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Reputation Resources Results

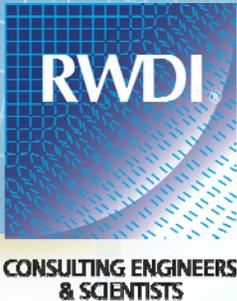


Generating an Hour-By-Hour Model-Ready Marine Emission Inventory

J. Wayne Boulton, Michael Van Altena, Darrell Devine, Xin Qiu
RWDI AIR Inc., Guelph, Ontario, Canada

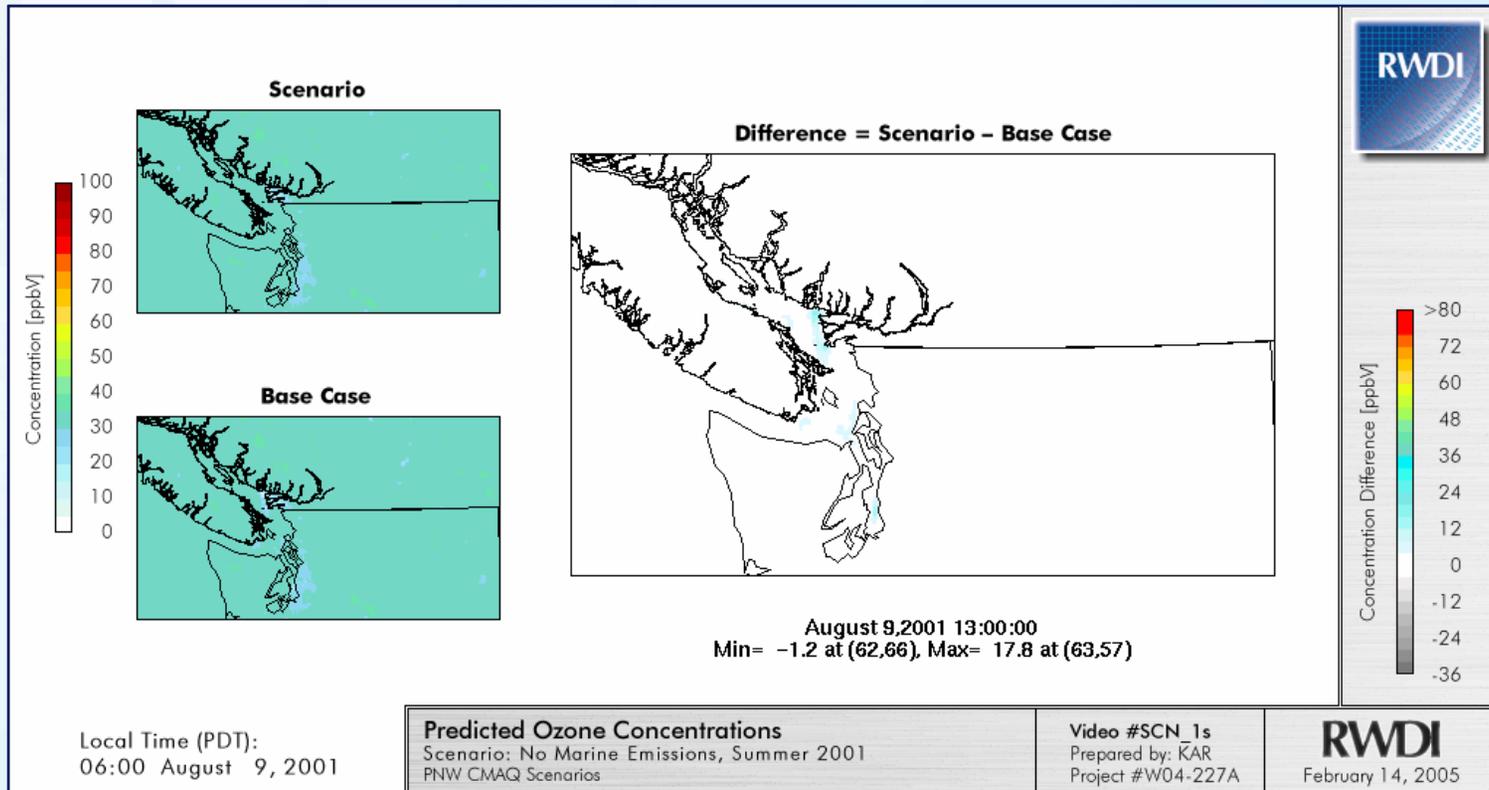
Colin di Cenzo, Andrew Green
Environment Canada, Vancouver, British Columbia, Canada

US EPA 17th International Emission Inventory Conference
“Inventory Evolution – Portal to Improved Air Quality”
June 2-5, 2008, Portland, Oregon



Purpose of the Study

1. Quantify impacts of a Sulphur Emission Control Area (SECA) on smog ($PM_{2.5}$, O_3), visibility, acid deposition, etc.
2. Enhance the PNW-CMAQ modelling system



Previous results for O_3 – all marine vessel emissions removed

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Related Presentation

Session: Innovative EI Development

Presenter: Andrew Green (Environment Canada)

Focus: BC Chamber of Shipping (COS) activity data compilation and emission inventory preparation

Every Three to Seven Minutes: The Unprecedented Detail of The 2005-2006 British Columbia (BC) Ocean-Going Vessel Emissions Inventory

Authors: Chamber of Shipping of BC, SIMES Consulting Ltd., Metro Vancouver, and Environment Canada
 Poster created by David Wright
 Inventory is available on the chamber of shipping website: www.chamber-of-shipping.com

The Emissions Inventory

- Included all commercial deep-sea vessels over 20 metres in length which called at a BC port
- April 1, 2005 to March 31, 2006
- Emissions from all engines and boilers in all modes of activity
- 1,420 ships made 2,557 voyages during the period
- Nitrogen oxides (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs), particulate matter (PM₁₀), fine particulate matter (PM_{2.5}), carbon monoxide (CO), ammonia (NH₃), and fuel consumption
- Carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O)
- All BC coastal waters to a boundary approximately 50 nautical miles offshore

Key Data Sources

- High-resolution Coast Guard Vessel Traffic Operation Support System (VTOS) Track Data (vessel location and speed at 3.7 minute intervals)
 - Used to determine time in mode, main engine load factors per voyage segment using separate algorithms for cargo and cruise ships, and geographic and temporal information
- Survey data collected by the Chamber of Shipping on engine, boiler and fuel characteristics for each vessel making a port call in BC during the study period
 - Used to determine auxiliary engine, boiler fuel use, and fuel sulphur content
 - Survey was administered by ship's agents and followed up individually (per voyage) with shipping lines
 - A double of follow-up surveys were administered to clarify auxiliary engine use at berth and to obtain unique engine power information at variable vessels for each individual cruise ship
- Lloyd's Marine Intelligence unit data for main engine power
- Emissions factors (mostly from ENTEC or IPCC)



Image 1 (above): Ship in survey net. Photo: © David Green

Results

Emissions = Engine Size × Engine Load Factor × Time in Mode × Energy-specific Emissions Factor

Emissions were estimated for all modes of activity

- Underway
- Manoeuvring
- At berth (or berthing)
- Anchoring (and related transits)

Findings and Benefits

- Some results were unexpected and changed conventional wisdom
 - Ships were plougher than expected, particularly if weighted for emissions
 - Boiler emissions are significant
 - Emissions results are lower than estimated in previous emissions inventories
- High level of detail (temporal and spatial) can be used in future analyses
 - Small-scale (e.g. individual ship plumes, local emissions, etc)
 - Specific behaviours (e.g. anchorage use, fuel sulphur content)
 - Database enables subsequent analyses much easier (e.g. analysis of ship emissions reduction scenarios)
- Involvement of the shipping industry fostered engagement in emissions management
- Results were more accurate and credible than previous inventories because of industry involvement

Features of Note

The inventory achieved an unprecedented degree of precision by combining:

