Impacts of Shipping Emissions

current, projected, maximum feasible reductions

Focus: International Arctic Transportation Assessment

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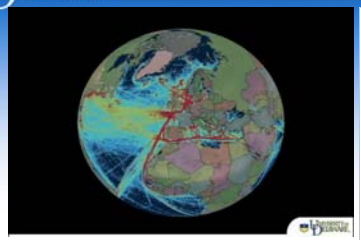
Workshop on Black Carbon and Ozone as Short Lived Climate Forcers
March 3-4, 2010, Chapel Hill, NC

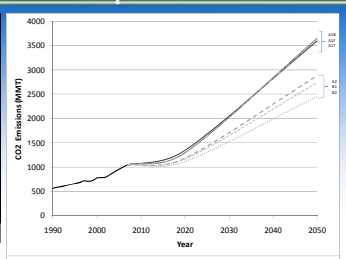
Motivation for this work

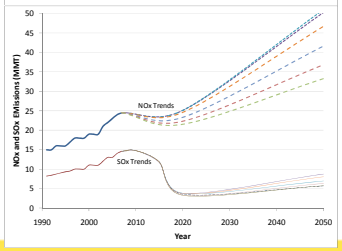
Assessing continent-to-continent transport requires we include non-negligible, fast-growing sources between continents (e.g., ships).

- International shipping is part of the global supply chain moving goods, and it has some unique properties with regard to climate
  - It is the only mode likely to switch from cooling to warming in next decades as short-lived aerosols are reduced through IMO sulfur reduction regulations
    - Fuglestvedt, Jan S., Terje Berntsen, Veronika Eyring, D.S. Lee, Robert Sausen and Ivar S. A. Isaksen, 2009. Shipping emissions: From cooling to warming of climate - and reducing impacts on health. *Environ. Sci. Technol*, 43 (24): pp. 9057-9062.
  - Ships operate in sensitive ecosystems including tipping points for climate change (e.g., Arctic)
- Black carbon particles are considered to be short-lived forcers with significant warming potential
  - Especially where particles accelerate warming of ice sheets
  - Lower sulfur do NOT affect rate of ship diesel BC emissions
- Regional scale modeling needs high-resolution, seasonal inventories (at least)

Global trends and impact issues







- Shipping today: ~3+% of global CO_2, growing with economic demand
- Northern hemisphere ocean activity makes ships a mid-range source:
  - O_3, PM, SOx, etc.
- Particle emissions contribute to clouds and change precipitation
  - Proximity to coastlines may interact with coastal clouds, fog, etc.

What we are doing

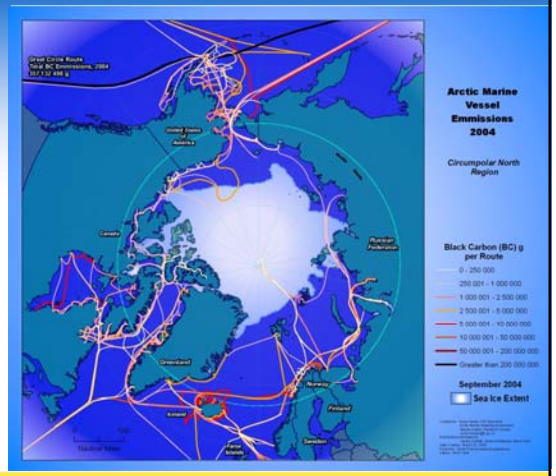
- Worked with Arctic Council project called AMSA to process data on ~16,000 annual ship trips into emissions inventory
- Updated these activity-based inventories with new information
  - Produced base-year seasonal inventories for 2004
  - Used scenario model to produce 2020 and 2030 seasonal inventories, including modeling of potential diversion route emissions
  - Evaluated control technologies, determined a MFR control level
  - Produced future inventories with MFR
- Working with atmospheric modelers to assess impacts
- Working on policy pathways and implementation issues

