

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

# 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



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

#### 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 burnby-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

#### 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



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



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



Average modeled ground-level PCDD/F concentrations (fg TEQ/m3) from 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) 8 Gulfport (0.00095)
- 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)

- 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 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

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

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• 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

behave

due to

partitioning

Due to plume

average

occurred

spill site

~25% of the

PCDD/F was

within 250 km

of the DWH site

deposited

emitted

rise, the highest

deposition flux

approximately

50-75 km away

from the DWH



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

• 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



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

## Indicators of Success

- The HYSPLIT–SV model has been used successfully in the past, e.g., Cohen, *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 in ES&T

### **Collaborators/Partners**

- USEPA Exposure Analysis and Risk and Linda Phillips)
- Heist, S.T. Rao)
- Prediction (NCEP)

#### **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

Draxler, Artz, et al (2002), Modeling the Atmospheric Transport and Deposition of PCDD/F to the Great Lakes, Environ. Sci.

independent peer reviews (both internal and external) and was recently published







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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

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• NOAA Office of Response and Restoration (ORR) NOAA National Centers for Environmental

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). Aerosta Sampling of PCDD/PCDF Emissions from the Gulf Oil Spill In Situ Burns Environ. Sci. Technol. 44, 9431–9437

| Aerostat Sampling of PCDD/PCDF<br>Emissions from the Gulf Oil Spill In  | undertaken to quantify the emissions from in situ burns,<br>most comprehensive at-sea effort being the Newfoundla<br>offshore burn experiments (2). Particle and gas concent  |
|---|---|
| Situ Burns  | tions sampled by aircraft-borne instruments were develop<br>into emission factors (3) using a carbon balance approa<br>(mass of pollutant per mass of fuel carbon). Other measu   |
| IOHANNA AURELL'AND<br>BRIAN K. GULLETT'''<br>AUS. Environmental Protection Agency, Office of Research<br>and Development, National Risk Management<br>Besearch Laboratory, Research Thangle Park,<br>North Carolina 27711, United States  | ments were made using samplers aboard remotely control<br>marine vessels and techered aerostats (4).<br>Emissions of polychlorinated diberuzodioxins and po<br>chlorinated diberuzodurans (IPCD)/PCDF from the oil buu<br>are of interest due to their health effects (5) includi<br>immunotoxicity, carcinogenicity, and teratogenicity. T<br>potential for PCDD/PCDF emissions from the Gulf in 3<br>uurus exists due to the apparent presence of the perrequisi  |
| Received October 21, 2010. Revised manuscript received<br>October 28, 2010. Accepted October 28, 2010.  | conditions for formation: incomplete combustion, the pr-<br>ence of trace metals as catalysts, and availability of chlori<br>in the seawater. Few measurements of PCDD/PCDF ha<br>been made from oil fires and only one (2) to our knowled  |
| Emissions from the in stu, burning of oil in the Guif of Mexico dark the castsorphic failure of the Depender Horizon drilling platform were samplelefor golychlornated dihexcolosions and polychlornated dihexcolosions matches and polychlornated dihexcolosions matches of the source a particle of for dark via a tathered aurosate to ottermine and characteristic emissions of PCOD. The dark of the source source of the source source source matches source sou | from an ac-sea burn similar to those of the Call'In situ burn<br>lesulus from toos samples at sea level ever reported<br>indistinguishable from background levels, leading to c-<br>conclusion that CDD/PCDF even to forms different of<br>parts (6, 7). Similar conclusions were reached duri<br>performental, nenoscale hums; (6) when ground-base<br>in both of these cases the PCDD/PCDF sampling ware do<br>at sea/ ground beet, apparently outside of the visible plum<br>sequestions remain regarding their ability to resolve when<br>or not PCD/PCDF are formed.<br>To measure the potential emissions of PCDD/PCDF for<br>he Gall in situ of hums, an aerostat-lofted instrum<br>package was used to sample the plume emissions<br>factor.  |
| Introduction  | Materials and Methods<br>Aerostat Operations at Sea. A 4.0-m diameter, helium-fill  |
| The Desponter Horizon oil drilling platform located in the<br>Golf M Mexico. one and managed by Transoceanfor Bittish<br>Pertoleum (IIP), caught fire on April 20, 2010 and sark. Elseen<br>These were lost and the ensuing of local resulted in an<br>investment of the second of local results of the second<br>Gaust (USCG) and BP underbook operations to collect and<br>other through surfaced all holds, accoundanced on<br>Standar Tigniter' house placed an incredulary stanter charge<br>collection boom through surfaced all holds, accoundanced on<br>Standar Tigniter' house placed an incredulary stanter charge<br>acad thracy which the boom's oil good to promote egiption.<br>Under appropriate conditions of the oil and the seavistic<br>tate, the collected oil would gight be submitting that between<br>a stat here with the boom's oil good to promote egiption.<br>The state horizon of the USCG estimated that between<br>(1) in situ burns between April 28, 2010 and July 18, 2010<br>(2).   | aerostat (Singlisher model, Aerial Products Inc, FL) was us<br>to fol an instrument package termed the "Thypt" into<br>iso for an instrument package termed the "Thypt" into<br>anathed from the deck of the NV Allison /teise Corporation<br>Spectra telber. Tetheread aerostat flight operations we<br>conducted in accordance with regulations for moor<br>oil spill operations, several additional operational requi-<br>ments were coordinated with the Federal Aviation Admi<br>istration (FAA) and Incident Command Post (ICP). The<br>requirements included daily altitude restrictions, a dedicat<br>Advisory Frequency, and availability of a signal flare<br>necessary to visually alert aircraft to our presence. The F<br>published a daily Notice to Atrimen (NOTAM) advising pill<br>that tethered aerostat operations were hering, conduction<br>to the Deepwater Horizon source, any position changes<br>to the Deepwater Horizon source, any position changes<br>to the Deepwater Horizon source, any position changes<br>to the Deepwater Horizon source, any position changes |
| * Corresponding author e-mail: gullett.brian@epa.gov; phone:<br>(9)/95.541-1534; fax; (9)/95.541-0554.<br>* National Research Council? Post Doctoral Fellow to the U.S.<br>Environmental Protection Agency.<br>* U.S. EPA.  | unlikely event it became loose from its tether. Filling t<br>aerostat with helium and lofting the Flyer to the sampli<br>altitude took approximately 30 min. The MV Allison m<br>neuvered directly underneath the burn plumes, maintain<br>a distance of at least three to five burn diameters from t   |