Inter-relationship between subtropical Pacific sea surface temperature, Arctic sea ice concentration, and the North Atlantic Oscillation in recent summers and winters

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Abstract

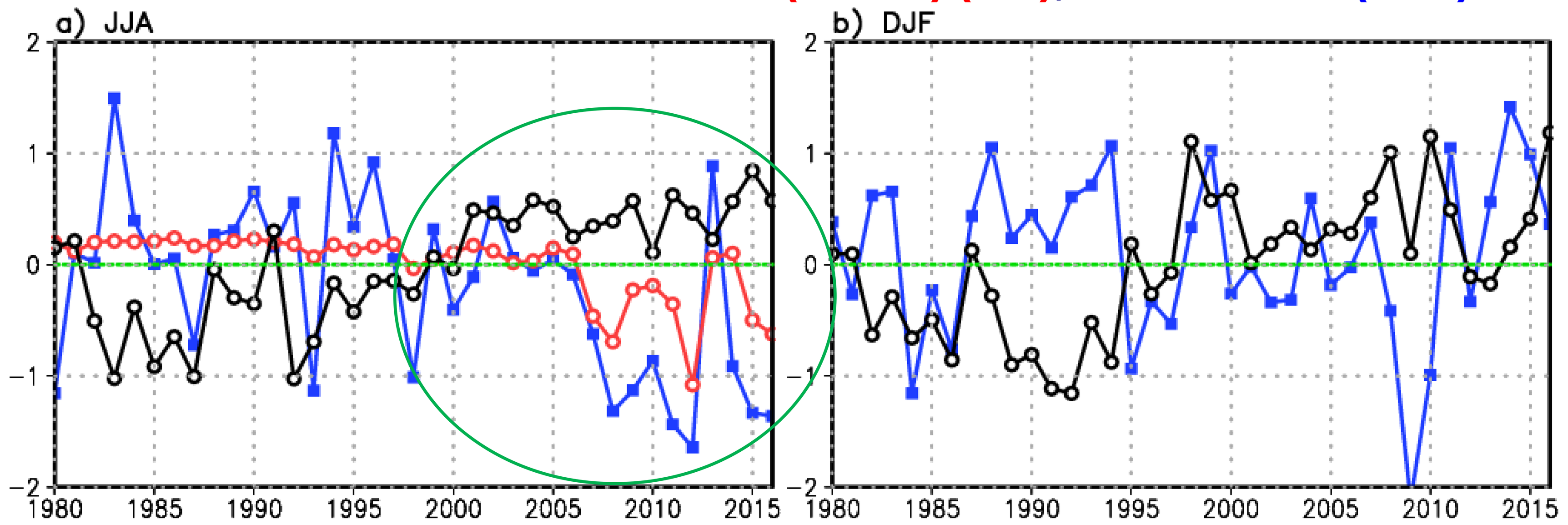
The inter-relationship between subtropical western–central Pacific sea surface temperatures (STWCPSST), sea ice concentration in the Beaufort Sea (SICBS), and the North Atlantic Oscillation (NAO) are investigated for the last 37 summers and winters (1980–2016). Lag–correlation of the STWCPSST×(–1) in spring with the NAO phase and SICBS in summer increases over the last two decades, reaching *r* = 0.4–0.5 with significance at 5 percent, while winter has strong correlations in ~1985–2005. Observational analysis and the atmospheric general circulation model experiments both suggest that STWCPSST warming acts to increase the Arctic geopotential height and temperature in the following season. This atmospheric response extends to Greenland, providing favorable conditions for developing the negative phase of the NAO. SIC and surface albedo tend to decrease over the Beaufort Sea in summer, linked to the positive surface net shortwave flux. Energy balance considering radiative and turbulent fluxes reveal that available energy that can heat surface is larger over the Arctic and Greenland and smaller over the south of Greenland, in response to the STWCPSST warming in spring.

