Satellite assisted aerosol correlation in a sequestered CO_2 leakage controlled site

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ABSTRACT

Currently one of the main challenges in CO_2 storage research is to grant the development, testing and validation of accurate and efficient Measuring, Monitoring and Verification (MMV) techniques to be deployed at the final storage site, targeting maximum storage efficiency at the minimal leakage risk levels. For such task a mimetic sequestration site has been deployed in Florianopolis, Brazil, in order to verify the performance of monitoring plataforms to detect and quantify leakages of ground injected CO_2, namely a Cavity Ring Down System (CRDS) - Los Gatos Research - an Eddy Covariance System (Campbell Scientific & Irgason) and meteorological tower for wind, humidity, precipitation and temperature monitoring onsite. The measurement strategy for detecting CO_2 leakages can be very challenging since environmental and phytogenic influence can be very severe and play a role on determining if the values measured are unambiguous or not. One external factor to be considered is the amount of incoming solar radiation which will be the driving force for the whole experimental setup and following this reasoning the amount of aerosols in the atmospheric column can be a determinant factor influencing the experimental results. Thus the investigation of measured fluxes CO_2 and its concentration with the aforementioned experimental instruments and their correlation with the aerosol data should be taken into account by means of satellite borne systems dedicated to measure aerosol vertical distribution and its optical properties, in this study we have selected **CALIPSO** and **MODIS** instrumentation to help on deriving the aerosol properties and CO2 measurements.

Keywords: Carbon Sequestration, Aerosols, CALIPSO, MODIS

1. INTRODUCTION

The geologic sequestration of carbon dioxide (CO2) from the combustion of fossil fuels is one of the most acceptable mitigation method for greenhouse gas. Quite a number of sites, both at pilot of near industrial scale have been deployed in the recent past years.[1] The efforts so far were concentrated in the geological aspects of the sites being used and ancillary technology for continuous monitoring of leakages that might origin from the gases being sequestered or from other sources which could not have been correctly assessed when the site was established. Most of the methodology lays on the simulation of leakages of CO2 to the surface in order to determine if various monitoring techniques have the ability to detect and quantify the CO_2 lost to the atmosphere.[2,3] In September 2013, it was carried out the first CO_2 injection campaign on the The Ressacada

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Farm CO_2 MMV Lab, in which discrete, small volumes of gaseous food-grade industrial CO_2 with ($\delta^{13}C$ signature of -32 ppmil were injected into the ground, tdown to 3 m in depth. After some latency time, which was one of goal variable to be obtained, the injected gas then naturally released into the atmosphere, which enabled us the simulation of a steady and continuous leak event. This field campaign was run over 12 days, for 24 hours a day, at injection rate levels low enough not to offer any risks to the formation integrity and enabled the simultaneous assessment of CO_2 behavior in the soil, in the groundwater, at the surface and in the air. In this paper we introduced the aerosol contents in the atmosphere present during the injection campaign by means of CALIPSO and MODIS sattelites and their aerosol products in order to have a correlation with the leakeage events and the atmospheric aerosol content and optical properties at that time in a sense the aerosol could modulate the radiation reaching the ground and thus enhancing or not the leak rate as well observing the presence of different sources of aerosol which could be together withother remote source gases brought into the site and thus affecting the overall CO_2 contribution into the field area with the caveat our gas amounts were this time very small still detectable by some of the instruments *in situ*.

2. SITE OVERVIEW

The Brazilian Pilot Project, or The Ressacada Farm CO2 MMV Lab,[4] was installed at Santa Catarina Federal University (UFSC), in Florianopolis, Santa Catarina State, Brazil, is an experimental cell with an area of $6.28\,km^2$, geolocated at $27^o41'2.19''$S and $48^o32'42.11''$W, made available for the R&D Project by the University Agronomic Sciences Department (UFSC/CCA). The site location choice was justified by complying regulatory and geophyscal rules for deploying experimental projects targeting soil and aquifer remediation A panoramic view of the research carried out at *Ressacada* site shown in figure 1

Figure 1. Ressacada Experimental Site: From left to right panel (a)&(b) location in Brazil and mesoscale; (c) local scale.

