

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

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Objective

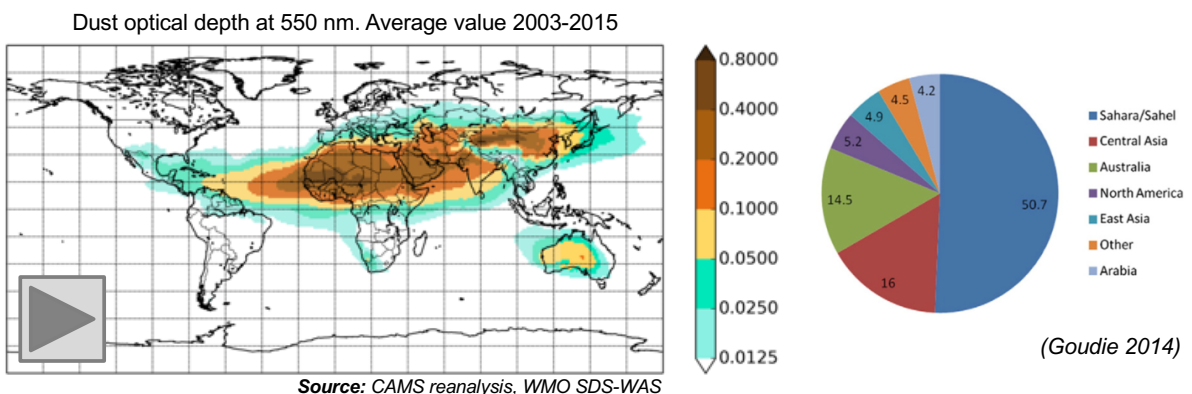
- How to answer properly the (*apparently simple*) research question “**does desert dust impact human health?**”
- **Workshop materials** available at, <http://www.aureliotobias.com/isee2019dust/>

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

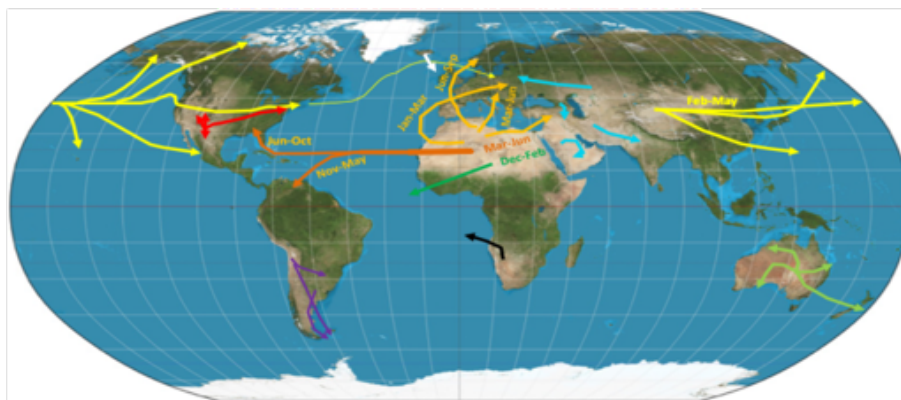
Introduction

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



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)



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 et al. 2011*)

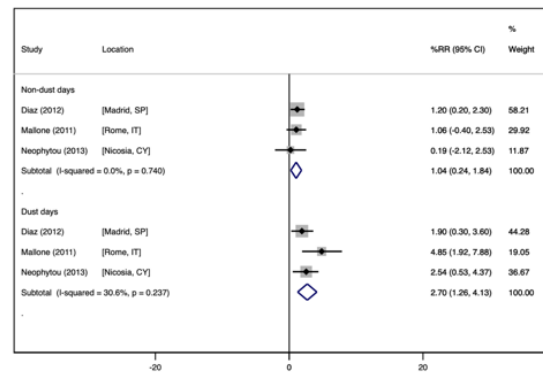
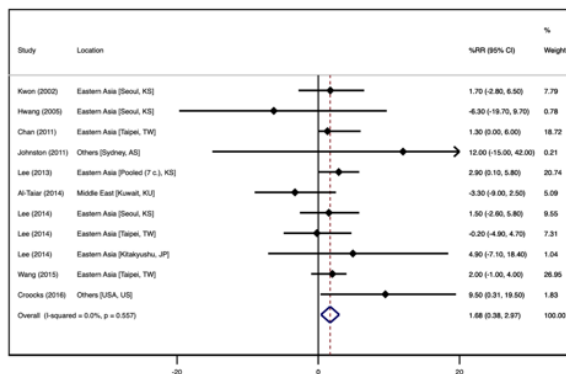
3) Carry microorganisms and toxic biogenic allergens (*Griffin et al. 2001, Ho et al. 2008*)

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 PM₁₀ on dust and non-dust days**



(Tobías et al., under review)

