The vertical structure of Arctic warming

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Global warming

Globally averaged surface temperature
Effects of Arctic warming

• Retreat of Arctic sea ice
• Melting of glaciers
• Shrinking snow and permafrost areas
Arctic sea ice
September
1979 2007
Arctic sea ice extent

Summer ice

- annual
- winter (JFM)
- spring (AMJ)
- summer (JAS)
- autumn (OND)
Why global warming?

An increased global greenhouse effect due to increasing concentrations of carbon dioxide and other greenhouse gases.
Why Arctic amplification?

- Ice-albedo feedback.
- Increased heat transport in atmosphere and ocean.
- Atmospheric surface layer greenhouse warming.
Vertical structure of Arctic warming in ERA-40
Heat transport across 60° N

Blue and red colour: negative and positive temperature anomalies on March 16 1996

Arrows: energy transport anomalies on March 11 1996
Heat transport across 60º N

Blue and red colour: negative and positive temperature anomalies on March 16 1996

Arrows: energy transport anomalies on March 11 1996

Green contours: 850-hPa geopotential heights on March 11 1996
Composite lagged regression of Arctic temperature on energy transport from ERA-40 reanalysis
Atmospheric Northward Energy Transport (ANET)

Atmospheric energy components

\[ I = c_v T \quad \text{Internal} \]
\[ \Phi = gz \quad \text{Potential} \]
\[ k = \frac{1}{2} U^2 \quad \text{Kinetic} \]
\[ H = Lq \quad \text{Latent} \]

Energy transport across 60°N

\[
\int_{\Phi=60N}^{p_b} \int_{p_t}^{p_b} v (I + \Phi + k + H) \frac{dp}{g} \, dx
\]
Vertical structure of Arctic warming in ERA-40

Total summer warming

Fraction explained by ANET

Significance
Vertical structure of Arctic warming in Japanese re-analysis
Vertical structure of Arctic warming in NCEP/NCAR re-analysis
Comparing re-analyses with HARA (radiosonde archive)
Future climate warming
Year 2100
Future Arctic sea ice
(Stroeve et al., 2007)
Conclusions

• The Arctic is warming rapidly.
• Arctic sea ice quickly vanishing.
• A significant fraction of the Arctic amplification is due to increased heat transports.
• Future warming: Ice-albedo feedback and heat transports.