Regional Commercial Marine Vessel Inventories and Forecasts

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Chair's Seminar
California Air Resources Board
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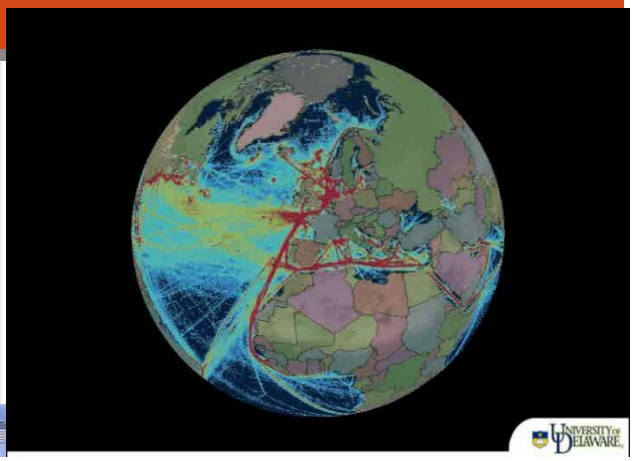


Air Resources Board

Review of ARB Project Objectives

1. Provide spatially resolved baseline CMV inventory of emissions at regional scale
2. Evaluate port-based inventories for potential agreement, validation
3. Spatially forecast future CMV emissions
4. Forecast future-year ship emissions under potential SECA designation

ARB focus on West Coast U.S. coastlines;

SECA Team focus … North America

Overview and Summary

North American inventory for base-year

- Best practices: activity-based inventory uses ship data and empirical spatial network
- Most current power-based emissions factors

Power-based trends used for forecasting

- First-order indicator of proportional change in emissions, adjusted for control measures

Forecasts are primarily extrapolations of BAU that can be bounded and/or adjusted

- Validated by comparison with other modal trends and with ship trade-energy models
- Validated by comparison at multiple scales

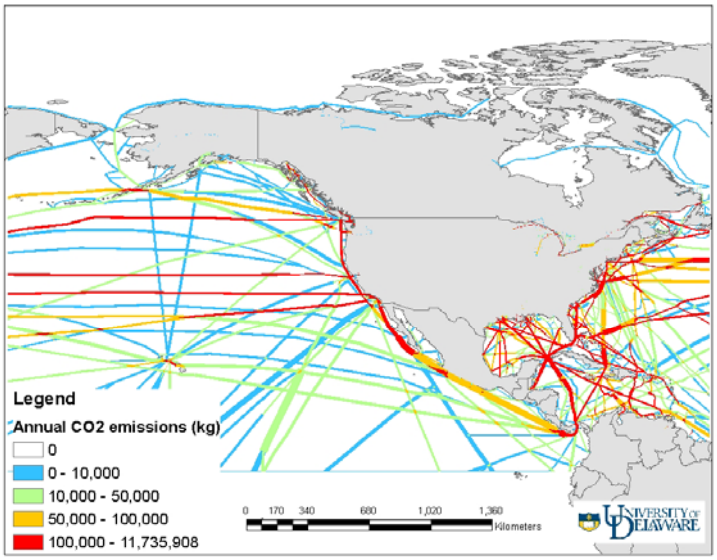
North American CMV Emissions

- Baseline 2001 results:
  - ~47 Mtons fuel and ~2.4 Mtons of SO_2 globally
  - ~30 Mtons fuel, ~1.6 Mtons SO_2 in project domain
- Growth trends for North America ~5.9% per year

Ship emissions growth rates are faster than GDP

Future emissions with IMO-compliant SECA will be greater than base year emissions in 2002.

