Impact of the deposition of different compounds in natural areas of Colombia: Initial characterization and analysis of satellite and ground data available

Seminar PhD Mathematical Engineering

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Mathematical Modelling Research Group

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Outline

- Problem statement
- Theoretical framework
    - Methodologies used to estimate the transport of contaminants
    - Data assimilation methodology and observation impact to evaluate models
- Current research questions
- Initial characterization of the data available
- Current research questions (Recap)
- References

Problem statement

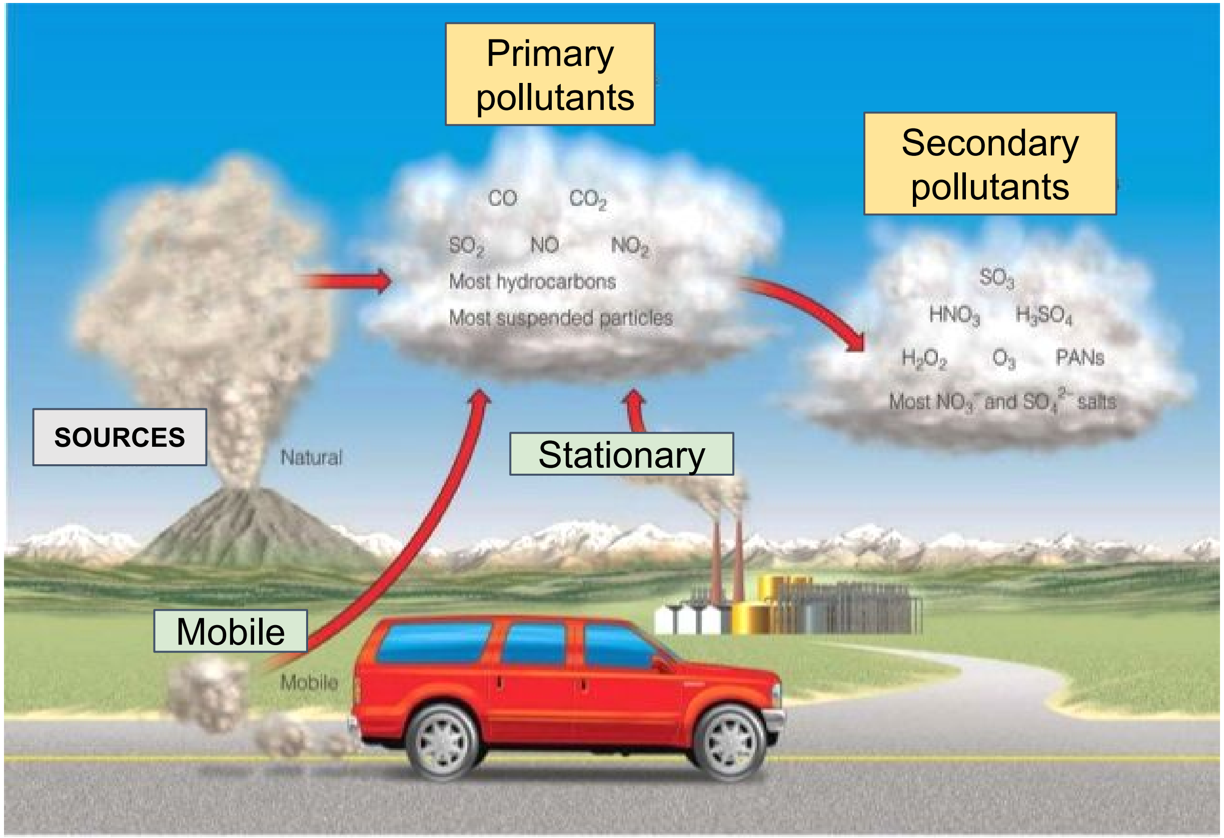


Image reference: sciencescene.com/Environmental%20Science/Graphics/1503.jpg

Primary and secondary contaminants sources

The term "air pollution" could seem something related to the recent years but, the importance of this for the human being, was recognized far before 18th century when scientist like **Rutherford** and **Lavoisier** discovered the chemical composition of atmospheric pollutants.

(Segers A., 2002)

Problem statement

With deaths projecting to reach **3.6 million per year in 2050**, air pollution will soon overtake contaminated water and poor sanitation as the world's leading environmental cause of premature deaths (Green *et al.*, 2013).

(El Colombiano Photo/Róbinson Sáenz Vargas)

(AFP Photo/Raul Arboleda)

9,2 % of the deaths in the valley are related to the contamination problem (Metropolitan Area of Medellín, 2016)

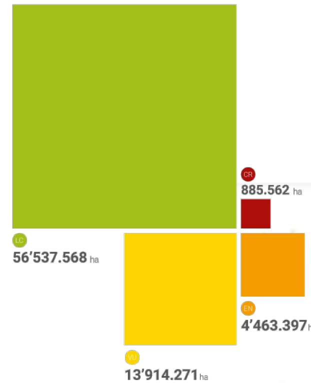
The air quality in cities of the Aburrá Valley (Medellín, Colombia) and neighboring cities is among **the worst** in Colombia.

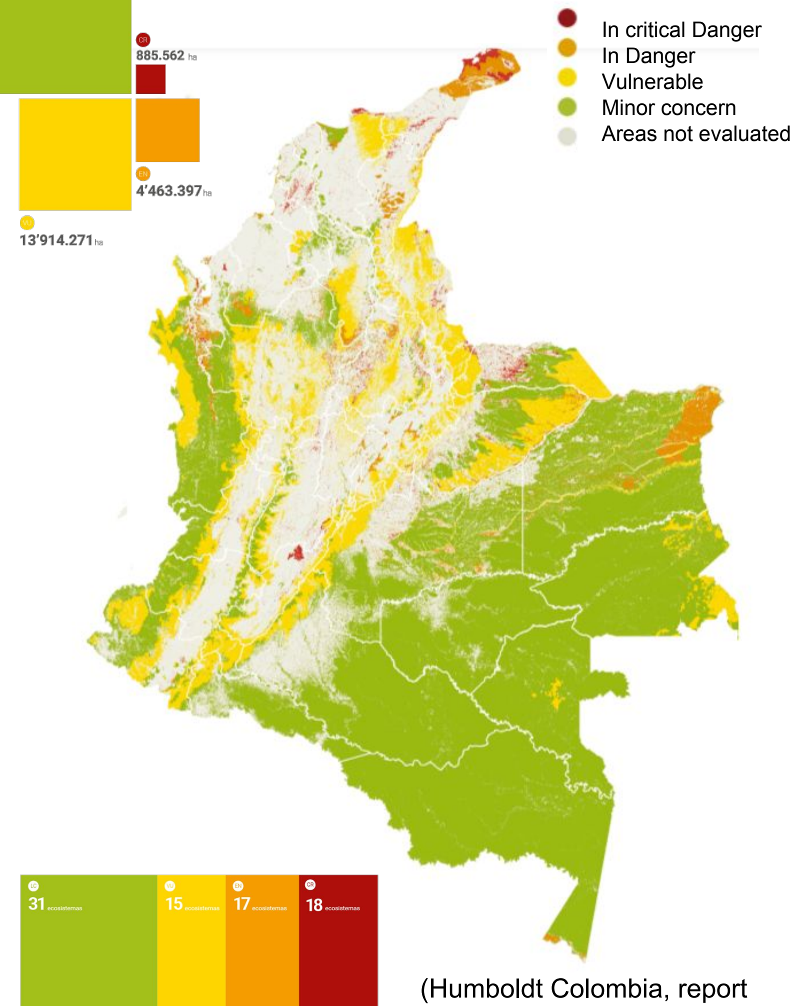
Problem statement

Distribution of National Natural Parks and paramo ecosystems in relation to major urban centres in Colombia

Colombia, o**ne of the 17 Megadiverse countries in the world**, containing the highest diversity in bird and butterfly species

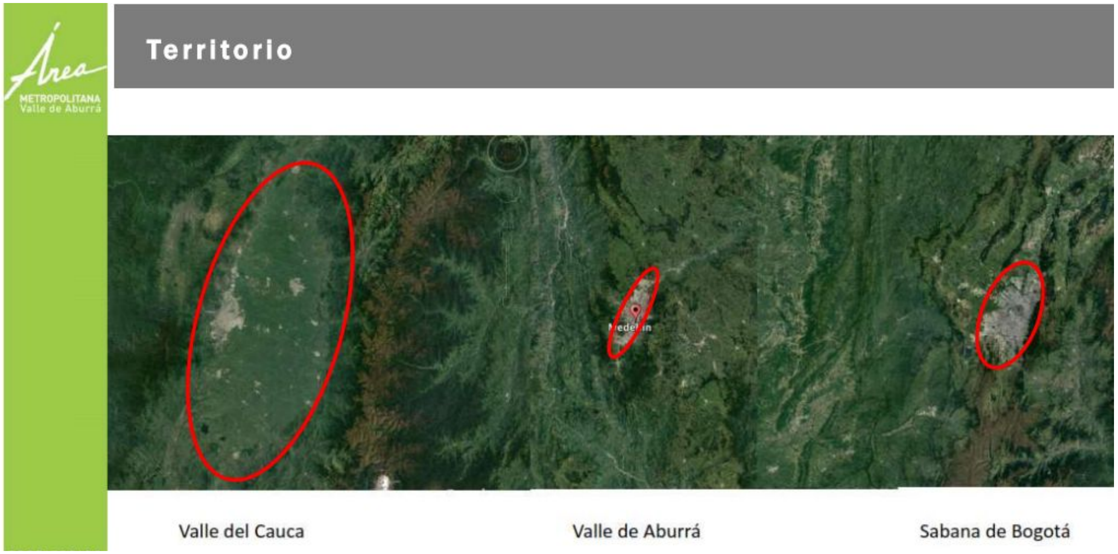
Bioeconomy, sustainable utilization of the biodiversity and integrated agricultural production system, are seen as major pillars of growth





