Aviation Emission Inventory for Greek Airports

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Introduction

Civil aviation is a significant and preferable transport mode for medium- and long-haul trips. Since it affects the economic growth of the surrounded areas, global air traffic has increased significantly in recent years. According to traffic statistics compiled by the International Civil Aviation Organization (ICAO, 2013) in 2013 the world total scheduled passenger-kilometres performed increased by about 5.5% over 2012 — international and domestic services combined. Despite the better economic climate in Europe, the traffic of the European airlines increased less than the world average in 2013, growing at 3.8% (ICAO, 2013). In Greece the complex topography (many islands spread at the Aegean and Ionian Sea) in combination with the increasing demands due to tourism have led to the construction of several airports. According to Tsilingiridis 2009, the evolution of total air traffic in Greek airports from 1980 to 2005 revealed an increase of about 55% in total flights. However, the recent economical crisis has negatively affected air transportation. As shown in Figure 1 the number of national flights decreased from 2009 due to mergers of Greek airlines a fact that consequently led to the abolishment or merge of several national routes; 25% decrease is observed in national flights from 2009 to 2012.

Whilst aviation brings economic benefits, it has considerable environmental impacts both at a local airport level and at a regional and global level. The aviation fuels (jet fuels) used by aircrafts, which consequently determine the type and quality of pollutants emitted, are kerosene (jet kerosene) and gasoline (jet gasoline). The corresponding pollutants and gases produced are: CO_2, CO, HC, NOx, particles and SO_2.The aviation emissions during the Landing and Take Off (LTO) cycles affect directly the air quality in surrounding areas and are related to the potential for health impacts on residential populations. Since more airports are close to urban areas it is very important to calculate accurately emissions from air traffic (Kesgin 2006, Pham et al. 2010, Turgut and Rosen 2010).

Concerning the estimation of aviation emissions in Greece, Symeonidis et al. 2004 developed the first formal database for air pollutant emissions from transport in Greece. The aviation activities were summarized per month, aircraft type and flight type (domestic, international) and the calculated emissions were allocated to a 30 km radius from the centre of each airport. Results revealed that air transport generates a relatively small proportion of the total transport emissions of pollutants NOx, CO, NMVOC and the GHG CO_2. Tsilingiridis (2009) analysed the evolution of aircraft air pollutant emissions in Greek airports from 1980 to 2005. Emissions were estimated for Landing and Take Off (LTO) cycles covering 38 civil airports. The high increase of emissions followed the increase of air traffic by 2.4 times from 1980 to 2006. The Athens airport had the higher contribution to total air traffic, as well in total emissions, but with decreasing trend (59.0% in 1980 - 42.2% in 2005). Changes in aircraft fleet composition together with changes of each airport contribution in total civil aviation traffic influenced the increase rates of each air pollutant. Average per flight emissions from 1980 to 2005 have shown increased trend for NOx, decreased trend for VOC and CO and almost stable per flight emissions for SO_2 and $PM_{2.5}$.

The present work aims to estimate air pollutants emissions from aircraft movements at Greek airports for the period 2006-2012. The annual emissions per airport were also disaggregated spatially in gridded form and temporarily in hourly values in order to be used as part of a comprehensive emission inventory by photochemical models.

Methodology

The emissions from the combustion process in aircrafts engines were calculated for the 38 airports in the Greek territory by using the Tier 2 approach from the EMEP/EEA air pollutant emission inventory guidebook 2013 (EEA, 2013). The methodology allows the estimation of emissions during the LTO-cycle by means of the following equation:

$$E_{i,\,total} = \Sigma\,(EF_{i,\,j} \times \text{number of flights}_{i,\,k})$$

where $E_{i,\,total}$ is the annual emission of pollutant i for the airport k and the aircraft type j, $EF_{i,\,j}$ is the emission factor for pollutant i and the aircraft type j while number of $\text{flights}_{j,\,k}$ is the number of flights of aircraft type j at the airport k. According to ICAO, the LTO-cycle includes all activities near the airport that take place below a height of 3 000 ft (914 m).

