Inspire Create Transform

UNIVERSIDAD EAFIT®

Medellín Air qUality Initiative

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Outline

Introduction
Why MAuI
Model Predictive Control
Measurement
Models
Uncertainty reduction
Challenges
Conclusions

Introduction

Marzo 6 2018 9:52 am

Marzo 11 2018 9:53 am

Why MAuI?

UNIVERSIDAD
DE ANTIOQUIA
1803

WORKSHOP
Atmospheric Pollution and its Impacts

Área METROPOLITANA Valle de Aburrá

ICETEX
Invertimos en el talento de los colombianos

ruta n MEDELLÍN
CENTRO DE INNOVACIÓN Y NEGOCIOS

Alcaldía de Medellín
Cuenta con vos
SAPIENCIA
Agencia de Educación Superior de Medellín

parque arví Corporación 10 años

SESQUICENTENARIO

UNIVERSIDAD NACIONAL DE COLOMBIA

DRI Desert Research Institute

UNIVERSIDAD DE ANTIOQUIA

UNIVERSIDAD NACIONAL de MAR DEL PLATA

Particle Vision Die Partikelspezialisten

TU Delft

UNIVERSIDAD NACIONAL DEL CENTRO DE LA PROVINCIA DE BUENOS AIRES

UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

POR MI RAZA HABLARA EL ESPIRITU

UNAM

VERITAS IUSTITIA LIBERTAS

FREIE UNIVERSITÄT BERLIN

LOUIS BOLK INSTITUUT

UNI FR

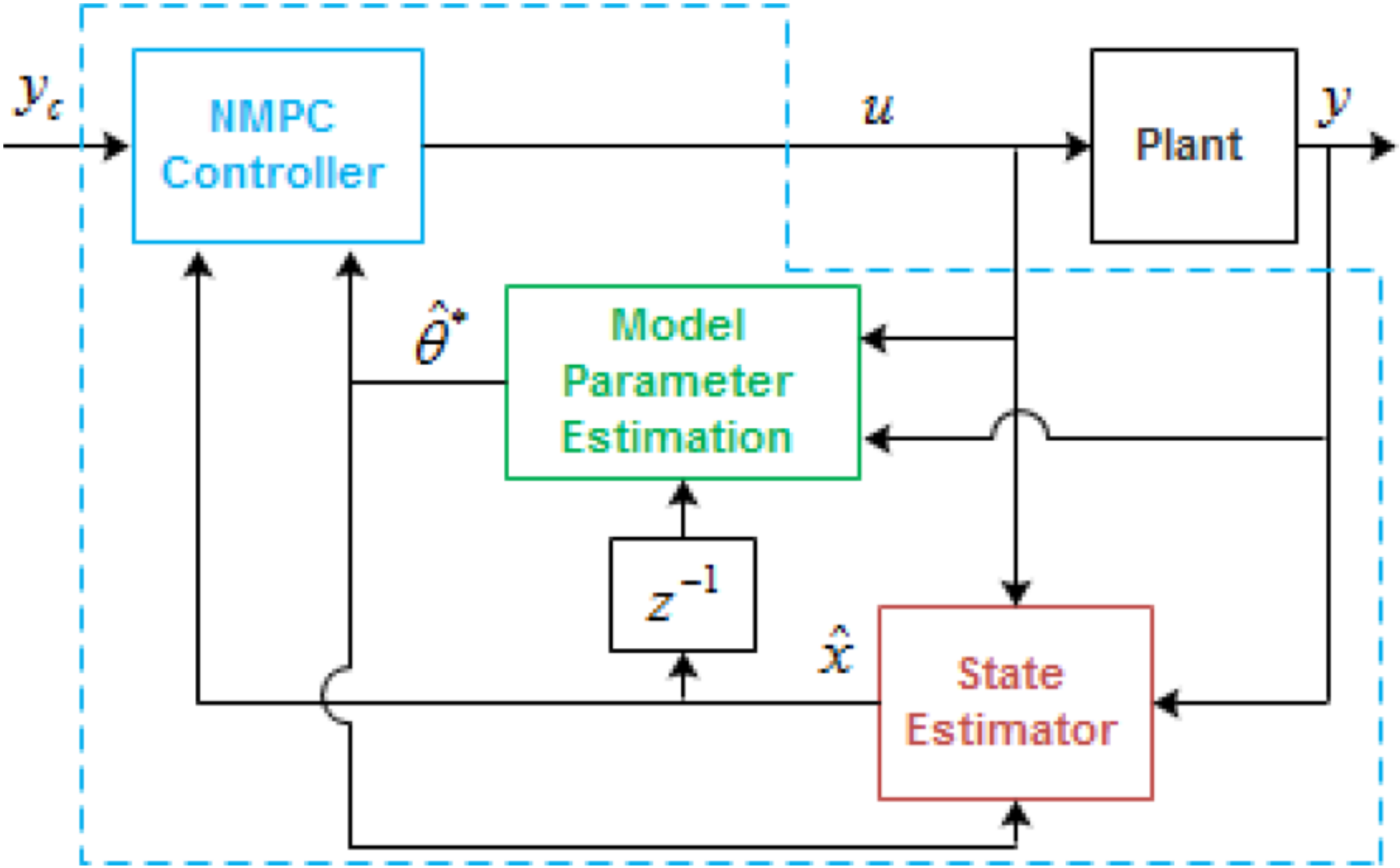
UNIVERSITÉ DE FRIBOURG

