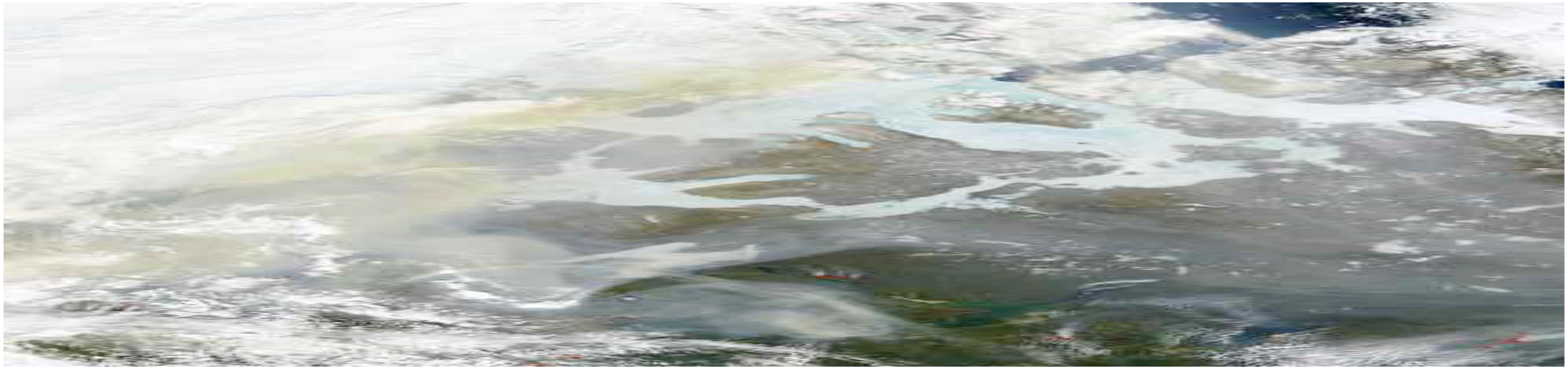


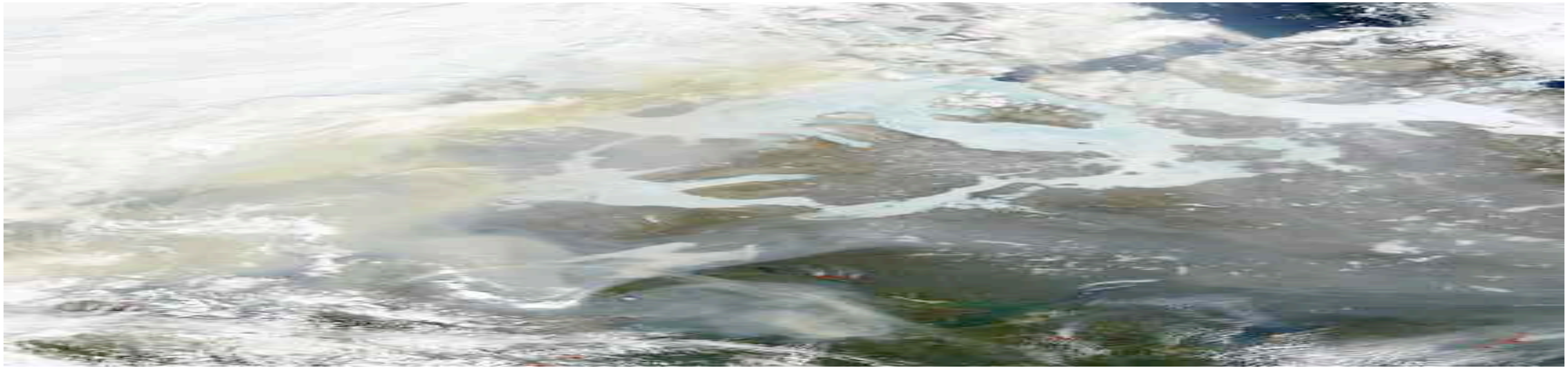
Arctic Pollution: Sources, Pathways & Impacts

Kathy LAW

LATMOS/IPSL-CNRS-UVSQ-UPMC

CHANTIER ARCTIQUE FRANÇAIS 3 June 2013

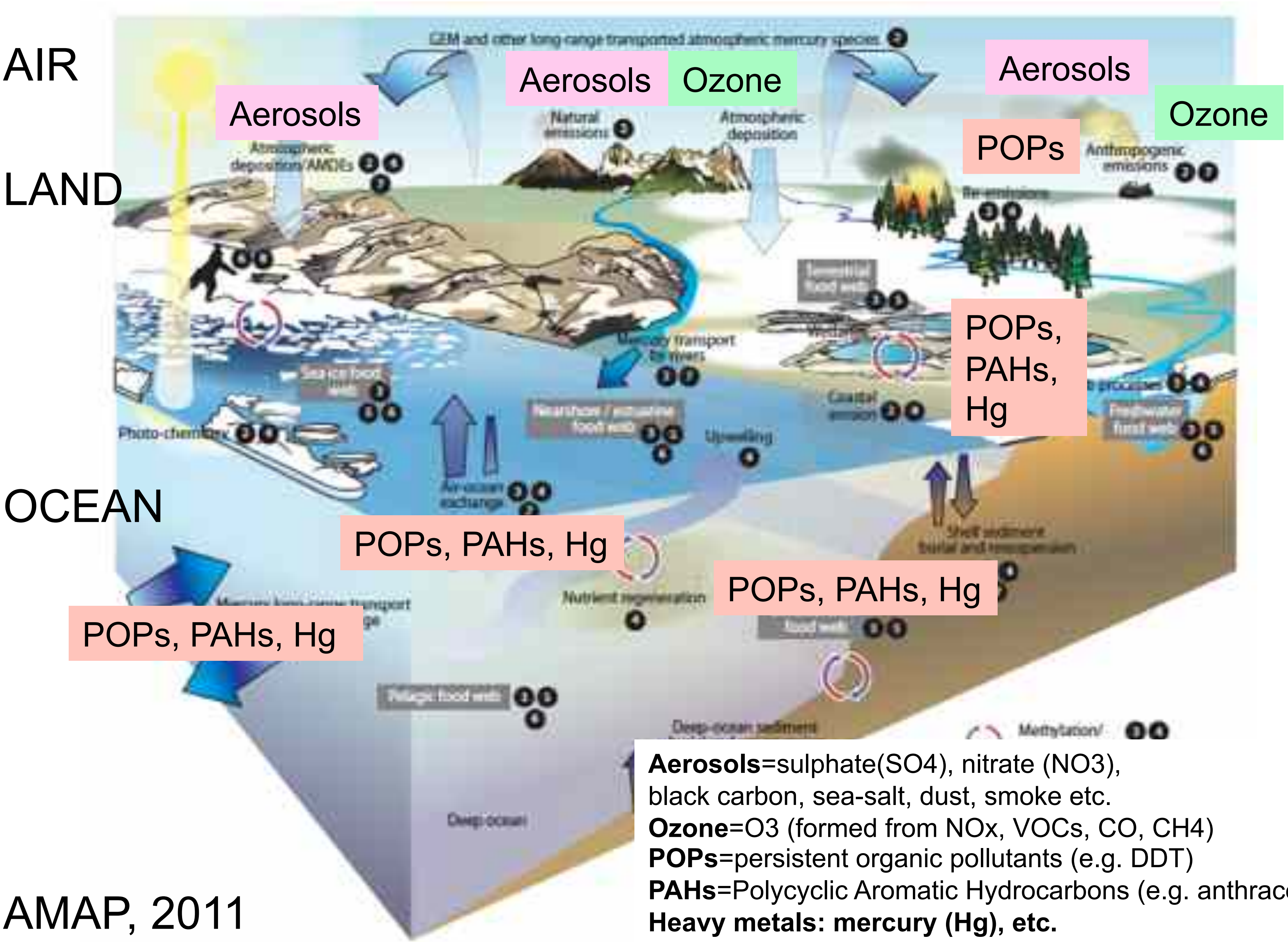
LATMOS



Outline

- Motivation – why Arctic pollution?
- Long-range transport of pollution from mid-latitudes
- Local Arctic pollution
- Conclusions & perspectives

Arctic Pollution – what is it?



Aerosols=sulphate(SO4), nitrate (NO3), black carbon, sea-salt, dust, smoke etc.
Ozone=O3 (formed from NOx, VOCs, CO, CH4)
POPs=persistent organic pollutants (e.g. DDT)
PAHs=Polycyclic Aromatic Hydrocarbons (e.g. anthracene)
Heavy metals: mercury (Hg), etc.

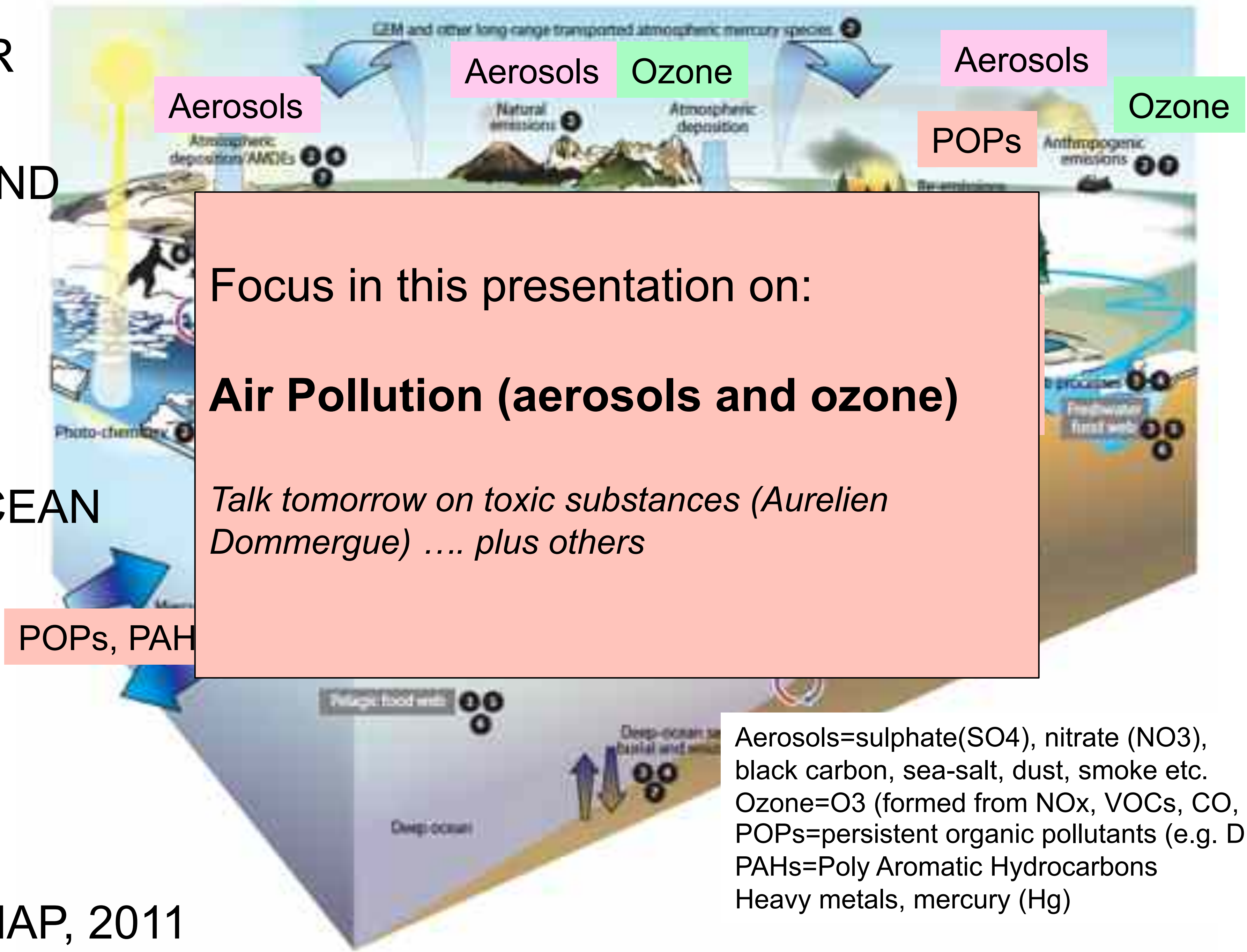
AMAP, 2011

Arctic Pollution – what is it?

AIR

LAND

OCEAN



Focus in this presentation on:

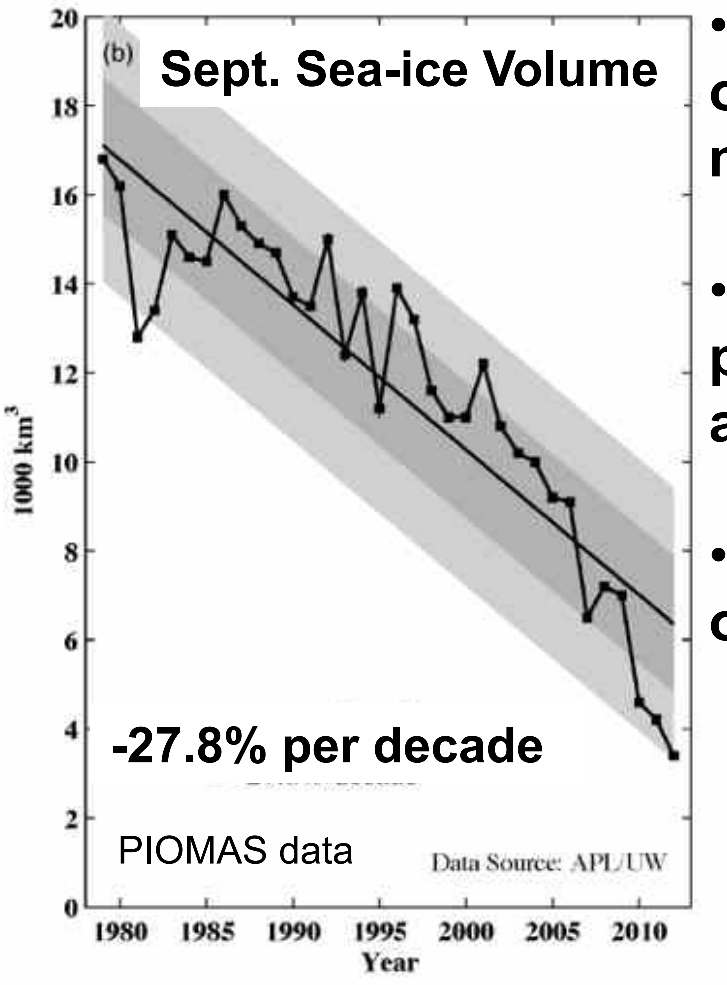
Air Pollution (aerosols and ozone)

Talk tomorrow on toxic substances (Aurelien Dommergue) …. plus others

Aerosols=sulphate(SO4), nitrate (NO3), black carbon, sea-salt, dust, smoke etc.
Ozone=O3 (formed from NOx, VOCs, CO, CH4)
POPs=persistent organic pollutants (e.g. DDT)
PAHs=Poly Aromatic Hydrocarbons
Heavy metals, mercury (Hg)

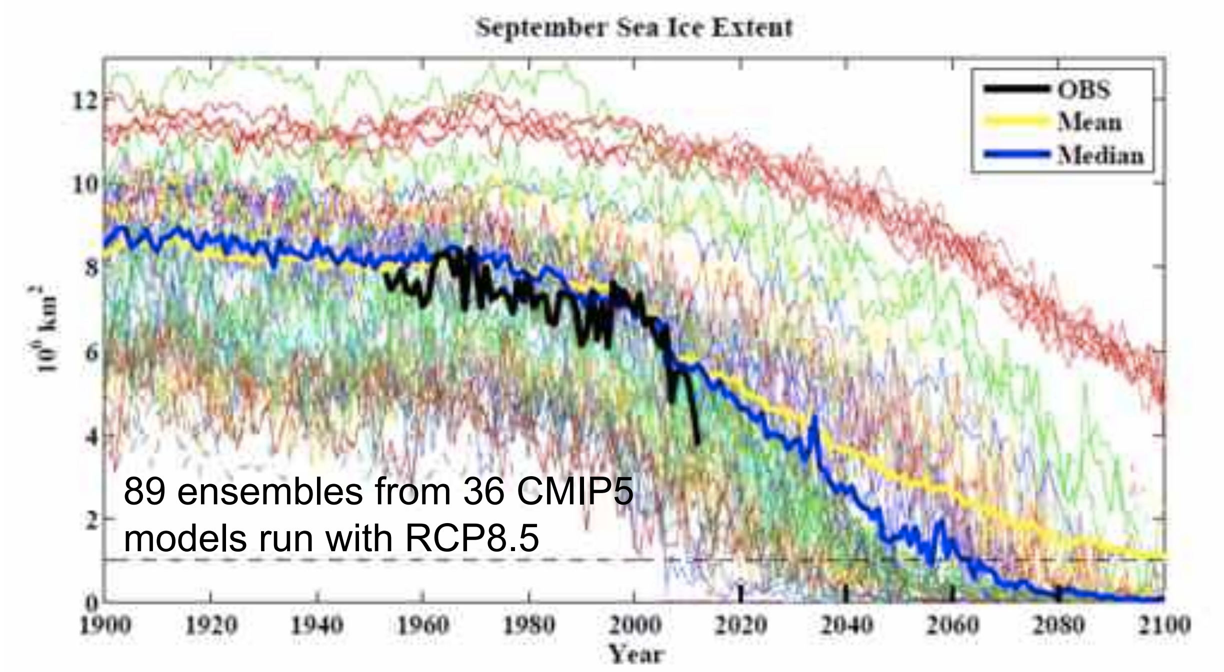
AMAP, 2011

Air Pollution - Motivation: Sea-ice decline



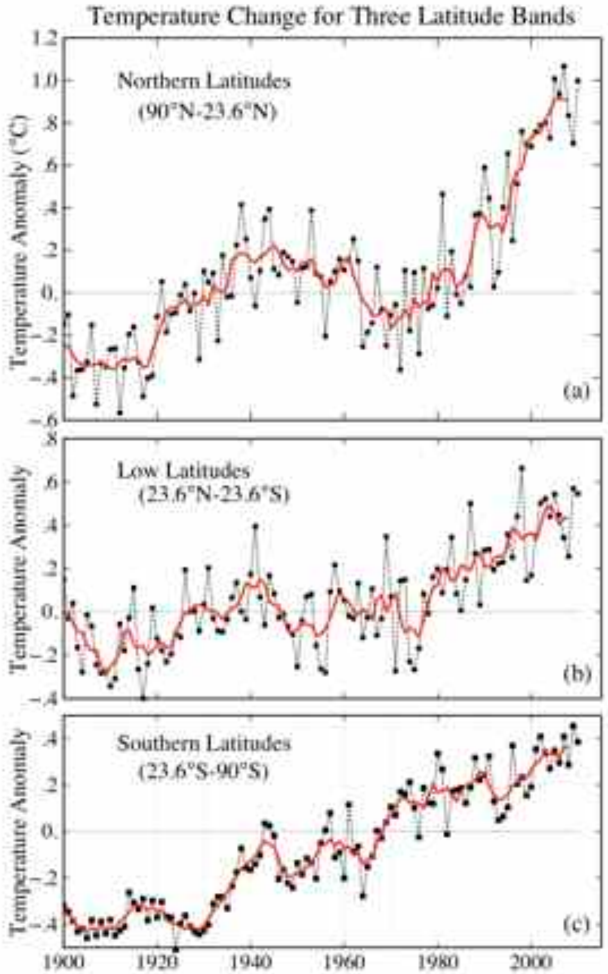
Overland and Wang, GRL (2013)

- Observations show much faster disappearance of Arctic summer sea-ice (2020-2030) than IPCC models (2040-2060)
- Why? Atmosphere-ice-ocean feedbacks – possibly representation of Arctic clouds and aerosol-cloud interactions
- Implications for Arctic shipping & exploitation of resources (local pollution)

