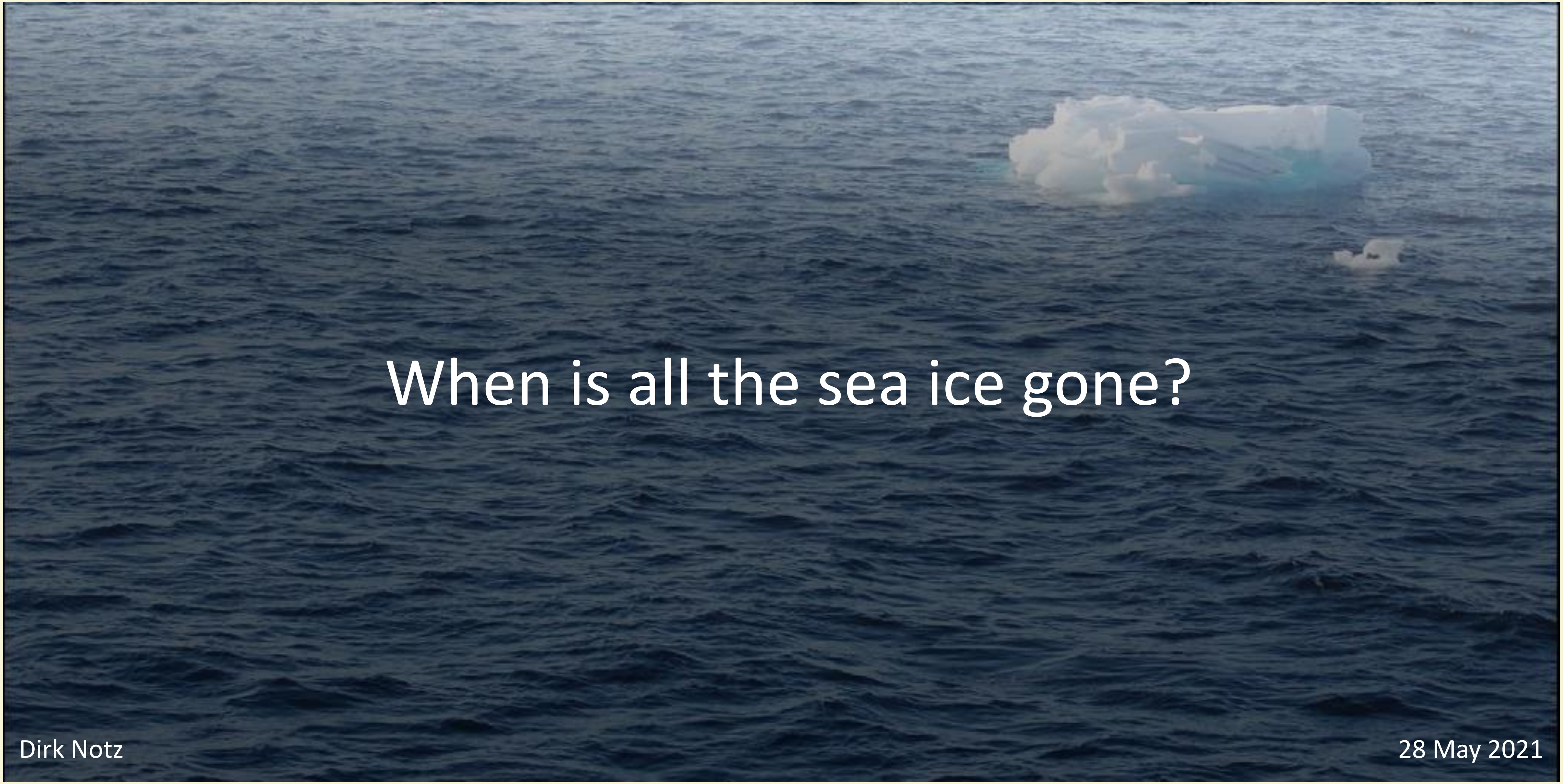


When is all the sea ice gone?

Dirk Notz

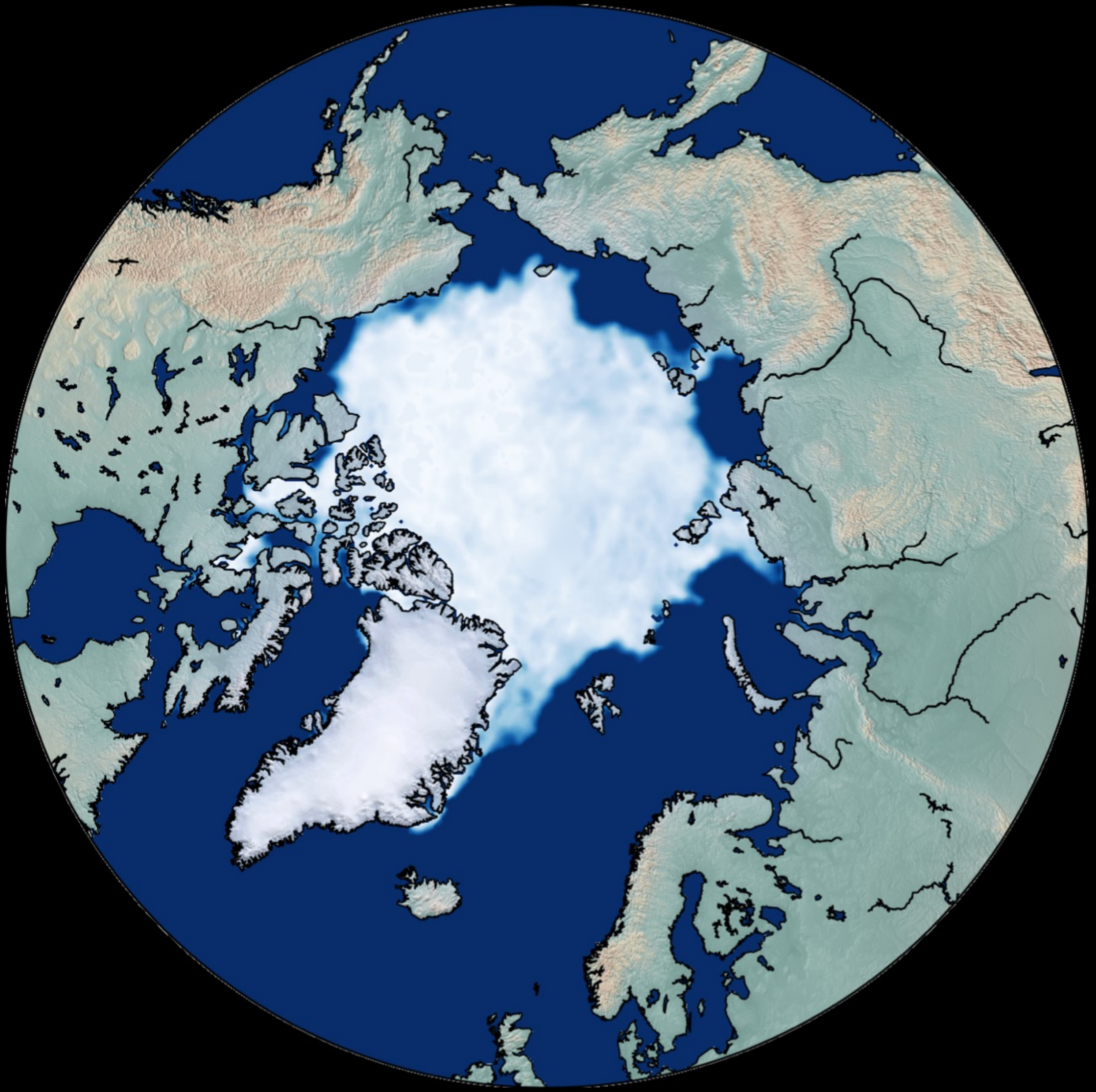
28 May 2021

When is all the Arctic summer sea ice gone?

Dirk Notz

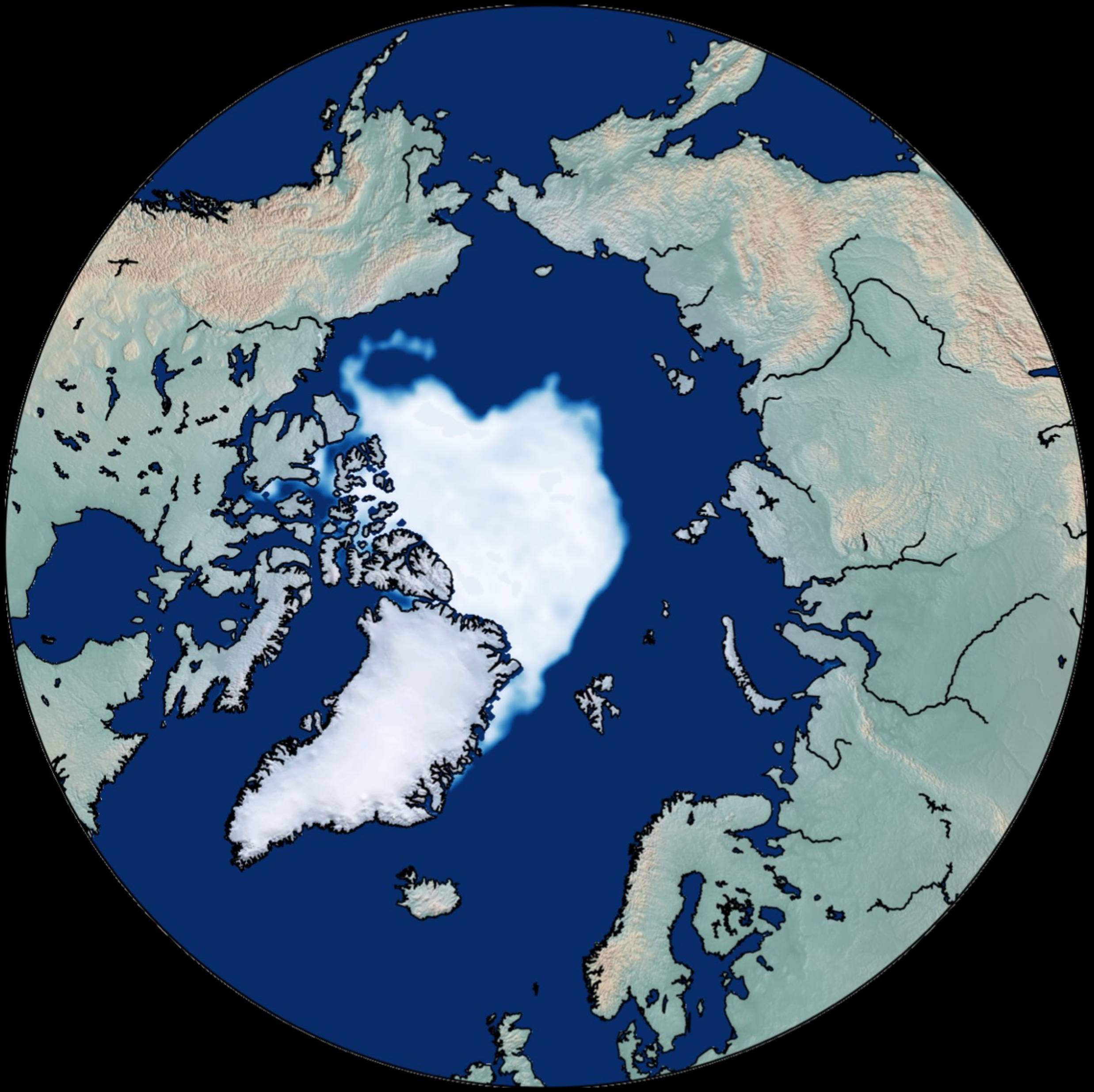
28 May 2021

21. September 1992



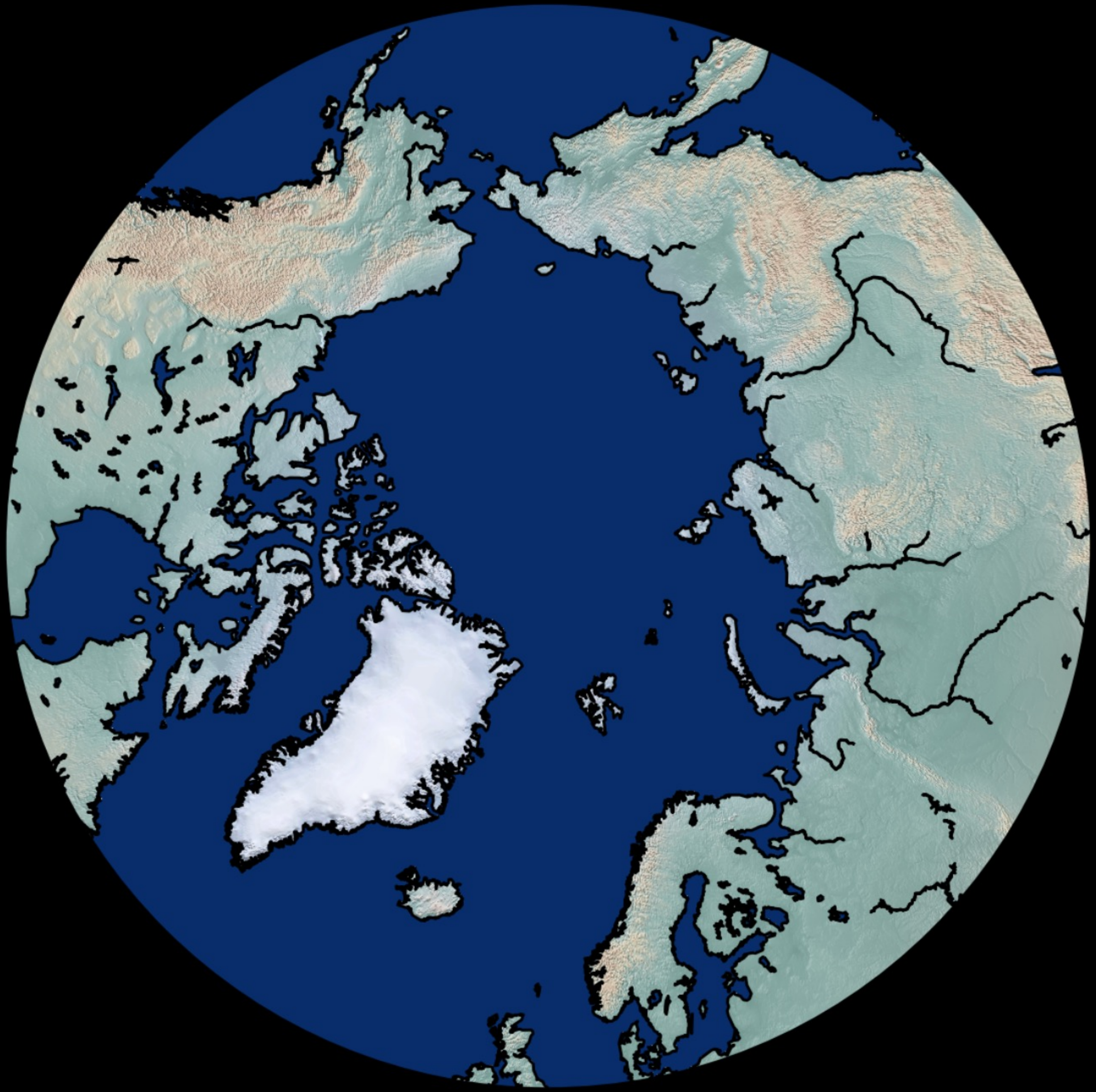
Daten: OSISAF

21. September 2020



Daten: OSISAF

21. September 20xx



Overview

1. When is the Arctic sea-ice free according to classical science?
2. When is the Arctic sea-ice free according to climate models?
3. Ways forward

Overview

1. When is the Arctic sea-ice free according to classical science?
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3. Ways forward

Classical Science

A four step approach

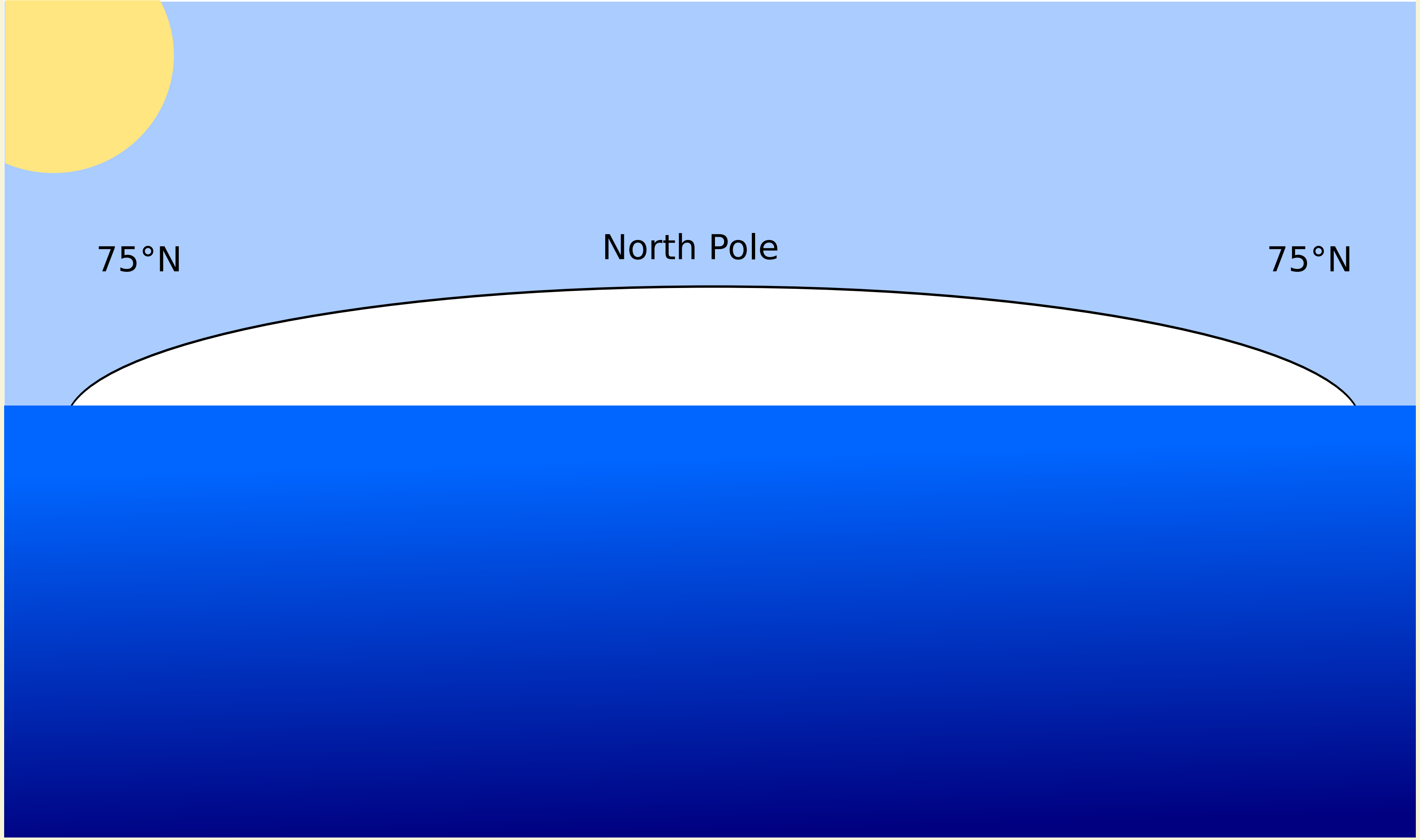
1. Formulate a question
2. Develop a theory or model to answer this question
3. Obtain measurements to test theory/model
4. Compare measurements with theory/model

