Towards an AIS-based Marine Emissions Inventory Model

Michael Aldridge[1], Daniel Bizer-Cox[1], Jarrod Brown[1], Sarah Roberts[1], Isabela Brown[2,3]

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[1]U.S. EPA, Office of Transportation and Air Quality

[2]ORISE participant at U.S. EPA, OTAQ

[3]Eastern Research Group

Outline

- Project goal and scope
- Emissions inventory equation
- Overview of Automatic Identification System (AIS) data
- Model methodology
- AIS data QA
- Model outputs
- Summary

Goal and scope

Goal:

Develop a method for estimating commercial marine vessel emissions at a high spatial/temporal resolution, using AIS data

Scope:

- Use 2017 AIS data to generate inputs for the 2017 National Emissions Inventory
- Initially limit to Category 3 (C3) vessels
  - – Vessels with engine cylinders > 30 L

General emissions inventory equation

$$Emissions\ (g) = \sum_{Vehicles} Activity(hrs) \cdot Power(kW) \cdot EmissionFactor\left(\frac{g}{kW \cdot h}\right)$$

Data Sources

unique vessels in AIS data set

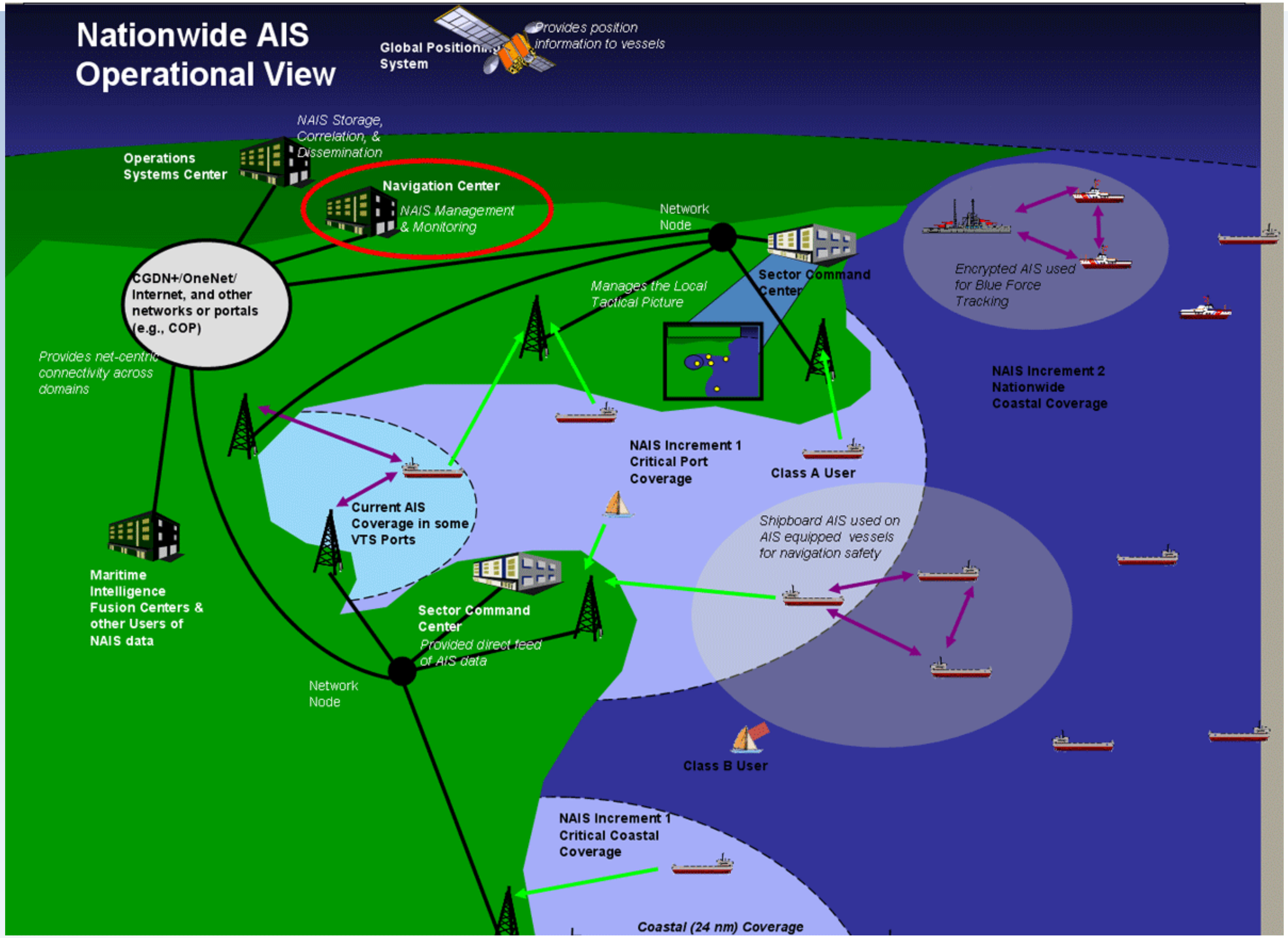
Duration of AIS messages

AIS & registry data

emissions measurements

Automatic Identification System (AIS)

- Vessel locating system using radio transponders on ships
- Designed as a safety protocol for collision avoidance, navigational aid, search and rescue
- Messages include Ship ID, position, speed, and ship dimensions
- Internationally mandated on ships greater than 300 GT.



http://www.navcen.uscg.gov

Contents of an AIS message

Static Fields

- MMSI #
- IMO #
- Name
- Draft
- Ship Type (limited detail)
- Overall dimension

Dynamic fields

- Timestamp
- Longitude
- Latitude
- Speed Over Ground
- Course Over Ground
- Heading

Ship registry data

Data sources: Lloyds registry, Clarksons

- 503,216 unique vessels (100,991 C3)

Provides ship details not contained in dynamic AIS messages:

- Length, width, maximum draft
- Engine bore and stroke
- Propulsive engine power
- Auxiliary engine power
- Vessel service speed

