INTERNATIONAL CONFERENCE

Reducing air pollution from ships in the Mediterranean Sea

March, 18th 2019 Madrid

Impact of Air Pollution on heritage sites

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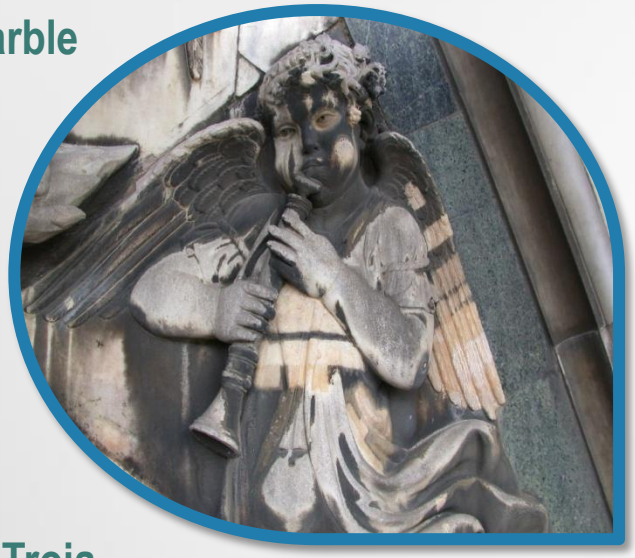
Cultural Heritage at Risk

Black crust on Marble
Milan Cathedral



Pluvial
Flooding -
Ferrara
Cathedral

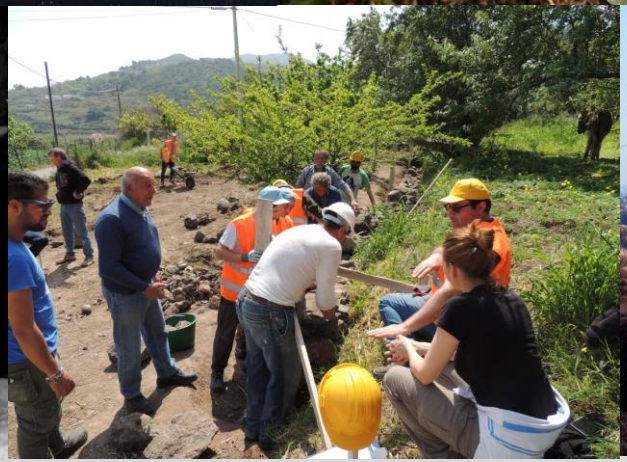
Flood – Troja,
Prague

Megalithic
Temples,
Malta

2018 EUROPEAN YEAR OF CULTURAL HERITAGE #EuropeForCulture

Cultural Heritage at Risk

AEOLIAN ISLANDS
WORLD HERITAGE SITE



Safeguarding Cultural Heritage at Risk

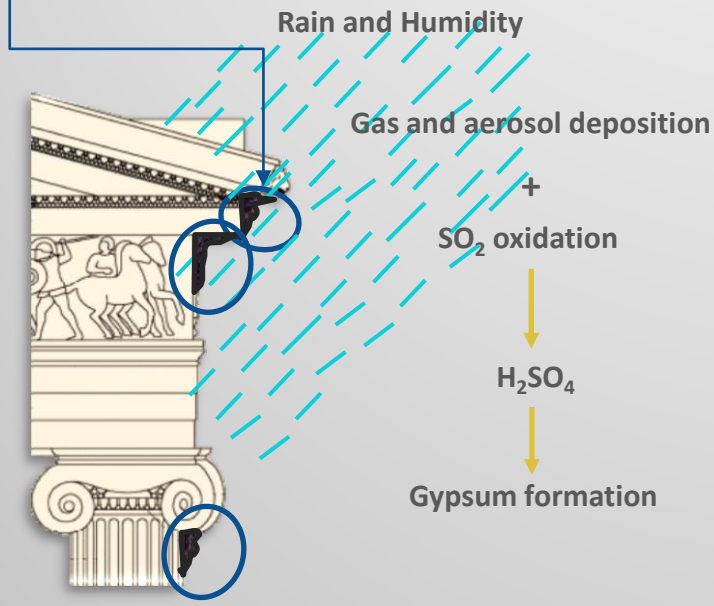
2018 EUROPEAN YEAR OF CULTURAL HERITAGE #EuropeForCulture

- To encourage the **sharing and appreciation** of Europe's cultural heritage as a **shared resource;**
- To raise awareness of **common history and values;**
- To reinforce a sense of belonging to **Europe;** and
- To better **protect, safeguard, reuse, enhance, valorise** and **promote** Europe's cultural heritage.