Classical Science

Richard Feynman

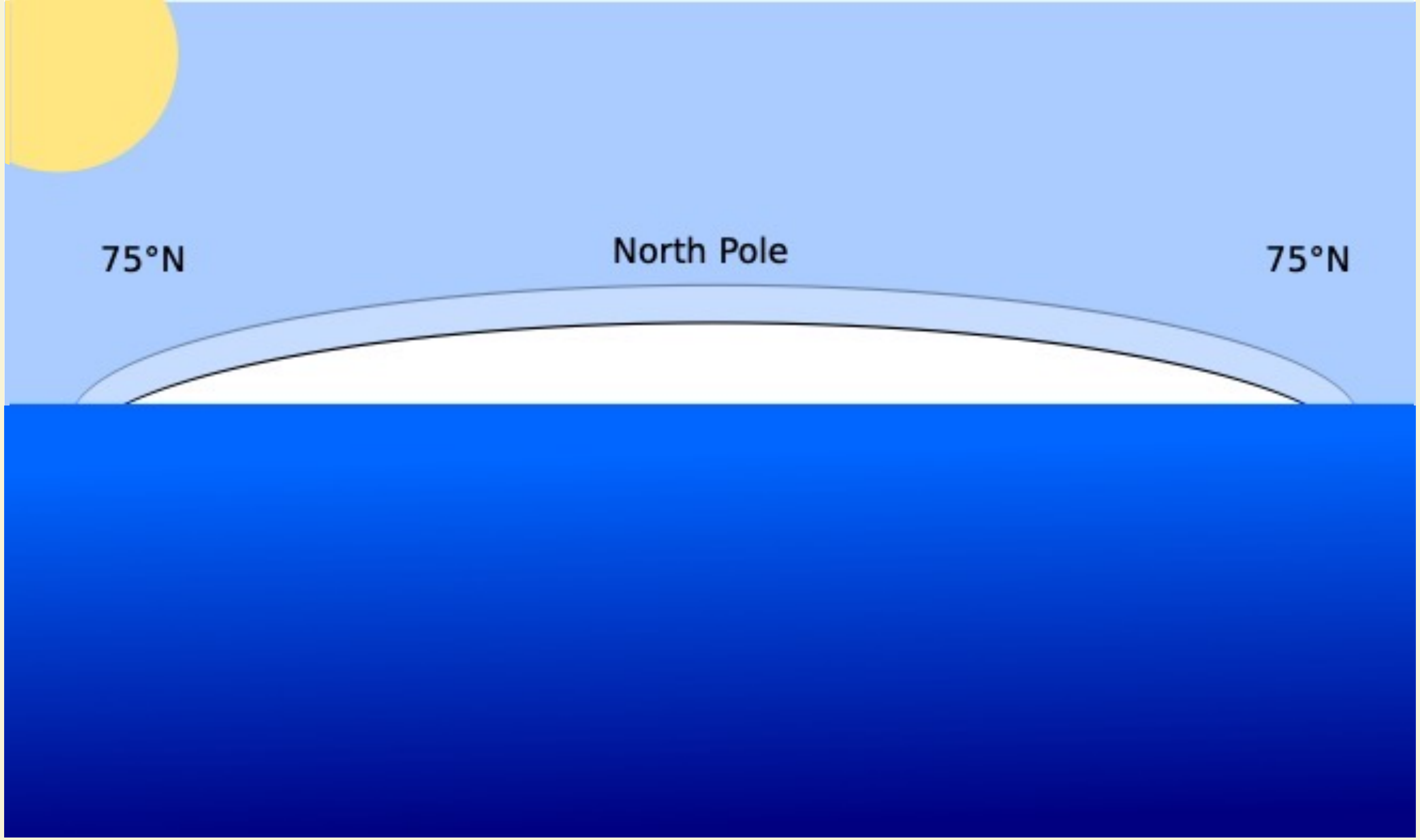
“It doesn’t matter how beautiful your theory is.
It doesn’t matter how smart you are.
If it doesn’t agree with experiment, it’s wrong.”

A conceptual view of Arctic sea-ice loss



Notz and Stroeve, Science, 2016

A conceptual view of Arctic sea-ice loss



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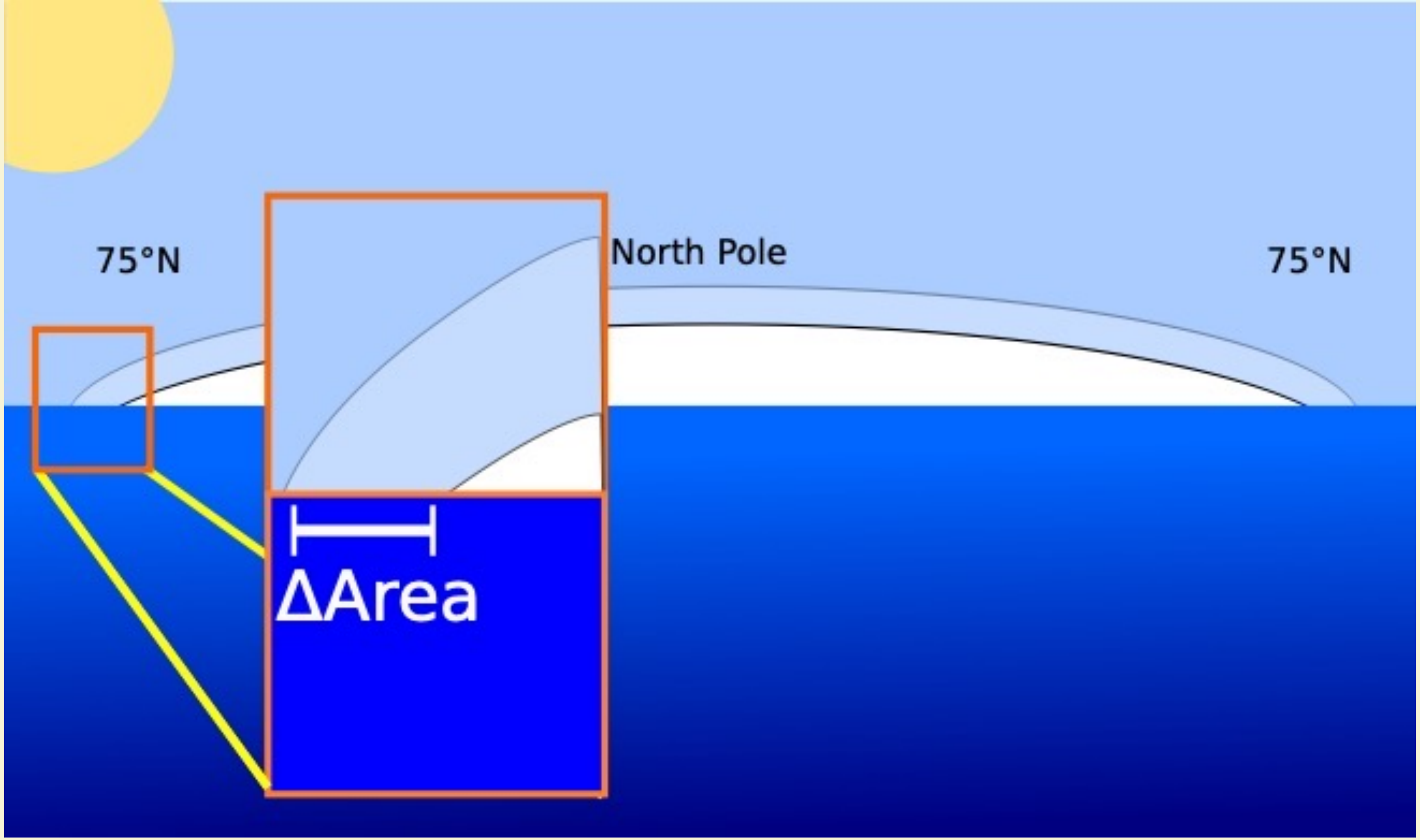

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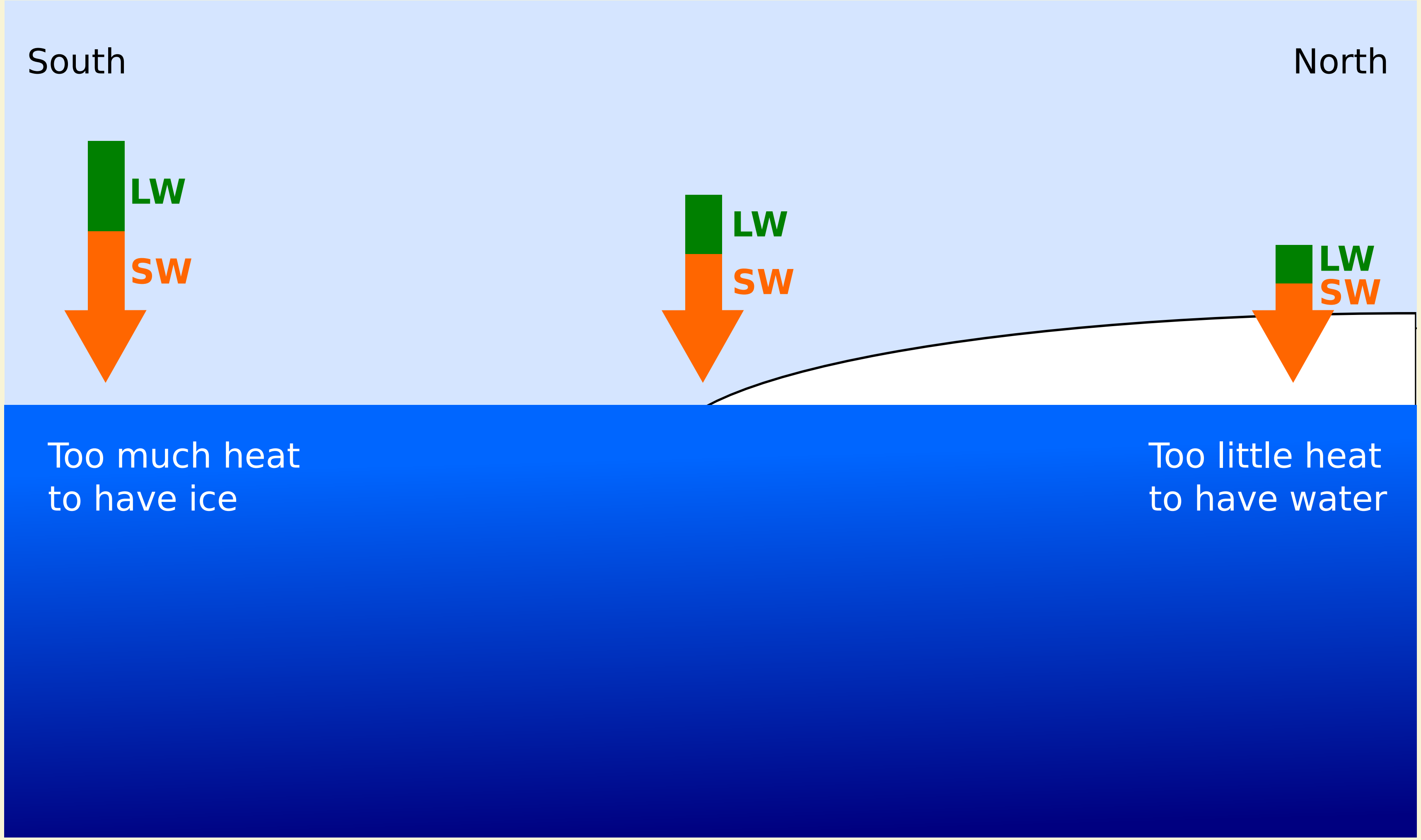
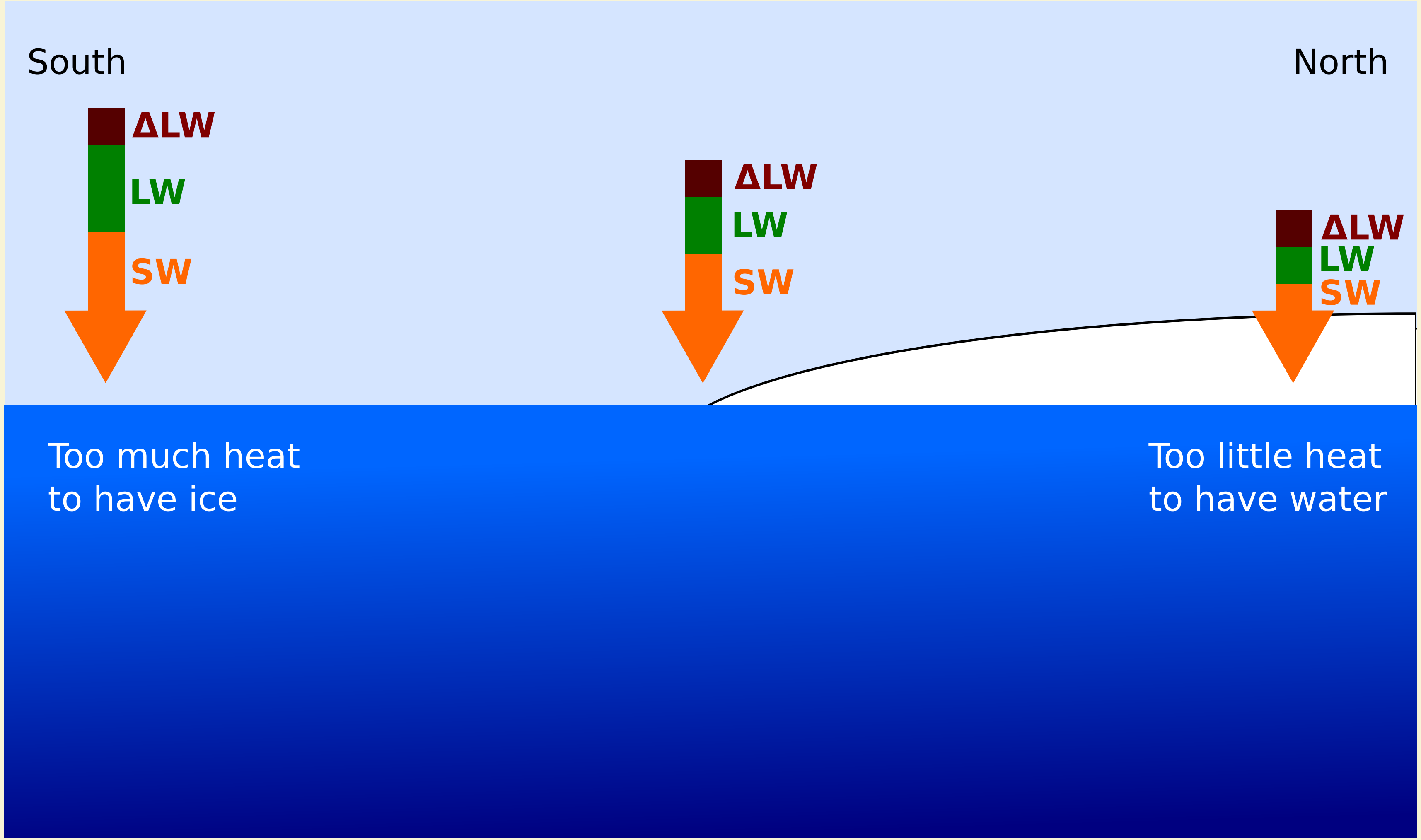
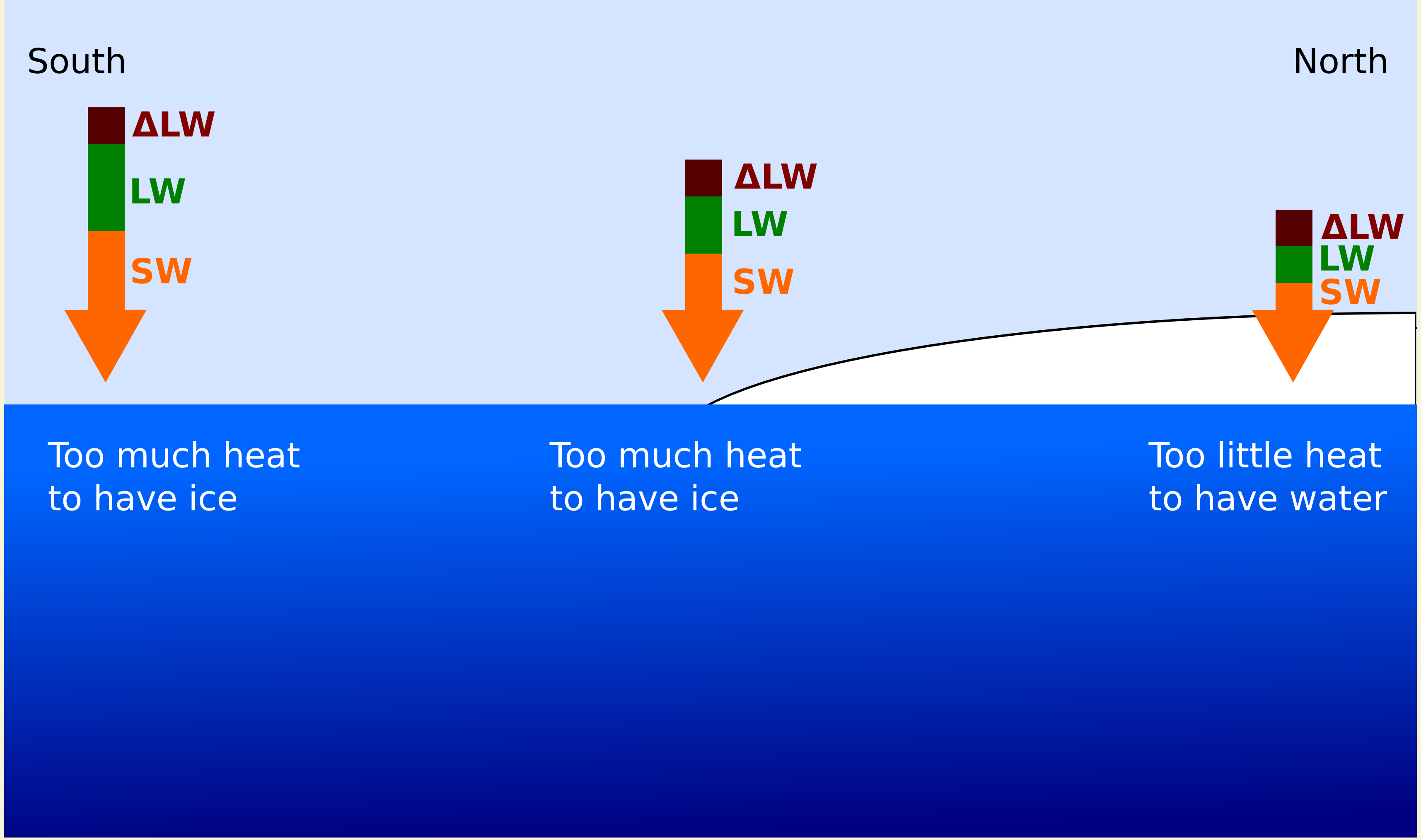


