Project group Number	10
Project Acronym	E3M
Project title	**E**valuating the **E**fficiency of **E**mergency **M**easures taken to reduce or mitigate air pollution episodes in urban areas
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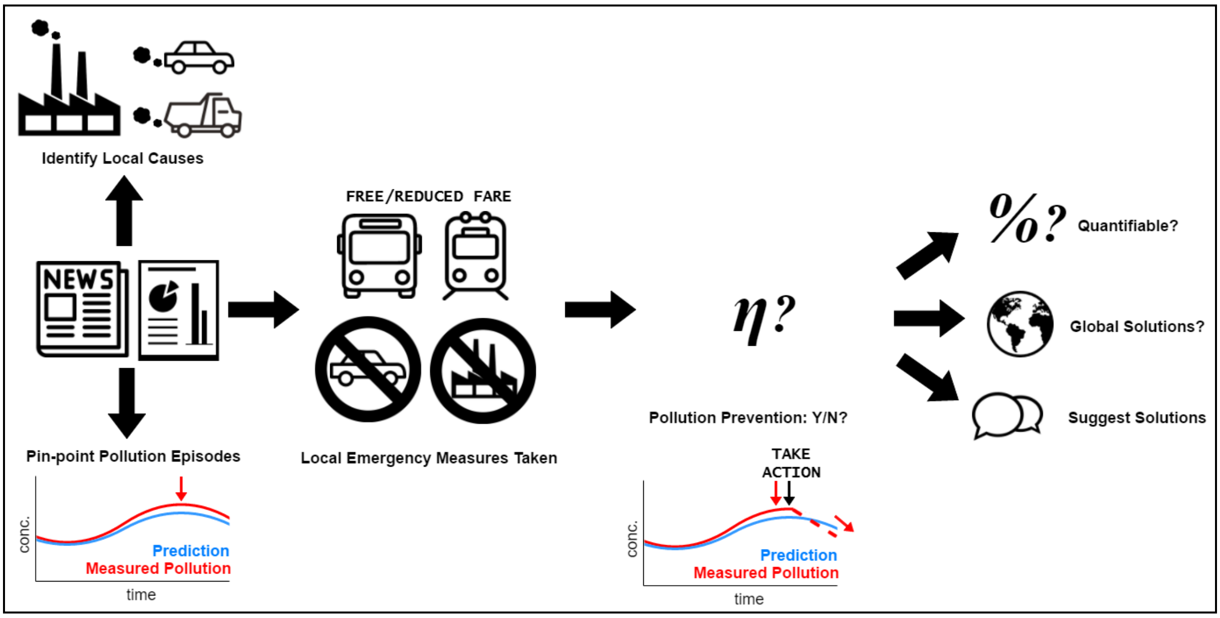

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1. EXECUTIVE SUMMARY

Cities are facing air pollution episodes resulting in health impacts of local habitants and breach of air quality standards. Based on regional pollution dispersion models, cities often take emergency measures to reduce emissions during these events. This report presents an evaluation of some of these emergency measures by quantifying their effectiveness in reducing the concentrations of the pollutant in question.

Cases of pollution episodes and public air quality data were gathered by media review. Two winter cases from Europe and three summer cases from California, USA were investigated. Data on weather conditions, predicted and measured concentrations were gathered and analysed to verify if emergency measures were effective.

To reduce PM10 concentrations in Brussels in March 2014, the city imposed a speed limit of 50 km/hr. Only minor differences in PM10 concentrations were found between traffic and suburban zones. On the first day after the limit PM10 concentrations actually increased slightly, and on the third day dropped to half when wind speed increased to its usual levels. The emergency measure was found to be ineffective.

In March 2014 Paris suffered an important PM10 pollution event of 13 days. Free public transportation was implemented all-over the event but it was not effective. After 12 days, alternative traffic was applied and seemingly produced an improvement; however, the driving force is most likely the wind gained speed and dispersed the pollutants.

In Bay Area, California, the measure against ozone was to offer Free Transportation Days (FTD). In 5 out of 6 cases, after the measure took place, ozone level was reduced - but often with temperature reduction and increase in wind speed. Similar to Brussels case, main contributor to ozone level change was the weather condition and not the measure implemented. Though effectiveness of FTD was inconclusive, generally two days of consecutive FTDs were more effective than single-day FTD.

2. CONTEXT, POSITION AND OBJECTIVES OF THE PROJECT

2.1. CONTEXT, SCIENTIFIC, SOCIAL AND ECONOMIC ISSUES

Air pollution is one of the major problems plaguing many countries globally. It is particularly severe in urban areas, where most of the world's population resides. According to a recent report by WHO (2016), air pollution leads to 3 million premature deaths - making it the world's single largest environmental risk – and a number of admissions in hospitals, especially of vulnerable groups in the populations: children and older people.

Generally, pollutants disperse with wind. However, under certain climatic conditions they tend to accumulate and persist in high concentrations in the atmosphere. These conditions can last a few days to up to a week, and are referred to as Peak Pollution Episodes. These conditions are predicted by dispersion and meteorological models. Responsible local governments take emergency measures when warned of peak pollution by pollutant dispersion models.

The cities choose from a wide array of emergency measures, such as:

- Setting a lower speed limit for nearby highways,
- Offering free or reduced-fare public transportation to encourage passengers to leave their car,
- Banning trucks and other heavy vehicles from city centres,
- Banning wood burning,
- Imposing alternating circulation, based on number plates (odd-even),
- or banning some industrial activities outright.

The aim of this project is to evaluate the efficiencies of such emergency measures. As different cities around the world adopt different measures, it provides a good opportunity to learn from each other's approaches. How well these measures are communicated will also certainly play a role in their effectiveness.

2.2. POSITION OF THE PROJECT

Each country has limits on concentrations on various pollutants. WHO (2016) also has recommendations and guidelines, which are generally considerably stringent than those adopted by countries. The main air pollutants that are taken into account for outdoor air quality are presented in Table 1, alongside their limit values set by EU and WHO. Only most pollutants most dangerous for human health and that are more likely to be found in urban areas are listed. The exhaustive list is too large for the scope of the project.

These limits on pollutant concentrations are monitored at national level and reported to the European Environmental Agency (EEA) which validates them. The EU sets Air Quality (AQ) directives, and independent nations can set more stringent limits if they want.

In Europe, associated to 24-hour mean (or lesser) limit values there is a number of permitted exceedances each year. Air pollution dispersion models can predict pollution peak due to change in weather patterns. Some cities do not respond to these alerts - i.e., they take no emergency measures. Some other cities concentrate on long term strategies and do away with any emergency measures.

Table 1 Pollutants and concentration limits (Air Quality in Europe – 2015 report)

Pollutant	Concentration	EU limit	WHO Guideline
PM 2.5	µg/m³	25 - annual mean	10 - annual mean 25 - 24-hour mean
PM 10	µg/m³	40 - annual mean 50 - 24-hour mean	20 - annual mean 50 - 24-hour mean
Ozone (O_3)	µg/m³	120 - 8-hour mean	100 - 8-hour mean
Nitrogen dioxide (NO_2)	µg/m³	40 - annual mean 200 - 24-hour mean	40 - annual mean 200 - 24-hour mean
Sulphur dioxide (SO_2)	µg/m³	125 - 24 hour mean 350 - 1-hour mean	20 - 24 hour mean 500 - 10-minute mean

Alternative circulation based on odd-even number plates is a permanent (i.e., 365 days a year) measure in cities such as Mexico City and Sao Paulo. As it is a long-term measure, it is not relevant for this project.

2.3. STATE OF THE ART

The project aims to investigate a relatively new phenomenon, and there has been little to no research on this subject. According to Ben Barratt from King's College London, the effect of short-term actions is difficult to assess. "The weather changes all the time, the emissions change all the time and trying to pin down whether a particular emergency scheme works or not is hard." (Mathiesen, 2014).

2.4. OBJECTIVES, ORIGINALITY AND INNOVATIVE NATURE OF THE PROJECT

Emergency measures are implemented, ideally instantly on the next day, after predictions of air pollution peaks or actual incidents of pollution peaks, aiming to reduce pollution level measured in the next days to less than the predictions assuming business-as-usual. The urgent demand of emergency measure implementation makes knowledge of emergency measures, including their efficiency, a key component of rapid decision-making regarding corrective actions.

The objective of the project is to evaluate efficiency of emergency measures for air pollution episodes on pollution prevention and reduction. The main focus of the project is on short-term measures that are taken to reduce or prevent air pollution, making health-related warnings (e.g. warning for residents to stay indoors and avoid going outside) and long-term measures (e.g. de-promoting diesel-engine vehicles) outside the scope of the project.

With increasing numbers of air pollution episodes occurring in Europe and around the world over the years, the study aims to investigate if locally applied emergency measures are effective, and if they are effective as "global measures" so that different cities and countries, each with its own local contexts, can benefit from applying the measures. Additionally, if plausible, additional objectives include a study in quantifying the impact of emergency measures, e.g. percentage of air pollution prevented; comparison of effectiveness of measures across different cities and contexts; and suggestions of effective emergency measure combinations. The approach to evaluate both the efficiency of emergency measures - not only to come up with emergency measures - and the global applicability of the measures - recognizing the cultural, social, and economic contexts surrounding the success and failure of emergency measures - marks the innovative nature of the project.

