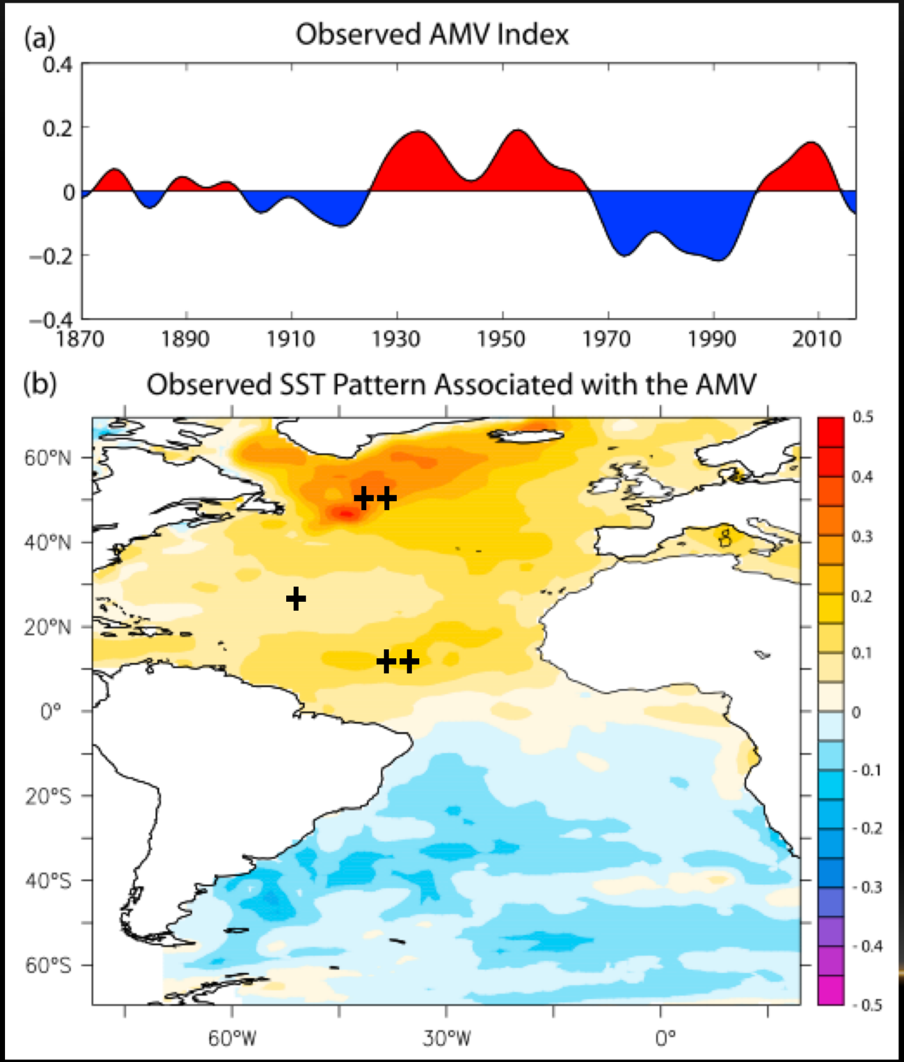
Atlantic Multidecadal Variability (AMV)

Outline

- What is the AMV?
- AMV mechanisms
- Impacts of the AMV

What is the AMV?



- AMV is associated with a dipole SST pattern over the entire Atlantic. The AMV+ is characterized by positive SST anomalies in the North Atlantic and negative SST anomalies In the South Atlantic.
- A period of about 60-80 years.
- The SST anomalies in the Northern hemisphere are generally stronger than those in the Southern hemisphere.
- The SST anomalies in the Northern Hemisphere are characterized by a horse-shoe pattern, with stronger SST anomalies over the subpolar North Atlantic and the tropical Atlantic and weaker warming in between.
- In addition to SST, coherent multivariate low-frequency variability exists in sea surface salinity, upper ocean heat/salt content, tropical North Atlantic subsurface temperature, and surface turbulent heat fluxes.
- The AMV is also known as the Atlantic Multi-decadal Oscillation (AMO)

