

Future Projections of Sea Level Change

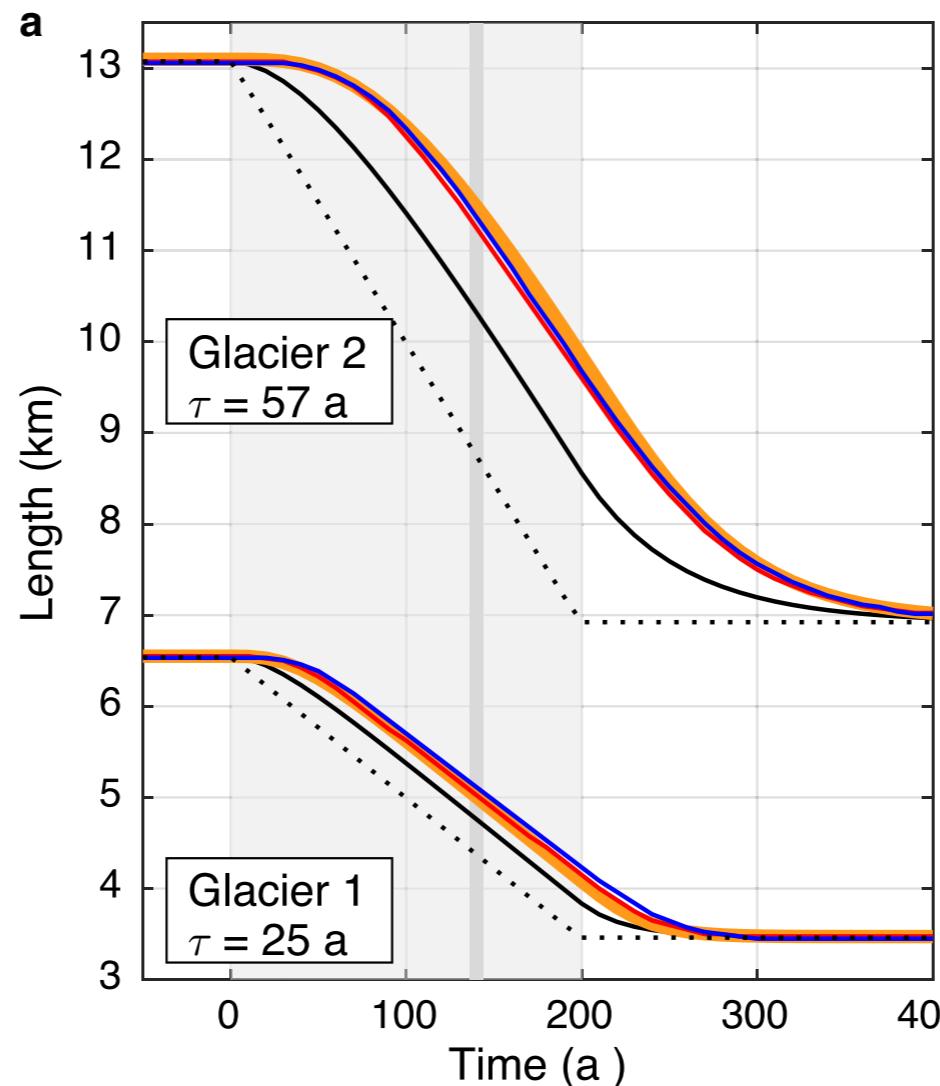


You are driving on a rainy bridge, going 70 MPH. Suddenly, you lose control and start skidding towards a truck stopped in front of you. What do you do?

If you know that you are going to hit the truck for sure, would you do anything differently?

Sea Level Commitment: Earth's runaway car

Mountain glaciers: A Toyota Prius with brand-new brake pads

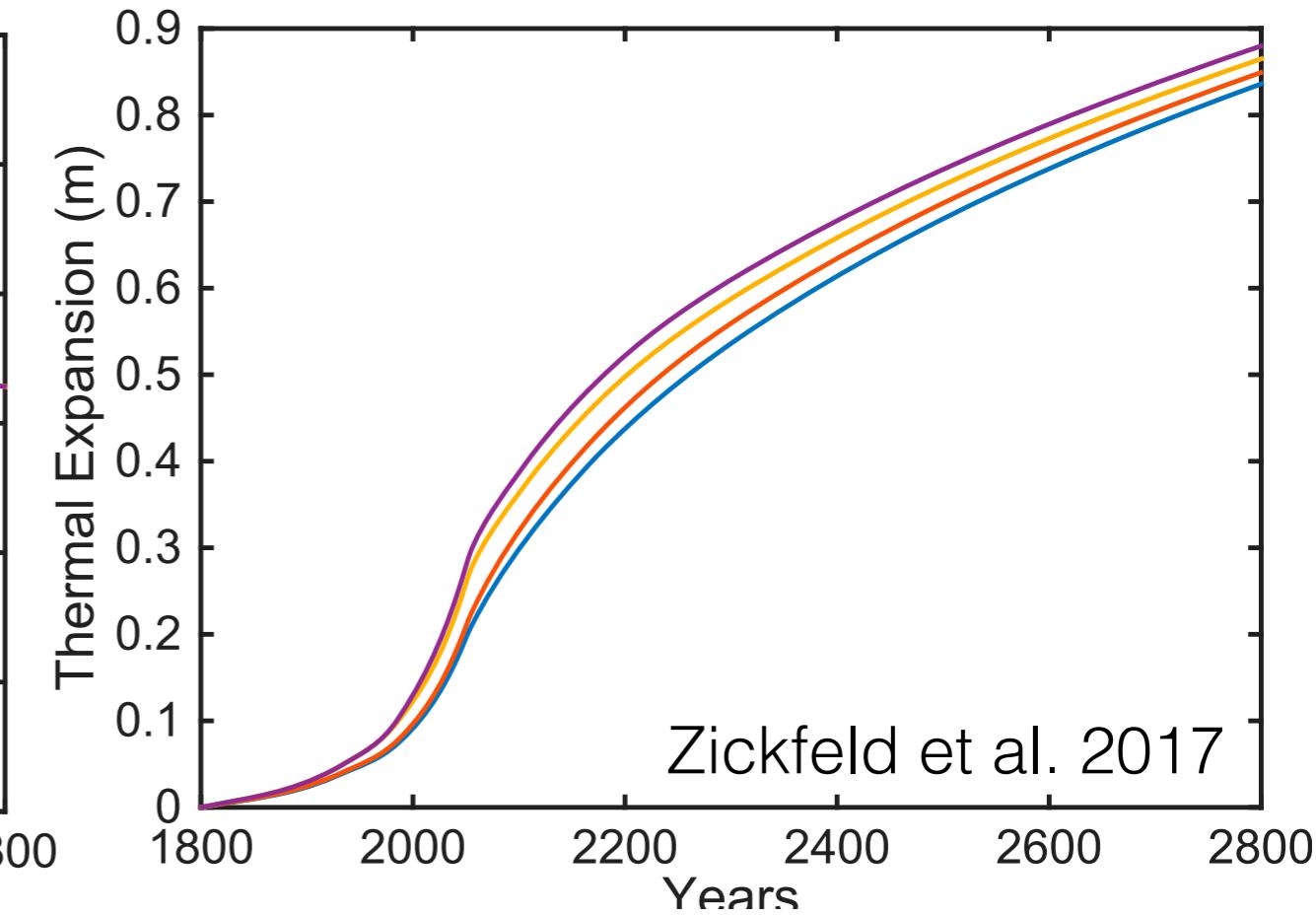
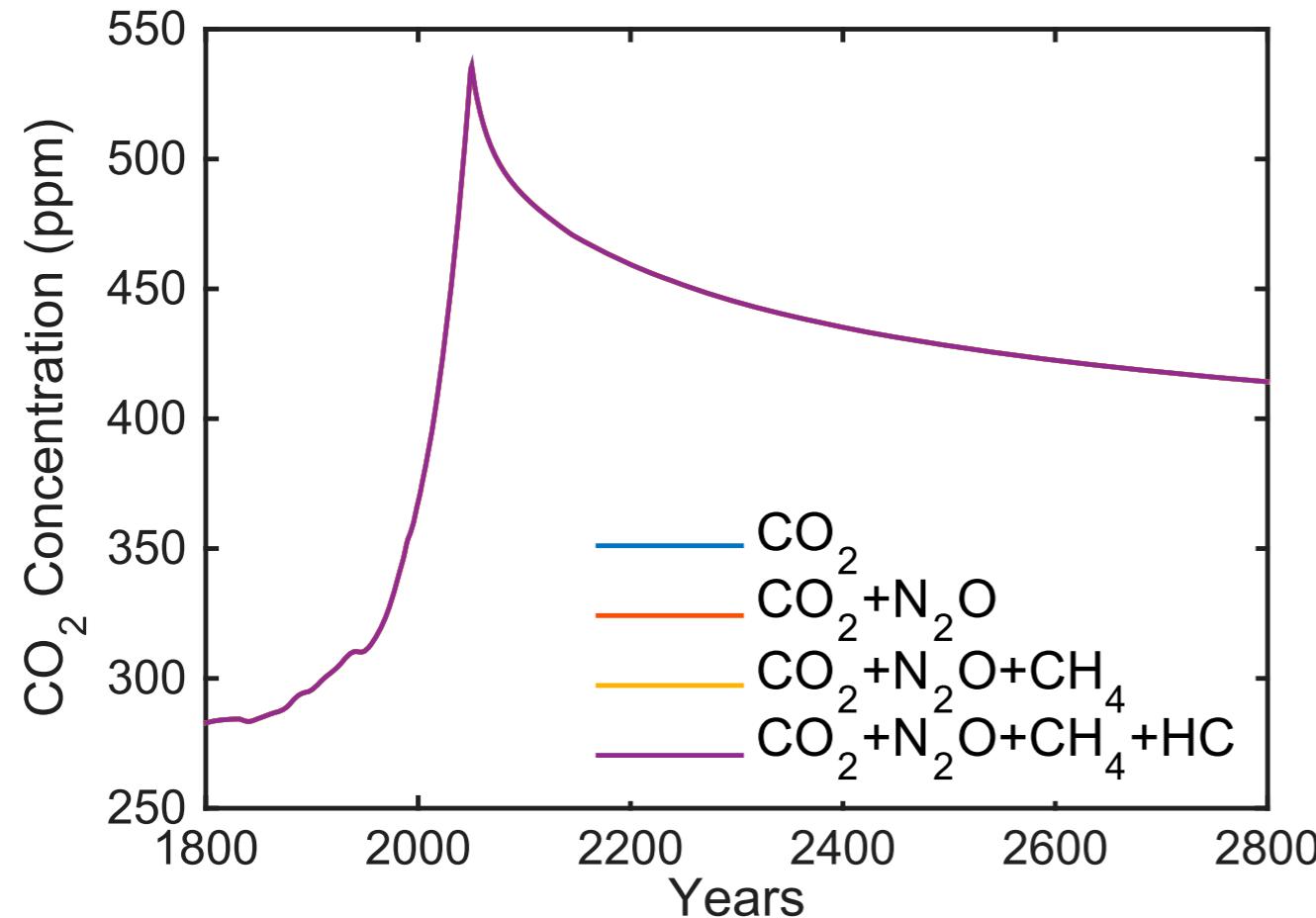


Christian et al. 2018

Even if we stop emitting greenhouse gases today, mountain glaciers would continue to melt for a few decades (and some are definitely going to disappear)

Sea Level Commitment: Earth's runaway car

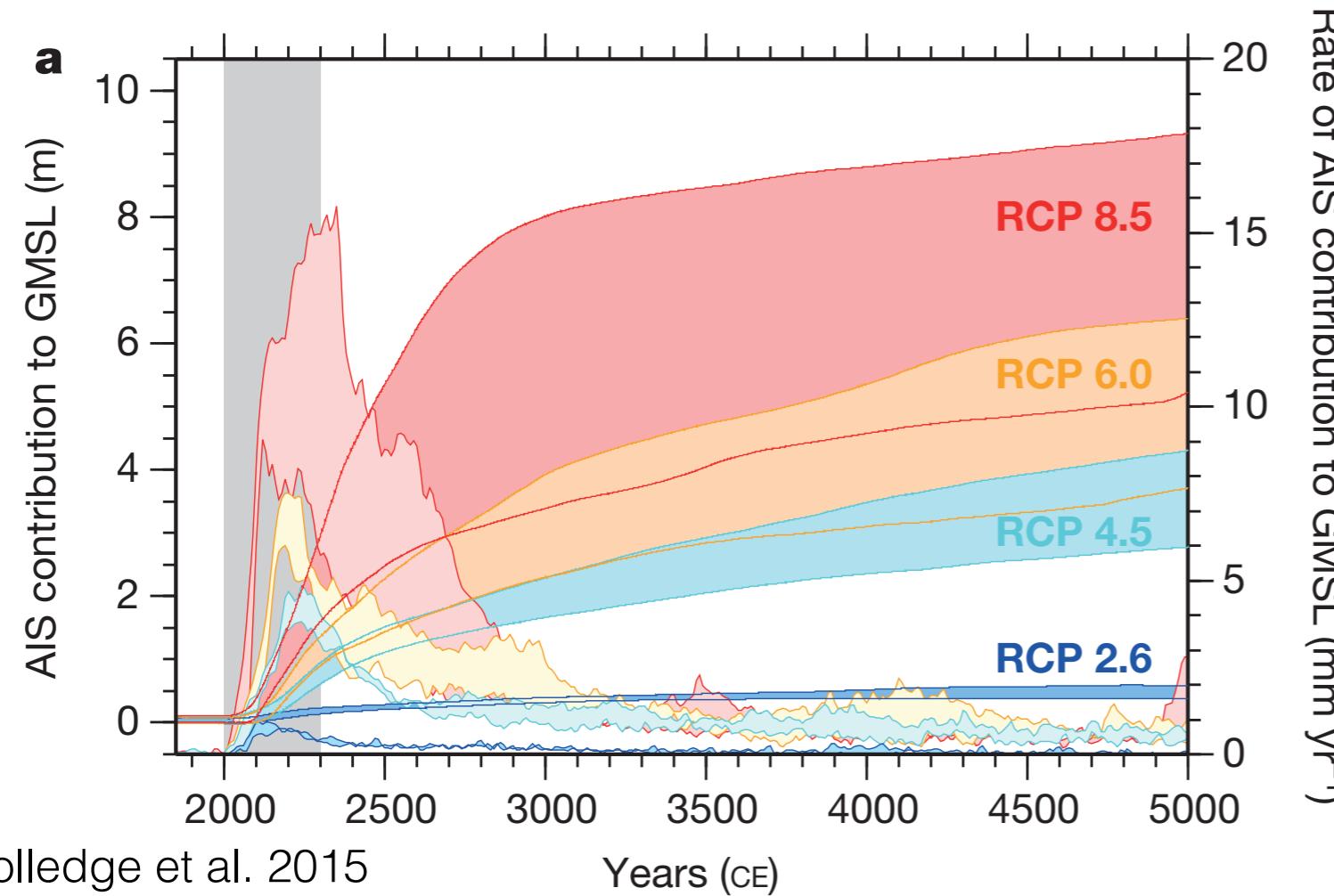
Thermal expansion: A minivan that's due for maintenance



