Predictable variations of the carbon sinks and atmospheric CO_2 growth in a multi-model framework

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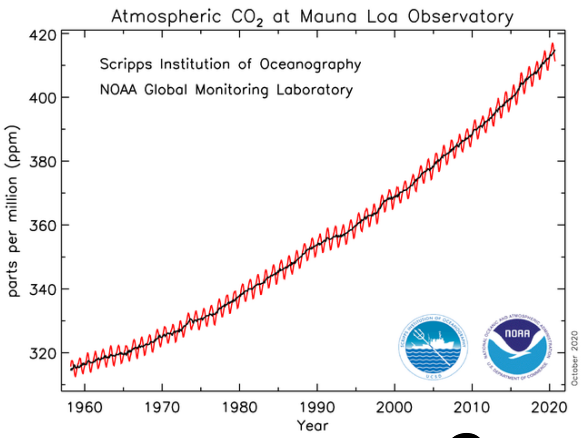
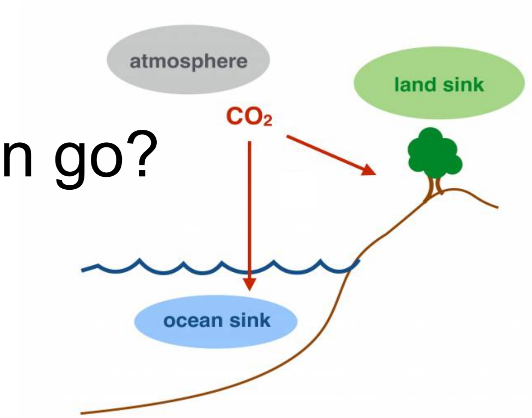
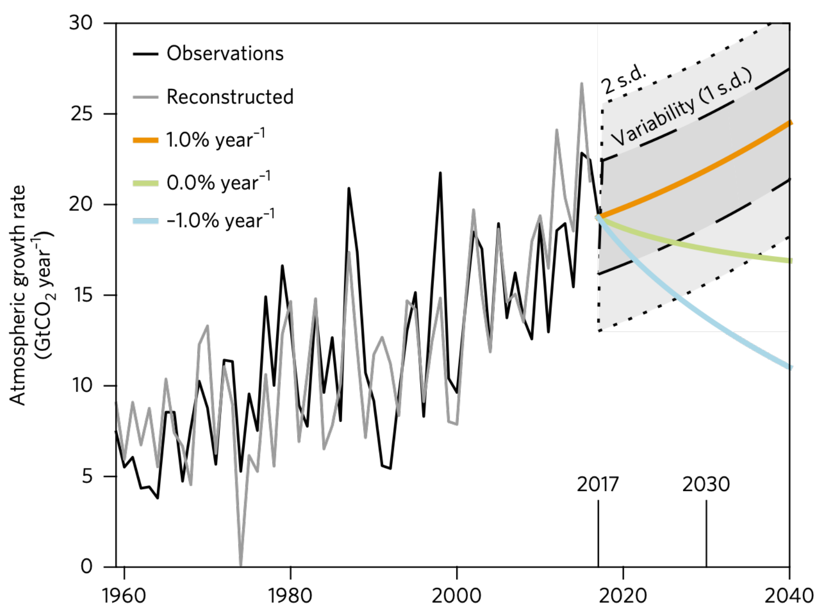


Where does the carbon go?



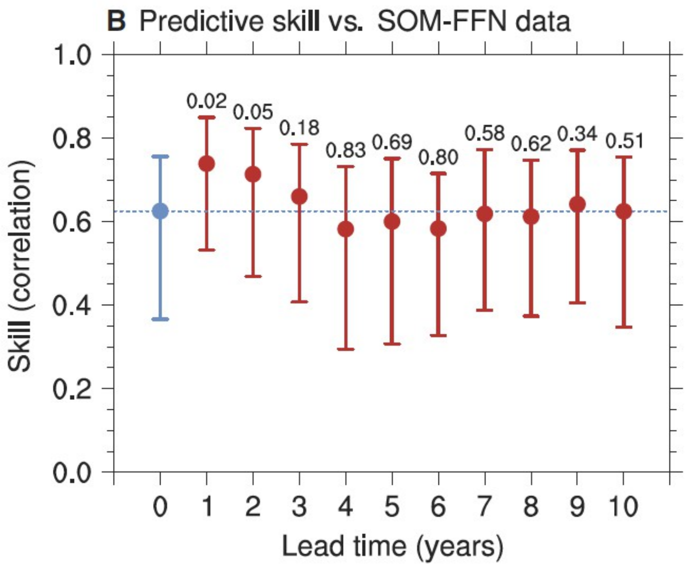
Can we predict if atmospheric CO_2 changes slower or faster as expected from changes in emissions?

