Troposphere-stratosphere response to large-scale North Atlantic Ocean variability in observations and an atmosphere/ocean coupled model

N.-E. Omrani, Jürgen Bader, N. S. Keenlyside & Elisa Manzini
• Observed AMV-NAO relationship
• Role of stratosphere
• Role of ocean/atmosphere two-way coupling
NAV/NAO coupling: 500 year control simulation using atmosphere/ocean coupled MPI-ESM model

Observations, 1870-2009, HAD-SST and SLP

MPI-ESM coupled model, T63,L95
Observed NAV/NAO relationship

Multidecadal NAO and SST-NAV

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Warm (1951 to 1960) - Control (1961 to 1990)

- Observed warming in 1950s was associated with negative NAO.
- Atmospheric model driven by observed warm SST-conditions shows that negative NAO seen in 1950s can be driven by the observed warm Atlantic conditions only by resolving the stratosphere.

HAD-SST (JFM)

Z1000hPa (JFM), NCEP

Z1000hPa (JFM), high-top model MAECHAM5 (T63,L39, zmax=80km)

Z1000hPa (JFM), low-top model ECHAM5 (T63,L19, zmax=30km)
Warm(1951 to 1960)-Control(1961 to 1990): How is the stratosphere involved?

In both observation and model simulation we have precursory stratospheric warming and vortex weakening that propagate into the troposphere.
Warm (1951 to 1960) - Control (1961 to 1990): How is the stratosphere involved?

**A)** Zonally averaged U (10hPa, 60°N) high-top, Control

**B)** Zonally averaged U (10hPa, 60°N) high-top, Warn

**C)** Low-top, control

**D)** Low-top, Warm

Precursory stratospheric warming and vortex weakening seen around DEC is due mainly to the shift of extreme circulation change towards more Major Stratospheric Warming (MSW), which can be simulated only in high-top configuration.
NAV/NAO coupling: 500 year control simulation using atmosphere/ocean coupled MPI-ESM model

Composite Analysis based on NAV-index from 500 year model simulation (T63L95) confirms that warm/cold NAV are associated with negative/positive NAO as observed
Understanding of the role of the two-way ocean/atmosphere coupling: Experiment set-up

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Standalone atmospheric model experiments driven by NAV for warm and for cold

The control experiment is driven by climatological SST from the coupled model (Model resolution: T63L95)
Two-way ocean atmosphere interaction:
1) increases the strength and seasonal persistence of the tropospheric response
2) but strongly decreases the stratospheric response to the warm North Atlantic Conditions.
Stratospheric response of stand-alone atmospheric model to warm NA-conditions taken from the coupled model

A) Warm composite of 30hPa geopotential height, coupled, JAN

B) Warm composite of 30hPa geopotential height, coupled, FEB

C) Response of 30hPa geopotential height, uncoupled, JAN

D) Response of 30hPa geopotential height, uncoupled, FEB

Coupled Model

Stratospheric response is much stronger in the coupled than in the uncoupled mode

Stand-alone atmosphere model
Stratospheric response of stand-alone atmospheric model to warm NA-conditions taken from the coupled model

The Tropospheric response to warm conditions (seen in the coupled mode) is well reproduced in the uncoupled mode.

Coupled Model

Stand-alone atmosphere model
Mechanisms proposed for the response of NAO to high latitude Atlantic warming

- High latitude SST-warming
- Turbulent heat flux in to the lower troposphere
- Reduction of baroclinicity
- Explaining the negative NAO

This mechanisms is not able to explain our response, since our low-top model can not respond to the NAV.
Dynamics of the response to warm conditions

Why? Still unclear

Upward wave propagation

High latitude stratospheric warming and vortex weakening

Still controversial

Warming in the high latitude North Atlantic regions

Reduction of the lower tropospheric baroclinicity

This will contribute to negative NAO in addition to the reduction of the baroclinicity due to the turbulent heat flux from the ocean.
Upward wave flux

Weaker westerlies

Climatological stratosphere & high-latitude westerlies

Warming in atmosphere

Warming in the Ocean

Tropopause

Reduced baroclinicity

SST+

T+

Downward stratosphere/troposphere coupling

Turbulent heat flux from the ocean

30N

Pole
Response to the cold phase, troposphere

The tropospheric response to cold conditions (seen in the coupled mode) is not well reproduced in the uncoupled mode.
Response to the cold phase, stratosphere

Stratospheric changes in the coupled mode are much weaker in the cold phase and cannot be reproduced by the uncoupled mode.
Conclusions

• Both NAO and stratosphere respond to Warm NAV conditions

• Only our high-top model configuration is able to simulate the tropospheric response to the large-scale NAV-warming

• Stratosphere/troposphere downward coupling can provide the troposphere with additional warming and changes in the baroclinicity and contribute to the NAO-changes

• The changes in the atmosphere seen in the cold NAV-phase of the coupled model are not well reproduced by the stand-alone atmosphere model configuration

• Active two-way ocean-atmosphere interaction plays an important role in shaping and modulating the structure and strength of the atmospheric response to the NAV
Observed NAV/NAO relationship

Multidecadal NAO and SST-NAV

Warm/cold NAV are associated with negative/positive NAO