Testing a Promising Remote Sensing of Methane with *in situ* Observations of Emissions from a Natural Marine Hydrocarbon Seep

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ABSTRACT :

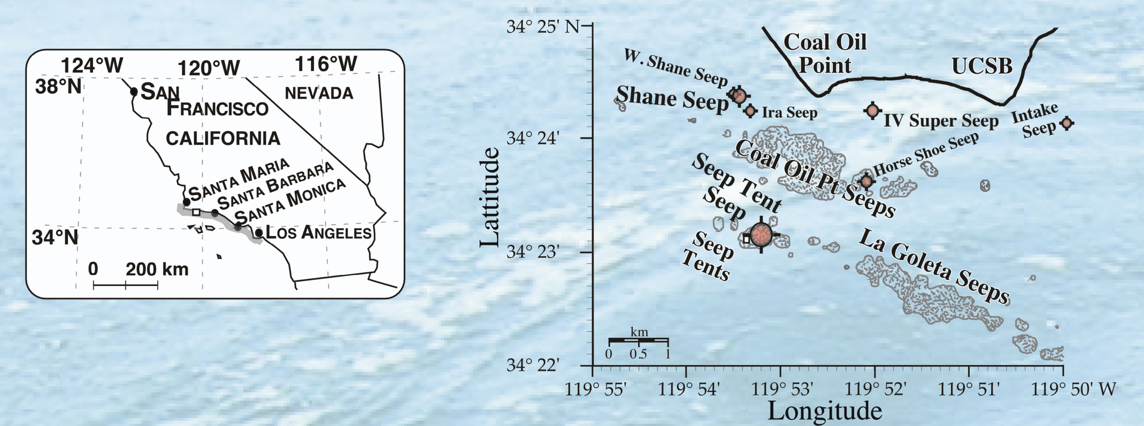
The sources and sinks of methane, an important greenhouse gas, are poorly constrained. Remote sensing techniques can significantly improve our understanding of sources and sinks. Field and laboratory studies used spectral and in-situ chemical measurements of methane emissions from natural marine seepage and radiative transfer calculations to test the feasibility of remote sensing from the AVIRIS platform on this marine source. Numerical MODTRAN simulations show that although most of the spectral region between 2200 and 2340 nm is sensitive to methane it is only mildly sensitive to water vapor interference.

Repeated transects of an intense marine seep area were conducted and Flame Ion Detector (FID) measurements made of the methane plume. Based on a Gaussian plume model of observations, methane column abundances were calculated and showed values of 0.5 g m-2 to a downwind distance of 70 m. MODTRAN calculations showed that this was well above the noise equivalent detection level of AVIRIS.

During a separate field study, three FIDs at 2.2, 3.6, and 5 m above the sea surface recorded methane concentrations as high as 200 ppm while transecting an active seep area. Contemporaneously, spectra were obtained with a field spectrometer. Several plumes were identified from the FID data. A clear relationship was shown between the presence of methane plumes along the incident pathlength and the presence of methane absorption features in spectra, while methane absorption features above atmospheric background were not observed outside the plumes

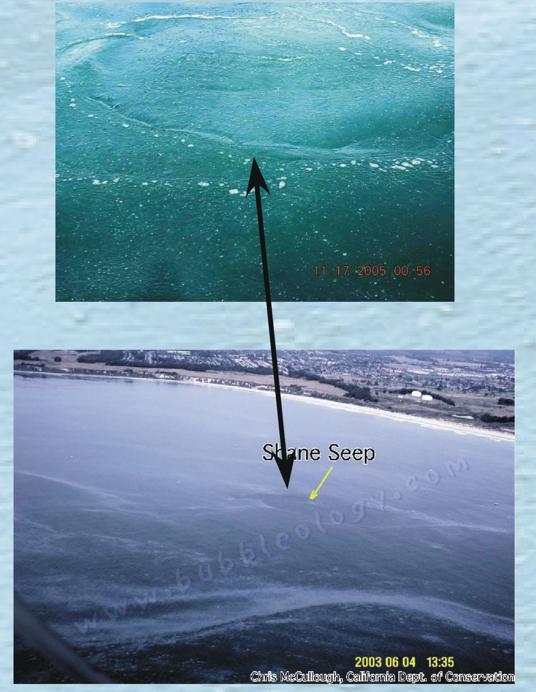
Results published - Leifer, I., D. Roberts, J. Margolis, and F. Kinnamen, In-situ sensing of methane emissions from natural marine hydrocarbon seeps: A potential remote sensing technology, *Earth Plan. Sci. Lett.* **245**, 509-522.

