The role of downward infrared radiation in the recent Arctic winter warming trend and the subsequent impact on midlatitudes

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1. Introduction

- During the past three decades, the most rapid warming at the surface has occurred during the Arctic winter. This warming trend is known as Arctic Amplification.
- Various theories have been proposed for Arctic Amplification: (1) ice-albedo feedback, (2) poleward heat and moisture transport, (3) water vapor and cloud feedbacks. We present evidence that an increase in the downward infrared radiation (IR) associated with remote wave forcing is primarily responsible for the Arctic surface air temperature (SAT) trend, and then investigate the processes that drive these changes in the downward IR.

2. Data and Method

- 1977-2012 ERA-interim DJF (SAT, specific humidity, 250-hPa streamfunction, surface fluxes) and NSIDC Arctic sea-ice data are used.
- The surface energy budget is used to examine which processes drive the inter-decadal SAT trend, i.e.,

$$\Delta G = \Delta I_d - \Delta(\varepsilon\sigma T_s^4) + \Delta F_{sh} + \Delta F_{lh} + \Delta C, \quad (1)$$

where Δ is the trend, G is the storage, I_d downward IR, $\varepsilon\sigma T_s^4$ upward IR, F_{sh} and F_{lh} surface sensible and latent heat flux, and C conduction. For an infinitesimally thin surface layer, G can be neglected. Ignoring ΔC and solving for ΔT_s yields,

$$\Delta T_s = (\Delta I_d + \Delta F_{sh} + \Delta F_{lh})/(4\varepsilon\sigma T_s^3). \quad (2)$$

Figure 1 shows that downward IR is the main driver of the SAT trend. To investigate what processes drive the downward IR trend, we express the downward IR as

$$IR(\lambda, \theta, t) = IR_{index}(t)\,\Delta I_d(\lambda, \theta) + \text{residual}, \quad (3)$$

and then regress different variables Y against $IR_{index}(t)$:

$$\Delta(Y) = [r\sigma(Y)/\sigma(IR_{index})]\Delta IR_{index}. \quad (4)$$

The linear correlation r expresses the intra-seasonal relationship between Y and IR_{index}.

