The Role of Downward Infrared Radiation in Arctic Amplification

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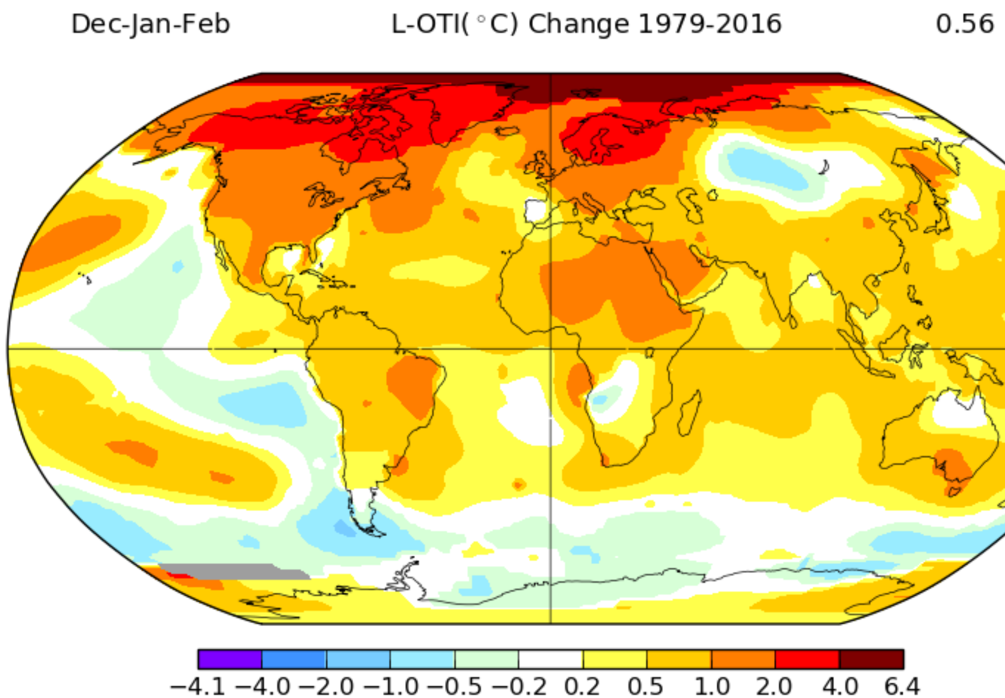
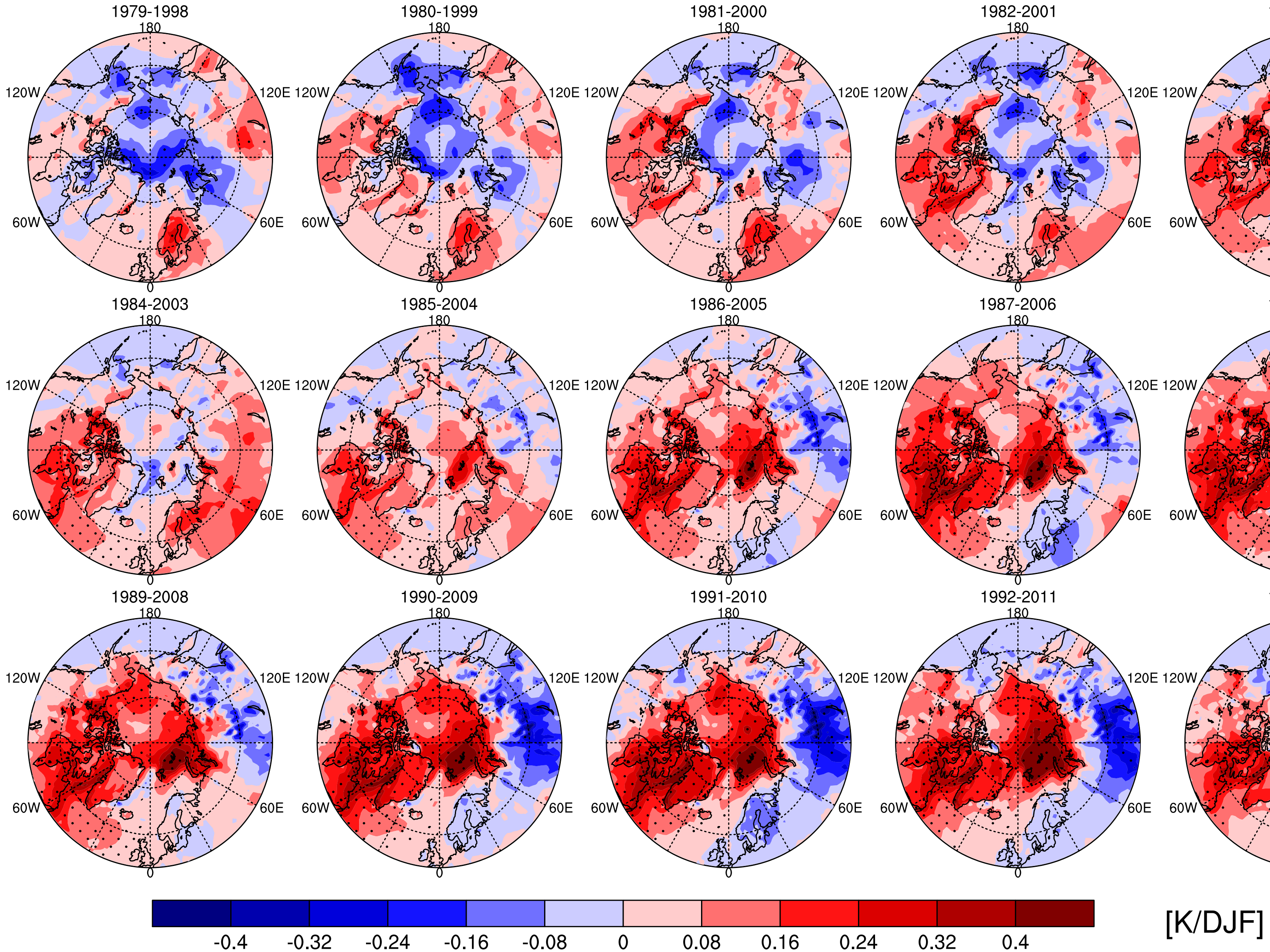
Question: What process accounts for the inter-decadal Arctic Amplification trend?



