Arctic Aerosols: Sources and Composition

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Aerosol terminology

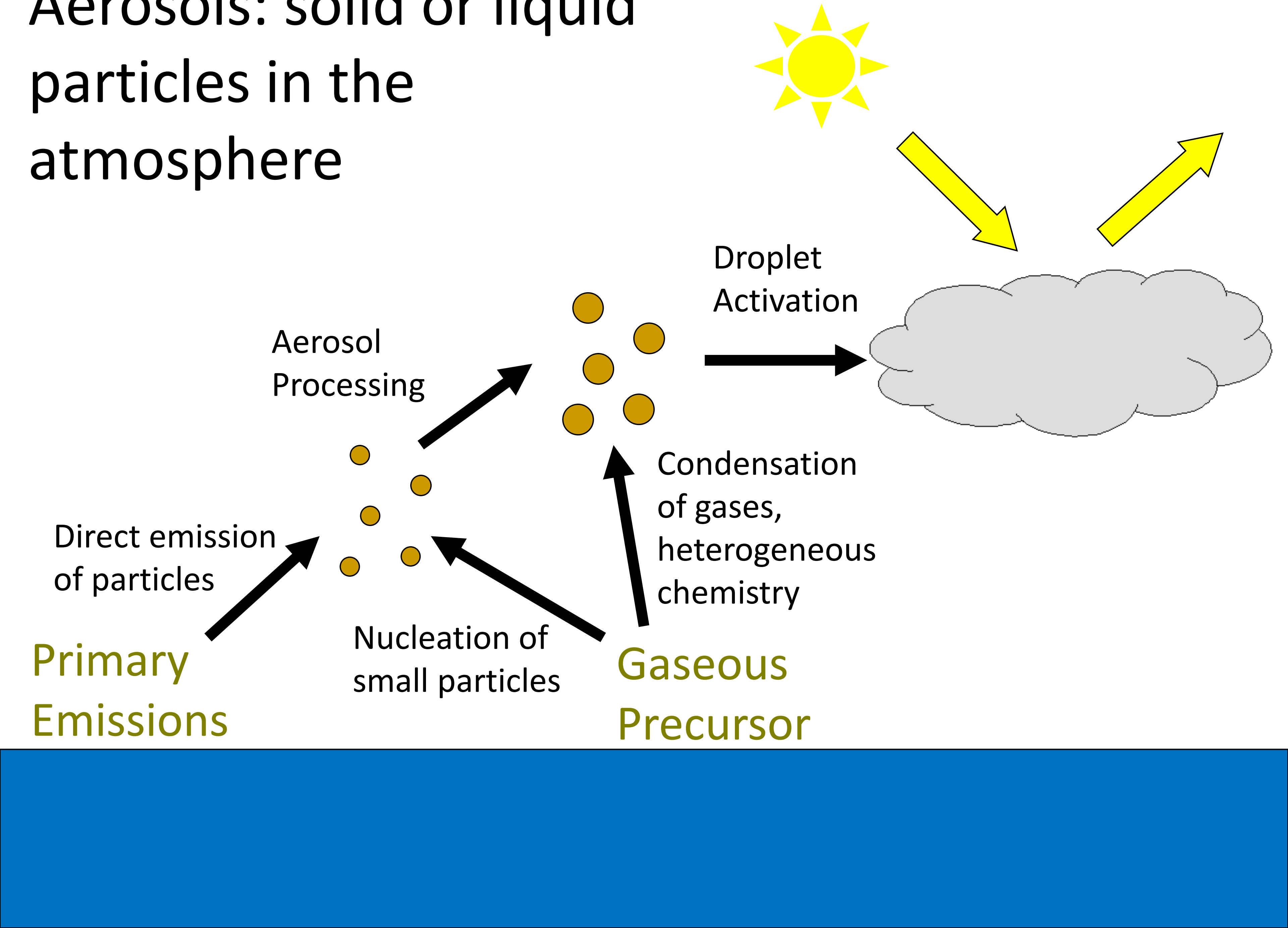
- **Aerosol** – a dispersion of solid and liquid particles suspended in gas (air)

Note: "aerosol" is defined as the dispersion of both particles and gas, but in common practice it is used to refer to the particles only!

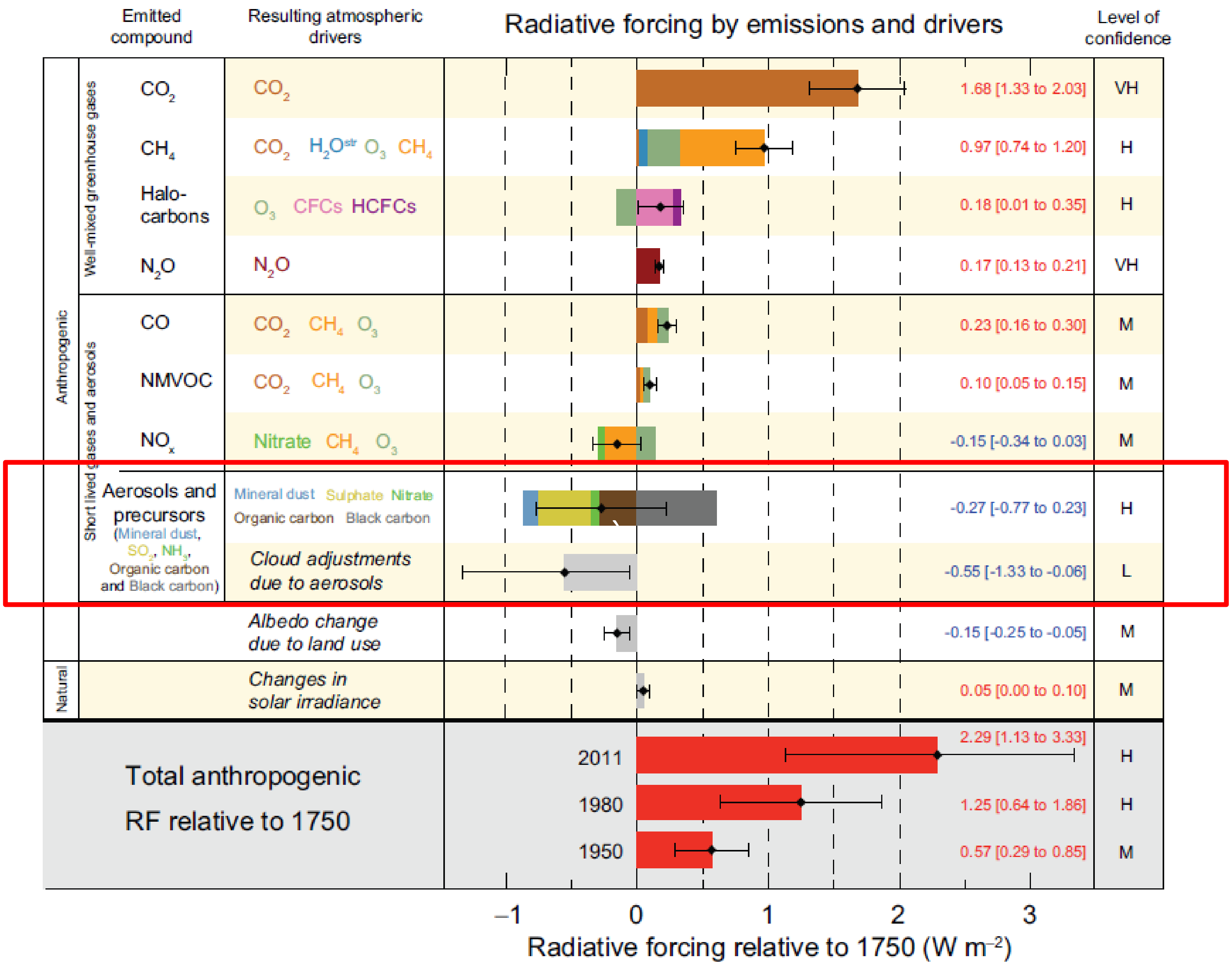
- **Primary aerosol** – atmospheric particles that are emitted or injected directly into the atmosphere.
- **Secondary aerosol** – atmospheric particles that are created by low-volatility gas phase molecules
  - **Condensation** onto existing particles
  - **Nucleation** of new particles

Primary and secondary may be natural or anthropogenic

Aerosols: solid or liquid particles in the atmosphere



Uncertainties Due to Aerosols



IPCC AR5, 2013

How much aerosol is there?

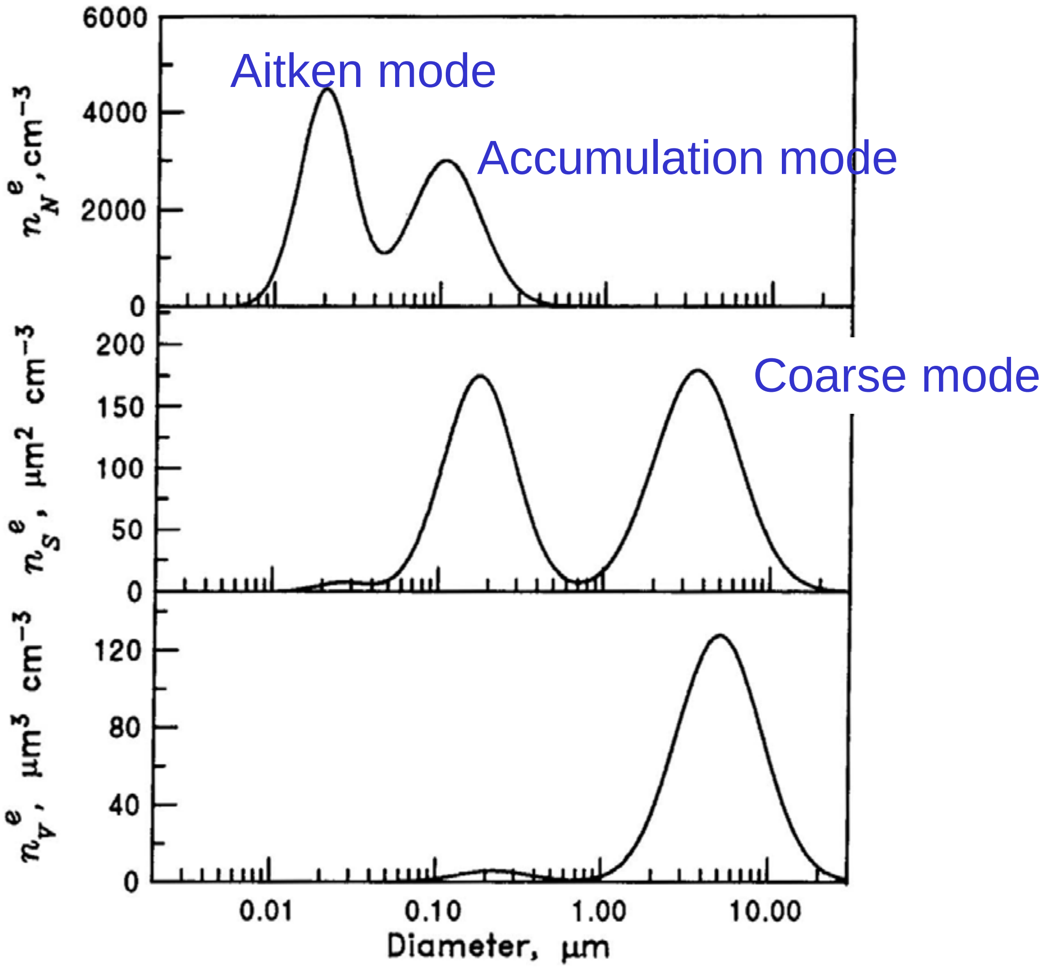
- Total mass concentration is between 1-100 μg m^{-3} (Arctic: < 1 μg m^{-3})
  - Total mass of air ~1 kg m^{-3}
  - ~1-100 ppb_{mass}
- Total number concentration is between 100-100,000 # cm^{-3} (Arctic: ~ 1-200 cm^{-3})