- Detailed information on each vessel's behaviour (location and speed every 3.7 minutes)
- Detailed information on engine/boiler & fuel characteristics for each vessel (industry-administered survey enjoying a 95% response rate)

- The inventory was a co-ordinated effort among many elements of the shipping industry and regulatory agencies
- Chamber of Shipping conducted most of the inventory development in-house
- PM₁₀ emission factor was estimated per-voyage segment as a function of surveyed fuel sulphur content for each vessel

Vessel Class	Total Emissions in Study Area (tonnes per year)										
	NOx	SOx	COx	HC	PM10	PM2.5	CO	CH4	N2O	NH3	Other
Bulk/Veget	6,028	4,311	272,407	212	292	228	229	29	7	9	274
Container	8,918	6,633	341,944	353	505	455	739	45	3	8	370
Cruise Ship	6,099	4,492	414,962	203	415	370	489	32	15	9	387
General Cargo	3,256	2,358	148,494	157	197	177	287	18	4	3	201
Ro-Ro	209	159	12,222	18	12	10	22	1	0	0	12
Motor/Veget	878	395	35,223	32	31	48	73	4	1	1	53
Carrier	1,082	794	51,280	28	87	80	95	3	1	1	88
Total	26,553	18,413	1,278,054	834	1,054	1,439	2,298	129	36	28	1,062

Table 2: Total emissions within the study area, by vessel class

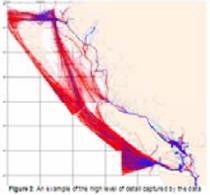


Figure 2: An example of the high level of vessel activity in the study area

Challenges

- Imperfect vessel track data
 - Gaps in tracking data time-consuming to address
 - Many minor issues remain unaddressed
- Flaws in the survey design resulted in ambiguous survey responses
- The large size of the database complicated quality verification and results analysis
- Accuracy of the main engine load factor algorithm (as a function of speed relative to land)
- Boundary rules with Puget Sound inventory

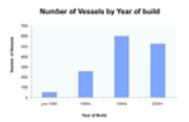


Figure 3: The age of the ships monitored during the study period

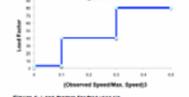


Figure 4: Load factors for test cases

Future Improvements

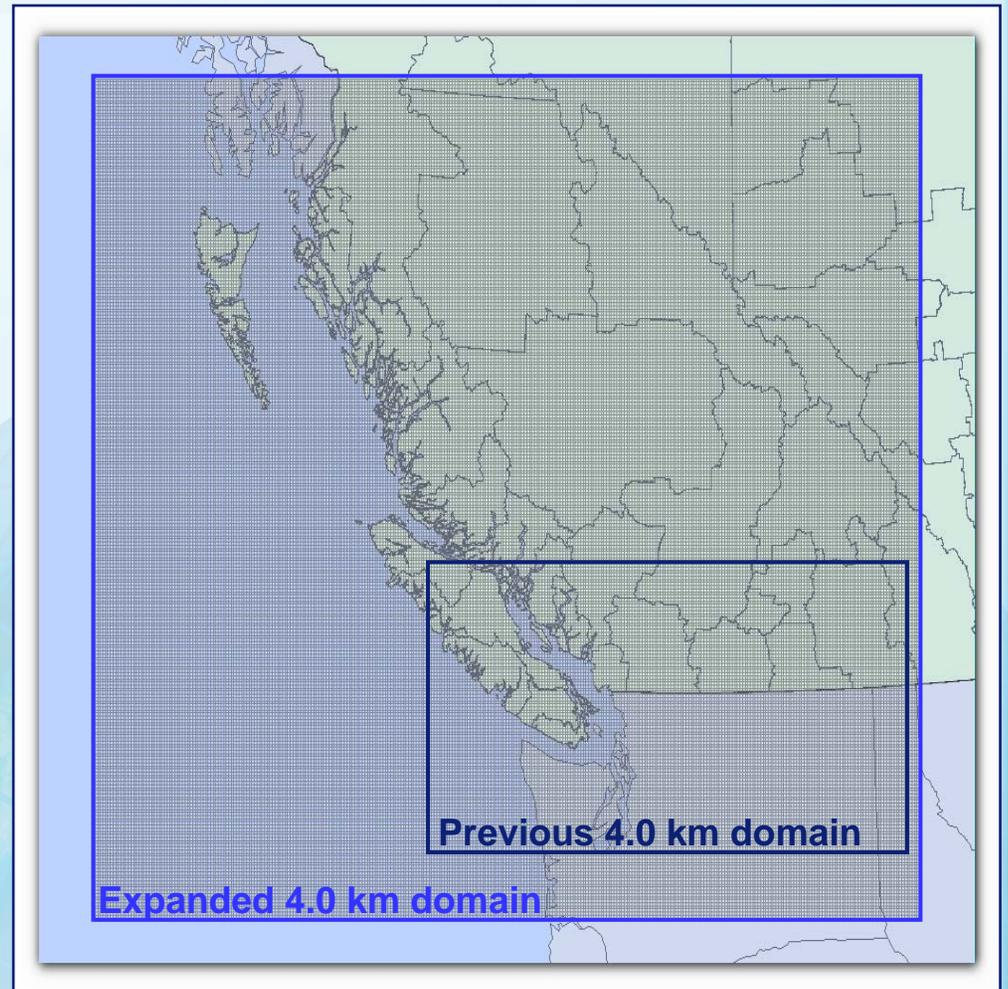
- Use ODS to verify vessel tracks and analyze results
- Use Automatic Identification System (AIS) track data as it becomes available
- Design the survey to eliminate the possibility of ambiguous answers
- Track data consolidation (e.g. underway intervals longer than 3.7 minutes) to save time
- PM₁₀ emission factor as a function of fuel sulphur content continues to evolve (e.g. for boilers)



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PNW-CMAQ Model Configuration Meteorology

- Migrated to GEM 2.5 km outputs:
 - Summer (Aug 09-31, 2001)
 - Winter (Dec 01-13, 2002)
- Modified GEM-MCIP
- Domain expanded to ~350,000 km² at 4.0 km grid resolution to cover primary shipping routes
- ~87,000 grid cells (~ 7 x more than the US 36 km national domain)





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PNW-CMAQ Model Configuration Emissions & Photochemistry

Emissions Processing

- 2002 US NEI + 2002 Env Can CAC EI base inventories
- Biogenic emissions generated using MEGAN (ver 2.04) with updated land cover data (pre-processed in ArcGIS)
- Migrated from SMOKE version 2.1 to version 2.3
- Spatial surrogates for new domain generated in EIGIS

