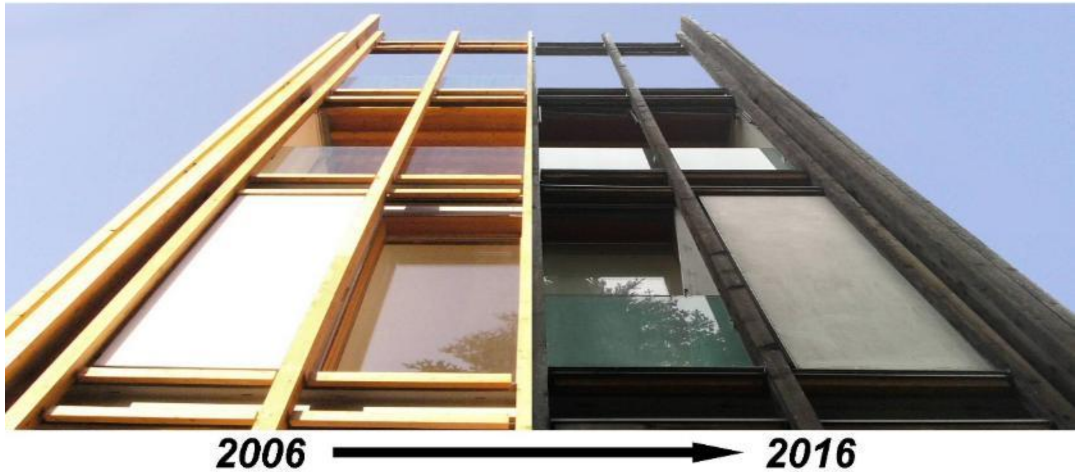

Modelling of weathering

Jakub & Anna Sandak

COST Action FP1407 Training School:
Service life of modified wood - Understanding Test Methodologies

SWORFISH project – modeling of wood appearance

Live presentation of the software

COST Action FP1303: state-of-the-art book

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Elsevier › Books & Journals › Engineering › Civil and Structural Engineering › Building Materials › Performance of Bio-based Building Materials

Performance of Bio-based Building Materials

1st Edition

Authors: Dennis Jones, Christian Brischke

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Expected Release date: June 1, 2017

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Description

Performance of Bio-based Building Materials provides guidance on the use of bio-based building materials (BBBM) with respect to their performance. The book focuses on BBBM currently present on the European market. The state-of-the-art is presented regarding material properties, recommended uses, performance expectancies, testing methodology, and related standards.

Biomaterials performance models

different approaches for modeling:

- «white box» or «black box»

different aspectes for modeling:

- modeling of wood properties (thermo-hygro)
- decay
- mould
- mechanical performance
- service life planning (factor method)
- **weathering / aesthetics**

Weathering

- Weathering is the general term used to define the **slow degradation** of materials exposed to the weather condition.
- The rate of weathering varies within **timber species**, **function of product, technical/design solution, finishing technology** applied but most of all on the **specific local conditions**.
- The process leads to a slow **breaking down of surface fibres**, their **removal**, and in consequence to a **roughening of the surface** and **reduction of the glossiness**.
- The formation of discontinuities on the wooden surface can cause penetration of the **wood-decaying biological agents** into the material structure and influencing mechanical performances of the load-bearing members.

“Facades” change in time

original state

1 month

3 months

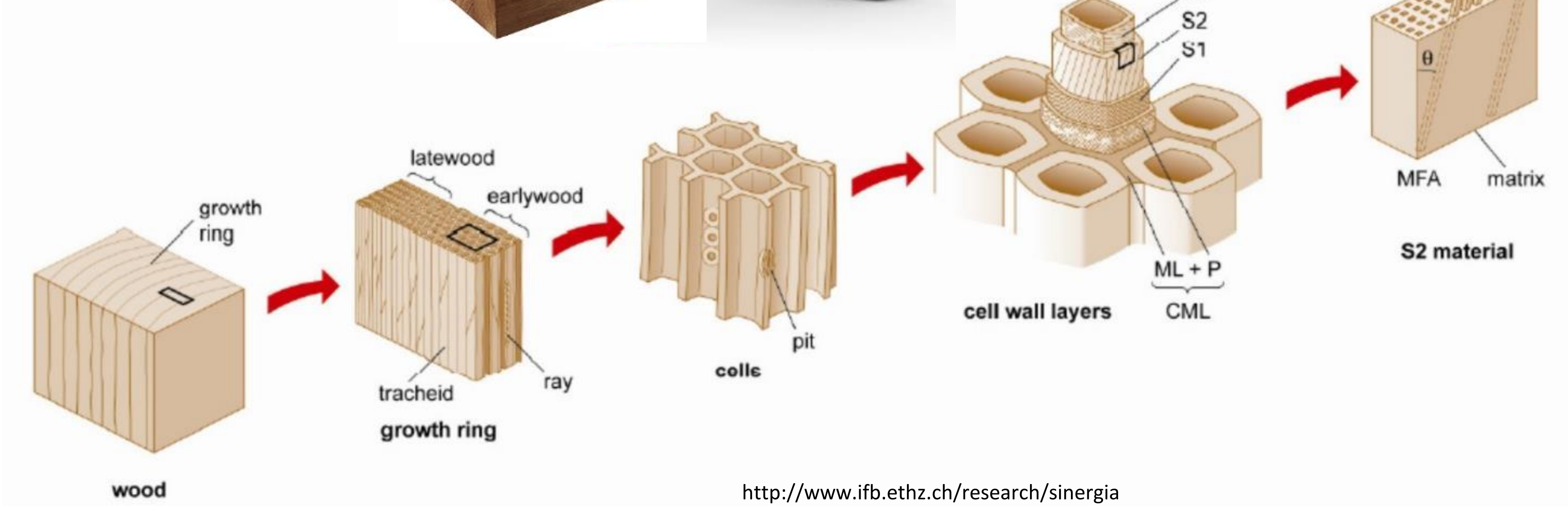
6 months

9 months

12 months

Mechanisms of (wood) surface weathering

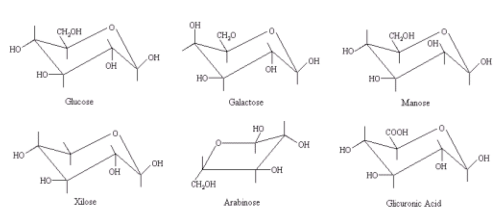
- Different levels:
  - molecular
  - cellular
  - tissue
  - macro

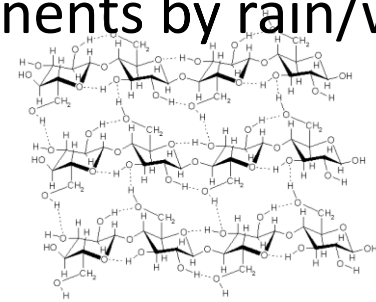


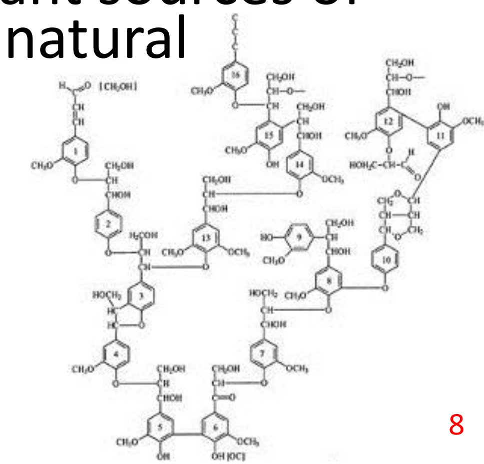
http://www.ifb.ethz.ch/research/sinergia

Molecular level

- The absorption of UV light emitted by the sun induces lignin degradation and the photo-oxidation of functional groups (–CH2, –CH or –OH) of constitutive polymers:
  - the photo-degradation of lignin is indicated by a rapid decrease in the lignin content accompanied by generation of carbonyl groups
  - degradation of cellulose is indicated by a loss of its weight and reduced degree of polymerization
  - the degradation rates for the amorphous regions in carbohydrates are faster than in lignin
  - crystalline regions of cellulose are considered as chemical structures most resistant against weathering.
- hydrolysis and oxidation reactions are other significant sources of changes to bio-material molecular structure during natural weathering
- leaching of degradation components by rain/wind



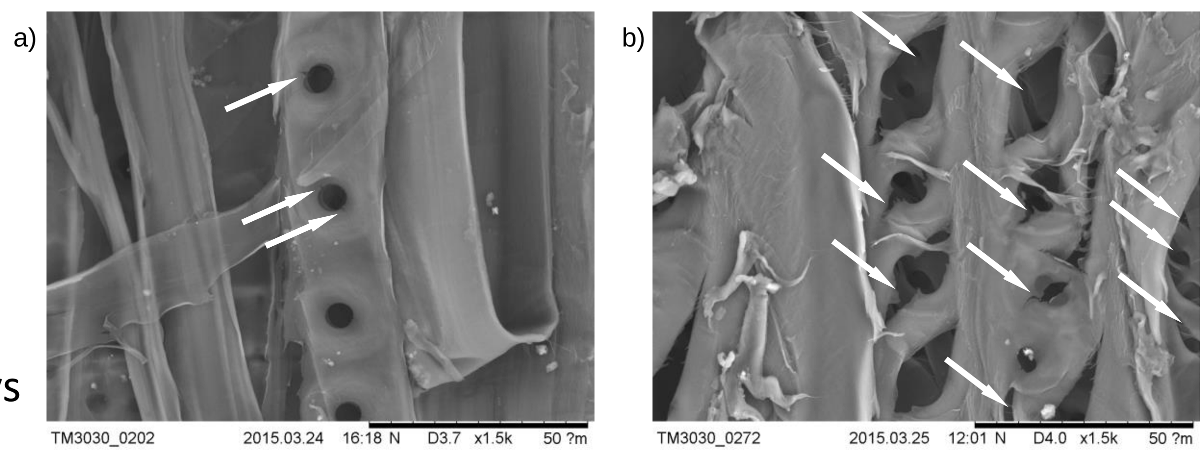




Cellular level

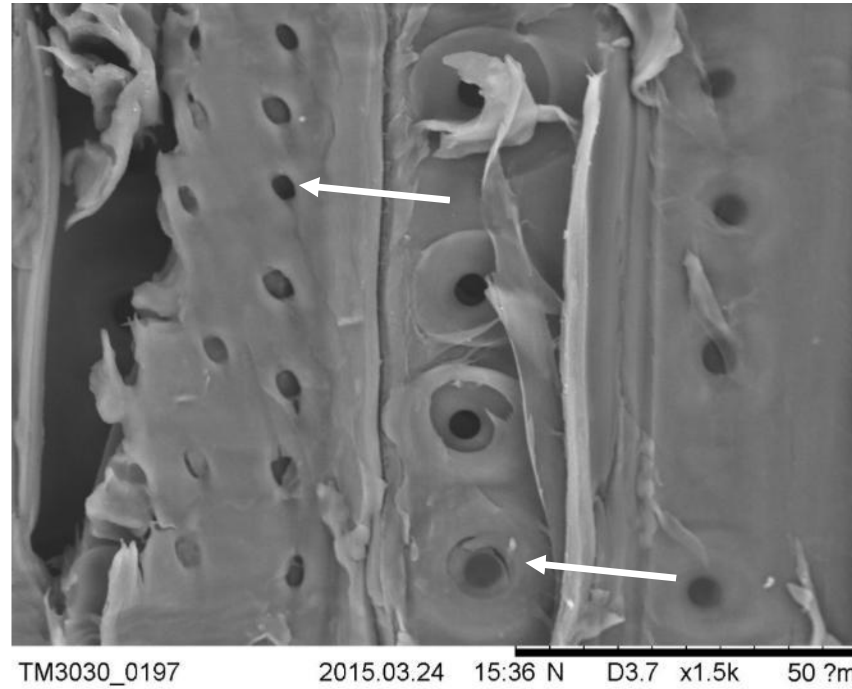
- chemical changes lead to a slow break down of surface fibres, removal and subsequent roughening of the surface and decrease of its glossiness.
- the graying process follows a particular sequence:
  - photodegradation of cell wall polymers by sunlight
  - washing out degradation products by rain
  - colonization of the surface by staining fungi able to metabolise remaining wood chemical components
- pitch cracks are generated as the result of the mechanical stresses within the cell wall are caused by cycling moisture variations
- Disconnection of surface cells, being an effect of the breakdown of the middle lamella is observed early after the weathering starts

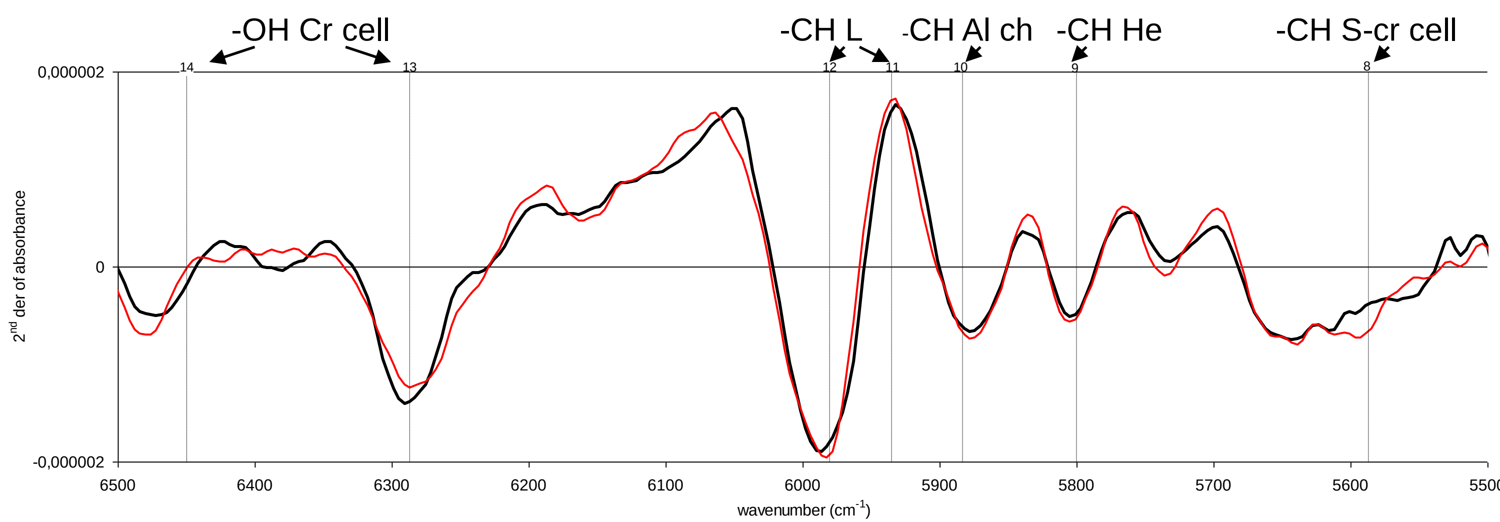
7 days



24 days


001A
4 days
001D

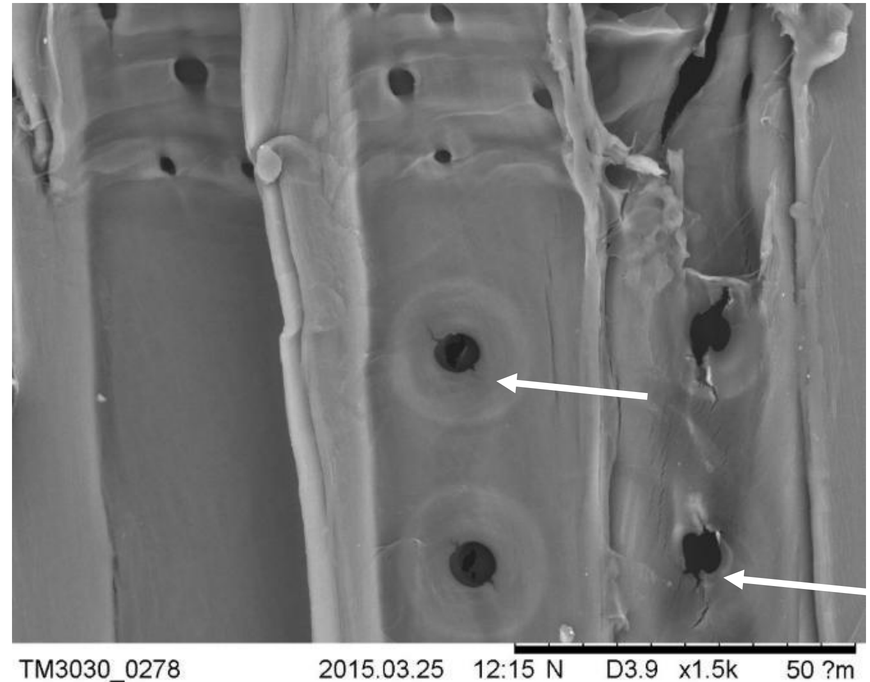

TM3030_0197 2015.03.24 15:36 N D3.7 x1.5k 50 ?m

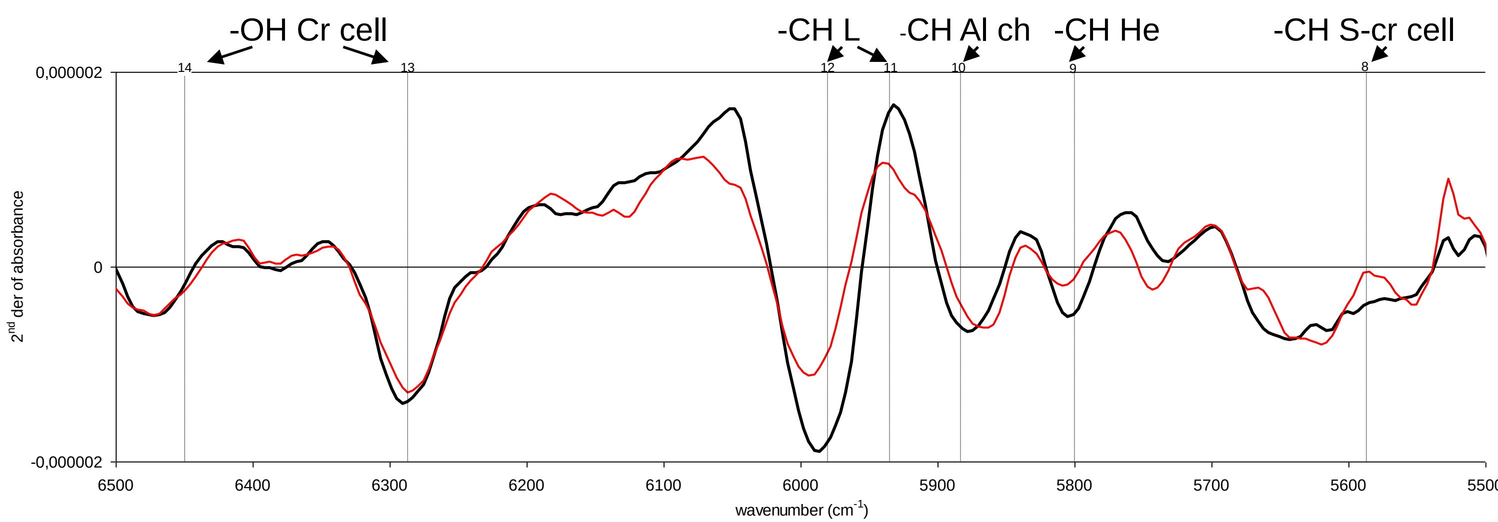

-OH Cr cell
-CH L
-CH Al ch
-CH He
-CH S-cr cell
14
13
12
11
10
9
8
0,000002
0
-0,000002
2nd der of absorbance
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
wavenumber (cm-1)


001A

11 days


001G


TM3030_0278
2015.03.25
12:15 N
D3.9
x1.5k
50 ?m


-OH Cr cell
-CH L
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0
-0,000002
2nd der of absorbance
6500
6400
6300
6200
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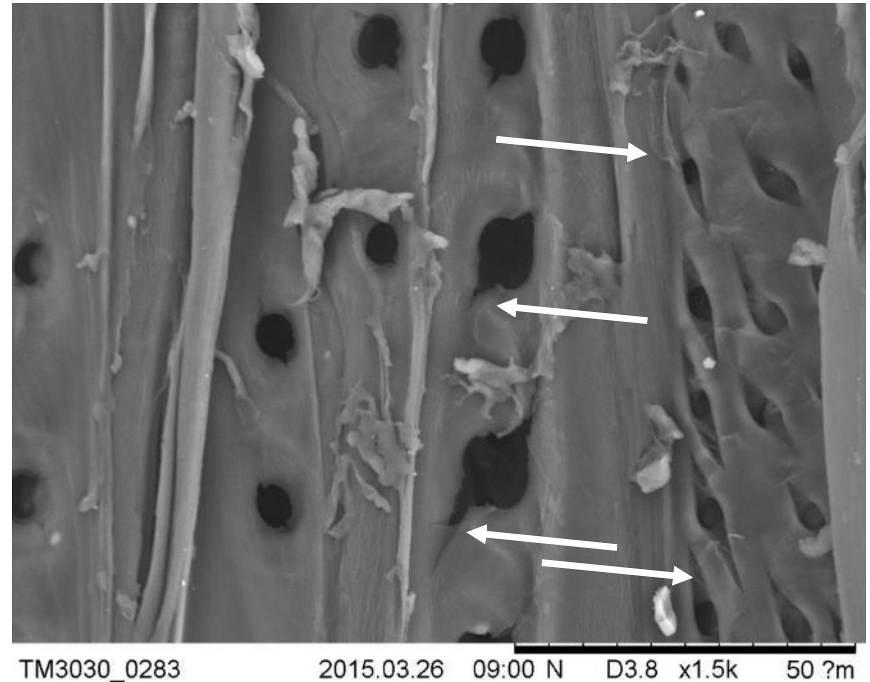
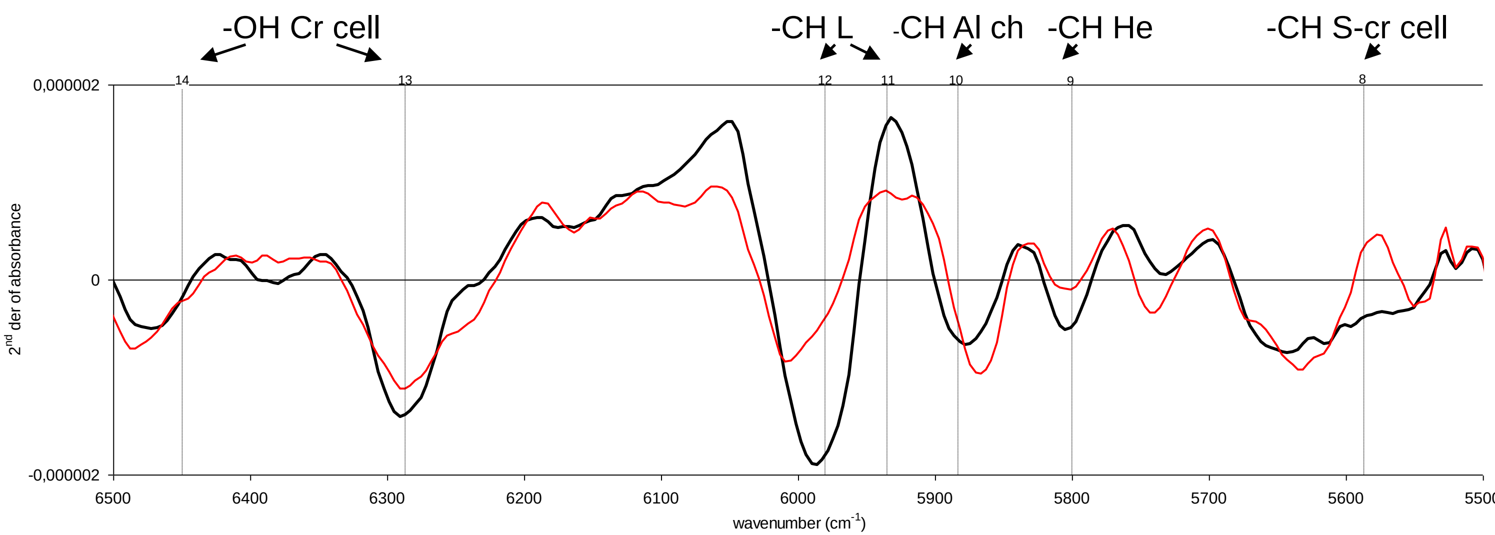
6000
5900
5800
5700
5600
5500
wavenumber (cm-1)


