Explaining and constraining the spread in projections of Arctic sea ice

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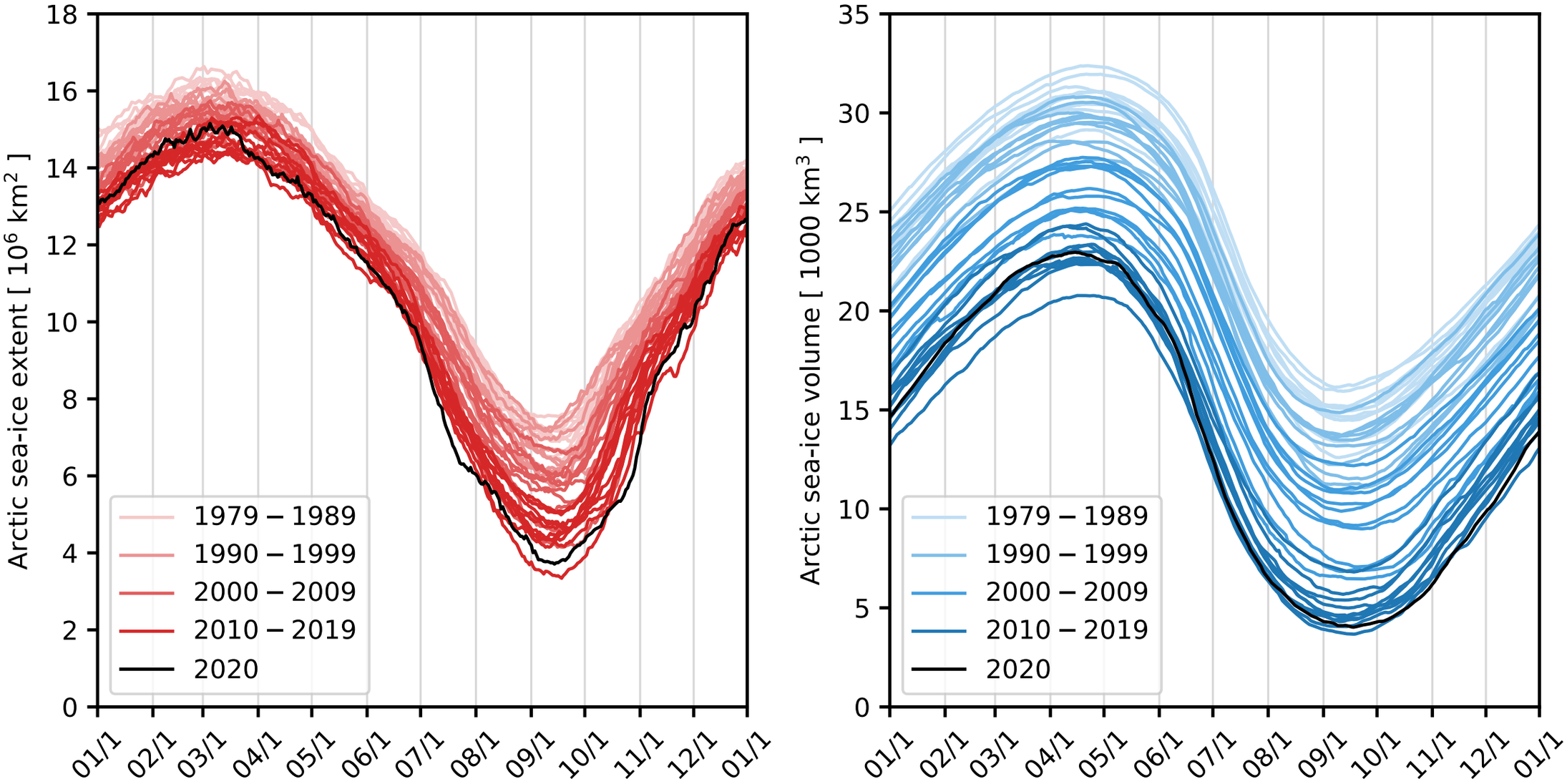
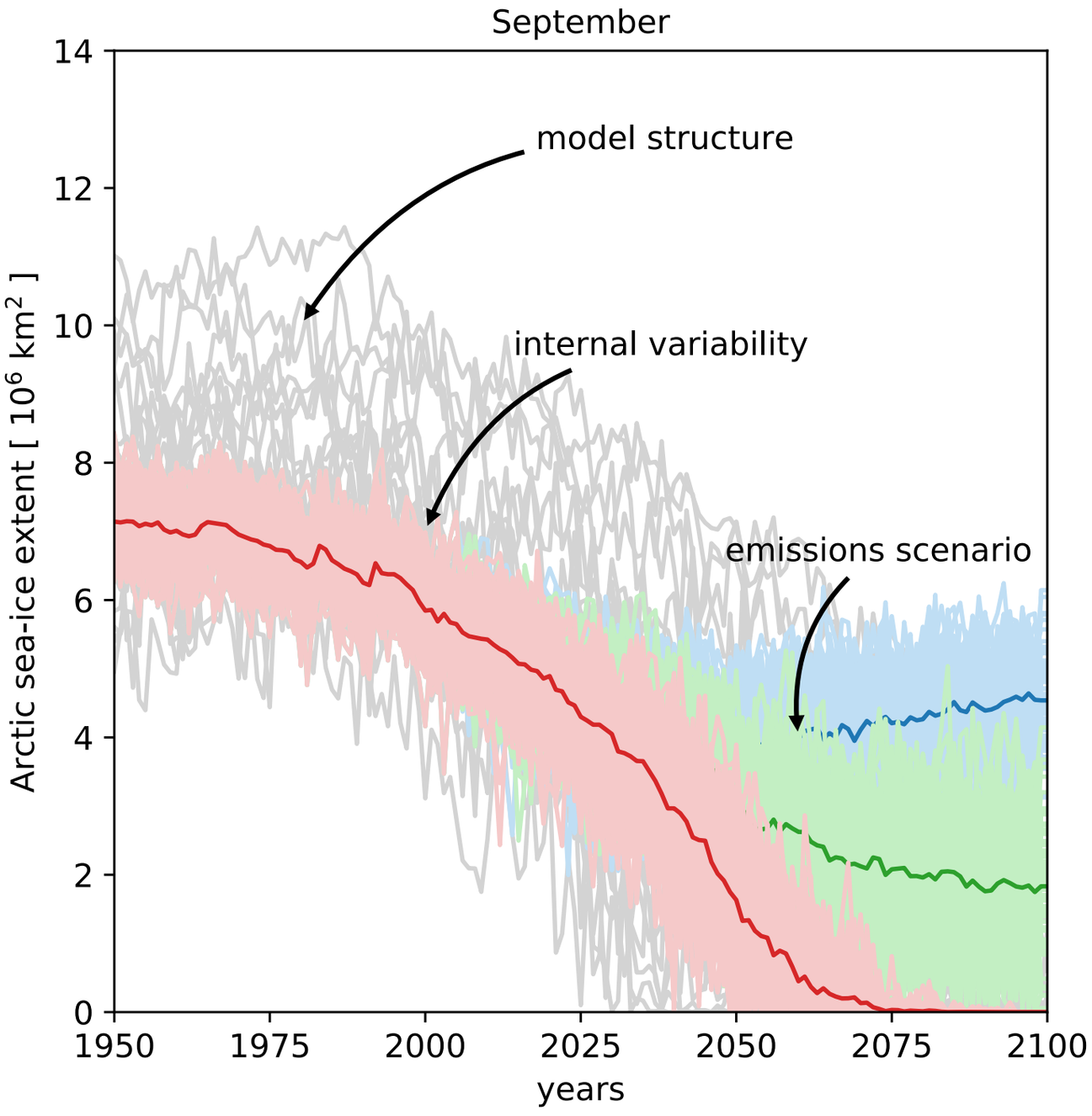
Arctic sea ice has undergone striking changes over satellite record



Schweiger et al., (2011); Perovich and Polashenski, (2012); Stroeve and Notz, (2018)

Uncertainty in projections of Arctic sea ice

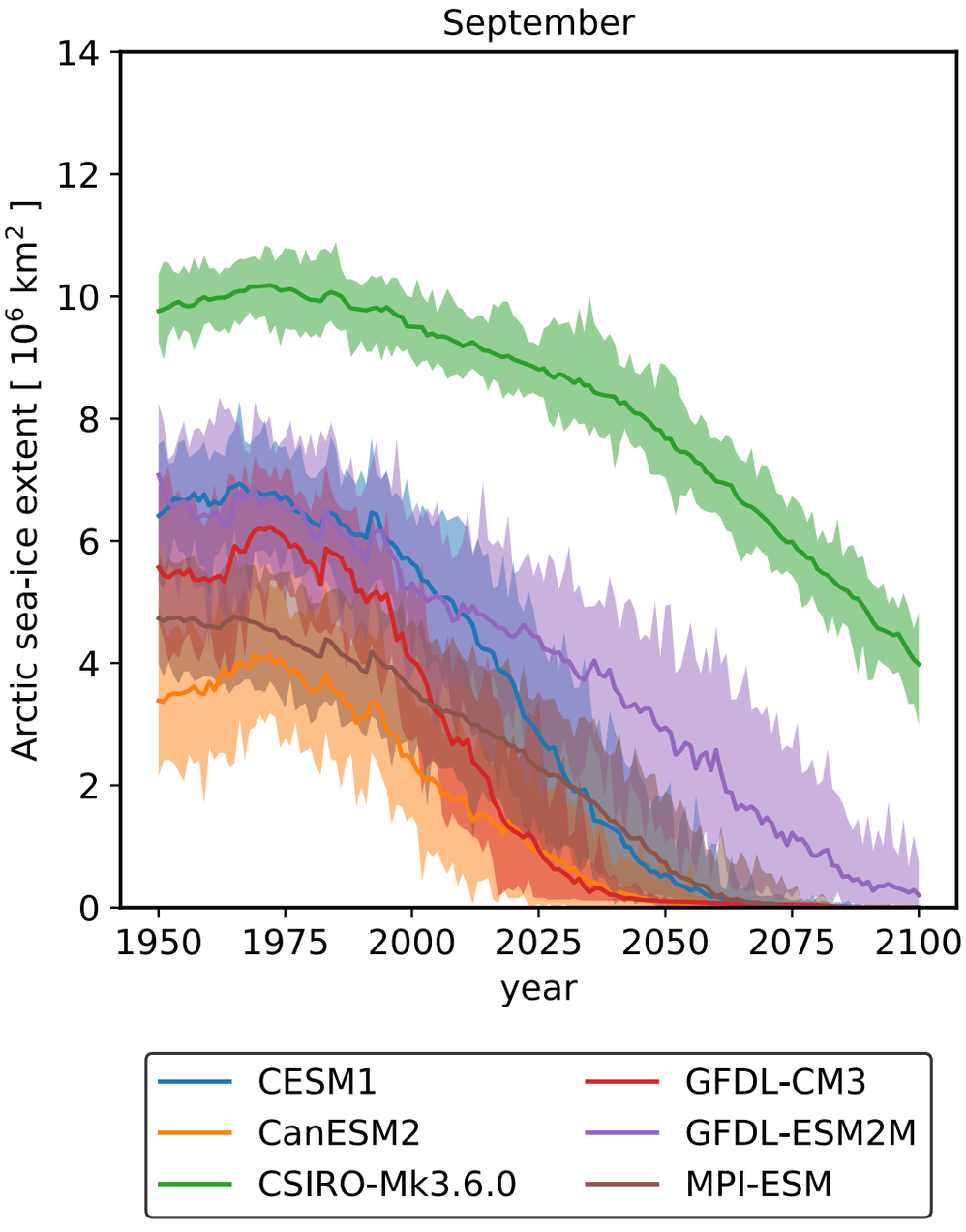
model structure, internal variability, and emissions scenario



Hawkins and Sutton, (2009); Swart et al., (2015)

Partitioning uncertainty in Arctic sea ice projections using large ensembles

$$\underbrace{T(x,t)}_{\textbf{total uncertainty}} = \underbrace{M(x,t)}_{\textbf{model structure}} + \underbrace{I(x,t)}_{\textbf{internal variabiltiy}} + \underbrace{S(x,t)}_{\textbf{emissions scenario}}$$



Hawkins and Sutton, (2009); Deser et al., (2020); Lehner et al., (2020)