Base year 2002 inventory: applied network model (STEEM), activity based methods for "all" NA traffic



Baseline CMV Results for North America

	NOx as NO_2	SO_2	CO_2	HC	PM	CO	Fuel Use
United States EEZ							
West Coast	135,000	80,200	4,817,000	4,470	11,300	10,500	1,480,000
East Coast	255,000	151,000	9,095,000	8,440	21,300	19,900	2,800,000
Gulf Coast	174,000	103,000	6,201,000	5,750	14,500	13,600	1,910,000
Great Lakes	16,200	9,620	578,000	540	1,350	1,260	178,000
Alaska	63,300	37,600	2,260,000	2,100	5,300	4,940	697,000
Hawaii	20,500	12,200	732,400	680	1,720	1,600	226,000
Canada EEZ							
West Coast	21,900	13,000	781,000	720	1,830	1,700	241,000
East Coast	96,200	57,200	3,440,000	3,190	8,050	7,500	1,060,000
Great Lakes	10,100	5,980	359,000	330	840	800	111,000
Mexico EEZ							
West Coast	99,400	59,100	3,550,000	3,290	8,320	7,800	1,090,000
Gulf Coast	107,000	63,700	3,827,000	3,550	8,970	8,000	1,180,000
Total Coastal regions	998,000	593,000	35,640,000	33,100	83,500	77,900	10,980,000
Non-coastal regions	1,740,000	1,040,000	62,200,000	57,700	146,000	136,000	19,170,000
Total in Domain	**2,740,000**	**1,630,000**	**97,800,000**	**90,800**	**229,000**	**214,000**	**30,160,000**

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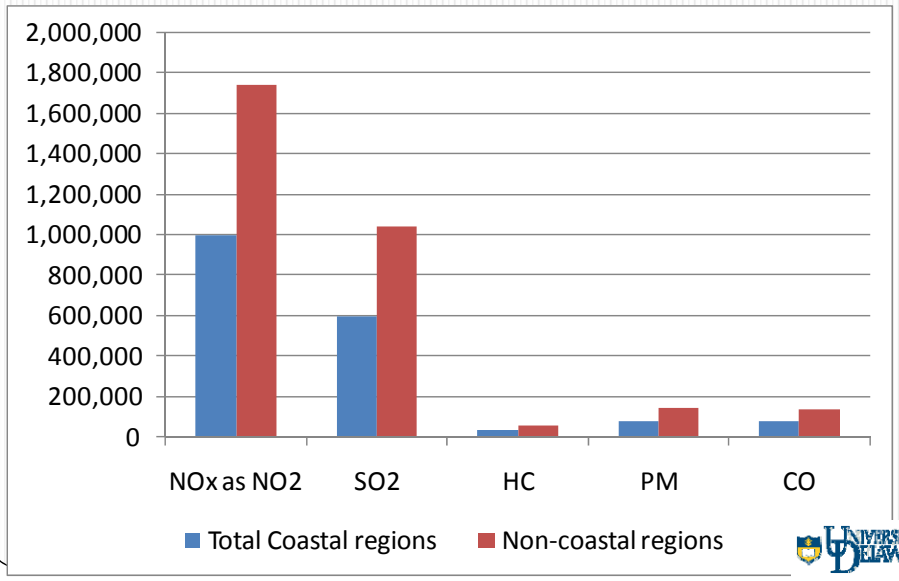
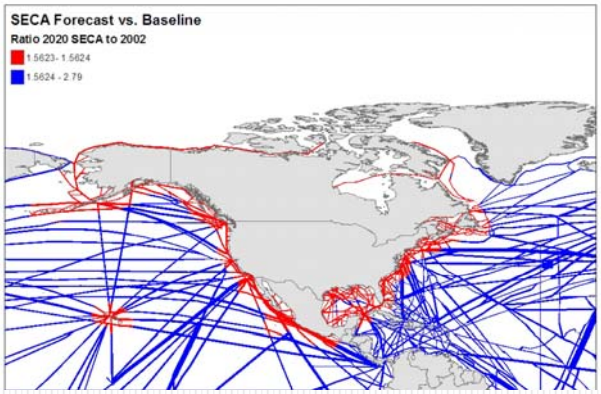
Baseline results graphically



