Subsea Dispersant Injection (SSDI) minimized VOC Exposures to Surface Workers

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Background

- The 2010 *Deepwater Horizon* tragedy led to the prolonged release of oil at 1500 m some 66km from the Louisiana shoreline
- This led to substantial slicks and potential volatile organic vapors above the wellhead, where some 20 vessels were attempting to stop the flow by various means, including drilling interception wells
- Workers were protected by Industrial Hygiene guidelines that ensured they were not exposed to VOC levels >50ppm
- Subsea dispersant injection was initiated to minimize such exposure
  - By lowering interfacial tension between oil and water at the wellhead, dispersants would generate smaller oil droplets that rise more slowly, allowing more time for dissolution of VOC and potential drift from the area

The SIMOPS zone

- A 5 mile diameter area above the leaking wellhead was designated the SIMULTANEOUS OPERATIONS zone
  - Vessels drilling relief wells
  - Vessels attempting to plug the leaking well
  - Vessels maintaining ROV monitoring such work
  - Vessels spraying slicks with water or dispersant to minimize VOC
- Vessels equipped with Honeywell AreaRAE detectors
  - Non-specific photo-ionization (10.6eV; 117nm) of VOC larger than ethane
    - Report highest 15 min rolling average of each hour
- Individual workers equipped with Personal Breathing Zone monitors
  - Air drawn through a filter which is subsequently analyzed each shift

BP chose very conservative exposure limits

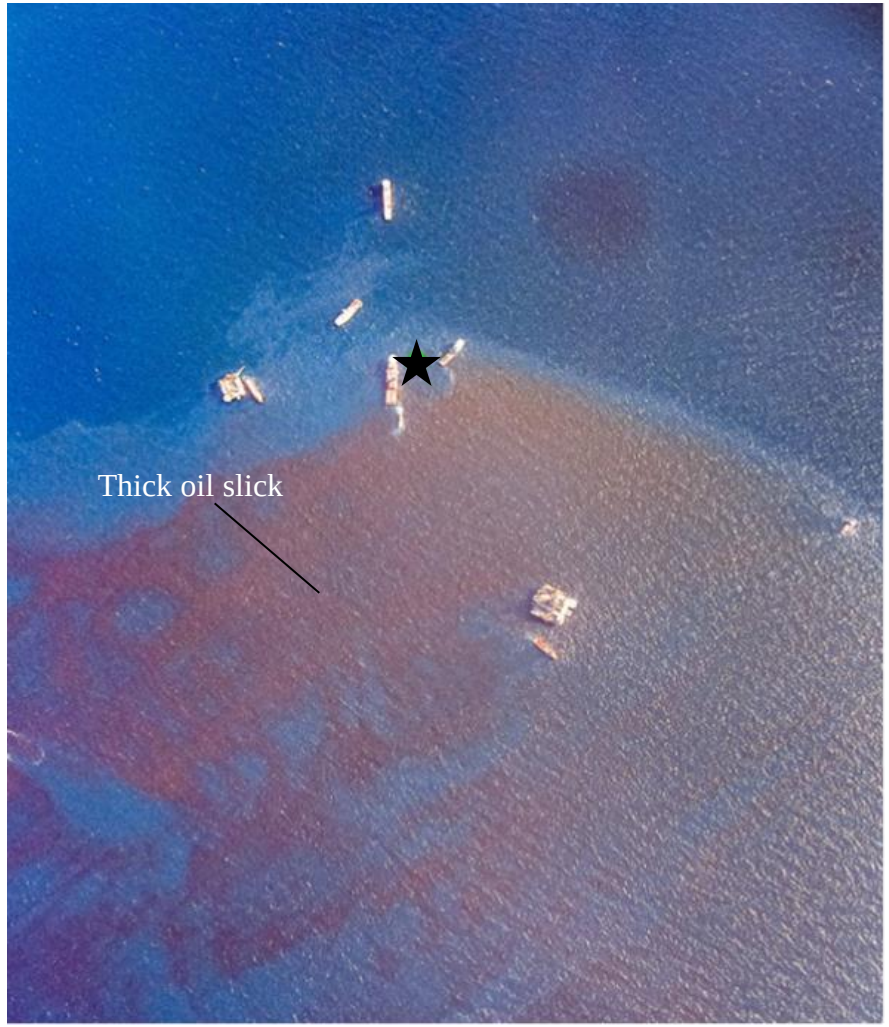
Agency	Recommended Exposure Limit (REL)	Permissible Exposure Limit (PEL)	Threshold Limit value (TLV)
National Institute for Occupational Safety and Health (NIOSH).	110 ppm		
Occupational Safety and Health Administration (OSHA)		620 ppm	
American Conference of Governmental Industrial Hygienists (ACGIH)			62 ppm
BP & NIOSH		50 ppm	

- Workers removed from topsides if PEL exceeded
  - Sheltered in place below decks

