Stratospheric Connection to Arctic Sea Ice Coverage

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1. Overview

The downward coupling of stratospheric circulation anomalies related to stratospheric sudden warmings (SSWs) into the troposphere can create persistent (~2 months) anomalies in the state of the North Atlantic Oscillation (NAO). This long persistent time scale may be capable of impacting climate components that have a much longer time scale than the atmosphere. Indeed, previous research demonstrated that the very low-frequency component of stratospheric circulation anomalies can induce changes in the ocean and its circulation (Reichler et al. 2012, Waugh 2014).

In the present research we are interested in the impact of SSW related intraseasonal NAO fluctuations on the coverage of Arctic sea ice. Previous research by Deser et al. (2000) already demonstrated that the dominant pattern of winter (January-March) sea ice variability is associated with the NAO. Here, we want to find out whether the impact of SSWs on the NAO is strong and long enough to affect Arctic sea ice. A related question is whether the increased frequency of SSWs during the 2000s is consistent with the rapid decrease in Arctic sea ice during this time.

2. Method

We analyze observations of sea ice, NCEP/NCAR reanalysis, and a long control integration with a stratospherically-enhanced version of the GFDL CM2.1-L48 climate model:

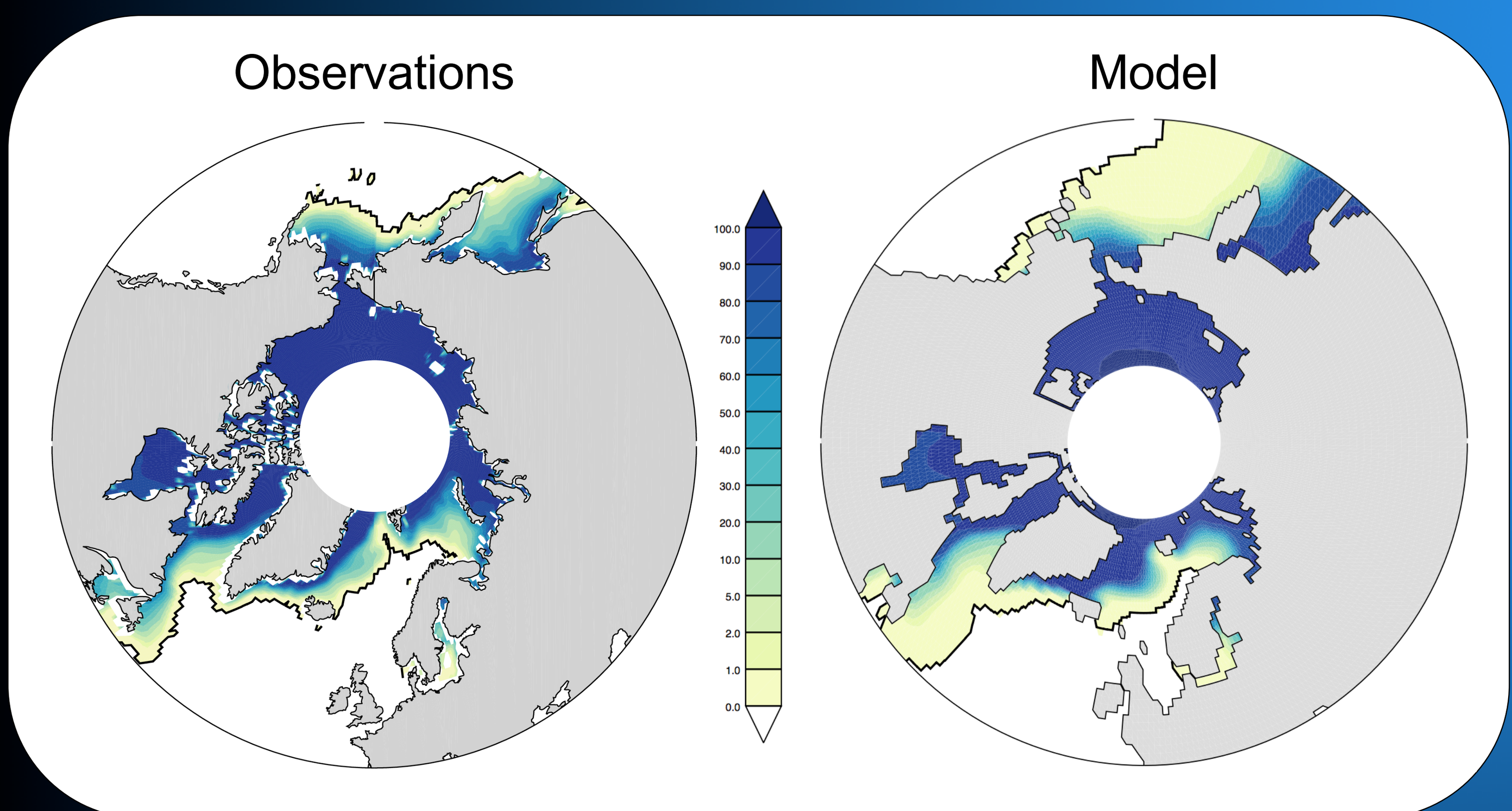
- daily NCEP/NCAR reanalysis (1979-2014)
- daily observed sea ice from NASA and NSIDC (Cavalieri et al. 1996) (1979-2014)
- GFDL climate model CM2.1-L48: control run (7100 years)

