Linkages between midlatitude humidity and summer amplification of Arctic midtropospheric warming

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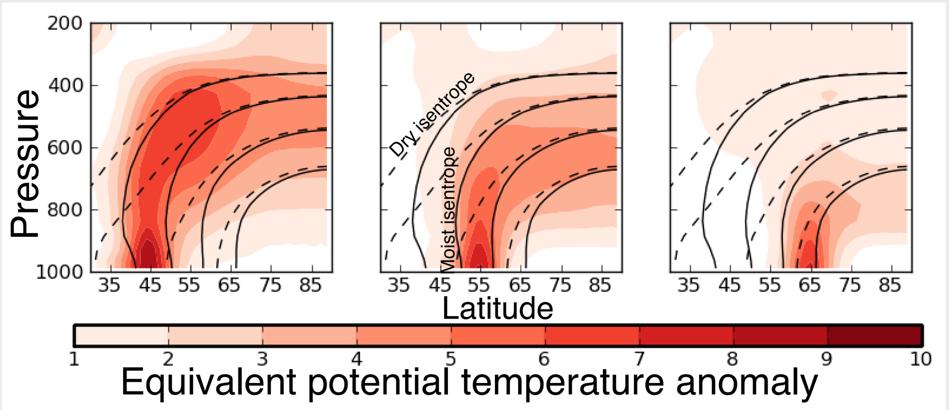
1. Introduction

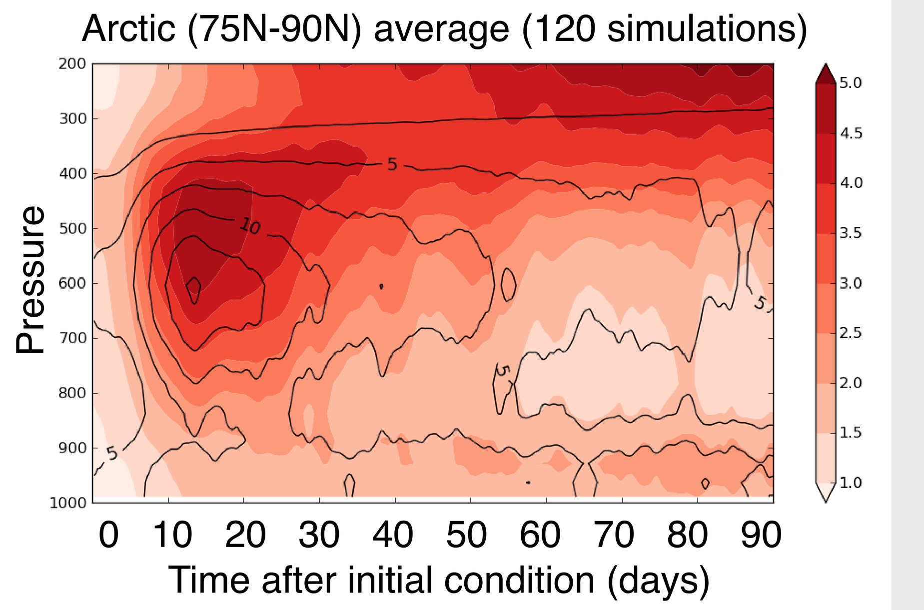
Abstract

In both observational and modeling studies, Arctic amplification is not only observed near the Arctic surface but is also noticeable in the whole atmospheric column, especially during the summer months. While near-surface Arctic warming has been attributed to reduced sea ice cover and increased ocean heat transports, midtropospheric Arctic warming, on the other hand, has been more closely associated with intensified atmospheric heat transport driven by midlatitude surface warming. The mechanisms that could intensify the atmospheric heat transport under anthropogenic forcing have however received little attention and are currently not well understood.

Initial condition experiments [Fajber et al., in prep.]



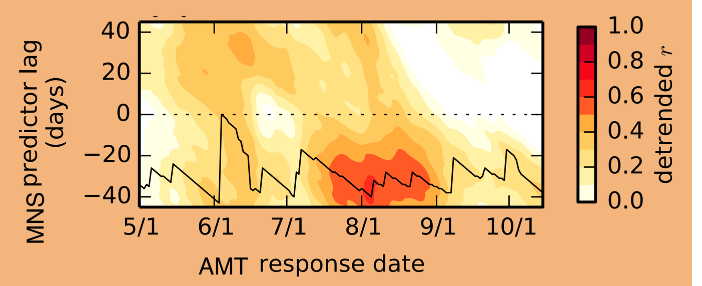
- Initial condition experiments in a Simple Moist GCM with anomalies specified at different latitudes show a propagation from the midlatitudes to the Arctic,
- Anomalies close to the Arctic cannot propagate high in the troposphere,
- Anomalies are constrained to lie below their source moist isentrope,
- Equivalent pot. temperature (θ_e) anomalies reaching the Arctic are always slightly lower than at their source; this is expected because it is an adiabatic invariant on short time scales.



