DEVELOPING A CITY-LEVEL AIR QUALITY FORECASTING: THE MEXICO CITY EXPERIENCE

Beatriz Cárdenas, Armando Retama

WRI México

06/25/2020

Motivation

- Can we **anticipate** a severe pollution episode?
- Can we use a robust model to evaluate with reasonable accuracy **the impacts** of management actions?

The challenge

- What do we **have**?
- What do we **need**?
- What do we **know**?

What do we have?

- The **need** and **motivation**.
- A continuously **updated emissions inventory**.
- A robust **air quality monitoring network**.
- **Trust and support** from the authorities and economic resources.

What do we need?

IT resources

If we want an operative robust model, then we need to increase the **computing power**

- high processing speed,
- parallel processing,
- a lot of processing cores.

and a **huge amounts of storage**!

(also, connectivity, environmental controlled room, power, redundancy, etc.)

Data Center (with HPC and storage systems)
Cost: US$ 750,000.00
Implementation time: 12 months

The data center provide:

- Processing: cluster with 96 cores
- Storage: 100 TB

What do we need?

Emission inventories

Highly spatial and temporal resolution emission inventory with the following characteristics:

- accurate,
- representative,
- reliable,
- updated,
- auditable.

Review of the current emission inventory (in-house)
Cost: US$ 250,000
Implementation time: 18 months

What do we know?

Knowledge

How much do we know about what is happening in the atmosphere of the MCMA?

Two intensive scientific campaigns provided *state-of-the-art* knowledge about atmospheric chemistry and physics over Mexico City,

- MCMA-2003
- MILAGRO-2006

also the model parametrizations tested in these campaigns were used in our model.

Scientific campaigns
Cost: US$ A LOT!!
Scientific research: years
Integration into the model: 12 months

What do we know?

Knowhow

Expertise was required for the set-up, testing and release of the model.

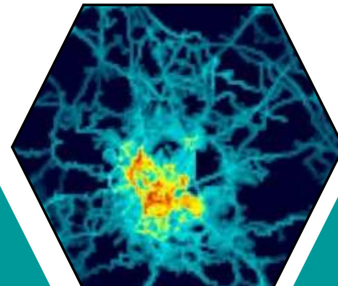
Throughout the development of the process we had the collaboration and support from the Barcelona Supercomputing Center (BSC).

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

The Air Quality Forecast System

Emission Inventory with high resolution ($1km^2$), audited and updated every two years

SEDEMA, has High-performance computing with 92 cores



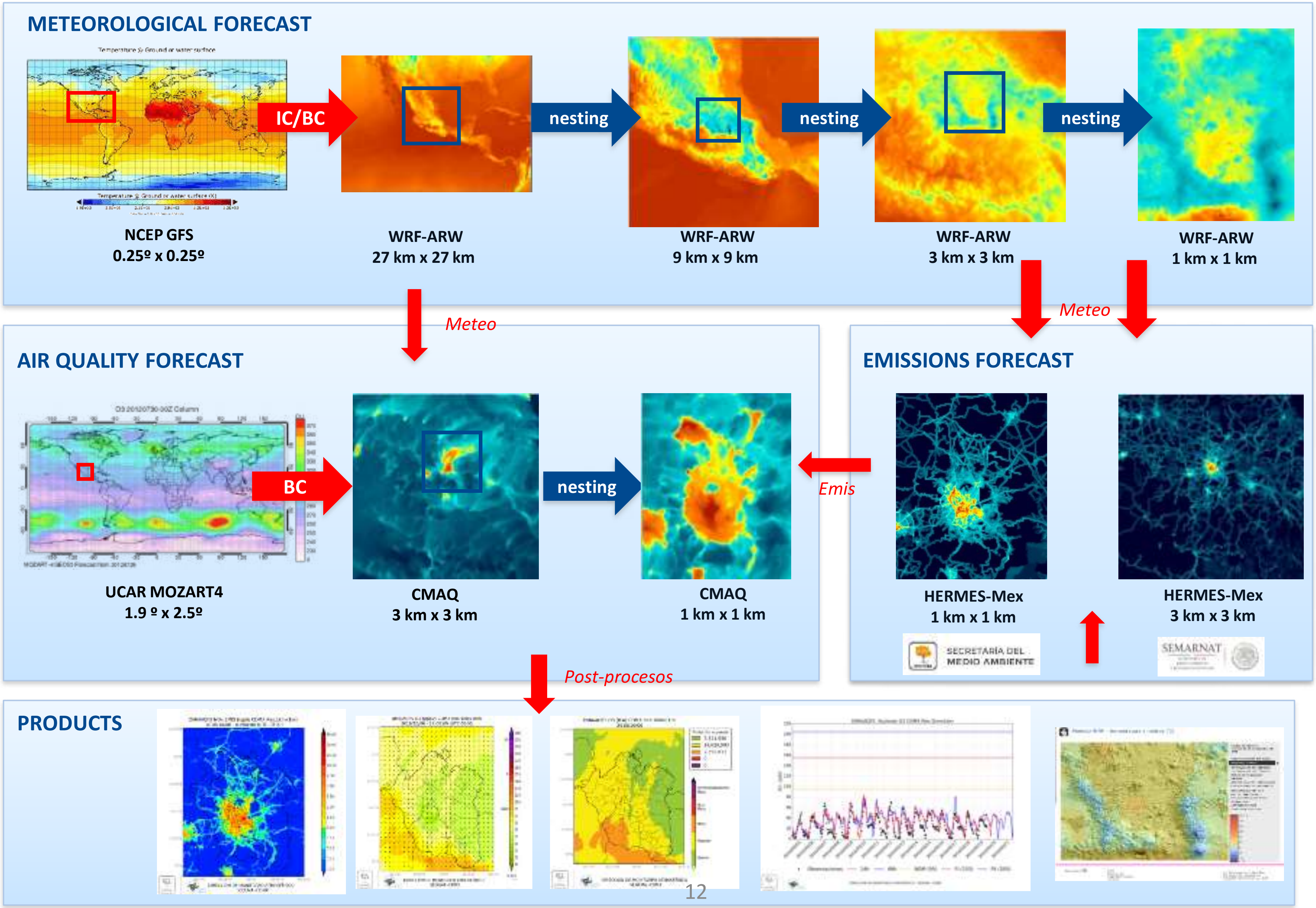
SEDEMA has specialized personnel in modeling, inventories, systems, monitoring and analysis

