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TECHNIQUES FOR MEASURING ATMOSPHERIC CO2 USING HYPER SPECTRAL IMAGING

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Abstract: CO2 is a greenhouse gas that plays vital role in regulating Earth's surface temperature through radiative forcing and greenhouse effect. Airborne sensors have a great potential of measuring carbon dioxide emissions at local and regional scale. For measuring CO2 using hyperspectral data provided by airborne sensor (AVIRIS), a radiative transfer simulation is carried out for applying different techniques. This paper describes different techniques for measuring concentration of atmospheric CO2 using hyperspectral imaging includes, Cluster- Tuned Matched Filter (CTMF), Joint Reflectance and Gas Estimator (JRGE), Spectral Fitting Algorithm, Continuum Interpolated Band Ratio (CIBR).

Keywords: Carbon Dioxide, Hyperspectral data, AVIRIS

I. INTRODUCTION

CO_2 is an integral part of carbon cycle, photosynthesis and global warming. CO_2 absorbs electromagnetic radiation, this absorbed energy at different wavelength add heat in atmosphere. The higher the concentration of greenhouse gases like carbon dioxide in the atmosphere, the more heat energy is being absorbed by Earth's atmosphere, which causes global warming. So measurement of it is needed to reduce the concentration of it. Airborne sensors have potential measuring carbon dioxide emissions at local and regional scale. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) was the first imaging sensor to measure the solar reflected spectrum from 400 to 2500nm at 10 nm intervals. These radiance spectra are measures as images of 11km width and up to 800 km length with 20 m spatial resolution. AVIRIS spectral images are acquired from the Q-bay of a NASA ER-2 aircraft from an altitude of 20,000m. Radiative Transfer Models are use for simulate the spectrums of AVIRIS data. There are different radiative transfer models developed globally to study different phenomena. Some of them are MODTRAN, LOWTRAN, ATCOR, LibRadtran, etc.

II. RELATED WORK

Past and ongoing satellite mission have provided the ability to monitor global carbon dioxide concentrations at coarse spatial resolution, including the Atmospheric Sounding Interferometer (ASI: Crevoisier et al. 2009), the Atmospheric Infrared Sounder(AIRS: Jiang Chahine, Olsen, Chen & Yung, 2010), the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY: Schnesing et al., 2008), Greenhouse Gas Observing Satellite (GOSAT: Saitoh, Imasu, Ota, & Niwa, 2009), the Orbiting Carbon dioxide Observatory(OCO-2), Carbon Monitoring Satellite (CarboSat; Velazo et al., 2011). Airborne sensors offer the potential to better constrain local emissions. The researchers at NASA had main objective was to establish minimum carbon dioxide anomalies as thresholds for plume detection in simulated images and in AVIRIS C data acquired over power plants[1]. R. Marion, R. Michel and C. Faye developed a method Joint Reflectance and Gas Estimator (JRGE) to estimate a set of atmospheric gas concentrations in an unknown surface reflectance context from hyperspectral images[2]. The main objective of this paper was to provide a comprehensive mathematical framework for the joint retrieval of gas absorber amounts and ground reflectance from hyperspectral data. Robert O. Green developed a simple spectral fitting algorithm to attempt to quantify the carbon dioxide abundance in each AVIRIS spectrum[3]. C Spinetti, V Carrere, M F Buongiorno, A J Sutton, and T Elias had implemented the basic concept of the CIBR to retrieve the volcanic CO2 columnar abundance and then the CO2 concentration, developed a new mapping technique in the wavelength range from 1900nm to 2100nm where CO2 molecules have an absorption lines[4].

III. METHODOLOGY

There are different techniques available for measuring concentration of atmospheric CO2.

