A box modeling approach for air quality management in Aburra Valley

Aproximación a un modelo de caja para la gestión de la calidad del aire en el Valle de Aburrá

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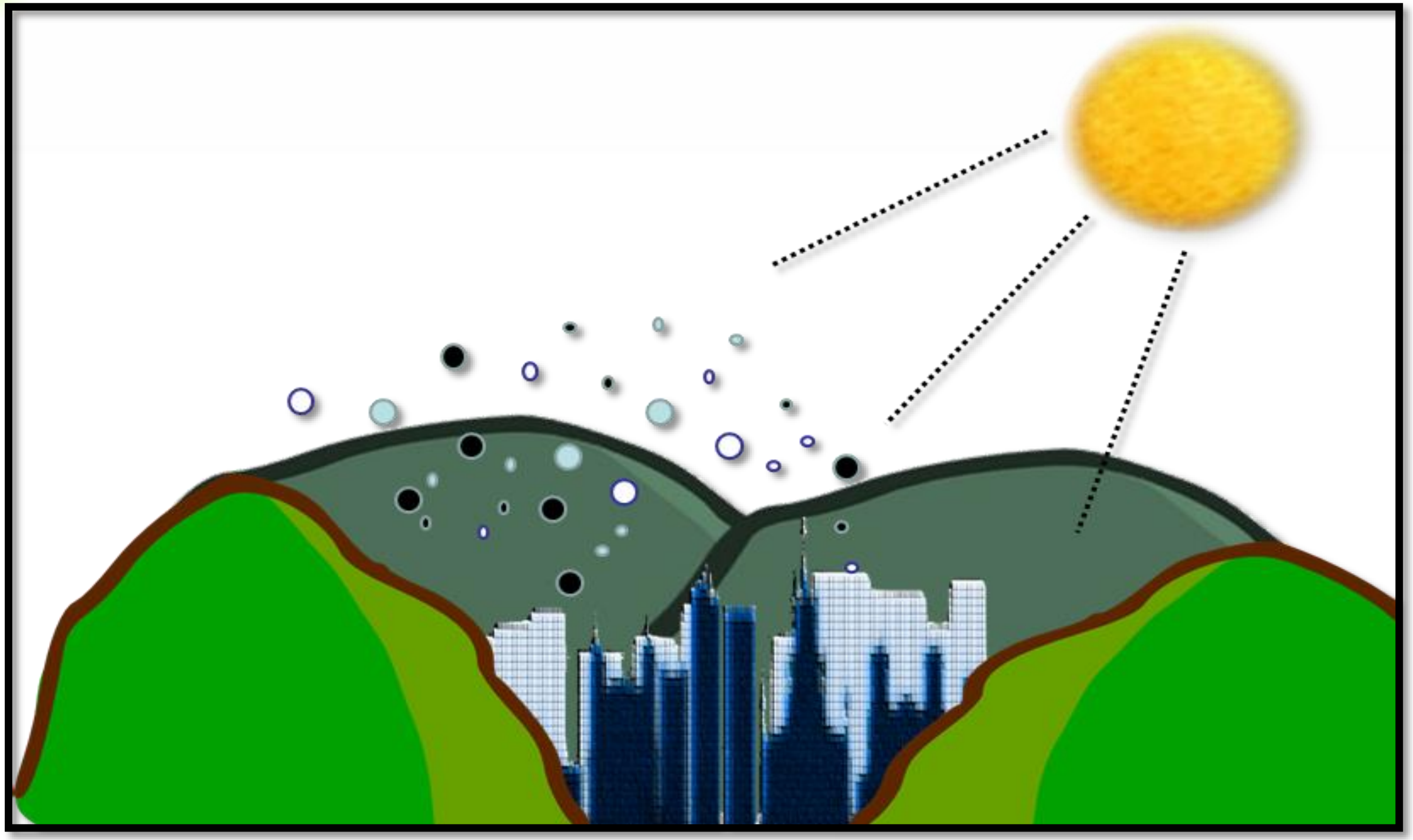
The industrialization, motorized mobility and other economics dynamic evolved in Aburra Valley harms the air quality.

Environmental concerns due to air pollution in Aburra Valley are mainly associated to high concentrations of fine particulate matter ($PM_{2.5}$).

There are also problems related to exceedances of ozone air quality standard, but to a lesser extent [1-3].

