Arctic Chemistry And Climate

Connaught Summer Institute 2016

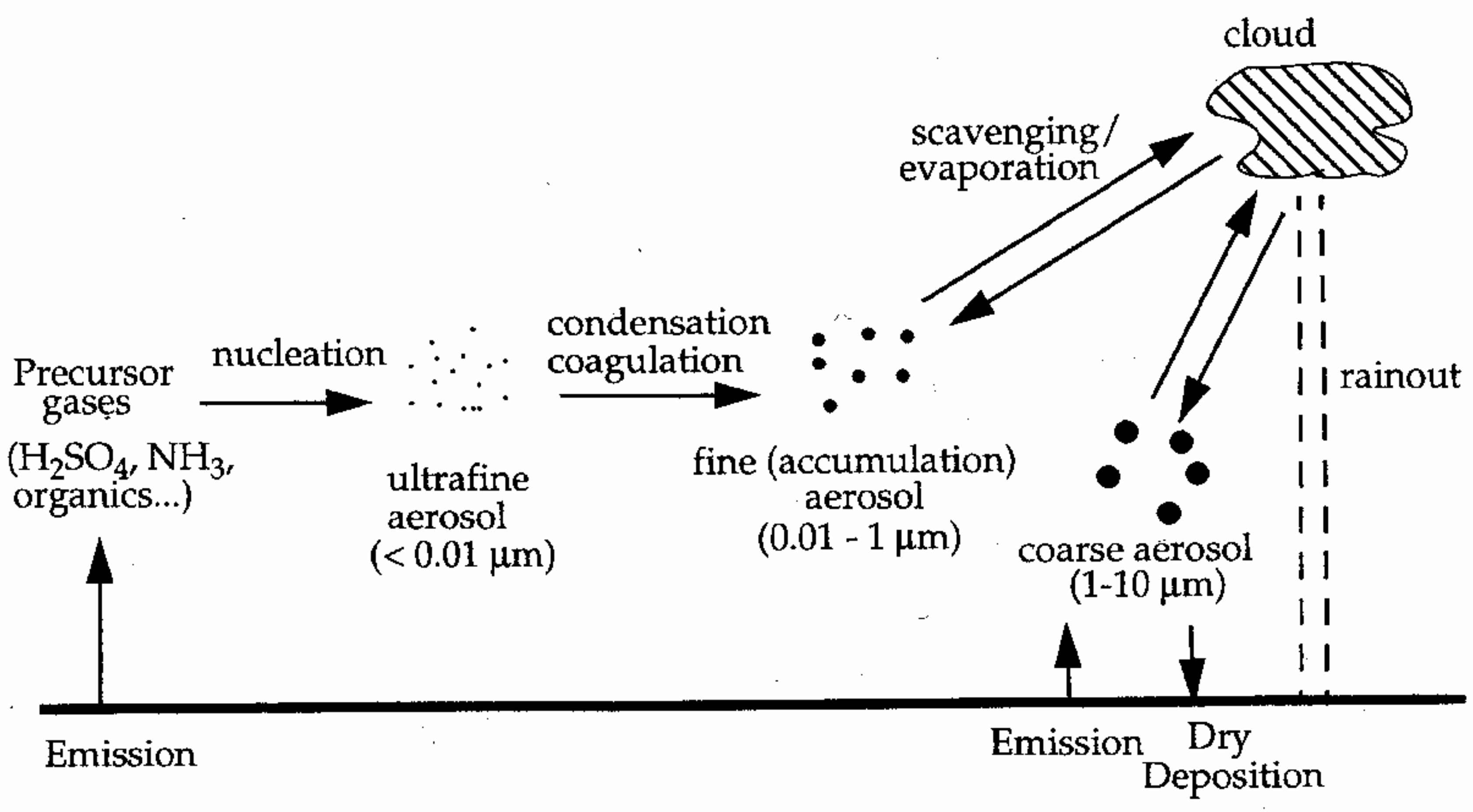
William (Bill) Simpson

Geophysical Institute and Department of Chemistry,
University of Alaska Fairbanks
http://www.uaf.edu/chem/simpson
email: wrsimpson@alaska.edu
phone: 907 474-7235

What I want to cover

- What processes affect Arctic CCN and INP?
- Basic chemical processes related to aerosol particles
- Transport from lower latitudes
- Arctic Haze and Black Carbon
- New particle formation
- Big picture changes

Where do particles come from?



From "Atmospheric Chemistry" by Daniel Jacob

Arctic Aerosol Particles

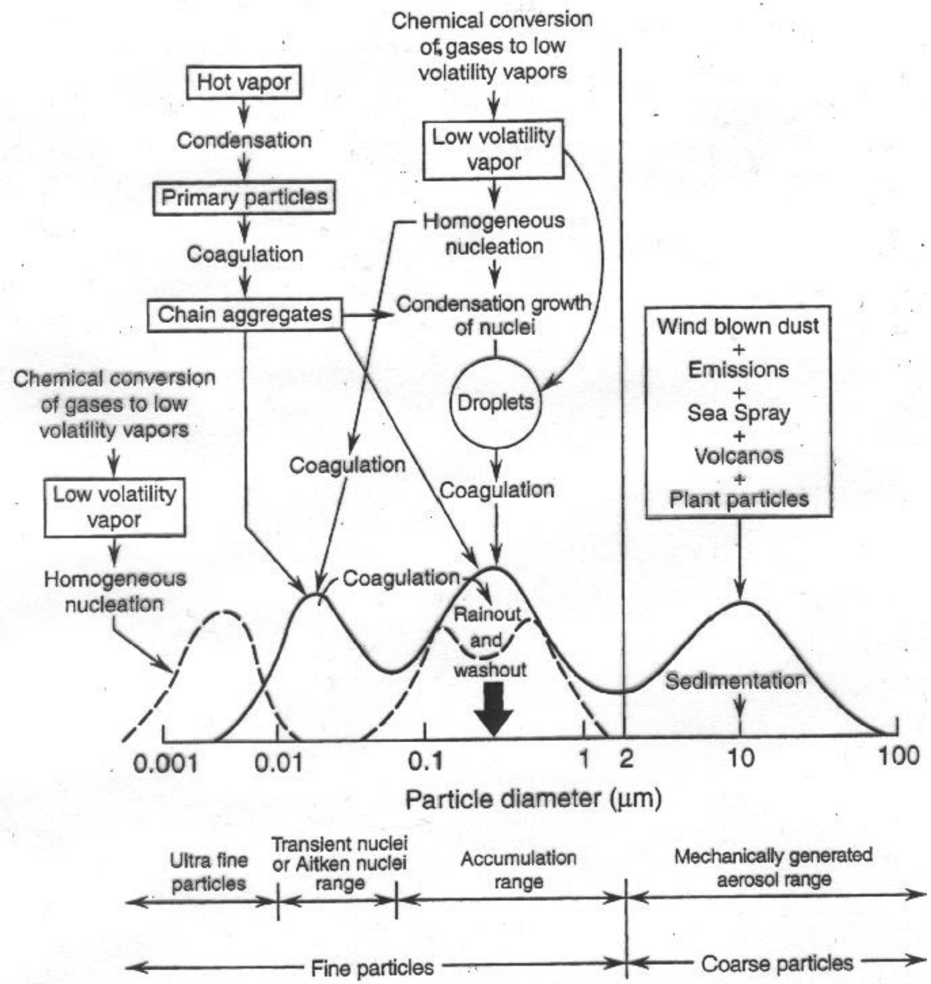


FIGURE 9.7 Schematic of an atmospheric aerosol size distribution showing four modes. The original hypothesis of Whitby and co-workers is shown by the solid, trimodal curves, and the fourth, ultrafine particle mode, as well as the two peaks sometimes observed in the accumulation mode are shown by the dashed lines (adapted from Whitby and Sverdrup, 1980).

Sources:

Emission in Arctic

Transport to Arctic

Formation in Arctic

Modification in Arctic

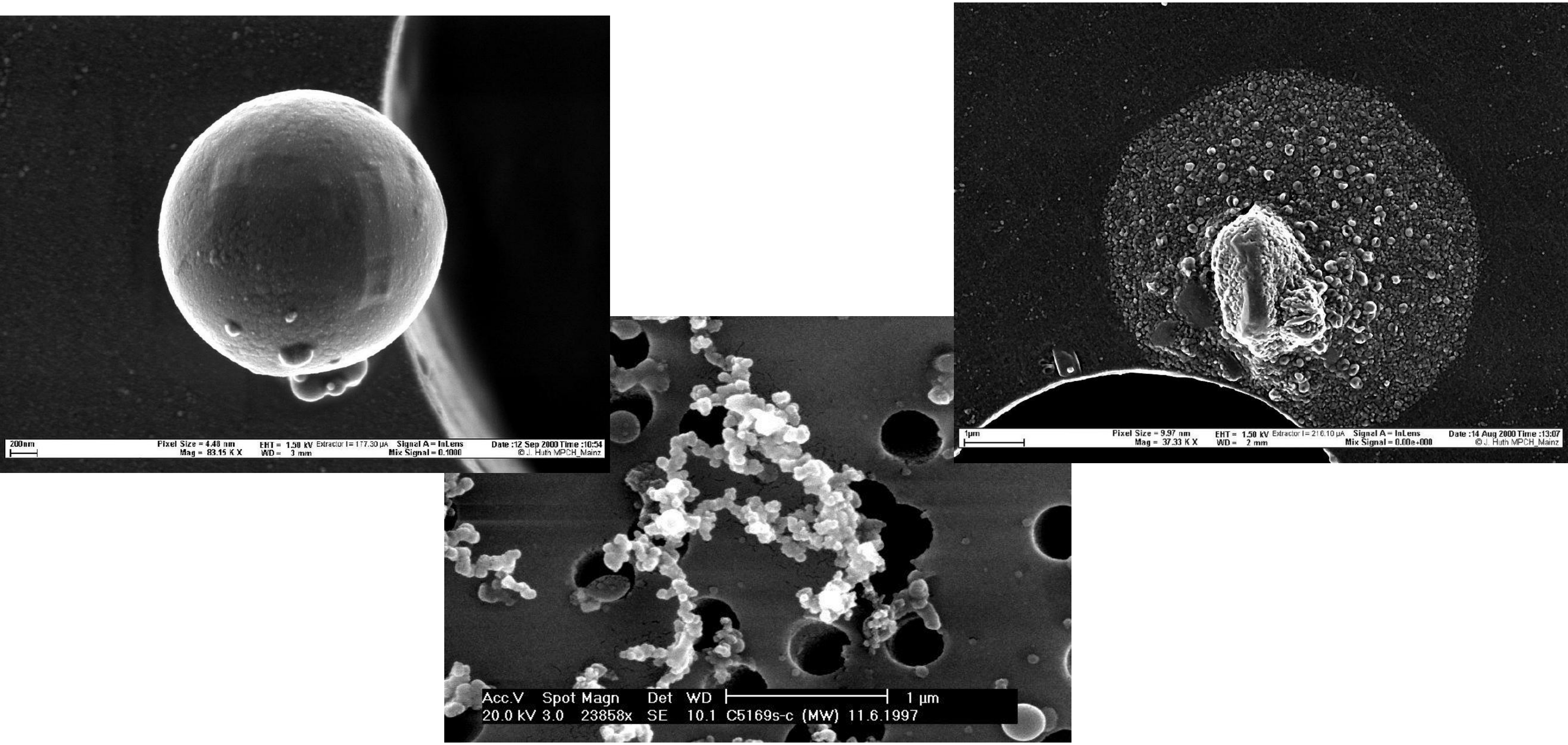
Sinks:

Low in winter/spring

High in summer/fall (scavenging)

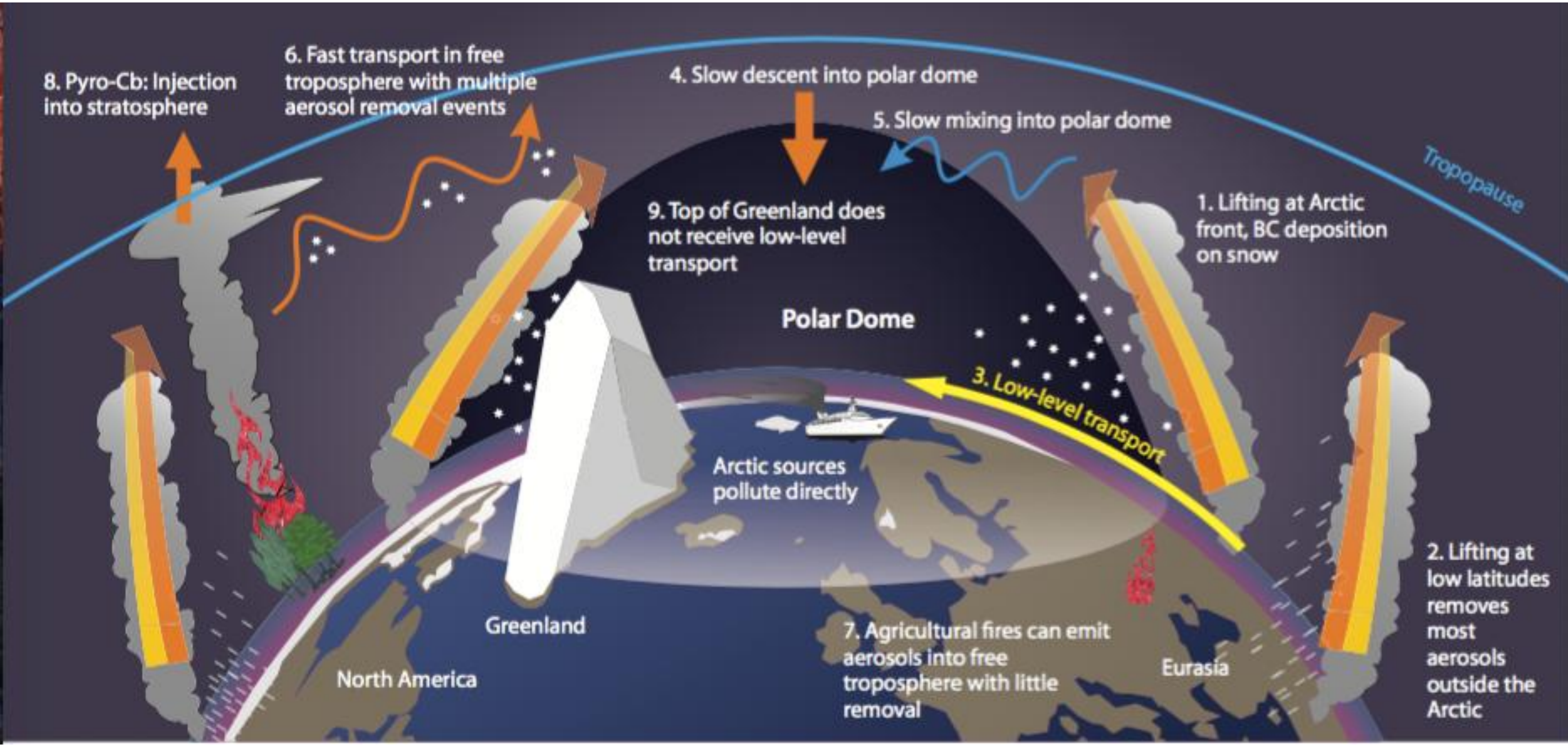
From "Chemistry of the upper and lower atmosphere" by Finlayson-Pitts and Pitts

Aerosol particle electron microscopy

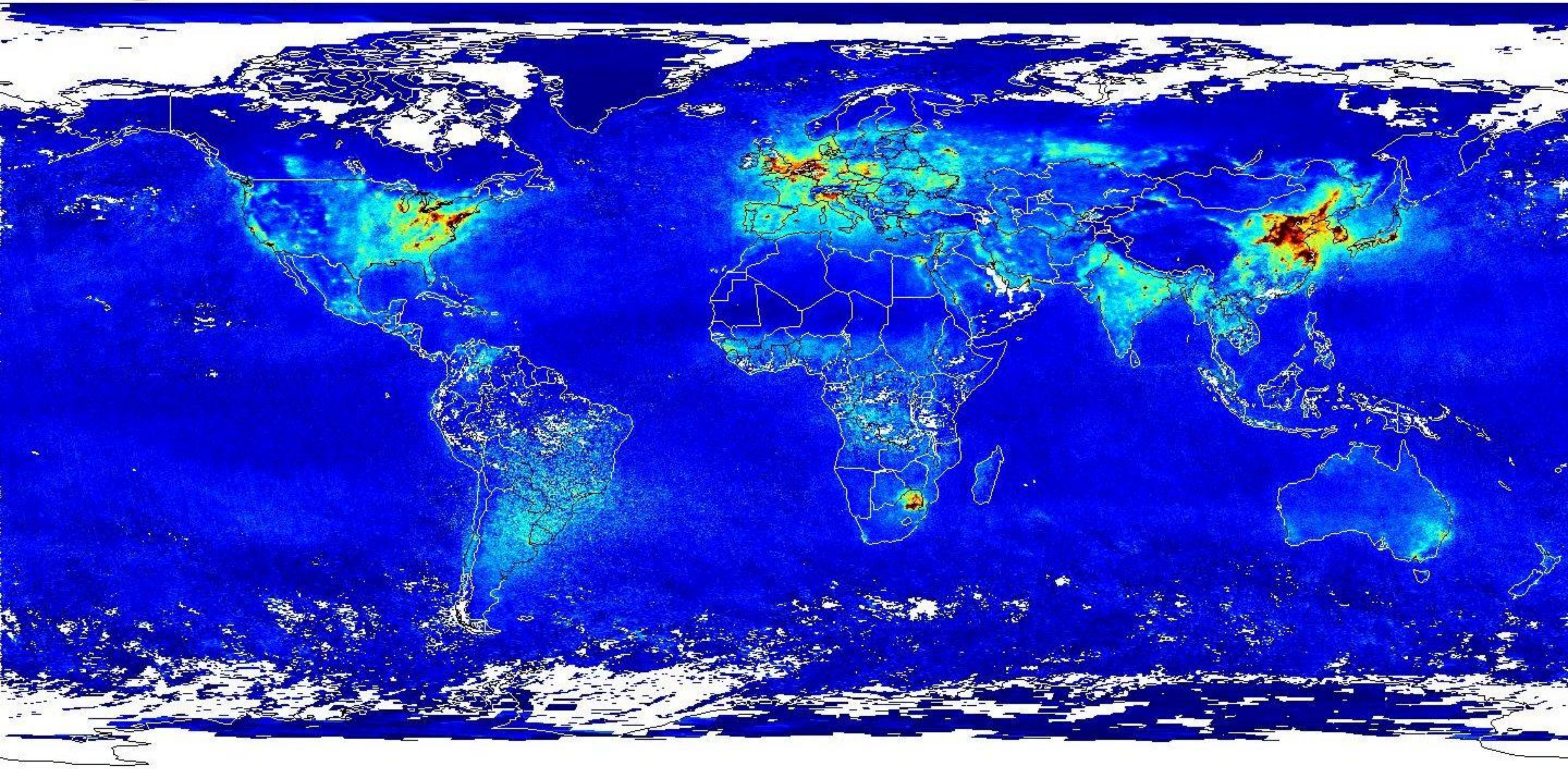


Images from Max Planck Institute for Chemistry, Mainz, Germany, http://www.mpch-mainz.mpg.de/

