

**“In and Out Air Strategies.
From Climate Change to Microclimate.
Library, Archives and Museum
Preservation Issues”**

5-6 March 2009

Bibliothèque nationale de France

<http://www.ifla.org/VI/4/pac.htm>

Conférence internationale “Entre deux airs”, Bibliothèque Nationale de France, 5-6 mars 2009

Microclimate and air pollution in the Louvre Palace

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and

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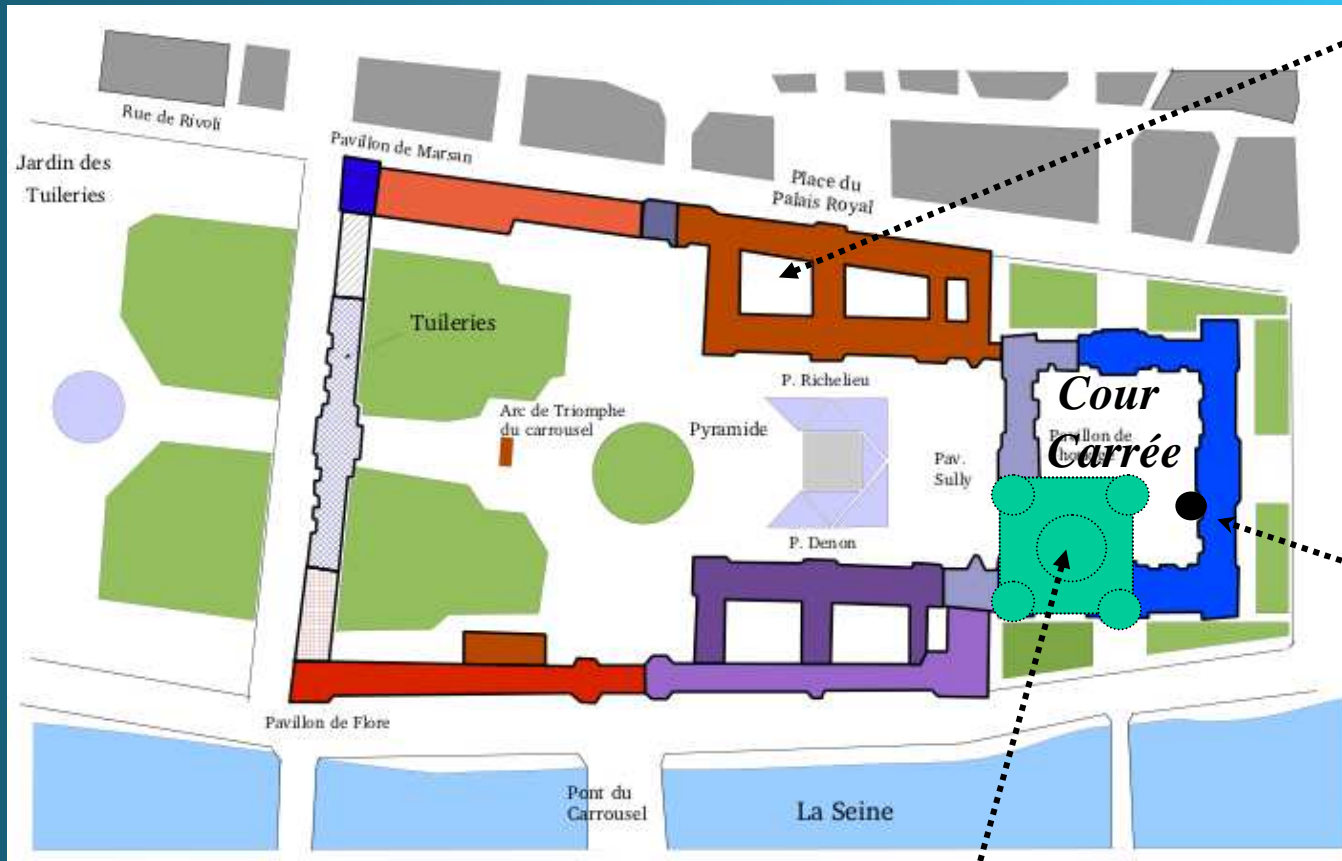
Research Director

National Council for Research, Padua, Italy

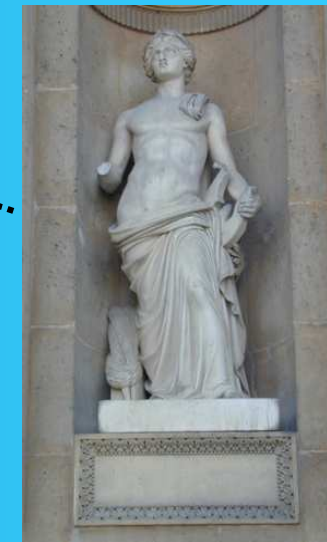
The Louvre: some historical data

The construction of the Louvre has been performed in a continuous manner from the 12th to the 20th Century, from *Philippe-Auguste* to *Mitterrand*

- 1180 : construction of a fortress along the river Seine by *Philippe-Auguste*
- 1546 : destruction of the fortress, construction of the first aisle of the future Cour Carrée by *François 1er*
- 1624-1670 : the Cour Carrée is completed by *Louis XIII* and *Louis XIV* ...
- 1852-1870: the Pavillon Richelieu and the Cour du Ministre (future Cour Marly) are constructed by *Napoléon III...*
- **1958-1962 : 1st general cleaning of the Louvre façades planned by *A. Malraux***
- 1984-1988 : “Grand Louvre Programme” and construction of the “Louvre Pyramid” ordered by *Mitterrand*. The Cour Marly is dedicated to the sculptures originally at the Marly Castle near Saint Germain and Versailles.
- **1985-1996 : 2nd general cleaning of the façades and statues**



2- Cour Marly:
Microclimate



1- Statue of Apollo:
Air pollution

Philippe-Auguste fortress

1 -The statue of Apollo: a record of the Parisian air pollution history

- In Carrara marble
- Dating from the middle of the 19th Century
- Exposed in a niche, *sheltered from rain*

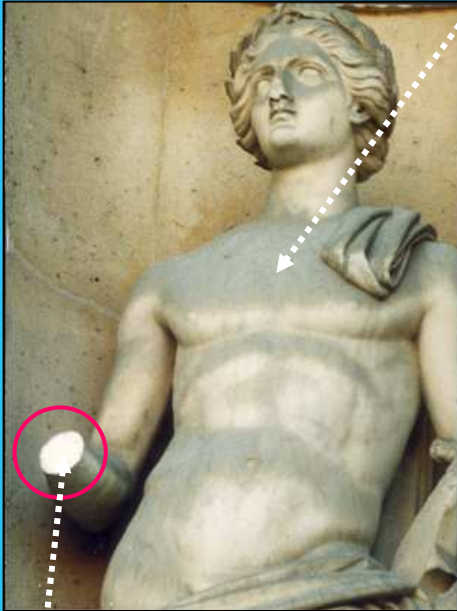
- 1985 : *white* because cleaned by dry sandblasting
- 1985 to 1994: turned to *grey* by dust deposition (soiling)
- 1994 : the right hand was broken by a vandal and found at the foot behind the statue



1994

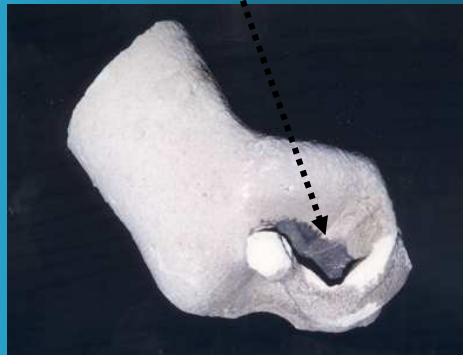
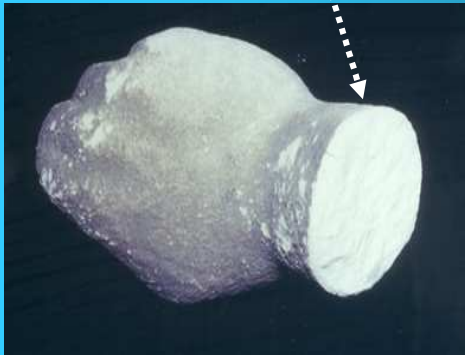
in 1994

...the surface of the statue is grey...



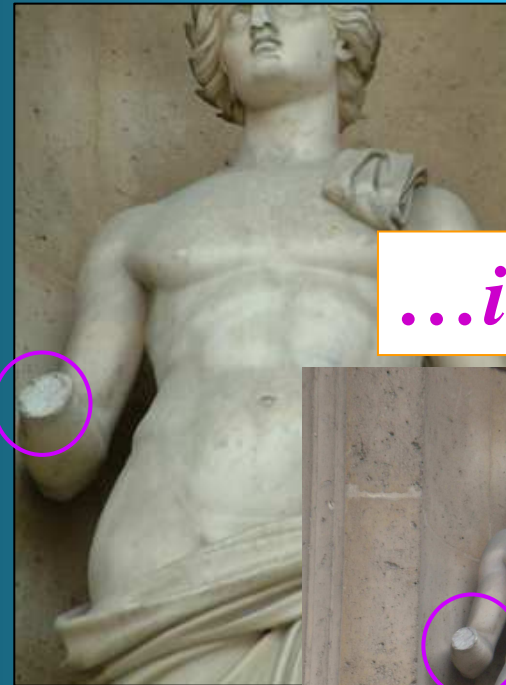
*... except the broken arm which is **white**...*

*... and the hollow of the hand, which is **black**...*

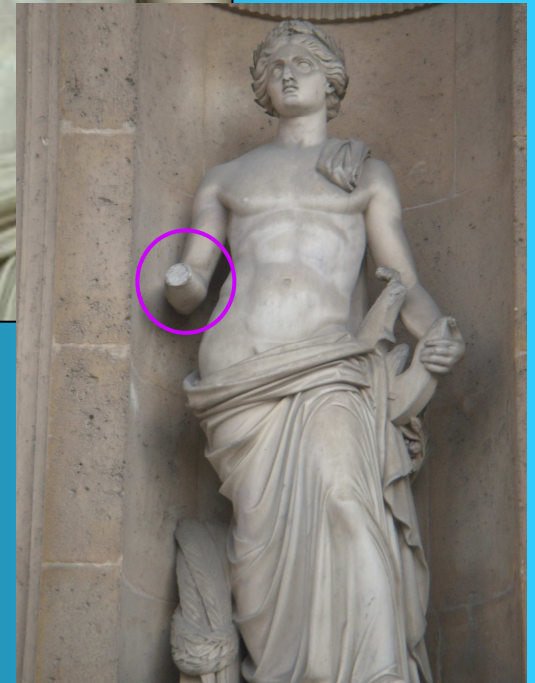


in 2004...

