Modelling desert dust exposure events for epidemiological short-term health effects studies

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31st Annual Conference of the International Society of Environmental Epidemiology
Utrecht, The Netherlands, 24th August 2019

Objective

- How to answer properly the *(apparently simple)* research question **"does desert dust impact human health?"**

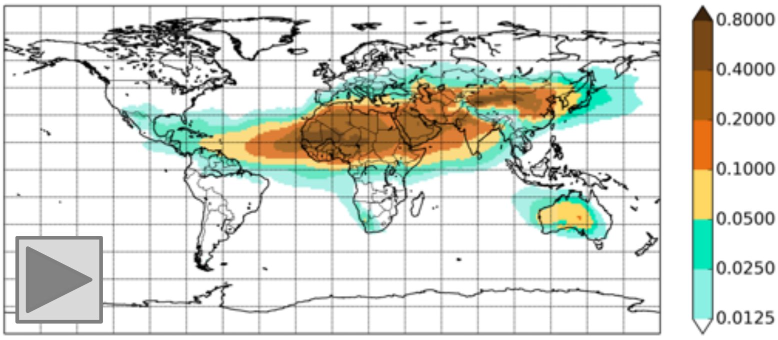
Outline

1. Introduction
2. Dust as binary metric
    - Methods to identify dust events
    - Dust as exposure, confounder and effect modifier
3. Dust as continuous exposure
    - Methods to quantify dust events
    - Two-sources and three-sources model
4. Discussion

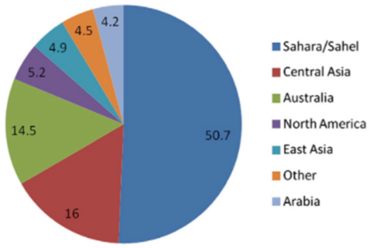
Introduction

- **Desert dust** play a significant role in different aspects of weather, climate and atmospheric chemistry and **represent a serious hazard for environment and health**

Dust optical depth at 550 nm. Average value 2003-2015



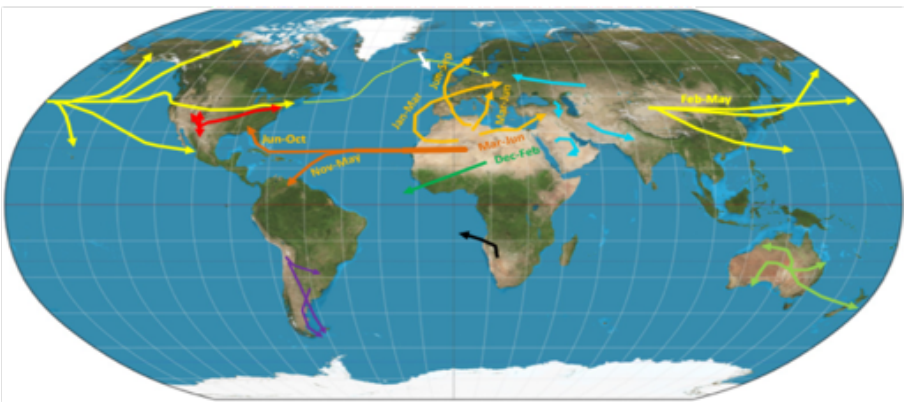
Source: *CAMS reanalysis, WMO SDS-WAS*



(Goudie 2014)

Introduction

- **Dust storms last 1-24h at source points**, and depending on meteorological conditions **can be transported at surface level or lofted to high altitudes** (up to 10 km)



(Goudie 2014)

Introduction

- The **air quality influence of dust** is a complex issue
- Dust is typically **made up of crustal components**, clay minerals and salts, and it can:

1) **Increase particulate matter ambient concentrations**

	Eastern Asia			Europe		
	n	mean	(sd)	n	mean	(sd)
PM10						
Non-dust days	38	59.2	(25.4)	21	37.1	(6.9)
Dust days	38	142	(79.6)	21	55.2	(30.9)
PM2.5						
Non-dust days	3	35.6	(0.8)	16	22.0	(5.7)
Dust days	3	54.7	(8.9)	16	25.5	(4.9)

(Tobías et al., under review)

2) **Carry Anthropogenic pollutants,** previously deposited in the source areas or trapped by the high dust air mass during its atmospheric transport *(Mori 2003, Rodríguez el al. 2011)*

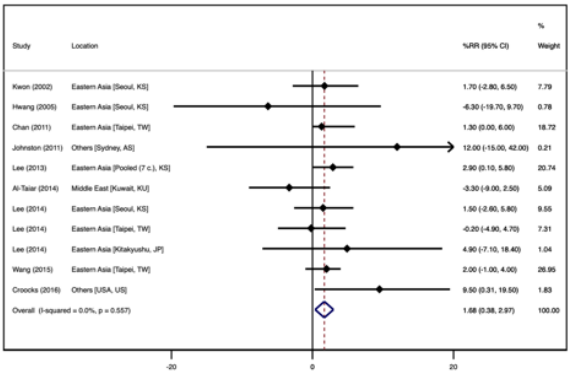
3) **Carry microorganisms** and toxic biogenic allergens (*Griffin et al. 2001, Ho et al. 2008)*

Introduction

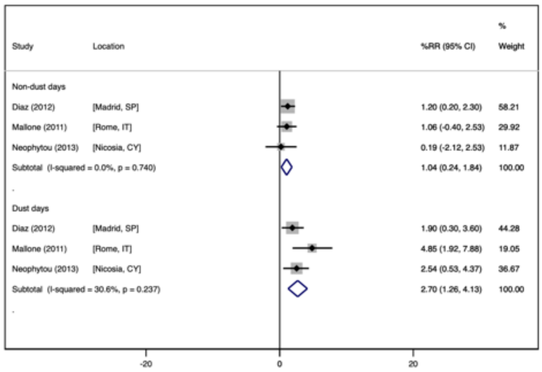
- Evidence on **health effects** of desert dust **remains unclear** *(Hashizume et al. 2010, Karanasiou et al. 2012, Longeville et al. 2013, Zhang et al. 2014)*
- Main **differences** on,
  - **Study design** and statistical analysis
  - **Methods to identify** dust events
  - **Metric of dust** exposure (binary or continuous)

Introduction

- Percentage increase of risk for cardiovascular mortality on **dust days versus non-dust days**



- Percentage increase of risk for cardiovascular mortality for a **rise of 10 mg/m³ of PM$_{10}$ on dust and non-dust days**



(Tobías et al., under review)

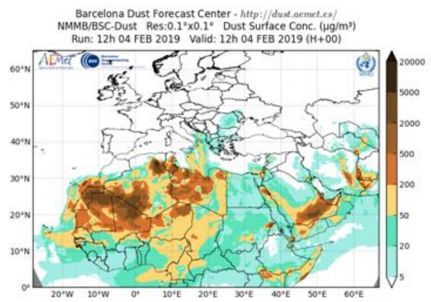
Research framework

- To quantify the **short-term health effects** of desert dust
- Use an ecological **time-series design**
- Analysis with overdispersed **Poisson regression**
- **Data collection** at daily level,
  - Health outcome as mortality/morbidity counts
  - Temperature
  - **Dust exposure** …

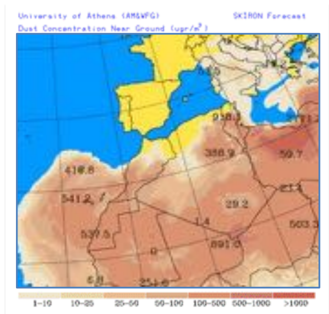
Identification of dust events

- **Combination of tools**: aerosol maps (BSC-DREAM, SKIRON, NAAPS-NRL) satellite images (MODIS) and air masses back-trajectories (HYSPLIT) *(Pey et al. 2013)*

