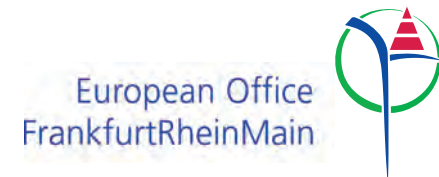


Ultrafine Particles

in Airport Regions



Ultrafine Particles in Airport Regions

23 March 2017

Rue Montoyer 21, 1000 Brussels

Welcome Words



Dear reader,

Supporting the reduction of ultra-fine particles (UFPs) to the minimum is crucial to preserve a comfortable and healthy lifestyle for residents living in airport regions. Airport Regions Conference is the best-placed organisation to ensure sustainable future aviation policy that keeps these concerns in mind. The voice of airport regions must be heard and taken into account and by involving all stakeholders – which is the only guarantee that all parties can benefit from aviation activities – we succeed in achieving this goal. We would be happy to see our contributed expertise and feedback being translated into additional tools to improve quality of life for our citizens.

The ARC approach is built-up with local touches from our members coming from all over Europe. This shows that all Europeans can efficiently contribute to the wider definition of policies.

Sergi Alegre Calero,
ARC President

List of speakers



Jeroen Staelens

Flanders Environment Agency

Jeroen holds a PhD in Bioscience Engineering (UGent) and is working as a scientific collaborator at Flanders Environment Agency (VMM). He is carrying out and coordinating air quality research, with a focus on (ultrafine) particles and ammonia in the ambient air. He supervised the studies on UFP in the European Joaquin project (Joint Air Quality Initiative, INTERREG IV-B) and is responsible for the UFP monitoring by VMM.

Ultrafine particles in urban environments (p. 7)

This presentation aims to give a general introduction on ultrafine particles (UFP), tackling the following questions. What are the characteristics and sources of UFP? Which measurement techniques are available? What is the current state of UFP monitoring and regulation? Which UFP concentrations are typically found in ambient air in urban environments and how does this vary in space and time? Is there a relationship between UFPs and other known air pollutants?



Jan Peters

VITO NV (The Flemish Institute of Technological Research)

Jan holds a PhD in Bio-science Engineering (UGent, KUL). He is a researcher at the Laboratory for Air Quality Measurements at VITO. His main activities are situated in the domain of (ultrafine) particles and dust in industrial and urban environments. These activities include the deployment of temporary monitoring networks with state-of-the-art monitoring technology, the interpretation of the monitoring results in relation to explanatory factors, speciation of particles, and the evaluation and selection of suitable reduction techniques. Jan is also active in international research projects on air quality sensor development.



Evelien Frijns received her Master degree in Physical Geography in 2002 from the University of Amsterdam (Netherlands). From 2002 till 2007 she worked as an environmental consultant specialised in soil contamination and remediation. Since 2007 she is an aerosol research scientist at VITO and her current research activities address questions in the areas of exposure assessment strategies for ultrafine and nanoparticles in occupational settings and ambient air. She collaborates closely with toxicologists and modellers to assess the risk of ultrafine and nanoparticles. Evelien is a member of several working groups for standardisation (CEN/TC352 Nanotechnologies, ISO/TC229 Nanotechnologies, CEN/TC137 Assessment of workplace exposure to chemical and biological agents) and of the OECD WPMN Steering Group Exposure measurement and mitigation. Evelien is also active in the Belgian Society of Occupational Hygiene (BSOH).

UFP concentrations in the region of Brussels Airport (p. 32)

Ultrafine particle (UFP) emissions from aircraft engines have been associated with increased UFP concentrations in areas surrounding airports. A monitoring study was performed in an area around Brussels Airport, Belgium in 2015. The objective of the study was to investigate the potential contribution of operations at Brussels Airport on the local air quality at surrounding residential areas. Therefore, the concentration of UFP, black carbon (BC) and nitrogen oxides (NO_x) were measured at different locations near the airport. The methodology and measurement results will be presented.



Dominique Lazarski

UECNA (European Union Against Aircraft Nuisances)

A former attorney at law, with Clifford-Chance and then with Freshfields, Dominique Lazarski was involved in French and international business transactions. She became a member of a local residents' organisation fighting to minimise nuisances when Ryanair started expanding in France using Beauvais-Tillé airport, nearby her house. She is amongst others vice-president of the French union against aircraft nuisance – UFCNA. Dominique Lazarski became president of UECNA, the European Union against aircraft nuisances, two years ago. UECNA is the only NGO in Europe whose sole purpose is the protection of the citizens living in the vicinity of airports across Europe from noise and emissions resulting from aviation activities.

Airports, emissions and residents (p. 59)

This presentation stresses the health risks of inhaling fine and ultrafine pollutant particles. Risks include asthma, lung cancer, and, most recently, heart disease, but a growing body of evidence suggests that such exposure can also harm the brain, accelerating cognitive aging, and may even increase risk of Alzheimer's disease and other forms of dementia.



Jesper Aberly Jacobsen

Copenhagen Airport

Jesper holds a MSc in Geology and works as Senior Project Manager for Copenhagen Airports Environmental Affairs. Jesper has 20 years of experience with various environmental issues and is as an in-house consultant in relation to challenges for airport operations and in that perspective the effects that this has on soil, water and air. Copenhagen Airports is a public limited company that operates two airports in Denmark.

The challenge of UFP at Copenhagen Airport (p. 76)

An introduction to the Copenhagen Airports Air Quality Program with special attention to ultrafine particulate matter (UFP). The presentation will summarise the actions to fight UFP and give a summary of the CPH cohort study on health effects. related to airport outdoor working environment.



Inmaculada Gomez Jimenez

OBSA (Observatory of Sustainability in Aviation)

Inmaculada has a PhD in Environmental Sciences with over 10 years of experience, she works as an environmental expert at the Observatory of Sustainability in Aviation of SENASA since its creation in 2007. She was involved in the creation of the Spanish Initiative for aviation biofuels (Bioqueroseno.es), is a member of the working group for alternative fuels of ACARE. She was the Project Coordinator of the ITAKA project on alternative fuels. Before working at SENASA she has been a professor of Environmental Economics and Landscape planning, and worked on several research projects.

Effects of the fuel composition on the UFP emissions. Biojet (p. 89)

The ITAKA project has performed several tests, using an APU, on the effects of the biojet blends in the emissions patterns from combustion, looking at different emissions. The tests have shown significant decreases in the mass and size (so also number) of non-volatile particulate matter. This research has been made relevant to the ICAO discussions about emissions standards (CAEP). One of the major conclusions is that synthetic fuels, like biojet, can help airports to reduce these emissions on particulate matter.



Yoann Mery
Safran Aircraft Engines

Yoann has a PhD and is an expert engineer. He has been working at the combustor design team at Safran Aircraft Engines since 2010. First, as a research engineer with the particular focus on pollutant prediction, advanced simulation (L.E.S.) and combustion instabilities (2010-2013), and then, in charge of the operability performances of combustors. Nowadays he is a combustion expert (pollution and operability), and responsible for the upcoming emissions and smoke certification of the Silvercrest engine.

Pollutant emissions from aircraft engines, relevant regulation and technology mitigation (p. 101)

The presentation will address issues on the creation end of the ultrafine particles life cycle. The different mechanisms which impact how the particles are created in the combustion chamber of aircraft engines will be described and discussed. These mechanisms are strongly dependent on the technology choices, which will be introduced briefly. Combustor technologies have been influenced by stringent regulations, and have continuously evolved since they were introduced in the 1990's. This evolution will be presented, with a particular focus on the new nvPM (non-volatile particulate matters) standard.



Vicente Franco
European Commission, DG Environment, Clean Air Unit

Vicente Franco is a policy officer at the European Commission (DG Environment, Clean air unit) working on emissions from road transport. Before joining the EC in Brussels, Vicente was a researcher at the International Council on Clean Transportation Europe (a Berlin-based NGO) and at the vehicle emission laboratories of the EC's Joint Research Centre in Italy.

Clean air in Europe: Air quality challenges around airports (p. 119)

This presentation provides an overview of EU air quality legislation, and puts air pollutant emissions from airport areas in context and presents some of the specific air quality challenges facing this type of infrastructure.



Ultrafine particles in urban environments

Jeroen Staelens
Flanders Environment Agency (VMM)

Ultrafine Particles in Airports Regions
23 March 2017, Brussels

**VLAAMSE
MILIEUMAATSCHAPPIJ**

Overview

- ▶ **General introduction on ultrafine particles**
 - Characteristics and sources
 - Measurement techniques
 - Monitoring and standardization
 - Health relevance and regulation
- ▶ **Ultrafine particles in urban environments**
 - Typical number concentration and size distribution
 - Variation in space and time
 - Relationship to other pollutants
- ▶ **Conclusions**

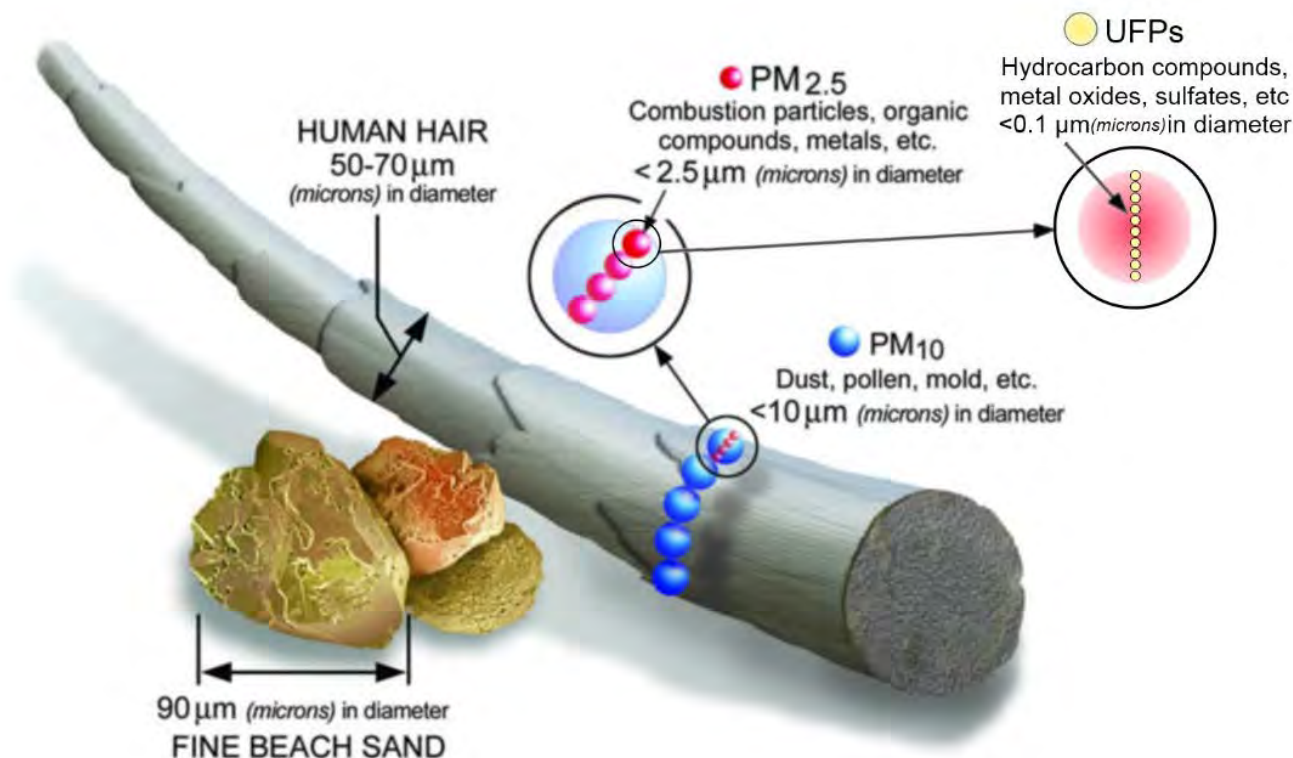
Aerosol

Solid or liquid particles suspended in air



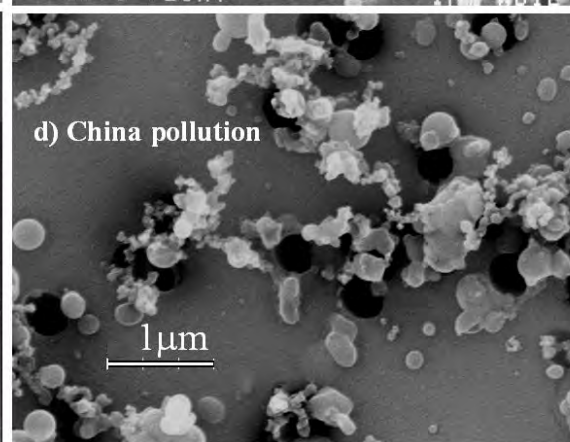
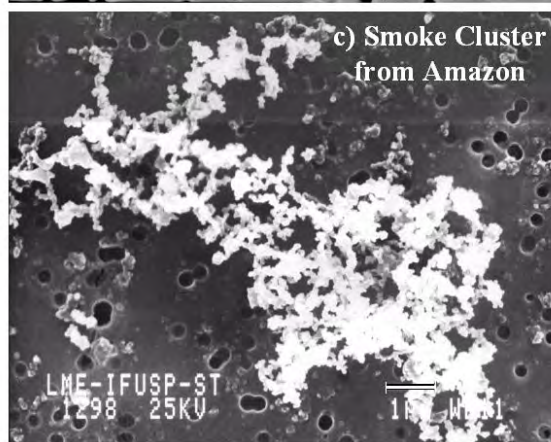
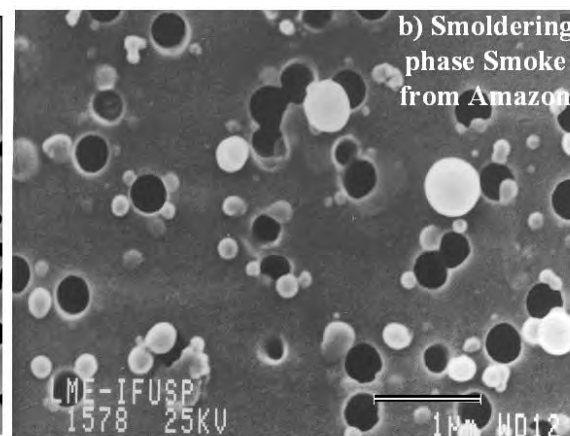
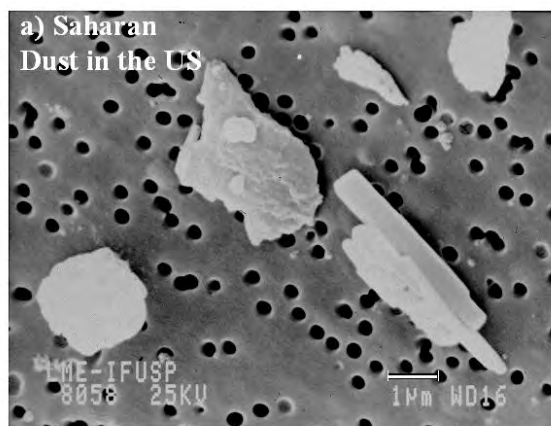
Particulate matter (PM)

Classified according to size (aerodynamic diameter)



PM is heterogeneous

Varying size, shape, composition



Ultrafine particles (UFP)

- ▶ **Particle smaller than 100 nm (0.1 μm) in (mobility) diameter**
 - Part of PM_{10} and $\text{PM}_{2,5}$
 - Nucleation (0-20/30 nm) and Aitken (20/30-100 nm) modes
- ▶ **Low mass, high number**
 - Small contribution to mass concentration of PM ($\mu\text{g}/\text{m}^3$)
 - Large contribution to number of particles
- ▶ **Typically expressed by particle number concentration**
 - Number of particles/ cm^3
 - But also e.g. surface area concentration

Particle sizes



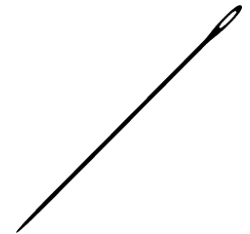
Macro: 10 m
balloon



25 cm
soccer ball



3.5 cm
ping pong ball



0.1 mm
tip of needle

Micro: 100 μm

2.5 μm

350 nm

1 nm

Sources of (ultra)fine particles

► PM

- Emission by natural and anthropogenic activities
- Households, transport, industry, agriculture, ...

► UFP

- Combustion processes: traffic, wood burning, ...
- Photochemical induced nucleation

► After emission

- Dilution and rapid transformation
- Coagulation, absorption, secondary particle formation
- Greater spatial and temporal variation than fine PM

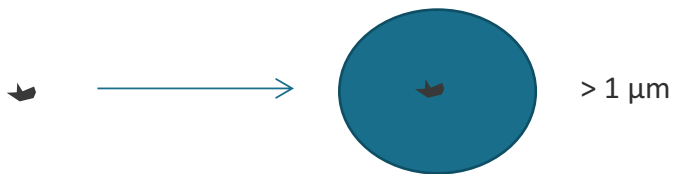
How to measure the total number of particles?

► Optical particle counter?

- Light scattering by single particles
- But: UFP too small for detection

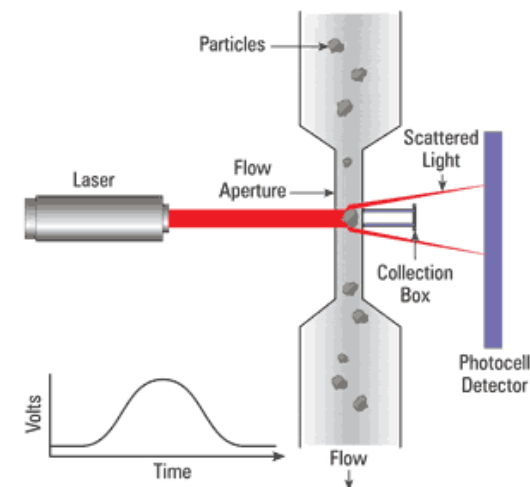
► Condensation particle counter (CPC)

- Particle enlarged via condensation of vapour onto a single particle



► Air sampling

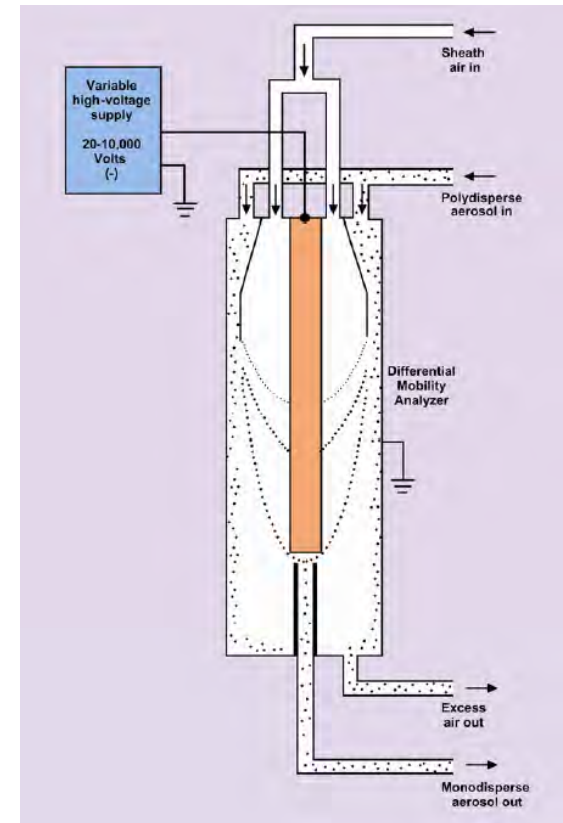
- Important to minimize particle losses



(www.machinerylubrication.com)

How to measure the size distribution of particles?

- ▶ **Charger (neutralizer)**
 - Particles with known charge distribution
- ▶ **Electrostatic classification**
 - Size classification based on electrical mobility (function of diameter and charge)
- ▶ **Particle counter**
 - Particle number per mobility class



Monitoring and standardization

- ▶ **No limit values for UFP in ambient air**
 - No systematic environmental monitoring
- ▶ **Increasing awareness of significance of small particles**
 - Development of robust monitoring instruments
 - Progress towards standardization (+2 years = EU standard?)

TECHNICAL SPECIFICATION	CEN/TS 16976
SPÉCIFICATION TECHNIQUE	
TECHNISCHE SPEZIFIKATION	August 2016
ICS 13.040.20	
English Version	
Ambient air - Determination of the particle number concentration of atmospheric aerosol	

Health relevance of UFP

► PM

- Heterogeneous mixture of fractions with likely varying effects
- Clearly demonstrated respiratory and cardiovascular effects

► UFP

- Deep penetration in lungs
- Transport in blood -> can translocate to tissues and organs

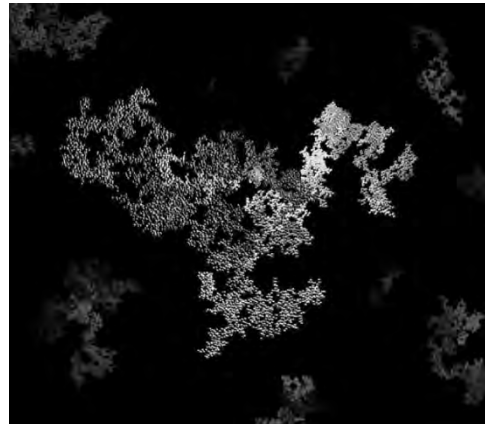
► REVIHAAP (WHO 2013) on UFP

- Epidemiological evidence: still limited
- Toxicological studies: UFP likely linked to biological pathways and responses that differ from PM₁₀ and PM_{2.5}



Regulation road traffic

- ▶ **EU vehicle emission standards for particle number (PN)**
 - Passenger cars and light duty (Euro 6): $\text{PN} < 6 \times 10^{11}$ per km
 - Heavy duty (Euro VI): $\text{PN} < 6-8 \times 10^{11}$ per kWh



Source: SLAC National Accelerator Laboratory

Soot - black carbon (BC)

► Black carbon

- Main sources: (diesel) combustion engines, wood and coal burning, fires
- Variable mixture of particulate material

► “Soot”

- Black carbon (light absorption)
- Elemental carbon (thermal-optical)

► WHO (Janssen et al. 2012)

- $PM_{2.5}$ as primary health indicator
- BC as indicator for combustion PM



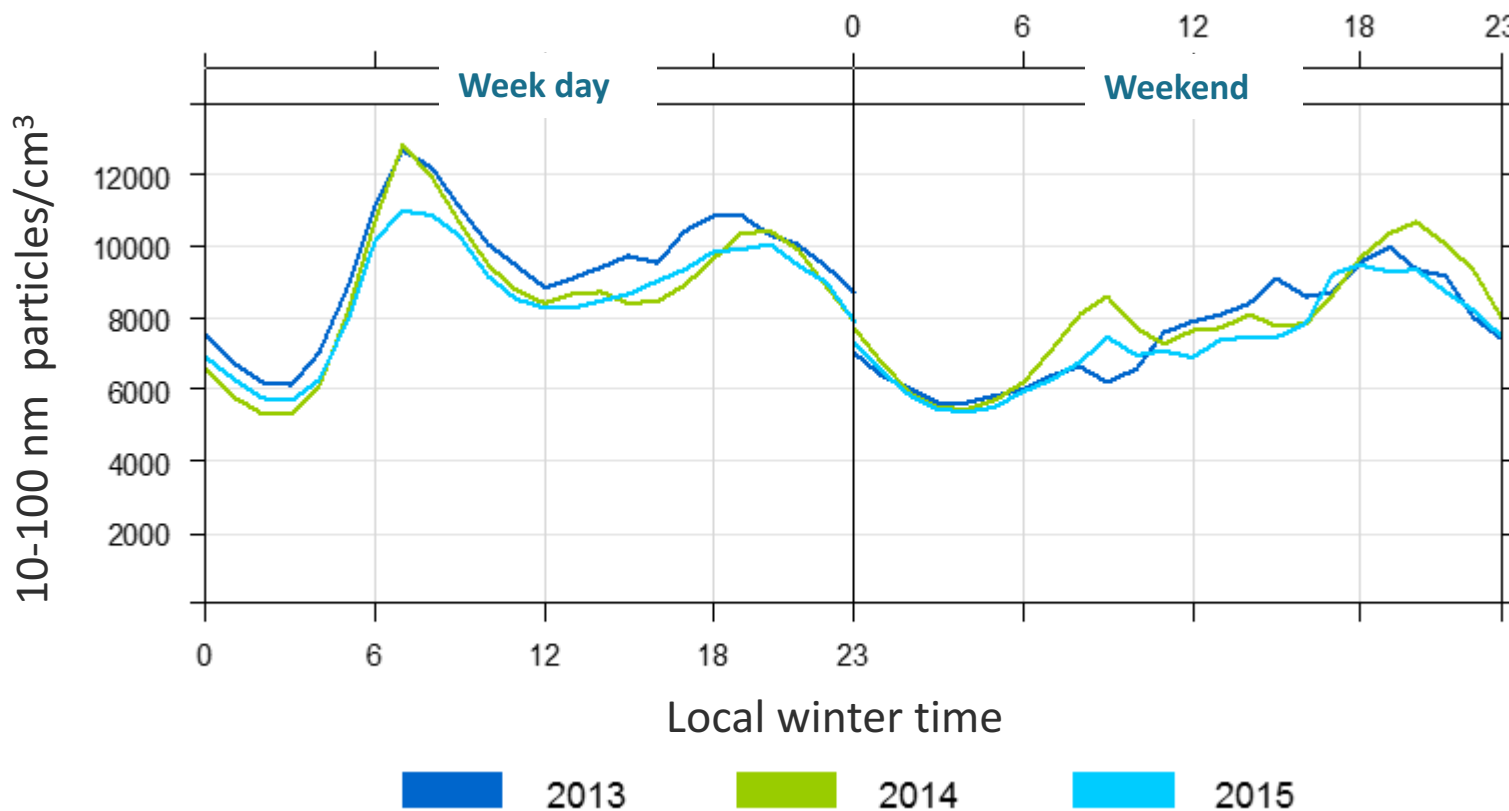
UFP in urban environments

- ▶ **UFP measurements in NW Europe**
 - Antwerp, Amsterdam, Leicester, London
 - Intra-urban variation within cities



Variation in time

Diurnal cycle UFP for urban background Antwerp



Variation in space and time

Diurnal cycle TNC for 5 sites in Antwerp (1/2)

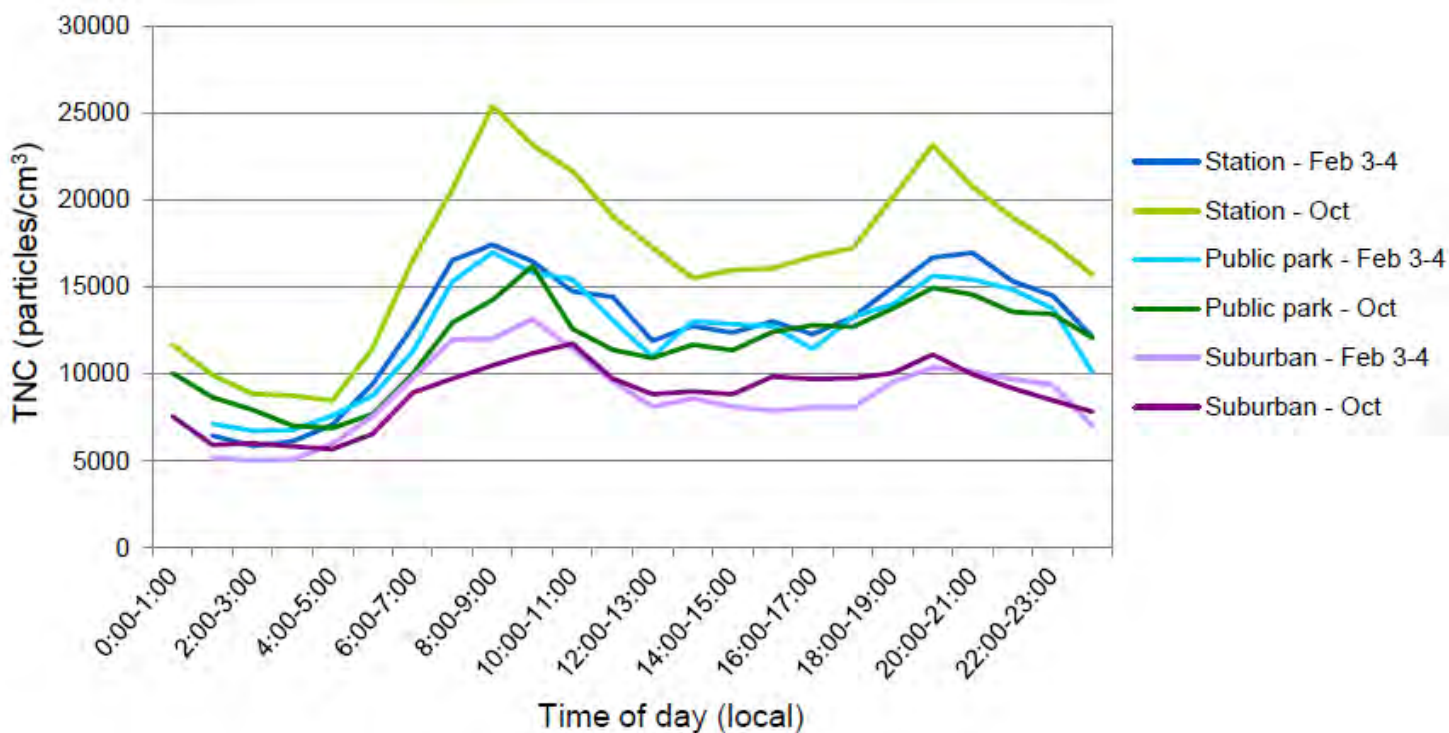


Figure 17: Hourly average total number concentration (TNC) at the monitoring station, public parc and suburban site on week days of the February and October campaigns