Study Area - Coal Oil Point Seep Field

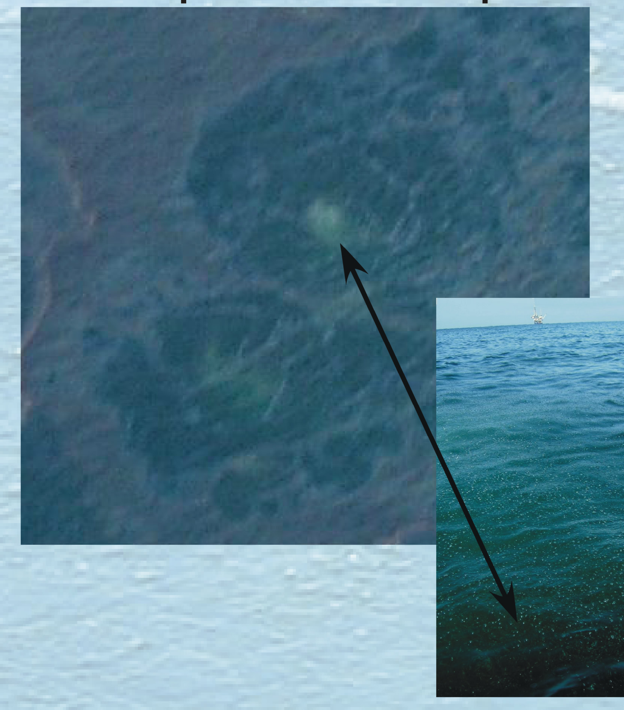


Location of informally named seeps in the Coal Oil Point seep field, Santa Barbara Channel off the coast of Santa Barbara, California. Inset shows the southwest US. Small rectangle noted by arrow shows study area shown in main panel. Gray areas in C) indicate regions of high bubble density from sonar returns.

