Computer modelling of dimensional response and stress fields in wooden artworks

Lukasz Bratasz, Bartosz Rachwal

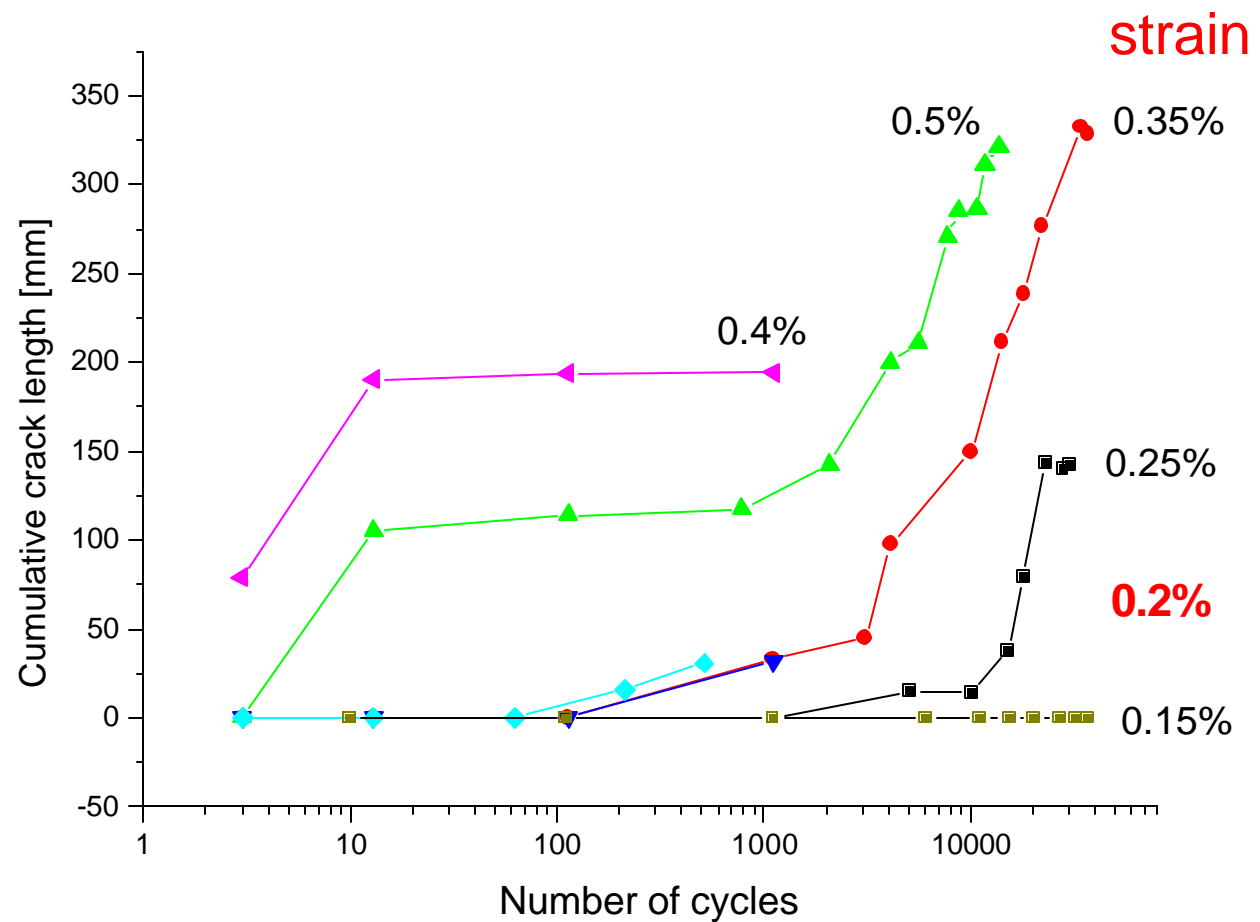# Aim

To translate critical strain values determined in the fatigue tests into allowable RH variations

Cumulative crack length in the decorative layer vs number of strain cycles

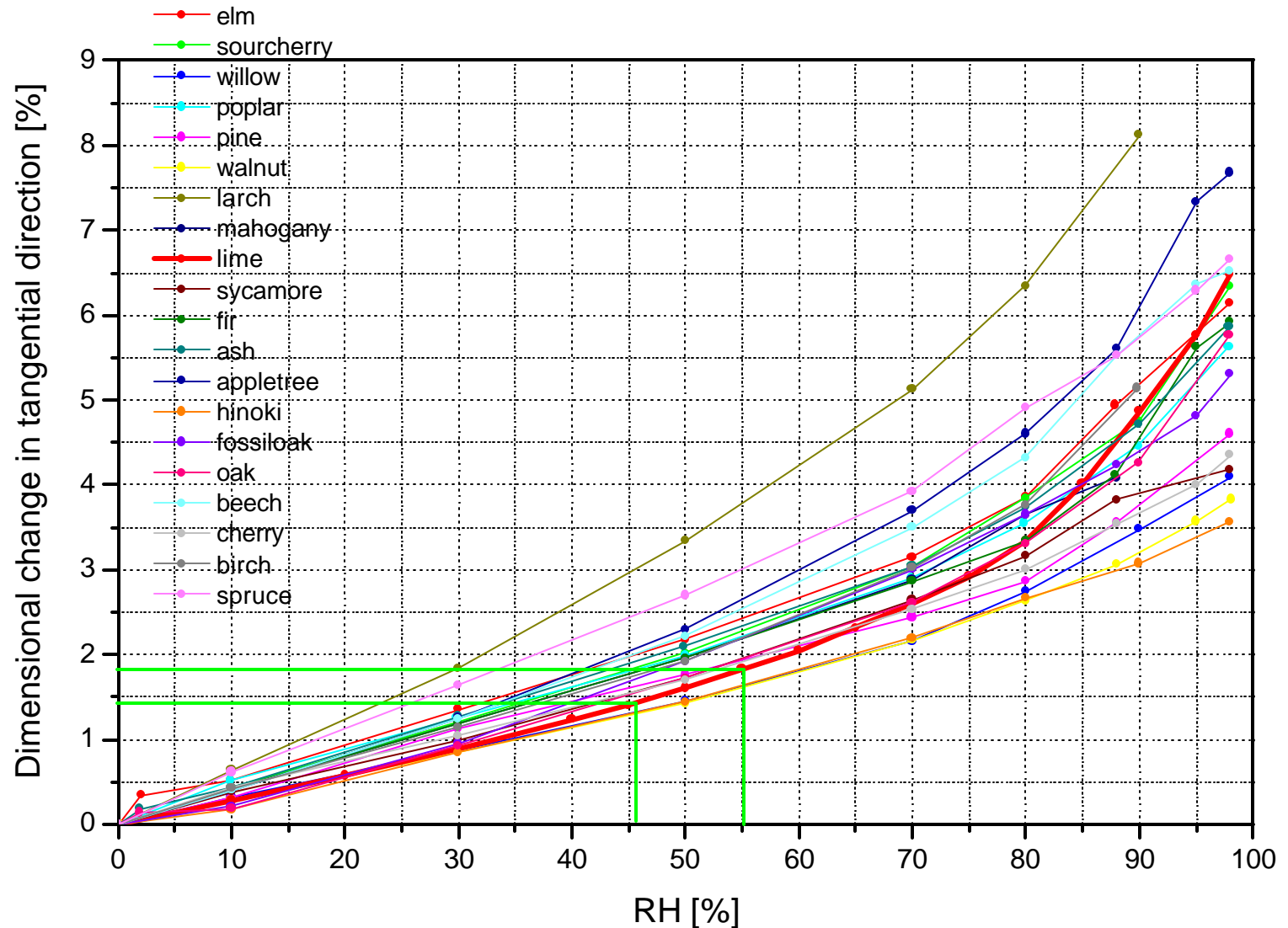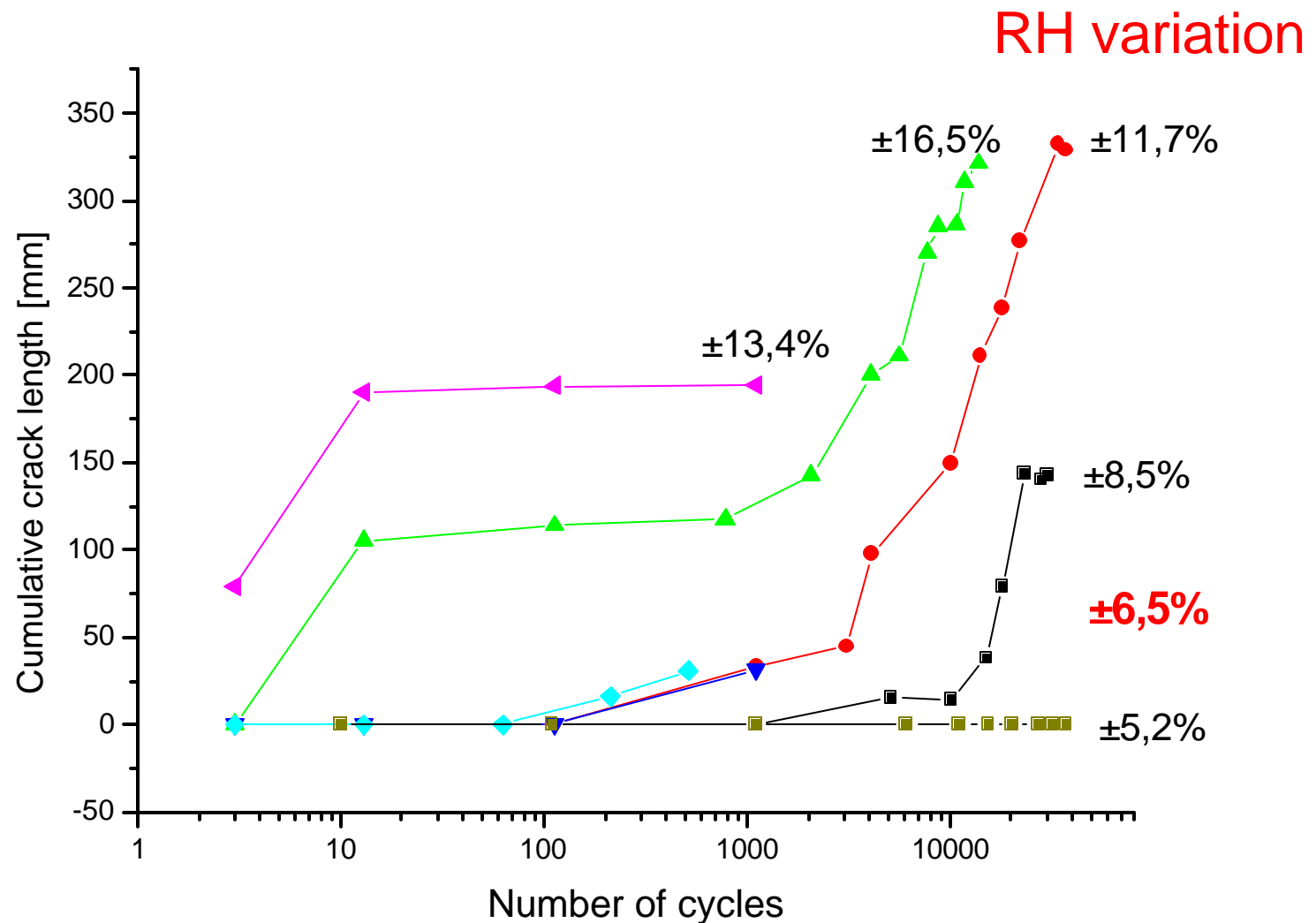# RH variation for a given strain is calculated from the swelling isotherm - lime wood is typical