The total number of commercial flights (passenger flights, freight and mail flights) per airport and type of aircraft on an annual scale were provided by the Greek Civil Aviation Authority and the Eurostat database (Eurostat, 2013). The data included domestic and international flights for the period 2006-2012 (Fig.1 – left). Emission factors corresponding to emissions during the LTO cycle per aircraft type were given by the EMEP / EEA Guidebook 2013 (http://eea.europa.eu/emep-eea-guidebook). For aircraft types with no available data, emissions per LTO cycle were calculated based on information for the engine type of the respective aircraft provided by the ICAO. The top ten airports concerning air traffic are shown in Figure 1-right indicating the predominance of the Athens airport.

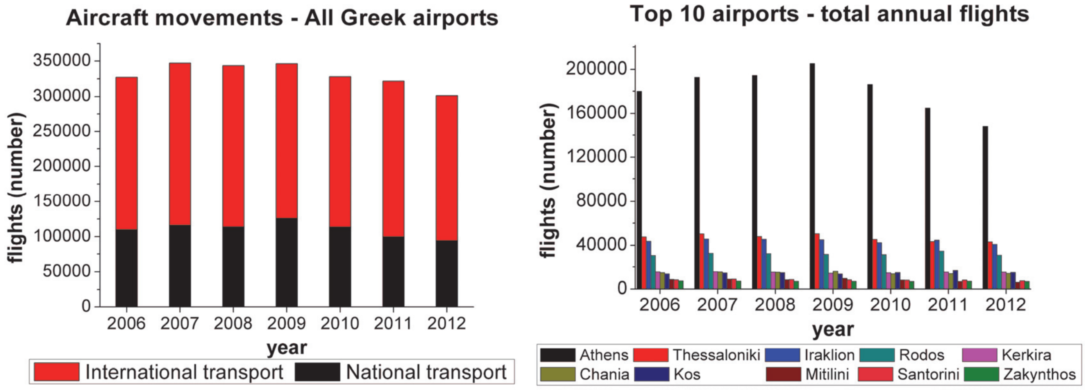

Figure 1: Annual distribution of international and national flights at the Greek airports (left) and temporal variation of flights at the 10 most populated Greek airports (right).ational emissions from all the Greek airports for the period 2006 – 2012.

The emissions calculated from the above procedure were spatially allocated on a 6 km resolution grid over Greece with the use of a Geographic Information System (GIS) having the airport's coordinates and area as surrogate data. The above grid was constructed in Lambert Conformal Conic coordinate system.

For the temporal disaggregation of the annual emissions to monthly values, monthly emissions profiles per airport from the Eurostat database were used. Afterwards, weekly, daily and hourly disintegration coefficients were developed for each airport specialised for each year, based on the number of flights derived from historical flight data (www.flightstats.com). Due to the seasonal variability of the number of flights the same weekly, daily and hourly coefficients were attributed to months of the same season.

Results and Discussion

The annual total emissions variation of CO, NOx, NMVOC, SO_2 and $PM_{2.5}$ for the period 2006 – 2012 is presented in Figure 2. Generally, CO emissions prevailed among the others while a decline in total emissions was observed for all pollutants which can be attributed to the reduction of total flights (Fig.1-left). The percentage difference from 2006 to 2012 was 90% for CO, 23% for NOx, 47% for NMVOC, 26% for SO_2 and 65% for $PM_{2.5}$. As shown in Figure 1-left the number of flights decreased from 2010 due to mergers of Greek airlines that consequently led to the abolishment or merge of several national routes; 25% decrease in national flights from 2009 to 2012. Concerning the emissions per airport, results revealed that the Athens airport had the highest contribution to all emissions e.g. 40% for NOx, 41% for CO and 37% for SO_2 for the year 2012 while the airports of Thessaloniki, Heraklion and Rodos followed with 24%, 9% and 7% percentage share in total CO emissions for 2012, respectively (Table 1). As for the monthly variation many airports especially at the Greek islands faced a burst of aviation emissions during the summer period (not shown here).