ISAC

Air Pollution impact on Heritage

DAMAGE PROCESS	OUTDOOR MATERIALS MAINLY AFFECTED	CLIMATE PARAMETERS	POLLUTANTS
 SOILING, BLACK CRUST FORMATION	• Marble • Limestone • Sandstone with carbonate matrix • Air-setting and hydraulic mortar • Cement mortar and concrete • Glass	• Rain amount • Time of wetness (T, RH) • Light	• SO_2 • NO_2 • PM, PM_{10}, $PM_{2.5}$ • C fractions of PM (EC, OC) • Soluble salt fraction of PM (SO_4^{2-}, SO_3^{2-}, NO_3^-, NO_2^-, Br^-, HPO_4^{2-}, Cl^-, CHO_2^-, $C_2H_3O_2^-$ AND $C_2O_4^{2-}$) • VOC

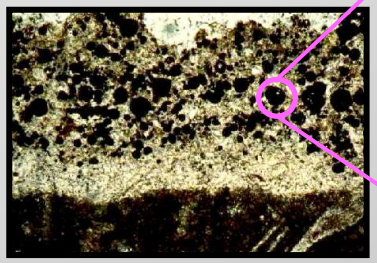


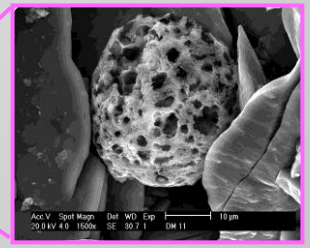
Black crust formation on surfaces partially sheltered from rain wash-out

Microscopic aspect

Black crust

Marble/limestone





carbonaceous particles

Air Pollution impact on Heritage

DAMAGE PROCESS	OUTDOOR MATERIALS MAINLY AFFECTED	CLIMATE PARAMETERS	POLLUTANTS
	• Marble • Limestone • Sandstone with carbonate matrix • Air-setting and hydraulic mortar • Cement mortar and concrete	• Rain amount • Rain pH • Time of wetness (T, RH)	• SO_2 • HNO_3 • CO_2 • PM, PM_{10}, $PM_{2.5}$
	• Marble • Limestone • Sandstone with carbonate matrix • Air-setting and hydraulic mortar • Cement mortar and concrete • Glass	• Rain amount • Time of wetness (T, RH) • Light	• SO_2 • NO_2 • PM, PM_{10}, $PM_{2.5}$ • C fractions of PM (EC, OC) • Soluble salt fraction of PM (SO_4^{2-}, SO_3^{2-}, NO_3^-, NO_2^-, Br^-, HPO_4^{2-}, Cl^-, CHO_2^-, $C_2H_3O_2^-$ AND $C_2O_4^{2-}$) • VOC
	• Carbonate and silicate stones • Air-setting and hydraulic mortar • Cement mortar and concrete • Wood	• Rain amount • T • RH • Solar radiation	• OC FRACTION OF PM • SOLUBLE SALT FRACTION OF PM (NO_3^-, $C_2H_3O_2^-$)
	• Metals: steel, zinc, copper, bronze, lead	• Rain amount • Rain pH • T • RH	• SO_2 • HNO_3 • O_3 • PM, PM_{10}, $PM_{2.5}$ • H_2S • COS • CH_3COOH, CH_2O_2 • NH_3 • Soluble salt fraction of PM (SO_4^{2-}, NO_3^-, Cl^-)
	• Glass	• Rain amount • Rain pH • T • RH	• SO_2 • HNO_3 • O_3 • PM, PM_{10}, $PM_{2.5}$ • Soluble salt fraction of PM (SO_4^{2-}, NO_3^-, Cl^-)
	• Sandstone • Limestone • Air setting and hydraulic mortar • Cement mortar and concrete • Brick	• RH cycles • Rain pH • T	• PM, PM_{10}, $PM_{2.5}$ • Soluble salt fraction of PM (SO_4^{2-}, Cl^-, NO_2^-, NO_3^-, Ca^+, Na^+, Mg^{2+}, K^+)

