Winter sea ice projected to decrease but remain sensitive to the North Atlantic Oscillation

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1 Motivation

There is strong observational evidence that interannual winter sea ice concentration variability in the North Atlantic is forced by the North Atlantic Oscillation (NAO) (Deser et al. 2000; Venegas and Mysak 2000; Deser and Teng 2008). Modeling studies indicate that NAO-forced sea ice variations in turn provide a negative feedback onto the NAO (Magnusdottir et al. 2004; Deser et al. 2004; Kvamsto et al. 2004; Deser et al. 2007). Here, we consider how the sea ice-NAO relationship changes in a warming environment by examining January-March mean data in two runs of the NCAR Community Climate System Model version 3 (CCSM3): a 500-year control run at 1990 conditions and a 21^{st} century run forced by the IPCC A1B greenhouse gas scenario.

2 Sea ice and the NAO: control run

Similar to observations, the control run of the CCSM3 has a dipole leading EOF of sea ice concentration (Fig. 1a), with centers of action in the Labrador and Barents Seas. The principal component of this leading sea ice concentration EOF is significantly correlated ($r = 0.45$) with the NAO index (Fig. 1b).

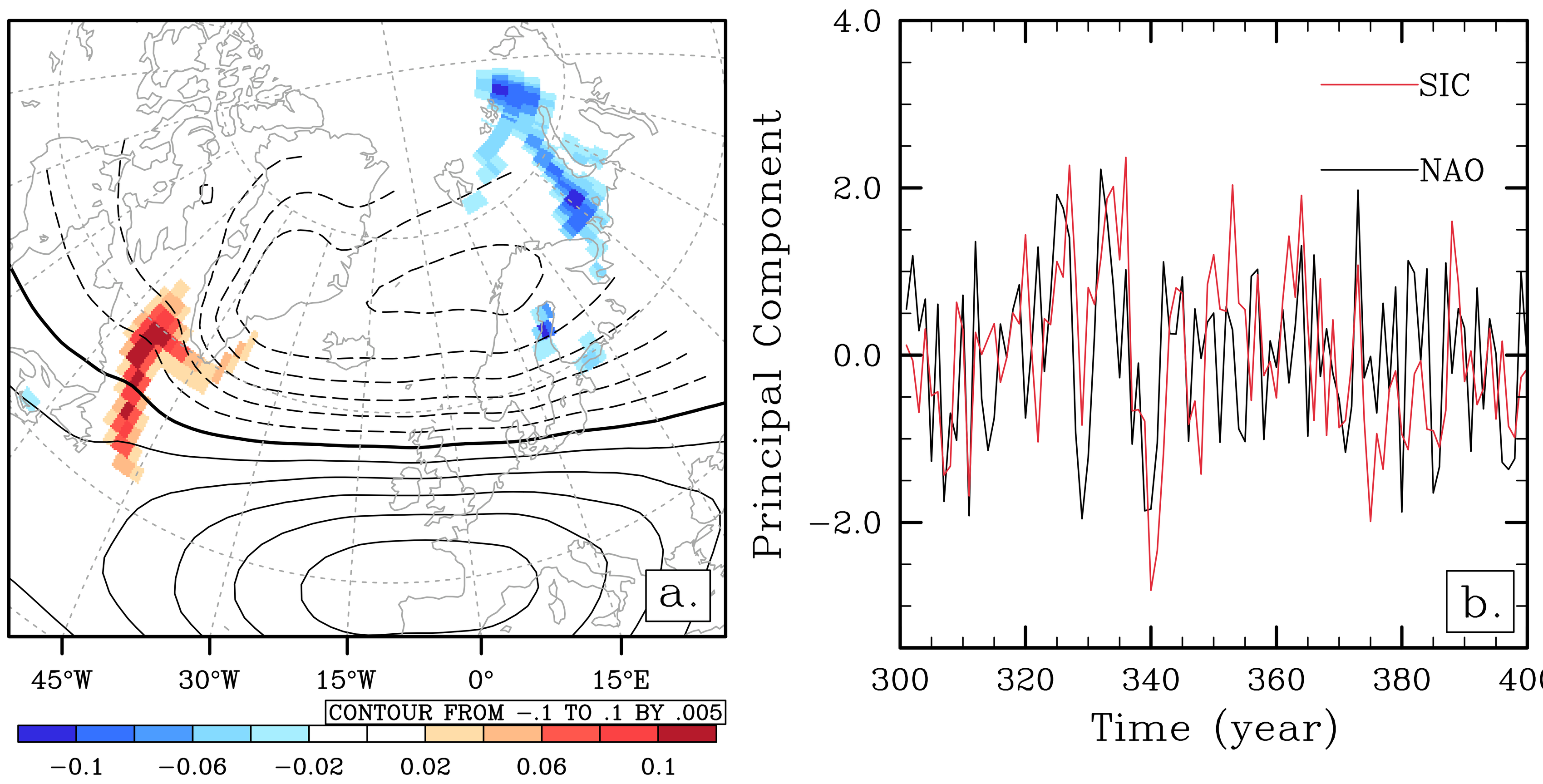

