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megaCITY - Zoom for the Environment

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Preface

For this deliverable it was originally envisaged to use the Orbiting Carbon Observatory (OCO), a NASA Earth System Science Pathfinder Project (ESSP) mission designed to make precise, time-dependent global measurements of atmospheric carbon dioxide from an Earth orbiting satellite. Unfortunately, on February 24, 2009, OCO failed to reach orbit. The study presented here thus relies on model results only. In particular, trajectory analysis have been made for different megacities and emission hot spots in Europe (and for Cairo). Satellite observations to monitor air pollution and outflow are dealt with in other CityZen deliverables (D1.1.4, D1.1.6 and D1.1.7).

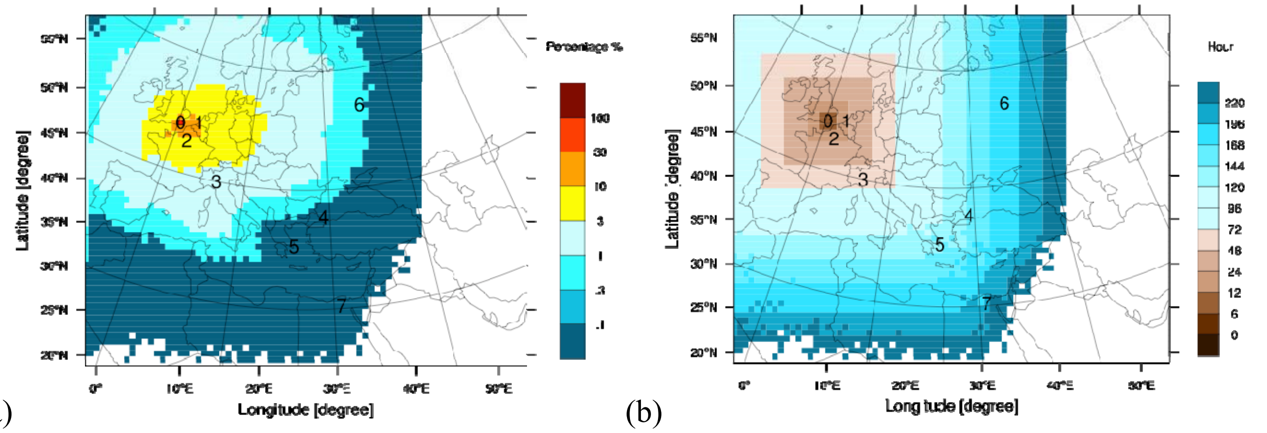
Evaluation of transport pathways based on model results

Modelling approach - The transport pathways that drive the impact of selected megacities and large urban agglomerations on air quality over Europe have been investigated using back trajectory analysis. Trajectories were computed according to the method described by Pettersen (1956) as a forward trajectory using an 81-km grid resolution (NCEP/NCAR data) meteorology data. Trajectories at approximately 700 m height have been used to define air pollution transport patterns from pollution sources, in a regional scale. They are based on 30-year (1961-1990) reanalysis data (NCEP/NCAR), available for every 6 h (Kindap et al., 2009). The computed probability depends on the grid size and increases with the trajectories length, with very small changes for trajectories longer than 8 days (Kindap et al., 2009). An air parcel is released once every 6h and a total of **42,368** air parcels (trajectories) have been released during the selected **30** years (between 1961–1990). The computed probability for any air parcel's arrival, is dependent on the size of the grid squares and the length of the trajectories. In general, the probability of the arrival increases with the length of the trajectories, but for trajectories longer than 8 days no significant probability change is computed (Saltbones et al., 2000; Kindap et al., 2008; Kanakidou et al., 2011). For the present study, 10-day forward air mass trajectories have been used.

Results –Transport pathways of air masses originating from selected anthropogenic emission hot spot areas to the surrounding locations.