Modeling main engine power

$$P = \frac{\rho \cdot C(v, D) \cdot S(D) \cdot v^3}{2\eta}$$

Holtrop-Mennen model*:

- Models hull resistance at speed using estimated vessel shape and surface area
- Uses vessel specific hull information
- Uses AIS speed and draft data

P = Power
V = speed
D = draft
ρ = seawater density
C = hull resistance coef.
S = hull wetted surface area
η = engine efficiency

*Holtrop, J., and G. G. J. Mennen. 1982. *International Shipbuilding Progress* 29: 166-170

C3 emission factors

C3 Emission factors were updated using the following sources:

- Buhaug, O., et al. (2009). Second IMO GHG Study 2009. London: International Maritime Organization.
- Cooper, D., and Gustafsson, T. (2004). Methodology for Calculating Emissions from Ships: 1. Update of Emission Factors. Norrköping: IVL (Swedish Environmental Research Institute).
- ENTEC (2002). Quantification of Emissions from Ships Associated with Ship Movements Between Ports in the European Community, Chapter 2. UK: European Commission.
- IMO (2012). 2012 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships. MEPC 63/23, annex 8.
- IMO (2015). Third IMO Greenhouse Gas Study 2014: Executive Summary and Final Report. London: International Maritime Organization.
- Kristensen H. O. (2012). Energy Demand and Exhaust Gas Emissions of Marine Engines. Project No. 2010–56, Emissionsbeslutningsstottesystem, Work Package 2, Report No. 05.
- Starcrest Consulting Group, LLC (2015). Port of Long Beach Air Emissions Inventory—2014.
- Wärtsila (2014). Solutions for Marine and Oil and Gas Markets

Model Flow (Category 3 vessels)

AIS Handling Library

Ship Power Library

Ship Emissions Library

AIS Data

AIS Data Formatting

AIS Data Cleaning

Flag for ECA vs. Non-ECA

Ship Registry Data

Vessel Characteristics Assignment

- Ship Category
- Engine Type & Tier
- Ship Type & Sub Type

Filter for C3

Calculate Operating Mode

Calculate Main Engine Power

Assign Auxiliary/Boiler Engine Loads

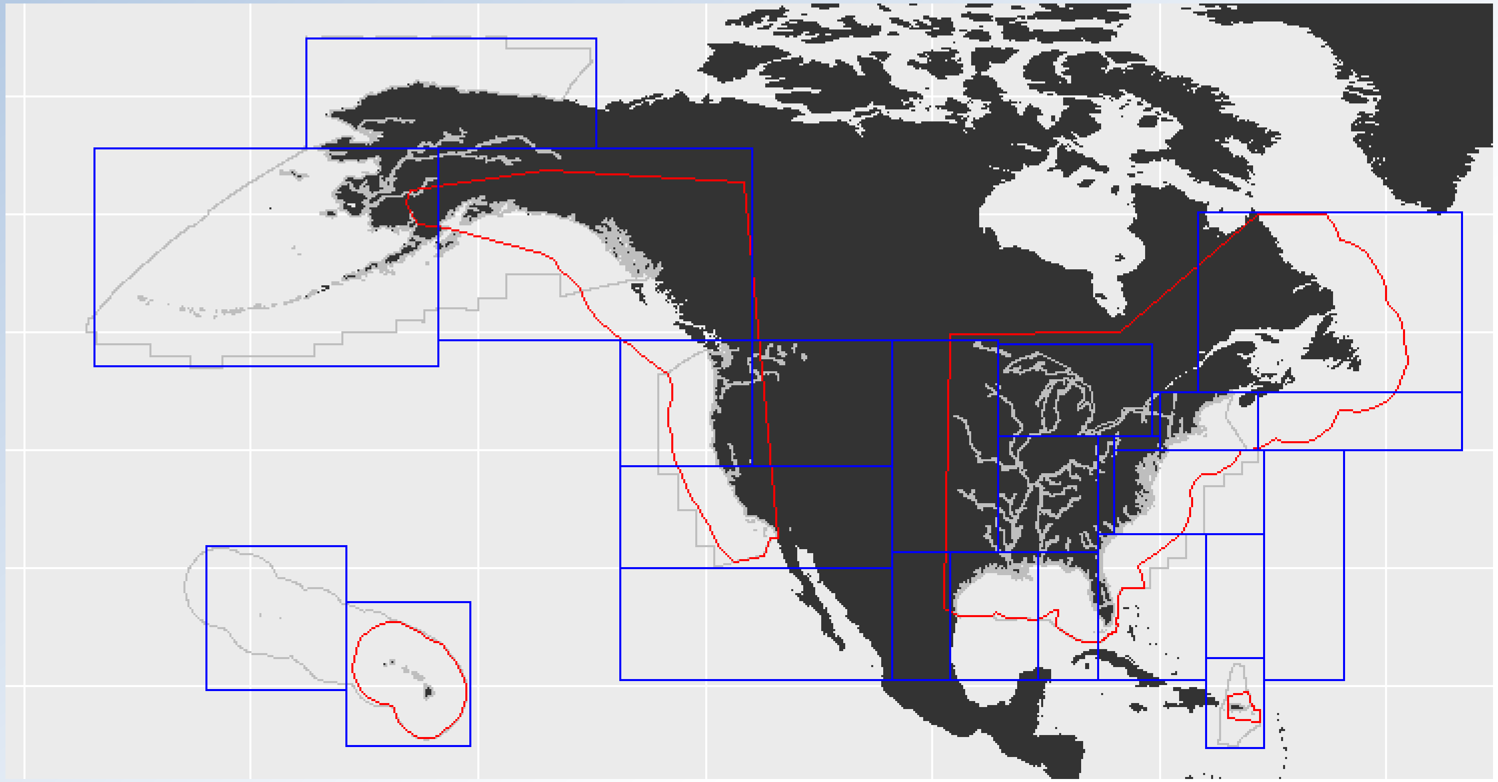
Calculate Emission Factors x Low Load Adjustment

Emissions = Time From Previous Message x Engine Load (kW) x Emission Factor(g/kWh) x Low Load Adj.

