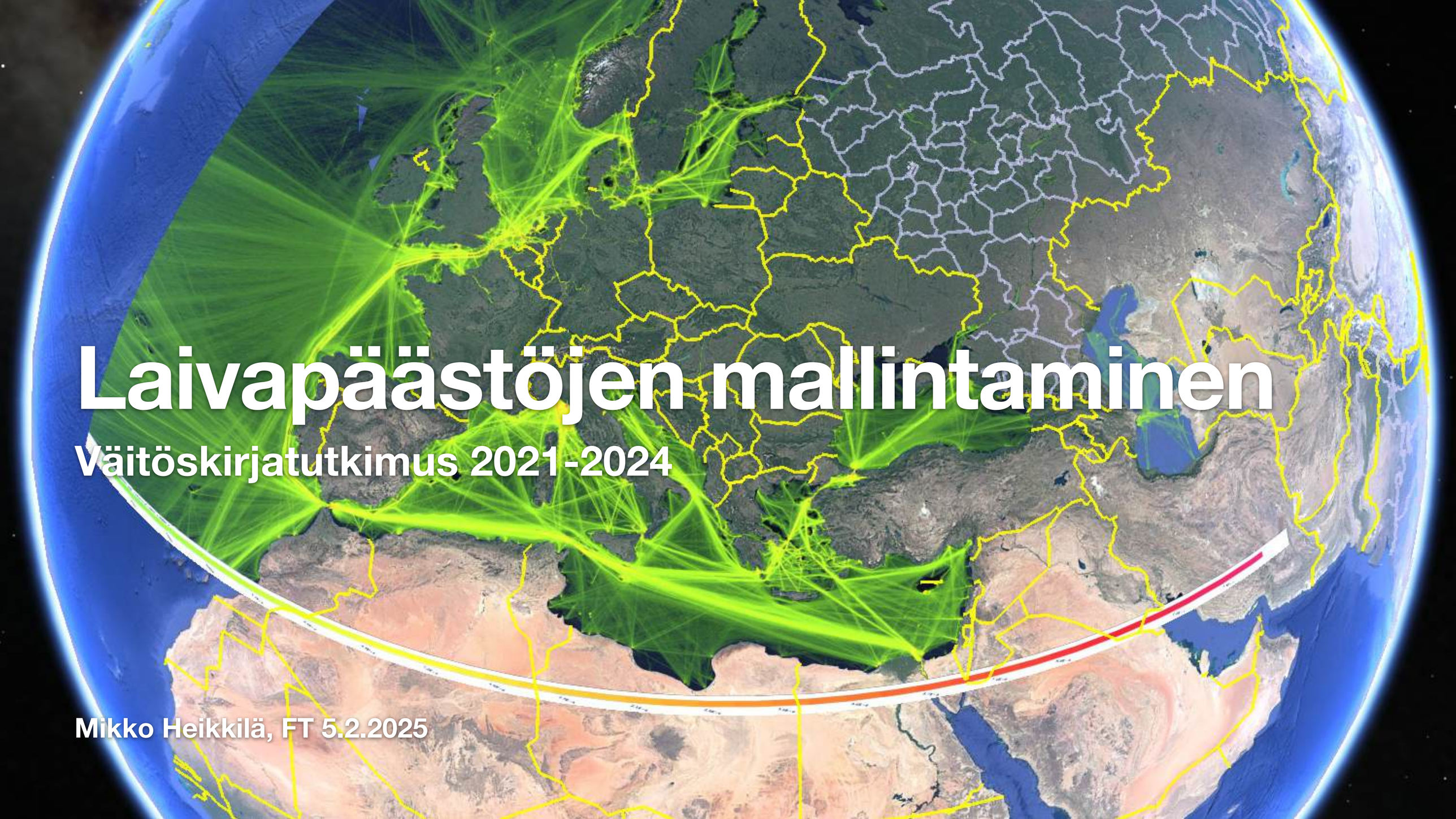


Laivapäästöjen mallintaminen

Väitöskirjatutkimus 2021-2024

Mikko Heikkilä, FT 5.2.2025

Curriculum vitae

- Vahtiperämies 2012 (Turku)
- Merikapteeni 2016 (Turku)
- Holland America Line 2013-2014
- Silja Serenade 2015
- Stad Amsterdam 2015-2016
- Royal Caribbean 2016-2019
- The World 2019
- Hondius 2020-2021
- Meriaura 2021-2022
- Ilmatieteenlaitos 2022-2025
- Ekami / Merikarhu 7.1.2025-

Esityksen sisältö

- Miksi mallinnamme ylipäätänsä mitään?
- Mitä päästöjä meriliikenteestä syntyy
- Ilmatieteenlaitoksen STEAM
- Bottom up vs Top Down
- Laivaliikenteen NO_2 ja $PM_{2.5}$ Helsingissä
- Musta hiili ja nopeusrajoitus Utössä
- STEAM vs REAL kahdella LNG-laivalla