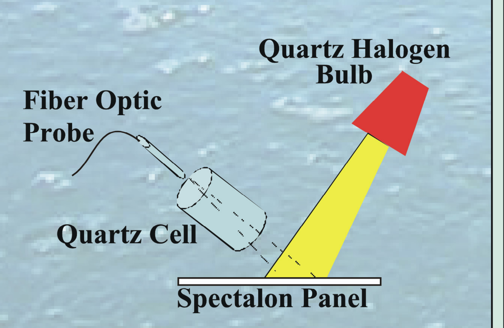
Shane Seep

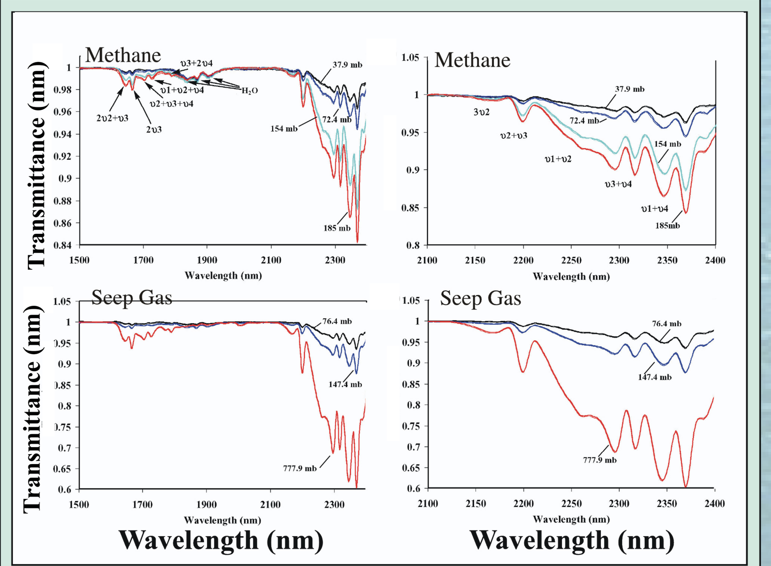


Seep Tent Seep



Lab Study Seep Gas Spectral Characterization





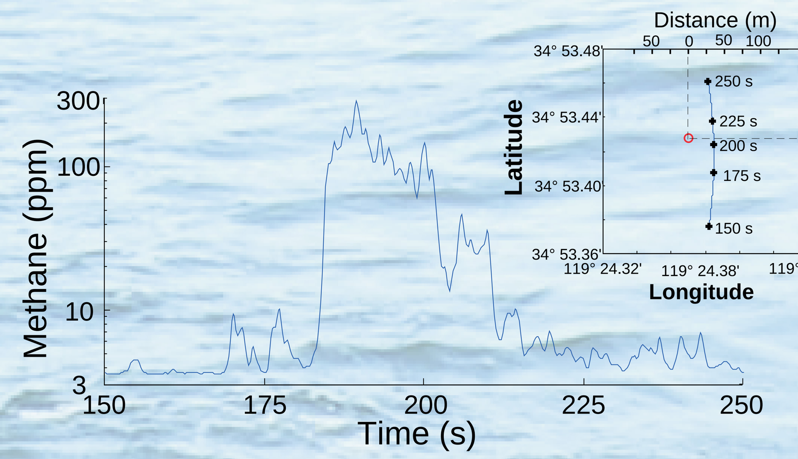
Methane and seep gas transmittance measured in the laboratory for a range of methane partial pressures through a 10-cm optical cell. Remainder of cell is nitrogen, with some water contamination.

Seep gas = 91.2% CH_4, 7.5% CO_2, 1.1% C_2H_6, 0.2% C_3H_8

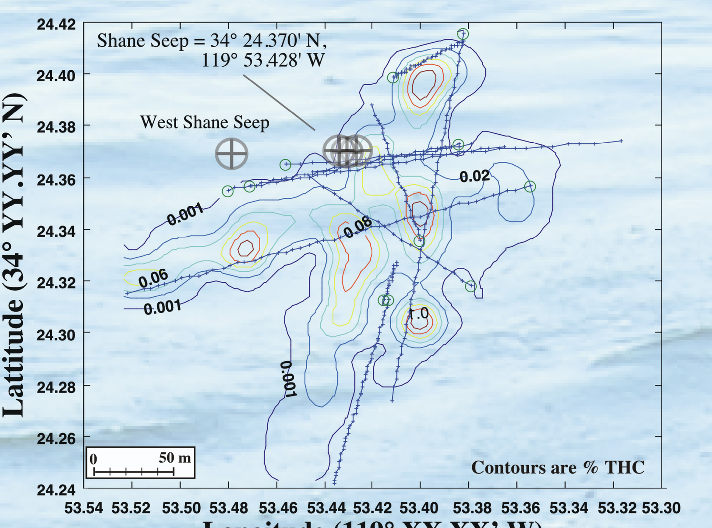
Field Study Phase 1-Plume Chemical Characterization

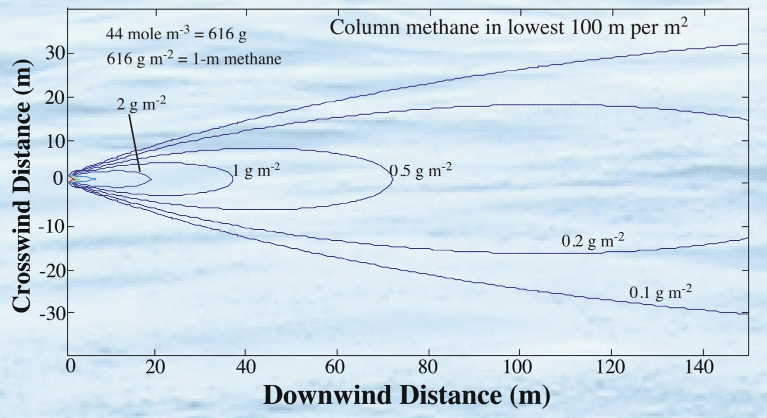
Approach: Repeated transects of the plume with flame ion detectors, contour the data, and fit with a Gaussian plume using boat measured wind data.

