COST Action FP1303 Short Term Scientific Mission:

Development of an algorithm for computation of the weather dose used for natural weathering models

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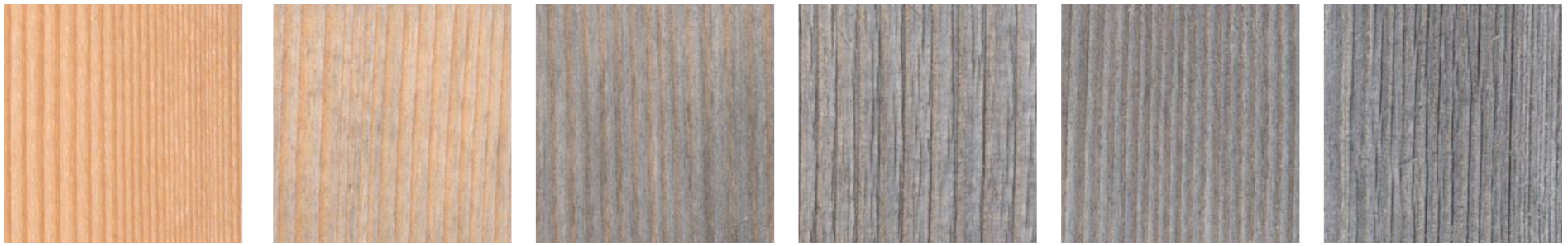
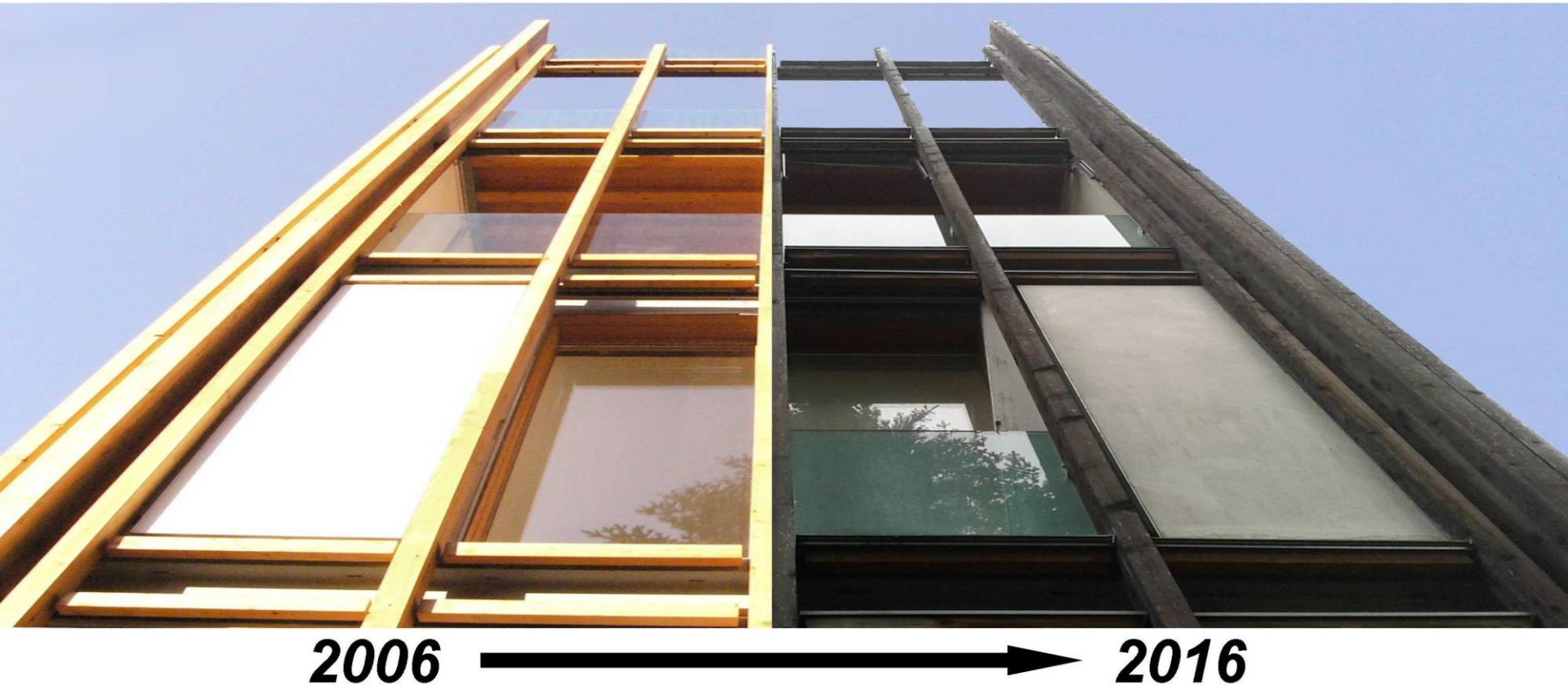
Weathering

