Response of a Coupled Ocean-Atmosphere Model to Greenland Ice Melting

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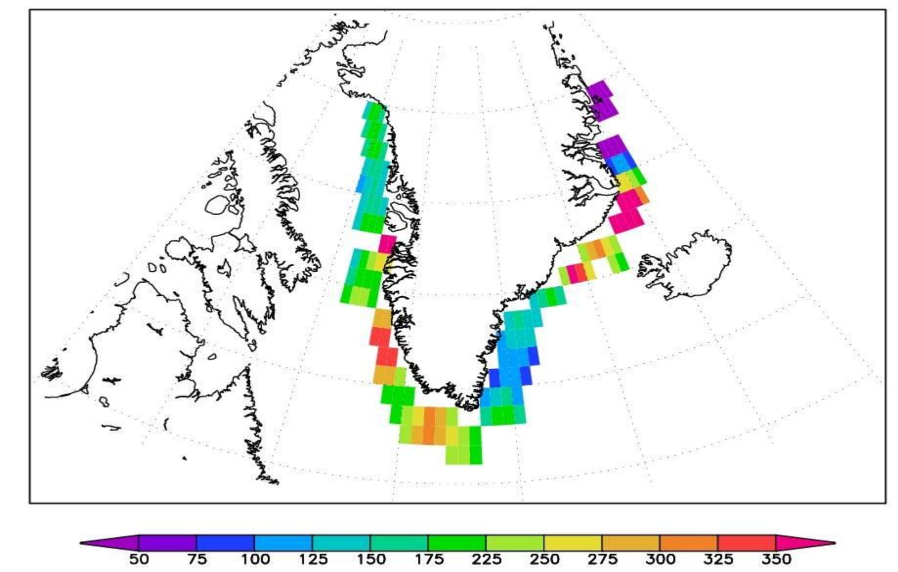
Abstract

We investigate the transient ocean-atmosphere response to a realistic freshwater anomaly around Greenland. A 50-year long simulation of a coupled atmosphere-ocean general circulation model (CGCM) is compared with another one of the same length in which Greenland melting is prescribed as additional freshwater entering the sub-polar North Atlantic. The focus of our analysis is on the pathways and time scales by which a respective perturbation is communicated globally. Within three months after applying the perturbation, the negative sea surface temperature (SST) anomalies resulting from the Greenland melt water freshwater anomalies in the North Atlantic generate a local baroclinic response in the atmosphere. This response perturbs the wintertime upper level jets in the atmosphere, which quickly communicate this perturbation to the North Pacific leading to anomalies in the North Pacific circulation and sea level pressure. This fast tele-connection triggers remote ocean-atmosphere interactions, which generate SST and sea level anomalies in the North Pacific. A similar albeit weaker response is reproduced in an uncoupled Atmospheric model with prescribed SST anomalies around Greenland signifying the role of atmosphere in instant spreading of these perturbations across the globe. Adding a similar perturbation during Northern Hemisphere summer generates a similar response in the Pacific, not instantly in summer due to weaker upper level atmospheric jet during that time, but later during winter months, highlighting the enhanced sensitivity of the coupled system to winter time SST anomalies in the high-latitude Atlantic. Exact mechanism of how these small SST anomalies around Greenland translate into a widespread global response need more analysis and experiments.

Model and Experiments

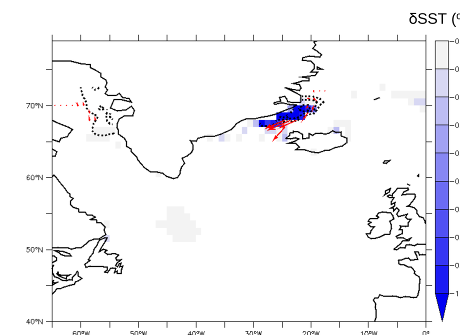
Model used is University of California, Los Angeles (UCLA) CGCM consisting of the UCLA atmospheric model, with advanced PBL and cloud parameterizations, coupled to the MIT oceanic GCM (OGCM). The setup is discussed by Stammer et. al. (2011). From an initial spun up state of 30 years the following sets of experiments were conducted. Each set consisted of a reference run and a perturbed run and comprised of 10 ensemble members based on different initial atmospheric conditions.