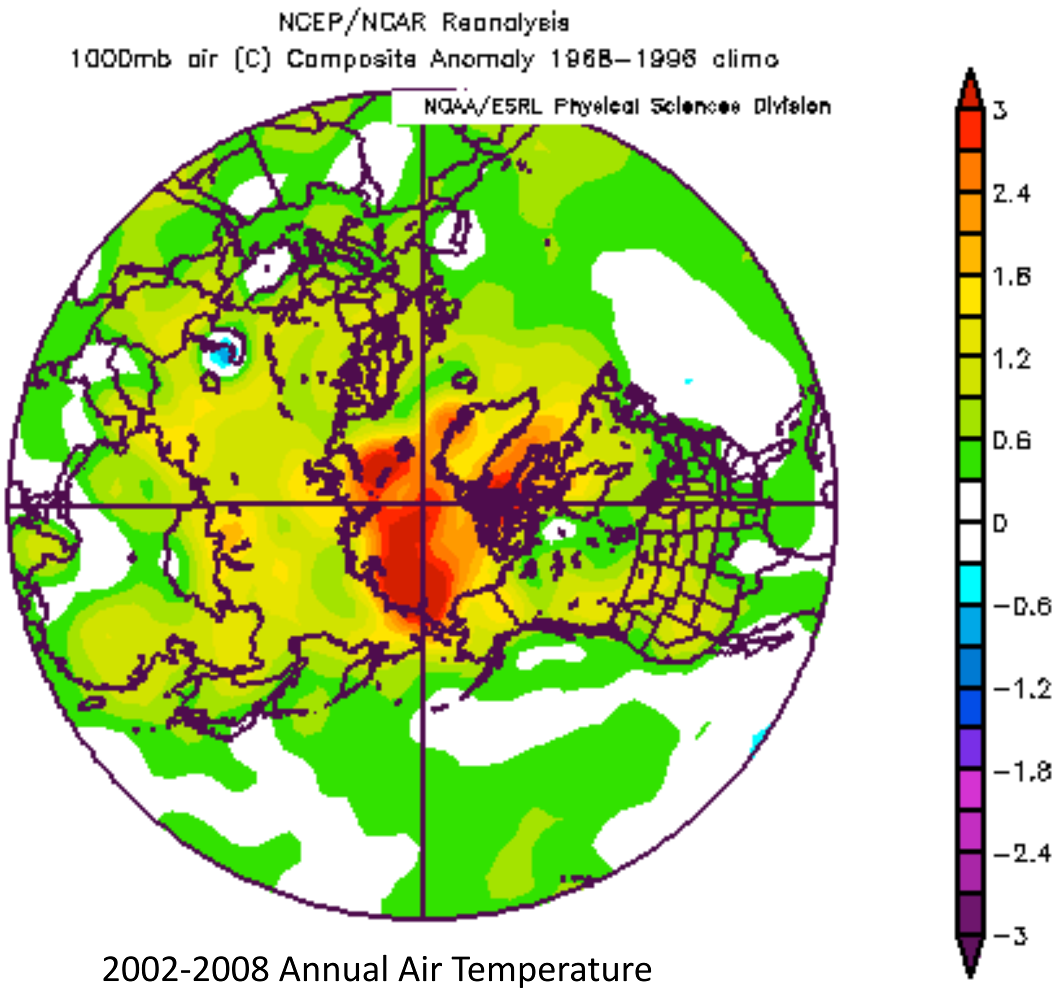


Air Pollution - Motivation: Arctic Amplifcation

The Arctic is Earth's fastest-warming region

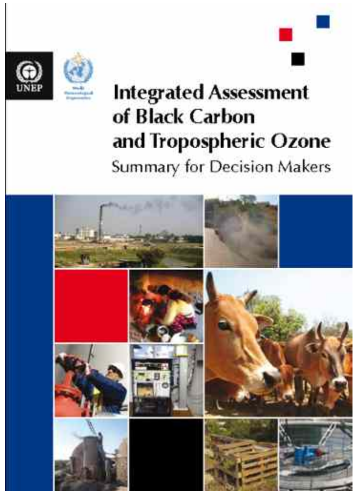


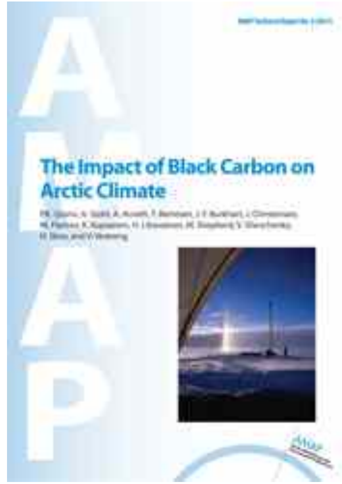
http://data.giss.nasa.gov/gistemp/



2002-2008 Annual Air Temperature Anomalies Relative to 1968-1996

CO2 + warming pollutants (ozone, black carbon) + methane





Motivating questions:

What is the contribution of pollutants (ozone and aerosols) and methane to Arctic climate change?

A lot of interest in mitigating short-lived pollutants (also climate forcers), e.g. UNEP, **Climate & Clean Air Coalition** (http://www.unep.org/ccac/), Arctic Council AMAP Expert Group on Black Carbon & Ozone

To what extent will Arctic warming lead to new local sources of Arctic pollution (e.g. shipping, oil/gas extraction) that can impact climate, regional air quality & ecosystems (deposition)?

Ozone Sources & Impacts

Ozone:

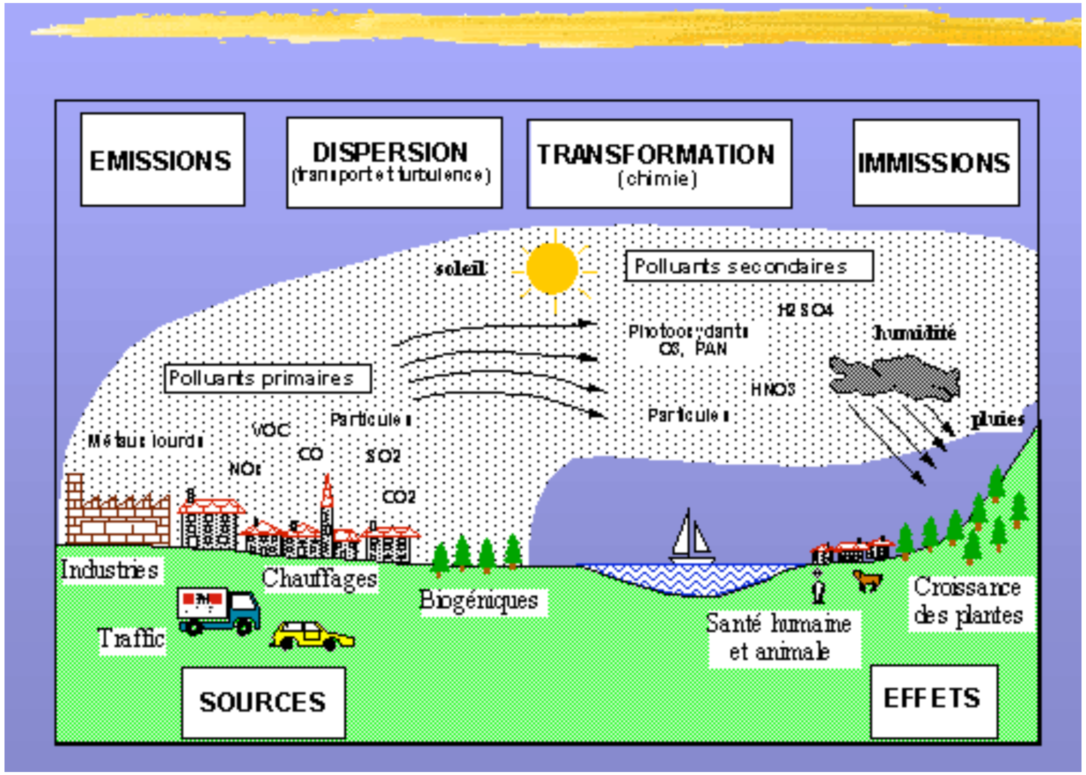
Secondary pollutant produced from precursor gas emissions (NOx, CO, hydrocarbons, CH4) → ***transported away from emission regions***

Anthropogenic emissions:

Combustion (power generation, vehicles, shipping), industrial processes, agriculture fires, ..

Natural emissions:

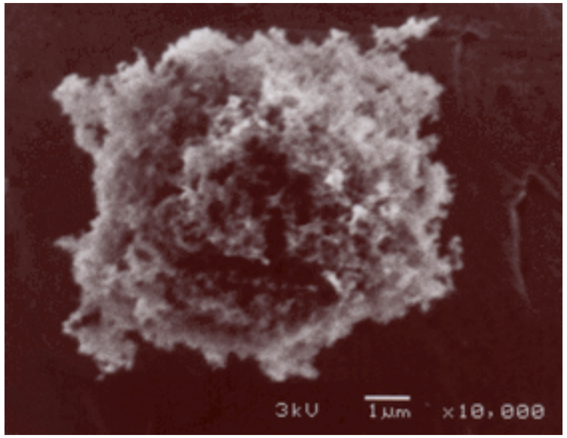
Forest fires, lightning, soils, vegetation



Impacts (even at low concentrations):

- Human health (> 35 ppbv)
- Vegetation (crops) (8hr ave > 40 ppbv)
- Climate (poss. 25% surface temp. warming)

Aerosol Sources



Aerosols:

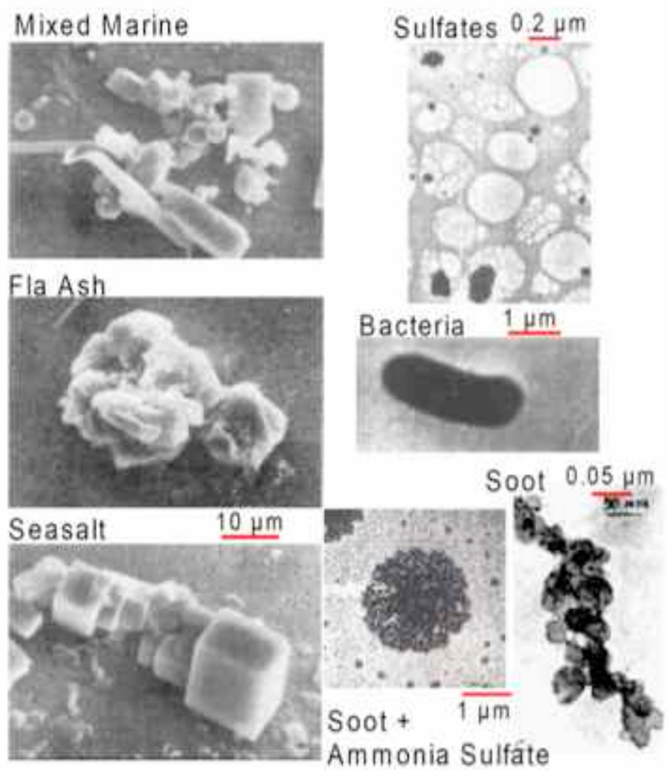
Many types, often mixed (sulphate (SO4), nitrate (NO3), black carbon, organics, etc.)

Anthropogenic emissions:

Combustion (power generation, vehicles), industrial processes, agriculture fires, ….

Natural emissions:

Oceans (DMS→sulphate, sea-salt), boreal forest fires, dust, ….



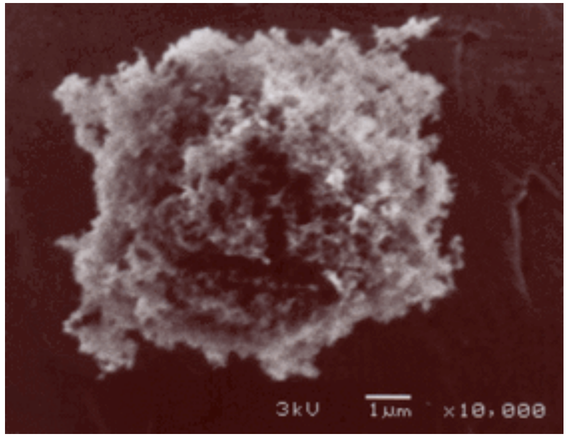
Aerosol Impacts

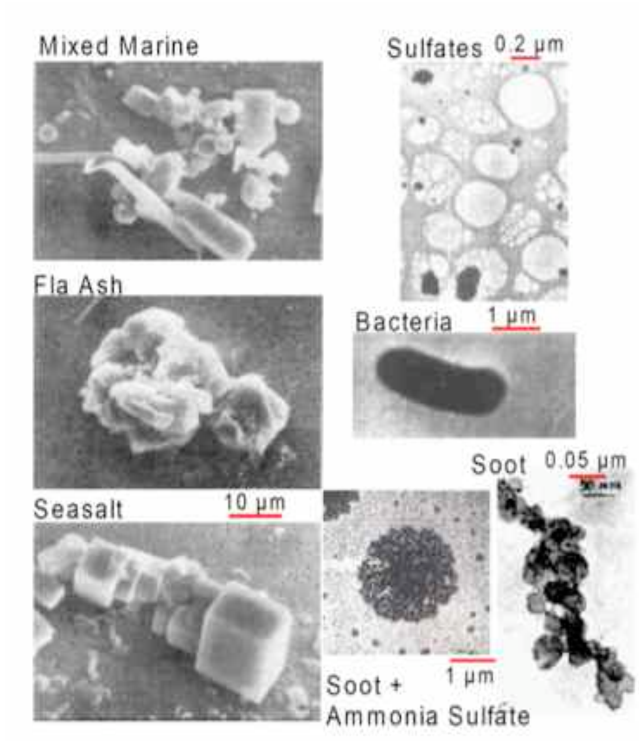
- **Regional air quality** (health) impacts even at very low concentrations

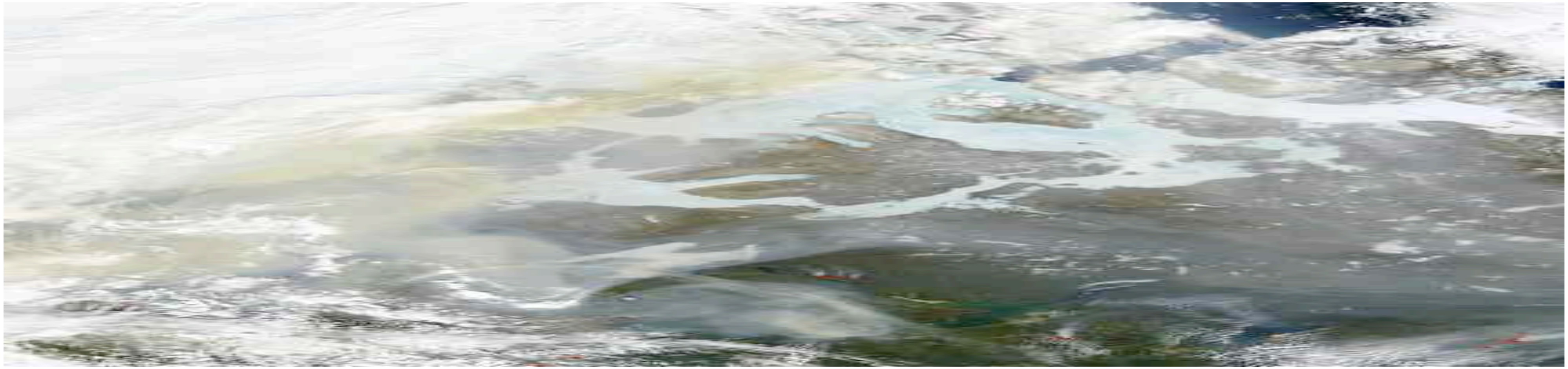
- **Visibility** (Arctic Haze) – long-range transport

- **Climate**
  - aerosols can warm (e.g. black carbon) or cool (e.g. sulphate) the atmosphere
  - deposition of aerosols (soot, dust) on snow/ice can change (darken) the surface albedo (→earlier snow-melt)
  - Aerosol-cloud interactions (indirect effects)
  - **Black carbon** may be second most important climate warming agent (*RF=1.1 Wm*$^{-2}$) after CO_2 (Bond et al., 2013)

- **Deposition** to ecosystems (e.g. nitrate, sulphate)







Long-range Transport of Pollution to the Arctic

- Observations
- Transport pathways & pollution origins (past, present, ….)
- Pollution processing during transport ….

”Dirty ice” reports by Nansen and Nordenskiöld

“Everywhere where the snow from last winter has melted away, a fine dust, gray in color, and, when wet, black or dark brown, is distributed over the inland ice in a layer …”

Nordenskiöld, A. E., Science, 1883

Courtesy A Stohl (NILU)

Arctic Pollution – Arctic Haze

Pictures: A.-C. Engvall (NILU)

Arctic Haze

”Arctic Haze” first observed in the 1950s by pilots (perhaps earlier)

Few pollution sources within the Arctic itself, Arctic remote from major pollution sources

→ **Long-range transport**

Removal processes are slow or absent (scavenging by rainout, photochemical processes)

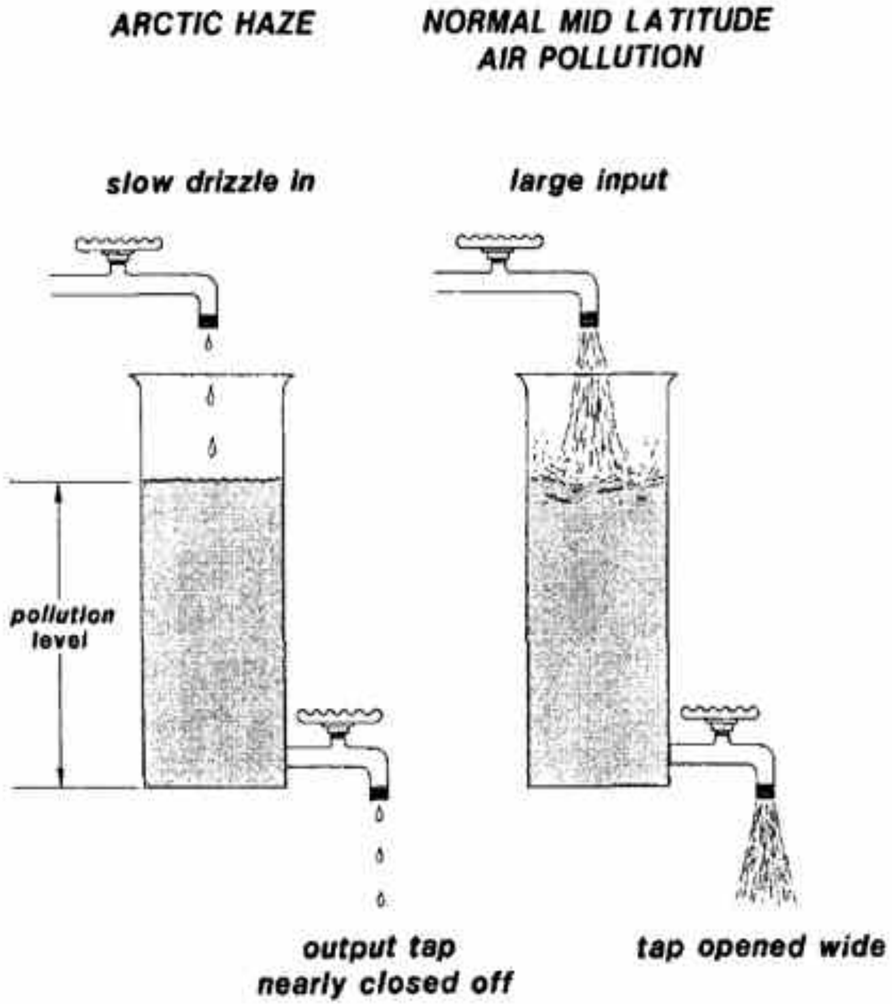
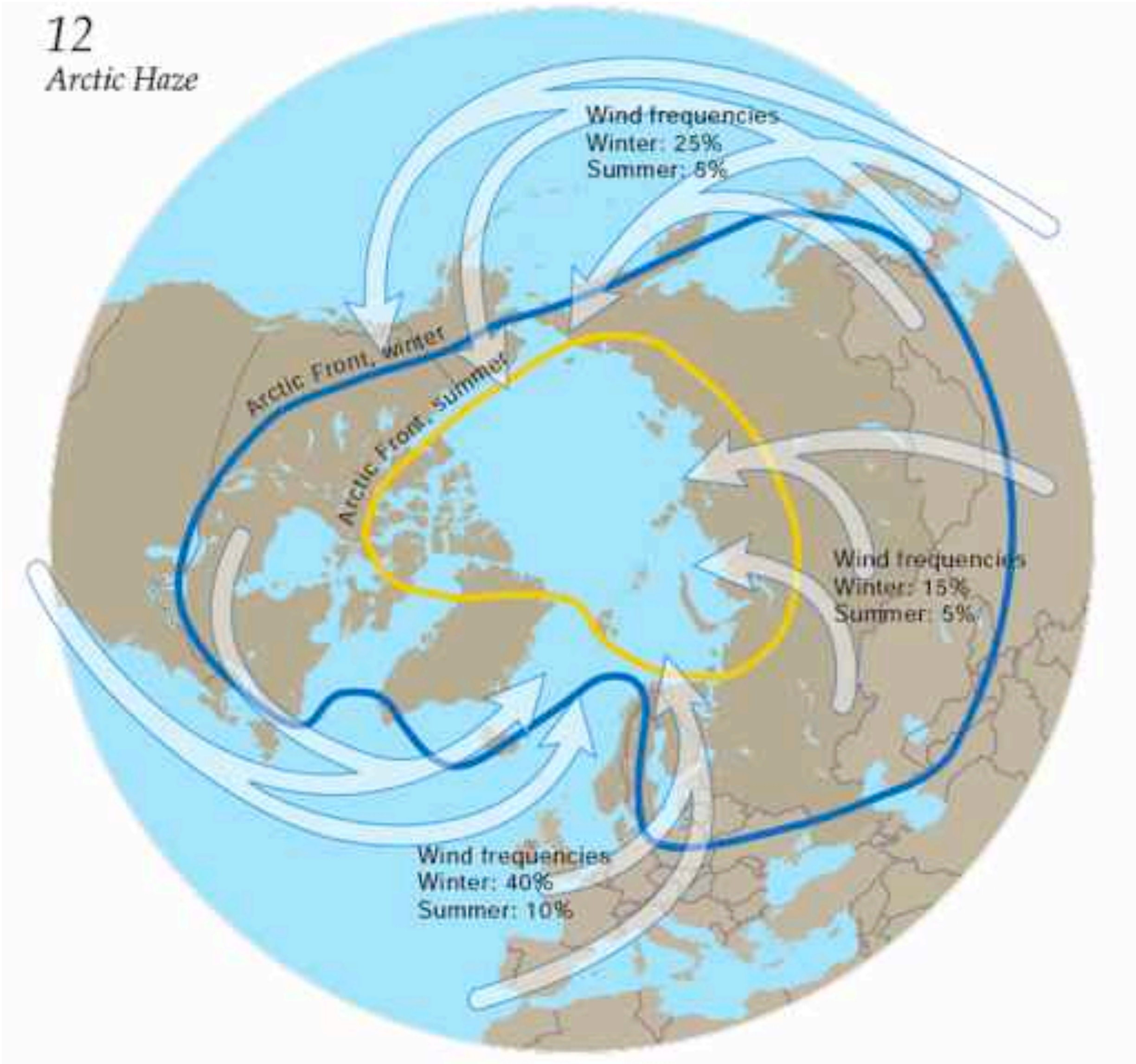


FIG. 6. Cartoon showing why pollution builds up in the Arctic regions. Removal mechanisms for scrubbing the atmosphere clean operate more slowly in the polar regions.

