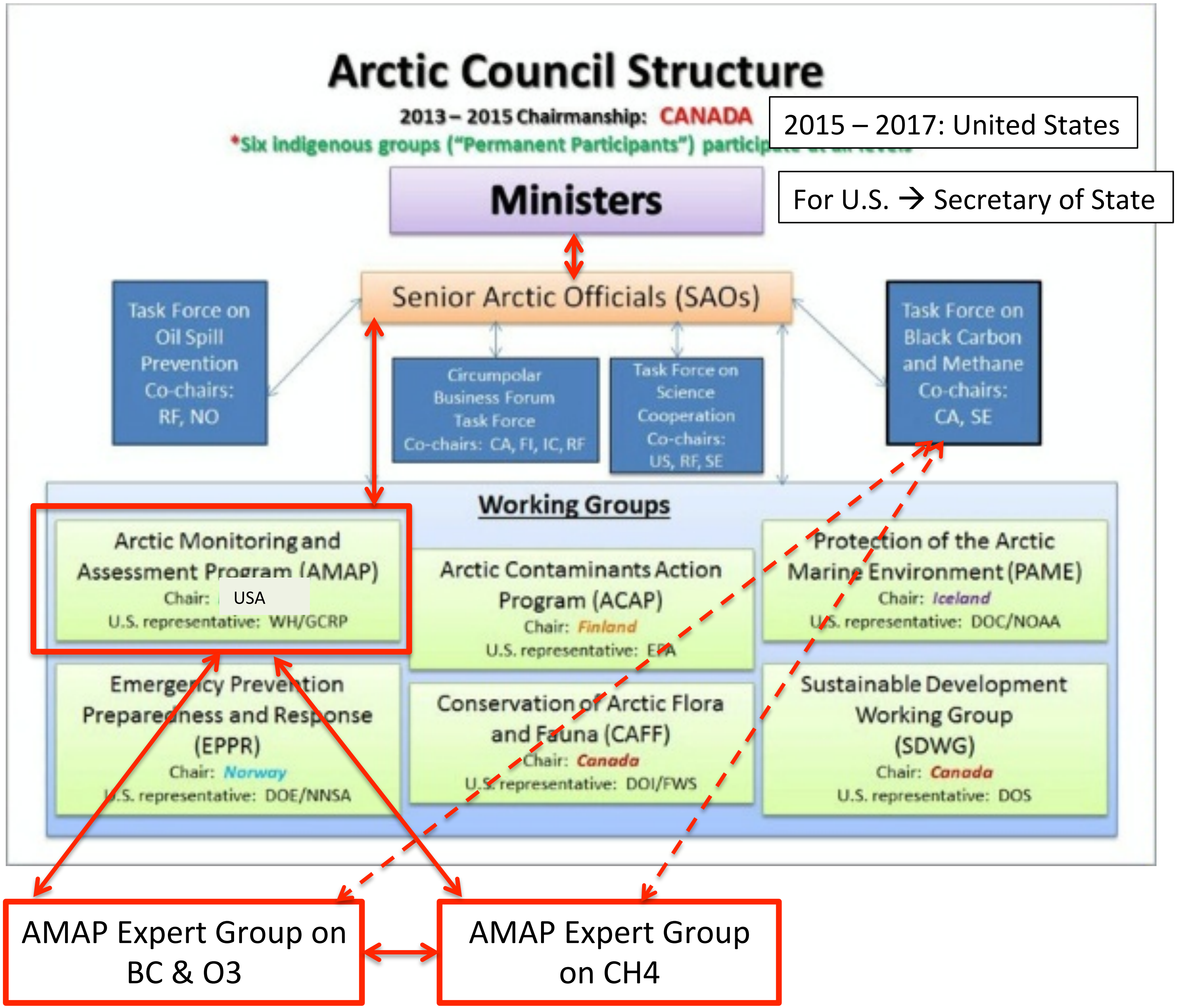
Key Findings of the AMAP 2015 Assessment on Black Carbon and Tropospheric Ozone as Arctic Climate Forcers

AMAP
Arctic Monitoring and Assessment Programme

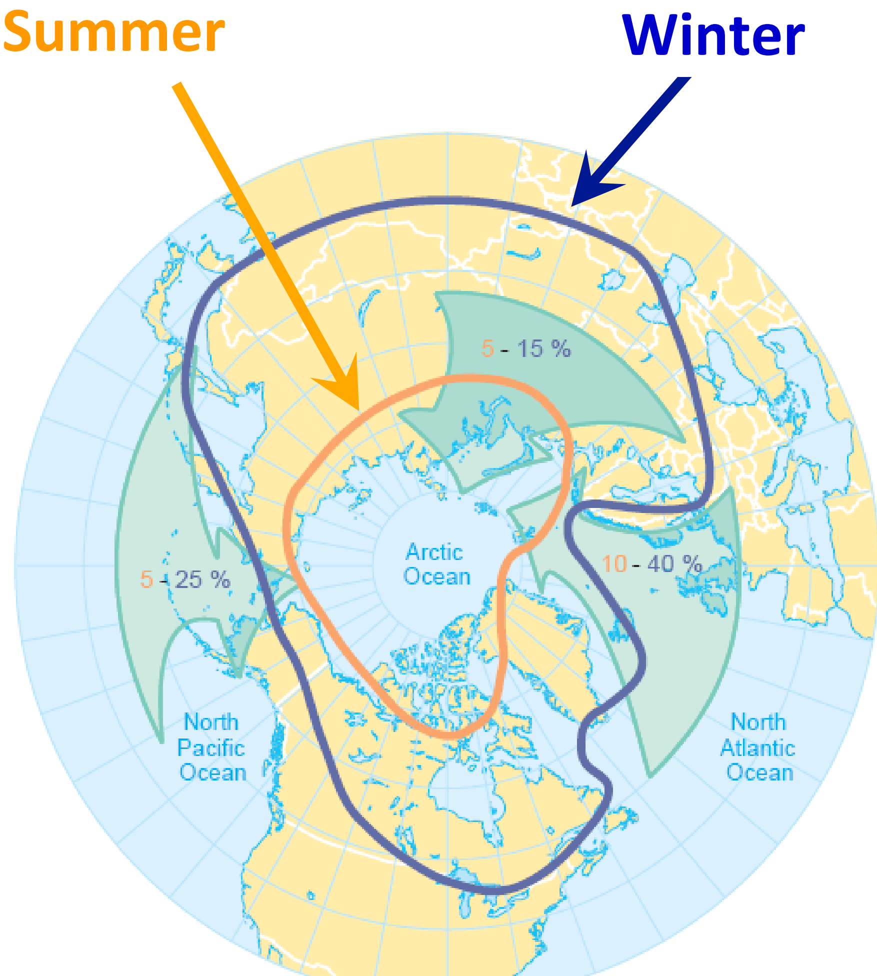
Lead authors: Patricia K. Quinn (NOAA PMEL) and Andreas Stohl (NILU)

Authors: Steve Arnold, Alexander Baklanov, Terje Berntsen, Jesper Christensen, Sabine Eckhardt, Mark Flanner, Andreas Herber, Ulrik Korsholm, Kaarle Kupiainen, Joakim Langer, Kathy Law, Sarah Monks, Boris Quennehen, Knut von Salzen, Maria Sand, Julia Schmale, Vigdis Vestreng, Christine Wiedinmyer

Contributing authors: Chaoyi Jiao, Sangeeta Sharma, Maryam Namazi, Ribu Cherian, Nikos Daskalakis, Chris Heyes, Øivind Hodnebrog, Maria Kanakidou, Zbigniew Klimont, Marianne Lund, Gunnar Myhre, Stelios Myriokefalitakis, Dirk Olivie, Johannes Quaas, Jean-Christophe Raut, Bjørn Samset, Michael Schulz, Ragnhild Skeie, David Parrish, Markus Amann


