Formation and Climate Impacts of Arctic Haze

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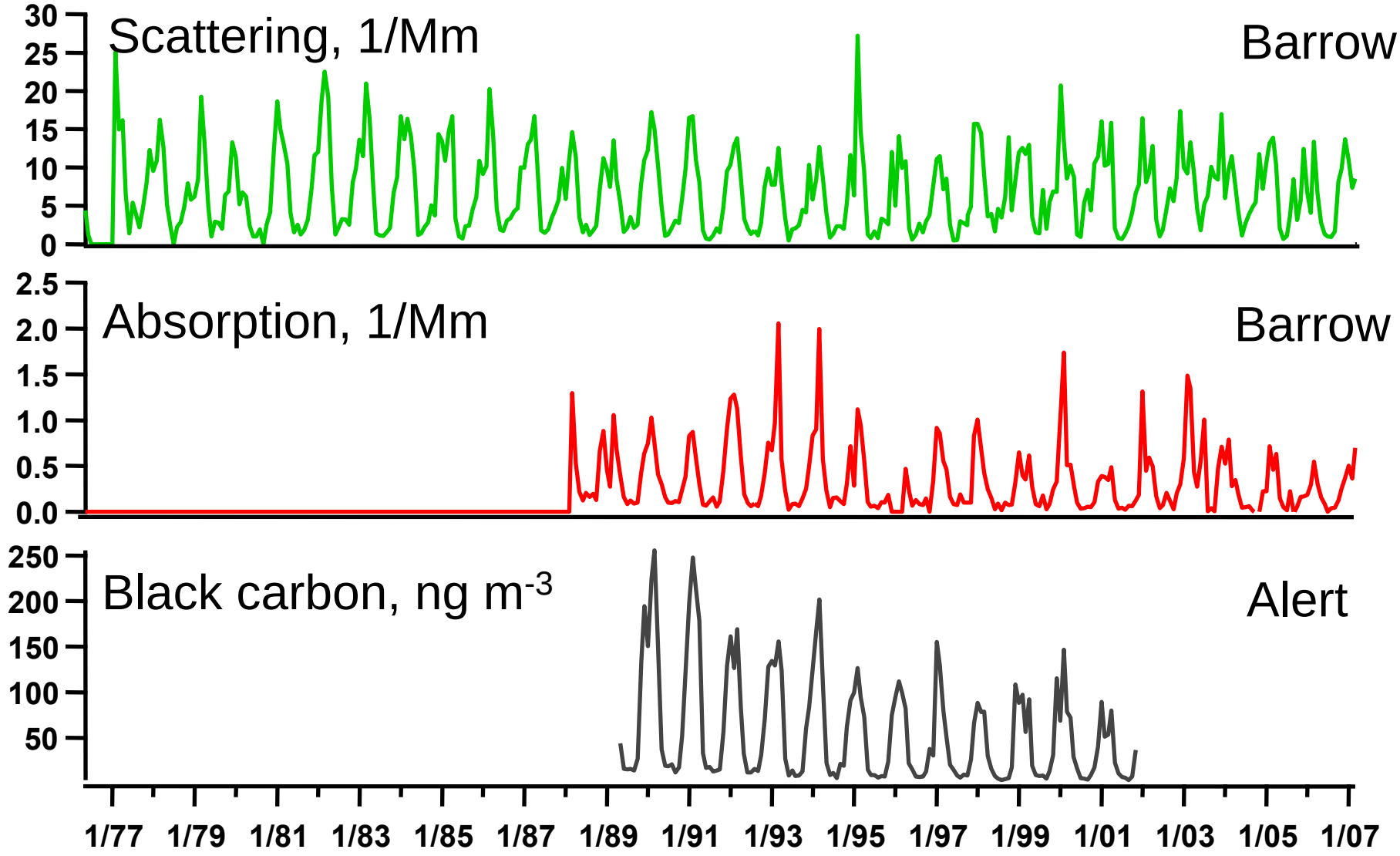
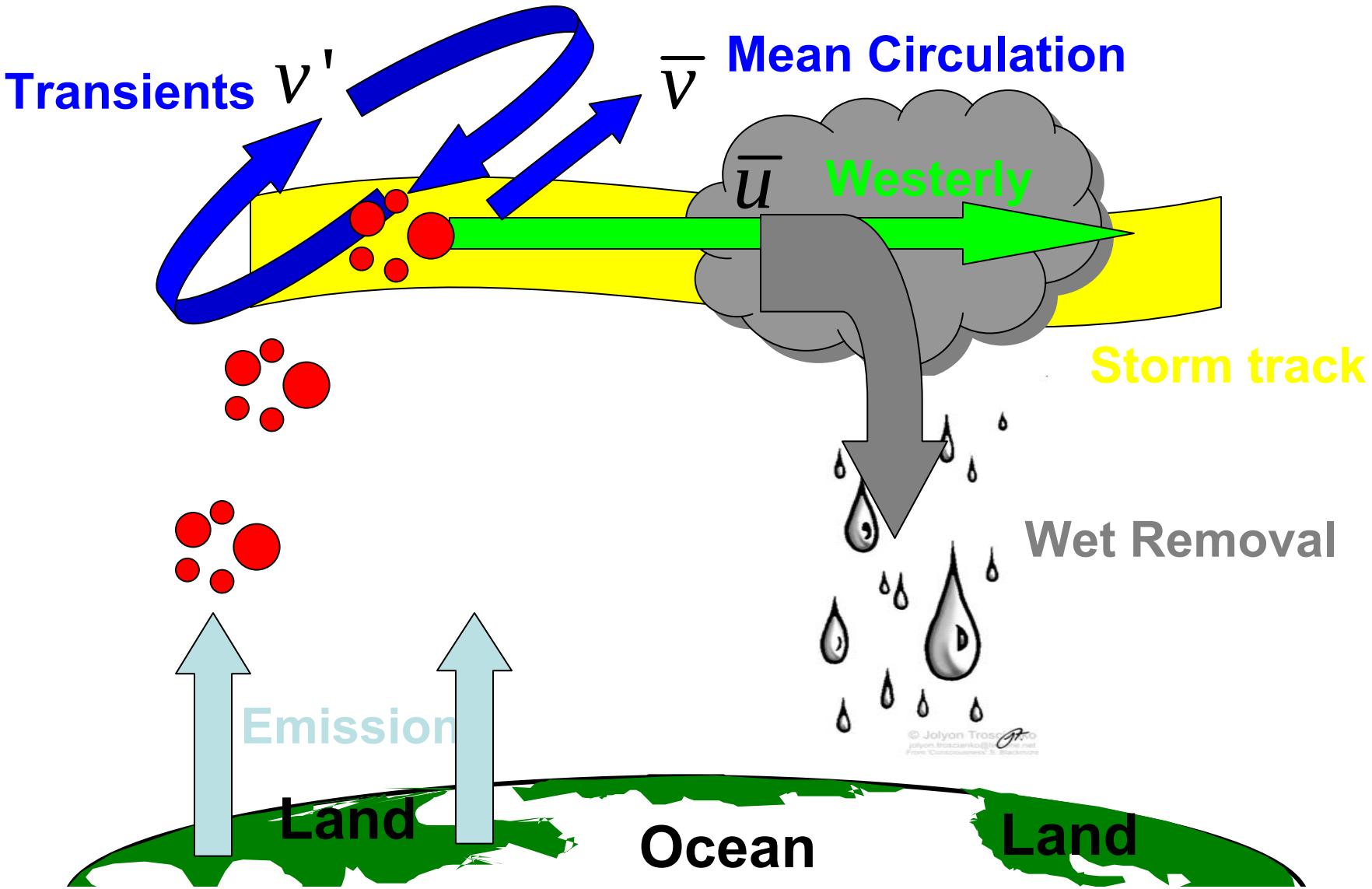
Seasonality and Inter-annual Variability of Arctic Haze



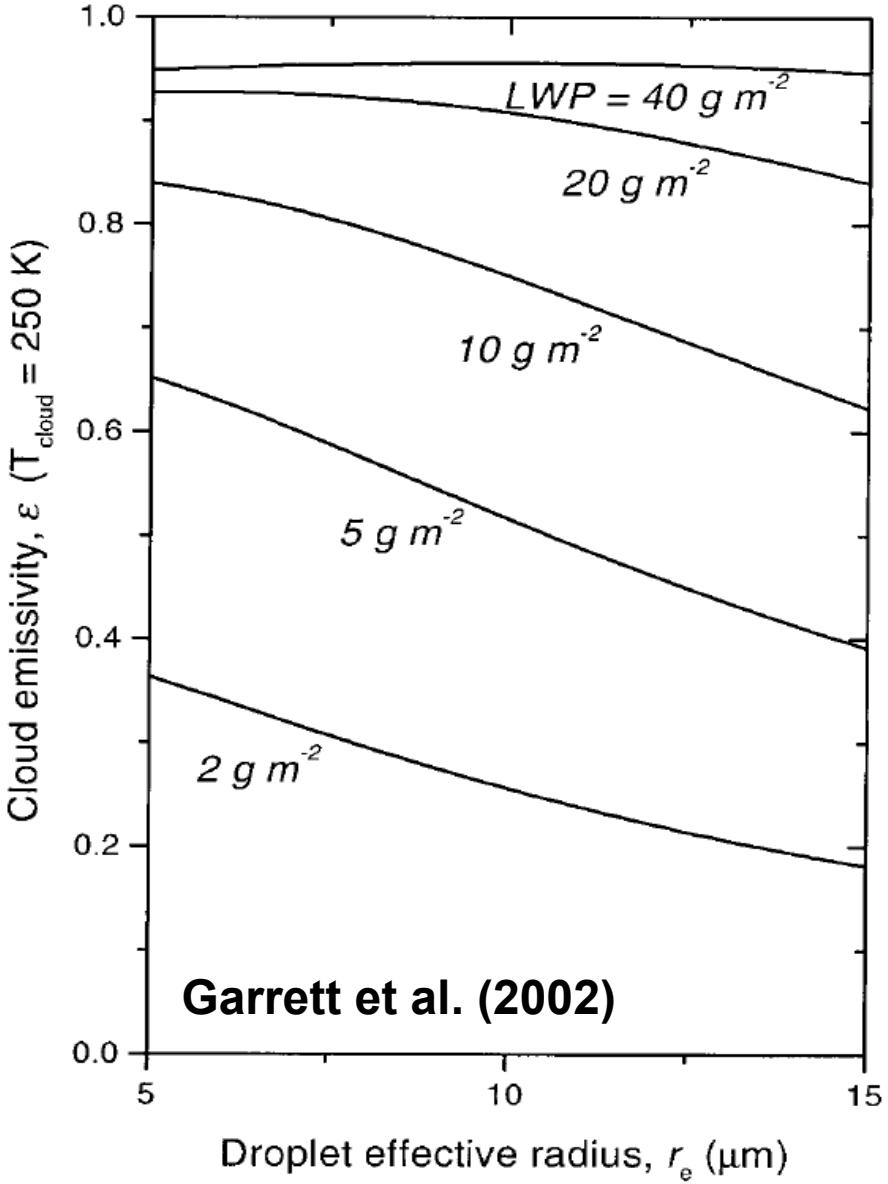
Monthly mean data

Quinn et al. (2006)

"How Do Aerosols Penetrate Storm Track?"
- A Conceptual Picture of Meridional Transport



LW Emissivity as a function of LWP and Effective Radii



In theory, two types of LW indirect effects:
1st smaller radii;
2nd higher LWP.

Surface LW downward cloud forcing of ~65 W m^{-2} suggested by SHEBA.

Model Physics and Chemistry in AM3

- **Convection Parameterization**

Move from the relaxed Arakawa-Schubert (RAS) in AM2 to the Donner deep convection scheme (Donner, 1993) and the University of Washington (UW) shallow convection scheme (Bretherton et al., 2003). By providing in-plume updraft velocity, the latter two are ideal for implementing aerosol/cloud microphysics.

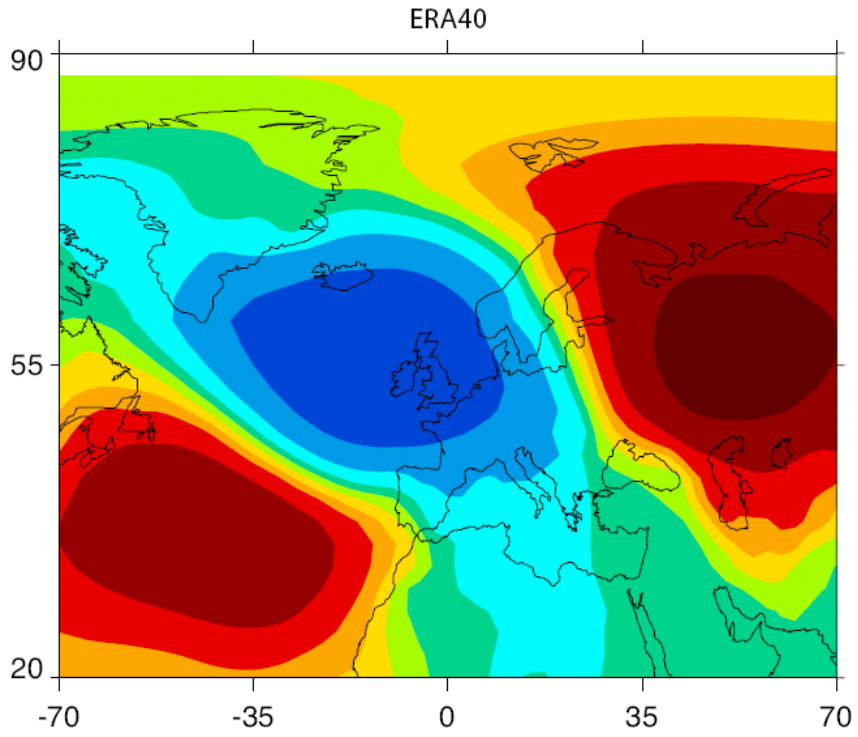
- **Aerosol-Liquid Cloud Interactions**

A prognostic scheme of cloud droplet number concentration (Ming et al., 2007) with an explicit treatment of aerosol activation at cloud base (Ming et al., 2006).

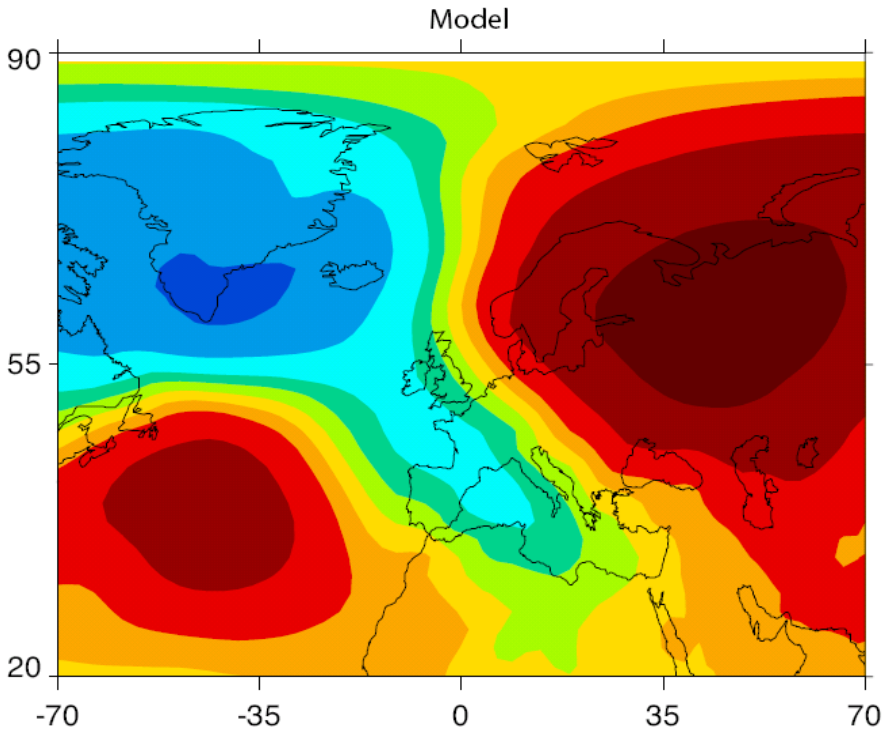
- **Online aerosol transport and tropospheric and stratospheric chemistry**

