Monitoring the impact of microclimate on panel paintings

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Acknowledgements

For the Mona Lisa study:
Joseph Gril, Elisabeth Ravaud, Jean-Christophe Dupré, Patrick Perré, David Dureisseix, Olivier Arnould, Paolo Dionisi Vici, Daniel Jaunard, Patrick Mandron, Bertrand Marcon, Julien Colmars, …

For the Beato Angelico study:
Paolo Dionisi Vici, Paola Mazzanti, Linda Cocchi, Damiano Zazzeri, Magnolia Scudieri, …

Content of this presentation

- Main objectives of this presentation
- Constraints for monitoring original Panels
- Monitoring the “Mona Lisa” (Louvre, Paris)
- The Deformometric Kit
- Permanent, transient and steady-state deformations; hysteresis
- Monitoring the Beato Angelico’s panels in San Marco Museum (Florence, Italy)
- Results from monitoring: micro-climate, deformations of the wooden support, relationships between them, hysteresis
- Conclusions

Main objective of this presentation

To inform about some experiences carried out to monitor the actual dynamic behavior of the wooden support of original Panels placed in their usual exhibition location during a long monitoring period (years) as caused by the fluctuations of surrounding microclimate (T, RH)

Expected main outputs of this kind of studies

To analyze the behavior of individual supports, in order to:

- provide bases for evaluating the impact of climate on their conservation
- help making decisions for future restoration interventions

To provide reference data for calibrating and validating numeric models

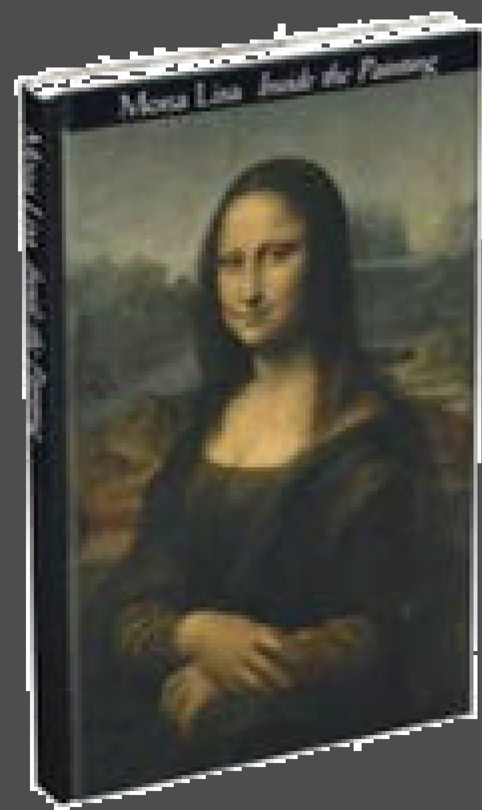
Constraints in monitoring original panels

- No interference with the public observing the artwork
- No damage to the artwork
- Accessibility to the artwork, for installation of equipment and for downloading data
- Acceptable cost (money, time, …)

Monitoring the "Mona Lisa"

This still ongoing study is led by Joseph Gril (several of the following slides are based on his work)

- The panel's structure and geometry
- Questions asked by the Curators
- Chronology of the study
- Measuring the panel's properties
- Monitoring the panel's behavior
- Modeling the action of the frame
- Outcomes and comments



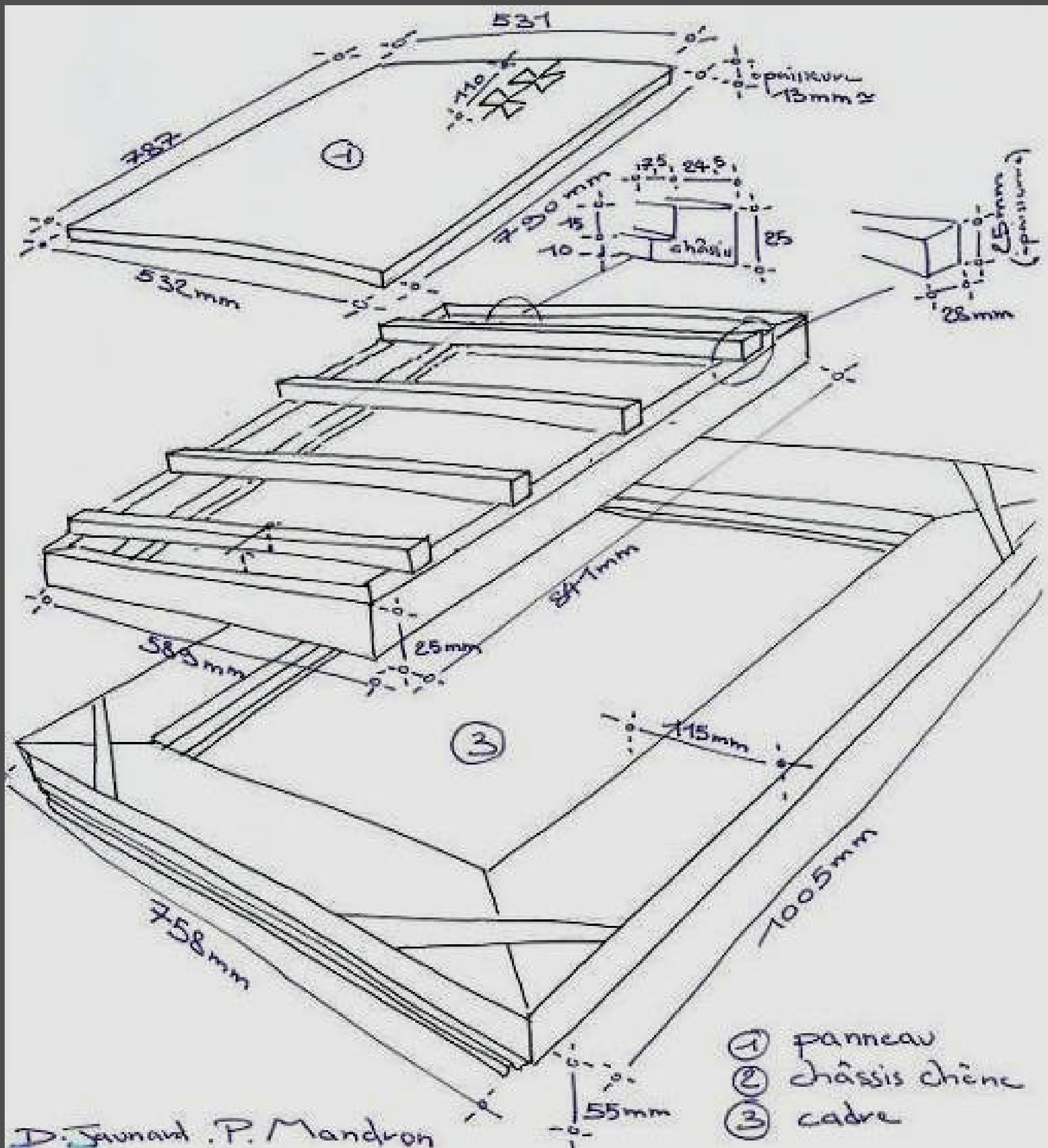
Mona Lisa: Inside the Painting, J.-P. Mohen et al (eds), Abrams, N.Y., 2006

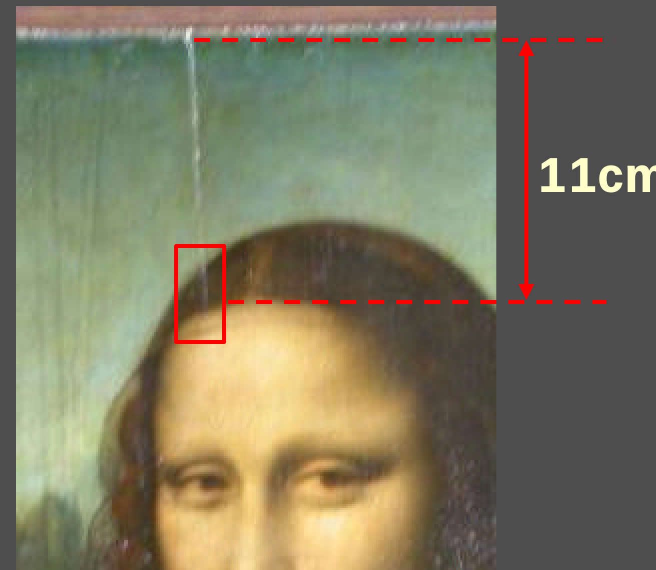
The Panel's structure and geometry

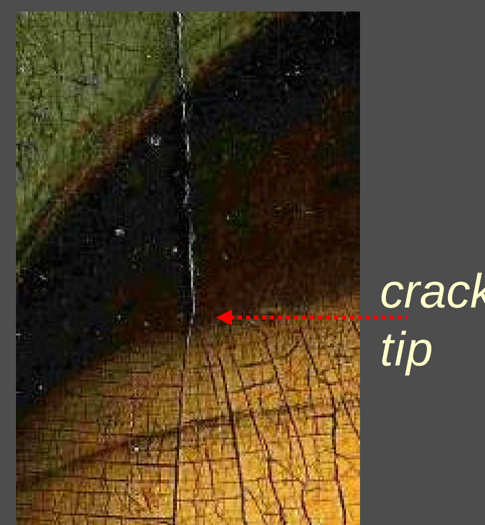
The "Mona Lisa" is painted on a panel of Poplar (*Populus alba* L.) ~79 x 53 cm, ~ 13 mm thick, which (see the following slides):

- features a complex double curvature, resulting from the mechanical constraints and the compression set
- is affected by a ~11 cm-long crack, older than the cracquelure, running through the whole thickness, having influenced the pattern of permanent curvature
- is inserted in an Oak frame ("châssis-cadre"), and is slightly forced against it by means of four cross-beams, which hold it flatter than it would be if unconstrained

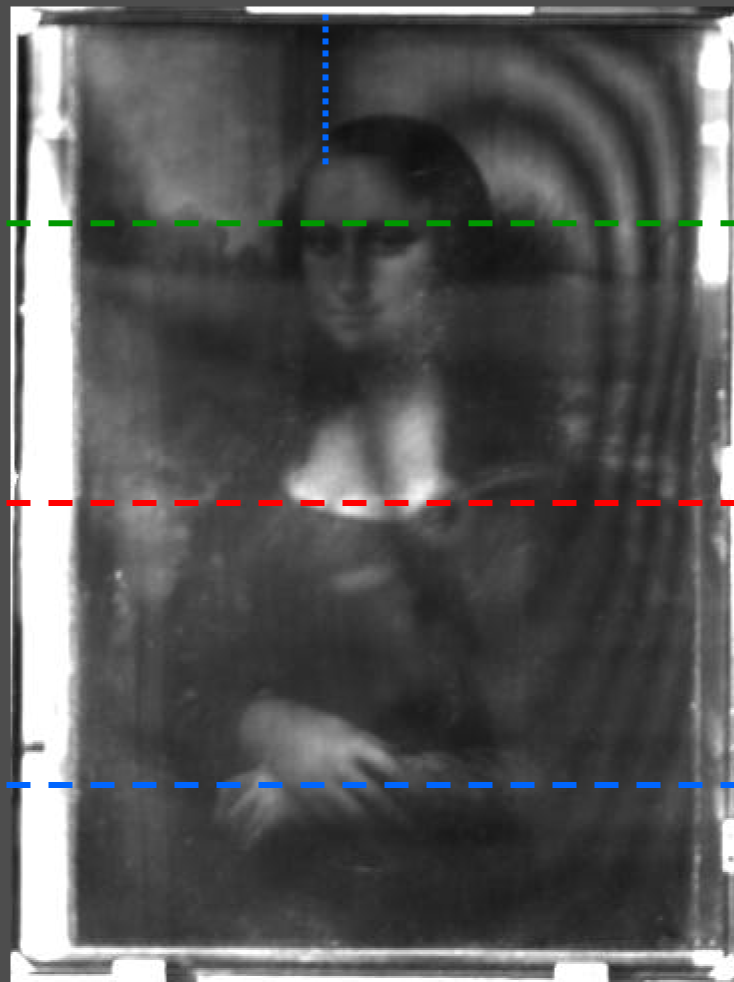
The frame, the wooden panel and the crack