Size distributions

Number distribution
$n_n(\log D_p)=dN/d \log D_p$

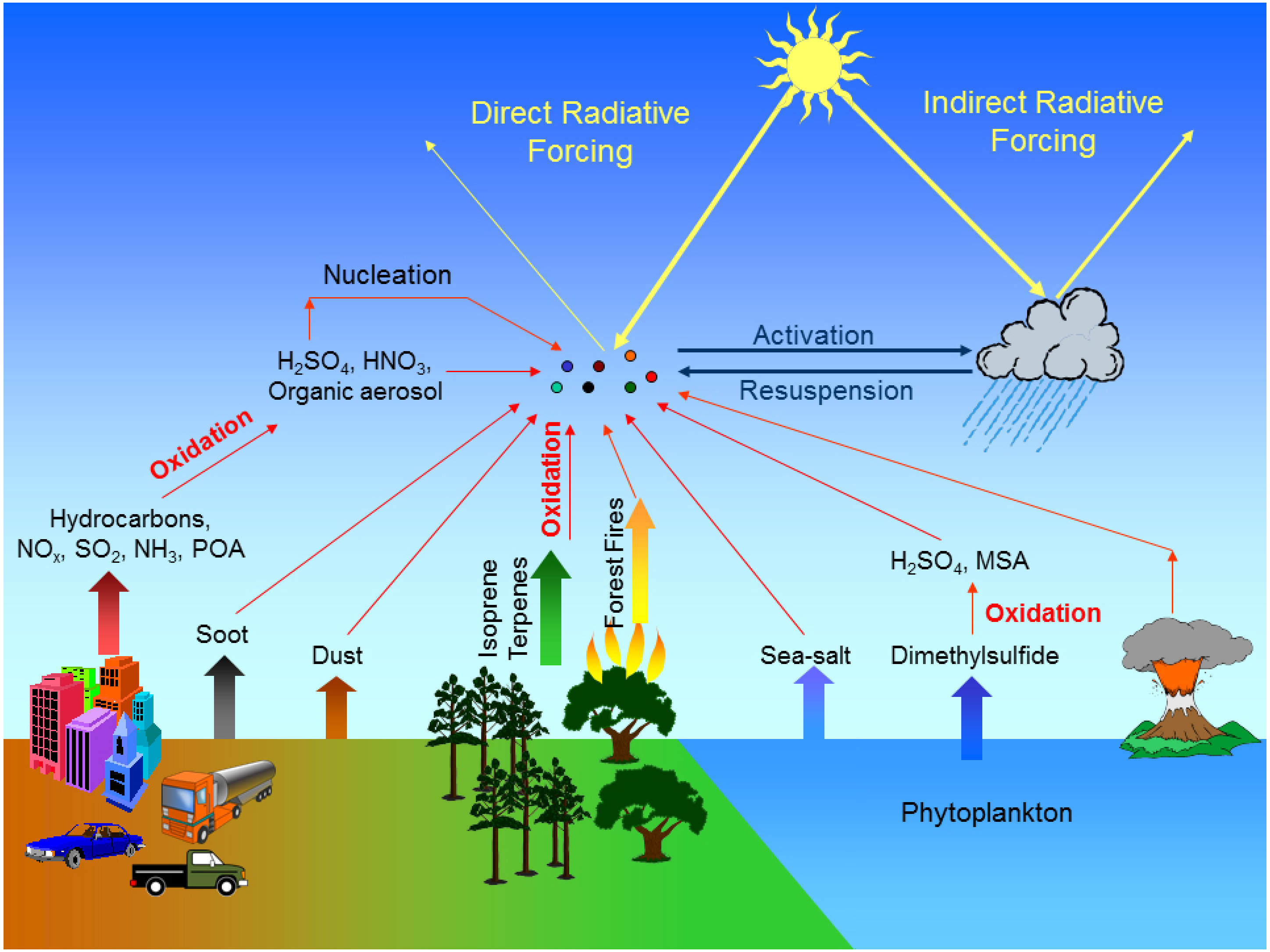
Surface area distribution
$n_s(\log D_p)= dS/d \log D_p$

Volume distribution
$n_v(\log D_p)=dV/d \log D_p$



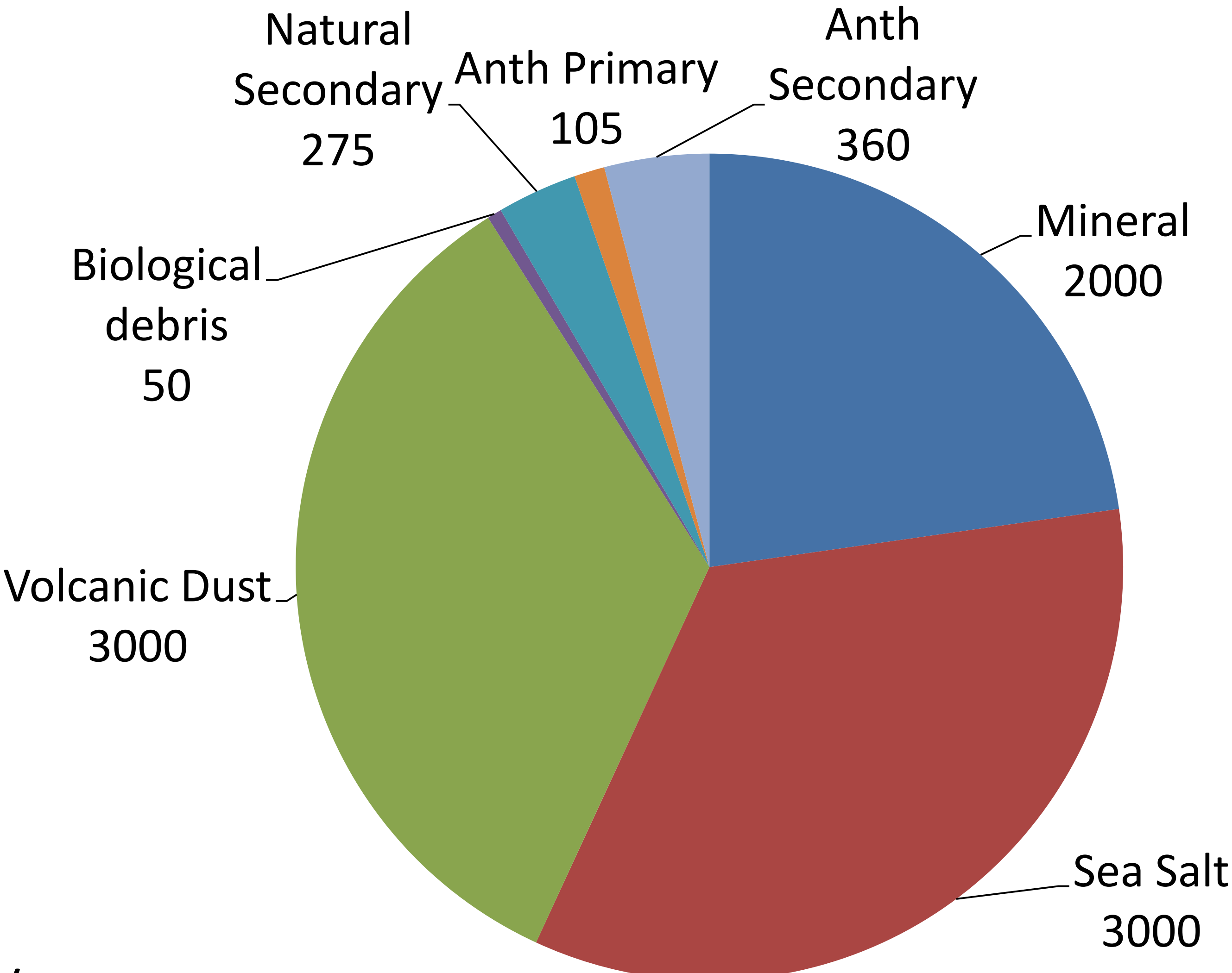
Seinfeld and Pandis, <u>Atmospheric Chemistry and Physics</u>

