Relationships between the North Atlantic Oscillation and isentropic water vapor transport into the lower stratosphere

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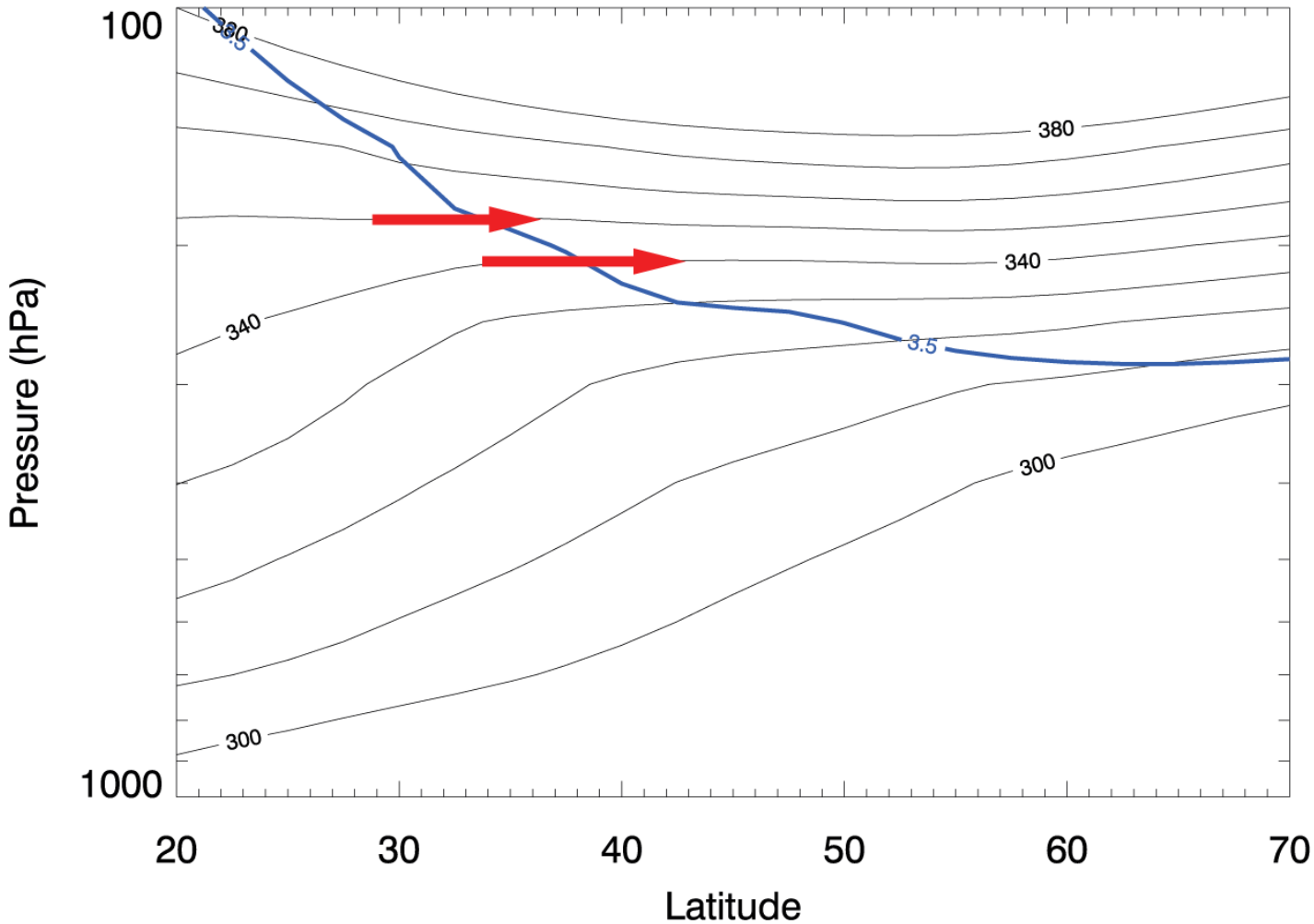
June 27, 2007

Introduction: Lower Stratospheric Water Vapor

- Radiative balance: Interacts with outgoing infrared
  - Small amounts of water vapor, but still significant (e.g., Goody 1964)
  - Relative changes more influential than absolute changes
- Chemistry: Interacts with ozone, carbon monoxide and methane
  - Source of OH in the troposphere and stratosphere
- Dynamics: Interacts with General Circulation
  - Represents a useful diagnostic tracer
  - Also influences the circulation
- Sources of LS water vapor
  - Mean meridional circulation: tropical convection & cold trap
  - Direct injection by extratropical convection
  - Quasi-horizontal isentropic transport from tropical upper troposphere
  - Methane oxidation in the stratosphere

