LIFE13 ENV/ES/000263

MEASURES TO IMPROVE AIR QUALITY IN THE SUBWAY SYSTEM

CSIC Consejo Superior de Investigaciones Científicas

TMB Transports Metropolitans de Barcelona

LIFE13 ENV/ES/000263

Implementing Methodologies and Practices to Reduce air pollution Of the subway enVironmEnt

01/10/2014 - 31/03/2018

The **objective** of the project is to provide to the local and national transport authorities of European countries the appropriate measures and strategies to reduce concentrations of inhalable particulate matter (PM1, PM2.5 and PM10) and identify distinctive chemical components in underground rail air.

On platforms	PM10 (µg/m³)	PM2.5 (µg/m³)	Reference
Barcelona	87-325	21-186	*Querol et al. 2012*
Barcelona	133	13-154	*Moreno et al. 2014; Martins et al. 2015*
Budapest	155	51	*Salma et al. 2007*
London	1000–1500	270–480	*Seaton et al. 2005*
Los Angeles	78	57	*Kam et al. 2011*
Paris	200	61	*Raut et al. 2009*
Seoul	359	129	*Kim et al. 2008*
Stockholm	357	199	*Johansson & Johansson 2003*
Taipei	51	35	*Cheng et al. 2008*

Inside train	PM10	PM2.5	Reference
Barcelona	36-100	11-32	*Querol et al. 2012*
Barcelona		19-75	*Martins et al. 2015*
Los Angeles	31	24	*Kam et al. 2011*
Taipei	41	32	*Cheng et al. 2008*

VARIABLES

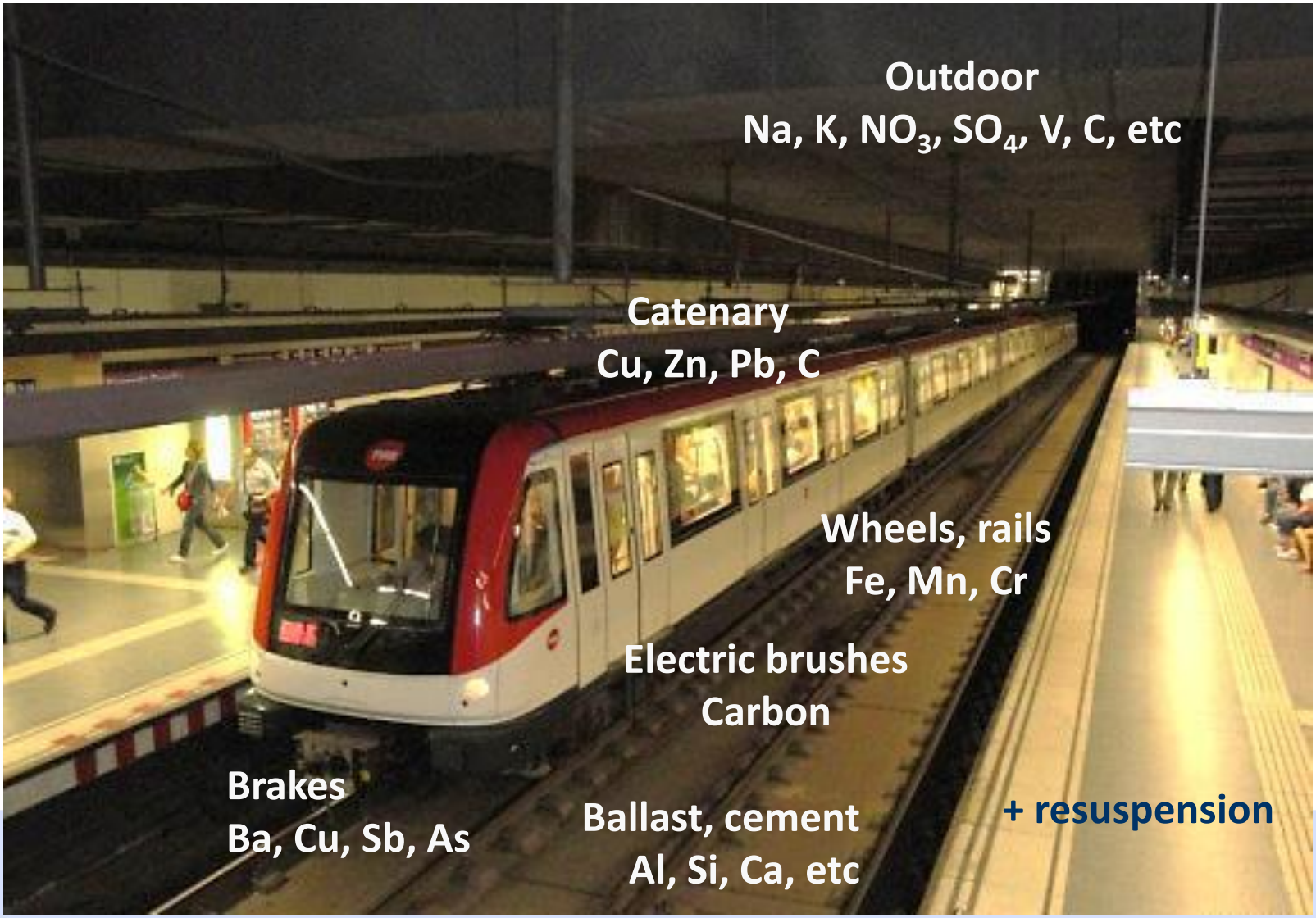
- ✓ Station design: single/double track, access points, depth, ventilation systems, platform door systems
- ✓ Train frequency and piston effect
- ✓ Passenger numbers
- ✓ Train design: braking systems, wheels, air conditioning, etc.
- ✓ Contamination by outside city air
- ✓ Ferruginous environment influenced by brake pad chemistry

We need to determine the sources of PM and their contribution to air quality in platforms and inside trains to reduce their impact.

Testing mitigation strategies :

- ✓ *Emissions for specific components (brakes, rails, catenary),*
- ✓ *Activities in the tunnel ,*
- ✓ *Effect and practicability of applying anti-resuspension product to the ballast before placement,*
- ✓ *Changes in ventilation protocols .*