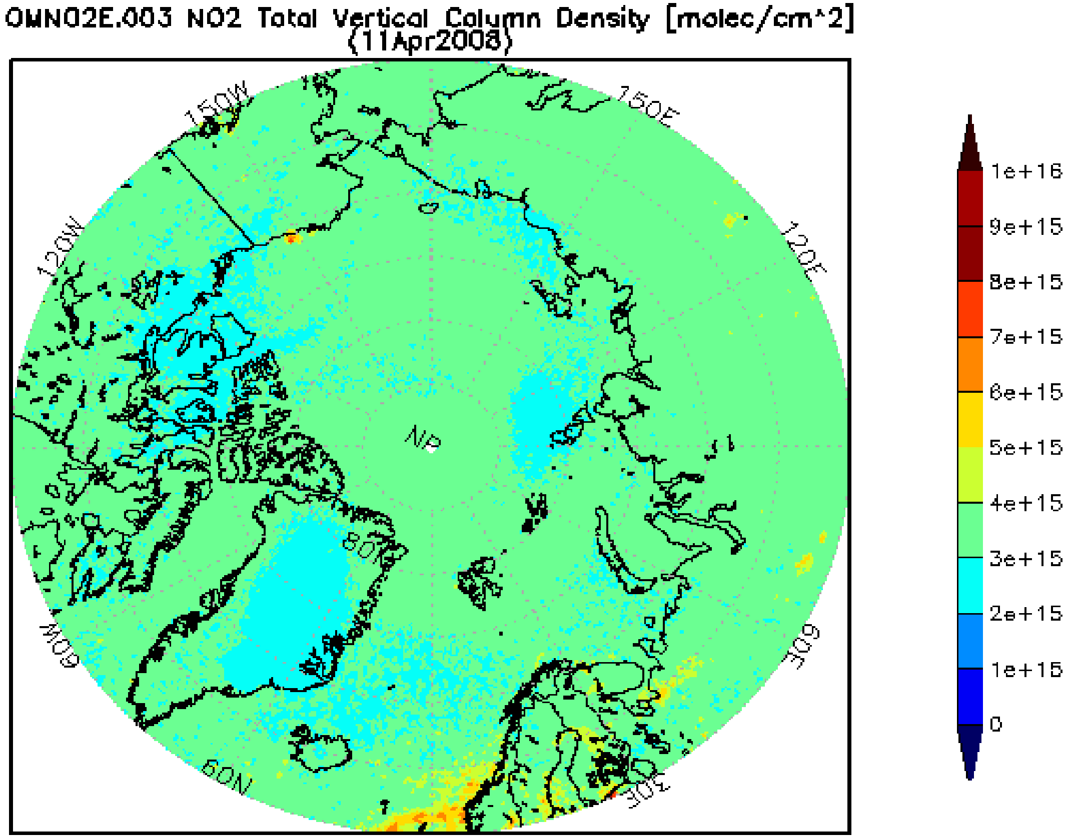
Arctic transport pathways



NO_2 (combustion) observations



The Arctic has few sources of pollution



Most Arctic pollution comes from lower latitudes

Arctic Haze affects atmosphere

Arctic haze in Svalbard, Norway. Photo: Juergen Graeser, Alfred-Wegener Institute, Germany

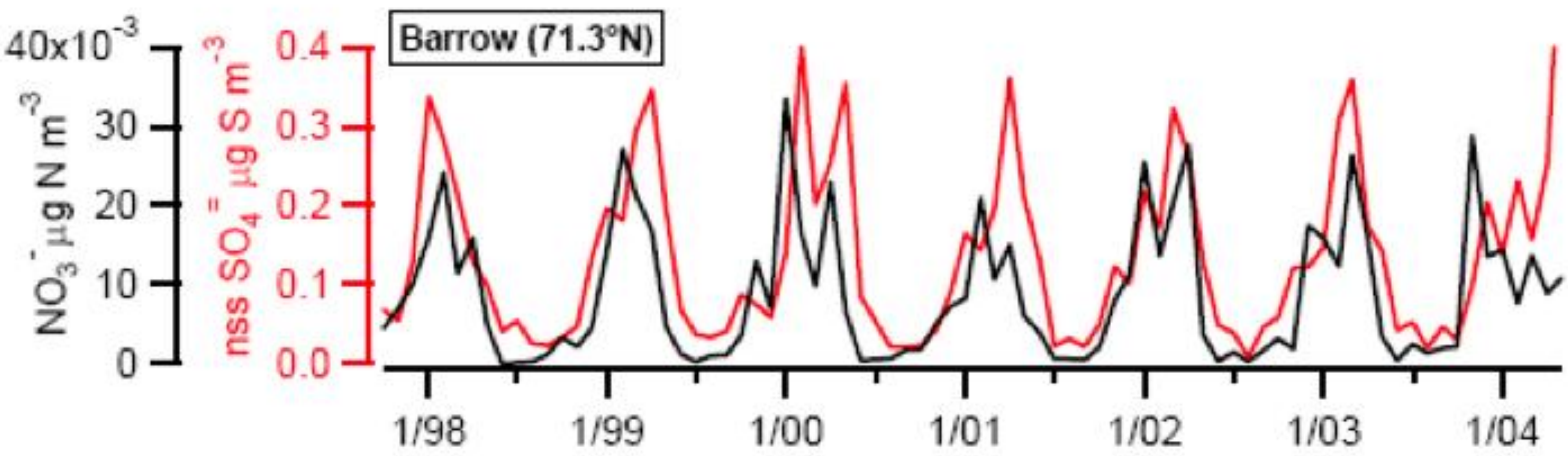
Early aircraft flights noticed a winter/spring Arctic pollution phenomenon in Alaska, known as Arctic haze (e.g. Mitchell, 1957). This phenomenon was extensively studied by Glenn Shaw, of UAF, and it is a result of pollution from lower latitudes enhanced by inefficient dispersal of pollutants and slow removal rates (Shaw, 1995).

Mitchell, J. M. J.: Visual range in the polar regions with particular reference to the Alaskan Arctic, J. Atm. Terr. Phys., Spec. Suppl., 1, 195-211, 1957.

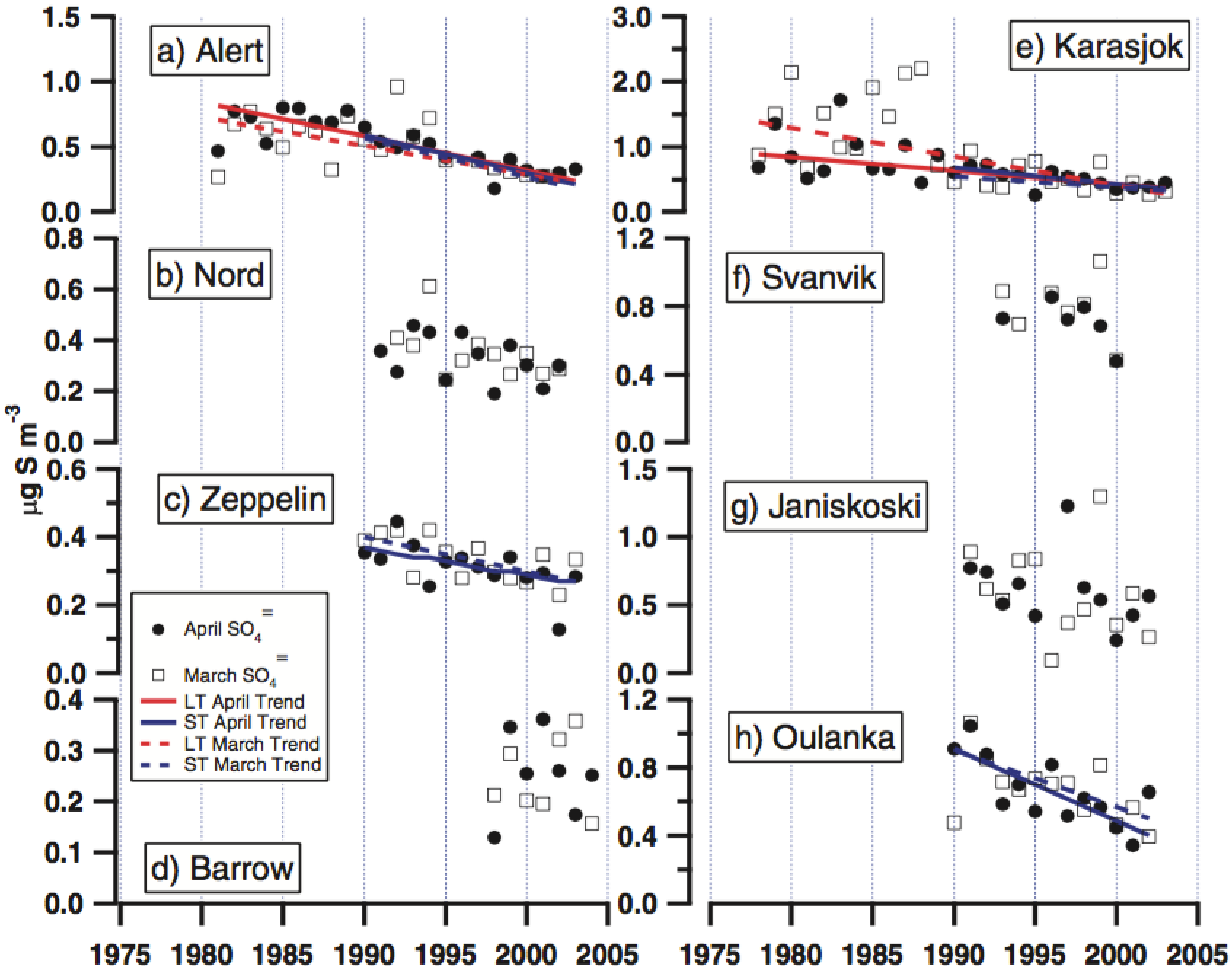
Shaw, G. E.: The Arctic haze phenomenon, Bull. Am. Meteorol. Soc., 76, 2403-2413, 1995.