In the detection of SSWs we follow the "WMO criterion", which is based on a reversal of the zonal mean zonal wind at 10 hPa and 60N. We form SSW composites from both observations and the model:

- observations: 22 SSWs (61%)
- model: 4017 SSWs (66%)

3. Sea Ice Climatology I_c Before SSWs

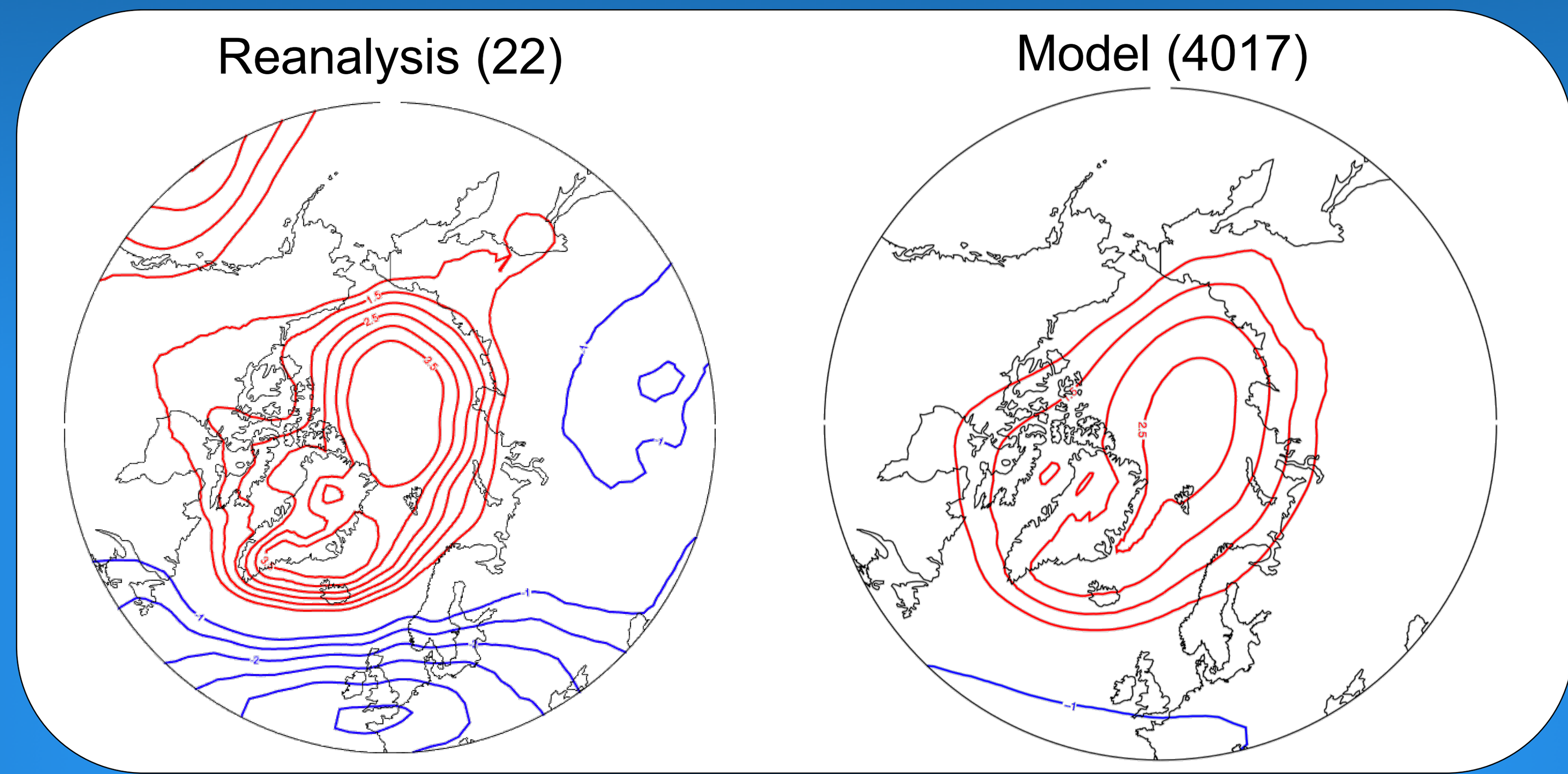
We compare the sea ice coverage at day 0-5 of SSWs from observations and the model. The model simulated ice coverage is fairly realistic. These distributions represent the base line against which we compare the subsequent ice changes.