Shaw (1995): **BAMS** *76*, 2403-2413

Average transport patterns to the Arctic

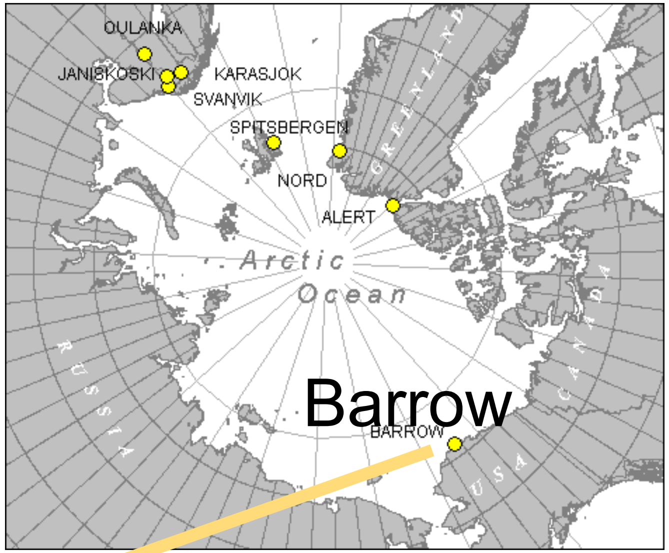


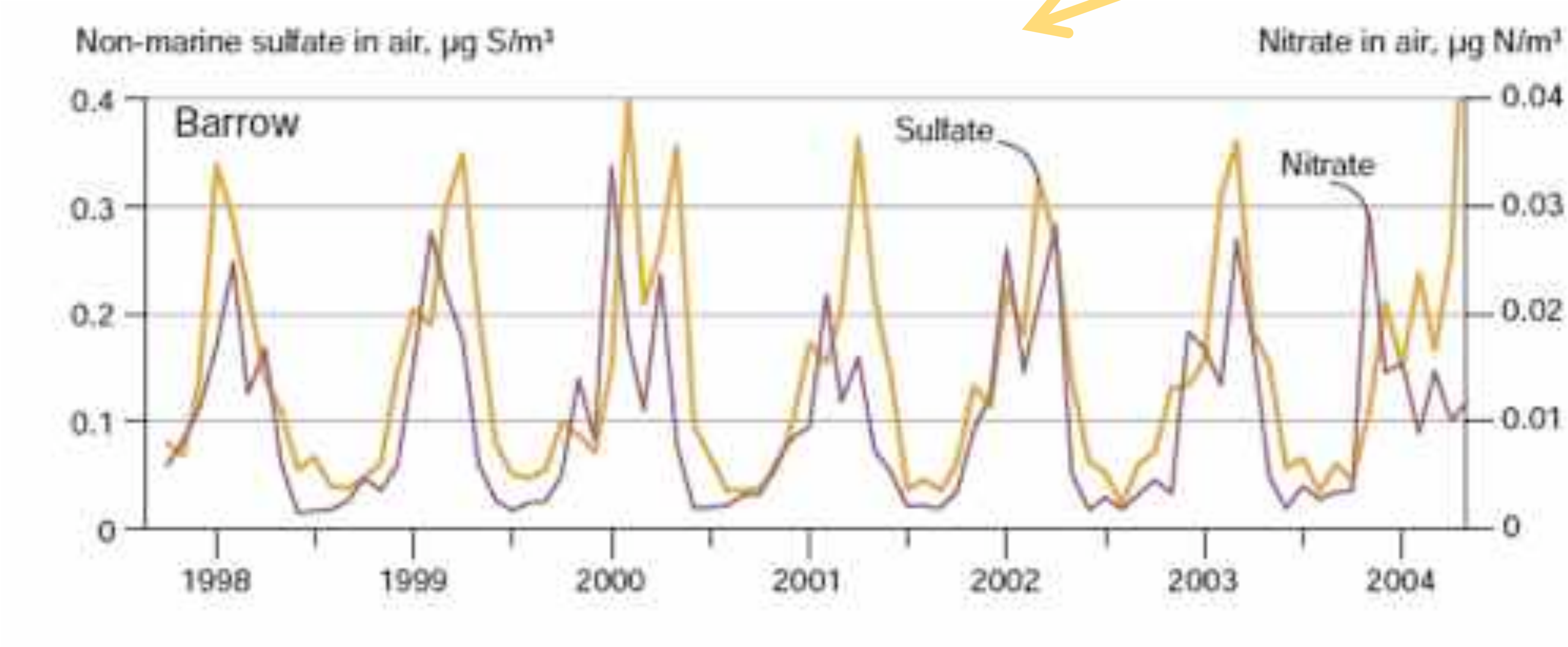
Winter: anthropogenic pollution (Europe, Asia)

Summer: higher latitude sources important (e.g. fires in Siberia, Alaska/ Canada)

AMAP, 2006

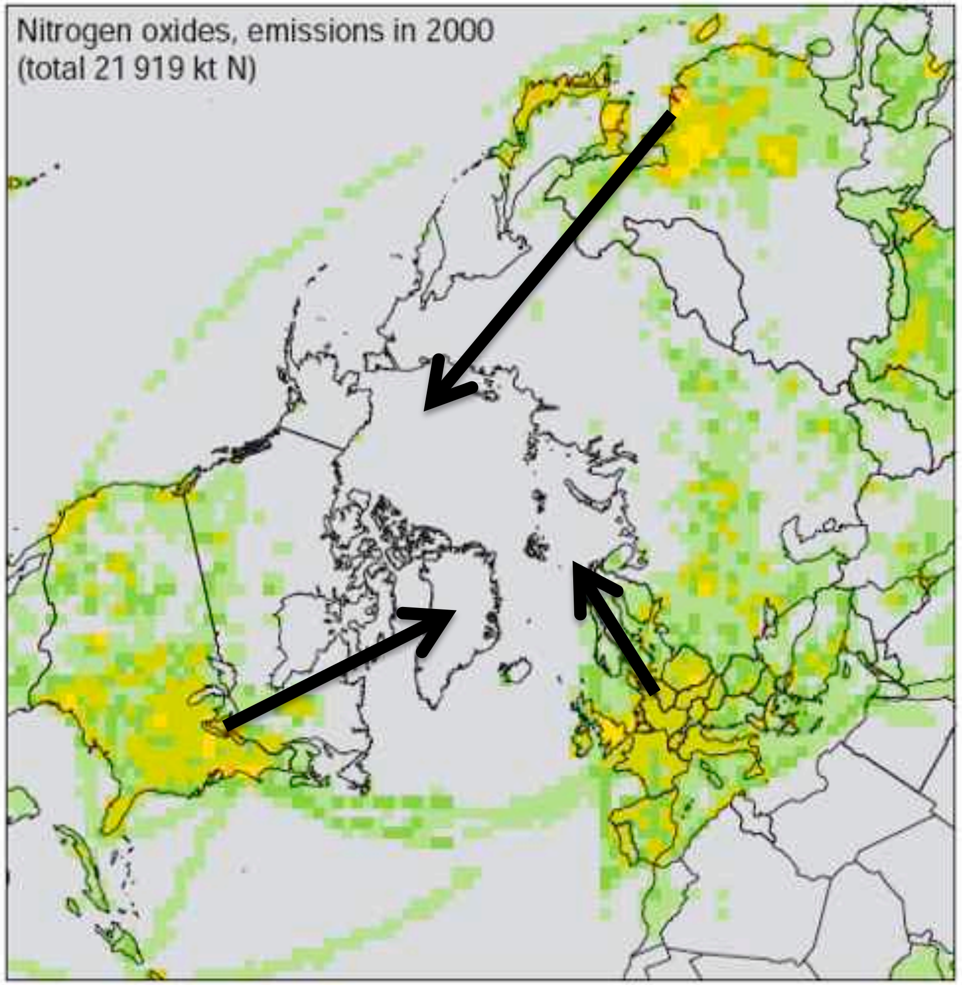
Arctic Haze: maximum pollution in winter & early spring (surface sites)



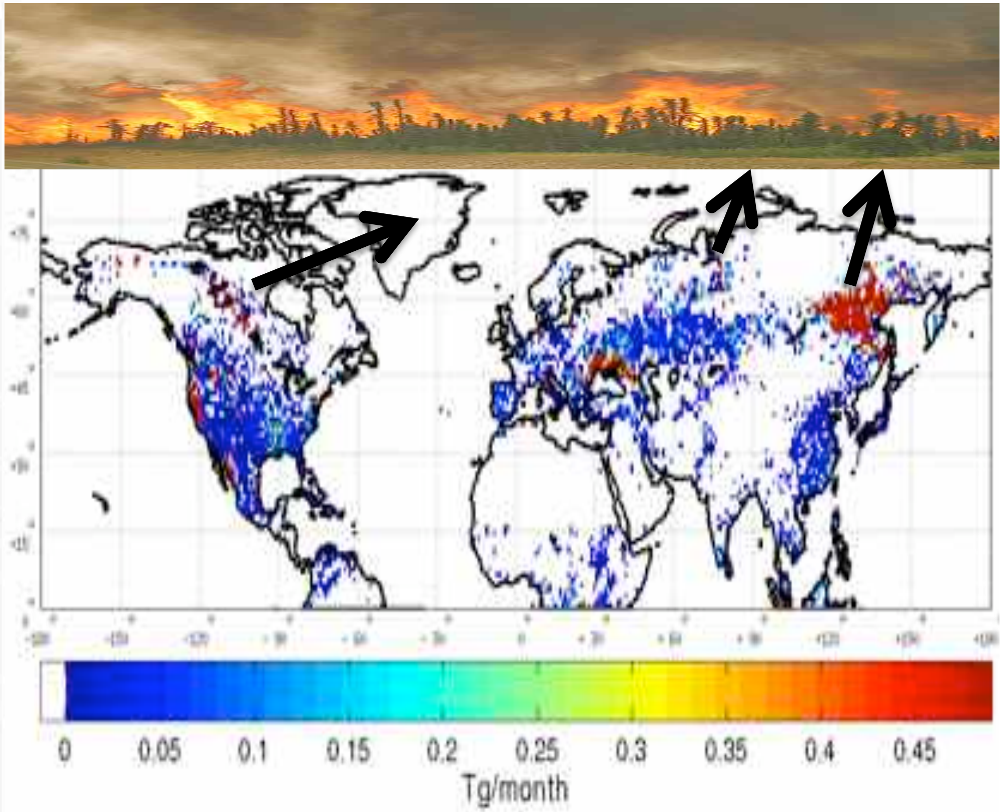


AMAP, 2006

Emissions: Anthropogenic & Fires

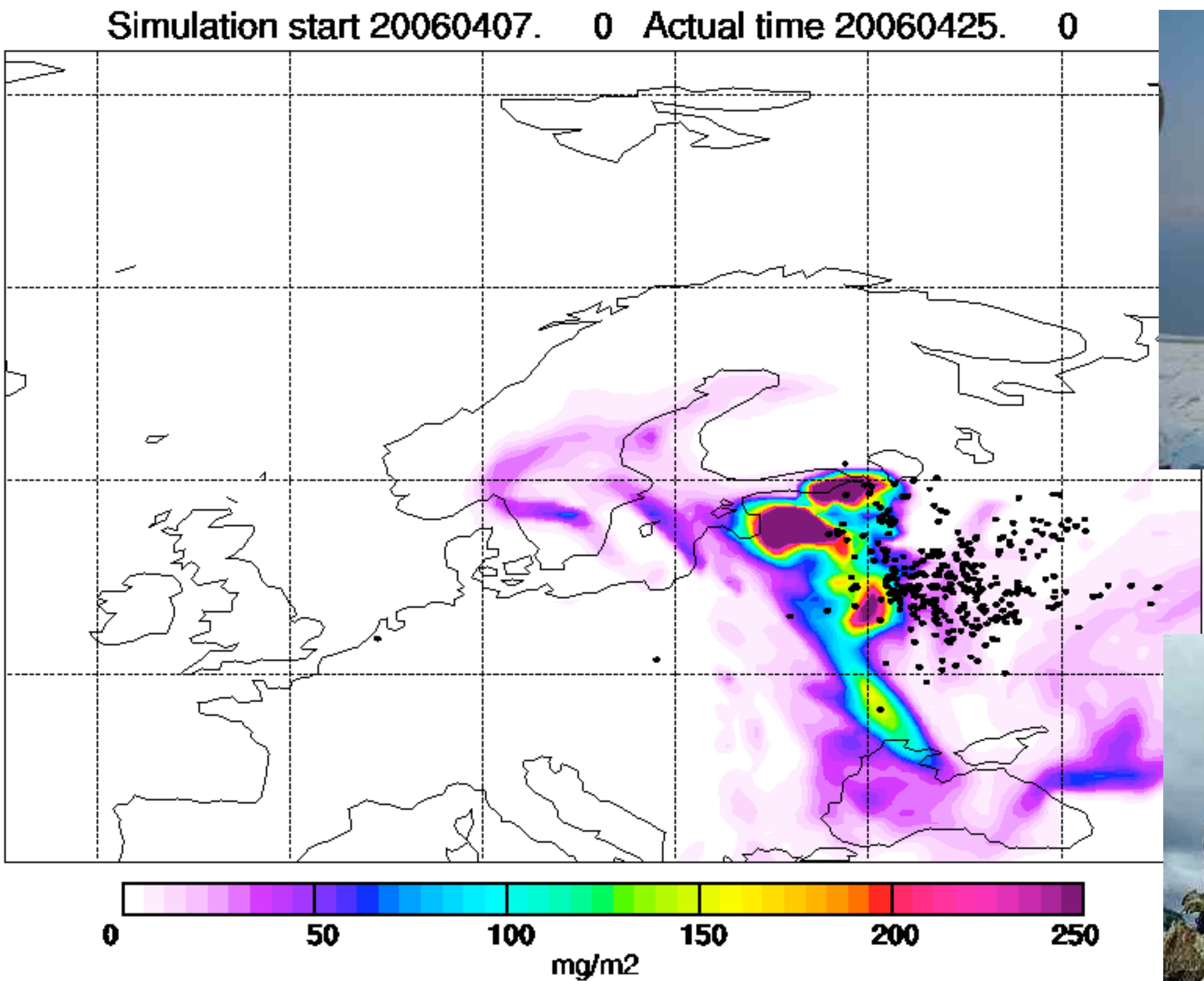


Anthropogenic: combustion, power generation, etc.
Differences in regional trends



Agricultural burning: spring/ autumn
Boreal forest fires: spring/ summer
Large year to year variations

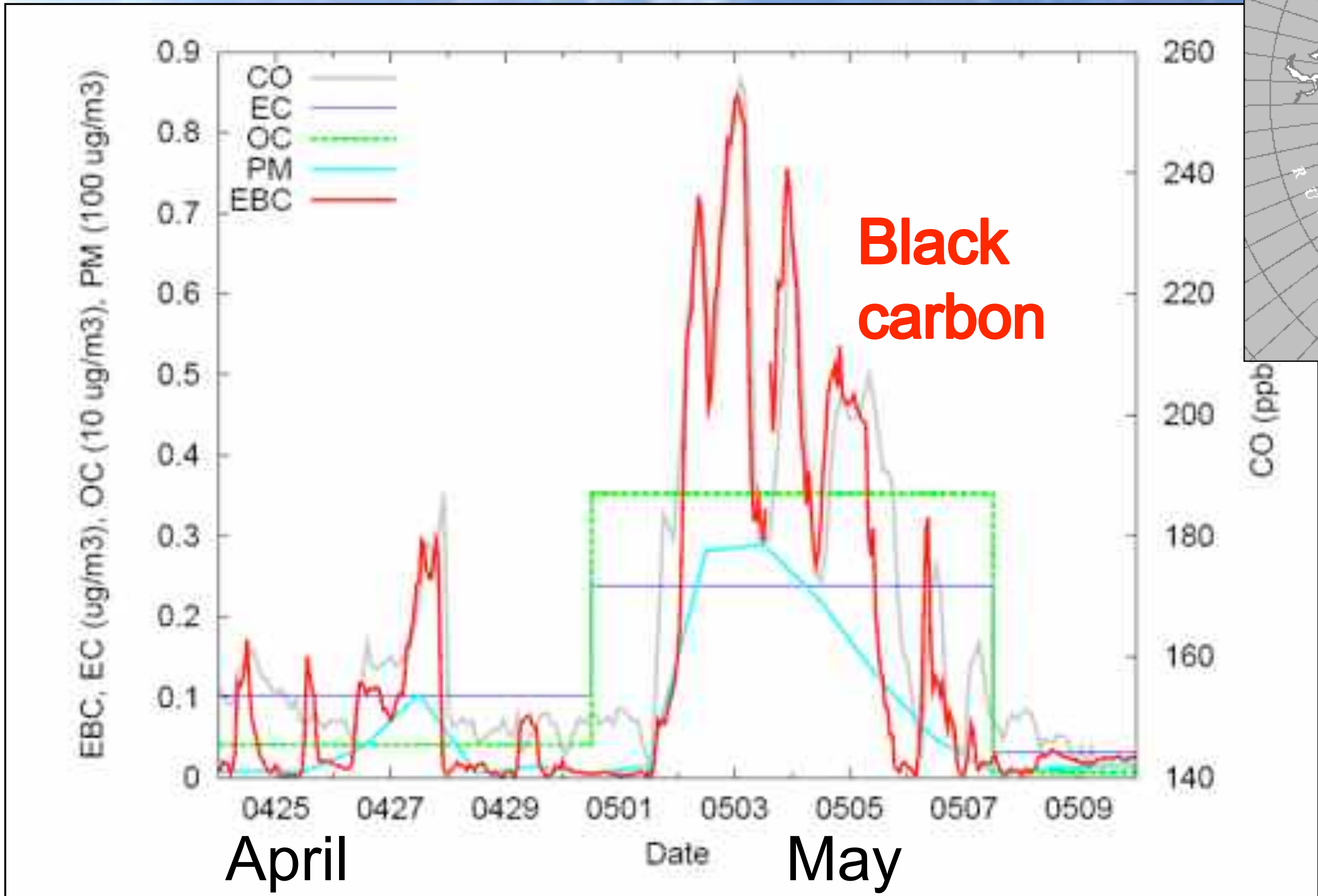
Spring: transport of agricultural fire plumes



Stohl et al., ACP, 2007

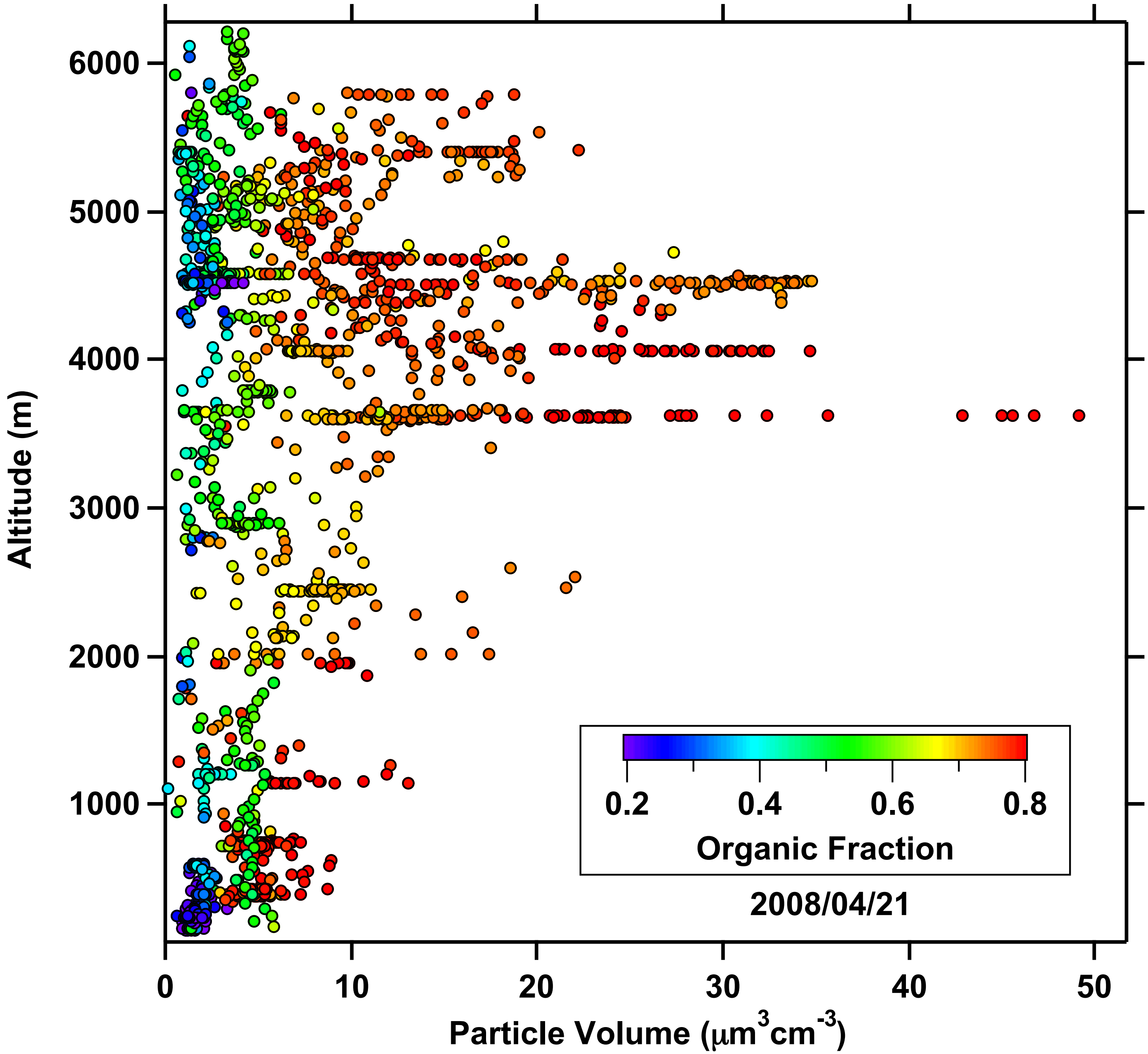
Pollution Event: Svalbard

New records measured for practically all observed compounds (carbon monoxide, aerosols, etc.) (surface)