UNIVERSITÄT FREIBURG

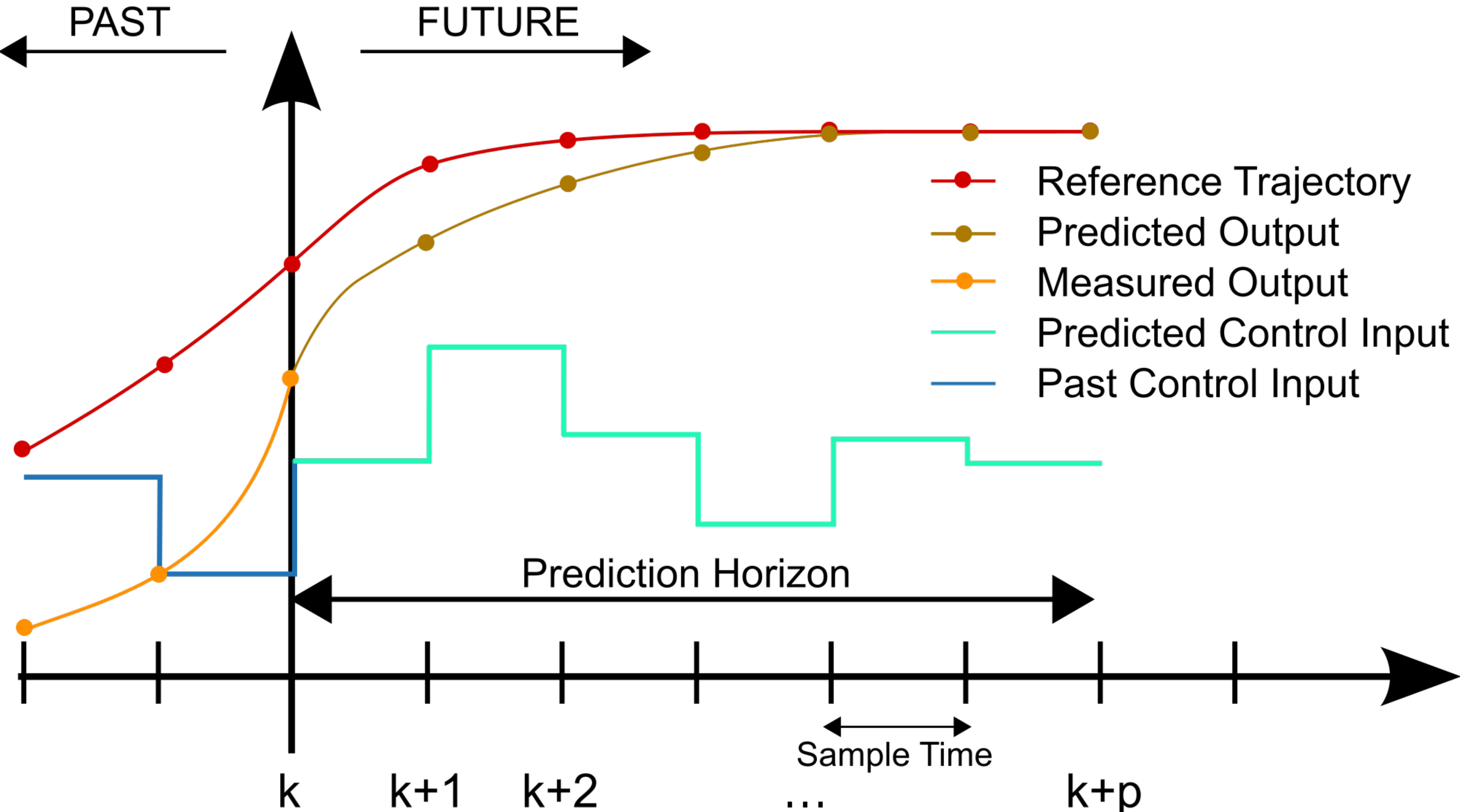
VU VRIJE UNIVERSITEIT AMSTERDAM

TNO innovation for life

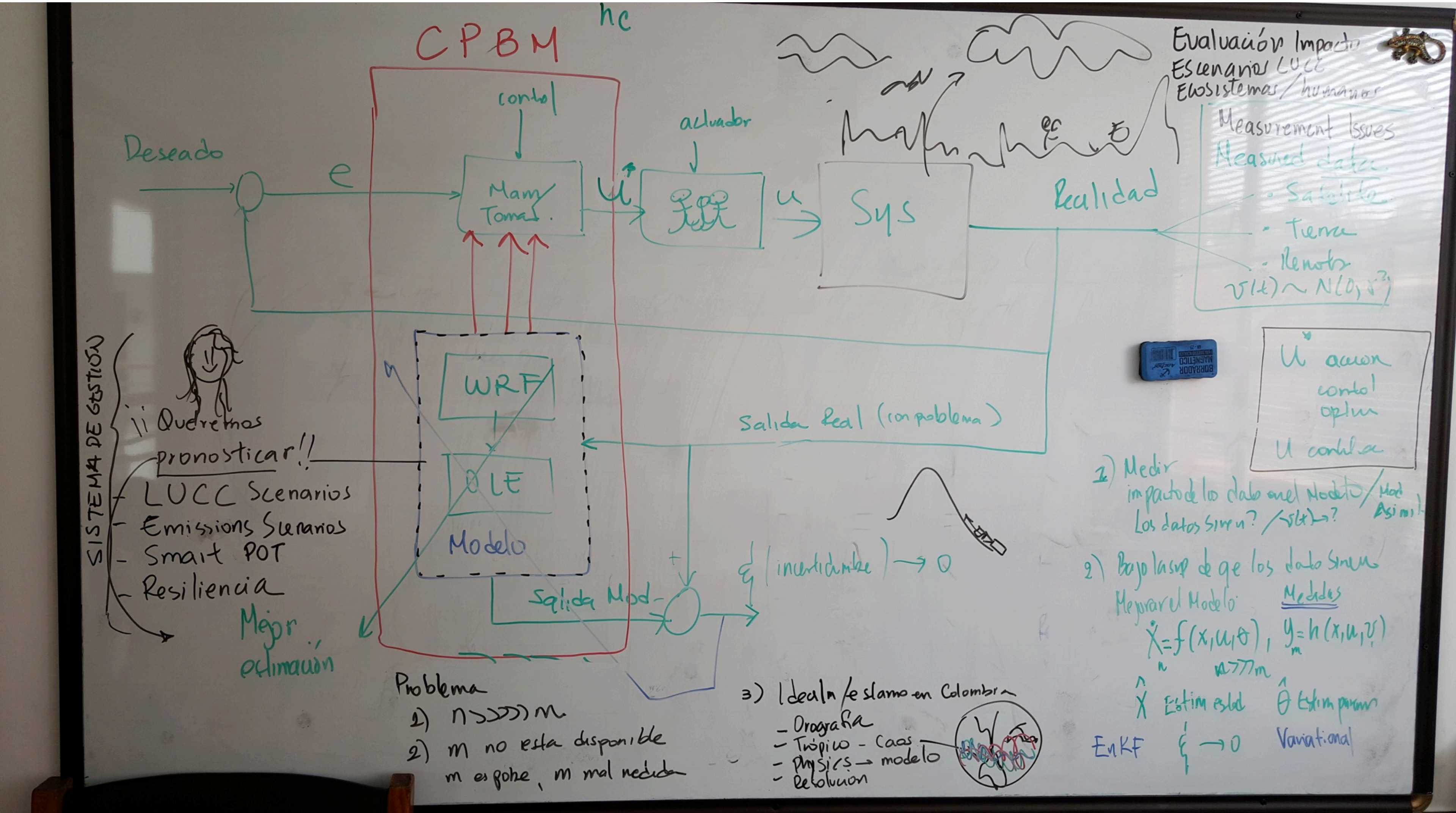
Model Predictive Control



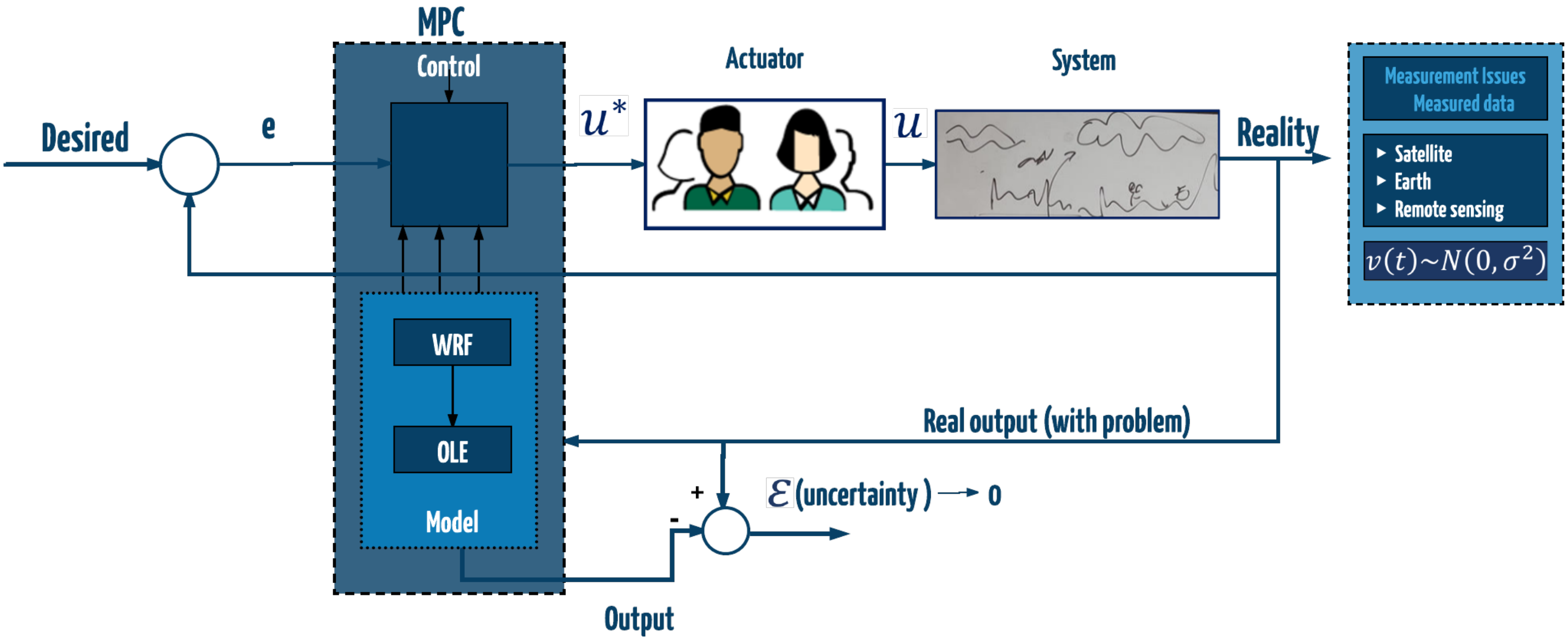
Model Predictive Control



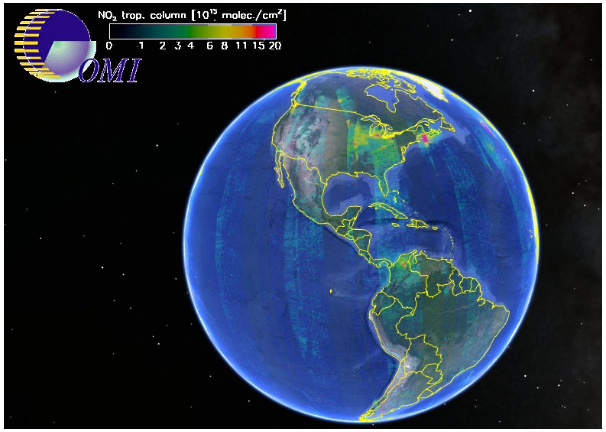
Model Based Predictive Control Scheme

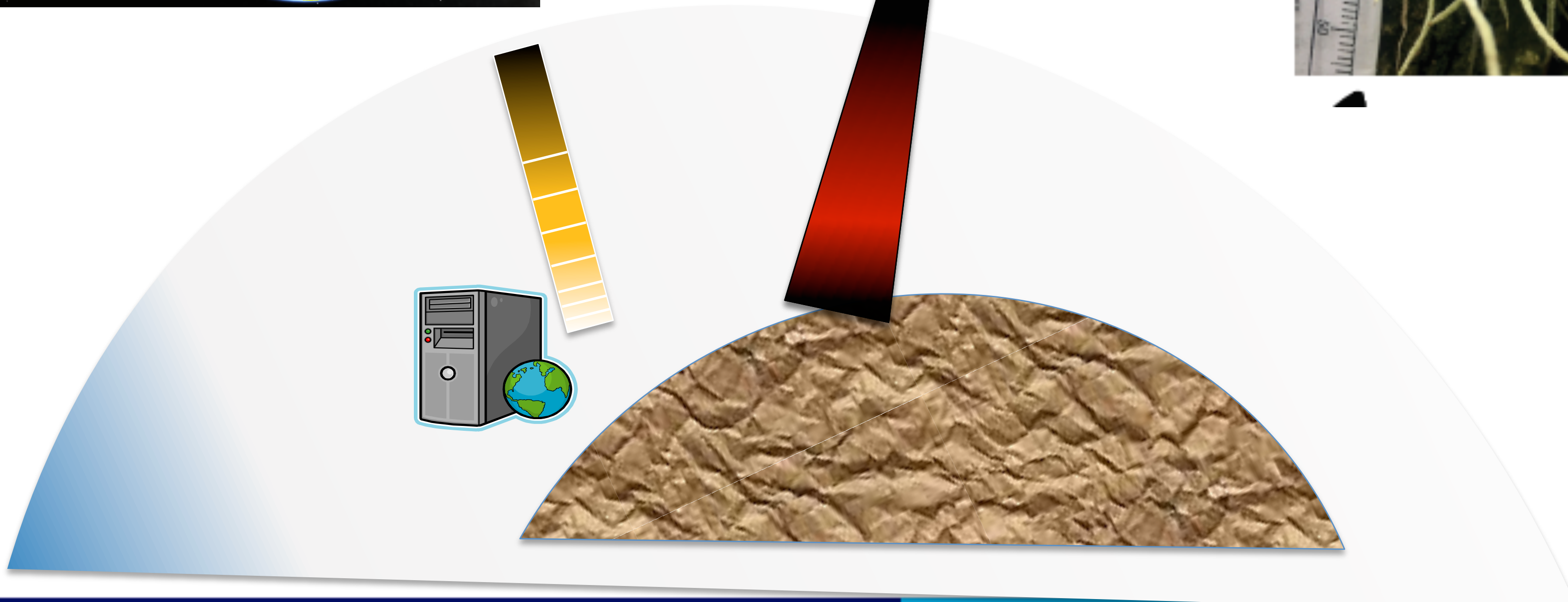


Model Based Predictive Control Scheme

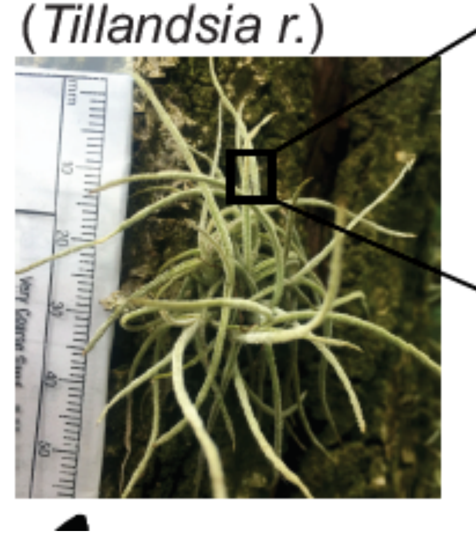


Measurement

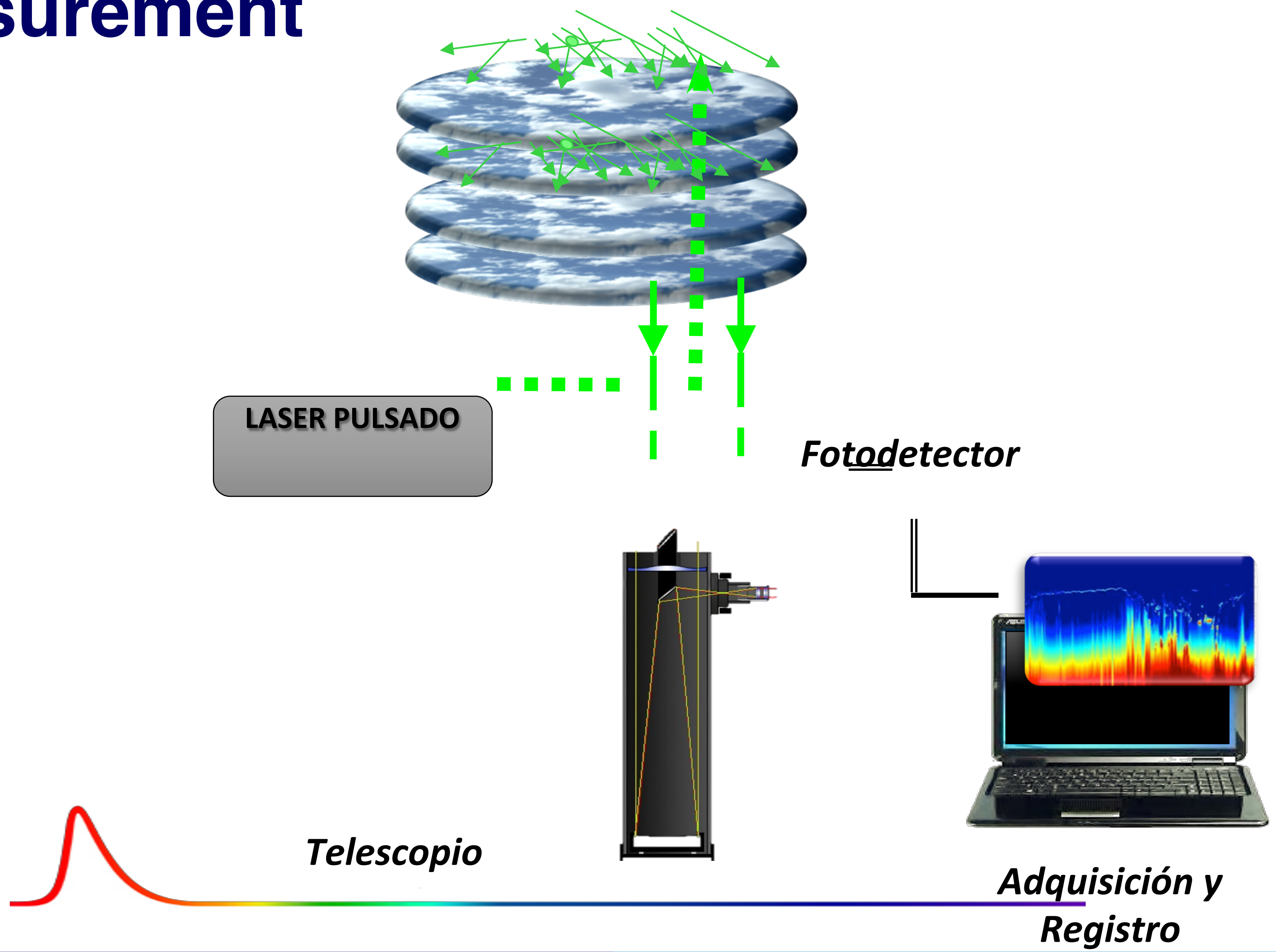




Biomonitor
(*Tillandsia r.*)



Measurement



Models

Chemistry transport Model
LOTOS- EUROS

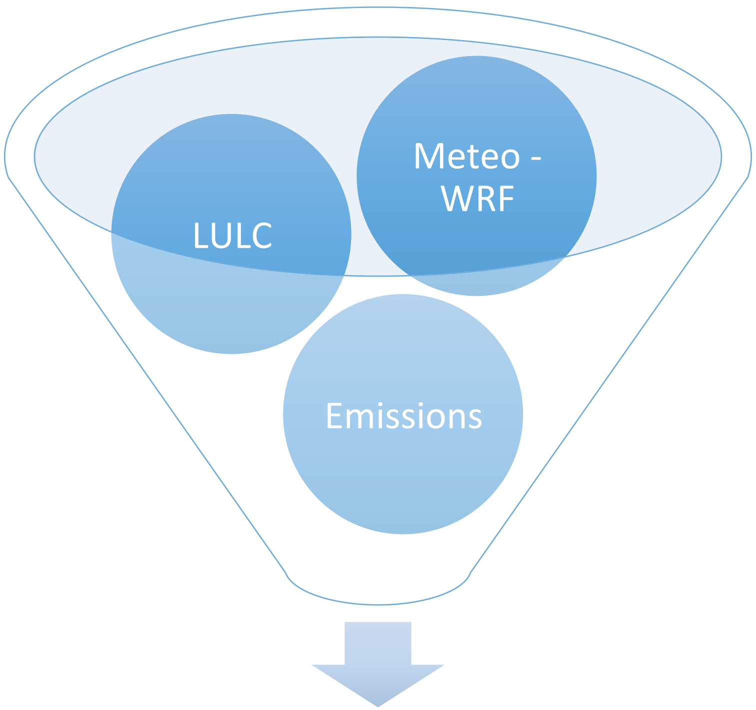
$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + V\frac{\partial C}{\partial y} + W\frac{\partial C}{\partial z} = \frac{\partial}{\partial t}\left(K_h\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right)$$

$$+ E + R + Q - D - W$$

TNO innovation for life

Models

Chemistry transport Model
LOTOS- EUROS



LOTOS EUROS

Models

Weather research Forecast WRF

$$
\begin{aligned}
&\partial_t U + m_x\left[\partial_x(Uu) + \partial_y(Vu)\right] + \partial_\eta(\Omega u) \\
