

SamudrACE– Coupled Climate Simulations with ACE and Samudra

NeurIPS 2025 Workshop: Tackling Climate Change with Machine Learning

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External partners



M²InES



GFDL



LLNL



NVIDIA

SamudrACE: AI emulator of coupled global climate models

Why coupled emulator? We need it to predict coupled phenomena such as El Niño and to model long-term response to CO₂

3D ocean and sea ice:

- 5-day steps
- 19 vertical levels
- Original 0.25° horizontal resolution regridded to 1°

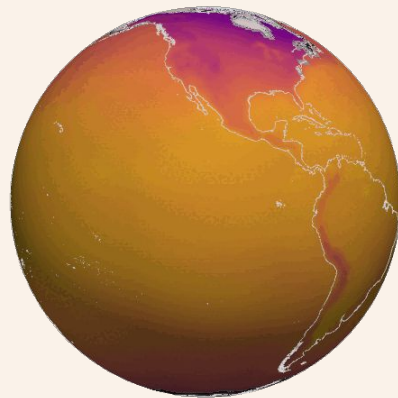
3D atmosphere and land surface:

- 6-hour steps
- 8 vertical levels
- 1° horizontal resolution

SamudrACE is **7350x less energy intensive** than a traditional GCM simulation, and with one NVIDIA H100 GPU generates an **1500 year simulation in 24 hours** (~100x faster)

SamudrACE

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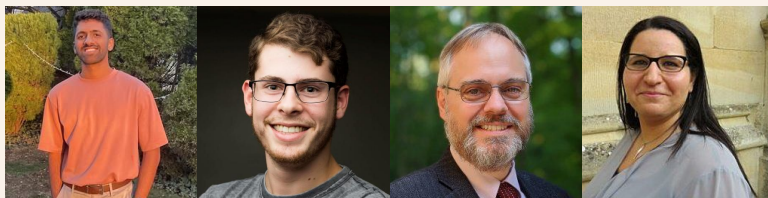


Surface temperature and sea ice concentration from a 40-year rollout

Prior work: Samudra

Samudra is a 3D global ocean emulator:

- Forced by atmosphere surface fluxes
- Full ocean depth
- 5-daily time step
- Stable, accurate, and no drift for long rollout

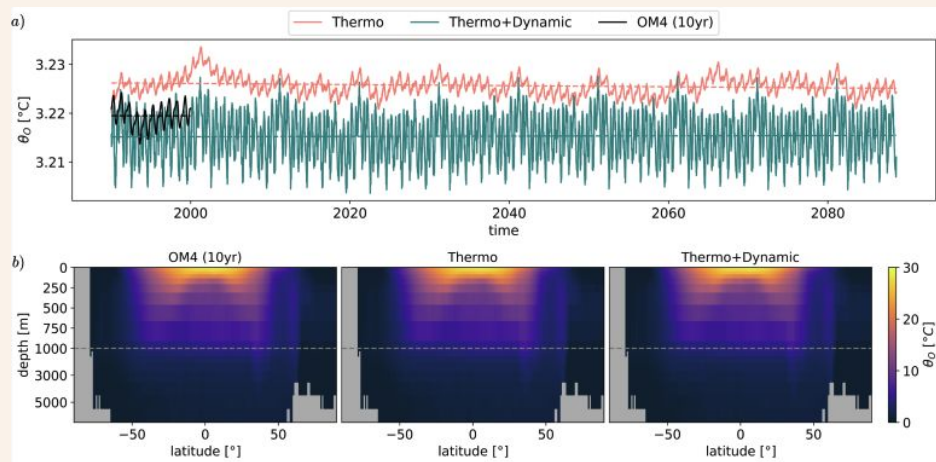
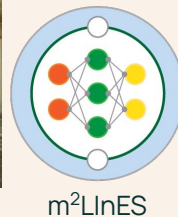