001A

28 days


001L


TM3030_0283
2015.03.26 09:00 N D3.8 x1.5k 50 ?m


-OH Cr cell
-CH L
-CH Al ch
-CH He
-CH S-cr cell
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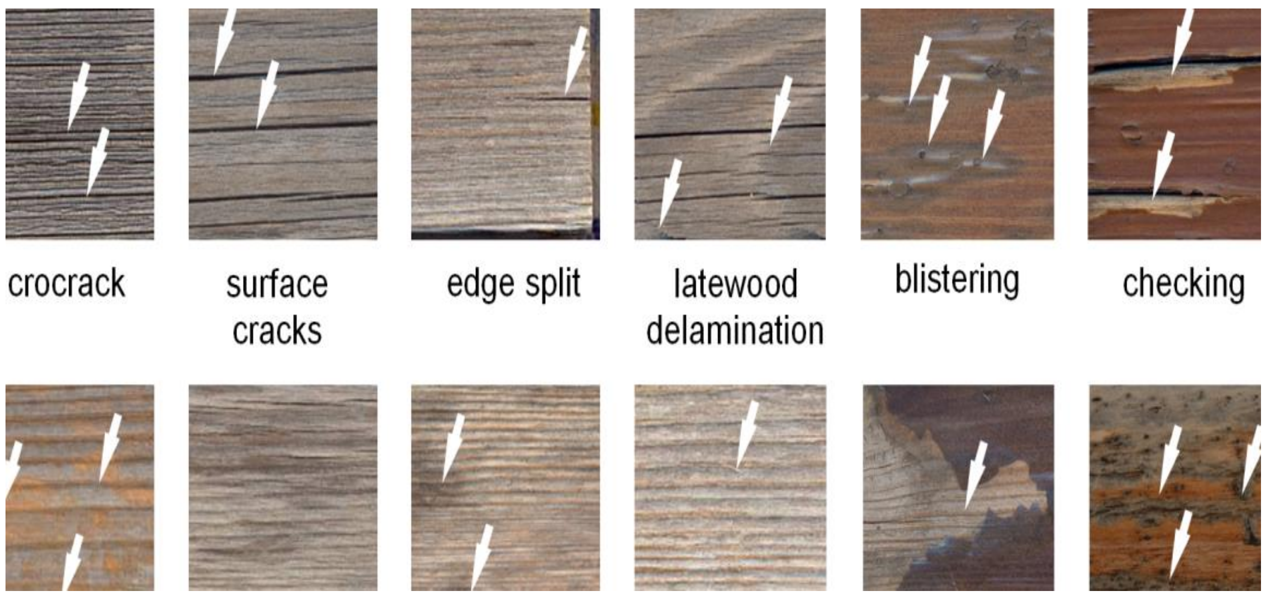
-0,000002
2nd der of absorbance
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
wavenumber (cm-1)

Tissue level

- early wood is more susceptible to damage due to weathering than latewood, since cells in early wood have thinner/weaker cell walls and relatively high porosity
- surface cracks on the radial section occur primarily at the annual ring border
- early wood erodes more quickly than latewood and measurable attrition can be noticed already after a few weeks of exposure

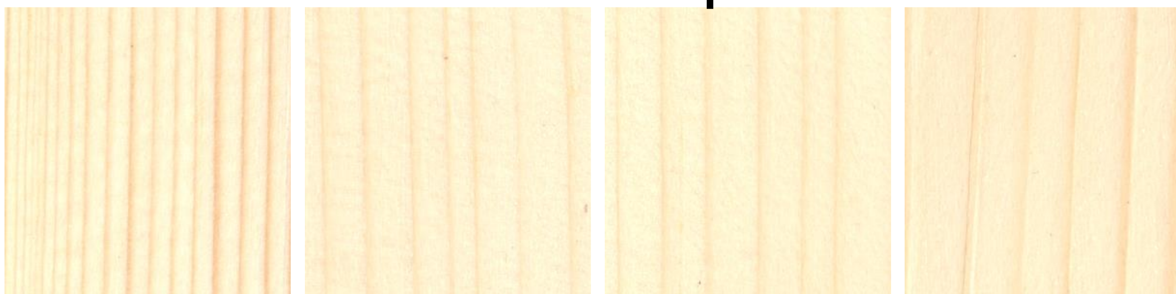
Macro level

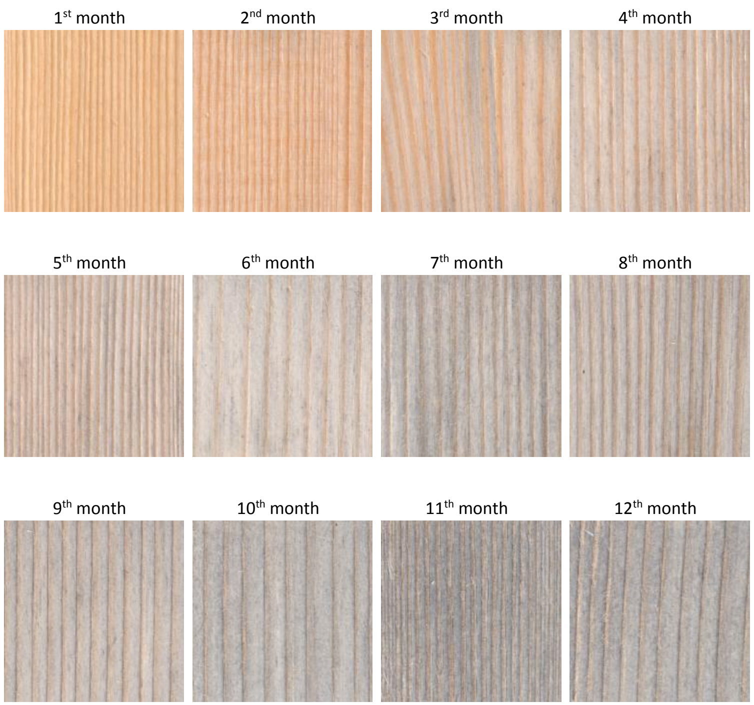
- changes of the visual appearance: color, roughness, surface checking, dirt uptake, and growth of mold are the most apparent effects of weathering
- dramatic changes to the surface color occur already after a few months of exposure:
  - the surface became gradually grey till mold or fungi further alter the color
  - in most cases the surface gloss decreases with the progress of surface weathering
  - surface roughness increasing monotonously along the weathering time
  - surface defects may appear on untreated and coated surfaces of bio-materials



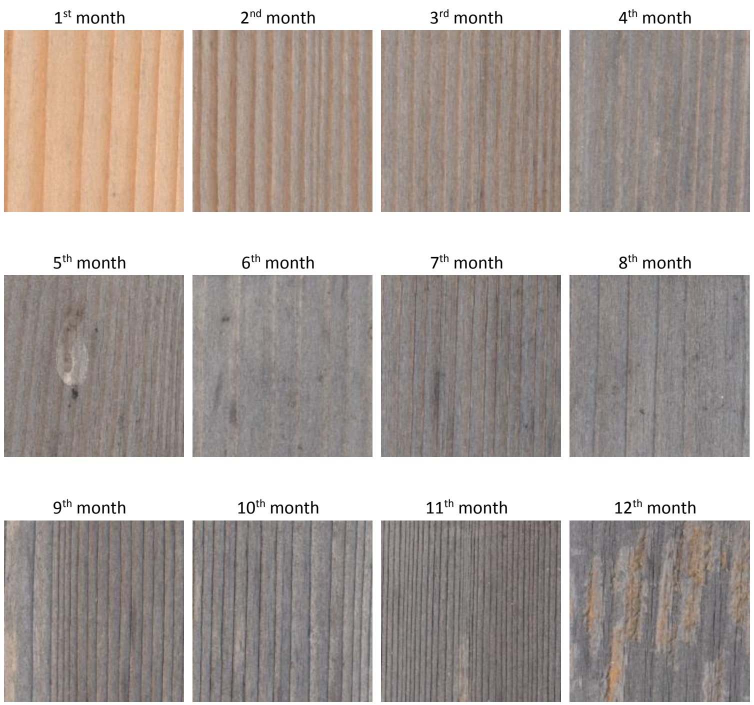
Weathering effect on wood apearance

Reference samples



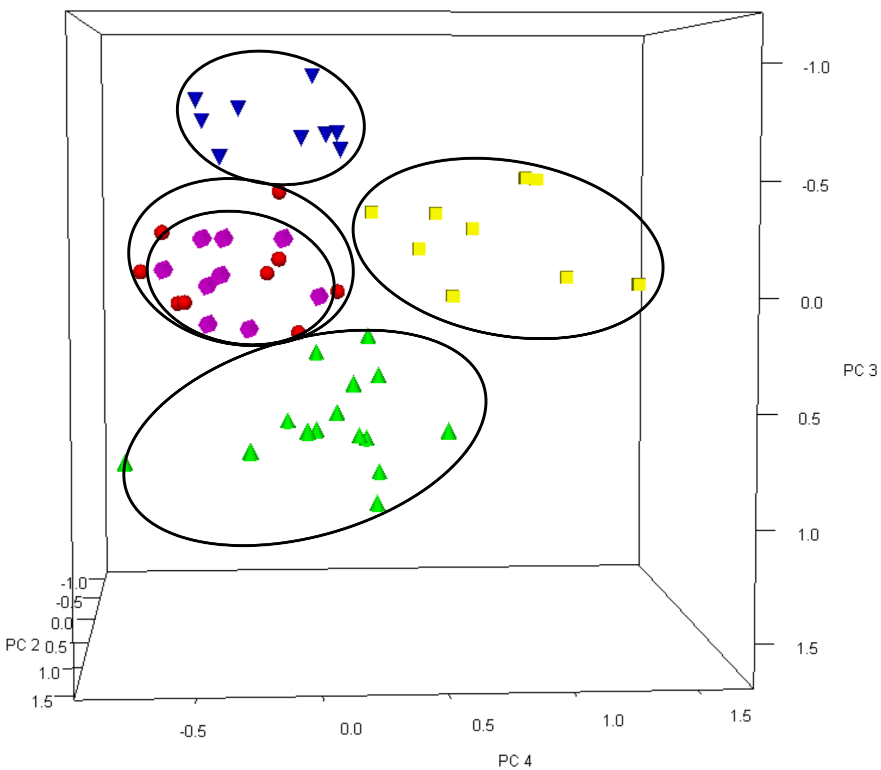


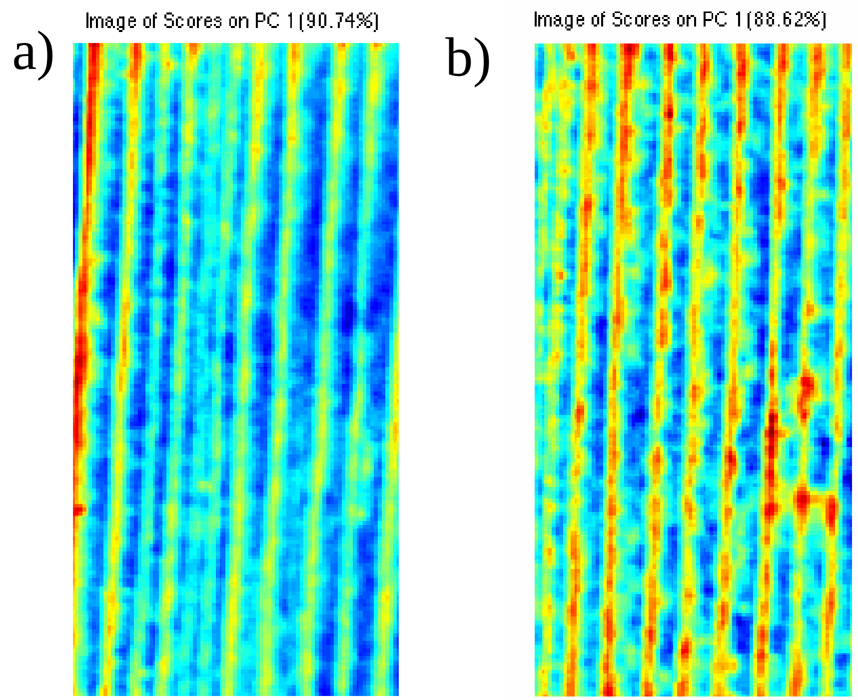
#22 (UK-Bangor)



#20 (Turkey)

Changes to early/late wood (PCA)



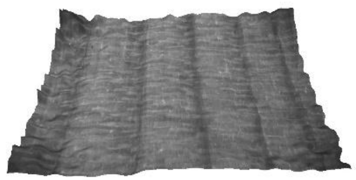


PCA of samples exposed for >20 days against: ● South ▼ West ■ North ■ East ▲ Reference

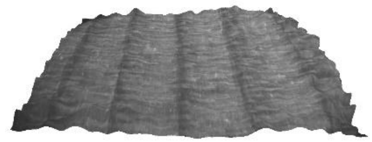
PCA analysis performed on not weathered (a) and sample after 28 days of weathering (b)

Surface erosion: Depth of field

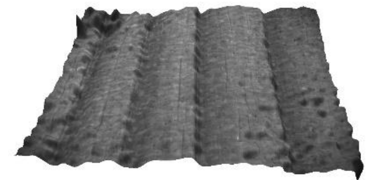
1st month



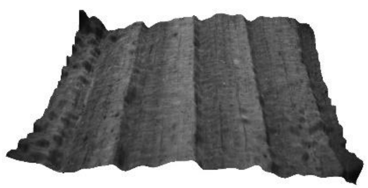
2nd month



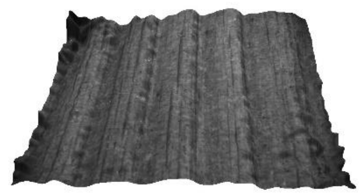
3rd month



4thmonth

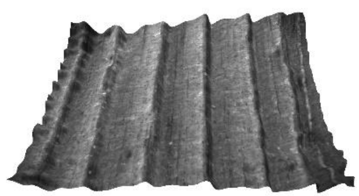


5th month

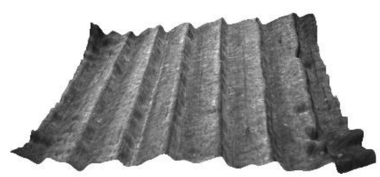


6th month

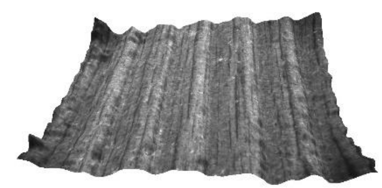
7th month



8th month

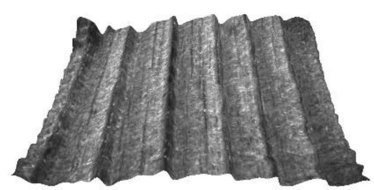


9th month

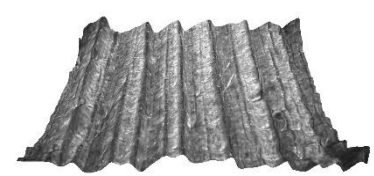


10th month

11th month



12th month



Preparation of reference data

- development of high quality numerical models requires access to an extensive data set of reference information containing a wide range of weathering scenarios

	aesthetics				surface property		
sensor	*colour*	*pattern*	*gloss*	*roughness*	*chemistry*	*moisture*	*pollutions*
colormeter	✓						
gloss meter			✓	✓			
stylus				✓			
laser displ. sensor				✓			
VIS spectrometer	✓						
NIR spectrometer					✓	✓	✓
moisture meter						✓	
CCD camera	✓	✓		✓			
hyperspectral camera	✓	✓			✓	✓	
IR camera		✓				✓	
XRF spectrometer							✓

Non-destructive & easy-to-use sensing techniques usable for characterization of weathered wood

Degradation of bio-materials during service life

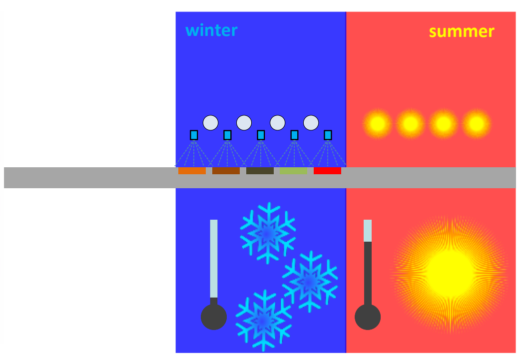
- artificial weathering: QUV, Suntest and custom weathering machines
- natural weathering: stations located at different locations
- in-field inspections of the real buildings
- living laboratory/model house

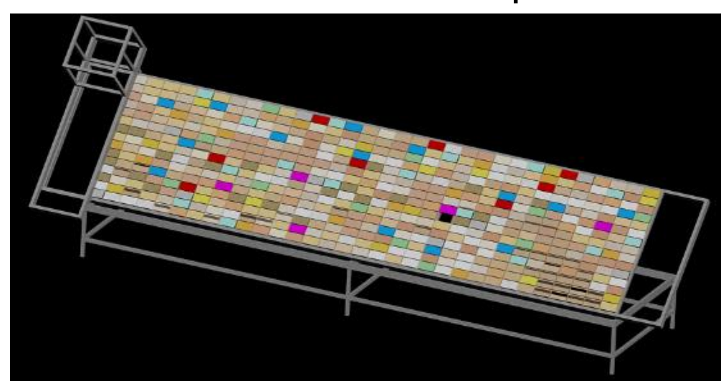

digital camera

weather station

Arduino moisture & temperature

MicroNIR





Multi-sensor assessment

- data collected from diverse instruments are often based on dissimilar foundations and reflect varying material properties
- some sensors may be more accurate than others, depending in each case on the specific application conditions
- the data collected from different sensors are usually correlated with each other, which makes it necessary to interpret these together
- in most cases raw data acquired by sensors are not suitable for direct interpretation and even more for multi-sensor data fusion - pre-processing is indispensable:
  - electronic signal conditioning: amplification, filtering, compensation, etc.
  - numeric signal manipulation: normalization, filtering, correction, derivative, integration, noise reduction, smoothing, interpolation, averaging, convolution, etc.
  - digital signal processing: compression, filtering, wavelet analysis, Fourier transform, etc.
- the usual result of the data fusion process is a matrix containing series of parameters corresponding to single sample/case, collected at a given moment or over a defined period of time

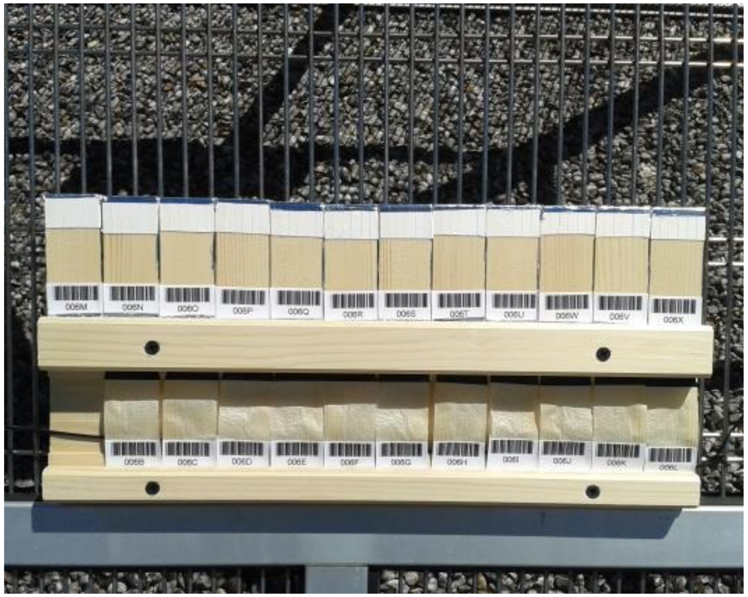
“Heritage” of the COST FP1006 Round Robin test

- 28 sets of samples (*Picea abies*) were exposed in 16 locations in Europe and Brazil.
- Samples were collected after 0, 1, 2, 4, 7, 9, 11, 14, 17, 21, 24 and 28 days of weathering + every month during one year
- Characterized with color CIE Lab, VIS, NIR and MIR spectra, imaging, gloss, XRF, roughness, microscopy, TGA, hyperspectral imaging

Round Robin test set-up

18 locations,

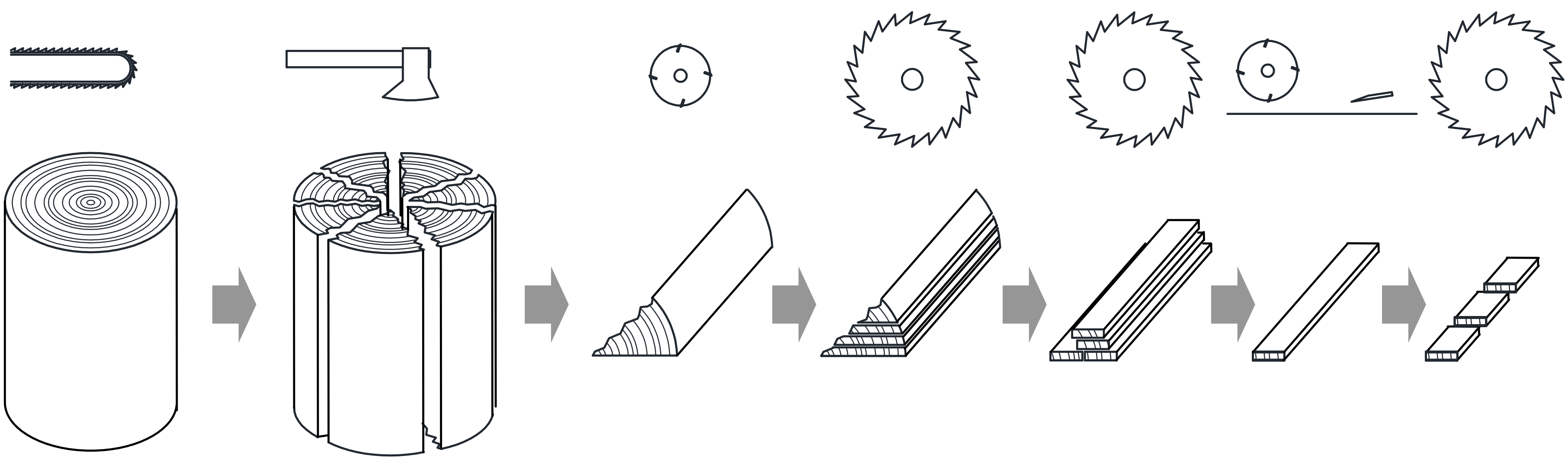
28 samples sets



samples weathered for one year, collected every month

Experimental samples

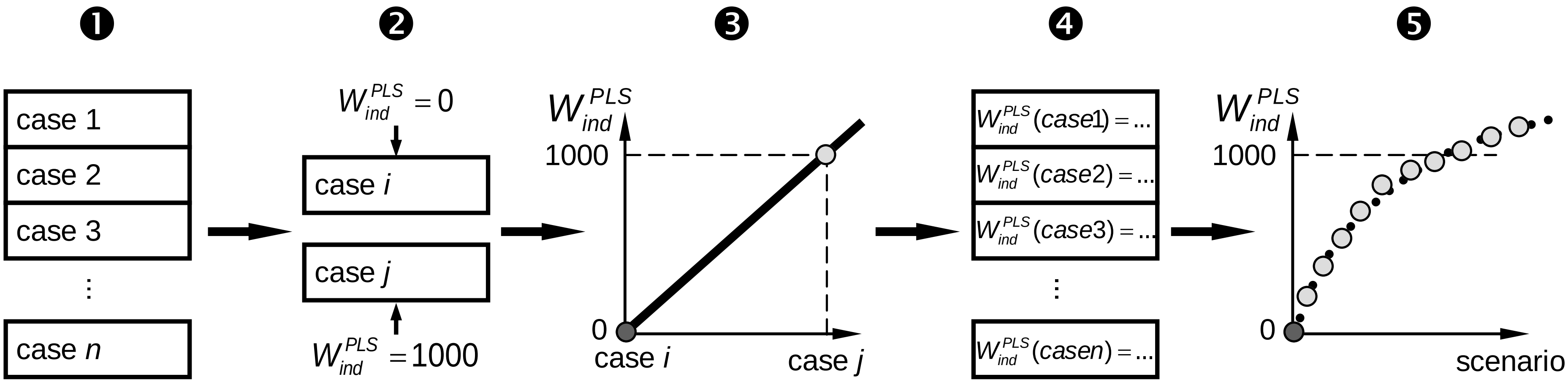
- one piece of Norway spruce (*Picea abies*)
- the efficient surface 30 x 30mm
- conditioned in 20°C, 60%RH