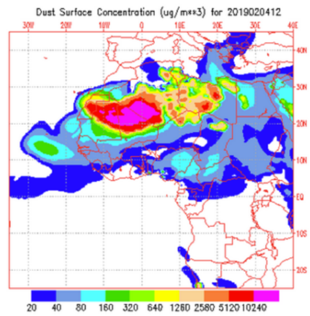
MMMB-BSC-dust



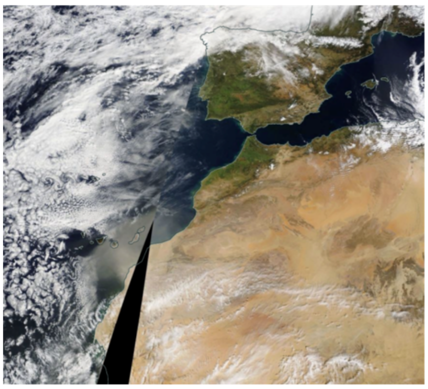
SKIRON



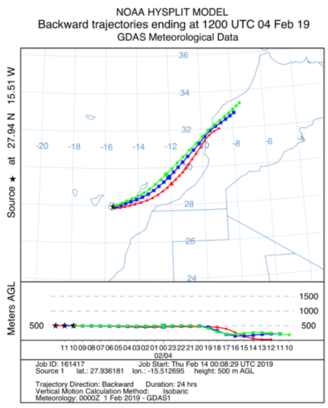
NAAPS - NRL



MODIS

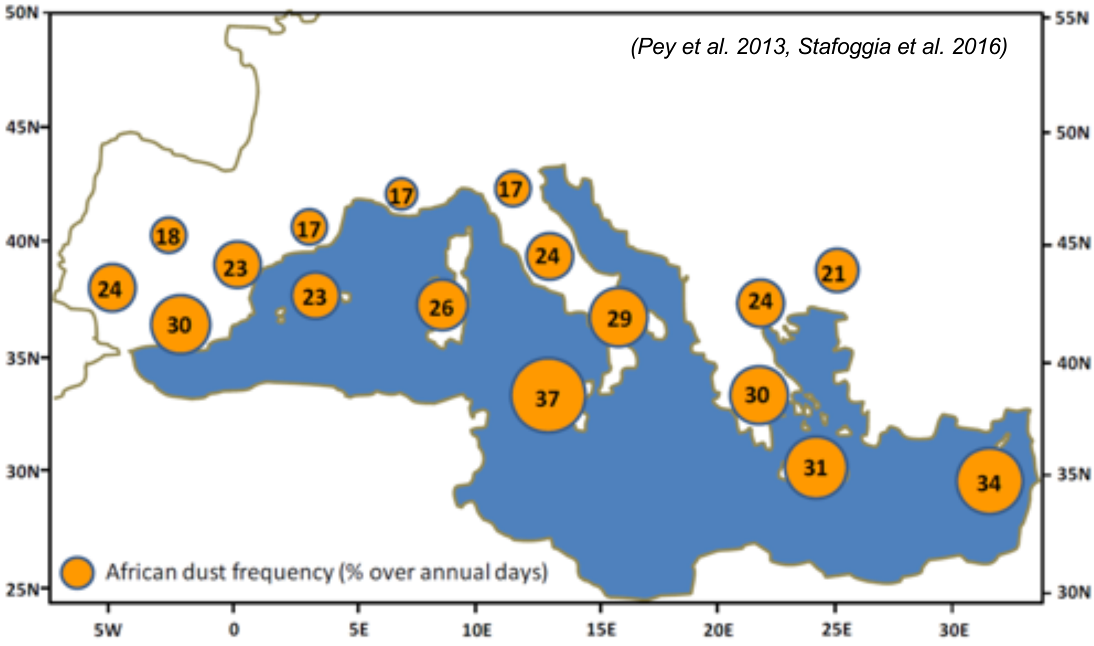


HYSPLIT



Saharan dust event
Canary Islands,
4 Feb. 2019, 12:00 h

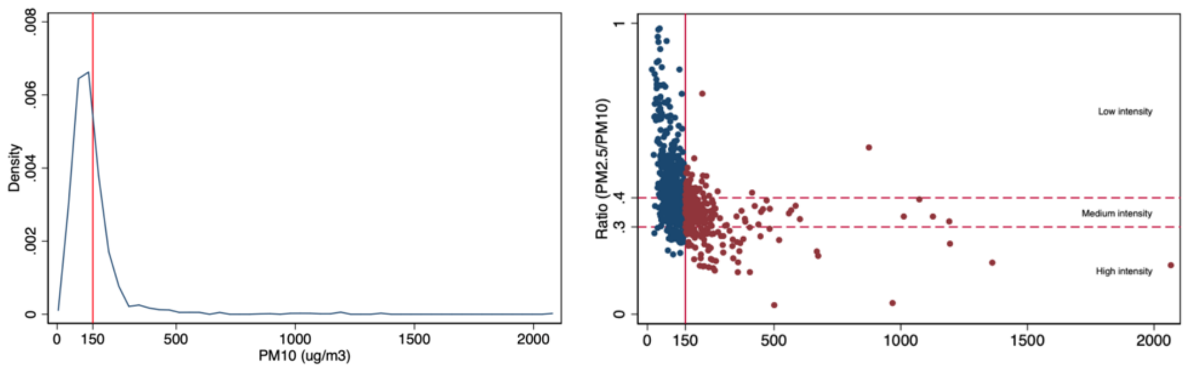
Identification of dust events



Identification of dust events

- **Threshold exceedance of PM concentrations** *(Thalib et al. 2012, Krasnov et al. 2013, Al-Taiar et al. 2014)*

PM_{10} concentrations in Ahvaz, Iran, during MED and non-MED days (2015-2017)

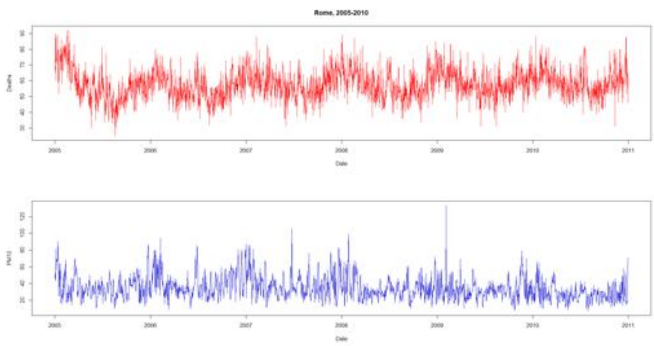


(Shahsavani et al., under review)

Identification of dust events

- **Combination of tools**: aerosol maps (BSC-DREAM, SKIRON, NAAPS-NRL) satellite images (MODIS) and air masses back-trajectories (HYSPLIT) *(Pey et al. 2013)*
- **Threshold exceedance** of PM concentrations *(Thalib et al. 2012, Krasnov et al. 2013, Al-Taiar et al. 2014)*
- **Visual inspection** reducing horizontal visibility to <10 km: **China** (*Ma et al. 2016)*, **Japan** *(Kashima et al. 2016)*, **Korea** *(Lee at al. 2013)* and **Caribbean** *(Akpinar-Elci et al. 2015)*
- **Registries for dust storms**, U.S. National Weather Service storm database *(Crooks et al. 2016)*

Case study



Data description

- Rome, 2005-2010 daily data
- Simulated natural mortality counts
- Real data on dust events, PM10, and air temperature

date:	current date (from 1/1/2005 to 31/12/2010)
trend:	progressive number from 1 to 2191
yy:	year
mm:	month
dd:	day of the month
dow:	day of the week
allnat:	daily mortality counts for non-accidental causes (simulated data)
temp:	daily mean air temperature
dust:	binary (0/1) variable for dust advection days
pm10:	daily PM10 concentrations
pm10natural:	daily PM10 concentrations from natural sources
pm10local:	daily PM10 concentrations from non-natural sources

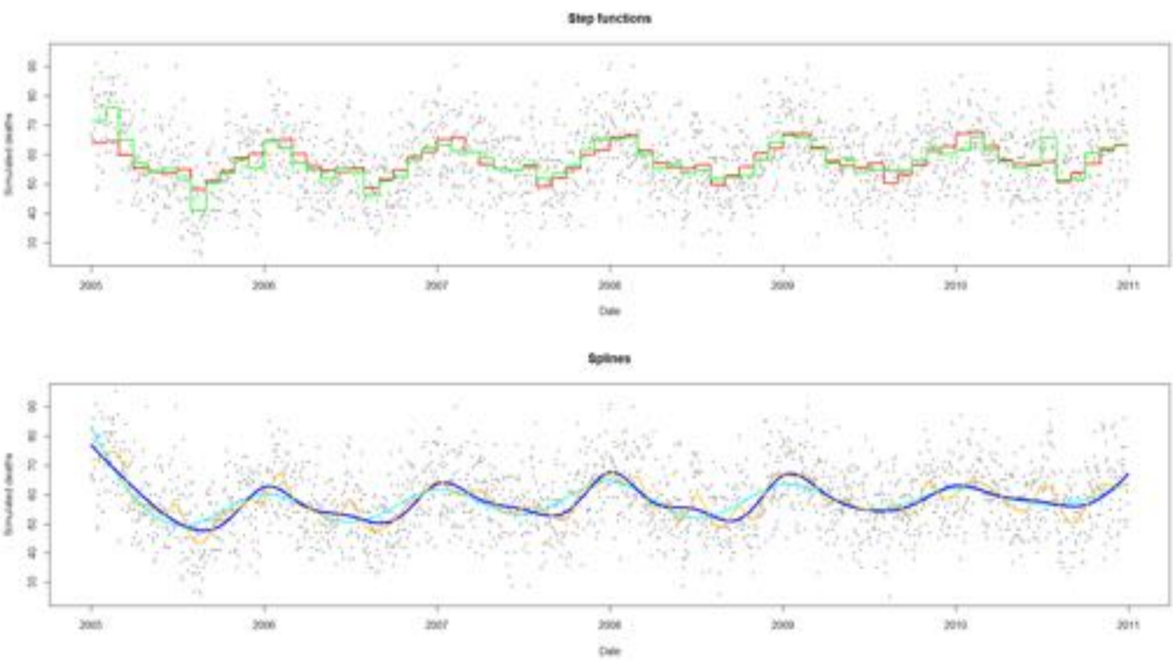
Case study

- **Core model** adjusted for:
  - Time-trend using natural cubic splines
  - Weekdays using dummy variables
  - Air temperature using the MED-PARTICLES approach, with natural cubic splines for cold and warm temperatures *(Stafoggia et al. 2013, Stafoggia et al. 2016)*