Data and Model experimental design

SIC data: HadISST.2 (http://www.metoffice.gov.uk/hadobs/hadisst2/data/download.html)
Atmospheric reanalysis: MERRA-2 (0.625 °× 0.5° longitude-latitude resolution)
Global model: NASA GEOS-5 AGCM
Experiments:

1) Exp CTL: Climatological SST is prescribed globally.
2) Exp SPW: forced by the same SST as Exp CTL, except over the subtropical western-central Pacific (130°–200°E, 0°–35°N) where 1°C warming has been added to climatology.
3) Warming is imposed only for spring (MAM) and fall (SON) to explore their warming impact on the atmospheric responses in the following seasons of summer (JJA) and winter (DJF).
4) Initialized in February, and integrated through February next year.
5) Atmospheric initial conditions from MERRA-2
6) 20 members (initial dates: February 9 – 28)

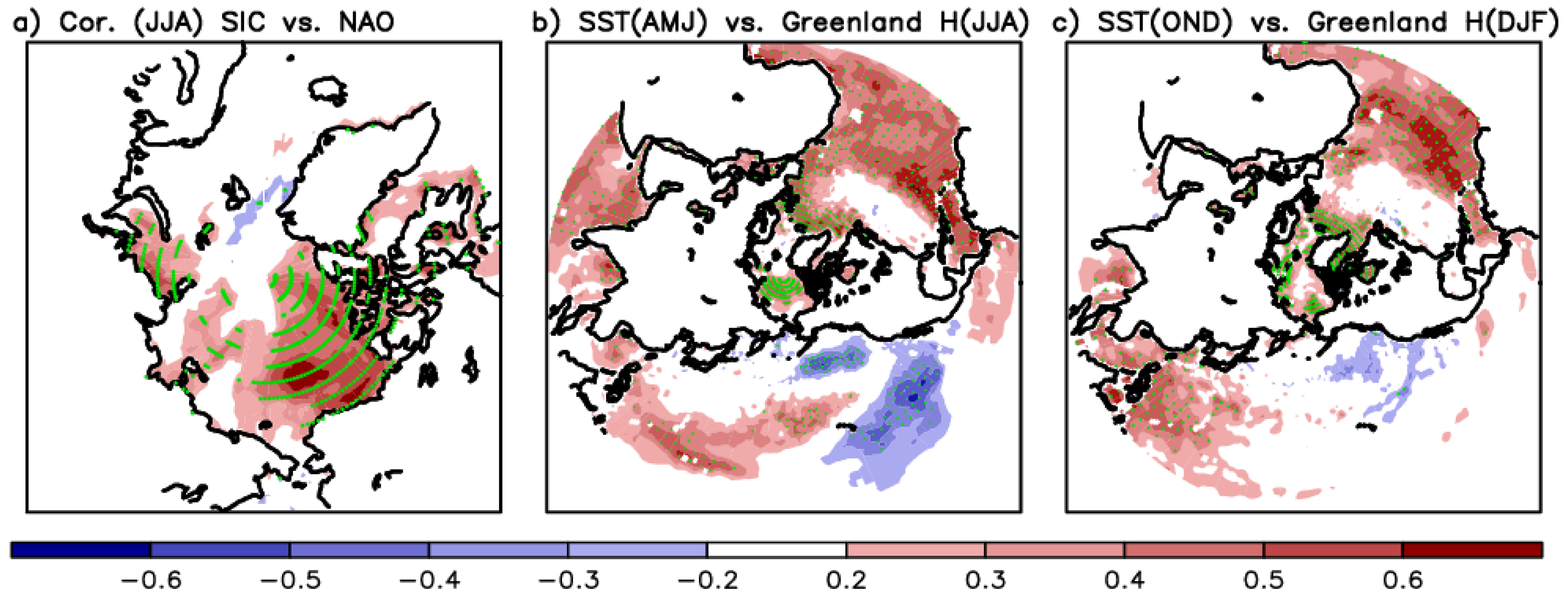
Subtropical western-central Pacific SST (STWCPSST) (black), Sea ice concentration over Beaufort Sea (SICBS) (red), and the NAO (blue)



SST anomaly is for AMJ (left) and OND (right), respectively, to indicate the SST impact that leads the variation of SICBS and NAO phase in the following summer (JJA, left) and winter (DJF, right).

