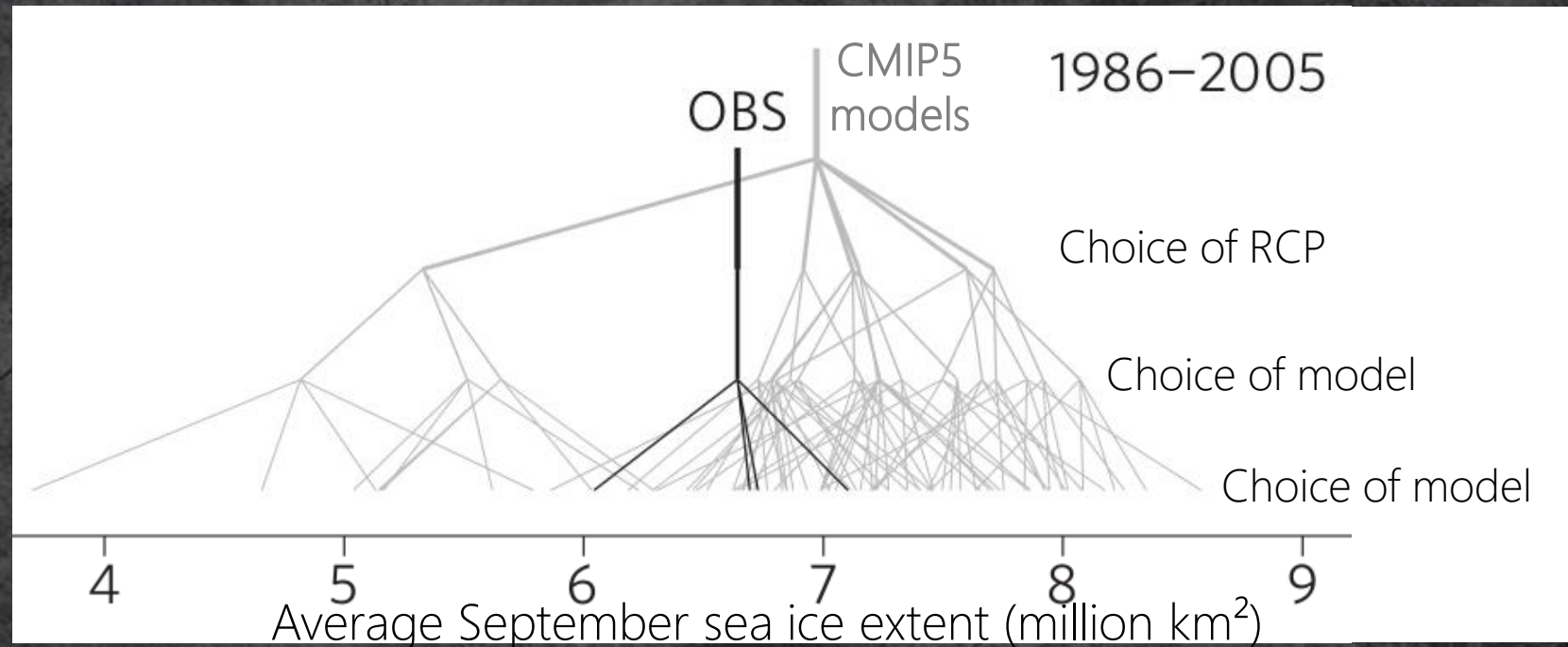
See also (for particular events): [Zhang and Kutson, BAMS, 2013],
[Guemas et al., BAMS, 2013], [Kauker et al., GRL, 2009]

Thermodynamic impacts on sea ice dynamics



<http://assets.carbonbrief.org/wp-content/uploads/2016/05/Stock-arctic-sea-ice-scene.jpg>