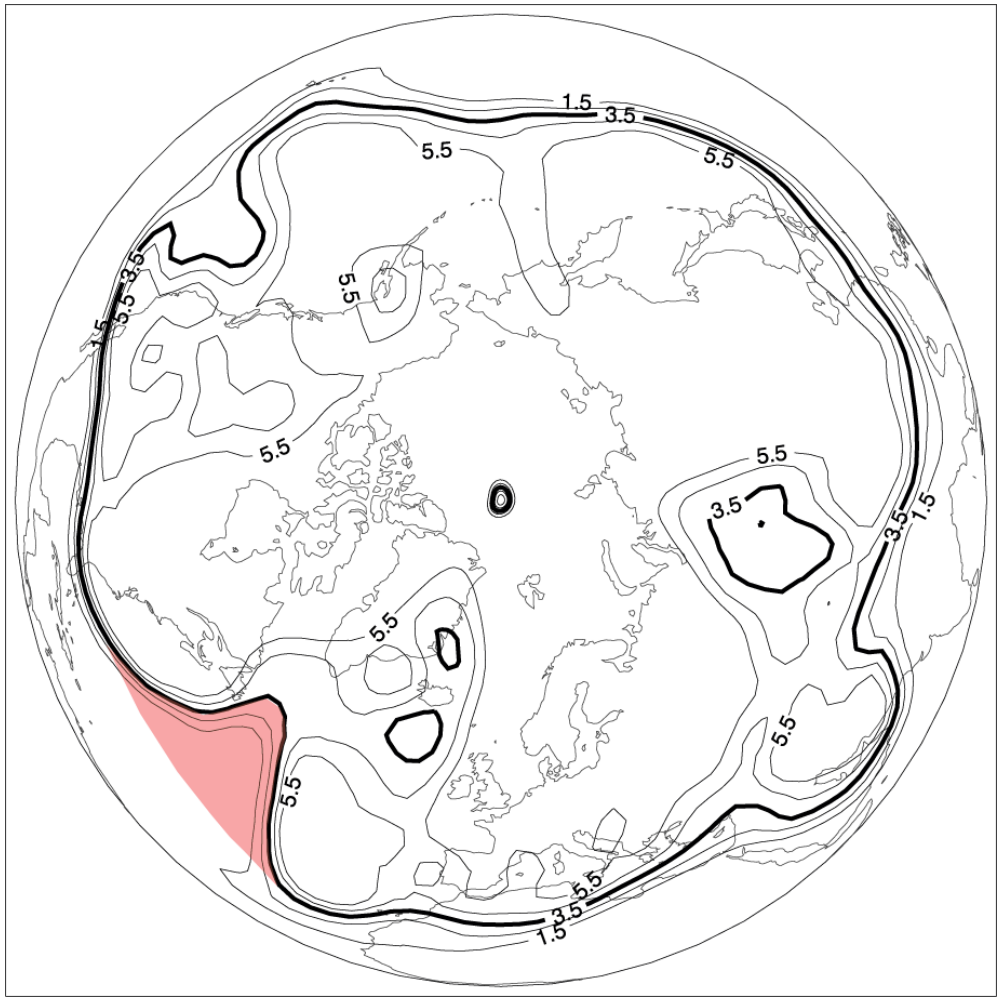
Introduction: Isentropic Transport of Water Vapor

- Isentropes cross the dynamical tropopause, enabling transport



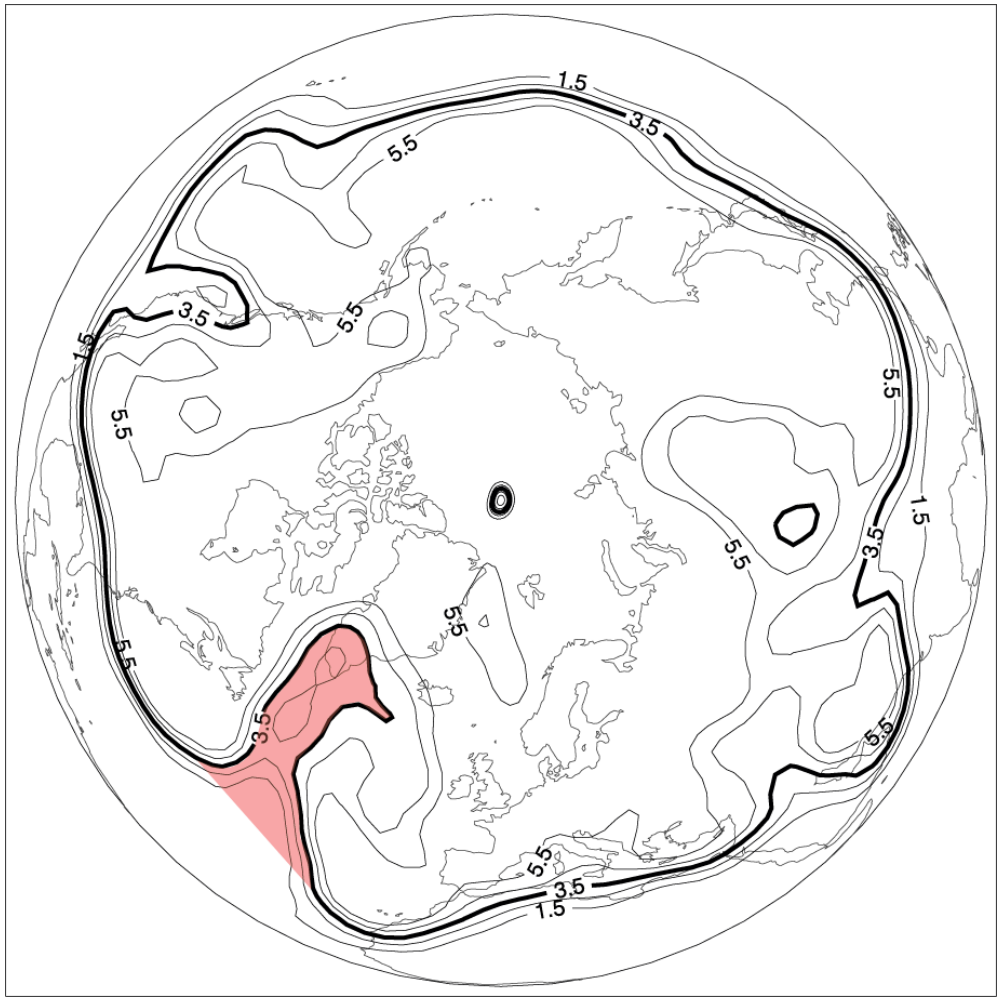
Introduction: Isentropic Transport of Water Vapor