Robust Atmospheric Monitoring System of the CDMX (SIMAT): 34 stations for automatic monitoring

The scientific experience obtained during the two major campaigns was used: MCMA in 2003 and MILAGRO 2006

Collaboration with the Barcelona Supercomputing Center

The Air Quality Forecast System

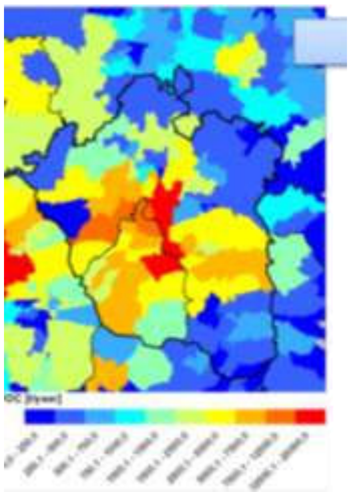


WRF-ARW parameterization

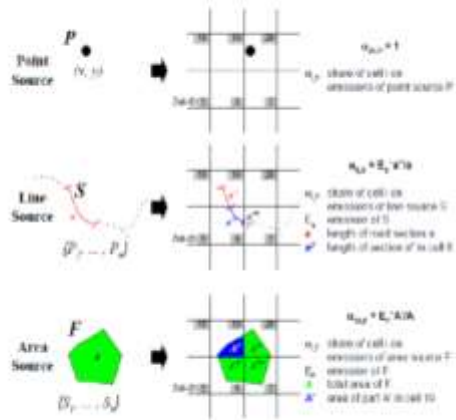
Física	Parametrización	Justificación
Planetary boundary layer (PBL)	YSU	Se trata del esquema de PBL más efectivo para la zona metropolitana de la Ciudad de México según los estudios de Fast *et al.* (2007) y de Foy *et al.* (2009) realizados en el marco de la campaña MILAGRO.
Land surface model	*Noah Land Surface Model*	Esta opción se empleó en las simulaciones realizadas en el marco de las campañas MCMA-2003 (de Foy *et al.*, 2006) y MILAGRO (Zhang *et al.*, 2009), así como, en el proyecto MIRAGE y en el estudio de López-Espinosa y Zavala-Hidalgo (2012)
Cumulus parameterization	*Kain-Fritsch scheme*	Utilizado en las simulaciones realizadas en el marco de las campañas MCMA-2003 (de Foy *et al.*, 2006) y MILAGRO (Zhang *et al.*, 2009), así como, en el proyecto MIRAGE y en los estudios de Cui y De Foy (2012) y López-Espinosa y Zavala-Hidalgo (2012)
Longwave radiation	RRTM	Utilizado en las simulaciones realizadas en el marco de las campañas MCMA-2003 (de Foy *et al.*, 2006) y MILAGRO (Zhang *et al.*, 2009), así como, en el proyecto MIRAGE y en los estudios Cui y de Foy (2012) y López-Espinosa y Zavala-Hidalgo (2012)
Shortwave radiation	Goddard	Utilizado en el estudio de Cui y de Foy (2012) para analizar el efecto de isla de calor de la ZMVM
Surface layer	*Revised MM5 scheme*	En el proyecto MIRAGE y en el estudio de Cui y de Foy (2012) se utilizó el esquema MM5 *similarity*. Se decidió usar una versión actualizada de este esquema la cual apareció a partir de la versión WRF3.4
Microphysics	*WRF Single-Moment 5-class scheme* (WSM5)	En las simulaciones realizadas en la campaña MILAGRO (Zhang *et al.*, 2009) y el estudio de Cui y de Foy (2012) se utilizó el WSM6. La única diferencia entre el WSM5 y el WSM6 es que este último incorpora también los procesos de granizo.