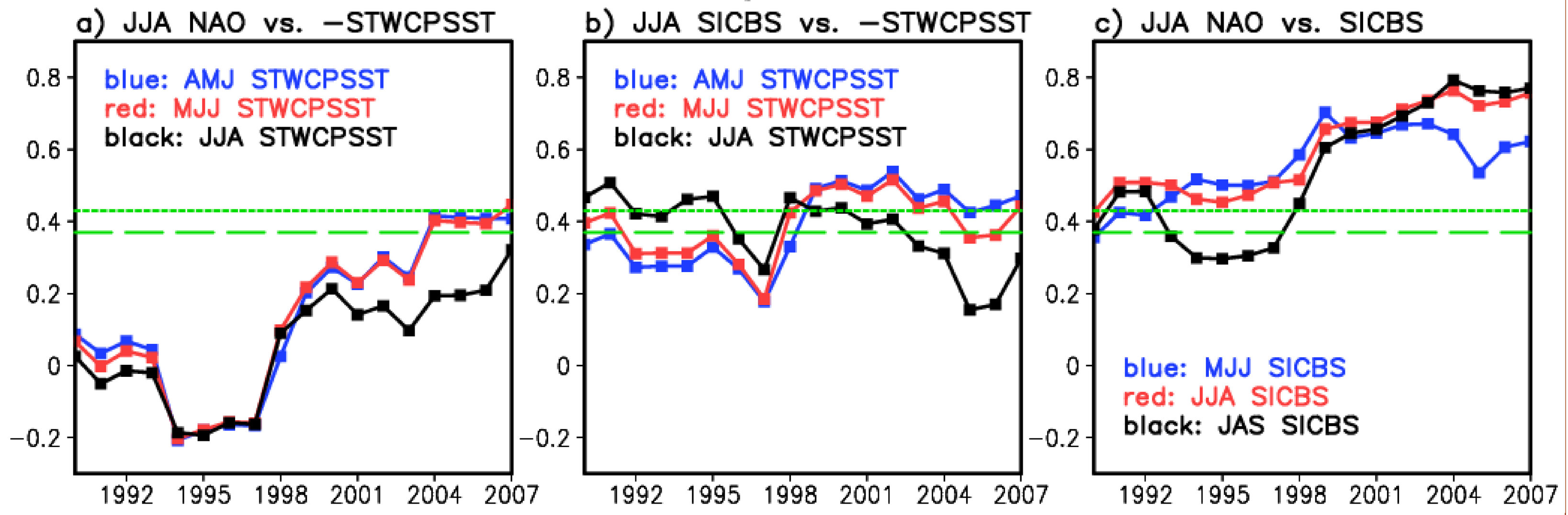
Since 2006, seasonal mean NAO was in negative phase in 10 summers (out of 11).
The SICBS co-vary with the NAO phase in the 21st century summers.
STWCPSST (AMJ) shows a negative relationship with the summer NAO phase in the 21st century.

Temporal correlations (simultaneous (a) and time-lagged (b,c))



STWCPSST is positively correlated with geopotential height over the Arctic (b,c) → STWCPSST increase (decrease) is associated with development of the negative (positive) phase of the NAO.

Time variation of lag-correlations (20 year moving window)