With global awareness in consideration, the geographical scope of the study thus includes countries in Europe, North America, and Asia - including in France, Spain, Italy, India, and USA - the latter with particular focus on the state of California. The incidents to be studied are framed within 2011-2017, as recent data is valued but environmental agencies often published analysis regarding pollution episodes some months or years after the incidents occurred.

3. METHODOLOGY

This section of the report describes in detail the proposed scientific methodology envisioned to carry out this project. It is followed by management plan, where various deadlines and scheduled meetings are presented.

3.1. SCIENTIFIC METHODOLOGY

The project has been divided into six sequential tasks, as follows:

Task 1: Data collection

Firstly, news websites and environmental agencies will be scanned to find out where and when peak pollutions episodes have plagued city dwellers around the world. To be relevant to this project, only cases where cities have taken some emergency measures in countries where measured pollutant concentrations are freely available will be considered. All relevant information such as the pollutant concerned, the timeline of the decisions and alerts issued, and the meteorological conditions will be collected.

Task 2: Linking pollutants with local emissions information

Different pollutants have different sources, and the predicted peak pollution may concern only one of the many pollutants. To understand if the measures are appropriate, it is important to know the source of the pollutant that is forecasted to exceed the safety limit, which can vary from one region to another. This information is important to assess the appropriateness.

Task 3: Comparing the forecasted and measured concentrations

For each peak pollution episode, a timeline of pollutant concentrations will be built. The predicted concentrations will be plotted on the measured concentrations, allowing an easy visualisation of the difference. The alerts issued shall also be marked on the timeline. Assuming the forecasted concentrations would have been the measured concentrations in the absence of emergency measures, a quantitative analysis can be performed.

Task 4: Evaluating the appropriateness of these measures

For each smog episode, knowing the information on the source(s) of pollutant(s), and the timeline of concentrations (forecasted and measured) and alerts issued, a critical analysis can be carried out. The efficiency of each adopted emergency measure can be evaluated based on how effectively it reduced the pollutant concentrations. The response time, the link between source targeted and the pollutant in question will also be evaluated.

Task 5: Comparing the episodes and their responses.

Until now, each pollution episode has been studied independently. These can now be compared and contrasted on the basis of their effectiveness, whether they are appropriate or not, and if the authorities have been reactive in implementing the measures.

Task 6: Alternative measures.

In this concluding stage of the project, alternative emergency measures will be proposed. With better understanding of the links between the pollutants, measures taken, and alerts issued across many smog episodes, the most promising episode could be chosen and improved upon to use in the future.

3.2. PROJECT MANAGEMENT

The project is supervised under Mr Adrien Bouzonville, an independent environmental consultant specialising in air quality assessments based in Nantes, France.

Meetings are mostly scheduled according to the completion of each task, with occasional e-mail communication regarding progresses and obstacles. Methods of meeting are mainly video-conference, with occasional face-to-face meeting. Minute of the meeting is summarized by a team member after a meeting and sent to the supervisor and all team members to ensure similar understanding of the past meeting among all members.

The project also aims to be carbon-neutral in its creation. Team members are to maintain an activity log of project-related tasks, tracking number of internet search using search engines, web page accessed, hours of video-conference taken place, etc. At the end of the project, the carbon-emission equivalent of the activities will be evaluated, and carbon credits will be purchased in order to neutralize the carbon footprint of project-related activities. The proposed project plan is presented in Figure 1.

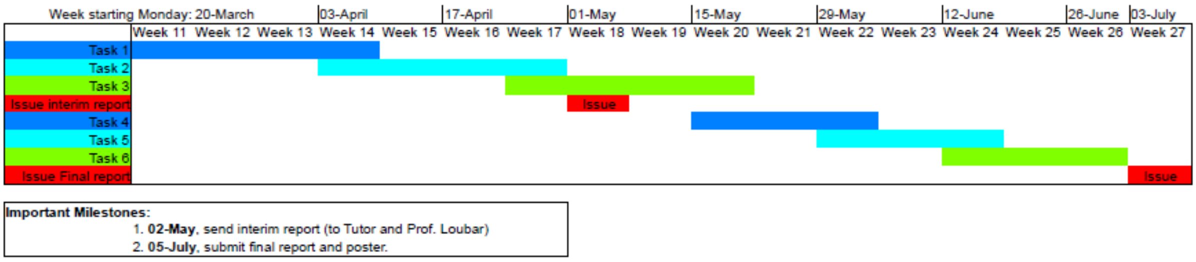

Figure 1 Project Gantt Chart

4. EXPLOITATION OF RESULTS

From a media review of past peak pollution episodes, the following episodes were found where the city authorities took some emergency measures up on receiving an alert.

Table 2 Peak pollution episodes within targeted geographical location and timeframe

No.	Country	City	Year	Pollutant concerned and Measures taken
1	Belgium	Brussels	2014-March	Speed limited to 50km/hr to limit PM10 concentrations.
2	France	Paris	2014-March	Free public transport; alternative circulation (odd-even) to limit PM10
3	USA	Bay Area, CA	2006-June and July	6 Free Transportation Days (4 events) to limit Ozone concentration.
4	USA	Bay Area, CA	2007-August	2 Free Transportation Days (1 event) to limit Ozone concentration.
5	USA	Bay Area, CA	2008-June	1 Free Transportation Day (1 event) to limit Ozone concentration.

By no means this is an exhaustive list, the following criterion had to be met for selection:

- Urban areas had to enact an emergency measure to try to tackle the pollutant;
- There should be a reliable weather and pollutant concentration monitoring in-place;
- These data should be validated and accessible to public.

4.1. EPISODE 1: BRUSSELS, BELGIUM

In response to the elevated concentrations of PM10 on Wednesday 12th March 2014, the city of Brussels imposed a speed limit of 50 km/hr in the city for the two following days. (SudInfo, 2014). This measure was announced on the 12th March 2014. It is the Brussels city policy to act should the PM10 concentrations exceed 70 μg/m^3.

Figure 2 shows the Temperature and Wind Speed in Brussels in the month of March of 2014. This data has been retrieved from Weather Underground (2014a).

Figure 3 presents the PM10 concentrations in Brussels, from two monitoring stations – on termed Traffic, and another Background (suburban). The presented concentrations are daily averages i.e., 24-hour averages. It is recalled that the limit concentration is 50 μg/m^3.

The city of Brussels has 5 air quality monitoring stations measuring PM10, three of them assigned 'Background' and the remaining two termed 'Traffic'. In Figure 3 only one of each kind has been presented for clarity. The complete list of monitoring stations and their measured concentrations has been presented in section Appendix 8.1. This data has been downloaded from EEA's open access database.