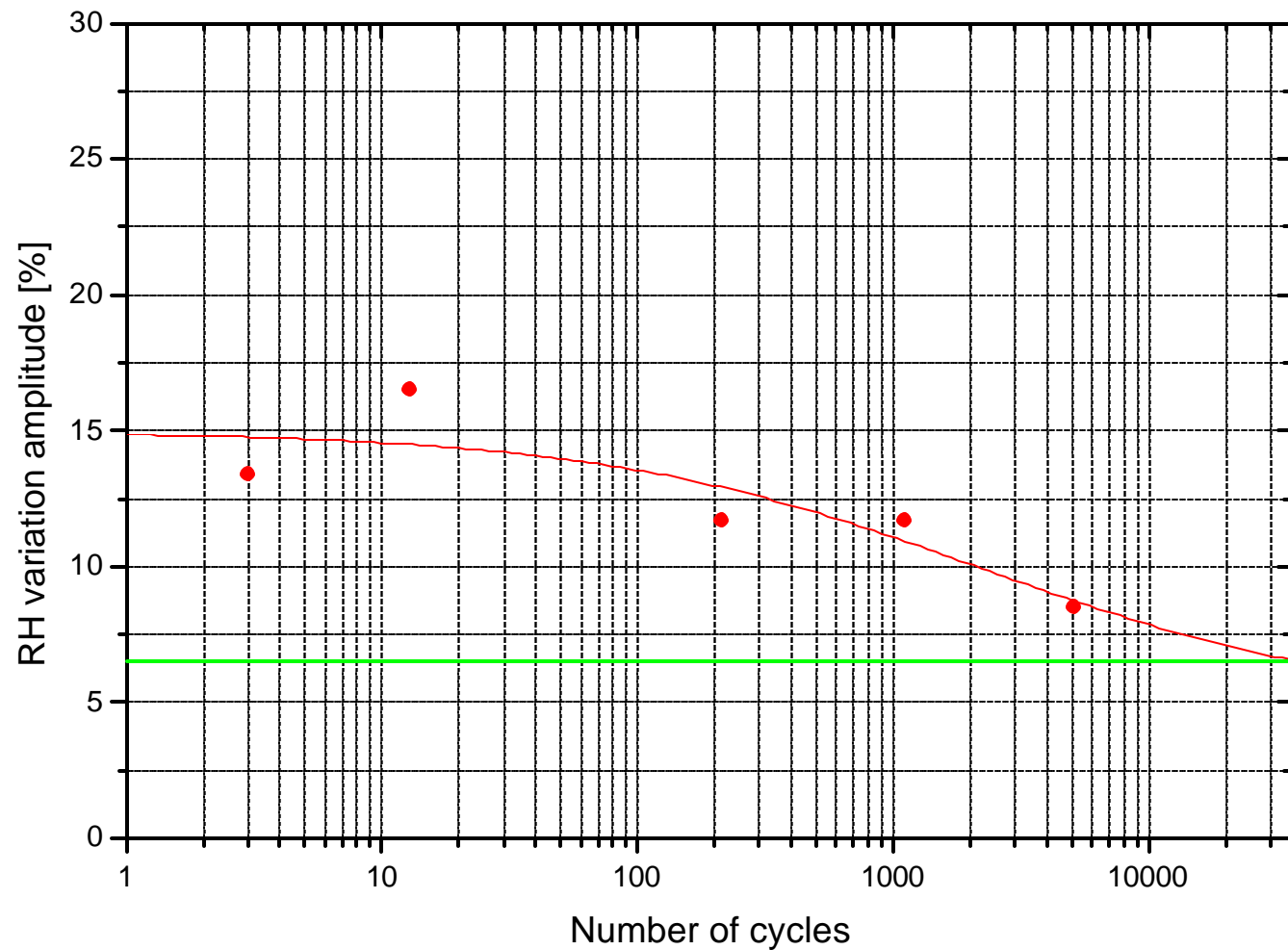# RH variation for a given strain is calculated from the swelling isotherm - lime wood is typical
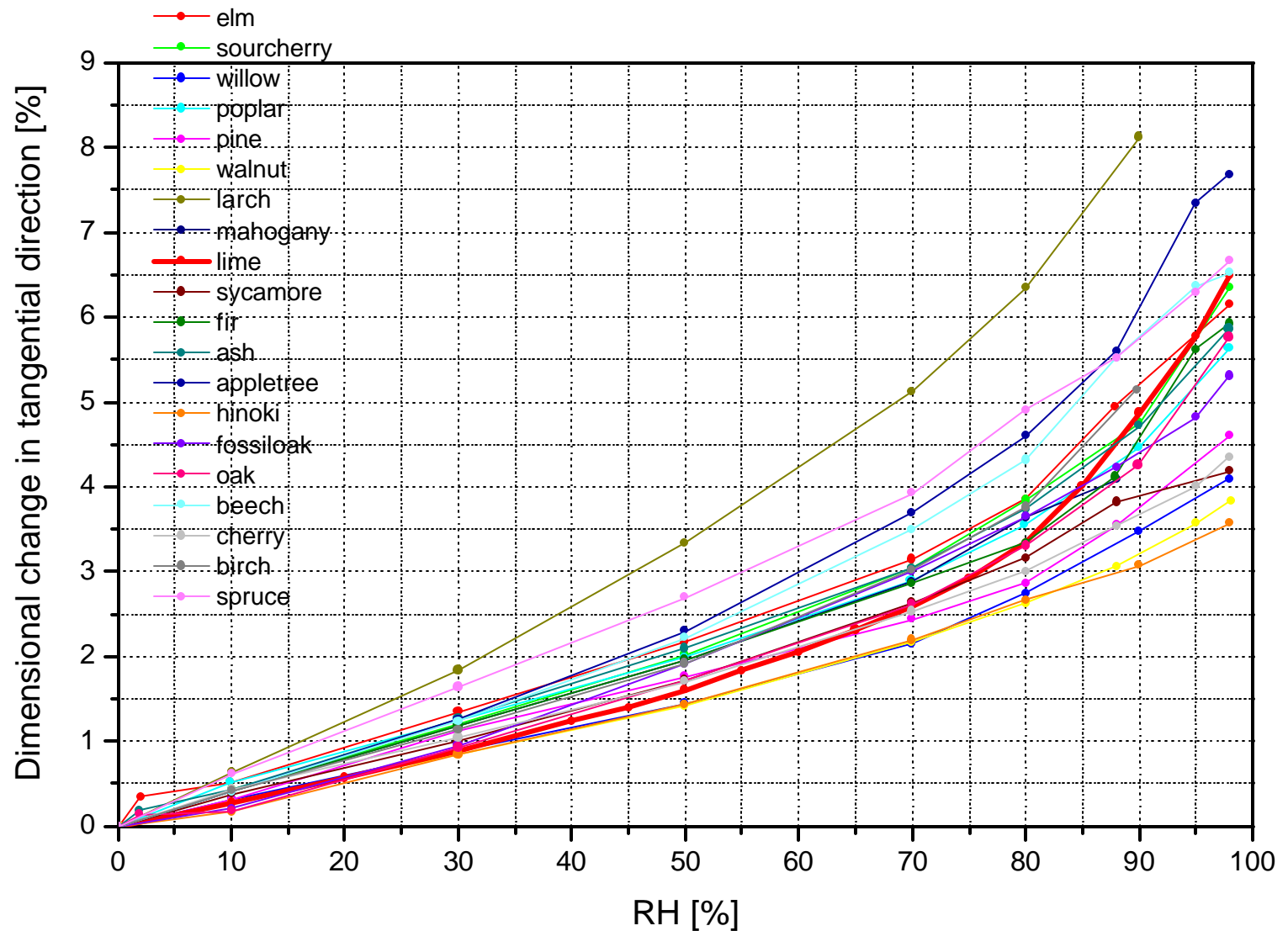
RH variations centred at 50%rh corresponding to the mismatch between wood and gesso