$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t)$$

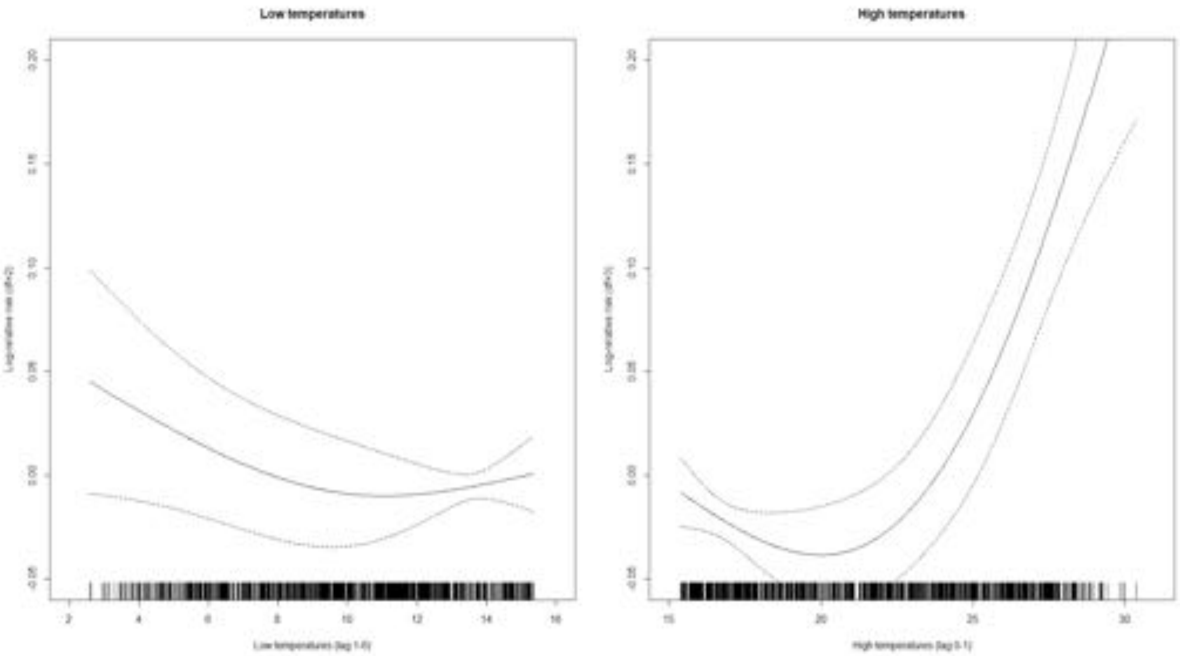
Case study

- Time-trend adjustment



Case study

- Air temperature adjustment



Dust as binary metric

- **Risk factor**

1st RESEARCH QUESTION

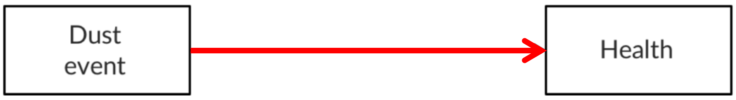
- **Is mortality higher on DUST days compared to NO-DUST days?** (after accounting for time trends and meteorology)?

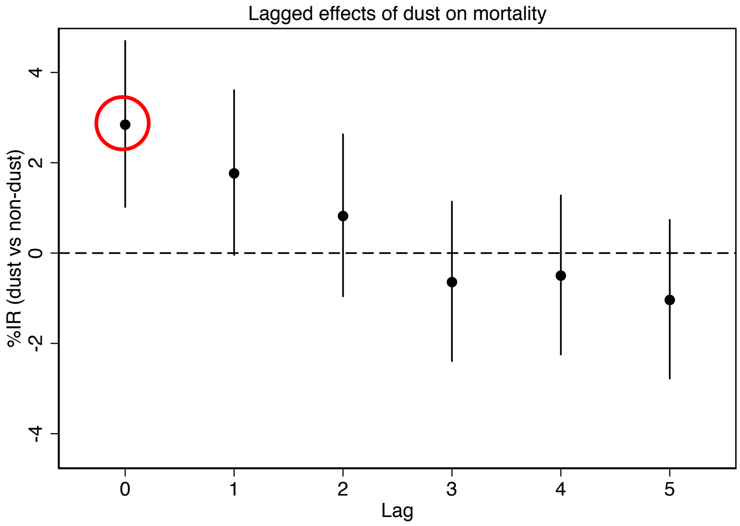
- Mortality increases by **3.5% (95%CI: 1.3, 5.7)**

$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \boldsymbol{\beta dust_t}$$

Dust as binary metric

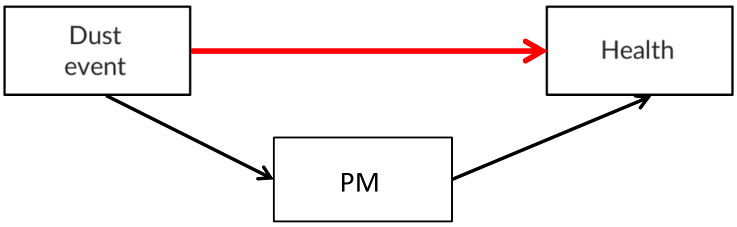
- **Risk factor**





Dust as binary metric

- **Risk factor**



2nd RESEARCH QUESTION

- Is mortality higher on DUST days compared to NO-DUST days, **independently from PM10 increase?**

- Mortality increases by **3.1% (95%CI: 0.9, 5.5)**

$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \boldsymbol{\beta_1 dust_t + \beta_2 PM_t}$$

Dust as binary metric

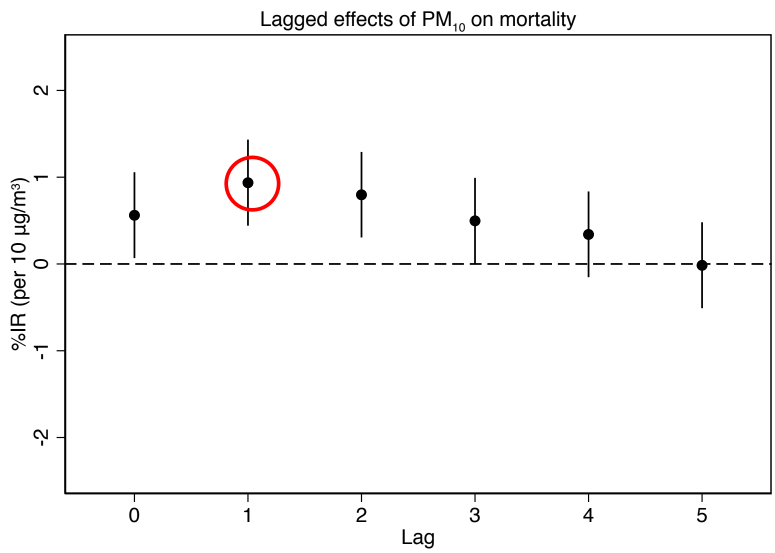
- **Confounder**

Step 1. Check if PM10 is associated with mortality

- Mortality increases by **0.5% (95%CI: -0.1% 1.1)** per each 10 μg/m^3 increase in PM10

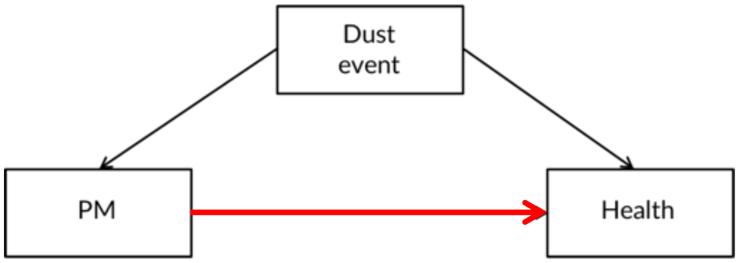
$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \beta_1 dust_t + \beta_2 PM_t$$

Dust as binary metric



Dust as binary metric

- **Confounder**



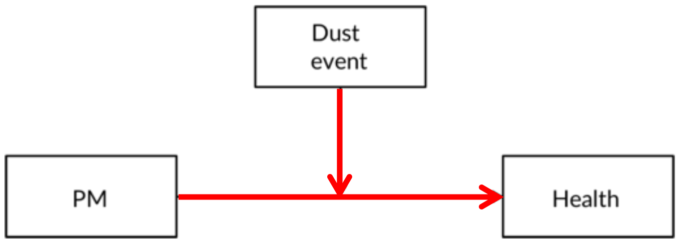
Step 2. Check if PM10 is associated with mortality, independently on DUST events

- Mortality increases by **0.4% (95%CI: -0.2, 1.0)** per each 10 $\mu g/m^3$ increase in PM10, **independently on DUST events**

$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \beta_1 dust_t + \beta_2 PM_t$$

Dust as binary metric

- **Effect modifier**



RESEARCH QUESTION

- Is the association between PM10 and mortality **different on DUST versus NO-DUST days?**