Photo: AFP

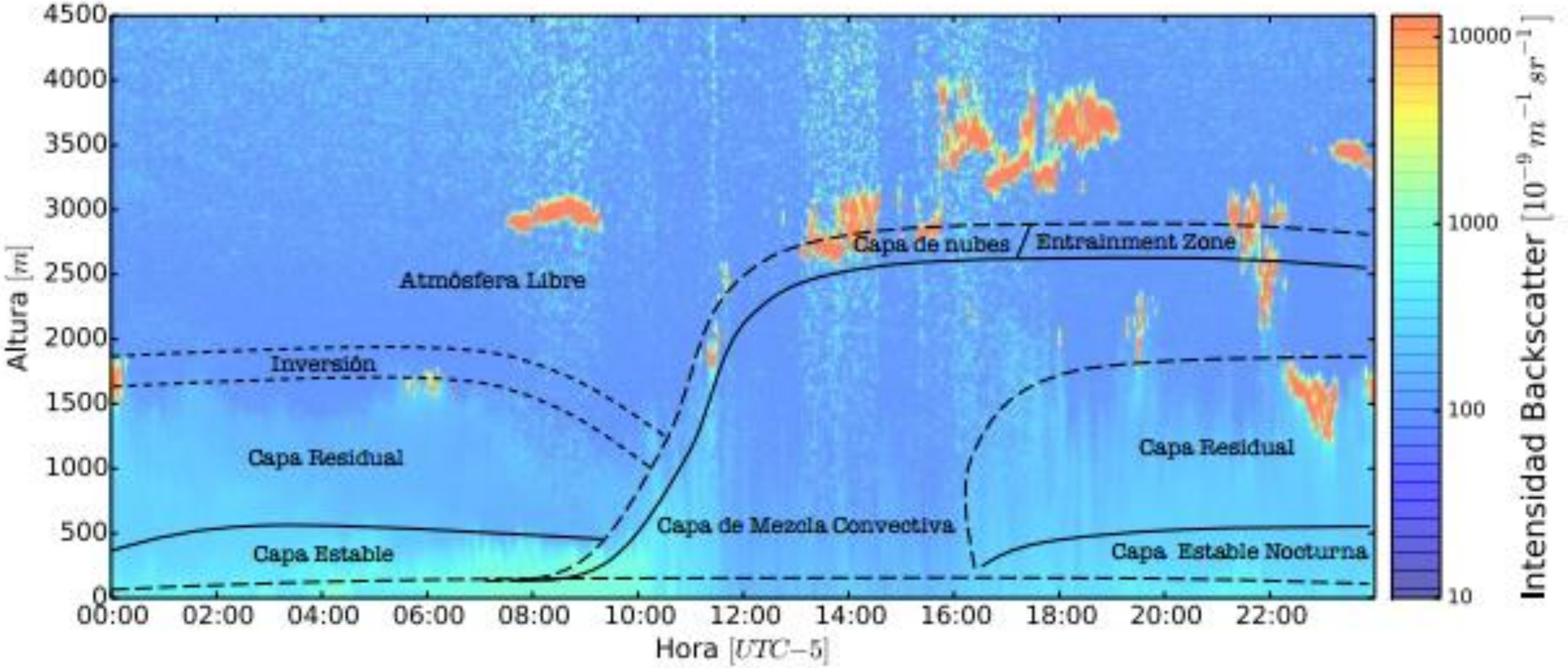


The air pollutants are emitted in the axis of the valley, mainly from mobile sources [3].

The pollution is not easily evacuated outside the valley due to the obstacle that the mountains imply to the advective wind.

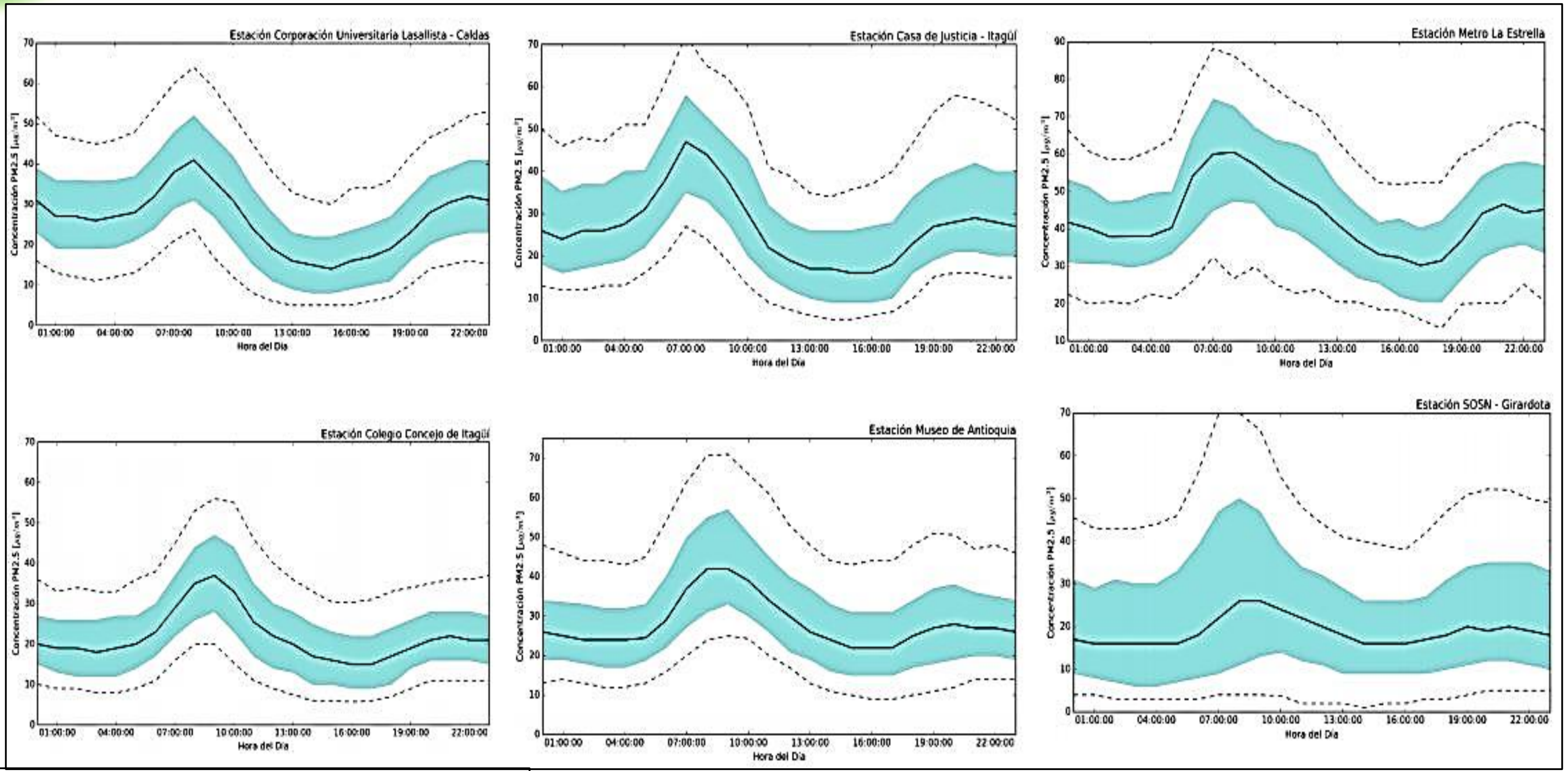
Also the top of the atmospheric boundary layer retains contaminants that rise convectively