Aerial photographs before and after SSDI application

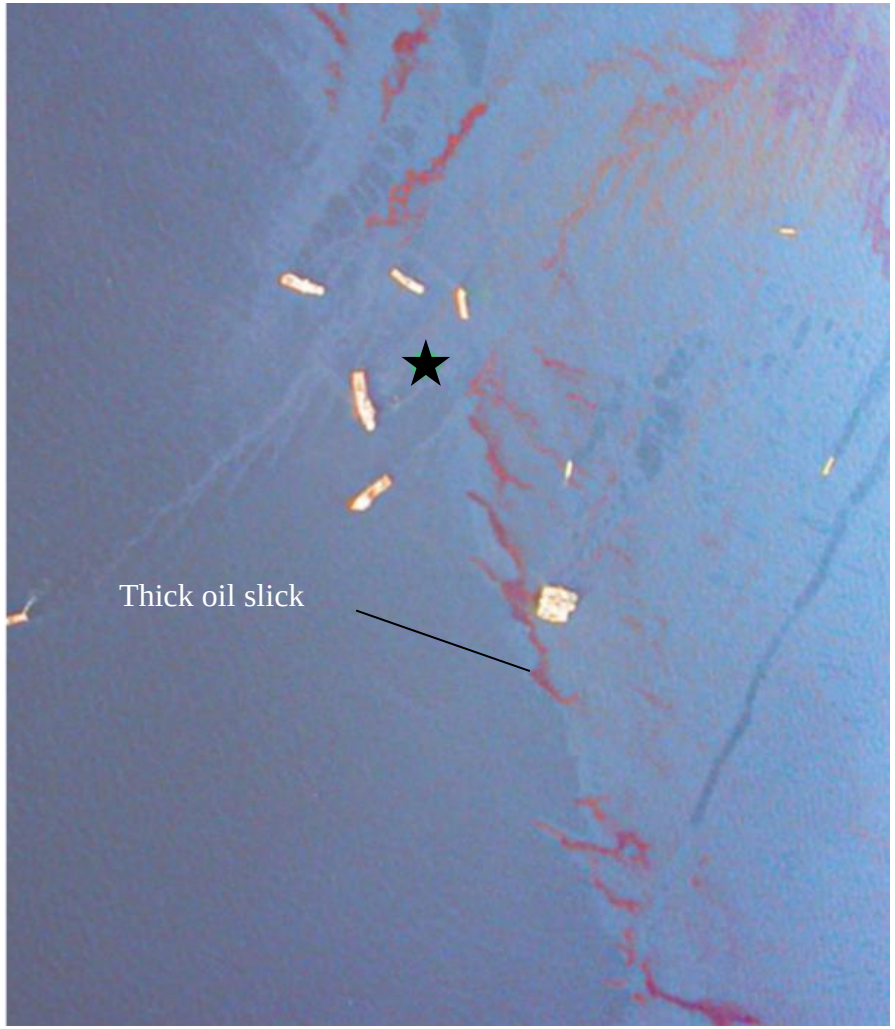
BEFORE SSDI

8:52 am (CST) on May 9, 2010



11 hr after SSDI initiated

5:05 pm (CST) on May 10, 2010



Source: Ocean Imaging Corp.

Data

- Publicly available

Title	Source (s)	No. data points	No. of zeros	Maximum value
SSDI rate	• https://data.gulfresearchinitiative.org/data/BP.x750.000:0018 • https://www.diver.orr.noaa.gov/documents/20233/39182/BP+Dispersant+Volumes+Logs.zip/6c33d118-b946-584b-3ece-d7b2e6b3a467	77 939	9 123	14.3 GPM[c] 24.4 GPM
AreaRAE VOC measurements	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0086261.	90294[a]	42130	2999 ppm
Personal monitoring VOC data	https://data.gulfresearchinitiative.org/data/BP.x750.000:0007	1272[b]	0	50 ppm
Weather data	https://www.ndbc.noaa.gov/download_data.php?filename=42040c2010.txt.gz&dir=data/historical/cwind/			
Ocean current data	https://www.ndbc.noaa.gov/station_page.php?station=42916			