N:o 196 (2024)

ADVANCES IN BOTTOM-UP MODELLING OF ATMOSPHERIC EMISSIONS ORIGINATED FROM SEAGOING VESSELS

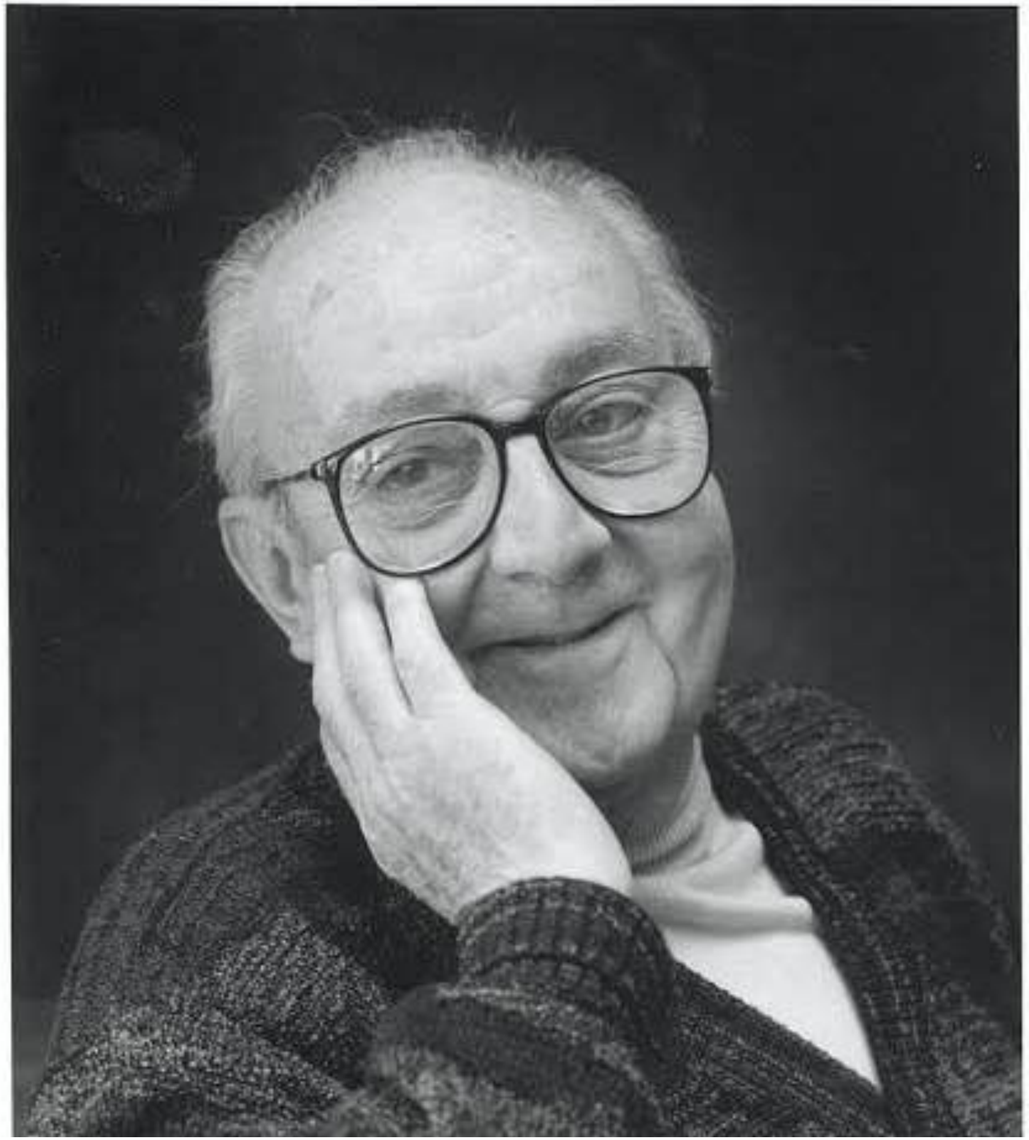
MIKKO HEIKKILÄ

Institute for Atmospheric and Earth System Research
Faculty of Science
University of Helsinki
Helsinki, Finland

Doctoral dissertation, to be presented for public discussion with the permission of the Faculty of Science of the University of Helsinki, in Auditorium E204, Physicum, on the 15th of November, 2024 at 10 o'clock.