3. INSTRUMENTATION

3.1 In-situ Equipment

Atmospheric measurements included a CO_2/H_2O Open Path Eddy Covariance System (OPECS/ECS)(IRGASON Campbell Scientific, Inc.) mounted 8 m upwind of the CO_2 injection point, and a CO_2 ($\delta^{13}C$) Isotope Gas Analyzer (IGA) (Carbon Dioxide Carbon Isotope Analyzer, model 912-0003, Los Gatos Research Inc.), with the sampling line and detector sheltered downwind of the well. The ECS measurements had a fast response component (IRGASON+Sonic anemometer) and a slow one (meteorological tower). A complete set of meteorological sensors was installed on site on a 10 m high meteorological tower (UT30, Campbell Scientific Inc). The whole surface meteorology kit included: horizontal wind speed and direction; atmospheric pressure; atmospheric temperature; rain gauge (Campbell, TB4); total radiation. A 2-D sonic anemometer and the CO_2/H_2O detectors were assembled in a 2-m high tripod next to the meteorological tower. Data were collected on a continuous basis,

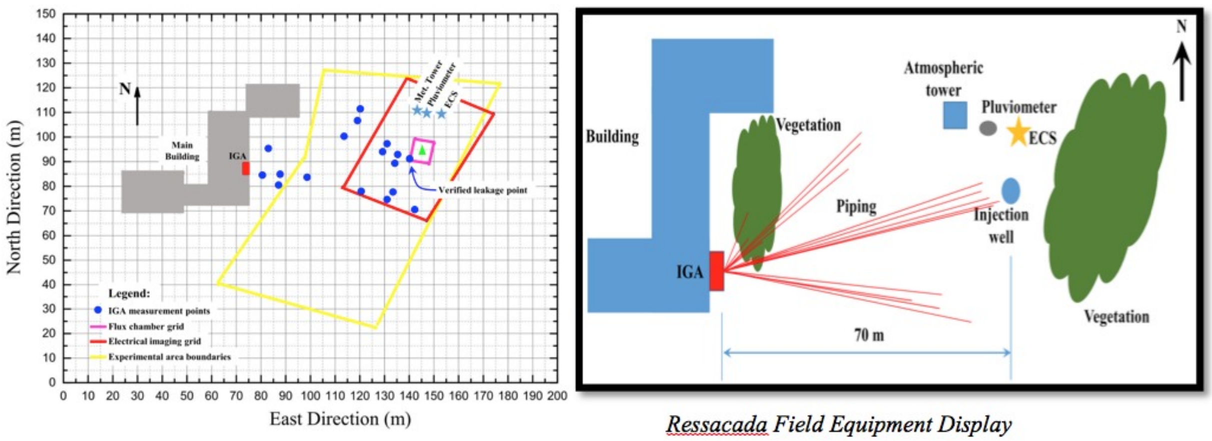

Figure 2. Ressacada Experimental Site: Equipment location and field display.

being stored at a 20 Hz frequency digital datalogger with wireless transmission (CR 1000 Campbell Scientific Inc / CM1000 + NL 340). Additionally, data could be stored in memory cards or transmitted via modem to the local network, from which they were periodically downloaded. Energy supply was granted by the solar panels installed on the tower. The whole setup diagram can be seen in Figure 2.

