#vEGU21

20 April 2021

Arne Richter Award for Outstanding ECS Lecture 2020

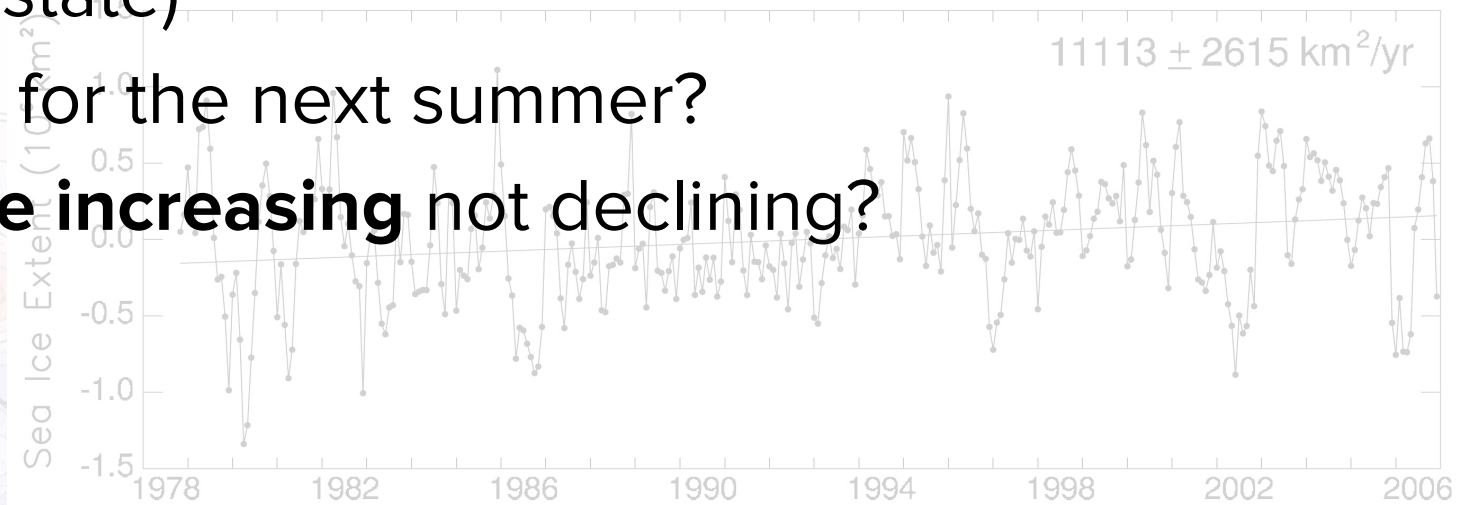
Making informed use of observations and climate models to advance understanding of past and future sea ice changes