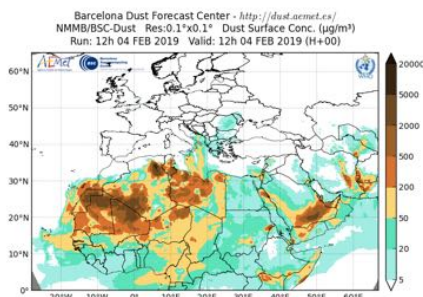
Research framework

- 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 ...**

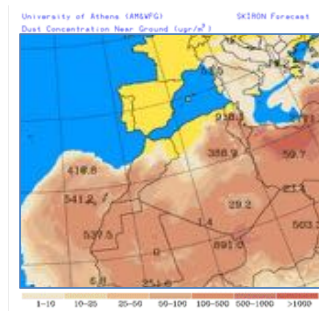
Identification of dust events

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

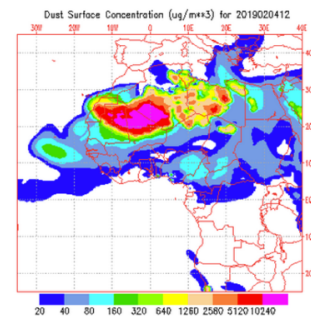
MMMB-BSC-dust



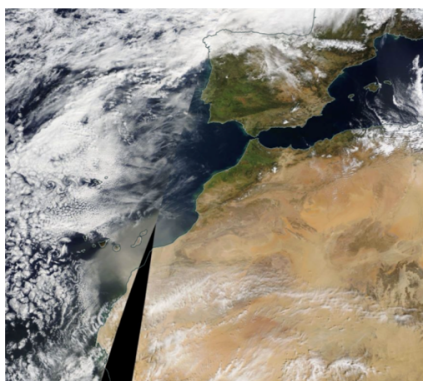
SKIRON



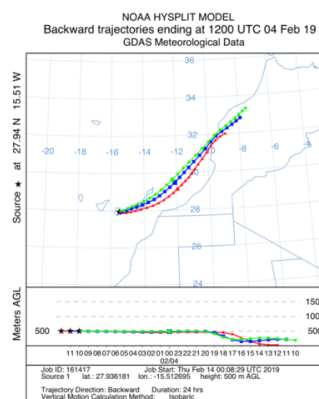
NAAPS - NRL



MODIS

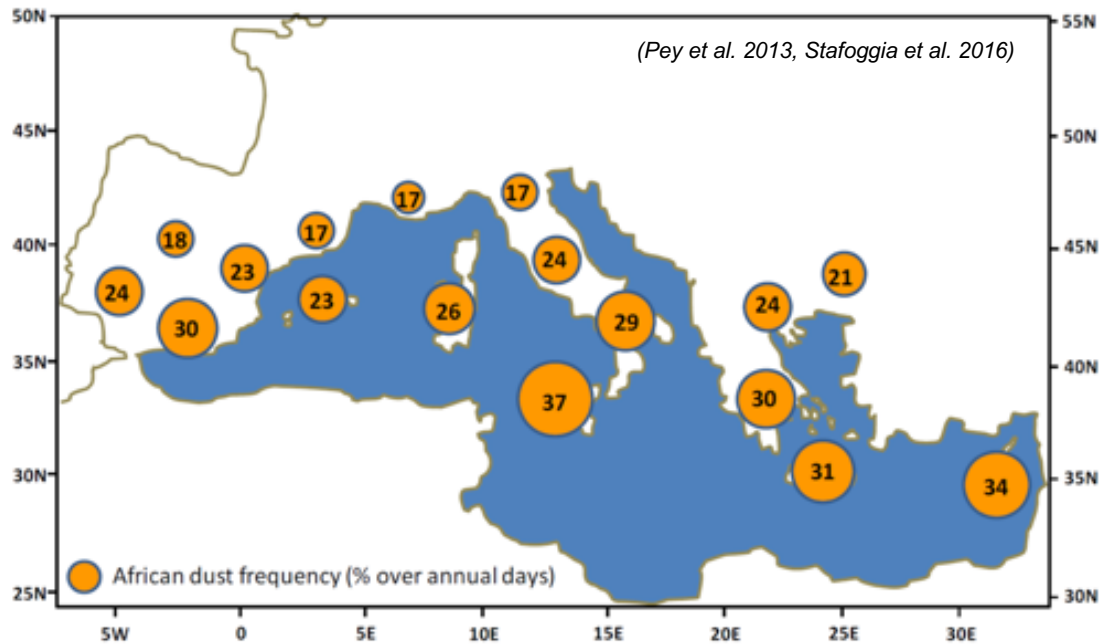


HYSPLIT



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

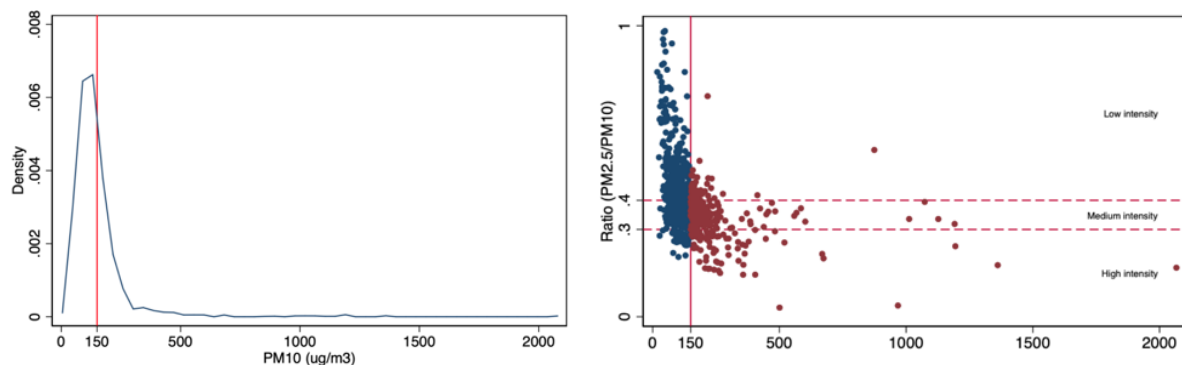
Identification of dust events



Identification of dust events

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

PM₁₀ concentrations in Ahvaz, Iran, during MED and non-MED days (2015-2017)



(Shahsavani et al., under review)

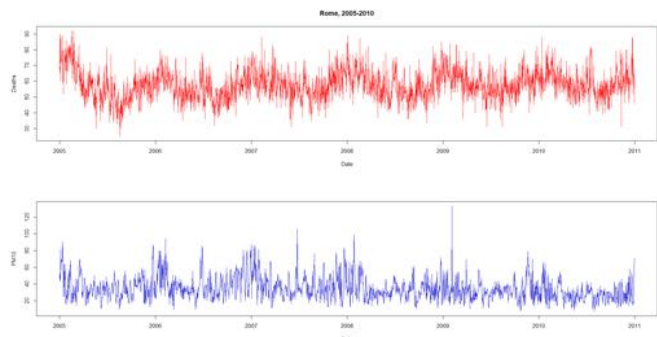
Identification of dust events

- **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 et 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

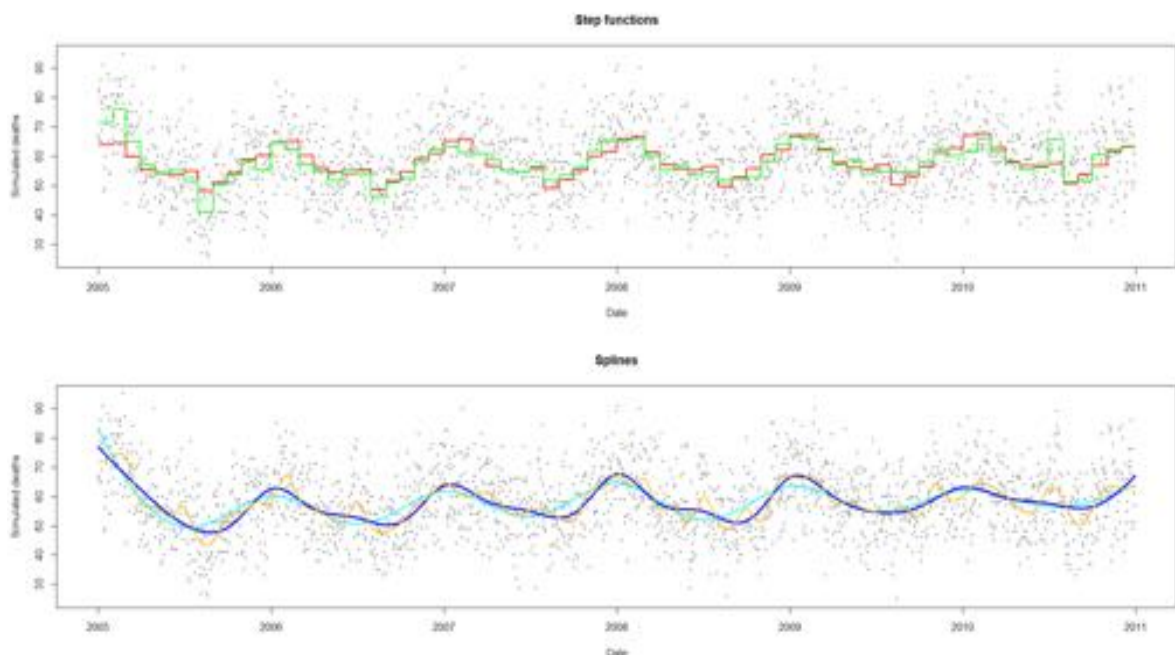
Case study

- **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*)

