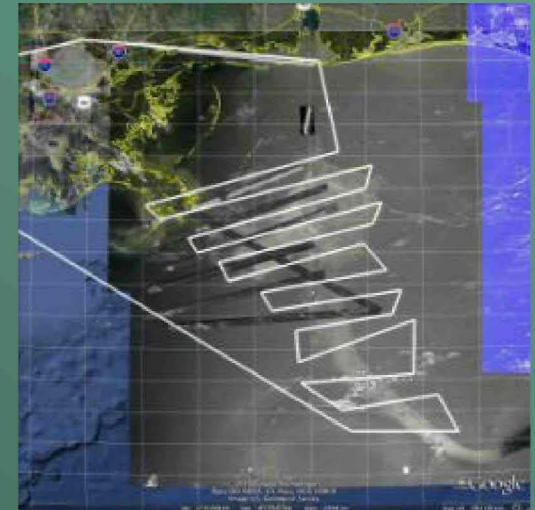




MASS BALANCE 101

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U.S. Department of the Interior
U.S. Geological Survey

What is Mass Balance?

The mass balance concept is based on the fundamental physical principle that matter can neither be created nor destroyed.

www.massbalance.org

The screenshot shows a web browser window titled "Mass Balance - Windows Internet Explorer" with the address bar displaying "http://www.massbalance.org/about". The website features the Biffaward logo and a navigation menu. The main content area is titled "what is mass balance?" and includes a search bar, a list of links, and a diagram illustrating the mass balance concept.

what is mass balance?
Mass Balance UK project website

The mass balance concept is based on the fundamental physical principle that matter can neither be created nor destroyed. Therefore, the mass of inputs to a process, industry or region balances the mass of outputs as products, emissions and wastes, plus any change in stocks, hence the term 'mass balance' is used to describe this type of analysis. When applied in a systematic manner this simple and straightforward concept of balancing resource use with outputs can provide a robust methodology for analysing resource flows.

The diagram illustrates a mass balance unit boundary. It shows a central box labeled "Reuse/recycling" with a circular arrow inside. To the left, an arrow labeled "Inputs" points into the box, with "Raw materials Imports" written below it. To the right, an arrow labeled "Outputs" points out of the box, with "Disposal Exports Products" written below it. Below the box, a vertical arrow labeled "Change in stock" points downwards, with "Unit boundary" written below it.

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Mass Balance – Forward and Inverse

- Mass Balance run in a forward direction starting from a discharge rate can be used to compute a daily and cumulative **Oil Budget**
- Run in reverse Mass Balance starts with an oil budget and computes a **Discharge Rate**
- The two are the same if all sources of available oil are accounted for and all losses are quantified.

Mass Balance – Accounting

- In an industrial process where all inputs, outputs, and losses are known, Mass Balance is simple accounting
- In a deep water oil spill, inputs, outputs, and losses are not all known and may need to be assumed
- The same assumptions need to be used in both the forward and inverse oil spill mass balance for the results to be comparable.

Mass Balance – Measured and Computed

- **Oil Budget** uses a measured discharge rate and computes available oil at the sea-surface
- **Mass Balance** uses measured available oil at the sea-surface and computes a discharge rate

Mass Balance – Assumptions

- Losses due to:
 - Natural dispersion
 - Oil/water ratio in skimmed oil
 - Beached oil
 - Chemical dispersion - sea-bottom and sea-surface
 - Biodegradation
 - Evaporation and dissolution

Mass Balance – Oil Budget Calculation

- Start with a measured discharge rate
- Subtract contained oil
- Subtract naturally and chemically dispersed oil
- Subtract evaporated oil
- Subtract skimmed oil
- Subtract burned oil
- Subtract beach collection
- **RESULT = Available oil**



Mass Balance – Oil Budget Calculation

Discharge Rates - 2010 9/17/10

Average Daily Discharge Rate: 2,200
 2010 Discharge Rate: 2,200
 2011 Discharge Rate: 2,200
 2012 Discharge Rate: 2,200
 2013 Discharge Rate: 2,200
 2014 Discharge Rate: 2,200
 2015 Discharge Rate: 2,200
 2016 Discharge Rate: 2,200
 2017 Discharge Rate: 2,200
 2018 Discharge Rate: 2,200
 2019 Discharge Rate: 2,200
 2020 Discharge Rate: 2,200

Overall Budget Rates:
 Overall Budget Rate: 2,200
 2010 Budget Rate: 2,200
 2011 Budget Rate: 2,200
 2012 Budget Rate: 2,200
 2013 Budget Rate: 2,200
 2014 Budget Rate: 2,200
 2015 Budget Rate: 2,200
 2016 Budget Rate: 2,200
 2017 Budget Rate: 2,200
 2018 Budget Rate: 2,200
 2019 Budget Rate: 2,200
 2020 Budget Rate: 2,200