The Second Climate Mode (SM) of the North Atlantic – European Sector

ERA40

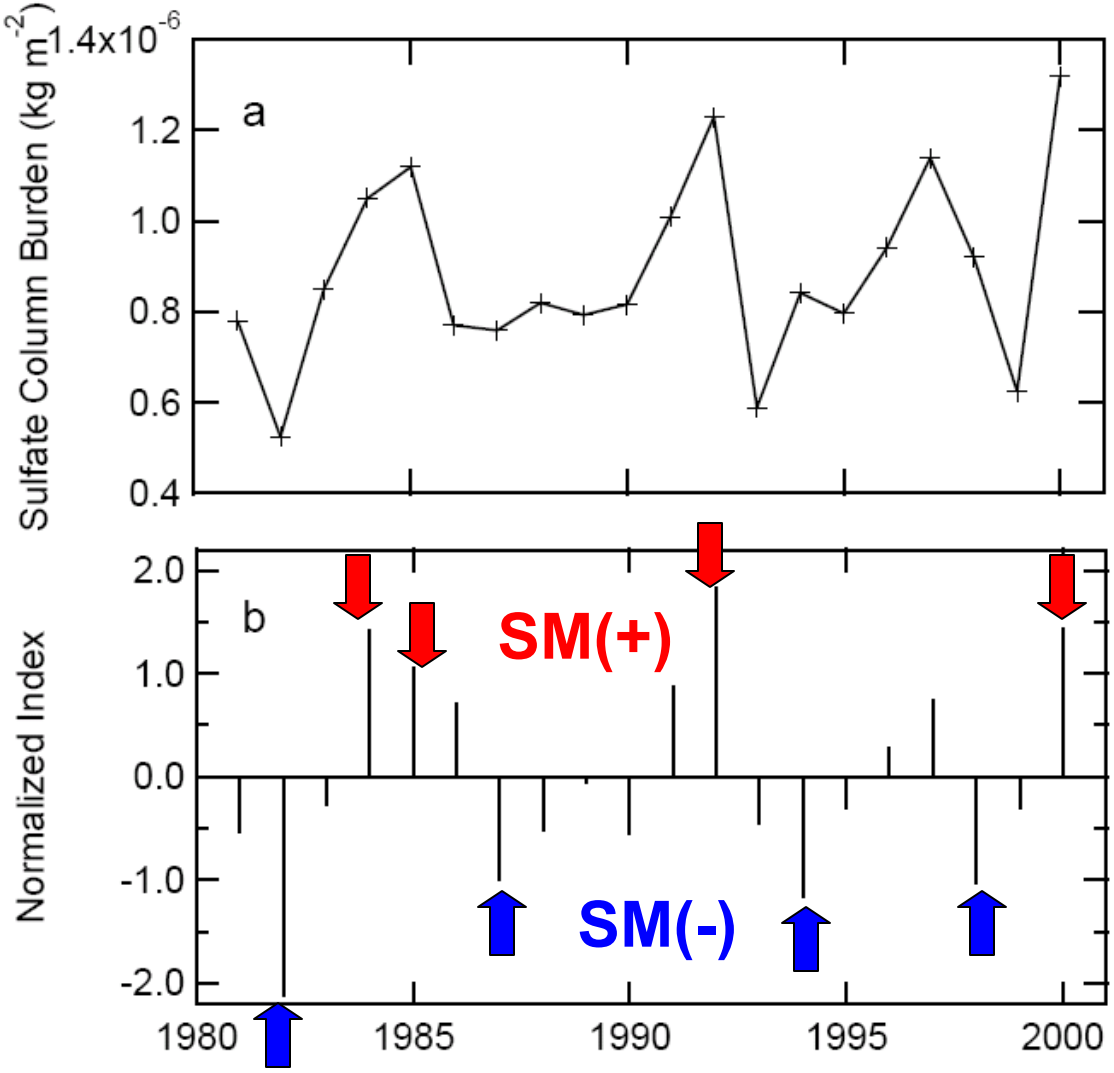


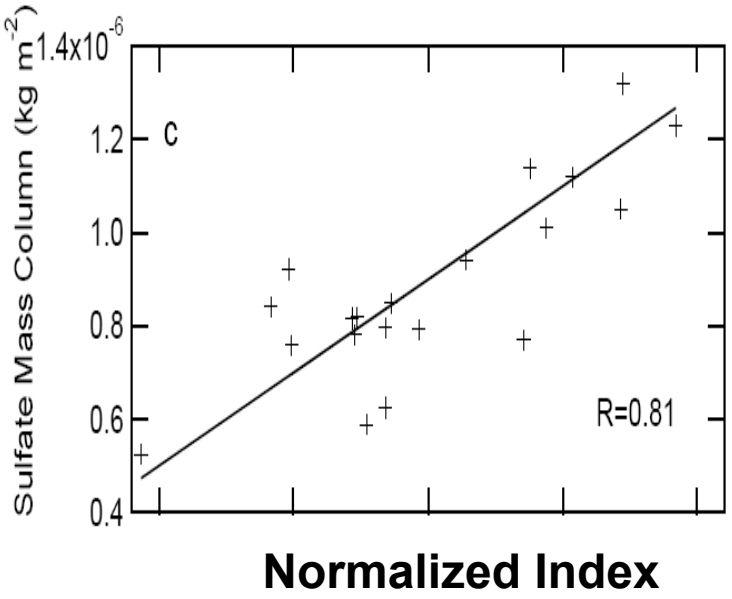
AM3



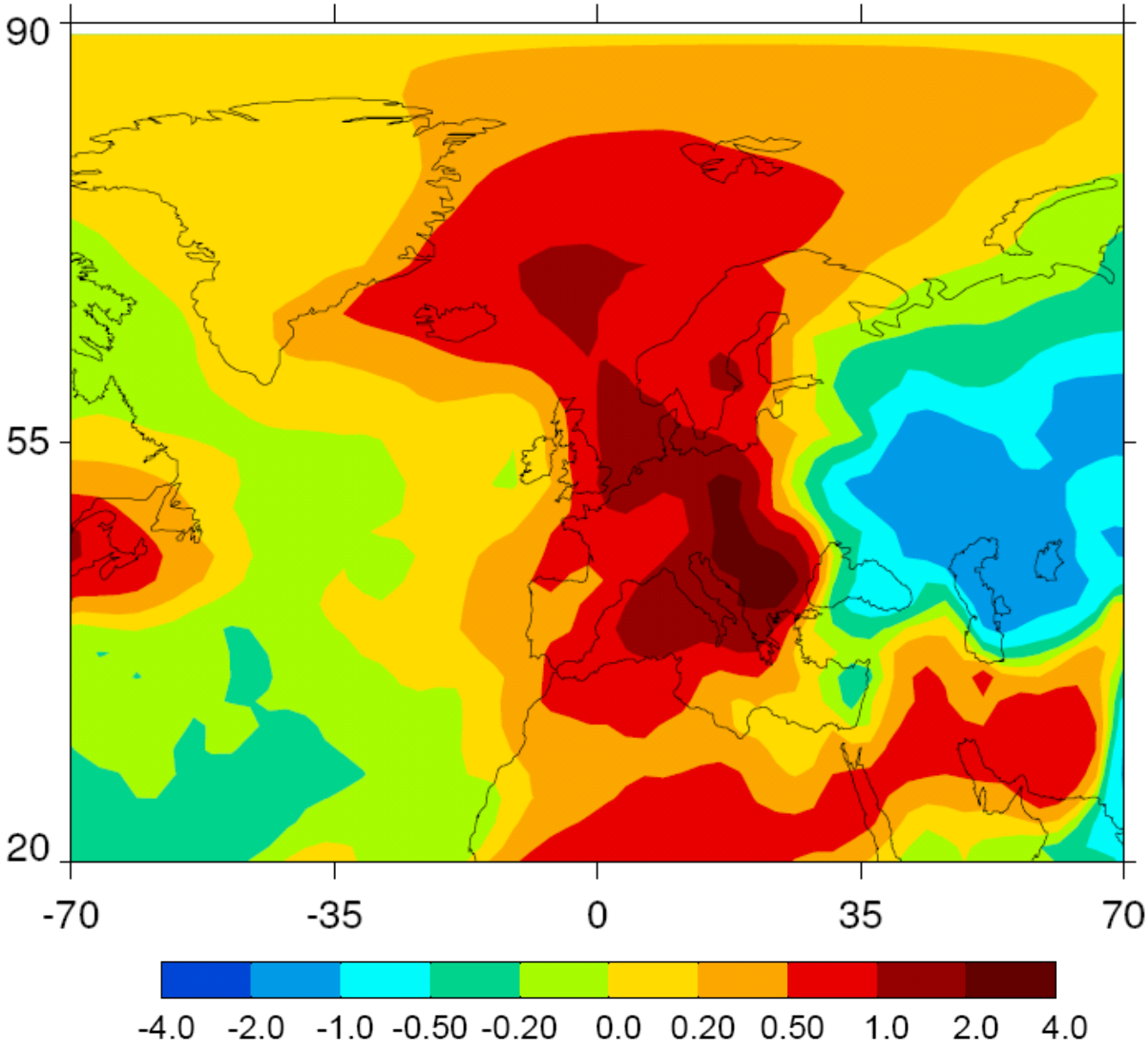
18% of total ariation

Correlation Between Simulated Arctic Haze and SM

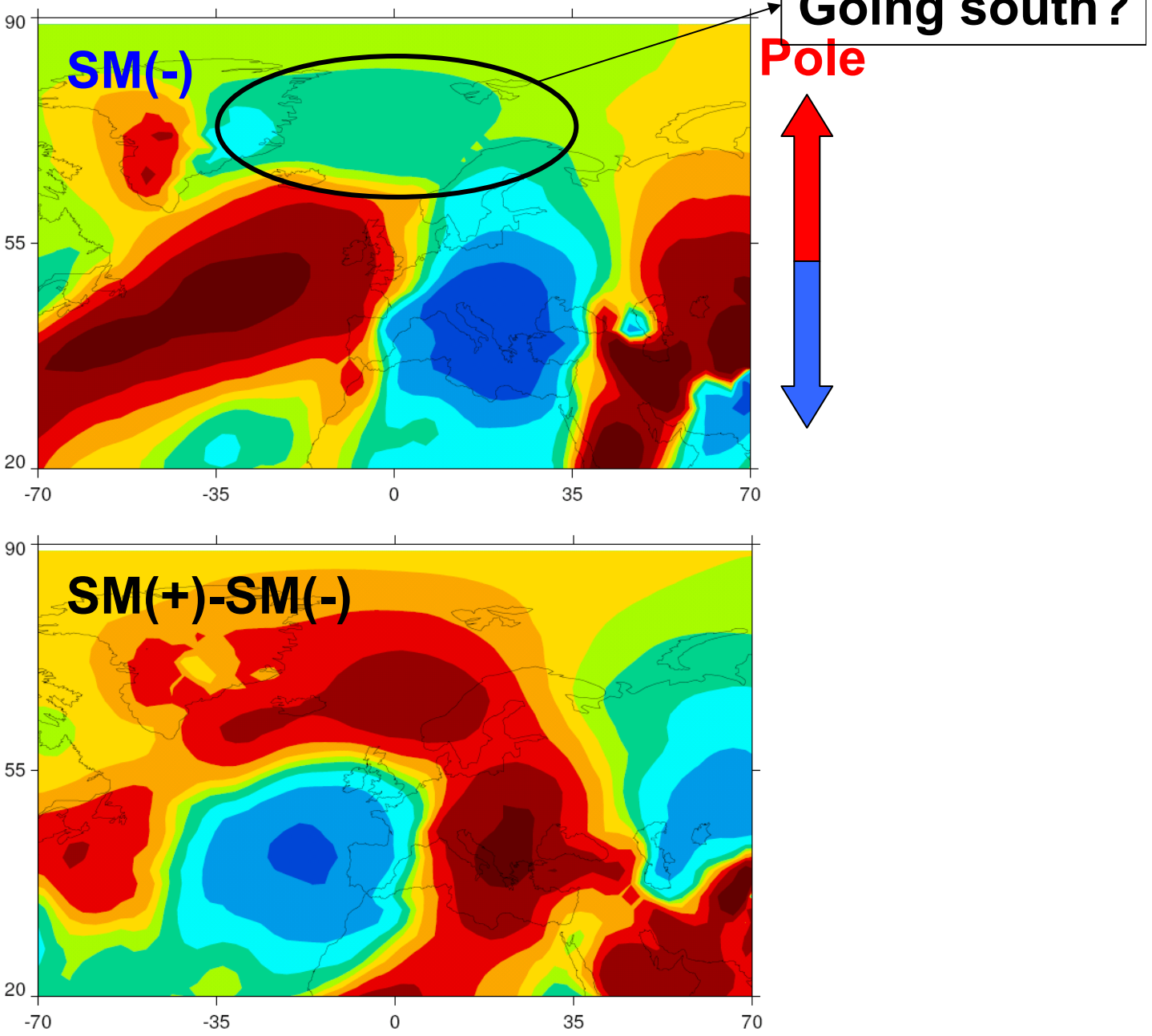




Difference in Sulfate Column Burden between SM(+) and SM(-)

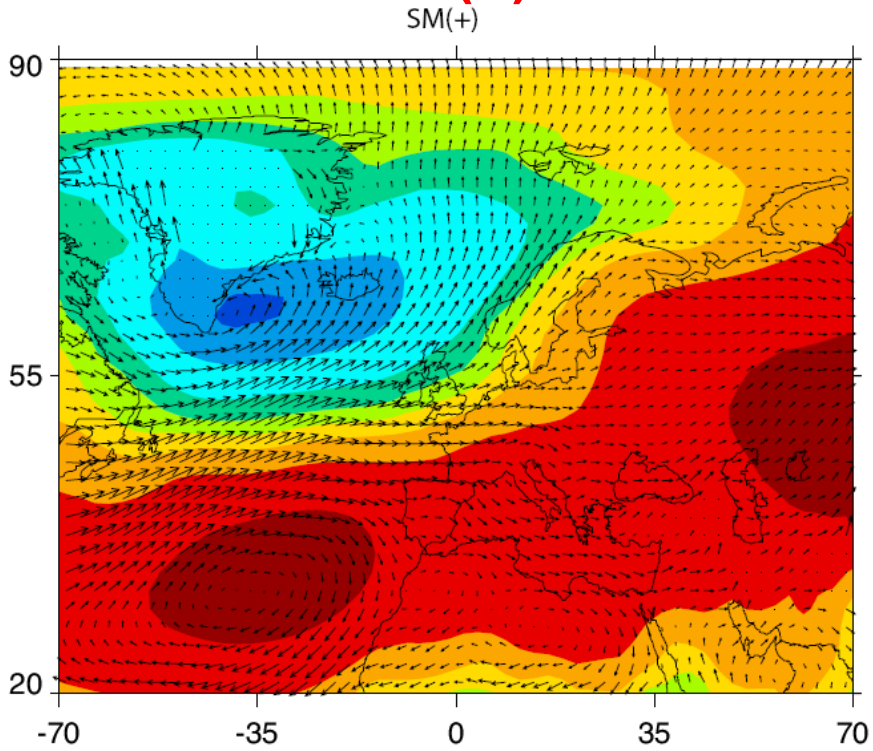


Transport of Sulfate by Mean Circulation $\overline{VC}$

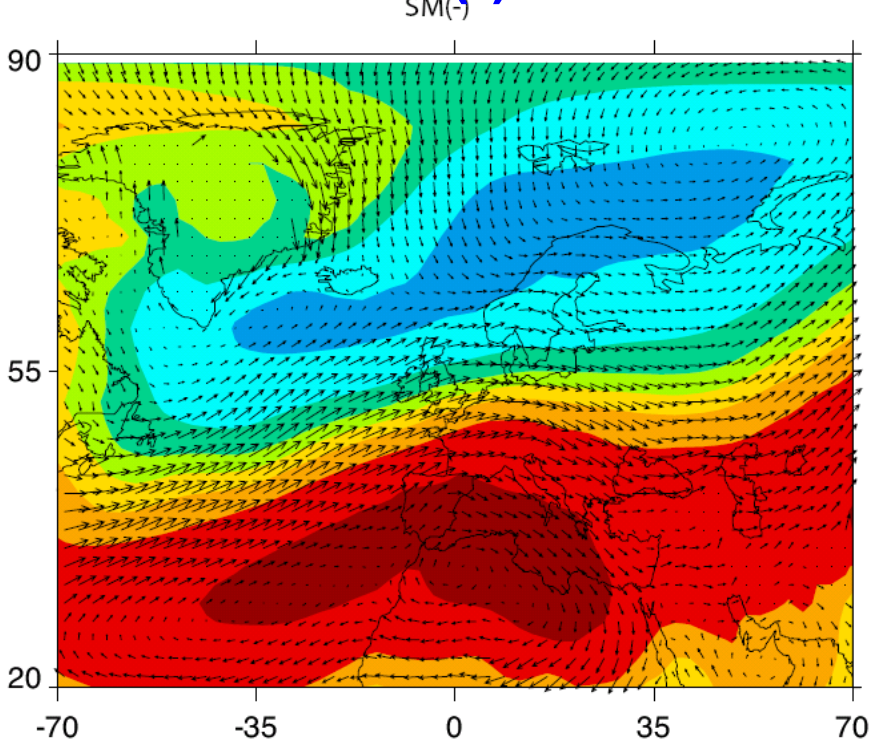


850-hPa Mean Winds and SLP Anomalies in SM(+) and SM(-) Years

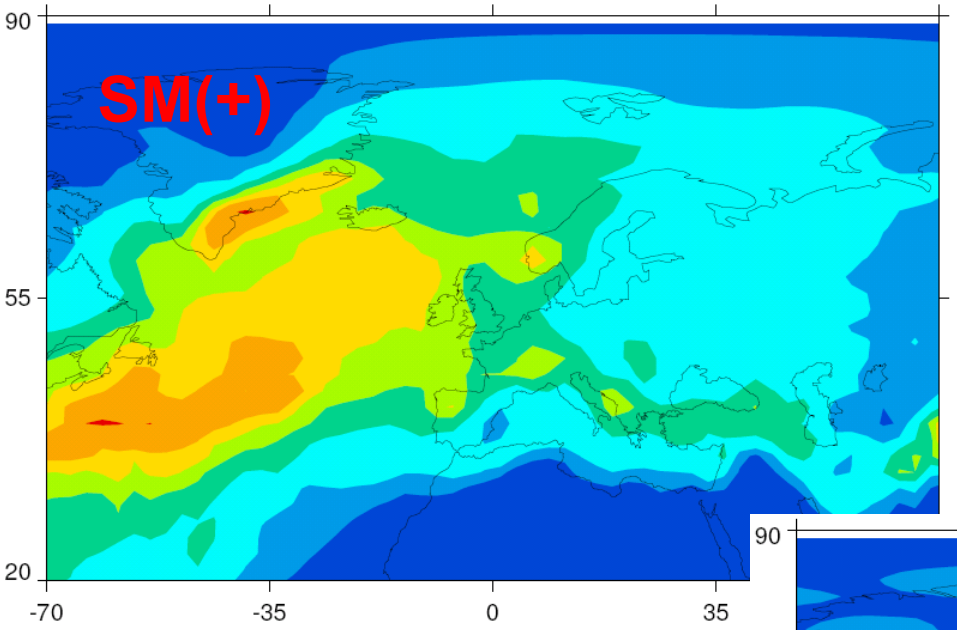
SM(+)