Site: Shane Seep



Example transect. Inset shows boat and Shane Seep (source) locations, and corresponding times.

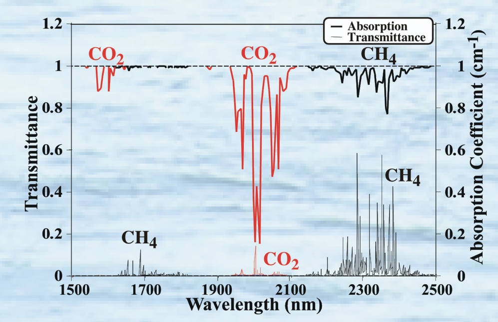




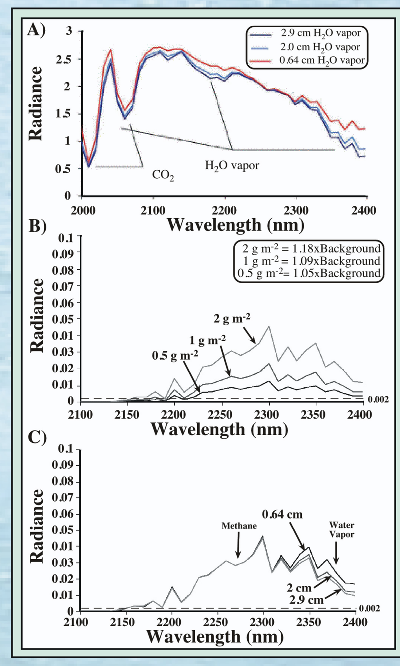
Contour plot of vertical integration of Gaussian plume fit to observations showing methane column thickness.

Contour map of Shane Seep atmospheric total hydrocarbon (THC) concentration (%). Lines show boat tracks, with ticks indicating measurement points and circles show transect starting points. The location of major plumes at Shane Seep and of West Shane Seep are indicated by targets. Distance scale shown on figure. For the contour, measurements were gridded to 0.01' latitude-longitude bins and measurements in each bin averaged. Winds were light (2 m s^{-1} to 2.8 m s^{-1}) from WNW. Near surface currents were onshore, towards the north at ~0.5 m s^{-1}. The shoreline is north-northeast from Shane Seep.

Radiative Transfer Calculation of AVIRIS Feasibility



Atmospheric methane and carbon dioxide absorption coefficient calculated from HITRAN 2004 at a 1 nm spectral interval, assuming a Lorenz shape function at standard temperature and pressure and B) atmospheric transmittance calculated using MODTRAN 4v3.1 between 1500 and 2500 nm. Methane and carbon dioxide bands are labeled on the figure. MODTRAN simulations assumed an airmass for a mid-latitude, temperate atmosphere and were convolved to a 5 nm full-width half-maximum and spectral sampling.



A) MODTRAN simulation of reflected radiance from a 100% reflectant surface with background methane and variable column water vapor of 0.64, 2.0, and 2.9 cm.

B) Radiance residuals from MODTRAN simulation after subtracting background radiance for various plume methane columns and a 2-cm column water vapor.