ISAC

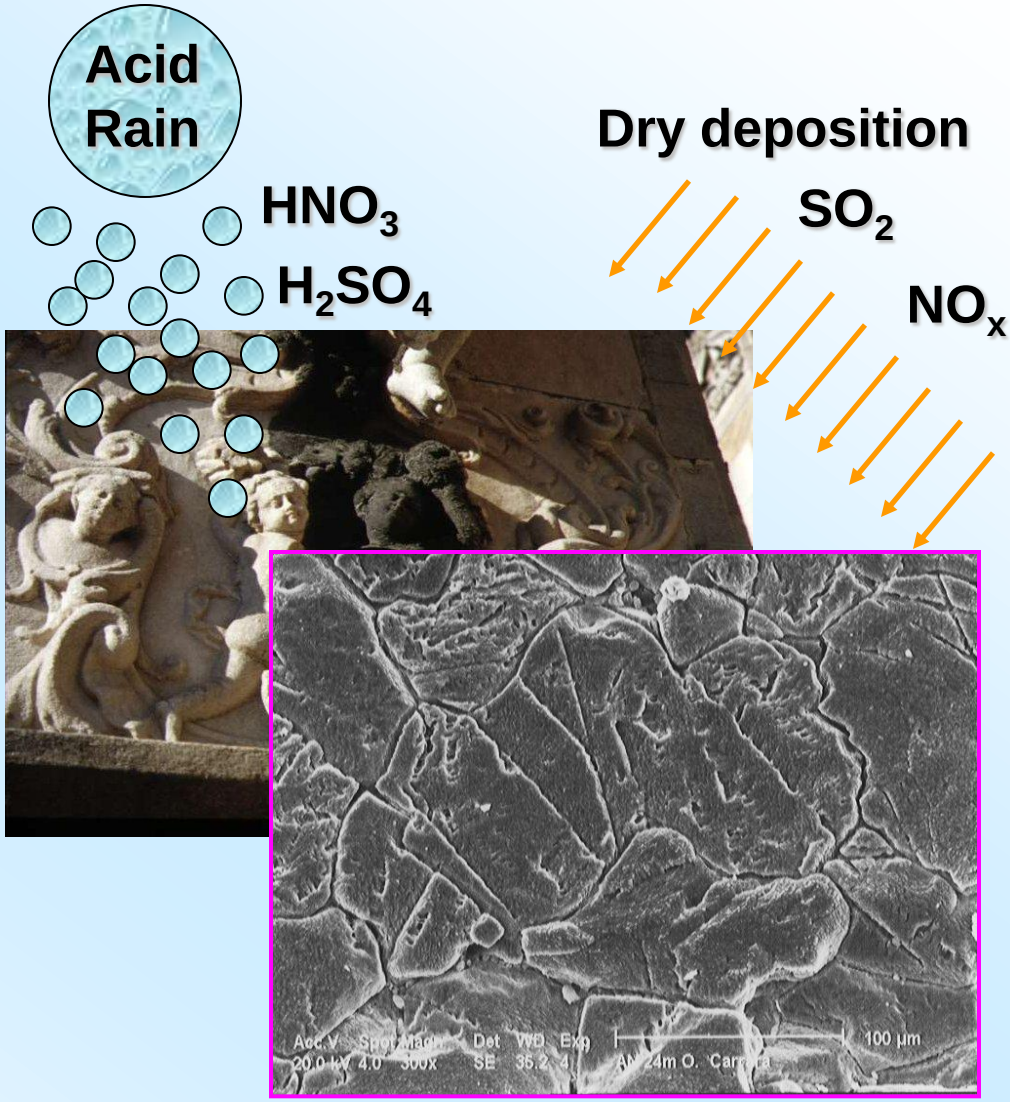
SURFACE RECESSION OF CARBONATE STONES

Material dissolution due to the chemical attack induced by:

1. **Clean rain** (rain at pH 5.6 in equilibrium with 330 ppm CO_2 – karst effect)
2. **Acid Rain** (additional acidity due to anionic components, such as SO_4^{2-}, NO_3^-……)
3. **Dry deposition** (gaseous pollutants occurring between precipitation events)