- Remove emissions allocated to transits out of region(s) of interest
- Aggregate emissions by shapefile or raster as a heatmap

AIS data source

- AIS Data requested from US Coast Guard NAIS data set: https://www.navcen.uscg.gov/?pageName=NAISmain
- 5 minute intervals
- Request broken into regions due to file size constraints
- As received from USCG:
  - 480 csv files (158 GB)
  - ~1.3×10^9 total records



Data request areas
N.A. ECA
2017 NEI modeling area

AIS data cleaning

As received, our AIS data has many records that are invalid for emissions estimates:

- Fishing buoys and pleasure craft contribute a huge proportion of vessel IDs and messages
- Messages with duplicate timestamps and different locations
- Transponder errors can make ships appear to be on land
- Reported ship speeds > 1000 mph

Final Dataset:

- 13.2% of original AIS dataset retained
- 98.9% of C3 observations with valid IDs retained

Identify and Remove Unusable AIS Data

Vessels without Valid ID

Vessels with Valid ID unavailable in our ship registry dataset

Filter for Category 3 Vessels

Remove Duplicate Records

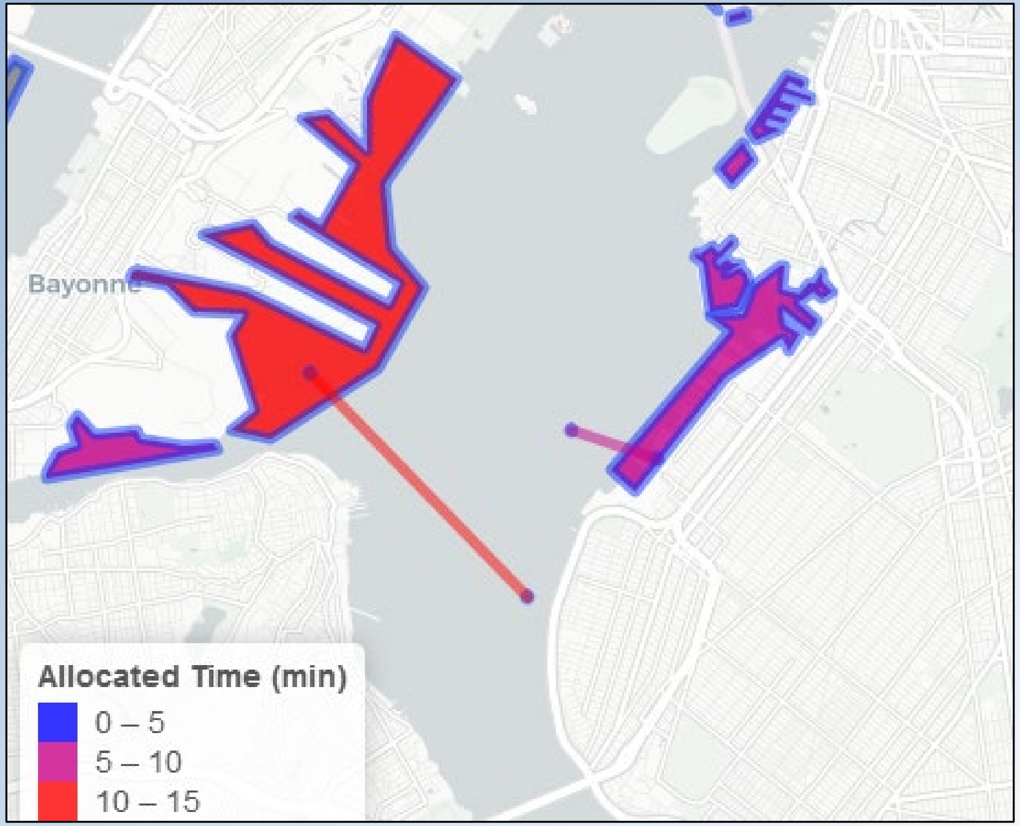
Remove Vessel Records with Duplicate Timestamp but Different Locations