Atmospheric aerosol sources



https://www.bnl.gov/today/body_pics/2016/03/aerosol-sources-hr.jpg

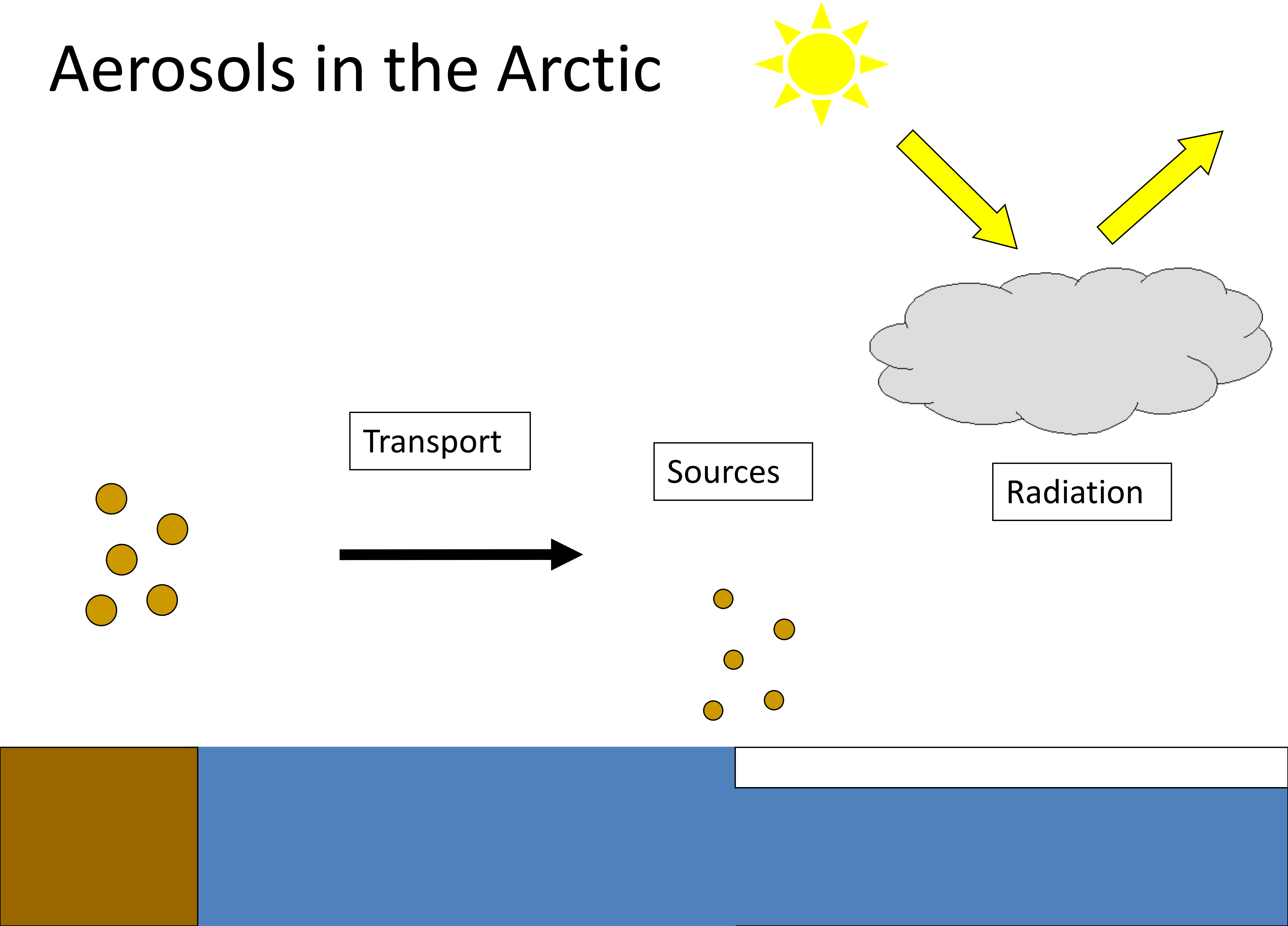
Global Aerosol Source Contributions



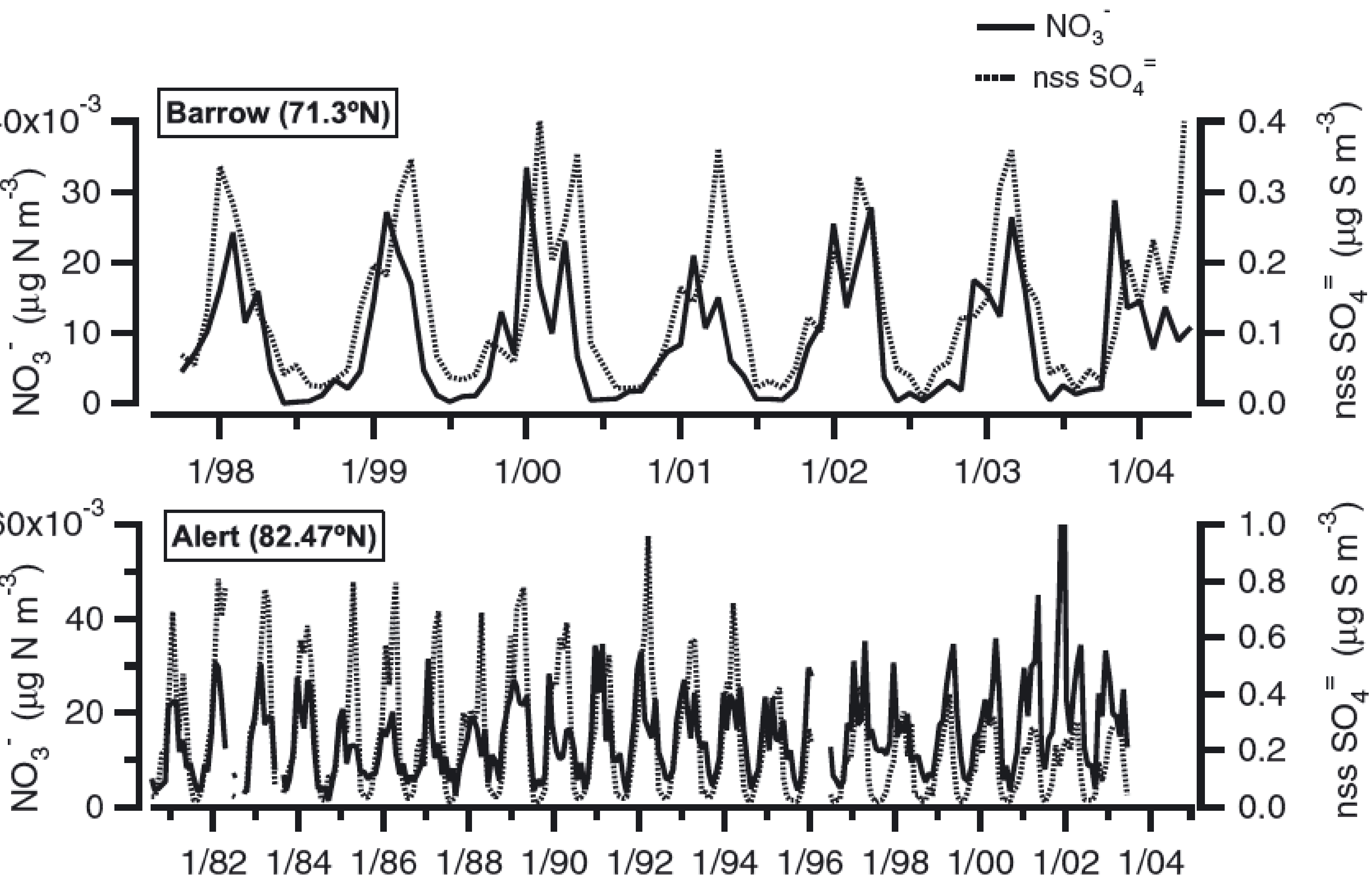
Units: Tg/yr

Seinfeld and Pandis, Atmospheric Chemistry and Physics

Aerosols in the Arctic



Seasonality of Arctic Aerosol Mass

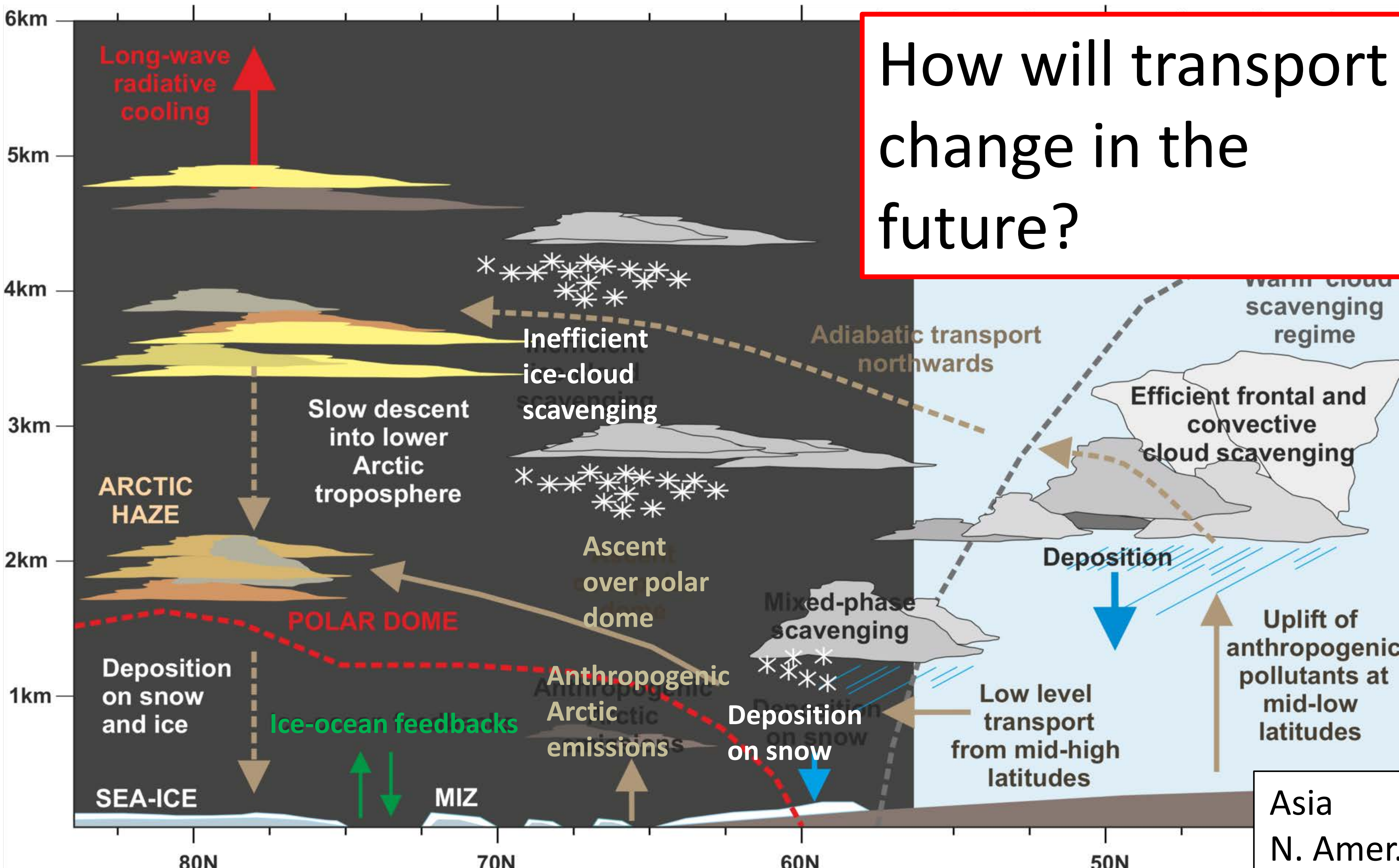


Quinn **2007** *Tellus B*, 59, 99

Arctic Haze

http://www.esrl.noaa.gov/csd/projects/arcpac/photos/inter_dc8.php?num=0

Winter Transport to Arctic

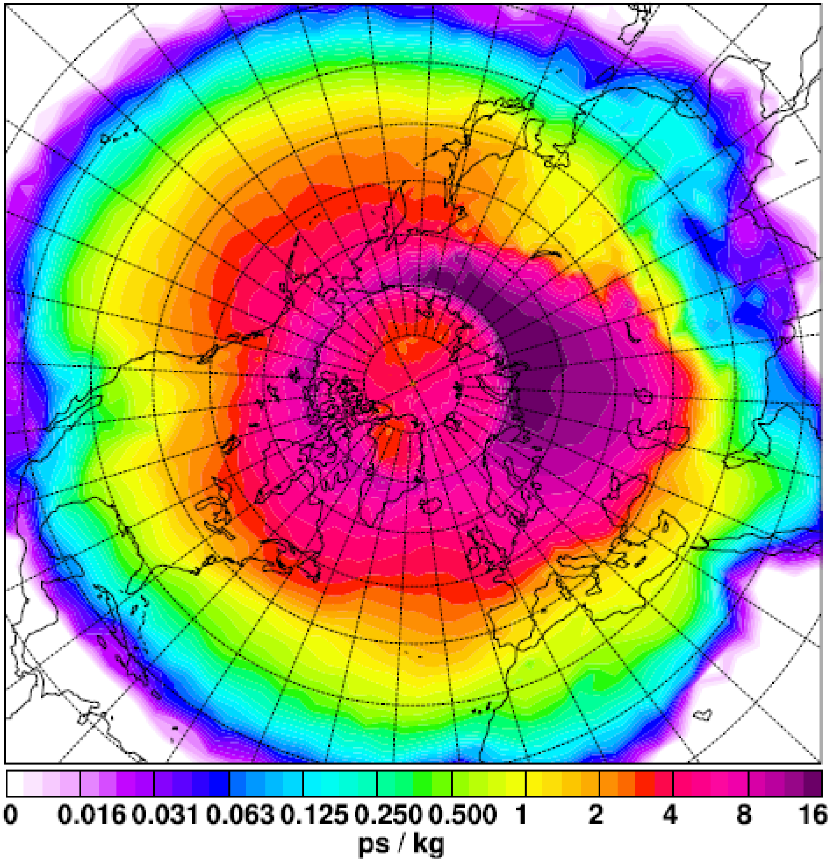


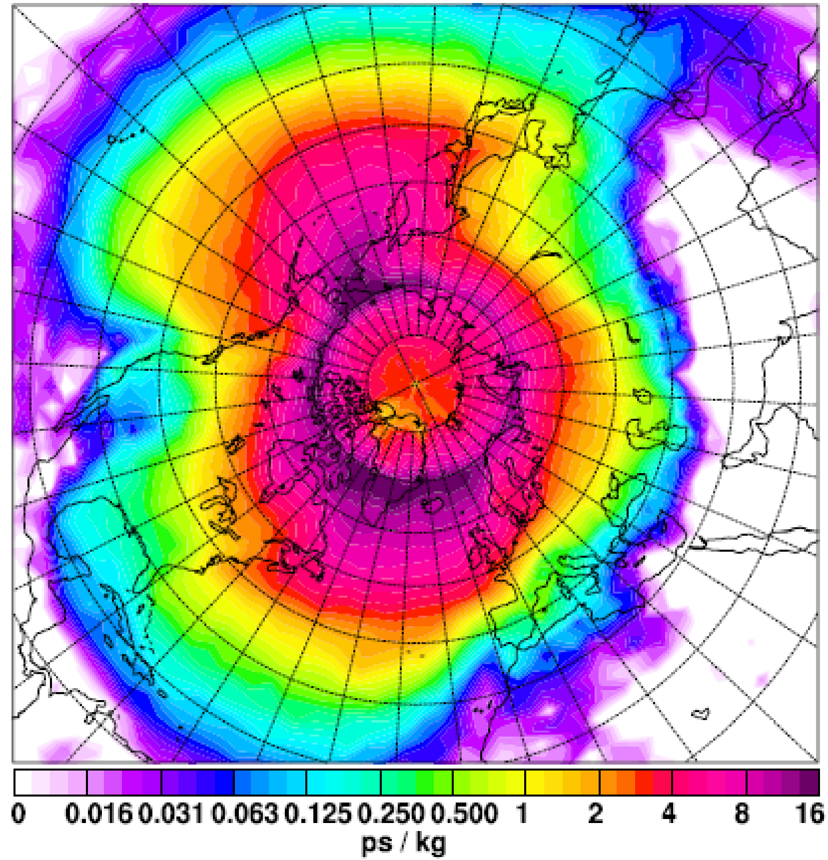
How will transport change in the future?

Asia
N. Amer.
Europe

Arnold et al. **2016** *Elementa*, 4, 104

Seasonal Transport into the Arctic





Winter
- **northern Eurasia influence**
- **no solar radiation**
- **stable inversions**
- **minimal deposition**
- **shorter transport time**

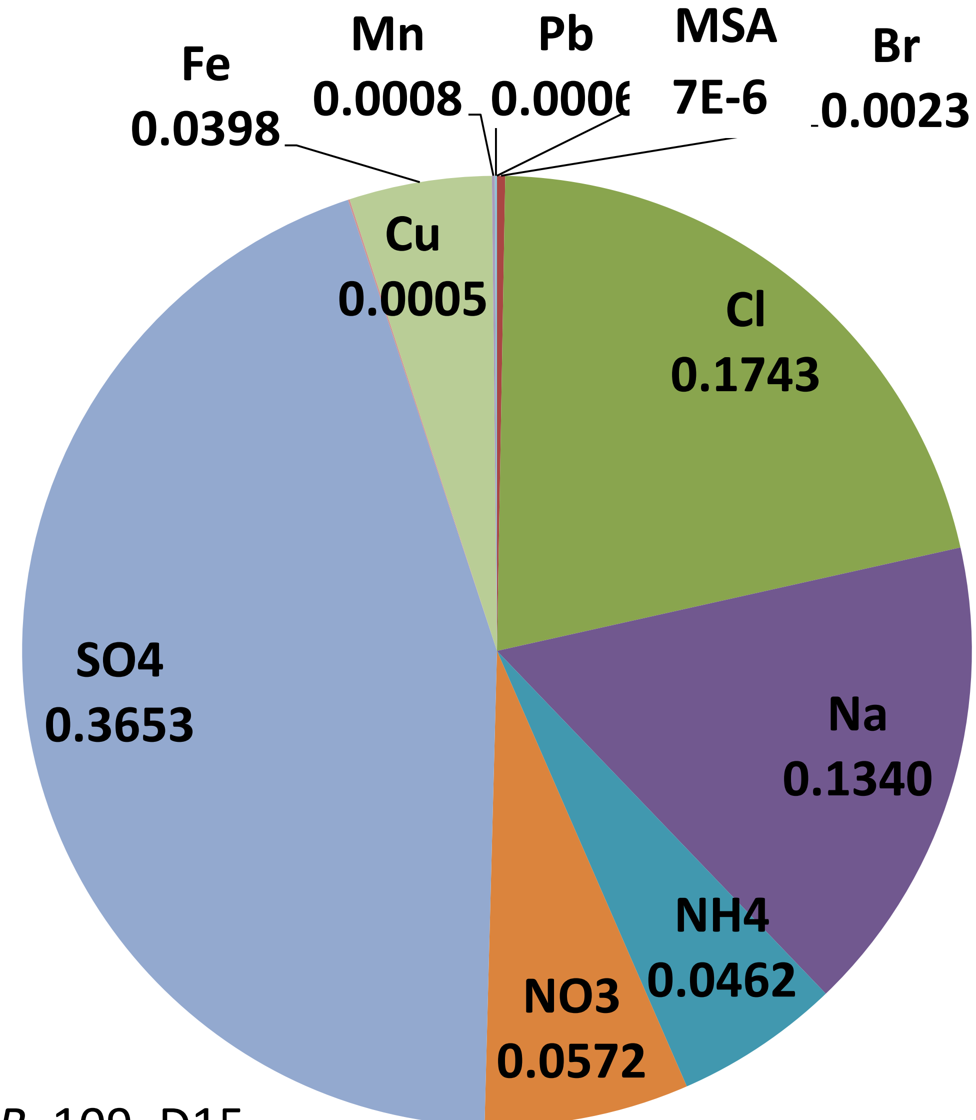
Summer
- **less continental influence**
- **solar radiation**
- **convection**
- **large rate of wet deposition**
- **longer transport time**

Stohl **2006** *J. Geophys. Res.*, 111

Average Aerosol Composition at Alert: 2006

Black Carbon
0 – 0.15 µg/m3

Organics???