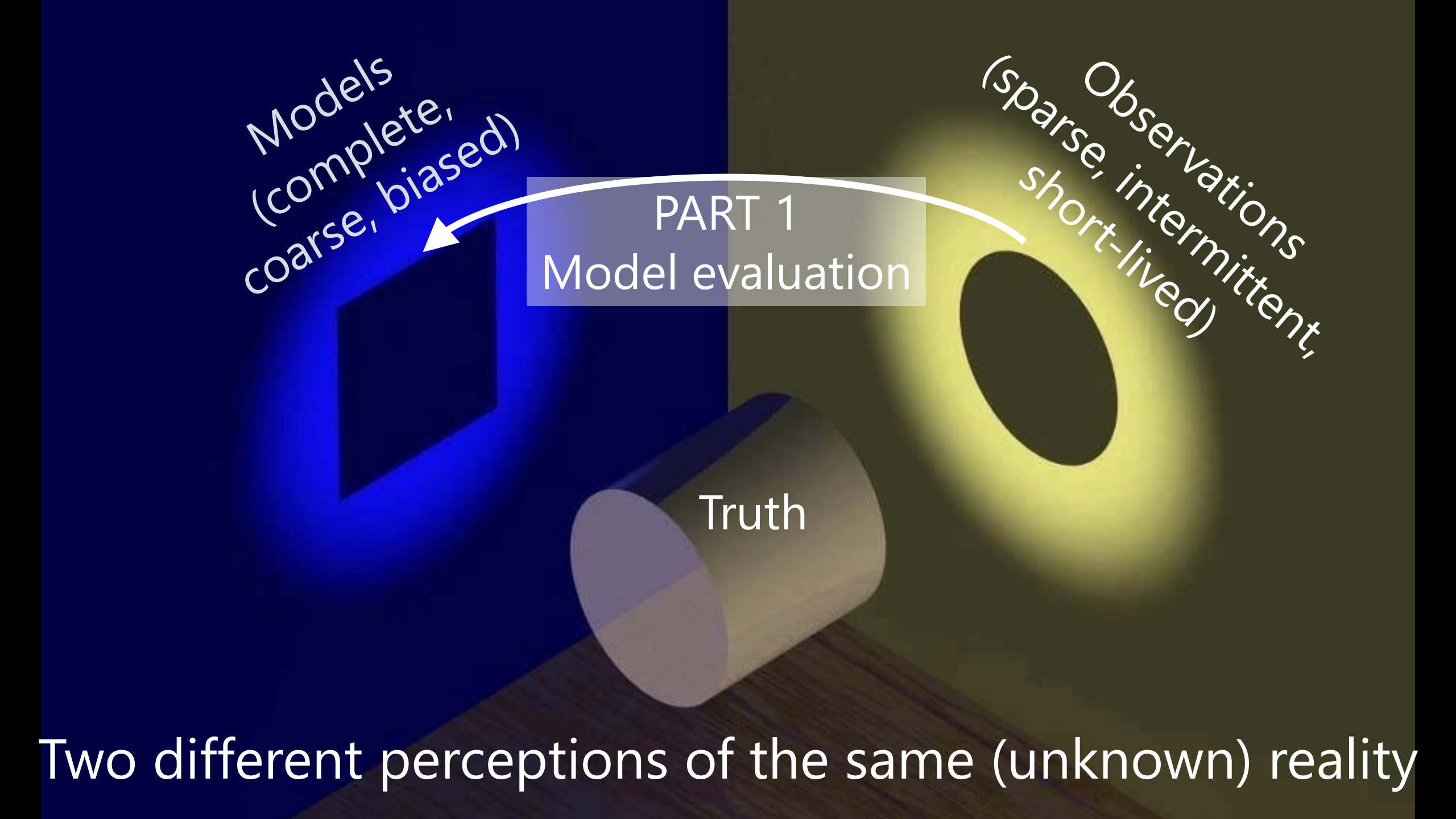
François Massonnet

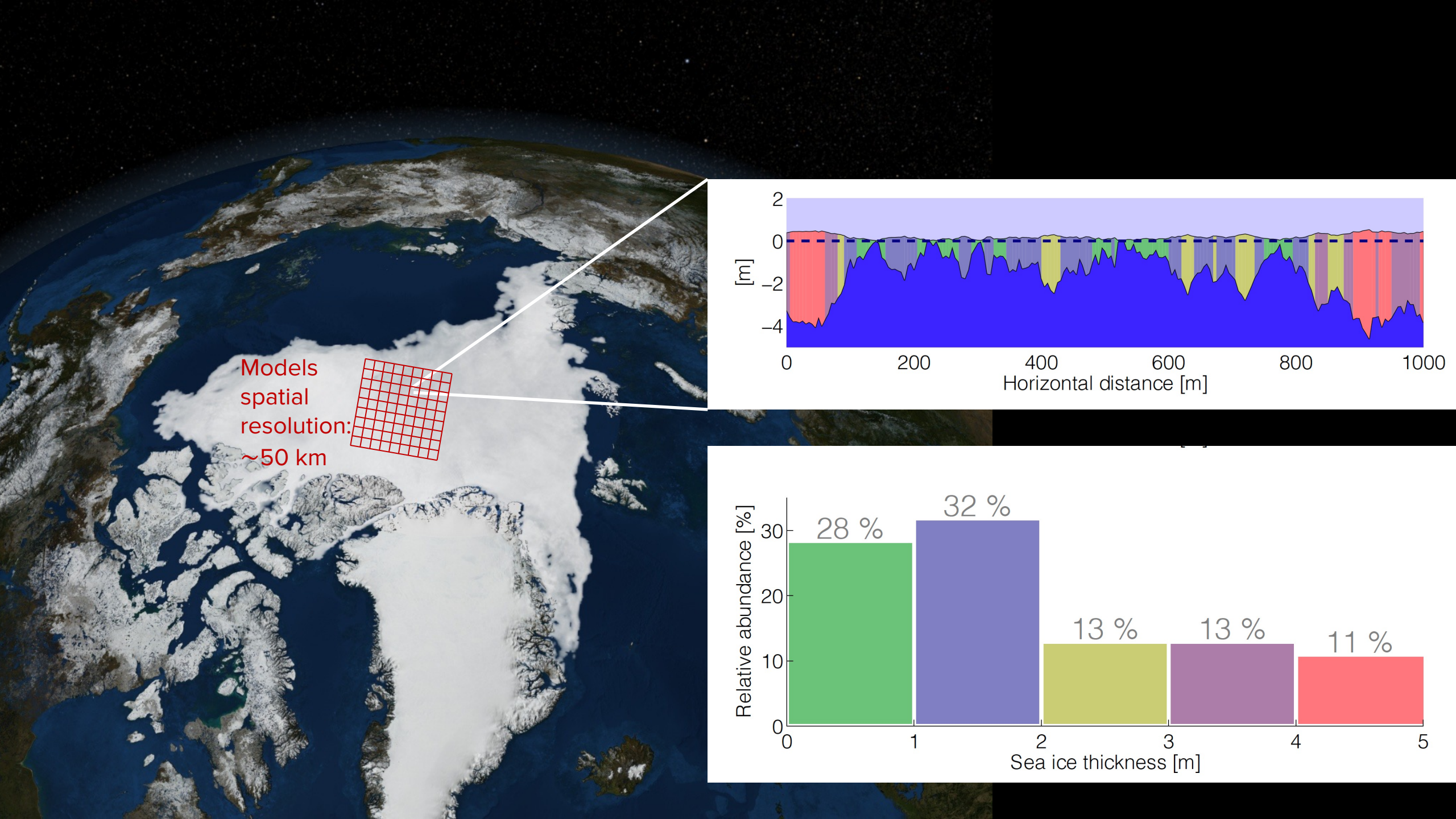
With a big thanks to all colleagues, friends and family!

Polar regions and sea ice: state of affairs in the late 2000s

- Are **summer-ice-free Arctic conditions** avoidable?
- What are the causes for the large **spread in Arctic sea ice extent projections**?
- What are the sources of **systematic model errors**? (sea ice trends, variance, mean state)
- Can we **predict sea ice** for the next summer?
- Why is **Antarctic sea ice increasing** not declining?

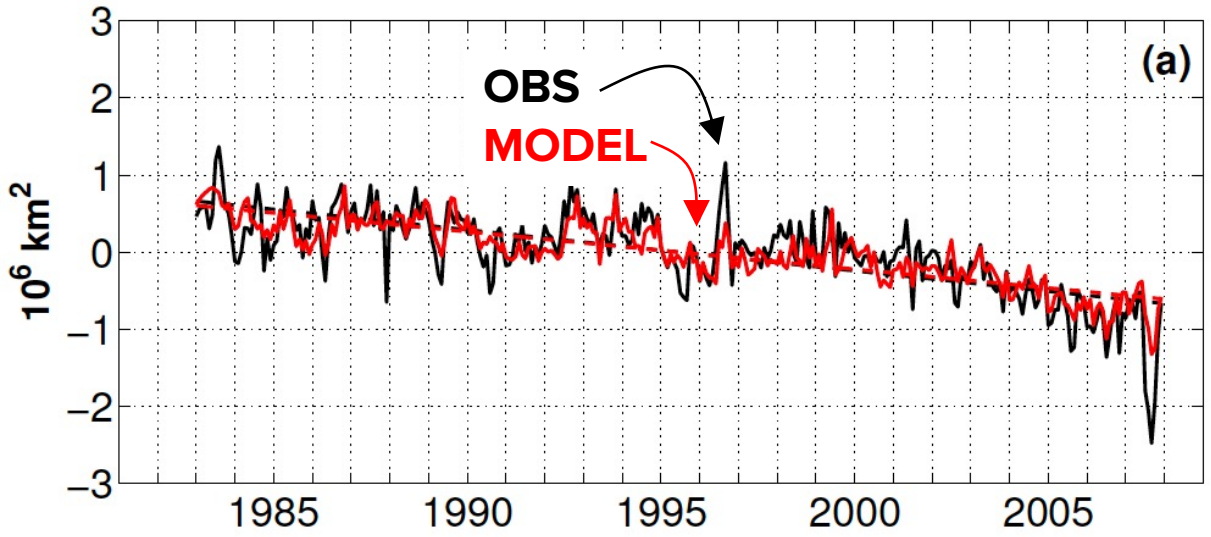



Models
(complete,
coarse, biased)
Observations
(sparse, intermittent,
short-lived)
PART 1
Model evaluation
Truth
Two different perceptions of the same (unknown) reality

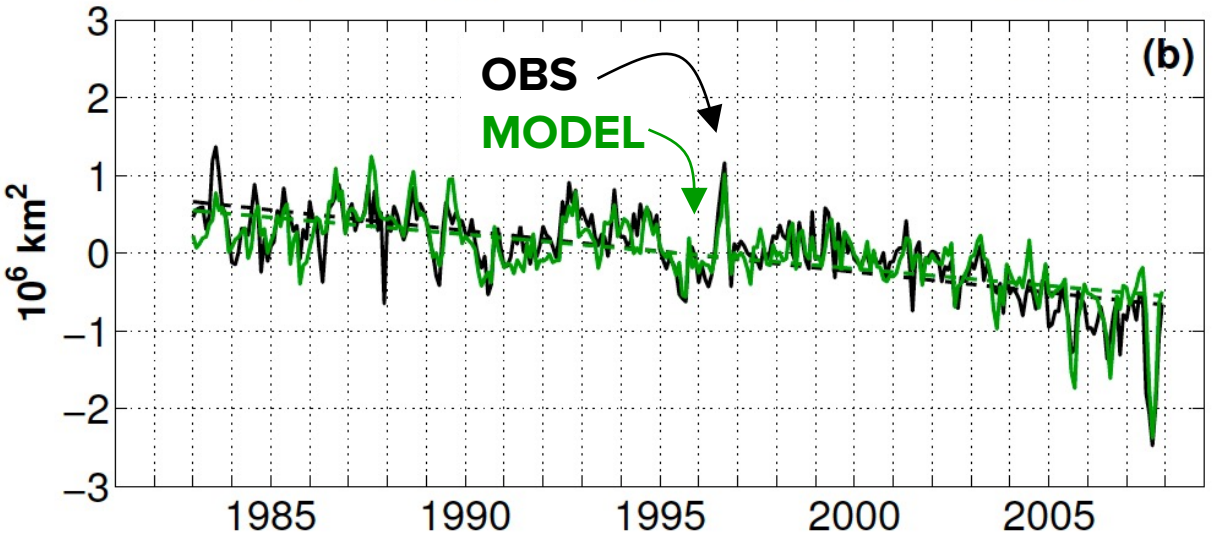

Models
spatial
resolution:
~50 km
2
0
−2
−4
[m]
0
200
400
600
800
1000
Horizontal distance [m]
Relative abundance [%]
30
20
10
0
28 %
32 %
13 %
13 %
11 %
0
1
2
3
4
5
Sea ice thickness [m]