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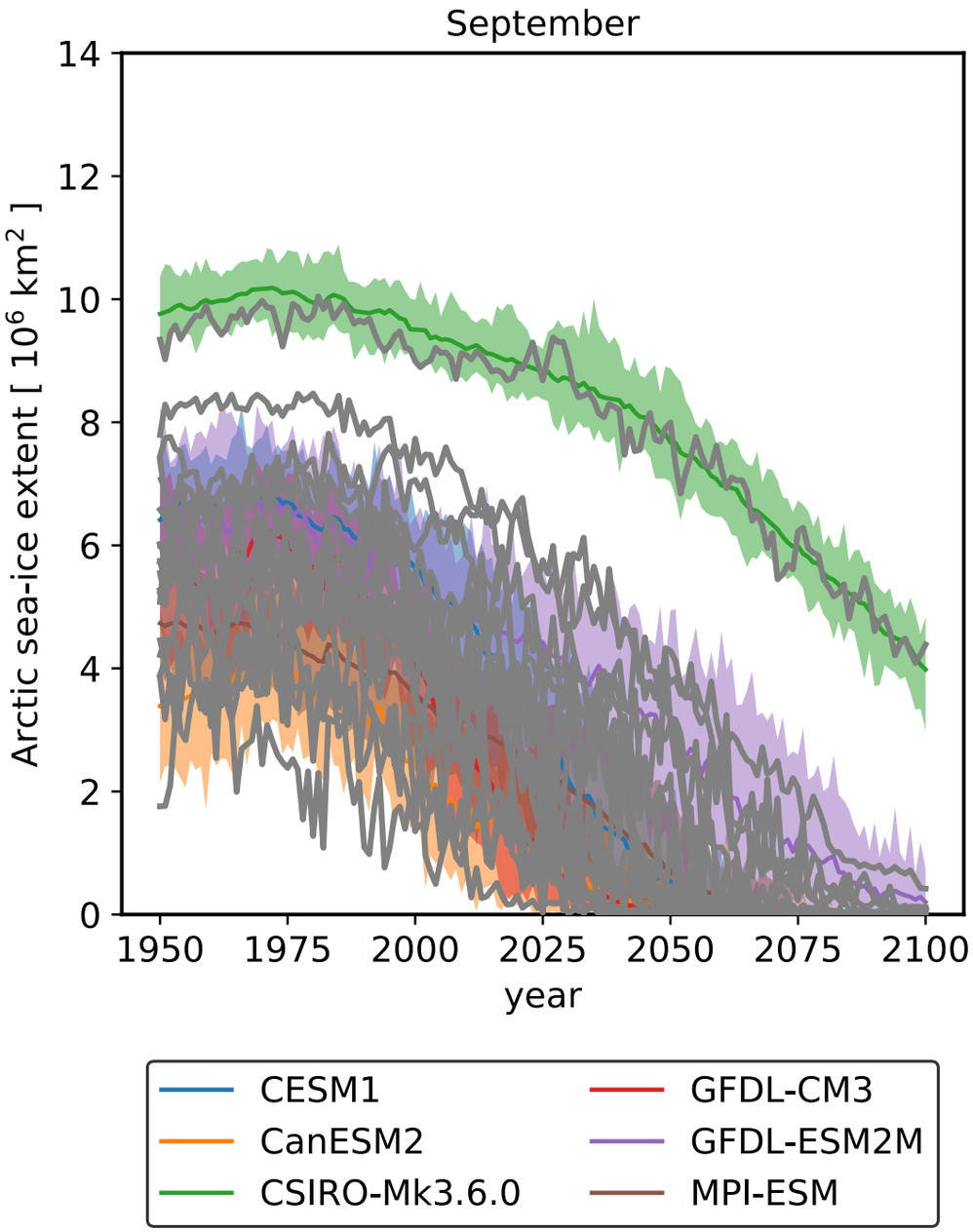

- MMLEA uniquely allows us to quantify uncertainty in projections of Arctic sea ice as it is fairly representative of CMIP models

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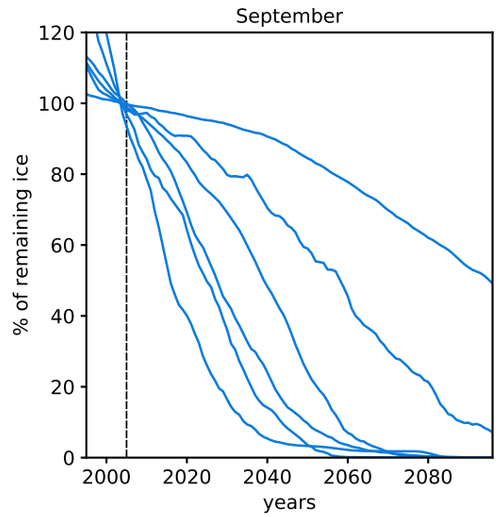

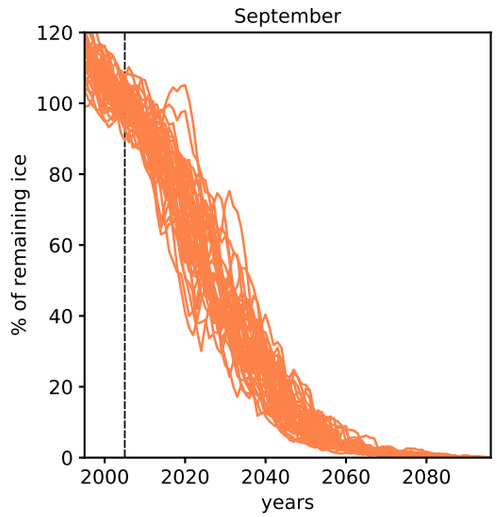

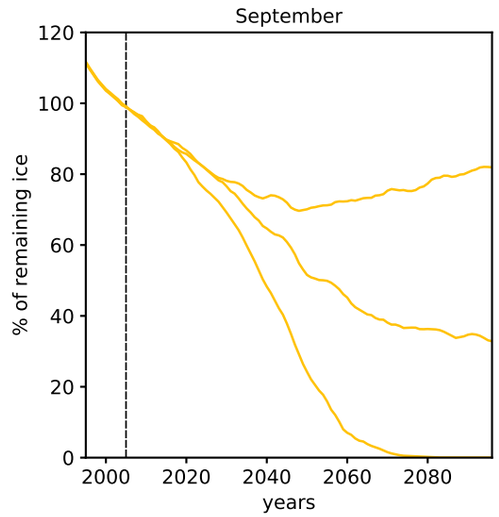

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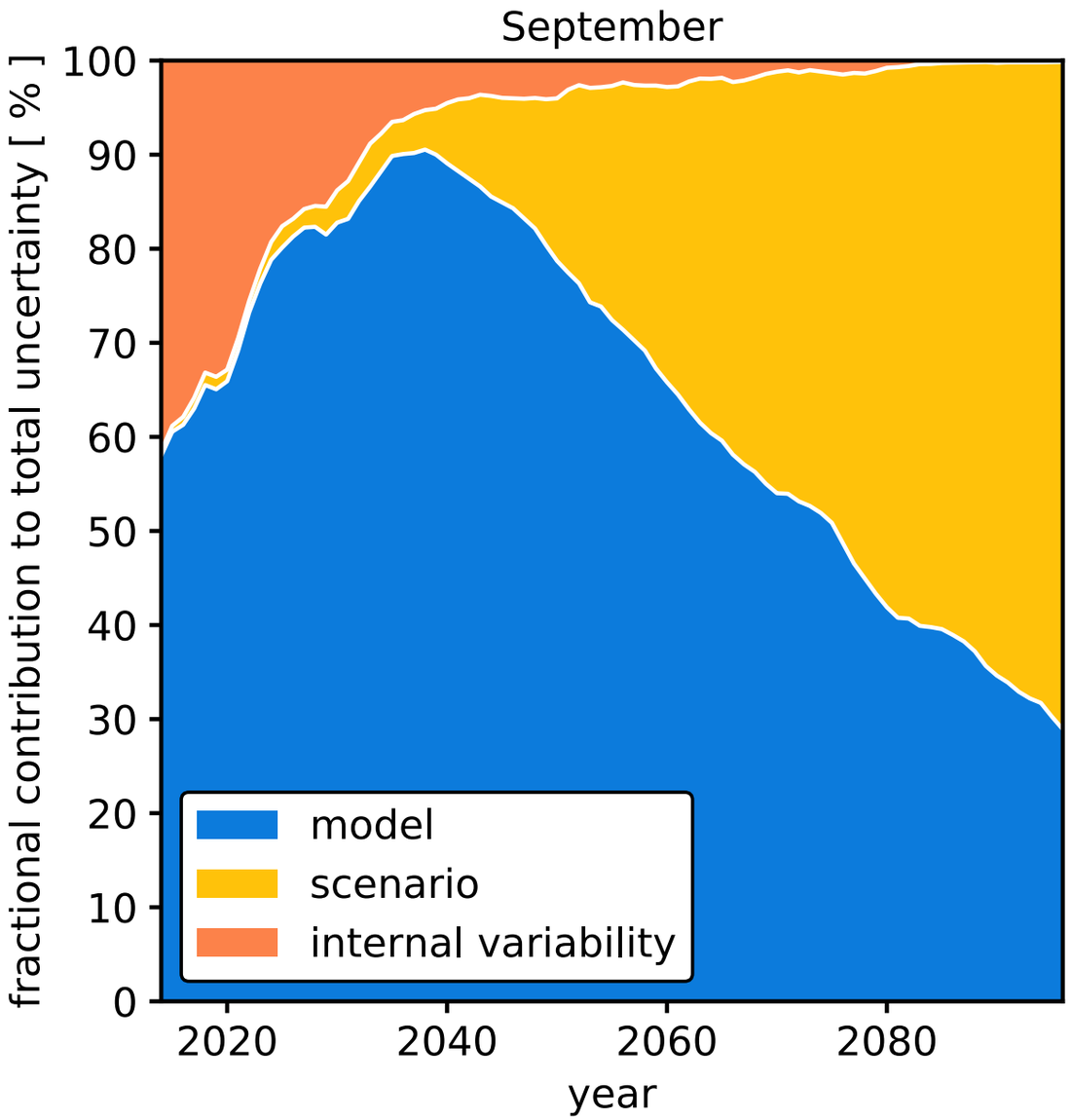