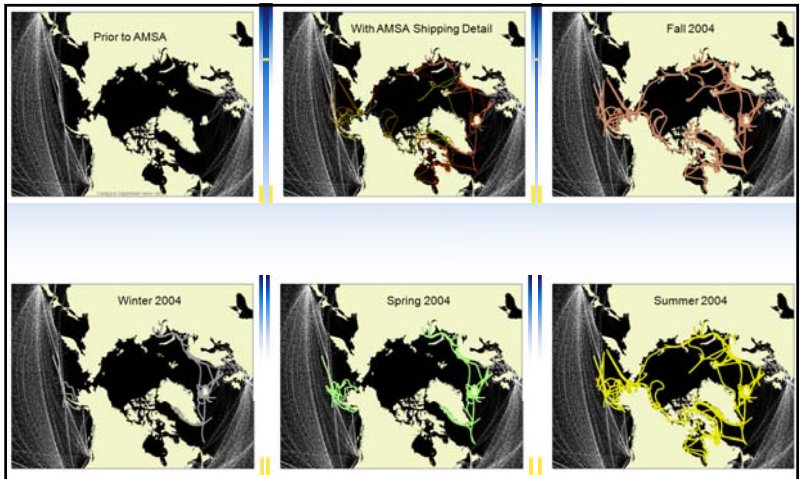
Our High-growth scenario loosely aligns with …

- AMSA and Arctic Council scenarios for continued growth, so-called:
  - ***Arctic Saga*** "a healthy rate of Arctic development that includes concern for the preservation of Arctic ecosystems and cultures and shared economic and political interests"
  - ***Arctic Race*** "lack of an integrated set of maritime rules and regulations, and insufficient infrastructure to support such a high level of marine activity"
- Scenarios developed here should be valuable for impact assessment by scientists that produce results relevant for policy decision making regarding the sensitive Arctic region.

Arctic Shipping?

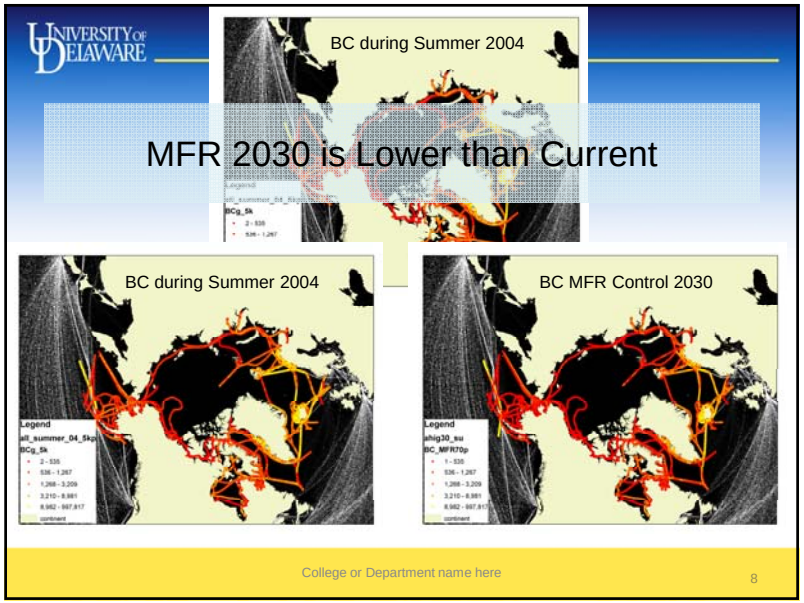
- ***Black Carbon particles*** (invisible soot) also have warming effects and help to melt sea ice.
- International shipping emissions contribute significantly to global climate change and health impacts, with potentially disproportionate impacts from shipping in the Arctic region.
- We produced an activity-based inventory of emissions for Arctic shipping.





