

International Conference
New Indicators for a Better World
Ravenna, 26 September 2013



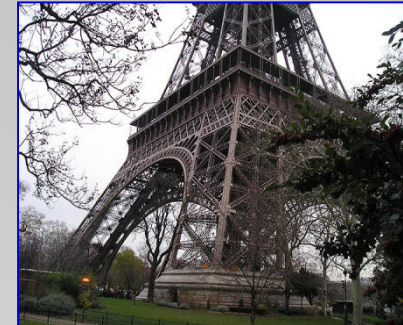
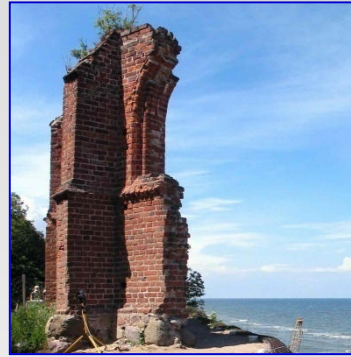
***INDICATORS FOR AIR POLLUTANTS
AND CLIMATE CHANGE: IMPACT ON
CULTURAL HERITAGE***

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ENVIRONMENT – CULTURAL HERITAGE



CLIMATE/POLLUTION PARAMETERS

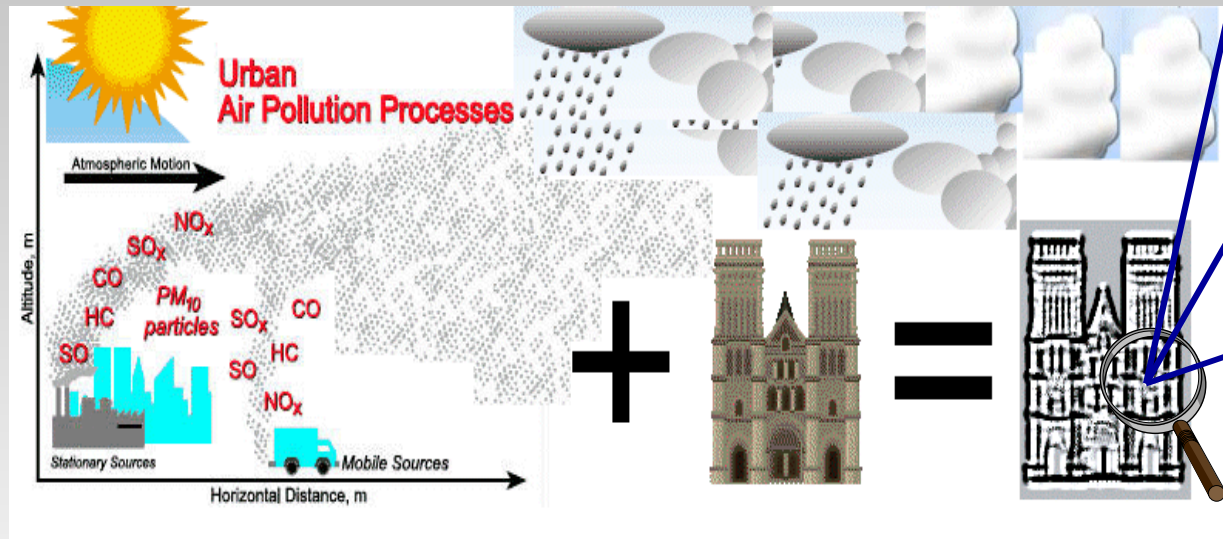
- Temperature
- Relative Humidity
- Precipitation
- Wind
- Gas (SO_2 , NO_x)
- Particles
- Sea salts
- pH precipitation



COMBINATION
ACCUMULATION

MATERIALS

- Stone/Masonry Materials:
 - Marble
 - Limestone
 - Sandstone
 - Bricks
 - Clay containing mat.
- Wood
- Metals
 - Iron
 - Bronze
 - Copper
 - Lead
 - Zinc
- Glass



- Damage layer and black crust formation
- Chemical dissolution (surface recession)
- Salt crystallisation (decohesion, powdering)

BLACK AREAS

- Rain sheltered areas
- Calcite  gypsum (Sulphation process - SO_2)
- Carbonaceous particle deposition



BLACK CRUSTS

WHITE AREAS

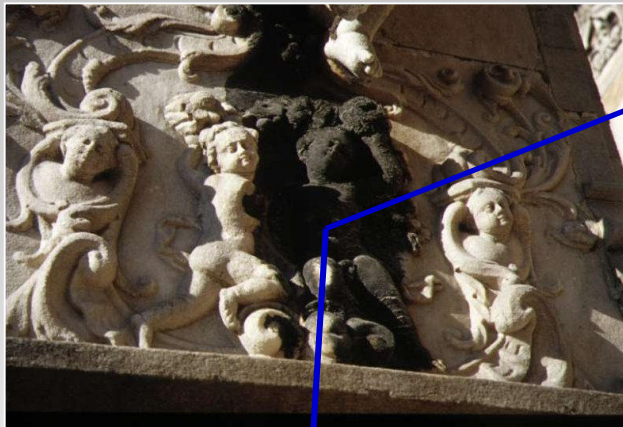
- Rainwashed areas
- Chemical dissolution
- Material loss



SURFACE RECESSION

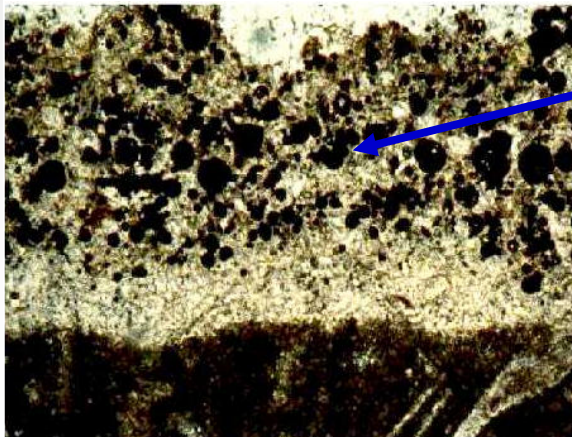
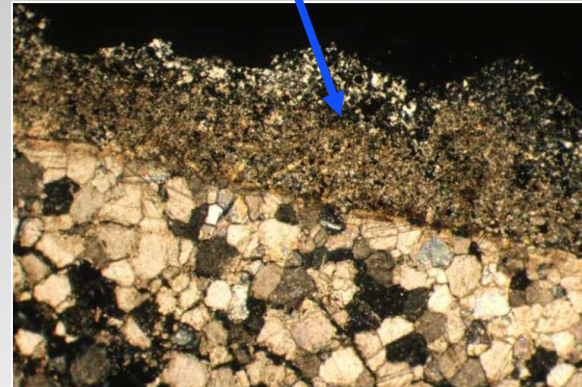