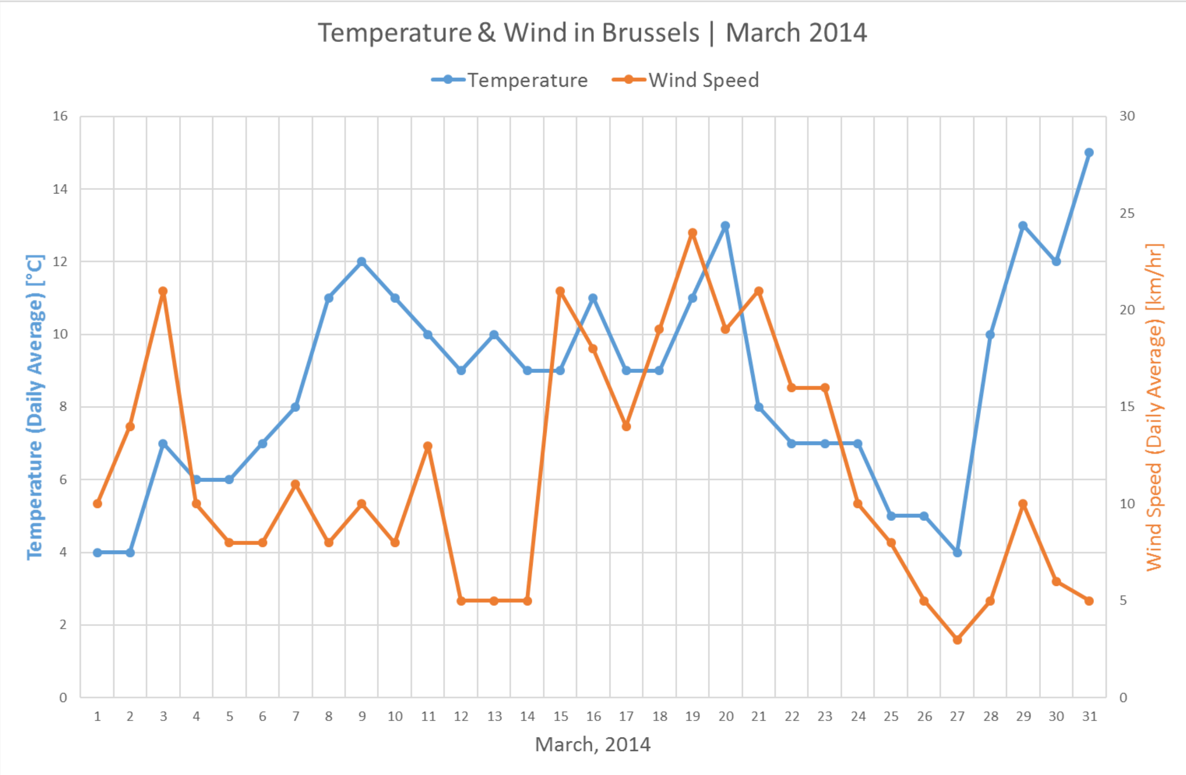

Figure 2 Temperature and Wind Speed (daily averages) | Brussels March 2014

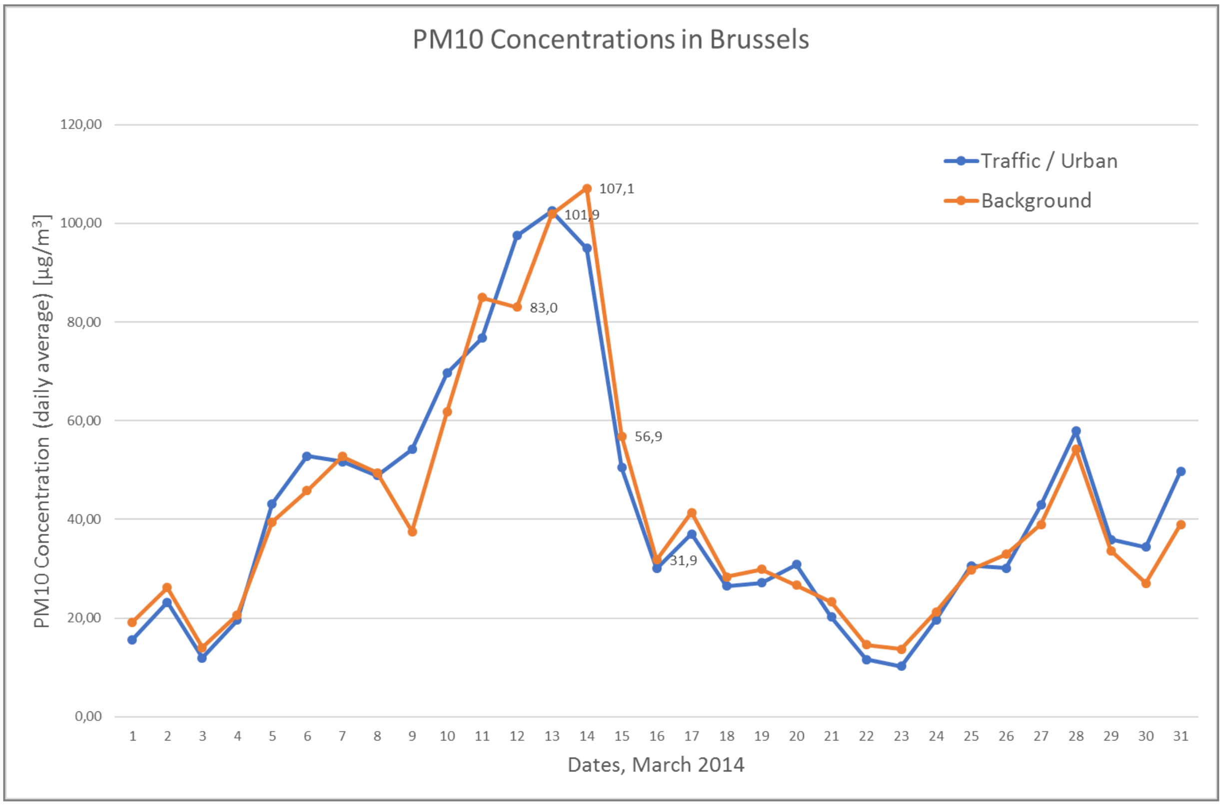

Figure 3 PM10 Concentration (daily averages) | Brussels March 2014

The emergency measure was announced on the 12th and came into effect the next day on the 13th. The measure targeted the speed limit of 50 km/hr was imposed on all vehicles in the city and its suburbs. One of the main sources of PM10 is traffic, and it is a source most often targeted in emergency measures. Table 3 presents the urban PM10 concentrations 4 days before and after the emergency measure was announced.

Table 3 Evolution of the Peak Pollution Episode days around the Emergency Measure

Date	Wind Speed [km/hr] Daily average	Urban PM10 concentration [μg/m³] Daily average	% change in Urban PM10 concentration
9th March 2014	10	54.2	-
10th March 2014	8	69.7	+28.5%
11th March 2014	13	76.8	+10.2%
12th March 2014	5	97.5	+27.1%
Emergency Measure: Speed limit comes into force the 13th March.			
13th March 2014	5	102.5	+ 5.2%
14th March 2014	5	95.0	- 7.4%
15th March 2014	21	50.5	- 46.9%
16th March 2014	18	30.0	-40.5%

A detailed discussion of these results is presented in Section 5.1.

4.3 EPISODE 2: PARIS, FRANCE

In 2011, the European policy has strengthened the regulation regarding outdoor air quality. Currently, the regulation on PM10 concentration advises cities to have fewer than 35 days per years in a city with more than 50 μg/m³ (1999/30/EC - French decree 2002). But pollution episodes are very challenging to predict and it is even more difficult to act on them. In this study, the PM10 pollution event that took place in Paris for 14 days in March 2014 will be analysed (AIRPARIF, 2017a; INERIS, 2017). And the effect of the measures taken by the city during this time will be discussed.

The first days of the event i.e. 5th - 8th March were due to anticyclonic conditions characteristic of winter, high temperature inversion and a very low wind speed (AIRPARIF, 2017a; Weather Underground, 2014b). Consequently, the PM10 produced in the local area were caught above Paris and lead to an overshoot of the standard 50 μg/m³ of PM10 concentration. This information level is the first indicator of PM10 pollution, residents should avoid breathing in an outdoor air above this level more than 35 days per year (1999/30/EC - French decree 2002).

As shown in Figure 4, the wind blew from North-East during 11th-12th (Weather Underground, 2014b). Unfortunately, the wind was filled with pollutants which added to the pollutants already generated and locked above the city since the 5th (AIRPARIF, 2017). This phenomenon lead to an overshoot of the warning level (80 μg/m³). As the second indicator of PM10 pollution, the warning level overshoot implies a very polluted air.

On the 13th and after, as shown in Figure 4, the anticyclonic conditions blocked the pollutants around and the temperature inversion even added the local PM10 production to the already highly polluted atmosphere.

From the 15th, a wind blowing from west allowed a dispersion of the particles and the end of the temperature inversion allowed the end of the event.

To summarise, the overshoot of the information level began with a local pollution, enhanced by an import from north-east in the middle of the event and then an addition of local pollution again.

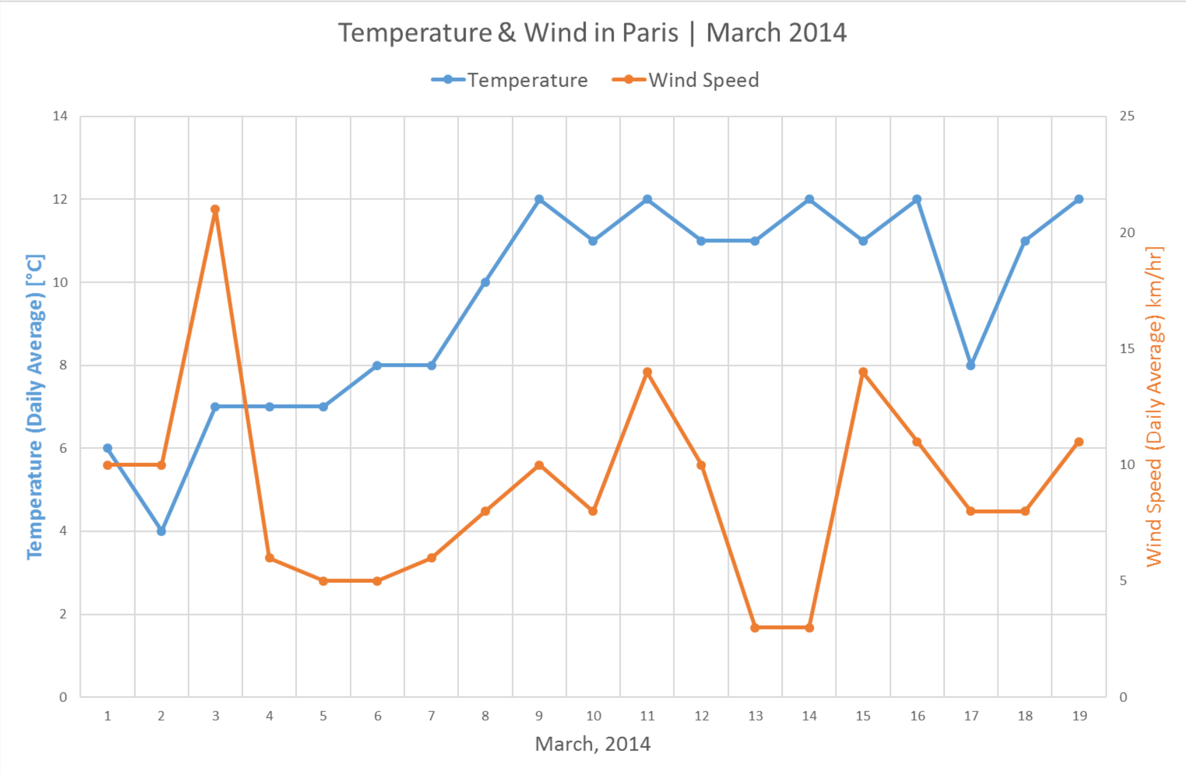

Figure 4 Temperature and Wind Speed (daily averages) | Paris 1st – 19th March 2014