3.2 SatteIite based Instruments

The CALIPSO satellite was launched in April 2006 and flies in a 705 km sun-synchronous polar orbit with an equator-crossing time of about 13:30 local solar time, covering the whole globe in a repeat cycle of 16 days.[5] The CALIOP data products are assembled from the backscatter signals measured by the receiver system and are divided in two categories: level 1 products and level 2 products. Level 1 products are composed of calibrated and geolocated profiles of the attenuated backscatter signal and are separated into the total attenuated backscatter profile at 1064 nm, the total attenuated backscatter profile at 532 nm (i.e., the sum of parallel and perpendicular signals) and the perpendicular attenuated backscatter signal at 532 nm.[5,6] The level 2 products are derived from the level 1 products and three different level 2 products are distributed according to the layer products, profile products and the vertical feature mask (VMF). The set of CALIPSO algorithms uses an aerosol classification scheme to assign each aerosol layer to one of the six aerosol types, dust, biomass burning, clean continental, polluted continental, marine, and polluted dust.[7] The MODIS sensor is on board the polar orbiting satellites AQUA launched in 2002. The sensor was the first designed to obtain global observations of aerosols with moderate resolution (between 250m and 1000m depending on the wavelength used). MODIS has 36 spectral bands between 0.4 and 14.5 μm, allowing the generation of several products related to aerosol, such as aerosol optical depth over the ocean and land with a resolution of 10x10 km (at nadir), and the size and type distribution over oceans and type of aerosol over the continent.[8,9] In this study 550 nm AOD product from aerosol Level 2 were used. The overpasses closest to experimental site are shown in Figure 3.

4. RESULTS

4.1 CO_2 Measurements

From August 29^{th} to October 1^{st} 2013, pre-injection and post-injection background measurements were conducted. The same measuring tools were deployed throughout the CO_2 injection campaign, which took place from September 10^{th} thru 21^{st} 2013. Background conditions indicated CO_2 average atmospheric concentrations around 388 $\pm$ 5 ppmV and isotopic ratio $\delta^{13}C$ signature ranging between -6 to -15 ppmil; average CO_2 atmospheric fluxes were predominantly negative around -20$\mu mol\ s^{-1}\ m^{-2}$. The whole period is depcted in Figure 4 showing the variance enhancement after the CO_2 injection, however one can notice the average values does not

Figure 3. CALIPSO Overpasses over Ressacada Experimental Site

overcome 460 ppm. During the injection period, the average conditions were slightly higher: 410 to 450 ppmV of CO_2 concentration and isotopic ratio about -17 ppmil. There was a recorded peak measurement, the highest atmospheric concentrations (maximum leakage) were registered on September 21^{st}, with peak concentrations around 1200 ppmV and isotopic ratio of -25 ppmil. These numbers seem to confirm a perturbation likely to be derived from our controlled leakage experiment, but also indicated that there was considerable dilution due to the atmospheric air. Atmospheric flux values ranged from -30 to $+20 \mu mol\ s^{-1}\ m^{-2}$ during the release, with the caveat that there may be some compromise due to intermitent rainfall. Figure 5 shows the detected fluxes obtained by the ECS system which presents the same temporal evolution as the concentration ones. The pair of systems, namely the ECS and CRDS-LRG are compared in Figure 6 which allow us to realize the same response in almost all events, with the exception of September $09th$ were there is a lag of one day between each day, when the CRDS system had a peak one day ealier then the ECS.