Data: European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-Interim) data

Linear SAT trends for 15 different 20-year segments



Surface Energy Budget Analysis

Trend (Δ) 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 ΔC and ΔG. 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; Δ = trend;

  $(\delta f/\delta x_i) = r\sigma(_{SAT})/\sigma(x_i)$ = regression coefficient

x_1 = downward IR

x_2 = surface heat flux

x_3 = horizontal temperature advection;

x_4 = adiabatic warming/cooling

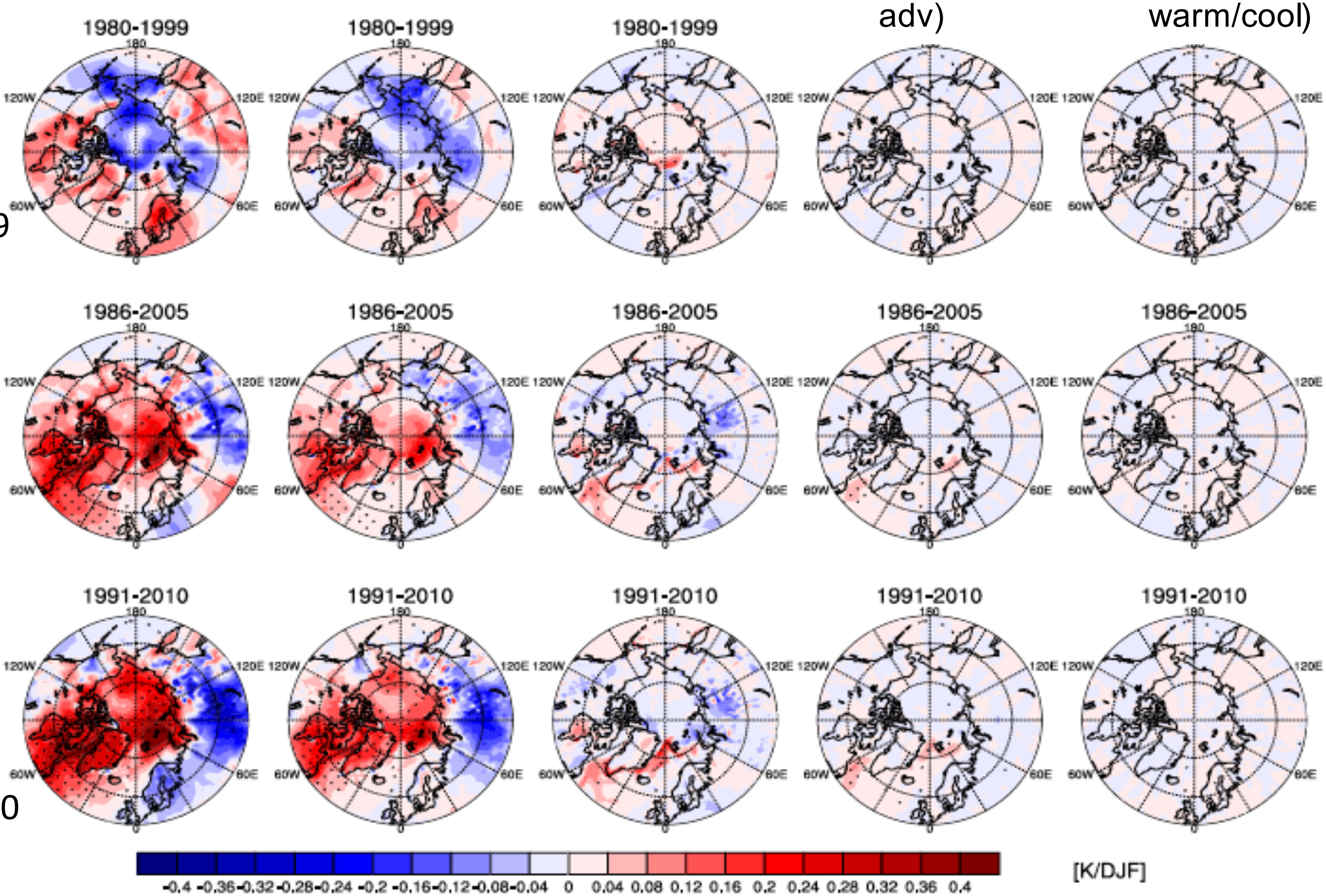
- For each winter, DJF mean values of f and x_i for are subtracted in the regression coefficient calculation
- Regression coefficient expresses the intraseasonal relationship between f and x_i

Surface Energy Budget

SAT trend | SAT (Downward IR) | SAT (surf heat flux) | SAT (horiz temp adv) | SAT (adiabatic warm/cool)

Cooling Period 1980-1999

Warming Period 1991-2010



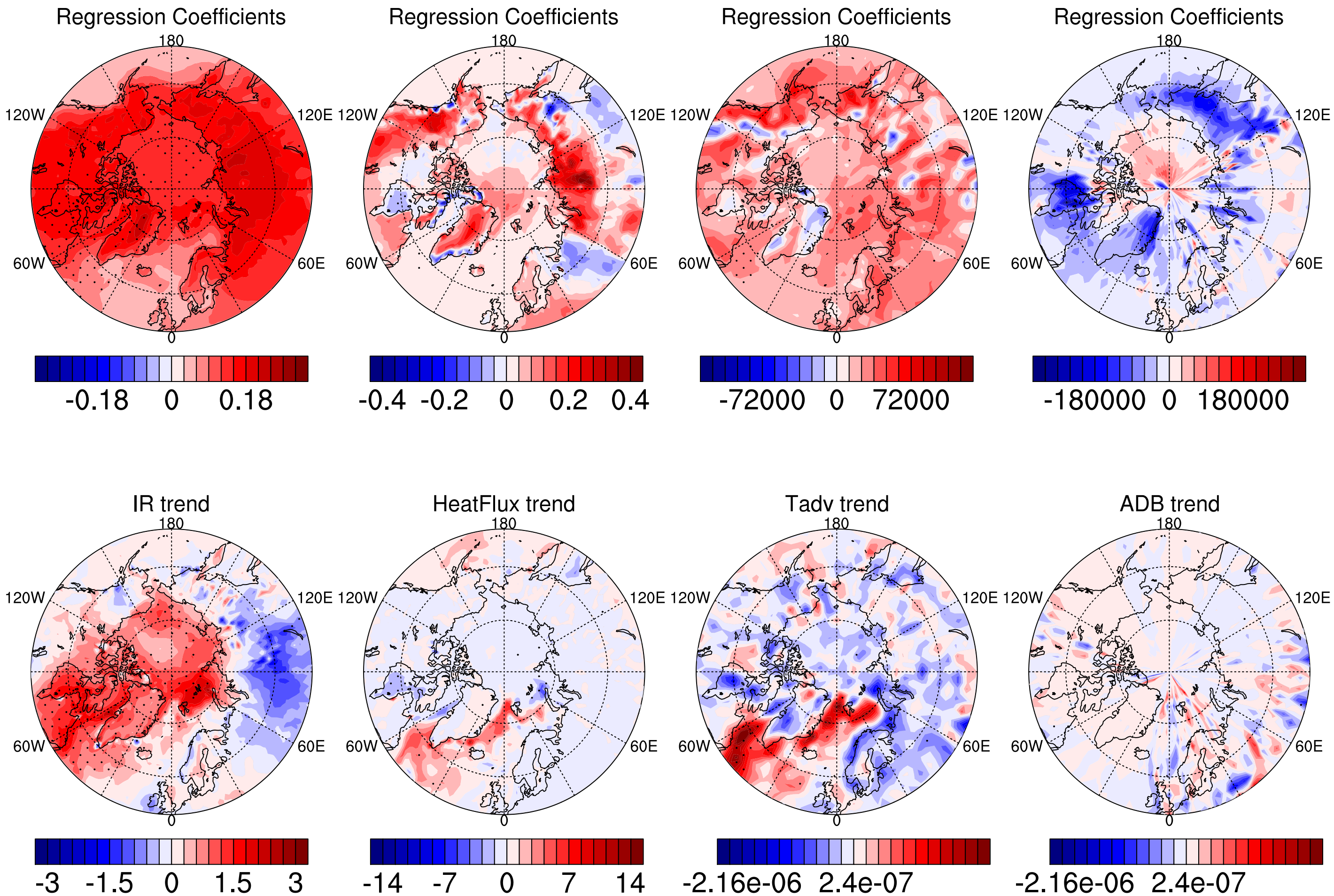
SAT trend driven primarily by trend in downward IR, not by the surface heat flux trend