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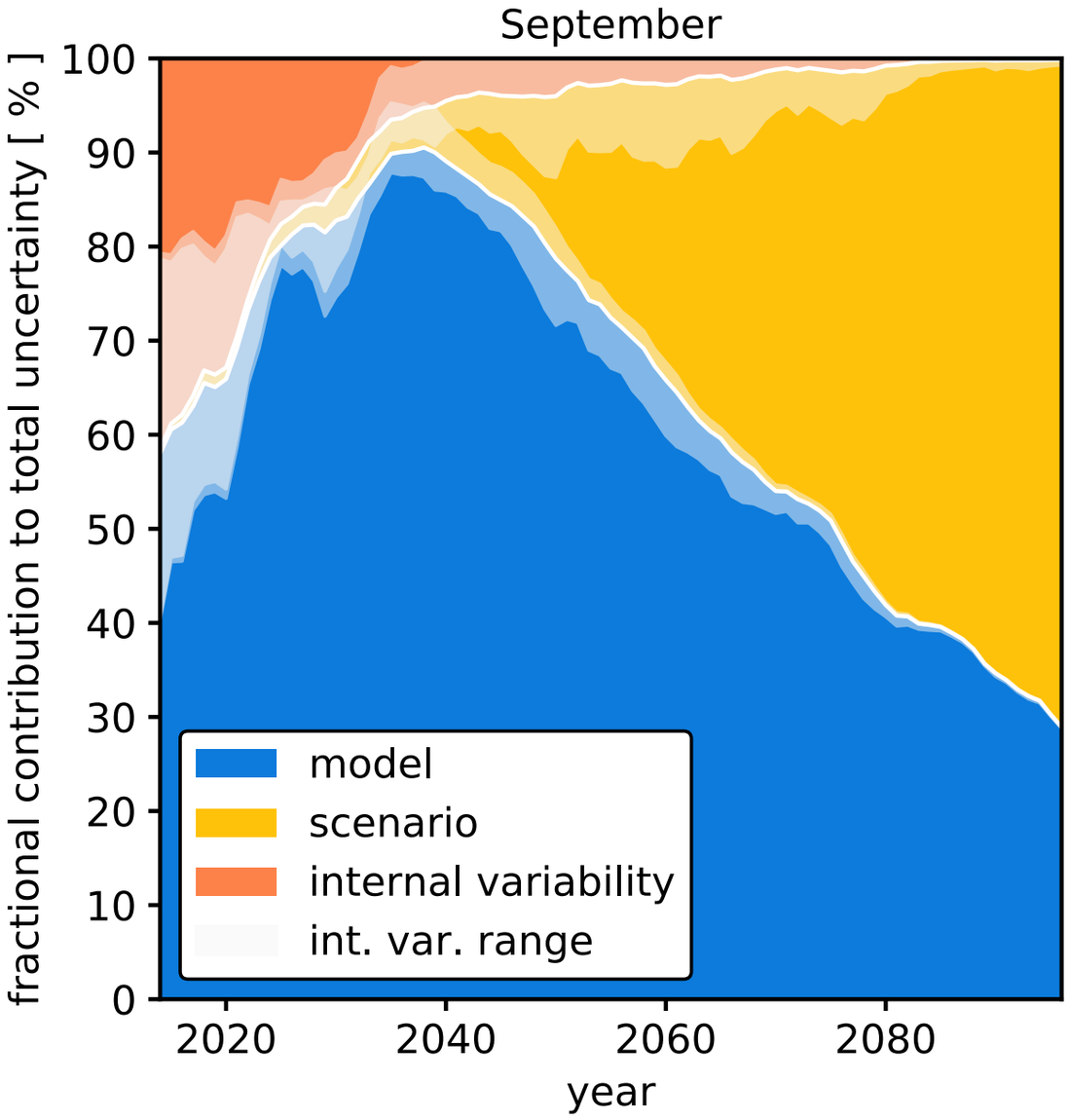
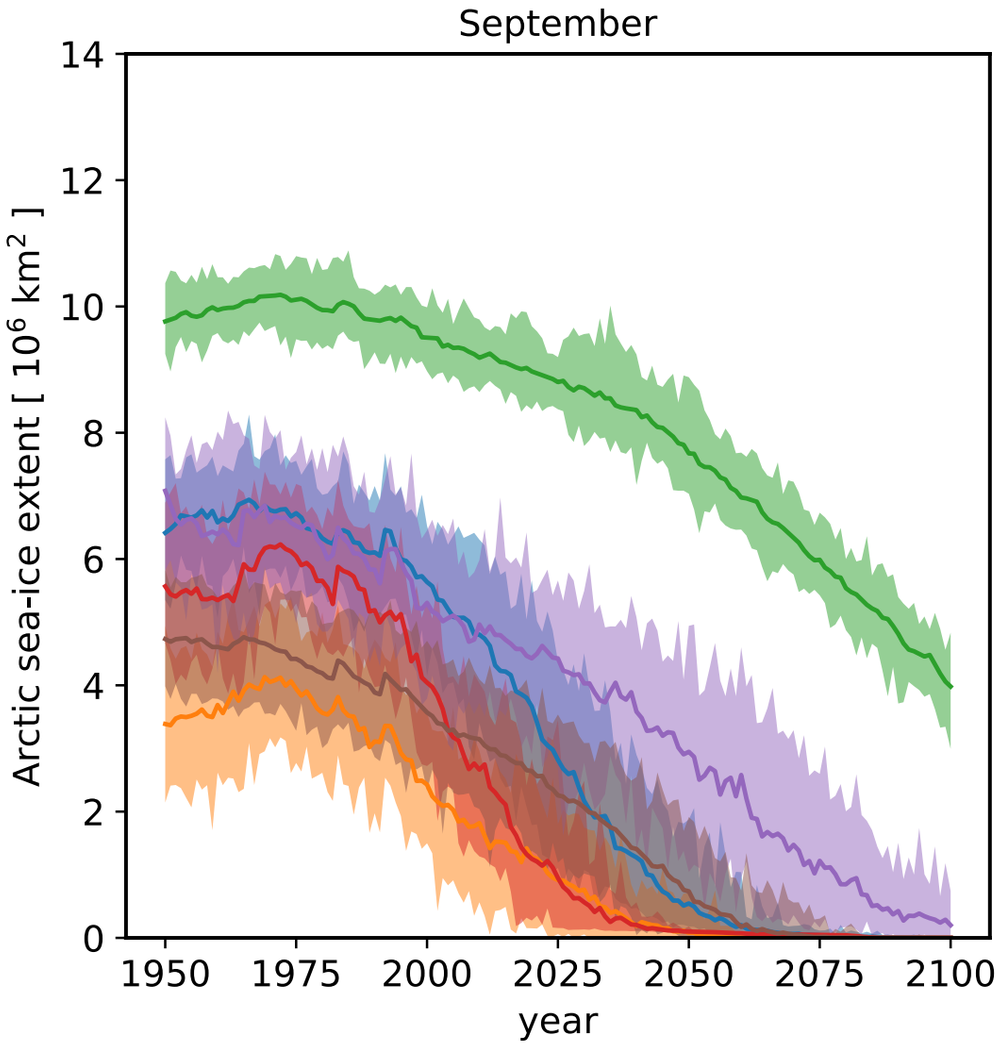
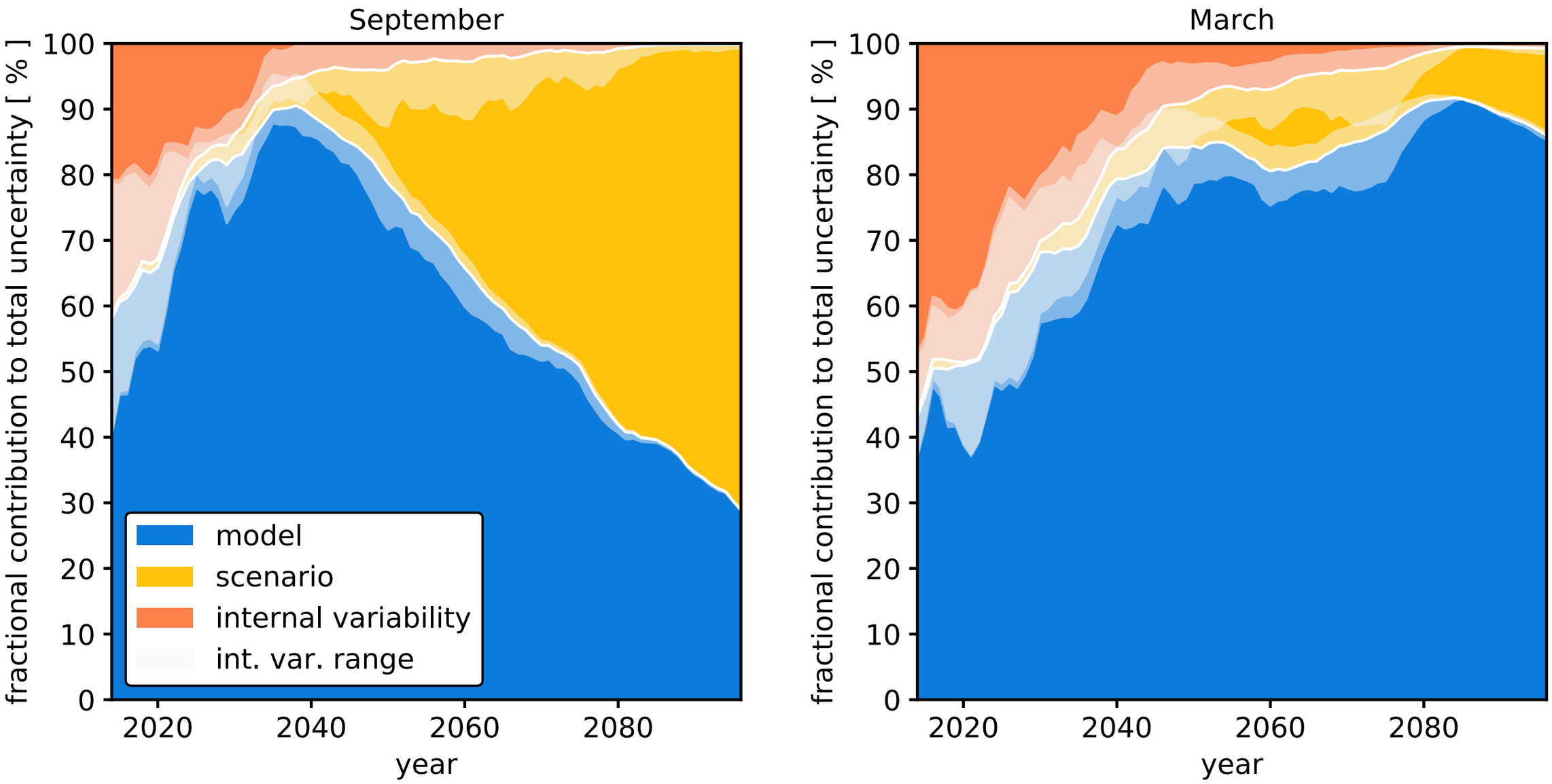




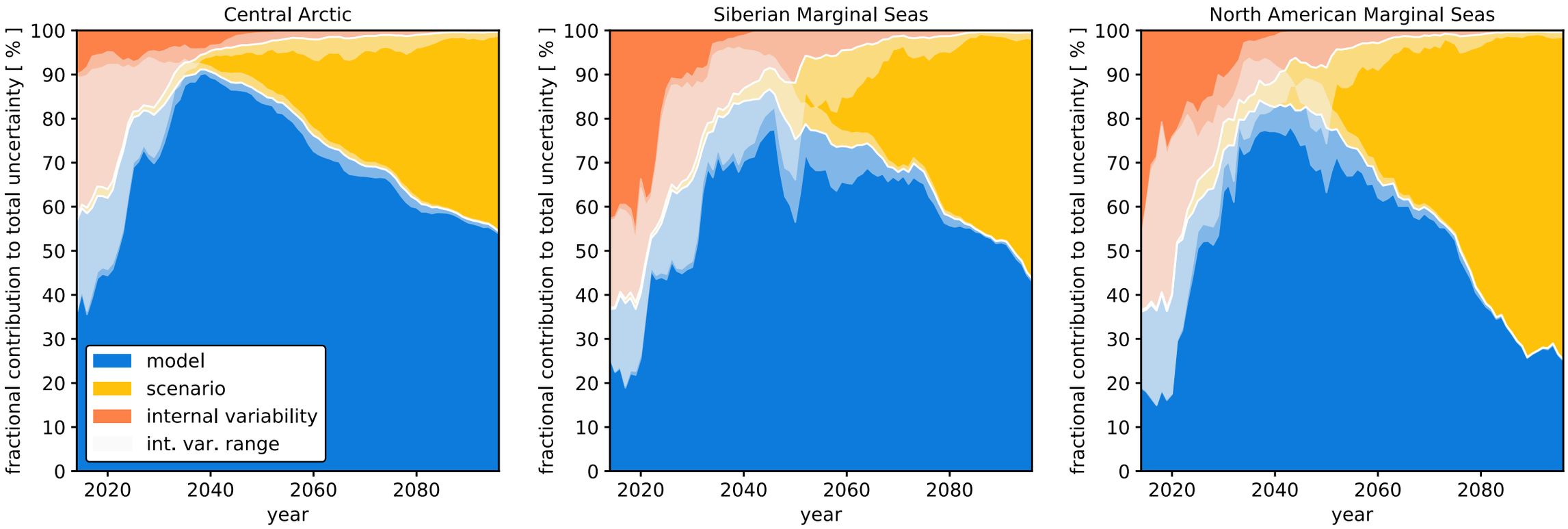
Partitioning uncertainty in Arctic sea ice projections using large ensembles

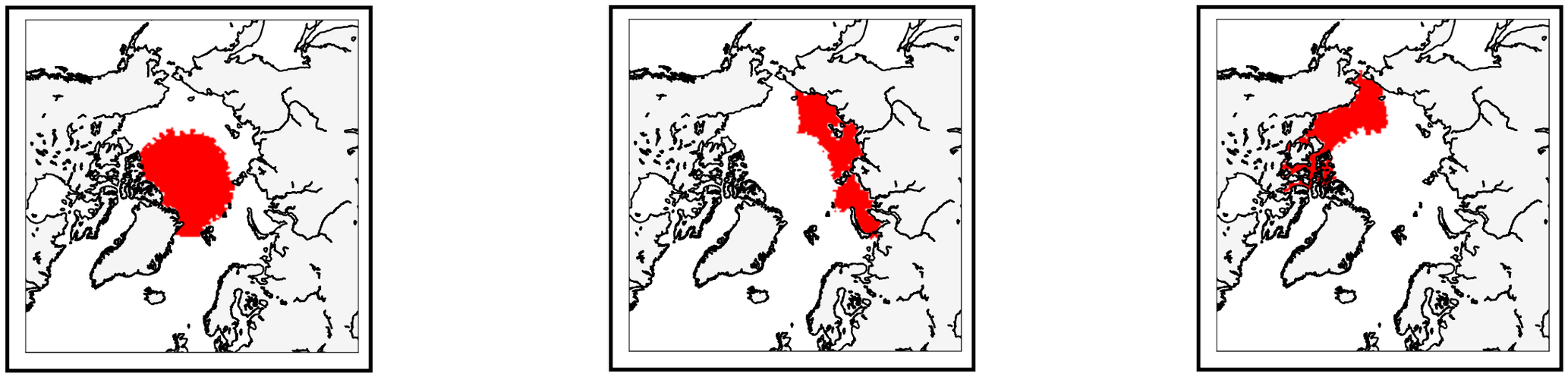
Internal variability impacts wintertime projections at longer lead times



Partitioning uncertainty in *regional* projections of Arctic sea ice

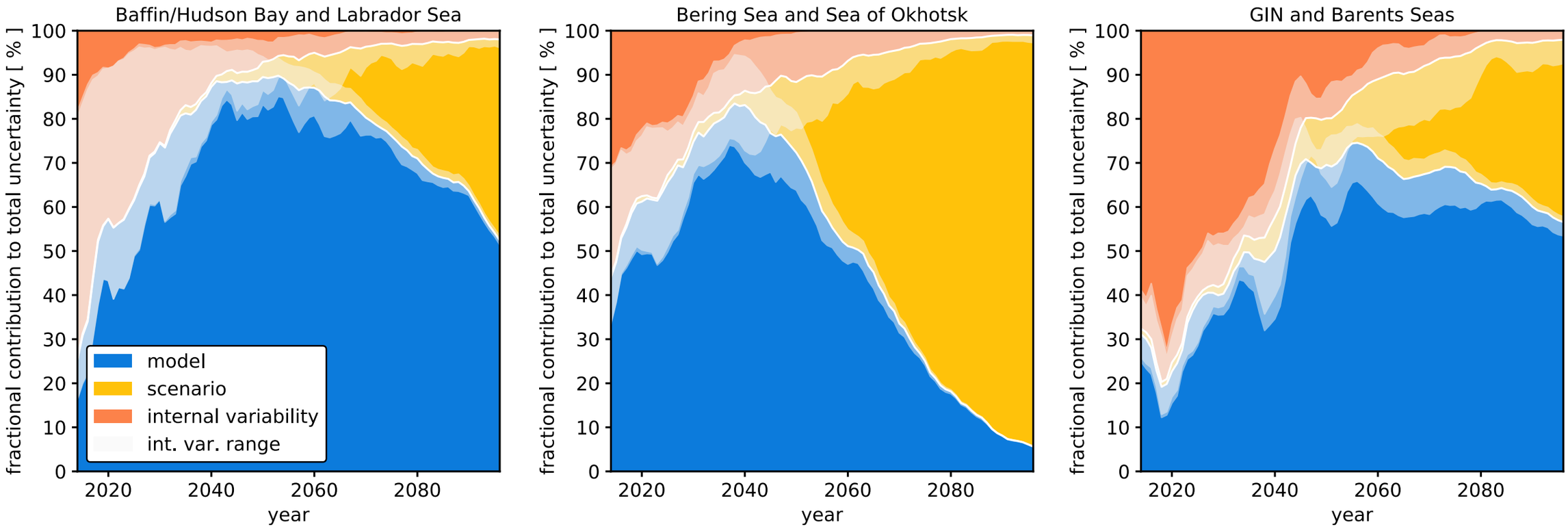
Arctic sea ice in July, August, and September over 21st century