Emissions model (HERMES-Mex):An emission processing tool for Mexico

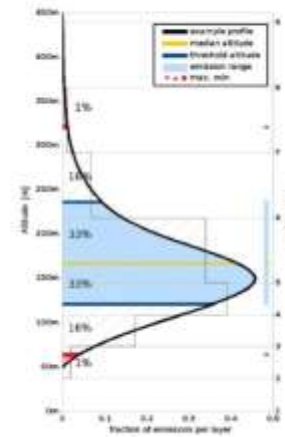
Official Emission Datasets



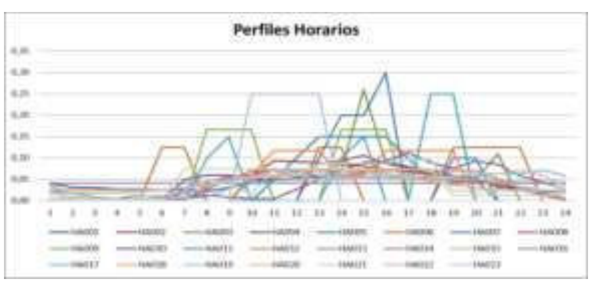
Spatial Allocation



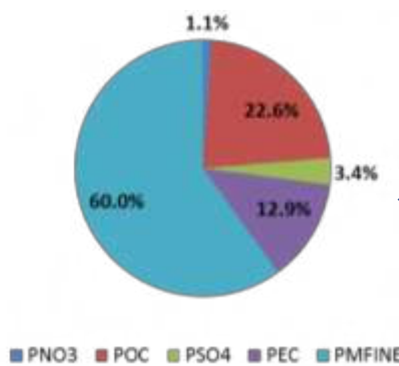
Vertical Allocation



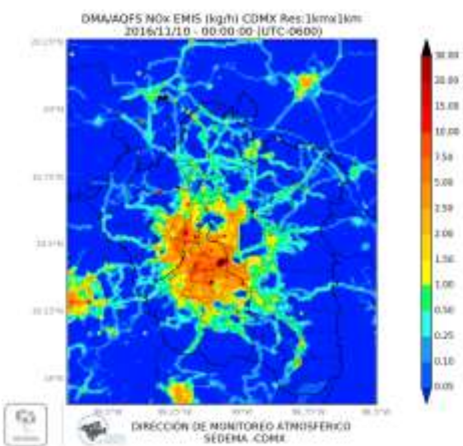
Temporal Allocation



Chemical Speciation

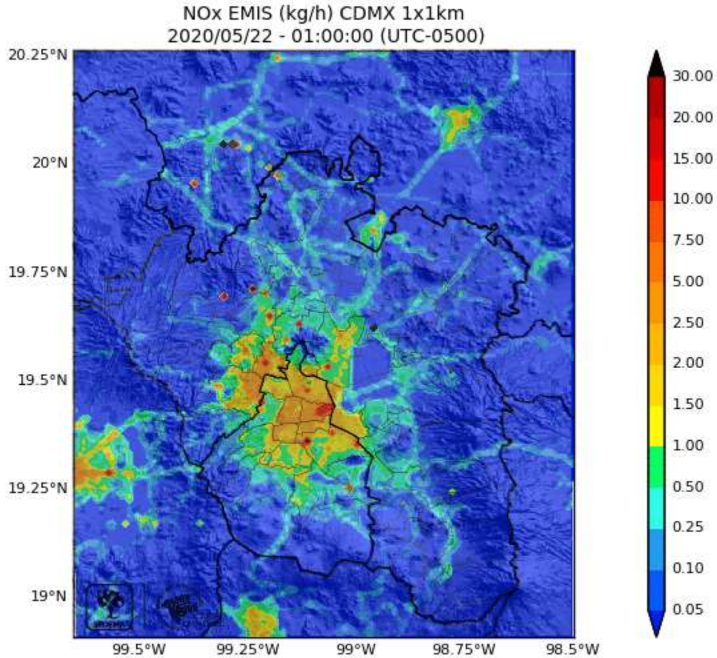


CMAQ ready emission data

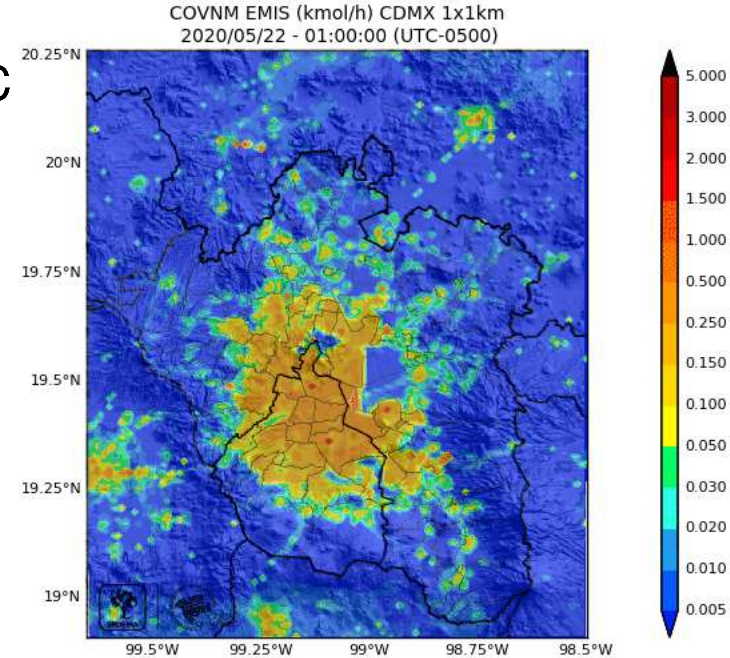


Guevara et al. (2017)