“All models are wrong - but some are useful”

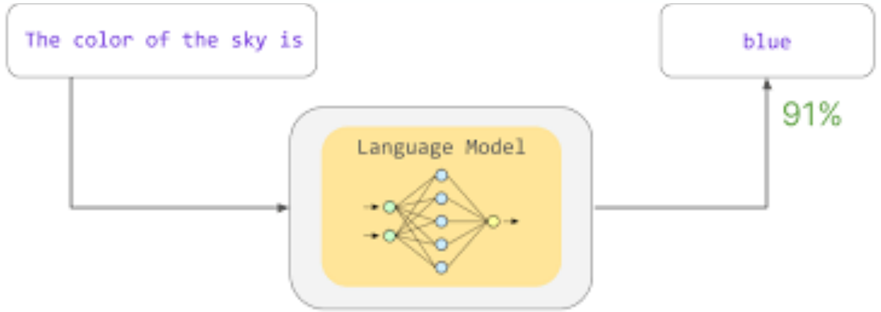
George Box (1987)

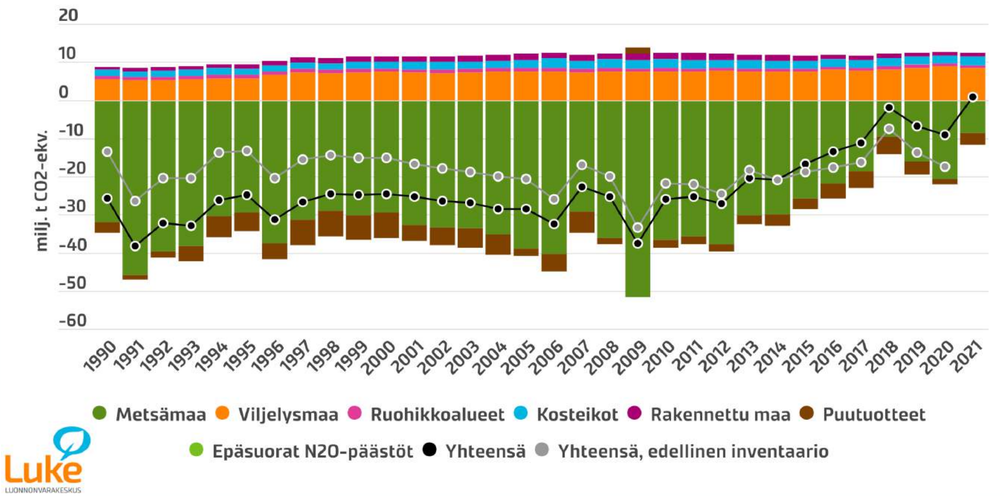


Miksi ylipäätään mallinnetaan?

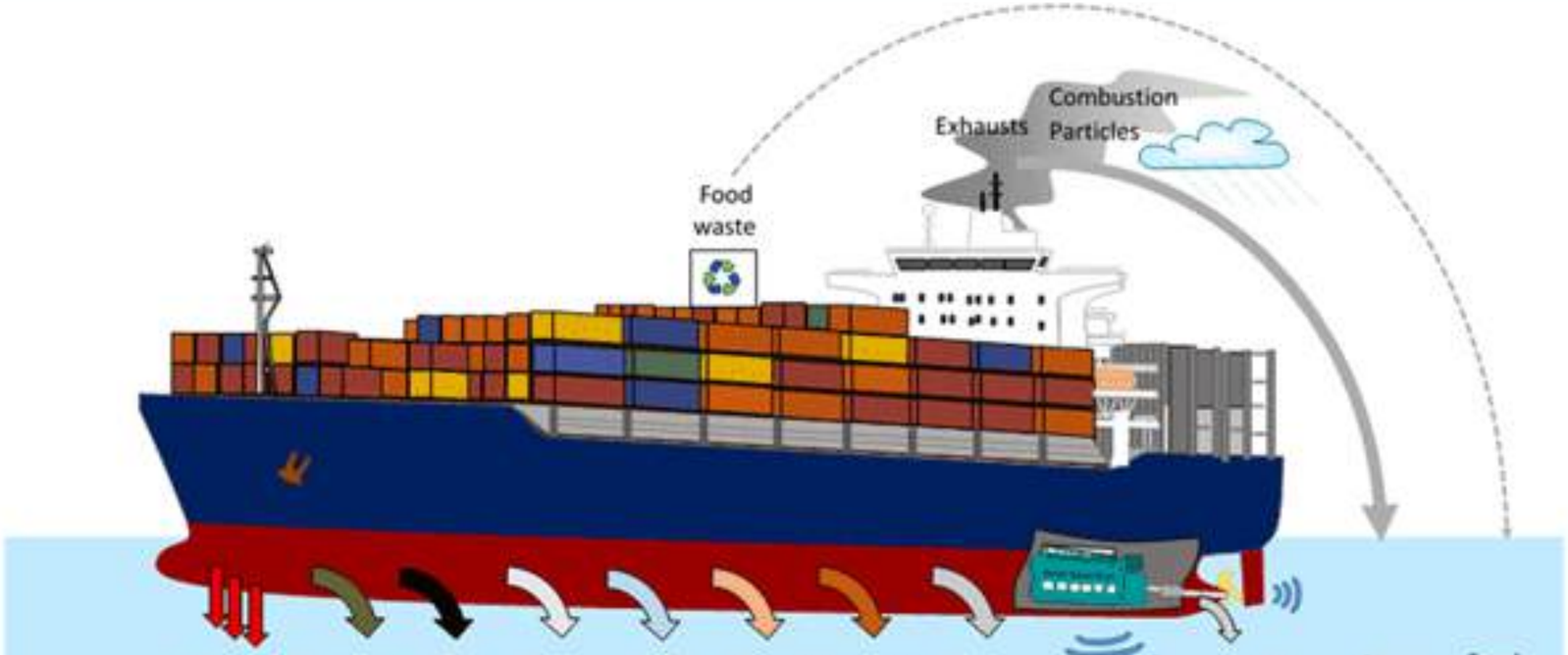
- Kaikkea ei voida mitata
- Mittauksiinkin liittyy epätarkkuutta
- Mallien avulla voi täydentää puuttuvia datapisteitä
- Malleilla voi ennustaa tulevaa