(Humboldt Colombia, report 2016)

Problem statement



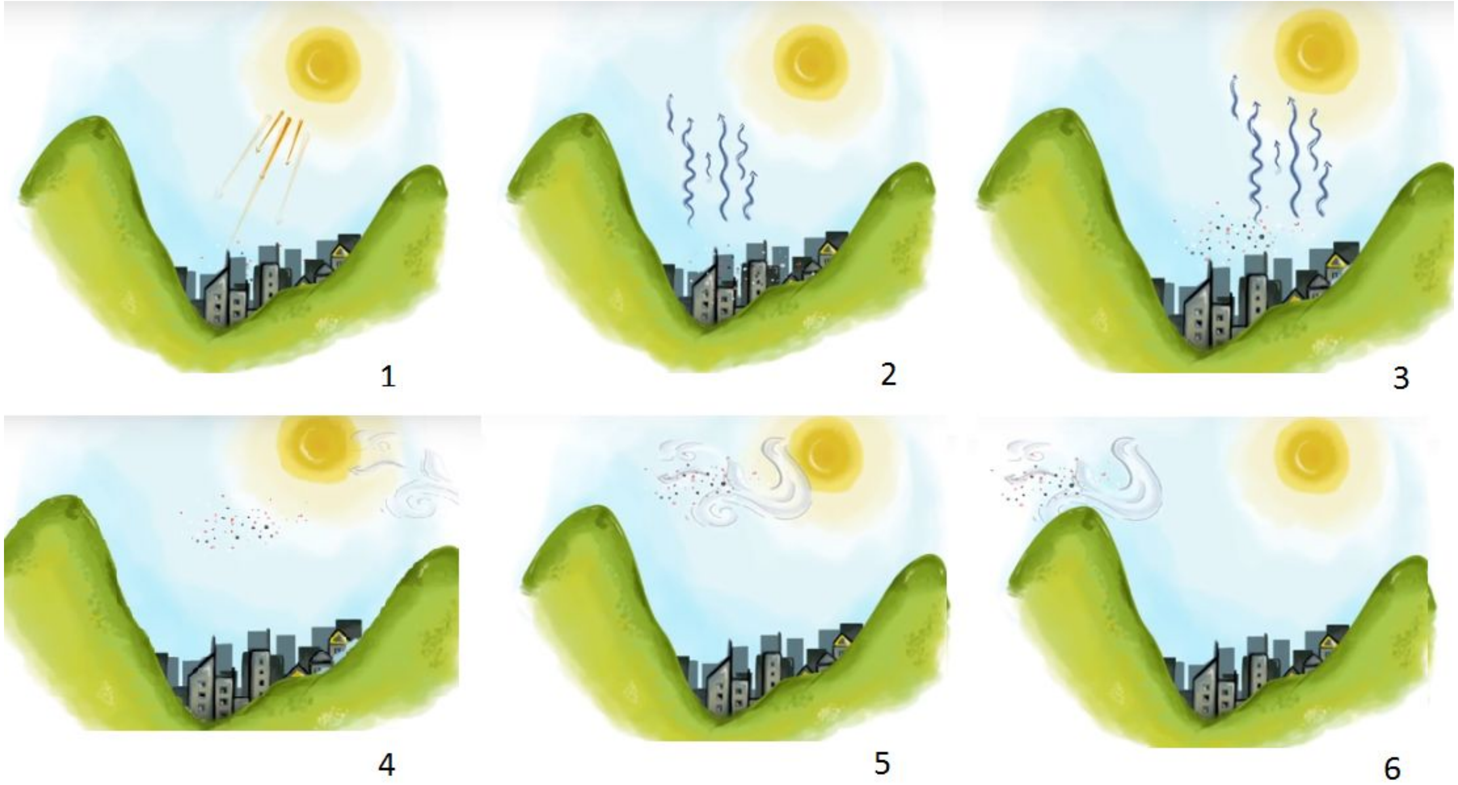
(Metropolitan Area of Medellin, 2016)

Topographical characteristic of Aburrá deep-seated mountain valley

"The fact that the Medellín Valley is much more polluted by heavy metals than the Cali area, is certainly not only due to the higher industrialization degree and the heavier traffic, ***but to a considerable extent also to the topographic situation and climatic features of this region*** *The Cali Yumbo area is much more open, and at least in the hours of the afternoon a cleaning up of the atmosphere can take place when strong western winds blow away the polluted air masses."*

(Schrimpff, 1983)

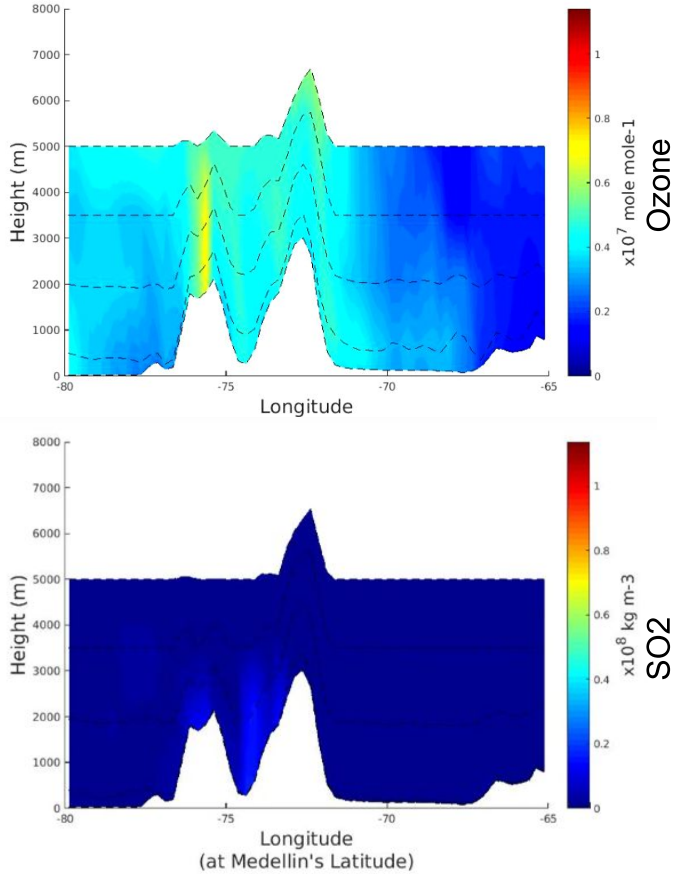
Problem statement



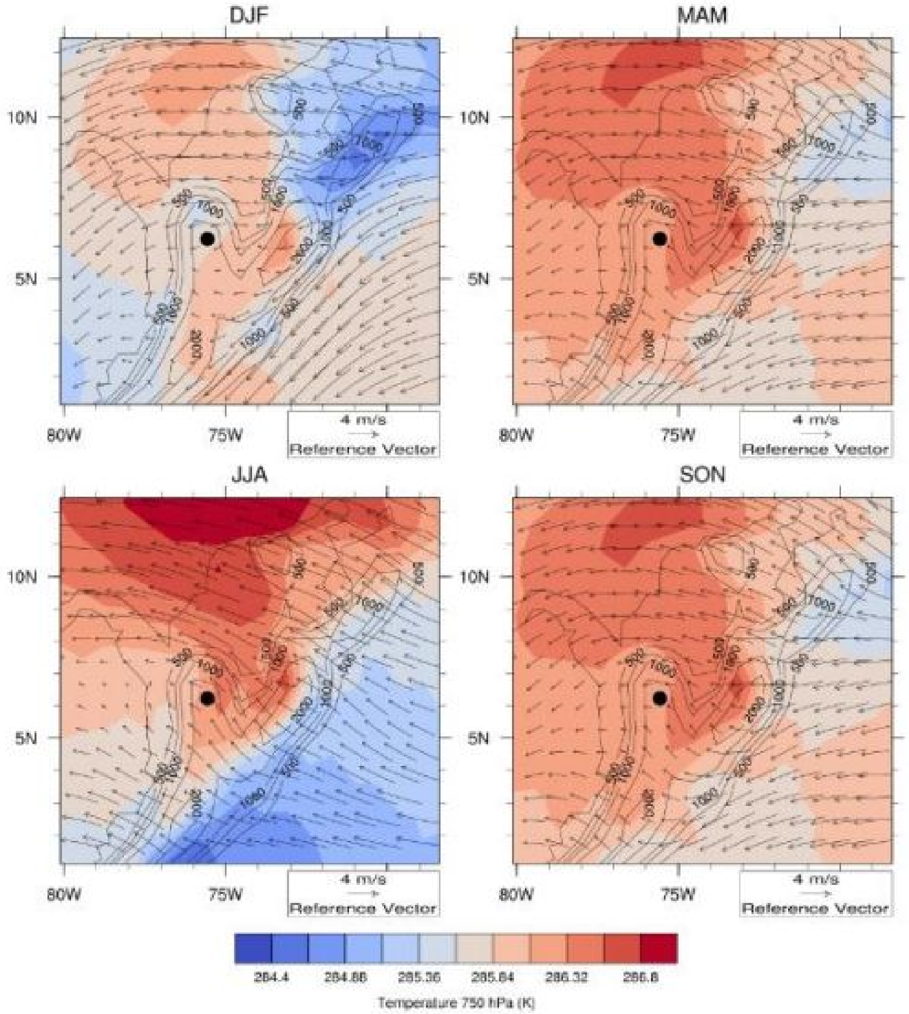
(Collage made from SIATA video Images)