Adding complexity to a sea ice model leads to improved Arctic mean sea ice state and variability (all other things being equal)

Anomalies of Arctic sea ice extent (1983-2007)



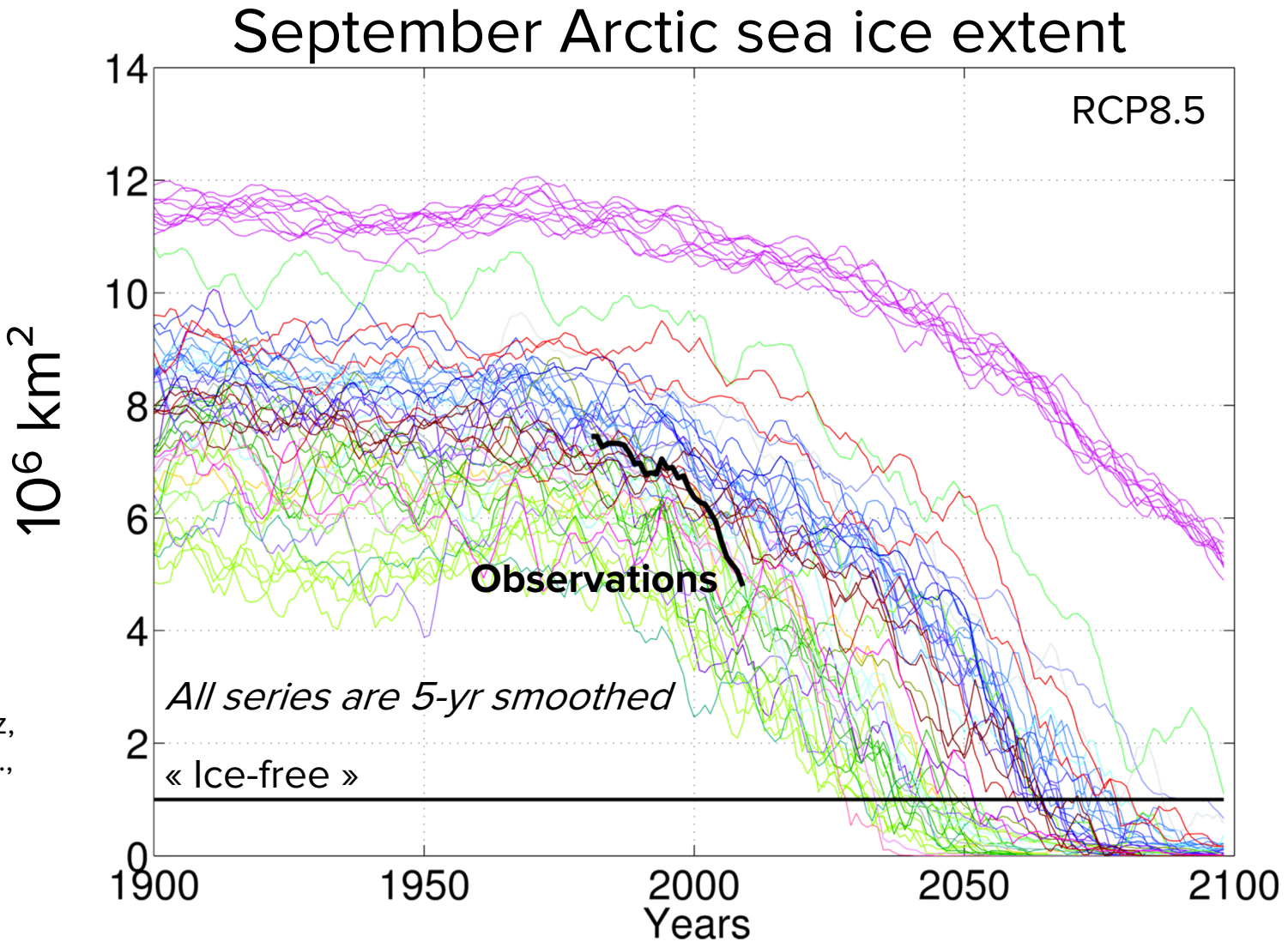
Sea ice model with **no explicit sub-grid scale distributio**n of sea ice thickness



Sea ice model with @ of sea ice thickness

Massonnet, F., Fichefet, T., Goosse, H., Vancoppenolle, M., Mathiot, P., & König Beatty, C. (2011). On the influence of model physics on simulations of Arctic and Antarctic sea ice. *The Cryosphere*, *5* (3), 687–699. https://doi.org/10.5194/tc-5-687-2011

Summer Arctic sea ice projected to vanish before 2100, but when?



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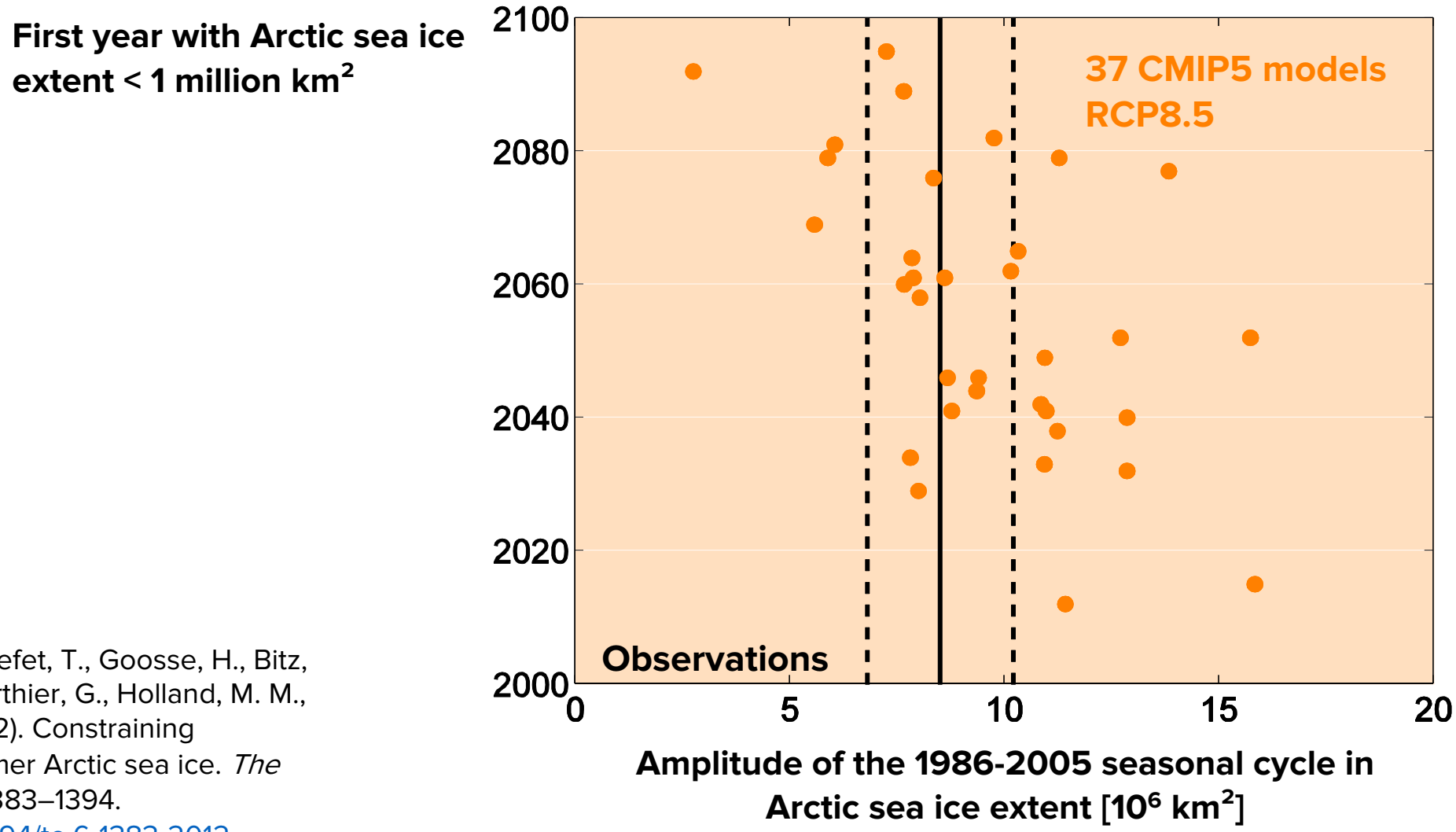
Emergent constraints on future Arctic sea ice changes