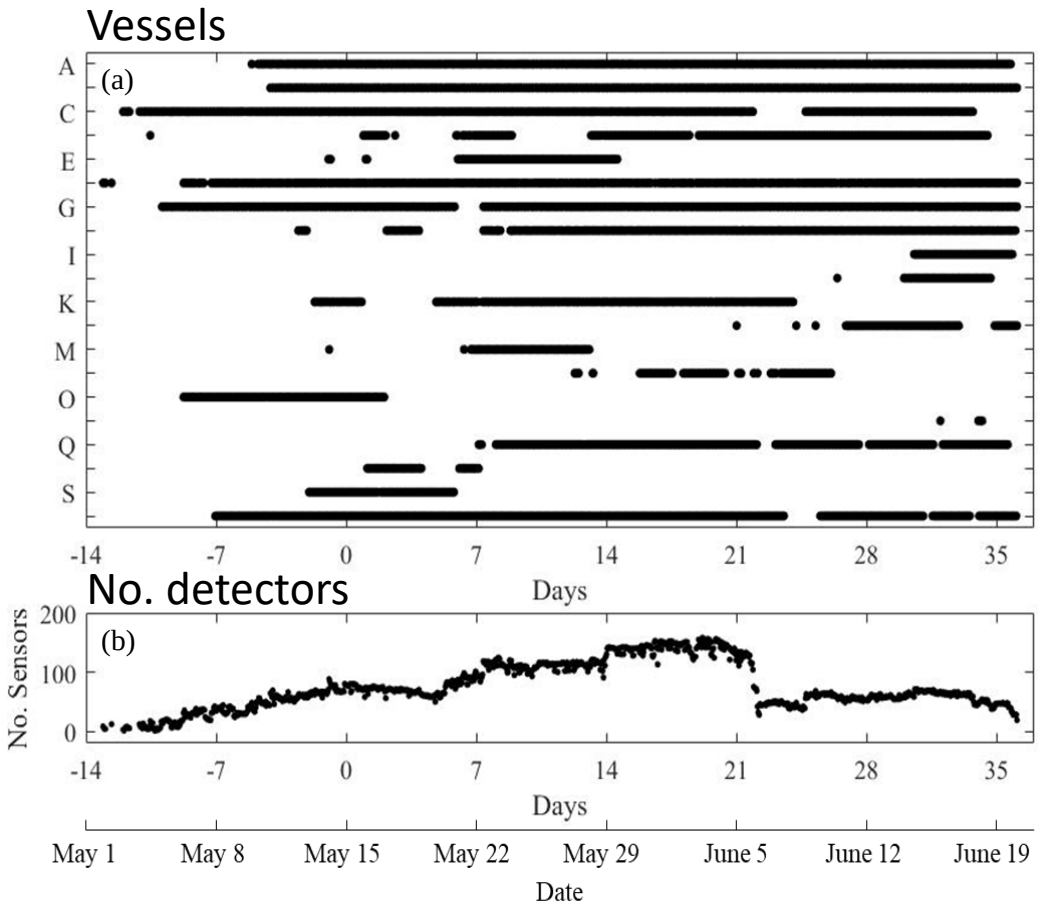
[a]Duplicates removed. [b]Data from within SIMOPS zone. [c]GPM represents gallons per minute.

Caveats

- The Deepwater Horizon tragedy was a spill of national significance:
  - "a spill that, due to its severity, size, location, actual or potential impact on the public health and welfare or the environment, or the necessary response effort, is so complex that it requires extraordinary coordination of federal, state, local, and responsible party resources to contain and clean up the discharge"

  - Data collection for anything other than immediate use was not the highest priority.
  - Nevertheless we found AreaRAE data BEFORE and AFTER SSDI was initiated
    - This was key to addressing whether SSDI was **effective**
    - Furthermore, SSDI was administered at varying rates, allowing us to address **dose-dependence**

AreaRAE Data



Identifier	Name	Primary Activity	Approximate Personnel	No. Area RAE detectors
A*	Development Driller 2	Drilling relief well 2	176	42
B	Development Driller 3	Drilling relief well 1	200	14
C	Discoverer Enterprise	Subsurface oil capture	200	52
D	Q4000	Top Hat operation	133	15
E	Blue Dolphin	Top Kill operation	50	8
F	Skandi Neptune	SSDI	50	18
G	Ocean Intervention III	SSDI	50	18
H	Rem Forza	VOC suppression	25	24
I	Tyler Stephen	VOC suppression	25	6
J	K Marine 7	VOC suppression	25	18
K	Monica Ann	VOC suppression	25	6
L	Helix Express	Riser Pipelayer	100	6
M	Stim Star 3	Subsea intervention	50	7
N	Seacor Vanguard	Subsea intervention	50	5
O	Ironhorse	Subsea intervention	50	6
P	Olympic Challenger	Subsea intervention	50	4
Q	Boa Deep C	Subsea intervention	50	12
R	Boa Sub C	Subsea intervention	50	4
S	Helix Producer 1	Subsea intervention	100	5
T	Energy 21 South Timbalier	standby	100	18