Internal variability of Arctic sea ice remains high

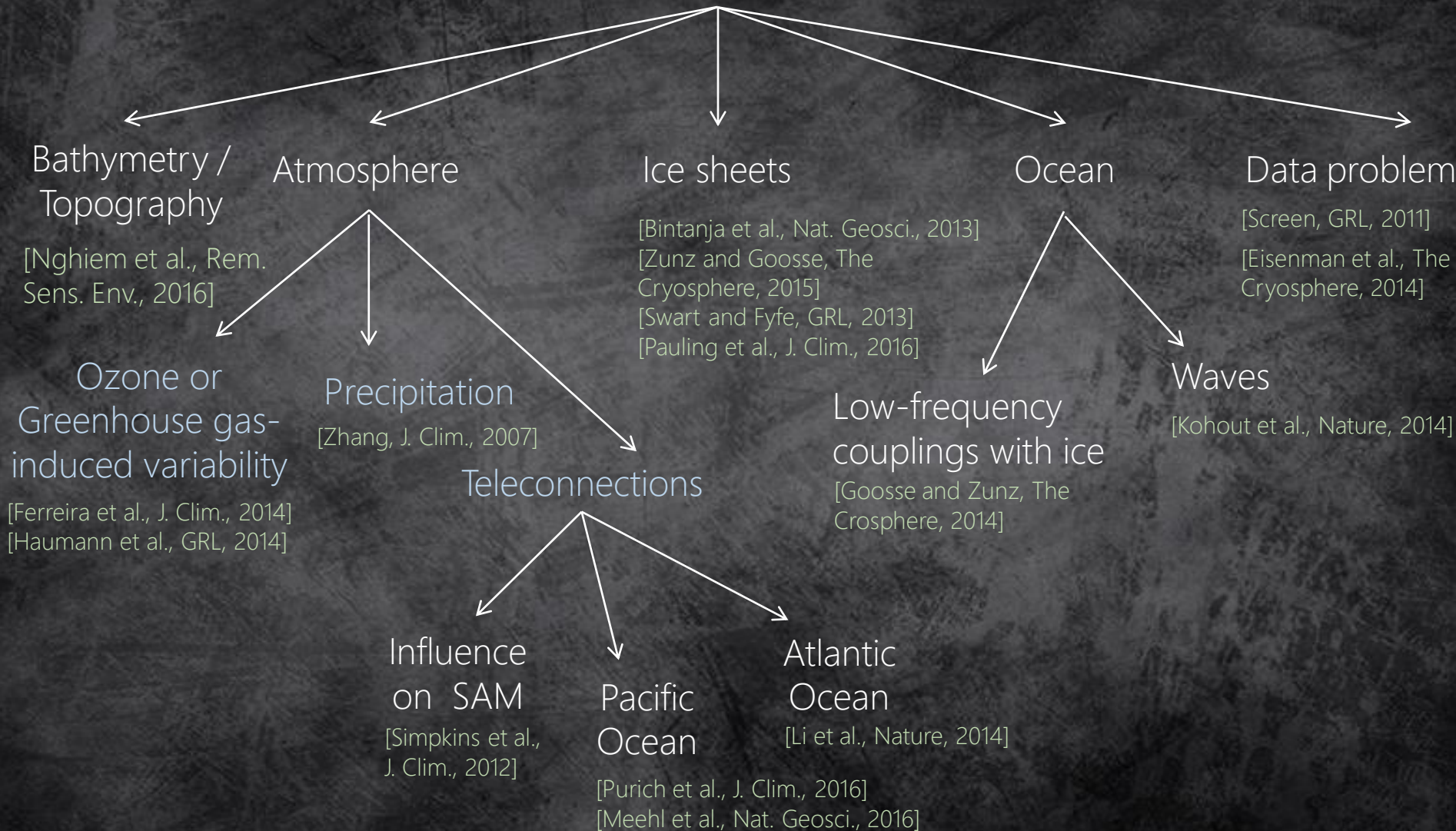


[Swart et al., Nat. Clim. Change, 2015]

[Ding et al., Nature Clim. Ch., 2017] → ~30-50% of summer ice loss is caused by internal variability

[Kay et al., GRL, 2011] → ~44% of ice loss is due to internal variability

What drives Antarctic sea ice variability?



What drives sea ice variability?

Arctic

Thermodynamic forcing has chief influence

Internal variability plays a role

Atmosphere-ice interactions

Antarctic

No simple explanation
Multiple potential drivers

Very large internal variability, power at frequencies from year to decades

Ocean-sea ice interactions

Sea-ice variability

Observed?

Unusual?

Well modelled?

Attributable?

