# Phytoplankton response under SAI differs due to upgrading MARBL configuration from 3p1z to 4p2z

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# Outline

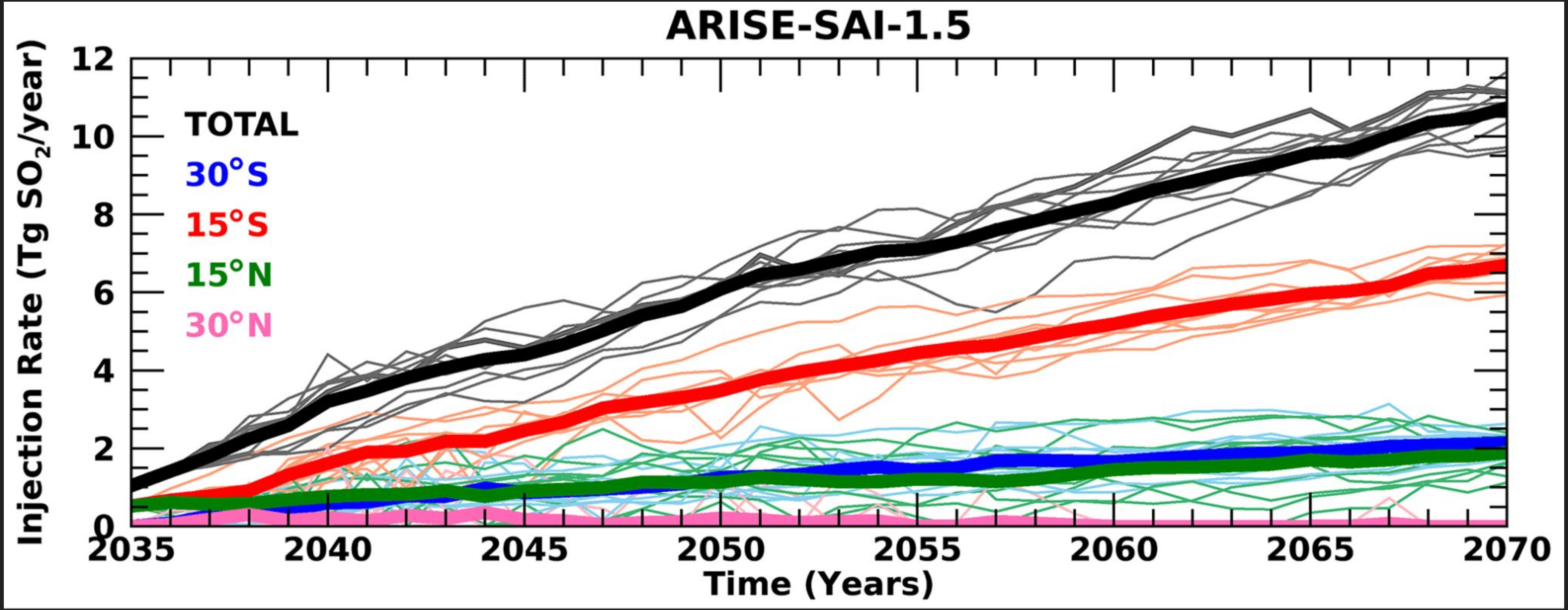
1. introduce arise-sai project
2. introduce 4p2z configuration with explicit calcifiers
3. basic chemical changes in the ocean under ssp2-4.5 then under sai-1.5
4. how does phytoplankton respond to warming and acidification?
5. how do calcifiers respond and why?
6. why is natural variability of calcification so different?

# Assessing Responses and Impacts of Solar Intervention on the Earth system with Stratospheric Aerosol Injection (ARISE-SAI; Richter et al., 2022)

What is ARISE-SAI?

- 10 ensembles using CESM2(WACCM6-POP2-MARBL3p1z) where sulfate aerosols are injected into the stratosphere to maintain global surface temperatures at 1.5°C above the pre-industrial mean, while $CO_2$ emissions follow SSP2-4.5
  - A controller algorithm is used to determine the latitude at which to inject the aerosols so global surface temperatures remain constant while the pole-to-equator temperature gradient does not change.
  - because it used a 3p1z configuration of MARBL there was NO explicit calcifying phytoplankton!

# Assessing Responses and Impacts of Solar Intervention on the Earth system with Stratospheric Aerosol Injection (ARISE-SAI; Richter et al., 2022)



# Introducing ARISE-SAI-**4p2z**

- We ran a single simulation of ARISE-SAI with an updated MARBL-4p2z configuration.

