Pieces of the Arctic Freshwater Puzzle: Clues from Space, the Surface, and a GCM

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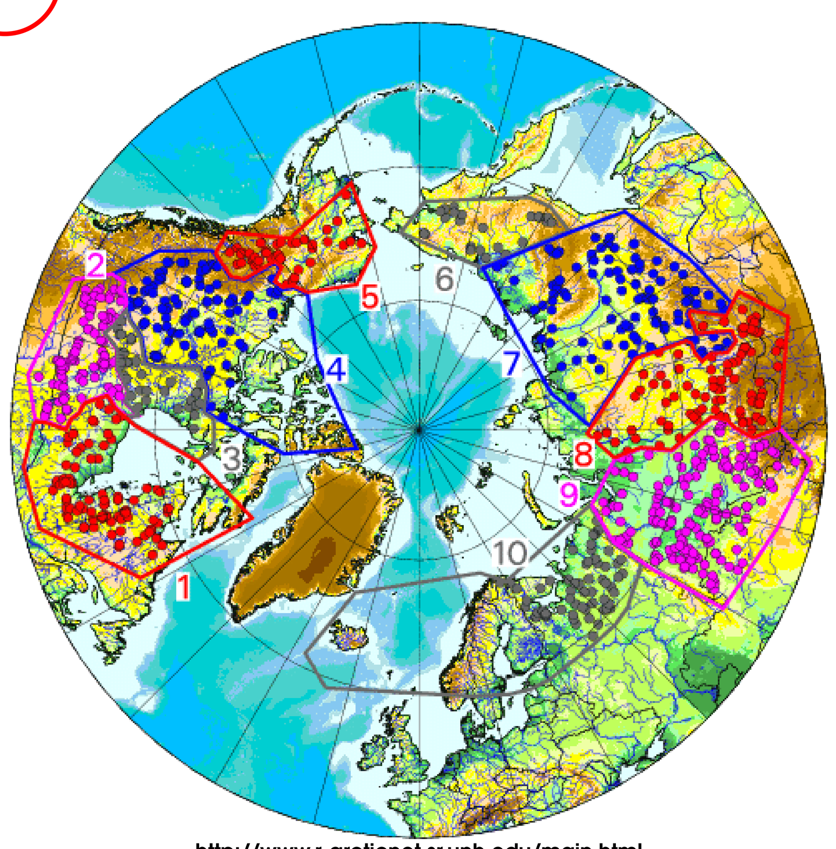
1 R-ArcticNet River Drainage Basins

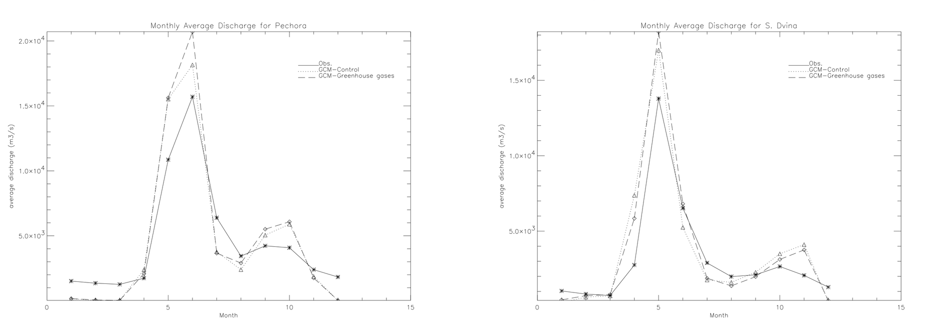


http://www.r-arcticnet.sr.unh.edu/main.html

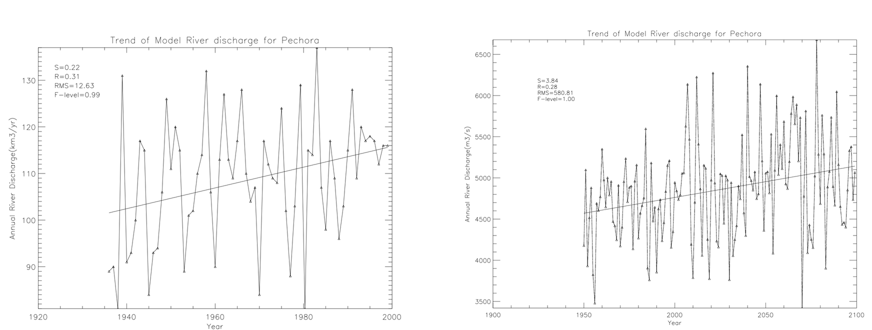
1. South and East Hudson Bay
2. Nelson
3. Northwest Hudson Bay
4. Mackenzie
5. Yukon
6. Anadyr Kolyma
7. Lena
8. Yenisei
9. Ob
10. Barents, Norwegian Sea

