Thermal inversion influence on the mixing layer height during a record pollutant event at Paris megacity

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Sciences de l'environnement
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SITE INSTRUMENTAL DE RECHERCHE PAR TÉLÉDÉTECTION ATMOSPHÉRIQUE

Introduction

- Paris megacity suffers several pollution events per year affecting the health of its inhabitants
- Emergency actions to mitigate the pollution effects (for large pollution event)
  - These actions have a large socio-economic impact
- The magnitude of the pollution event is estimated using:
  - PREV'AIR chemistry-transport operational modeling system
  - CHIMERE chemical transport model
- However, there are differences between observations and simulations:
  - Up to 50% in the PM2.5 time series
  - Large uncertainties on NH3 and organic matter concentrations remain
- Differences due to uncertainties in both :
  - chemical processes
  - dynamical and radiative processes

Can we use the remote-sensing measurements to:
- *Improve the knowledge of the dynamical processes?*
- *Contribute to the daily air-pollution forecasts?*

Atmospheric dynamical processes and pollution events

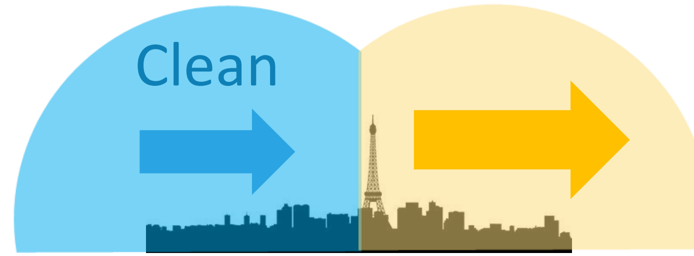
Three different atmospheric dynamical processes leading decreases of the particular matter concentration (PM):

1. The advection of clean air masses
2. The dilution of the pollutants due to an increase of the Mixing Layer (ML)
3. Diffusion of pollutants from the ML to the free troposphere

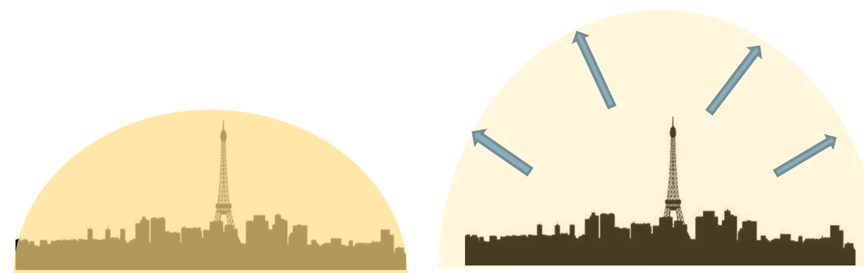
~~Clean-air advection~~
+
~~Dilution~~
+
~~Diffusion~~

$\Rightarrow \uparrow \mathrm{PM}$

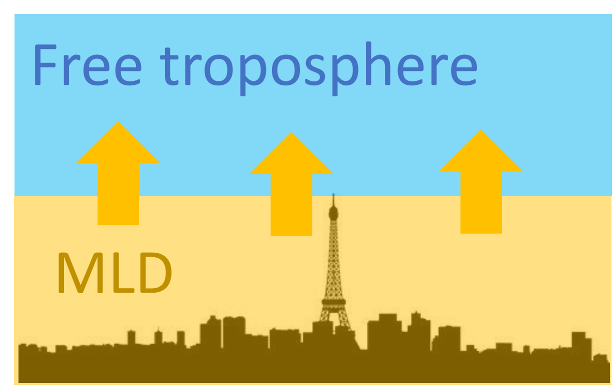
Long period ⇒ pollution event



Clean-air advection

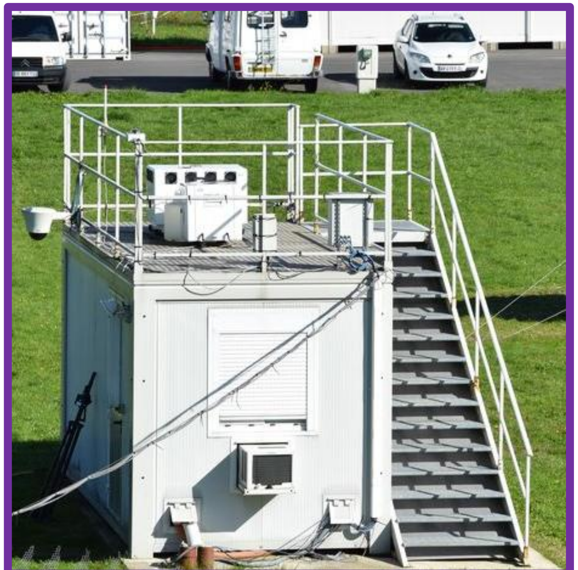


Dilution



Diffusion

INSTRUMENTATION AND METHODOLOGY



Doppler lidar:
Leosphere, WLS70
3D wind components
Vertical resolution:50 m [0,1-2 km]
Temporal resolution: 10 min
Horizontal wind accuracy: 0.1 m/s
Wind direction accuracy: 2°