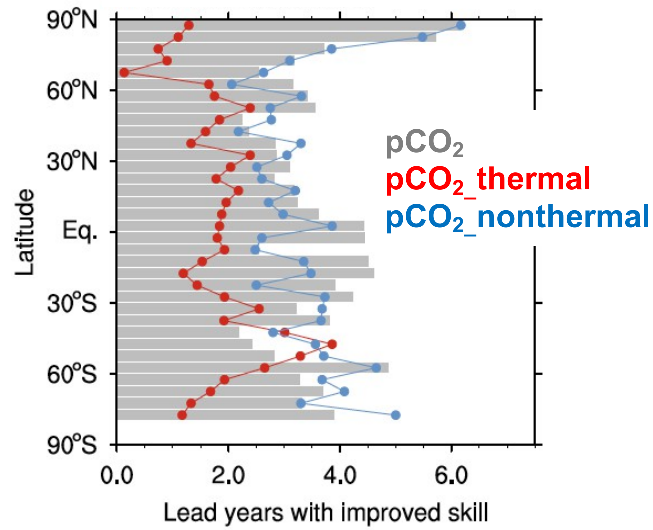


Peters at al., 2017

Evidence of predictability of the natural carbon sinks

Ocean C sink predictability is established in single models





The global ocean C sink is predictable for 2 years in hindcasts assessed vs. observations and for 3 years in idealized frameworks. Longer regional predictability is found.

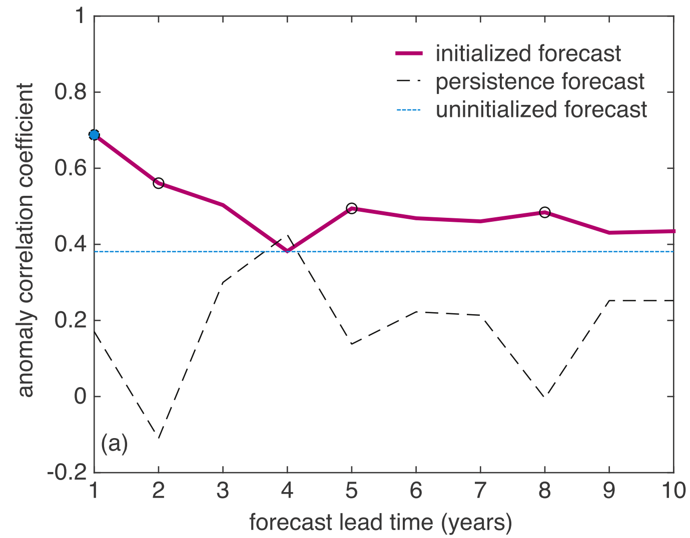
Shorter-term <3 years (longer-term >3 years) predictability of the ocean C sink is maintained by the thermal (nonthermal) drivers.