Chemistry Model

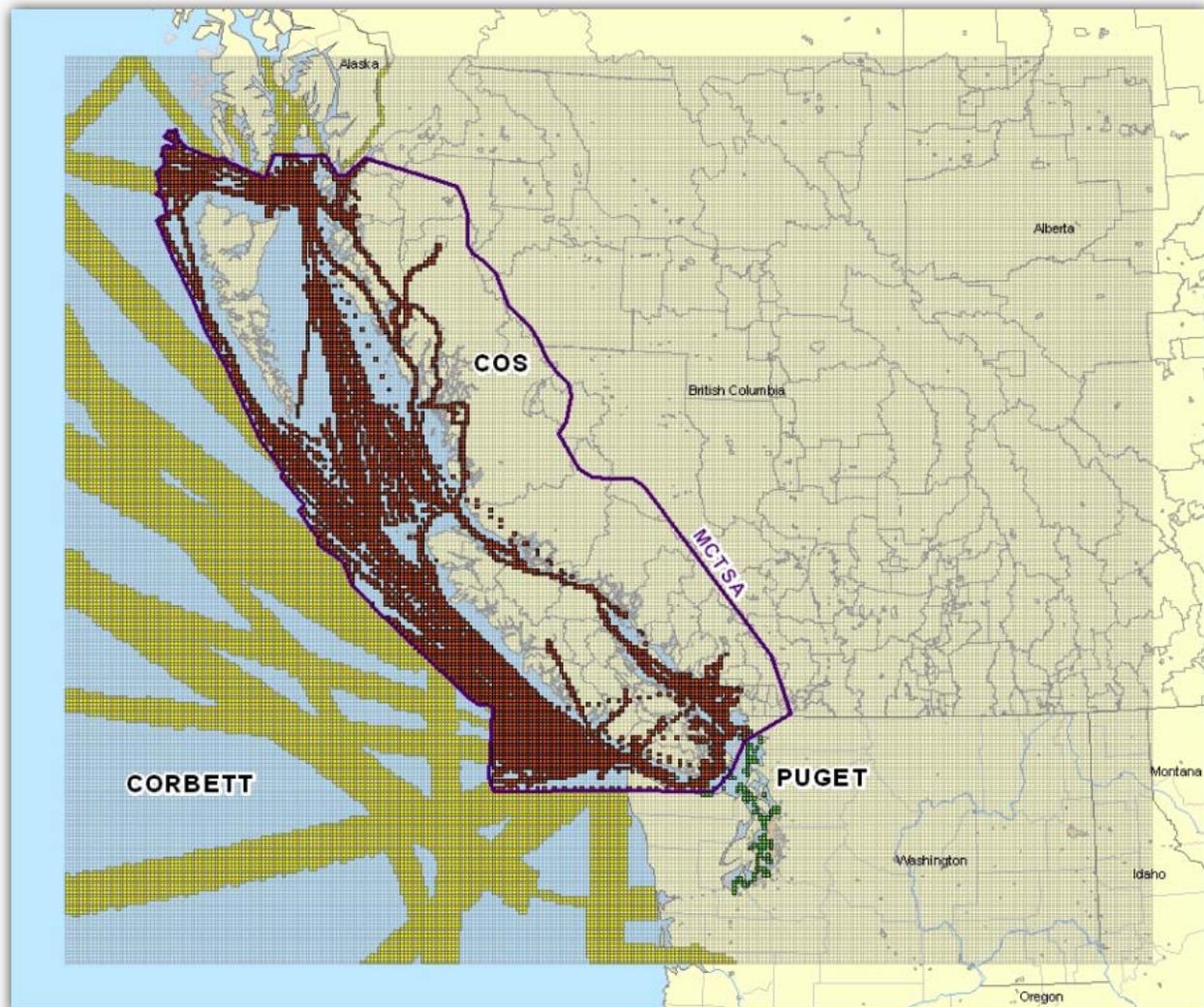
- Migrated from CMAQ version 4.4 to 4.6
- Migrated from SAPRC-99_ae3_aq to SAPRC-99_ae4_aq chemical mechanism with sea salt

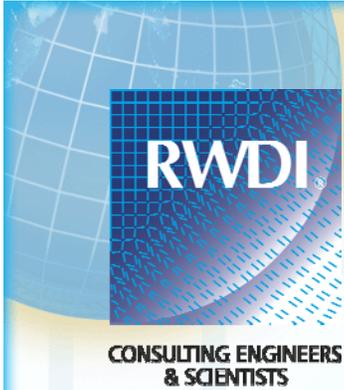
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Marine Emissions Inventories 2005 Base Year (scaled to 2001)

- CORBETT
(gold)
- PUGET
(green)
- BC Chamber
of Shipping /
COS (red)





Marine Emissions Inventories CORBETT Inventory

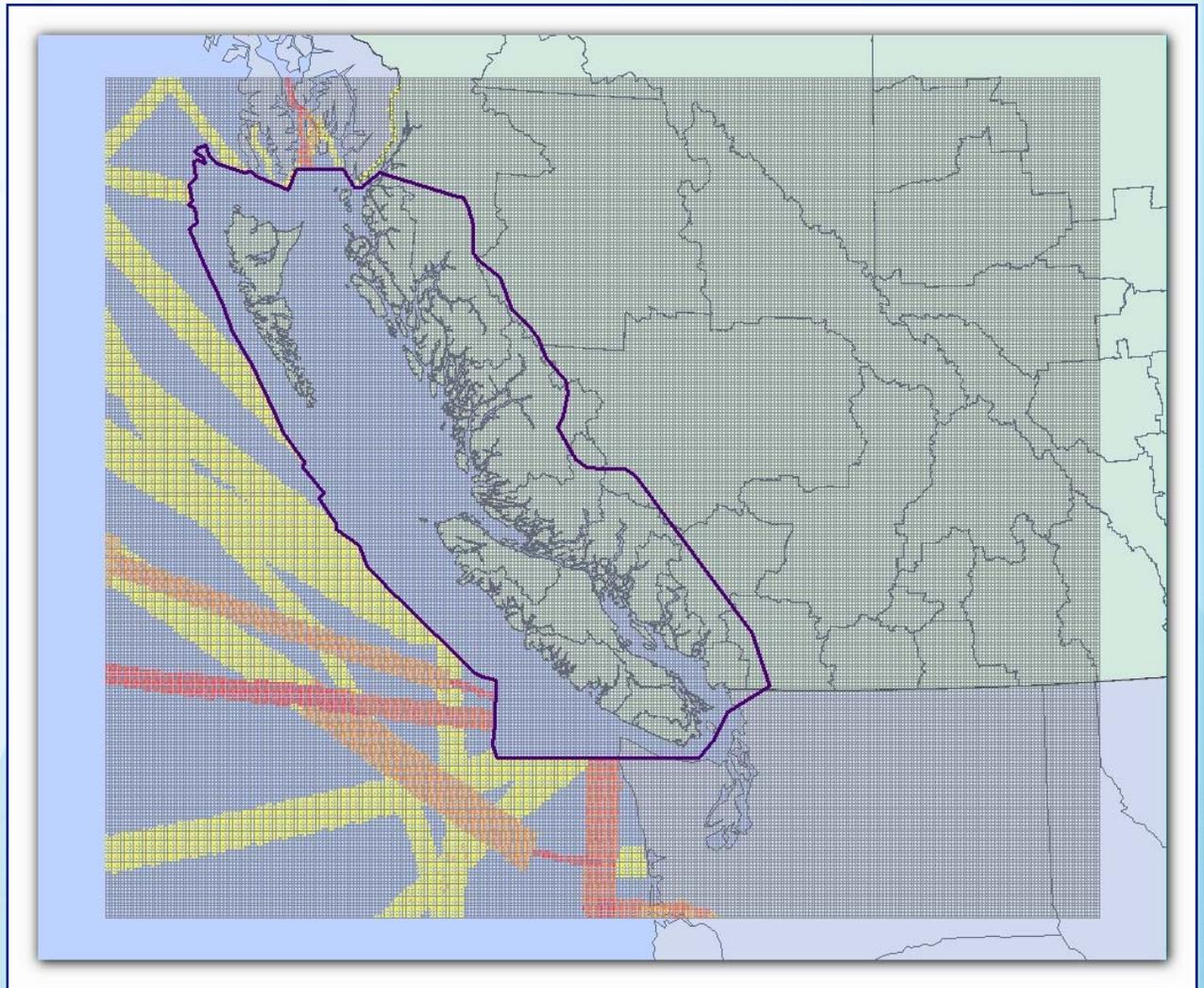
- Developed by Dr. J. Corbett at the University of Delaware
- Emissions geographically and temporally allocated based on empirical waterway network, historical ship movements, and ship attribute data
- Monthly and annual gridded emissions of SO_x (as SO_2), NO_x , CO_2 , PM, HC, and CO
- Interpolated pre-gridded emissions to the PNW-CMAQ 4.0 km model domain and projection
- Exported as annual ORL point source format for SMOKE
- Flat temporal profile (365/24/7) assumed



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Marine Emissions Inventories CORBETT Inventory

Gridded annual
 SO_x emissions
clipped to edge of
MCTSA (purple
outline)





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Marine Emissions Inventories Puget Inventory