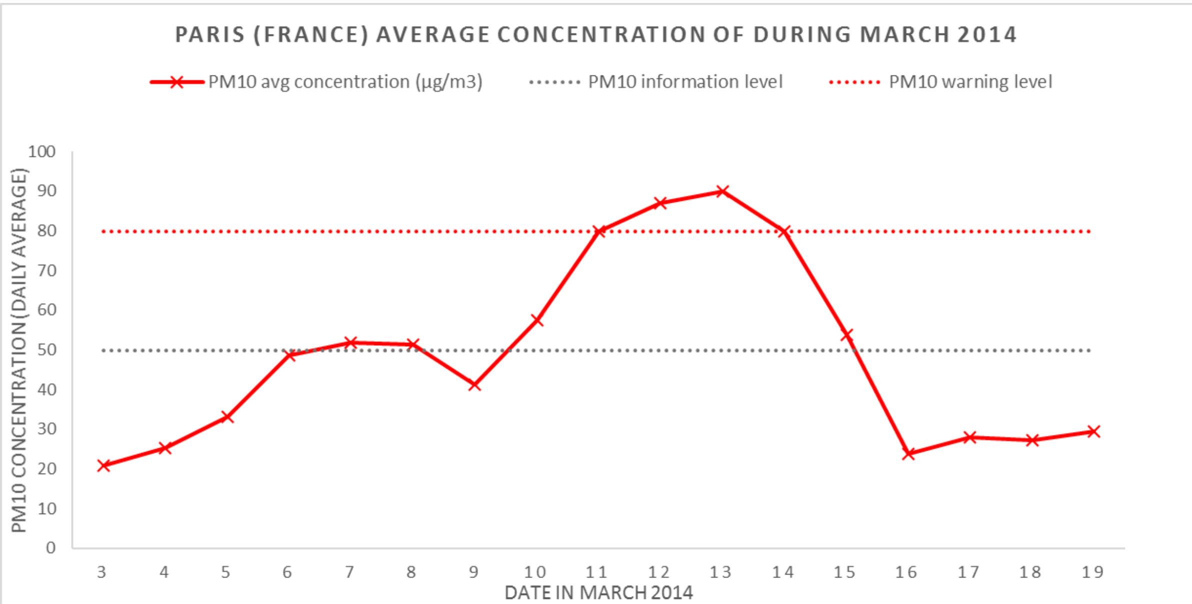

Figure 5 PM10 Concentrations (daily averages) | Paris 3rd – 19th March 2014

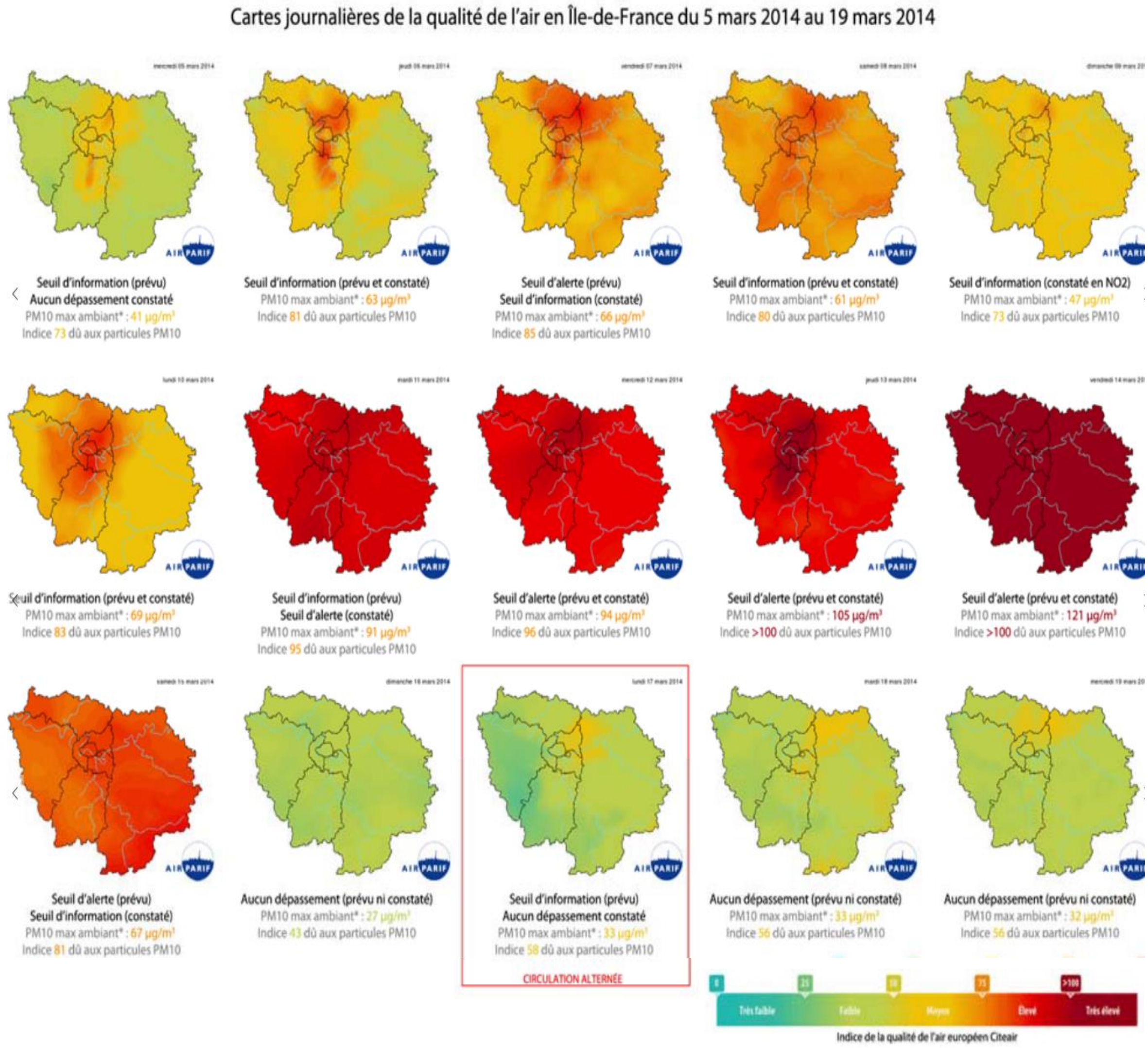

Figure 6 Daily map of air quality in the area of Paris from the 5th – 19th March 2014

4.4 EPISODE 3: 2008 BAY AREA, CALIFORNIA, USA

Although mobile polluters including cars, trains, and airplanes causes 75% of air pollution in South Coast and the rest of the air pollution is caused by households (The Guardian, 2015), California has been inactive in terms of emergency measures against smog episodes due to vehicle exhausts and ozone formation during 2011-2017, relying more on voluntary measures and long-term policy approaches (Barboza, 2015; Cabanatuan, 2008; Gardner, 2014; Spare the Air, 2017). By expanding the years of interest to 2006-2017, Free Transportation Days (FTDs), organized by Bay Area local government, were identified:

> "Each year for a certain number of Spare the Air days that occur on **non-holiday weekdays,** many Bay Area transit agencies offer free rides to encourage

public transportation use over cars. The number of allocated fare-free days varies from year to year, depending on available funding.” (Spare the Air, 2017)

In contrast to other case studies, in California duration of pollution episode was not define, instead FTDs were designated, usually three days per year, depending on the budget. It was phased out in 2008 with only one FTD, before being terminated in 2008. (Cabanatuan, 2008; Sebastian, 2006).

Historical data available was on ozone AQI value. An AQI-ozone concentration conversion table was made using tools provided by AirNow (2017a, b).