BLACK CRUSTS FORMATION AND SOILING

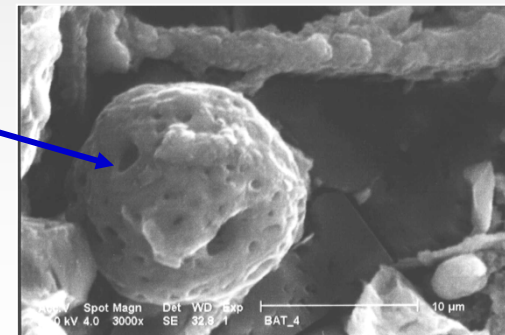


BLACK CRUSTS

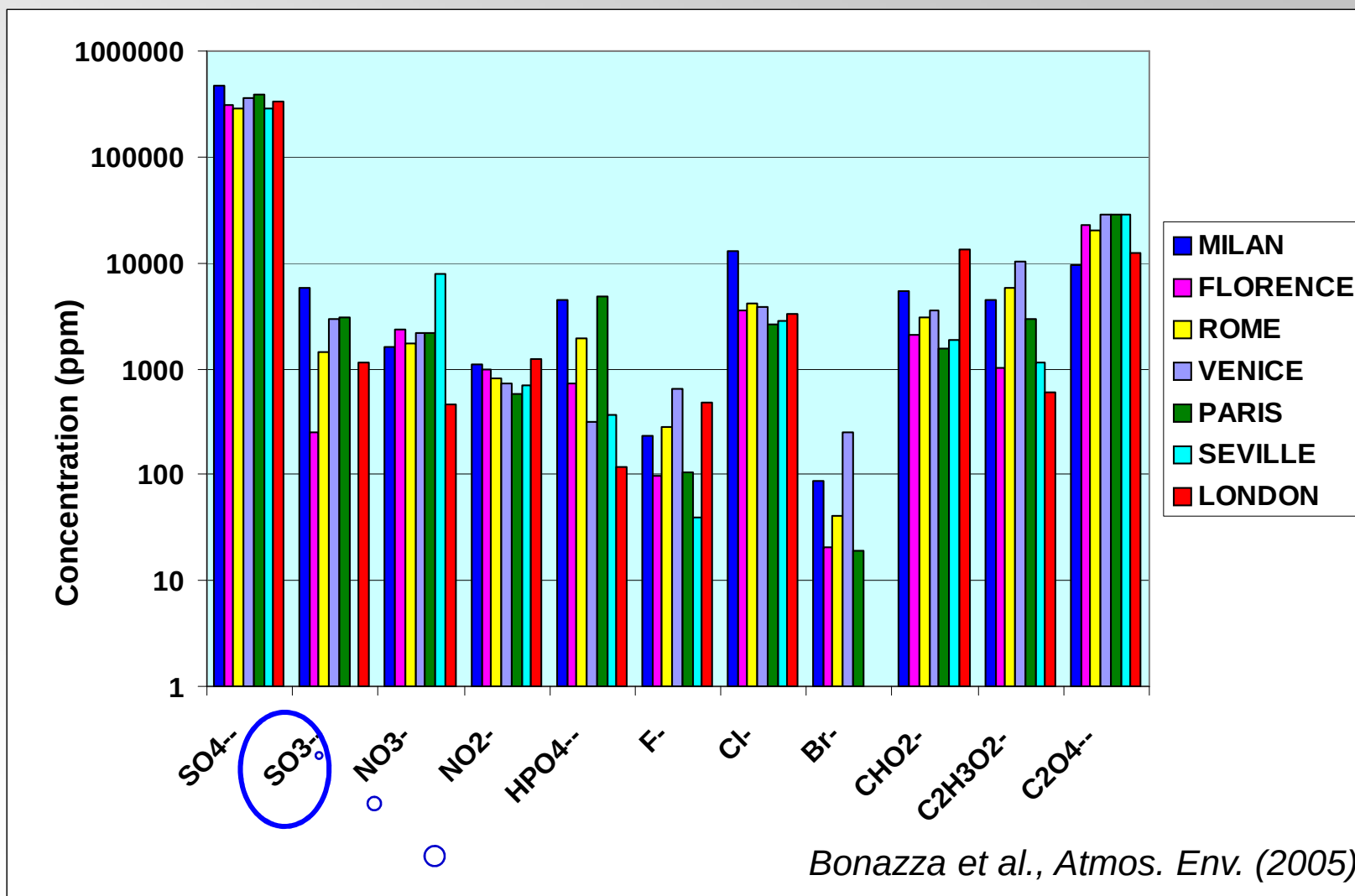
SULPHATION
gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)



**Carbonaceous
particles**



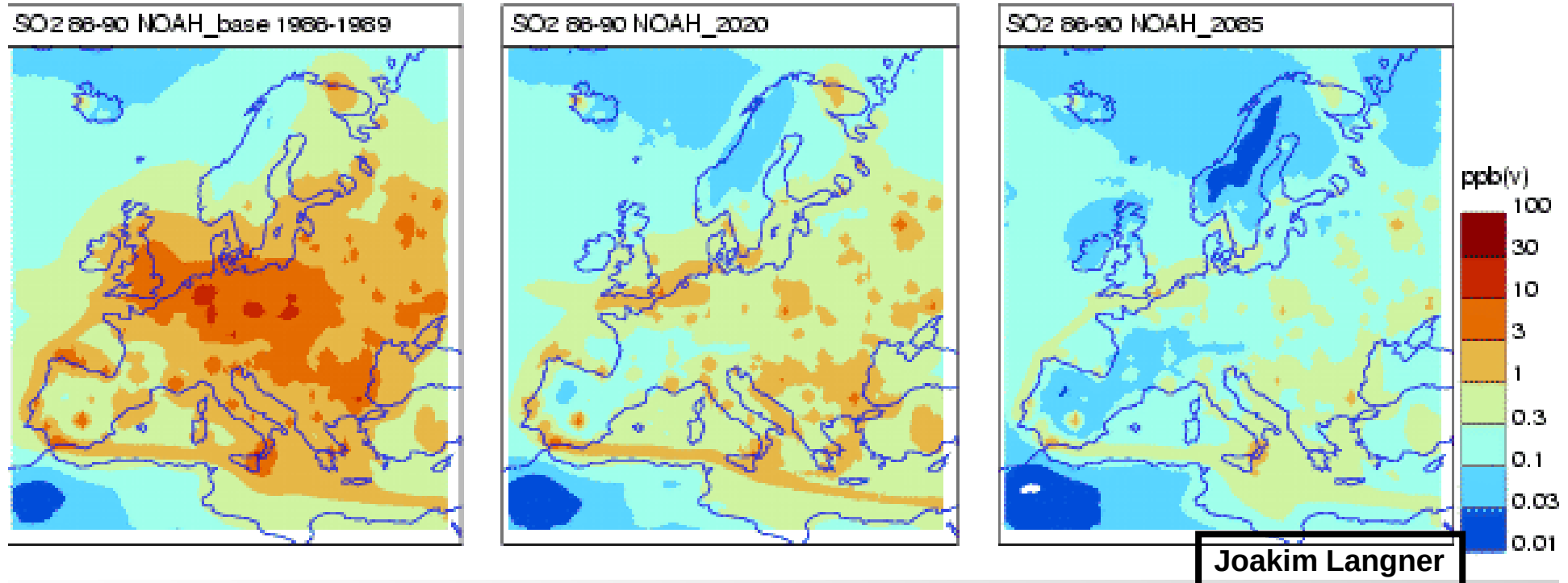
SOLUBLE ANION CONCENTRATION ($\mu\text{g/g}$), IC



SO₂ dry deposition

FUTURE SCENARIO OF SO₂

NOAHs ARK SSPI-CT-2003-501837



Shift in modern urban atmospheres from a SO₂ dominated situation to a multipollutant situation

SULPHATION PROCESS DECREASE

CARBON IN THE BLACK CRUSTS/DAMAGE LAYERS

$$TC = CC + EC + OC \rightarrow NCC$$

Stone
substrate

- Atmospheric deposition
- Biological weathering
- Surface treatments

Particles emitted by
combustion processes

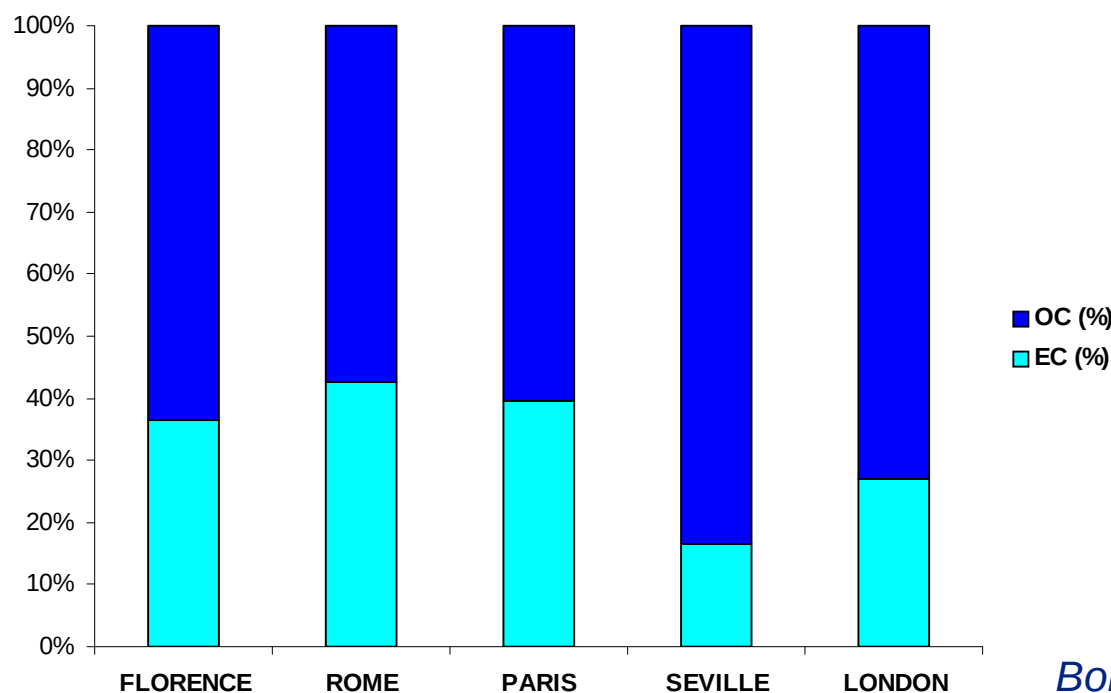
Ghedini et al., EST (2006)

Fixed and mobile combustion
sources

CARAMEL EVK4-CT-2000-00029

CRUSTS European Monuments (carbonate stone)

OC prevails on
monuments in
European towns



due to
urban traffic

Bonazza et al. Atmos. Env. (2005)

