Can Arctic Sea Ice Melting Lead to More Summer Heat Extremes?

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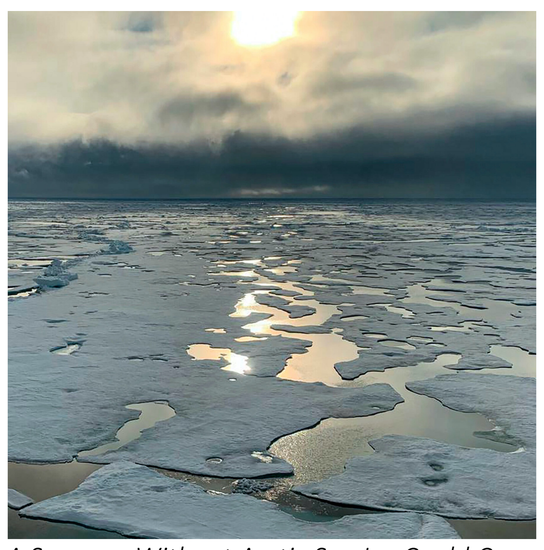
Motivation



A Summer Without Arctic Sea Ice Could Come a Decade Sooner Than Expected
New York Times, 6 June 2023

- **Arctic sea ice cover** in September **has halved** since the 1970s[1]. This trend projects to continue, with models predicting that a high-emission scenario will lead to a **fully ice-free summertime Arctic ocean by 2100**.
- We expect this to impact other parts of the climate in the summer, not only in the Arctic but possibly **worldwide**.
- We want to know what changes to expect, and to understand the **mechanisms** that cause these changes.
- This study uses climate models to examine how **summertime temperatures** and **wind speeds** will likely react to the expected melting of Arctic sea ice over the next century.