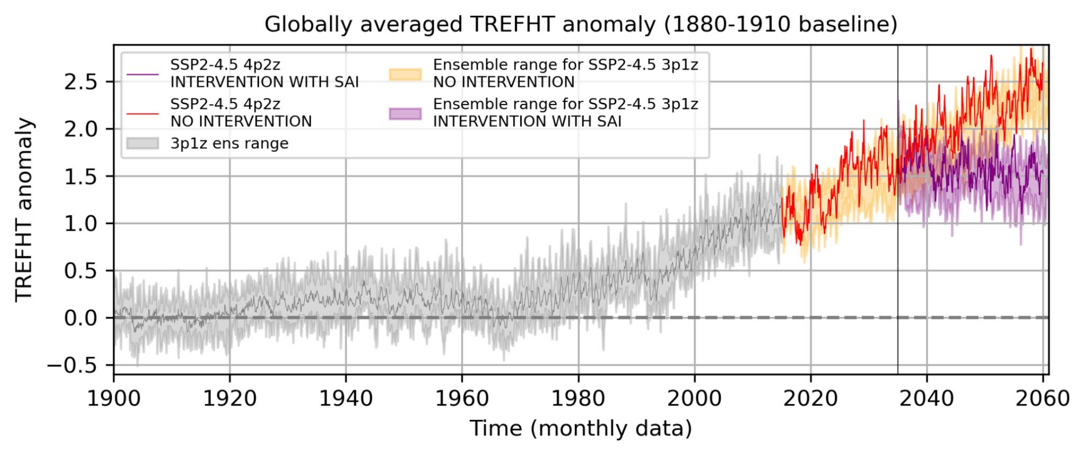
- Includes EXPLICIT representation of coccolithophores that:
    - uptake carbon
    - produce calcium carbonate
    - have varying shell thickness as a function of aqueous $CO_2$ concentration

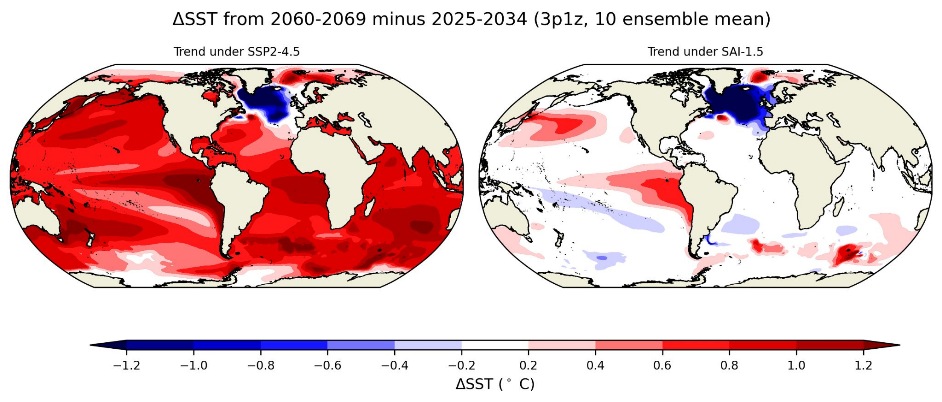
- Simulation begins in 2015
    - SAI begins during 2035, when global mean surface temperatures rise to 1.5°C above the pre-industrial mean.
    - Simulation ends in 2070.

**3p1z** = small phytoplankton, diatoms, diazotrophs, zooplankton
**4p2z** = 3p1z + coccolithophores, zooplankton divided into two different size classes

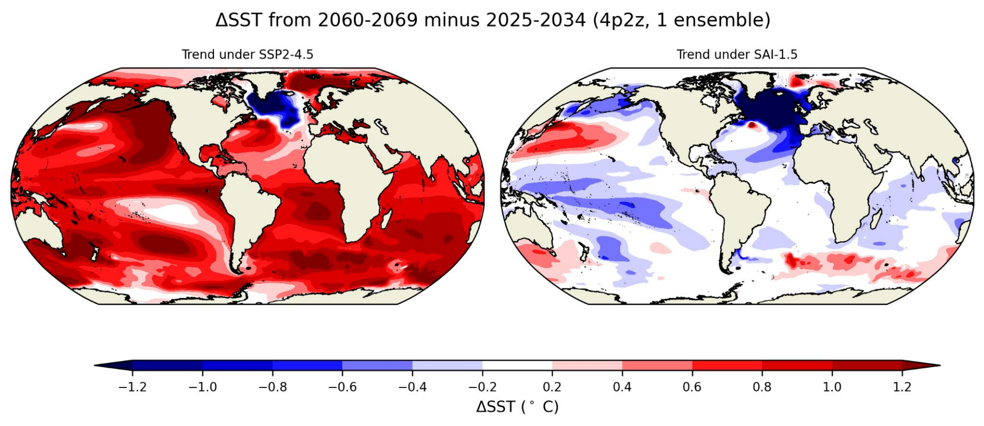
# Physical climate state under SAI

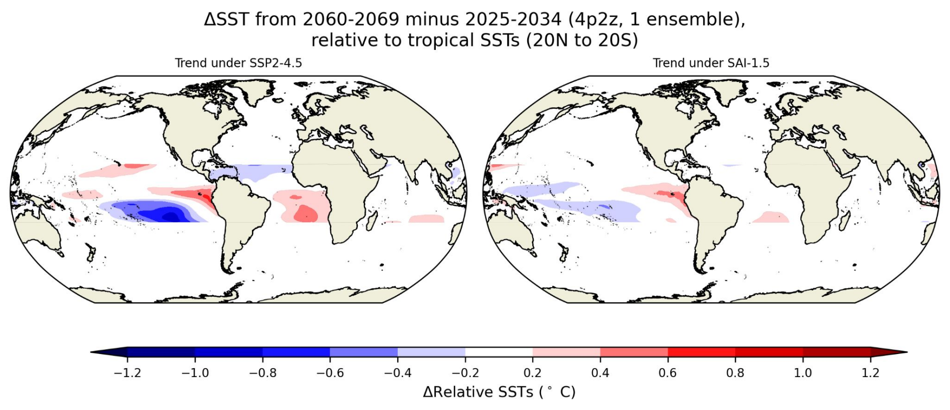
- SAI reduces global surface temperatures while maintaining the ITCZ position.
- Despite best efforts to avoid unintended consequences, there are still regional temperature variations
- El Nino-like warming remains under SAI, AMOC related cooling unchanged.