Surya Dheeshjith

Adam Subel

Alistair Adcroft

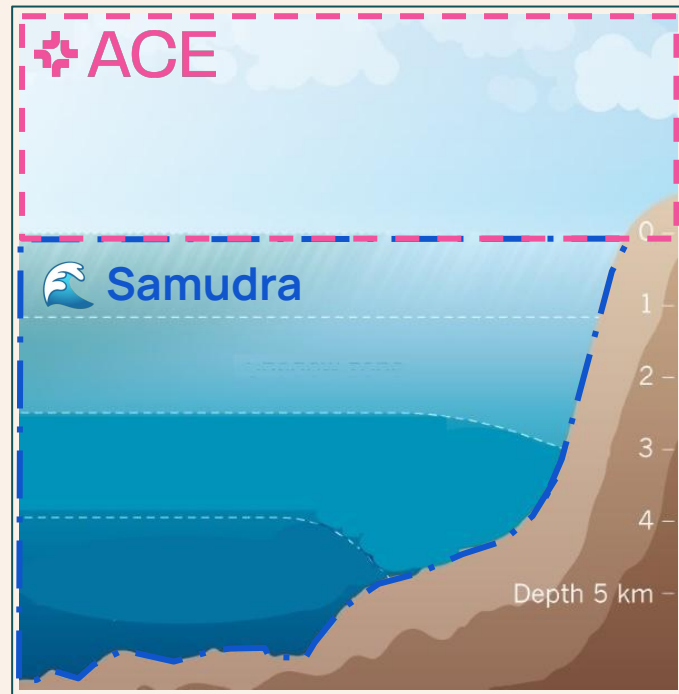
Laure Zanna



Dheeshjith et al. 2025

This work: SamudrACE

- SamudrACE is built on top of ACE and Samudra with some notable changes:
 - Add sea ice concentration and thickness as prognostic variables in Samudra
 - Use individual surface fluxes predicted from ACE as boundary forcing for Samudra
- Trained on 200-year of preindustrial control coupled simulation from GFDL's Climate Model version 4 (piCM4)
 - 155 years for training, 5 years for validation, and 40 years for testing



(Duncan et al. 2025)

