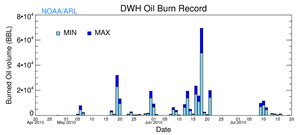
Modeling the Atmospheric Fate and Transport of Dioxin Emitted During *in-situ* Burning of Oil from the Deepwater Horizon Spill

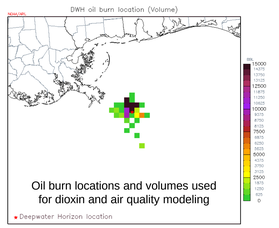
Mark Cohen, Roland Draxler, Richard Artz, Steven Fine, Hyun Cheol Kim, Daewon Byun
Air Resources Laboratory, Silver Spring, MD

Goal

Estimate the atmospheric deposition and ground-level air concentrations of dioxin resulting from the ocean-surface burning of oil from the Deepwater Horizon spill, to support a screening level assessment of health risks due to inhalation and due to consumption of dioxin contaminated seafood



Volume of oil burned each day in barrels



Oil burn locations and volumes used for dioxin and air quality modeling

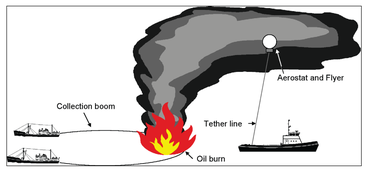
Above two figures from: Daewon Byun & Hyun Cheol Kim, *Controlled Oil Burn Data for the Deep Water Horizon Gulf Oil Spill*, NOAA ARL, 2010

Context

- As one of the methods to respond to the oil spill, 410 separate *in-situ* burns were carried out between April 28 and July 19, burning an estimated 222,000-313,000 barrels of oil (~5% of the total amount of leaked oil)
- Polychlorinated dibenzo-p-dioxins and furans (referred to as PCDD/F or "dioxin") are formed in trace amounts during combustion
- The presence of chlorine in the combustion environment can enhance PCDD/F formation
- The marine environment has relatively high levels of chlorine, and so there was concern that the oil burning activities might be releasing harmful levels of dioxin
- There are 209 different PCDD/F congeners; 2,3,7,8-TCDD is the most toxic and is one of the most potent carcinogenic compounds ever discovered

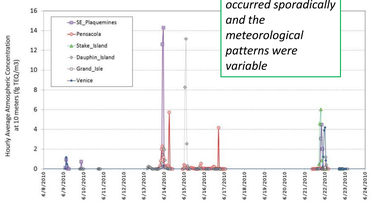
Approaches

- EPA measured dioxin in DWH-oil-burning plumes to estimate an emissions factor for *in-situ* oil burning
- ARL analyzed burn-by-burn data (relayed by NOAA NOS/OR&R) to create a dataset suitable for model input
- ARL assembled/archived/extracted gridded meteorological data for use in atmospheric dioxin simulations, including both ARL's regional modeling and EPA's near-field modeling
- ARL modeled the regional fate and transport of emitted dioxin, on a congener-specific and burn-by-burn basis, using a specially configured version of the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model designed to simulate the atmospheric fate and transport of *semi-volatile* pollutants such as PCDD/F (HYSPLIT-SV)
- EPA modeled the near-field dispersion of dioxin emitted from the burns with the AERMOD model to assess the inhalation exposure of workers in the immediate vicinity of the burns
- EPA used the air concentration results of the AERMOD and HYSPLIT-SV modeling to estimate the cancer risk due to dioxin inhalation as a result of DWH *in-situ* oil burning to nearby workers and the general public, respectively
- EPA used the atmospheric deposition results of the HYSPLIT-SV modeling as input to a marine food chain model to estimate dioxin concentrations in fish and cancer risk to the general public from fish consumption



Schematic illustration of the in situ burn operations and plume sampling

Figure 1 from Aurell and Gullett, *Aerostat Sampling of PCDD/PCDF Emissions from the Gulf Oil Spill In Situ Burns*, **Environ. Sci. Technol. 44**, 9431–9437, 2010



Ground-level dioxin concentrations were very episodic, because burns occurred sporadically and the meteorological patterns were variable