The atmospheric boundary layer (ABL) is strongly influenced by the land surface, which time scale is less than the day and length scale is less than or equal to layer [4].



Taken from [5]

The layer height is configured by friction with surface roughness and orographic effect, by the moistness availability, surface winds, radiative heating and subsidence of air full of dense particles [6], [7].

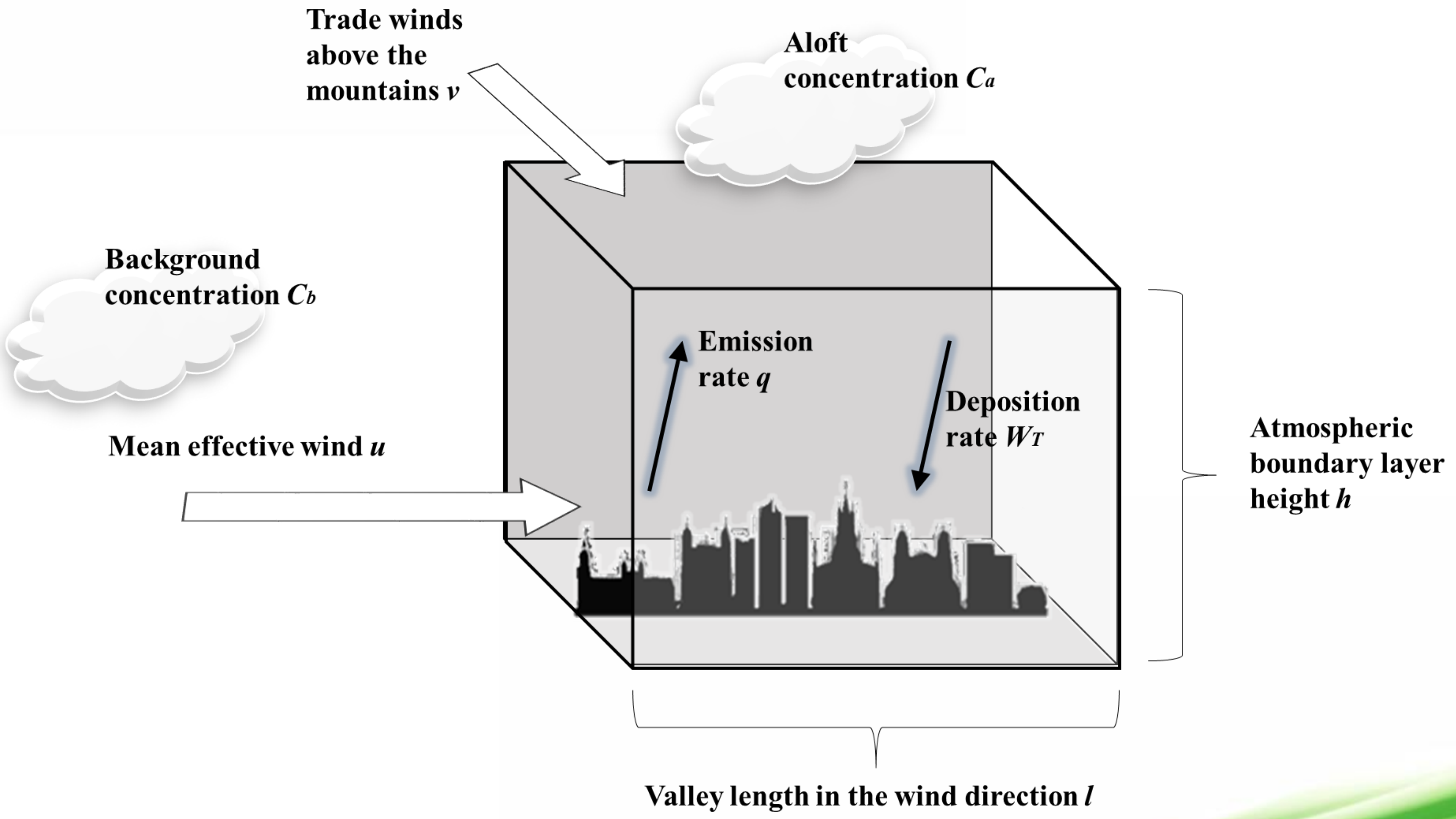


Taken from [1]