4. Surface Response to SSWs (days 5-60)

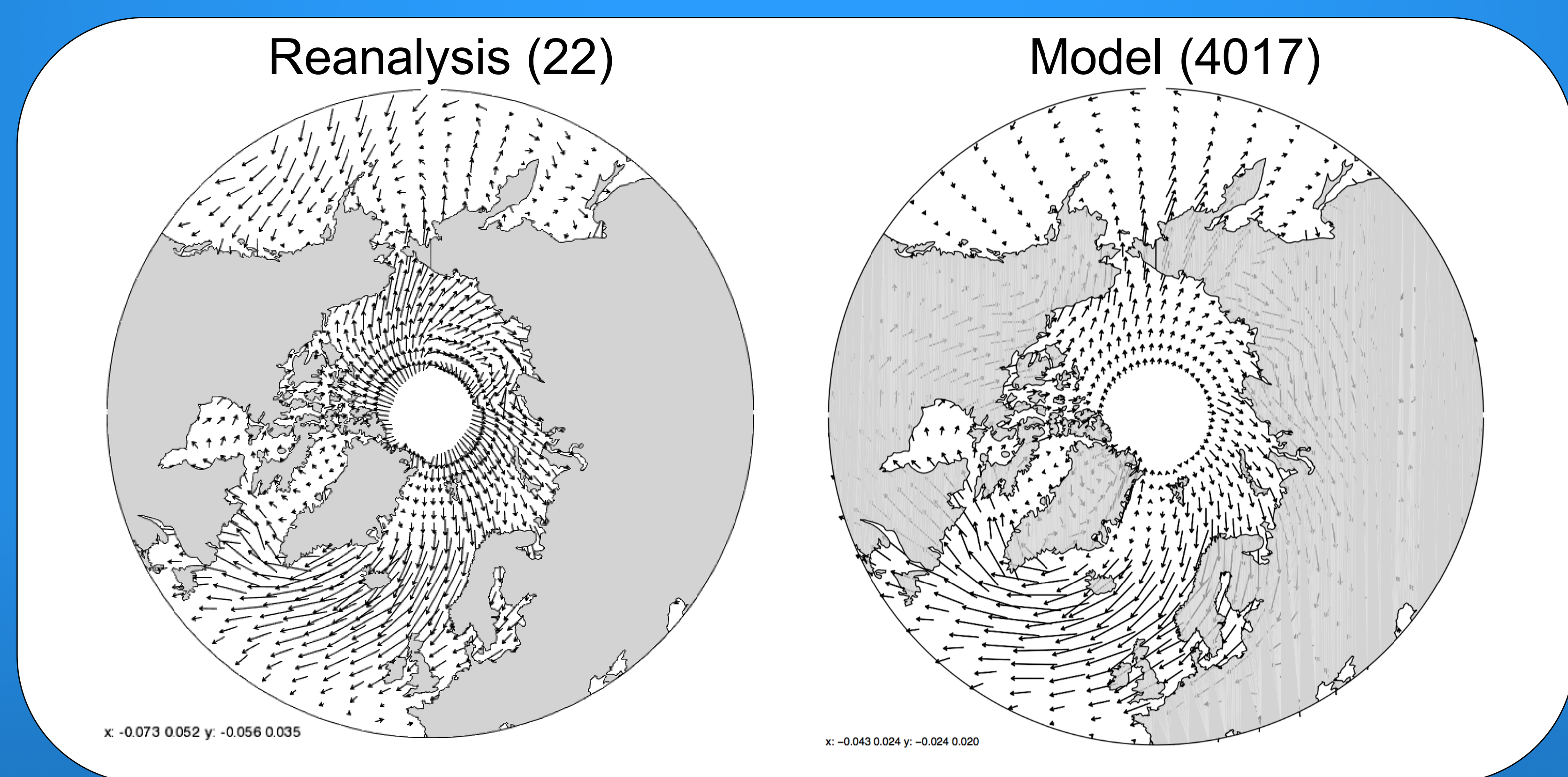
a. Sea Level Pressure (SLP)