Aburrá valley normal meteorological conditions

Problem statement



"The Volcano of the Aburraes"

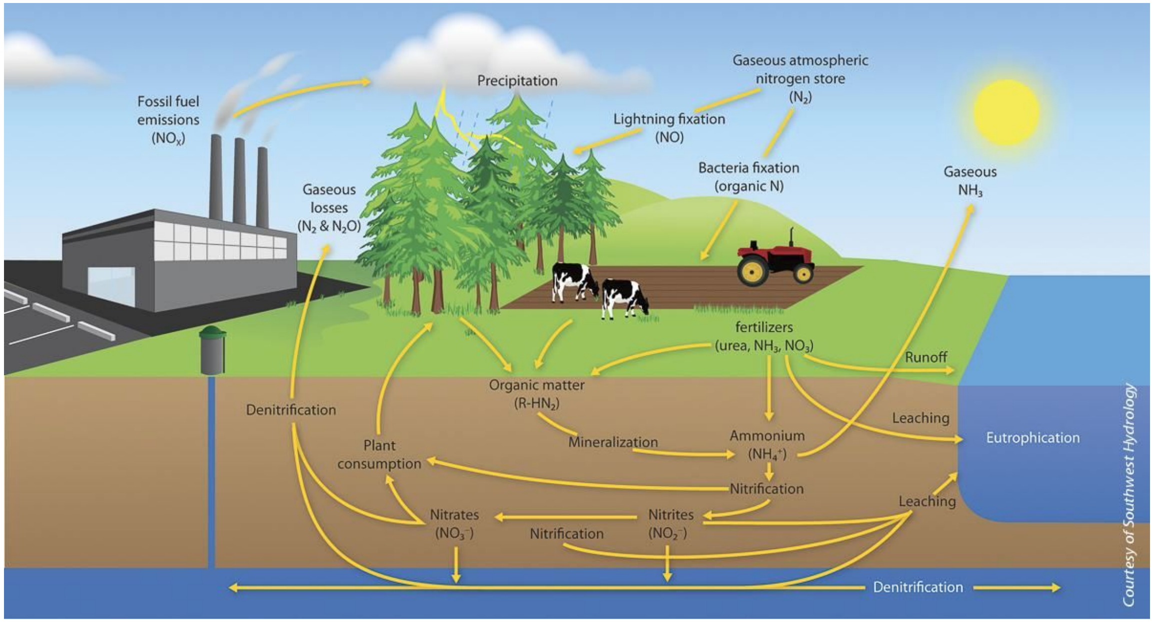


Long-term seasonal variations of the wind (750 hPa) and temperature (at the surface) fields in South America

Problem statement

Critical load

One single nitrogen atom , moving along its biogeochemical pathway in ecosystems, can have a multiple negative impacts in sequence, “nitrogen cascade” (Galloway et al., 2003).



Nitrogen cycle

Eutrophication: “Nutrient pollution”

Affection to photosynthetic activity

(https://www.nasa.gov/topics/earth/features/soybeans.html)

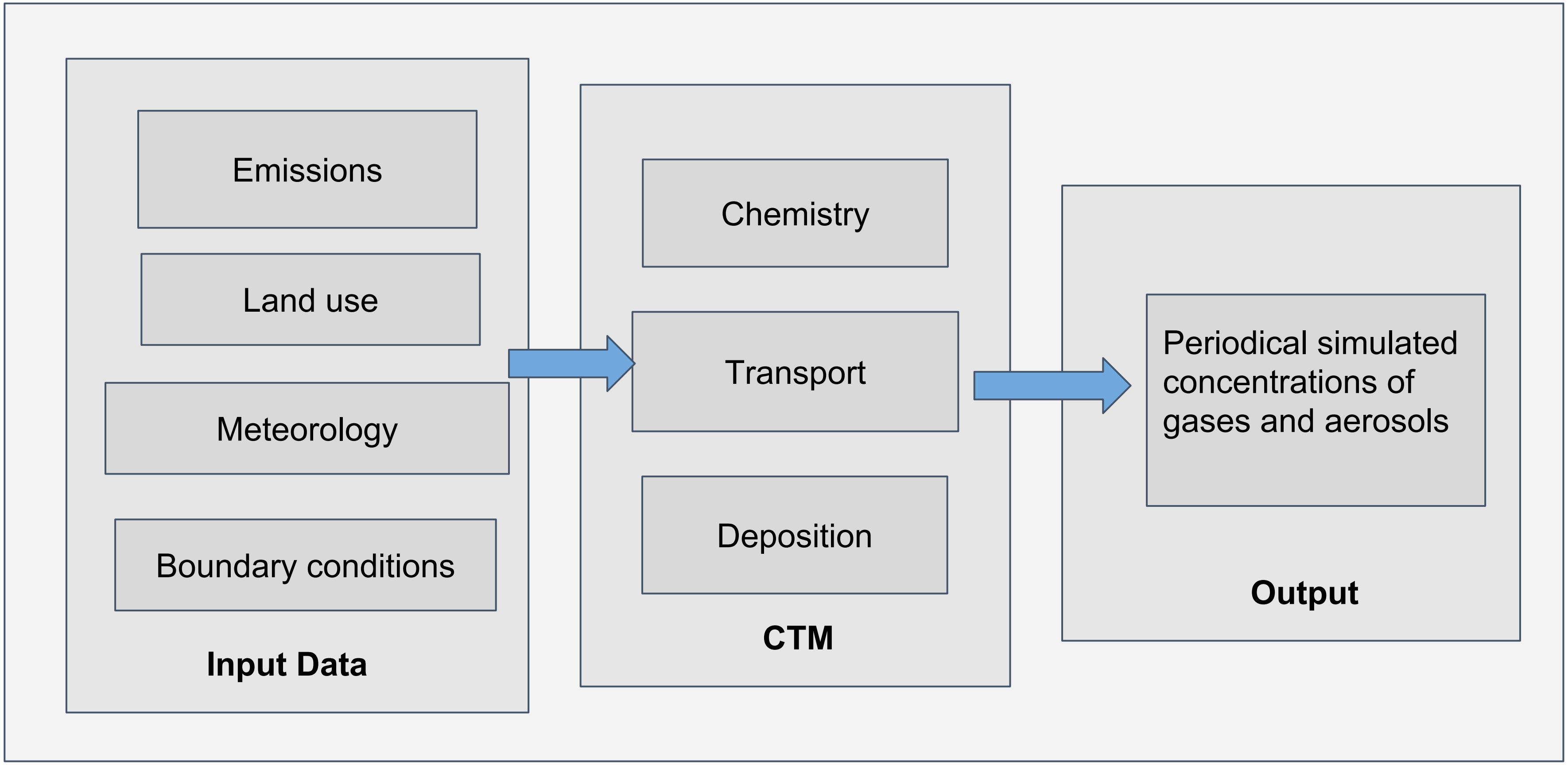
Methodologies used to estimate the transport of contaminants

Chemistry transport model (CTM)

Compute numerical model which simulates the atmospheric chemistry and transport

Theoretical framework

Methodologies used to estimate the transport of contaminants



Theoretical framework

CTM Chemistry Transport Models: LOTOS-EUROS (Long Term Ozone Simulation)

Advection

Diffusion

$$\frac{\partial C}{\partial t} = -\nabla \cdot (\mathbf{u} \cdot \mathbf{C}) + \frac{\partial}{\partial \mathbf{v}}(K_{\mathbf{v}} \frac{\partial C}{\partial \mathbf{v}}) + E + R + Q - D - W_e$$

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + V\frac{\partial C}{\partial y} + W\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}(K_h \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(K_h \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(K_h \frac{\partial C}{\partial z}) + E + R + Q - D - W_e$$

Diffusion coefficients:

$$K_h = \eta T_{def}$$

$$T_{def} = \sqrt{\left[\left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right)^2 + \left(\frac{\partial U}{\partial x} - \frac{\partial V}{\partial y}\right)^2\right]}$$

W V U	Wind components each direction
E	Entrainment and detrainment
R	Generation/consumption by chemical reactions
Q	Emissions
D W_e	Dry and wet deposition processes