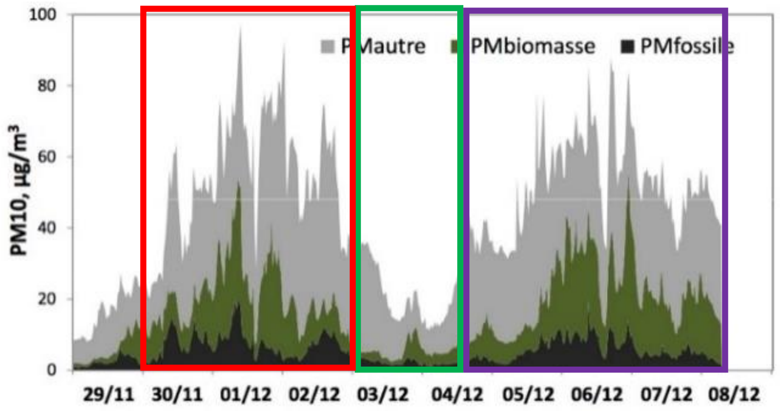
Backscatter lidar:
Vaisala Ceilometer CL31
Backscattering intensity at 905 nm
Vertical resol: 5 m
Temporal resol: 30 s
MLD determined using the STRAT+ (Pal et al., 2013)

Radiosondes: Modem M10 (at 00h and 12h UTC), Trappes 15 km West from SIRTA (MeteoFrance)
TEOMS-FMDS: PM10 concentration

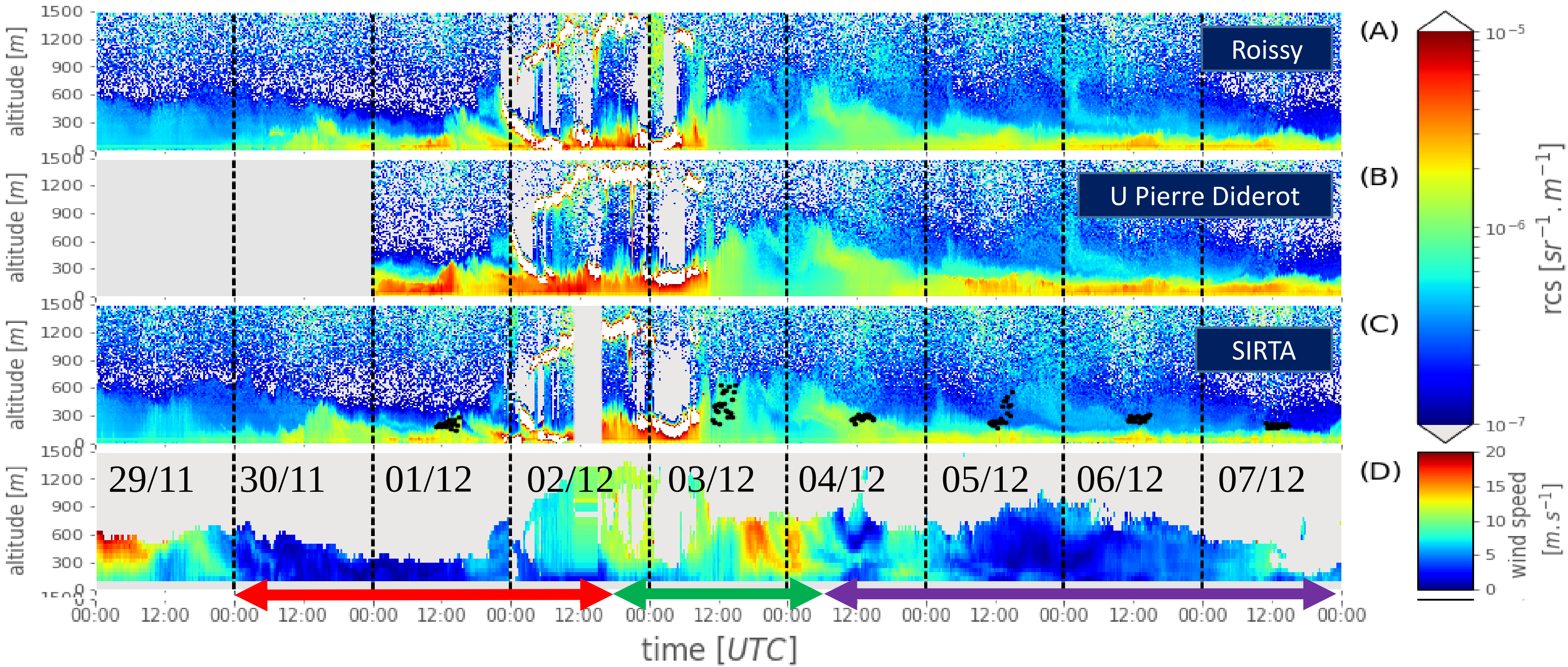
Pollution event: December 2016

- 29th November to 7th December 2016
- AIRPARIF network → daily mean PM10 ~150 µg/m³