PM SOURCES IN UNDERGROUND SYSTEMS



Frontal brake pad

Lateral brake pad

Cu catenary

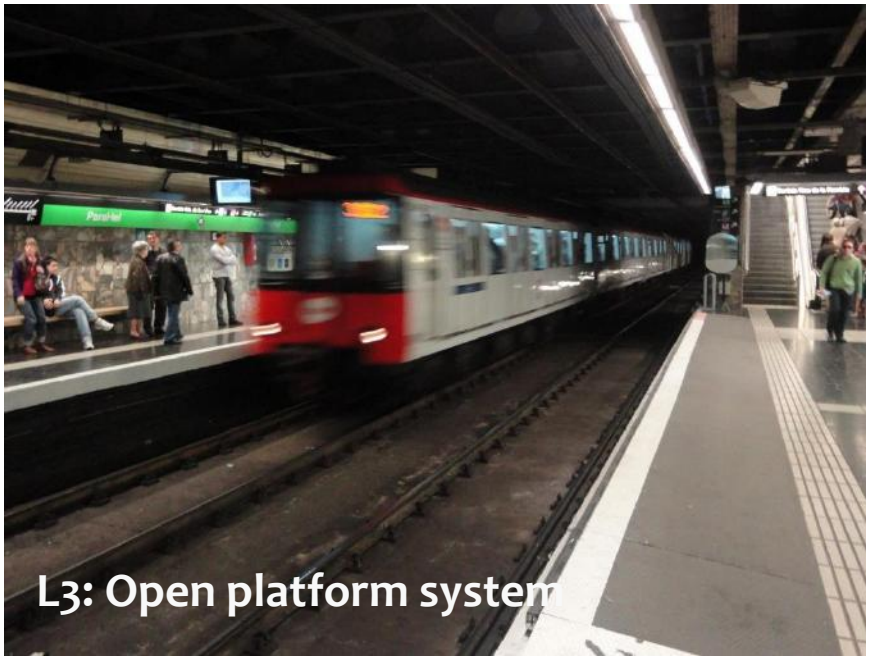
2cm

Wheels

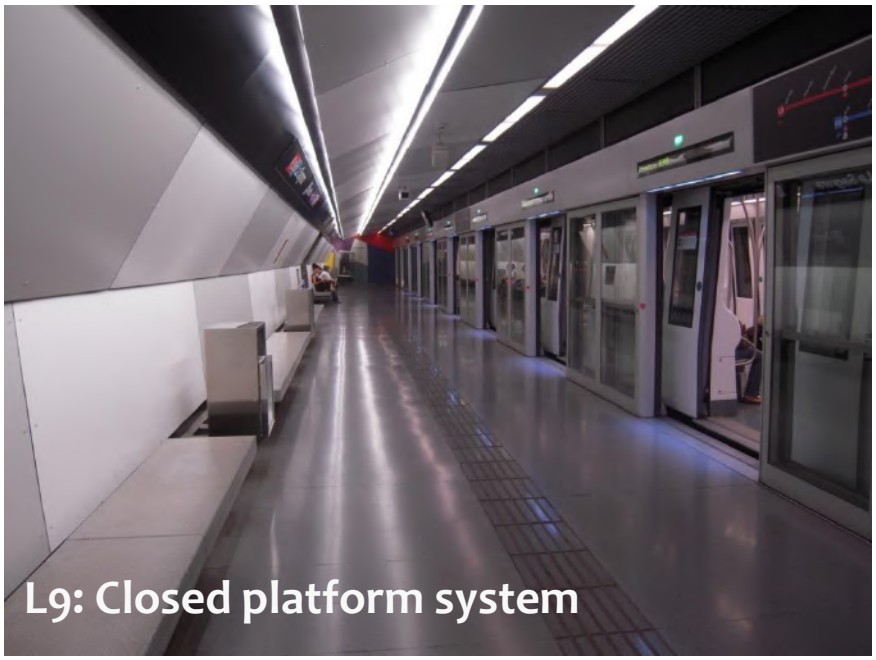
	BALLAST	CATENARY	BRUSHES	PANTOG.	BRAKES		RAIL	WHEEL
wt %					*lateral*	*frontal*		
C	<0,1	<0,1	95,4	78,7	24	40,4	0,8	0,50
ppm								
Al	83008	<0,1	0,03	719	529	22603	15	<0,1
Ba	591	10	28	85	14331	40002		0,1
Ca	23491	<0,1	0,1	1207	27857	35516		<0,1
Cu	35	950000	1000	197104	35436	193	160	1000
Fe	29705	9000	3000	1353	329000	17239	979595	980000
K	29221	<0,1	<0,1		83	2609		<0,1
Mg	9783	<0,1	<0,1	272	25800	43558		<0,1
Na	21952			1064	<0.01	3715		
S	163	<0,1	<0,1	3178	30800	17813	110	<0,1
Li	28				<0,01	7,5		
Ti	2716	53	28	43	60	1473	30	9,8
V	61	17	1	18	2,2	34	15	15
Cr	76	131	22	18	132	69	300	1173
Mn	646	40	1	16	3099	569	11300	7000
Co	5,2	1,4	<0,1	1,3	14,5	8,1		80
Ni	39	54	9,1	20	104	18	210	782
Zn	61	102	115	122	52220	10682		6
As	2,1	2,9	<0,1	2,9	22	4,9		51
Rb	112				0,8	8,0		
Sr	160	3,9	1,7	4,7	295	1905		<0,1
Cd					1,7			
Sn	2,9	0,9	15	2,9	15,3	3,1	20	95
Sb		12	4,9	30	3059	43	25	24
La	20				1,2	7,7		
Ce	43				0,9	16		
W	39	1,8	1,6		<0,01	1,8		91
Pb	17	2,4	4,2	8,6	1260	7,8		<0,1
Bi					1,6			

BCN Metro

1.25 million passengers per weekday
50% of public transport loading
Average journey time (inside train) 12 minutes



L3: Open platform system



L9: Closed platform system

METHODOLOGY AND WORK PLAN

Total Carbon

Organic

Acidic digestion

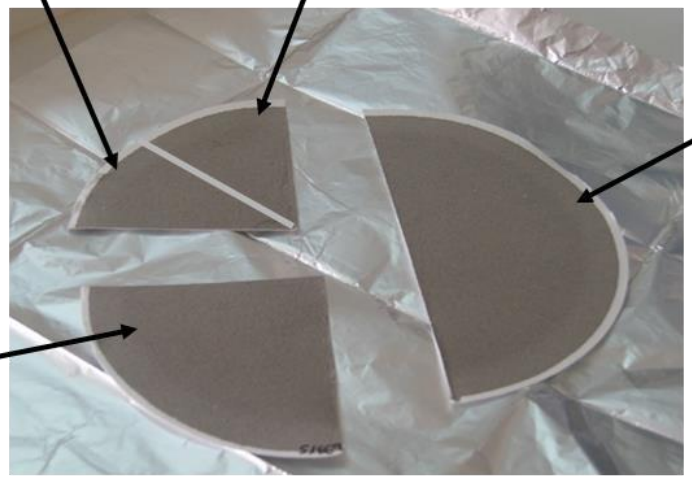
Leaching

Ion Chromat.:

NO_3^-, Cl^-, $SO_4^=$

Colorimetry FIA and ICP-AES:

NH_4^+, K^+, Mg^{2+},…



ICP-AES:

Al, Ca, K, Na, Mg, Fe, Ti, P

ICP-MS:

Li, Ti, V, Cr, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Cd, Sn, Cs, Ba, La, Ce, Pr, Nd, Hf, Tl, Pb, Bi, Th, U

METHODOLOGY AND WORK PLAN

OPS 3330

particle number 0.3–10 µm (16 channels) - 5 min.

Dusttrak

PM10, PM2.5, PM1 mass concentrations - 5 min.

IAQ

CO, CO2, T, HR (levels) - 5 min

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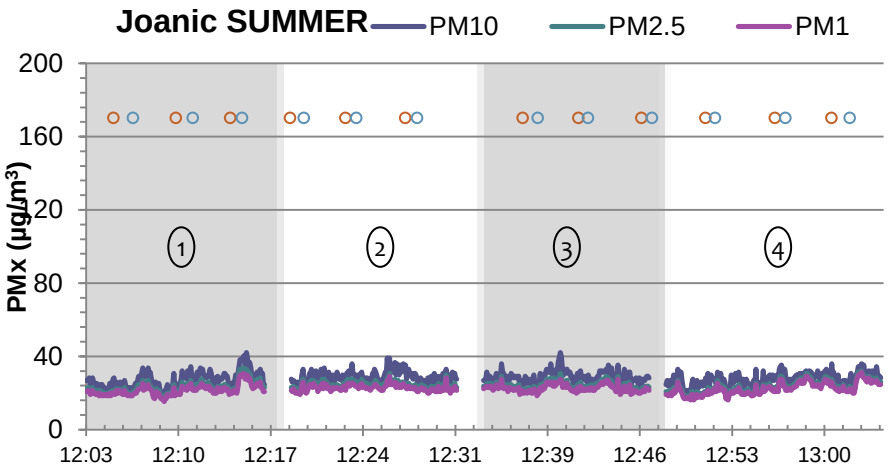
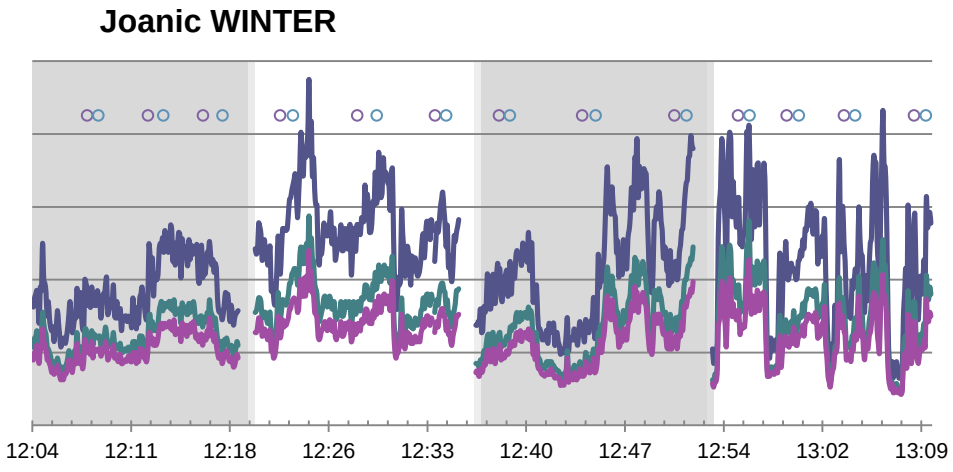
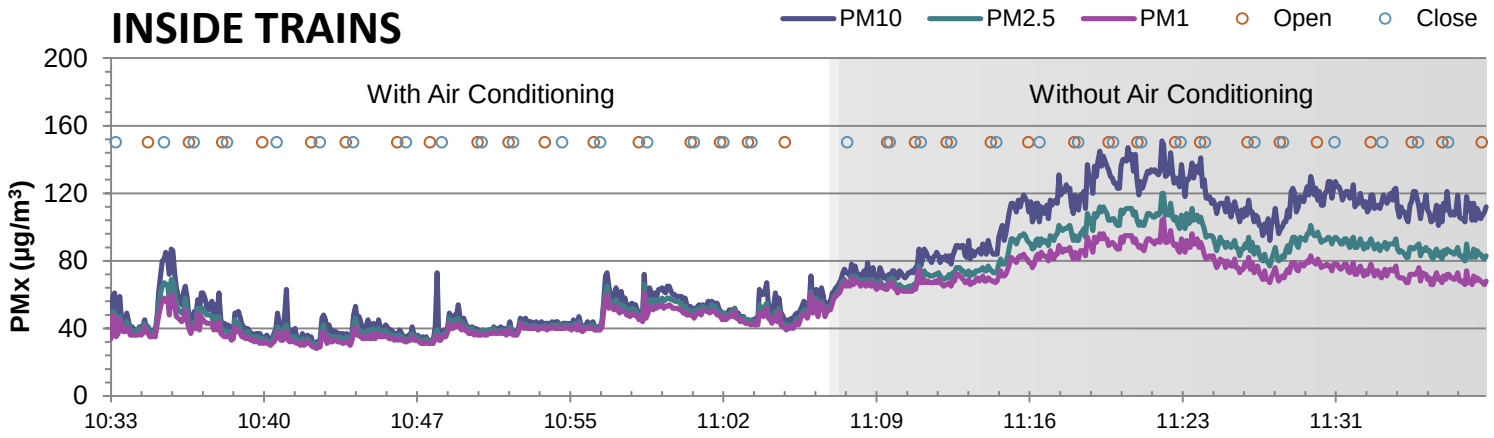
VARIABLES: PLATFORM & TRAIN VENTILATION