The SLP response in the reanalysis exhibits the well-known negative phase of the NAO, with pressure anomalies reaching values of +/- 3 hPa. The model exhibits a similar but weaker response. This may be interpreted as a model deficiency, but it also may be related to taking an average over a much larger ensemble of events.



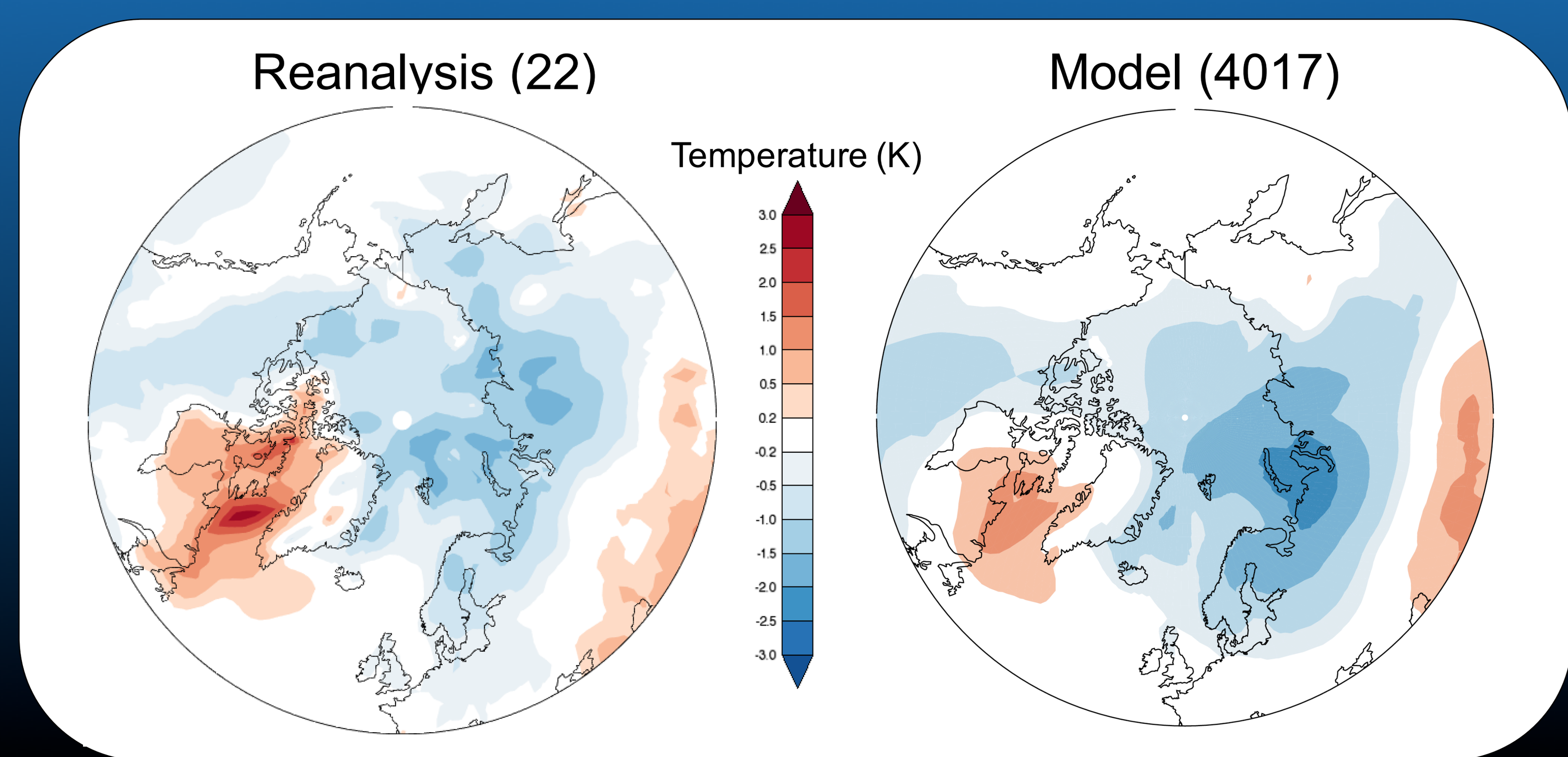
b. Wind stress & dynamic ice changes