Predictable?

Important at all?

Sea-ice variability

Observed?

Unusual?

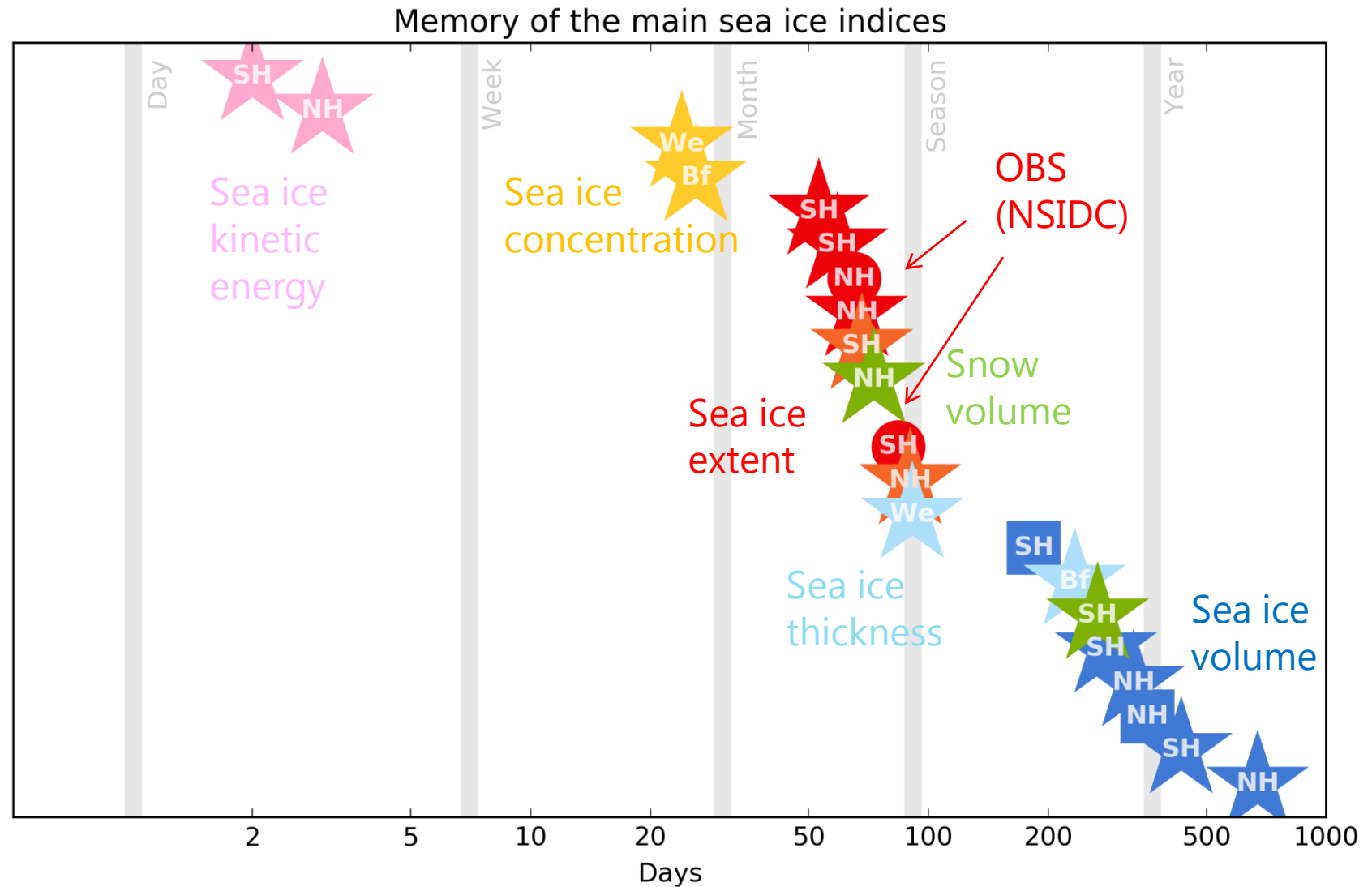
Well modelled?

Attributable?