Day	Year	Discharge Rate	Recovery Rate	Evaporation Rate	Skimming Rate	Burning Rate	Chemical Dispersant Rate	Surface Oil Rate	Subsurface Oil Rate	Remaining Oil Rate
1	2010	2200	0	0	0	0	0	0	0	2200
2	2010	2200	0	0	0	0	0	0	0	4400
3	2010	2200	0	0	0	0	0	0	0	6600
4	2010	2200	0	0	0	0	0	0	0	8800
5	2010	2200	0	0	0	0	0	0	0	11000
6	2010	2200	0	0	0	0	0	0	0	13200
7	2010	2200	0	0	0	0	0	0	0	15400
8	2010	2200	0	0	0	0	0	0	0	17600
9	2010	2200	0	0	0	0	0	0	0	19800
10	2010	2200	0	0	0	0	0	0	0	22000
11	2010	2200	0	0	0	0	0	0	0	24200
12	2010	2200	0	0	0	0	0	0	0	26400
13	2010	2200	0	0	0	0	0	0	0	28600
14	2010	2200	0	0	0	0	0	0	0	30800
15	2010	2200	0	0	0	0	0	0	0	33000
16	2010	2200	0	0	0	0	0	0	0	35200
17	2010	2200	0	0	0	0	0	0	0	37400
18	2010	2200	0	0	0	0	0	0	0	39600
19	2010	2200	0	0	0	0	0	0	0	41800
20	2010	2200	0	0	0	0	0	0	0	44000
21	2010	2200	0	0	0	0	0	0	0	46200
22	2010	2200	0	0	0	0	0	0	0	48400
23	2010	2200	0	0	0	0	0	0	0	50600
24	2010	2200	0	0	0	0	0	0	0	52800
25	2010	2200	0	0	0	0	0	0	0	55000
26	2010	2200	0	0	0	0	0	0	0	57200
27	2010	2200	0	0	0	0	0	0	0	59400
28	2010	2200	0	0	0	0	0	0	0	61600
29	2010	2200	0	0	0	0	0	0	0	63800
30	2010	2200	0	0	0	0	0	0	0	66000
31	2010	2200	0	0	0	0	0	0	0	68200
32	2010	2200	0	0	0	0	0	0	0	70400
33	2010	2200	0	0	0	0	0	0	0	72600
34	2010	2200	0	0	0	0	0	0	0	74800
35	2010	2200	0	0	0	0	0	0	0	77000
36	2010	2200	0	0	0	0	0	0	0	79200
37	2010	2200	0	0	0	0	0	0	0	81400
38	2010	2200	0	0	0	0	0	0	0	83600
39	2010	2200	0	0	0	0	0	0	0	85800
40	2010	2200	0	0	0	0	0	0	0	88000
41	2010	2200	0	0	0	0	0	0	0	90200
42	2010	2200	0	0	0	0	0	0	0	92400
43	2010	2200	0	0	0	0	0	0	0	94600
44	2010	2200	0	0	0	0	0	0	0	96800
45	2010	2200	0	0	0	0	0	0	0	99000
46	2010	2200	0	0	0	0	0	0	0	101200
47	2010	2200	0	0	0	0	0	0	0	103400
48	2010	2200	0	0	0	0	0	0	0	105600
49	2010	2200	0	0	0	0	0	0	0	107800
50	2010	2200	0	0	0	0	0	0	0	110000
51	2010	2200	0	0	0	0	0	0	0	112200
52	2010	2200	0	0	0	0	0	0	0	114400
53	2010	2200	0	0	0	0	0	0	0	116600
54	2010	2200	0	0	0	0	0	0	0	118800
55	2010	2200	0	0	0	0	0	0	0	121000
56	2010	2200	0	0	0	0	0	0	0	123200
57	2010	2200	0	0	0	0	0	0	0	125400
58	2010	2200	0	0	0	0	0	0	0	127600
59	2010	2200	0	0	0	0	0	0	0	129800
60	2010	2200	0	0	0	0	0	0	0	132000
61	2010	2200	0	0	0	0	0	0	0	134200
62	2010	2200	0	0	0	0	0	0	0	136400
63	2010	2200	0	0	0	0	0	0	0	138600
64	2010	2200	0	0	0	0	0	0	0	140800
65	2010	2200	0	0	0	0	0	0	0	143000
66	2010	2200	0	0	0	0	0	0	0	145200
67	2010	2200	0	0	0	0	0	0	0	147400
68	2010	2200	0	0	0	0	0	0	0	149600
69	2010	2200	0	0	0	0	0	0	0	151800
70	2010	2200	0	0	0	0	0	0	0	154000
71	2010	2200	0	0	0	0	0	0	0	156200
72	2010	2200	0	0	0	0	0	0	0	158400
73	2010	2200	0	0	0	0	0	0	0	160600
74	2010	2200	0	0	0	0	0	0	0	162800
75	2010	2200	0	0	0	0	0	0	0	165000
76	2010	2200	0	0	0	0	0	0	0	167200
77	2010	2200	0	0	0	0	0	0	0	169400
78	2010	2200	0	0	0	0	0	0	0	171600
79	2010	2200	0	0	0	0	0	0	0	173800
80	2010	2200	0	0	0	0	0	0	0	176000
81	2010	2200	0	0	0	0	0	0	0	178200
82	2010	2200	0	0	0	0	0	0	0	180400
83	2010	2200	0	0	0	0	0	0	0	182600
84	2010	2200	0	0	0	0	0	0	0	184800
85	2010	2200	0	0	0	0	0	0	0	187000
86	2010	2200	0	0	0	0	0	0	0	189200
87	2010	2200	0	0	0	0	0	0	0	191400
88	2010	2200	0	0	0	0	0	0	0	193600
89	2010	2200	0	0	0	0	0	0	0	195800
90	2010	2200	0	0	0	0	0	0	0	198000
91	2010	2200	0	0	0	0	0	0	0	200200
92	2010	2200	0	0	0	0	0	0	0	202400
93	2010	2200	0	0	0	0	0	0	0	204600
94	2010	2200	0	0	0	0	0	0	0	206800
95	2010	2200	0	0	0	0	0	0	0	209000
96	2010	2200	0	0	0	0	0	0	0	211200
97	2010	2200	0	0	0	0	0	0	0	213400
98	2010	2200	0	0	0	0	0	0	0	215600
99	2010	2200	0	0	0	0	0	0	0	217800
100	2010	2200	0	0	0	0	0	0	0	220000