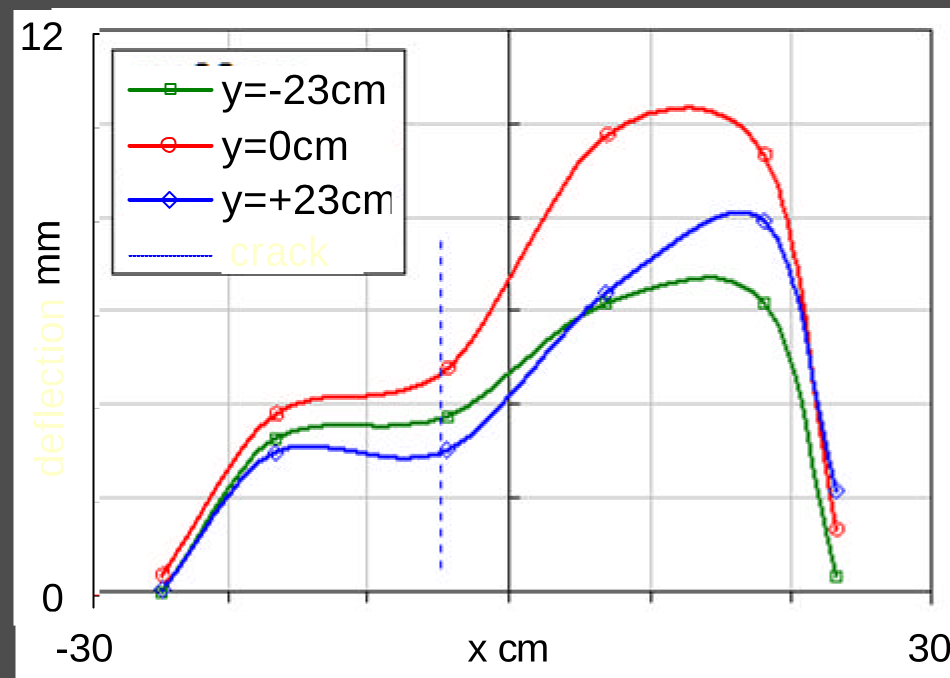




The shape of the panel



Observation of the surface topography by means of the "Shadow Moiré" technique



Three profiles of the panel, as measured manually by means of a comparator

Note:

- the double curvature
- the relationship with the crack

Questions asked by the Curators (2004)

- Evaluate climatic specifications for the new display case
- Assess the risk of crack propagation
- Suggest possible modifications to the frame
- Improve the follow-up procedure (the display case gets opened yearly, to check the conditions of the painting)

Chronology of the study

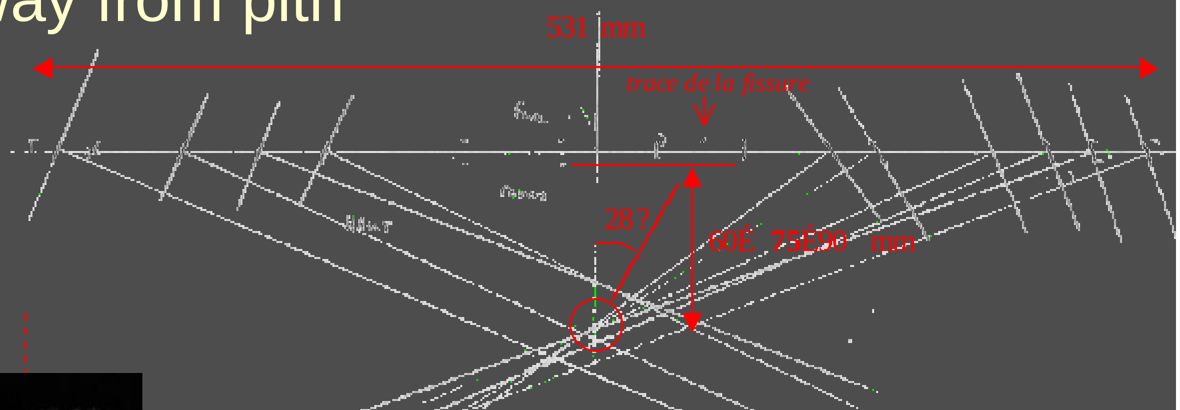
- October 2004 ~ April 2005: Observation of wood structure, evaluation of boundary conditions, setting up of techniques and equipments for manual and automatic measurements
- December 2006: Improved equipment for automatic monitoring
- Every year since 2005: the group is present at the opening of the display case, and performs manual measurements, data download, etc.
- 2006: Book is published “Au coeur de la Joconde” –“Mona Lisa: inside the painting” – “Im Herzen der Mona Lisa“
- Since 2005: computer modeling investigated in increasing depth

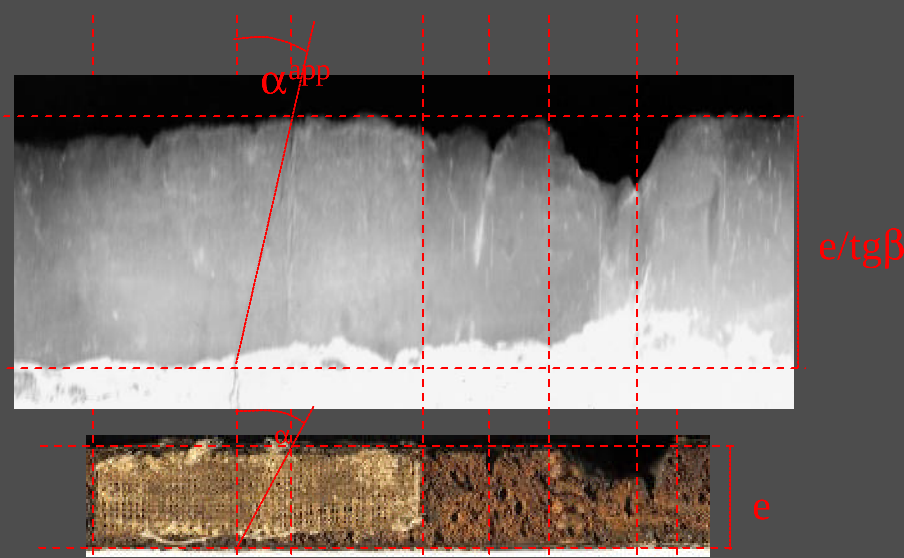
Collecting data about wood structure

Orientation of grain and rings:

- flat sawn, 5~10cm away from pith
- rather straight grain

Crack follows LR plane





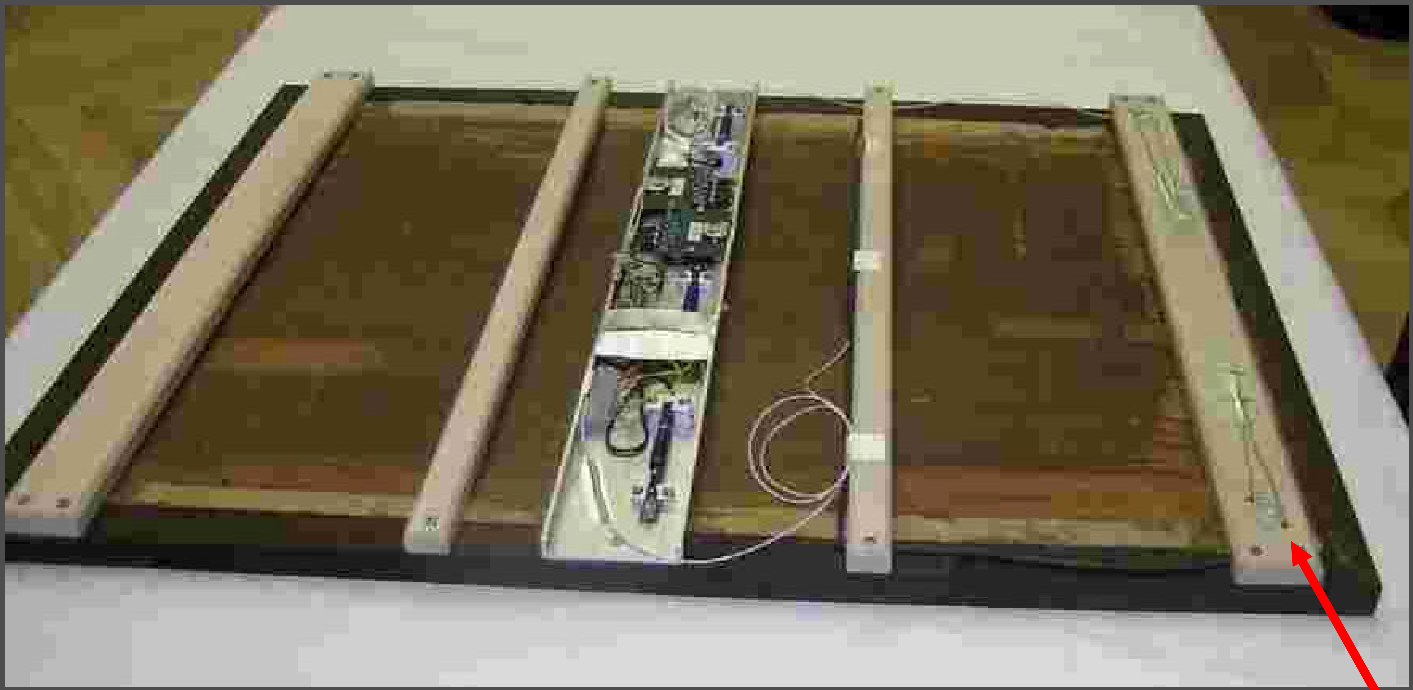
Measuring the panel's properties

Manual measurement of deflection

weight → density → 3D rigidity tensor

Manual measurement of force between panel and cross-beams

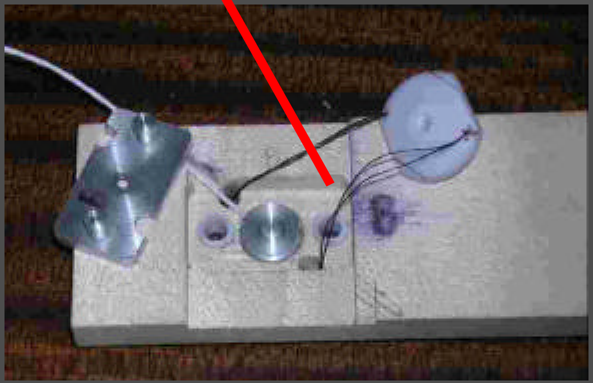
Monitoring the panel's behavior



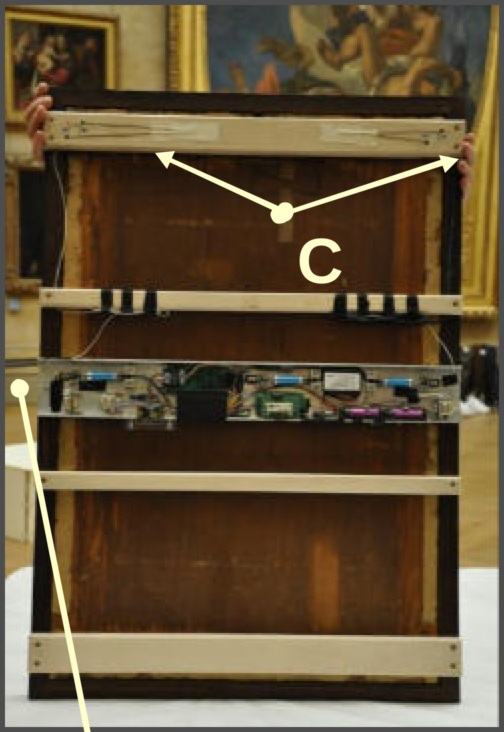
New cross-beams and Aluminum crossbar (max 15 mm thickness) ...