Figure 1: For January-March means in the control run: (a) Contouring shows the leading EOF of sea-level pressure which is the loading pattern for the NAO index with negative values dashed, and shading shows the leading EOF of sea-ice concentration. (b) SIC is the principal component associated with the sea ice EOF in panel a and the NAO is the principal component associated with the sea-level pressure EOF in panel a.

The surface wind anomalies associated with the positive polarity of the NAO force two phenomena that account for the ice diplole. First, the positive NAO is associated with anomalously equatorward fluxes of sea ice into the Labrador Sea and poleward fluxes of sea ice out of the Barents Sea (vectors, Fig. 2a). The shading in Fig. 2a shows the correlation between the NAO and changes in sea ice area due to dynamic processes $(\partial a_i/\partial t)_d$, which includes sea ice convergence. As implied by the sea ice velocity anomalies, $(\partial a_i/\partial t)_d$ is positive (negative) over the Labrador (Barents) Sea. Second, considering heat flux integrated over the depth of the oceanic mixed layer ($\mathbf{F}$), the postive polarity of the NAO supports $\mathbf{F}$ anomalies into the Barents Sea and out of the Labrador Sea. As a result, basal ice growth is decreased (increased) through the marginal ice zone within the Barents (Labrador) Sea (Fig. 2b).