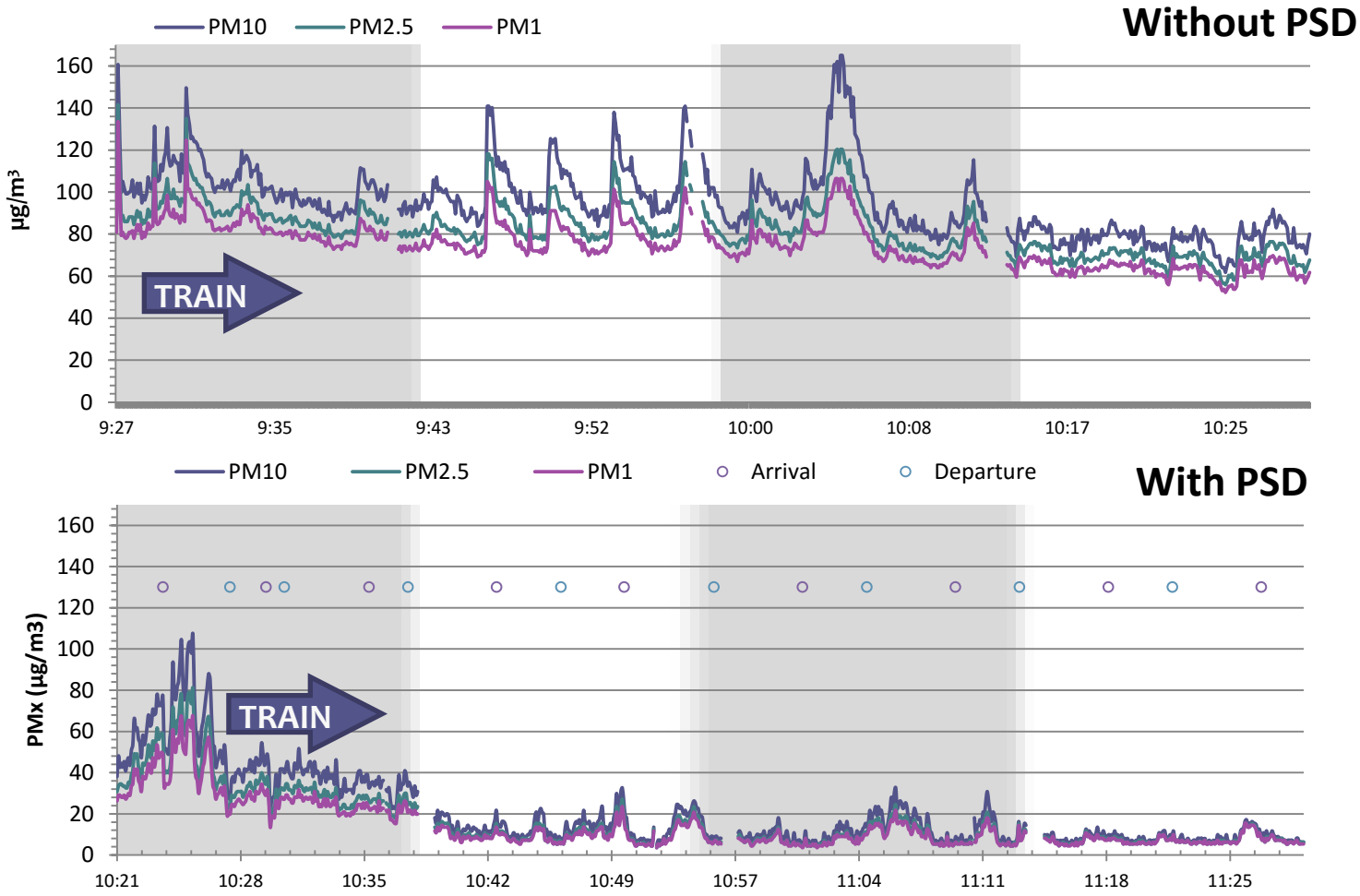






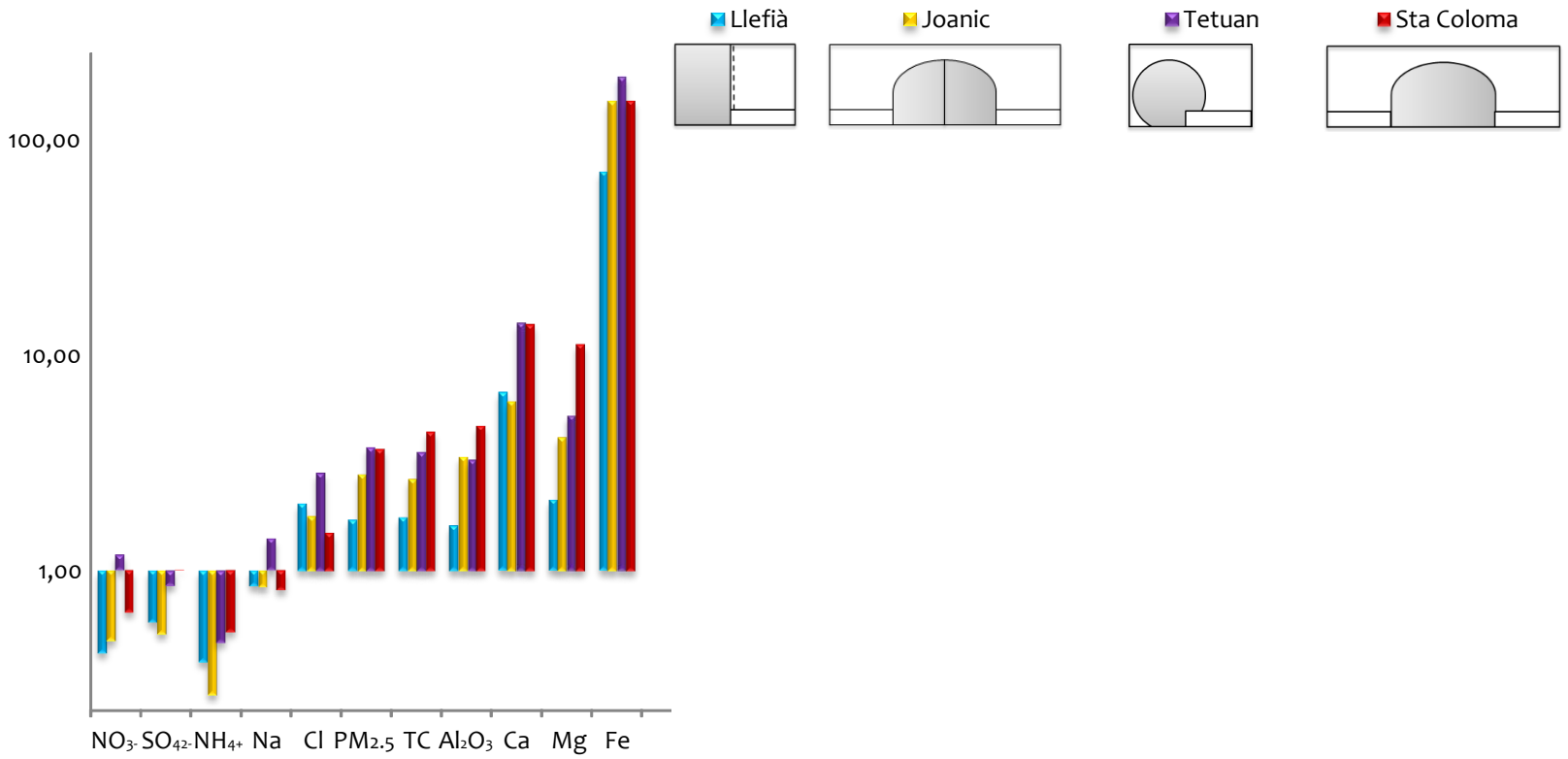
Martins et al 2015, Sci. Total Env. 511, 711-722

VARIABLES: STATION DESIGN AND PISTON EFFECT



SUBWAY PM CHEMISTRY

Subway/Barcelona outdoor



CAMPAÑAS MEDICION IMPROVE LIFE – METRO BARCELONA (2015)

	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M
Enero				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
																						SAGRERA L5 – CAMBIO BALASTO, TRAVIESAS, VIAS (1)															
Febrero							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28			
Marzo							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Abril			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					
Mayo					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
Junio	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1						
Julio			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
Agosto						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Septiembre		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						
Octubre				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
Noviembre							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Diciembre		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					

PALAU REIAL L3 – APORTACION BALASTO (1) – con agua

A/A TRENES L3 (1) – serie 3000

MARIA CRISTINA L3 – APORTACION BALASTO (2) – con polvo antiresuspensión

A/A TRENES L3 (1) – serie 3000-1

MARIA CRISTINA L3 – polvo antires.