It is proposed to model the 2.5 microns particulate matter behavior, affected by horizontal ventilation, ABL height and emission rates.

The aim is to give a first approximate diagnosis of the pollutants amount reduction that would help to improve the air quality and avoid critical pollution episodes.

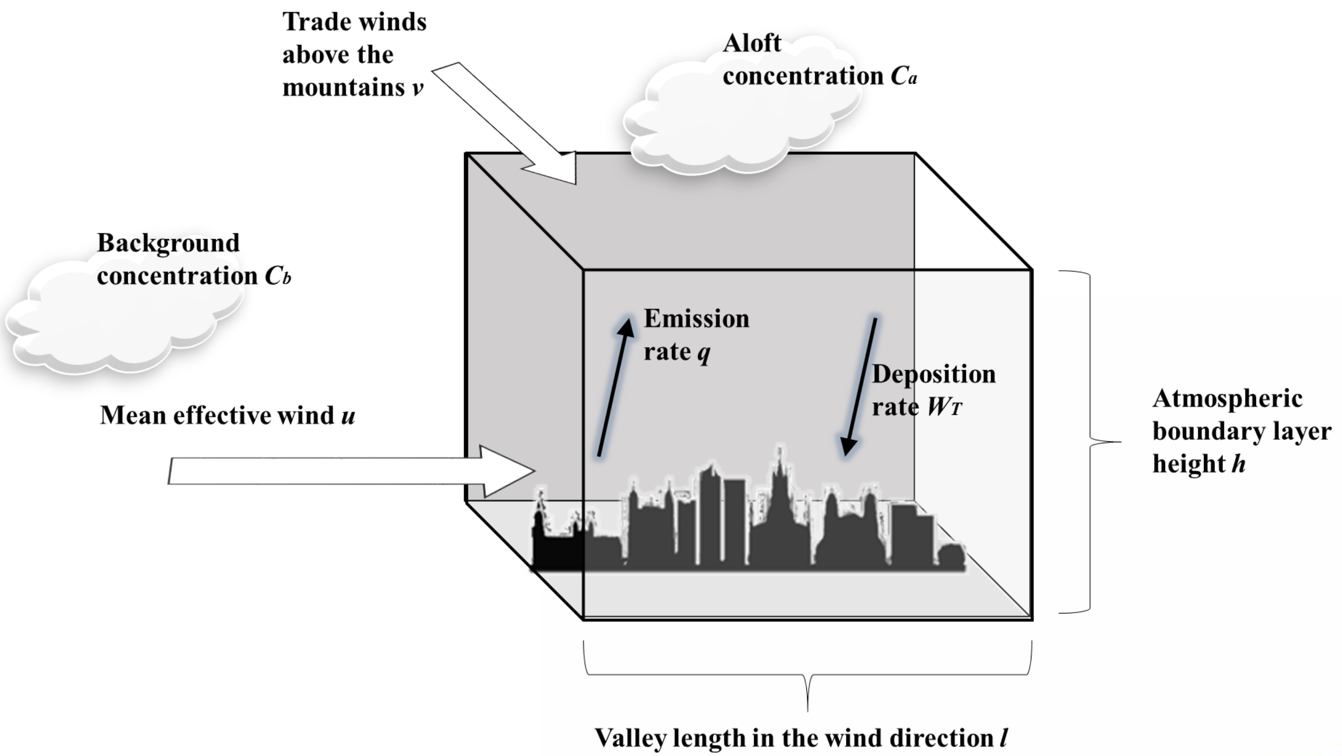
BOX MODEL



Trade winds above the mountains *v*
Aloft concentration C_a
Background concentration C_b
Emission rate *q*
Deposition rate W_T
Mean effective wind *u*
Atmospheric boundary layer height *h*
Valley length in the wind direction *l*

Change in the pollutant concentration column throughout the length of the valley = Incoming flow column − Incoming flow column + Emission throughout the valley − Deposition throughout the valley + Entrainment of pollutant by layer expansion

$$l \cdot \frac{\partial(h \cdot \bar{c})}{\partial t} = h \cdot \bar{u} \cdot \bar{c}_b - h \cdot \bar{u} \cdot \bar{c} + l \cdot q - l \cdot w_T \cdot \bar{c} + l \cdot \frac{\partial h}{\partial t} \cdot \bar{c}_a$$



There are not enough studies about background environmental pollution in Aburra Valley

But It's know that most $PM_{2.5}$ emissions are caused by mobile sources (about 80% of total pollutant amount produced) [3].