*...the section of the arm has turned from white to **grey** due to new dust deposition (soiling)...*



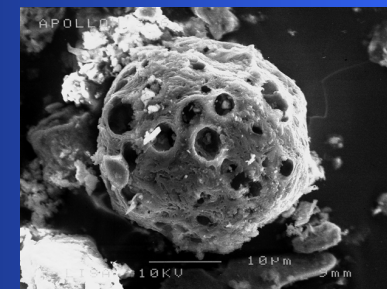
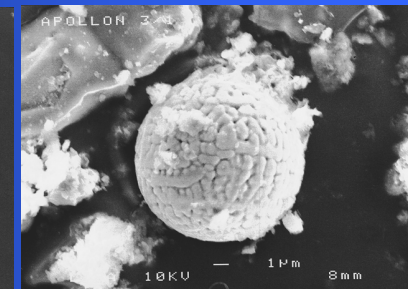
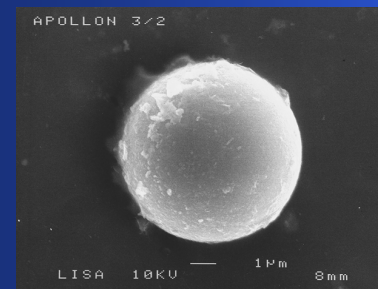
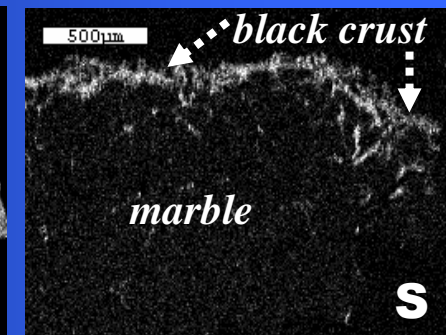
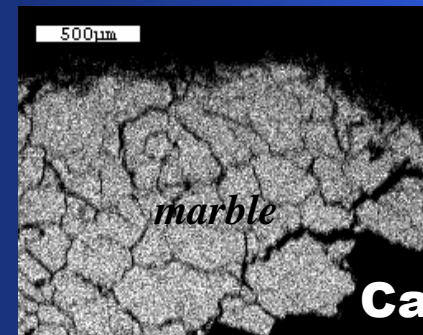
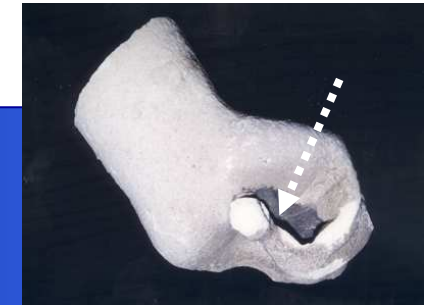
...in 2009



The black crust in the hollow of the Apollo's hand

Probably formed before the 1st cleaning (1962) or, less probably, between the 1st and the 2nd cleaning (1962 to 1985)

- 200 μm in thickness
- in gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) cementing particles
- containing numerous micrometric *fly-ash*:
 - *alumino-silicated* or *iron-rich* produced by **coal combustion**
 - *carbonaceous* and *spongy* produced by **heavy fuel-oil combustion**



The grey deposits on the arm section

Formed by dust deposition :

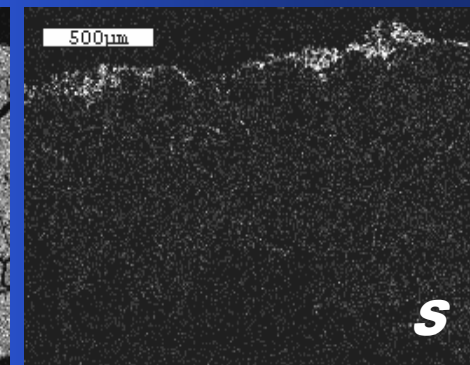
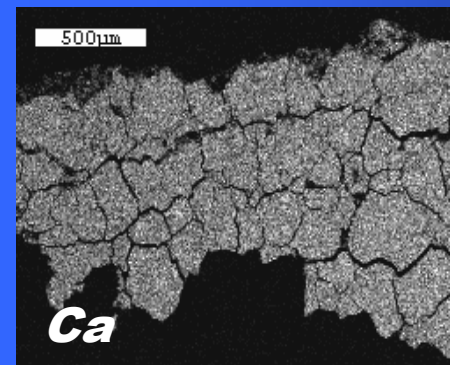
- on the entire statue after the 1st cleaning campaign (1985)
- on the broken section between 1994 and 2009



➤ Thinner than the black crust : 50 μm

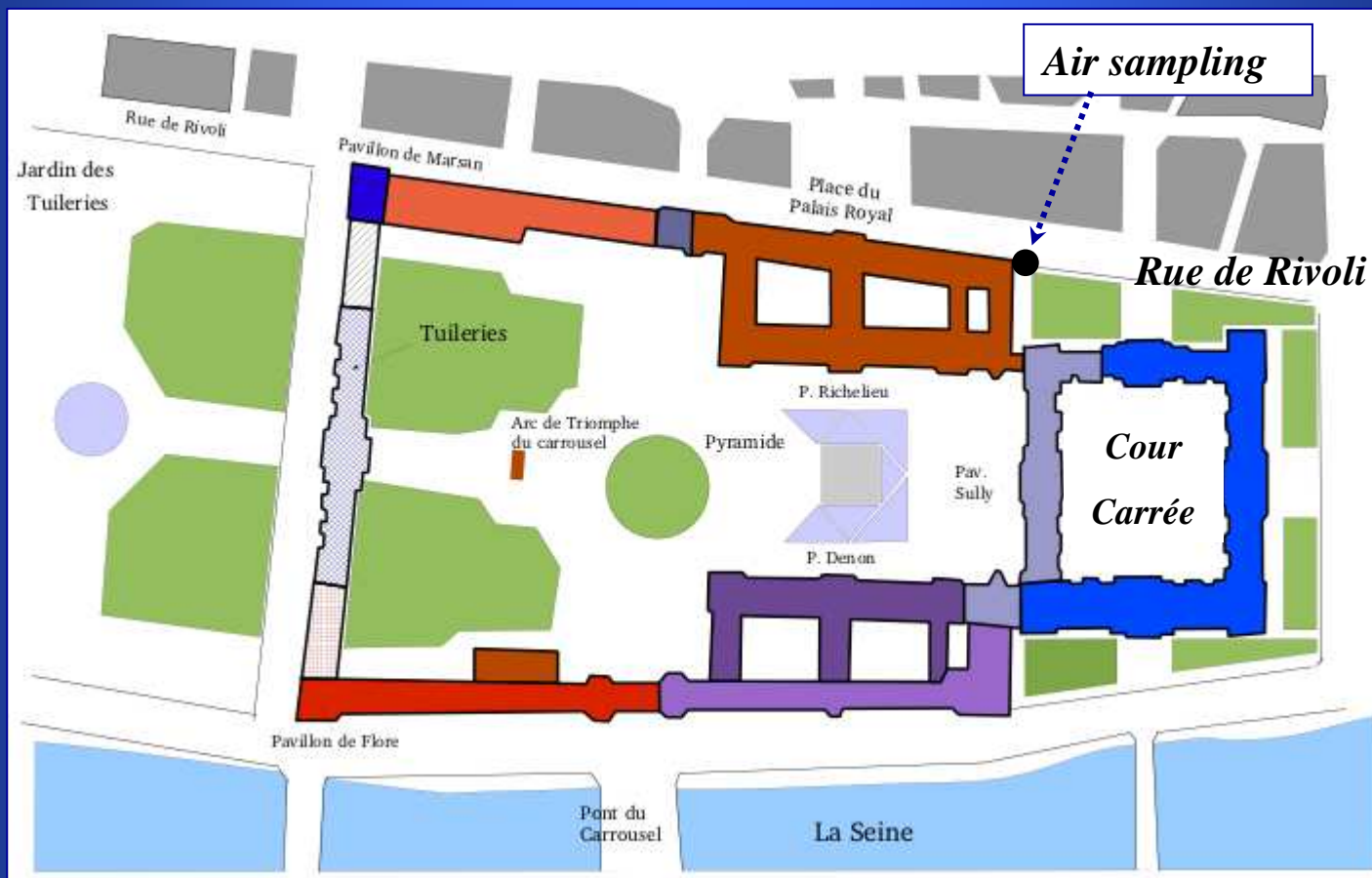
➤ $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ crystals

➤ Containing nanometric *carbonaceous soot*, present in the grey deposit and in the air



Sampling the air in the Louvre environment outside

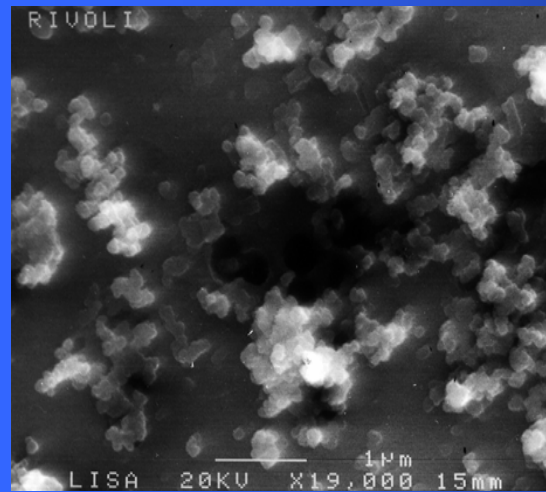
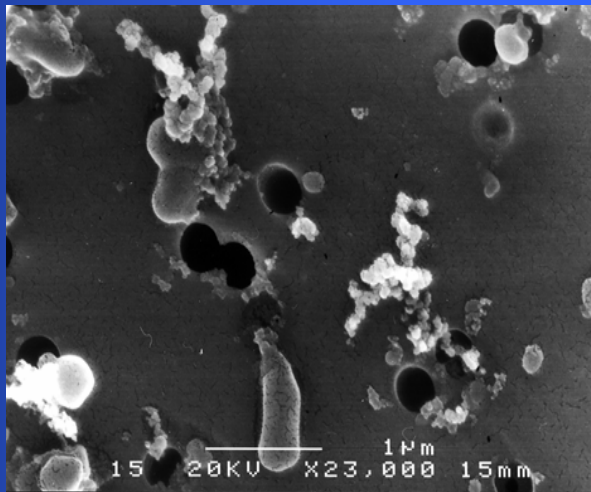
In 1994, the year of the breaking of the hand of Apollo statue,
a campaign of air filtration was performed rue de Rivoli,
outside the Cour Carrée



Particulate content of the air in the Louvre environment outside

Presence of numerous *carbonaceous soot*:

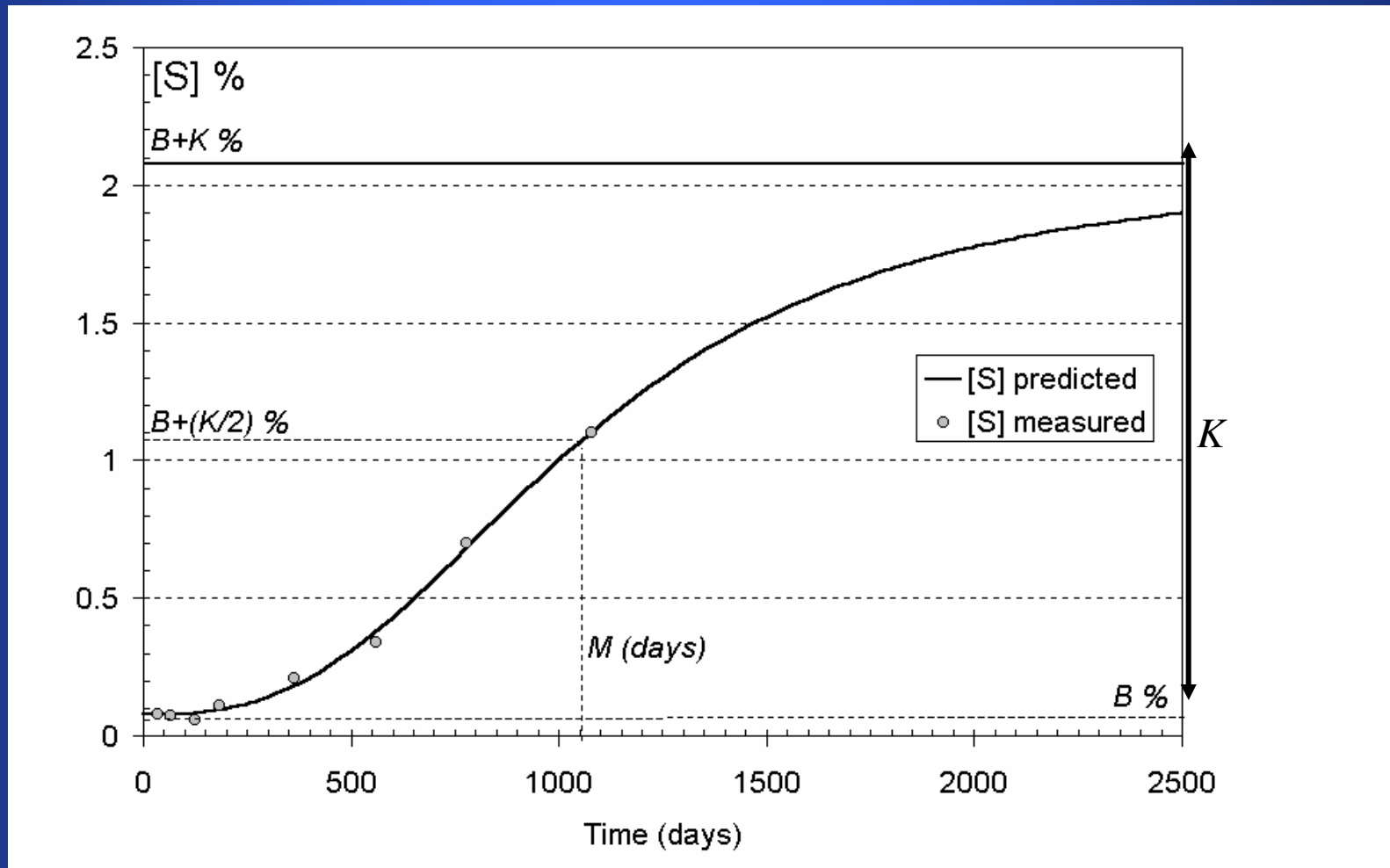
- individual spheres of 50 nm forming clusters of 1 to 15 μm
 - containing Sulphur
- emitted by combustion of light fuel-oil or gasoline in engines, or natural gas in urban heating system



That confirms the predominant contribution of *traffic* to air pollution in the last decades :

- less SO_2 and fly-ash
- more NO_x and fine carbonaceous soot

Modeling the evolution of the *sulphation* of the Parisian monumental limestones *under* their surface

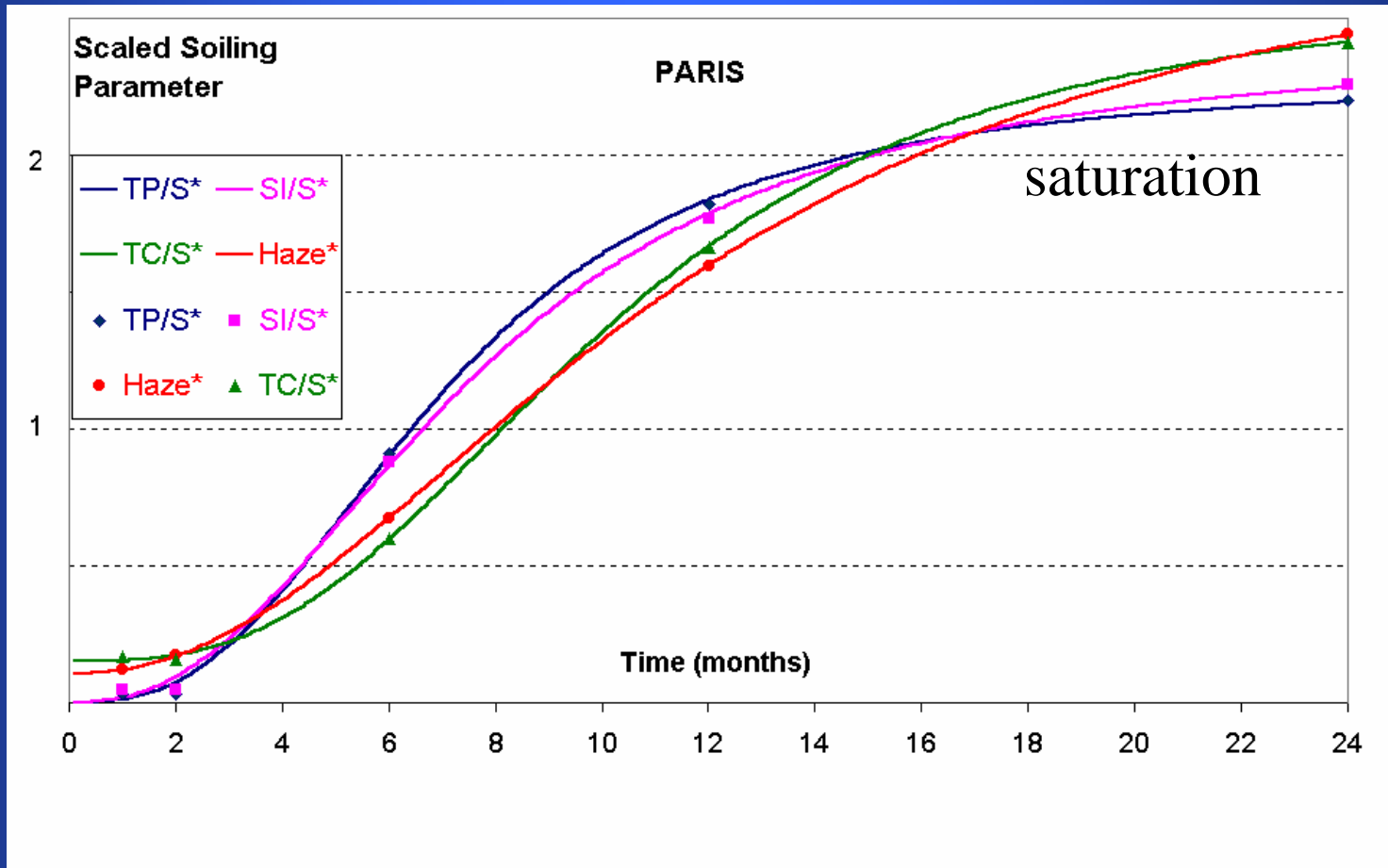


Hill model:

$$Y(t) = B + \frac{K}{1 + \left(\frac{M}{t}\right)^H}$$

$$[S]\% (t) = 0,08 + \frac{2}{1 + \left(\frac{1056}{t}\right)^{2.73}}$$

Modeling the evolution of the *soiling* of the monumental surfaces in Paris



Hill model:
$$Y(t) = B + \frac{K}{1 + \left(\frac{M}{t}\right)^H}$$

Soiling (t) = B +
$$\frac{26,16}{1 + \left(\frac{8,97}{t}\right)^{2,14}}$$

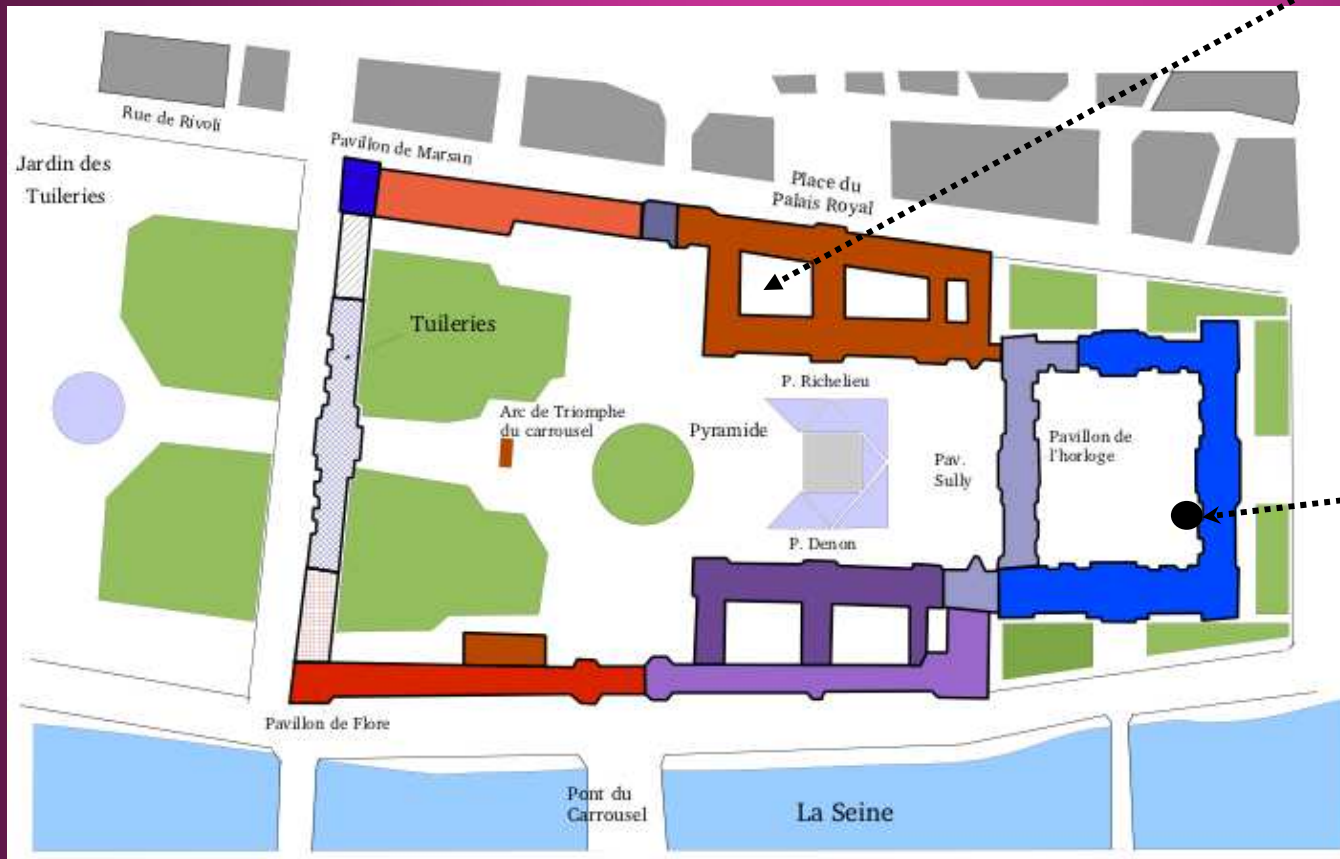
Conclusions concerning the statue of Apollo