Arctic Council Structure
2013 – 2015 Chairmanship: CANADA
2015 – 2017: United States
*Six indigenous groups ("Permanent Participants") particip
Ministers
For U.S. → Secretary of State
Senior Arctic Officials (SAOs)
Task Force on Oil Spill Prevention Co-chairs: RF, NO
Circumpolar Business Forum Task Force Co-chairs: CA, FI, IC, RF
Task Force on Science Cooperation Co-chairs: US, RF, SE
Task Force on Black Carbon and Methane Co-chairs: CA, SE
Working Groups
Arctic Monitoring and Assessment Program (AMAP)
Chair: USA
U.S. representative: WH/GCRP
Arctic Contaminants Action Program (ACAP)
Chair: Finland
U.S. representative: EPA
Protection of the Arctic Marine Environment (PAME)
Chair: Iceland
U.S. representative: DOC/NOAA
Emergency Prevention Preparedness and Response (EPPR)
Chair: Norway
U.S. representative: DOE/NNSA
Conservation of Arctic Flora and Fauna (CAFF)
Chair: Canada
U.S. representative: DOI/FWS
Sustainable Development Working Group (SDWG)
Chair: Canada
U.S. representative: DOS
AMAP Expert Group on BC & O3
AMAP Expert Group on CH4

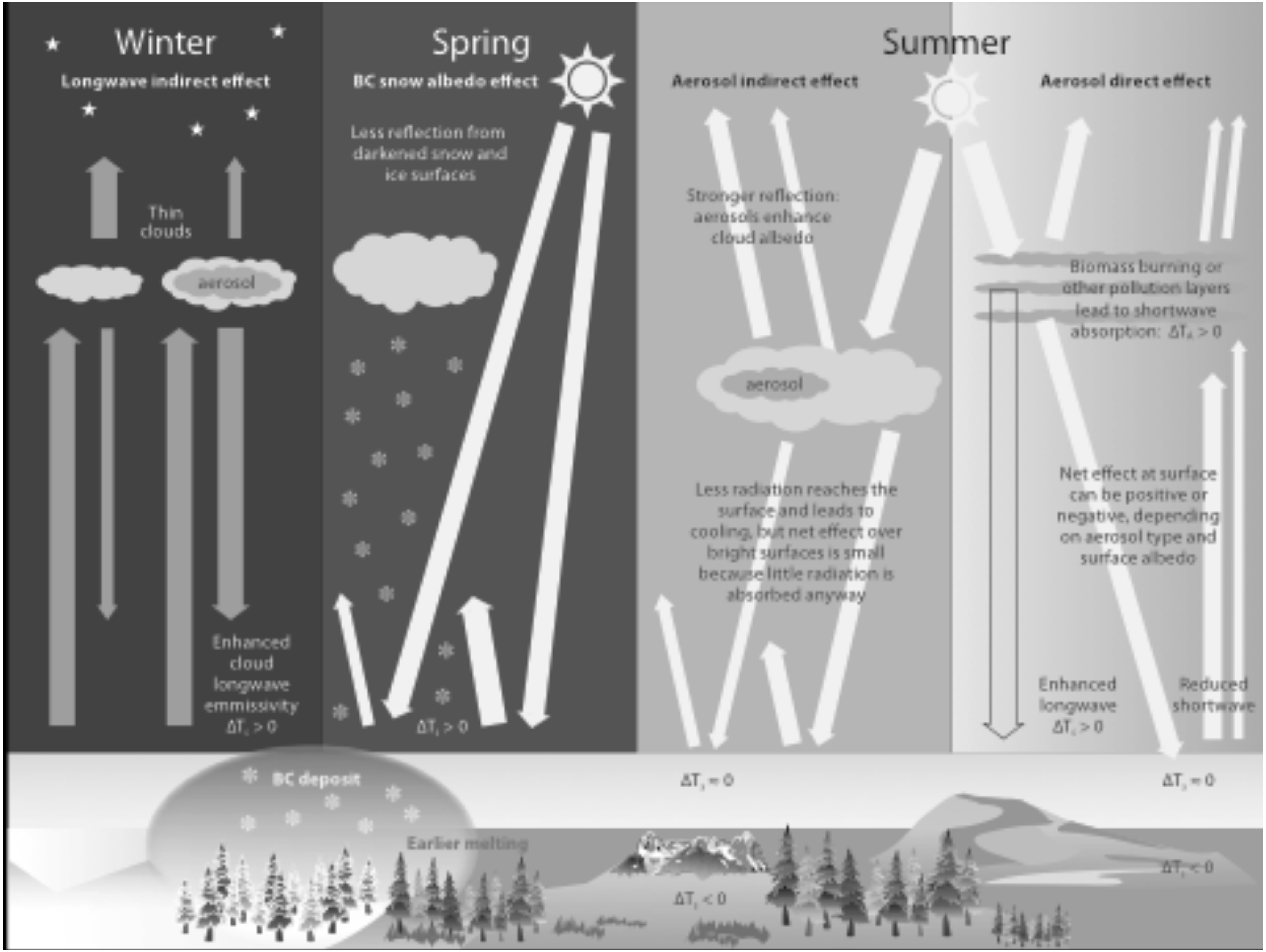
Long-Range Transport of Pollutants to the Arctic



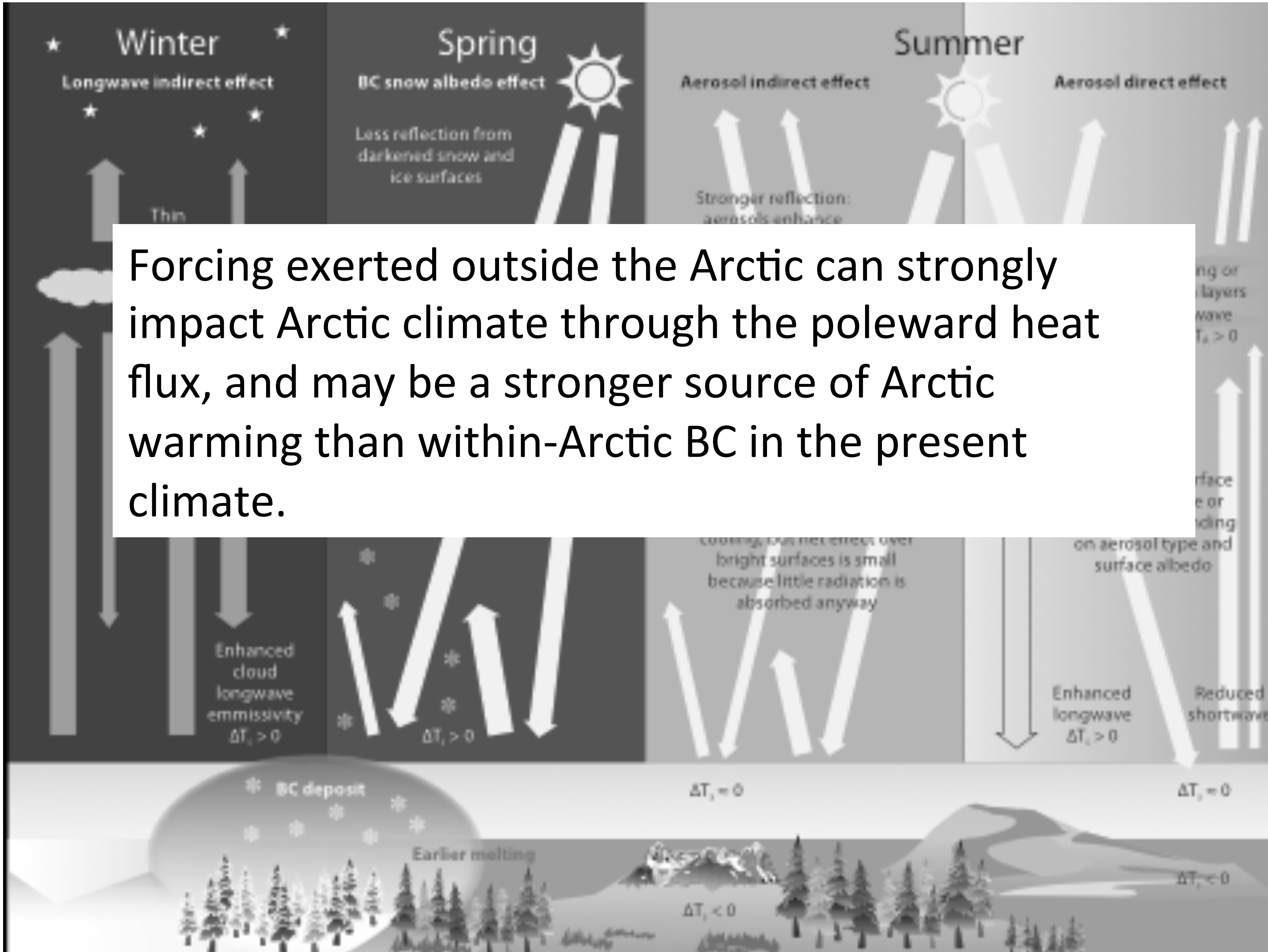
Mean position of the Arctic Front in Winter and Summer