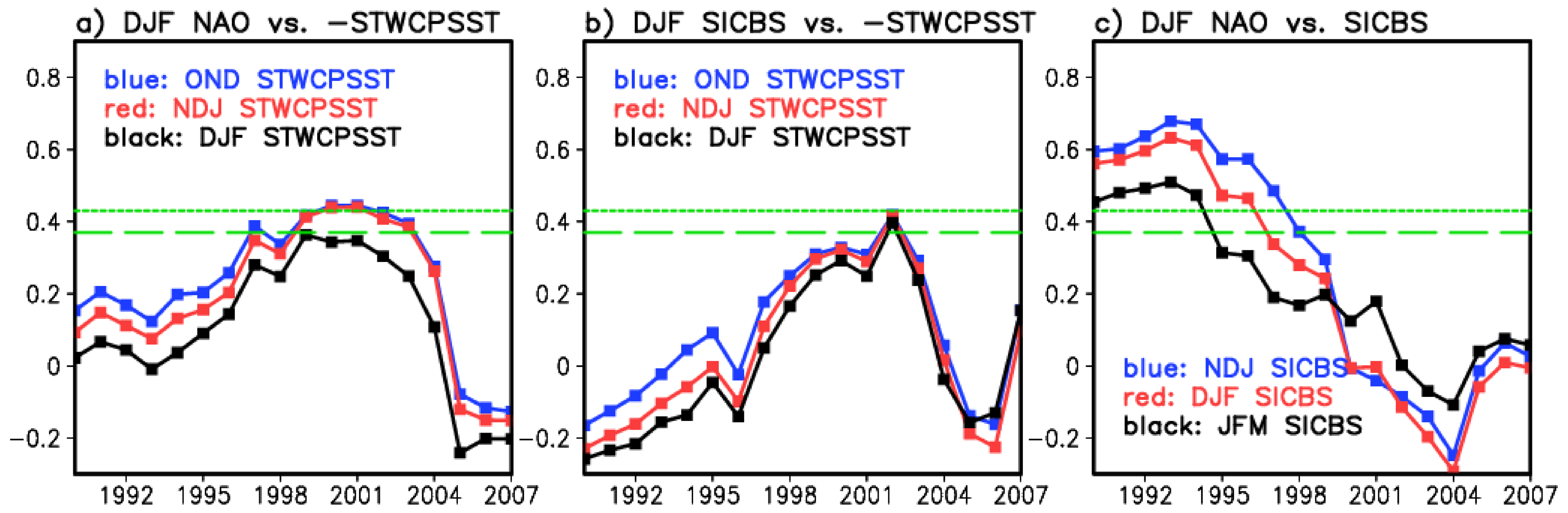


(x-axis : the center of the individual 20 year windows)

a) Linkage between the STWCPSST increase (decrease) and the negative (positive) phase of the summer NAO is clearer in recent period (21st century), with the maximum correlation greater than 0.4 when the STWCPSST×(–1) leads the NAO by a month or two months.