- Developed by Starcrest Consulting Group for Puget Sound Maritime Air Forum
- Emissions by vessel name and coordinate
- Annual emissions SO_x , NO_x , CO, PM, HC, N_2O , CH_4 , CO_2
- No timestamps / temporal information
- Common coordinates (i.e., several records per location) resulting in localised “hot-spots”
- Lat/Lon coordinate pairs overlaid onto model grid
- Exported as annual ORL point source format for SMOKE
- Flat temporal profile (365/24/7) assumed



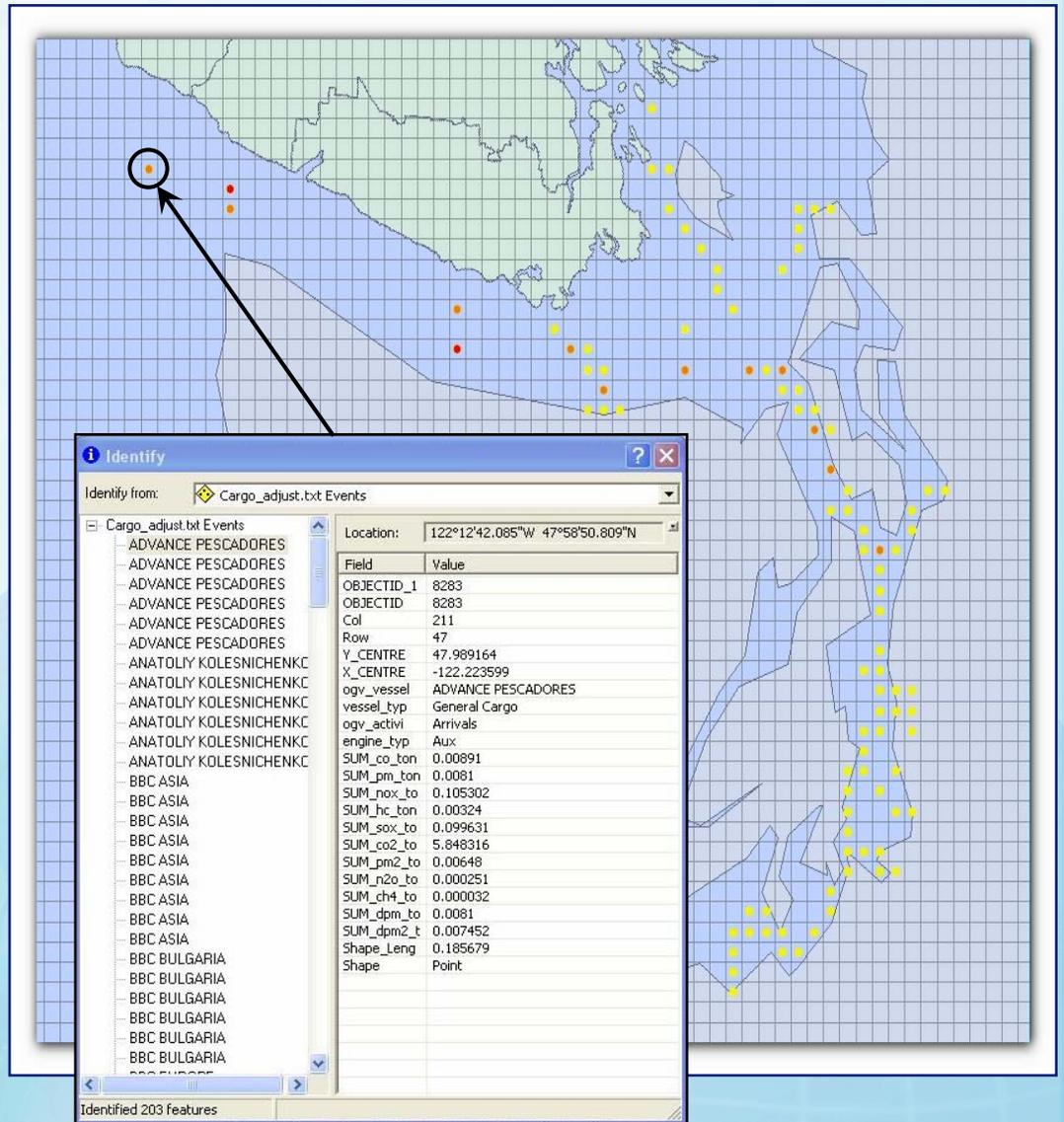
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Marine Emissions Inventories PUGGET Inventory

Annual SO_x emissions (raw points)

Few unique locations and large distances between points

Multiple ships on multiple voyages summed into annual emissions over a small number of grid cells





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Marine Emissions Inventories Chamber of Shipping (COS)

- Compiled by BC Chamber of Shipping in collaboration with Environment Canada, Greater Vancouver Regional District, and other stakeholders
- All ocean waters within the Marine Communications & Traffic Services Association (MCTSA), ~50 M offshore
- All commercial deep-sea vessels 20 m and longer that called at a BC port from April 1, 2005 to March 31, 2006
- Totals: 1,428 ships comprising 3,565 voyages
- Based on Coast Guard tracking data of vessel location and speed at **3-7 minute intervals!**



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Marine Emissions Inventories Chamber of Shipping (COS)

- Vessel tracking data used to compute location, time in mode, main engine load factor per segment travelled, etc.
- Engine loads and emissions computed at terminus of each segment (i.e., destination vertex)
- Vessel surveys for engine, boiler, and fuel characteristics
- Auxiliary engine power and load factors, boiler fuel use, and fuel sulphur content all determined from surveys
- Lloyd's Register used to compute main engine power
- Emissions computed every 3-7 minutes for SO_x , NO , N_2O , VOCs, PM_{10} , $\text{PM}_{2.5}$, NH_3 , CH_4 , CO , and CO_2

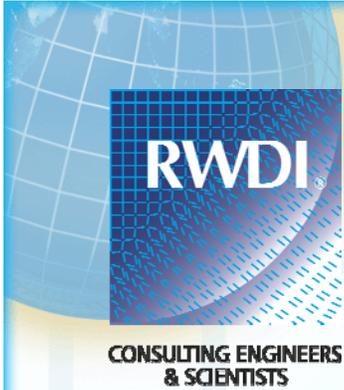
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Marine Emissions Inventories Chamber of Shipping (COS)



- Raw dataset (4.0+ Gb ASCII file with >4.0 Million elements) imported into SQL Server
- Separate tables created by month and vessel activity
- Migrated into ArcGIS as enterprise geodatabase
- Ship locations overlaid onto model grid
- Emissions summed by grid cell by hour for each Voyage



Marine Emissions Inventories Chamber of Shipping (COS)