Stohl et al. (2007)

Spring 2008: Boreal fire plumes superimposed on sulfate haze "background"



Spring 2008

Decoupling between PBL and free troposphere

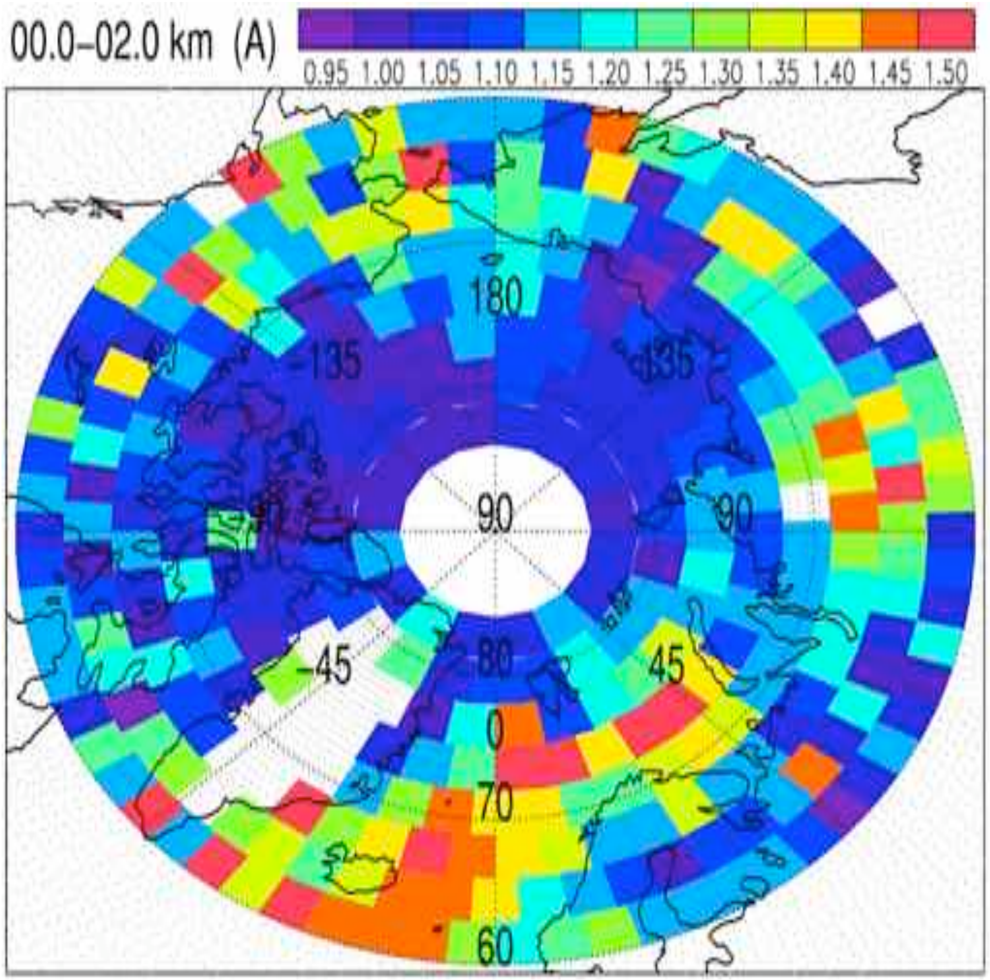
Higher concentrations aloft (4-7km) ?

NOAA/P3 ARCPAC aircraft data (POLARCAT)

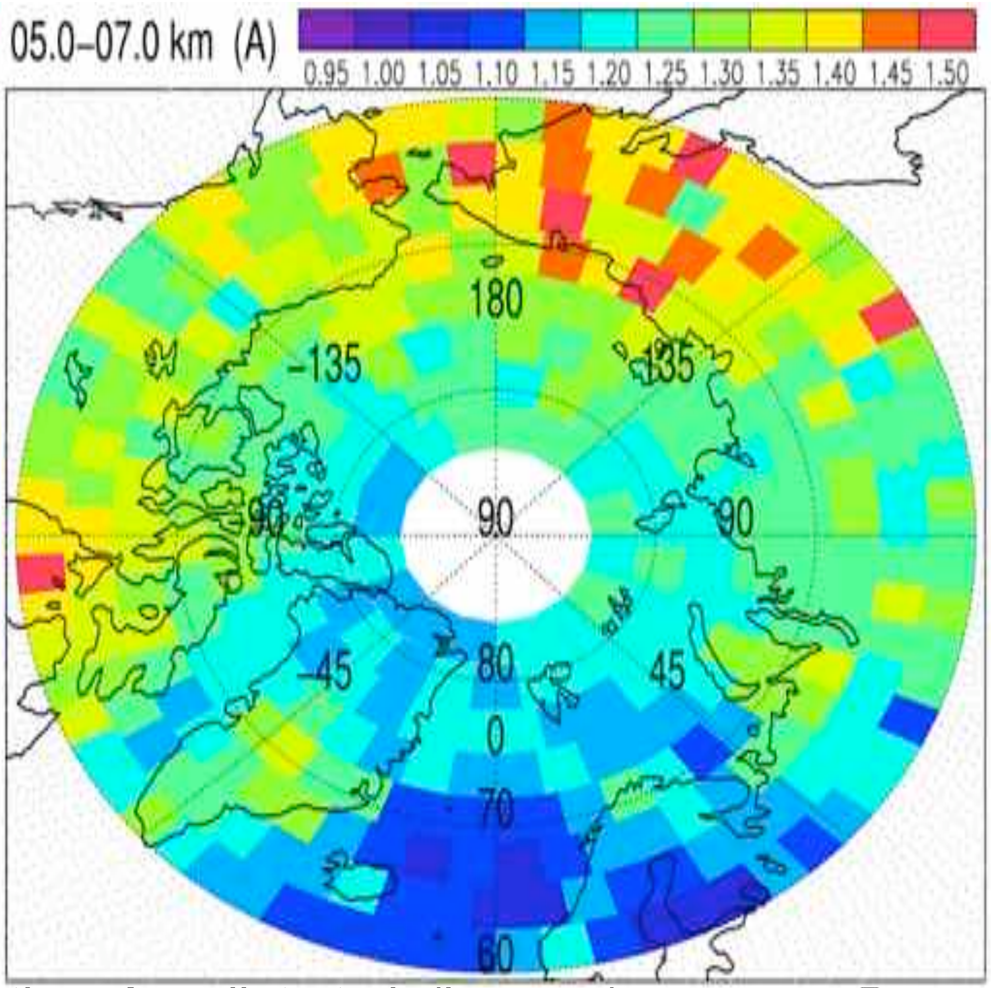
courtesy Chuck Brock et al./NOAA

Aerosol distributions (CALIPSO) - April 2008

0-2 km



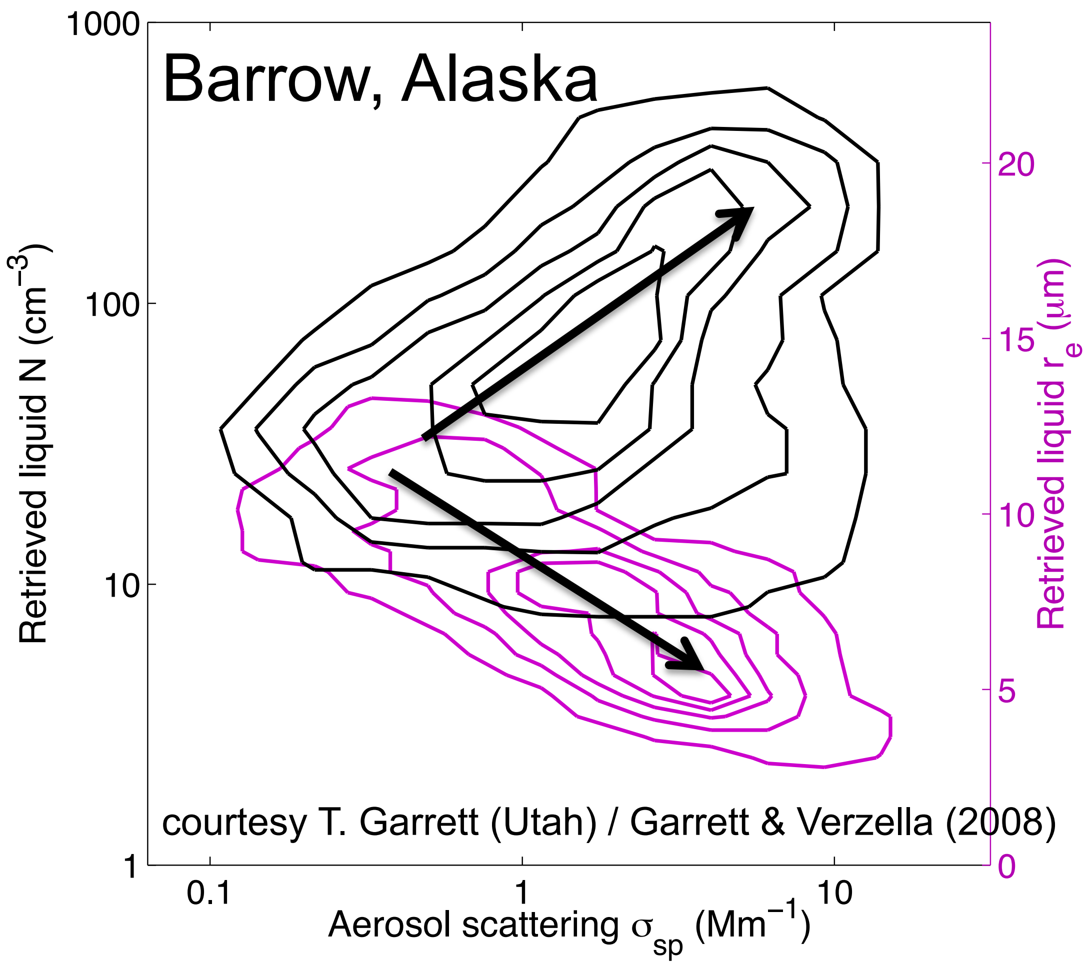
5-7 km

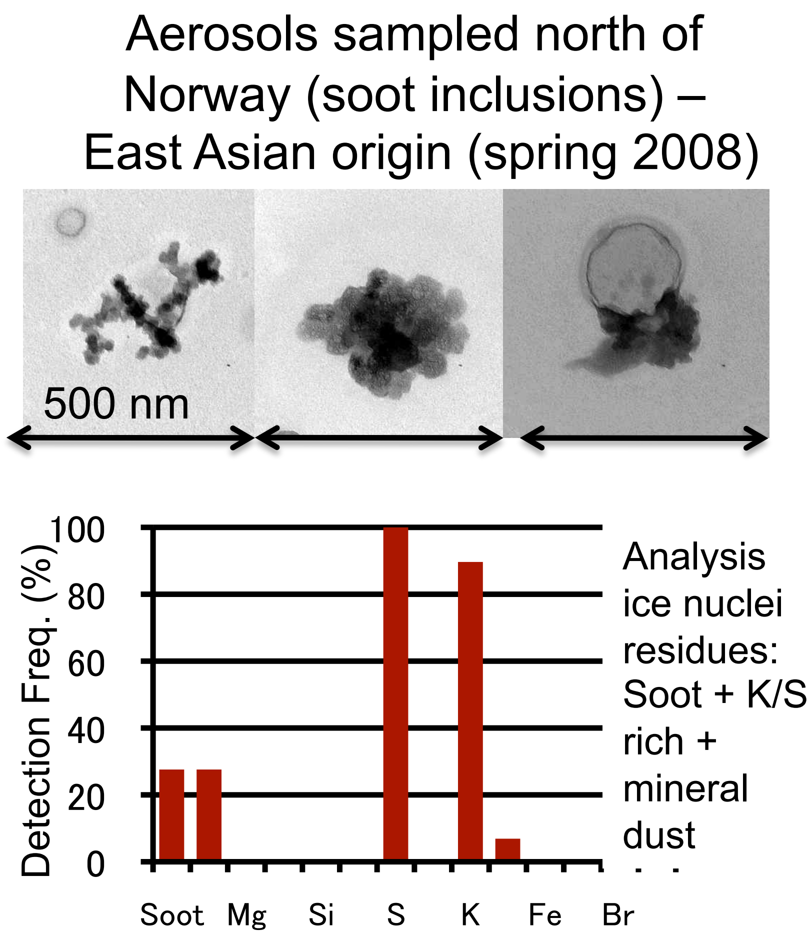


532 nm aerosol scattering ratio – Ancellet et al. (in prep.)

CLIMSLIP-ANR

Aerosols & cloud interactions





Quennehen et al. (2012)

More aerosols (effective cloud condensation nuclei):
→ smaller cloud droplets (re)
→ higher concentration droplets (N)

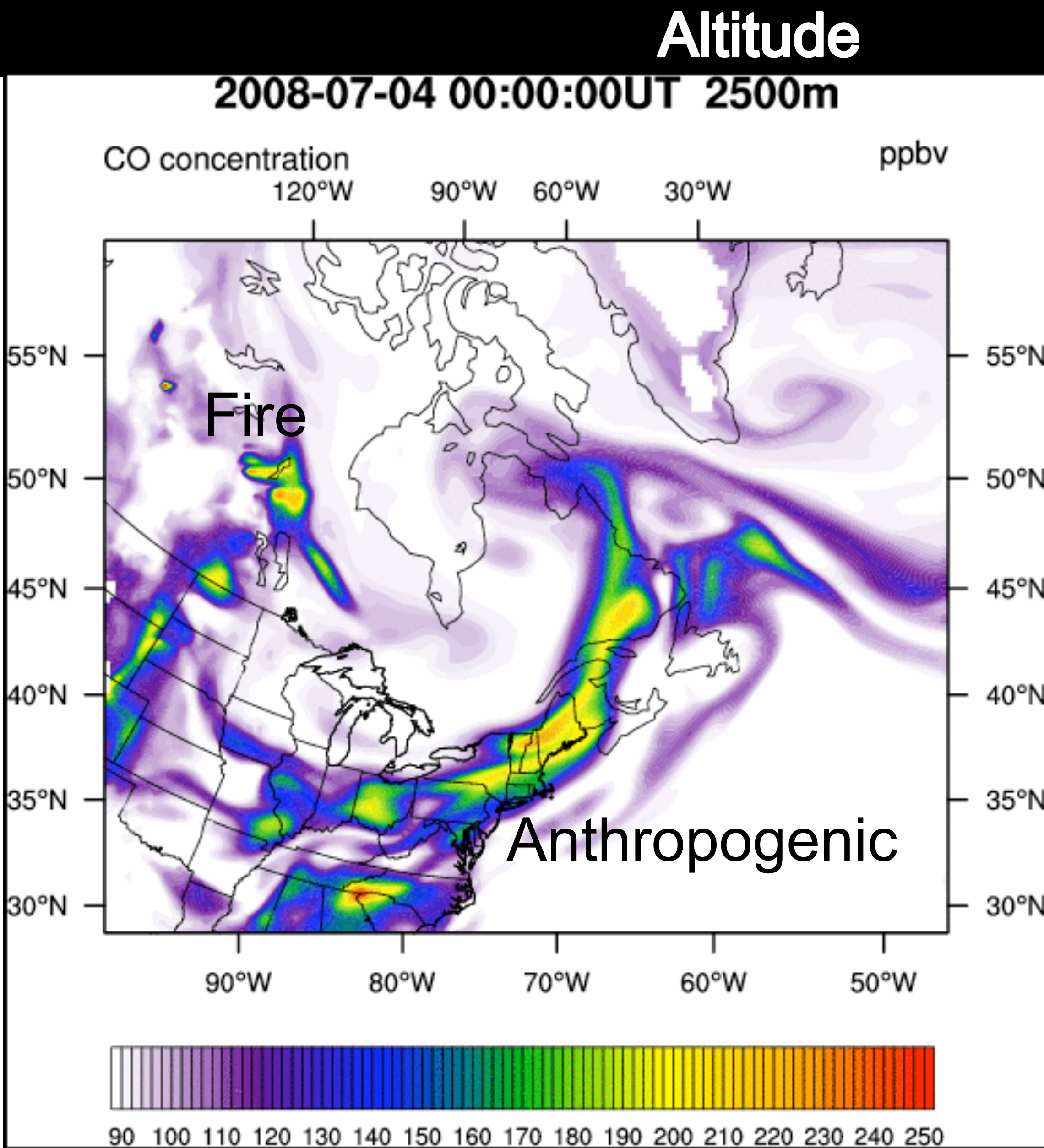
Summer:

Pollution transport from North America to Greenland

4 July – 7 July 2008

CO plumes uplifted from 1-2km to 8km by synoptic fronts

Aerosols lost by washout in summer



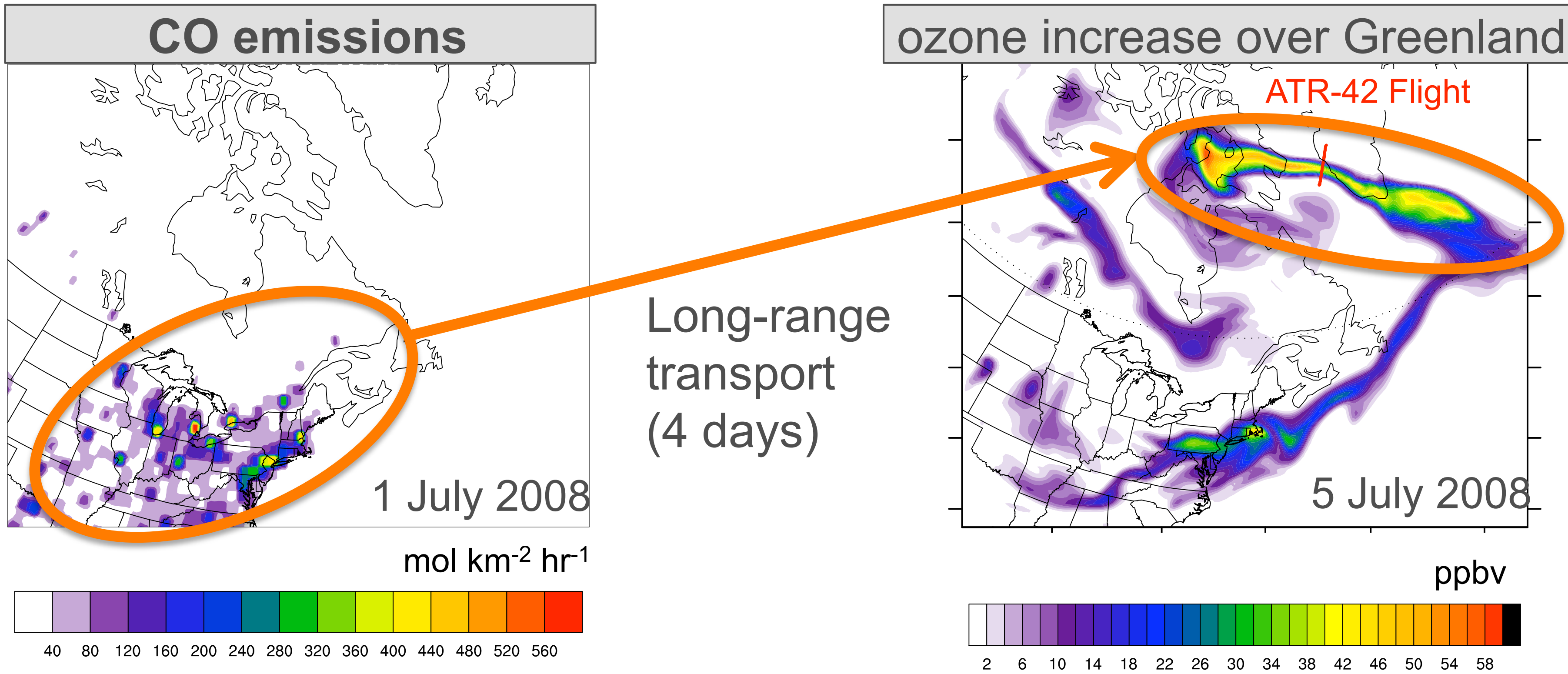
WRF-chem model simulations
Thomas et al. (2013)

CLIMSLIP-ANR

POLARCAT

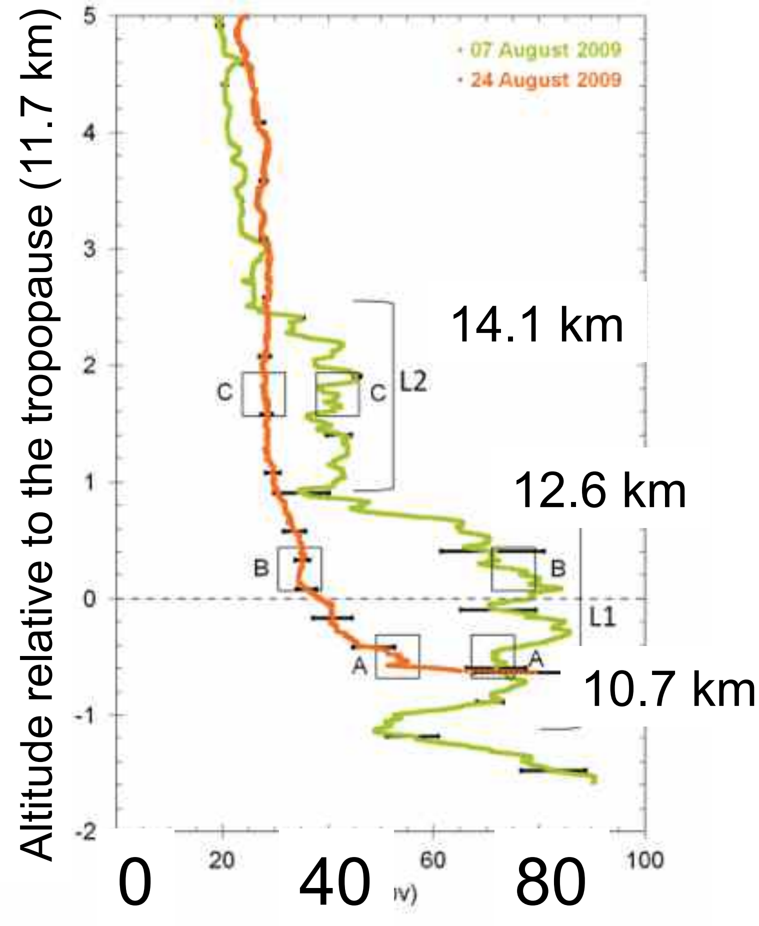
→ ozone production during long-range transport to the Arctic (summer 2008)

Thomas et al., ACP, 2013.