Table 4 AQI-Concentration Conversion Table for Ozone, focusing on AQI 0-200 out of the full range of AQI 0-500 (adapted from AirNow 2017b)

Level of Health Concerns					
Good (AQI 0-50)		Moderate (AQI 51-100)		Unhealthy for Sensitive Groups (AQI 101-150)	
AQI	**Ozone concentration (8-hour average)**	**AQI**	**Ozone concentration (8-hour average)**	**AQI**	**Ozone concentration (8-hour average)**
10	11 ppb	60	58 ppb	110	74 ppb
20	22 ppb	70	61 ppb	120	76 ppb
30	32 ppb	80	64 ppb	130	79 ppb
40	43 ppb	90	67 ppb	140	82 ppb
50	54 ppb	100	70 ppb	150	85 ppb

As ozone pollution is linked with UV radiation and hence temperature, temperature plots are also included in the forecasted-measured pollution level comparison graph. Data was obtained from weather station in Concord Buchanan Field, CA, US (NOAA, 2008).

Two types of forecasted pollution level were used: Next-Day (pollution level of an upcoming day is predicted on the day before, allowing some time for emergency measures to be planned), and Same-Day Forecasts (pollution level of a day is forecasted on the same day, aiming to give higher accuracy but provide less time to prepare any action).

Information of Concord city (Contra Costa county, San Francisco Bay Area air basin) was used as a representative as it was one of the cities with high level of ozone near and during the pollution episode (Air Quality Index (AQI) value higher than 100) which also had a complete data of ozone level measured (AirNow, 2008a; 2008b).

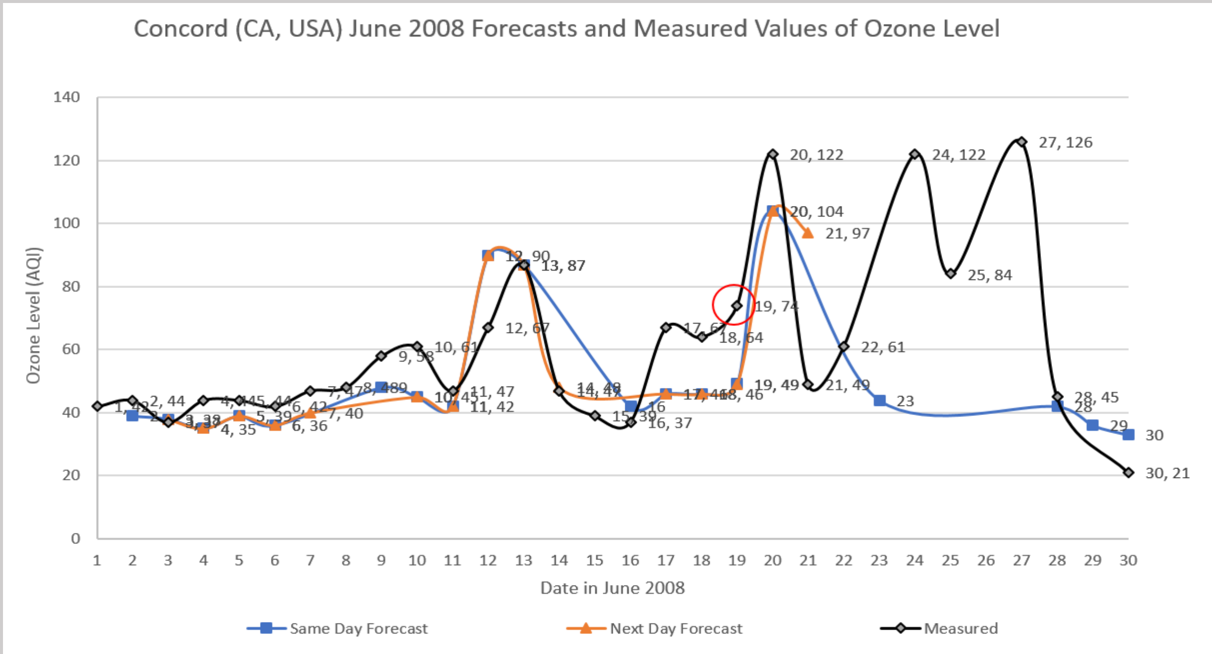

Figure 7 Ozone level as forecasted and measured at Concord, CA, between 1-30 June 2008 (AirNow 2008a, 2008b; NOAA 2008)

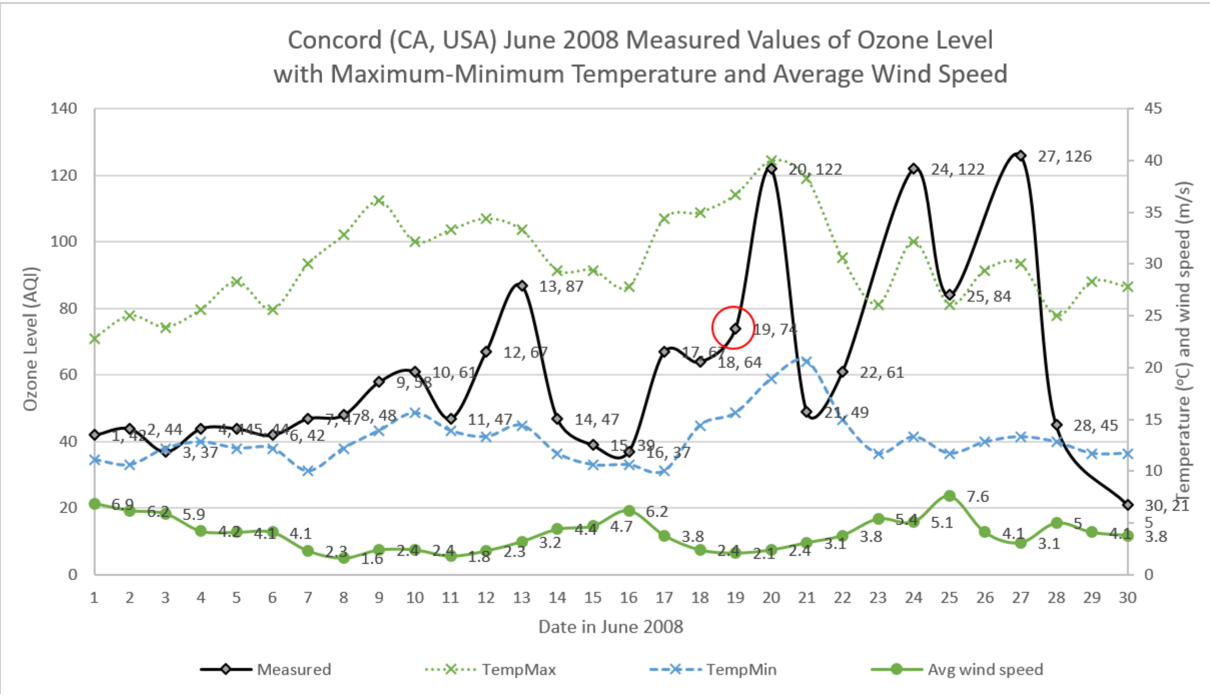

Figure 8 Ozone level as measured and temperature-average wind speed at Concord, CA, June 2008 (AirNow 2008a, 2008b; NOAA 2008)

In 2008, the FTD was on 19th June 2008 (circled in red in

Figure 7 Ozone level as forecasted and measured at Concord, CA, between 1-30 June 2008 (AirNow 2008a, 2008b; NOAA 2008)7 and 8); itself not a pollution peak predicted, but may be meant to help reduce pollution level of 20th June as maximum temperature peaked and wind speed remained low (below 3 m/s during 19th-21st June). Combined with California's basin-like geography that confines pollution among three mountains surrounding it (Littman & Magill, 1953), the shortage of pollution dispersion by wind and the likely increase in UV contributed to the ozone peak.

After FTD, the ozone peak measured remained high and also higher than the predicted level as seen in Table 5. However, on 21st June the ozone level reduced significantly although temperature remained high and wind speed remained below 3 m/s. It be that FTD on 19th June had slower impacts than anticipated, making the reduction in pollution peaks apparent on 21st June instead of the intended 20th June; that increasing wind speed from 21st - 23rd June contributed significantly to ozone dilution. The possible cause of less transportation on weekends were considered but later marked as insignificant as there was little evidence of weekday-weekend transportation-pollution fluctuation.

Table 5 Change in Ozone levels before and after FTD on 19th June

Date	Wind Speed [m/s]	Maximum Temperature [°C]	Ozone AQI Level	Ozone 8-hour Concentration [ppb]	% Change in Ozone AQI Level	% Change in Ozone Concentration
15th June	4.7	29.4	39	42	-	-
16th June	6.2	27.8	37	40	-5.13	-4.76
17th June	3.8	34.4	67	60	+81.08	+50.00
18th June	2.4	35	64	59	-4.48	-1.67
Emergency Measure: Free Transportation Day on 19th June						
19th June	2.1	36.7	74	62	+15.63	+5.08
20th June	2.4	40	122	77	+64.86	+24.19
21st June	3.1	38.3	49	53	-59.84	-31.17
22nd June	3.8	30.6	61	58	+24.49	+9.43

With only one FTD in 2008, it can be challenging to draw conclusions about impacts of the emergency measures taken. It may be that the reduction in emission was delayed, giving results at least two days after (22nd June) instead of on the next day (21st June) after the emergency measures were taken (19th June); or it may be that the increase in wind speed and the decrease in temperature induced more significant reduction in ozone level than the implemented emergency measures. To identify pollution fluctuation pattern, historical data of 2006-2007 FTDs were studied.