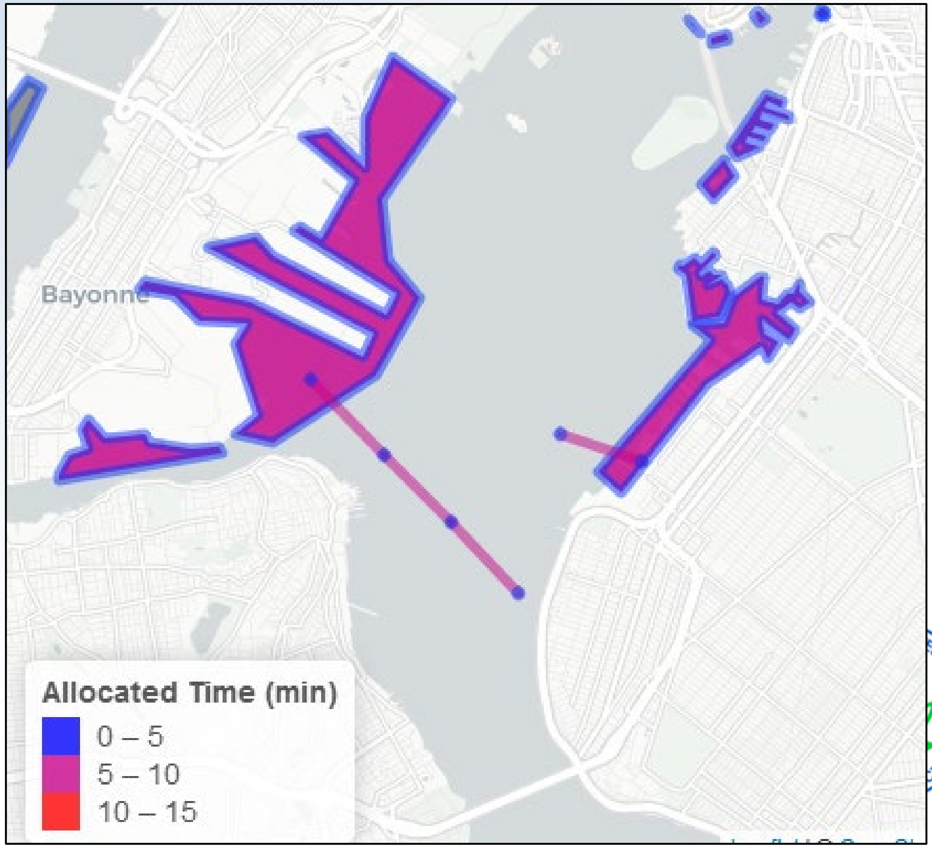
Remove Unreported Speeds

Remove Erroneous Speeds

Temporal gap filling

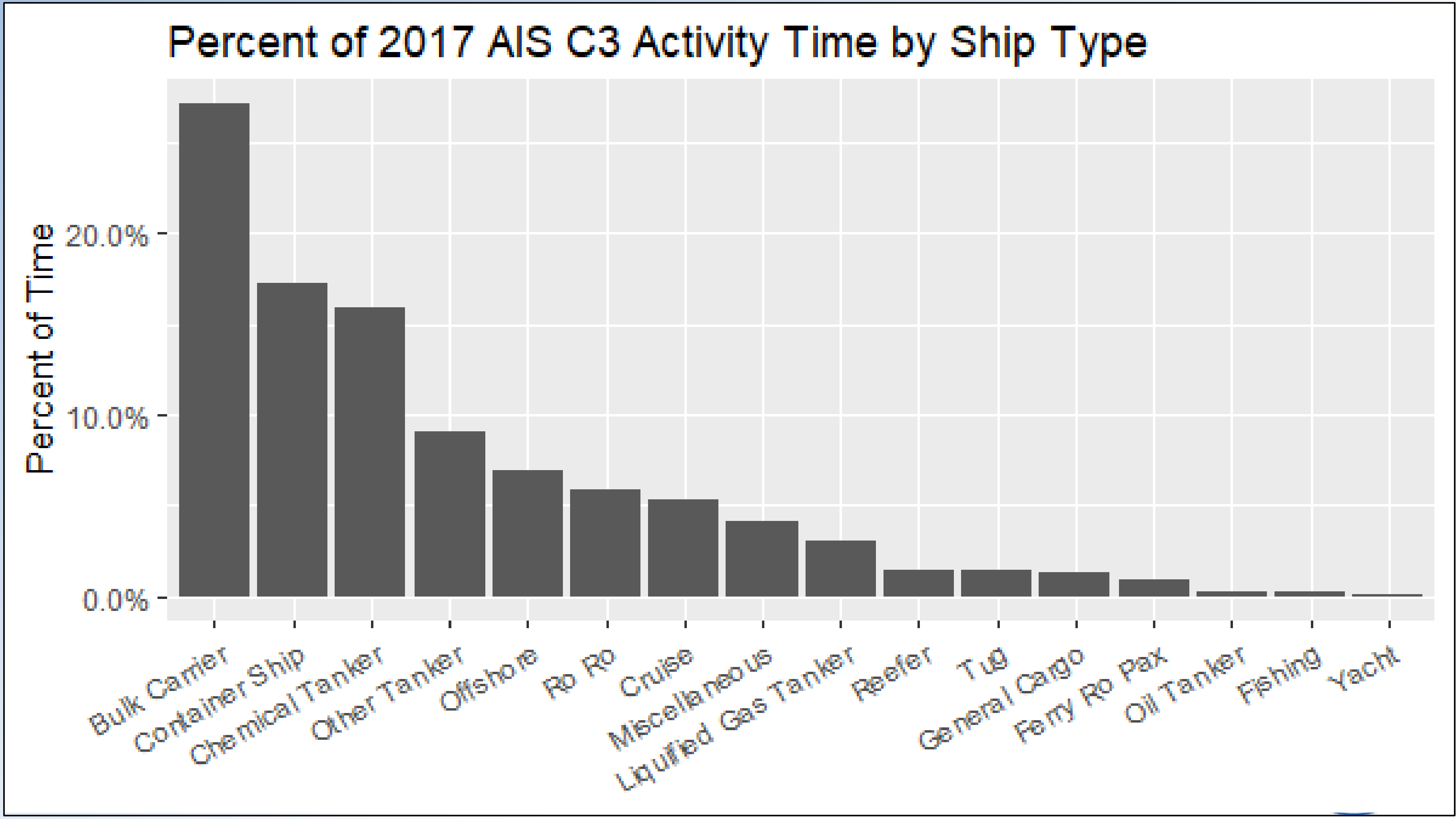
- In the model, emissions are allocated to AIS points (rather than lines)
- Each point should represent a similar time-span, but as received data has time gaps
- Missing points skew the spatial distribution of calculated emissions
- Temporal gap filling corrects these issues