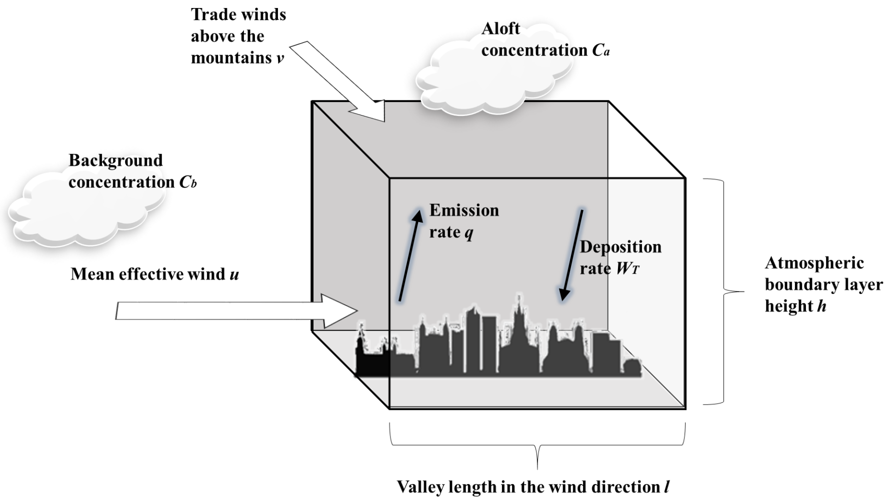
Therefore, the terms associated with the background concentration are not considered in this study.

Change in the pollutant concentration column throughout the length of the valley = Incoming flow column − Incoming flow column + Emission throughout the valley − Deposition throughout the valley + Entrainment of pollutant by layer expansion

$$l \cdot \frac{\partial (h \cdot \bar{c})}{\partial t} = h \cdot \bar{u} \cdot \bar{c}_b - h \cdot \bar{u} \cdot \bar{c} + l \cdot q - l \cdot w_T \cdot \bar{c} + l \cdot \frac{\partial h}{\partial t} \cdot \bar{c}_a$$

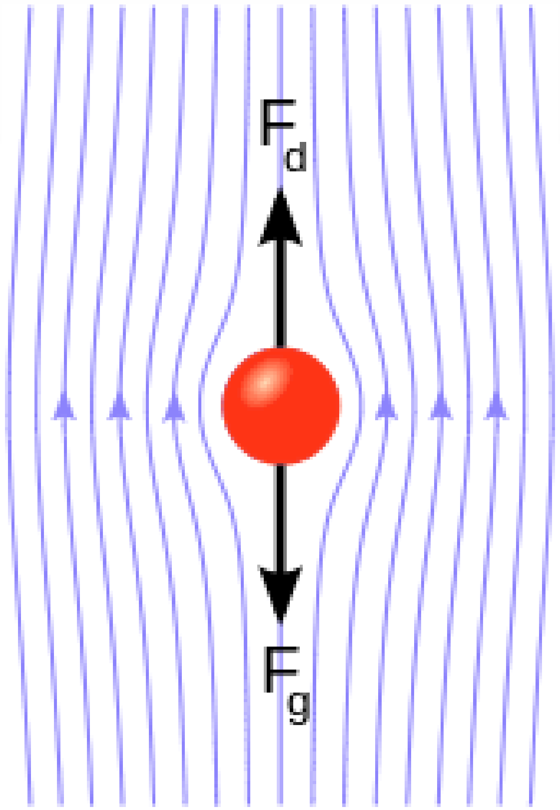
Background concentration

Aloft concentration



Particulate matter concentration depends on emission rate as the only positive term.

Unlike, the horizontal advection is the most important mass output proportional to ABL height.



So as not add complexity to the model, the precipitation is not considerate. Therefore, the model works with the terminal velocity of suspended particles, which can be parameterized from the density and the particle size [8].