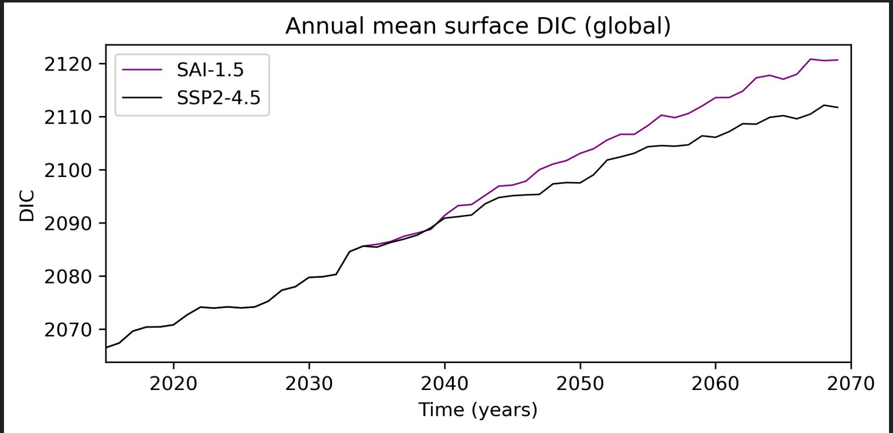
# Physical climate state in SAI (4p2z)

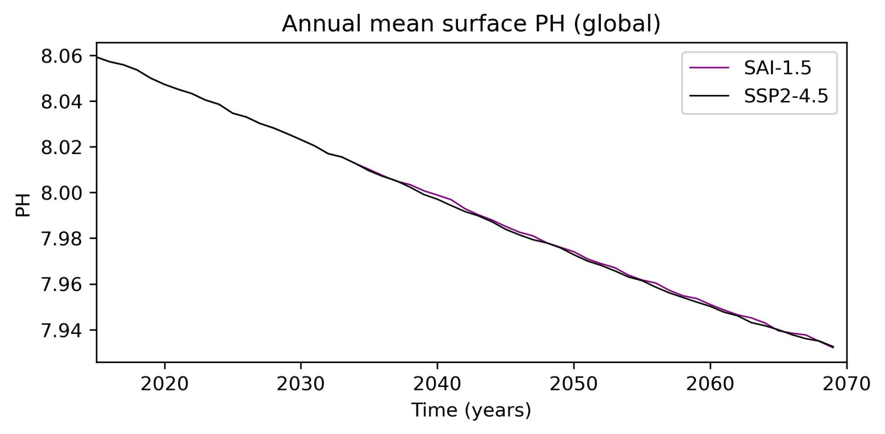


# Chemical changes under SAI (4p2z)

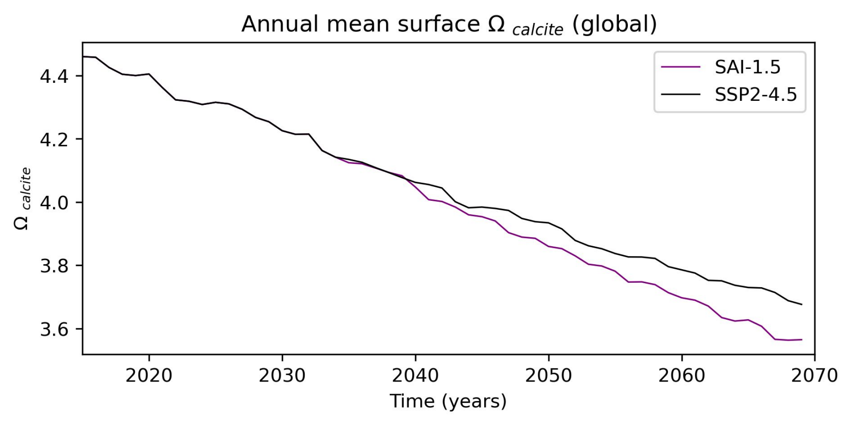
- Surface DIC increases at a faster rate under SAI compared to SSP2-4.5 because of greater uptake under colder temperatures.
- pH shows little difference between SSP2-4.5 and SAI despite carbon uptake.