Variation in space and time

Diurnal cycle TNC for 5 sites in Antwerp (2/2)

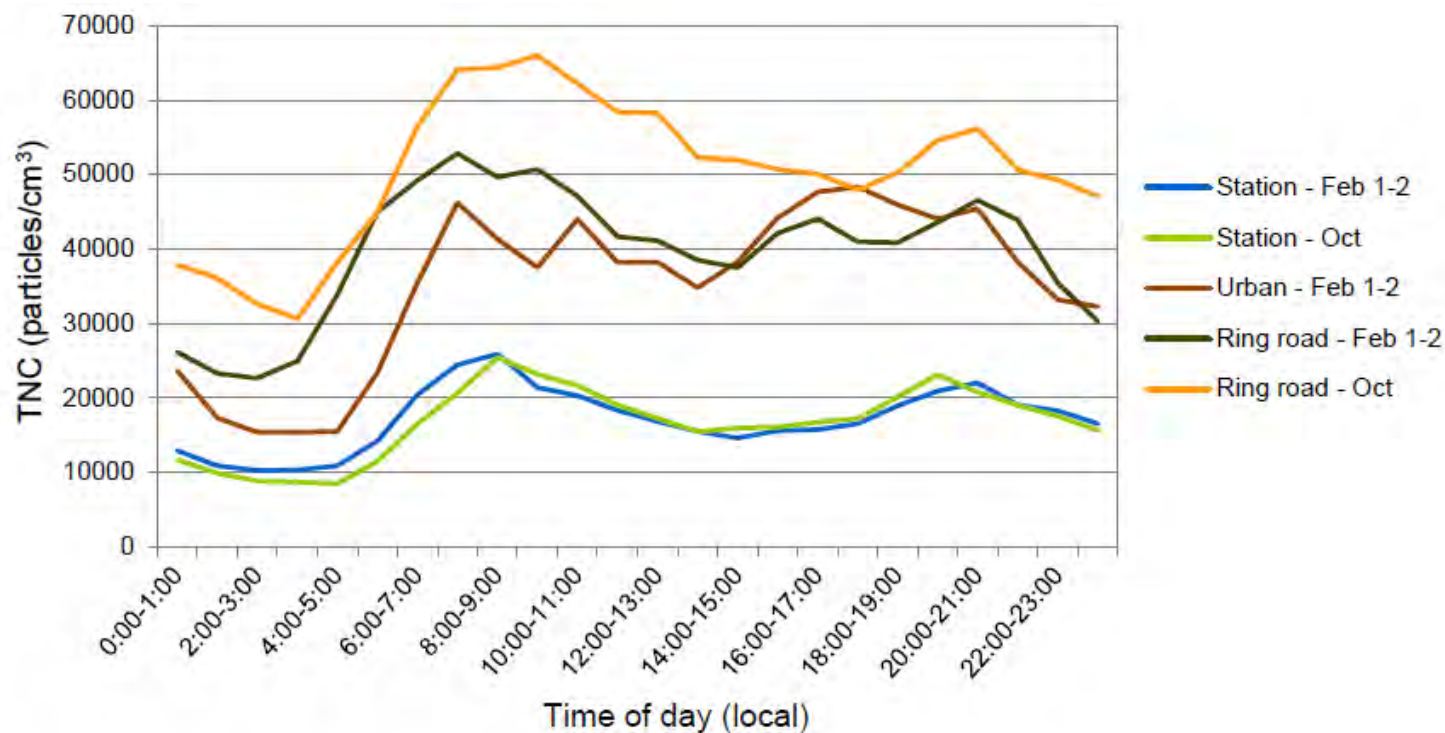
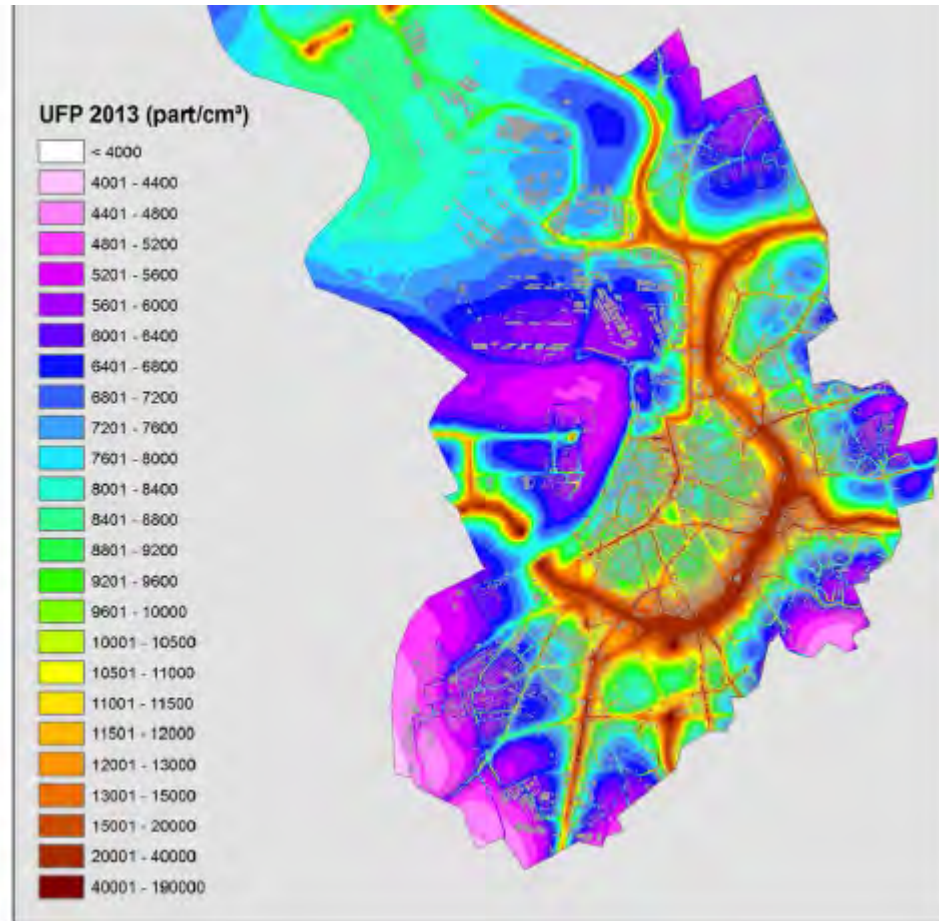


Figure 18: Hourly average total number concentration (TNC) at the monitoring station, urban site and ring road site on week days of the February and October campaigns

UFP modelling

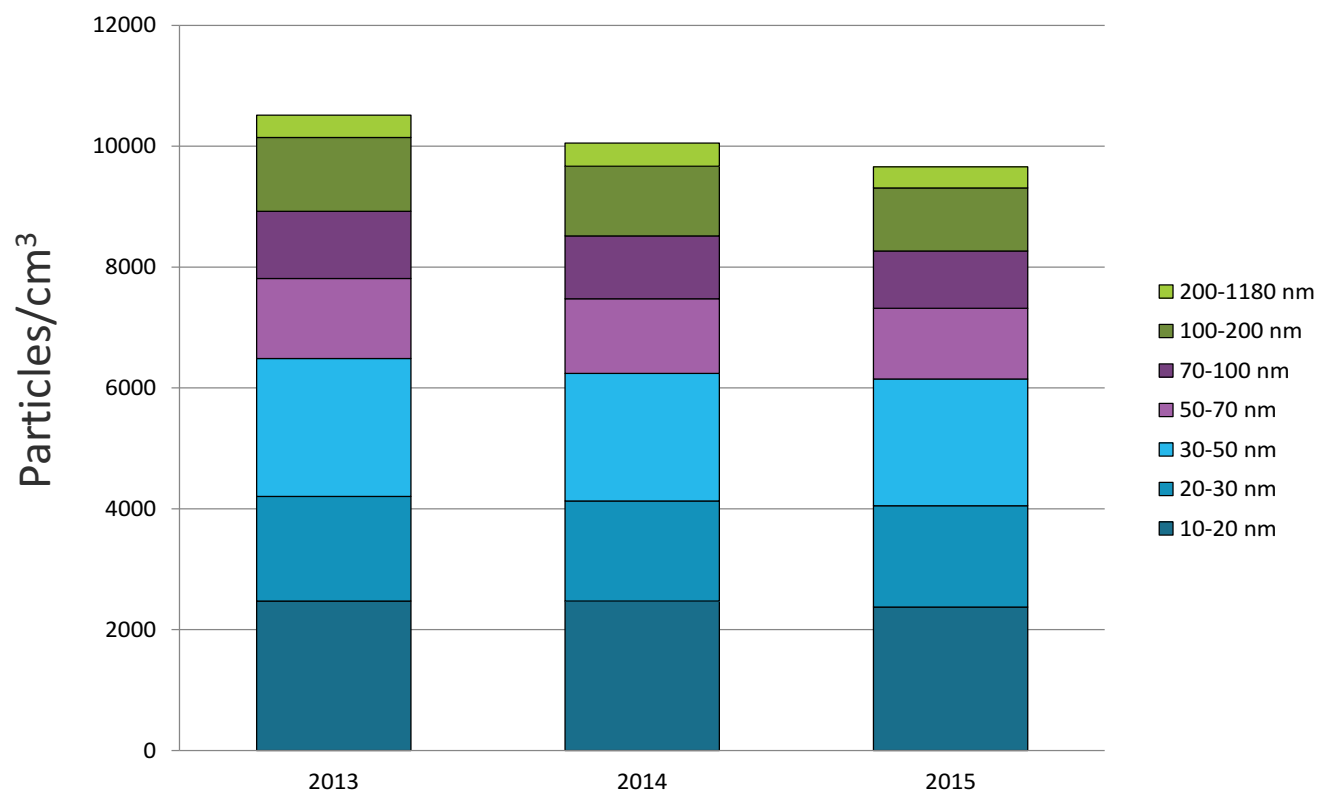
Antwerp

IFDM-OSPM
model



Particle size distribution

Annual mean UFP for urban background Antwerp



Source: VMM (2016)

Particle size distribution

Urban background sites in 3 cities

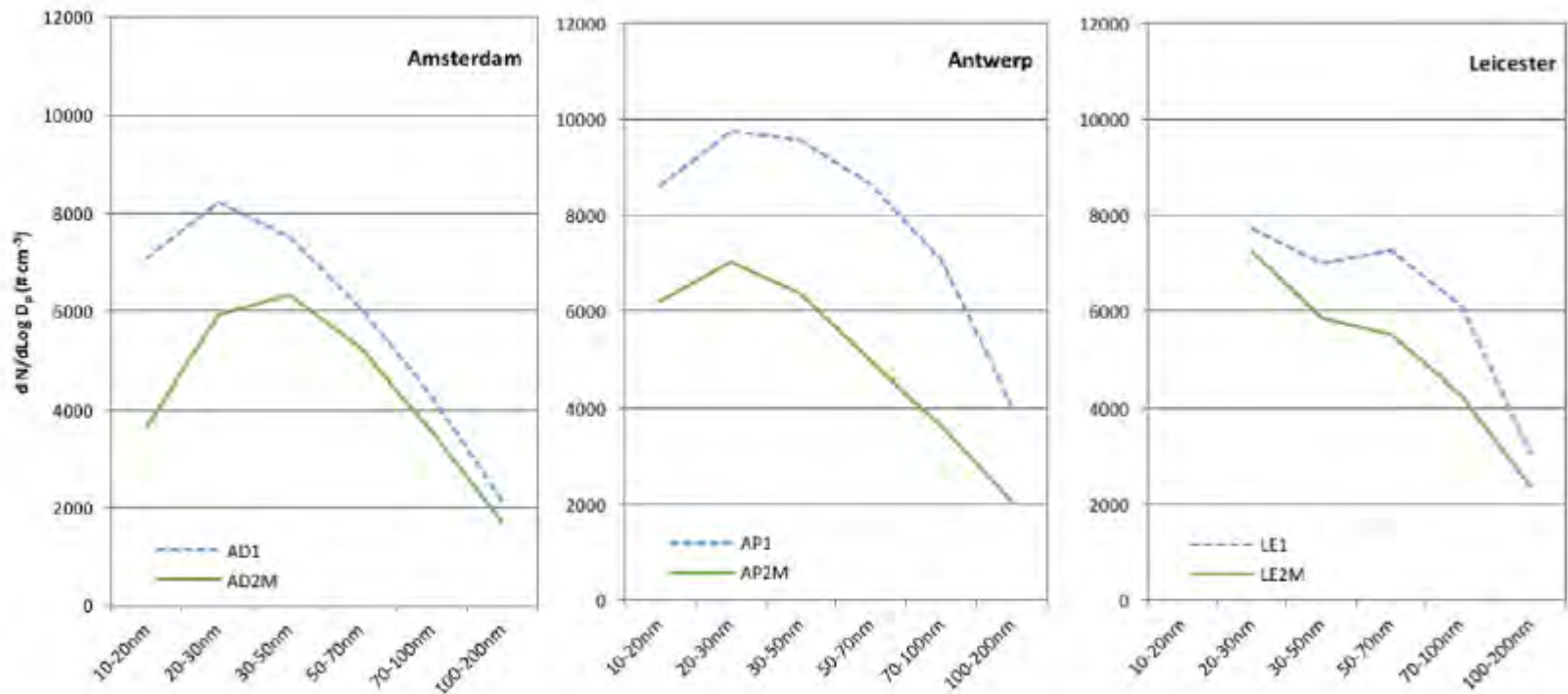


Fig. 8. Average size-resolved PNC ($dN/d\log D_p$) at the fixed (1; dashed blue line) and mobile unit (2M; solid green line) locations in Amsterdam (left), Antwerp (middle) and Leicester (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Relationship to other pollutants

Black carbon (BC) and nitrogen oxides (NO_x)

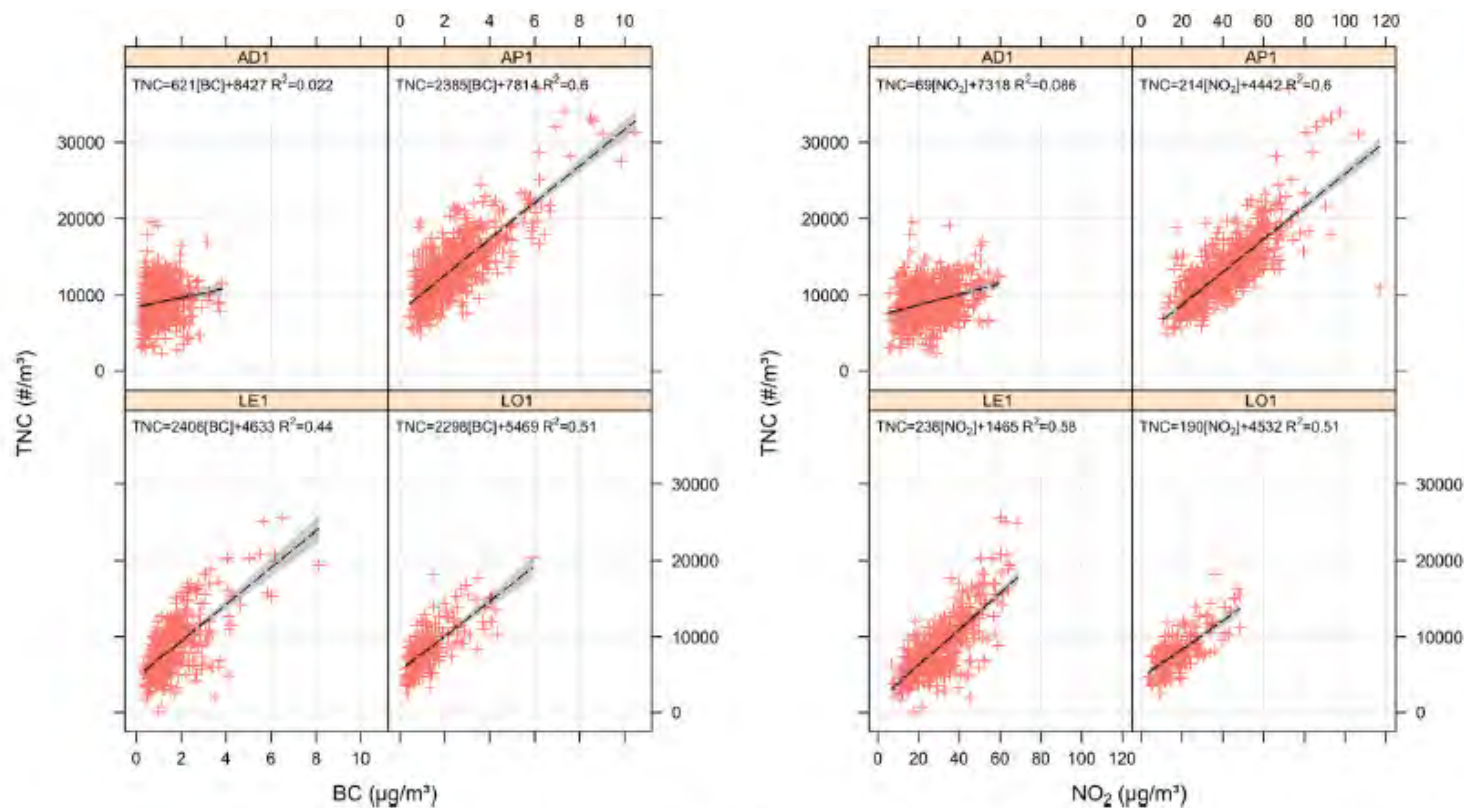


Fig. 5. Regression plots of daily-averaged BC (left; µg/m³) and NO₂ (right; µg/m³) versus TNC (#/cm³) at the fixed monitoring sites (AD1, AP1, LE1 and LO1).

Source: Hofman et al. (2016)

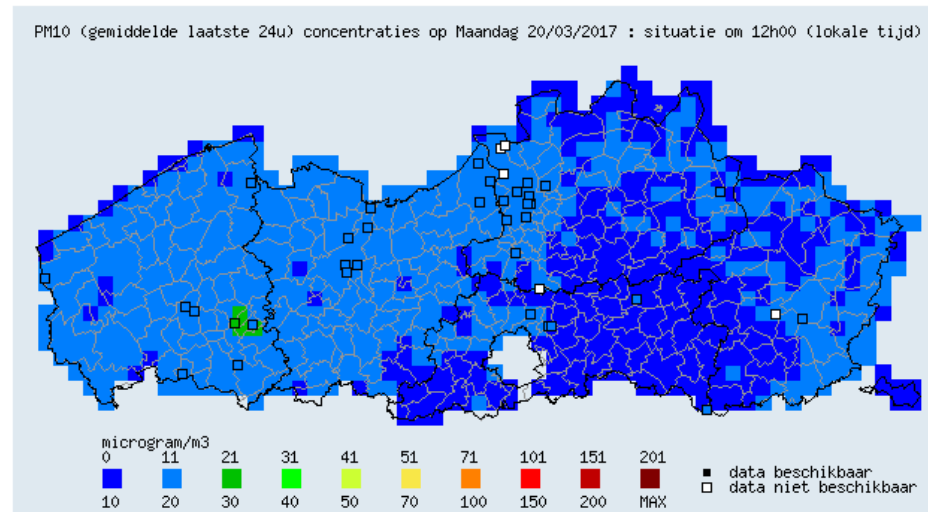
Conclusions

- ▶ **UFP in urban environments in NW Europe**
 - Quality assurance is important for comparable UFP data
 - Large variation in total number concentration
 - Road traffic-related variation in time and space
 - Importance of local source contributions
 - Comparable size distributions between and within cities
 - UFP related with BC and NO₂, but depends on site/period

www.vmm.be

► Website VMM

- More information
- Actual air quality data
- Publications
- ...



Thank you

Questions?

j.staelens@vmm.be

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UFP CONCENTRATIONS IN THE REGION OF BRUSSELS AIRPORT

INTRODUCTION

Emissions from aircraft engines: quantity and size distribution

- » US EPA study (Kinsey, 2009)
- » Depends on fuel consumption, fuel type, engine properties, engine cycle, engine temperature
- » PM emission between 10^{15} to 10^{17} particles per kg fuel
- » Size distribution unimodal with maximum between 3 and ca. 100 nm
- » In general largest contribution to number concentration of particles from 10 to 30 nm



From report EPA-600/R-09/130

INTRODUCTION

UFP in airport regions



Antwerp
12 000 pt/cm³
to 40 000 pt/cm³ near
busy road

	UFP Concentrations (pt/cm ³)	
Peak concentrations UFP	200 000 - 2 000 000 pt/cm ³	Blast fence Take-off (motor load)
250 m from the airport	20 000 pt/cm ³	
2 km from the airport	15 000 pt/cm ³	
15 km from the airport	3 000 pt/cm ³	

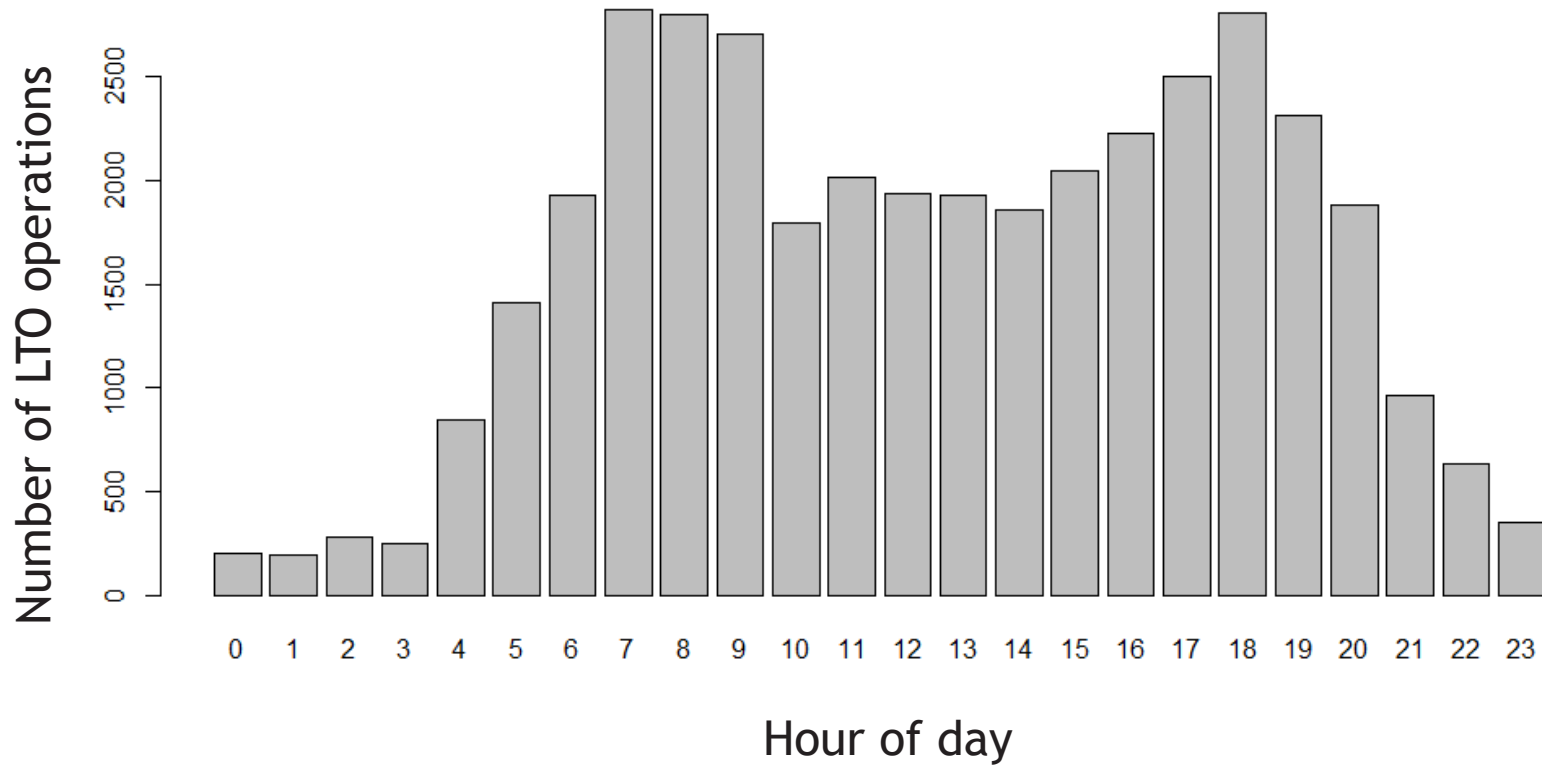
INTRODUCTION

Brussels Airport



INTRODUCTION

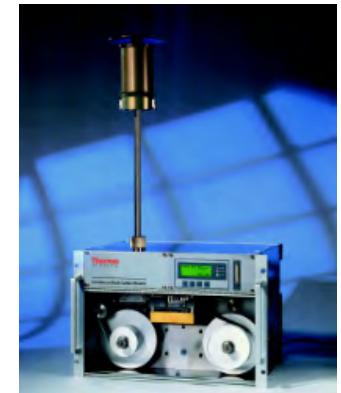
Brussels Airport



MEASUREMENTS

Equipment for UFP monitoring

- » UFP
 - » Scanning Mobility Particle Sizer (SMPS) and CPC
 - » 4 locations
 - » 5-min scans
 - » Synchronized clock
 - » Diffusion correction
 - » 7 Size classes (eg. 10-20 nm)
- » NO_x
 - » Chemiluminescence analyzer
- » BC
 - » Multi-angle absorption photometer (MAAP)
 - » Dual-wavelength aethalometer AE22
 - » Multi-wavelength aethalometer AE33
- » PM10
 - » Reference filter sampler (Leckel SEQ47/50)



