

Changing Arctic Aerosol Chemistry

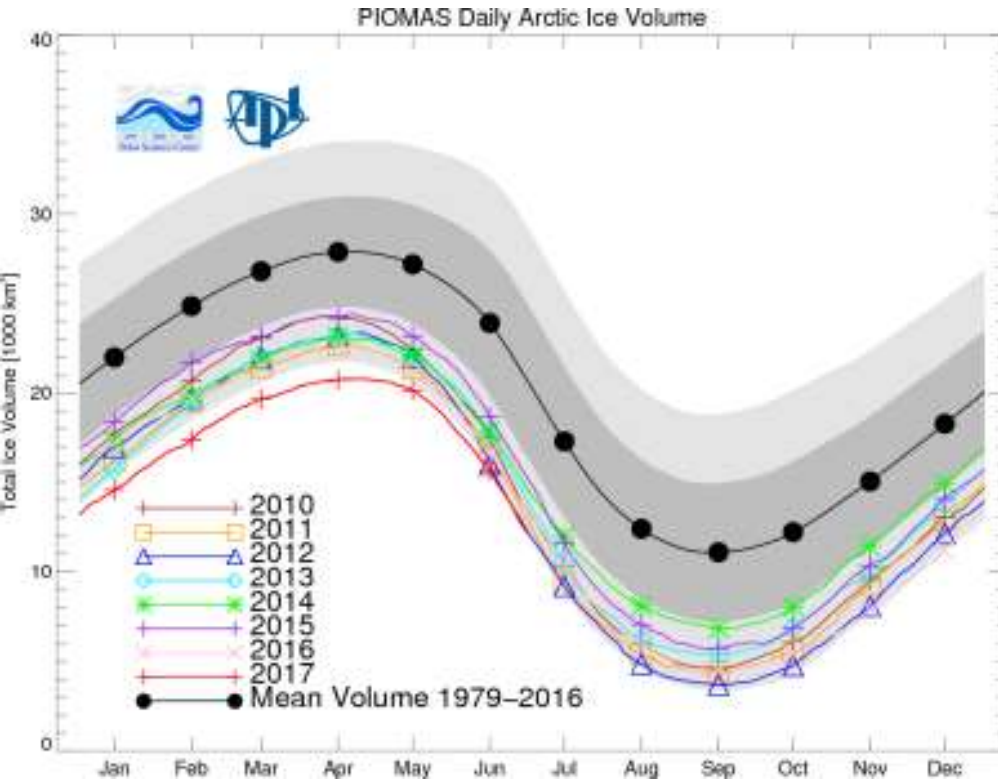
Beach at Utqiagvik, AK
August 2015
(during offshore drilling
in Chukchi Sea)

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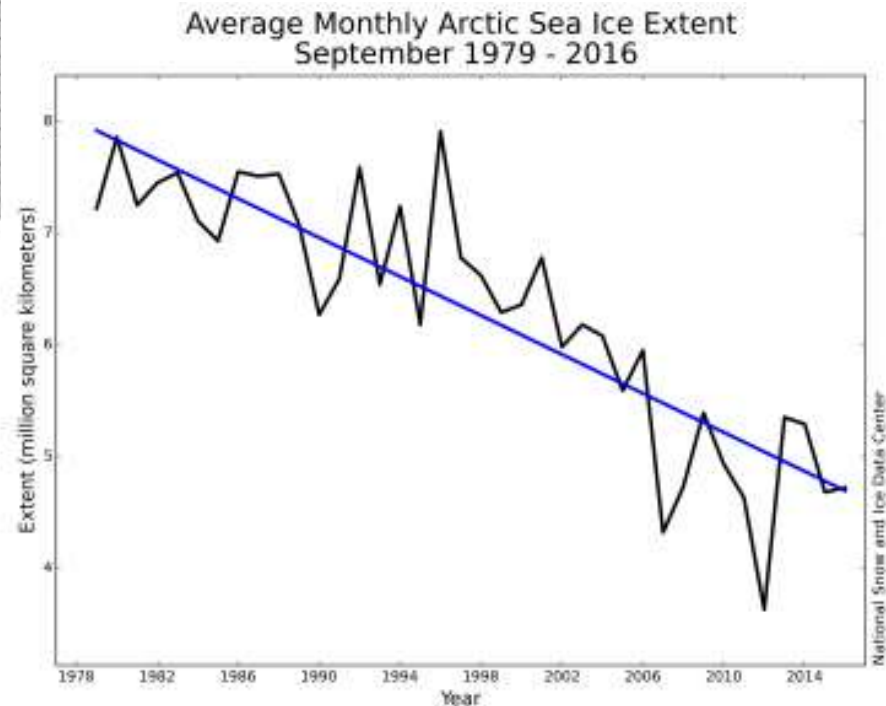
Decreasing Arctic Sea Ice



Sea Ice High = April

Sea Ice Low = September

- Complete summertime sea ice loss predicted by 2050, possibly even within the next decade or two (Overland & Wang, 2013)