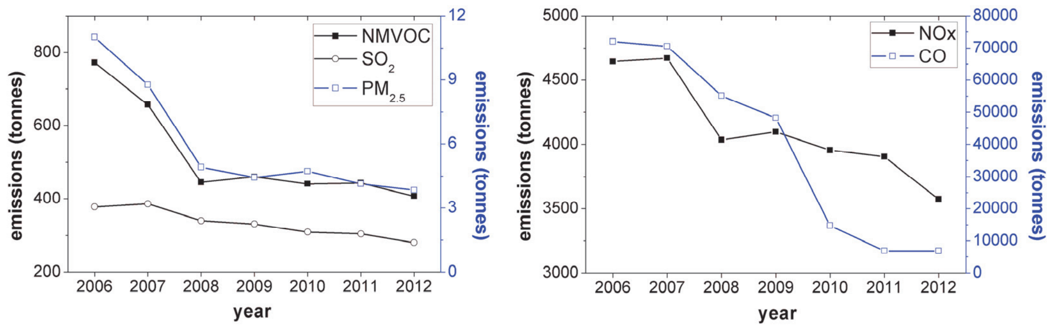

Figure 2: Annual national emissions from all the Greek airports for the period 2006 – 2012

Table 1: Total number of flights and annual emissions for the year 2012 at the top 10 airports

Airports	Flights	NOx (tn)	NMVOC (tn)	CO (tn)	SO_2 (tn)	$PM_{2.5}$ (tn)
Athens	148,198	1,440.39	174.59	2,818.66	104.10	1.42
Thessaloniki	43,106	403.56	45.95	1,690.76	32.63	0.38
Iraklion	40,858	431.22	45.96	601.49	34.11	0.44
Rodos	30,896	326.31	36.21	446.56	25.70	0.24
Kerkira	15,292	162.02	15.65	176.23	13.15	0.17
Chania	14,120	137.99	13.69	151.63	11.53	0.06
Kos	14,972	134.90	13.18	157.76	11.66	0.06
Mitilini	5,972	42.29	5.18	54.05	3.63	0.09
Santorini	7,442	69.96	7.32	69.66	5.45	0.05
Zakinthos	6,718	69.12	6.30	103.72	5.72	0.06
All airports	**301,287**	**3,573.75**	**6,816.12**	**407.20**	**279.90**	**3.84**

Analyzing the annual distribution of flights (Fig.3) and emissions of NOx and CO for two major airports (Fig.4) the continuous reduction in CO emissions (except for the year 2007 for Rodos airport) can be observed which is associated with the reduction in domestic flights. The CO emissions are mainly affected by the type of aircraft. The merger of domestic flights to regional airports led to the replacement of multiple smaller aircrafts by larger capacity aircrafts concluding to lower emissions per LTO cycle. NOx emissions are generally related to the number of flights presenting an increase the first four years for the Athens airport while from 2009 to 2012 a decrease of 27% was observed following a 28% reduction in the number of flights. As for the Rodos airport, the 11.7% increase in flights caused an increase of 9.5% in NOx emissions in 2011.

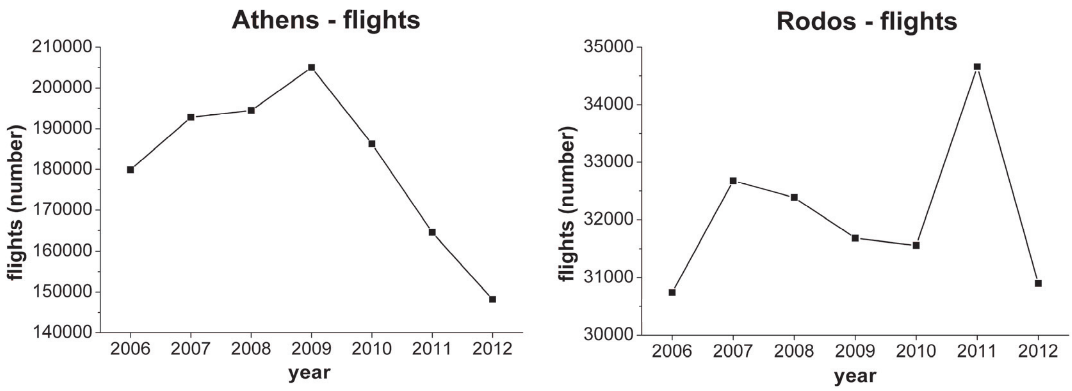

Figure 3: Annual distribution of total flights (domestic and international) for the Athens (left) and Rodos (right) airports.