Energy Budget (regression coefficients and trends)

Downward IR | Surface Heat Flux | Horizontal Temp Advection | Adiabatic Warming/Cooling

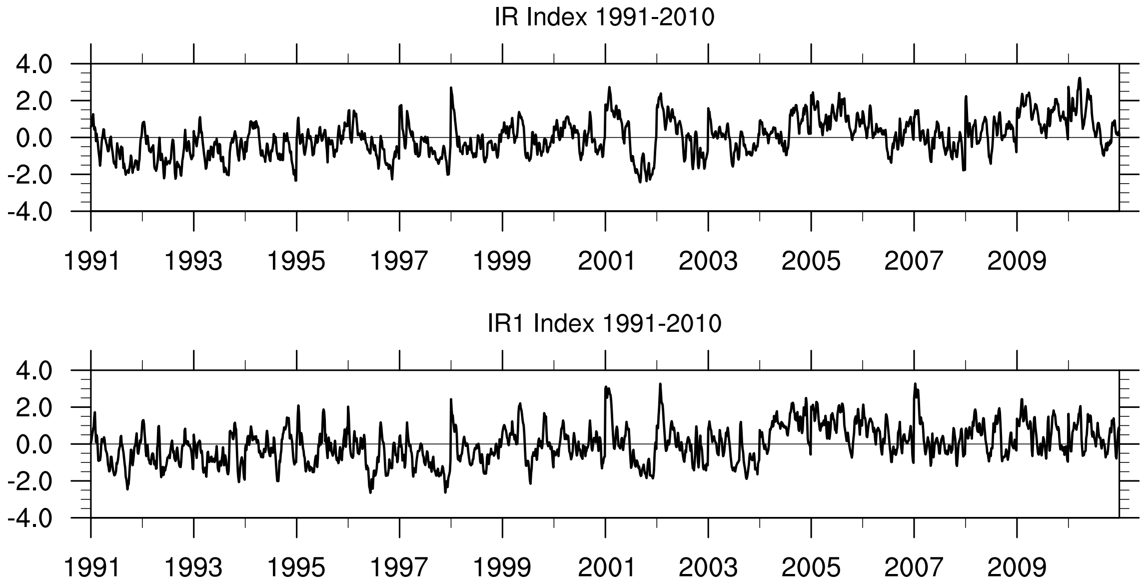
Regression Coefficients

Trends



Downward IR Trend Index

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



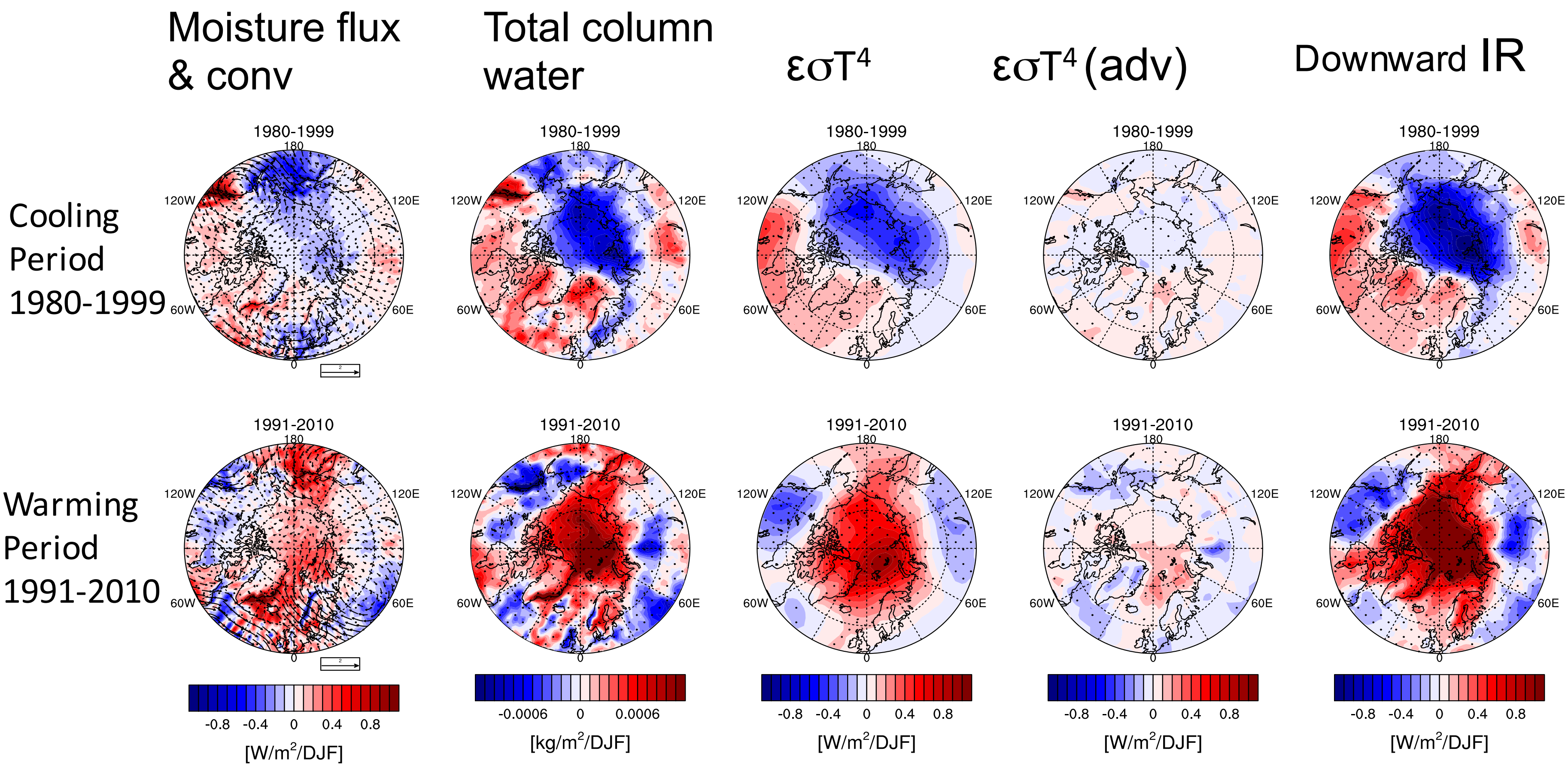
$$\mathrm{IR}(\boldsymbol{x},t) = \mathrm{IR}_{index}(t)\mathrm{IR}_{trend}(\boldsymbol{x}) + \text{residual}$$