- 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

Forcing mechanisms by Black Carbon within the Arctic

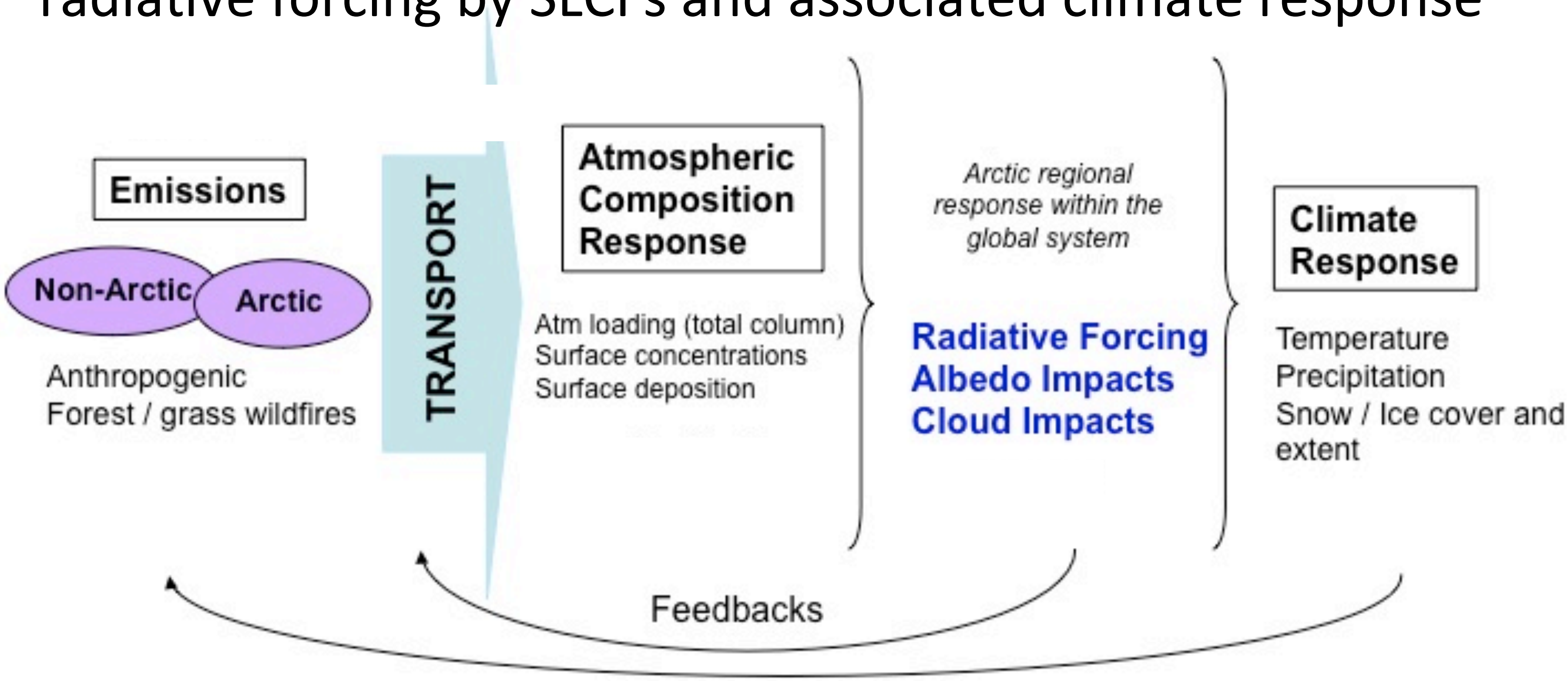


Forcing mechanisms by Black Carbon within the Arctic



Forcing exerted outside the Arctic can strongly impact Arctic climate through the poleward heat flux, and may be a stronger source of Arctic warming than within-Arctic BC in the present climate.

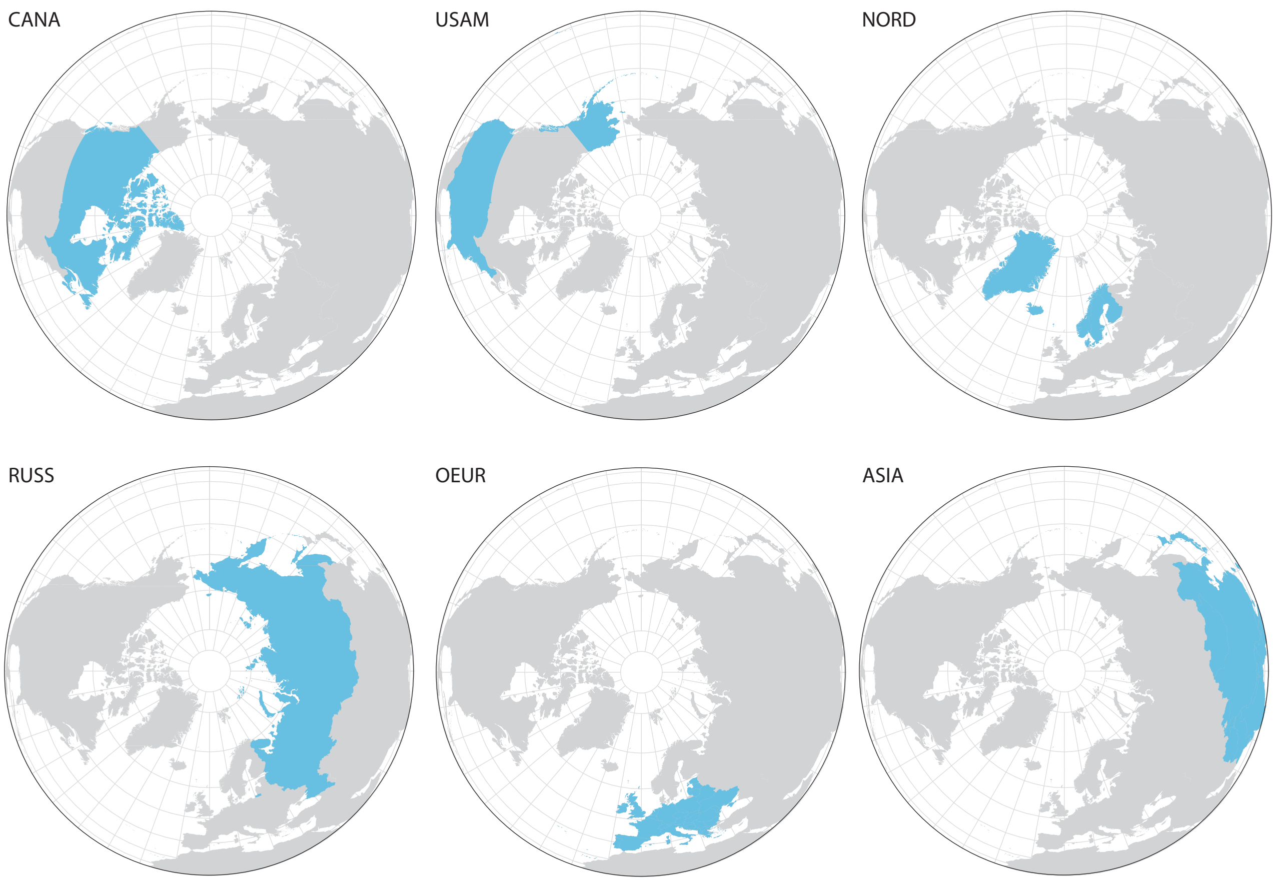
AMAP Global Climate Model approach to calculating the radiative forcing by SLCFs and associated climate response