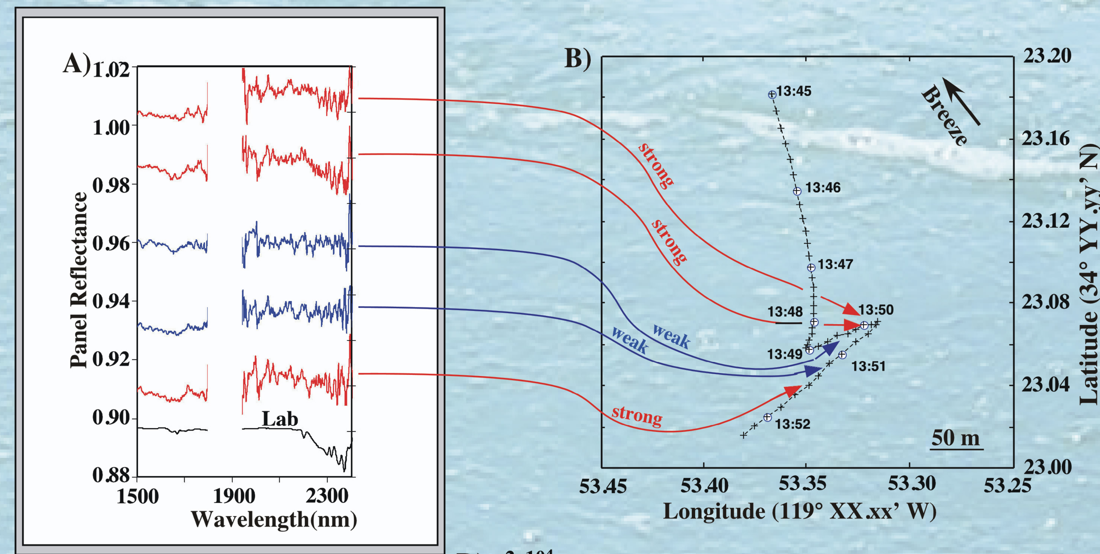
C) Radiance residuals for methane at 1.18 times background (2 g m-2) and variable column water vapor. Methane and water column heights labeled on figure. Dashed line at 0.002 radiance is noise equivalent delta radiance for AVIRIS.

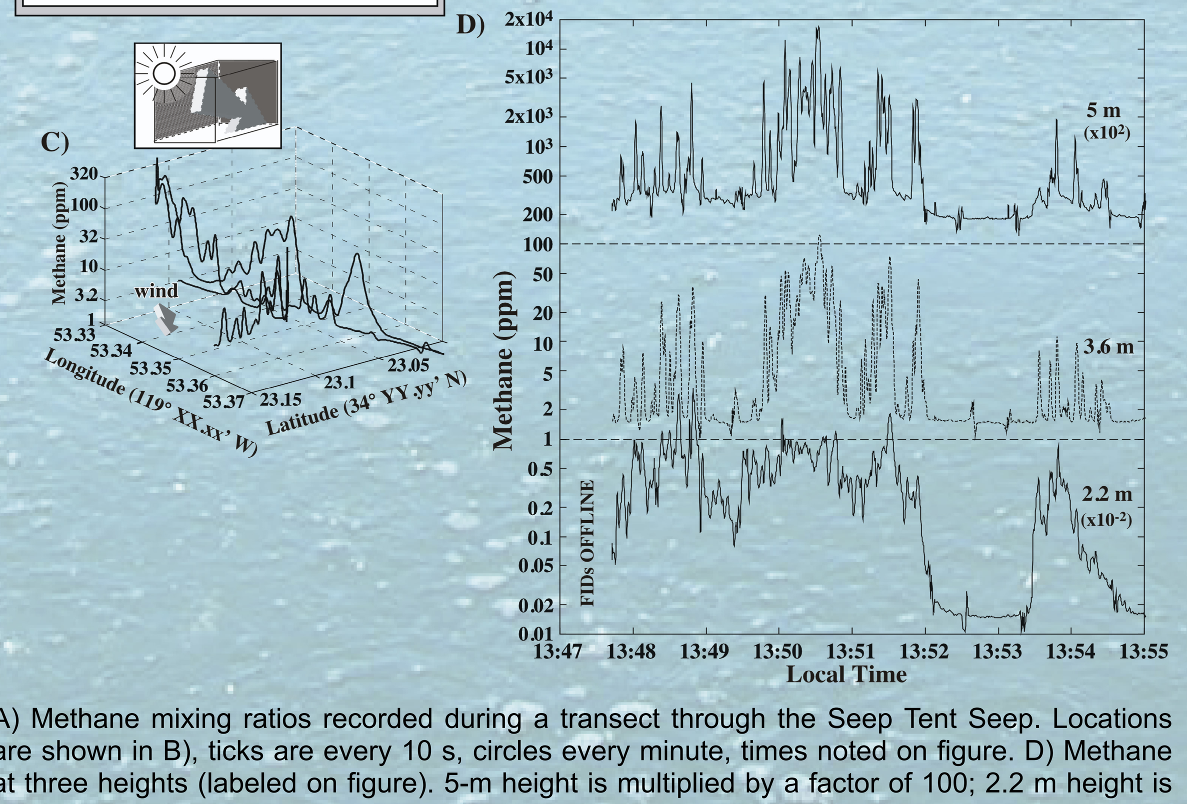
Calculations show it is *feasible*!!!