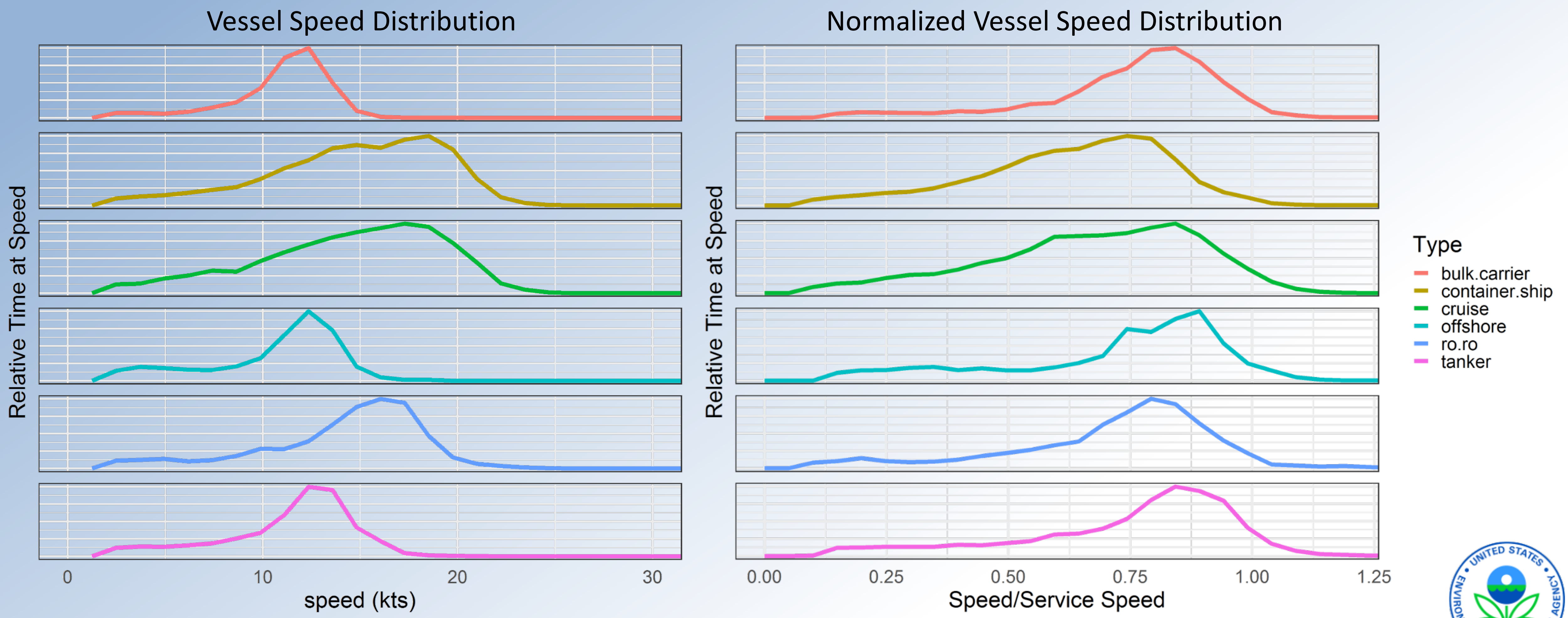


2017 C3 AIS activity data

- 11,248 vessels
- 1.3×10^8 records
- 1.7×10^7 hours of activity

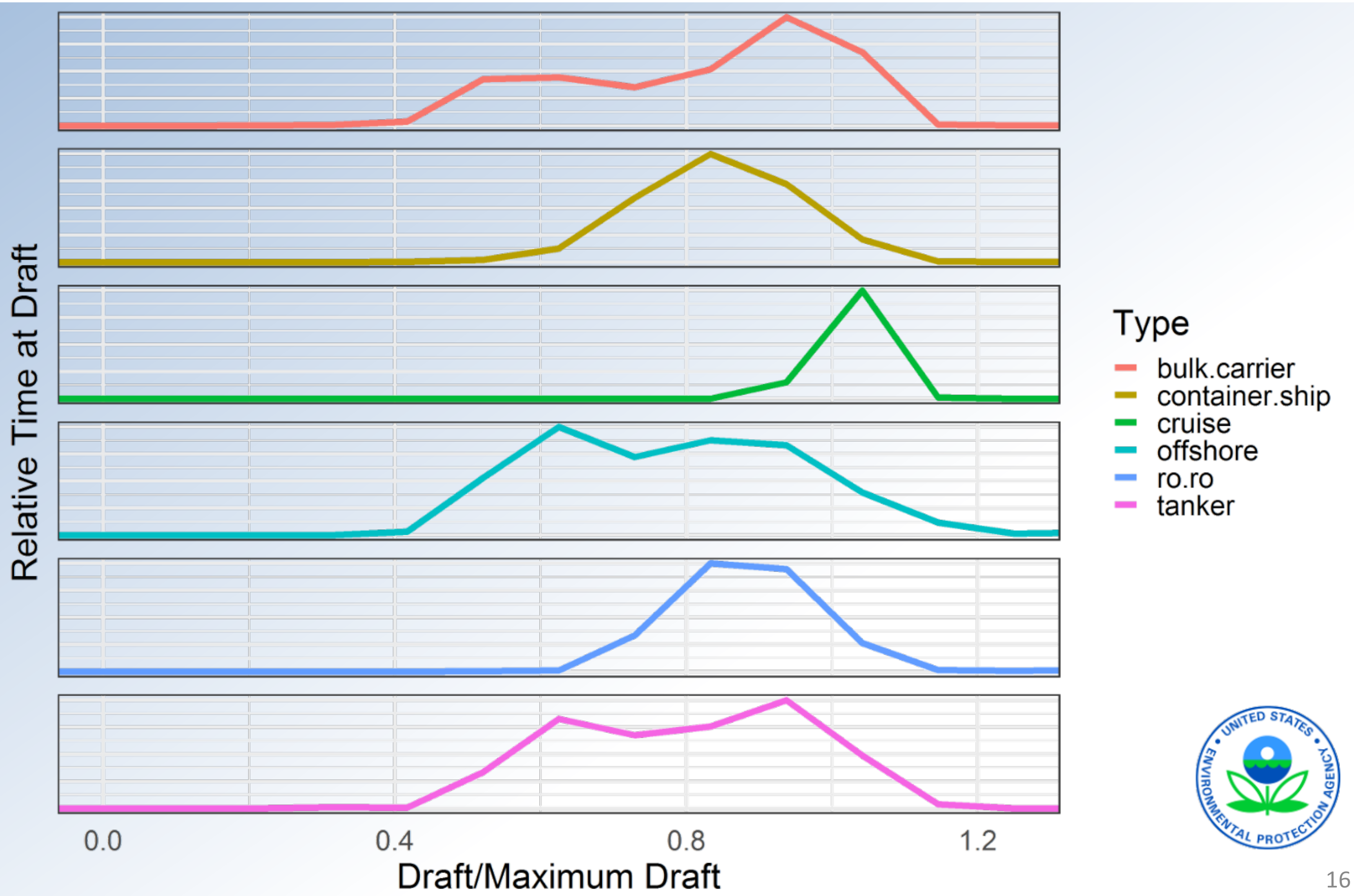


Vessel speed distributions