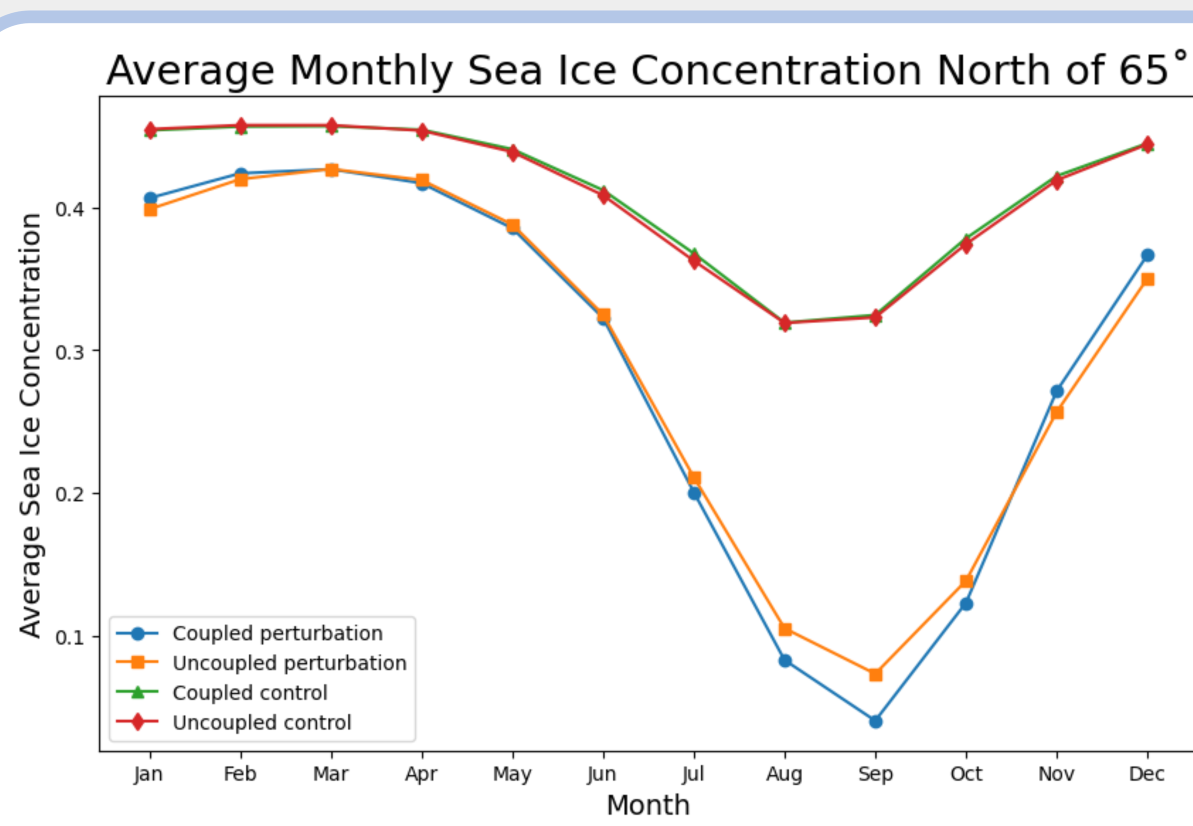
Questions

How does daily average temperature react to melting Arctic sea ice?
- Specifically, we look at 2-meter temperature and 850-hPa (~1.5 km) temperature.
- We examine mean temperatures as well as extreme values.

How does 500-hPa (~5.5 km) zonal wind react to melting Arctic sea ice?
- Zonal wind is wind's eastward/westward component.
- Slower wind can allow weather patterns to stall, increasing the probability of heat extremes.

What is the mechanism that transports these impacts outside the Arctic?
- We use both an atmosphere-only model configuration and an atmosphere-ocean coupled model configuration and examine the differences in output.

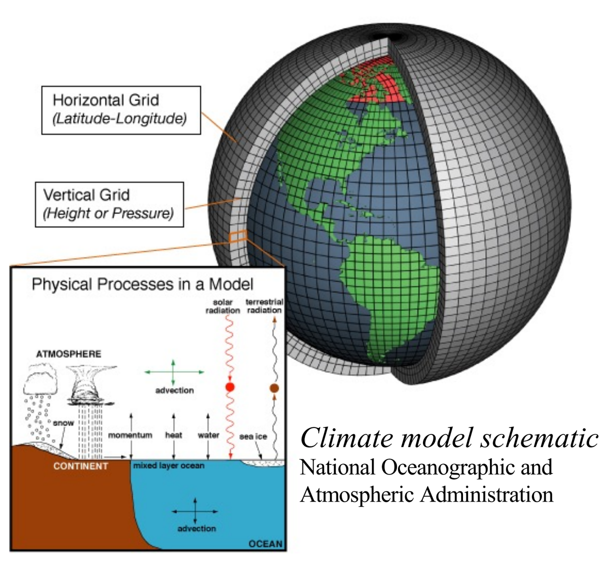
