The Impact of Black Carbon on Arctic Climate: AMAP Expert Group on Short-Lived Climate Forcers

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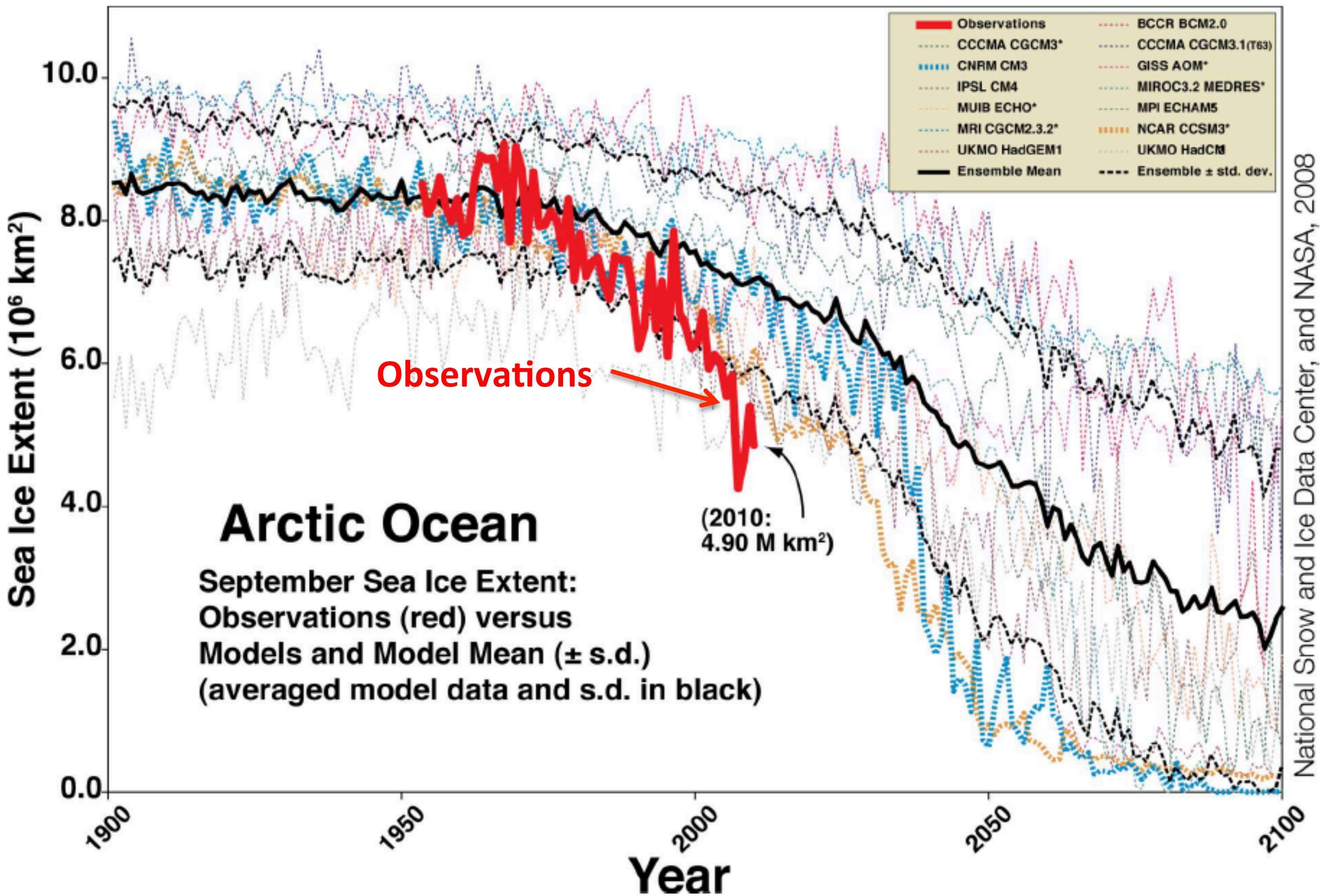
Observed sea ice loss has occurred at a faster rate than predicted by any of the modeling scenarios in the IPCC AR4