Units: µg/m3

Sharma et al. **2004** *JGR*, 109, D15

http://www.ec.gc.ca/donneesnatchem-natchemdata/, accessed Jul 13, 2017

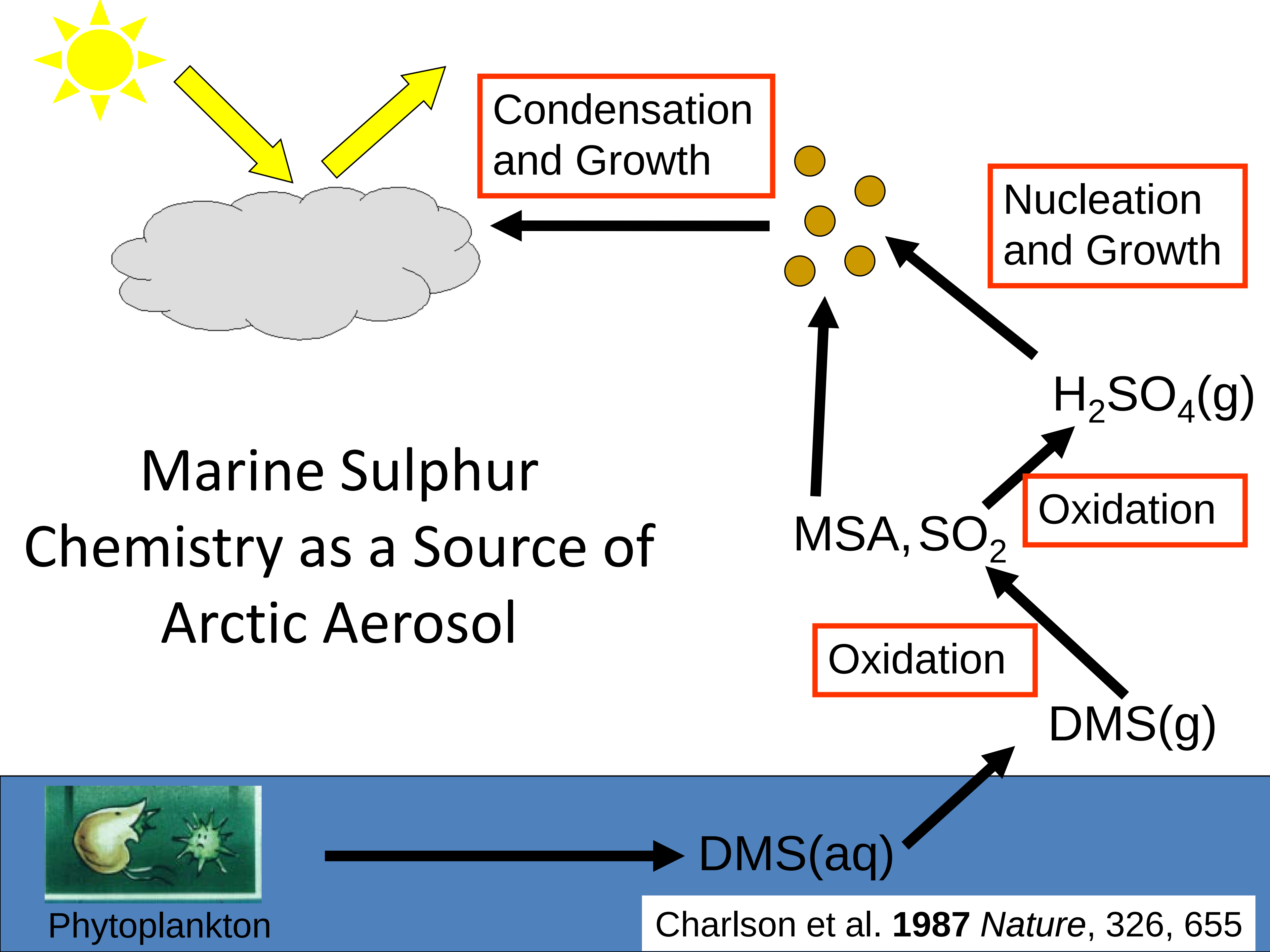
Sources of Arctic Aerosol: 1980-1995

- Photochemical sulphate
- Anthropogenic sulphate
- Mixed photochemical sulphate / sea salt
- Biogenic sulphur (MSA)
- Sea salt
- Smelter
- Soil
- Nitrate, bromine, iodine
- *Biomass burning*

Future Sources:
Shipping
Oil extraction
????

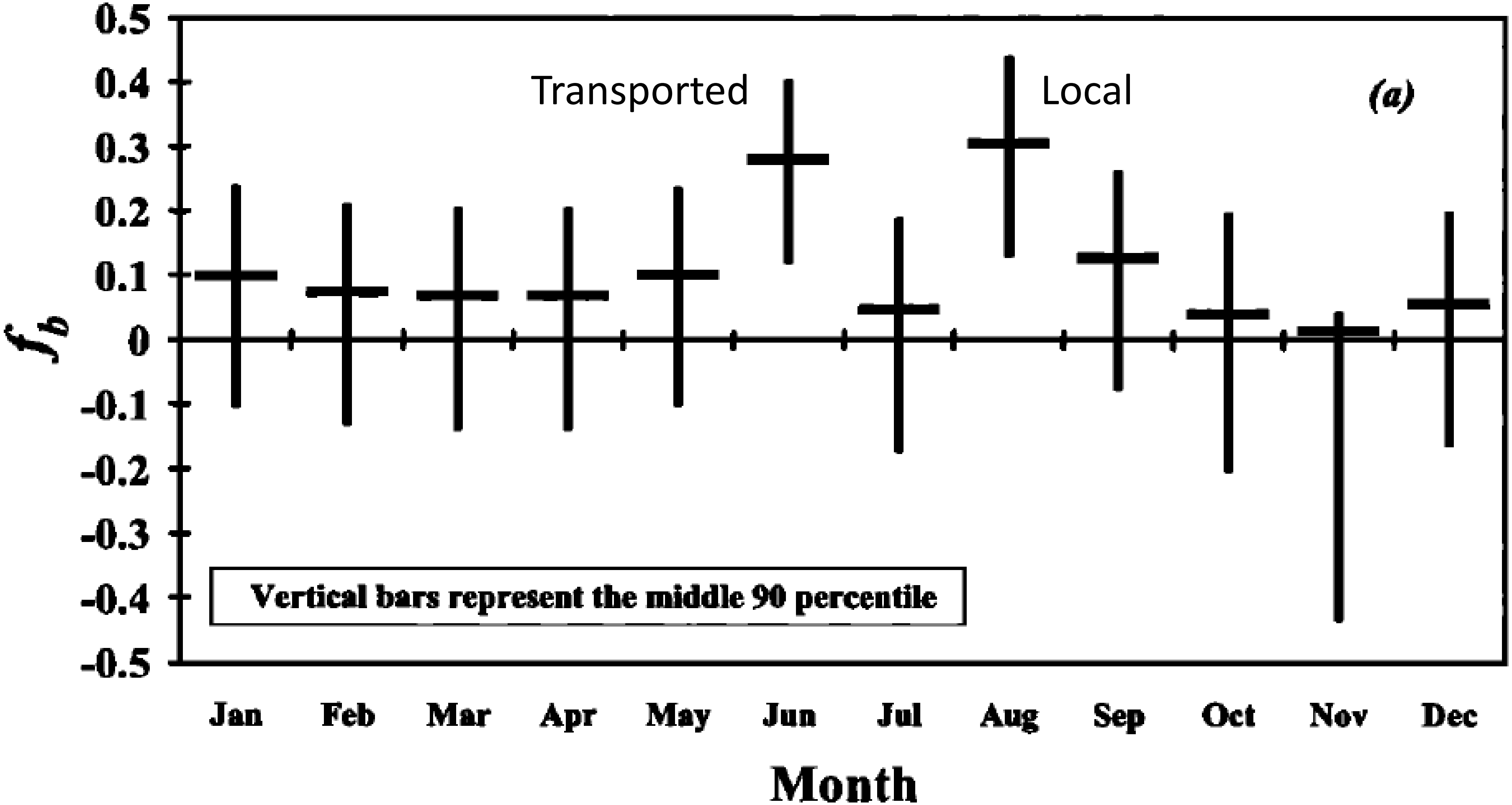
Sirois and Barrie **1999** *JGR-Atmosphere*, 104, 11599

Marine Sulphur Chemistry as a Source of Arctic Aerosol



Charlson et al. **1987** *Nature*, 326, 655

Biogenic sulphate



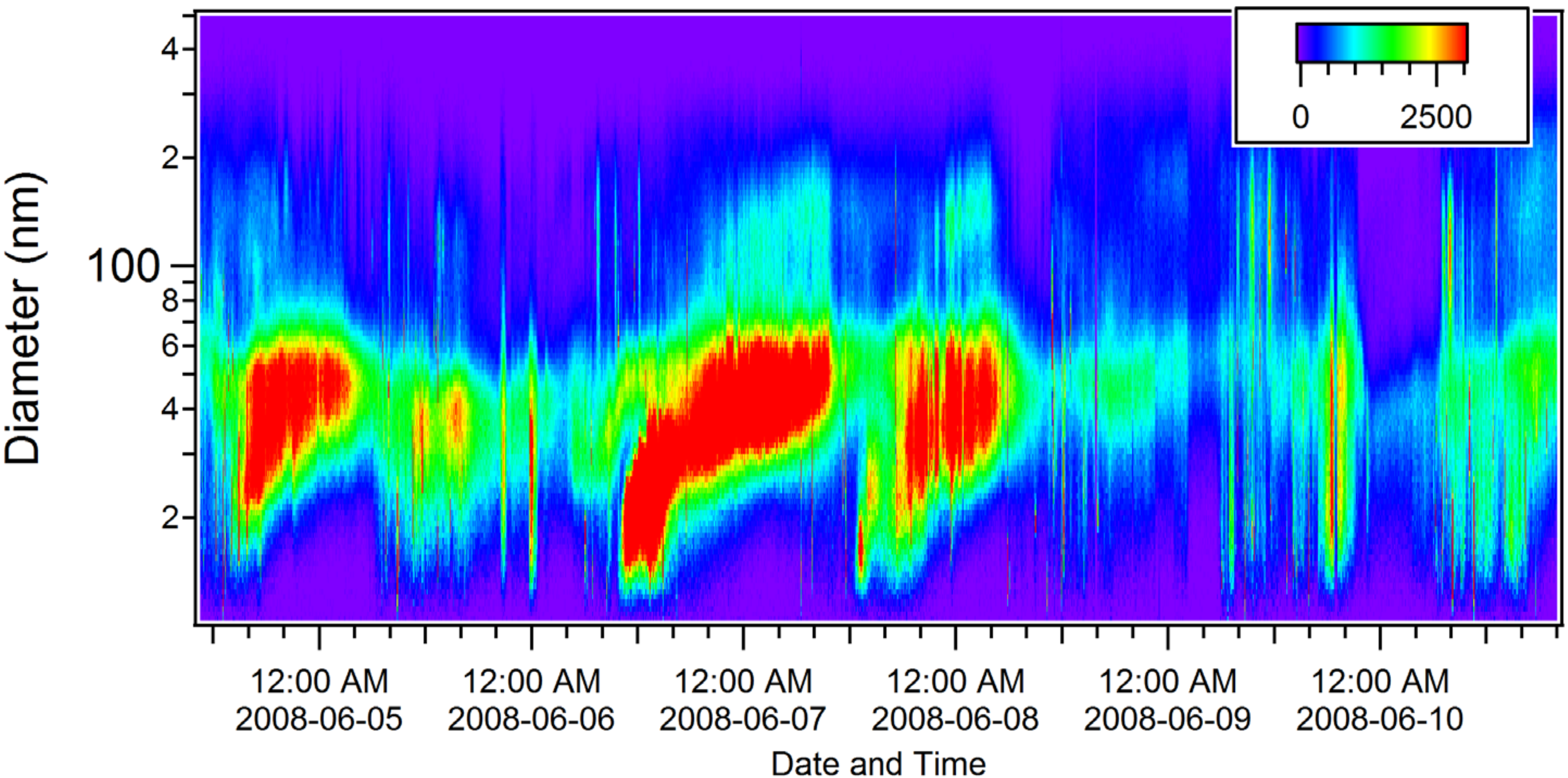
Li and Barrie **1993** *J Geophys Res*, 98, 20613

Nucleation in Marine Environments

- too many existing particles for nucleation to occur in boundary layer
- driven by sulphuric acid
- nucleation in free troposphere
  - colder, cleaner, greater solar radiation

Nucleation and Growth

Nucleation / Growth at Whistler Mountain
"Banana Plot"