The probability that an air mass originating from each one of the selected megacities or large urban agglomerations reaches another location over Europe within the next 10 days has been calculated and depicted in the 'probability' plots together with the corresponding travel time (that is always shorter or equal to 10 days) depicted in the associated 'travel time' plots. These values are averaged over the studied 30 years period and provide climatological information on the recent years outflow of short lived air pollutants (lifetime shorter than 10 days) from large agglomerations in Europe. The impact of a specific pollution hot spot to the other large agglomeration over Europe is provided more precisely in the Tables that summarize the statistics for the urban locations in focus. The results are shown below and discussed for each city that acts as source area, accounting all Europe and precisely the other selected cities as receptor points. Both the probability of arrival trajectories and the average travel time are provided. Each pair of figures depicts the extent of the pollution plume of each one of the studied sources. London, Benelux, Paris, Milan, Istanbul, Athens, Moscow and Cairo have been adopted as source locations for the present analysis. Note that during transport air masses are mixed with regional emissions and are physically and chemically aging. The evaluation of the overall impact of the pollution centres to the downwind locations has to account for both transport and transformation of air pollutants. The present analysis focuses on the transport patterns only.

1. *Outflow of London pollution*



(a) (b)

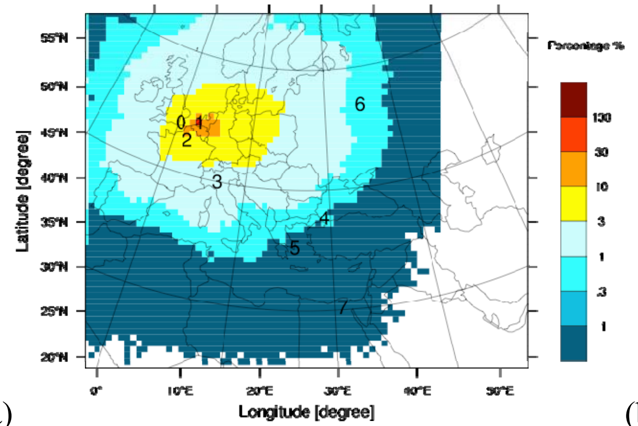
Figure 1. Climatological Outflow of air pollution from London: (a) probability of trajectories departing from London to reach other locations over Europe withing less than 10 days and (b) associated travel time; averaged over the 30-years period 1960-1990.

It can be seen that on 30 year average, London pollution plume extension to the surrounding areas shows the west flow patterns of air circulation in the mid latitudes. The plume reaches Paris and Benelux within about 18 hours in 11% and 7% of the studied cases respectively whereas it needs 10 times longer times (180 h) to reach Moscow (0.6% of the cases). In 2% of the cases and within 60 hours air masses departing from London area reach Milan.

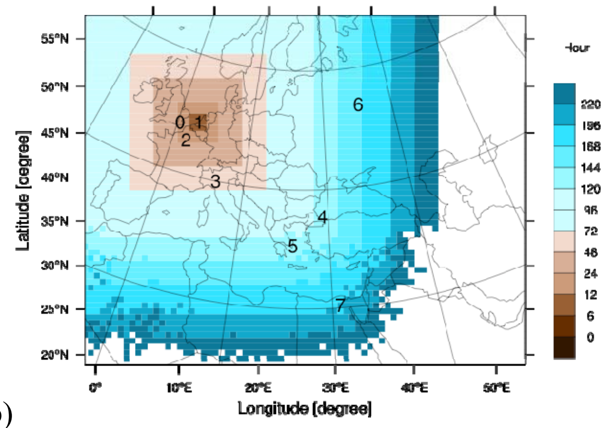
Table 1. Probability of air masses departing from London to affect the selected urban agglomerations and corresponding average travel time.