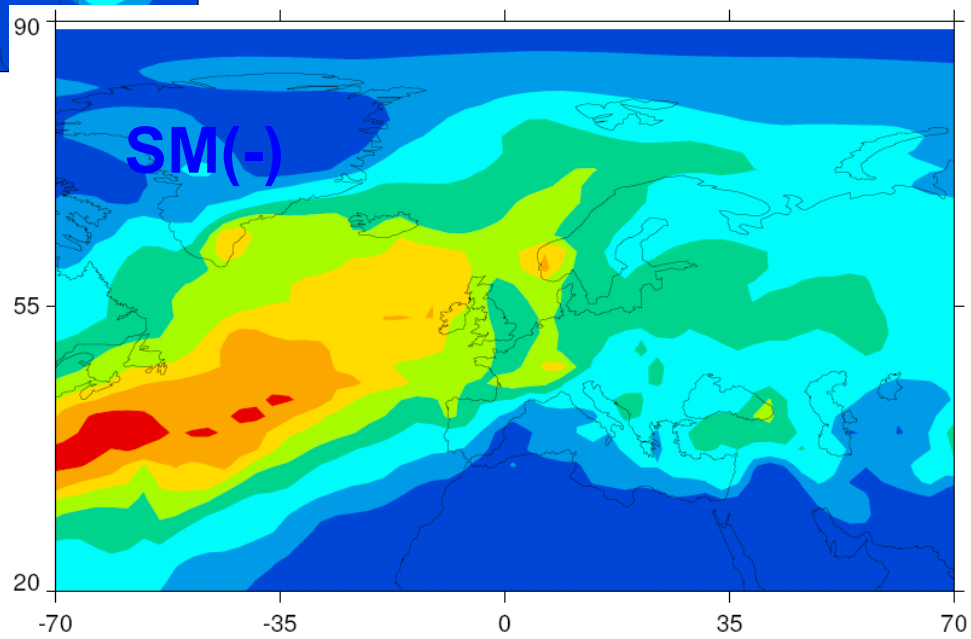


SM(-)

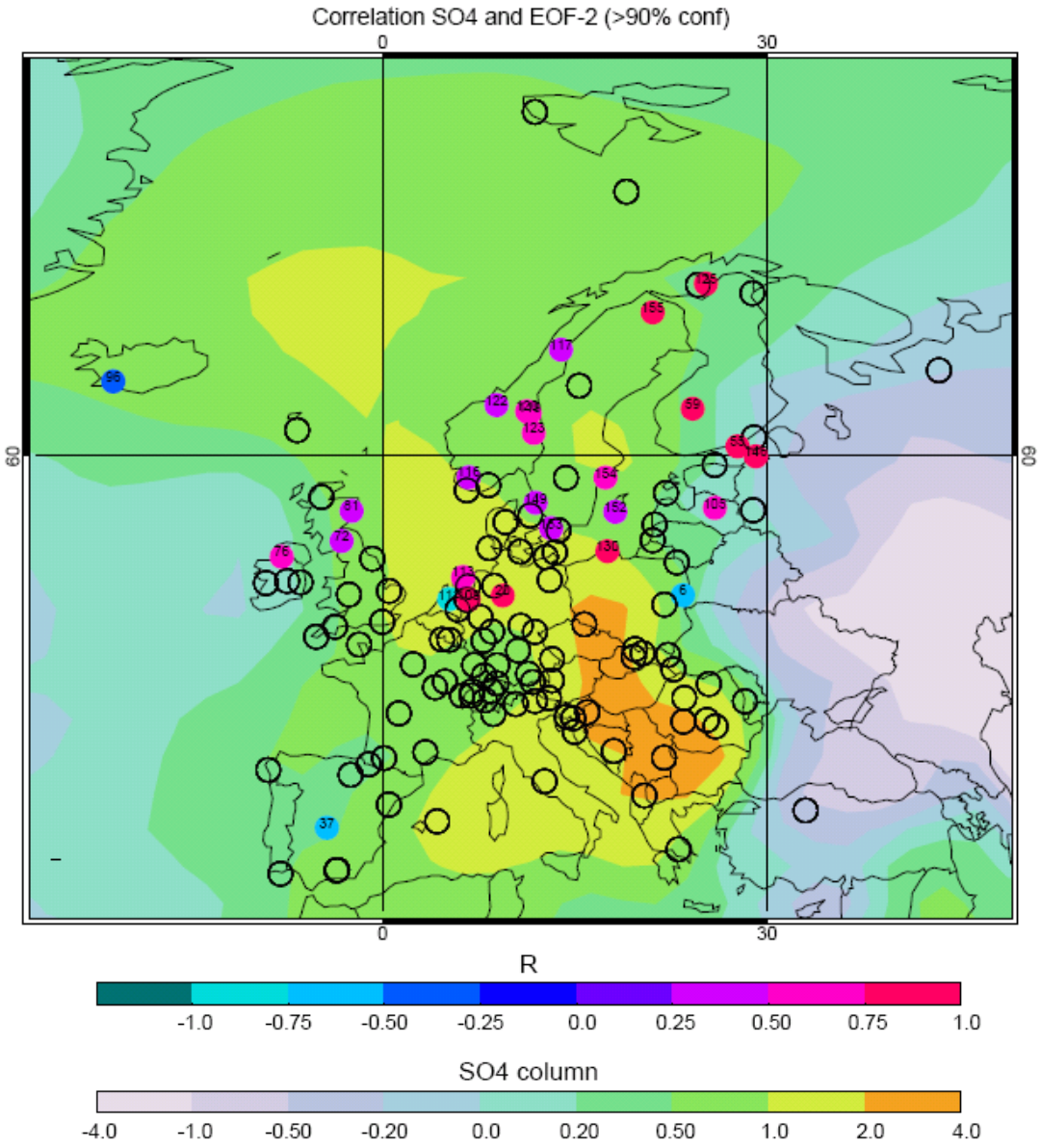


Position of Storm Track (Precipitation as Proxy) in Difference Phases of SM

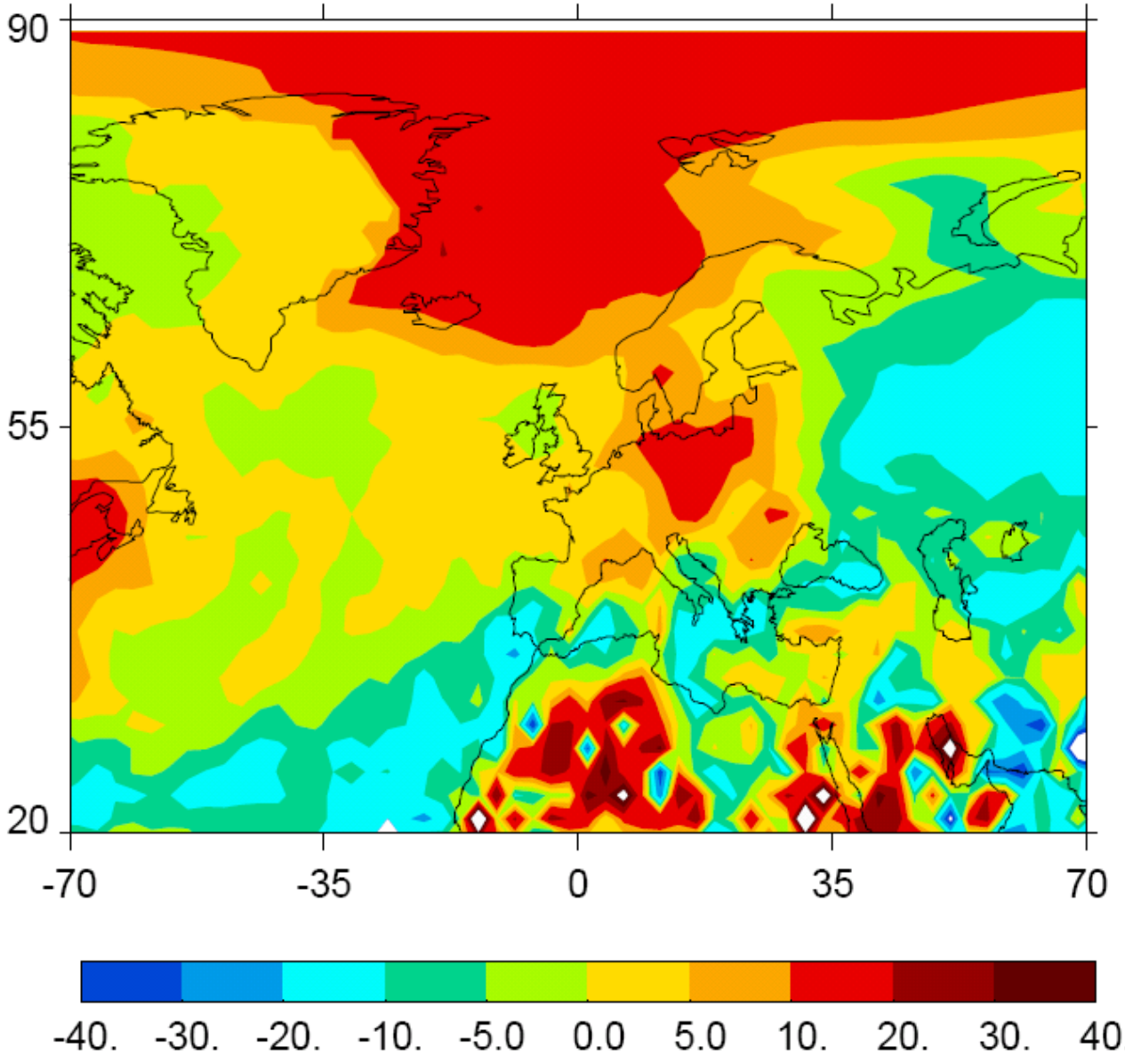




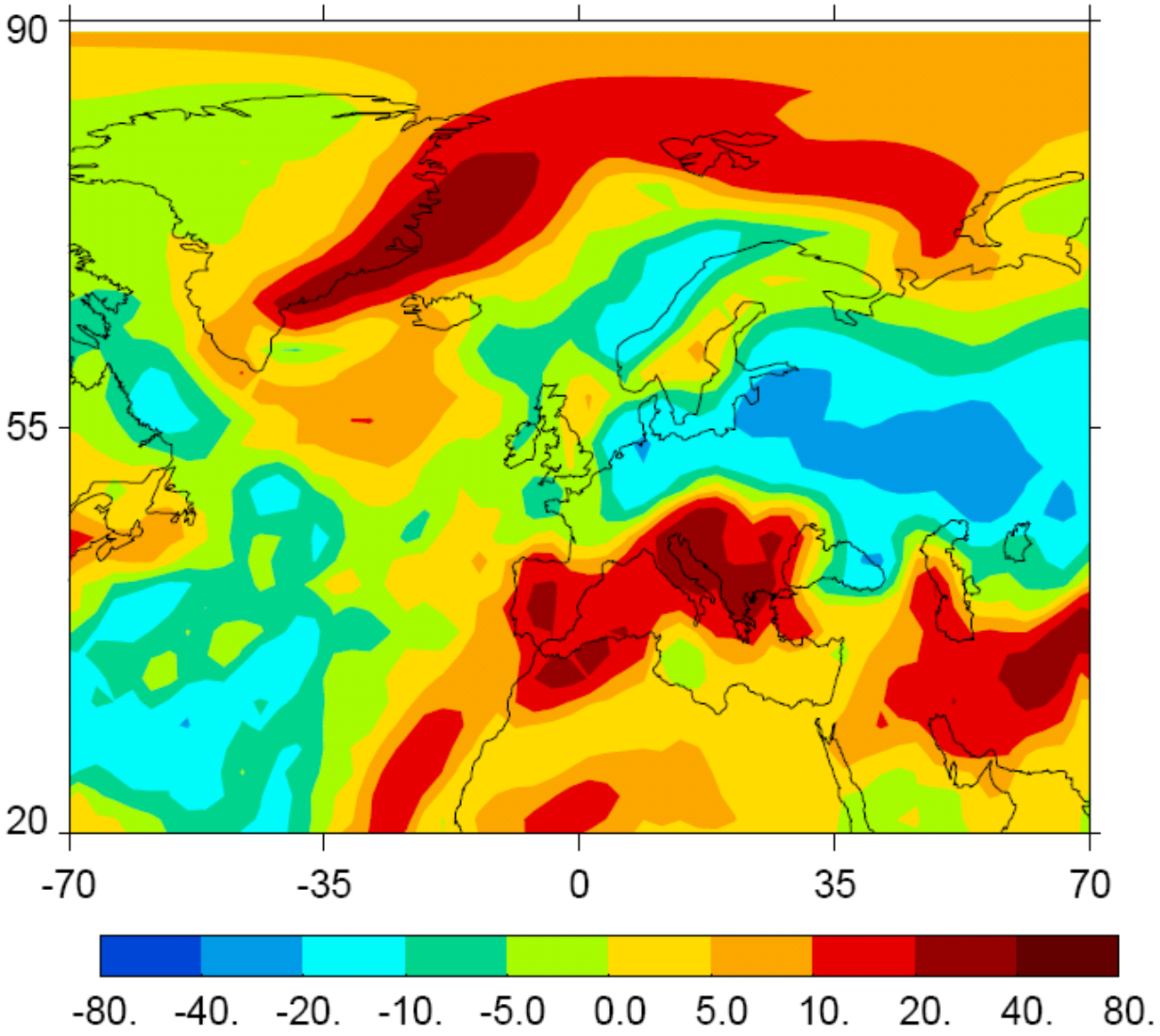
Correlation Between EMEP (European Monitoring and Evaluation Program)-measured sulfate and ERA40-based SM Indices



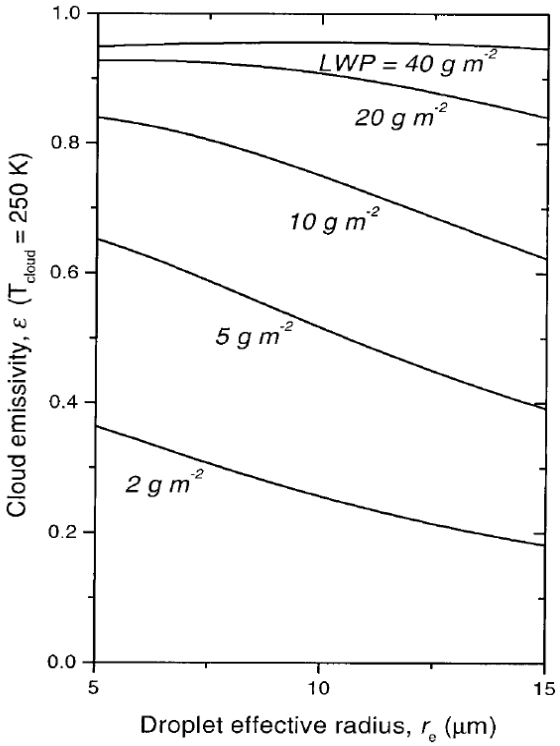
Difference in Cloud Droplet Number Concentrations between SM(+) and SM(-)