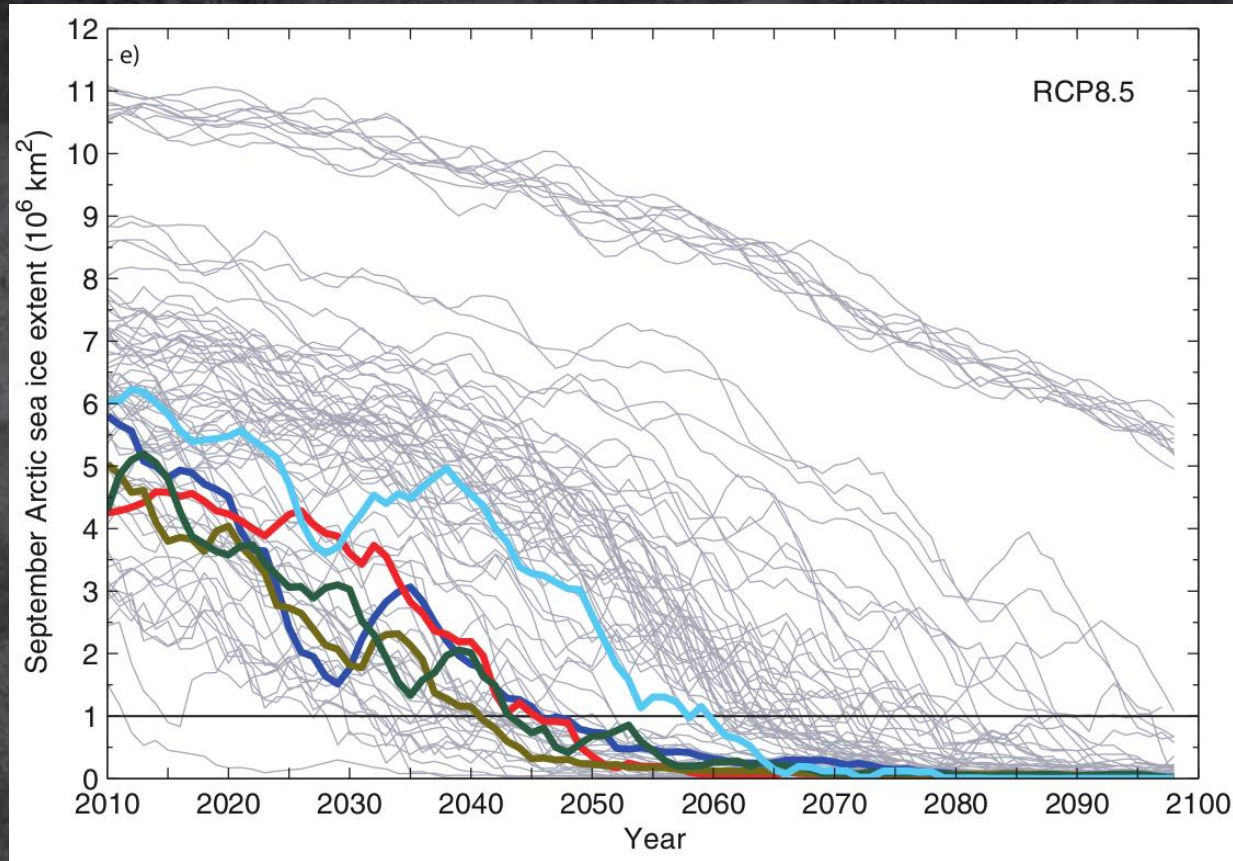
Predictable?

Important at all?

Persistence is the key source of predictability
at sub-seasonal to seasonal time scales