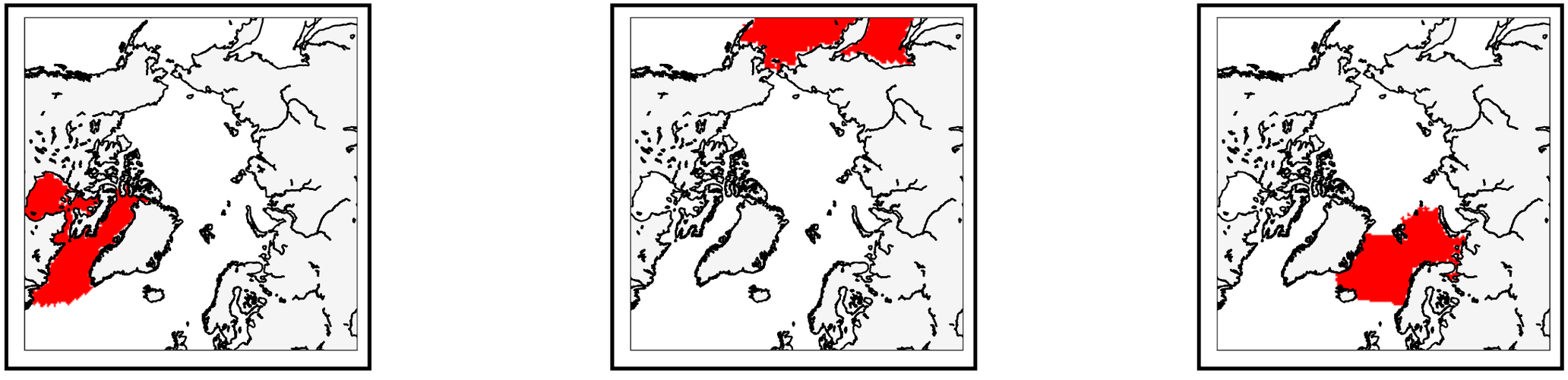




Partitioning uncertainty in *regional* projections of Arctic sea ice

Arctic sea ice in January, February, and March over 21st century

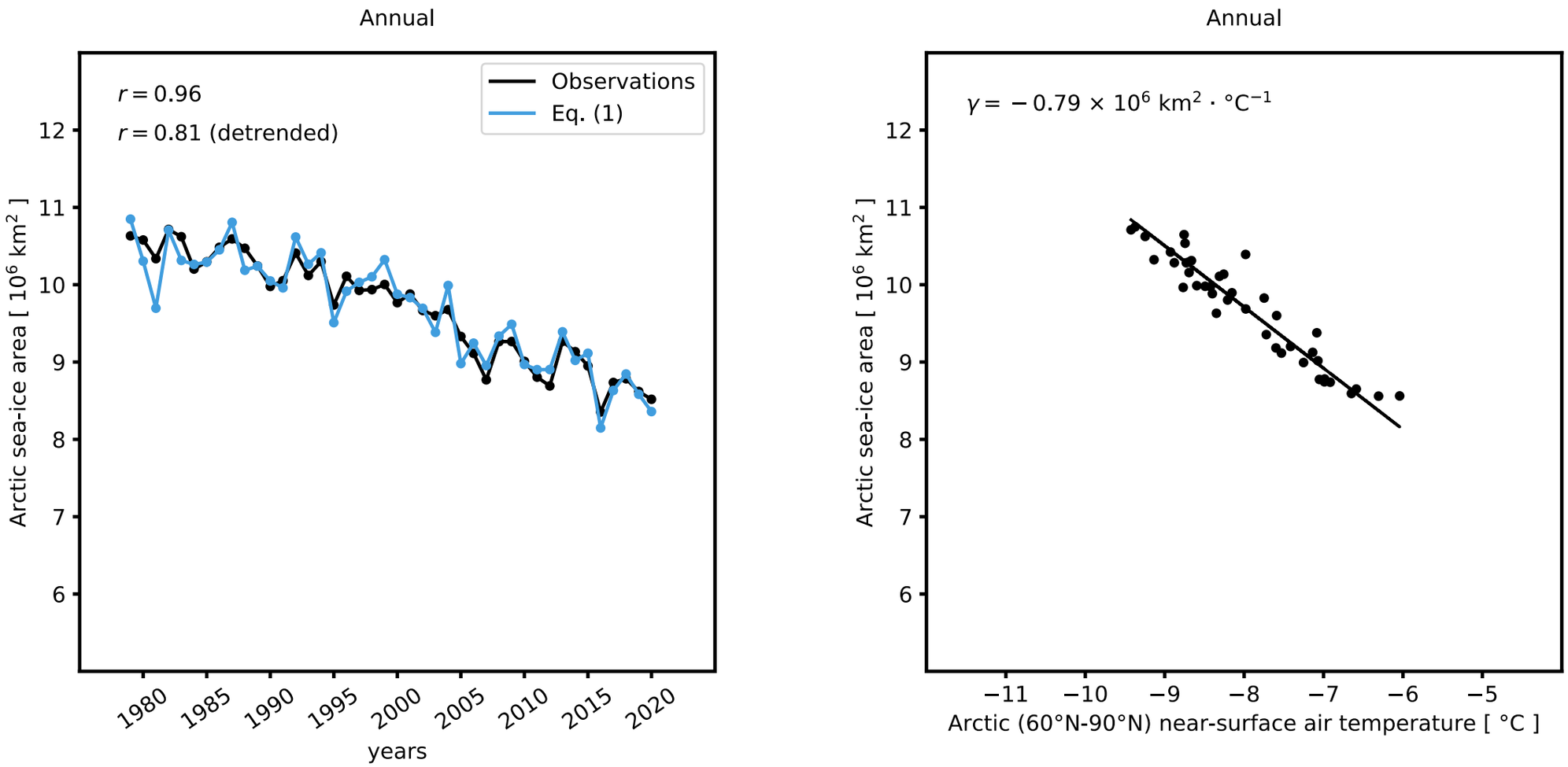




Can we reduce model uncertainty?

Reconstructing observed Arctic sea-ice area

$$A_f = A_c + \gamma \cdot (T_f - T_c)$$



- Annual Arctic sea-ice area (SIA) is well approximated via an expression that determines future SIA using present SIA and the sensitivity of sea ice to Arctic temperature changes

- Captures the long-term trend, inter-annual variability, and explains over 60% of the detrended variability

Winton, (2011); Mahlstein and Knutti, (2012)

Reconstructing observed Arctic sea-ice area

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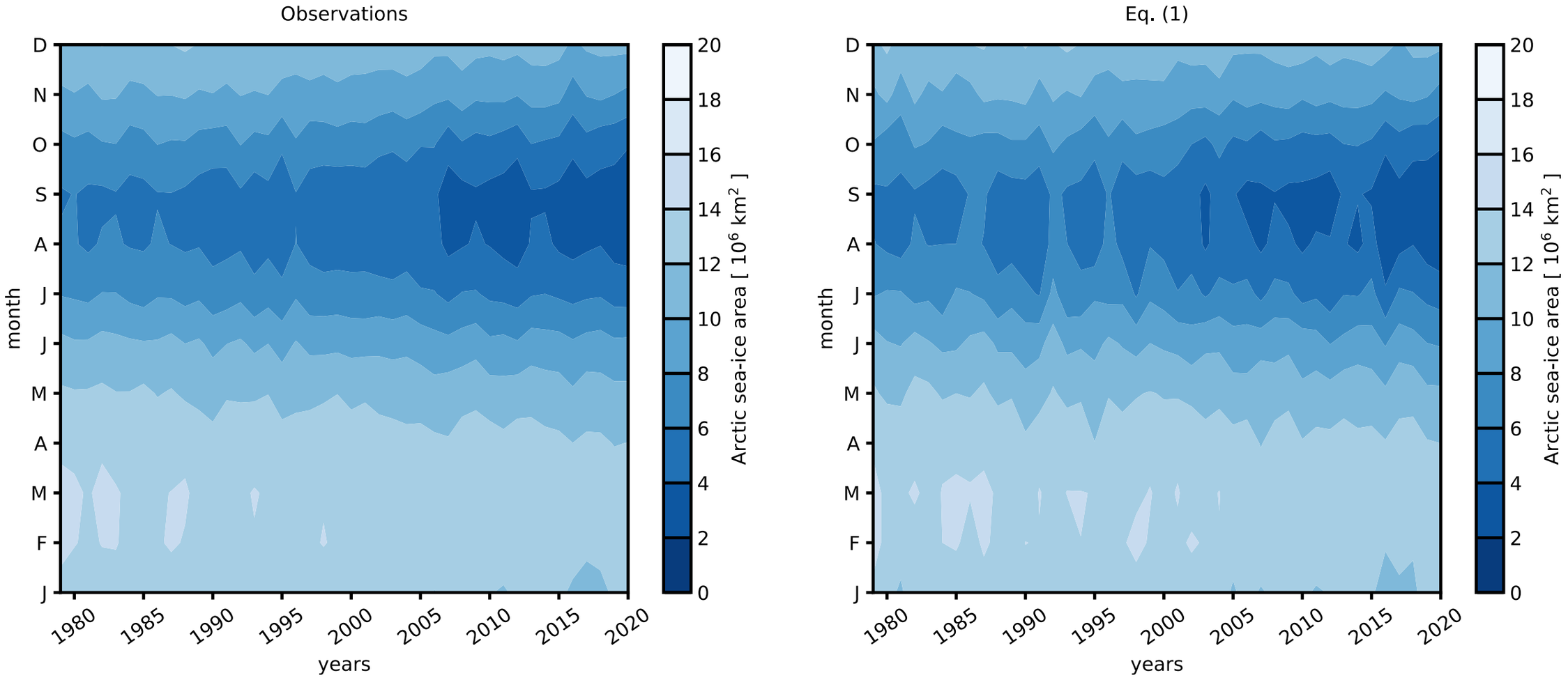


- Expression also captures the large decline of summer Arctic SIA and more muted decline of winter Arctic SIA

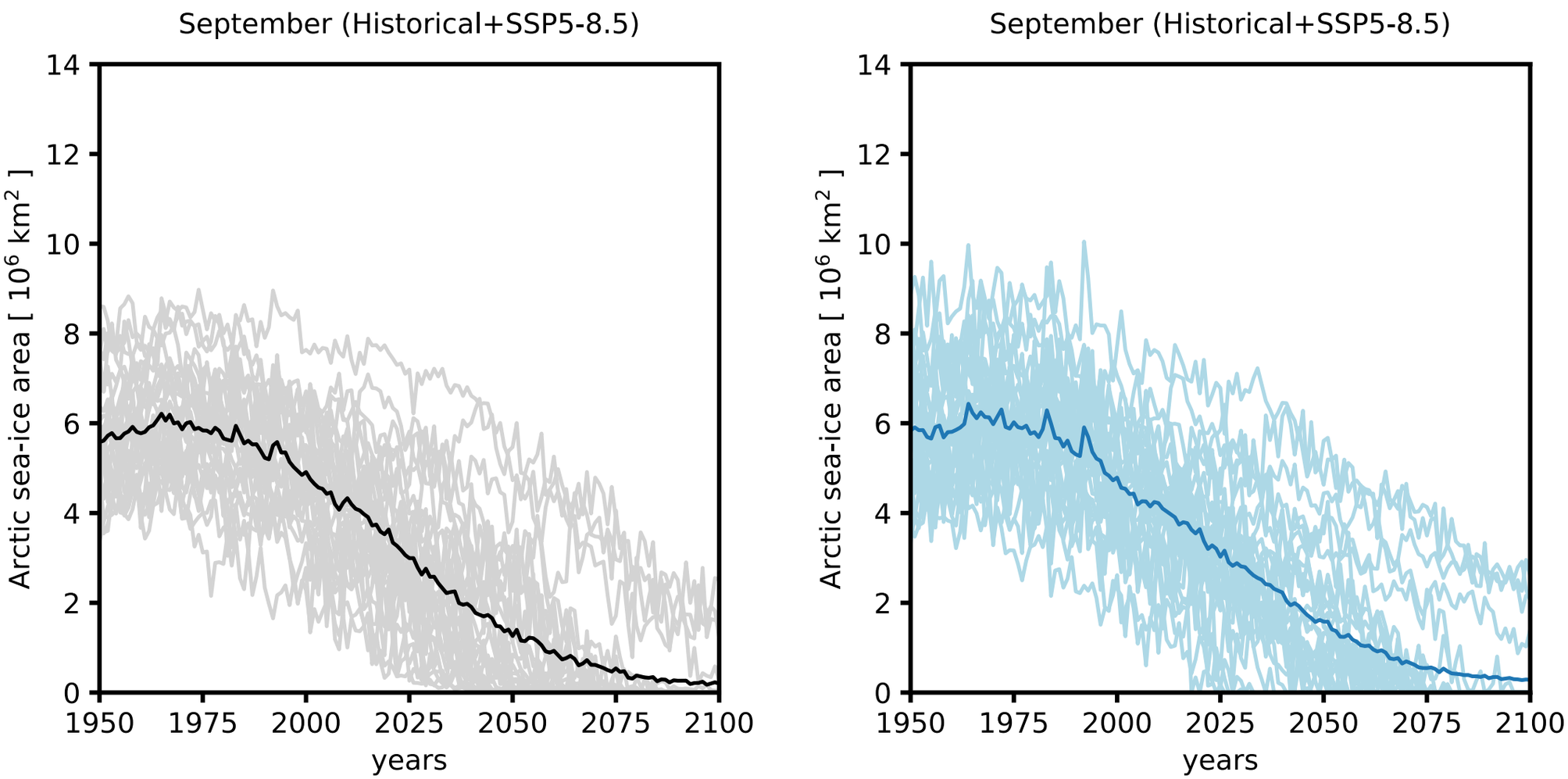
Winton, (2011); Mahlstein and Knutti, (2012)