A. Cluster-Tuned Matched Filter (CTMF):

Firstly carry out the simulation analogous to AVIRIS data using radiative transfer model. Radiative transfer model calculates different simulated spectrum based on different values of reflectance, water vapour concentration, solar zenith angle, path length, aerosol optical depth for 2000 and 2060 nm wavelength. Then, simulated spectrums are convolved using the sensor response function of AVIRIS. Now calculate a residual radiance by subtracting the spectrum with no elevated carbon dioxide concentration. To determine minimum detectable carbon dioxide anomalies a residual radiance values are compared to the noise equivalent delta (NEdl) radiance of AVIRIS. NEdl is the minimum change in radiance distinguishable from sensor noise. NEdl values were calculated from sensor specific radiometric models that included photon and read noise for each spectral band. Apply CTMF detection algorithm to the simulated spectrum. CTMF use k-means algorithm for clustering the pixels. Then a match filter tuned for each cluster is applied to the image using equations:

Where, j is for cluster, �� is the CTMF and represents and n-dimensional vector of optimal weights, n is the number of spectral bands, inverted covariance matrix, b is the n-dimensional target spectrum, is a n-dimensional vector for the ith pixel in class j, f is the resulting CTMF score.

CTMF score shows in fig. 1is the carbon dioxide anomalies. The highest positive score shows the source point of carbon dioxide.

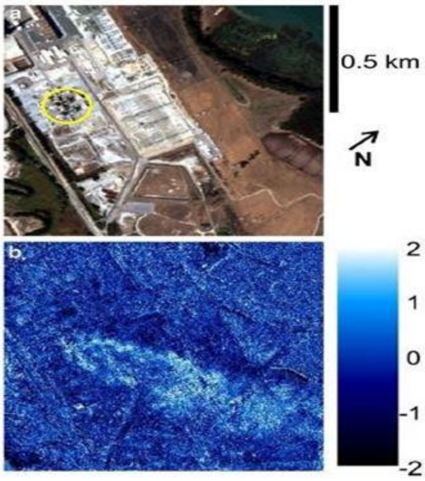


Fig. 1 a) A true color composite of a 2011 AVIRIS C image. Moss Landing power plant is in the center left portion of the image, with the location of four stacks indicated by the circle. b) CTMF scores for the same AVIRIS C image [1].

B. Joint Reflectance and Gas Estimator (JRGE)

This is a two step algorithm which first estimates the surface reflectance and then the densities of the plume gases. It is based on mathematical description of the physical characteristics of the signal. Surface reflectance estimator, firstly construct the smoothing spline estimator then choose the smoothness parameters to controls the tradeoff between the fidelity to the data and the global smoothness of the reflectance estimator.