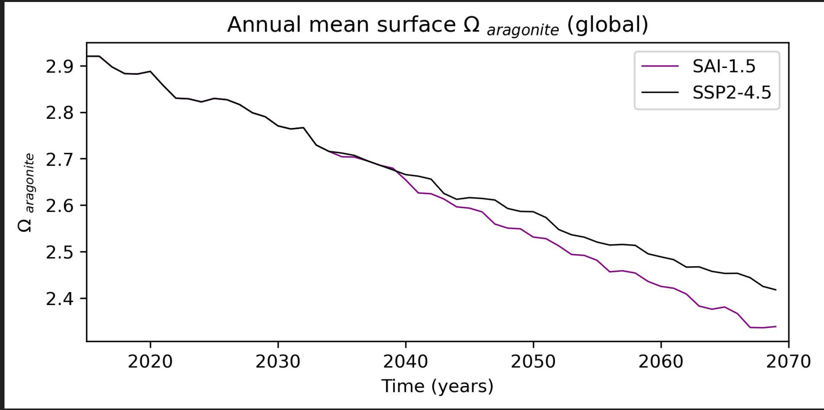


# Chemical changes under SAI (4p2z)

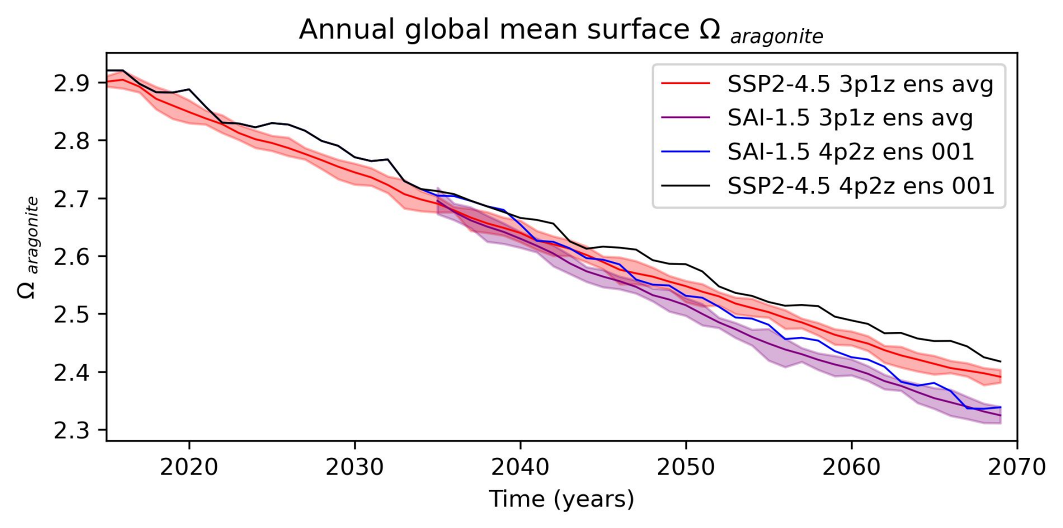
- Ωaragonite and Ωcalcite decline under SSP2-4.5 and SAI.
- SAI exacerbates decline, making it harder for corals and coccolithophores to make shells.



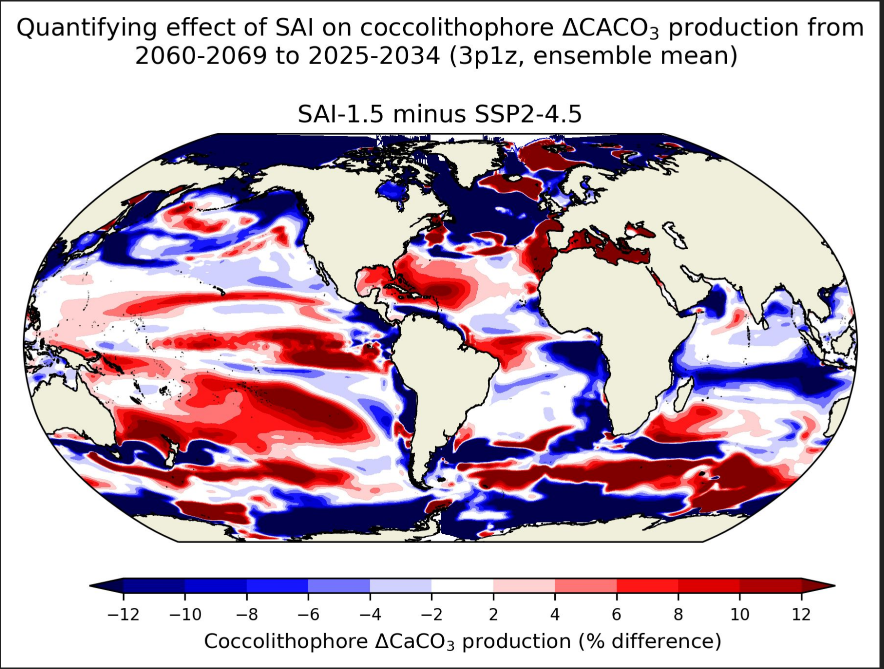
# Differences between 3p1z and 4p2z?