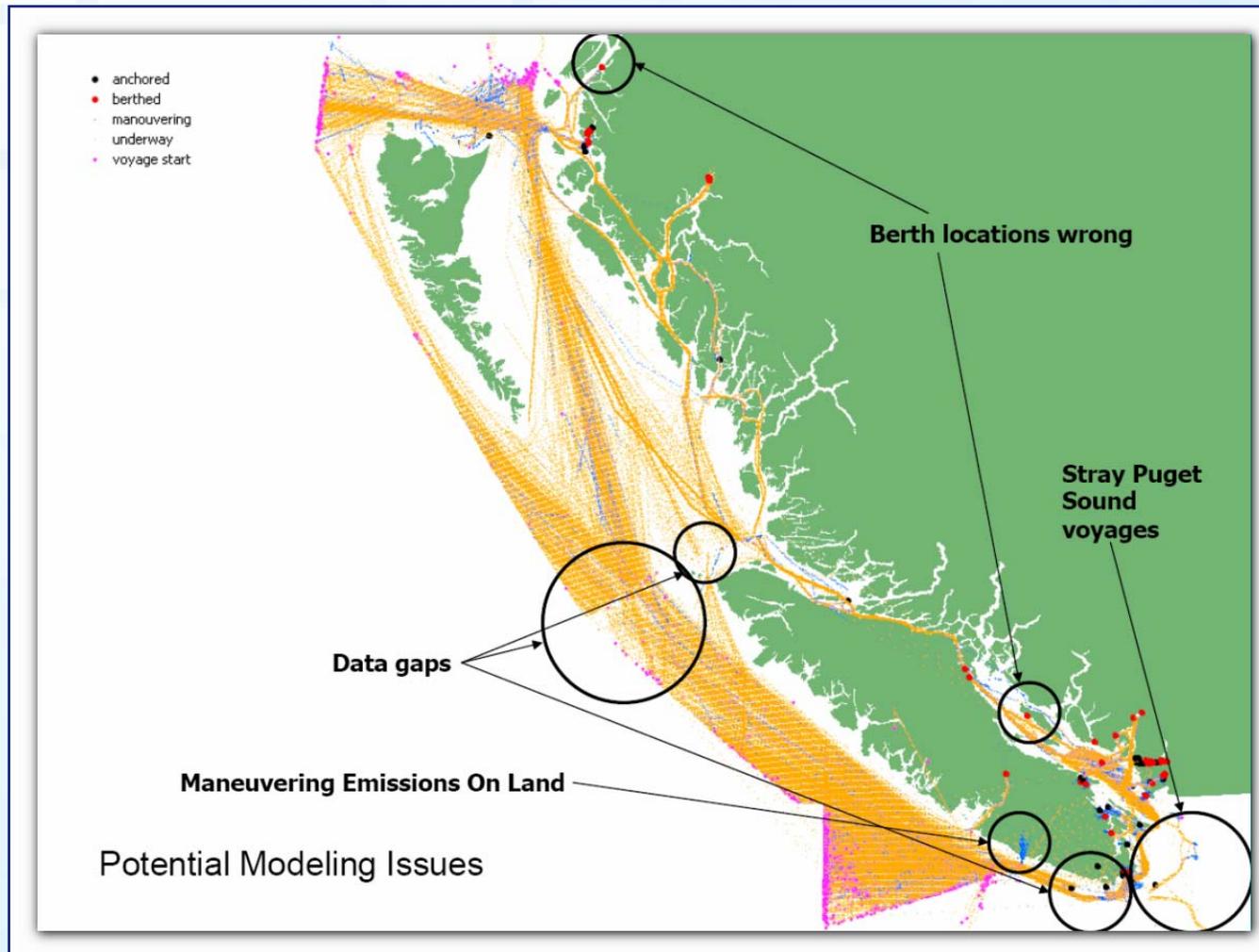
- Emission scenario changes (e.g., switch to 0.1% fuel sulphur content within 50 M of shore) unique by:
 - Location
 - Vessel Type / Engine Class
 - Bulk Carrier, Container, Cruise Ship, Cargo, Motor Vehicle Carrier, Tanker, Misc
 - Vessel Activity
 - Manoeuvring, Underway, Anchored, Berthed
- All emissions summed by grid cell for each hour
- Grid cell centres used as stack coordinates
- Program developed to export hourly emission files (EMS-95 CEM format, one file per day) for input to SMOKE

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Marine Emissions Inventories Chamber of Shipping (COS)

Lots of data sometimes means lots of problems...

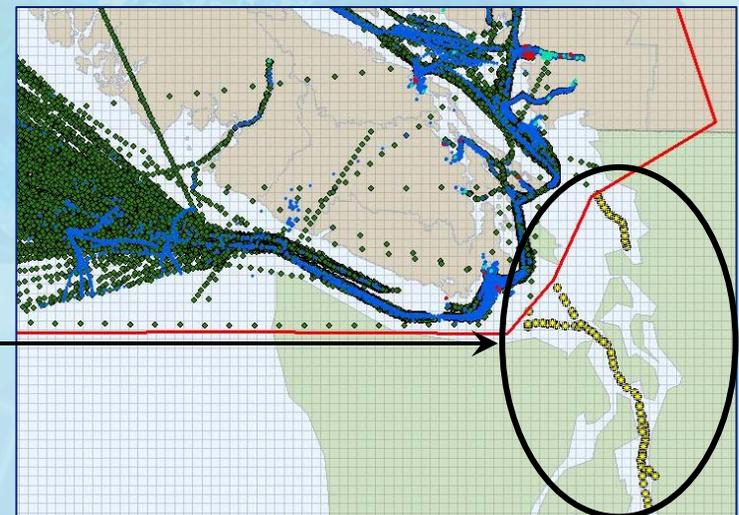
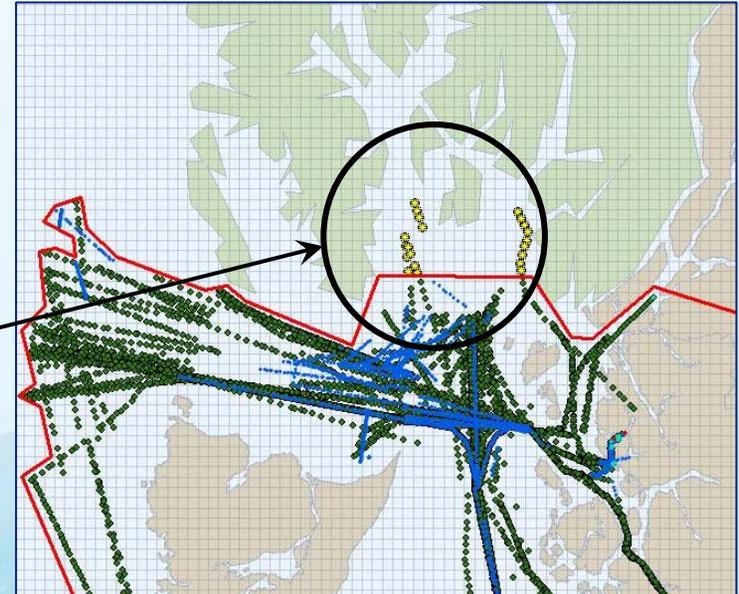
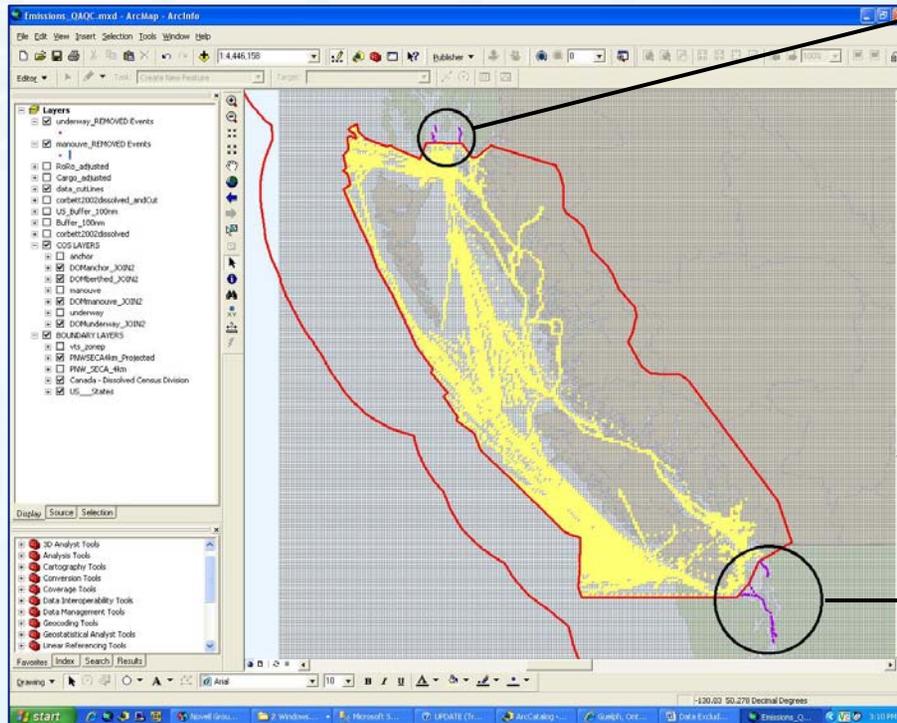


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Marine Emissions Inventories Chamber of Shipping (COS)

Overlapping inventories manipulated to
avoid double counting...





