

Taking Stock: Where are we on defining, measuring and controlling black carbon?

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4th ICCT Workshop on Marine BC
Washington, DC, USA
October 2017

The logo for the International Council on Clean Transportation (icct). It features the lowercase letters 'icct' in a bold, dark blue font. The letter 'i' has a small blue circle above it. Below the letters, the full name 'THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION' is written in a smaller, blue, all-caps font.

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My goals for this presentation

- Present you with an overview of progress to date on:
 - Defining BC
 - Measuring BC
 - Controlling BC
 - Estimating BC (inventories)

IMO BC work plan

- MEPC 62 agreed to a work plan to consider the impact on the Arctic of BC emissions from shipping and instructed BLG (now PPR) to:
 - Develop a definition of BC
 - Identify the most appropriate method(s) to measure marine BC
 - Investigate appropriate control measures

Progress on the IMO BC work plan

| Year | Meeting | Outcomes |
|------|---------|---|
| 2015 | MEPC 68 | <ul style="list-style-type: none">• Adopted Bond et al. (2013) definition of BC, as agreed to at 1st BC technical workshop (Ottawa) |
| 2016 | PPR 3 | <ul style="list-style-type: none">• PPR endorsed EUROMOT measurement reporting protocol refined at the 2nd BC technical workshop (Utrecht) and field tested in subsequent research |
| 2017 | PPR 4 | <ul style="list-style-type: none">• Canada and the Netherlands submitted a summary of 3rd BC technical workshop (Vancouver) on BC measurement and control• Agreed to identify the most appropriate method for measuring marine BC at PPR 5• Agreed to to finalize appropriate control measures for BC at PPR 6 |

Upcoming IMO actions on BC

| Year | Meeting | Expected Outcomes |
|------|---------|---|
| 2018 | PPR 5 | <ul style="list-style-type: none">Finalization of BC measurement reporting protocolIdentification of the most appropriate method for measuring BC |
| 2019 | PPR 6 | <ul style="list-style-type: none">Finalization of appropriate control measures for consideration by MEPC |
| 2019 | MEPC 74 | <ul style="list-style-type: none">Discussions on BC control measures and policies could begin |

The definition of BC is settled

BC is a distinct type of carbonaceous material, formed primarily in flames, is directly emitted to the atmosphere, and has a unique combination of physical properties:

1. BC strongly absorbs visible light with a mass absorption coefficient (MAC) value above $5 \text{ m}^2 \text{ g}^{-1}$ at a wavelength $\lambda = 550$ nanometers (nm)
2. BC is refractory, with a vaporization temperature near 4000 K
3. BC is insoluble in water, in organic solvents including methanol and acetone, and in other components of atmospheric aerosol; and
4. BC exists as an aggregate of small carbon spherules.

How best to measure BC is the critical question at this point

- IMO has asked members to look at 4 methods:
 - Filter Smoke Number (FSN)
 - Photo Acoustic Spectroscopy (PAS)
 - Multi Angle Absorption Photometry (MAAP)
 - Laser Induced Incandescence (LII)
- Many researchers in this room have experience with these instruments.
- Many researchers have found good agreement with FSN and PAS. LII correlated well, but there's limited experimental data. The most BC emission factor data we have to date comes from FSN measurements.
- Several have stated that MAAP is not fit for purpose.