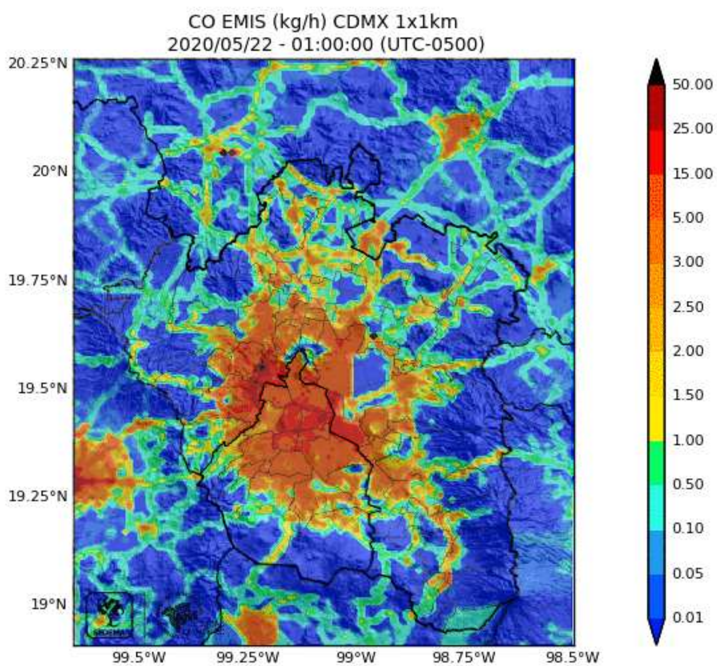
NO_X



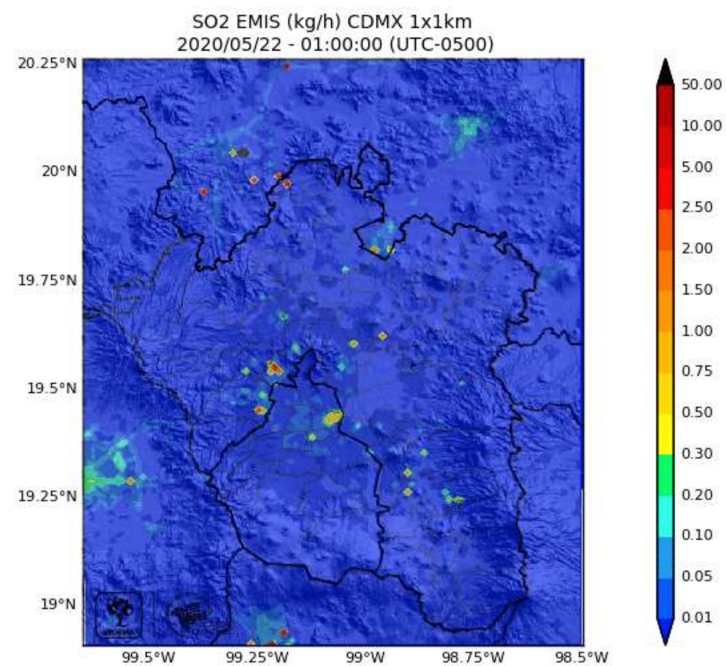
VOC



CO

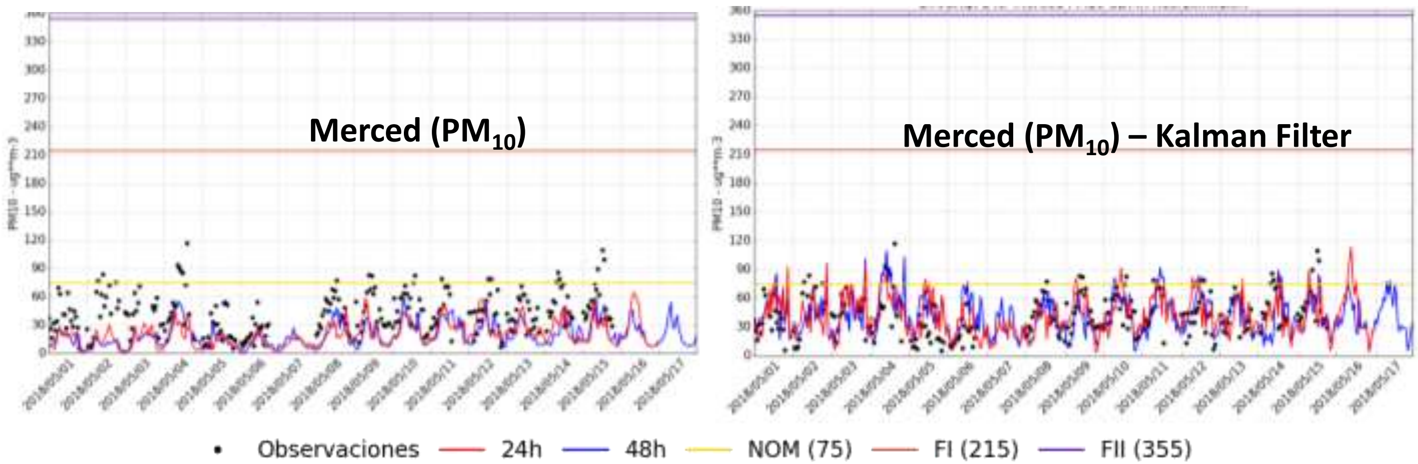


SO_2

