Data Assimilation Schemes in Colombian Geodynamics - Cooperative Research Plan for 2017 - 2020 Between Universidad EAFIT and TUDelft, With the Help of Universidad de Antioquia and Universidad Nacional de Colombia Sede Medellin

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Analysis of the data and infrastructure the early warning system of Medellin and Metropolitan Area SIATA

Medellin Air qUality Initiative MAUI

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2. ABSTRACT

SIATA (SIATA, for its initials in Spanish) is the early warning alert system of Medellin and Metropolitan areas and the administrative department of disaster risk management DAGRD (DAGRD, for its initials in Spanish). It is a project of science and technology that has the support of the public services company of the city EPM (http://www.epm.com.co/site/) and a company dedicated to the energy production ISAGEN (https://www.isagen.com.co/). In this report, the available SIATA infrastructure to the development of the project is presented and analyzed. The different sensors and their spatial distribution over the region are shown as well as the web platforms that this entity possesses for access to the information. From the data we acquired, we made temporal, frequency and covariance analysis for the Ozone and Particulate Matter 2.5 and the results were compared with the results of data from the MACC (Monitoring Atmospheric Composition & Climate) project in order to obtain more knowledge of the resources we currently have to compare the performance of the models which we will work.

3. INTRODUCTION TO THE EARLY WARNING ALERT SYSTEM (SIATA)

The air quality in cities of the Aburra Valley (Medellin, Colombia; and neighboring cities) is among the worst in Colombia. The topographical and meteorological characteristic of this deep-seated mountain valley generate atmospheric stabilities that trap pollutants for part or most of the day, especially during the biannual transition periods of the Intertropical Convergence Zone (ICZ). The valley is nestled within highly complex mountainous terrain that heightens its atmospheric stability (Herrera, 2015) and accentuates its poor air quality through thermal inversion episodes (Rendón et al., 2015) that result in low rates of air exchange (Bedoya, 2009).

The SIATA project (https://siata.gov.co) operates a network of sensors that monitor, among many other things, meteorological conditions and air quality parameters in the Aburra Valley, it was born in 1999 as a thesis from Luz Jeannette Mejia of a network for monitoring the rain (EAFIT, 2014) which started with 20 manual pluviometry sensors with the SIMPAD, first name of the DAGRD. In 2004 SIATA was recognized as a metropolitan process and the Mayor of Medellin and the Metropolitan area were linked to the project. Universidad EAFIT is the executor of the project.

(a) (b)

Figure 1 a) SIATA Logo. b) Logo from SIATA support institutions

The Aburra Valley spans roughly 60 km in length, and has an average width of 6 km. The mountains that surround it rise from about 1300 up to 2800 m.a.s.l.. Figure 2 shows a comparison between Medellin and another two important cities in Colombia that are surrounded by mountains, notice how narrow is Medellin compared with the other two, one of the reasons that the pollutant level are increasing notably in the last years.

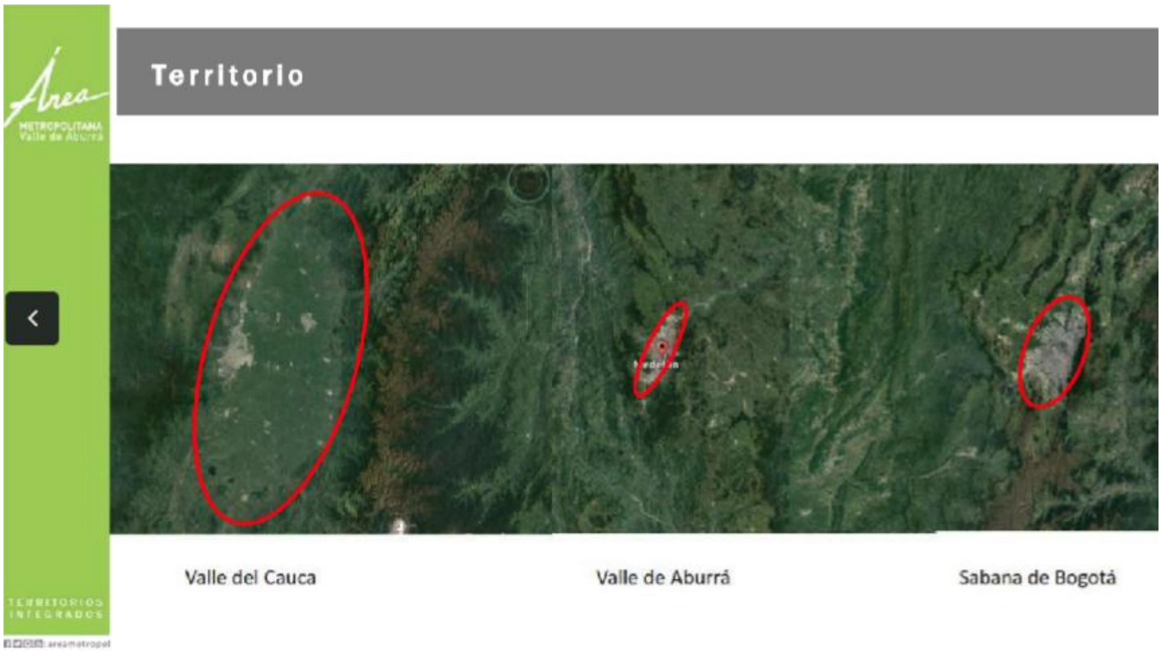

Figure 2 Comparison between three Colombian cities surrounded by mountains

SIATA infrastructure is getting a lot of attention in the recent years because the contamination situation problem is getting worse and it has become a tool used for taking decisions by the people in charge of the city. We explore initially this tool, to understand how it can works for our project, identifying the characteristics that the stations has, and understand how we can use this data to activities of data assimilation to be used with the models in the future.

4. SPATIAL DISTRIBUTION AND CHARACTERISTICS OF THE STATIONS

SIATA currently has different network of sensors dedicated to specific purposes (https://siata.gov.co/sitio_web/index.php/monitoreo#consolidado_estaciones). There are: pluviometry, level, meteorological, real time and infrared camera, disdrometers, accelerograph, soil monitoring, electric field monitoring, pyranometer networks and remote sensors capabilities like the hydro meteorological radar, a radiometer, a ceilometer network and a vertical wind profiler. In the Table 2 is possible to see a consolidated report of the sensing capabilities that SIATA already has in operation. Nowadays the total number of stations that SIATA has in the valley of different networks is 183 and outside 12.