1 - The particle content of the old black crust and of the recent grey deposits records the *changes in fuel used in Paris* :

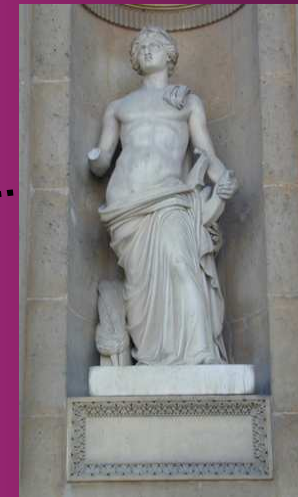
- *coal and heavy-fuel oil until the second half of the 20th century: micrometric fly-ash*
- *light-oil, gasoline and natural gas since the middle of the 20th century: nanometric carbonaceous soot*

2 - Sulphation and soiling reach *saturation* with time

2 -The microclimate in the Cour Marly



2- Cour Marly: microclimate



1- Statue of Apollo: Air pollution

The Cour Marly gathers the original sculptures ordered
by Louis XIV and Louis XV
for the Castle of Marly near Saint Germain and Versailles

The most famous sculptures are:

“Les Chevaux de Marly” by Coustou (1745)

“Les Chevaux ailés” by Coysevox (1702)

Nowadays *copies* are displayed around the Concorde Square
at the entrance of the Champs Elysées and the Tuileries Garden

The *Cour Marly*, open in 1993, has been covered with a *glass dome* designed by Peter Rice which creates a particular microclimate, with marked *daily* and *seasonal cycles*

The Cour is made in *three levels* and is connected through doors and windows to the Pyramid and the French Sculpture Department

Indoor temperature and humidity are controlled by air conditioning system

The Cour has *trees* that simulate the Marly Castle environment but stimulate *micro-organisms* growth which might infect the Museum

The Cour Marly in the Louvre

View from E to W



To the French Sculpture
Department

Air conditioned slits

View from W to E

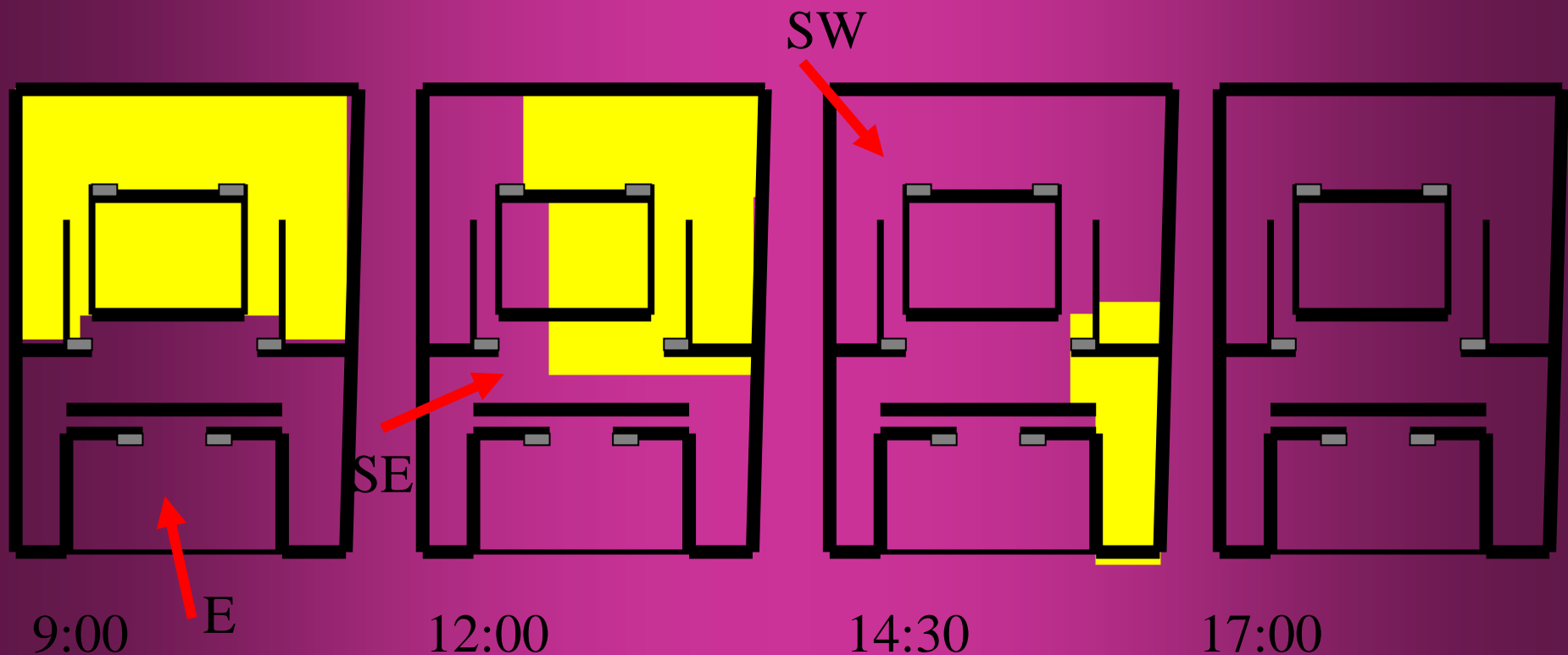


To the Pyramid

Air conditioned slits

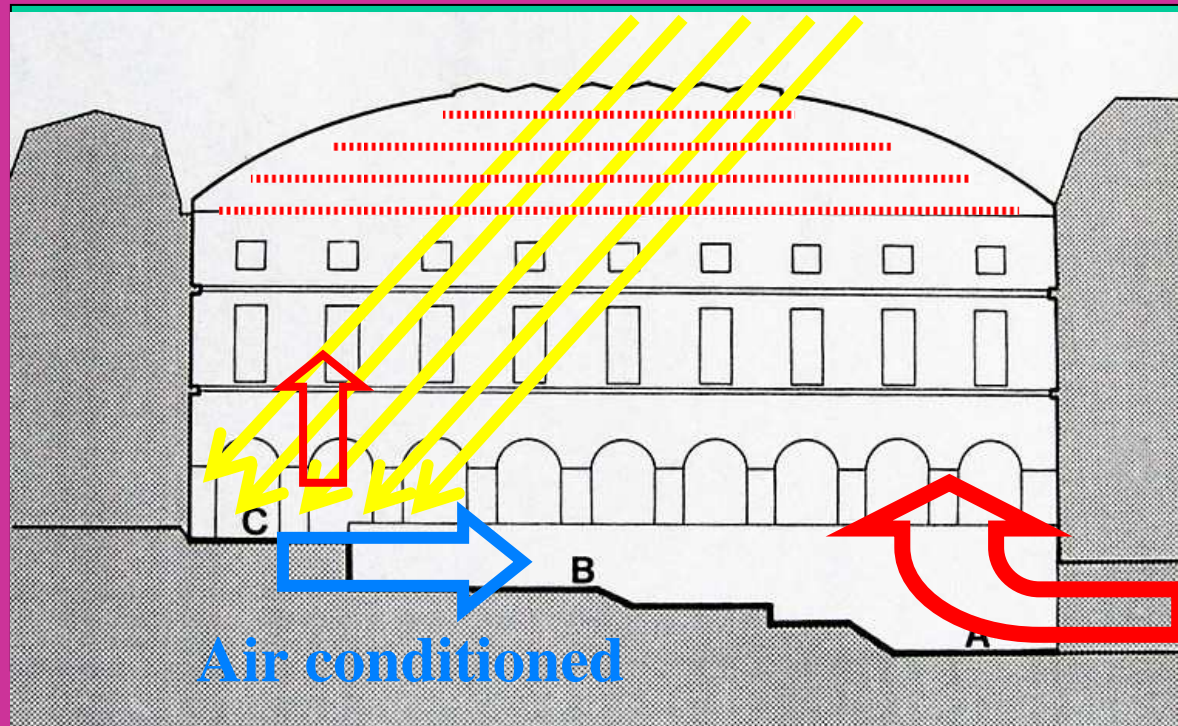
Solar radiation falling on the Cour Marly at Mid August

Solar beams calculated after astronomic formulae and the architectural shield of the building



In *summertime* and *by day*: **hot roof**

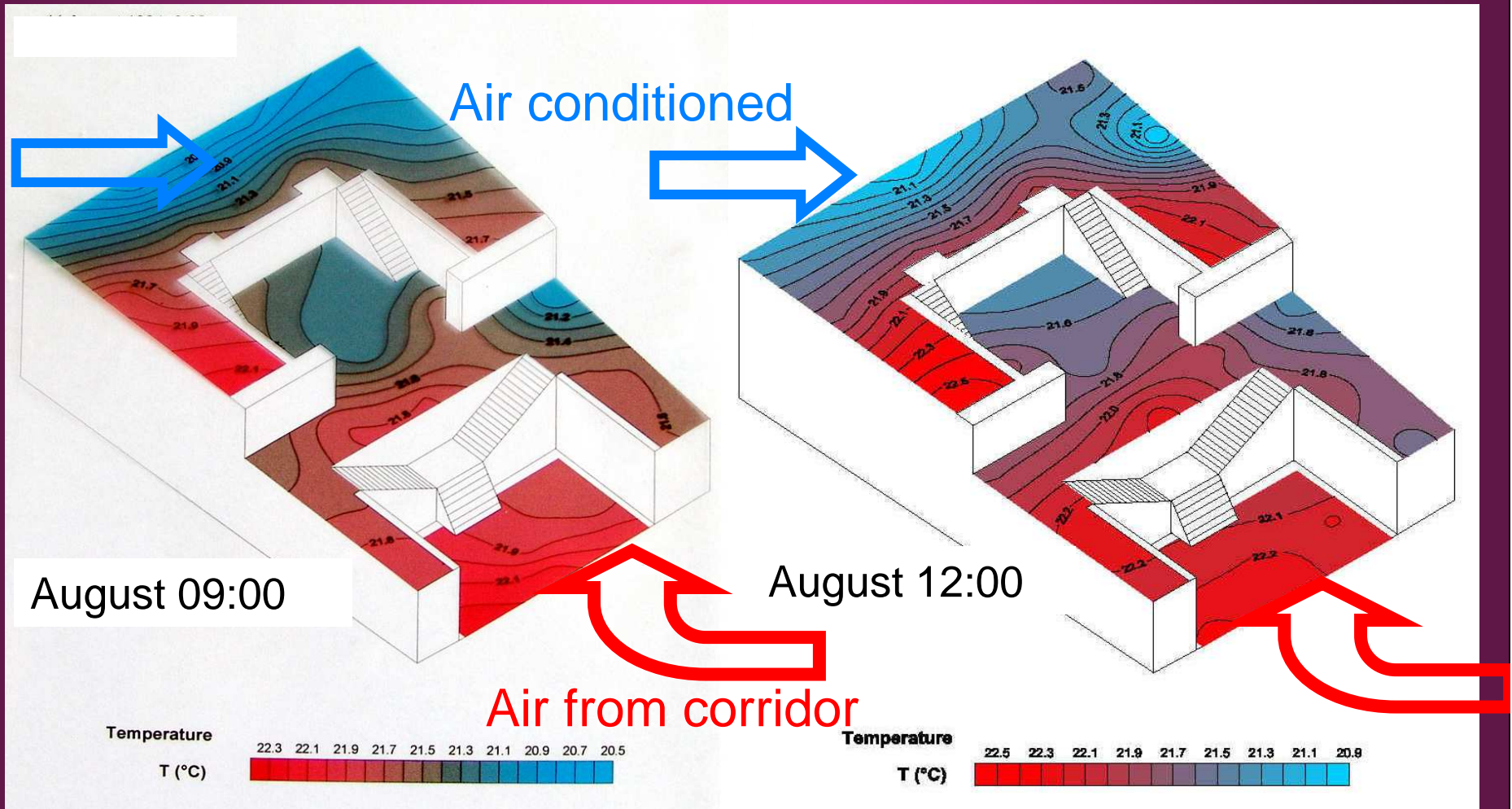
- greenhouse effect and air layering under the roof
- near the floor: air mixing