Zhang et al. 2019

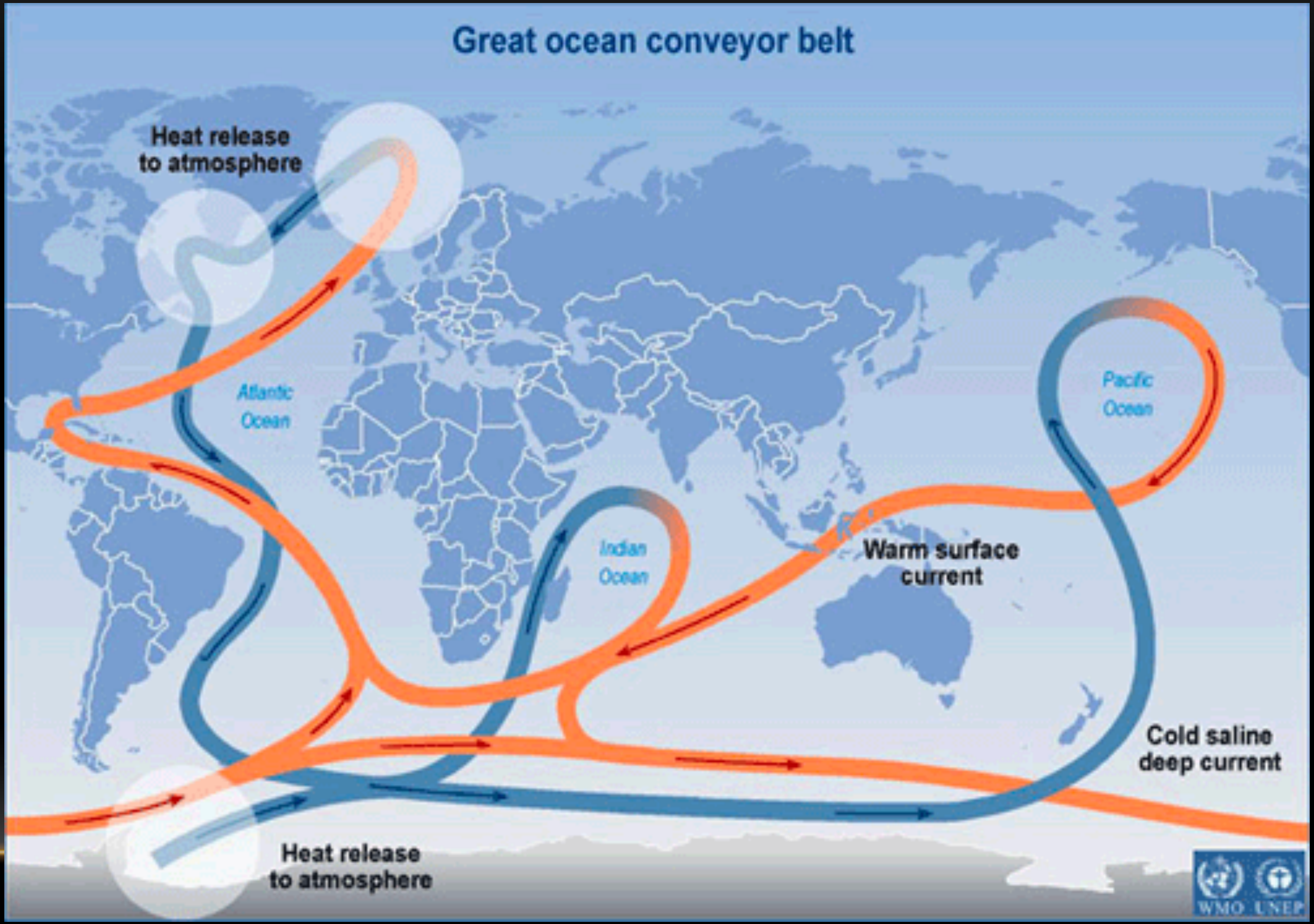
Hypotheses for AMV Mechanisms

The mechanisms of the AMV are a controversial topic.

- The AMV is an internal mode of climate variability driven by the Atlantic Meridional Overturning Circulation (AMOC) (Zhang et al. 2019).
- The AMV is a red noise response of the North Atlantic SST to stochastic atmospheric-induced surface heat flux forcing , especially associated with the NAO (Clement et al. 2015). The ocean is a relatively slowly varying system. The response can have a much longer time scale than the forcing.
  - In this theory, ocean dynamics is not involved, but some studies suggested the hypothesized mechanisms without the AMOC can not explain the observed AMV magnitude or the observed multivariate coherent variability (e.g., Zhang et al. 2019).
- The AMV results from the time-varying competing effects of green house gases (warming) and sulfate aerosols (cooling) on the North Atlantic SST (e.g., Mann et al. 2014; Booth et al. 2012)
- Volcanic aerosols are an important pacemaker for AMV through their direct radiative impacts on tropical North Atlantic SSTs (Ottera et al. 2010; Mann et al. 2021)
- Delworth et al. (2017) emphasized the role of ocean dynamics in generating extratropical Atlantic SSTA as a delayed response to the AMOC but suggested that atmospheric processes, such as aerosols or dust emissions, may play an important role in forcing the tropical North Atlantic SST.