Arctic Haze Timeseries

- Barrow observations show a springtime peak in particulates that carry anthropogenic tracers and are largely sulfate / nitrate pollution
- Persistent during "springtime" – April



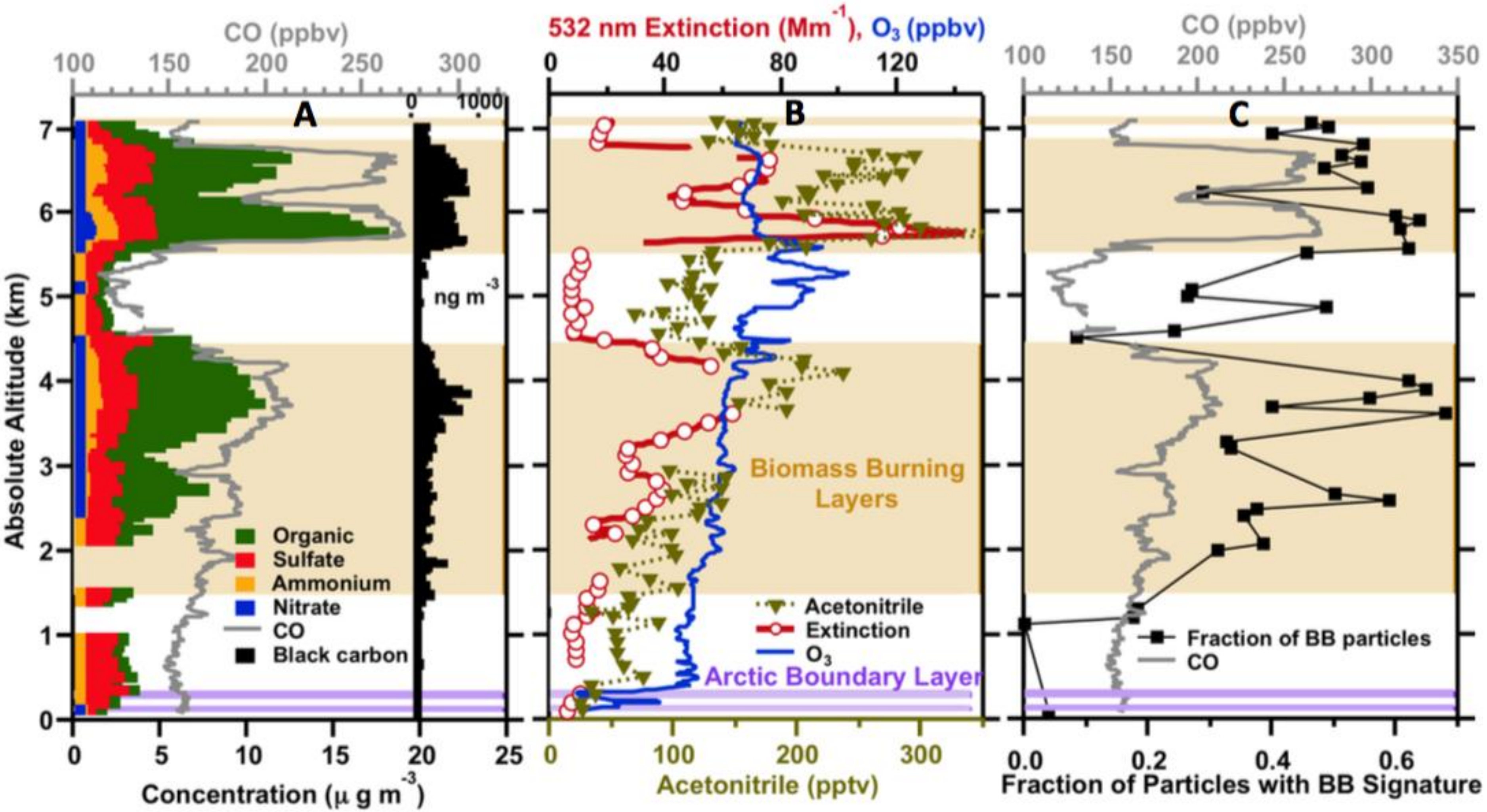
March + April Haze is declining



- Springtime sulfate, April = filled circle, March = open box.
- Significant linear trends are shown.
- Declines are 50-80% from ~1980 to ~2004

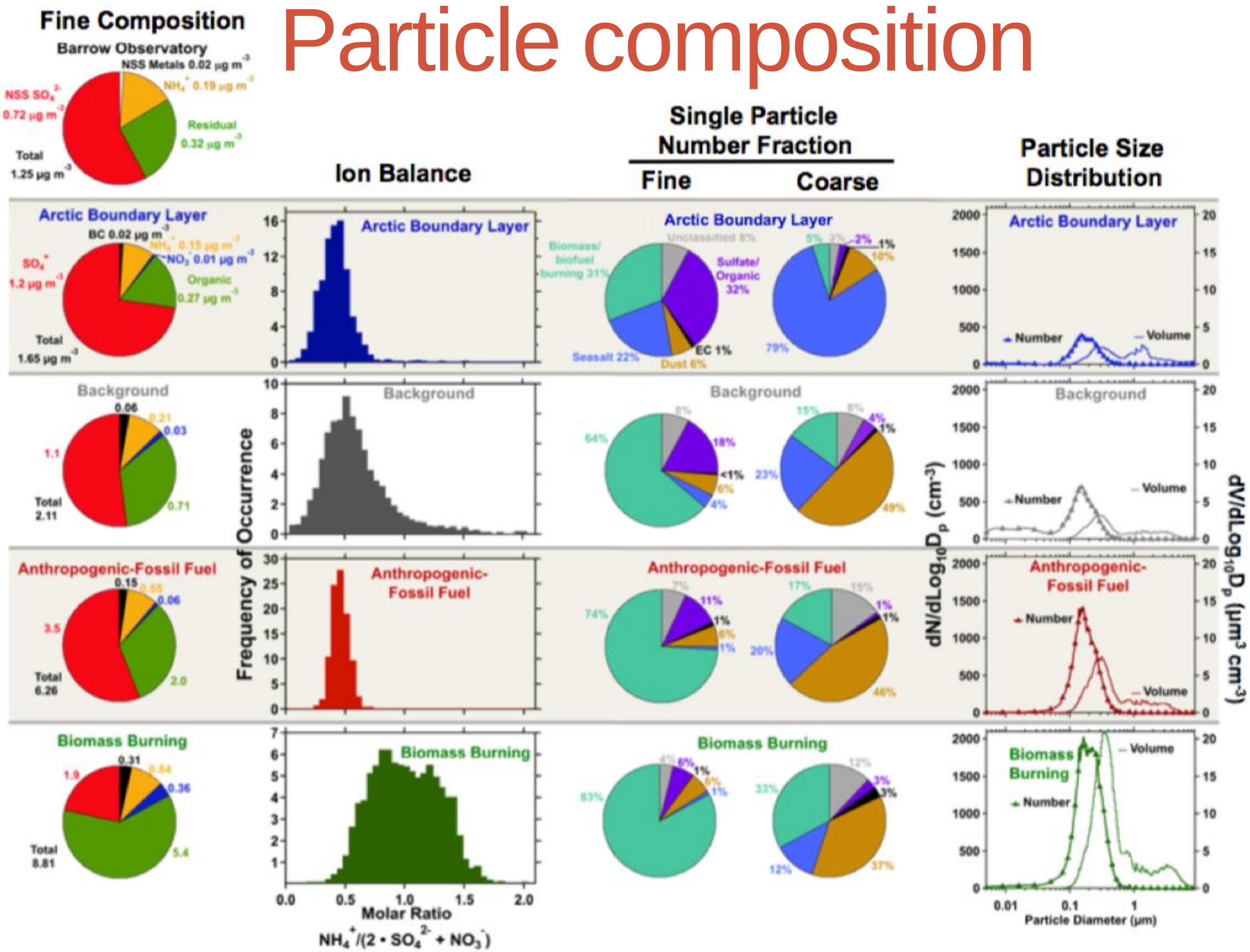
Quinn et al. (2007), doi: 10.1111/j.1600-0889.2006.00238.x

Pollution layers aloft (ARCPAC)