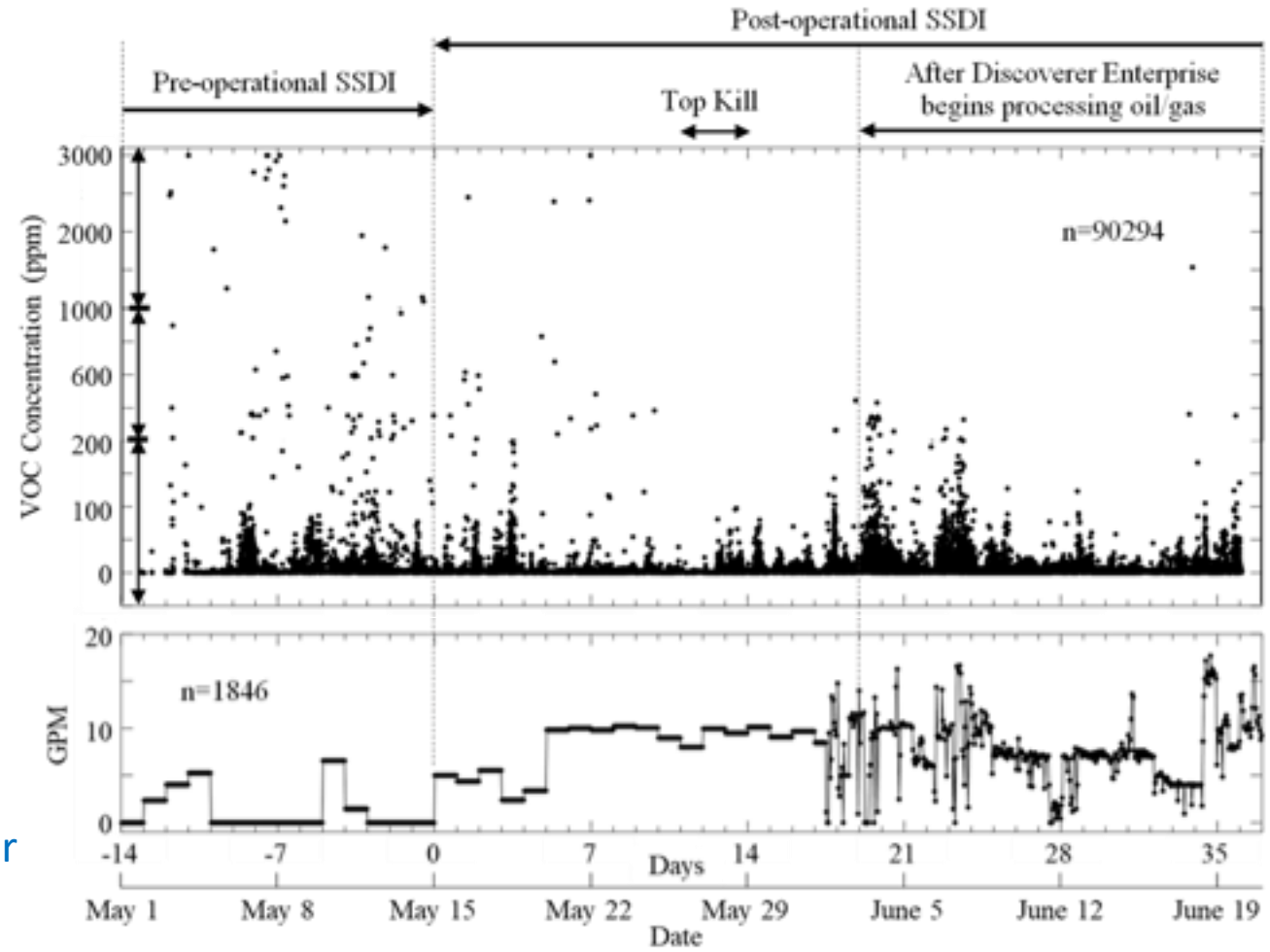
90294 data points
42130 were 0

About 1000 workers on any day

AreaRAE and SSDI Data

AreaRAE
ppm

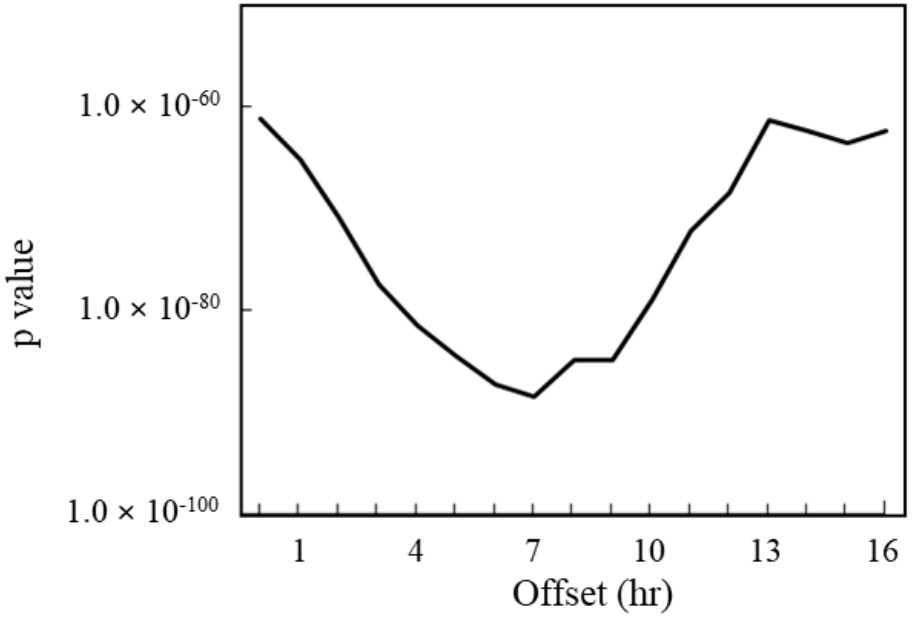
SSDI
GPM
actually plotted per hour



About 50% = 0

Droplet rise time

- SSDI rate measured at seafloor; AreaRAE measuring ambient air
  - How long before a change in SSDI rate is reflected in a change of VOC?
    - Group data into more or less than 6GPM
    - Apply an offset, and calculate the p-value of the difference
- Suggests rise time of untreated and undertreated oil was 7 hours
  - Reasonably concordant with other estimates
- All subsequent analyses offset VOC by 7hrs from SSDI



So what do the AreaRAE data tell?