- Low wind speed (<2m/s)
- Low MLD (<300 m)
- On 3rd December:
  ↑ ML and wind speed>5m/s → ↓PM10

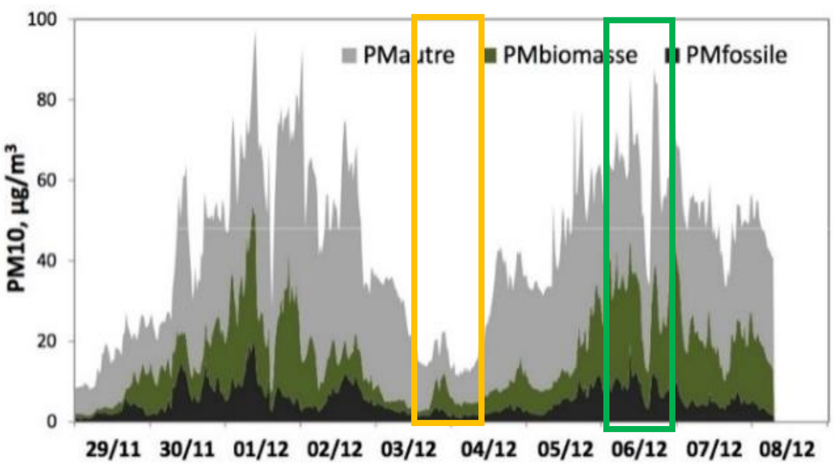


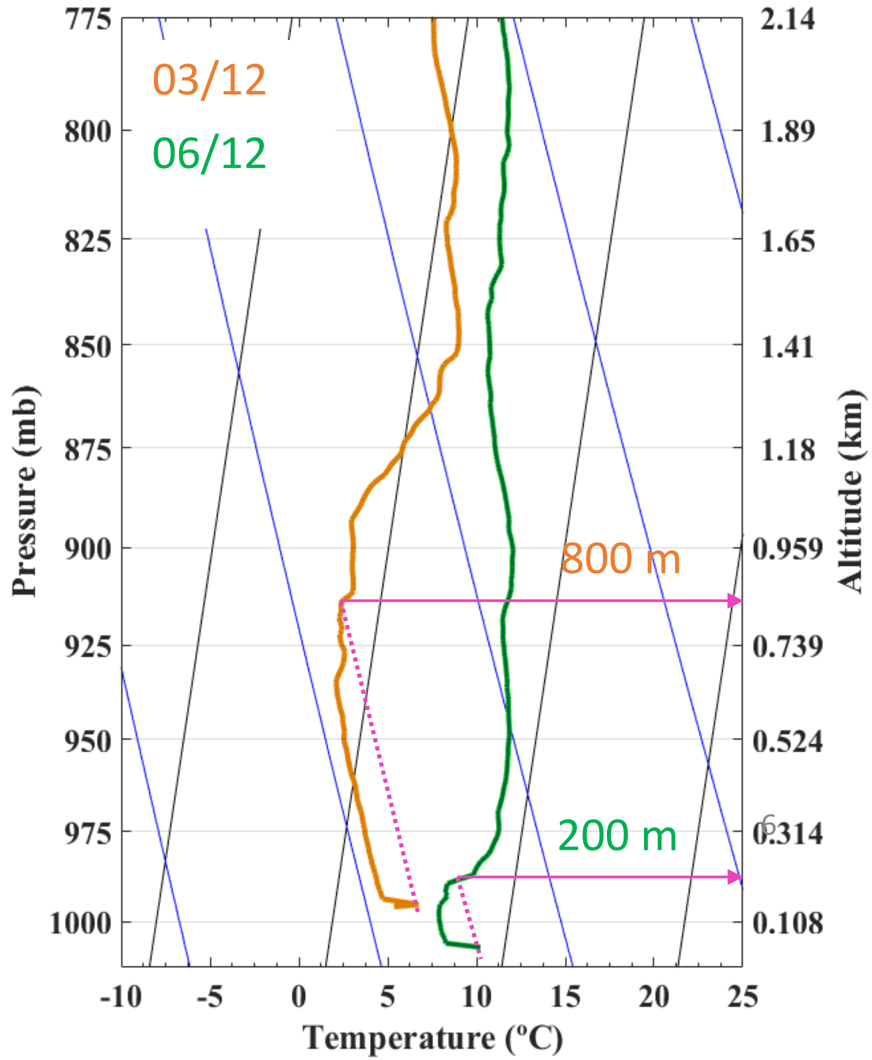
Clear relationship between ML, wind speed and PM10



Pollution event: December 2016

- 03/12 Vs 06/12: The temperature at 300 m increased 10°C! ⟹ strong inversion!