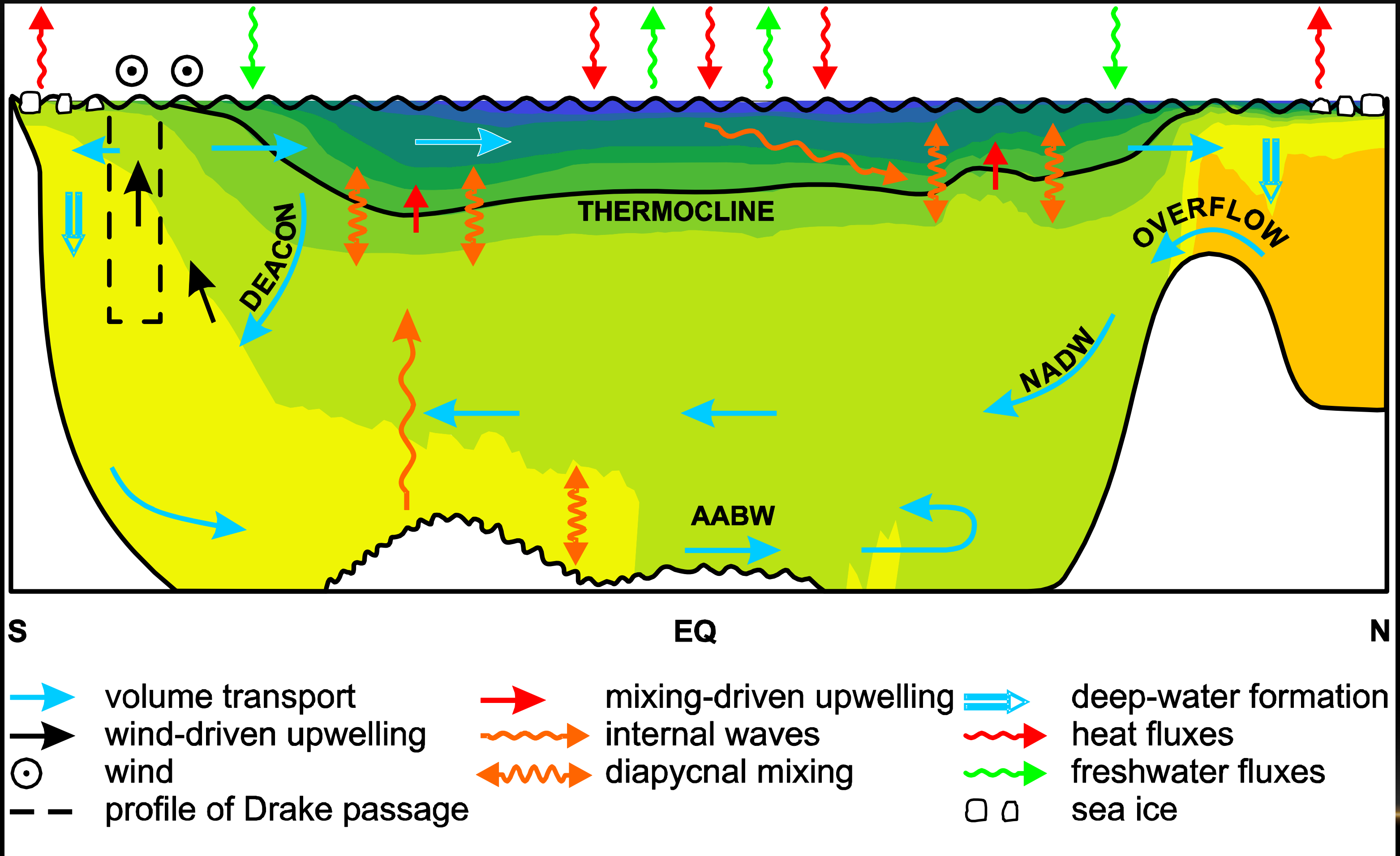
Thermohaline Circulation: The Global Conveyor Belt

- Deep ocean circulation is density driven.
- The ocean conveyor gets its "start" in the Norwegian Sea. This loss of heat to the atmosphere makes the water cooler and denser, causing it to sink to the bottom of the ocean.
- This cold bottom water flows south of the equator all the way down to Antarctica.
- Eventually, the cold bottom waters returns to the surface through mixing and wind-driven upwelling, continuing the conveyor belt that encircles the globe.