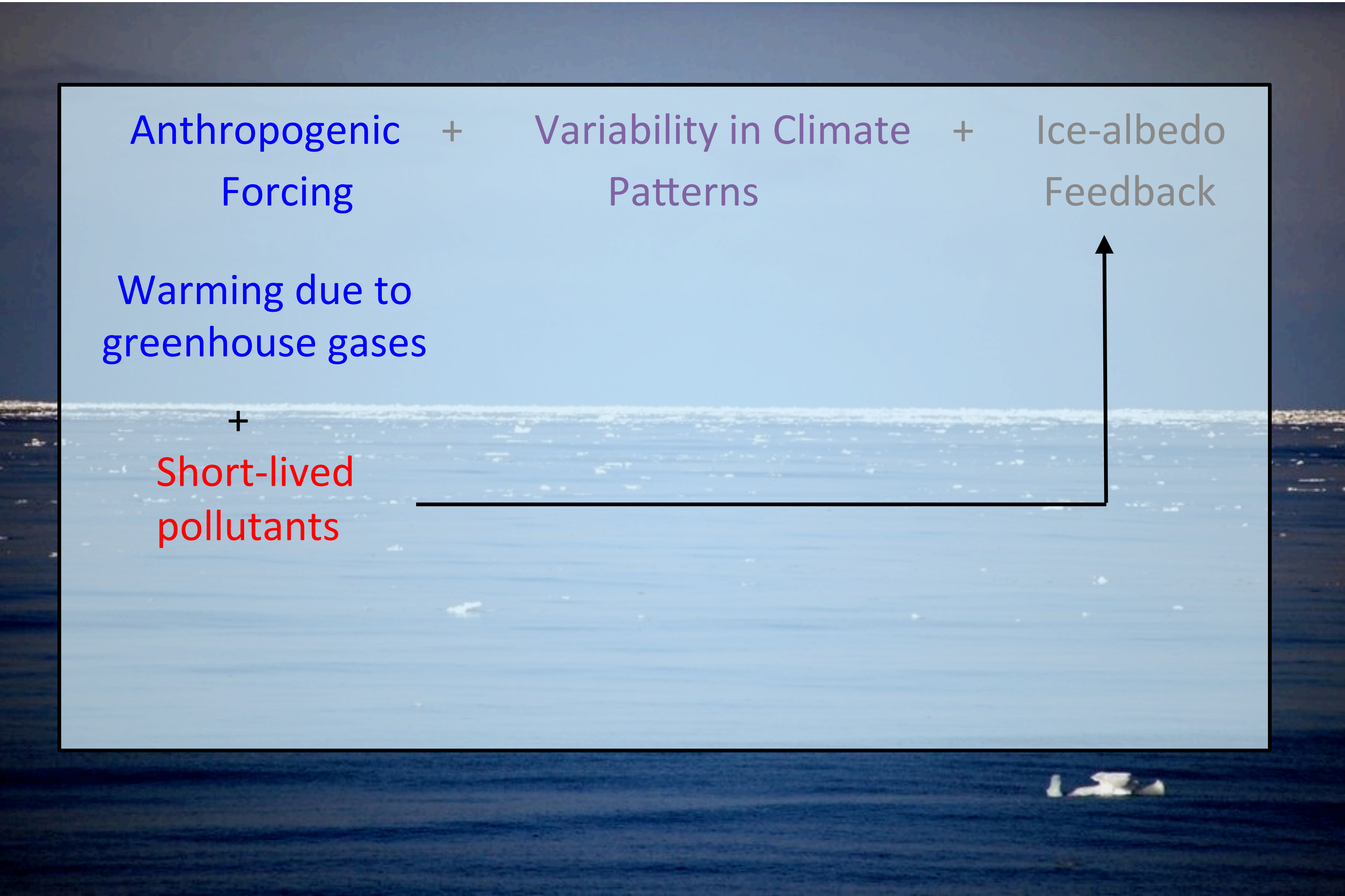


Potential factors contributing to rising Arctic temperatures and sea ice loss

Anthropogenic Forcing + Variability in Climate Patterns + Ice-albedo Feedback

Warming due to greenhouse gases

Potential factors contributing to rising Arctic temperatures and sea ice loss

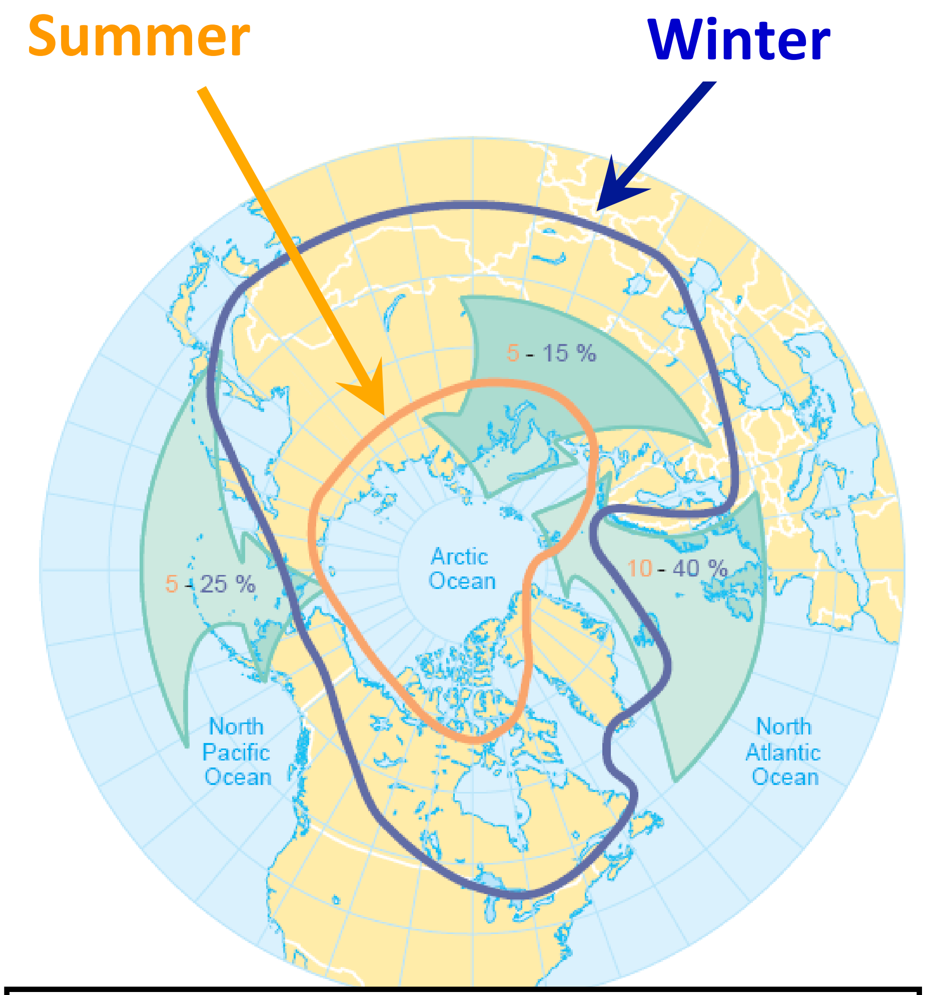


Long- versus Short-Lived Pollutants in the Arctic

Pollutant	Atmospheric Lifetime
Black Carbon	Days to weeks
Tropospheric Ozone	Days to weeks
Methane	~ 9 years
Carbon Dioxide	Up to 200 years

For within-Arctic forcing, pollutants need to be transported to the Arctic.

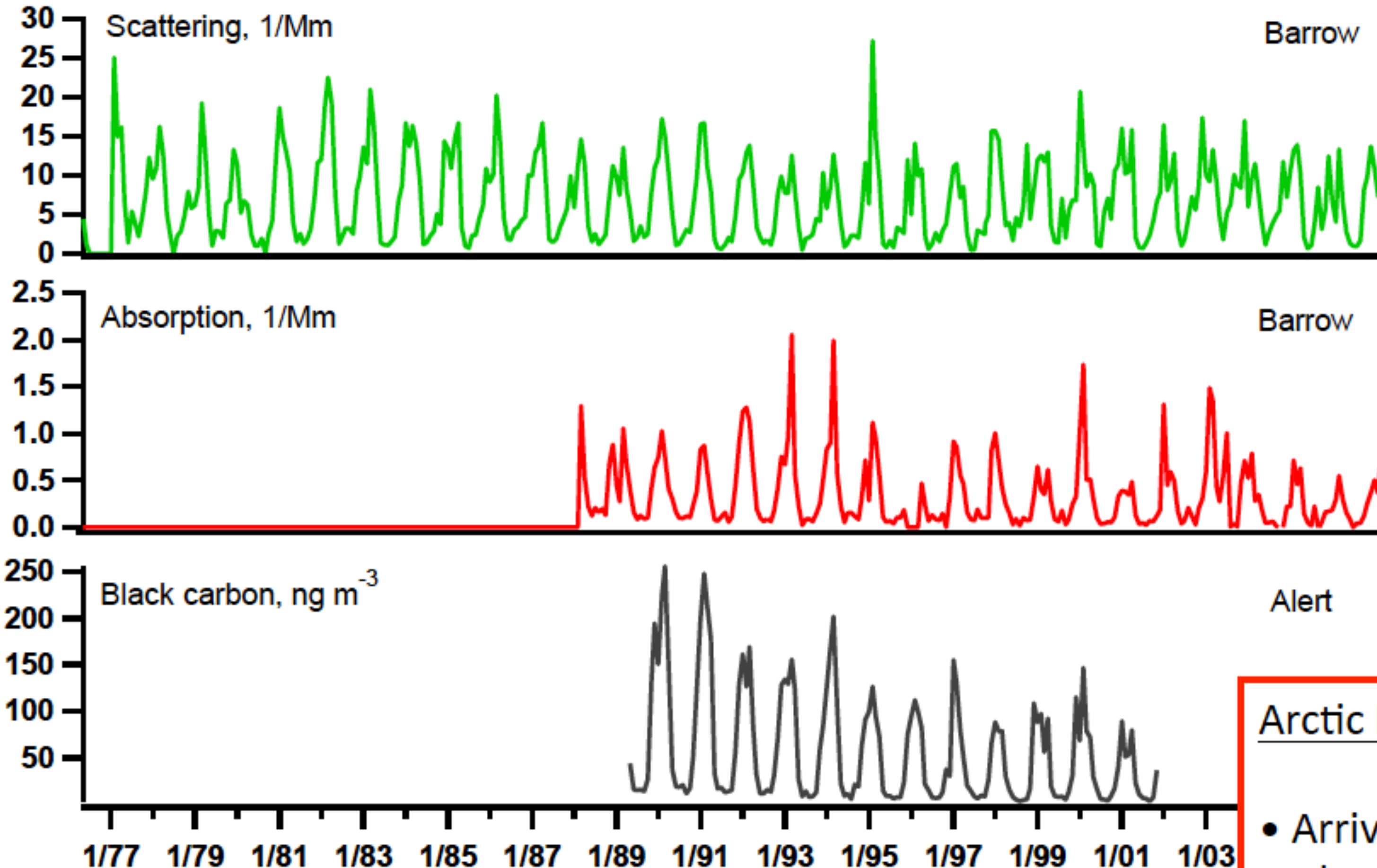
Long-Range Transport of Pollutants to the Arctic



Mean position of the Arctic Front in Winter and Summer

- The Arctic Front (temperature gradient) forms a barrier to transport of pollutants.
- Summer – the front is confined to a much smaller, high latitude region.
- Winter - the front can extend to 40°N over northern Europe and Asia.
- Northern Eurasia is the major source region to the Arctic at low altitudes:
  - extension of Arctic Front to near 40°N at this longitude
  - snow-covered surfaces (reduces temperature gradient)
  - lots of pollution sources
- Warmer source regions and convective fire plumes can impact higher altitudes within the Arctic

Seasonality of Pollutant Transport to the Arctic

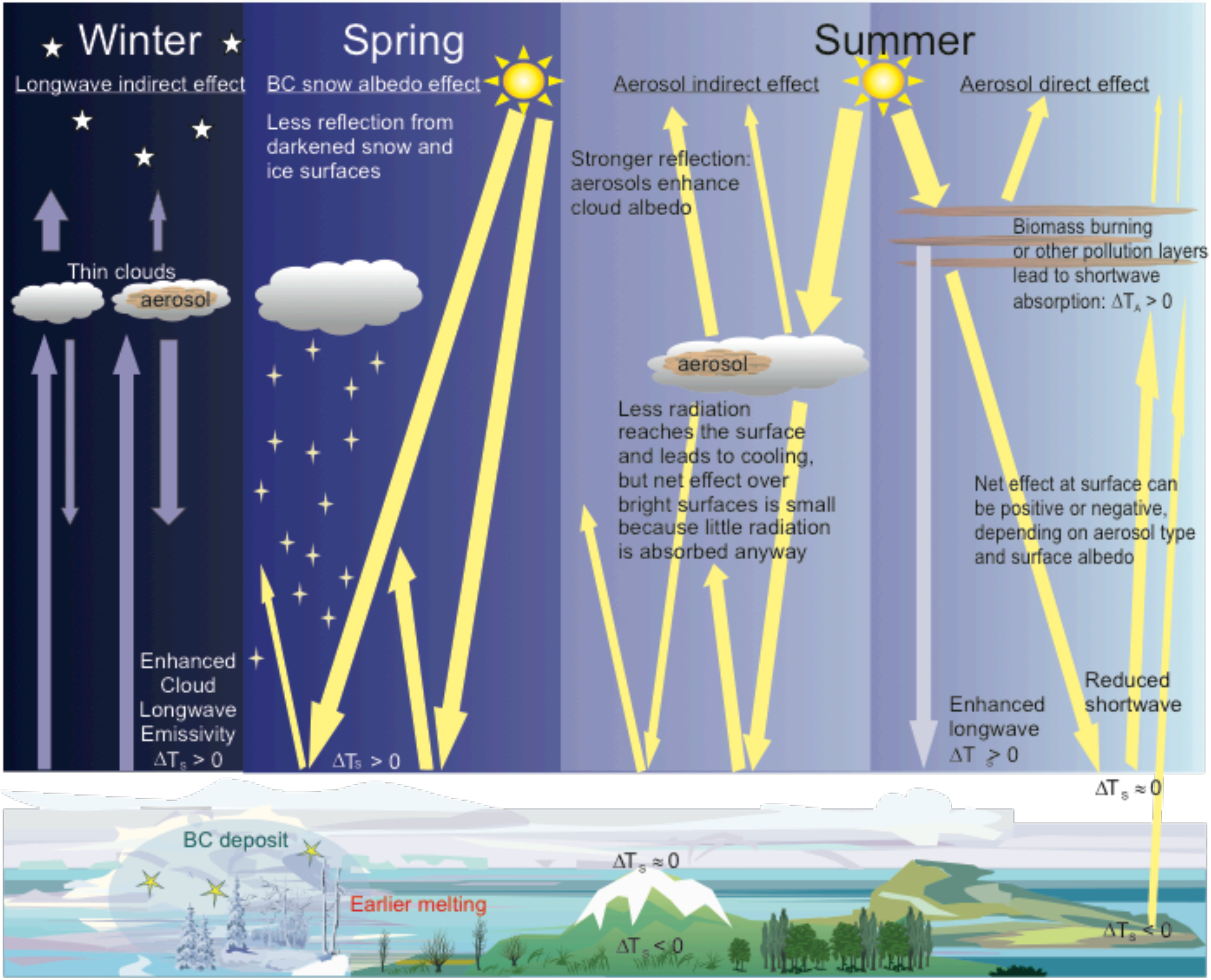


Monthly averaged values

Quinn et al., Tellus, 2007

Arctic Haze

- Arrives late winter/ early spring
- Includes tropospheric aerosols, ozone, and ozone precursors