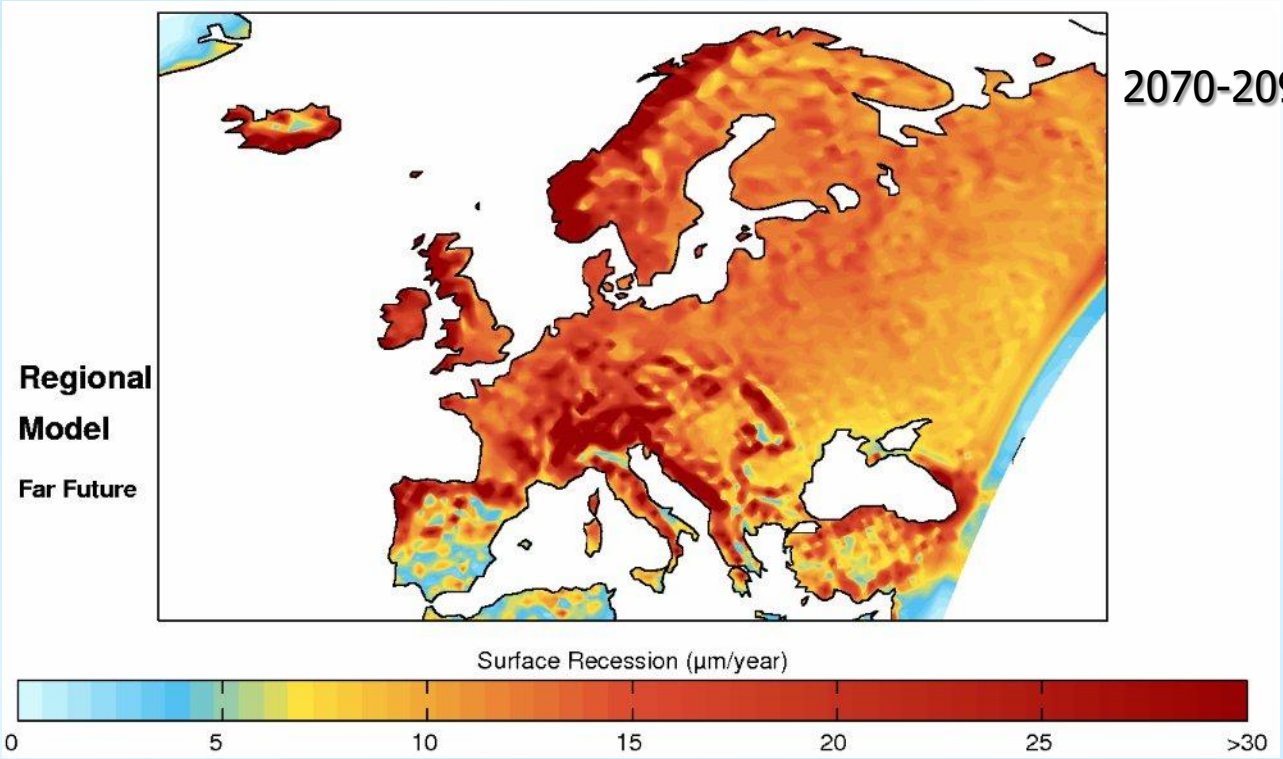
+

Material surface erosion due to the mechanical effect of rain



"Gutta cavat lapidem"

SURFACE RECESSION



Surface recession is expected to be higher in the areas that will be more affected by precipitation, that are the mountain chains (Alps, Carpathians, Pyrenees) and the westerlies exposed areas, reaching values higher than 30 µm/year

Bonazza et al. 2009. STOTEN

Coastal areas of Mediterranean Basin

Coastal areas are complex and fragile eco-cultural-systems that need specific consideration for their best preservation.

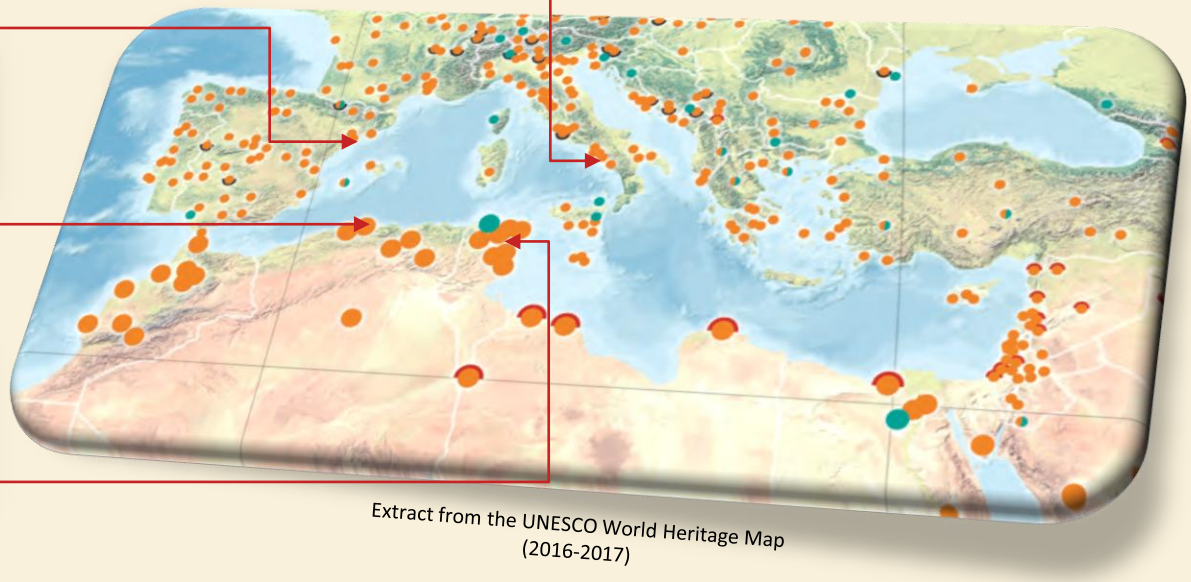
Observing the UNESCO World Heritage Map is noticeable the abundance of cultural heritage sites (in orange) that raise on the littoral zones.

Costiera Amalfitana (Italy) © OUR PLACE The World Heritage Collection

Archaeological Ensemble of Tárraco (Spain) © Instituto del Patrimonio Cultural de España.

Kasbah of Algiers (Algeria) © UNESCO

Archaeological Site of Carthage (Tunisia) © Editions Gelbart



Extract from the UNESCO World Heritage Map (2016-2017)

Heritage in Coastal areas of Mediterranean Basin

COASTAL AREAS (monuments, landscapes, etc.)