Amplitude of the RH variation vs number of cycles after which damage appears

The first step approximating the
allowable RH variations

- RH-induced wood movement causing strain in the gesso layer of around 0.2% corresponds to a very narrow variation of $\pm$ 6.5%rh centred at 50%rh for lime wood in the tangential direction

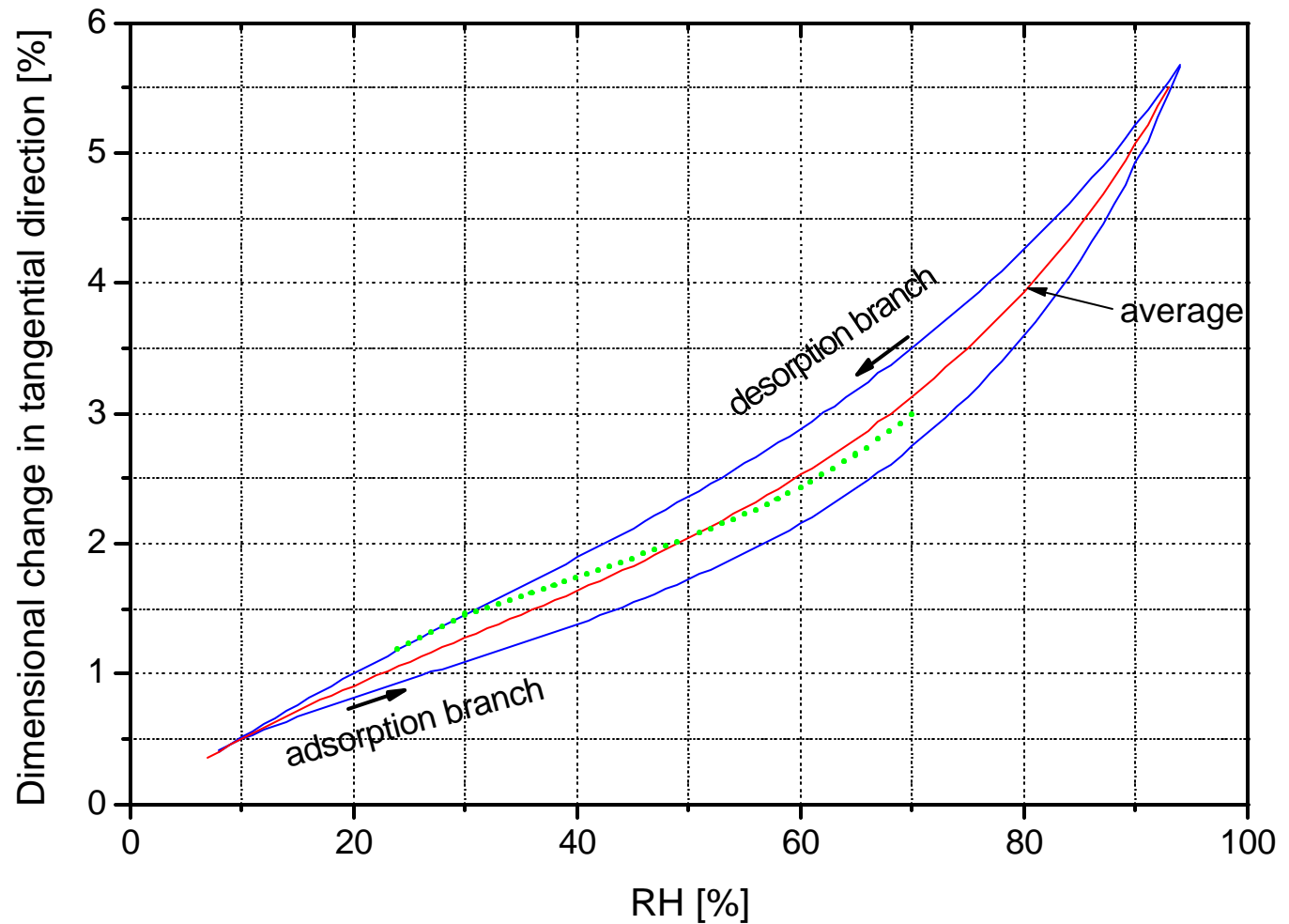- further effects need to be taken into account

Further effects

The safe range of RH variations is broader due to several phenomena:

– hysteresis in swelling/shrinkage

– slow response of wood to short-term variations in RH

– ability of the panels to deform

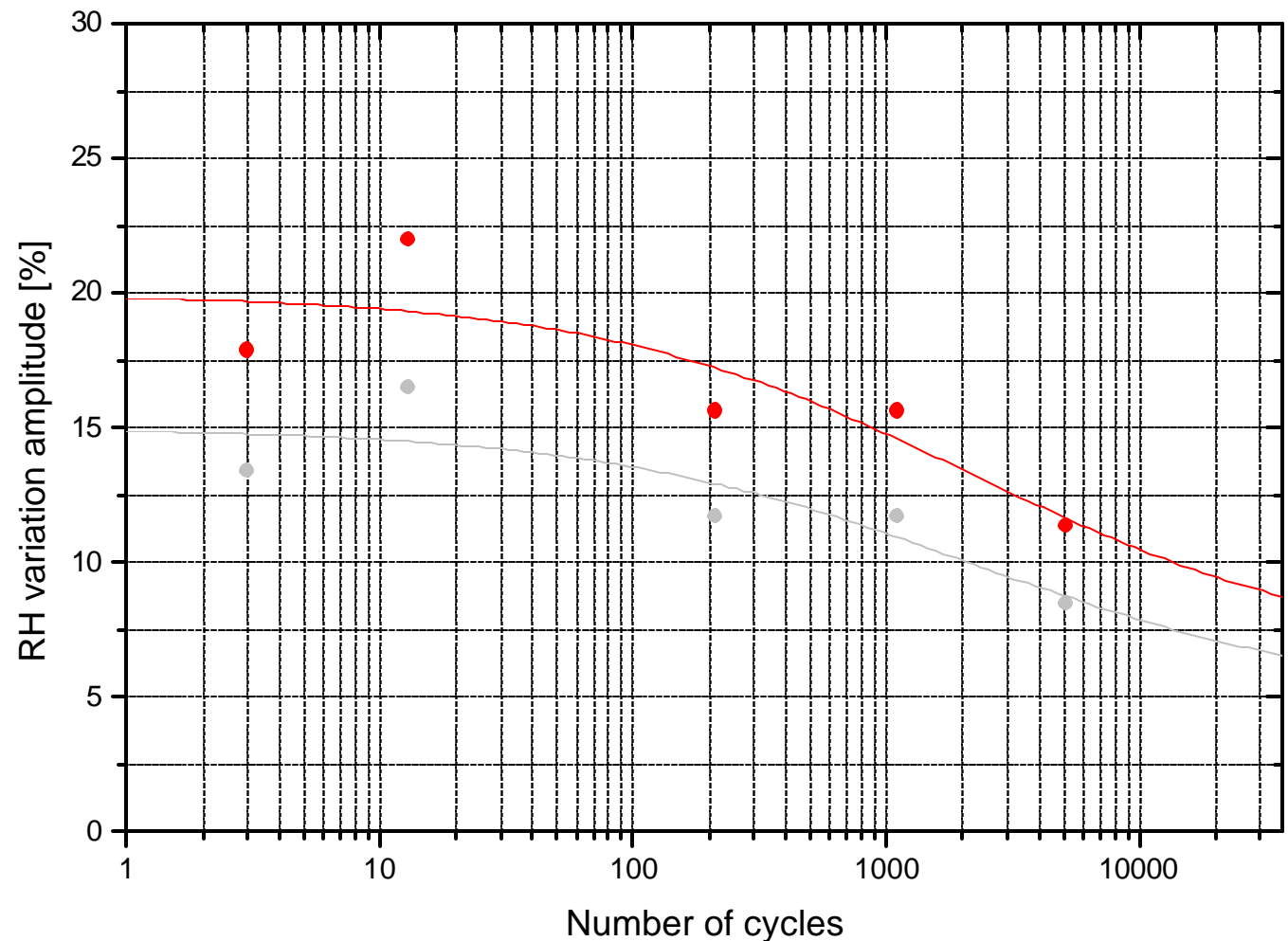# Hysteresis loop between the swelling/shrinkage isotherm for lime-wood

Strain reduction due to the hysteresis

reduction of strain for various RH changes
centred at 30%, 50% and 70% RH is
approximately 25%

