Mississippi Canyon 252

ASSESSMENT PLAN: ESTIMATING OFFSHORE SURFACE OIL VOLUMES OF SELECT PORTIONS OF THE DEEPWATER HORIZON OIL SPILL USING AVIRIS IMAGING SPECTROSCOPY DATA

Approval of this Offshore Oil Volume AVIRIS Assessment Plan is for the purposes of obtaining data for the Natural Resource Damage Assessment. Each party reserves its right to produce its own independent interpretation and analysis of any data collected pursuant to this work plan. Each party agrees that 1) all such independent interpretations and analyses of work plan data will be clearly identified as those solely of the interpreting party and 2) they will further clearly indicate that such interpretations or analyses do not necessarily represent the interpretation or analyses of any other party to this work plan.

This plan will be implemented consistent with existing trustee regulations and policies. All applicable state and federal permits must be obtained prior to conducting work.

The trustees have developed a preliminary conceptual model of the DWH release, potential pathways and routes of exposure, and potential receptors. This preliminary model has informed the trustees' decision to pursue the studies outlined in the work plan. By signing this work plan and agreeing to fund the work outlined, BP is not endorsing the model articulated in the work plan.

_____ _____

Department of Commerce Trustee Representative Date

_____ _____

Department of Interior Trustee Representative Date

_____ _____

Louisiana Trustee Representative Date

_____ _____

BP Representative Date

Introduction

Efforts are underway to evaluate the impact of the Deepwater Horizon/Mississippi Canyon 252 (MC252) oil spill on aquatic life in the northern Gulf of Mexico in order to quantify injury for the purposes of a Natural Resource Damage Assessment (NRDA). The purpose of this Assessment Plan is twofold: 1) describe specific analyses to be performed utilizing Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS) hyperspectral remote sensing data to assess the volume of surface oil on a daily basis related to the Deepwater Horizon incident and 2) extrapolate those findings to broad-coverage satellite data for most or all of the oil spill on open water to support the ongoing Deepwater Horizon Oil Spill NRDA.

One of the goals of oil spill remote sensing is the development of a rapid and quantitative method to map the locations of oil spills and to assess their chemistry and volume of oil present on the water's surface. While simple color or multispectral imagery can show locations of oil, it is difficult to assess relative thickness or volume with such data due to complex reflections and scattering of light in the oil and water, the dependency of the reflected light on scene illumination, and varying viewing geometry. Large oil spills in a marine environment tend to be spatially heterogeneous, with changing chemical and physical properties on a range of scales. Although such spills can be challenging to map with traditional remote sensing methods, a relatively new high spatial and spectral resolution remote sensing method was recently used to assess the surface portion of the Deepwater Horizon oil spill.

Clark et al. (2010) present a method to derive oil thickness, oil:water ratio, and volume from remotely sensed spectral data of near-infrared spectral absorption features for this oil spill on May 17, 2010. Their remote sensing data came from a NASA imaging spectrometer, which was flown over offshore portions of the spill on various days in May, and July through October, 2010. This instrument, the AVIRIS, collected 456 scenes covering the spill over open-ocean and along Gulf Coast shoreline extending from Florida to Texas (Figure 1). AVIRIS has been used in a wide variety of geological and biological studies, primarily because of its relatively high spectral resolution, high signal-to-noise ratio (S/N), and variable spatial scale (Green et al., 1998). It is typically flown aboard aircraft at altitudes ranging from 2 to 20 km resulting in spatial sampling of 2 to 20 meters per pixel. AVIRIS collects reflectance spectra in 224 continuous spectral channels covering the 0.38 to 2.5 micron wavelength range with an approximate 10-nanometer sampling interval and bandpass width (Green et al., 1998) enabling diagnostic absorption features to be measured and thus different materials to be fingerprinted.

