Observed cloud anomalies associated with the North Atlantic Oscillation and their radiative feedback

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Anomalous cloud-radiative effects damp the NAO

Li et al., 2016
What is the impact of the cloud-radiative effects on the NAO?
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Analyze 5-day mean data:
- CloudSat/CALIPSO
- CERES-Syn1deg
- ERA-Interim reanalysis & forecasts
High-level cloud incidence climatology
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5-day mean NAO timeseries (DJF 2006/2007)

Clim
Cloud anomalies associated with positive NAO+

*Stippling shows non-statistically significant grid points*
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Vertical profiles of the anomalies associated with NAO

Data: CloudSat/CALIPSO
Vertical profiles of the anomalies associated with NAO

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Vertical profiles of the anomalies associated with NAO

Data: CloudSat/CALIPSO
Surface Pressure Tendency perspective
Surface Pressure Tendency perspective

\[
\frac{\partial p_{sfc}}{\partial t} = \rho_{sfc} \frac{\partial \phi_p}{\partial t} + \rho_{sfc} R_d \int_{sfc}^{p_2} \frac{\partial T_v}{\partial t} d\ln p + g(E - P) + RES_{PTE}
\]
Surface Pressure Tendency perspective

\[
\frac{\partial p_{sfc}}{\partial t} = \frac{Dp}{\rho_{sfc}} R_d \int_{sfc}^{p_2} \frac{\partial T}{\partial t} d\ln p + g(E - P) + RES_{PTE} \quad EP
\]

Knippertz & Fink, 2008
Fink et al., 2012
Surface Pressure Tendency perspective

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\frac{\partial p_{sfc}}{\partial t} = \rho_{sfc} R_d \int_{sfc}^{p_2} \frac{\partial T_v}{\partial t} d\ln p
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Fink et al., 2012
Surface Pressure Tendency perspective

\[ \frac{\partial p_{sfc}}{\partial t} = \frac{Dp}{\rho_{sfc} R_d} \int_{sfc}^{P_2} \frac{\partial T_v}{\partial t} d\ln p \]

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\frac{\partial p_{sfc}}{\partial t} = Dp = \rho_{sfc} R_d \int_{sfc}^{p_2} \frac{\partial T_v}{\partial t} d\ln p
\]

\[
ITT = + \rho_{sfc} R_d \int_{sfc}^{p_2} - \vec{v} \cdot \vec{\nabla}_p T_v d\ln p \quad \text{(TADV)}
\]

Knippertz & Fink, 2008
Fink et al., 2012
Surface Pressure Tendency perspective

\[
\frac{\partial p_{sfc}}{\partial t} = \frac{Dp}{\rho_{sfc}R_d \int_{sfc}^{p_2} \frac{\partial T_v}{\partial t} d\ln p}
\]

\[
ITT = + \rho_{sfc}R_d \int_{sfc}^{p_2} \left( \nabla \cdot \vec{v}_p T_v d\ln p \right)
\]

\[
+ \rho_{sfc}R_d \int_{sfc}^{p_2} \left( \frac{R_d T_v}{c_p p} - \frac{\partial T_v}{\partial p} \right) \omega d\ln p
\]

\(TADV\)
\(VMT\)

Knippertz & Fink, 2008
Fink et al., 2012
Surface Pressure Tendency perspective

\[ \frac{\partial p_{sfc}}{\partial t} = \frac{Dp}{\rho_{sfc}R_d} \int_{sfc}^{p_2} \frac{\partial T_v}{\partial t} d\ln p \]

\[ ITT = + \rho_{sfc}R_d \int_{sfc}^{p_2} (\nabla \cdot \nabla_p T_v) d\ln p \quad (TADV) \]

\[ + \rho_{sfc}R_d \int_{sfc}^{p_2} \left( \frac{R_d T_v}{c_p p} - \frac{\partial T_v}{\partial p} \right) \omega d\ln p \quad (VMT) \]

\[ + \rho_{sfc}R_d \int_{sfc}^{p_2} \frac{T_v Q}{c_p T} d\ln p \quad (DIAB) \]

\[ + RES_{ITT} \]

Knippertz & Fink, 2008
Fink et al., 2012
Schematic illustration of the PTE

\[ ITT = + \rho_{sfc} R_d \int_{sfc}^{P_2} - \vec{v} \cdot \nabla_T T_v \, d\ln p \]
\[ + \rho_{sfc} R_d \int_{sfc}^{P_2} \left( \frac{R_d T_v}{c_p p} - \frac{\partial T_v}{\partial p} \right) \omega \, d\ln p \]
\[ + \rho_{sfc} R_d \int_{sfc}^{P_2} \frac{T_v Q}{c_p T} \, d\ln p \]
\[ + RES_{ITT} \]

Temperature Advection
Vertical Motions
Diabatics

Fink et al., 2012
Schematic illustration of the PTE

\[
ITT = + \rho_{sfc} R_d \int_{sfc}^{p_2} - \vec{v} \cdot \vec{\nabla} p T_v d\ln p \\
+ \rho_{sfc} R_d \int_{sfc}^{p_2} \left( \frac{R_d T_v}{c_p p} - \frac{\partial T_v}{\partial p} \right) \omega d\ln p \\
+ \rho_{sfc} R_d \int_{sfc}^{p_2} \frac{T_v Q}{c_p T} d\ln p \\
+ RES_{ITT}
\]

Temperature Advection
Vertical Motions
Diabatics

Fink et al., 2012
Surface Pressure Tendency analysis
Cloud-radiative effects damp the NAO+

Data: ERA-Interim
Summary

The changes in clouds associated with the NAO lead to substantial changes in cloud-radiative effects which leads to a heating dipole in the N. Atlantic region.

The heating dipole suggests that the anomalous CRE associated with the NAO have a negative feedback on the NAO timescale from the perspective of the surface pressure tendency equation.