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (Hour)
0	London (Source)			
1	Benelux	4666	11	18
2	Paris	2812	7	18
3	Milan	796	2	60
4	Istanbul	142	0.4	144
5	Athens	107	0.3	138
6	Moscow	243	0.6	180
7	Cairo	9	0.02	210

2. *Outflow of Benelux pollution*



(a)



(b)

Figure 2. Climatological Outflow of air pollution from the Benelux area: (a) probability of trajectories departing from Benelux to reach other locations over Europe withing less than 10 days and (b) associated travel time; averaged over the 30-years period 1960-1990.

Air masses from Benelux that is subject to same general air circulation characteristics with London are similarly transported to the surrounding regions with some asymmetry favoring the eastern flow.

Thus both London and Paris are reached by air masses leaving Benelux (6% of the cases each) within the first 18 hours of their travel whereas in 2% of the cases the air masses in on average about 60 hours reach Milan region.

Table 2. Probability of air masses departing from Benelux to affect the selected urban agglomerations and corresponding average travel time.

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (Hour)
0	London	2533	6	18
1	Benelux (Source)			
2	Paris	2469	6	18
3	Milan	735	2	60
4	Istanbul	252	0.6	126
5	Athens	168	0.4	126
6	Moscow	300	0.7	162
7	Cairo	15	0.04	198

3. *Outflow of Paris pollution*

Air pollution from Paris that is located to the South East of London and South West of Benelux is preferentially transported to the East (6% of the air masses leaving from Paris reach Benelux) than to the west (4% of the air masses reach London area) following the general eastward flow of general atmospheric circulation. It reaches the Milan area in more than 3% of the cases after 42 hours.