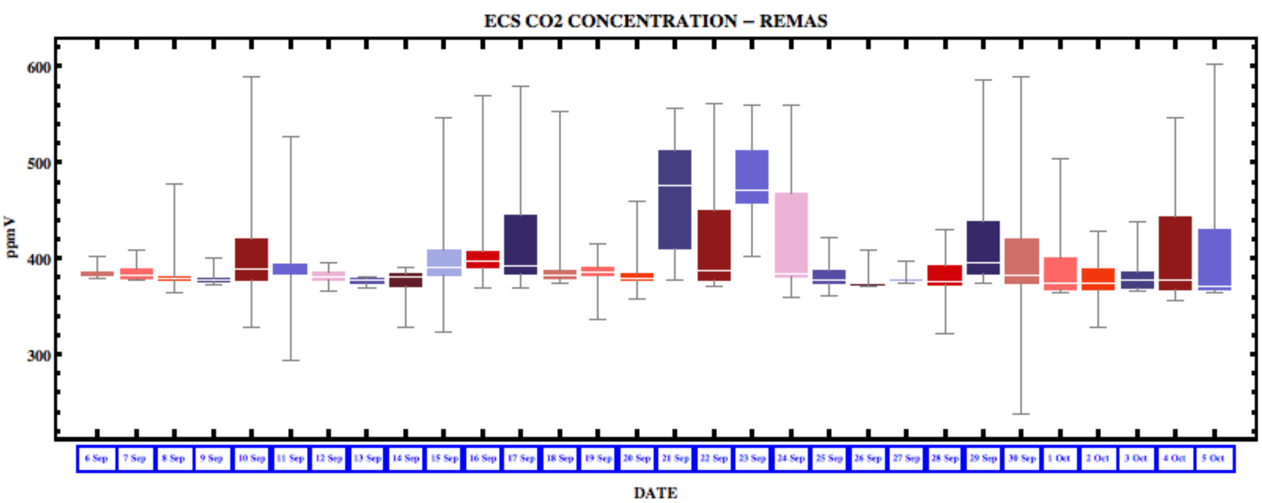

Figure 4. CO_2 concentrations extracted from the ECS during the Induced Leakeage Campaign.

4.2 Aerosol optical properties

A total of 6 overpasses of the CALIPSO satellite occured during the period of September, 01^{st} to $30t^{th}$ 2013 over the Ressacada Site. All the selected overpasses ocurred within the horizontal distance of 22.5 and 93.3 km. The red dot represents the Ressacada-UFSC campus where the field campaigns were conducted and the green lines

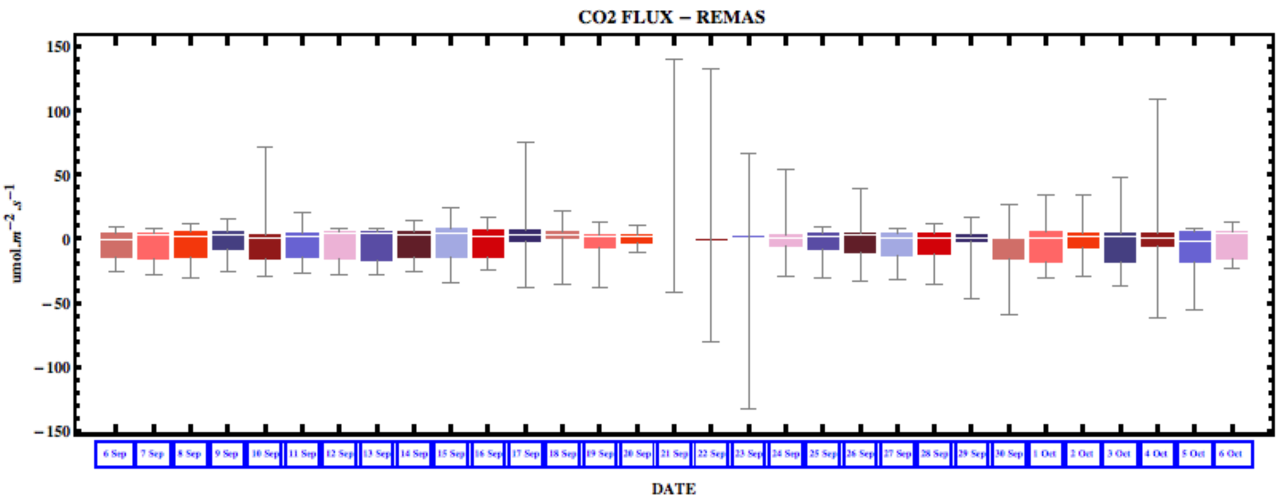

Figure 5. CO_2 fluxes extracted from the ECS during the Induced Leakeage Campaign.