Hypothetical IMO-compliant SECA (1.5% S) reduces future emissions from BAU

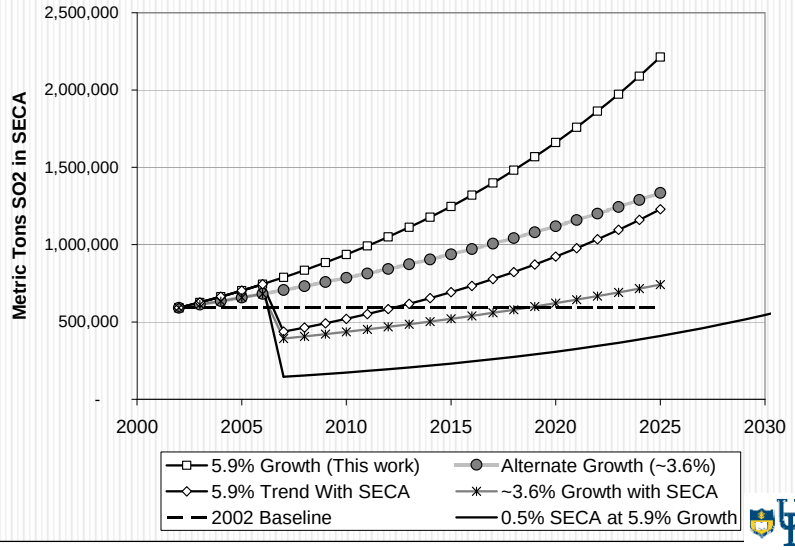
... but not compared to base year



- Reduces 700,000 metric tons from 2020 no-SECA
- Increases by ~2 million Mtons over 2002 base-year

Robust insight, even using other growth rates

Different growth rates simply change ***when*** this is forecast to occur

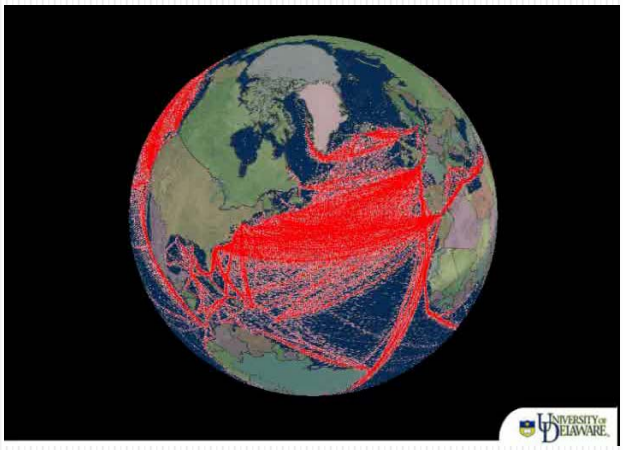


Advancing Ship Inventory Methods

Beginning with global traffic proxy, we developed a network of shipping routes to be solved analytically for a set of known voyages.

Ship traffic differs by vessel type

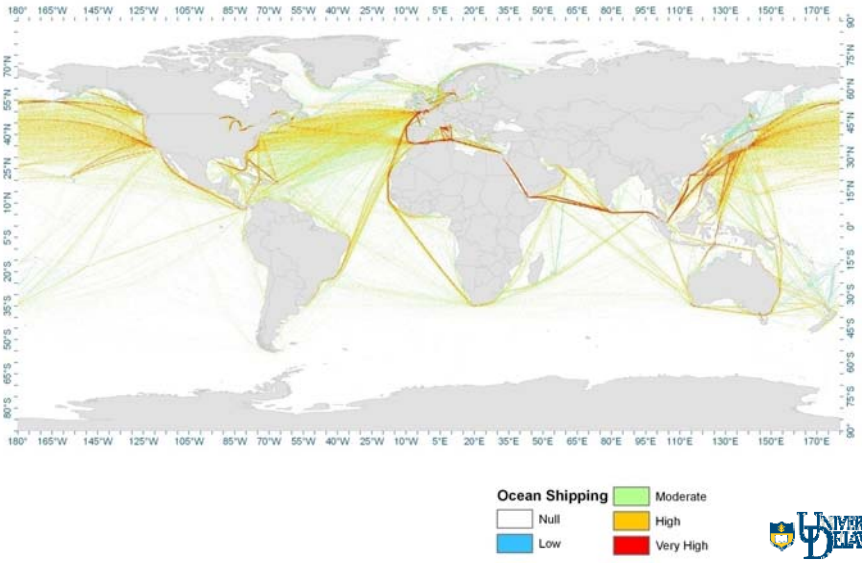
- Containership
- Tanker
- Bulk Carrier
- General Cargo
- Refrigerated Cargo
- Ro-Ro
- Passenger