TARRAGONA L3 - VENTILACION

A/A TRENES L3 (2) – serie 3000-1

Calibración equipos en CSIC

A/A TRENES L3 (2) – serie 3000-2

A/A TRENES L3 (2) – serie 3000-2

A/A TRENES L3 (2) – serie 3000-2

SANTA COLOMA L1 – CAMBIO CARRIL (1)

JOANIC L4 – CAMBIO CARRIL (2)

Leyenda: Obras — Días en blanco - condiciones normales

Aportacion balasto — D. en blanco – c.n., en verde balasto con agua y/o con polvo antiresuspension

Ventilación — D. en blanco- c.n. en violeta cambio ventilacion

Cambio carril — Depende de obras, medimos al menos 1 semana antes y 1 despues del cambio

Aire Acond. en trenes

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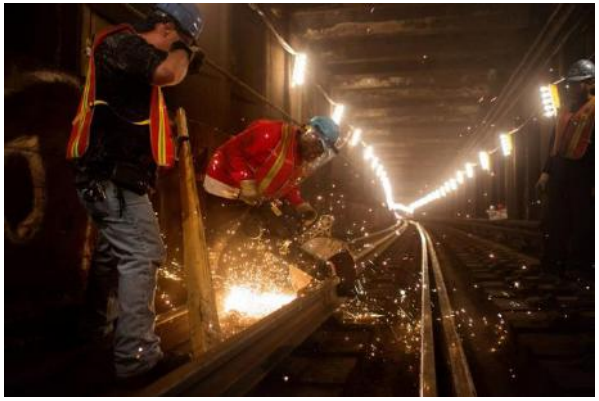
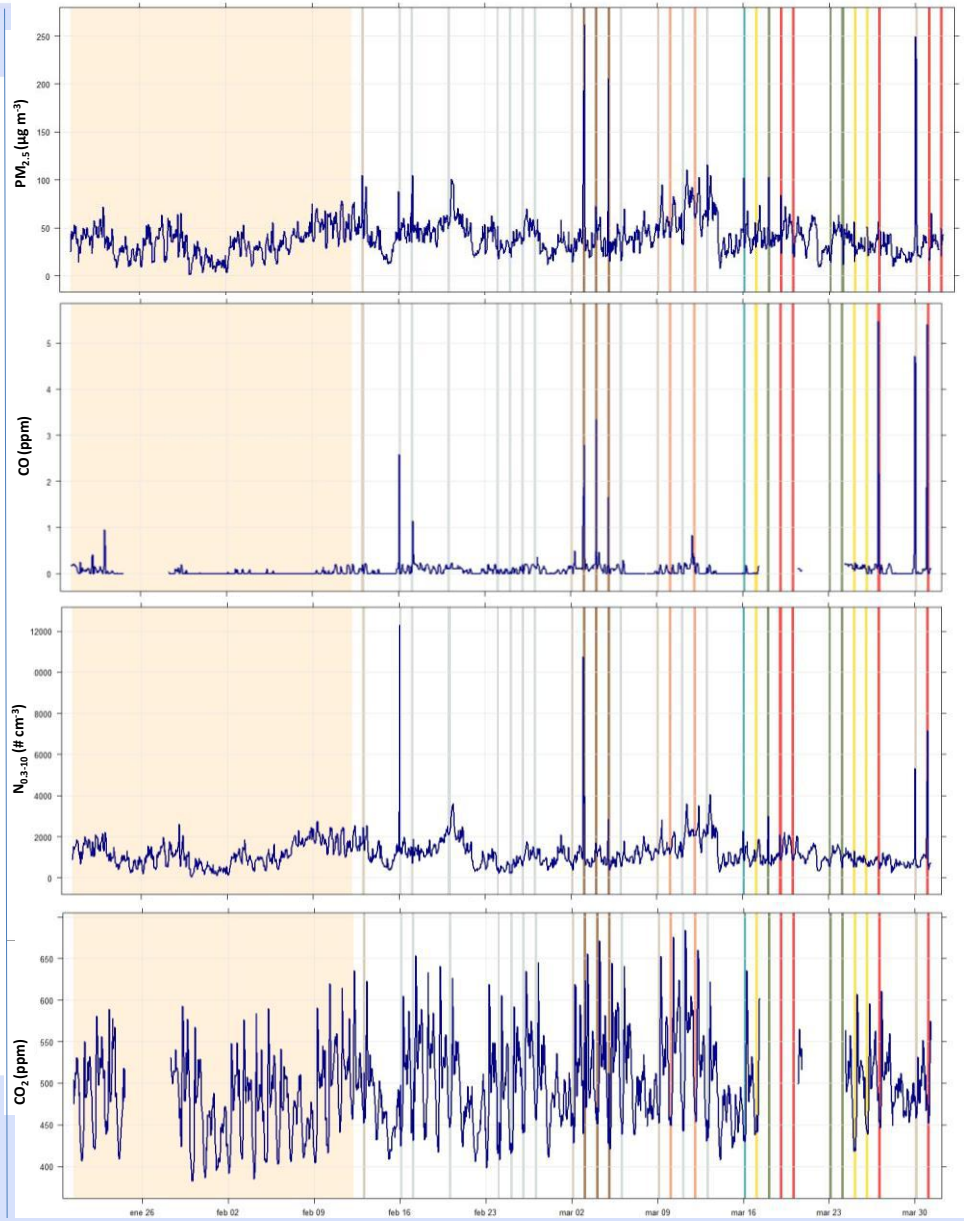
SAGRERA L5

MAINTENANCE WORKS

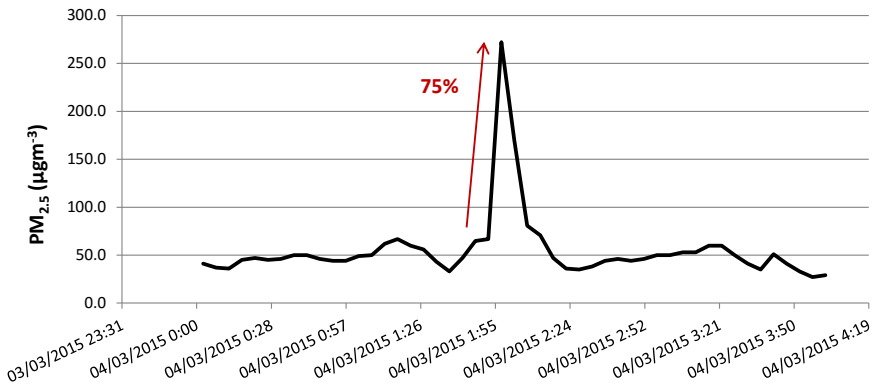
Railway major nightworks: sleeper and track replacement.

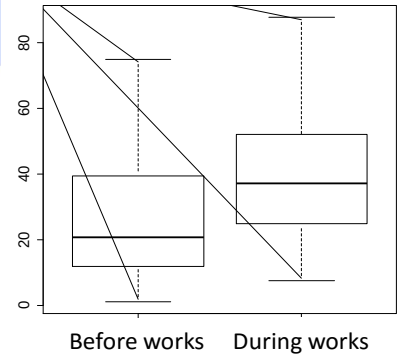


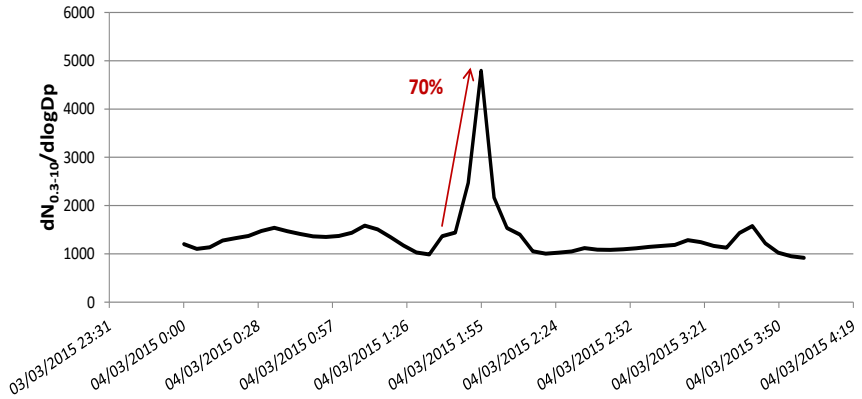
- ✓ Rail cut and movement (abrasion)
- ✓ Ballast levelling (some is removed)
- ✓ Positioning new tracks and sleepers
- ✓ Welding
- ✓ Addition and levelling of new ballast (gasoline engine machinery)