Unpublished data

Ambient Nucleation Rates in Boreal Forest

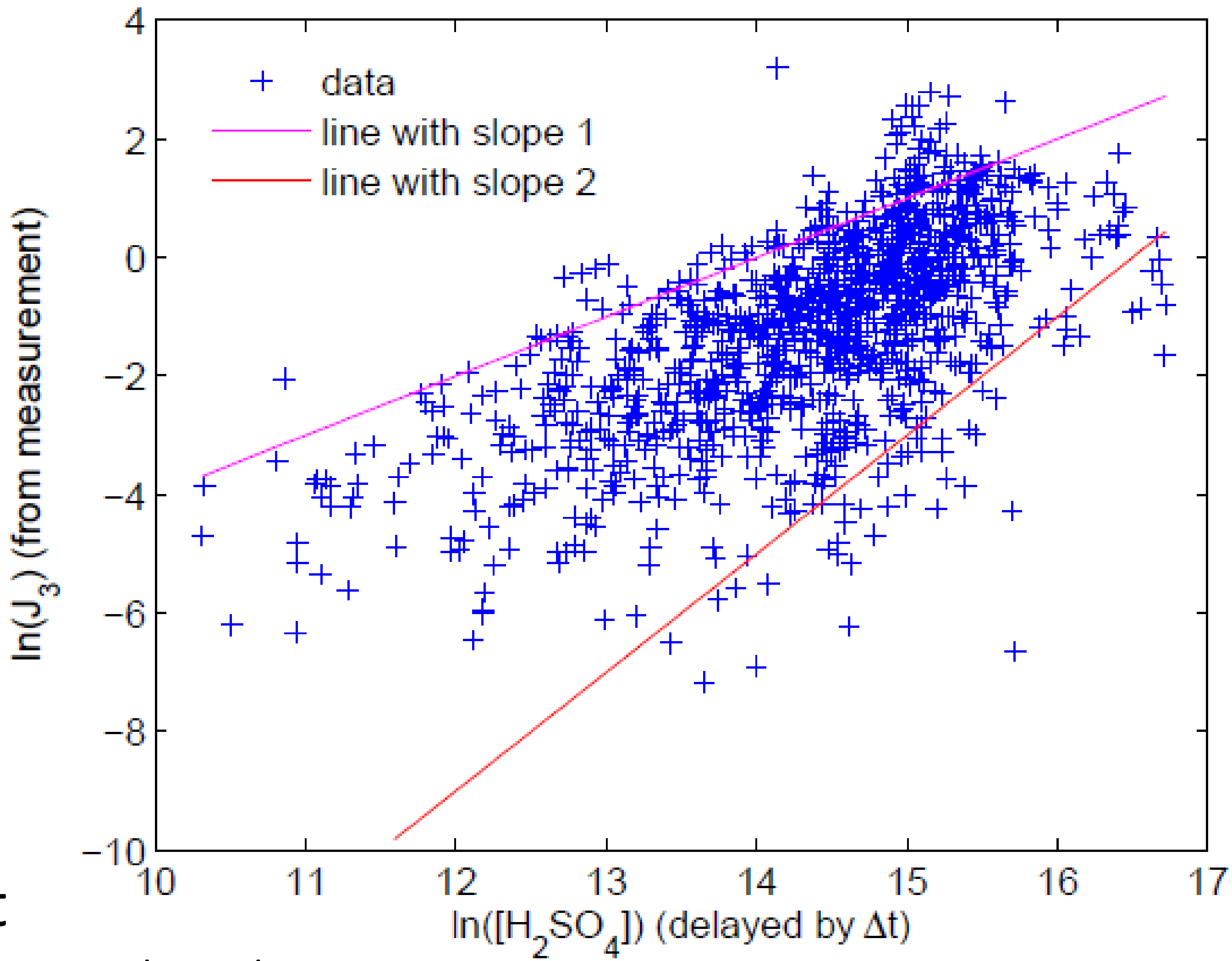
Activation

A: 0.4-3.0 x 10^{-6} /s

Kinetic

K: 0.2-1.4 x 10^{-12} cm3/s

Nucleation Rate



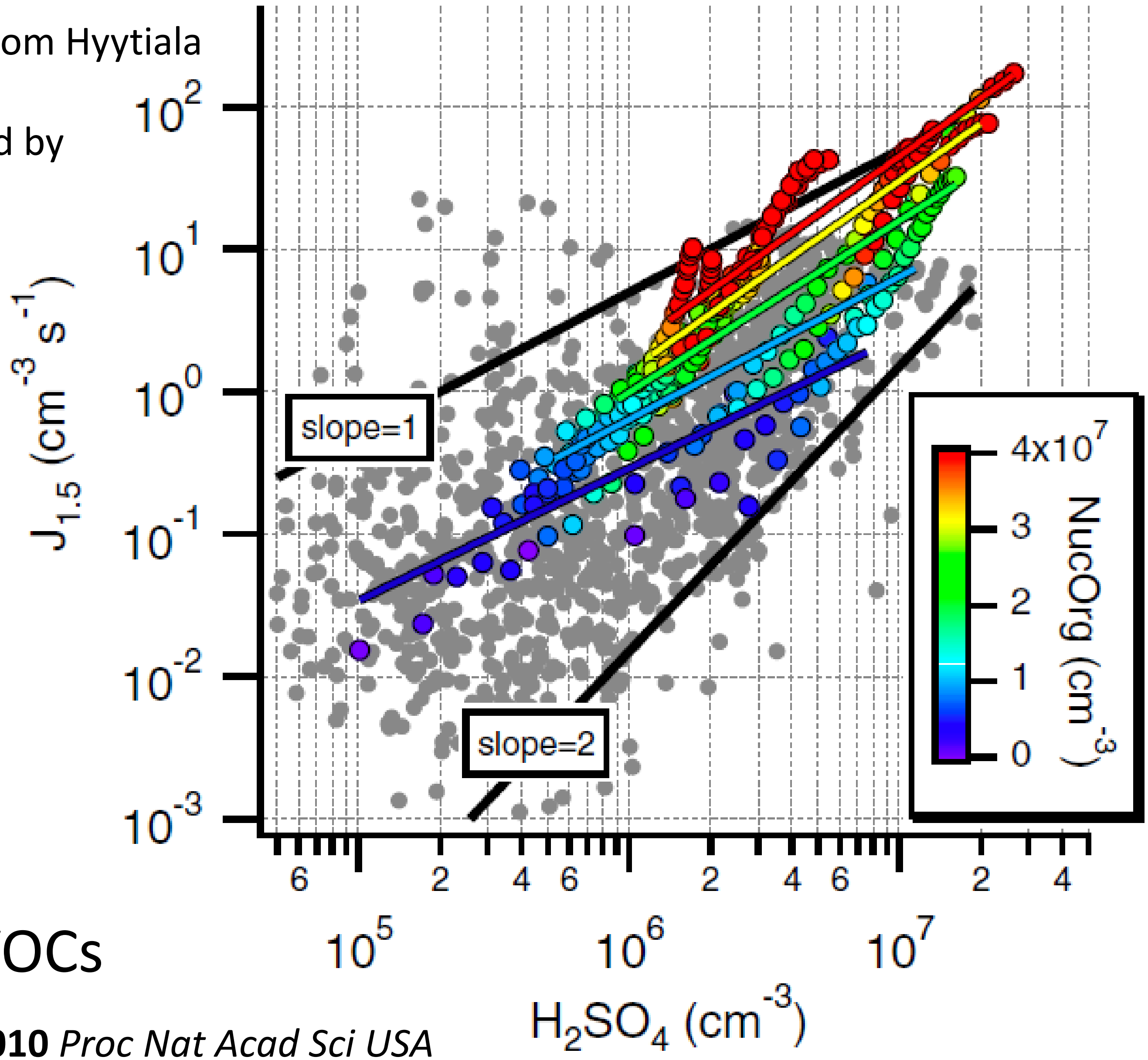
H2SO4 is main component

Sihto et al., **2006** *Atmos Chem Phys*

Organics Contribute to Nucleation

Grey dots:
Ambient data from Hyytiala

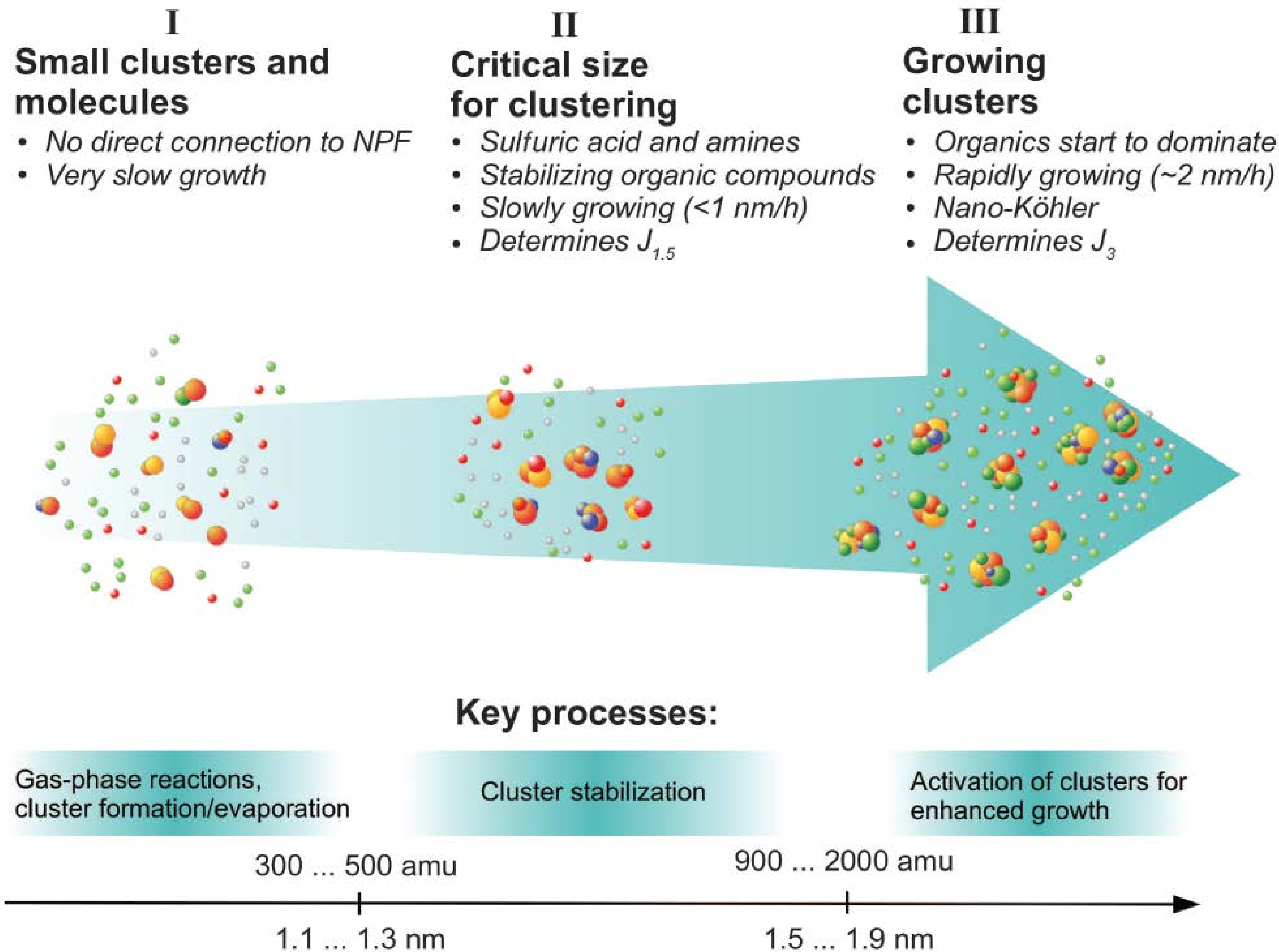
Organics formed by
TMB oxidation



<u>As do:</u>
NH3
Amines
Biogenic VOCs

Metzger et al. **2010** *Proc Nat Acad Sci USA*

Schematic of Particle Formation



Kulmala, **2013** *Science*

Nucleation in Marine Environments

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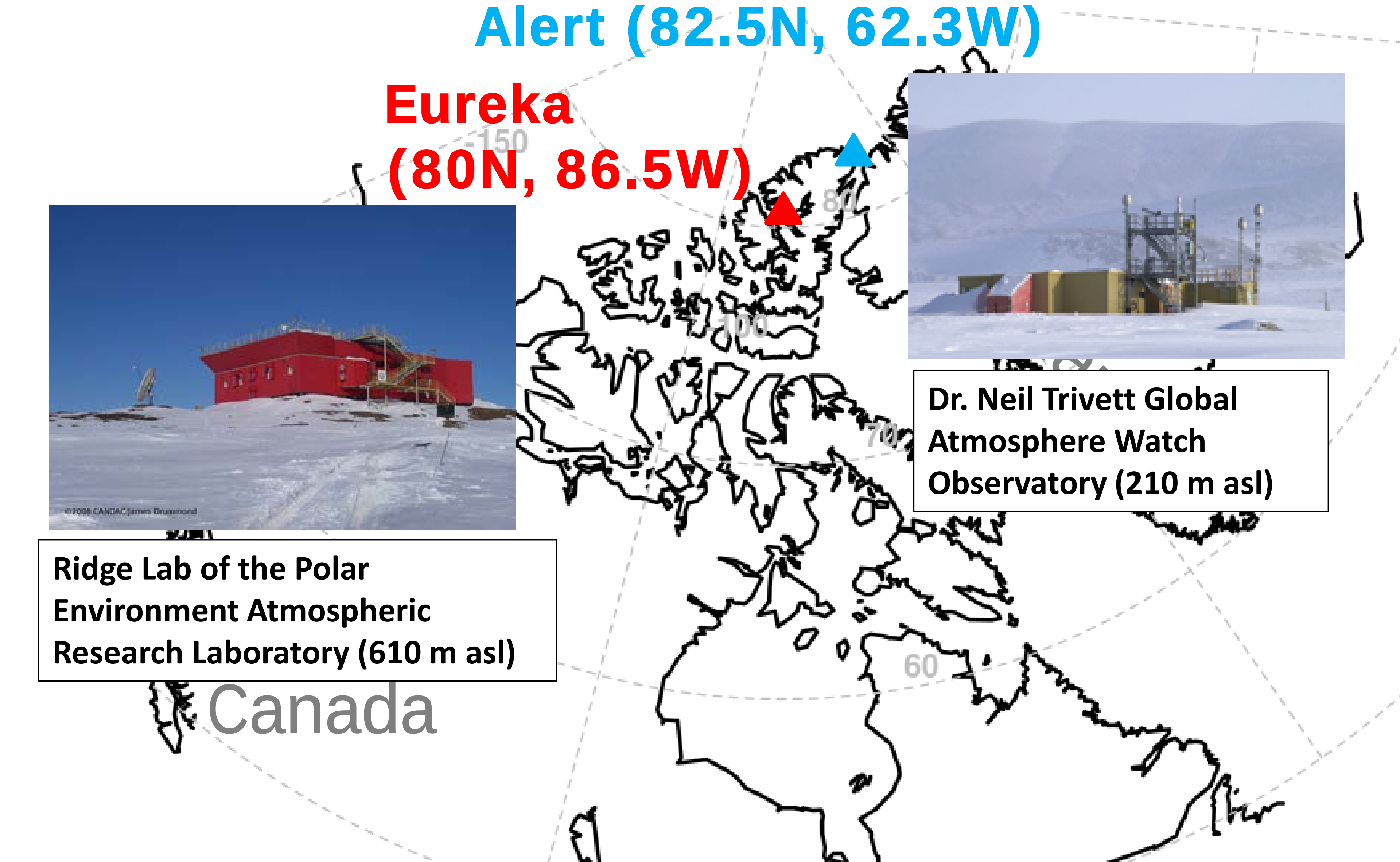
Particle Growth in Canadian High Arctic