PRE-COMPARISON INSTRUMENTATION

September 2015

» GOAL

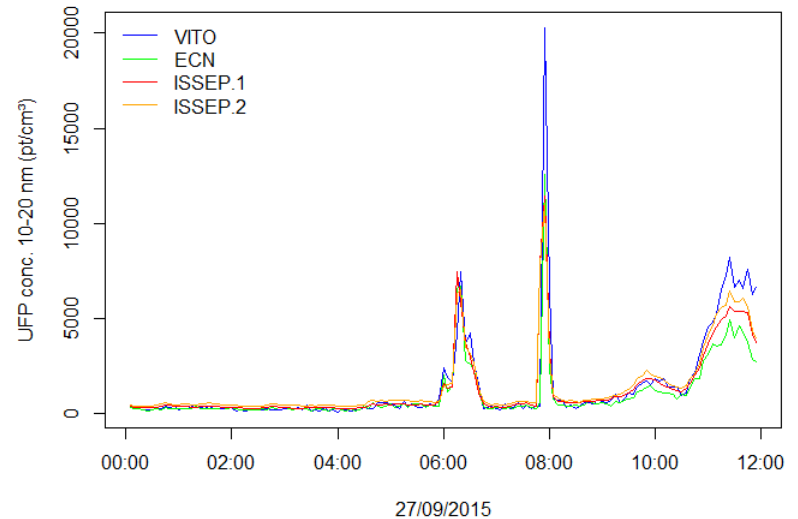
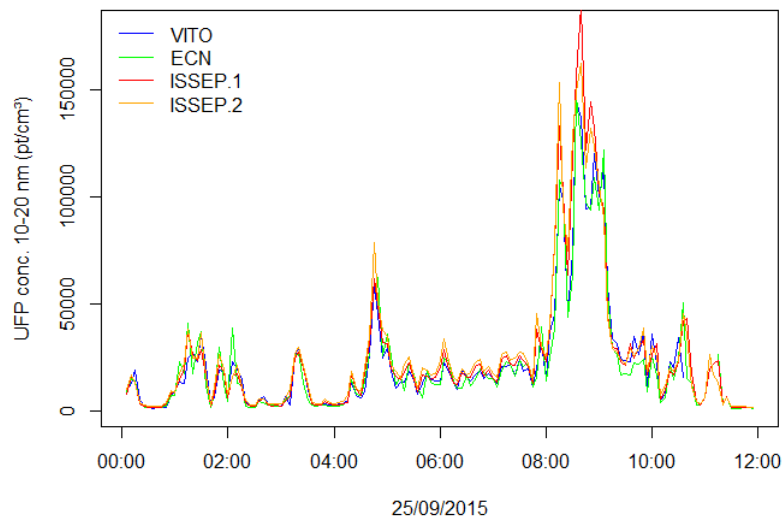
- » Comparison of measurement infrastructure at 1 location
- » 1 month (2 weeks data)
- » Calculating correction factors



PRE-COMPARISON INSTRUMENTATION

September 2015

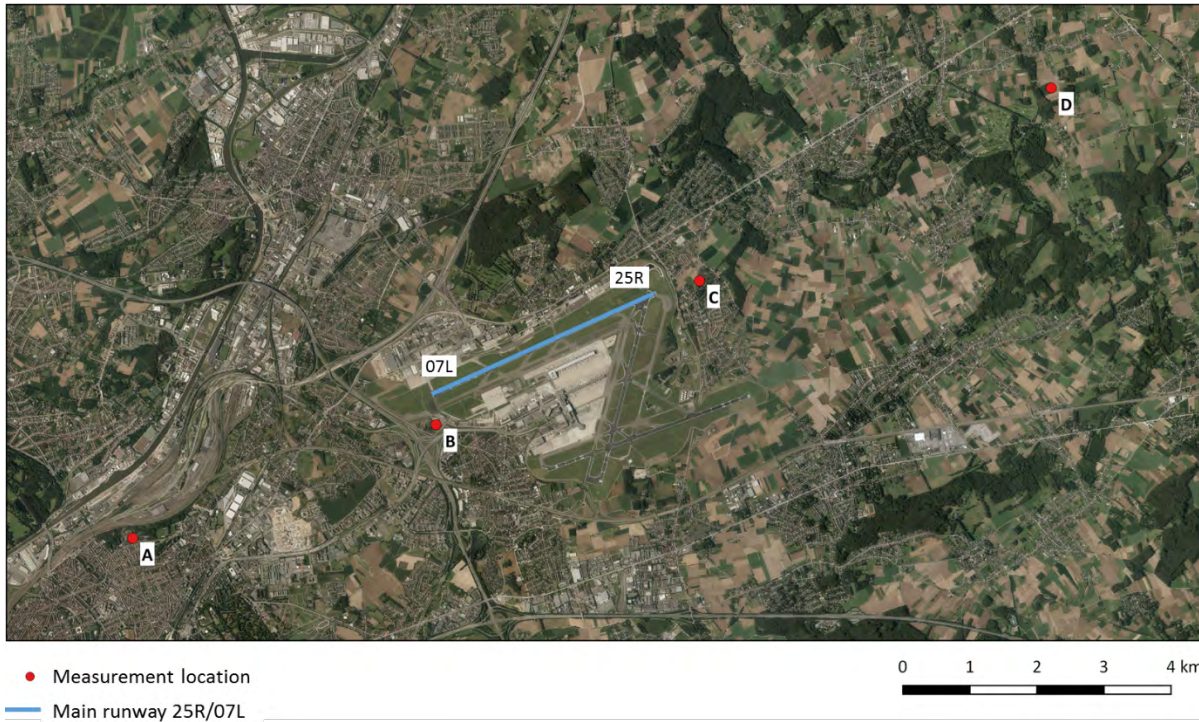
» After applying correction factor: good comparability (predominantly < 5% deviation)



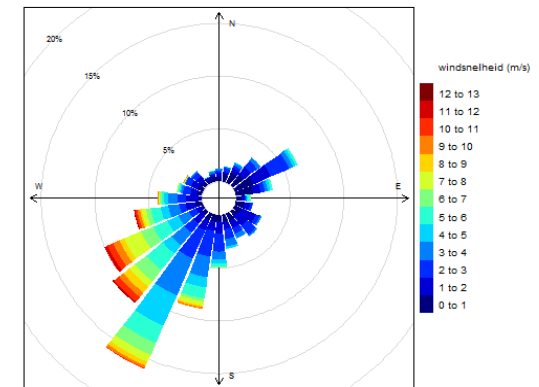
» Also good comparison BC-analyzer after correction

MEASUREMENT LOCATIONS

In line with 07L/25R at varying distance from the airport



Site		Distance
A	Urban	-5 000 m
B	Urban/ Traffic	-250 m
C	Urban	+ 750 m
D	Rural	+ 7 000 m



- » Measurements in October - November 2015
- » Dominant SW wind direction (A and B upwind / C and D downwind)

RESULTS

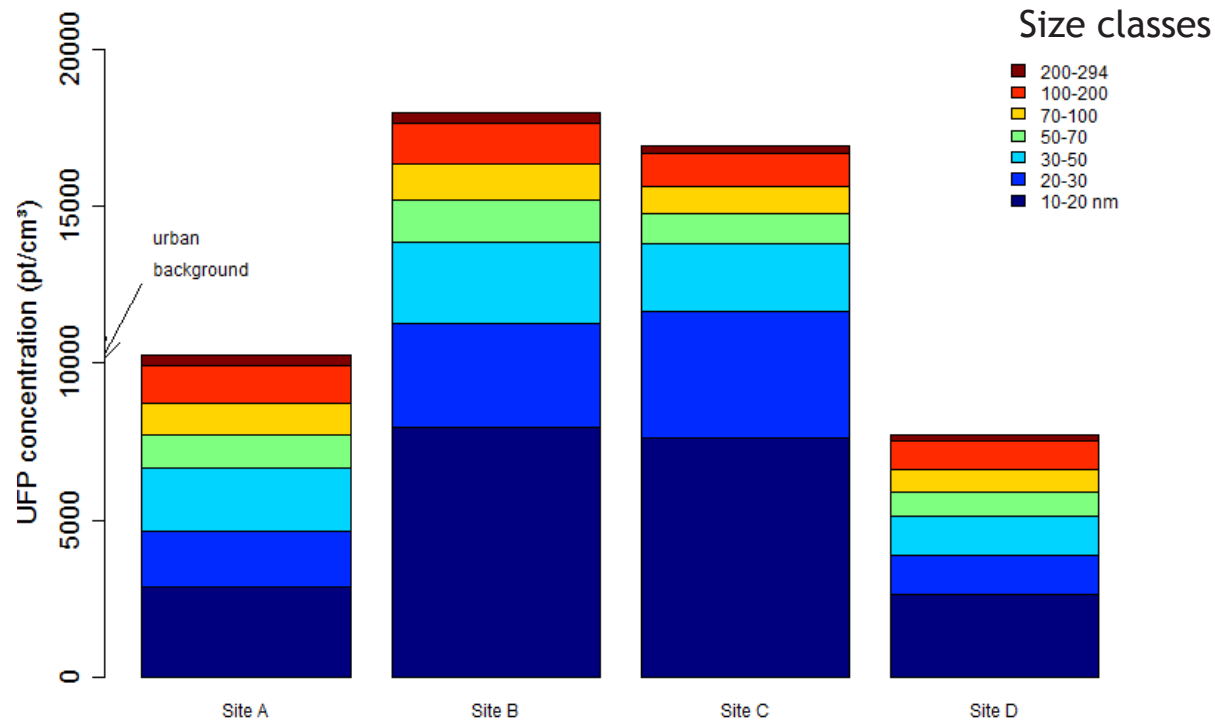
UFP measurements

- » Simultaneous measurements at four locations (17 278 measurements with time-resolution of 5 mins)
- » 7 Size classes (10 - 20 nm/20 - 30 nm/30 - 50 nm/50 - 70 nm/70 - 100 nm/100 - 200 nm/ 200 - 294 nm/ Total UFP 10 - 294 nm)

Distance from airport (m)	Location	Average 10-20 nm		P99 10-20 nm	
		<i>pt/cm³</i>	<i>ratio</i>	<i>pt/cm³</i>	<i>ratio</i>
-5000	A, Urban	2 891	1,1	10 063	0,5
- 250	B, Urban/Ring Road	8 119	3,1	68 992	3,5
+750	C, Urban	7 776	3,0	74 370	3,7
+7000	D, Rural	2 615	1	19 660	1

- » Significant increase at sites near the airport (B, C) in comparison with the more distant sites (A, D), both average as peaks
- » Peak concentration (P99) of 10-20 nm particles is 2 times higher at site D (rural) compared to site A (urban)

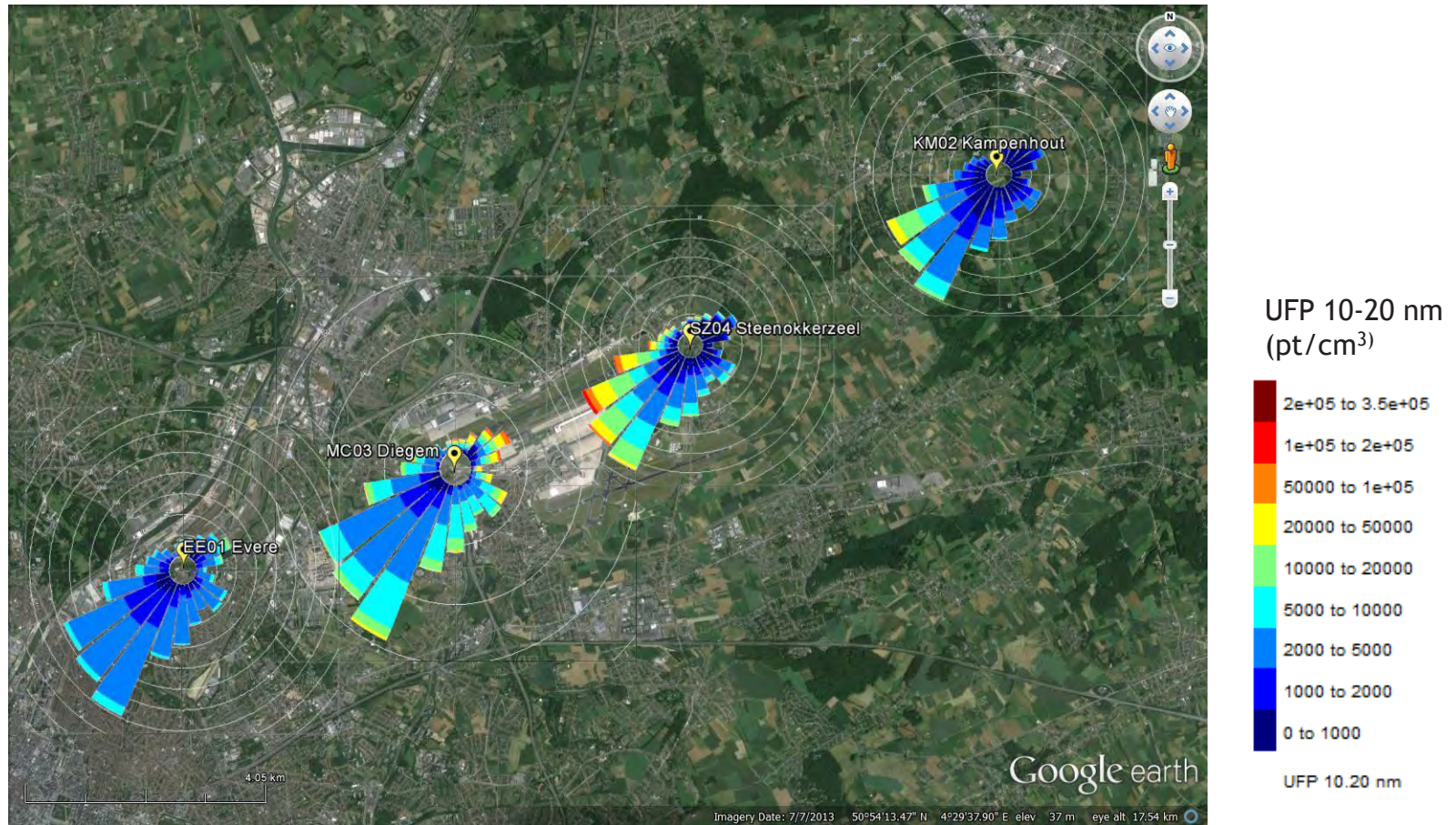
RESULTS



- » 10-20 nm particles are dominant UFP-fraction at sites B (45%) and C (45%) near the airport in contrast to the more remote sites D (35%) and A (28%)
- » The concentration of larger particles > 30 nm is comparable at sites A, B and C, and lower at rural site D

RESULTS

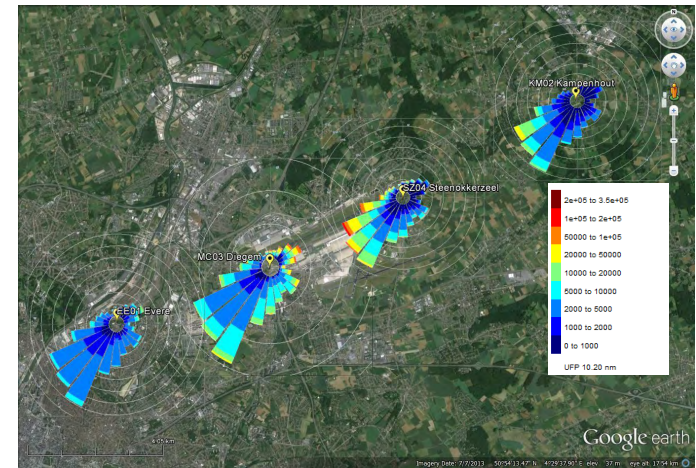
Pollution rose: 10-20 nm UFP concentration In function of wind direction



RESULTS

Pollution rose: 10-20 nm UFP concentration In function of wind direction

- » Increased concentrations in direction of the airport at all sites
- » Peaks of 10-20 nm UFP-concentration under downwind conditions
 - » 6% of time $>50\,000\text{ pt/cm}^3$ at site C under downwind conditions
 - » 11% of time $>50\,000\text{ pt/cm}^3$ at site B under downwind conditions
 - » Never $>50\,000\text{ pt/cm}^3$ at sites A and D
 - » Significantly increased concentration ($>20\,000\text{ pt/cm}^3$) at site D at 7 km from the airport



RESULTS

Estimated downwind contribution of the airport to the number concentration of 10-20 nm particles

» Additive model

	Site A -5000 m	Site B -250 m	Site C +750 m	Site D +7000 m
Mean	-*	20 560	15 440	-*
3 th quartile	-*	27 960	20 380	-*
P90	1 548	58 345	44 626	5 240
P95	4 306	81 776	66 206	9 353
Maximum	19 380	275 900	255 200	36 670
* Not estimated due to overcompensation				

RESULTS

UFP concentration in function of airport activities

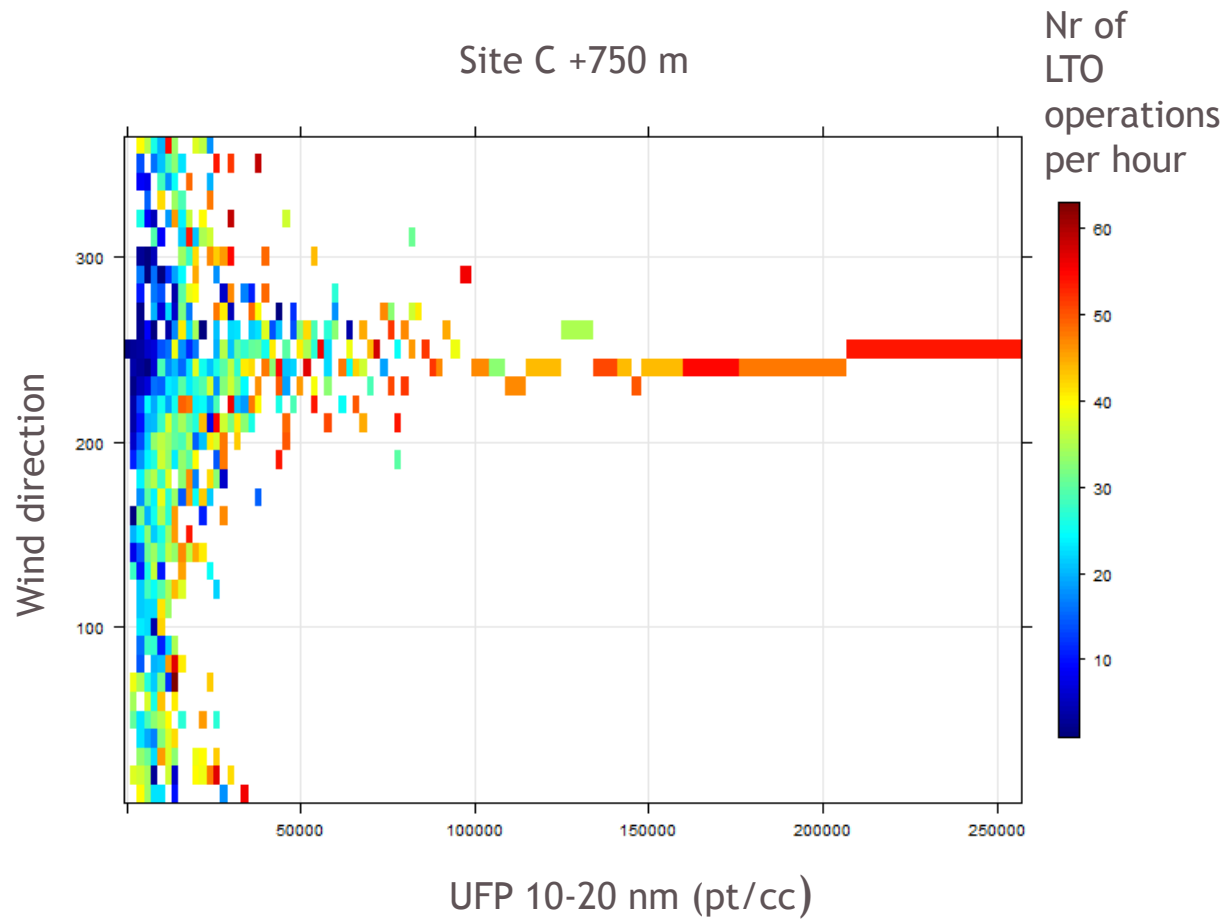
DAG	25R		07L		25L		07R		19		01	
	opstijgen	landen	opstijgen	landen	opstijgen	landen	opstijgen	landen	opstijgen	landen	opstijgen	landen
jan/15	7347	2382	17	112	1	4739	432	0	326	246	3	316
feb/15	6760	2013	101	25	1	4539	1036	9	83	71	1	1041
mrt/15	7586	2214	138	195	7	5047	1276	2	122	72	26	1229
apr/15	6615	1896	134	113	6	4384	2944	1	87	1	1	2790
mei/15	8691	2729	69	120	1	4936	962	0	487	865	0	828
jun/15	2947	6952	397	400	0	2	0	0	4810	201	2522	2451
jul/15	3643	8497	259	547	0	0	0	0	6071	7	767	805
aug/15	8635	4657	605	961	0	3331	474	1	330	184	19	130
sep/15	7825	2215	108	144	4	5169	2421	5	217	133	4	2223
okt/15	7688	2276	207	103	4	5063	2103	116	99	17	3	1985
nov/15	8726	2814	1	0	0	5703	0	0	165	25	38	56
dec/15	8166	2619	0	0	3	5357	0	0	166	79	0	0

- » Access to LTO data
- » Number of departures from 25R in October and November 2015 comparable with other months excl. June and July
- » Representative for year-round activities
- » Comparable with LTO numbers of 2016

RESULTS

UFP concentration in function of airport activities

- » Hourly aggregated data
- » LTO data runway 25R
- » Wind direction
- » 10-20 nm UFP concentration



RESULTS

UFP concentration in function of airport activities

- » Linear regression model (based on hourly data)
 - » Dependent variable : UFP-concentration 10-20 nm
 - » Independent variables: interaction of departure and arrivals at runway 25R with wind direction (factor variable), wind speed and height of the atmospherical mixing layer
 - » Use of interaction terms because effect of LTO at 25R on UFP-concentration varies with wind direction
- » Site C (+750 m)
 - » 60% of the variability in 10-20 nm UFP-concentration is explained by the model ($R^2_{\text{adj}} = 0,60$)
 - » Significant variables are LTO activities at 25R under downwind conditions
 - » Model is less performant for larger sized UFPs

klasse	10-20	20-30	30-50	50-70	70-100	100-200	200-294
R ²	0,60	0,55	0,32	0,28	0,31	0,33	0,40

- » Site D (+7000 m)
 - » 51% of the variability in UFP-concentration explained by the model ($R^2_{\text{adj}} = 0,51$)
- » Site B (-250 m): 32% explained by the model, site A (-5000 m): only 9%

RESULTS

Other parameters

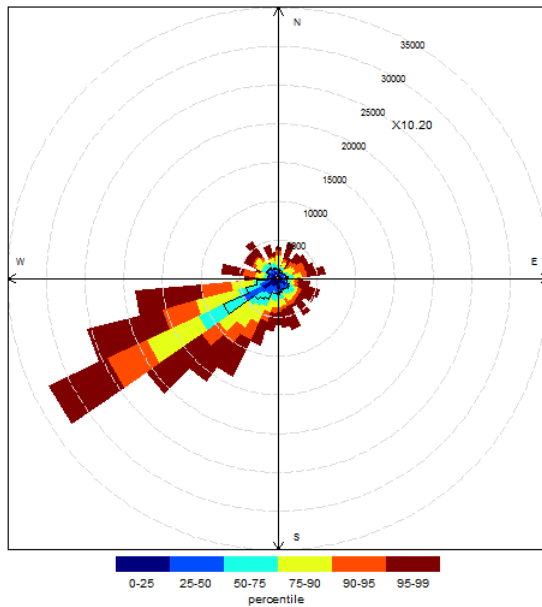
		Site A Urban	Site B Urban/traffic	Site C Urban	Site D Rural
BC	1 st quartile	0.9	0.9	0.8	0.5
	Median	1.4	1.4	1.3	1.0
	Mean	1.9	1.9	1.8	1.3
	3 rd quartile	2.4	2.4	2.3	1.8
	Maximum	16.8	16.8	13.1	6.7
NO _x	1 st quartile	26.6	32.7	19.1	11.8
	Median	45.3	55.7	32.2	21.5
	Mean	65.1	83.1	48.3	29.6
	3 rd quartile	76.1	97.5	55.8	35.3
	Maximum	828.6	1 417.7	485.6	335.1
PM ₁₀	1 st quartile	17	16	15	14
	Median	21	21	19	18
	Mean	24	25	21	19
	3 rd quartile	30	31	25	24
	Maximum	48	69	40	40

- » The contribution from aircraft emissions to BC, NO_x and PM₁₀ is limited in comparison with the contribution from other sources.
- » Strong contrast with UFP number concentration

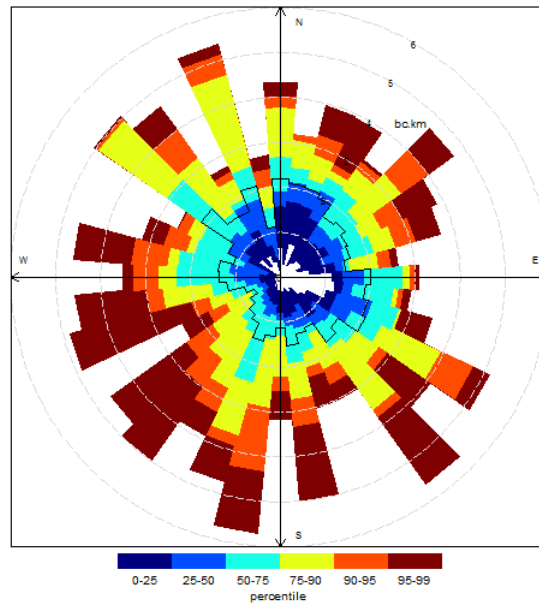
RESULTS

Other parameters

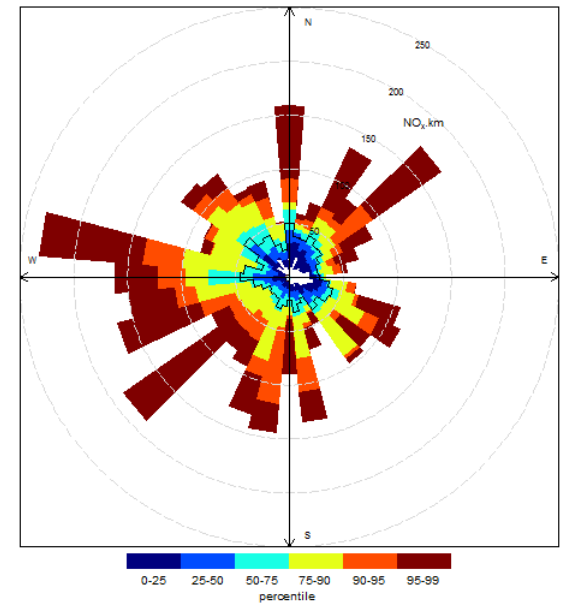
UFP 10-20 nm



BC



NO_x



Location D +7000 m

CONCLUSION

UFP concentration in the region of Brussels Airport

- » The UFP-concentrations are variable in time as a result of the dynamic of the UFP sources and meteorological conditions
- » UFP-concentrations in the airport region decrease with distance, however significant contributions are observed at 7 km from the airport (most distant site in this study)
- » The 10-20 nm UFPS is the dominant fraction near the airport
- » The 10-20 nm UFP contribution from the airport under downwind conditions at nearby sites is estimated to be in the range of:
 - » 20 000 to 30 000 pt/cm³ during 25% of the time
 - » 45 000 to 60 000 pt/cm³ during 10% of the time
 - » 65 000 to 80 000 pt/cm³ during 5% of the time
- » There is a clear relationship between aircraft operations, wind direction and the 10-20 nm UFP-concentration in the region of Brussels Airport

CONTACT INFORMATION

- » Report available at <https://www.vmm.be/publicaties/ufp-en-bc-metingen-rondom-de-luchthaven-van-zaventem> (In Dutch, extensive summary in English)
- » Article submitted: Spatiotemporal variation in ultrafine particles near Brussels Airport (Belgium)