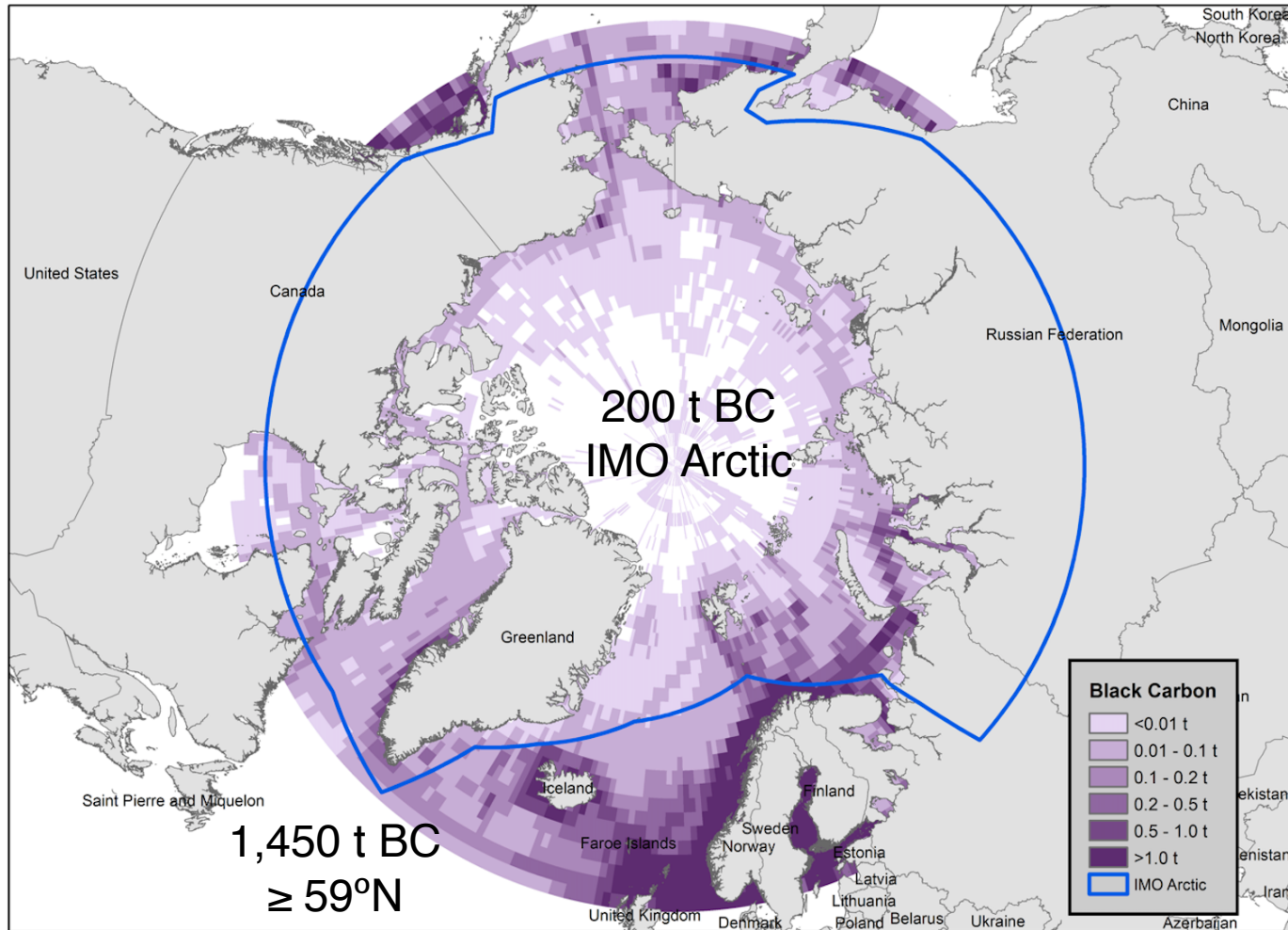
Appropriate BC control measures are also needed – we'll learn more about this today

- Technologies
 - Diesel particulate filters
 - Fuel switching
 - LNG (but need to be careful about life-cycle GHGs)
 - SCR and low-PM engine recalibration (burn hotter to reduce BC, and use SCR to address higher NO_x)
 - Energy efficiency ship designs and retrofits
 - Scrubbers (SO_x reduction w/ BC reduction co-benefits)
 - Alternative fuels and propulsion technologies (biofuels, hydrogen, batteries, etc.)
- Operations
 - Slow steaming
 - Shore power

Inventories – understanding how much (and where) ship BC is emitted

| Study | Inventory Year | BC (kilotonnes) | Fuel consumption (million tonnes) | BC EF (g/kg fuel) |
|----------------------------|----------------|-----------------|-----------------------------------|--------------------------|
| Global BC Inventory | | | | |
| Bond et al. (2013) | 2000 | 100 | - | 0.17-0.85 |
| Dentener et al. (2006) | 2000 | 130 | 182 | 0.69 |
| Fuglestvedt et al. (2010) | 2000 | 197 | 182 | 1.08 |
| Eyring et al. (2005) | 2001 | 50 | 280 | 0.18 |
| Lack et al. (2008) | 2001 | 133 | 254 | 0.53 |
| Dalsøren et al. (2009) | 2004 | 39 | 216 | 0.18 |
| Eyring et al. (2010) | 2005 | 160 | 300 | 0.53 |
| Buhaug et al. (2009) | 2007 | 120 | 333 | 0.36 |
| Comer et al. (2017b) | 2015 | 67 | 247 | 0.27 |
| BC in the Arctic | | | | |
| Corbett et al. (2010) | 2004 | 1.25 | 3.5 | 0.35 |
| Peters et al. (2011) | 2004 | 1.15 | 3.3 | 0.35 |
| DNV (2013) | 2012 | 0.052 | 0.3 | 0.18 |
| Winther et al. (2014) | 2012 | 1.58 | 4.5 | 0.35 |
| Comer et al. (2017a) | 2015 | 1.45 | 4.4 | 0.30-0.56 (0.34 avg.) |