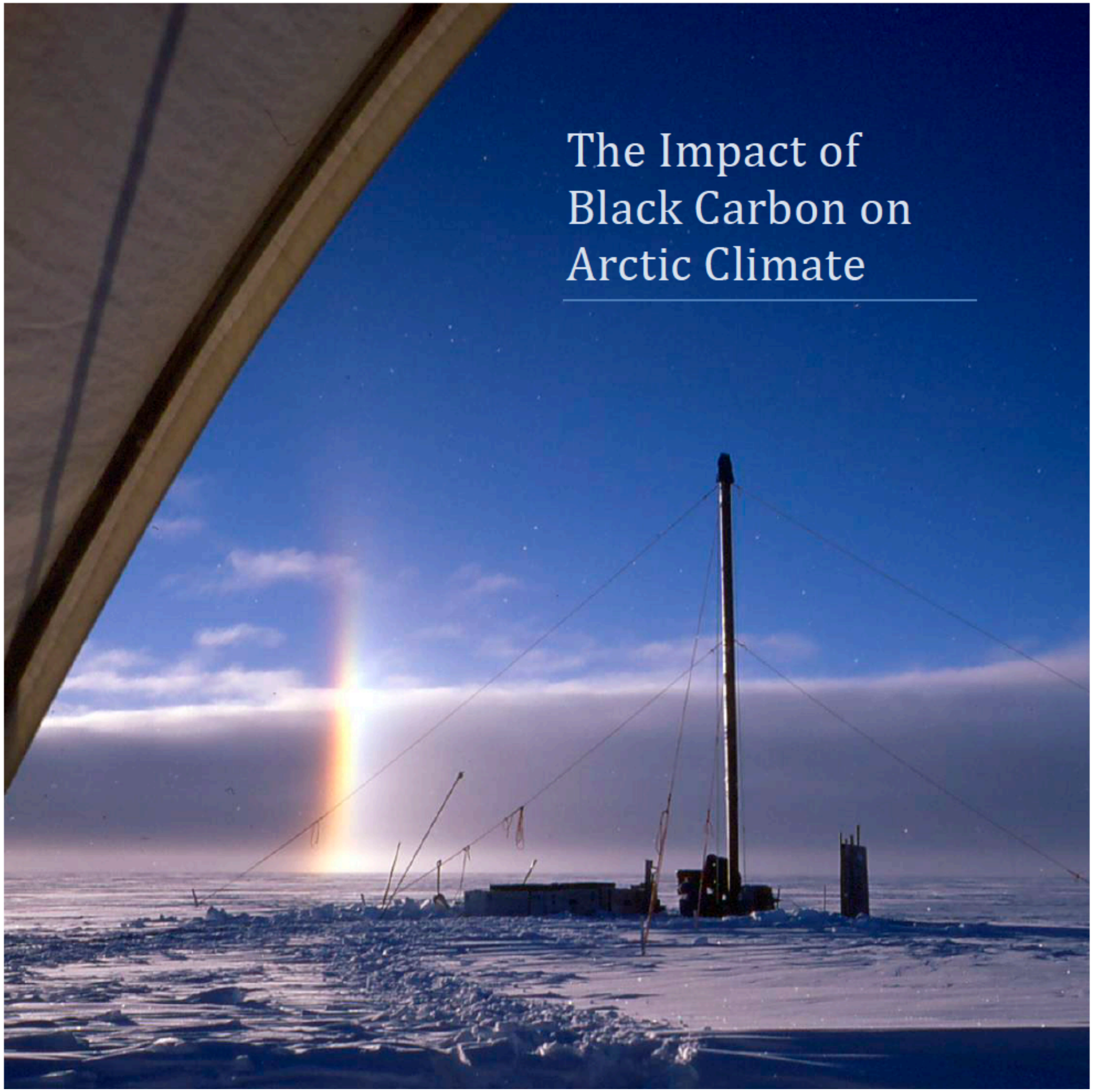

Winter
Spring
Summer
Longwave indirect effect
BC snow albedo effect
Aerosol indirect effect
Aerosol direct effect
Less reflection from darkened snow and ice surfaces
Stronger reflection: aerosols enhance cloud albedo
Biomass burning or other pollution layers lead to shortwave absorption: ΔT_A > 0
Thin clouds
aerosol
aerosol
Less radiation reaches the surface and leads to cooling, but net effect over bright surfaces is small because little radiation is absorbed anyway
Net effect at surface can be positive or negative, depending on aerosol type and surface albedo
Enhanced Cloud Longwave Emissivity ΔT_s > 0
ΔTs > 0
Enhanced longwave ΔT_s > 0
Reduced shortwave
ΔT_s ≈ 0
BC deposit
Earlier melting
ΔT_s ≈ 0
ΔT_s < 0
ΔT_s < 0

Expert Group

Formed in 2009 by AMAP

Short-Lived Climate Forcers

- provide scientific and technical advice regarding
    - formulation of mitigation strategies
    - assessment of Arctic climate benefits of mitigation strategies
    - identification of measures to reduce emissions
    - recommendations for further immediate actions



AMAP Expert Group on Short-Lived Climate Forcers:

1st Assessment Report published in 2011

http://www.amap.no/documents/doc/the-impact-of-black-carbon-on-arctic-climate/746

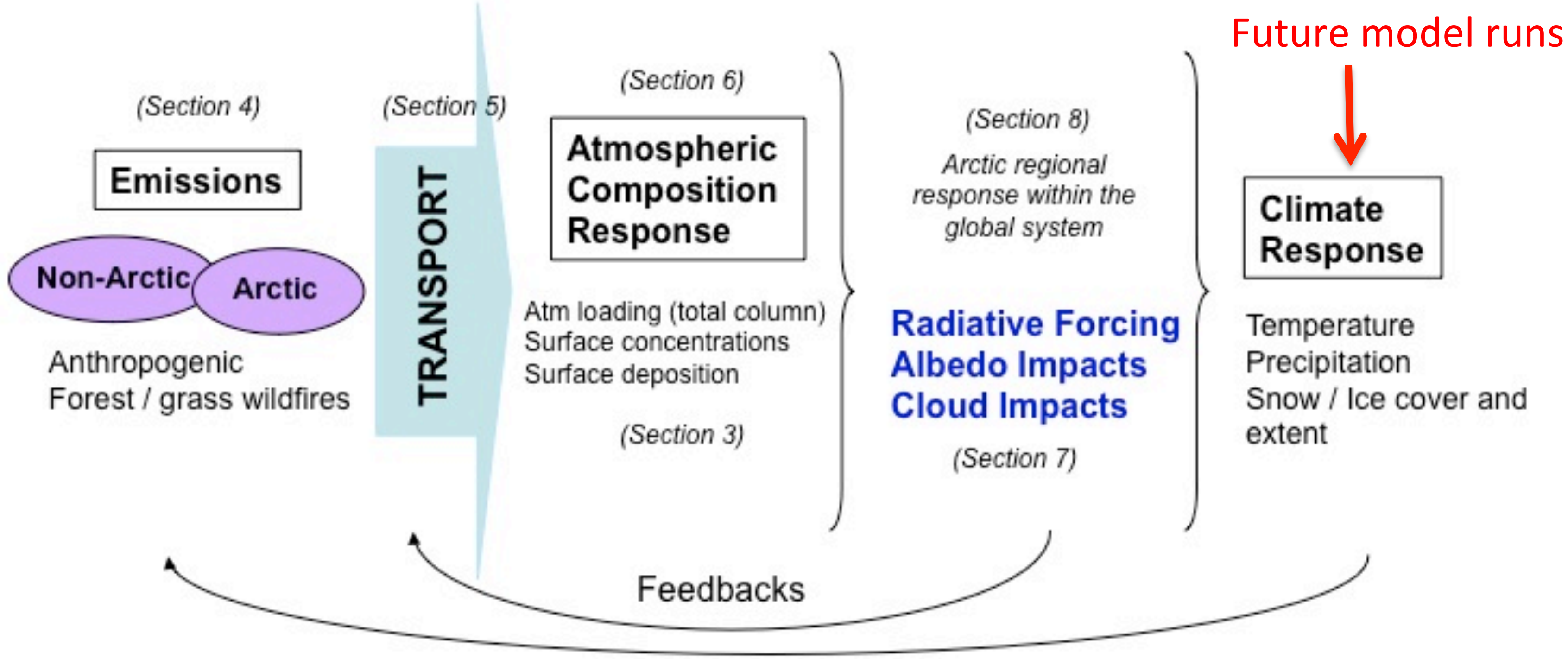
- Background information on BC (emission regions and sectors, properties, transport pathways to the Arctic, etc.)
- Trends in Arctic BC in snow and aerosol
- Model simulated radiative forcing

Questions addressed by AMAP model simulations:

Which geographical regions have the largest impact on the Arctic in terms of emissions of BC and associated within-Arctic radiative forcing?