- Atmospheric thermal inversion blocks :
  I. the ML growths (**dilution**)
  II. the particle **diffusion** from ML to the free troposphere

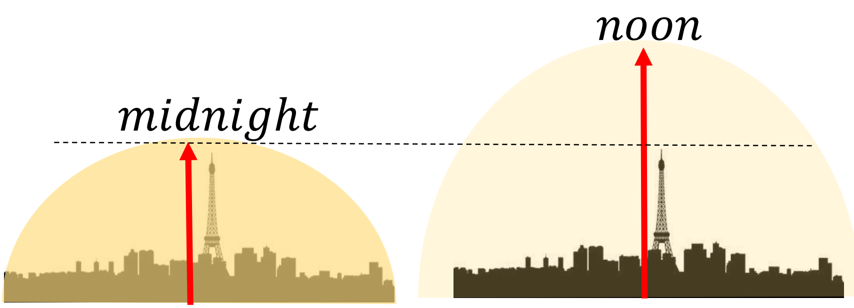
Pollution events are linked to atmospheric dynamical processes!

Dynamical processes proxies?

Proxy:

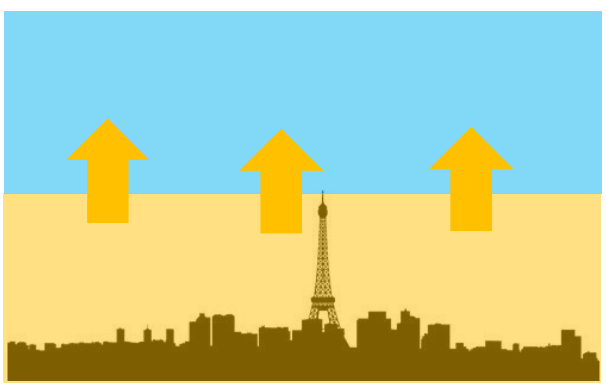
Clean-air advection

wind speed



Dilution

Mixing layer depth?

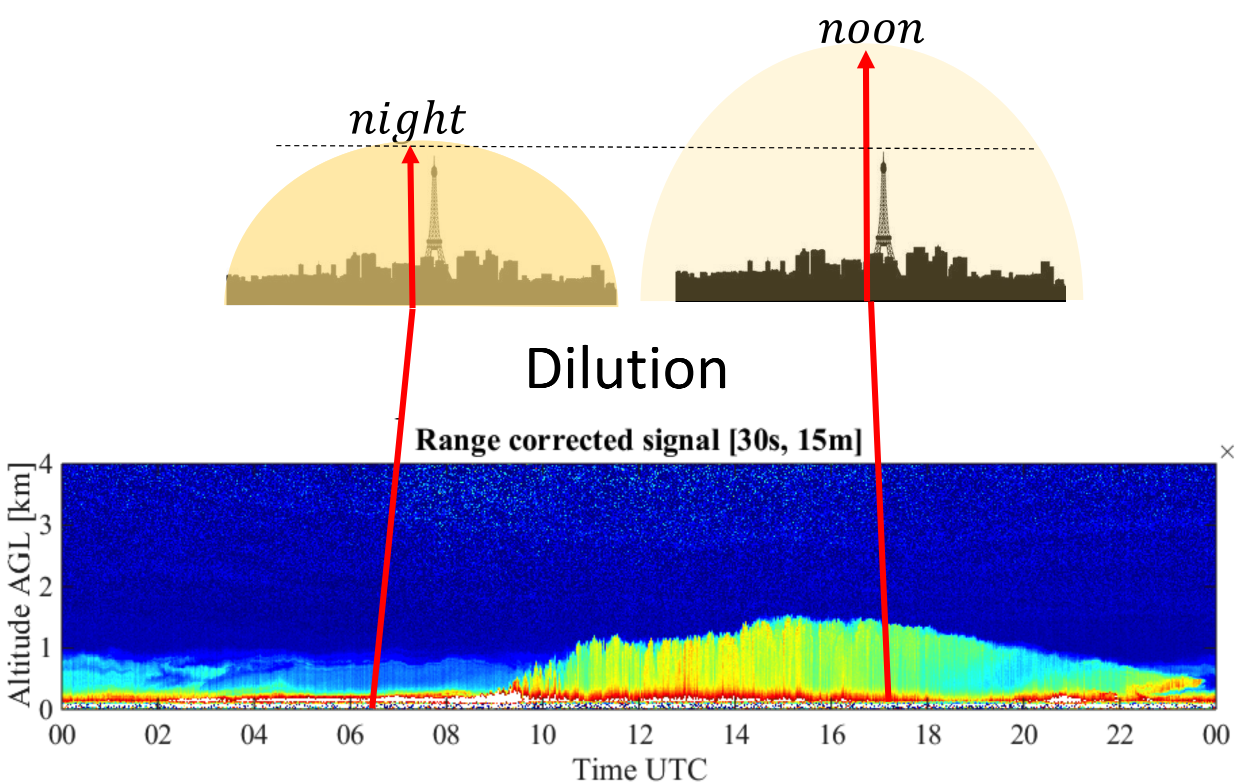


Diffusion

?