Table 1 Summary of the sensors of SIATA

MUNICIPIO	PLUVIÓMETROS	NIVEL	METEOROLÓGICAS	DISDRÓMETROS	HUMEDAD	ACELERÓGRAFOS	CEILÓMETROS	MOLINOS DE CAMPO ELÉCTRICO	CÁMARAS	TOTAL DE SENSORES EN EL MUNICIPIO
Barbosa	1	1	3	1	0	2	0	0	0	8
Girardota	4	0	0	0	0	1	0	0	0	5
Copacabana	4	1	1	0	0	1	0	0	0	7
Bello	6	5	0	0	0	0	0	0	0	11
Medellín	49	16	9	1	2	22	2	3	9	113
La Estrella	3	1	0	0	1	2	0	0	0	7
Sabaneta	5	5	0	0	2	1	0	0	0	13
Itagüí	3	2	1	0	0	1	1	0	0	8
Envigado	1	1	0	0	0	1	0	0	0	3
Caldas	3	2	1	1	0	1	0	0	0	8
San Pedro (vereda El Tambo)	1	0	0	0	0	0	0	0	0	1
Guarne	1	0	1	1	0	0	0	0	0	3
Guatapé	0	0	0	1	0	0	0	0	0	1
Santa Rosa de Osos	0	0	0	1	0	0	0	0	0	1
Salgar	2	2	0	0	0	0	0	0	0	4
Samaná	1	0	0	1	0	0	0	0	0	2
GRAN TOTAL	84	36	16	7	5	32	3	3	9	195

SIATA hydro meteorological radar (Figure 3) was the first of this class installed in the country. It is located in the municipality of Santa Elena and the information it brings is concerned about clouds and precipitation. It is submitted each five-minute covering the 90 % of the region of Antioquia, having a range radio of 240 km. In the images at left there in Figure 3 is the high white structure that cover the antenna of the radar. Right image show how the data represented for the radar in the API of the SIATA looks like.

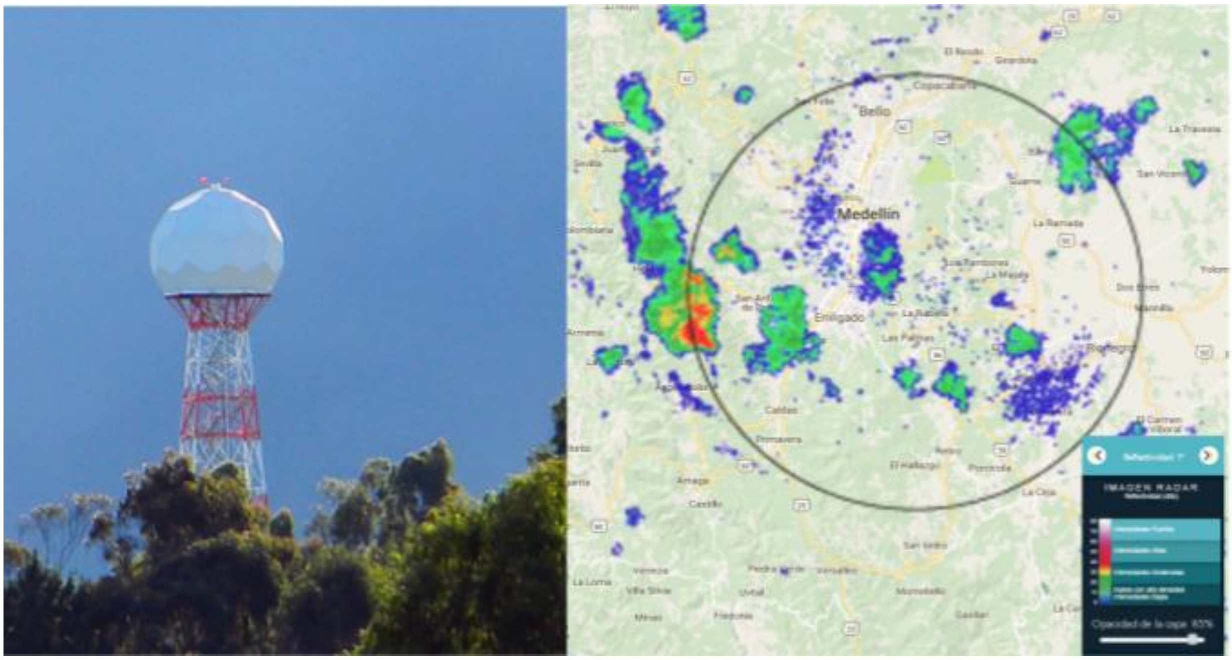

Figure 3 Hydrometeorological radar from SIATA

SIATA has three ceilometers CL-51 from the company Vaisala (http://www.vaisala.com)(Figure 4 center and left). This instruments allow a backscattering profiling range from 0 to 15 km and a cloud reporting range from 0 to 13 km which have been used to study the dynamic of the boundary layer through the cycles that the atmosphere of the valley daily experience (Herrera L, 2015). Figure 4 Right shows the position of ceilometers over the valley.