The wind stress anomalies are consistent with the negative phase of the NAO and the SLP anomalies in (a). The magnitudes of the vector anomalies amount to about 10% of the respective climatologies. The model simulated wind stress response is again very similar to the reanalysis, except over the N-Pacific. These wind stress anomalies are expected to induce **dynamical changes** in sea ice coverage.



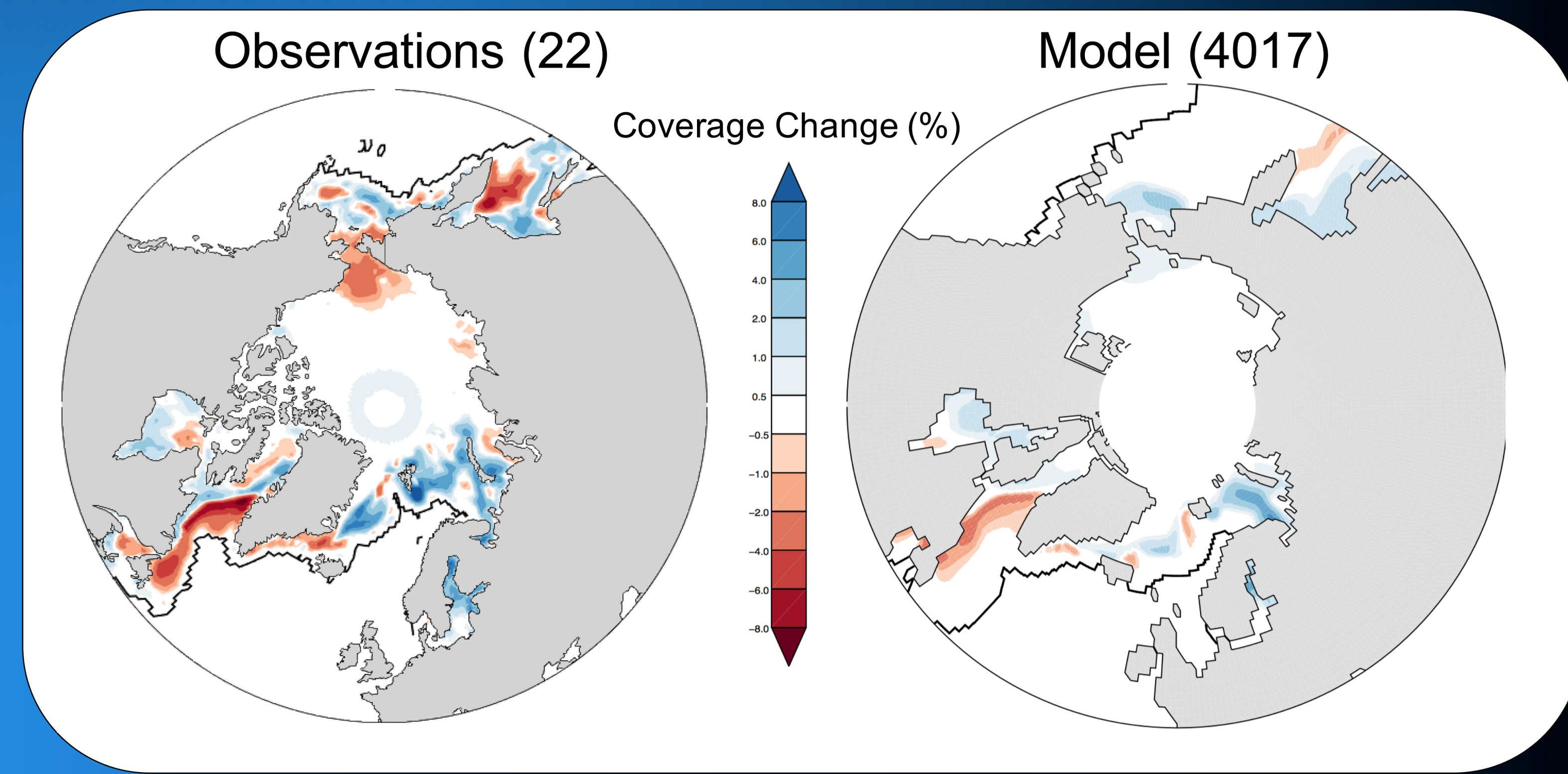
c. Temperature & thermodynamic ice changes