&\qquad +(m_x/m_y)(\alpha/\alpha_d)\left[\mu_d(\partial_x\phi' + \alpha_d\partial_x p' + \alpha'_d\partial_x\overline{p}) + \partial_x\phi(\partial_\eta p' - \mu'_d)\right] = F_U \\
&\partial_t V + m_y[\partial_x(Uv) + \partial_y(Vv)] + (m_y/m_x)\partial_\eta(\Omega v) \\
&\qquad +(m_x/m_y)(\alpha/\alpha_d)\left[\mu_d(\partial_x\phi' + \alpha_d\partial_x p' + \alpha'_d\partial_x\overline{p}) + \partial_x\phi(\partial_\eta p' - \mu'_d)\right] = F_U \\
&\partial_t W + (m_x m_y/m_y)[\partial_x(Uw) + \partial_y(Vw)] + \partial_\eta(\Omega w) \\
&\qquad\qquad -m_y^{-1}g(\alpha/\alpha_d)[\partial_\eta p' - \bar{\mu}_d(q_v + q_c + q_r)] + m_y^{-1}\mu'_d g = F_W,
\end{aligned}
$$

$$\partial_t\mu'_d + m_x m_y[\partial_x U + \partial_y V] + m_y\partial_\eta\Omega = 0$$

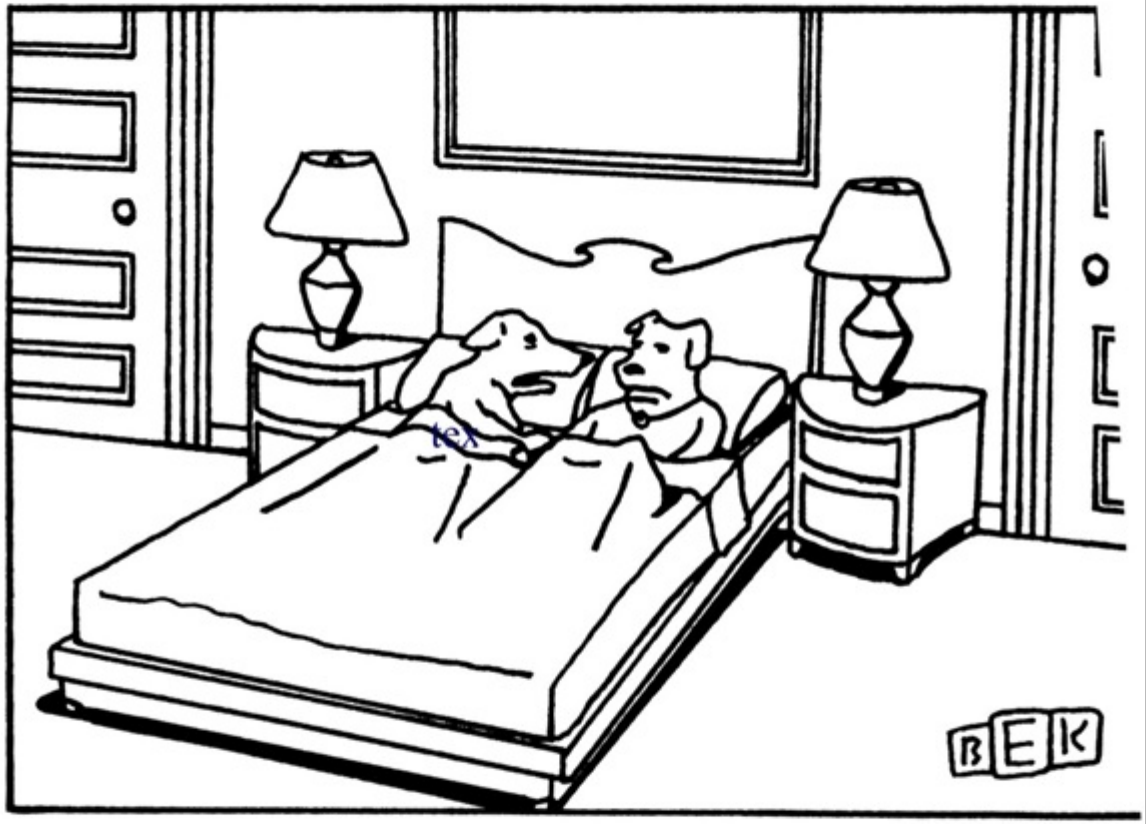
$$\partial_t\phi' + \mu_d^{-1}[m_x m_y(U\partial_x\phi + V\partial_y\phi) + m_y\Omega\partial_\eta\phi - m_y g W] = 0.$$

$$\partial_t\Theta + m_x m_y[\partial_x(U\theta) + \partial_y(V\theta)] + m_y\partial_\eta(\Omega\theta) = F_\Theta$$

$$\partial_t Q_m + m_x m_y[\partial_x(Uq_m) + \partial_y(Vq_m)] + m_y\partial_\eta(\Omega q_m) = F_{Q_m}.$$