- A multi-model ensemble was used to estimate the contributions of emissions of non-CH4 Short-Lived Climate Forcers (SLCFs) to changes in Arctic climate.
- Impacts of emissions were first evaluated in terms of atmospheric direct and indirect and snow/ice radiative forcing in the Arctic (> 60N).
- Arctic equilibrium surface temperature response was then derived by translating the radiative forcings with the use of climate sensitivity parameters (e.g., Shindell and Faluvegi, 2009) for atmospheric direct and snow/ice radiative forcing.
- Within-Arctic and Extra-Artic forcing were included in the analysis.

Emissions from which geographical regions most impact Arctic atmospheric composition and climate?

Canada **United States** **Nordic Countries**



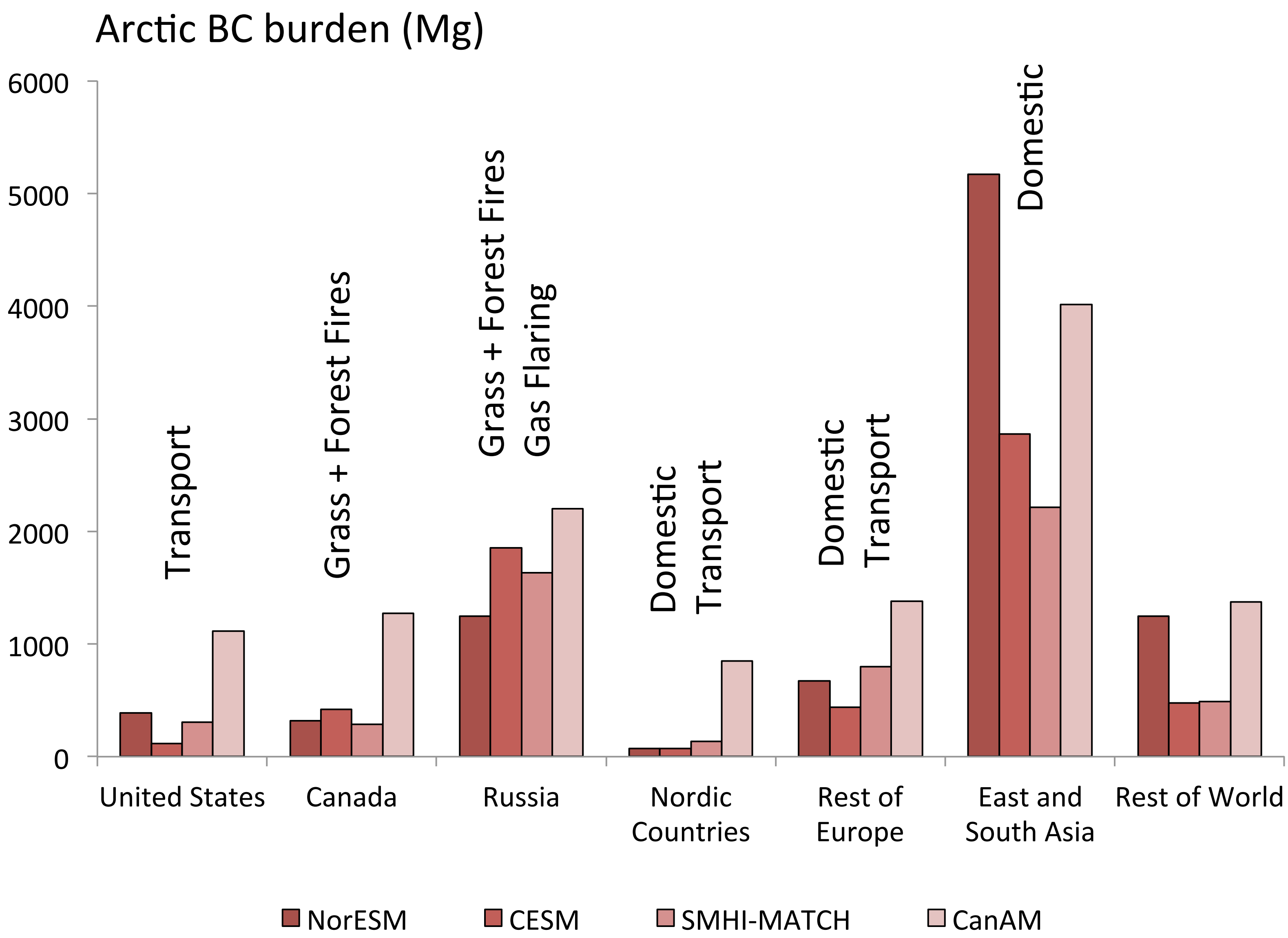
Russia **Rest of Europe** **East and South Asia**

Also included Rest of world (ROW)