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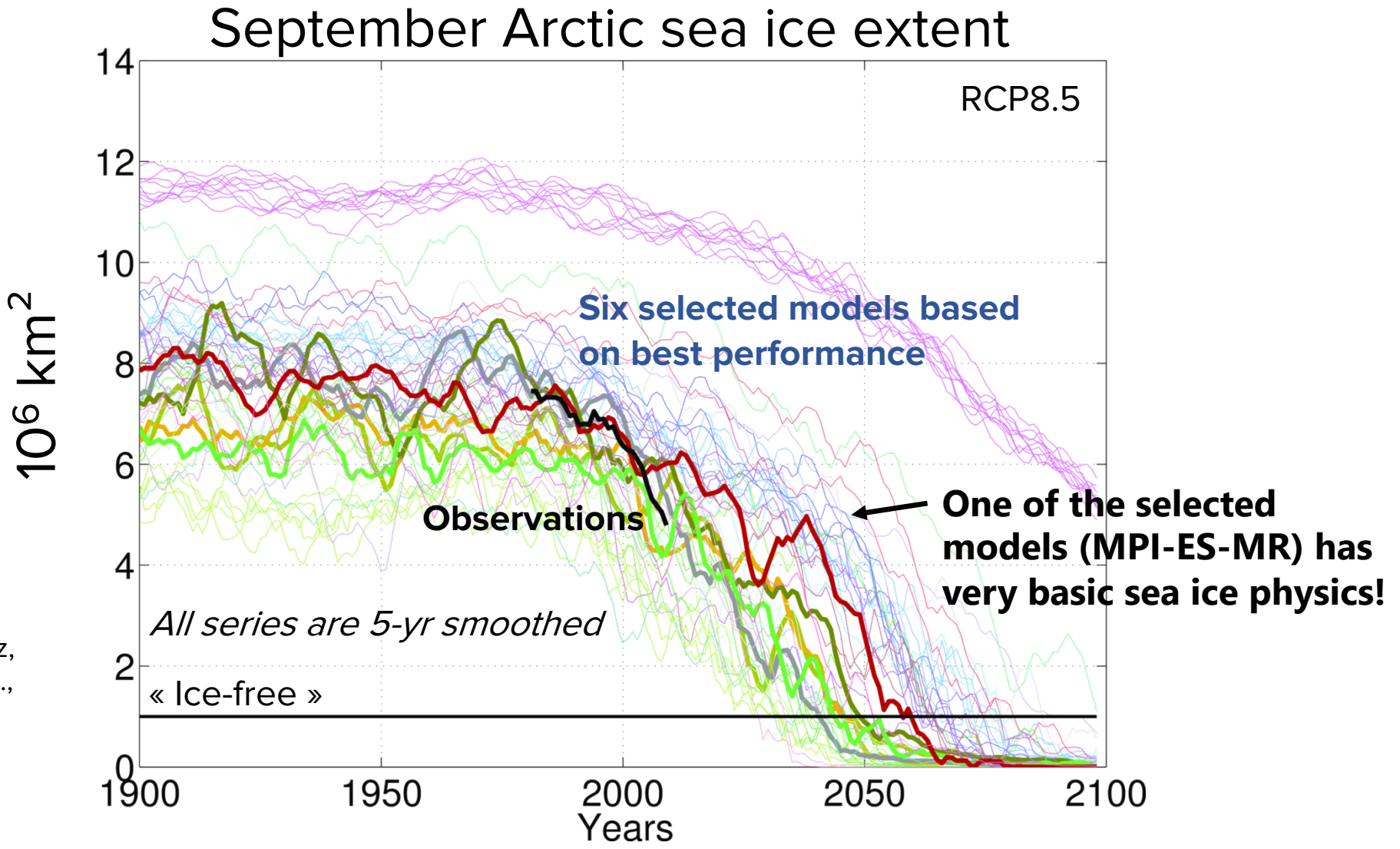
Summer Arctic sea ice projected to vanish before 2100, but when?



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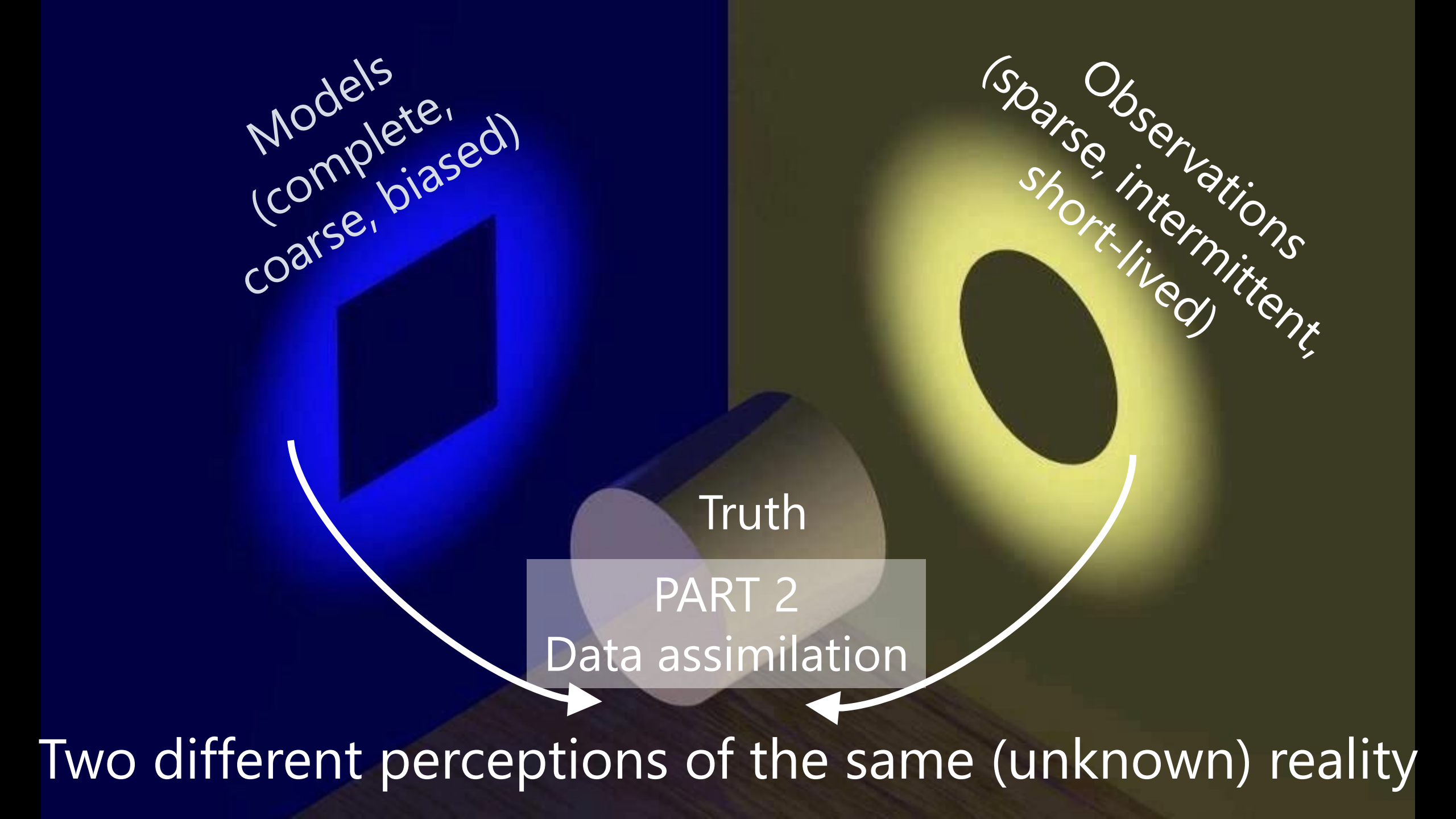
What are the causes for the **spread in Arctic sea ice extent projections**?