Record Arctic Sea Ice Loss

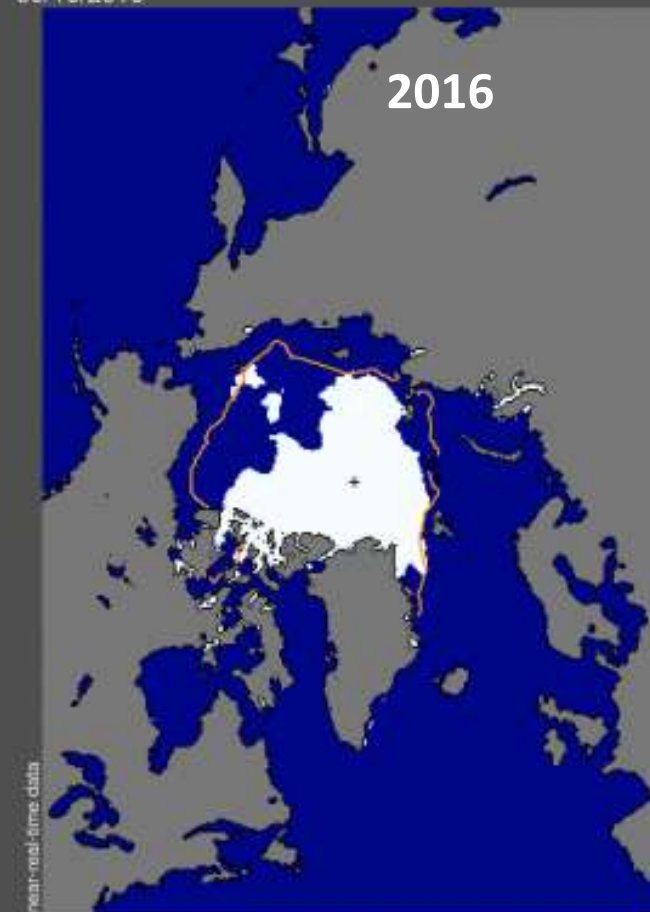
Sea Ice Extent
Sep 2012



Total extent = 3.6 million sq km

median
ice edge

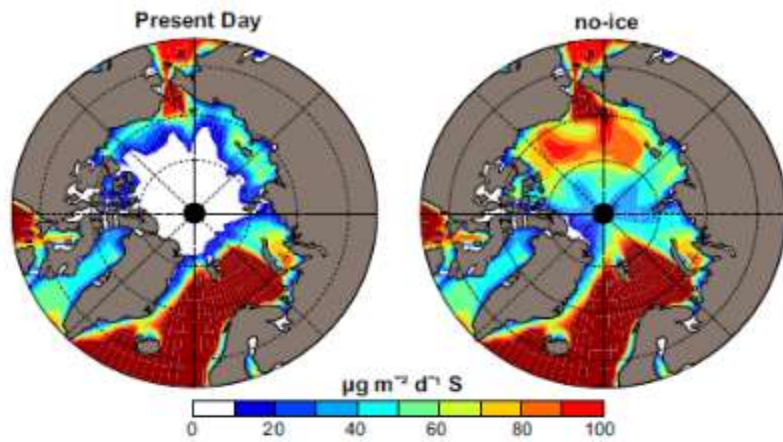
Sea Ice Extent
09/10/2016



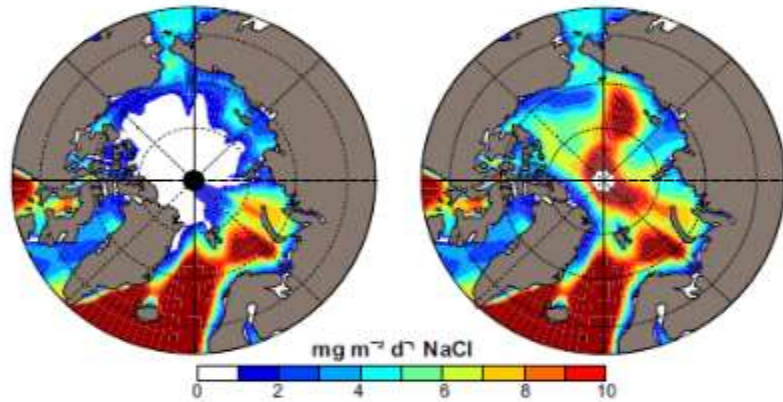
median
1981-2010

Model Simulations of Increased Oceanic Emissions due to Arctic Sea Ice Loss

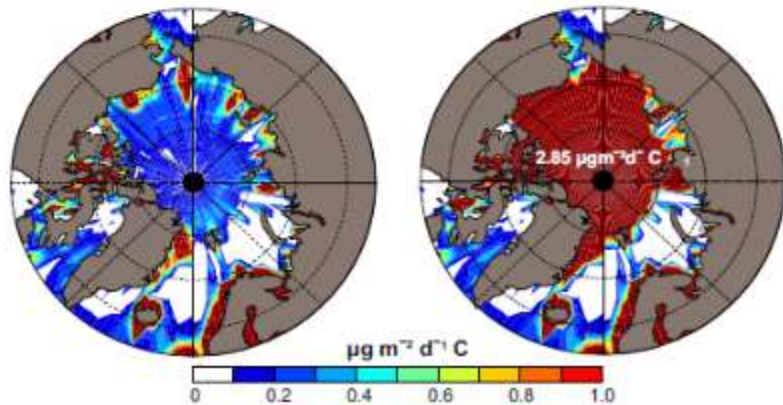
- Dimethylsulfide (aerosol precursor)
- Primary aerosols: Sea salt & marine organic carbon



(a) DMS flux

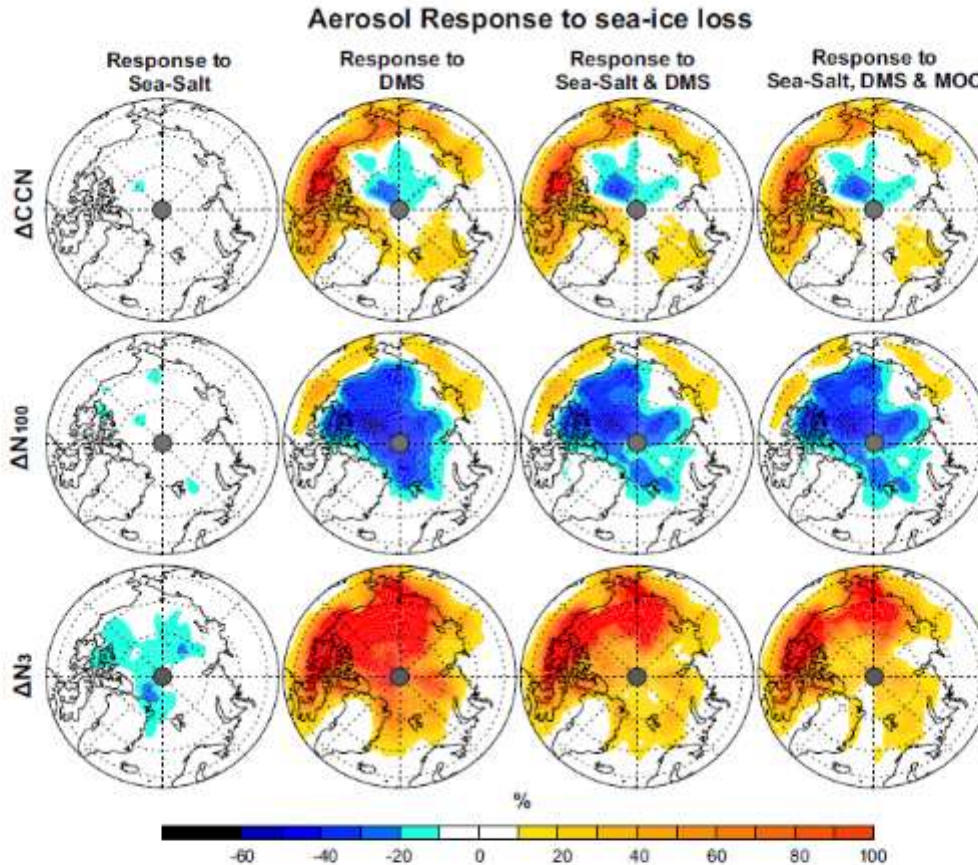


(b) Sea-Salt flux



(c) Marine OC flux

Complex Response of Increased Oceanic Emissions



Change in cloud condensation nuclei concentrations

Change in conc. of particles > 100 nm (scavenging from drizzling stratocumulus)

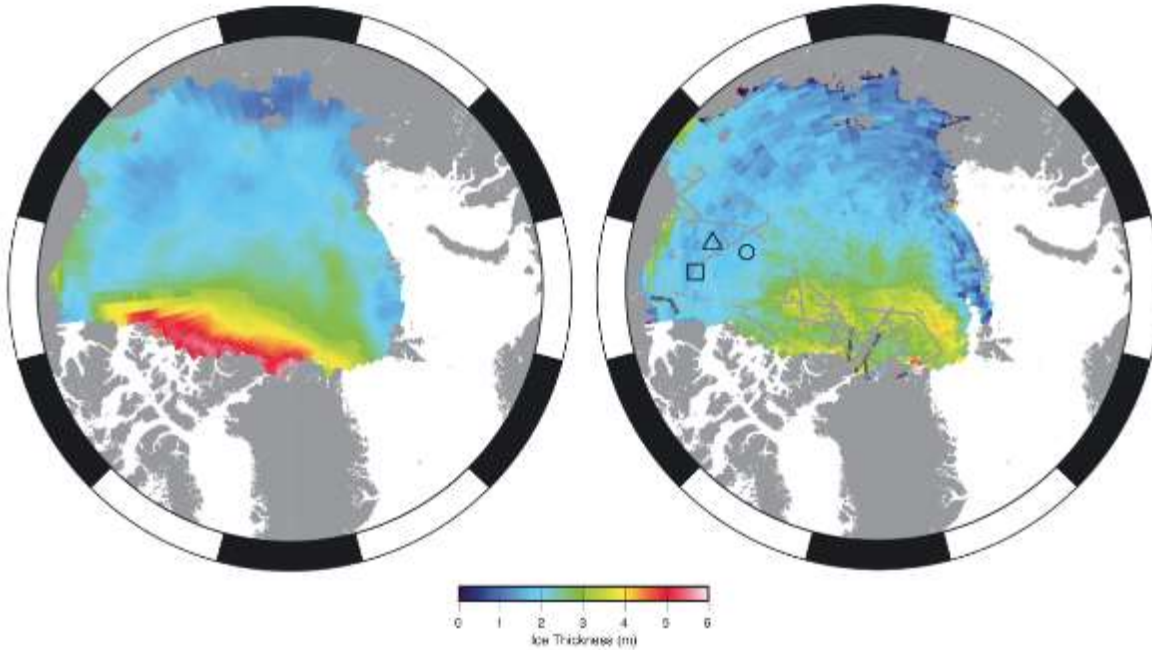
Change in conc. of particles > 3 nm

Figure 4. Response of modelled surface level aerosol concentrations due to complete loss of sea ice: CCN (top), N₁₀₀ (middle) and N₃ (bottom). Different aerosols and precursors are allowed to respond to the ice loss: sea-salt flux (column 1), DMS flux (column 2), sea-salt and DMS flux combined (column 3) and all aerosol (sea-salt, DMS and marine organic carbon flux) (column 4).

Complex and highly uncertain feedbacks between increasing marine emissions and clouds

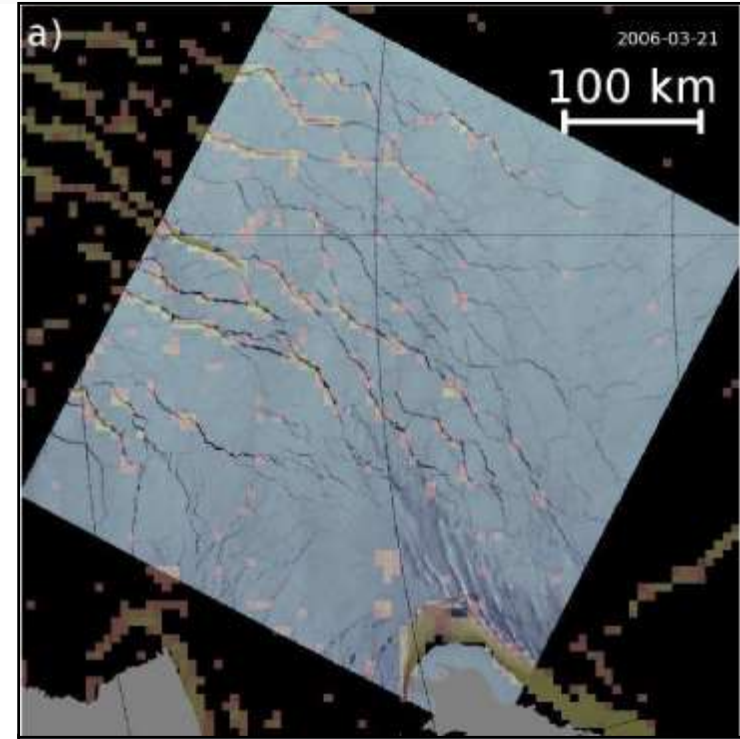
Winter/Spring: Decreasing Ice Thickness & Increasing Ice Fracturing (Lead Formation)?