Vessel draft distributions

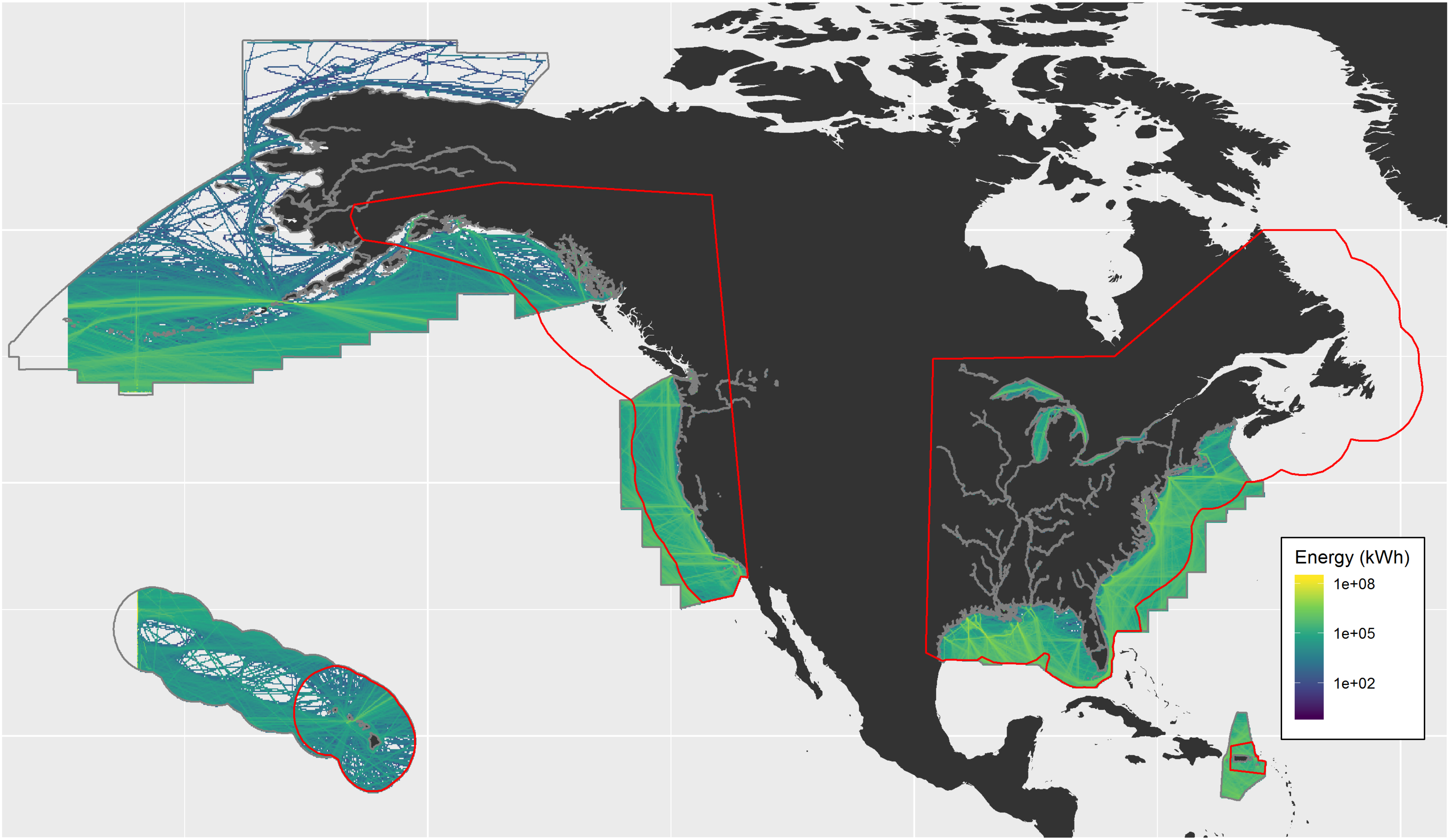
- Bulk goods (dry and liquid) are often only shipped one-way resulting in bi-modal draft distributions
- Cruise ships stand out because their draft rarely changes