- Differences in present-day simulated **mean state** explain much of the spread in Arctic sea ice projections

- Sea ice model physics is important to set the mean state, but in coupled mode, it appears to be **overshadowed by other influences**, including:
  - Internal climate variability
  - Atmospheric and oceanic forcings


Models
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(sparse, intermittent,
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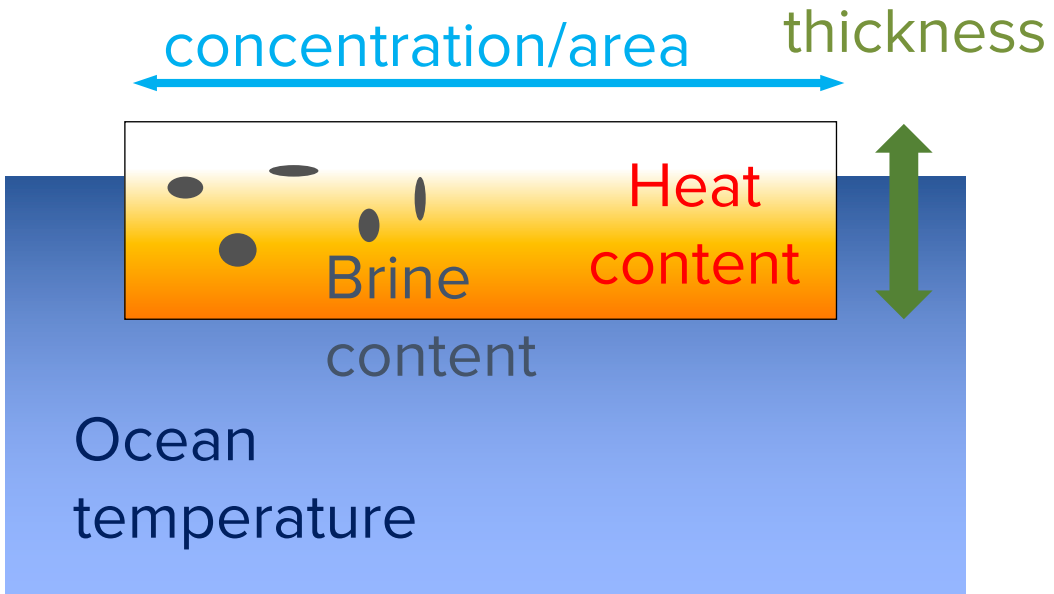
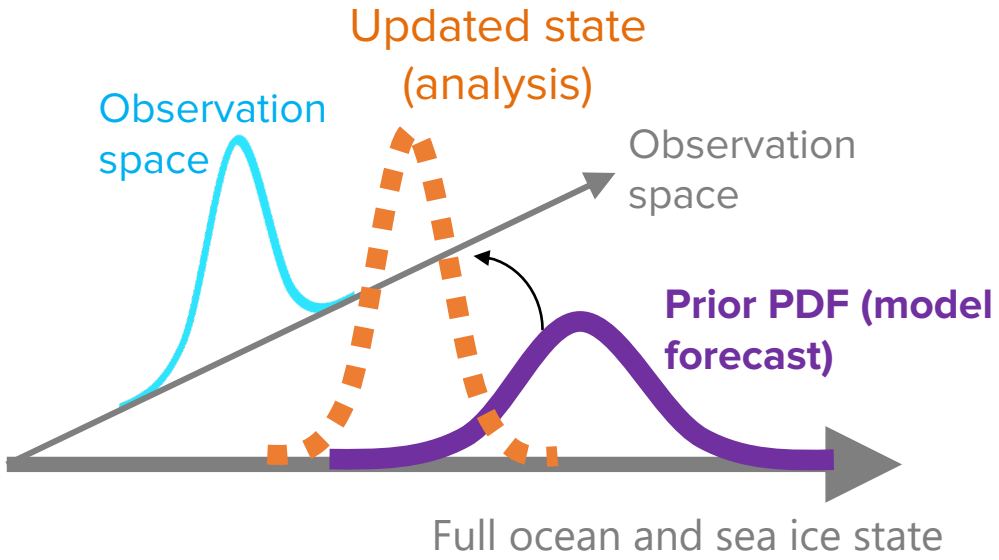
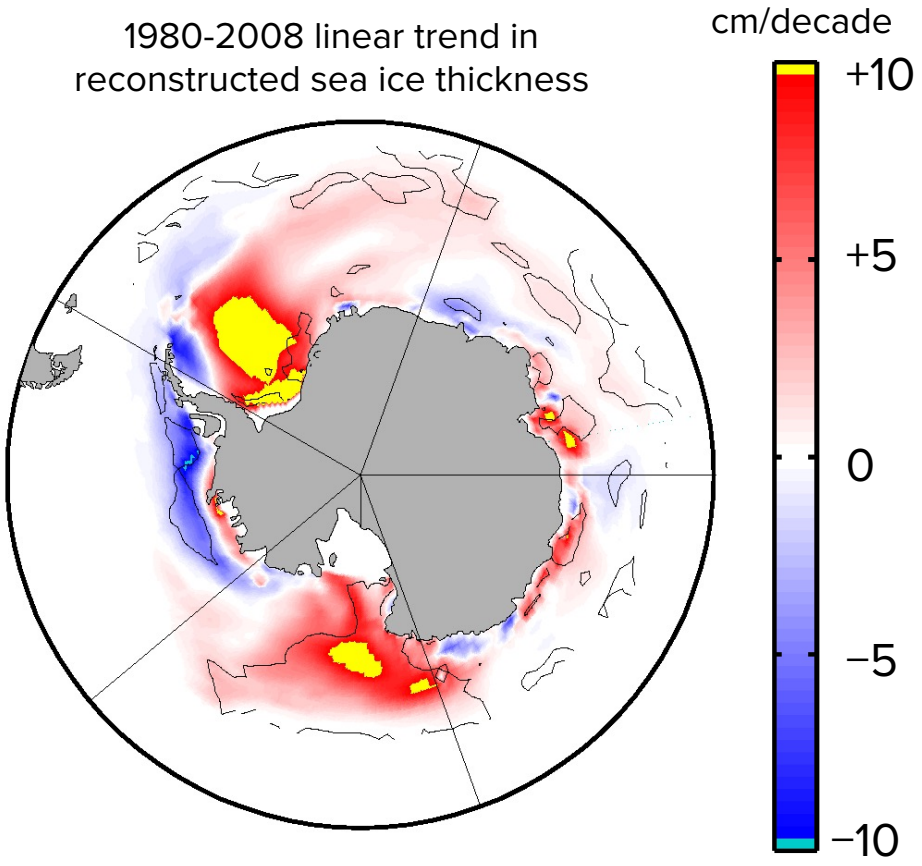
Truth
PART 2
Data assimilation
Two different perceptions of the same (unknown) reality