- That VOC levels varied widely, and that average and mean values suggested minimal exposure that was decreased by SSDI

Event	Days	p value * (Kolmogorov-Smirnov)	Median	Mean	Standard Deviation	Fraction of VOC>50 ppm
All events						
Pre-SSDI	< 0	7.21×10^{-63}	0.103	15.78	142.33	3.45%
Post-SSDI	≥ 0	($VOC_{pre}>VOC_{post}$)	0.025	3.19	26.78	0.92%

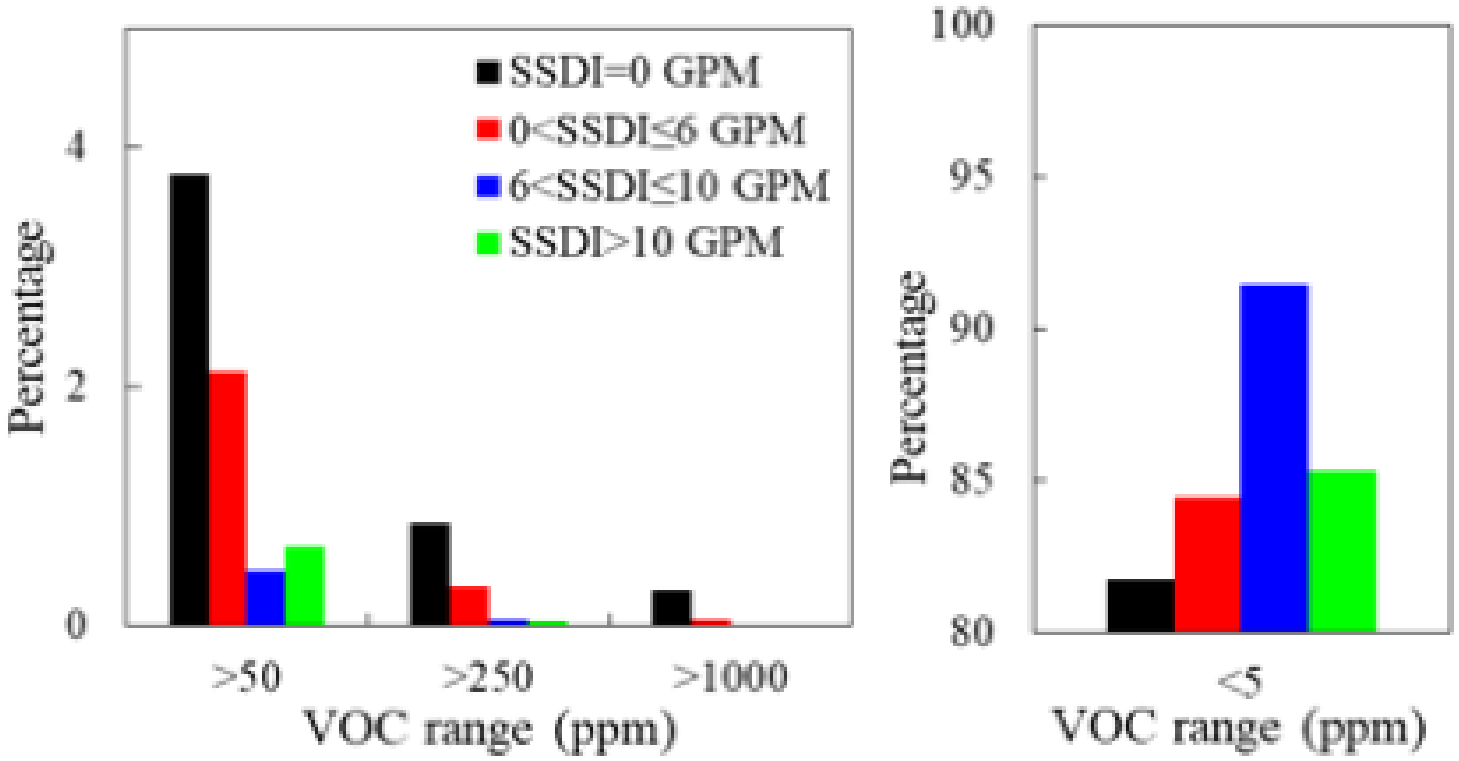
* Similar p-values were obtained after removing one vessel at a time from the data set

VOC were statistically significantly reduced during TopKill, and increased during gas flaring during the collection of oil and gas by the Discoverer Enterprise. These differences were much smaller than those associated with SSDI. For details see the Marine Pollution Bulletin paper in press (Zhao et al.)

