

Pollution impact on cultural heritage in coastal areas of the Mediterranean Basin

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Mediterranean
Shipping
Conference

**Reducing air pollution
from ships in the
Mediterranean Sea**

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- Heritage and the environment have indissoluble link between the naturalistic and cultural aspect
- The built heritage is totally embedded in the surroundings, even for centuries and/or thousand years, therefore it is in equilibrium with it
- As for the ecosystems, variations of this equilibrium (both slow and fast changes) can alter the physical and chemical state of the materials belonging to heritage
- These changes can derives both from natural effects and human activities
- Considering specifically air pollution, there are several sources, such as industries, vehicular traffic, heating, etc. and ship emissions (particularly in coastal areas)



Torre Astura (Rome, Italy).
Painted by Franz Schreyer
(1858–1938)









Torre Astura (Rome, Italy).
1193-1496




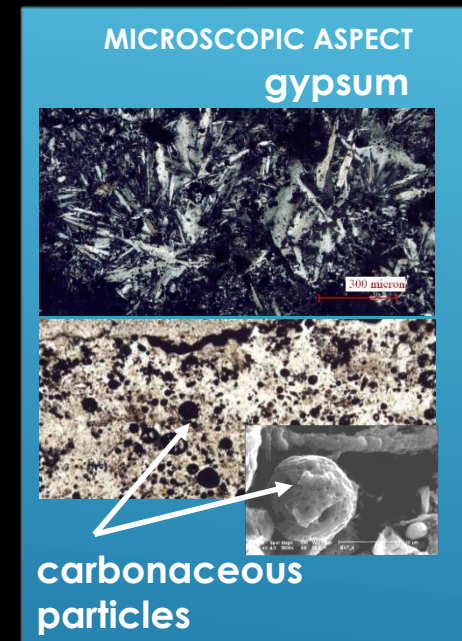
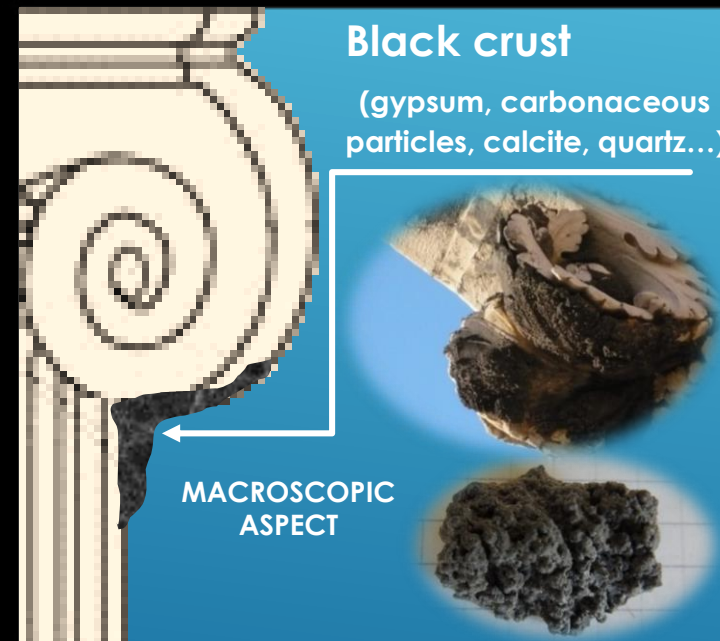
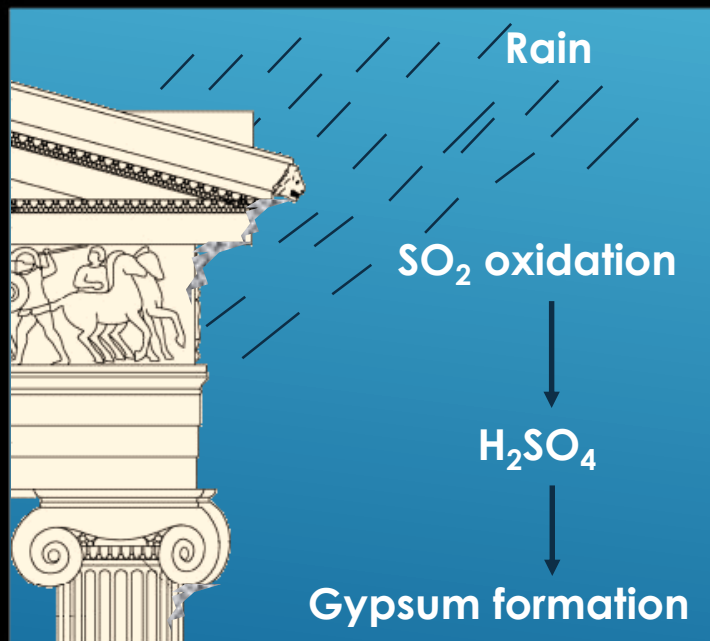
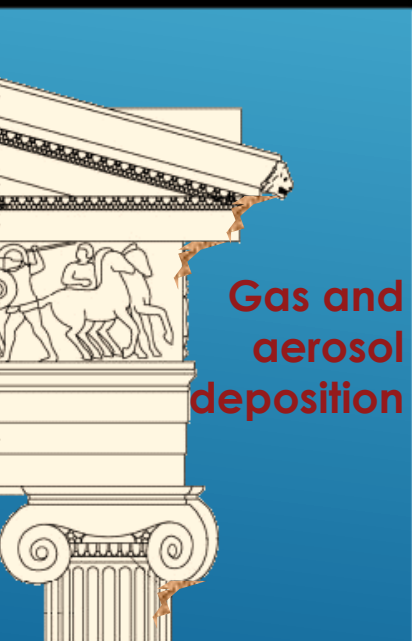
Through time...