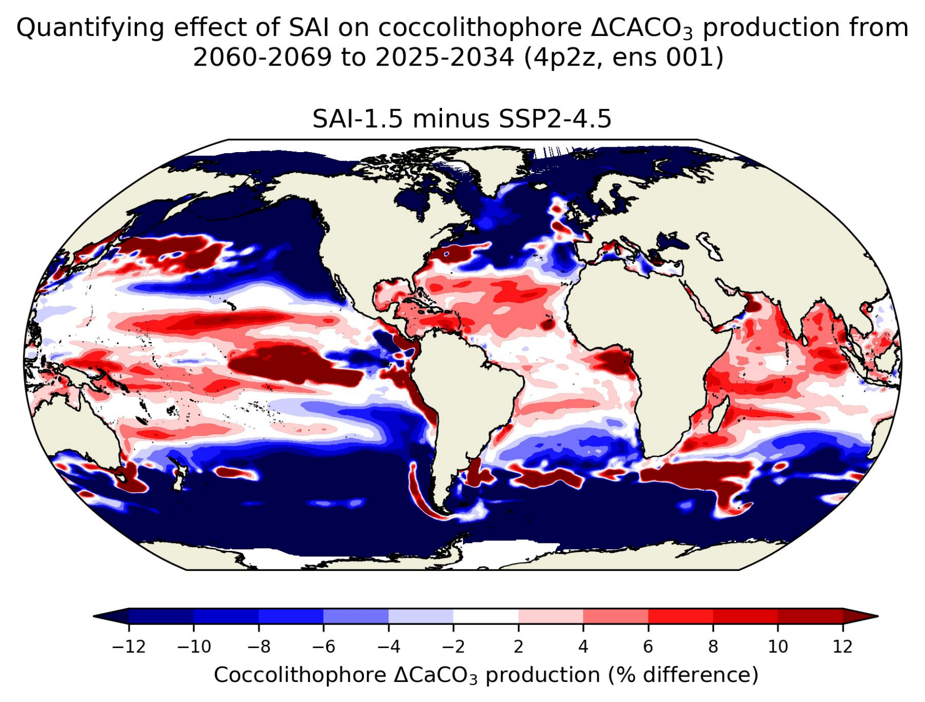
- Inclusion of an explicit calcifier can affect global patterns of alkalinity (Krumhardt et al., 2020)
- 4p2z and 3p1z have different base states for variables such as Ωaragonite, important for corals.



# Effect of SAI on calcification in 3p1z and 4p2z

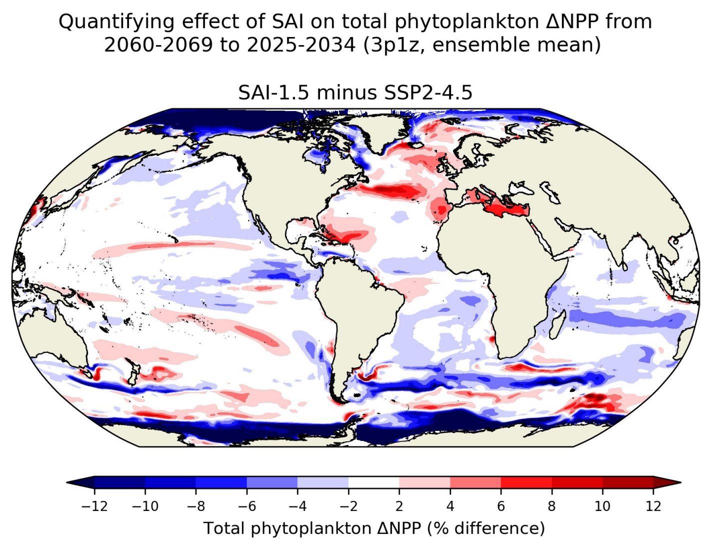
- A lot of similarities, but notable differences.