Notz and Stroeve, Science, 2016

A conceptual view of Arctic sea-ice loss



A conceptual view of Arctic sea-ice loss



Notz and Stroeve, Science, 2016

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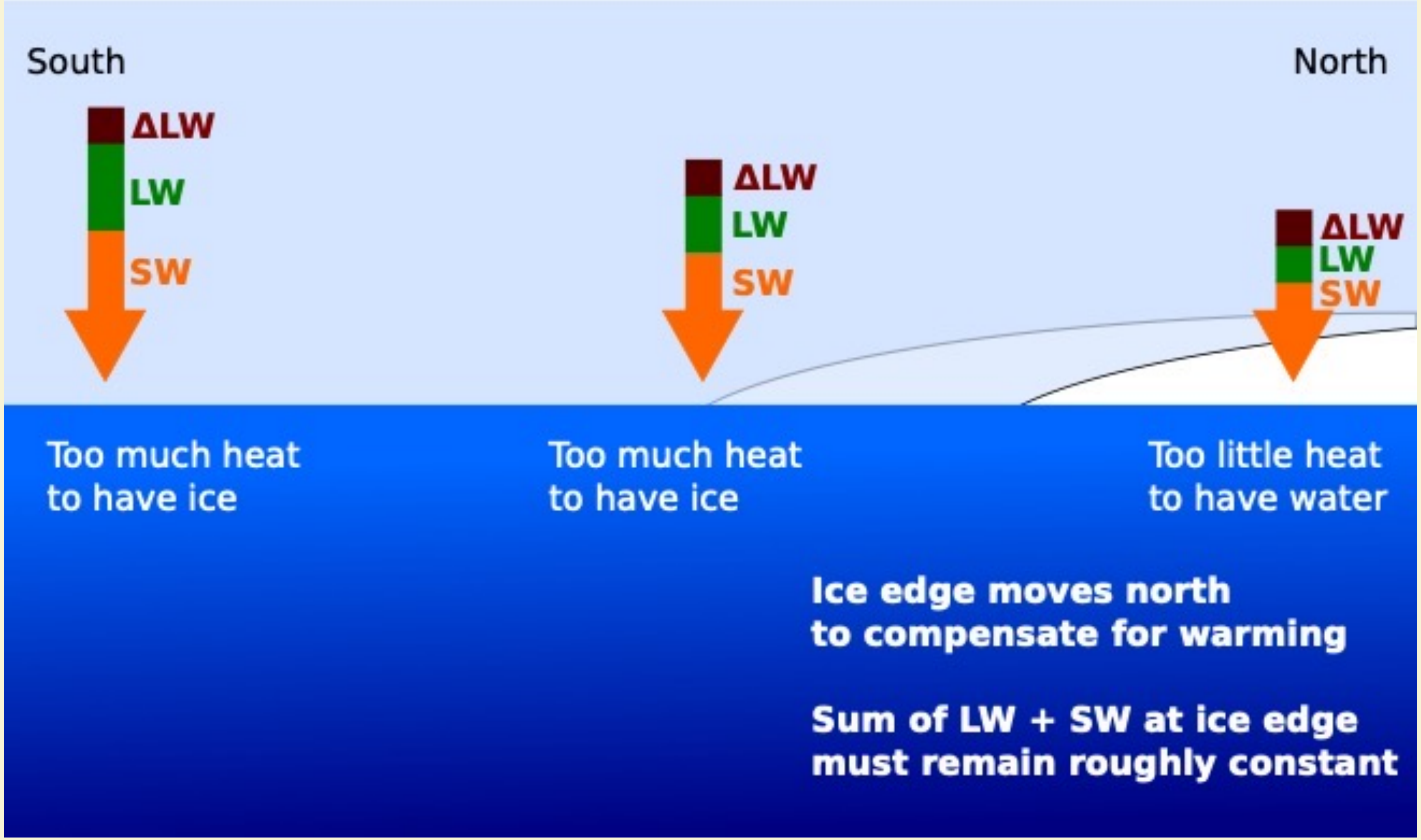


Notz and Stroeve, Science, 2016

A conceptual model of Arctic sea-ice loss

1 $\Delta LW \sim$ Emissions

For each ton of CO_2 emissions, incoming longwave radiation increases roughly linearly (empirical result).

Notz and Stroeve, Science, 2016

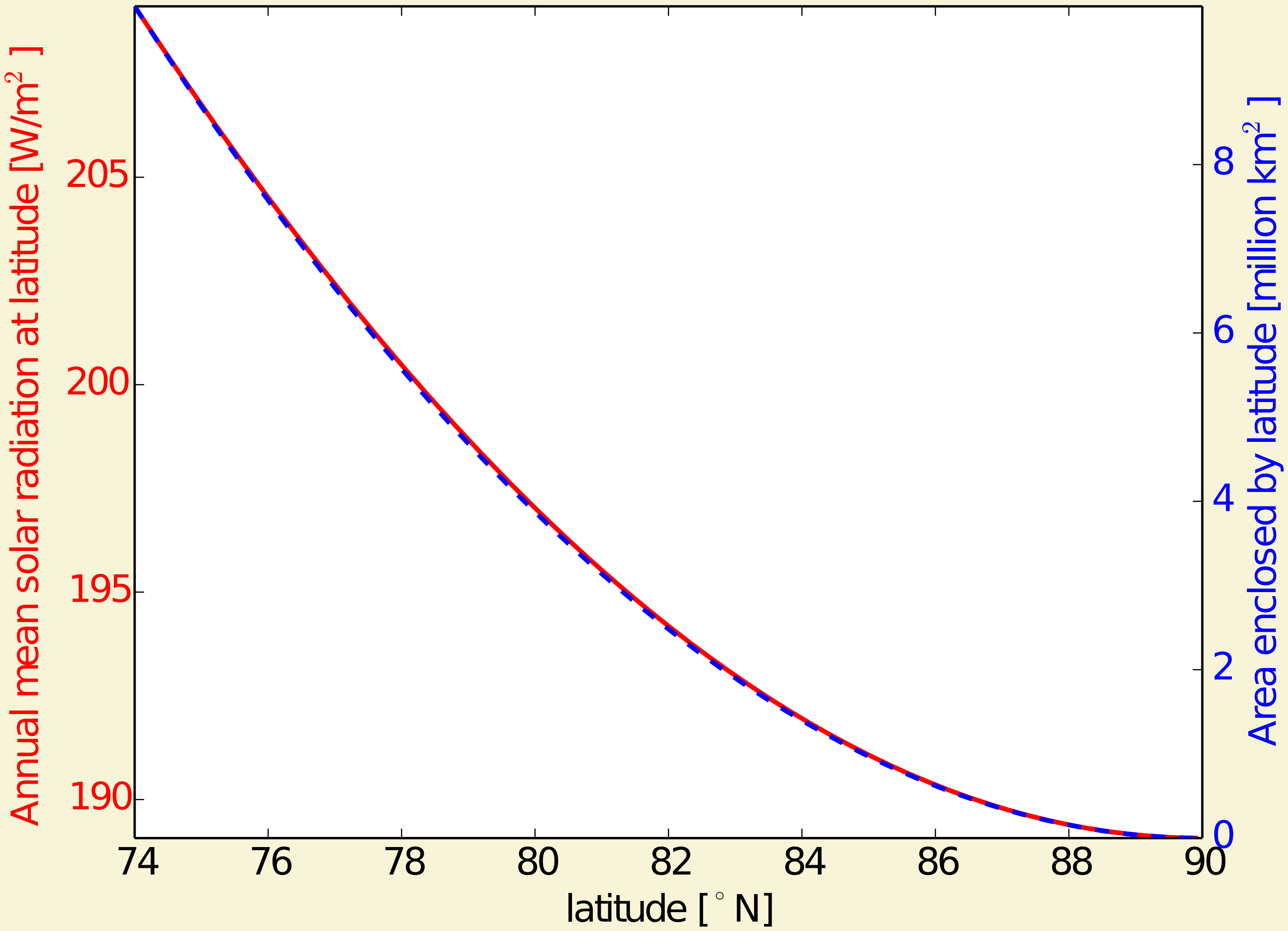
A conceptual model of Arctic sea-ice loss

1 $\Delta LW \sim$ Emissions
For each ton of CO_2 emissions, incoming longwave radiation increases roughly linearly (empirical result).

2 $\Delta SW_{\text{ice edge}} \approx -\Delta LW$
To compensate for increase in net incoming LW by, say, 1 W/m^2, ice edge moves North until net incoming SW is decreased by 1 W/m^2

Notz and Stroeve, Science, 2016

SIA and mean solar irradiance as a function of latitude



Notz and Stroeve, Science, 2016

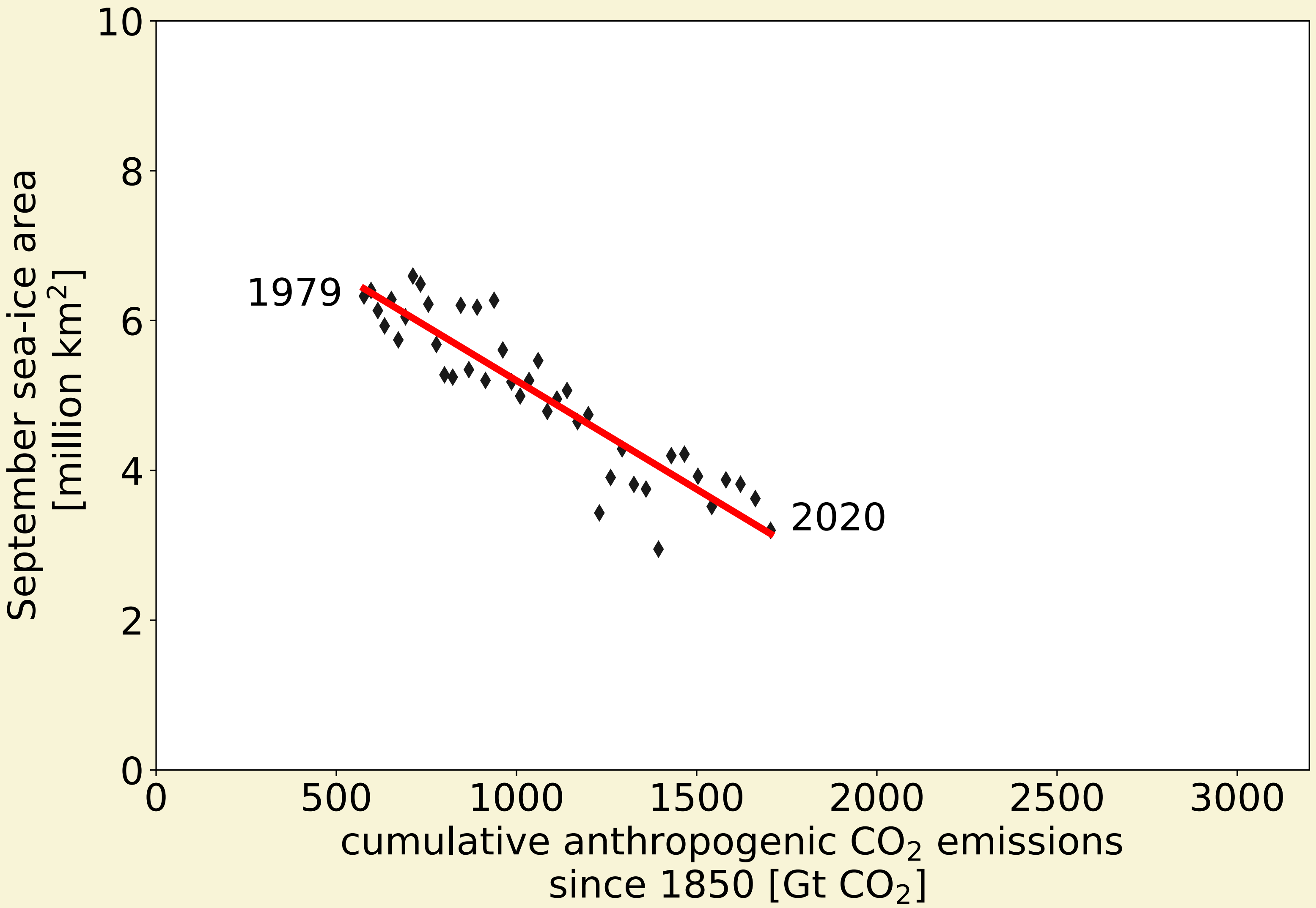
A conceptual model of Arctic sea-ice loss

1. $\Delta LW \sim$ Emissions
   For each ton of CO_2 emissions, incoming longwave radiation increases roughly linearly (empirical result).
2. $\Delta SW_{\text{ice edge}} \approx -\Delta LW$
   To compensate for increase in net incoming LW by, say, 1 W/m^2, ice edge moves North until net incoming SW is decreased by 1 W/m^2
3. $\Delta SIA \sim \Delta SW_{\text{ice edge}}$
   The change in sea-ice area is linearly related to change in incoming SW radiation at the ice edge.