- 50 year runs, without (**Control**) and with perturbation (**Perturbed**), in which a freshwater perturbation of 0.0275 Sv around Greenland is applied. This perturbation is five times the size of the present day estimated ice melting rates. Both sets are initialized using January initial conditions.
- 10 year runs in which the coupled model is **initialized from July** without/with Greenland melt water anomalies applied.
- 1 year **Atmosphere only** runs in which the model is forced without/with monthly mean SST anomalies in a region around Greenland resulting from the ocean only run described by Stammer et. al. (2011).



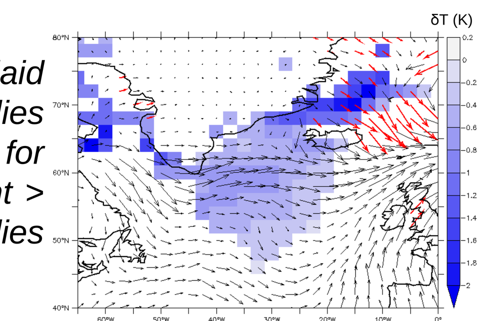
Surface freshwater flux anomalies (in m³/s) equivalent to 5 times the recent (170 GT per annum; Luthke 2006) estimates of Greenland melt water loss

Local Response around Greenland



Vectors (red) of ocean surface current anomalies (cm/s) overlaid over SST (shaded) anomalies (°C) around Greenland averaged for JFM for year 1 from Coupled Run. The black dashed contours represent negative SSS anomalies with a contour interval of 0.2 psu. For all three parameters only the anomalies that are significant > 95% are shown.

There is an enhancement of East Greenland Current by 1 cm/s in the region of maximum salt anomalies which results in advection of cold water from north and subsequently bringing in cold anomalies over there.

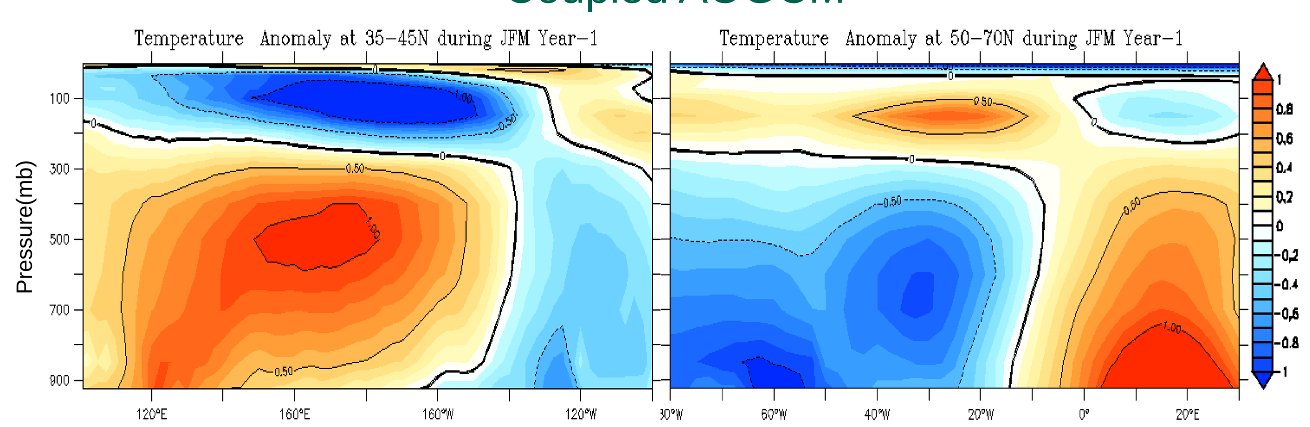


Vectors of boundary layer wind anomalies (m/s) overlaid over atmospheric boundary layer temperature anomalies (shaded) anomalies (°C) around Greenland averaged for JFM of year 1 from CR. Anomalies that are significant > 95% are shown. Red vector indicate wind anomalies which are > 95% significant.