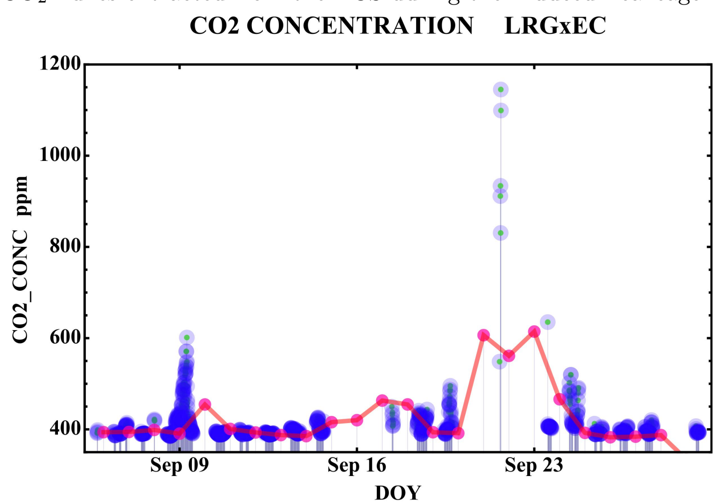

Figure 6. CO_2 concentration extracted from the ECS vs LRGS during the Induced Leakeage Campaign.

are the CALIPSO overpasses for the campaign period. From the Total attenuated backscatter profiles at 532 nm at the maximum altitude of 6 km, there are no defined aerosol layers on the measuring on September 22^{th} and September 29^{th}. The total attenuated backscatter signal was attenuated due mid and high altitude clouds between 5 to 10 km of altitude for measurements on September 22^{th} and low altitude clouds, around 1.5 km of altitude. The Total attenuated backscatter profiles at 532 nm at the maximum altitude of 6 km are presented in figure 3. Each Total attenuated backscatter profile was average at 300 profiles with 333 meters of horizontal resolution, given a total of 100 km of horizontal resolution. As can be seen, there are no defined aerosol layers on the measuring on September 22^{th} and on September 29^{th} there was detected only backscatter signal from low clouds. Figure 7 shows the histogram of AOD distribution retrieved by CALIPSO satellites over the region of Ressacada-UFSC during the period of 1st to 30th September 2013 using the 532 nm channel. As can be seen, AOD for smoke aerosol achieved values of approximately 0.5. Figure 8 shows the aerosol classification type by CALIPSO satellite for the same period. Mostly of aerosols detected were classified as Polluted Continental or smoke, with a lidar ratio value of 70 sr. 25% of aerosols are classified as smoke (type 6), around 23% are classified as polluted continental (type 5) and 24% are classified as clean marine (type 1). As can be seen in Figure 9, the AOD for CALIPSO and AQUA agrees very well with September 6th, 10th, 13th. However, AOD from AQUA is very lower for 26^{th}, probably due any cloud contamination in the retrieval. For CALIPSO and