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t)$$

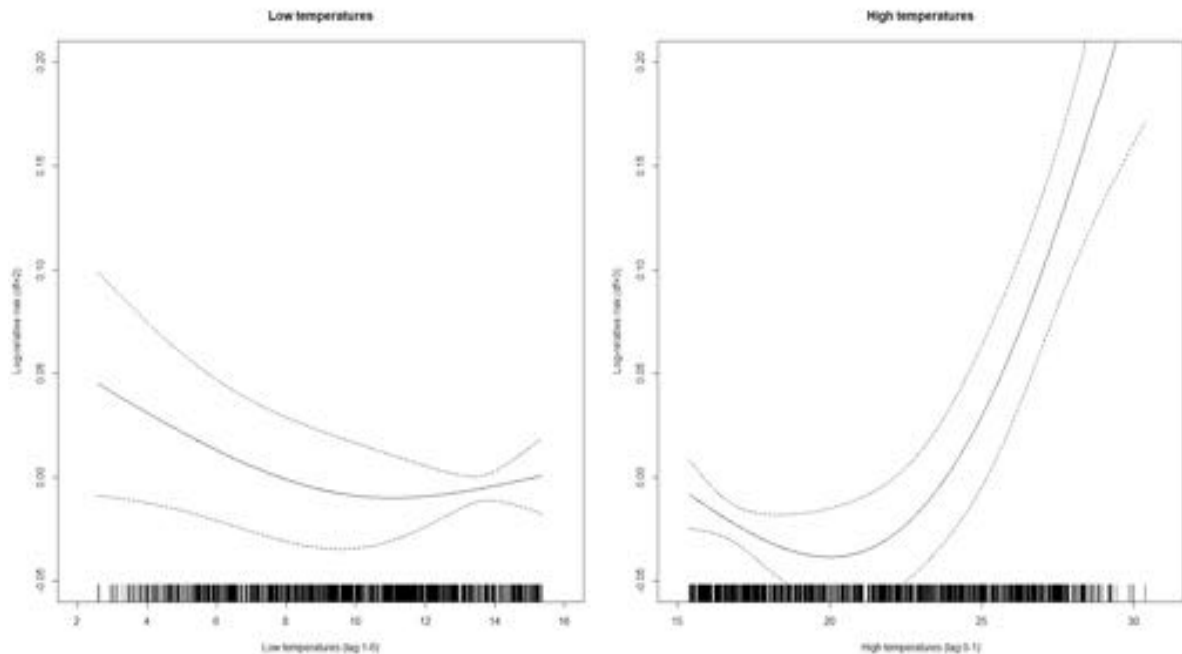
Case study

- Time-trend adjustment



Case study

- Air temperature adjustment



Dust as binary metric

- Risk factor



1st RESEARCH QUESTION

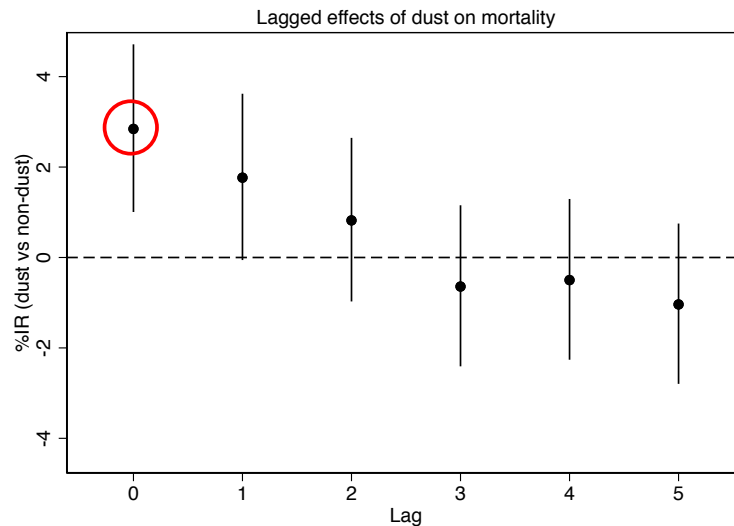
- Is mortality higher on DUST days compared to NO-DUST days? (after accounting for time trends and meteorology)?

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

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta \text{dust}_t$$

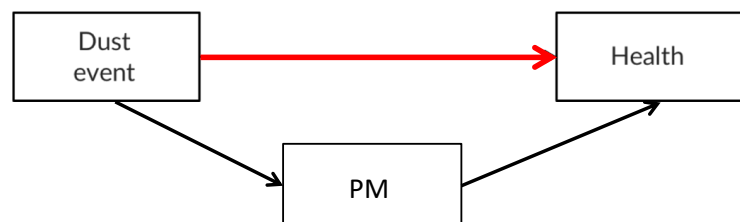
Dust as binary metric

- Risk factor



Dust as binary metric

- Risk factor



2nd RESEARCH QUESTION

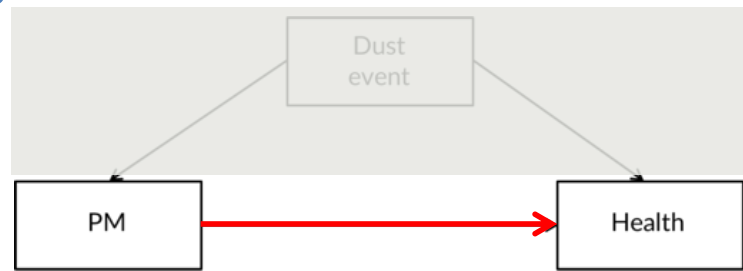
- Is mortality higher on DUST days compared to NO-DUST days, **independently from PM10 increase?**

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

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta_1 \text{dust}_t + \beta_2 \text{PM}_t$$

Dust as binary metric

- **Confounder**

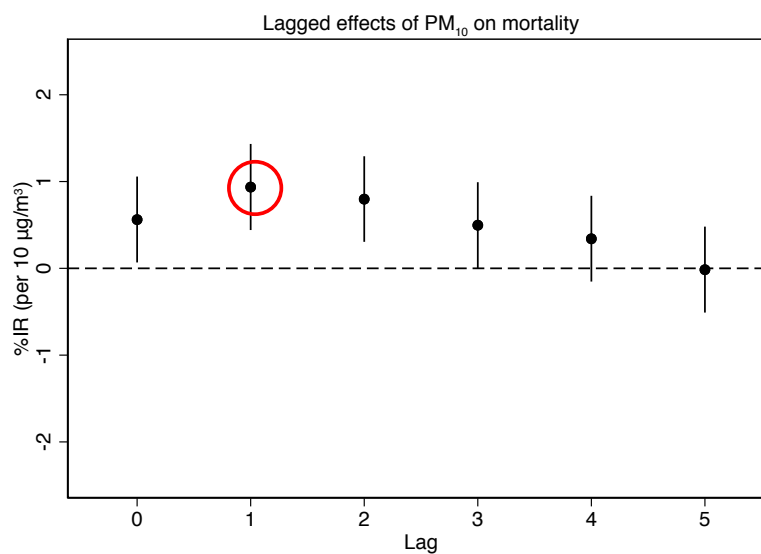


Step 1. Check if PM10 is associated with mortality

- Mortality increases by **0.5% (95%CI: -0.1% 1.1)** per each 10 $\mu\text{g}/\text{m}^3$ increase in PM10

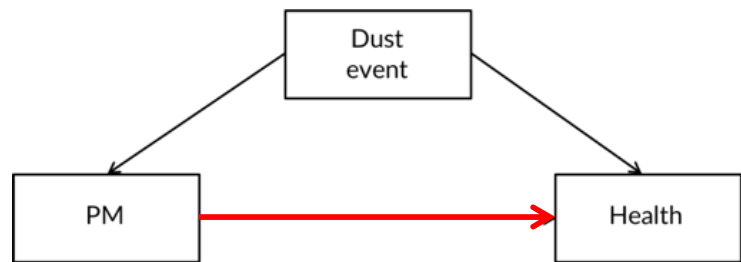
$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta_1 \text{dust}_t + \beta_2 \text{PM}_t$$

Dust as binary metric



Dust as binary metric

- **Confounder**



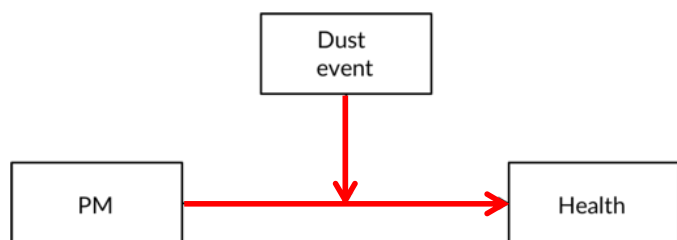
Step 2. Check if PM10 is associated with mortality, independently on DUST events

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

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta_1 \text{dust}_t + \beta_2 \text{PM}_t$$

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

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta_1 \text{dust}_t + \beta_2 \text{PM}_t + \beta_3 \text{dust}_t * \text{PM}_t$$

