OFFSHORE HYDROCARBON SEEPAGE CHARACTERIZATION THROUGH SPECTROSCOPY, MULTIVARIATE STATISTICS AND OPTICAL REMOTE SENSING

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1. INTRODUCTION

Remote sensing has been a key tool for ocean slicks monitoring and new discoveries based on offshore seepage detection. In this context, this contribution has a two-fold objective. Firstly, in order to spectrally characterize hydrocarbons (HCs), we conducted VNIR-SWIR-TIR spectral measurements of petroleum samples yielded from large, off-shore oil fields sited at sedimentary basins of Brazil. Secondly, we employed these spectral signatures in an attempt to map and characterize a substantial HC seepage verified at the Campos basin (Rio de Janeiro coast – Brazil) using ASTER multispectral imagery.

2. HYDROCARBON CHARACTERIZATION BY VISIBLE-INFRARED SPECTROSCOPY

2.1. Materials and Methods

HCs samples yielded from foremost Brazilian basins were measured for: **(i)** Reflectance within the VNIR-SWIR interval **(ii)** Directional Hemispherical Reflectance (DHR) and Emissivity within the TIR interval. Samples were prepared simulating the behavior of an oil seepage (or spill) and other experiments previously described [1]. Experiments were conducted under conditions of controlled geometry, as well as under different periods of exposition of the oil to the environment. In order to evaluate the possibility to detect seepages remotely, HC spectra were resampled to the spectral resolution of Hyperion (220 bands/VNIR-SWIR) and ASTER (14 bands/VNIR-SWIR-TIR). Hydrocarbon spectra interpretation can be facilitated by means of multivariate statistics, considering principal component analysis (PCA) and partial least square analysis (PLS). Such analysis can assist the detection of patterns, clusters, similarities/dissimilarities, such as the API grade of oils. In addition, PLS allows for the computation of unknown response values; in this case API gravity, using a regression model [2], [3].

2.2. Results

Our measurements indicate that in the visible range crude oils have no diagnostic features, but low and flat reflectance spectra, which concurs with previous investigations. In contrast, diagnostic features were distinguished in the NIR-SWIR interval (Fig. 1a) (see also [4]). PCA and PLS of continuum-removed spectra of crude oil allowed the separation of oils according to the API gravity. The partial least-squares analysis (PLS) indicates Root Mean Squared Error of Prediction (RMSEP) of 0.59669 for the API gravity of the samples. PCA and PLS of continuum-removed spectra of oil standing over water and crude oil and oil/water spectra resampled to Hyperion and ASTER bandwidths also allowed a qualitative separation of HCs and API gravity prediction.

Direct measurements of emissivity and DHR (directional hemispherical reflectance) measurements converted to emissivity based on the Kirchhoff law ($E=1-R_{DHR}$) indicated that both crude oil and oil standing over water show lower emissivity than water (see also [1]). In addition, experimental results also prompted some key TIR spectral features (Fig. 1b). As for the VNIR-SWIR range, using the TIR interval it is also possible to qualitatively (API, viscosity) isolate different oil samples based on spectral features between 3-6.3 μm. However, in contrast to that achieved with ASTER/VNIR-SWIR bandwidths, crude oil spectra resampled to ASTER/TIR resolution (5 bands) are unable to segregate samples by their API. This outcome is predictable since all ASTER TIR bands are concentrated between 8-14 μm - a region where HCs produce no spectral features but a flat emissivity for oil and water.

3. CASE STUDY: CAMPOS BASIN SEEPAGE

A modern tool used for new oil discoveries in frontier areas is remote sensing (RS), mainly based on seepage detection by orbital images. Concurrently, there is a grown demand for real time pollution monitoring, which requires the usage of innovative RS techniques. Considering the laboratory progress discussed earlier, this case study aims the detection and qualitative classification of an offshore seepage. In November/2004, a large seepage was recorded by the sensor/satellite ASTER/TERRA. This seepage was positioned above the Campos basin (Marlim Field), which is situated on the continental platform/ slope of the southeastern Brazilian coast and is comprised in the largest operating petroleum province in the country.