Hongmei Li at al., Science Advances 2019

Similar findings in other single model studies:
Séférian et al., 2018; Lovenduski et al., 2019; Fransner et al., 2020; Spring and Ilyina, 2020

Evidence of predictability of the natural carbon sinks

Less evidence for Land C sink predictability in single models



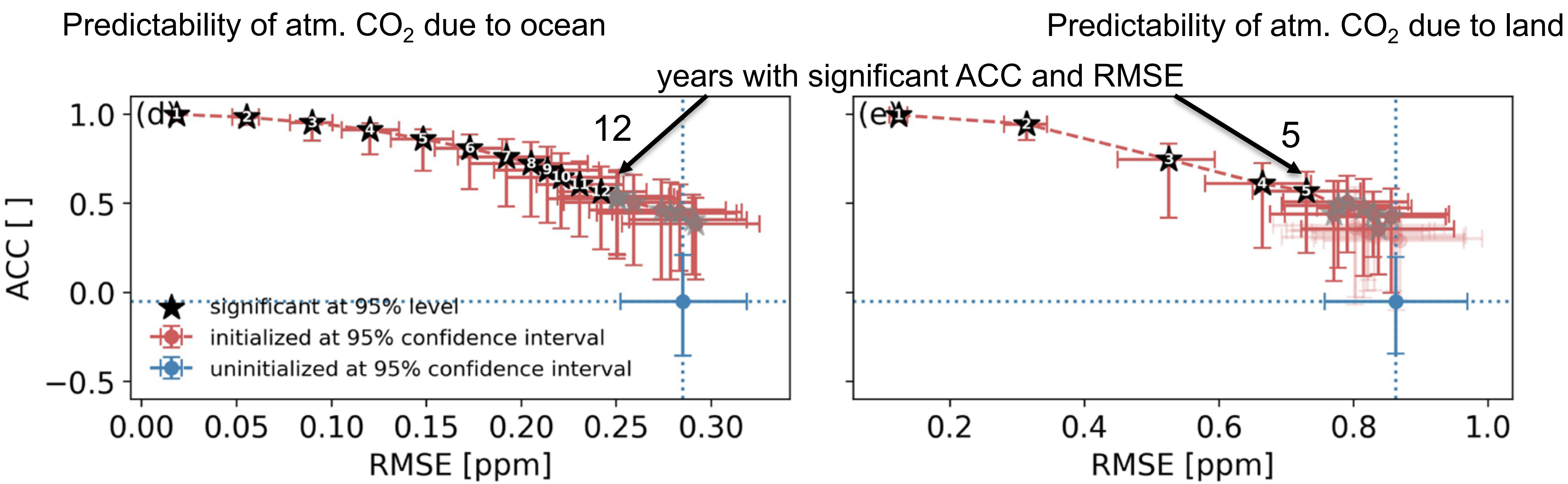
Up to 2 years potential predictability for terrestrial C flux. Assessement is challenged by the lack of suitable observational products.

Lovenduski et al. ERL 2019

Similar findings in the fewer other single model studies:
e.g. Séférian et al., 2018; Spring and Ilyina, 2020; Zeng et al., 2008

If natural C sinks are predictable, can atmospheric CO_2 growth rate be predicted?

In a 'perfect model' framework, atm. CO_2 variations due to ocean only are predictable for 12 years and due to land only for 5 years. Terrestrial C sink limits atm. CO_2 predictability.



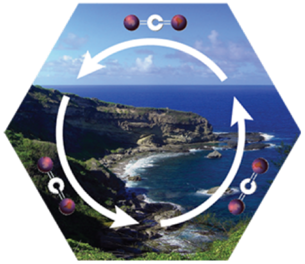
Spring and Ilyina, GRL 2020

Multi-model framework

Table S1. Overview of prediction systems and initialization techniques.