- Mortality increases by **0.3% (95%CI: -0.3, 1.0)** per each 10 $\mu g/m^3$ increase in PM10 **during NON-dust days**
- Mortality increases by **0.8% (95%CI: -0.3, 1.0)** per each 10 $\mu g/m^3$ increase in PM10 **during DUST days**

$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \beta_1 dust_t + \beta_2 PM_t + \beta_3 dust_t{*}PM_t$$

Dust as binary metric

Main exposure

- **All dust events are treated in the same way** since do not quantify the dust, not providing information on the dose-response relationship
- Studies in Eastern Asia show **increase of cardiovascular mortality** and **respiratory/child asthma morbidity** during days with dust events

Effect modifier

- **PM is a mixture of natural and local sources**, even within the dust days. It is not possible to attribute the health effects to a given source
- Studies in Europe show **larger effect of PM_{10} and $PM_{10\text{-}2.5}$ on cardiovascular mortality** and **respiratory morbidity** during days with dust events but similar effects for **$PM_{2.5}$**

Quantification of dust events

- EU reference method (Directive 2008/50/EC)

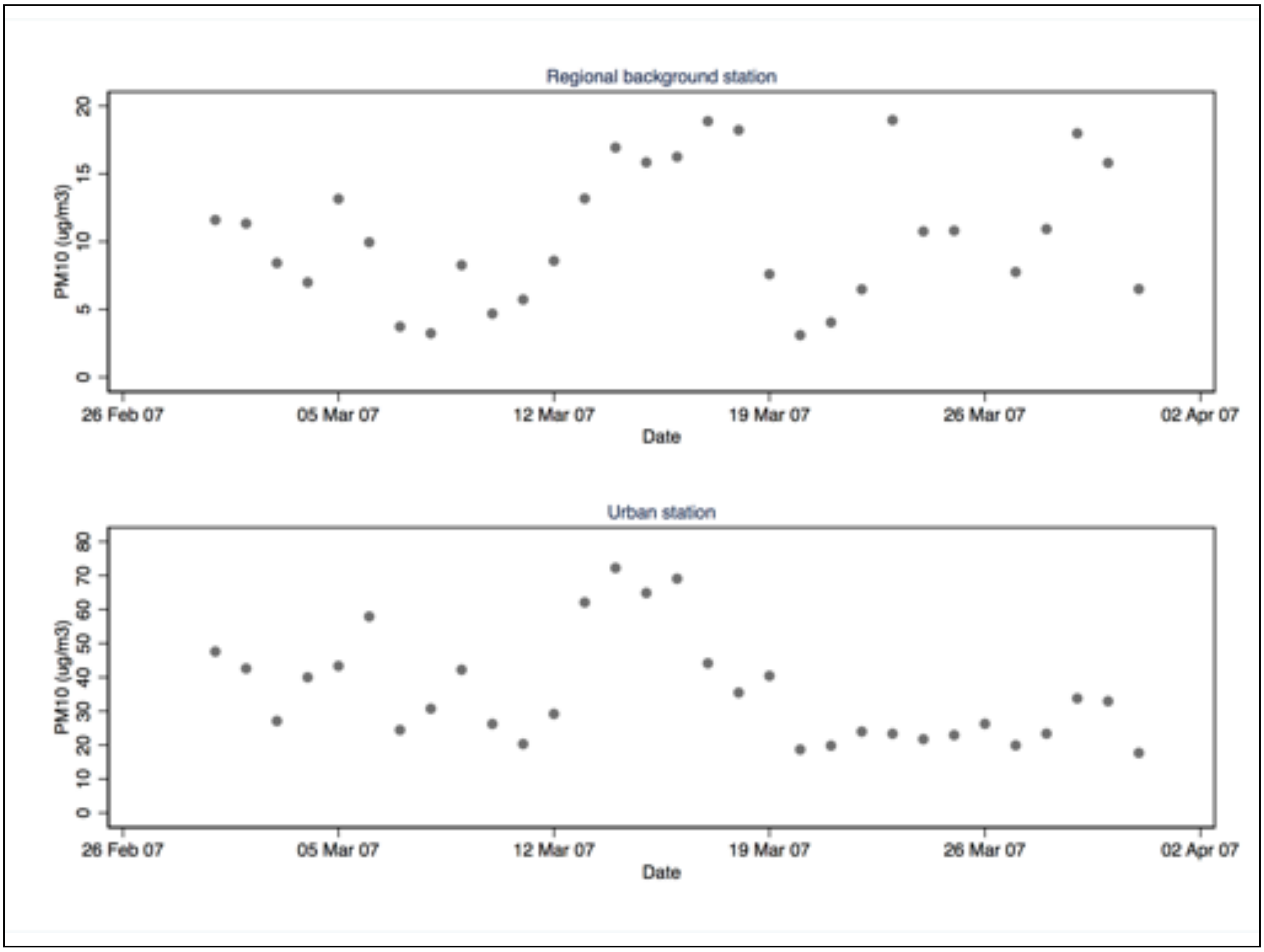
EUROPEAN COMMISSION

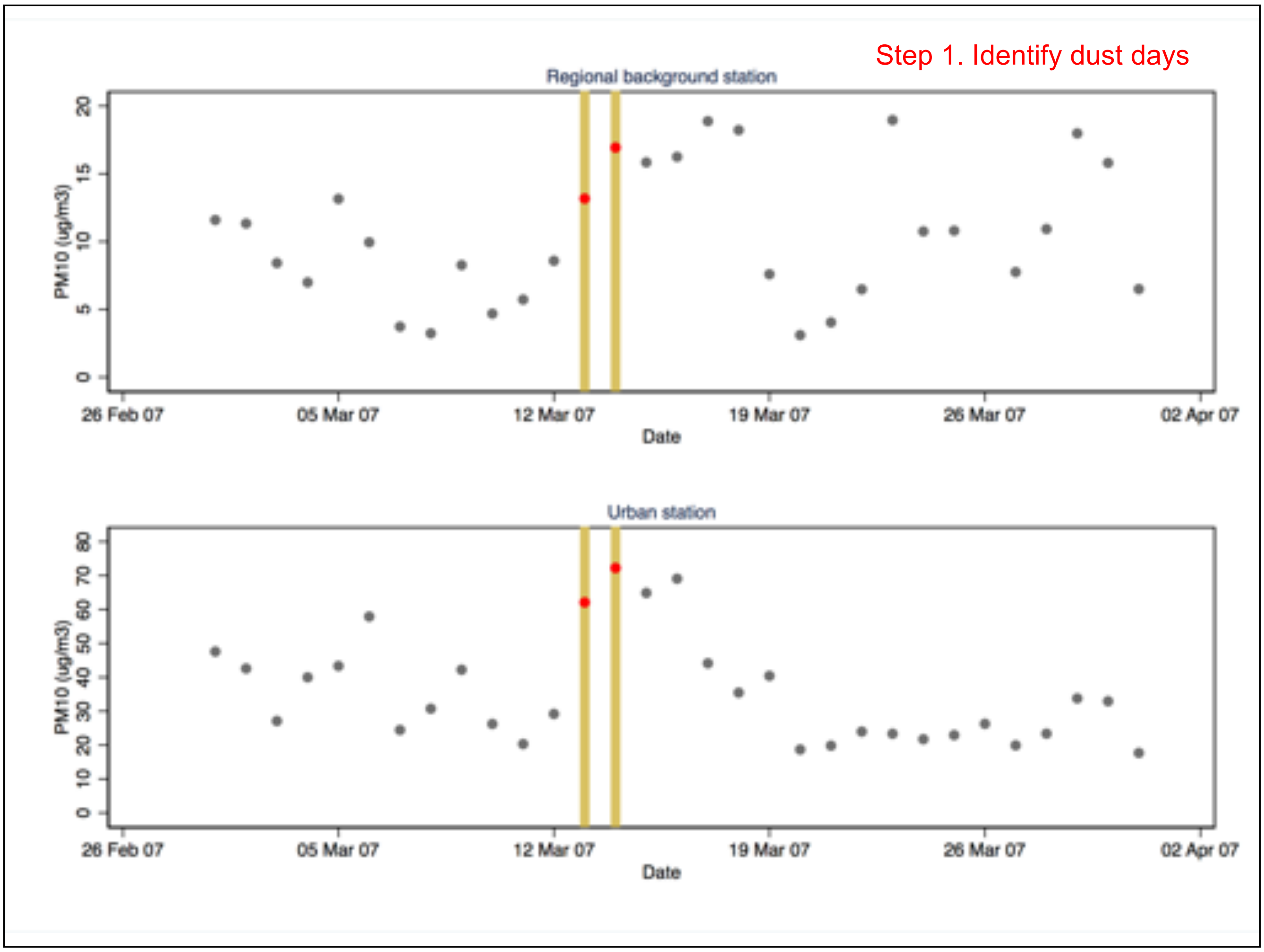
Brussels, 15.02.2011
SEC(2011) 207 final