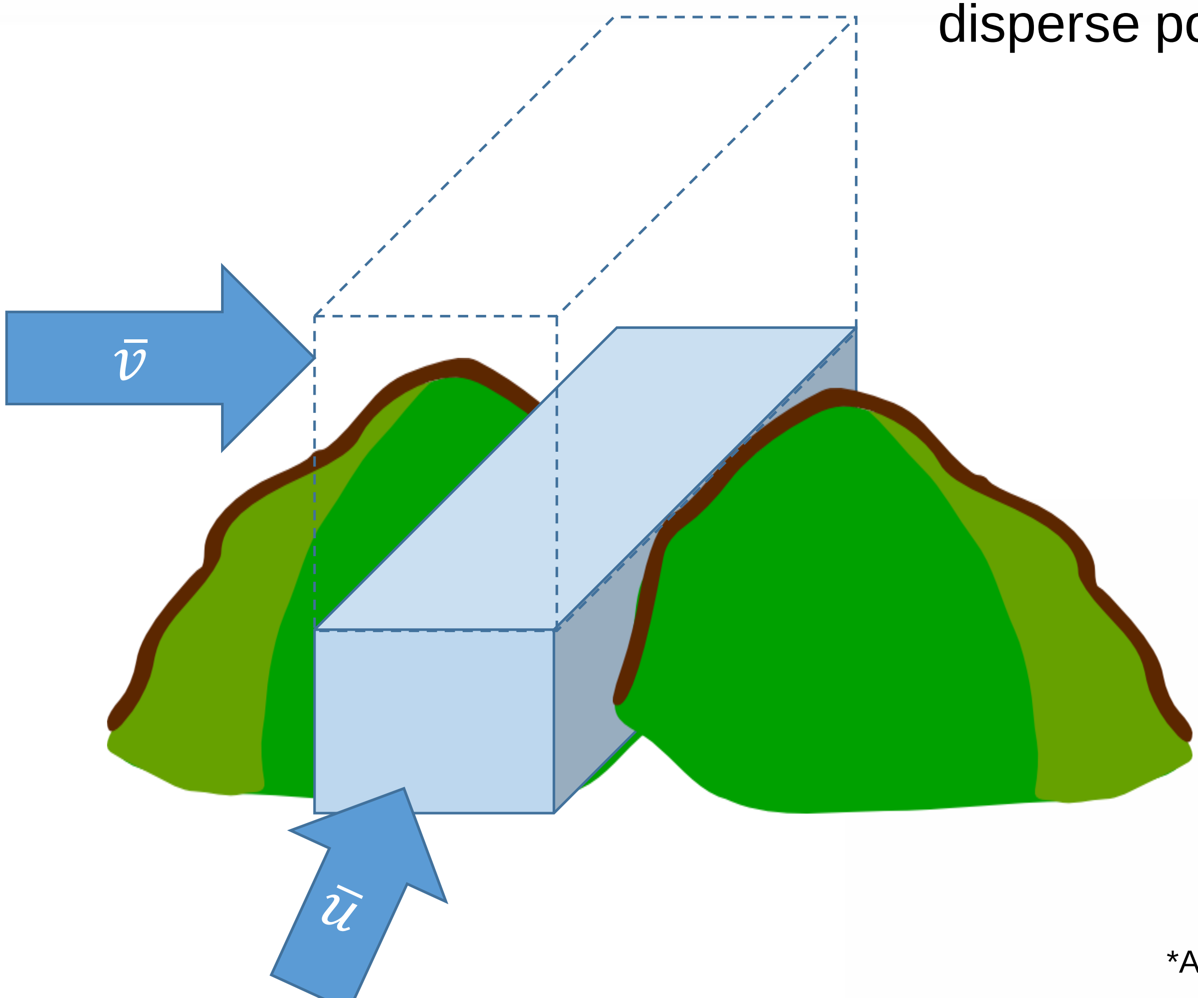
$$\kappa = (4\,\rho\,g\,d)\,/\,(3\,w_T{}^2)$$

Due to the small characteristic scale of the particulate matter, the dry deposition term w_T be on the order of 10^{-5} m/s.

$$l \cdot \frac{\partial(h \cdot \bar{c})}{\partial t} = -h \cdot \bar{u} \cdot \bar{c} + l \cdot q - l \cdot w_T \cdot \bar{c}$$

When the top of the ABL* rises above the mountains height, the trade winds can easily blow across the urban atmosphere and help disperse pollution.