Dust as binary metric

Main exposure

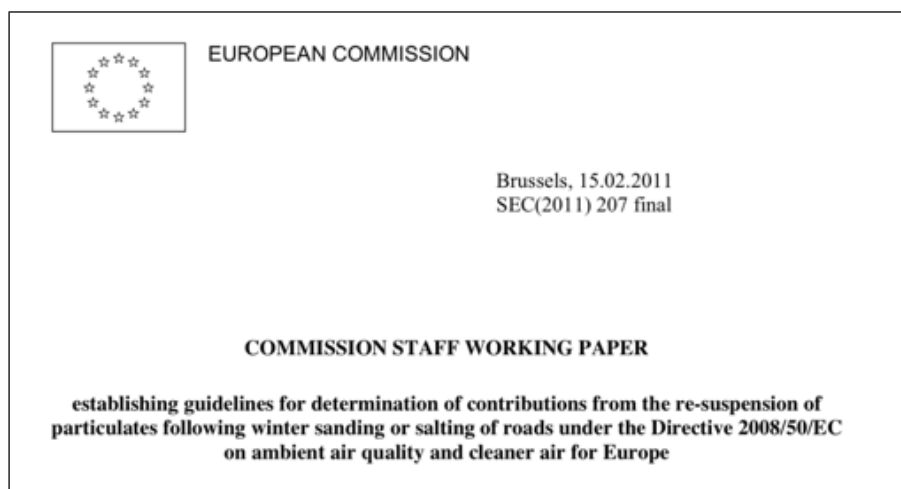
- **All dust events are treated in the same way** since do not quantify the dust, not providing information on the dose-response relationship
- Studies in Eastern Asia show **increase of cardiovascular mortality** and **respiratory/child asthma morbidity** during days with dust events

Effect modifier

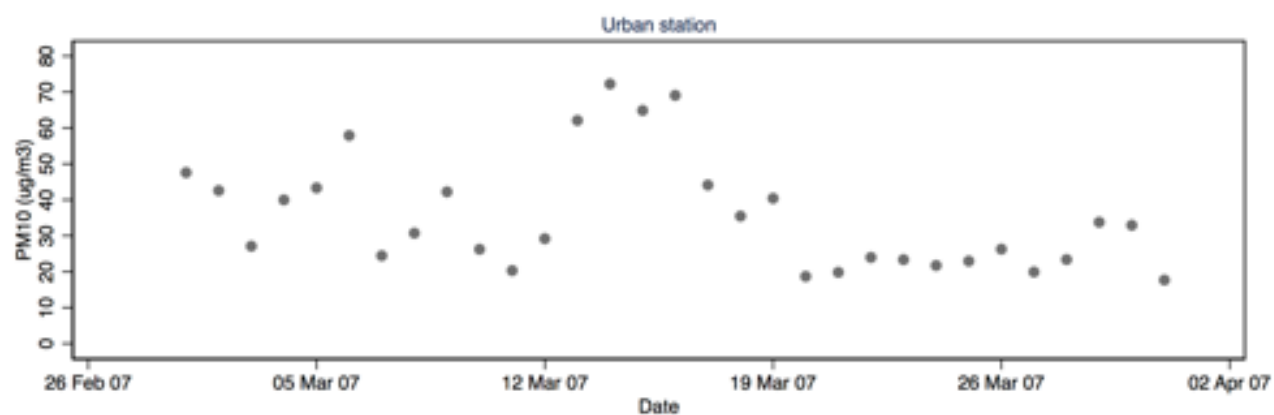
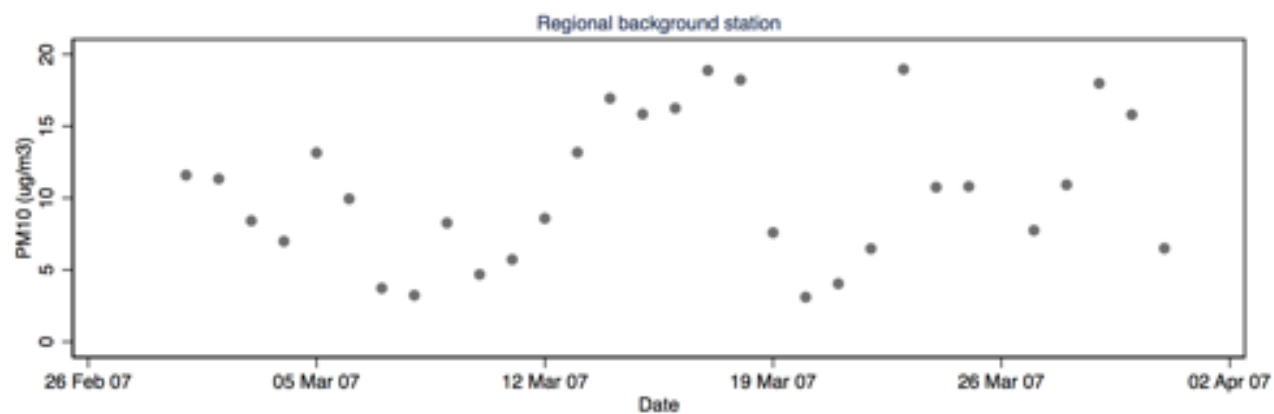
- **PM is a mixture of natural and local sources**, even within the dust days. It is not possible to attribute the health effects to a given source
- Studies in Europe show **larger effect of PM₁₀ and PM_{10-2.5} on cardiovascular mortality** and **respiratory morbidity** during days with dust events but similar effects for **PM_{2.5}**

Quantification of dust events

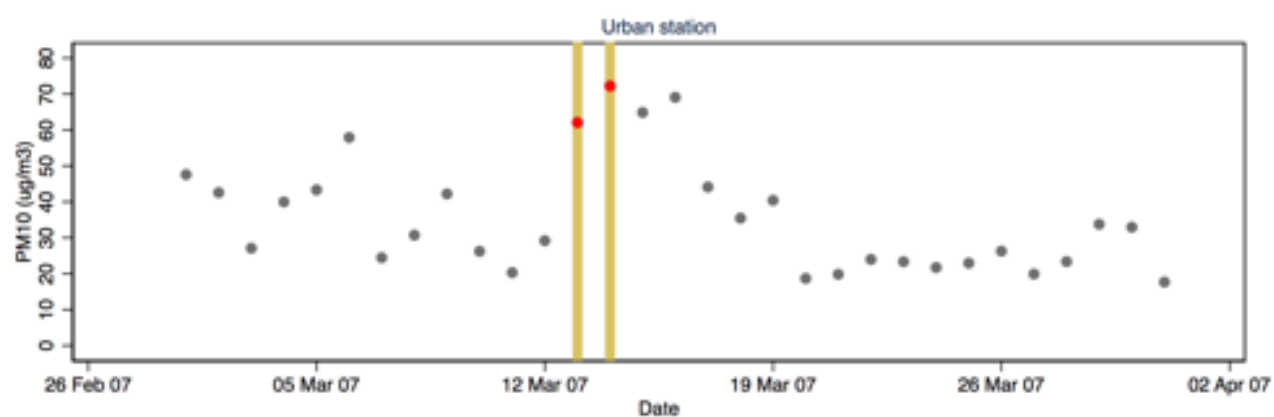
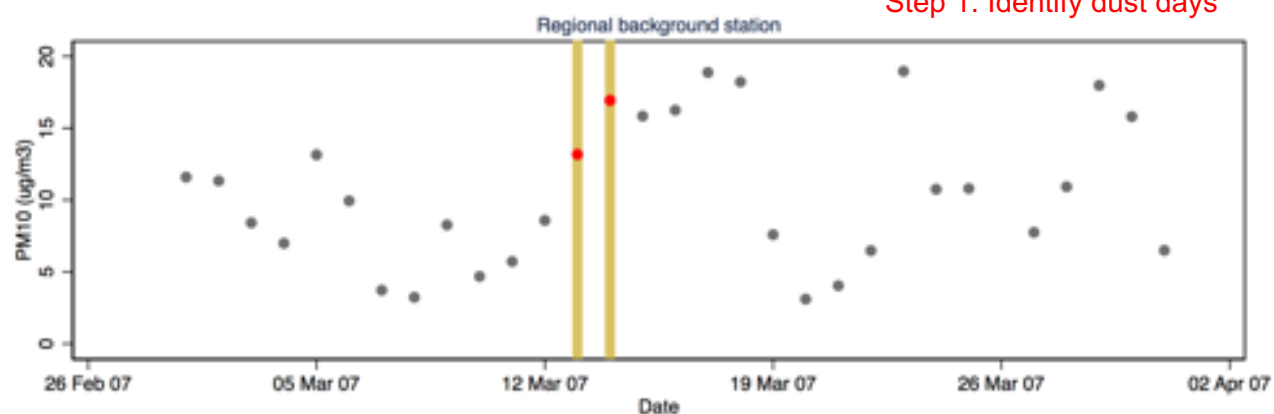
- EU reference method (Directive 2008/50/EC)