The Great Ocean Conveyor Belt Source: IPCC

A schematic meridional section of the Atlantic Ocean

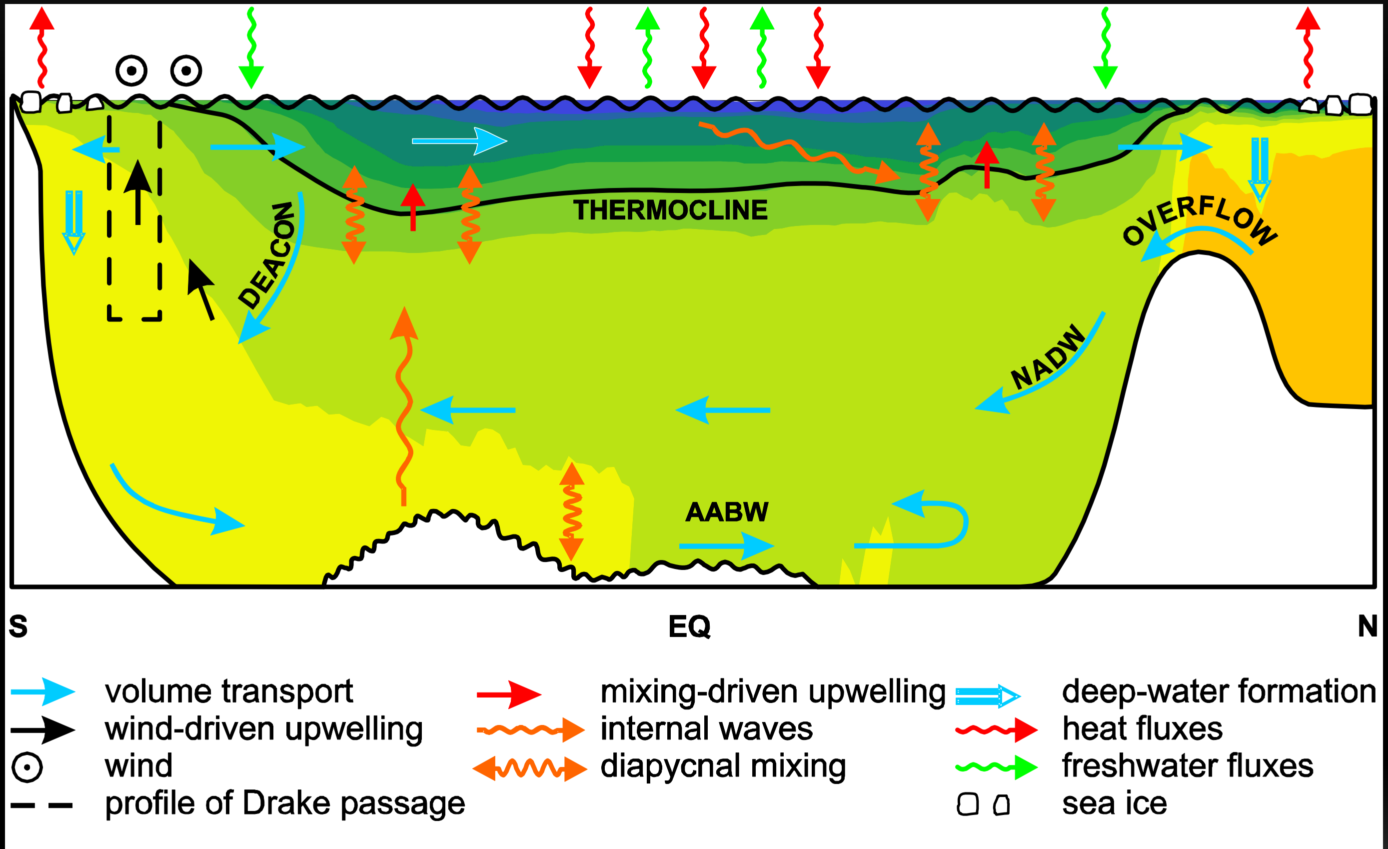


The Atlantic Meridional Overturning Circulation (AMOC) consists of two primary overturning cells:

1) An upper cell: northward flowing warm, saline water in the upper 1000 m of the Atlantic Ocean, the cooling and freshening of the water sinking at high latitudes of the North Atlantic, and the southward return flow of cold water at the depth of 1500-4500 m.
2) A deep cell: Antarctic Bottom Waters (ABW) flow northward below depths of about 4,500 m and gradually rise into the lower part of the southward-flowing North Atlantic deep water.