- But means and medians are NOT the appropriate metrics for assessing exposure to toxicants
  - Rather it is exceedances of exposure limits that is germane

Exceedance of various levels of VOC

- All data, regardless of other operations

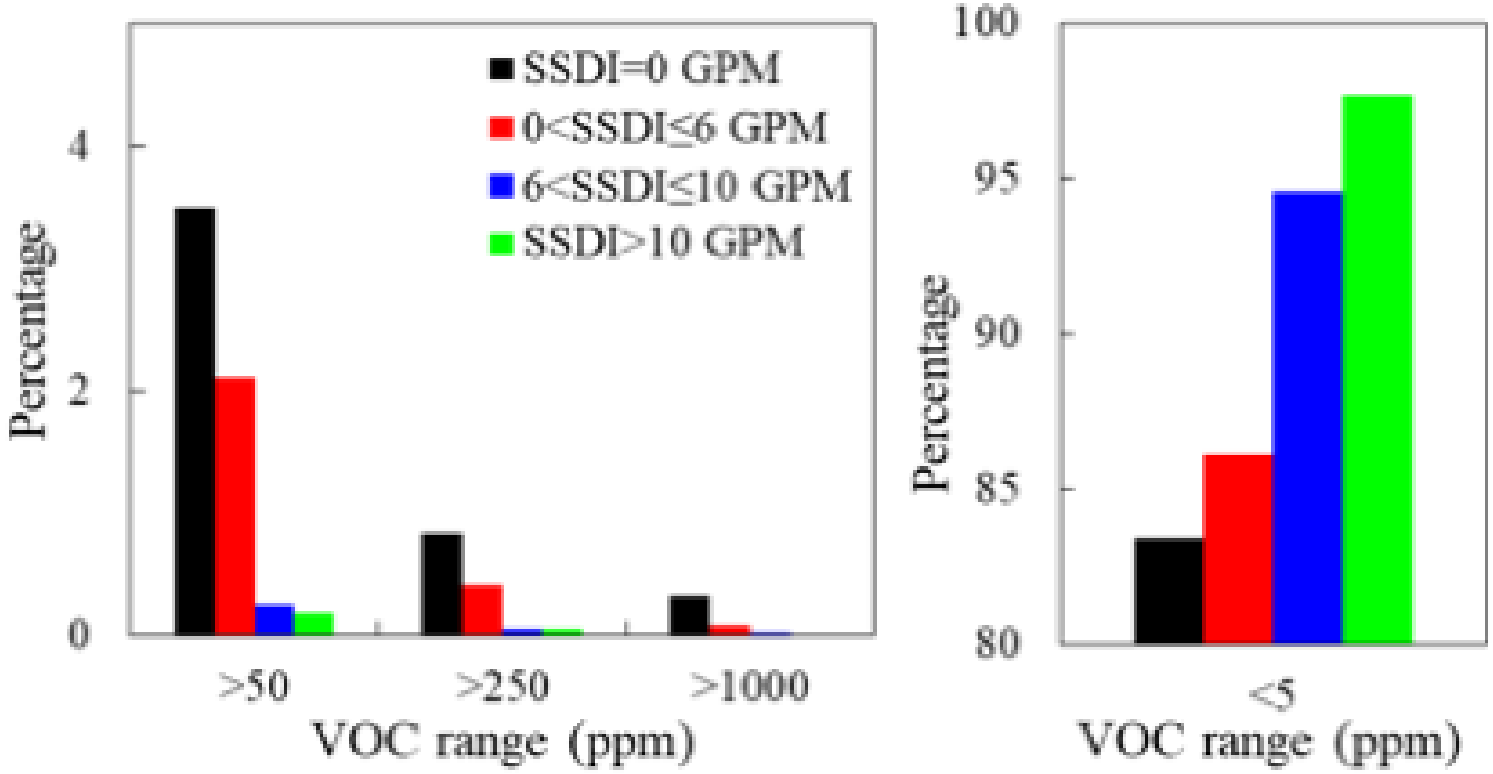


SSDI >10 GPM actually averaged 11.1GPM over 45 hours in the range of 10-16.5 GPM

- Note that reduction was not a trivial decrease, but a large effect

Exceedance of various levels of VOC

- Before oil and gas processing on *Discoverer Enterprise*



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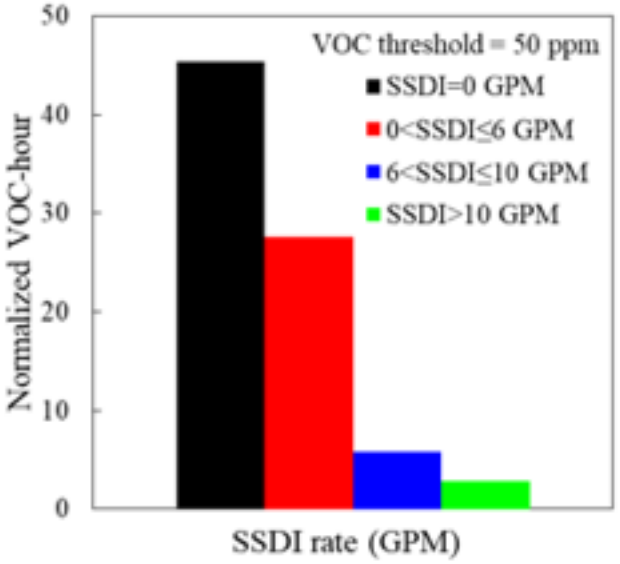
The concept of 'VOC-hours'

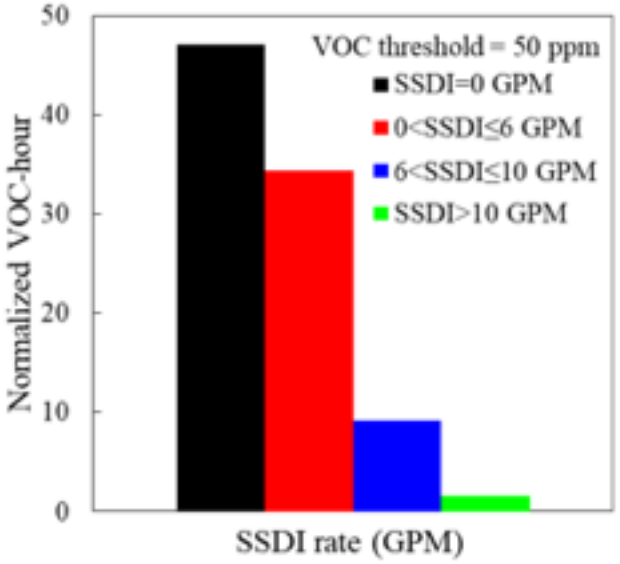
- Similar to 'degree-days' used in heating and cooling