Climate Model Experiments



We have two model configurations, and data from two different experiments on each, for a total of four experiment runs. In the **control runs**, sea ice concentration is set to average values between 1980-1999. In the **perturbation runs**, it is set to projected average values between 2080-2099.

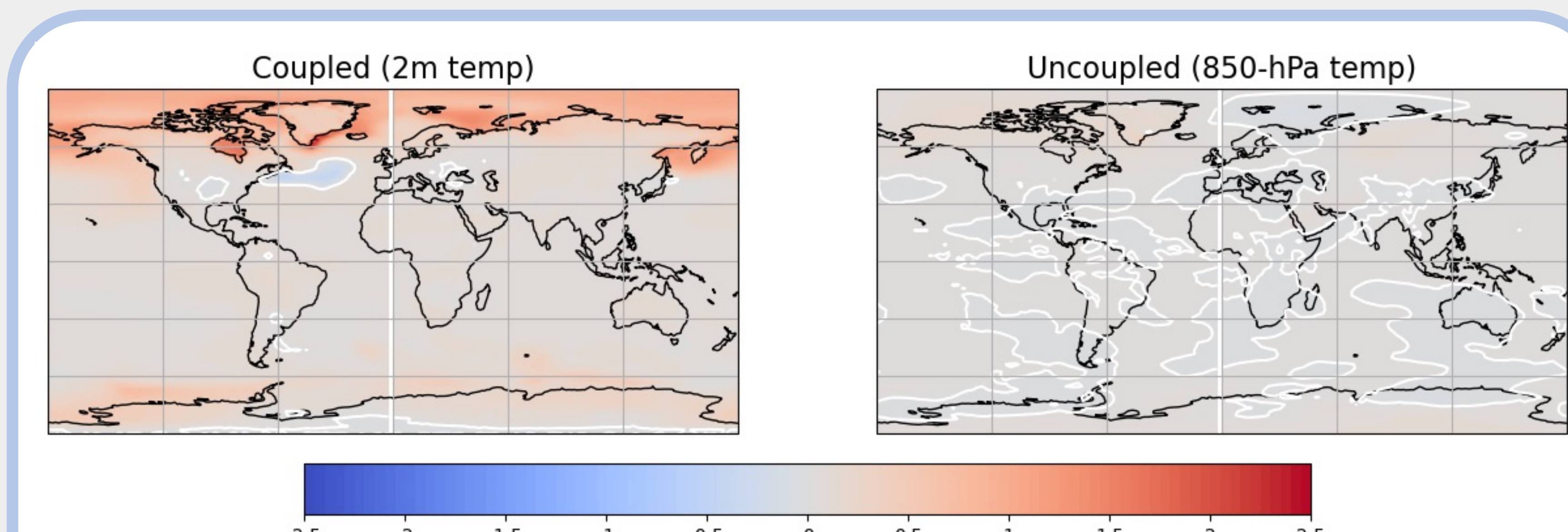
One set of experiments uses an **atmosphere-ocean "coupled"** model configuration[2], which consists of an atmospheric component and ocean component paired together. The other set uses an **atmosphere-only "uncoupled"** configuration[3], which has the same atmospheric component but no ocean component. Differences in output can therefore be attributed to ocean dynamics.

