The link between tropical convection and the Arctic warming on intraseasonal and interdecadal time scales

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Tropically-Excited Arctic warMing mechanism

An intensification and localization of warm pool tropical convection can warm the cold-season Arctic (Lee et al. 2011a,b, Yoo et al. 2011, 2012a,b) via the convective excitation of poleward propagating Rossby waves which transport heat and moisture poleward, and induce sinking motion over the Arctic & enhanced downward infrared radiation

Does the TEAM mechanism make a large contribution toward Arctic amplification?

Does the TEAM mechanism contribute to the melting of Arctic sea ice?
Poleward moisture flux ➔ down-IR ➔ sea-Ice melting
Poleward moisture flux and downward IR

(70 – 90N down-IR vs. 70N poleward moisture flux)

Pentad correlation (a)
daily correlation (moisture flux vs. downIR) (b)

Poleward moisture flux and sea-ice melting
(sea-ice melting rate vs. 70N poleward moisture flux)

Km²/day

r = 0.57

moisture flux leads
downIR leads

Poleward moisture flux (Kg m/s)

sea-ice melting rate

Poleward moisture flux (Kg m/s)
OLR composites (based on downward IR)

Red colors $\rightarrow$ anomalously low OLR
Arctic warming is preceded by anomalously strong convection over the Warm Pool region
(3) Future projections (from models)

Multi-model mean changes in surface air temperature (°C, left) and precipitation (mm/day) A1B Scenario, 2080-2090 relative to 1980-1999

IPCC (2007)
“Advances in climate modeling and reconstruction of paleoclimates from proxy data have resolved some controversies but have underscored areas where understanding of greenhouse climates remains imperfect. **Latitudinal temperature gradients are particularly problematic.**”

from *Warm Climates in Earth History (Huber et al. 2002)*

Baroclinic eddy heat flux = \(-\text{Diffusivity} \times \text{mean gradient}\)

What other mechanisms?
Inspiration of the TEAM hypothesis: Rossby waves excited by a tropical heat source cause equatorial superrotation [Saravanan 1993]

In a superrotating state, there must be a process other than baroclinic eddy heat flux that maintains the weak temperature gradient
Proposed mechanism for polar amplification:
Tropical Rossby wave source, poleward wave propagation, & high-latitude adiabatic warming (Lee et al. 2011)

- $\text{CO}_2$ warming causes tropical convective heating to be more localized
- Convective heating excites Rossby waves
- Rossby waves propagate poleward, transporting westerly momentum equatorward: eastward acceleration in tropics
- Atmosphere adjusts toward a balanced state
- Poleward heat and moisture transport by the waves (and increased downward IR)

![Diagram showing the proposed mechanism for polar amplification involving tropical Rossby wave source, poleward wave propagation, and high-latitude adiabatic warming.](image)

Eastward acceleration: $[u'v'] > 0$

Westward acceleration: $[u'v'] < 0$

Poleward Rossby propagation:

$$C_{gy} \mu [u'v']$$

Adiabatic warming
tropical perturbation run - control run

Surface temperature

250-hPa height and winds
Testing the hypothesis with ECMWF reanalysis


Surface temperature

Downward IR flux

Direct consequence of Rossby wave dynamics

Horizontal temperature advection + Adiabatic warming

Surface heat flux
The findings so far:

Dynamical processes & downward IR radiative flux warms the Arctic on intraseasonal time scales

Questions:

1. Are these two processes linked?

2. How does the inter-decadal time-scale Arctic warming occur through Rossby wave dynamics which takes place on intraseasonal time scales?
Daily evolution associated with the 250-hPa streamfunction trend pattern

250-hPa streamfunction  
Downward IR flux  
Surface temperature

Lag-5

Lag0

Lag5

Lag10
Joint Self-Organizing Map: 250-hPa Streamfunction Convective Precipitation
Time evolution of the SOM pattern frequency

Positive PNA

ENSO (warm events)

Positive circumglobal streamfunction pattern
SOM patterns, trend, and frequency of occurrence

Sea Ice/Global Mean Temp (GHG)

Global Mean Temp (GHG)

Sea Ice

6.5-7.5 day timescale for patterns
Lagged-correlations between Arctic sea ice and SOM frequency

Negative (positive) lags:
sea-ice leading (lagging) SOM frequency
Anomalous zonal wind associated with SOM patterns

SOM1

SOM2

SOM3

SOM4
Conclusions

1. The TEAM mechanism provides a link between tropical convection, Arctic amplification, and a reduction of Arctic sea ice.

2. The TEAM mechanism arises from enhanced and localized Warm Pool tropical convection which excites poleward propagating Rossby waves that transport heat and moisture poleward, and increases downward IR.

3. The inter-decadal time-scale Arctic warming occurs through changes in the frequency of occurrence of a small number of intraseasonal-scale teleconnection patterns that warm the Arctic.

4. Arctic sea-ice area anomalies are associated with SOM patterns that project onto the NAM. The sea-ice area anomalies lead the SOM frequency of occurrence anomalies with lead times of up to 12 months. The sea ice and SOM patterns are linked through changes in the strength of the stratospheric polar vortex. The recent decline in the NAM index may be explained by the downward trend in Arctic sea ice.
Arctic sea-ice concentration and temporal variations
(Dec 15 - Mar 31)

(a) sea-ice concentration

(b) Intra-seasonal variance
Warmer climate has a smaller equator-to-pole temperature gradient.
Does localized tropical convective heating increase as the climate warms?
Anomalous OLR associated with SOM Patterns

SOM1

SOM2

SOM3

SOM4
Surface Air Temperature Response to Madden-Julian Oscillation

MJO Phase 1

MJO Phase 5