DAMAGE PROCESS	OUTDOOR MATERIALS MAINLY AFFECTED	CLIMATE PARAMETERS	POLLUTANTS
 SURFACE RESSION	<ul style="list-style-type: none"> MARBLE LIMESTONE SANDSTONE WITH CARBONATE MATRIX AIR-SETTING AND HYDRAULIC MORTAR CEMENT MORTAR AND CONCRETE 	<ul style="list-style-type: none"> RAIN AMOUNT RAIN PH TIME OF WETNESS (T AND RH) 	<ul style="list-style-type: none"> SO₂ HNO₃ CO₂ PM, PM₁₀, PM_{2.5}
 SOILING, CHANGE OF COLOUR, BLACK CRUST FORMATION	<ul style="list-style-type: none"> MARBLE LIMESTONE SANDSTONE WITH CARBONATE MATRIX AIR-SETTING AND HYDRAULIC MORTAR CEMENT MORTAR AND CONCRETE GLASS 	<ul style="list-style-type: none"> RAIN AMOUNT TIME OF WETNESS (T AND RH) LIGHT 	<ul style="list-style-type: none"> SO₂ NO₂ PM, PM₁₀, PM_{2.5} CARBON FRACTIONS OF PM: EC AND OC SOLUBLE SALT FRACTION OF PM: SO₄²⁻, SO₃²⁻, NO₃⁻, NO₂⁻, Br⁻, HPO₄²⁻, Cl⁻, CHO₂⁻, C₂H₃O₂⁻ AND C₂O₄²⁻ VOC
 BIODETERIORATION	<ul style="list-style-type: none"> CARBONATE AND SILICATE STONES AIR-SETTING AND HYDRAULIC MORTAR CEMENT MORTAR AND CONCRETE WOOD 	<ul style="list-style-type: none"> RAIN AMOUNT T RH SOLAR RADIATION 	<ul style="list-style-type: none"> OC FRACTION OF PM SOLUBLE SALT FRACTION OF PM: NO₃⁻, C₂H₃O₂⁻
 CORROSION	<ul style="list-style-type: none"> METALS: STEEL, ZINC, COPPER, BRONZE, LEAD 	<ul style="list-style-type: none"> RAIN AMOUNT RAIN PH T RH 	<ul style="list-style-type: none"> SO₂ HNO₃ O₃ PM, PM₁₀, PM_{2.5} SOLUBLE SALT FRACTION OF PM: SO₄²⁻, NO₃⁻, Cl⁻ H₂S COS CH₃COOH AND CH₂O₂ NH₃
 LEACHING	<ul style="list-style-type: none"> GLASS 	<ul style="list-style-type: none"> RAIN AMOUNT RAIN PH T RH 	<ul style="list-style-type: none"> SO₂ HNO₃ O₃ PM, PM₁₀, PM_{2.5} SOLUBLE SALT FRACTION OF PM: SO₄²⁻, NO₃⁻, Cl⁻
 SALT CRYSTALLISATION	<ul style="list-style-type: none"> SANDSTONE LIMESTONE AIR SETTING AND HYDRAULIC MORTAR CEMENT MORTAR AND CONCRETE BRICK 	<ul style="list-style-type: none"> RH CYCLES RAIN PH T 	<ul style="list-style-type: none"> PM, PM₁₀, PM_{2.5} SOLUBLE SALT FRACTION OF PM: SO₄²⁻, Cl⁻, NO₂⁻, NO₃⁻, Ca⁺, Na⁺, Mg²⁺, K⁺