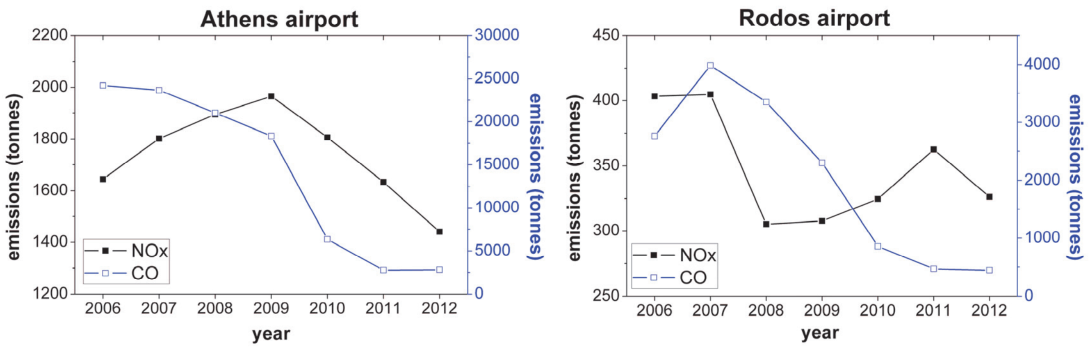

Figure 4: Annual CO and NOx emissions from the Athens (left) and the Rodos (right) airports.

The most popular aircraft types that arrive and depart at the Athens and Rodos airports are analysed in Figure 5. Boeing 737 (B737), Airbus 320 (A320) and Dash 8 are the predominant types for both airports. However, the significant decrease in B737 flights from 2010 has been coupled by the increase in A320 at the Athens airport while there is also an increasing trend in A320 flights at the Rodos airport. A320 is related to lower CO LTO emissions comparing to B737.

The temporal profiles for the year 2010 for the Athens and the Rodos airports are presented in Figure 6. Athens is the largest Greek airport while Rodos is a representative tourist island. The monthly profiles revealed seasonal variation in flights which was particularly pronounced at the airport of Rodos. Flights increased gradually from spring and reached a summer peak in August following the touristic period. At the Athens airport lower values were reported in February, November and December and greater values during the summer. Concerning weekly profiles the busiest days for the Athens airport were Monday and Friday while for the Rodos airport Thursday and Sunday of the summer and autumn months. Figure 5-right shows the hourly profiles for two typical days (Friday and Sunday) in winter and in summer. It is obvious that the aircraft traffic remains stable from the morning until late evening at the Athens airport. On the contrary, the daily distribution of flights at the airport of Rhodes depends on the season with winter schedule to be more stabilised regardless of the day due to domestic flights and the absence of international touristic charter flights.

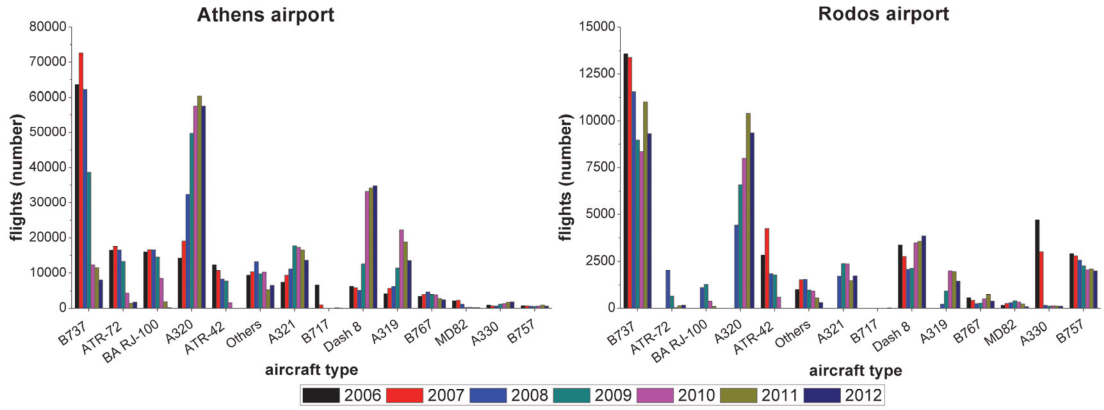

Figure 5: Annual variation of total flights per aircraft type in Athens and Rodos airports.