Applying the linear expression to coupled climate models

$$A_f = A_c + \gamma \cdot (T_f - T_c)$$

climate models

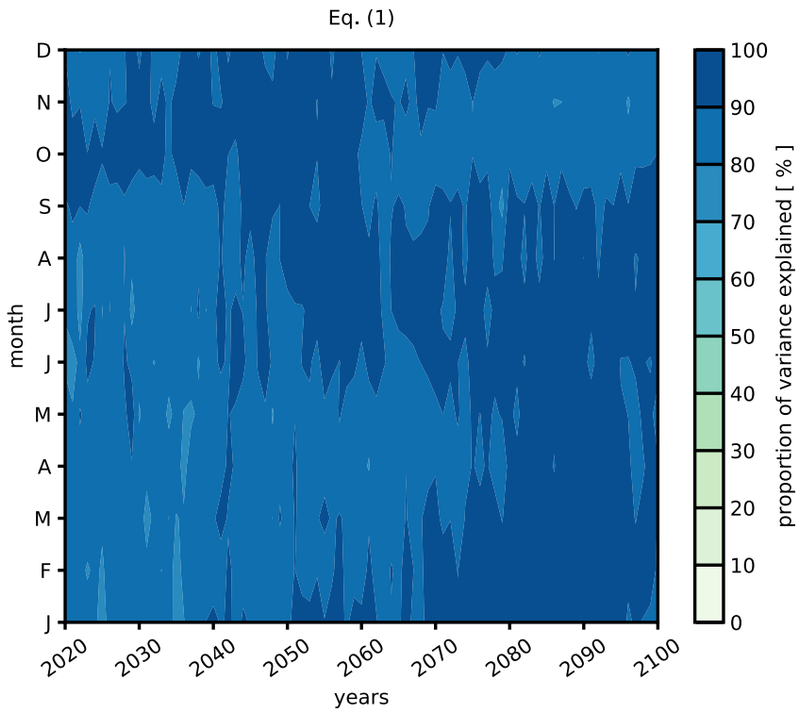
Eq. (1)



- September Arctic SIA calculated from Eq. (1) bears a strikingly similarity to GCMs

Breakdown of model uncertainty in projections of Arctic sea-ice area

$$A_f = A_c + \gamma \cdot (T_f - T_c)$$



- Approximately 70-95% the inter-model variance in CMIP6 GCMs is explained by Eq. (1) across all months

Breakdown of model uncertainty in projections of Arctic sea-ice area

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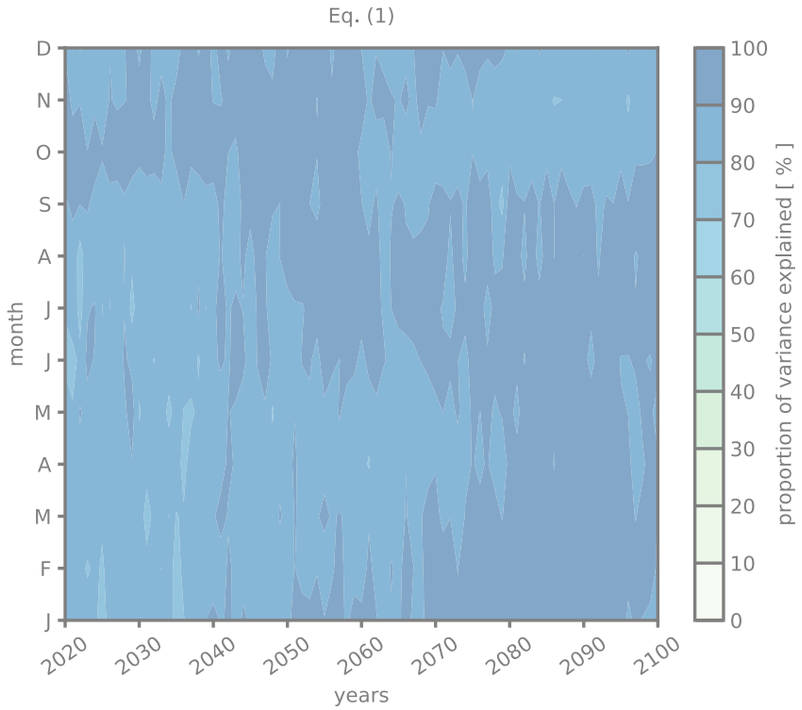

- **What can we make of the inter-model spread in projections of Arctic SIA and how does each term contribute to the total uncertainty?**

- **If mean-state biases were reduced across GCMs in the future, how much more certain is the date of an ice-free Arctic?**

- **How would an emergent constraint on Arctic warming based on this expression change projections of Arctic SIA?**

Breakdown of model uncertainty in projections of Arctic sea-ice area

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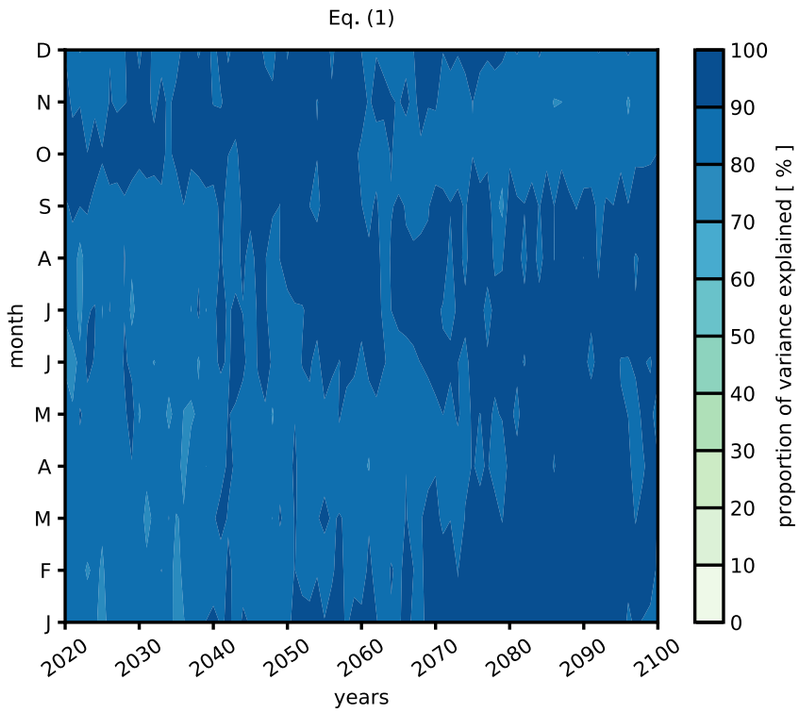
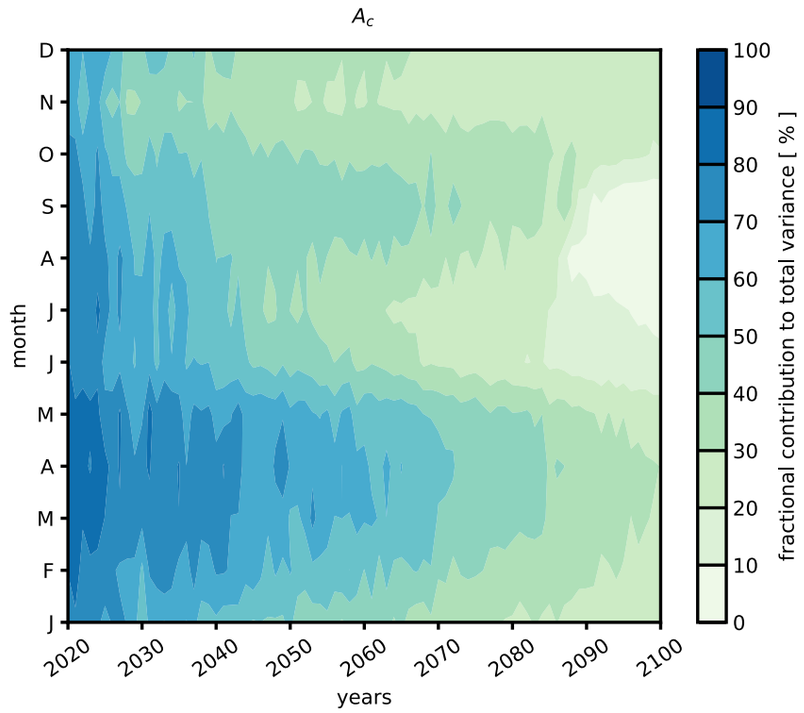
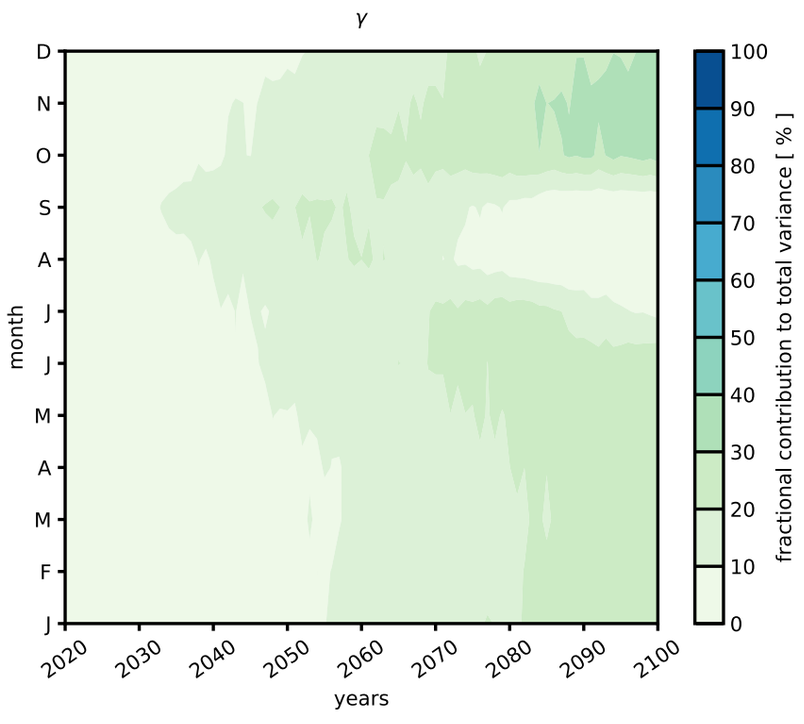
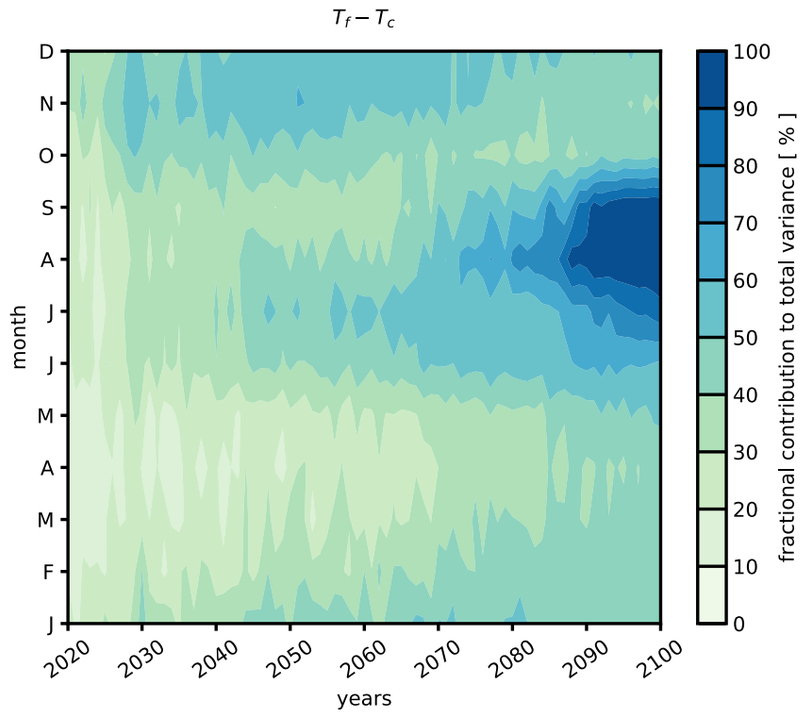