OLD-MODERN CRUSTS

MILAN CATHEDRAL



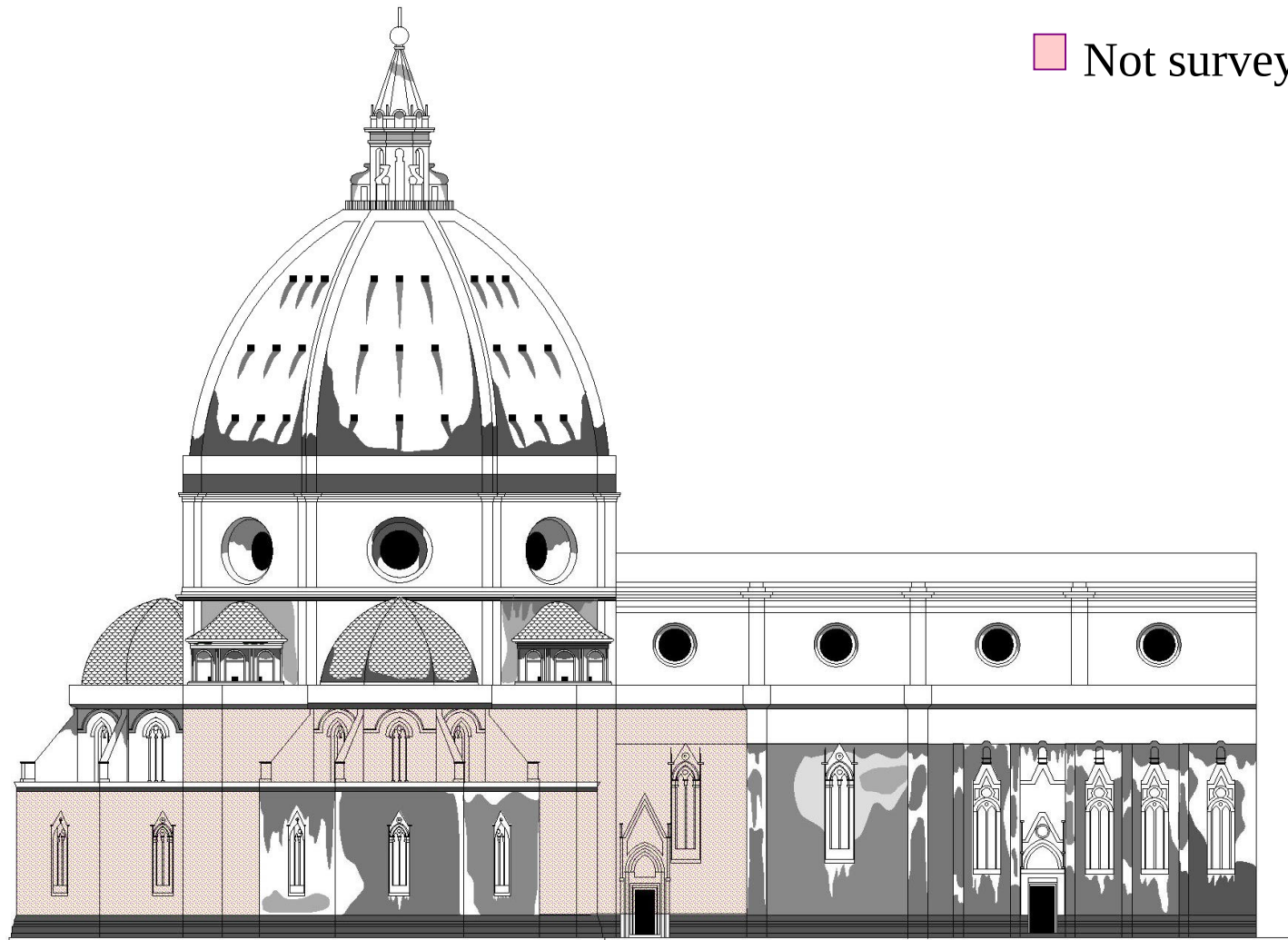
SITE	MONUMENT	AGE (years)	EC (%)	OC (%)	EC/OC
MILAN	CATHEDRAL	500	1,73	0,70	2,48
MILAN	CATHEDRAL	500	1,17	0,53	2,20
MILAN	CATHEDRAL	500	1,70	0,62	2,75
VENICE	CORNER PALACE	500	1,52	0,71	2,16
VENICE	CORNER PALACE	500	0,78	0,67	1,17
ROME	VITTORIANO	100	1,34	1,62	0,83
ROME	VITTORIANO	100	0,93	1,16	0,80
RAVENNA	P. RASPONI	100	0,88	1,67	0,53
FLORENCE	S.M. DEL FIORE	50	0,66	1,11	0,59



VITTORIANO MONUMENT, ROME

Modern crusts are richer in organic compounds

St. Maria del Fiore, Florence



Tav. 5.1.2 - Rilievo di strato di deposito 1954

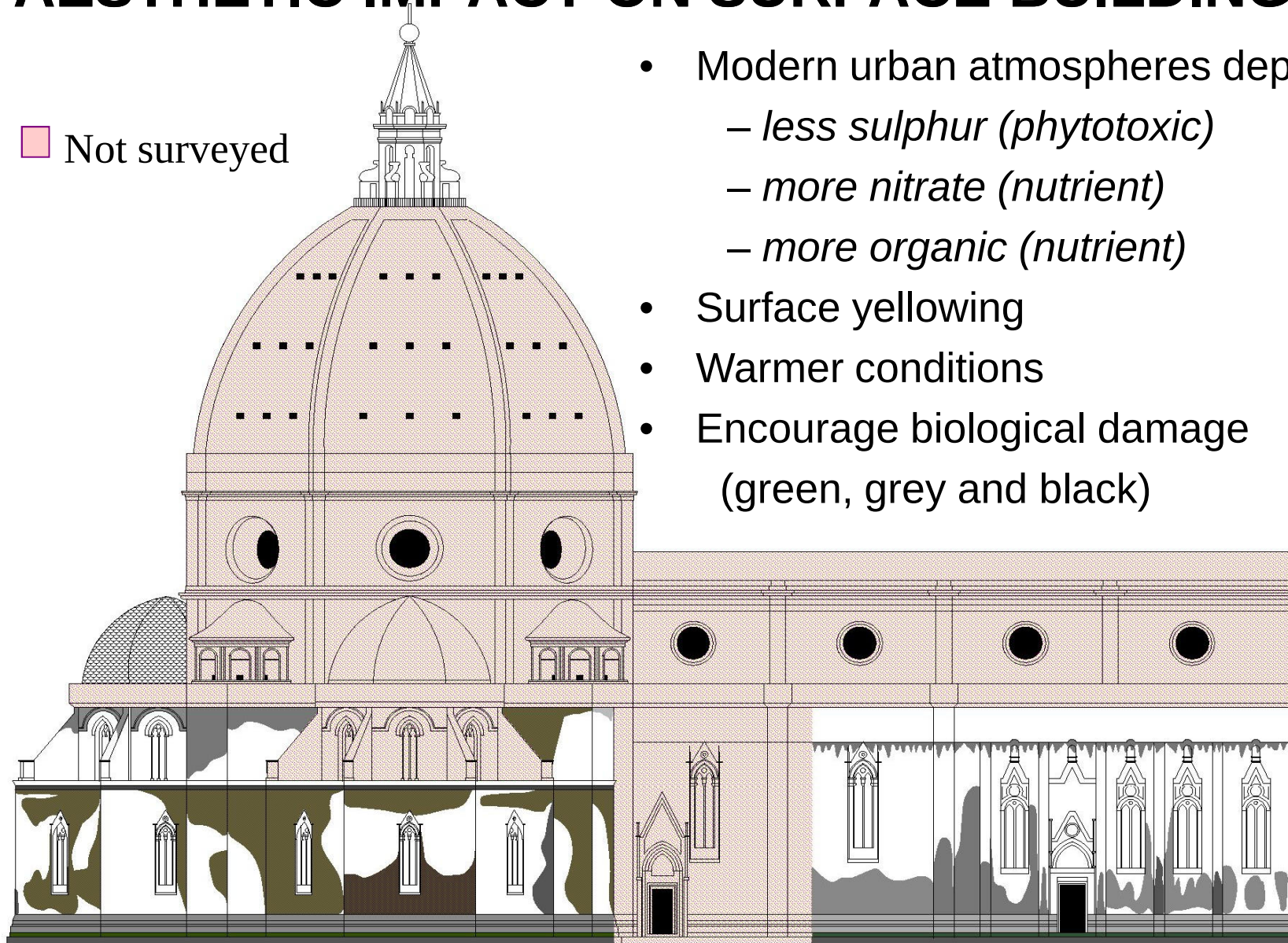
Lucia De Prato

1954-1955



AESTHETIC IMPACT ON SURFACE BUILDINGS

■ Not surveyed



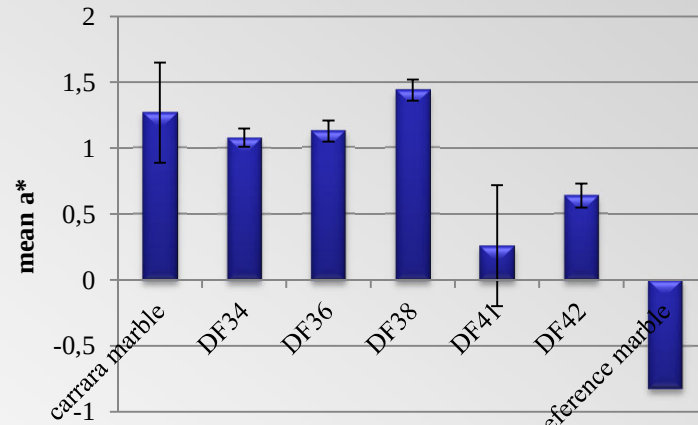
- Modern urban atmospheres deposit
 - *less sulphur (phytotoxic)*
 - *more nitrate (nutrient)*
 - *more organic (nutrient)*
- Surface yellowing
- Warmer conditions
- Encourage biological damage (green, grey and black)