Estimates of Arctic sea ice thickness



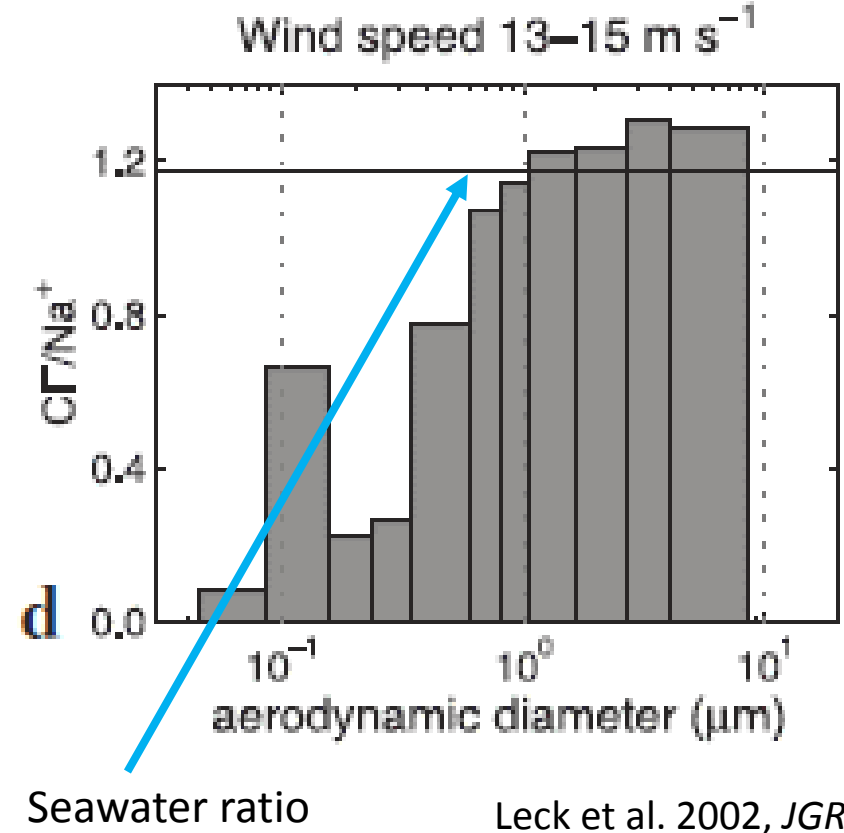
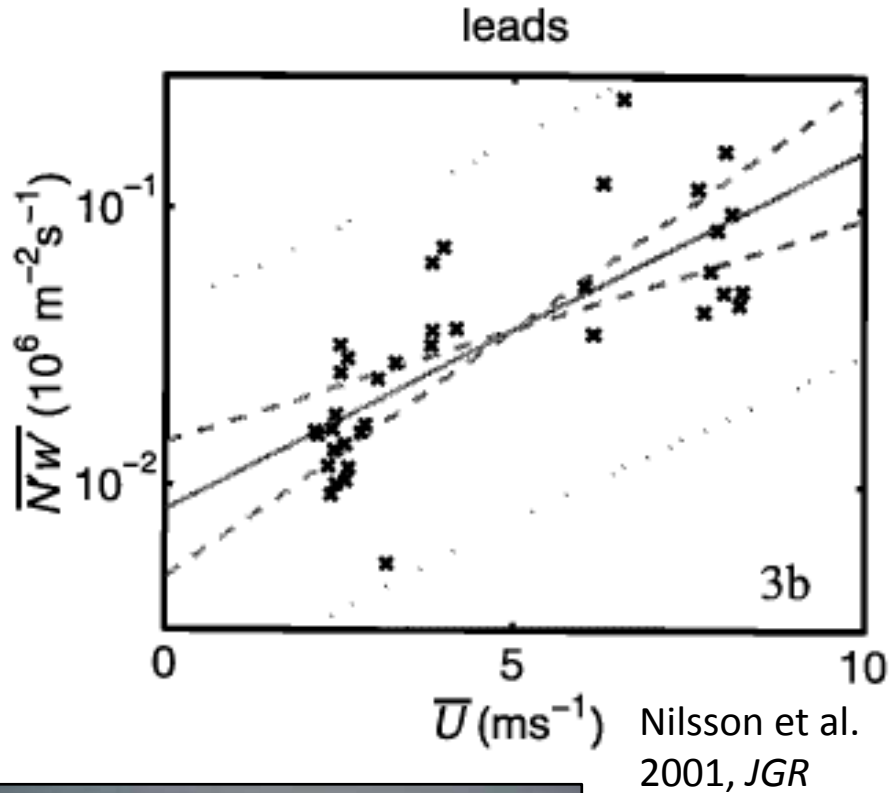
2004-2008 February/March
estimate from ICESat

2012 February/March estimate
from CryoSat-2



Leads as a Source of Sea Spray Aerosol

Wind-dependent particle source ~10x smaller than open water



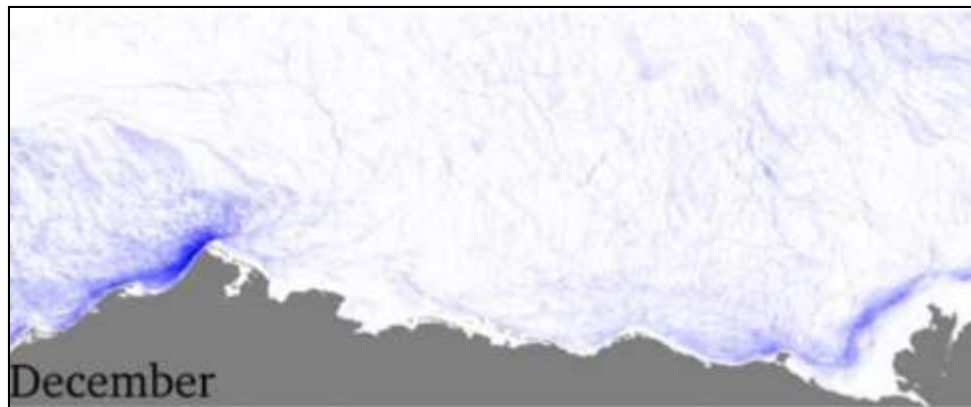
Preferential production of supermicron sea spray aerosol



Seasonality of Open Water near Utqiagvik

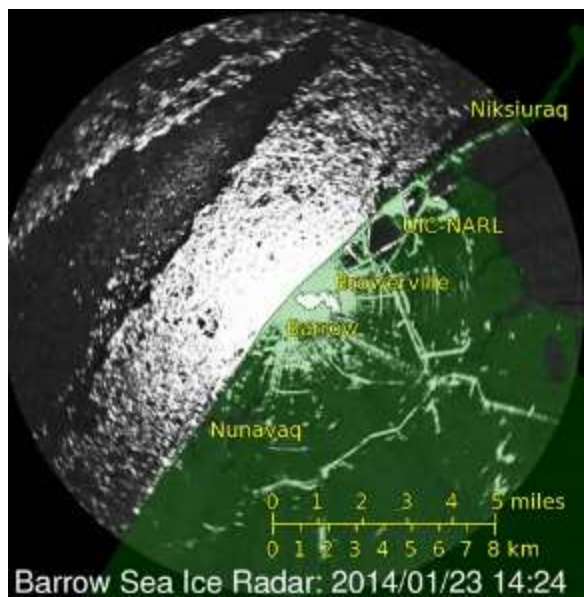
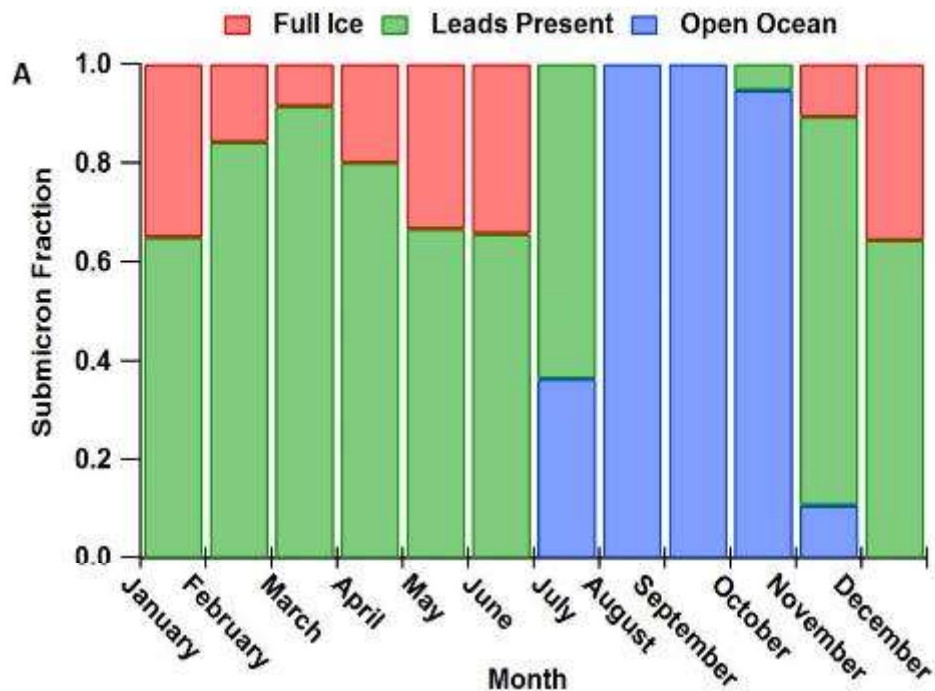
May et al. 2016, *JGR*