Trade driven by commodity demand & resource supply

Trade import patterns are clear …

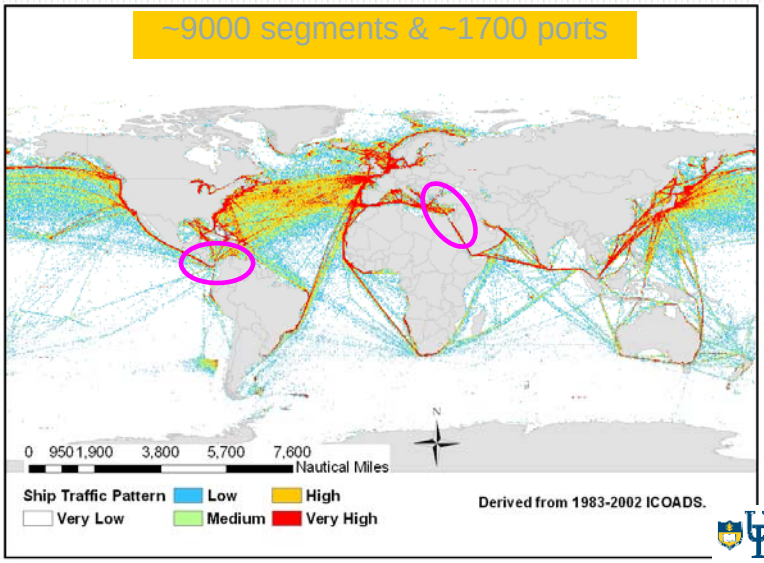
… and connected to domestic freight system



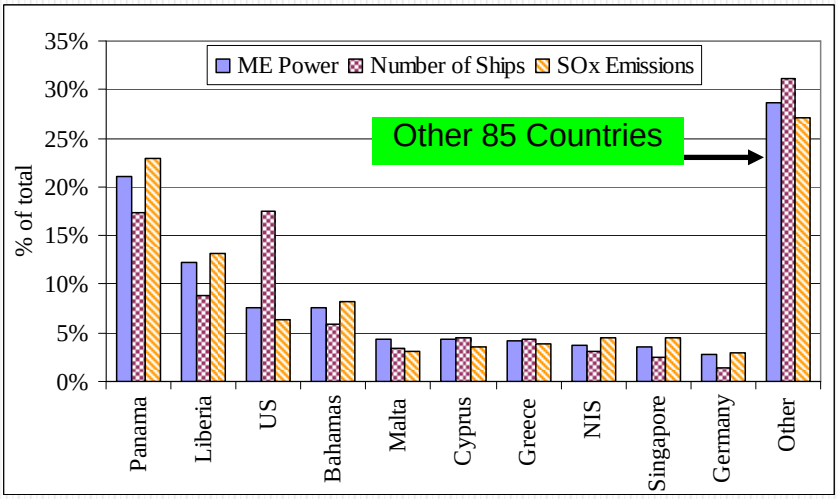
Integrating top-down & bottom-up:
Linking GIS with nonroad modeling

- 20 years of data to define (global) network
- "Complete" North American data for ship calls
- GIS tools are now sophisticated enough to assign trips to a network of routes
- We then follow "best-practices" for inventory
- Addresses major critique of top-down results
- Remaining limitations similar to regional studies