- Planetary waves perturb the dynamical tropopause ...



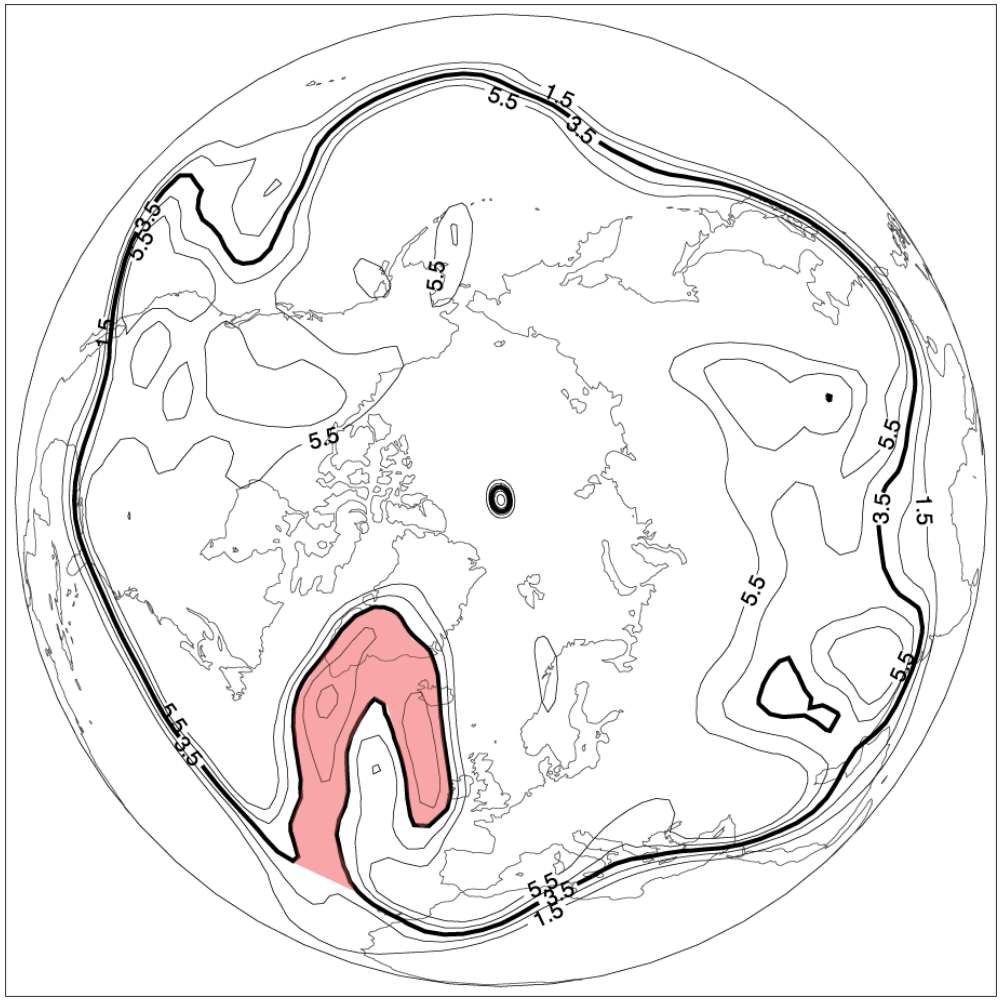
Introduction: Isentropic Transport of Water Vapor

- ... the tropopause stretches and starts to fold ...



Introduction: Isentropic Transport of Water Vapor

- ... and the wave begins to break ...