OIL BUDGET (Best Estimate) EXECUTIVE SUMMARY

Last Update: 6/18/2010

	Cumulative Total	Current Assumptions
Discharged	1,071,000	18k bbls/day discharged until 4/4/10 - 23k bbls/day after that
Recovered via RITT and Top Hat	91,833	Based on actual oil amount recovered
Dispersed Naturally (Surface & Subsurface)	93,579	10% by volume of surface oil
Evaporated	280,737	50% per volume of available surface oil
Amount Available for Recovery	606,849	
Skimmed	68,440	10% of oily water collected is oil
Burned	91,792	Based on surface area and thickness calculations on site before burning
Dispersed Chemically (Surface & Subsurface)	53,626	Surface: oil dispersed = dispersant 1:3 Surface: dispersant impacts 25% of treatable oil Subsurface: oil dispersed = dispersant 1:5
Total Dispersant Used	17,483	note: converted fr. gals to bbls - total taken from last operational report
Remaining	390,991	

1 bbl = 42 gal

Mass Balance – Discharge Rate Calculation

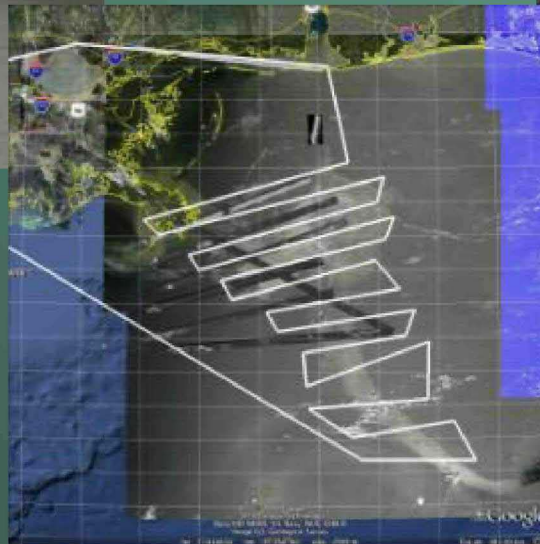
- Start with a measured sea-surface oil volume
- Add beach collection
- Add burned oil
- Add skimmed oil
- Add evaporated oil
- Add naturally and chemically dispersed oil
- Add contained oil