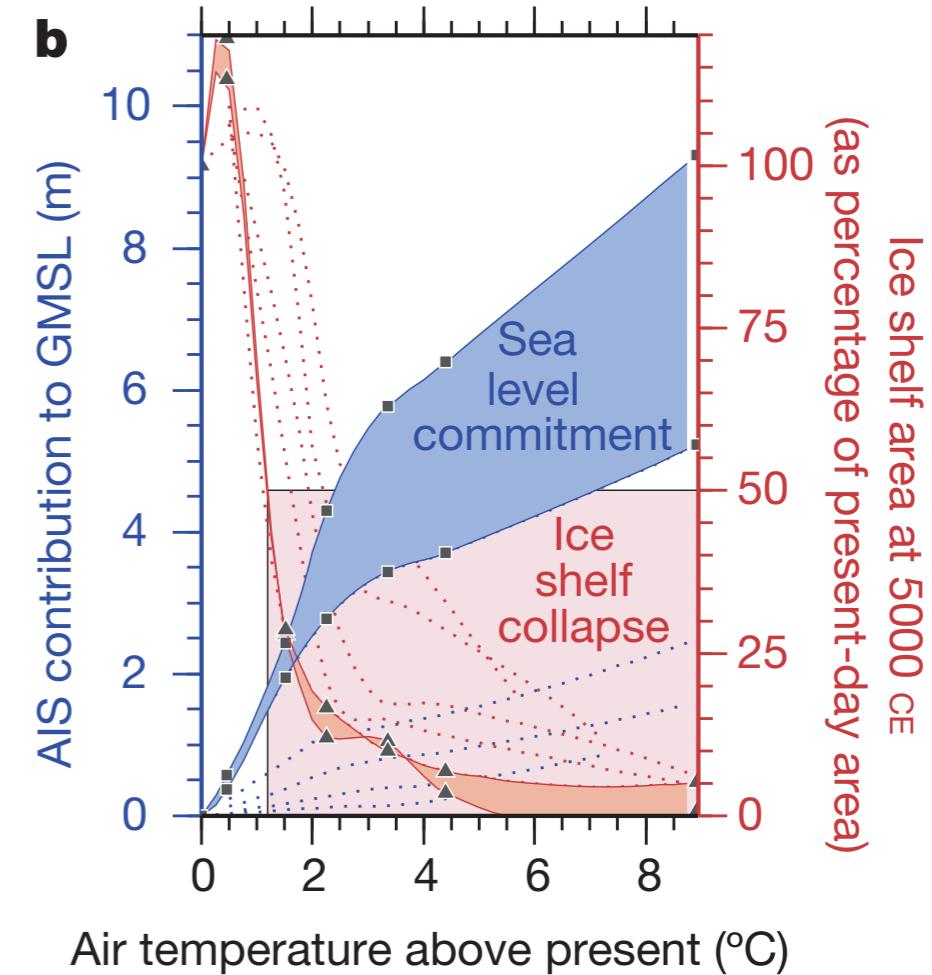
Even if we stop emitting greenhouse gases today, the ocean would continue to slowly absorb heat and expand for hundreds of years

Sea Level Commitment: Earth's runaway car

The Antarctic Ice Sheet: A poorly-maintained 18-wheeler



Antarctic melt contributes to sea level for 1000's of years even if we stop emitting greenhouse gases today.

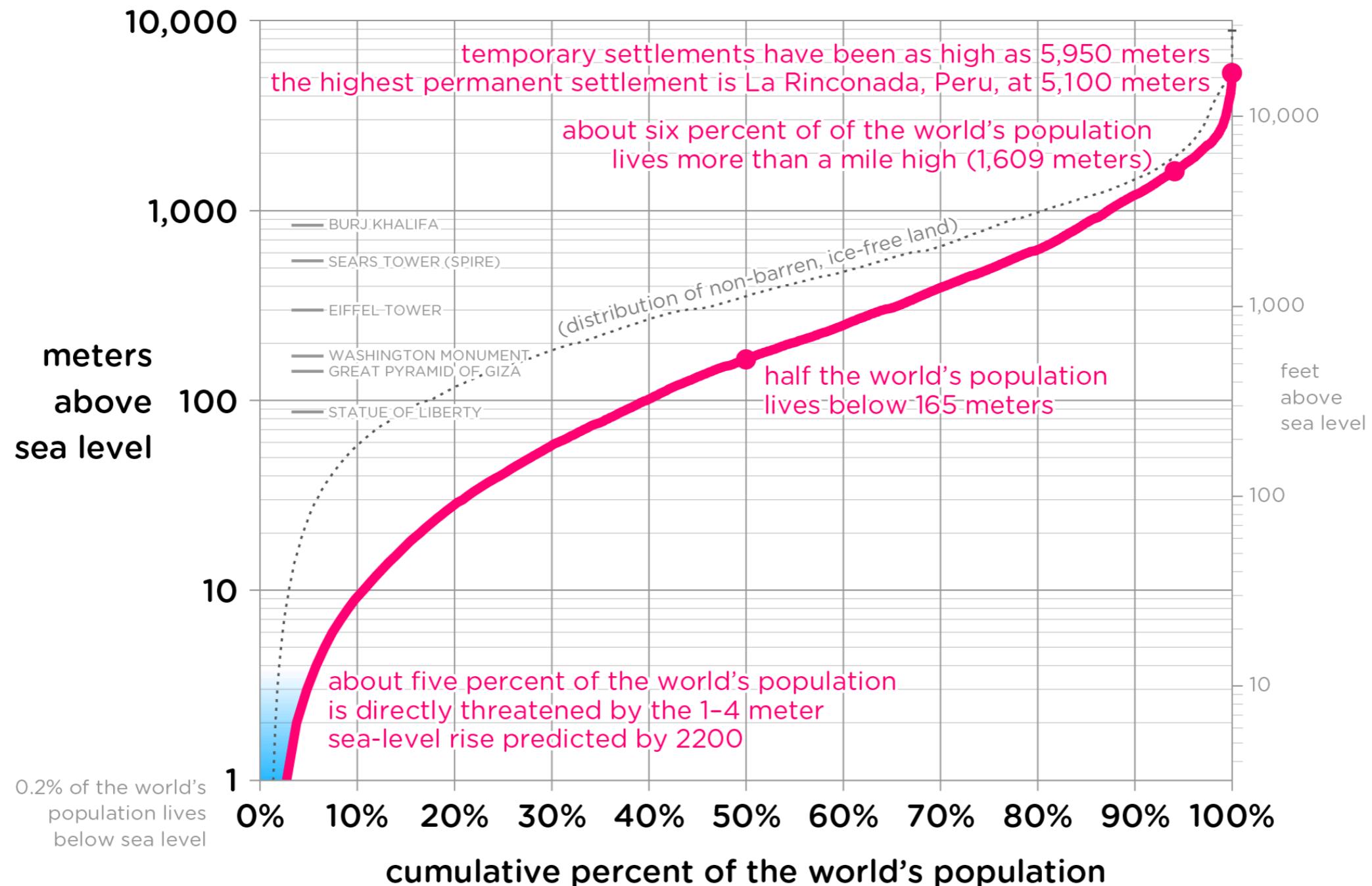


Sea level
“commitment”
depends on total
climate change

Why the committed response?

- The car: it takes time to slow down the current inertia based on the car’s size and effectiveness of brakes
- Glaciers: their “inertia” (time to adjust to climate changes) depends on their size too
 - Mountain glaciers (100s feet of ice): decades
 - Antarctic/Greenland glaciers (1000s feet of ice): centuries/millennia

Why it still makes sense to hit the brakes



population data from GRUMP; elevation from GTOPO30; sea-level rise from doi:10.1002/2014EF000239
graph by bill rankin, www.radicalcartography.net, CC BY-NC-SA 2016

Every 1 cm of additional sea level rise, threatens an additional 1 million people

A discussion question: what sorts of uncertainties might there be in projecting sea level (or anything else)?

In the realm of sea level projections, which things fit into these quadrants of this matrix?

Knowns

Known Knowns

Things we are aware of and understand.

Unknowns

Unknown Knowns

Things we understand but are not aware of.

Known Unknowns

Things we are aware of but don't understand.

Unknown Unknowns

Things we are neither aware of nor understand.

Knowns

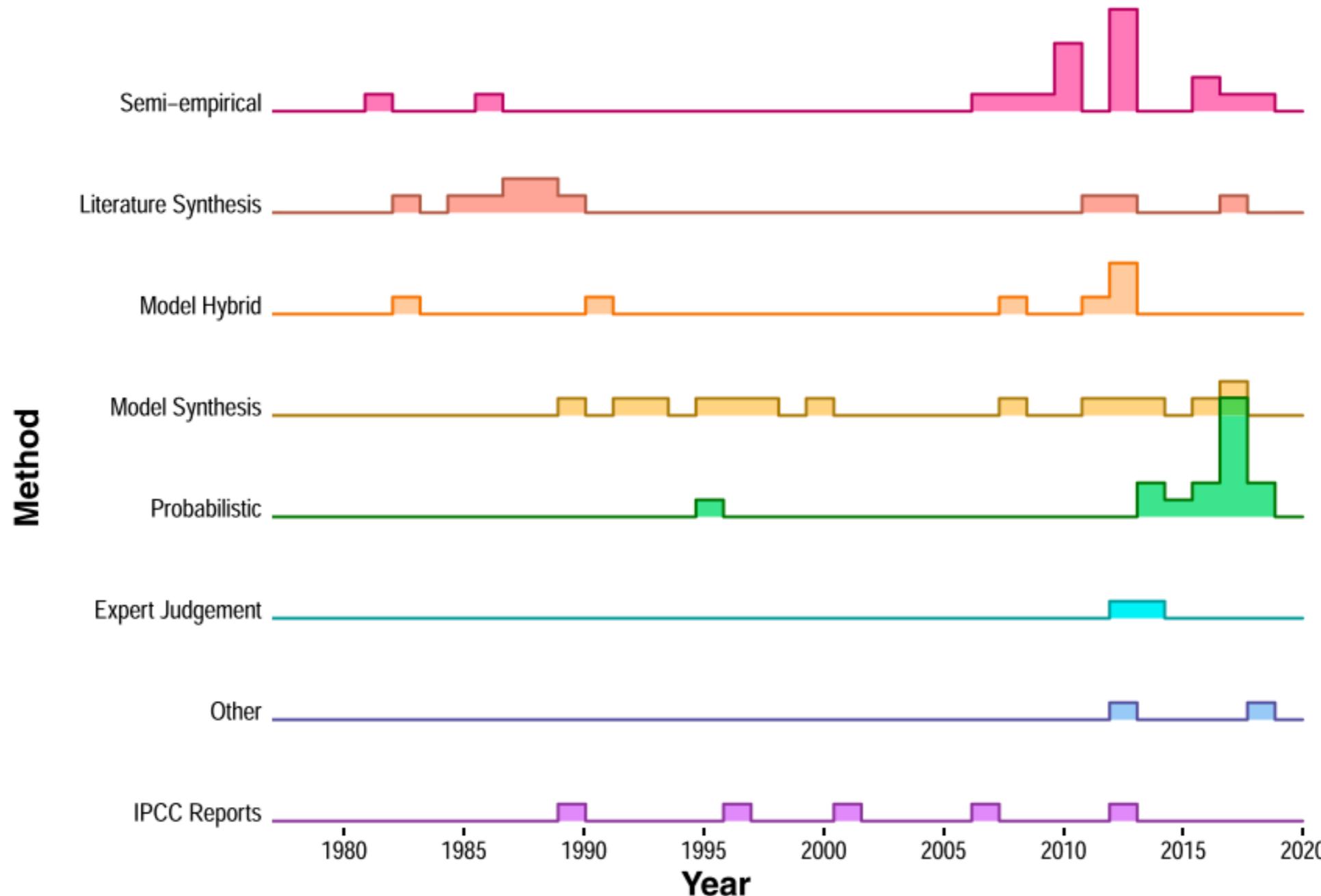
Unknowns

The three essential facts about future sea level rise

1. The rate of future sea level rise is highly uncertain, but we do know some things about it (**uncertainty**)
2. There will be some amount of continuing sea level rise for at least hundreds of years into the future (**commitment**)
3. The amount of future sea level rise depends sensitively on decisions we make about future emissions of greenhouse gases (**agency**)