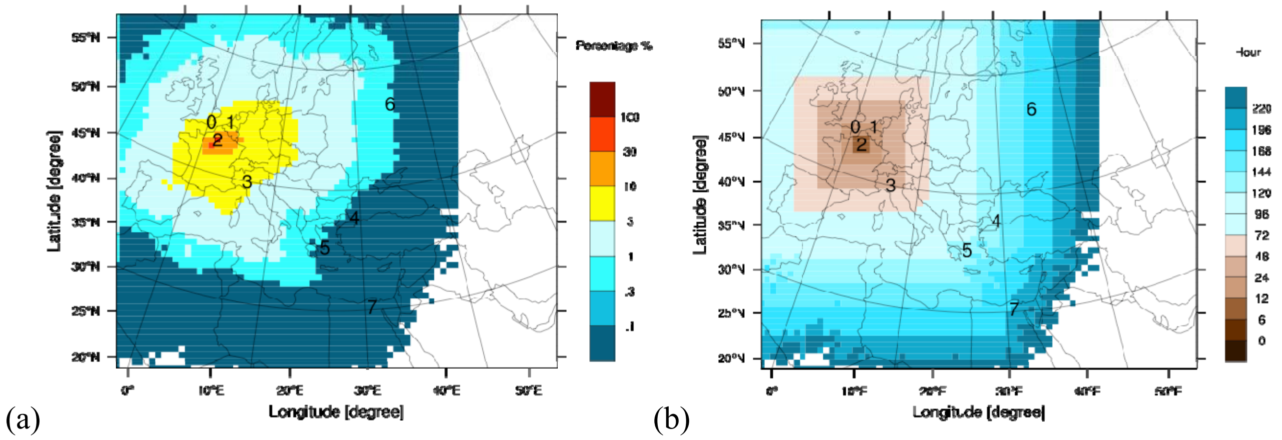


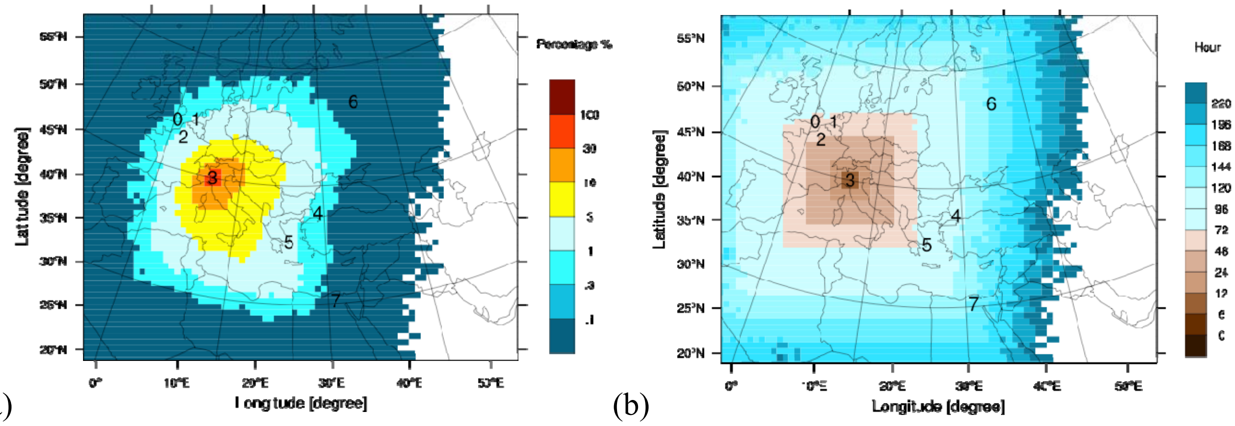
Figure 3. Climatological Outflow of air pollution from the Paris area: (a) probability of trajectories departing from Paris to reach other locations over Europe withing less than 10 days and (b) associated travel time; averaged over the 30-years period 1960-1990.

Table 3. Probability of air masses departing from Paris to affect the selected urban agglomerations and corresponding average travel time.

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (Hour)
0	London	1580	4	18
1	Benelux	2397	6	18
2	Paris (Source)			
3	Milan	1338	3.2	42
4	Istanbul	156	0.4	138
5	Athens	168	0.4	132
6	Moscow	214	0.5	174
7	Cairo	22	0.1	204

4. *Outflow of Milan pollution*

Milan located in the Centre of South Europe close to the North coast of the Mediterranean Sea splits its pollution in the surrounding regions. Its plume extends preferentially in the South-East direction. However, in 0.7% of the studied cases air masses form Milan area reach London within 66hours from departure; similar time they need those (1% of the cases) that reach the Benelux region; whereas the mostly affected among the megacities located NW of Milan is Paris that is affected by 1.3% of the air masses departing from Milan. These air masses reach Paris within 42 hours. On the other hand the pollution outflow from Milan reaches North Africa and the East Mediterranean as seen in Figures 4a,b (1.2% of the cases reach Athens within 84 hours from departure). It even affects Istanbul (0.8% of the cases after 4.5 days of travel over Europe).



(a) (b)

Figure 4. Climatological Outflow of air pollution from Milan: (a) probability of trajectories departing from Milan to reach other locations over Europe withing less than 10 days and (b) the associated travel time; averaged over the 30-years period 1960-1990.

Table 4. Probability of air masses departing from Milan to affect the selected urban agglomerations and corresponding average travel time.

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (Hour)
0	London	304	0.7	66
1	Benelux	432	1	66
2	Paris	533	1.3	42
3	Milan (Source)			
4	Istanbul	325	0.8	108
5	Athens	512	1.2	84
6	Moscow	131	0.3	144
7	Cairo	116	0.3	144