Brock et al., ACP (2011) doi:10.5194/acp-11-2423-2011

Particle composition



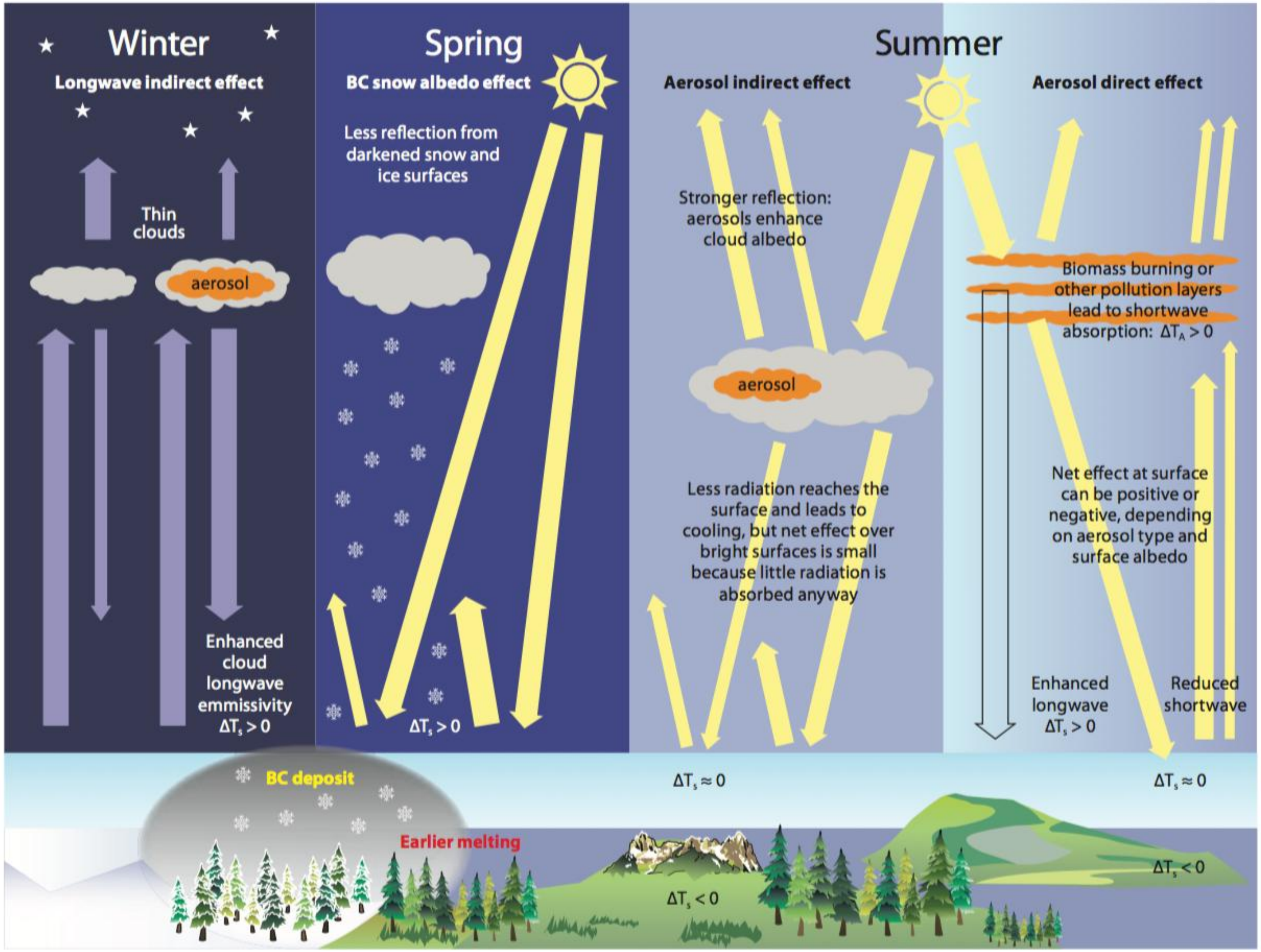
Brock et al., ACP (2011) doi:10.5194/acp-11-2423-2011

Haze and transport

- Springtime “haze” is largely acidic sulfate particles from outside the Arctic transported into the Arctic that persist and build due to low deposition rates.
- Arctic haze is decreasing due to emissions controls / decreased Russian activities
- Layers of pollution persist aloft for long periods and retain signatures of their sources

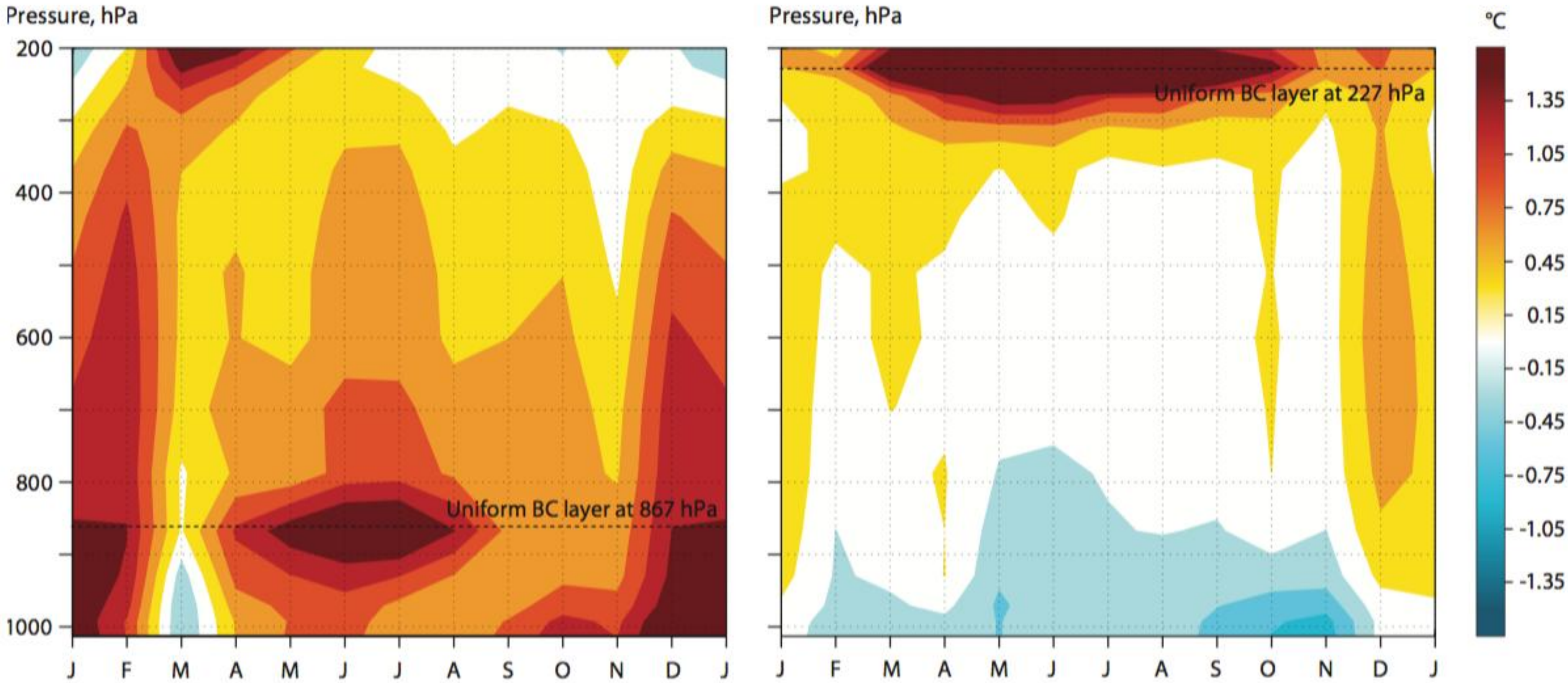
- Elemental carbon (or black carbon = BC) is also transported by similar means and can affect the Arctic.

BC forcing effects on the Arctic



AMAP report, Black Carbon and Ozone as Arctic Climate Forcers 2015

Effect of BC depends upon altitude



Same amount of BC injected at different altitudes

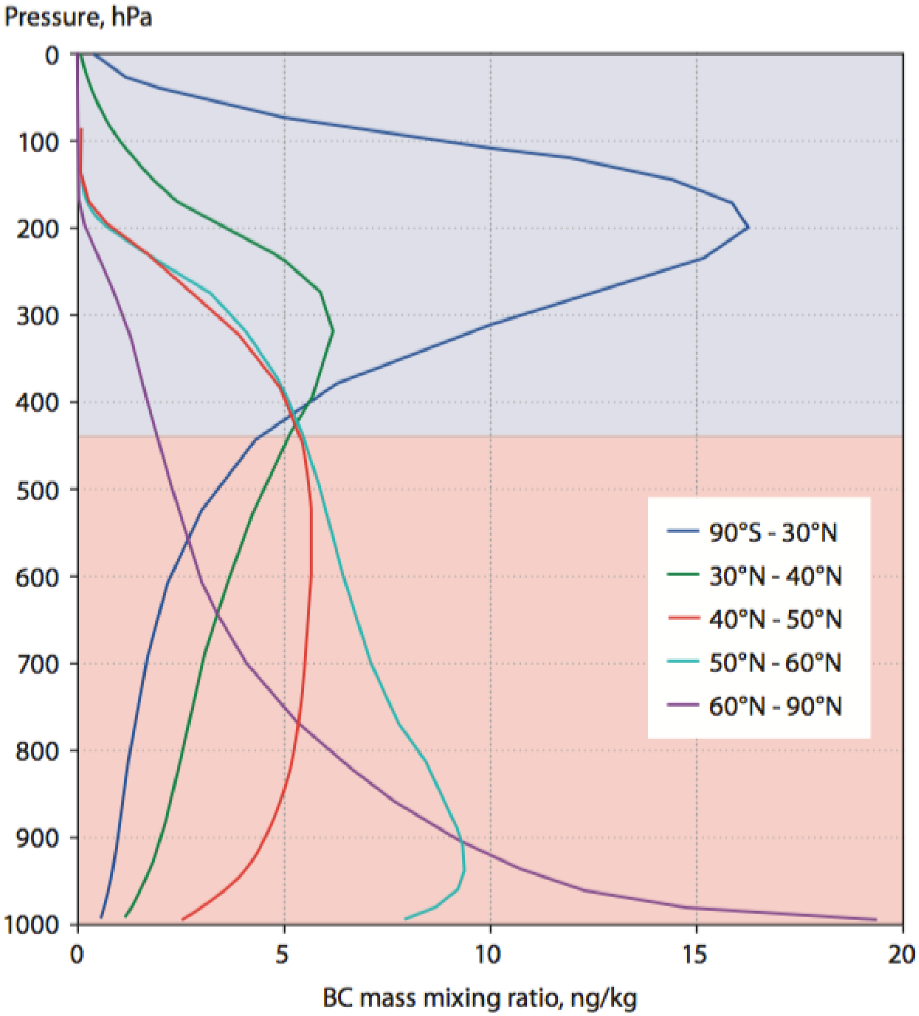
From Flanner (2013), JGR 118:1840-1851.

BC effects

- BC at low altitude both directly warms the atmosphere via absorption and can deposit, where it can enhance snowmelt and decrease surface albedo (SW warming)
- BC aloft heats the atmosphere but cools the surface by “dimming”.

- Deposition of BC is challenging to model because its deposition processes (e.g. wet deposition) depend on its surface state and model results vary greatly.