- Divide by number of days of oil discharge



- **RESULT = Average Daily Discharge Rate**

Mass Balance – Discharge Rate Calculation

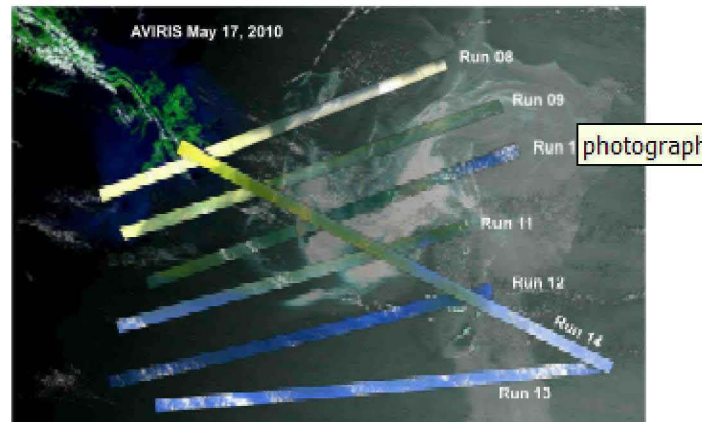


Mass Balance – Discharge Rate Calculation



Estimated Minimum Discharge Rates of the Deepwater Horizon Spill—Interim Report to the Flow Rate Technical Group from the Mass Balance Team

By Victor F. Labson, Roger N. Clark, Gregg A. Swayze, Todd M. Hoefen, Raymond Kokaly, K. Eric Livo, Michael H. Powers, Geoffrey S. Plumlee, and Gregory P. Meeker



Open-File Report 2010-1132

U.S. Department of the Interior
U.S. Geological Survey

<http://pubs.usgs.gov/of/2010/1132/>



Mass Balance – Discharge Rate Calculation

<u>Low minimum</u>	<u>High minimum</u>	<u>Explanation</u>
66,000	120,000	2 percent area “thick” oil from imagery
33,500	67,000	10 percent area “dull” oil
<u>29,500</u>	<u>59,000</u>	<u>88 percent area “sheen” oil</u>
129,000	246,000	Total observed on surface
23,500	23,500	skimmed oil
<u>11,500</u>	<u>11,500</u>	<u>burned oil</u>
164,000	281,000	Subtotal as of May 17, 2010
<u>109,000</u>	<u>185,000</u>	<u>40 percent evaporation and dissolution</u>
273,000	466,000	Total estimated as of May 17, 2010
12,500	21,500	Daily average per 21.7 days
<u>67,000</u>	<u>114,000</u>	<u>assumed subsea dispersion</u>
340,000	580,000	estimated leaked as of May 17

Overflights



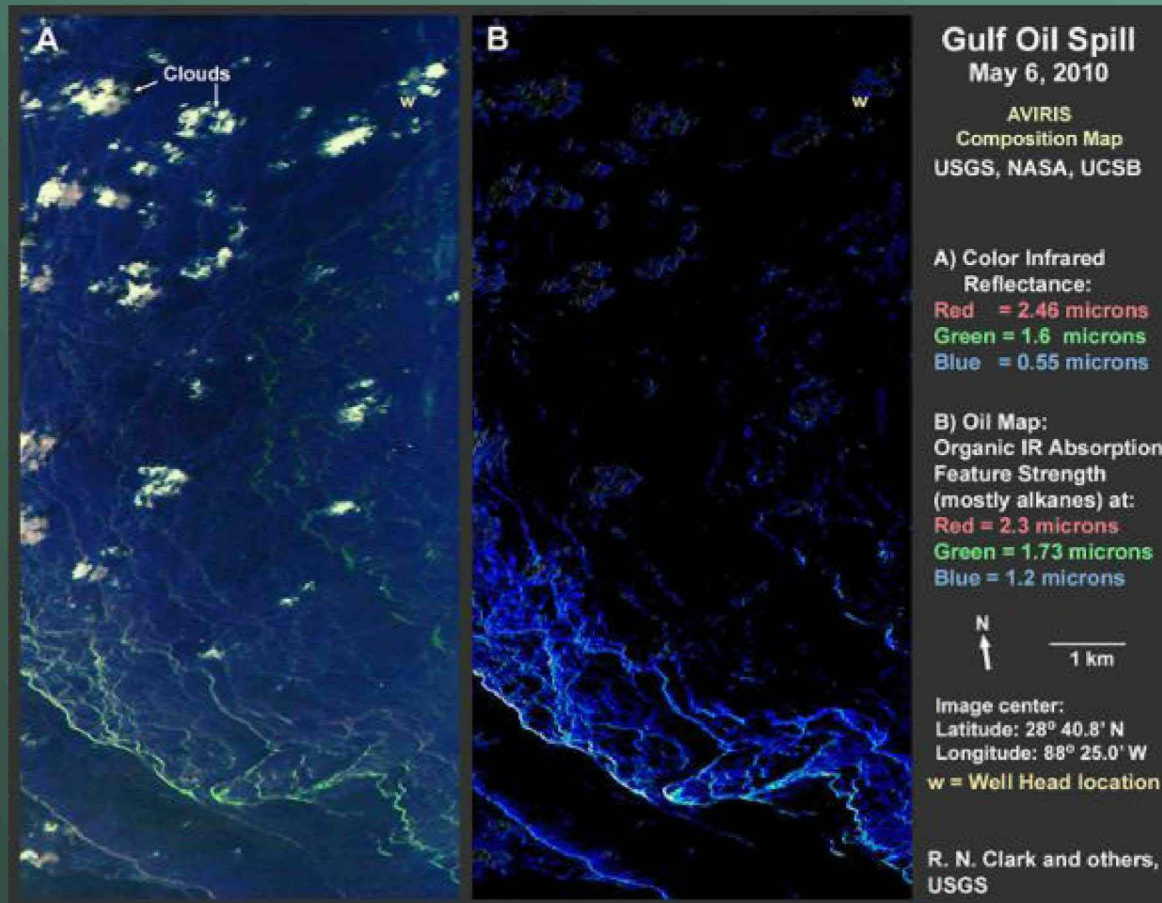
NASA ER-2 with AVIRIS leaving Houston for Gulf overflight.