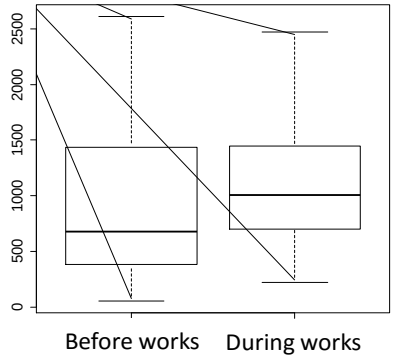


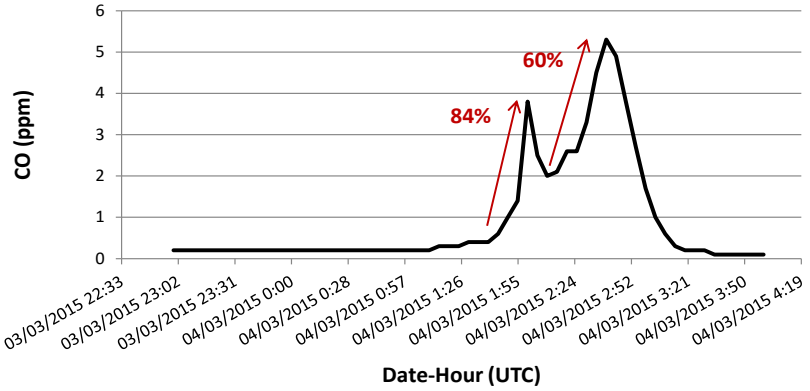
MAINTENANCE WORKS

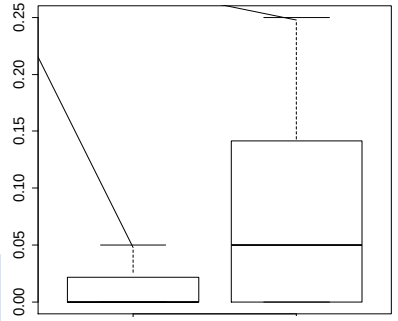












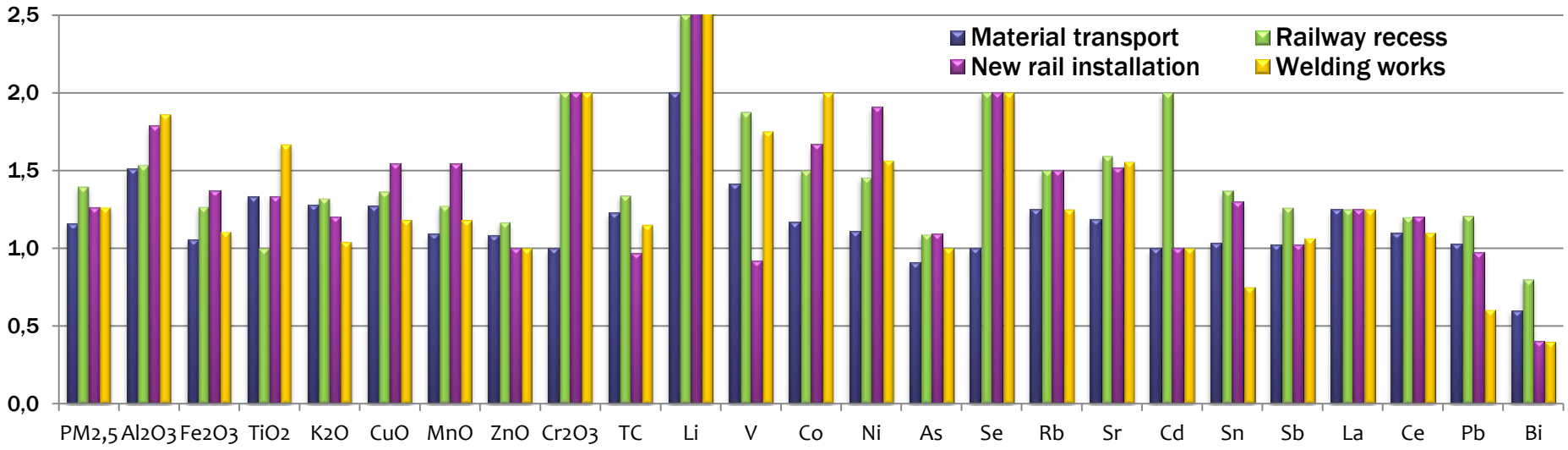
Average concentrations during works **(1:00-4:00h CET),** comparing periods before and during work activities

MAINTENANCE WORKS

	$PM_{2.5}$		$N_{0.3-10}$		CO	
	Mean	Median	Mean	Median	Mean	Median
Before works period (working hours)	26	21	903	682	0,05	<0.01
After works period (working hours)	46	37	1342	1009	0,32	0,05
	Working hours					
Material transport	63	47	1433	1269	0,56	0,06
Railway recess	46	41	1421	1028	0,14	0,07
New rail instalation	36	35	858	765	0,06	0,04
Welding	36	32	1547	957	1,69	0,15
Material transport+Railway recesss	93	59	2430	1336	0,96	0,39
Welding +Railway recess	55	59	1690	1754	0,10	0,04
Material transport +New rail instalation+Welding	49	36	1239	963	<0.01	<0.01
New rail instalation +Welding	38	32	1008	749		
Before works period (operation hours)	36	36	1173	1117	0,03	<0.01
After works period (operation hours)	42	40	1185	1064	0,08	0,06
	Working days (operation hours)					
Material transport	43	39	1198	1108	0,10	0,08
Railway recess	52	47	1453	1270	0,10	0,10
New rail instalation	35	32	903	848	0,12	0,12
Welding	42	41	1204	1119	0,07	0,08
Material transport+Railway recesss	34	32	867	831	0,13	0,10
Welding +Railway recess	63	62	1832	1907	0,07	0,01
Material transport +New rail instalation+Welding	41	39	1036	972	0,02	<0.01
New rail instalation +Welding	41	42	1092	1085	0,19	0,20

+ 16% $PM_{2,5}$

MAINTENANCE WORKS



Increment > 50%

Transport: Al, P, Li, Mo

Railway recess: Al, P, Cr, Li, V, Co, Se, Rb, Sr, Mo, Cd (Pb, Bi, Sb, Sn, V, Zn)

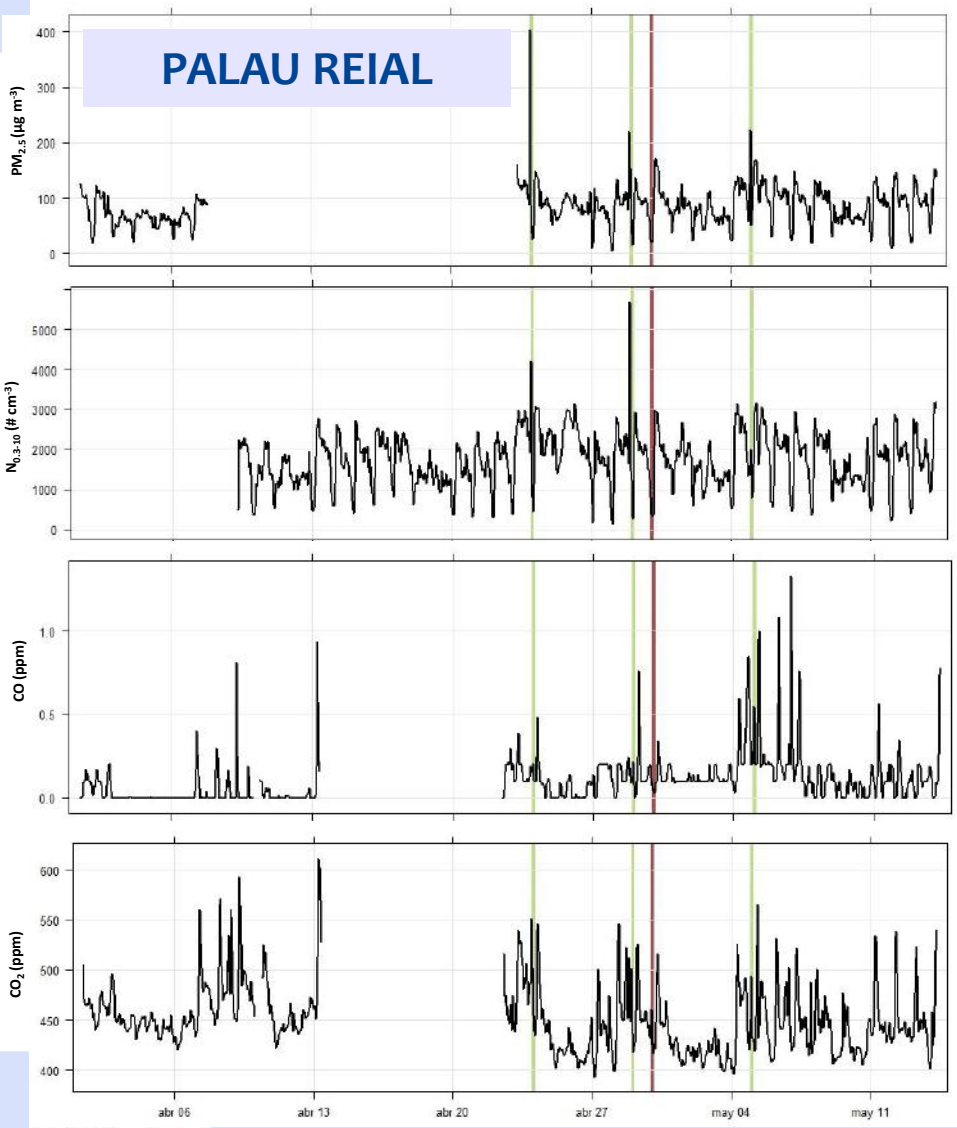
New rail: Al, Cu, Mn, Cr, Li, Se, Mo, Co, Ni, Rb, Sr, (Fe, Cu, Mn, Ni)