Model	CanESM5	CESM-DPLE	GFDL-ESM2	IPSL-CM6A-LR	MIROC-ES2L	MPI-ESM-LR	MPI-ESM1.2-HR	NorCPM1
Resolution Atmosphere	T63, 47 levels	1.0°, 30 levels	2.5° lon 2.0° lat, 24 levels	2.5°x1.3°, 79 levels	T42, 40 levels	T63, 47 levels	T127, 95 levels	1.9x2.5°, 26 levels
Resolution Ocean	ORCA1, 45 levels	1°, 60 levels	1°, 50 levels	1°, 75 levels	Tripolar (∼1°), 62 levels	1.5°, 40 levels	0.4°, 40 levels	1°, 51 levels
Initialization ocean	ORAS5 3D T-S anomalies, SST relaxed to OISSTv2; sea-ice concentration relaxed to HadISST.2, CMC analysis; thickness assimilation	Ocean-sea-ice forced at the surface with atmospheric states and fluxes (modified COREv2)	GFDL's ECDA for WOD, argo, SST	EN4 SST and Atlantic SSS	Full-field 3D T-S	ORAS4 3D T-S anomalies	ORAS4 3D T-S anomalies, sea-ice concentration anomalies from NSIDC	EKF for HadISST2 + OISSTV2 SST, EN4 T,S profiles
Initialization atmosphere	ERA-40 and ERA-Interim: vorticity, divergence, log(p), T; full field	CESM Large Ensemble	GFDL's ECDA with NCEP-DOE reanalysis 2	N/A	JRA55 wind and T; full field	ERA-40 and ERA-Interim: vorticity, divergence, log(p), T; full field	ERA-40 and ERA-Interim: vorticity, divergence, log(p), T; full field	N/A
Ensemble size	20	40	12	10	10	10	10	20
Start years	1961-2017 yearly from 1 Jan. for 10 years	1954-2015 yearly from 1 Nov. for 10 years	1961-2017 yearly from 1 Jan. for 10 years	1961-2014 yearly from 1 Jan.	1980-2017 yearly from 1 Jan. for 10 years	1961-2014 yearly from 1 Jan. for 10 years	1961-2014 yearly from 1 Nov. for 10 years	1959-2017 yearly from 15 Oct. for 10 years
Forcing	cmip6	cmip5	cmip5	cmip6	cmip6	cmip5	cmip6	cmip6

Ilyina et al. in review



Climate-Carbon Interactions in the Current Century

Multi-model framework

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Forcing	cmip6	cmip5	cmip5	cmip6	cmip6	cmip5	cmip6	cmip6

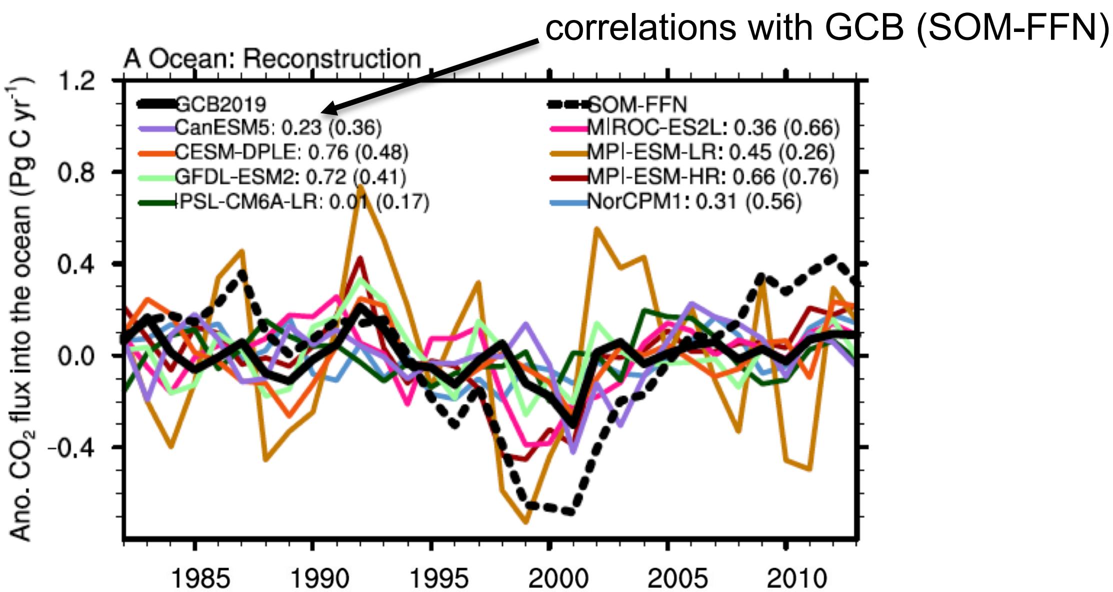
8 ESMs
5 from CMIP6 3 from CMIP5
Different designs
Different ensemble size