$$\partial_\eta\phi' = -\bar{\mu}_d\alpha'_d - \alpha_d\mu'_d.$$

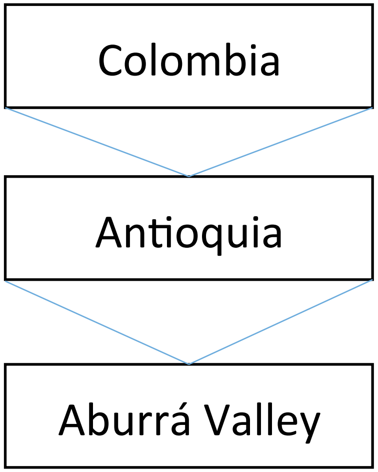
Uncertainty Reduction



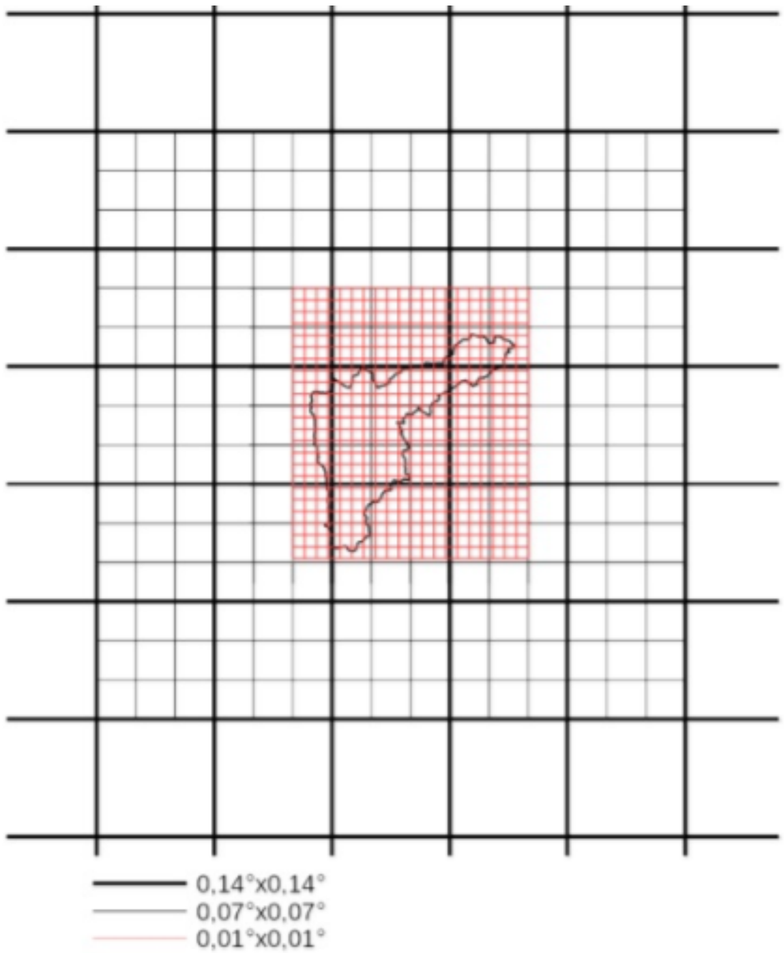
"Since we're both being honest, I should tell you I have fleas."

Modeling and Simulation

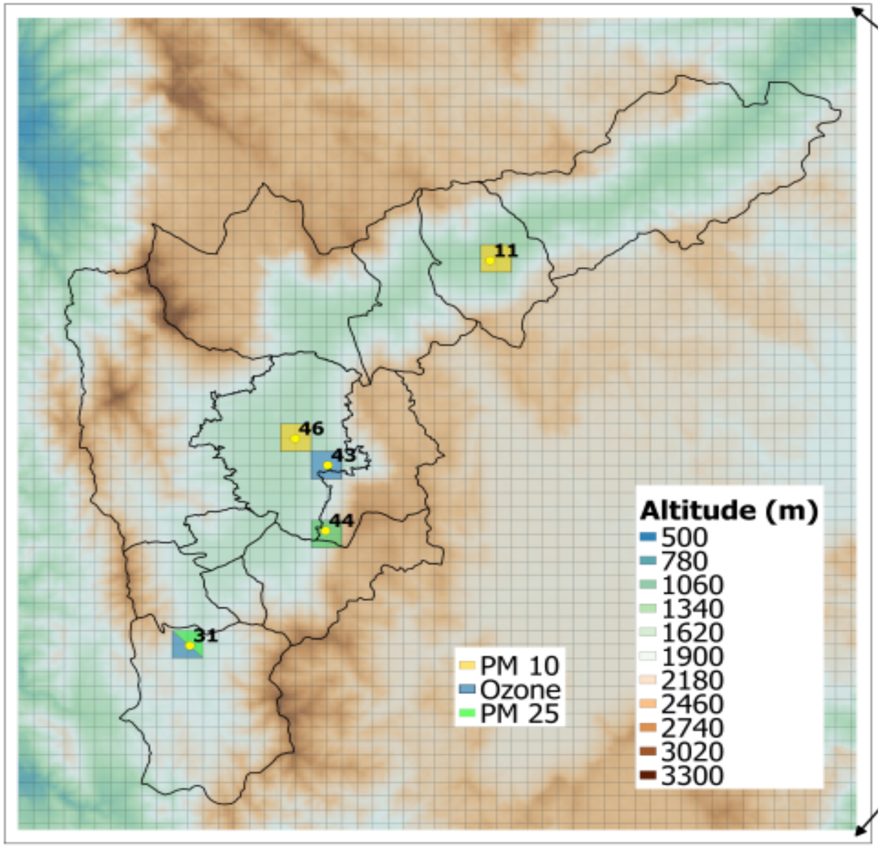
Nested domains



0.7	Degrees	77.86 Km Long x 77,71 Km Lat
0.14	Degrees	15.6 Km Long x 15,4 Km Lat
0.07	Degrees	7.8 Km Long x 7,7 Km Lat
0.01	Degrees	1.11 Km Long x 1,1 Km Lat

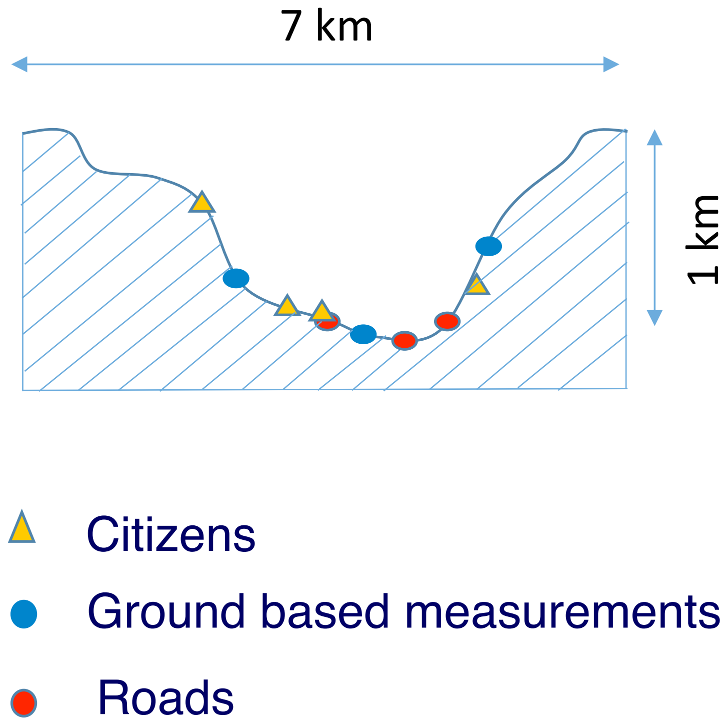


Model assimilation for Medellin



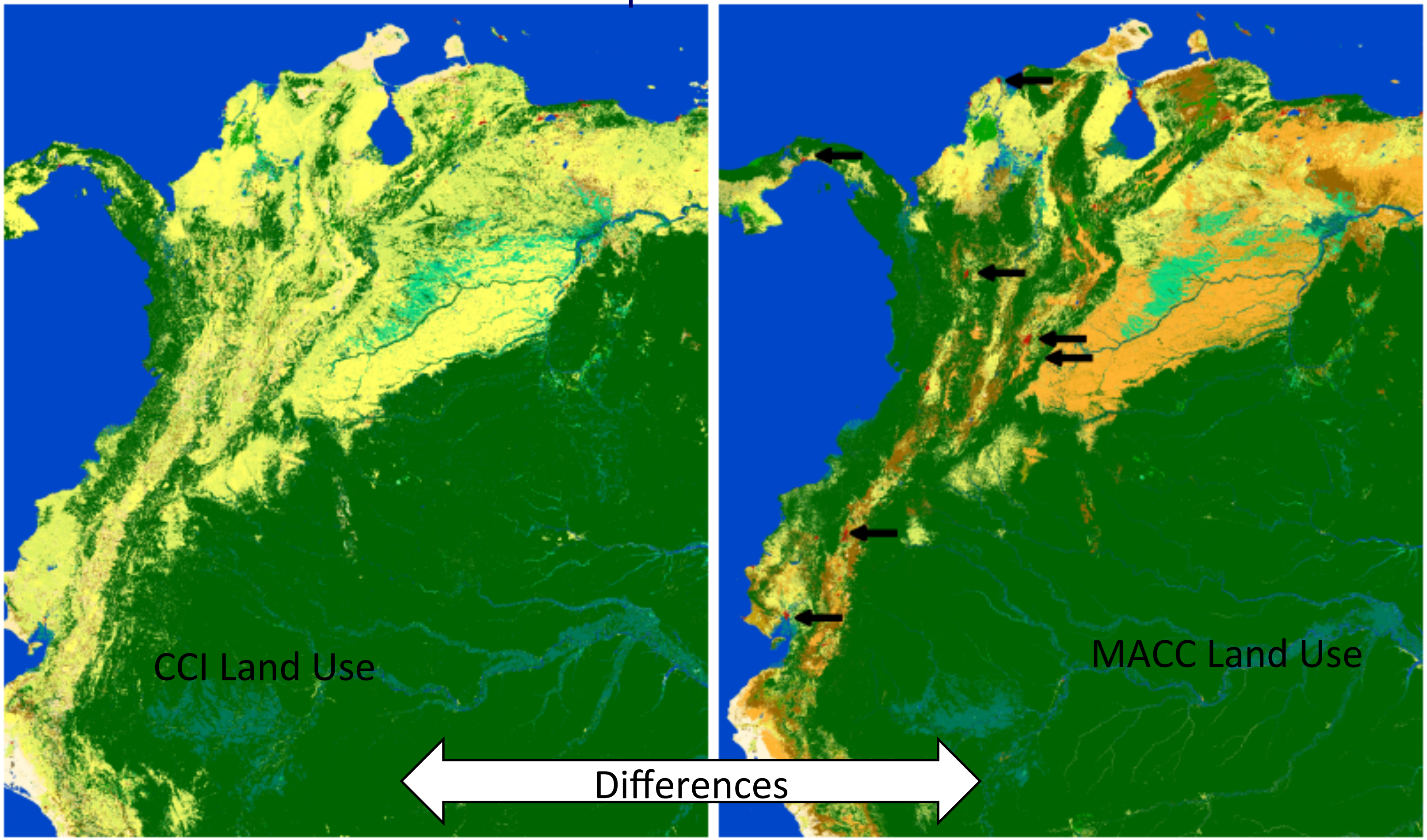
Topographical map of the region under study, showing the political boundaries of the Aburrá Valley cities.