3.2. Materials and Methods

For this study we employed an ASTER scene acquired by 23rd November 2004, obtained from NASA at processing level 1B, as well as AST_04, AST_05 and AST_08 Level-2 products and spectral data presented in the previous section. The pre-processing of ASTER image included: (i) cross-talk correction; (ii) conversion of radiance to apparent reflectance and atmospheric correction through the *Atmospheric CORrection Now* (ACORN) software, using the MODTRAN-4 model.

3.2.1. Partial Least Square Analysis

A PLS model using 77 laboratory spectra resampled to ASTER resolution and continuum-removed was built for the characterization of the HC seepage observed at the Campos basin. The model included all laboratory spectra acquired for oil over water and has a RMSEC of 3.5937 and a RMSEP of 3.9969.

3.2.2. Spectral Classification and Spectro-Spatial Classification by Neural Networks (NN)

In order to map the oil over water, we tested both spectral and neural network classification techniques. Spectral classification of n-dimensional data involves the comparison of the spectral signature of each image pixel, which has an unknown composition, with the spectral signature of reference materials, namely endmembers. Although originally developed for hypespectral data processing, this technique can be adapted to multiespectral data (i.e., ASTER) [5]. Digital classification of ASTER data by neural networks is useful for hydrocarbon seepage detection, since it aims to recognize hidden patterns in the scene pixels based on the available bands and spatial resolutions. For this classification, reflectance data were processed through an unsupervised NN system called *Fuzzy Clustering,* which is part of the GeoXplore software [6].

3.3. Results

3.3.1. Partial Least Square Analysis

Focusing on the qualitatively classification of seeped oil, 10 spectra obtained along the Campos seepage were inserted in the model described in section 3.2.1. The average result of API gravity obtained for the Campos seepage (Marlim field) was 19.6 +/- 1.37. The oil currently produced at the Campos Basin (Marlim) has a known °API between 17 and 21. Therefore, there is a plausible match between the real and the predicted API values. This is a demonstration, possibly for the first time, that the API grade of off-shore oil seepages can be indeed assessed using orbital images.

3.3.2. Spectral Classification and Spectro-Spatial Classification by Neural Networks

The best results of spectral classification were obtained using the linear spectral unmixing algorithm and endmembers extracted from the image considering VNIR-SWIR bands only. The advantage of this algorithm is that it considers that the reflectance spectrum of any pixel is a linear combination of the spectra of all endmembers inside that pixel; which are only water and oil in this case (Fig. 2). NN classification not only mapped the oil seepage, but also segregated patches of oil with different thickness over the ocean water (Fig. 3). This type of spectro-spatial analysis is particularly interesting for offshore seepage detection as it evaluates spectral and geometrical (shapes) variables, without requiring training points.

4. CONCLUSION

The spectral study presented here provided the identification of NIR-SWIR-TIR diagnostic features of crude oils, oil standing over water and oil-water emulsion. In this research, apparently for the first time, reflectance, directional hemispherical reflectance and emissivity spectra were tested for qualitative characterization of HCs.

The outcome seems very promising, since the qualitative separation of HCs (i.e. API, viscosity) was achieved, even when oil is over ocean water. Spectra extracted from ASTER pixels coinciding with known oceanic oil seepage and HC spectra obtained in laboratory were studied by PLS. This analysis permitted a unique prediction of the API gravity of the off-shore seepage here analyzed. The overall results comprised in this contribution represent an important progress for HC seepage detection and characterization.