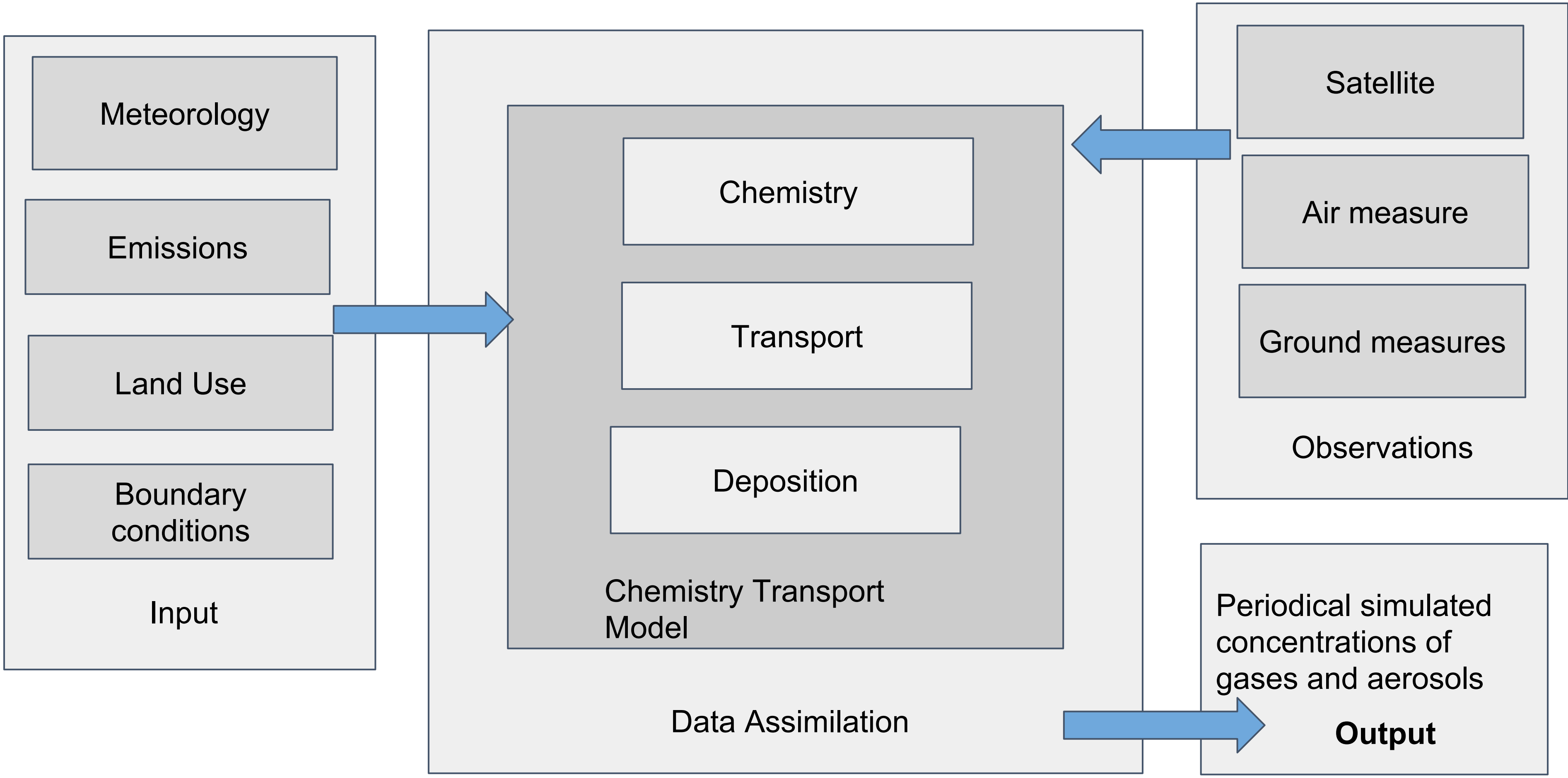
$$\frac{\partial C}{\partial t} = -\Lambda C$$

$$\Delta D = C_0(1 - e^{-\Lambda t})\Delta z$$

Contribution depositions

Theoretical framework

Methodologies used to estimate the transport of contaminants



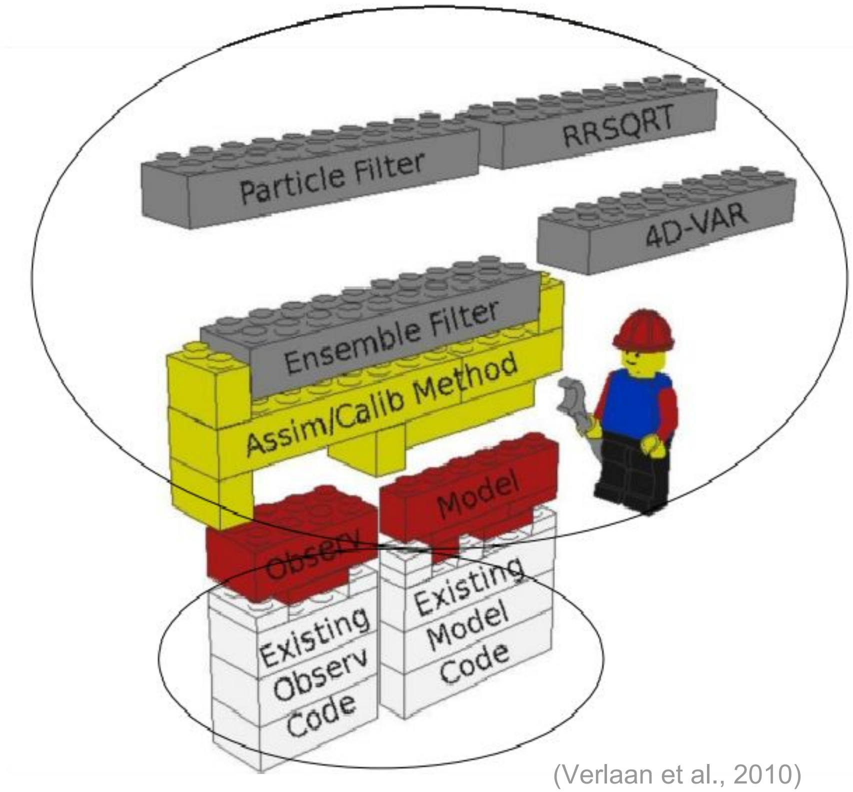
Theoretical framework

Data assimilation: "Formal techniques for structured integration of data and models" (Deltares)

- Improvement of real time forecasts
- Calibration of uncertain model parameters
- Uncertainty analysis
- Study the potential value of new observations
- Estimation of uncertain sources

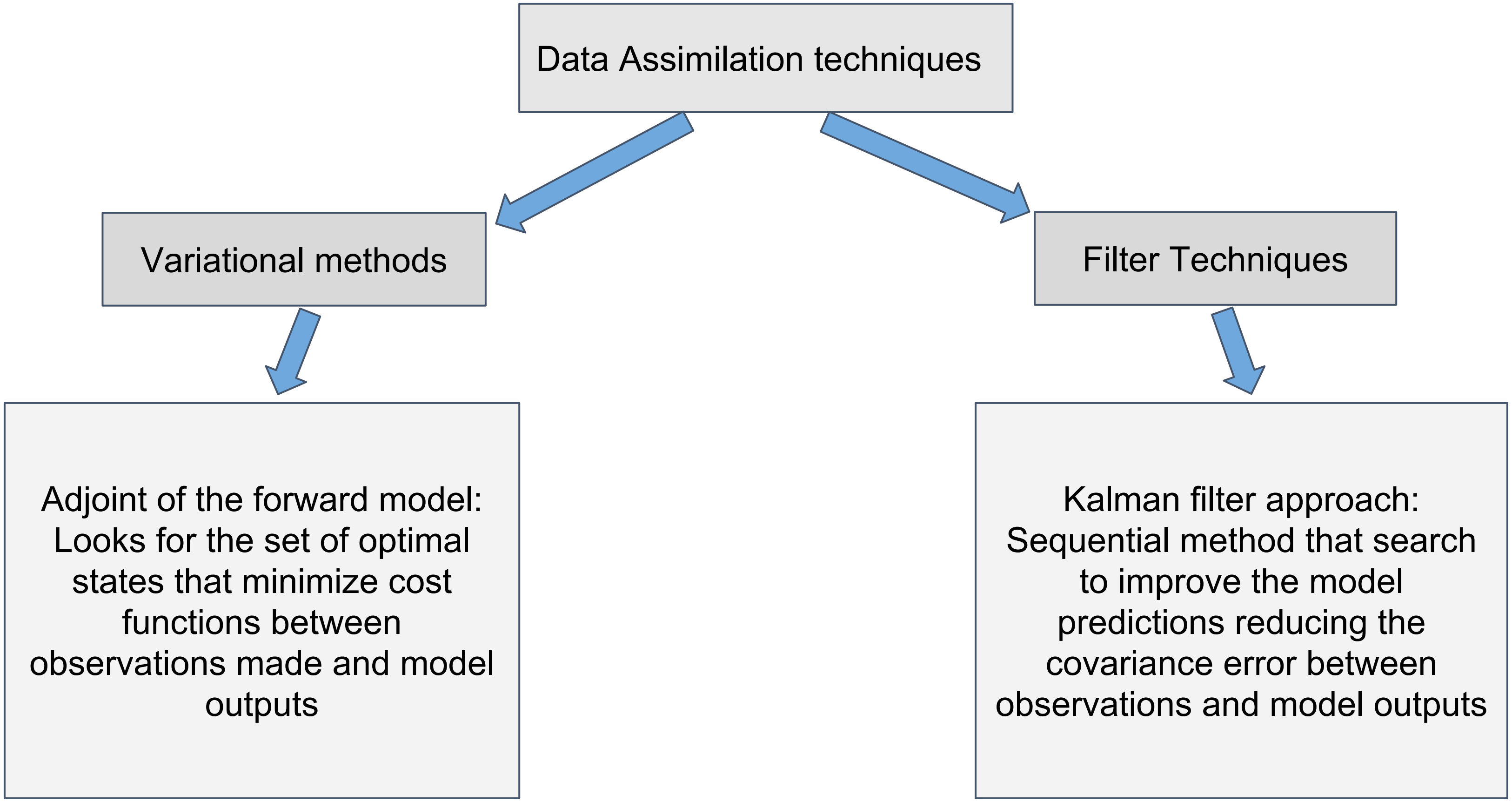
Assimilation: Finding the most likely state of the model