Jan Peters
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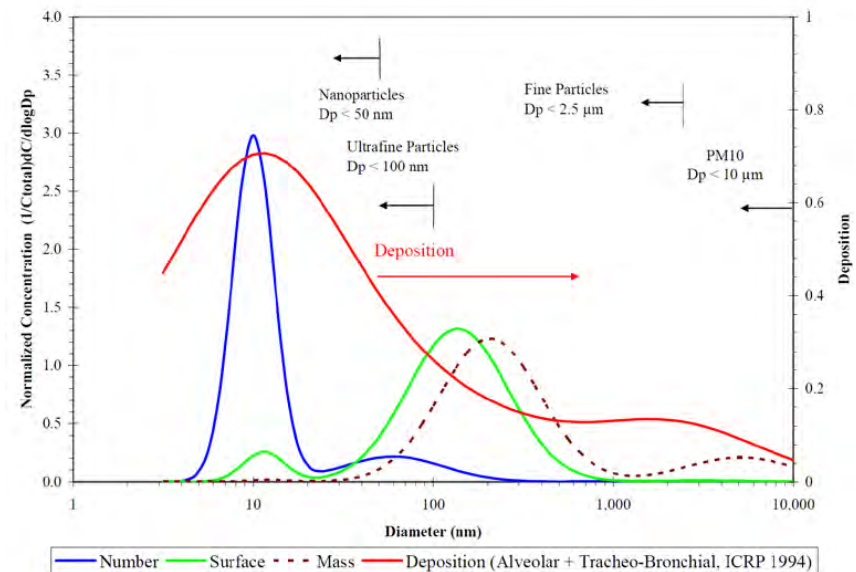
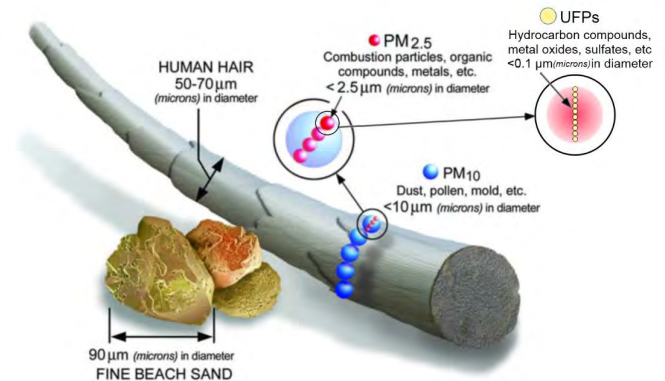
Evelien Frijns
evelien.frijns@vito.be
VITO NV | Boeretang 200 | 2400 Mol
Phone tel: +32 14 33 53 67



INTRODUCTION

Ultrafine particles (UFP)

- » < 100 nm in diameter
- » Limited contribution to the mass concentration
- » High contribution to the number concentration
- » Emitted by combustion engine
- » After emission:
 - » In suspension for minutes - hours - days
 - » Growth, reactions
 - » Eventually :
 - » Deposition
 - » Wash out
 - » Inhalation



MEASUREMENT LOCATIONS

A (Evere EE01)



B (Diegem MC03)



C (Steenokkerzeel SZ02 en SZ04)



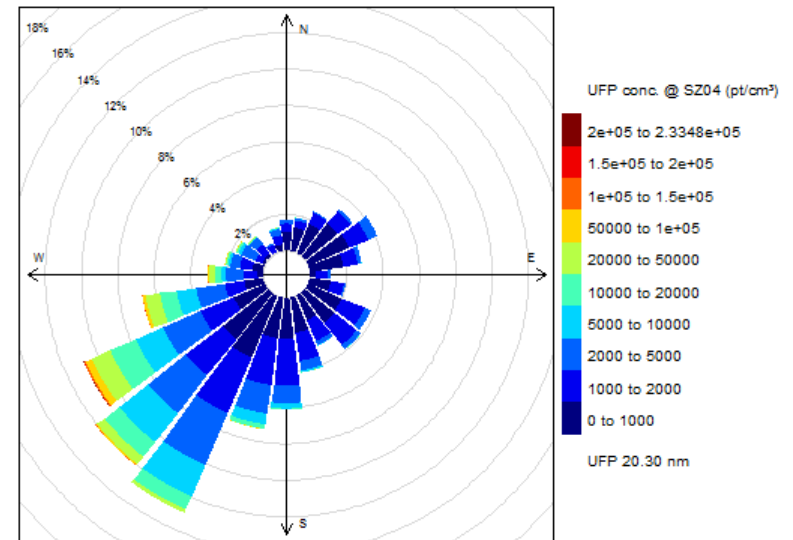
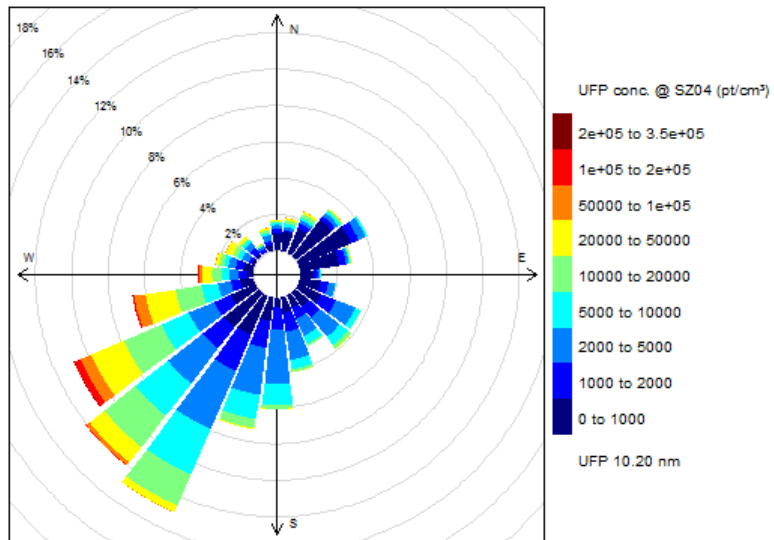
D (Kampenhout KM02)



RESULTS

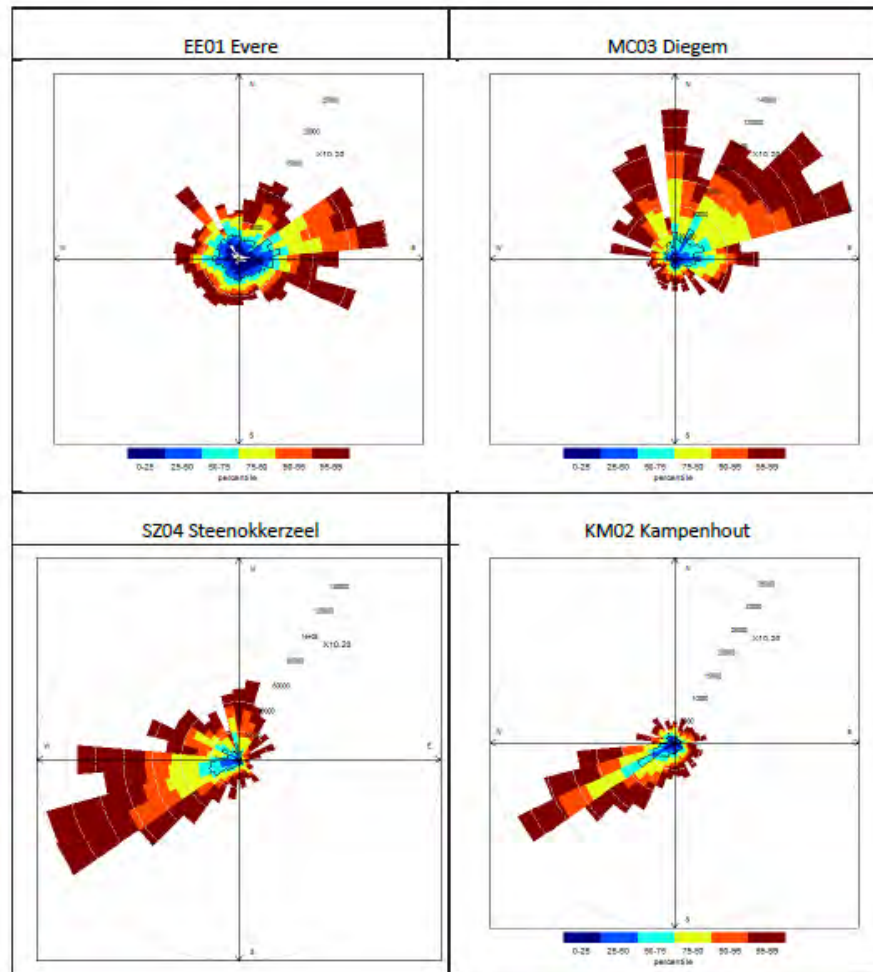
In function of the wind direction

» Pollution roses (example site C)



RESULTATEN

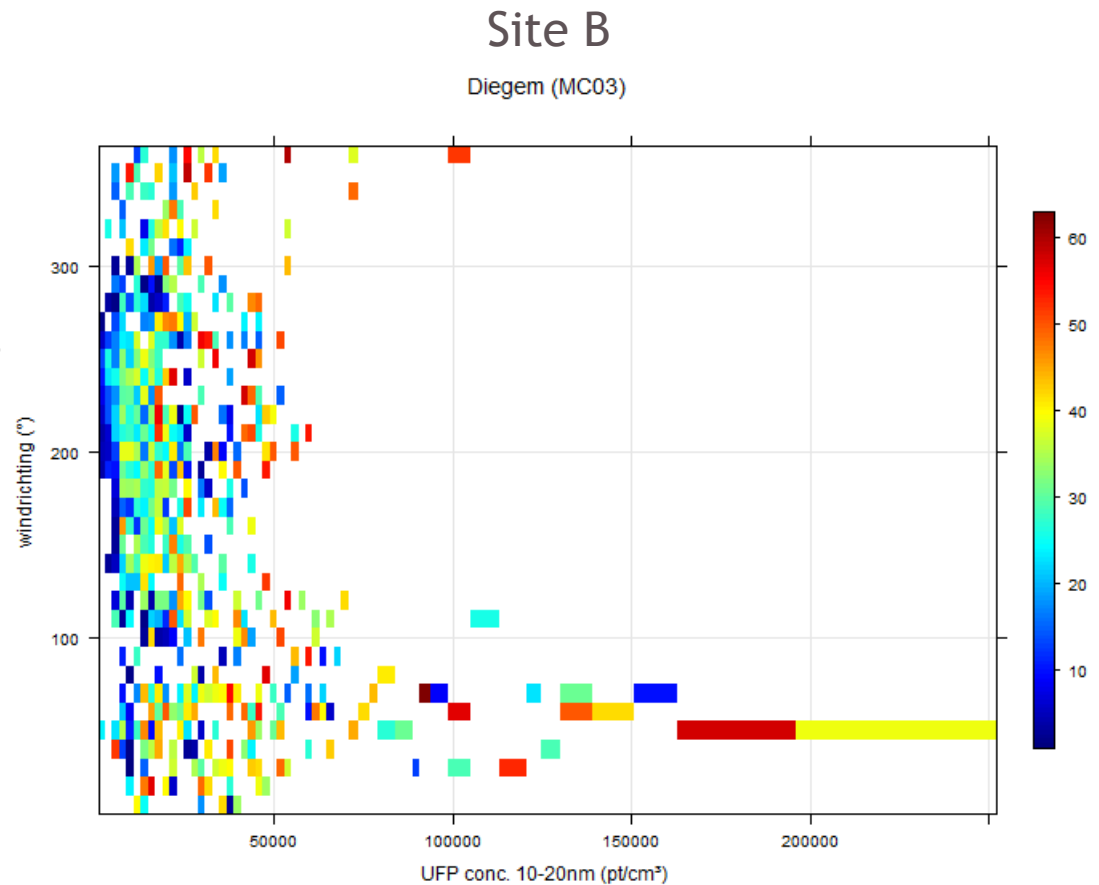
Polaire percentielplots



RESULTS

UFP concentration in function of airport activities

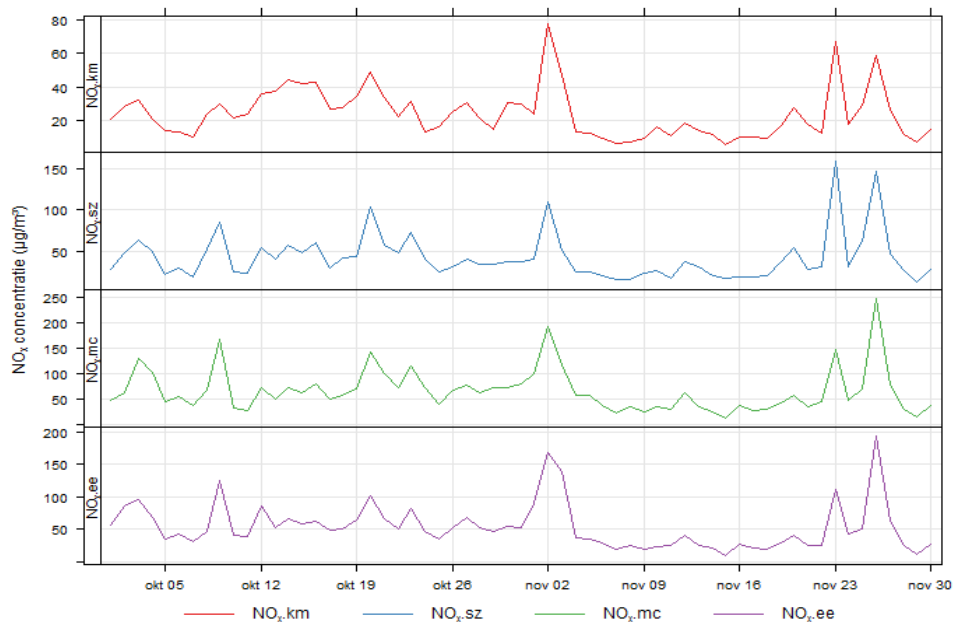
- » Hourly aggregated data
- » LTO data
- » Wind direction
- » 10-20 nm UFP concentration
- » Period of downwind conditions much shorter at site B



RESULTATEN

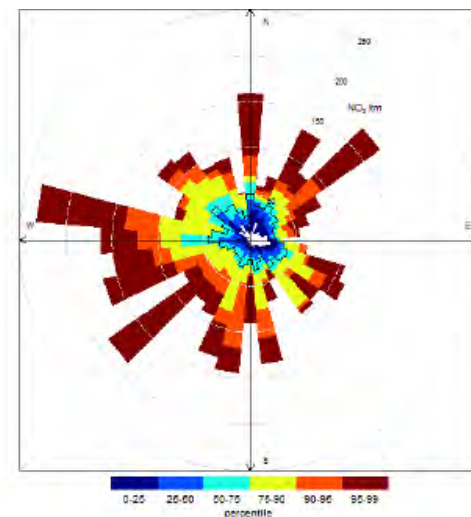
Andere parameters: NO_x

- » De dag-tot-dag fluctuaties van de NO_x concentratie is vergelijkbaar tussen de vier meetlocaties
- » De hoogste concentraties worden waargenomen in Diegem, gevolgd door Evere en Steenokkerzeel



	NO _x KM02	NO _x SZ04	NO _x MC03	NO _x EE01
1 ^{ste} kwartiel	11,8	19,1	32,7	26,6
Mediaan	21,5	32,2	55,7	45,3
Gemiddelde	29,6	48,3	83,1	65,1
3 ^{de} kwartiel	35,3	55,8	97,5	76,1
Maximum	335,1	485,6	1417,7	828,6

KM02 Kampenhout



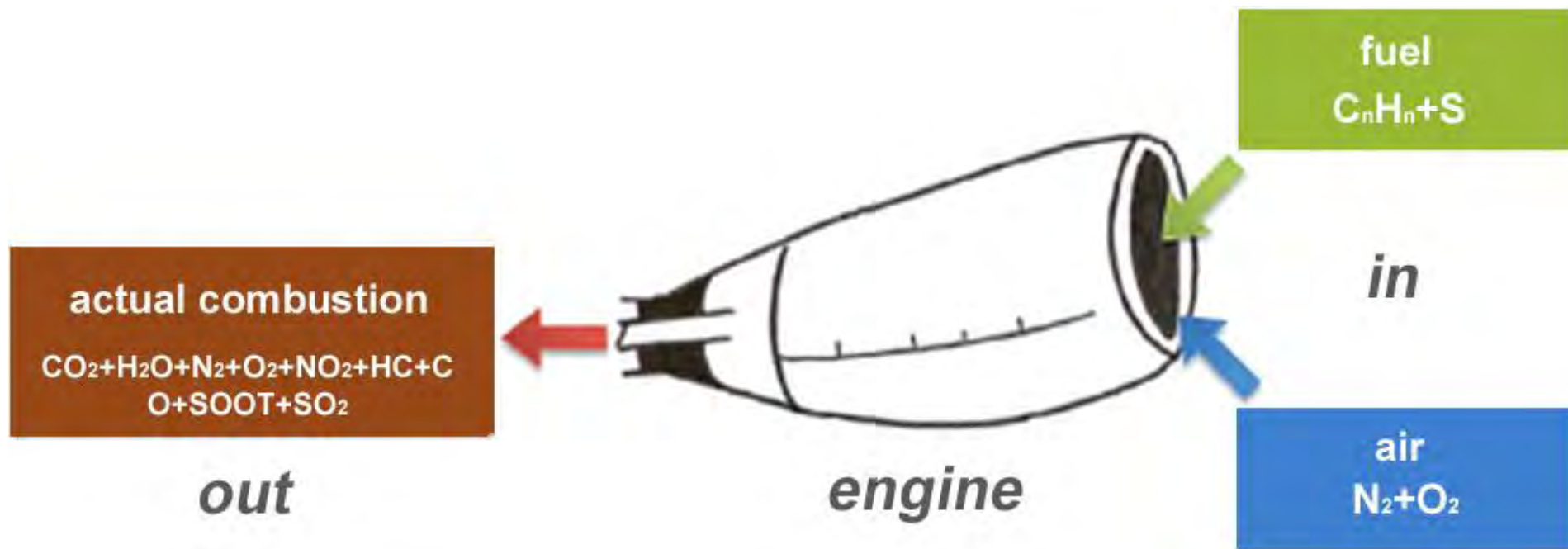


Airport Region Conference
Workshop on ultra-fine particles
23 March 2017

Airports, Emissions and Residents
Dominique Lazarski
President



Aviation, which pollutants?



Drawing from « Les émissions polluantes des aéronefs » (*polluting emissions by aircrafts*) – 2015 - STAC / Service Technique de l'Aviation Civile, (*technical services of the French civil aviation administration*)



Aviation's pollution, double jeopardy

At high altitude : impact on climate change

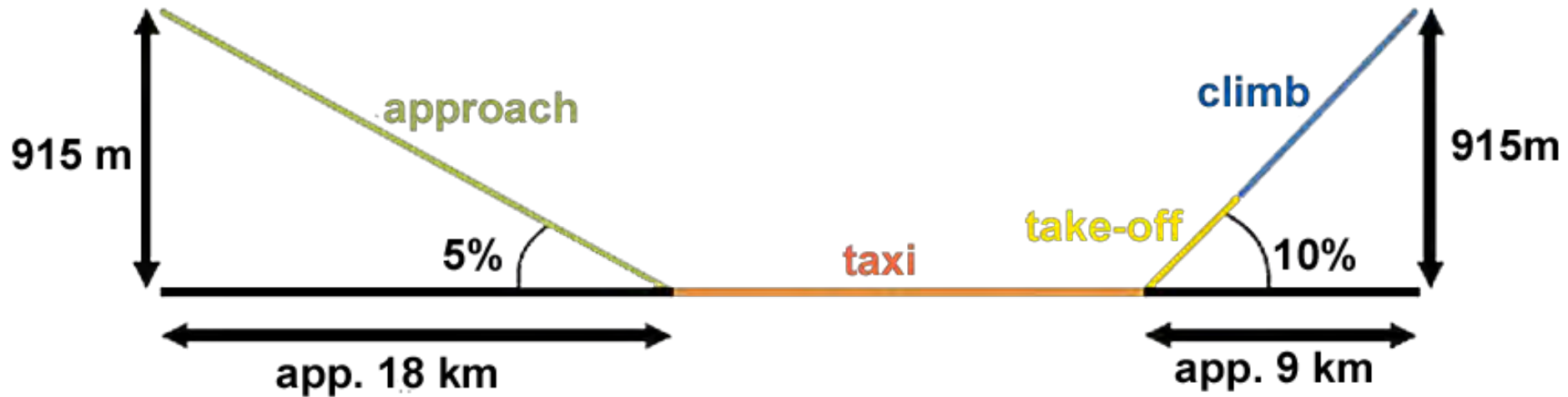
- Called greenhouse gas :
- CO₂, H₂O (contrails), Nox, etc.

At low altitude : impact on local pollution

- Two main pollutants: nitrogen oxides (NO_x), and particles including ultra-fine particles, and several other pollutants including sulphur oxide (SO), volatile organic components VOC, carbon monoxide CO
- Emissions at low altitude are defined by ICAO - landing / take-off cycle (LTO cycle)



The LTO Cycle



Drawing from « Les émissions polluantes des aéronefs » (*polluting emissions by aircrafts*) – 2015 - STAC / Service Technique de l'Aviation Civile, (*technical services of the French civil aviation administration*)



What is the problem?

Kerosene =
Diesel fuel

Aviation =
Diesel

In terms of types of emissions and impact on
public health



Impacts on Health

NOx and particles (the finest the more dangerous) are very dangerous for bronchi

**no protection against them
an invisible enemy**

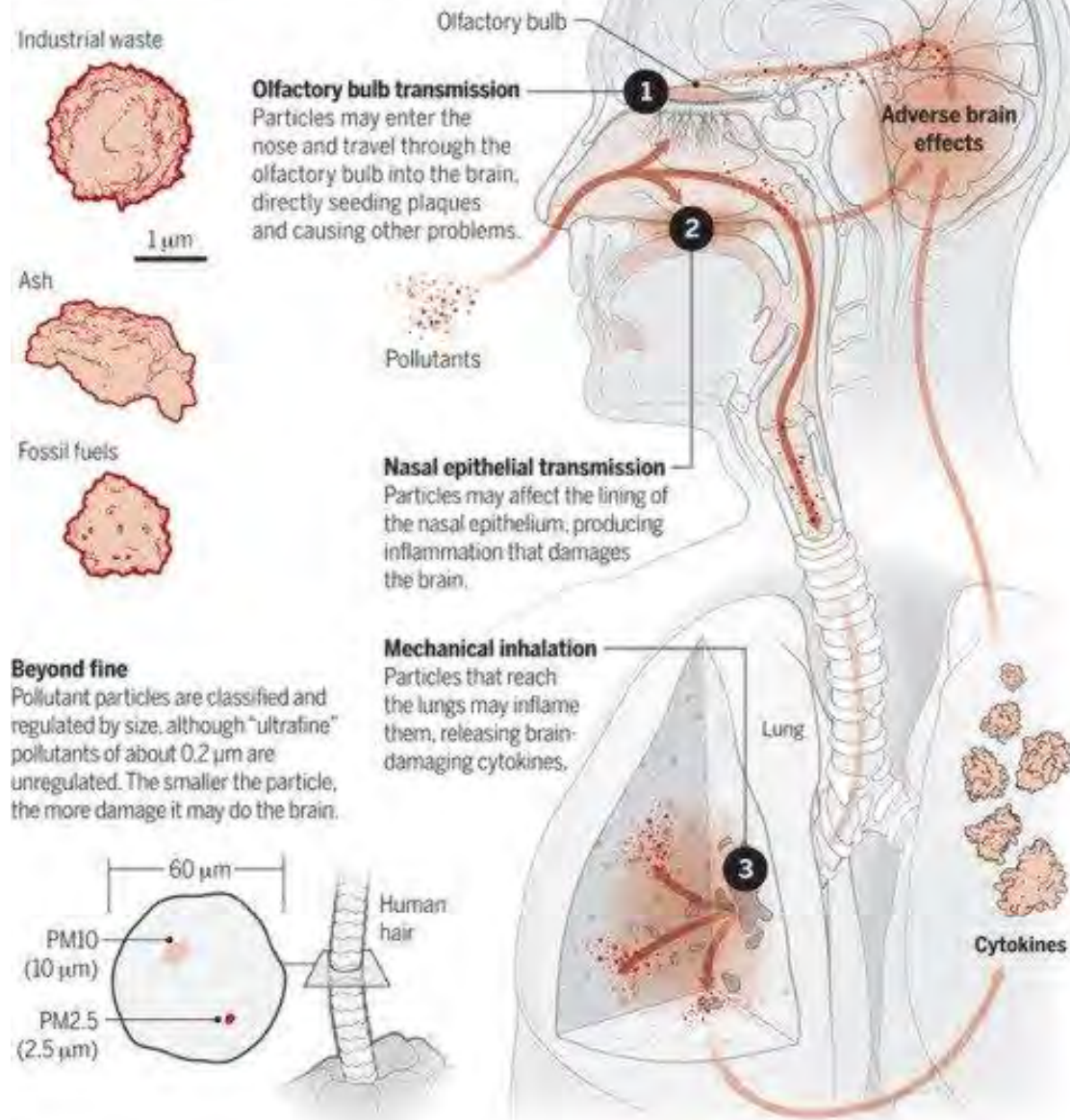
Effect on Health: increase of lung / bronchi diseases in the vicinity of airports

- **Infant bronchiolitis**
- **Asthma – the number of persons suffering from asthma has doubled in the last 20 years**
- **Cardiovascular diseases**
- **Cancer (WHO claims that diesel has proven with certainty to cause cancer)**
- **Death**

Among the residents in the vicinity of airports, infants, children and elderly are the more affected

Modes of attack

Pollutant particles might make their way to the brain and damage it directly, or they might attack it from a distance, by triggering the release of inflammatory molecules.



Impacts on the brain?

"Some of the health risks of inhaling fine and ultrafine pollutant particles are well-established, such as asthma, lung cancer, and, most recently, heart disease. But a growing body of evidence suggests that such exposure can also **harm the brain, accelerating cognitive aging**, and may even increase risk of Alzheimer's disease and other forms of dementia."