Data assimilation is a mathematical solution to the problem of finding the state that minimizes misfit to observations, given uncertainties

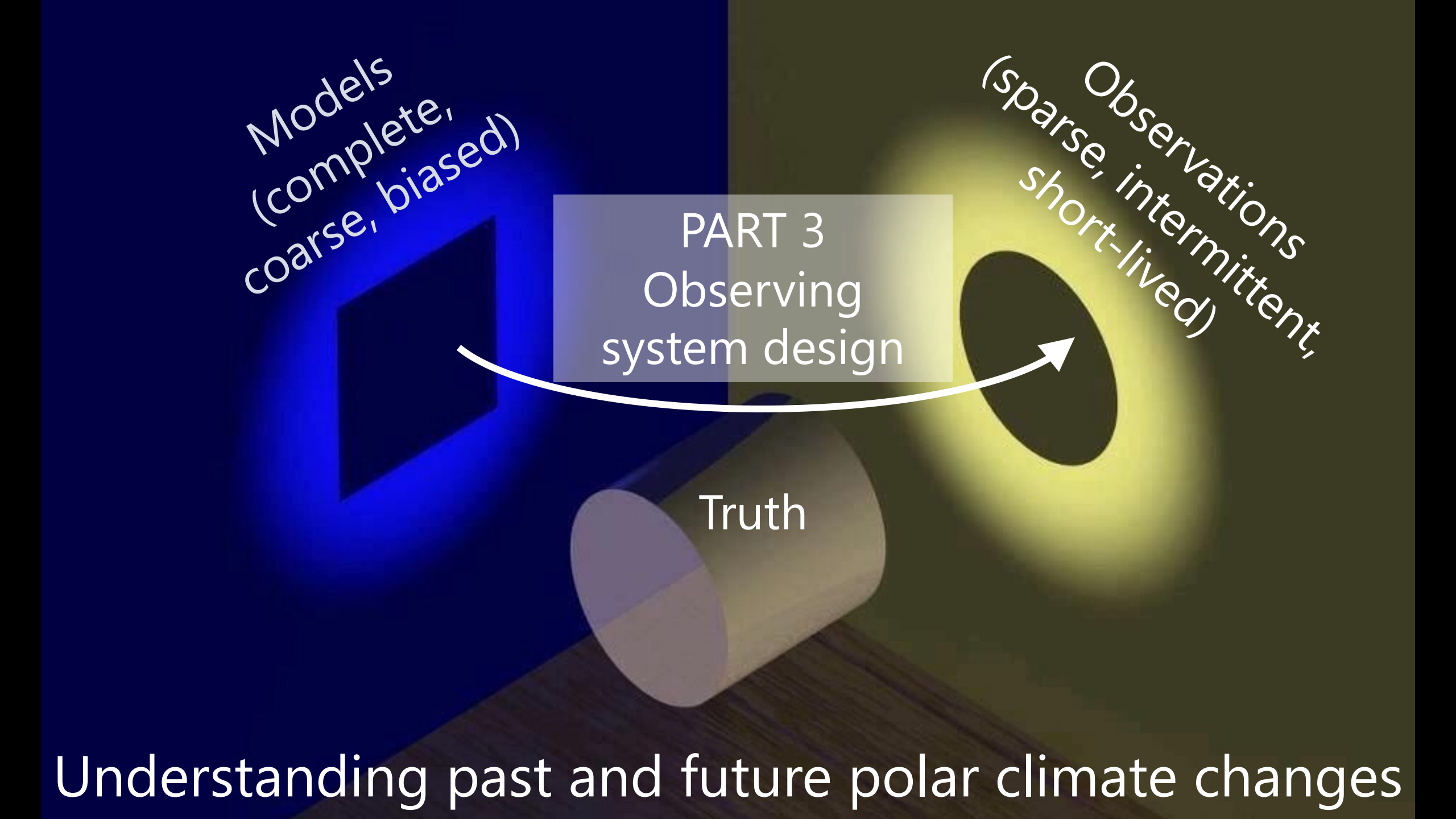




The increase in Antarctic sea ice extent is not accidental: it is confirmed by an increase in sea ice volume

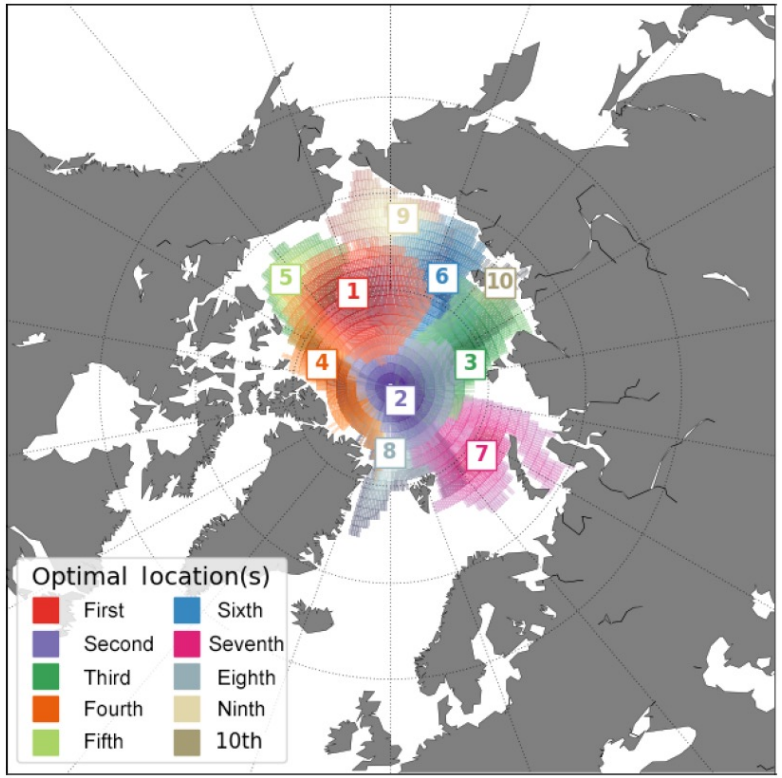


Massonnet, F., Mathiot, P., Fichefet, T., Goosse, H., König Beatty, C., Vancoppenolle, M., & Lavergne, T. (2013). A model reconstruction of the Antarctic sea ice thickness and volume changes over 1980–2008 using data assimilation. *Ocean Modelling*, *64*, 67–75. https://doi.org/10.1016/j.ocemod.2013.01.003