4.2. EPISODE 4: 2007 BAY AREA, CALIFORNIA, USA

In 2007 there were two consecutive FTDs which is considered as one emergency measure event: 29th-30th August (Wednesday and Thursday, circled in red in Figure 9 and Figure 10) (BART, 2007). One day after implementation, 50% of ozone concentration was observed; however, it should be noted that the reduction was also linked to slight reduction in temperature while wind speed remained relatively stable (Figure 10), while it correlated little with the weekend-weekday cycle.

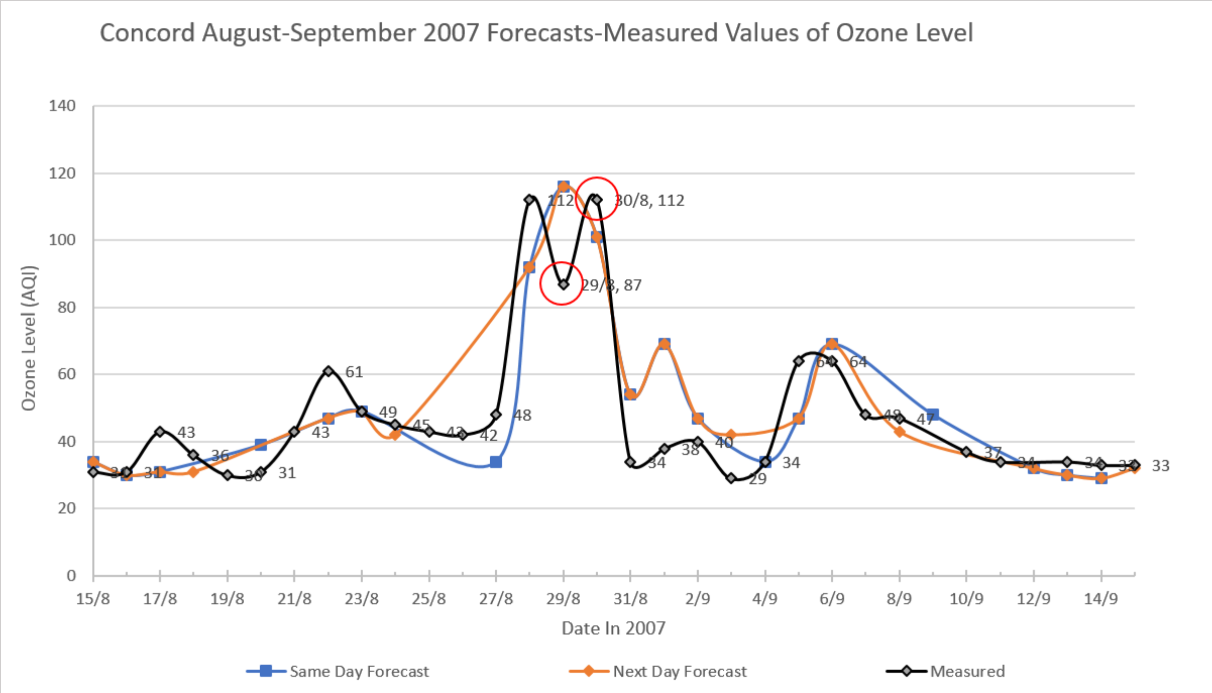

Figure 9 Ozone level as forecasted and measured at Concord between 15 August - 15 September 2007 (AirNow 2008a, 2008b; NOAA 2008)

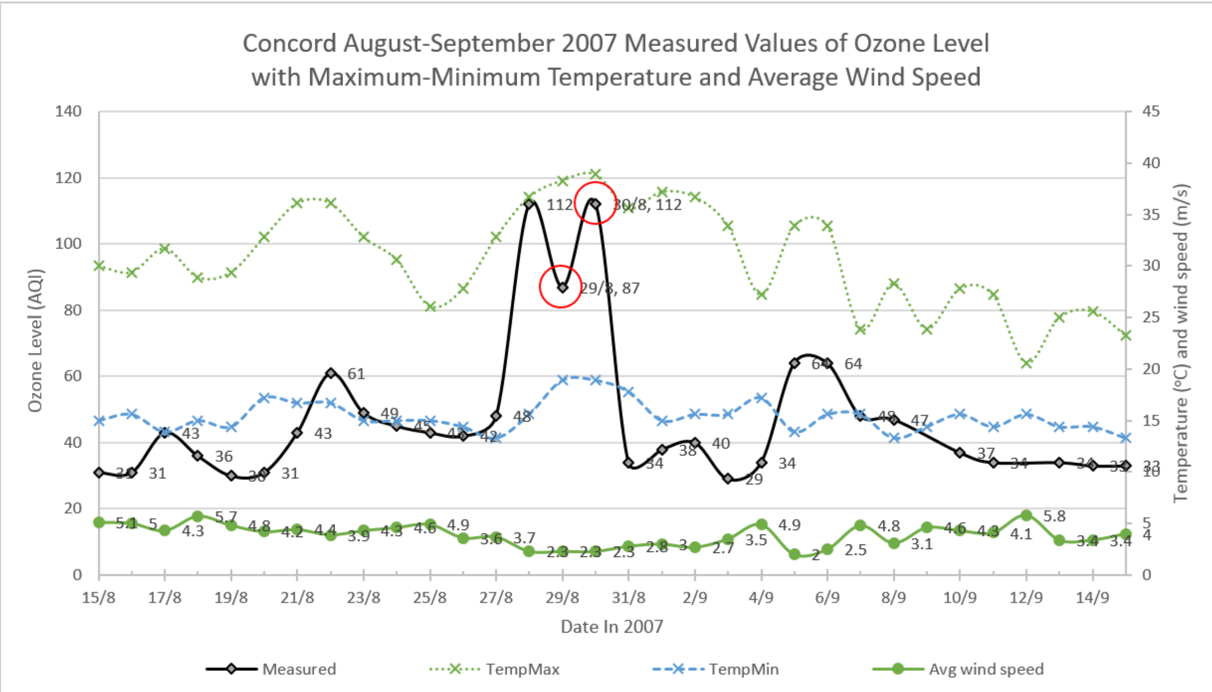

Figure 10 Ozone level as measured at Concord with temperature range and wind speed between 15 August – 15 September 2007 (AirNow 2008a, 2008b; NOAA 2008)

Table 6 Change in Ozone levels before and after FTDs on 29th and 30th August

Date	Wind Speed [m/s]	Maximum Temperature [°C]	Ozone AQI Level	Ozone 8-hour Concentration [ppb]	% Change in Ozone AQI Level	% Change in Ozone Concentration
25th August	4.9	26.1	43	43	-	-
26th August	3.6	27.8	42	45	-2.33	+4.65
27th August	3.7	32.8	48	52	+14.29	+15.56
28th August	2.3	36.7	112	74	+133.33	+42.31
Emergency Measure: Free Transportation Day on 29th and 30th August						
29th August	2.3	38.3	87	66	-22.32	-10.81
30th August	2.3	38.9	112	74	+28.74	+12.12
31st August	2.8	35.6	34	37	-69.64	-50.00
1st Sept.	3	37.2	38	41	+11.76	+10.81
2nd Sept.	2.7	36.7	40	43	+5.26	+4.88
3rd Sept.	3.5	33.9	29	31	-27.50	-27.91

4.3. EPISODE 5: 2006 BAY AREA, CALIFORNIA, USA

In 2006, six FTDs were announced, allocated into 4 events of emergency measures: 22nd-23rd June; 26th June; 17th June; and 20th-21st July (Thursday, Friday, Monday, Monday, Thursday and Friday respectively; marked in red circles in and) (Golden Gate Transportation Committee, 2006). For all 4 events, reductions in ozone concentrations (14.8%, 21.4%, 17.6% and 15.0% respectively) can be observed as soon as one day an FTD event. The ozone reductions were also linked with reduced temperature and increased wind speed, while coincided less with weekday-weekend cycle than the 2008 case.