Introduction: Isentropic Transport of Water Vapor

- ... potentially resulting in substantial cross-tropopause mass transport

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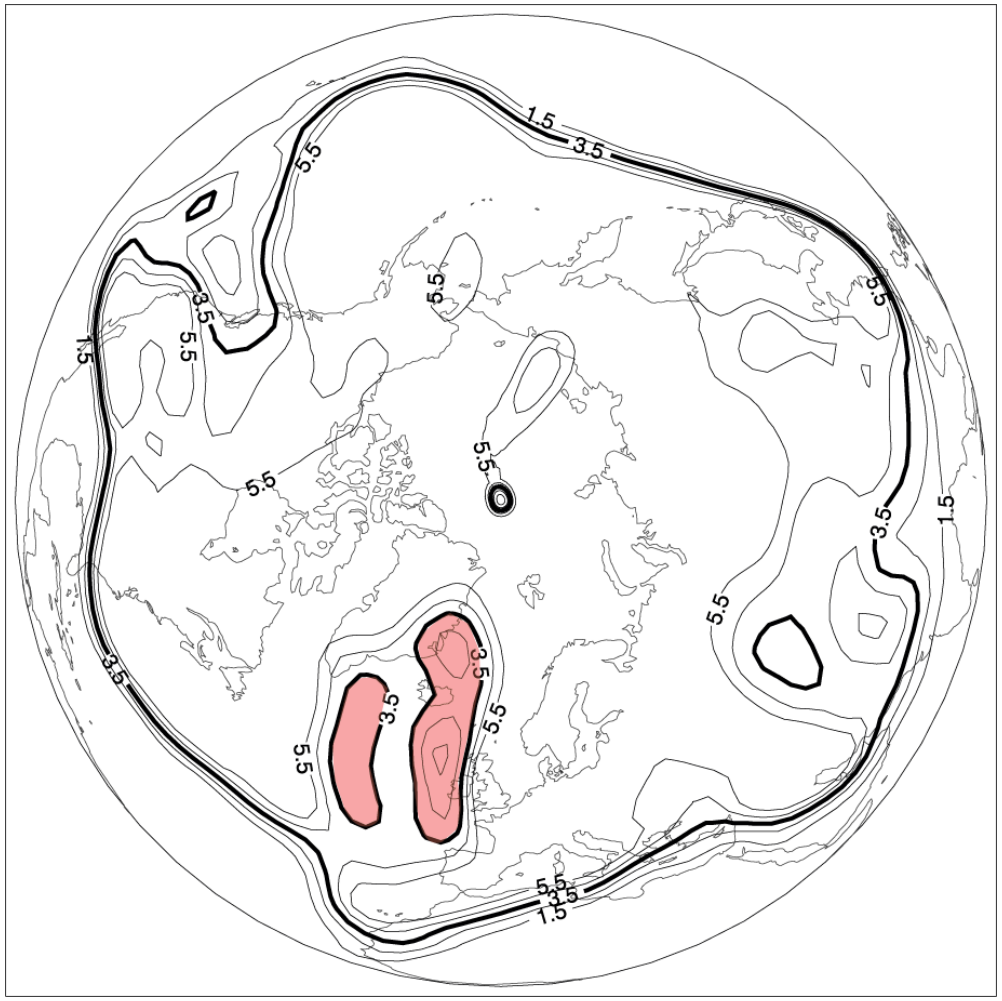
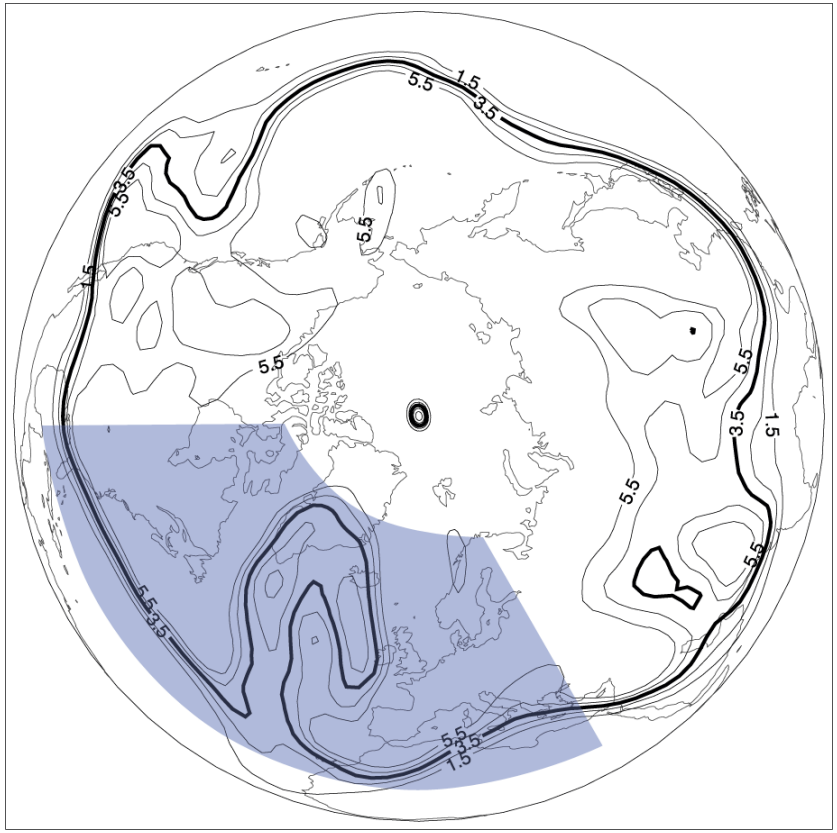