Source of BC effect on atmosphere



- BC that is emitted at low latitudes rides higher on the polar dome, while Arctic-emitted BC appears at low altitude
- Red region is warming the surface, Blue is cooling the surface (warming occurs aloft)

AMAP report, Black Carbon and Ozone as Arctic Climate Forcers 2015

Modeled net effect of BC by source

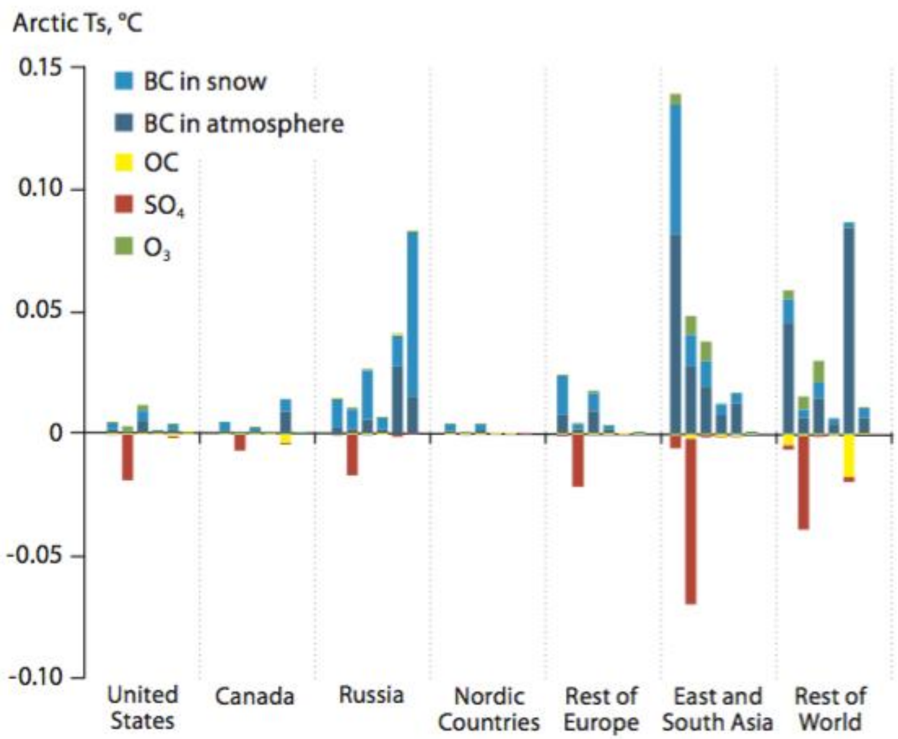


Figure 11.14 Arctic equilibrium surface temperature response due to direct forcing by black carbon (BC), organic carbon (OC), sulfate (SO_4) and ozone (O_3) averaged over the models CESM, NorESM, SMHI-MATCH and Oslo-CTM. Each bar represents the different emission sectors for each source region specified on the X-axis. The sectors for each emission region are 1) Domestic, 2) Energy+Industry+Waste, 3) Transport, 4) Agricultural waste burning, 5) Forest fires and, 6) Flaring. The temperature changes were derived by translating the radiative forcings with the use of climate sensitivity parameters (see Sect. 7.4 for details).

- Arctic equilibrium surface temperature response due to direct forcing.
- BC warms. Sulfate cools.
- Russian flaring BC and Asian domestic BC have largest effects
- Sulfate cools, but everybody is cleaning up their sulfate emissions.

Source: AMAP report 2015

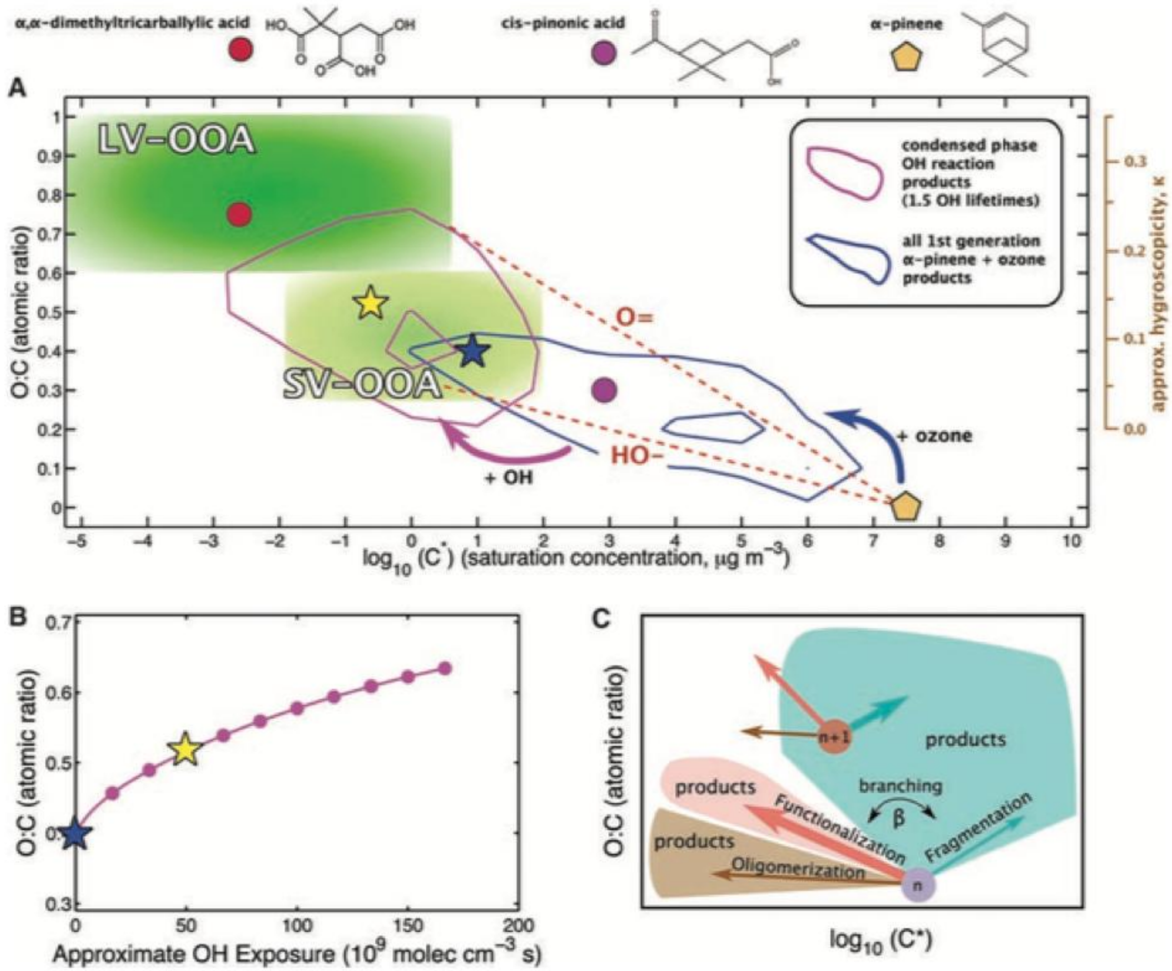
Chemical transformations

- Most of the prior slides have focused on transport of particles into the Arctic.

What about chemistry?

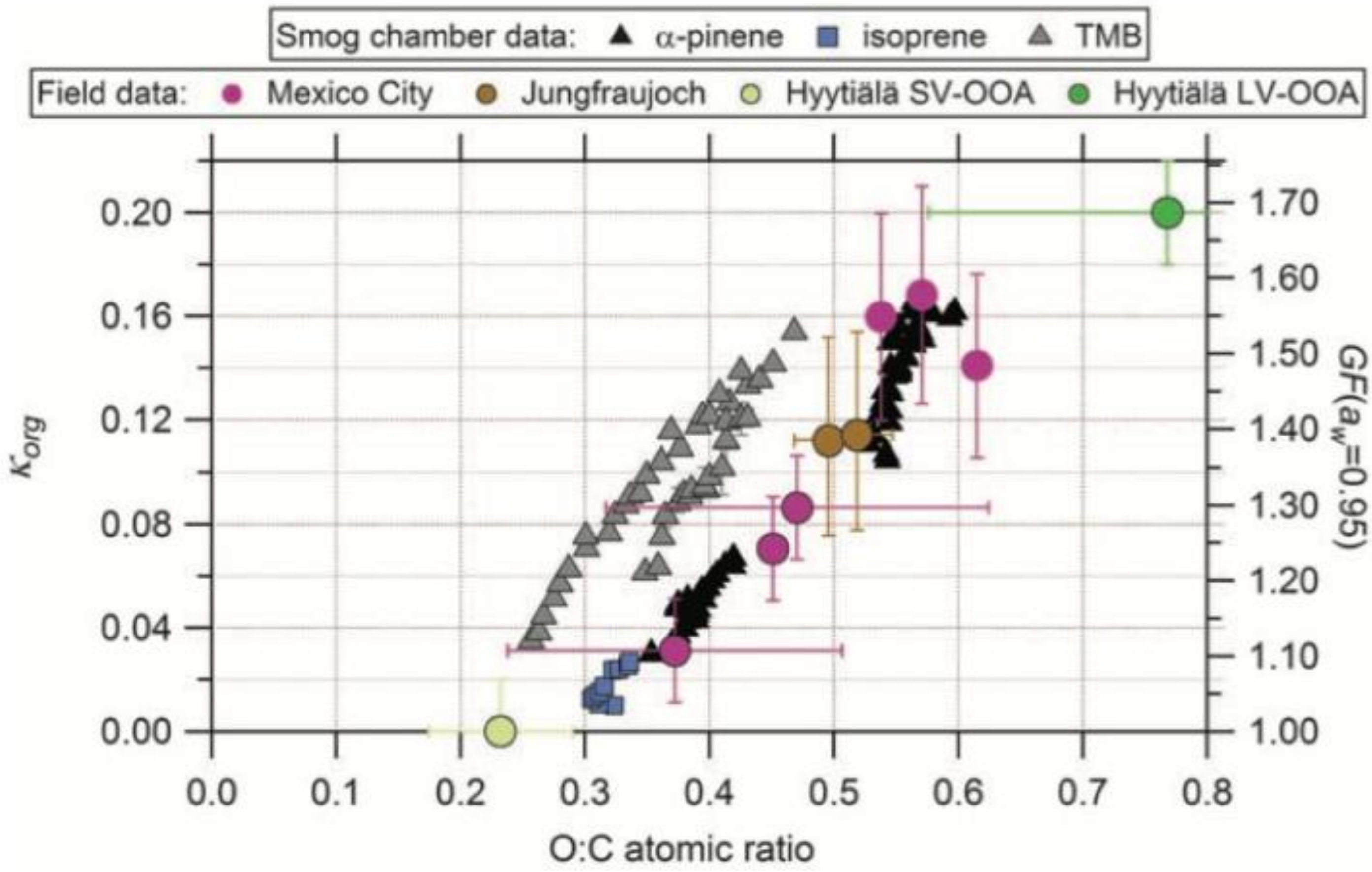
- The atmosphere oxidizes (adds oxygen) to biogenic and anthropogenic gases, which leads to their removal from the atmosphere and nutrient or pollutant fluxes to biosphere
  - **Oxidation controls the lifetime of greenhouse gases**
- The oxidation products can become particles or modify particles, which affects climate through direct and indirect radiative effects
  - **Chemistry affects cloud and ice condensation nuclei.**