Ilyina et al. in review

Climate-Carbon Interactions in the Current Century

Multi-model reconstruction of carbon sinks

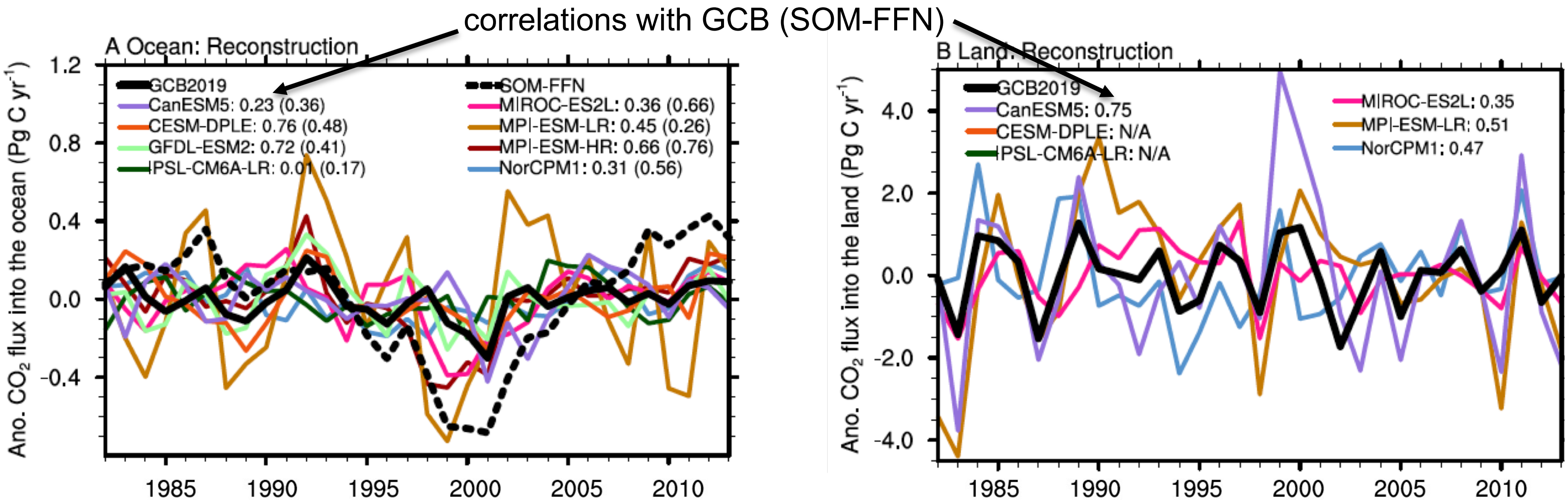
CO_2 flux reconstructions suggest stronger multi-year variations of the ocean and land carbon sinks.



Ilyina et al., GRL in review

Multi-model reconstruction of carbon sinks

CO_2 flux reconstructions suggest stronger multi-year variations of the ocean and land carbon sinks. Air-land CO_2 flux reconstructions outperform the uninitialized simulations in all models.