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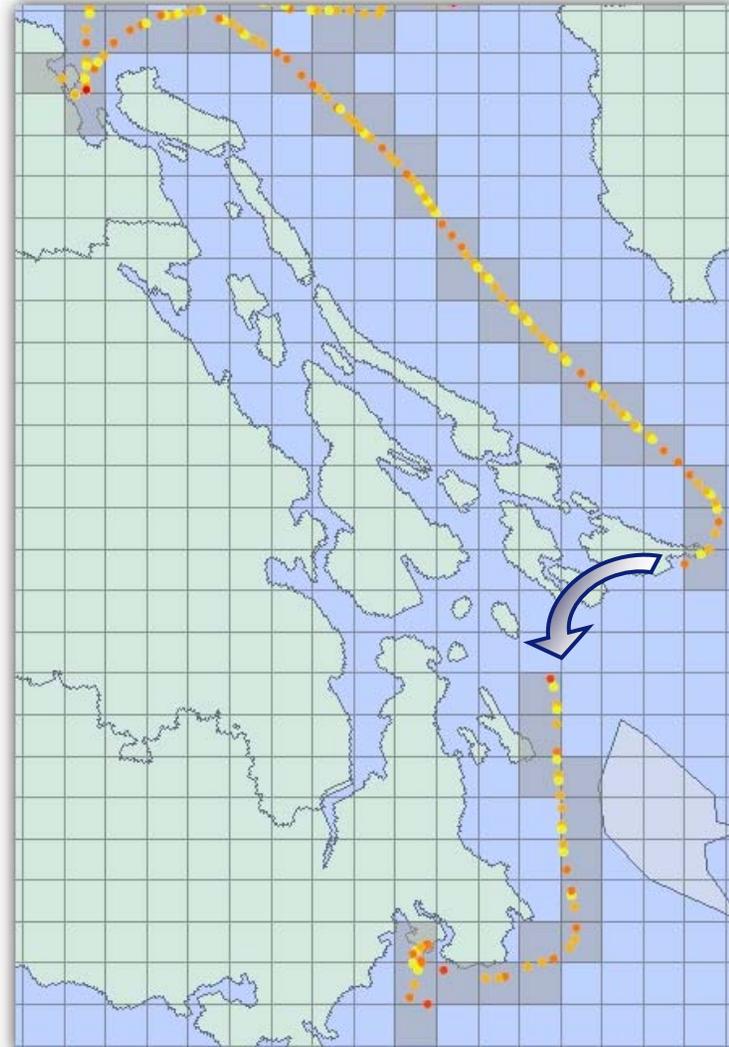
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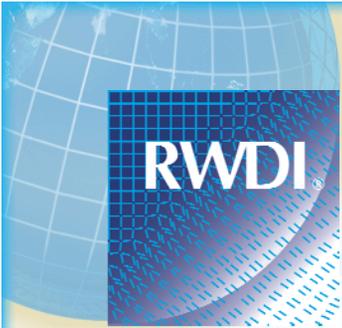
Marine Emissions Inventories Chamber of Shipping (COS)

Point by point SO_x emissions from a single “underway” vessel / voyage combination from the COS inventory

Most grid cells contain several individual emission records (points)

Emissions from “gaps” where the tracking signal was “lost” en route are collapsed into the next vertex for that voyage (by sequential timestamp), resulting in local hotspots



The logo for RWDI (Consulting Engineers & Scientists) features a blue globe with a grid pattern on the left and a blue square with a white grid pattern on the right containing the letters 'RWDI' in white.

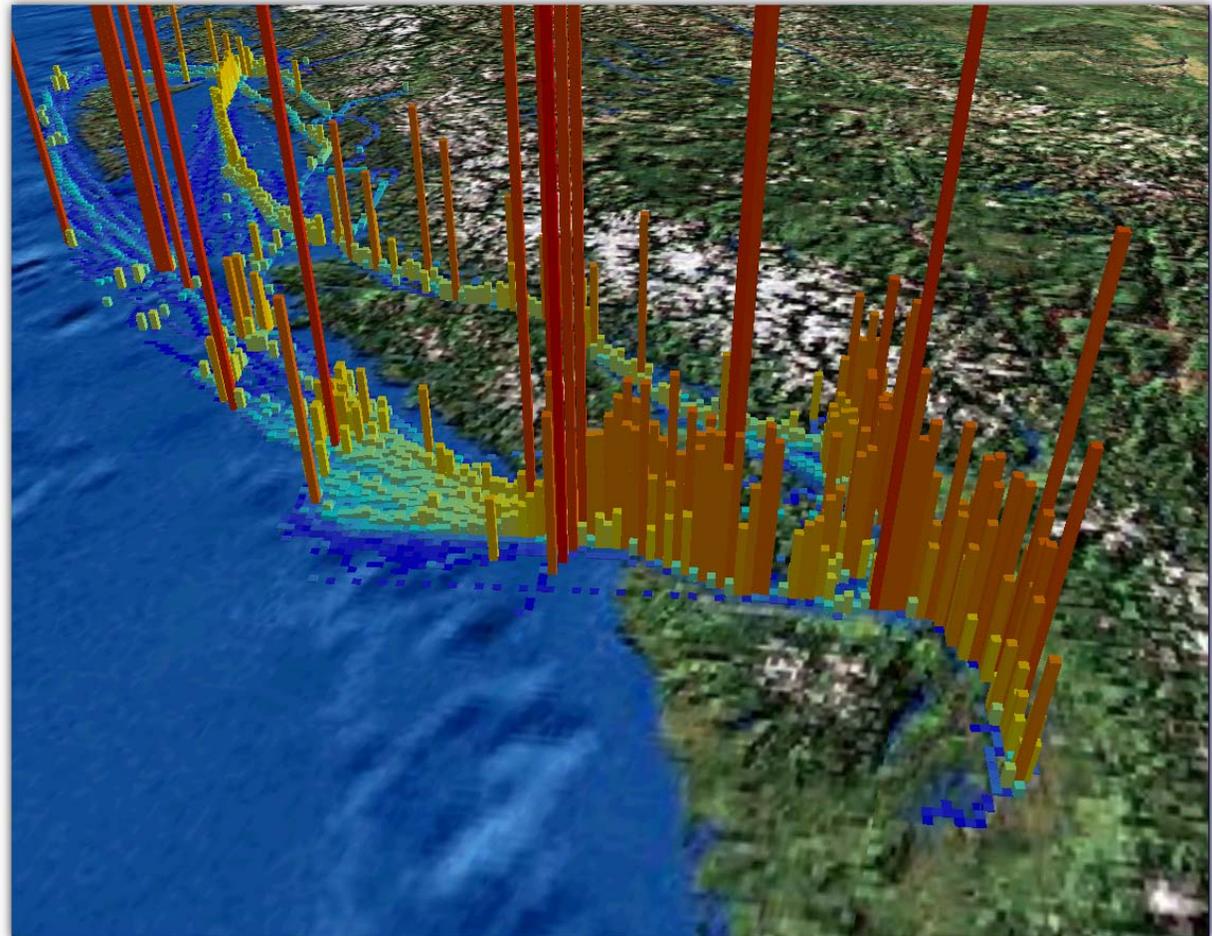
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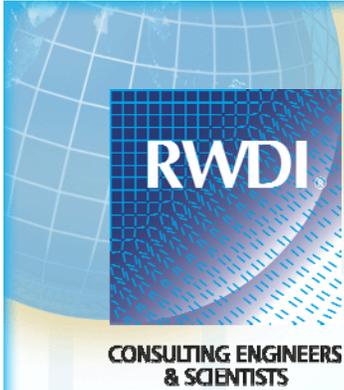
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Marine Emissions Inventories Chamber of Shipping (COS)