Continuous monitoring (recording every 20 mins) of deflection, forces, humidity...

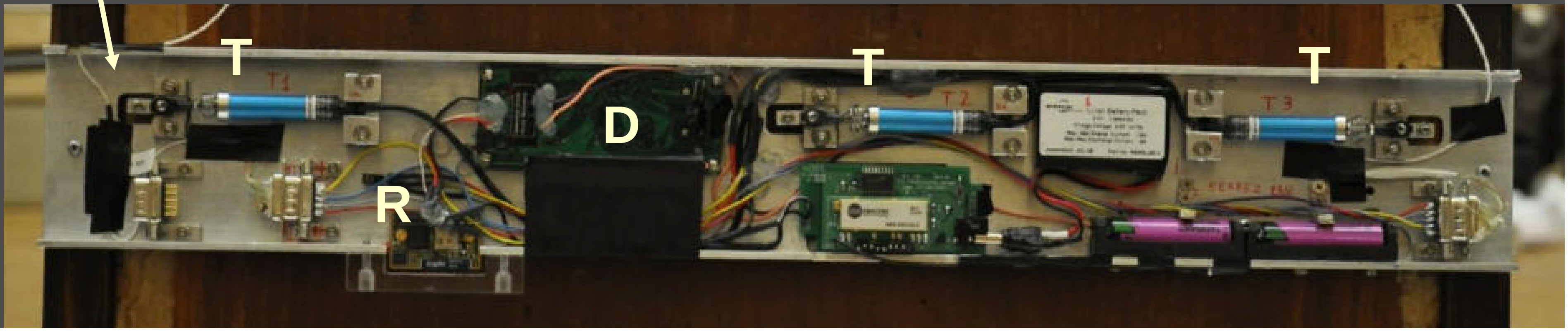
Two sub-miniature load cells monitor the forces between panel and upper cross-beam



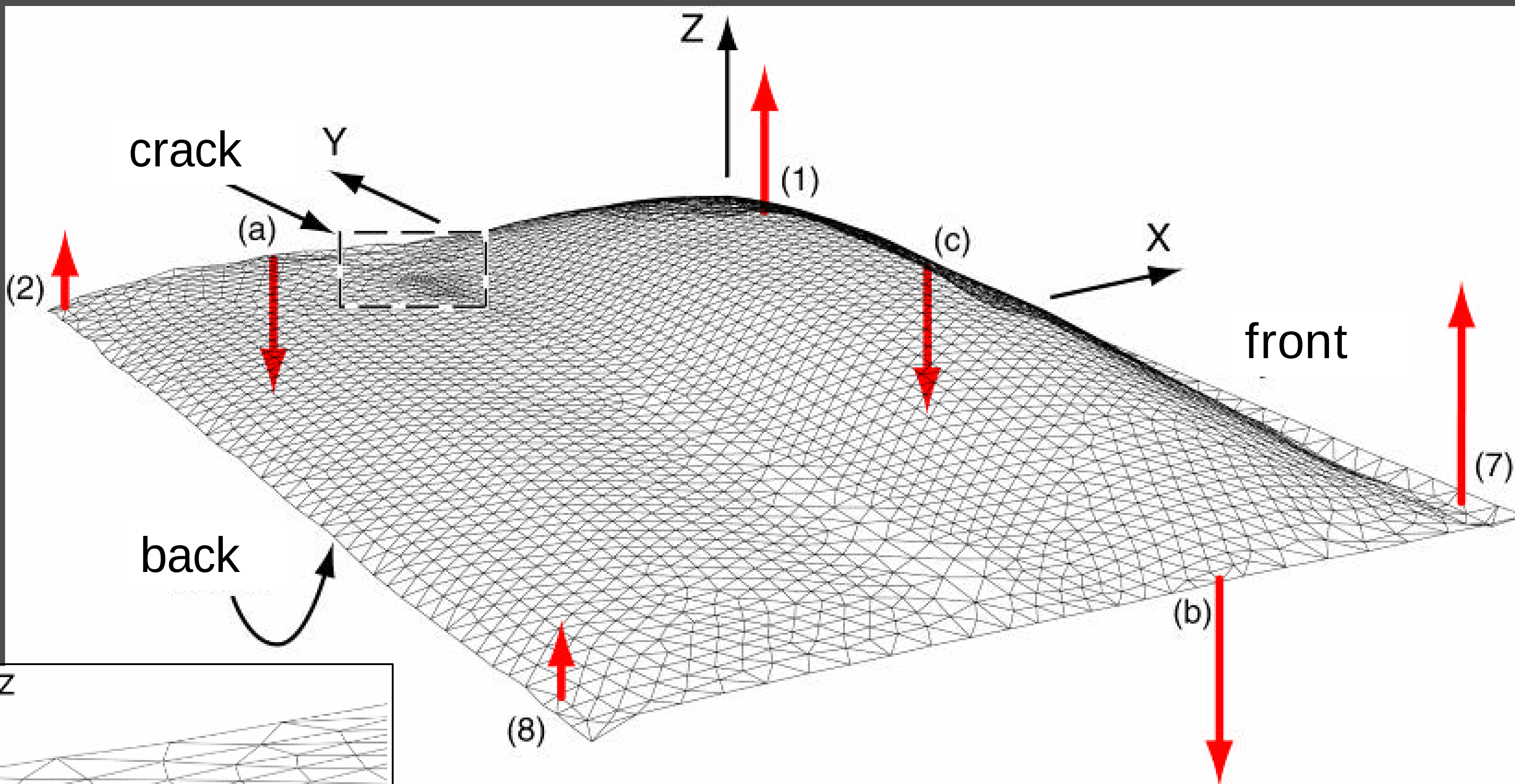
The monitoring equipment in greater detail

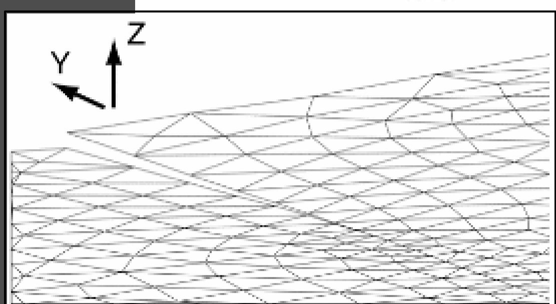


+ Two sub-miniature load cells (C) monitor forces between panel and upper cross-beam
+ The Aluminum "deformometric crossbeam" (here the latest version, implemented in 2009) includes:
- three transducers (T, blue), monitoring the cupping deformation
- a data-logger (D), powering transducers and load cells, and recording data
- a radio system (R), which on (coded) demand transmits data out of showcase



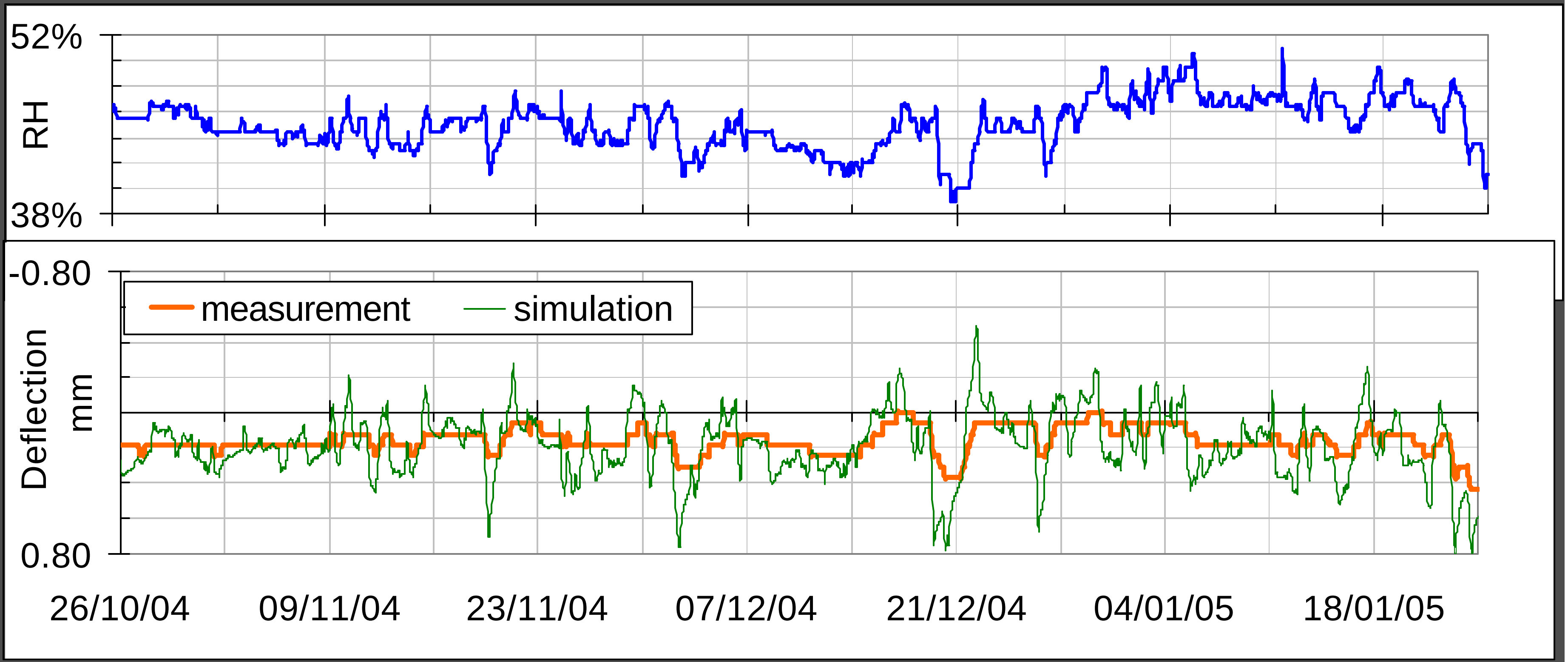
Mechanical model of the panel
(2006, see book)





- Finite element mesh
- Actions of the cross-beams and frame
- Very low elastic energy release in case of crack propagation → *no* risk!

Hygromechanical simulation of the panel's response to (limited) climatic fluctuations (J. Gril et Al.)