Arctic BC inventory, 2015



Source: Comer et al. (2017). *Prevalence of heavy fuel oil and black carbon in Arctic shipping, 2015 to 2025*. ICCT. Available at: <http://www.theicct.org/staff/bryan-comer>

Global BC inventory, 2015

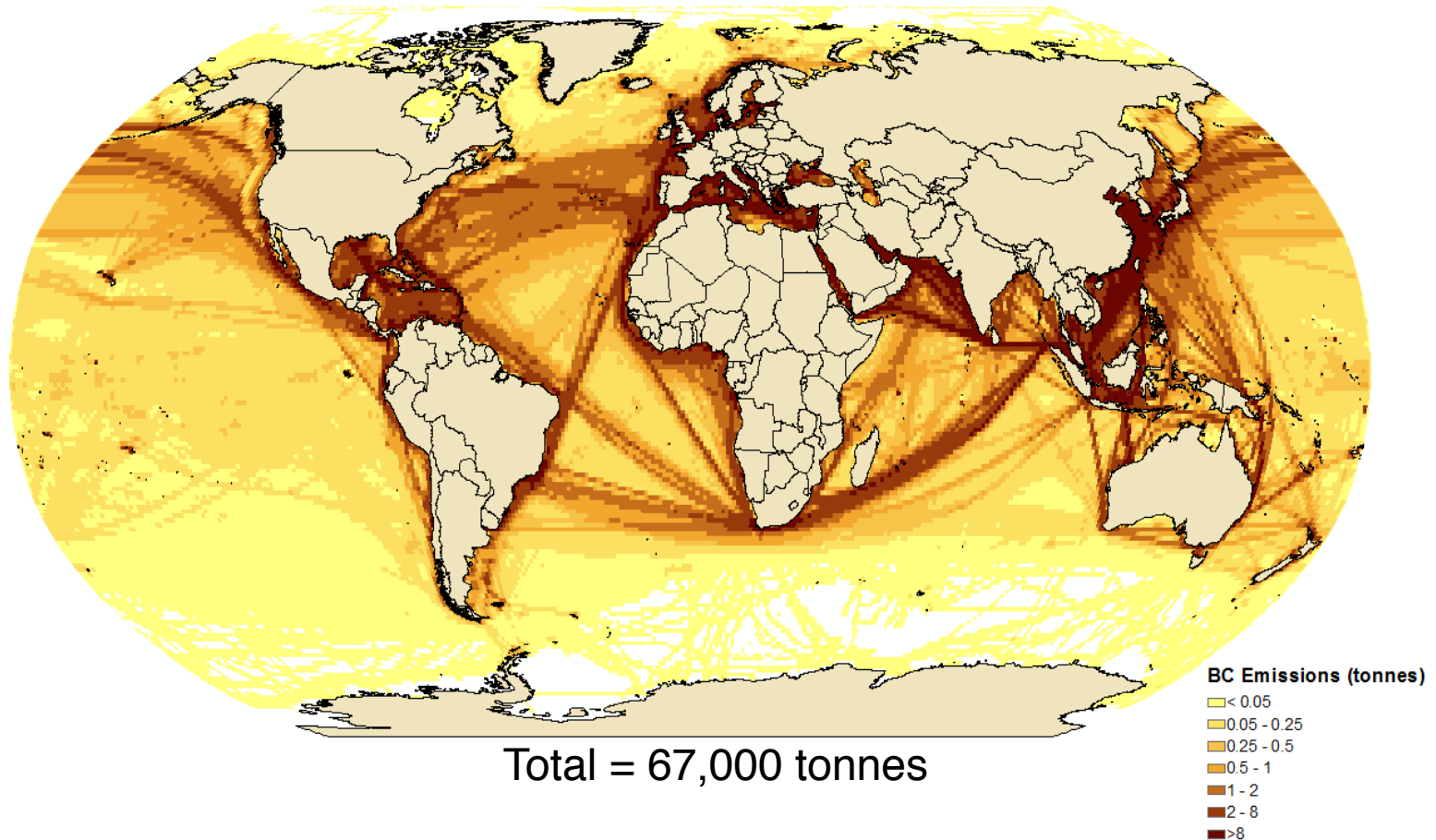
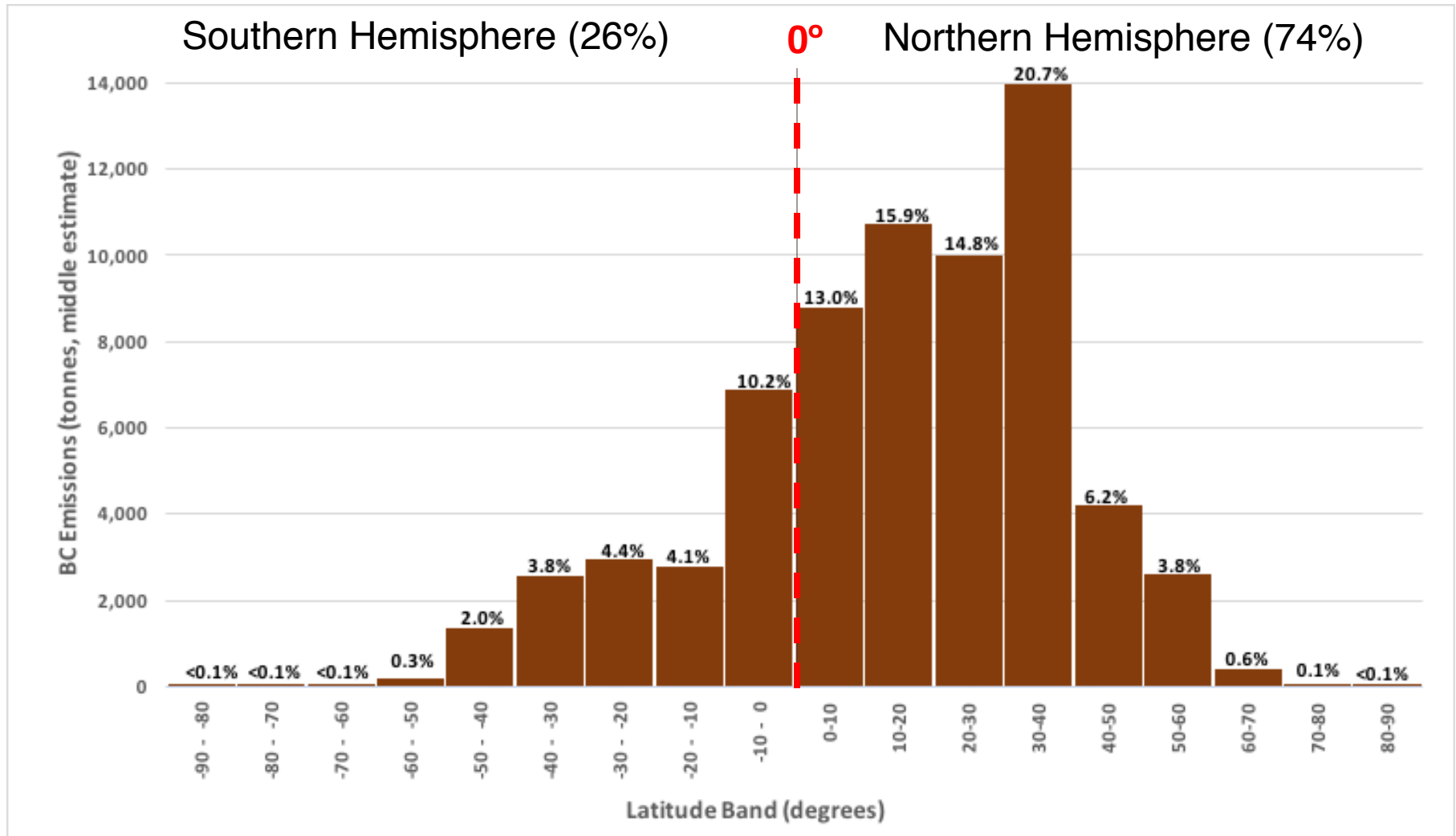
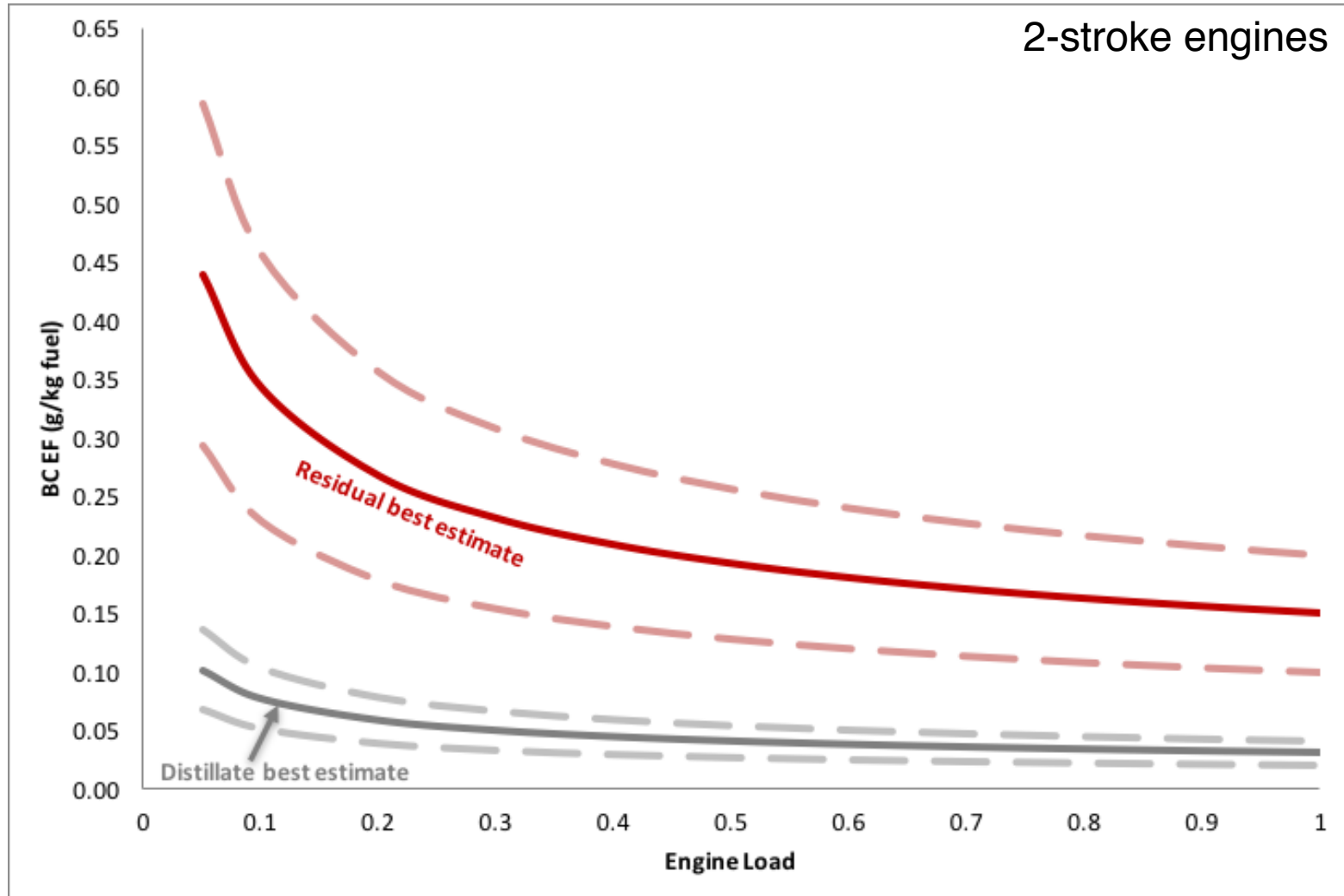