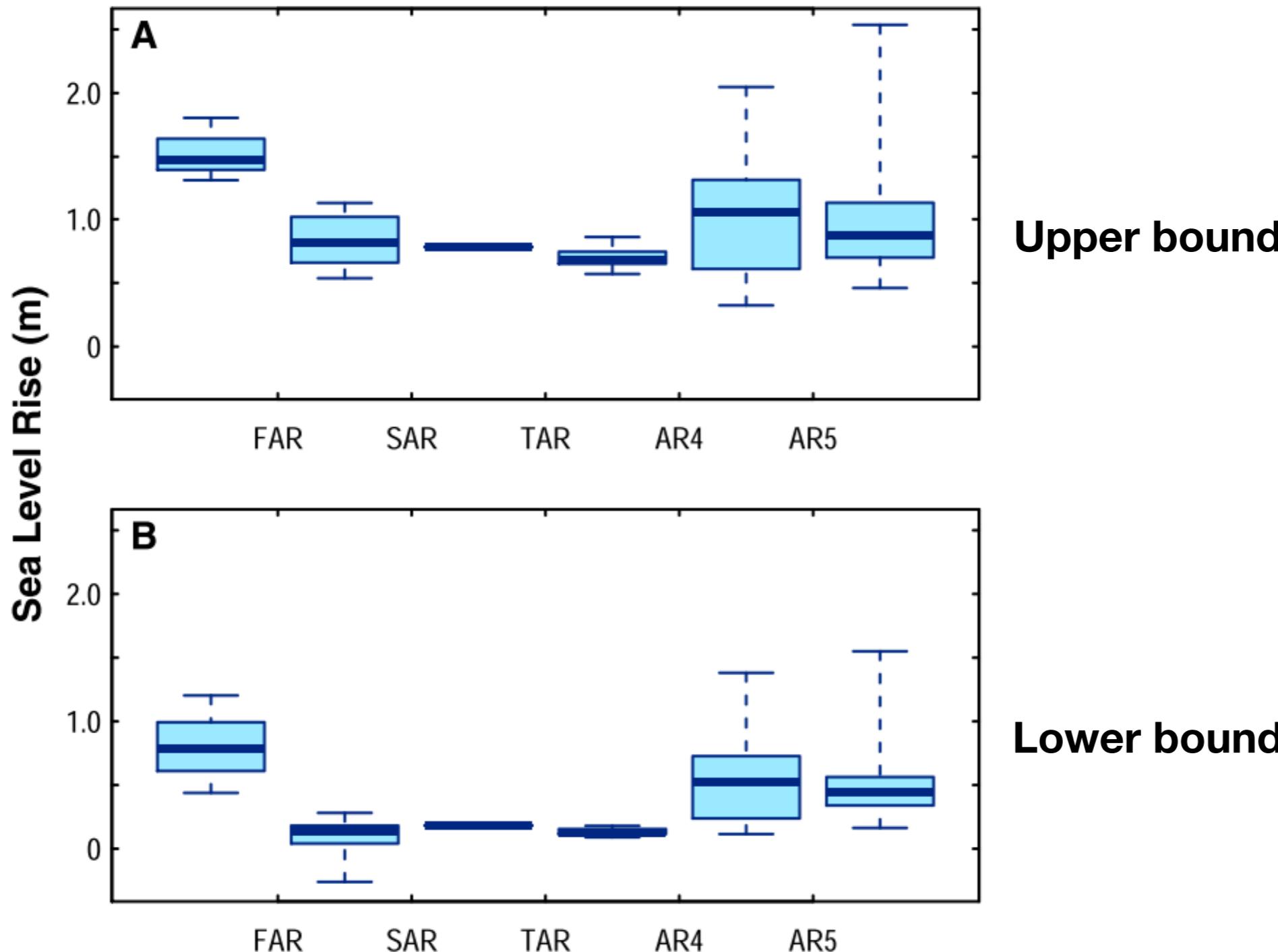
The history of sea level projections

A history of comprehensive sea level projections

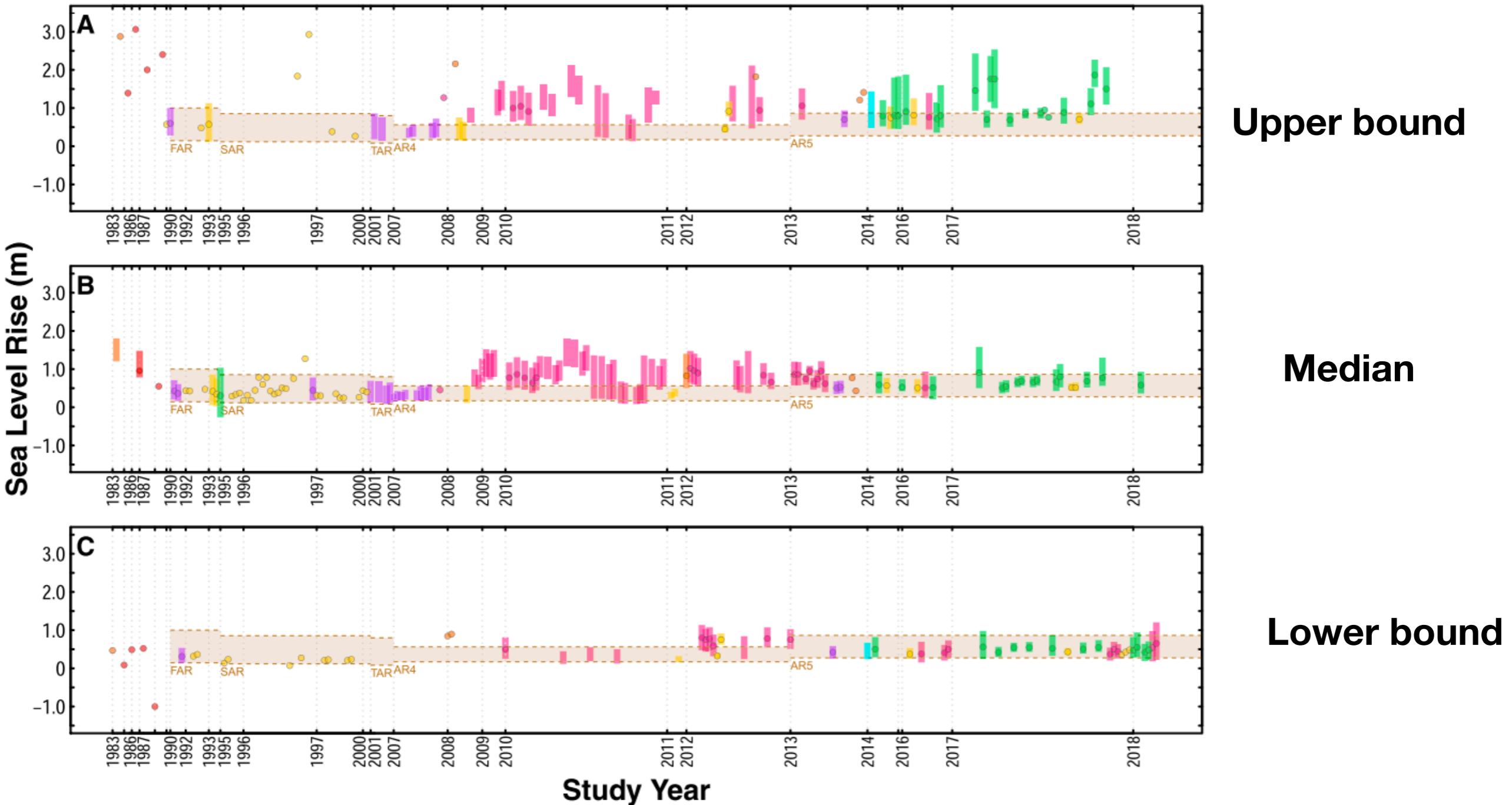


A history of comprehensive sea level projections

“Official” IPCC projections for 2100

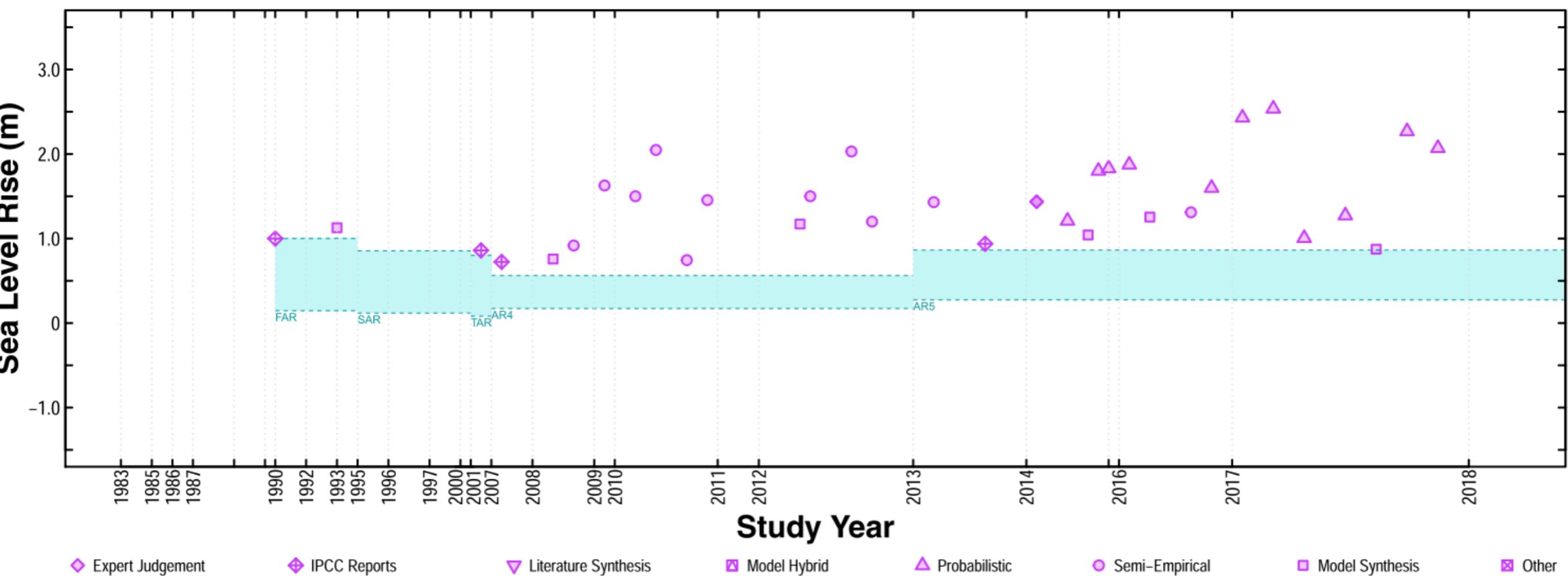


A history of comprehensive sea level projections



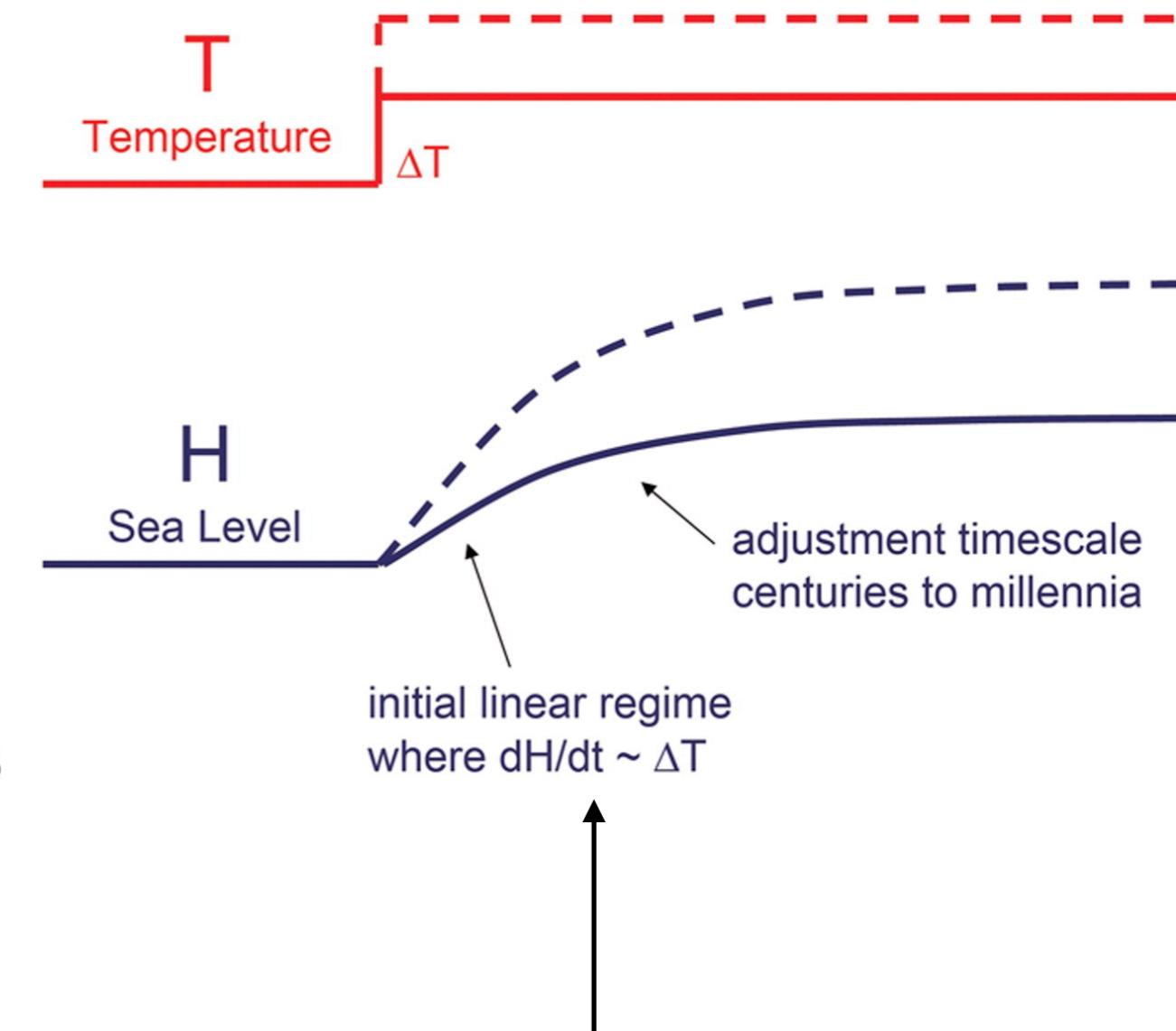
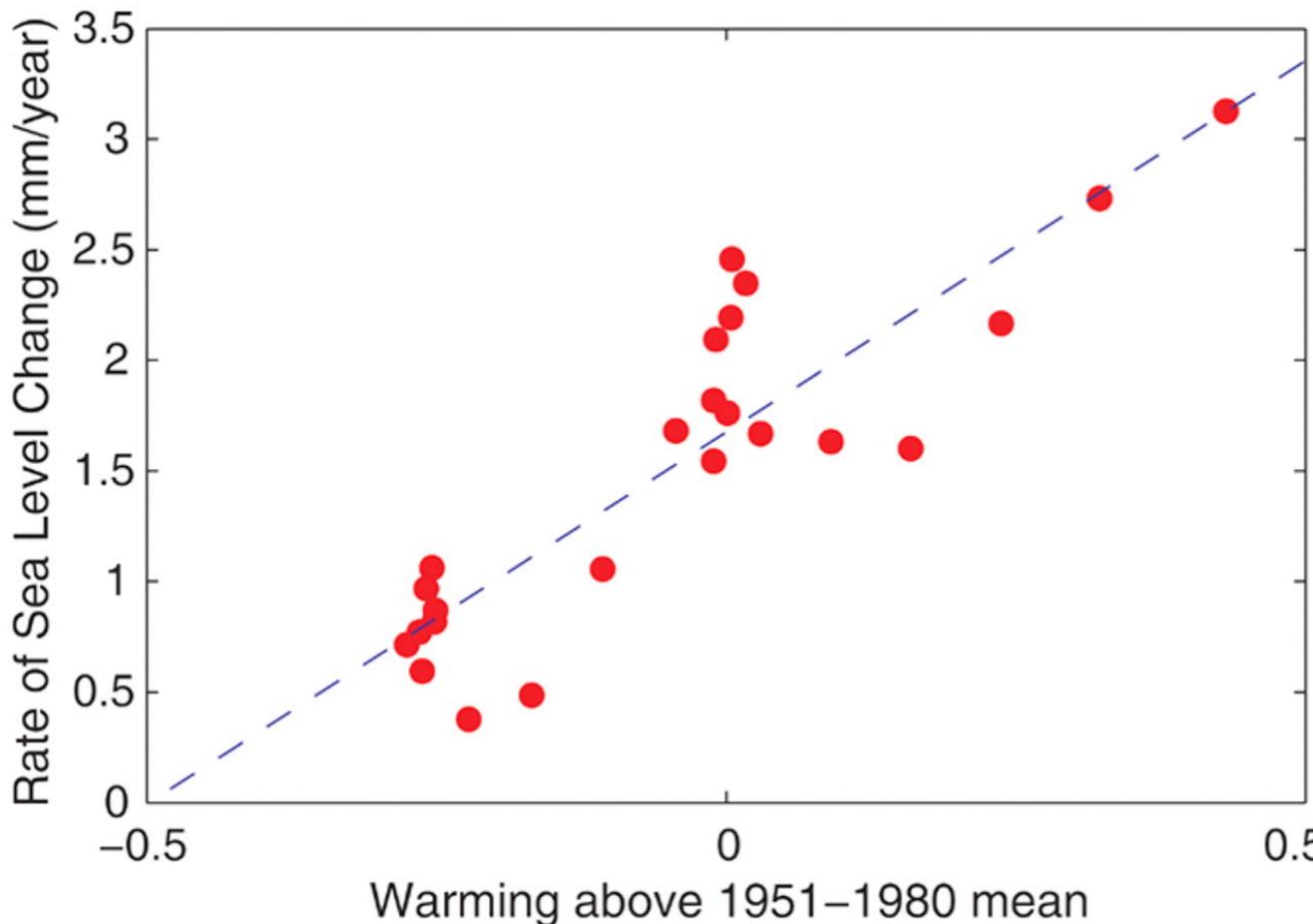
A history of comprehensive sea level projections