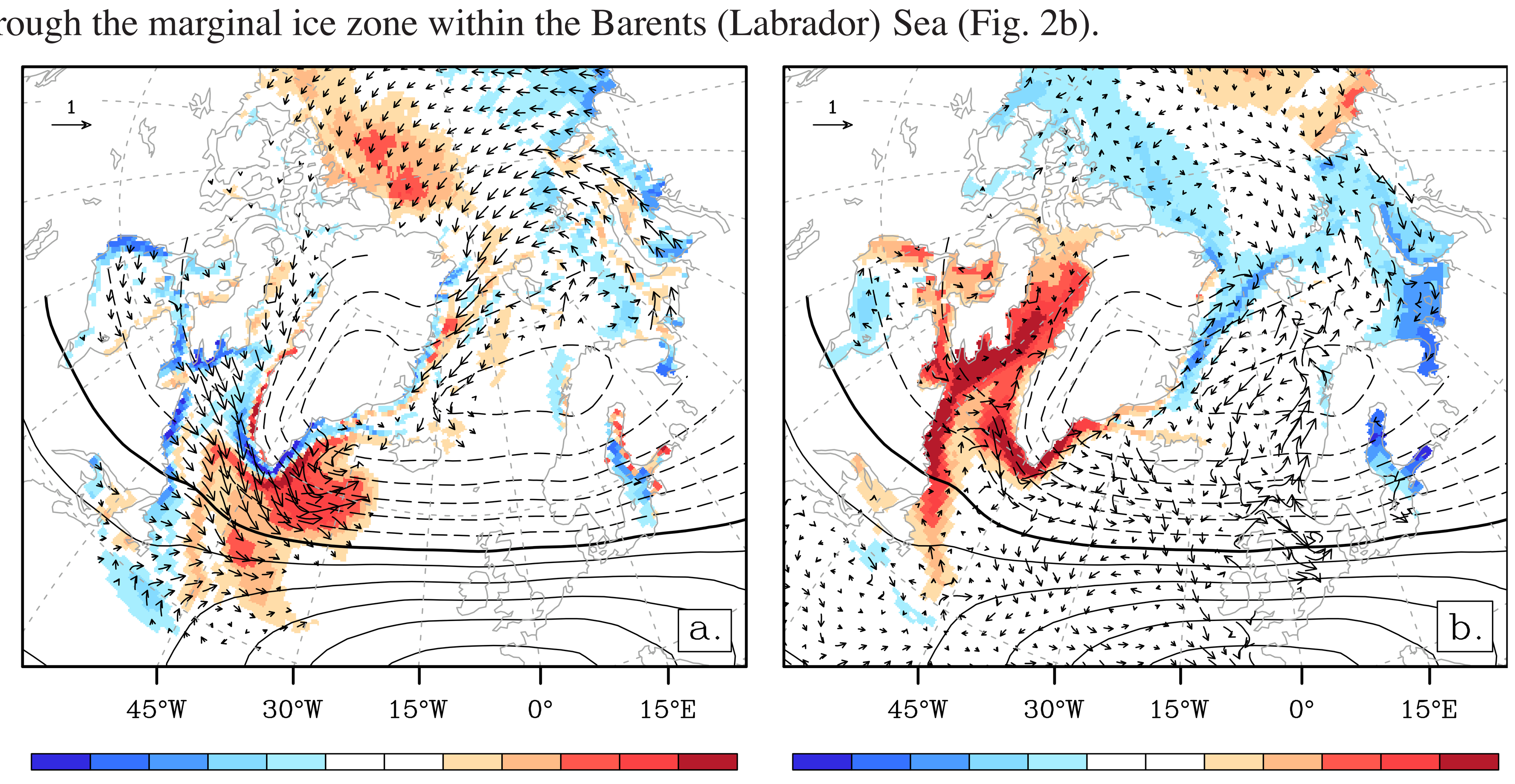

Figure 2: Both panels are for the control run and have the loading pattern of the NAO contoured. a. Vectors show the correlation between the NAO and components of sea-ice velocity, and shading shows the correlation between the NAO and the change in sea ice area due to sea-ice dynamics. b. Vectors show the correlation bewteen the NAO and components of heat flux integrated over the depth of the oceanic mixed layer, and shading shows the correlation between the NAO and basal ice growth.

3 Sea ice and the NAO: 21^{st} century run

In the A1B forced run, poleward oceanic heat transport results in a loss of winter sea ice over much of the marginal ice zone, as indicated by the leading EOF of sea ice concentration (shading, Fig. 3a) and its principal component (red line, Fig. 3b). This sea ice loss is well-correlated ($r = 0.94$) with the leading principal component of oceanic heat flux integrated through the depth of the mixed layer (black line, Fig. 3b). The EOF associated with this leading heat flux principal component (vectors, Fig. 3a) indicates enhanced heat flux poleward along the eastern side of the North Atlantic basin and equatorward along the western basin.