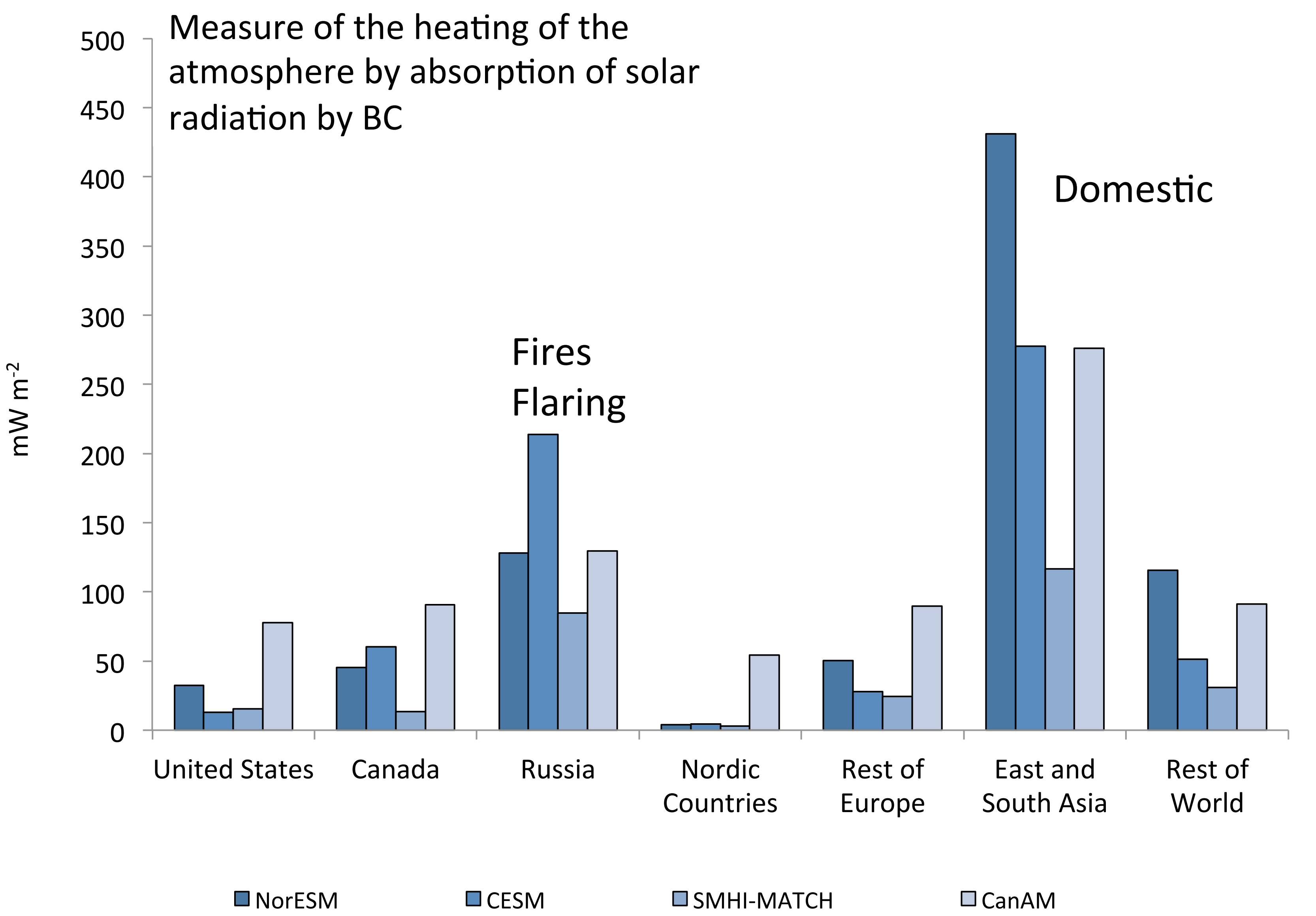
Emissions from which source sectors most impact Arctic atmospheric composition and climate?

- Domestic combustion (seasonally varying)
- Transport
- Energy production and industrial processes
- Gas flaring
- Agricultural waste burning
- Grass and forest fires
- Shipping emissions – current and projected

Contribution of different emission regions to BC burdens in the Arctic as simulated by four models using the same emissions for 2010



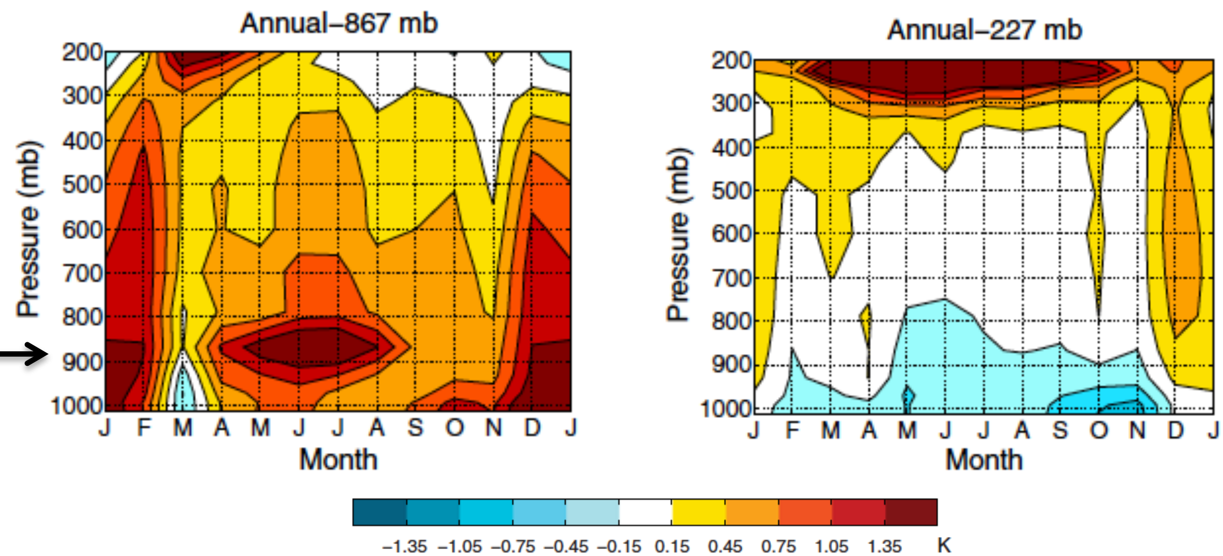
Arctic annual mean BC atmospheric direct RF (in mWm^{-2}) for each emission region



Radiative forcing is not a suitable metric for assessing Arctic surface temperature response because:

- Species (BC) that absorb solar radiation in the upper Arctic troposphere may cool the surface despite exerting a positive radiative forcing (Shindell and Faluvegi, 2009: Sand et al., 2013; Flanner, 2013)