Just the upper bound of projections



Empirical sea level projections

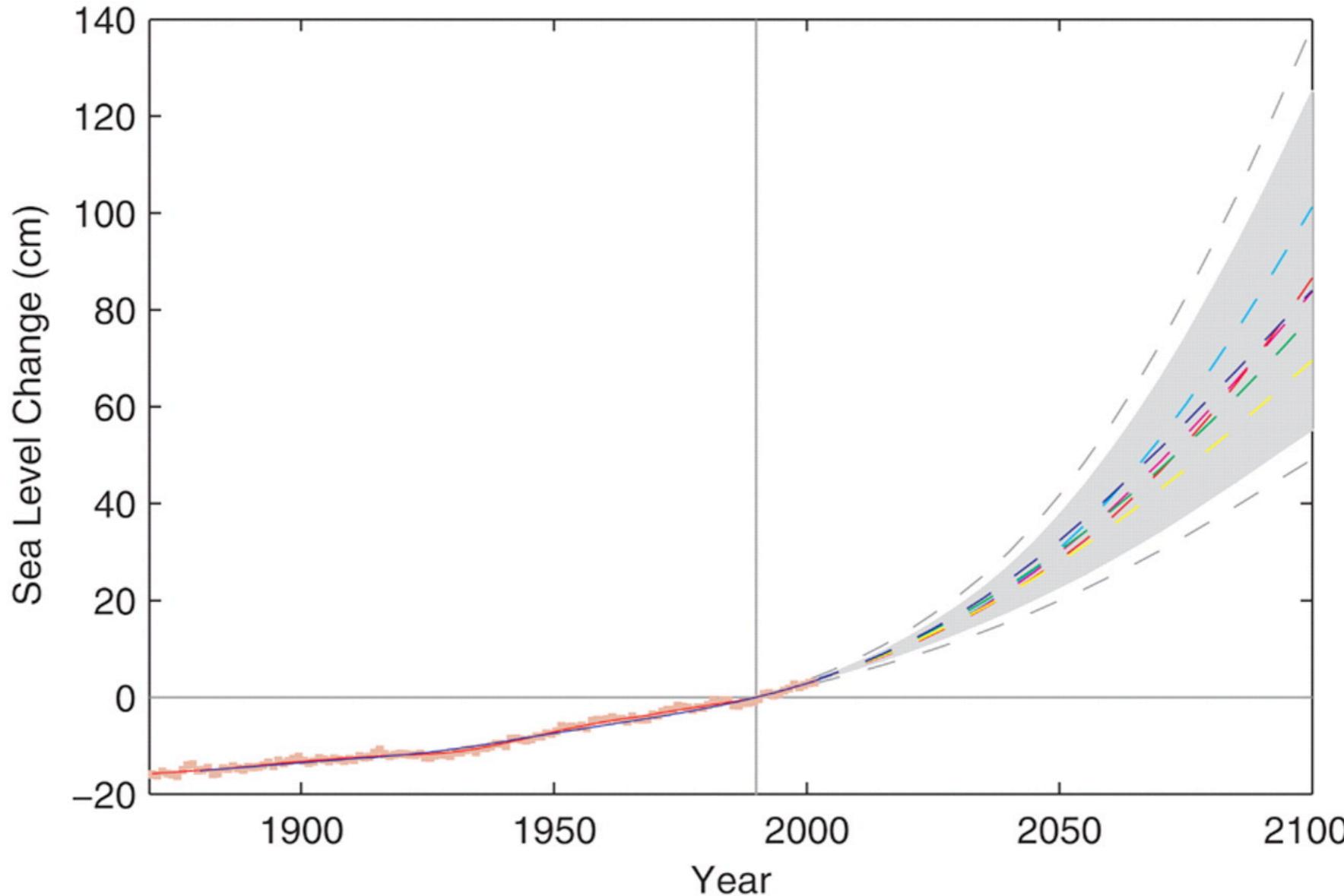
The “semi-empirical” method based on recent sea level



Rahmstorf (2007) noticed that the rate of recent sea level rise is approximately proportional to global mean temperature

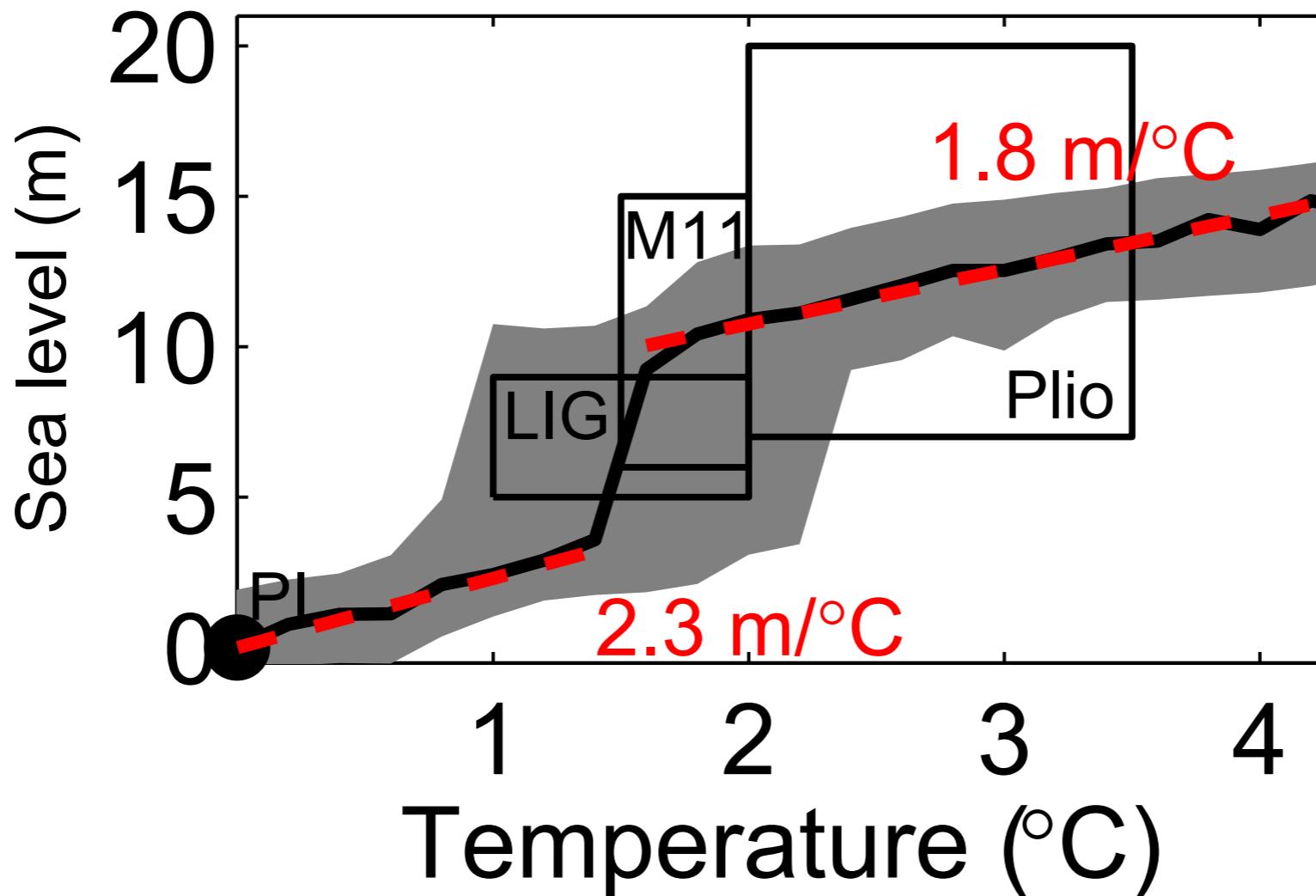
True if this assumption holds

The “semi-empirical” method based on recent sea level



Resulting projections with uncertainty - based on the assumption that the types of processes that contributed to setting the rate of sea level rise in the last century will also be the important processes in the next century

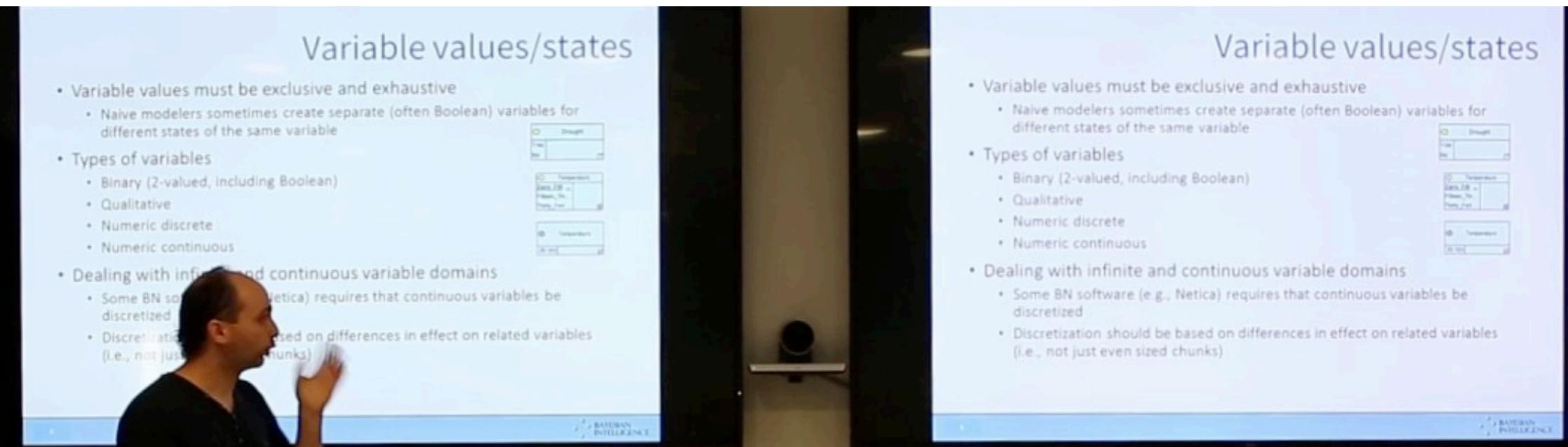
The “semi-empirical” method based on past sea level



Total sea level rise (i.e. commitment) due to some change in global mean temperature from models (line) with paleo-sea level estimates in boxes (Levermann et al. 2013)

Structured Expert Judgement

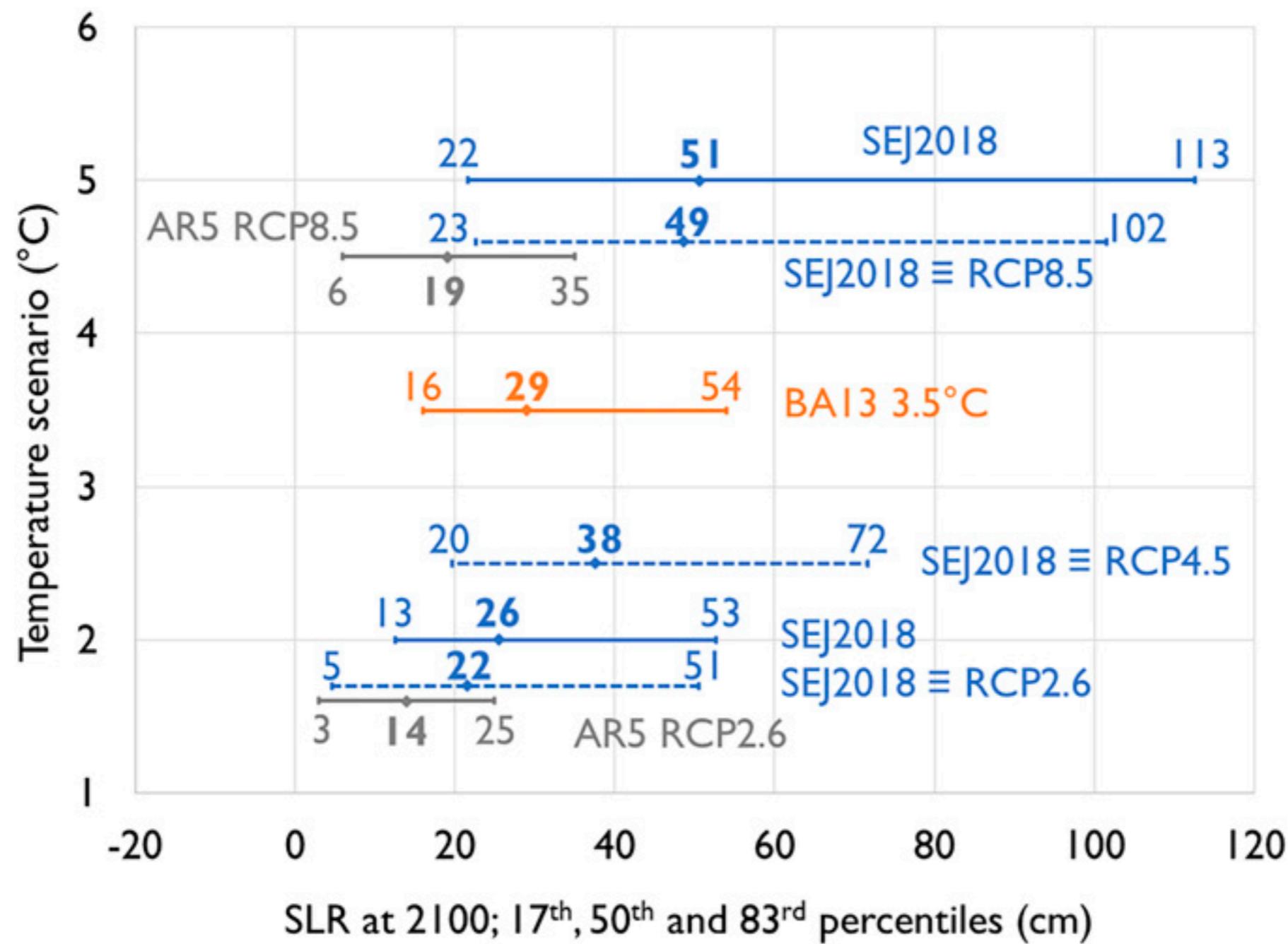
What is “structured expert judgement”?



“SEJ (as opposed to other types of expert elicitation) weights each expert using objective estimates of their statistical accuracy and informativeness (22), determined using experts’ uncertainty evaluations over a set of seed questions from their field with ascertainable values (Methods).”

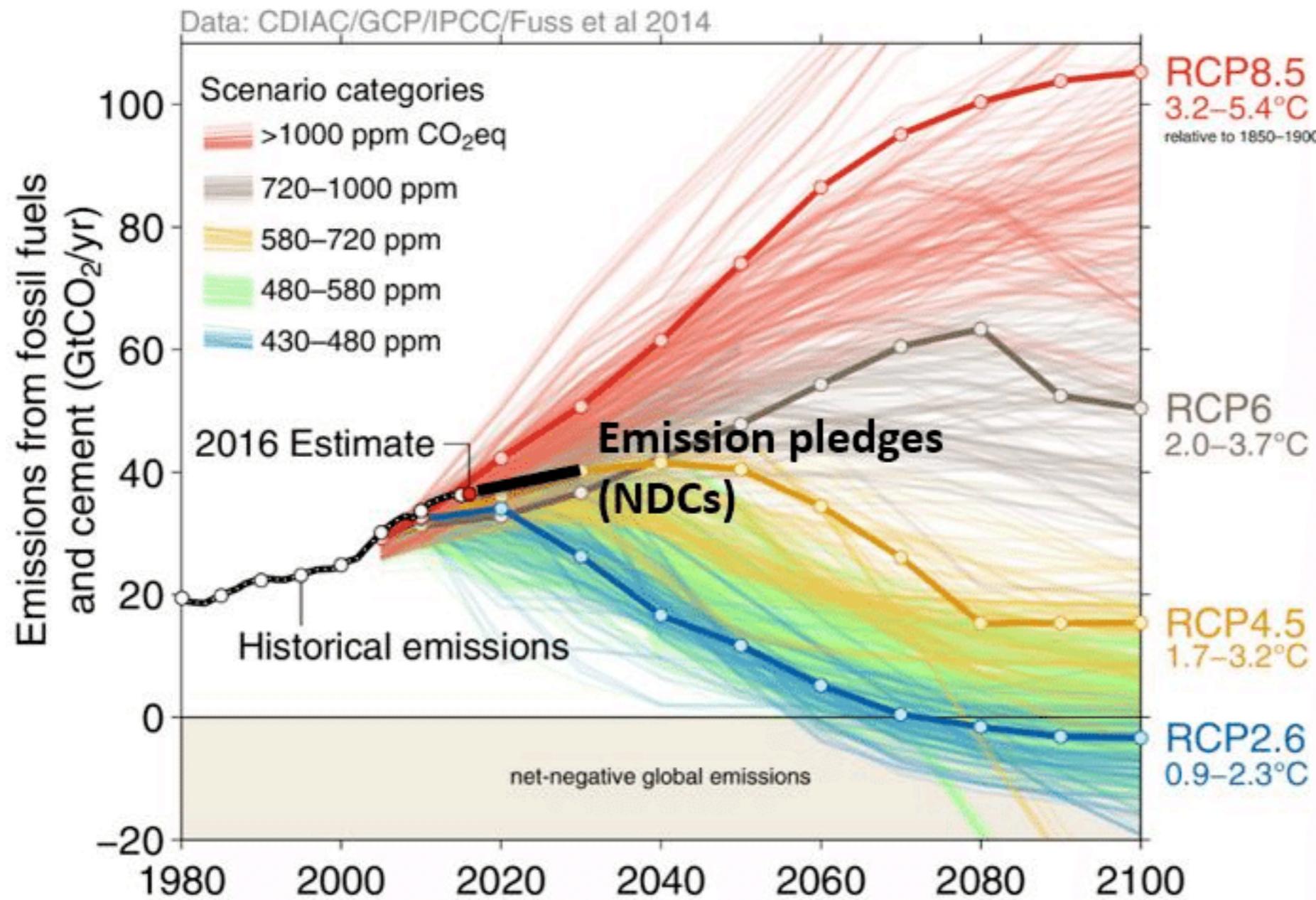
Bamber et al. (2019)