Grossi et al., 2006; Bonazza et al., 2007; Grossi et al., 2008, Smith et al., 2010

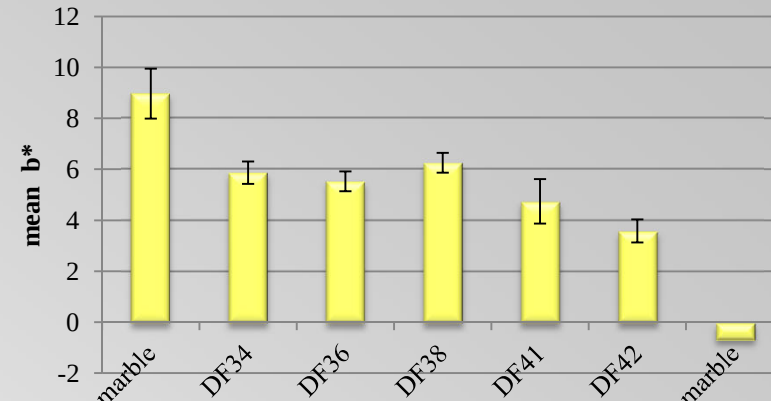
Tav. 5.1.3 - Rilievo di strato di degrado 2010

2010

AESTHETIC IMPACT ON SURFACE BUILDINGS



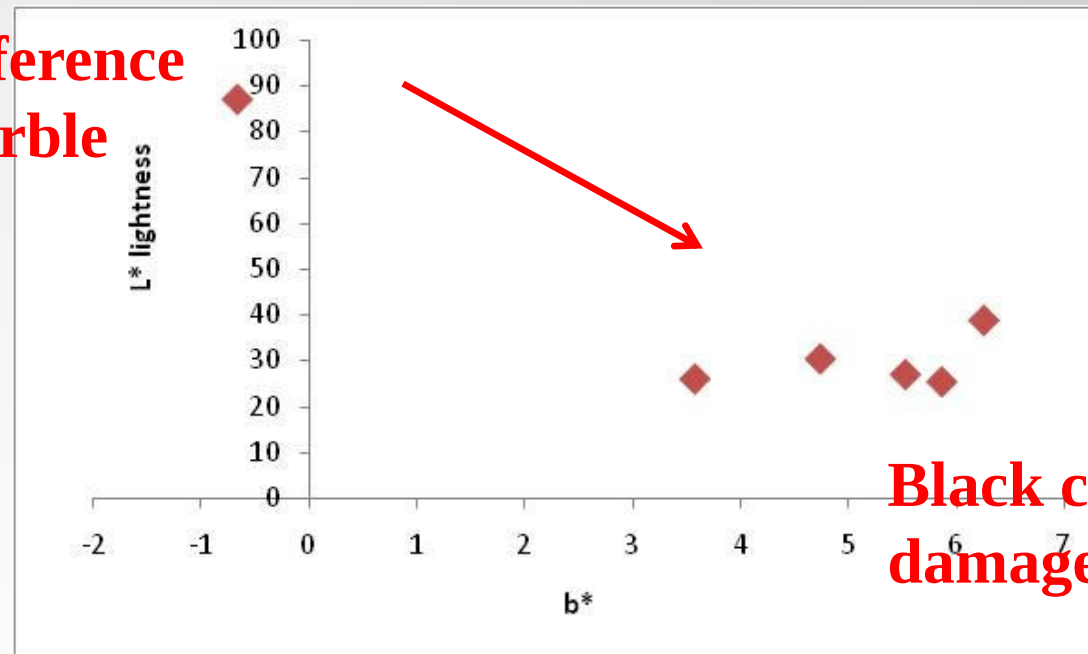
Increase a*: more red



Increase b* : more yellow

Reference marble

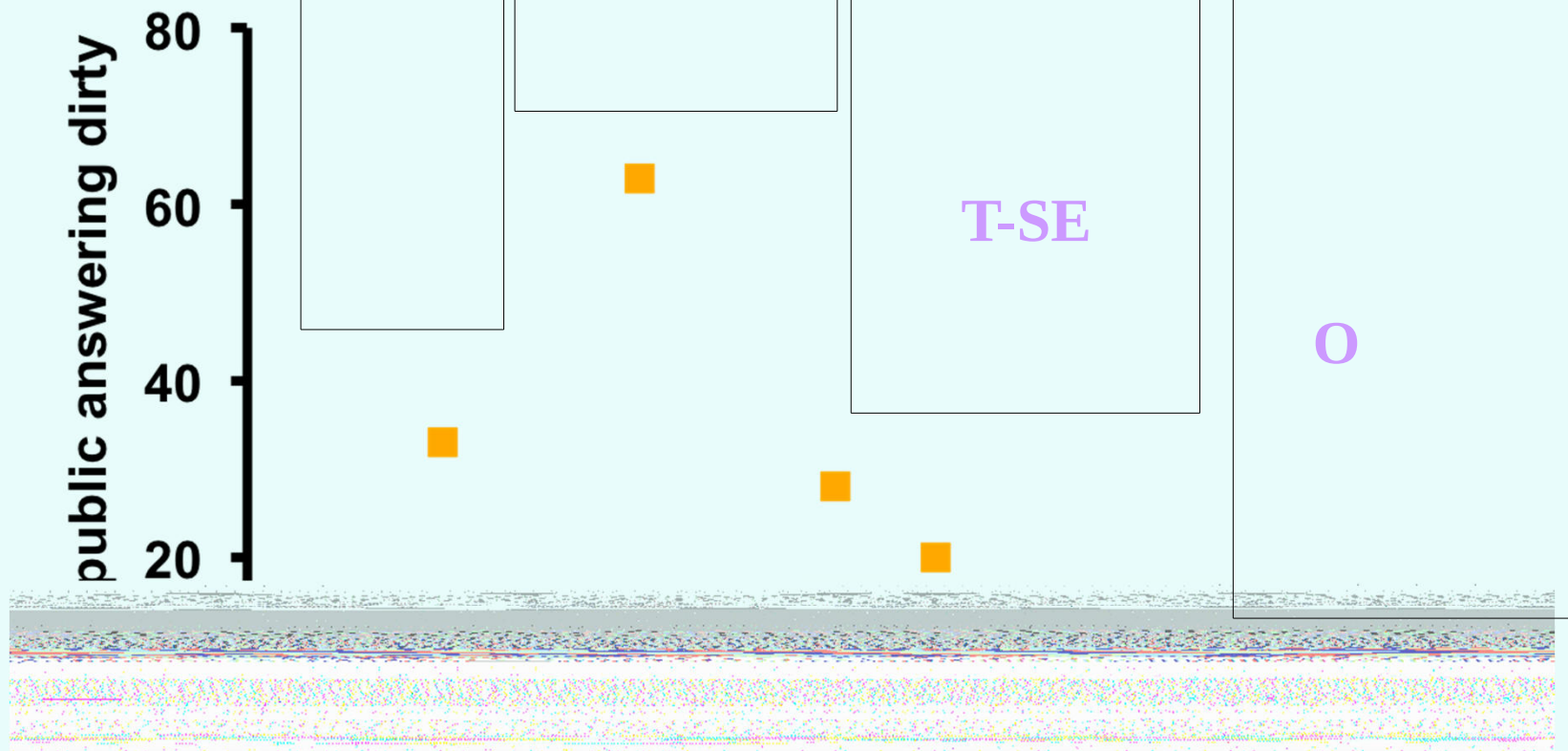
Florence



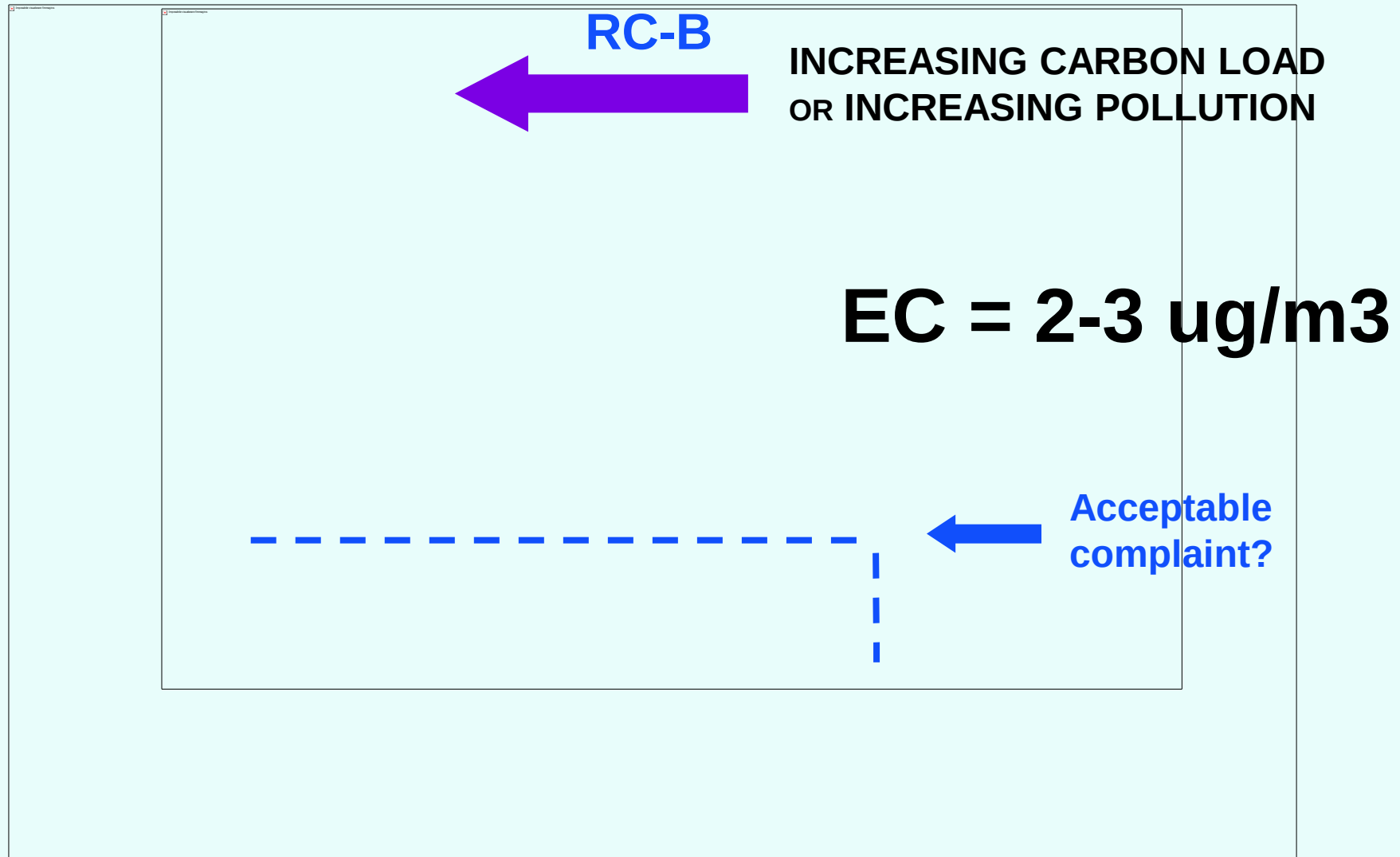
Black crusts / damage layers

EC Project Teach

COLOUR vs DIRTINESS