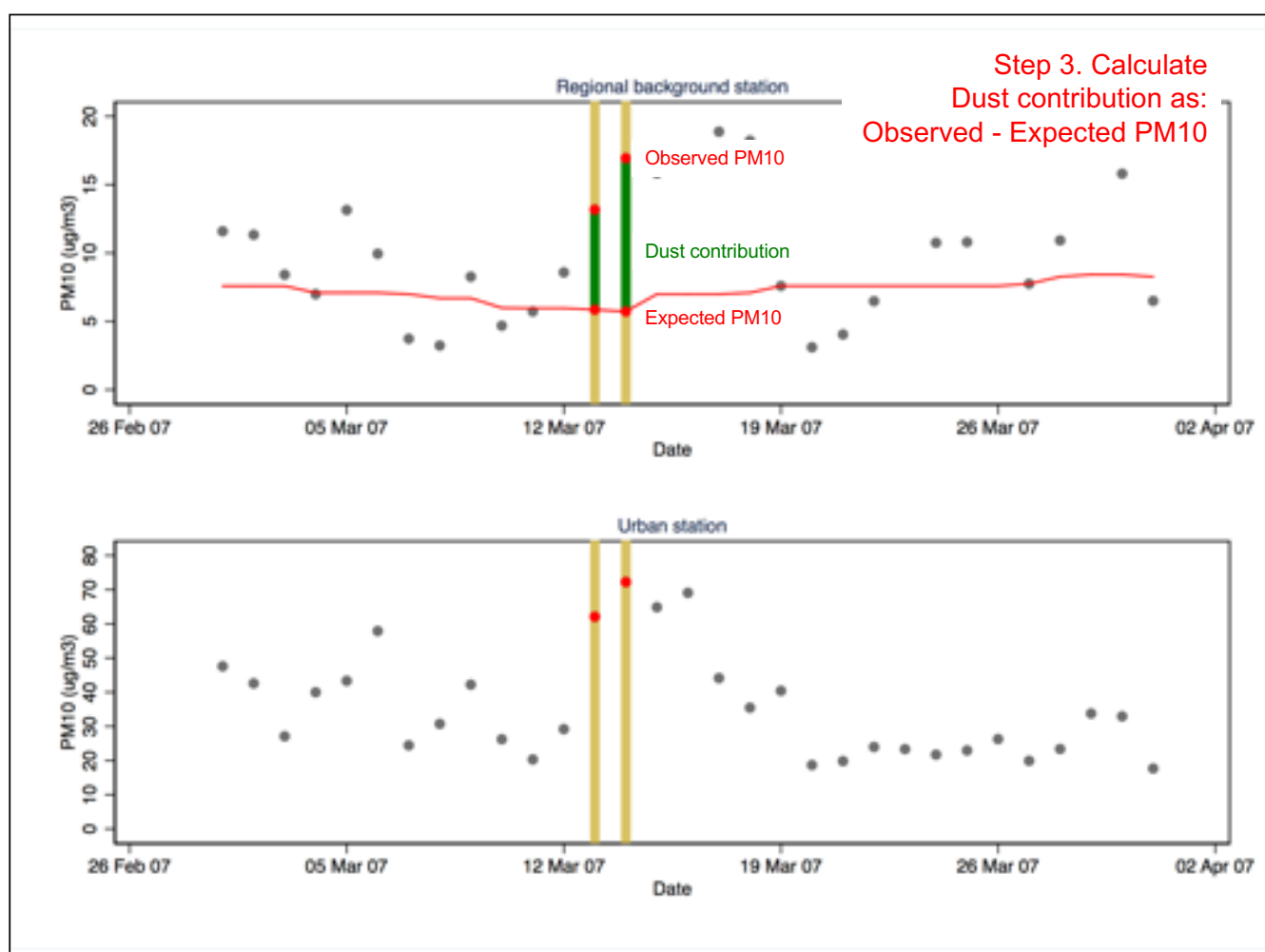
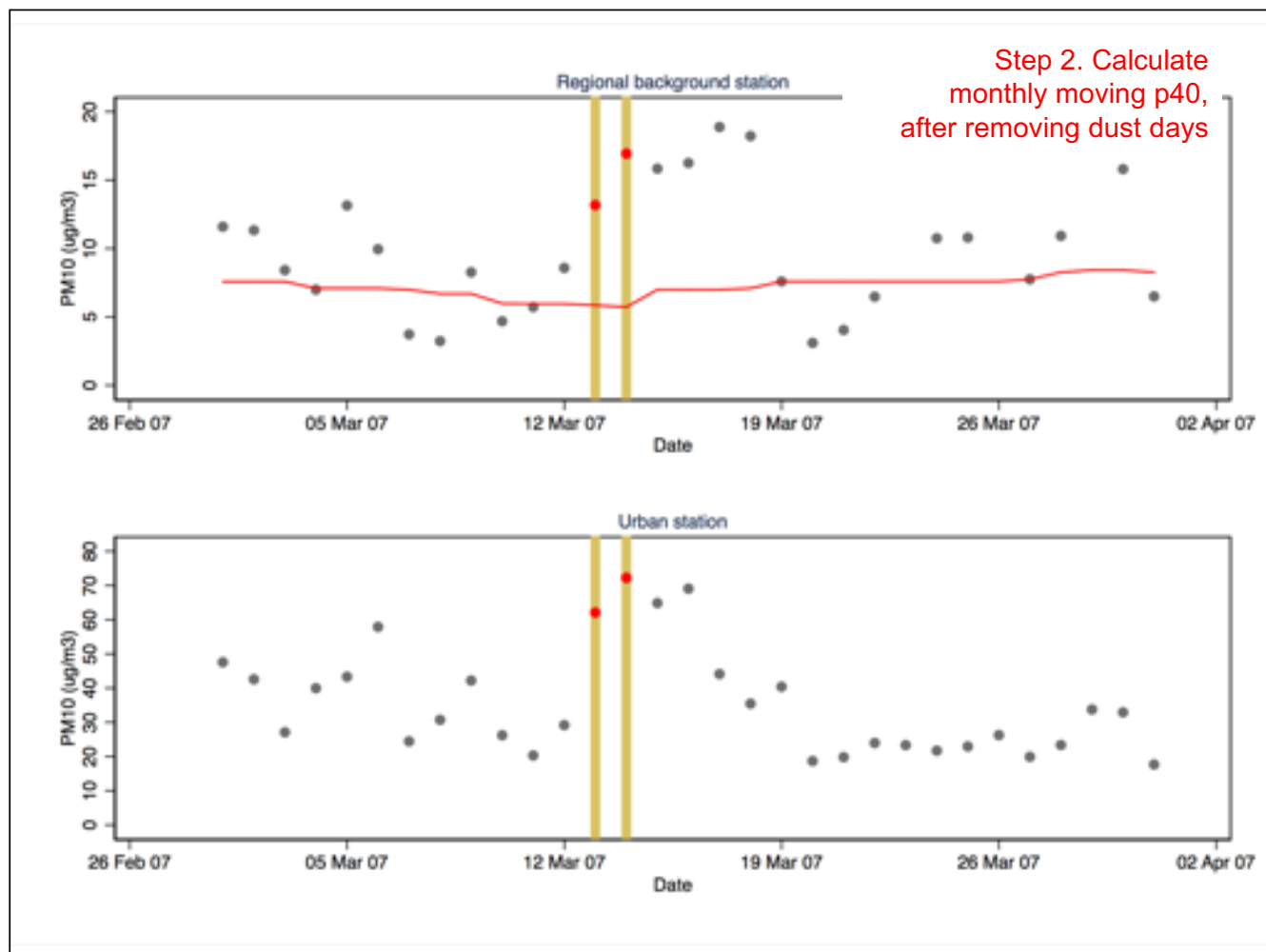