Pollution impact on cultural heritage – a brief review

DAMAGE PROCESS	OUTDOOR MATERIALS MAINLY AFFECTED	CLIMATE PARAMETERS	POLLUTANTS
 <p>BLACK CRUST FORMATION</p>	<ul style="list-style-type: none"> MARBLE LIMESTONE SANDSTONE WITH CARBONATE MATRIX AIR-SETTING AND HYDRAULIC MORTAR CEMENT MORTAR AND CONCRETE 	<ul style="list-style-type: none"> RAIN AMOUNT TIME OF WETNESS (T AND RH) 	<ul style="list-style-type: none"> SO₂ NO₂ PM, PM₁₀, PM_{2.5} CARBON FRACTIONS OF PM: EC AND OC SOLUBLE SALT FRACTION OF PM: SO₄²⁻, SO₃²⁻, NO₃⁻, NO₂⁻BR⁻, HPO₄²⁻, Cl⁻, CHO₂⁻, C₂H₃O₂⁻ AND C₂O₄²⁻ VOC



BLACK CRUST FORMATION ON SURFACES EXPOSED TO RAIN WETTING, BUT PROTECTED BY WASHING OUT

DAMAGE PROCESS	OUTDOOR MATERIALS MAINLY AFFECTED	CLIMATE PARAMETERS	POLLUTANTS
 <p>SURFACE RECESSION</p>	<ul style="list-style-type: none"> MARBLE LIMESTONE SANDSTONE WITH CARBONATE MATRIX AIR-SETTING AND HYDRAULIC MORTAR CEMENT MORTAR AND CONCRETE 	<ul style="list-style-type: none"> RAIN AMOUNT RAIN PH TIME OF WETNESS (T AND RH) 	<ul style="list-style-type: none"> SO₂ HNO₃ CO₂ PM, PM₁₀, PM_{2.5}

LIPFERT FUNCTION – Surface recession

$$L = 18.8 \cdot R + 0.016 \cdot [H^+] \cdot R + 0.18 (V_{ds} [SO_2] + V_{dN} [HNO_3])$$

↓ Clean rain
Karst phenomenon
↓ Acid rain
 ↓ Dry deposition

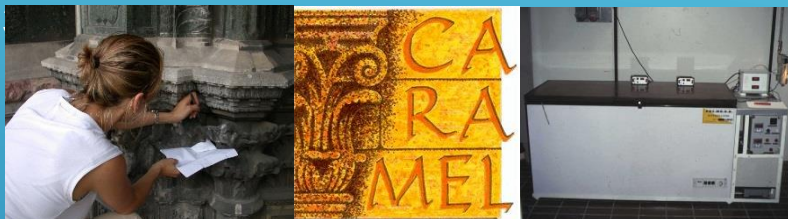


Legend	
L:	surface recession per year (µm/year)
18.8:	intercept term based on the solubility of CaCO ₃ in equilibrium with 330 ppm CO ₂ (µm/m)
R:	precipitation (m/year)
0.016:	constant valid for precipitation pH in the range 3-5
[H ⁺]:	hydrogen ion concentration (µmol/l) evaluated from rain yearly pH
0.18:	conversion factor from (cm/s) (µg/m ³) to µm
V _{ds} :	deposition velocity of SO ₂ (cm/s)
[SO ₂]:	SO ₂ concentration (µg/m ³)
V _{dN} :	deposition velocity of HNO ₃ (cm/s)
[HNO ₃]:	HNO ₃ concentration (µg/m ³)