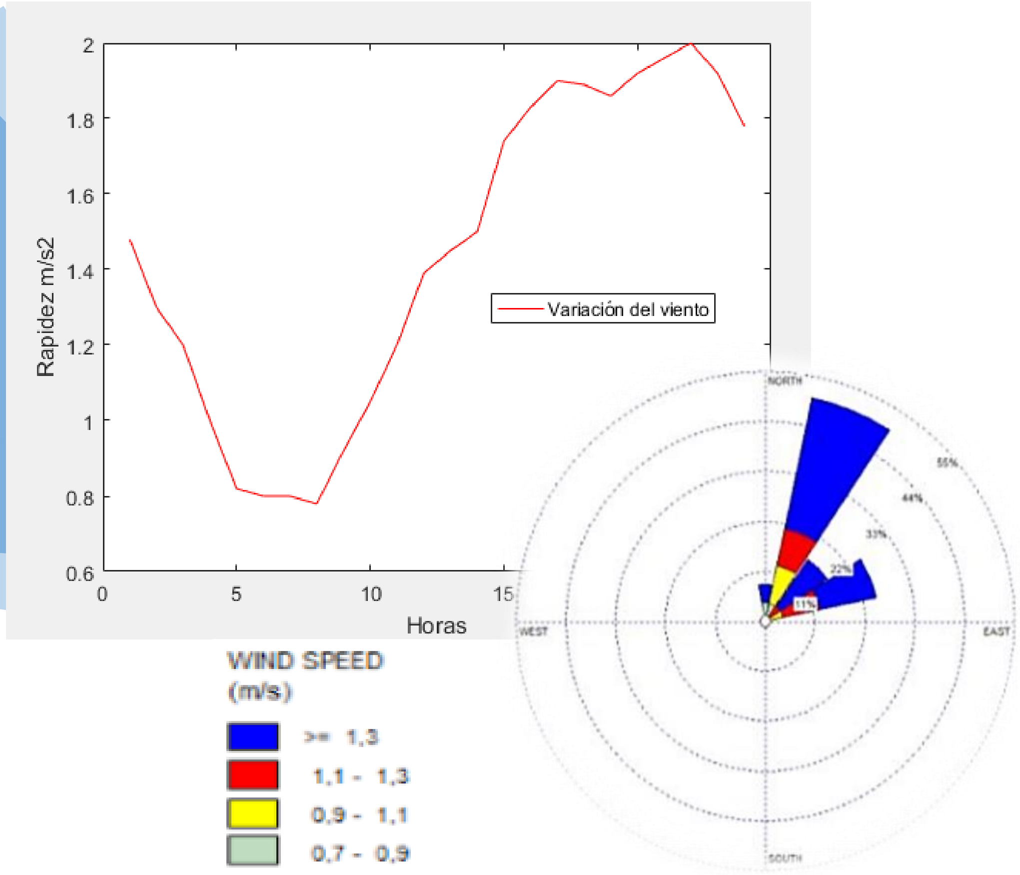
The term is replaced by $h_I u + h_A v$



$$h \leq 1\text{km} \quad \begin{cases} h_I = h \\ h_A = 0 \end{cases}$$

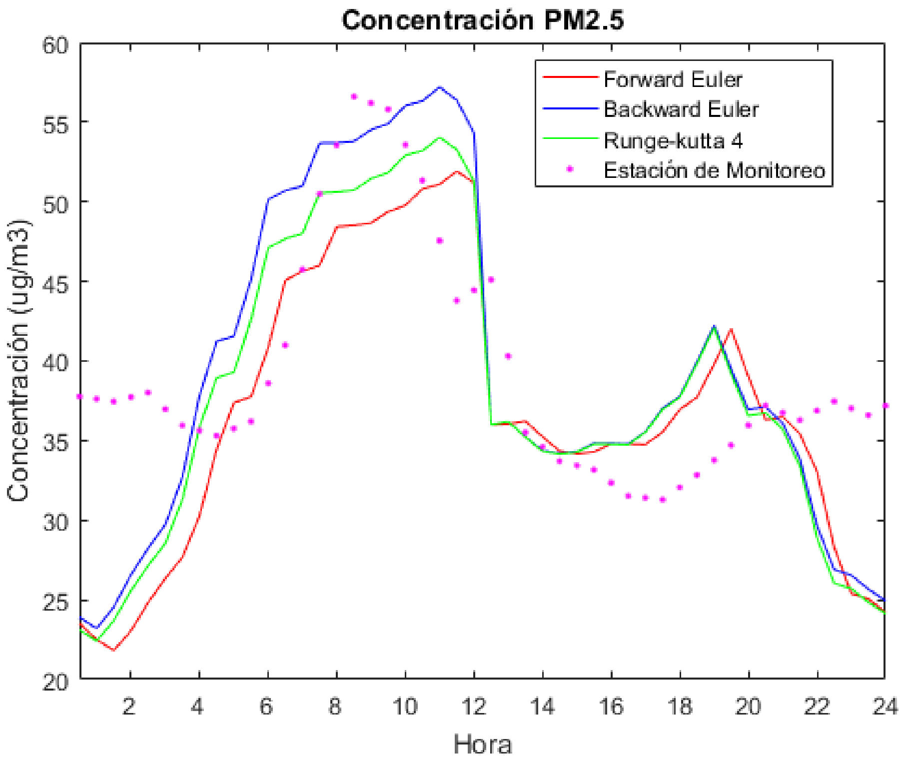
$$h > 1\text{km} \quad \begin{cases} h_I = 1km \\ h_A = h - 1km \end{cases}$$