Methods for numerical modeling of weathering

#1: regression models

Regression models



Modeling of weathering with partial least squares approach:

❶ - collection *n* sets of data corresponding to different cases

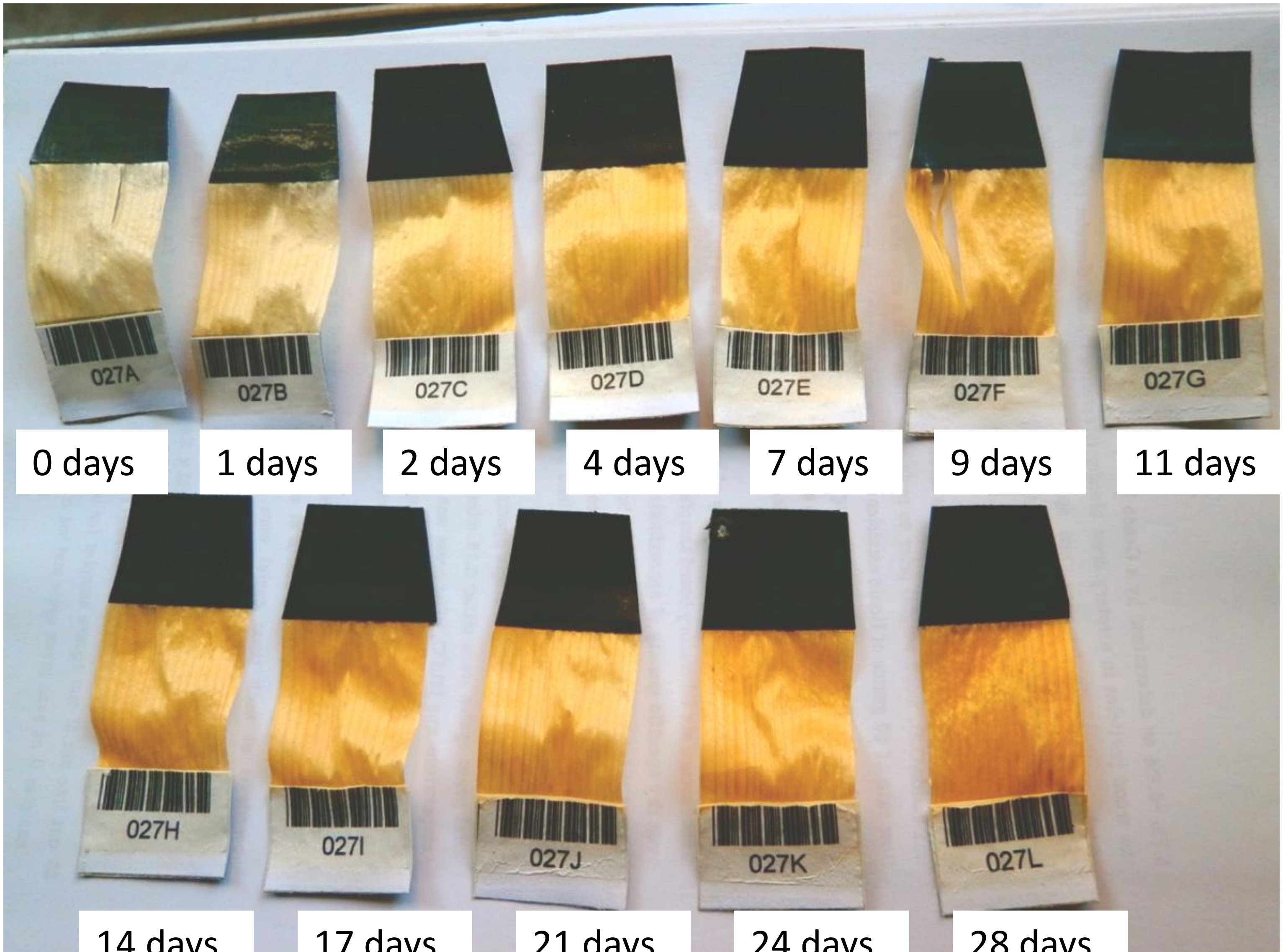
❷ - selection of two reference cases representing initial stage of weathering and a reference state

❸ - development of PLS model on the base of two reference points

❹ - apply PLS model for prediction of the weathering indicators for all cases from the collection

❺ - data mining and prediction of the weathering indicators

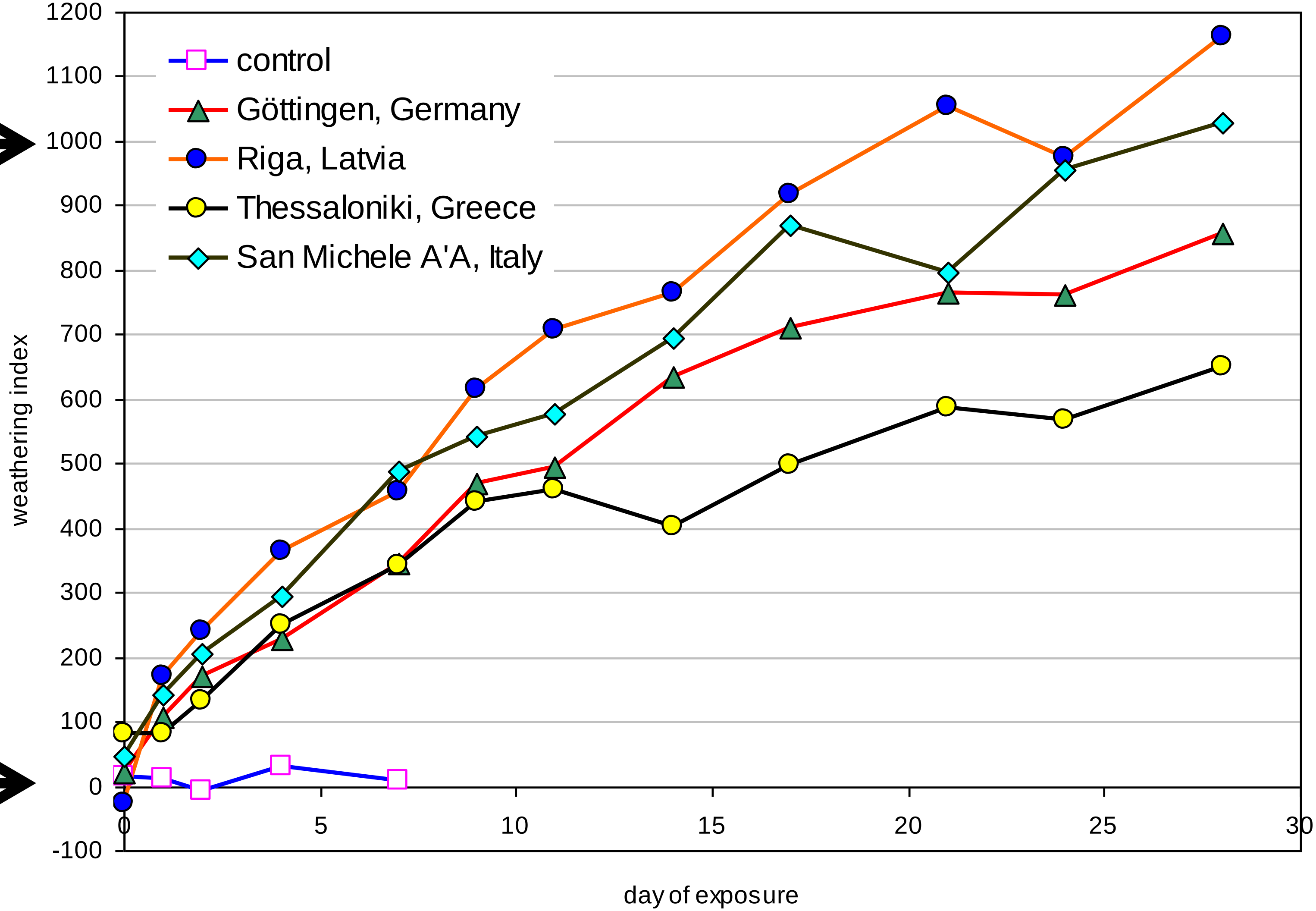
what is the degradation stage?



Weathering index estimated on the base of NIR spectra

weathered (reference)

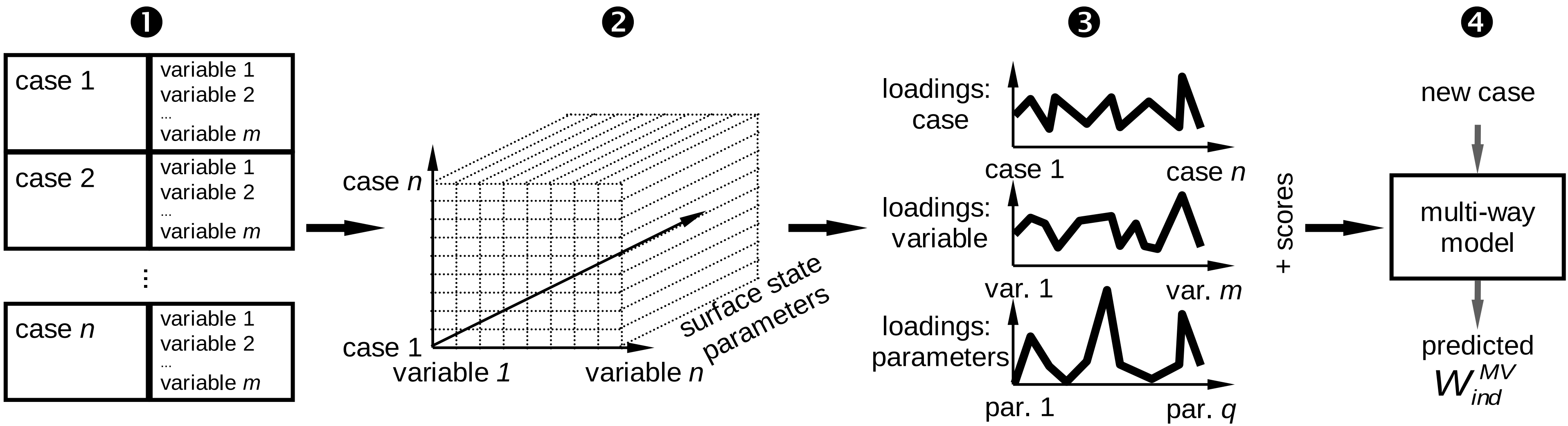
no weathered



Methods for numerical modeling of weathering

#2: multiway models

Multi-way approach for modeling



Modeling of weathering with multi-way approach:

❶ - collection series of corresponding data sets,

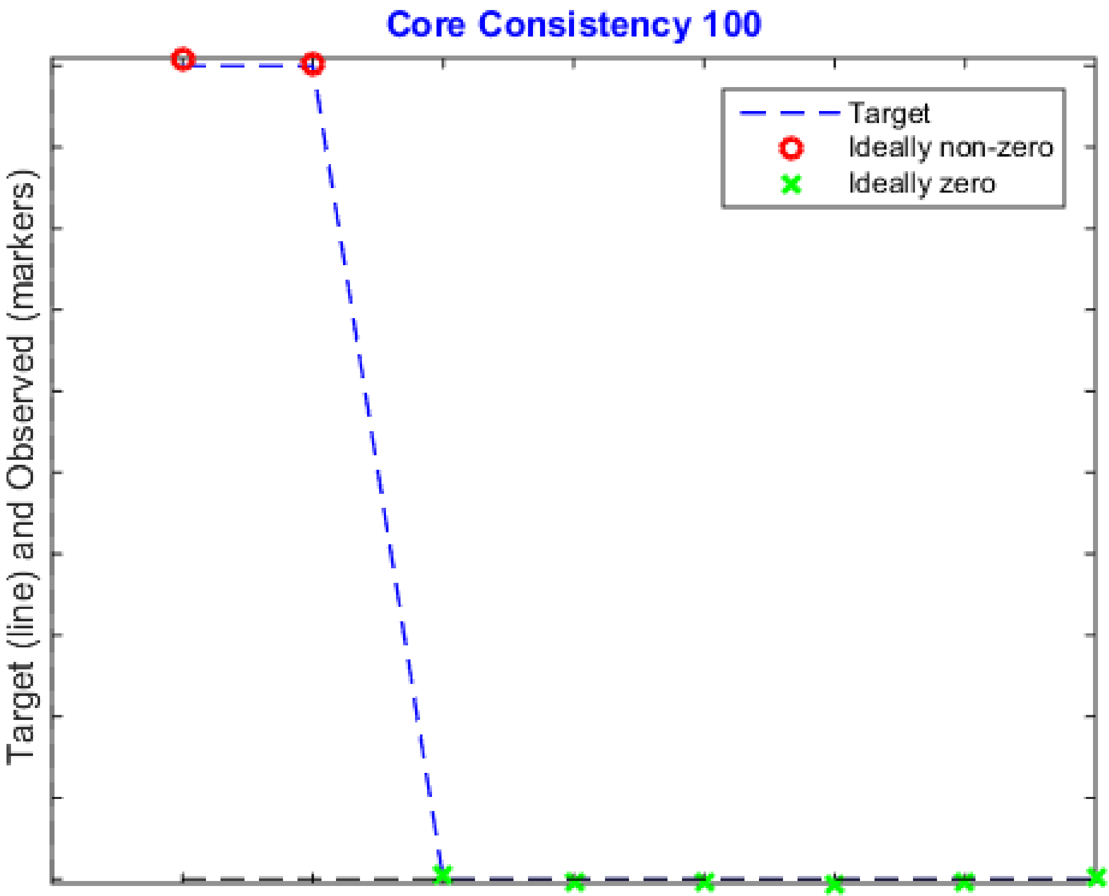
❷ - unfolding data,

❸ - development of multi-way model including loadings and scores,

❹ - apply multi-way model for prediction of the weathering indicator for unknown case