5. *Outflow of Istanbul pollution*

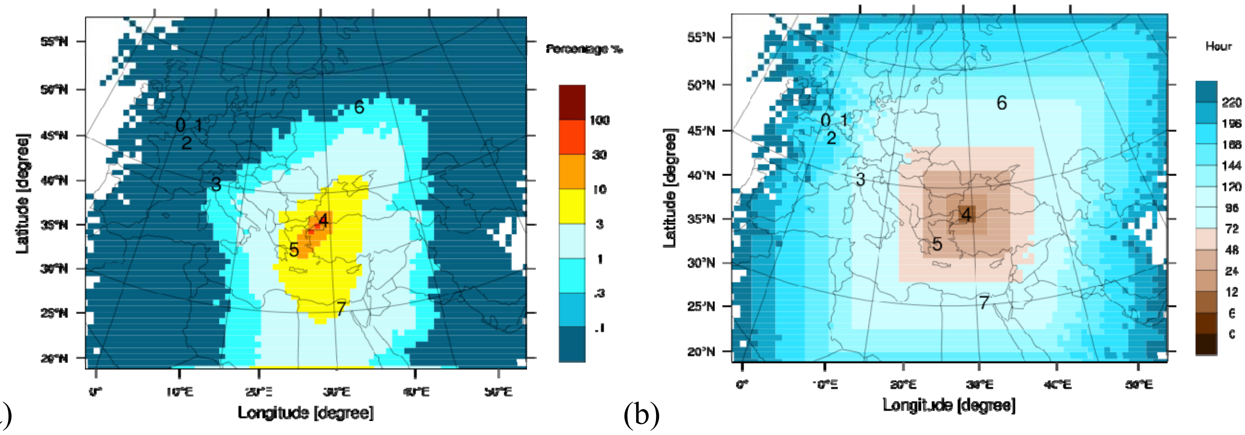


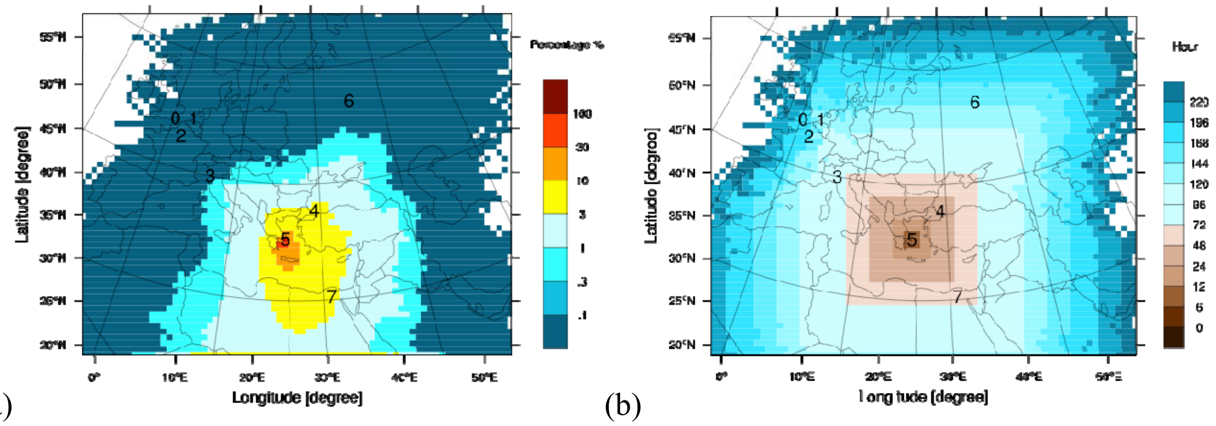
Figure 5. Climatological Outflow of air pollution from Istanbul: (a) probability of trajectories departing from Istanbul to reach other locations over Europe withing less than 10 days and (b) the associated travel time; averaged over the 30-years period 1960-1990.

Istanbul pollution has little to inexistent impact on NW European megacities and large urban agglomerations as seen in Figures 5a,b.The air pollution from Istanbul megacity that is located on two continents, Europe and Asian, separated by the Bosporus straight, is exported mainly in the North-East / South-West direction (Koçak et al.,2011) as seen in Figure5a. Thus, air masses overpassing Istanbul reach Athens in 14% of the studied cases with relatively short mean travel time of 30 hours and they need an extra 60 hours to reach Cairo (in 3% of the studied cases).