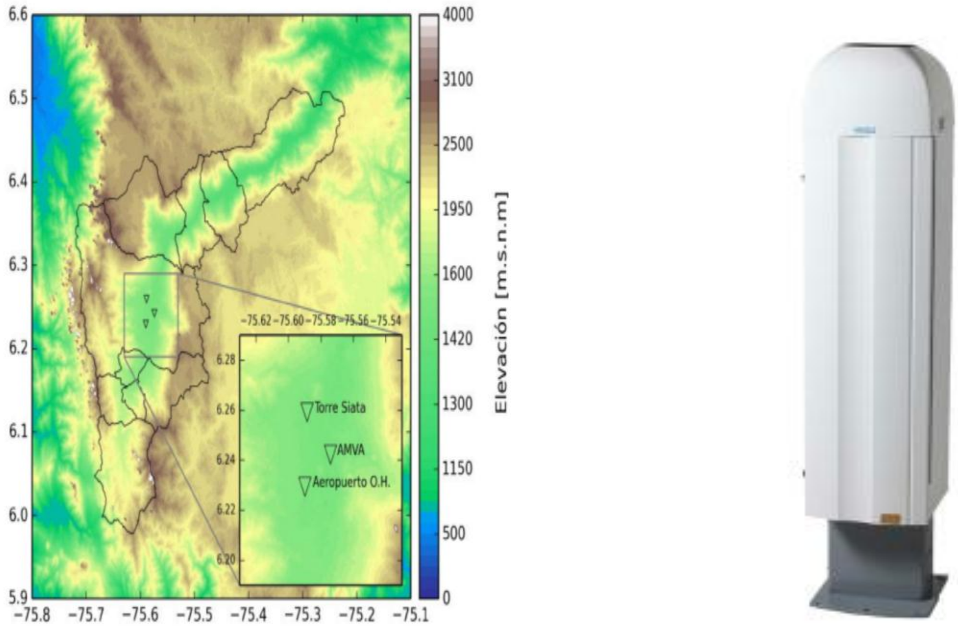

Figure 4 Ceilometer used by SIATA Vaisala CL-51 and location of them over the valley (Herrera, 2015)

Another instrument is the wind radar vertical profiler (Figure 5). It is used to understand the wind pattern of the city at different altitudes. It is from the brand RAPTOR VAD-DL, designed and built by Detect company (http://www.detect-inc.com). This instrument reach altitude of measure that range from 0 to 8 kilometers And is useful for understanding the dynamics of the boundary layer. The altitude the instrument provides depends of the different spatial resolutions it can provide. It works on 1290 MHz and has a time resolution of 5 minutes (Herrera, 2015). This instrument is located in the regional airport in a central part of the valley

Figure 5 Vertical wind profiler SIATA

The data we are interested to make the analysis are from the air quality network sensors. The sensor that SIATA use for measure the pollutants related to air quality is the PQ 200 monitor stations. This is a certified EPA instrument that have the possibility to measure PM 10, PM 2.5, PM coarse and PM 1.0 with a flow range of 10-20 LPM. Next figure shows the instrument and a map where the air quality sensors are located.

Figure 6 PQ 200 BGI Mesa Labs Ambient air particulate sampler used by SIATA

In the Figure 7 the station related to measures of pollutants are referenced in the Aburra valley. It is important from this image to notice that there are not too much points with measurements in the city.

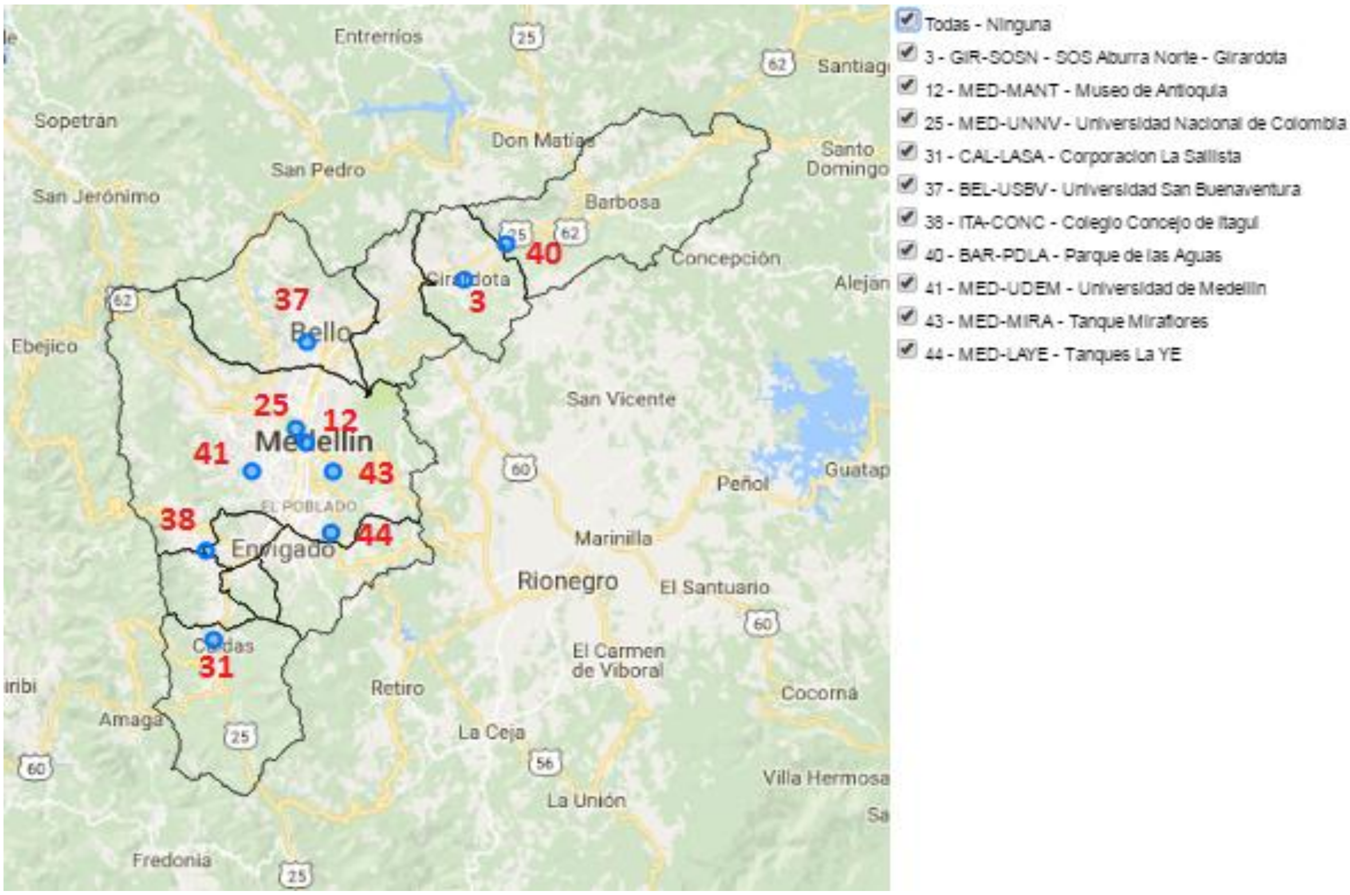

Figure 7 Spatial distribution of the stations

SIATA has another program called “Scientific Citizens” (Figure 8). This is an initiative to involve the people of the city into the problems of contamination giving them a low cost sensor which is connected to the wifi network. The first campaign of this clouds was of 100 units measuring PM2.5 and PM10, CO, NO_2, O_3, and some meteorological variables. The next campaign of clouds will have more than 200 units and will begin the at the second semester of 2017.