SETTING LIMITS FOR SOILING



Pollution impact on modern cement built heritage

Centennial Hall, Poland



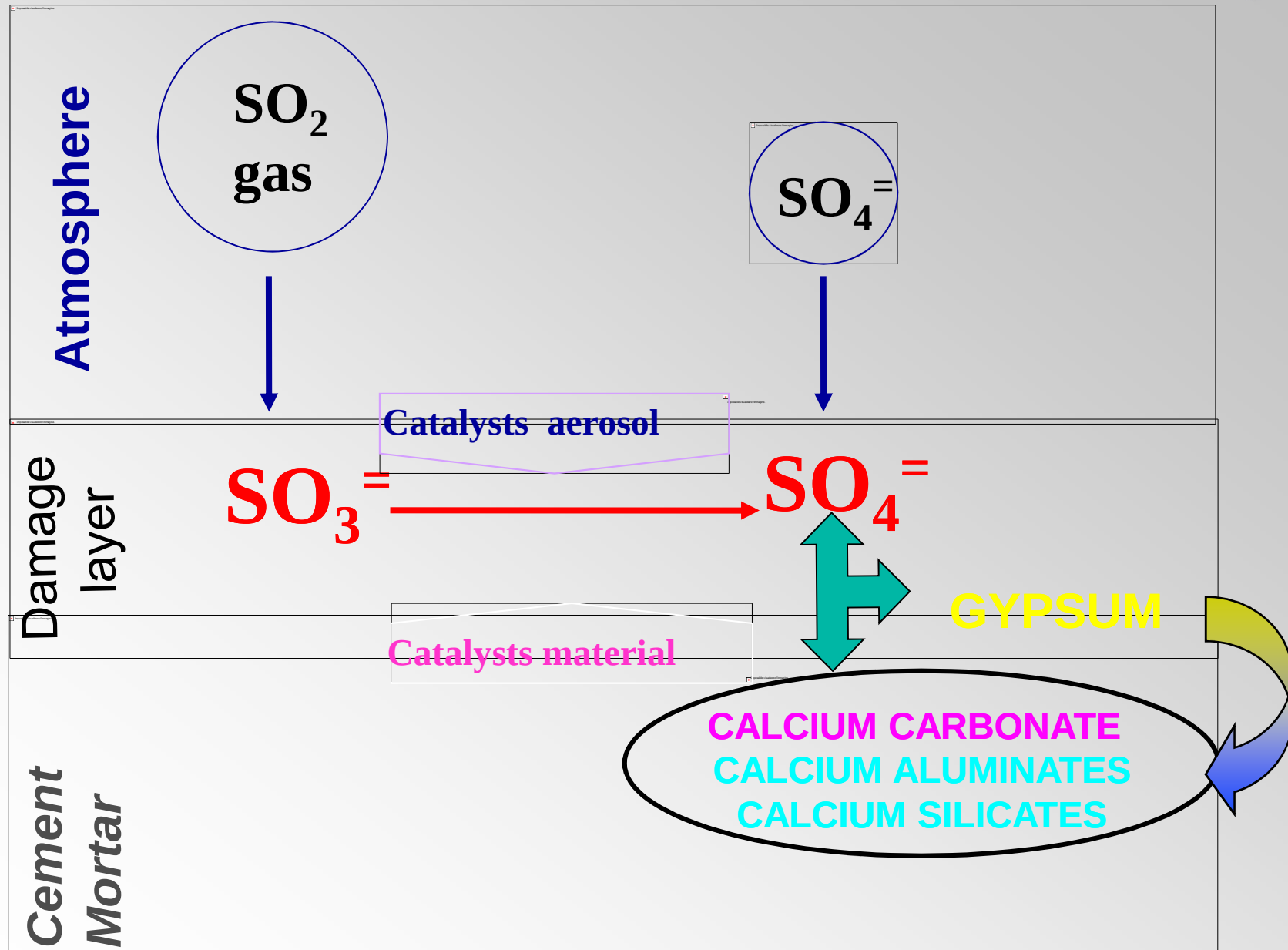
Vulnerability of building materials is different depending on chemical composition and porosity

Reactivity to SO₂

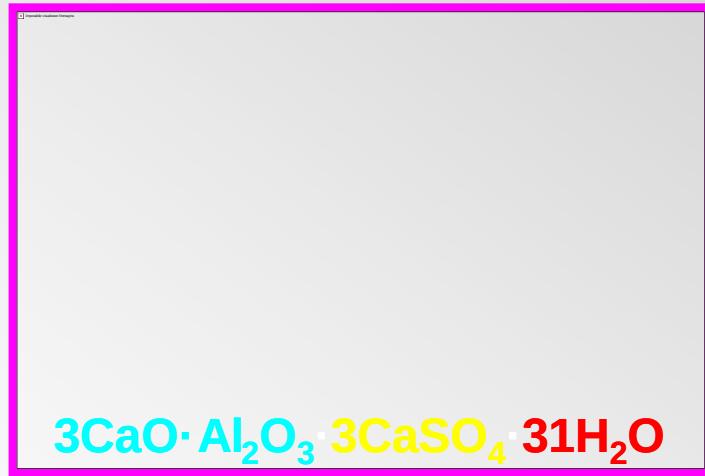


SIMULATION CHAMBER TEST

Gypsum formation on cement



SECONDARY DAMAGE PRODUCTS



Gypsum + Calcium aluminate



ETTRINGITE

Gypsum + Calcium silicate



THAUMASITE



Sabbioni et al., Atmos. Env. (2001)

