The Role of Downward Infrared Radiation in Arctic Amplification

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Aspen Workshop on Polar Amplification, Aspen, Colorado, June 12-16, 2017
Question: What process accounts for the inter-decadal Arctic Amplification trend?

Data: European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-Interim) data
Linear SAT trends for 15 different 20-year segments

[K/DJF]
Surface Energy Budget Analysis

Trend ($\Delta$) of the Surface Energy Budget terms (Lesins et al. 2012)

\[
\Delta C = \Delta I_d + \Delta I_u + \Delta F_{sh} + \Delta C
\]

- Storage (very small)
- Downward IR
- Upward IR
- Surface turbulence heat fluxes
- Conduction through ice

Expressing the upward infrared radiation (IR) as $-\varepsilon \sigma T_s^4$, the energy balance equation can be written as

\[
\Delta T_s = (\Delta I_d + \Delta F_{sh} + \Delta C - \Delta G)/(4\varepsilon \sigma T_s^3)
\]

Neglect $\Delta C$ and $\Delta G$. $T_s$ and SAT are highly correlated ($r=0.97$; Chen et al. 2003) over most of the Arctic.
Trend Calculation

- $\Delta f = (\delta f / \delta x_i) \Delta x_i$; $f =$ SAT; $\Delta =$ trend;
  
  $$(\delta f / \delta x_i) = r \sigma_{SAT} / \sigma(x_i) = \text{regression coefficient}$$

- $x_1 =$ downward IR
- $x_2 =$ surface heat flux
- $x_3 =$ horizontal temperature advection;
- $x_4 =$ adiabatic warming/cooling

- For each winter, DJF mean values of $f$ and $x_i$ for are subtracted in the regression coefficient calculation

- Regression coefficient expresses the intraseasonal relationship between $f$ and $x_i$
Surface Energy Budget

SAT trend driven primarily by trend in downward IR, not by the surface heat flux trend

Cooling Period 1980-1999

Warming Period 1991-2010
Energy Budget (regression coefficients and trends)

Regression Coefficients

Surface Heat Flux

Horizontal Temp Advection

Adiabatic Warming/Cooling

Regression Coefficients

Downward IR

Trends

IR trend

HeatFlux trend

Tadv trend

ADB trend
Downward IR Trend Index

Downward IR trend index obtained by projecting daily downward IR (poleward of 70N) onto downward IR trend pattern

\[
IR(x,t) = IR_{\text{index}}(t)IR_{\text{trend}}(x) + \text{residual}
\]

\[
IR_{\text{index}}(t) = \frac{\sum_{i,j} IR(x,t) IR_{\text{trend}}(x) \cos \theta}{\sum_{i,j} IR_{\text{trend}}(x)^2 \cos \theta}
\]

\text{e-folding time scale} = 10 \text{ days}
What processes drive the downward IR trend?

Obtained from regression against the IR index

Downward IR trend is driven largely by a trend in the intrusions of warm moist air into the Arctic
Moisture flux (convergence) & 250-hPa streamfunction
(1991-2010 trends)

Total moisture flux trend

Moisture flux trend due to circulation trend

Moisture flux trend due to specific specific humidity trend

Moisture flux trend due to transients

250-hPa Streamfunction
Daily Evolution

Lagged pattern correlations between regressed fields and trend patterns

- Upward IR
- SAT
- Downward IR
- Moisture flux convergence
- Total Column Water
- Surface heat flux
Daily evolution (lagged regressions)

Downward IR

Upward IR

Net IR

Heat flux

Surface air temperature

Downward heat flux

Upward heat flux
An increase in the frequency of moisture intrusion events
Downward IR Trend Index

IR index time series is consistent with increase in the amplitude and frequency of moisture intrusion events.
Diabatic Heating Trend Index

Diabatic heating trend index obtained by projecting daily diabatic heating (JRA-55 Reanalysis data) (30° W-60° E, 60° N-90° N) (Greenland and Barents Seas) onto diabatic heating trend pattern

\[ DH(x,t) = DH_{index}(t)DH_{trend}(x) + \text{residual} \]

\[ DH_{index}(t) = \frac{\sum_{i,j} DH(x,t)DH_{trend}(x) \cos \theta}{\sum_{i,j} (DH_{trend}(x)^2 \cos \theta)} \]

\text{e-folding time scale} = 10 \text{ days}
250-hPa wave activity fluxes & streamfunction: Wave activity \textit{transits} the Arctic

Lag - 4
Lag - 2
Lag 0
Lag + 2
Lag + 4
Lag + 6
Lag + 8
Lag + 10

[10^6 m^2/s]

\begin{align*}
\text{Lag - 4} & : \quad \text{Wave activity transits the Arctic} \\
\text{Lag - 2} & : \\
\text{Lag 0} & : \\
\text{Lag + 2} & : \\
\text{Lag + 4} & : \\
\text{Lag + 6} & : \\
\text{Lag + 8} & : \\
\text{Lag + 10} & :
\end{align*}
250-hPa wave activity fluxes & JRA-55 diabatic heating

Convective heating

Convective and large-scale condensational heating
Temporal evolution of skin temperature
CONCLUSIONS

• **Arctic Amplification**: Most of the inter-decadal Arctic surface warming trend arises from a trend in downward IR, not a trend in the surface heat flux (ice albedo feedback). The downward IR increase is due to moisture flux intrusions associated with poleward propagating Rossby waves, which bring warm moist air in the Arctic.

• **Moisture intrusions** appear to be increasing in their frequency and amplitude.

• The Rossby waves rapidly transit the Arctic and return to lower latitudes, suggesting that **upward surface heat flux** and **Arctic sea ice loss** may have little effect outside of the Arctic.