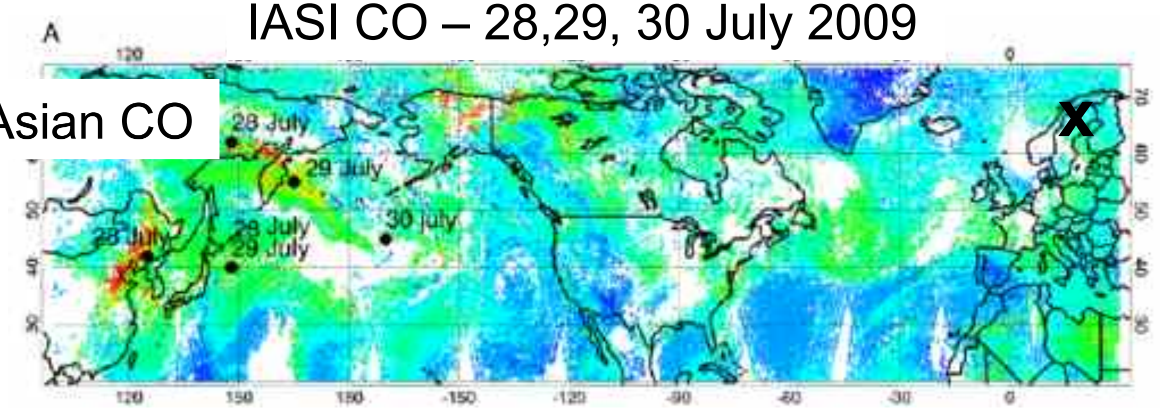
Regional model simulated significant ozone production in plumes - up to 50 ppbv - during transport to the Arctic (mainly anthropogenic + fires, in this case) → ***summer ozone max. over Greenland (Summit)***

Pollution transport into the upper troposphere & lower stratosphere (from mid-latitudes)

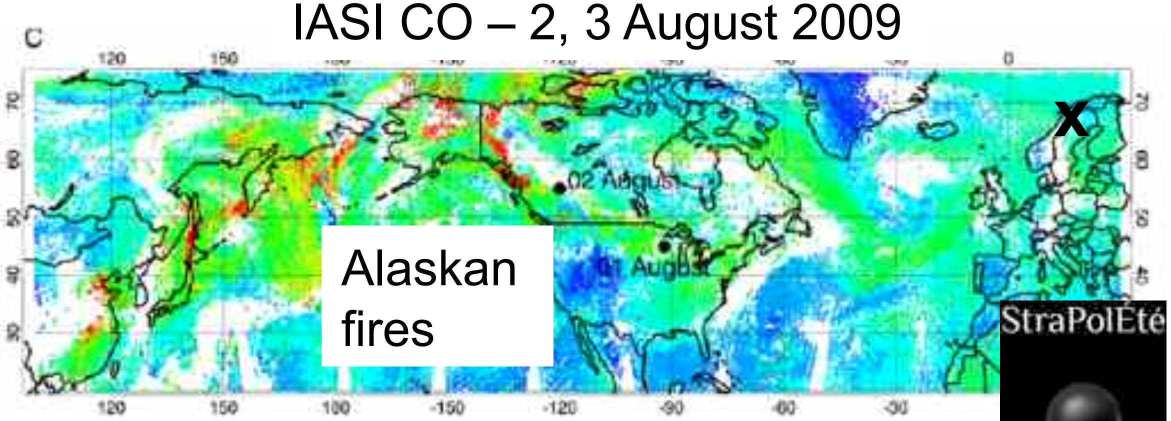


CO (ppbv)
SPIRALE balloon data, northern Sweden

IASI CO – 28,29, 30 July 2009



IASI CO – 2, 3 August 2009



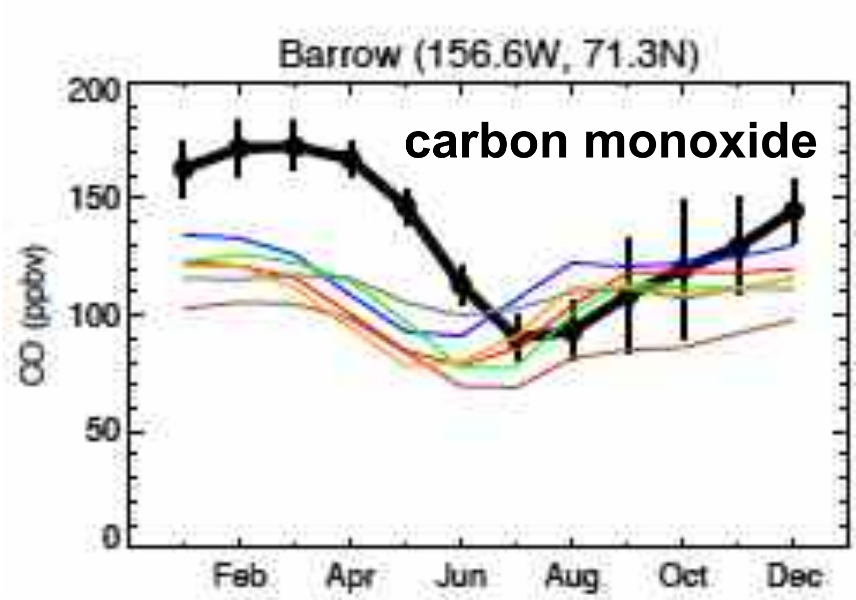
Krysztofiak et al. (2012)

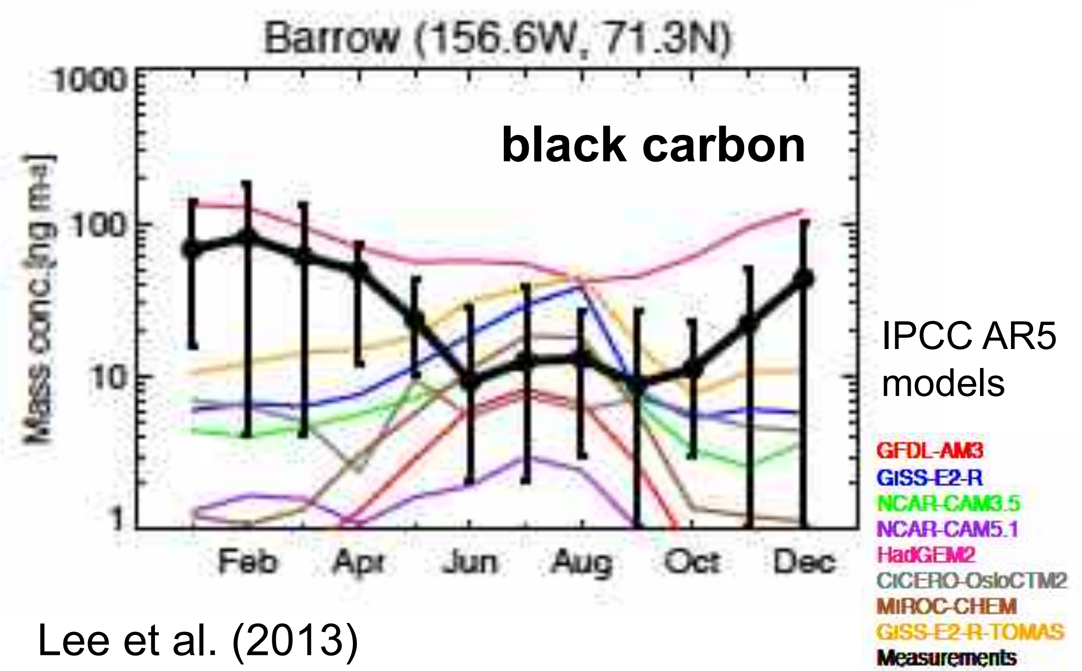
Observed seasonal cycles vs models?

Models have problems simulating seasonal of pollutants:

CO: emissions or lifetime during transport (photochemistry)

Black carbon: large variability – some recent improvements (washout, …), but ..

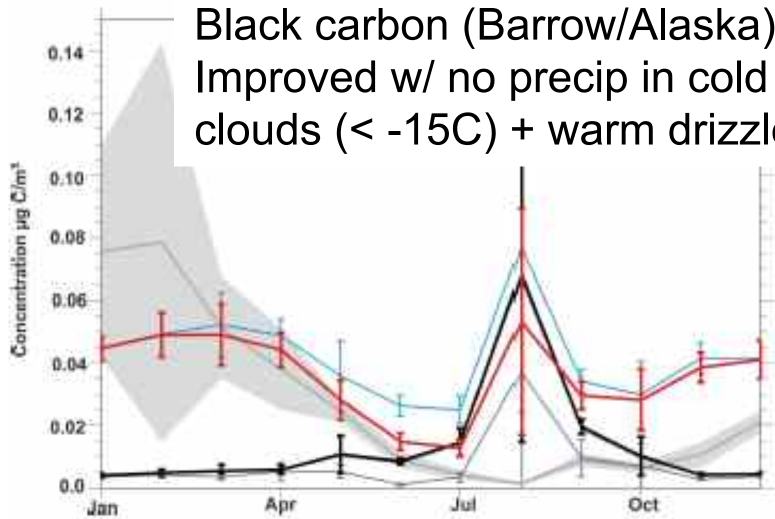




IPCC AR5 models

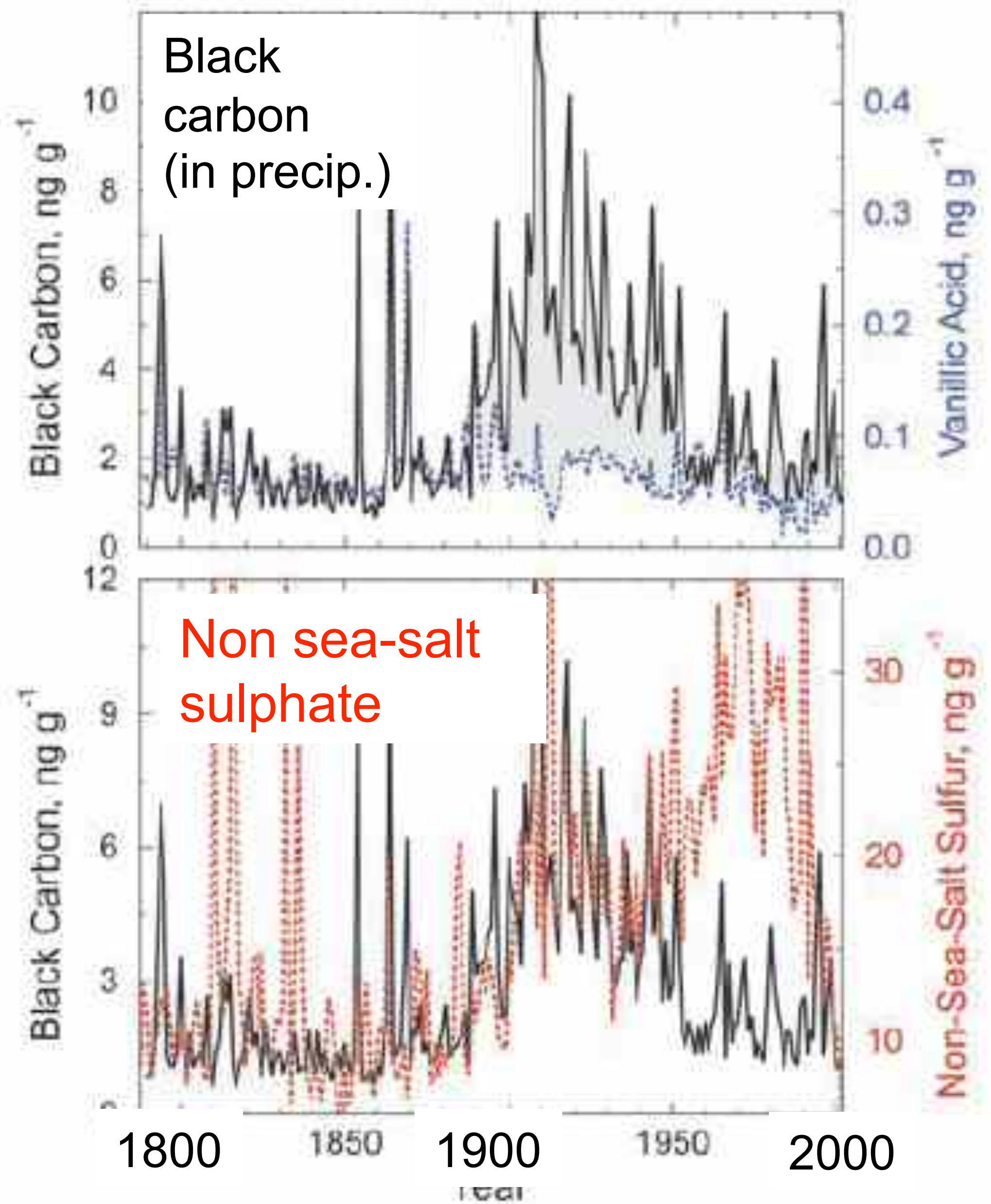
Lee et al. (2013)

Black carbon (Barrow/Alaska)
Improved w/ no precip in cold ice clouds (< -15C) + warm drizzle



Browse et al. (2012)

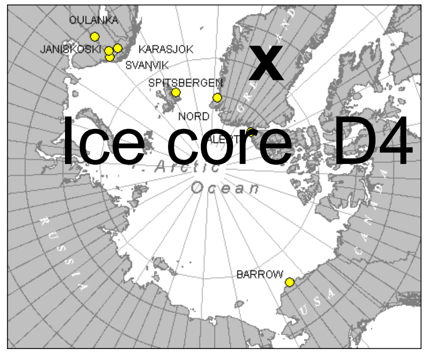
Past changes from ice cores



Significant increases in black carbon (BC) between 1900-1960 (anthropogenic origin), declined then increasing again?

Sulphate aerosol increased from 1900 up to mid-1990s, rapid decline recently …

Data from Greenland – mainly influenced by emissions from North America

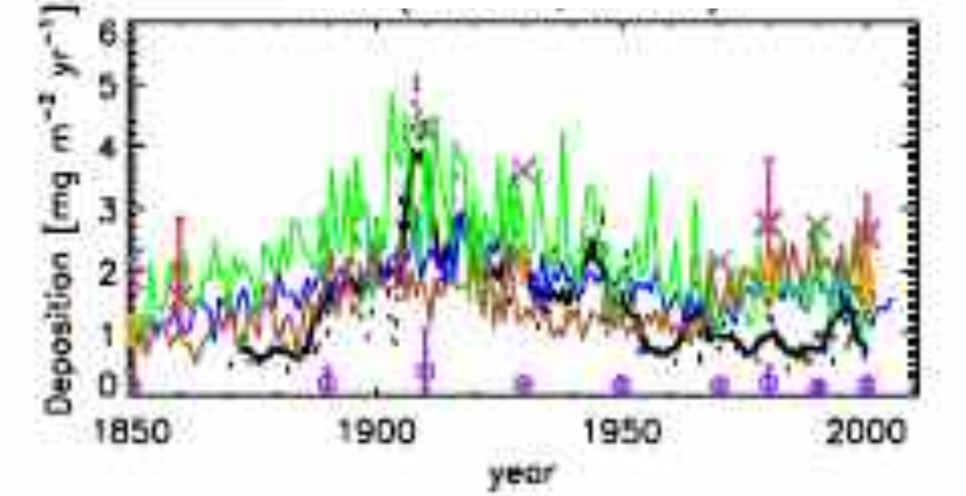


McConnell et al. (2007)

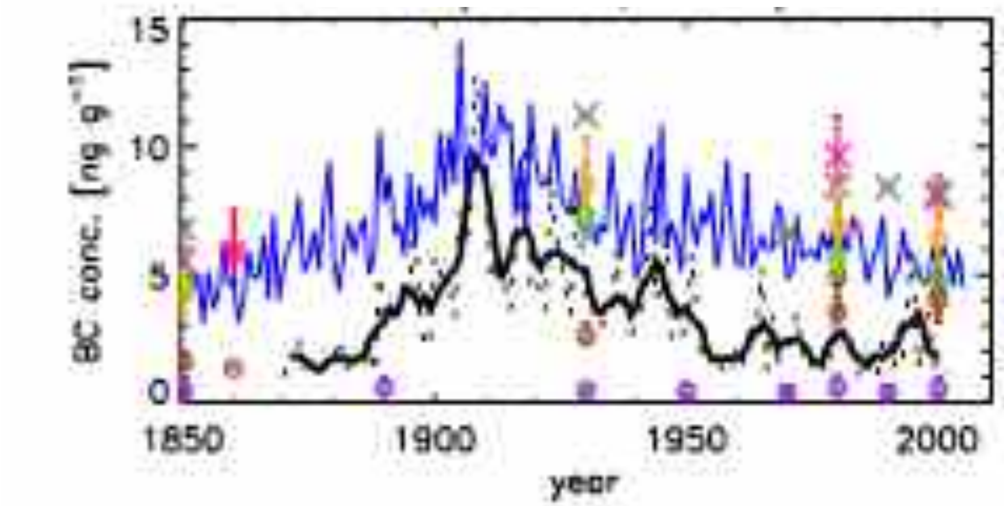
IPCC AR5 models

Ice core records vs models?