Topographical characteristic of Aburrá deep-seated mountain valley



Sources of uncertainty of L.E in Colombia

Inputs Land Use/ Land Cover to be updated



Data assimilation relies on the use of an extension for high dimensional systems of the classical approach for filtering called the Kalman Filter

$$\mathbf{x}_k = \mathcal{M}_{k,k-1}(\mathbf{x}_{k-1}) + \mathbf{u}_k,$$

$$\mathbf{y}_k = \mathcal{H}_k(\mathbf{x}_k) + \mathbf{v}_k.$$

$\mathbf{x}_k \in \mathbb{R}^{m_x}$ $\mathbf{y}_k \in \mathbb{R}^{m_y}$ $\mathbf{u}_k \in \mathbb{R}^{m_x}$ $\mathbf{v}_k \in \mathbb{R}^{m_y}$

$\mathcal{M}_{k,k-1}\colon \mathbb{R}^{m_x} \to \mathbb{R}^{m_x}$ $\mathcal{H}_k\colon \mathbb{R}^{m_x} \to \mathbb{R}^{m_y}$

[Evensen, 2009]

$\mathbf{u}_k$ and $\mathbf{v}_k$ are independent white noise

The EnKF is a modification that uses Monte Carlo approach to estimate the minimum variance solution to the state estimation problem.

At the analysis step in the EnKF, an ensemble of the system state, is generated with sample mean ans covariance as the analysis state and error covariance matrix with the ensemble n typically much smaller than the dimension mx in large scale applications.

$$\mathbf{X}^a_{k-1} = \{\mathbf{x}^a_{k-1,i}: i = 1, 2, \ldots, n\}$$

By propagating the analysis ensemble through the transition operator, we obtain forecast ensemble at the next data assimilation cycle.

$$\mathbf{X}_k^f = \{\mathbf{x}_{k,i}^f : \mathbf{x}_{k,i}^f = \mathcal{M}_{k-1,k}(\mathbf{x}_{k-1,i}^a) + \mathbf{u}_{k,i}, i = 1, 2, \ldots, n\}$$

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

Two types of data assimilation:

- Related to the Ensemble Kalman filter for state estimation

$$\mathbf{x}^a_{k,i} = \mathbf{x}^f_{k,i} + \mathbf{K}_k[\mathbf{y}^s_{k,i} - \mathcal{H}_k(\mathbf{x}^f_{k,i})], \quad \text{for} \quad i = 1, 2, \ldots, n,$$

$$\mathbf{K}_k = \hat{\mathbf{P}}^{xy}_k (\hat{\mathbf{P}}^{yy}_k + \mathbf{R}_k)^{-1},$$

$$\hat{\mathbf{S}}^f_k = \frac{1}{\sqrt{n-1}}[\mathbf{x}^f_{k,1} - \hat{\mathbf{x}}^f_k, \ldots, \mathbf{x}^f_{k,n} - \hat{\mathbf{x}}^f_k],$$

$$\hat{\mathbf{S}}^{yy}_k = \frac{1}{\sqrt{n-1}}[\mathbf{y}^f_{k,1} - \hat{\mathbf{y}}^f_k, \ldots, \mathbf{y}^f_{k,n} - \hat{\mathbf{y}}^f_k],$$

$$\mathbf{x}^a_{k,i} = \hat{\mathbf{x}}^a_k + \sqrt{n}(\mathbf{L}_k \mathbf{C}_k \mathbf{\Xi}_k)_i, \quad \text{for} \quad i = 1, \ldots, n$$

$$(\delta \mathbf{x}_{k,i})_j = (\hat{p}^j_{xy,k} / \hat{p}^f_{yy,k}) \delta y_{k,i}, \quad j = 1, \ldots, m_x,$$

- Variational methods for the parameter estimation

$$X(t_{i+1}) = M_i X(t_i), \quad i = 1, \ldots, m-1, \; X(t_{i+1}) \in \Re^n$$

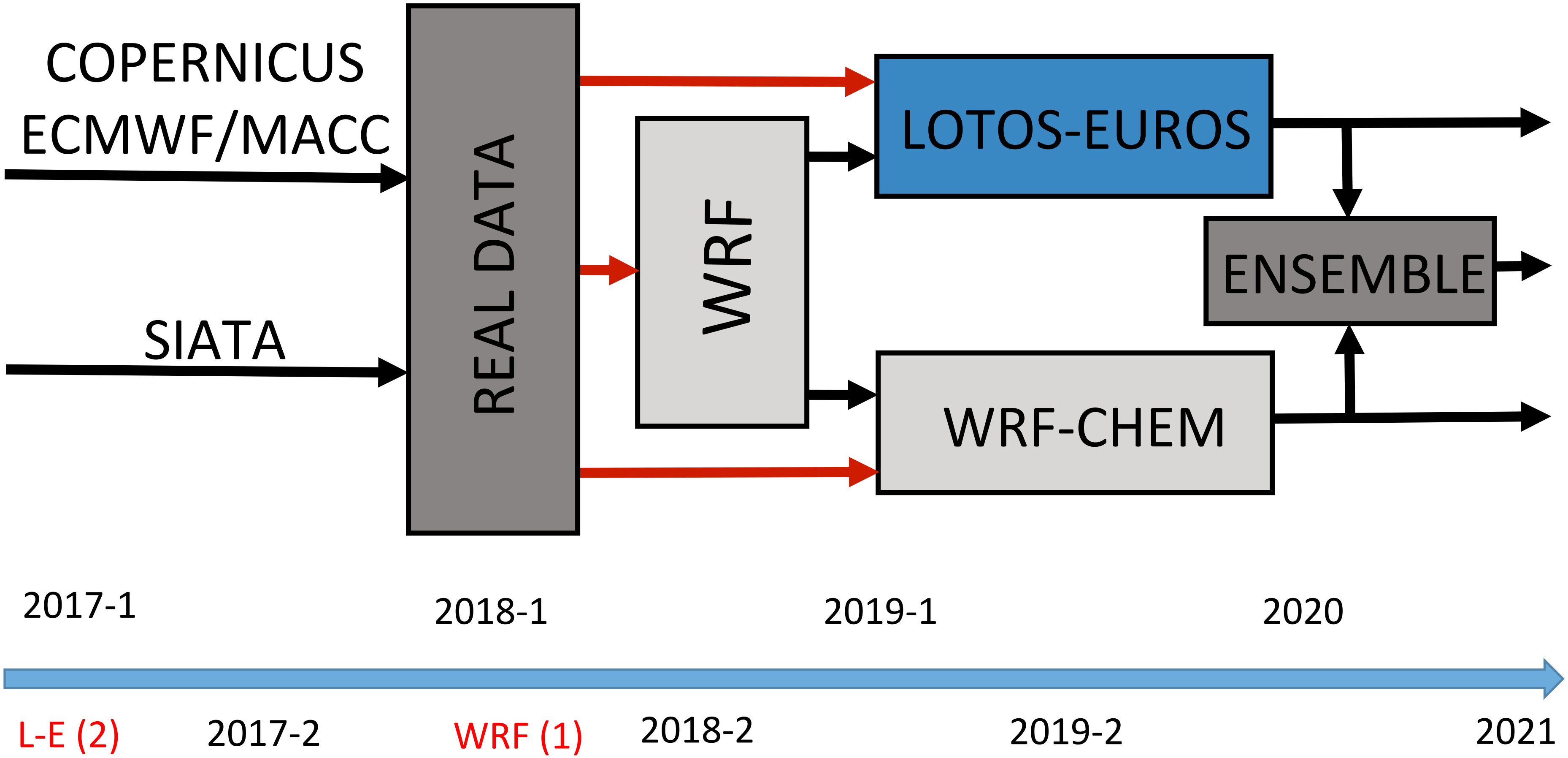
$$Y(t_i) = H(X(t_i)) + \eta(t_i), \qquad H : \Re^n \to \Re^q$$

$$J(X_0) = \frac{1}{2}(X^b - X_0)^T B_0^{-1}(X^b - X_0) + \frac{1}{2}\sum_i (Y(t_i) - H(X(t_i)))^T R_i^{-1}(Y(t_i) - H(X(t_i))),$$

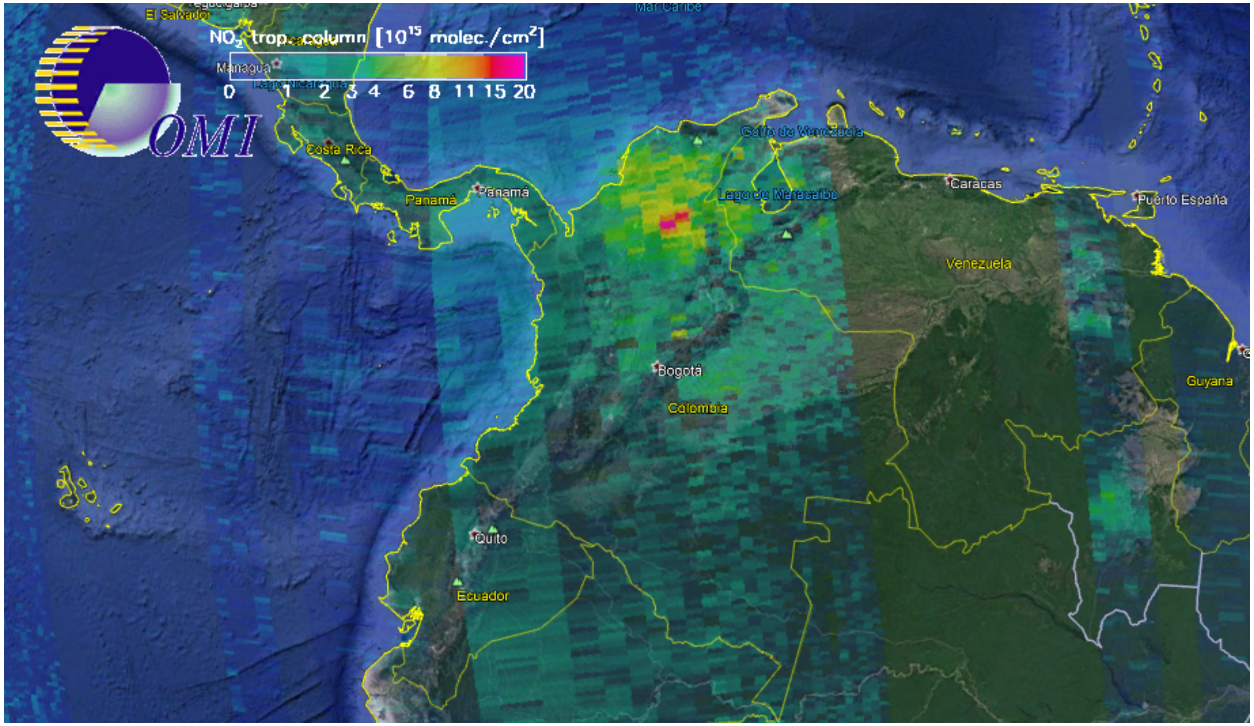
[Barbu 2010, Krymskaya, 2013, Sebacher, 2014, Altaf 2015, Fu et al, 2015, Lu et al, 2015, Krymskaya, 2013, Tijana et al, 2014 Verlaan and Sumihar, 2016]