The polluted brain

Emily Underwood*

+ See all authors and affiliations

Science 27 Jan 2017:

Vol. 355, Issue 6323, pp. 342-345

DOI: 10.1126/science.355.6323.342

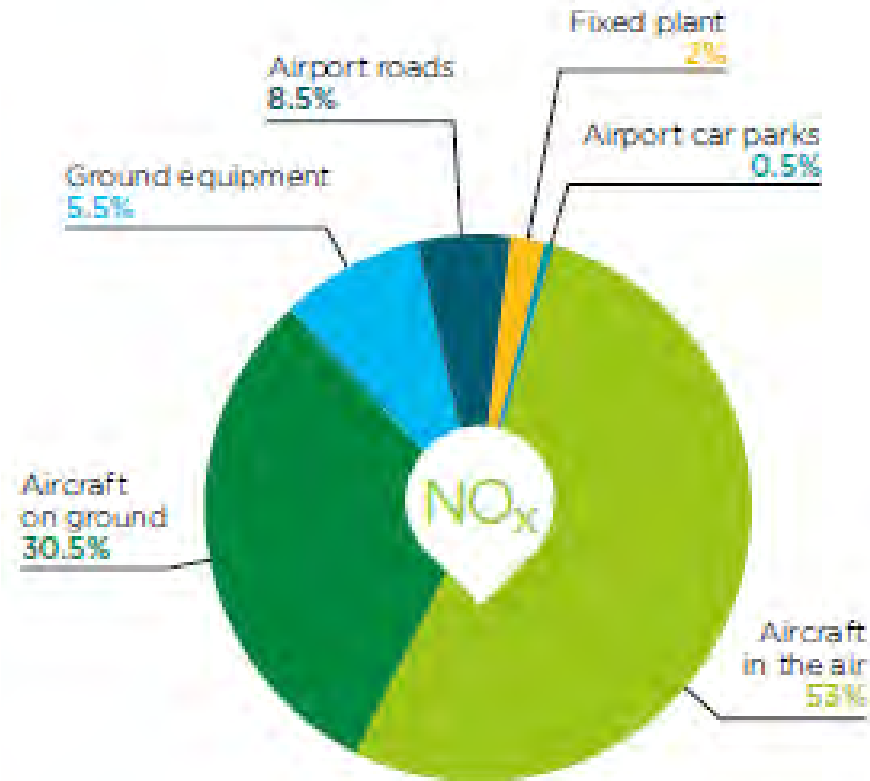


No abatement system

- Aviation has not abatement system available to avoid or even reduce emissions.
- Between 1990 and 2015, emissions of NO_x from aviation have doubled while emissions from other transports were reduced by 40%
- With the increase of traffic forecasted in the next 10 years, NO_x for example will increase by 43% between 2014 and 2035 (2016 European Aviation Environmental Report) – on the mid-term aviation will be the biggest contributor of emissions compared with other modes of transport



Airport emissions, the example of NO_x



Of the total emissions of NO_x at an airport, 83.5% is due to aircrafts

On-airport emission sources for oxides of nitrogen (NO_x) for Gatwick (2010) and Heathrow (2013) airports – in *UK aviation and air quality - An information paper : Our contribution, the challenges and opportunities* by Sustainable Aviation

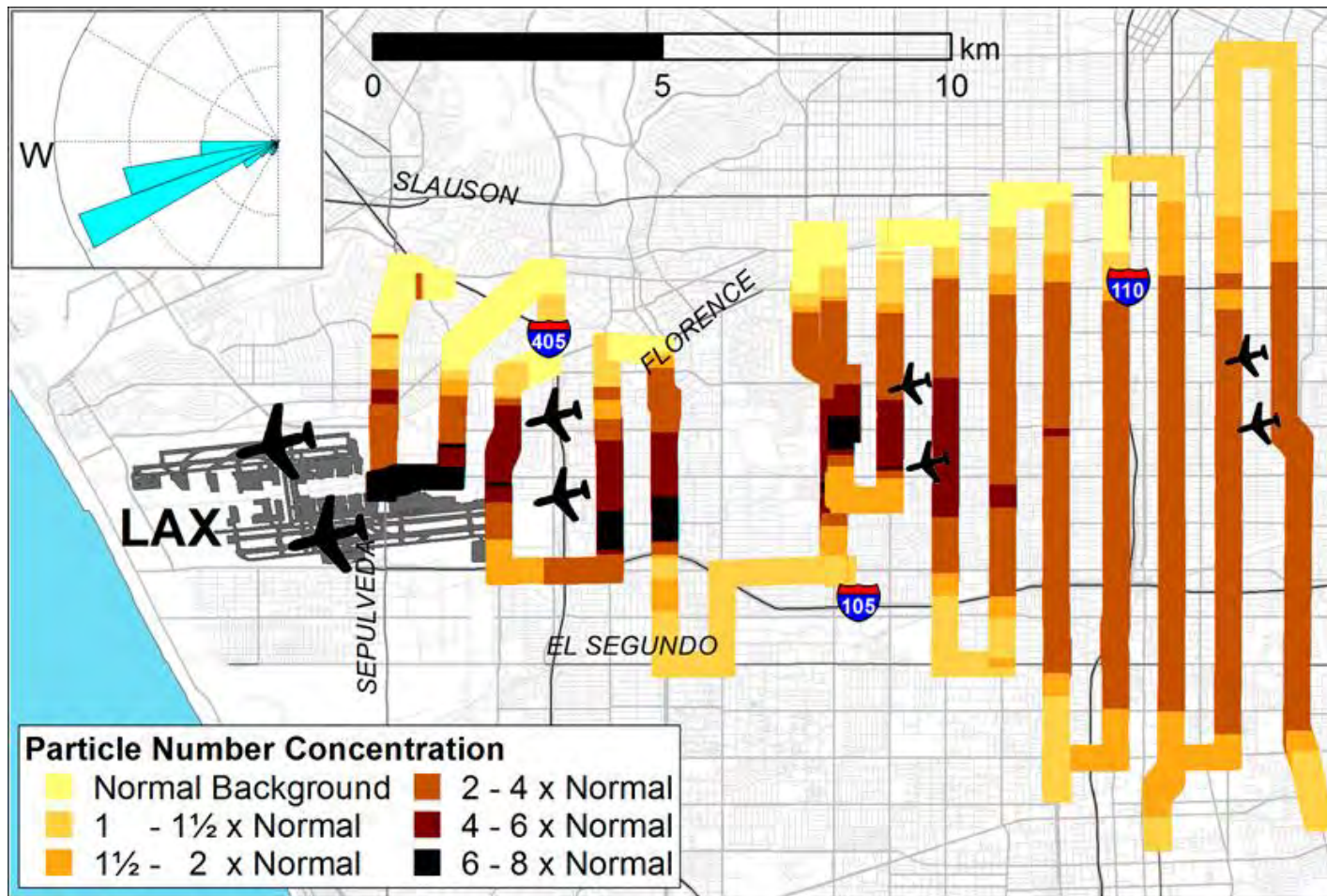


Airport emissions, ultra-fine particles

- Several studies in Europe
 - Copenhagen (2009-2011) – measures at the airport show that UFP are 3 times higher than in the more polluted streets of the town
 - Amsterdam (2012) – UFP are 3 times higher 7km downwind of Schiphol airport
- Los Angeles airport - several studies evidence a higher concentration downwind from the airport



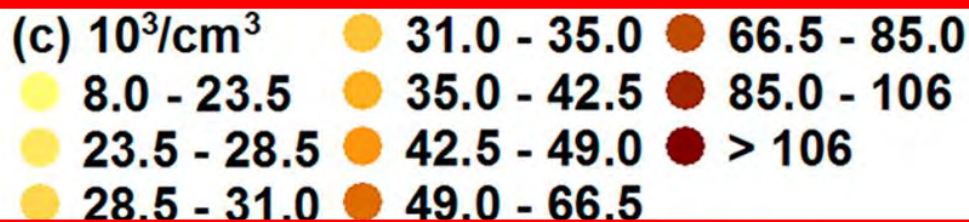
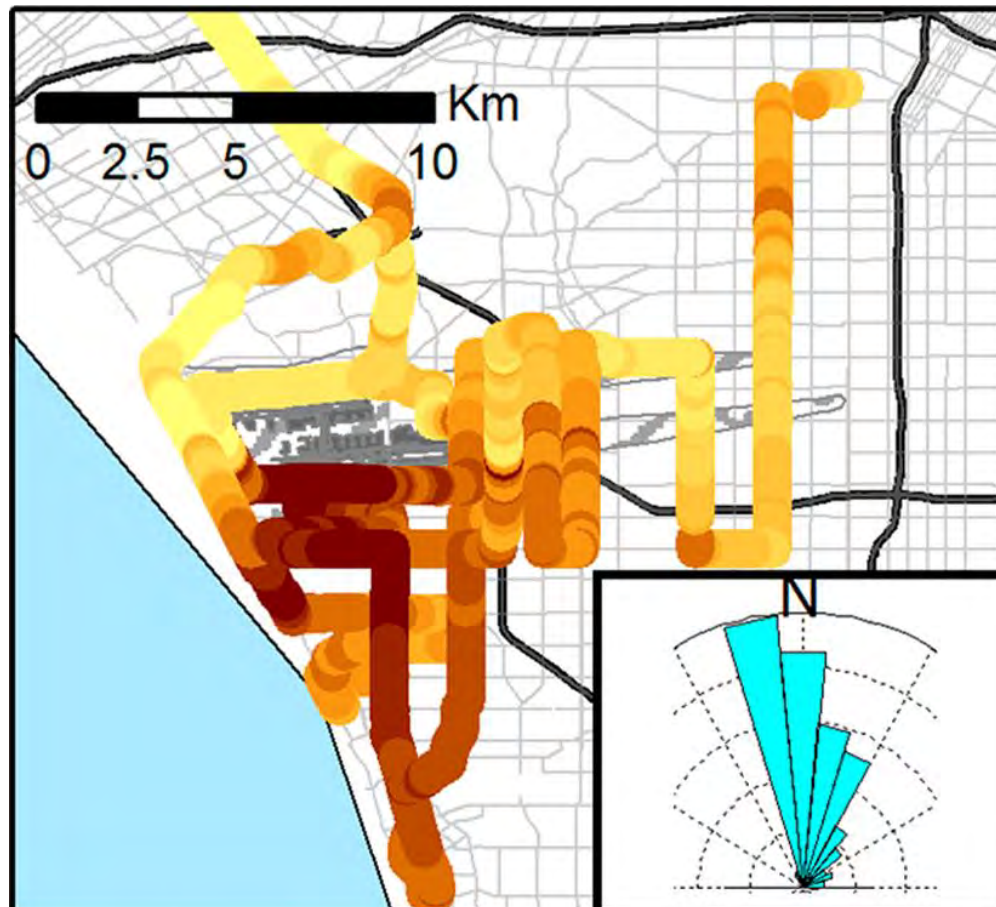
LAX study - 2014



Emissions from an international airport increase particles concentrations 4-fold at 10 km downwind - Neelakshi Hudda, Tim Gould, Kris Hartin, Timothy V. Larson, and Scott A. Fruin – in ACS Publications (American Chemistry Society) – Environmental Science & technology 2014



LAX study - 2014



Emissions from an international airport increase particles concentrations 4-fold at 10 km downwind -
 Neelakshi Hudda, Tim Gould, Kris Hartin, Timothy V. Larson, and Scott A. Fruin – in ACS Publications (American Chemistry Society) – Environmental Science & technology 2014



LAX study – 2014 - quote

These results suggest that **airport emissions are a major source of particles in Los Angeles**

that are of the **same general magnitude as the entire urban freeway network**

They also indicate that the **air quality impact areas of major airports may have been seriously underestimated**



A trick to reduce emissions

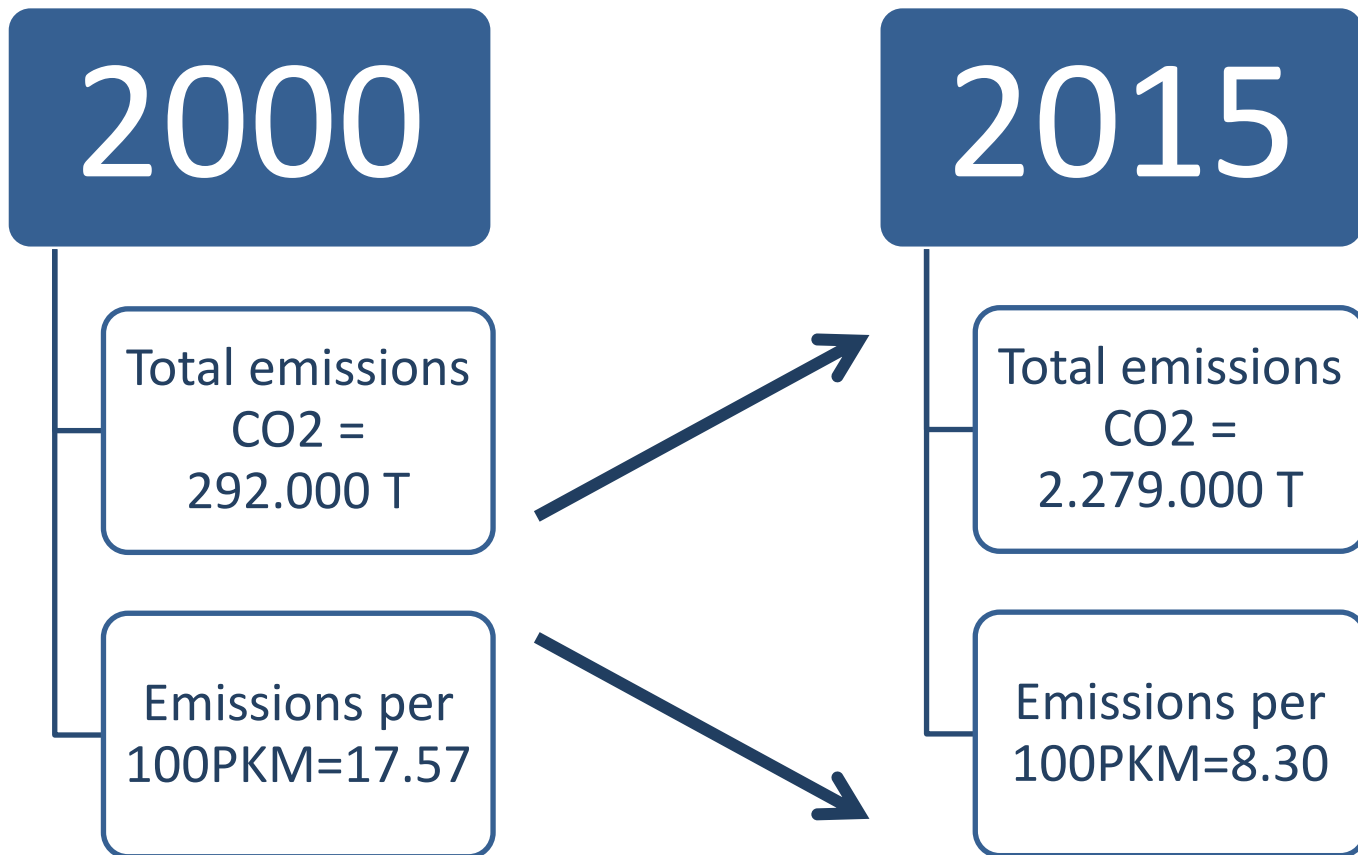
A magic trick : Emissions per PKM equivalent

- If the number of passengers (or tons of freight) increases faster than the number of movements, which is the case at present since a big effort is put on the filling ratio of planes : it will be concluded that a reduction of air pollution has been achieved when in fact pollution will have increased!
- For example, if the emissions increase by 30% and the number of passengers increase by 50%, the authorities will declare that emissions will have decrease by 14%
- Instead of taking actions to reduce emissions for the sake of the population, public authorities manipulate figures to make them look better



Manipulation of data

The example of Beauvais-Tillé airport (France)



The same applies to all types of emissions



Our expectations

There is a structural imbalance between the powerful aviation lobby and the residents living in the vicinity of airports.

Economic impacts of air transport are magnified to seduce politicians and decisions are only taken in the light of one argument: jobs, jobs, jobs

It is time to think public health - Public authorities are accountable to the citizens, they must take responsibility

The role of public authorities, governments and local authorities is to protect the populations and adopt regulations that will result in a reduction of toxic emissions



FRAPEST

**Flugzeug-Abgase
können tödlich sein!**

→ The challenge of UFP at Copenhagen Airport



Jesper Abery Jacobsen
Senior Project Manager, Environmental Affairs

November 2016

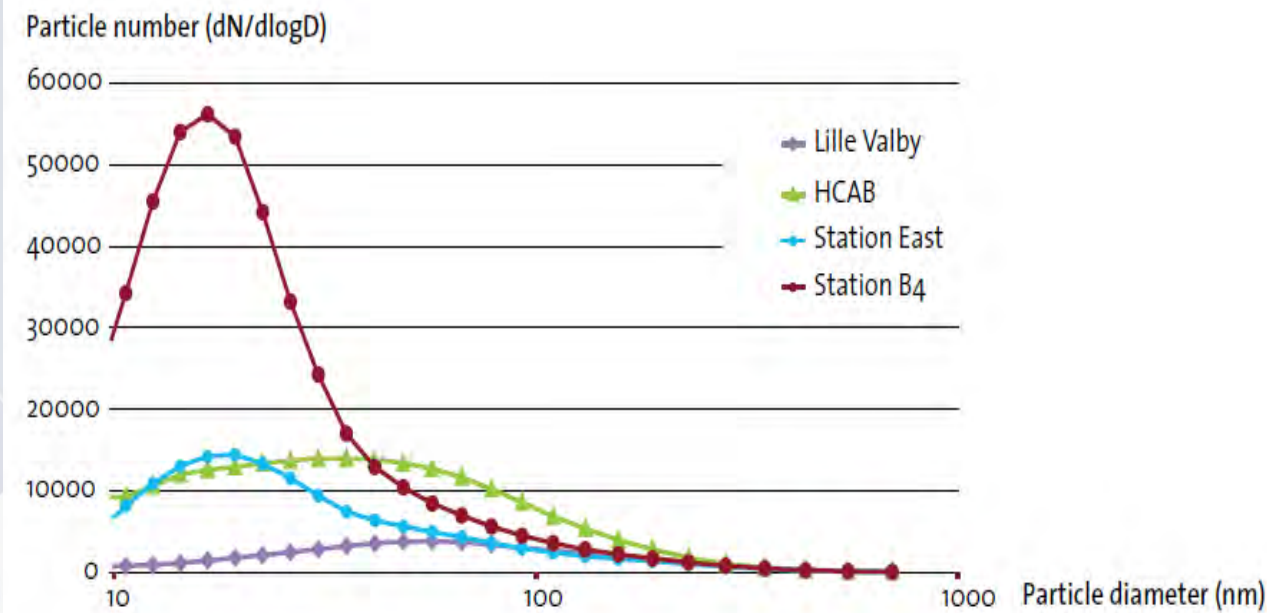
Copenhagen Airport

- Copenhagen Airport is the main international Airport for Denmark
- 29. mill. Passengers
- 265.784 operations
- 165 destinations
- 2.400 employees in CPH
- 23.000 employees in total



The Challenge

- Handling personnel with cancer diagnosis – claimed to be related to exhaust from diesel engines
- High amounts of ultrafine particles
- No accept criteria for ultrafine particles



CPH survey on air pollution parameters (24 different VOC and 9 aldehydes)
– all where within limit values

High amounts of UFPs compared to central Copenhagen streets

Behaviour



APU regulation

GSE in idle

Ground Support Equipment



Green GSE

**Infrastructure
for Green GSE**

Stand technology and operations



**Stand policy
– PCA and power
at stands with
jetways**

**Limit running of
jet engines**

Research and analysis



Regulation

**Research
engagement**

**Robust
monitoring
scheme**

➔ **Copenhagen Airports Air Quality Program**



Welcome to CPH

Take care of yourself and
your ground-servicing crew

- APU must only be used:

5 min after "on block"

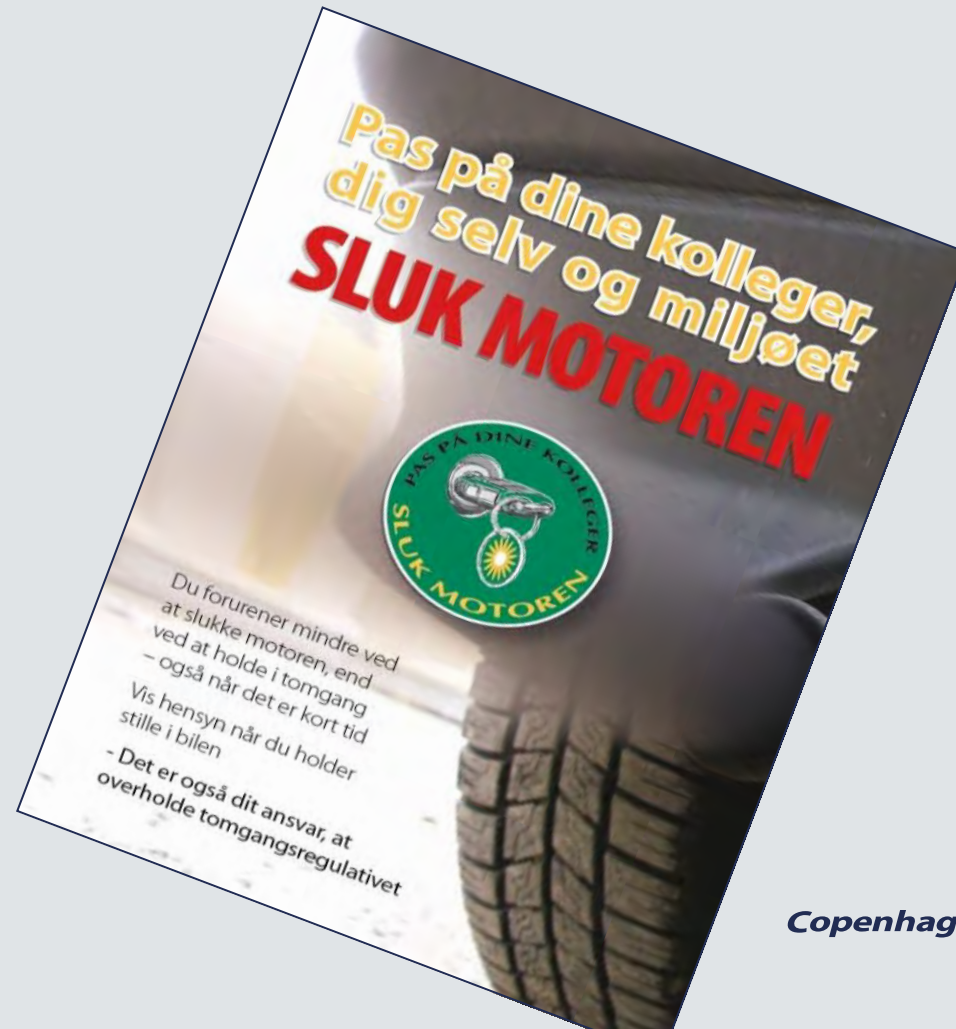
5 min before expected "off-block"

Copenhagen Airports

CPH

BEHAVIOUR

→ Aiming to reduce non productive idling of all kinds of engines



Copenhagen Airports

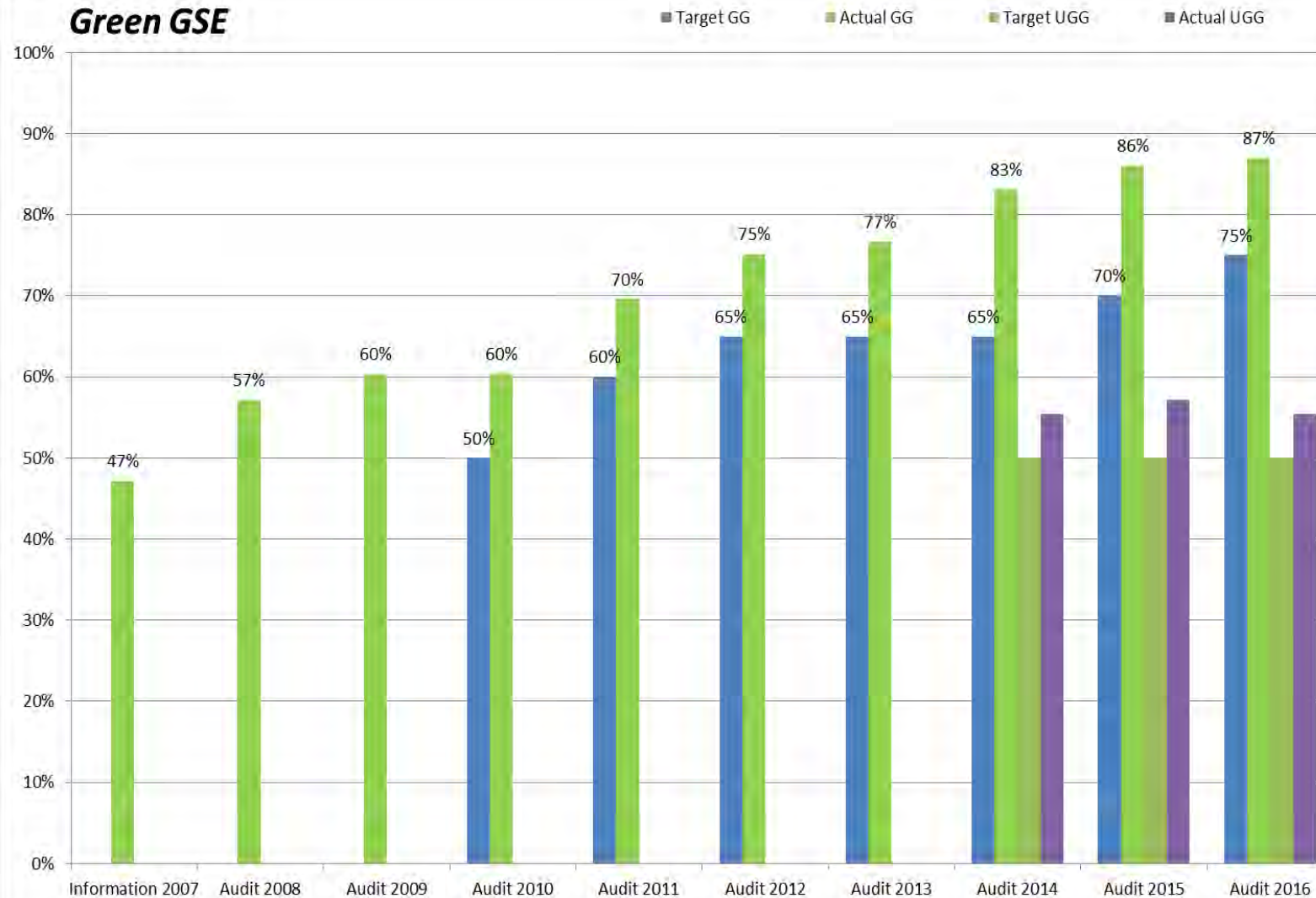
CPH



Campaigns on Awareness

Ground Support Equipment

Green GSE



Please help us reduce emissions - and save fuel!
Pay attention to the AIP for CPH/EKCH

**AIP
AD2-EKCH-7
6.3 PARKING**
Shut down main engines
when "on-block"

**AIP
AD2-EKCH-7
6.2 TAXIING**
Shut down
as many engines as possible
when taxiing

**AIP
AD2-EKCH-7
6.2 APU**
APU can only be used
5 minutes after "on-block"
and 5 minutes before
estimated "off-block"
(with a fee
exemption)

Your
active
cooperation
is highly
appreciated



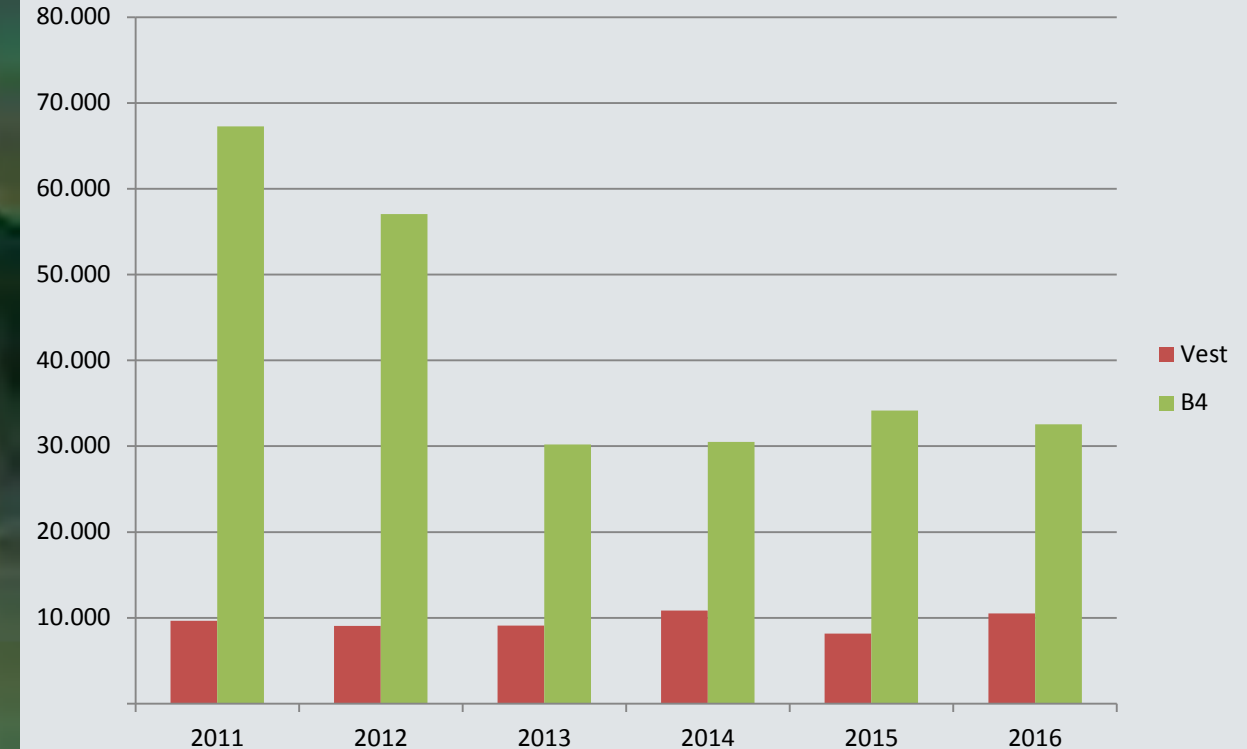
Copenhagen Airports **CPH**

**WE CARE
ABOUT YOU ✈️
- AND OUR
SURROUNDINGS**

Copenhagen Airports **CPH**



➔ Stand Technology and Operations



Annual mean particle numbers
- showing significant reduction

➔ Research and analysis

Cohort Study

- Purpose: Investigate the correlation between outdoor work in an airport and a number of specified diseases
- Total Cohort approx. 70.000 males
- 6,500 persons working airside in the airport from 1985 to 2013
- Research from Bispebjerg Hospital and National Institute of Public Health, University of Southern Denmark (Research produced 2011 – 2016)
- Financed by The Fund for Working Environment Research under the Danish Ministry of Employment and Copenhagen Airports



Cohort Study

Conclusions

- No sign of increased risk related to working airside and ischemic heart disease, cerebrovascular disease (stroke), COPD (chronic obstructive pulmonary disease) or Asthma
- The statistical data is too small to get valid information on Lung- and Bladder cancer
- This is the first study of its kind
- The scientists recommends further research
- http://niph.dk/upload/forsvar_karina.pdf
- http://www.arbejdsmiljoviden.dk/nyt/nyheder/2016/december/19_partikelforurening-paavirker-ikke-lufthavnsansattes

Slutrapport til Arbejdsmiljøforskningsfonden, projekt nr. 22-2011-09

Helbredsskader og partikelforurening i Københavns Lufthavn, Kastrup.