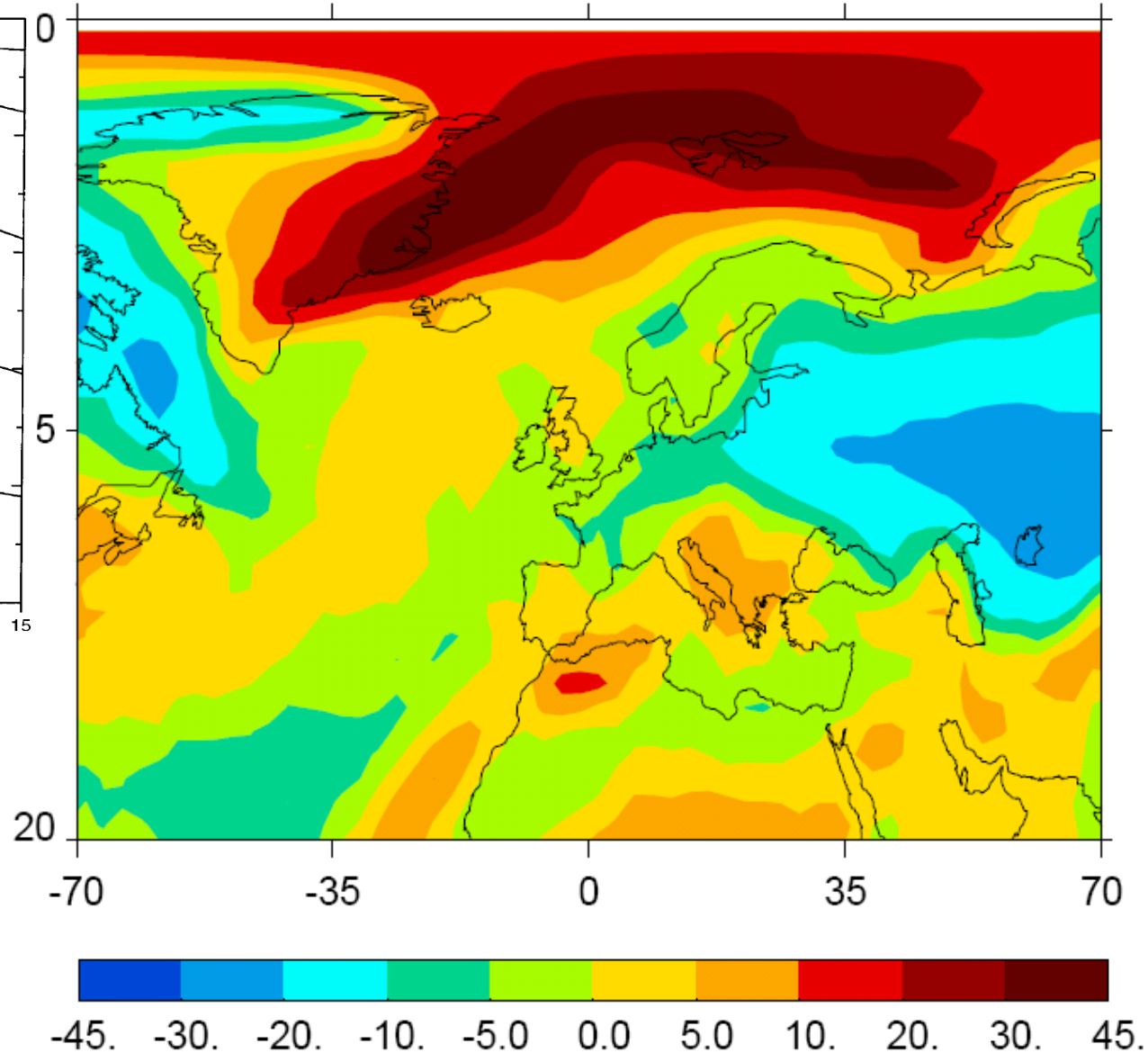


Difference in LWP between SM(+) and SM(-)



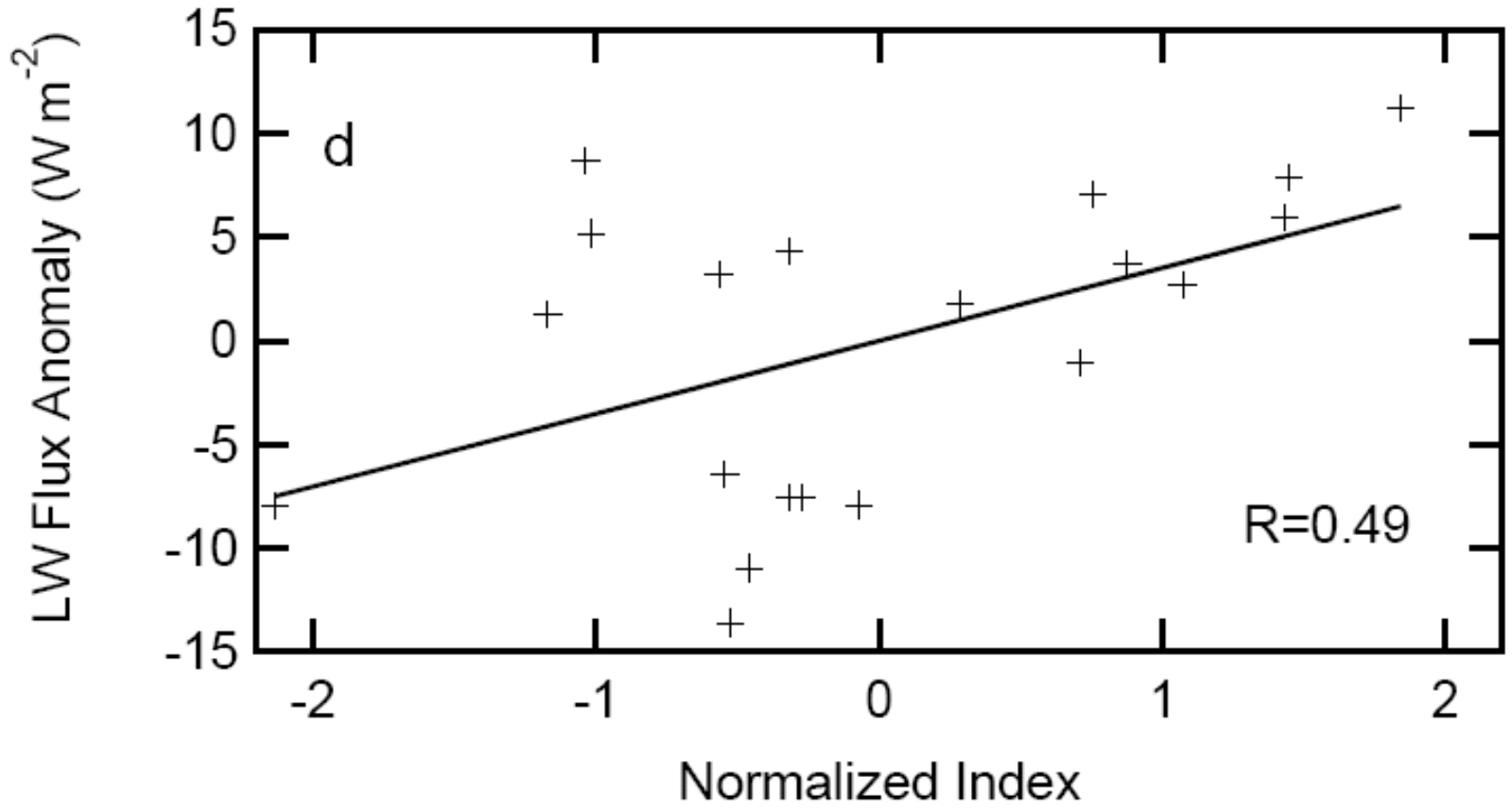
Difference in Surface LW Downward Flux between SM(+) and SM(-)



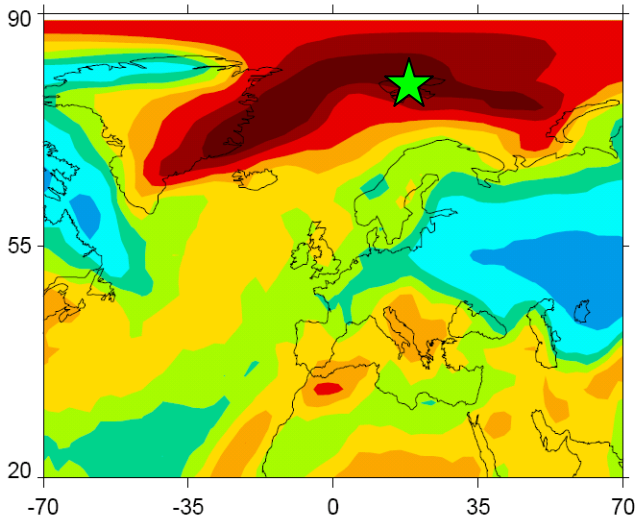


Average increase of 6.5 W m^{-2} (3.4 W m^{-2} attributed to the 2nd LW indirect effect)

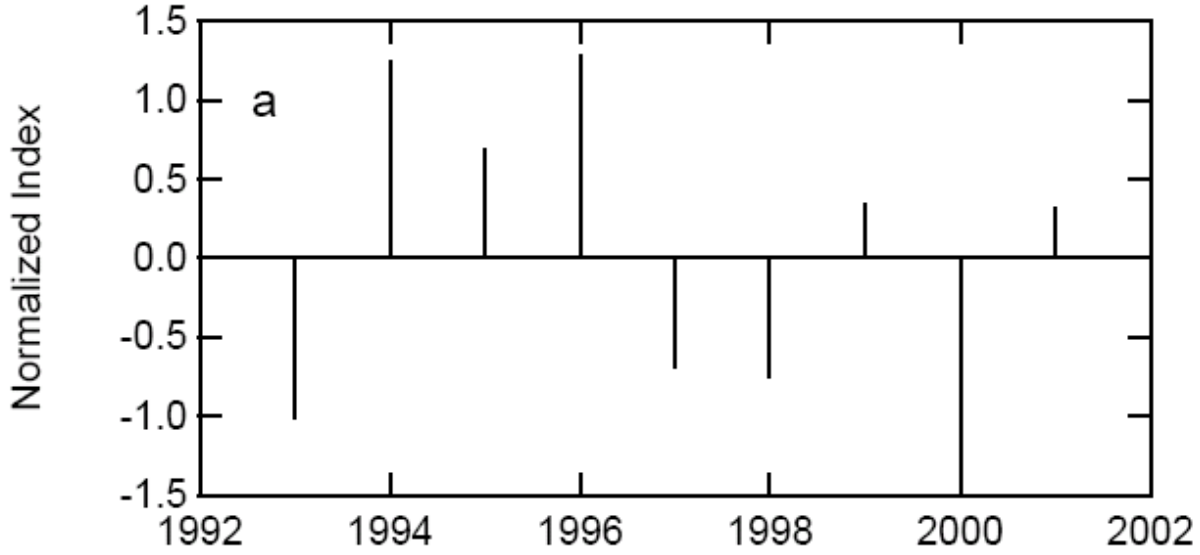
Correlation Between Simulated Surface LW Downward Flux and SM

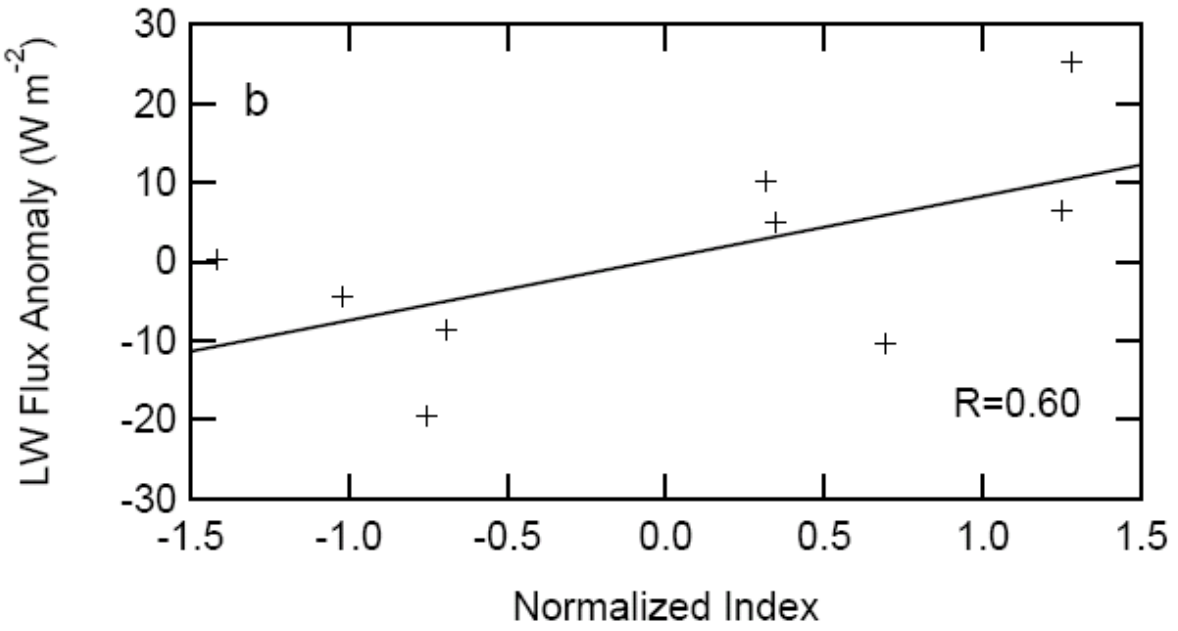


Correlation Between BSRN (Baseline Surface Radiation Network)-measured Surface LW Downward Flux and ERA40-based SM Indices

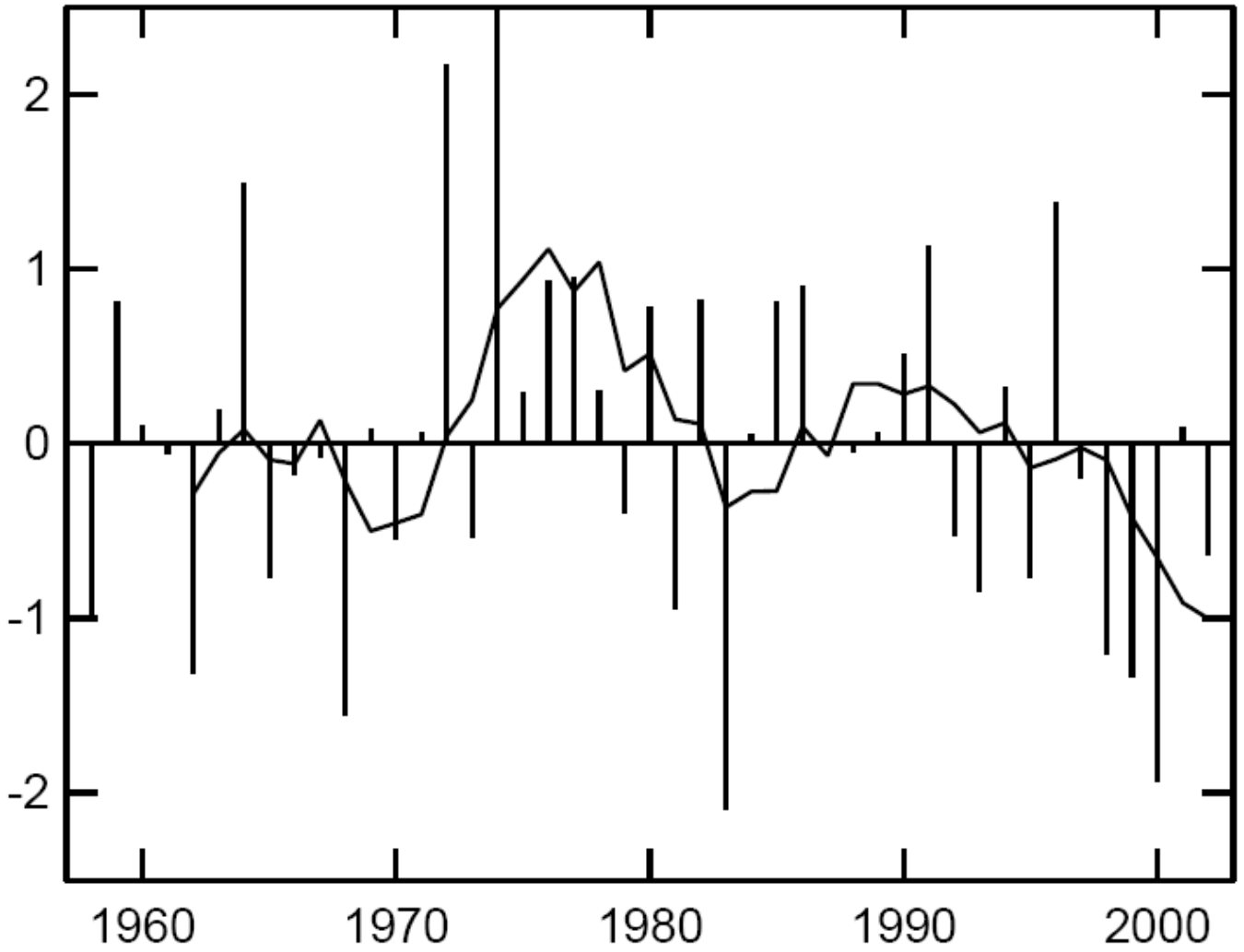


Spitsbergen
(79N 12E)