Bamber et al. (2019) structured expert judgement from sea level rise experts



Process-based sea level projections

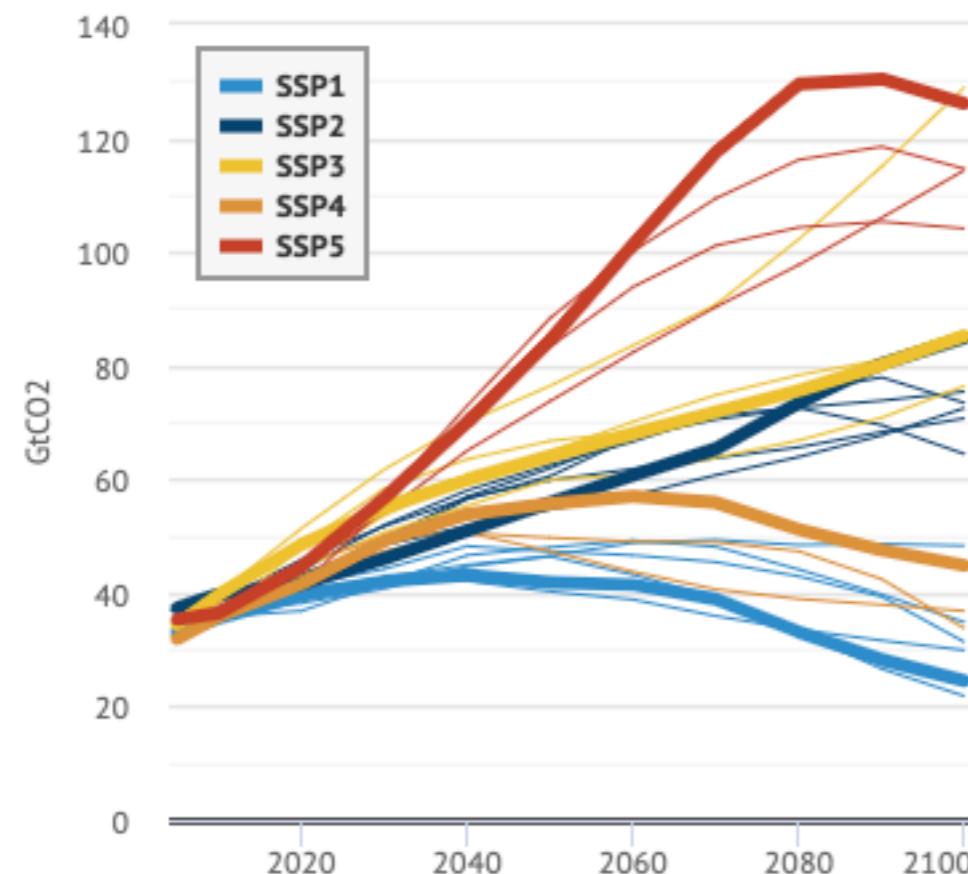
What goes into a sea level projection?



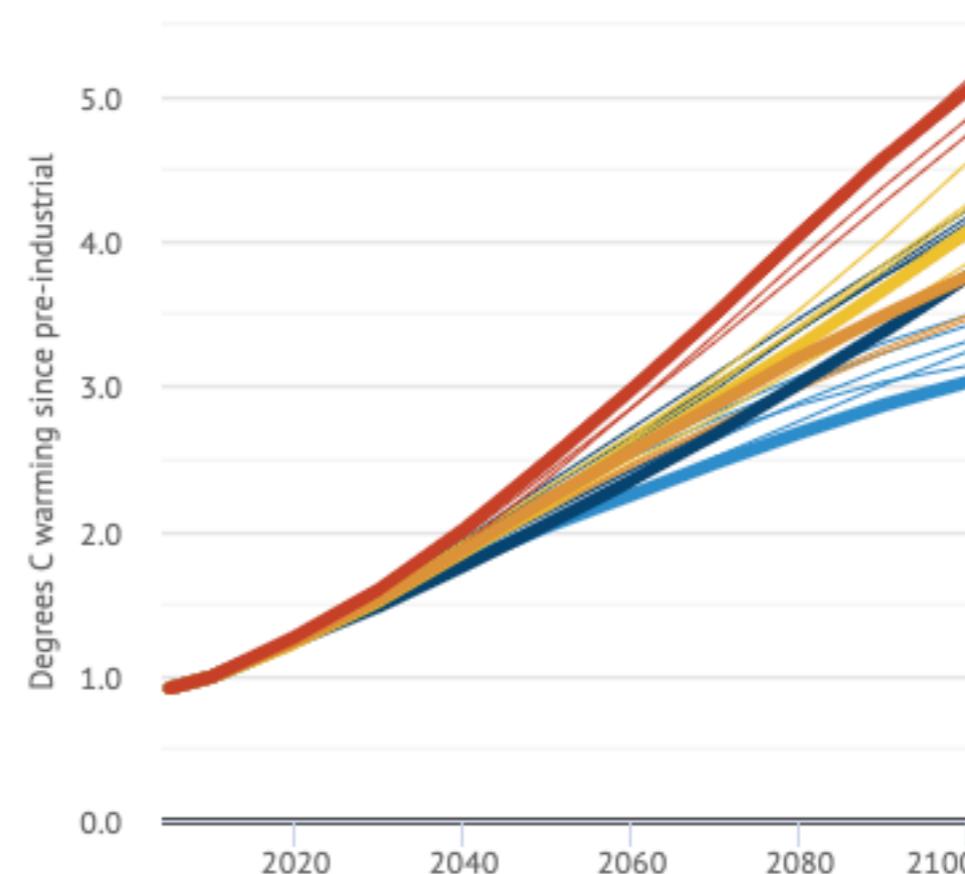
RCP =
Representative
Concentration
Pathway (a
potential
scenario for how
much
greenhouse gas
humans will emit
in the future)

What goes into a sea level projection?

CO2 emissions for SSP baselines



Global mean temperature



CB

SSP = Shared Socioeconomic Pathway (a potential scenario for how future economic development will be realized w.r.t. emissions and adaptation spending)

All projections are a conditional statement: “if this, then that”

What goes into a sea level projection?

SSP1: Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation)

SSP2: Middle of the Road (Medium challenges to mitigation and adaptation)

SSP3: Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation)

SSP4: Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation)

SSP5: Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation)

(Riahi et al. 2017)

What goes into a sea level projection?

Equation of state of seawater for determining thermal expansion

Density of sea water

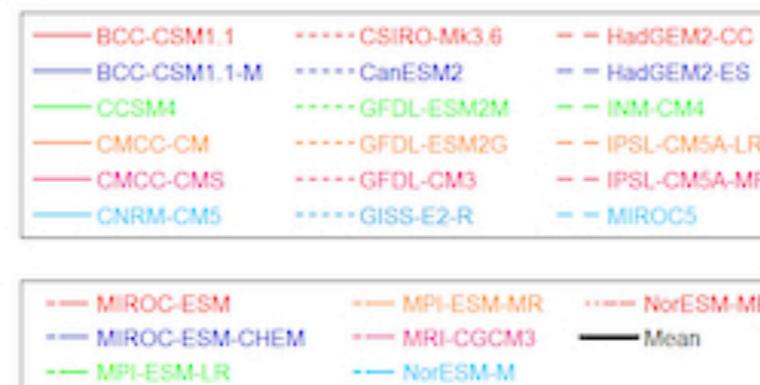
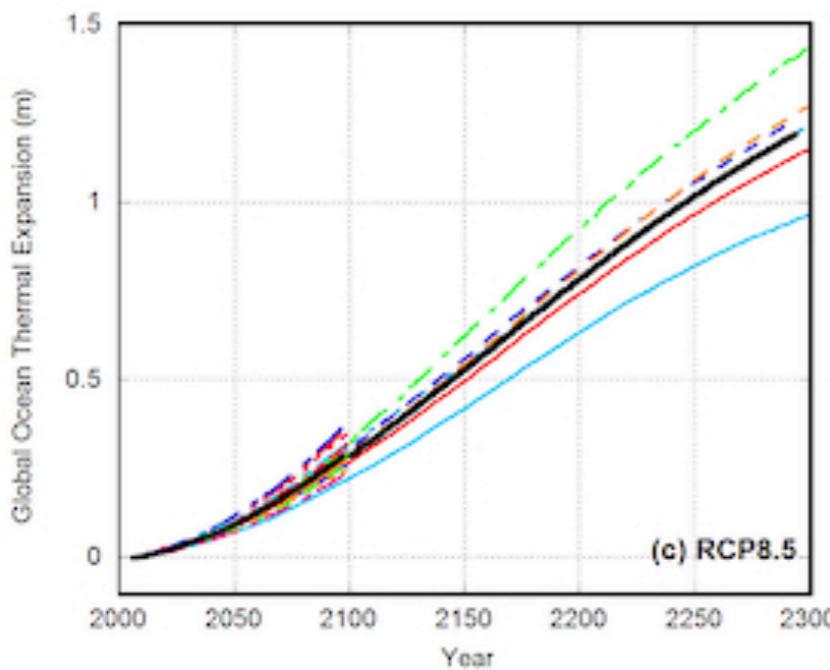
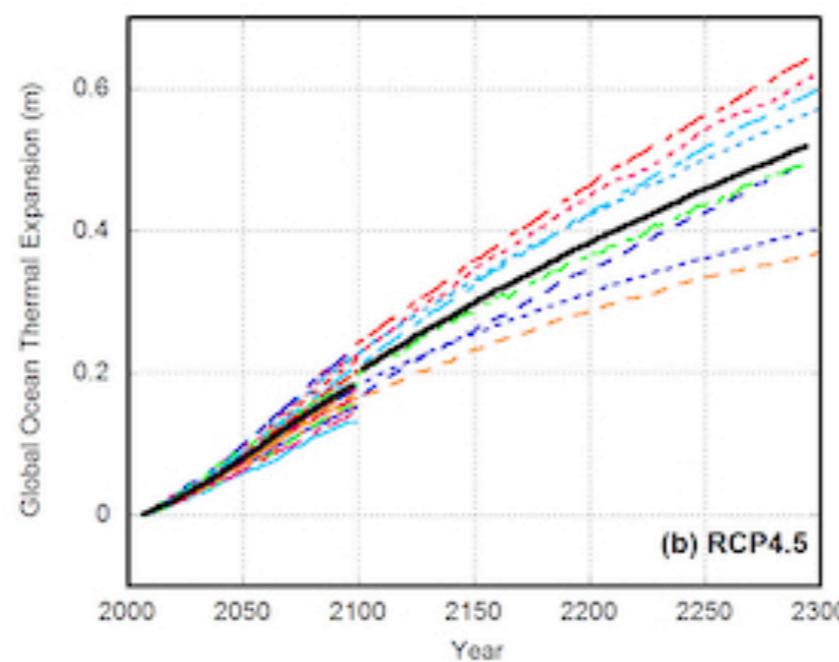
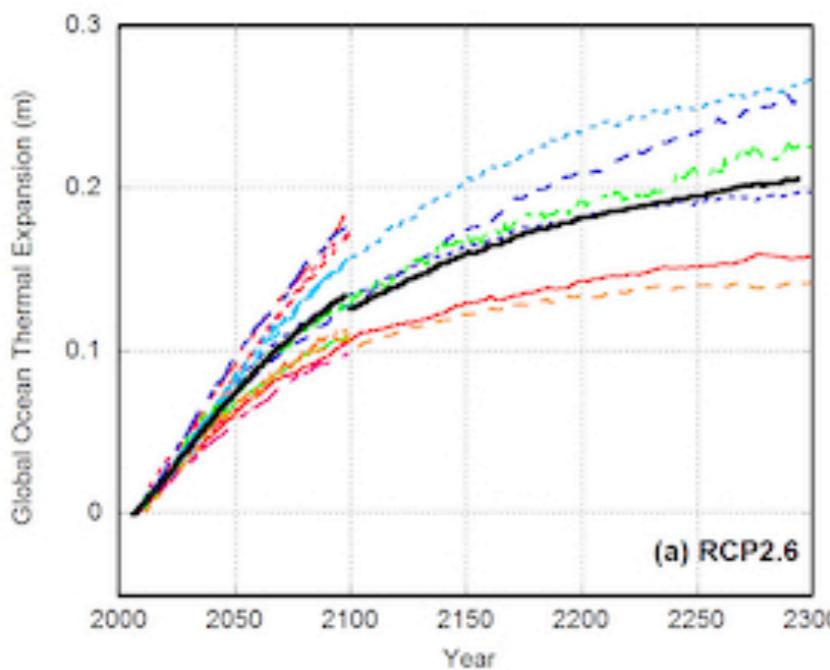
Coefficients have been determined very accurately from experiments and observations

$$\rho_{sw} = \rho_{ref}[-\alpha_T(T - T_{ref}) + \beta_S(S - S_{ref})]$$

Change in ocean temperature and salinity depends strongly on the dynamics of the ocean and atmosphere

What goes into a sea level projection?