Potential for sea spray aerosol emissions all year

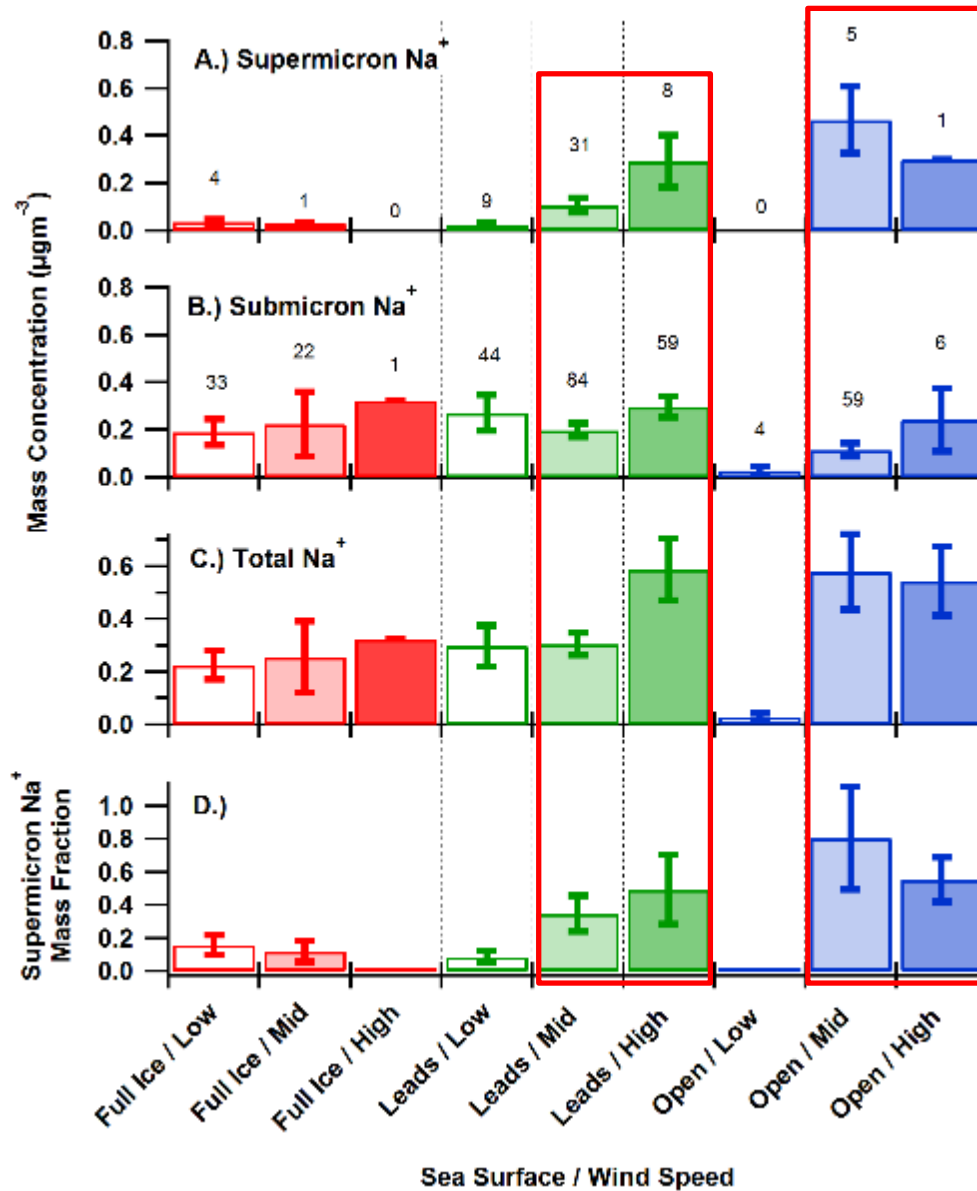


Eicken et al. 2006, *MMS*

Fraction of NOAA Observatory submicron particle 1-5 day sampling periods:



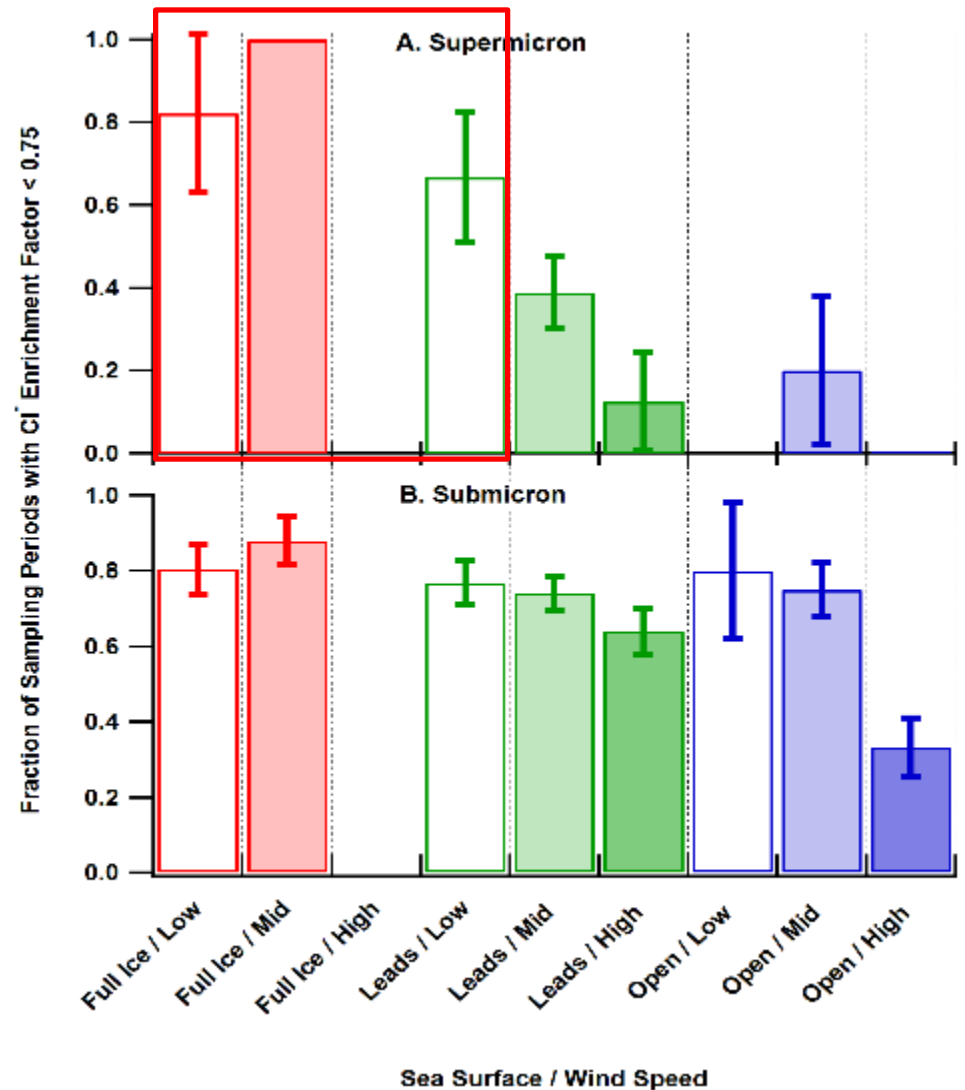
Increased Supermicron SSA under >4 m/s Wind Speeds and Open Water or Lead Conditions