3-D representation
of SO₂ emissions for
a single month from
the pre-processed
2005 COS inventory

Note the spatial
distribution of
emissions and local
“hotspots”





Marine Emissions Inventories SMOKE Modelling

Stack Parameters used in SMOKE (from EC/CARB/ EPA)

- Stack Height: 20.0 m (65.6 ft)
- Stack Diameter: 0.80 m (2.6 ft)
- Gas Exit Velocity: 25.0 m/s (82.0 fps)
- Gas Exit Temperature: 282 °C (539.6 F)

SMOKE recompiled to handle large number of point sources:

- Corbett = 11,794 point sources (annual emissions, flat profile)
- Puget = 142 point sources (annual emissions, flat profile)
- COS = 5,038 point sources with hourly varying emissions (equivalent of 120,912 sources per day)

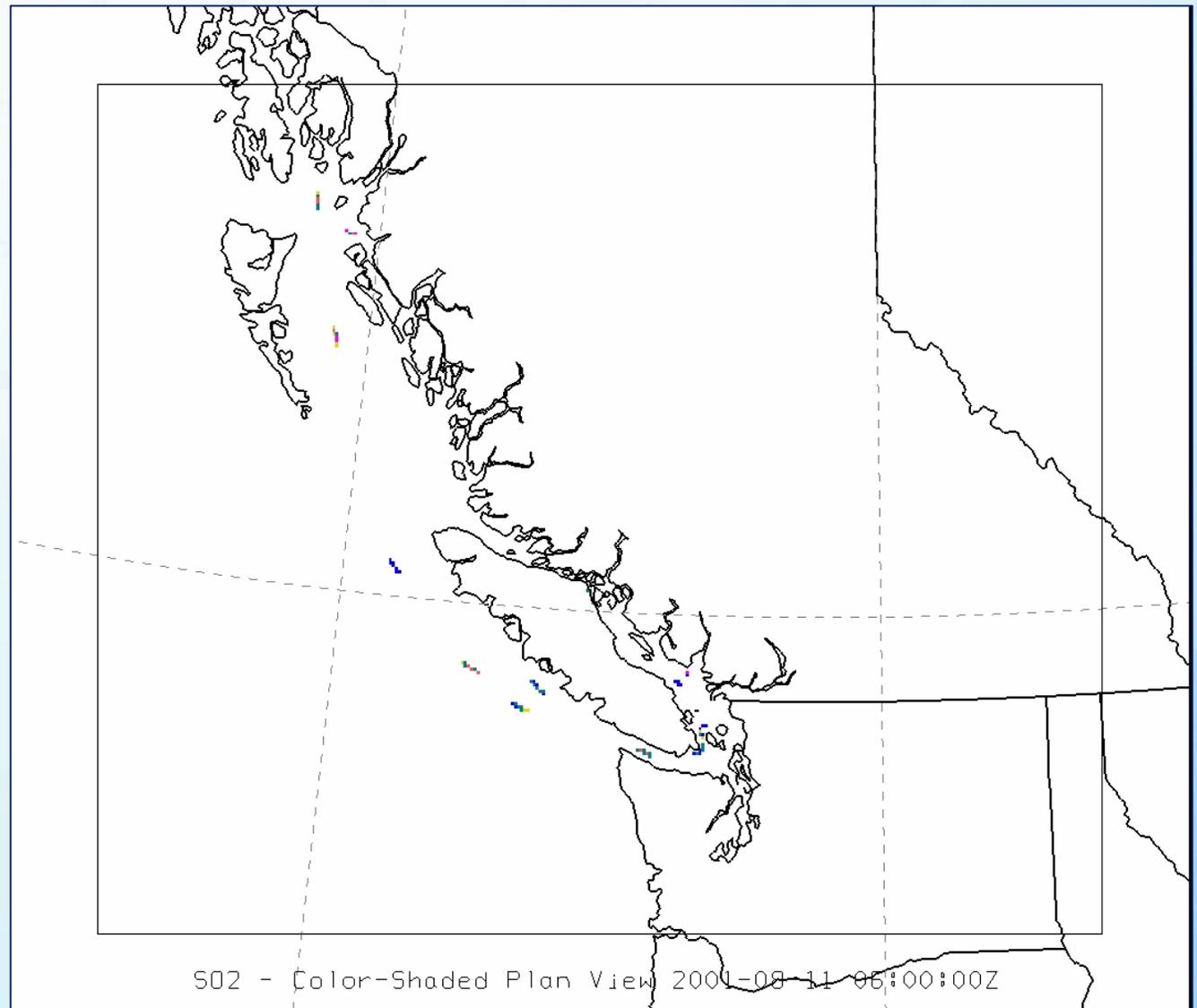
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Preliminary SMOKE Model Results Gridded SO₂ Emissions

SMOKE Outputs

- SO₂ Emissions
- COS only
- Underway
- Aug. 11, 2001
- Second vertical layer (~60m)
- Colours proportional to emissions



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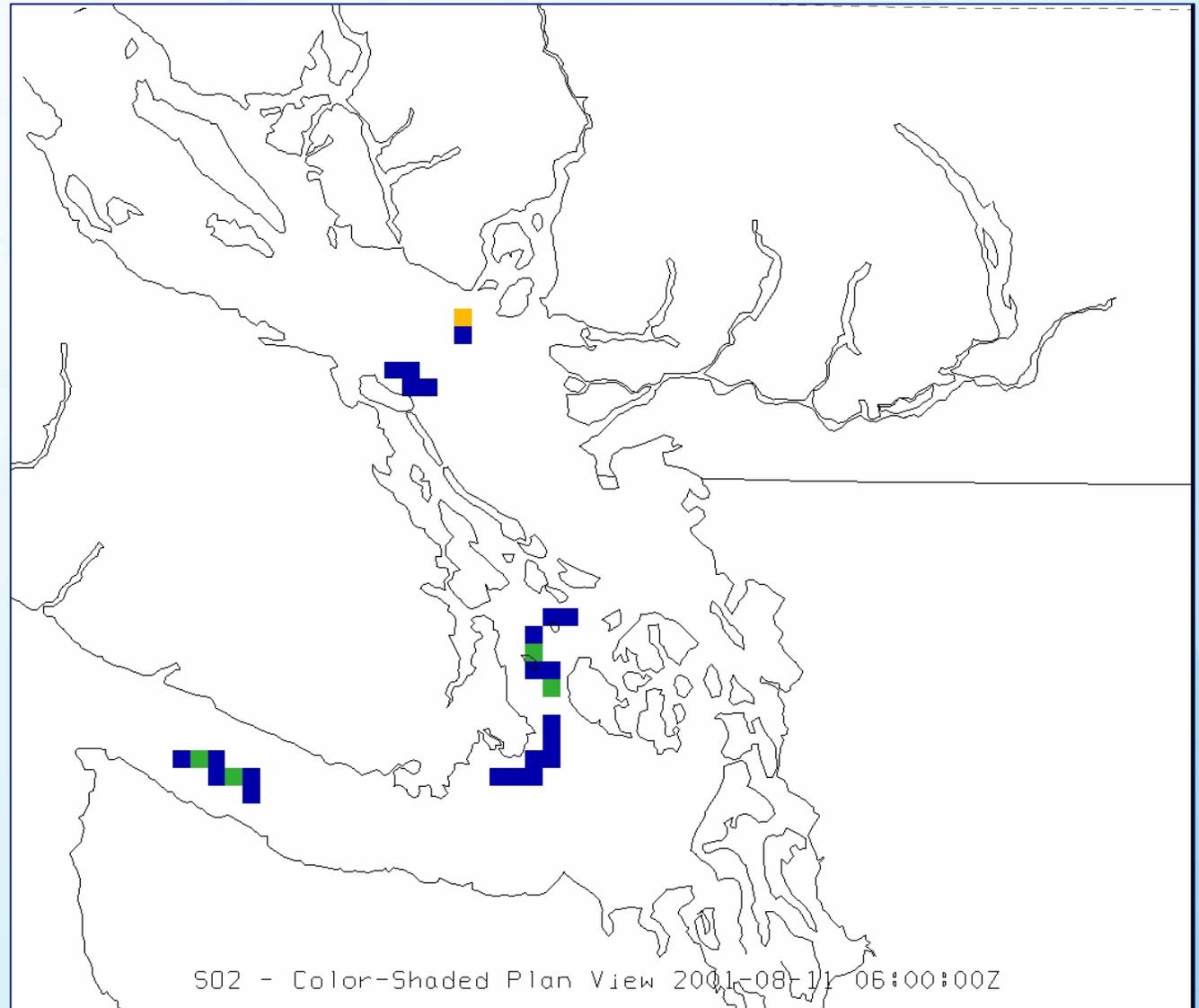
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Preliminary SMOKE Model Results