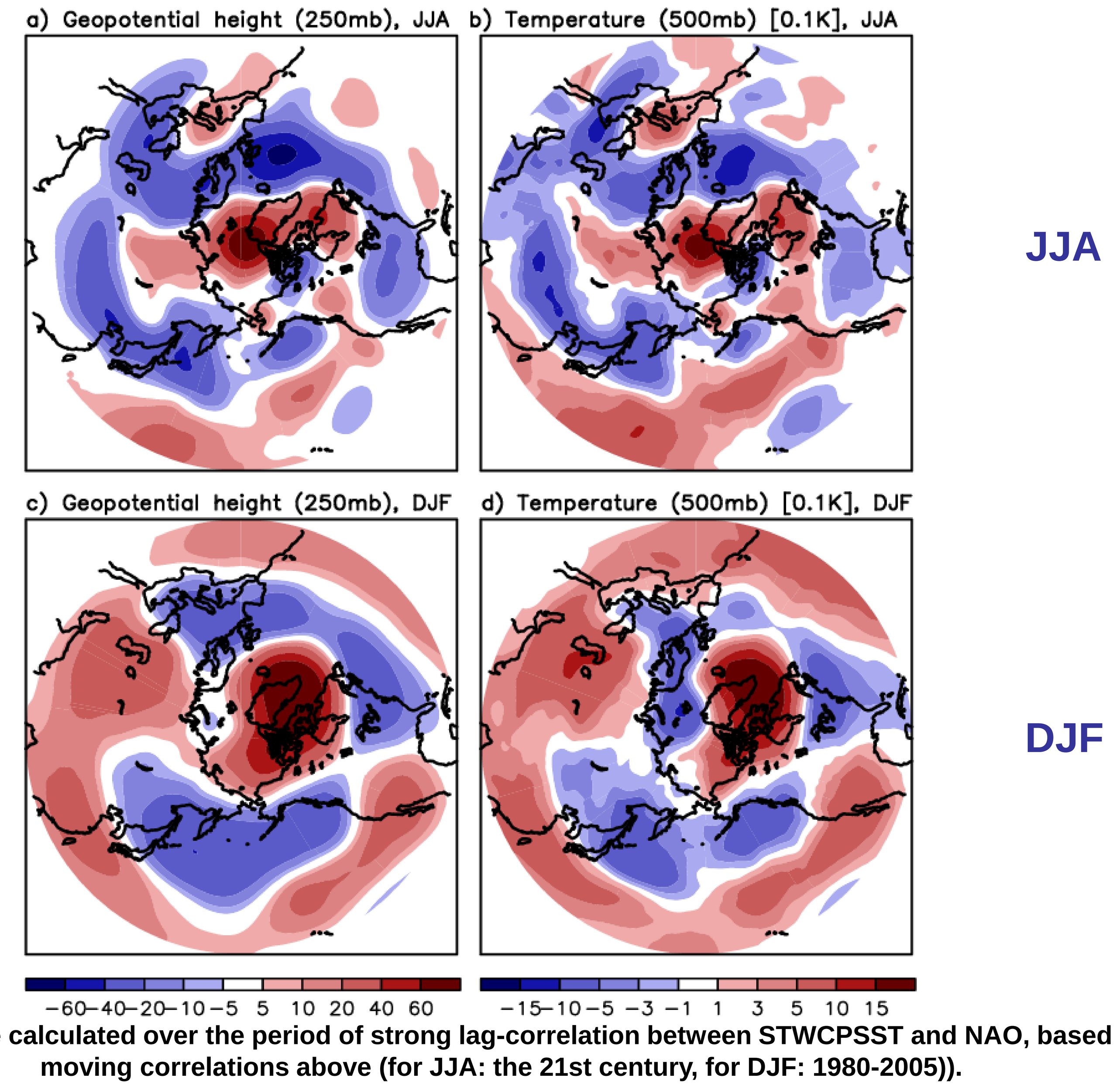
b) The STWCPSST×(–1) leads the summer SICBS by one or two months (corr. ~ 0.5) : The STWCPSST variation in spring could explain about 25% of the variance of summer SICBS.

c) High correlation between NAO and SICBS at both positive and negative lag implies possibility of their strong linkage and positive feedback.



In winter, statistically significant lag-correlations between STWCPSST and NAO/SICBS are found at the moving windows centered in ~2000.