Hence: $\Delta SIA \sim$ Emissions

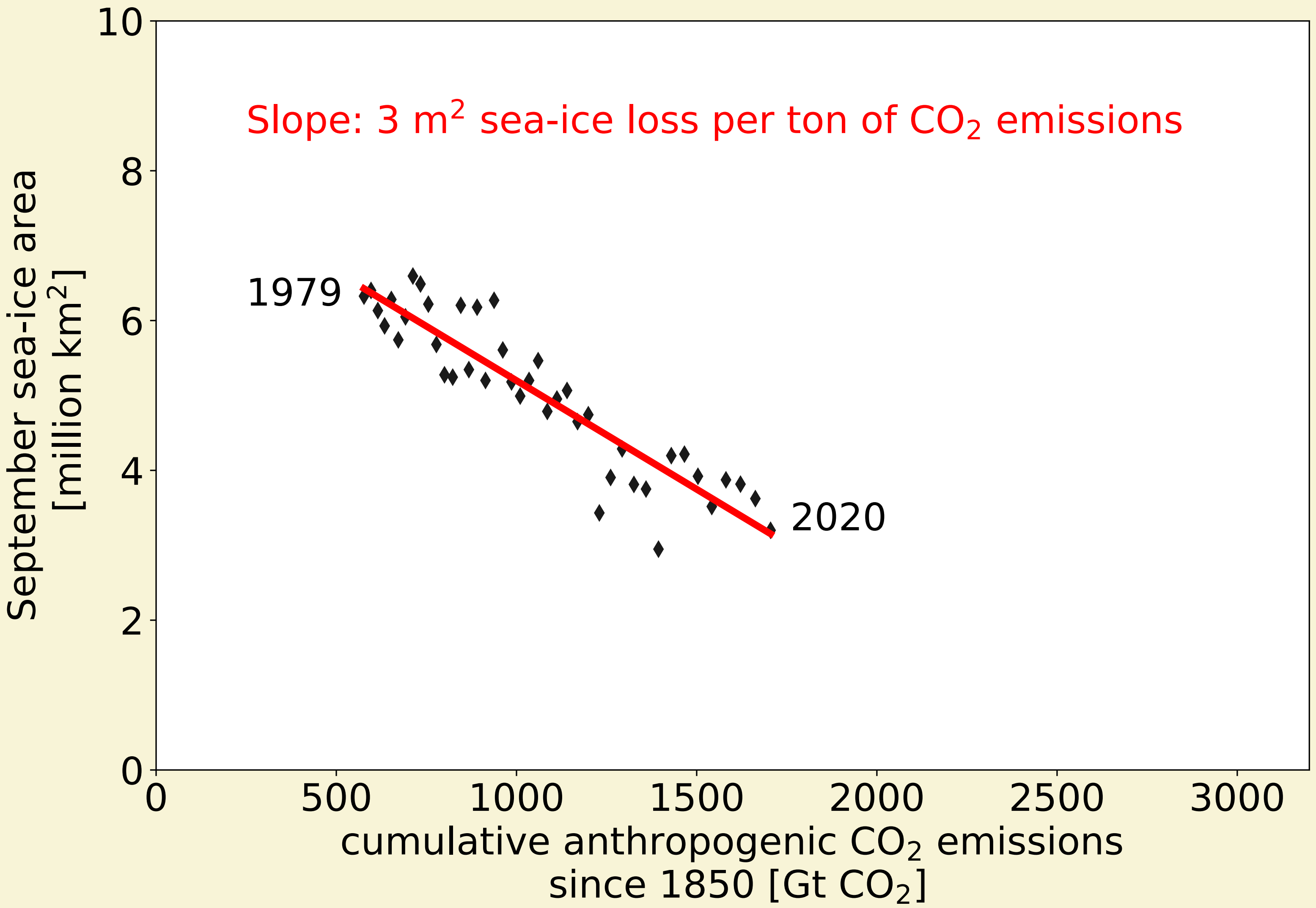
Notz and Stroeve, Science, 2016

Sea-ice loss is linearly related to CO_2 emissions



Notz and Stroeve, Science, 2016

Sea-ice loss is linearly related to CO_2 emissions



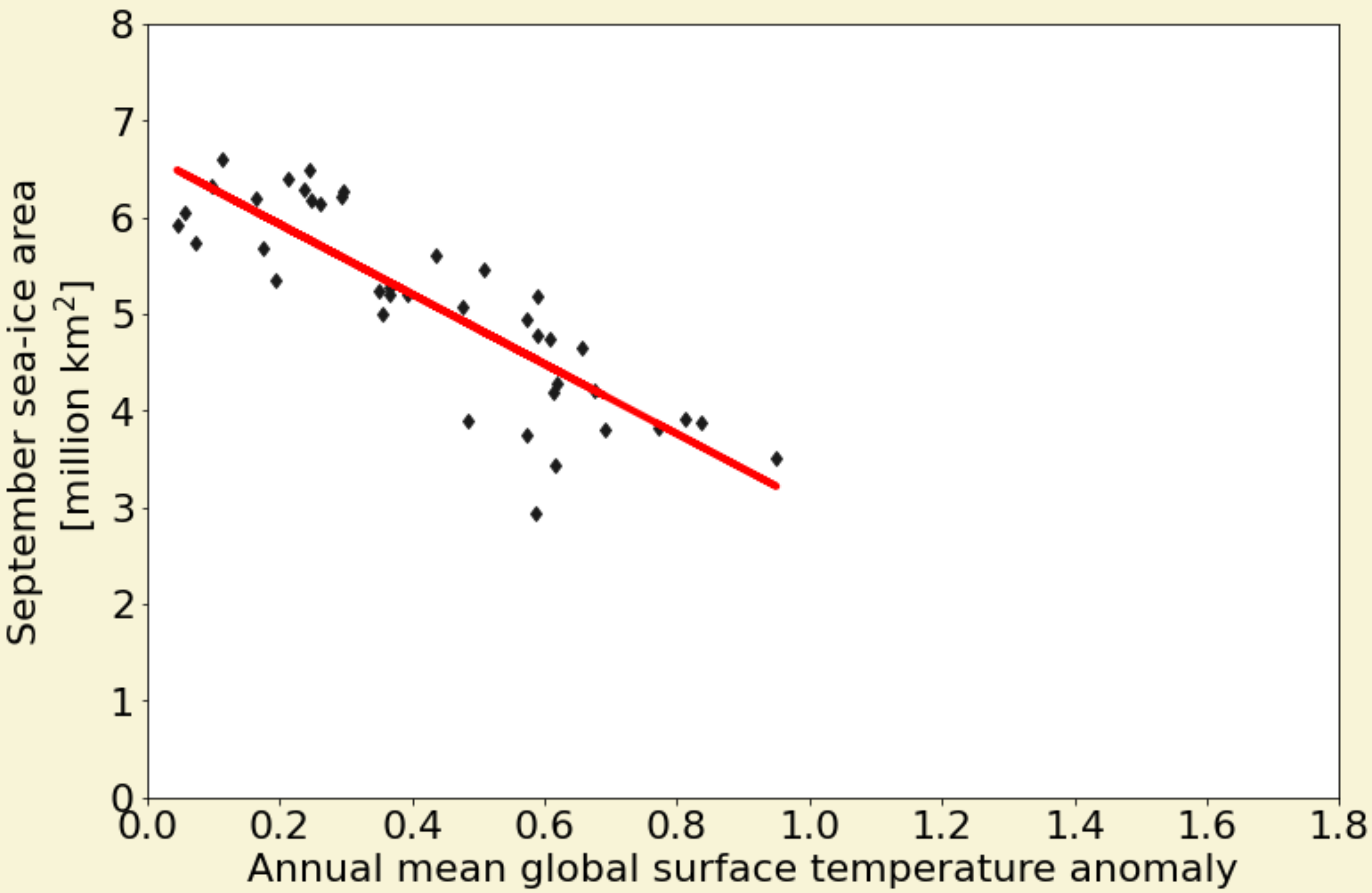
Notz and Stroeve, Science, 2016

A conceptual model of sea-ice loss

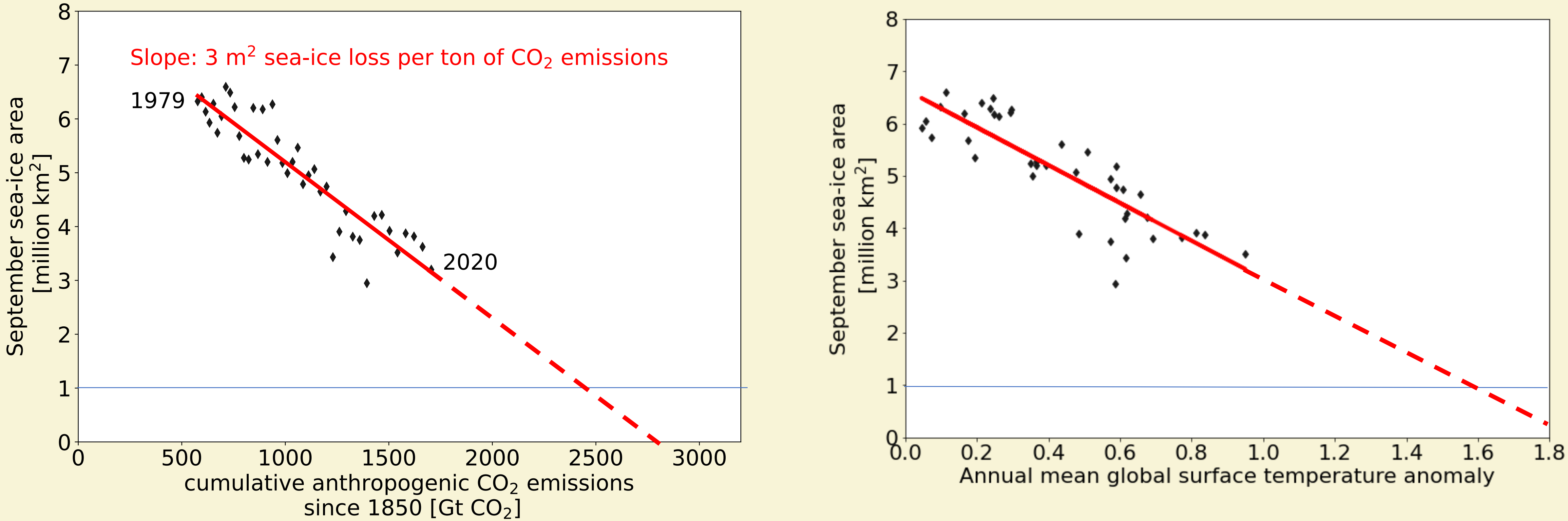
1. $\Delta LW \sim$ Emissions **or ΔT**
   For each ton of CO_2 emissions, incoming longwave radiation increases roughly linearly (empirical result).
2. $\Delta SW_{\text{ice edge}} \approx -\Delta LW$
   To compensate for increase in net incoming LW by, say, 1 W/m^2, ice edge moves North until net incoming SW is decreased by 1 W/m^2
3. $\Delta SIA \sim \Delta SW_{\text{ice edge}}$
   The change in sea-ice area is linearly related to change in incoming SW radiation at the ice edge.

Hence: $\Delta SIA \sim$ Emissions or ΔT

Sea-ice loss is linearly related to global mean temperature rise



Linearity allows for estimate of ice-free Arctic threshold



Based on the conceptual model and the observed sensitivity, the Arctic will on average be practically sea-ice free throughout September for future CO_2 emissions of around 800 Gt and for a global warming of around 1.6 °C.

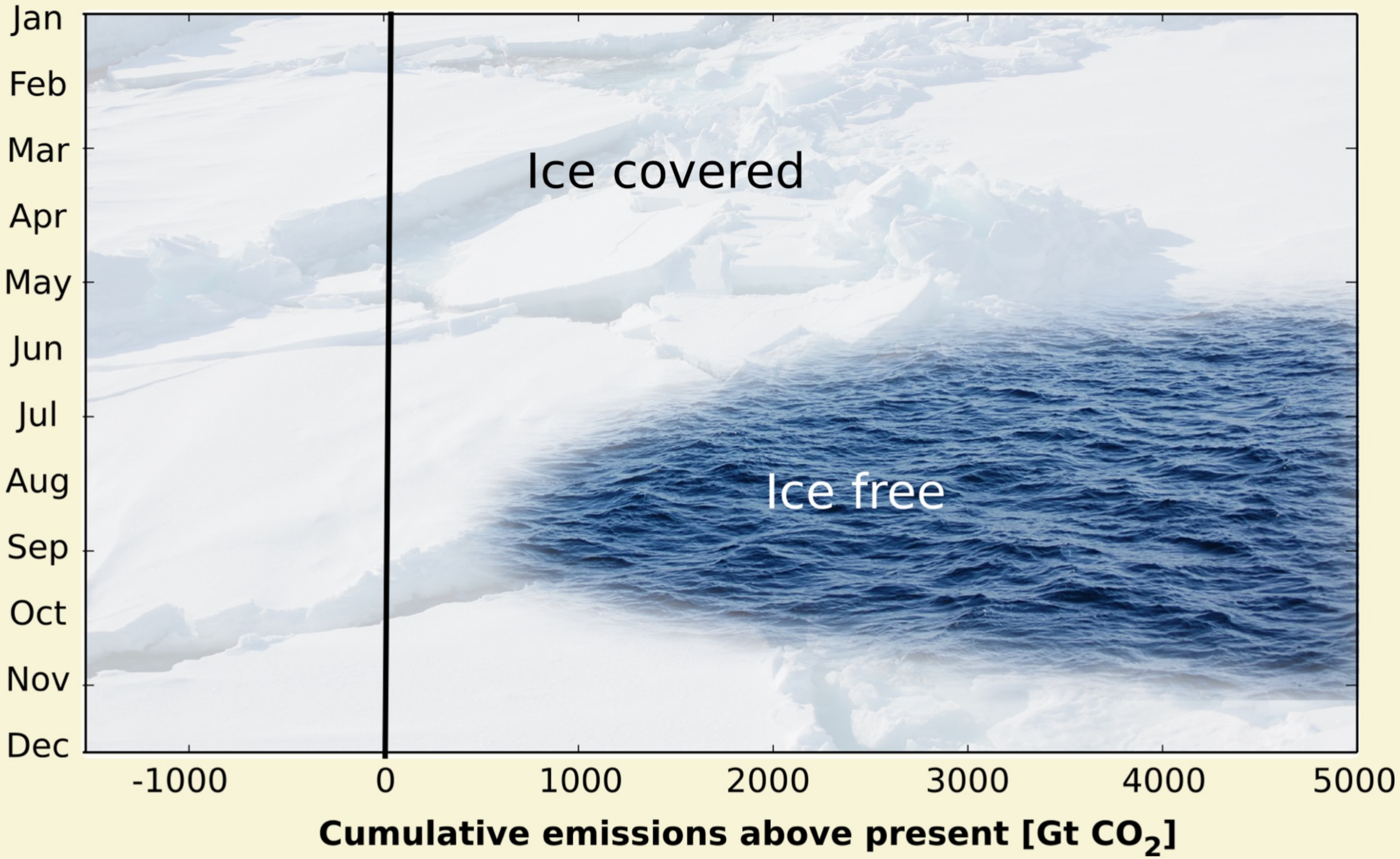
What about internal variability?

- Observed fluctuations around linear trend line are usually below 1 million km^2
- The standard deviation of the 1953-1978 HadISST sea-ice area record in September is 0.36 million km^2, giving a 2σ interval of around 0.7 million km^2
- Assuming an internal variability of 2σ = 1 million km^2 and the observed sensitivities (e.g., 3 m^2 / ton), we get an uncertainty range from internal variability of around 300 Gt of future CO_2 emissions and 0.3 °C of future global warming

Based on the conceptual model and the observed sensitivity, the Arctic will on average be practically sea-ice free in September for future CO_2 emissions of around 800±300 Gt and for a global warming of around 1.6±0.3 °C.

Notz and Stroeve, Curr. Clim. Change Reports, 2018

Future sea-ice evolution



Stroeve and Notz, Env. Res. Lett., 2018; Notz and Stroeve, Curr. Clim. Change Reports, 2018

Insights from conceptual model and observations

- Based on the conceptual model and the observed sensitivity, the Arctic will on average be practically sea-ice free in September for future CO_2 emissions of around 800±300 Gt and for a global warming of around 1.6±0.3 °C.
- Current CO2 emissions are around 40 Gt per year, so for current emissions the Arctic will be sea-ice free throughout September for the first time in 10 to 25 years
- In all SSP emission scenarios, future emissions of CO_2 exceed 500 Gt, so the Arctic will become practically sea-ice free at least occasionally in all plausible future emission scenarios.

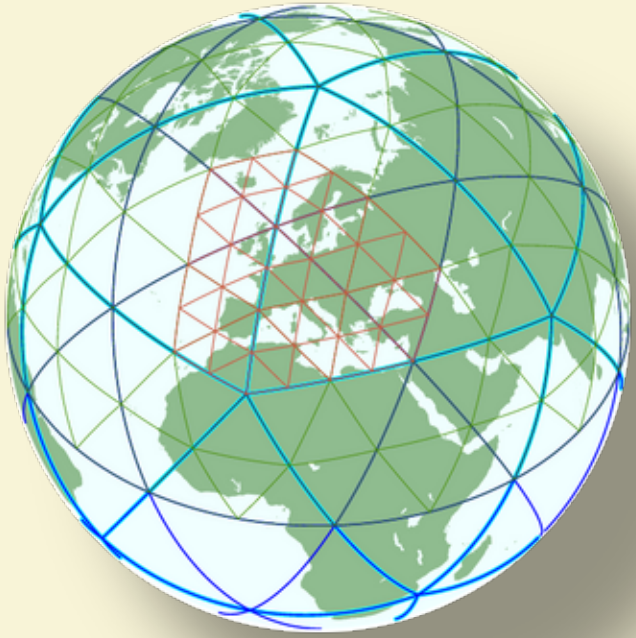
Overview

1. When is the Arctic sea-ice free according to classical science?
2. When is the Arctic sea-ice free according to climate models?
3. Ways forward

How can we use a climate model?

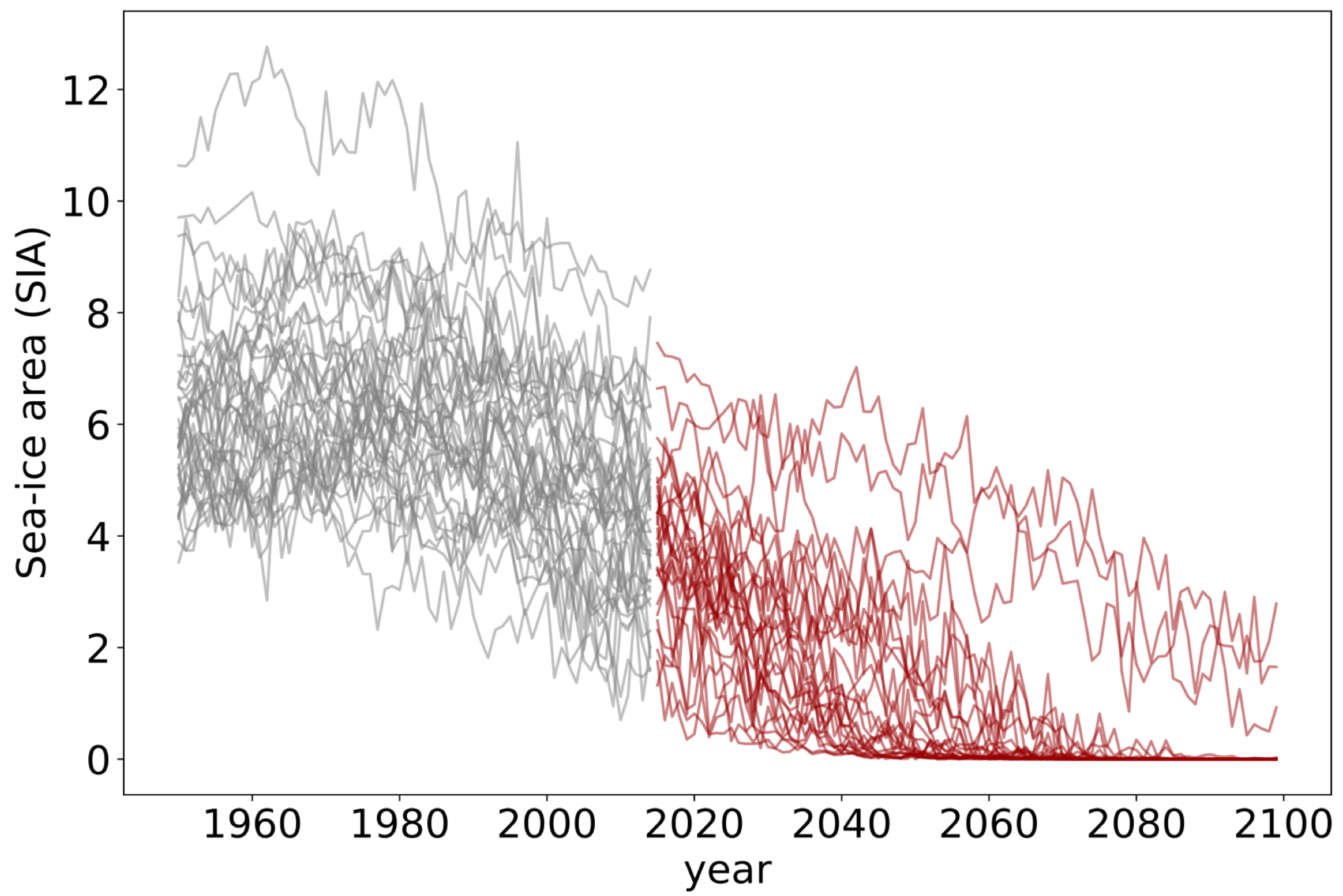
- …as a tool that can be used as a proxy for reality by help of observations
- ...as a tool that can be used as a proxy for reality by help of understanding

Climate models with observations as a proxy for reality?