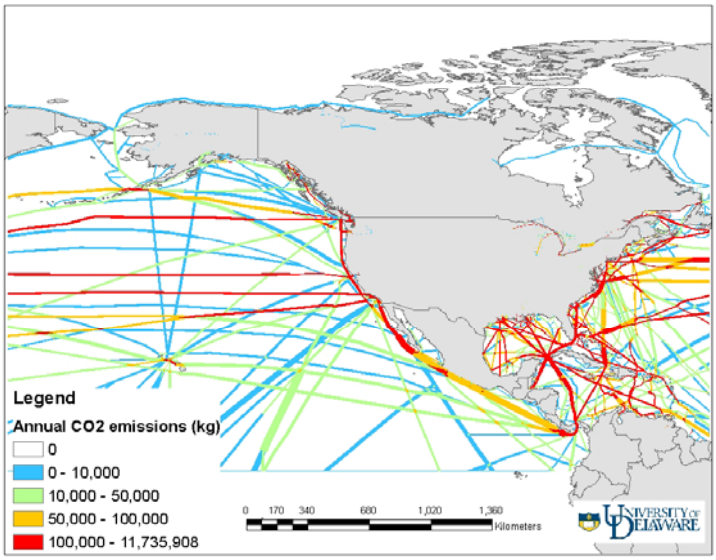
Building Empirical Network



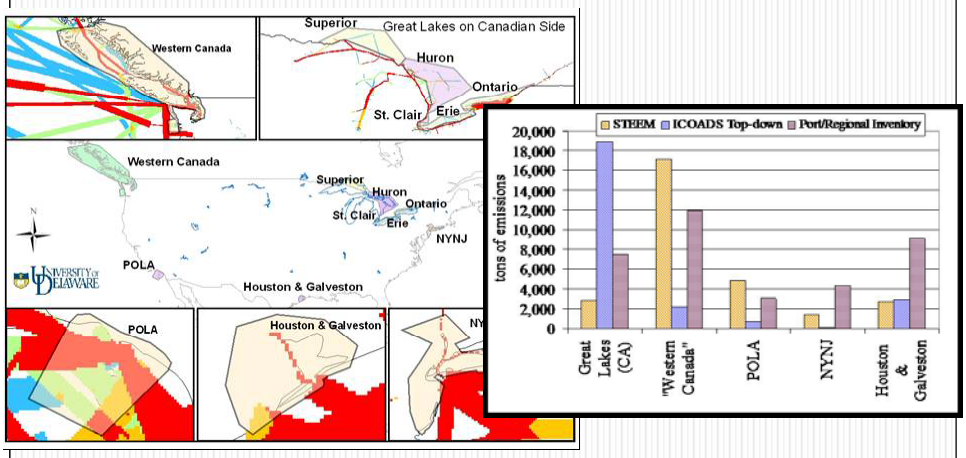
SO_2 Emissions by Ship Flag & Type



Base year 2002 inventory: applied network model (STEEM), activity based methods for "all" NA traffic



Validation: No systematic bias, but room to improve – toward convergence at all scales



We are interested to learn how port-based adjustments contribute to these insights

Forecasting Future Activity, Energy Use and Emissions

We develop bounded forecasts by evaluating a variety of trends and forecasts from economic trade data to energy and fuel projections.

Forecasting North America CMV emissions

Task 3 Forecast how baseline emissions may change in future years.

Task 4 Forecast future-year ship emissions under a potential IMO-compliant SECA equal to or less than 1.5% S by weight.

Critical freight forecasting questions

- What are freight energy and activity patterns?
  - STEEM provides baseline (Tasks 1 and 2)
- What is forecast trend in energy needed?
- Where is future freight activity be located?

- Each involves uncertainty and bounding
  - May be validated with some independence
- Emerging convergence on current baseline
  - Improving spatial allocation of better estimates
- Continuing work on future usage and location
  - Modal analyses need integration and coupling

Premises from which to forecast freight

Comparison and Validation

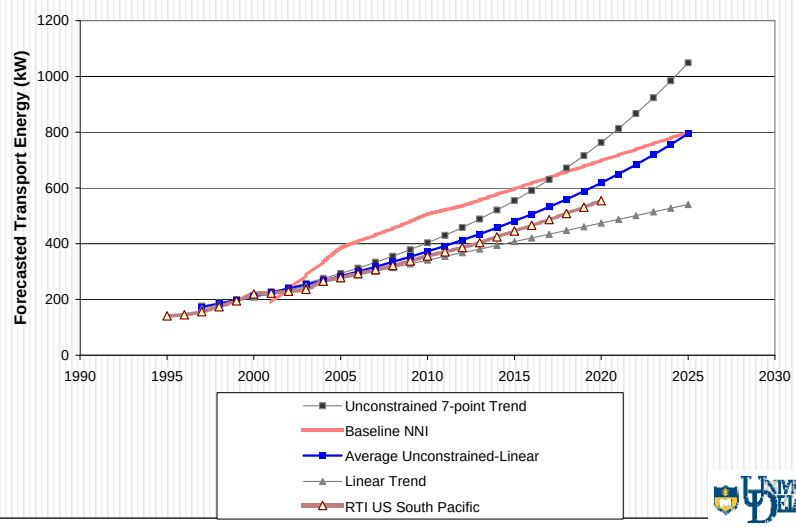
- Define the forecast domain broadly through multiple perspectives on freight and economy
- Consider first principles: work-energy relationship
- Recognize heterogeneity at all scales
- Look for surprise, avoid overconfidence