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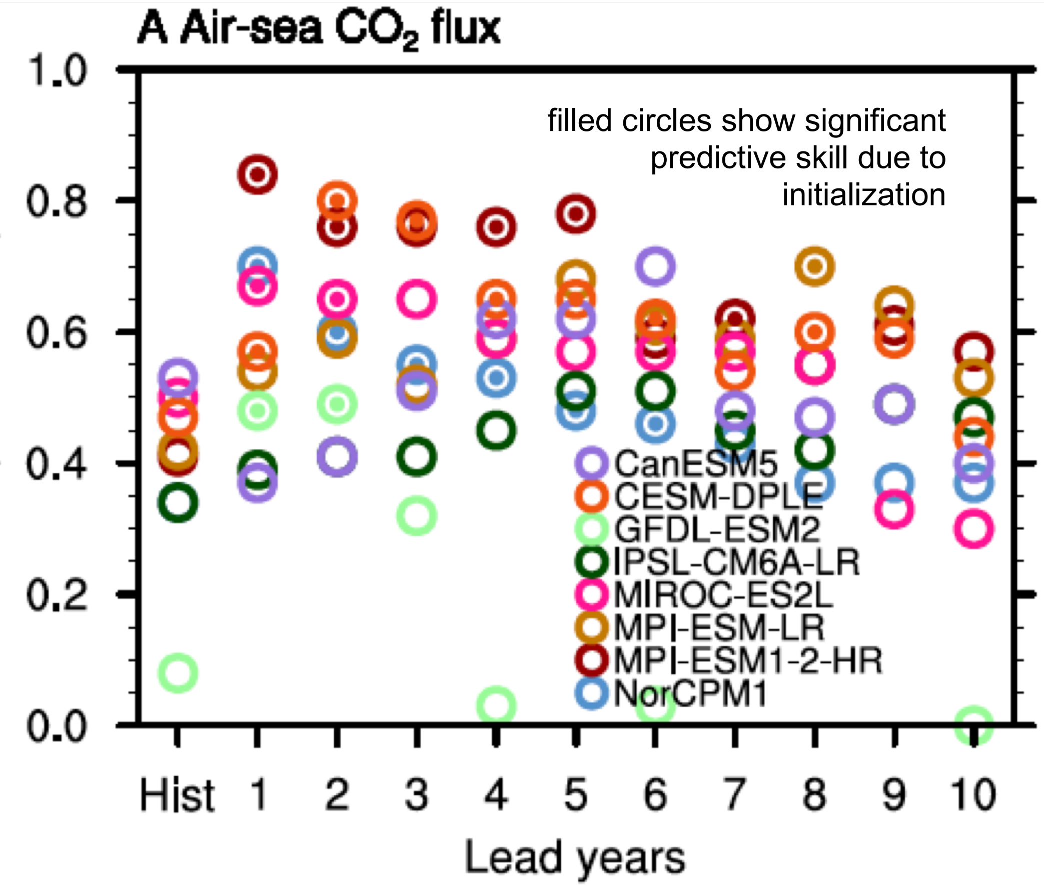
Multi-model assessment

Predictive skill of the global ocean carbon sink due to initialization is up to 6 years, with longer up to 10 years regional predictability in single models.



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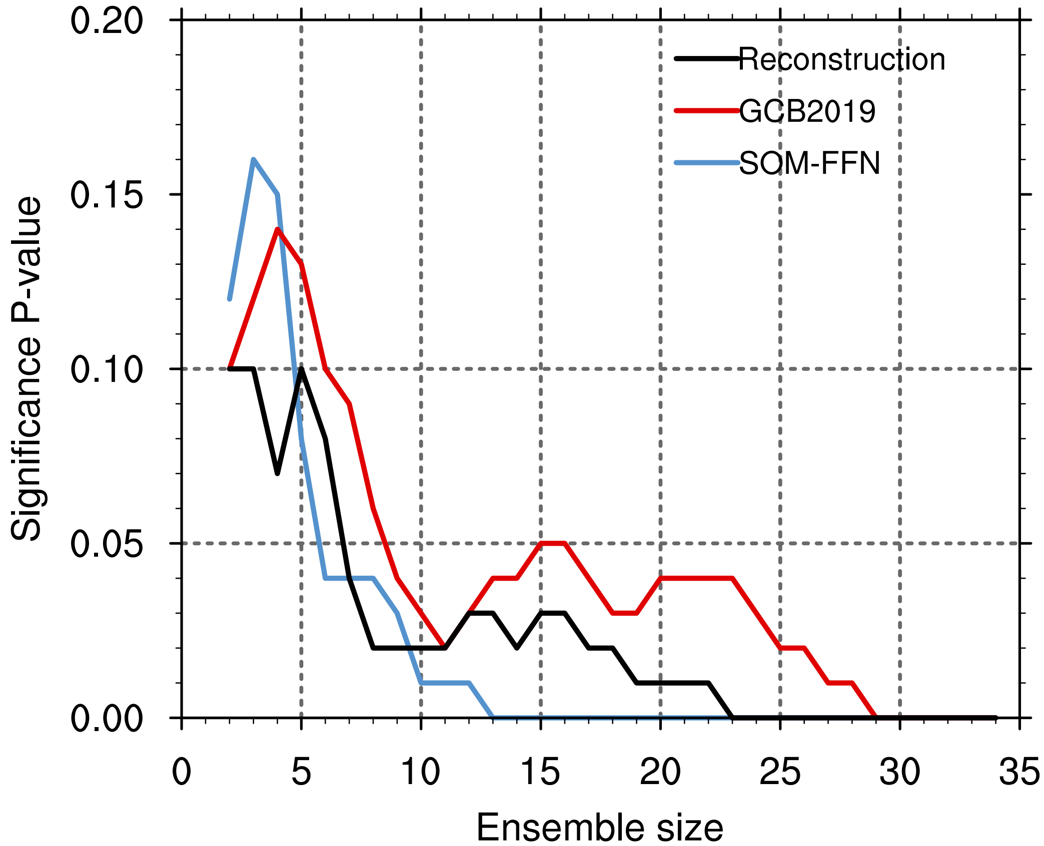
Multi-model assessment