BC deposition fluxes - Greenland



BC snow concentrations - Greenland

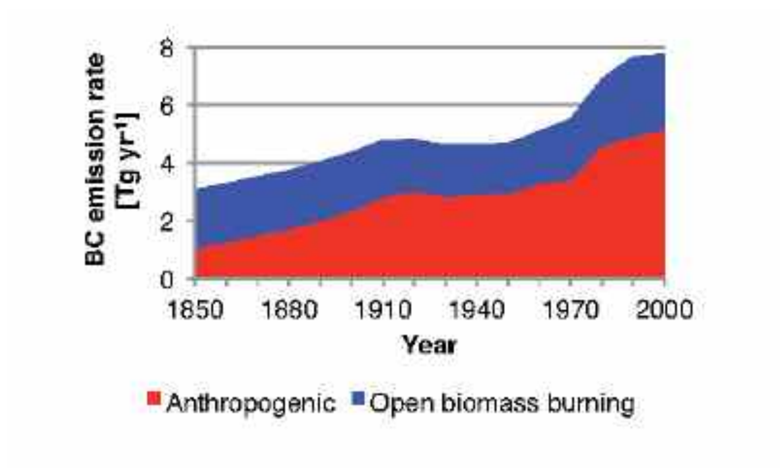


Lee et al. (2013)

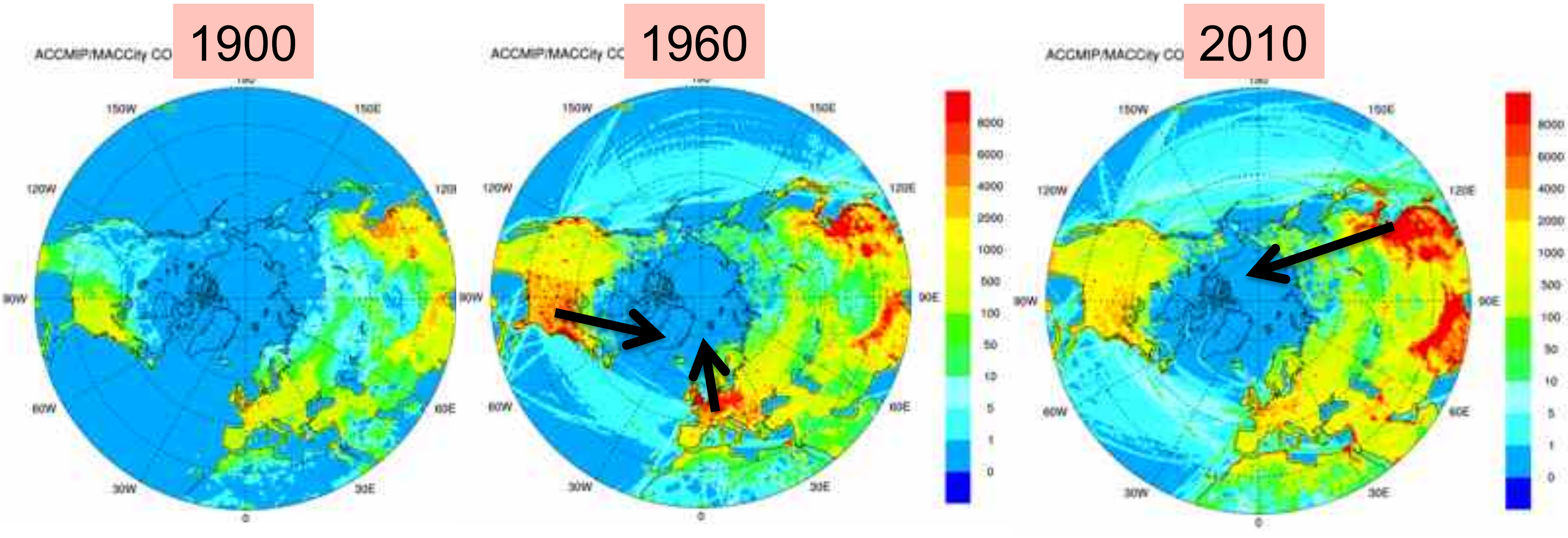
IPCC CMIP5 simulations:

Deposition fluxes of black carbon (top) generally simulated better than black carbon snow concentrations (bottom)

Modelled trends not very good from 1950 onwards → emissions?, ageing or loss processes?



Trends in anthropogenic emissions?



MaCCity CO emissions

Is this the whole story for the Arctic?

courtesy C. Granier/I. Bouarar (LATMOS)

Local Sources of Pollution:

- Shipping

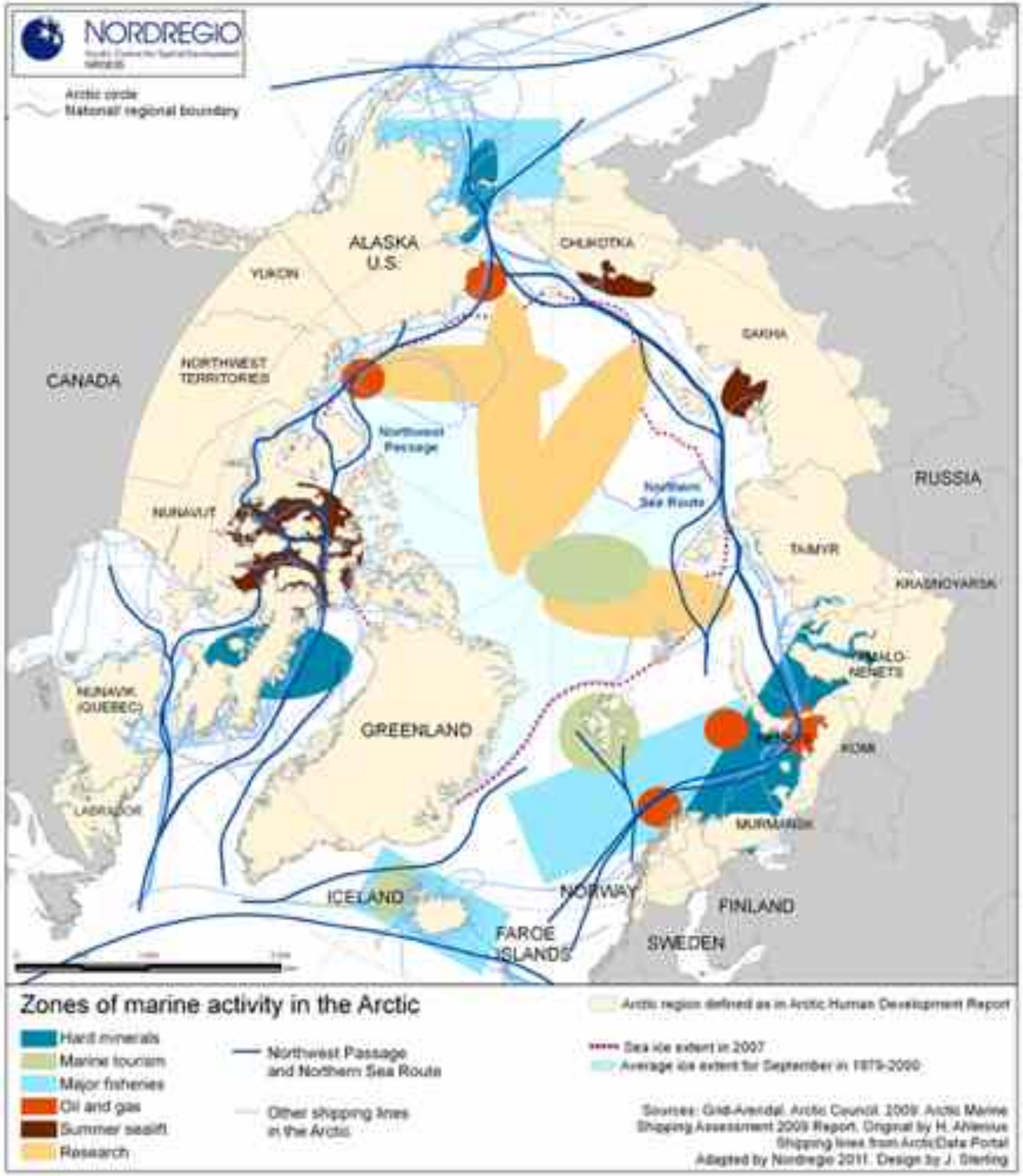
- Resource extraction (oil/gas/minerals)
- Associated infrastructure and urbanization
- Arctic – natural emissions, specific chemistry, meteorology …

Currently low (?) but likely to increase …

Significant resources in the Arctic

Oil/gas
Minerals
Fisheries

Tourism
Shipping



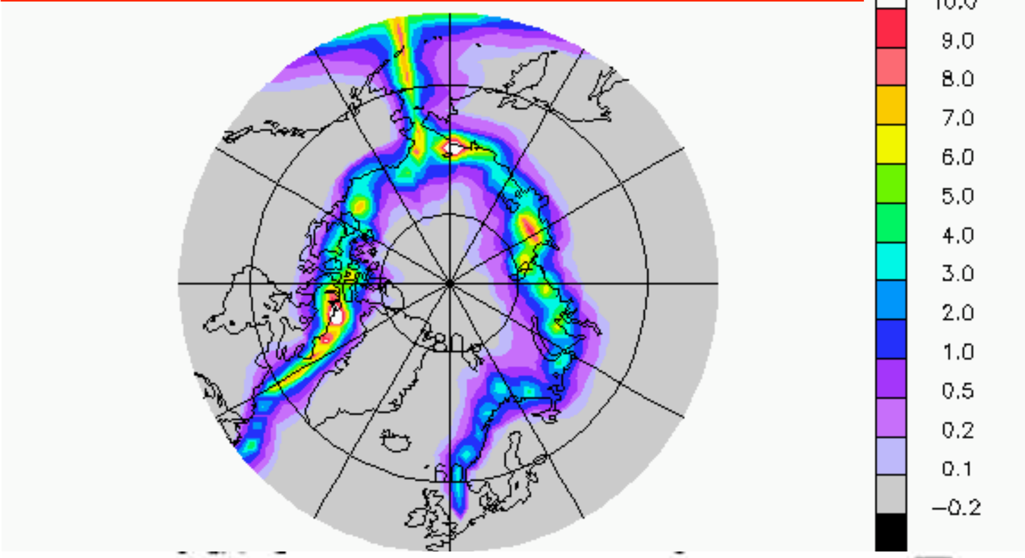
Source of pollutants:

Shipping:
NOx,VOCs, black carbon, SO2

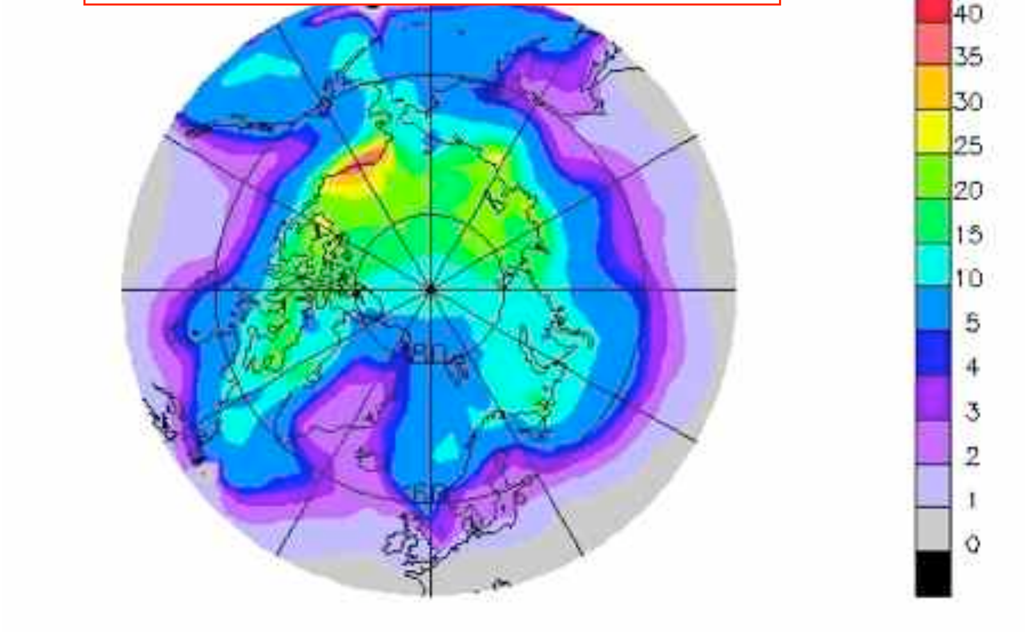
Oil/gas:
VOCs, CO, CH4, black carbon, ….

Shipping: future impacts on ozone

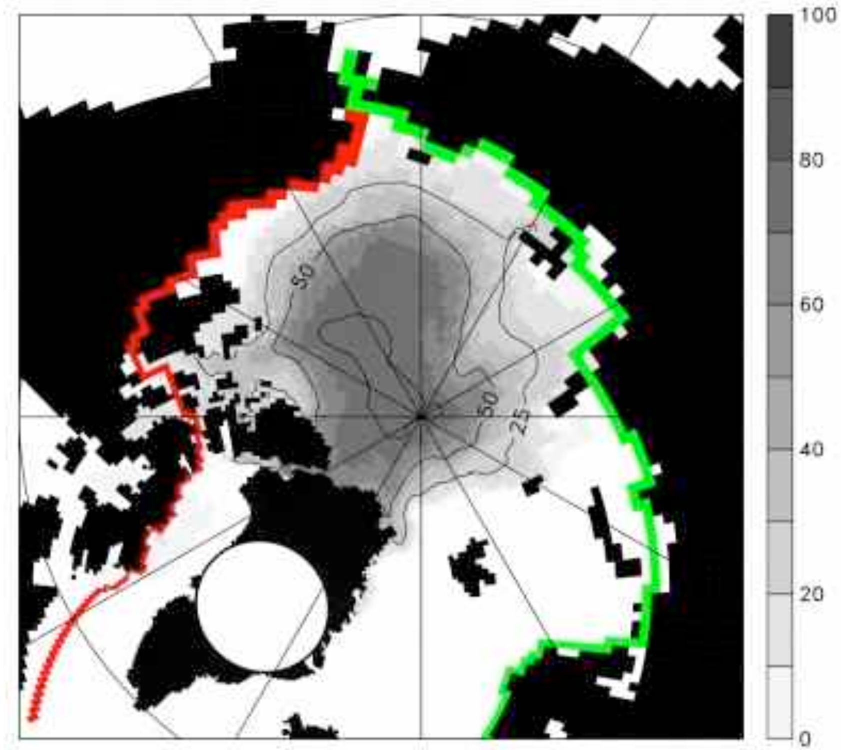
NOx difference (ppbv) - 1.4Tg yr-1 added



Surface ozone difference, ppbv



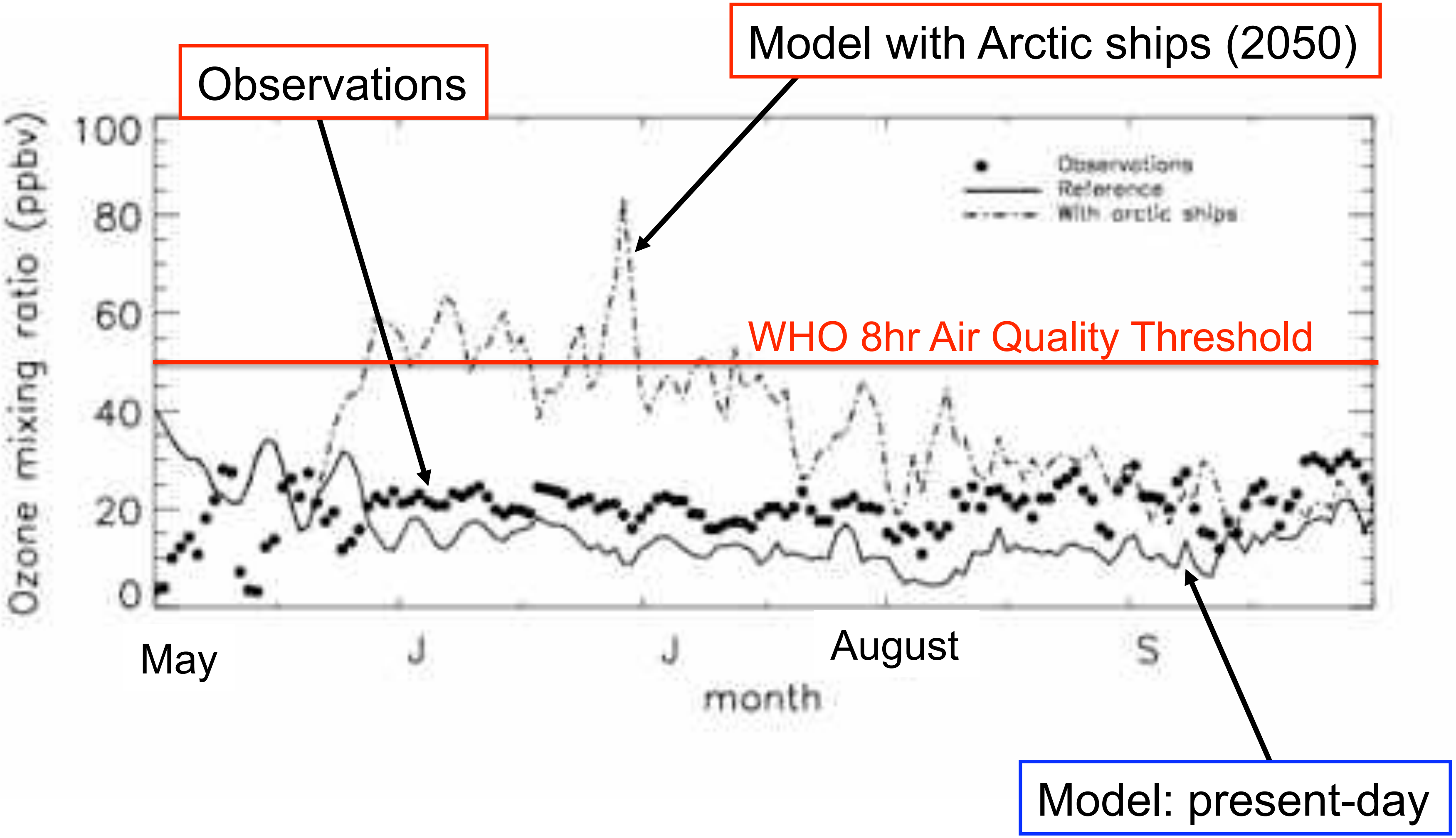
Predicted impact of future shipping on surface NOx and ozone (2050-2000)



Granier et al., 2006

Shipping: future impacts on regional air quality?

Surface ozone in Barrow, Alaska



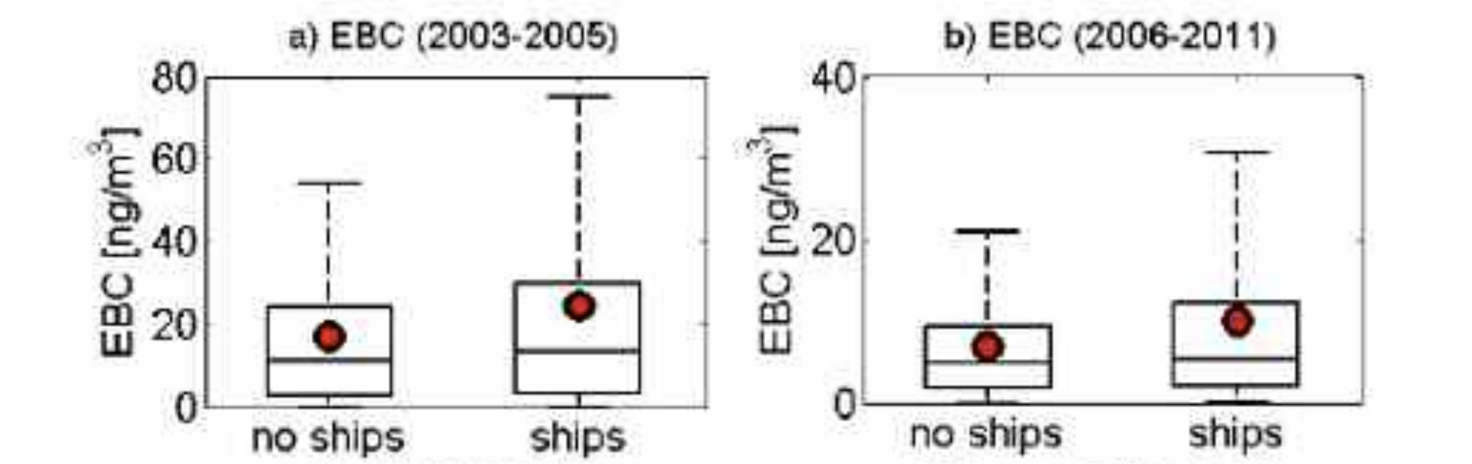
Granier et al., 2006

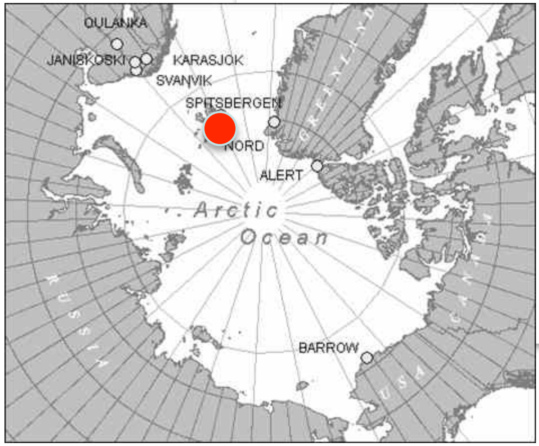
Impact of cruise ships on black carbon (present-day)

Observed summertime black carbon with & without cruise ships in harbour (Spitzbergen)