Validated for carbonate rocks with porosity lower than 25%

ORIGIN OF DAMAGE

- **FP5 CAMEL - CARbon content And origin of damage Layers in European Monuments** (2001-2003)
<https://cordis.europa.eu/project/rcn/5420>

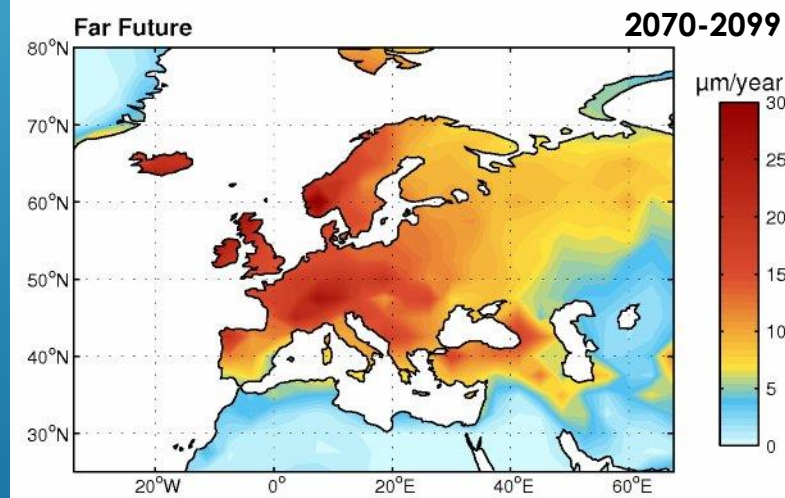
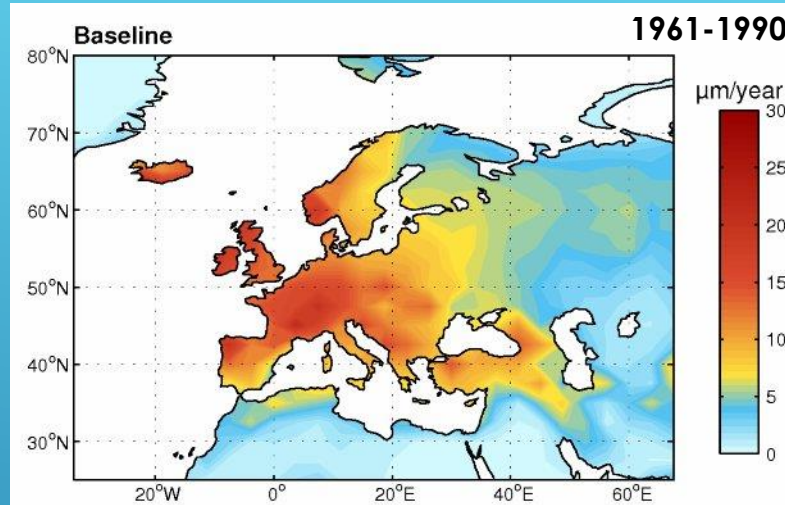


- **FP7 TeACH - Technologies and Tools to prioritise Assessment and diagnosis of air pollution impact on immovable and movable Cultural Heritage** (2008-2012)
www.teach-project.eu/