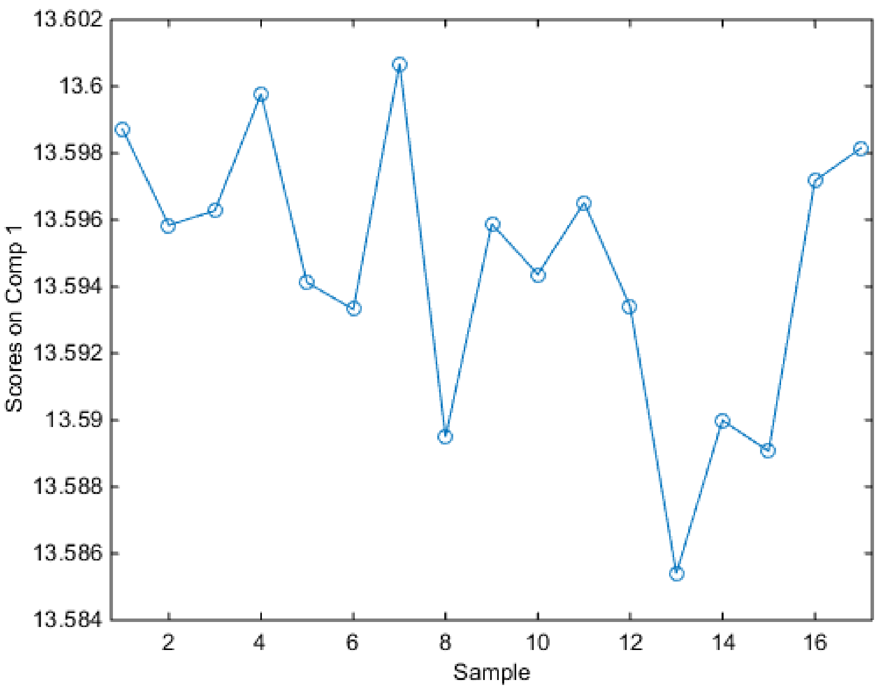
NIR parafac

- Consistency plot

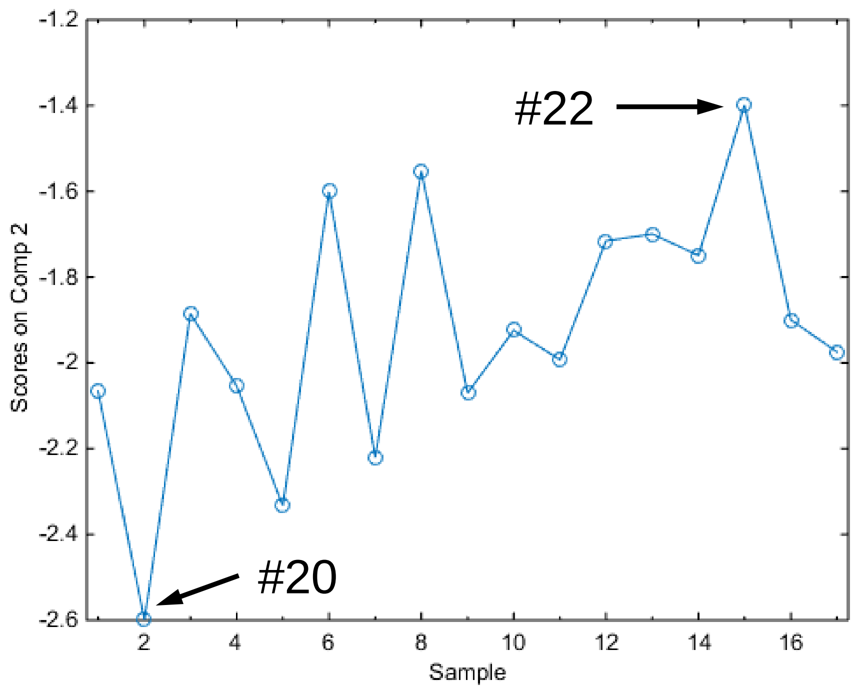


NIR parafac

- Effect of exposure location - identification of extreems locations



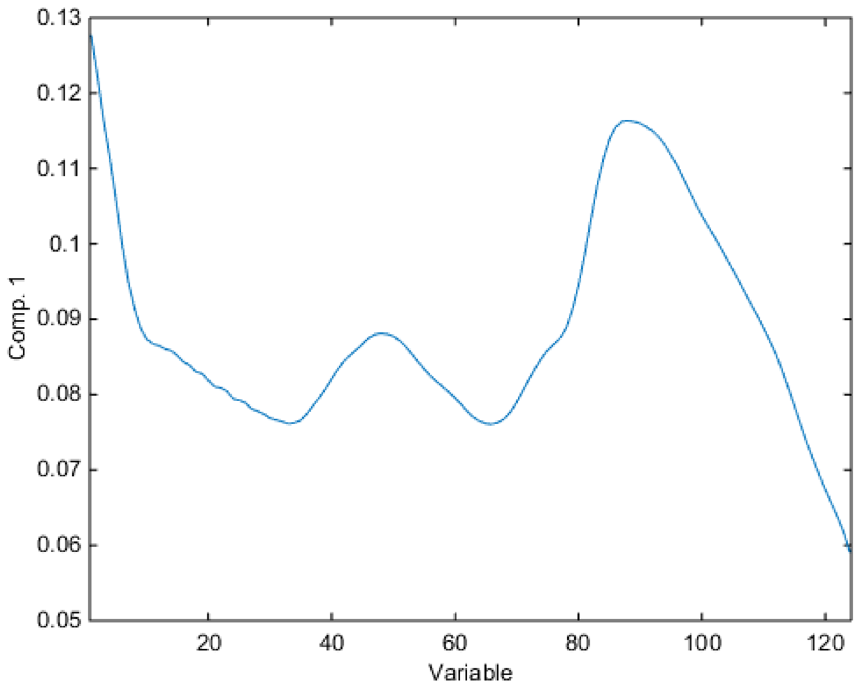
Component 1



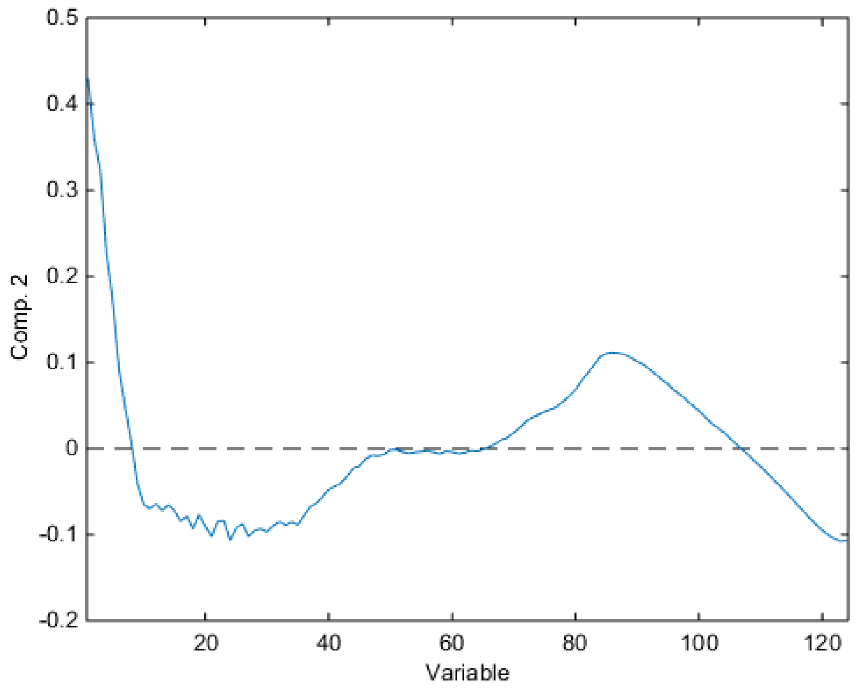
Component 2

NIR parafac

- Effect of spectra – identification of wavelengths important for degradation



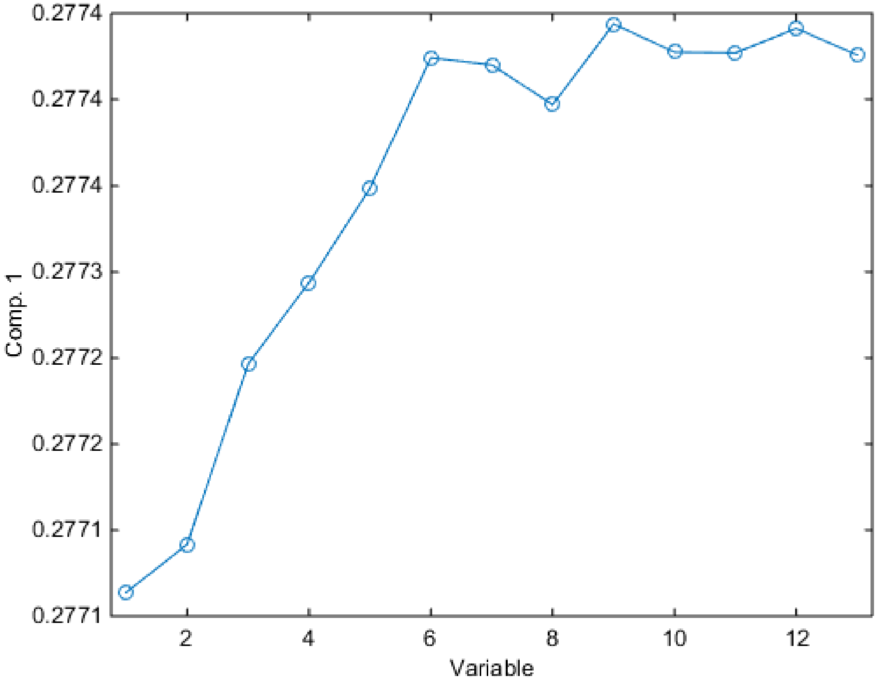
Component 1



Component 2

NIR parafac

- Effect of degradation time – kinetic of weathering



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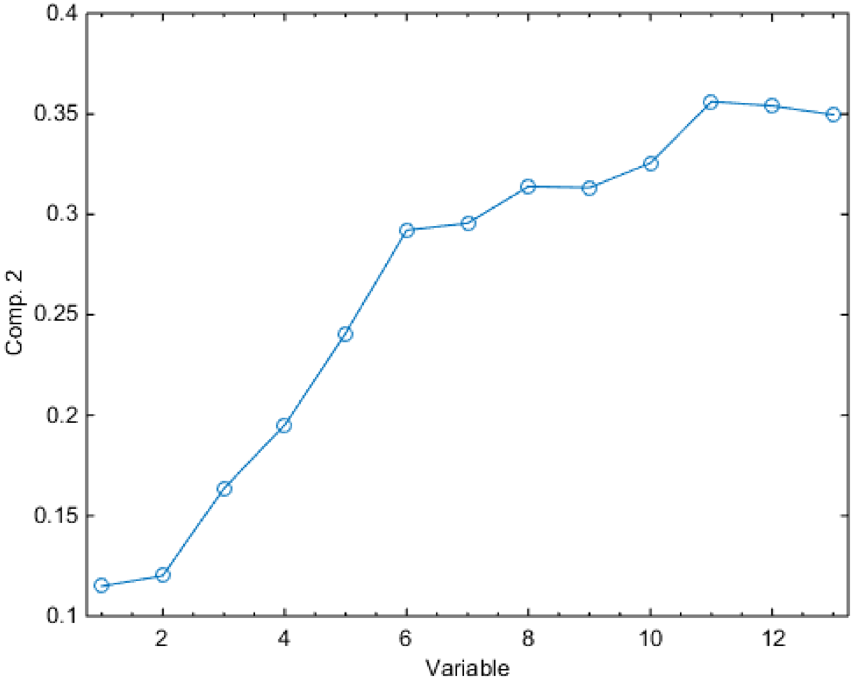
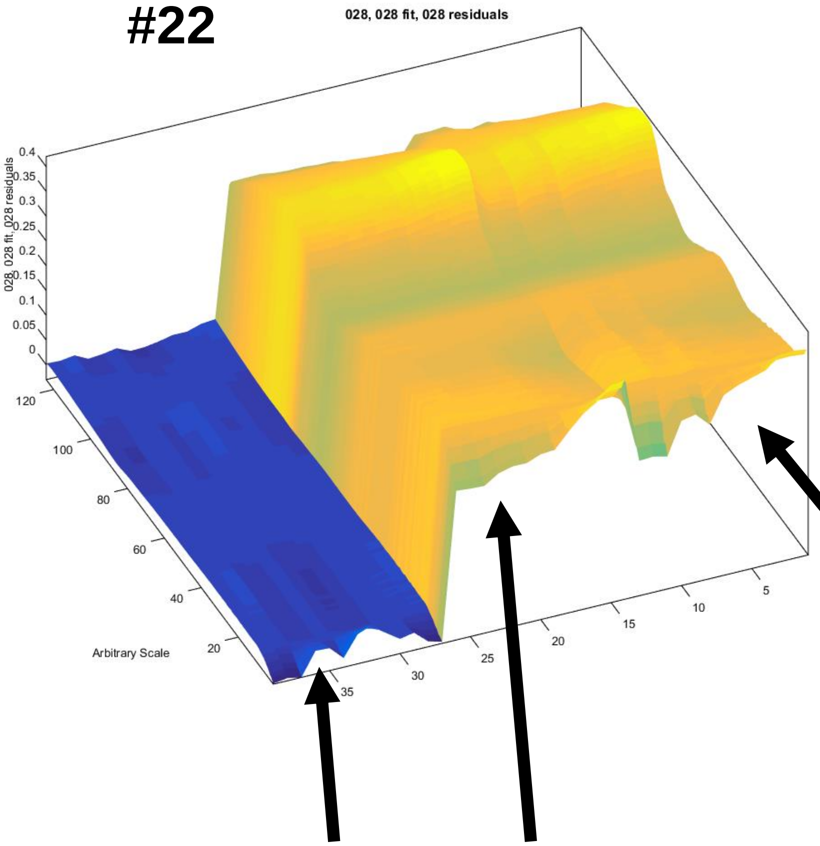


Component 2

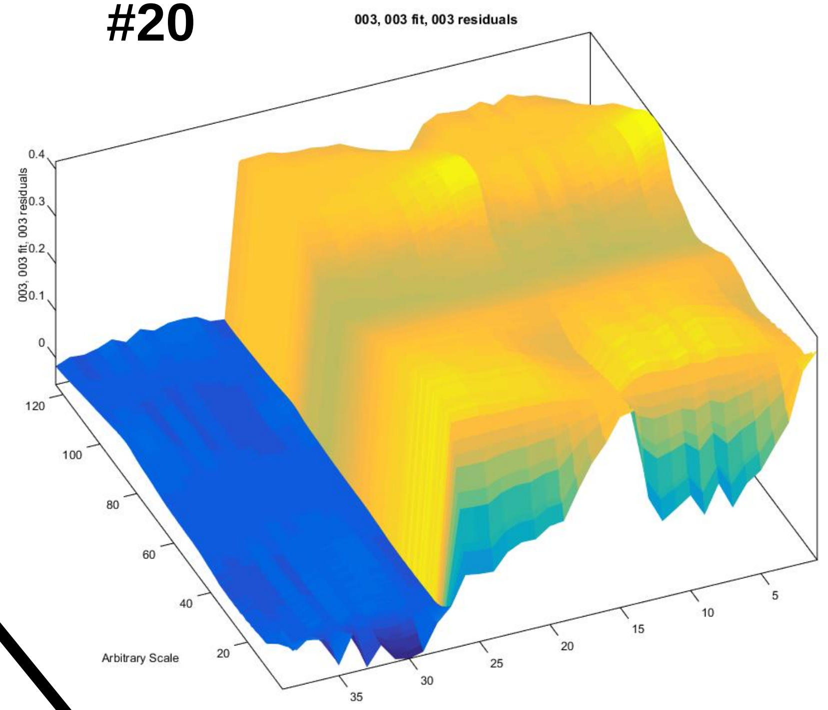
NIR parafac

Reconstructed spectra with parafac

#22



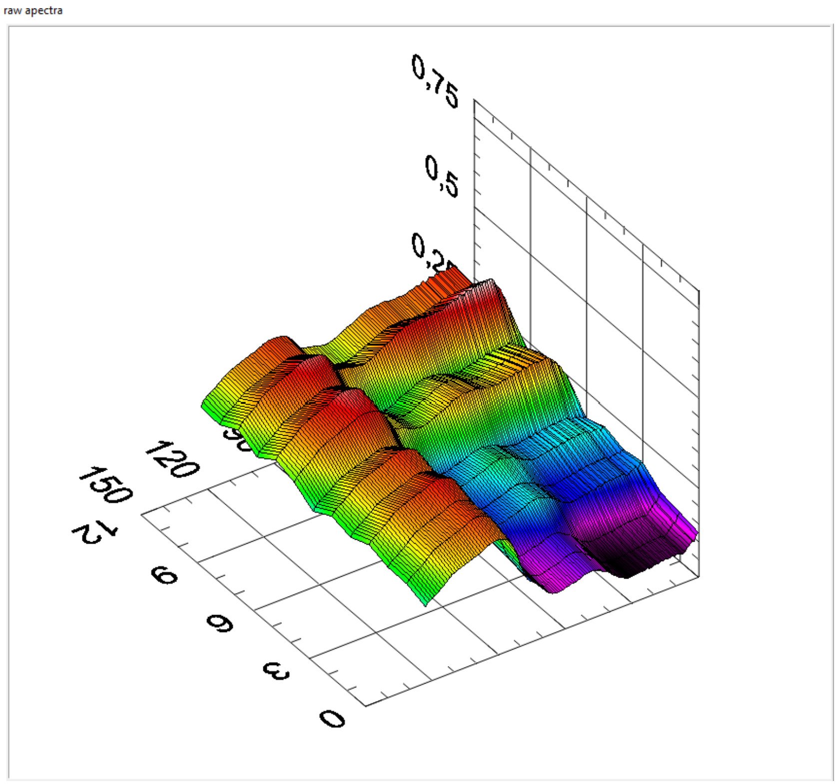
#20



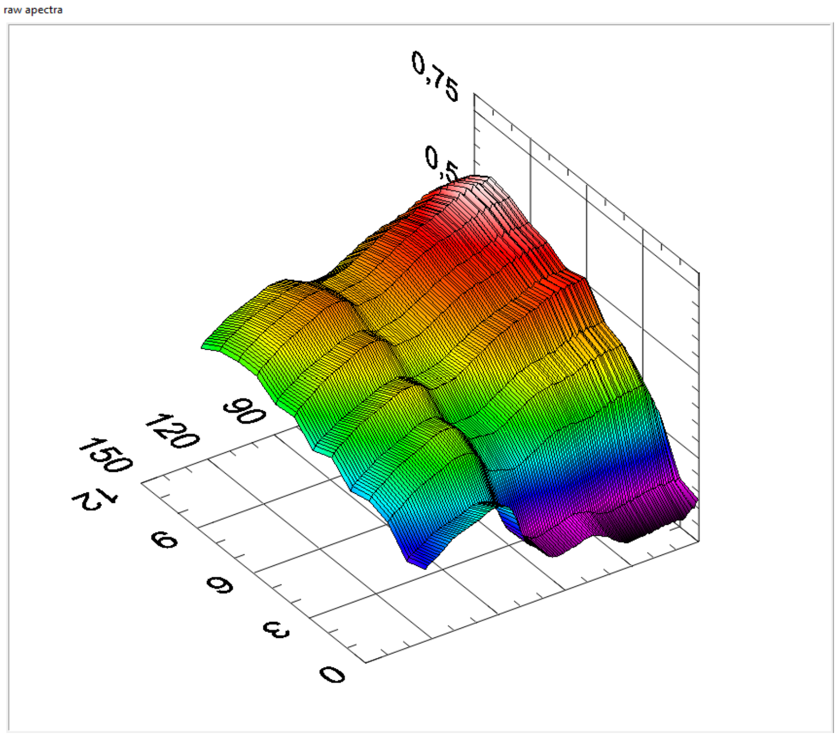
Residuals, modeled (reconstructed) and raw spectra

2D correlation spectroscopy

#22 (UK)

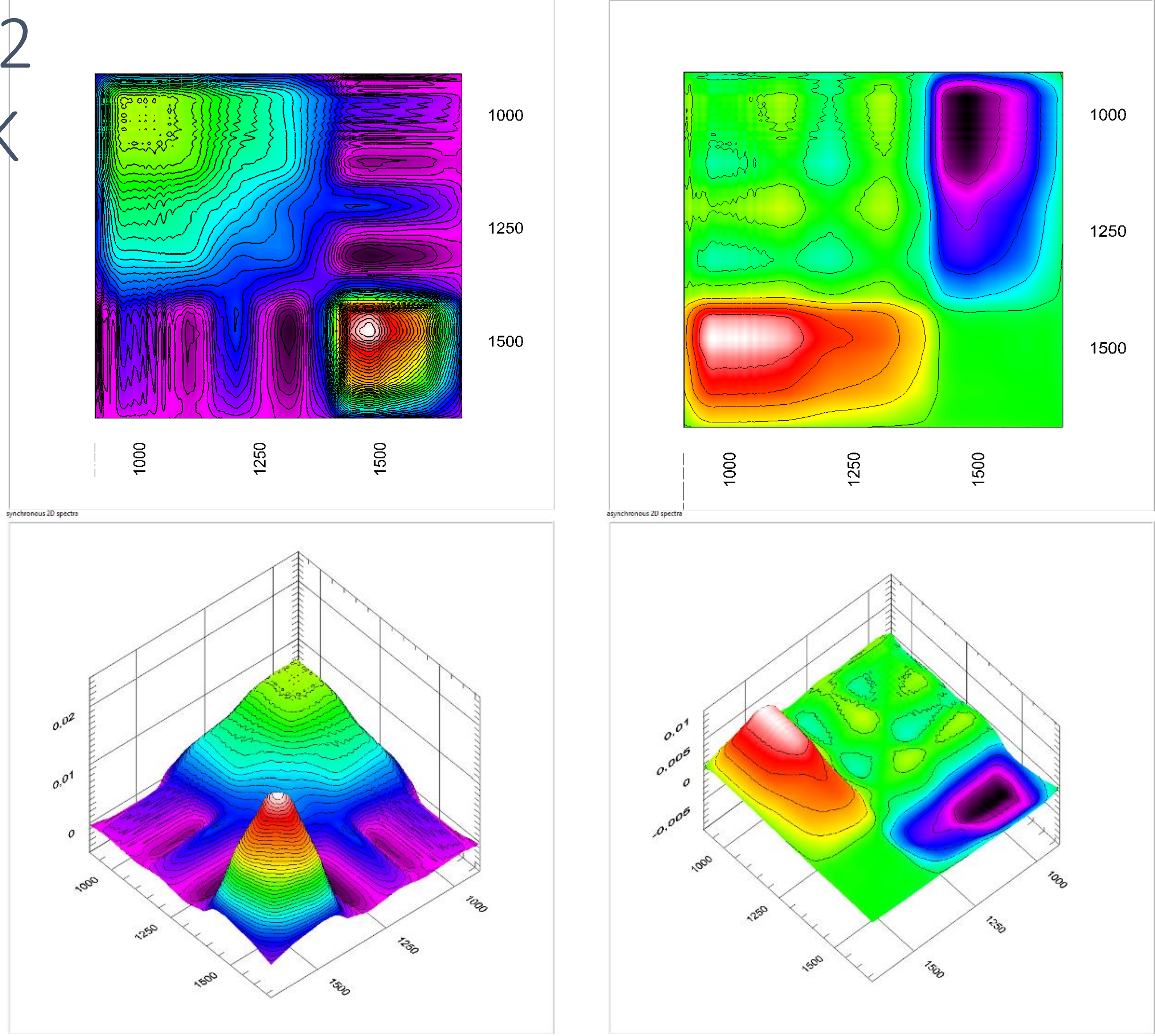


#20 (Turkey)



Raw spectra

#22 UK


1000
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synchronous 2D spectra
asynchronous 2D spectra
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1000
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1000
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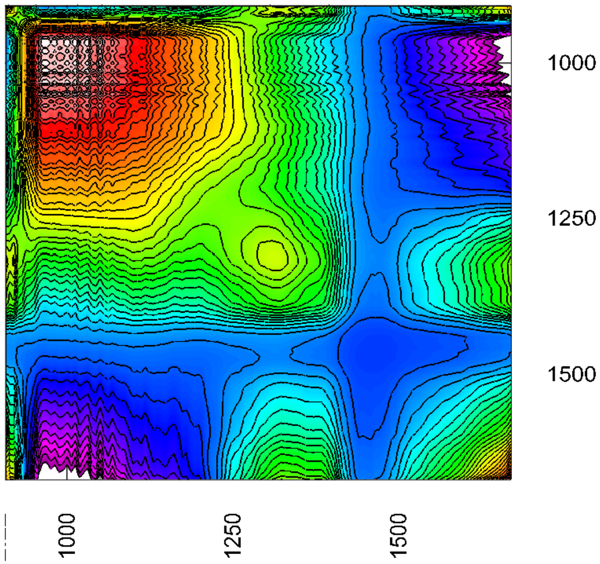
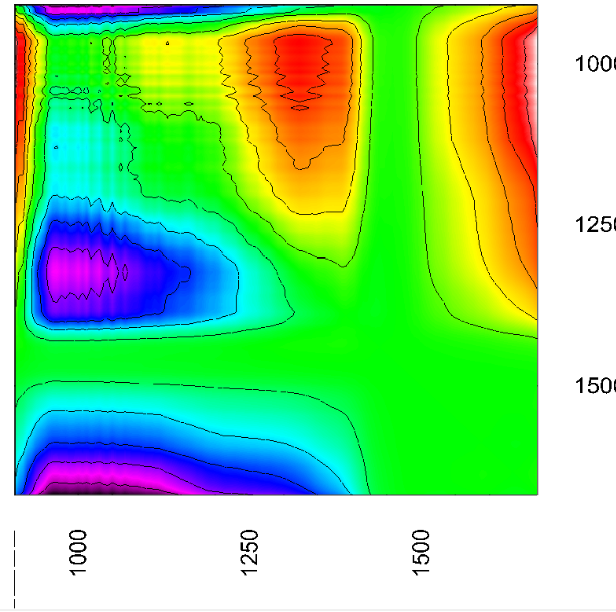
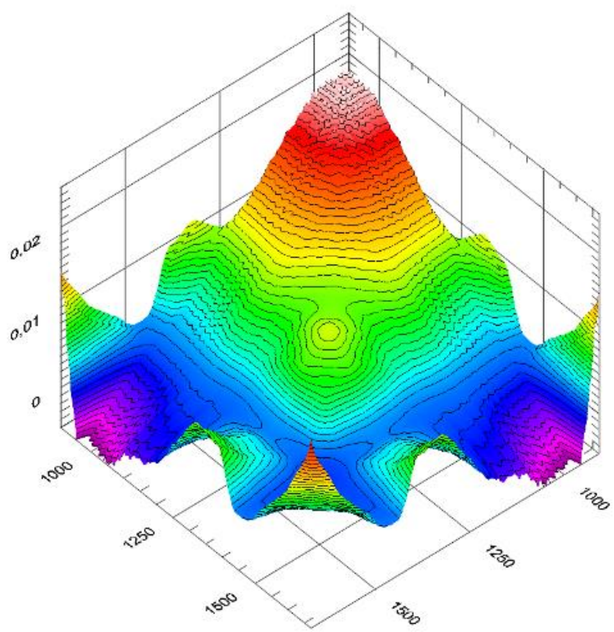
1250
1500

#20
TR

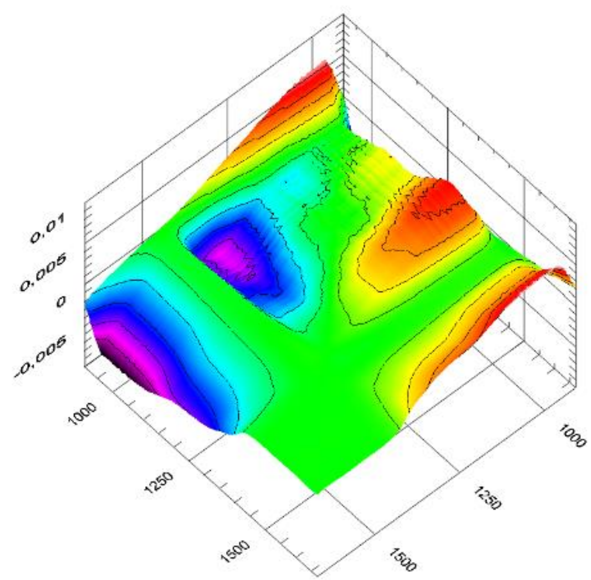




synchronous 2D spectra



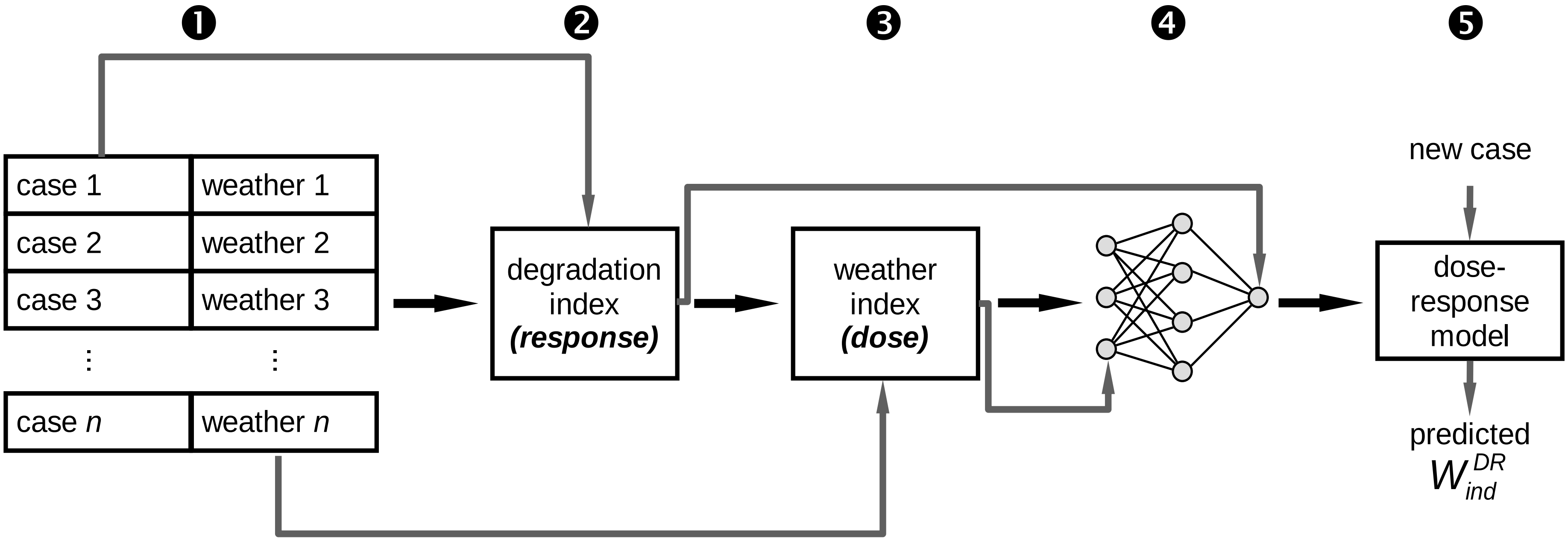
asynchronous 2D spectra



Methods for numerical modeling of weathering

#3: dose-response models

Dose-response models



Modeling of weathering with dose-response approach:

❶ - collection of *n* sets of data corresponding to different cases including meteorological records

❷ - computation of the degradation index as a system response

❸ - computation of the weather dose

❹ - application iterative numerical modeling algorithm for prediction of the degradation index on the base of the weather dose

❺ - use of dose-response model to predict the weathering indicator for any case sample

DEFINITIONS: # Weather dose *D*

- is a **quantity of energy** provided to the system and such energy affects changes of material due to weathering
- the value of ***D*** **depends on the climate data**: $D = f(T, H, Q)$ where *T* – surface temperature, *H* relative humidity of air close to the surface, *Q* –direct solar radiation
- the value of ***D*** **does not depend on the history**: $D(t) \neq f(D(t-1))$
- The dose *D* can be defined for different periods of time (minute, hour, day, month) but it preserves the energy balance low: D(1-3) = D(1) + D(2) + D(3)

DEFINITIONS: Material state

- Is a **set of characteristics** describing current status of the material regarding process of degradation by weathering
- Parameters describing material state are for example:
  - *CIE Lab* or *CIE dE*
  - FT-NIR spectra converted to the weathering index (value 0 to 1000)
  - HI-NIR spectra converted to the weathering index (value 0 to 1000)
  - Visual assessment according to well defined procedure
  - Any other objective parameter changing along the weathering (gloss, roughness, etc.)