Olemme oppineet elämään mallien virheiden kanssa





Laivasta pääsee muutakin kuin pakokaasua



	Biofouling & Antifouling	Ballast water	Black water	Grey water	Tank cleaning	Cooling water	Scrubber water	Bilge water	Noise	Stern tube oil	Atmos. deposition	Food waste
Acidifying substances							x				x	
BOD/COD		x	x	x								x
Halocarbons, POP		x										
Hydrocarbons, PAH		x		x	x		x	x		x	x	
Litter, PM					x						x	x
Metals	x			x		x	x	x		x		
NIS	x	x	x	x								
Nutrients, N, P		x	x	x	x		x	x			x	x
Energy/noise									x			
Shipping regulations	AFS	BWMC	MARPOL Annex IV	MARPOL Annex IV	MARPOL Annex I		MARPOL Annex VI	MARPOL Annex I		MARPOL Annex I	MARPOL Annex VI	MARPOL Annex V

STEAM

Ship Traffic Emission Assessment Model

- Ilmatieteenlaitoksen laivapäästömalli
- Ensimmäinen versio 2009 Itämerelle
- 2012 laajennus koko globaali meriliikenne
- 2017 reititysalgoritmi ja laajennus vesipäästöihin
- Mallinnukset saatavilla Copernicus / CAMS
- Toimii pohjadatana leviämismalleissa

Atmos. Chem. Phys., 9, 9209–9223, 2009
www.atmos-chem-phys.net/9/9209/2009/

Atmospheric Chemistry and Physics

A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area

J.-P. Jalkanen[1], A. Brink[2], J. Kalli[3], H. Pettersson[1], J. Kukkonen[1], and T. Stipa[1]

[1]Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland
[2]Åbo Akademi, Process Chemistry Center (CMC), Tuomiokirkontori 3, 20500 Turku, Finland
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Received: 15 May 2009 – Published in Atmos. Chem. Phys. Discuss.: 17 July 2009
Revised: 27 November 2009 – Accepted: 27 November 2009 – Published: 7 December 2009

Atmos. Chem. Phys., 12, 2641–2659, 2012
www.atmos-chem-phys.net/12/2641/2012/
doi:10.5194/acp-12-2641-2012

Atmospheric Chemistry and Physics

Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide

J.-P. Jalkanen[1], L. Johansson[1], J. Kukkonen[1], A. Brink[2], J. Kalli[3], and T. Stipa[1]

[1]Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland
[2]Åbo Akademi, Process Chemistry Center (CMC), Tuomiokirkontori 3, 20500 Turku, Finland
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Received: 9 June 2011 – Published in Atmos. Chem. Phys. Discuss.: 5 August 2011
Revised: 20 February 2012 – Accepted: 2 March 2012 – Published: 12 March 2012