Calibration: Finding the most likely model fitting the data

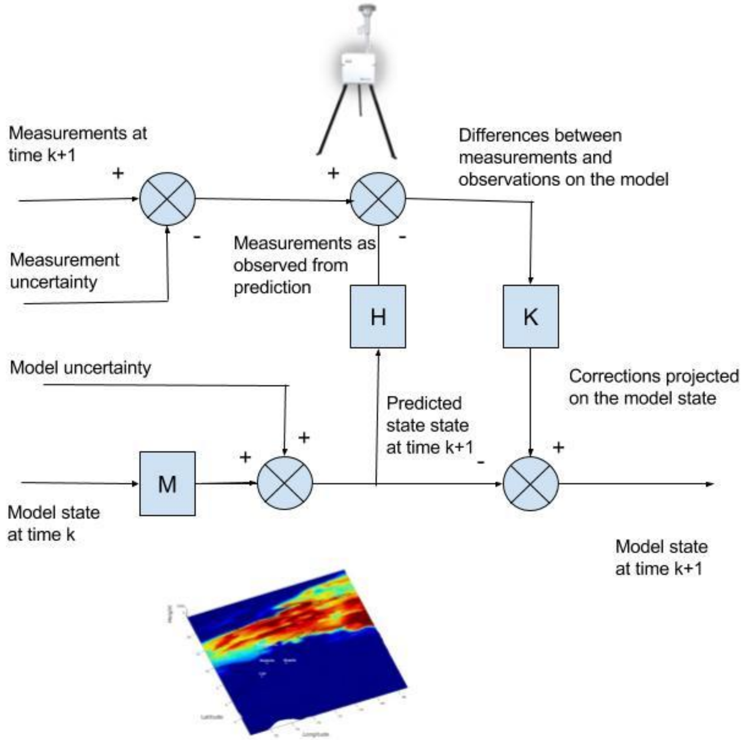


(Verlaan et al., 2010)

Theoretical framework



Theoretical framework



Consider a nonlinear discrete time given by:

State vector	$x(k+1) = Mx(k) + w(k)$
Observation	$y(k) = Hx(k) + v(k)$

$v(k) \quad w(k) \longrightarrow Q(k) \quad R(k)$

Independent Gaussian random vector

Respective Covariances control variables

M Transition matrix

H Observation matrix

$$\widehat{x}(k|k) = \widehat{x}(k|k-1) + \mathbf{K}[\mathbf{y}(k) - H\widehat{\mathbf{x}}(k|k-1)]$$

The EnKF is a modification that uses Monte Carlo approach to estimate the minimum variance solution to the state estimation problem (Evensen G., 2009).

Theoretical framework

Observation sensitivity experiments: Study the impact of various sets of observations on the accuracy of the subsequent forecast

$$J(k,l,m) = (y(k+m) - H\widehat{x}(k+m|l))' R^{-1} (y(k+m)) - H\widehat{x}(k+m|l))$$

(Todling, 2012)

In particular we are interested at the impact of the observations at the most recent analysis update

$$\widehat{x}_s(k|k) = \widehat{x}(k|k-1) + s\mathbf{K}[\mathbf{y}(k) - H\widehat{\mathbf{x}}(k|k-1)] \qquad 0 \leq s \leq 1$$

$$J_s(k,m) = (y(k+m) - H\widehat{x}_s(x+m|k))' R^{-1} (y(k+m)) - H\widehat{x}_s(k+m|k))$$

Theoretical framework

When a new observation is available, the analysis step is used to compute the analysis ensemble from its forecast based on the sample covariance matrix of the forecast ensemble

$$\triangle J(k,m) = J_1(k,m) - J_0(k,m)$$

$$\begin{aligned}\Delta J(k,m) \approx {} & [(\mathbf{y}(k+m) - H\hat{\mathbf{x}}(k+m|k)) + (\mathbf{y}(k+m) - H\hat{\mathbf{x}}(k+m|k-1))]' \\ & \mathbf{R}(k+m)^{-1}\mathbf{D}(k+m|k-1)\mathbf{D}(k|k-1)' \\ & \left(\mathbf{D}(k|k-1)\mathbf{D}(k|k-1)' + \mathbf{R}(k)\right)^{-1}(\mathbf{y}(k) - H\hat{\mathbf{x}}(k|k-1)) \quad (18)\end{aligned}$$

(Verlaan, 2016)

Current research questions

- What kind of satellite information or ground based sensor networks would help us to have more data of interest to increase the spatial and chemical resolution of the different compounds from the data we have available today from the models that we are working with.

- How can we apply techniques to retrieve more information of the observations measured when we experience in them uncertainty due to the systematic error presented like the techniques used by (Van Damme M. et al., 2015)?

- Is it possible, under linearity and stationarity assumptions, to use the observation impact analysis methods developed by Verlaan and Sumihar, 2016 to improve the Data Assimilation Schemes over LOTOS-EUROS model forecasting on Colombia?

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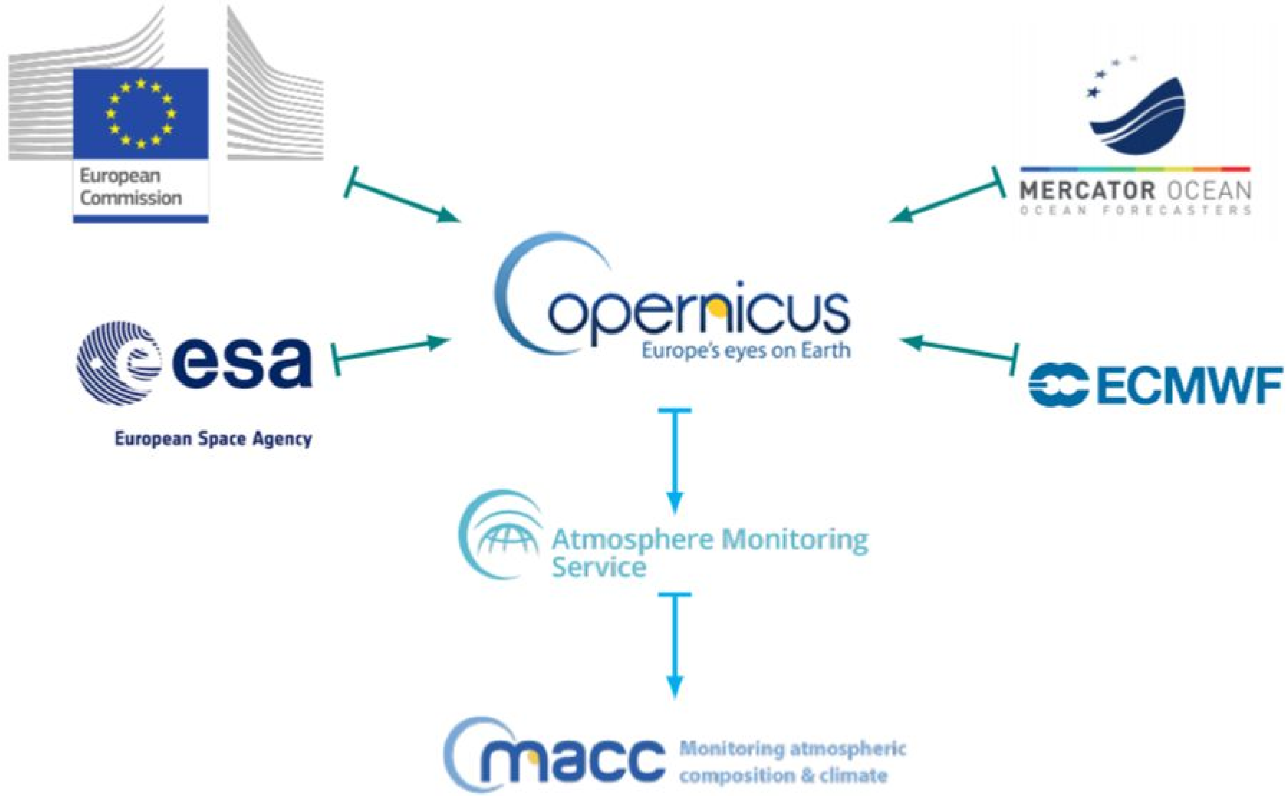
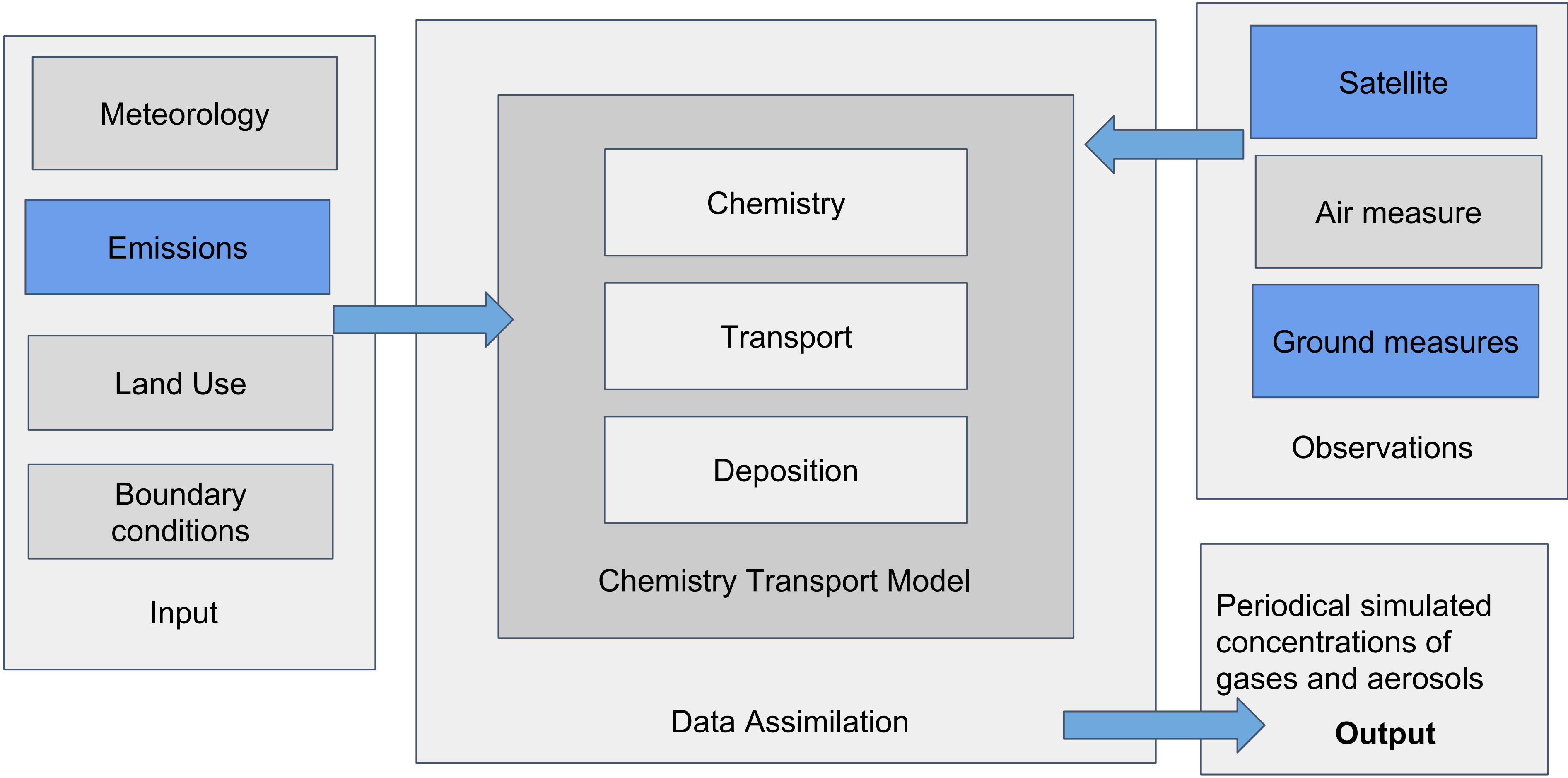
Sources of data