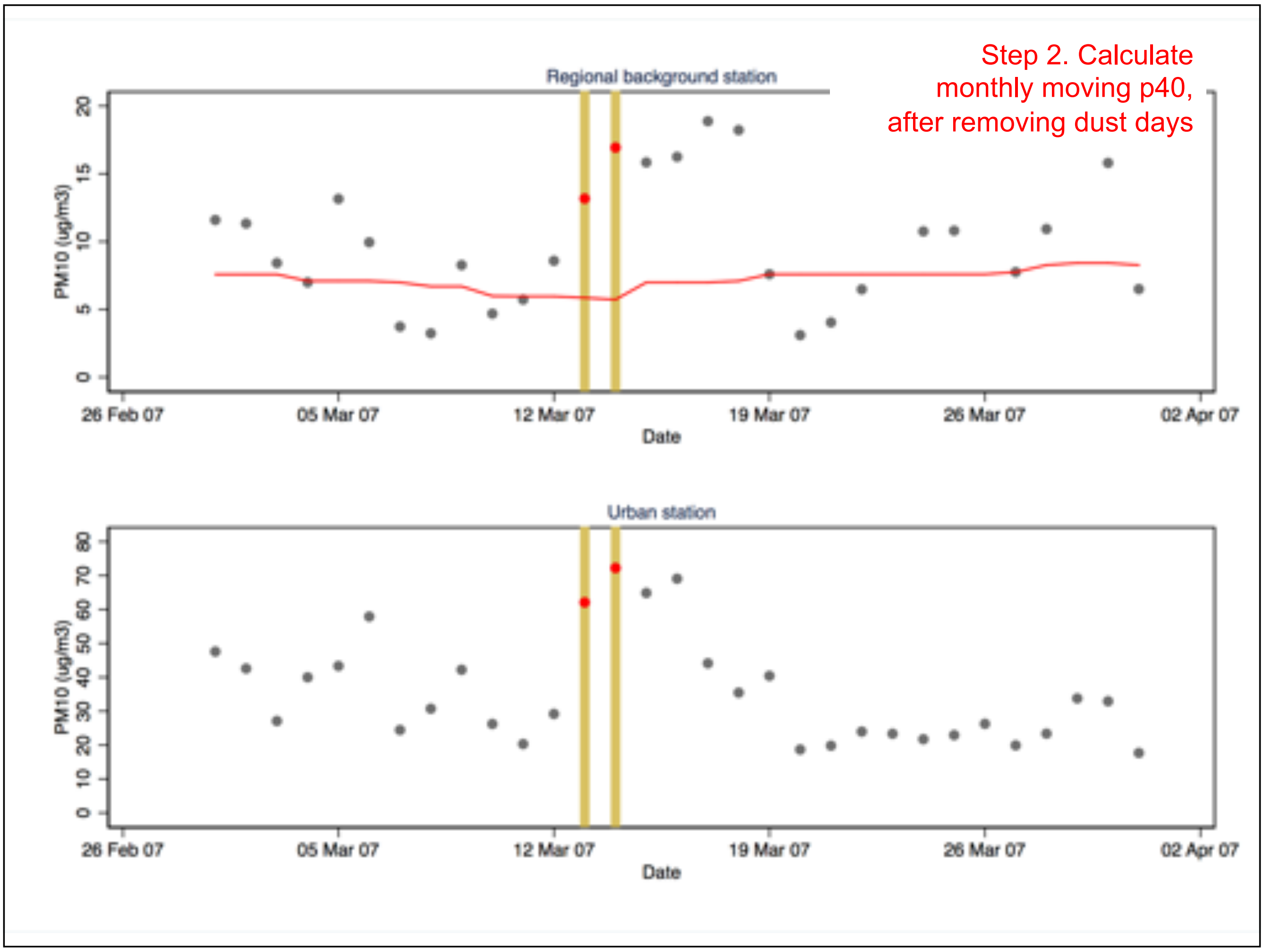
COMMISSION STAFF WORKING PAPER

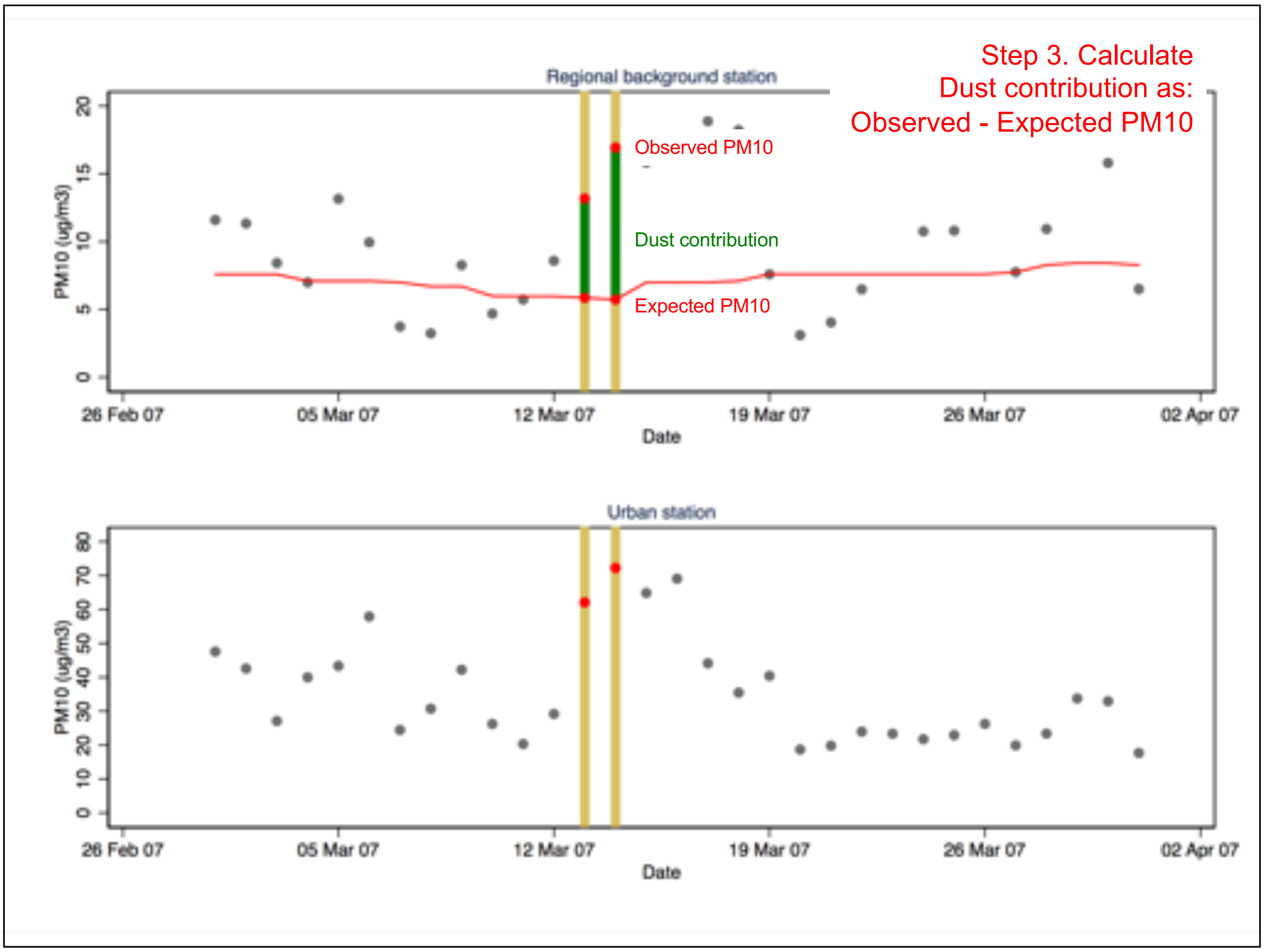
establishing guidelines for determination of contributions from the re-suspension of particulates following winter sanding or salting of roads under the Directive 2008/50/EC on ambient air quality and cleaner air for Europe