Which combustion sources have the largest impact on the Arctic?

Global Climate Model approach to calculating the radiative forcing by BC and associated climate response

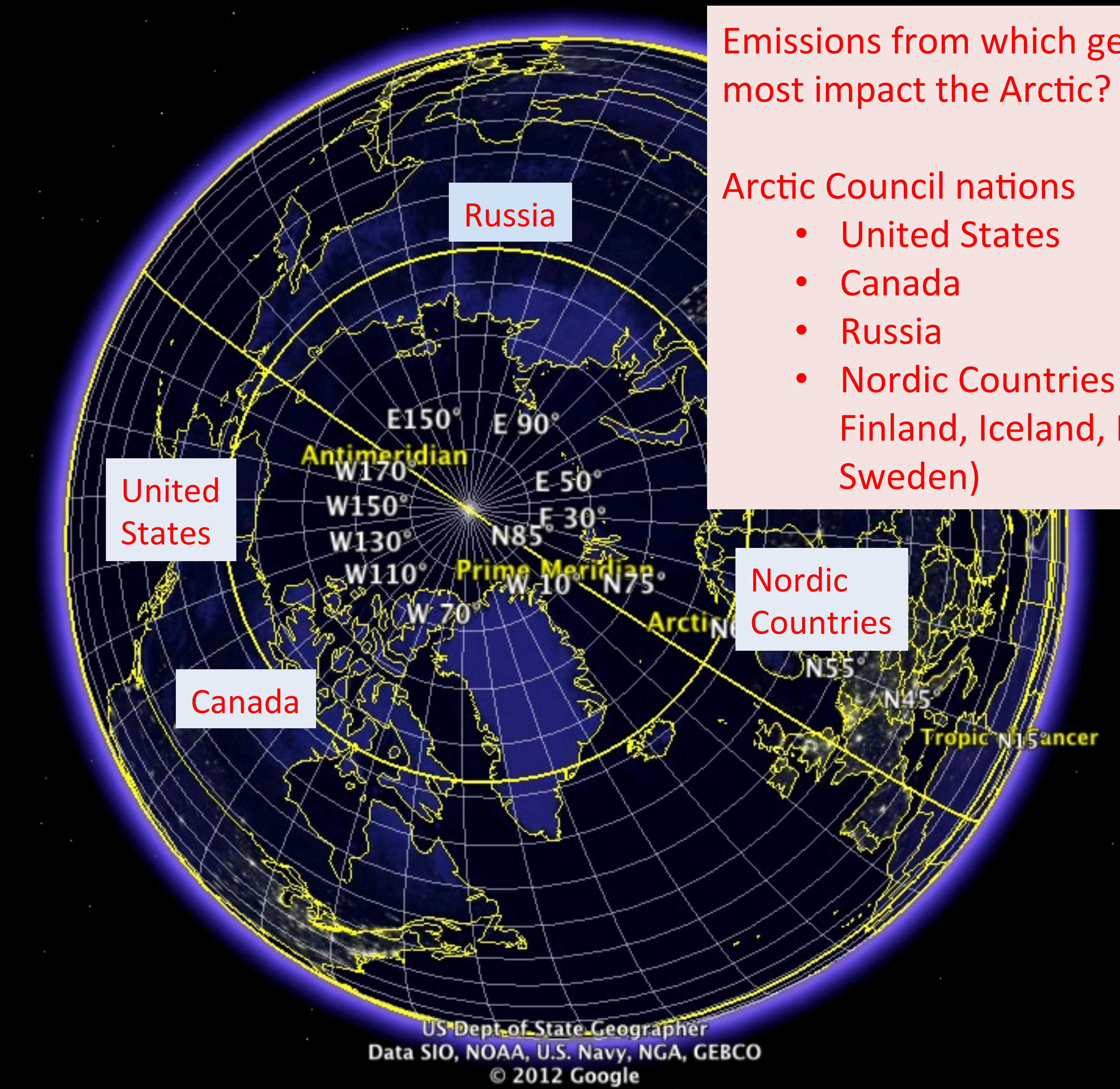


- AMAP simulations included BC and co-emitted particulate organic carbon
- BC-snow albedo forcing
- Atmospheric direct forcing

Emissions from which geographical region most impact the Arctic?

Arctic Council nations

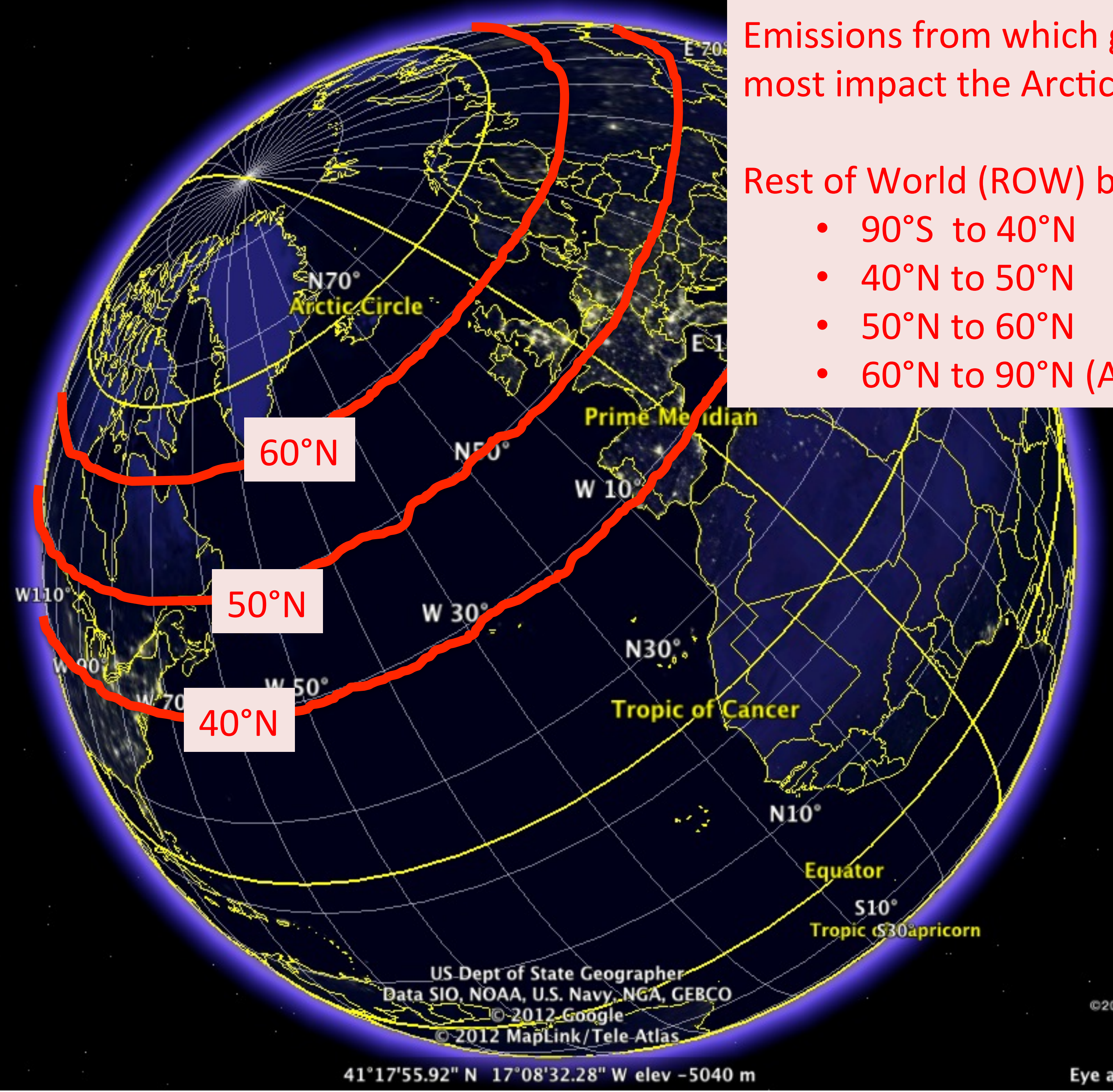
- United States
- Canada
- Russia
- Nordic Countries (Denmark, Finland, Iceland, Norway, and Sweden)



Emissions from which geographical region most impact the Arctic?

Rest of World (ROW) by latitude band

- 90°S to 40°N
- 40°N to 50°N
- 50°N to 60°N
- 60°N to 90°N (Arctic)



Which combustion emissions have the largest impact on the Arctic?