- **The observed trend for deflection could be predicted by a heat & mass transfer + hygromechanical model (TransPore 1D, P. Perré et al)**
- ***Partial permeability through paint layer* had to be assumed**
- **Predicted short-term response *not* observed**

Mona Lisa, outcomes and comments

- Techniques applied are not unusual, but this study generated high media impact due to worldwide fame of painting
- An occasion of true collaboration between Wood Scientists and Conservators, Restorers, Curators
- Data obtained so far provides valuable information on panel behavior (data acquisition is ongoing)
- Data analysis and mechanical modeling provided promising results – work in progress

The “Deformometric Kit” (DK)

What it is

<u>It is together an equipment and a method:</u>

- not significantly invasive,
- simple and inexpensive,
- self-powered,
- conceived, designed and made at DEISTAF (Univ. of Florence)

What it is used for

<u>Its main purpose</u> is to carry out measurements and monitorings:

- in virtually any environment
- of any desired duration (minutes, hours, weeks, years …)
- of the deformation dynamics of wooden objects
- mainly in connection with environmental hygrothermal fluctuations

The "Deformometric Kit" (DK)

How it is made

Various designs are possible, according to situations and requirements

In the following I will mostly deal with the design used in San Marco Museum.

In short, the DK is made of the following components:

- one or more displacement transducers (typically, of the potentiometric type, which allows for very low power consumption)
- a self-powered data-logger (which powers the transducers, reads them and records data with the desired frequency)
- specifically designed fixtures, to mount transducers with desired geometry on the wooden object
- electrical connections

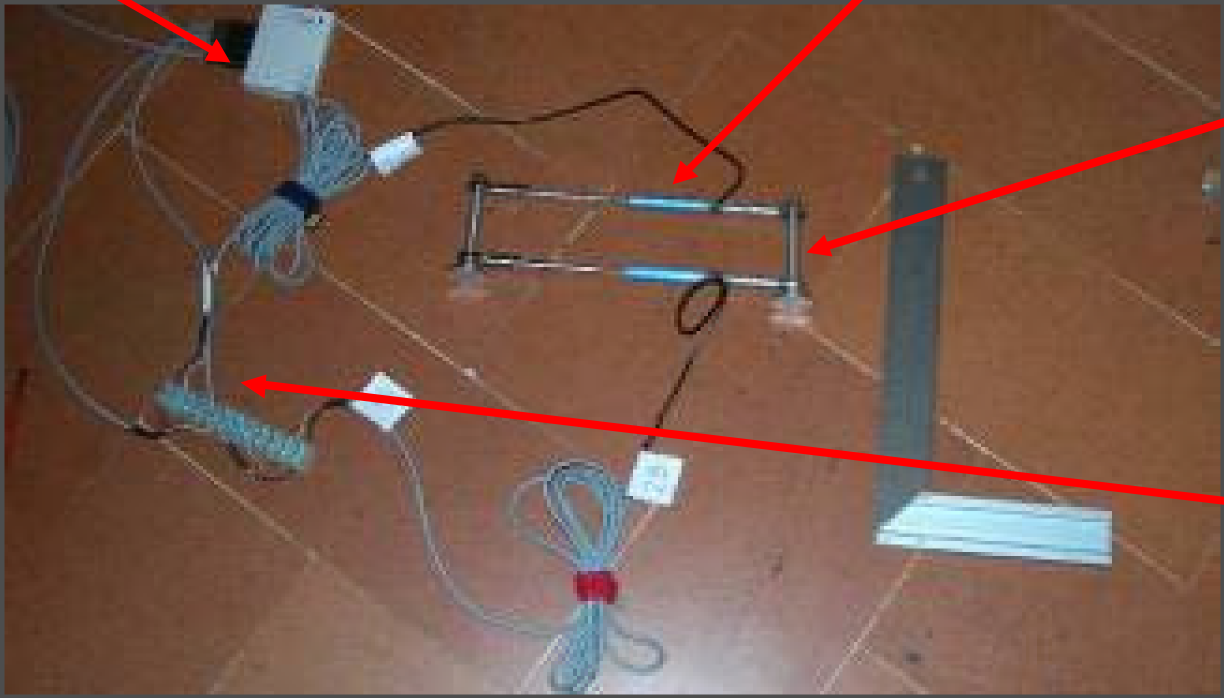
The DKs used in San Marco Museum

2 potentiometric displacement transducers, stroke 30 mm

Self-powered 4-channels data-logger

Mounting fixtures (Aluminum and steel)

cables, connectors, terminals, …



A DK mounted on a small mock-up panel

Self-powered 4-channel data-logger (battery lasts > 1 year)

In this case: 2 transducers + Temperature + Relative Humidity

In other cases: 4 transducers = 2 DKs

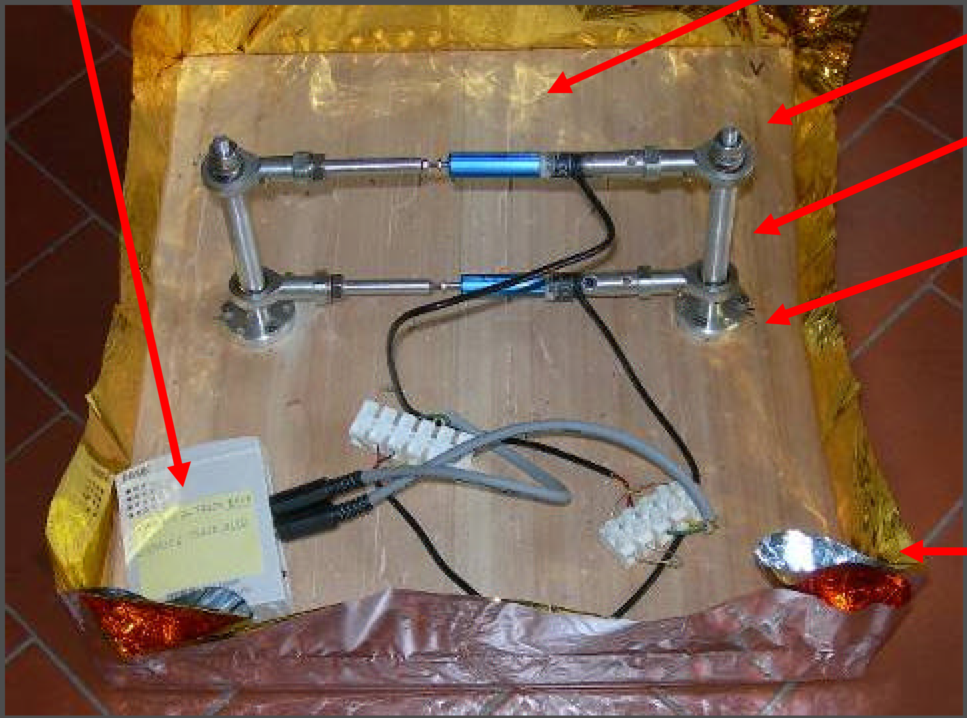
Poplar panel, 30x30x3 cm

ball joint

“column”

Base, secured with three inox screws Ø 3 x 20 mm

(aluminum foil, to waterproof front and edges)



Installing the DKs

1) After their location has been established and marked, the two "columns" of each DK get secured on the rear face of the Panel
2) The transducers (already calibrated and partly pre-assembled) are installed
3) Electric connections are completed

(3 DKs mounted on the Tryptich)

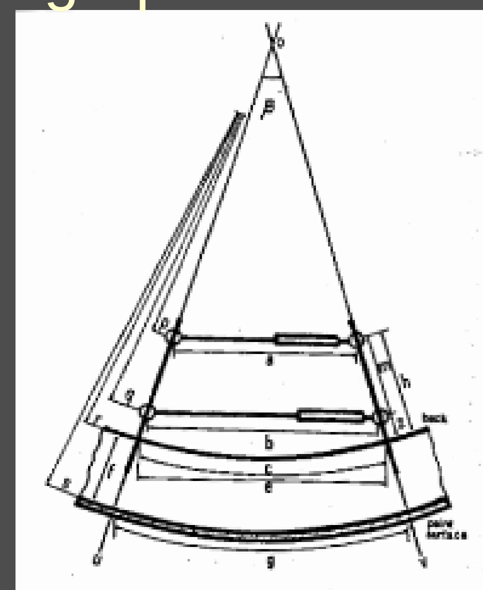
Installing the DK – No damage !

The securing screws are placed at safe distance from the paint layer !

In other cases, different securing methods can be used (e.g. adhesives)

Data downloading and processing

With current settings, data need to be downloaded at most every 96 days, to prevent the logger's memories from filling-up



The collected data are processed and analyzed by means of a spreadsheet, based on simple geometrical relationships, providing satisfactory accuracy and precision

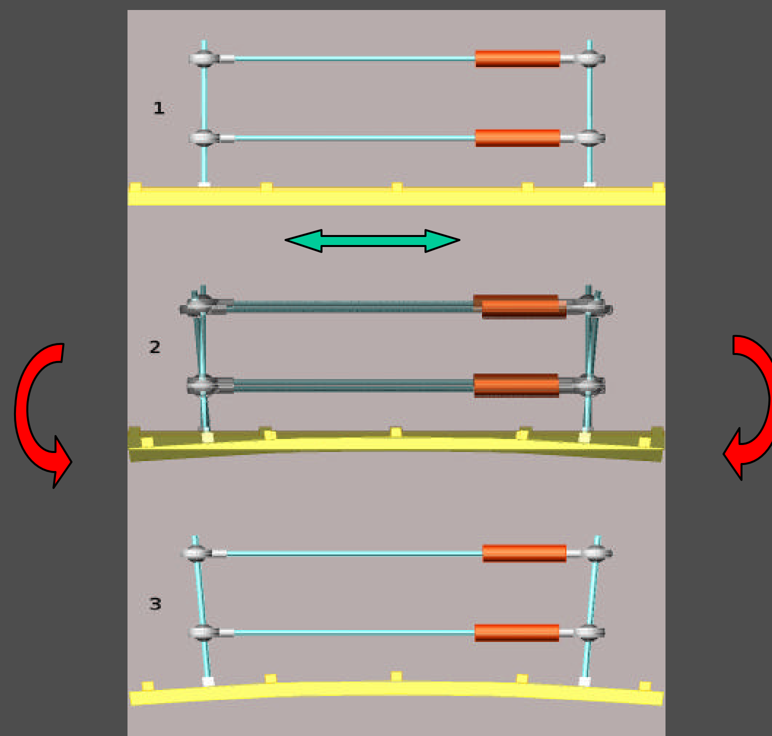
Parameters describing deformation

The two transducers of each DK provide two independent measurements.