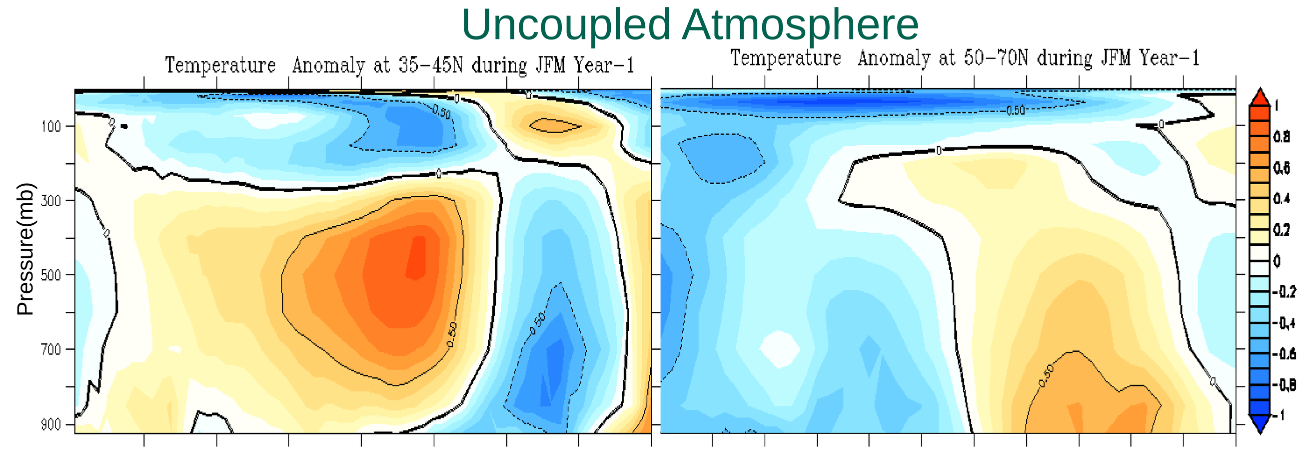
During first three months (JFM) we observe a strengthening of winds east of Greenland in south east direction; strengthening of westerlies south of Greenland and cold anomalies in air temperature around Greenland with a maxima around the region of maximum SST anomalies.