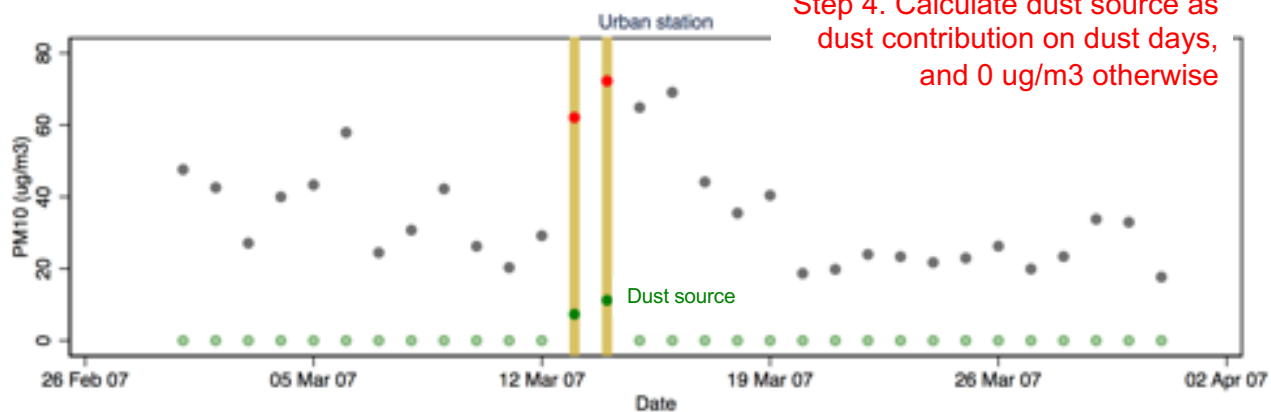
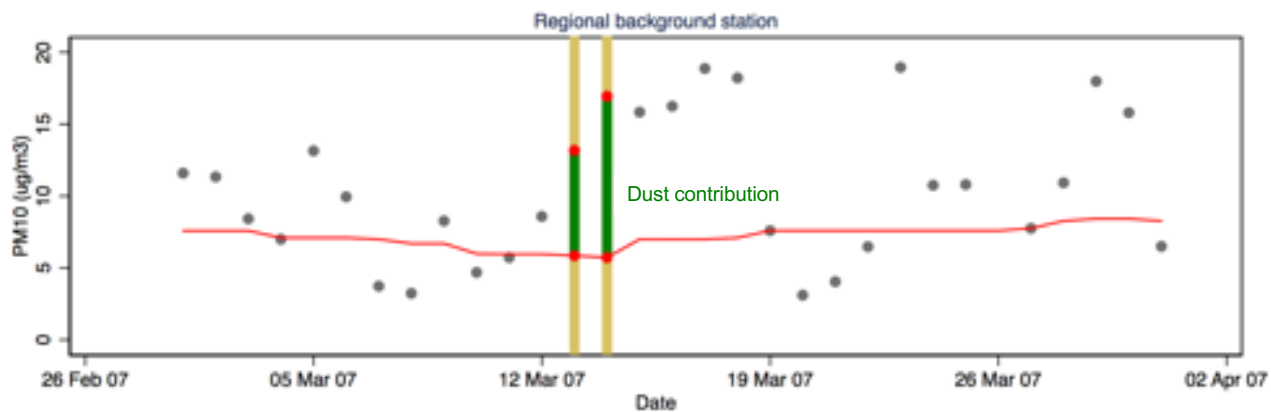
<http://data.europa.eu/eli/dir/2008/50/oj>



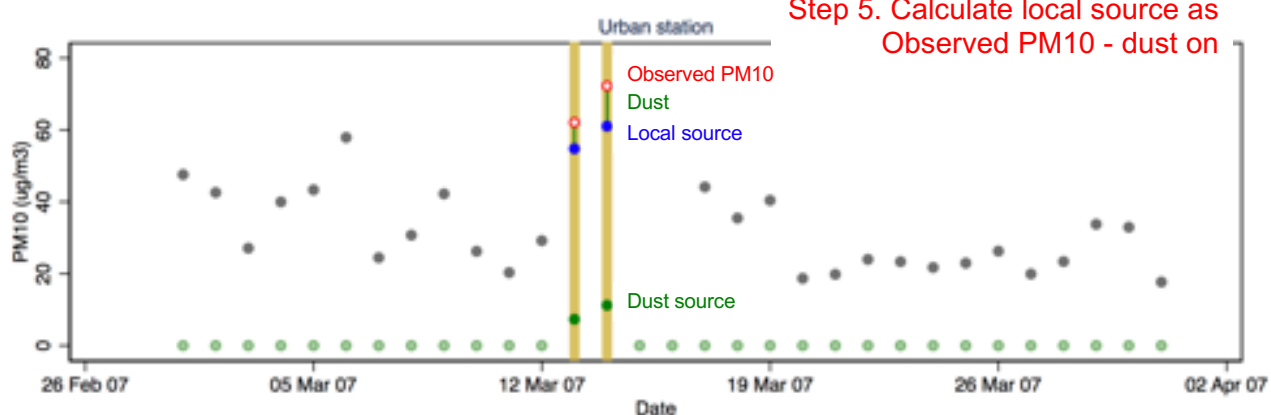
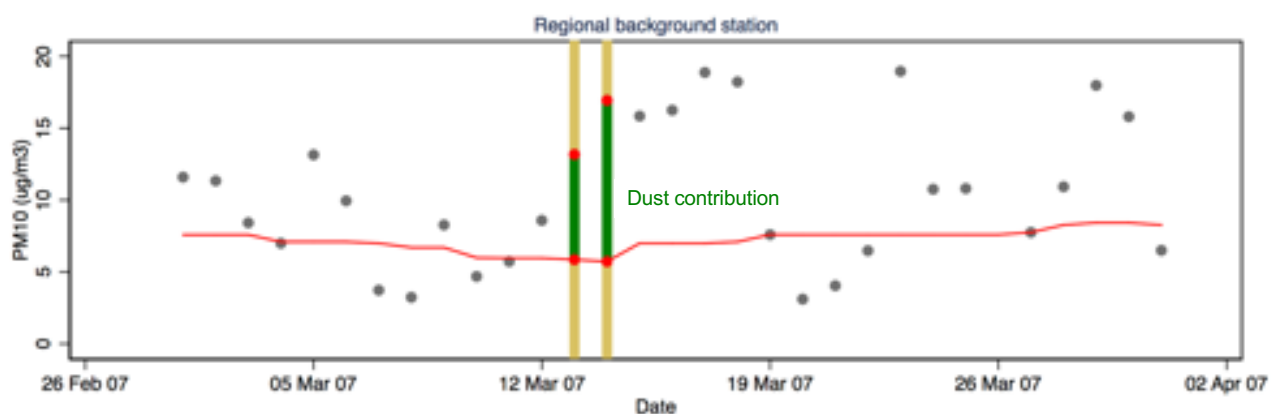
Step 1. Identify dust days