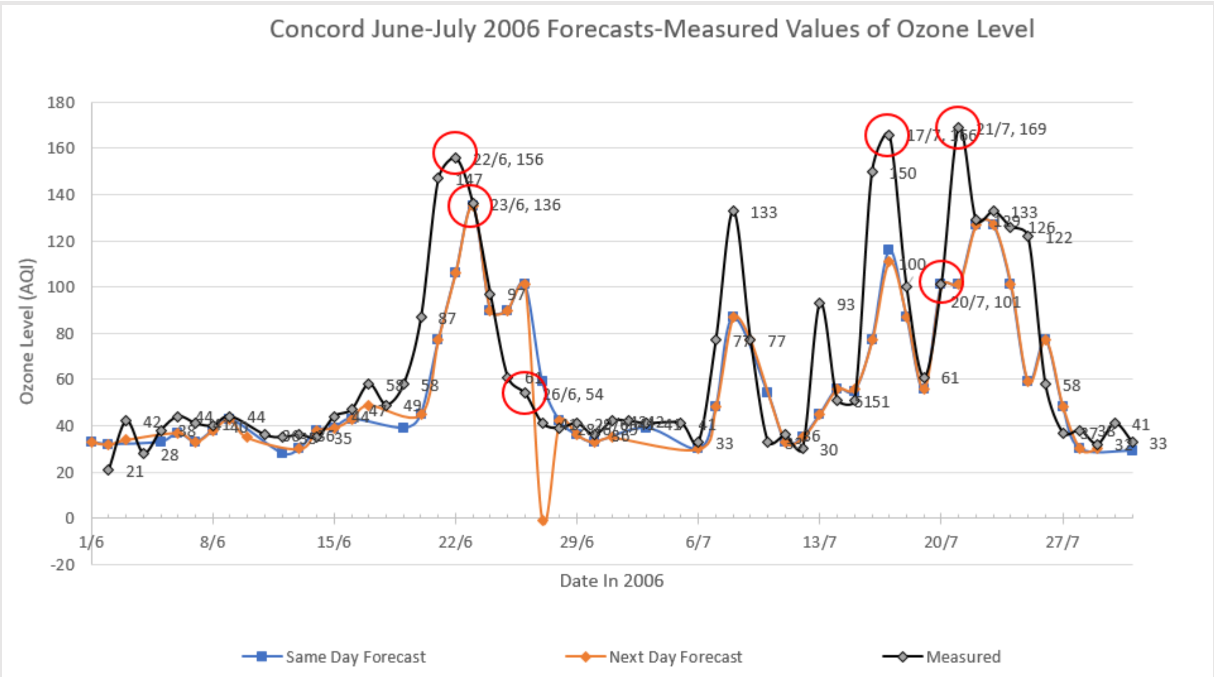

Figure 11 Ozone level as forecasted and measured at Concord between 1 June – 31 July 2006 (AirNow 2008a, 2008b; NOAA 2008)

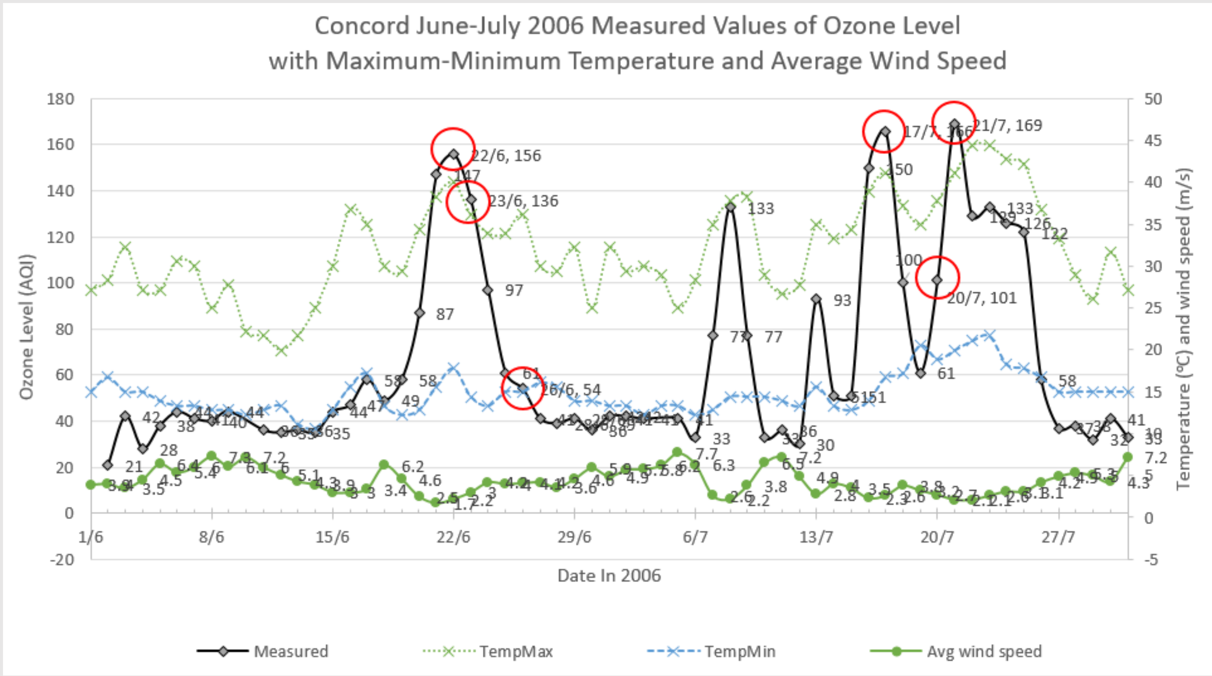

Figure 12 Ozone level as measured at Concord with measured temperature range and wind speed between 1 June – 31 July 2006 (AirNow 2008a, 2008b; NOAA 2008)

Table 7 Change in Ozone levels before and after FTDs on the six FTDs of 2006

Date	Wind Speed [m/s]	Maximum Temperature [°C]	Ozone AQI Level	Ozone 8-hour Concentration [ppb]	% Change in Ozone AQI Level	% Change in Ozone Concentration
18th June	6.2	30	49	53	-	-
19th June	4.6	29.4	58	57	+18.37	+7.55
20th June	2.5	34.4	87	66	+50.00	+15.79
21st June	1.7	38.3	147	84	+68.97	+27.27
Emergency Measure: Free Transportation Day on 22nd and 23rd June						
22nd June	2.2	40	156	88	+6.12	+4.76
23rd June	3	36.1	136	81	-12.82	-7.95
24th June	4.2	33.9	97	69	-28.68	-14.81
25th June	4	33.9	61	58	-37.11	-15.94
Emergency Measure: Free Transportation Day on 26th June						
26th June	4.1	36.1	54	56	-11.48	-3.45
27th June	4.2	30	41	44	-24.07	-21.43
28th June	3.6	29.4	39	42	-4.88	-4.55
29th June	4.6	32.2	41	44	+5.13	+4.76
13th July	2.8	35	93	68	+126.83	+54.55
14th July	4	33.3	51	55	-45.16	-19.12
15th July	3.5	34.4	51	55	0.00	0.00
16th July	2.3	38.9	150	85	+194.12	+54.55
Emergency Measure: Free Transportation Day on 17th July						
17th July	2.6	41.1	166	92	+10.67	+8.24
18th July	3.8	37.2	100	70	-39.76	-17.65
19th July	3.2	35	61	58	-39.00	-17.14
Emergency Measure: Free Transportation Day on 21st and 22nd July						
20th July	2.7	37.8	101	71	+65.57	+22.41
21st July	2.1	41.1	169	93	+67.33	+30.99
22nd July	2.1	44.4	129	79	-23.67	-15.05
23rd July	2.6	44.4	133	80	+3.10	+1.27
24th July	3.1	42.8	126	78	-5.26	-2.50
25th July	3.1	42.2	122	77	-3.17	-1.28

5. DISCUSSION

5.1. EPISODE 1: BRUSSELS, BELGIUM

The pollutant concerned by the peak pollution episode in March 2014 in Brussels is PM10. The measured concentrations from EEA database has been analysed. Ideally the comparison is to be done with historical prediction data. However, this data is hard to find. Hence only the weather data and the pollutant concentration data was compared. The following observations can be made:

- There is difference between the concentrations measured in stations Traffic and Background is minor, and in some cases the Background concentrations are greater. This could be because of improper placement of monitoring stations.
- High concentrations were observed up to 4 days before any emergency measure was announced. The PM10 concentration was 69.7 on the 9th of March, and it continued to increase while the response was taken only 3 days later, on the evening of the 12th, to come into effect the next morning. This points to improper timing of the measure, and failure to predict the lack of wind.

The following remarks can be made from studying the evolution of PM10 concentrations.

- The wind-speed was low and constant the first two days of emergency measure (13-14 March, at 5 km/hr), during which PM10 concentrations actually increased by 5.2% the first day, and dropped by 7.4% the second day.
- The weather changed the third day, wind-speed daily average jumping to 21 km/hr from 5 km/hr. The PM10 concentrations on the day dropped by 47%, getting very close to pre-alert levels.

5.2. EPISODE 2: PARIS, FRANCE

The pollutant concerned by the peak pollution episode in March 2014 in Brussels is PM10. This episode occurred under the same climatic conditions as the episode in Brussels discussed in Section 5.1. The emergency measures employed were:

- Free public transportation to encourage commuters to leave their personal vehicle at home and utilize the public transport from the 5th of March to the end of the event;
- On the 17th of March, Alternative circulation was introduced to cut down the number of vehicles contributing to the pollution.

The following remarks can be made from studying the daily PM10 concentrations

- The wind speed remained constant at 5km/hr on the 13th and 14th, leading to the buildup PM10 concentrations, during which the city announced free public transport for commuters
- The alternative circulation was announced This implementation took place only during the 17th of March, the last day of the pollution event.