- Domestic combustion (wood burning stoves for heat and cooking)

- Transport (diesel engine combustion)

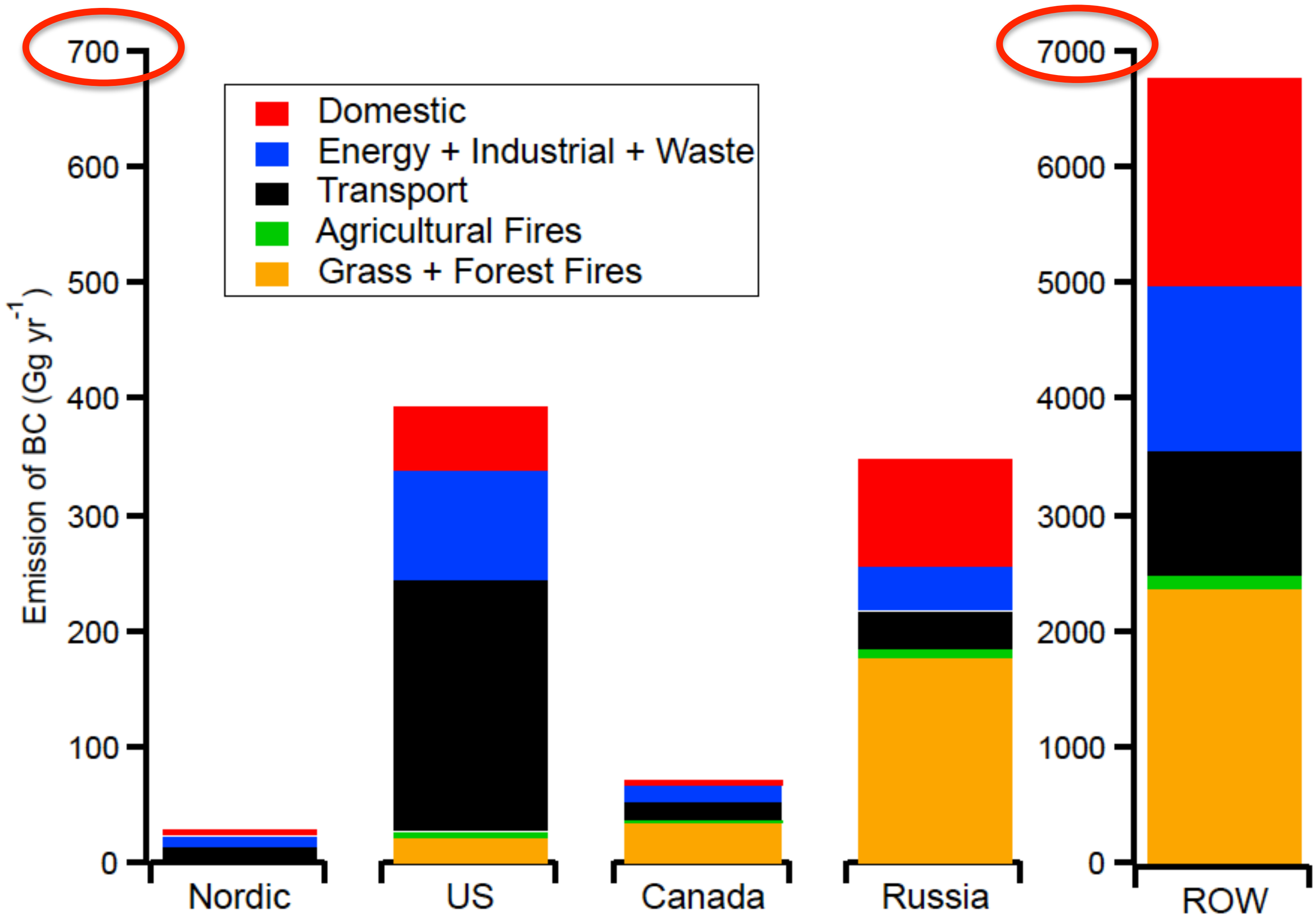
- Energy production and industrial processes

- Agricultural fires
- Grass and forest fires

- Shipping emissions – current and projected

Emissions of BC by Sector and Region

Note different y-axes for Arctic Council Nations and ROW!



Lamarque et al., ACP, 2010

Emissions of BC by Sector and Region

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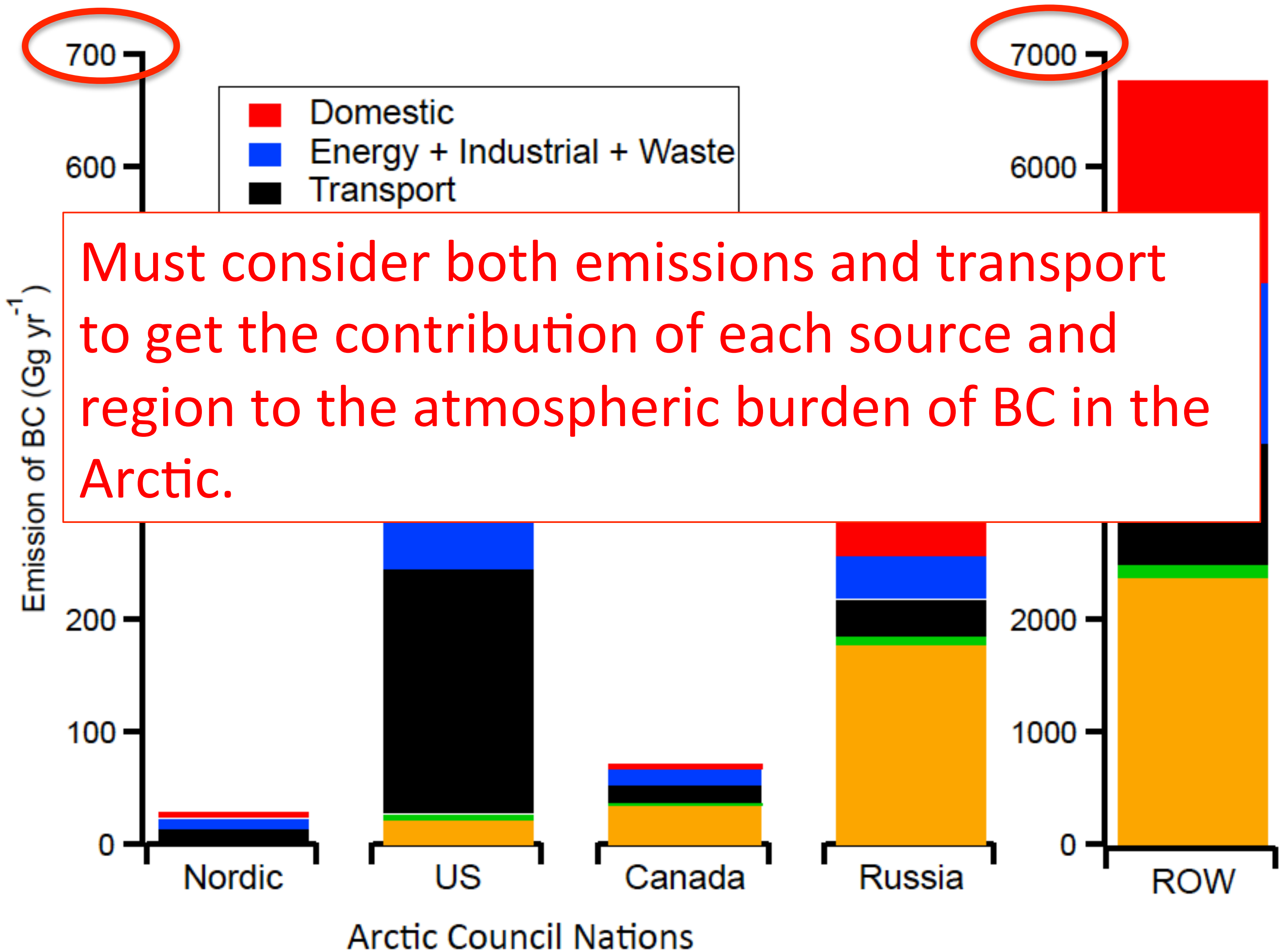
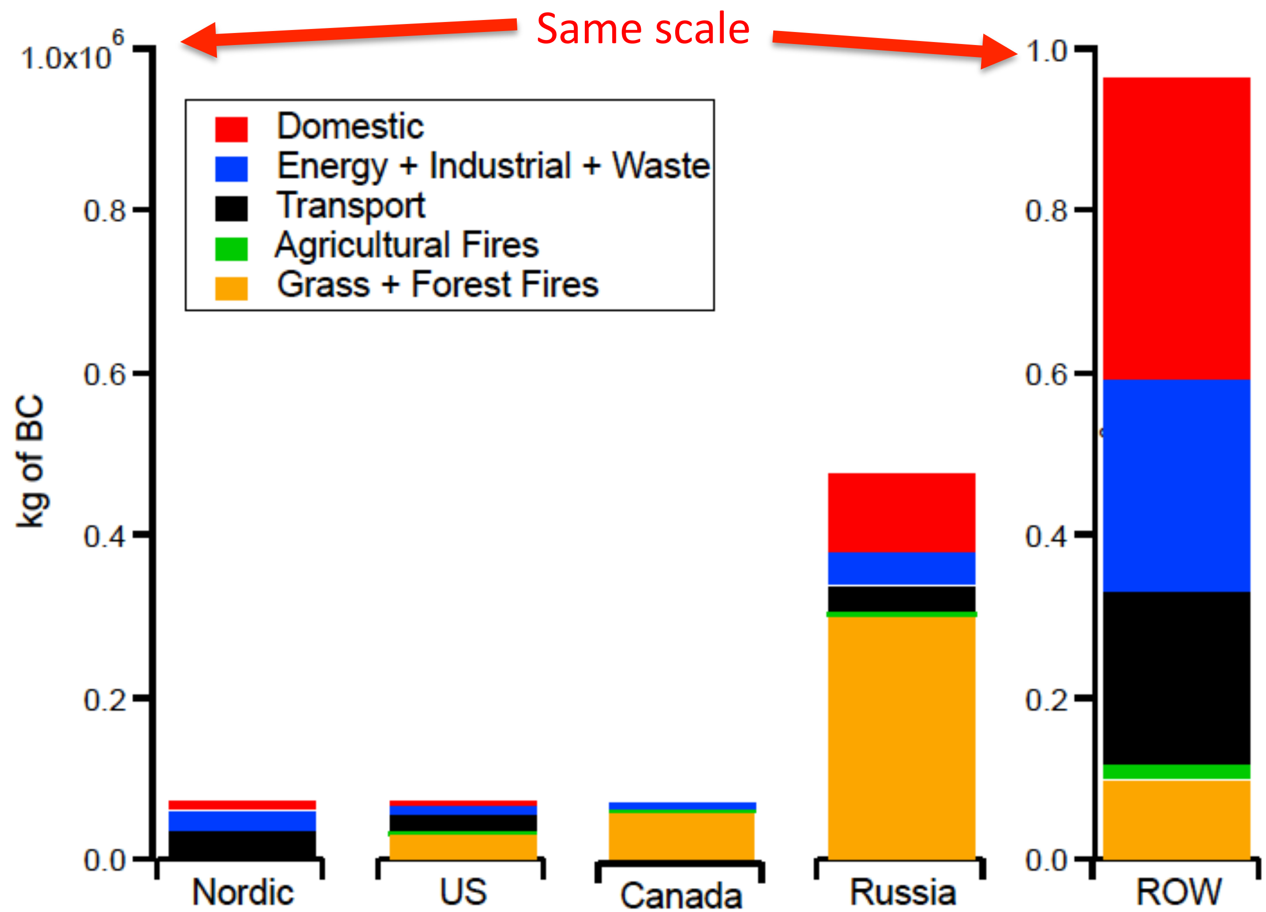