Observations versus Model Output

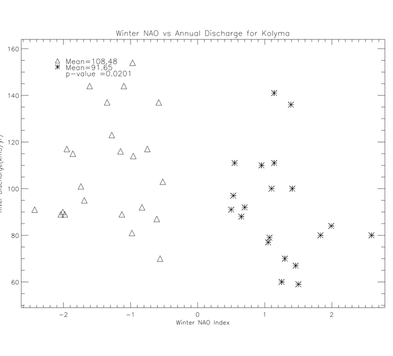
Observed river discharge from six Arctic-draining rivers (from R-ArcticNet Data base) is compared with output from the NASA/GISS GCM over the past 50 years. Here we show GCM and observations of the annual discharge from the Pechora and S. Dvina Rivers, both of which are located in Area 10 above. GCM output includes constant 1950 greenhouse gas (GHG) concentrations ("control") and increasing GHGs at 0.5% per year after 1990 ("GHG"). Both observations and model output indicate that the first peak results from snow melt while the second arises from the later precipitation maximum.

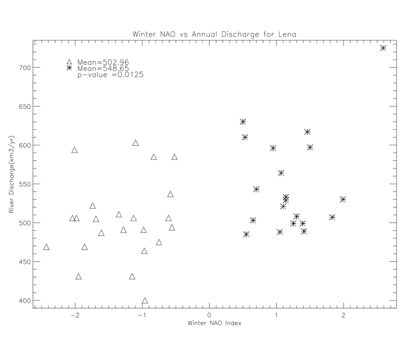


In addition to capturing the annual cycle of these rivers, the GCM also realistically simulates trends in river discharge. The figures below compare time series of annual mean river discharge from the Pechora River from observations (left) and from the GCM (right). Rivers in western Eurasia were not simulated as successfully.

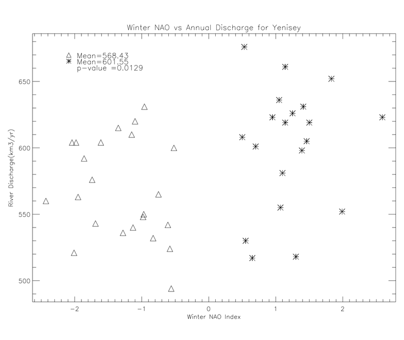


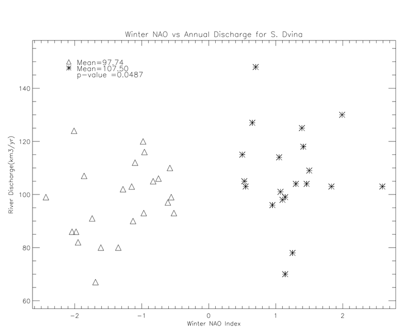
River Discharge and the NAO

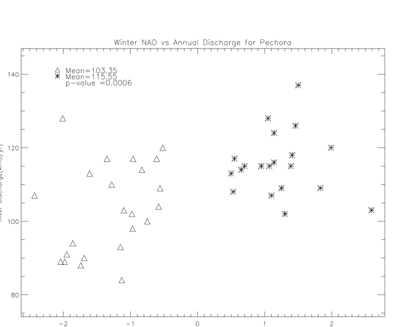




Observed river discharge differs significantly in years with an extreme positive (> 0.5) versus a negative (< -0.5) NAO index. All rivers except the Kolyma have larger discharge in +NAO years, consistent with moisture advection patterns in opposing NAO phases.