Black carbon

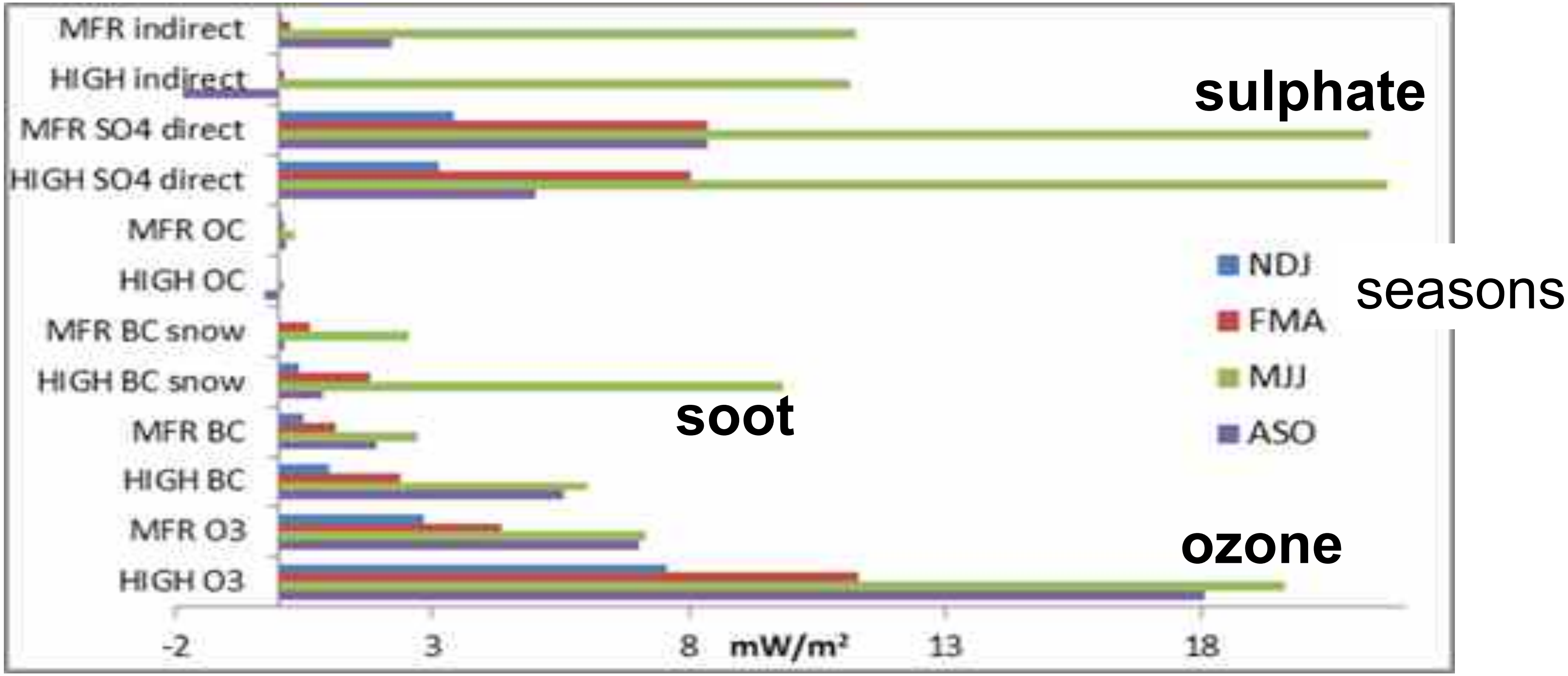
daytime





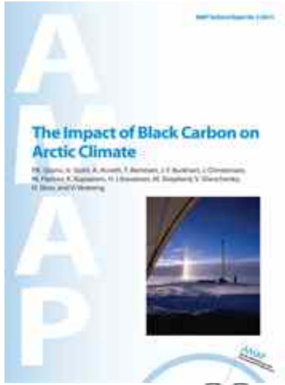
Eckhardt et al., (2013, ACPD)

Radiative Forcing (RF) 2004-2030 in the Arctic from shipping for HIGH and Max. Feasible Reduction (MFR) emission scenarios



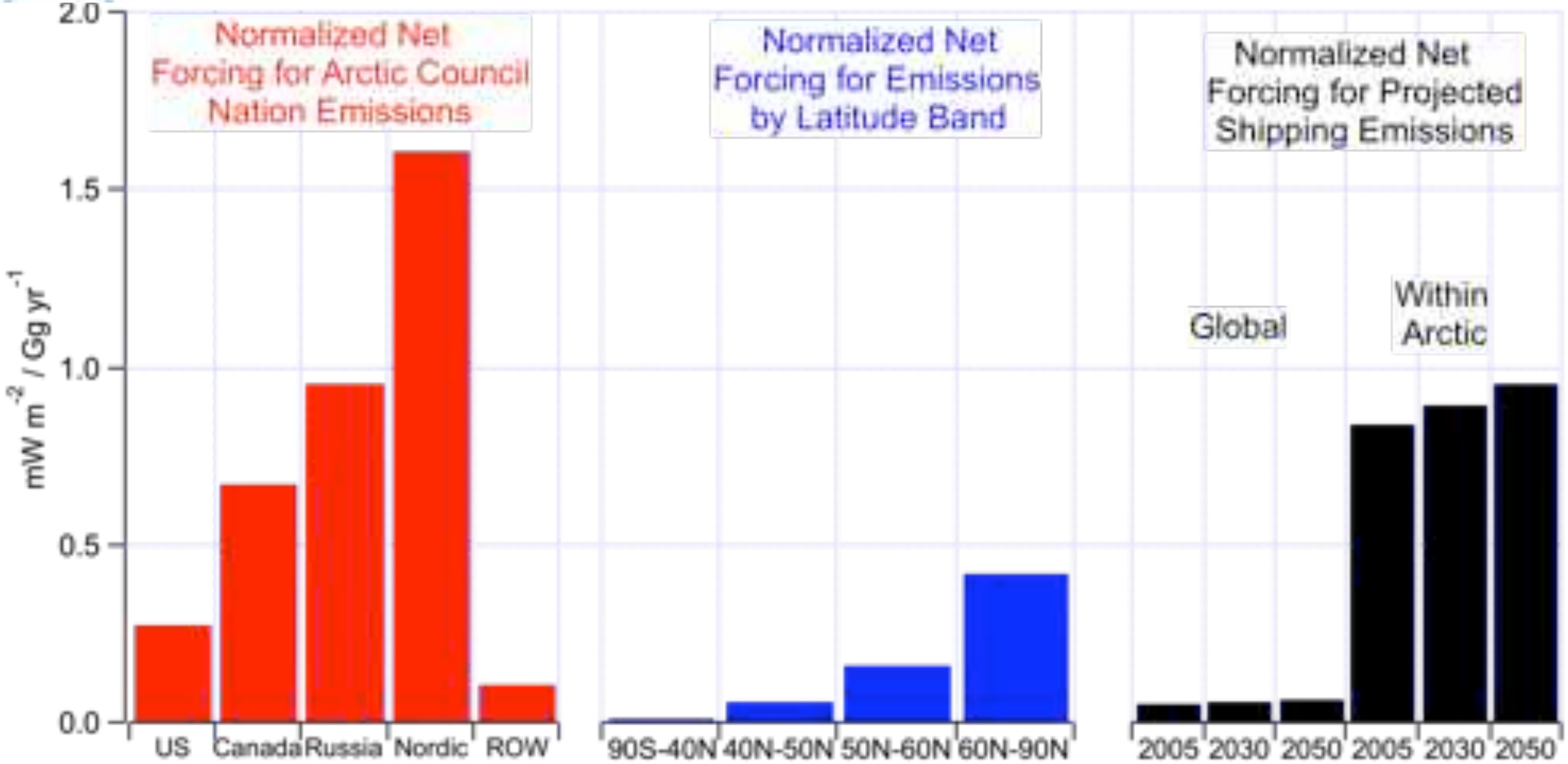
- **Proposed regulation of SO2 ship emissions could lead to significant warming from reduced sulphate (spring)**
- Ozone dominates forcing during Arctic summer/spring (HIGH scenario)
- Forcing due to atmospheric BC and deposition on snow/ice significant in Arctic spring (summer)

Dalsoren et al. (2013)



AMAP BC Report:

Near Arctic black carbon emissions have much higher impact on Arctic climate



Normalized Net Forcing (Atmospheric Direct RF (BC) and BC-Snow/Ice RF) due to emissions from Arctic Council Nations, latitude bands, and **global and within-Arctic shipping** (NCAR climate model)

Many uncertainties about ship emissions

Little data in Arctic about factors impacting ship emissions

E.g. ships emit more soot at low engine loads (speeds) – ships not tuned to operate in these conditions

Arctic? Ships likely to travel more slowly …

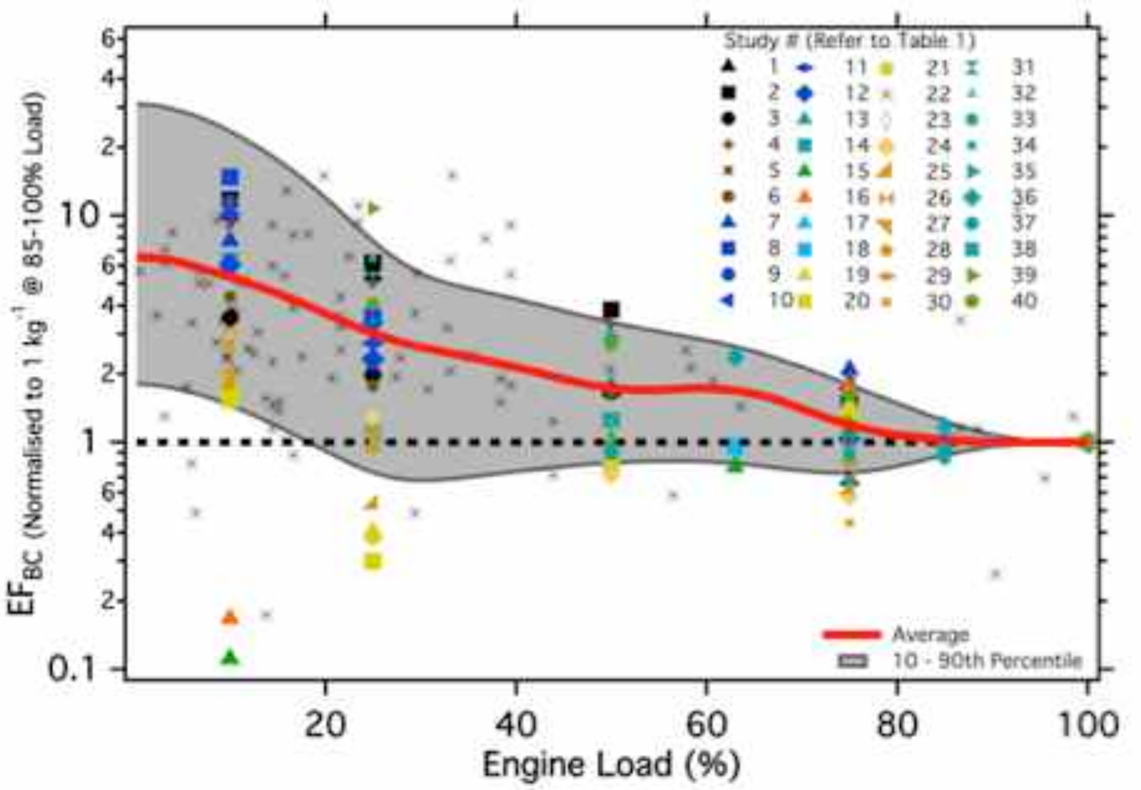
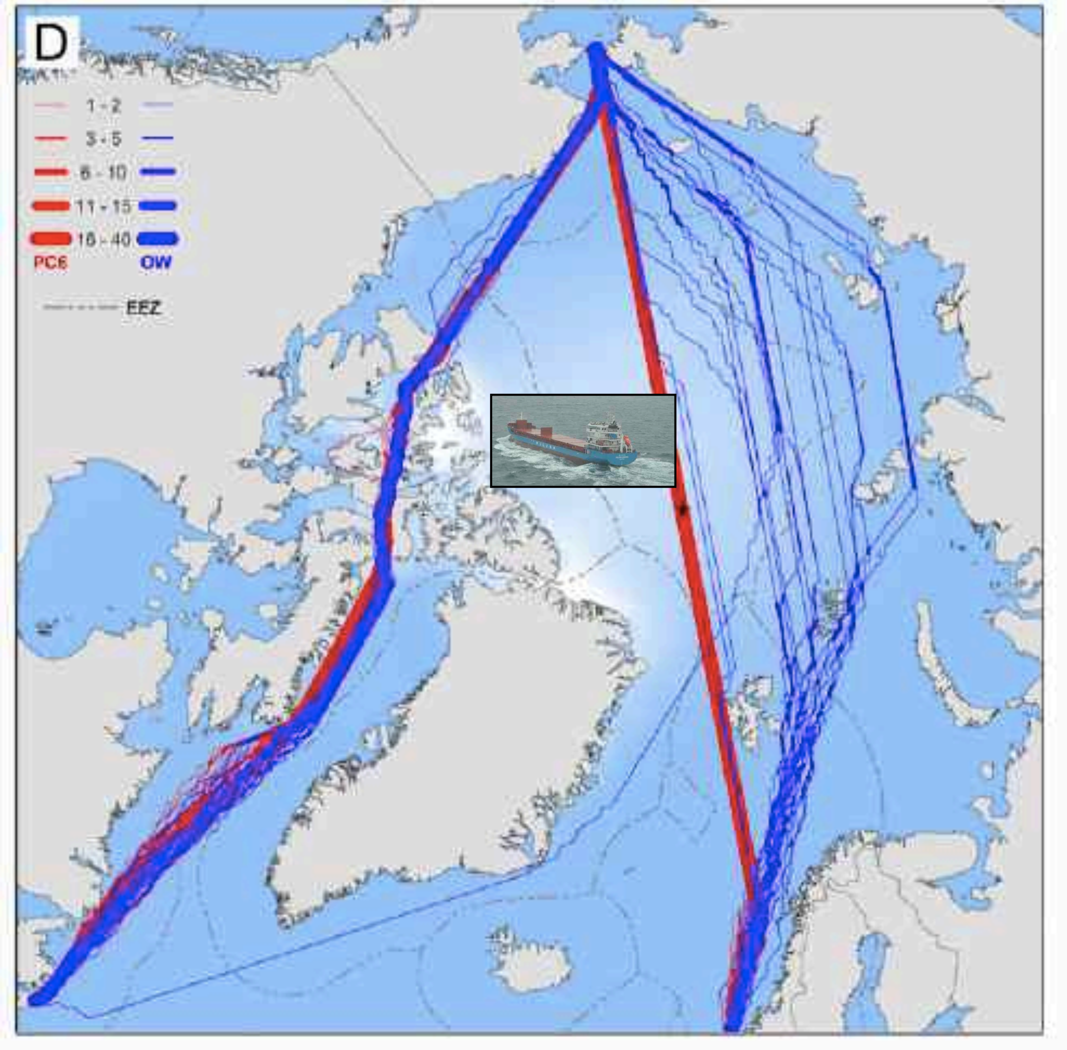


Fig. 2. The relationship between EF_{BC} and ship engine load. Average = red, 10th and 90th percentile = grey.

Lack et al. (2012)

Future emission scenarios?



New Polar Class ships → sailing directly across Pole?

Smith and Stephenson, PNAS, 2013

Cross-Polar Sea Routes (2050, September)
Based on sea-ice predictions from 7 climate models (RCP8.5)

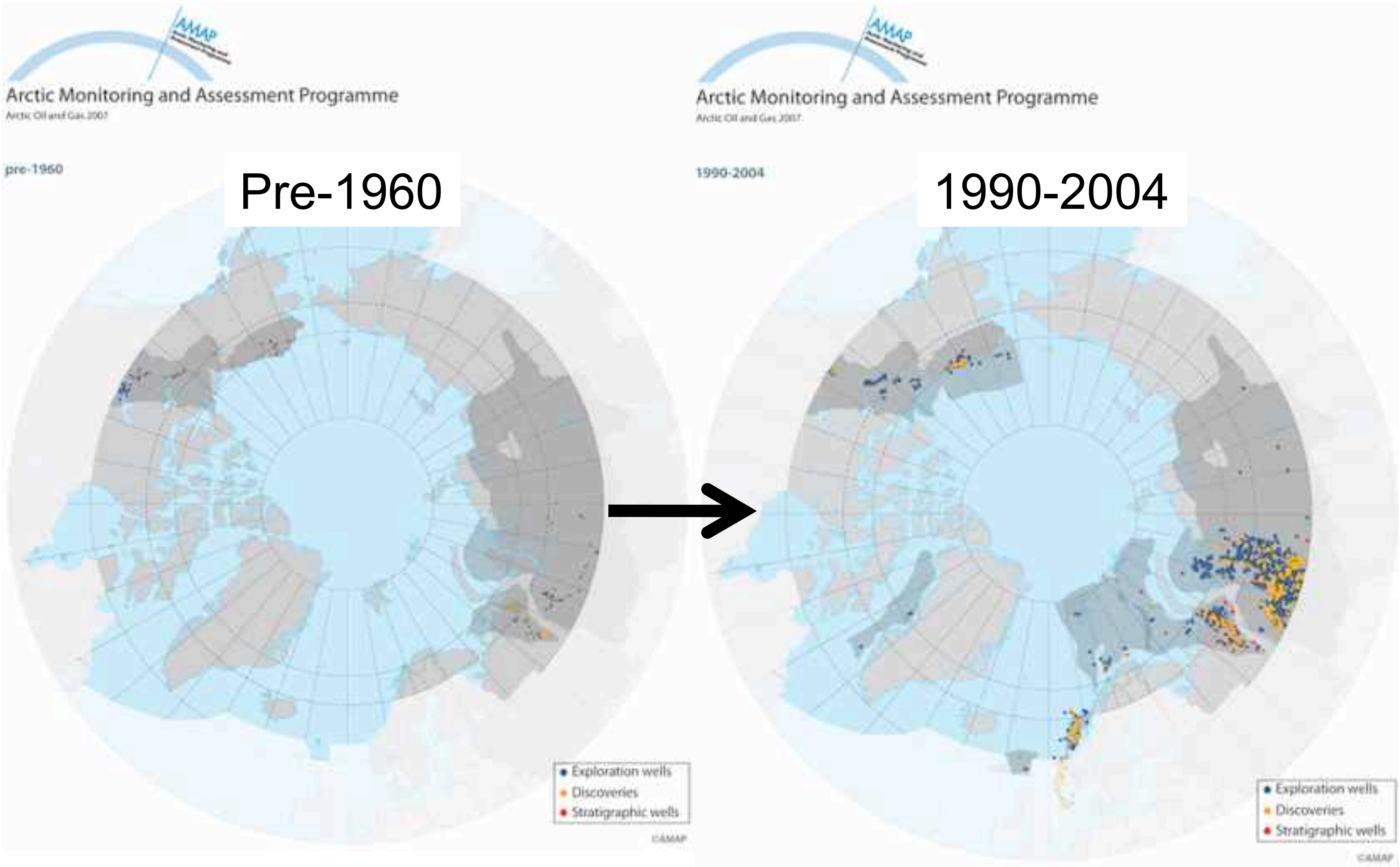
Climate change: increased maritime access but reduced land access → shifting transport patterns?

Implications for transport, urbanization, industrial development, etc. ??

Stephenson et al. (2011)

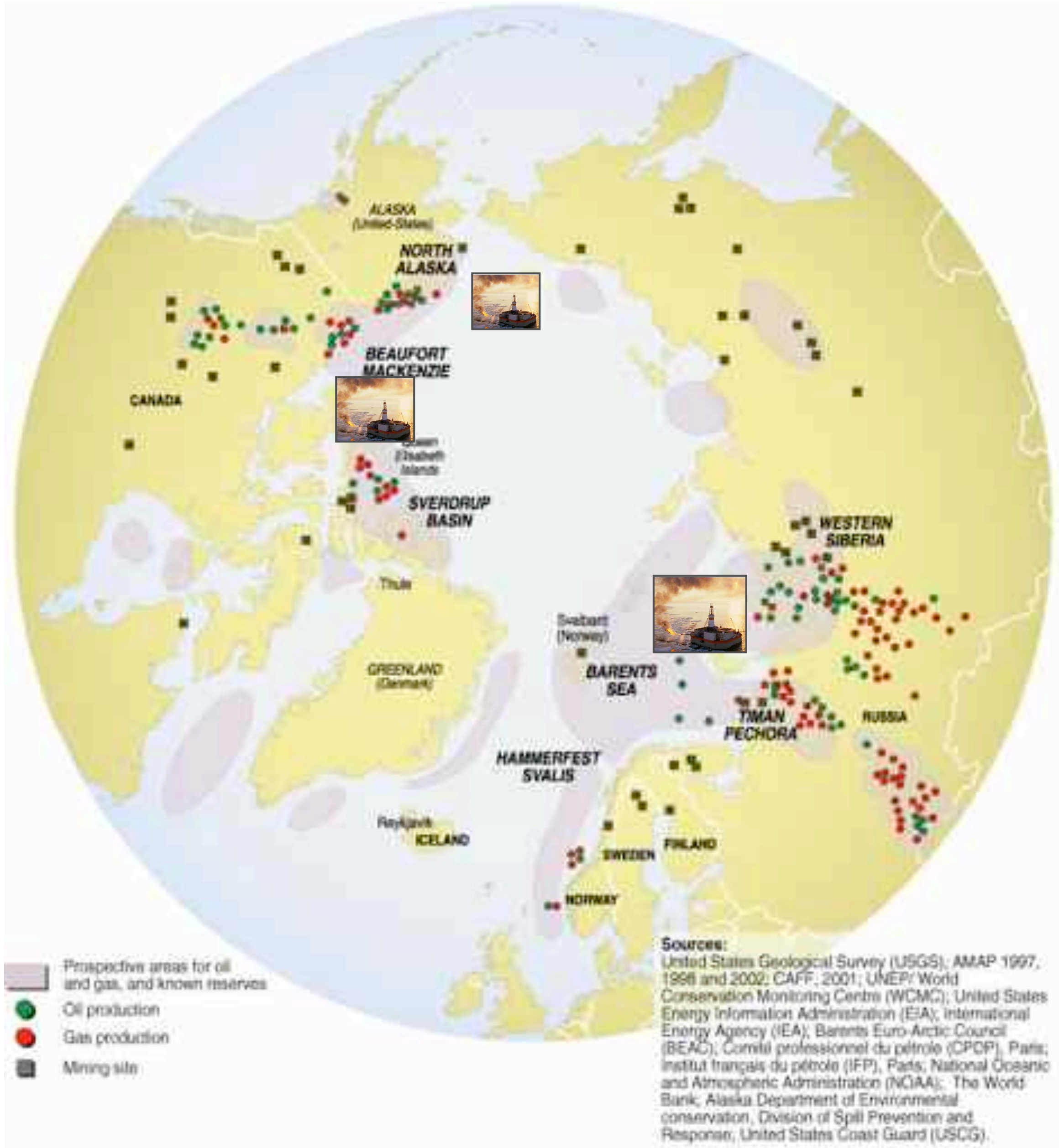
Baseline (2000-2014)-Mid-century (2045-2059):
Green - newly formed maritime access to Type A (light icebreaker) vessels.
Red - lost winter road potential for 2,000 kg ground vehicles.