Dynamical processes proxies?

- Dilution is driven by the increase of the MLD from night-time to day-time:



- Thus, we define the dilution parameter as: $D = \dfrac{MLD\ at\ noon}{MLD\ at\ night}$

Low $D \Rightarrow$ weak dilution

Large $D \Rightarrow$ strong dilution

Dynamical processes proxies?

- Diffution is driven by the intensity of the thermal inversions
- An air-mass bubble at surface level at temperature T_s will rise to the top of the inversion, Height(T_{inv}), if it is heated up to the adiabatic temperature of T_{inv}, named θ_{inv}

- The **diffusion** can be quantified by:

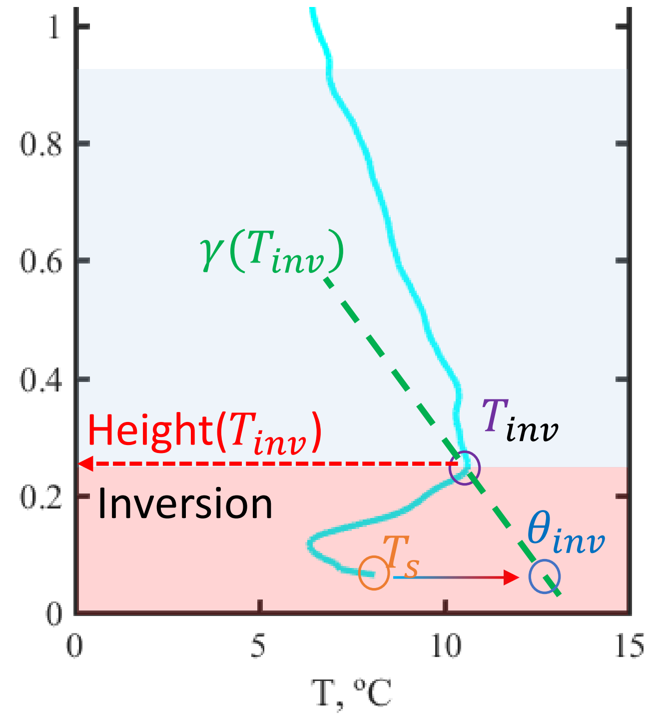
$$\Delta(\theta_{inv}, T_s) = \frac{\theta_{inv} - T_s}{\text{Height}(T_{inv})}$$

named 'inhibition parameter'

$\Delta(\theta_{inv}, T_s) \gg 0 \Rightarrow$ strong inversion $\Rightarrow$ low diffusion

$\Delta(\theta_{inv}, T_s) \ll 0 \Rightarrow$ no inversion $\Rightarrow$ high diffusion

Thermal inversion scheme



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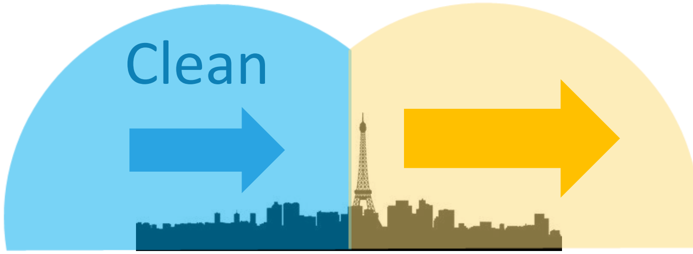
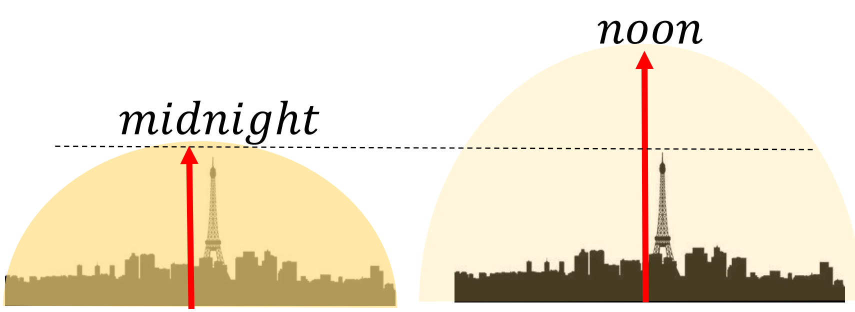
Dynamical processes proxies?