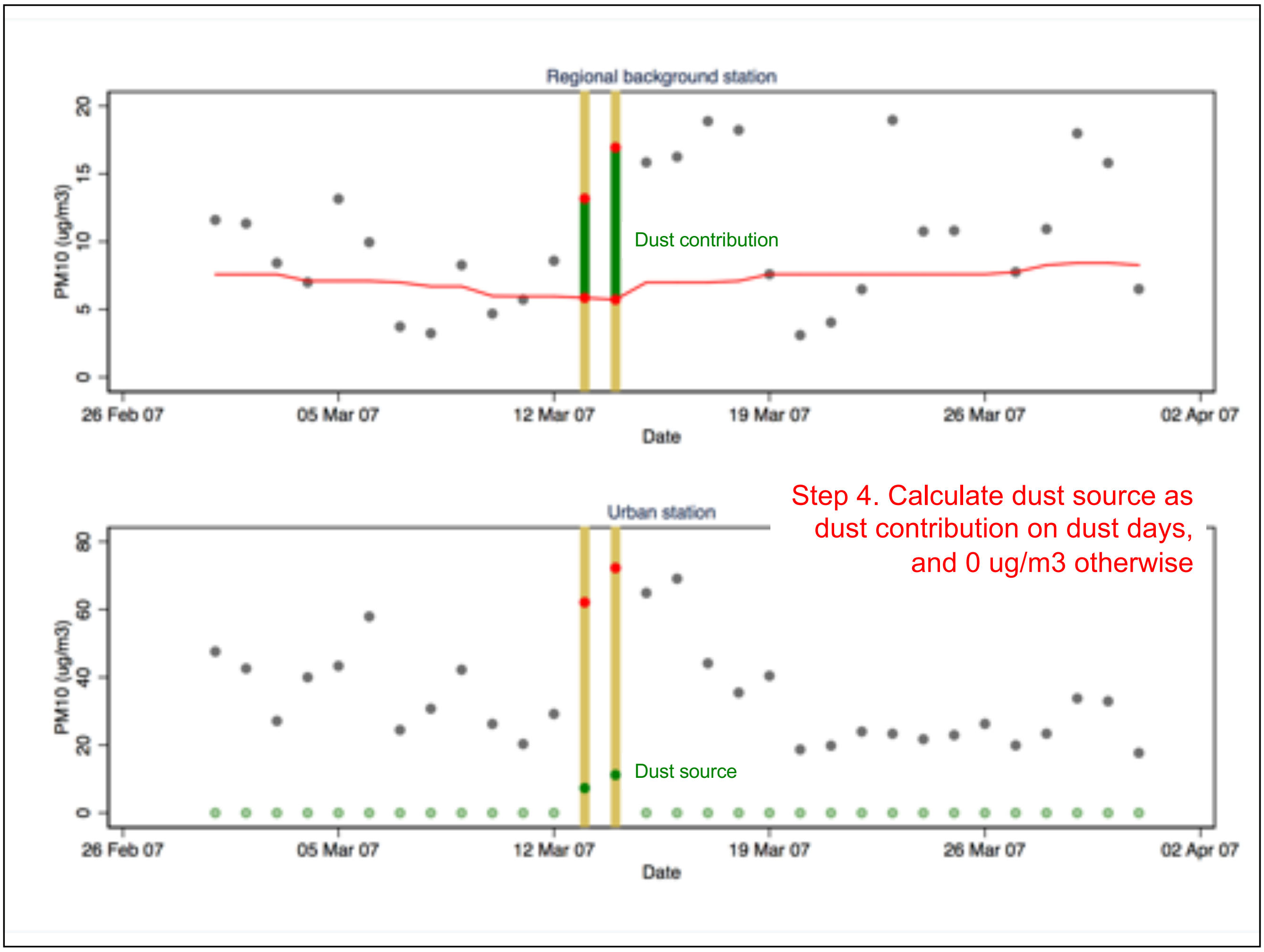
http://data.europa.eu/eli/dir/2008/50/oj


Regional background station
PM10 (ug/m3)
0
5
10
15
20
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date
Urban station
PM10 (ug/m3)
0
10
20
30
40
50
60
70
80
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date

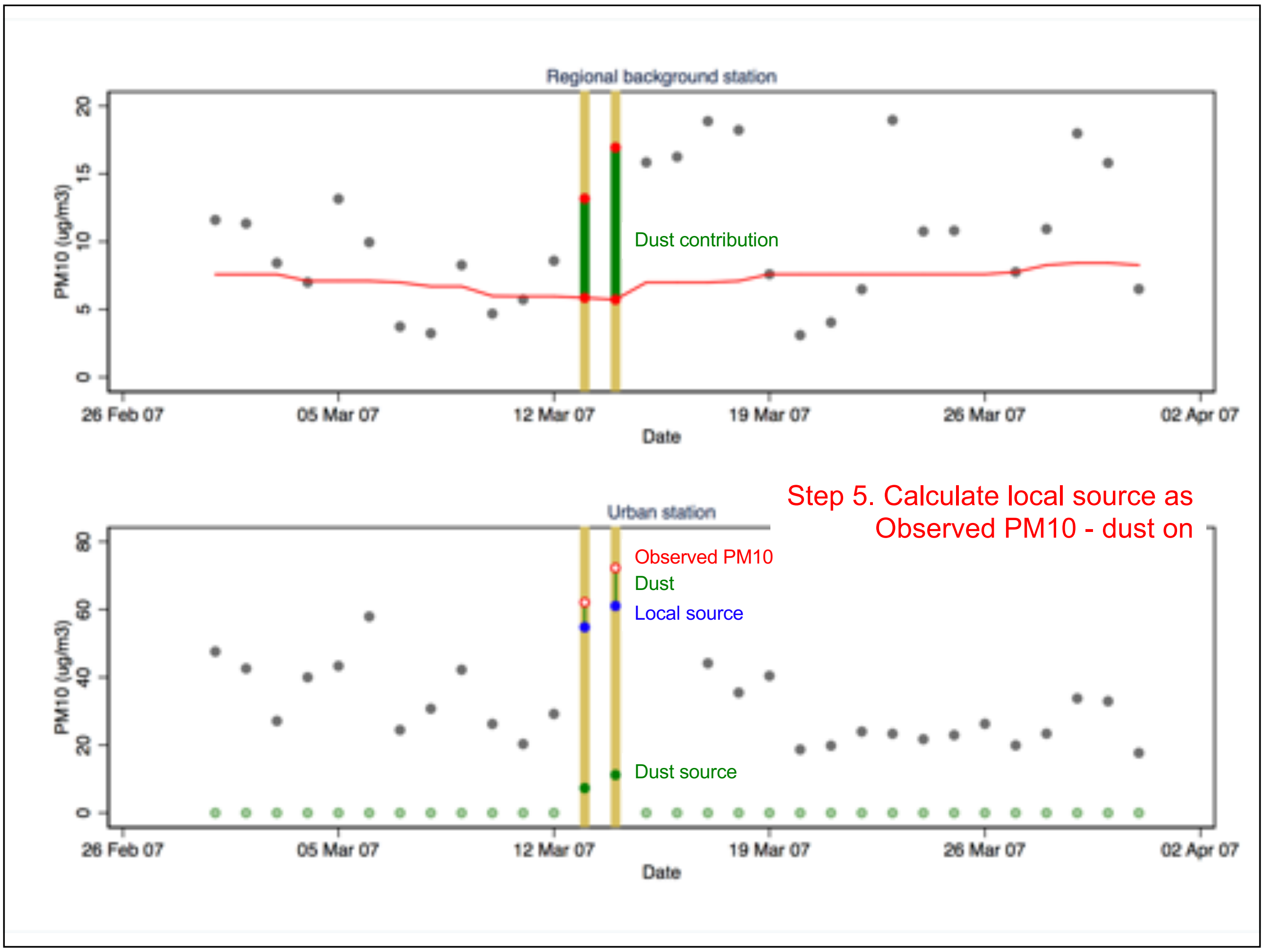

Step 1. Identify dust days
Regional background station
PM10 (ug/m3)
0
5
10
15
20
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date
Urban station
PM10 (ug/m3)
0
10
20
30
40
50
60
70
80
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date


Step 2. Calculate monthly moving p40, after removing dust days
Regional background station
PM10 (ug/m3)
0
5
10
15
20
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date
Urban station
PM10 (ug/m3)
0
10
20
30
40
50
60
70
80
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date