A climate model to estimate ocean heat uptake



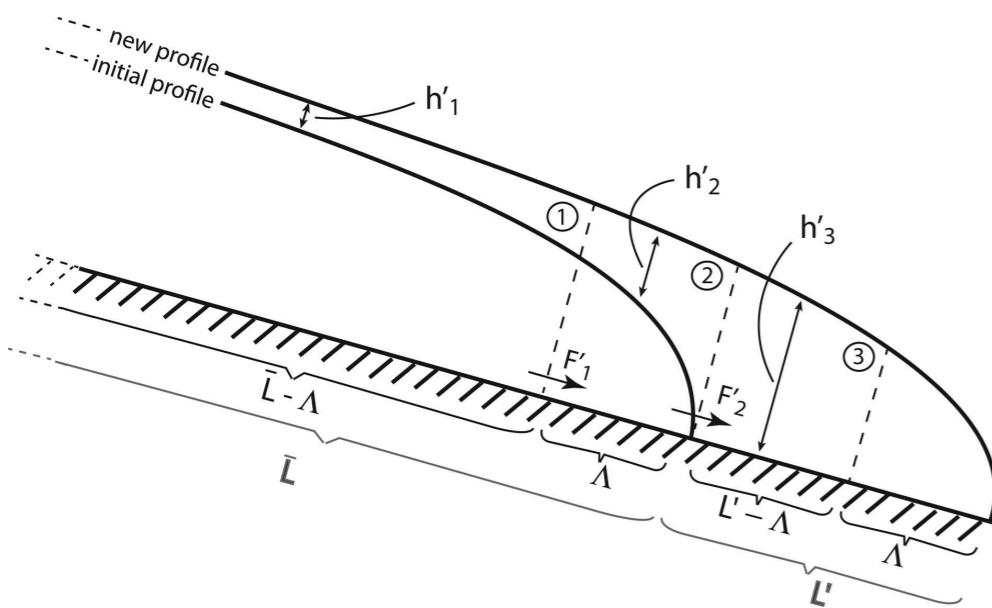
There are many climate models, each which makes slightly different assumptions about how to describe the evolution of the climate system

MIPs = model intercomparison project (all the major climate models are run with the same RCPs, and then compared)

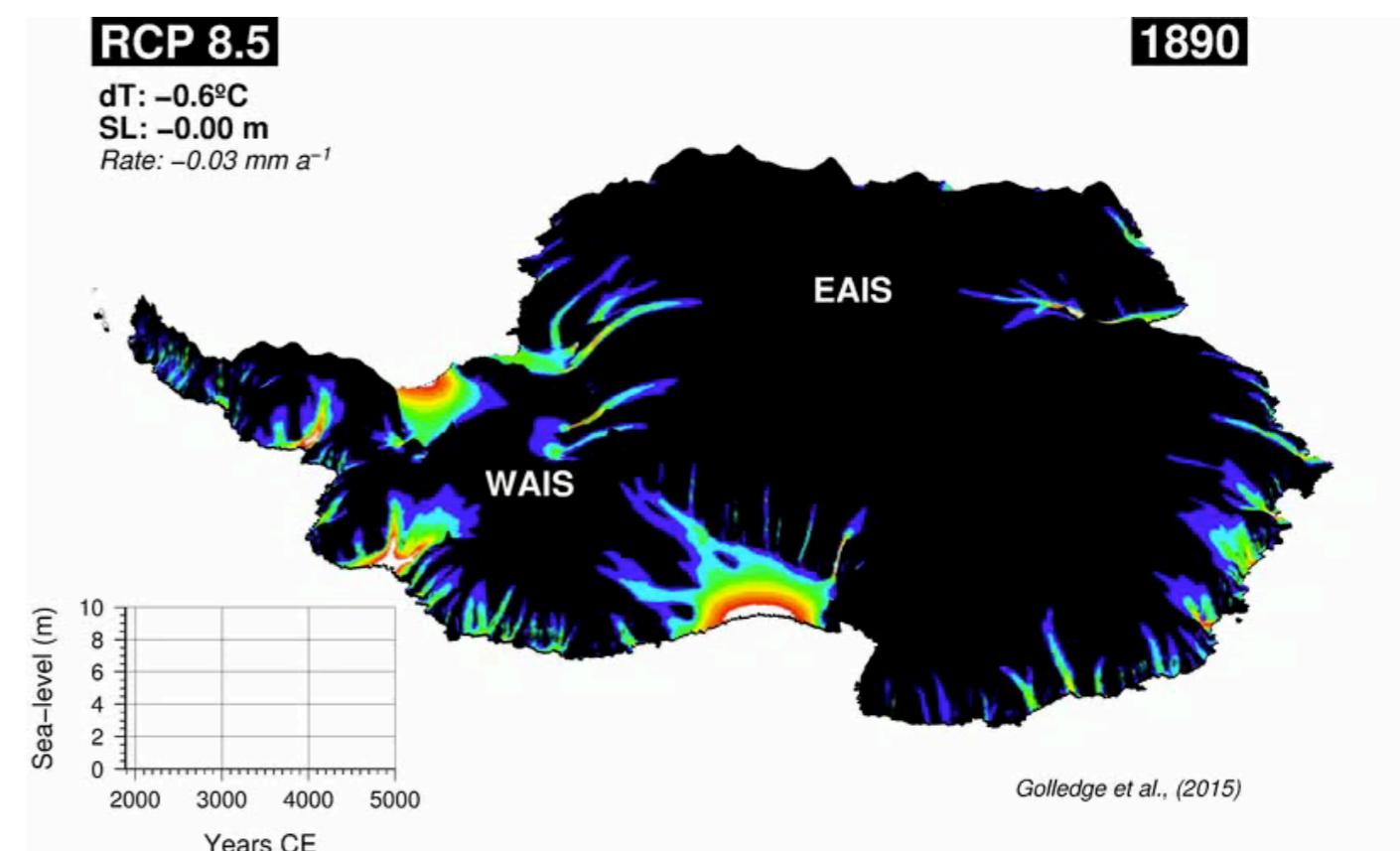
Yin 2012

What goes into a sea level projection?

A model of glaciers and/or ice sheets - which can come in many different forms



A very simple glacier model -
3 equations (Roe and Baker 2013)

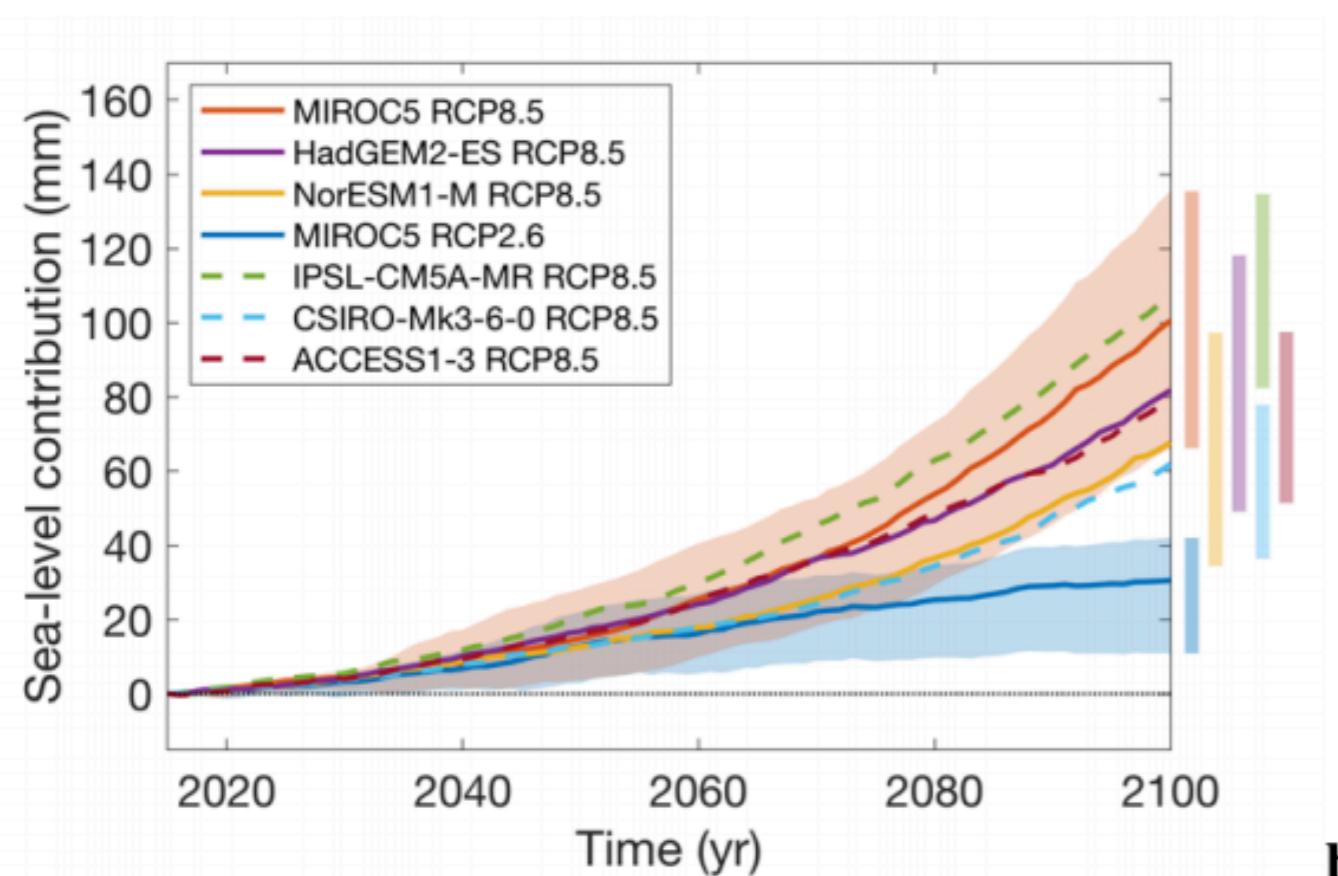


A complicated glacier model -
millions of equations (PISM; UAlaska)