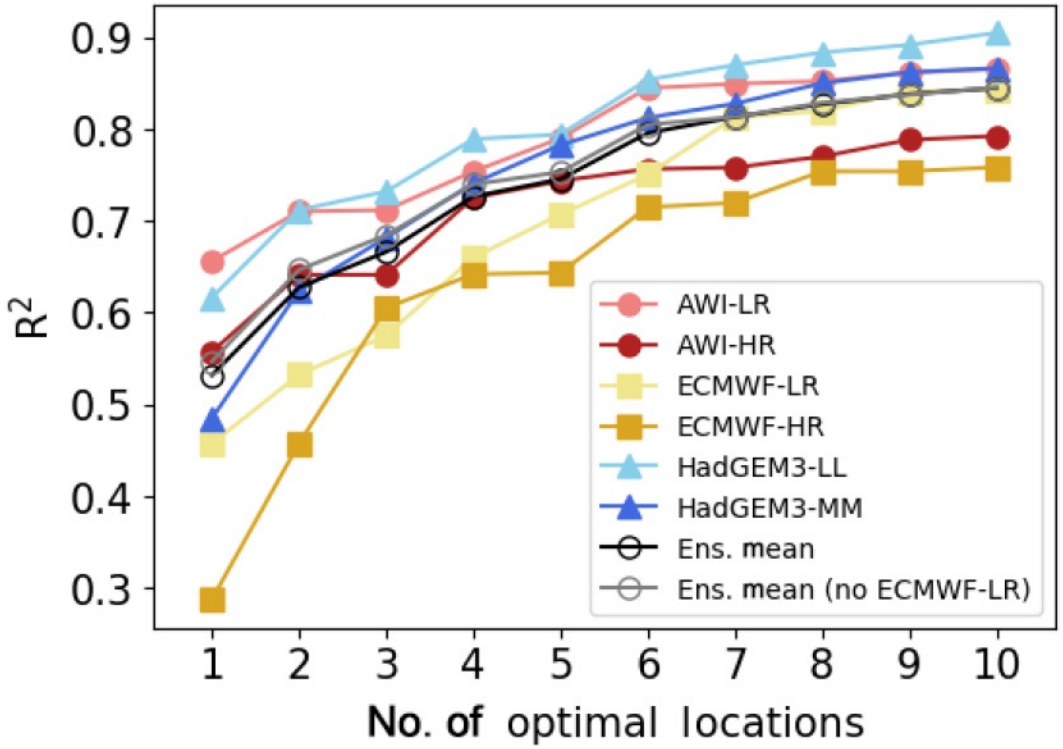


Understanding past and future polar climate changes

The knowledge of sea ice thickness at a handful of discrete locations is enough to reconstruct sea ice volume anomalies (according to models)



Fraction of explained variance in sea ice volume anomalies reconstructed from *x* measurements



Ponsoni, L., Massonnet, F., Docquier, D., Achter, G. V., & Fichefet, T. (2020). Statistical predictability of the Arctic sea ice volume anomaly: Identifying predictors and optimal sampling locations. *The Cryosphere*, *14*(7), 2409–2428. https://doi.org/10.5194/tc-14-2409-2020

Observations and models are not independent entities, but rather two facets of the same (unknown) truth. When combined together, they provide a better estimate of the truth than if they were used separately

Observations feed the development of numerical sea ice models, just as numerical experimentation with sea ice models can guide the development of future observations.

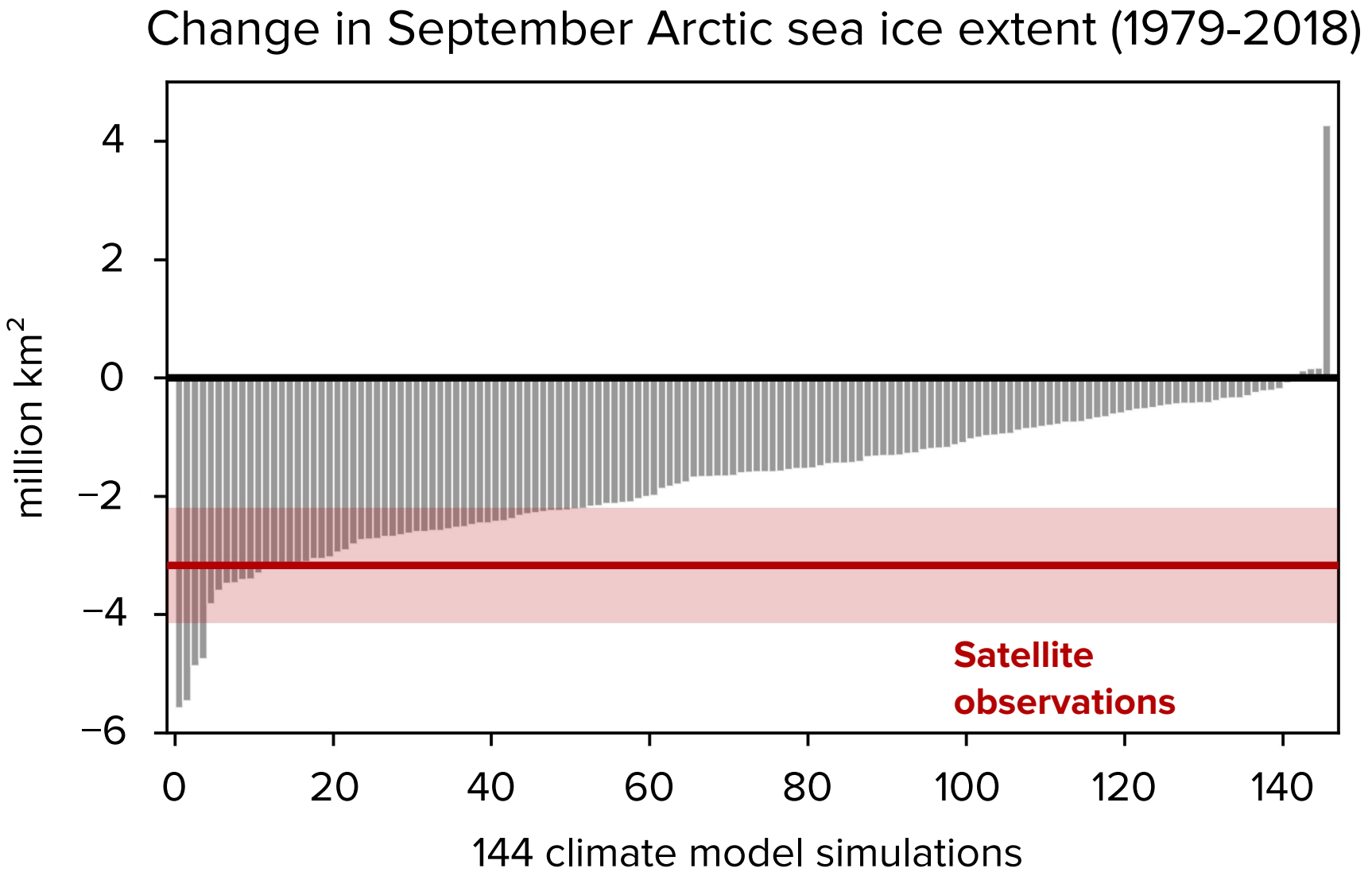
In the context of climate change studies, the development of sea ice models must be done by acknowledging that other influences (oceanic, atmospheric) impact the sea ice state