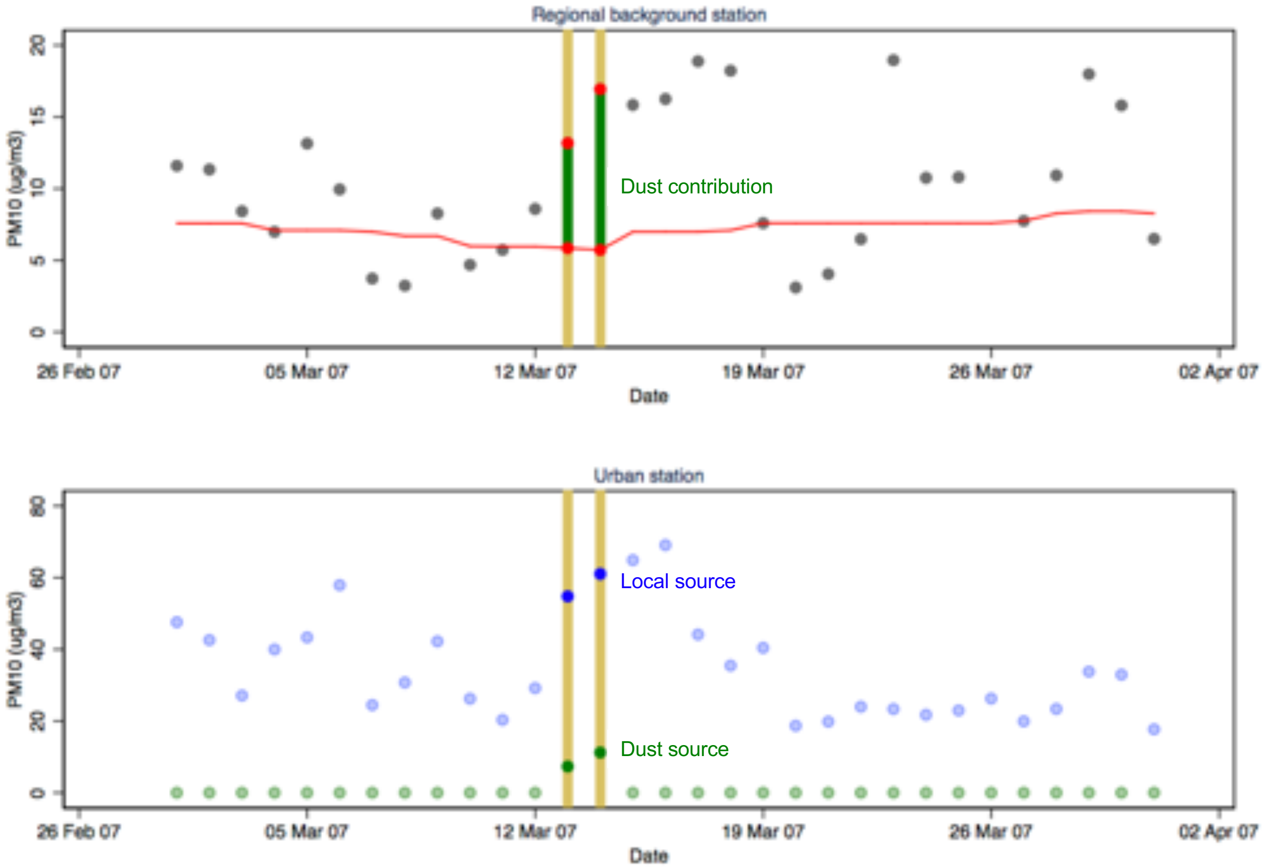

Step 3. Calculate Dust contribution as: Observed - Expected PM10
Regional background station
Observed PM10
Dust contribution
Expected PM10
PM10 (ug/m3)
0
5
10
15
20
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date
Urban station
PM10 (ug/m3)
0
10
20
30
40
50
60
70
80
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Date



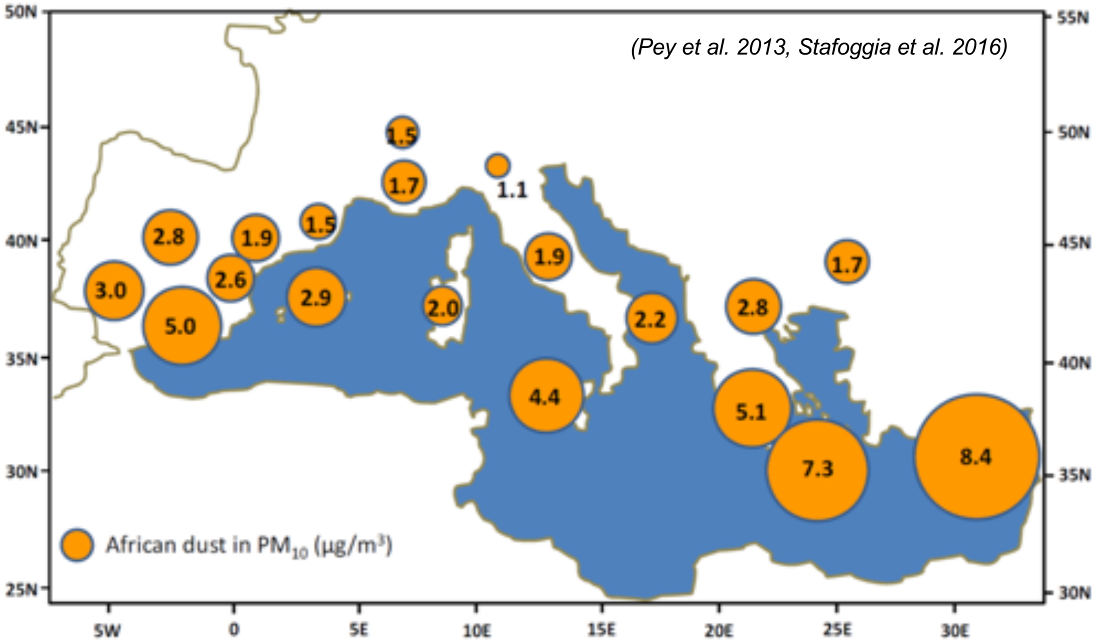
Regional background station
PM10 (ug/m3)
Dust contribution
Date
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Urban station
Step 4. Calculate dust source as dust contribution on dust days, and 0 ug/m3 otherwise
Dust source



Regional background station
PM10 (ug/m3)
Dust contribution
Date
26 Feb 07
05 Mar 07
12 Mar 07
19 Mar 07
26 Mar 07
02 Apr 07
Urban station
Step 5. Calculate local source as Observed PM10 - dust on
Observed PM10
Dust
Local source
Dust source



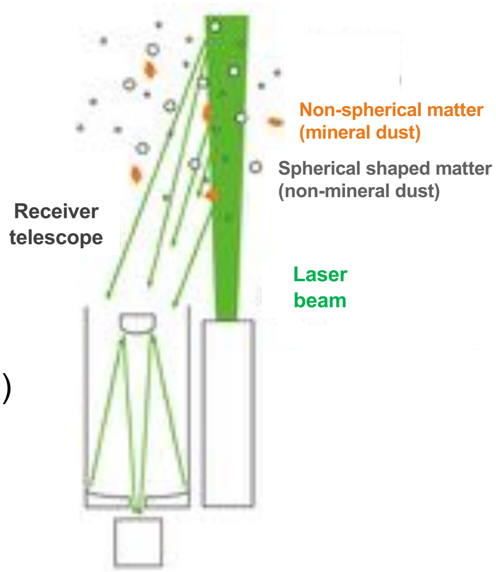
Quantification of dust events



Quantification of dust events

- **LIDAR** (Light Detection and Ranging) measurement
- Optical remote sensing technology that **measures properties of scattered light**
- It **differentiates the shape of particles** not differentiate their size
- **Key issues** to consider
  - Which height?
  - Which cut-off?
  - Conversion from extinction coefficient (/km) to concentration (µg/m^3)?

  (Ueda et al. 2014)

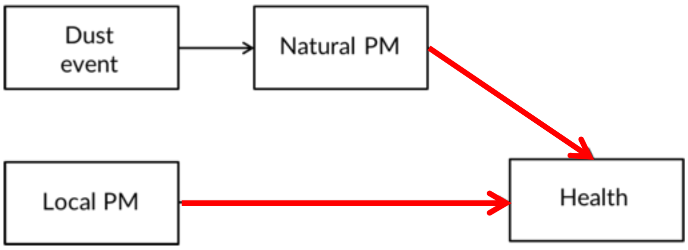


Quantification of dust events

- **EU reference method** (Directive 2008/50/EC)
- **LIDAR** (Light Detection and Ranging) measurement
- Dust concentrations at surface from **ensemble multi-model products**
  - **SDS-WAS**: Prepares regional forecast of a numerical weather prediction model incorporating parameter of all de major phases of the atmospheric dust cycle
  - **MERRA-2**: Global reanalysis to assimilate space-based observations of aerosols and their interactions with other physical processes in the climate system
  - **JRAero**: Global aerosol reanalysis assimilating maps of aerosol optical depth from MODIS onboard the Terra and Aqua satellites

Dust as continuous exposure

- **Two sources**
  - Natural (dust)
  - Local (anthropogenic)



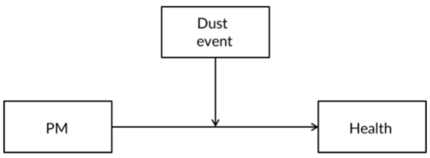
RESEARCH QUESTION

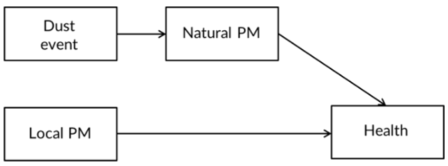
- **Are natural and local sources of PM10 independently associated with mortality?**

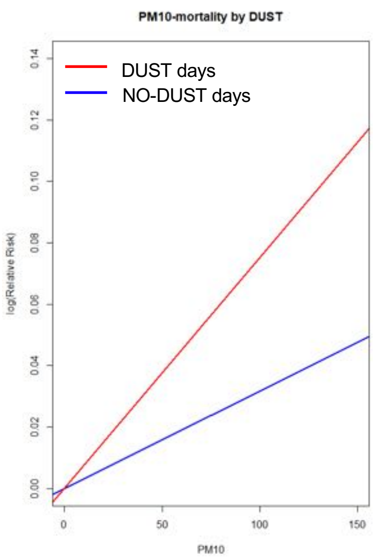
- Mortality increases by **1.3% (95%CI: 0.0, 1.7)** per each 10 ug/m3 increase in **natural (dust) PM10**
- Mortality increases by **0.4% (95%CI: -0.2, 1.1)** per each 10 ug/m3 increase in **local (anthropogenic) PM10**

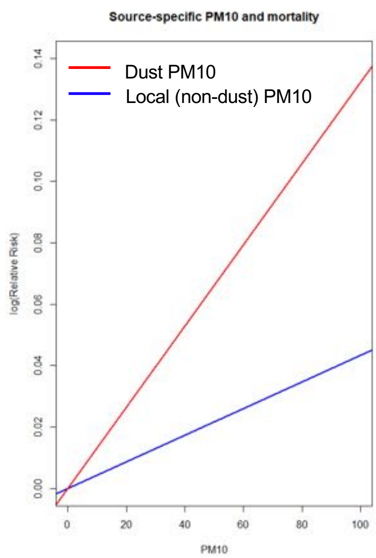
$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \boldsymbol{\beta_1 PM_{natural}} + \boldsymbol{\beta_2 PM_{local}}$$

Dust as continuous exposure



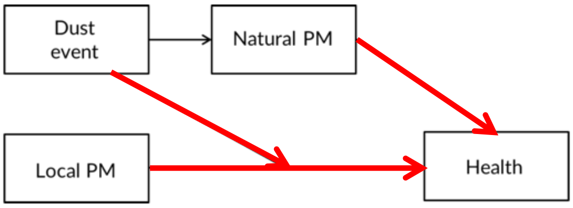






Dust as continuous exposure

- **Three sources**
  - Dust
  - Anthropogenic on **dust** days
  - Anthropogenic on **non-dust** days



RESEARCH QUESTION
1. Is the association between local (non-desert) PM10 with mortality different on DUST versus NO-DUST days?
2. Are these associations independent from natural (desert) PM10?