10-15 nm

Laboratory test

ETTRINGITE

FORMATION

ETTRINGITE

DISSOLUTION / DECOMPOSITION

TAUMASITE

FORMATION

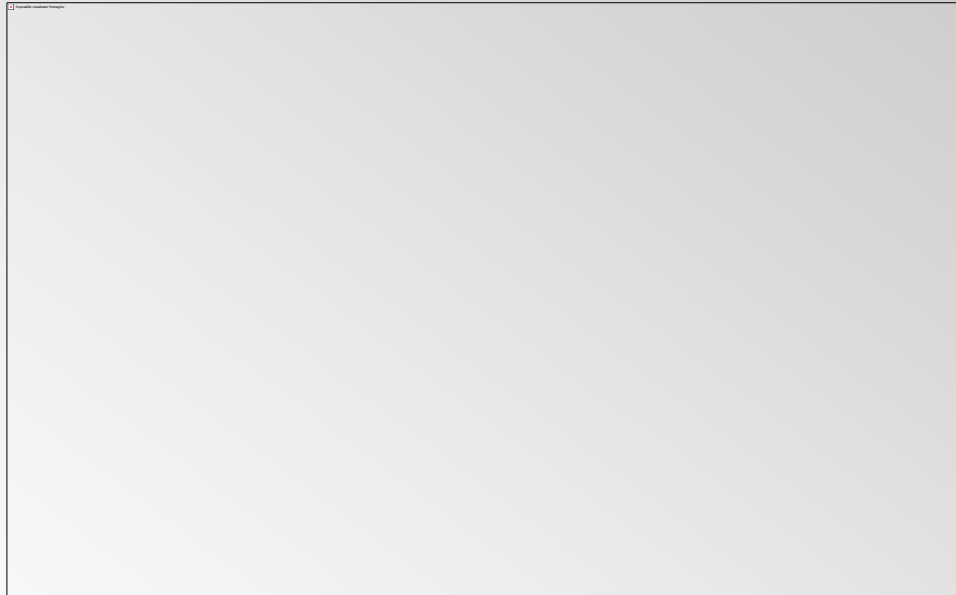
BREAKDOWN BY EXPANSION

**Damage occurs in
spite of SO₂
decreases**

EC Project EDAMM



CLIMATE CHANGE: WATER CYCLE



Yearly precipitation 2070-2099

Structural damage

Erosion

Dissolution

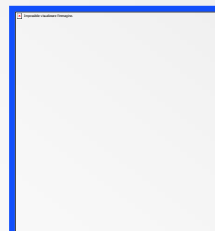
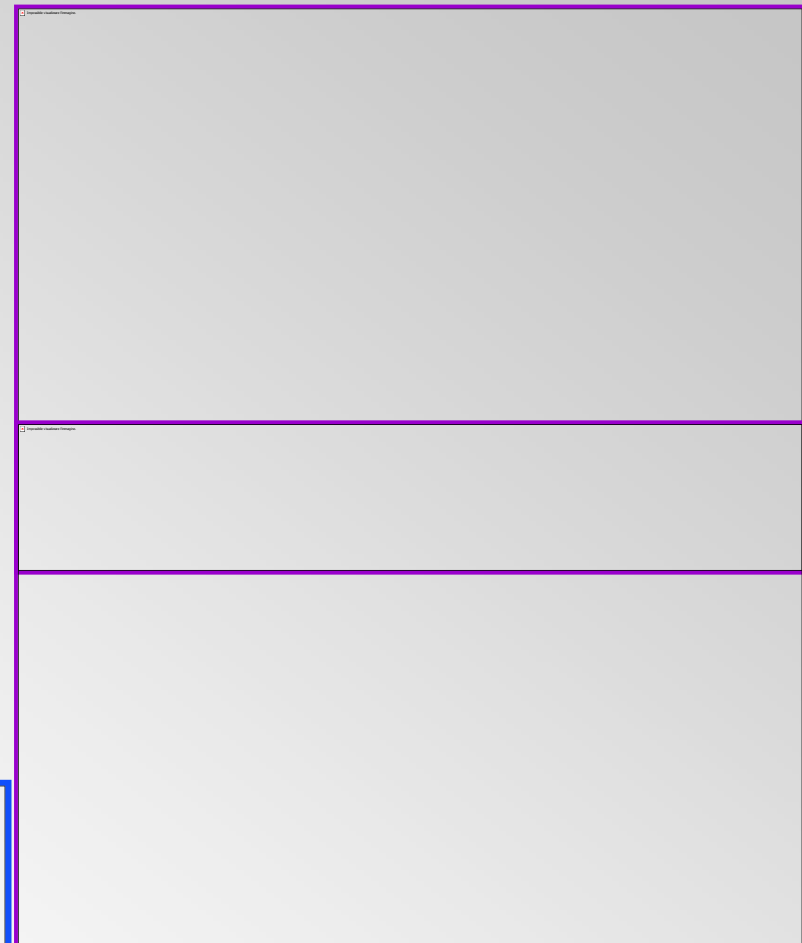
Swelling-shrinkage

Frost damage

Salt crystallization

Biodeterioration

***Major cause of
deterioration (XXI century)***





Relative humidity cycles =75.5%

(Salt crystallisation)



Brick Masonry

2070-2099

Salt crystallisation



Increase

Decrease

....general increase.....

Western Europe. Temperate fully humid climates: highest potential for salt damage and possible higher number of transitions in summer. Climates with dry summers: lesser frequency of transitions in summer (Grossi et al., 2011)

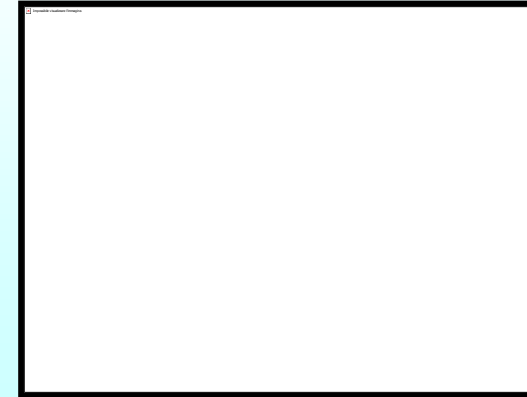
Biomass Accumulation on Monuments



2070-2099

Linked to temperature and precipitation

Biomass Accumulation on Monuments



Linked to temperature and precipitation
Projections valid for rural areas



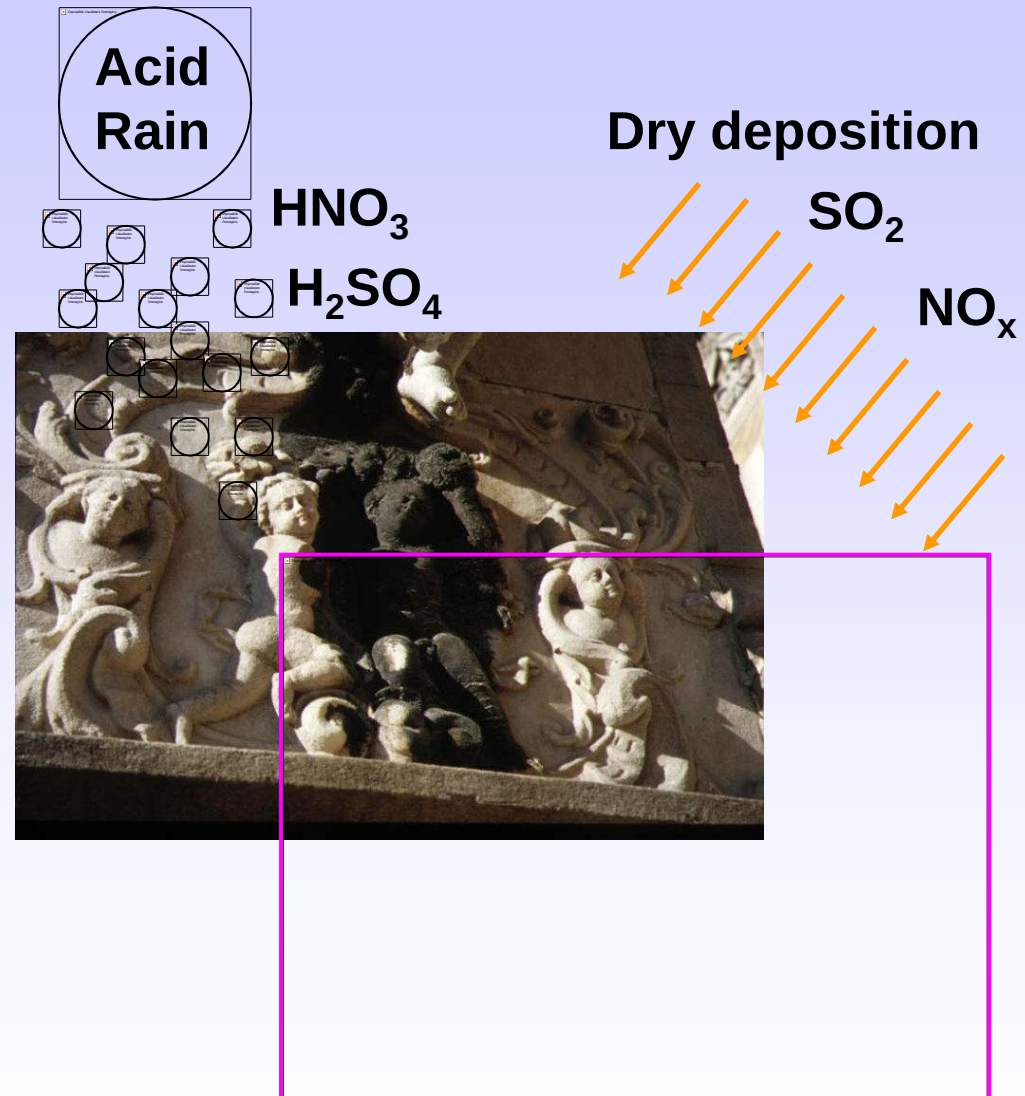
SURFACE RECESSION OF CARBONATE STONES

Material dissolution due to the chemical attack induced by:

1. **Clean rain** (rain at pH 5.6 in equilibrium with 330 ppm CO₂ – karst effect)
2. **Acid Rain** (additional acidity due to anionic components, such as SO₄²⁻, NO₃⁻.....)
3. **Dry deposition** (gaseous pollutants occurring between precipitation events)

+

Material surface erosion due to the mechanical effect of rain



“Gutta cavat lapidem”

SIMPLIFIED LIPFERT FUNCTION

$$L = 18.8 \cdot R$$

L_v intercept term based on the solubility of CaCO_3 in equilibrium with 330 ppm CO_2 ($\mu\text{m/m}$) at 20 ° C

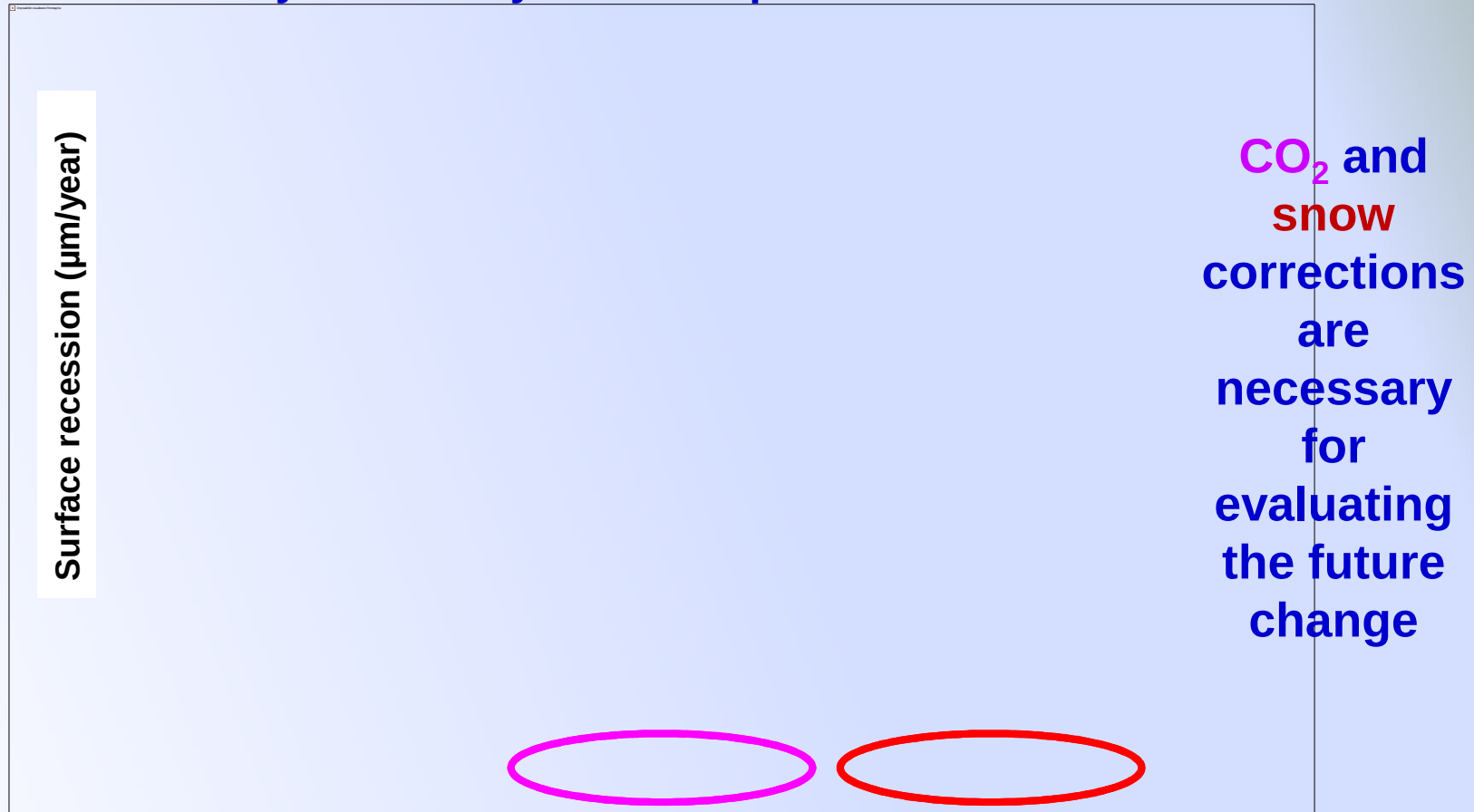
RAIN : PRECIPITATION
NOT INCLUDING SNOW

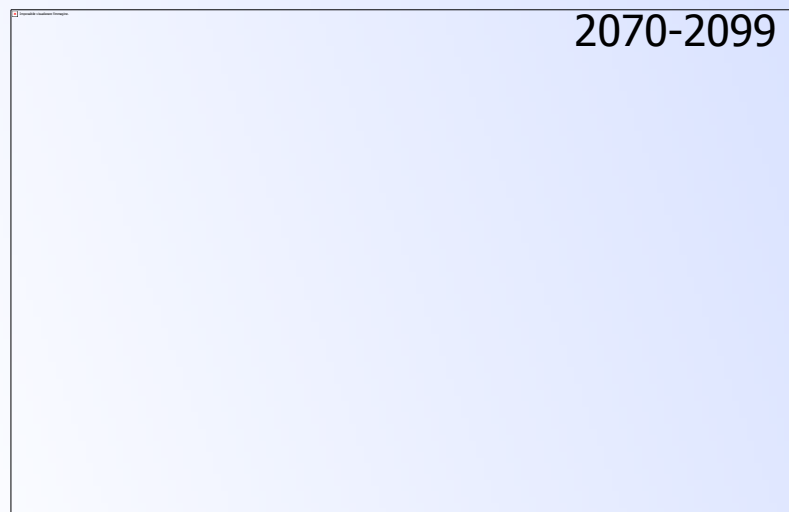
L_v need to be corrected for future scenarios:

L_v was recalculated on a daily basis correcting for the predicted temperature and the CO_2 increase from 330 in 1961 to 750 ppm in 2099 as suggested under A2 emission scenarios : L_v ranges from 18.8 and 21.8 $\mu\text{m/m}$

CORRECTION FOR SNOW EFFECT

Lipfert function assumes that precipitation arrives only in liquid phase. The snow effect has been taken into account by allowing no recession for days with daily mean temperature less than 0 ° C.