Choosing the Growth Trend Proxy

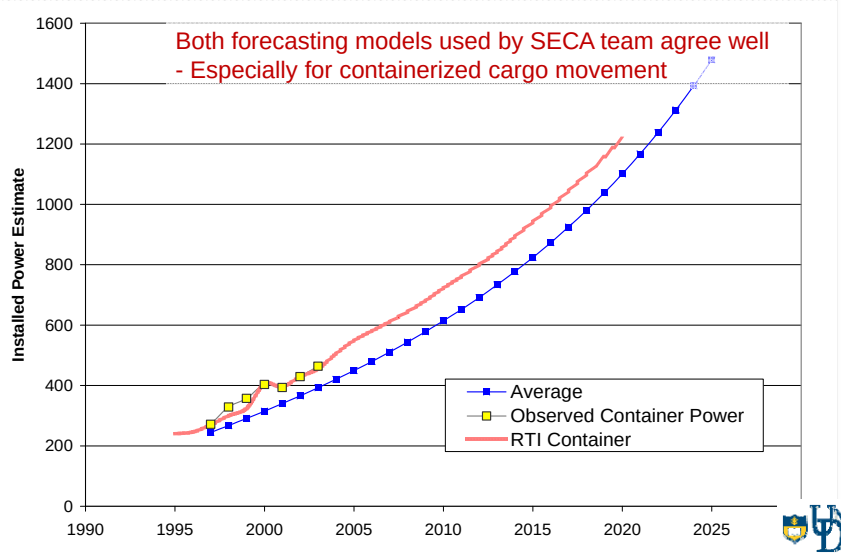
- Emission factors units: g/kWh or kg/tonne fuel
  - Average emissions factors are 0th order proxies
- Emissions ∝ power or fuel (1st order)
  - Vessel activity (load, speed, hrs) ∝ installed power (fuel rate)
  - ***Work done*** $= F*d \approx \frac{1}{2}mv^2 \propto$ mass and speed of movement
- Vessel size and/or speed is less direct (2nd order)
  - Size of ship ∝ power, but modified by hull design and ballast
  - Number of ship visits ∝ speed, but modified by route logistics
- Cargo throughput is less direct still (3rd order)
  - Cargo tons ∝ *f*(power, size, speed), modified by capacity loaded
- Other proxies include: TEUs, GDP, other modes, $ value, etc.
  - All poorer predictors of emissions than power-based

We use 1st order indicators of emissions growth

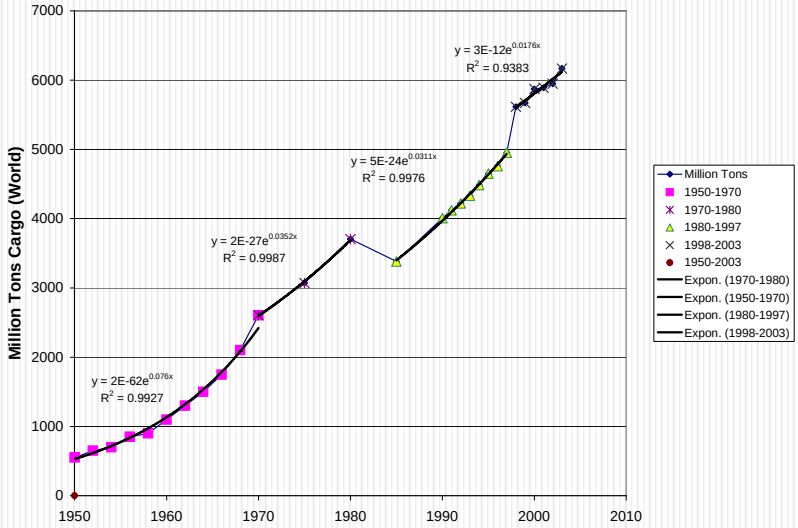
Adjusted power-based trend averaged exponential and linear curve-fits to data