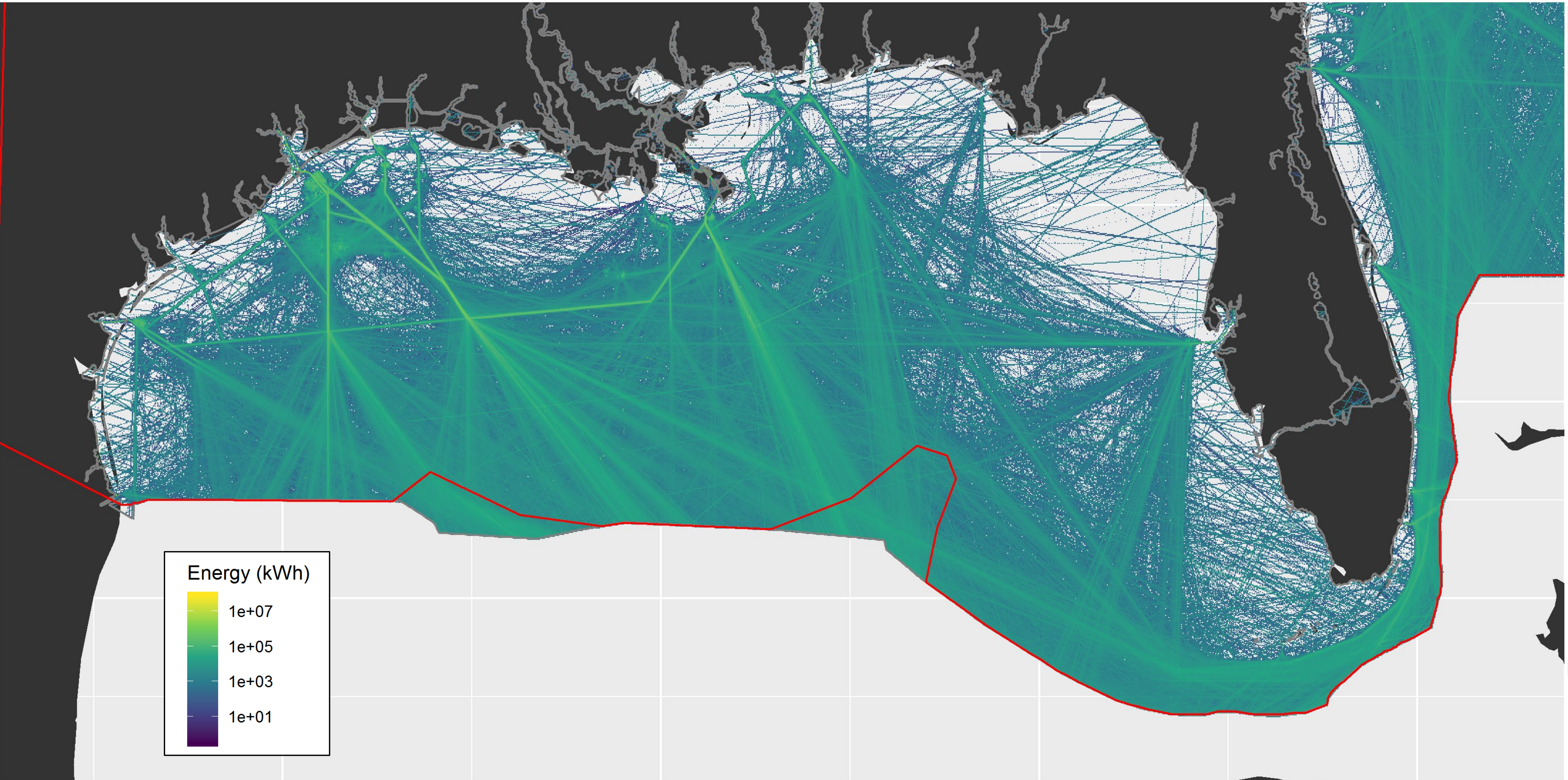
2017 modeled C3 vessel emissions

Ship Type	Activity (kWh)	Hydrocarbons (tons)	CO_2 (tons)	NO_x (tons)	SO_2 (tons)	PM 2.5 (tons)	PM 10 (tons)
Container	1.43E+10	1.32E+04	1.08E+07	2.51E+05	8.59E+04	1.21E+04	1.31E+04
Tanker	9.31E+09	7.44E+03	7.59E+06	1.28E+05	2.73E+04	4.50E+03	4.89E+03
Bulk Carrier	7.49E+09	6.29E+03	5.58E+06	1.23E+05	4.33E+04	6.11E+03	6.65E+03
Passenger	3.84E+09	1.78E+03	2.97E+06	4.51E+04	4.84E+03	1.05E+03	1.14E+03
RoRo	3.34E+09	2.37E+03	2.58E+06	5.09E+04	1.30E+04	1.93E+03	2.10E+03
Offshore	9.62E+08	1.19E+03	7.48E+05	1.77E+04	2.75E+03	5.04E+02	5.48E+02
Miscellaneous	6.85E+08	5.79E+02	5.16E+05	1.11E+04	2.84E+03	4.35E+02	4.73E+02
Reefers	4.20E+08	2.76E+02	3.17E+05	6.96E+03	3.27E+03	4.35E+02	4.73E+02
General Cargo	2.01E+08	1.78E+02	1.66E+05	2.86E+03	4.01E+02	7.85E+01	8.53E+01
Service Vessels	5.46E+06	2.41E+00	4.18E+03	6.07E+01	3.06E+00	1.10E+00	1.19E+00
Total	**4.05E+10**	**3.33E+04**	**3.12E+07**	**6.36E+05**	**1.84E+05**	**2.71E+04**	**2.95E+04**
ECA%	**64.95%**	**70.95%**	**67.77%**	**60.69%**	**7.04%**	**21.82%**	**21.82%**