From the geometrical relationships, two independent parameters describing deformation are obtained

As most significant, we chose:
- cupping angle (sexagesimal degrees)
- expansion

of the painted surface (not of the paint layers !), perpendicular to grain (%)



The main mechanisms producing cupping of panel paintings (in very short summary…)

“Steady state” cupping:

- Produced by the direction of the growth rings in individual boards (how the board was sawn ? wood anisotropy)
- Connected to the average moisture content of the boards, and hence to the average climate acting on boards

“Transient” cupping:

- Produced by moisture gradients across board’s thickness
- Such gradients are produced by the differences in vapor permeability between front and back face of Painting (influence of paint layers)
- Increases with: (1) increasing difference in permeability between the two faces, and (2) increasing speed and magnitude of the variations of environment’s RH
- Tends to fade out in time, when RH remains stable

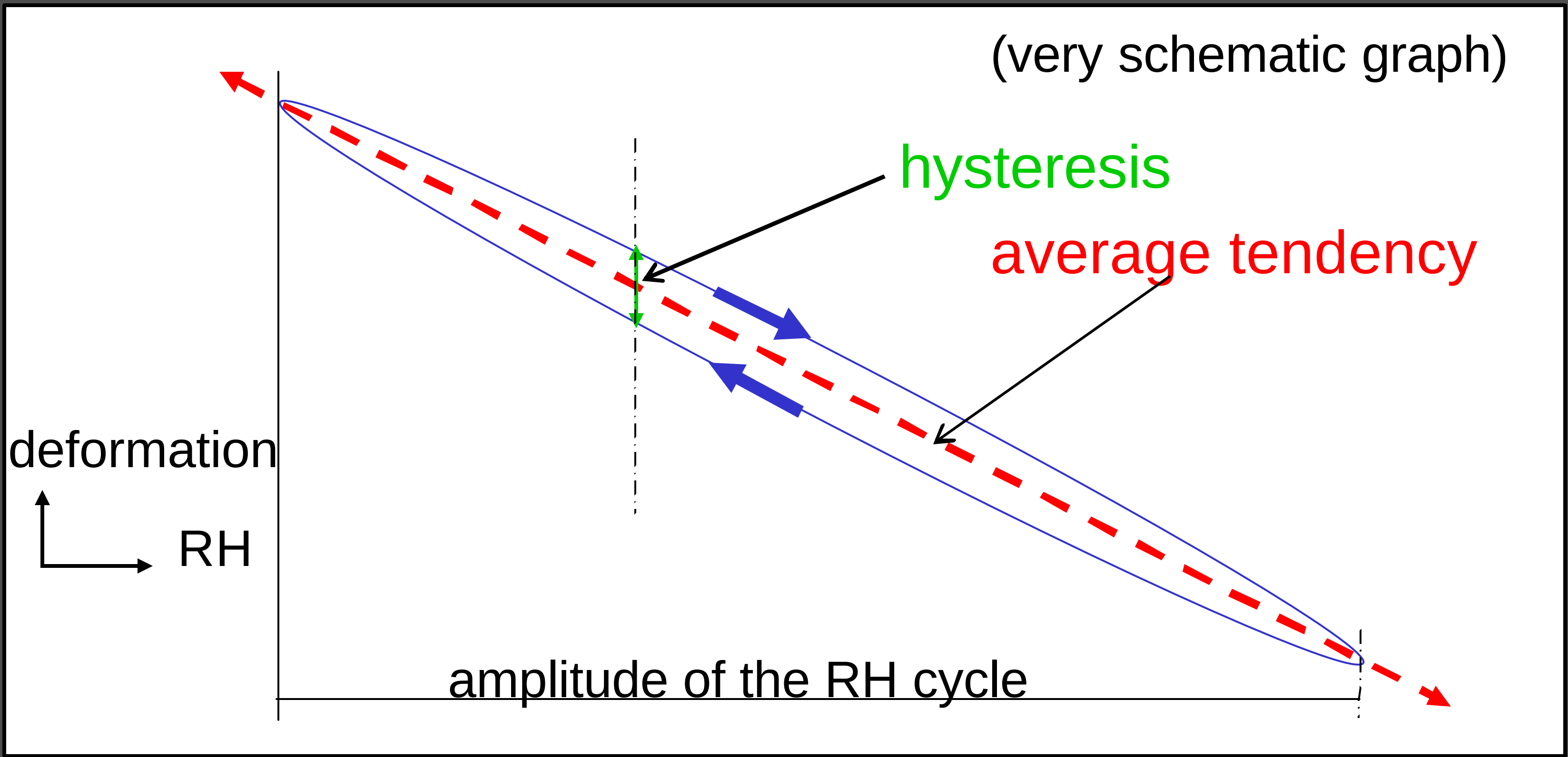
“Permanent cupping”: Produced in the course of time (centuries) by compression set on the back face

Hysteresis (in very short summary…)

A behavior typically shown by wood subjected to complete cycles of Relative Humidity (RH)

The deformation tends to “trail behind” RH (in quantity, not in time). For a given value of RH:

- deformation is larger if RH is decreasing (upper branch)
- deformation is smaller if RH is increasing (lower branch)



Monitoring the Beato Angelico's panels in San Marco Museum

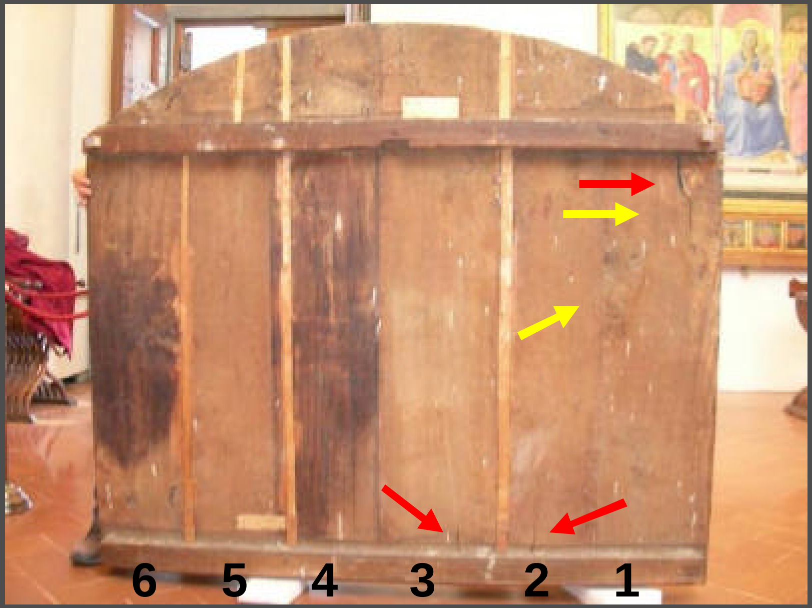
- Dr. Magnolia Scudieri, the Director of San Marco Museum (Florence) advocated this study, and strongly encourages it
- Two large panels by Beato Angelico are presently being monitored; I will report here about one of them
- Two small mock-up panels are also placed in the same Museum hall and monitored
- Two medium-size mock-up panels are placed in our Department's climatic chambers, in order to study the influence of spring-connected cross-beams
- All such mock-up panels are made of Poplar (*Populus alba* L.) wood, are ~30 mm thick like the original panels; edges are waterproofed to reproduce moisture diffusion as in larger panels

The “Triptych of San Pietro Martire”

This altar-piece (tempera on wood, 137x168 cm) was painted by Beato Angelico (Fra’ Giovanni da Fiesole, ~1400-1455) possibly in 1425 for the monastery of San Pietro Martire (Florence, no longer extant)

Exhibited in the “Sala dell’Ospizio”, San Marco Museum, together with several other paintings by Angelico (including the “Pala del Bosco ai Frati”, presently also being monitored)

The wooden support



The support is made of six planks of Poplar (*Populus alba* L.) wood, 28-30 mm thick, glued along the edges

Some of the glued joints failed, were repaired with the "incuneatura" (wedging) technique; some failed again

Two (possibly non-original) nailed cross-beams are present

Large knots and slope-of-grain are present in some planks (↗); as well as some cracks, mostly near lower part and cross-beam (↗)

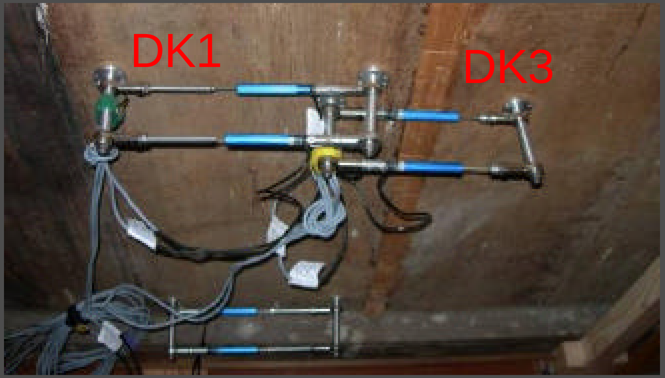
Installation of three DKs

DK1: centre of board 3, showing no singularities

DK2: centre of the same board, low end, near a cross-beam and related cracks

DK3: across the glued edge joint between boards 2 & 3 ("wedged", but glue failed again)

Data-loggers provide power and read data (transducers, air T and RH) at 15 minutes interval



Monitoring period and type of results

Data from ~1 year monitoring are reported here (for brevity, only from DK1)

All the four seasons of one year are covered (10 June 2008 ? 14 July 2009)

To simplify, only two “climatic seasons” will be discussed:
- “winter”, when the heating is ON, and doors are mostly closed (more dry and constant climate)
- “summer”, when the heating is OFF, and doors are often kept open during the day (more moist and variable climate)

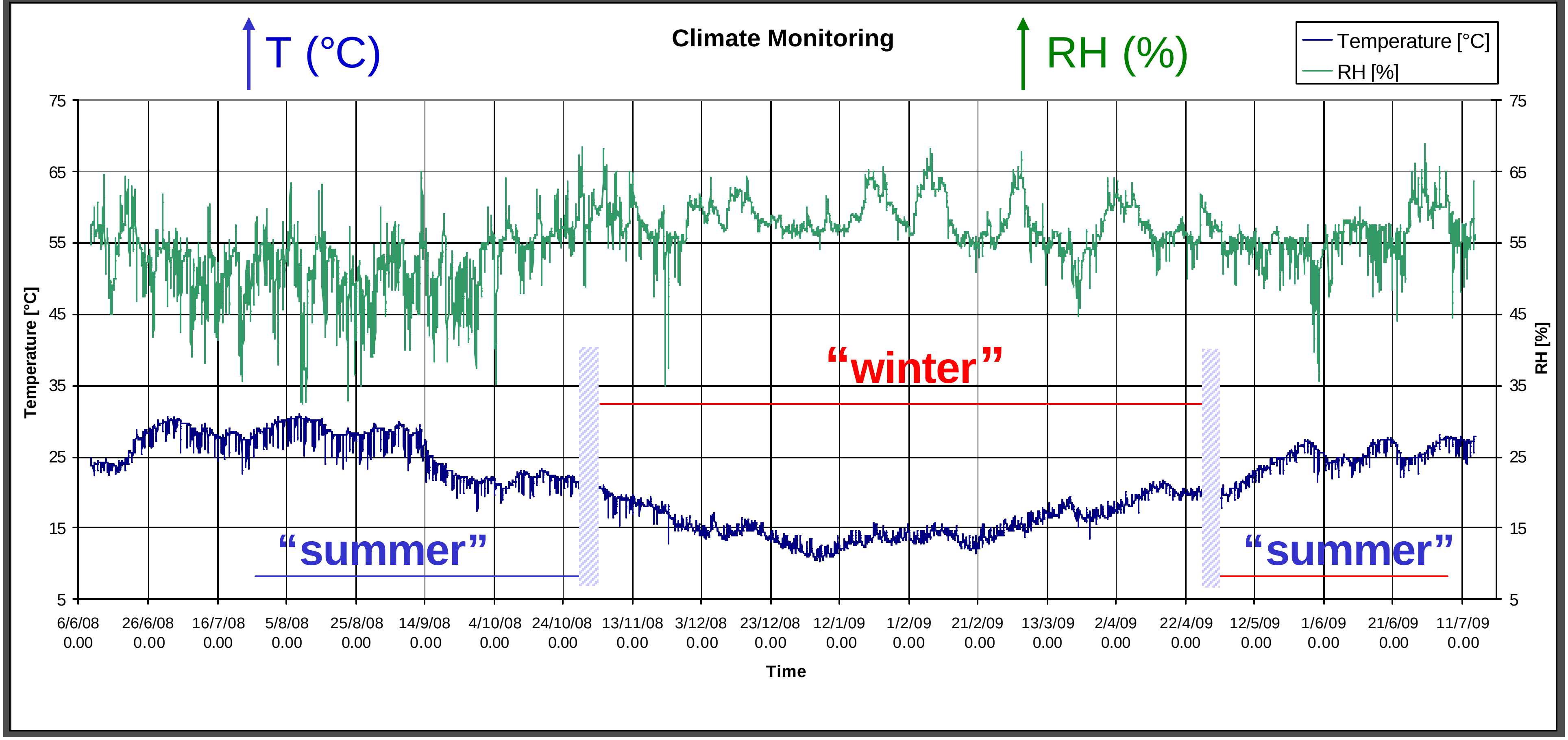
- Results are here expressed as visual graphs