Global Atmosphere Response

Coupled AOGCM



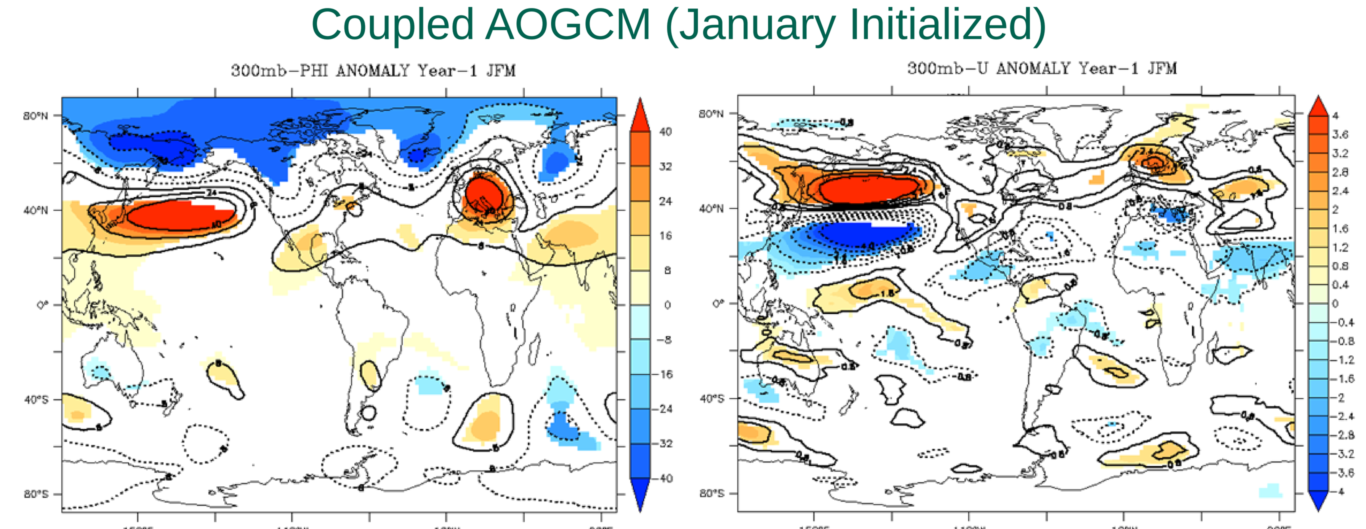
Uncoupled Atmosphere



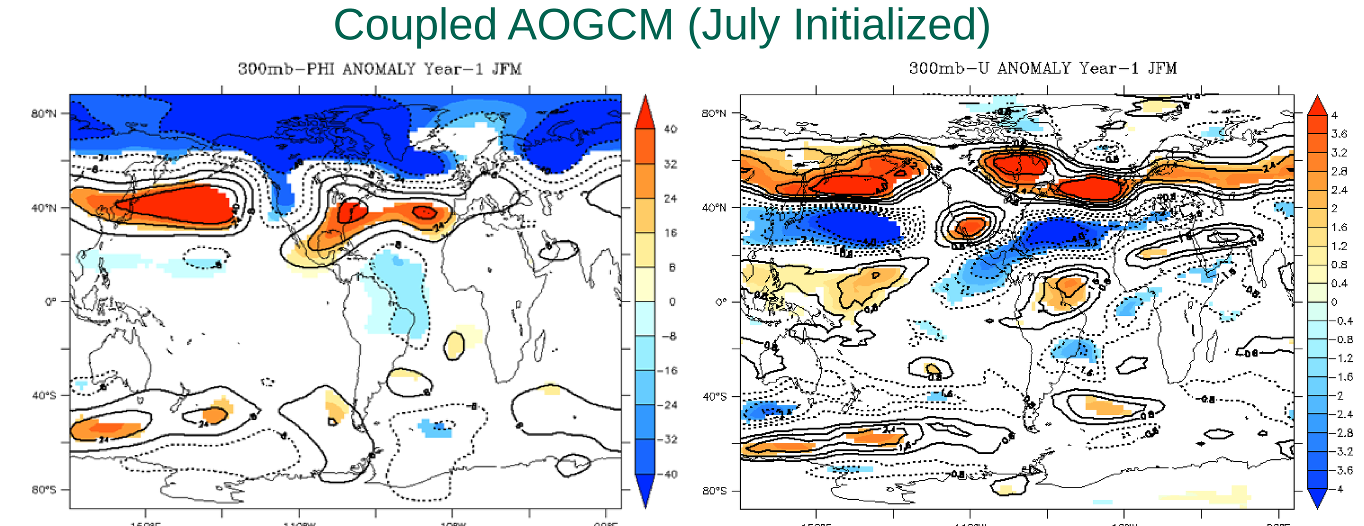
*Height (in mb) -longitude plot of the year-1 JFM **Temperature** Anomaly (°C) averaged between 35N-45N (**left**) in the Pacific Ocean and between 50N-70N. (**Right**) in the Atlantic Ocean from Coupled **(top)** and Atmosphere only (bottom) runs.*

The enhanced response in the eastern Pacific is due to ocean feedback in the coupled system. The Atmosphere only model response patterns are similar , but weaker due to missing feedback from the ocean.