Atmospheric Environment 167 (2017) 403–415

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution

Lasse Johansson*, Jukka-Pekka Jalkanen, Jaakko Kukkonen

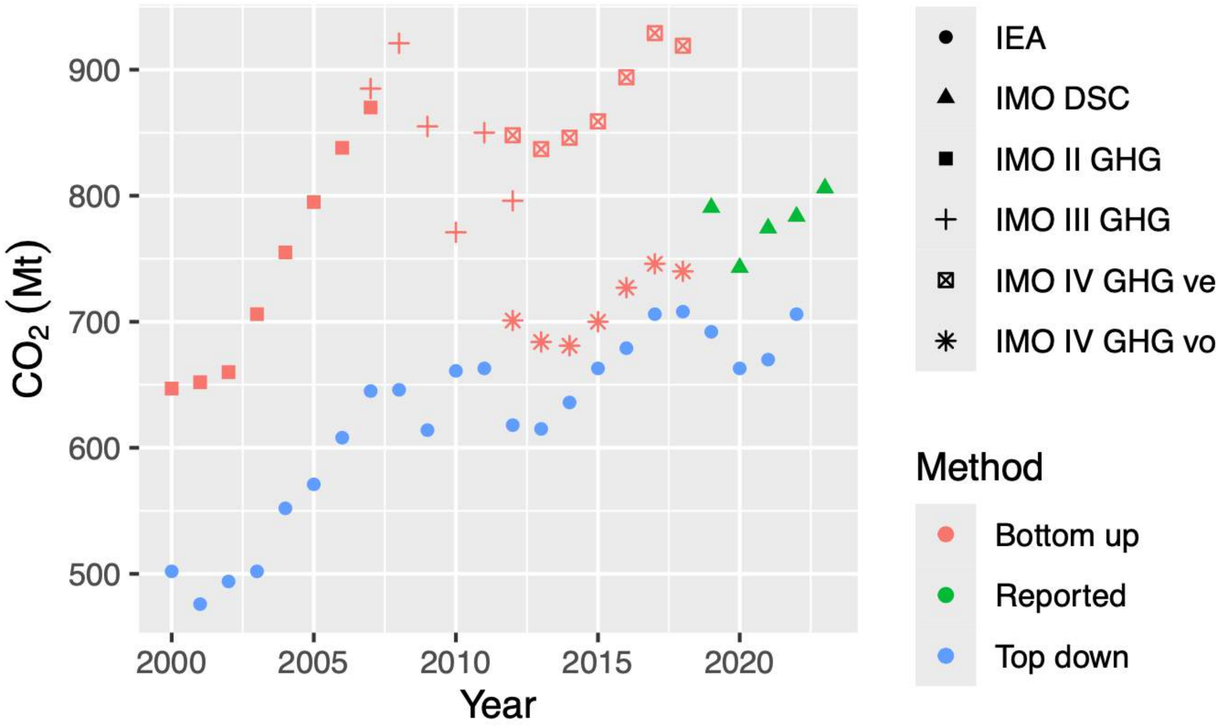
Finnish Meteorological Institute (FMI), Erik Palmenin aukio 1, 00101 Helsinki, Finland

HIGHLIGHTS

- A model (STEAM3) for the assessment of global shipping emissions is presented.
- The modelling is based on ship activities given by AIS, for more than 300,000 ships.
- A route generation algorithm is used to handle large gaps in the AIS-data.
- Data-assimilation is used to assign physically realistic properties for each ship.
- Results for global shipping emissions have been analysed and presented for 2015.

Bottom up vs Top Down

- Top Down -menetelmässä kerätään polttoaineenkulutustieto ja kerrotaan se päästökertoimilla (IEA)
- Bottom Up mallinnetaan koneteho, siitä polttoaineenkulutus ja siitä päästökertoimilla päästöt
- 2019 asti saatavilla IMO DSC raportoitu kv meriliikenteen polttoaineenkulutusdata vuosittain



Bottom-up mallinnus vastuslaskennalla

$$R_T = R_W + R_E$$

$$R_W = R_F + R_R$$

$$R_F = C_F * 0.5 * Rho_w * v^2 * S$$

$$C_F = 0.0075/(log_{10}(Rn) - 2)^2$$

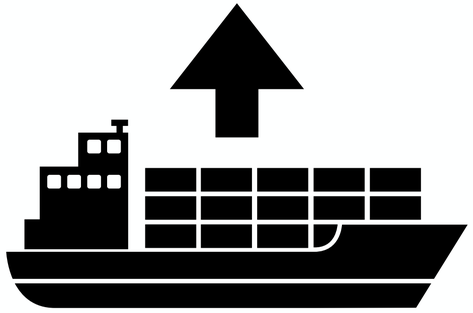
$$Rn = v * L_{wl}/Nu$$

$$R_R = C_R * 0.5 * Rho_w * v^2 * BT/10$$

$F_{ME}(kg/s)$

$P_{ME}(kW)$

$R_T(kN)$



$ID + SOG(kts)$

Osatyö 1

- Helsingin satamaterminaalien NO_2 ja $PM_{2.5}$ -tuntipitoisuuksien ja laivaliikenteen tilastollinen yhteys
- Ilmanlaatupitoisuudet HSY:ltä, laivaliikenne Traficomista, säätiedot Ilmatieteenlaitokselta
- Assosiaatio ja efekti laskettiin tilastollisella mallilla
- Tulos: lähdöt nostavat NO_2-pitoisuutta