ERA40-based Long-term Trend of SM

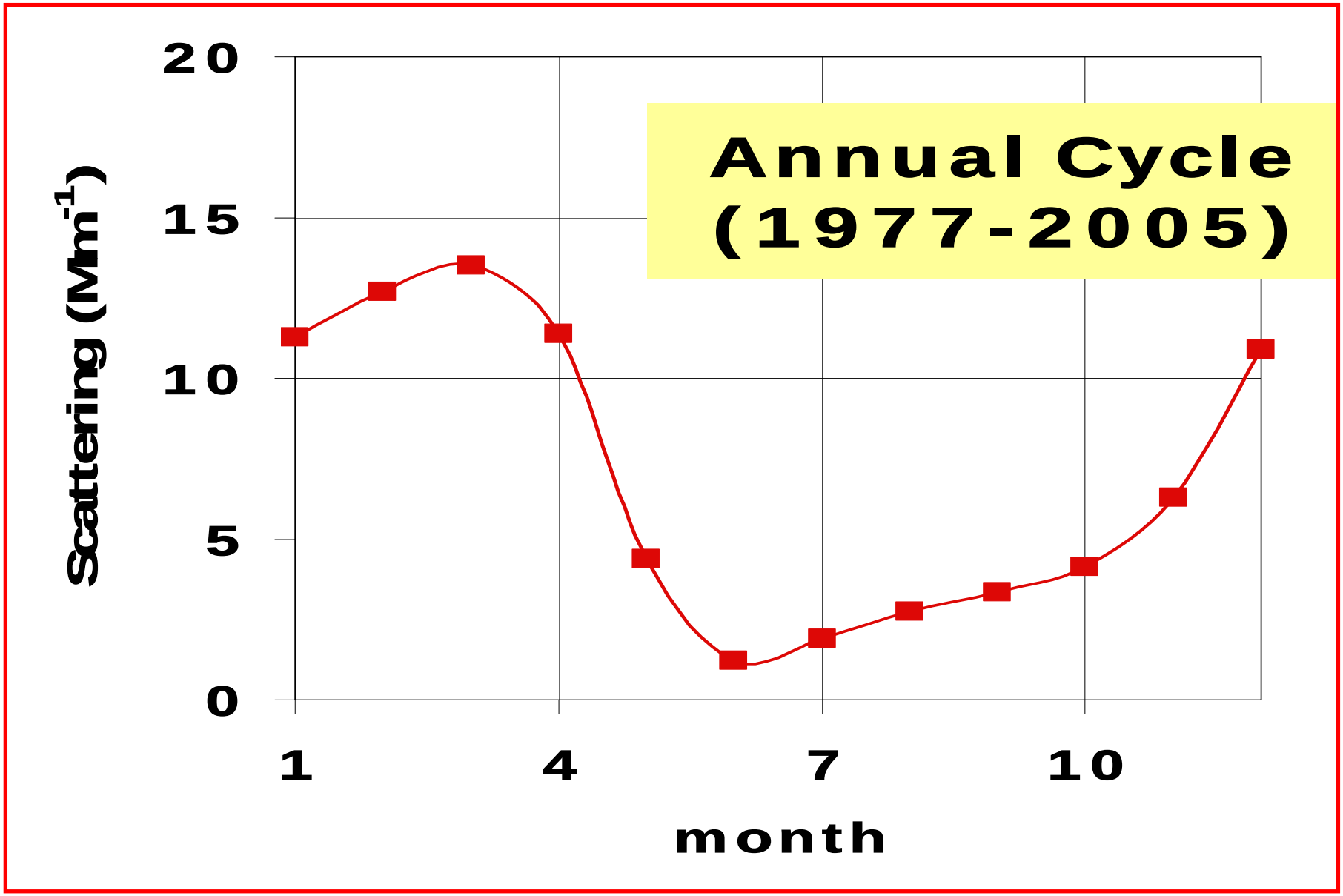


Conclusions

- The Second Mode, though less prominent than NAO, is key to modulating long-range transport of aerosols to the Arctic;
- A positive phase of SM doubles the amount of Arctic haze, and results in significant increase in surface LW downward flux;
- This mechanism is important for understanding Arctic climate variability and change.

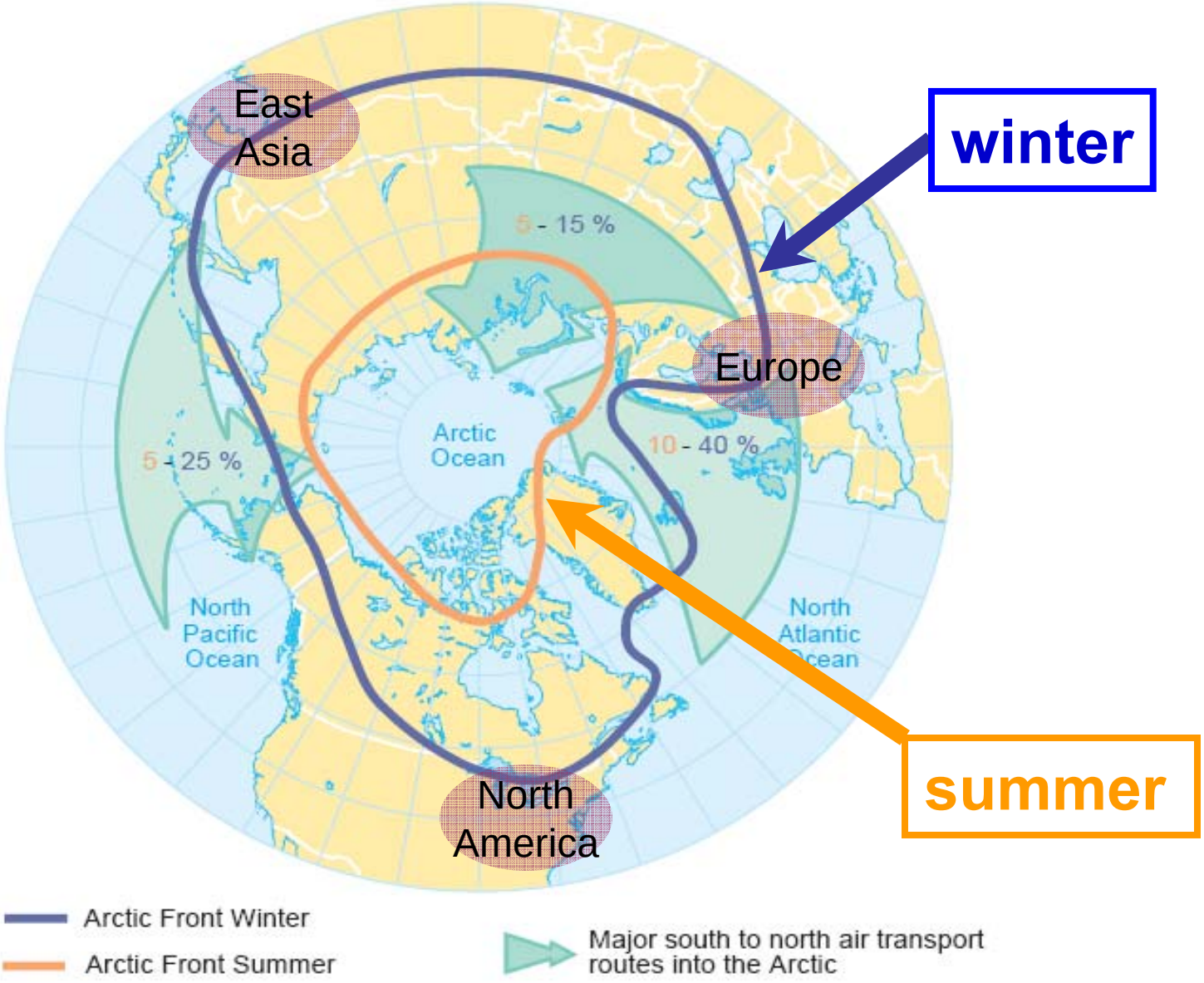
- Ice Nuclei – a major wild card … (Prenni et al., 2007)