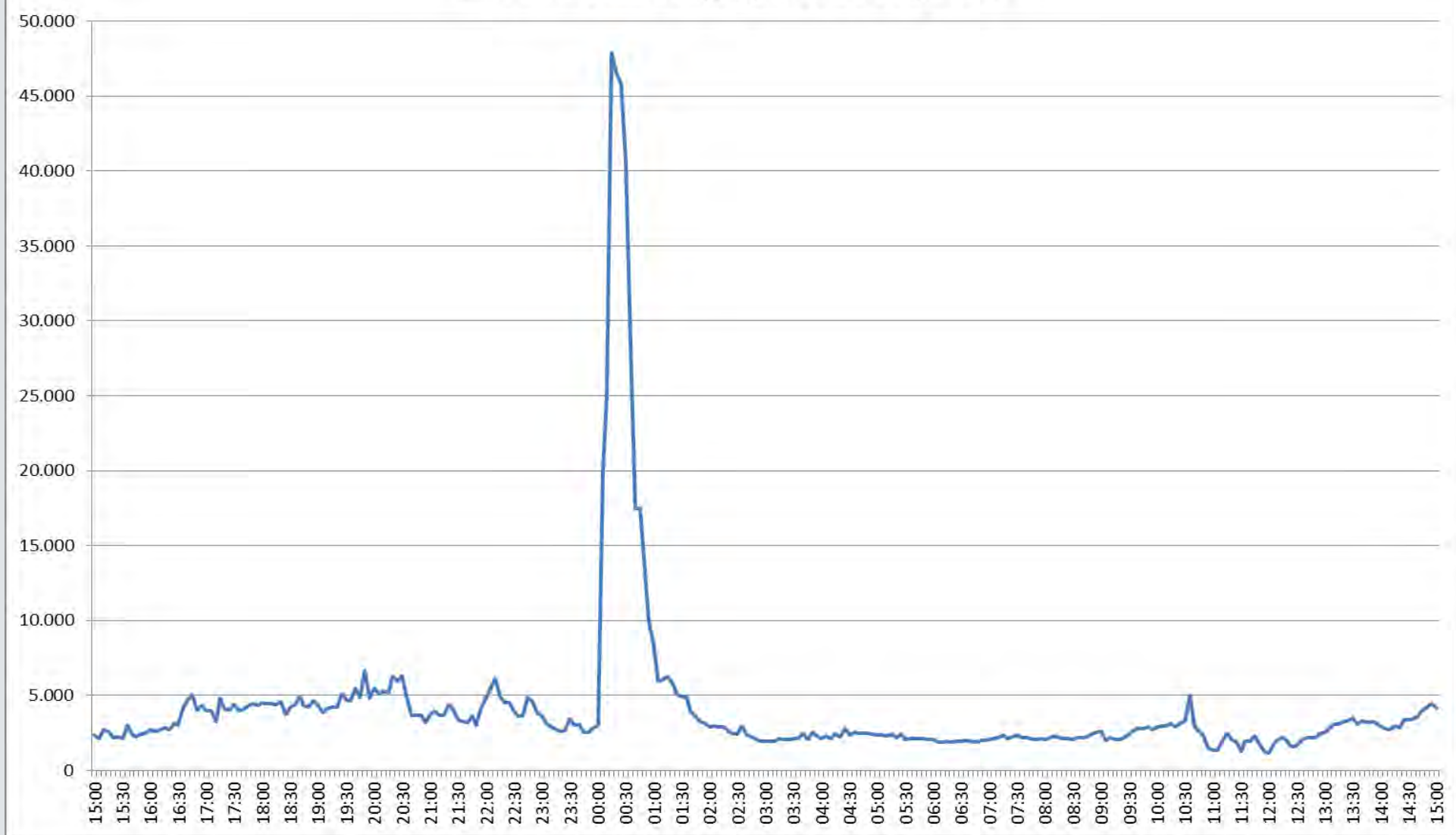


REGION H
Bispebjerg
Hospital

STATENS INSTITUT
FOR FOLKESUNDHED
SYDDANSK UNIVERSITET

KØBENHAVNS
UNIVERSITET

Copenhagen Airports CPH



➔ Research and analysis



Ultrafine Particles at Airports

Discussion and assessment of ultrafine particles (UFP) in aviation and at airports in 2012

ACI EUROPE Environmental Strategy Committee
Autumn 2012



QUESTIONS

Effects of the fuel composition on the UFP emissions

Biojet

Inmaculada Gómez Jiménez. Observatory of Sustainability in Aviation

Ultrafine Particles in Airport Regions

Thursday, March 23, 2017

The **EU Advanced Biofuels Flightpath** sets up the objective to achieve **2 million tons of sustainable biofuel per year in 2020**.

A **key point** is to promote and create an efficient **value chain**, from **supply-biomass cultivation and conversion-** up to **DEMAND** (airlines and standards).



ITAKA linked supply and demand by connecting the **full value-chain**: feedstock grower, biofuel producer, distributor and airlines.



	SENASA Project Coordinator		
	Airbus Group		Asociația Centrul de Biotehnologii Microbiene BIOTEHGEN
	Camelina Company España (CCE)		Compañía Logística de Hidrocarburos S.A. (CLH)
	Consorzio per la Ricerca e la Dimostrazione Sulle Energie Rinnovabili (RE-CORD)		École Polytechnique Fédérale de Lausanne (EPFL)
	EMBRAER		Manchester Metropolitan University (MMU)
	Neste		SkyNRG

- ✓ demonstrate the readiness of SPK large-scale production & use



LOGISTICS and LARGE SCALE USE TESTS:

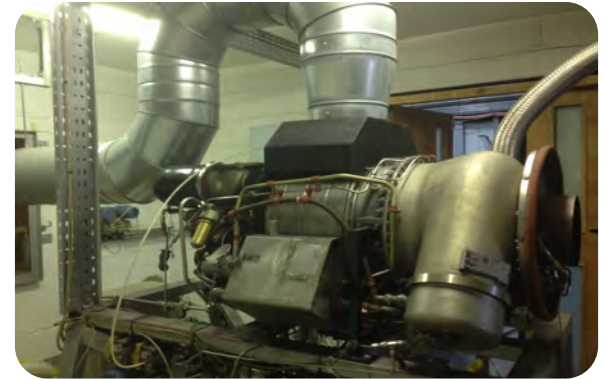
Engine and fuel systems testing

- ✓ **18 flights** AMS-AUA-BON [A330-200]: no detrimental effects on operation, similar or slightly better fuel consumption
- ✓ **80 flights** OSL-AMS [E190] with biojet ~50/50, no significant differences
- ✓ **2 APU tests** for **pollutant emissions**: reduction in fuel flow, significant reduction in the SAE smoke number and nvPM, small reduction in CO. No change in NO_x or UHC.



APU tests Methods

- ~ 500 engines in ICAO emissions database (good fleet representation from a subset of 30 engines)
- Combustion efficiency on all modern hardware (independent of OEM) is asymptotically approach 100% (e.g. GE90 is 99.6% at idle). Differences in hardware are increasingly second order effects; **First order effects come from changes in fuel chemistry.**
- An APU is a good model for main engine gas turbines:
 - ✓ Qualitative data and trends are very similar,
 - ✓ Considerably lower fuel usage (typically 30 g/s compared with 2000 g/s),
 - ✓ Ease of access and considerably lower costs (factor x10),
 - ✓ An APU is a critical safety device on all ETOPS aircraft & APU emissions contribute appreciably to AQ at airports.



Garrett Honeywell GTCP85 APU

APU tests

Emissions effects increasing blend

Engine performance:

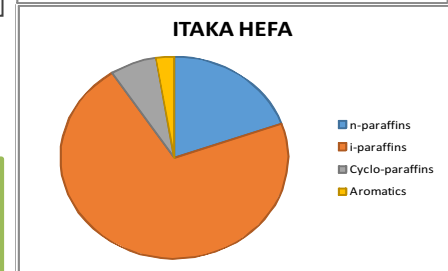
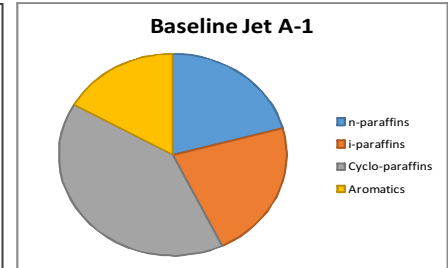
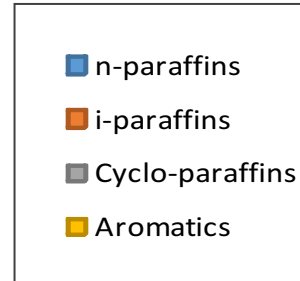
- ✓ A reduction in fuel flow (kg/sec)
- ✓ A small reduction in the engine EGT (Exhaust Gas Temperature)

Gaseous emission species:

- ✓ CO is **slightly reduced**
- ✓ UHC is no change / slightly reduction
- ✓ NO_x remains approximately constant
- ✓ CO₂ is **linearly reduced**
- ✓ H₂O is linearly increased

Particulate matter characterization:

- ✓ A pronounced and linear **reduction in SAE smoke number**.
- ✓ A significant **reduction in nvPM mass & number emissions** is accompanied by a move to smaller size.



↓ 50-60% UFP mass
↓ 30-40% UFP
numb.

40 → 30 nm

ITAKA: significantly different chemical composition to JetA1

© ITAKA; Simon Christie (MMU)



*This project has received funding from the **European Union's Seventh Framework Programme** for research technological development and demonstration under grant agreement **No 308807***

OSLO Use of biojet at airport

- Since Jan. 2016, Oslo Gardermoen is using a blend of biojet at the airport fuel system, with no separation
- There is a challenge to find biojet in the market, because of lack of demand
- Depending on the biojet type, blend can reach up to 50% v.v, what could reduce up to a 60% the nvPM



press release

22/01/2016

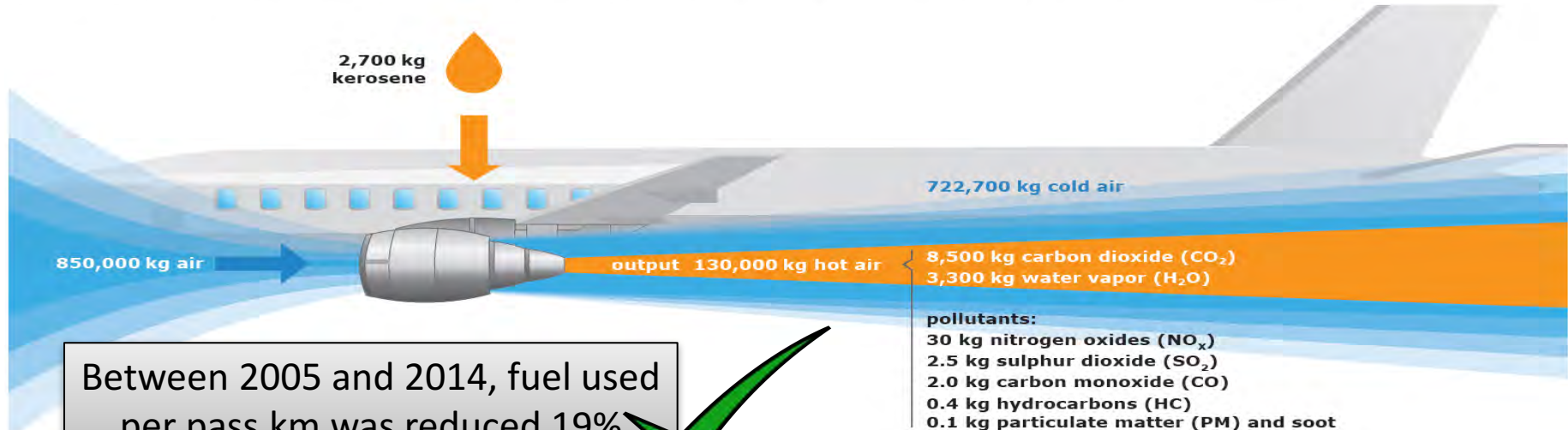
ITAKA provides sustainable fuel for worldwide's first biojet supply via hydrant system at Oslo Airport

- Sustainable biojet from camelina oil produced in EU by the ITAKA project will be made available to all airlines landing at Oslo airport.
- For the first time, the sustainable biojet will be supplied from the airport's main fuel farm, via the existing hydrant mechanism.



The numbers Mitigating ALL emissions

Emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers (Source: FOCA)

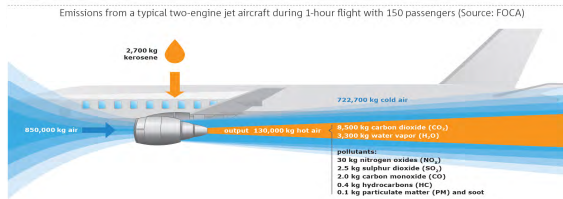


But +77% CO₂ from 1990 to 2005 in the EU (EFTA) (+5% 2005-14) (+44% 2005-35)

Per kg jet → 3,15* kg CO₂

The numbers

Growth forecast



1,000 t (EU)	2005	2014 (% vs. 2005)	2035 (% vs. 2005)
nvPM	2.67	2.38 (-11%)	3.16 (+18%)
nvPM below 3,000 feet	0.15	0.13 (-14%)	0.17 (+11%)

European Aviation Environmental Report 2016

We need solutions No sector can be out of concern

You know this reality, aviation needs to make its part



www.obsa.org





POLLUTANT EMISSIONS FROM AIRCRAFT ENGINES

RELEVANT REGULATION AND TECHNOLOGY MITIGATION

UFPs Event – Brussels, 23 March 2016

Olivier Penanhoat (Olivier.penanhoat@safrangroup.com)

Presented by Yoann Mery (Yoann.mery@safrangroup.com)



ICAO standards on aircraft engines pollutant emissions

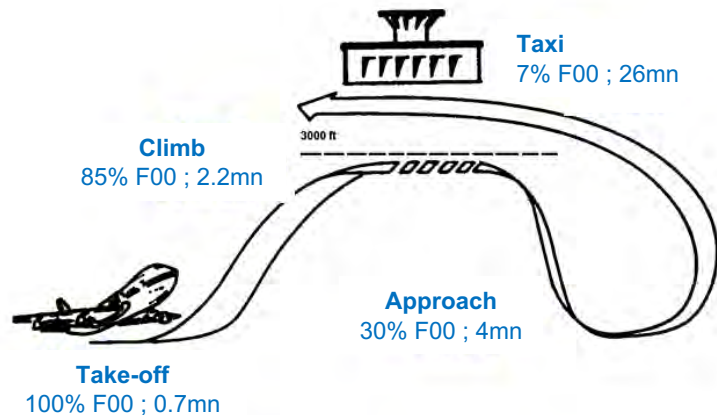
Regulation on aircraft engines emissions (Turbofan et Turbojet with a take-off thrust above 26.7kN) is internationally established by ICAO.

- ◆ Pollutants currently regulated: NO_x (NO&NO₂), CO, UHC (Unburnt Hydro-Carbons, expressed as CH₄), smoke (through smoke number), and non volatile Particulate Matter (nvPM).
- ◆ ICAO LTO cycle (Landing & Take-Off): it is a cycle which is representative of aircraft operations at airports, inside the atmospheric boundary layer I (taken equal to 3000 feet).

$$\frac{D_p}{F_{00}} = \frac{\sum_i W f_i * E I_i * t_i}{F_{00}}$$

Labels for the equation:

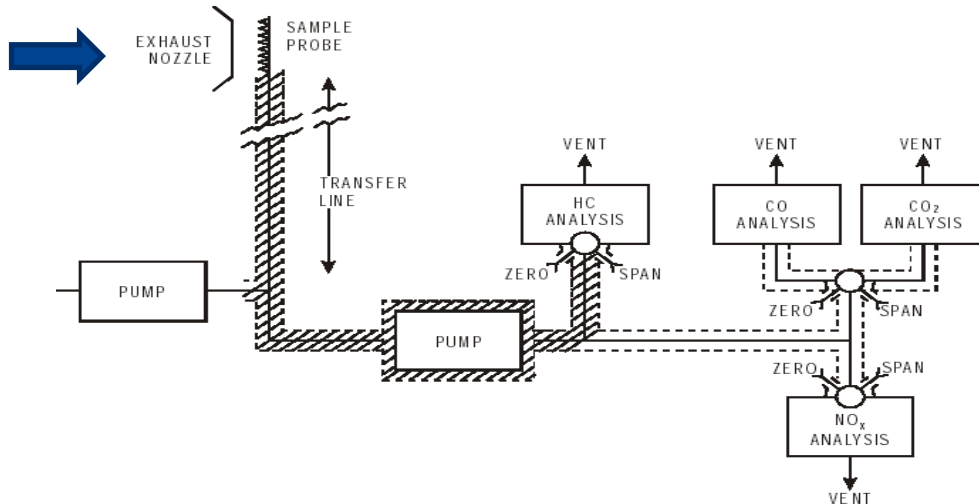
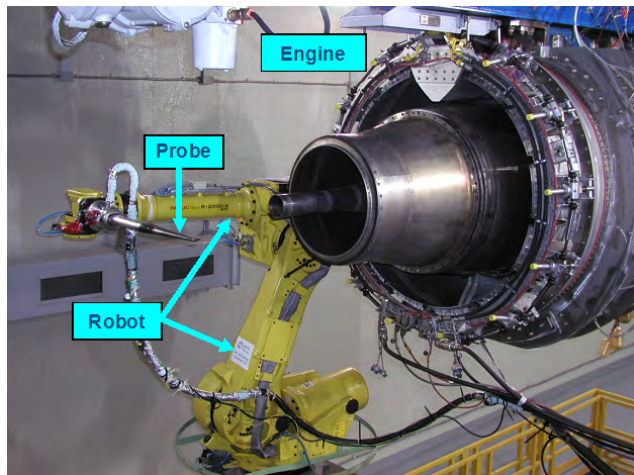
- D_p : Total quantity of emitted species (g)
- F_{00} : Take-off thrust (kN)
- $W f_i$: Fuel flow (kg/s)
- $E I_i$: Emission Index g(species)/kg(fuel)
- t_i : Time duration of each engine regime
- F_{00} (denominator): Take-off thrust (kN)



- ◆ Certified measurements respect a rigorous protocol defined by ICAO. They are publicly available on a data base managed by EASA: <http://www.easa.europa.eu/document-library/icao-aircraft-engine-emissions-databank>

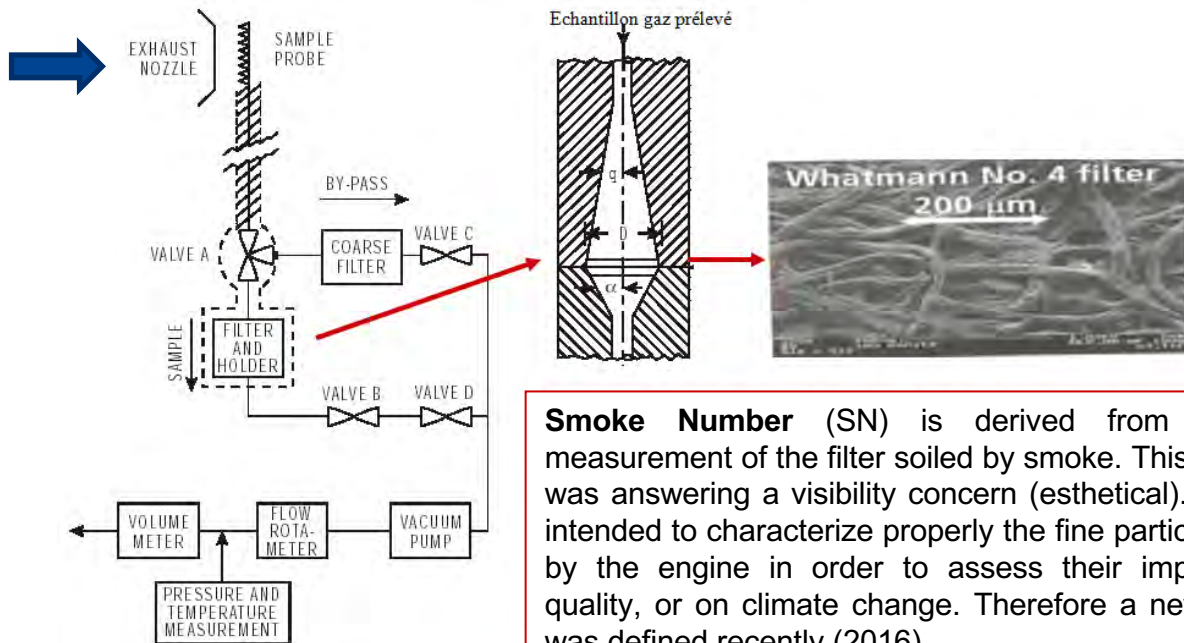
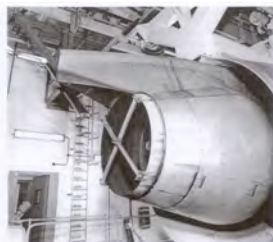
Measurement of gaseous pollutants (NO_x, CO, UHC)

- ❖ Exhaust gases are sampled and analysed, for the 4 engine operating points of the ICAO LTO cycle.



Measurement of Smoke

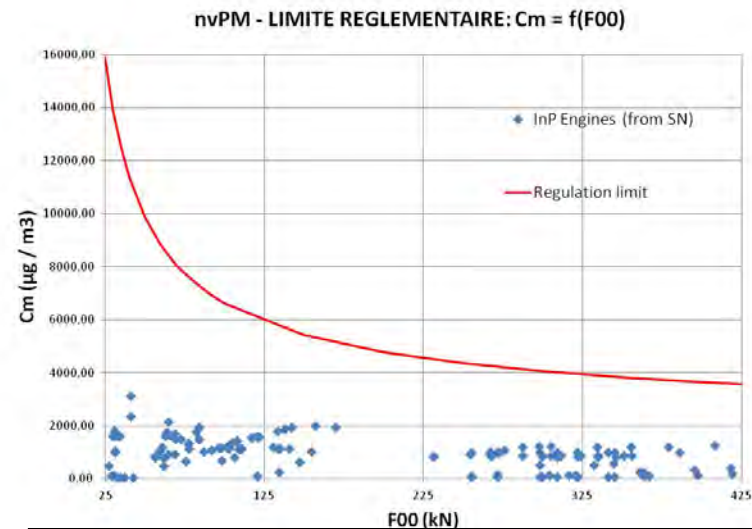
- ❖ Sampled gases go through a filter and contaminate it. Engine smoke level is quantified by a « Smoke Number », derived from filter reflectivity measurements.



Smoke Number (SN) is derived from reflectivity measurement of the filter soiled by smoke. This parameter was answering a visibility concern (esthetical). It was not intended to characterize properly the fine particles emitted by the engine in order to assess their impact on air quality, or on climate change. Therefore a new standard was defined recently (2016).

New ICAO standard specific to particles (nvPM)

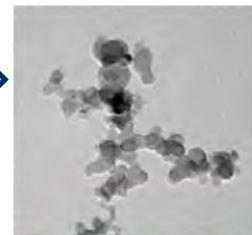
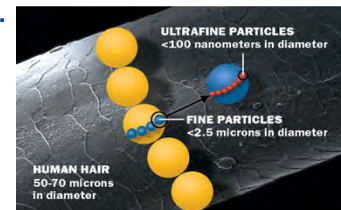
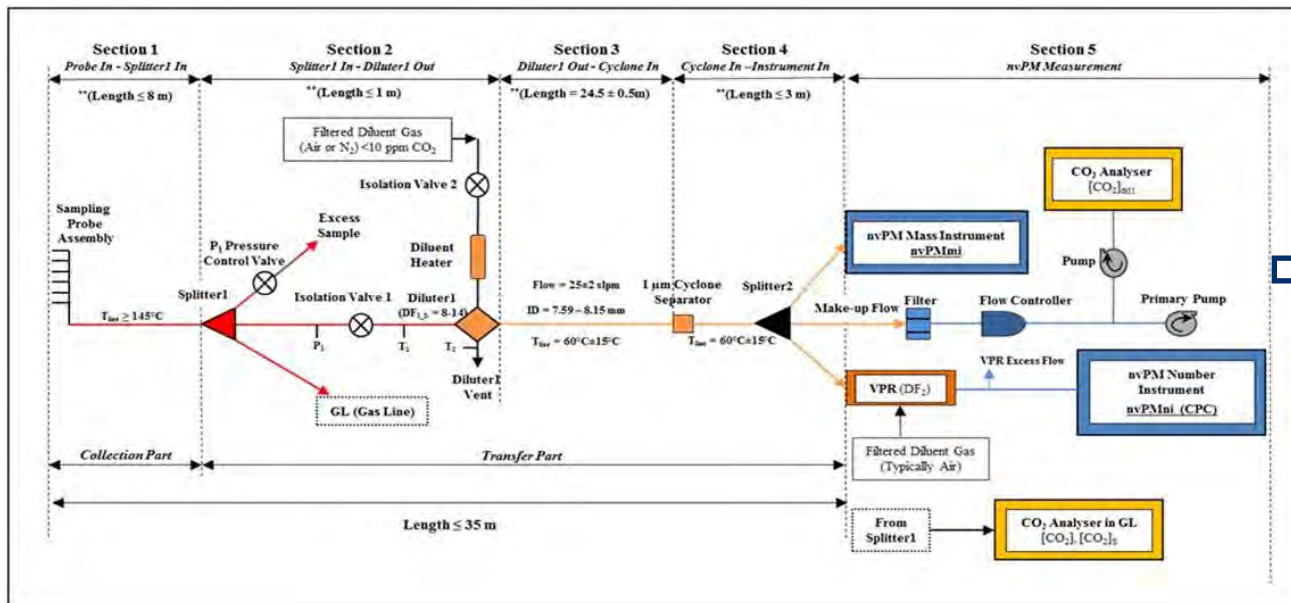
- ❖ The 1st international standard on aircraft engines particles was validated in 2016. It is based on average mass concentration at the engine exit, of non volatile Particulate Matter (**nvPM**) ; It will apply to all in production (InP) engines after 1/01/2020, with a take-off thrust $F_{00} > 26.7\text{kN}$
- ❖ A 2nd standard is being built. It will be based on the LTO cycle (**DP/ F_{00} type metric expected**).



$$\text{nvPM mass concentration limit line } [\mu\text{g}/\text{m}^3] = 10^{\{3+2.9 \times F_{00}^{-0.274}\}}$$

Measurement of non volatile Particles (nvPM)

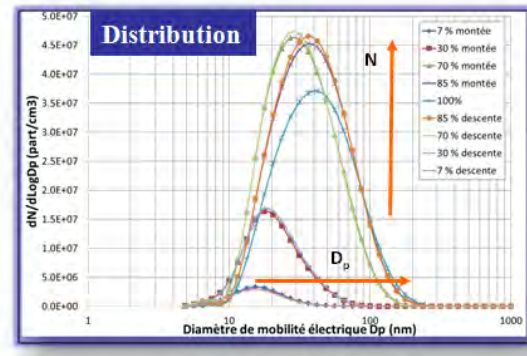
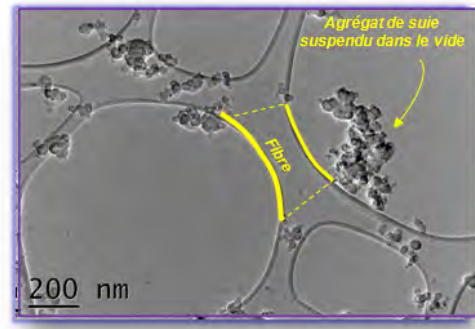
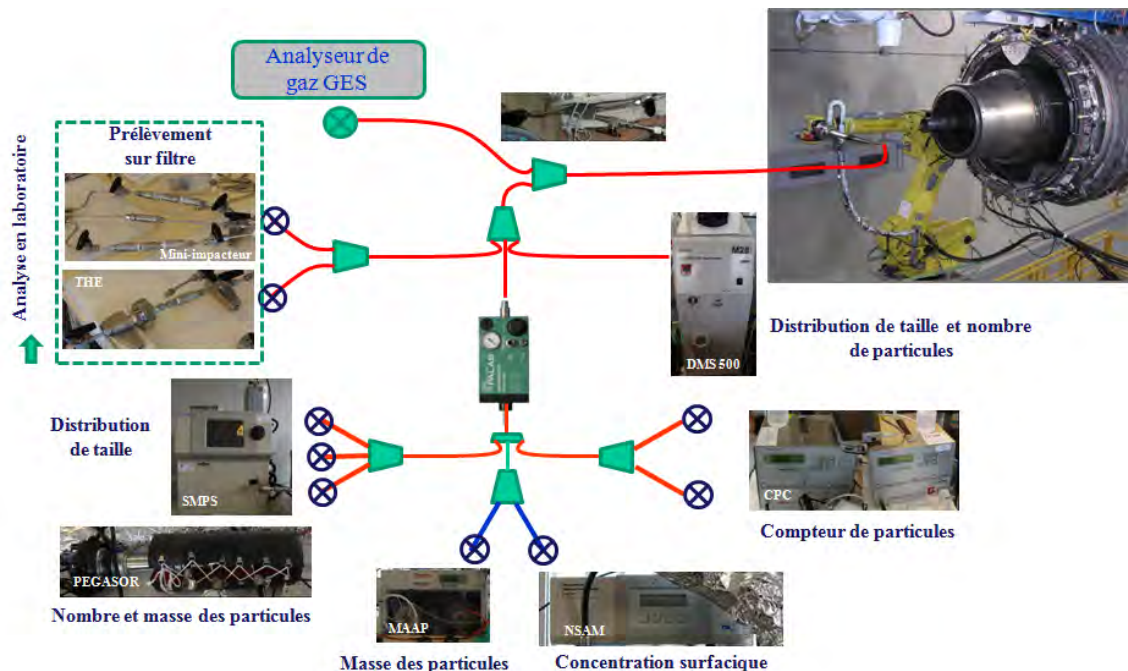
- ❖ **nvPM (non volatile Particulate Matter)**, are measured with a strict protocol in order to guarantee expected quality and the minimum variability linked to the measurement system and its operation. This protocol was validated by CAEP (ICAO Committee of Aviation Environmental Protection) in 2016.
- ❖ Raw measurement of mass concentrations (g/m^3) & number concentrations ($\text{\#/m}^3$) are performed. Using sample CO_2 concentration, Emissions Indices in mass (g/kg) and number ($\text{\#/kg}$) are derived.