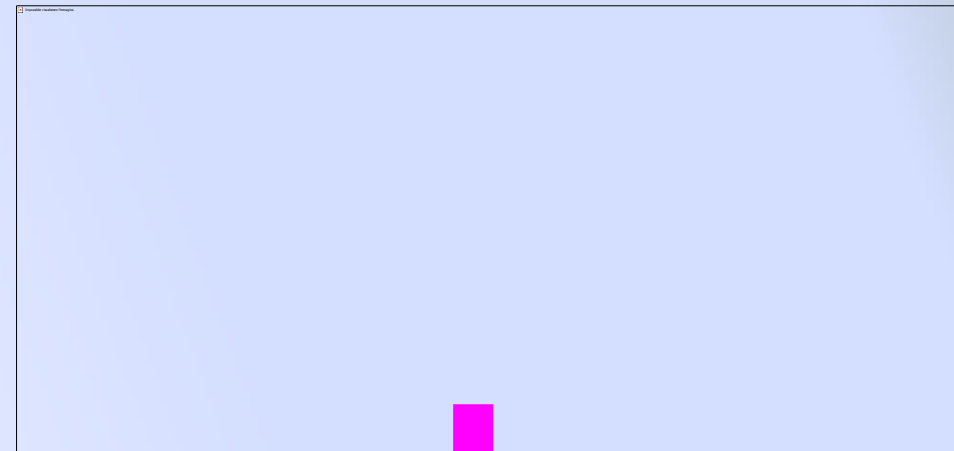
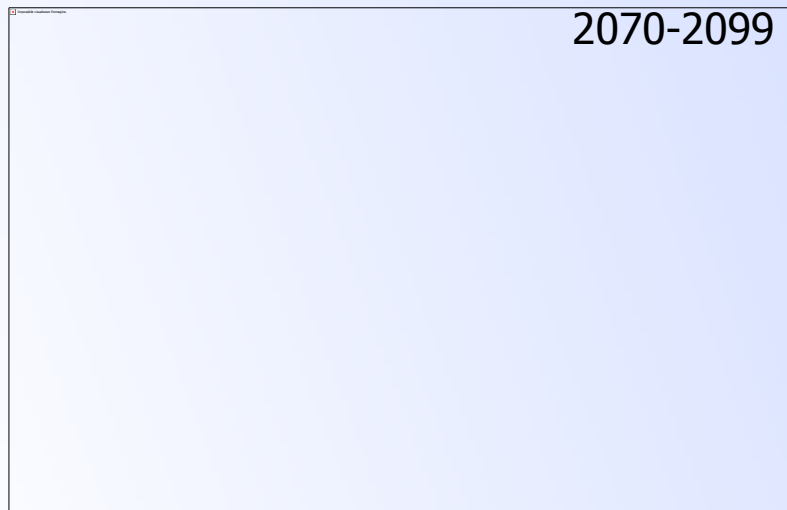
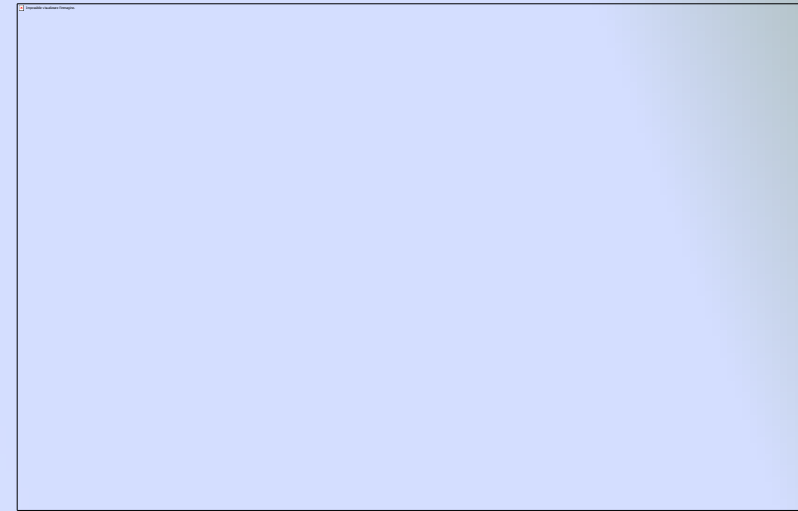


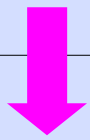
General model HadCM3

*Absolute values
of surface
recession*

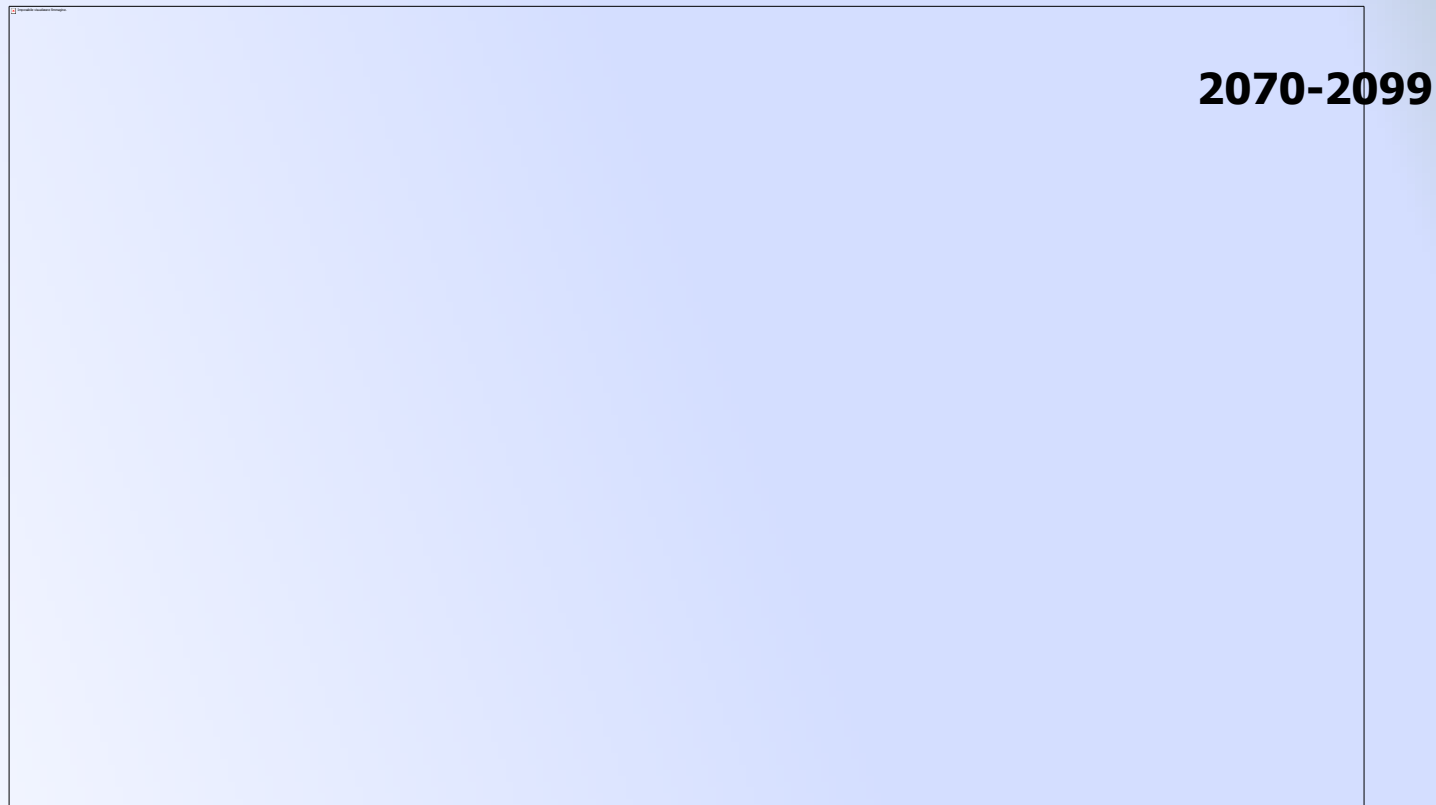
***Central Europe, UK, Iceland,
Scandinavian Peninsula and
the northern Spain will
experience the
highest
surface recession
(20-30 $\mu\text{m}/\text{year}$)***

MAPPING SURFACE RECESSION




30% increase

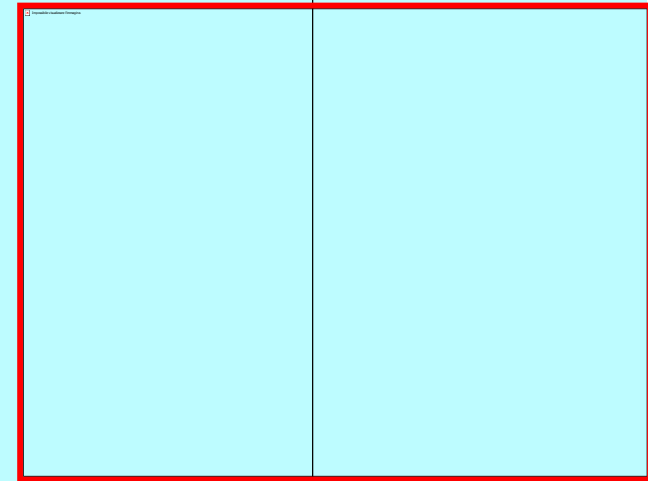
MAPPING SURFACE RECESSION



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 $\mu\text{m}/\text{year}$

Bonazza et al. Science of the Total Environment 2009

THERMAL STRESS



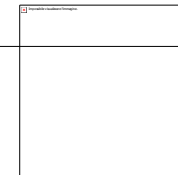
The Mediterranean Basin in general will continue to experience the highest level of risk.

In the near and far future thermal stress will threaten more and more Central Europe.



GUIDELINES FOR THE PREVENTIVE CONSERVATION OF MONUMENTS LOCATED IN URBAN AREAS

- Identify and prioritize climate parameters and pollutants causing **deterioration**, depending also on the sensitivity of materials and the environmental context in which monuments are located.
- Define risks of cultural heritage by adopting **continuous environmental monitoring close to monuments** as a valuable tool. Definition of risks allows heritage managers to single out the priorities for greater investment in preservation and funding of actions to reduce the cause.
- Promote actions aimed at reducing exposure of cultural heritage to harmful agents
- Mitigate the negative causes by regulation at regional and local levels aimed at the reduction of pollutants, especially in **developing urban plans for a sustainable mobility**.



THANKS

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