Proxy:



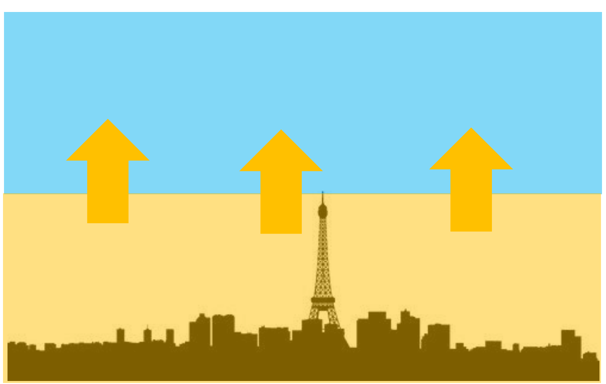
Clean-air advection

wind speed



Dilution

$$\frac{MLD\ at\ noon}{MLD\ at\ night}$$



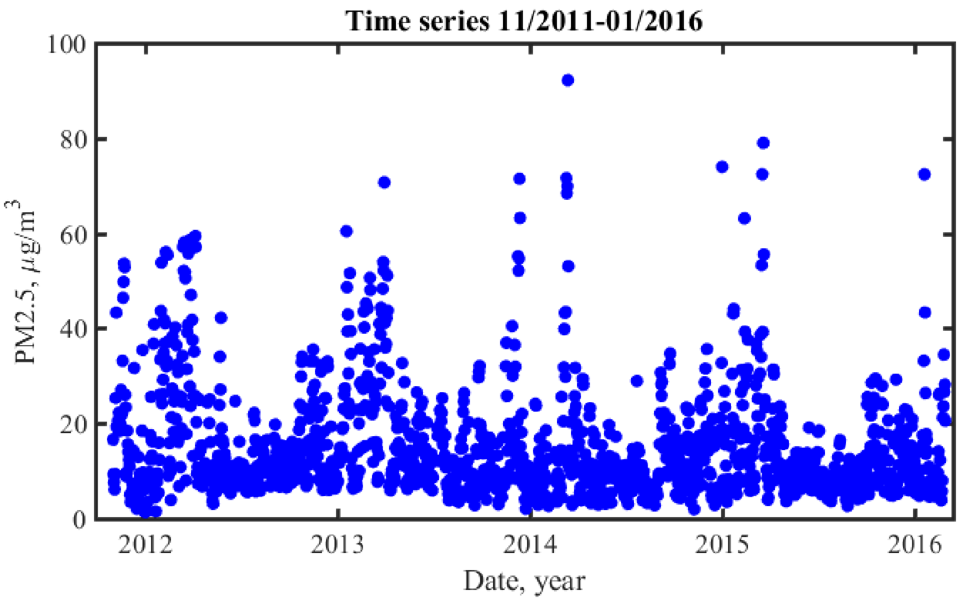
Diffusion

$$\Delta(\theta_{inv}, T_s)$$

(inhibition parameter)