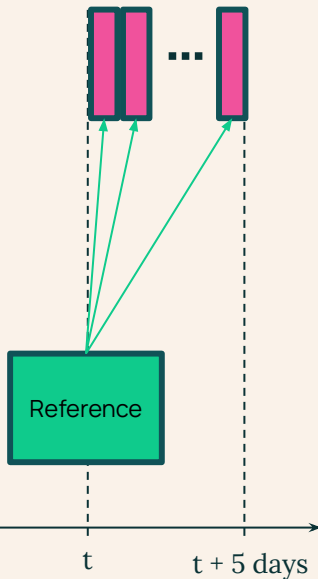
Coupled training setup: 2 stages

Pretraining in uncoupled mode then coupled fine-tuning

a) Uncoupled atmosphere

Atmosphere, 6-hr
snapshot surface
temperature and
time avg fluxes

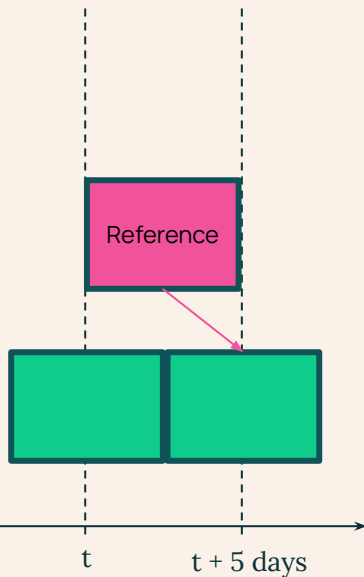
Ocean, 5-day
updates of SST /
sea ice



b) Uncoupled ocean

Atmosphere,
5-day avg
surface fluxes

Ocean, 5-day
updates

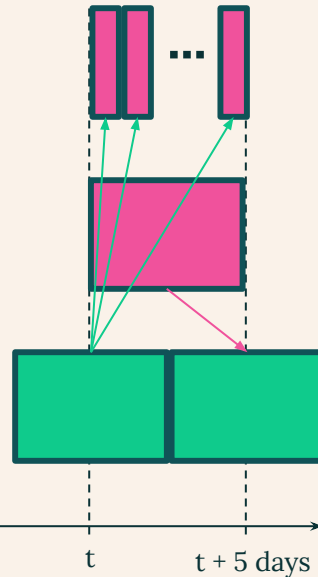


c) Coupled

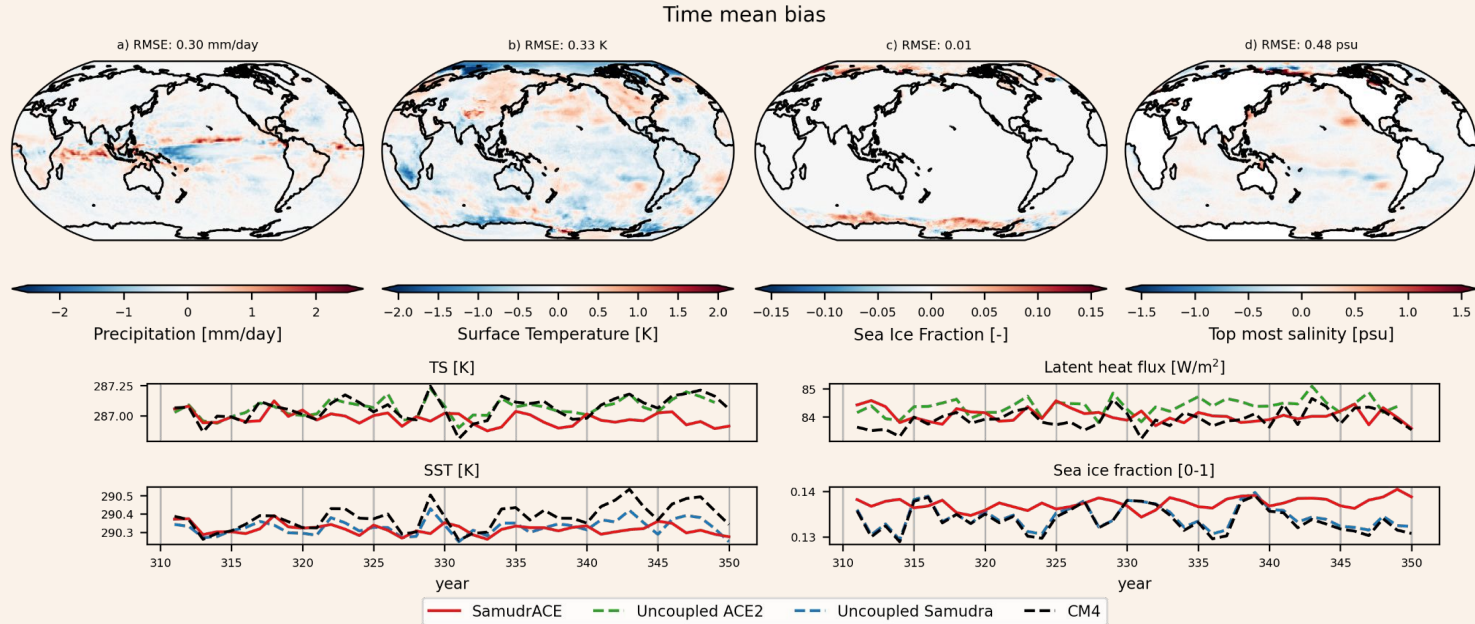
Atmosphere, 6-hr
snapshot surface
temperature and
time avg fluxes

Atmosphere,
5-day avg
surface fluxes

Ocean, 5-day
updates states



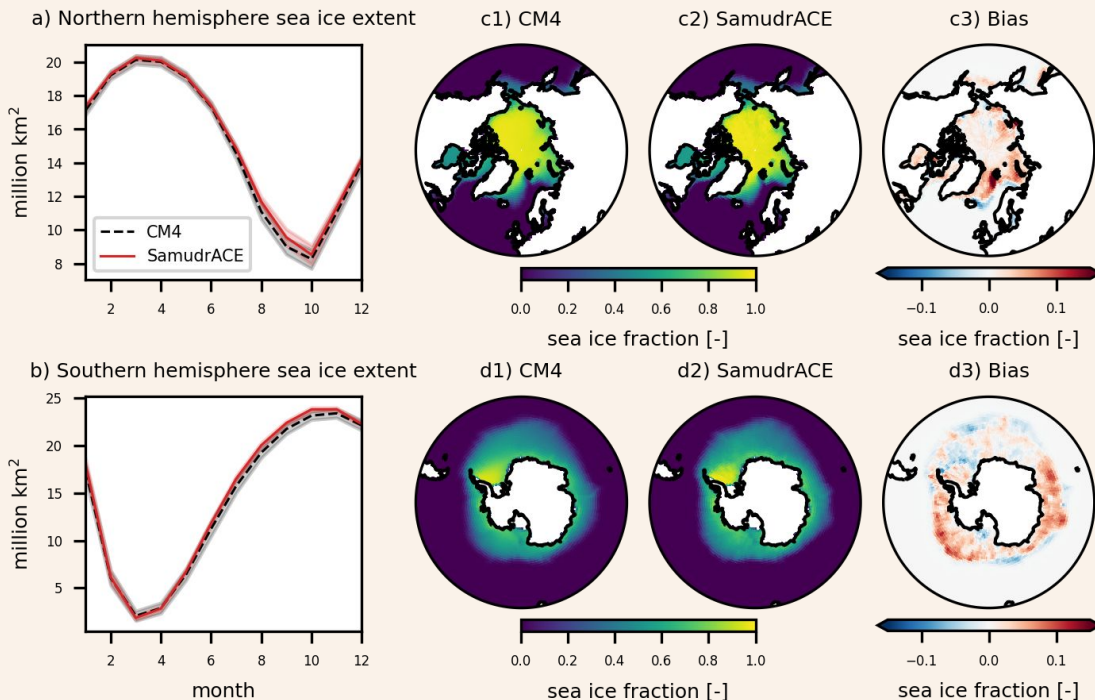
Stable and accurate long term climate skills