2. Previous Results: Summer propagation of θ_e anomalies from midlatitudes to the Arctic in MERRA and ERA-INTERIM [Laliberté & Kushner 2014]

Lead-lag correlations between the midlatitude near-surface (MNS) and the Arctic midtroposphere (AMT)

Correlations between detrended MNS θ_e anomalies and detrended AMT θ_e anomalies at different dates and lags shows a signal at the late summer AMT from MNS anomalies 20 to 40 days earlier. This is a clearly seasonal signal that occurs when the Northern Atmosphere is very warm and moist.



Summary

a) In reanalyses, a strong signal links temperature and moisture anomalies from the midlatitudes to the Arctic midtrosphere in late summer.

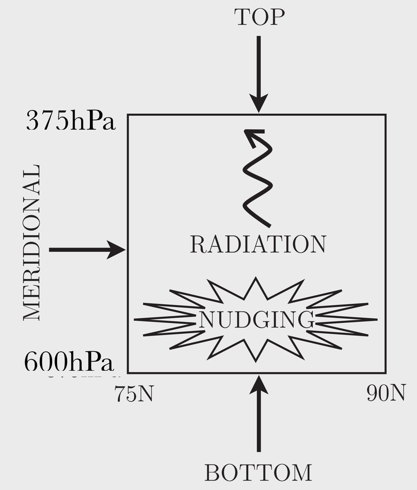
b) In MERRA, this linkage is covariant with meridional heat influxes. These influxes have a strong trend but so does the reanalysis nudging, suggesting that models might not be able to consistently reproduce this linkage.

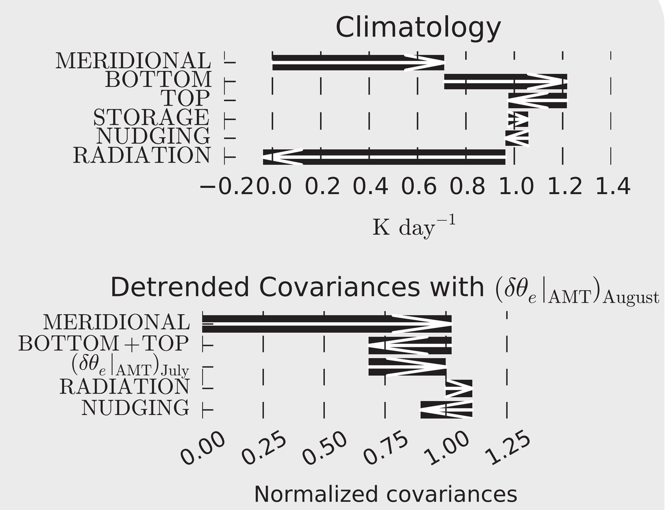
August AMT heat budget

In MERRA, the climatology (top right) shows a balance between radiative cooling and meridional heat influx. Vertical heat influxes are also non-negligible.

However, interannual August AMT θ_e anomalies are mostly driven by meridional heat influxes, with some persistence from July and some impact from vertical convergence (middle right). Surprisingly, the interannual variability in reanalysis nudging appears to be more important than radiation.