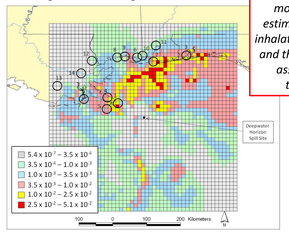
Hourly PCDD/F concentrations estimated by the HYSPLIT-SV model (at 10m) for June 8-24 at several locations in the Gulf of Mexico region resulting from dioxin emissions from *in-situ* oil burning

Accomplishments

PCDD/F emitted from oil-burning was successfully modeled using the HYSPLIT-SV model under a very time sensitive, evolving, multi-agency, high-priority situation with potential public-health consequences

● *Ground-level air concentrations of PCDD/F were estimated throughout the region*

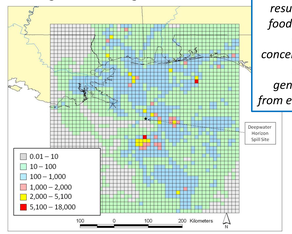
EPA used these model results to estimate on-shore inhalation exposure and the cancer risk associated with that exposure



Average modeled ground-level PCDD/F concentrations (fg TEQ/m3) from April 28 – July 22, 2010

● *Atmospheric deposition of PCDD/F was estimated throughout the region*

EPA used these model results as input to a food chain model to estimate dioxin concentrations in fish and risks to the general population from eating those fish

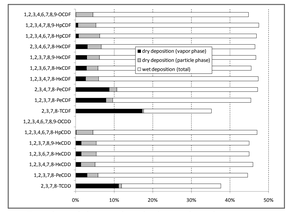


Total PCDD/F deposition flux (fg TEQ/m2) over the entire modeling period April 28 – July 22, 2010

Illustrative locations shown, numbered in descending order from highest to lowest average concentration (fg TEQ/m3):

1 – S.E. Plaquemines (0.019)
2 – Dauphin Island (0.016)
3 – Pensacola (0.012)
4 – Venice (0.0072)
5 – Stake Island (0.0069)
6 – Pascagoula (0.0011)
7 – Grand Isle (0.0010)
8 – Gulfport (0.00095)
9 – Biloxi (0.00066)
10 – Grand Bay NERR (0.00065)
11 – Mobile (0.00052)
12 – Slidell (0.00025)
13 – Houma (0.00018)
14 – New Orleans (0.00008)

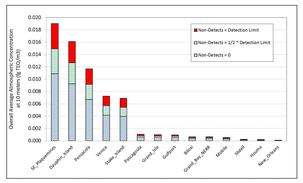
● *The modeling was done on a congener-specific basis, and results for the 17 toxic 2,3,7,8-substituted congeners were combined to produce summary results as Toxic Equivalents, using standard toxic equivalency factors; both dry and wet deposition were considered*



Fraction of the total emissions of each congener deposited over the *entire* modeling domain (the *entire* domain was 10^0 x 10^0, centered at the spill, twice as big as the 5^0 x 5^0 "results display" grid shown above)

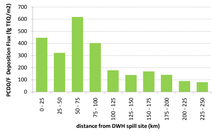
Different congeners behave differently due to variations in physical-chemical properties, including those that affect vapor-particle partitioning

● *The analysis produced results for different assumptions regarding the treatment of non-detects (ND's) in the emissions factor measurements, assuming ND=0, ND= 0.5 x Detection Limit (DL), and ND = DL*



Average modeled concentrations at 10 meter elevation for the entire modeling period at 14 selected locations in the Gulf of Mexico region

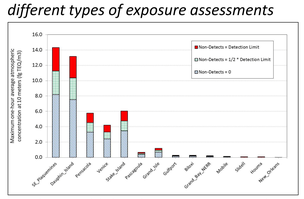
● *Numerous mass balance calculations were carried out – including the results immediately above and the two plots below -- to provide insights into the regional fate and transport of PCDD/F*



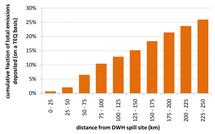
Average dioxin deposition flux (fg TEQ/m2) at different distances away from the DWH spill site

Due to plume rise, the highest average deposition flux occurred approximately 50-75 km away from the DWH spill site