Figure 8 Low cost sensor platform and app to monitoring it

Although these clouds are made from low cost electronics with what is known electronics for develop through integration, the current performance of these has been a success. They have developed an app to monitor each unit and the sensors reproduce the variability of the behavior of the pollutants. This kind of developments are important because allows to start to have measures that have greater spatial resolution and the cost compared against the price of EPA (United States Environmental Protection Agency) is considerable low

5. DATA ACQUISITION

Ground-based data were obtained from the SIATA data web portal (data available upon request). in this link https://siata.gov.co/siata_nuevo/index.php/mapa is possible to access to each measure. This API is used to display graphic visual information from the different network station available, the data from the meteorological radar, different forecast methods, satellite information like the Global Geostationary weather satellite NASA, Geospatial information, and the network of cameras among other information of interest that can be displayed. In the green square in Figure 8 the different options to be displayed over the map are located. Once one option is selected in the gear in the same green square at the bottom, different widgets can be displayed like the ones in the blue square where some options for the visualization can be changed. In the red square, the active layers selected are displayed

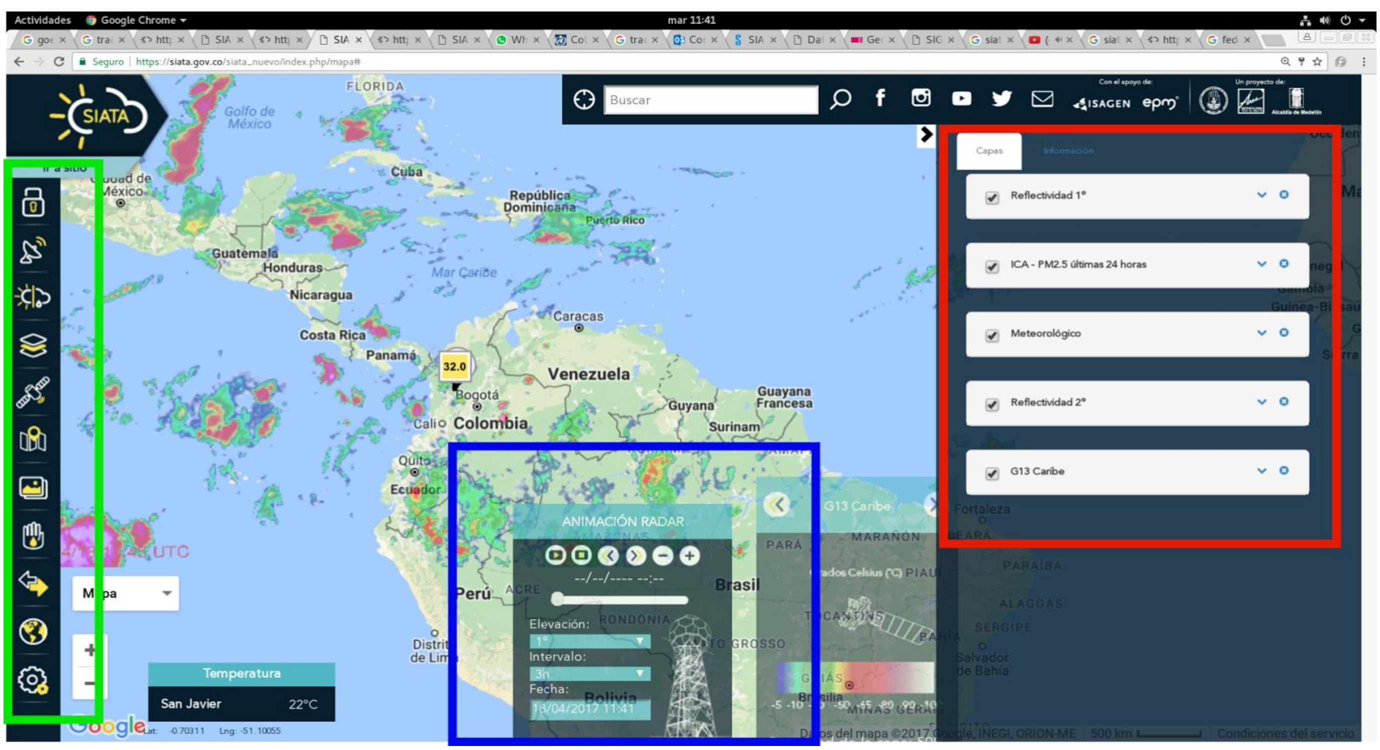

Figure 9 SIATA Geoportal API for visualizate the data of interest

In the link http://siata.gov.co:8018/descarga_siata/index.php/index2/ is possible to download the data from the SIATA stations. Once you create a login to register, you can access to the platform to ask to download the available data (green square left) just having to mention in a few words what are you doing with the data (blue square). There is also possible to select the data from the period of time that you need. Once you finish you can download the data in a .csv format.