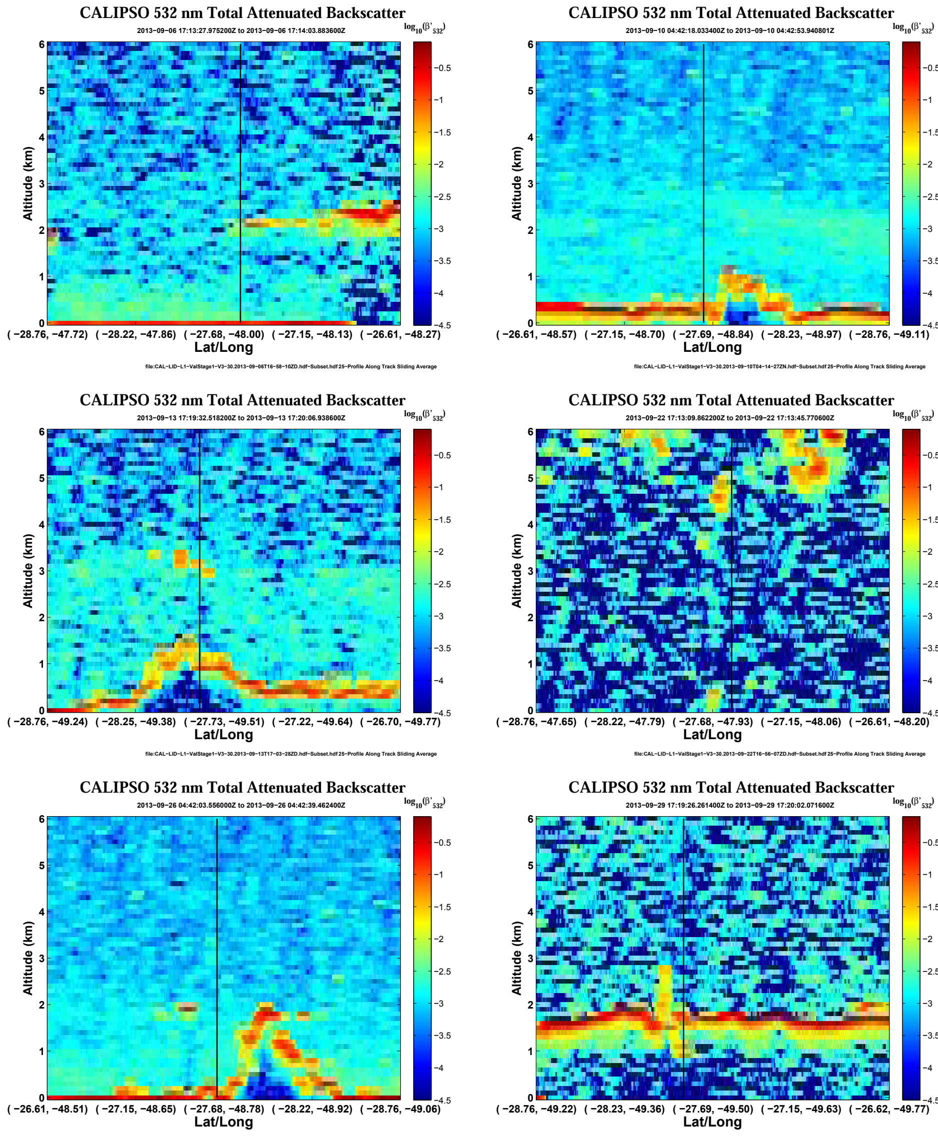

Figure 7. Total attenuated backscatter profiles at 532 nm measured by the CALIPSO satellite over the region of Ressacada-UFSC during the period of 1^{st} to 30^{th} September 2013.

TERRA comparisons, CALIPSO AOD agrees very well with TERRA AOD for 10^{th} and 13^{th}, however, there are not good agreements for September 06^{th} and 26^{th}. Maybe because of atmospheric chances during the day since TERRA overpasses Ressacada site during the morming and CALIPSO overpasses was during afternoon. On September 22^{th} and 29^{th} there are no AOD retrievals due cloud contamination. Regionally the AOD variation according to latitude retrieved by CALIPSO showed very little variation as the site is located nearby the largest city in the area. Besides beggining in September 6^{th} there is an increase in the aerosol load as one can see an increase in the AOD values MODIS plataform not observed in CALIPSO as there was no close overpass, following there is a decrease to a minimum AOD in September 9^{th} followed by an increase until Spetember 14^{th} when a cold front reached the site and given the cloud cover there was no mean to extract the aerosol during this period. From the previous Figure 7 there are elements of air mass transport in September $6th$, $13th$ and $26th$ that together with the information of Figure **??** when showed the most predominant aerosols were clean marine (type 1) and biomass burning (type 6), the latter always is followed by an increase in combustion products such as CO, NO_x and CO_2.

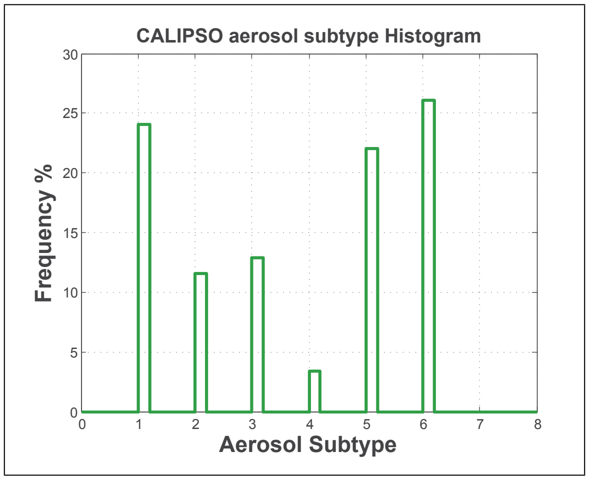

Figure 8. Histogram of Lidar ratio and aerosol subtype according to the CALIPSO satellite classification over the region of Ressacada-UFSC during the period of 1^{st} to 30^{th} September 2013.