atmosphere

MDPI

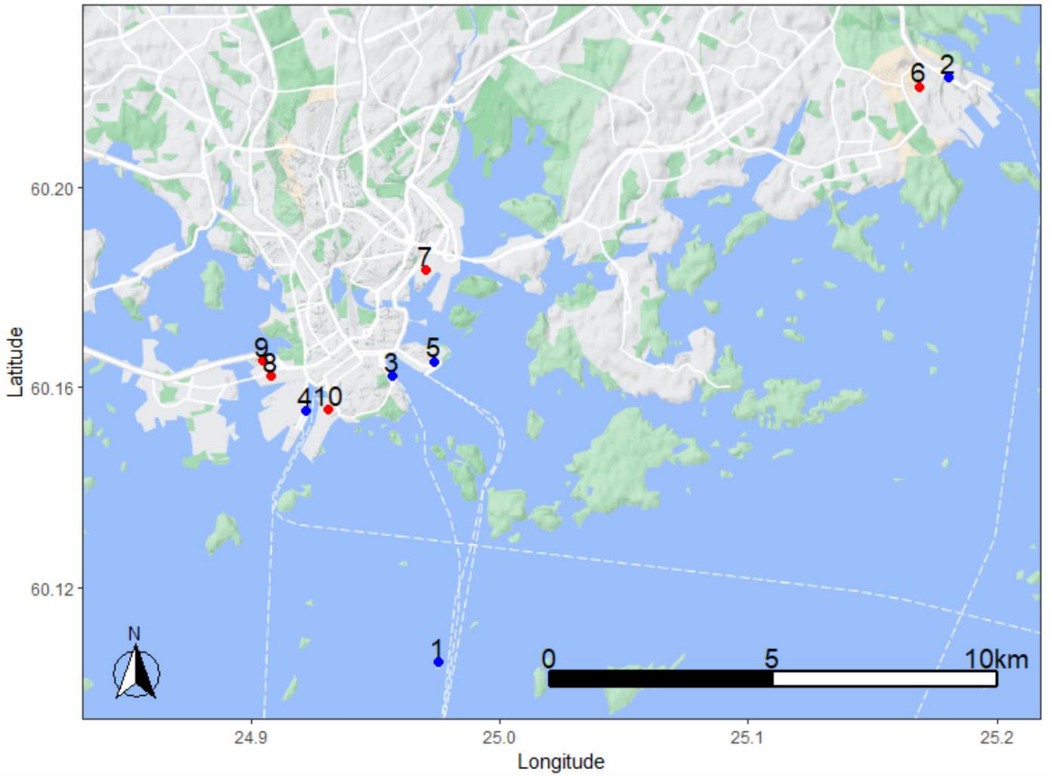
Article

The Association between Vessel Departures and Air Pollution in Helsinki Port Area 2016–2021

Mikko Heikkilä * and Jukka-Pekka Jalkanen

Department of Atmospheric Composition Research, Finnish Meteorological Institute, 00560 Helsinki, Finland; jukka-pekka.jalkanen@fmi.fi
* Correspondence: mikko.heikkila@fmi.fi

Abstract: European ports are struggling to install enough shore power connections to follow the European Commission initiative, which insists ships that lie alongside to be plugged in and have their auxiliary engines off in EU ports by 2030. The port of Helsinki is one of the busiest passenger ports in the world handling on average more than 10 million international passengers per year. As passenger ships consume more fuel than other vessel types, the shore power regulation poses



Osatyö 2

- Mustan hiilen päästöt Utön ohittavien laivojen pakokaasupluumeista
- Päästökertoimen laskeminen CO_2:ta avuksi käyttäen ideaalikaasun yhtälöllä
- Konekuorman mallintaminen STEAM -metodologialla
- Tulos: nopeusrajoitus laskee CO_2e-päästöä, mutta nostaa BC-päästöä

Atmos. Chem. Phys., 24, 8927–8941, 2024
https://doi.org/10.5194/acp-24-8927-2024

Atmospheric Chemistry and Physics
Open Access
EGU
Research article

The local ship speed reduction effect on black carbon emissions measured at a remote marine station