Backup Slides

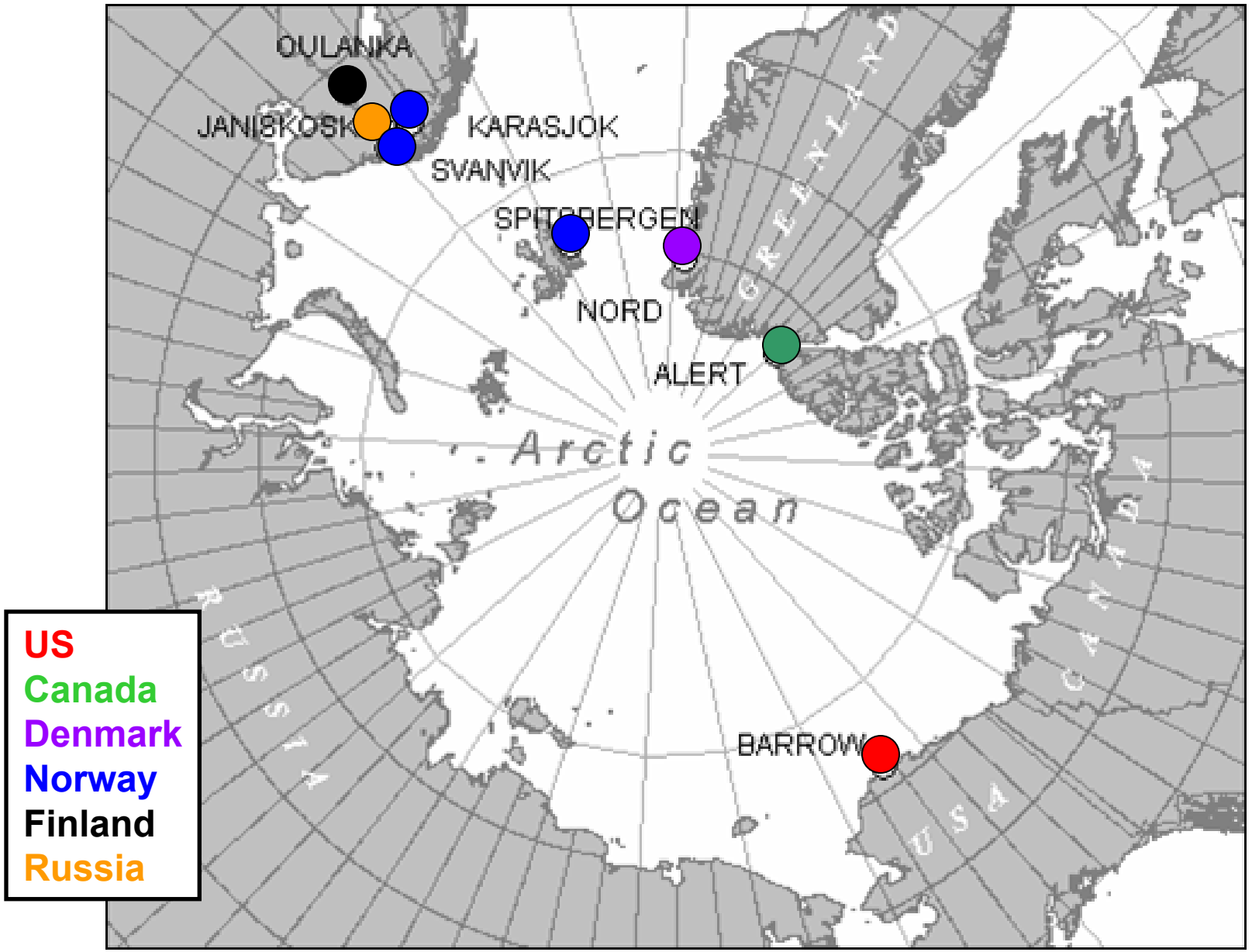

Annual Cycle
(1977-2005)
Scattering (Mm-1)
20
15
10
5
0
1
4
7
10
month

Long-range Transport of Mid-latitude Air Pollutants to the Arctic

Mean position of the Arctic Front

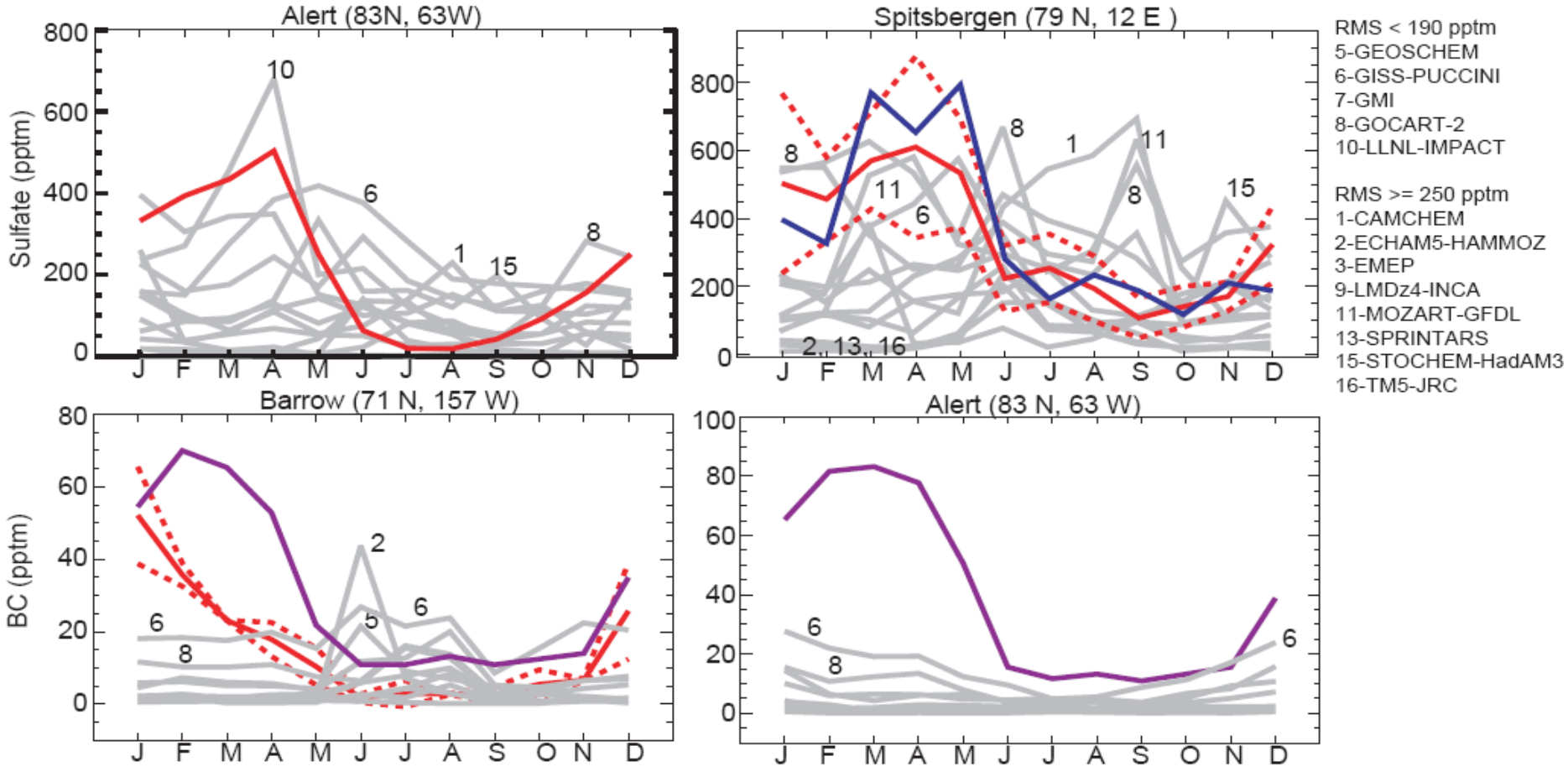


Locations of Long-term Arctic Monitoring Stations



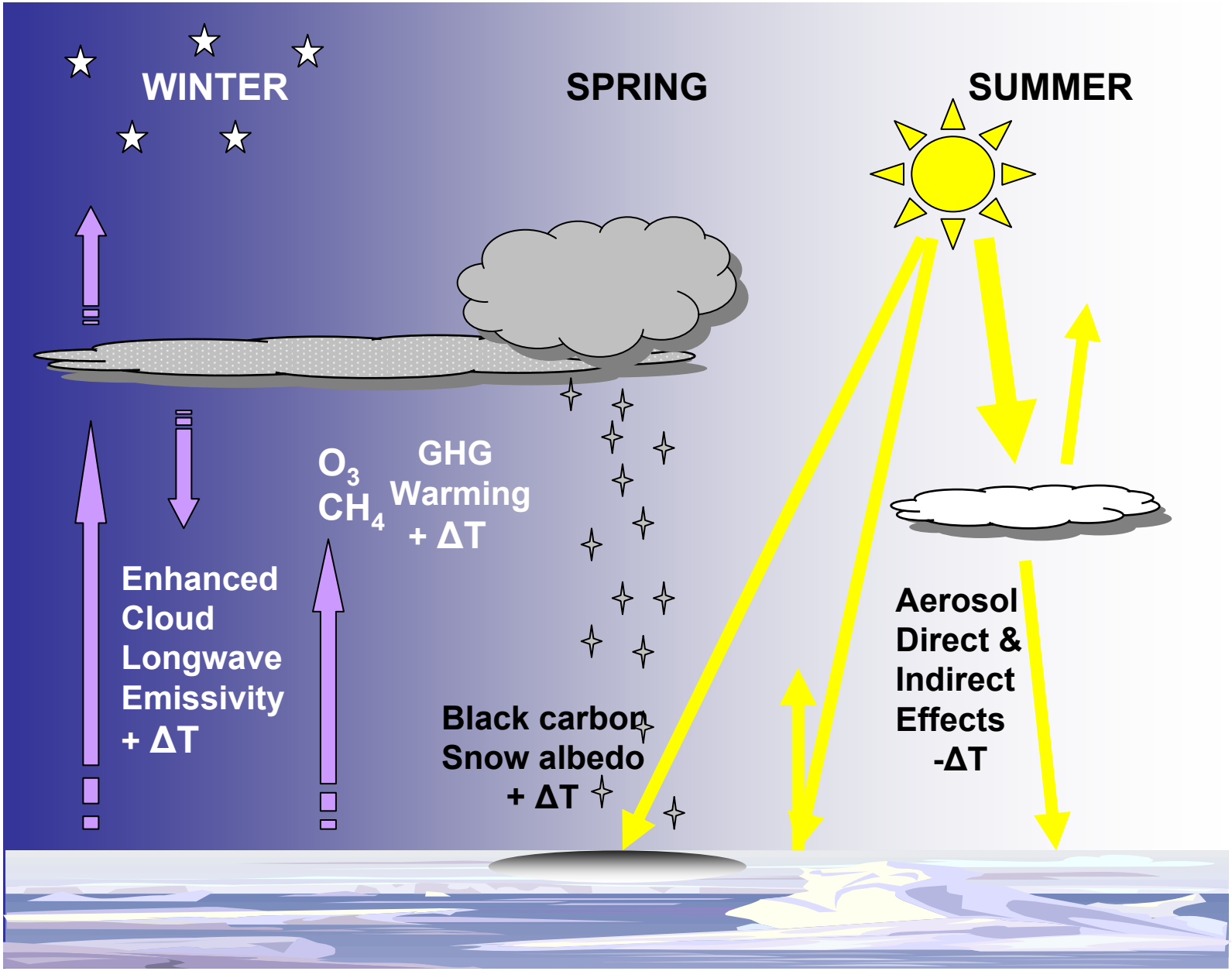
Model Deficiency in Simulating Seasonality

Chemistry Transport Models (w/ reanalyzed meteorology) and General Circulation Models participating in the Hemispheric Transport of Air Pollutant (HTAP) project.

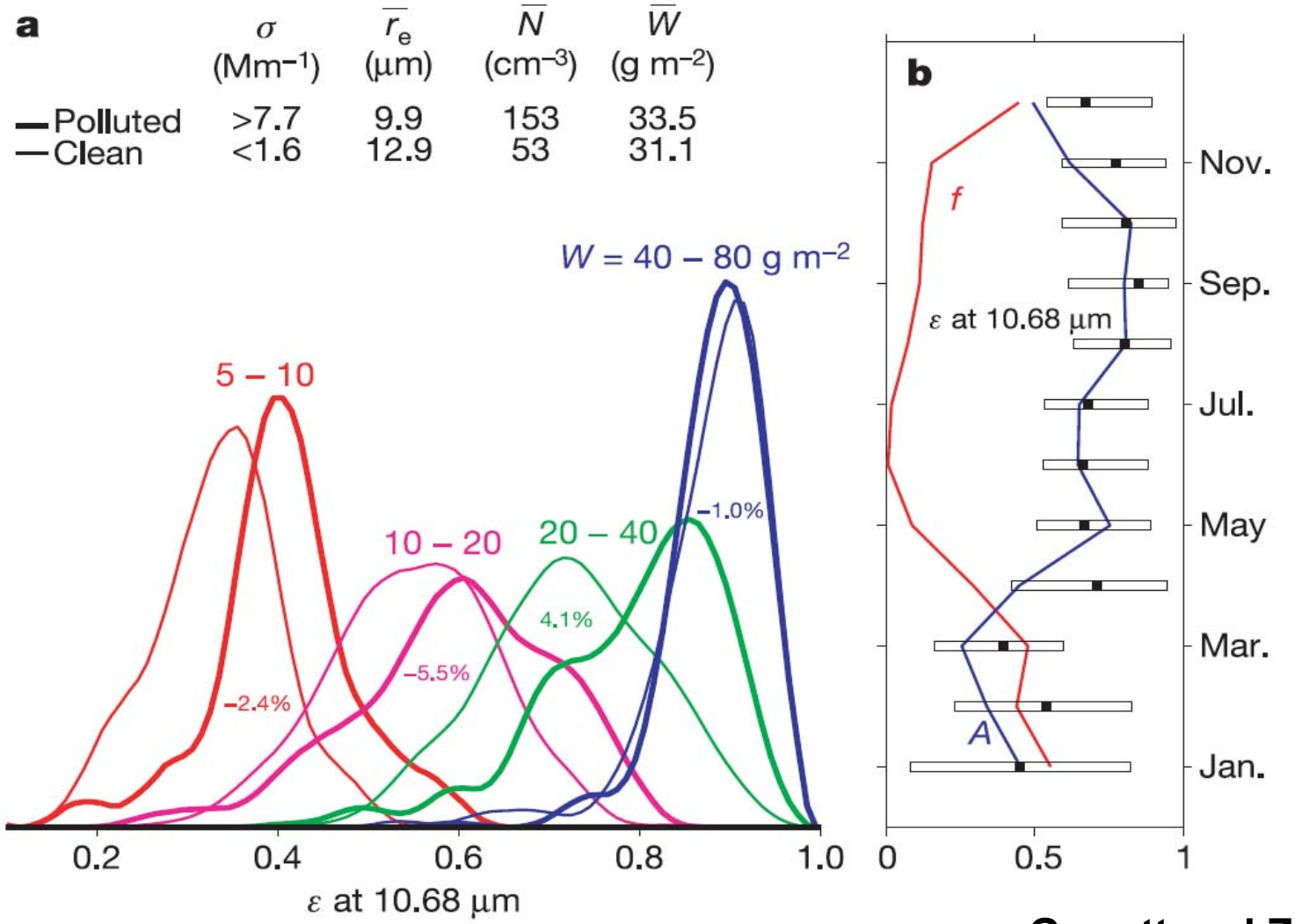


Shindell et al. (2008)

Arctic Haze Affects Climate in Multiple Ways



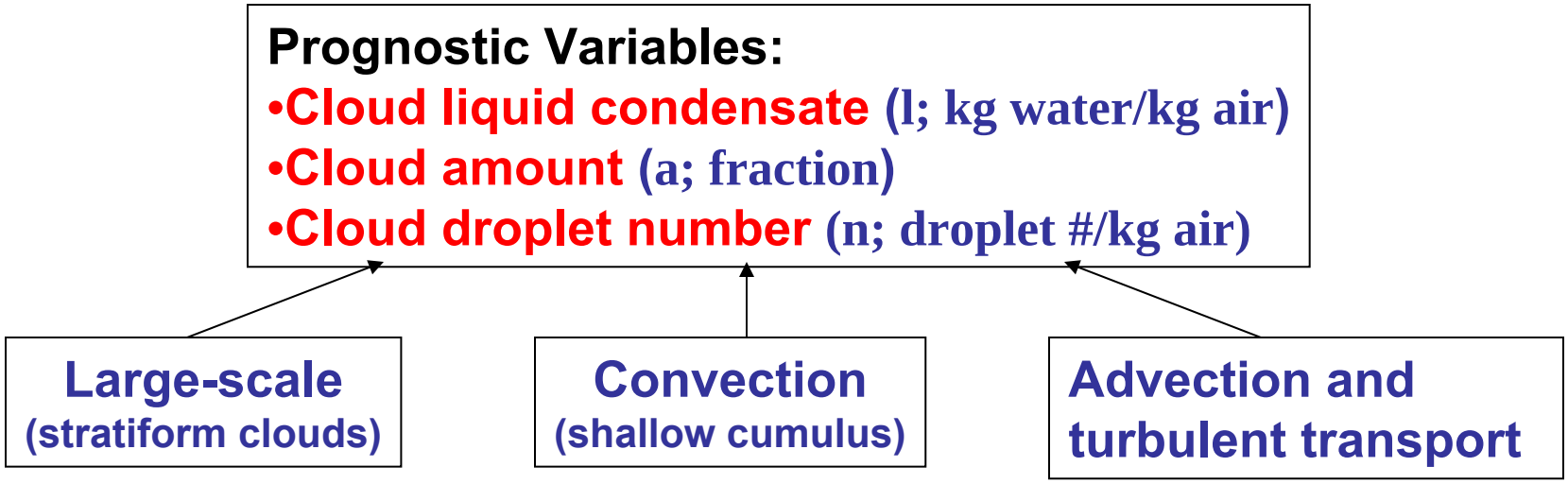
1st LW Indirect Effect of Arctic Haze (Smaller Radii)



Garrett and Zhao (2006)

A Prognostic Scheme of Cloud Droplet Number

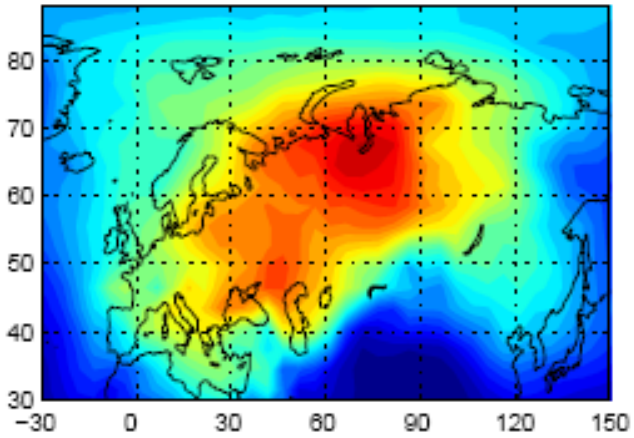
Ming et al. (JAS, 64, 1189, 2007)



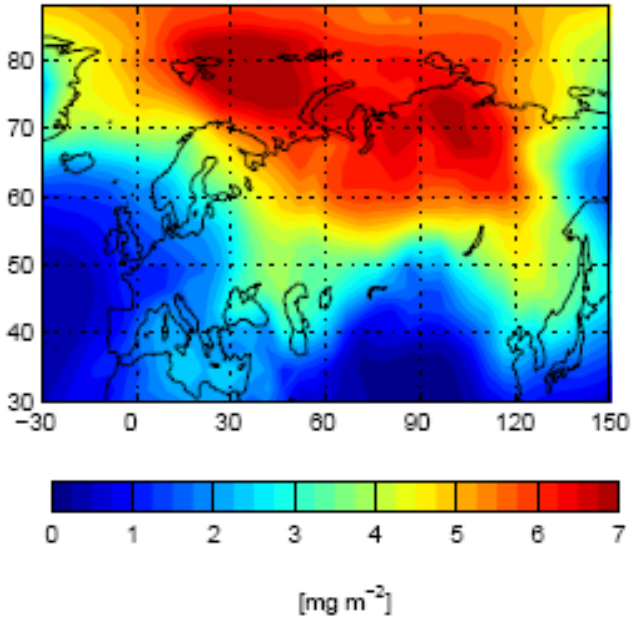
- Source and sink terms for cloud liquid condensate, amount and droplet number are fully consistent;
- Droplet activation at cloud base is parameterized following *Ming et al. (JAS, 63, 1348, 2006)*, and is determined by aerosol properties (chemical composition and size) and model-derived updraft velocity;
- Multiple aerosol types (sulfate, OC and sea salt) are treated as CCN;
- Evolution of droplets interacts with dynamics and meteorology.

Transport of European Tracer for NAO+ and NAO- Conditions
(December, January, February composites for 1980 - 1993)

NAO-, 8 – 10 days



NAO+, 8 – 10 days

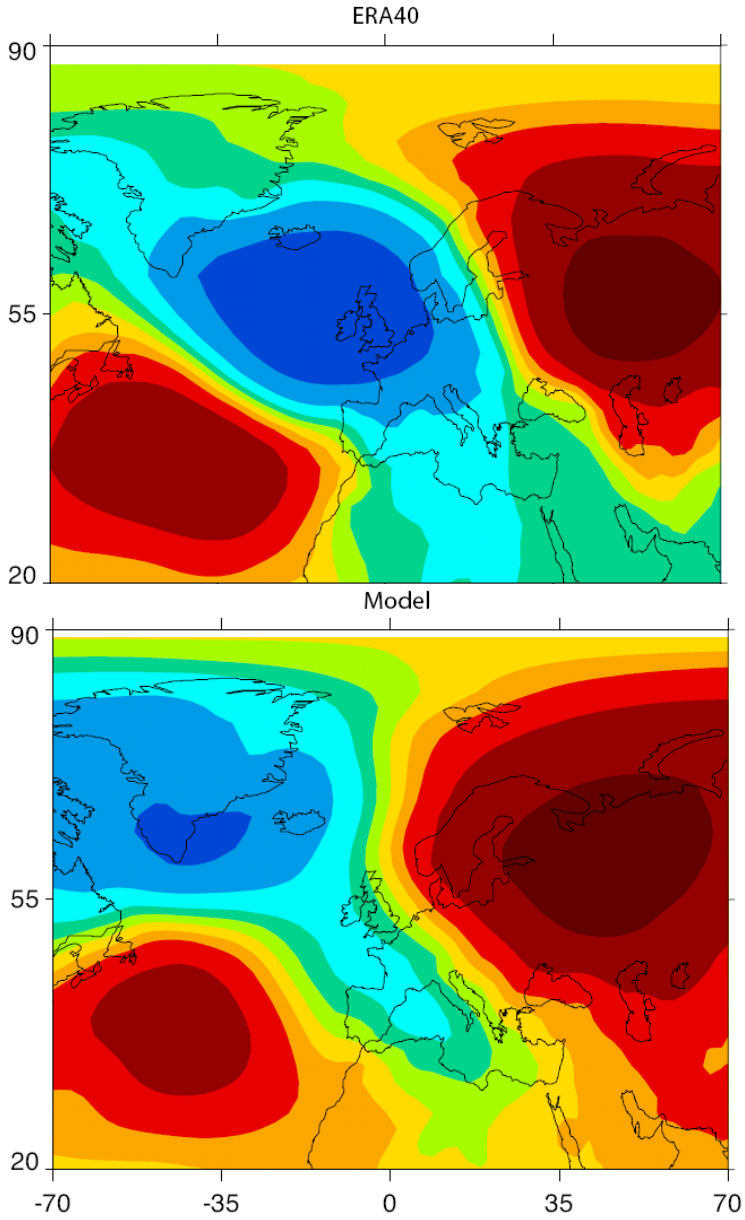


• After 8 to 10 days, most of the European tracer is found North of the Arctic circle for the NAO+ case.

• Surface concentrations in the Arctic winter are enhanced during NAO+ phases due to changes in transport from Europe and North America.