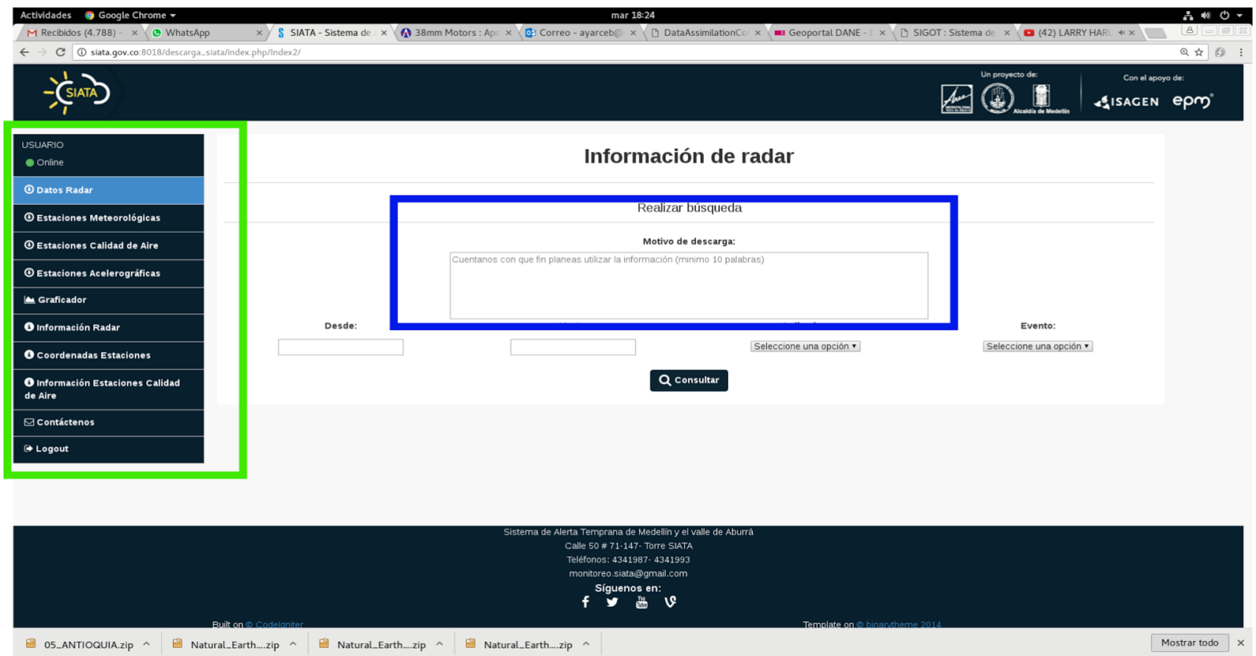

Figure 10 SIATA Platform to require the data

The availability of the data appears with a flag marker with the number 1 just at the side of the value from each sensor. Each sensor is measuring one time per hour. When there is no data available the value that the sensor report is -9999. That is how you can process the data removing first the data that doesn't have too much sense

6. DATA ANALYSIS

The present analyses were conducted on data corresponding to the period between March 31, 2015; and April 30, 2016. This period encompasses a 2016 episode of acutely poor air quality in the Aburra Valley. The stations were chosen based on the availability of measurements for PM2.5 and O3 for the same period as the MACC data. Data were available with a temporal resolution of 1 hour. The Satellite-based information to compare was obtained from the MACC project (http://www.gmes-atmosphere.eu/), which is the functioning instrument of the Copernicus Atmosphere Monitoring Service. The spatial resolution is approximately 80 km, with 36 vertical layers that span from 1000 hPa to 100 hPa. MACC data were available with a temporal resolution of 3 hours.

Data for all SIATA stations for each time were averaged (discarding absent data points caused by the periods that different institutions operate the network or damage in the stations) to obtain a valley-wide average. Time-series, frequency and distributional analyses were performed to characterize and understand the data available for this region in preparation for their use in air quality modelling efforts.

For the mentioned analysis resolution, four quadrants covered the municipal areas of the Aburra Valley cities (Figure 11). The corresponding data quadrants were centered at 6.6667°N, 75.9375°W (Q1); 6.6667°N, 75.2344°W (Q2); 5.9649°N, 75.2344°W (Q3); 5.9649°N, 75.9375°W (Q4). The location of each station used in this study is shown in Figure 11 (orange boxes). showing the political boundaries of the Aburra Valley cities;