Figure 2 shows lab spectra of a water-in-oil emulsion at different thicknesses. Emulsions are relatively bright in the near-infrared (up to 60% reflectance) compared to water and they have diagnostic organic absorptions in the 1.2, 1.7, and 2.3 micron regions. Changes in the depths and shapes of these absorption features and the slopes of their continua can be used to calculate the thickness of emulsion slicks on the ocean surface, and their oil-to-water ratio. AVIRIS provides spectra similar to these for each pixel it measures over emulsion slicks. There are about 10 million pixels, each covering an 8 x 8 meter area in a typical AVIRIS flight line collected over the spill on May 17. Clark et al. (2010) used a spectral shape-matching system called Tetracorder (Clark et al., 2003) to analyze each pixel in AVIRIS images to create maps of the distribution of thick oil like that shown in Figure 3. AVIRIS oil volume estimates derived from Tetracorder spectral mapping can be used to extrapolate the density of oil on a per pixel basis to concurrent broad band visible satellite images that provide a more synoptic view of the oil spill.

Objectives and Goals

The existing AVIRIS data will be analyzed to address the following objectives:

1) Determine the volume of surface crude oil floating on the ocean surface for areas imaged by AVIRIS on days when surface conditions (e.g., wind, waves, and sun angle) permit quantitative estimates.

2) Use AVIRIS-derived surface oil volume estimates on a per pixel basis for the core of the spill and surrounding sheen covered areas. Values of the average oil volume/unit area for thick oil and sheens will be extrapolate to similar areas of thick oil and sheens not covered by AVIRIS on contemporaneous satellite/airborne images for selected days with the goal of providing synoptic quantitative oil volume inputs for ocean hydrodynamic models.

Activity 1. Select and prepare relevant AVIRIS data.

During the May to October, 2010 Gulf deployment, AVIRIS was flown on an NASA ER-2 to maximize aerial coverage and at different times on a De Havilland Twin Otter to cover selected areas at high spatial resolution. Ground resolution varies between 3.5 and 20 meters and image widths vary between 2 and 12 km depending on the altitude at which data were collected. Images can be up to a hundred or more km in length. We will process AVIRIS data acquired on days selected in cooperation with other members of the DWH Surface Oil Fate & Transport Group (SOFTG) that have contemporaneous satellite coverage that can support extrapolation of surface oil volumes to large portions of the offshore spill. Data processing will involve radiative transfer conversion from radiance to apparent reflectance with a final correction using already acquired field reflectance measurements of ground calibration sites. Images will be georeferenced to the map projection adopted by the SOFTG for cross-comparison of imagery from different airborne and orbital platforms.

Activity 2. Synthesis of water-in-oil emulsions for spectral mapping.

A method for synthesizing water-in-oil emulsions will be devised using DWH crude oil (if available) or a similar sweet crude oil from the Gulf of Mexico. Emulsions will be made over a range of oil-to-water ratios with variable concentrations of air bubbles to simulate the possible range in crude oil emulsions likely to have existed in the DWH oil spill. Air bubbles in the emulsions influence how light scatters and can limit the depth photons penetrate into emulsions. The concentration, size, and distribution of air bubbles in synthetic emulsions will be studied microscopically using an SEM environment chamber. Reflectance spectra of the synthetic emulsions will be measured at various thicknesses to provide a library of emulsions that cover the range of oil:water:air ratios and thicknesses likely to have existed in the DWH spill. The effects of oil dispersants on the spectral signature of emulsions and sheens will also be evaluated.

Activity 3. Development of a radiative transfer model for mapping oil thickness.

Crude oil has a very strong UV electronic absorption responsible for its black color in the visible. The intensity of this UV absorption can be used to estimate the thickness of crude oil sheens. Near-infrared absorptions have different sensitivities to oil thickness and emulsion state. Radiative transfer software will be developed to model the depth and shape changes of the UV to near-IR absorptions to provide a library of calculated spectra with various oil thicknesses. Model spectra in this library will be checked

against laboratory spectra of emulsions and oil sheens of known thickness. The model spectra will be used to extend laboratory work to cover conditions not covered by the laboratory work due to limited time and resources.

Activity 4. Tetracorder mapping of AVIRIS data to derive oil volumes.