Field Study Phase 2 Plume Spectral-Chemical Characterization

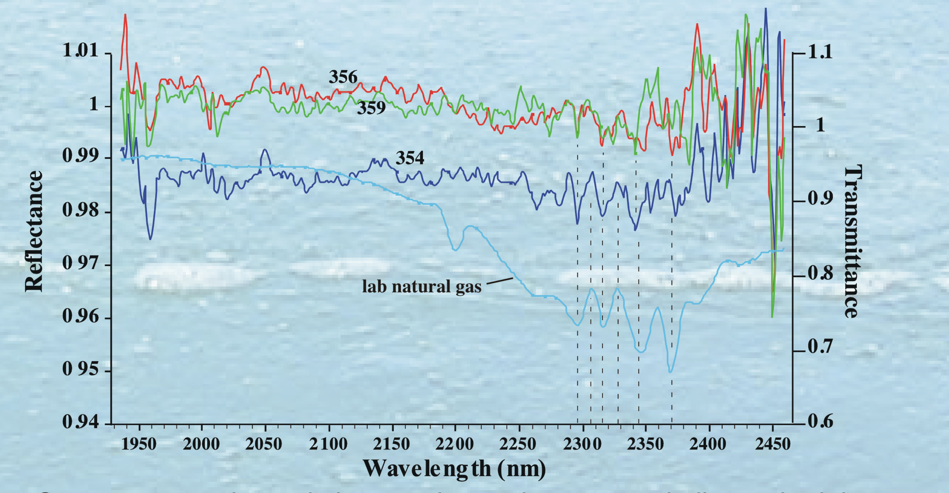
Approach - Collect FID data at 3 heights and spectral data during a plume transect