MFR: Use BC Control Technology

- Multiple technologies reduce PM from diesels
  - Water-in Fuel Emulsions
  - Engine modifications (slide valves)
  - Seawater scrubbers (limited performance)
  - Particulate Filters (with low-sulfur diesel)
  - Others
- We evaluated the potential for maximum feasible reduction
  - Control is about 70% unless significant changes in fuel sulfur
  - Cost effectiveness ranges from ~$4,000 to ~$30,000 per ton PM
    - Similar to literature for other modes: Michael Q. Wang, Examining cost effectiveness of mobile source emission control measures, Transport Policy, 2004


BC during Summer 2004
MFR 2030 is Lower than Current
BC during Summer 2004
BC MFR Control 2030
College or Department name here
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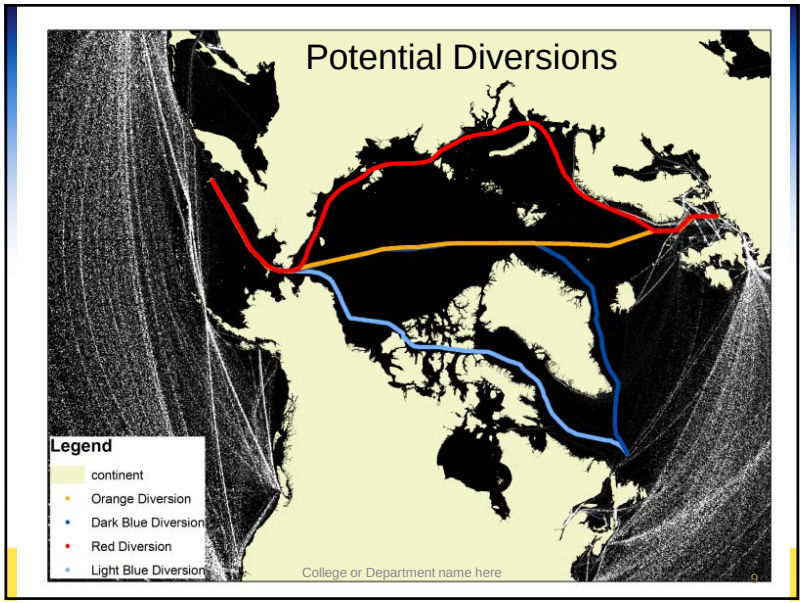
Potential Diversions
Legend
continent
Orange Diversion
Dark Blue Diversion
Red Diversion
Light Blue Diversion
College or Department name here
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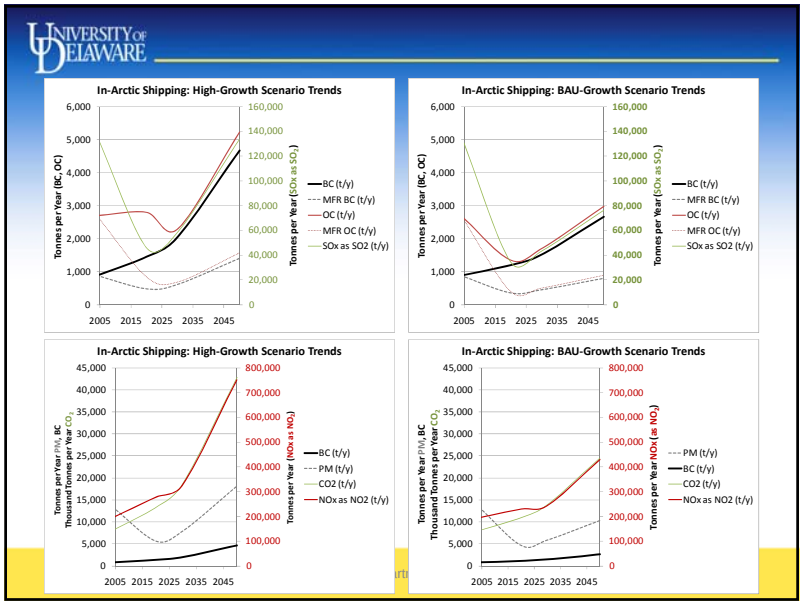
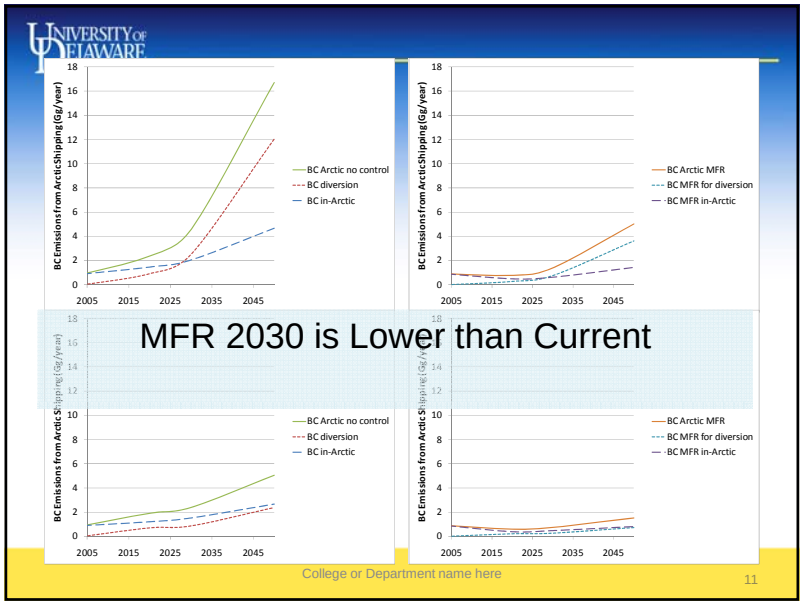