3. SAT Trends

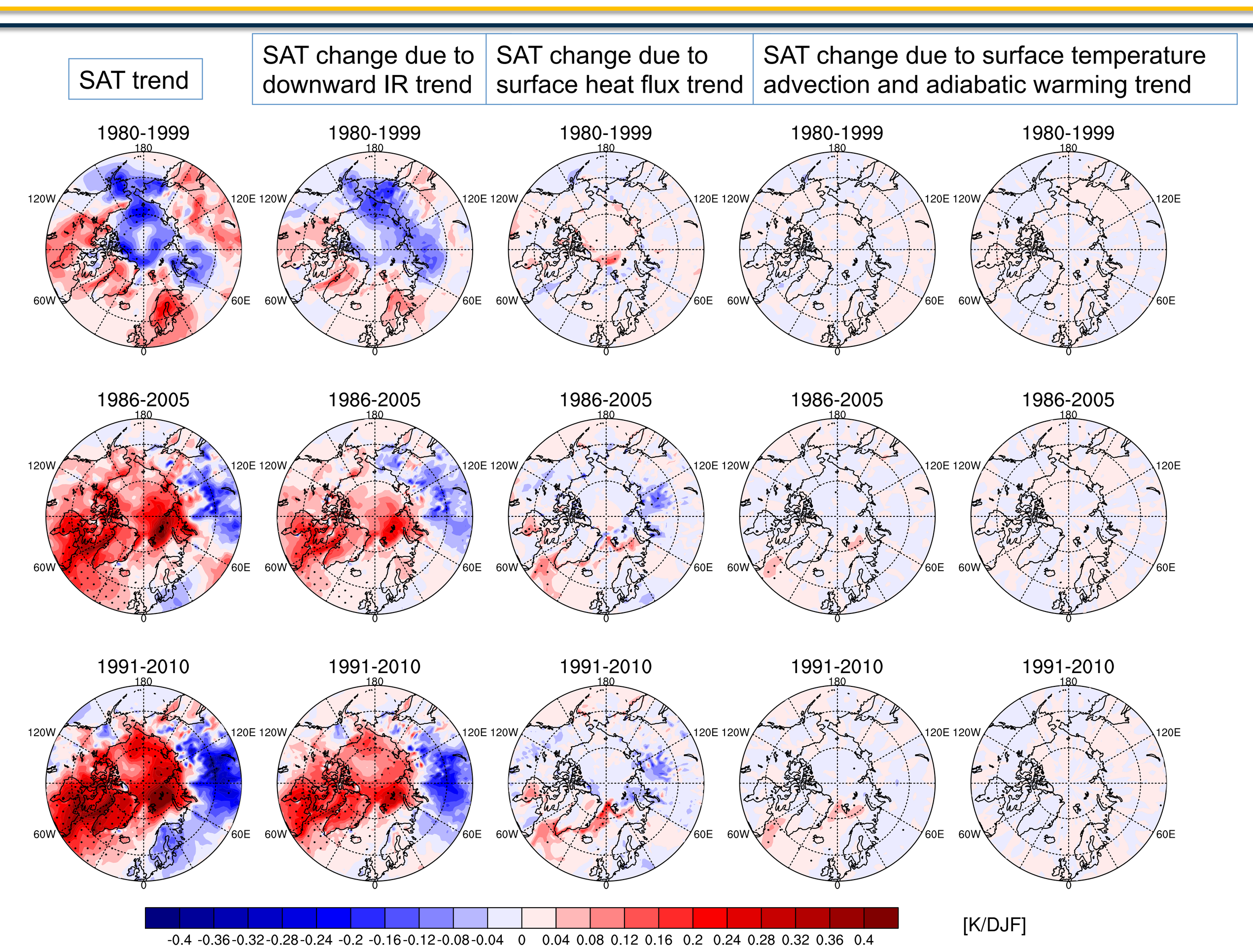


Figure 1: The trend of SAT (leftmost column) and the SAT trend obtained by linear regression against each term on the right-hand-side of equation (2).