Introduction: The NAO and Wave Breaking

- The two phases of the NAO are associated with two types of wave breaking (e.g., Benedict et al, 2004)
  - ▷ Positive phase :: anticyclonic wave breaking (LC1 eddy life cycle)
  - ▷ Negative phase :: cyclonic wave breaking (LC2)
- Wave breaking promotes cross-tropopause tracer transport
  - ▷ Ozone (e.g., Stohl et al, 2003; Jing et al, 2005)
  - ▷ Water vapor (e.g., Dethof et al, 2000)
  - ▷ Other long-lived tracers (such as methane and carbon monoxide)
- While the number of wave breaking events peaks during summer, the occurrence of strong, deeply penetrating wave breaking events peaks during winter while the NAO is active (Waugh and Polvani, 2000)
- Accordingly, we hypothesize that the wintertime NAO will be strongly linked to cross-tropause tracer transport
- Use normalized NAO index from the NOAA CPC

Method: Contour Advection with Surgery

- A technique for advecting material contours (Waugh and Plumb, 1994)
- 3.5PVU contour on 340K surface; advect for 5 days using ERA-15 winds
- Focus on North Atlantic region (90°W to 30°E, 20°N to 70°N)



Method: Contour Advection with Surgery

- Surgery (Dritschel 1988,1989) removes features below a specified scale
- Final contour integrated with daily surgery is new dynamical tropopause
- Contrast final contours with and without surgery to calculate transport

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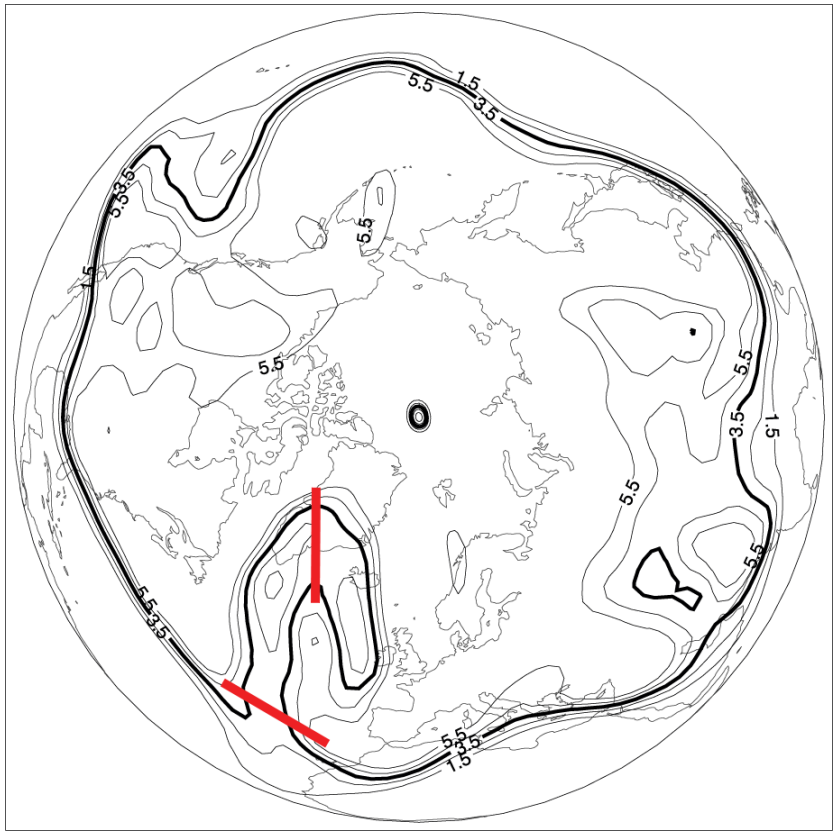