- This measure contributed to reduce the PM10 pollution production related to traffic by 15% and of 20% concerning NO_x. These number were deduced by AIRPARIF by comparing the forecast of ESMERALDA and their actual measures combined with an analysis of the traffic by comparing the situation in the 10th and 17th of March according to the data of HEAVEN1.
- According to their study, the reduction of the pollution generation during the rush hour in the evening is 6 times more effective than in the morning. However, the agency does not explain this difference, maybe it was because of the referenced day (a special event occurs the 10th and not the 17th) or it could be due to the delay in the implementation.

Of course, the effects of the alternative traffic were much more effective close to big traffic area, and especially in the *petite couronne*.

- In the countryside, the total pollution generation decreased by 2%
- In the city, the generation curbed by more than 6%

Furthermore, the generation reduction reached 30% in some high traffic area during the evening rush hour. In addition, NO_x generation was curb by 10% in the area of Paris. N_{Ox} is not the pollutant we are concerned about in this event, however it is interesting to note the fact that alternative traffic is even better to reduce NO_X than PM10 generation.

5.3. EPISODE 3-5: BAY AREA, CALIFORNIA, USA

From the 3 episodes and the 6 FTD events, it can be observed that:

- The emergency measures targeted personal vehicle use, while other mobile polluters such as trucks, trains, and airplanes were not addressed.
- Out of the 6 events, 5 FTD events successfully correlated with a reduction in ozone level.
- Impacts of temperature and wind speed overrode any ozone reduction made by the FTD, such as one-day FTD in 2008 where the measured ozone level increased after the FTD, higher than that predicted value, which coincided with raising temperature and slight decrease in wind speed (2.4 to 2.1 m/s).
- Fluctuating temperature and wind speed had make it challenging to isolate the impact of FTDs on pollution reduction. The only FTD data with rather stable temperature and wind speed before and after FTDs was 29th-30th August 2007, where the two-day FTDs were followed by a significance reduction in measured ozone AQI level.
- It is likely that two or multiple consecutive FTDs were more effective in reducing ozone level than one-day FTDs, and may be able to reduce ozone level despite high temperature and low wind speed (20th and 21st July 2006).

Considering the data available, it can be noted that additional data can contribute greatly to the improved accuracy of the analysis of Free Transportation Days, including:

- **Isolation of background and traffic pollution levels:** FTD aimed to reduce traffic pollution, but it was challenging to verify without information on the background pollution level already present regardless of changes in the number of targeted pollution sources
- **Data on direct transport pollutants such as NO_x**: Ozone is a secondary pollutant formed by NO_x and VOCs reacting under UV irradiation. Using it as a marker for pollution level is susceptible to additional factors such as UV irradiation (linked with temperature), and it is possible that, for a given amount of NO_x present, the ozone concentrations measured will be different between days with different temperature. As NO_x is a target pollutant of FTD, analysis of its efficiency can be done more directly and with less uncertainty if data on predicted and measured NO_x is available.
- **Direct record of ozone concentration:** The dataset used is in AQI level, which while can be converted to 8-hour ozone concentration using AirNow tools, the relationship between the two parameters is not linear and it can be time-consuming to manually convert AQI into concentration. Record on ozone concentration or conversion codes can facilitate the analysis.
- **Number of (private) motorized vehicles:** As year passes, it is likely that the number of motorized vehicles increases, which should be noted and used in normalization while episodes on different years are studied together.
- **Number of participants in each day of FTD:** To estimate the numbers of private vehicles not in use on an FTD**.**

6. CONCLUSION

From the Brussels case study, it can be concluded that the emergency measure was decided upon quite late, and poorly predicted. And even when it was enacted, it did not target all the sources of the pollutant (PM10). The chosen emergency measure of limiting traffic speed to 50 km/hr was found to be not effective (increase of 5.2% the first day in PM10 concentration, and decrease of 7.4% the second day). It was the change in weather conditions (wind speed) that dispersed the pollutants and resulted in lower concentrations in Brussels.

The Paris peak pollution episode studied is from the same time period (March 2014) as the Brussels case. The emergency measured are both free public transportation and alternative circulation, hence different than those employed in Brussels. In the end, this exceptional measure resulted in a reduction of 4% and 8% from PM10 and NOX emissions, respectively. Like the former study, the conclusion is that the wind speed increase was the main cause of the PM10 concentrations dropping, and the emergency measures were ineffective in addressing the problem.

For the California cases, the Free Transport Days targeted only private vehicles and had no measure against other motorized vehicles or sources of air pollutants such as households. By analyzing the impact of FTDs on ozone level, it can be concluded that pollution level is highly related to the weather conditions than to an implemented FTD, and high temperature and low wind speed on a given day may suppress improvement in air pollution level by the emergency measures. However, implementing two or more consecutive days of Free Transportation may be able to reduce ozone level despite high temperature and low wind speed, nonetheless, its impact on reducing ozone level is likely to be less than a reduction in temperature and/or an increase in wind speed. But as the results of FTD on air quality improvement was not consistent, it is challenging to gauge whether they were implemented at the appropriate time, or decided upon too late. The inconclusiveness of the effectiveness evaluation of the emergency measures may be one of the causes for the termination of Free Transportation Day on Spare the Are Days in Bay Area, California.

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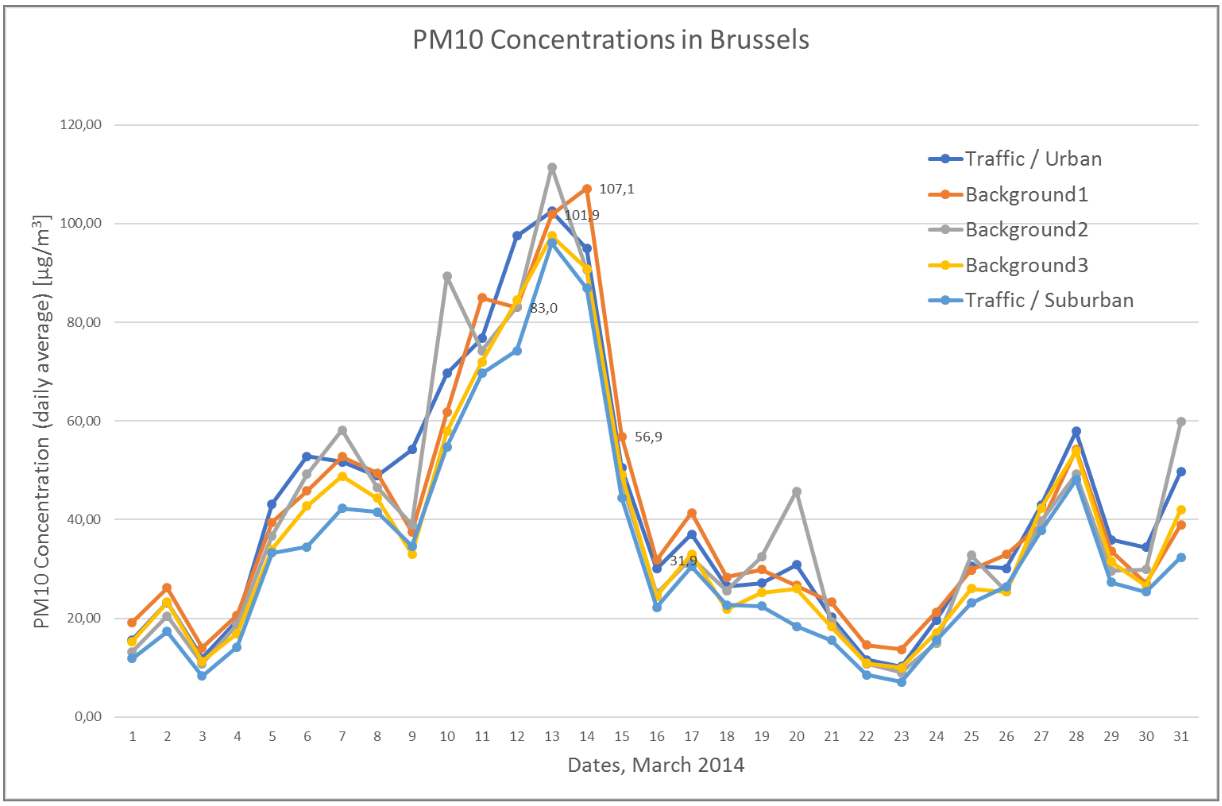
8. APPENDIXES

8.1. EPISODE 1 BRUSSELS MARCH 2014

The traffic stations in Brussels measuring PM10 and their designations are presented in the table below:

City_name	Station_EoI_ Code	Station_name	Type Of Measurement Station	Area Of Measurement Station
Bruxelles / Brussel	BETR001	41R001 - MOLENBEEK	Traffic	urban
Bruxelles / Brussel	BETR012	41R012 - UCCLE	Background1	suburban
Bruxelles / Brussel	BETMEU1	41MEU1 - MEUDON	Background2	suburban
Bruxelles / Brussel	BETB011	41B011 - BERCHEM S.A	Background3	suburban
Bruxelles / Brussel	BETWOL1	41WOL1 - WOL.ST.L.	Traffic	suburban

The PM10 concentrations in the month of March 2014 from all the above 5 stations are presented below.



PM10 Concentration from 5 stations | Brussels March 2014