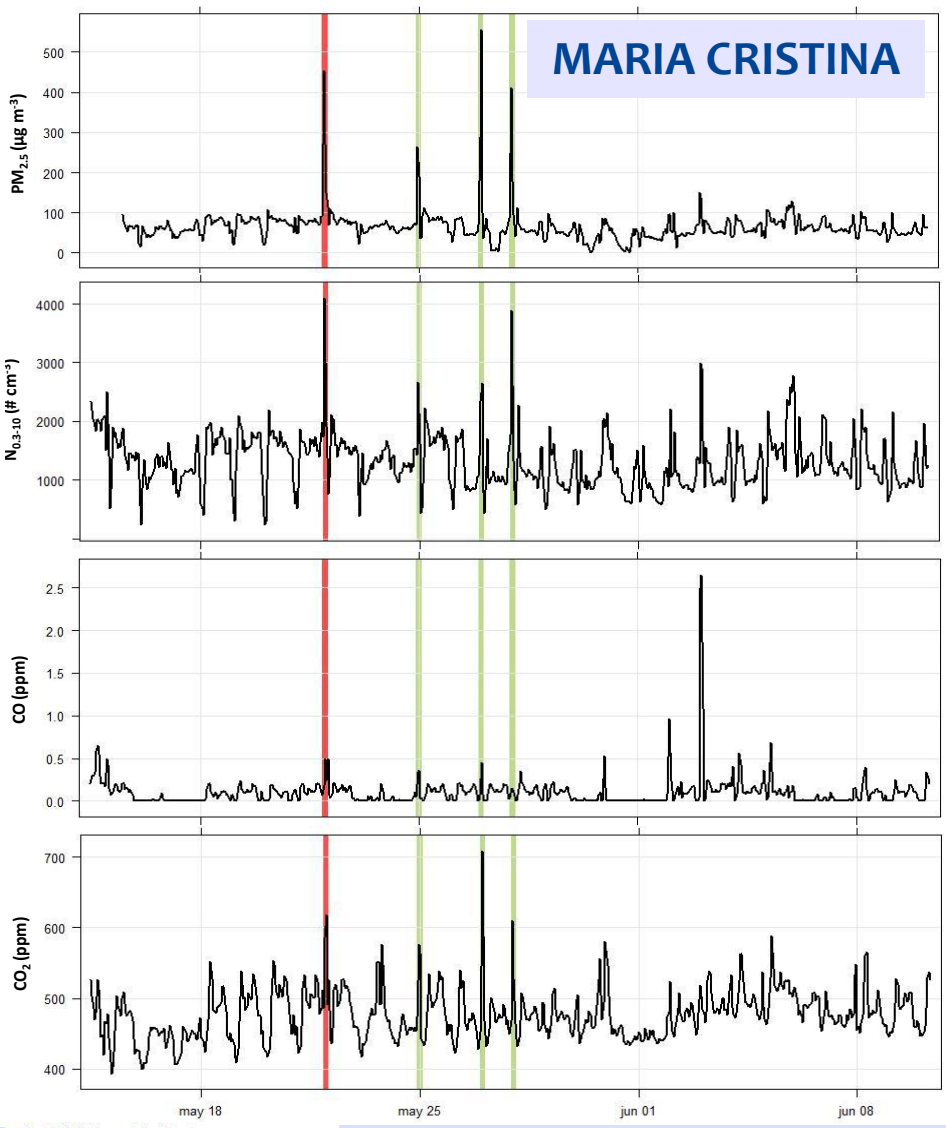
Welding: Al, Ti, P, Cr, Li, Se, Rb, Mo, V, Co, Ni, Sr, Mo

PALAU REIAL/MARIA CRISTINA L3

ADDITION OF NEW BALLAST

ADDITION OF NEW BALLAST





ADDITION OF NEW BALLAST

WITH WATER

a) PALAU REIAL

05-24h	No activity	Addition of ballast/Track tamping
$PM_{2.5}$ (μgm^{-3})	80.3 / 579	111.3 / 76 (39%)
$N_{0.3\text{-}10}$ ($^{\#}$ cm^{-3})	1684.5 / 764	2245.8 / 76 (33%)
CO (ppm)	0.08 / 708	0.16 / 73

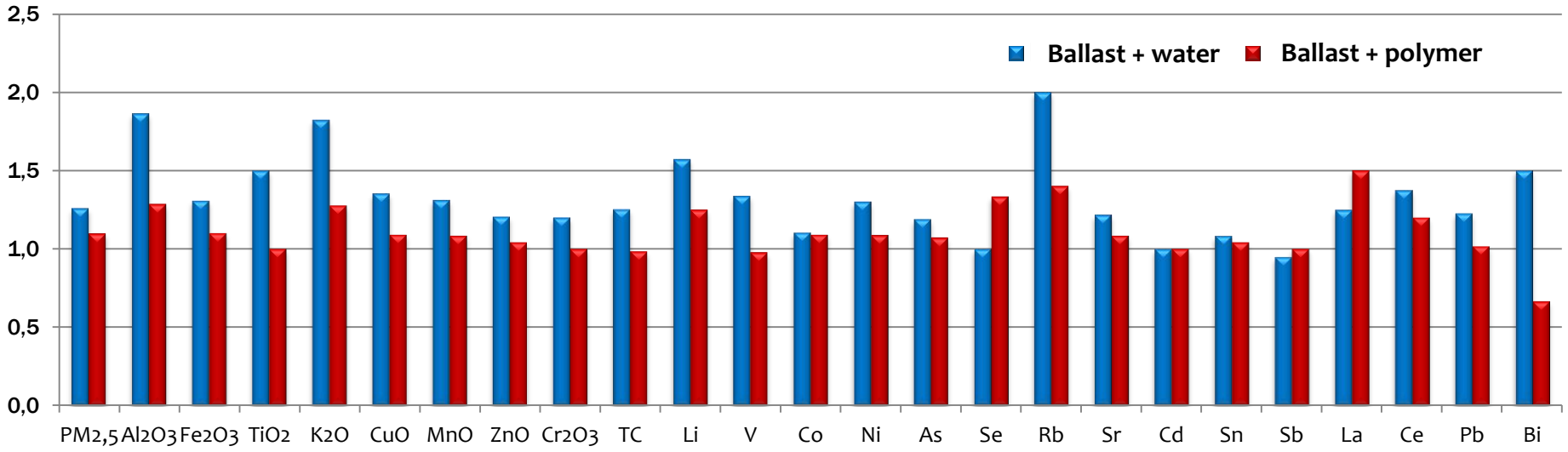
ADDITION OF NEW BALLAST

WITH WATER

WITH POLYMER

	a) PALAU REIAL		b) MARIA CRISTINA	
05-24h	**No activity**	**Addition of ballast/Track tamping**	**No activity**	**Addition of ballast/Track tamping**
$PM_{2.5}$ (μgm^{-3})	80.3 / 579	111.3 / 76 (39%)	60.95 / 529	61.9 / 62
$N_{0.3-10}$ ($^{\#}$ cm^{-3})	1684.5 / 764	2245.8 / 76 (33%)	1290.98 / 560	1322.39 / 62
CO (ppm)	0.08 / 708	0.16 / 73	0.08 / 551	0.11 / 62