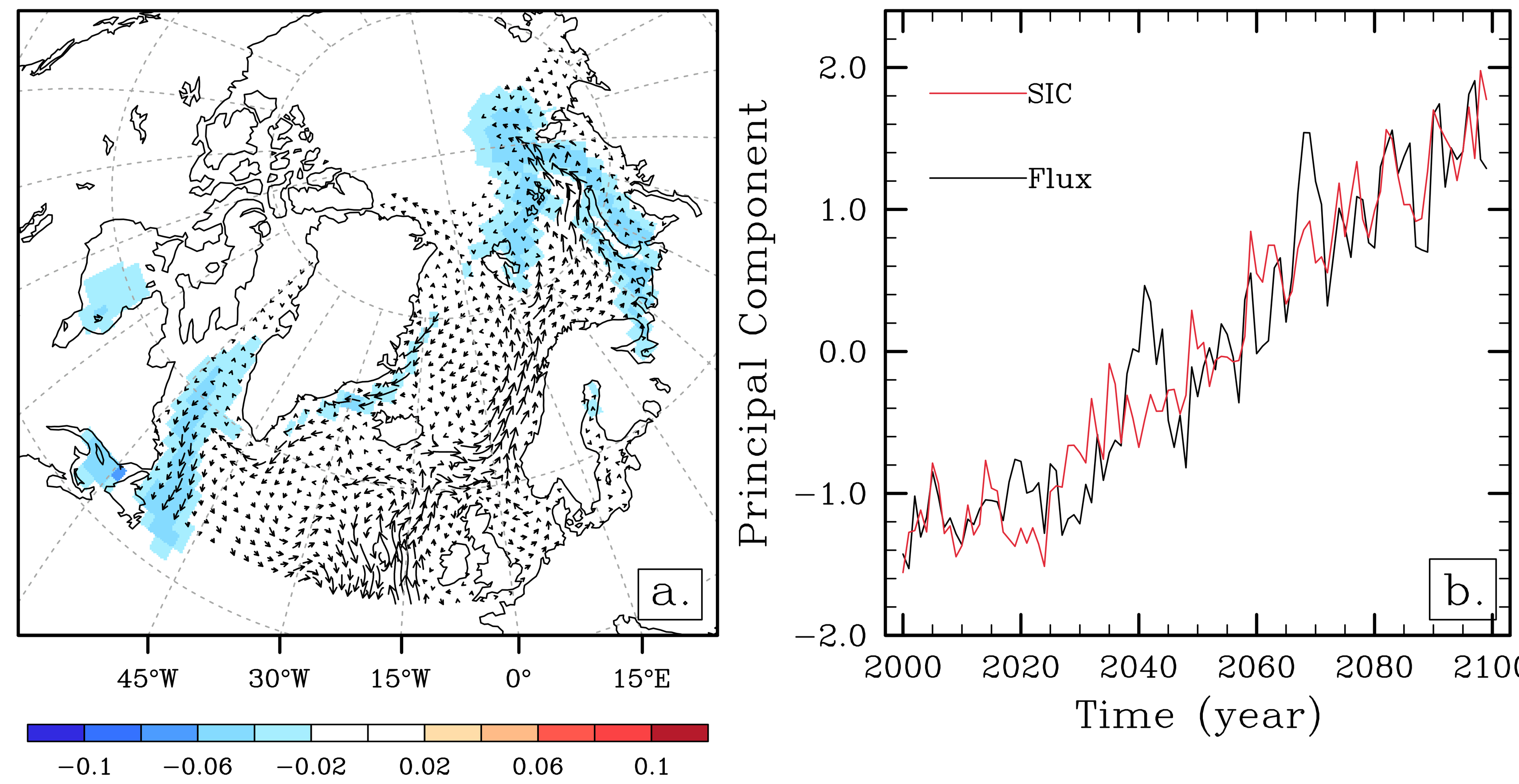

Figure 3: For the A1B run: a. shading shows the leading EOF of sea ice concentration and vectors show the leading EOF of heat flux integrated over the depth of the oceanic mixed layer. b. SIC is the principal component associated with the sea ice EOF in panel a and Flux is the principal component associated with the oceanic heat flux EOF in panel a.

The second EOF of sea ice concentration in the forced run (Fig. 4a) has a dipole configuration resembling control EOF 1, but the Labrador Sea center of action is stronger and expanded westward toward the Canadian coast, and the Barents Sea center of action is weaker and shifted southeast toward the Russian coast. The principal component associated with this second sea ice EOF is significantly correlated ($r = 0.50$) with the forced NAO (Fig. 6b).

The expanded Labrador Sea center of action is consistent with the idea that wind-driven sea ice concentration variability over the Labrador Sea is occurring over a broader region because of the contracted marginal ice zone. The weakening of the Barents Sea center of action is consistent with the idea that poleward surging of oceanic heat flux associated with the A1B forcing (Fig. 3) overwhelms the heat flux anomalies associated with the NAO-driven oceanic heat flux pattern (Fig. 2).