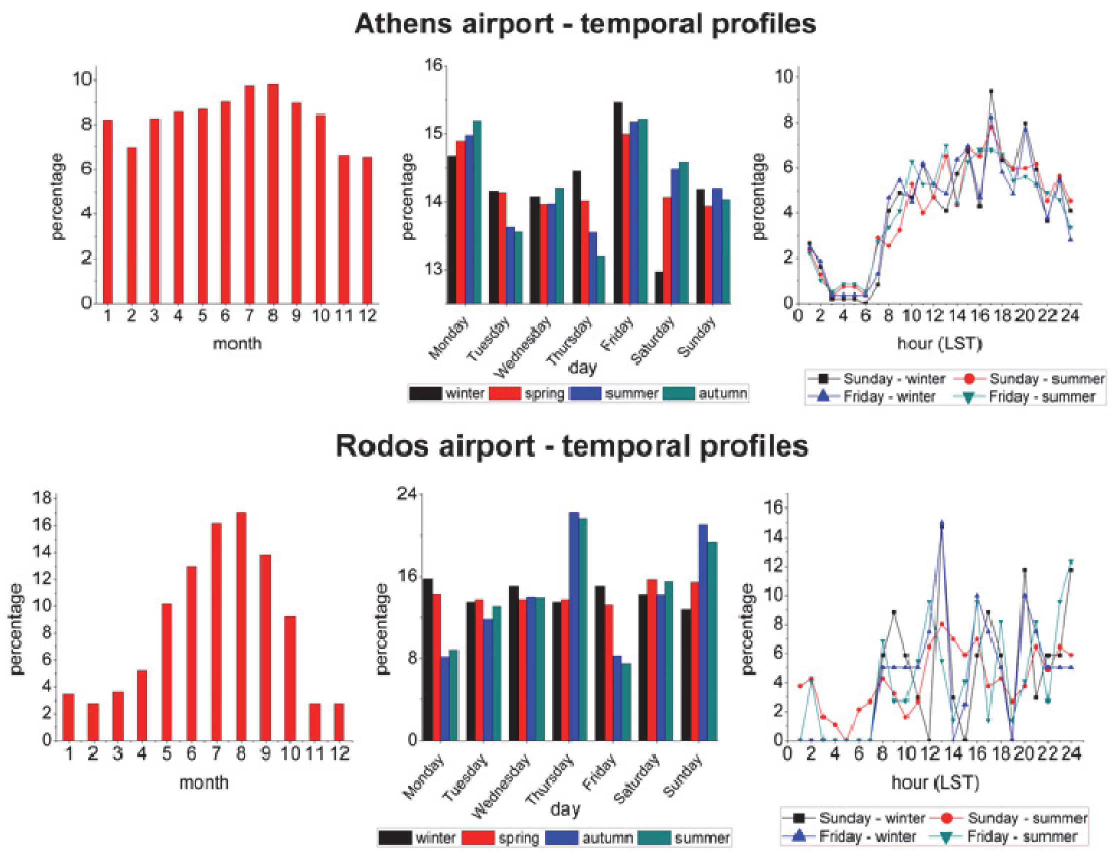

Figure 6: Monthly, weekly and hourly profiles developed for the Athens (top) and Rodos (bottom) airports.

Conclusions

The emissions from the combustion process in aircrafts engines during the LTO cycle were calculated for the 38 airports in the Greek territory by using the Tier 2 approach from the EMEP/EEA air pollutant emission inventory guidebook 2013. The emission factors for each aircraft type were given by the International Civil Aviation Organisation (ICAO) Engine Emissions Databank and the EMEP/EEA air pollutant emission inventory guidebook 2013.

Results revealed that CO emissions prevailed among pollutants while a decline in total emissions was observed for all pollutants which can be attributed to the reduction of total flights and the aircraft types used. The Athens airport had the highest contribution to all emissions while the airports Iraklion, Thessaloniki, Rodos and Corfu followed. The aircraft types determine the emissions at the airport.

Monthly, weekly and hourly emissions profiles were developed for each airport based on historical air traffic. A summer peak was observed in August following the touristic period. Concerning weekly profiles the busiest days for the Athens airport were Monday and Friday while for the airport at a typical touristic island Thursday and Sunday of the summer and autumn months. The aircraft traffic remains stable from the morning until late evening at the Athens airport. On the contrary, results showed a different spreading of flights during day in summer at the tourist areas when morning and evening flights were added.

Acknowledgements

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