The models were run for 100 years to let the variables reach equilibrium at the new sea ice level. Then, 200 years of daily-average data for temperature and wind speed were recorded.

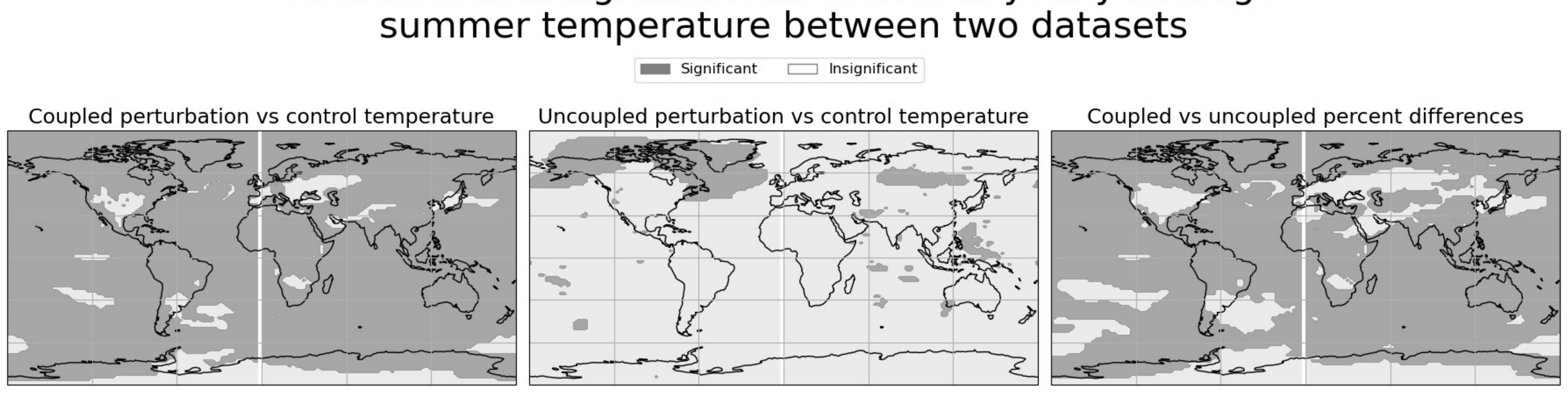


Climate model schematic
National Oceanographic and Atmospheric Administration

Change in Temperature Means



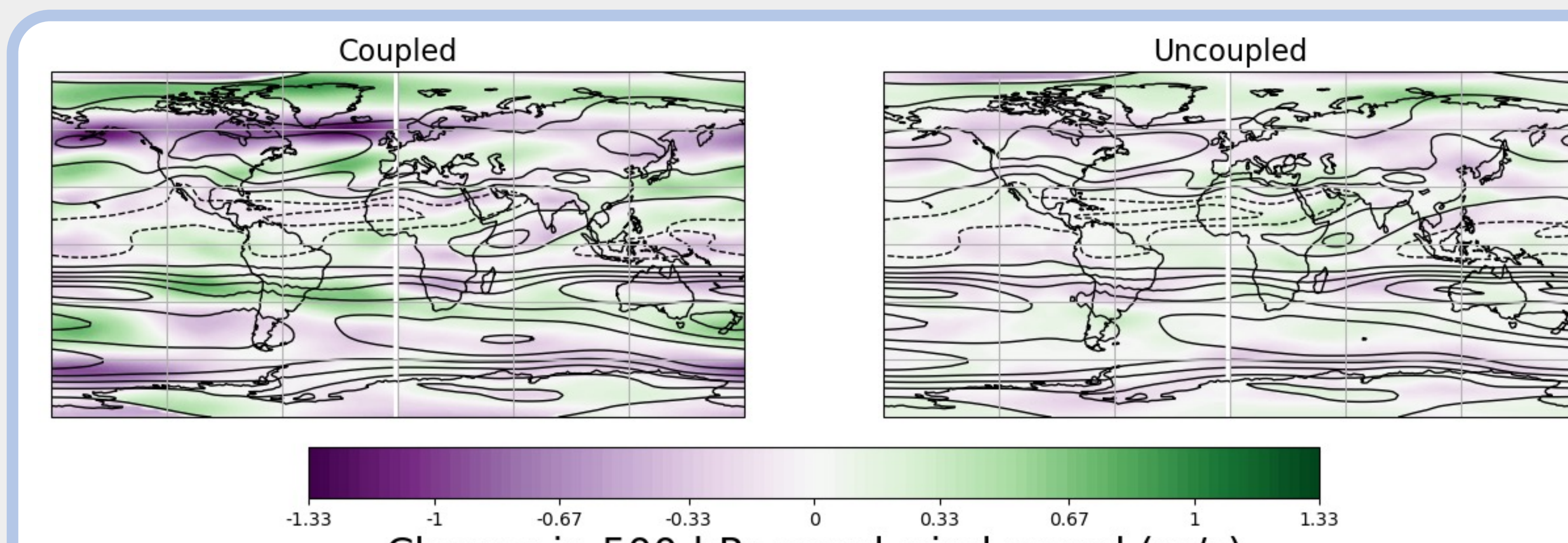
- We only have 2-meter temperature data in the coupled runs, and 850-hPa (~1.5 km) temperature data in the uncoupled
  - To compare, we assume that temperature changes at the same rate in these different levels of the atmosphere.
- Regions of zero change are marked with white contour lines.
- We see generally **rising temperatures in the coupled experiments**, with **amplification in the Arctic**.
  - Particular regions of interest are the southern tip of Greenland (strongest increase) and the area directly south of it (strongest decrease).
- Responses are more varied and less amplified in the uncoupled experiments.



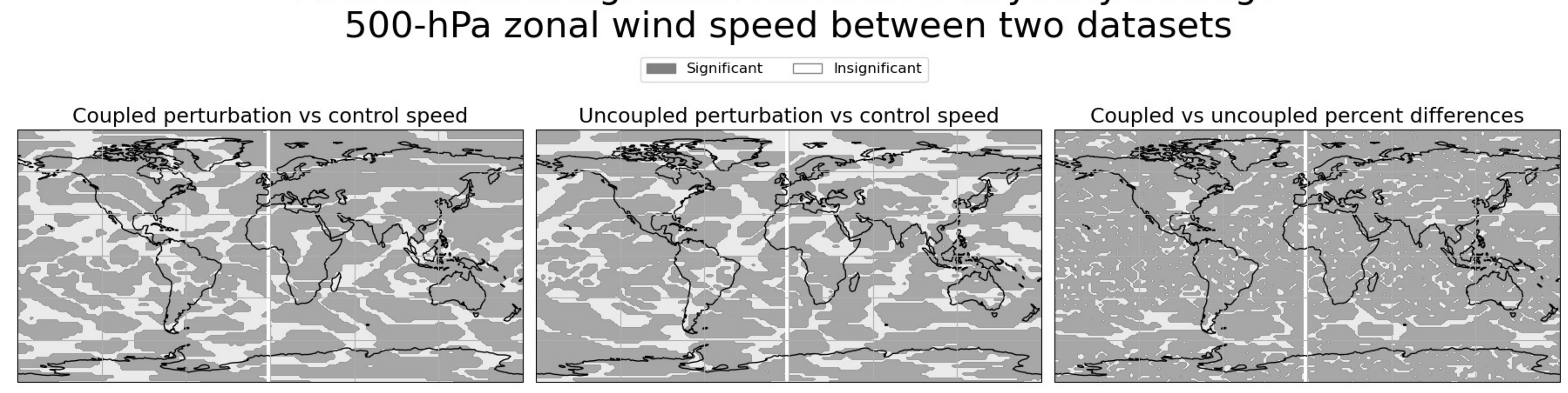
Using paired t-tests, we find that Earth's surface sees
- 92.4% significant differences between the coupled runs
- 7.6% significant differences between the uncoupled runs
- 83.6% significant differences between the coupled difference and the uncoupled difference.