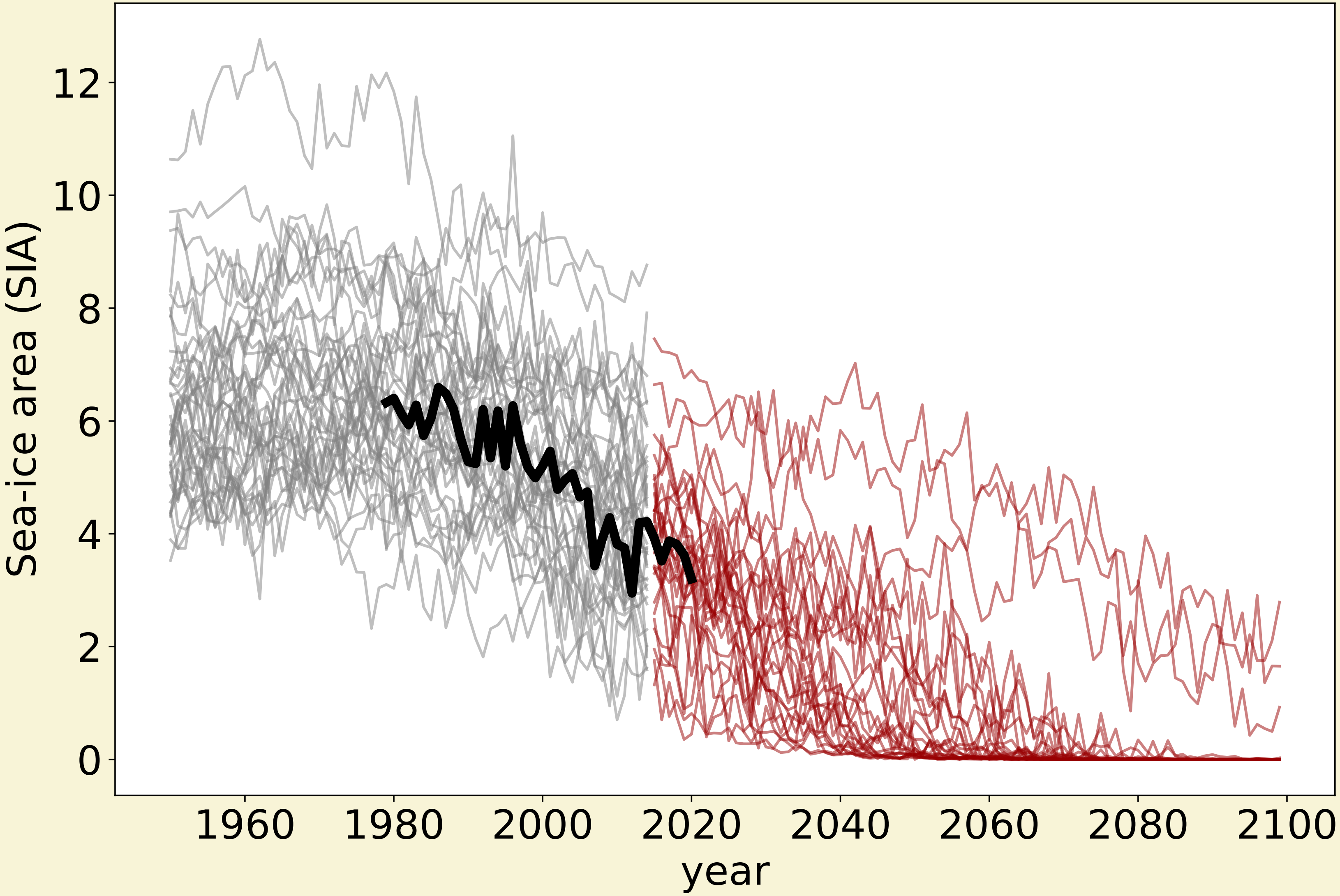


+ Observations =

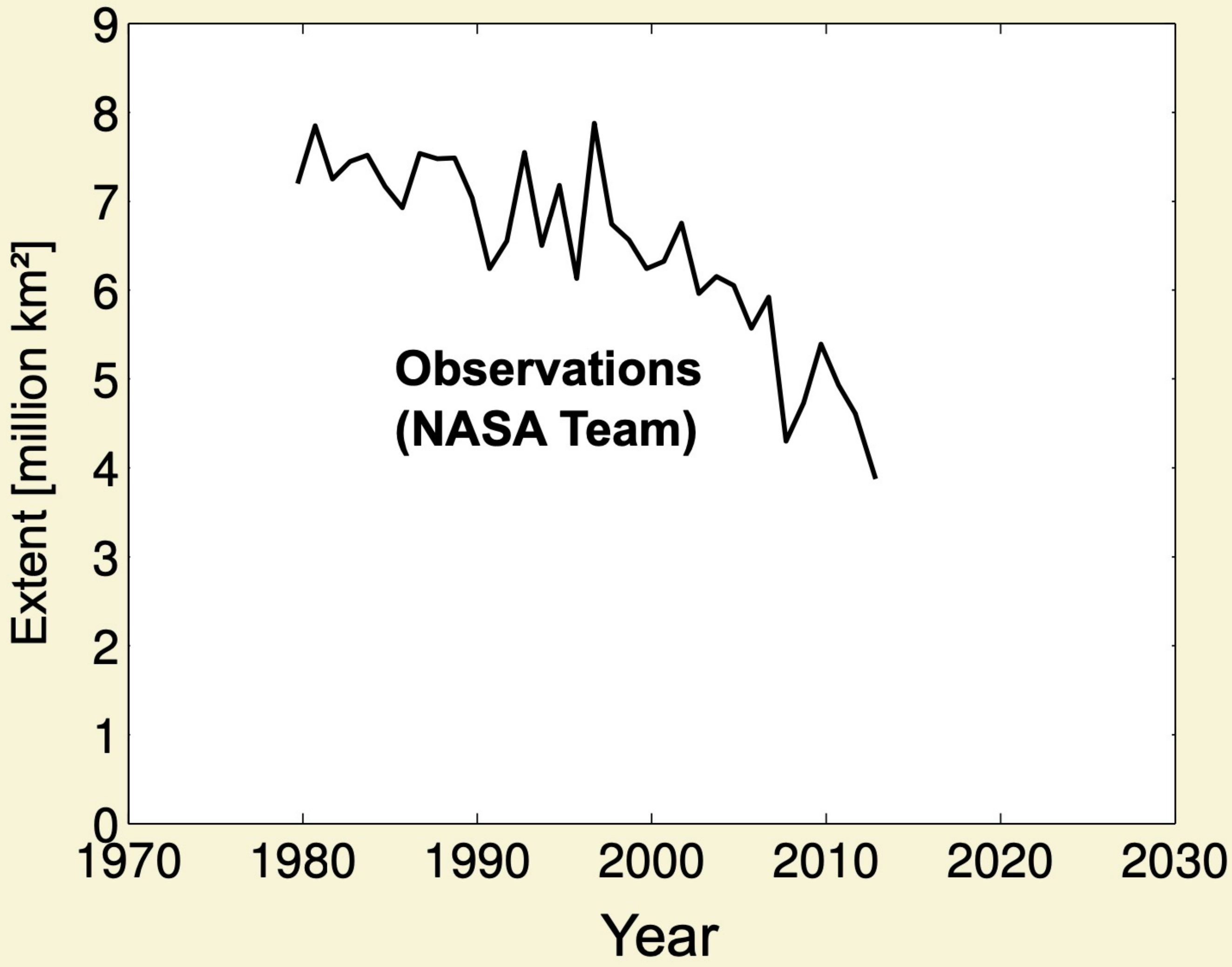
September Arctic sea-ice area in CMIP6 SSP5-8.5



September Arctic sea-ice area in CMIP6 SSP5-8.5



Selecting a “good” model



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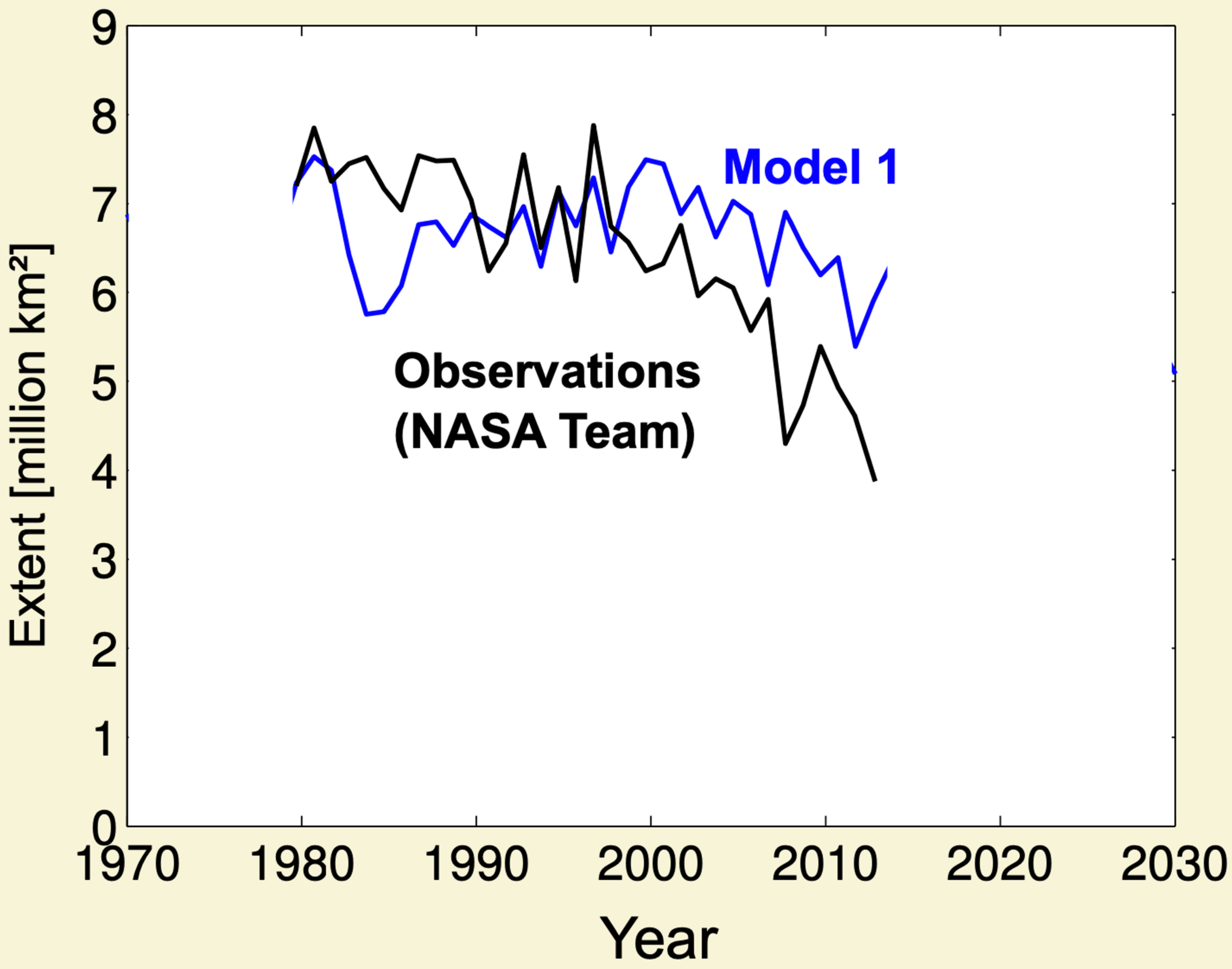

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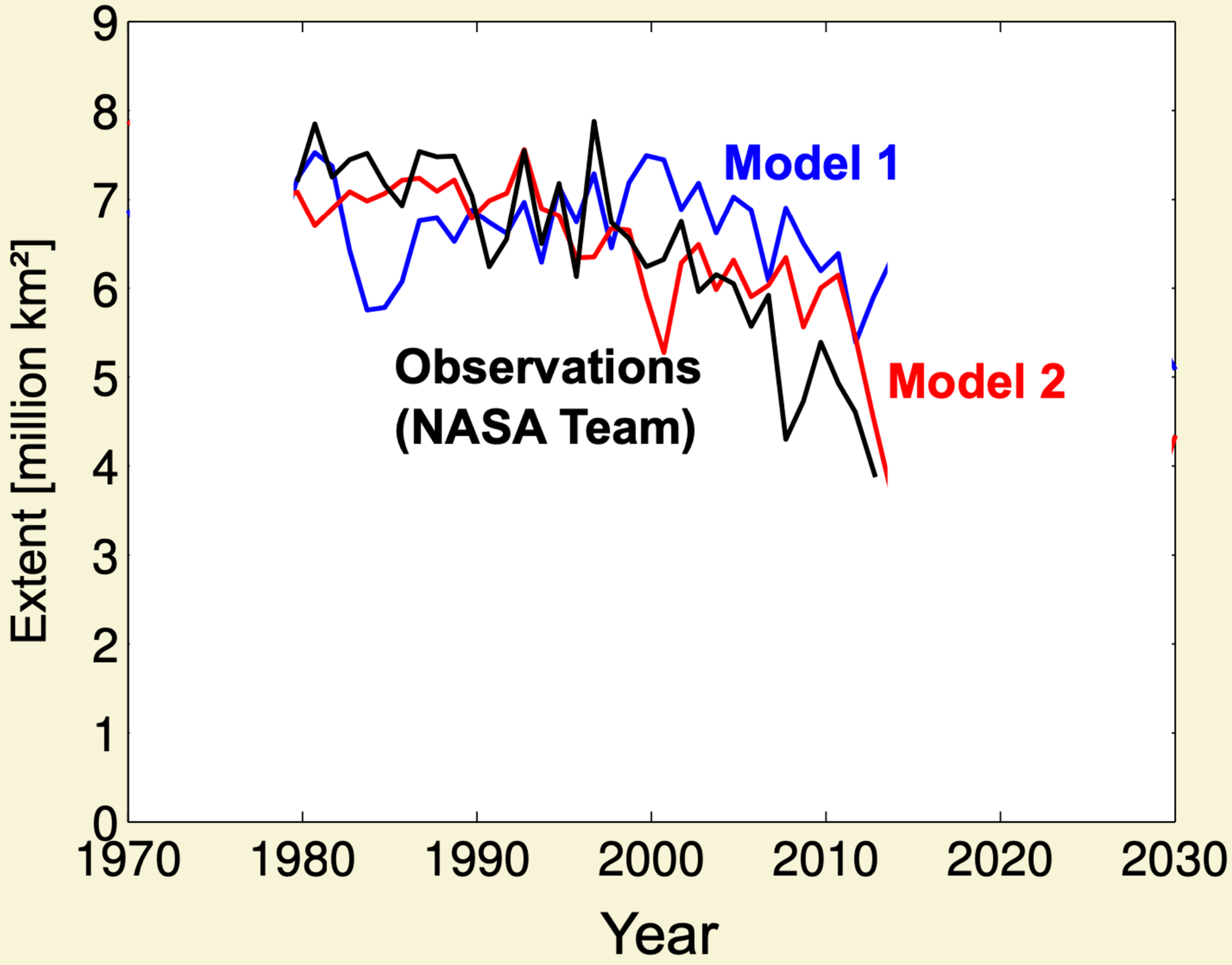
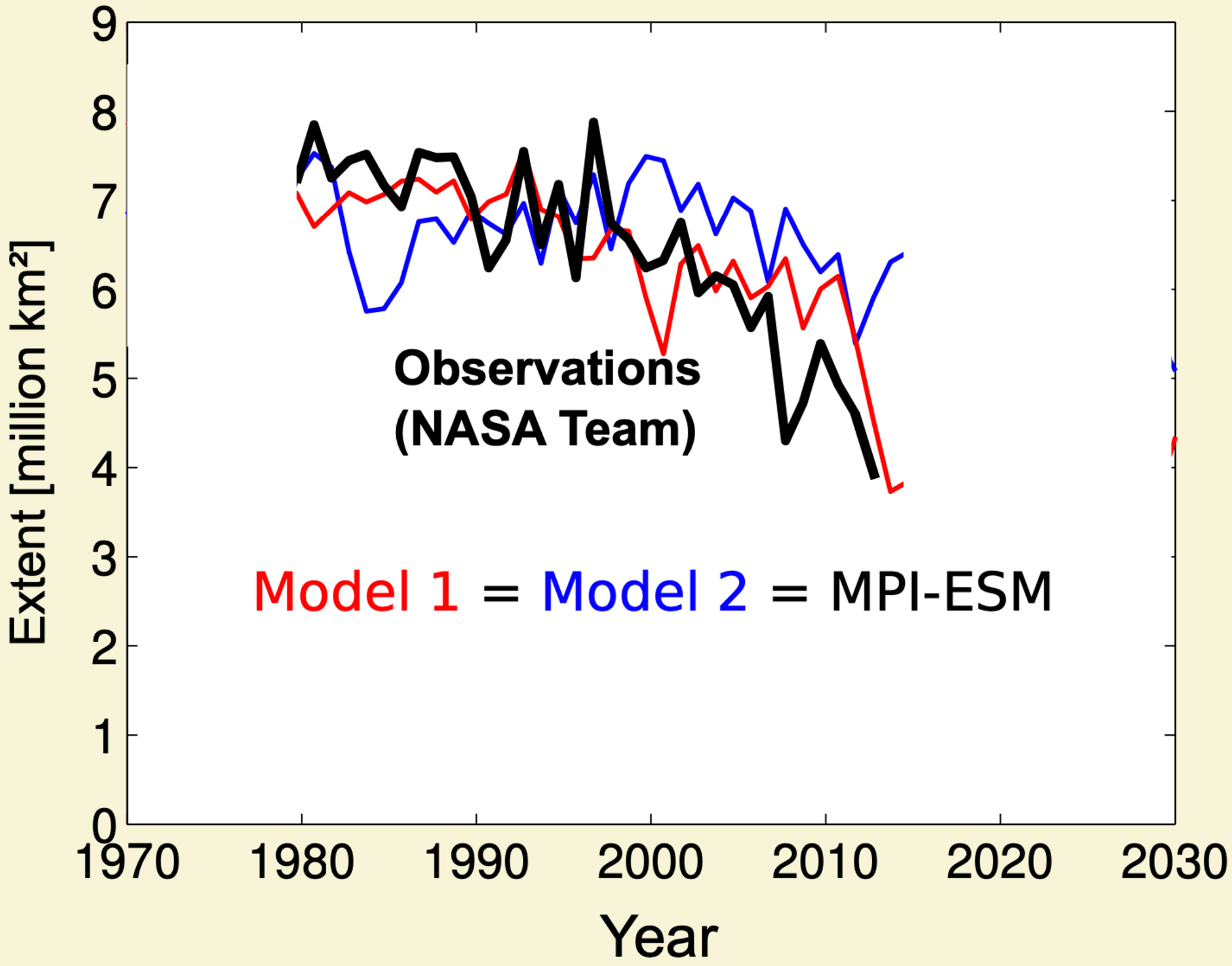
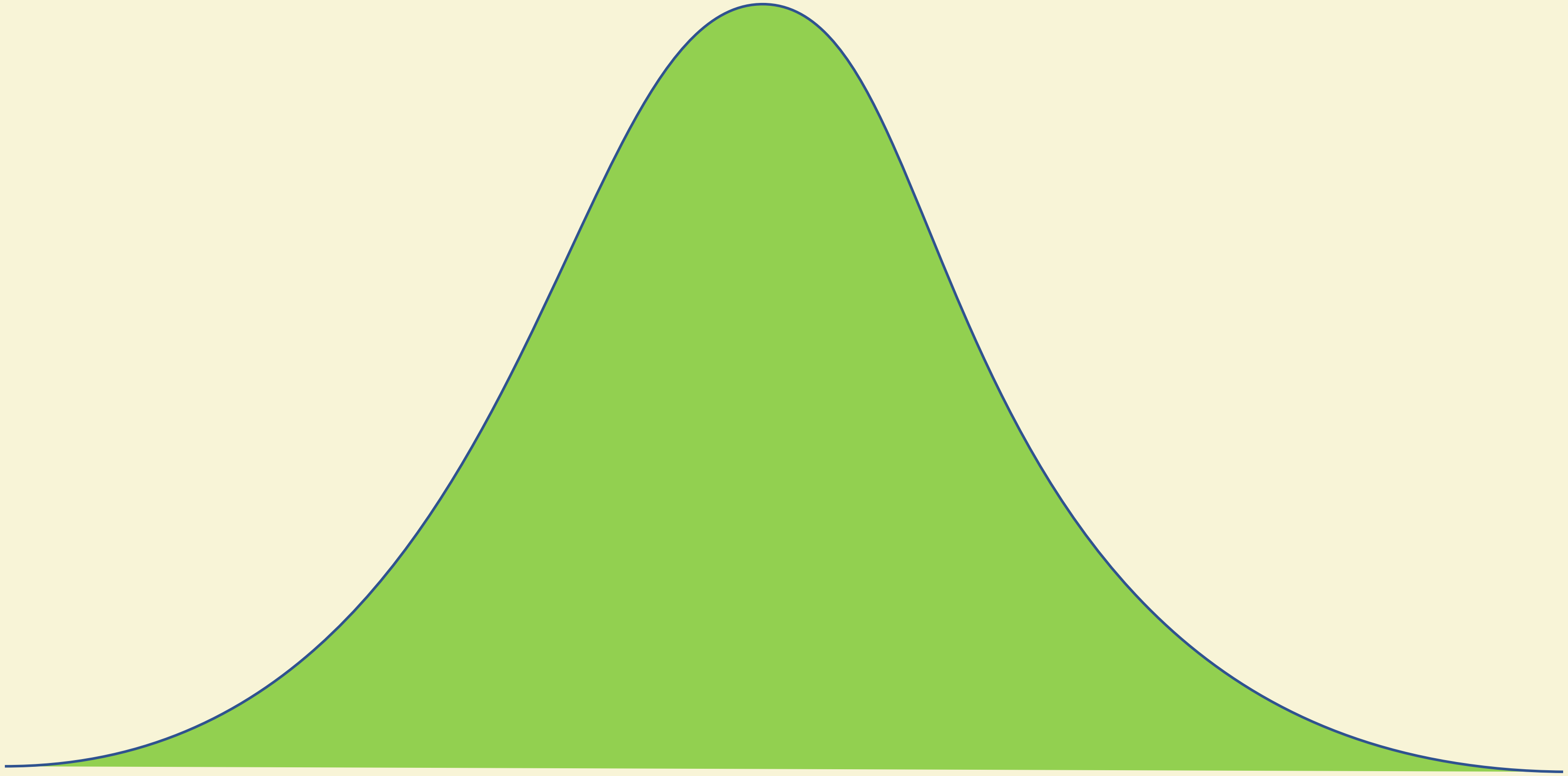