In-Arctic Shipping: High-Growth Scenario Trends
In-Arctic Shipping: BAU-Growth Scenario Trends
Tonnes per Year (BC, OC)
Tonnes per Year (SOx as SO2)
BC (t/y)
MFR BC (t/y)
OC (t/y)
MFR OC (t/y)
SOx as SO2 (t/y)
In-Arctic Shipping: High-Growth Scenario Trends
In-Arctic Shipping: BAU-Growth Scenario Trends
Tonnes per Year PM, BC
Thousand Tonnes per Year CO2
Tonnes per Year (NOx as NO2)
PM (t/y)
BC (t/y)
CO2 (t/y)
NOx as NO2 (t/y)


BC Emissions from ArcticShipping (Gg/year)
BC Arctic no control
BC diversion
BC in-Arctic
BC Arctic MFR
BC MFR for diversion
BC MFR in-Arctic
MFR 2030 is Lower than Current
College or Department name here
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Other comparisons of note

- High-Growth Scenario:
  - Our estimated sum (.752 Tg NO_X in-Arctic plus 1.9 Tg NO_X from diversions) results in 2.652 Tg NO_X or ~0.7 Tg N – within the range of 0.65 to 1.3 Tg N estimated by Granier et al

Granier, C.; Niemeier, U.; Jungclaus, J. H.; Emmons, L.; Hess, P.; Lamarque, J.-F.; Walters, S.; Brasseur, G. P., Ozone pollution from future ship traffic in the Arctic northern passages. *Geophysical Research Letters* ***2006, 33, (L13807), 5.***

- BAU-Growth Scenario:
  - With BAU and lower diversion rates, we are about 2-4 times greater than Paxian et al, ES&T, 2009.
    - mostly due to our including of in-Arctic traffic (inclusion), and/or differences in assumed BC EFs (uncertainty).

Paxian, A.; Eyring, V.; Beer, W.; Sausen, R.; Wright, C., Present-Day and Future Global Bottom-Up Ship Emission Inventories Including Polar Routes. *Environmental Science & Technology* ***2010.***

- Norwegian-focused work on coastal shipping:

Dalsøren et al , focused on Norwegian coastal shipping: ~3.8 Tg CO_2 in 2000, forecasting growth in 2015 to as much as 4.9 Tg CO_2 – a growth rate of ~1.8%/year. Comparison of in-Arctic emissions by ship-type for the Norwegian data with a DNV report showed that all transport vessel inventories reported here are within 10% to 20% of the DNV estimates

Acknowledgements

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