Tetracorder is a spectral shape-matching system developed by the USGS (Clark et al., 2003). Calibrated AVIRIS data from Activity 1 will be mapped for oil thickness, oil:water:air ratio, and areal coverage on a per pixel basis. Spectral libraries derived from Activities 2 and 3 will be used to map different types of slicks and sheens in the DWH oil spill, where covered by AVIRIS data, to derive estimates of the average oil volume/km^2 for thick oil down to sheens. These values will be extrapolated to similar areas of thick oil and sheens not covered by AVIRIS on contemporaneous satellite/airborne images for days selected in cooperation with other members of the SOFTG. In this way volume estimates on a per kilometer basis will be derived for selected days for areas covered by surface oil.

Activity Schedule

Activities 1, 2, and 3 are relatively independent of each other and will run concurrent to each other. Activity 4 will begin after the earlier activities are completed. AVIRIS data for the most promising days will be run first and that information provided to members of the SOFTG for extrapolation to their satellite image datasets.

Sampling and Data Handling

MC 252 NRDA chain-of-custody procedures will be observed at all times for field samples. All materials associated with the collection or analysis of field samples under these protocols or pursuant to any approved work plan, except those consumed as a consequence of the applicable sampling or analytical process, must be retained unless and until approval is given for their disposal in accordance with the retention requirements set forth in paragraph 14 of Pretrial Order # 1 (issued August 10, 2010) and any other applicable Court Orders governing tangible items that are or may be issued in MDL No. 2179 IN RE: Oil Spill by the Oil Rig "DEEPWATER HORIZON" (E.D. LA 2010). Such approval to dispose must be given in writing and by a person authorized to direct such action on behalf of the state or federal agency whose employees or contractors are in possession or control of such materials.

All laboratory data will be collected, managed and stored in accordance with written SOPs. The appropriate training on particular equipment or in the conduct of specific laboratory studies for all personnel involved with the project shall be documented and those records kept on file for the duration of this project.

Copies of analytical and non-analytical field data will be provided to BP or its representative, if they participate cooperatively in the analysis work plan, and the Louisiana Oil Spill Coordinator's Office (LOSCO) within a reasonable time frame once field data collection, QA analyses and data entry procedures are complete but no later than 6 months following its collection.

Budget

The cost for this 2012 Offshore Oil Spill Volume AVIRIS plan is $96,718. The Parties acknowledge that this budget is an estimate, and that actual costs may prove to be higher.

Supplies

Durable Goods: All durable equipment purchased by BP for this study will be returned to BP or their designated representatives at the conclusion of its use for this study if requested.

Consumables: Because of the large data volume involved in storage and processing of imaging spectrometer data, we will purchase 48 2TB SATA Disks configured as RAID 5 arrays and 2 disk enclosures for handling and backup of the DWH AVIRIS data and derived products. These disks and enclosures will be kept by the USGS for storage of the DWH AVIRIS data after this project is completed.

Principal Investigator

Gregg Swayze (303 236-0925, gswayze@usgs.gov) U.S. Geological Survey, Crustal Geophysics & Geochemistry Science Center, Denver, Colorado

Co-Investigators

Roger Clark (303 236-1332, rclark@usgs.gov) U.S. Geological Survey, Crustal Geophysics & Geochemistry Science Center, Denver, Colorado
Role: Algorithm development and science strategy co-lead

K. Eric Livo (303) 236-1388, elivo@usgs.gov) U.S. Geological Survey, Central Region Mineral Resources Science Center, Denver, Colorado
Role: Spectral data calibration lead

References

Clark, R.N., G.A. Swayze, K.E. Livo, R.F. Kokaly, S.J. Sutley, J.B. Dalton, R.R. McDougal, and C.A. Gent, 2003, Imaging spectroscopy: Earth and planetary remote sensing with the USGS Tetracorder and Expert Systems: Journal of Geophysical Research, v. 108, no. E12, 5131, doi:10.1029/2002JE001847, 44 p.

Clark, R.N., Swayze, G.A., Leifer, I., Livo, K.E., Kokaly, R., Hoefen, T., Lundeen, S., Eastwood, M., Green, R.O., Pearson, N., Sarture, C., McCubbin, I., Roberts, D., Bradley, E., Steele, D., Ryan, T., Dominguez, R., and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Team, 2010, A method for quantitative mapping of thick oil spills using imaging spectroscopy: U.S. Geological Survey Open-File Report 2010-1167, 51 p. http://pubs.usgs.gov/of/2010/1167/

Green, R.O., Eastwood, M.L, Sarture, C.M., Chrien, T.G., Aronsson, M., Chippendale, B.J., Faust, J.A., Pavri, B.E., Chovit, C.J., Solis, J., Olah, M.R., and Williams, O., 1998, Imaging spectroscopy and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Remote Sensing of Environment, v. 65, p. 227-248.