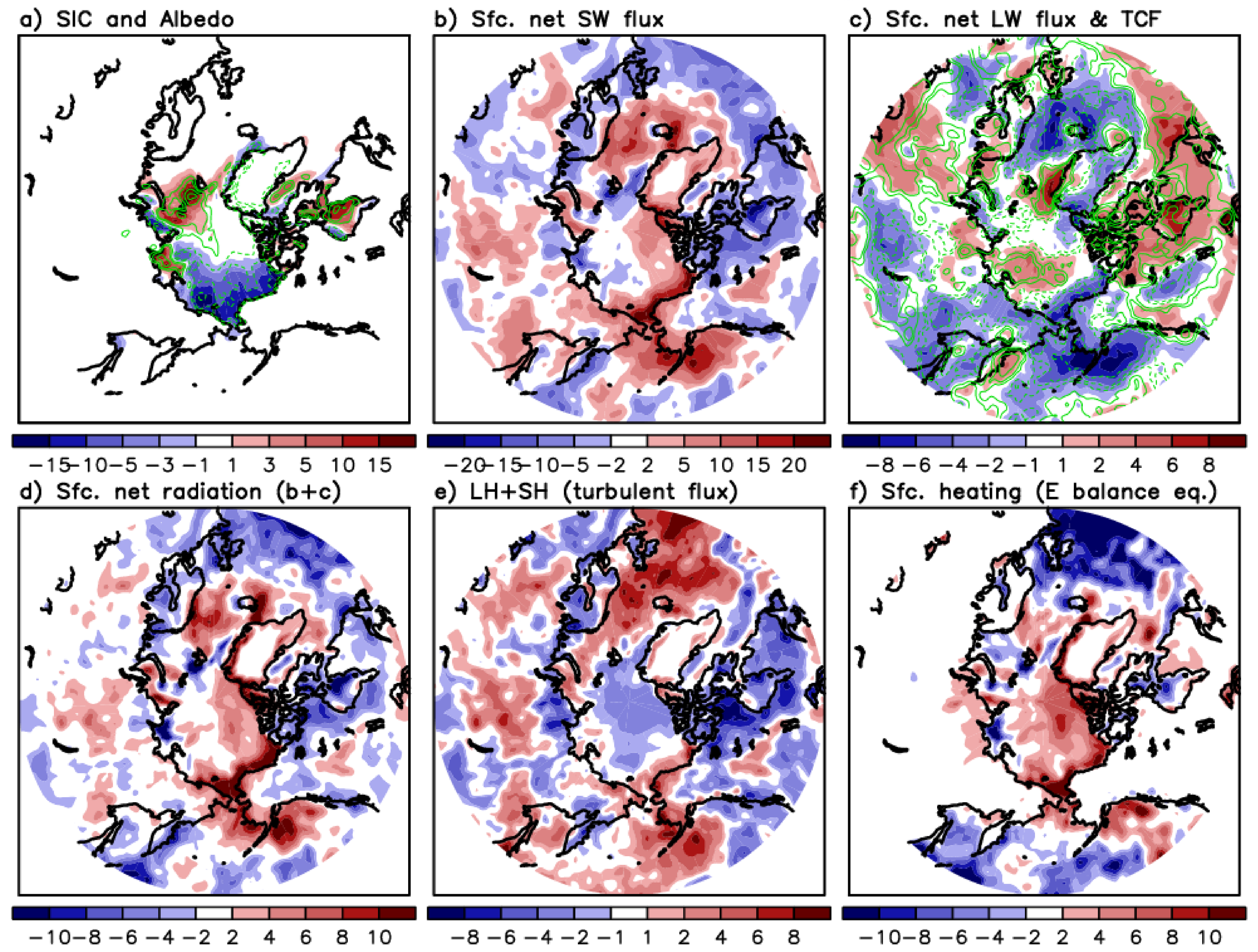
Differences in height/temperature during JJA (a,b) and DJF (c,d) (Diff. based on the STWCPSST in preceding season: warm minus cool)



(Differences are calculated over the period of strong lag-correlation between STWCPSST and NAO, based on the moving correlations above (for JJA: the 21st century, for DJF: 1980-2005)).