Thank you

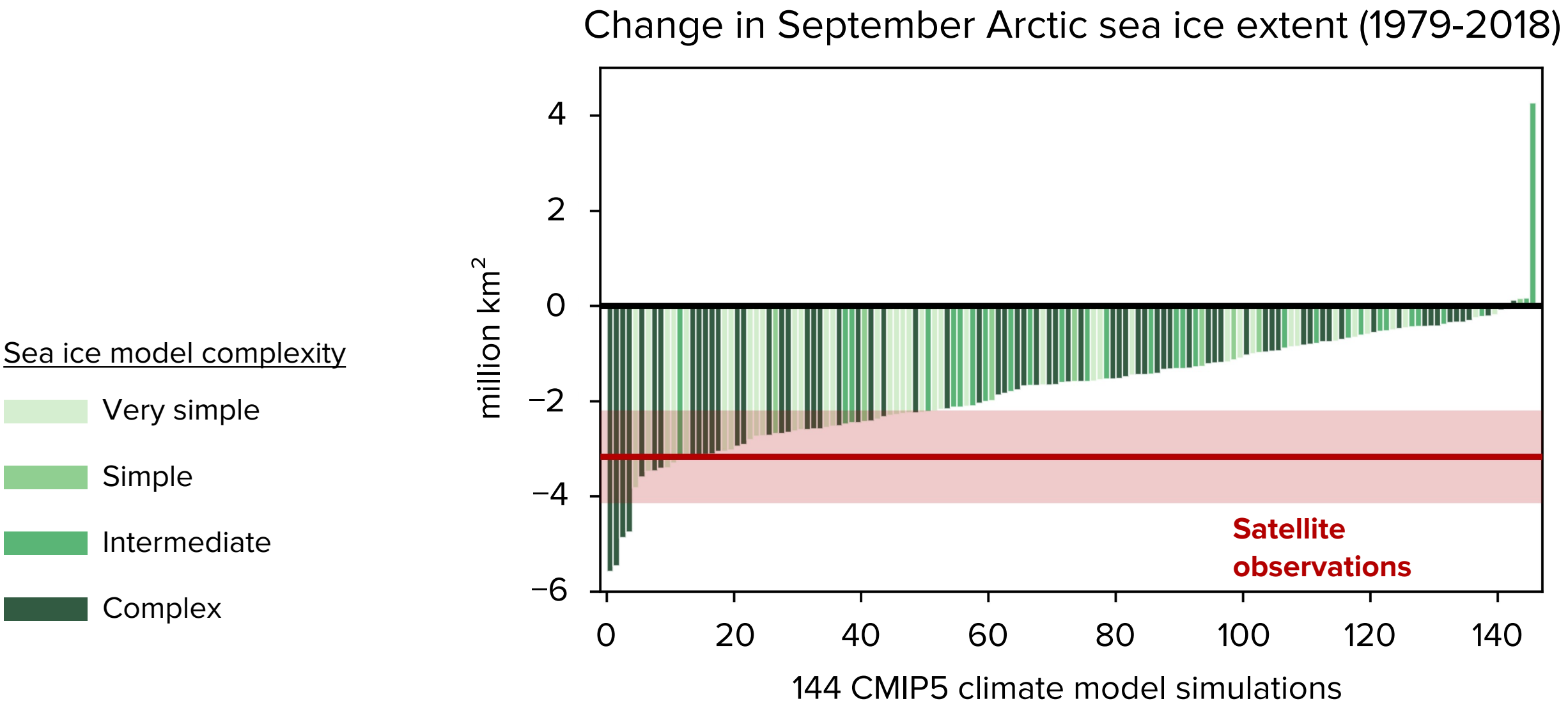
Thierry Fichefet, Hugues Goosse, Martin Vancoppenolle, Dirk Notz, Thomas Jung, Irina Sandu, Cecilia Bitz, Marika Holland, Paco Doblas-Reyes,

APPLICATE.eu
Advanced prediction in polar regions and beyond

Climate models all capture the first-order response of sea ice to forcing



But there is **no clear link between sea ice model complexity and performance** in coupled models



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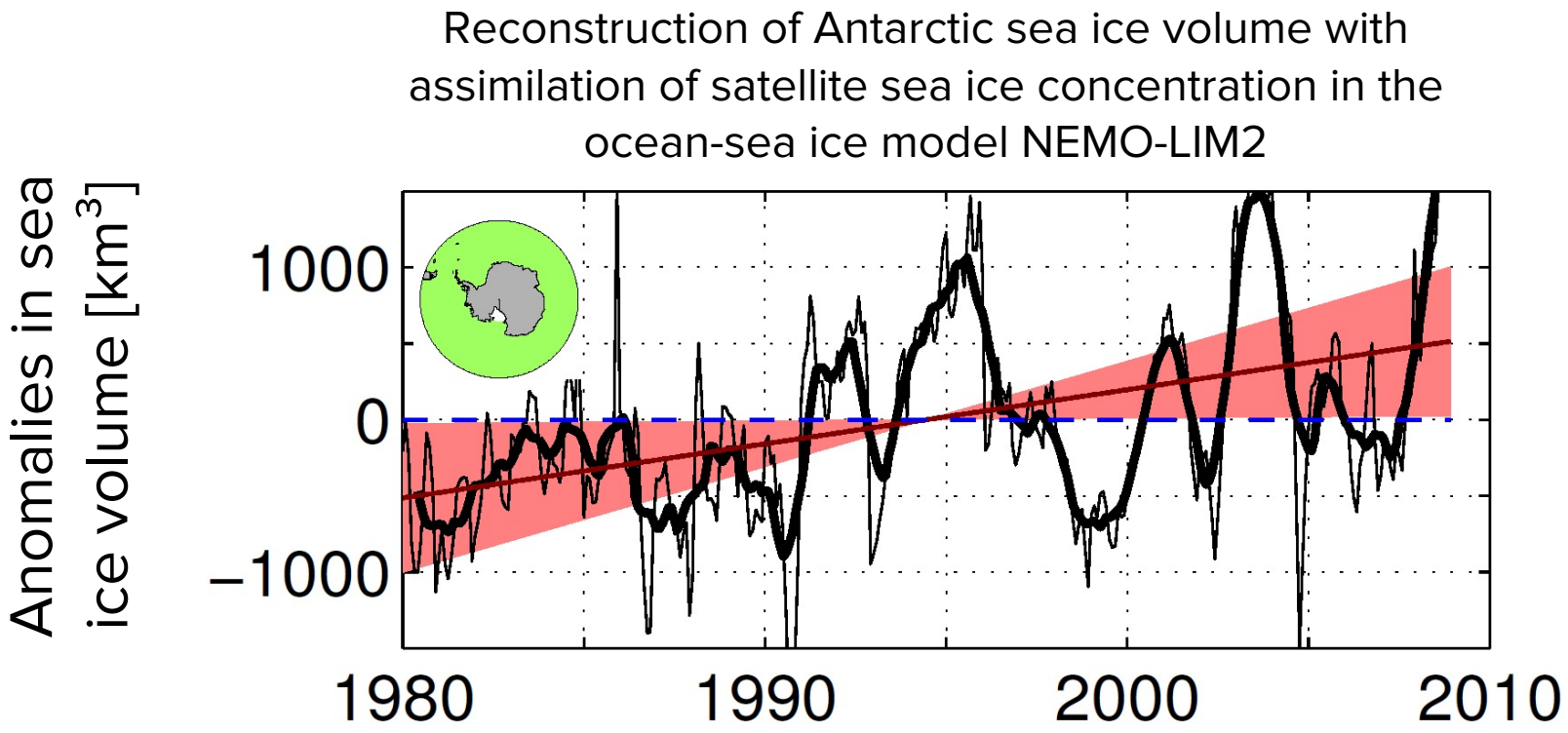

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Polar Regions are viewed by many as "observational deserts", as in-situ measurements there are indeed scarce relative to other regions. The increasing availability of satellite observations does not entirely solve the problem, due to persistent uncertainties in the derived products. Climate models have been instrumental in completing the big picture, but they are themselves subject to errors, some of which are systematic. How to take advantage of the respective strengths of observations and models, while minimizing their respective weaknesses? To illustrate this point, I will discuss how recent advances in data assimilation, model evaluation, and numerical modeling have enabled progress on addressing important questions in polar research, such as: what are the causes of the recent Antarctic sea ice variability? What might the future of Arctic sea ice look like? How to improve the skill of seasonal sea ice predictions? How should the existing observational network be improved at high latitudes? What are the priorities in terms of modeling? By running through these cases, I will provide support for the emerging hypothesis that "the whole is greater than the sum of its parts": treating observations and climate models as two noisy instances of the same, unknown truth, gives access to answers that would not have been possible using each source separately.