$$\mathrm{IR}_{index}(t) = (\textstyle\sum_{i,j}\mathrm{IR}(\boldsymbol{x},t)\ \mathrm{IR}_{trend}(\boldsymbol{x})\cos\theta)/(\textstyle\sum_{i,j}\mathrm{IR}_{trend}(\boldsymbol{x})^2\cos\theta)$$

e-folding time scale = 10 days

What processes drives 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

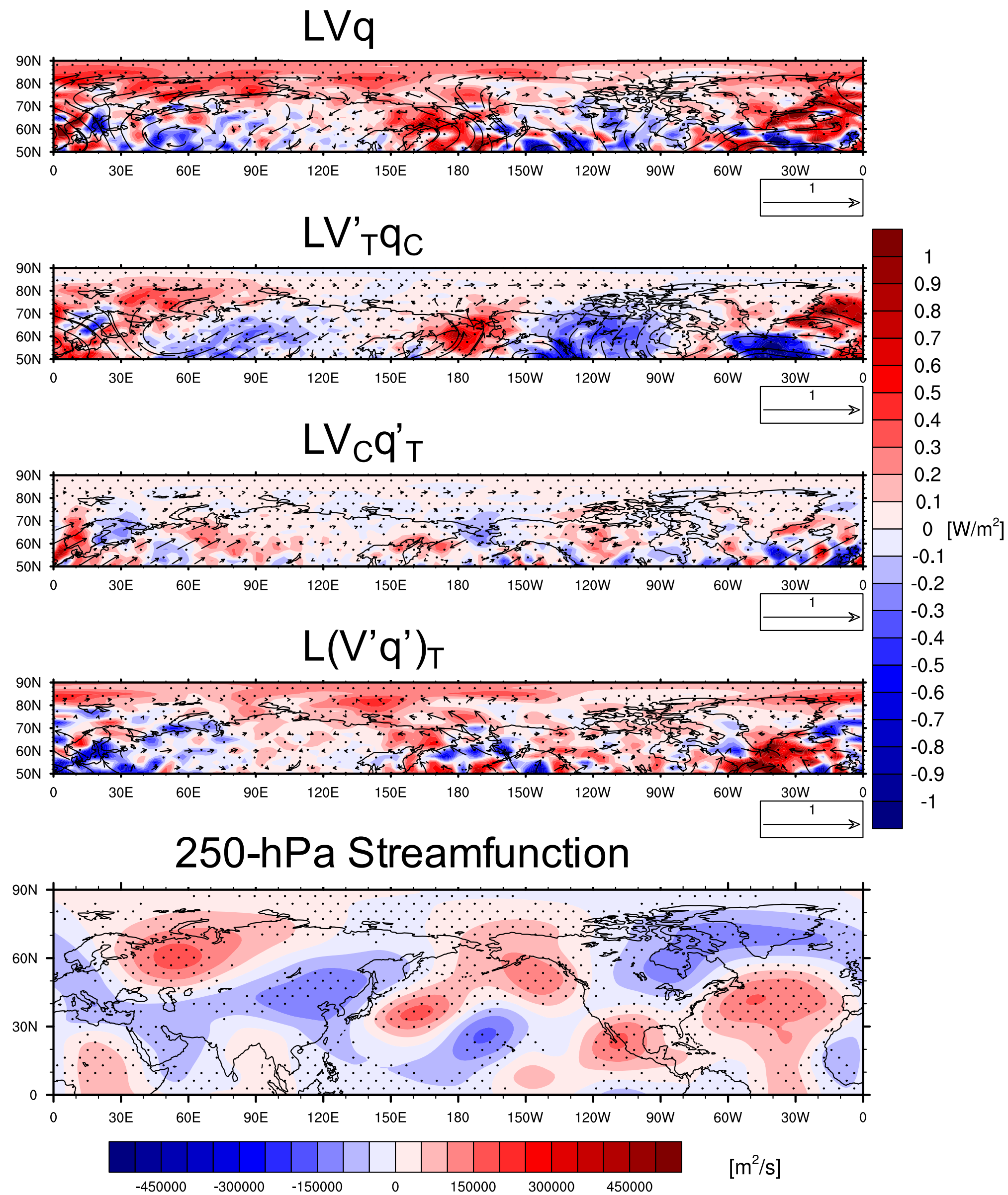
Moisture flux (convergence) & 250-hPa streamfunction (1991-2010 trends)