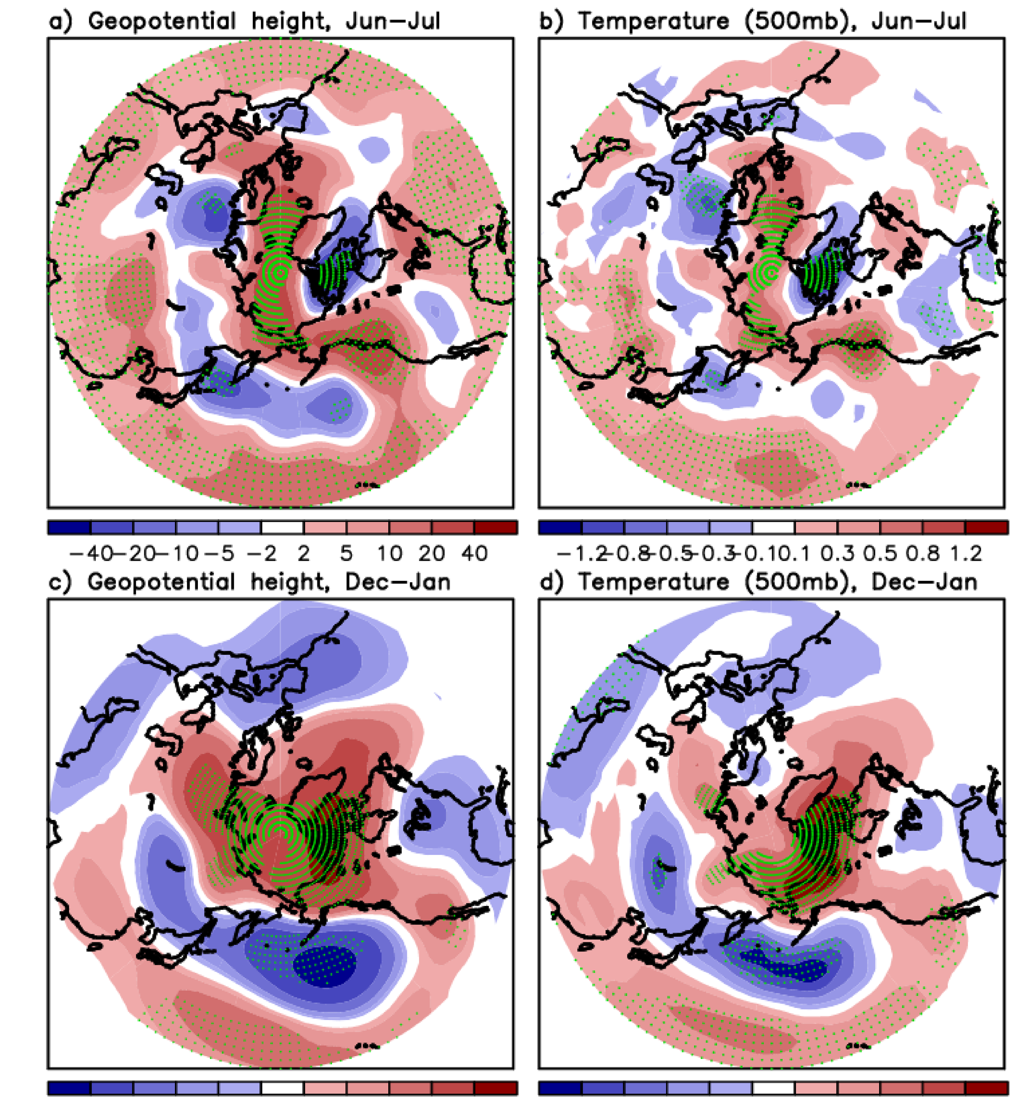
Height/temperature anomaly pattern with alternate sign along the STWCP, NW Pacific and Aleutian Low, and Arctic / NE Canada. Height/temperature increase over Greenland and decrease south of it is apparent, resembling the pattern of the negative phase of the NAO.

Differences in radiative and heat fluxes during JJA (21st century) (Diff. based on the STWCPSST in spring: warm minus cool)



a) Decrease in JJA SIC and albedo over the Beaufort Sea, when STWCP is warm in spring.
b) More absorption of the SW flux over the Beaufort Sea. Positive sfc. net SW flux over the Beaufort Sea and Greenland. Negative over the south of Greenland.
c) Pattern of the sfc. net LW flux difference is quite consistent with the patter of total cloud fraction difference (contoured). Below average cloud fraction and net LW flux near the Beaufort Sea coast and Greenland in summer when STWCP is warm in spring.
d) Sfc. net radiation (net SW + net LW) is large across the Beaufort Sea and Greenland
e) Latent and sensible heat flux is negative anomaly (downward) when STWCP is warm.
f) Energy balance: radiative flux minus turbulent flux is larger over the Arctic and Greenland (i.e., ground heat flux), and smaller over the south of Greenland.

Model experiment: Exp SPW – Exp CTL, and Discussion



Arctic & Atlantic: Positive upper-level height/T anomaly over the Arctic and Greenland, and a negative anomaly over the central-eastern Atlantic, resembling the (–) phase of the NAO.

Pacific: The negative height/T anomaly over the mid-latitudes, along with the positive anomaly over the STWCP, where 1°C warming above climatology is prescribed.

Discussion: It is likely that the Arctic gets warm and the NAO is in the negative phase in response to the STWCP warming. But, there are other factors (e.g., internal variability) that contribute to determination of the NAO phase: not always the negative phase of the NAO in the event of STWCP warming (e.g.: recent winters and near neutral NAO in 2017 summer).