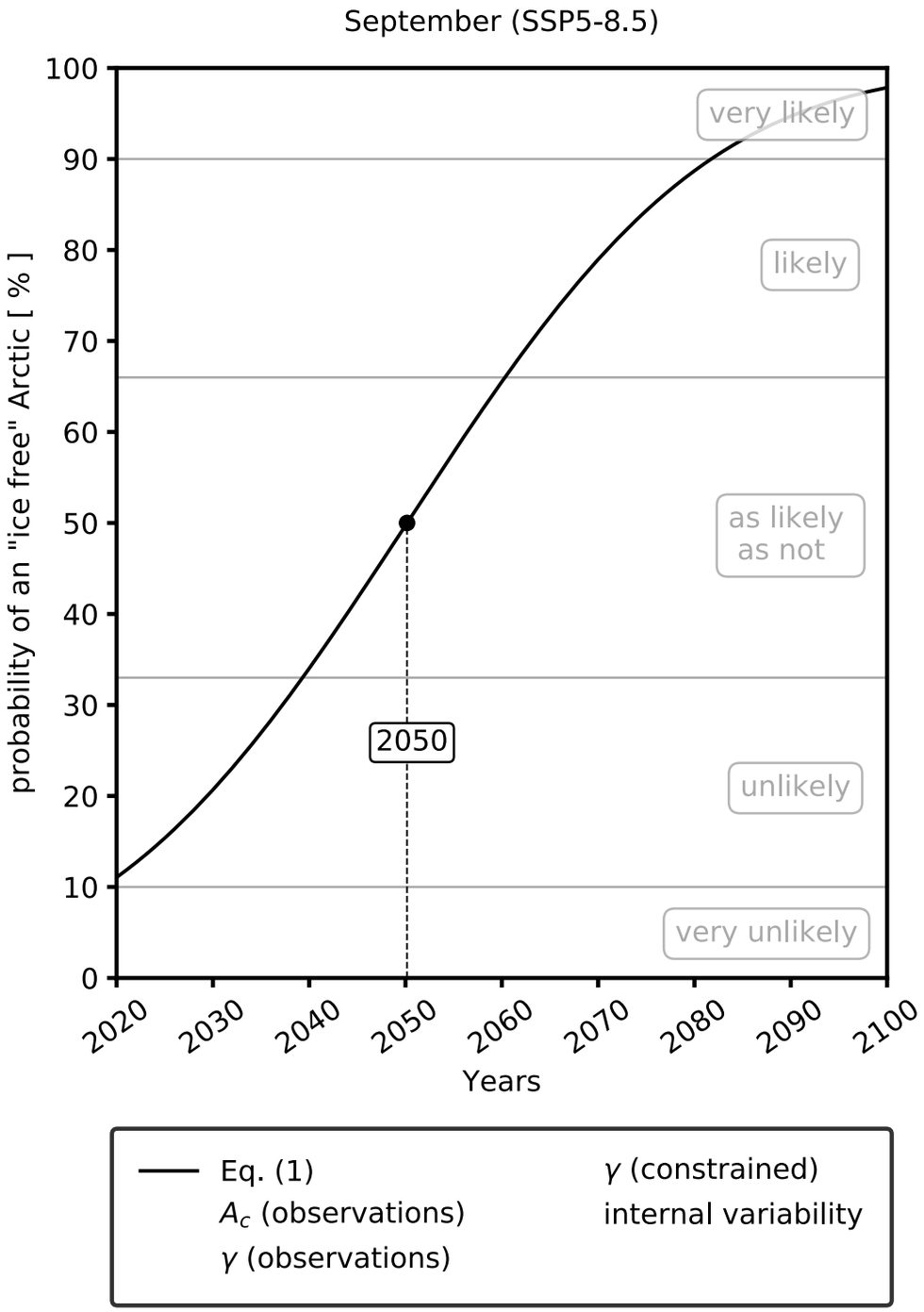




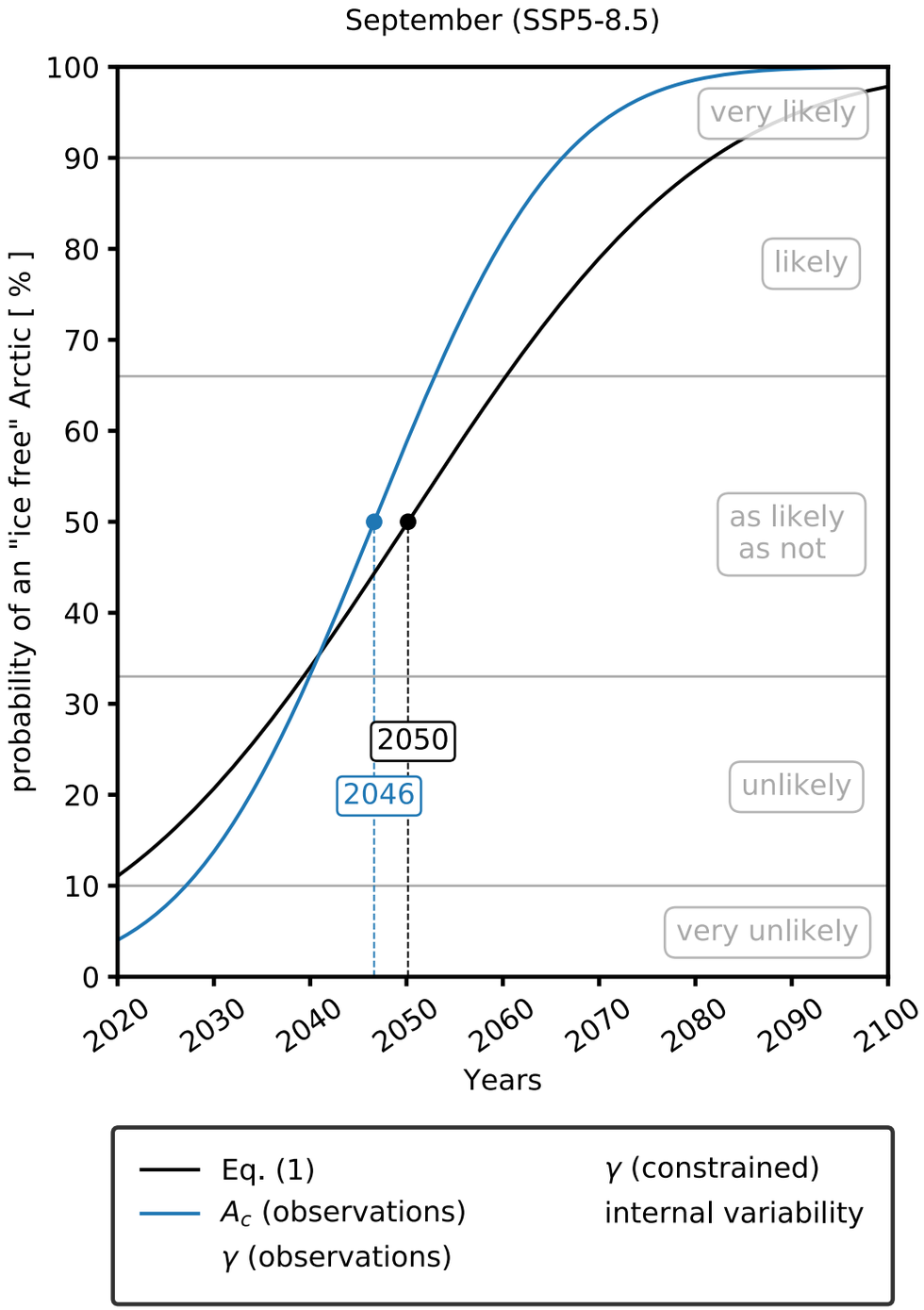
- Approximately 70-95% the inter-model variance in CMIP6 GCMs is explained by Eq. (1) across all months
- Majority of the inter-model spread arises from present day biases in simulated Arctic SIA
- Some contribution from inter-model differences in the local sea ice sensitivity
- Remaining inter-model spread arises from model differences in Arctic warming

Constraining the date of an ice-free September in the Arctic

$$A_f = A_c + \gamma \cdot (T_f - T_c)$$



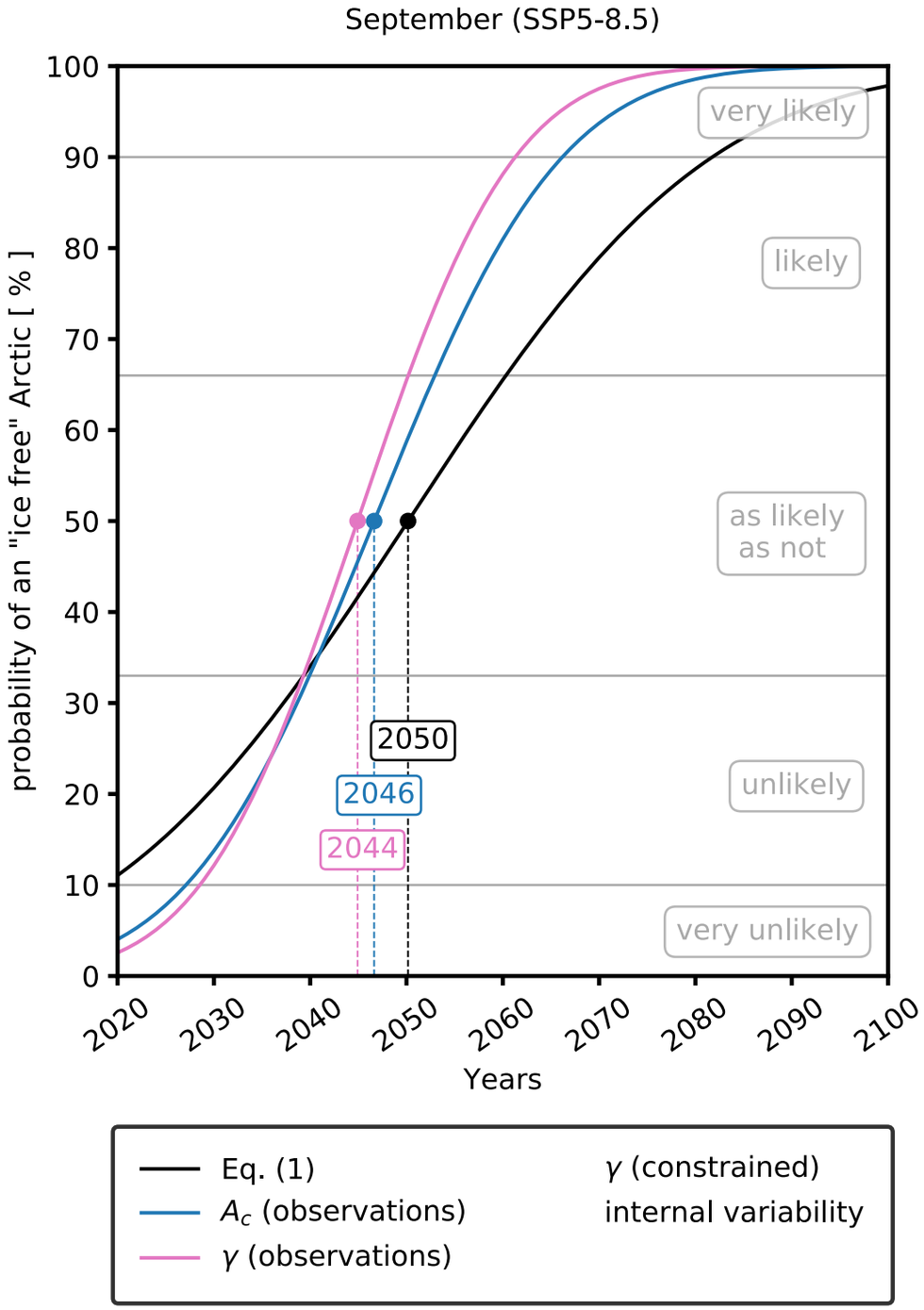
Constraining the date of an ice-free September in the Arctic



$$A_f = A_c + \gamma \cdot (T_f - T_c)$$

reducing mean-state biases

Constraining the date of an ice-free September in the Arctic



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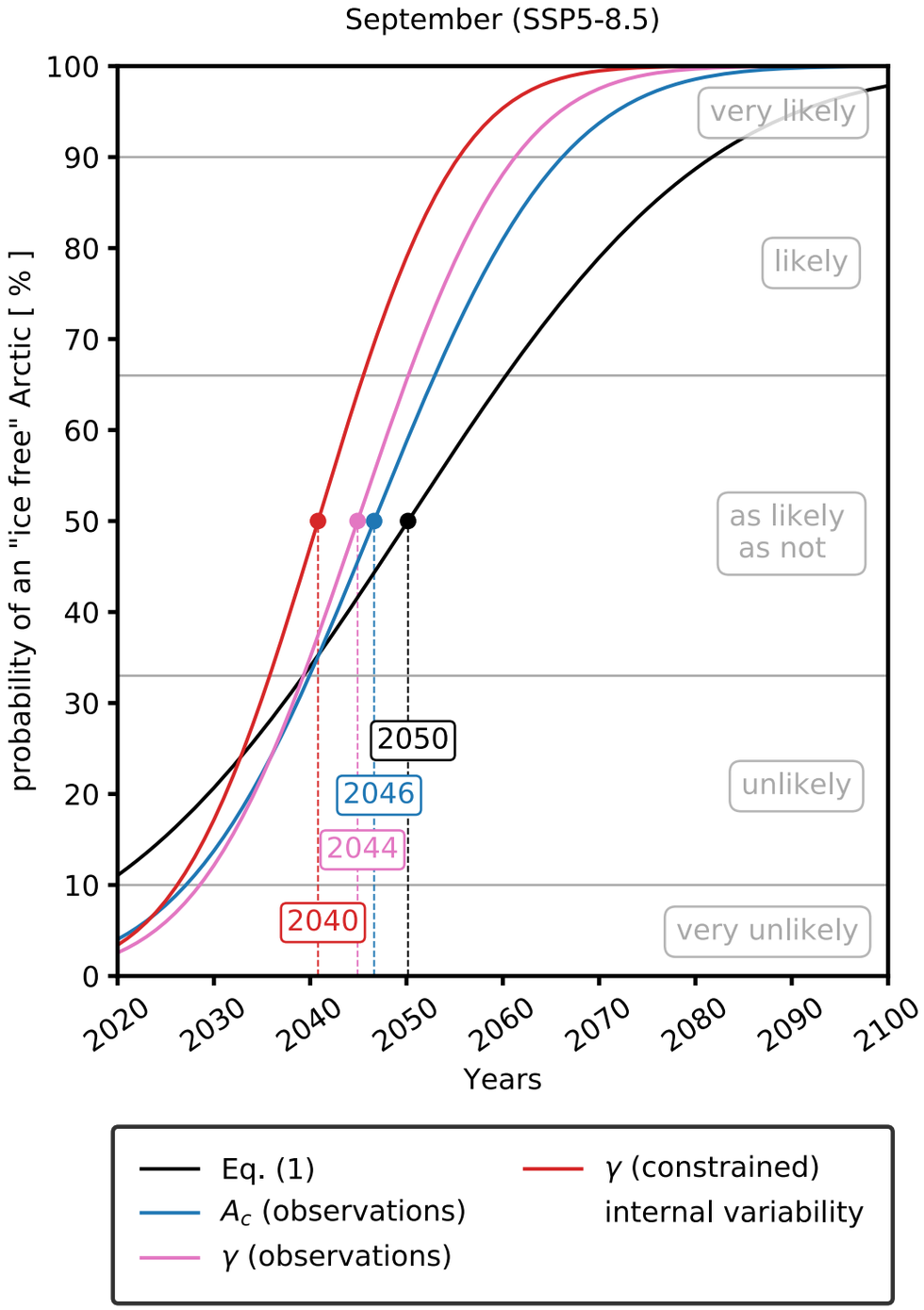
correcting the local sea ice sensitivity