Secondary organic aerosol (SOA)



Jimenez et al. (2009), DOI: 10.1126/science.1180353

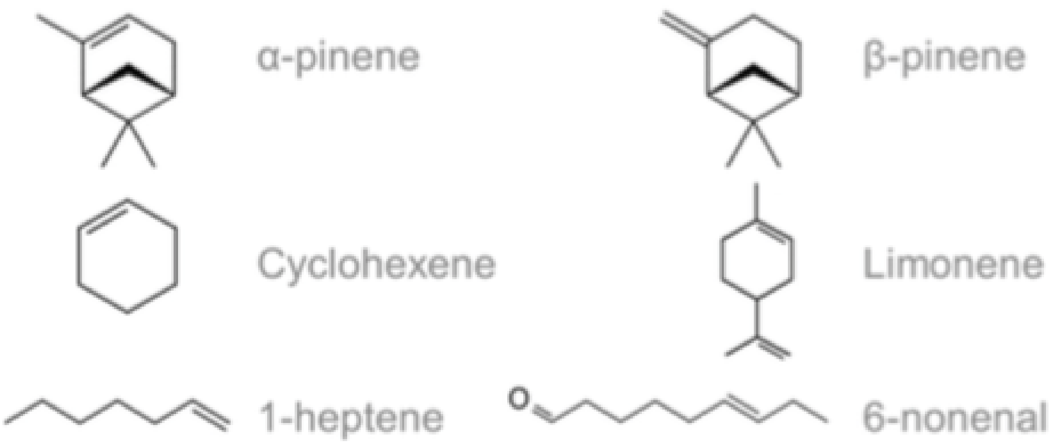
SOA in laboratory and field



Jimenez et al. (2009), DOI: 10.1126/science.1180353

Biogenic organic SOA precursors

a

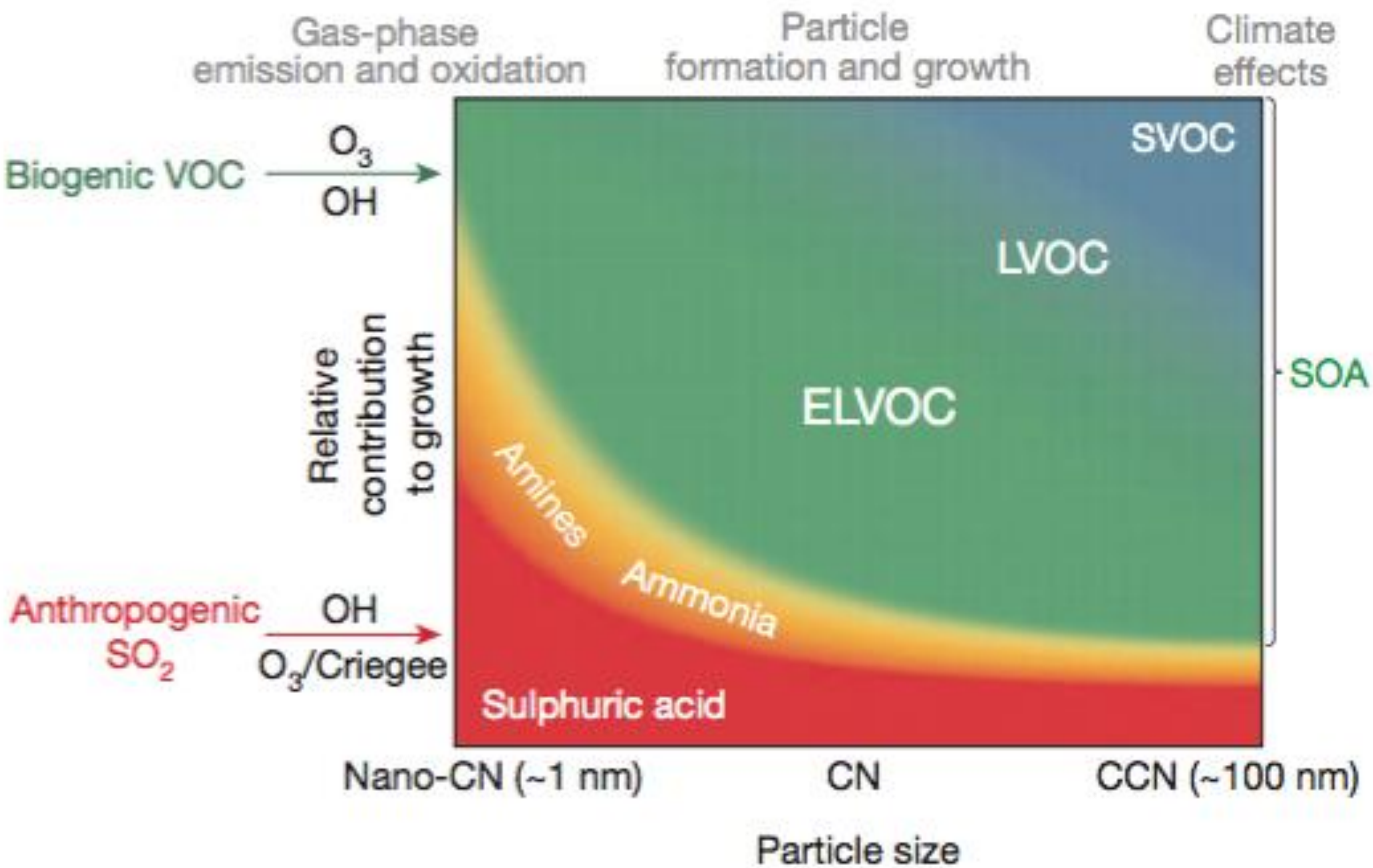


b

VOC	ELVOC molar yield
Cyclohexene	4%
α-pinene	7%
Limonene	17%
ß-pinene	<0.1%

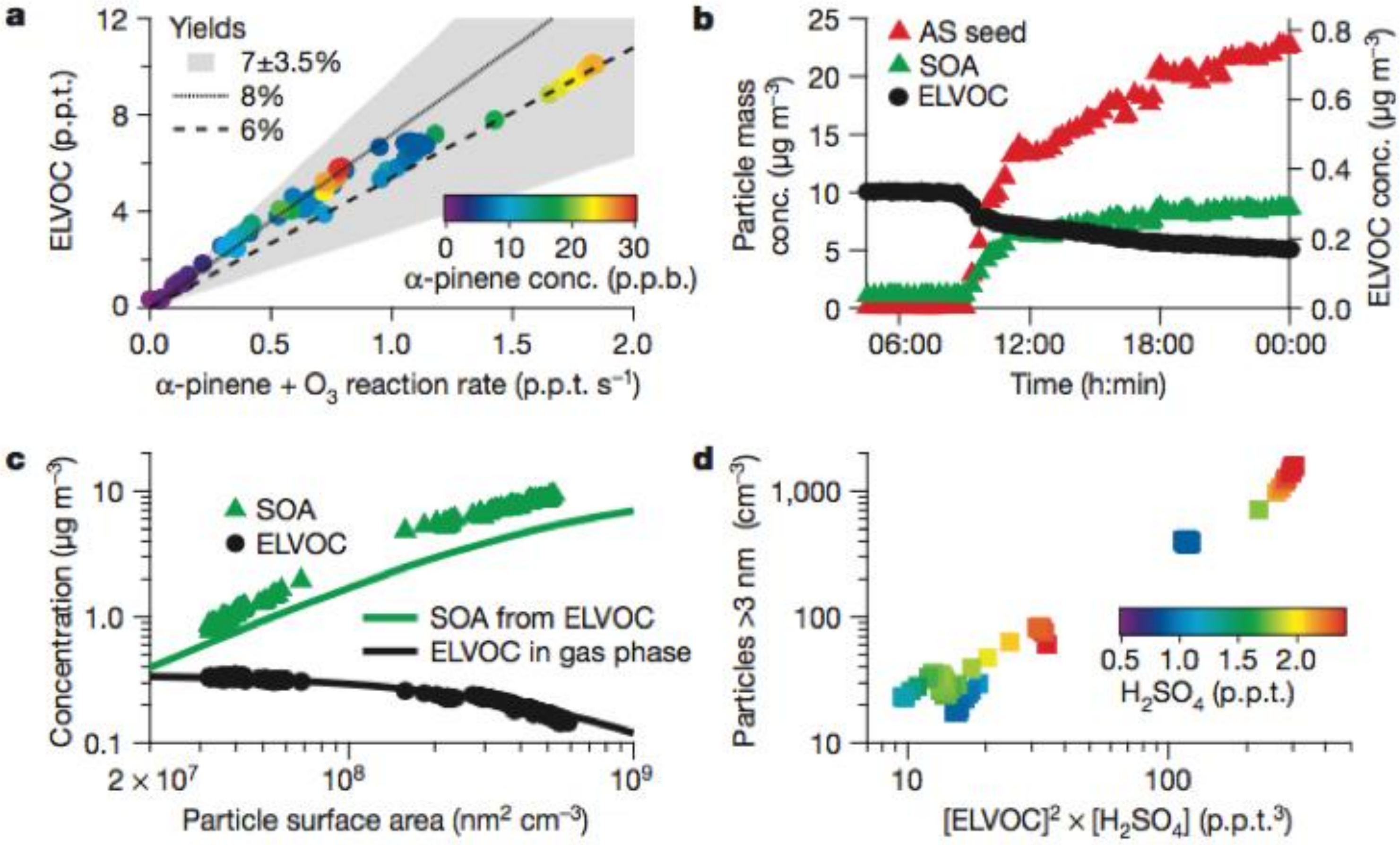
- Ehn et al. (2014), doi:10.1038/nature13032, showed in chamber studies that α-pinene rapidly produced extremely low volatility organic compounds (ELVOC), which then make new particles.
- The mass spectrum of these species matches those seen at a boreal forest site in Hyytiälä, Finland