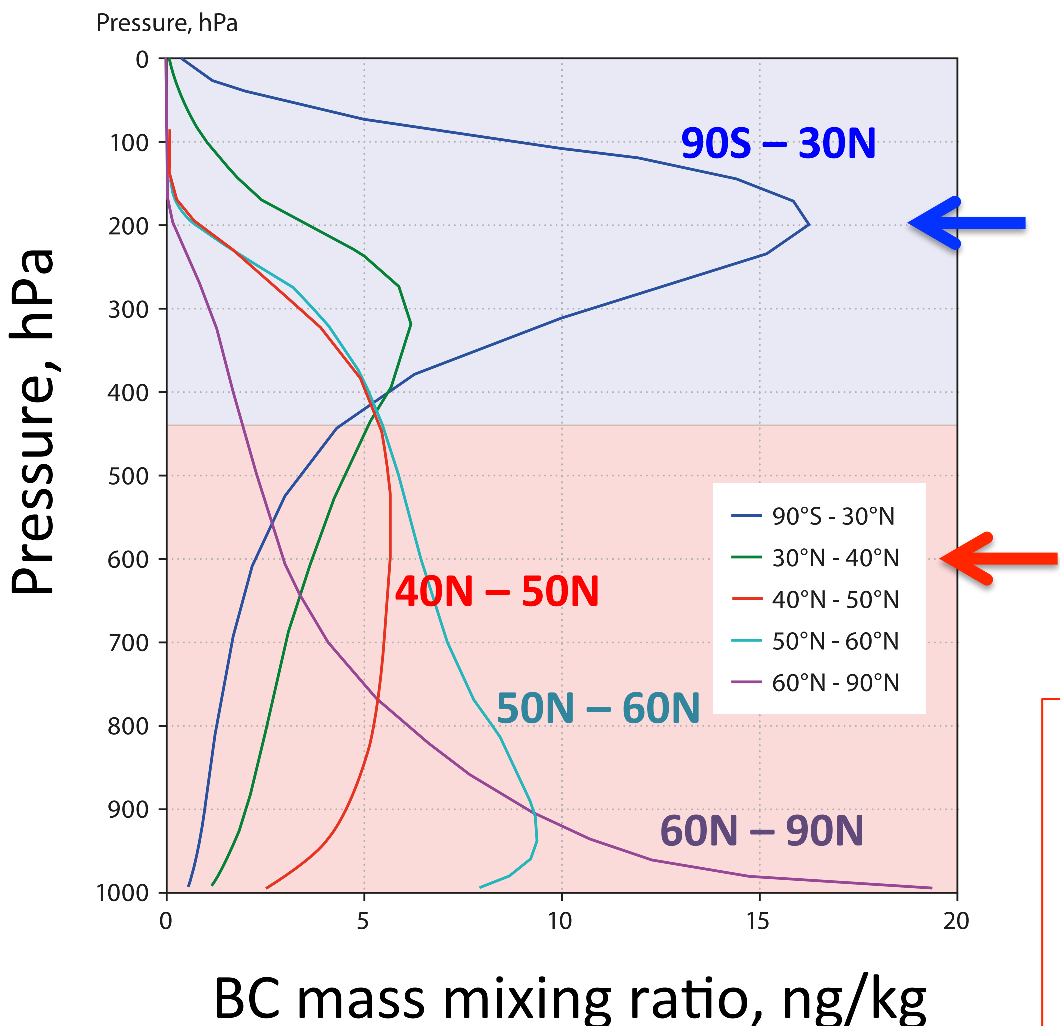
BC layer near the surface



BC layer aloft

- BC in the lower atmosphere warms by depositing energy near the surface by either atmospheric heating or BC in snow and ice
- BC aloft cools the surface due to surface dimming and a reduction in poleward heat flux into the Arctic resulting from heating of the upper troposphere by BC

Simulated vertical profiles of BC in the Arctic atmosphere caused by emissions from different latitude bands



Altitudes where BC is expected to cool the Arctic surface

Altitudes where BC is expected to warm the Arctic surface

BC emissions from low latitudes that reach the Arctic are more likely to reside at high altitudes where they exert a cooling effect.

(Flanner, 2013)

Radiative forcing is not a suitable metric for assessing Arctic surface temperature response because:

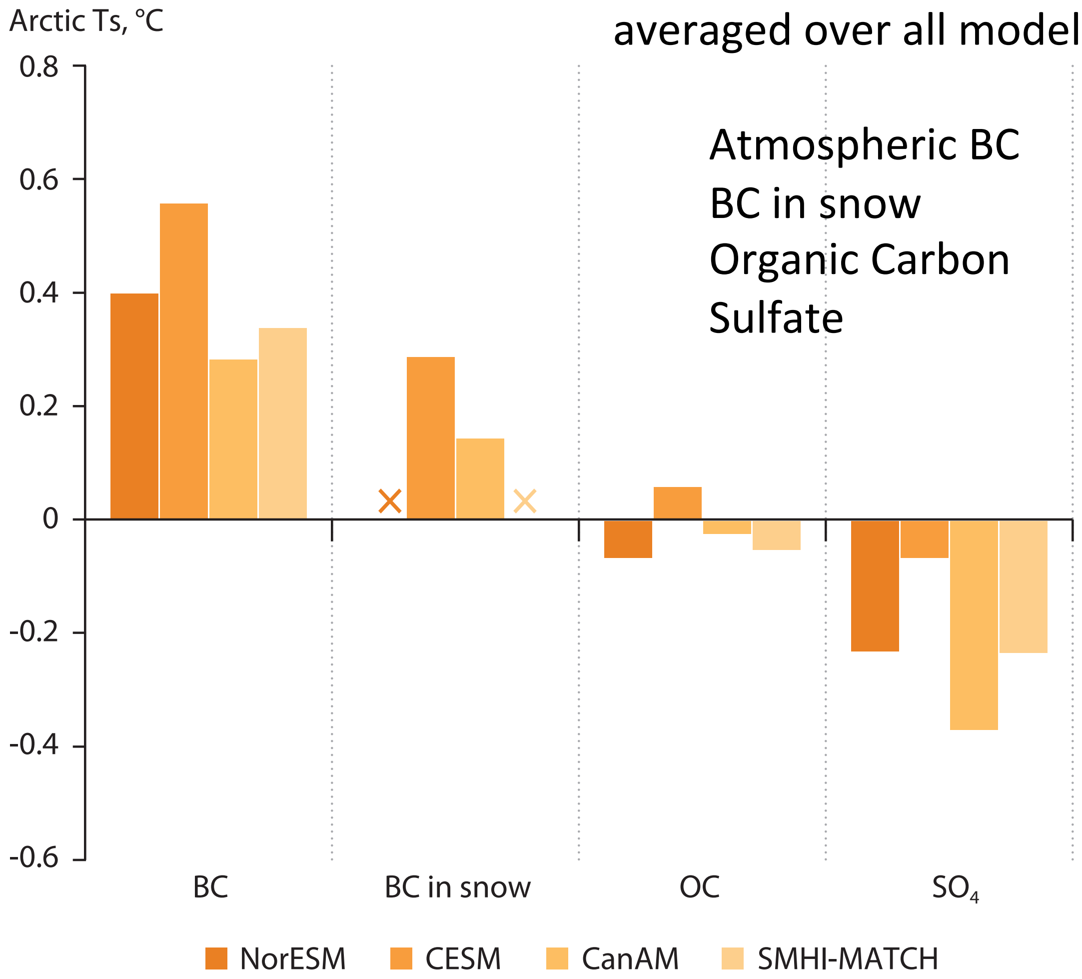
- Species (BC) that absorb solar radiation in the upper Arctic troposphere may cool the surface despite exerting a positive radiative forcing (Shindell and Faluvegi, 2009: Sand et al., 2013; Flanner, 2013)

- Radiative forcing by BC outside of the Arctic can cause substantial Arctic warming by increasing the poleward heat flux

- Forcing by the snow/albedo effect triggers strong local feedbacks enhancing regional warming.

As a result, calculated radiative forcings were translated into the Arctic equilibrium surface temperature response using regional climate sensitivity parameters.

Global (total) contributions to annual-mean Arctic equilibrium surface temperature response (K) due to atmospheric BC, organic carbon (OC), and sulfate, and BC in snow