Table 5. Probability of air masses departing from Istanbul to affect the selected urban agglomerations and corresponding average travel time.

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (hour)
0	London	15	0.04	156
1	Benelux	47	0.11	132
2	Paris	17	0.04	174
3	Milan	174	0.4	108
4	Istanbul (Source)			
5	Athens	5894	14	30
6	Moscow	248	0.6	114
7	Cairo	1291	3	90

6. *Outflow of Athens pollution*



(a) (b)

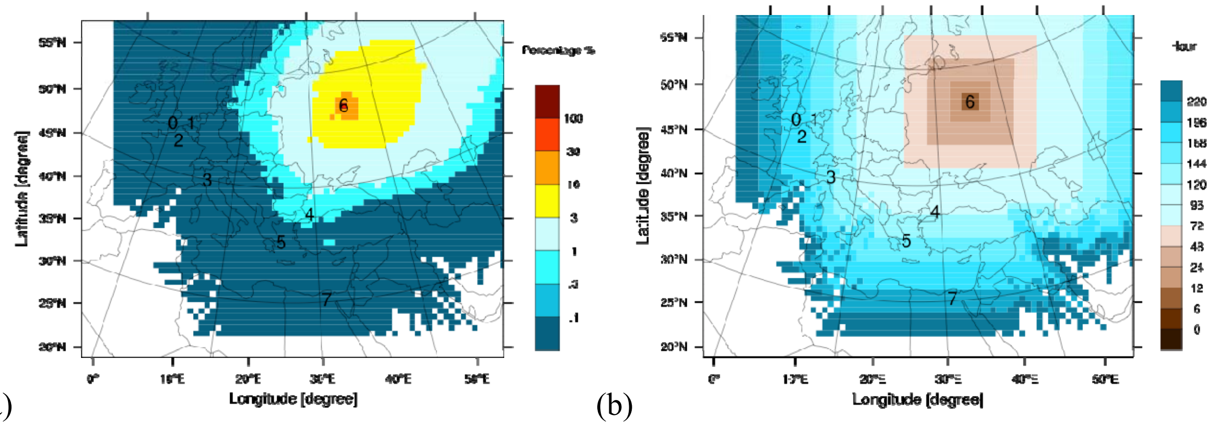
Figure 6. Climatological Outflow of air pollution from Athens: (a) probability of trajectories departing from Athens to reach other locations over Europe withing less than 10 days and (b) the associated travel time; averaged over the 30-years period 1960-1990.

From the above analysis, it is shown that Athens (located in the Southern East Mediterranean) is affected by transported air masses from megacities and large urban agglomerations of Central and South Europe as well as the Istanbul that is located close-by to the North-East. The Athens plume itself is transported mainly towards south-east over the East Mediterranean Sea. However, in 3.7 of the studied cases air masses over passing Athens reach Istanbul (in southern winds regime) within about 30 hours. Under North-West flow, Athens plume can reach Cairo (in 3.7% of the studied cases) within about 60 hours.

Table 6. Probability of air masses departing from Athens to affect the selected urban agglomerations and corresponding average travel time

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (hour)
0	London	12	0.03	180
1	Benelux	24	0.06	126
2	Paris	21	0.05	168
3	Milan	187	0.5	78
4	Istanbul	1544	3.7	30
5	Athens (Source)			
6	Moscow	104	0.3	144
7	Cairo	1577	3.7	60

7. *Outflow of Moscow pollution*



(a) (b)

Figure 7. Climatological Outflow of air pollution from Moscow: (a) probability of trajectories departing from Moscow to reach other locations over Europe withing less than 10 days and (b) the associated travel time; averaged over the 30-years period 1960-1990.