Must consider both emissions and transport to get the contribution of each source and region to the atmospheric burden of BC in the Arctic.

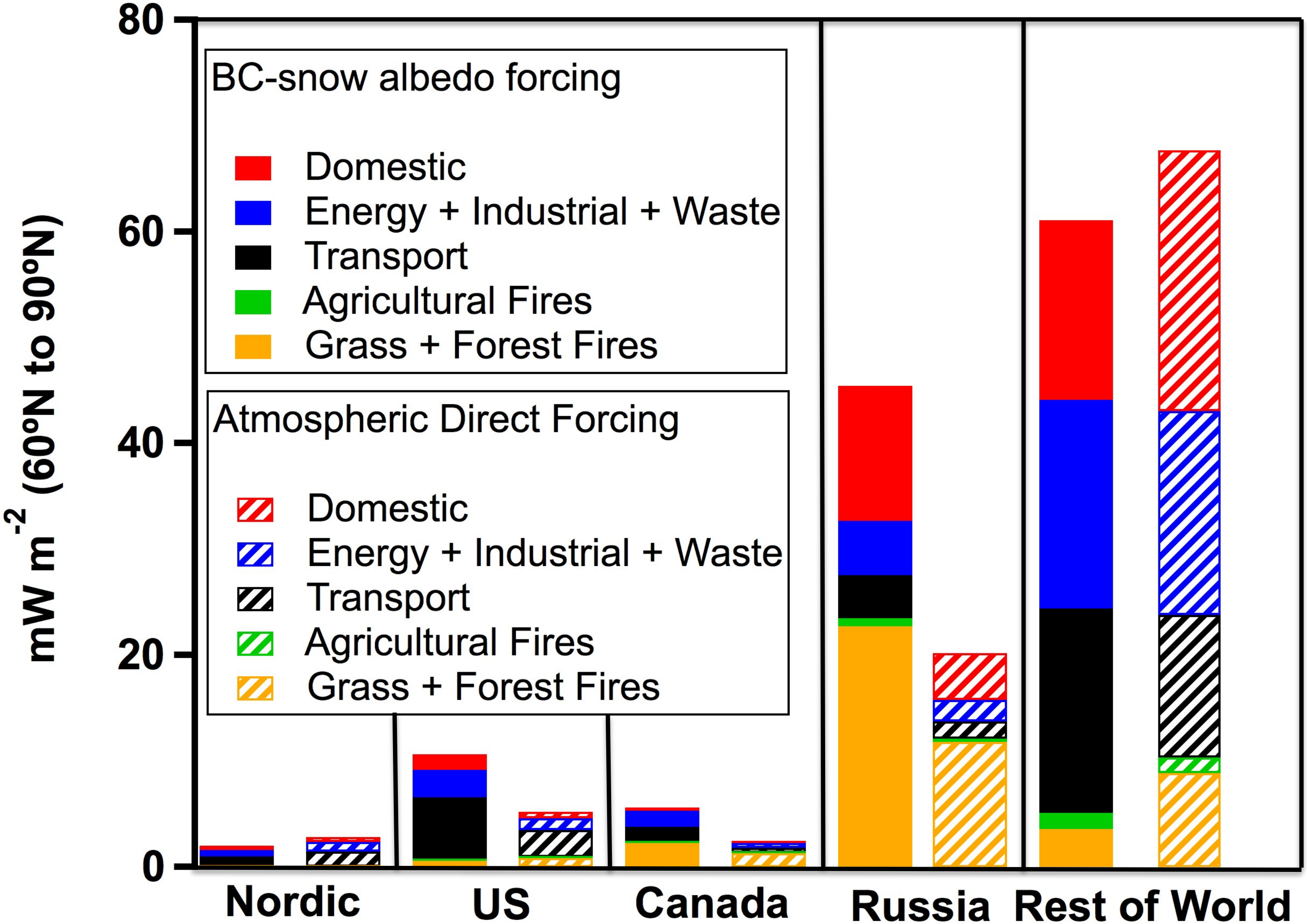
Lamarque et al., ACP, 2010

Model-calculated change in the annual tropospheric burden of BC (kg) in the Arctic atmosphere (60°N to 90°N) due to emissions in indicated regions

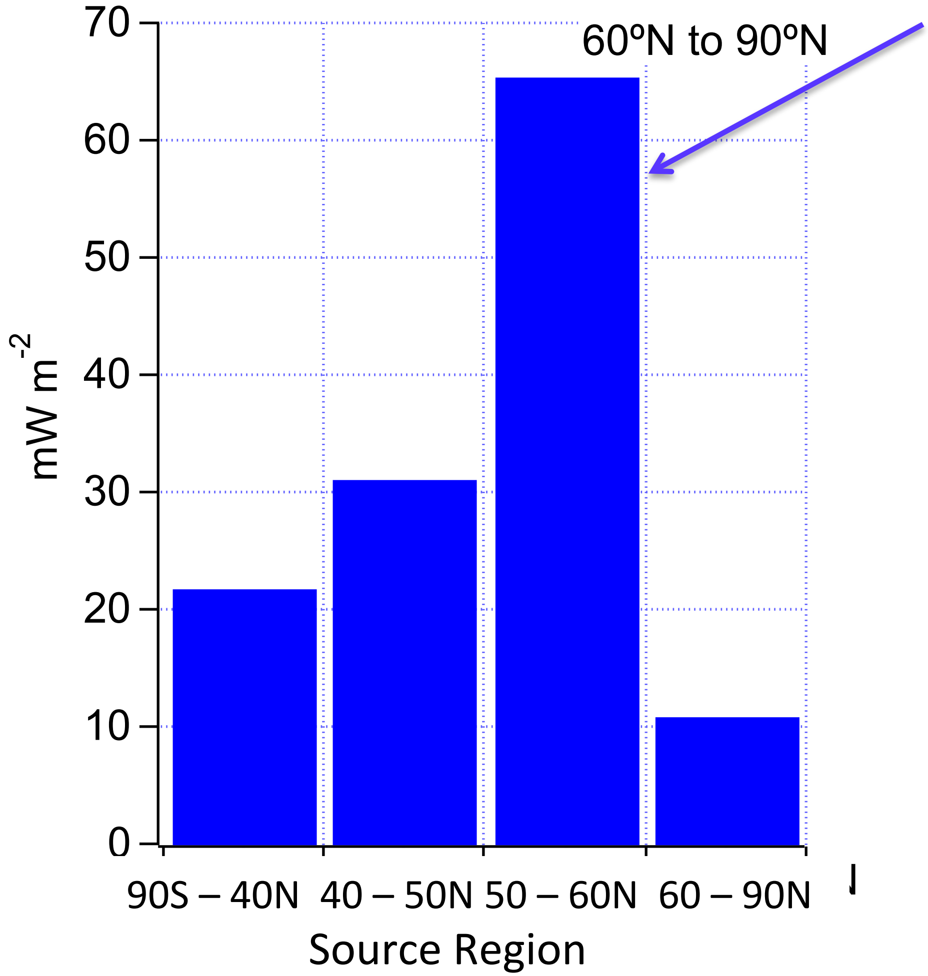


- The burden of BC in the Arctic due to emissions in Arctic Council Nations and the Rest of the World (ROW) is roughly the same.
- Russian and Canadian BC burden is dominated by Grass + Forest Fire Emissions
- US BC burden is dominated by Diesel Combustion and Forest Fire Emissions
- Nordic BC burden is dominated by Diesel Combustion

Forcing by BC in the Arctic due to the Transport of Emissions from the Regions and Source Sectors Shown