All data



16-fold reduction

Before oil and gas processing on *Discoverer Enterprise*

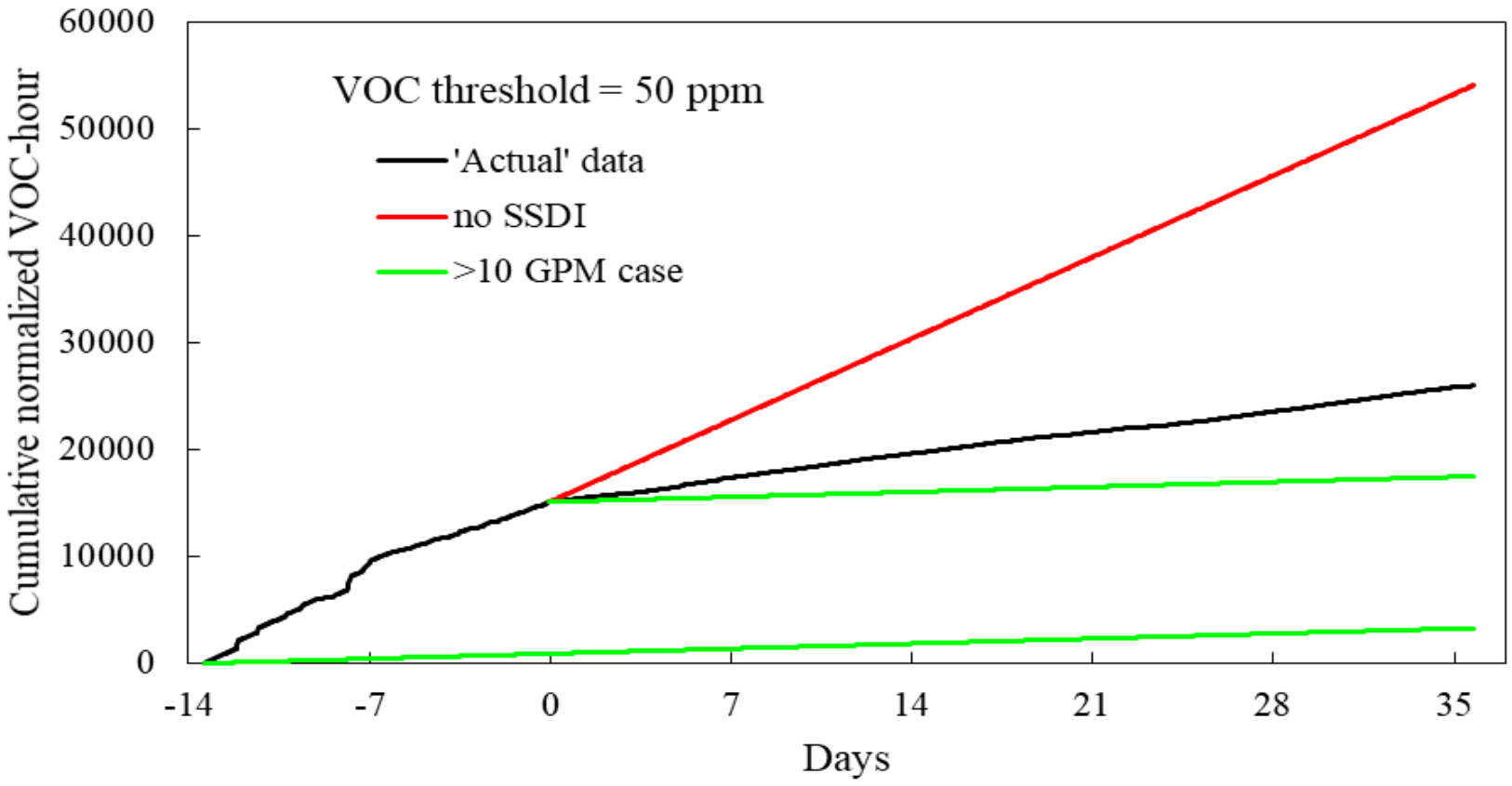


29-fold reduction

SSDI >10 GPM actually averaged 11.1GPM over 45 hours in the range of 10-16.5 GPM

What if SSDI had started earlier?

- Or more consistently?



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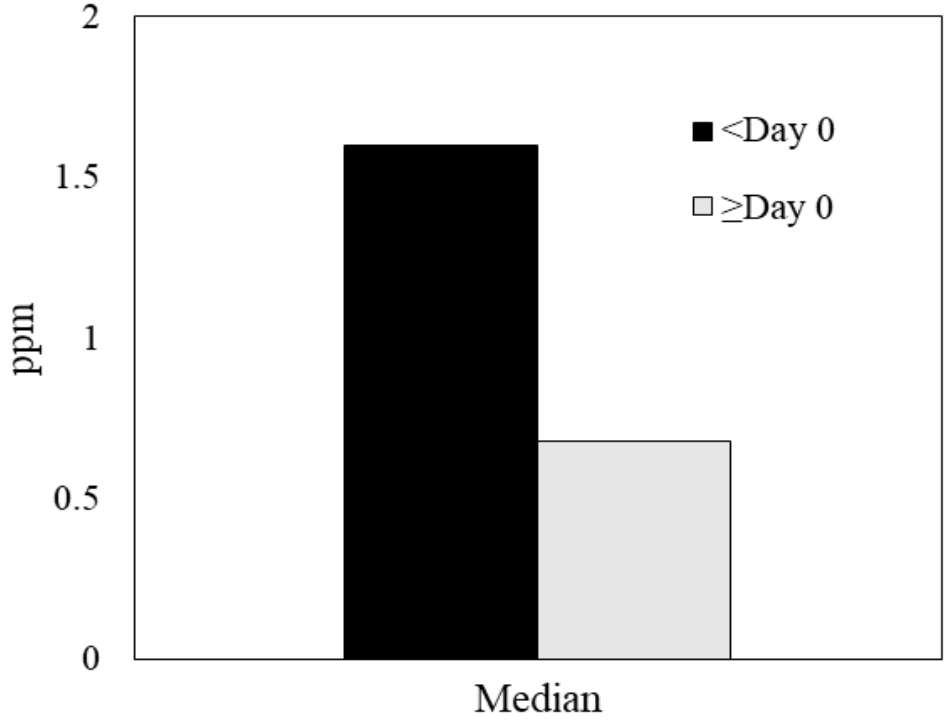
Personal monitoring data

- No personal monitoring data exceeded 50 ppm for the shift
  - Likely because workers sheltered in place when highest AreaRAE data were reported.
- Nevertheless, median exposures were lower when SSDI was operational



Summary

- Workers were protected from exposure to VOC
  - Regardless of SSDI
- SSDI significantly reduced VOC in the SIMOPS area
  - Exceedances of the 50ppm standard decreased by 29-fold when little flaring occurred
  - Even when gas was flared during oil and gas collection, SSDI decreased exceedances of the 50ppm standard by 16-fold.
- This meant that workers could work with fewer interruptions
- SSDI should be incorporated in response plans for deepsea blowouts

- Dispersion also likely substantially decreased the residence time of dispersed oil in the environment
  - Several labs have shown that the half-life of dispersed oil is 1-3 weeks