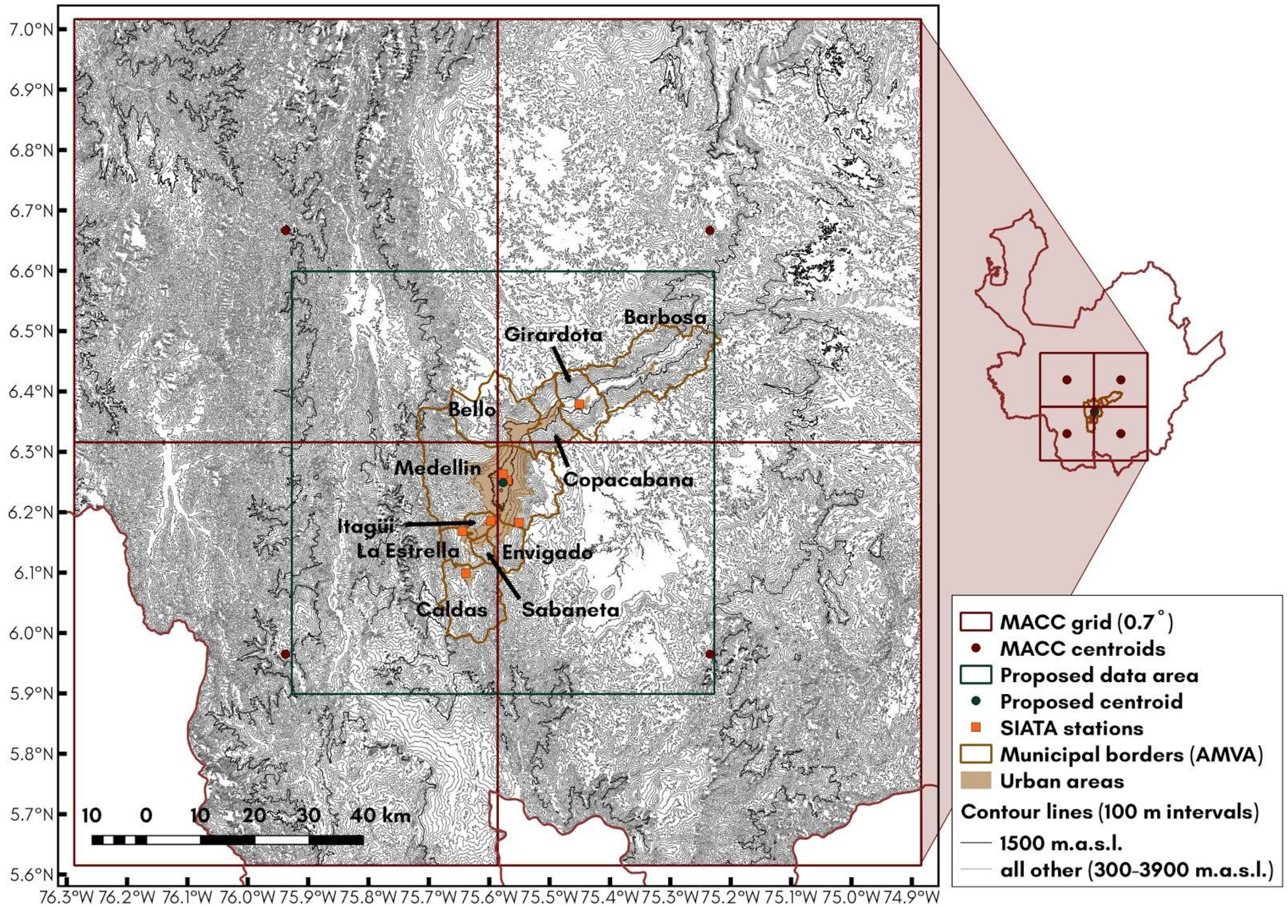

Figure 11 Map of the region under study with the MACC grid and the SIATA station localization

Due to the different nature of the data under analysis, we performed at least three different analyses to establish similarities in both qualitative and quantitative perspectives: Frequency analyses – the data preprocessed with median-subtraction, zero-padded (up to 215 points) were transformed via Fast Fourier Transform (FFT), and the resulting spectra were normalized to the maximum amplitude. Distribution analyses – the probability density functions were constructed from data segregated in day and night.

Figure 12 shows, in the upper graphic, how looks the crude data from a particular station. In this case for example the data for the variable ozone for a station in the downtown of the city (Station 12 Figure 7). In the second graphic in red we can see the data conditioned to avoid the missing information. When we made the frequency analysis (button down graphic) we see the daily cycle with its respective harmonics for this variable. The meaning of this is the well-known behavior of this compound which has a photochemical reaction, that is the reason to have this daily cycle here.

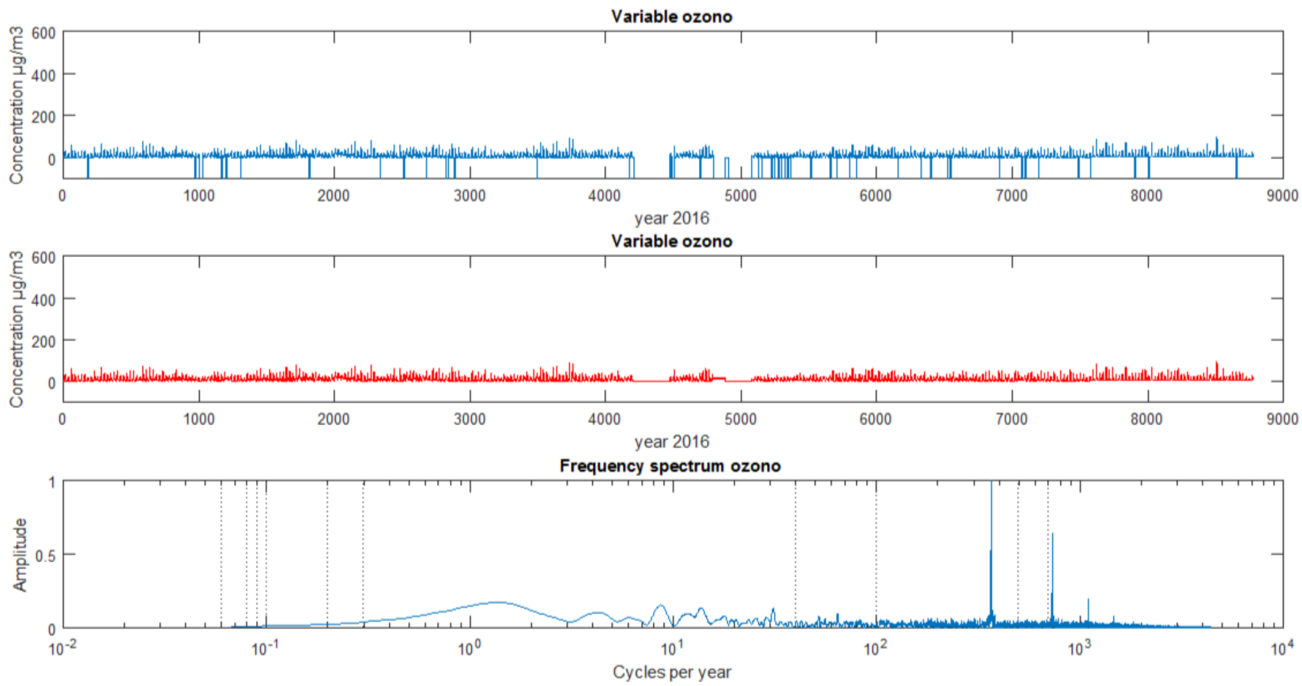

Figure 12 Data for the variable Ozone for 2016 of the station 12 SIATA (Museo de Antioquia)

Spectral analyses revealed identical frequency components for O3 in data from both sources (Figure 4). The PM2.5 spectrum presents a very strong low frequency component behavior compared to the other 2 substances. This can be related to its extreme concentrations during the month of March in contrast to the rest of the year.

In the same way, this analysis was made for the variable PM.5 (Figure 12.) One important difference in this variable is noticed in the frequency analysis where a component in another cycle specially the weekly cycle it is shown which suggest that the reduction of the vehicle sources in those days. The PM2.5 spectrum presents a very strong low frequency component behavior compared to the other 2 substances. This can be related to its extreme concentrations during the month of March in contrast to the rest of the year.