- Analytical processing, comparisons with mathematical models etc. are planned in a near future

Climate monitoring (T, RH)

"Summer": larger climatic excursions (hot external weather, doors opened daily)

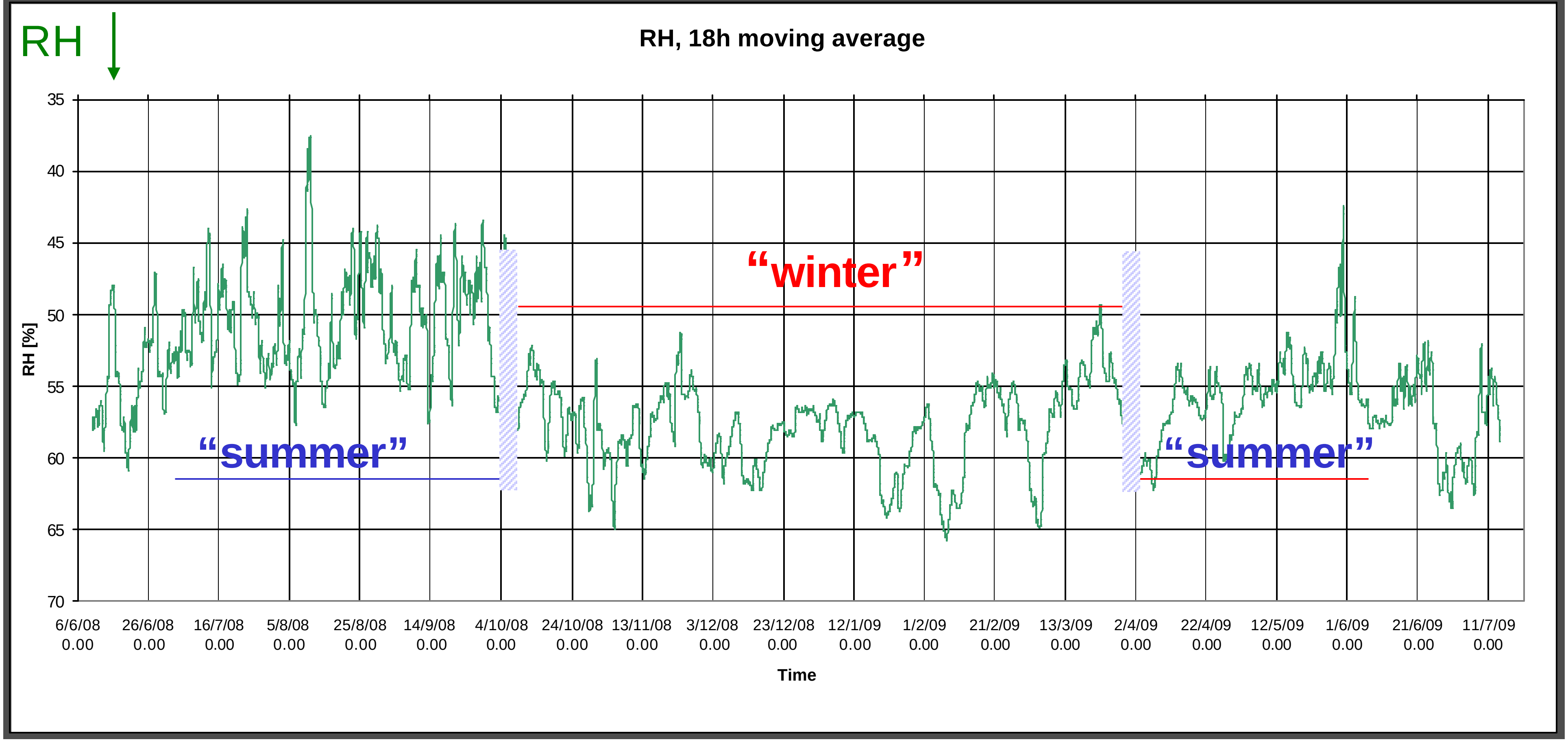
"Winter": heating plant on, doors kept closed



RH "smoothed" by a moving average (18-hour window)

- "Summer": RH more influenced by daily variations
- "Winter": RH shows slower variation rates

(Note: RH axis is reversed hereinafter)

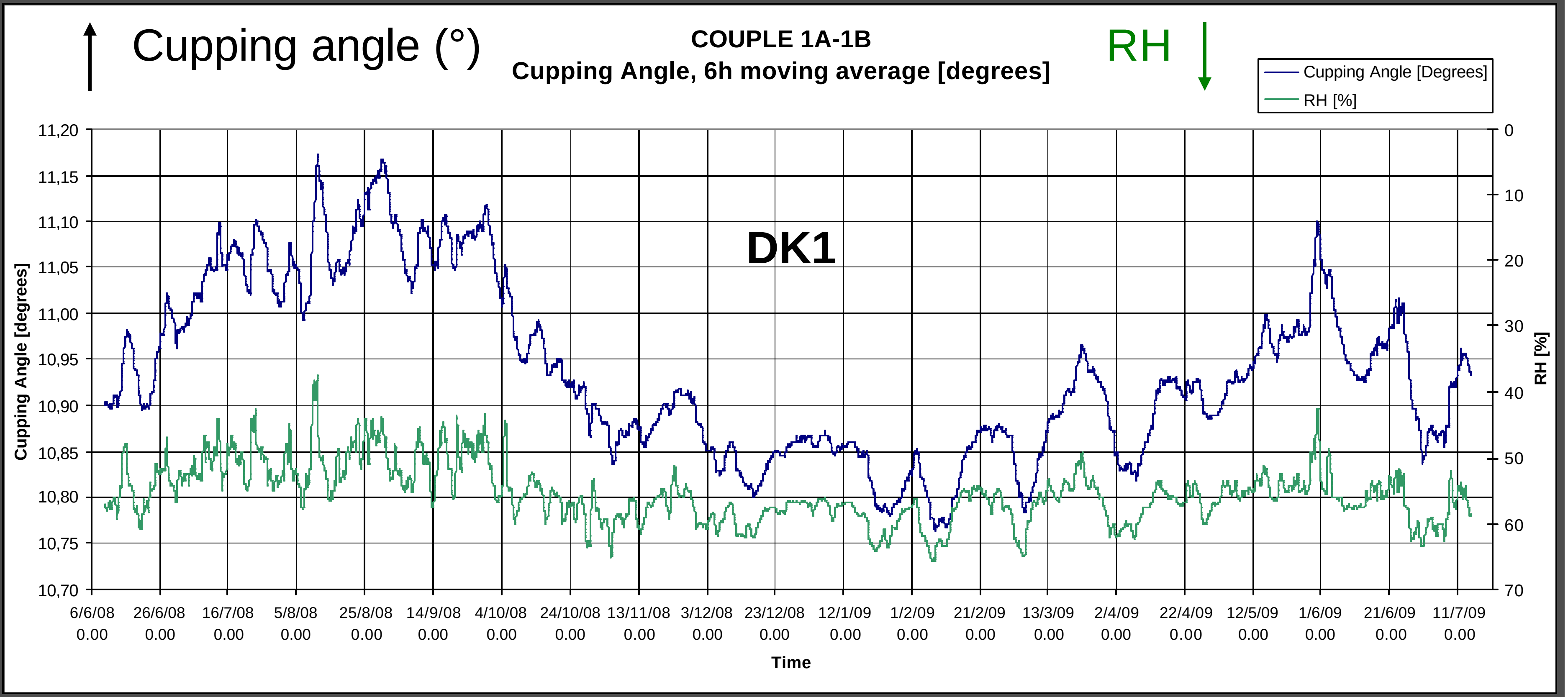


Temporal fluctuation in Cupping angle

The permanent deformations developed along the centuries (= initial status of monitoring) are here disregarded

Range of fluctuation in cupping angle is smaller than 2 °

A strong inverse relationship between angle and RH is evident

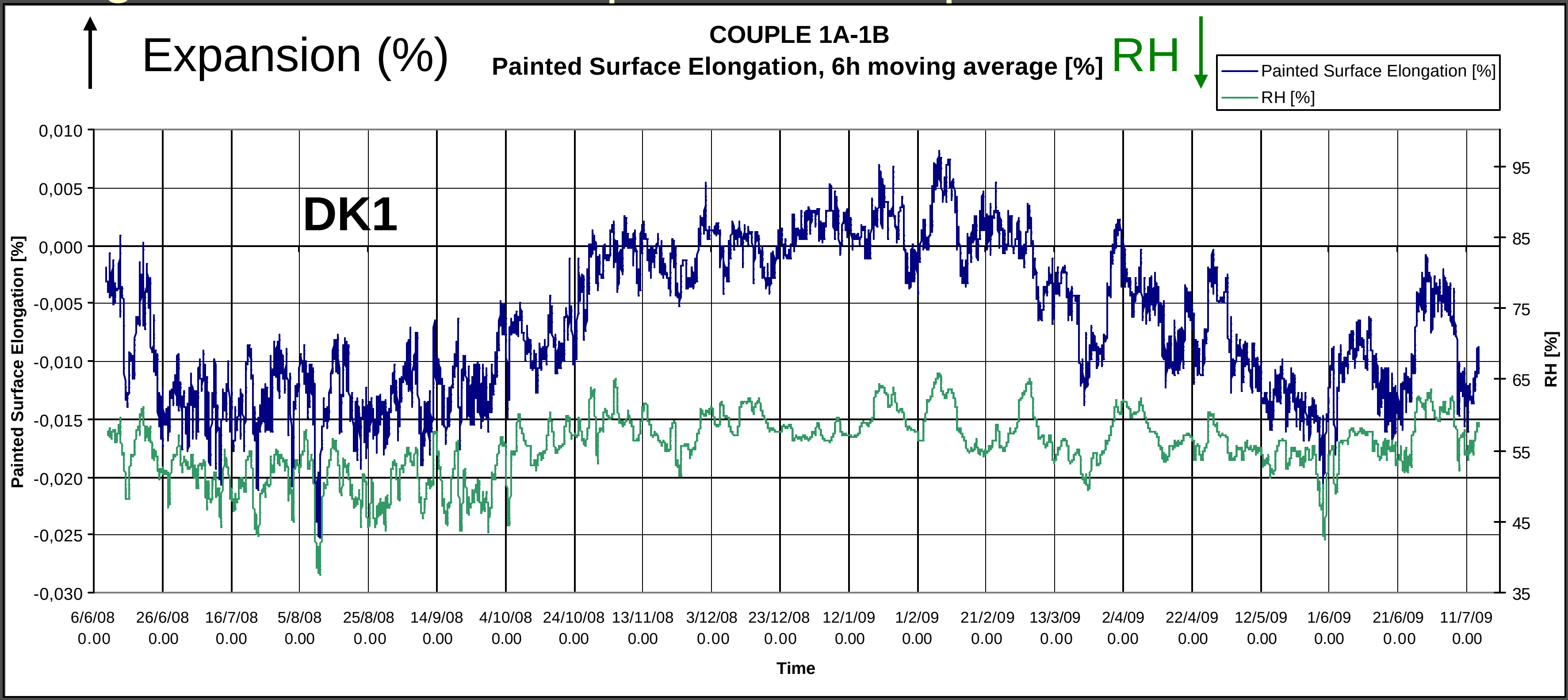


Temporal fluctuation of expansion

The % is computed referring to the initial status of monitoring

In this case Expansion is extremely small, of the order of 0.01 % (one hundredth of one percent) (near to the resolution capacity of the apparatus)