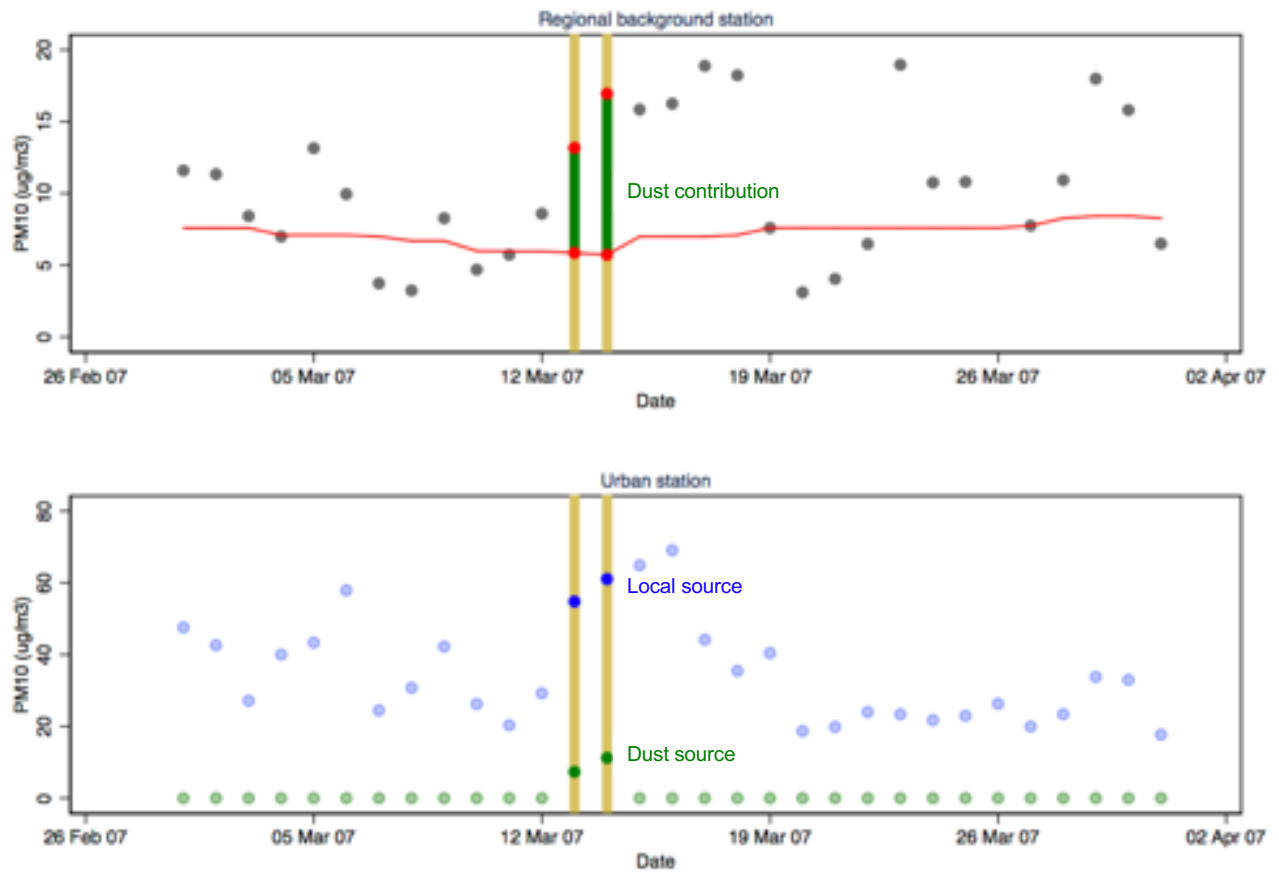




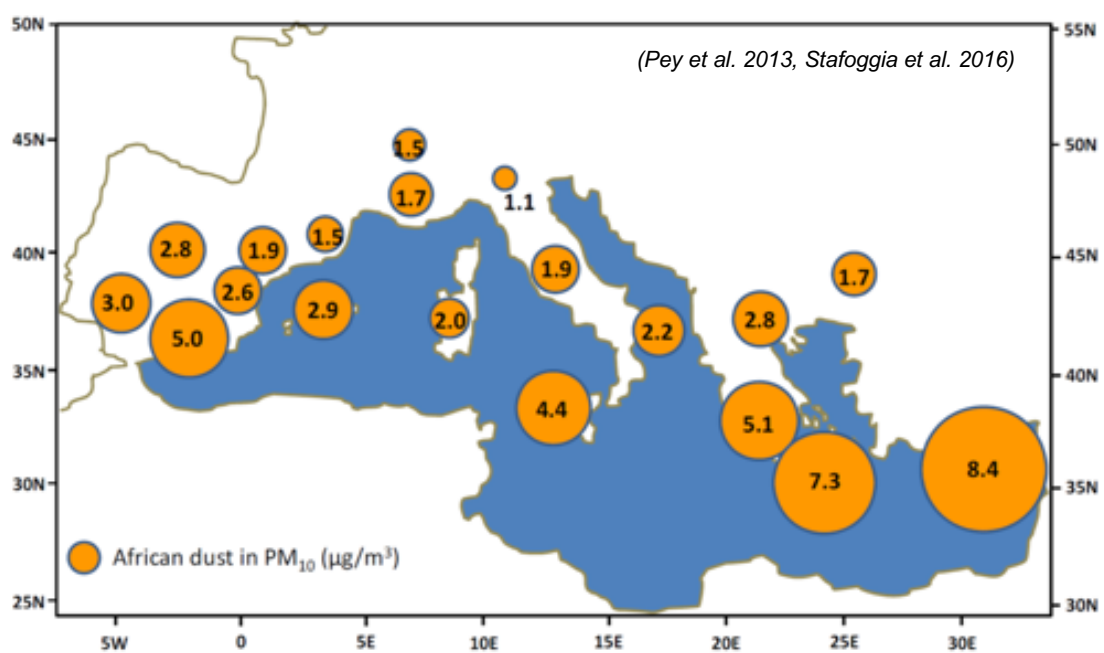
Step 4. Calculate dust source as dust contribution on dust days, and 0 $\mu\text{g}/\text{m}^3$ otherwise



Step 5. Calculate local source as Observed PM10 - dust on



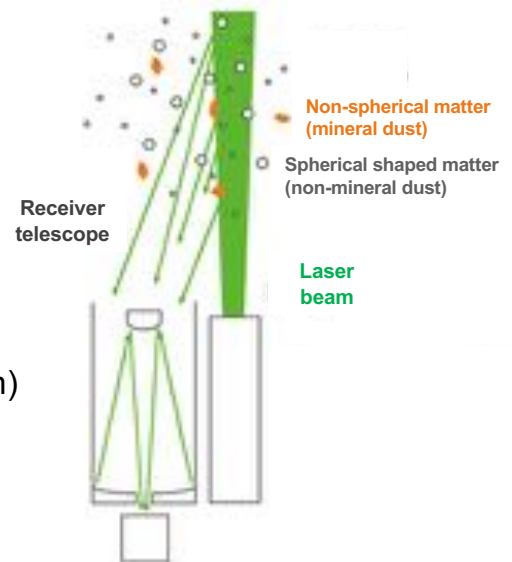
Quantification of dust events



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 ($\mu\text{g}/\text{m}^3$)?