https://www.youtube.com/watch?v=bjAOqMf3DUY&t=119s

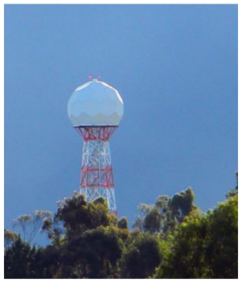
Sources of data



Methodologies used to estimate the transport of contaminants



Initial characterization of the data available



Hydrometeorological radar

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

Summary of the sensor of SIATA

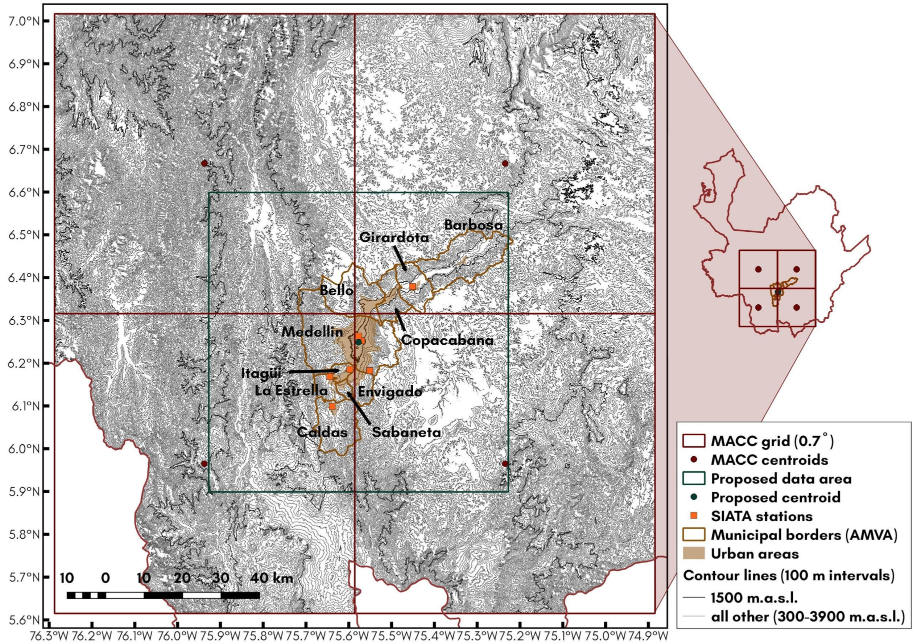
SIATA Vaisala CL-51

Raptor VAD-DL Detect inc

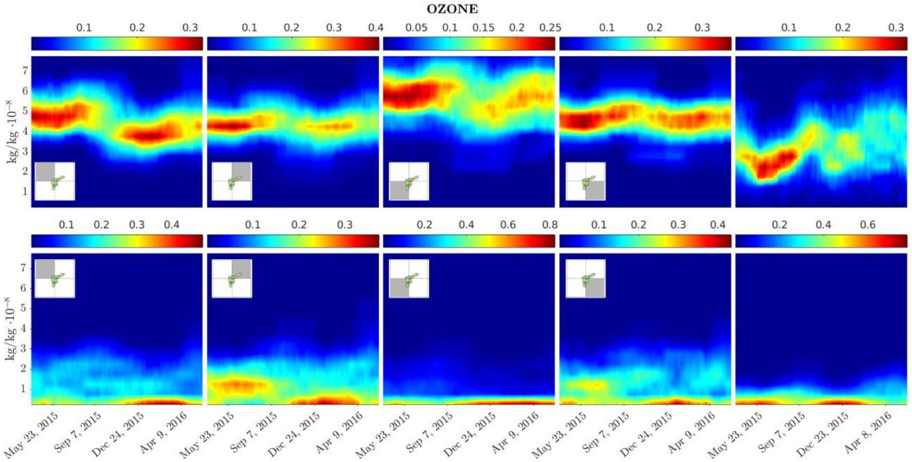
EPA regulated

105 until 2016

Initial characterization of the data available



Topographical map of the region under study, showing the political boundaries of the Aburrá Valley cities;

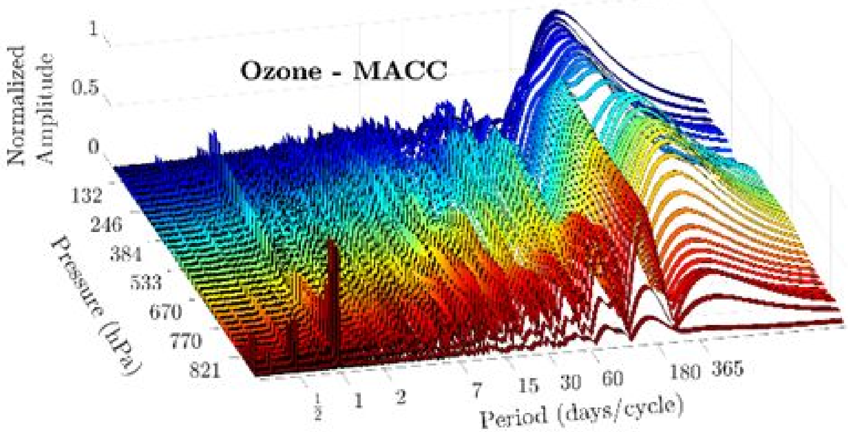


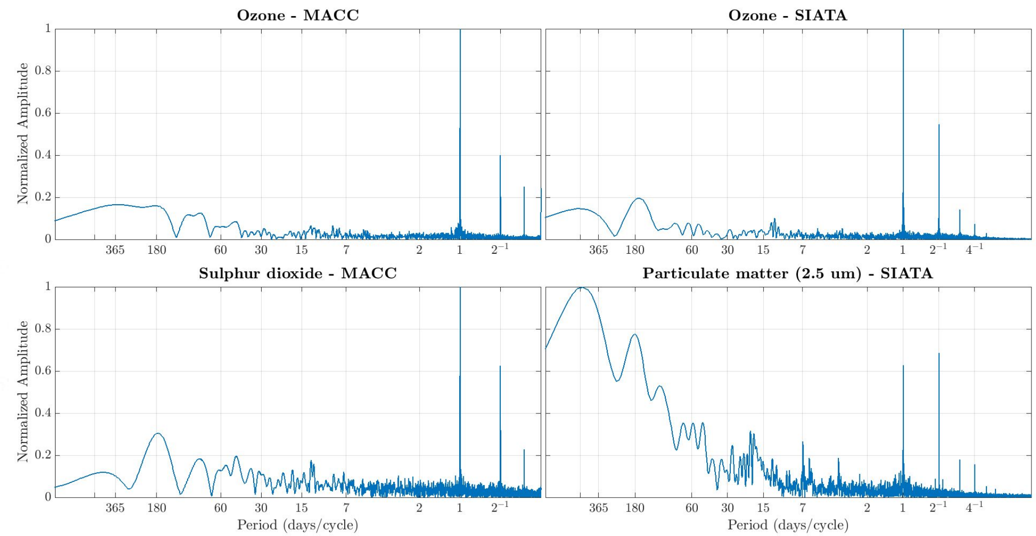
Moving histograms for the ozone concentration

	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

Correlation coefficients for MACC and SIATA O3

Initial characterization of the data available





MACC project (http://www.gmes-atmosphere.eu/), which is the functioning instrument of the Copernicus Atmosphere Monitoring Service.