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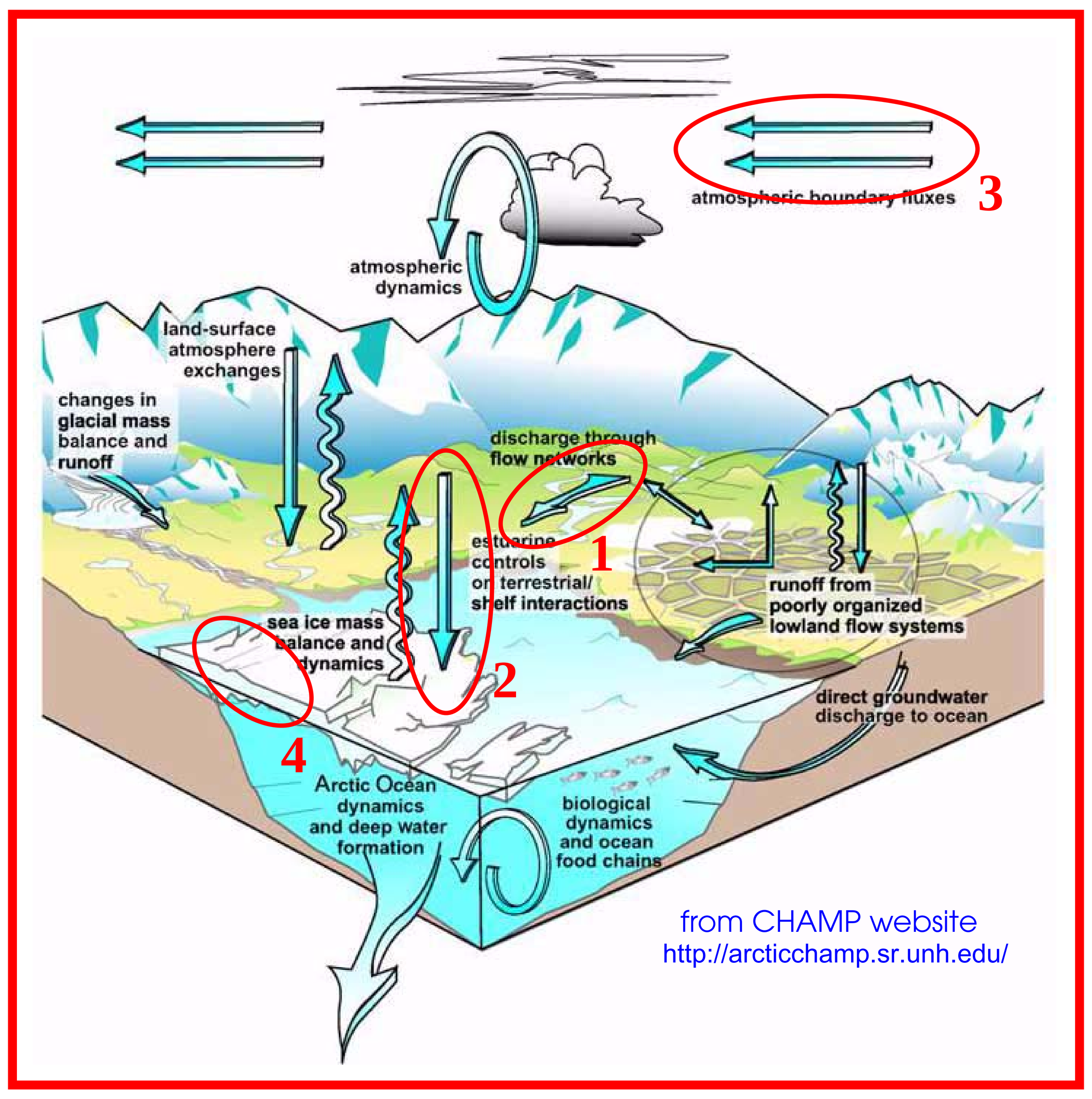
OVERVIEW

Freshwater plays a vital role in governing the physical structure of the Arctic Ocean, maintaining the cover of sea ice, and regulating the behavior of the thermohaline circulation. The lack of conventional measurements, complexities introduced by the existence of three water phases, and difficulties in interpreting high-latitude satellite observations all contribute to the challenge of assembling the Arctic Freshwater Puzzle. We attempt to locate a few missing pieces by combining observations of river discharge with climate model simulations and large-scale atmospheric circulation regimes. In the Barents Sea where the NAO wields its heaviest hand, we find a connection between runoff and sea ice extent in extreme NAO periods. New satellite retrievals offer information on atmospheric moisture fluxes and net precipitation over the ocean where gauges are absent and nearly useless if they existed. Bolstered by encouraging model performance, we look into the future to see changes in precipitation and river discharge...but are they telling the truth?

Sections of the poster correspond to numbered components of the Arctic freshwater budget labeled in the diagram below.



from CHAMP website
http://arcticchamp.sr.unh.edu/

4 Sea Ice, River Discharge, and the NAO

What happens to sea ice extent in the Barents Sea during positive winter NAO conditions? Two opposing effects:

=> positive NAO

=> increased heat and moisture transport into Eurasia

=> increased P-E, earlier snow melt

=> increased river discharge in summer

=> decreased surface-layer salinity in summer

=> sea ice forms more easily, thicker in fall and winter

=> increased sea ice in later months???????????