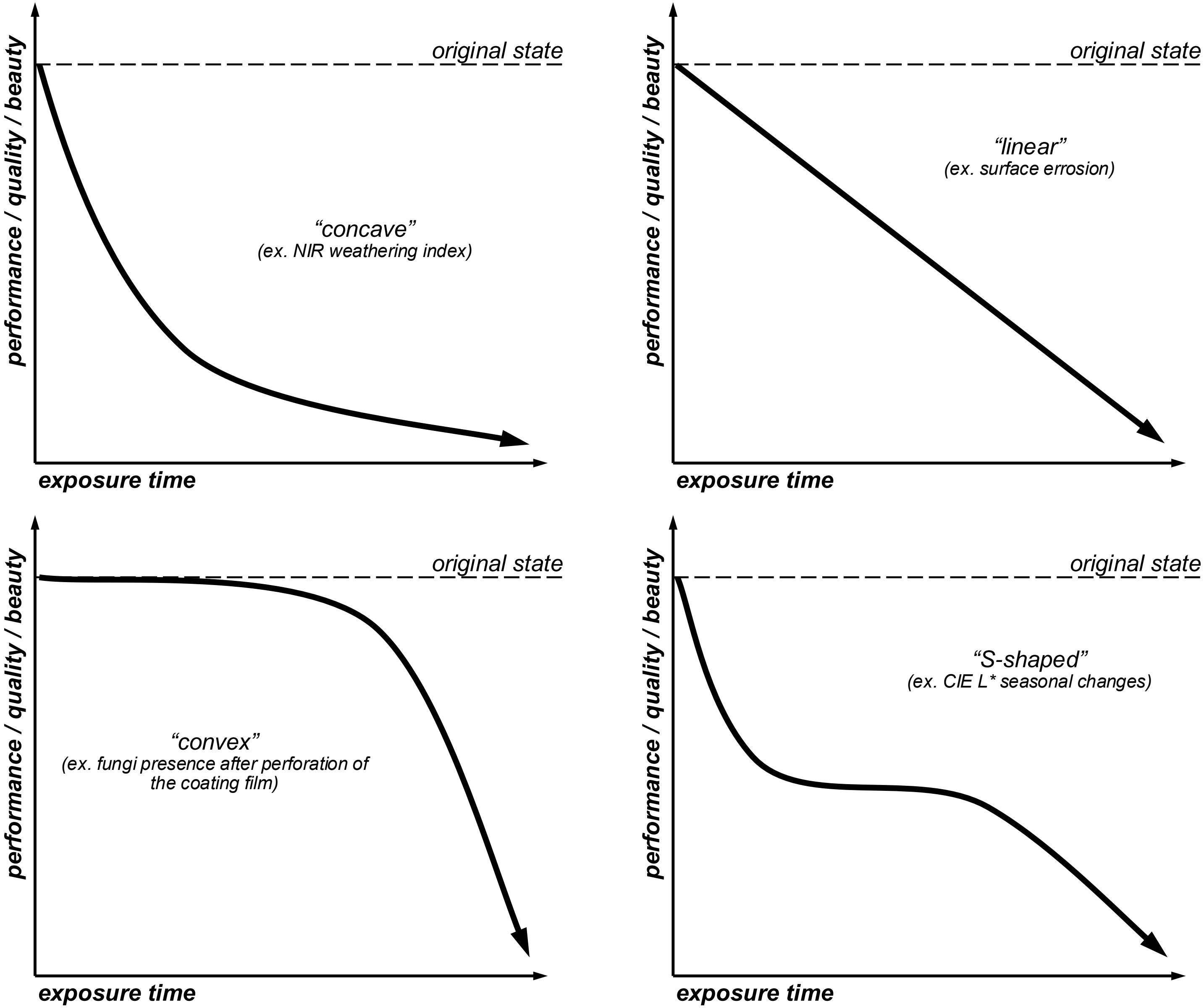
DEFINITIONS: Weathering progress/index *W*

- Is an **indicator describing how advanced is the progress of weathering** compare to the original state
- The progress of weathering *W* is not really correlated to time but it **is related to the cumulative weather dose *D***
- There is a **universal path of the weathering progress** that can be defined for any material state characteristics independently, on the base of material state analysis
- The kinetics of material state characteristics may be different in relation to time but is always related to the sum of doses ΣD.

DEFINITIONS: Model curve of weathering

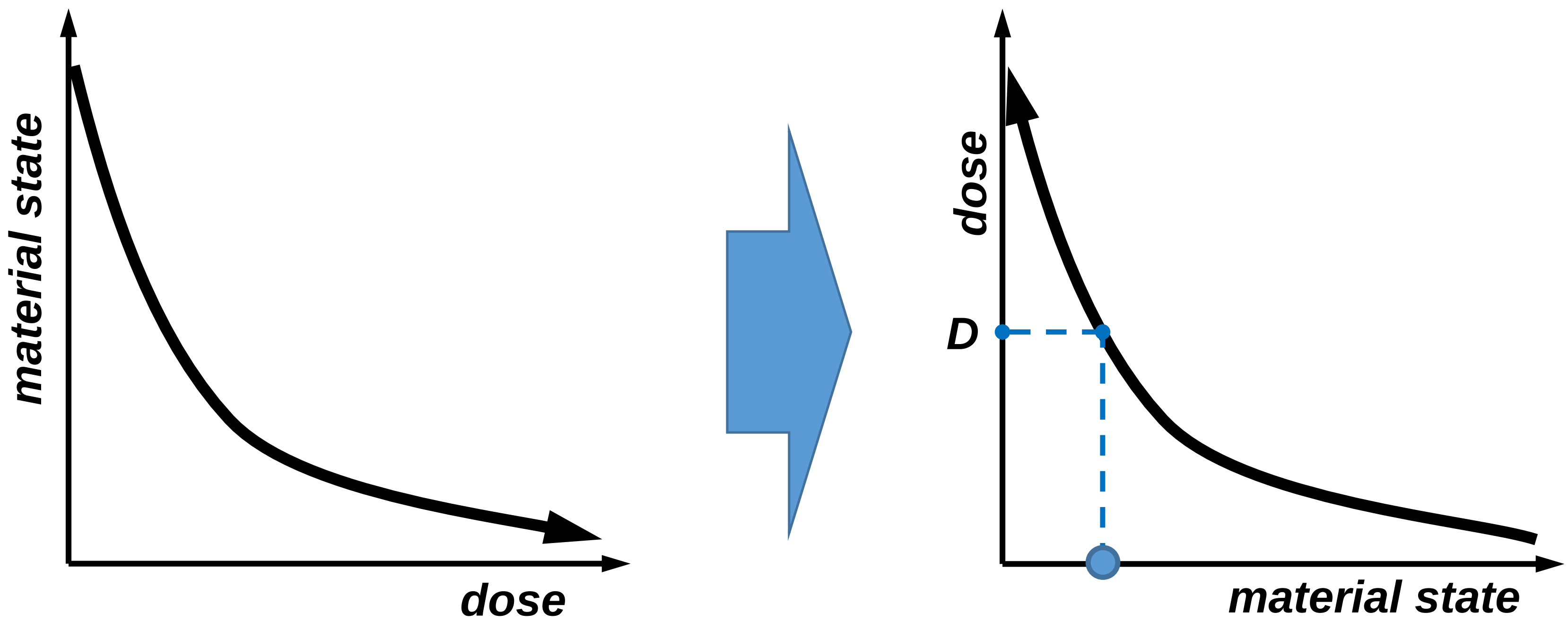
- Is a function **linking material state with the weather dose** *D*
- The model curve is computed on the base of **experimental data**
- The horizontal axis corresponds to the normalized weathering progress in the range of 0 (not weathered surface) to 1000 (state of the common reference weathering)
- The model curve of weathering should be determined on the big dataset
- The model curve can be built on the average trend or on the worst case scenarios

Examples of model curves

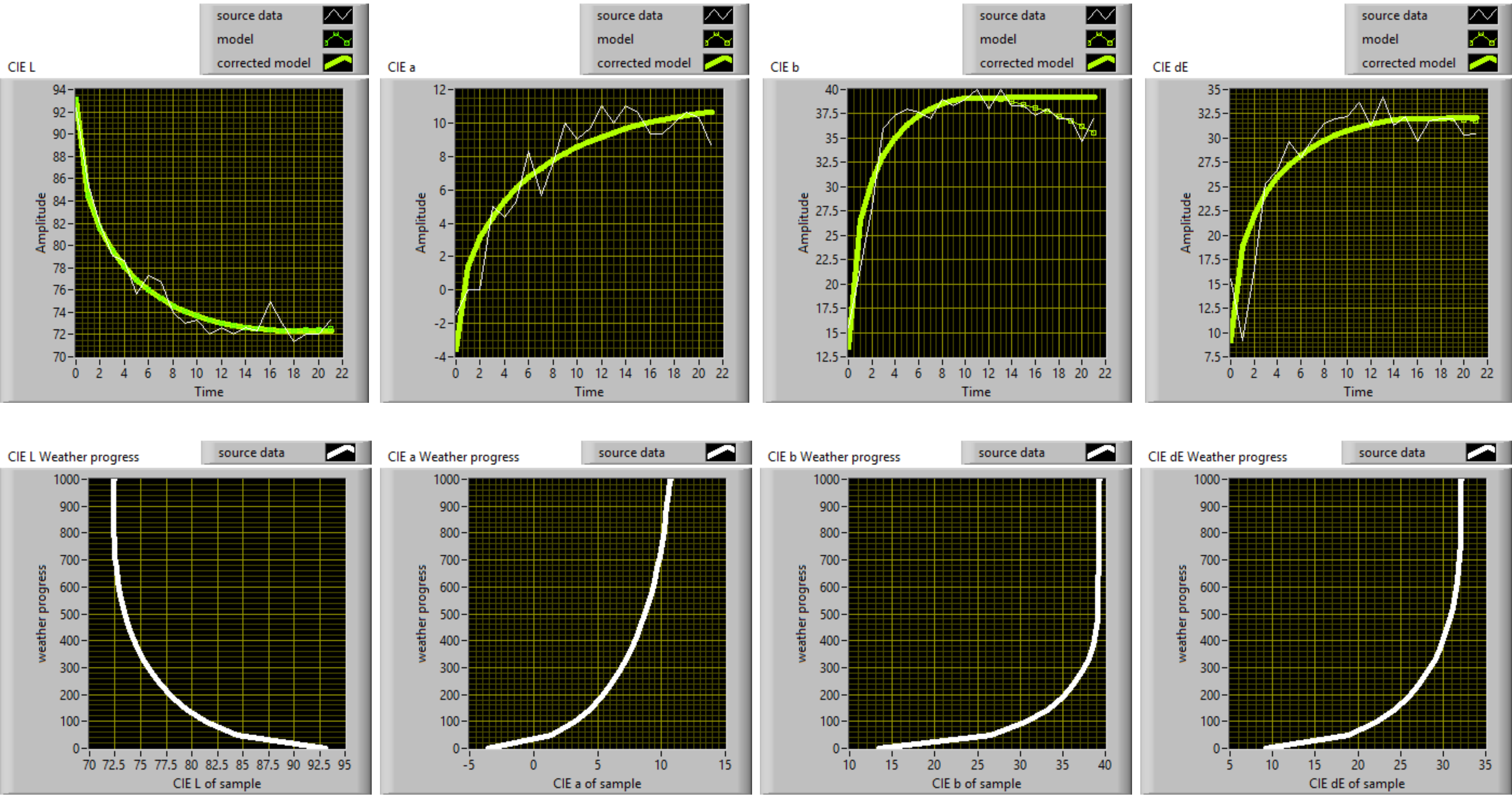


DEFINITIONS: # Inversed model curve of weathering

- It is a **variation of the Model curve of weathering**, where X and Y axis are inversed
- It is used for determination of the **total accumulated weather dose *D*** along the (time independent) weathering.
- The value of dose *D* is directly computed by the algorithm on the base of the given material state parameters



model curves of real weathering data

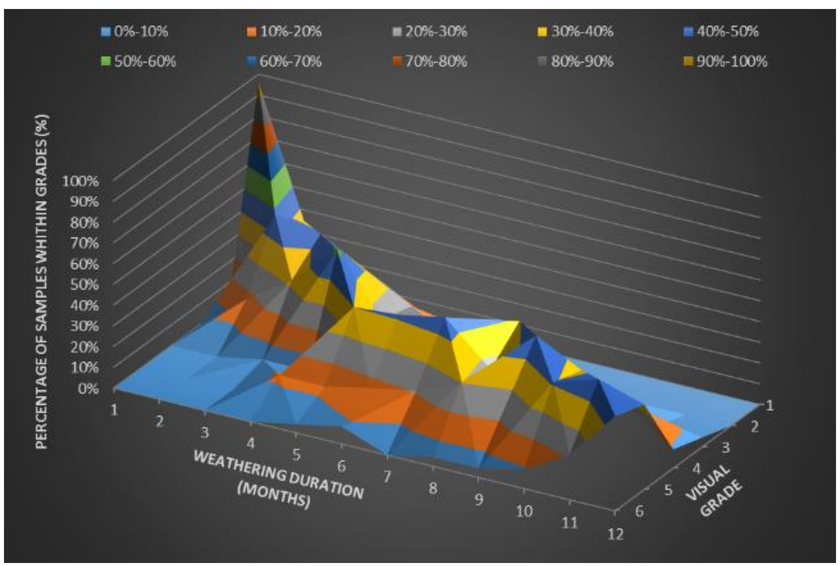


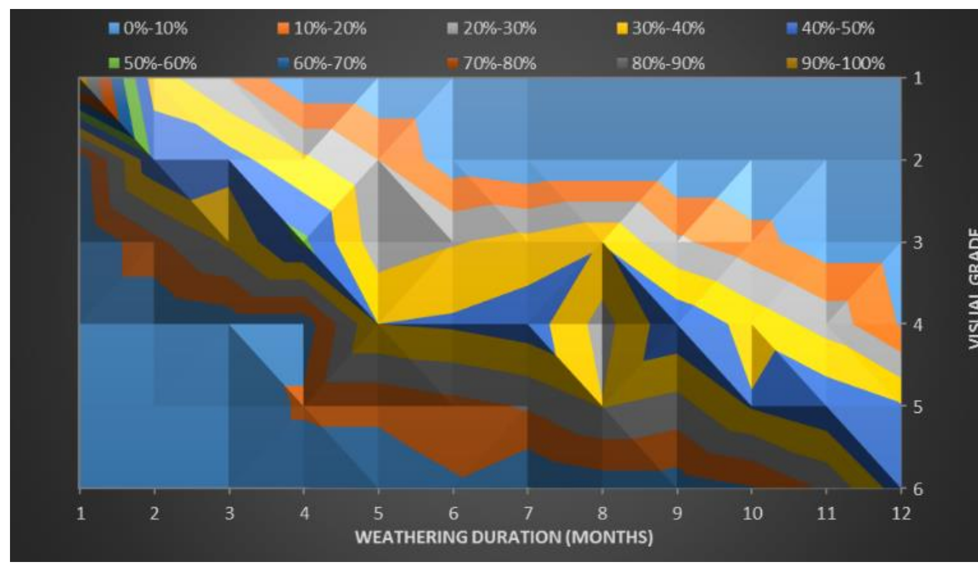
Presentation of the weathering progress to the numerical model

Samples apperance: expert grading

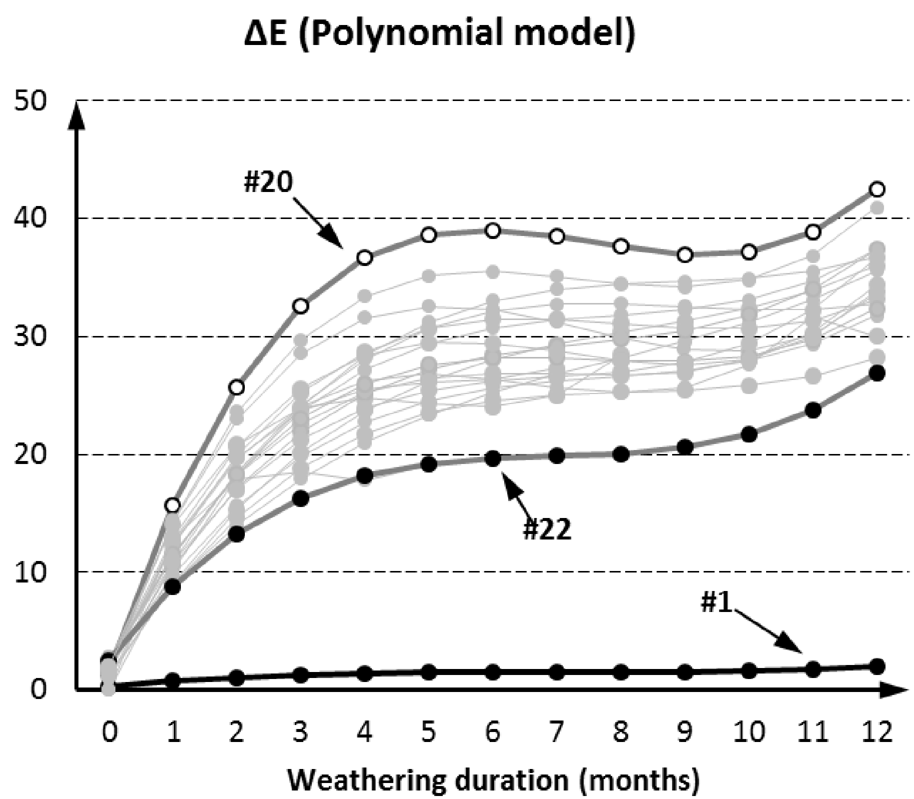
Visual grading

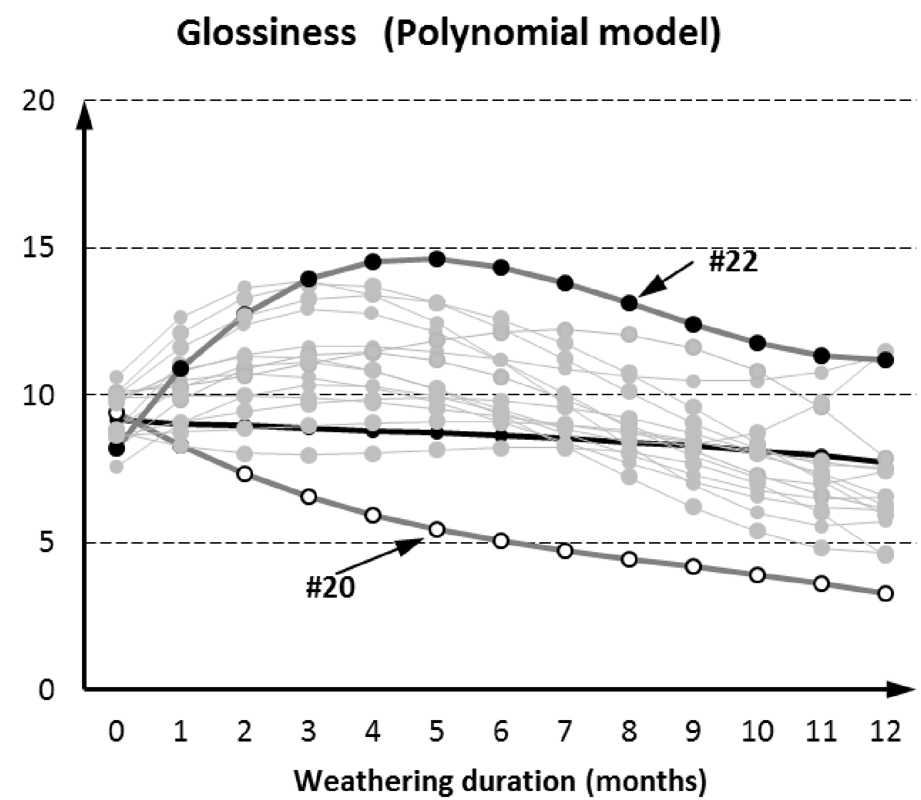
Grading	Degradation	Characteristics
0	No degradation	No colour changes
1	Small aesthetical changes	Yellow appearance
2	Mild aesthetical changes	Yellow grey appearance
3	Moderate aesthetical changes	Light grey colour
4	More intense changes	Grey colour with warm tonality, no visible cracks
5	Advanced changes	Dark grey colour with cold tonality, some raised fibres, surface erosion, no visible open cracks
6	Very advanced changes	Dark grey, uneven discolouration, surface erosion, presence of cracks, mould, algae



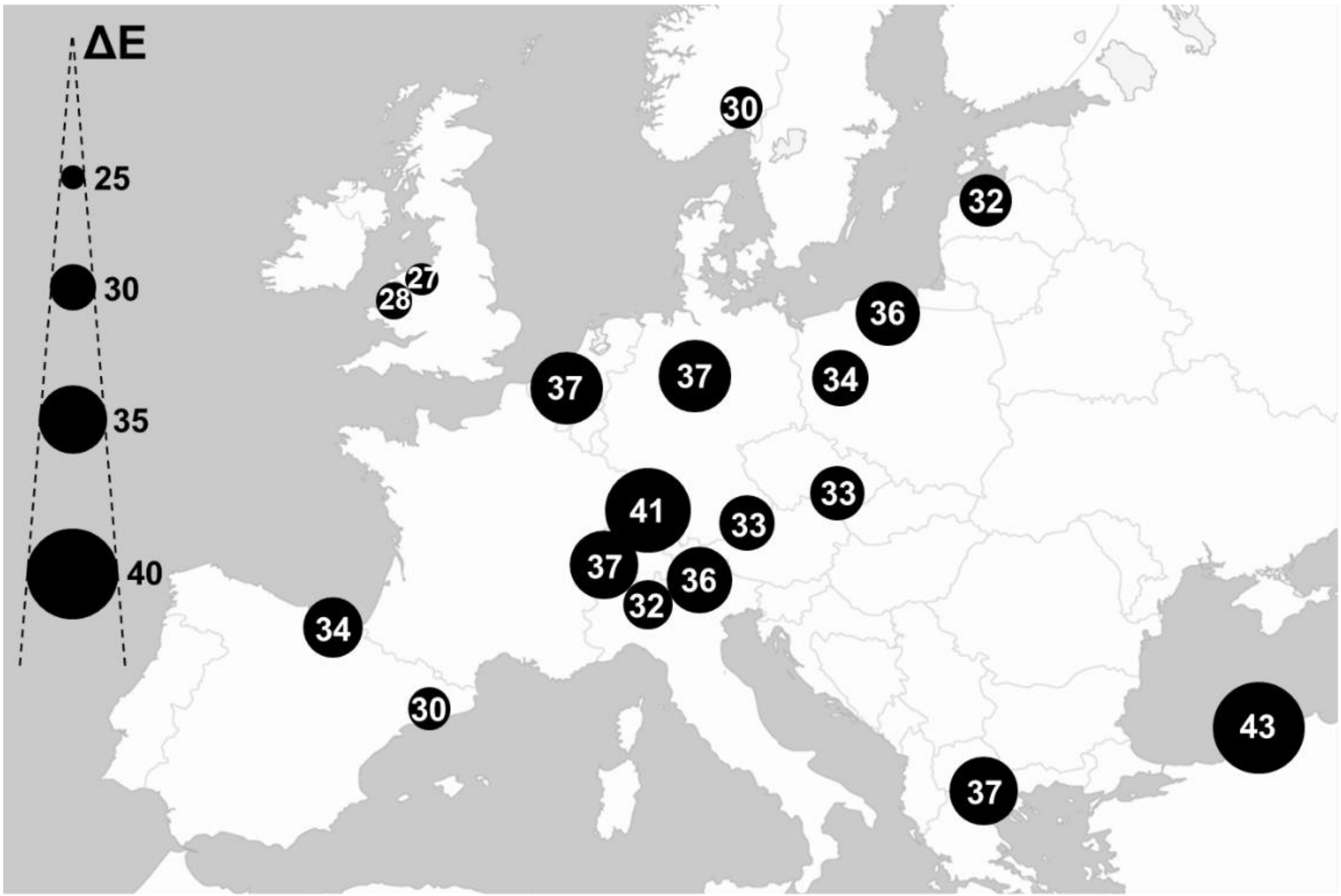


Changes in colour and glossiness





Long term weathering - △E



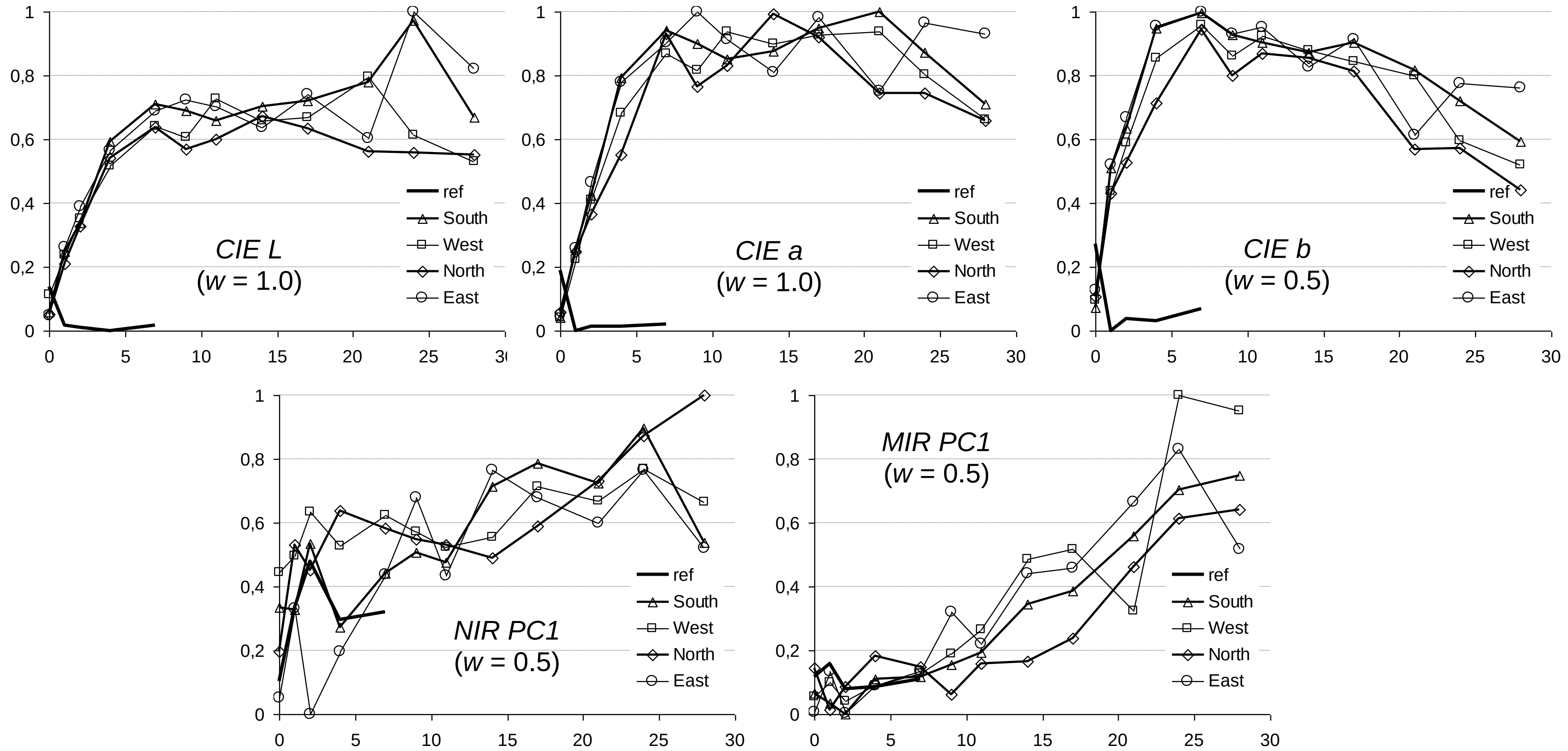
but…

Data is not the same as information

Too much **data** - too little **information**

(Harald Martens)