Amplitude of the allowable RH variation vs number of cycles - a correction due to the hysteresis
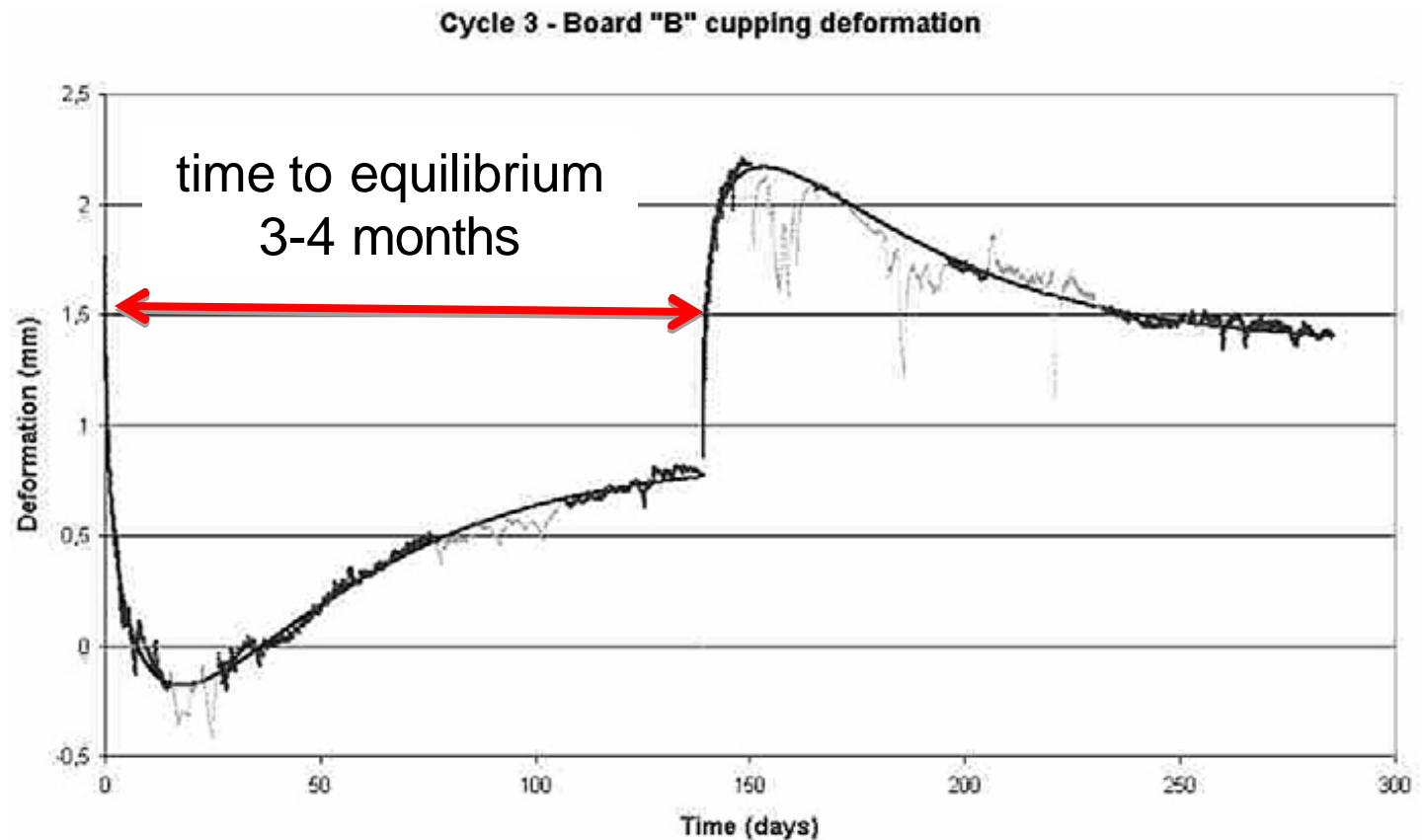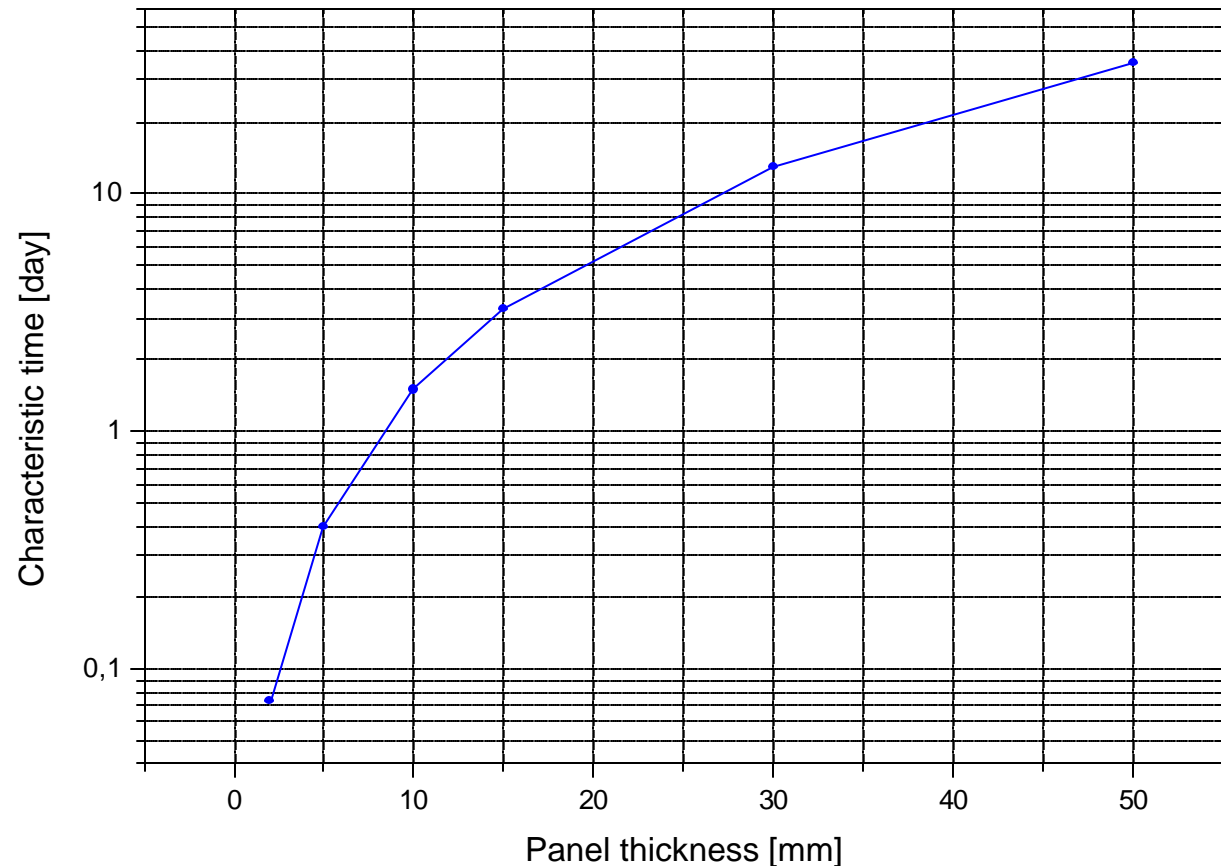
Slow response of wood to short-term variations in RH

Poplar panel 4 cm thick, RH 63 →45 →65%

P.D. Vici, P. Mazzanti, L. Uzielli, *J. Cult. Her.* 7 (2006) 37-48

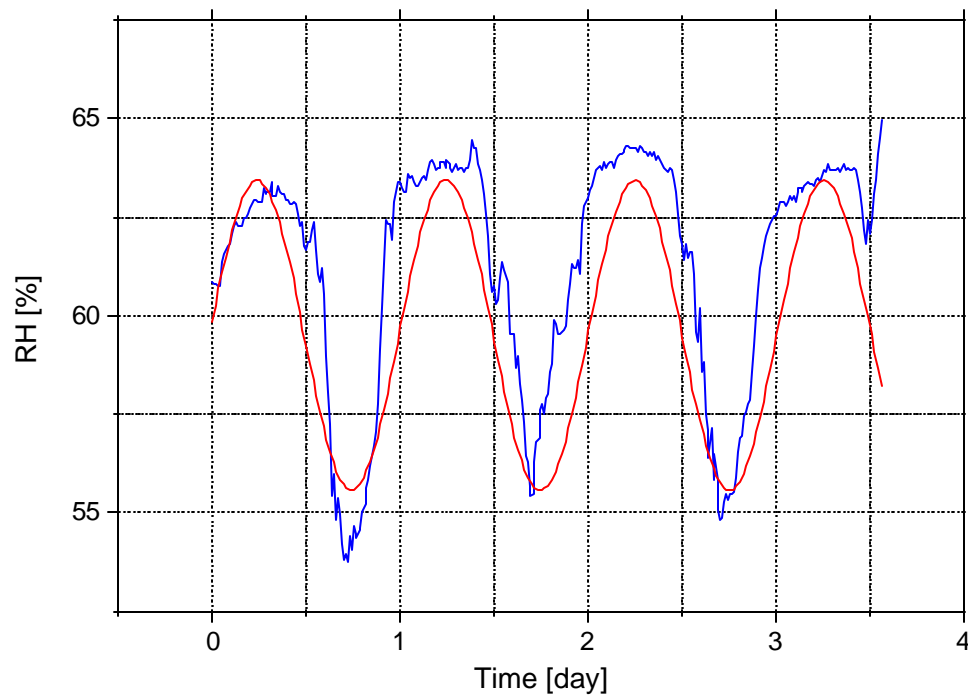Cycle 3 - Board "B" cupping deformation

time to equilibrium
3-4 months

Diffusion of moisture into wood

Time needed to achieve 63% of the final EMC in a panel with both faces free to exchange moisture, subjected to a step RH change