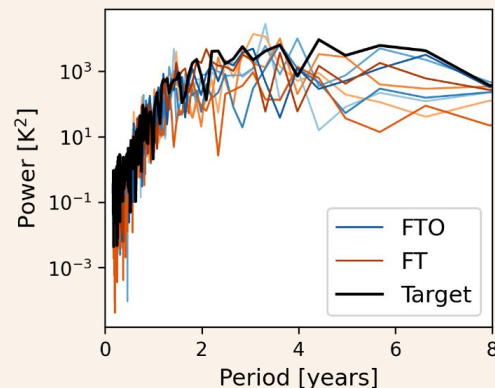
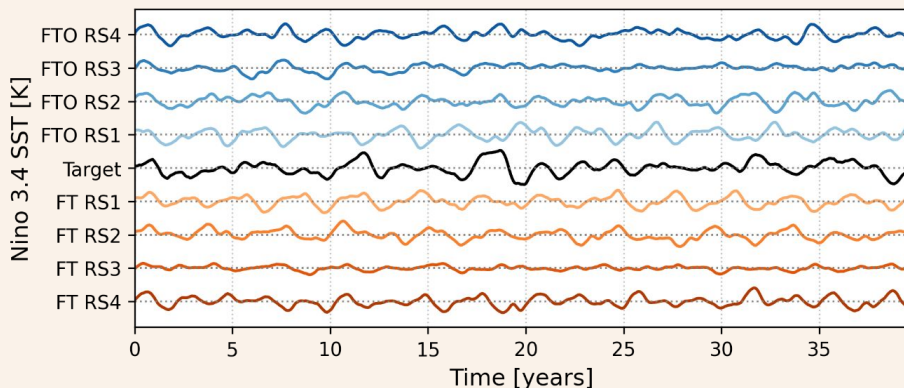
- Precipitation biases are concentrated in the tropics and surface temperature biases are largest in areas of sea ice and topographic features
- Similar time mean biases to the uncoupled component emulators

SamudrACE predicts accurate sea ice climatology

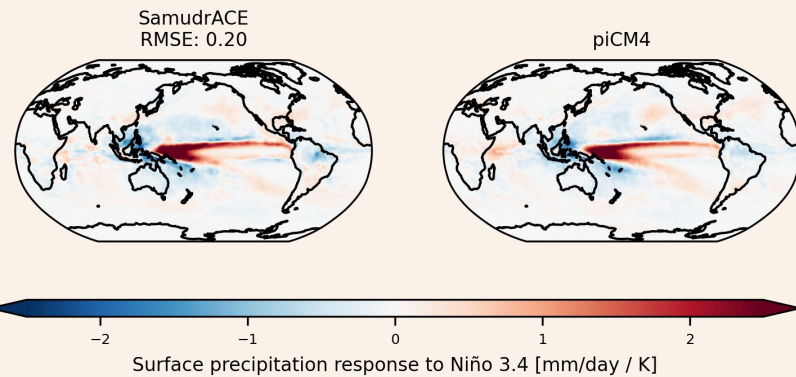
- Sea ice concentration is a prognostic variable in Samudra, which is an important quantity for coupling atmosphere-ocean
- Maintains good sea ice climatology with accurate seasonal cycle but slightly underestimates interannual variability in the SH



Coupled fine training strategies impact ENSO response



- Fine tuning strategies include: ocean MSE contributes to training losses (FTO) or both ocean and atmosphere MSE are considered (FT)
- One FT seed has almost no low frequency ENSO variability
- Generally loses low-frequency power beyond periods of 4 years



Summary

SamudrACE

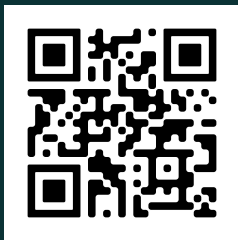
- maintains low climate biases comparable to its uncoupled component models
- generates realistic ENSO variability including the associated teleconnections to global precipitation patterns
- generally underestimates low-frequency variability on time scales longer than 4 years

It is easier and 100x faster to run than the reference model!

- Ongoing work include training SamudrACE to simulate climate change scenarios

Open source code, data and model checkpoints: github.com/ai2cm/ace
huggingface.co/allenai/SamudrACE-CM4-piControl

SamudrACE paper: [Duncan et al. 2025](#)



Thank you!

Scan to explore the model and paper!

<https://huggingface.co/allenai/SamudrACE-CM4-piControl>