From “Abrupt Climate Change” by Delworth et al. 2008

AMOC



- The AMOC plays an important role transporting heat from the South Atlantic and tropical Atlantic to the subpolar and polar North Atlantic, and the changes in the AMOC affect SST over the Atlantic.
- The AMOC must be maintained against the dissipation of energy. The energy sources for the ocean are wind stress at the surface, heat fluxes from the atmosphere, tidal motion, and heat fluxes through the ocean bottom.

From “Abrupt Climate Change” by Delworth et al. 2008

What may affect the AMOC?

- *How would an increase in freshwater flux in the subpolar North Atlantic affect the AMOC?*
  - Research suggested that massive freshwater flux in the subpolar North Atlantic resulting from collapsing of land-based ice sheets can abruptly weaken the AMOC.
- *Global warming?*
  - tends to weaken the AMOC both by warming the upper ocean in the subpolar North Atlantic and through enhancing the flux of freshwater into the Arctic and North Atlantic.
- *How about strong surface wind in the subpolar North Atlantic, such as wind anomalies in the NAO positive phase?*
  - Strong heat loss from ocean to the atmosphere and cold SST may help to enhance the North Atlantic deep water formation and lead to the positive phase of the AMV.

AMV Hypothesized Mechanism:
AMV, AMOC and NAO

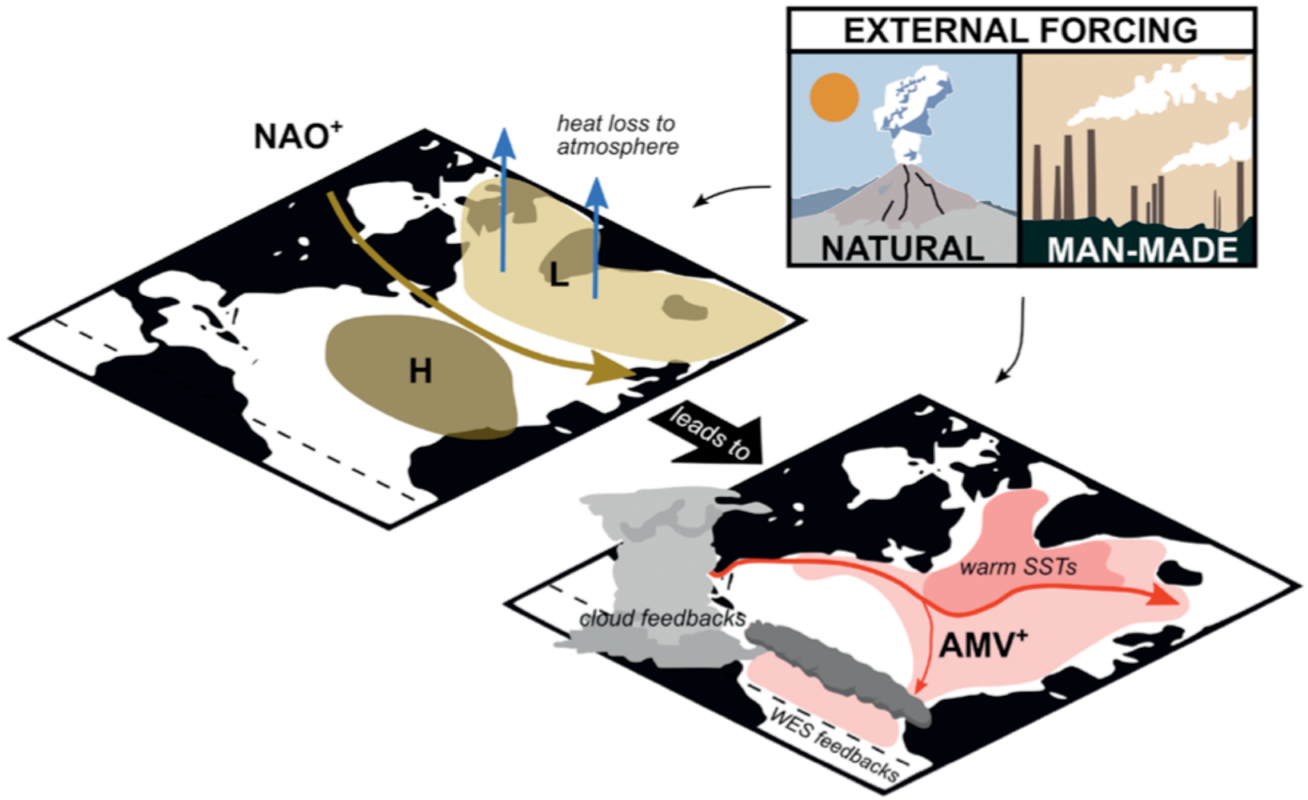
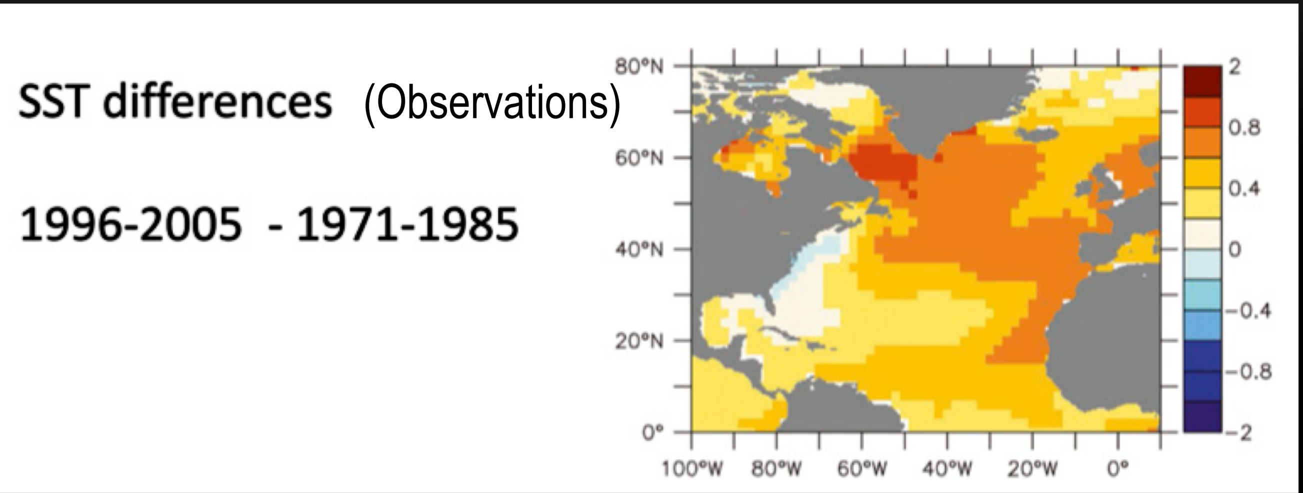