Hot air penetrates
by the corridor
from the Pyramid

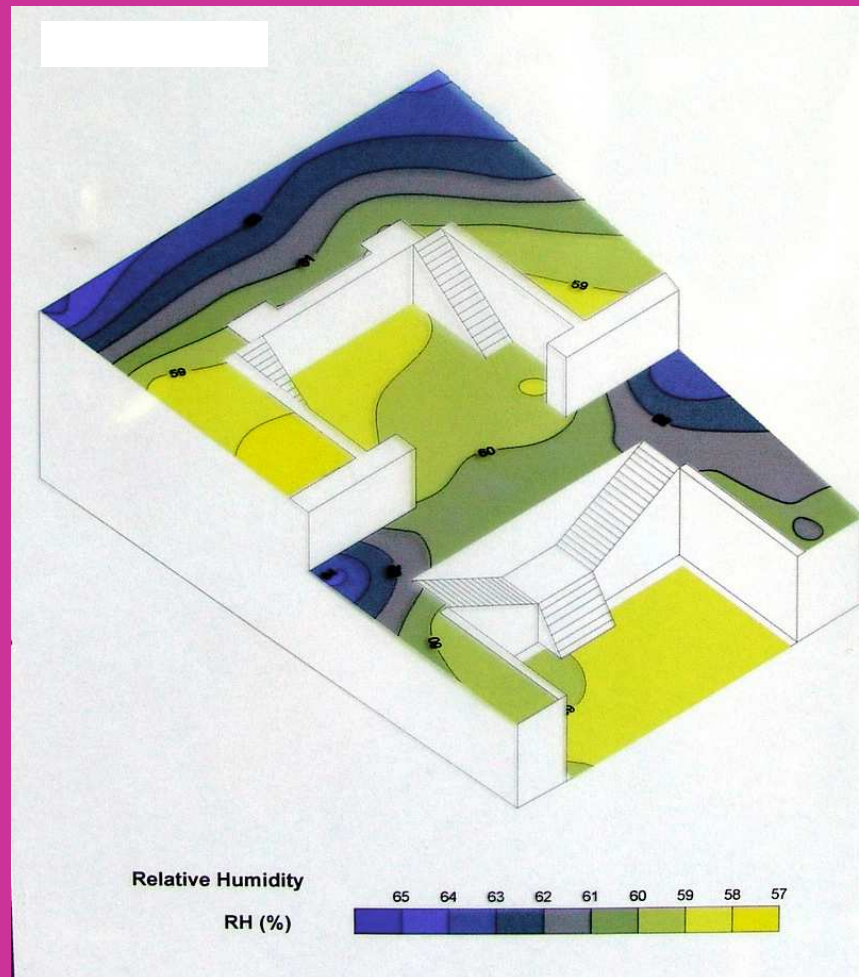
Temperature distribution on the floor *in summer*:

- Bottom level warmer than top level
- Very unstable situation
- But remains more or less the same from the morning to the evening



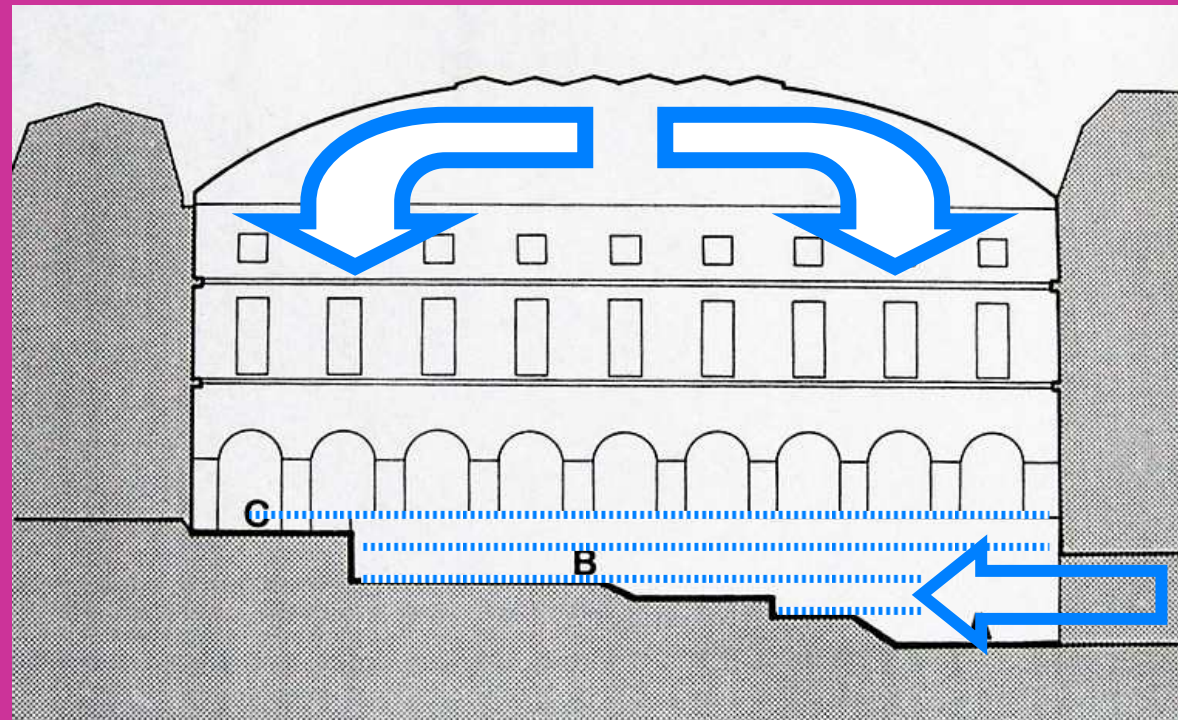
In Summer Relative Humidity is unbalanced

August 14:30



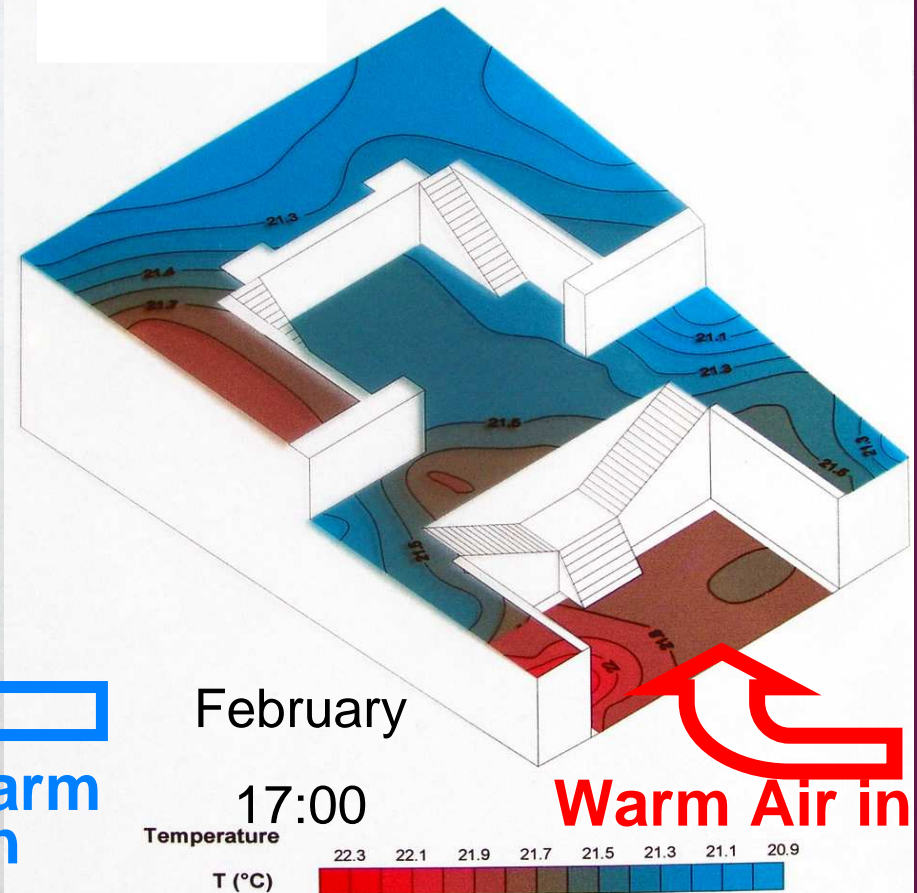
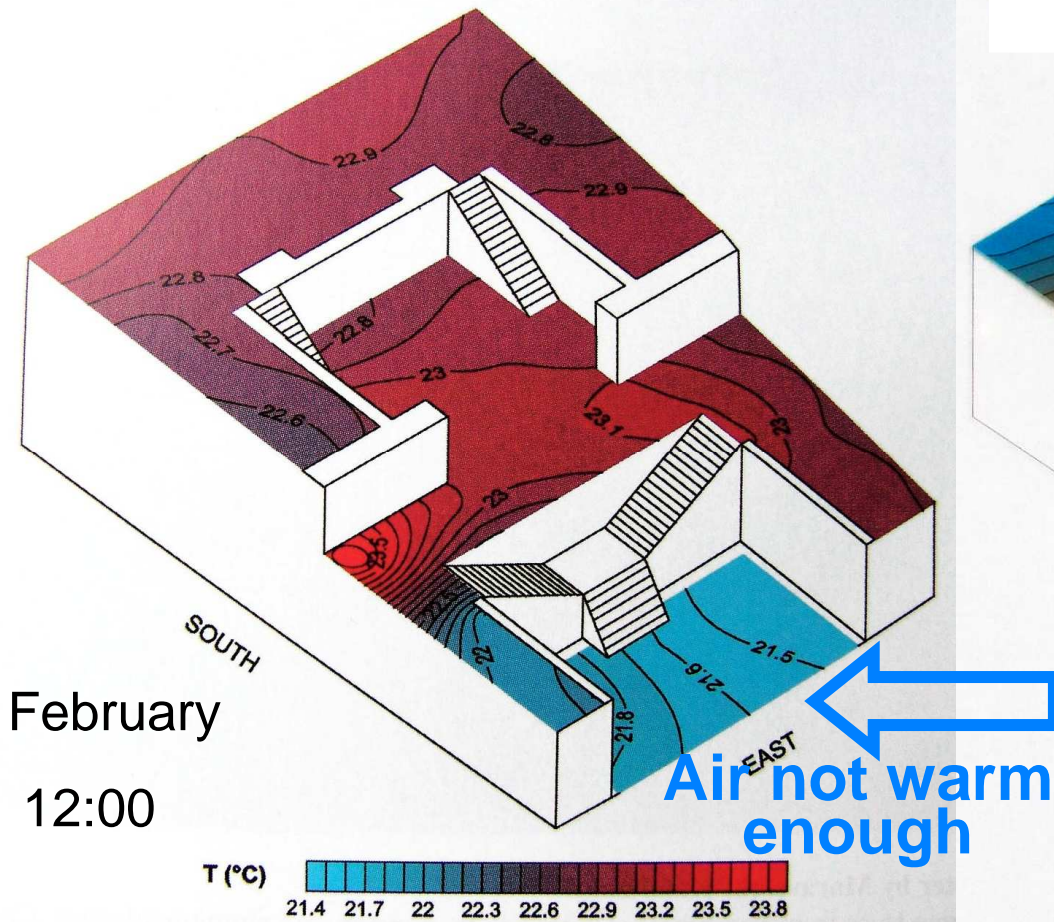
In *wintertime* and by *night*: **cold roof**