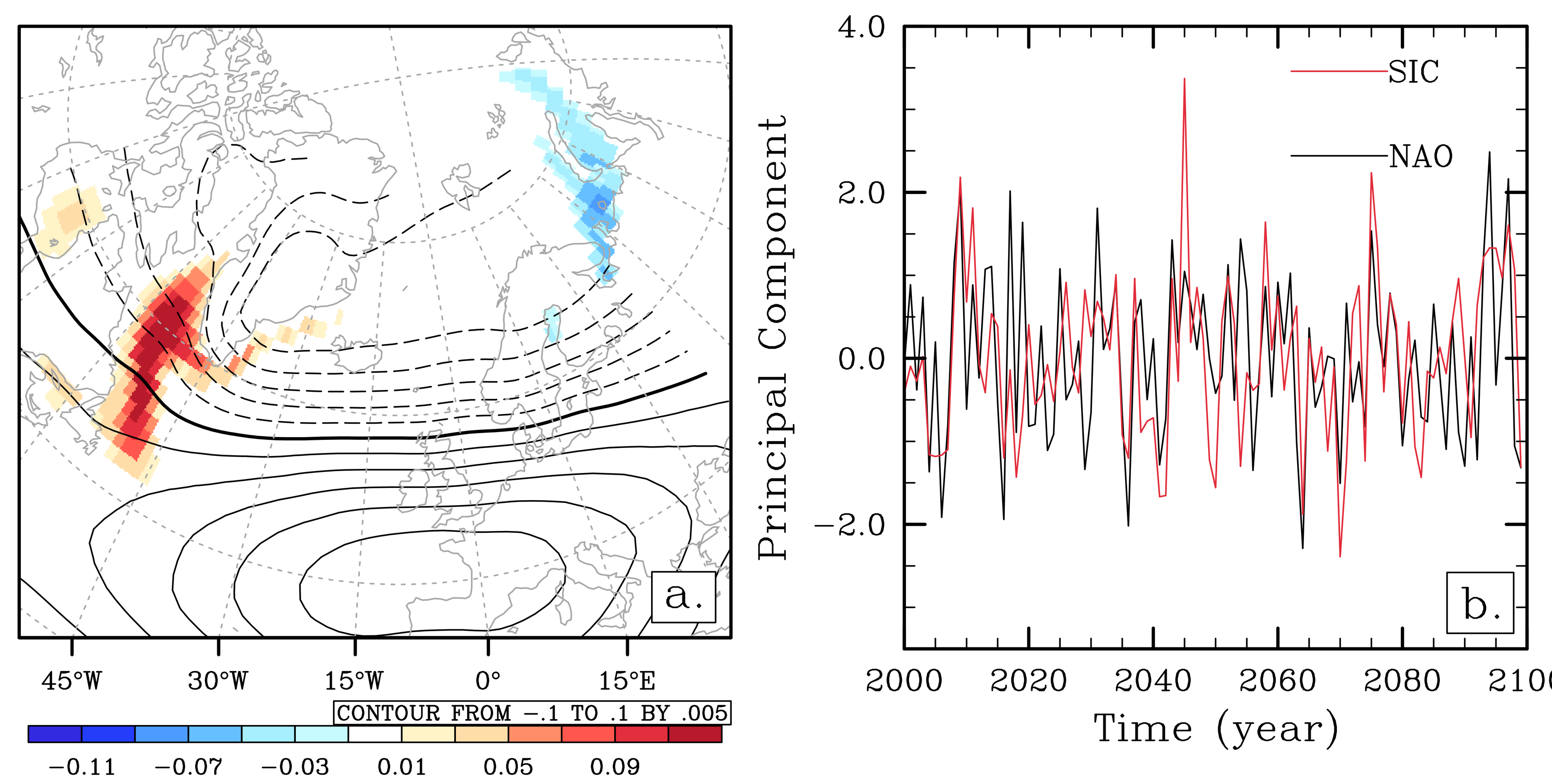

Figure 4: Same as Fig. 1, but for the A1B run.

4 Conclusions

- Similar to observations, the control run NAO surface winds support a dipole leading EOF of sea ice concentration by forcing sea ice velocities over the Labrador Sea and oceanic heat flux anomalies into the Norwegian Current
- Under the 21^{st} century A1B scenario, the leading sea ice concentration EOF reflects loss around the entire Atlantic marginal ice zone in association with a poleward flux of heat in the ocean
- The second EOF of forced sea ice concentration resembles the dipole pattern of the leading control run EOF except:
  - The Labrador Sea center of action is stronger and expanded toward the Canadian coast because of the contracted marginal ice zone
  - The Barents Sea center of action is weakened and shifted southeast toward the Russian coast because the poleward surging of oceanic heat flux associated with the A1B forcing overwhelms the NAO-driven heat flux pattern

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