Fig. 2. Schematic illustrating processes involved in AMV. The left-hand map shows typical NAO+ conditions with the Greenland low (~1,010 hPa) and the Azores high (~1,020 hPa) highlighted with the storm track illustrated between (brown arrow). NAO+ conditions result in heat loss from ocean to the atmosphere, particularly over the Labrador and Irminger Seas (blue arrows), leading to deep convection and cool SSTs, itself indicative of AMV−. Increased deep convection is linked with increasing northward ocean heat transport (red arrows), associated with a strong AMOC, leading to warmer SSTs, indicative of AMV+, as shown in the right-hand map. External forcing from natural solar and volcanic variability and from manmade aerosols have been proposed as additional drivers of AMV. Ocean–atmosphere feedbacks are important in the amplification and modification of AMV patterns including interactions with tropical and subtropical clouds and WES interactions.

- NAO+ conditions → heat loss from ocean to the atmosphere, particularly over the Labrador and Irminger Seas → cold SST and deep convection (itself indicative of AMV−)
- Increased deep convection → stronger AMOC and increased northward ocean heat transport (red arrows) → warmer SSTs and AMV+ (lagging NAO+ by ~10 yrs)
- The AMV+ conditions erode the meridional gradient of SST and lead to conditions favoring NAO−. Predominant NAO− conditions weaken the overturning and lead to AMV-.
- Ocean–atmosphere feedbacks are important in the amplification and modification of AMV patterns including interactions with tropical and subtropical clouds and wind-evaporation-SST (WES) interactions.
- External forcings are possible additional drivers of AMV.