- Cold air layering on the floor
- Cold air sinking along walls.
- Cold air penetrates by the corridor



Temperature distribution on the floor *in winter* is singular:

- In the morning: bottom level cold and top warmer (normal)
- In the afternoon: situation radically changed by the rise of temperature in the corridor



Air particulate pollution in the Cour Marly

	Carbonaceous Particles		Non-Carbonaceous Particles		
	Nano-soot	Biological	Fly-ash	Gypsum	Sea-Salt (Halite, Sylvite)
Elemental Composition	C	C+P	Si + Al / Fe	Ca + S	Na/K+ Cl
SUMMER Cour Marly	+	+	+	-	-
Rue de Rivoli	++	++	++	+	-
WINTER Cour Marly	+	+	+	-	-
Rue de Rivoli	+++	+	++	+	+

Air particulate pollution in the Cour Marly: Conclusions

1-Different *types* of particles of different *origins* penetrate the Cour Marly:
anthropic, marine, continental, biogenic

- 2-They follow *cyclic trends*:
- daily and seasonal variations of *air pollution* (car traffic, domestic heating...)
 - *Seasonal biological cycles* (pollens, spores)

3-The weak penetration of fine and coarse airborne particles has proven the real *efficiency* of air filtration system

4-The transportation of external particles by *mass tourism* is negligible
(very low concentrations)

5-The sculptures are not in danger of rapid soiling

The risk from plants

Plants require humidity and fertilizers, i.e. the ideal habitat for bacteria colonisation.

Bacteria can eventually migrate, being transported and spread by air motions, and may infest other areas in the museum

Plants constitute a potential risk to conservation, which should be carefully and regularly controlled



The top level and some trees



The top level and the French Sculpture Department

Cour Marly microclimate: Conclusions and perspectives

Although the indoor microclimate is controlled in both temperature and humidity *it varies daily and seasonally* being mainly forced by 4 factors:

1-*Solar radiation and nocturnal cooling* from the glass ceiling

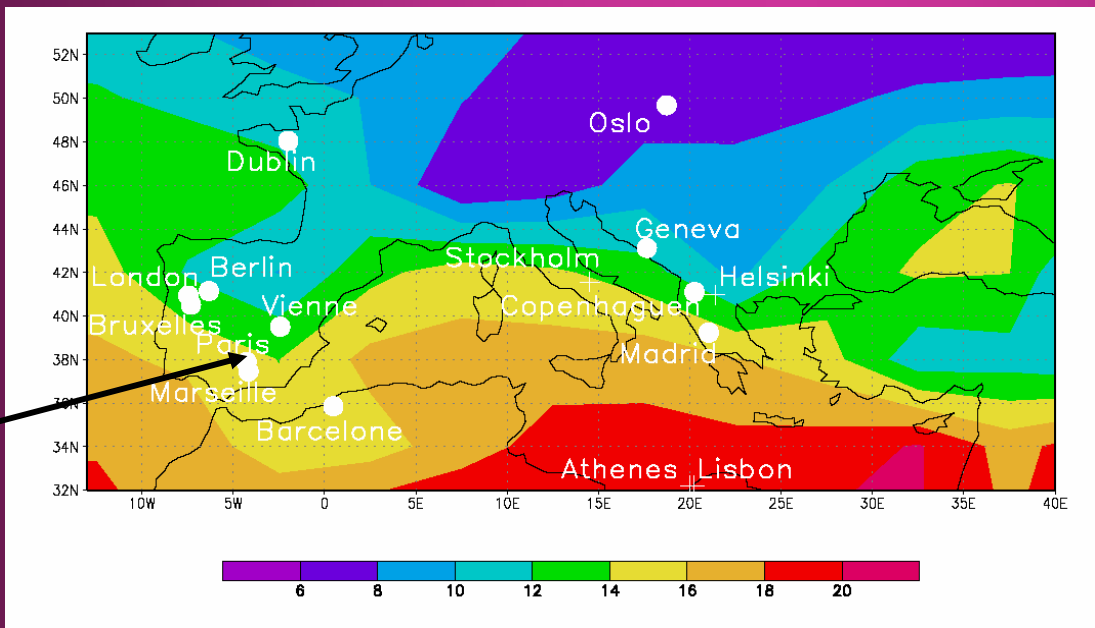
2-*Inflows of treated air from the climatisation intakes*

3-*Exchange of air* through the 4 doors connecting the bottom level to the *Pyramid area*

4-*Exchange of air with the Mediaeval Sculpture Department* at the top level

...But this situation might be in evolution due to climate change scenario

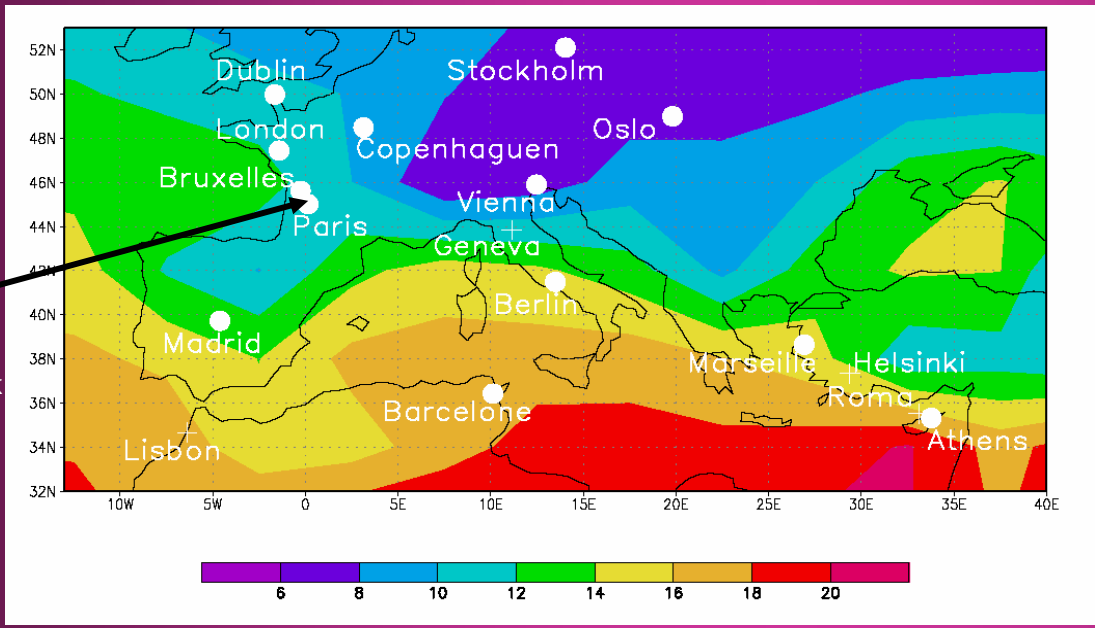
The future climate of Paris according to two climate models