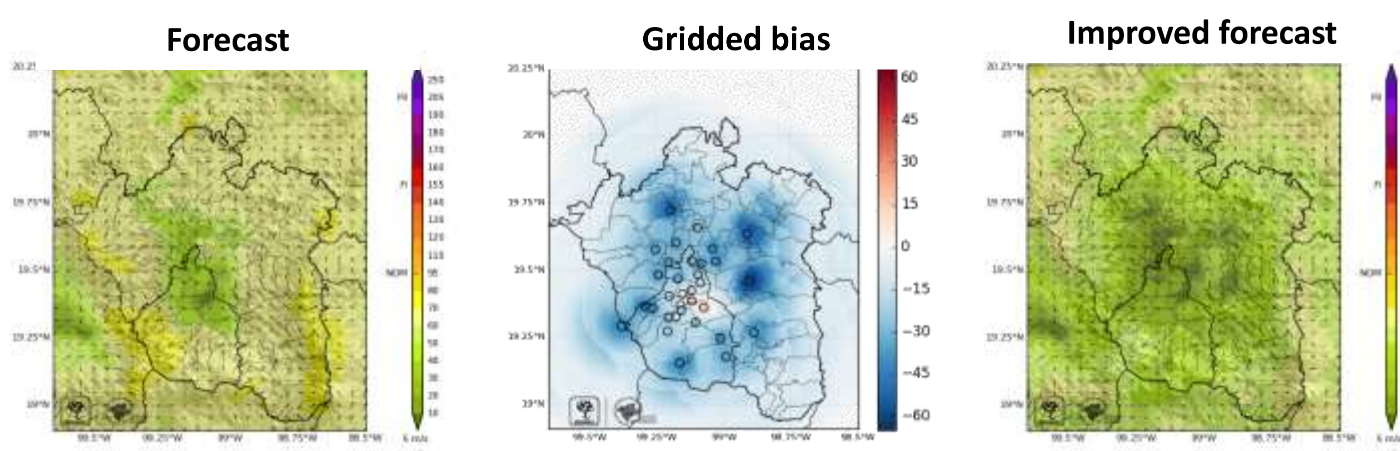


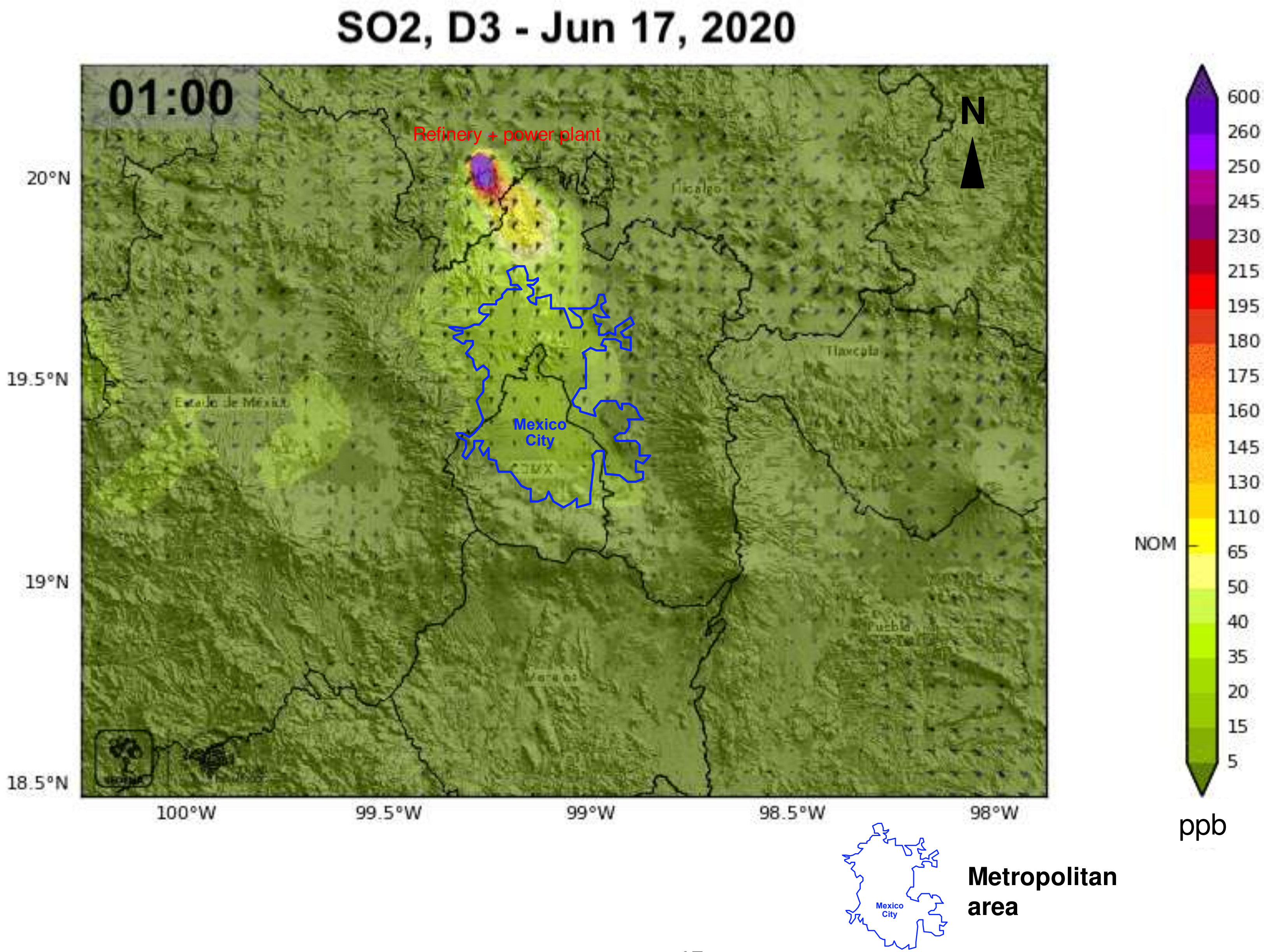
Data post-processing

Systematic error removal (Kalman Filter)