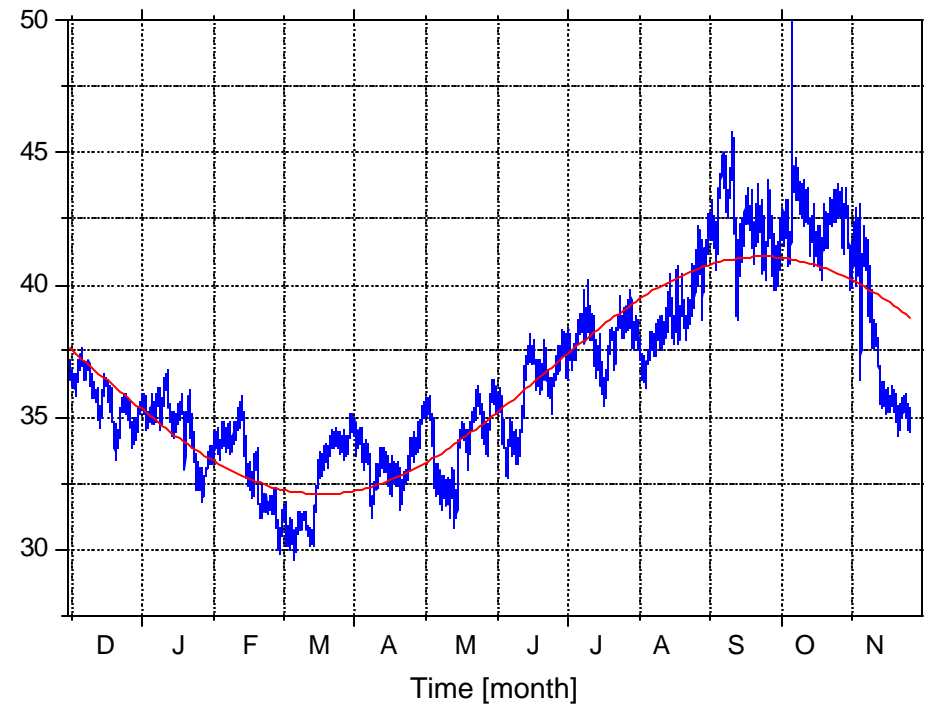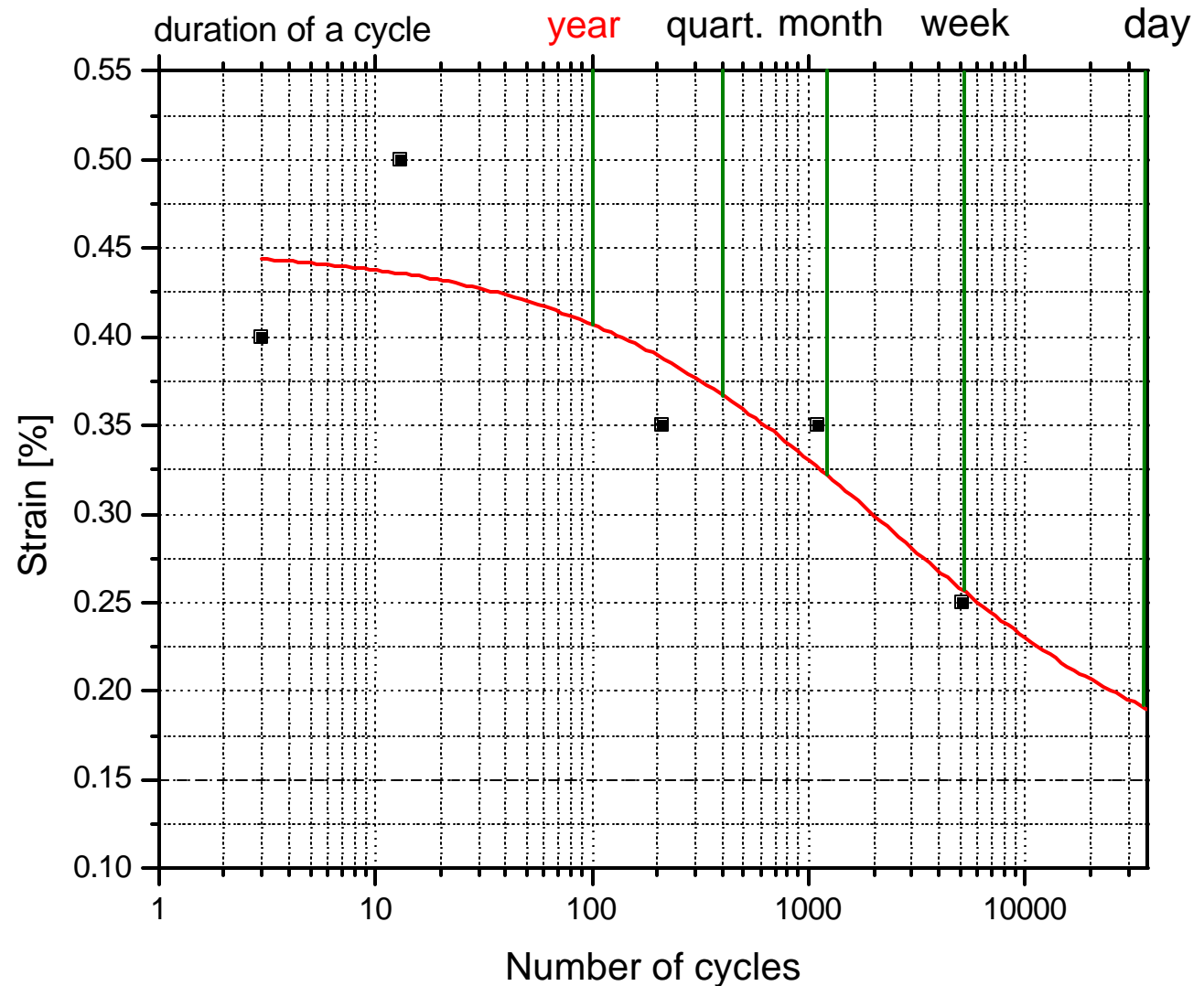# RH variations have various time scales

Diurnal variations
at Malbork Castle, Poland

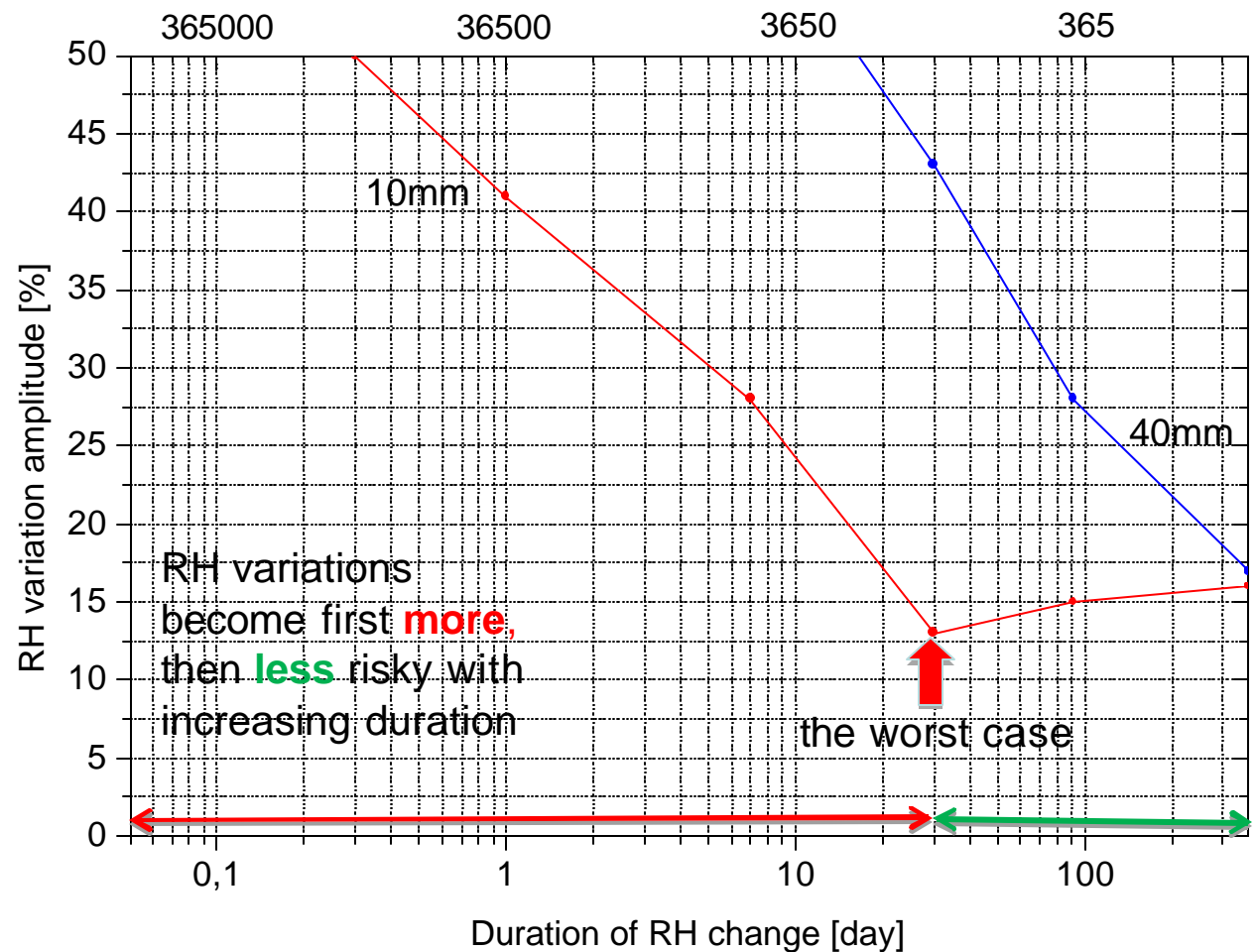Seasonal changes
at V&A Museum, London

Over 100 years wooden objects can endure larger strains if repeated less frequently. Yearly cycles give the maximum gain.