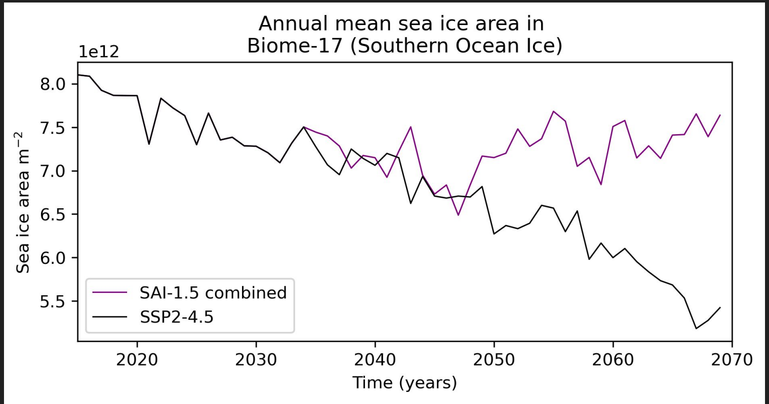


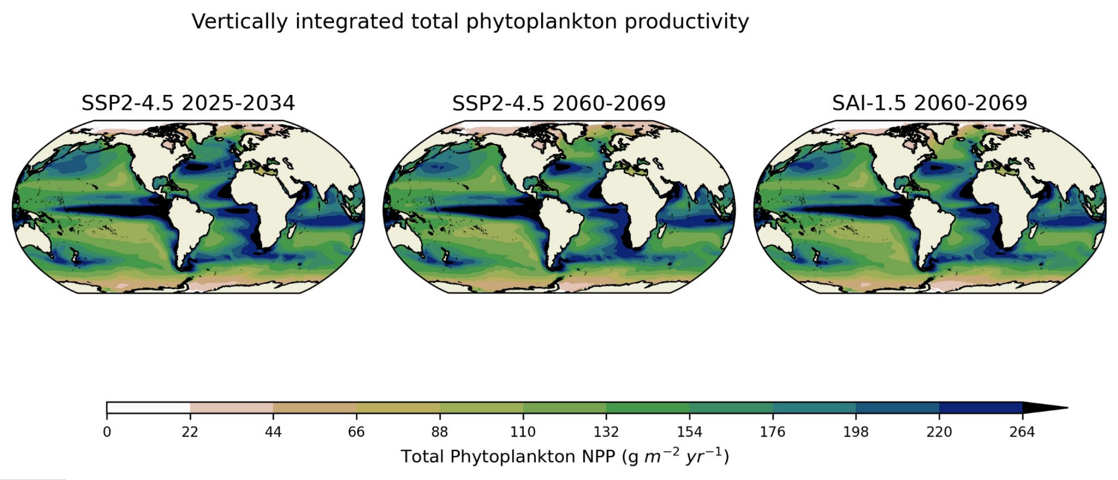



# Phytoplankton response to SAI (3p1z)

- Sea ice rebound under SAI removes gains in productivity at high latitudes



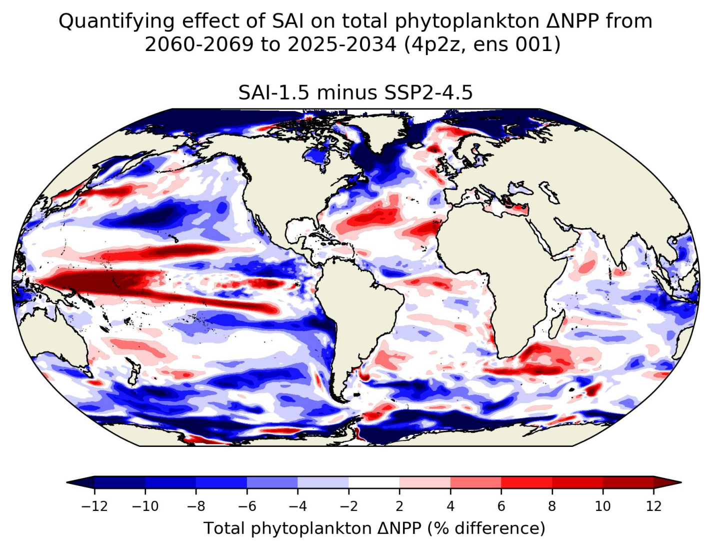



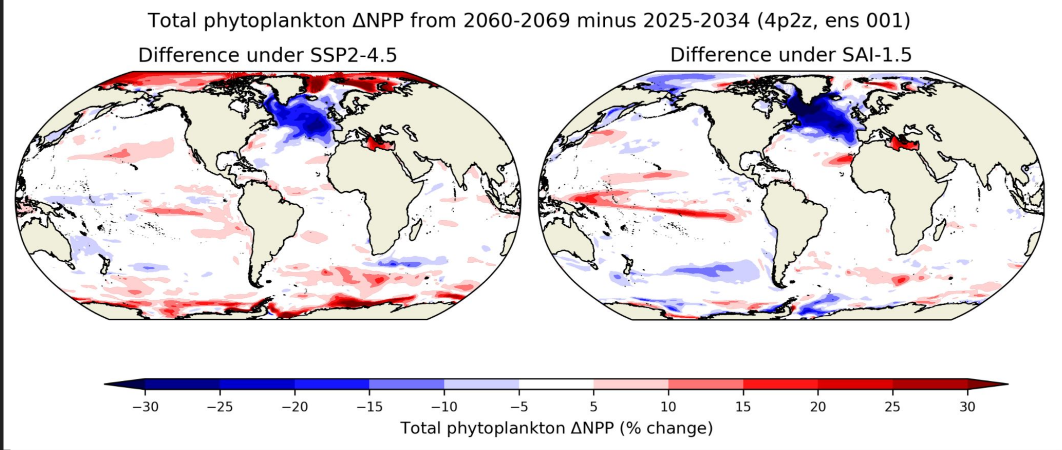



# Phytoplankton response to SAI (4p2z)

- Very similar patterns compared to 3p1z except for the Sargasso Sea decline.

- Decline in productivity under areas with sea ice rebound is obvious, despite only one ensemble member.