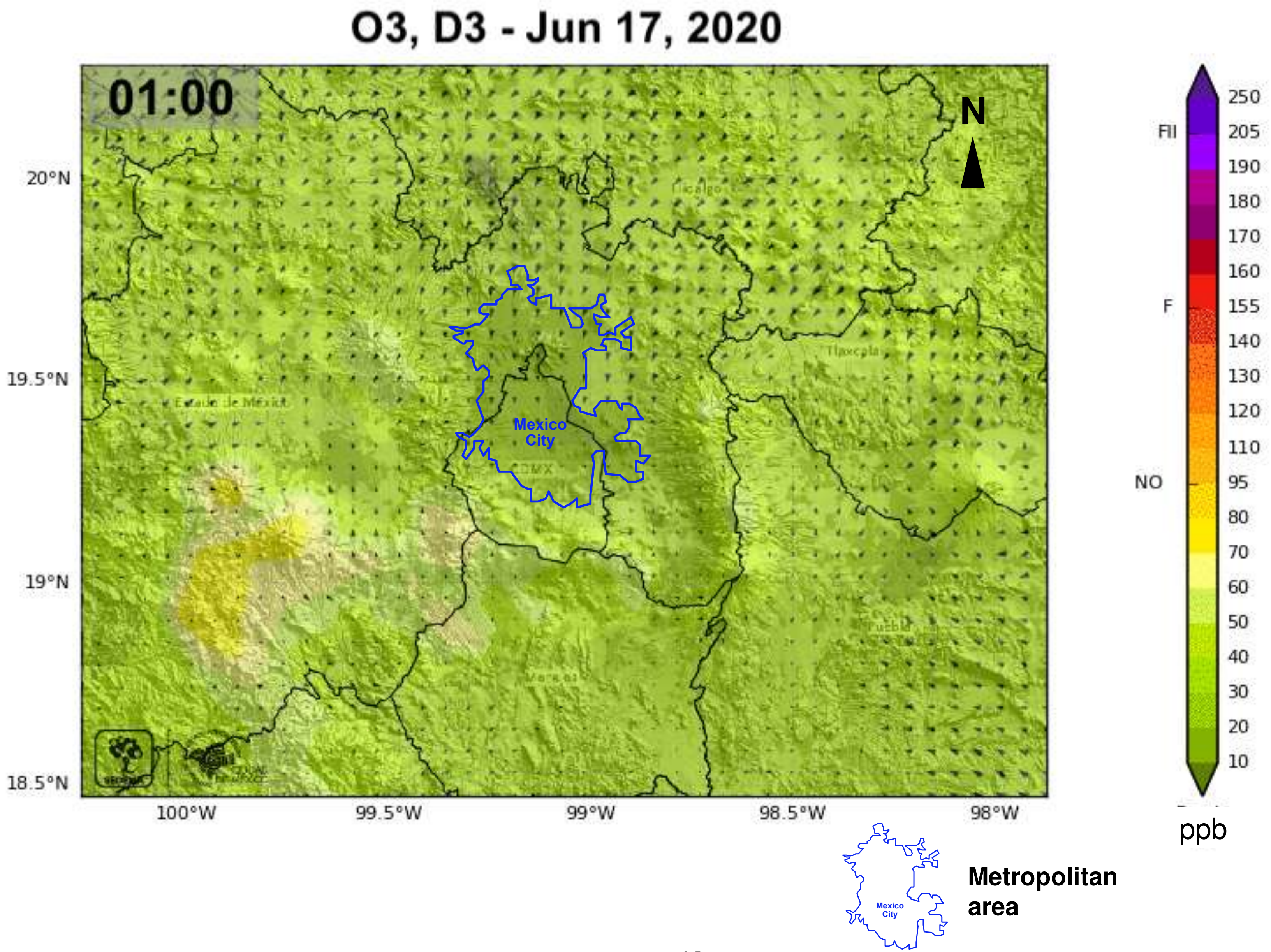


Spatial interpolation (Barnes scheme)

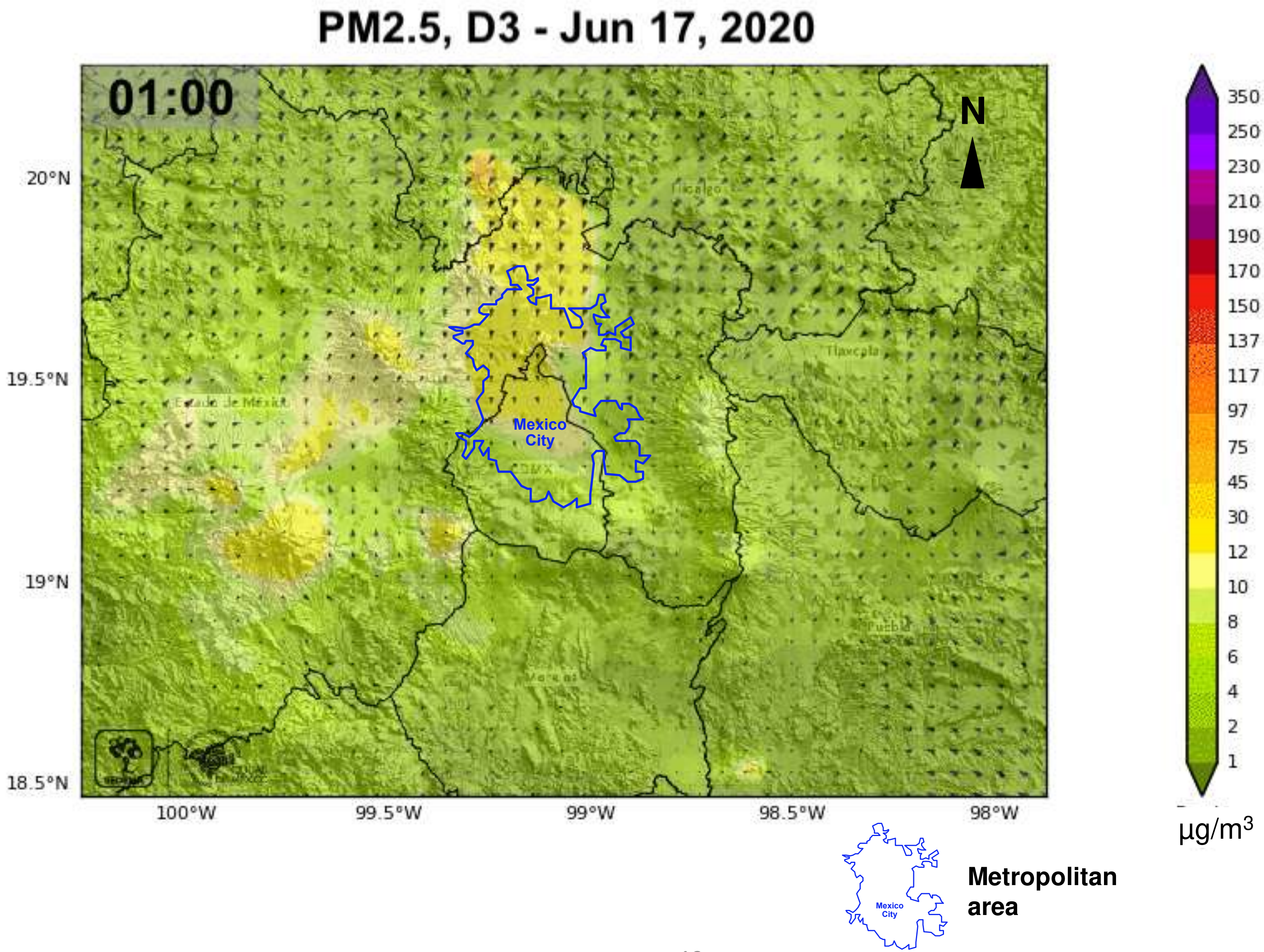




SO2, D3 - Jun 17, 2020
01:00
Refinery + power plant
N
Mexico City
20°N
19.5°N
19°N
18.5°N
100°W
99.5°W
99°W
98.5°W
98°W
600
260
250
245
230
215
195
180
175
160
145
130
110
NOM
65
50
40
35
20
15
5
ppb
Mexico City
Metropolitan area