Relationship between the amplitude of allowable RH variations and their duration

RH variations which will not cause damage of panels 10 or 40 mm thick during 100 years

RH variations become first **more**, then **less** risky with increasing duration

10mm

40mm

the worst case

RH variation amplitude [%]

Duration of RH change [day]

365000   36500   3650   365

Panel paintings undergo deformation (cupping)

Thin panels are subjected to a restraint by the applied gesso layer

Christh blessing the children, Lucas Cranach the Elder

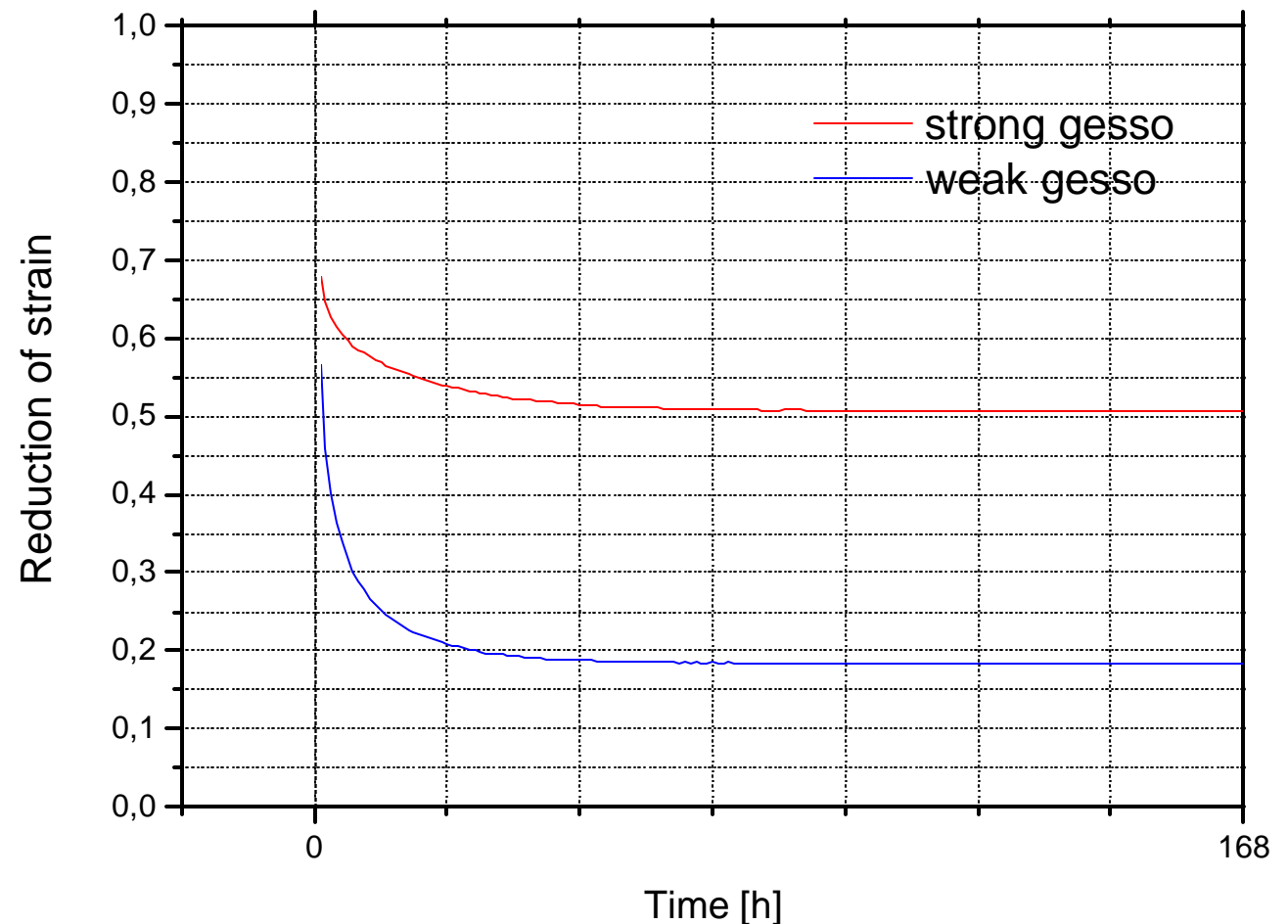lime panel
3-5 mm thick

Wawel Royal Castle, Krakow, Poland
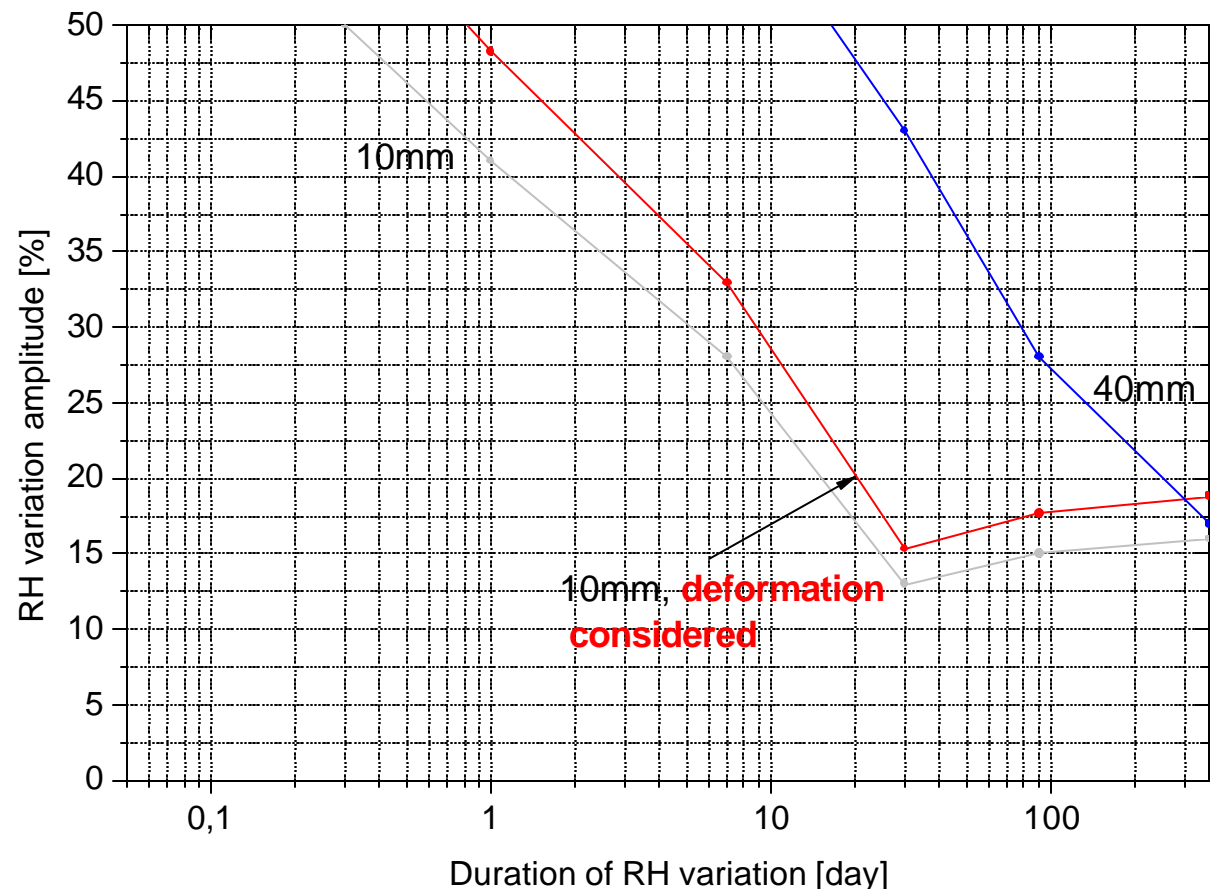
Deformation reduces strain at the painted surface