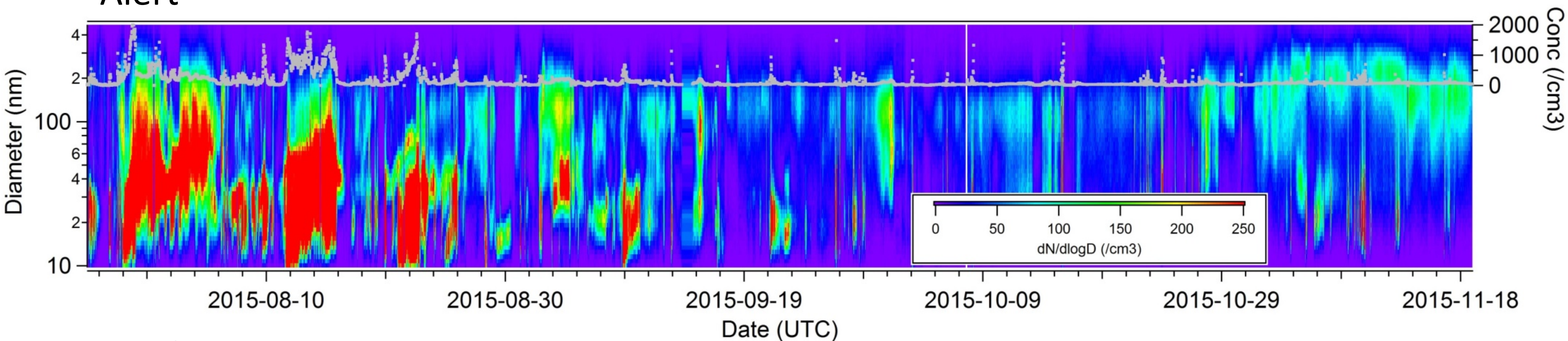


Ridge Lab of the Polar Environment Atmospheric Research Laboratory (610 m asl)

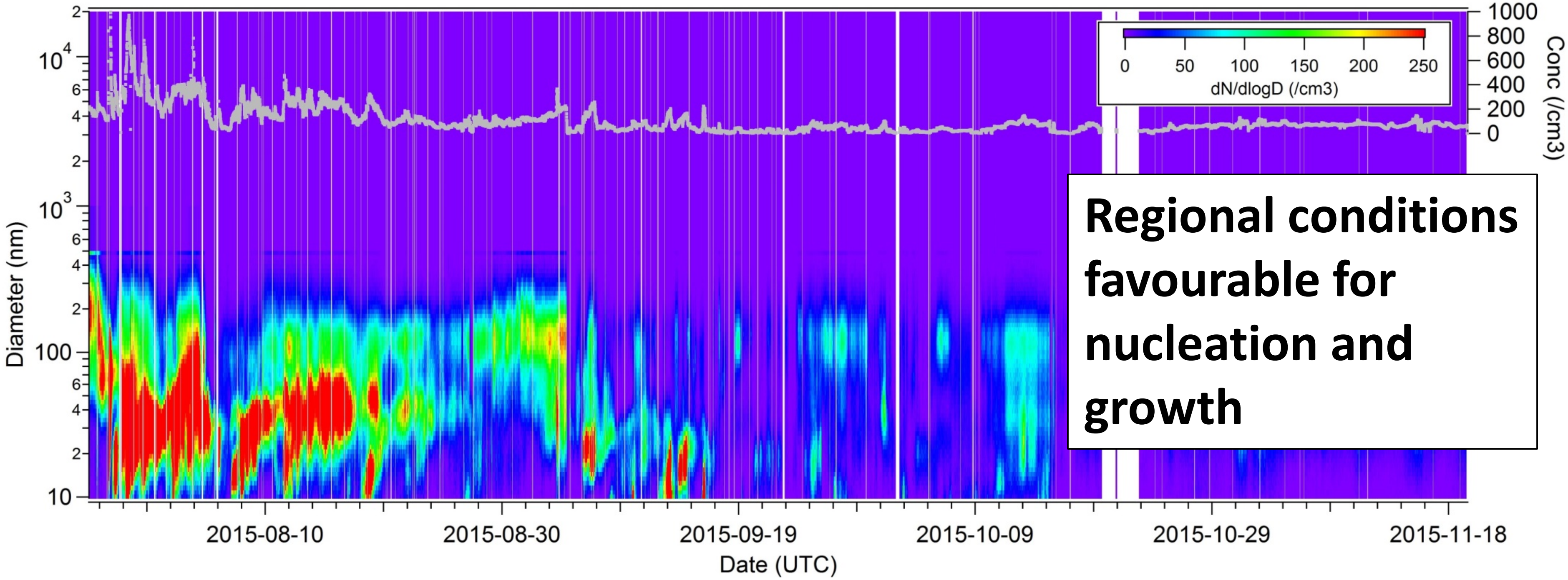
Dr. Neil Trivett Global Atmosphere Watch Observatory (210 m asl)