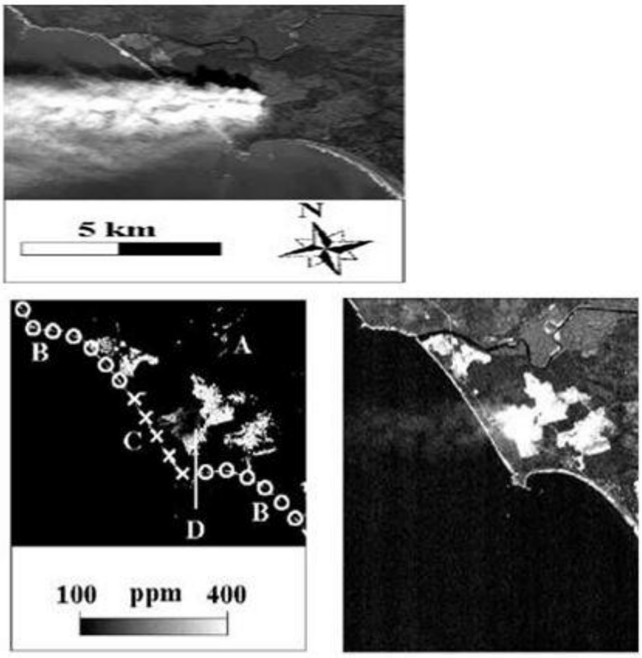


Fig. 2. AVIRIS images of Quinault prescribed fire (47.32 N, 124.27 W, AVIRIS 092194, run 10, scene 1, flight altitude: 20 km). (a) ��= 568:65 nm. West–northwest plume includes high concentrations of aerosols with typical high radiance value. (b) CO concentrations map computed for pixels with reflectance =0:1 within CO absorption bands. (Area A) Pixels not affected by burn. (Area B) Beach section (sand only) not affected by burn. (Area C) Beach section (sand only) under smoke plume. (Area D) High concentrations of aerosols near fire. (Black area) Algorithm not applied. (c) λ = 2057:50 nm. Near-infrared image within CO absorption band. Slight radiative effect of aerosols within plume and hot fire pixels are discernible [2].

C. Spectral Fitting Algorithm:

In addition to carbon dioxide features, the AVIRIS spectrum contains the integrated effects of the solar irradiance source, two-way transmittance, and scattering of the complete atmosphere and reflectance of the surface. These effects are modeled by radiative transfer model in modeled spectrum accounts for the source, atmosphere, surface, and geometry of the modeled observation. Radiative transfer code calculate a series of high- spectral-resolution spectra for the AVIRIS data set with varying amounts of carbon dioxide in thetmosphere by using AVIRIS observation geometry. These spectrums are convolved to the AVIRIS spectral calibration characteristics. Then normalize factors are calculated near 1985 and 2095 nm. These normalized factors are then linearly interpolated for the intervening AVIRIS spectral values. The absolute value of the difference between the AVIRIS measured spectrum and each simulated spectrums is calculated. The carbon dioxide value of the simulated spectrum gives the best fit is reported as the derived value for that AVIRIS spectrum.

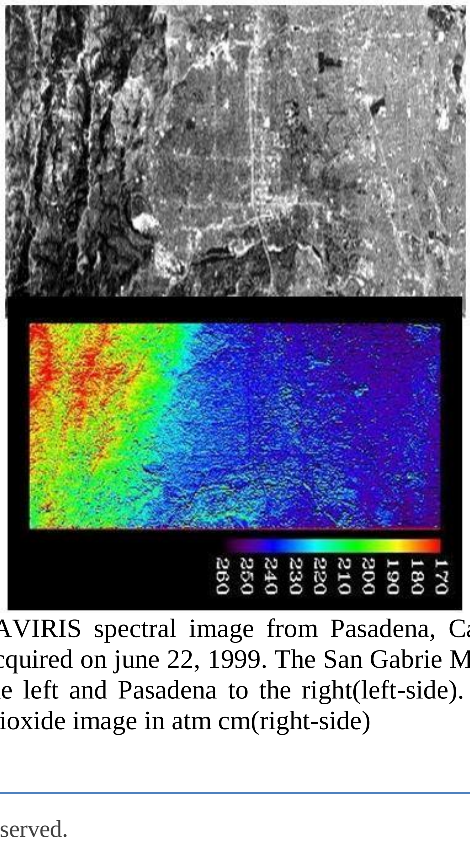


Fig. 3. AVIRIS spectral image from Pasadena, California, region acquired on june 22, 1999. The San Gabrie Mountains are to the left and Pasadena to the right(left-side). AVIRIS carbon dioxide image in atm cm(right-side)

D. Continuum Interpolated Band Ratio (CIBR):

This technique is based on the assumption that CO2 absorption lines in the spectrum are related to the CO2 concentration in the atmospheric column; the higher the gas concentration, as deeper the gas absorption lines. CIBR is use to retrieve the volcanic CO2 columnar abudance. The retrieval is based on solving the following equation:

$$CIBR = \text{[illegible]}\{-\propto(\text{[illegible]}).[CO_2]^{\beta(\text{[illegible]})}\} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Where,

$$CIBR = \frac{L_m}{\text{[illegible]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Lm is the band interpolated radiance, i.e. the radiance corresponding to the minimum of the gas.