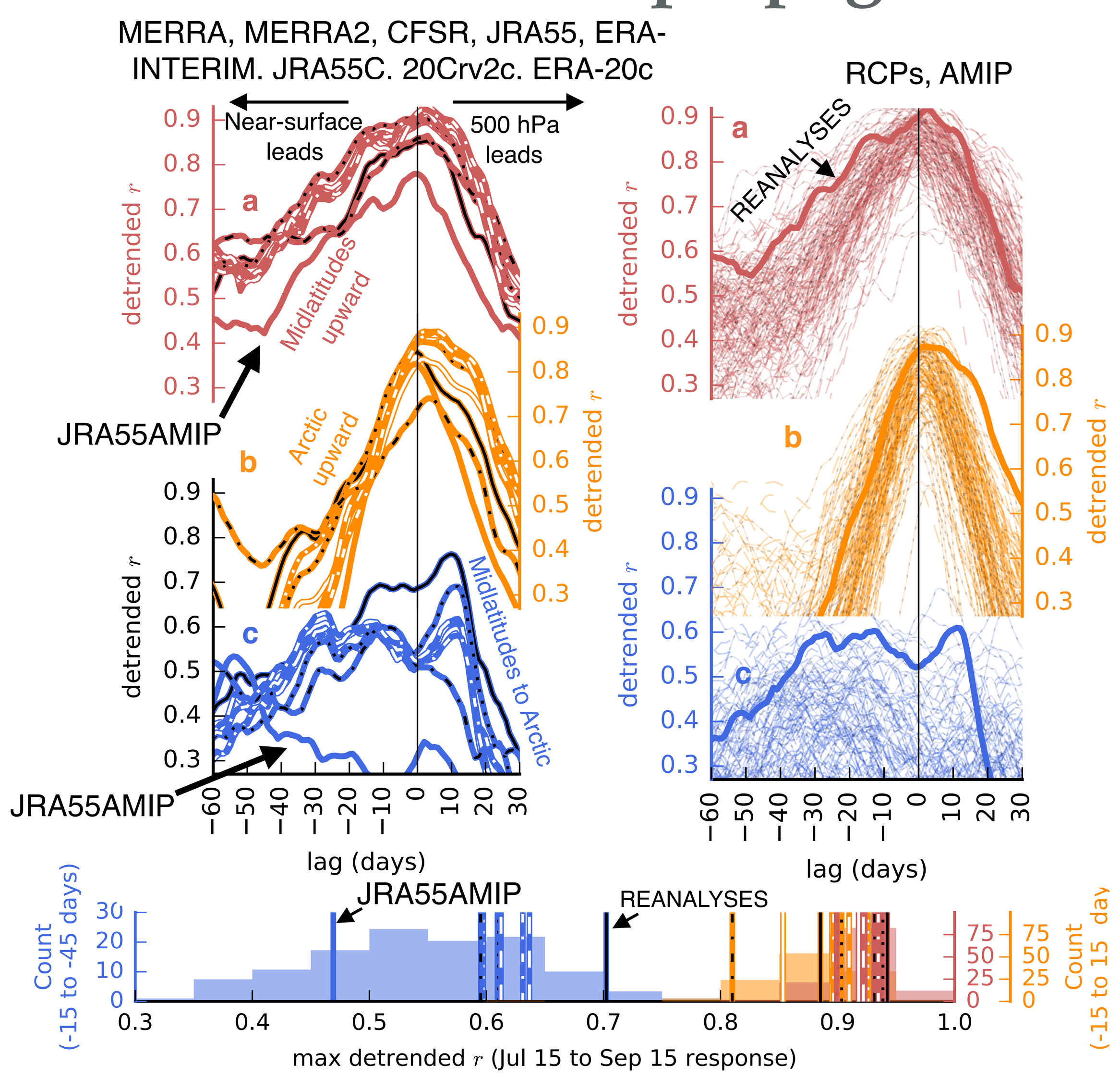
Over long time scales the heat budget is mostly closed, so the trends from the different components are in balance (bottom right) and the main balance is between the trend in meridional heat influx, the trend in radiative cooling and the trend in reanalysis nudging.





	Trend (K decade^{-1})
MERIDIONAL	1.99 ± 1.19
BOTTOM + TOP	−0.18 ± 1.13
$\{\theta_e\|_{AMT}\}_{July}$	0.40 ± 0.27
RADIATION	−0.95 ± 0.19
NUDGING	−1.09 ± 0.61
$\{\theta_e\|_{AMT}\}_{August}$	0.51 ± 0.38

3. Results: Summer propagation of warming from midlatitudes to the Arctic in models



Evolution of the Arctic Summer temperature profile

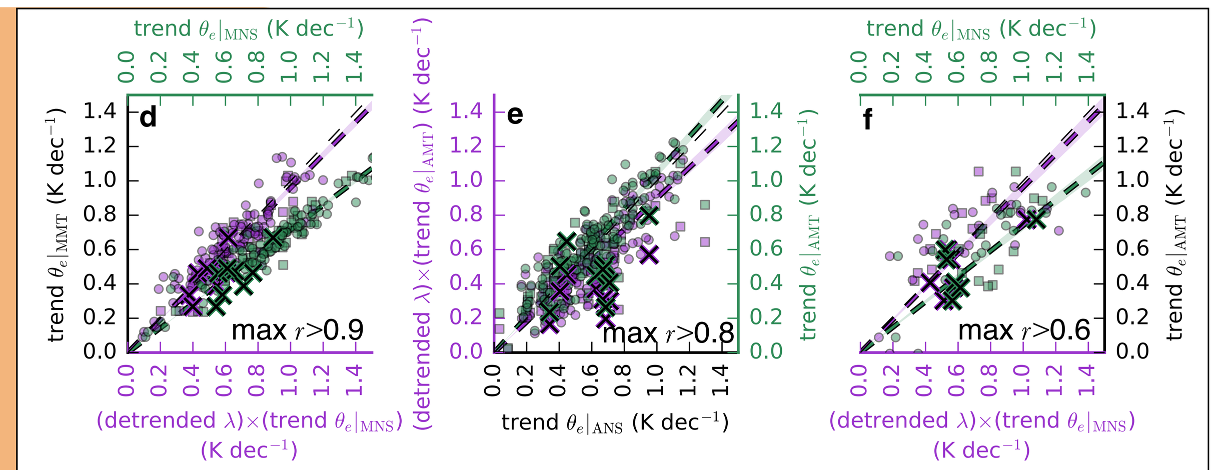
Moist adiabatic ascent followed by subsidence in the Arctic from the atmospheric circulation inferred by the lead-lag correlations presented here suggests that midlatitude temperature and moisture might constrain warming under anthropogenic forcing [Laliberté and Kushner, 2013]. The correlations have sensitivities λ, recovered using a linear regression between:

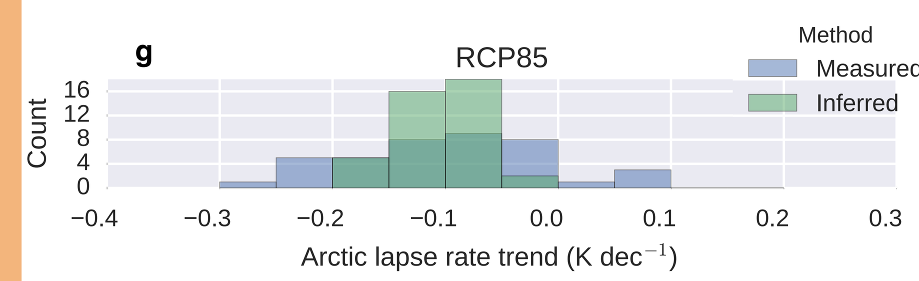
1) a midlatitude surface (MNS) θ_e predictor and a midlatitude tropospheric (MMT) θ_e response;
2) an Arctic tropospheric (AMT) θ_e predictor and an Arctic surface (ANS) θ_e response.
3) a midlatitude surface (MNS) θ_e predictor and an Arctic tropospheric (AMT) θ_e response;

These sensitivities can then be used to rescale the trend in predictor to match the trend in response (shown on the right in **d**, **e** and **f**, respectively). Because it results in a close one-to-one match, it means that:

i) sensitivities and MNS θ_e changes determine (the magenta line lands on the diagonal in **f**) AMT θ_e changes,
ii) which, in turns, determines most but not all (the magenta line lands slightly below the diagonal in **e**) ANS θ_e changes.

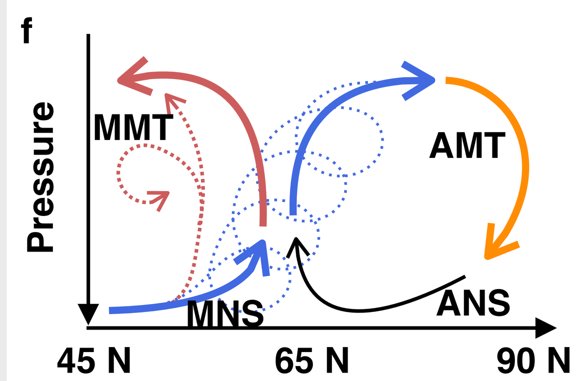
As a result, the inter model distribution in measured Summer Arctic lapse rate trends can be mostly inferred from sensitivities and midlatitude surface θ_e trends (shown in **g**).





Lead-lag correlation in Summer

The meridional overturning circulation (depicted on the right) drives different lead-lag correlations along its different branches. The moist adiabatic ascent of midlatitude air in the Arctic (blue arrows on the right) can be measured between MNS θ_e and AMT θ_e (shown in **c** above with thick lines). The other branches of the circulation (ascent in midlatitudes, red, and subsidence at the pole, yellow) can be measured similarly (**a** and **c** above). Models from the Coupled Model intercomparison projects (CMIP5) present a picture similar to reanalyses (thin lines above) albeit their correlations are less robust for ascents from the midlatitudes to the Arctic (shown in **c**). The histogram shown above confirms that although the ensemble capture this linkage, any single simulation might not.



Summary

Our investigation of CMIP5 models shows that:

a) Simulations capture the dynamics of the Summer high latitude atmospheric circulation;

b) Sensitivities obtained from model dynamics link trends along the different branches of the mid-to-high latitude atmospheric circulation;

c) These sensitivities and the midlatitude surface θ_e trends (driven in large part by moisture trends) suggest that moist adiabatic ascent from midlatitude is sufficient to explain the inter model distribution in Summer Arctic lapse rate trends under anthropogenic forcing.

References

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