This indicates that the **dominant driver** of temperature increase is **ocean-related**.

Change in Wind Speed Means



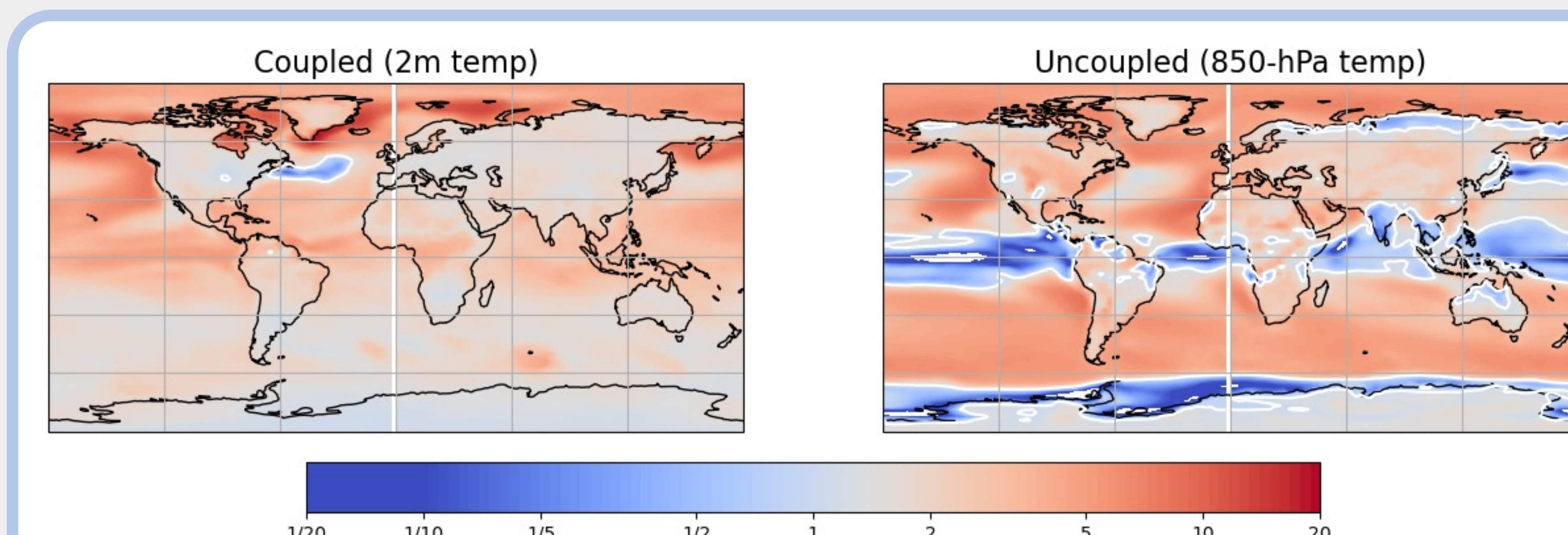
- Contour lines indicate climatology -- solid lines are westerly winds (west-to-east), and dashed lines are easterly.
- Over **North America** in the coupled configuration, we can see that the **jet stream shifts equatorward**, as winds are slowing down north of the peak and speeding up south of it.
  - This **aligns with the increase in temperature at the southern tip of Greenland**, where wind weakens, **and with the cooling south of it**, where it strengthens.