Overflights



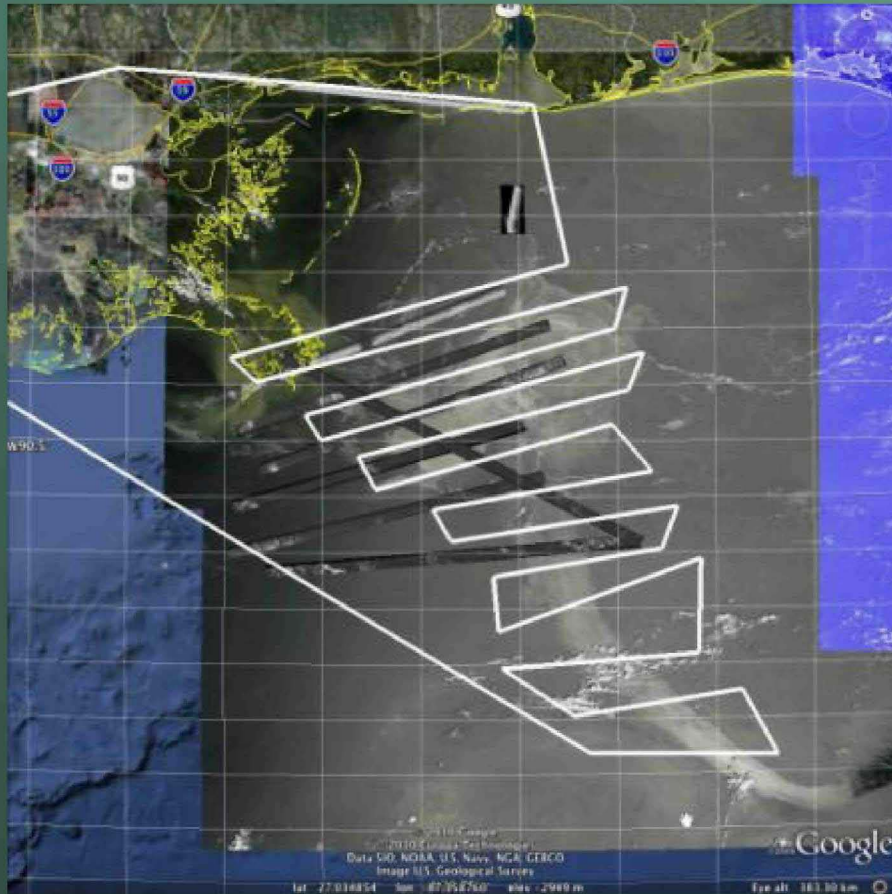
Image of oil emulsion from the Gulf of Mexico oil spill. Photograph taken on May 7, 2010, by Gregg Swayze/Sonia Gallegos during calibration sample collection cruise.

Overflights



Qualitative map of potentially thick oil in vicinity of well head.

Overflights



Quick look images of May 17 flight on May 17 MODIS image. White lines are May 18 flight plan. May 17 was flown at 28,000 feet for better resolution. May 18 at 45,000 feet for wider coverage

Overflights



May 17 AVIRIS
quick-look color
composite.