W_{ind} – single parameters



Weathering index - calculation

$$W_{ind} = \frac{\sum w_i \cdot p_i}{\sum w_i}$$

custom algorithm for multi-sensory data fusion and computation of weathering indicator was developed in LabView 2015 (NI)

the software normalizes the raw data (parameters) p_i as obtained by different sensors i and summarizes these, considering their importance (weight) w_i

Data fusion

Color parameters: L*, a*, b*

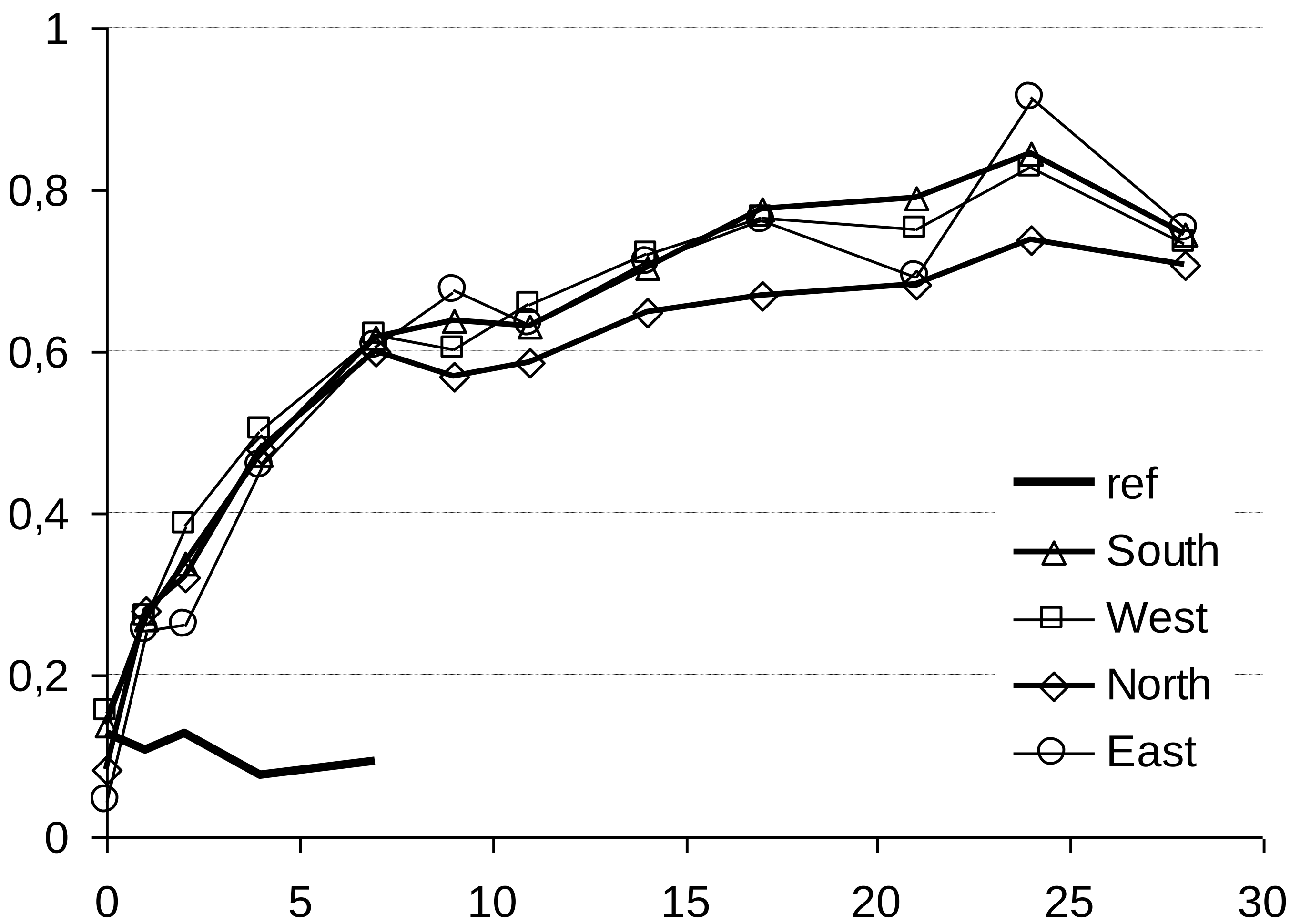
NIR absorbance at 5980cm^{-1} (band related to first overtone of CH stretching of lignin)

MIR absorbance at 1505cm^{-1} (band related to aromatic ring of lignin)

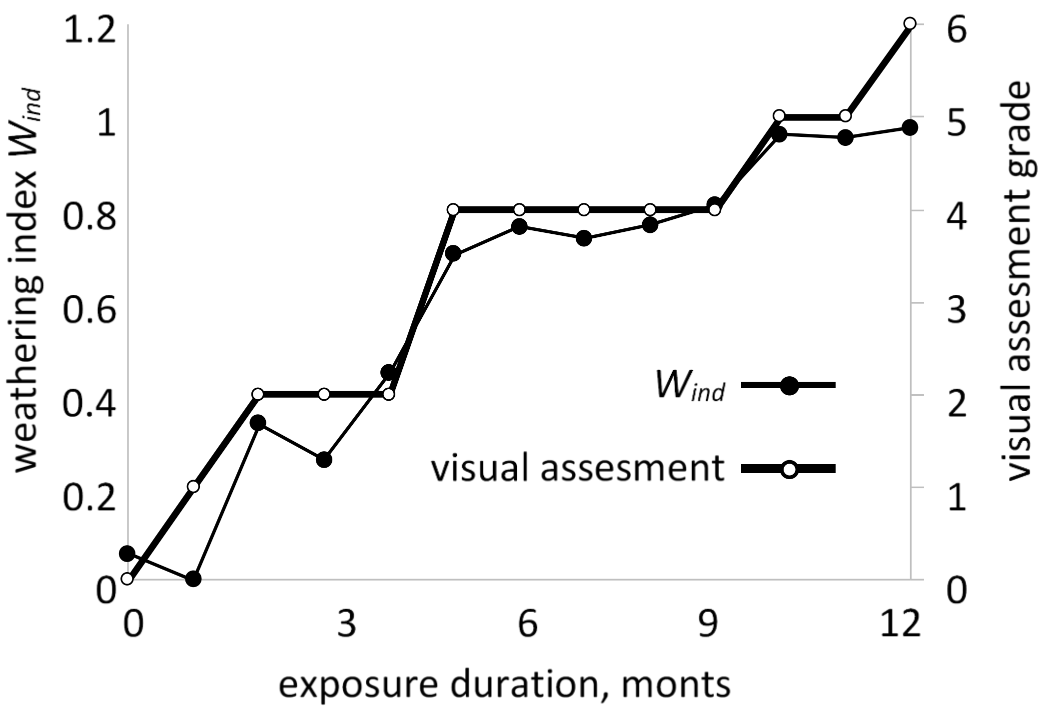
PC1 computed from the NIR spectra

PC1 computed from the MIR spectra

Weathering index - results



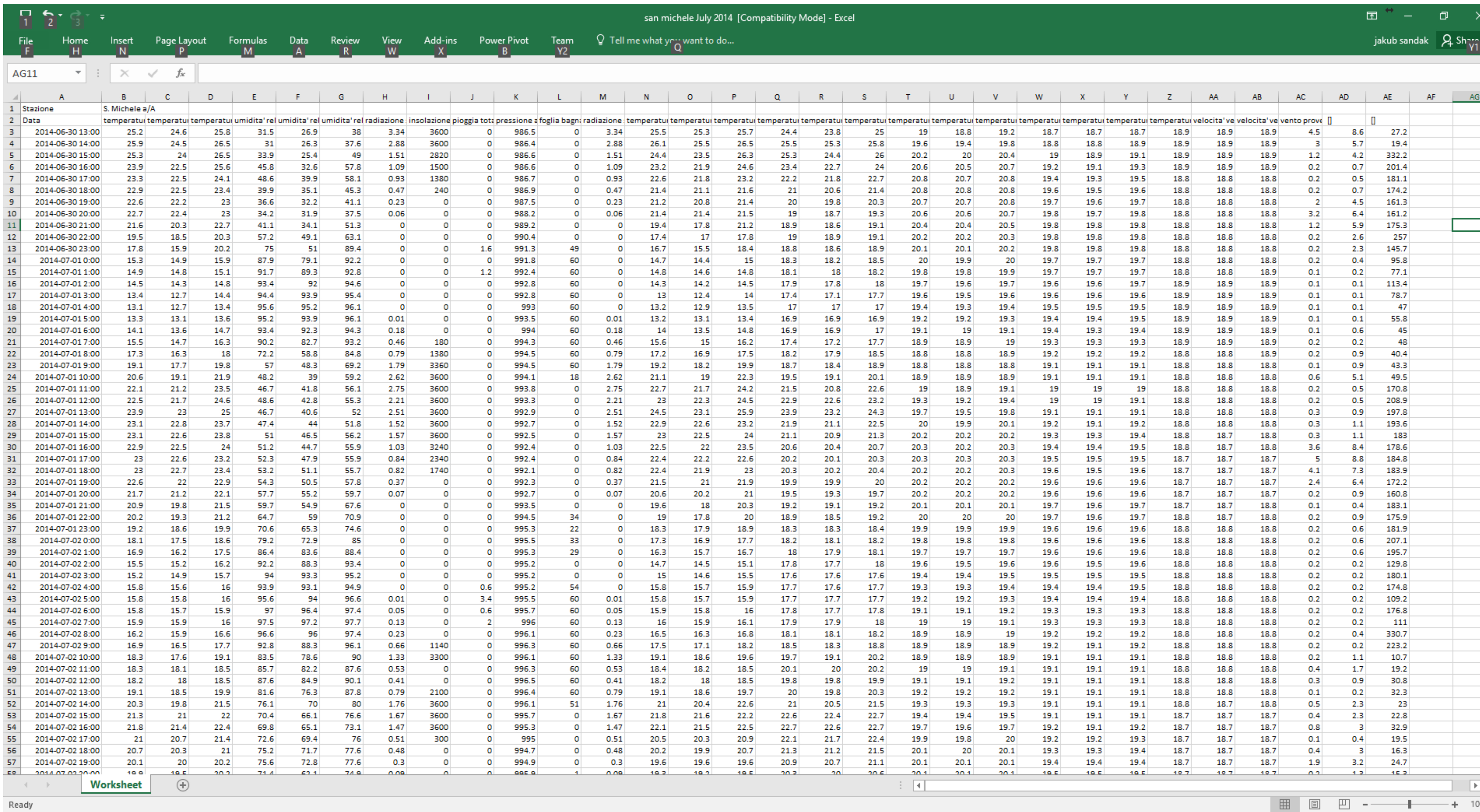
Weathering index – visual grading



Presentation of the climate data to the numerical model

Climate in Europe

Weather data: starting point



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	Stazione	S. Michele a/A																													
2	Data	temperatu	temperatu	temperatu	umidita' rel	umidita' rel	umidita' rel	radiazione	insolazione	pioggia tota	pressione a	foglia bagna	radiazione	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	temperatu	velocita' ve	velocita' ve	vento prove	[]	[]
3	2014-06-30 13:00	25.2	24.6	25.8	31.5	26.9	38	3.34	3600	0	986.5	0	3.34	25.5	25.3	25.7	24.4	23.8	25	19	18.8	19.2	18.7	18.7	18.7	18.9	18.9	18.9	4.5	8.6	27.2
4	2014-06-30 14:00	25.9	24.5	26.5	31	26.3	37.6	2.88	3600	0	986.4	0	2.88	26.1	25.5	26.5	25.5	25.3	25.8	19.6	19.4	19.8	18.8	18.8	18.9	18.9	18.9	18.9	3	5.7	19.4
5	2014-06-30 15:00	25.3	24	26.5	33.9	25.4	49	1.51	2820	0	986.6	0	1.51	24.4	23.5	26.3	25.3	24.4	26	20.2	20	20.4	19	18.9	19.1	18.9	18.9	18.9	1.2	4.2	332.2
6	2014-06-30 16:00	23.9	22.5	25.6	45.8	32.6	57.8	1.09	1500	0	986.6	0	1.09	23.2	21.9	24.6	23.4	22.7	24	20.6	20.5	20.7	19.2	19.1	19.3	18.9	18.9	18.9	0.2	0.7	201.4
7	2014-06-30 17:00	23.3	22.5	24.1	48.6	39.9	58.1	0.93	1380	0	986.7	0	0.93	22.6	21.8	23.2	22.2	21.8	22.7	20.8	20.7	20.8	19.4	19.3	19.5	18.8	18.8	18.8	0.2	0.5	181.1
8	2014-06-30 18:00	22.9	22.5	23.4	39.9	35.1	45.3	0.47	240	0	986.9	0	0.47	21.4	21.1	21.6	21	20.6	21.4	20.8	20.8	20.8	19.6	19.5	19.6	18.8	18.8	18.8	0.2	0.7	174.2
9	2014-06-30 19:00	22.6	22.2	23	36.6	32.2	41.1	0.23	0	0	987.5	0	0.23	21.2	20.8	21.4	20	19.8	20.3	20.7	20.7	20.8	19.7	19.6	19.7	18.8	18.8	18.8	2	4.5	161.3
10	2014-06-30 20:00	22.7	22.4	23	34.2	31.9	37.5	0.06	0	0	988.2	0	0.06	21.4	21.4	21.5	19	18.7	19.3	20.6	20.6	20.7	19.8	19.7	19.8	18.8	18.8	18.8	3.2	6.4	161.2
11	2014-06-30 21:00	21.6	20.3	22.7	41.1	34.1	51.3	0	0	0	989.2	0	0	19.4	17.8	21.2	18.9	18.6	19.1	20.4	20.4	20.5	19.8	19.8	19.8	18.8	18.8	18.8	1.2	5.9	175.3
12	2014-06-30 22:00	19.5	18.5	20.3	57.2	49.1	63.1	0	0	0	990.4	0	0	17.4	17	17.8	19	18.9	19.1	20.2	20.2	20.3	19.8	19.8	19.8	18.8	18.8	18.8	0.2	2.6	257
13	2014-06-30 23:00	17.8	15.9	20.2	75	51	89.4	0	0	1.6	991.3	49	0	16.7	15.5	18.4	18.8	18.6	18.9	20.1	20.1	20.2	19.8	19.8	19.8	18.8	18.8	18.8	0.2	2.3	145.7
14	2014-07-01 0:00	15.3	14.9	15.9	87.9	79.1	92.2	0	0	0	991.8	60	0	14.7	14.4	15	18.3	18.2	18.5	20	19.9	20	19.7	19.7	19.7	18.8	18.8	18.8	0.2	0.4	95.8
15	2014-07-01 1:00	14.9	14.8	15.1	91.7	89.3	92.8	0	0	1.2	992.4	60	0	14.8	14.6	14.8	18.1	18	18.2	19.8	19.8	19.9	19.7	19.7	19.7	18.8	18.8	18.9	0.1	0.2	77.1
16	2014-07-01 2:00	14.5	14.3	14.8	93.4	92	94.6	0	0	0	992.8	60	0	14.3	14.2	14.5	17.9	17.8	18	19.7	19.6	19.7	19.6	19.6	19.7	18.9	18.9	18.9	0.1	0.1	113.4
17	2014-07-01 3:00	13.4	12.7	14.4	94.4	93.9	95.4	0	0	0	992.8	60	0	13	12.4	14	17.4	17.1	17.7	19.6	19.5	19.6	19.6	19.6	19.6	18.9	18.9	18.9	0.1	0.1	78.7
18	2014-07-01 4:00	13.1	12.7	13.4	95.6	95.2	96.1	0	0	0	993	60	0	13.2	12.9	13.5	17	17	17	19.4	19.3	19.4	19.5	19.5	19.5	18.9	18.9	18.9	0.1	0.1	47
19	2014-07-01 5:00	13.3	13.1	13.6	95.2	93.9	96.1	0.01	0	0	993.5	60	0.01	13.2	13.1	13.4	16.9	16.9	16.9	19.2	19.2	19.3	19.4	19.4	19.5	18.9	18.9	18.9	0.1	0.1	55.8
20	2014-07-01 6:00	14.1	13.6	14.7	93.4	92.3	94.3	0.18	0	0	994	60	0.18	14	13.5	14.8	16.9	16.9	17	19.1	19	19.1	19.4	19.3	19.4	18.9	18.9	18.9	0.1	0.6	45
21	2014-07-01 7:00	15.5	14.7	16.3	90.2	82.7	93.2	0.46	180	0	994.3	60	0.46	15.6	15	16.2	17.4	17.2	17.7	18.9	18.9	19	19.3	19.3	19.3	18.9	18.9	18.9	0.2	0.2	48
22	2014-07-01 8:00	17.3	16.3	18	72.2	58.8	84.8	0.79	1380	0	994.5	60	0.79	17.2	16.9	17.5	18.2	17.9	18.5	18.8	18.8	18.9	19.2	19.2	19.2	18.8	18.8	18.9	0.2	0.9	40.4
23	2014-07-01 9:00	19.1	17.7	19.8	57	48.3	69.2	1.79	3360	0	994.5	60	1.79	19.2	18.2	19.9	18.7	18.4	18.9	18.8	18.8	18.8	19.1	19.1	19.1	18.8	18.8	18.8	0.1	0.9	43.3
24	2014-07-01 10:00	20.6	19.1	21.9	48.2	39	59.2	2.62	3600	0	994.1	18	2.62	21.1	19	22.3	19.5	19.1	20.1	18.9	18.9	18.9	19.1	19.1	19.1	18.8	18.8	18.8	0.6	5.1	49.5
25	2014-07-01 11:00	22.1	21.2	23.5	46.7	41.8	56.1	2.75	3600	0	993.8	0	2.75	22.7	21.7	24.2	21.5	20.8	22.6	19	18.9	19.1	19	19	19	18.8	18.8	18.8	0.2	0.5	170.8
26	2014-07-01 12:00	22.5	21.7	24.6	48.6	42.8	55.3	2.21	3600	0	993.3	0	2.21	23	22.3	24.5	22.9	22.6	23.2	19.3	19.2	19.4	19	19	19.1	18.8	18.8	18.8	0.2	0.5	208.9
27	2014-07-01 13:00	23.9	23	25	46.7	40.6	52	2.51	3600	0	992.9	0	2.51	24.5	23.1	25.9	23.9	23.2	24.3	19.7	19.5	19.8	19.1	19.1	19.1	18.8	18.8	18.8	0.3	0.9	197.8
28	2014-07-01 14:00	23.1	22.8	23.7	47.4	44	51.8	1.52	3600	0	992.7	0	1.52	22.9	22.6	23.2	21.9	21.1	22.5	20	19.9	20.1	19.2	19.1	19.2	18.8	18.8	18.8	0.3	1.1	193.6
29	2014-07-01 15:00	23.1	22.6	23.8	51	46.5	56.2	1.57	3600	0	992.5	0	1.57	23	22.5	24	21.1	20.9	21.3	20.2	20.2	20.2	19.3	19.3	19.4	18.8	18.7	18.8	0.3	1.1	183
30	2014-07-01 16:00	22.9	22.5	24	51.2	44.7	55.9	1.03	3240	0	992.4	0	1.03	22.5	22	23.5	20.6	20.4	20.7	20.3	20.2	20.3	19.4	19.4	19.5	18.8	18.7	18.8	3.6	8.4	178.6
31	2014-07-01 17:00	23	22.6	23.2	52.3	47.9	55.9	0.84	2340	0	992.4	0	0.84	22.4	22.2	22.6	20.2	20.1	20.3	20.3	20.3	20.3	19.5	19.5	19.5	18.7	18.7	18.7	5	8.8	184.8
32	2014-07-01 18:00	23	22.7	23.4	53.2	51.1	55.7	0.82	1740	0	992.1	0	0.82	22.4	21.9	23	20.3	20.2	20.4	20.2	20.2	20.3	19.6	19.5	19.6	18.7	18.7	18.7	4.1	7.3	183.9
33	2014-07-01 19:00	22.6	22	22.9	54.3	50.5	57.8	0.37	0	0	992.3	0	0.37	21.5	21	21.9	19.9	19.9	20	20.2	20.2	20.2	19.6	19.6	19.6	18.7	18.7	18.7	2.4	6.4	172.2
34	2014-07-01 20:00	21.7	21.2	22.1	57.7	55.2	59.7	0.07	0	0	992.7	0	0.07	20.6	20.2	21	19.5	19.3	19.7	20.2	20.2	20.2	19.6	19.6	19.6	18.7	18.7	18.7	0.2	0.9	160.8
35	2014-07-01 21:00	20.9	19.8	21.5	59.7	54.9	67.6	0	0	0	993.5	0	0	19.6	18	20.3	19.2	19.1	19.2	20.1	20.1	20.1	19.7	19.6	19.7	18.7	18.7	18.8	0.1	0.4	183.1
36	2014-07-01 22:00	20.2	19.3	21.2	64.7	59	70.9	0	0	0	994.5	34	0	19	17.8	20	18.9	18.5	19.2	20	20	20	19.7	19.6	19.7	18.8	18.7	18.8	0.2	0.9	175.9
37	2014-07-01 23:00	19.2	18.6	19.9	70.6	65.3	74.6	0	0	0	995.3	22	0	18.3	17.9	18.9	18.3	18.3	18.4	19.9	19.9	19.9	19.6	19.6	19.6	18.8	18.8	18.8	0.2	0.6	181.9
38	2014-07-02 0:00	18.1	17.5	18.6	79.2	72.9	85	0	0	0	995.5	33	0	17.3	16.9	17.7	18.2	18.1	18.2	19.8	19.8	19.8	19.6	19.6	19.6	18.8	18.8	18.8	0.2	0.6	207.1
39	2014-07-02 1:00	16.9	16.2	17.5	86.4	83.6	88.4	0	0	0	995.3	29	0	16.3	15.7	16.7	18	17.9	18.1	19.7	19.7	19.7	19.6	19.6	19.6	18.8	18.8	18.8	0.2	0.6	195.7
40	2014-07-02 2:00	15.5	15.2	16.2	92.2	88.3	93.4	0	0	0	995.2	0	0	14.7	14.5	15.1	17.8	17.7	18	19.6	19.5	19.6	19.6	19.5	19.6	18.8	18.8	18.8	0.2	0.2	129.8
41	2014-07-02 3:00	15.2	14.9	15.7	94	93.3	95.2	0	0	0	995.2	0	0	15	14.6	15.5	17.6	17.6	17.6	19.4	19.4	19.5	19.5	19.5	19.5	18.8	18.8	18.8	0.2	0.2	180.1
42	2014-07-02 4:00	15.8	15.6	16	93.9	93.1	94.9	0	0	0.6	995.2	54	0	15.8	15.7	15.9	17.7	17.6	17.7	19.3	19.3	19.4	19.4	19.4	19.5	18.8	18.8	18.8	0.2	0.2	174.8
43	2014-07-02 5:00	15.8	15.8	16	95.6	94	96.6	0.01	0	3.4	995.5	60	0.01	15.8	15.7	15.9	17.7	17.7	17.7	19.2	19.2	19.3	19.4	19.4	19.4	18.8	18.8	18.8	0.2	0.2	109.2
44	2014-07-02 6:00	15.8	15.7	15.9	97	96.4	97.4	0.05	0	0.6	995.7	60	0.05	15.9	15.8	16	17.6	17.7	17.8	19.1	19.1	19.2	19.3	19.3	19.3	18.8	18.8	18.8	0.2	0.2	176.8
45	2014-07-02 7:00	15.9	15.9	16	97.5	97.2	97.7	0.13	0	2	996	60	0.13	16	15.9	16.1	17.9	17.9	18	19	19	19.1	19.3	19.3	19.3	18.8	18.8	18.8	0.2	0.2	111
46	2014-07-02 8:00	16.2	15.9	16.6	96.6	96	97.4	0.23	0	0	996.1	60	0.23	16.5	16.3	16.8	18.1	18.1	18.2	18.9	18.9	19	19.2	19.2	19.2	18.8	18.8	18.8	0.2	0.4	330.7
47	2014-07-02 9:00	16.9	16.5	17.7	92.8	88.3	96.1	0.66	1140	0	996.3	60	0.66	17.5	17.1	18.2	18.5	18.3	18.8	18.9	18.9	18.9	19.2	19.1	19.2	18.8	18.8	18.8	0.2	0.2	223.2
48	2014-07-02 10:00	18.3	17.6	19.1	83.5	78.6	90	1.33	3300	0	996.1	60	1.33	19.1	18.6	19.6	19.7	19.1	20.2	18.9	18.9	18.9	19.1	19.1	19.1	18.8	18.8	18.8	0.2	1.1	10.7
49	2014-07-02 11:00	18.3	18.1	18.5	85.7	82.2	87.6	0.53	0	0	996.3	60	0.53	18.4	18.2	18.5	20.1	20	20.2	19	19	19.1	19.1	19.1	19.1	18.8	18.8	18.8	0.4	1.7	19.2
50	2014-07-02 12:00	18.2	18	18.5	87.6	84.9	90.1	0.41	0	0	996.5	60	0.41	18.2	18	18.5	19.8	19.8	19.9	19.1	19.1	19.2	19.1	19.1	19.1	18.8	18.8	18.8	0.3	0.9	30.8
51	2014-07-02 13:00	19.1	18.5	19.9	81.6	76.3	87.8	0.79	2100	0	996.4	60	0.79	19.1	18.6	19.7	20	19.8	20.3	19.2	19.2	19.2	19.1	19.1	19.1	18.8	18.8	18.8	0.1	0.2	32.3
52	2014-07-02 14:00	20.3	19.8	21.5	76.1	70	80	1.76	3600	0	996.1	51	1.76	21	20.4	22.6	21	20.5	21.5	19.3	19.3	19.3	19.1	19.1	19.1	18.8	18.7	18.8	0.5	2.3	23
53	2014-07-02 15:00	21.3	21	22	70.4	66.1	76.6	1.67	3600	0	995.7	0	1.67	21.8	21.6	22.2	22.6	22.4	22.7	19.4	19.4	19.5	19.1	19.1	19.1	18.7	18.7	18.7	0.4	2.3	22.8
54	2014-07-02 16:00	21.8	21.4	22.4	69.8	65.1	73.1	1.47	3600	0	995.3	0	1.47	22.1	21.5	22.5	22.7	22.6	22.7	19.7	19.6	19.7	19.2	19.1	19.2	18.7	18.7	18.7	0.8	3	32.9
55	2014-07-02 17:00	21	20.7	21.4	72.6	69.4	76	0.51	300	0	995	0	0.51	20.5	20.3	20.9	22.1	21.7	22.4	19.9	19.8	20	19.2	19.2	19.3	18.7	18.7	18.7	0.1	0.4	19.5
56	2014-07-02 18:00	20.7	20.3	21	75.2	71.7	77.6	0.48	0	0	994.7	0	0.48	20.2	19.9	20.7	21.3	21.2	21.5	20.1	20	20.1	19.3	19.3	19.4	18.7	18.7	18.7	0.4	3	16.3
57	2014-07-02 19:00	20.1	20	20.2	75.6	72.8	77.6	0.3	0	0	994.9	0	0.3	19.6	19.6	19.6	20.9	20.7	21.1	20.1	20.1	20.1	19.4	19.4	19.4	18.7	18.7	18.7	1.9	3.2	24.7