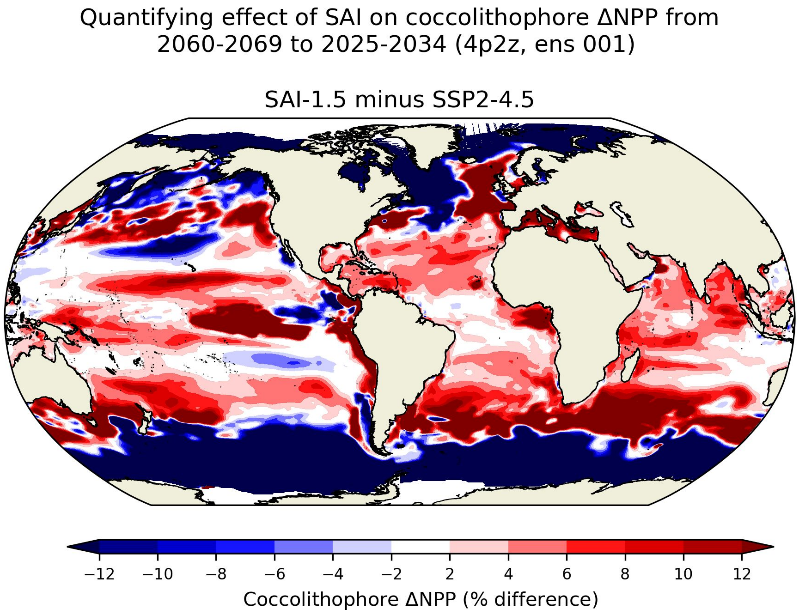


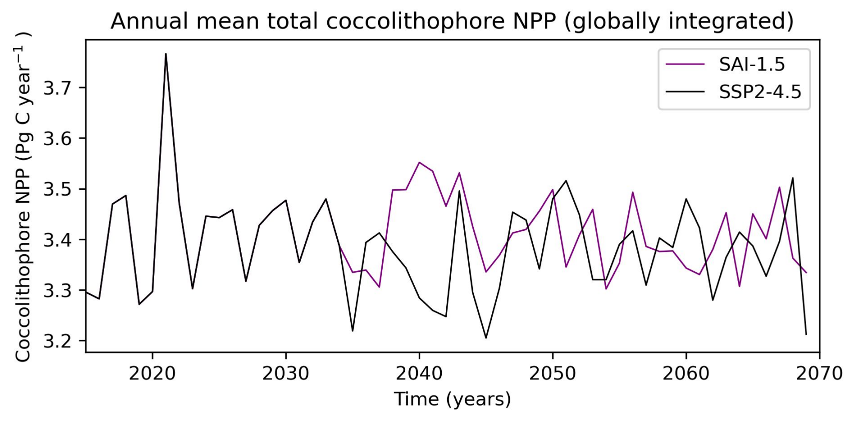



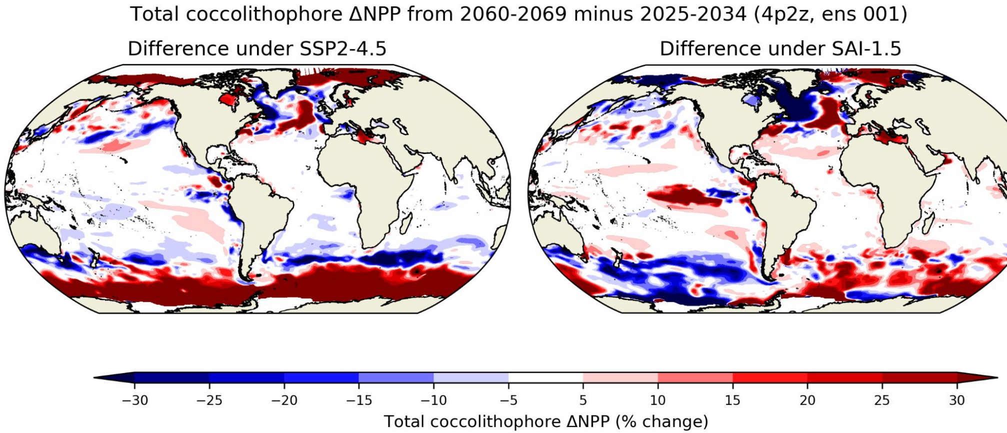
# Coccolithophore response to SAI

- No significant trends in global productivity.

- High regional variability.