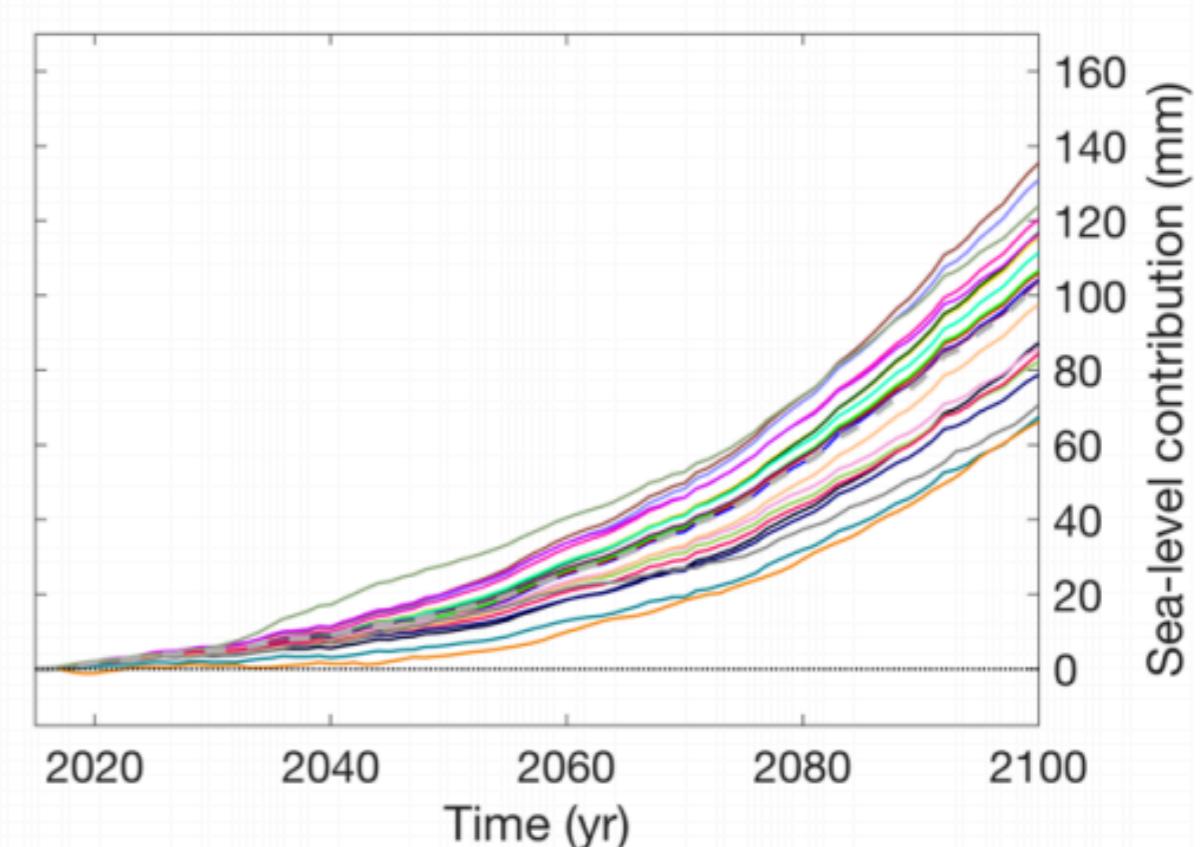
Ice sheet model projections

Different climate models,
mean of difference
Greenland ice sheet models

One climate model, different
Greenland ice sheet models

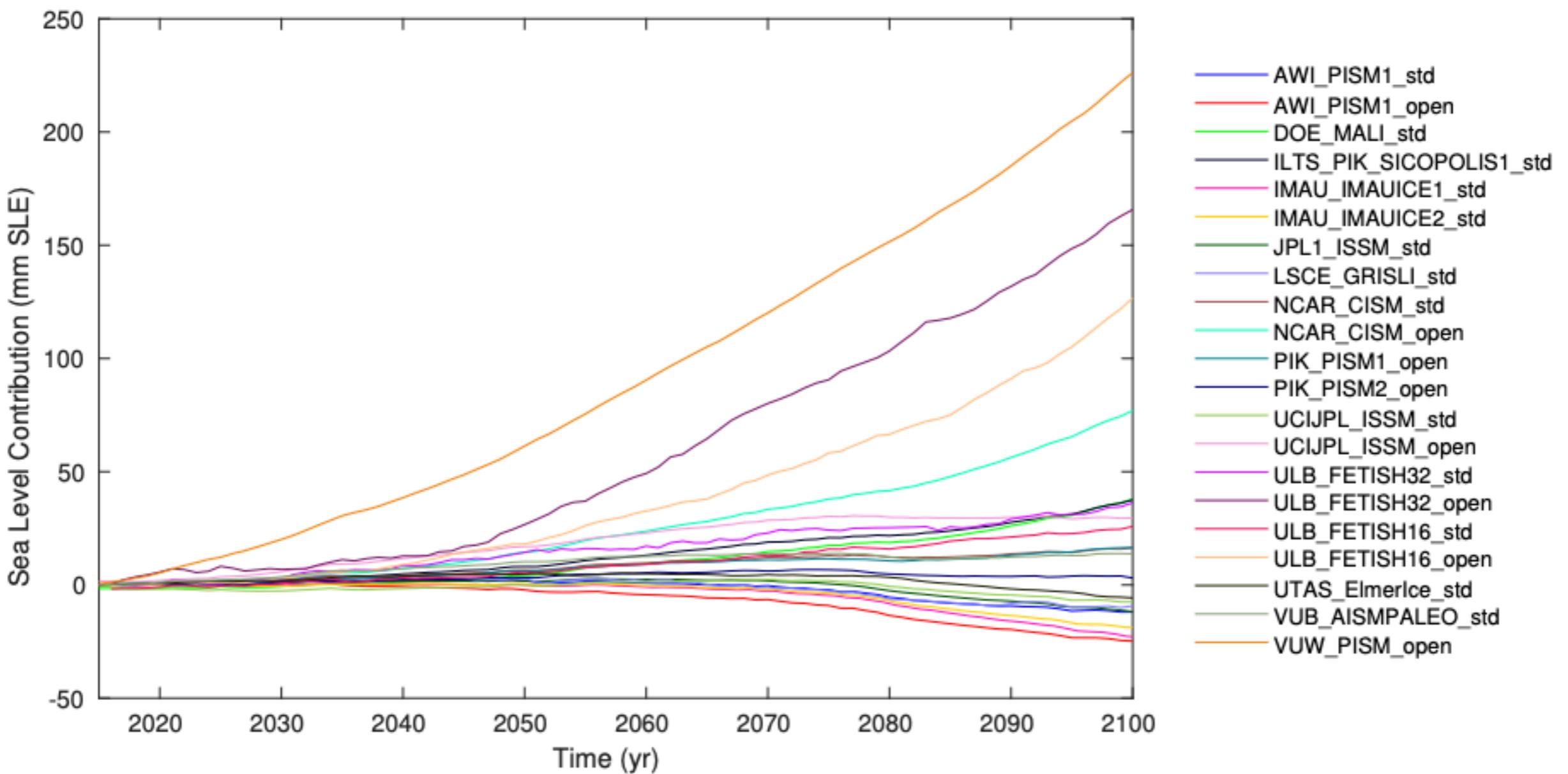


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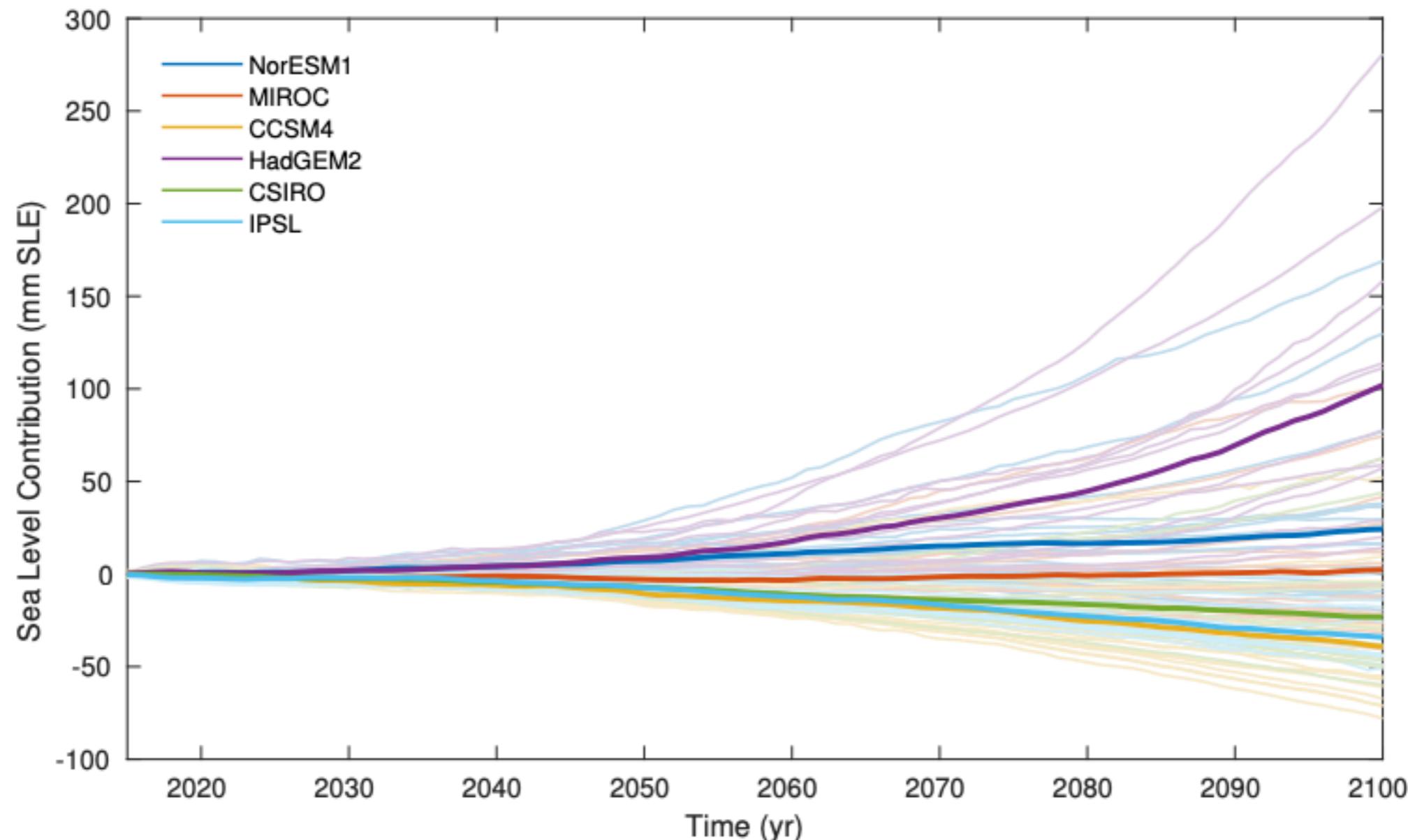
Ice sheet model projections

Same climate model, different Antarctic ice sheet models



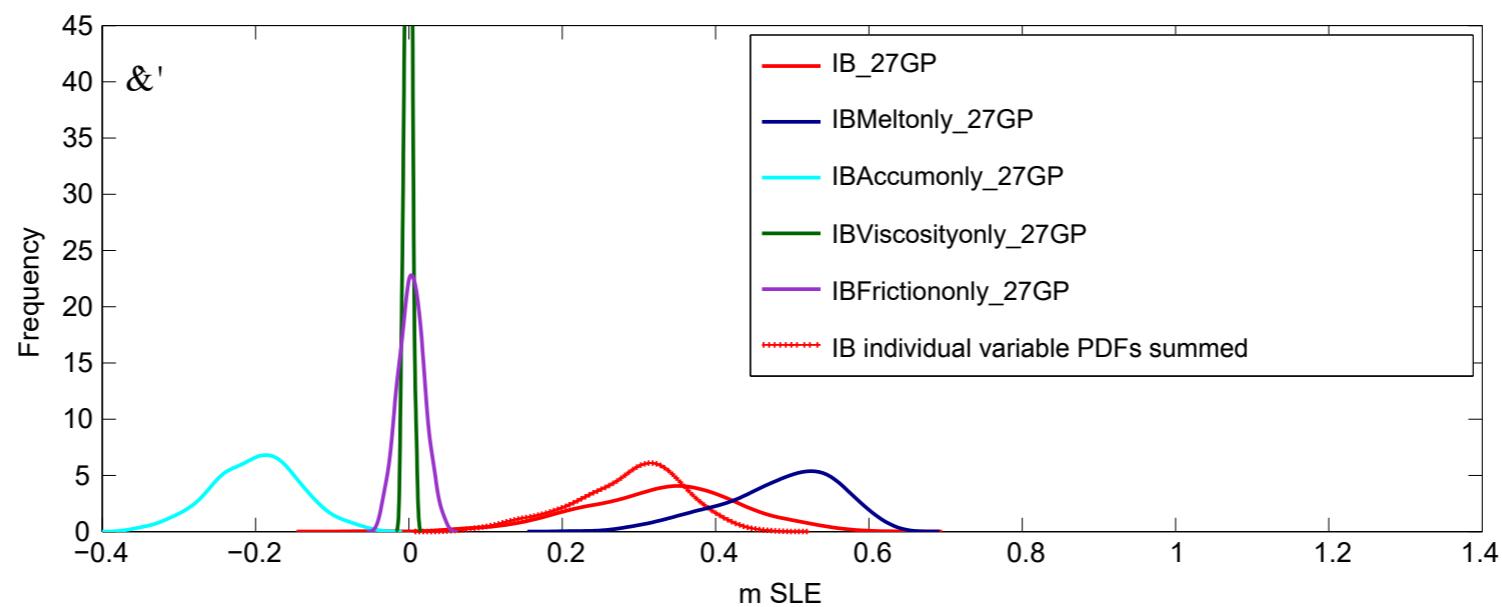
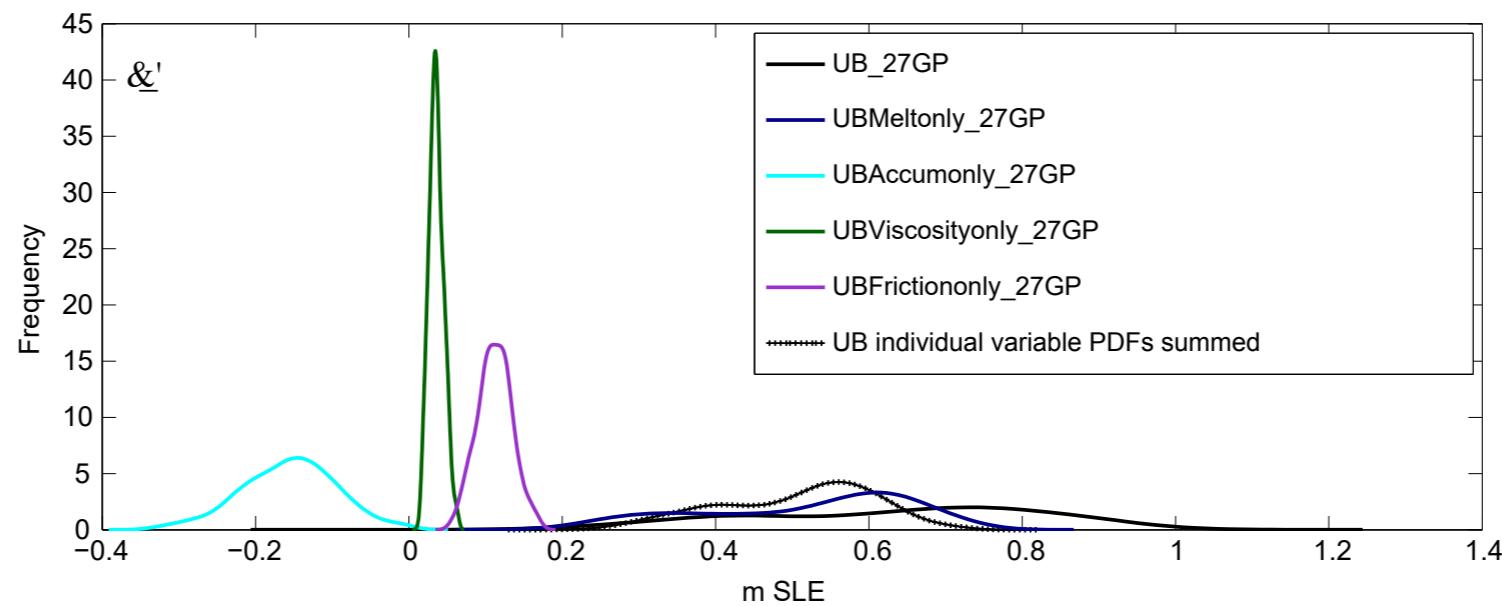
Ice sheet model projections

Different climate models (different colors), same Antarctic ice sheet models



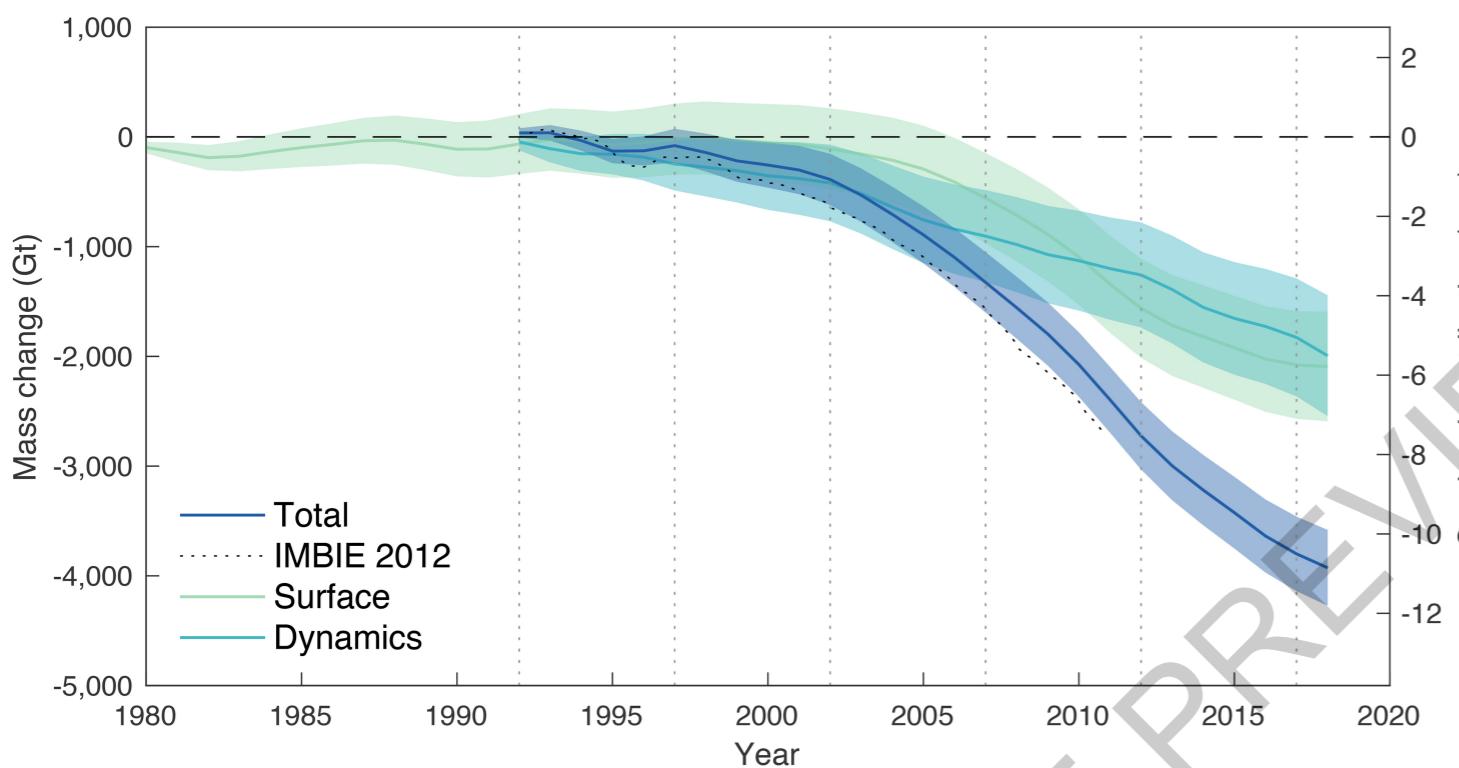
Ice sheet model projections

Same climate model, same Antarctic ice sheet model, many different parameter values selected in different ways

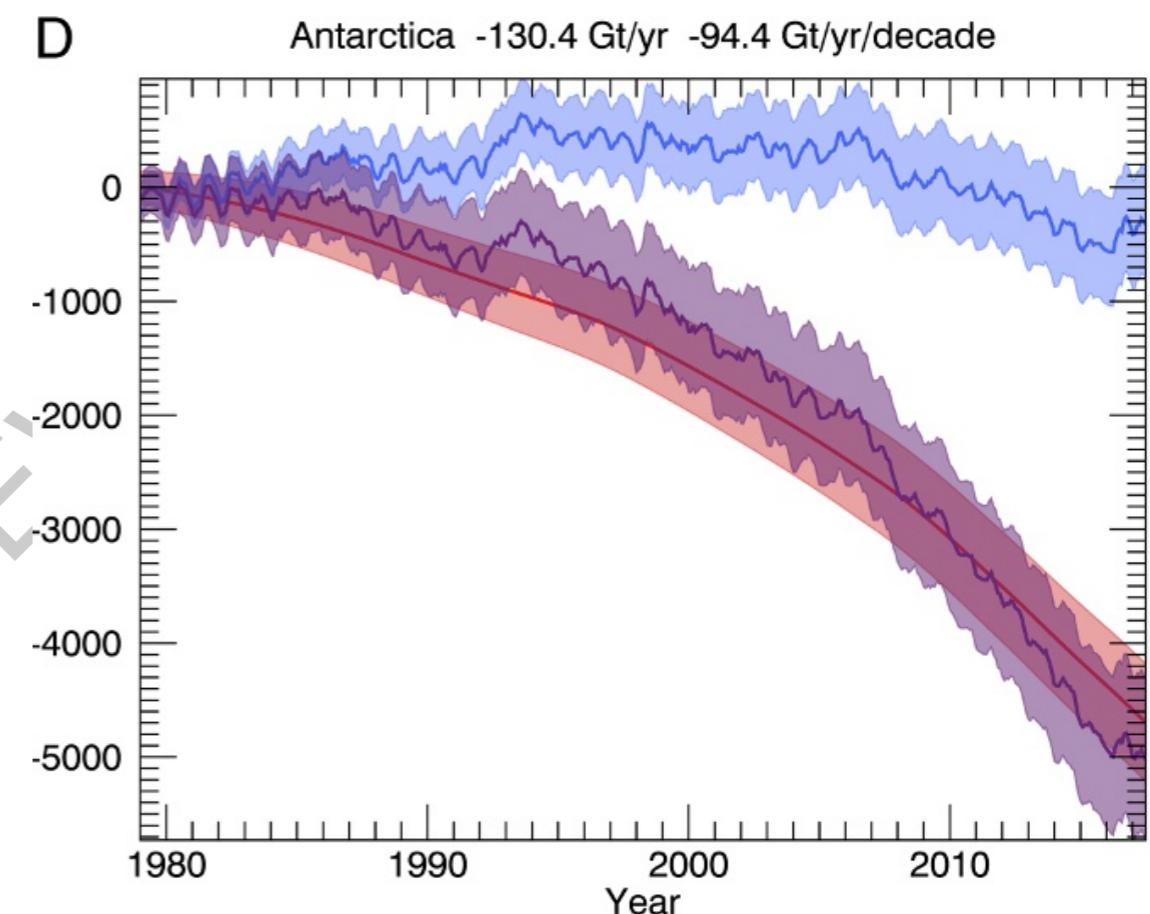


Why the difference between Greenland and Antarctica?