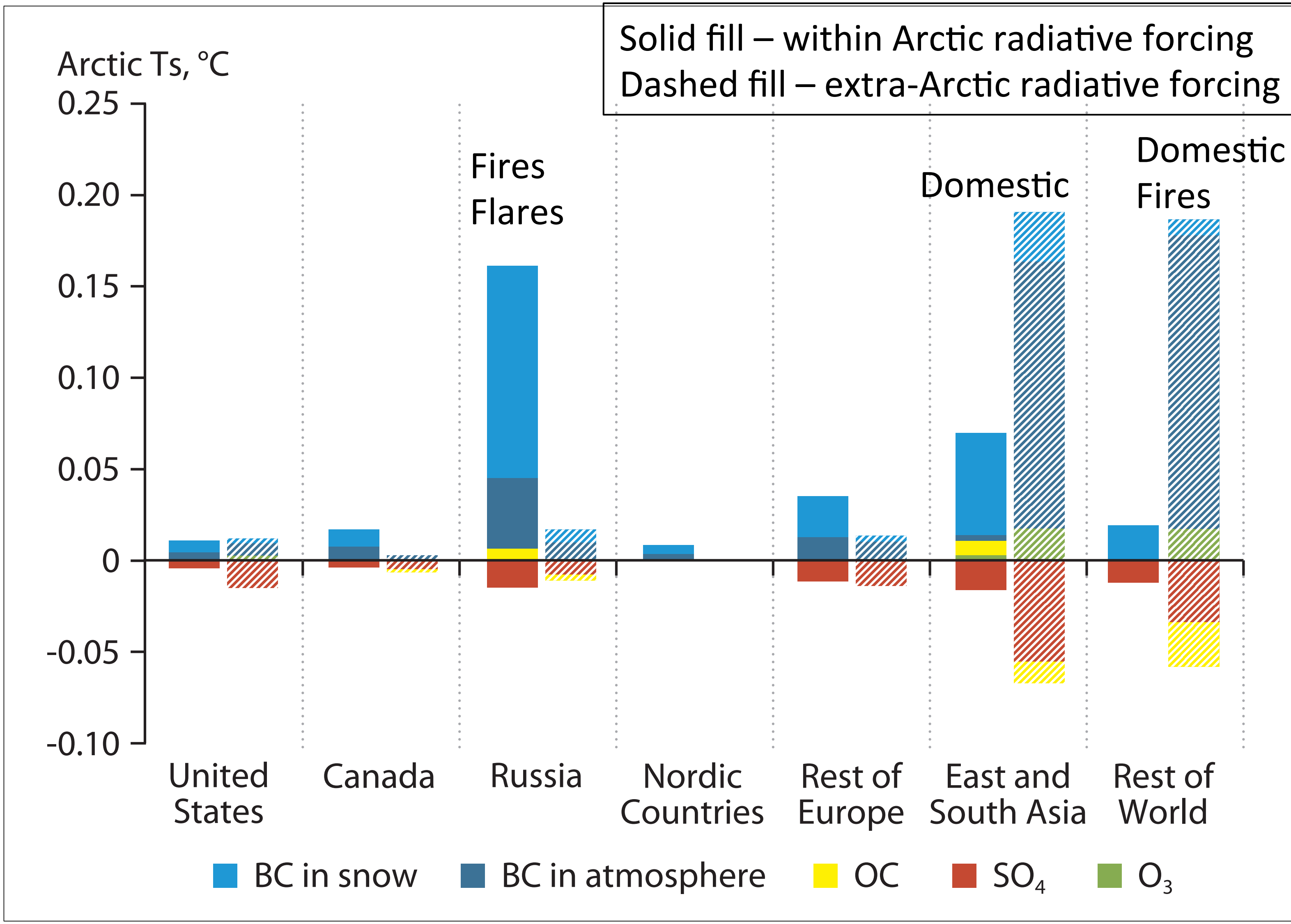


Net surface temperature response for all components averaged over all models is 0.35K:

Atmospheric BC	0.4
BC in snow	0.22
Organic Carbon	-0.04
Sulfate	-0.23

Does not include cloud indirect effects!

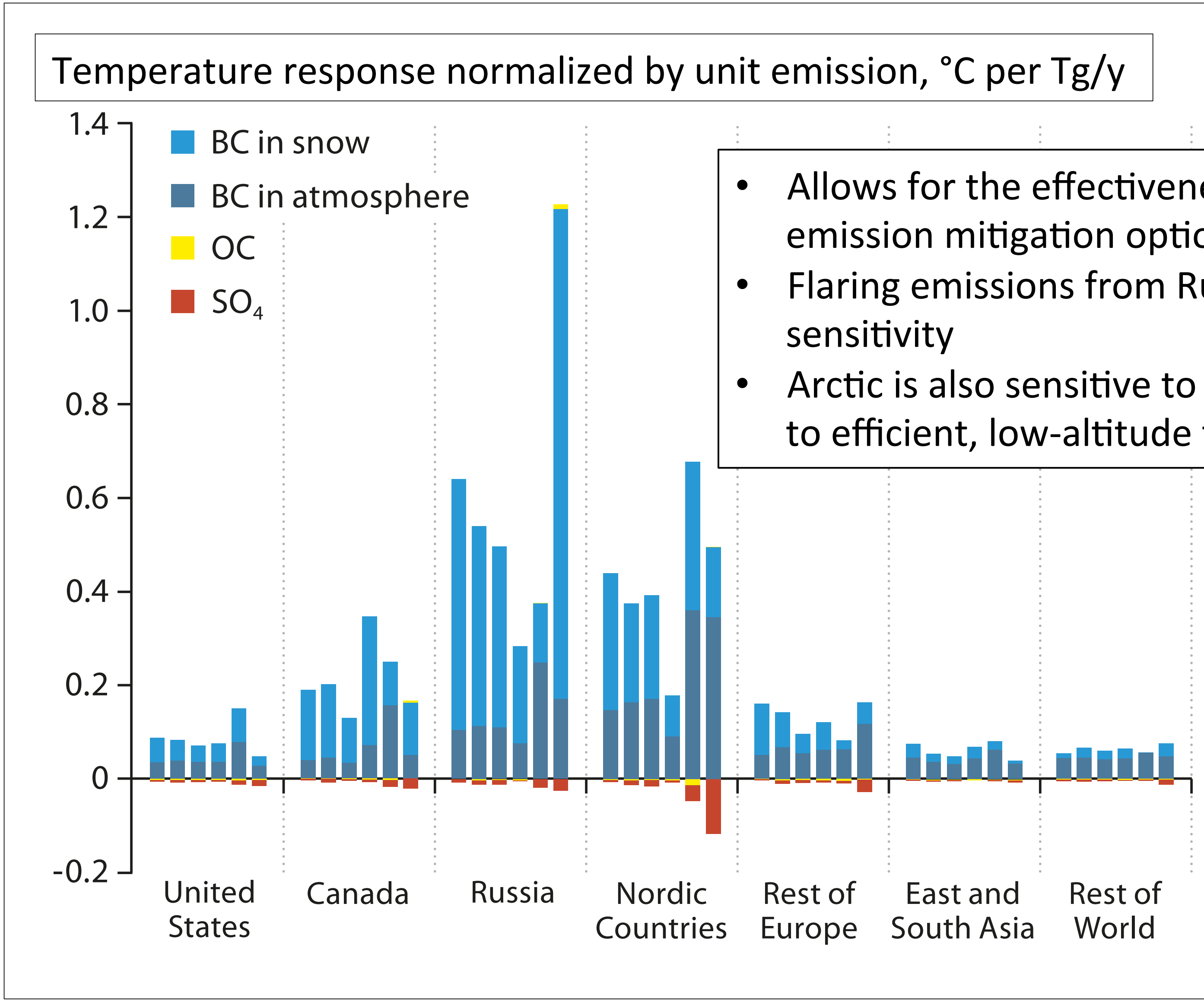
Global (total) contributions to annual-mean Arctic equilibrium surface temperature response (K) due to BC, OC, and SO4 from each emission region