Ensemble-Based twin experiments

Localization and impact quantification strategies

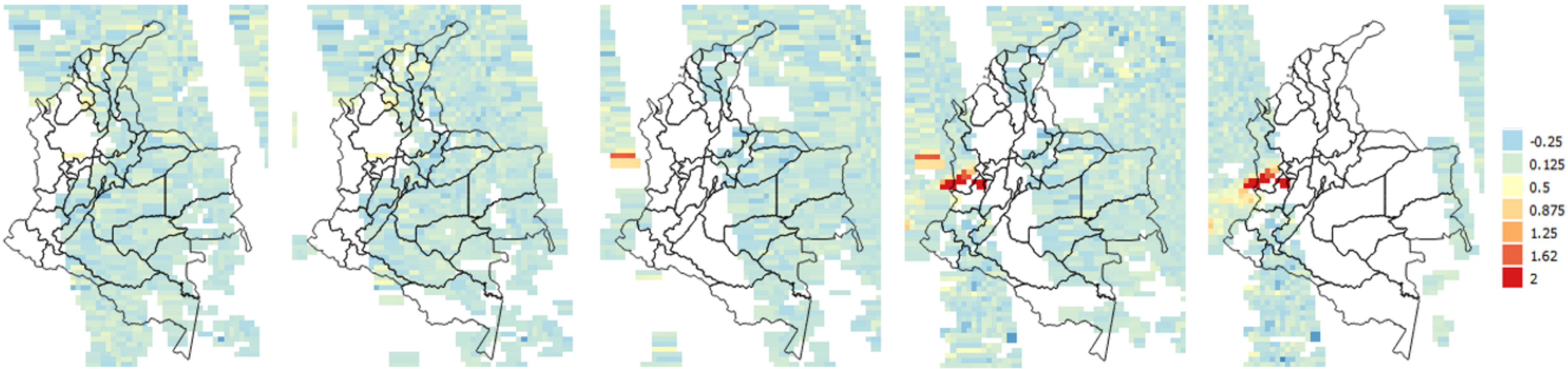


Challenges

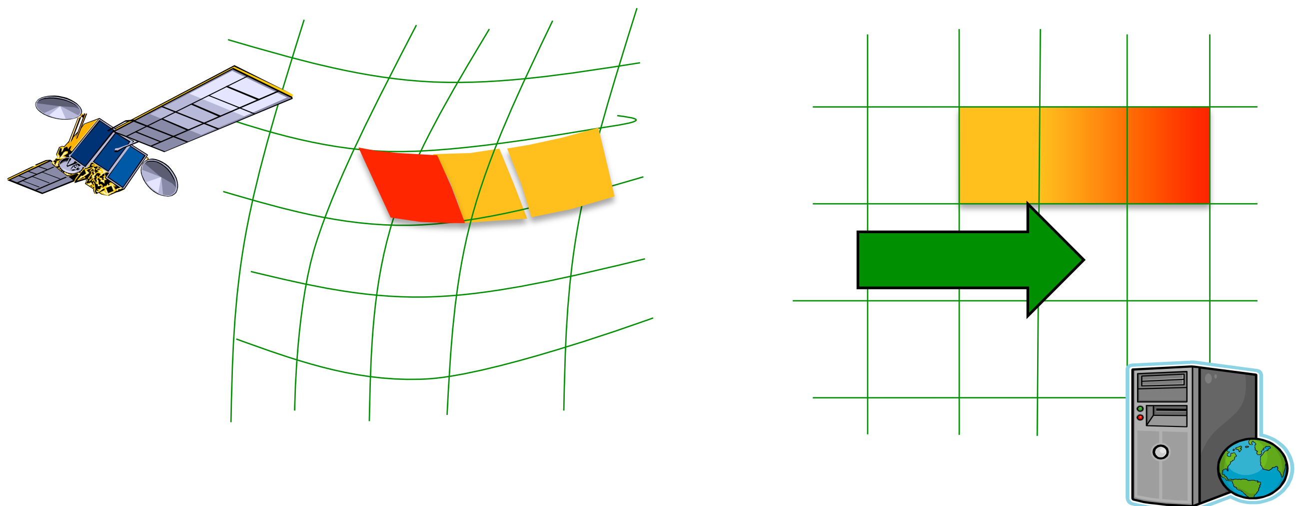


Spatial resolution: ~ 25 km x 25 km
Temporal resolution: 1 image per day of the same point, sun-synchronous orbit, 1:40 pm nadir capture over Colombia