Figure from our upcoming report *Black carbon emissions and fuel use in global shipping, 2015*.
Soon to be available at: <http://theicct.org/black-carbon-emissions-global-shipping-2015>

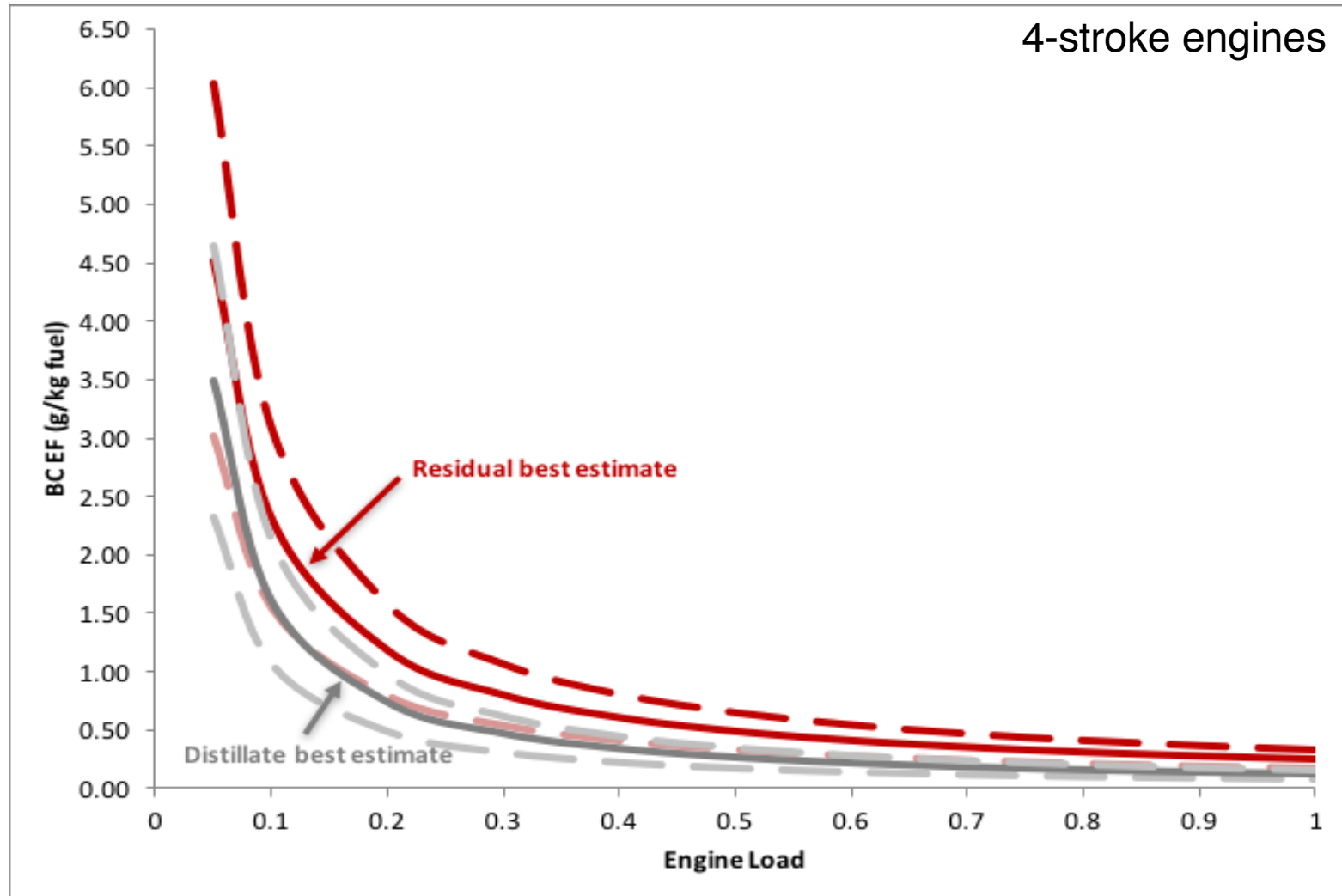
74% of BC emitted in the Northern Hemisphere



Global BC inventory uses BC EFs based on recent testing data and can be updated over time



4-stroke engine BC EFs (note the order of magnitude increase on the y-axis)



Conclusions

- We've defined BC
- We've measured BC
- We've identified many ways to control BC
- We've estimated BC in Arctic and global inventories
- Now we, the community interested in this topic, will need to share our expertise to help IMO make progress on BC by:
 - Identifying the most appropriate method(s) to measure marine BC
 - Identify appropriate control measures for marine BC

Thank you!

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Acknowledgements:

Dan Rutherford

Program Director, ICCT

Xiaoli Mao

Associate, ICCT

Climate and Clean Air Coalition

Naya Olmer

Associate, ICCT

Biswajoy Roy

Fellow, ICCT

Pisces Foundation

ClimateWorks Foundation