Gridded SO₂ Emissions

SMOKE Outputs

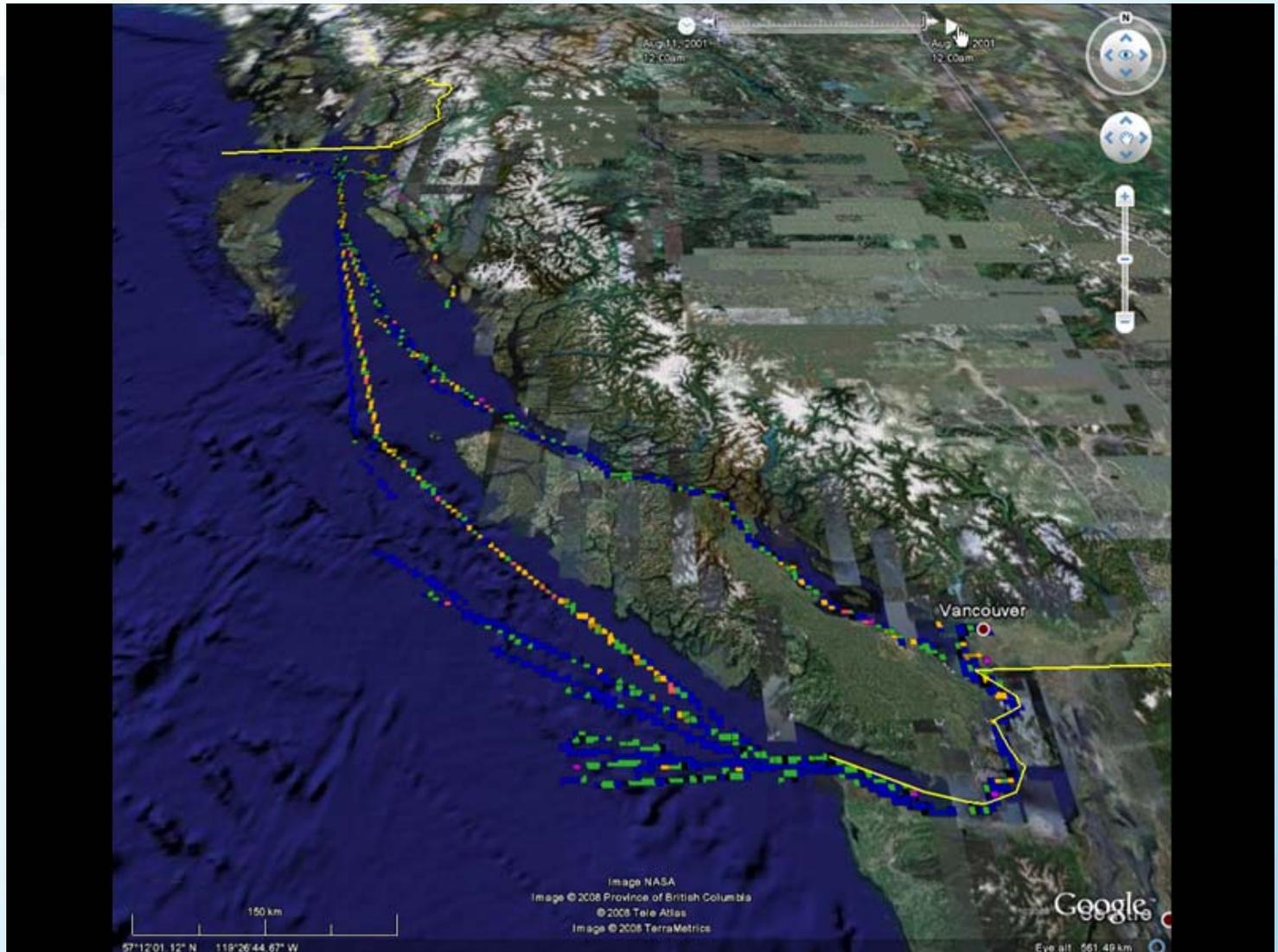
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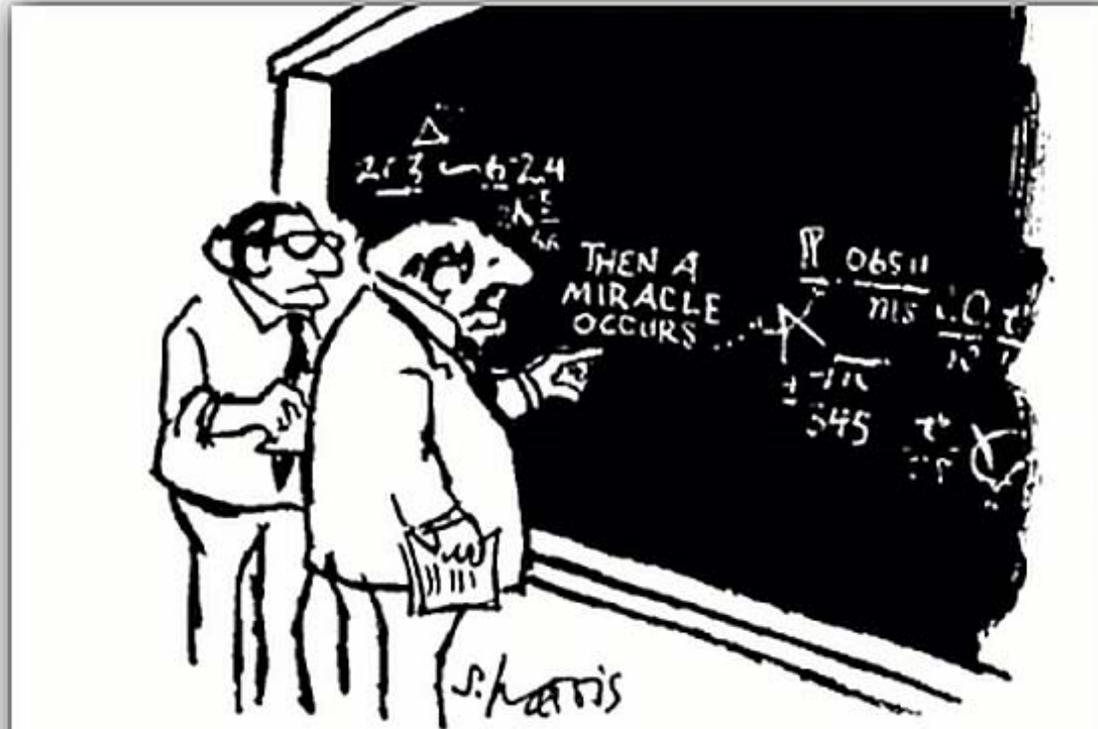
Preliminary SMOKE Model Results Gridded SO_x Emissions, Aug. 11



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Preliminary CMAQ Model Results...



"I THINK YOU SHOULD BE MORE EXPLICIT
HERE IN STEP TWO."

TO BE CONTINUED...



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Thank You!

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