Total moisture flux trend

Moisture flux trend due to circulation trend

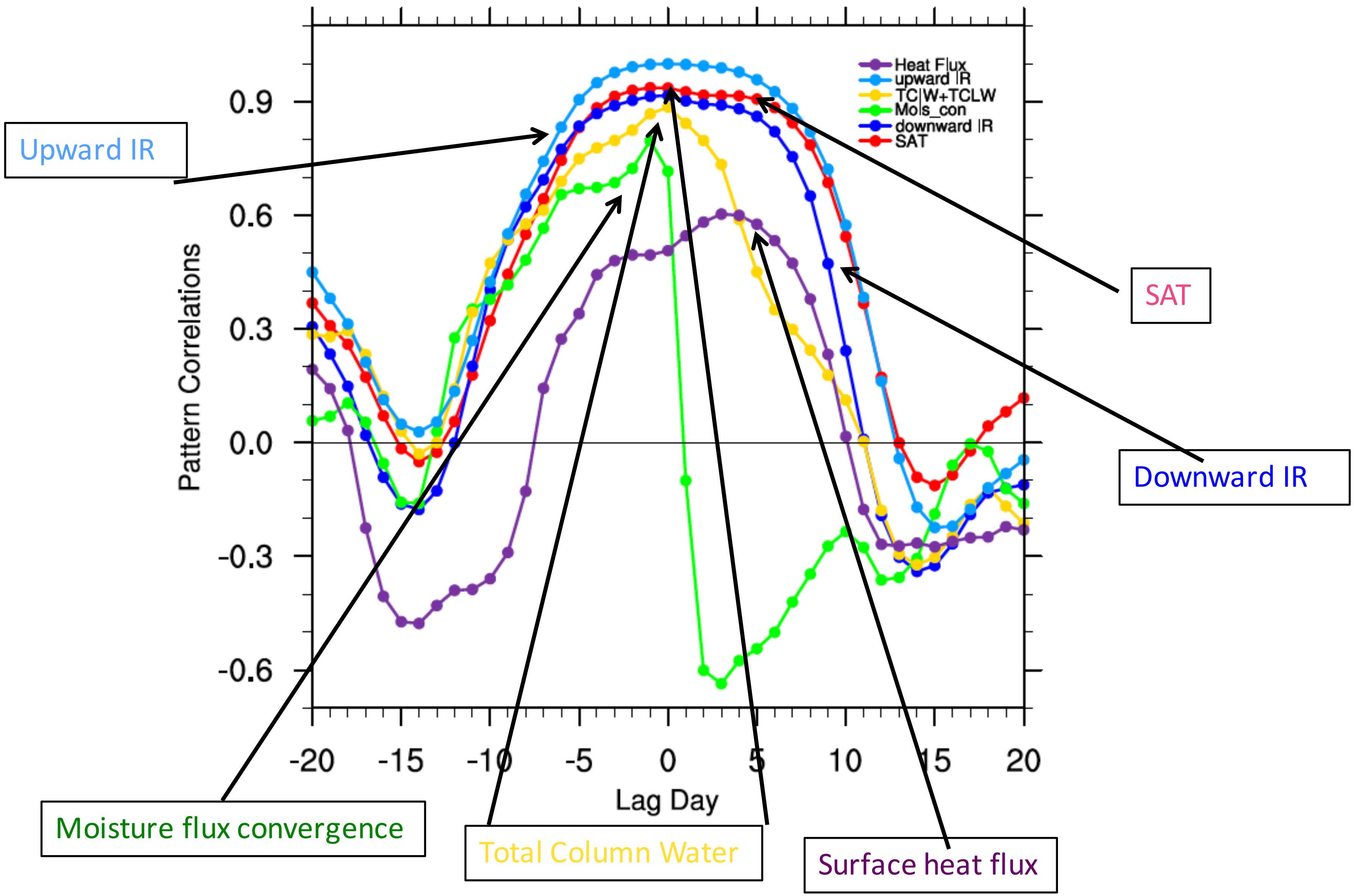
Moisture flux trend due to specific specific humidity trend

Moisture flux trend due to transients

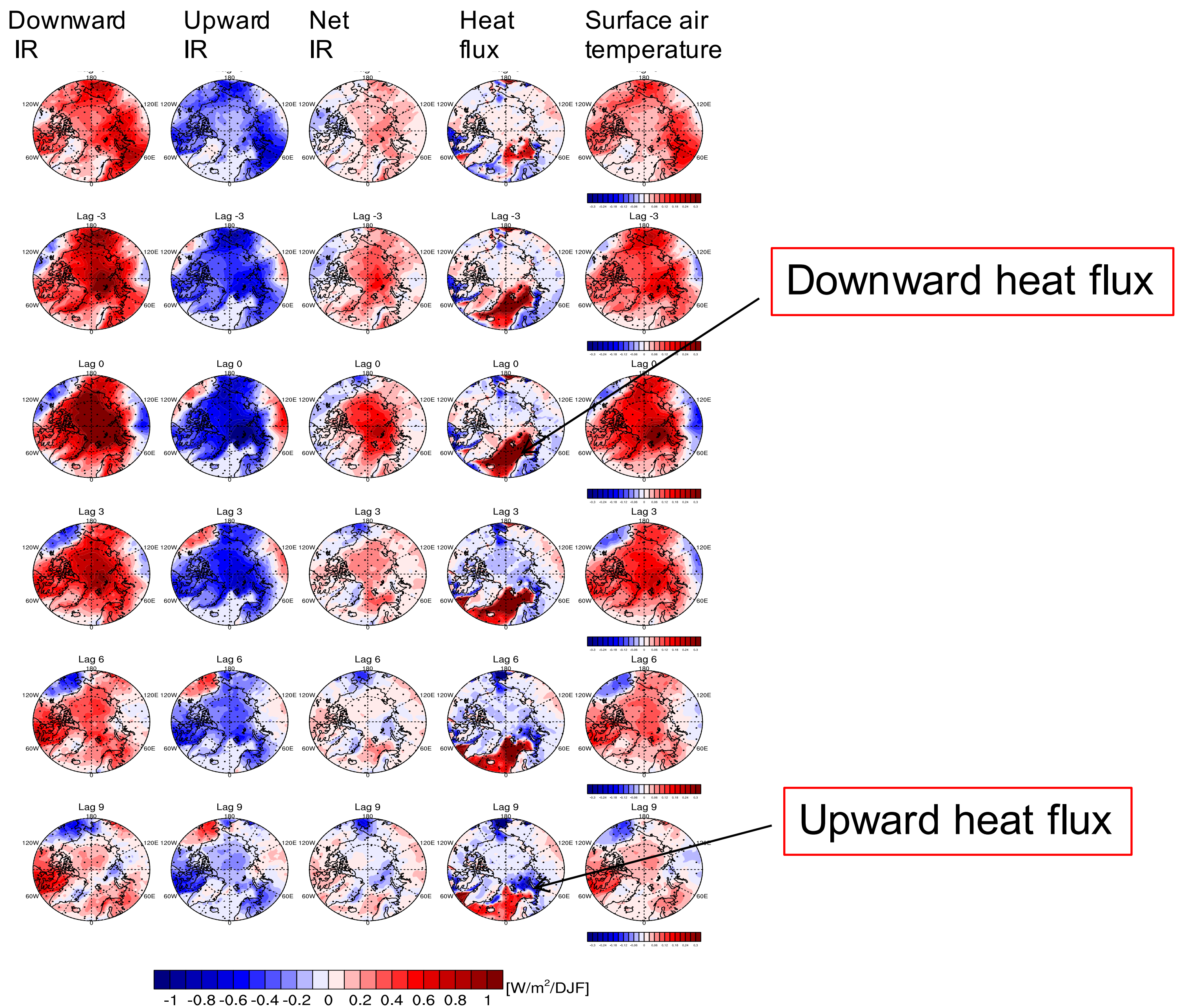


Daily Evolution

Lagged pattern correlations between regressed fields and trend patterns



Daily evolution (lagged regressions)



