Estimation, Validation, and Forecasts of Regional Commercial Marine Vessel Inventories

Forecast Inventories for 2010 and 2020

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11 December 2006

West Coast SECA Team Meeting
California Air Resources Board
Sacramento, CA

Air Resources Board

University of Delaware

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
- *Ship emissions growth rates are faster than GDP*
- *Future emissions with IMO-compliant SECA will be greater than base year emissions in 2002.*

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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

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

- We use 20 years of data to define (global) network
- We have “complete” North American data for port arrivals and departures & data for individual ships
- 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

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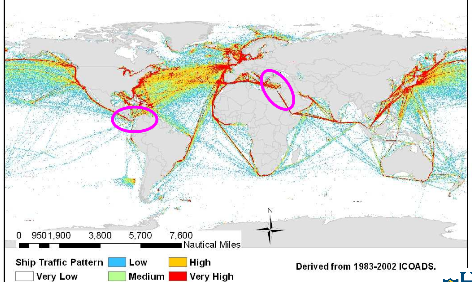
Building Empirical Network

~9000 segments & ~1700 ports
~170,000 ship trips/yr in North America



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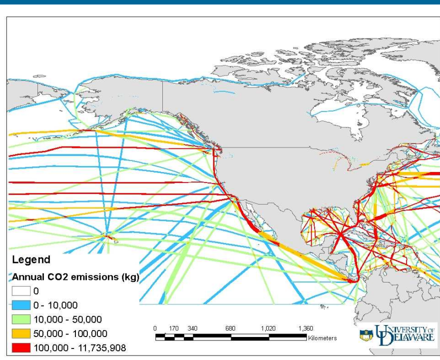
Base year 2002 inventory: applied network model (STEEM), activity based methods for “all” NA traffic



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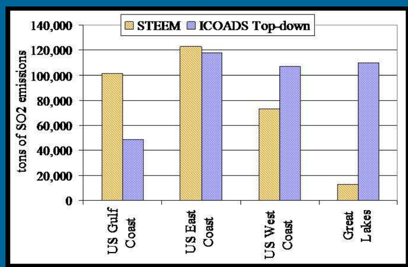
Validation: No systematic bias, but room to improve – toward convergence at all scales



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

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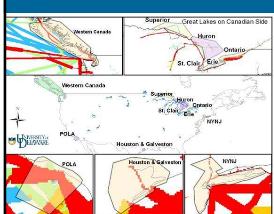

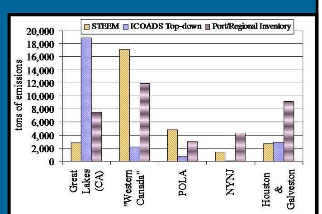

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Forecasting North America CMV emissions

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.

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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

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Forecasting: a suite of options

- Follow national methods, growth factors for each vessel type
- Look at port-specific growth rates and consider ways to blend (weighted average, straight average, etc.)
- Develop detailed stories (scenarios) or extrapolate from past
- Look at trade routes, within GIS context
  - Route-specific growth rates
  - Enables more explicit forecasting for power, etc.
  - Could be adapted into a modeling tool

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Premises from which to forecast freight

Choosing the Growth Proxy

- Emission factors units: g/kWh or kg/tonne fuel
  - Average emissions factors are 0^{th} order proxies
- Emissions ∝ power or fuel (1^{st} order)
  - Vessel activity (load, speed, hrs) ∝ installed power (fuel rate)
  - ***Work done = F*d ≈ ½mv²*** ∝ mass and speed of movement
- Vessel size and/or speed is less direct (2^{nd} 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 (3^{rd} 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 1^{st} order indicators of emissions growth

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

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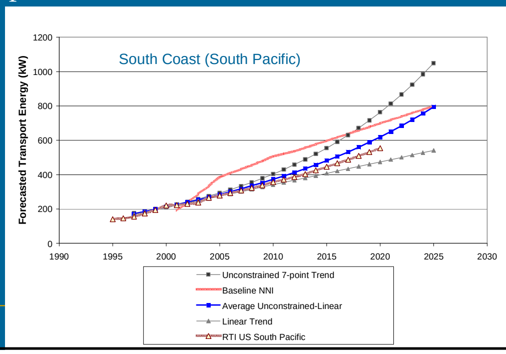
Adjusted power-based trend averaged exponential and linear curve-fits to data



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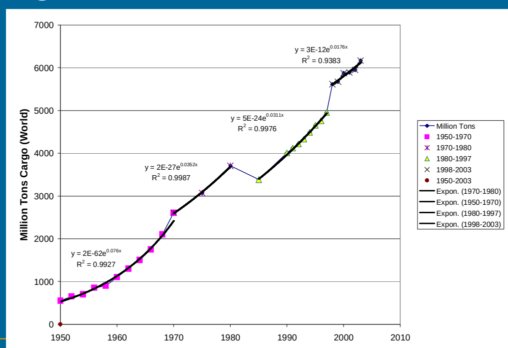
Cargo Movement Growth (Global)