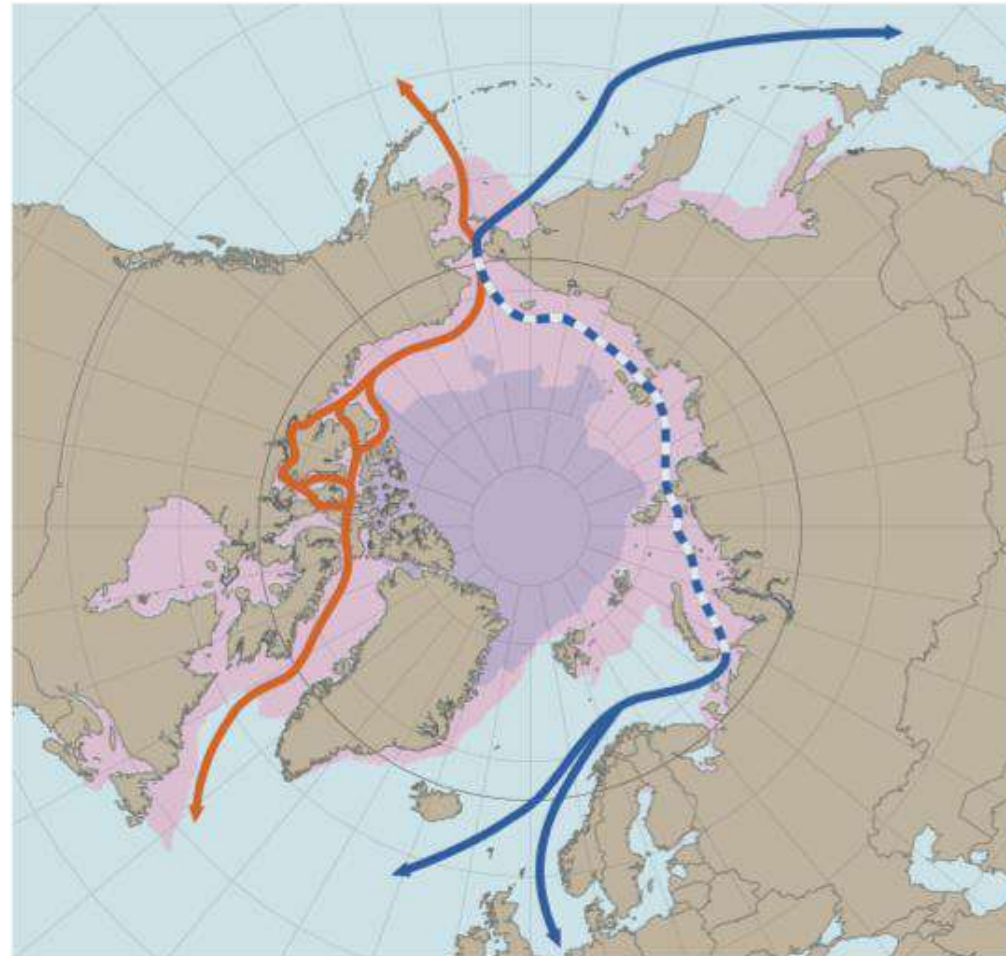
- NOAA Barrow Observatory: 2006-2009
- Used sea ice radar and meteorological data to classify particle sampling periods by sea ice condition (full ice, leads present, open water) and wind speed:
 - Low <4 m/s
 - Mid 4-7 m/s
 - High >7 m/s






Greater Influence by Transported SSA under Low Wind Speed and Full Ice Conditions

- During atmospheric transport, SSA undergo heterogeneous reactions, leading to release of chlorine from the particle phase to the gas phase.
- Therefore, a lower Cl^- enrichment ratio is indicative of atmospheric transport and a lack of locally produced SSA.
- This further suggests influence of SSA production from leads during high wind and lead conditions.



Loss of Sea Ice opening Arctic Shipping Routes



- | | |
|--|---|
|  Northwest Passage | Sea-ice extent 2015 |
|  Northeast Passage |  March |
|  Northern Sea Route |  September |

Increased Black Carbon Deposition from Arctic Shipping

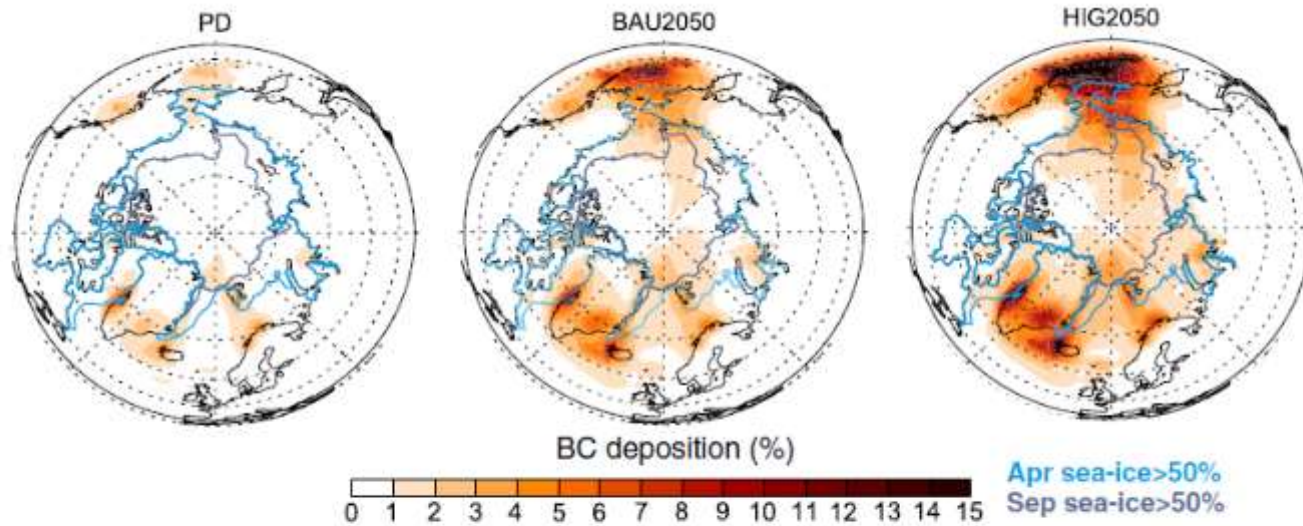
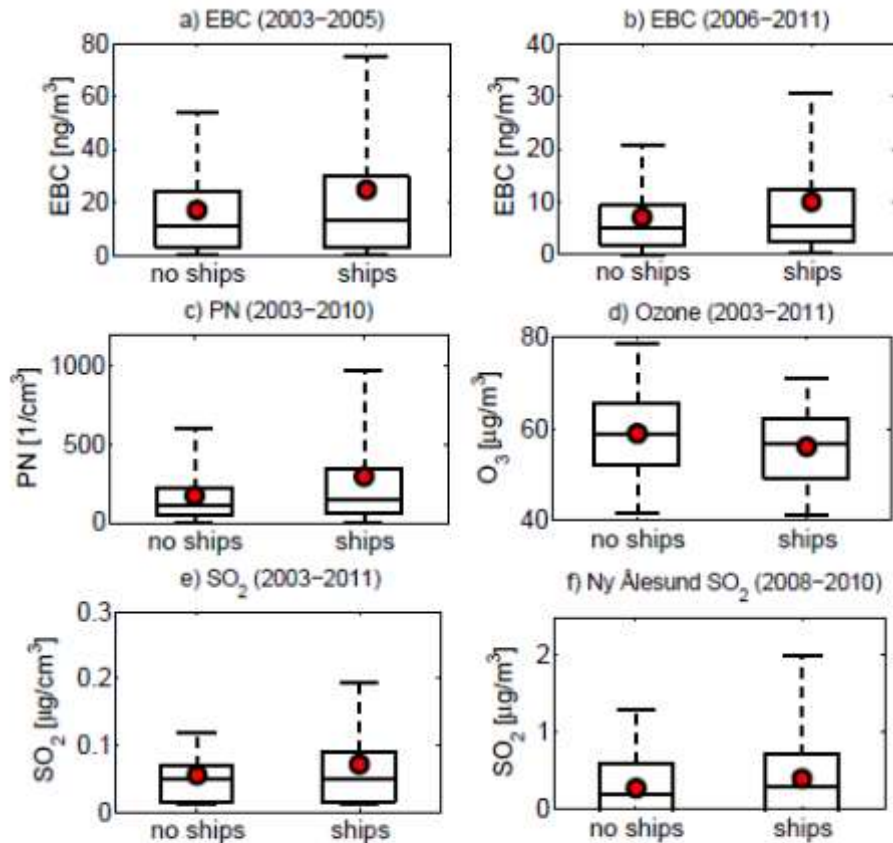


Figure 2. Contribution of Arctic shipping emissions to annual BC deposition in 2004 (left) and 2050 for the BAU (middle) and HiG (right) shipping scenarios. Also shown is the 2000 sea ice edge (sea ice fraction > 50%) in April (maximum) and September (minimum).

Increasing Shipping near Svalbard



- Ships increased total summer mean concentrations of SO₂, 60 nm particles, and equivalent black carbon (EBC) by 15, 18, and 11%
- >50 passenger cruise ships: enhancements in 60 nm particles and EBC by up to 81% and 72%

Fig. 4. Box and whisker plots of EBC (a, b), particle number concentration for particles in the 60 nm size bin (c), ozone (d), SO₂ at Zeppelin (e), and SO₂ at Ny Ålesund (f), for the two periods when ships are present in the harbor, or not. In the title of each panel the years used for the analysis are reported. The boxes extend from the 25th to the 75th percentile, the whiskers show the 5th and 95th percentile, and the thick red dots are the mean values. Data shown are for summer (June, July, August) daytime (06:00–18:00 UTC).