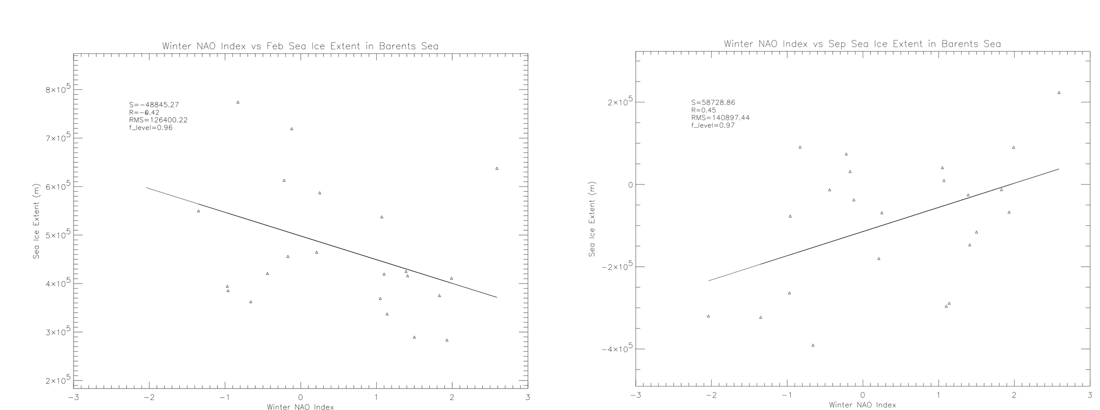
or....

=> increased offshore winds remove ice from Barents Sea

=> additional heat transport slows ice formation

=> reduced sea ice extent?????????

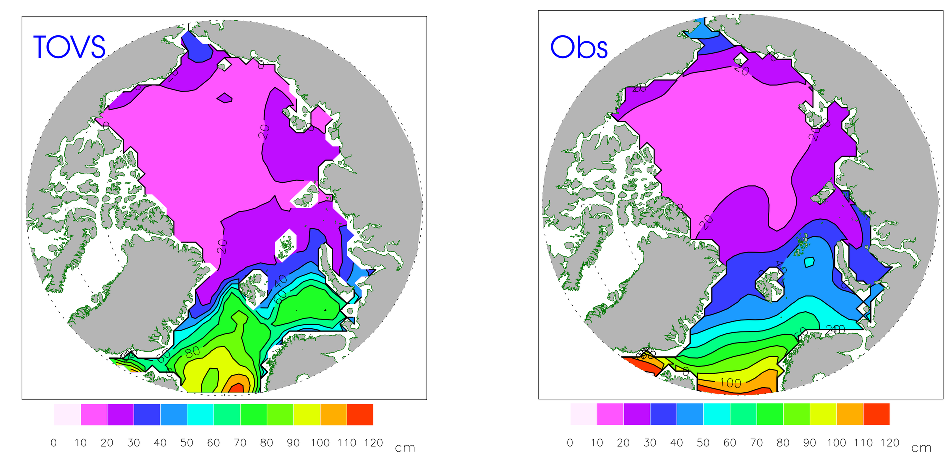
We find that **in winter months** (Feb. shown below), there is **less sea ice** in the Barents Sea **when the winter NAO index is positive**, therefore dynamic effects (stronger offshore winds) dominate. **In summer** (Sept. shown below) there is **more sea ice** in positive NAO conditions, thus it appears that decreased salinity may be linked with increased sea ice formation.



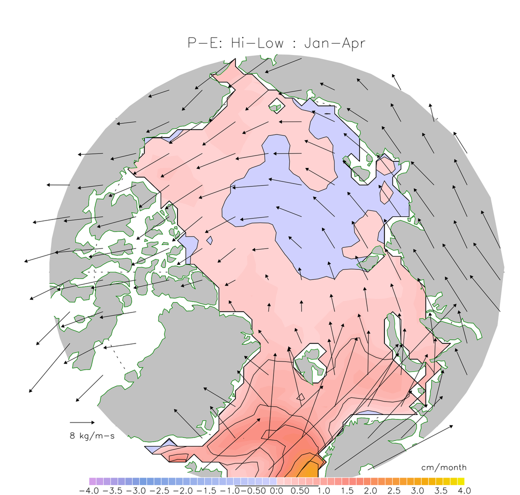
2, 3 A Satellite View of P-E and Moisture Flux