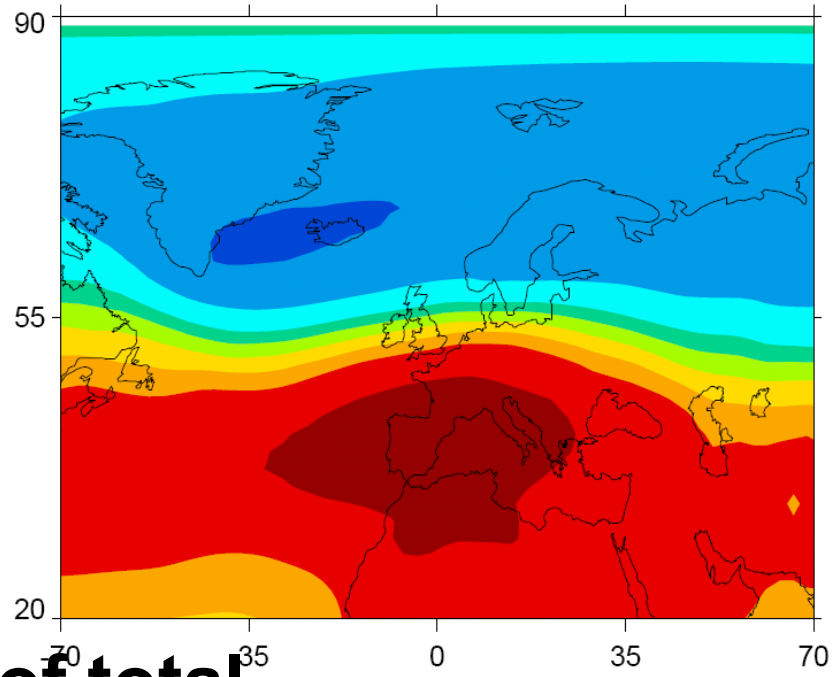
Eckhardt et al., ACP, 2003

The Second Climate Mode (SM) of the North Atlantic – European Sector



ERA40 SM

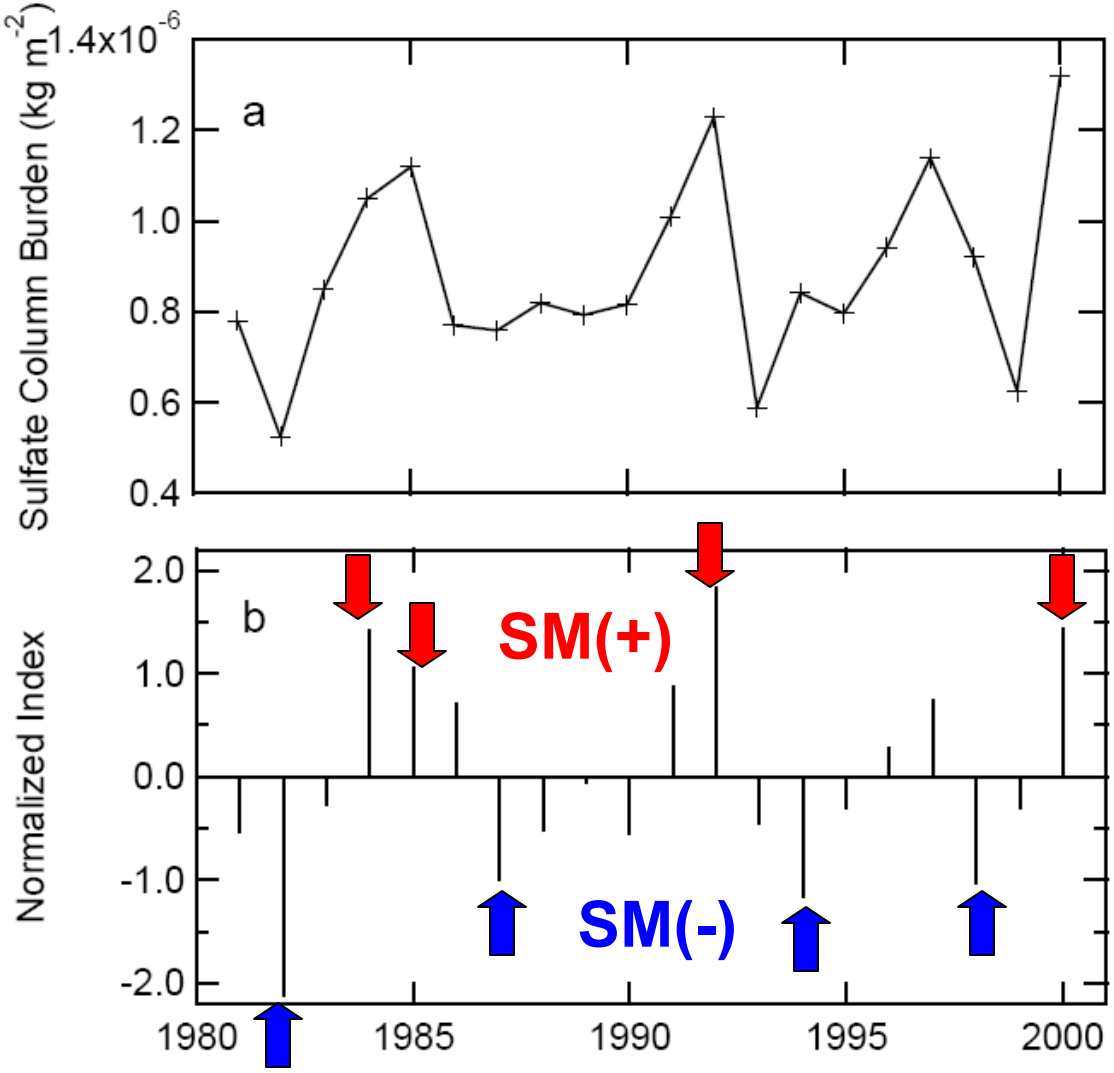
AM3 NAO 40%

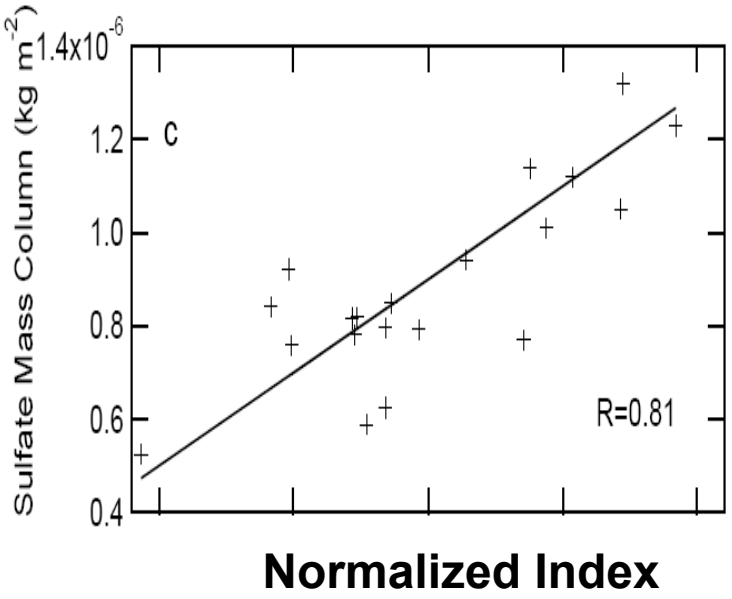


AM3 SM

18% of total variation

Correlation Between Simulated Arctic Haze and SM





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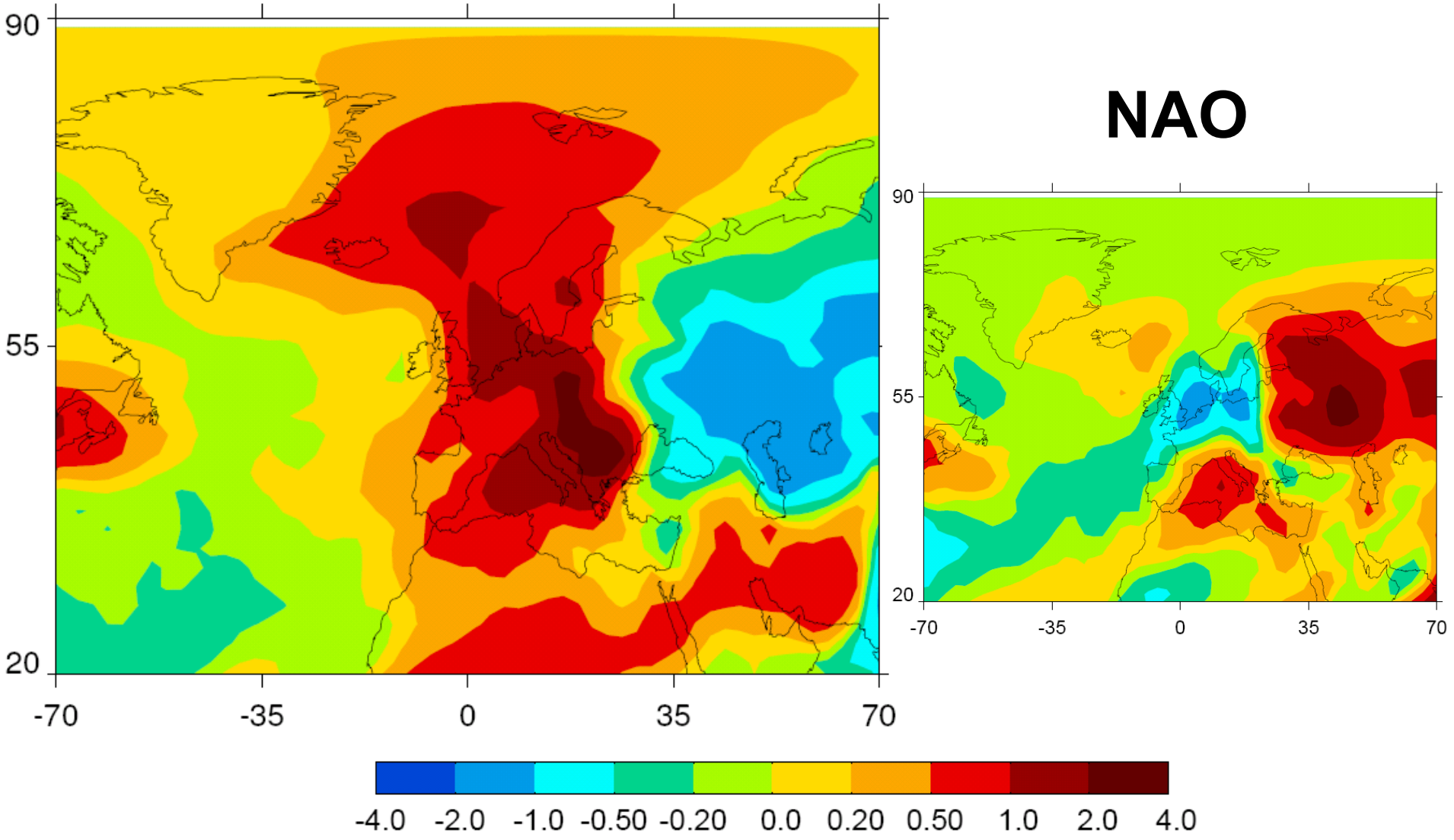
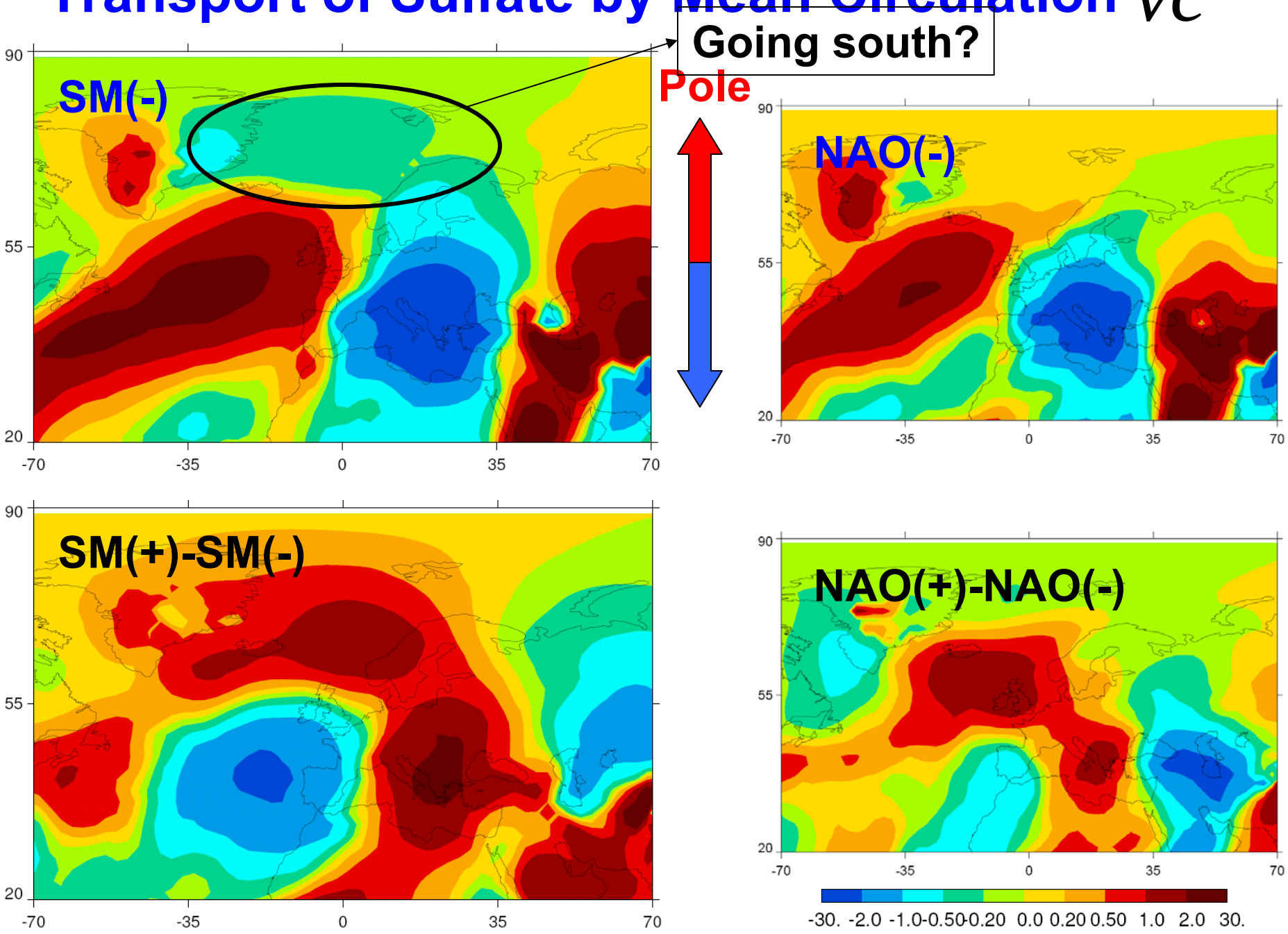
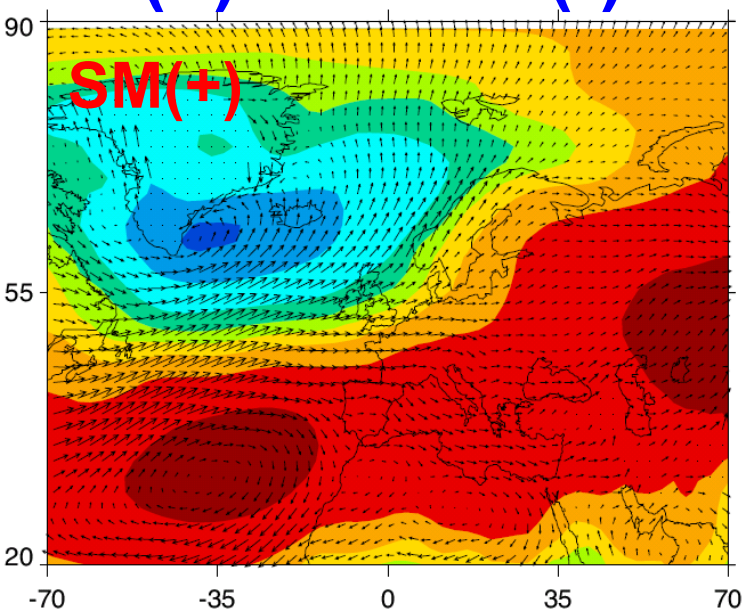
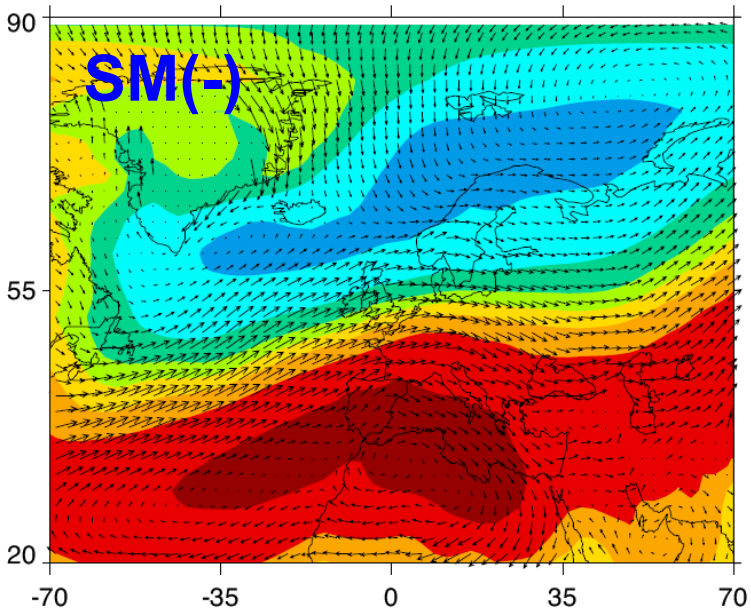