Future Greenland melt will likely continue to be dominated by surface melt, which is better understood than ice sheet flow dynamics



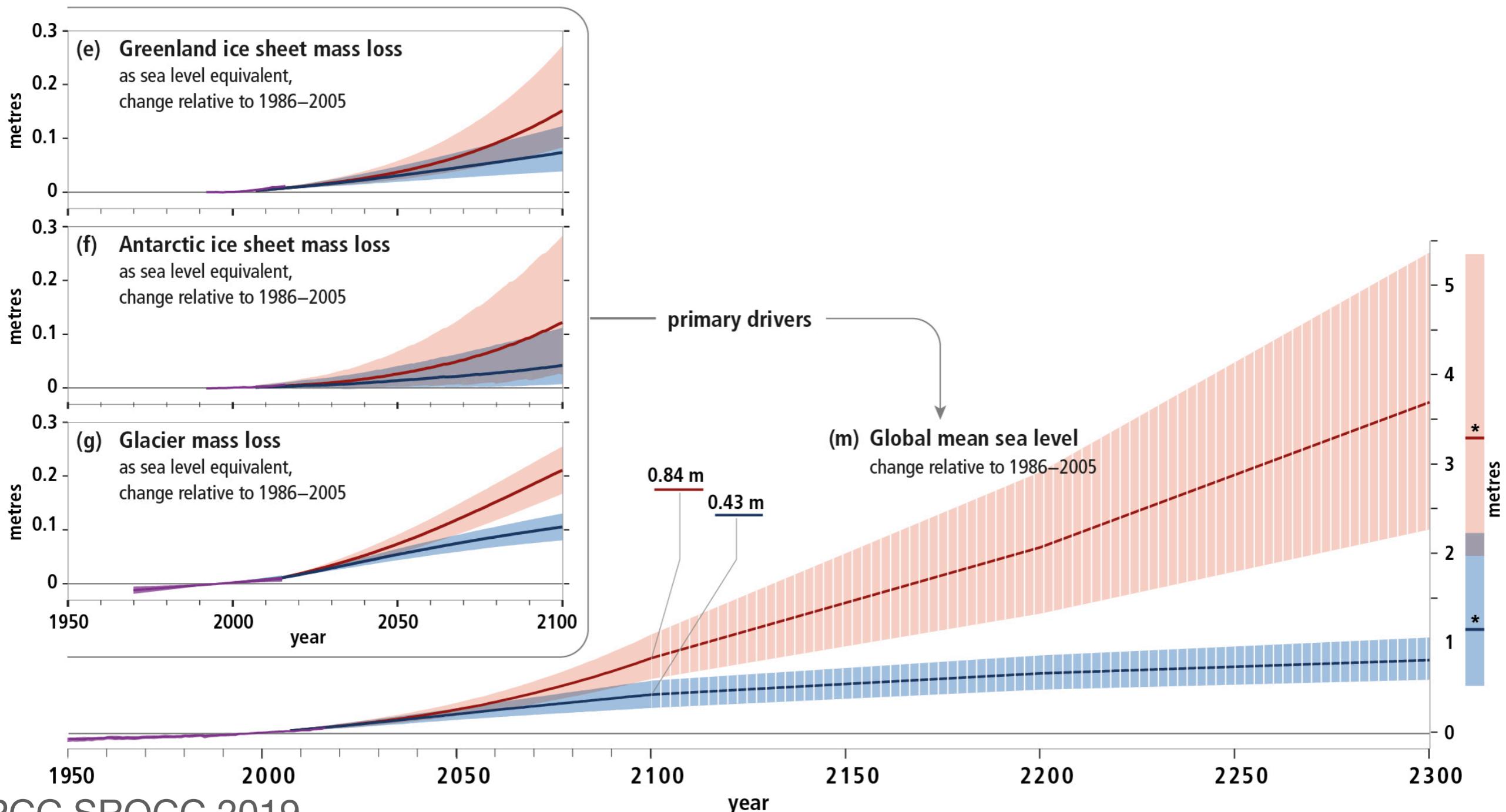
IMBIE Team 2019



Rignot et al. 2019

IPCC's Latest View

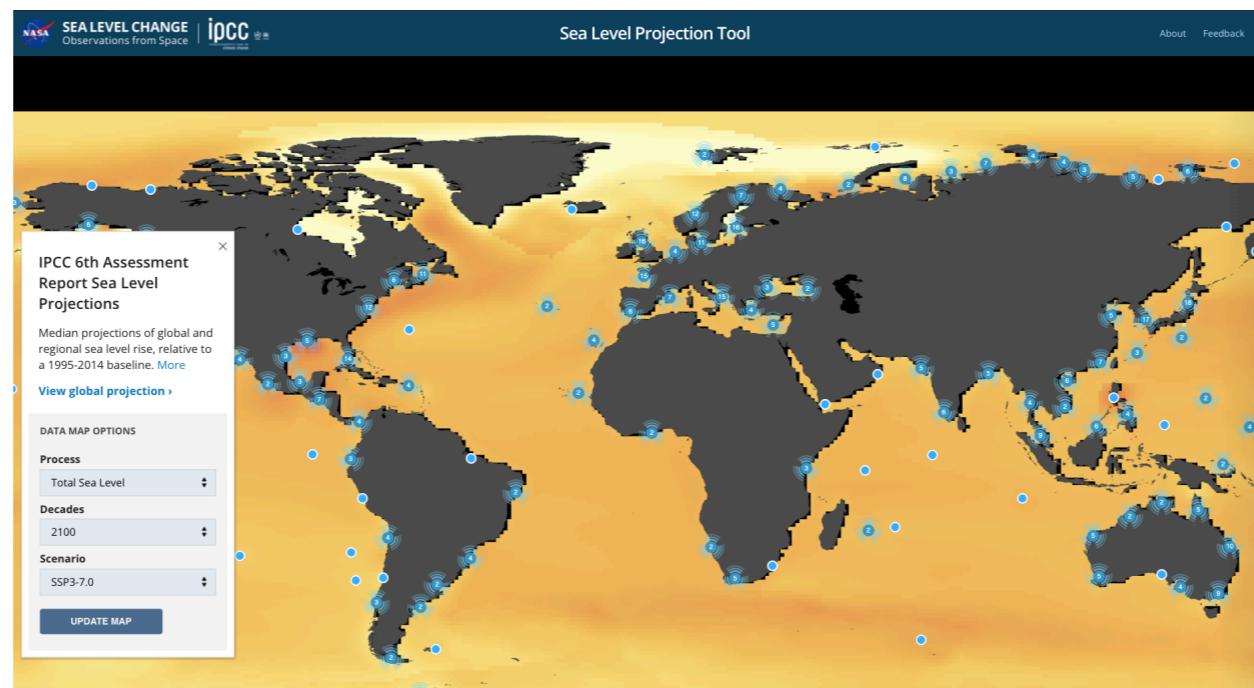
IPCC language tip: “likely” means 66% (+/-1 SD)



Regional sea level projections

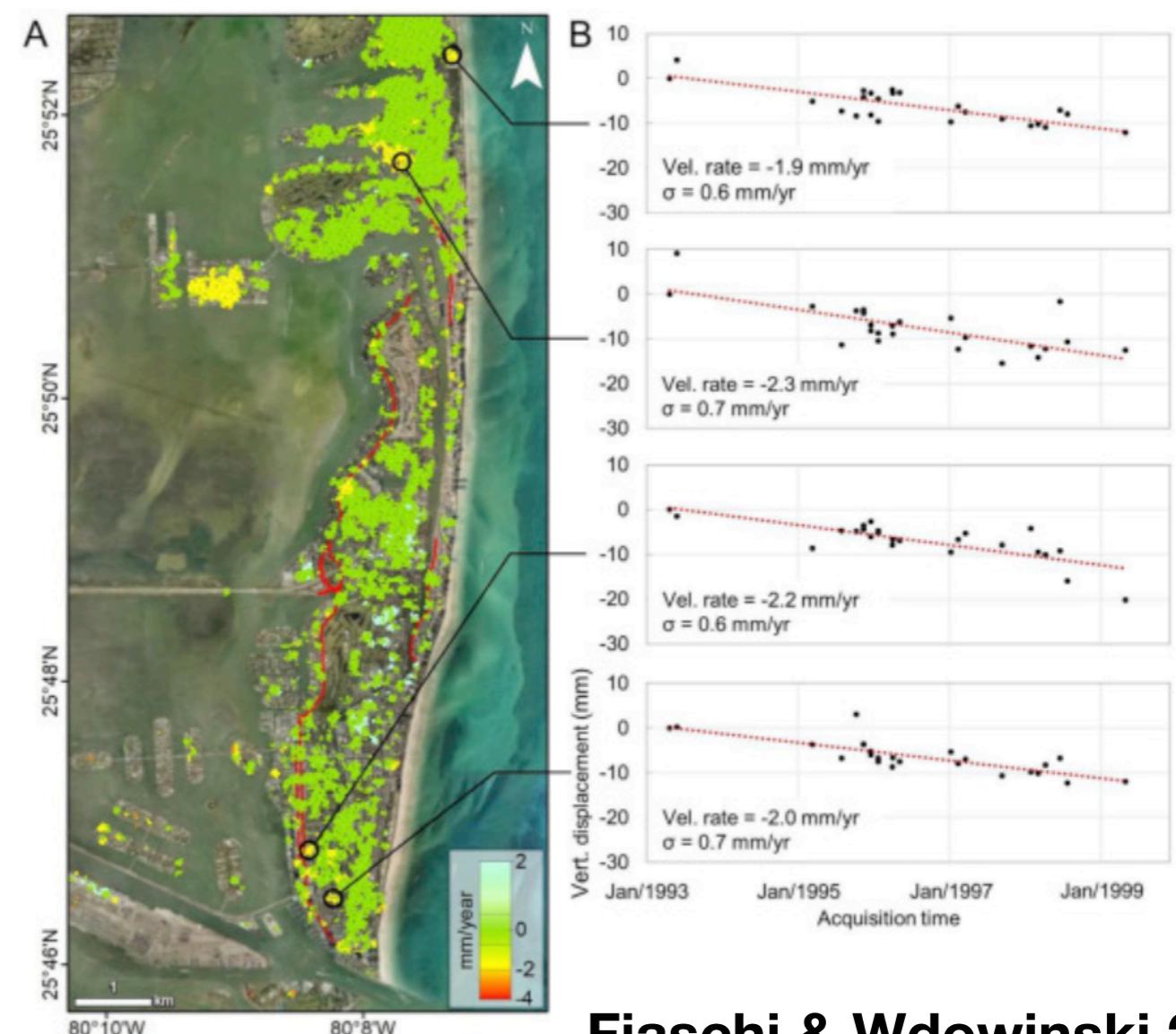
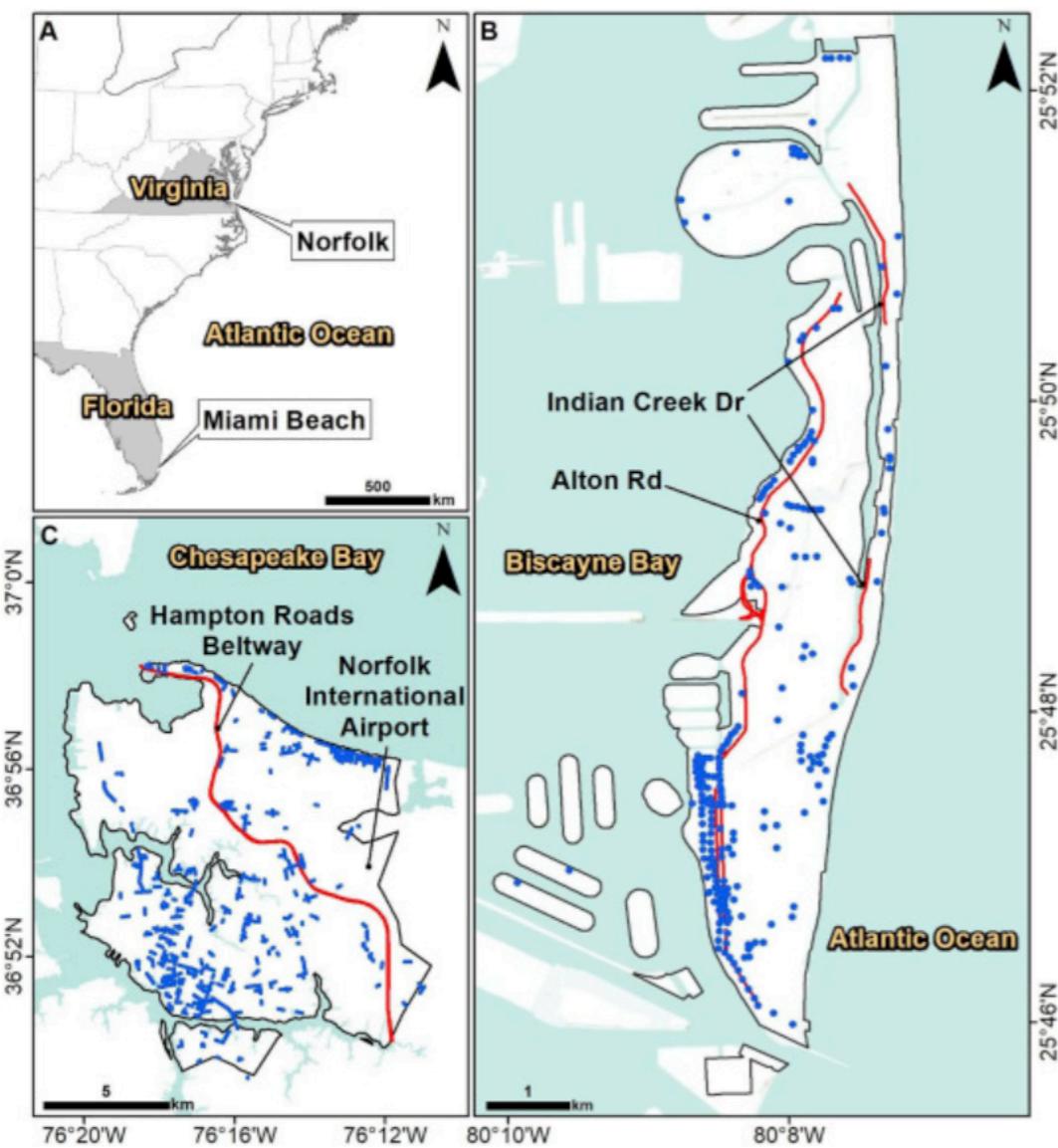
Regional sea level projections

- Many of the processes we have talked about generate large regional differences in sea level in the future
- In practice, adaptation to sea level is highly localized, so localized projections are needed
- <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool>



Local sea level projections

- Current projections are still relatively coarse (100's of kilometers), don't take into account strongly localized urbanization and climate variability



Hands-on activity with sea level projections