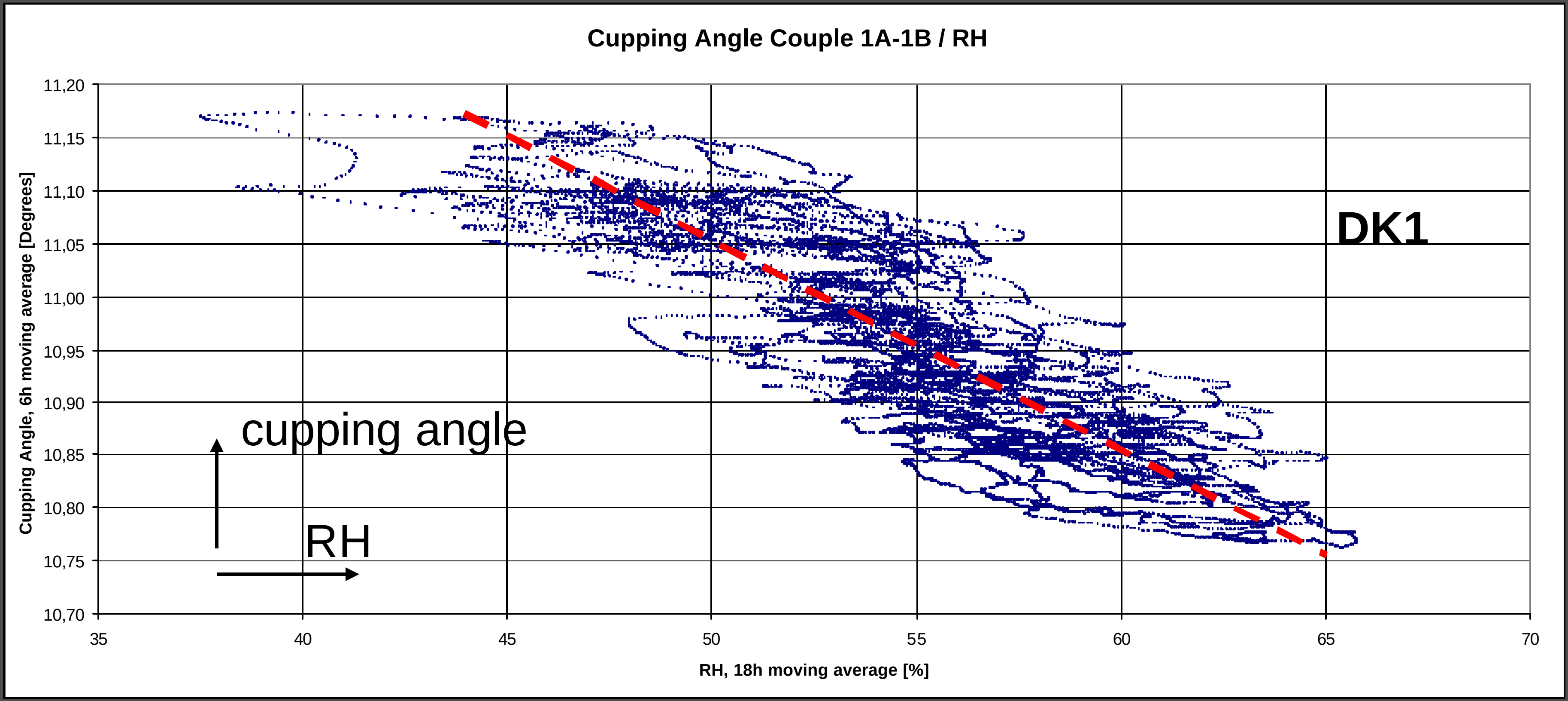
Strong inverse relationship between expansion and RH is evident



RH – cupping angle relationship

Linear trend (– – – – describes the "steady state" relationship): when RH increases, cupping angle decreases

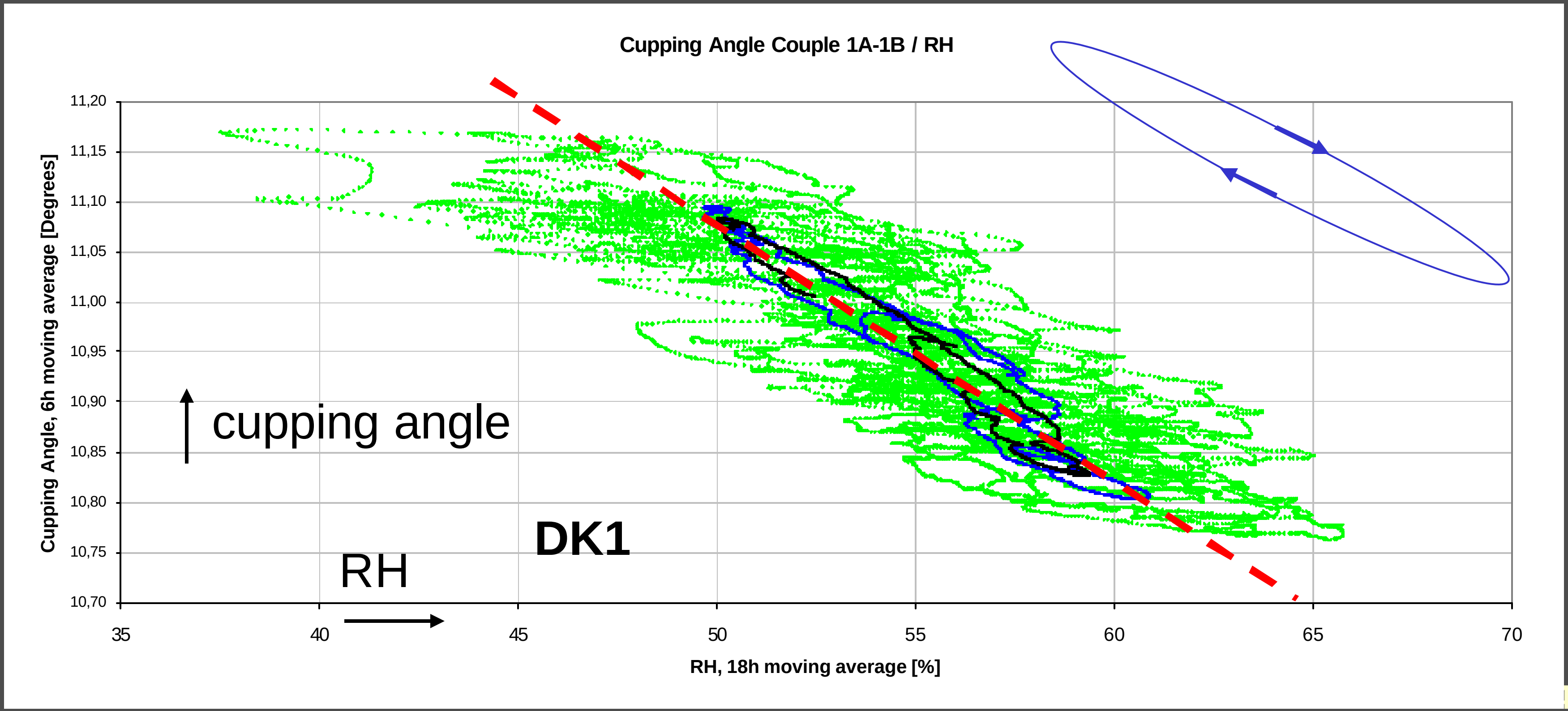
The actual relationship is much more complex and non-linear, because of superposition of (a) the transient cupping, and (b) hysteresis



RH – cupping angle relationship

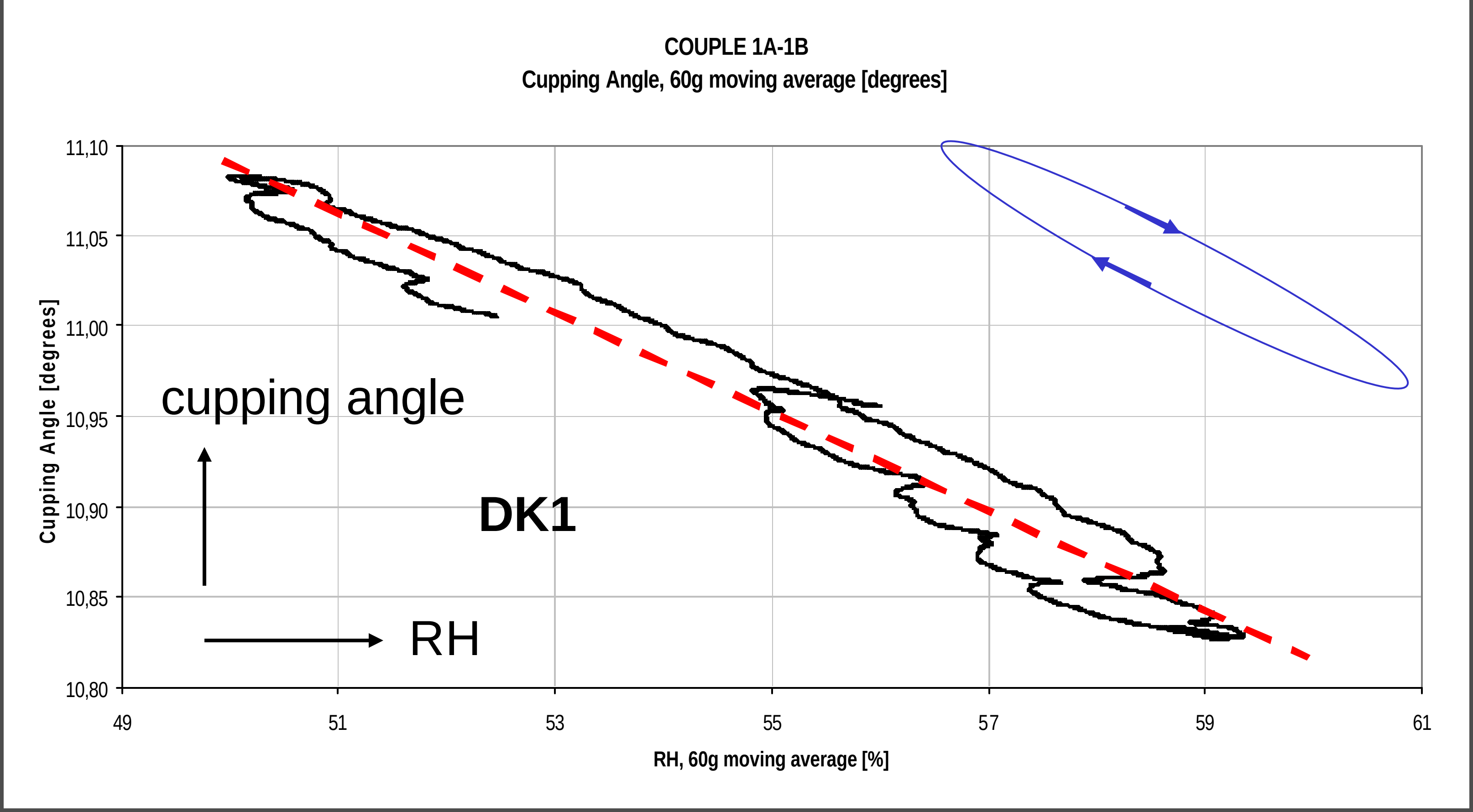
The experimental points (green) are here “smoothed” by means of a moving average (blue: 30-days window; black: 60-days window):