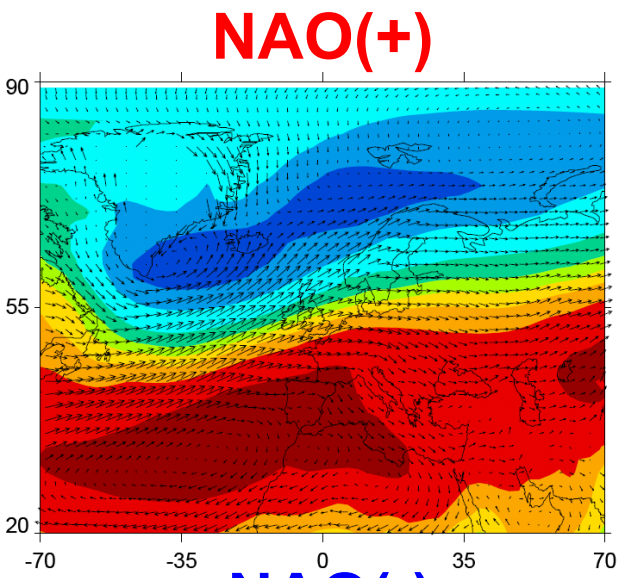
Transport of Sulfate by Mean Circulation $\overline{vC}$

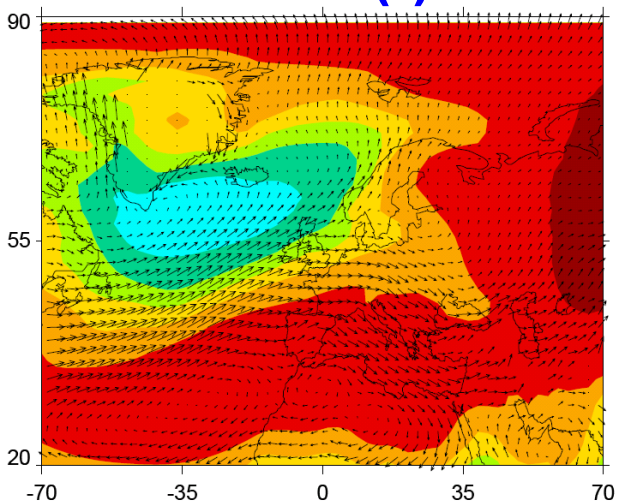


850-hPa Mean Winds and SLP Anomalies in SM(+) and SM(-) Years

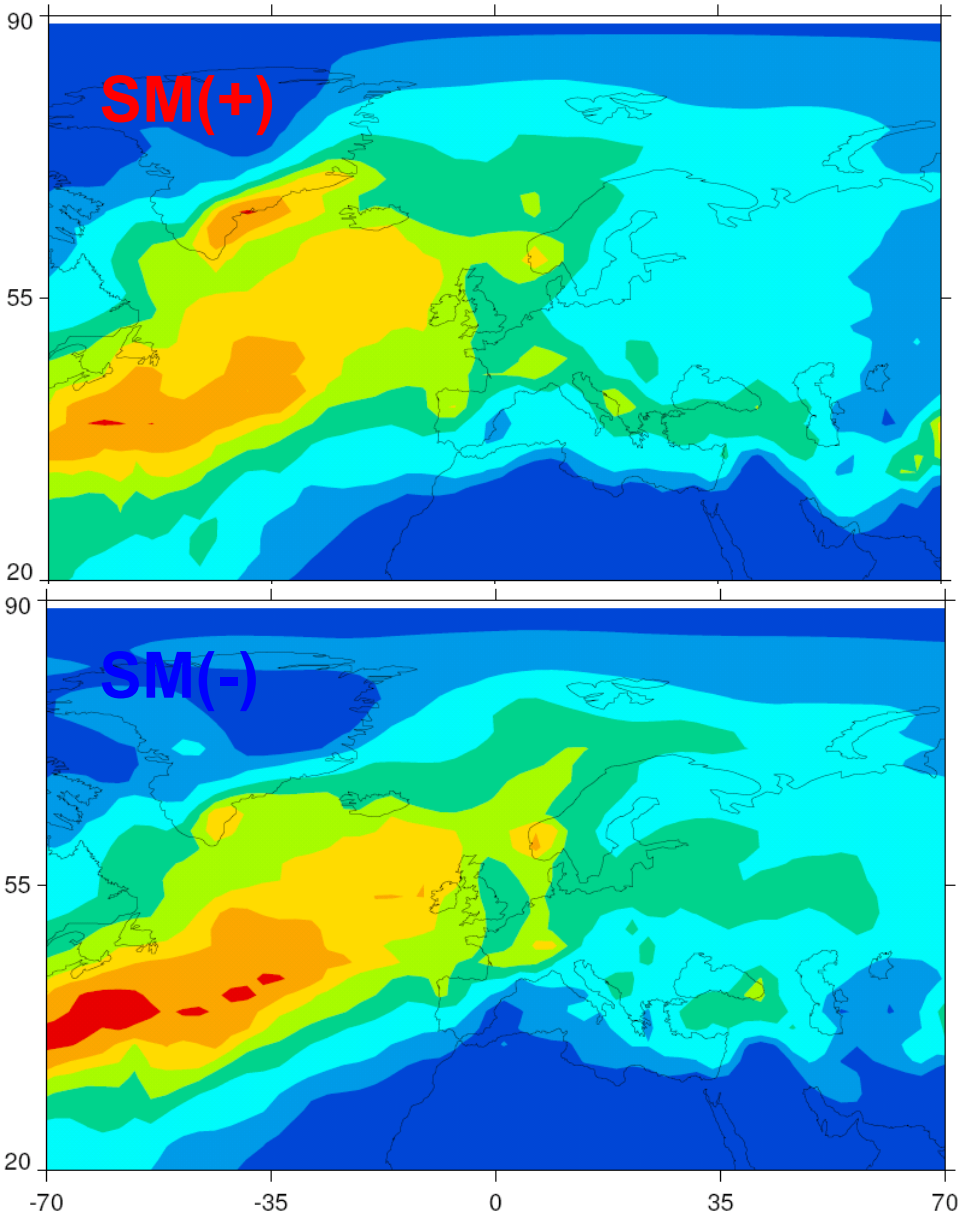




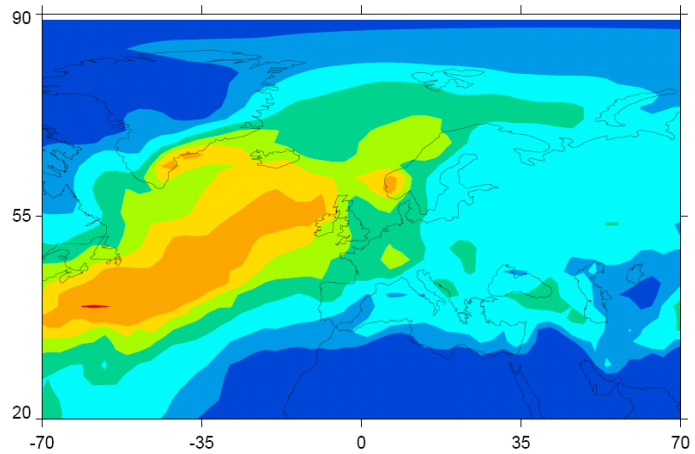




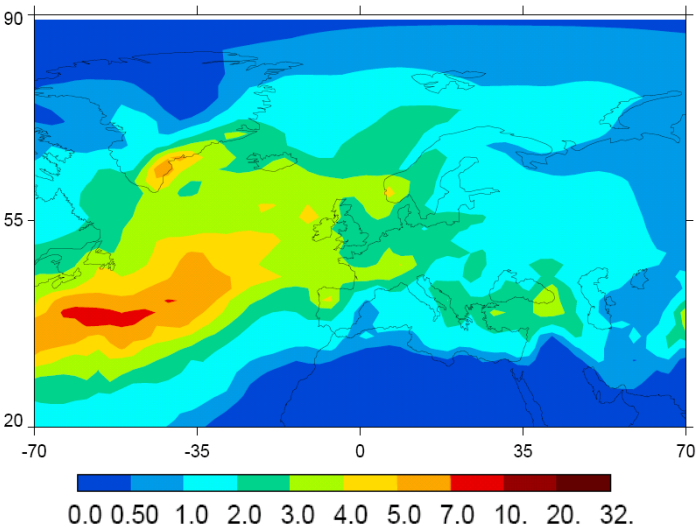
Position of Storm Track (Precipitation as Proxy) in Difference Phases of SM



NAO(+)

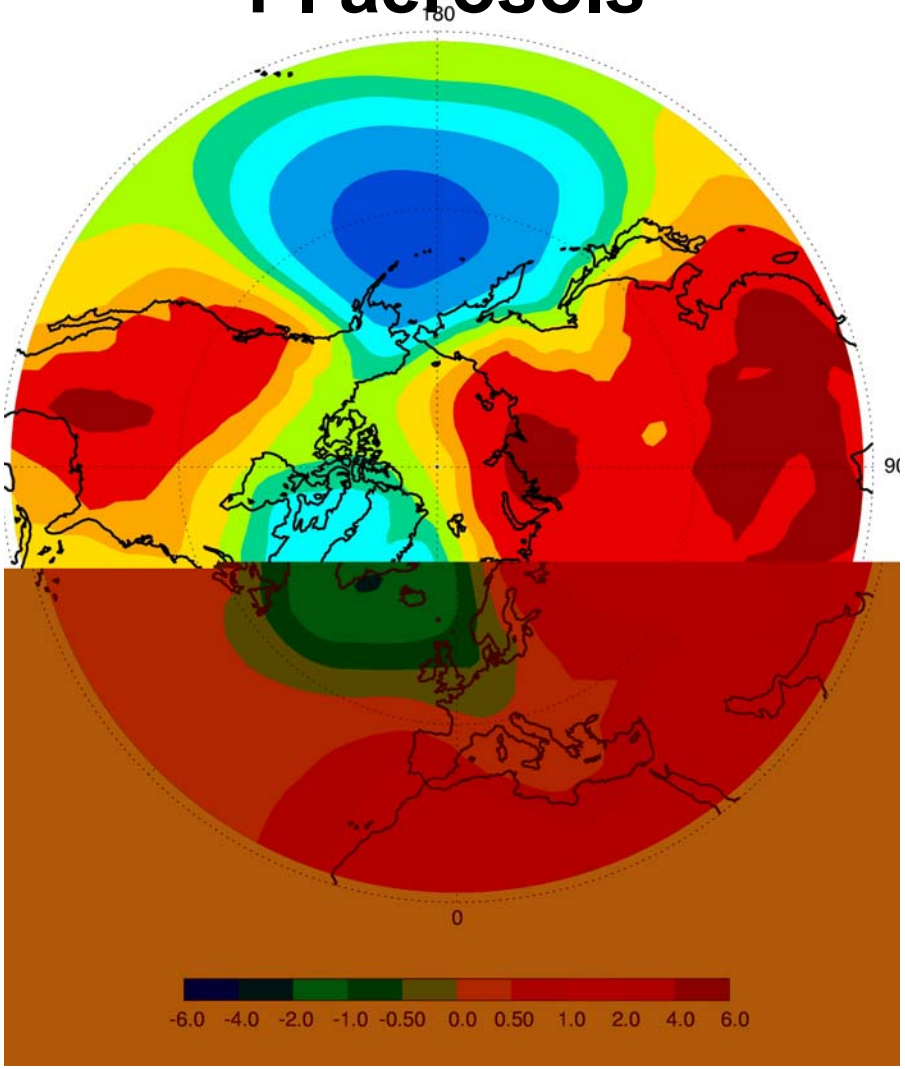


NAO(-)

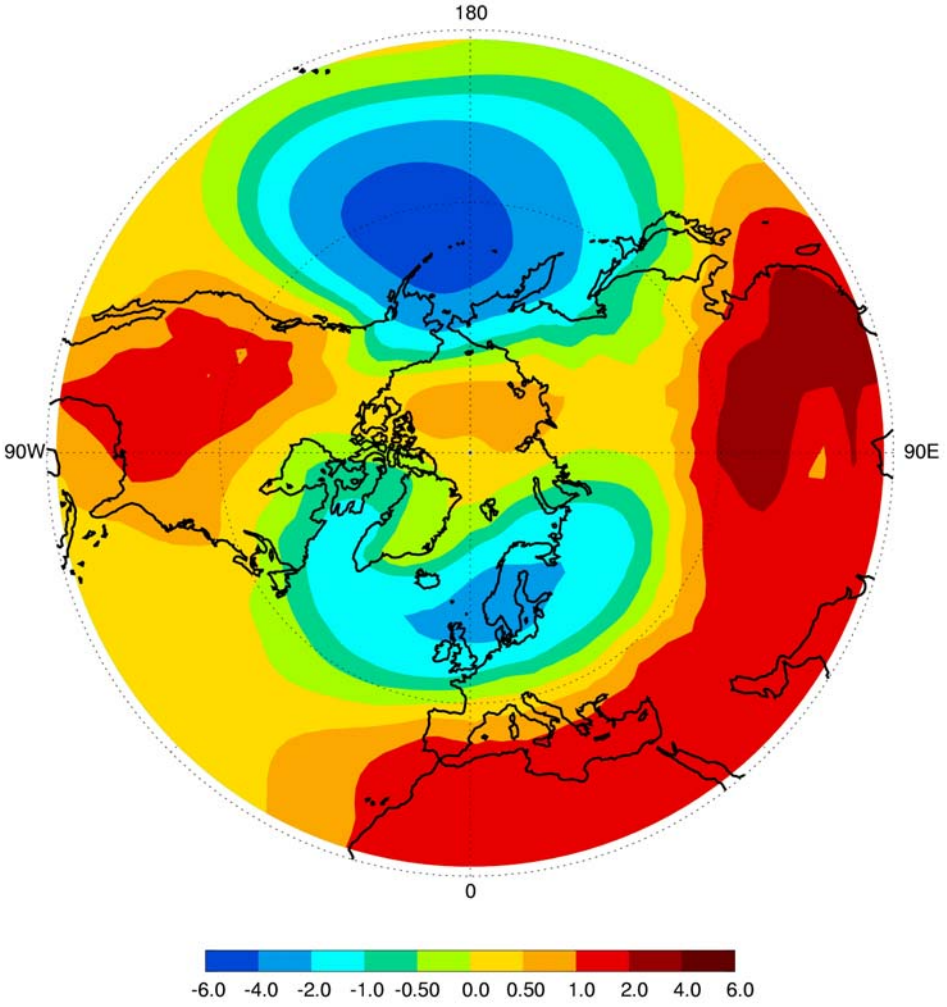


Change in SM in Response to Aerosol Effects

PI aerosols

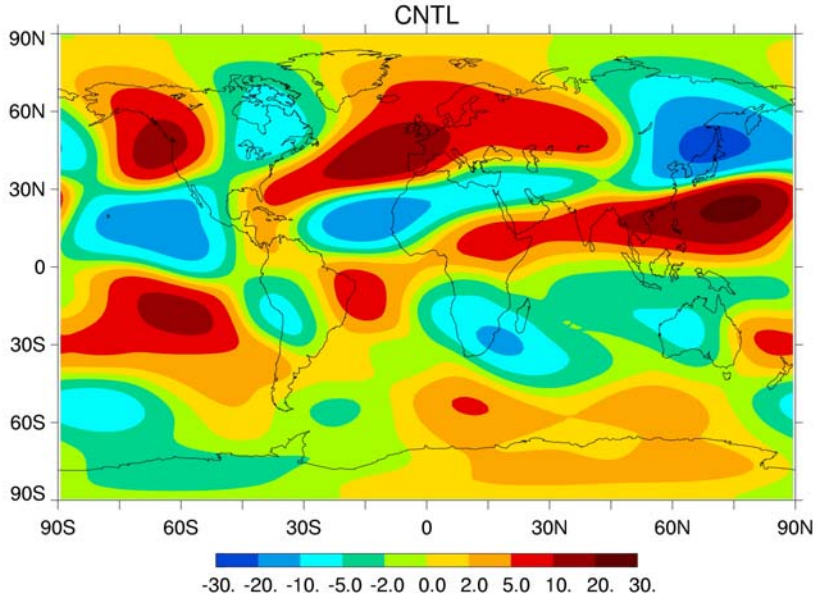


PD aerosols



Change in Stationary Eddy Stream Function in Response to Aerosol Effects

PI aerosols



PD minus PI