Constraining the date of an ice-free September in the Arctic



$$A_f = A_c + \gamma \cdot (T_f - T_c)$$

constraining the local sea ice sensitivity

Constraining the date of an ice-free September in the Arctic

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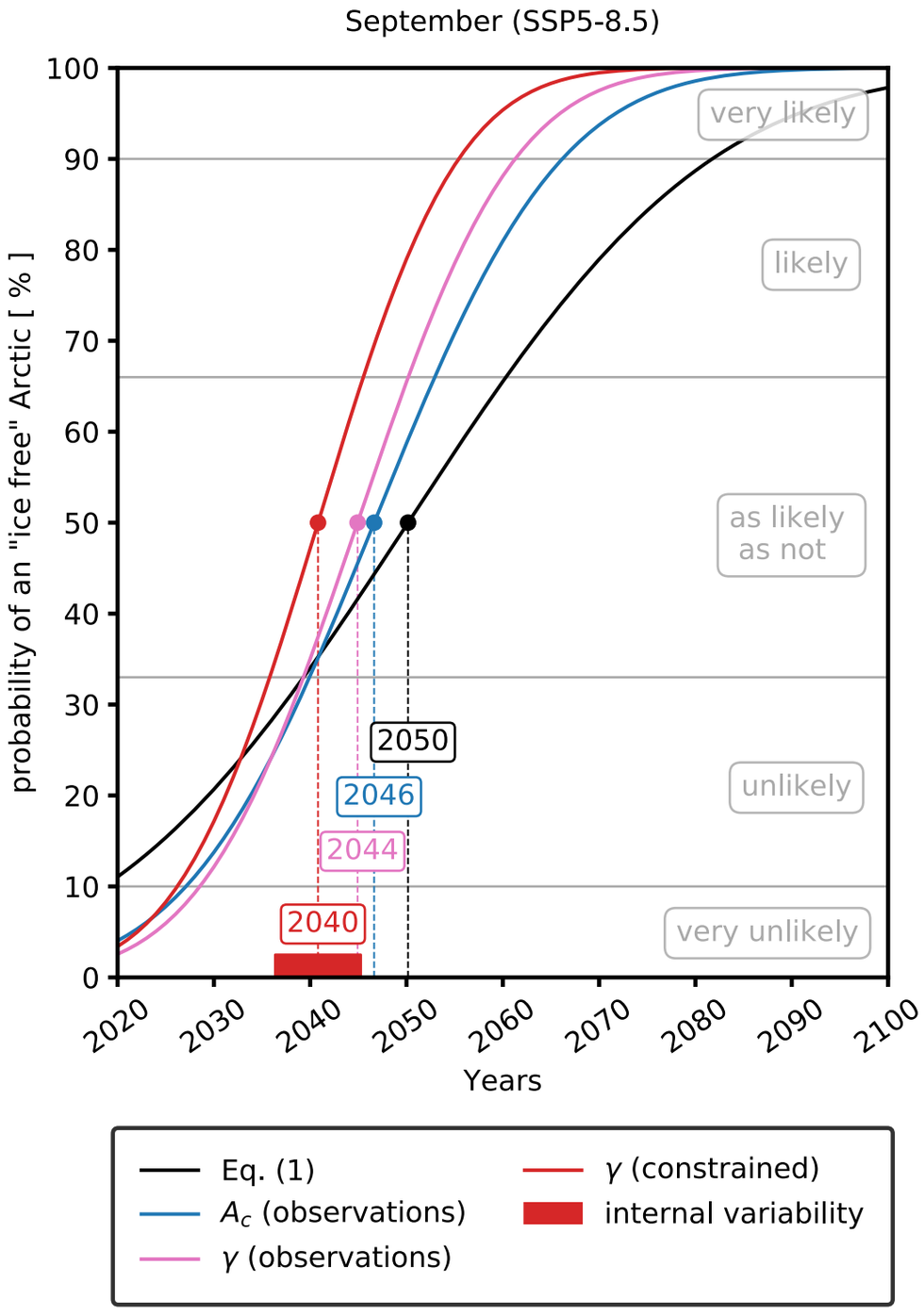
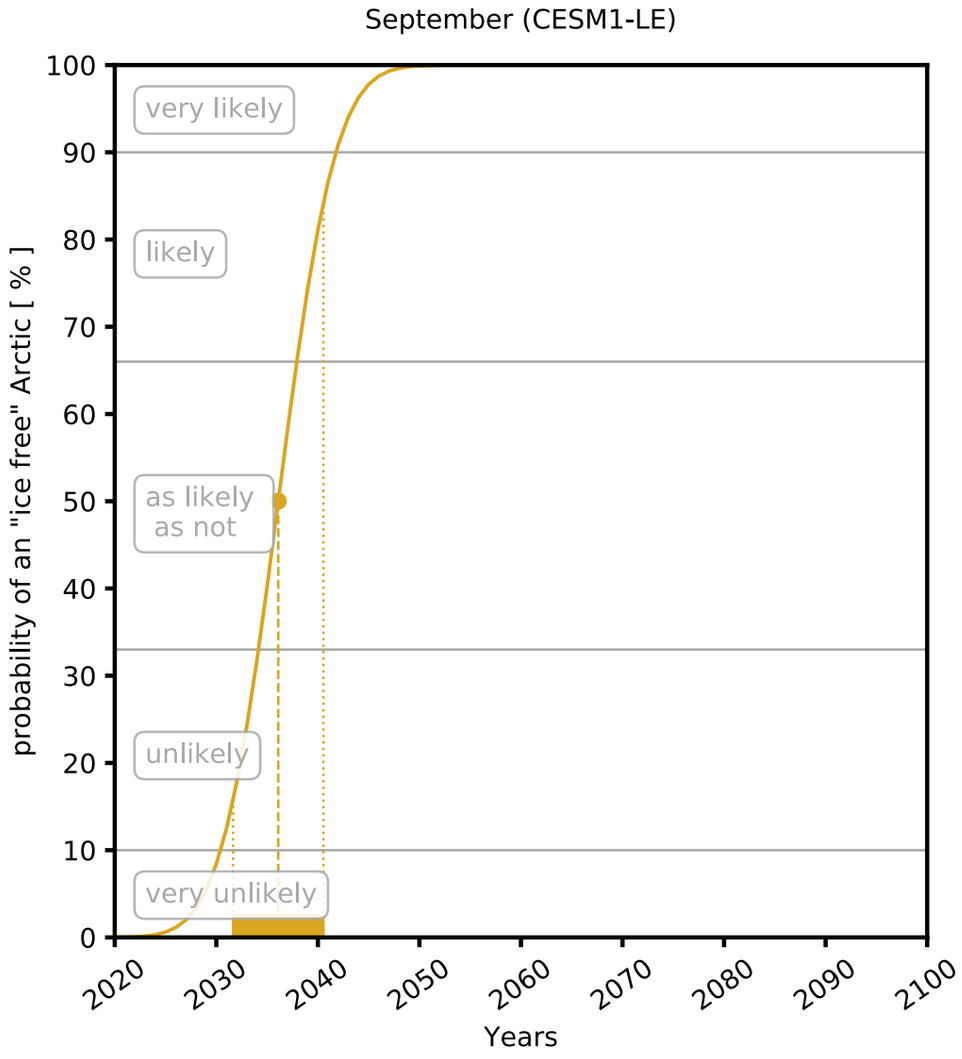
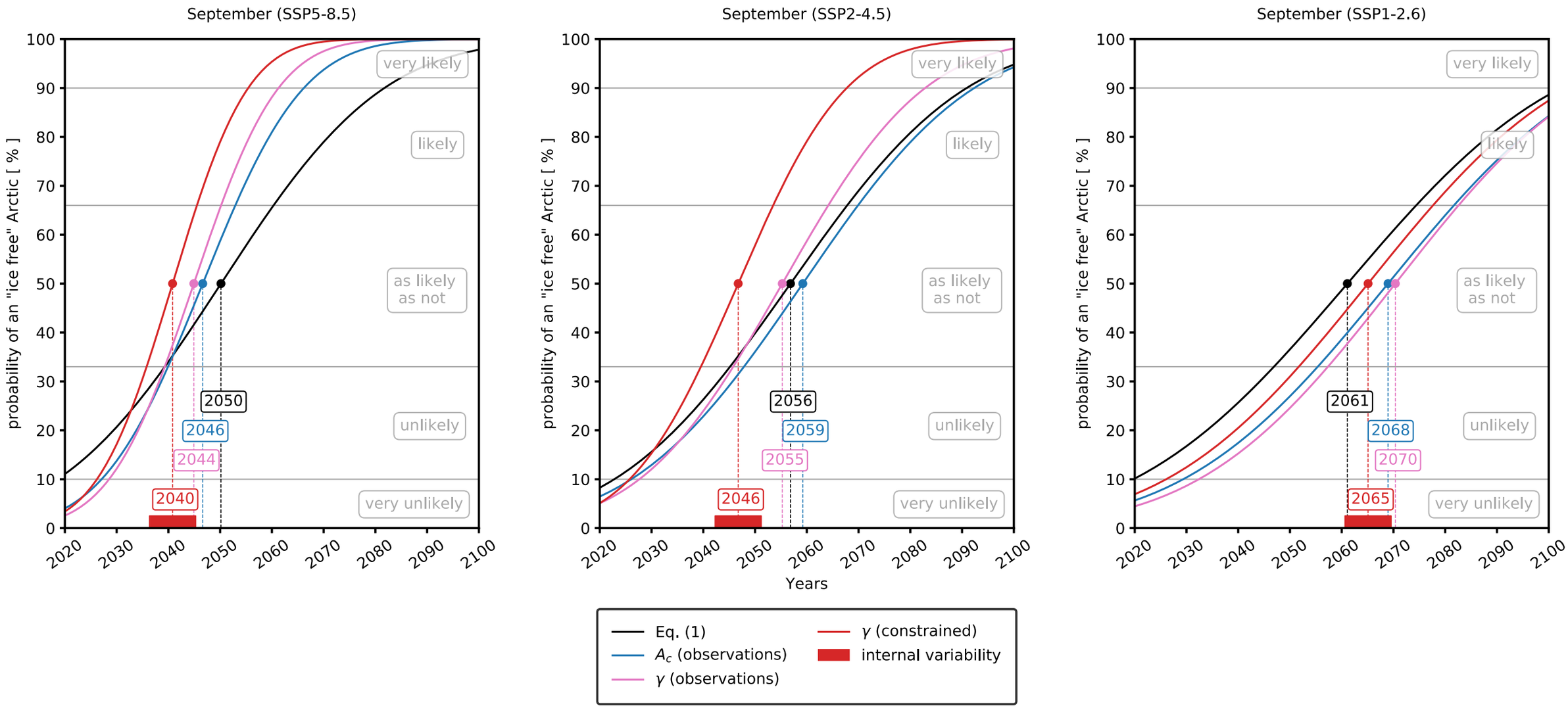


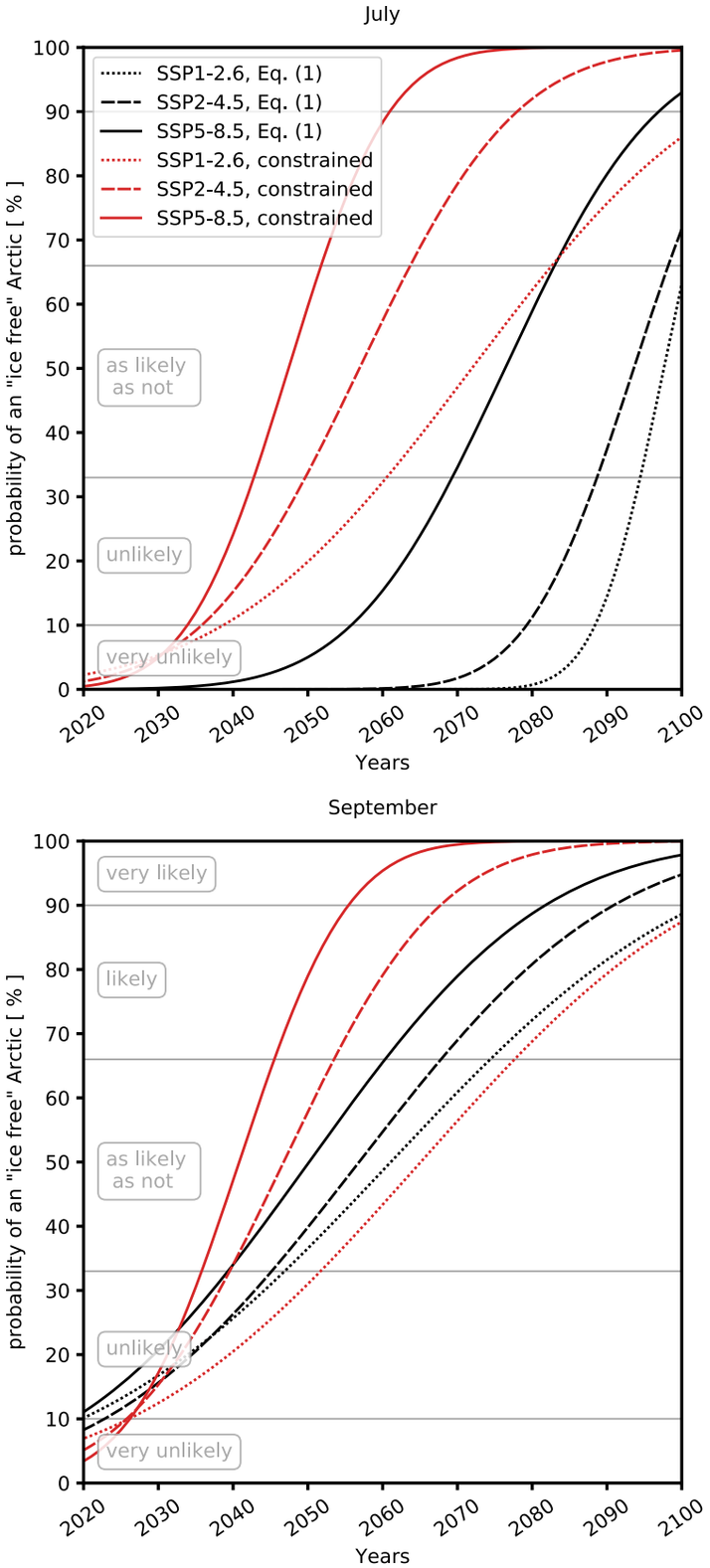


Constraining the date of an ice-free September in the Arctic



- Similar picture for medium-emissions scenario, but low-emissions scenario probability is reduced