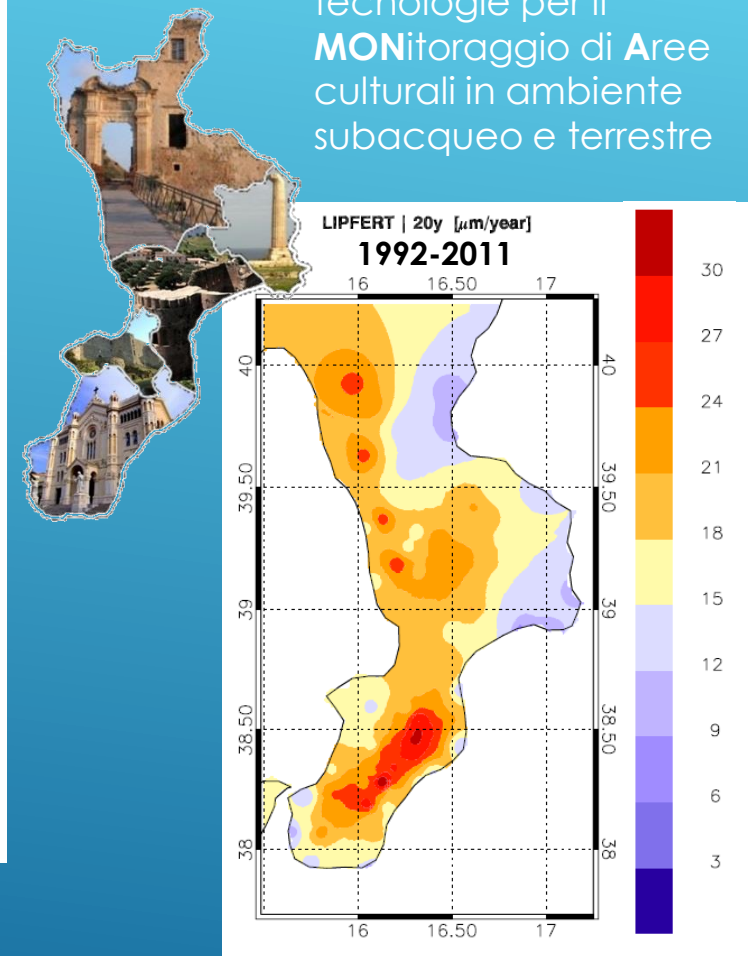
- **Safeguarding Cultural Heritage from Natural and Man-Made Disasters.** A comparative analysis of risk management in the EU, 2018

USE OF DAMAGE FUNCTION



- **FP 6 Noah's Ark - Global Climate Change Impact on Built Heritage and Cultural Landscapes**, (2004-2007)

- **SIMONA - POR CALABRIA FESR 2007/2013 - Sistemi e tecnologie per il MONitoraggio di Aree culturali in ambiente subacqueo e terrestre**