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

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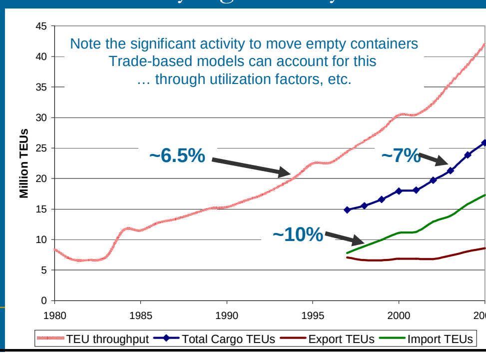
Containership energy use driven by strong growth in "heavy-leg" activity



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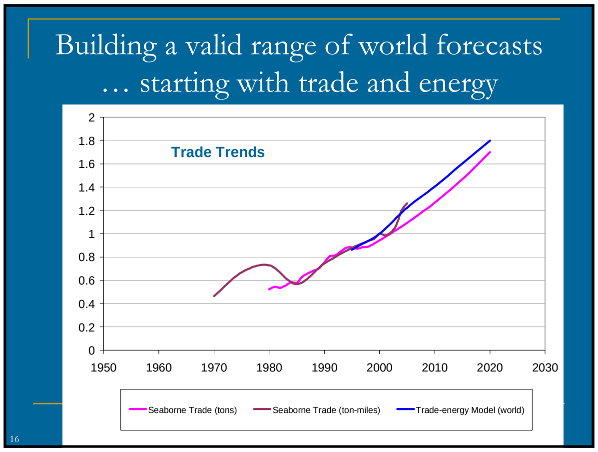
Building a valid range of world forecasts
… starting with trade and energy
Trade Trends
Seaborne Trade (tons)
Seaborne Trade (ton-miles)
Trade-energy Model (world)
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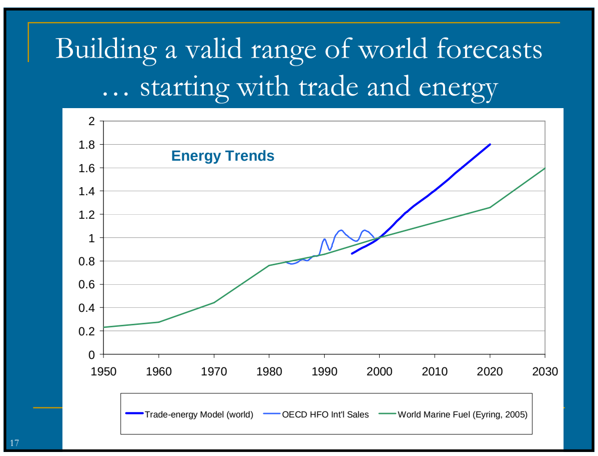
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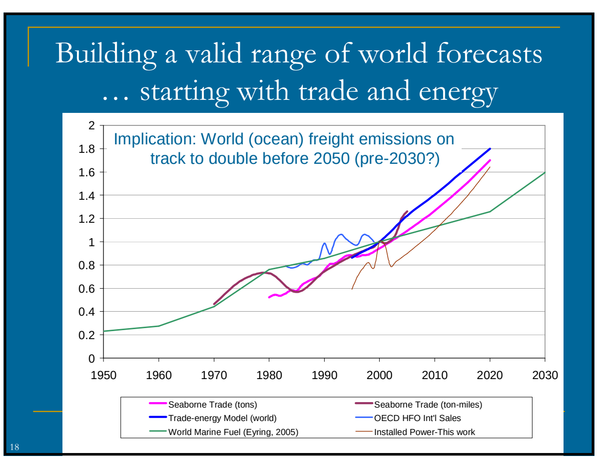
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Implication: World (ocean) freight emissions on track to double before 2050 (pre-2030?)
Seaborne Trade (tons)
Seaborne Trade (ton-miles)
Trade-energy Model (world)
OECD HFO Int'l Sales
World Marine Fuel (Eyring, 2005)
Installed Power-This work
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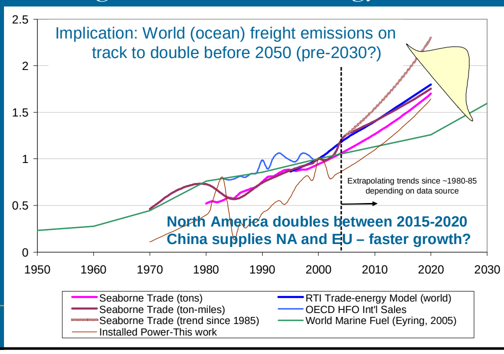
Building a valid range of world forecasts … starting with trade and energy



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

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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.