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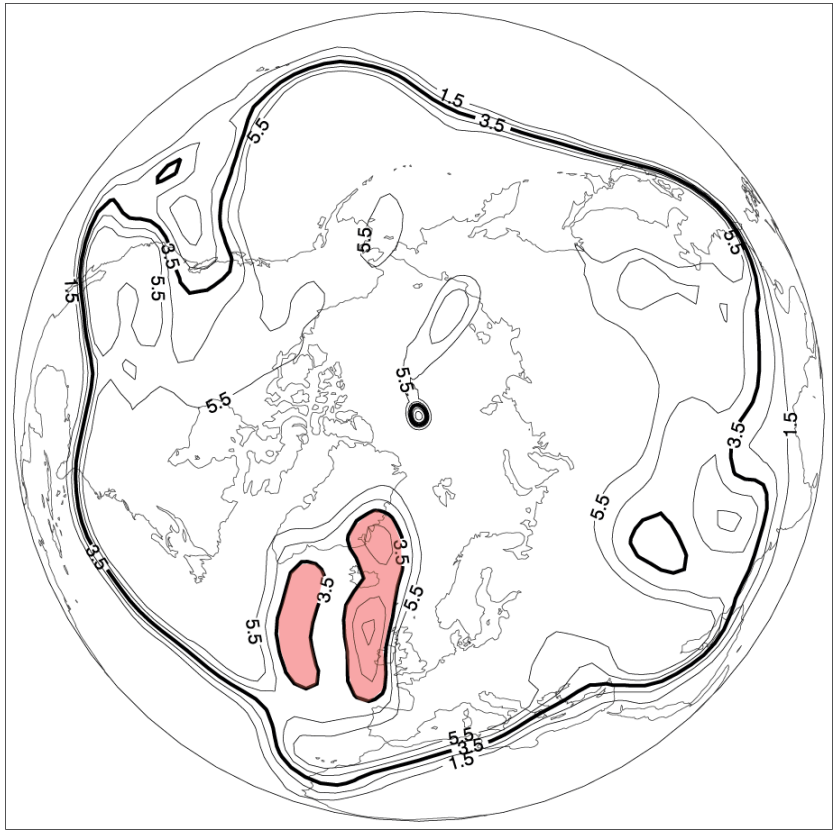
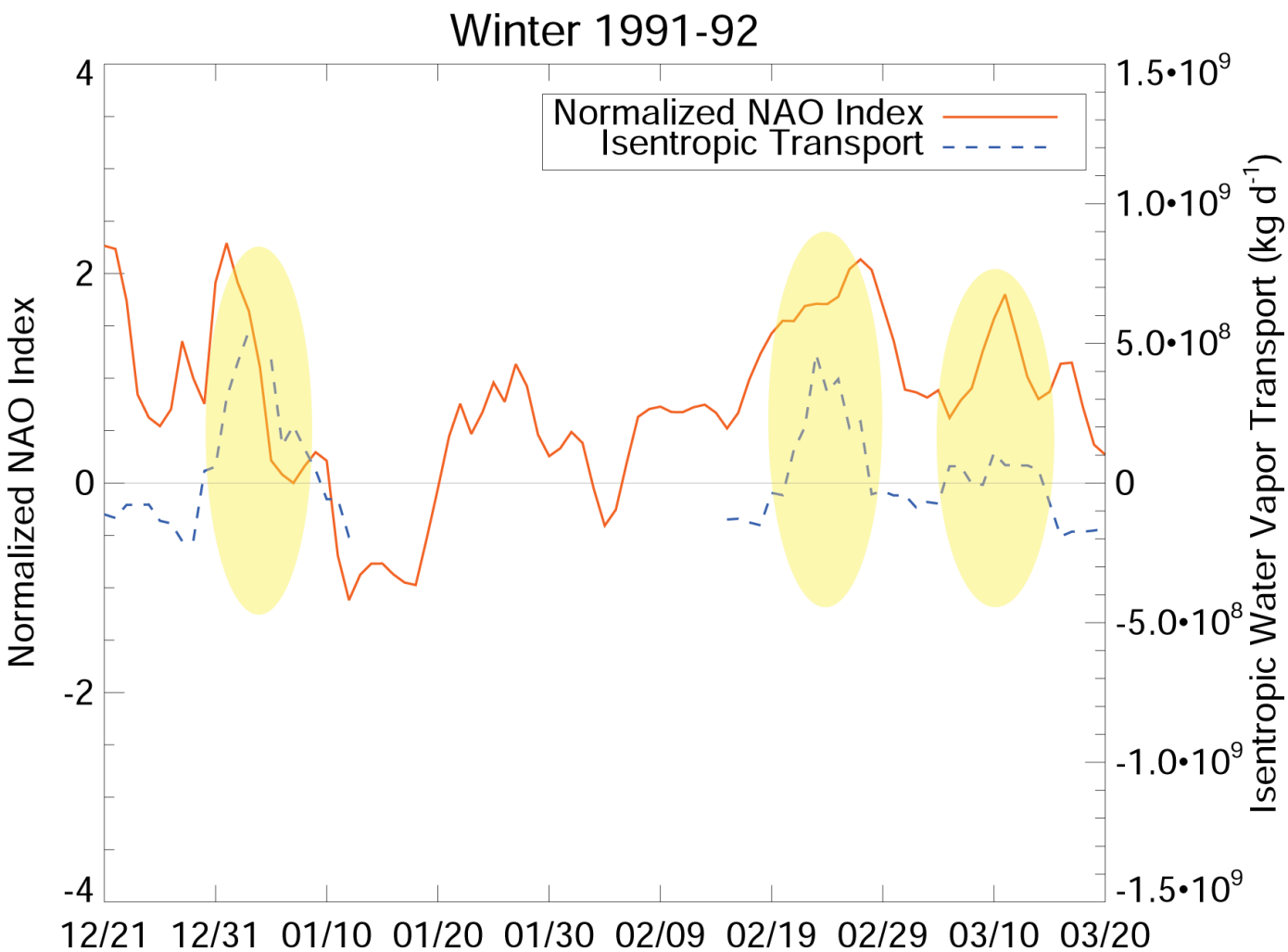