March 31, 2015; and April 30, 2016

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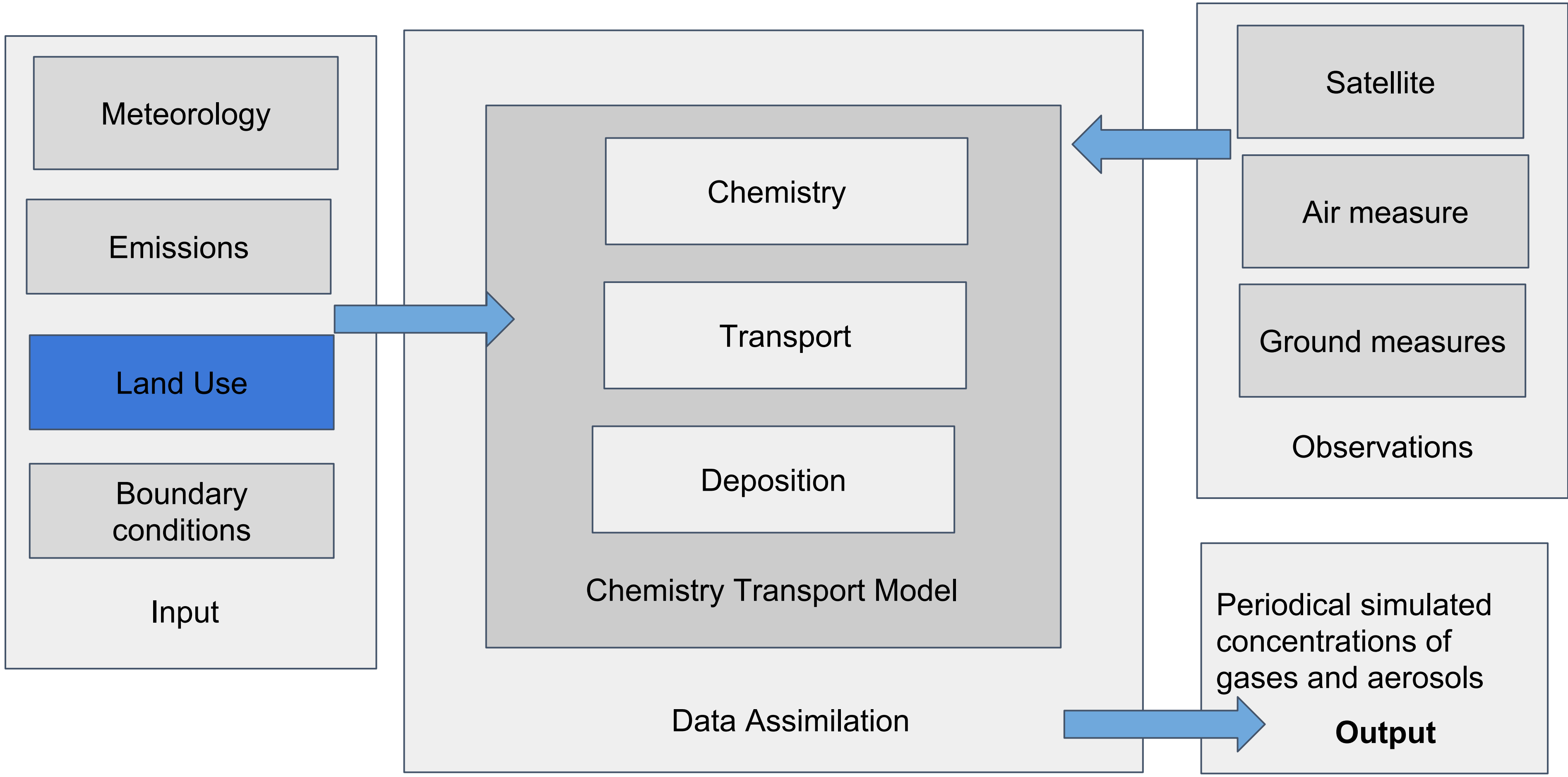
Methodologies used to estimate the transport of contaminants



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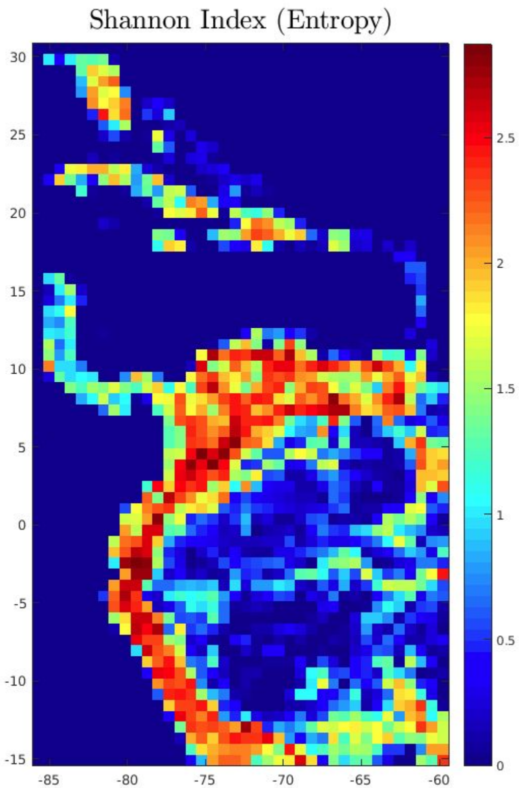
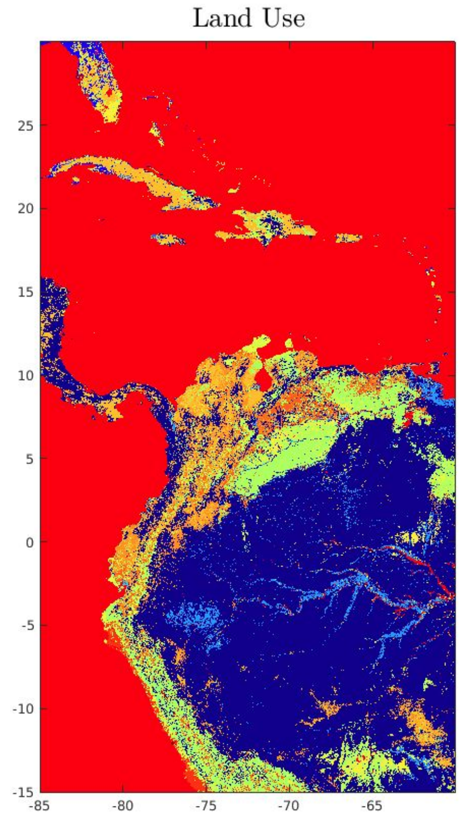
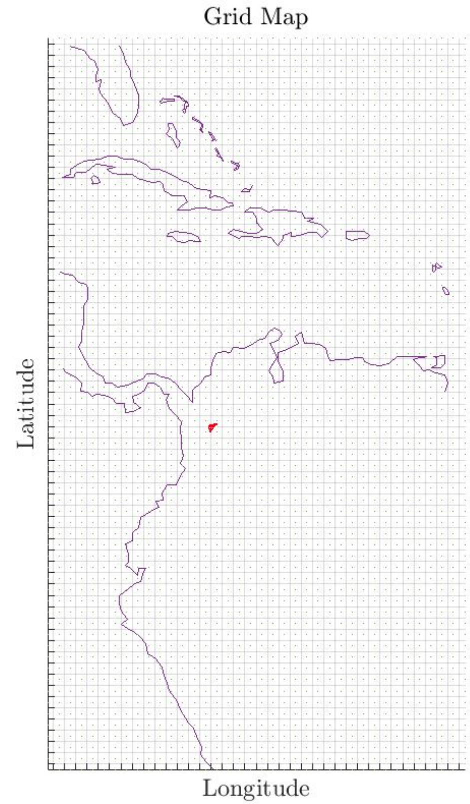
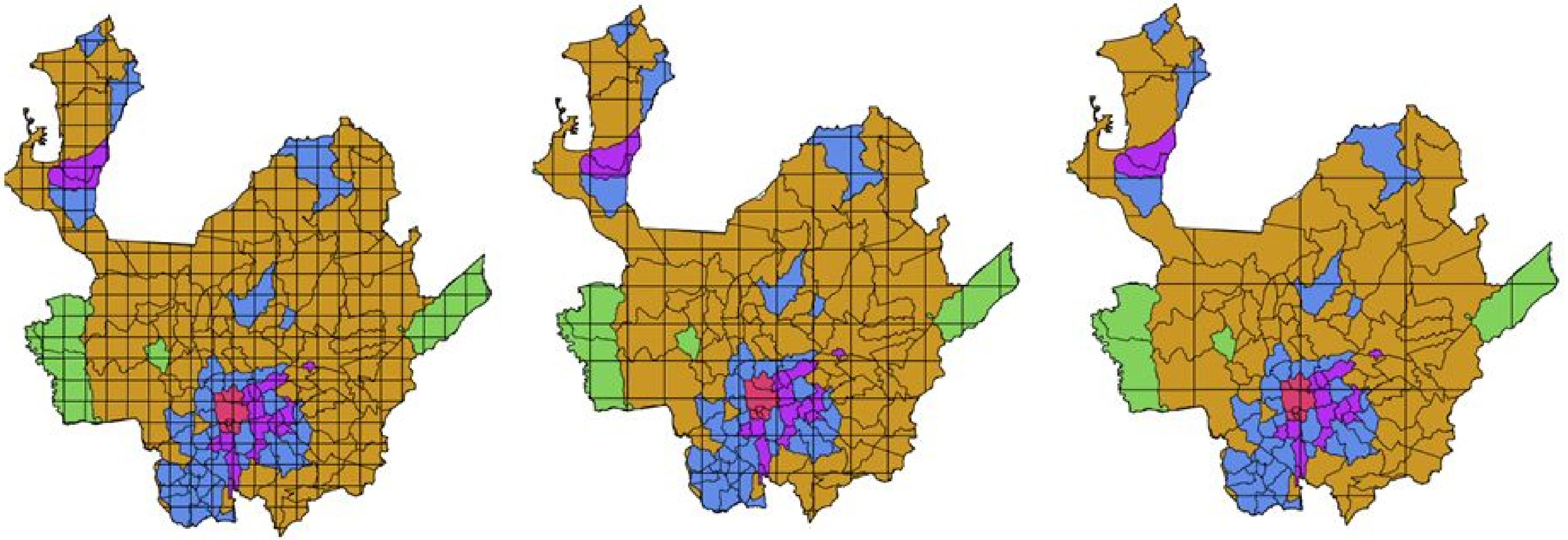