10nm to 100nm

Particles campaign on SaM146 engine – 2013 (Mermose* / DGAC)

❖ Snecma/Onera/IRSN campaign. First major scientific campaign at Snecma to measure non volatile fine particles behind an engine with an experimental chain from Onera.



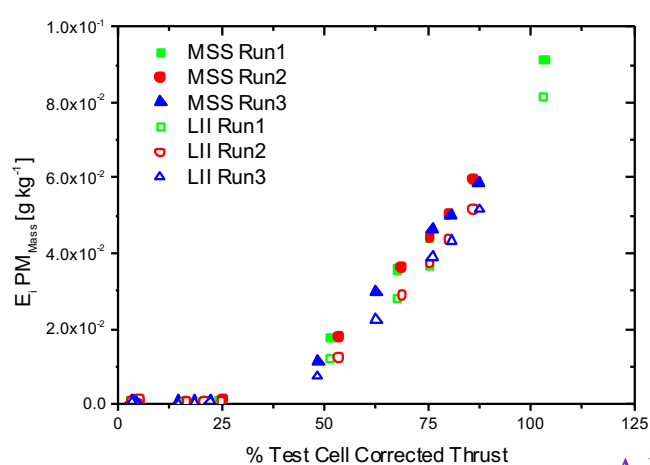
* The MERMOSE project: characterization of particle emissions of a commercial aircraft engine – 2016 - Journal of Aerosol Science

Ultra Fine Particles Event - Brussels - 23rd March 2017

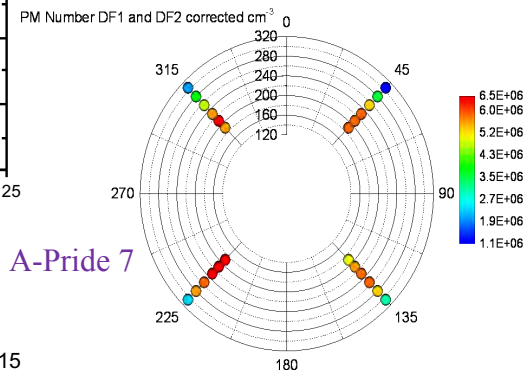
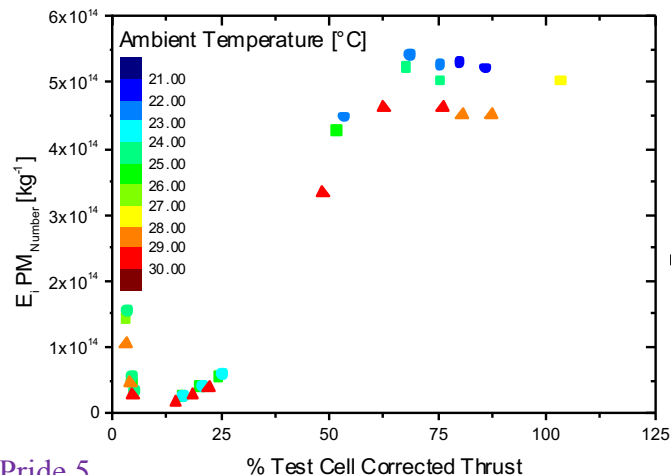
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Particles campaign on CFM56 – 2013 & 2014 (A-PRIDE* / FOCA)

❖ Swiss FOCA funded various campaigns (“A-PRIDE”) in Zurich, with EMPA. During A-PRIDE 5 campaign in 2013, compliant measurements of CFM56-7B26/3 particles emissions were performed. In 2014, Safran AE (&GE) was associated to the A-PRIDE 7 new campaign to evaluate the effect of fuel composition on particles.



A-PRide 5



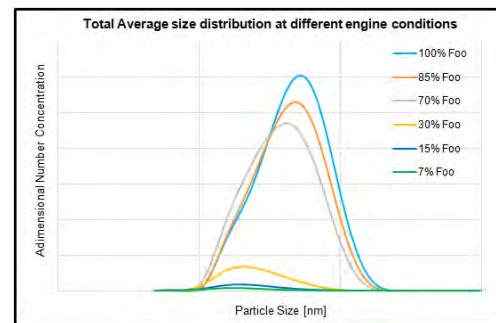
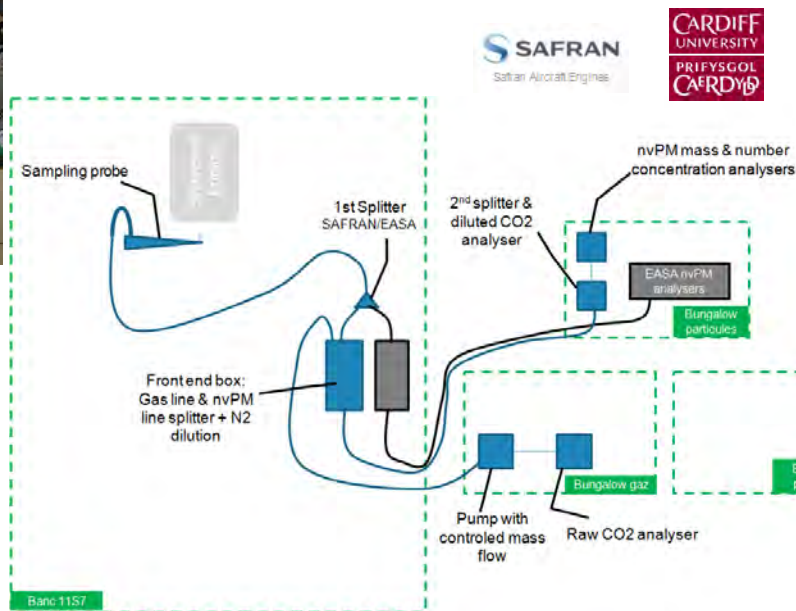
A-PRide 7

* Effects of Fuel Aromatic Content on Nonvolatile Particulate Emissions of an In-Production Aircraft Gas Turbine ; Env Sc. Techno 2015

Particles campaign on Silvercrest engine - 2016 (funded* by EC & EASA)



❖ The non volatile Particulate Matter measurement campaign on the Silvercrest business engine, supported by European contract, took place in July 2016 on 11S7 engine test bench at Safran Aircraft Engine Villaroche plant.



* nvPM engine measurement results at Safran Aircraft Engines – FORUM-AE workshop 9th March 2017 Berlin

Ultra Fine Particles Event - Brussels - 23rd March 2017

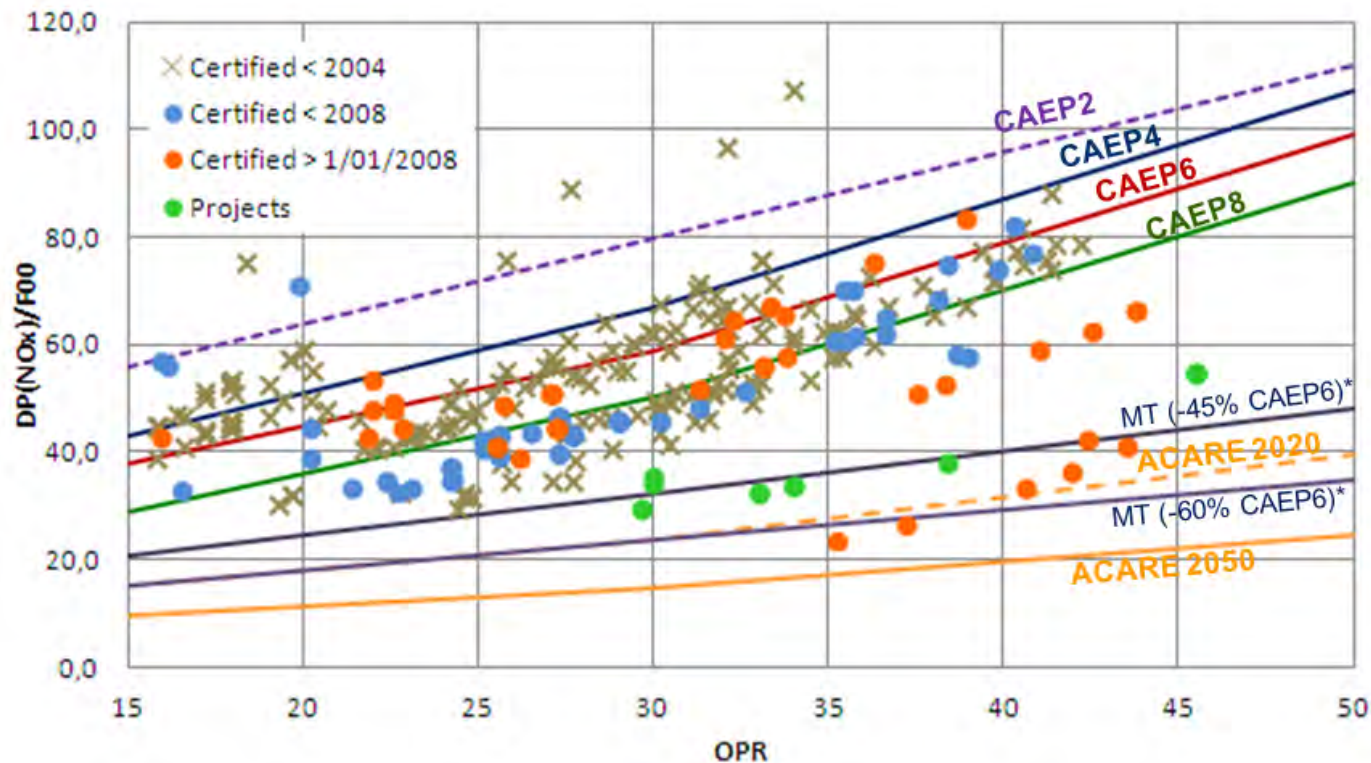
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Evolution of ICAO Standards on pollutant emissions

Standard	CAEP meeting date	NOx			Smoke / Particles	Standard CO / UHC
		Applicability date to new certified engines	Stringency increase (evaluated at OPR=30, F00=89kN)	Production cut-off?		
CAEP11	2019	s.o	Unchanged	?	2nd nvPM std (based on DP/F00)? Applicability > 2023	Unchanged
CAEP10	2016	s.o	Unchanged	No	1st international std on fines particles (~SN) applicability on 1/01/2020	Unchanged
CAEP8	2010	janv-14	-15% from CAEP6	No	Unchanged	Unchanged
CAEP6	2004	janv-08	-12% from CAEP4	Yes: 01/01/2013	Unchanged	Unchanged
CAEP4	1998	janv-04	-16% from CAEP2	No	Unchanged	Unchanged
CAEP2	1991	janv-96	-20% from CAEE	Yes: 01/01/2000	Smoke Number	Constant limit

Continuously more stringent NOx standard and technology response

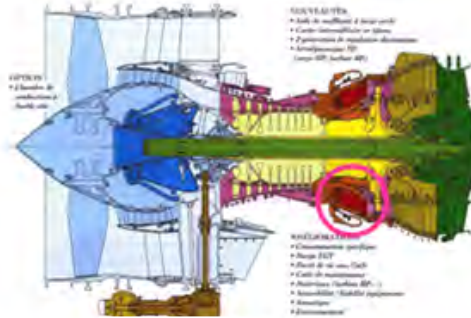
❖ Periodically the NOx limit has been reduced, which encourages technology improvements



Pollutant emissions mitigation technology



Aircraft



Engine



Combustion chamber

Aerodynamics
+
Structural mass

Thermopropulsive η
+
Mass

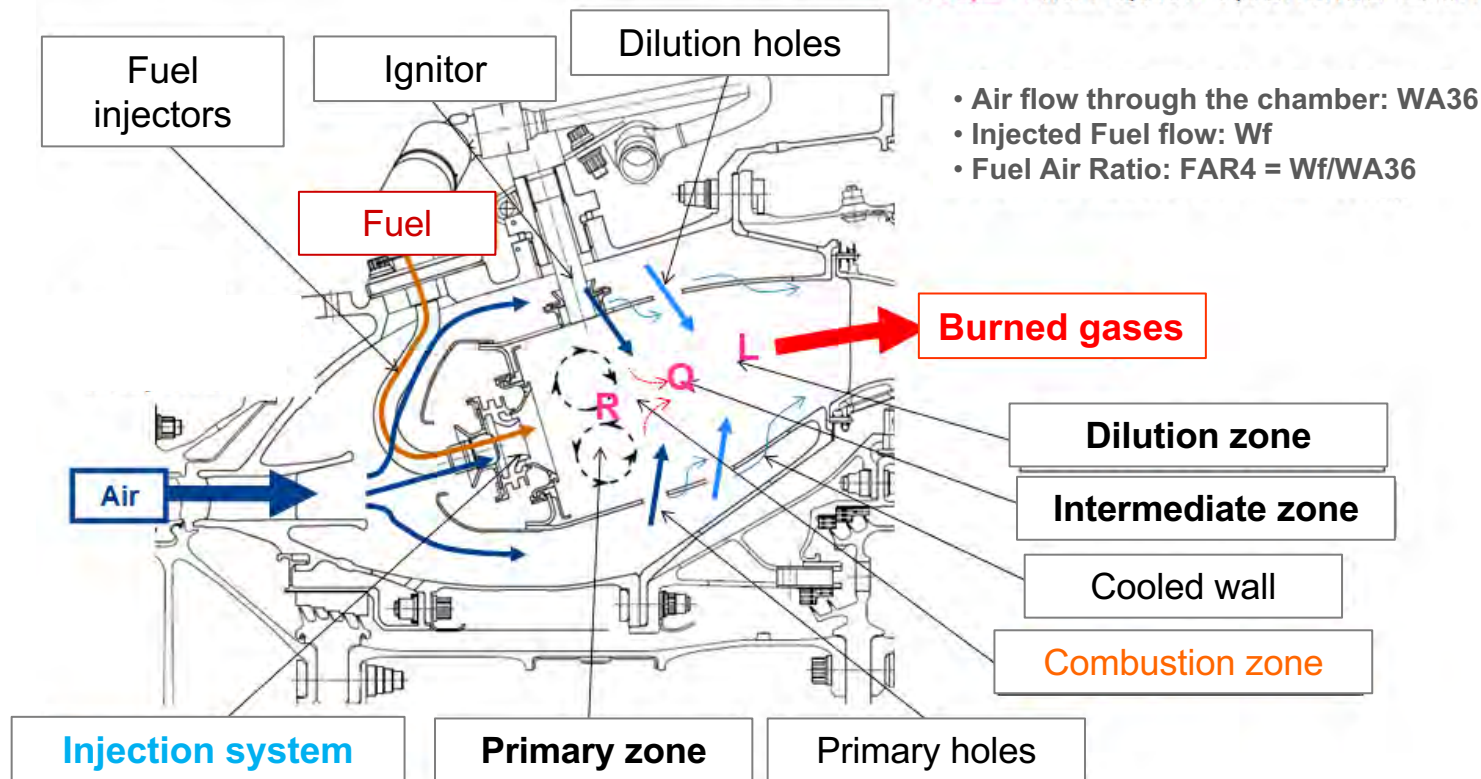
Combustion η
+
Combustion quality

CO₂ + H₂O + SO_x

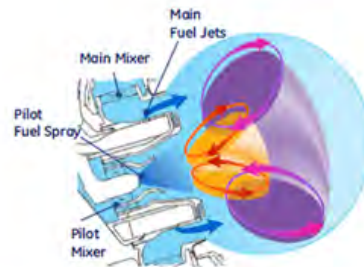
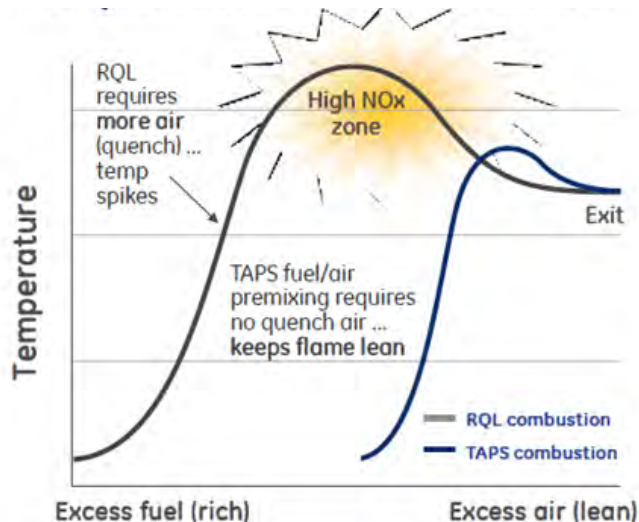
**NO_x, CO, UHC,
Smoke, particles**

Pollutant emissions mitigation technology: modern « RQL » combustors

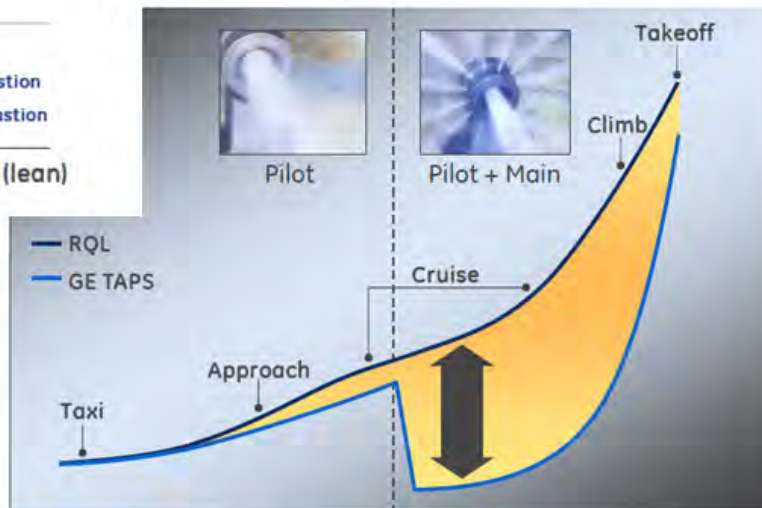
RQL=Rich Quick Quenched Lean



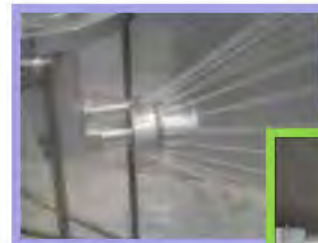
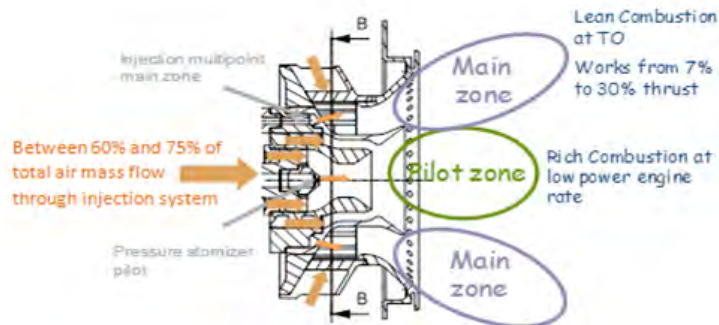
Pollutant emissions mitigation technology: lean combustion / « TAPS » solution



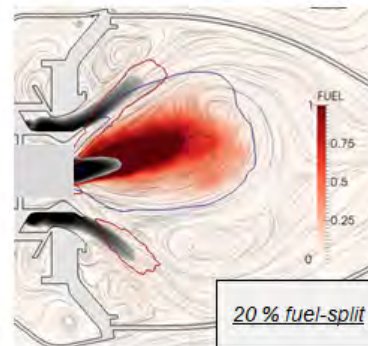
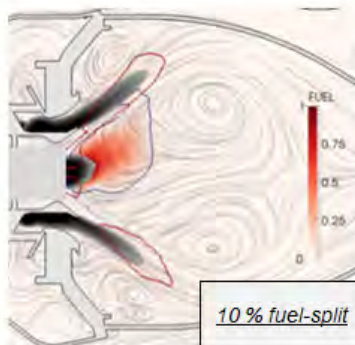
- TAPS technology certified by GE (CFM LEAP engine)
- Lean combustion to minimize NOx formation



Pollutant emissions mitigation technology: lean combustion / « MSFI » solution



- Lean combustion realised at Safran AE thanks to technology called MSFI (Multi-Staged Fuel Injection)
- Optimisation of fuel split between pilot injector and primary injector to minimise NO_x and satisfy operability constraints



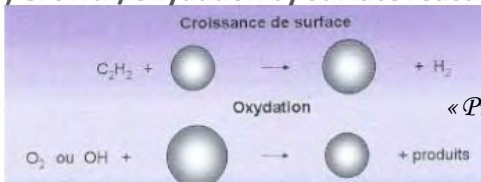
About particles: main formation mechanisms

A) Precursor species formation

Fuel Oxidation and formation of **C₂H₂ + PAH** depending on combustion process conditions and on the fuel composition

« gaseous precursors »

C) Growth/Oxydation by surface reaction



« Primary Particles »

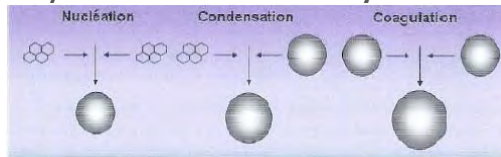
D) Agregation

Aggregates formation from primary particles and condensation of species derived from SO_x, NO_x, and unburnt hydrocarbons

« Aggregate Particles »

« Nucléi »

B) Nucleation & Growth by collisions

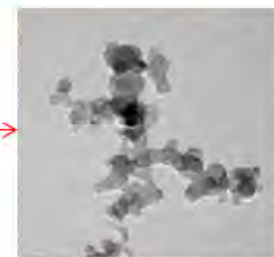


« Aromatics produced by combustion or initially present in fuel »

Principaux HAP (liste)

Composé chimique	Structure chimique	Composé chimique	Structure chimique
Acénaphtène		Quinazoline	
Chrysène		Carbazole	
Coronène		Fluoranthène	

Particles (nvPM)



10nm to 100nm

Prediction and understanding of PM2.5

❖ Today, Air Quality monitoring (European & global level) is generally based on **PM2.5** for particles. PM2.5 represent mass concentration of particles $<2.5\mu\text{m}$. They can hardly be measured at the engine exit because they are constituted of non volatile Particulate Matter (nvPM) now covered by the new standard, but also of volatile Particulate Matter (vPM), in gaseous phase at the engine exit and condensing later in the exhaust wake.

❖ These vPM are principally formed from oxidation of the sulfur contained in the fuel and from condensation of unburned hydrocarbons.

❖ **FOA3*** (First Order Approx.) method validated by ICAO (see also DOC9889) is most often used for inventories. It is expressed in the following way:

$$\text{❖ Elvol(S)} = 3.3\% * (M(\text{SO}_4)/M(\text{S})) * \text{FSC} \approx \text{FSC} \quad (\text{EI expressed in g/kg ; FSC en\%})$$

FSC = Fuel Sulfur Content ; FOA3 conservative value by default = 0.063%

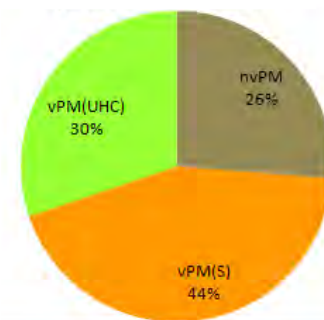
$$\text{❖ Elvol(UHC)} = x\% * \text{EI(UHC)}$$

$x\% = 11,5\%, 7,6\%, 5,6\%, 6,2\%$ for the 4 LTO cycle regime (7%, 30%, 85%, 100% F00)

❖ Fuel sulfur content reduction is then naturally beneficial on PM2.5 reduction at airports

* Methodology to estimate particulate matter emissions from certified commercial aircraft engines – Wayson et al - 2009

CFM56 PM2.5
composition from FOA3



Conclusions

- ❖ Aircraft engines (except APUs) respect a strict regulation defined at ICAO international level since 1981. Fine particles (non volatiles) are a more recent regulatory issue; a first international standard was agreed in 2016 and will be applicable to all in production engines after 1st January 2020.
- ❖ Pollutant emissions from certified engines are measured by all engine manufacturers following a precise regulatory protocol and are validated by different certification authorities (EASA, FAA...). They are public and are the background of all inventories.
- ❖ Manufacturers effort has been focusing for a long time on NOx reduction, and the most efficient and promising solution is based on Lean Combustion. It equips for instance le LEAP engine (on A320Neo and B737Max). Lean combustion is however also beneficial to fine particles reduction.
- ❖ PM2.5 emissions are not measured directly at engine exit. They come both from non volatile particles (newly measured) and from volatile particles in particular from fuel sulfur oxidation, and may be estimated with FOA3 methodology validated by CAEP.