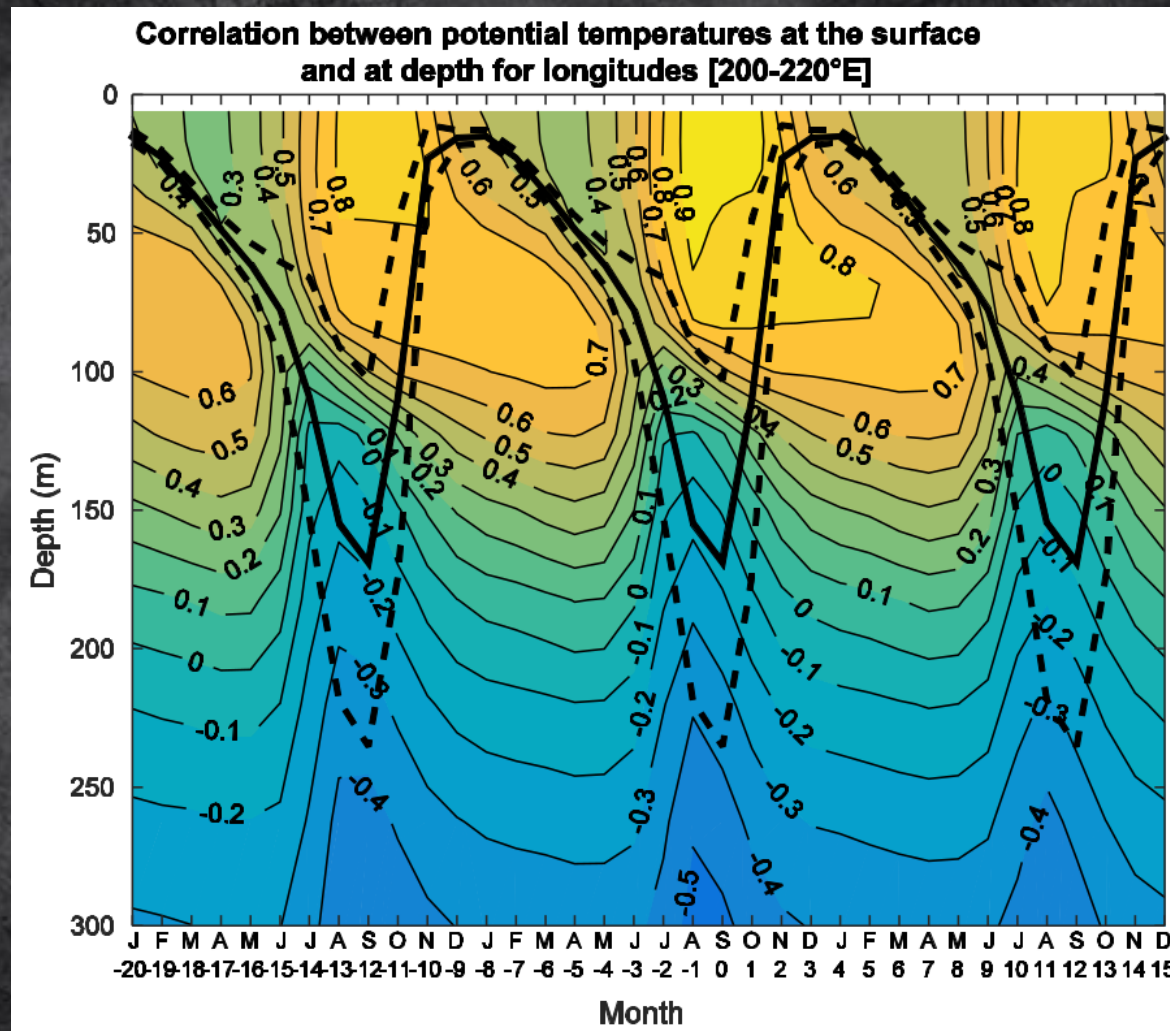
Long-term: projected ice-free Arctic by mid-century



[IPCC AR5 WG1, Chapter 12, 2013]

Subsequent studies have consistent findings, though the important role of internal variability has been pointed out in defining the first instance of ice-free conditions