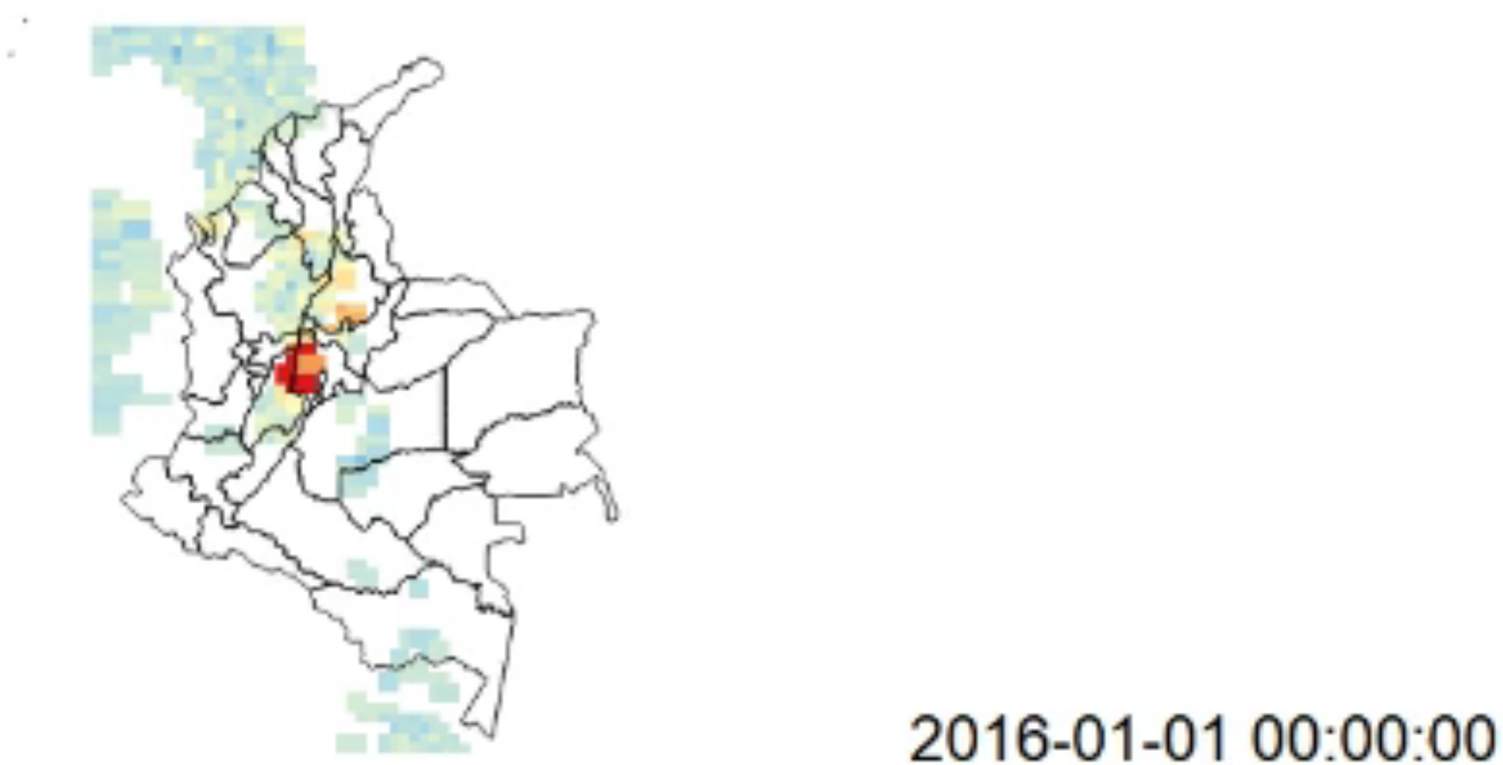
Challenges



2016-01-28 2016-01-29 2016-01-30 2016-01-31 2016-02-01

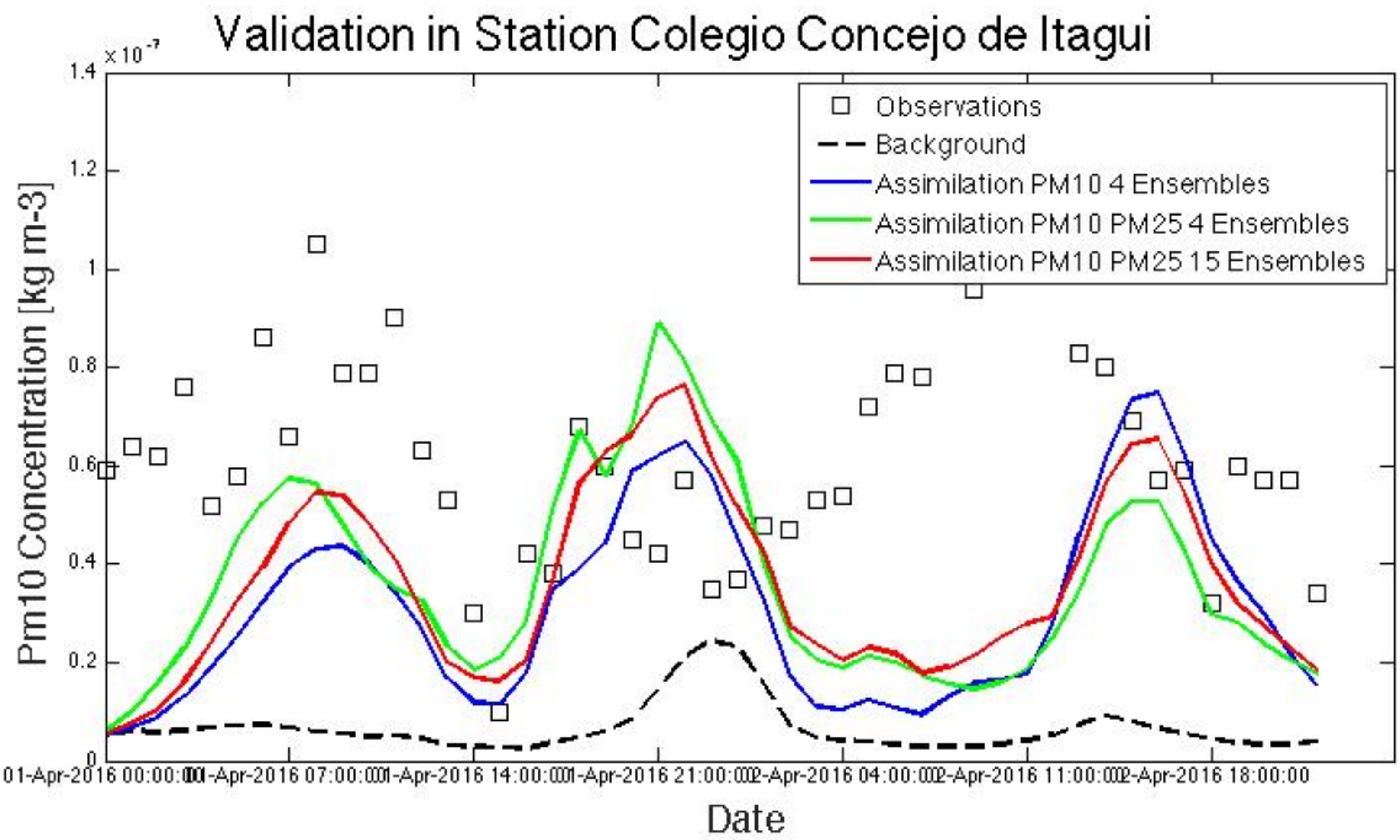


Challenges

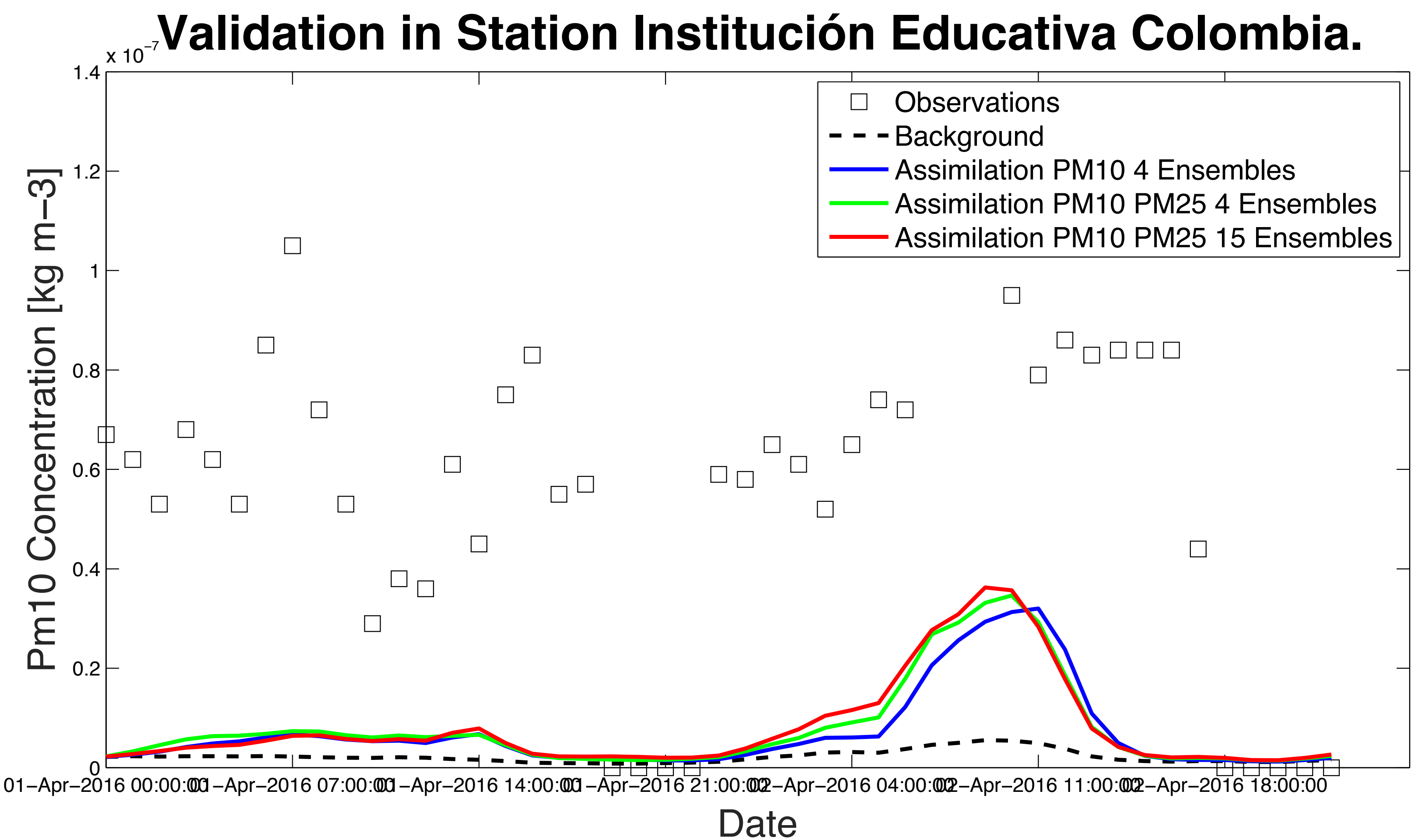


SO2 OMI data example

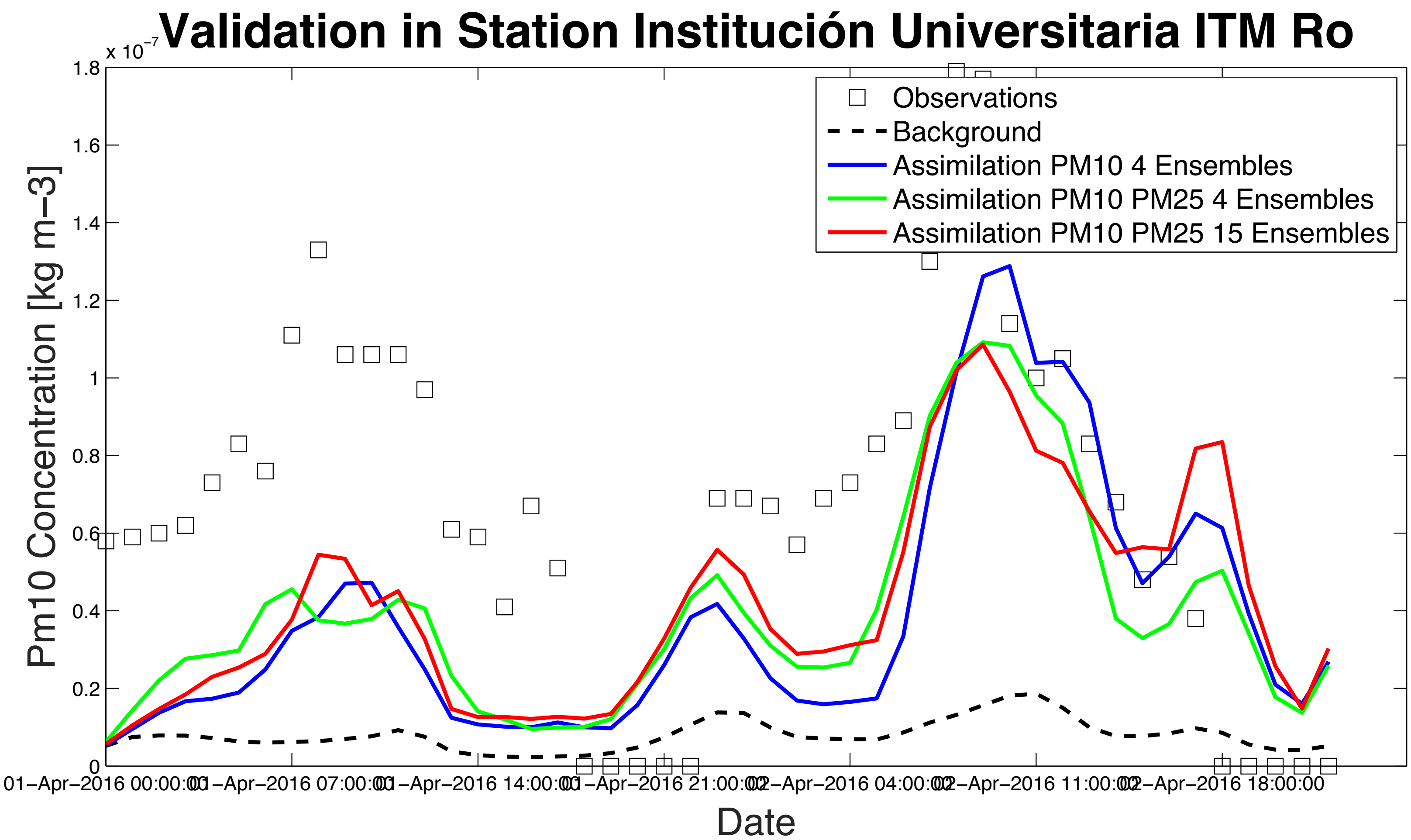
Conclusions



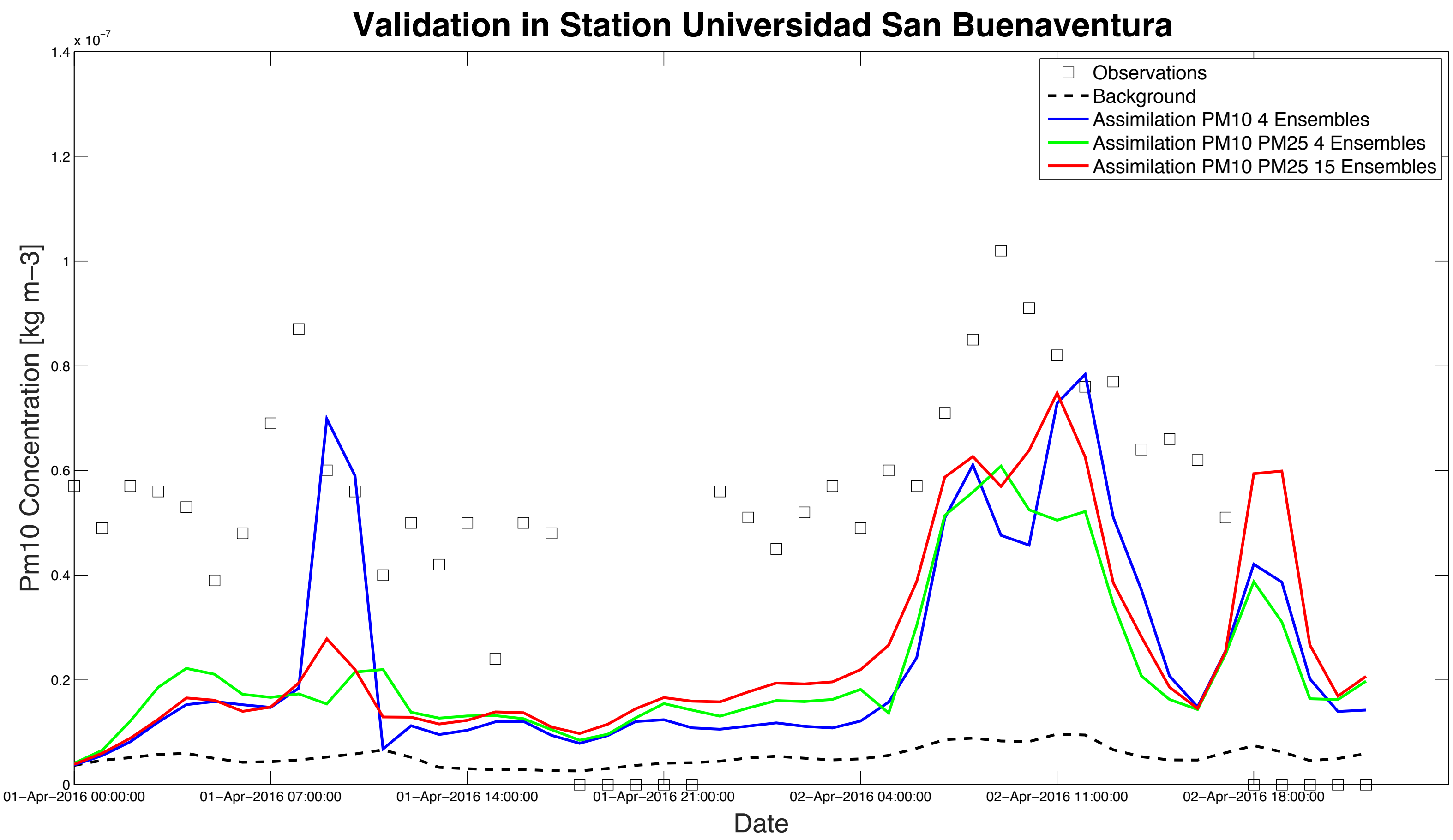
Conclusions



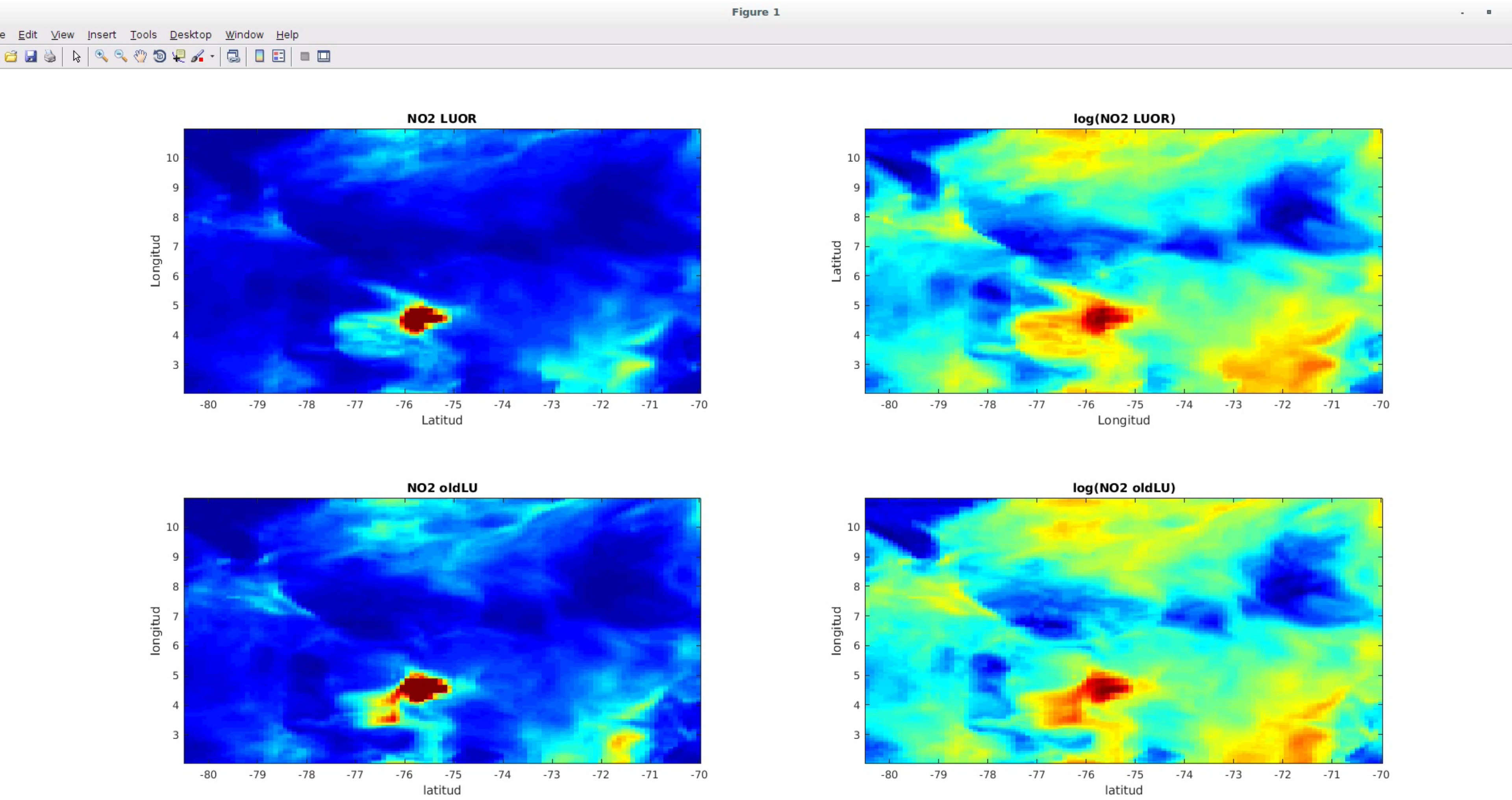
Conclusions



Conclusions



Conclusions



Conclusions

LOTOS-EUROS Coupling with a meteorological model like WRF. The WRF model is currently implemented in the region for the GIGA Research Group of the Universidad de Antioquia.