#1: Climate indices

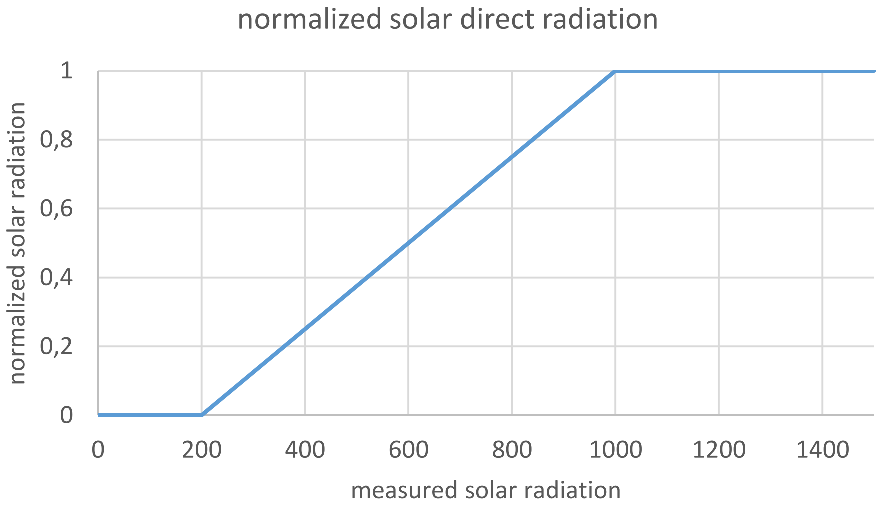
- **Scheffer climate index SCI =** $\frac{\sum_{Dec}^{Jan}[(T-35)(D-3)]}{30}$

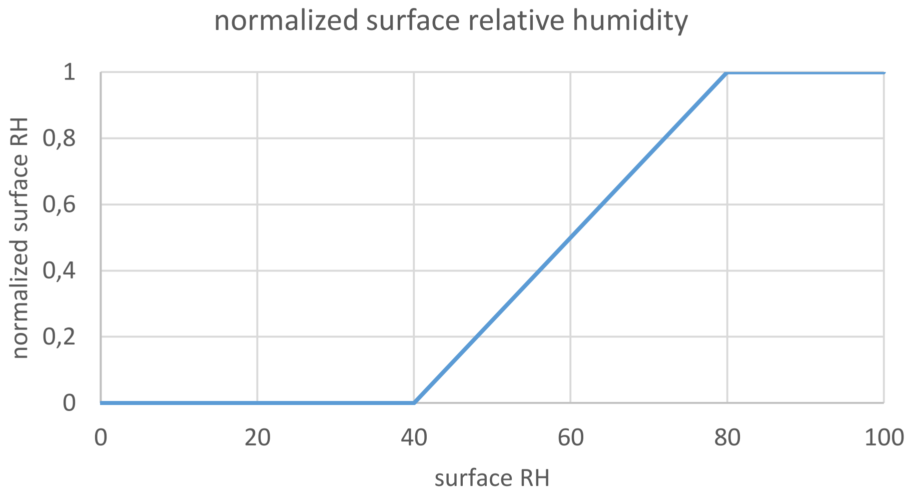
where:

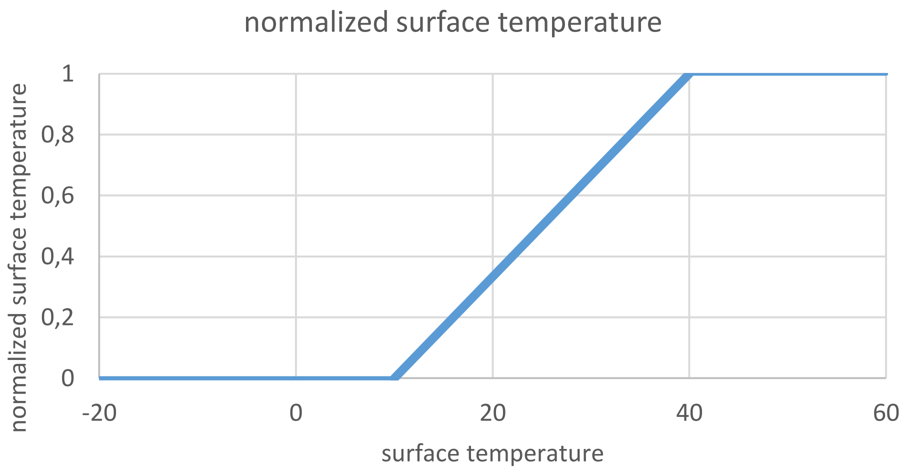
T = mean day temperature of the month [°F]

D = mean number of days with more than 0.001 inch of rain per month [-]

#2: Normalization of the hourly weather parameters by means of the logistic functions



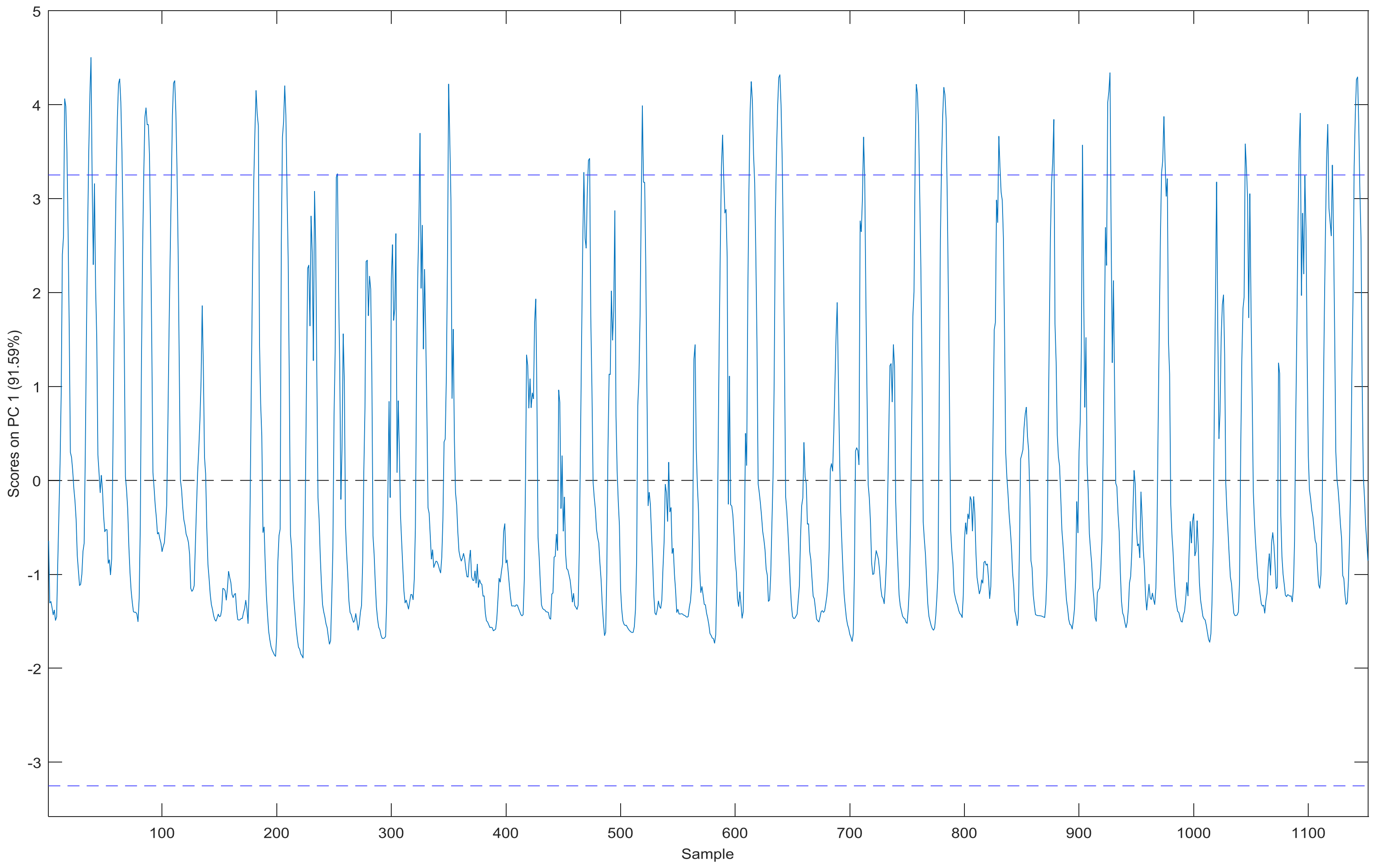




+ weighted average

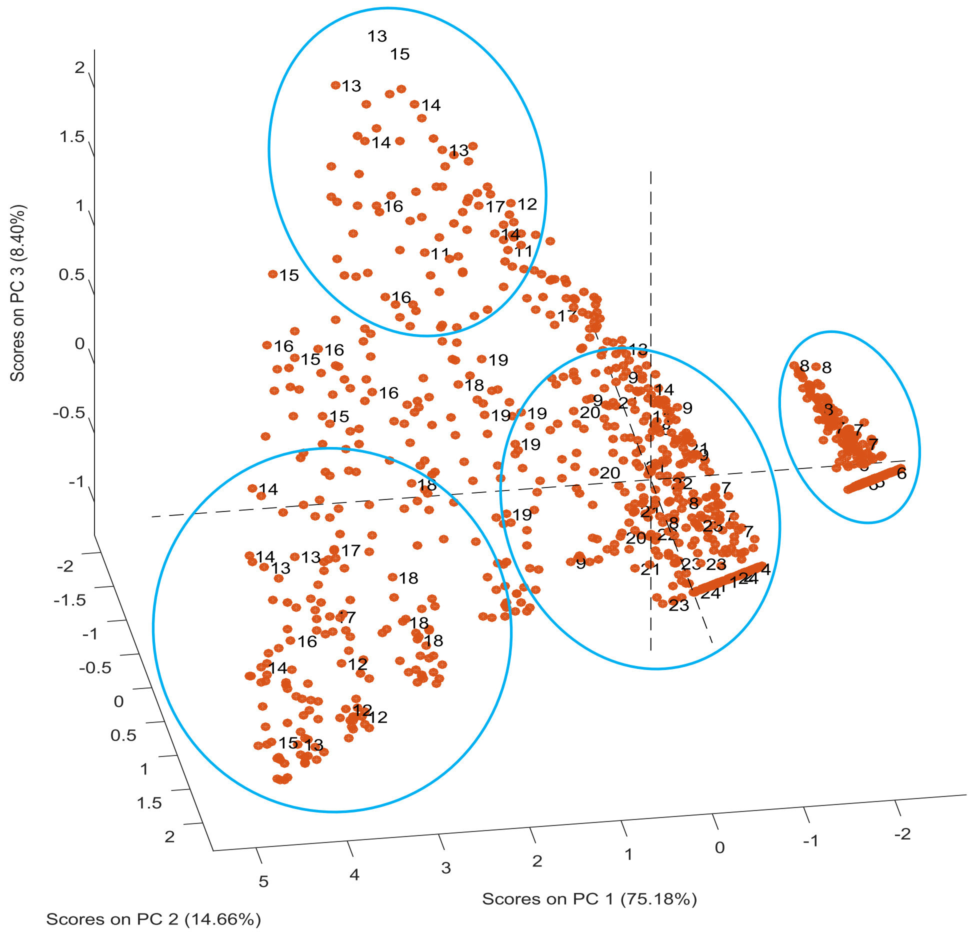
The normalized value of T, H and Q is determined on the base of transforming functions. The initial shape of each function is defined on the base of expert knowledge, but can be further modified by means of artificial intelligence methods, such as fuzzy-neural.

#3: Determination of the single PCA component describing hourly weather conditions



- 92% of the total variance recorded in the weather data described with a single PC!
- weather data from As (Norway) –thanks to Ingunn!

#4: multi-component PCA model describing hourly weather conditions



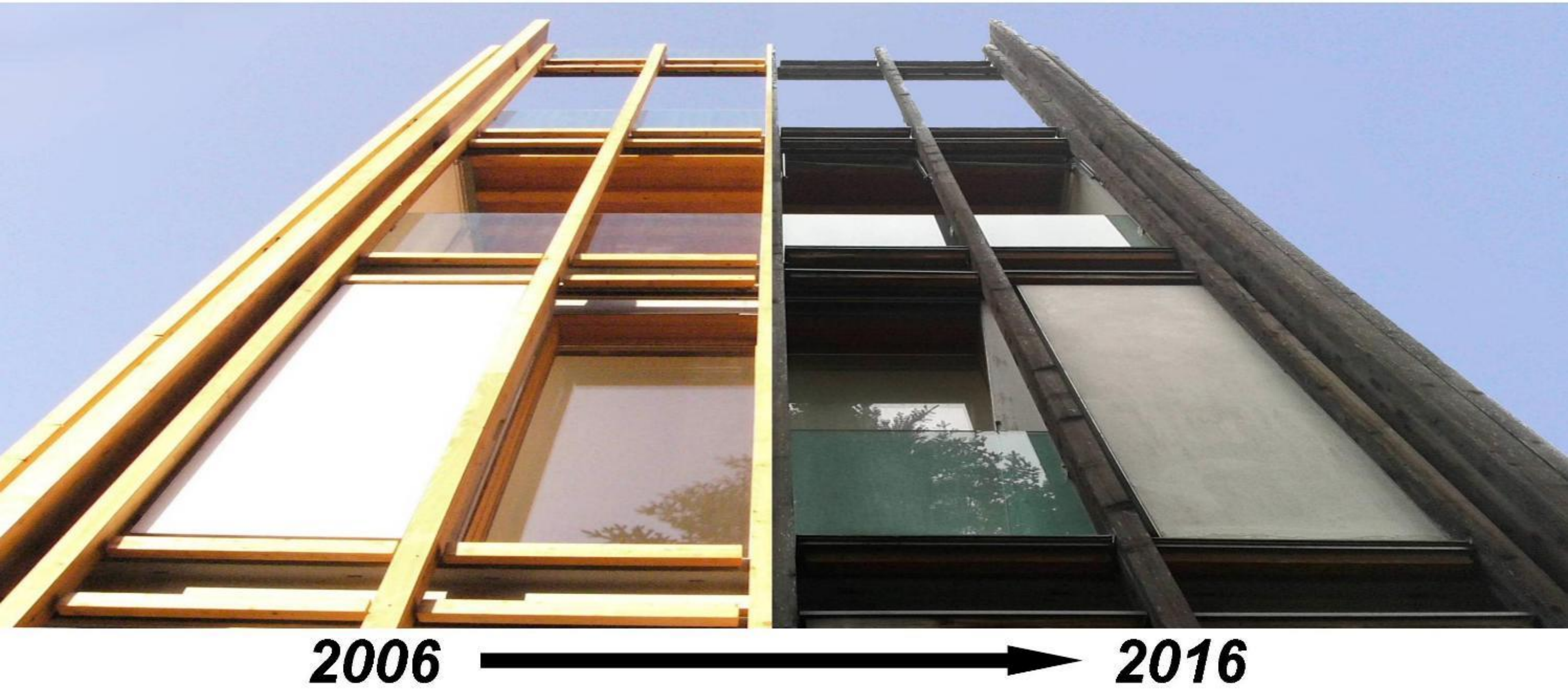
clustering periods of “similar weather”

Possibility for objective classification of data in to fuzzy values: “cold & sunny” “rainy”

Procedure for weather data treatment before its use in models

- Collect meteorological data in the standard Common Climate Data Format (CCDF), if such presented data are not available it is necessary to change it according to CCDF format requirements
- Compute T, H, and Q (T – surface temperature, H - relative humidity of air close to the surface, Q – direct solar radiation) on the base of meteorological data and custom software tools
- Present the processed weather data in a form of EXCEL template
- The preferred resolution of the weather data representation is 1 hour
- If 1-hour resolution is not possible, then average values over other period of time are used instead
- *Optionally: The structured data are presented to the PCA model and are converted in to a single value (PC1), closely related to the dose D (to be confirmed – work in progress)*
- Such structured weather data are presented directly to the modelling software

Appearance change of the unprotected wooden structure in time



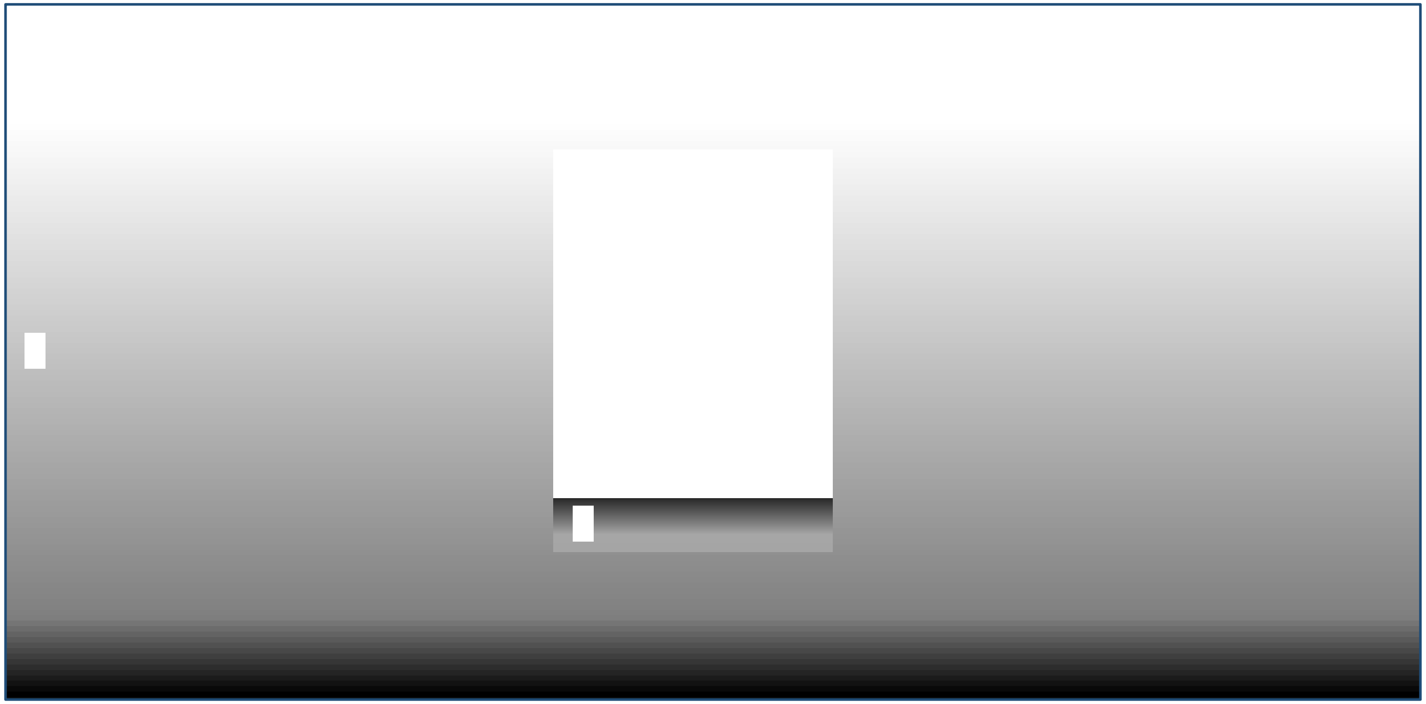
Challenge: is it possible to model it?