1. Mortality increases by **0.3% (-0.3, 1.0)** per each 10 ug/m3 increase in **local PM10 on NO-DUST days**, and by **1.6% (-0.2, 3.6)** on **DUST days. These estimates are NOT statistically different.**
2. **Natural PM10 is no longer associated with mortality (-0.1%; (-1.9,1.8))**

$$y_t = \beta_0 + s(t) + \Sigma\beta_i dow_{it} + s(temp_t) + \beta_1 PM_{natural} + \beta_2 PM_{local} + \beta_3 dust + \beta_4 dust*PM_{local}$$

Dust as continuous exposure

- Suitable to **estimate concentration-response functions** between PM sources and health outcomes, applicable in health impact assessment studies
- In regions **with large dust events and high concentrations of local pollutants,** would probably make no sense to investigate independent effects of desert and anthropogenic sources
- Few studies showed
  - **Larger effect of Asian dust than SPM** on mortality outcomes in Japan *(Kashima et al. 2012, 2016)*,
  - **Similar effects of Saharan dust and PM_{10}** on mortality and morbidity outcomes in Southern Europe *(Stafoggia et al. 2016)*
  - **Larger effect of anthropogenic PM_{10} during dust days** on cardiovascular mortality in Barcelona *(Pérez et al. 2012)*

Discussion

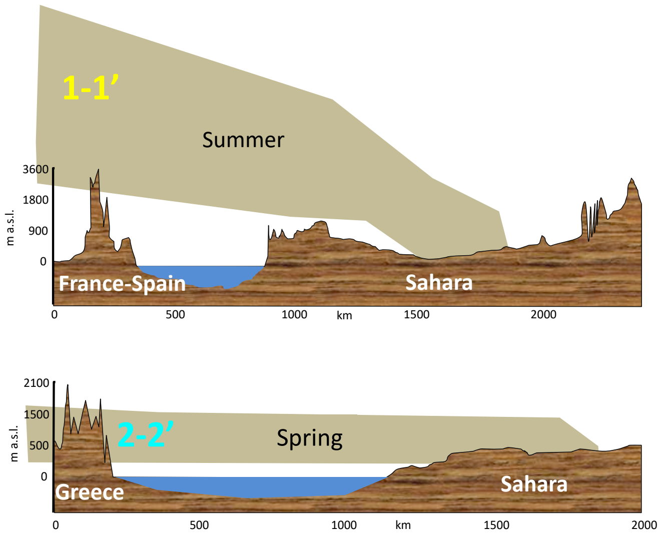
- A **proper understanding of dust exposures** in epidemiological studies would help to develop **appropriate measures to reduce local pollution** during dust events
- Need to **standardize epidemiological studies** with same methodological characteristics to **make health effects comparable** in and near to hot spots

		Rome (2005-2010)		Athens (2007-2009)	
Dust events	**Exposure**	**%IR**	**(95% CI)**	**%IR**	**(95% CI)**
Binary as risk factor	Dust *vs.* non-dust	2.8	(1.0 , 4.7)	1.4	(-0.4 , 3.2)
	Dust *vs.* non-dust $_{adj.}$	2.3	(0.6 , 4.4)	0.7	(-1.2 , 2.5)
Binary as confounder	PM_{10}	0.6	(0.1 , 1.1)	0.5	(0.2 , 0.9)
	$PM_{10\ adj.}$	0.5	(0.0 , 1.0)	0.5	(0.1 , 1.0)
Binary as effect	PM_{10}				
modifier	*on non-dust days*	0.3	(-0.2 , 0.9)	1.0	(0.2 , 1.8)
	on dust days	1.1	(-0.1 , 2.3)	0.3	(-0.2 , 0.8)
Continuous with	Local PM_{10}	0.5	(0.0 , 1.0)	0.7	(0.0 , 1.5)
2 sources	Dust PM_{10}	1.2	(0.0 , 2.3)	0.5	(0.0 , 1.0)
Continuous with	Local PM_{10}				
3 sources	*on non-dust days*	0.3	(-0.2 , 2.9)	1.0	(0.2 , 1.7)
	on dust days	2.2	(0.6 , 3.8)	-1.1	(-3.0 , 0.9)
	Dust PM_{10}	0.1	(-1.4 , 1.7)	0.5	(-0.0 , 1.0)

Discussion

Transportation

- Dust events over the **western basin** are more frequent with a moderate intensity and dust travels at very high altitudes
- While **eastern** induced by cyclones transporting dust at surface levels with shorter and intense events *(Karanasiou et al. 2012, Pey et al. 2013)*



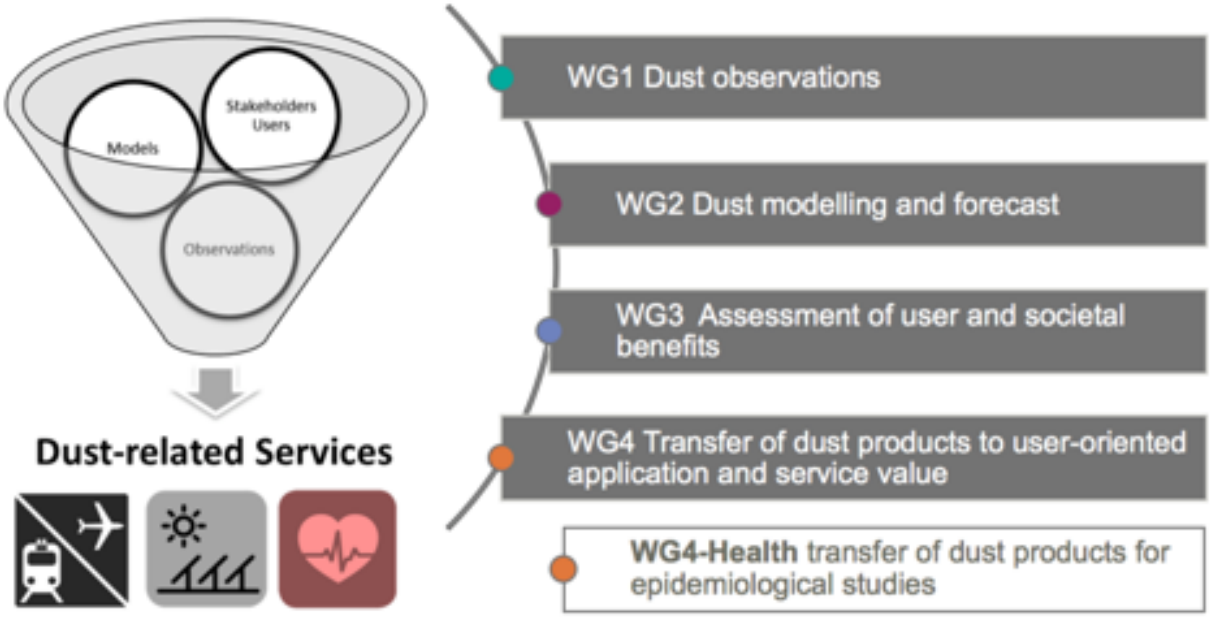
Discussion

Sources

- The **western** Mediterranean basin is affected by air masses from South Algeria and west Sahara, while **eastern** is from Libya and Egypt *(Pey et al. 2013)*
- Dust **clouds can absorb industrial pollutants** through journey over industrialised areas *(Rodríguez et al. 2001)* also microorganisms and toxic biogenic allergens *(Griffin 2001)*

Toxicity

- Local particles can be more toxic on dust days due to **reactions with gases or condensation of organic compounds** on the particles *(Pérez et al. 2012)*
- Dust episodes associated with a **lowering of the MLH enhancing local pollution** *(Pandolfi et al. 2014)*



Acknowledgements

- To **Xavier Querol**, **Masahiro Hashizume** and **Chris Ng** for their comments and suggestions
- To the **International Network to Encourage the Use of Monitoring and Forecasting Dust Products** (Cost action, CA16202)
- To the **Japanese Society for the Promotion of Science** (S18149) BRIDGE fellowship for research in Japan