Controversial Arctic cruise through Northwest Passage arrives in NYC

By Staff Reuters

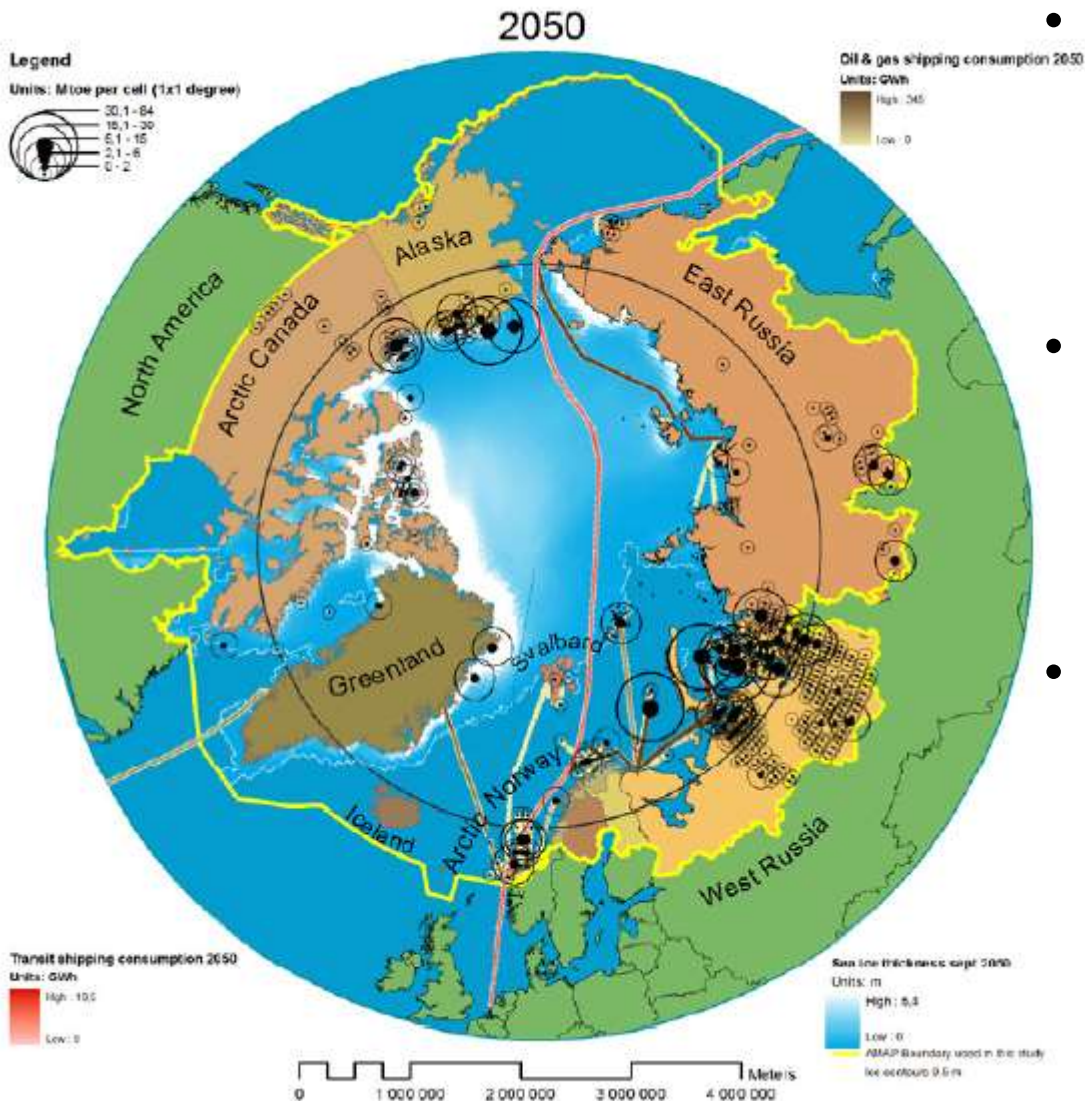
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WATCH ABOVE: The Crystal Serenity cruise ship arrived in New York on Friday after its ground-breaking but controversial voyage through the Northwest Passage, a trip that was made possible by warming temperatures that have melted ice cover in the Arctic.

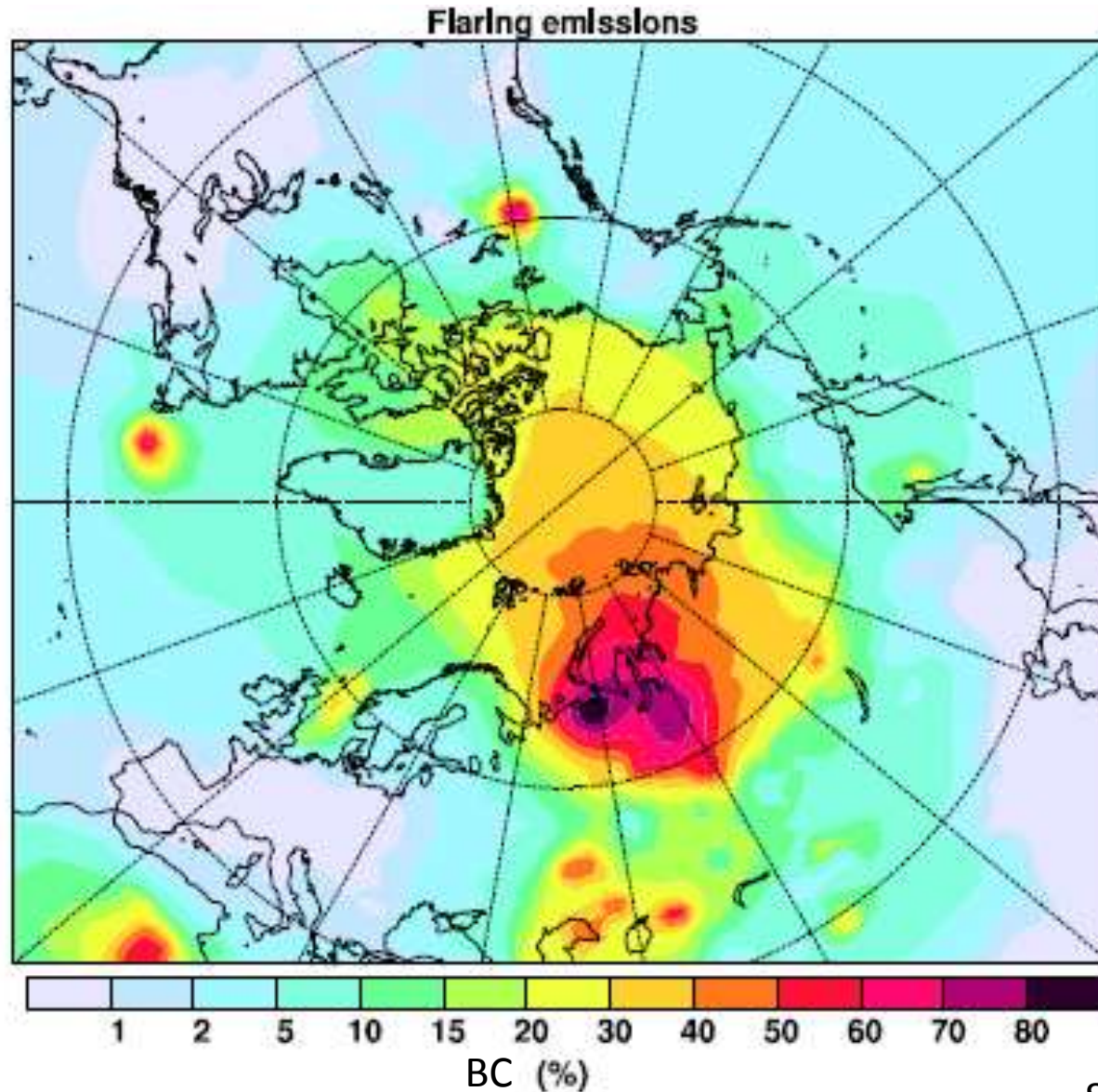
<http://globalnews.ca/news/2944705/controversial-arctic-cruise-through-northwest-passage-arrives-in-nyc/>

Increasing Arctic Development



- Arctic is estimated to contain ~30% and ~13% of the world's undiscovered gas and oil, respectively
- US Arctic oil and gas extraction emissions (VOCs, SO₂, NO_x, BC, OC,...) expected to increase ~3x by 2050, compared to 2004
- Arctic oil and gas shipping estimated to increase current emissions to 37 kt SO₂ (from 0.2 kt in 2004), 257 kt NO_x (from 0.2 kt), 14 kt PM (from 0.03 kt)

Russian Flaring – Source of BC



Go North for Oil SHELL PAID \$2.2 BILLION TO ACQUIRE 410 OFFSHORE LEASES IN THE ARCTIC OCEAN.