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



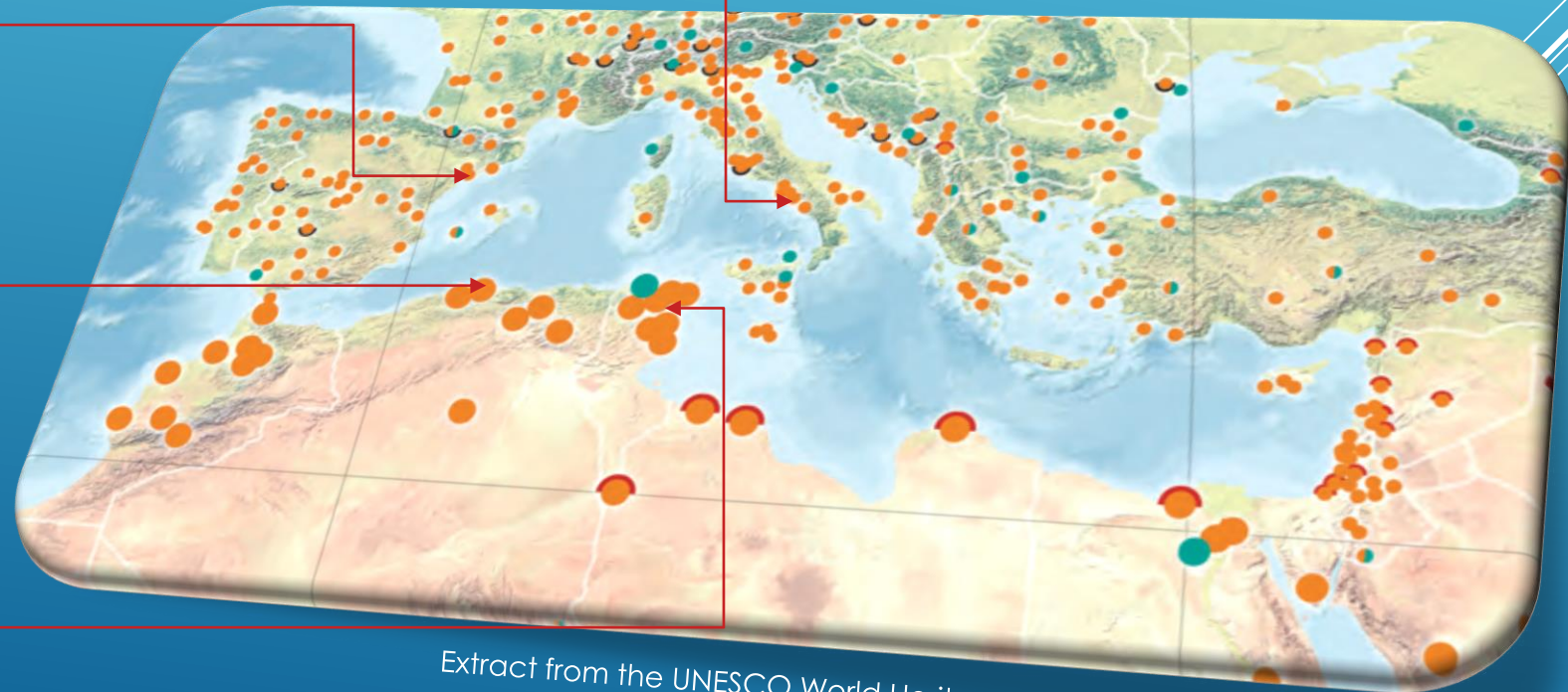
Kasbah of Algiers
(Algeria)
© UNESCO



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



Archaeological Site
of Carthage (Tunisia)
© Editions Gelbart



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

COASTAL AREAS (monuments, landscapes, etc.)



Venice (Italy)



UNDERWATER HERITAGE (monuments/ecosystems)



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



Baia (Naples, Italy)

AIR EMISSIONS

- Macropollutants:
 - SO_x , 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.