O3, D3 - Jun 17, 2020
01:00
N
20°N
19.5°N
19°N
18.5°N
100°W
99.5°W
99°W
98.5°W
98°W
Mexico City
FII
F
NO
250
205
190
180
170
160
155
140
130
120
110
95
80
70
60
50
40
30
20
10
ppb
Metropolitan area



PM2.5, D3 - Jun 17, 2020
01:00
N
20°N
19.5°N
19°N
18.5°N
100°W
99.5°W
99°W
98.5°W
98°W
Mexico City
350
250
230
210
190
170
150
137
117
97
75
45
30
12
10
8
6
4
2
1
µg/m³
Mexico City
Metropolitan area

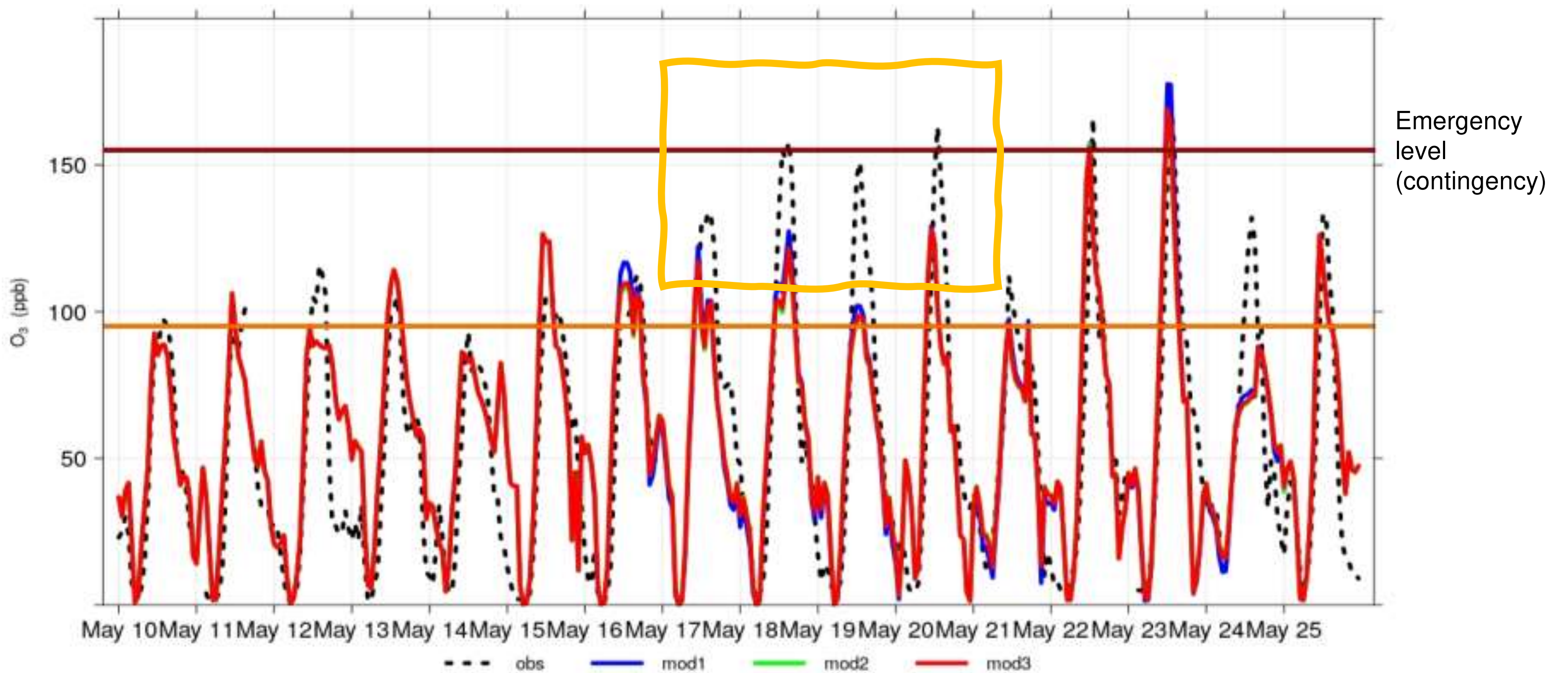
How well does the model work?

- After two years of intensive work, the model was released on February 2017.

- During the O_3 seasons (Feb 15 - Jun 15) of 2017-2019, the model predicted with reasonable precision the O_3 maximum (±10%) in ~80% of the days, for the 24-h forecast.

… but, the forecast can fail?

- In May 2017, the model underpredicted O_3 maximum during an O_3 episode.



- The analysis of this episode revealed that some specific wind patterns at local scale and nocturnal chemistry, were not properly simulated.