Siracusa (Italy)

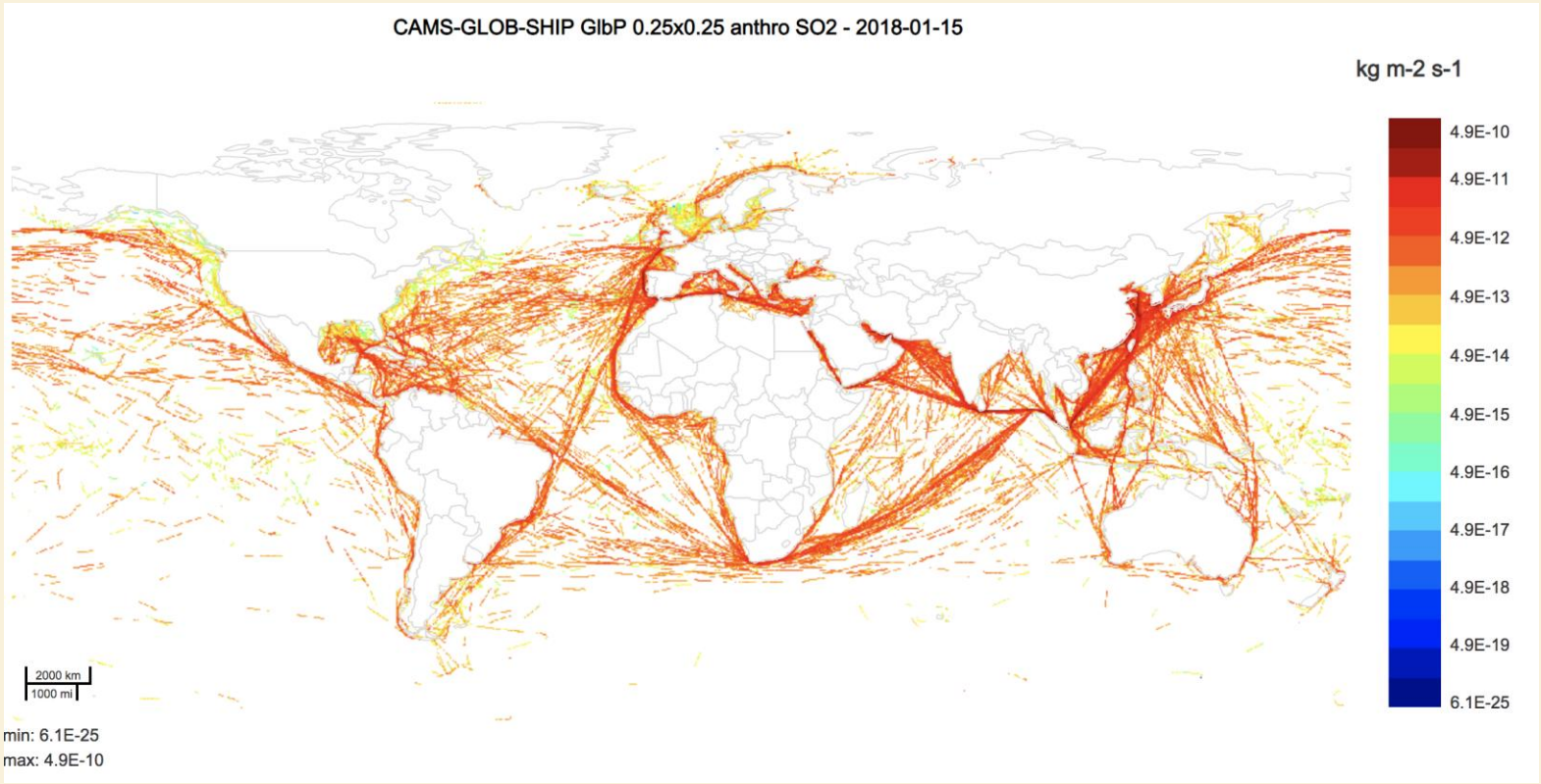
Tourism and commercial sectors

UNDERWATER HERITAGE (monuments/ecosystems)

Christ of the Abyss – San Fruttuoso (Genoa, Italy)

Baia (Naples, Italy)

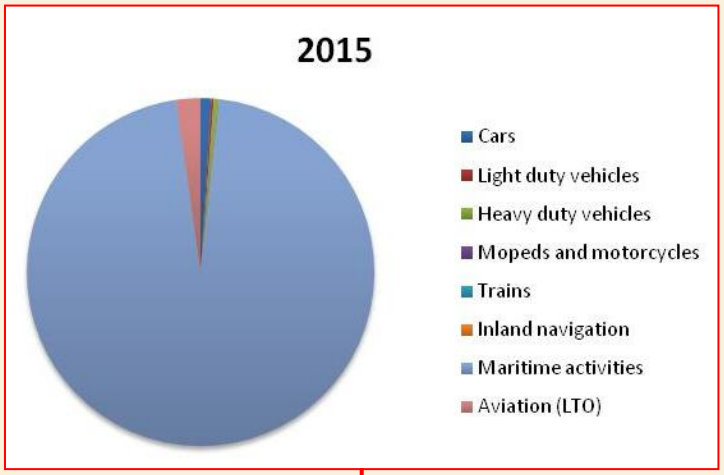
Global ship emissions for various chemical species (SO_2, SO_4^{2-}, CO, NO_x, EC, CO_2, OC, NMVOCs, ash)