thickness of a panel 1 cm

thickness of the gesso layer 1 mm
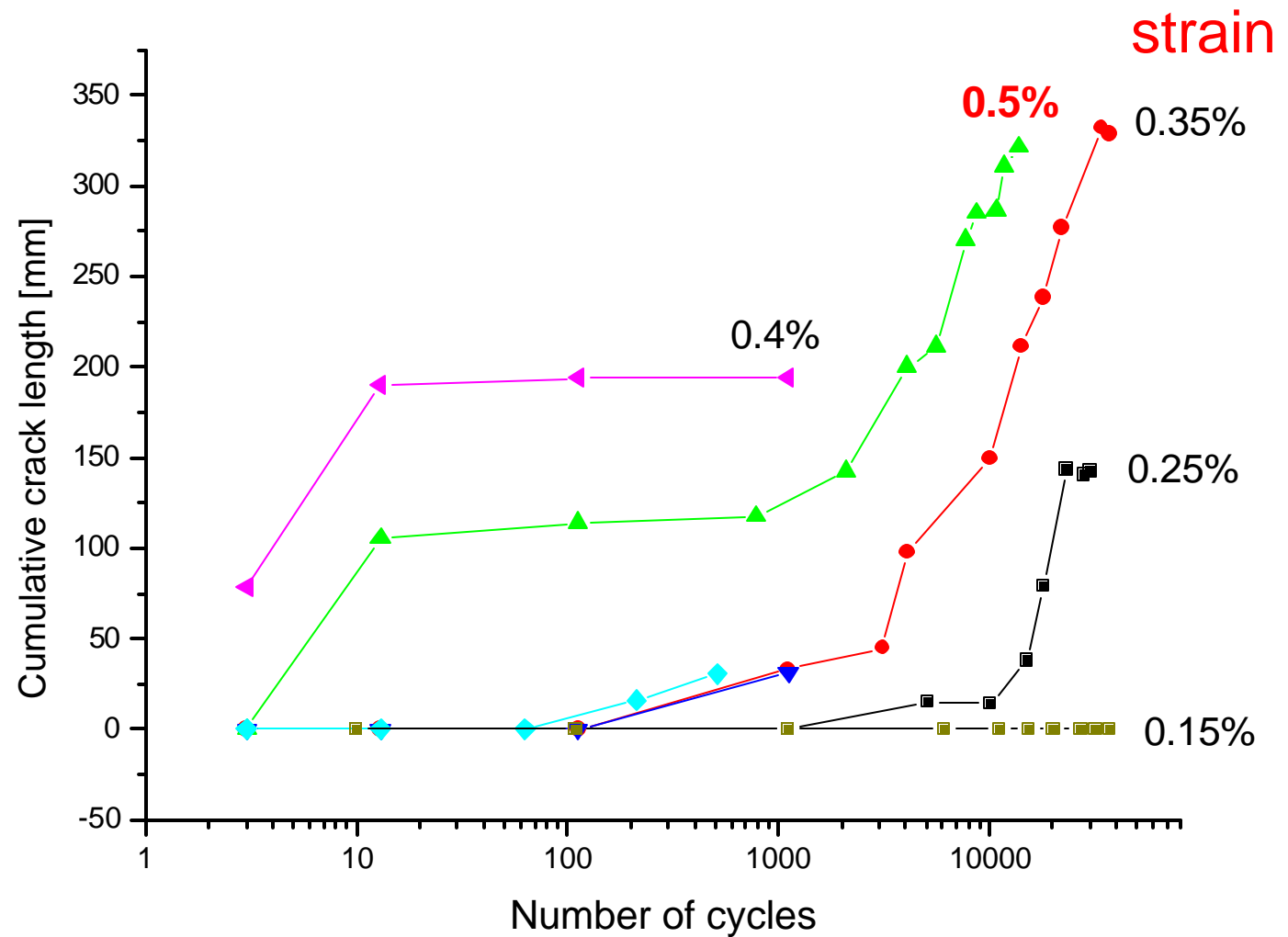
Relationship between the amplitude of allowable RH variations and their duration

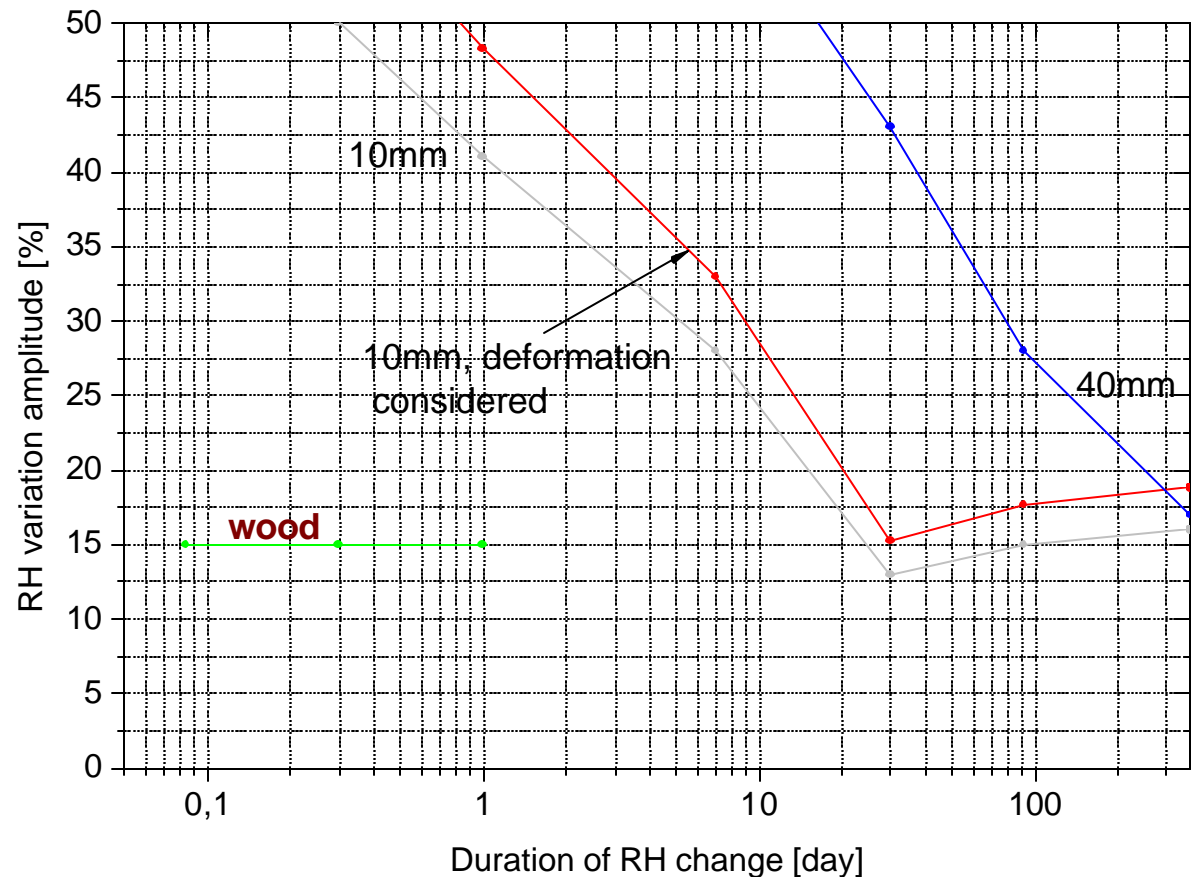RH variations which will not cause damage of panels 10 or 40 mm thick during 100 years

Critical strain for wood – 0.5%
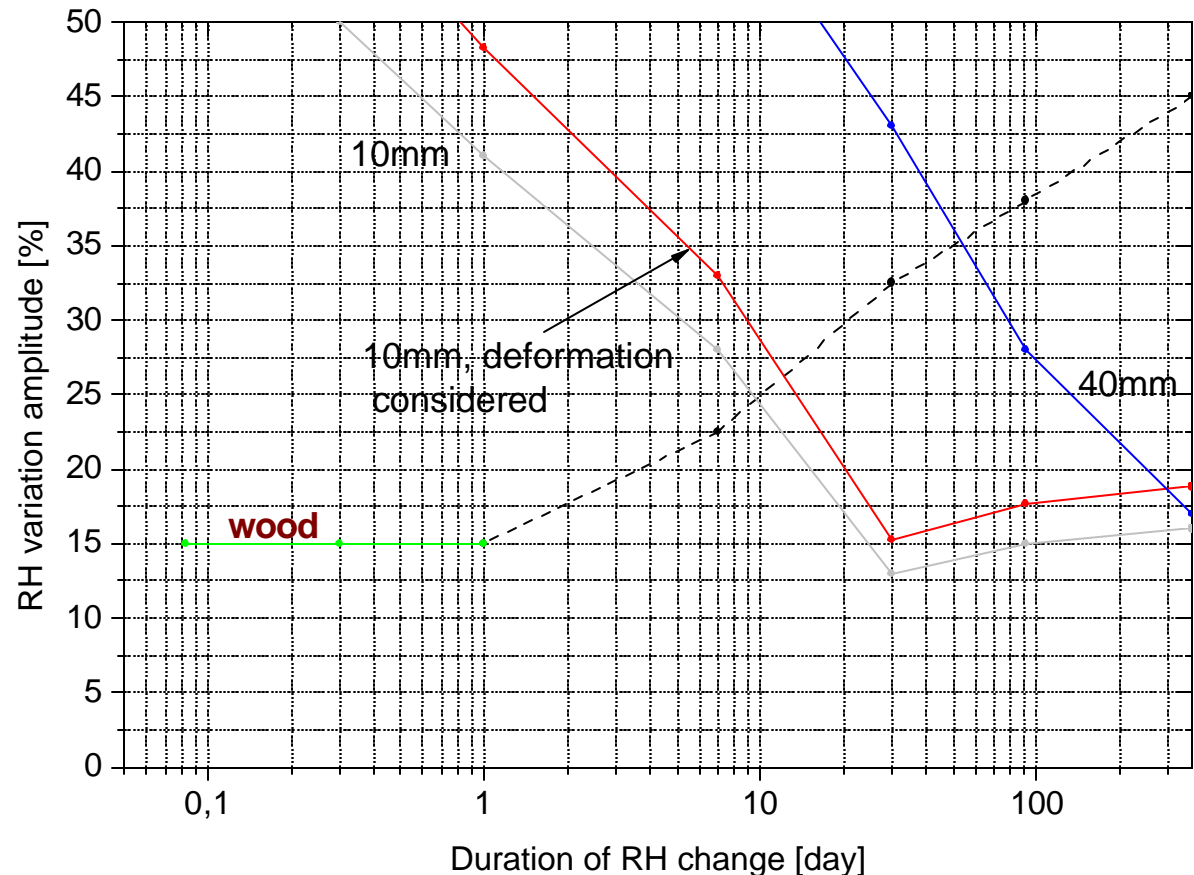
Relationship between the amplitude of allowable RH variations and their duration

S. Jakiela, L. Bratasz, R. Kozlowski, *Wood Science and Technology,* 42, (2008), 21-37

Relationship between the amplitude of allowable RH variations and their duration

B. Madson, *Forest Product Journal,* 25, 8 (1975), 48-53

Allowable RH variations - conclusions

RH-induced wood movement initiating damage after 100 years corresponds to a relatively narrow band of $\pm$ 15%rh centred at 50%rh

… even if the effects reducing strain have been taken into account

How does this compare to
international specifications?