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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

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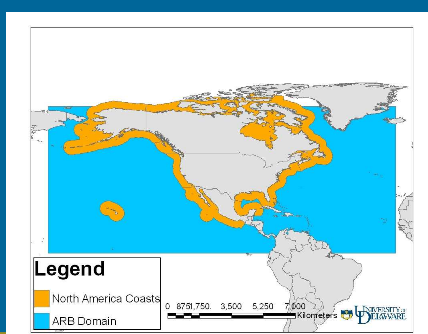
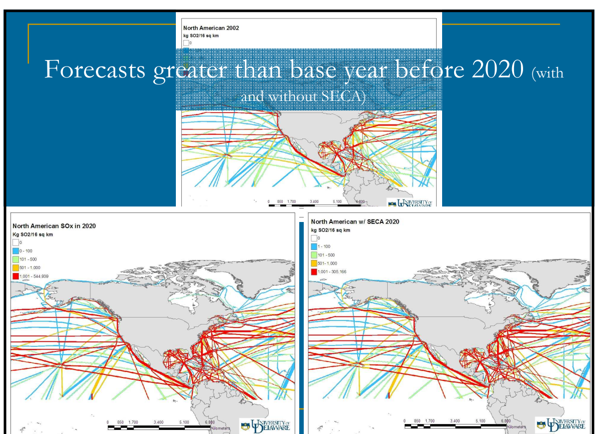
Results and Insights

- 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

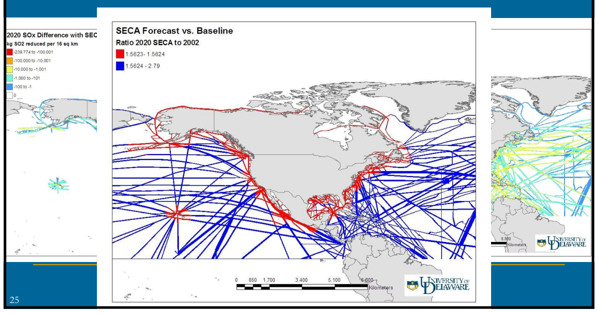
Model domain and hypothetical SECA



Forecasts greater than base year before 2020 (with and without SECA)



IMO-compliant SECA (1.5% S) reduces future emissions from BAU … but not compared to base year



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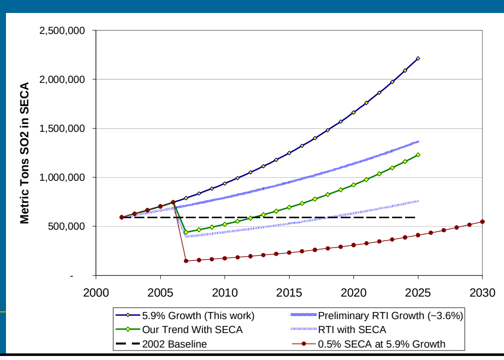
Robust insight, even using other growth rates

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



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Uncertainty and bounding

- *Base-year uncertainty – addressed in Tasks 1, 2*
- *Uncertainty in trend extrapolation – bounded through validation and comparison discussion*
- *Improvements could address*
  - *Incorporation of additional detail for change drivers*
  - *Incorporation of signals to modify technological change*
  - *Inclusion of fleet response to potential action*
- *Spatial limitations and opportunities for improvement*

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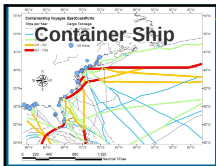
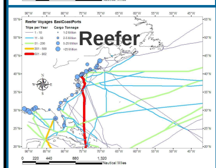
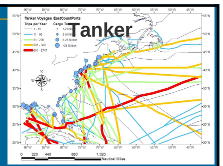
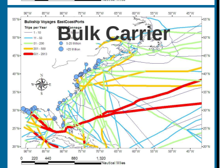


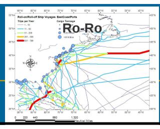


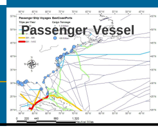
Next Steps

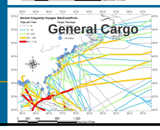
- Recognize different growth rates and re-forecast spatially
- Consider policy and technology interventions
- Couple better with economics trends
- **Go multimodal**
- **Expand globally**











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Acknowledgments:
Collaborators, sponsors, colleagues

- STEEM Model and North American Inventory:
  - 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
- NOAA Right Whale Research Grant; ICTC 2k2 team; US DOT Center for Climate Change; US DOT Maritime Administration

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Discussion welcome

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