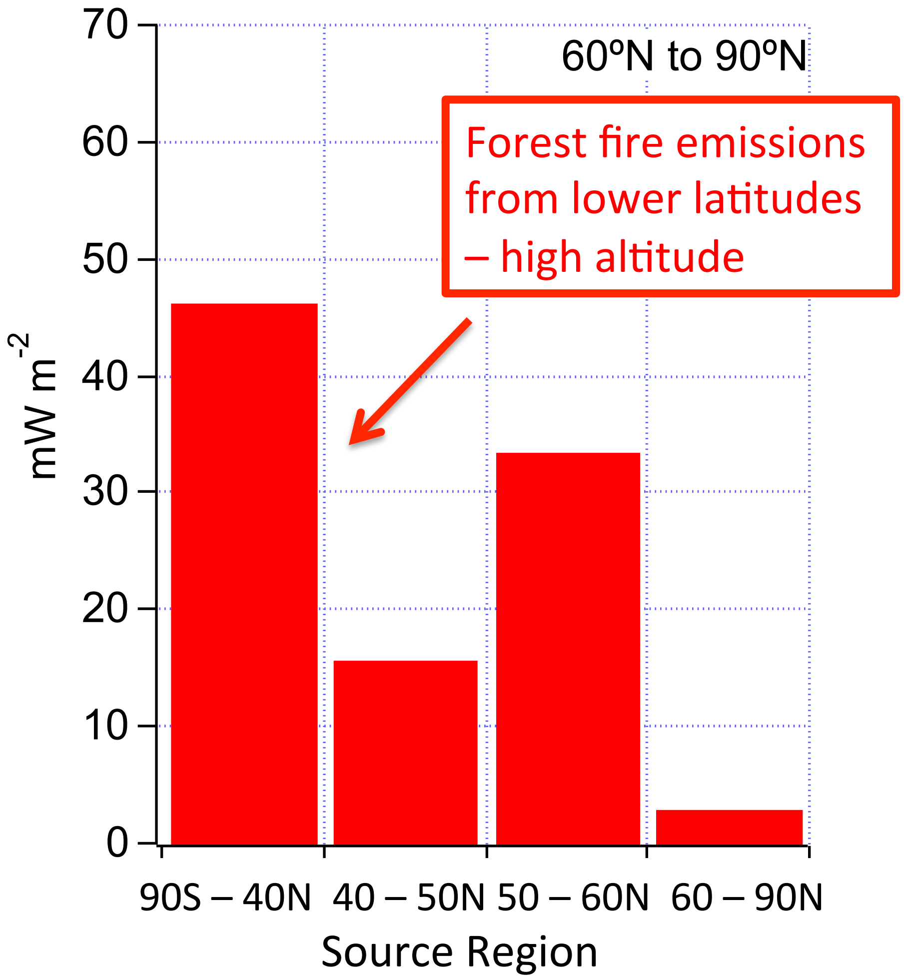


BC-Snow Albedo Forcing due to Emissions from Indicated Latitude Bands

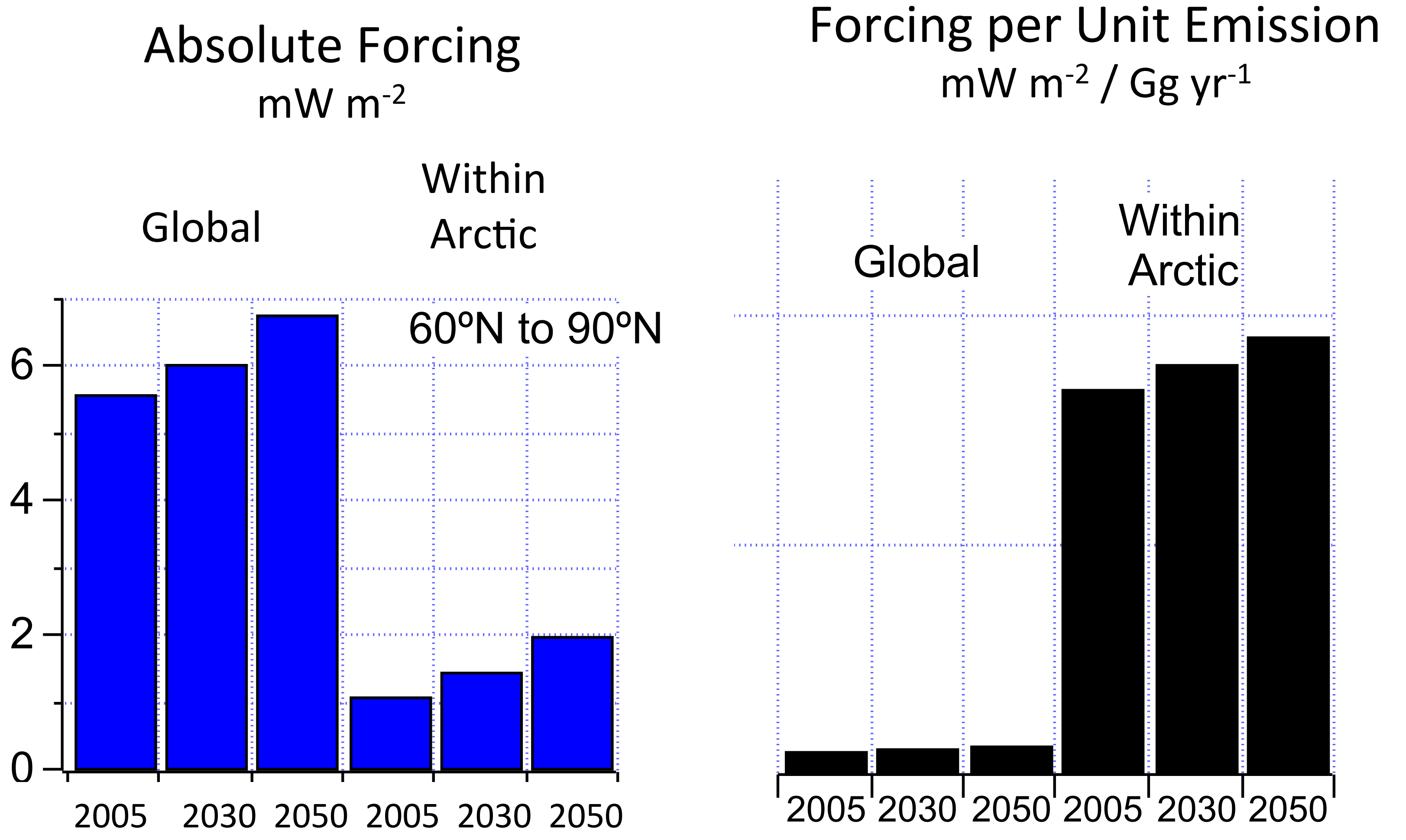


BC from sources closest to the Arctic is most likely to be deposited to the surface - strongest forcing.

Atmospheric Direct Radiative Forcing due to Emissions from Indicated Latitude Bands



BC-Snow Albedo Forcing for **Current and Projected Shipping Emissions of BC**: Global and Within-Arctic Emissions



Indicates the potential importance of limiting emissions within and close to the Arctic

Summary of Sources of BC to the Arctic and Resulting Radiative Forcing – What we can say for sure

- Source regions and sources types that dominate the burden of BC in the Arctic are fairly well understood.

- Forest and Grassland Fire emissions dominate the contribution from Canada and Russia to the burden of BC in the Arctic atmosphere. Agricultural fires can also make a significant contribution if they become Forest/Grass fires.

- Diesel combustion emissions dominate the contribution of U.S. and Nordic countries to the burden of BC in the Arctic atmosphere.

- Domestic (e.g., wood stove) sources within the Nordic countries and Russia make a substantial contribution to the burden of BC in the Arctic atmosphere. With further implementation of regulatory measures on transport emissions, the relative importance of domestic sources is likely to increase.

- Emissions in close proximity to or within the Arctic are more likely to be deposited to snow and ice surfaces and cause surface warming than emissions from further south.

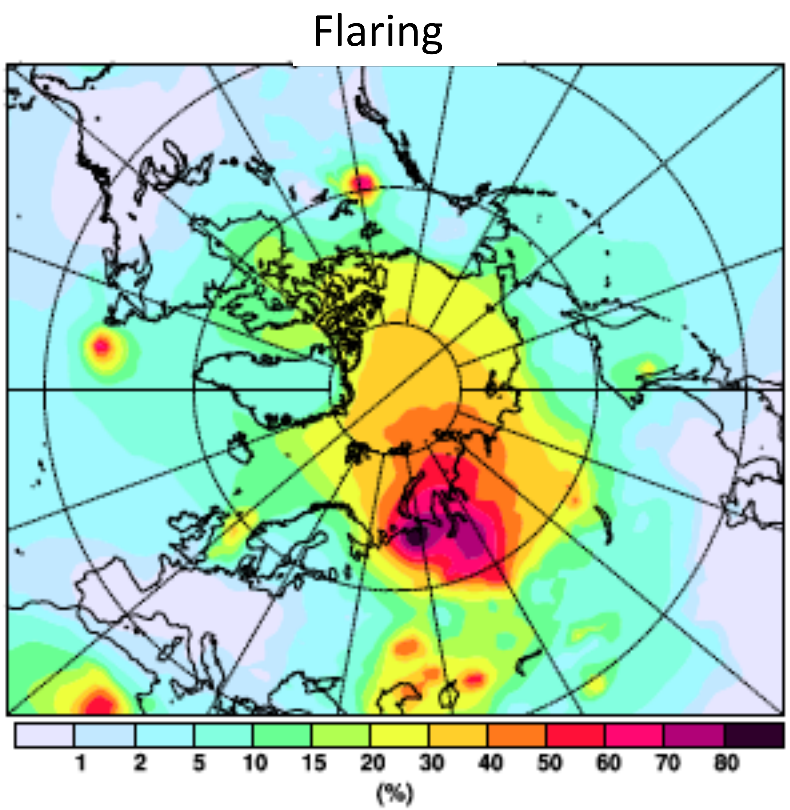
- Extra-polar forcing likely results in a poleward transfer of heat energy indicating the need to manage global emissions of BC and greenhouse gases.