Shannon Index $H' = -\sum_{i=1}^{R} p_i \ln p_i$

Initial characterization of the data available



GRID 0.14
ECMWF

GRID 0.25
LOTOS EUROS

GRID 0.7
MACC

Leyenda

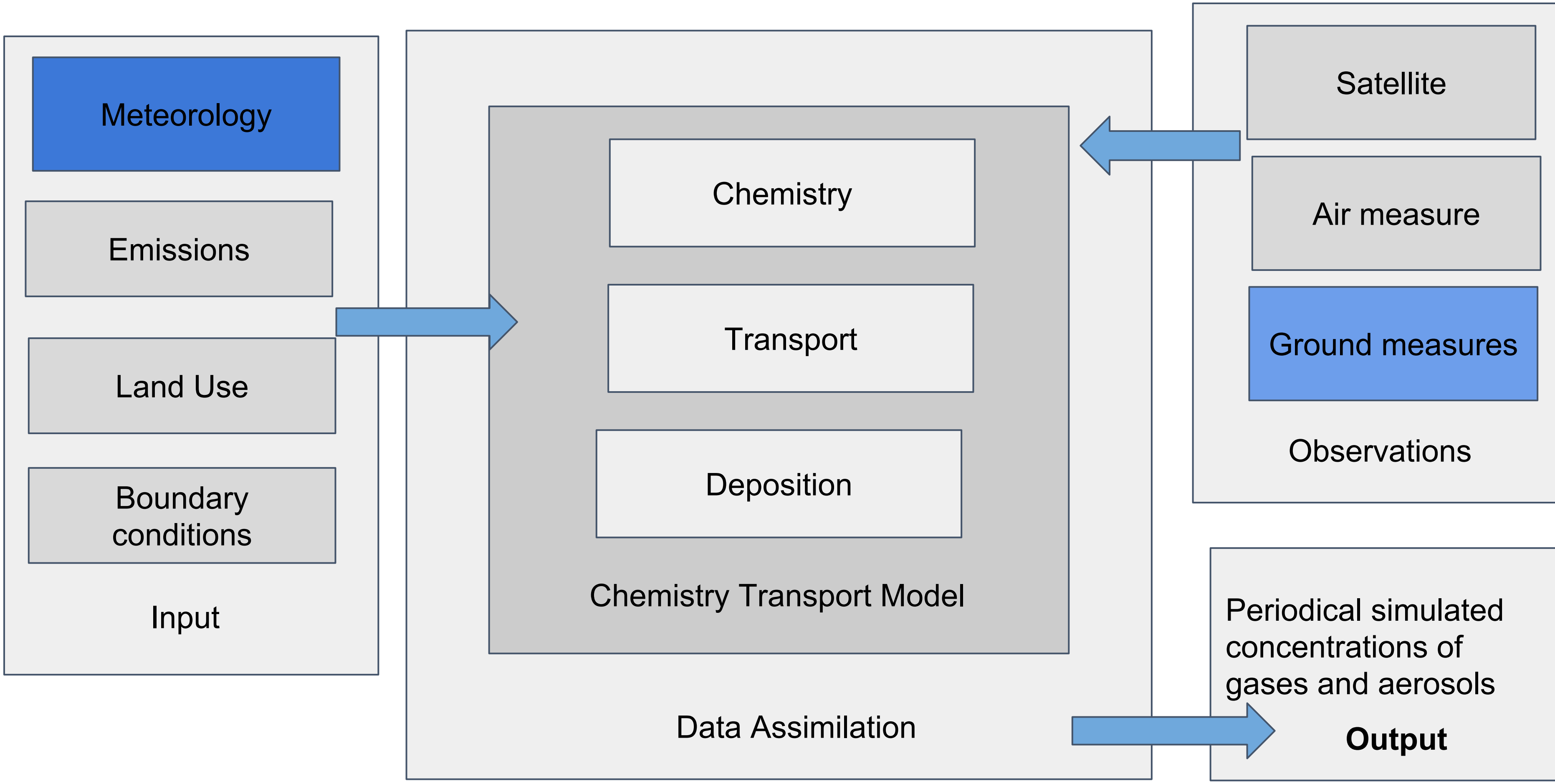
Densidad de poblacion

- <=10
- > 1000
- 101 - 1000
- 11 - 50
- 51 - 100

Numero total de habitantes por kilometro cuadrado (2011)

IGAC

Methodologies used to estimate the transport of contaminants



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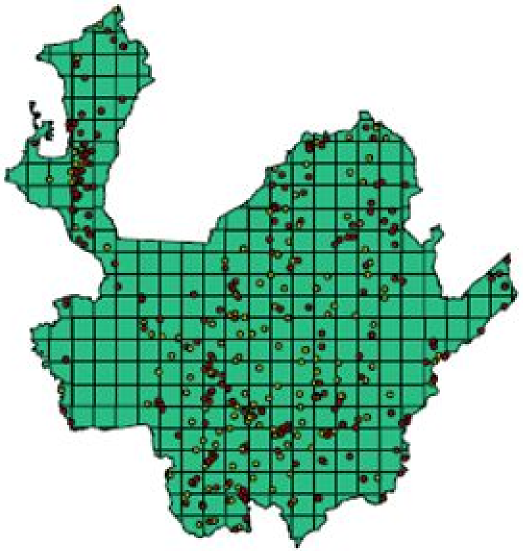
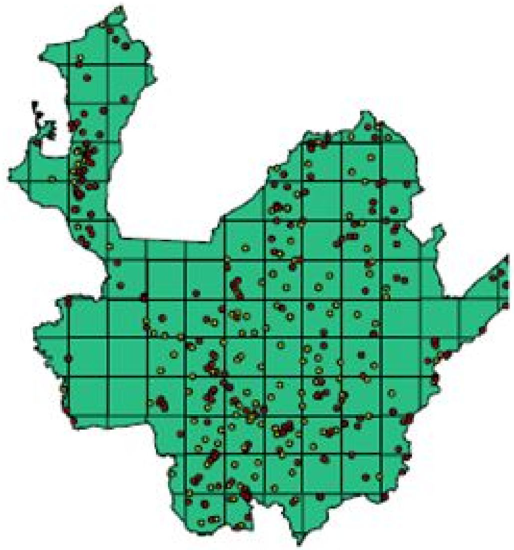


GRID 0.14
ECMWF



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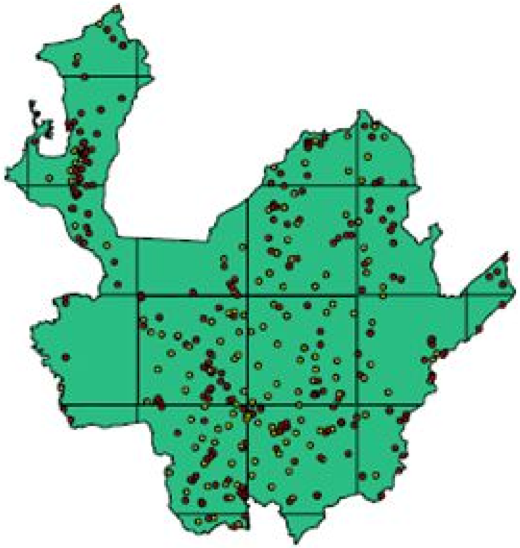
LOTOS EUROS



GRID 0.7
MACC

- Inactive stations
- Active stations

IDEAM stations

Current research questions

- What other satellite information or ground based sensor networks would help us to have more data of interest to increase the spatial and chemical resolution of the different compounds from the data we have available today from the models that we are working (LOTOS EUROS integrate with the WRF)

- How can we apply techniques to retrieve more information of the observations measured when we experience in them uncertainty due to the systematic error presented like the techniques used by (Van Damme M. et al., 2015)?

- Is it possible, under linearity and stationarity assumptions, to use the observation impact analysis methods developed by Verlaan and Sumihar, 2016 to improve the Data Assimilation Schemes over LOTOS-EUROS model forecasting on Colombia?.

Thanks

Questions

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