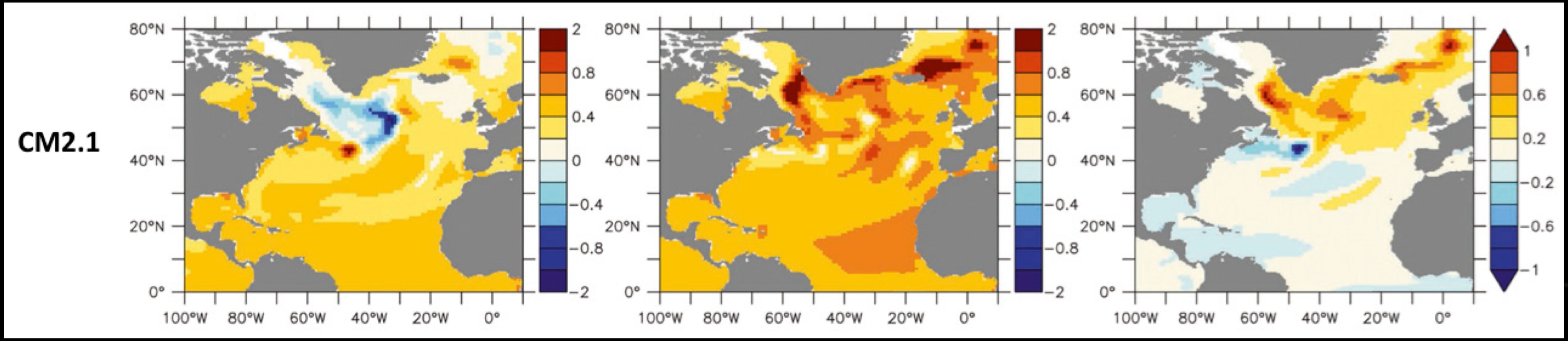
Role of the NAO in the AMV



Simulations using a fully coupled climate emodel

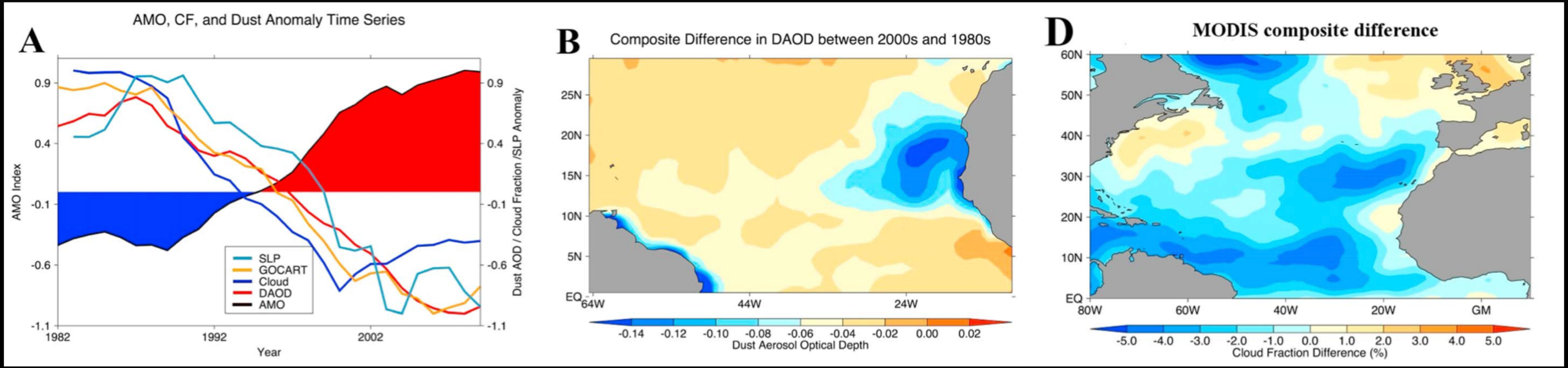
- HIST: Historical runs with time-varying radiative forcing
- HIST_NAO: surface heat flux anomalies of the NAO pattern were imposed on the model ocean; warming occurs further north compared to HIST.
- HIST_NAO minus HIST: The NAO-induced AMOC strengthening leads to the subpolar warming. The oceanic response to the NAO forcing in the tropical North Atlantic is relatively weak. Other atmospheric processes, such as aerosols or dust emissions, may play an important role in forcing SST in the tropical North Atlantic.

HIST | HIST_NAO | HIST_NAO minus HIST



Positive involved with low cloud and dust feedbacks amplify tropical North Atlantic Multidecadal Oscillation

Yuan et al. 2016



- Left: Normalized time series of the AMO index (filled), dust aerosol optical depth (AOD), ISCCP low cloud fraction, sea level pressure, and dust AOD from 1982 to 2009.
- Middle: (b) Dust AOD composite difference between the 2000s and the 1980s.
- Right: MODIS composite difference of low cloud fraction between three top (2003, 2004, and 2008) and bottom (2007, 2009, and 2011) AMO years during the MODIA time period.