Woods and Caballero (2016)

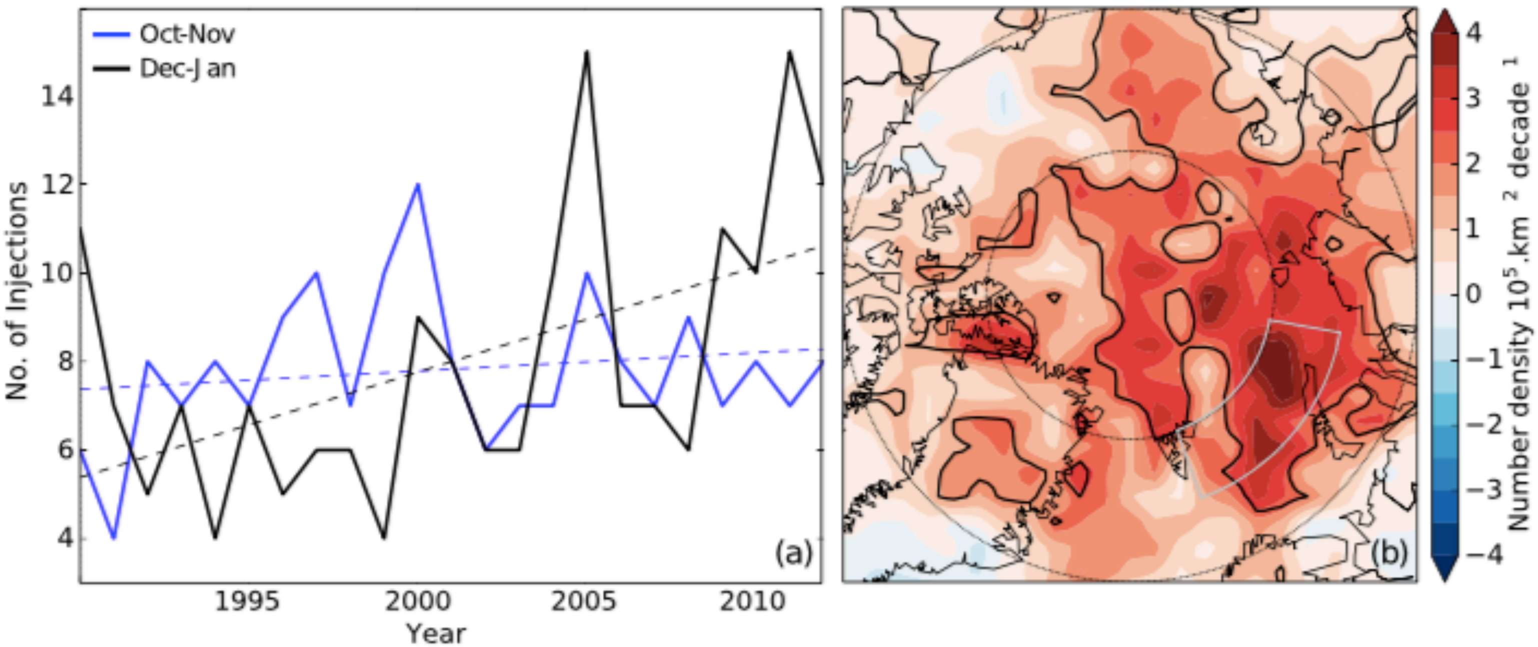
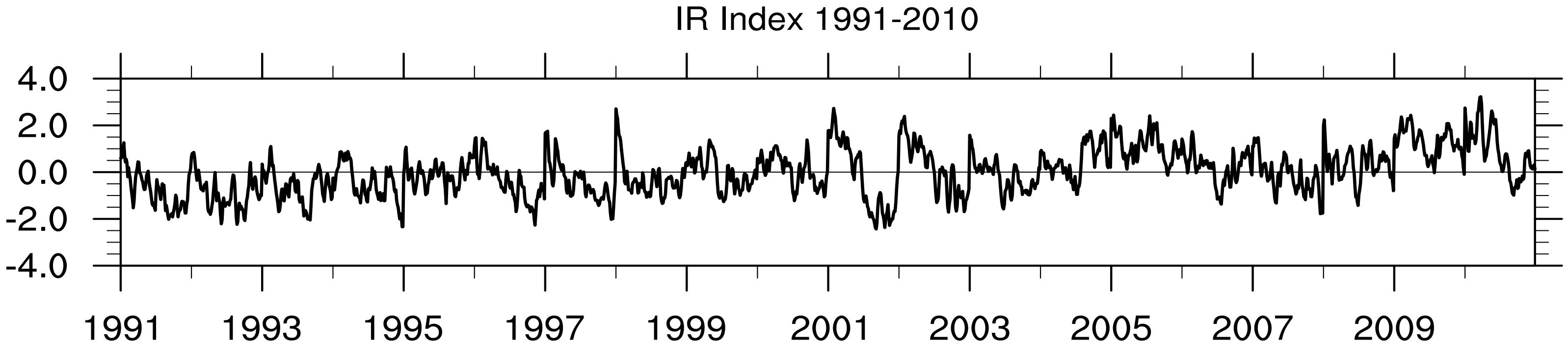
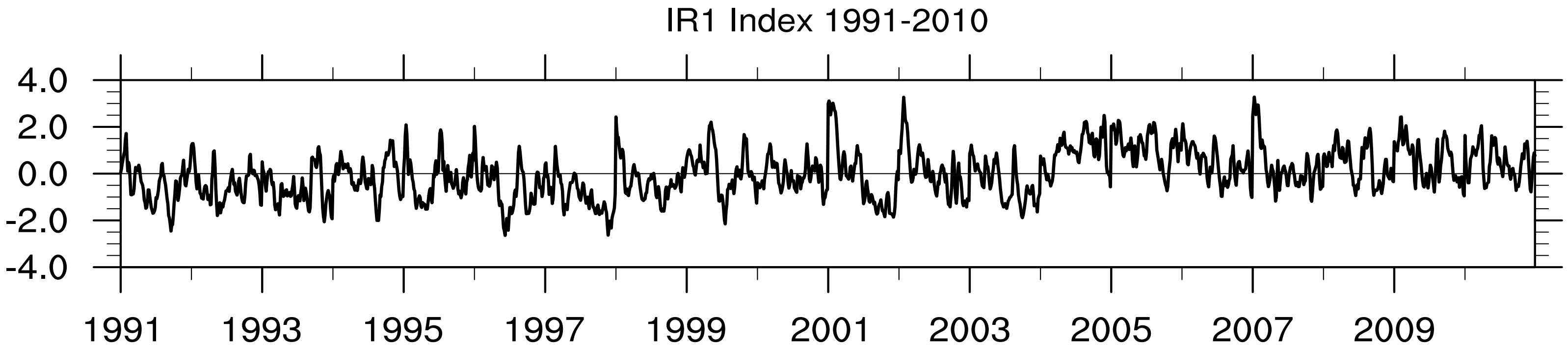