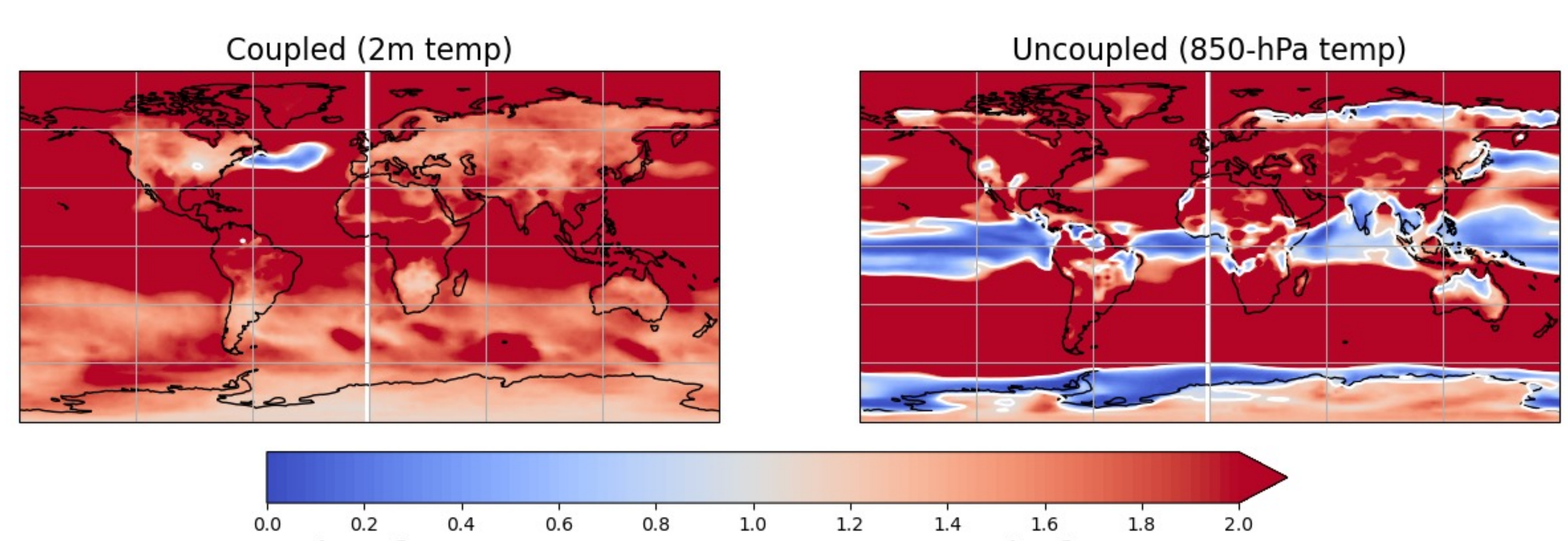
Using paired t-tests, we find that Earth's surface sees
- 66.5% significant differences between the coupled runs
- 66.2% significant differences between the uncoupled runs
- 78.7% significant differences between the coupled difference and the uncoupled difference.

This indicates that the **atmosphere and ocean both play a role** in driving this change.

Change in Temperature Extremes



- We define an extreme temperature value to be one that exceeds the 95th percentile of deviation from the control run's mean temperature on that day of the year.
- In the **coupled experiments**, we generally see **increases in the frequency of extremes**.
  - They increase **more steeply over the ocean**, but they also increase over land.
  - **Central/South America, Africa, and Southeast Asia** see the strongest land-based increases.
  - Near the Southern tip of Greenland, over 90% of temperatures in the perturbation run qualify as extreme.
- Results in the uncoupled experiments are more varied.
- Below, we cap the colorbar at 2 to more clearly show what's happening on land.



Conclusions

- **Temperatures increase globally** in response to melting Arctic sea ice, most strongly in the upper 30˚.
  - **Ocean coupling is necessary** to see this global increase.
- Wind speeds change globally as well, most notably with the **northern hemisphere's polar jet stream shifting equatorward**.
  - Ocean coupling leads to stronger changes, but they're **still significant in the atmosphere-only model**.
- The **shifting jet stream** above North America is **associated with the sharpest changes in temperature** observations.
- Many regions over the **ocean** experience **dramatic changes** in frequencies of extremes.
- **Central/South America, Africa, and Southeast Asia** see particularly big increases in extremes.
- The rest of the world experiences less drastic increases in extremes.

References

1: Perovich, D. et al. Sea ice cover. *Bull. Am. Meteorol. Soc.* **98**, S131–S133 (2017).
2: Danabasoglu, G. et al. The CCSM4 Ocean Component. *J. Clim.* **25**, 1361-1385 (2012).
3: Sun, L. et al. Mechanisms of Stratospheric and Tropospheric Circulation Response to Projected Arctic Sea Ice Loss. *J. Clim.* **28**, 7824-7845 (2015).