Museums, Galleries, Archives and Libraries, Chapter 21, ASHRAE Handbook – HVAC applications, ASHRAE - American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc. (2007)

Class of control	Short fluctuations	Seasonal adjustment in system set point	Collection risks
A precision control or seasonal changes, not both	± 5%	up 10%rh down 10% rh	small risk of mechanical damage to high-vulnerability artifacts, no risk to most artifacts
	± 10%	no change	
B precision control and seasonal changes	± 10%	up 10%rh down 10% rh	moderate risk of mechanical damage to high-vulnerability artifacts, tiny risk to most artifacts

Allowable RH variations - conclusions

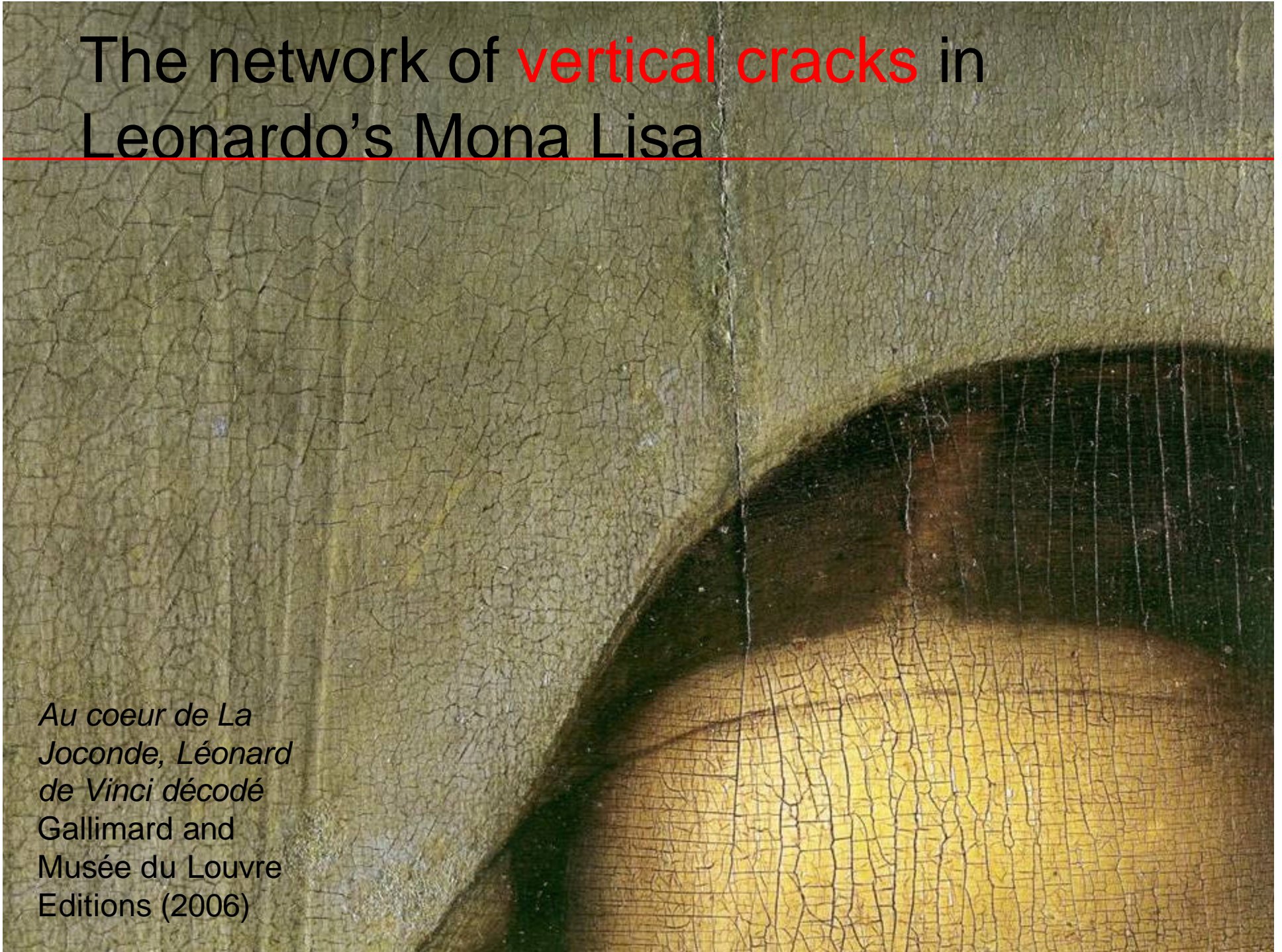Real-world RH variations in churches, historic buildings and many museums often exceed the $\pm$ 15%rh band

Therefore, the decorative layers are usually extensively cracked

The network of vertical cracks in Leonardo's Mona Lisa

Au coeur de La Joconde, Léonard de Vinci décodé Gallimard and Musée du Louvre Editions (2006)
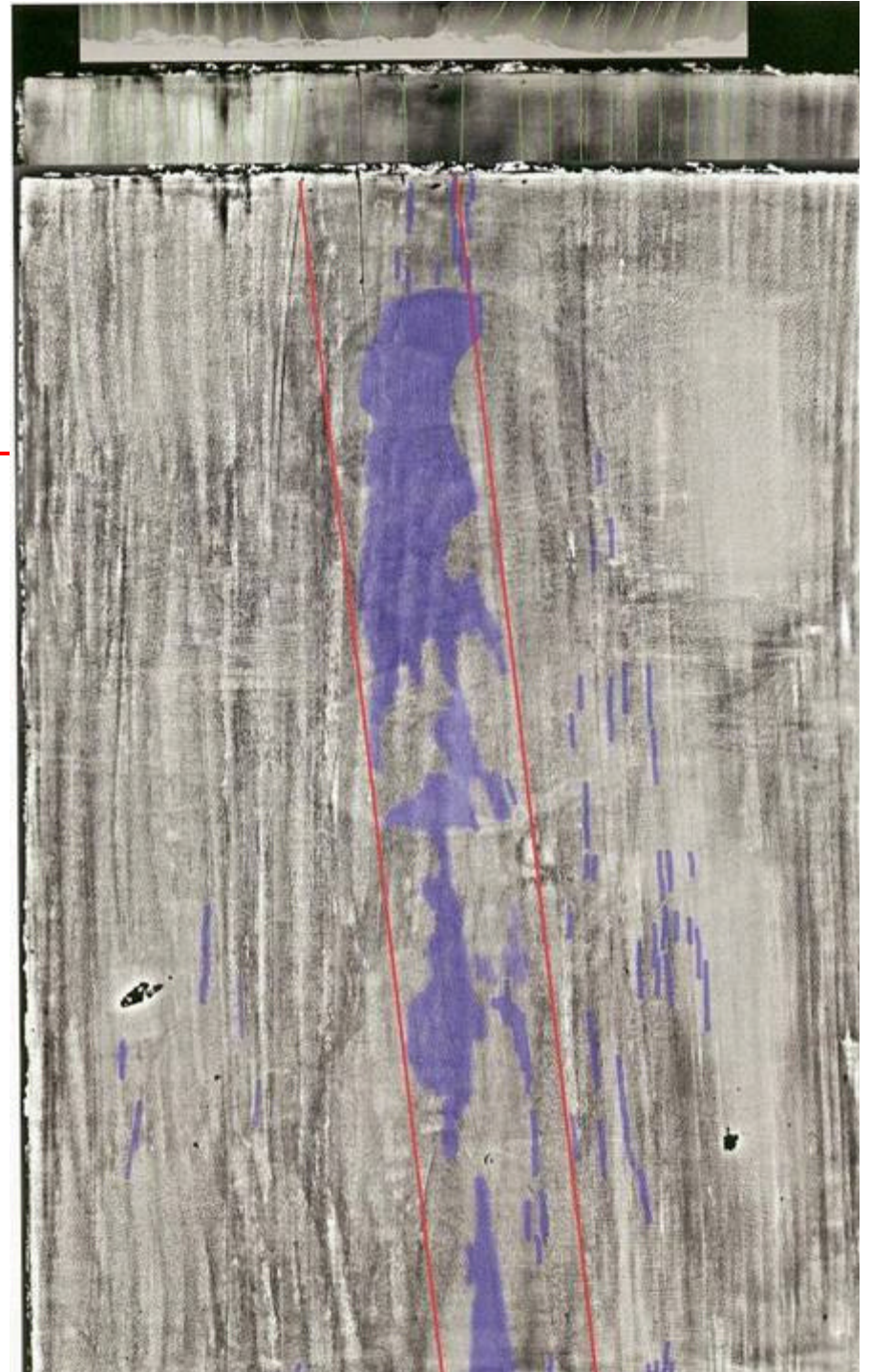
The network of vertical cracks in Leonardo's Mona Lisa

Au coeur de La Joconde, Léonard de Vinci décodé Gallimard and Musée du Louvre Editions (2006)

Next step – a correction due to cracking should be estimated

What is the critical wood movement above which damage in cracked decorative layer appears?

- experimental approach similar to one presented but for specimens with pre-cracked decorative layer

- numerical simulations

Going beyond the analysis of mechanical behaviour of painted wood

- analysis of historic climate - the acclimatisation or 'proofed-fluctuation' concept

- direct tracing non-recoverable micro-changes to objects to determine object-specific safe microclimates with a high precision

- attempts at a generalisation – 'population studies'