FIG. 8. (a) Total number of intrusion events during October–November (blue line) and December–January (black) for each year in the dataset. Dashed lines show linear fits. There is a significant trend in the number of intrusions during December–January of roughly 2.5 decade^{-1} ($p = 0.005$). (b) Linear trends in intrusion density during December–January. Solid black lines enclose trends significant at the 5% level. Gray lines show the Barents Sea box. Dotted lines show the 70° and 80°N latitude lines.

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

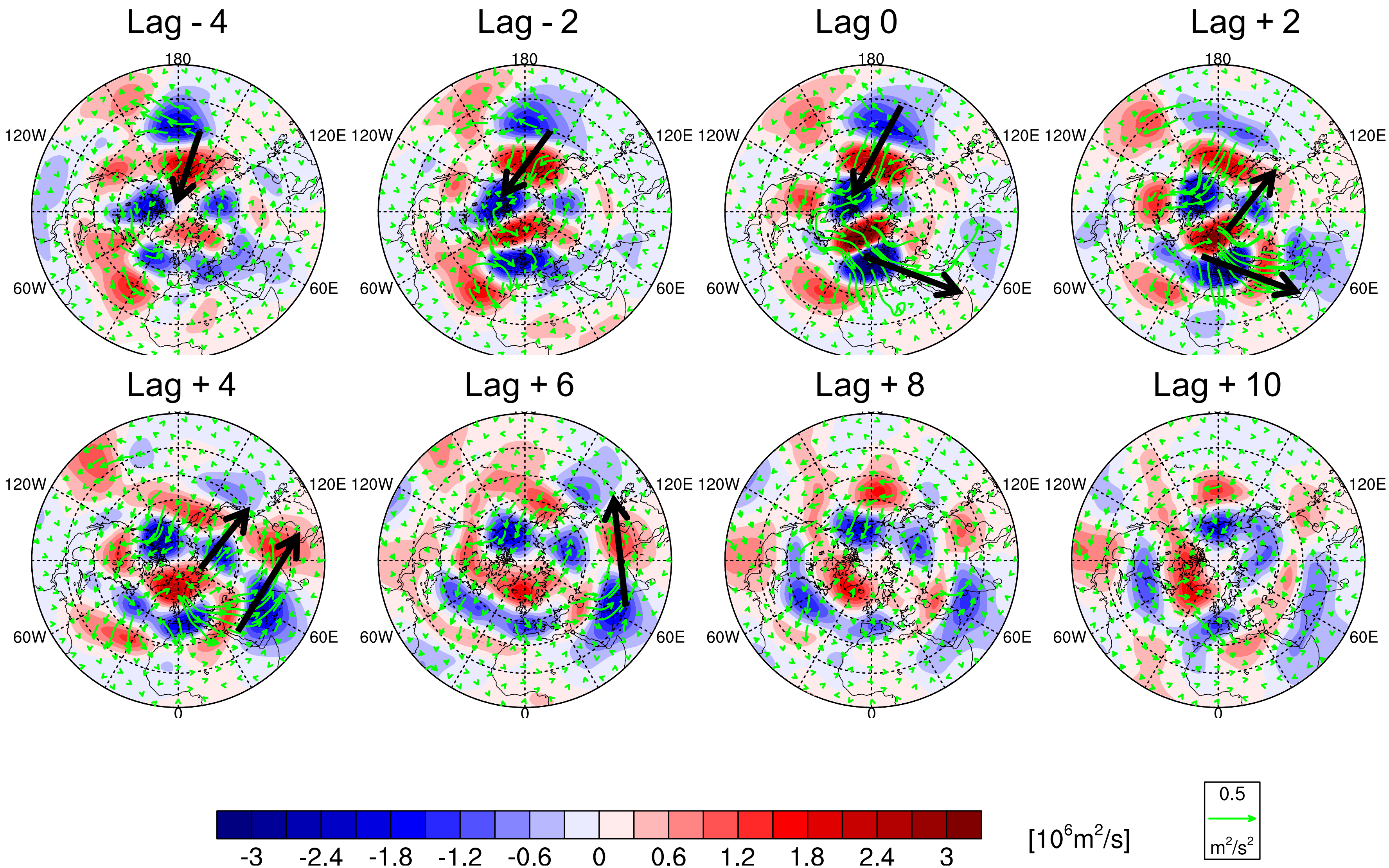
$$DH(\boldsymbol{x},t) = DH_{index}(t)DH_{trend}(\boldsymbol{x}) + \text{residual}$$

$$DH_{index}(t) = (\sum_{i,j} DH(\boldsymbol{x},t)\, DH_{trend}(\boldsymbol{x}) \cos\theta)/(\sum_{i,j} DH_{trend}(\boldsymbol{x})^2 \cos\theta)$$