- “transient” effects are wiped out
- the “steady state” trend is highlighted
- hysteresis is also revealed



RH – cupping angle relationship

The steady state trend and the hysteresis cycle are even better revealed by plotting only the curve obtained by means of the 60 days moving average



Conclusions from San Marco's monitoring

- Deformometric Kits show good performance, and can be "easily" applied in many situations
- Recorded data provide good indications about the dynamic deformation of the wooden support
- Different behaviors in different periods of the year are clearly identified
- Measured deformations are in San Marco's case quite limited
- Measured deformations are clearly related to the climatic fluctuations; however relationships depend on the "history" (amplitudes and rates) of the fluctuations

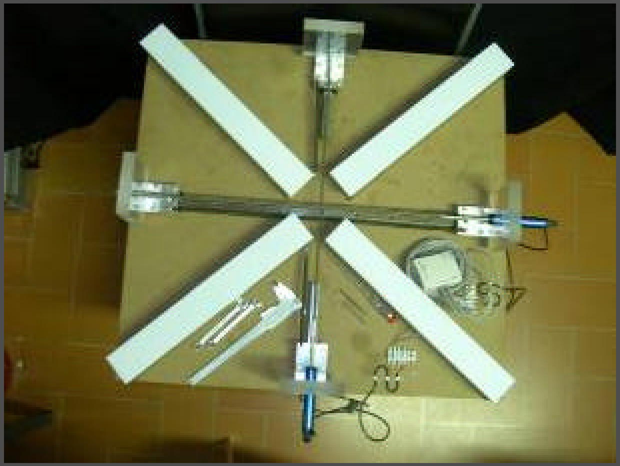
Conclusions concerning computer modelling

- Mathematical modeling will greatly profit from these data, and in return will allow for their expanded use
- Need exists for better knowledge of material properties of aged/ancient wood (Heat and mass transfer, Expansion ratios, Hysteresis, Viscoelastic and Mechanosorptive behavior, …)
- Need exists for improved & validated models for predictive simulation:
  - to be used for case studies, with adjustment of parameters
  - to support assessment & improvement of current conservation practices

Thank you for your attention !

….do we have more time?

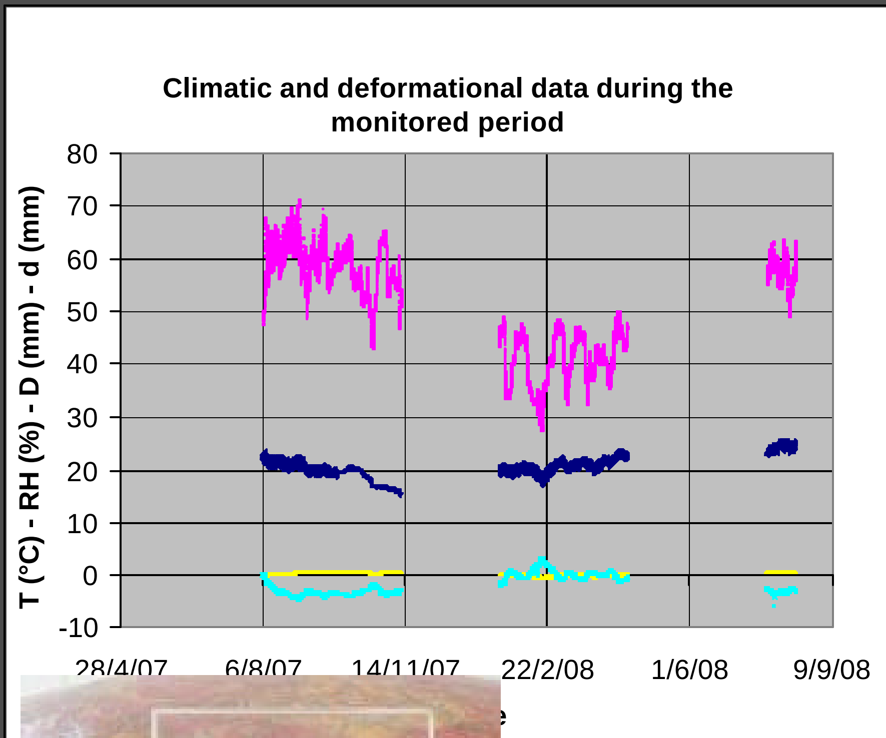
Examples of employing the DK (2)
Wooden parade shield, Museo Bardini (FI)

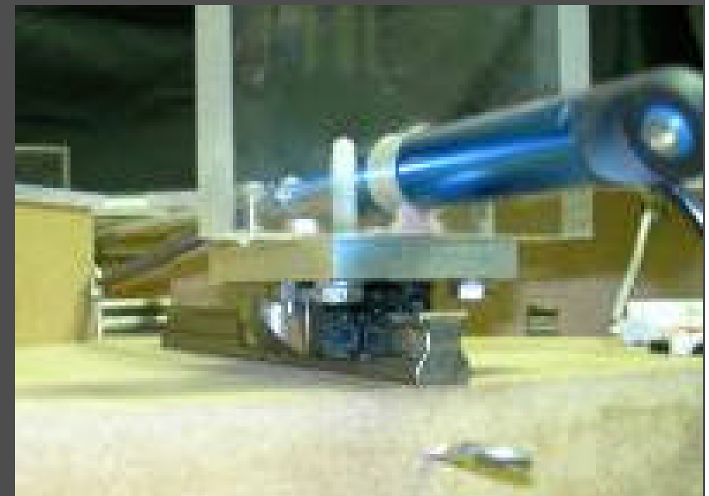


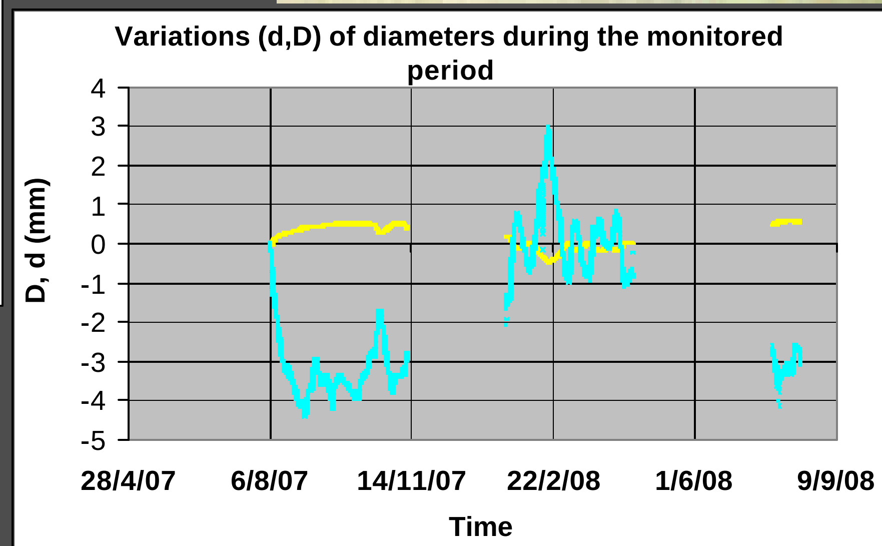
This unusual DK had been conceived in 1998 for the “Medusa” shield (at Uffizi Gallery, Florence) by Caravaggio (1598), which subsequently became unavailable

In 2007 it was used for a very similar laminated wood parade shield (n° 408) exhibited in Museo Bardini (Florence)
Objective of the monitoring: to measure the variations of its two perpendicular diameters, and of its peculiar “tortoise shell” shape

Monitoring the “Bardini” shield





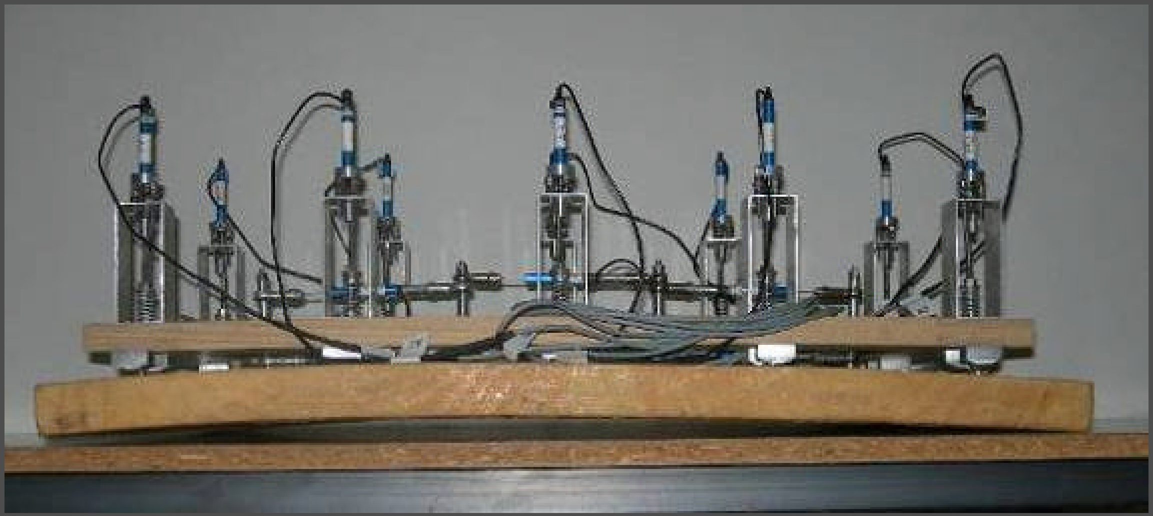


Monitoring revealed the shape and dimensional variations, produced by the environmental hygrothermal fluctuations

Examples of employing the DK (3)

Mock-up panel connected by springs to the back-frame

(Bertrand Marcon, PhD thesis, co-tutored at Universities of Montpellier and Florence)



Spring-connected back-frame was conceived and implemented several years ago by Opificio delle Pietre Dure (Florence)

We recently instrumented a mock-up panel, reproducing part of an original Triptych, in order to monitor the influence of the spring-connected back frame on panel’s deformations

Picture shows the transient cupping produced by a sudden step variation of RH, in DEISTAF’s climatic chamber