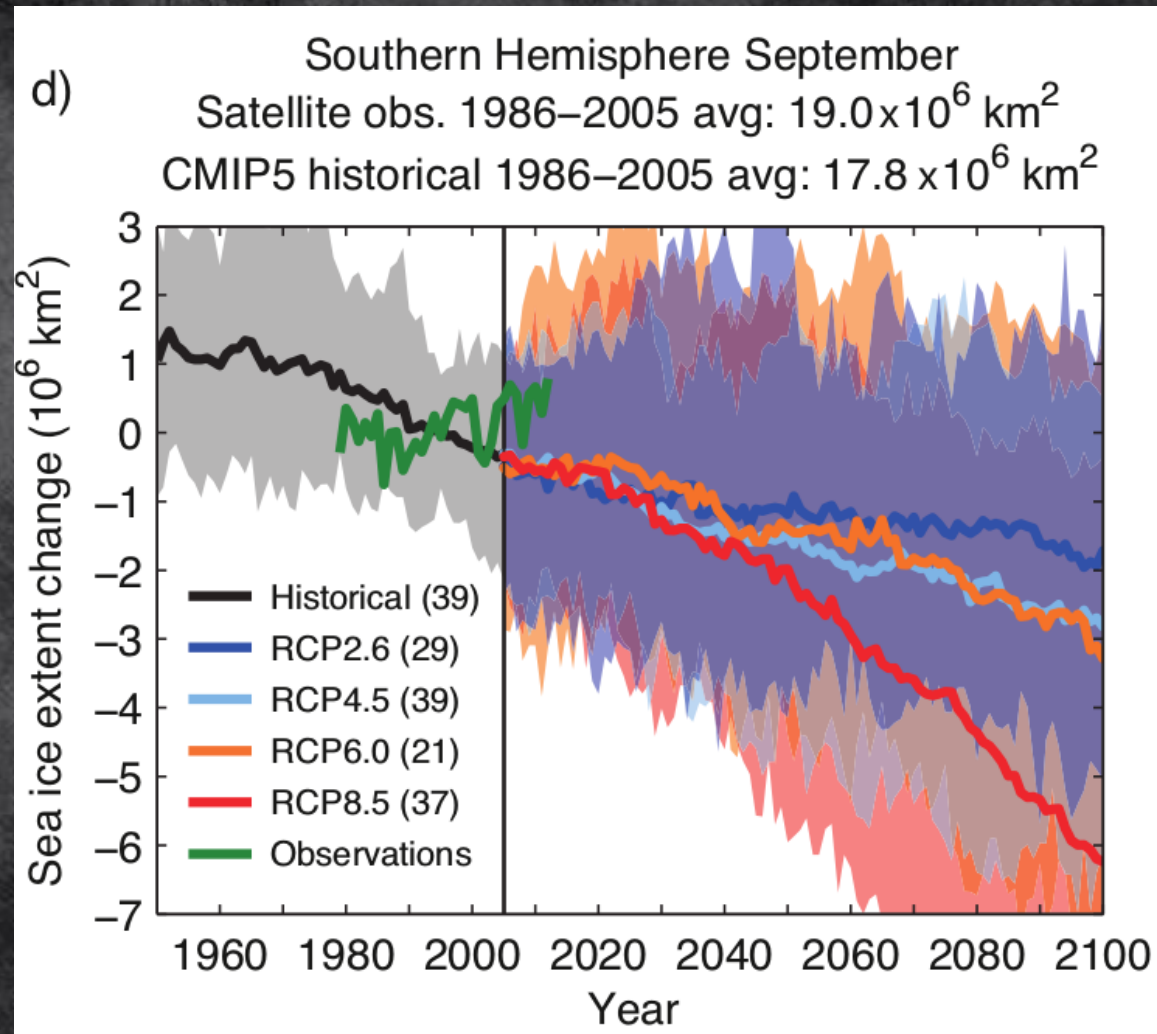
Antarctic sea ice predictability through storage of information at ocean depth



MPI-ESM
model

[Marchi et al., in prep.]

The sign of future Antarctic sea ice changes is unclear, internal variability will be a key player



Sea-ice variability

Observed?

Unusual?

Well modelled?

Attributable?

Predictable?

Important at all?

Sea-ice variability

Observed?

Unusual?

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Predictable?

Important at all?

Take home messages

What is new since the last IPCC assessment (2013)?

- Arctic sea ice: findings confirmed
- Antarctic sea ice: a can of worms is opened

What can we expect until the next assessment (2021)?

- Special Report on the Ocean and Cryosphere in a Changing Climate (2019)
- More process-based assessments (e.g., through Sea Ice MIP)
- Probably more sea ice records to come, and hence case studies

What are the main obstacles on our way?

- Internal variability
- Systematic model biases: sea ice response is not linear!
- Short and sparse observations; YOPP (2017-2019) is welcome

Thanks

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