New particle production methods



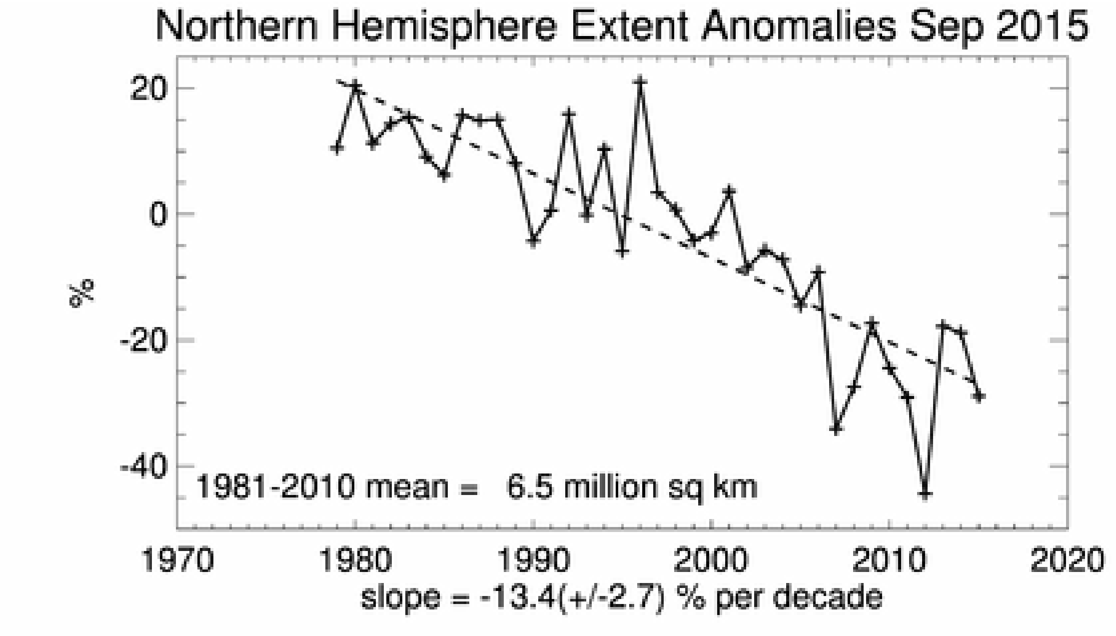
Ehn et al. (2014) Nature, doi:10.1038/nature13032

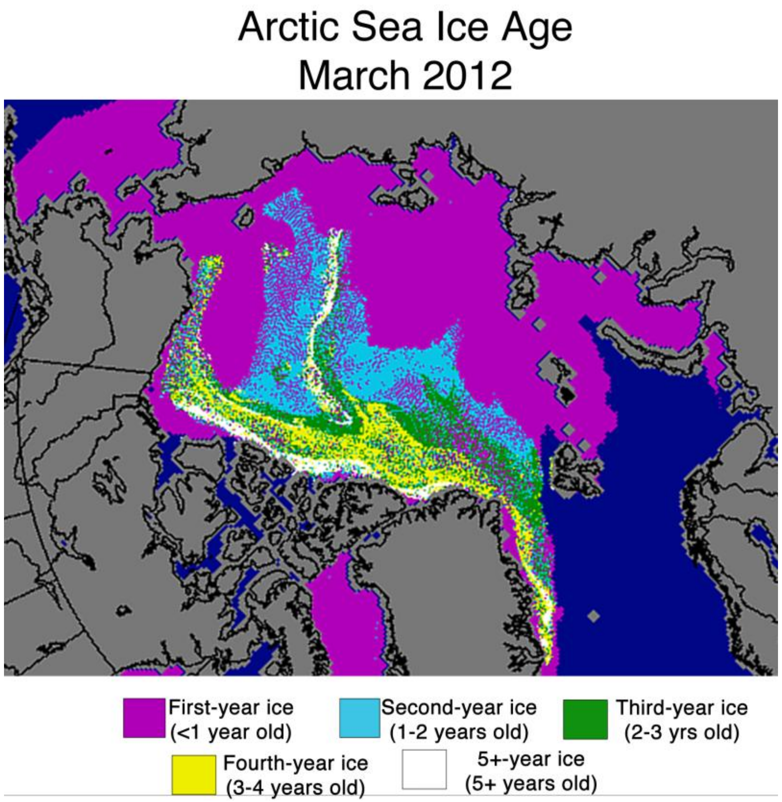
Chamber study results



Ehn et al. (2014) Nature, doi:10.1038/nature13032

Sea ice is changing

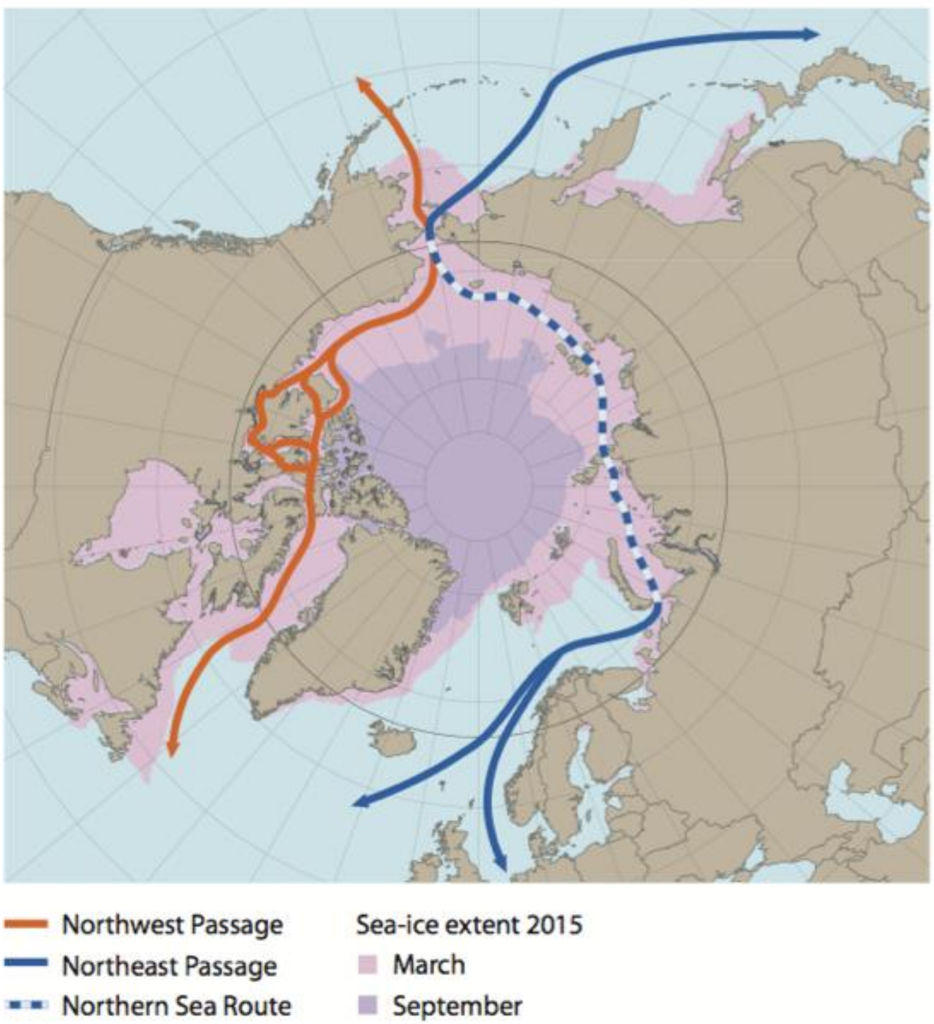




- Summer sea ice is declining.
- Winter sea ice is getting younger, saltier, more leads.
  How does this affect the air?

From NSIDC Arctic Sea Ice data. http://nsidc.org

Arctic shipping routes



- Trans-Arctic shipping is increasing.
- This would lead to direct injection into the Arctic of BC, and ozone / aerosol precursors.

Big questions

- What are the chemical, optical, and microphysical characteristics of aerosols in the Arctic in springtime?
- What are the source types (industrial, urban, biomass/biofuel, dust, sea-salt) of the aerosol components, and the absorbing components (soot) in particular?
- What are the microphysical and optical characteristics of optically thin clouds in the lower Arctic troposphere in springtime, and how do aerosol particles affect these cloud properties and vice versa?
- How does chemistry affect particles in the Arctic – Form new particles? Modify old ones?

Conclusion

- The Arctic needs better monitoring and better process-based modeling.
- Cloud-Aerosol-Climate coupling in the Arctic is a key future direction.
- Pollutant transformations and fate are different in the Arctic and need to be better understood.
- The Arctic atmosphere is highly stratified, complicating transport and chemistry, and with surface warming, this stratification may decrease.
- Sea ice changes are likely to change the Arctic atmosphere and climate in major ways.