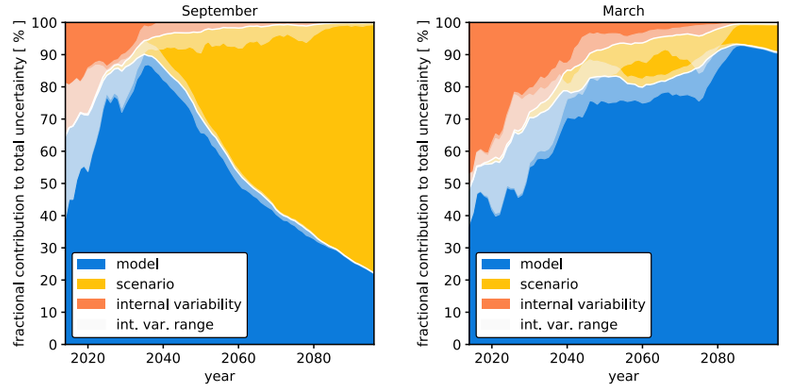
Constraining the date of an ice-free summer in the Arctic

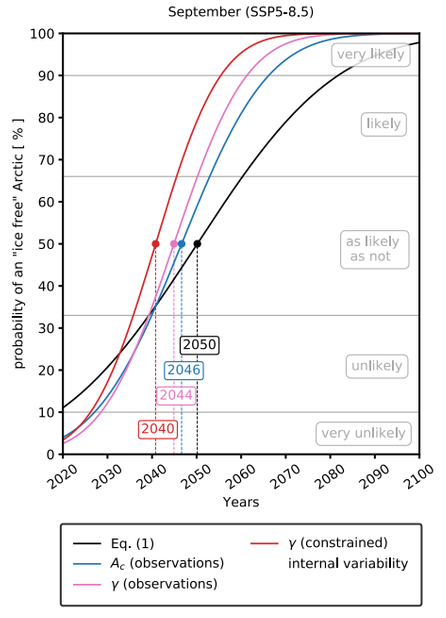


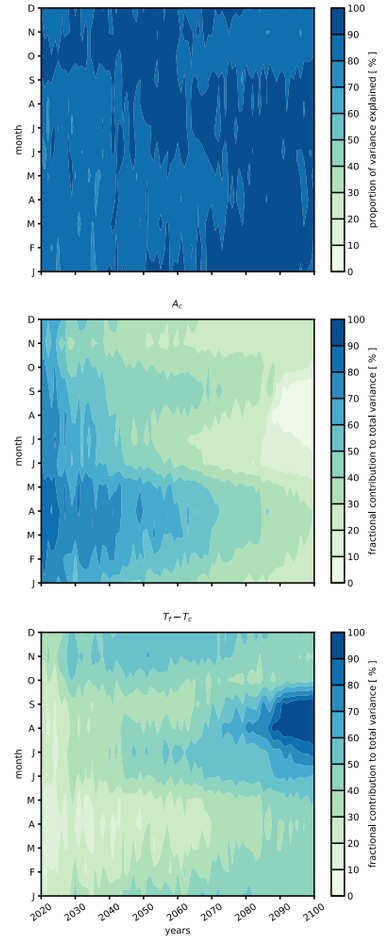
- Constrained projections suggest 15-30 years sooner than unconstrained CMIP6 models
- For high-emissions, 'likely' (>66% probability) year of ice-free summers in the Arctic is around 2060
- Medium- and low- emissions scenarios paint a different picture
- 'Likely' (>66% probability) year of ice-free summers in the Arctic is around 2080 for medium-emissions scenario and 2090 for low-emissions scenarios

Summary

- Projections of Arctic sea ice are dominated by model uncertainty
- Internal variability contributes up to 60% of total uncertainty in the first few decades and influences projection uncertainty at longer lead times in the wintertime
- Influence of internal variability is seasonally and regionally dependent, contributes more in regions influenced by ocean heat transport (e.g., GIN and Barents Seas)
- A simple linear expression emulates the future evolution of Arctic sea ice as simulated by GCMs with remarkable skill
- Present day biases in SIA account for the majority of inter-model spread in projections of Arctic SIA, with warming contributing much of the rest
- Constrained projections suggest 50% probability of ice-free conditions in September 2037-2044 under high emissions
- Ice-free conditions from July to October are `likely' (> 66% probability) to occur by 2060







Questions?

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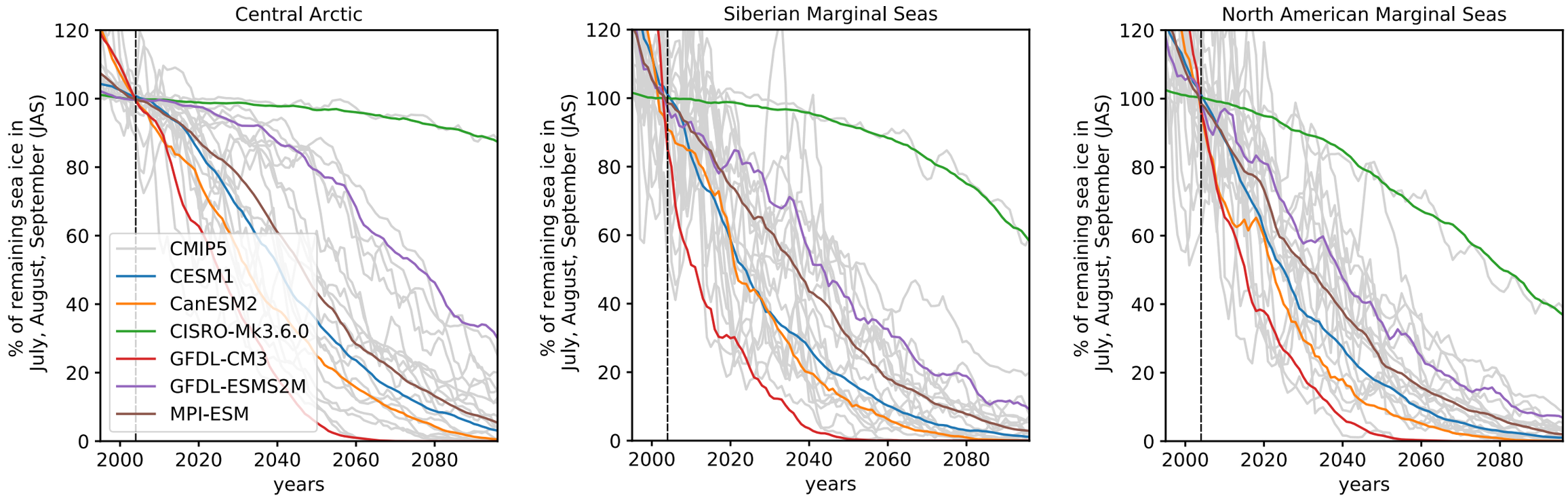
www.davebonan.com

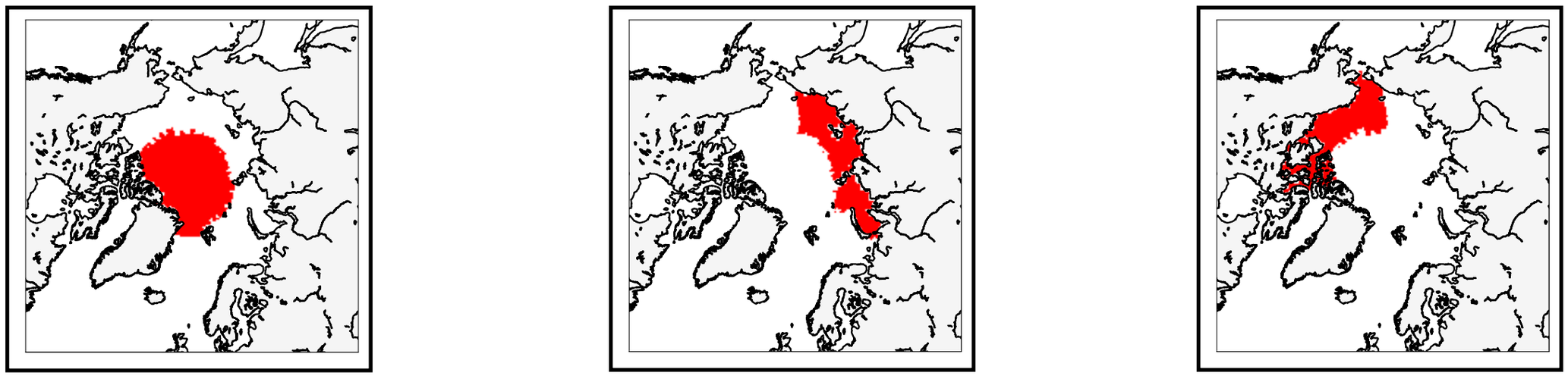
- Bonan, D.B., F. Lehner, and M.M. Holland (2021): **Partitioning uncertainty in projections of Arctic sea ice.** *Environmental Research Letters*. **16**. doi: 10.1088/1748-9326/ABE0EC

- Bonan, D.B., T. Schneider, I. Eisenman, and R.C.J. Wills: **Constraining the date of a seasonally ice-free Arctic.**

Partitioning uncertainty in *regional* projections of Arctic sea ice

Arctic sea ice in July, August, and September over 21st century





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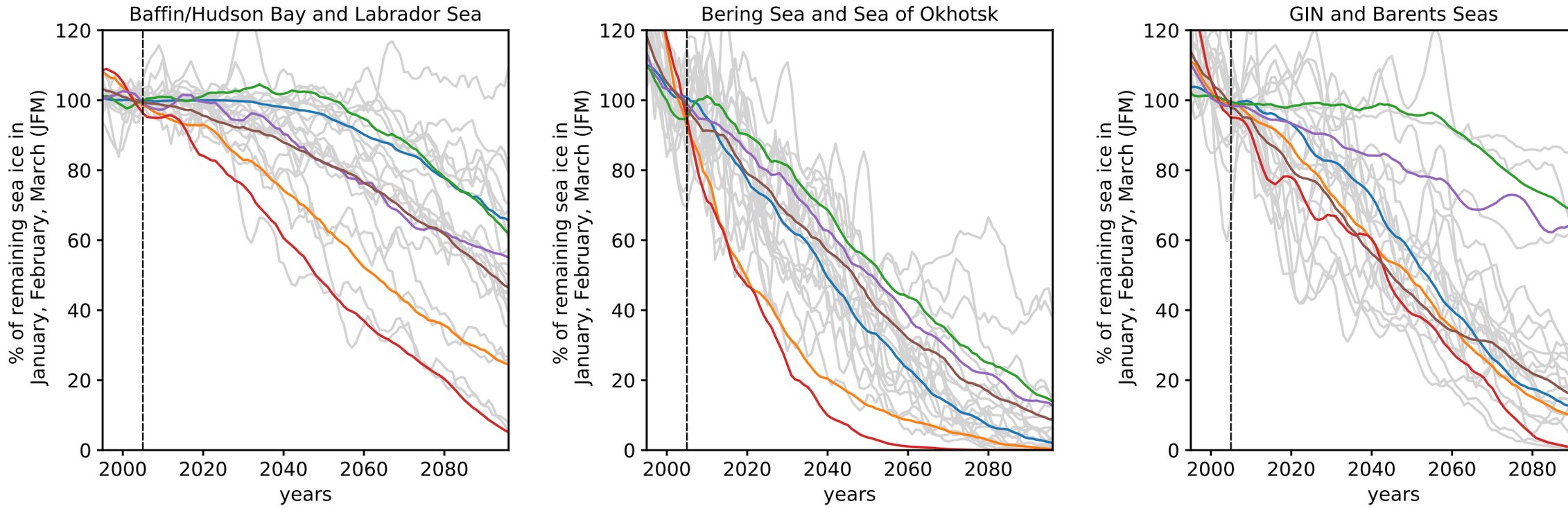

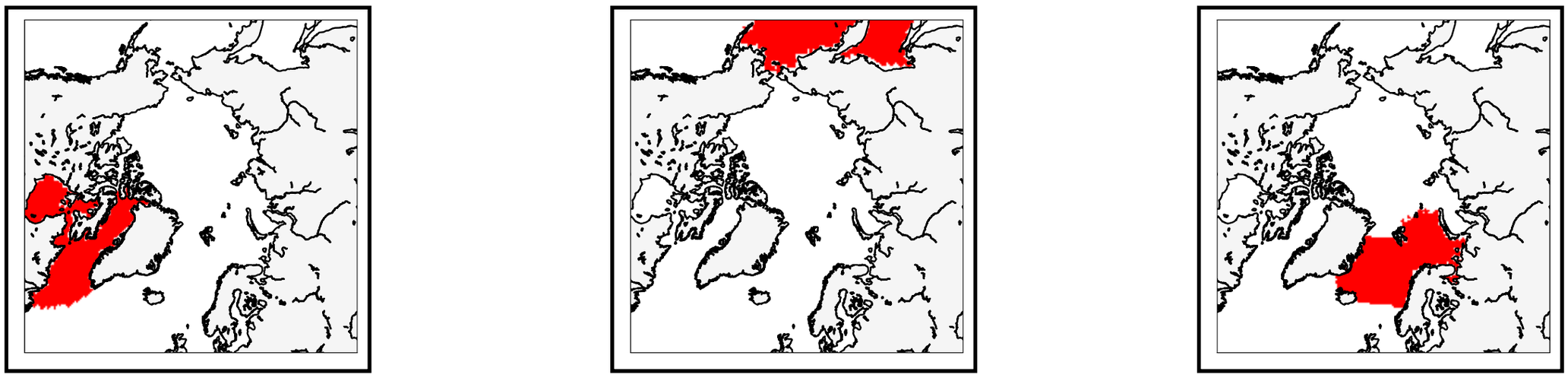

Comparison of probabilities using Eq. (1) and CMIP6 models