Coupled AOGCM (January Initialized)

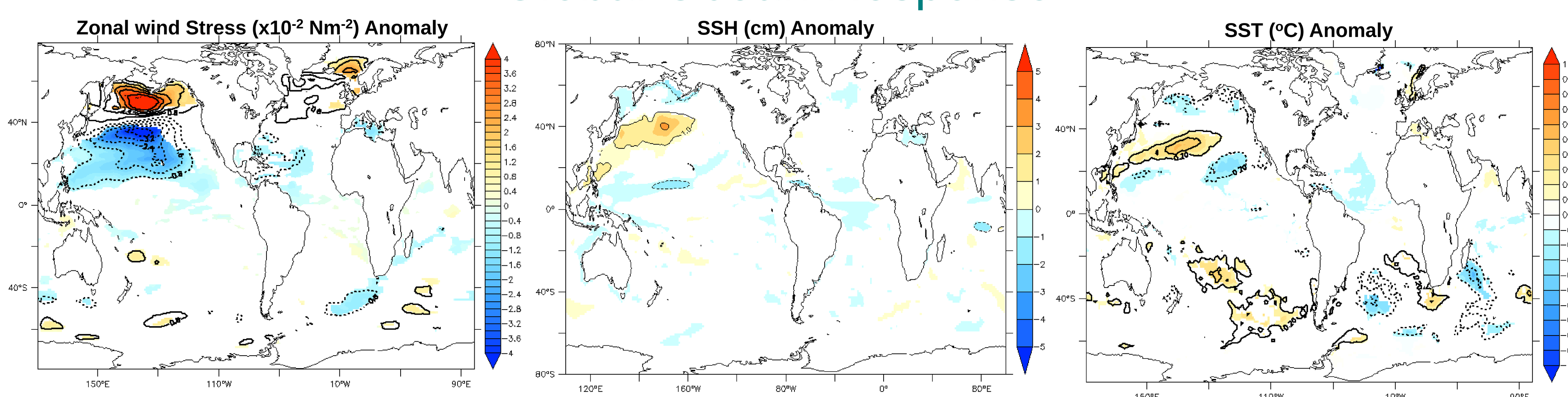


Coupled AOGCM (July Initialized)



***Left**: Contours of Geopotential Height anomalies (m) for year 1 average for JFM season from Coupled runs. **Right**: Zonal wind anomalies (m/s) at 300mb for year 1 JFM. **Top** panels are from January initialized runs while the **bottom** panels are from July initialized runs. The July initialized anomalies are shown for the subsequent JFM season. Anomalies > 95% significance are shaded*

Global Ocean Response



Anomalies from Year-1 JFM average: (left) wind stress (x10⁻² Nm⁻²), (middle) Sea surface height (cm) and (right) sea surface temperature (°C). Anomalies > 95% significance are shaded. .

The wind stress anomalies act upon the ocean surface and the north south gradient results in Ekman downwelling that causes the positive SSH anomaly centered at 40N. Correspondingly there are negative anomalies generated north of 50N and between the equator and 20N

Conclusions

- A coupled model shows a complex ocean-atmosphere response to freshwater anomalies added around Greenland.
- The perturbation caused around Greenland is communicated to the North Pacific via wintertime jet stream anomalies.
- The response is similar in the Atmosphere only (uncoupled) run, despite the magnitude being lower due to missing feedback from the ocean, signifying the role of atmosphere in spreading these anomalies instantly.
- Summer time initialized runs also result in a similar response, however not instantly but later during winter season.
- This fast North Atlantic-North Pacific tele-connection of perturbations via the atmosphere triggers perturbations in the wind stress and generate SSH anomalies in the North Pacific, which are larger than anomalies around the source.

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