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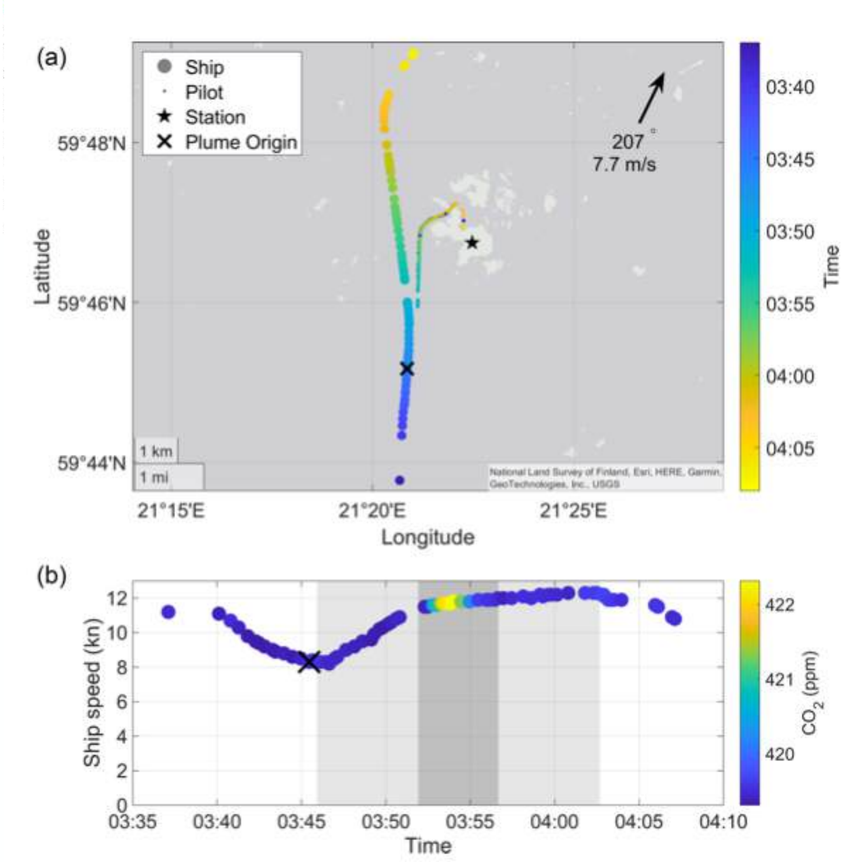
[1]Atmospheric Composition Research, Finnish Meteorological Institute, Helsinki, Finland
[2]Climate System Research, Finnish Meteorological Institute, Helsinki, Finland
Correspondence: Mikko Heikkilä (mikko.heikkila@fmi.fi)

Received: 27 November 2023 – Discussion started: 12 February 2024
Revised: 24 May 2024 – Accepted: 27 May 2024 – Published: 15 August 2024



Osatyö 3

- Mitatun ja mallinnetun välinen vertailu 2:lla LNG-käyttöisellä laivalla
- VTT:n mittaukset Aurora Botnialla ja MSC World Europalla 12/2022 ja 5/2023
- Parempi polttoaineenkulutuksen funktio diesel-sähköiselle laivalle
- Paremmat päästökertoimet (CO_2, CH_4, CO ja HCHO)
- Tulos: hotellikuorman arviointi ja sään vaikutus vaativat lisätutkimuksia

ATMOSPHERIC ENVIRONMENT: X 23 (2024) 100275

Contents lists available at ScienceDirect

Atmospheric Environment: X

journal homepage: www.journals.elsevier.com/atmospheric-environment-x

Comparing modelled and measured exhaust gas components from two LNG-powered ships

Mikko Heikkilä [a,*], Niina Kuittinen [b], Tiia Grönholm [a]

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ARTICLE INFO

Keywords:
Shipping emissions
Liquefied natural gas
Modelling

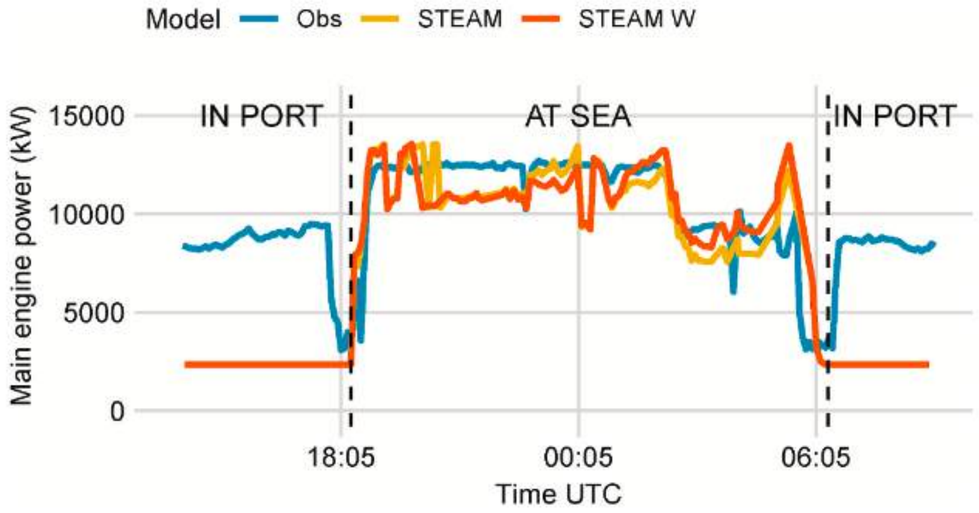
ABSTRACT

Bottom-up modelling is used frequently to estimate emissions produced by seagoing vessels, and the accuracy of modelling is dependent on the data the model is trained with. Observational studies can be used to increase the model accuracy. Here we compared data from two measuring campaigns conducted on board ships that use Liquefied Natural Gas (LNG) as primary fuel in internal combustion engines (ICE) in a diesel-electric setup with values obtained from the Ship Traffic Emission Assessment Model (STEAM).