Significance p-values evolve with ensembles size. As demonstrated for CESM-DPLE, a larger ensemble maintains the air-sea CO_2 flux predictive skill significance.



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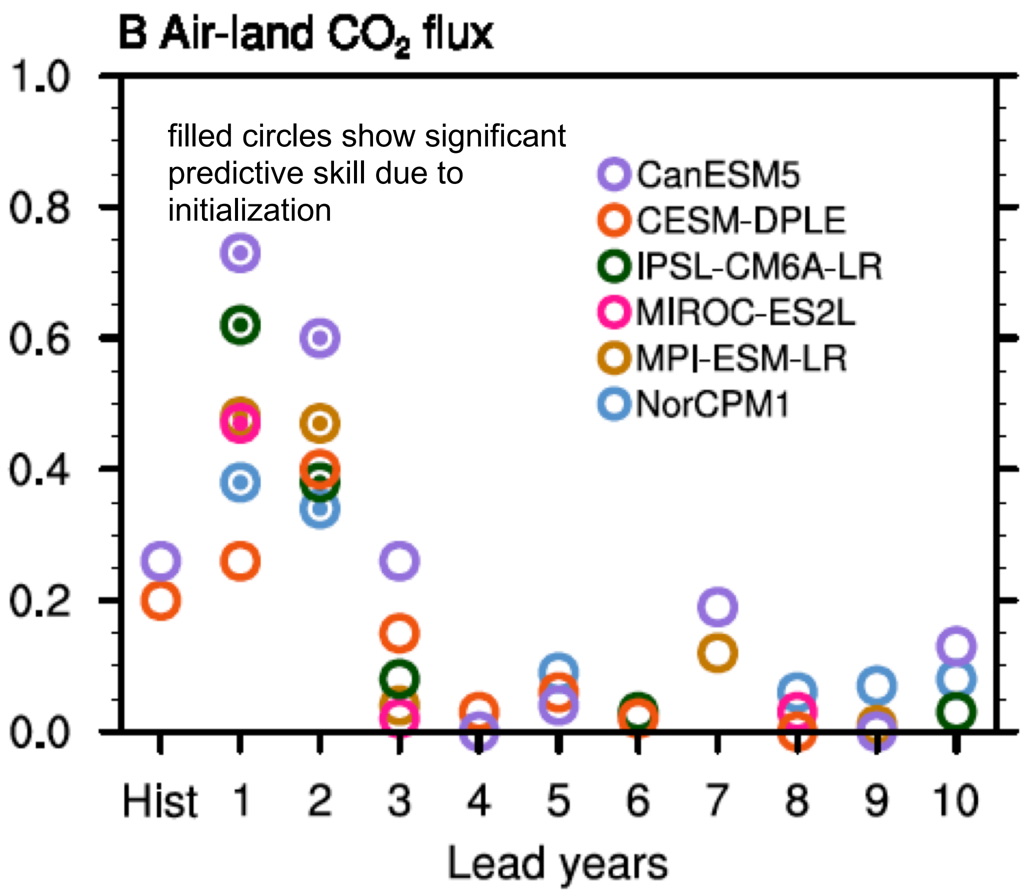
Multi-model assessment

Predictive skill due to initialization for the land carbon sink of up to 2 years is primarily maintained in the tropics and extra-tropics.