Selecting a “good” model



The impact of internal variability

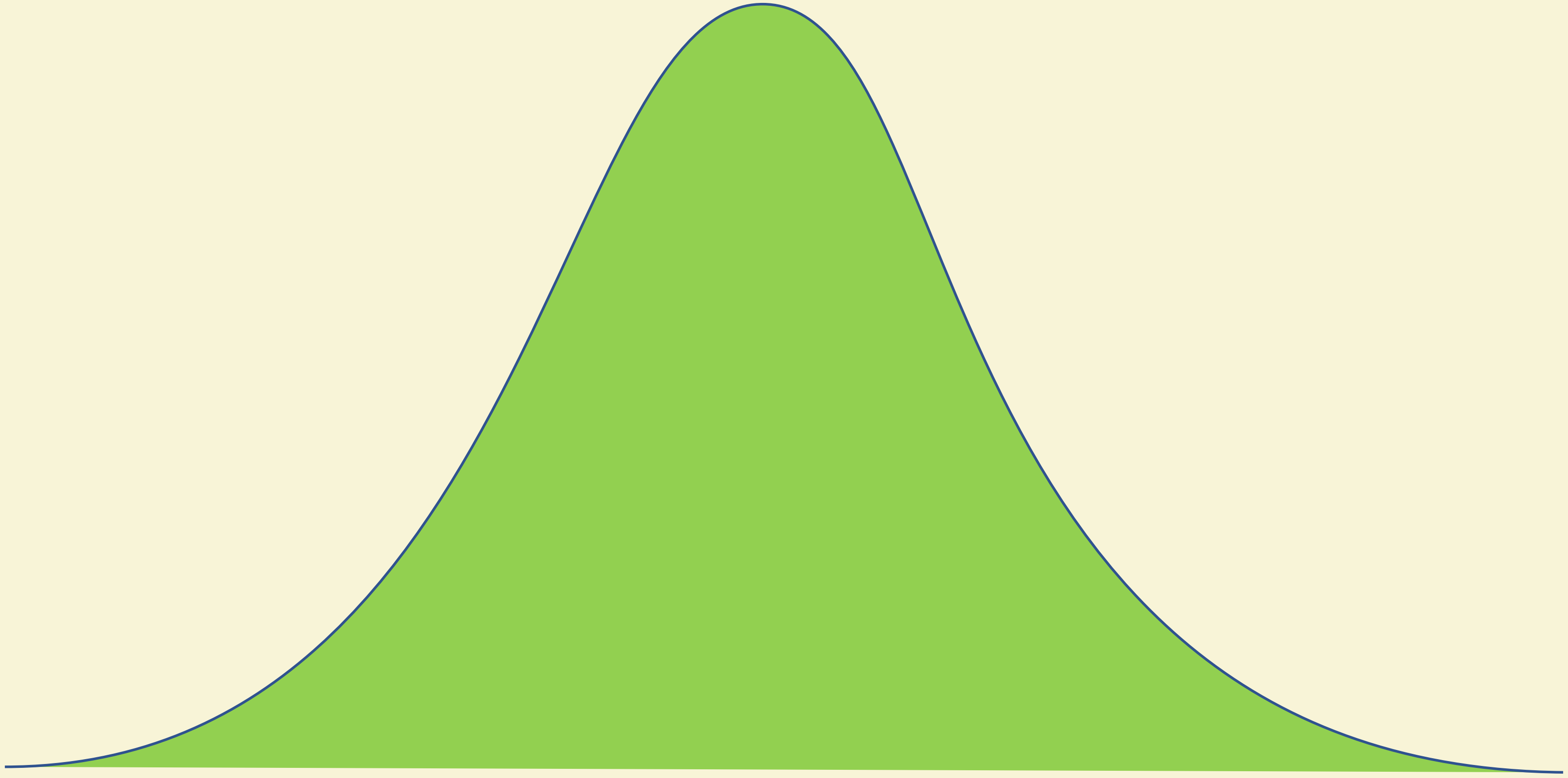
How a climate model
sees the world



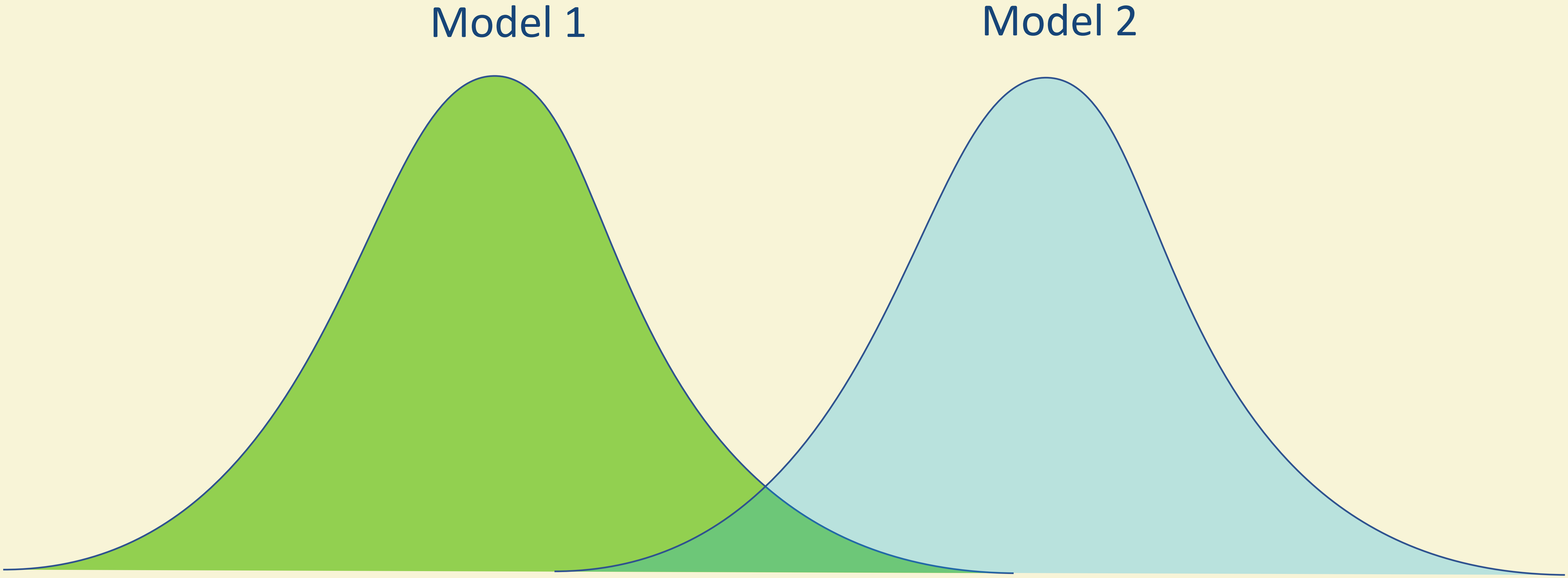
The impact of internal variability

How a climate model sees the world

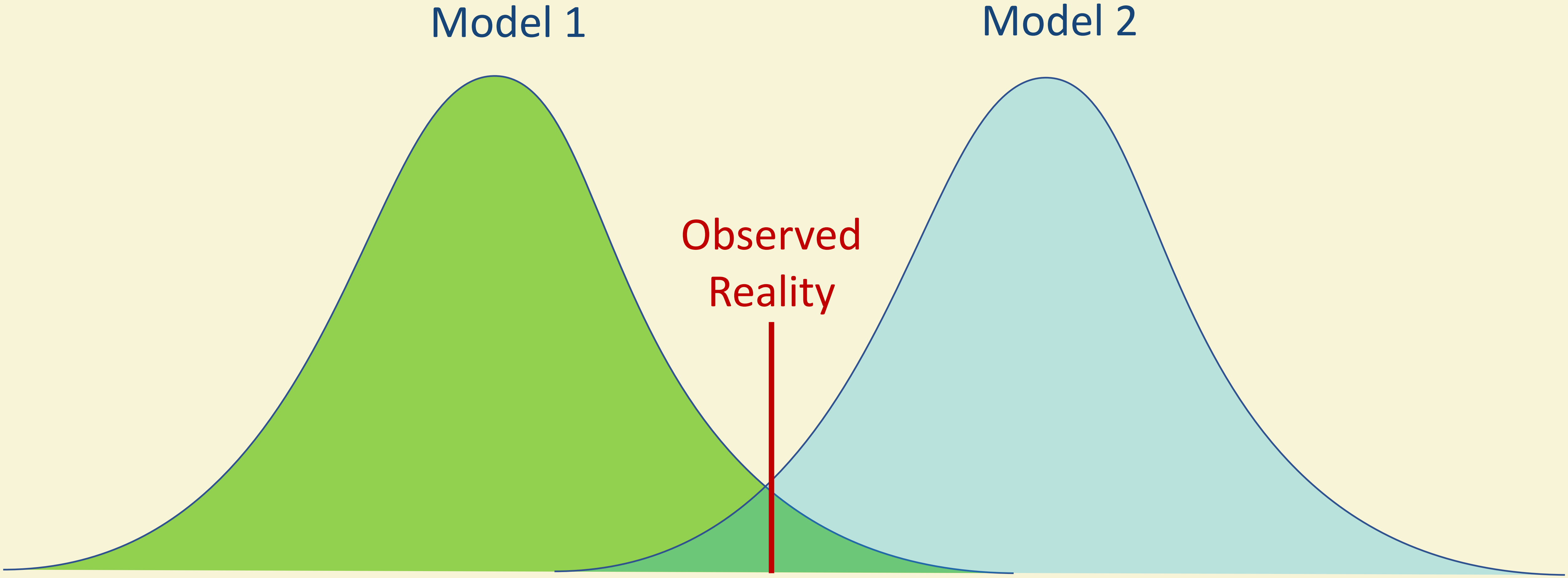
How we see the world



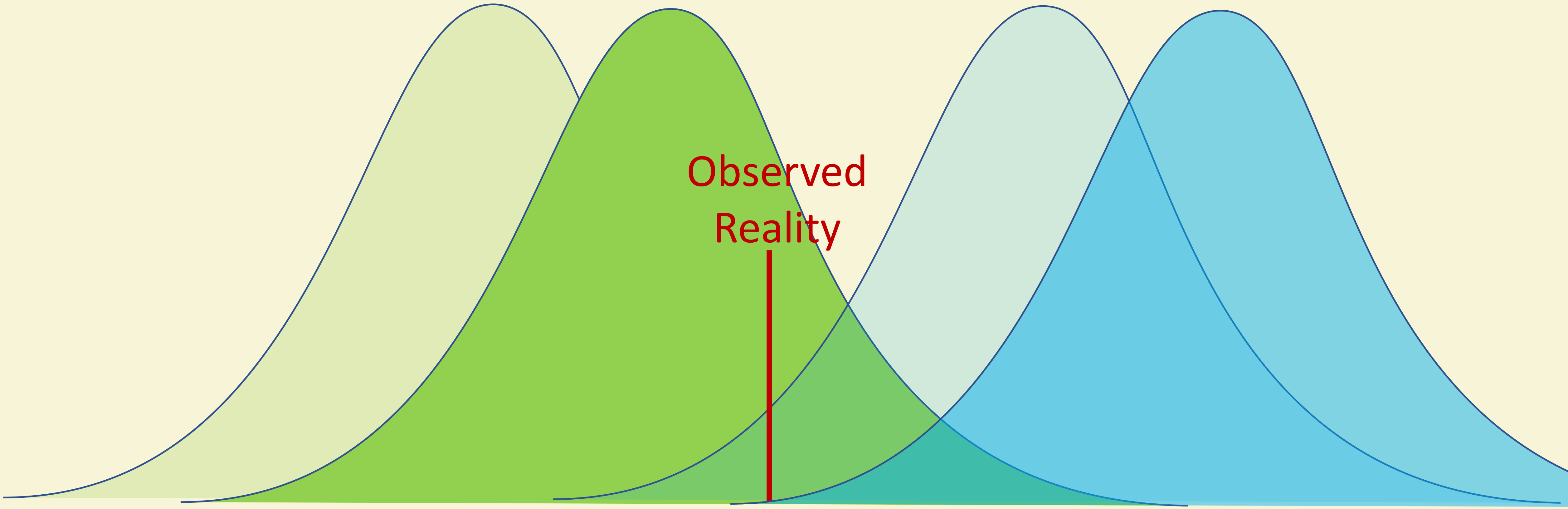
Model evaluation



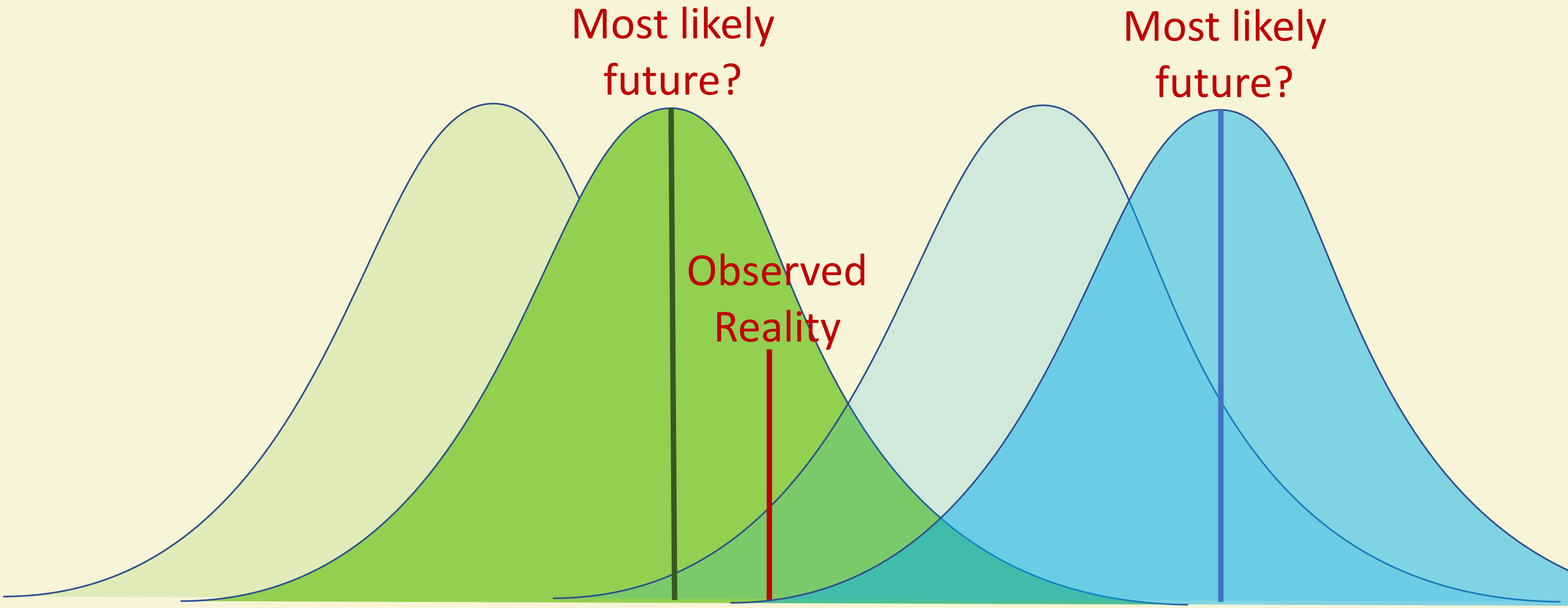
Model evaluation



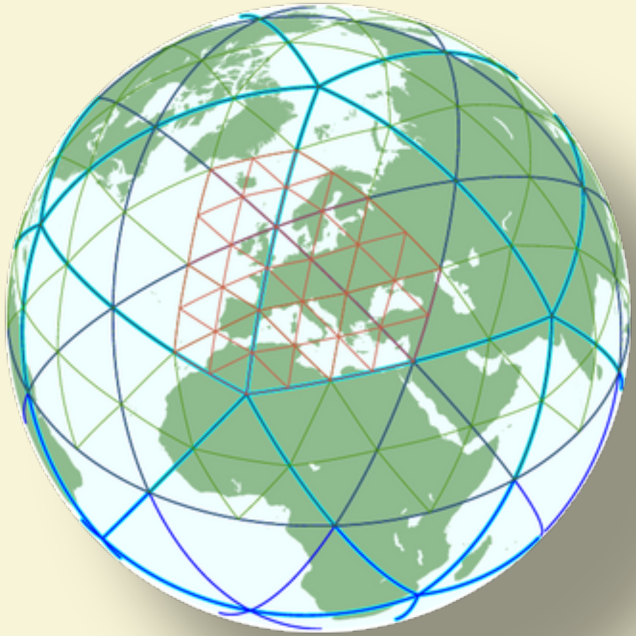
Projections