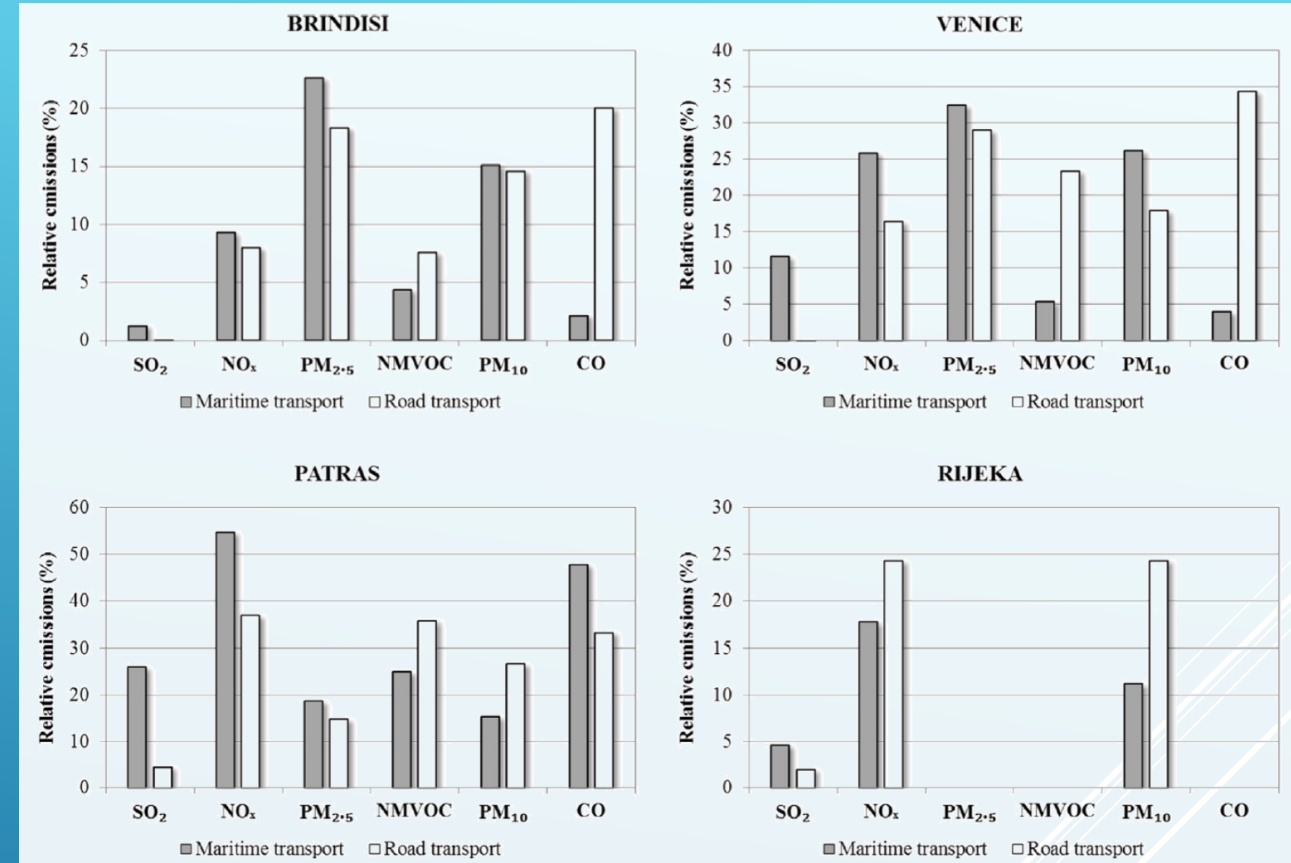
Financed by the European program for territorial Cooperation MED 2007/2013:

- **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 ActionNs.** The project studies the impact of passenger maritime traffic on air quality in five important port cities in the northern 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>



AIR EMISSIONS

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 $\text{PM}_{2.5}$, 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.

What are the possible impacts on Cultural Heritage exposed to these emissions?

BLACK CRUSTS FORMATION

- Materials carbonate based
 - Limestone
 - Marble
 - Sandstone with carbonate matrix
 - Air-setting and hydraulic mortar, etc.
- Sulfation by SO_2
 - Limestone to gypsum
 - Deposition of soot
 - Rain partially sheltered
- Surface recession
 - Rainwashed areas
 - May be white



As mentioned in the CAIMANs Project Final Report: “Air pollution mitigation of passenger ships needs complementary and integrated policies and planning, from international to national and local levels, to find the most effective solutions that **minimize the impact on population, the environment and the cultural heritage of Mediterranean port cities.**”

In Norway, the Norwegian Maritime Authority carried out a study to examine the effects of speed limitation on cruise ships operating in **Norwegian World Heritage fjords**, as well as the pollution from these ships in fjord areas.



Cruise ship in Norwegian fjords



Venice (Italy), from Green Port Cruise 2015,
Venice Port Authority (VPA)

The goal of Venice Port Authority (VPA) by law is to maintain harbor activities and to develop traffics, but these goals could be achieved only **preserving** both the **lagoon environment and the cultural heritage.**

For that reason, since 2007 VPA has adopted a **proactive strategy** to improve air quality that involves both compliance with existing regulations and **undertaking voluntary endorsements to reduce air emissions.**

- 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
- Necessity of address specific studies to this issue
- Existent projects, carried out on the naval emissions, can be suitable for the implementation also of the heritage sector
- Still lack of studies regarding the naval impact on underwater heritage

*Thank you for
your attention*

Three parallel white lines of varying lengths, slanted diagonally upwards from left to right, located in the bottom right corner of the image.