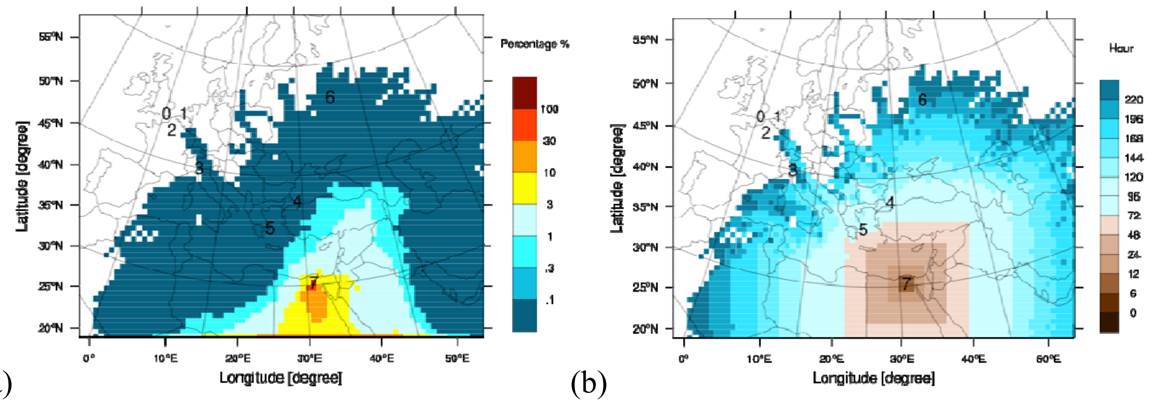
Moscow located in the mid and high latitudes zone of Westerly winds, has little influence on the air quality of the studied urban centres that are reached in less than 0.6% of the studied cases with travel times of at least 114 hours. Its plume extends towards north East thus mainly affecting rural and urban locations in Russia itself.

Table 7. Probability of air masses departing from Moscow to affect the selected urban agglomerations and corresponding average travel time

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (hour)
0	London	47	0.11	180
1	Benelux	62	0.15	162
2	Paris	45	0.11	174
3	Milan	29	0.07	144
4	Istanbul	255	0.6	114
5	Athens	129	0.3	144
6	Moscow (Source)			
7	Cairo	34	0.08	204

8. Outflow of Cairo pollution

Cairo outflow is mainly affecting south-southwest locations and the Arabian Peninsula. Under south wind conditions, associated with significant dust outbreaks, air masses over passing Cairo can reach Istanbul (0.16% of the cases with mean travel time of 4.5 days) and Athens (0.09% of the cases within about 78 hours).



(a) (b)

Figure 8. Climatological Outflow of air pollution from Cairo: (a) probability of trajectories departing from Cairo to reach other locations over Europe withing less than 10 days and (b) the associated travel time; averaged over the 30-years period 1960-1990.

Table 8. Probability of air masses departing from Cairo to affect the selected urban agglomerations and corresponding average travel time.

No	City	Number of Arriving Trajectories	Probability of Arriving Trajectories (%)	Average Travel Time (hour)
0	London	0	-	-
1	Benelux	0	-	-
2	Paris	0	-	-
3	Milan	1	-	234
4	Istanbul	67	0.16	108
5	Athens	38	0.09	78
6	Moscow	1	0	222
7	Cairo (Source)			

Summary remarks

The above analysis of pathways of transport of the outflow of selected urban centres points reflects the general air circulation patterns that link the mid and high latitude studied urban centres of London, Benelux, Paris and to a lesser extent Milan located in the zone of Westerly winds with significant interactions of air pollution. On the other hand, Istanbul, Athens and Cairo, in the East Mediterranean show strong interactions due to the north- south direction of winds (reflecting dominance of Etesian winds over the Aegean and the East Mediterranean winds).

As mentioned above, the present analysis focuses on the present day transport patterns only. However, climate change may modify the above analysed transport patterns and requires further investigation. In addition, during transport air masses are mixed with regional emissions and are physically and chemically aging. The evaluation of the overall impact of the pollution centres to the downwind locations has to account for both transport and transformation of air pollutants.

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