SO_2 emissions of transport sector in Italy (from ISPRA report)

Modalità di trasporto	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
	t									
Cars	61.375	26.233	4.953	1.296	225	223	227	235	244	215
Light duty vehicles	16.518	11.720	2.529	450	84	89	82	70	72	53
Heavy duty vehicles & bus	50.095	32.798	4.342	611	107	113	113	104	105	99
Mopeds and motorcycles	2.404	890	163	57	9	9	10	11	10	8
Trains	846	545	69	7,3	0,9	0,7	0,8	0,6	0,3	0,3
Inland navigation	119	91	11	1,9	0,3	0,3	0,4	0,4	0,4	0,4
Maritime activities	79.018	71.121	81.592	49.746	28.380	26.538	23.915	22.498	22.403	21.070
Aviation (LTO)	243	291	448	345	524	497	478	453	490	497
TOT	**211.651**	**143.940**	**100.102**	**52.513**	**29.332**	**27.472**	**24.826**	**23.372**	**23.325**	**21.942**

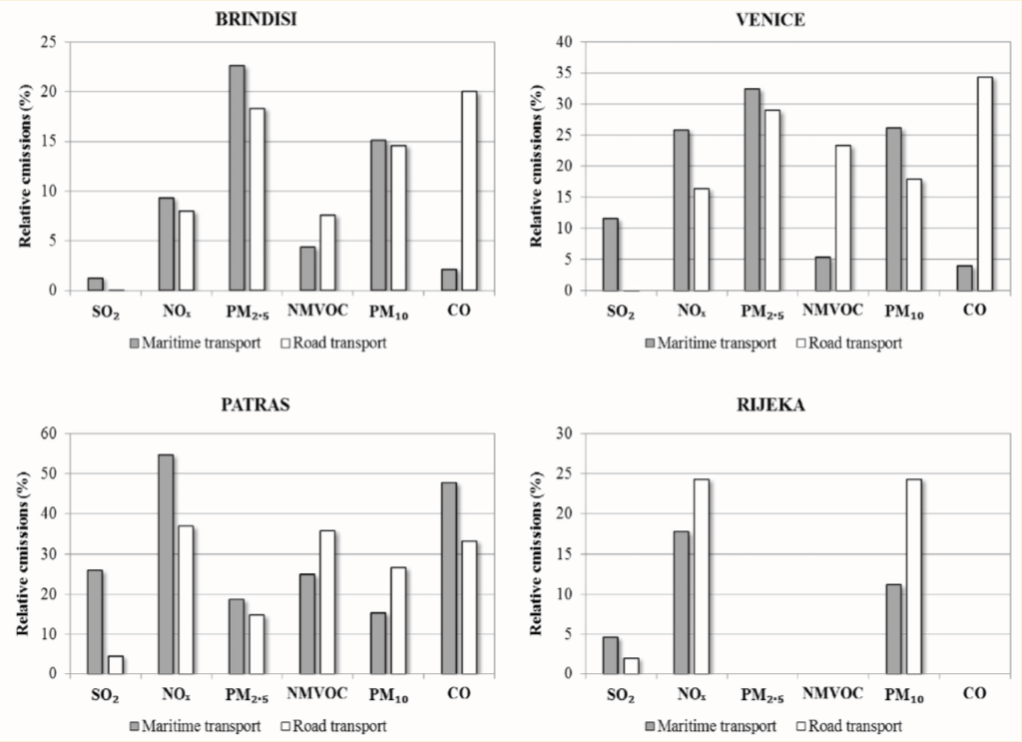
Fonte: ISPRA



[Bernetti, Contaldi and Sestili, 2017]

SO_2 emissions in port-cities

According to **POSEIDON Project**, which monitored ship emission in four port-cities, Brindisi and Venice (Italy), Patras (Greece) and Rijeka (Croatia), it was highlighted that the road traffic and maritime sector had comparable emissions especially for NO_X and $PM_{2.5}$, while **shipping** was noticed **as the transport sector mainly responsible for SO_2 emissions**.