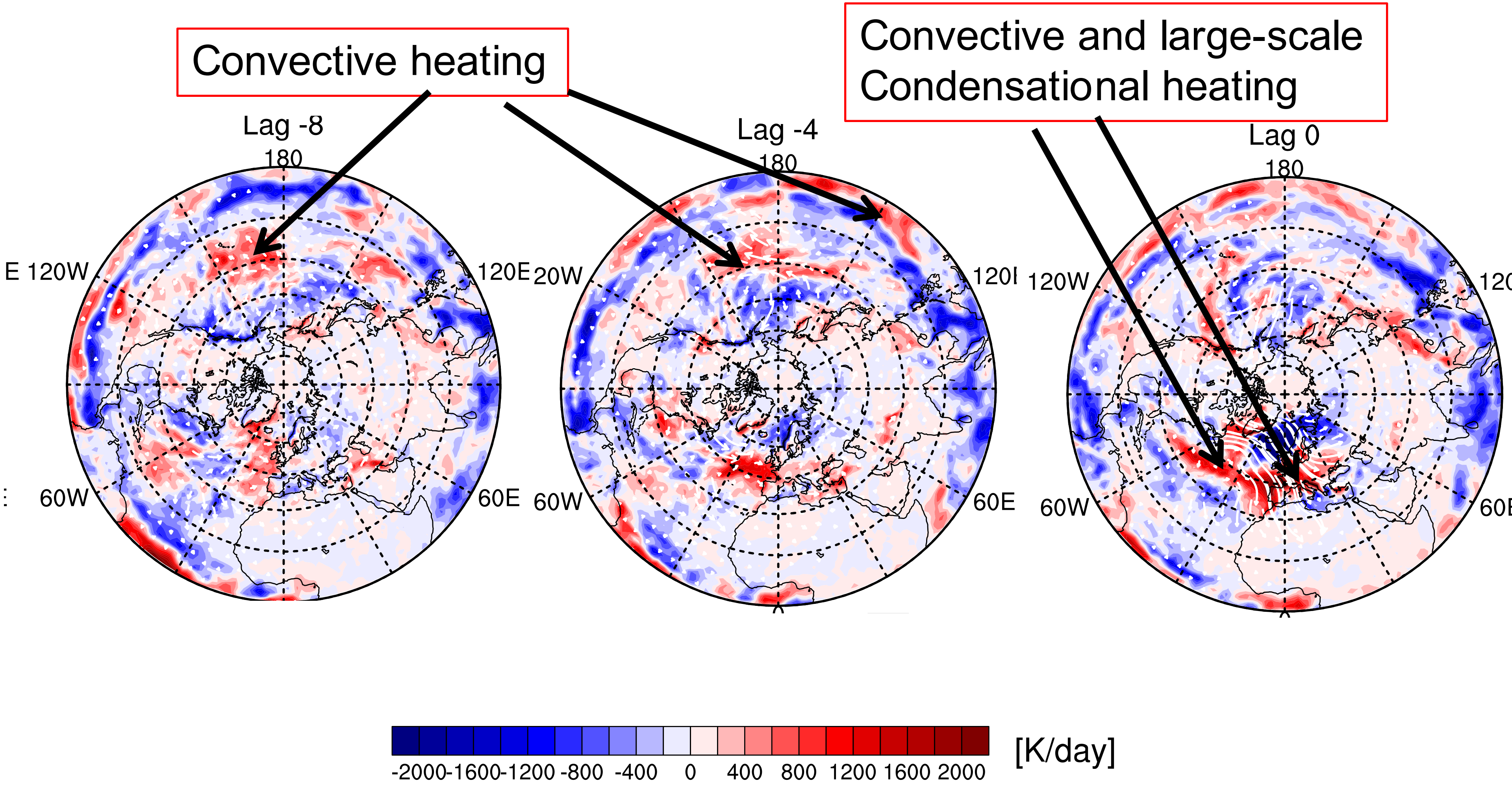
e-folding time scale = 10 days

250-hPa wave activity fluxes & streamfunction:

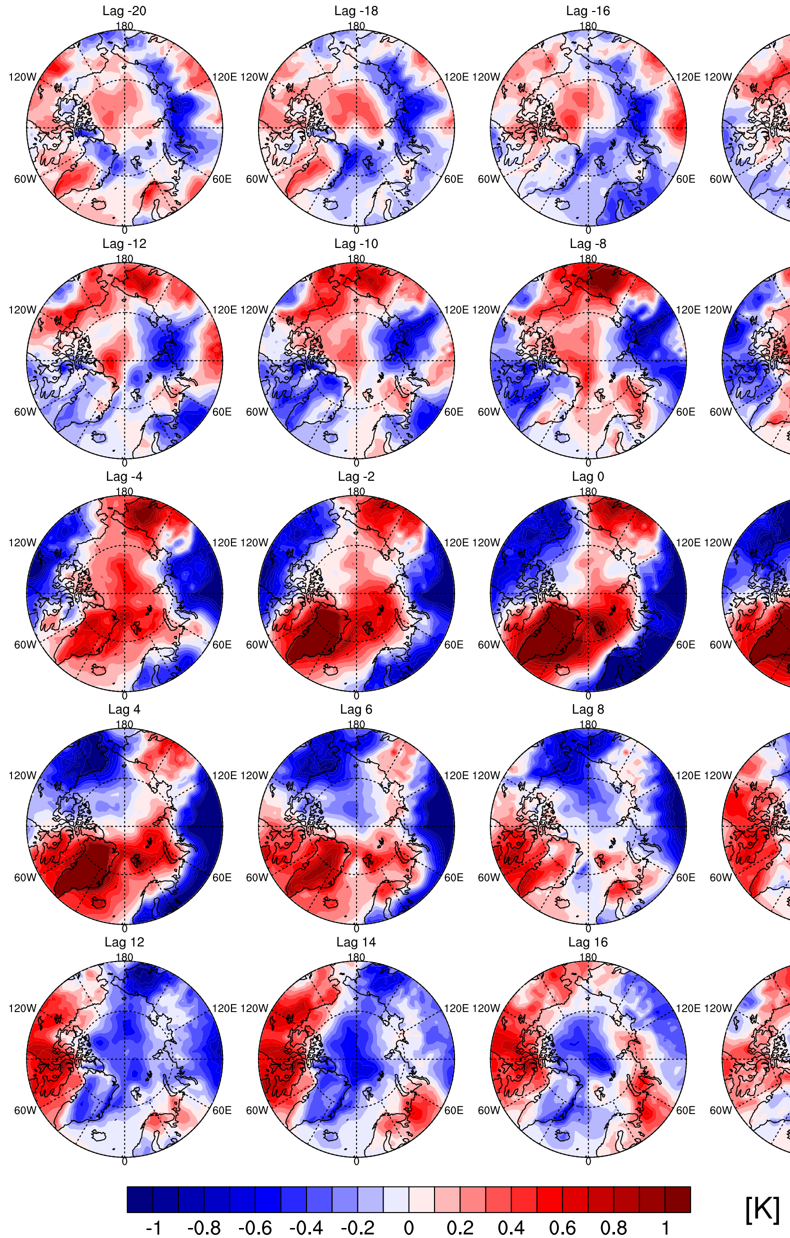
Wave activity **transits** the Arctic



250-hPa wave activity fluxes & JRA-55 diabatic 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.