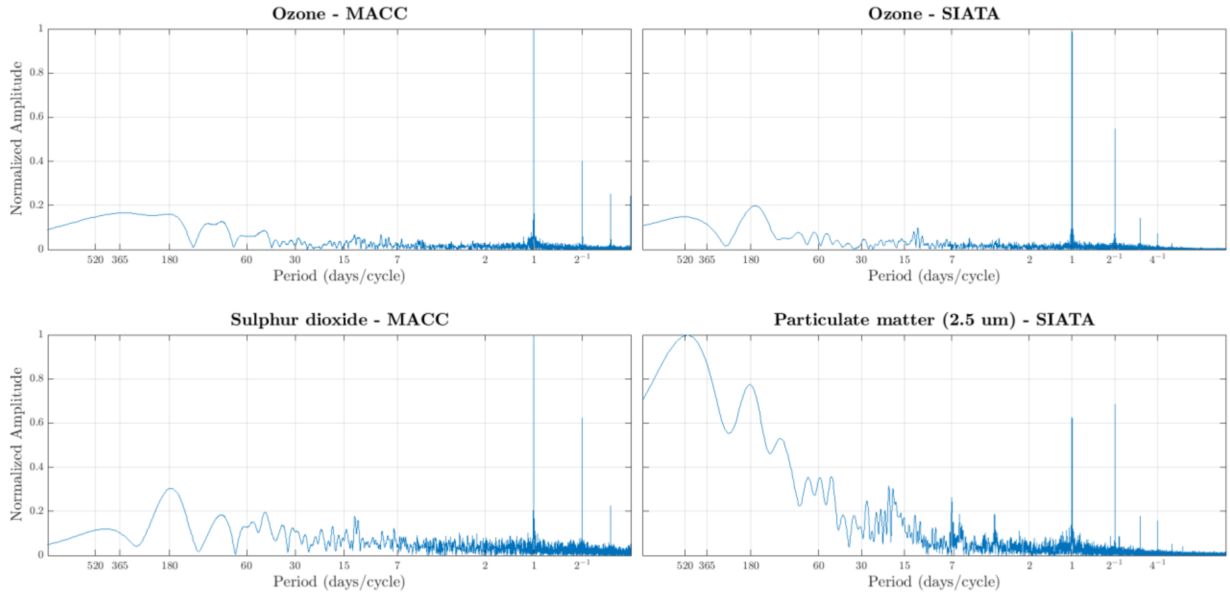

Figure 133 Frequency spectrum for the O3 for MACC and SIATA, PM2.5 for SIATA and SO2 for MACC

The graphics of the Figure 14 show the behavior of the compounds analyzed for each day for several months. Here it is possible to notice that the ozone has a behavior that have high dependency of it concentration with the sun intensity, due to the photochemical reaction of other components which make possible the generation of ozone in the planet boundary layer. For the PM 2.5 here it is possible to see high concentration values in the months from February to march for all hours of the day, what is consistent with the periods of environmental contingency that annually the city is facing. The PM2.5 spectrum presents a very strong low frequency component behavior, this can be related to its extreme concentrations during the month of March in contrast to the rest of the year.

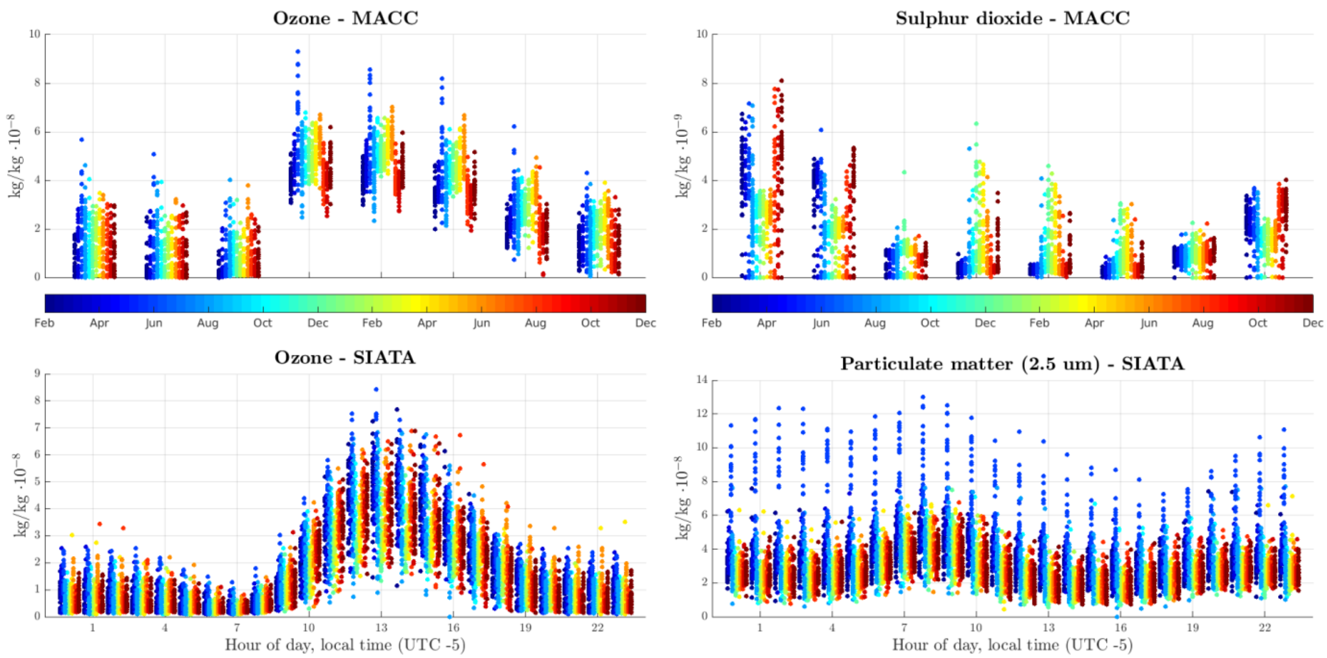

Figure 14 Dynamic of atmospheric pollutants O3 and PM 2.5 for the SIATA data from the valley.

Pearson correlations were calculated among the different MACC quadrants, and between each of them and the SIATA data to assess the ability of the MACC data to capture the intra-Valley conditions. It is inferred that MACC data are unable to resolve the valley's topography, as the correlation values (Table 2) between MACC points are considerable higher than the correlation with SIATA data.