4. Trends

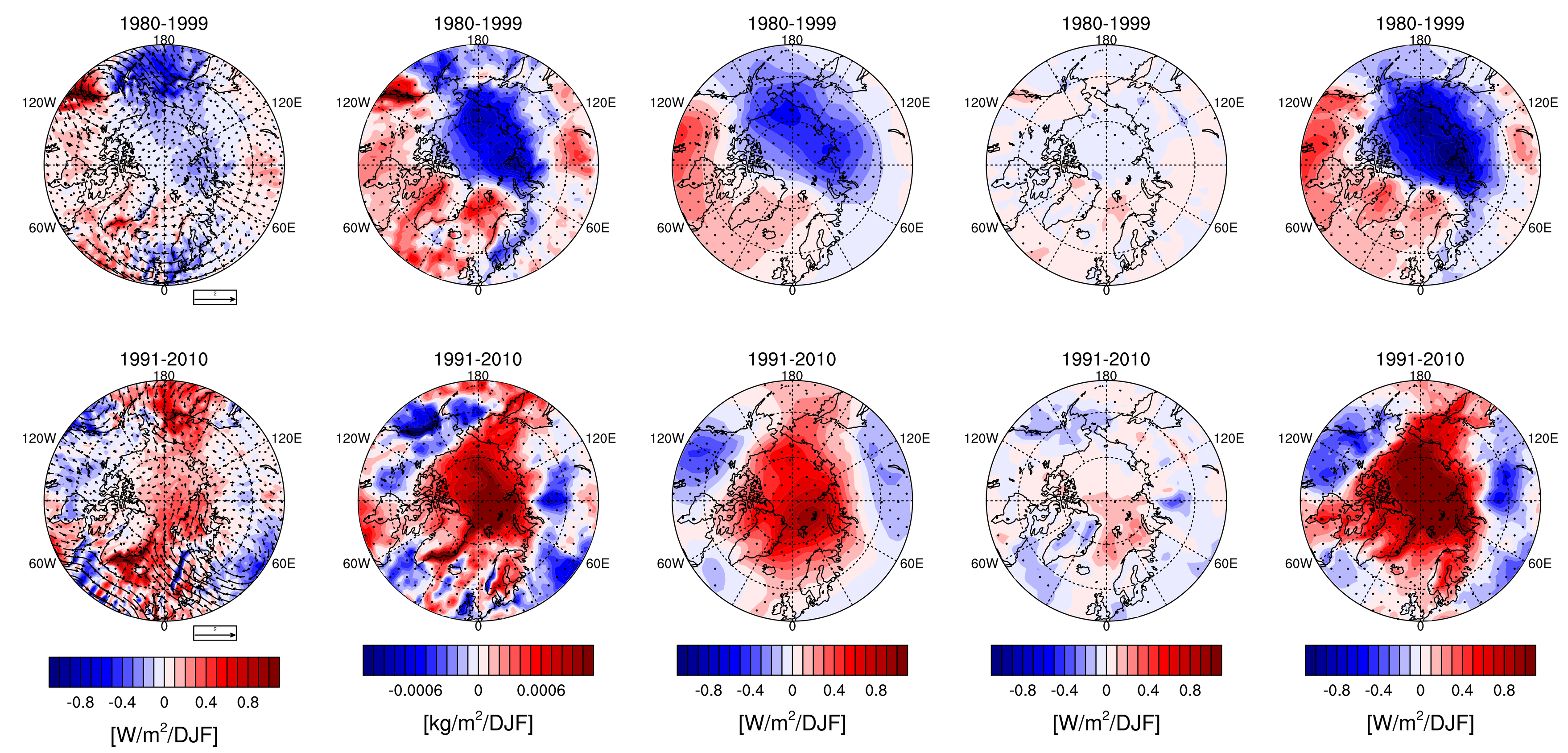


Figure 2

5. Driving mechanisms for downward IR

Latent heat release arising from a poleward moisture flux from midlatitudes followed by condensation is an important contributor to the increase in downward IR (compare the right and left columns in Fig. 2). Consistently, the total column water tend pattern (column 2 in Fig. 2) resembles the downward IR pattern, and the lowest layer σT^4 trend is similar to that of the downward IR.

The increase in liquid and frozen water, associated with the poleward moisture transport from midlatitudes, also contributes to the increase in downward IR.

The poleward moisture transport trend can be written as
$(\mathbf{v}q)_T = \mathbf{v'}_T q_c + \mathbf{v}_c q'_T + (\mathbf{v'}q')_T$.

From Fig. 3, it can be seen that most of the moisture flux trend is due to the wind field trend associated with a poleward propagating Rossby wave train.