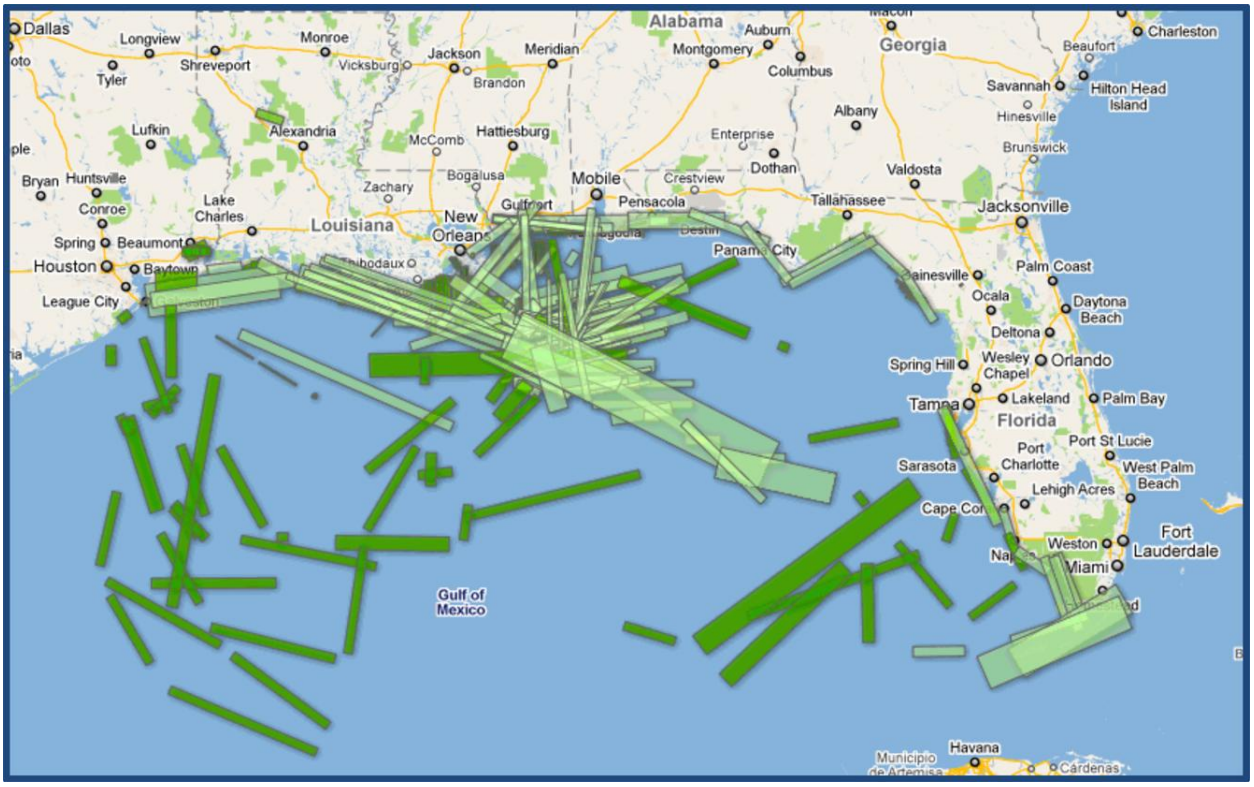

Figure 1. AVIRIS scenes collected over the Gulf of Mexico between May 6 and October 4, 2010. Scenes covered potentially impacted shoreline or open-ocean where oil was thought to be present based on interpretation of broad band satellite images. AVIRIS scene footprints vary as a function of aircraft altitude. Source http://aviris.jpl.nasa.gov/