Note ship tracks
through oil.

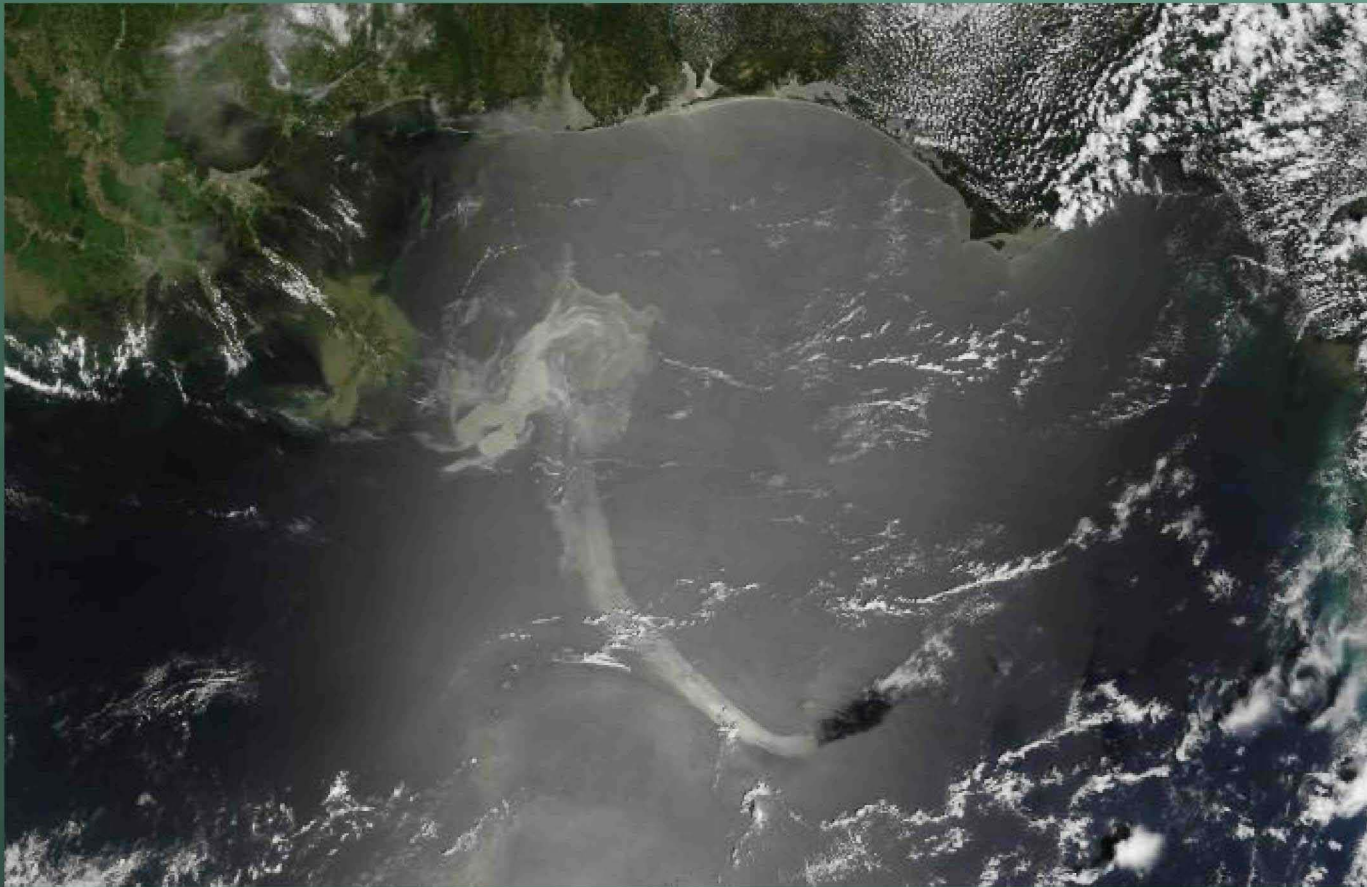
Imaging Spectroscopy

- Imaging Spectroscopy is a hyperspectral visible and infrared remote sensing method which maps chemical composition
- AVIRIS is much like a digital camera which measures visible and near-infrared light in 224 bands in a vast number of pixels
- Every chemical compound has a unique spectrum, or combination of reflection or absorption, analogous to our sensitivity to color in the visible spectrum