● *Results were produced for different averaging periods -- e.g., 3 hrs, 8 hrs, 24 hrs, and for the entire duration of the burns – to support different types of exposure assessments*



Maximum modeled one-hour average concentrations at 10 meter elevation for the entire modeling period at 14 selected locations in the Gulf of Mexico region



Cumulative fraction of dioxin emissions deposited at different distances away from the DWH spill site

~25% of the emitted PCDD/F was deposited within 250 km of the DWH site

Indicators of Success

- The HYSPLIT–SV model has been used successfully in the past, e.g., Cohen, Draxler, Artz, et al (2002), Modeling the Atmospheric Transport and Deposition of PCDD/F to the Great Lakes, *Environ. Sci. Technol.* **36**, 4831
- Based on these previous successes and its ability to respond rapidly, NOAA ARL was asked by the USEPA to assist in this important analysis
- EPA utilized these HYSPLT-SV results in their screening level risk assessment
- The analysis underwent several independent peer reviews (both internal and external) and was recently published in ES&T

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Screening Level Assessment of Risks Due to Dioxin Emissions from Burning Oil from the BP Deepwater Horizon Gulf of Mexico Spill

JOHN SCHAUM,*,† MARK COHEN,‡ STEVEN PERRY,§ RICHARD ARTZ,‡ ROLAND DRAXLER,‡ JEFFERY B. FRITHSEN,∥ DAVID HEIST,⊥ MATTHEW LORBER,# AND LINDA PHILLIPS⊥

U.S. EPA, Office of Research and Development, Washington, D.C., United States, †U.S. EPA, Office of Research and Development, Research Triangle Park, North Carolina, United States, and NOAA, Air Resources Laboratory, Silver Spring, Maryland, United States

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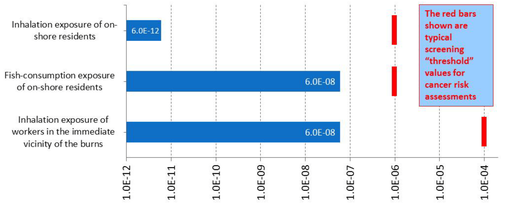
Upper-bound lifetime incremental cancer risk



The results of this screening analysis suggest that the risks from dioxin exposure from the oil burning activities were less than typical threshold values of concern

Collaborators/Partners

- *USEPA Exposure Analysis and Risk Characterization Group*, National Center for Environmental Assessment, Office of Research and Development, Washington DC (John Schaum, Jeffrey B. Frithsen, Matthew Lorber, and Linda Phillips)
- *USEPA Atmospheric Modeling and Analysis Division*, Office of Research and Development, Research Triangle Park, NC (Steven Perry, David Heist, S.T. Rao)
- *NOAA Office of Response and Restoration* (ORR)
- *NOAA National Centers for Environmental Prediction* (NCEP)

P. Anastas, C. Sonich-Mullin, and B. Fried (2010). Designing Science in a Crisis: The Deepwater Horizon Oil Spill. *Environ. Sci. Technol.* **44**, 9250-51

J. Aurell and B. Gullett (2010). Aerostat Sampling of PCDD/PCDF Emissions from the Gulf Oil Spill In Situ Burns. *Environ. Sci. Technol.* **44**, 9431–9437

Future Directions*

- ARL will carry out sensitivity analyses to examine the influence of key uncertainties on model results
- ARL will extend the HYSPLIT-SV model to simulate Polycyclic Aromatic Hydrocarbons (PAH's) and use this tool to assess exposure to PAH's as a result of oil burning activities
- ARL will evaluate the HYSPLIT-SV model further by additional comparisons against ambient dioxin measurements
- ARL will continue technology transfer and collaboration with Mexican government and academic scientists in applying the HYSPLIT-SV model to simulate atmospheric dioxin in Mexico
- ARL will extend the HYSPLIT-SV model to include a multi-media terrestrial and aquatic surface layers
- ARL will use the new Global Eulerian Model (GEM) capability of HYSPLIT (and HYSPLIT-SV) to simulate the global fate and transport of semi-volatile pollutants such as dioxin

** Depending on funding levels*