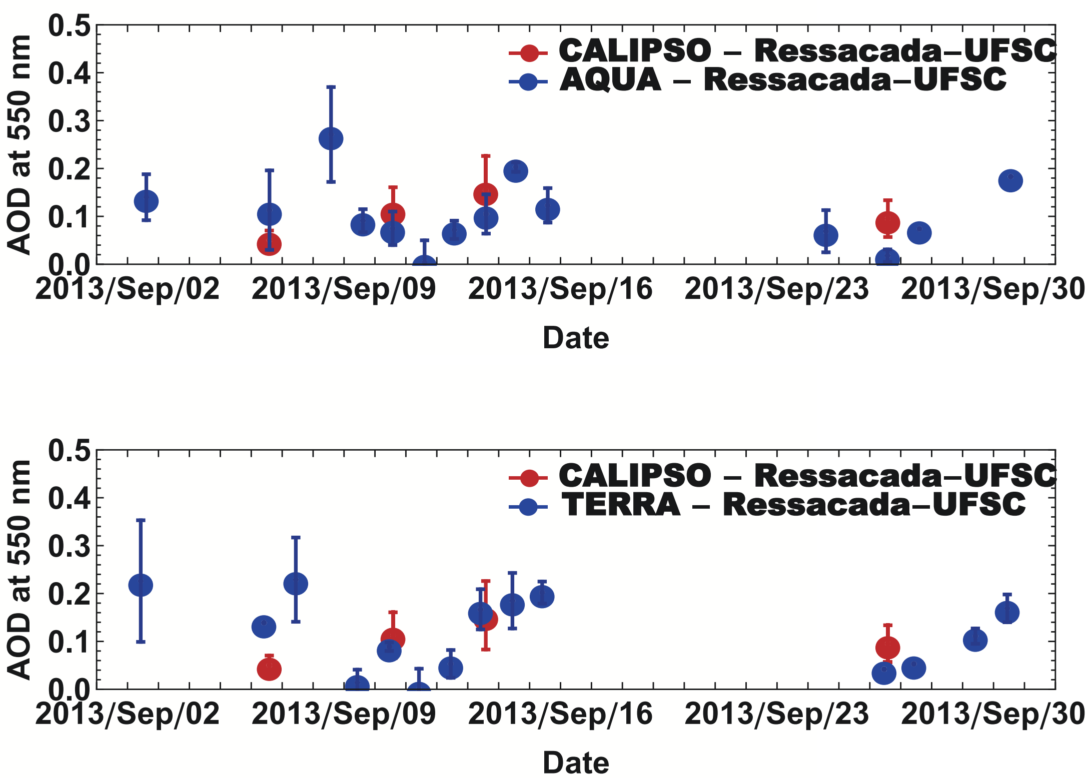

Figure 9. AOD distribution for AQUA and TERRA satellite and also for CALIPSO satellite over the region of Ressacada-UFSC during the period of September 1^{st} thru 30^{th} 2013.

5. CONCLUSIONS

We showed here some of the preliminary results of a correlation procedure between sattelite aerosol retrieval systems, CALIPSO and MODIS, and a ground in-situ controlled CO_2 leakage site data. The two dataset could pinpoint some of the modulated quantities involved in the process such as the total radiation which impact the dilution factors responsible for the gas spreadout and mixing after its release. Moreover during the CO_2 release campaign some of the anomalies in the background could be, at first approach, be understood from an external unidentified source or from the the gas release itself.

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