AMO+ is related to reduced low cloud fraction, reduced dust optical depth, reduced SLP, and weakened surface wind speed (not shown) in the tropical North Atlantic.

Positive feedbacks amplify tropical North Atlantic Multidecadal Oscillation (cont'd)

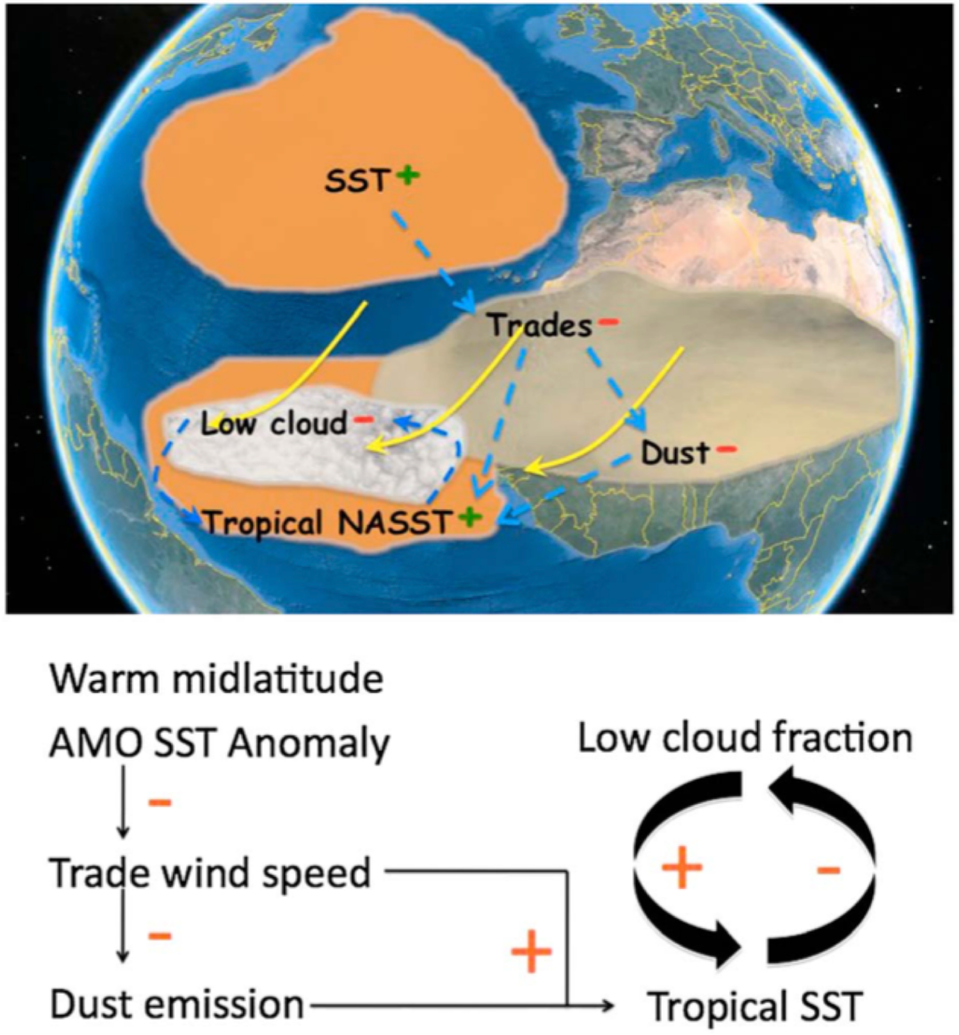


Figure 3. (top) A schematic and (bottom) flow diagram illustrating the proposed feedbacks and related processes. Warm SST anomaly in the North Atlantic introduces a cyclonic anomaly, which weakens trade winds. Weaker trade winds reduce dust emission over the Sahara and suppress dust transport toward the tropical Atlantic. They also contribute to reduce low cloud fraction over the tropical North Atlantic. Both responses yield warmer tropical North Atlantic SST.

Yuan et al. (2016) proposed two positive feedback processes:

1) SST-low cloud feedback: warm tropical SSTA —> reduced tropical inversion strength —> increase lateral mixing —> reduced low cloud fraction —> increased surface shortwave radiation —> warm tropical SSTA

2) SST-dust feedback: warm phase of the AMV —> an anomalous cyclone centered within 30-40N (NAO- like) —> reduced trade wind easterlies —> reduced dust emission in Africa and reduced dust transport over the North Atlantic —> reduced dust radiative cooling —> warm tropical SSTA

Yuan et al. 2016

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