*Atmospheric Boundary Layer

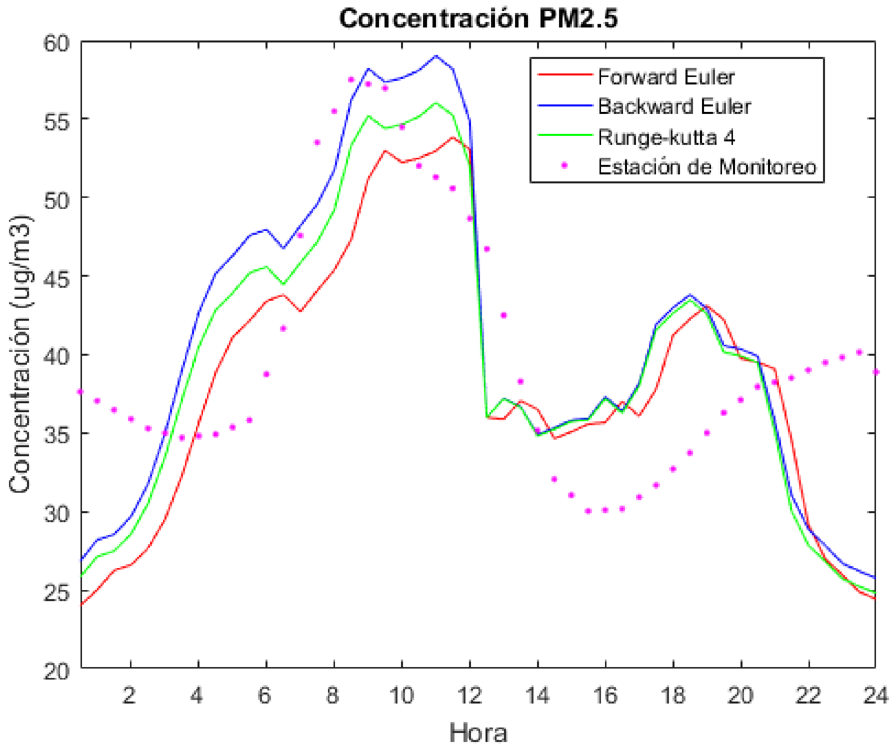


Data was taken from the Antioquia Museum's monitoring station (2014 – 2016) and the microwave radiometer (Oct. 2014 – Apr. 2016) managed by the Early Alert System for Medellin and Aburra Valley (SIATA).

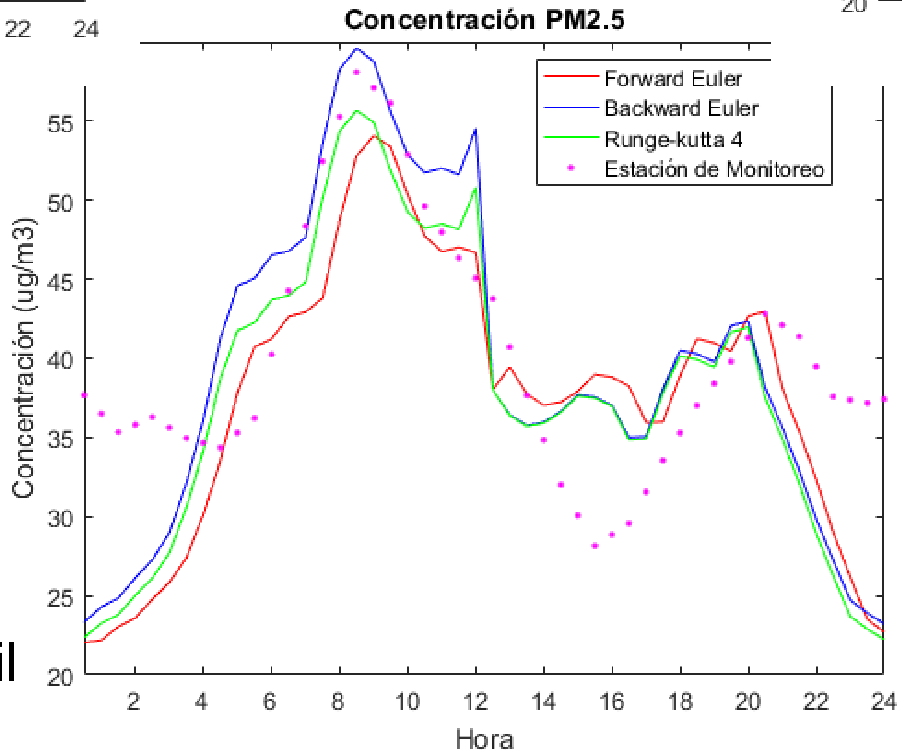
The differential equation of mass balance was solved using *Forward Euler*, *Backward Euler* and *Runge-Kutta4* approach, with a half-hour time scale.



Average day of January



Average day of November



Average day of April

Category	*PM2.5 (µg/m3)*
Good	0 – 12
Moderate	12.1 – 35.4
Unhealthy for sensitive groups	35.5 – 55.4
Unhealthy	55.5 – 150.4
Very unhealthy	≥ 150.5
Hazardous	

The results were analyzed according to the Air Quality Index for Aburra Valley (ICA), based on the Environmental Protection Agency (EPA) Methodology [9-10].

Month	*Minimum absolute average error*	**Percentage of emissions reduction needed to get an air quality category**					
January	17.5%	–	–	–	X	10%	70%
February	19.2%	–	–	–	X	25%	75%
March	21.6%	–	–	X	8%	42%	81%
April	18.1%	–	–	–	X	14%	72%
May	18.5%	–	–	–	–	X	65%
June	24.1%	–	–	–	–	X	66%
July	24.9%	–	–	–	–	X	71%
August	26.1%	–	–	–	–	X	73%
September	21.3%	–	–	–	–	X	68%
October	19.8%	–	–	–	X	9%	70%
November	17.8%	–	–	–	X	14%	72%
December	19.7%	–	–	–	X	20%	74%

The exes (X) indicates the ICA index calculated for the average day of each month.

The hyphen (-) indicates a higher index than the calculated value (worst air quality).

The percentages indicates how much emissions must be reduced to improve air quality.

CONCLUSIONS

Taking into account that vehicles are the majority responsible for particulate matter emissions in the Aburra Valley, pollution management also necessarily becomes the management of mobility and transport.

The results should not be interpreted as the product of linear relationships, cause and effect. Actually, the spatial and temporal variability of the ABL is not so trivial.

Nor is it true that the pollutants amount = number of vehicles.

This complexity supposes greater challenges for the management, justifying the modeling exercises that contribute to the understanding of the urban climatology.

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… ANY QUESTION?