(Ueda et al. 2014)



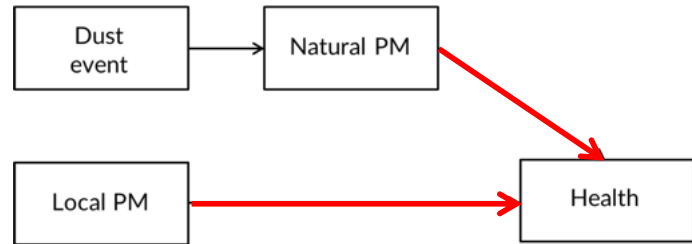
Quantification of dust events

- **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)



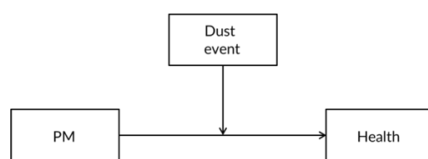
RESEARCH QUESTION

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

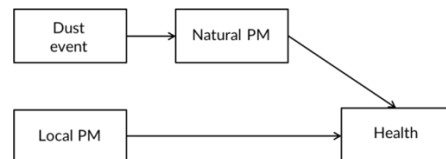
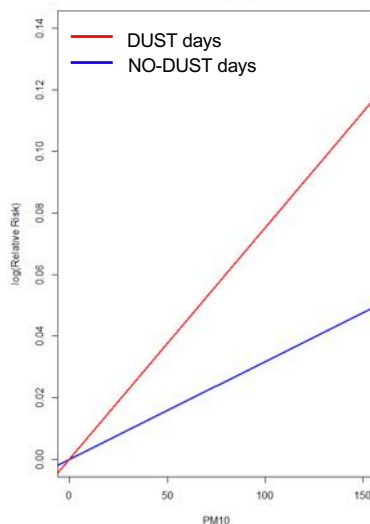
- Mortality increases by **1.3% (95%CI: 0.0, 1.7)** per each 10 ug/m3 increase in **natural (dust) PM10**
- Mortality increases by **0.4% (95%CI: -0.2, 1.1)** per each 10 ug/m3 increase in **local (anthropogenic) PM10**

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta_1 \text{PM}_{\text{natural}} + \beta_2 \text{PM}_{\text{local}}$$

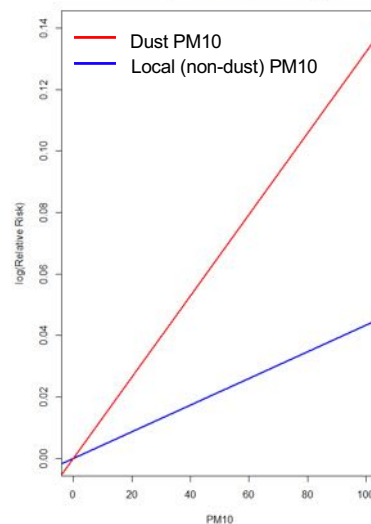
Dust as continuous exposure



PM10-mortality by DUST



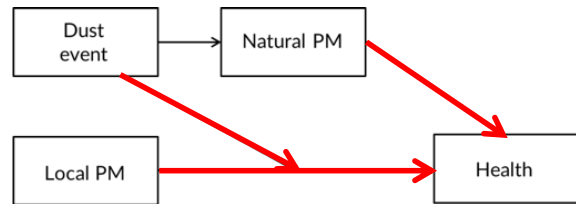
Source-specific PM10 and mortality



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))**

$$y_t = \beta_0 + s(t) + \sum \beta_i \text{dow}_{it} + s(\text{temp}_t) + \beta_1 \text{PM}_{\text{natural}} + \beta_2 \text{PM}_{\text{local}} + \beta_3 \text{dust} + \beta_4 \text{dust} * \text{PM}_{\text{local}}$$

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 PM₁₀** on mortality and morbidity outcomes in Southern Europe (*Stafoggia et al. 2016*)
 - **Larger effect of anthropogenic PM₁₀ during dust days** on cardiovascular mortality in Barcelona (*Pérez et al. 2012*)

Discussion

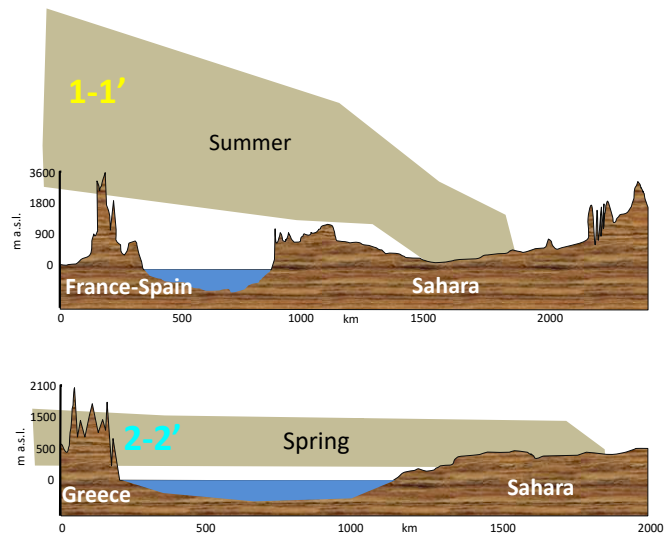
- A **proper understanding of dust exposures** in epidemiological studies would help to develop **appropriate measures to reduce local pollution** during dust events
- Need to **standardize epidemiological studies** with same methodological characteristics to **make health effects comparable** in and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

Dust events	Exposure	Rome (2005-2010)		Athens (2007-2009)	
		%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 modifier	PM ₁₀				
	<i>on non-dust days</i>	0.3	(-0.2, 0.9)	1.0	(0.2, 1.8)
	<i>on dust days</i>	1.1	(-0.1, 2.3)	0.3	(-0.2, 0.8)
Continuous with 2 sources	Local PM ₁₀	0.5	(0.0, 1.0)	0.7	(0.0, 1.5)
	Dust PM ₁₀	1.2	(0.0, 2.3)	0.5	(0.0, 1.0)
Continuous with 3 sources	Local PM ₁₀				
	<i>on non-dust days</i>	0.3	(-0.2, 2.9)	1.0	(0.2, 1.7)
	<i>on dust days</i>	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*)



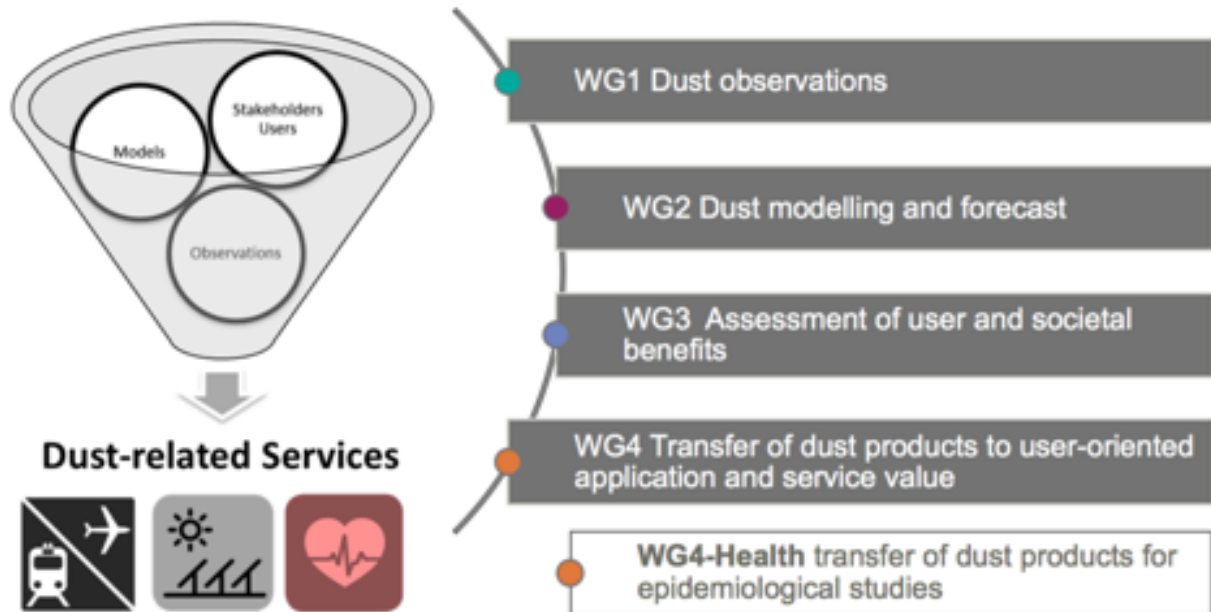
Discussion

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