Inflated uncertainty of future change

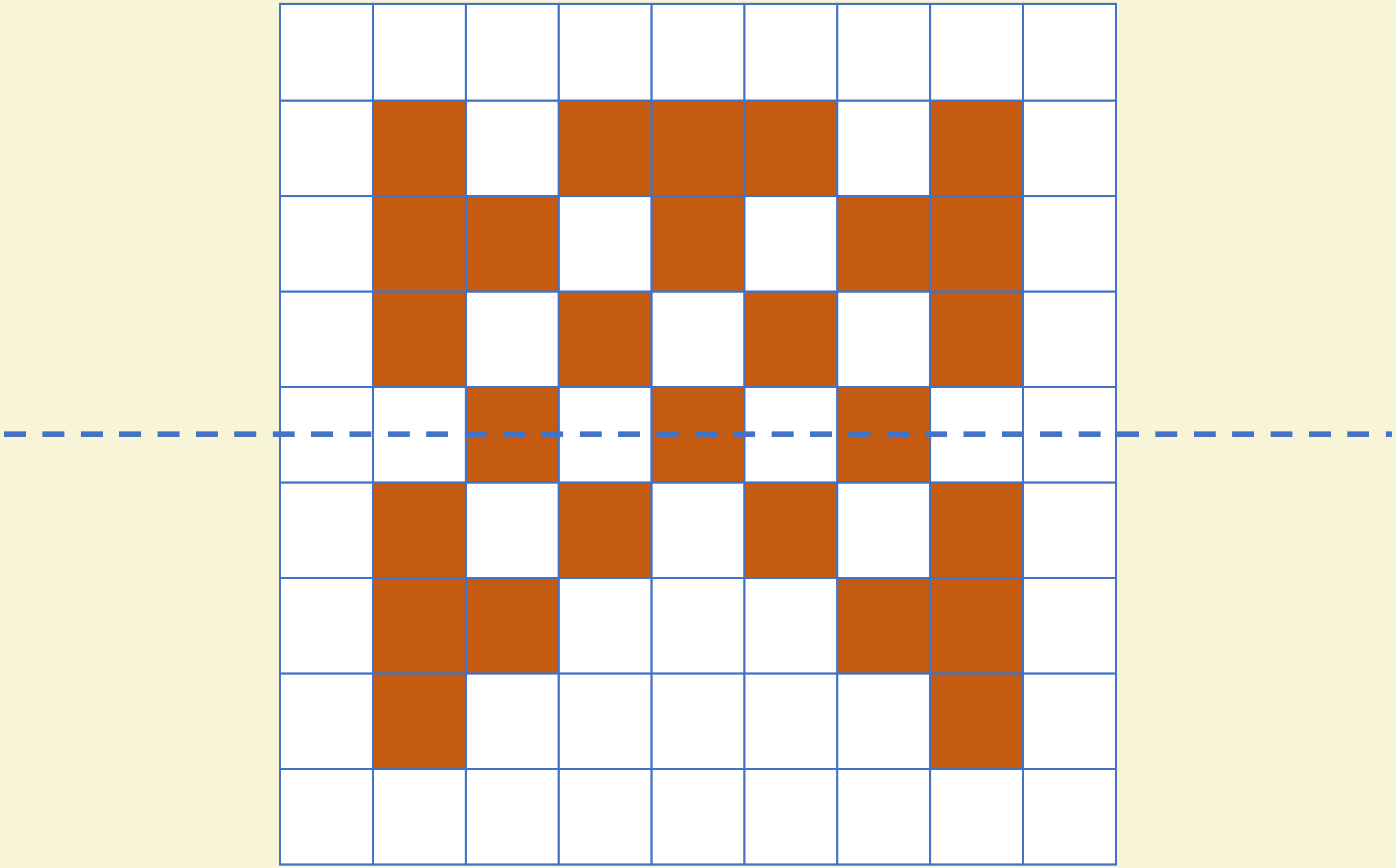


Climate models with understanding as a proxy for reality?



+ Understanding =

Can you make this symmetric around the horizontal line?



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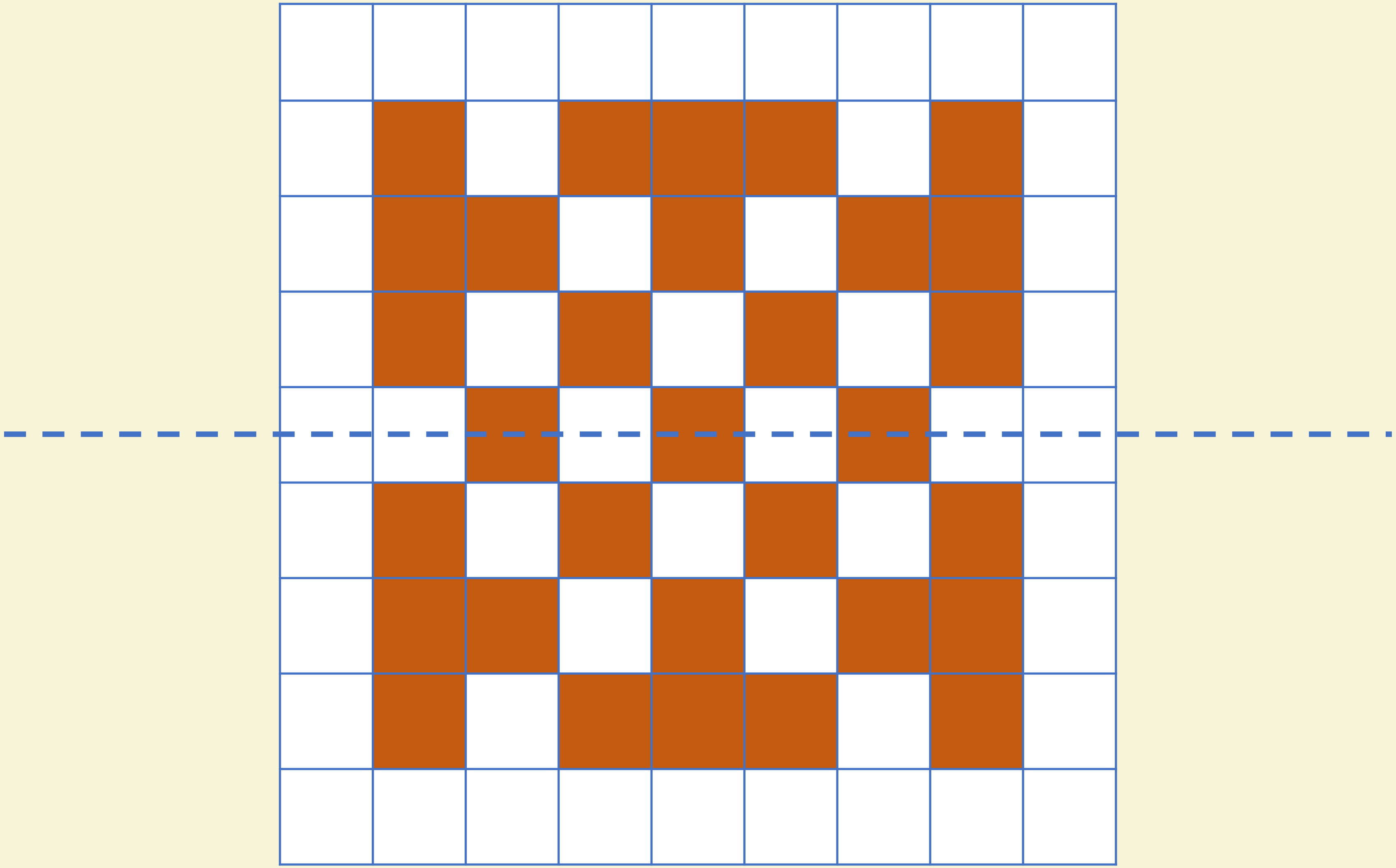

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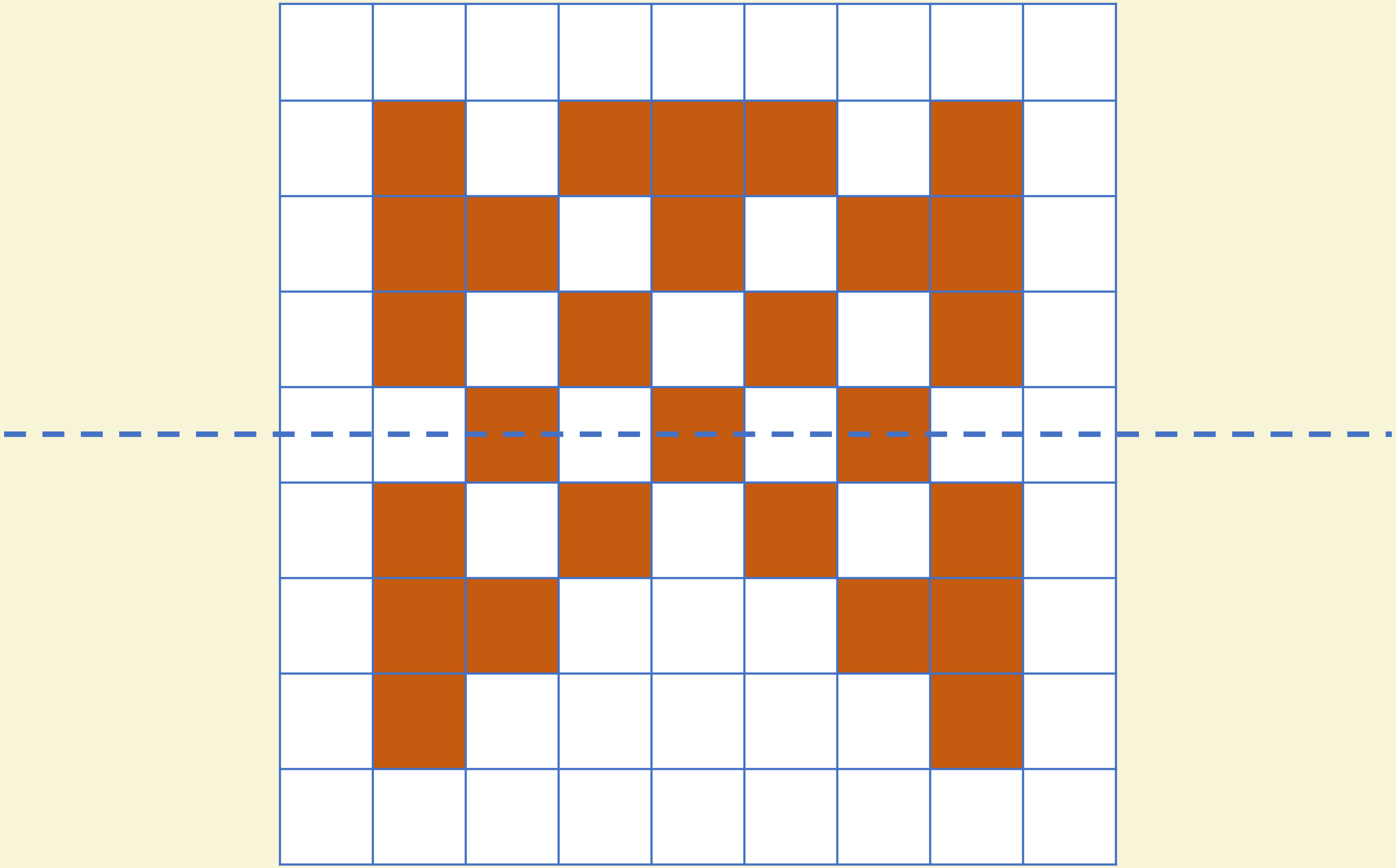

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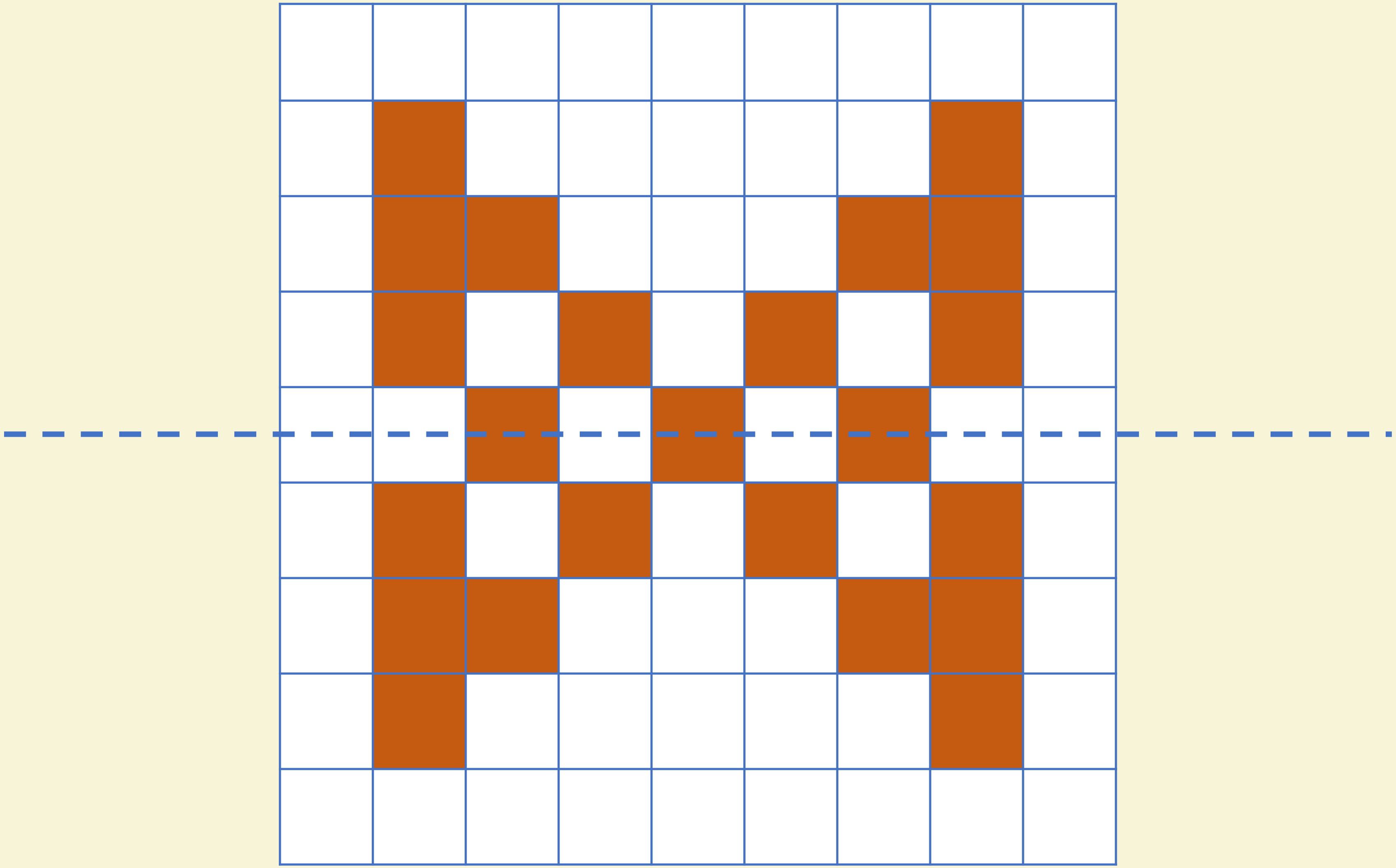