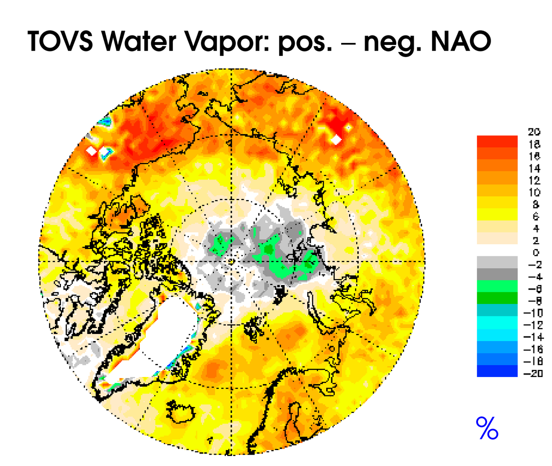
The TIROS Operational Vertical Sounder (TOVS) is being asked to provide information that it was never designed to do. This instrument has flown continually since 1979 on NOAA polar-orbiting satellites, measuring radiances in 28 channels in visible, IR, and microwave wavelengths. From its basic retrievals of temperature and moisture profiles, cloud properties, and surface temperature over the Arctic, we are estimating horizontally advected heat and moisture, 3D winds, net precipitation, surface radiation fluxes, and a variety of other climate-relevant parameters. Combined with information from other satellite sensors, surface observations, and model output, this resource shows great promise for opening new windows to the Arctic climate system. See References for information on algorithms and validation.

We illustrate this potential by first showing a 17-year climatology (1980 to 1996) of annual-mean net precipitation (P-E in cm yr^{-1}) derived from TOVS (left) compared with that assembled from observations by Legates and Willmott (1990) (right). The TOVS P-E is calculated using an aerological approach whereby retrieved moisture is advected by winds. For these calculations we use winds from the NCEP Reanalysis, but having discovered large biases in these wind fields in the Arctic, we are recalculating moisture parameters using new TOVS-derived 3D winds.



How do observed changes in river discharge correspond to changes in P-E? The next figure presents the differences in moisture flux and P-E in a period of positive Arctic Oscillation Index (closely related to the NAO) and a negative AO index. Large increases in net precipitation occur in the Atlantic sector where moisture fluxes are more vigorously transported moisture northeastward and where river discharge is larger in positive NAO periods. In the Laptev Sea area, P-E is reduced in positive AO periods, corresponding with reduced discharge from the Kolyma River in these conditions. The difference in moisture transport results from a combination of three factors: 1) changes in circulation patterns, which is the essence of the differing NAO/AO index, 2) changes in the strength of water vapor gradients, and 3) changes in the orientation between those gradients and the wind field.

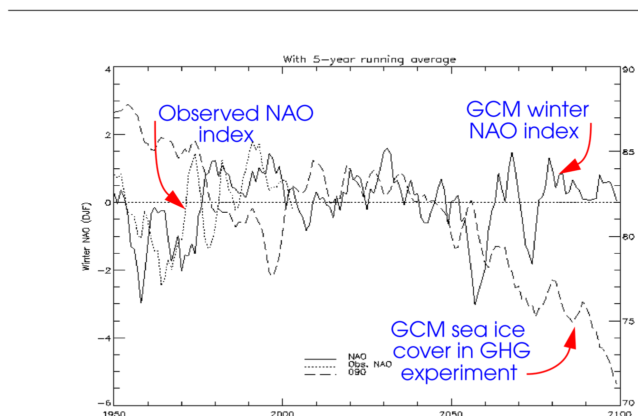




TOVS also gives us information we can use to decipher which of these factors are dominant in various regions at different times. The next plot shows the difference in annual-mean, total-column water vapor content in periods of positive versus negative NAO index (given in%). In most of the Arctic, water vapor content increases substantially (seasonally these changes are even larger), except near the North Pole, where amounts decrease. This pattern of change will have the effect of increasing the strength of the water vapor gradient, contributing to increased moisture fluxes and P-E in positive NAO periods.

What Does the Future Hold?

Clearly there are close ties between the AO/NAO and all components of the Arctic freshwater cycle. Recent tendencies for predominantly positive NAO indices have apparently led to increased net precipitation and runoff in the Eurasian Arctic, but interactions among the "players" are complex and their relative roles may change in the future. Models offer the only hope for planning for and adapting to future change. And the future, according to the GISS GCM, is not far away:



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