Containership energy use driven by strong growth in "heavy-leg" activity

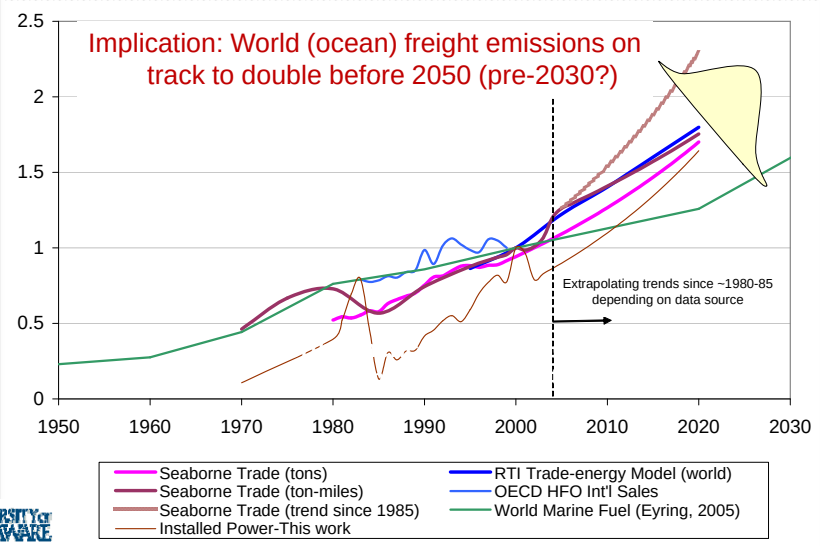


Cargo Movement Growth (Global)



UNCTAD, *Review of Maritime Transport, 2004*. 2004, United Nations: New York and Geneva, http://www.unctad.org/Templates/Page.asp?intItemID=2618&lang=1

Building a valid range of world forecasts … starting with trade and energy



Concept illustration credited to disucssions with M. Granger Morgan, Carnegie Mellon University

Power-based growth rate summary for commercial ships 2002 -2020 (CAGR)

Growth rates for North America are *generally higher* than world growth
Similar (within 2%) across all scales and regions
One NA growth rate justified – trend uncertainty greater than regional variation

Ports, or Region	Emissions Growth Rate
Los Angeles/Long Beach	5.24%
Oakland/San Francisco	5.68%
New York/New Jersey	6.03%
California (all ports)	5.53%
U.S. West Coast	5.93%
U.S. National	5.86%
Canada	6.57%
Mexico	5.06%
North America (U.S., Canada and Mexico)	5.86%

Growth rates represent an average of exponential and linear fit extrapolations, in CAGR

Insights from global comparison

- Extrapolating past data (with adjustments) produces a range of BAU trends that is bounded and reveals convergence; we may interpret convergence as describing a likely forecast.
- World shipping activity and energy use are on track to double by about 2030 (~2015 if one considers seaborne trade since 1985, ~2050 if one considers Eyring's BAU trend). Growth rates are not likely to be reduced without significant changes in freight transportation behavior and/or changes in shipboard technology.
- Confirming earlier discussion, trends in installed power are clearly coupled with trends in trade and energy. This reinforces the analysis of installed power as a proxy for forecasting growth, not only for use in baseline inventory estimates.

Discussion of Results

Reductions expected under IMO-compliant sulfur limits are offset by forecast growth in emissions.

This suggests that current IMO targets may be insufficient to achieve long-term mitigation of impacts.