Clean air in Europe

Air quality challenges around airports

**Vicente Franco, Zlatko Kregar
DG Environment – Clean Air Unit**

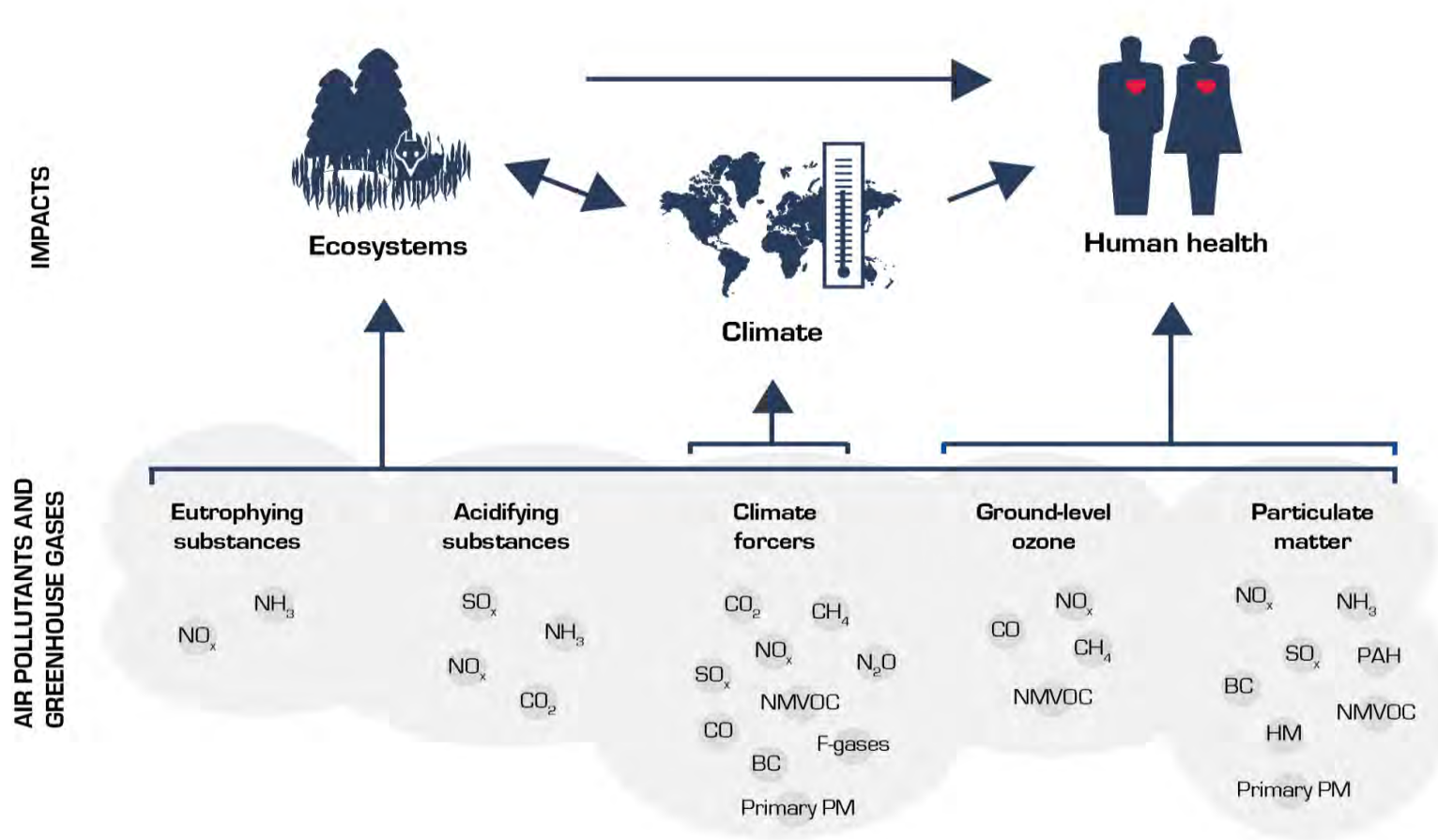
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- 1. Air pollution: EU context*
- 2. EU policy response*
- 3. Airport-specific challenges*

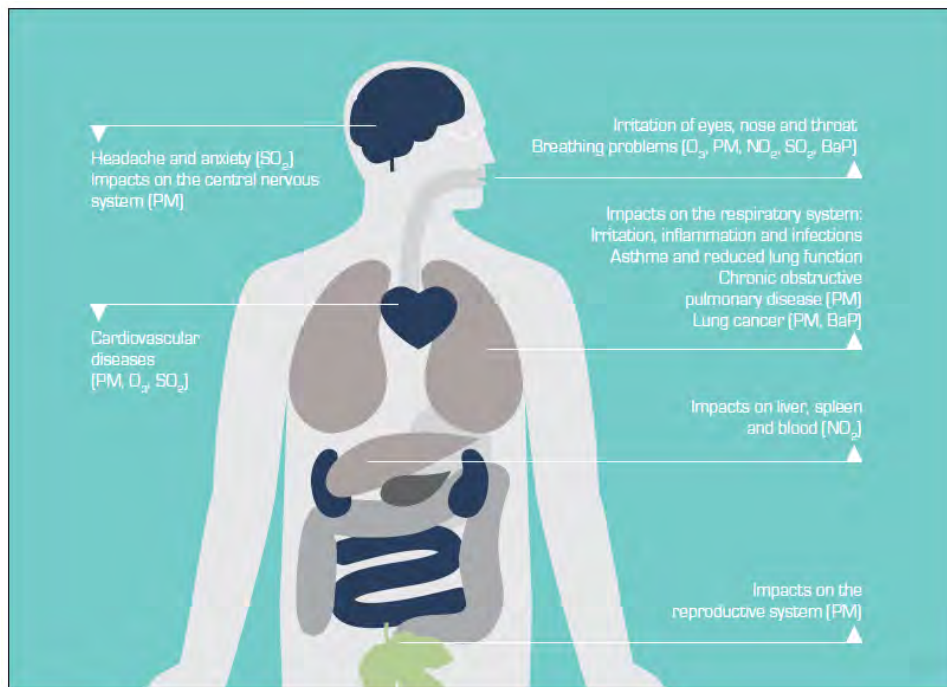
Index

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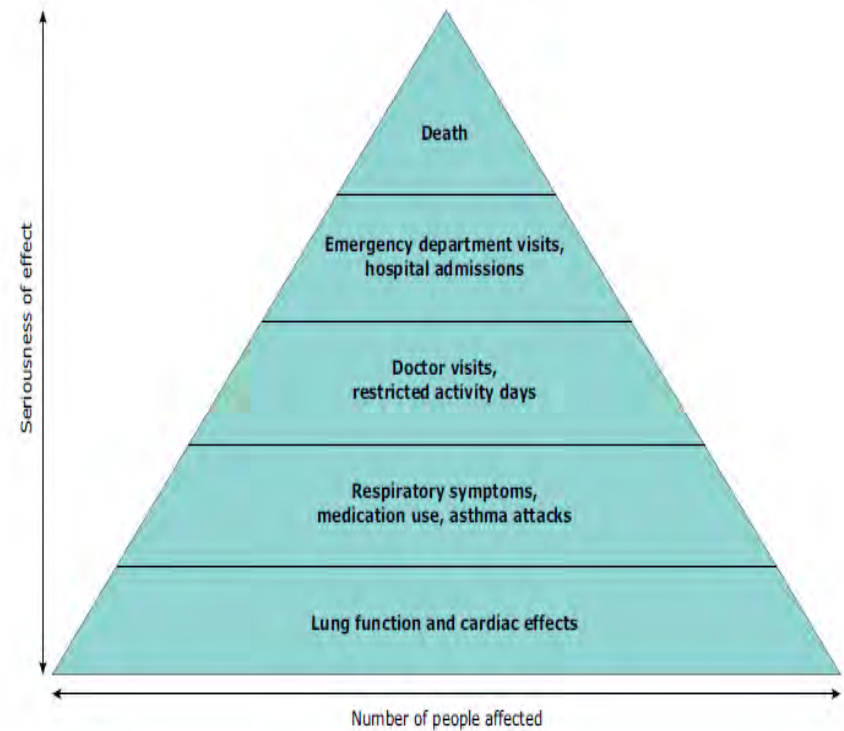
Why care about air pollution?



Air pollution: A significant threat to our health & well-being



Source: EEA, 2013f.



Source: Based on US EPA.



Air pollution in the EU

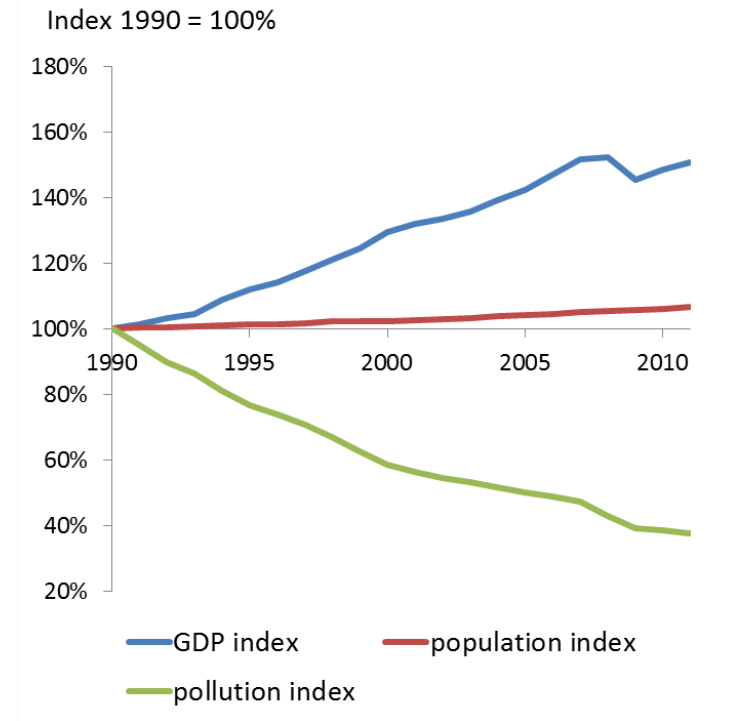
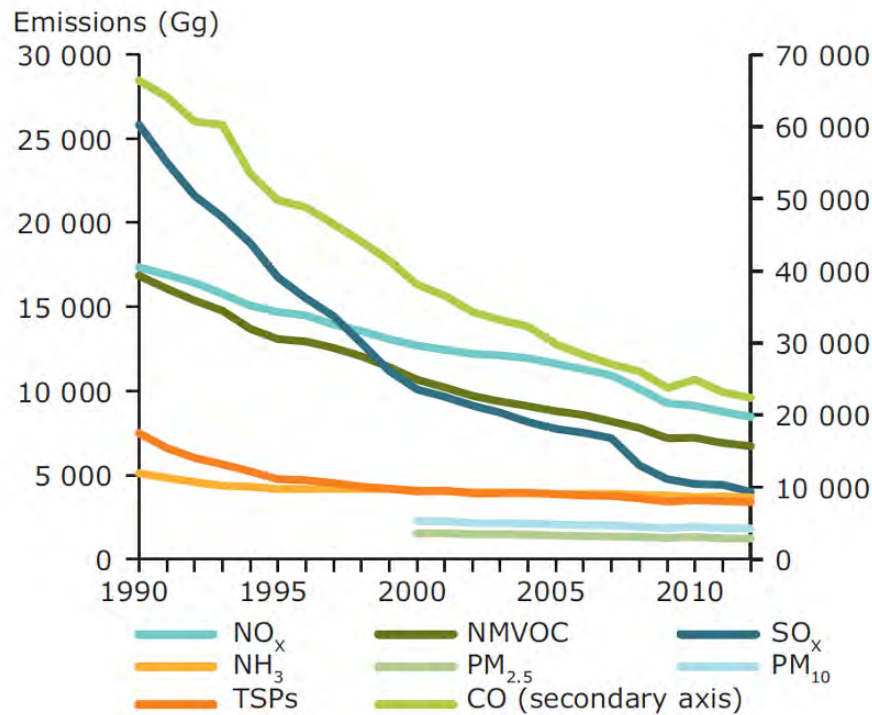
Despite considerable improvements in past decades, air pollution is still responsible for more than **400,000 premature deaths in Europe each year**. It also continues to damage vegetation and ecosystems.

The overall **external costs** of these impacts ranged between **€330-940 billion**, including labour productivity losses and other direct economic damage valued at €23bn per year in 2010.

Continued improvements in air pollution levels are expected under current legislation, but beyond 2030 only slow progress is expected.

Additional measures are needed if Europe is to achieve the long-term objective of air pollution levels that do not lead to unacceptable harm to human health and the environment.

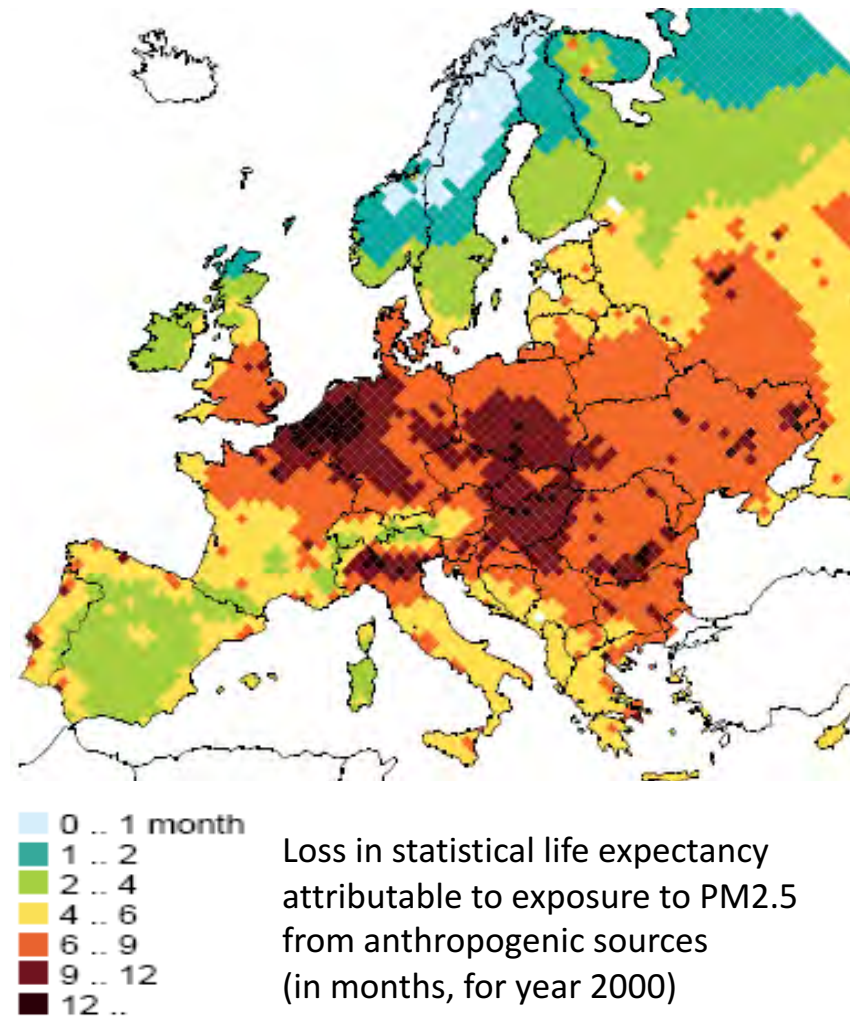
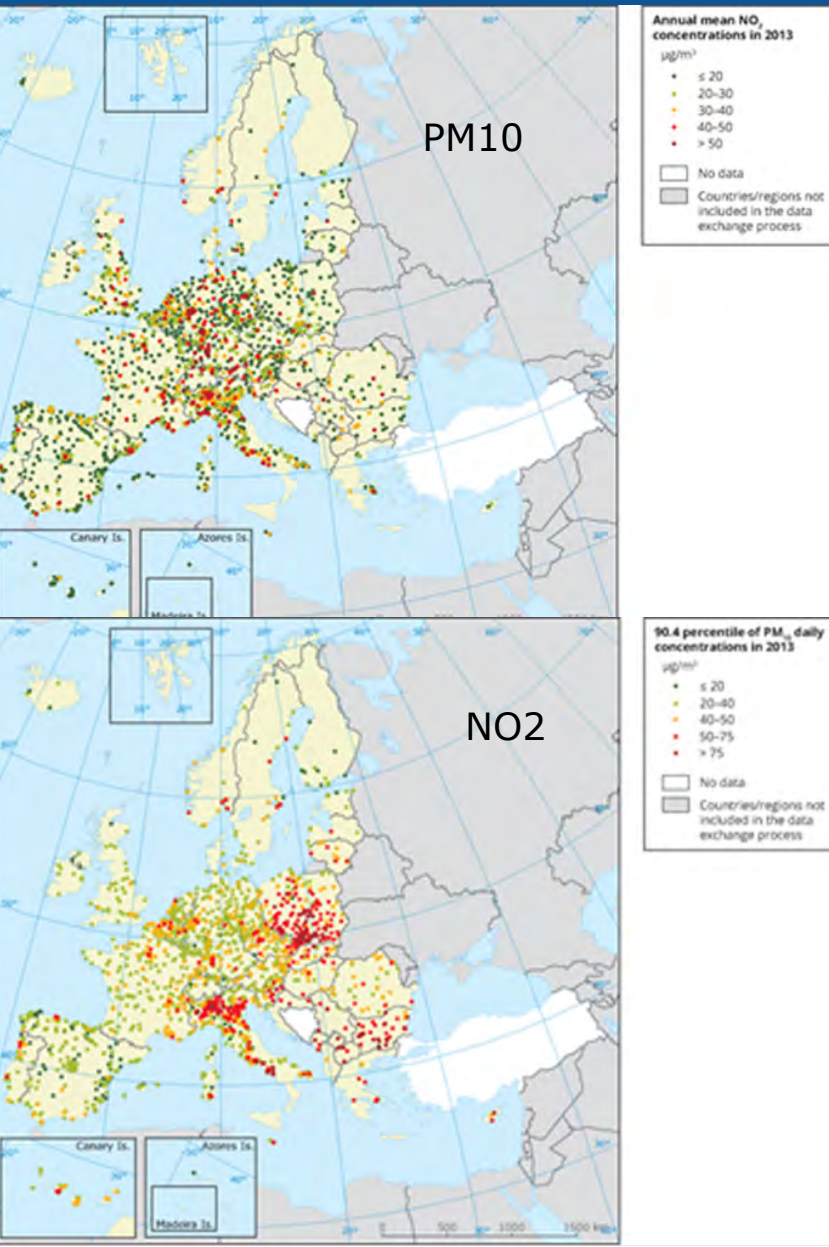
Air policy works: lower emissions



Source: EEA

Significant AQ exceedances persist (2013)...

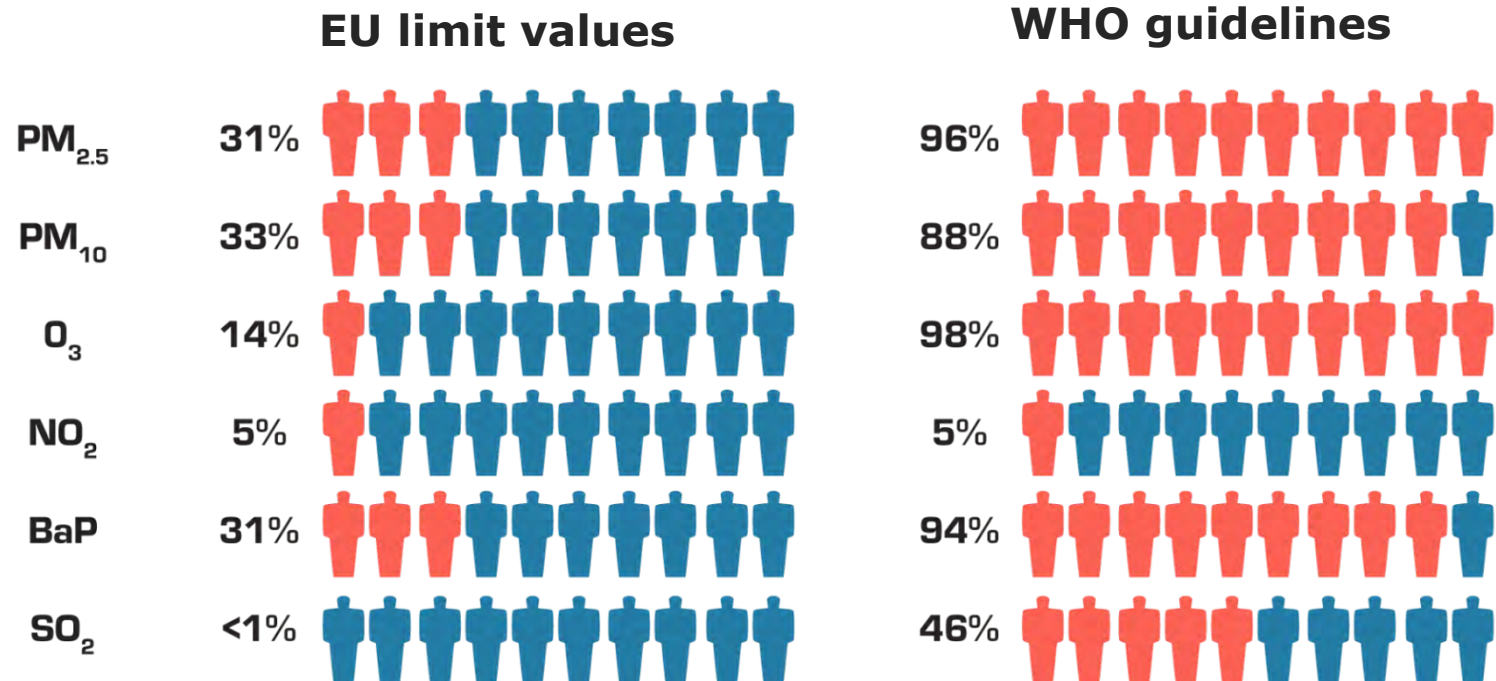
...which causes serious health risks



Source: EEA and IIASA

The problems will persist beyond compliance with current air quality legislation

EU urban population exposed to harmful levels of air pollution in 2011, according to:



Index

- 1. Air pollution: EU context*
- 2. EU policy response: NEC and AAQ directives***
- 3. Airport-specific challenges*

The Clean Air Policy Package

- From over 400.000 premature deaths a year now to around 200.000 in 2030 (50% reduction)
- Targets existing compliance problems:
 - Lower background pollution (within MS, intra-EU, global), implementation of existing EU legislation (IED, Marine Fuels,...)
 - Better governance: via enhanced intra and inter MS coordination (national- local) and enhanced integration of AQ into other policies.
- **Main instrument:** revised Directive on National Emission Reduction Commitments (National Emission Ceilings Directive, **NECD**)

50%

NEC Emission reduction commitments related to 2005			
	2020	2030	Δ '20-'30
SO ₂	59%	79%	20%
NO _x	42%	63%	21%
VOC	28%	40%	18%
NH ₃	6%	19%	13%
PM _{2.5}	22%	49%	27%

Benefits & costs of the new NECD

costs new NECD in 2030

- The effort for the new policy (in cost terms) is split:
 - 40% for the domestic sector
 - 37% for industry
 - 23% for agriculture
- Compliance costs: **€2,2 bn/year**
- External costs in the EU now: €330-940 billion



benefits new NECD in 2030

- 50% less premature deaths(PM & O₃ -precursors)
- 43% less restricted activity days
- 30% less eutrophication (NO_x, NH₃)
- 80% less acidification (SO₂, NH₃)
- Direct cost savings: €3 bn/year
- External cost reductions (health only): **€40 -140 bn/year**

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- 1. Air pollution: EU context*
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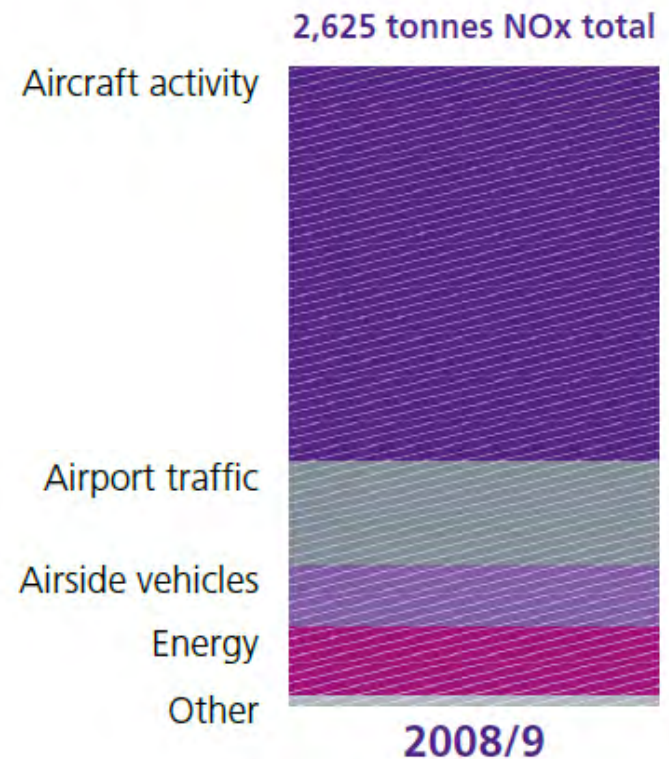
AQ around airports

Air quality around airports is **not separately addressed** via the Ambient Air Quality Directive, but airports and airfields are contained within air quality zones that must demonstrate compliance with ambient concentration limits.

Several air quality zones containing an airport report NO₂ exceedances, which may have been exacerbated by emissions from the airport (e.g. by increasing background levels).

Airport emission sources

- Emissions from aircraft: LTO emissions, taxiing and cruising emissions
- Emissions from ground operations (NRMM)
- Emissions from transport to/from airport sites
- Others (on-site energy generation, heating)



Source: Heathrow Air Watch. Heathrow's blueprint for reducing emissions (2016).

Emissions from aircraft: aspects to consider

- relative impact of flight phases
- emission characteristics (by plane type, fuel quality)
- dispersion characteristics
- relative impact compared to other airport sources
- PN emissions? impact of PN emissions?

Estimated impacts in context

Emissions from aircraft:

Table 2. Premature deaths per year in different regions due to the population exposure to aviation-attributable PM_{2.5} and ozone (90% confident intervals) calculated using the WHO-CRF.

	Full flight	LTO	LTO/FF (%)
North America	1 500 (850–2300)	650 (290–1300)	43
Europe	3 700 (2 100–5500)	1 800 (1 100–2600)	49
Asia	8 200 (3 700–13 000)	740 (420–1200)	9
Other regions	2 700 (1 400–4200)	780 (420–1300)	29
Global	16 000 (8300–24 000)	4000 (2400–6200)	25

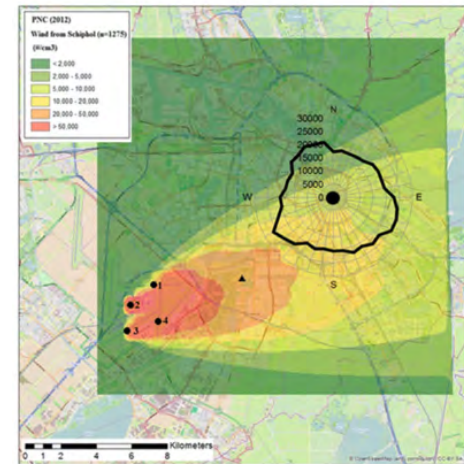
Source: Yim et al. Global, regional and local health impacts of civil aviation emissions. Environ. Res. Lett. 10 (2015) 034001

UFP an issue?

Emissions from aircraft:

*Schiphol study: [...] At the sites Adamse Bos (7 km downwind) and Cabauw (40 km downwind), PNC was elevated **by a factor of 3** and 20% downwind of Schiphol, respectively, compared to other wind directions"*

Source: Keuken et al. Total and size-resolved particle number and black carbon concentrations in urban areas near Schiphol airport (the Netherlands). *Atmospheric Environment* 104 (2015) 132e142



*"although there is considerable evidence that **ultrafine particles** can contribute to the health effects of PM, for ultrafine particles (measured by the number of particles) the data on concentration–effect functions are too scarce to evaluate and recommend an air quality guideline"*
– WHO, Review of evidence on health aspects of air pollution (REVIHAAP, 2013)

Summary and conclusions

- Air quality problems are a major burden in the EU's ecosystems, public health and economy
- Source legislation and AAQD, NECD have delivered substantial emission reductions, but exceedances of standards remain a problem in several 'hotspots'
- EU AQ legislation has ambitious reduction targets until 2030, provides a framework for MS to reach their AQ targets

Summary and conclusions

- Airports covered by EU AQ legislation, but not specific treatment (airports covered by air quality zones)
- Airport contribution to regional health burdens relatively small, but local impacts may be high
- Aircraft emissions have both local and regional/global impacts (50% split in Europe)
- It's not just about aircraft emissions!
- Opportunities for improvement (airside vehicles, transport to/from airport, incentives to cleaner aircraft)

More information

Air policy package and review:

[http://ec.europa.eu/environment/air/
review_air_policy.htm](http://ec.europa.eu/environment/air/review_air_policy.htm)

Thank you

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European Office
FrankfurtRheinMain



Airport Regions Conference
Rue Montoyer 21
1000 Brussels, Belgium