Aerosol Size Distribution

Alert



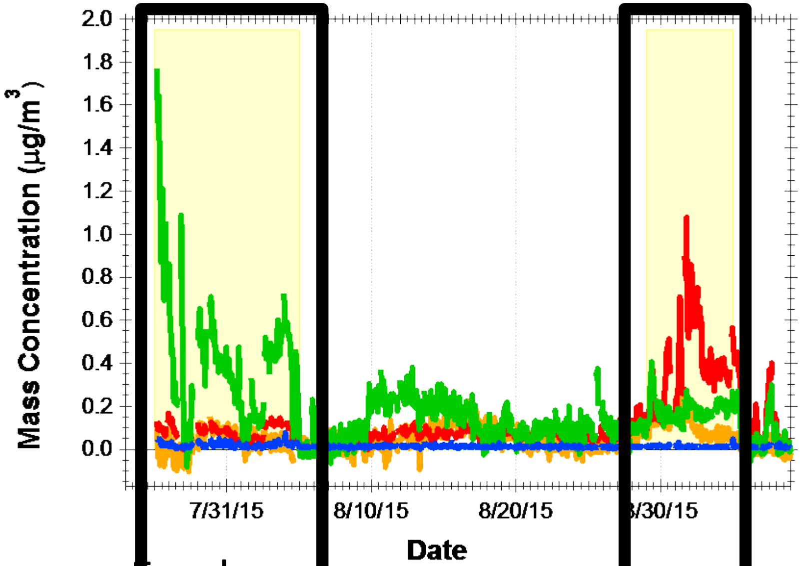
Eureka

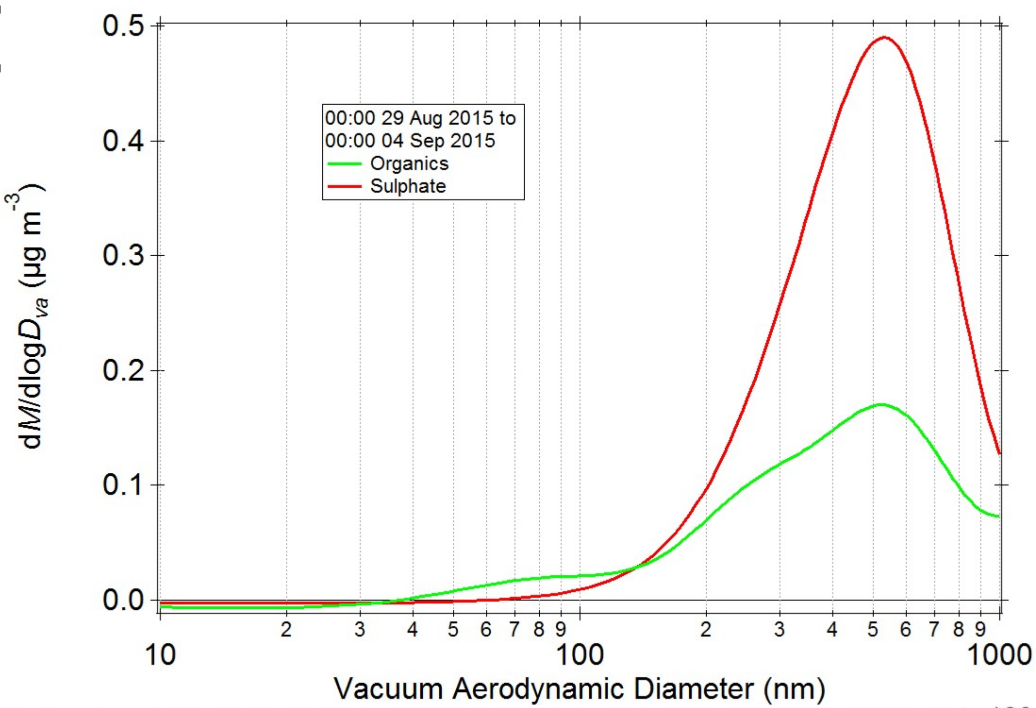


Regional conditions favourable for nucleation and growth

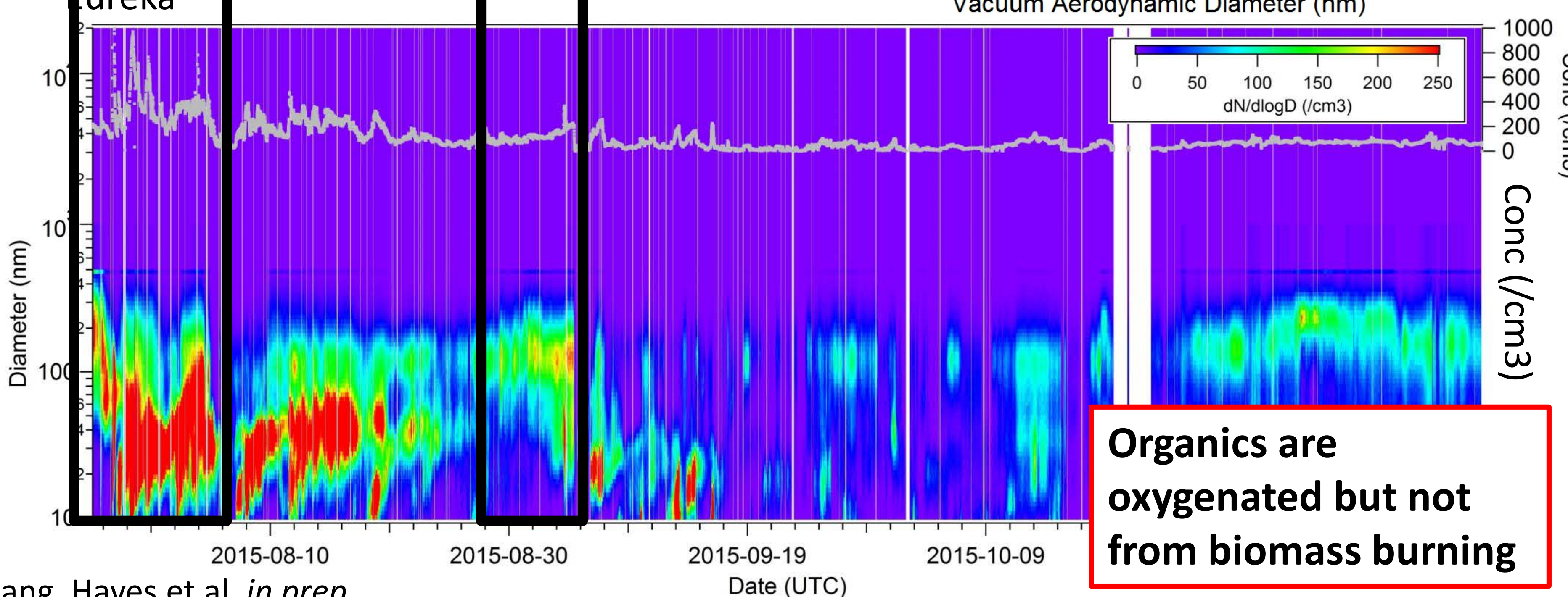
Chang, Hayes et al. *in prep*

Eureka Aerosol C





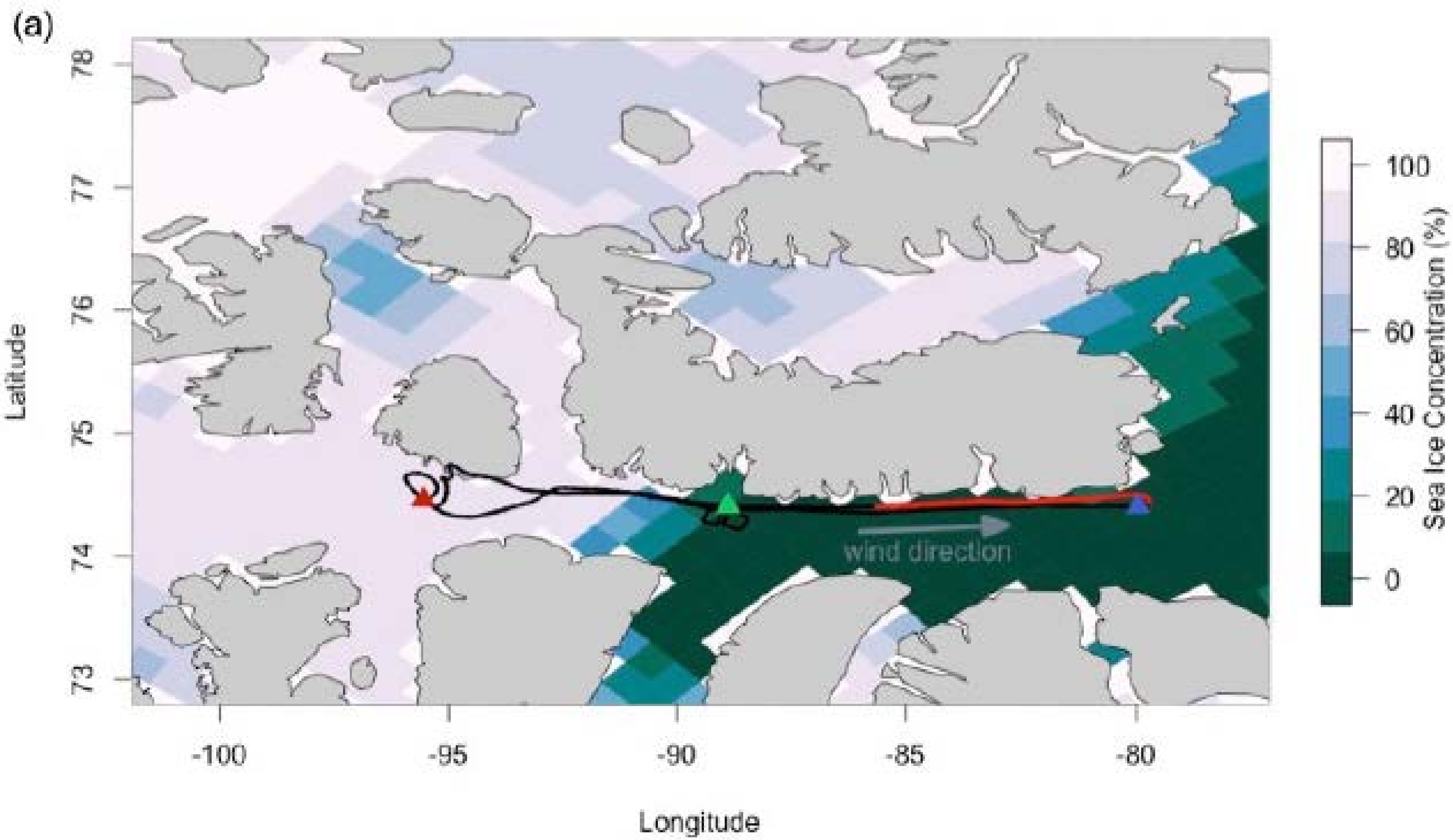
Eureka



Organics are oxygenated but not from biomass burning

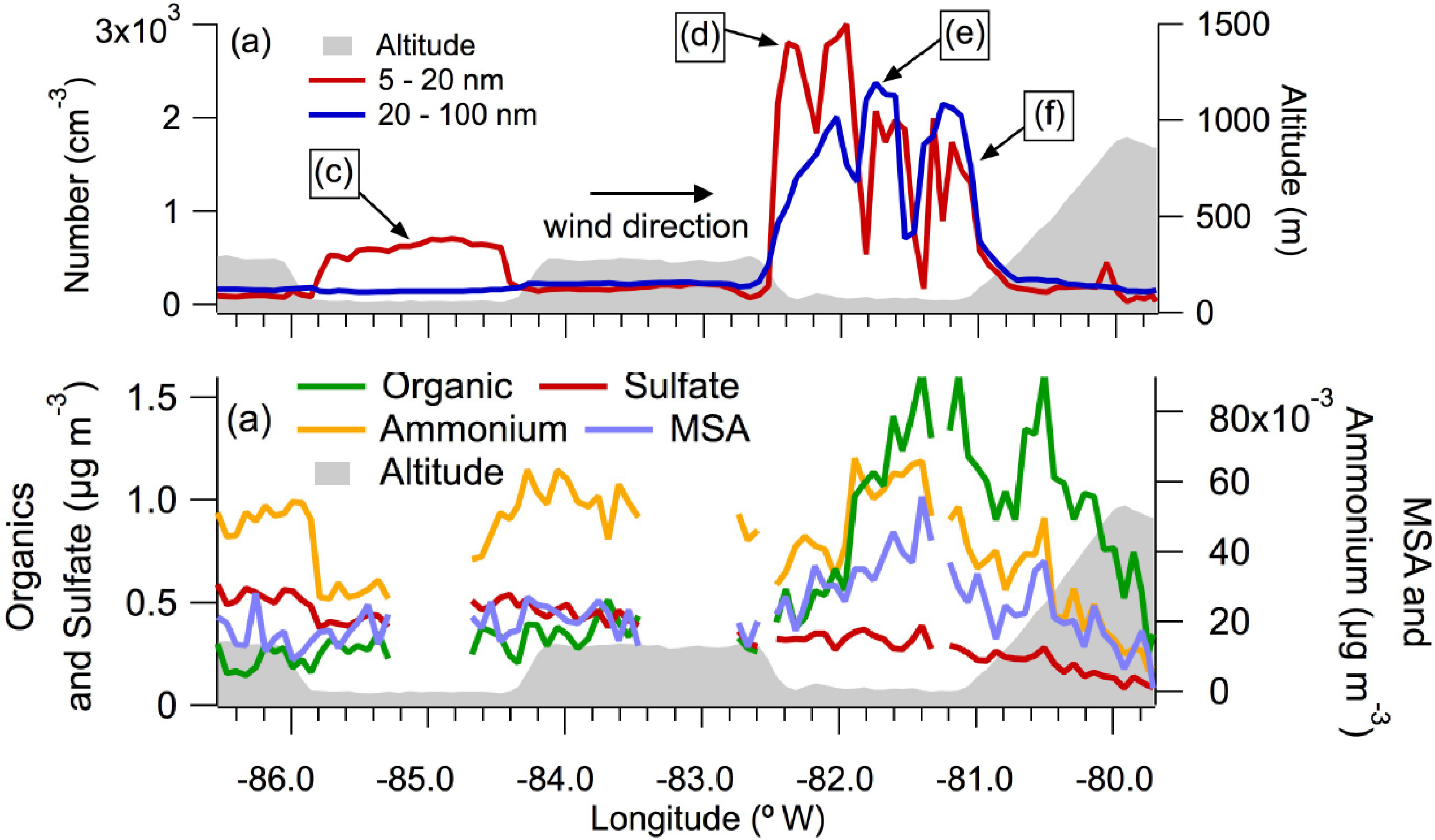
Chang, Hayes et al. *in prep*

NETCARE: Marine Emissions and Organics Contribute to Aerosol Growth



Willis et al. **2016** Atmos Chem Phys, 16, 7663

NETCARE: Marine Emissions and Organics Contribute to Aerosol Growth



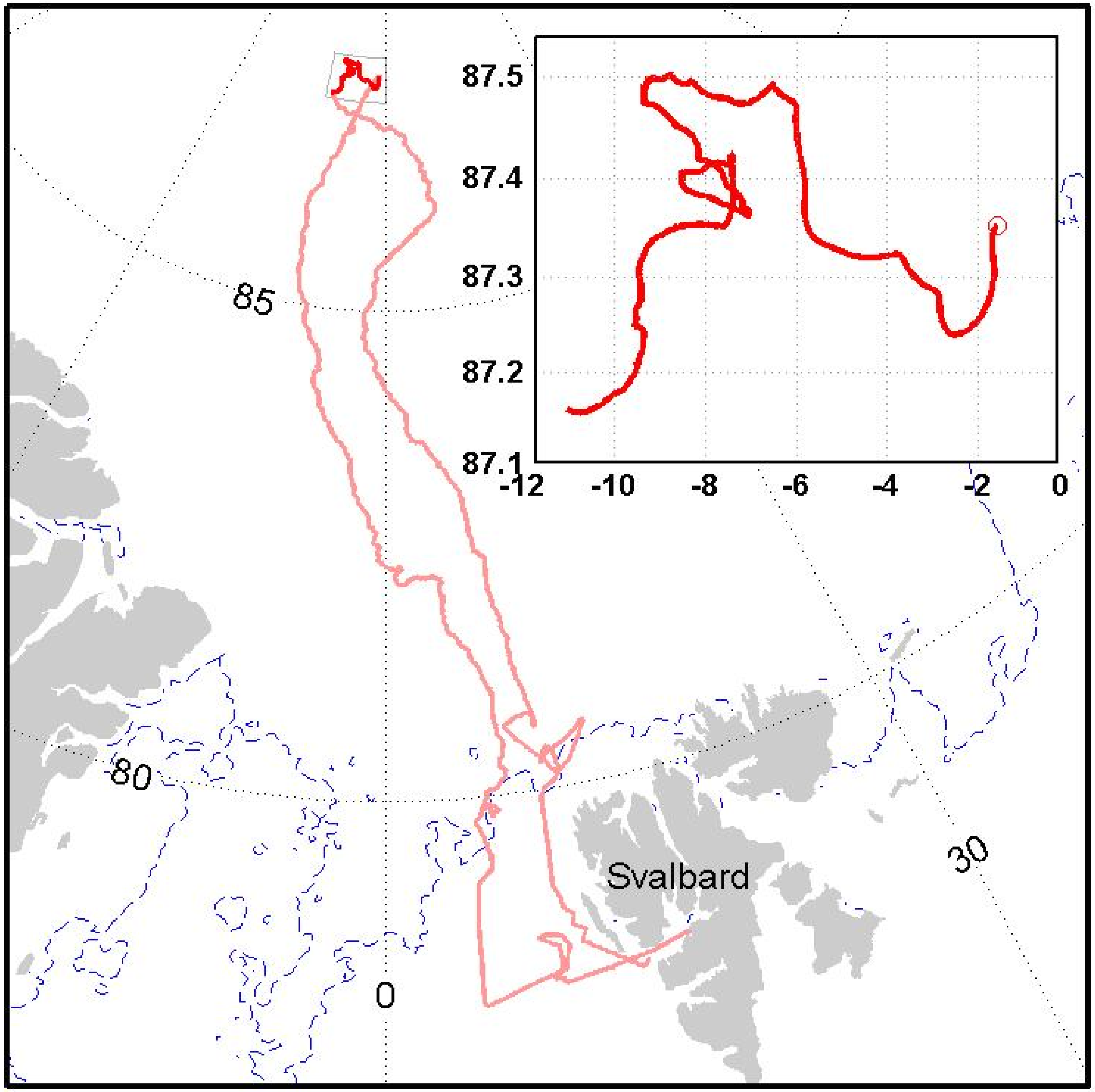
Willis et al. **2016** Atmos Chem Phys, 16, 7663

Other NETCARE Results

- E. Mungall – volatile organics originating from ocean surface
- J. Burkart, D. Collins – particle growth events in Canadian Arctic