*Hadley Centre Model, HadRM3H,
Scenario A2
in 2070*

Paris
=Cordoba

Background: mean annual temperature in the present climate



*Météo-France Model, Arpège,
Scenario A2
in 2070*

Paris
=Bordeaux

Thanks for your attention

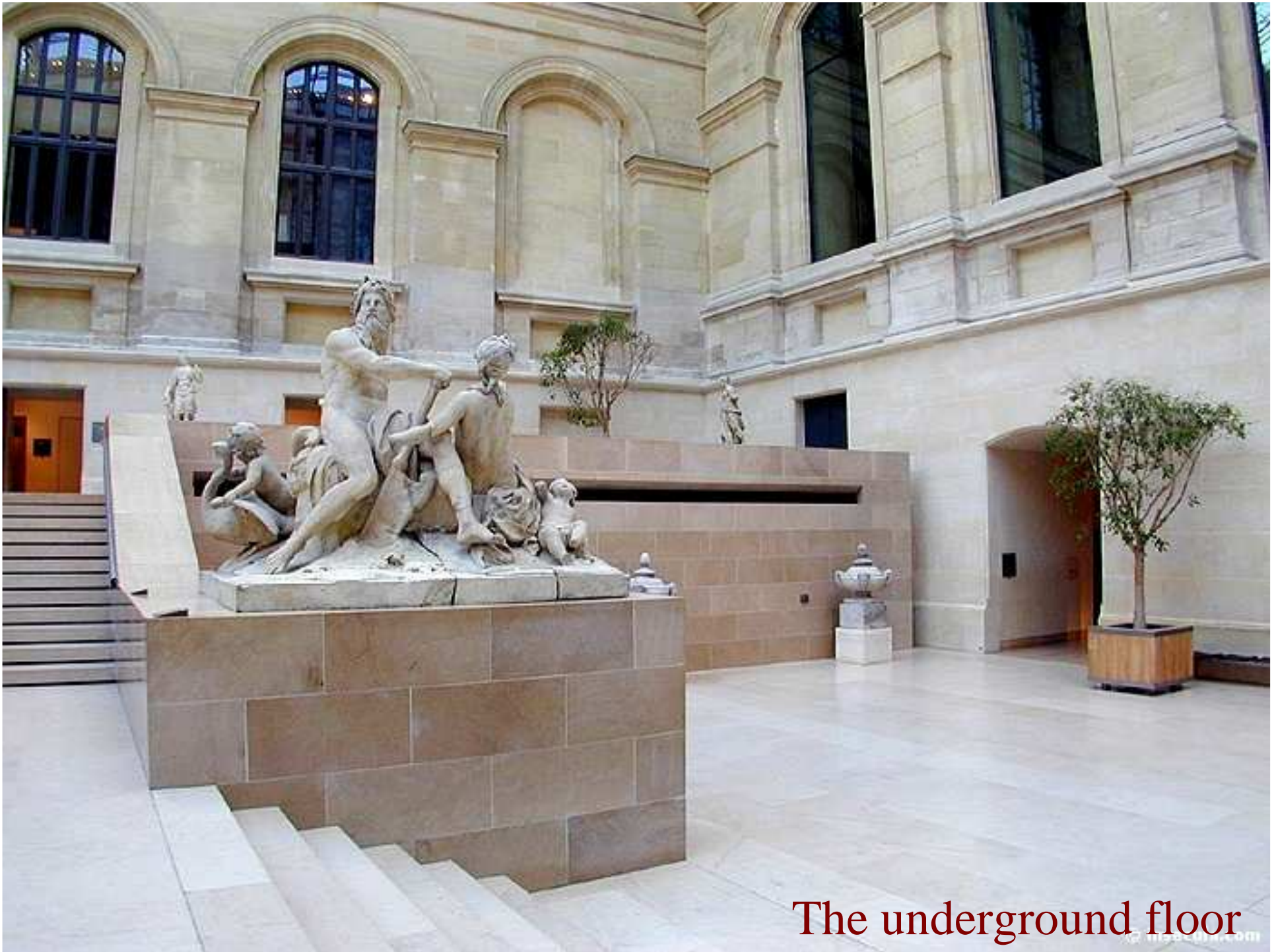




The top level and the French Sculpture Exhibition



The Mid floor



The underground floor



The underground floor



The Mid floor

1 – The statue of Rigaud

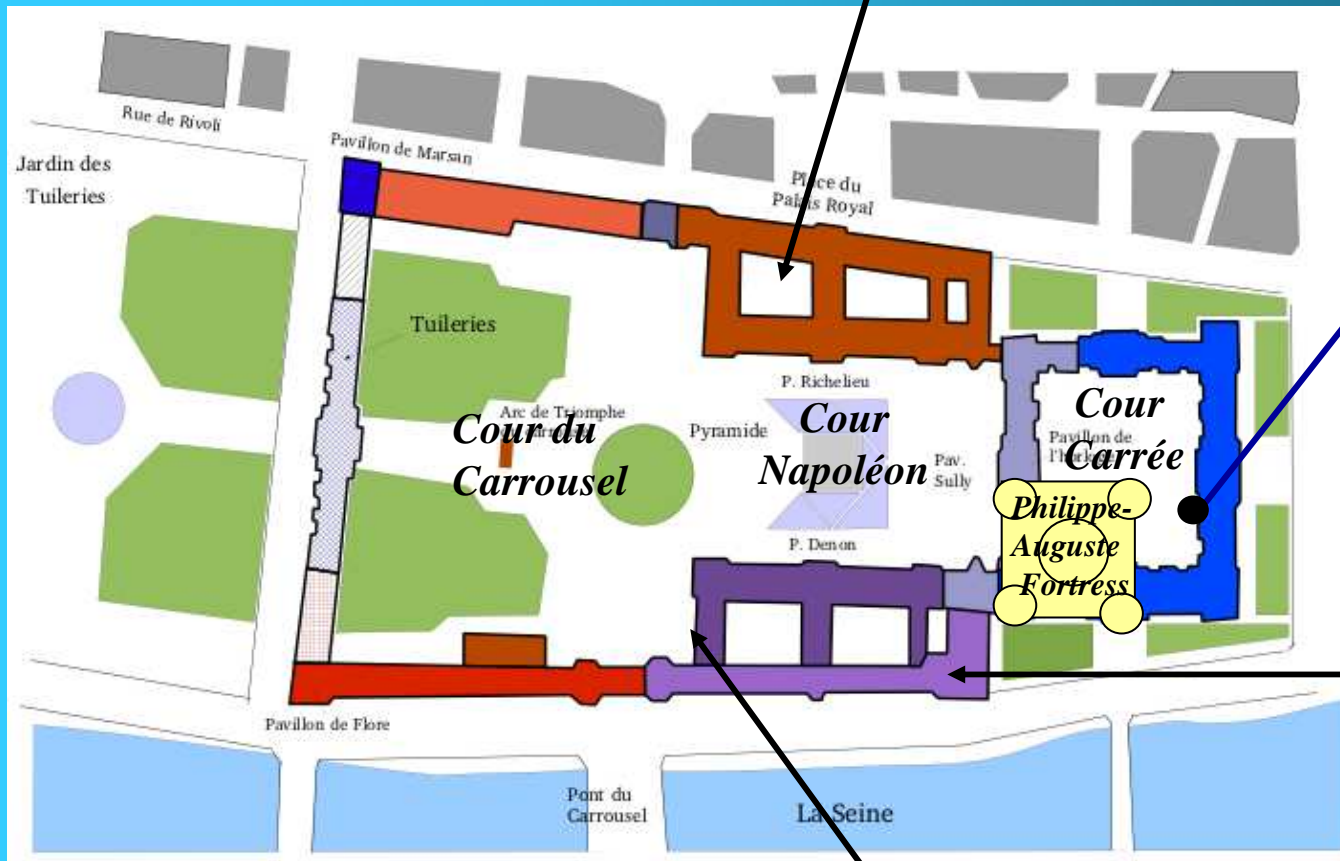




3- Cour Marly



2- Statue of Apollo



4- Salon Carré



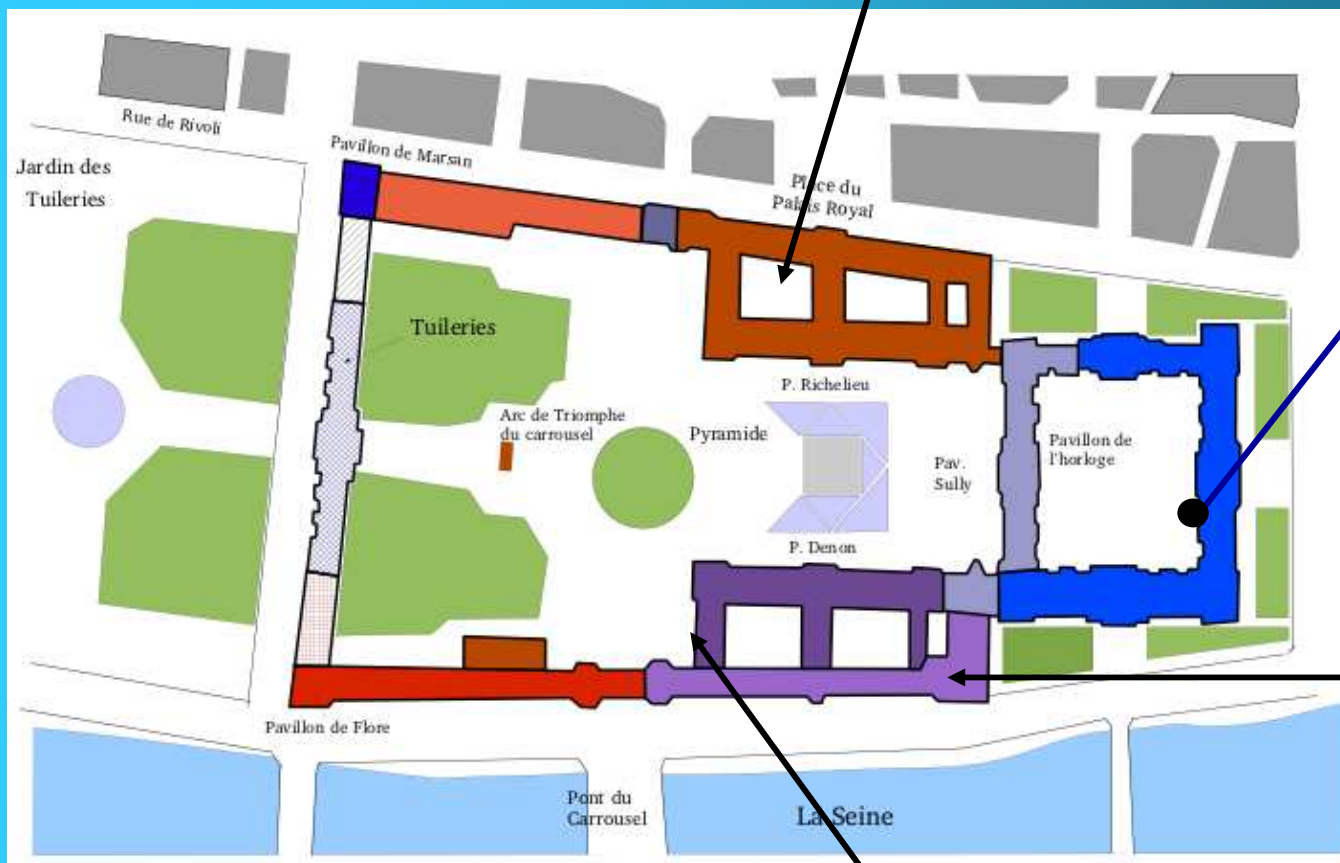
1 - Statue of Rigaud



4- Cour Marly



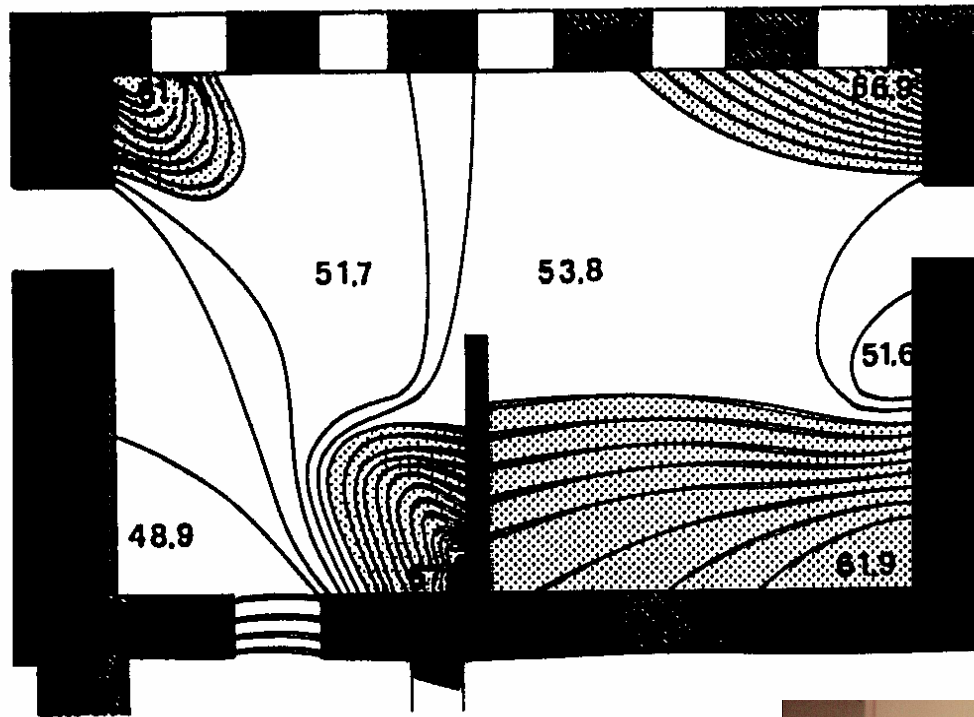
2- Statue of Apollo



3- Salon Carré

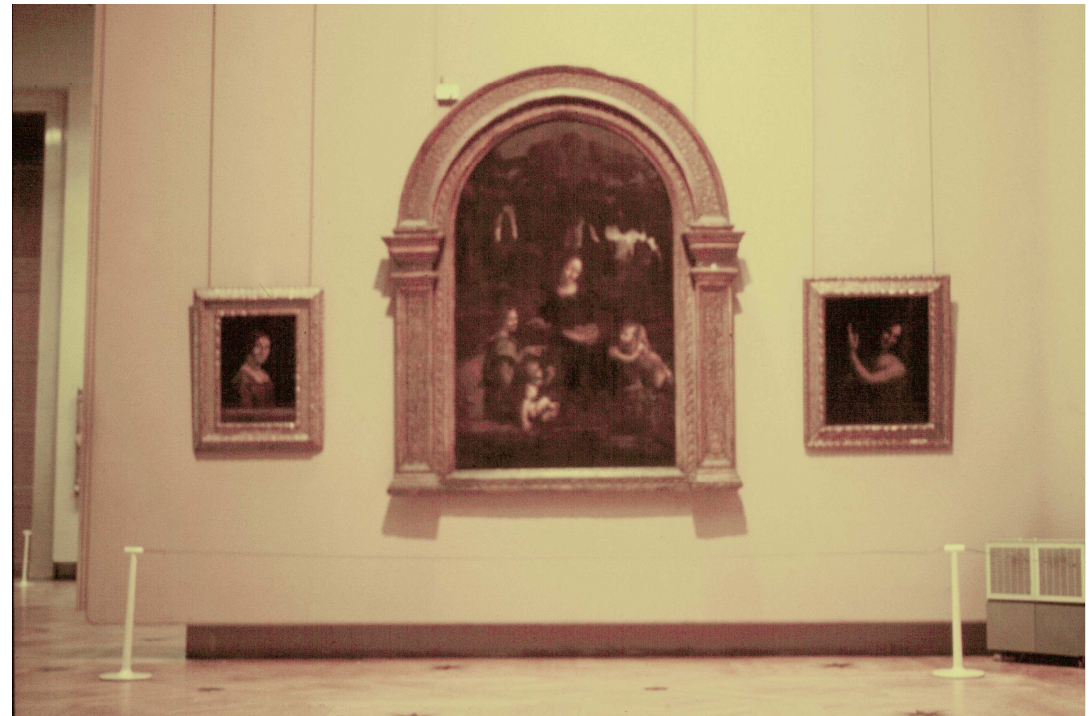


1- Statue of Rigaud



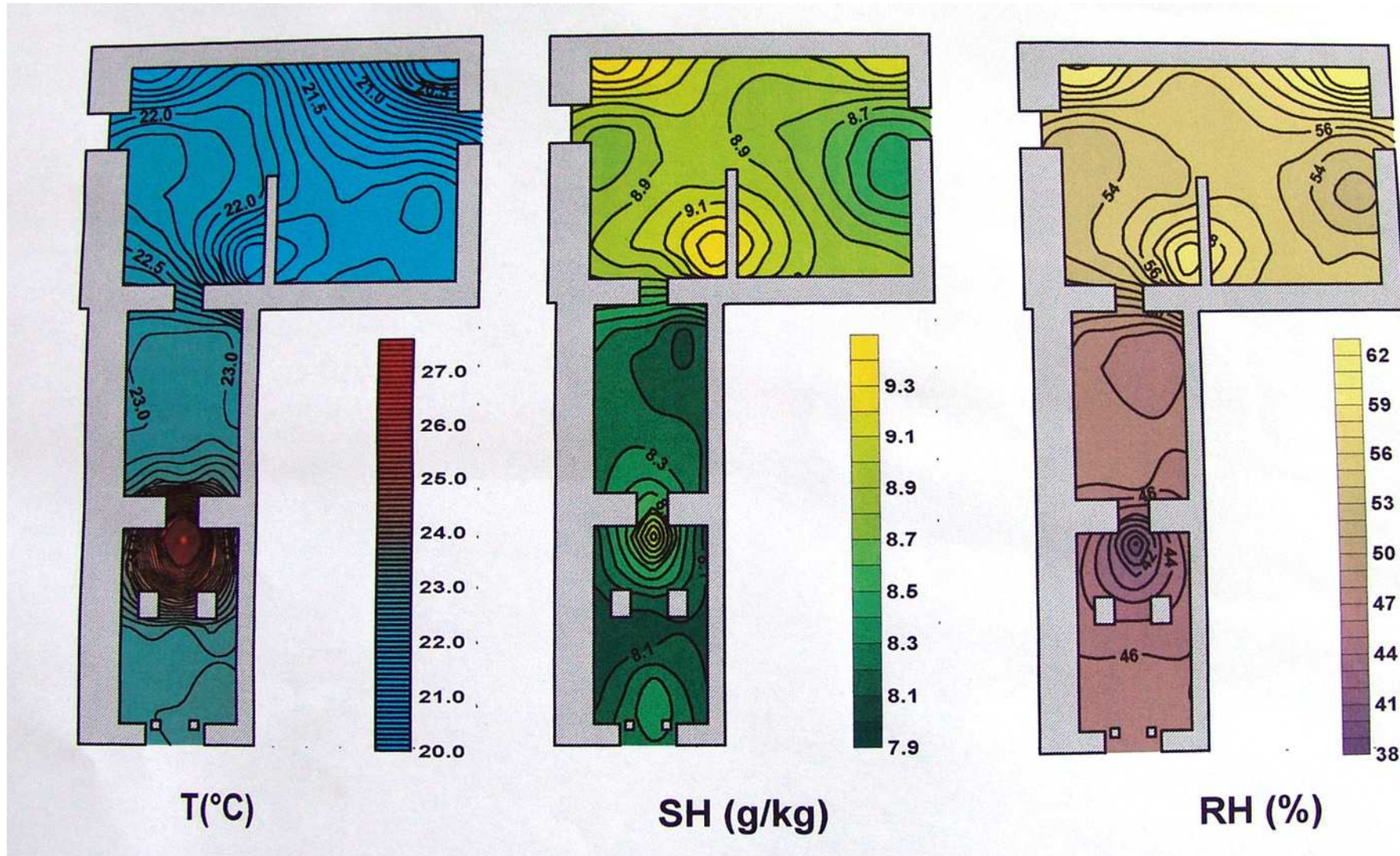
Humidifiers supply moisture to the entire room. **They form clouds of vapour which moist artworks, and dissipate after operation.** These cycles are repeated several times every day

Humidifiers should not be placed near paintings because fluctuations in moisture concentration will damage artworks.