Imaging Spectroscopy

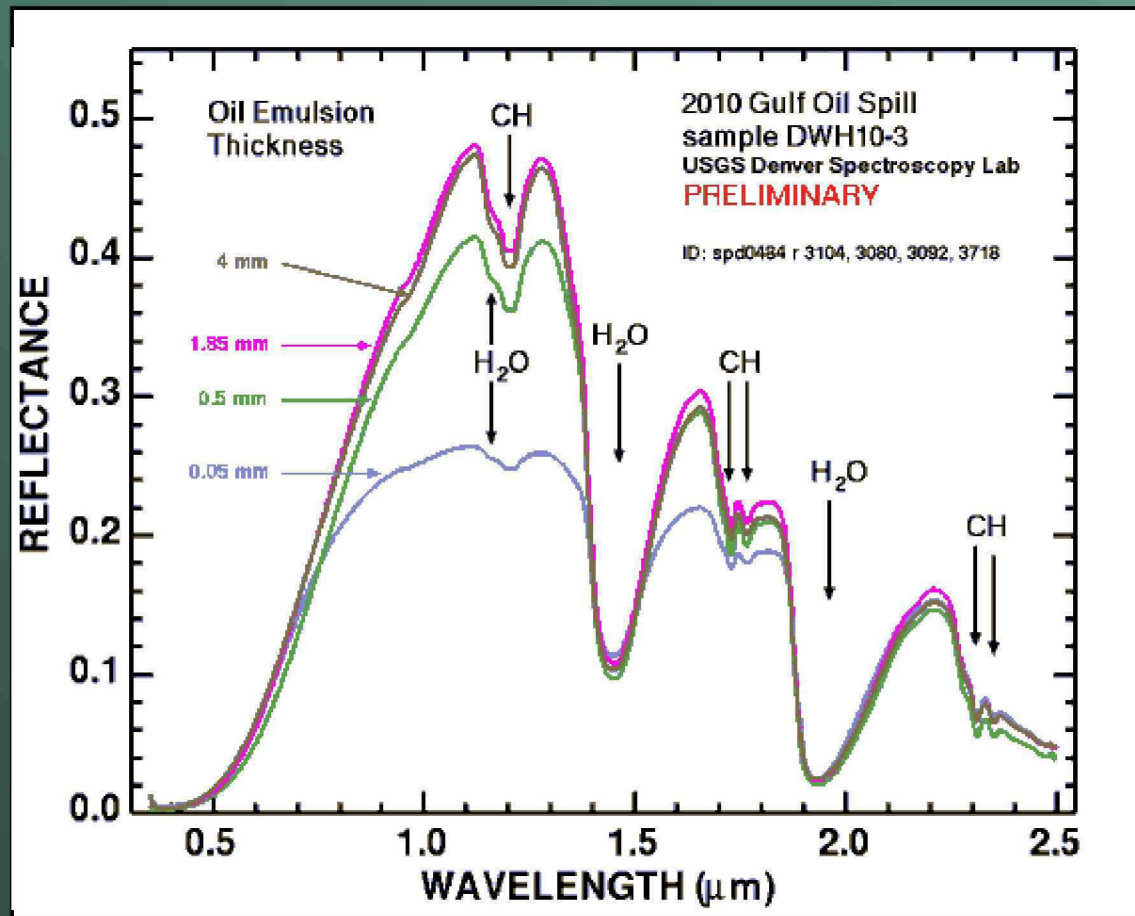
- AVIRIS is a NASA instrument housed at the Jet Propulsion Laboratory
 - Measures in pixels from 2 meters on a side to over 20 meters depending on mission plan
 - Chemical compounds are identified by matching to a spectral library of laboratory measurements of chemical compounds and mixtures of compounds
 - Resulting mapping reminiscent of Star Trek Tricorder, except this one is real
-

A Method for Quantitative Estimation of the Volume of Sea-Surface Oil



MODIS image showing the spill. AVIRIS has covered the central circular area with some of the extension to the southwest. No one can tell how much oil this image represents.