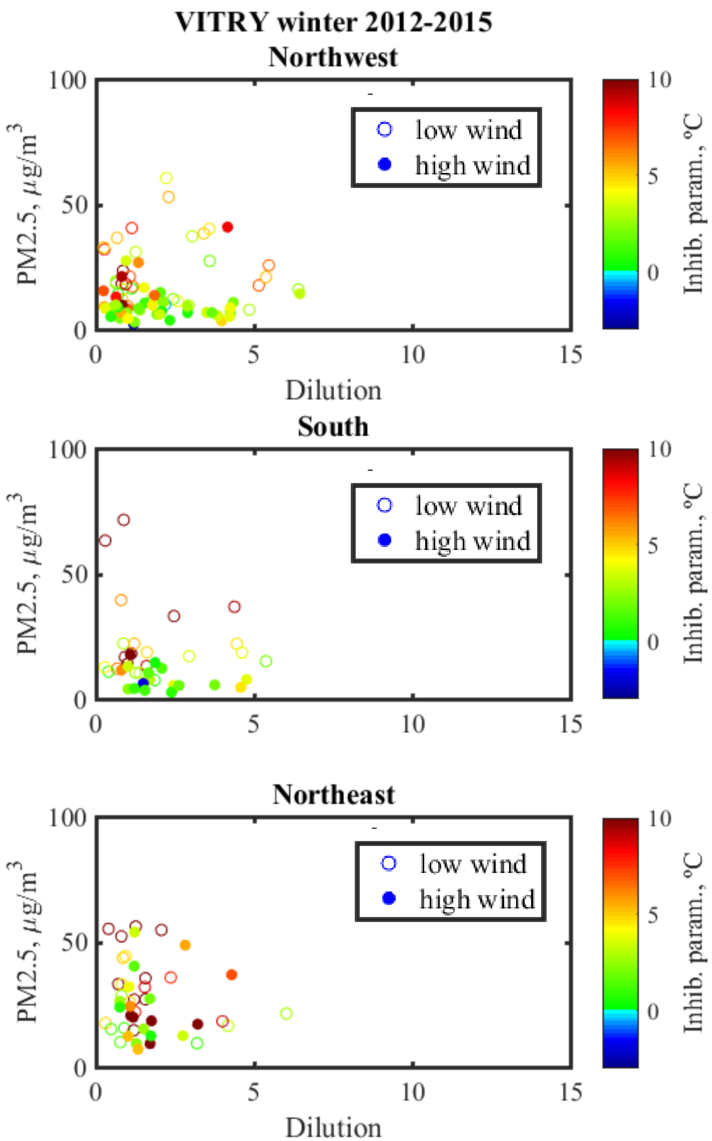
PM2,5 Vs dynamical processes: 2012-2015

- Seasonal working daily PM2.5 values on 2012-2015
- ReObs database and radiosondes to derive the dynamical-process proxies
- ACSM → aerosol chemical composition (origin/source)



PM2,5 Vs dynamical processes: 2012-2015

Seasonal working daily PM2,5 on 2012-2015

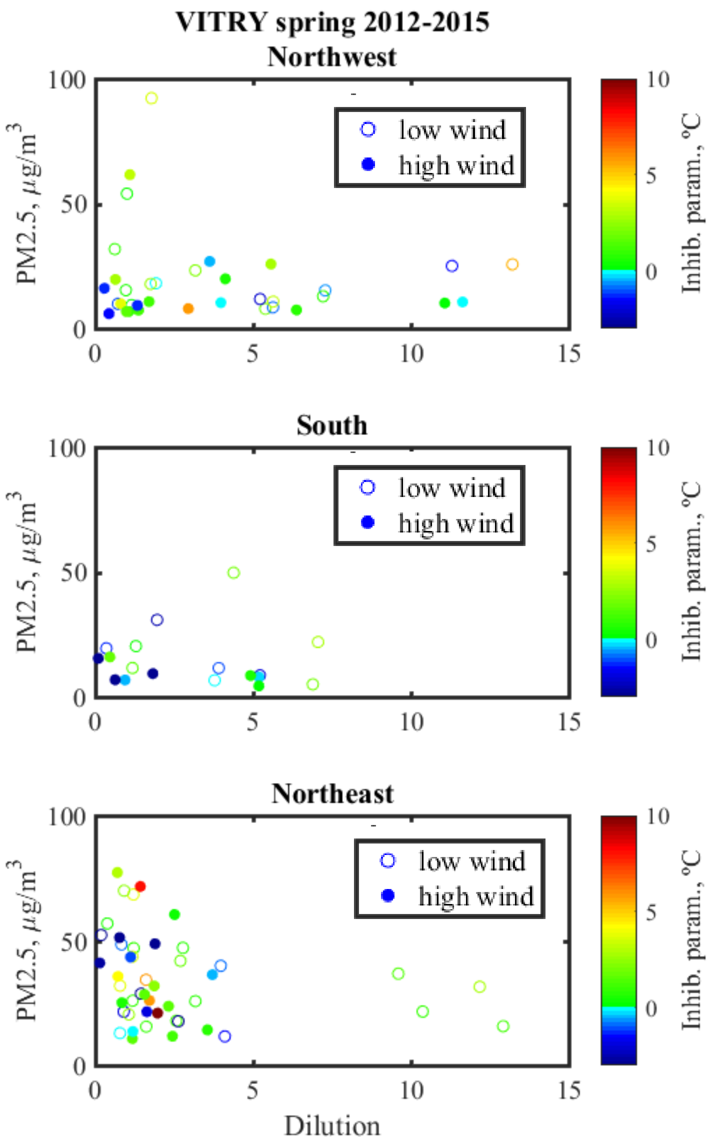


PROXIES		Largest PM2,5	
		SPRING	WINTER
DYNAMICAL PROCESSES	Wind direction		Northeast
	Wind speed		low (<3m/s)
	Dilution		<3
	Diffusion		low

- All 4 parameters are important.
- Low diffusion is required.