The Aisle Denon and Salon Carré

21 February 1995, h 09:30

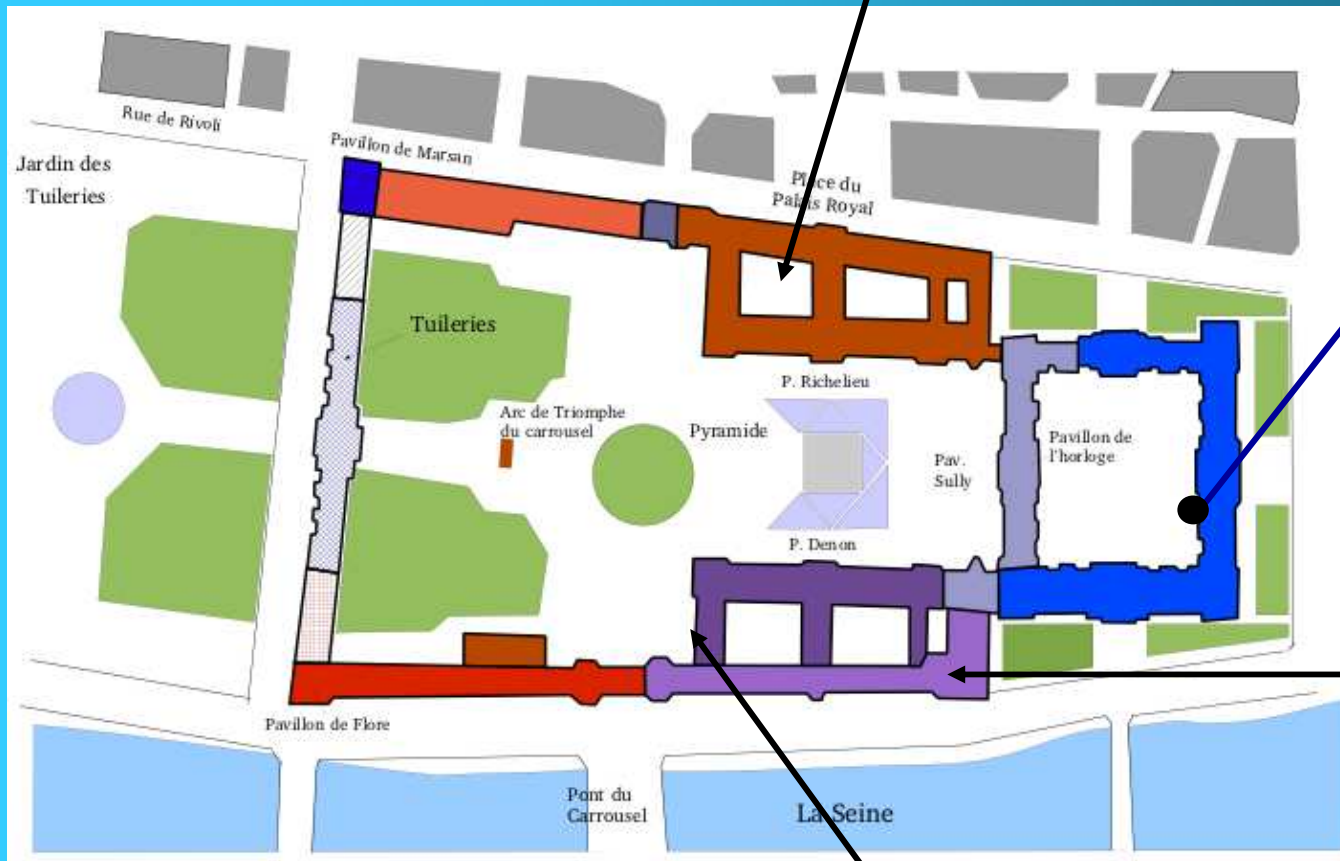




2- Cour Marly



2- Statue of Apollo



4- Salon Carré



1- Statue of Rigaud

La Cour Marly

Un grand nombre de sculptures extérieures sera déplacé dès la fin des années 1710, notamment aux Tuileries. La dispersion se poursuivra au cours de la Révolution et jusqu'au début de l'Empire. La plupart des oeuvres exposées dans la cour Marly proviennent de ces terres d'accueil. Nombre d'entre elles prélevées aux Tuileries, ainsi que les Chevaux de Marly, ont été remplacées par des moulages après leurs déplacements.

La nouvelle cour, inaugurée en 1993, offre un éclairage naturel grâce à une verrière conçue par Peter Rice.



Statues brought in in the past have preserved their
black crusts with pollution particles generated
centuries ago









Long-term forecasting of weathering: the impact of climate change

Application of the Dose-Response Function method:

$$\textit{Soiling} = (0,184.[SO_2] + 0,094.[PM_{10}] + 0,212.[T^\bullet] + 0,017.[HR]) / (1 + (245/t)^{1,3})$$