- 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

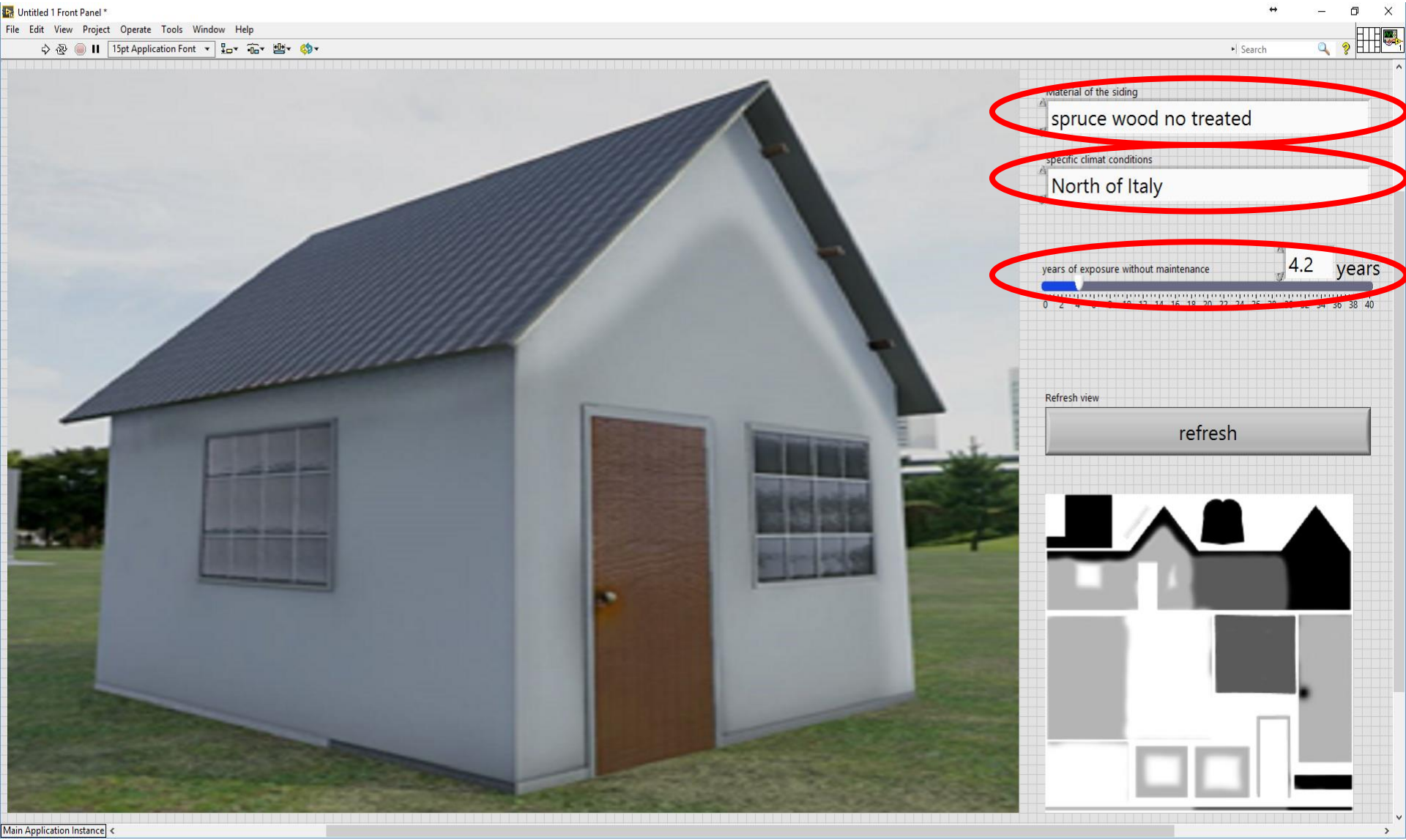


Appearance change of the unprotected wooden structure in time



Challenge: is it possible to model it?

BIO4ever project & modeling



“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
- Characterized with color CIE Lab, VIS, NIR and MIR spectra, imaging, gloss, XRF, roughness, microscopy, TGA, hyperspectral imaging

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.)