Resource extraction (oil/gas): past → present



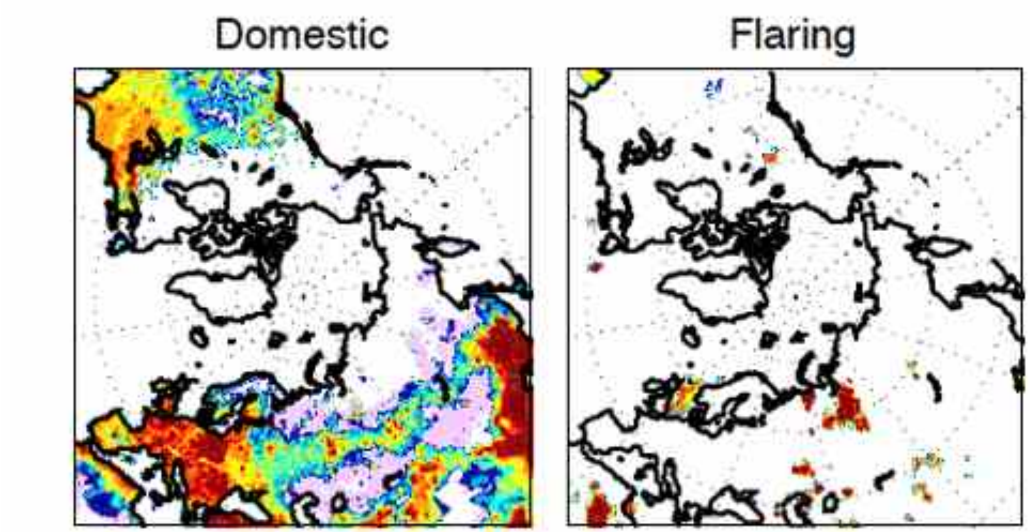
AMAP, 2007

Resource extraction (oil/gas/mining) present → future?

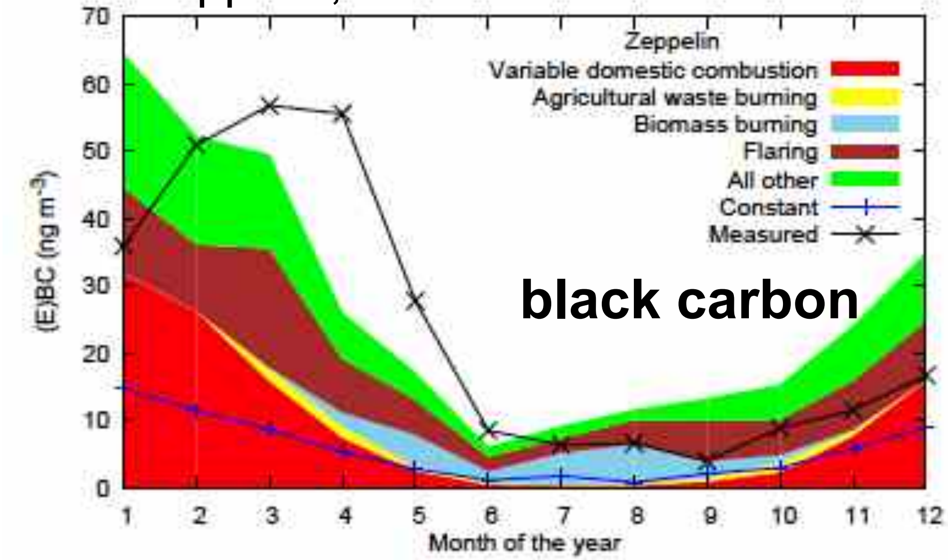


Very large uncertainties about pollutant emissions from these sources

Black carbon: present-day domestic & flaring emissions



Zeppelin, Svalbard



ECLIPSE emissions: 2008-2010

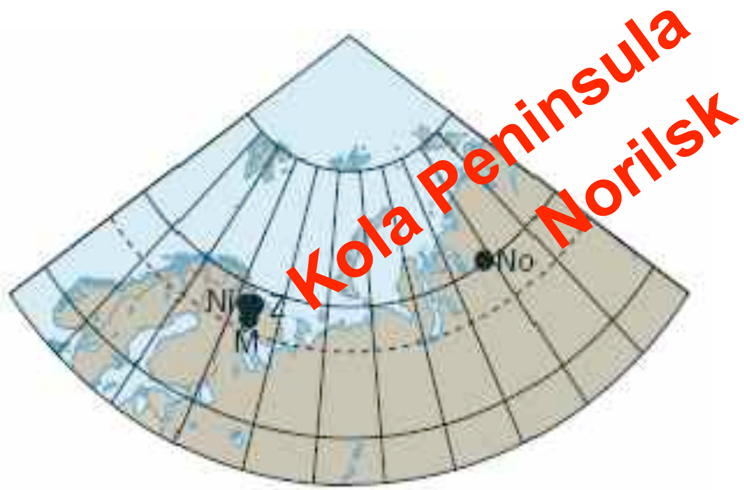
Improved oil/gas flaring emissions + seasonal cycle in domestic emissions (ECLIPSE-EU project)

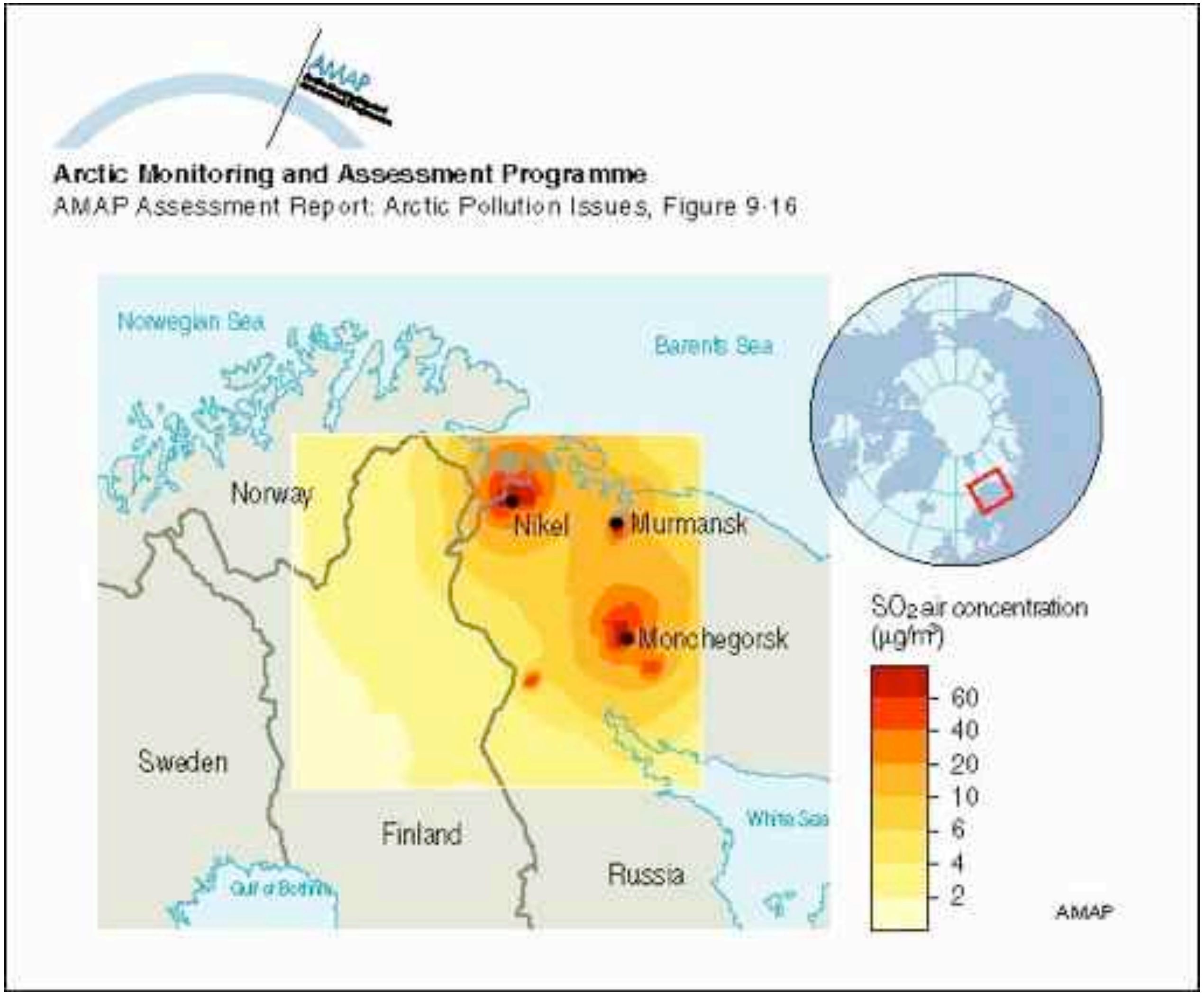
Significant local source of black carbon to the Arctic
(flaring alone: 40-50% surface Arctic BC)

Improves modelled seasonal cycle ….

Stohl et al., ACPD (2013)

Metal Smelting: Russia



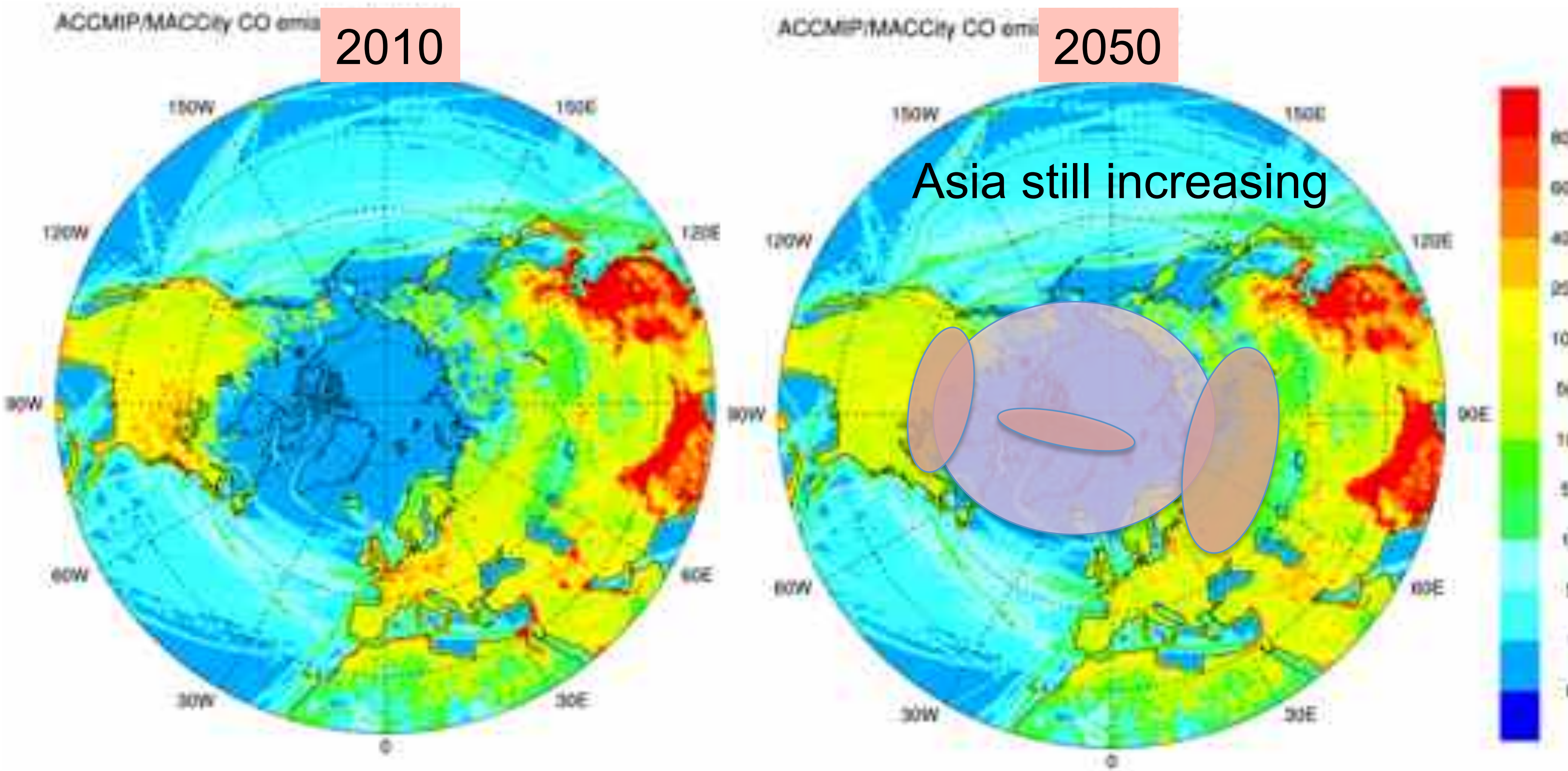


Copper smelting is large source of sulphur, heavy metals etc.

Already very polluted

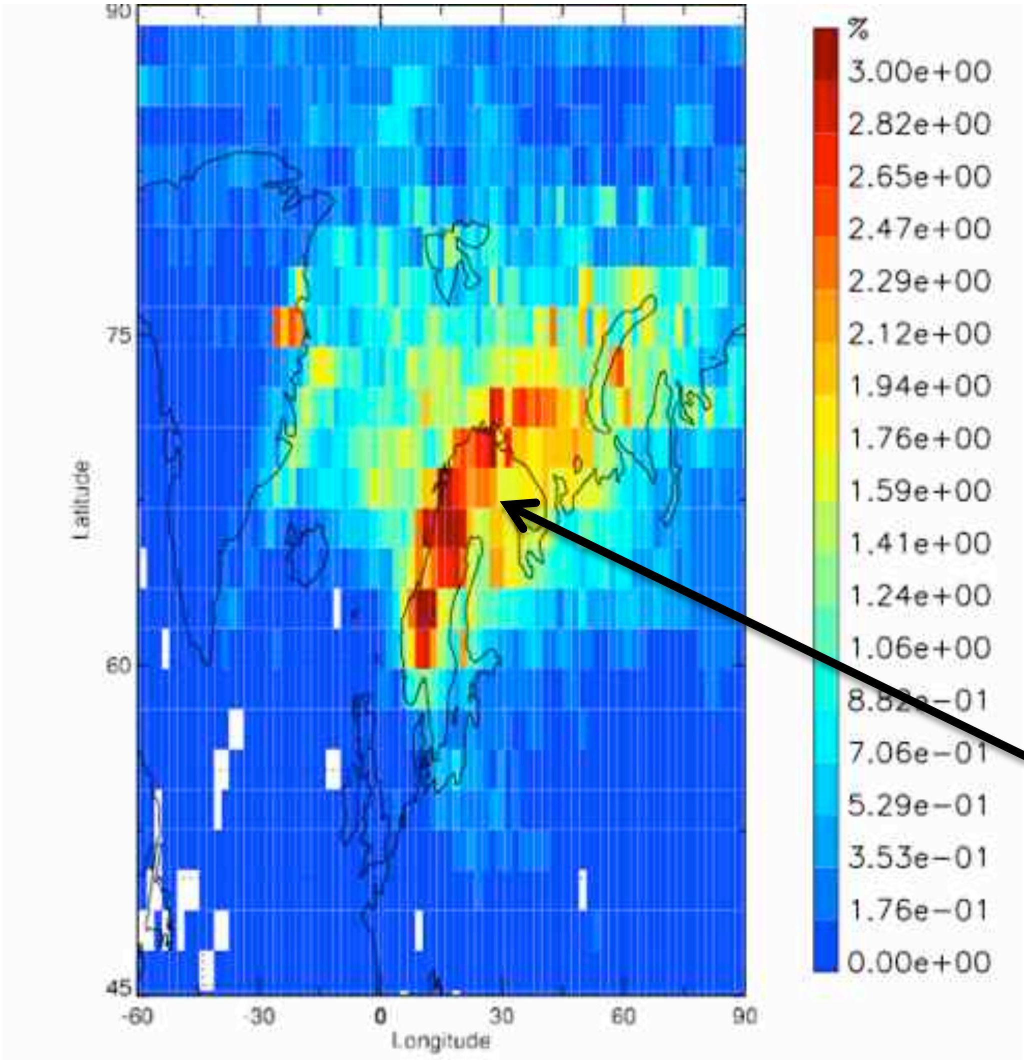
Poorly quantified local source …

Future Arctic emissions?



+ shipping,
resource extraction,
urbanization, ….

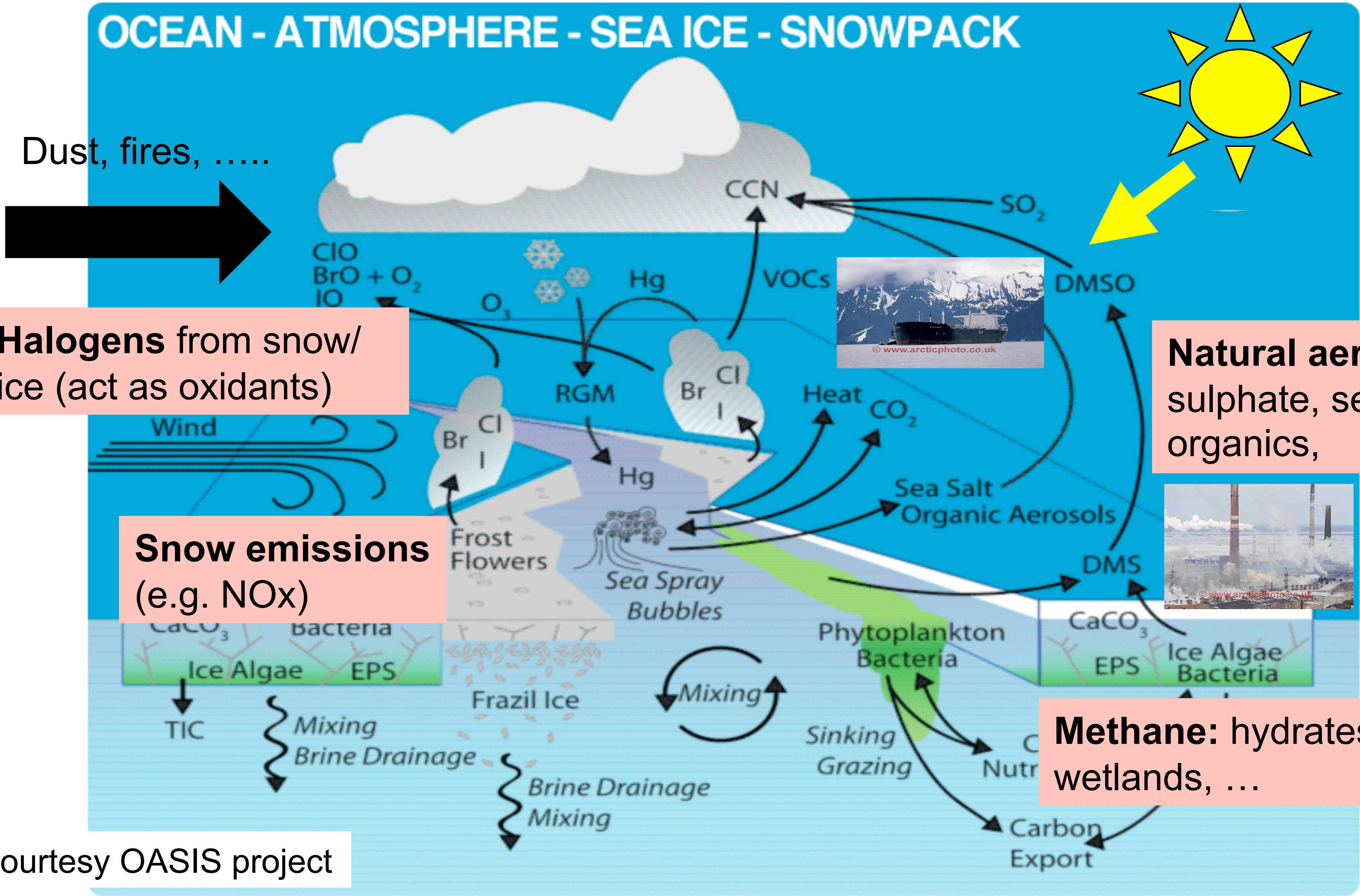
Impacts: nitrogen deposition to ecosystems?



Change in surface nitrate due to ship emissions (model run with/without present-day ships), *Dalsoren et al. (2007)*

Increased nitrate already observed in Arctic lake sediments (last 150 yrs), *Holtgrieve et al. (2011)*

Natural system: Arctic specific processes in lower troposphere (response to climate change?)



Halogens from snow/ ice (act as oxidants)

Natural aerosols: sulphate, sea-salt, organics,

Snow emissions (e.g. NOx)

Methane: hydrates, wetlands, …

courtesy OASIS project

Conclusions & Perspectives

• **Long-range transport** - important in the past (reasons for trends not clear) - likely to continue into future (Asian emissions)

• **Local sources of pollution** in Arctic not well quantified (already important) - likely to increase in the future (scenarios uncertain)

• **Natural emissions (processes)** – Arctic specific environment – need to understand interactions with local emissions especially in the context of a **changing climate**


Merci...