L [illegible] and L [illegible] are the two neighboring channels radiances outside the absorption region.

a and *b* are weighing coefficients (*a* + *b* = *1*) defined by the following expression:

$$\text{[illegible]} = \frac{\lambda_{\text{[illegible]}} - \lambda_m}{\text{[illegible]}} \quad \text{and} \quad \text{[illegible]} = \frac{\lambda_m - \lambda_{\text{[illegible]}}}{\text{[illegible]}}$$

$\propto$ [illegible] and [illegible] are the parameters related to the model variables, volcanic wapor concentration and volcanic aerosol respectively.

$[CO_2]$ is the unknown carbon dioxide columnar abundance(kg/m^2).

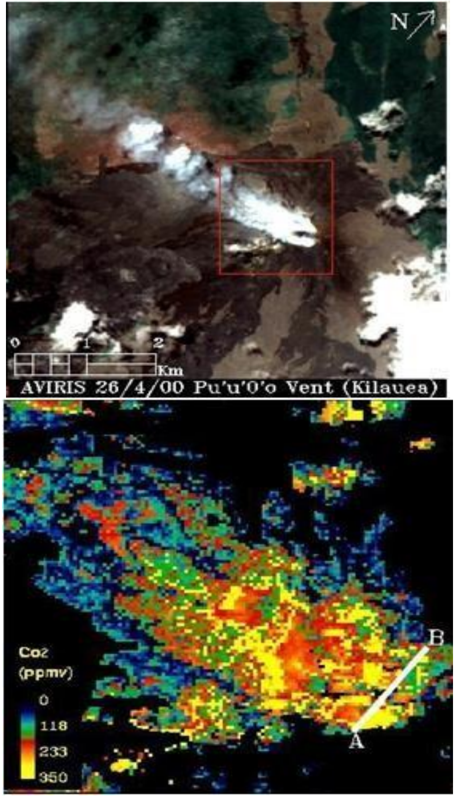
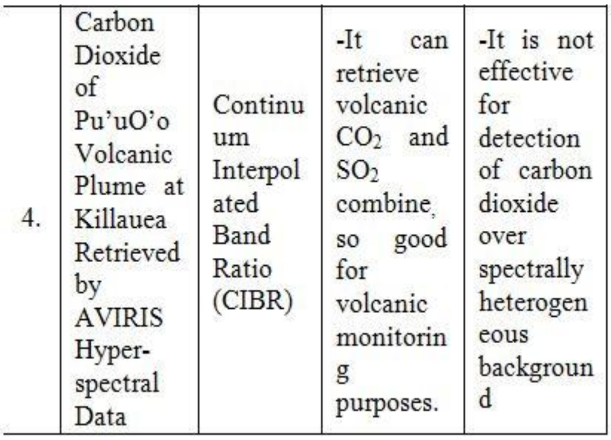


Fig. 4. Map of volcanic plume carbon dioxide on the left-hand side and AVIRIS image of Pu’uO’o vent plume acquired on 26th April 2000 in RGB composition on the right-hand side [4].

IV. COMPARISION

Sr No.	Title	Method	Advantages	Disadvantages
1.	High spatial Resolution mapping of elevated atmospheric carbon dioxide using airborne imaging spectroscopy: Radiative transfer modeling and power plant plume detection	Cluster-Tuned Matched Filter (CTMF)	-It is less sensitive to heterogeneous background	-Reduce delectability of carbon dioxide when signal to noise ratio is low and over dark surface
2.	Measuring Trace Gases in Plumes From Hyperspectral Remotely Sensed Data	Joint Reflectance and Gas Estimator (JRGE)	- A framework for the retrieval of both ground reflectance and trace gas amounts from hyperspectral remotely sensed data	-It is applicable for aerosol free atmosphere
3.	Measuring the Spectral Expression of Carbon Dioxide in the Solar Reflected Spectrum with AVIRIS	Spectral Fitting Algorithm	-Simple method and given correct result in Pasadena, California, region.	- Simulated spectrums must have to match with AVIRIS spectrum