Sept. 28, 2015: Shell announces stopping exploratory offshore drilling in Chukchi Sea

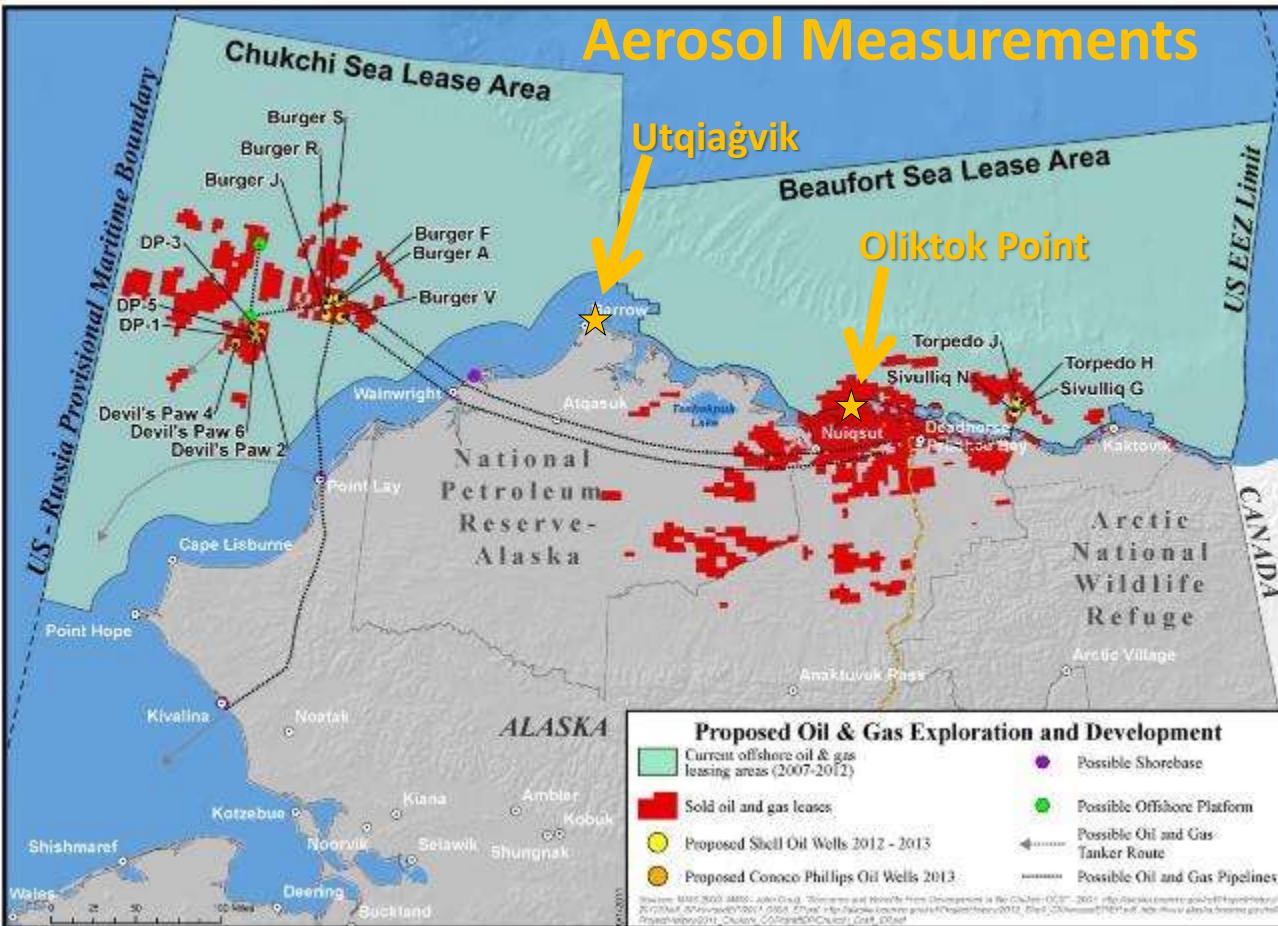
Dec. 2016: Joint U.S.-Canada ban on Arctic offshore drilling

April 2017: US Executive Order to expand Arctic drilling

July 13, 2017: Trump Administration approves exploratory offshore drilling by Eni in Beaufort Sea

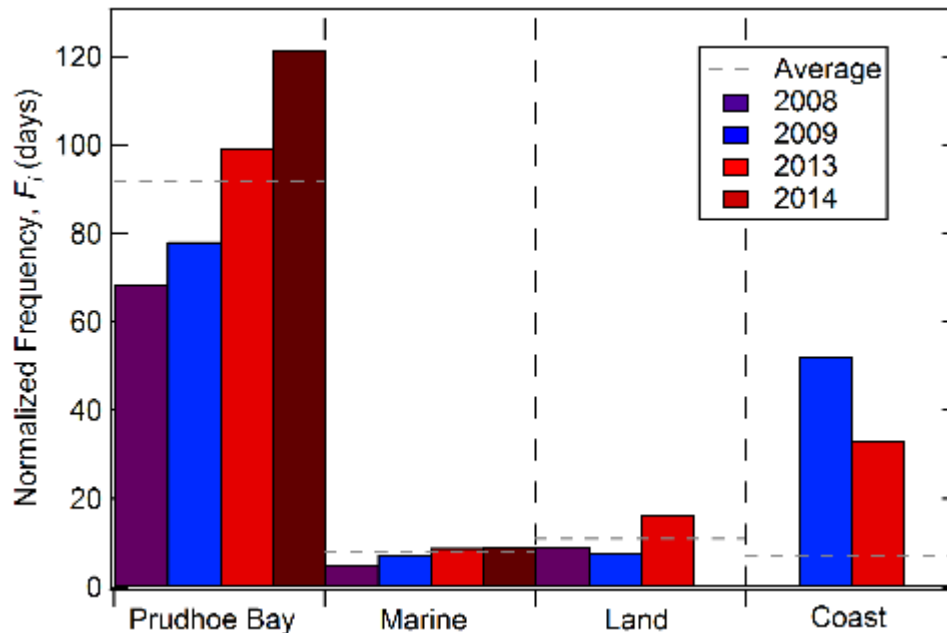
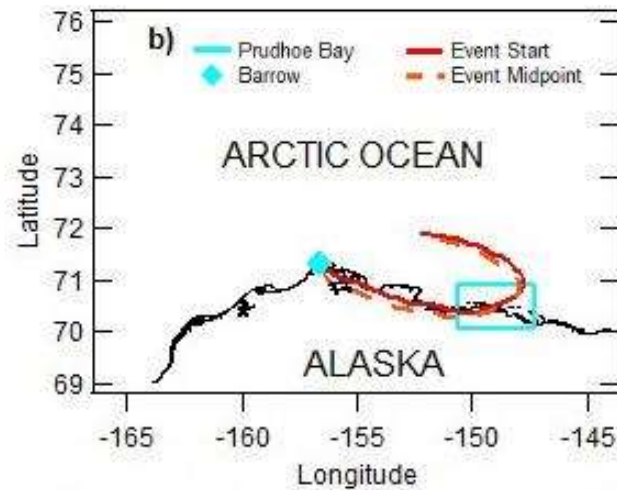
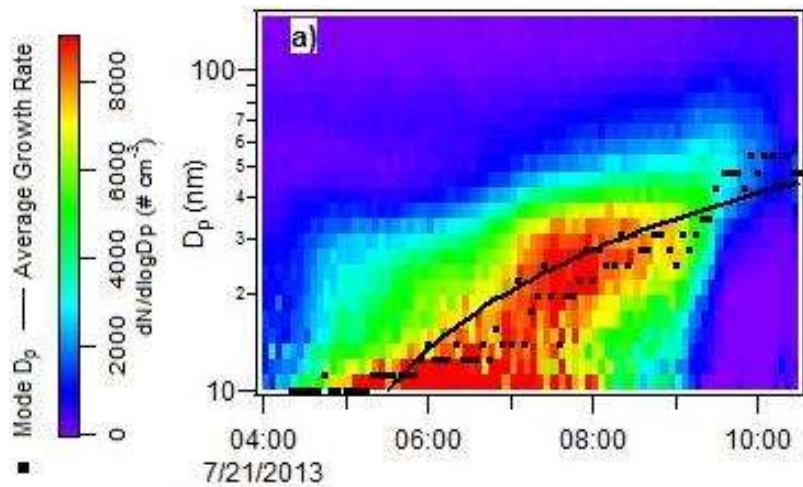
Prudhoe Bay – 3rd Largest Oilfield in North America

Aerosol Measurements



Emissions of primary absorbing aerosol (soot) and secondary aerosol precursors (SO_2 , NO_x , volatile organic compounds)

Atmospheric Aerosol Growth Events Observed at Utqiagvik, Alaska (2008-2015)