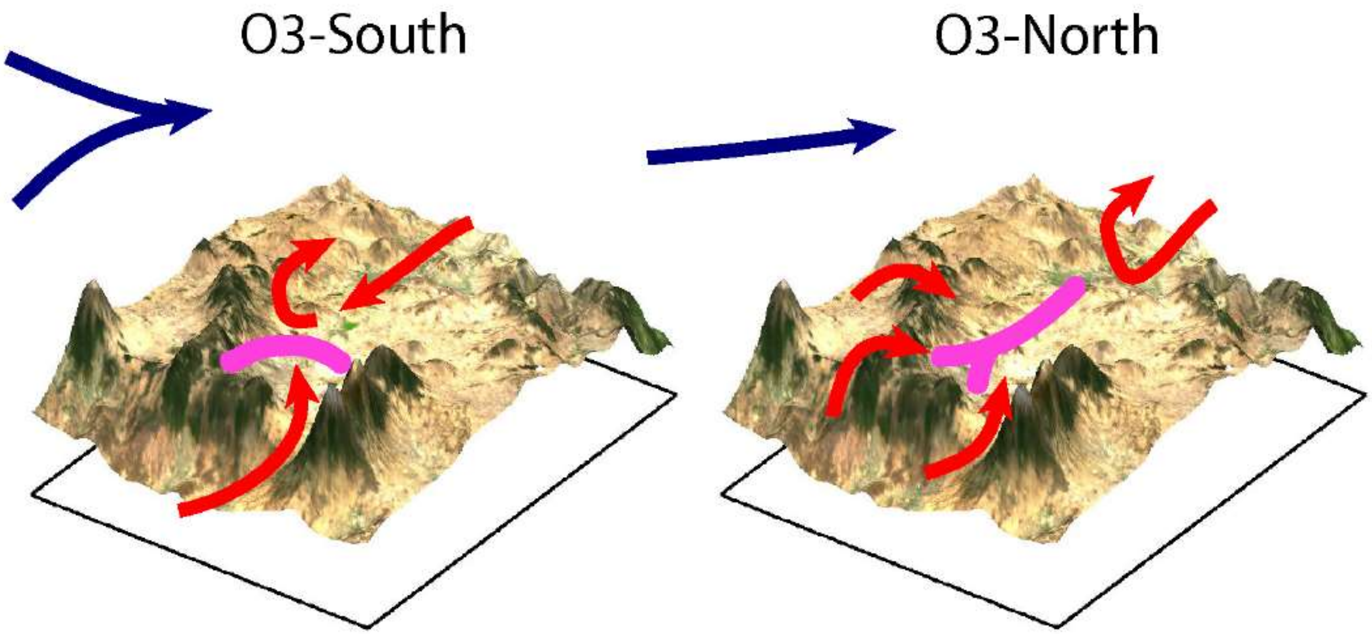


Image from: de Foy et al., *ACP*, 2108

- Even the regular good performance of the model, it is severely questioned when O_3 or $PM_{2.5}$ are underestimated, mainly during a pollution episode.
- The message at that moments was “It doesn't matter how good the forecast could be, a failure at the wrong moment can undermine the confidence in the model”.

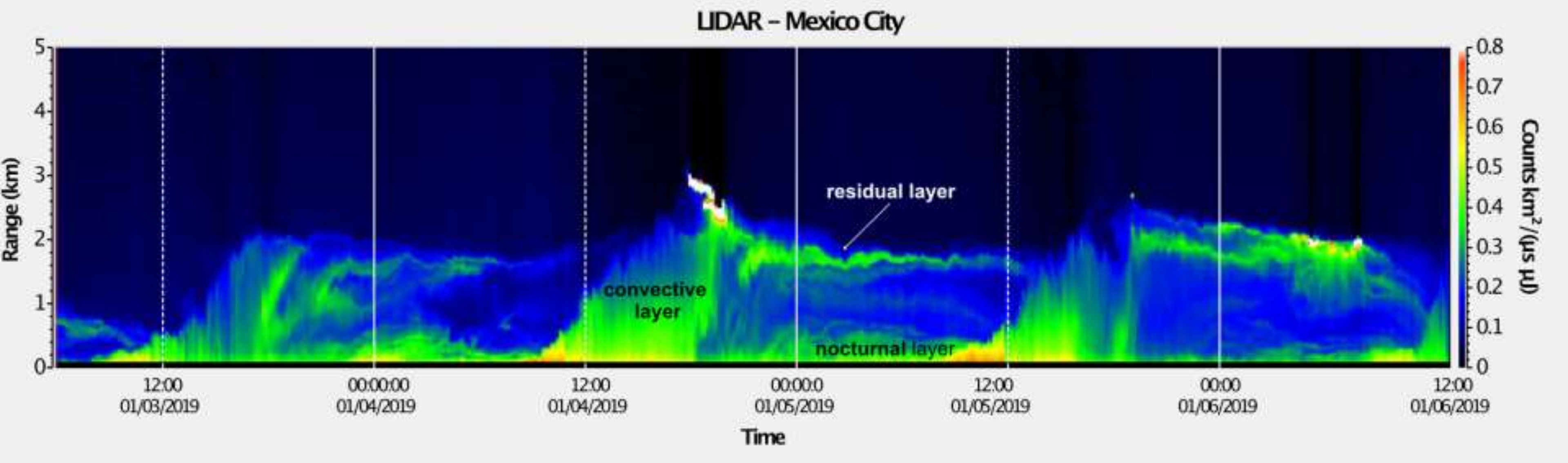
But, most important from the failed experiences is what we are learning. Currently, we know that the model has difficulties reproducing:

- subtle effects at the local and micro meteorology scales that have impacts on O_3 production, accumulation and dispersion;
- the role of nocturnal chemistry in the production of reactive species that contribute to the jump-start of photochemical activity in the morning;
- the short-time and short-scale complex interactions between the different sublayers within the atmospheric boundary layer.

Next steps

Atmospheric boundary layer:

- How spatial and temporal variations of the ABL sublayers are affecting pollutants dispersion and atmospheric chemistry?
- What is the most suitable boundary layer parameterization for the high-pollution episodes?
- Is the urban canopy model parameterization reflecting the multi-scale urban characteristics of the city?



Next steps

Chemistry:

- Are the current chemical mechanisms explaining the production of radicals, intermediate and secondary species during nocturnal and diurnal periods?
- Which is the role of emergent sources of VOCs in the production of secondary pollutants?

Take home messages

- The implementations of a forecast system is not an easy task.
- Emissions inventory are critical.
- The observations from the AQ monitoring networks are needed to the evaluate the performance of the model.
- The availability of local information about chemistry and physics will be important for the best parameterization of the model.

Thank you