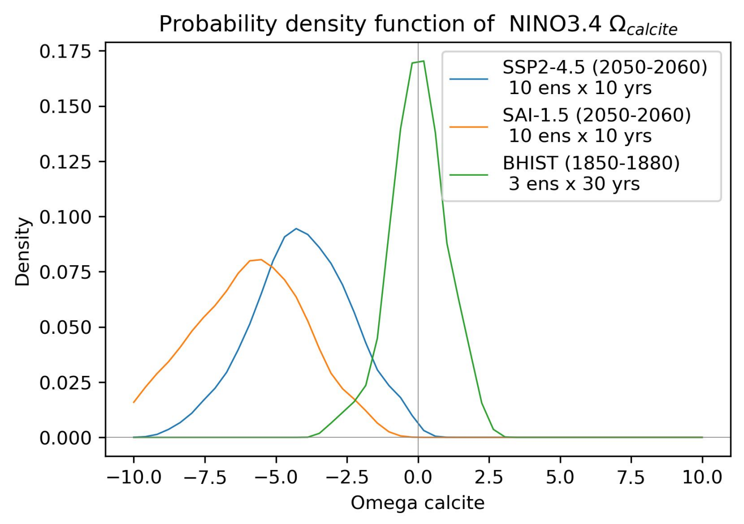


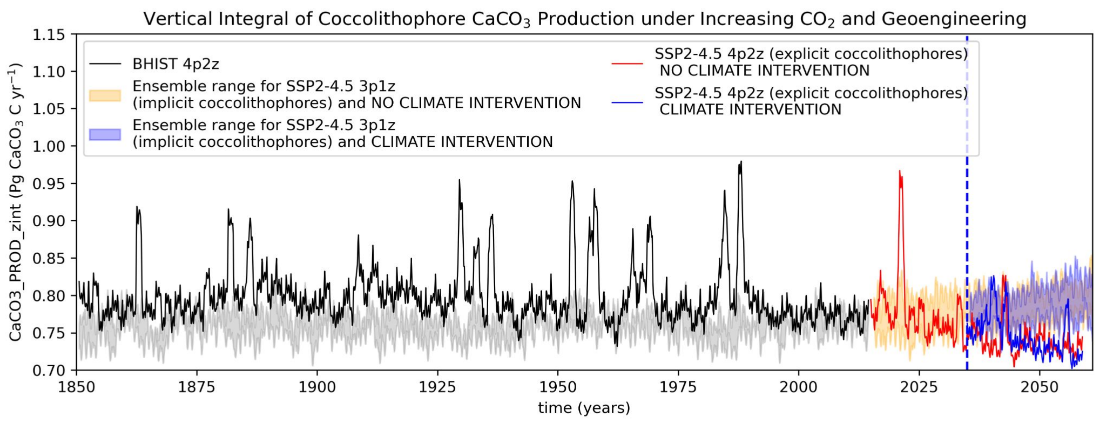



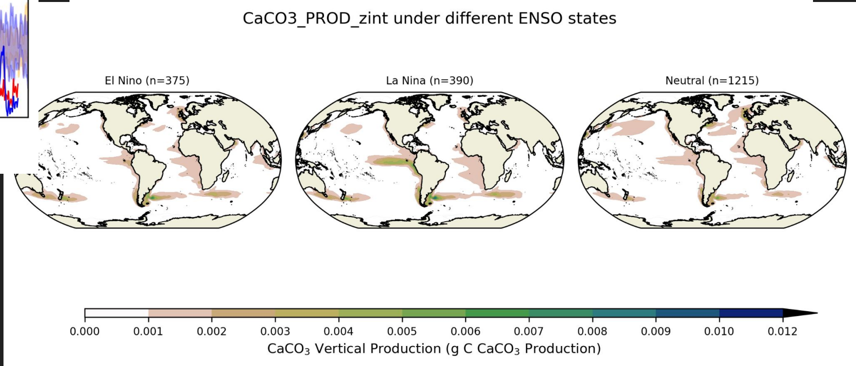



# Calcification signal linked to ENSO region

- Strong signal in Nino3.4 region Ωcalcite, suggesting ENSO can drive global calcification.

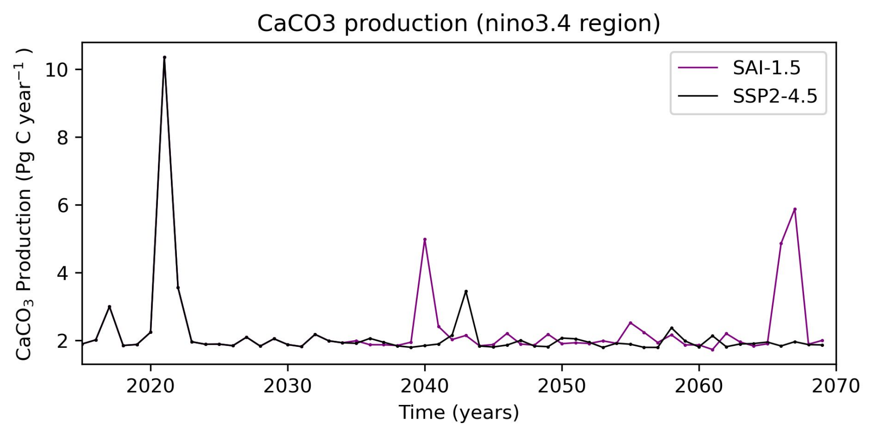


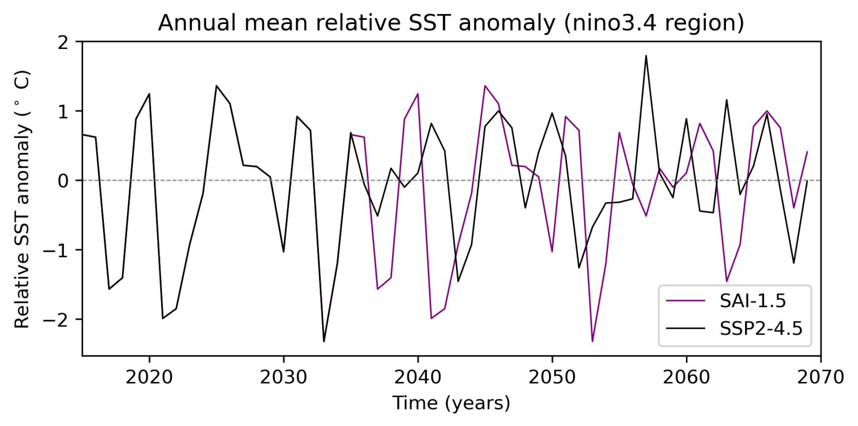



# El Niño effect on coccolithophores

- High amplitude La Niña-El Niño-La Niña swings cause high $CaCO_3$ anomalies that dominate global interannual $CaCO_3$ variability.



# Summary & Conclusions

- SAI can reach simultaneous temperature targets but spatial variability is still present.
- SAI-driven cooling enhances uptake of atmospheric carbon and thins shells of coccolithophores relative to SSP2-4.5.
- Calcification declines overall, productivity remains similar, but very large regional variability in phytoplankton response.