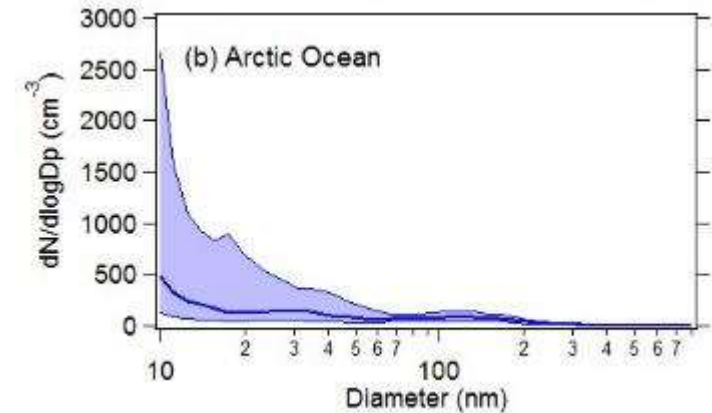
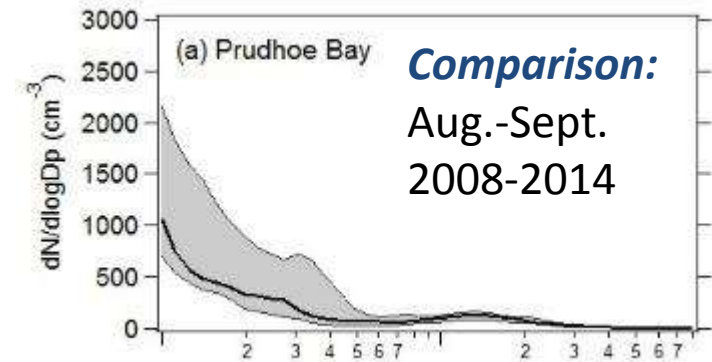
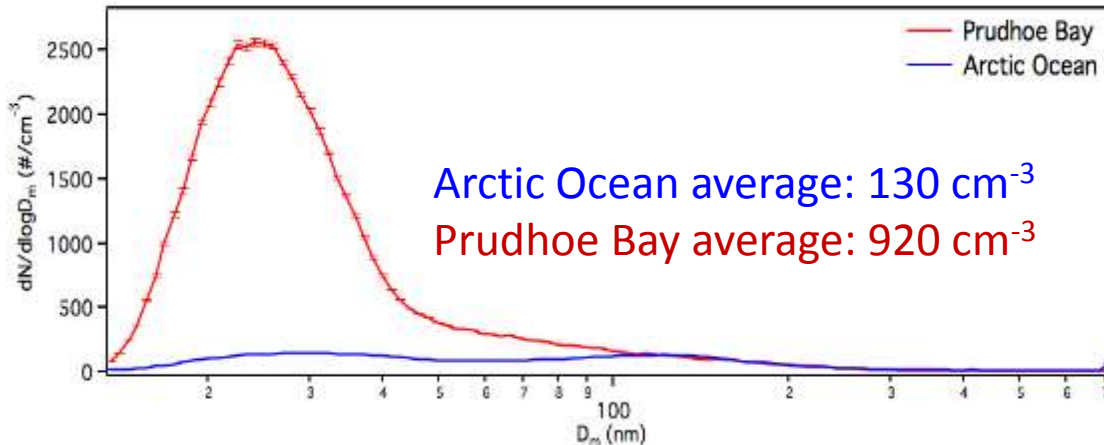


← Representation of the number of event days that would be expected if the wind direction observed at Barrow, AK always came from the specific source region

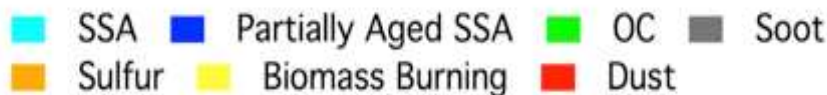
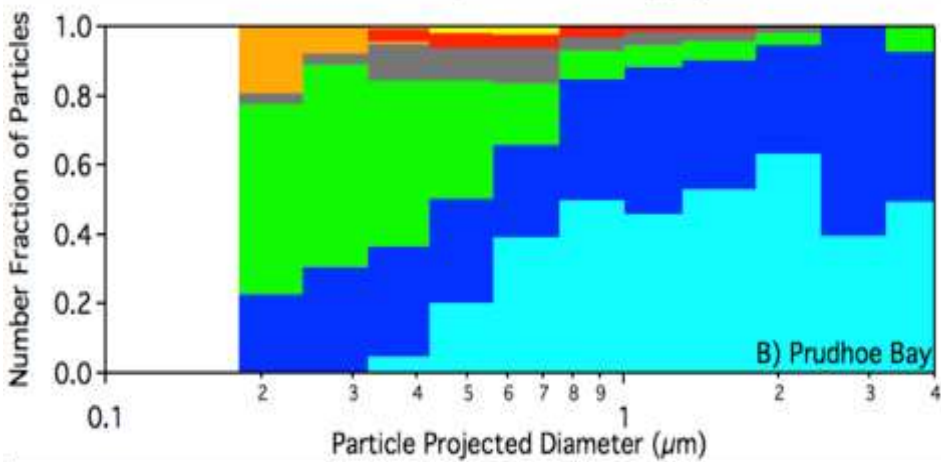
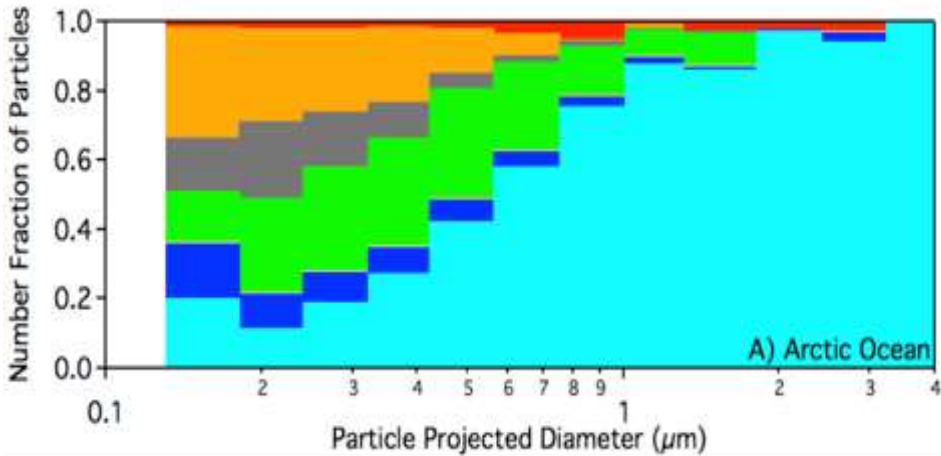
- Preferential occurrence of spring/summer aerosol growth events at Utqiagvik for Prudhoe Bay air masses

Utqiagvik: Summer (Aug.-Sept.) 2015

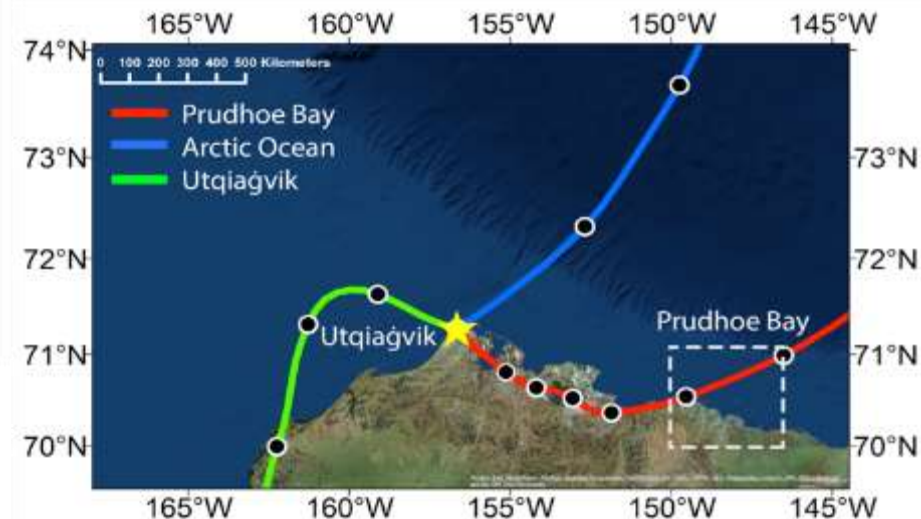
- Increased particle number concentrations under Prudhoe Bay air mass influence
- Long lifetimes of ultrafine particles due to slow coagulation and condensation lifetimes (transport < 24 h)



Transported Oil and Gas Extraction Emissions



- August – September 2015: Utqiagvik, AK
- Increased contributions from aged soot, organic carbon (OC)-sulfate, and aged sea spray aerosol (SSA) during Prudhoe Bay air mass influence



Sea Ice Loss =

- Increasing sea spray aerosol emissions year-round (from leads and open water)
- Changing cloud-aerosol feedbacks
- Increasing ship emissions and black carbon deposition
- Increasing oil and gas extraction development

- Highly uncertain effects on climate!