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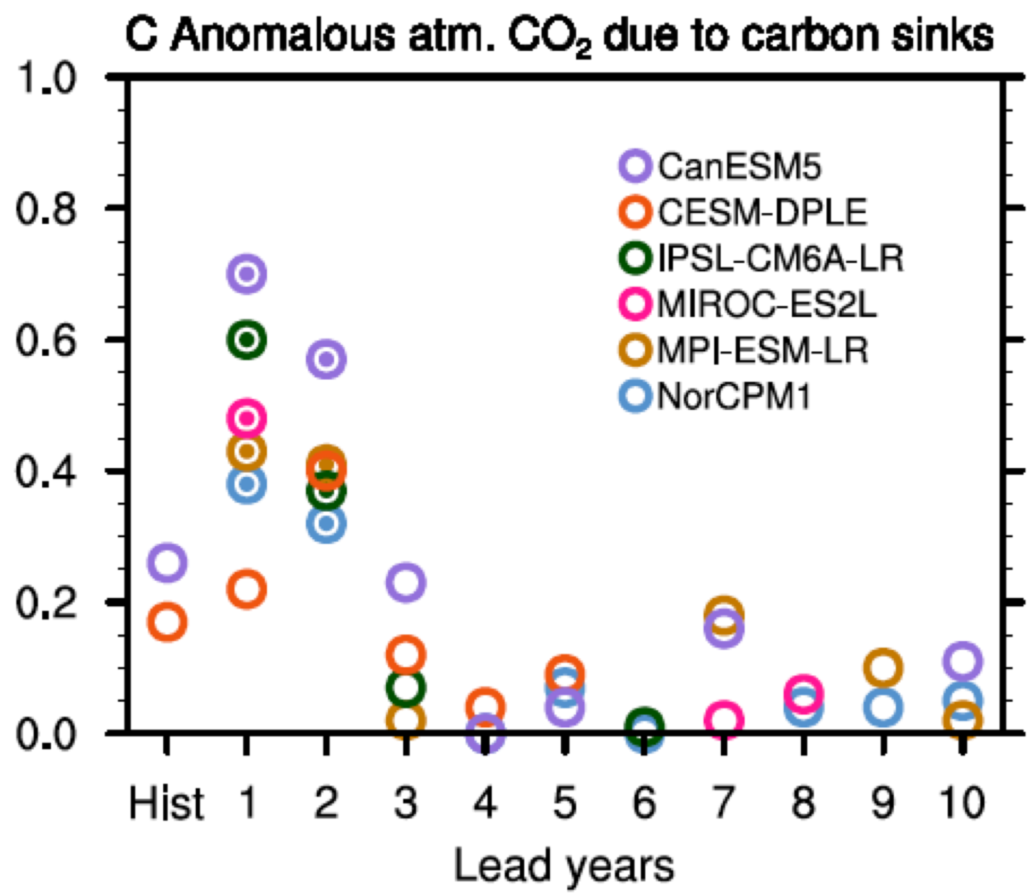
Multi-model assessment

Anomalies of atmospheric CO_2 growth rate are predictable up to 2 years and are limited by the land carbon sink predictability horizon.



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What is next?

Until now carbon predictions have been based on concentration-driven simulations, atmospheric CO_2 variations were diagnosed.

Evidence of 2 years predictive skill of atmospheric CO_2 growth rate in simulations with prognostic atm. CO_2 (emission-driven)

Summary

- Reconstructions, in which the observations are assimilated into the ESMs, appropriately capture multi-year variations of the carbon sinks and atmospheric CO_2 growth rate.
- Global atmospheric CO_2 is predictable for 2 years in hindcasts and 3 years in the idealized framework. This predictability is mainly limited by land, as terrestrial CO_2 flux is predictable for 2 years and oceanic CO_2 flux is predictable up to 6 years.
- We demonstrate the feasibility of carbon cycle predictions in informing the Global Stocktake process with the most accurate estimates of near-term carbon cycle outlooks.