Table 2 Correlation coefficients for MACC and SIATA O3.

	Q1	Q1	Q3	Q4	SIATA
Q1	1.0	0.89	0.90	0.86	0.70
Q2	0.89	1.0	0.86	0.90	0.72
Q3	0.90	0.86	1.0	0.88	0.77
Q4	0.86	0.90	0.88	1.0	0.74
SIATA	0.70	0.72	0.77	0.74	1,0

Moving histograms for night and day data show the data are clearly bimodally distributed (Figure 16), capturing the diurnal dynamics observed in Figure 2. The results for MACC model and SIATA ground observations for O3 agree in the representation of the day/night cycle. Deviations are present as the MACC model tends to overestimate the actual data. Top row presents daytime data; bottom row presents nighttime data. Insets indicate the MACC quadrant being analyzed. Abscissas correspond to the start of the analysis window and ordinates represent concentration of the species of interest

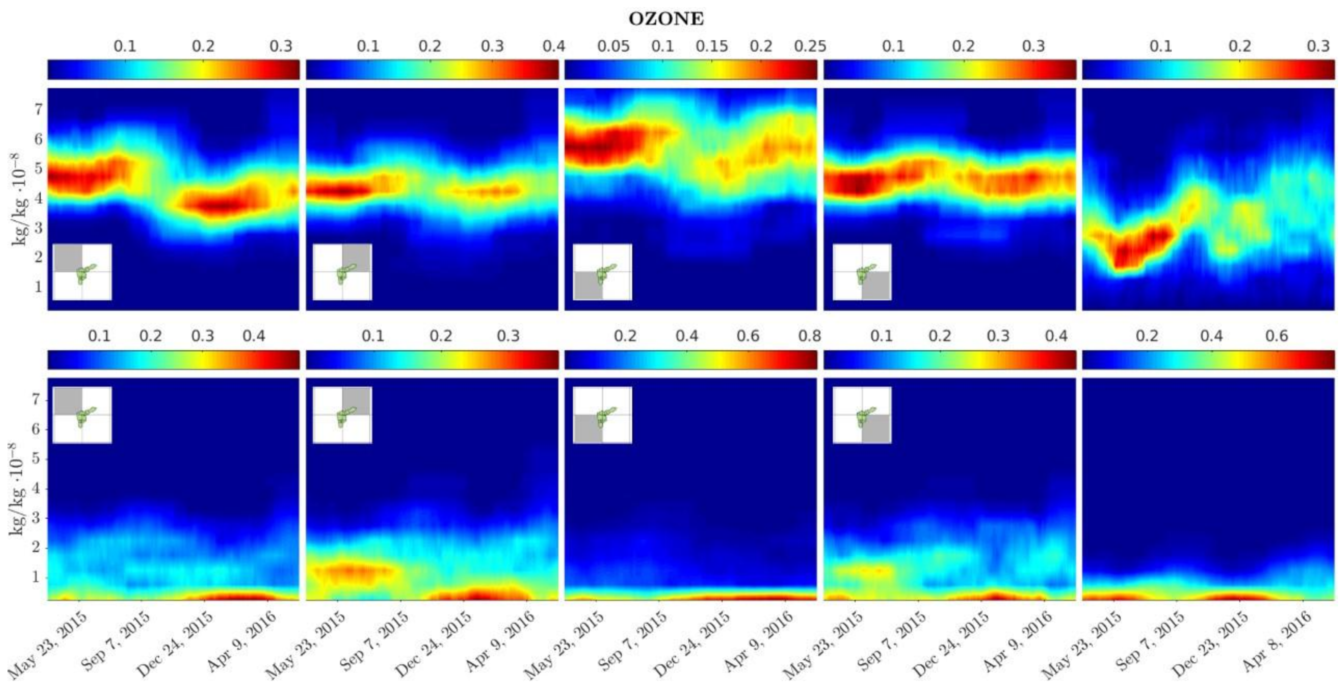

Figure 15 Moving histograms for the ozone concentration distribution.

7. CONCLUSIONS

The infrastructure that SIATA has, is considerable compared with the other principal cities in Colombia. The graphical way how they share the data in their platform is good and well explained for any kind of public.

Pollutant dynamics captured by MACC data resemble those present in SIATA data, despite the limited overlap between the MACC data quadrants and the urban areas of the valley. Daily dynamics are in accord with known atmospheric and chemical processes. Discrepancies between the two data sets may be related to the differences in resolution. Focused processing and reanalysis efforts will be needed to increase the resolution of satellite based data and from the SIATA network in order of enable detailed model performance assessment (e.g., Xing et al., 2015).

Due to the different nature of the data under analysis, we performed at least three different analyses to establish similarities in both qualitative and quantitative perspectives. With the aim of exploring the atmospheric pollutant data available for the Aburra Valley, we developed an analysis framework for evaluating data from different sources, and expanded the toolkit for evaluating modelling outputs

Although it is possible to reproduce the behavior of the data for Ozone of the SIATA network compared with the results for the model, there are inconsistencies that could be due to the resolution difference. It Is recommended to have more on ground base data to improve the spatial resolution. As well as trying to obtain a higher spatial resolution for the models.

In exploring the available data, our objectives were: to identify salient dynamics; to assess strengths and weaknesses in the available data, and develop criteria to suggest the need for more precise and strategic measurements; develop a comparison an analysis framework for evaluating data from different sources as well as modelling results; and to evaluate the suitability of the data for their use in data assimilation of regional models

8. IMMEDIATE FUTURE DIRECTIONS

1. Identify the areas in the most possible high resolution in the Aburra valley that produce more emissions of pollutants. This could be searching using databases or inventories with the data about the emissions.

2. How to have a measure about the quantity of pollutants that are coming out from the valley in order to have an estimate that allow us to work on our proposal concept that conceive the valley as a volcano, “The Volcano of Aburraes”. This concept pretends to make a similar between this concept and the plume of pollutants emission to apply to the models of transport in order to understand the ecosystem impacts that this city has in natural zones nearby.

3. Implementation of regional and local air quality models and study about the topic of data assimilation procedures

4. Research about how retrieve more information of the different networks of data available, research about the techniques that nowadays exists to optimize the information from a network of sensors.

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