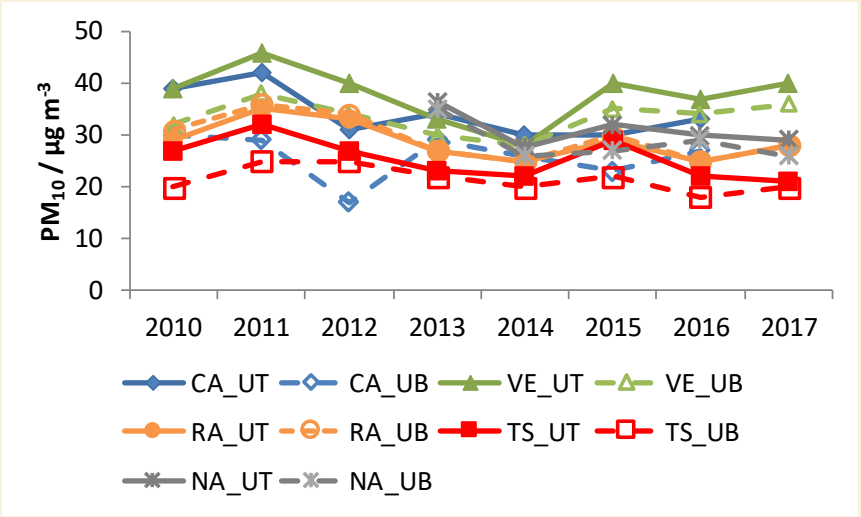


Comparison of relative emissions associated to maritime and road transport in four port cities

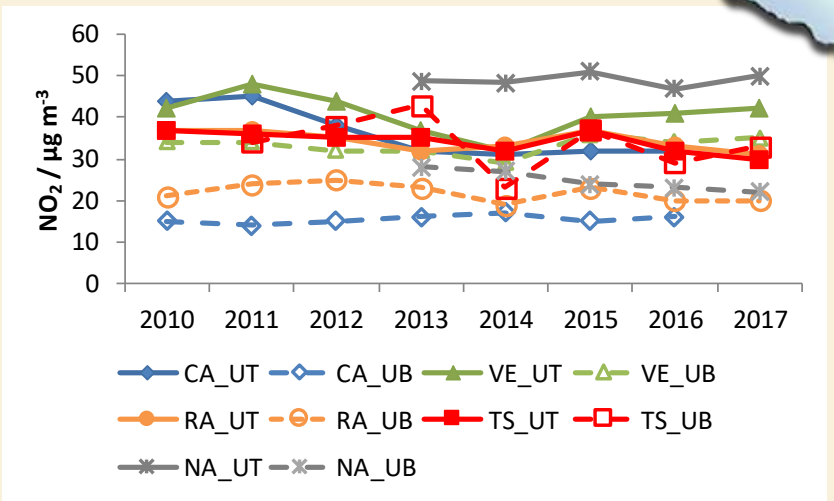
[E. Merico et al. 2017]

Pollution in coastal cities

- Concentration of air pollutants monitored by the Regional Agency for Environmental Protection of Italy:



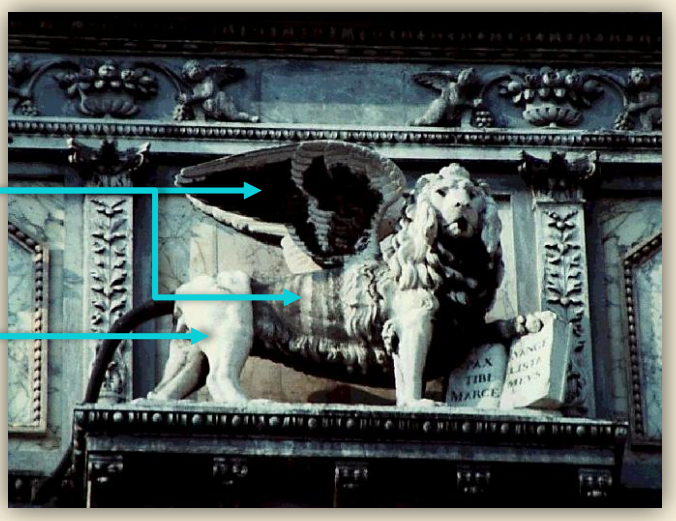
Legend:
UT = urban traffic-oriented monitoring stations
UB = urban background monitoring stations



How can naval traffic affect Cultural Heritage?

Materials carbonate based:

- ✓ Limestone
- ✓ Marble
- ✓ Sandstone with carbonate matrix
- ✓ Air-setting and hydraulic mortar, etc.