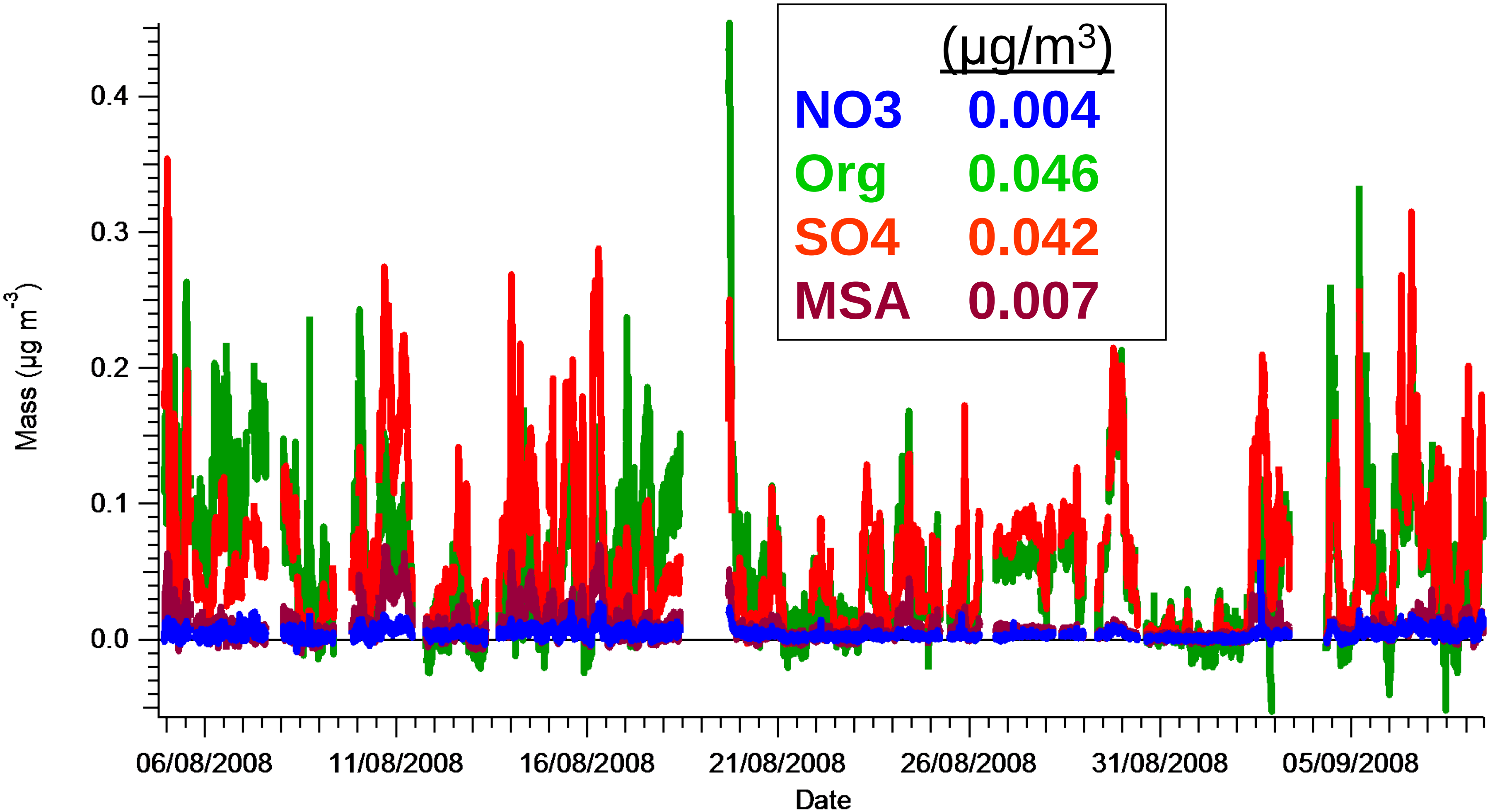
Summer Arctic Aerosol Composition and Sources

Arctic Summer Cloud and Ocean Study
Aug 1 – Sep 9, 2008



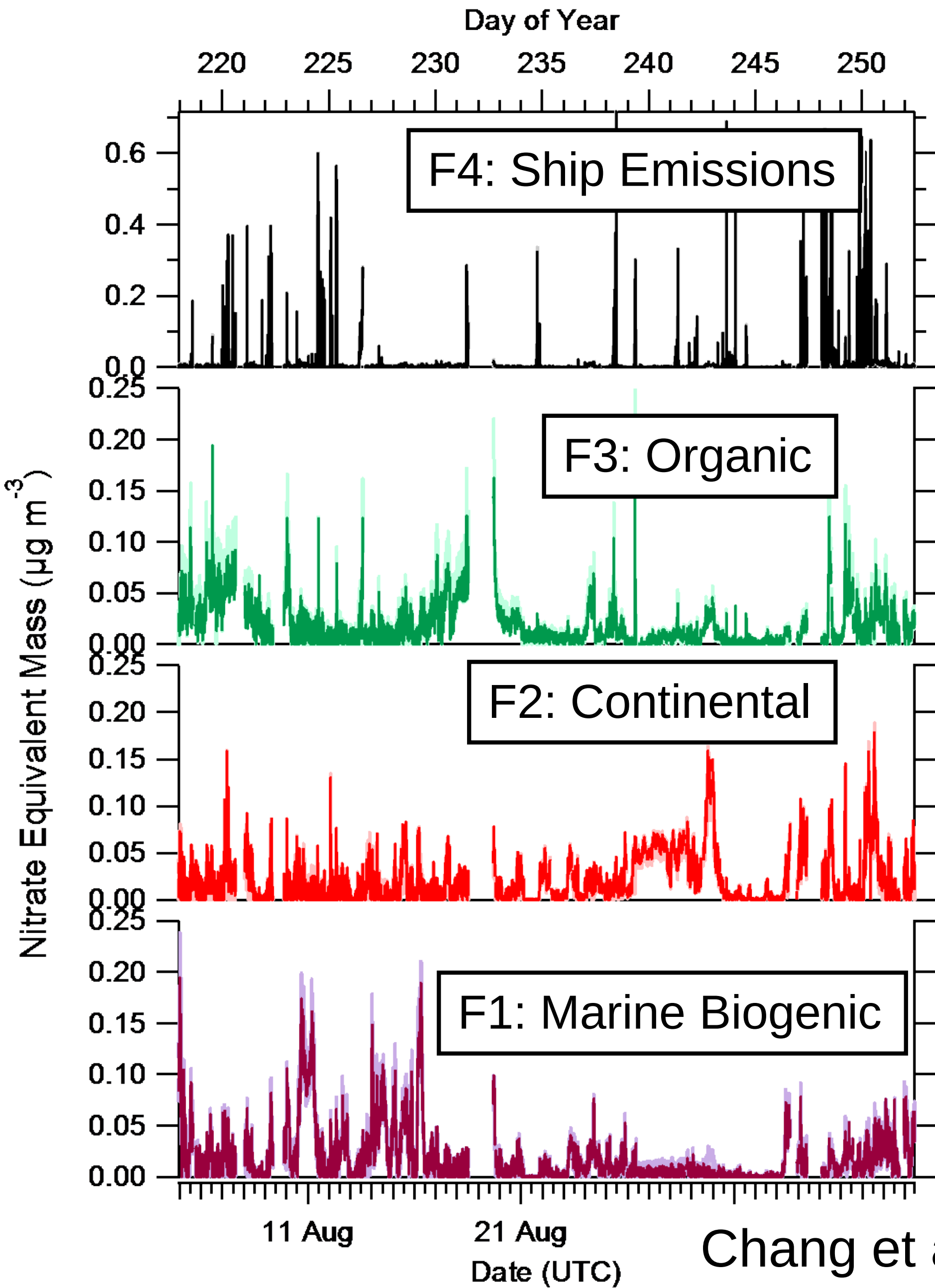
map courtesy of I. Brooks

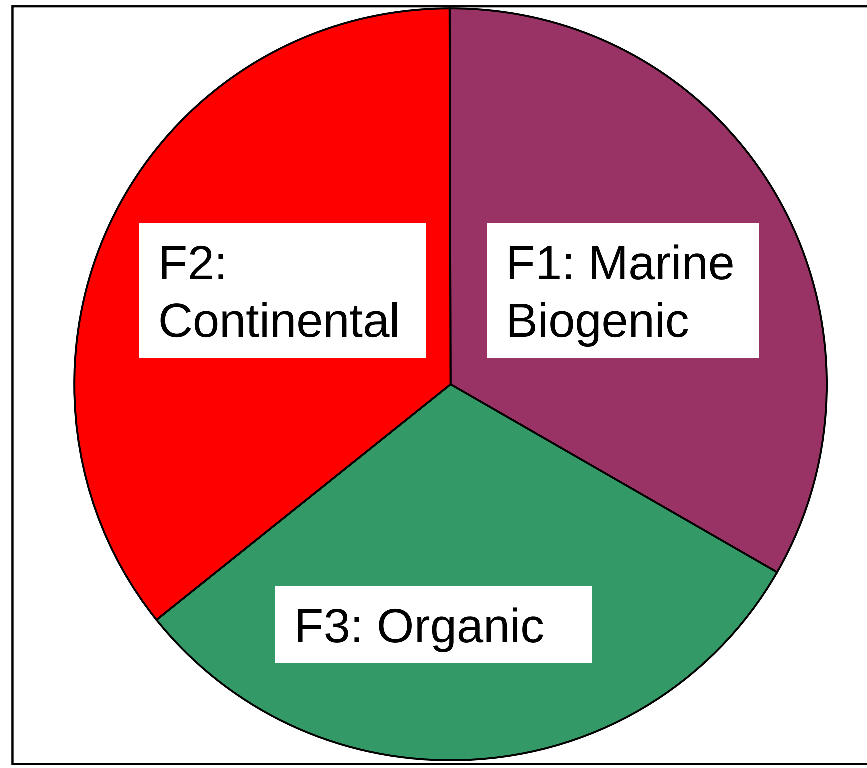
Aerosol Chemical Composition Measured by AMS



MSA fragmentation from Langley et al. **2010** *Atmos. Chem. Phys.*

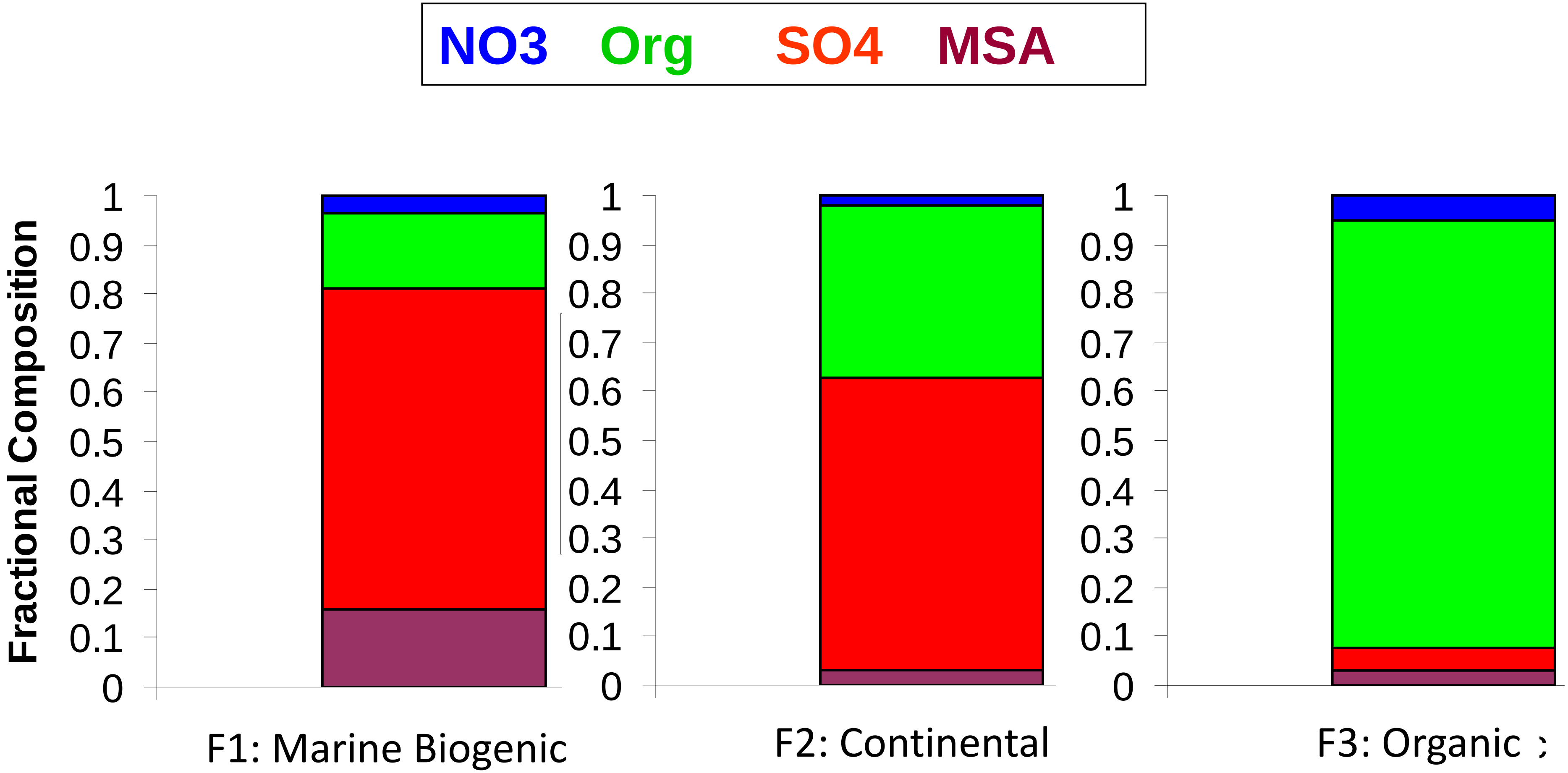
Factor Analysis





Chang et al. **2011** *Atmos. Chem. Phys.*, 11, 10619

Composition of Factors



Chang et al. **2011** *Atmos. Chem. Phys.*, 11, 10619

Summary

- winter aerosol is transported
- summer aerosol is more local
  - organic component is important
  - nucleation and growth observed and linked to marine sources
  - How will this change in future climate?
  - How will industrial activities affect aerosol processes?