Methods for numerical modeling of weathering

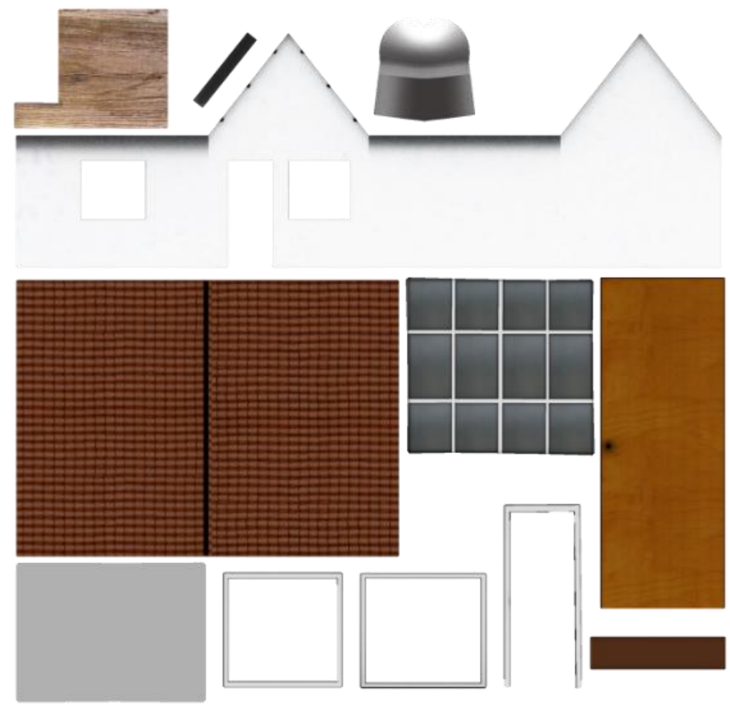
#4: visualization of deterioration

Texture #1 image representing distribution of late wood (dark) and early wood (light)

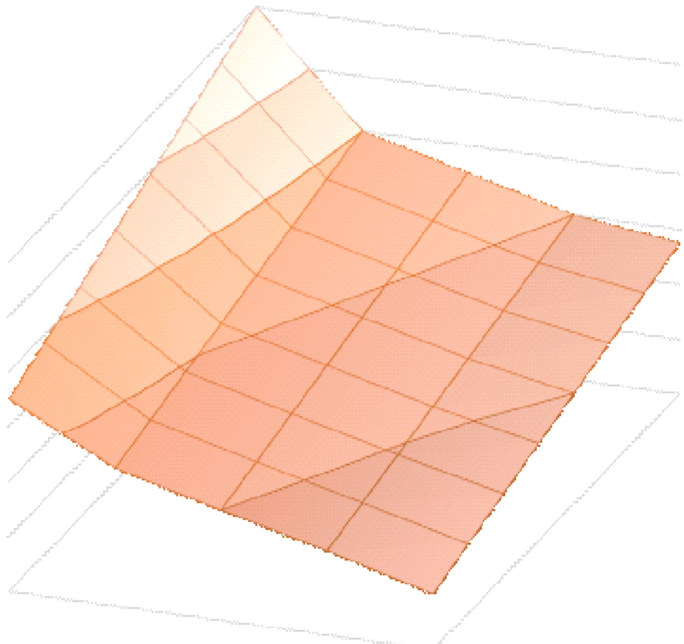
Texture #2 image representing distribution of weather dose D absorbed by the surface



3D model (left) reconstructed on the base of 2D diffuse texture #3 map (right)

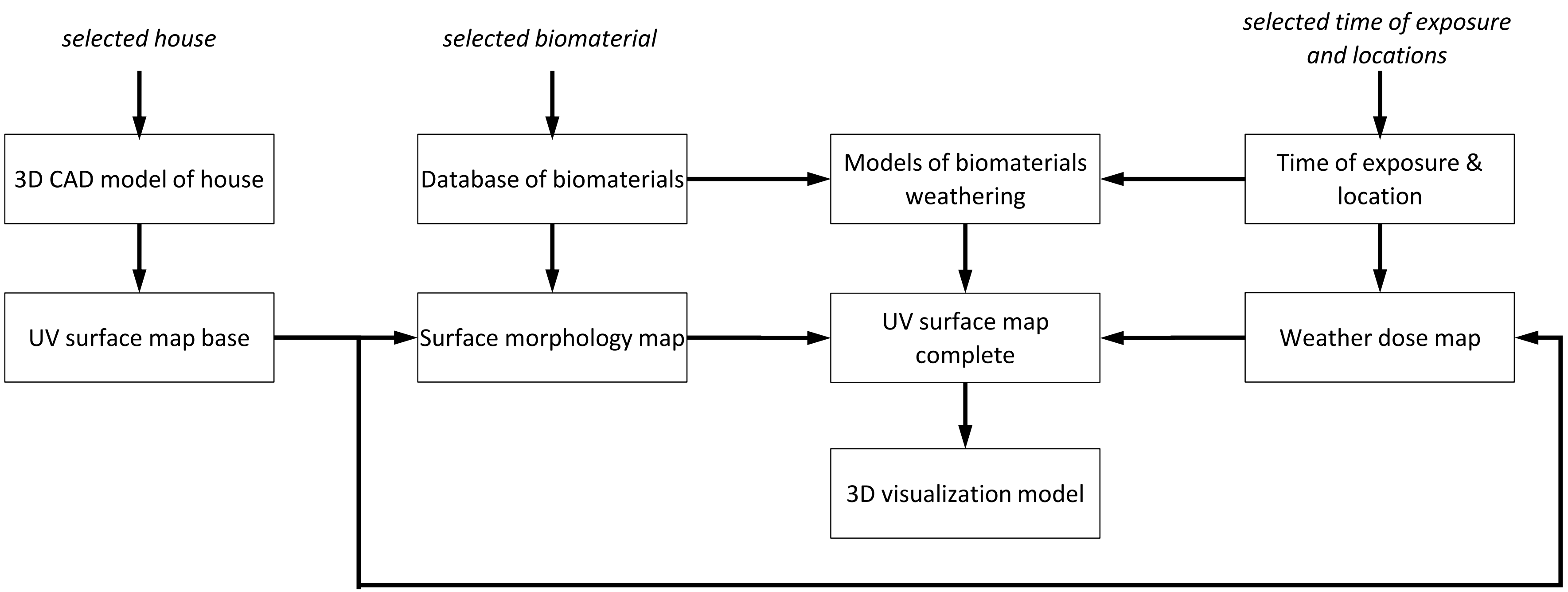


Numerical model for determination of the morphological map (texture #1) on the base of material definition (8-bit) and weather dose D (integer number from 0 to infinity)



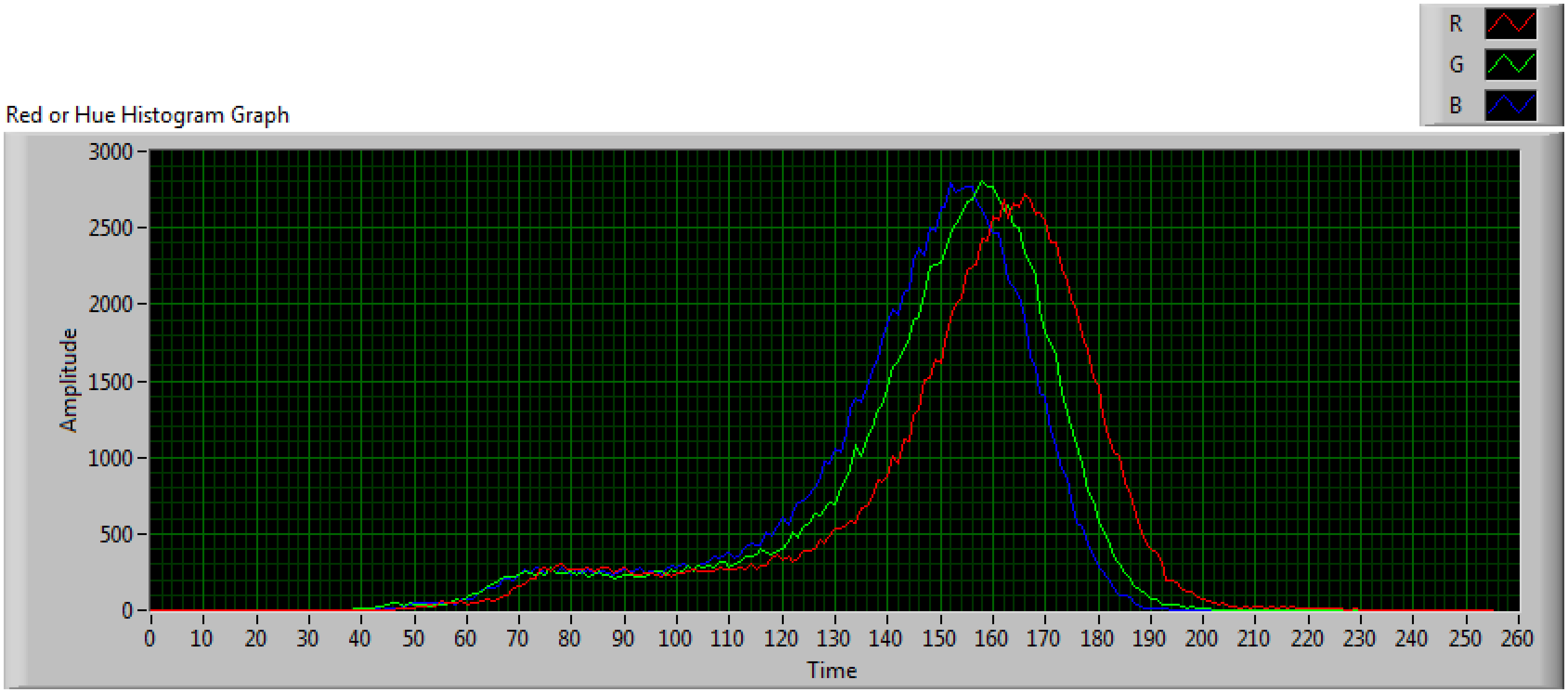
- The same principle will be implemented to model following attributes:
- R colour coordinate: R=f(D, M)
- G colour coordinate: G=f(D, M)
- B colour coordinate: B=f(D, M)
- Surface gloss: P=f(D, M)
- Surface roughness: S=f(D, M)

Flowchart of the data for 3D visualization of the building exposed to natural weathering

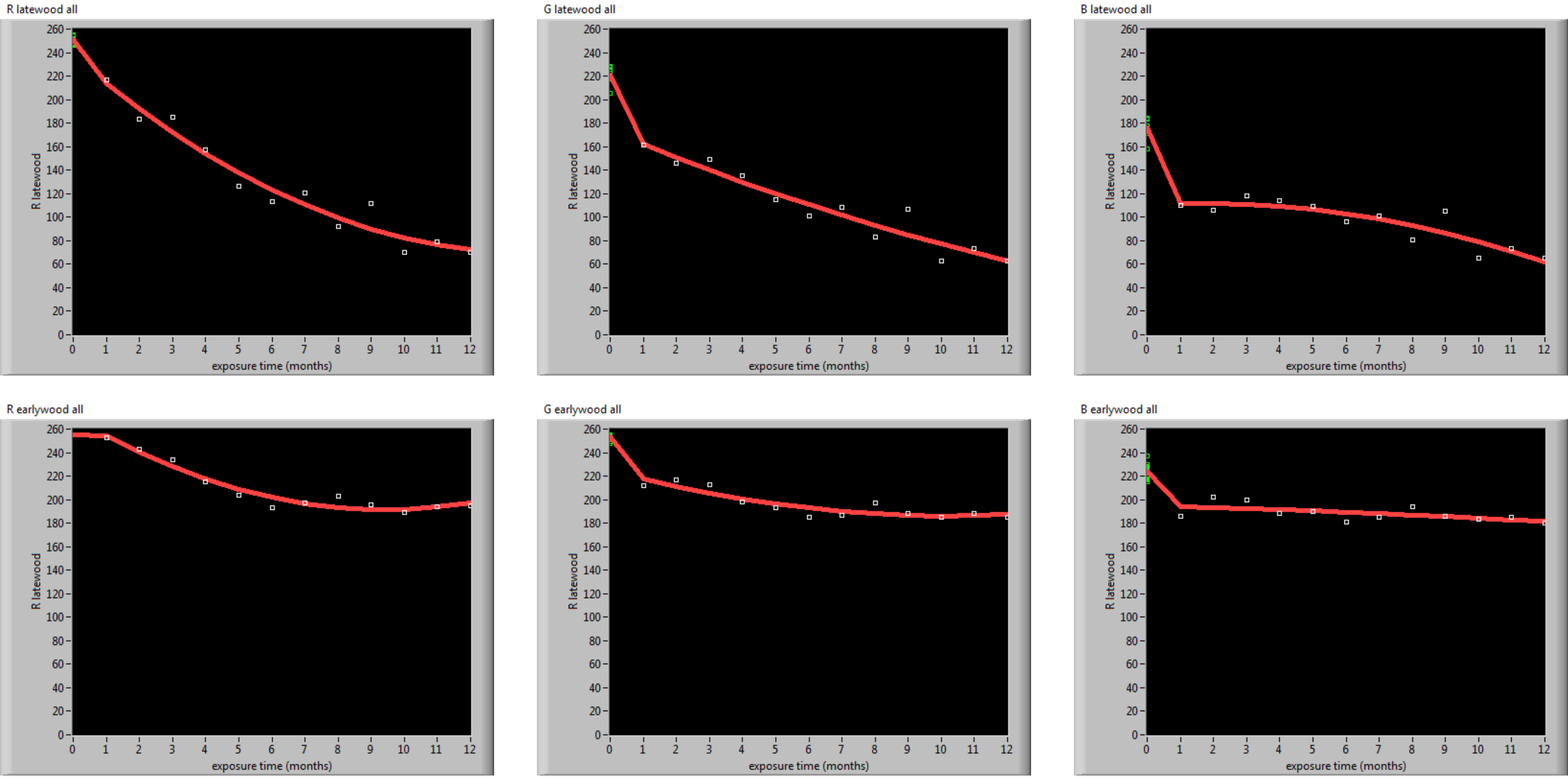


Source data

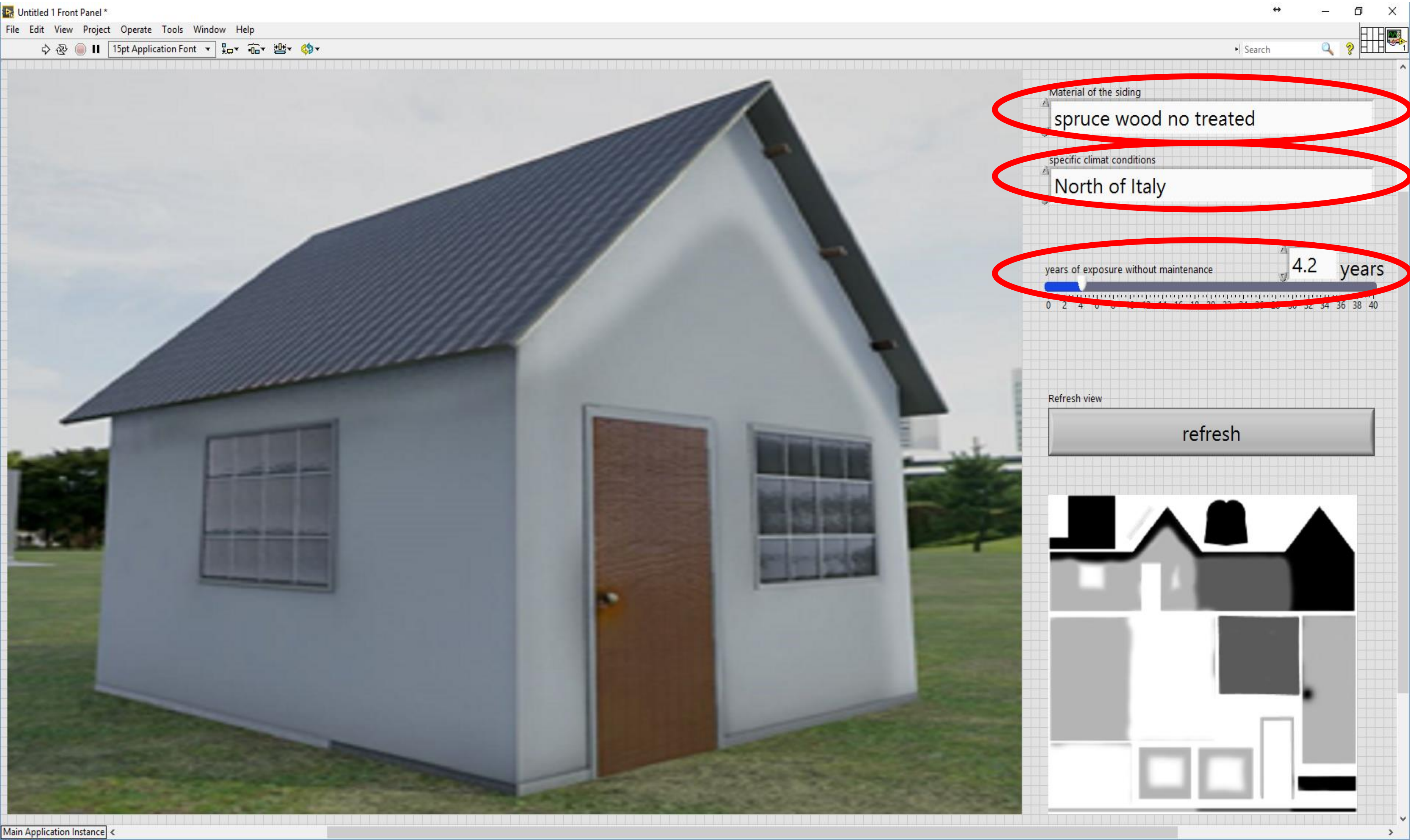
histogram of the weathered wood colour



Curves of the RGB colour changes for early and late wood in one year weathereing



BIO4ever project & modeling



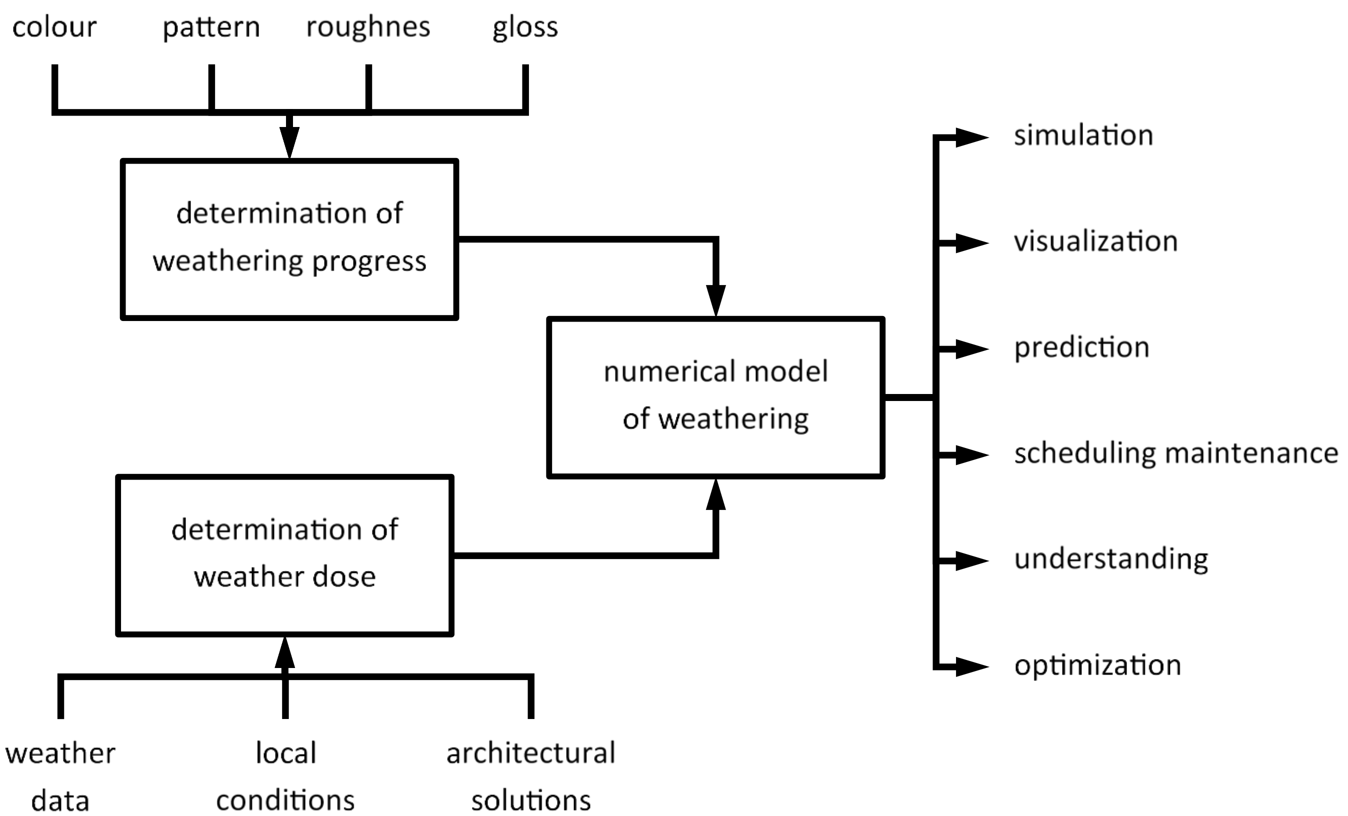
BIO4ever project – modeling of weateherd wood appearance

Live presentation of the software

Weathering models validation

- models should be **robust and general enough** to properly explain not only the variability within the data used within model development, but also within any other case, not necessarily included in the teaching dataset
- **validation procedure** confirms the exactness of the model's representation of the real systems and assures its high credibility
- external **validation with independent data** is always considered as an optimal solution, and therefore recommended for routine implementation
- a very important task is to assure a **continuous upgrade of the numerical models**: whenever possible, the software system should automatically acquire new knowledge along the service time and incorporate it with the original model

summarizing



Concluding remarks

- **Understanding the mechanisms** of weathering and the role of the altering factors **is fundamental** to assess the actual conditions of timber structures. It is **essential to predict the future performance**, and, possibly, to ensure a long-term preservation and maintenance.
- data obtained with different characterization methods + combined together as the weathering index are superior representation of the deterioration progress
- **Parafac** methods allow identification of driving mechanisms in complex multiway data sets (ex. extreme locations and kinetic of weathering)
- **2DSC** is useful for identification of peaks related to weathering
- determination of the **weather-dose response model** is essential to predict the future performance of timber façades elements
- the proper **conversion** of the weather data, including its **unification** and determination of the <u>surface temperature</u>, <u>relative humidity close to the surface</u> as well as <u>direct radiation</u> is fundamental for further numerical model development

Acknowledgments

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BIO4ever

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Thanks!

Comments/critics/problms?

Engineering is the art of modelling materials we do not wholly understand, into shapes we cannot precisely analyse so as to withstand forces we cannot properly assess, in such a way that the public has no reason to suspect the extent of our ignorance.

Dr. A. R. Dykes,
British Institution of Structural Engineers