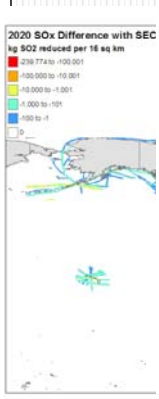
Results and Insights

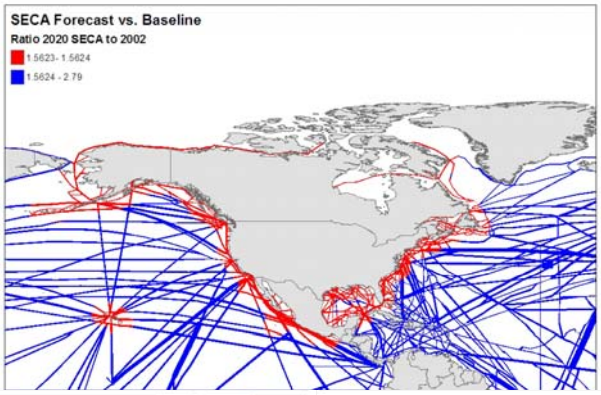
- Produced 2010 and 2020 forecast inventories
  - Used one North American growth rate for all regions
  - Adjusted for IMO-compliant NOx fleet introductions
  - No change assumed in average sulfur for BAU fuel
  - Power-based extrapolation assumes current improvements in efficiency continue without substantial changes in BAU
- Considered hypothetical SECA set to EEZ default
- Compared IMO-SECA future to BAU future
  - Compared also with base year results

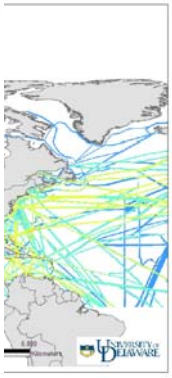
SECA-compliant increases in emissions?

Hypothetical IMO-compliant SECA (1.5% S) reduces future emissions from BAU

... but not compared to base year







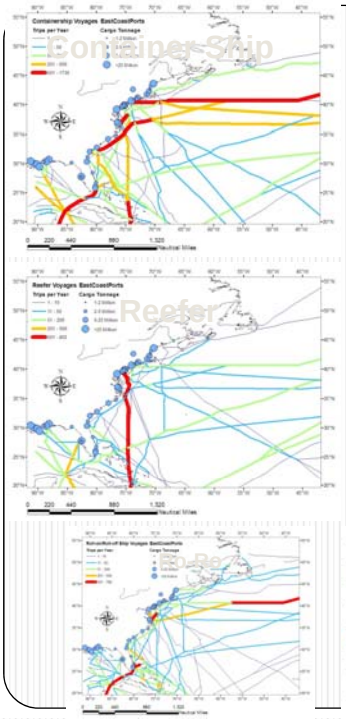
- Reduces 700,000 metric tons from 2020 no-SECA
- Increases by ~2 million Mtons over 2002 base-year

Future work ideas

Use these inventories to update recent ship-related health effects estimates.

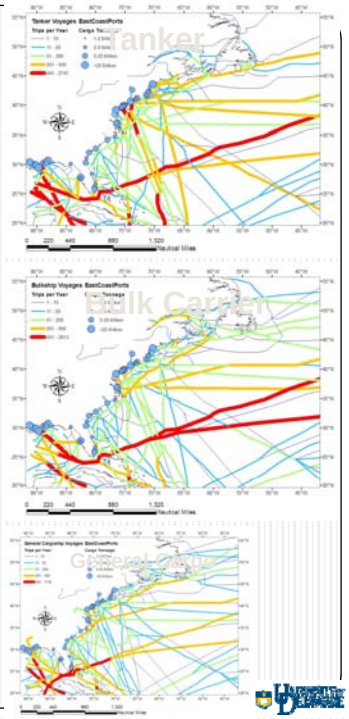
Model better known heterogeneity among major routes and ship types.

Connect these waterborne networks with multimodal goods movement.



Next Steps

- Recognize different growth rates and re-forecast spatially
- Consider policy and technology interventions
- Couple better with economics trends
- **Go multimodal**
- **Expand globally**



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  - California Air Resources Board; Council on Environmental Cooperation, EPA, other agencies
  - http://www.ocean.udel.edu/cms/jcorbett/sea/NorthAmericanSTEEM/
- Global inventory improvements and modeling:
  - Jeremy Firestone; James Winebrake; Clean Air Task Force; Prasad Kasibhatla
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Discussion welcome

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