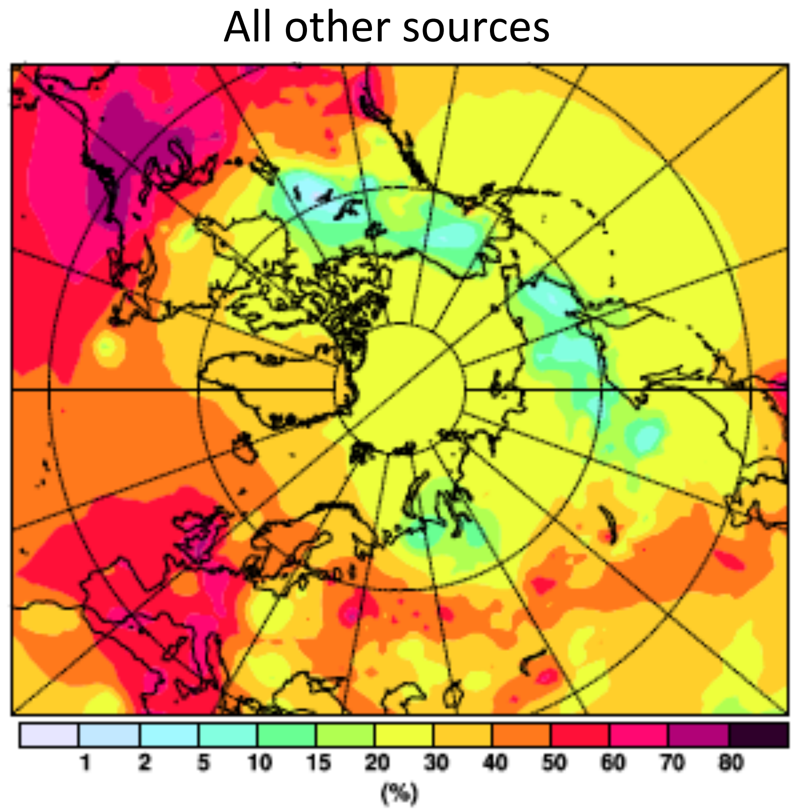
Next step: AMAP 2015 Assessment

- **Additional species**:
  - BC + co-emitted species (organic carbon, sulfur dioxide, nitrogen oxides, and non-methane volatile organic particulates)
  - Tropospheric ozone

- **Additional sector**:
  - Flaring (Arctic and global)

Simulated annual mean atmospheric surface concentrations of BC (ng/m3)



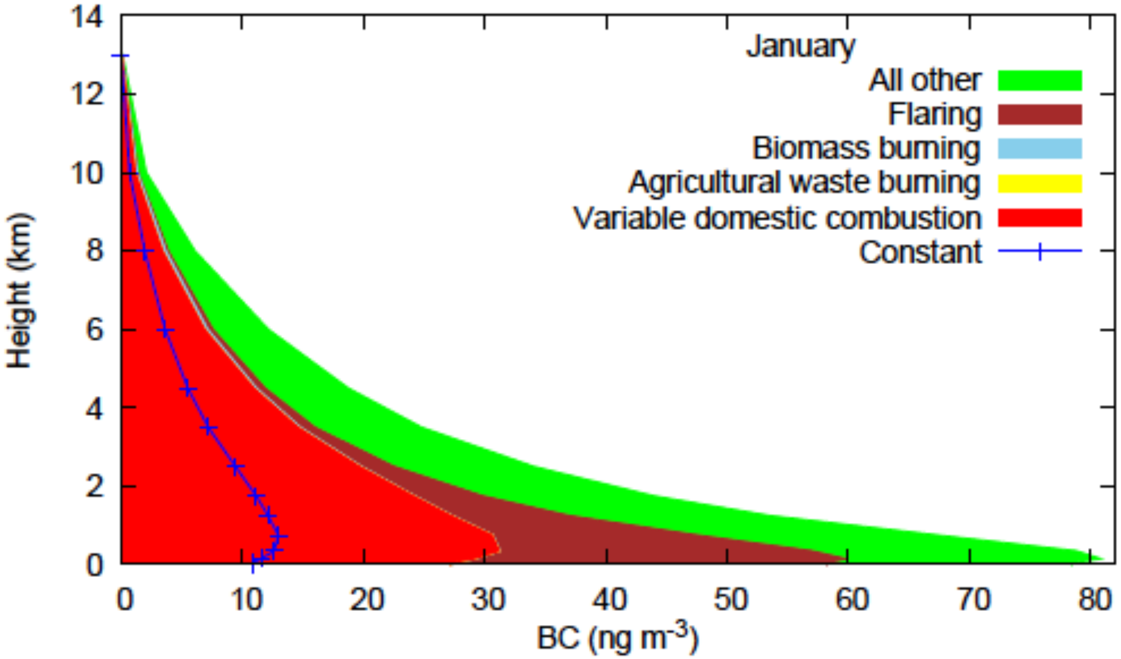


Gas flaring is estimated to contribute less than 3% of global BC emissions but has been modeled to contribute up to 52% of all Arctic BC near the surface.

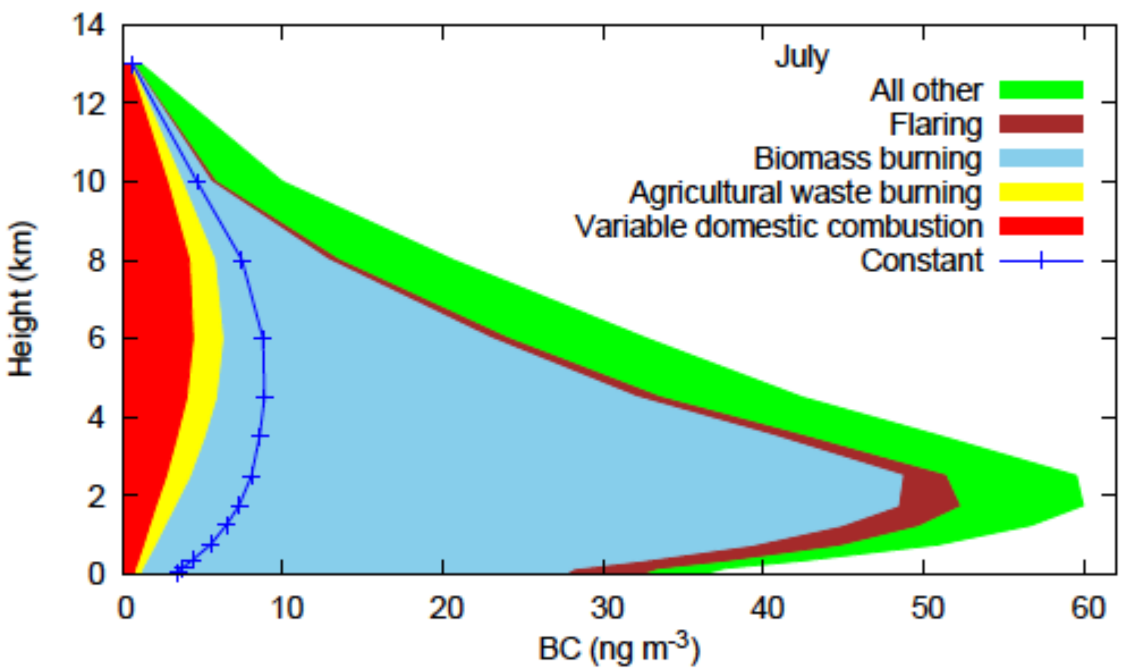
Stohl et al., ACP, 2013

Next step: AMAP 2015 Assessment

- **Additional species**:
  - BC + co-emitted species (OC, SO_2, NO_x, and non-methane VOCs)
  - Tropospheric ozone
- **Additional sector**:
  - Flaring (Arctic and global)
- **Additional source regions**:
  - Non-Arctic Europe
  - Asia
- **Monthly varying biomass burning, agricultural waste burning, and domestic combustion**



Simulated vertical profiles of BC concentrations for averaged over the Arctic and split by source category



Not taking into account seasonally varying emissions may be causing model biases in simulated BC concentrations in the Arctic (and in the mid-latitudes).

Stohl et al., ACP, 2013

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- **Monthly varying biomass burning, agricultural waste burning, and domestic combustion**

- **Simulation of climate response to emission reduction scenarios with several fully coupled ocean – atmosphere Earth System Models**

Timeline for AMAP Expert Group on SLCFs:

April 15 – June 1, 2014: Review by national experts

May – August, 2014: Finish forcing and climate response model simulations

August 2014: Complete report sent out for peer review

October 1 2014: Receive peer-review comments

November 1 2014: Final draft to AMAP for editing

Early 2015: Assessment published

Thank you for your attention!