WRF is able to do a representation of the meteorology in a higher resolution than the databases available for the region.

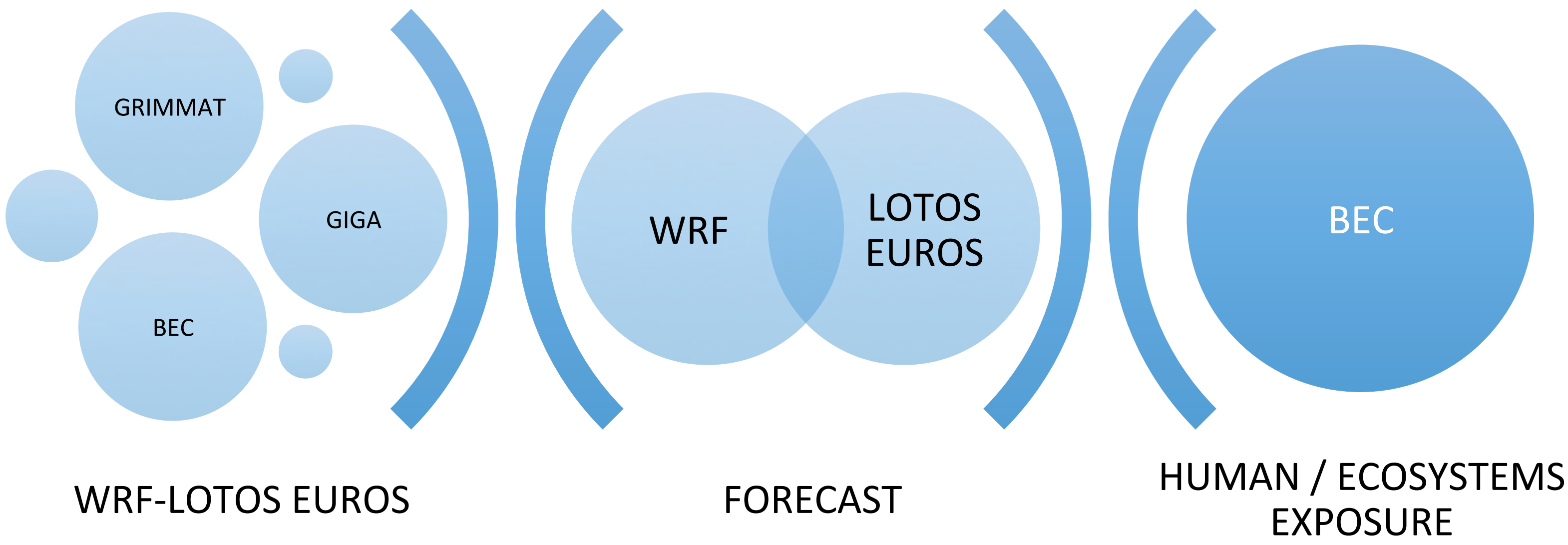
Data Assimilation and integration with Traffic models

European Research Council
Established by the European Commission

Scale-FreeBack

Advanced Grant 2015

Scale-Free Control for Complex Physical Network Systems


GRIMMAT
GIGA
BEC
WRF
LOTOS
EUROS
BEC
WRF-LOTOS EUROS
FORECAST
HUMAN / ECOSYSTEMS
EXPOSURE

Thanks

Thanks

CENTRO DE COMPUTACIÓN CIENTÍFICA APOLO – Pineda, Mateo y Andrés!

DIRECCIÓN DE INFORMÁTICA – Delio y Hugo!

Thank you all!