ADDITION OF NEW BALLAST

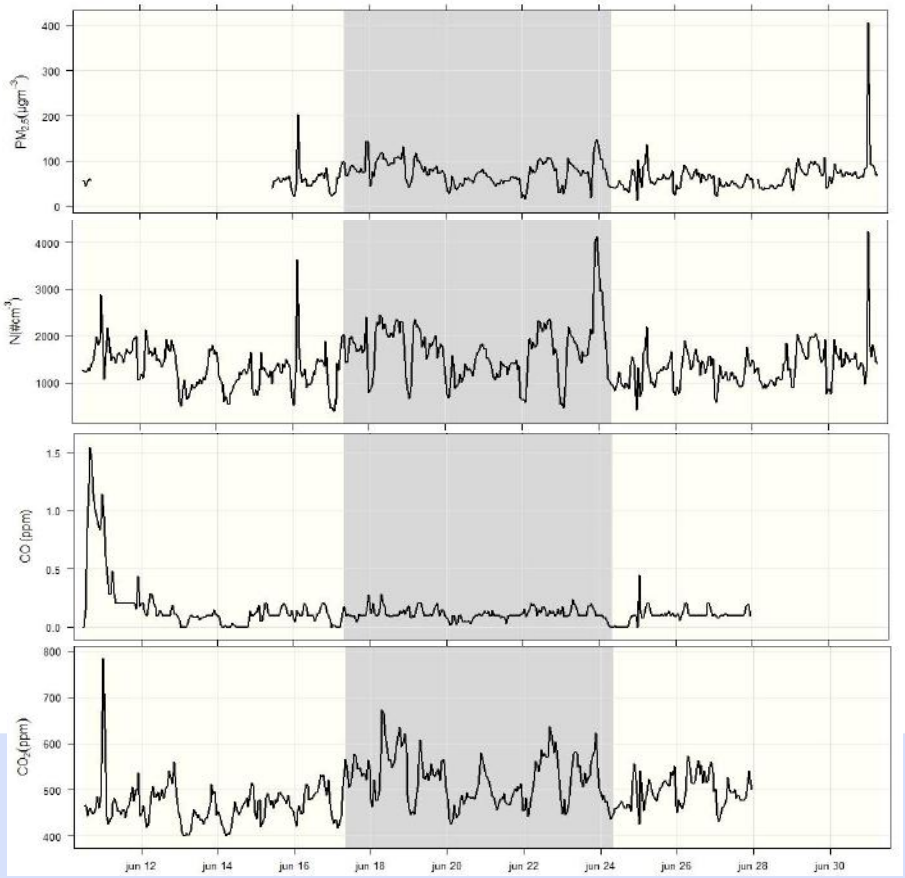


TARRAGONA L3

CHANGES IN VENTILATION SETTINGS

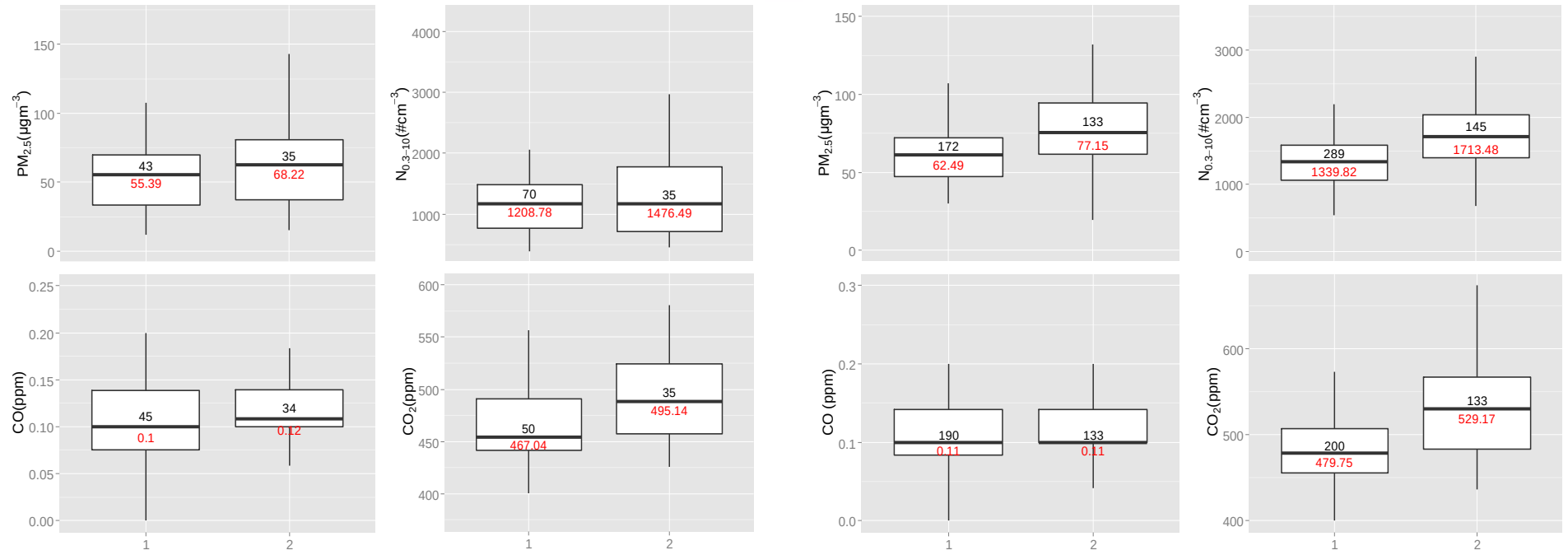
CHANGES IN VENTILATION

Week 1 10-17.06.2015		Week 2 17-24.06.2015		Week 3 24.06-01.07.2015	
DAY	NIGHT	DAY	NIGHT	DAY	NIGT
IMPULSION	CLOSED	EXTRACTION	CLOSED	IMPULSION	CLOSED



CHANGES IN VENTILATION

24-05h (ventilation closed) **05-24h** **(1: impulsion, 2: extraction)**



Ventilation Extraction> Impulsion		
	Difference (%)	p-value
$PM_{2.5}$	**18%**	<0.001
$N_{0.3-10}$	**22%**	<0.001
CO	-1%	>0.1
CO_2	**10%**	<0.001

CHANGES IN VENTILATION

- During this campaign PM concentrations increased by almost 20% on the platform when the ventilation setting was changed.
- This increase was observed immediately after the ventilation was changed.
- PM levels did not keep increasing during the week.
- The changes in daytime ventilation did not affect air quality on the platform during the night.
- With these results, a ventilation with impulsion of outdoor air is recommended over a ventilation with extraction of indoor subway air.
- We are carrying out a second campaign in the same station under winter conditions to corroborate the results.

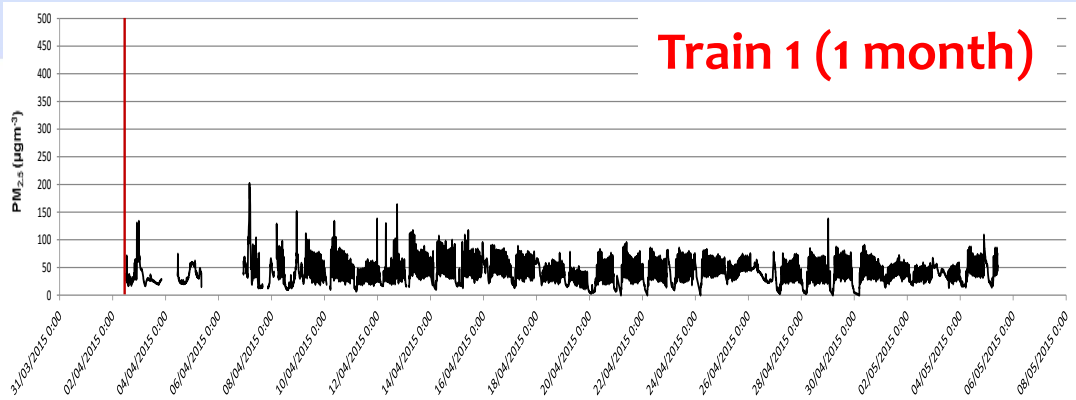
SUMMARY PLATFORM MEASUREMENTS

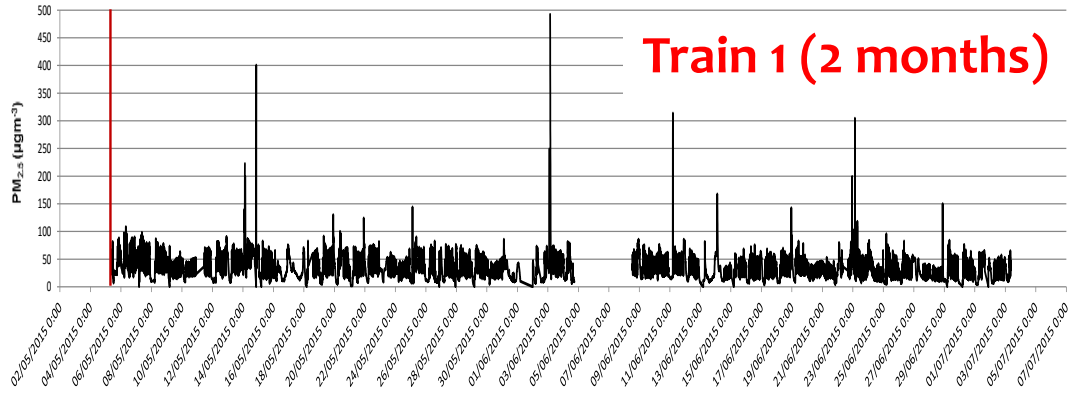
Increase in average concentrations during subway operating hours 5-24h