Russia: Warming due to BC emissions/forcing within the Arctic

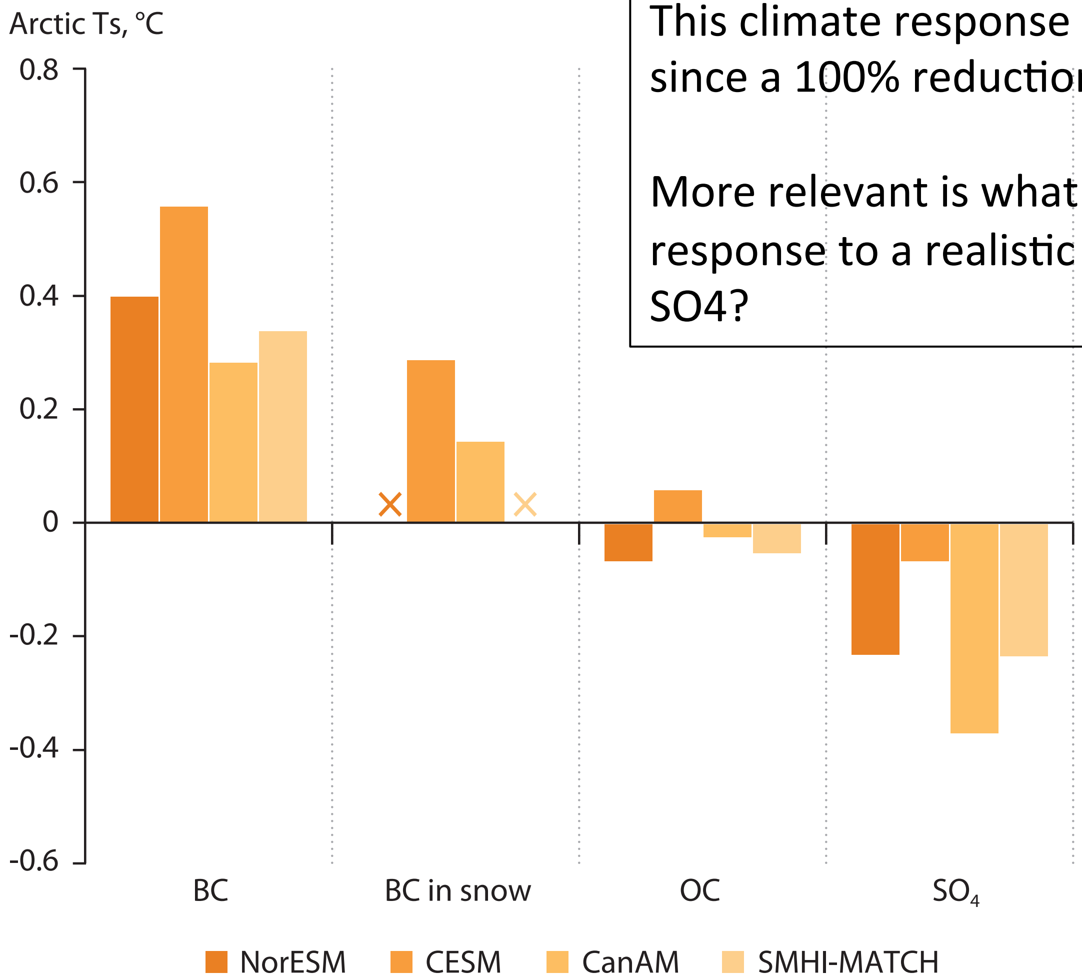
Asia & ROW: Warming due to forcing exerted outside of the Arctic and poleward heat transport

Arctic sensitivity (in K) per unit emission for each emission region and sector (Domestic, EIW, Transport, Agricultural waste burning, Forest fires, Flaring)



- Allows for the effectiveness of regional emission mitigation options to be evaluated
- Flaring emissions from Russia – largest sensitivity
- Arctic is also sensitive to Nordic emissions due to efficient, low-altitude transport

Global (total) contributions to annual-mean Arctic equilibrium surface temperature response (K) due to atmospheric BC, organic carbon (OC), and sulfate, and BC in snow

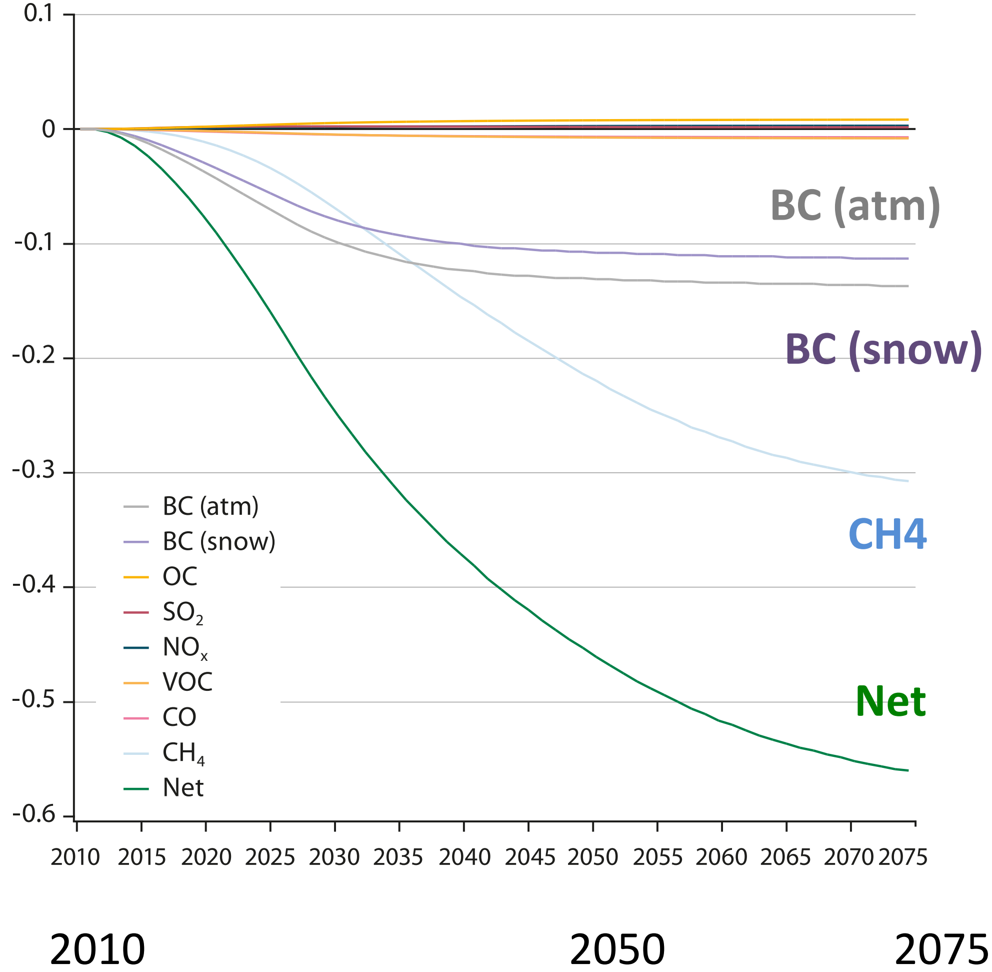


This climate response represents the upper limit since a 100% reduction in emissions is unrealistic.

More relevant is what might be the transient response to a realistic reduction in BC, OC, and SO4?

Transient climate response based on Regional Temperature Potentials (RTP): Estimate of reduced warming in the Arctic in response to a mitigation scenario designed to achieve large reductions in temperature response in the short term at the global scale (after UNEP/WMO, 2011 and Shindell et al., 2012).

Change in Arctic warming, °C



Averaged over 2040 – 2050 (in K):

Net -0.40

BC -0.23

CH4 -0.17

Agrees well with the corresponding net average from ensemble-mean climate states based on 4 ESMs (-0.3 to -0.6)

Note: SO2 emissions not aggressive in this scenario

Does not include cloud indirect effects

Summary

- The impact of emissions of BC, OC, and Sulfate in different regions and sectors on Arctic burden, radiative forcing, and equilibrium surface temperature have been estimated. Estimates of equilibrium surface temperature do not include cloud indirect effects.

- The best estimate of total Arctic equlibrium surface temperature response due to the direct effect of current emissions is 0.35K (0.40 from BC atm, 0.22 from BC snow, -0.04 from OC, -0.23 from SO4).

- Aerosol emissions from the domestic sector from East+South Asia have the largest warming effect in the Arctic.

- Emissions from Russia, Asia, and ROW roughly contribute the same amount of warming to the Arctic. For Asia and ROW, half of this warming comes from forcing exerted outside of the Arctic.

- Per unit emission, the Arctic surface temperature is most sensitive to Russian flaring emissions (mostly from BC in snow).

- Two models that include estimates of cloud indirect effects indicate that cooling effects by SO4 and OC emissions could be substantial. It is likely that reductions in sulfur emissions would partially counteract effects of reduced BC emissions on Arctic climate, which may limit the effectiveness of mitigation action.