4.	Carbon Dioxide of Pu'uO'o Volcanic Plume at Killauea Retrieved by AVIRIS Hyper-spectral Data	Continuum Interpolated Band Ratio (CIBR)	-It can retrieve volcanic CO_2 and SO_2 combine, so good for volcanic monitoring purposes.	-It is not effective for detection of carbon dioxide over spectrally heterogeneous background

V. CONCLUSION

This paper described different techniques for retrieval of atmospheric CO2 from airborne sensor data. Each technique has its own advantages and disadvantages, But CTMF (Cluster-Tuned Matched Filter) and CIBR (Continuum Interpolated Band Ratio) give more accurate results than other techniques. Based on our requirement we can improve these techniques.

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REFRENCES

[1] Philip E. Dennison, Andrew K. Thorpe, Eric R. Pardyjak, Dar A. Roberts, Yi Qi, Robert O. Green, Eliza S. Bradley, Christopher C. Funk," High spatial Resolution mapping of elevated atmospheric carbon dioxide using airborne imaging spectroscopy: Radiative transfer modeling and power plant plume detection", Remote Sensing Environment 139 (2013) 116-129.

[2] R. Marion, R. Michel and C. Faye,"Measuring Trace Gases in Plumes From Hyperspectral Remotely Sensed Data", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 42, NO. 4 APRIL 2004.

[3] Robert O. Green, "Measuring the Spectral Expression of Carbon Dioxide in the Solar Reflected Spectrum with AVIRIS", Tenth Annual JPL Airborne Earth Science Workshop, 2001.

[4] C Spinetti, V Carrere, M F Buongiorno, A J Sutton, and T Elias, "Carbon Dioxide of Pu'uO'o Volcanic Plume at Killauea Retrieved by AVIRIS Hyper-spectral Data", Remote Sensing of Environment 112(2008)3192-3199.

[5] National Oceanic & Atmospheric Administration (NOAA) – Earth System Research Laboratory (ESRL), Trends in Carbon Dioxide Values given are dry air mole fractions expressed in parts per million (ppm). For an ideal gas mixture this is equivalent to parts per million by volume (ppmv).

[6] George Joseph, Fundamental of Remote Sensing, 2nd Edition; Universities Press (India) Private Limited Hyderguda, Hyderabad , 2005.

[7] Robert O. Green, Michael L. Eastwood, Charles M. Sarture, Thomas G. Chrien, Mikael Arosson, Bruce J. Chippendale, Jessica A. Faust, Betina E. Pavri, Christopher J.Chovit, Manuel Solis, Martin R. Olah, and Orlesa Williams, "Imaging Spectroscopy ad the Airborne Visible/Infrared Imaging Spectrometer(AVIRIS)", REMOTE SENS. ENVIRON, 65:227-248(1998).

[8] Libradtran- Library Of Radiative Transfer Model, for calculating radiances, irradiance, and actinic fluxes in the solar and thermal spectral regions. http://www.libradtran.org

[9] Michael E. Schaepman, Susan L. Ustin, Antonio J. Plaza, Thomas H. Painter, Jochem Verrelst, Shunlin Liang," Earth system science related spectroscopy- An assessment", Remote Sensing of Environment 113 (2009) S123-S137.

[10] Prubhunath Prasad, Shantanu Rastogi, R. P. Singh, "Study of satellite retrieved CO2 and CH4 concentration over India", Advances in Space Research 54 (2014) 1993-1940

[11] Zhagn Miao, Zhang Xing-Ying, LIU Rui-Xia, HU Lie-Qun, " A study of the validation of atmospheric CO2 from satellite hyper spectral remote sensing", Advances in Climate Change Research 5 (2014) 131-135