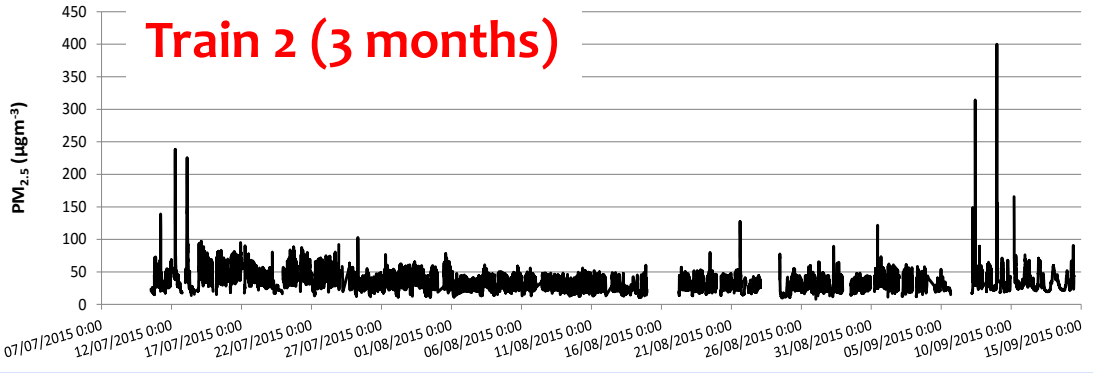
	Main tunnel works	Rail works	Ballast + water	Ballast + polymer	Ventilation change
	Sagrera	Joanic	Palau Reial	Maria Cristina	Tarragona
	Increase (%)				
$PM_{2.5}$	16%	18%	39%	2%	18%
$N_{0.3-10}$	1%	13%	33%	2%	22%
CO	22%	5%	50%	27%	--
CO_2	10%	2%	2%	0.2%	10%

INSIDE TRAINS

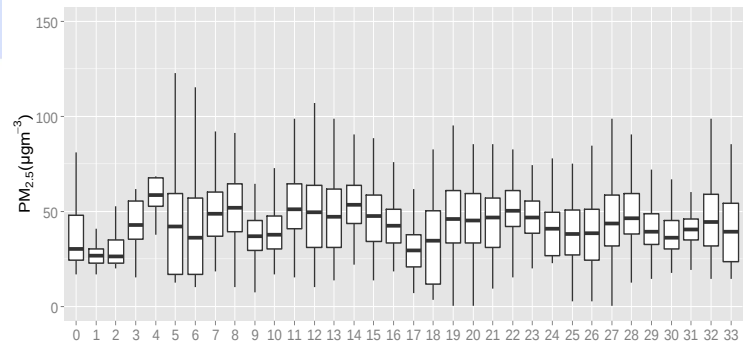
Localisation equipment	Date AC filter change	Days AC filter
TRAIN 1	02/04/2015	33 days
	05/05/2015	59 days
TRAIN 2	10/06/2015	90 days

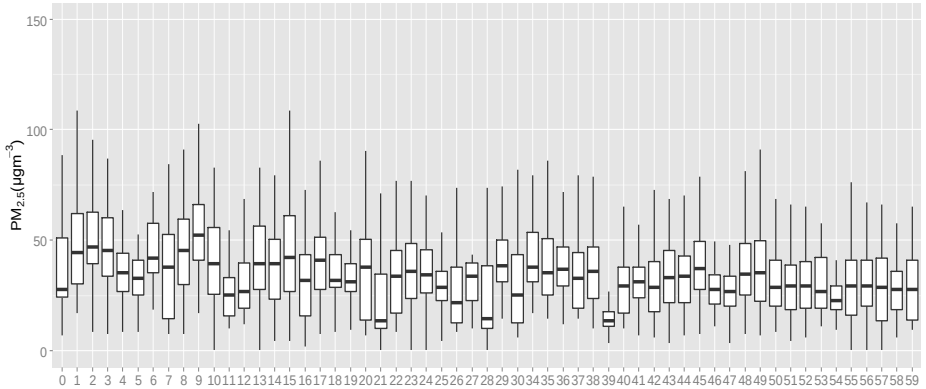


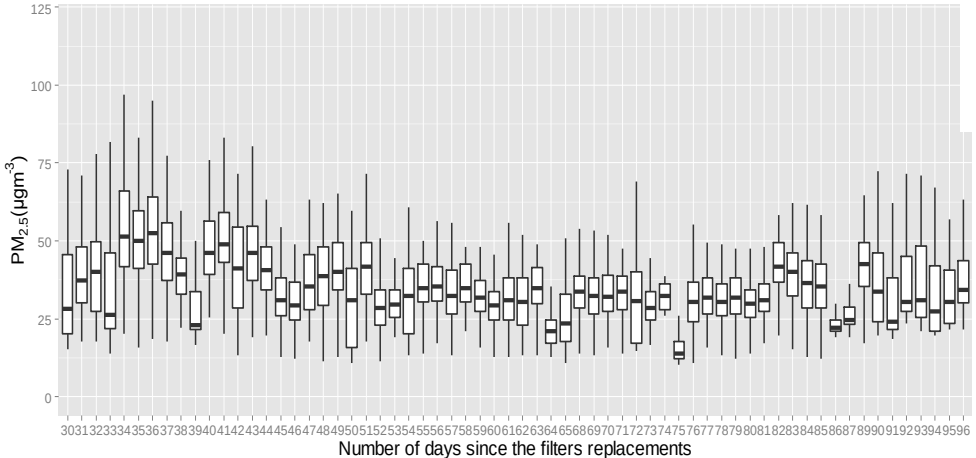




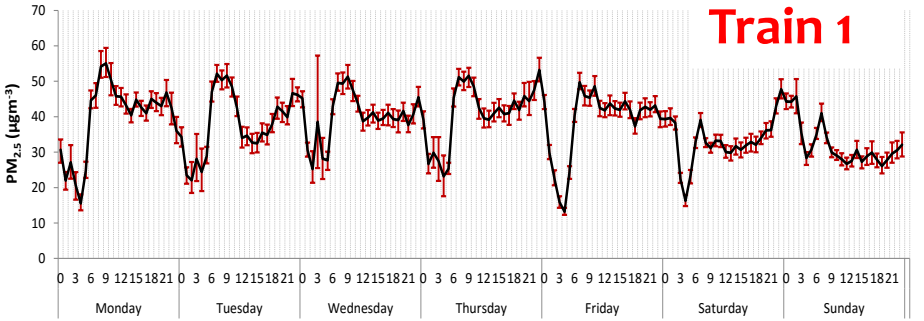
INSIDE TRAINS

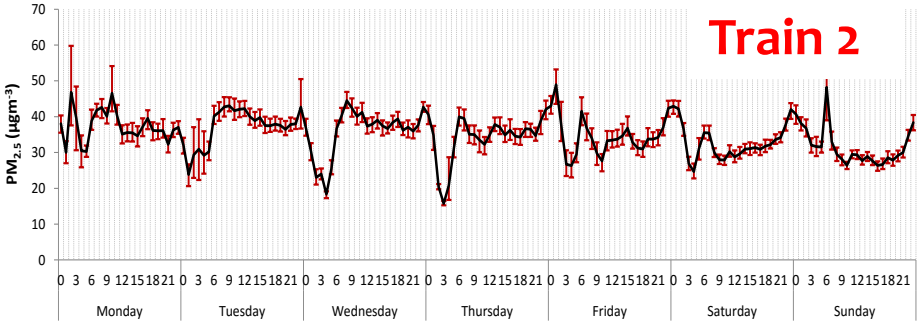






HOURLY CYCLE





CSIC Consejo Superior de Investigaciones Científicas

TMB Transports Metropolitans de Barcelona

INSIDE TRAINS

- $PM_{2.5}$ concentrations inside trains were 30-50% lower than the simultaneously measured concentrations on platforms of the same subway line.
- $PM_{2.5}$ levels measured inside the train were c. 20% higher during working days compared to weekends, showing that train frequency affects PM concentrations inside trains as well as on the platform.
- Unusual concentration peaks registered inside trains were related to night maintenance activities when the train is at the depot (e.g. cleaning activities such as graffiti removal, air compressed cleaning, etc.)
- No appreciable difference is observed in $PM_{2.5}$ levels after the AC filter has been operating for at least 3 months, indicating that in terms of air quality alone, it does not seem necessary to change these filters monthly as is done regularly at the moment.

CAMPAÑAS MEDICION IMPROVE LIFE – METRO BARCELONA (2016)

	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M	X	J	V	S	D	L	M
Enero					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
Febrero								1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
									St ILDEFONSO L5 - ZAPATAS FRENO																														
Marzo		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					
		TARRAGONA L3-VENTILACION																																			
Abril					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
					TARRAGONA L3-VENTILACION																								A ELEGIR ESTACION EN LINEA 9 SUR								
Mayo							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
							A ELEGIR ESTACION EN LINEA 9 SUR condiciones en estaciones nuevas			CIUDAD MERIDIANA L11 - ZAPATAS FRENO (Y CARRIL)																			APORTACION BALASTO (3) a) normal y b) con polimero								
Junio			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					
			APORTACION BALASTO (3) a) normal y b) con polimero																																		

SOME IMPROVE LIFE CONCLUSIONS SO FAR

- Ventilation is a key factor influencing air quality in both platforms and inside trains. Summer platform ventilation and air conditioning inside trains both improve air quality. Driving air into the tunnel system from outside produces better air quality than the reverse.
- Protocols regarding regular replacement of AC filters in trains should be re-examined.
- Platform screen door systems, in addition to improving safety, produce much better air quality than traditional open subway platforms.
- Extreme transient peaks in PM concentrations produced by night tunnel maintenance have a detectable, but much lower, short-term impact on daytime platform air quality. The most polluting activity is identified as that of ballast removal and replacement, producing abundant granitic rock dust.
- The treatment of ballast with anti-resuspension polymer has a detectable influence on daytime platform air quality, and is to be encouraged.