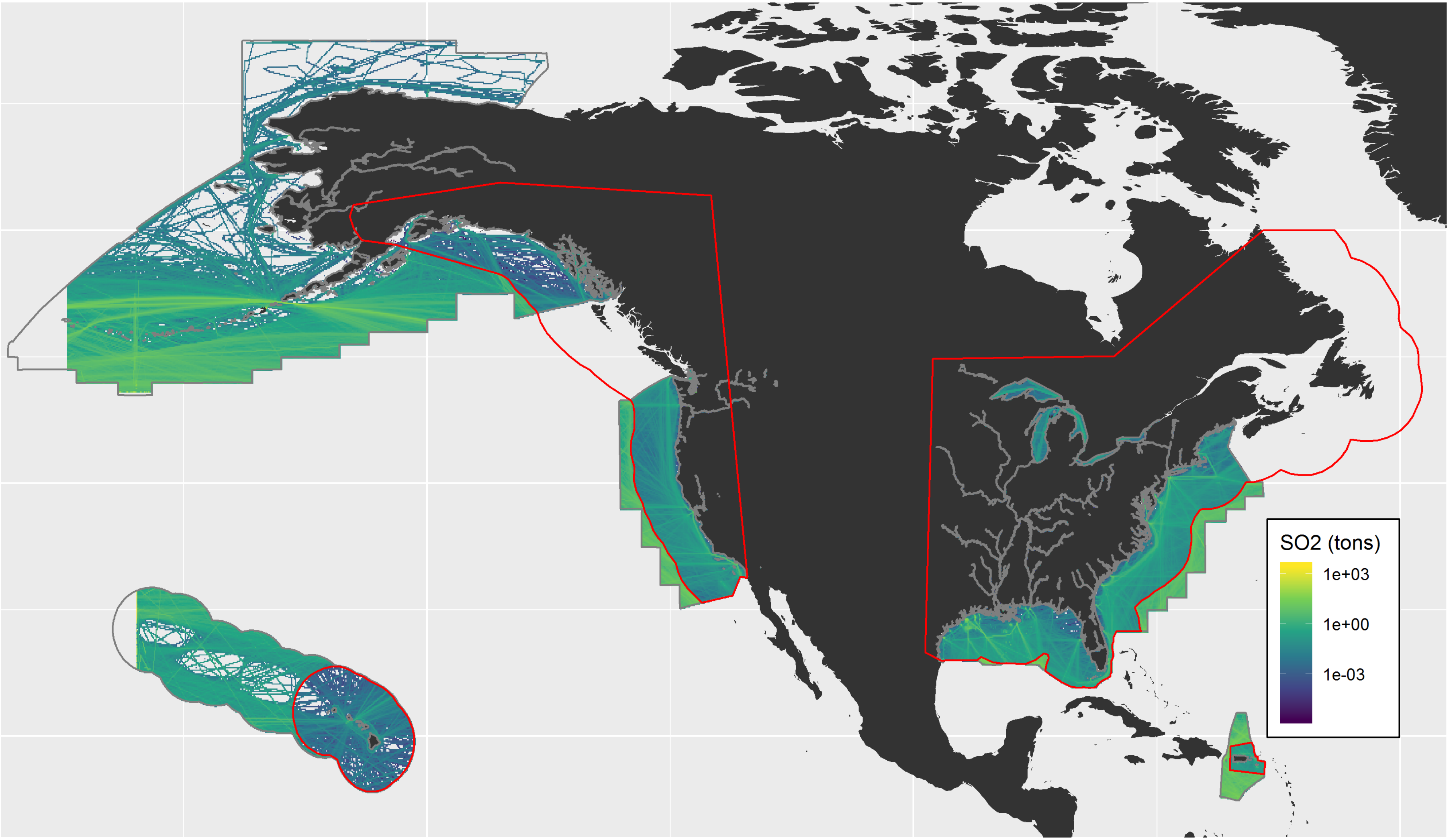
Vessel energy consumption



Vessel energy consumption



National Emissions SO_2

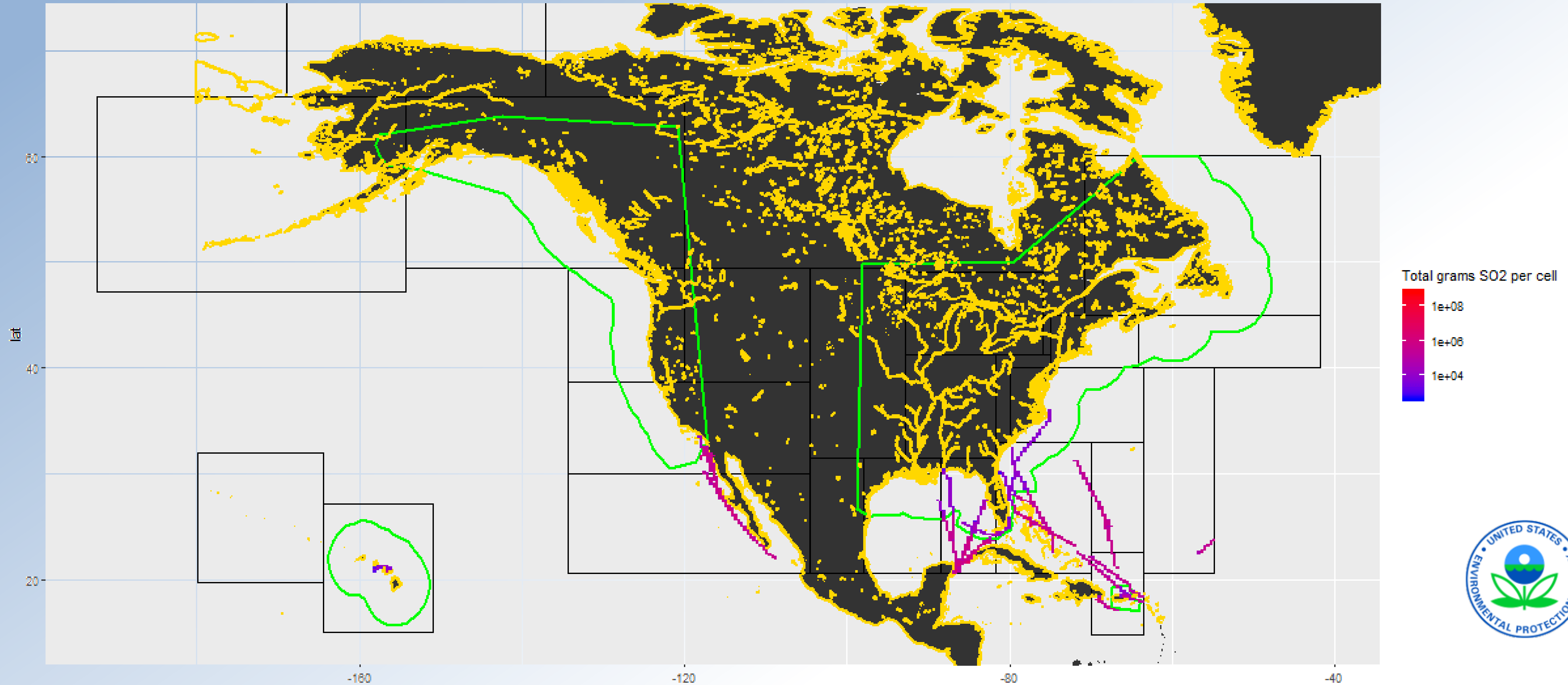


The model assumes fuel switching at the ECA boundary defined by the shape in red.

This causes the observed 10X increase in emissions outside of the shapefile boundary

Time-resolved emissions

Animation of 2017 SO2 Emissions from Cruise Ships ≥ 100,000 GT (1frame/day)



Summary

New emissions model framework using AIS data as an input

- AIS data allows the use of more refined propulsion power modeling
- Geospatial approach allows more precise modeling of ECA emissions
- Maintains high spatial and temporal resolution in output
- Requires significant data processing

Questions?