The model simulated temperature anomalies are realistic. These anomalies must be due to (1) ice changes and/or (2) anomalous temperature advection. (2) may induce **thermodynamic changes** in sea ice.



5. SSW / Sea Ice Relationship

Shown are SSW composite of anomalous sea ice coverage: days 5-60 minus days 0-5. The changes amount to ±10% of the climatology, and they occur mostly at fringes of ice edge (black line). SSWs do not induce a net change in sea ice coverage, only a redistribution of sea ice with increase and decrease in sea ice coverage being about the same. The model simulated sea ice response is again realistic, but the amount of change in reduced compared to the observations. This is expected given the weaker atmospheric surface response shown in (4).



6. Dynamical Ice Changes

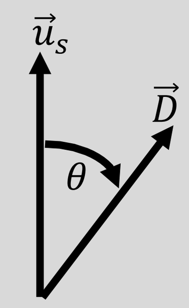
We next ask whether the sea ice response shown in (5) is due to anomalous advection of sea ice (=4b), thermodynamic influences (=4c), or due to a combination of both. To this end we construct a simple advection model, in which changes in sea ice are solely produced by anomalous surface winds $\vec{u}_s$' acting on the climatological sea ice distribution I_c shown in (3).

Simple advection model

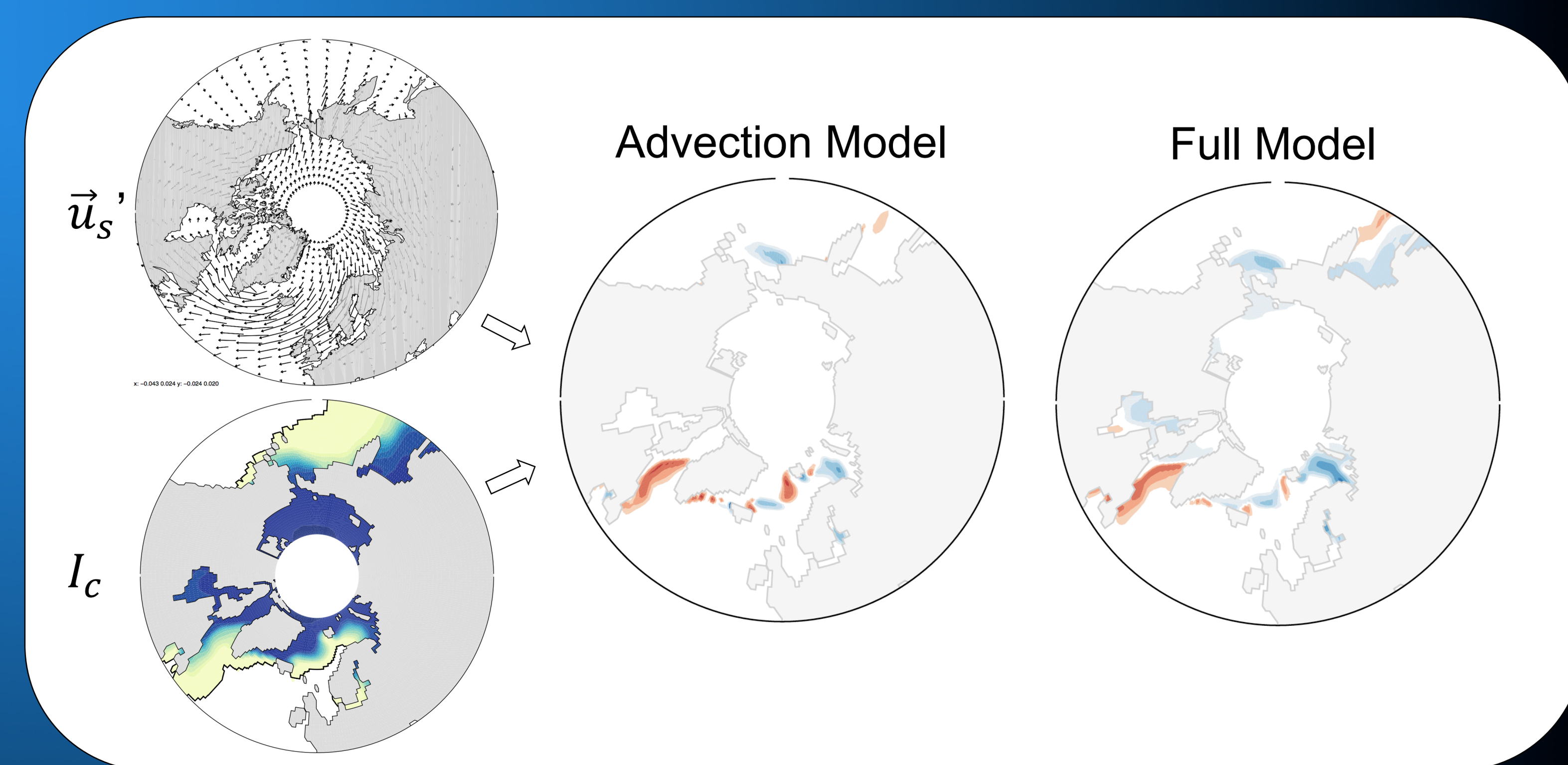
$$\frac{\partial I}{\partial t} = -\vec{D} \cdot \vec{\nabla} I_c$$

$$\vec{D} = \vec{u}_s{}' \, 0.01 \, \frac{100 - I_c}{100} e^{i\theta} \quad \text{(drift vector)}$$

$$\theta = -25°$$



The simple advection model explains most of the actual ice changes:



7. Conclusion

Stratospheric extreme events have a demonstrable impact on Arctic sea ice. This impact is consistent with a negative NAO following SSWs. The stratosphere may induce dynamical ice change related to ice drift due to anomalous wind stress, and thermodynamical ice change related to changes in ice production due to temperature advection. The dynamical and thermodynamical changes both work in tandem, but our simple advection model suggests that the dynamical effect dominates. Regions with increase and decrease in sea ice due to SSWs cause no net change in ice coverage. We conclude that the sea ice decline during the 2000s is unlikely to be caused by the unusual stratospheric circulation during that time.

8. References

- Cavalieri, D. J., C. I. Parkinson, P. Gloersen, and H. J. Zwally, 1997: Arctic and Antarctic Sea Ice Concentrations from Multichannel Passive-microwave Satellite Data Sets: October 1978 to December 1996, User's Guide. NASA Technical Memorandum 104647, 17 pages.
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