Site - Seep Tent Seep

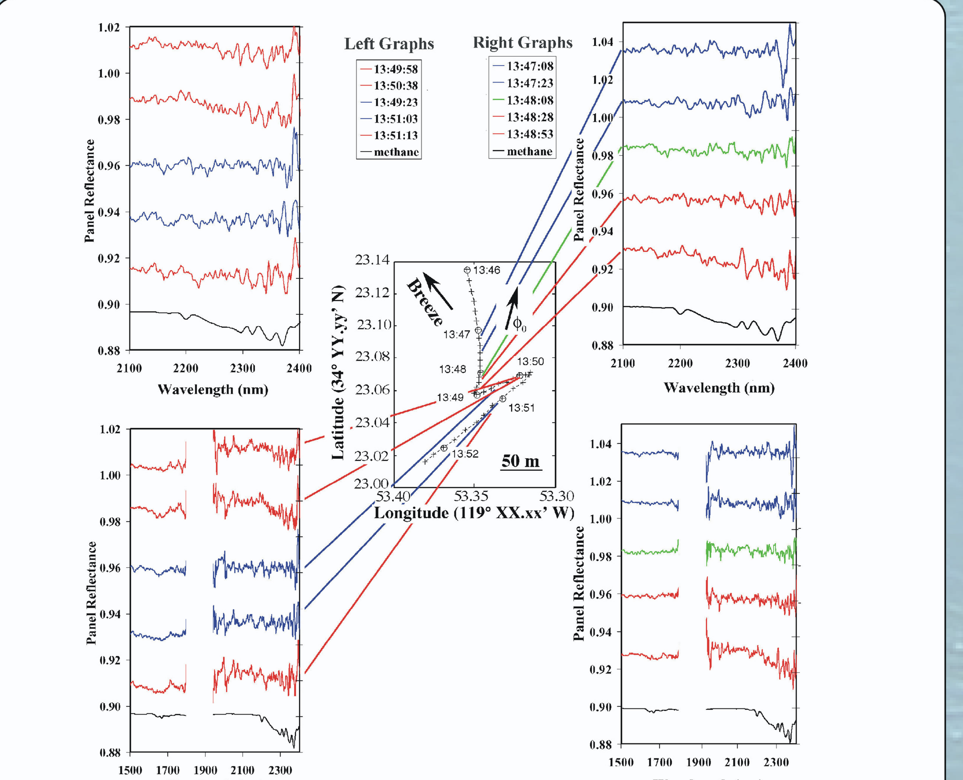




A) Methane mixing ratios recorded during a transect through the Seep Tent Seep. Locations are shown in B), ticks are every 10 s, circles every minute, times noted on figure. D) Methane at three heights (labeled on figure). 5-m height is multiplied by a factor of 100; 2.2 m height is multiplied by 0.01. Data was smoothed with a 1-s low pass filter. C) Three-dimensional plot of transect methane data at 3.6 m. Solar angle and wind direction on panel.

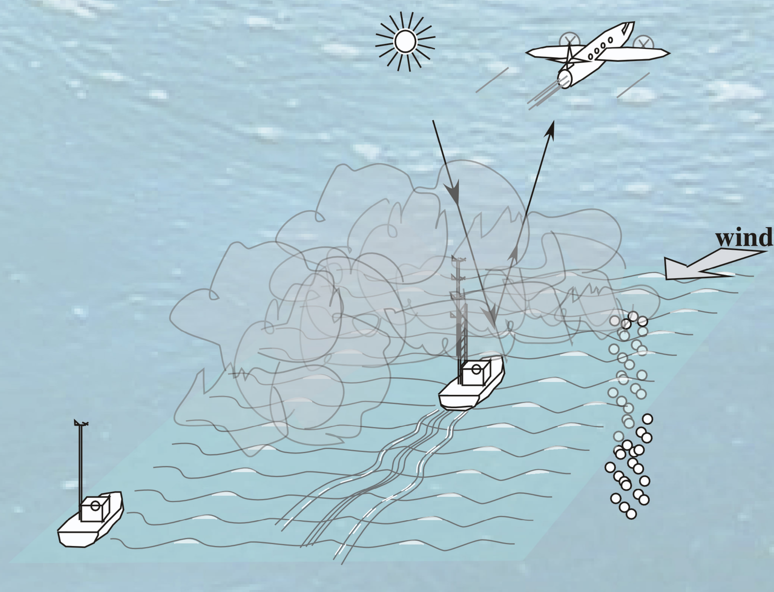


Some spectra showed clear methane signatures, similar to the lab seep gas (Blue), some did not (Red), and some were intermediate (Green).



Field spectra at various times along the boat trajectory showing strong methane absorption features (red), weak methane absorption features (blue), and intermediate absorption features (green). Upper panels show 2100 to 2400 nm wavelengths, while lower panels for a wider wavelength range (1500 to 2450 nm). In each panel, the lowest spectrum is from laboratory methane. Central panel shows boat trajectory. ϕ_o indicates solar direction (180° from the azimuth).

Conclusion and Future Efforts



A multipronged approach to assess the feasibility of remote sensing to measure atmospheric methane emissions was tested through laboratory and field studies and radiative transfer simulations. The study used natural marine hydrocarbon seeps due to the relative spectral uniformity of the sea surface, the locality of the seeps, and their clear identification by the visual and acoustic presence of bubbles.

These data represent the first attempt to use atmospheric measurements to investigate marine seep emissions. There was very good correlation between the *in-situ* methane plume observations and the appearance of methane absorption features in spectra where the solar pathlength passed through the methane plumes. Methane absorption features were confirmed by spectra obtained from the laboratory studies. Furthermore, the *in-situ* approach identified atmospheric methane sources from both bubble transport and air-water exchange from a dissolved plume.

Using a Gaussian plume fit to *in-situ* measurements of the methane plume originating from a seep area, radiative transfer calculations demonstrated that methane signatures from the seeps are within AVIRIS capabilities for a range of typical conditions. Using AVIRIS to identify methane emissions from the seeps was estimated to be feasible both from a Twin-otter (3 km altitude), and the ER-2 (20 km altitude). Field efforts are planned for 2008.