A Method for Quantitative Estimation of the Volume of Sea-Surface Oil



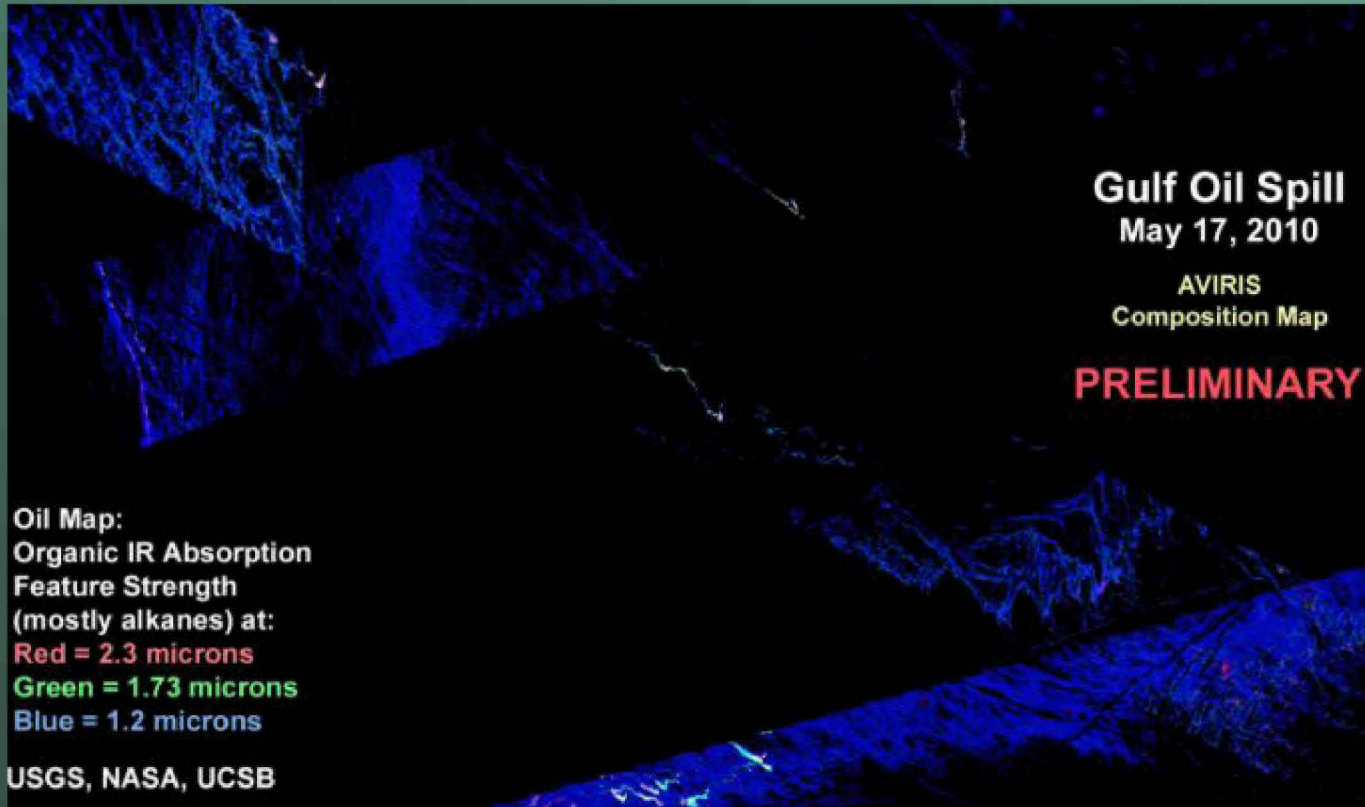
Infrared spectral change with thickness of oil emulsion from the Gulf of Mexico oil spill. Sample collected May 7, 2010.

This property allows us to do the volume estimate.

A Method for Quantitative Estimation of the Volume of Sea-Surface Oil

- Several oil-seawater emulsion samples collected from spill on May 7, 2010
- Field spectra measured of spill at the locations from which samples were collected
- Laboratory spectra also measured of samples
- Samples are being analyzed for organic chemical composition at USGS Menlo Park labs (R. Rosenbauer), and metals in USGS Denver labs

A Method for Quantitative Estimation of the Volume of Sea-Surface Oil



First look, May 17 AVIRIS composition map.

Additional oil-seawater samples needed from ocean plume

- For reflectance spectroscopy and chemical analysis
- Link laboratory chemical analyses to lab, field spectra and AVIRIS data, to enhance AVIRIS mapping of plume chemical composition
- Help understand chemical evolution of plume in the ocean prior to landfall
 - Degradation, transformation of oil
 - Transfer of heavy metal and organic contaminants to sea water

Future studies - 2 phase science plan

- **Phase 1 (June-early July 2010):**
 - AVIRIS will be mobilized to the Gulf to fly low altitude detailed mapping of the threatened and impacted coastal areas
 - Deep-sea transects for characterization and calibration.
 - Coordinated, contemporaneous, seaborne sampling and spectral calibration data collection
 - Laboratory analysis of transect oil samples.
 - **Phase 2 (July 2010):**
 - High altitude, regional AVIRIS data collection
 - Sea-surface oil volume mapping
 - Determination of sea-surface oil weathering
-

Mass Balance – Forward and Inverse

- Mass Balance run in a forward direction starting from a discharge rate can be used to compute a daily and cumulative **Oil Budget**
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MASS BALANCE 101