PM2,5 Vs dynamical processes: 2012-2015

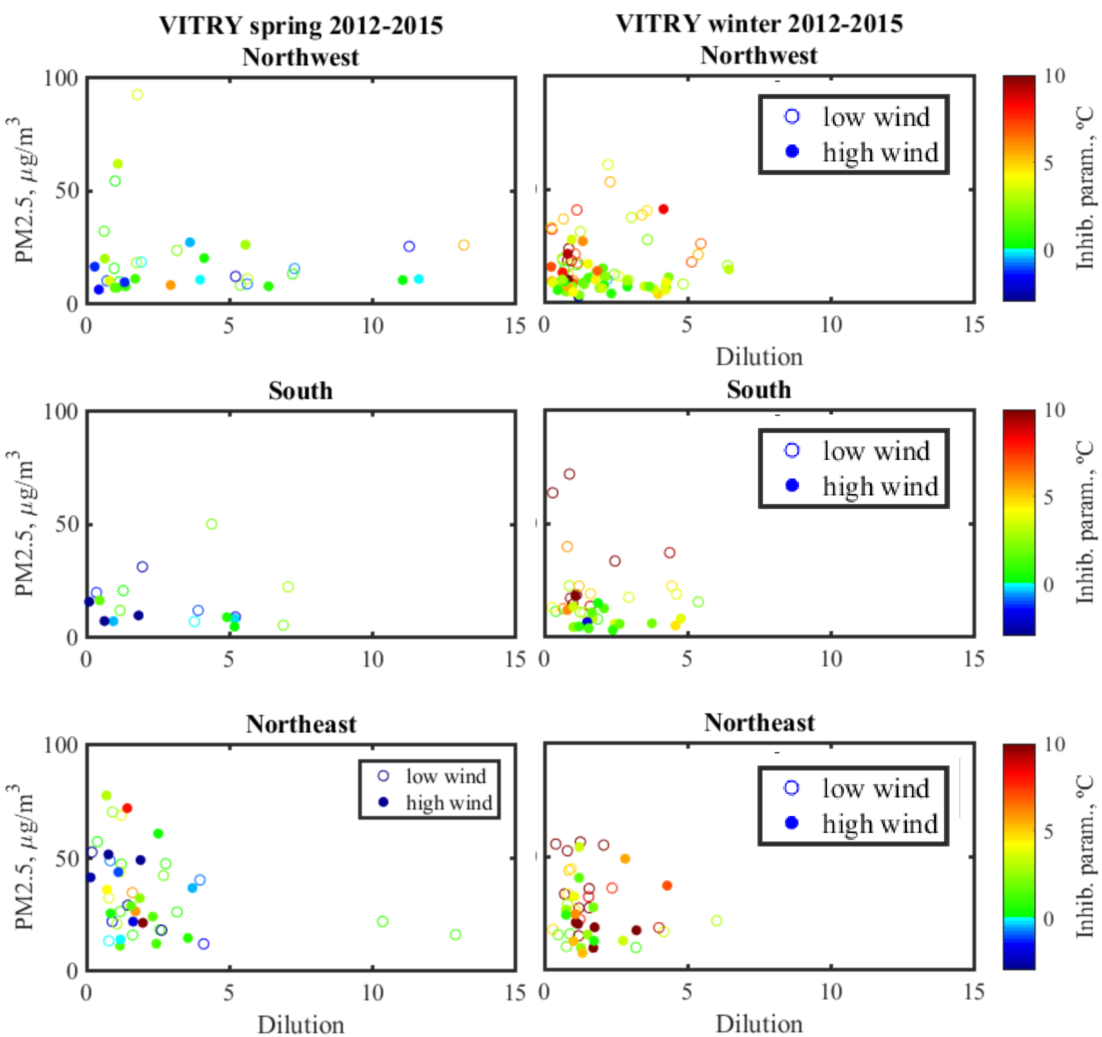
Seasonal working daily PM2,5 on 2012-2015



PROXIES		Largest PM2,5	
		SPRING	WINTER
DYNAMICAL PROCESSES	Wind direction	Northeast	
	Wind speed	-	
	Dilution	<5	
	Diffusion	-	

- Wind direction is more important than in winter.
- For NE dir, high PM25 for both low and high wind speed if dilution is low.
- Some cases of high dilution, but associated with low wind speed.

PM2,5 Vs dynamical processes: 2012-2015



- Higher inhibition parameter in winter.
- Higher dilution in spring.

PROXIES		Largest PM2,5 SPRING	Largest PM2,5 WINTER
DYNAMICAL PROCESSES	Wind direction	Northeast	Northeast
	Wind speed	-	low (<3m/s)
	Dilution	<5	<3
	Diffusion	-	low
CHEMICAL COMPOSITION	main component	NO3	Organic
	SO4/BC*	1,7	0,9

*larger values means transported aerosols

SO4/BC:

- transported aerosol in spring! (advected from NE)
- Local aerosol in winter!

Concluding remarks

- Combination of backscatter and Doppler lidars allows a deeper analysis of dynamical processes
- Thermal inversion blocks :
  I. the ML growths (dilution)
  II. the particle diffusion from MLD to the troposphere
- Dynamical processes proxies are useful to identify the origin of the pollution events
- Winter pollution events: low dilution and diffusion
- Spring pollution events: Northeast wind sector (transported aerosol)

Future work:

- Derive a combined parameter that can be used as indicator of high PM25 risk.

Thanks for your attention!

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