- Sulfation by SO_2 → **BLACK CRUSTS FORMATION**
  - ✓ Limestone to gypsum
  - ✓ Deposition of **soot**
  - ✓ Rain partially sheltered

- **SURFACE RECESSION**
  - ✓ Rainwashed areas
  - ✓ May be white

- **SALTS CRYSTALLIZATION**

Different approaches to study the impact of pollution on Cultural Heritage in coastal areas

- **LAB SIMULATION STUDY**
- **FIELD EXPOSURE TESTS**
- **CASE STUDY**

On sandstone in Belfast (UK)

«…the mobility of gypsum may have been enhanced by the presence of NaCl…»

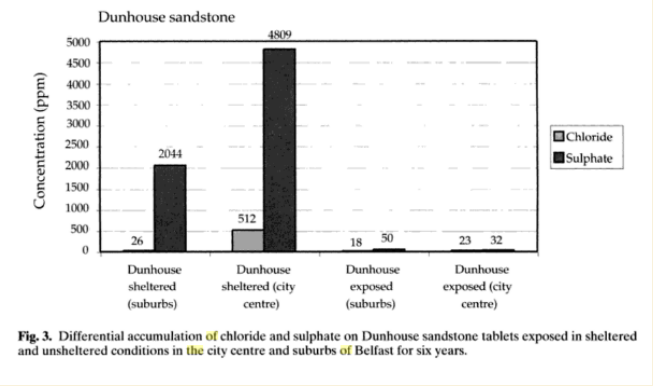


Fig. 3. Differential accumulation of chloride and sulphate on Dunhouse sandstone tablets exposed in sheltered and unsheltered conditions in the city centre and suburbs of Belfast for six years.

[Smith et al., 2002. Modelling the rapid retreat of building sandstones: a case study from a polluted maritime environment. https://doi.org/10.1144/GSL.SP.2002.205.01.25]

- **SAMPLES FROM HISTORICAL BUILDING** → e.g. Bilbao

«…Nitrate is the major soluble compound of the analysed subsamples…are supposed to come from harbour traffic (combustion of fuels) as well as from fuels used in industrial processes...»

[Martínez Arkarazo et al., 2007. An integrated analytical approach to diagnose the conservation state of building materials of a palace house in the metropolitan Bilbao (Basque Country, North of Spain). Analytica Chimica Acta 584, 350–359]

- **FIELD EXPOSURE TESTS**

e.g. ARQUEOMONITOR Project –ES → field exposure tests of metallic and stone samples underwater in Cadiz Bay

[http://arqueologianauticaysubacuatica.uca.es/arqueomonitor/; Camara et al., 2017]

FINAL REMARKS

- Need of enhancing the consciousness regarding the importance of protection of coastal natural & cultural heritage

- Ship emissions can affect the state of conservation of the materials belonging to cultural heritage, in particular buildings and outdoor monuments
- Need of mitigation strategies aiming at reducing emissions (Mediterranean ECA)
- Still lack of studies regarding the naval impact on underwater heritage

Thank you for your attention

What kind of emissions can be produced by ships?

AIR EMISSIONS

- Macropolluttants:
  - ✓ SO_2, NO_x, CO, CO_2 and O_3
  - ✓ Particulate matter (PM) – ! Black Carbon (BC)
  - ✓ Non-Methane Volatile Organic Compounds (NMVOCs)
- Micropollutants:
  - ✓ Metals
  - ✓ Organic species
- Other
  - ✓ Incineration of waste
  - ✓ Noise
  - ✓ Visual pollution

DISCHARGE TO SEA

- Sewage (black water)
- Grey water
- Oil and oily mixtures
- Wash water from scrubbers
- Garbage
- Ballast water

[Norwegian Maritime Authority. 2017. Pollution from ships in fjord areas with heavy cruise traffic – Report;
F. Liguori, S. Pillon, S. Patti. Progetto MED-CAIMANS. L'esposizione della popolazione agli inquinanti atmosferici dovuti alle navi crociera a Venezia: confronto tra scenario attuale e scenari futuri di sviluppo e di mitigazione. 2016.]

Recent and Relevant EU Projects on ship emissions

Financed by the European program for territorial Cooperation MED 2007/2013:

- **APICE 2010 – 2013 - Common Mediterranean strategy and local practical Actions for the mitigation of Port, Industries and Cities Emissions**
  The aim of the project was to develop a knowledge-based approach for air pollution mitigation and sustainable development of port activities, managed by spatial planning policies at local level, which included the territory around the ports.
  http://www.apice-project.eu/

- **CAIMANs 2014-2015 - Cruise and passenger ship Air quality Impact Mitigation ActioNs**
  The project studies the impact of passenger maritime traffic on air quality in five important port cities in the northen Mediterranean: Barcelona, Marseilles, Genoa, Venice and Thessaloniki.
  http://www.medmaritimeprojects.eu/section/caimans

- **POSEIDON 2014-2015 - Pollution monitoring of ship emissions: an integrated approach for harbours of the Adriatic basin**
  The POSEIDON project aimed at investigating the impact on air quality of four major harbours in the Adriatic/Ionian Seas (Brindisi, Patras, Rijeka and Venice), using a common state-of-the-art methodology based on emission inventories, numerical modelling and experimental results in order to produce comparable information useful to plan future actions and controls of emissions in the Adriatic/Ionian macroregion.
  http://www.medmaritimeprojects.eu/section/poseidon