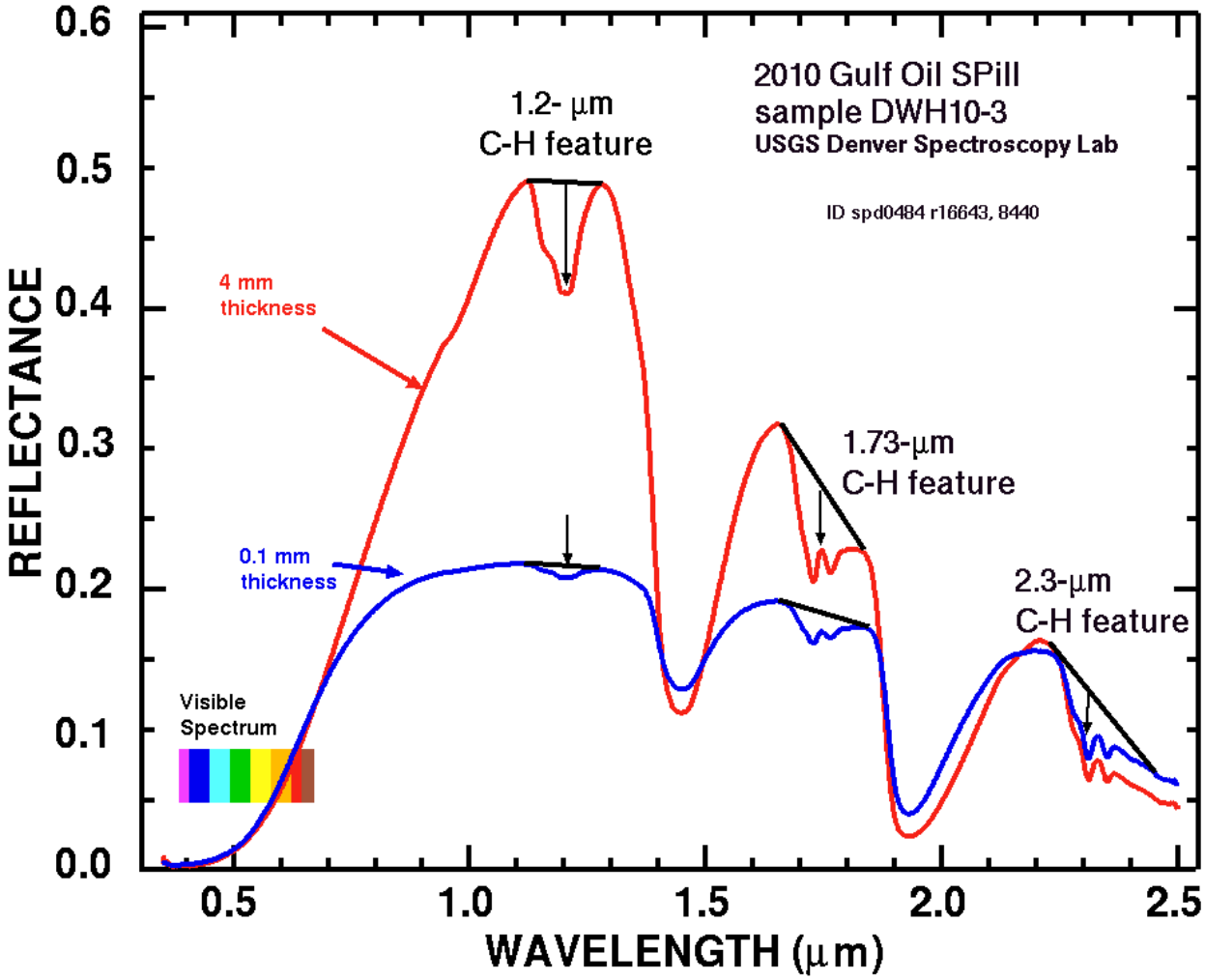

Figure 2. Laboratory reflectance spectra of oil emulsion from the Deepwater Horizon / Mississippi Canyon 252 oil spill. Sample collected May 7, 2010. At visible wavelengths the oil is very absorbing and does not change color significantly with thickness. At infrared wavelengths, both reflectance levels and absorptions due to organic compounds vary in strength with thickness. This sample contains approximately 40 percent water as determined by heat separation. Black lines over spectral absorptions are for illustrative purposes to better visualize absorption feature continuum endpoints. From Clark et al. (2010).