Data: UARS Microwave Limb Sounder

- Microwave Limb Sounder
  - Retrieval less affected by sharp gradients of temperature and humidity at the tropopause
  - Factor of two less sensitive to ice than to water vapor
  - Weighting function for H_2O at 215 hPa is insensitive to overworld
  - Horizontal and temporal resolutions lower than nadir satellites
- UARS MLS version 4.9 (1991-1993; see Read et al 1995, 2001)
  - 203 GHz: UT water vapor. Minimum $\sim$10ppmv, uncertainties $\sim$25%
  - 183 GHz: LS water vapor. Sensitive to lower mixing ratios.
  - Coverage alternates between NH and SH on a 36-day cycle
- For this study:
  - Swath data projected onto a daily grid at 215 hPa
  - Captures large-scale variations in H_2O consistent with isentropic PV
  - Use center point of advected areas as representative of mean humidity

Results: UARS MLS Time Series

- Close correspondence: positive NAO index and WV transport into the LS



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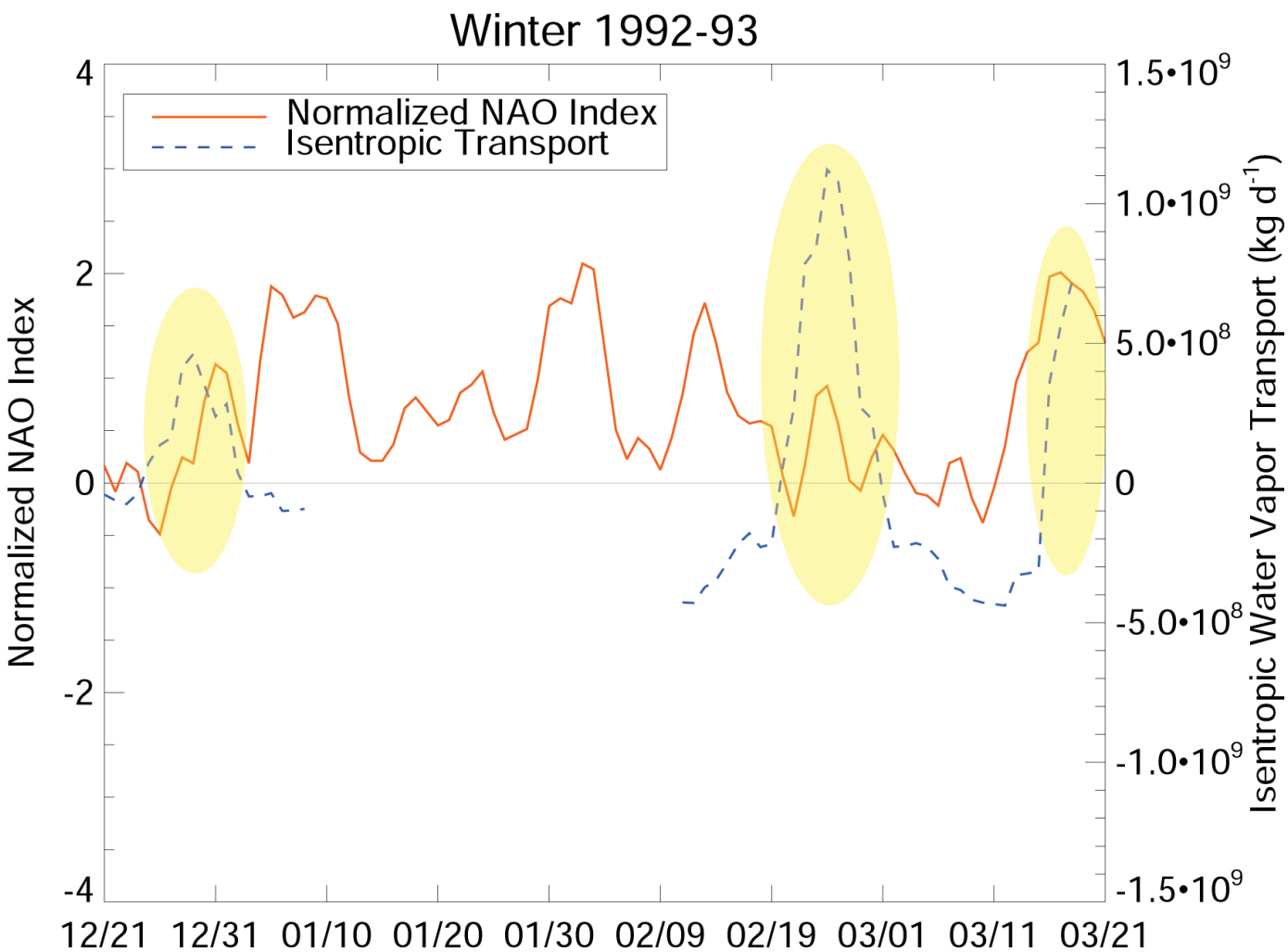
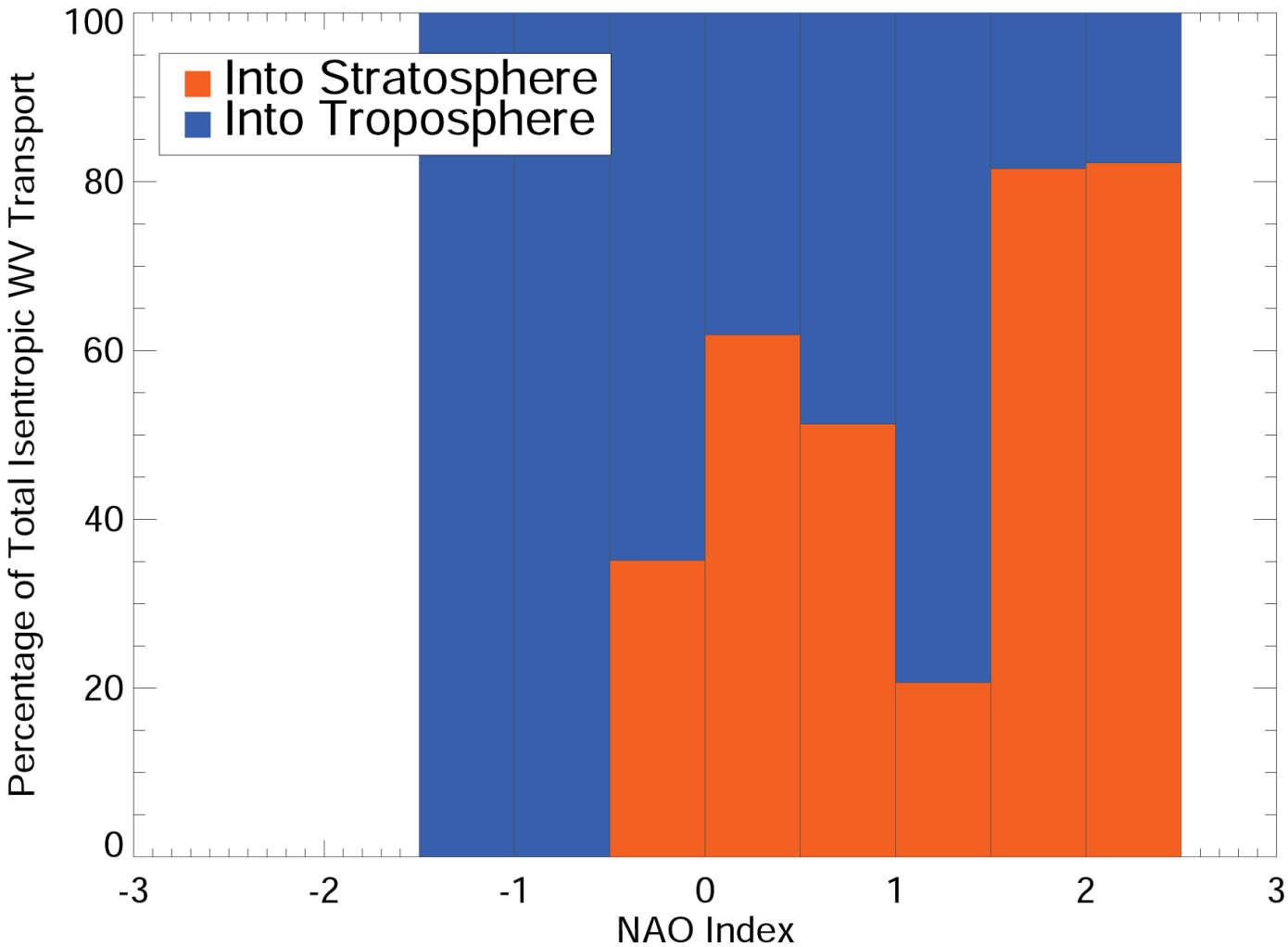