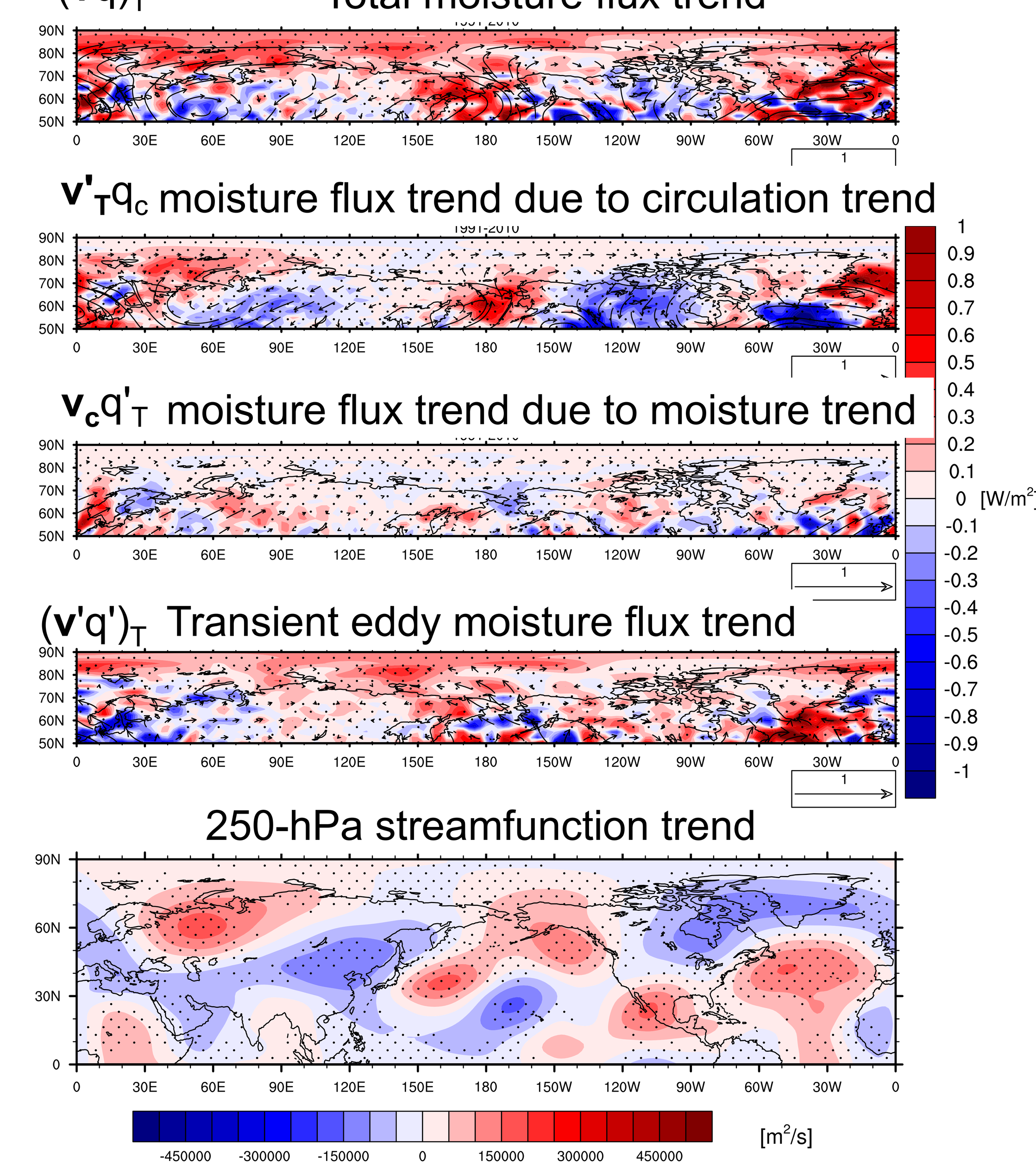
8. Conclusions

- The inter-decadal Arctic SAT trend (Arctic Amplification) is driven primarily by the trend in downward IR.
- The downward IR trend is driven by a poleward moisture flux from the midlatitudes followed by condensation and latent heat release.
- The moisture flux is associated with a wave activity flux that passes from the tropics through the midlatitudes into the Arctic and then southward toward the tropics.

6. Moisture flux and streamfunction trends

Figure 3: The trend of the vertically-integrated moisture flux vector and its convergence multiplied by latent heat of vaporization. (top four panels)

Moisture trend is least Important contributor.



7. Wave activity flux

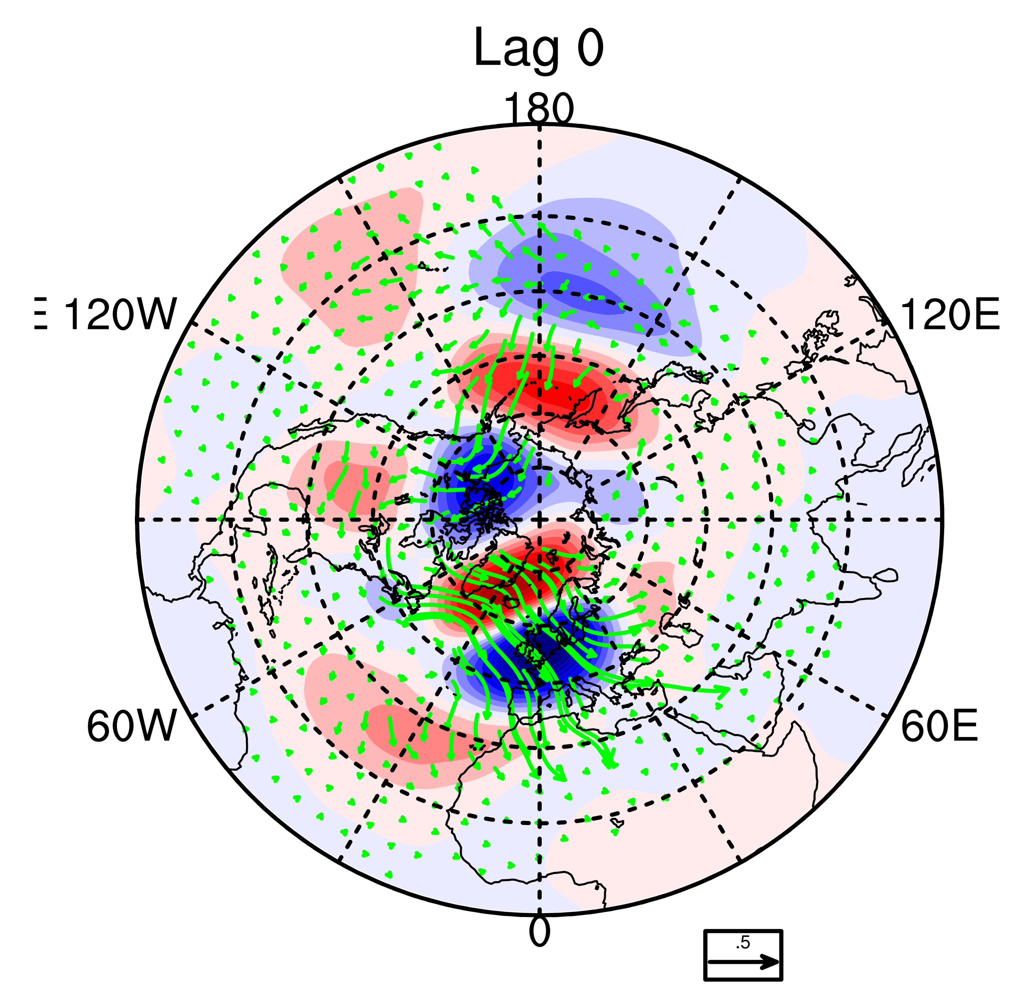


Figure 4: Wave activity flux. The downward IR trend is associated with an intraseasonal wave activity flux from the tropics into and then through the Arctic. This is followed by a wave activity flux southward into low latitudes.

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