The power demand for propulsion calculated using Automatic Identification System (AIS) data matched observations reasonably. The root mean square error between the modelled and observed power demand was 759–914 kW (28.6–34.5%) for the measured ropax vessel and 1869–1916 kW (16.7–17.1%) for the large cruise vessel over four voyages while the ships were underway. The discrepancy is largely explained by the auxiliary power demand, which was 4 times higher on the large cruise vessel than the model prediction.

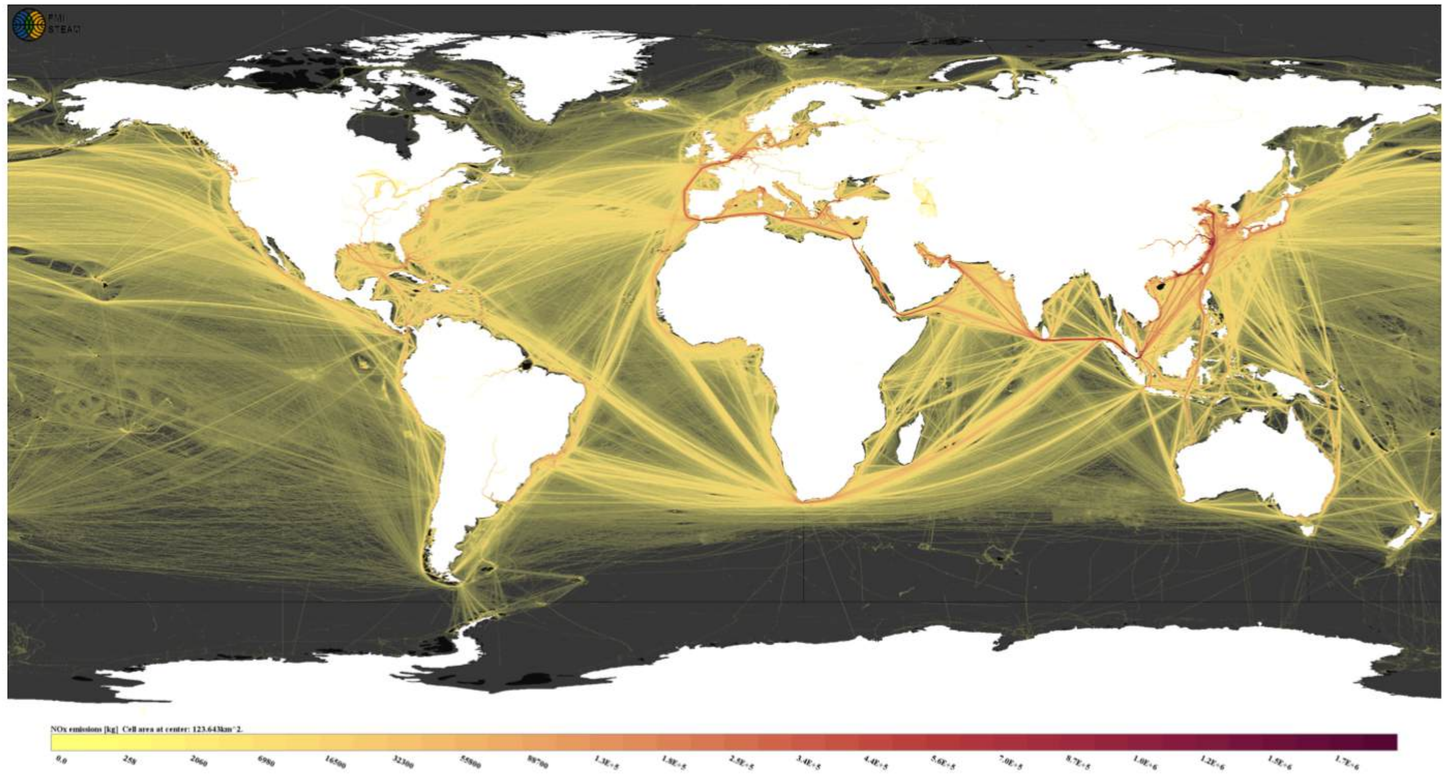
Using meteorological data to estimate the increase of resistance did not improve the goodness of fit between modelled and observed engine power demand. STEAM model's base-specific fuel consumption calculation method fits observed values reasonably when the engine load is over 50%, but ICEs used in constant speed mode have increased consumption at lower engine loads compared to variable speed ICEs.

The share of pilot fuel of total energy consumption was found to play a significant role in the emission factors for measured exhaust gas compounds. More accurate functions to model fuel consumption and emissions were



Väitöstutkimuksen johtopäätökset

- Bottom Up -metodi vaikuttaa parhaimmalta
- Mallia voi kehittää jatkuvasti
- AIS ei ole optimaalinen, mutta paras tarjolla olevista
- Tulevaisuuden polttoaineet aiheuttavat haasteen



Kiitos, kysymyksiä?