Results: Isentropic WV Transport vs. NAO Index

- WV transport into the LS is apparently enhanced during positive phase



Summary: Conclusions

- Relationship:
  - Close temporal correspondence between positive NAO index and WV transport into the wintertime North Atlantic LS
  - WV transport into the North Atlantic LS may be enhanced as the normalized NAO index increases
- Possible explanations
  - Anticyclonic breaking, which dominates during the positive phase of NAO, takes place at lower latitudes than cyclonic wave breaking, which dominates during the negative phase of NAO
  - Upper tropospheric air is more humid closer to the equator
- Implications for climate change
  - The NAO index exhibited a positive trend during the twentieth century, as did stratospheric water vapor; this relationship may help to explain why

Summary: Future Work

- Ongoing analysis using the EOS Aura microwave limb sounder (2004-present)
  - ▷ Substantial improvements over UARS in water vapor retrievals (lower minimum threshold and uncertainty)
  - ▷ Replace simplistic mapping technique with Fast Fourier synoptic mapping
  - ▷ Provides collocated observations of ozone and carbon monoxide
- Examine whether a similar relationship can be seen in ozone transport into the upper troposphere during the negative phase of the NAO
- Can nearby observations from other "A-train" satellite instruments such as AIRS (2002-present) or TES (2004-present) provide additional information on the transport of water vapor, ozone, CO or methane?

Future Work