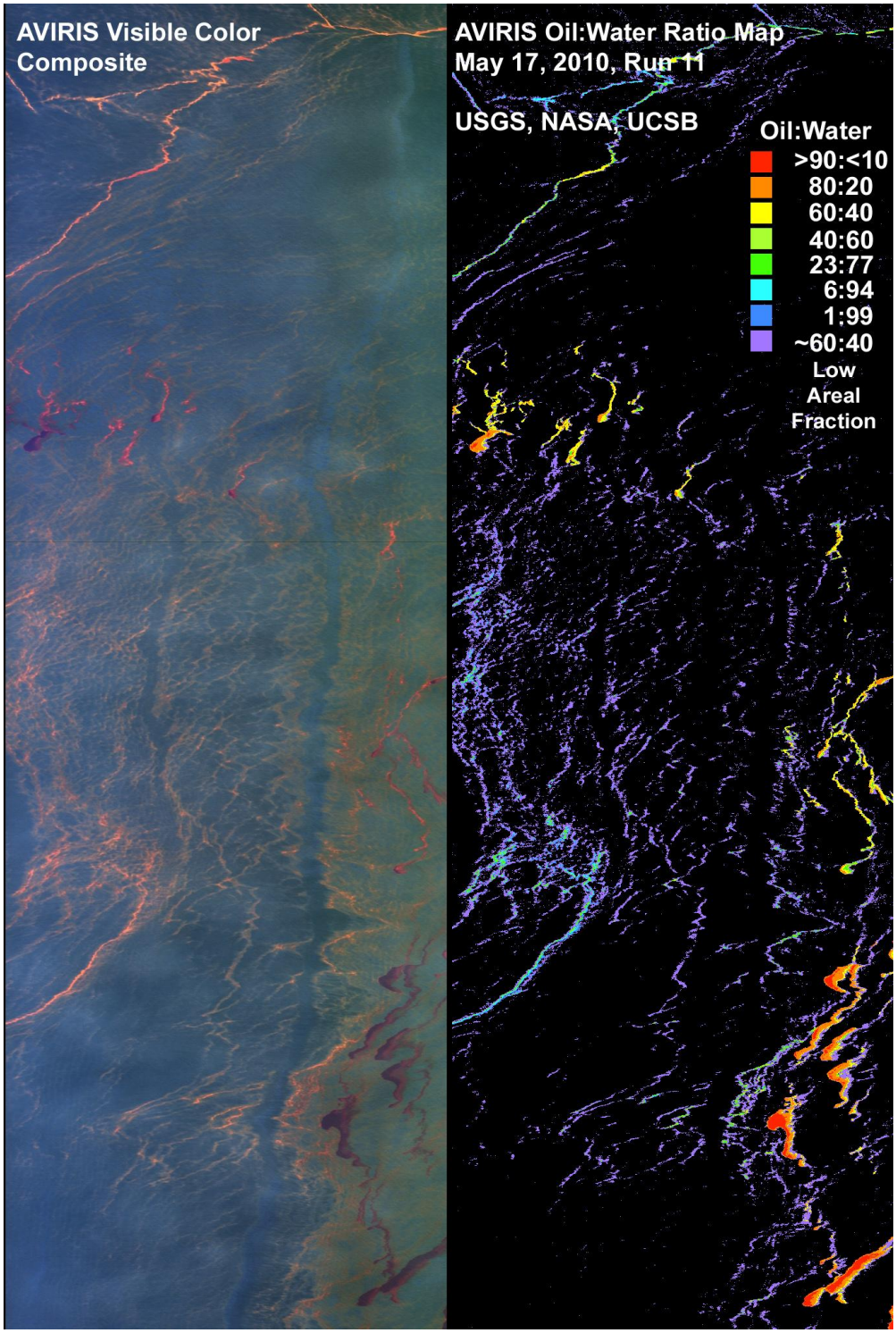

Figure 3. Tetracorder mapping results for oil-to-water ratio for a portion of AVIRIS run 11 acquired on May 17, 2010. Black areas on the right panel are where no thick oil was detected. The center of this image is about 12 km WSW of the incident site. From Clark et al. (2010).