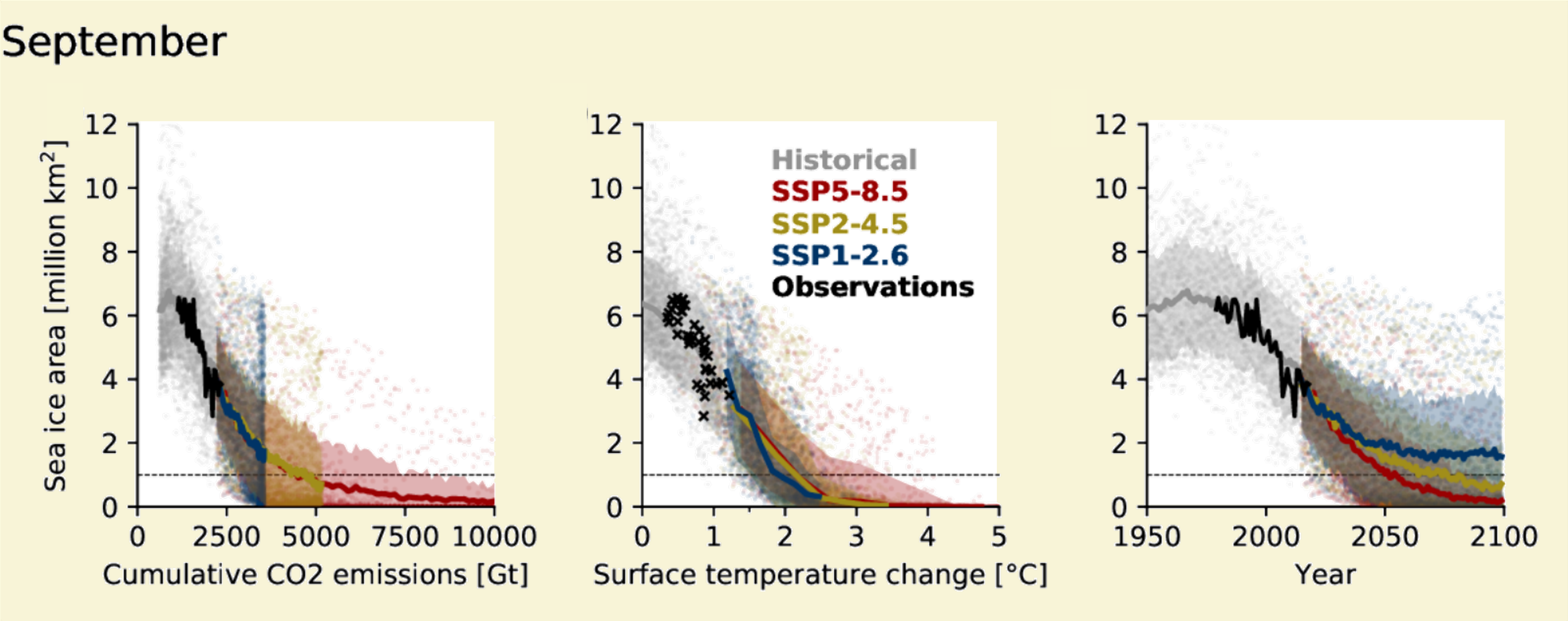
“People systematically overlook subtractive changes”

“Improving objects, ideas or situations […] requires a mental search for possible changes. Here we show that people systematically default to searching for additive transformations, and consequently overlook subtractive transformations.” (*Adams et al., Nature, 2021*)

The issue of climate model complexity

- We often assume that by adding processes to a climate model, we bring the model into closer agreement with "reality". While this only sometimes is true, adding processes always makes the models more complex
- By adding complexity, we might make the models less useful: The complexity of climate models already today implies that we often no more "understand" what they do. If they don't match our expectations, we usually assume the model to be flawed.
- To compensate for this complexity, we have started using emulators of climate models, as a workaround to reduce complexity. These can be understood as us admitting that model complexity must often be reduced for the models to be helpful

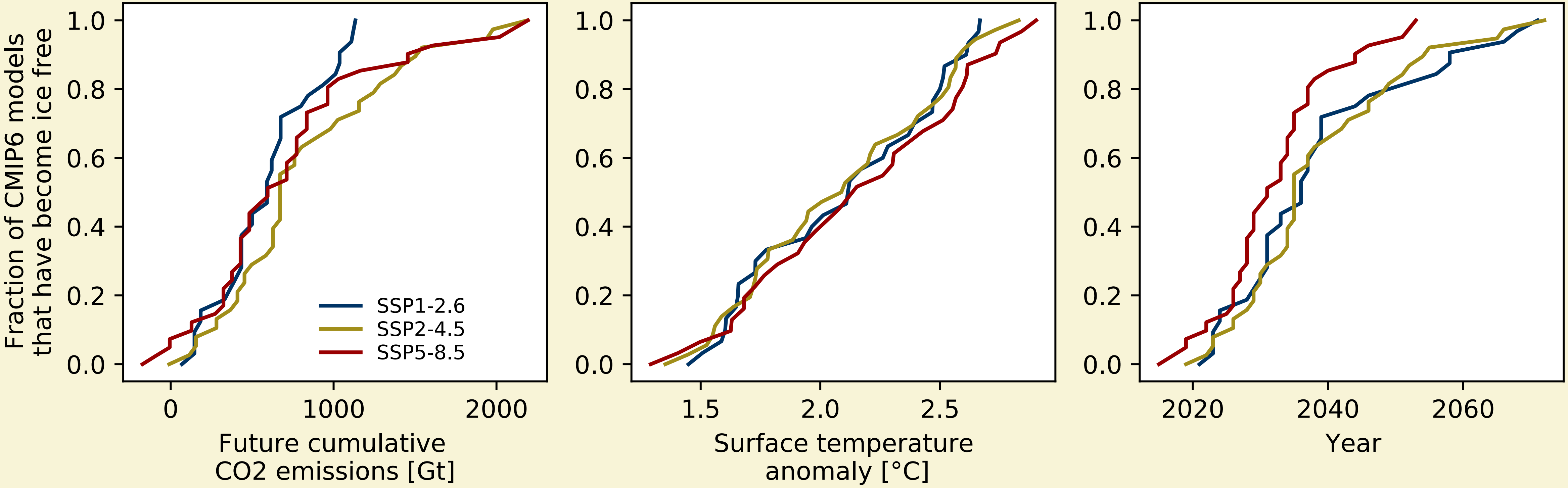
Arctic sea ice in CMIP6: September past and future



SIMIP Community, Geophys. Res. Lett, 2020

CMIP6 models: When is Arctic SIA < 1 million km²?

Models that capture the observed sensitivities in their internal variability



SIMIP Community, Geophys. Res. Lett, 2020

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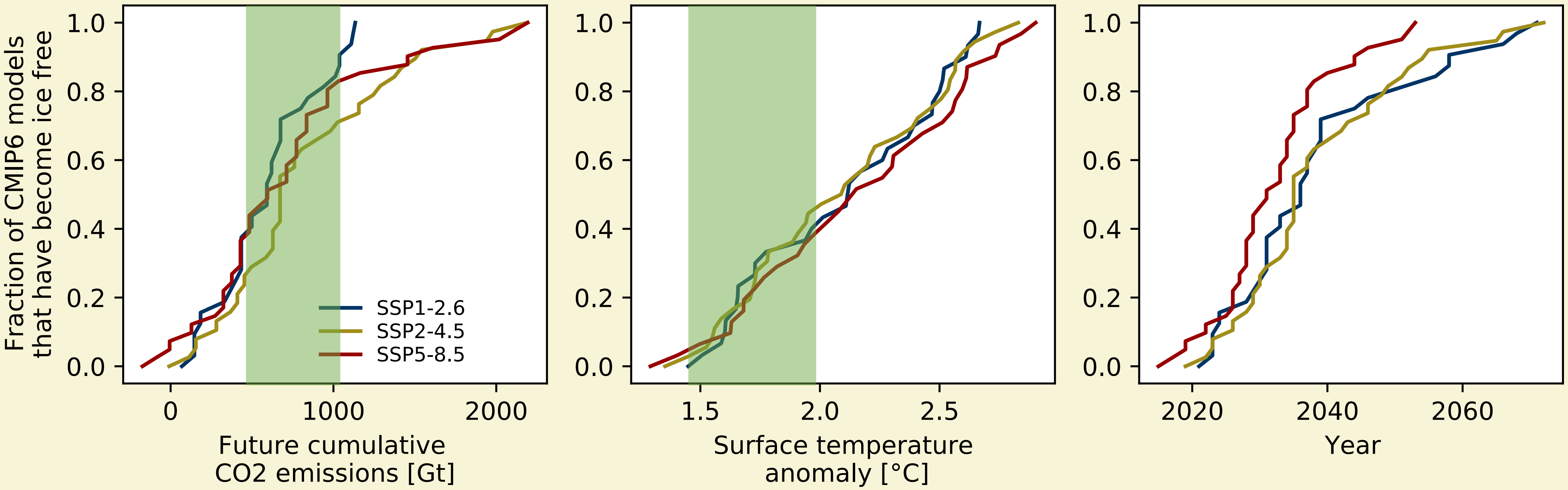


SIMIP Community, Geophys. Res. Lett, 2020

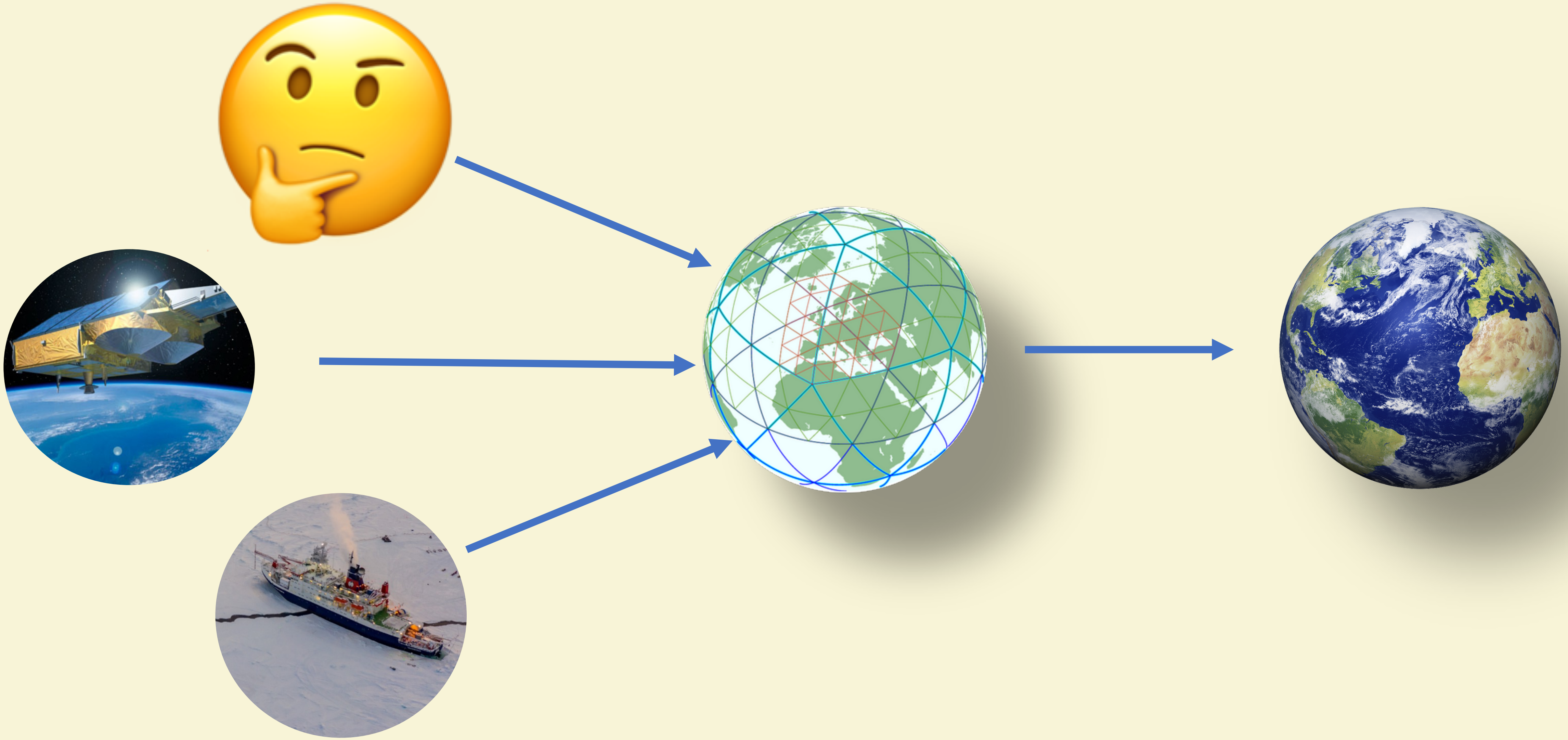
When is the Arctic sea-ice free for the first time?

- The added value of CMIP6 model simulations for answering this question is unclear:
  - As a function of CO_2, the CMIP6 model ensemble largely confirms the result from the simple conceptual model
  - As a function of global mean temperature, the CMIP6 model ensemble underestimates the observed sensitivity and reaches an ice-free Arctic at much higher warming levels than the conceptual model. I personally find the result from the conceptual model more convincing (but I'm biased…)
- It is unclear whether improvements of any kind will ever make the CMIP6 model ensemble more fit for answering this specific question than the simple conceptual model with observational constraints

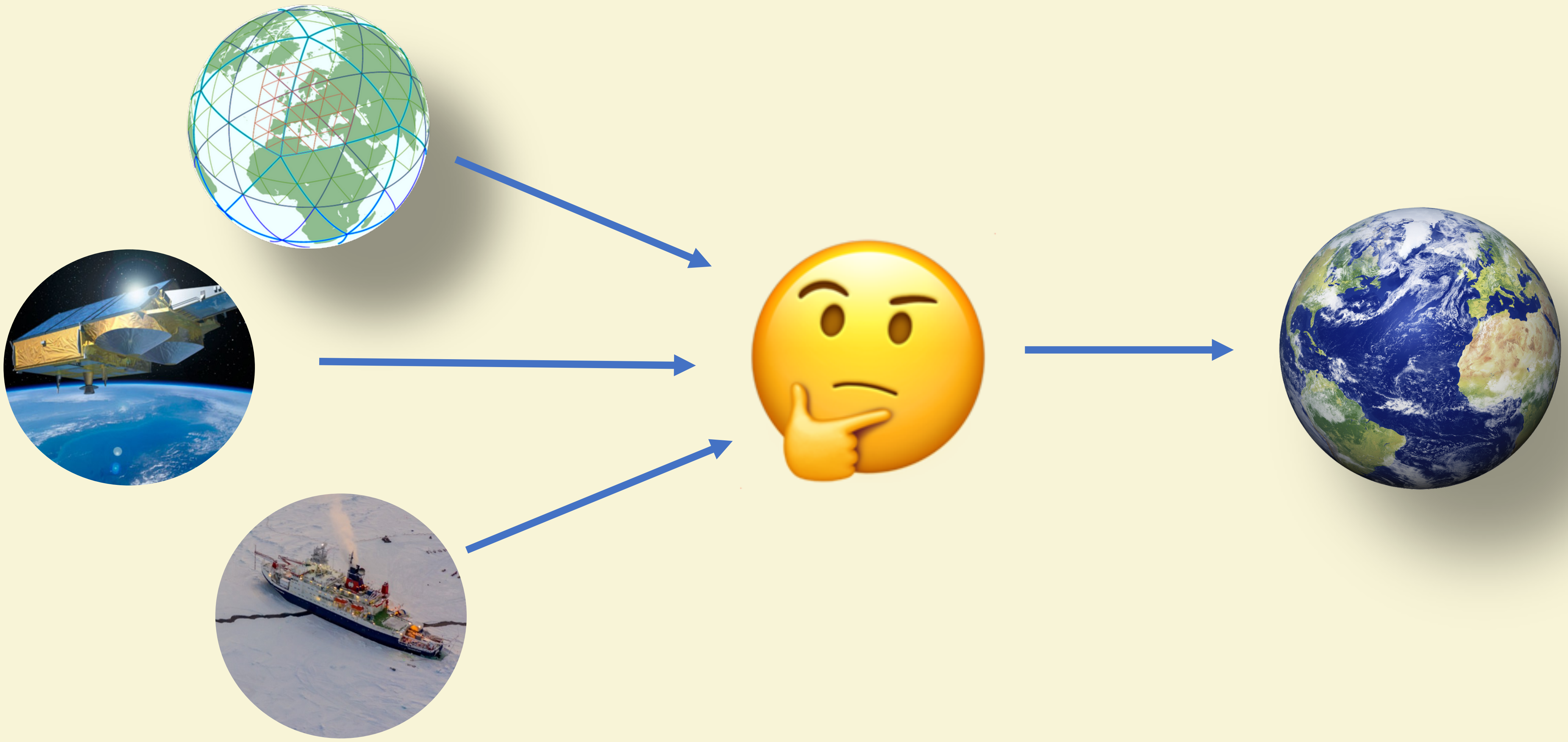
Overview

1. How do we gain insights in “classical” science?
2. When is the Arctic ice free based on this approach?
3. What can we learn from climate models?
4. Ways forward

How we maybe often work…



But maybe this is more promising...



Summary

- The Arctic will be practically sea-ice free in September for the first time for future CO2 emissions of 800±300 Gt
- Current emissions are 40 Gt per year.
- The Arctic will be practically sea-ice free in September for the first time for a temperature rise of 1.6±0.3 °C relative to pre-industrial levels
- CMIP6 climate models only add limited additional insight for this particular question relative to a conceptual model
- Climate models and measurements are both tools to inform our understanding. Bringing the two together on more equal grounds could be a promising route forward for understanding the climate system of our planet.