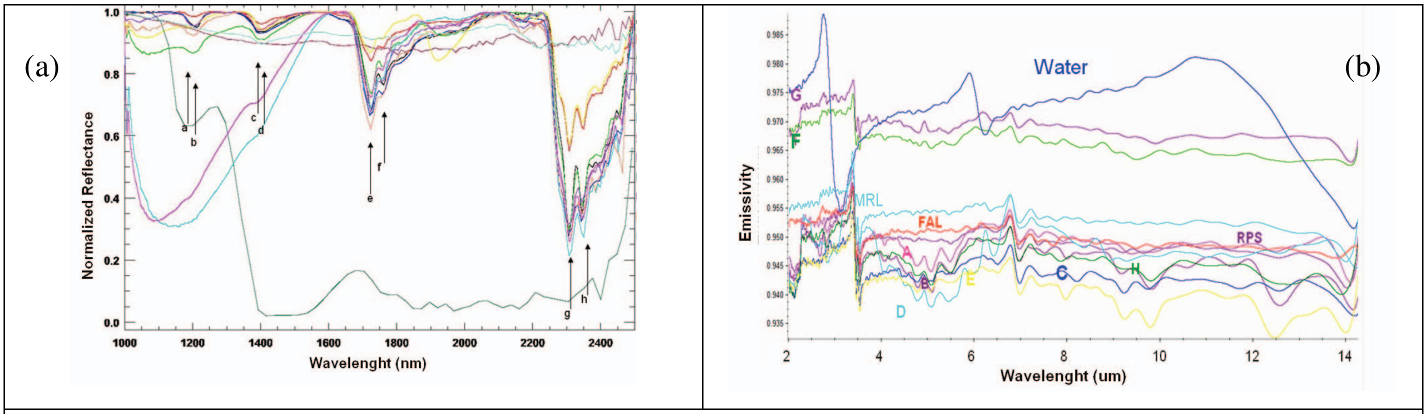

Figure 1. (a) NIR and SWIR spectra of crude oils. **(b)** Emissivity (TIR) spectra of crude oils and sea water. Spectra derived from DHR measurements and converted to emissivity based on Kirchhoff's law.

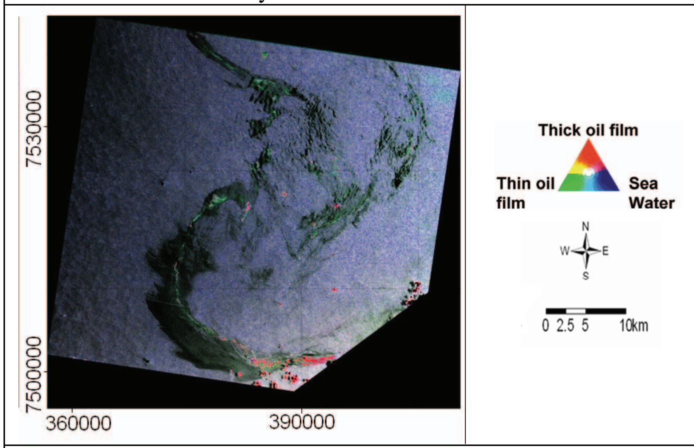

Figure. 2. Abundance map yielded by linear spectral unmixing of ASTER VNIR-SWIR data, considering endmembers (thick oil, thin oil and sea water) extracted from scene pixels.

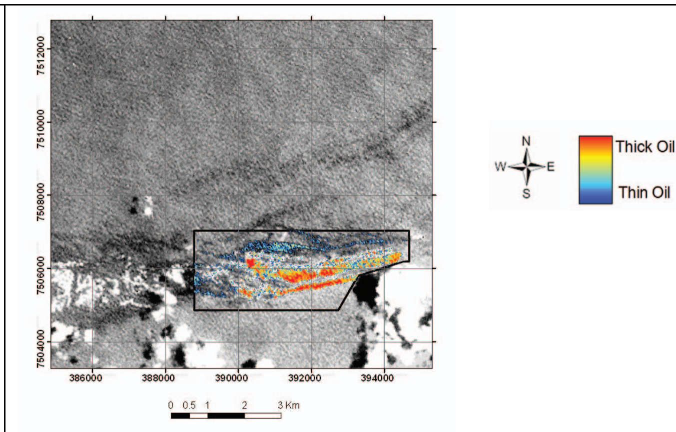

Figure 3. Section of the oil seepage mapped by spectro-spatial analysis through unsupervised, fuzzy clustering neural network.

5. REFERENCES

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