Defects appearing along the weathering

blistering

checking

peeling

moulds

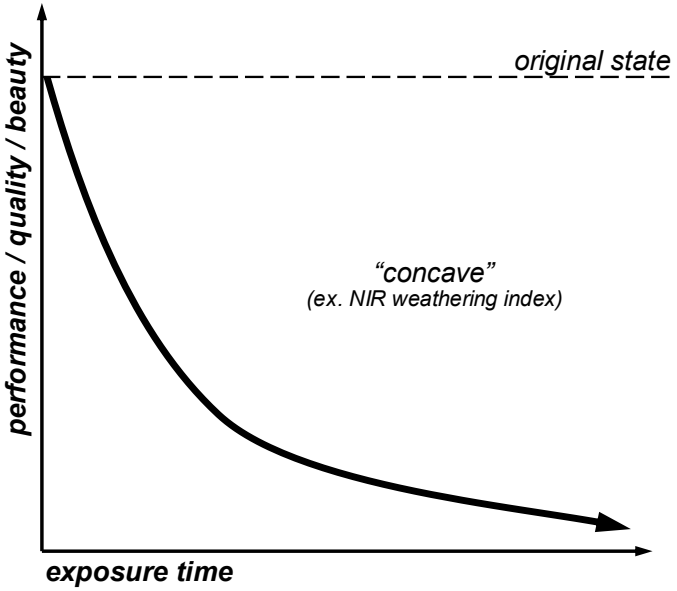
DEFINITIONS: Weathering progress/index *W*

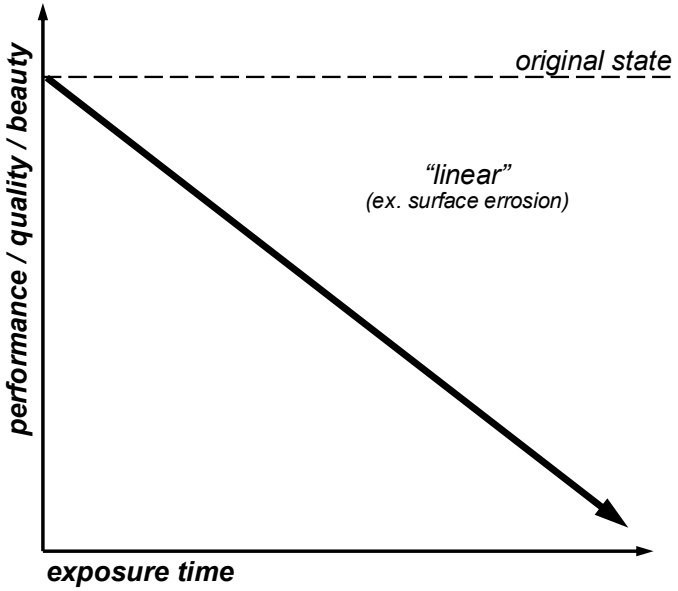
- Is an **indicator describing how advanced is the progress of weathering** compare to the original state
- The progress of weathering *W* is not really correlated to time but it **is related to the cumulative weather dose *D***
- There is a **universal path of the weathering progress** that can be defined 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.

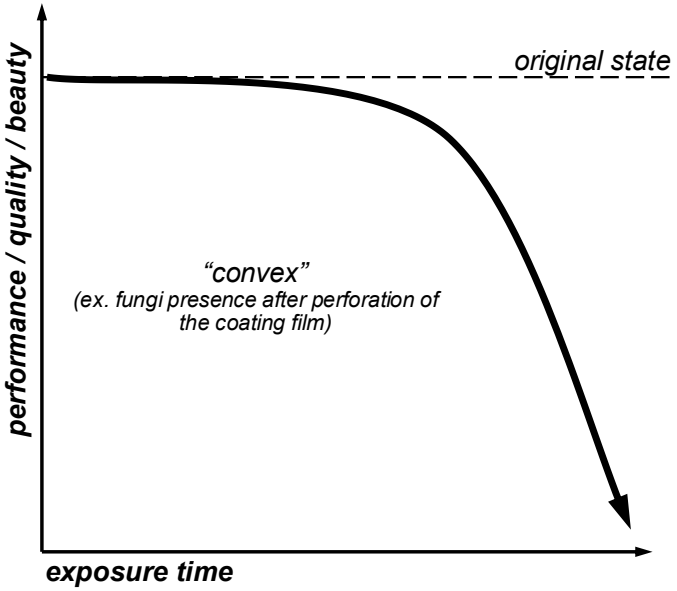
DEFINITIONS: Model curve of weathering

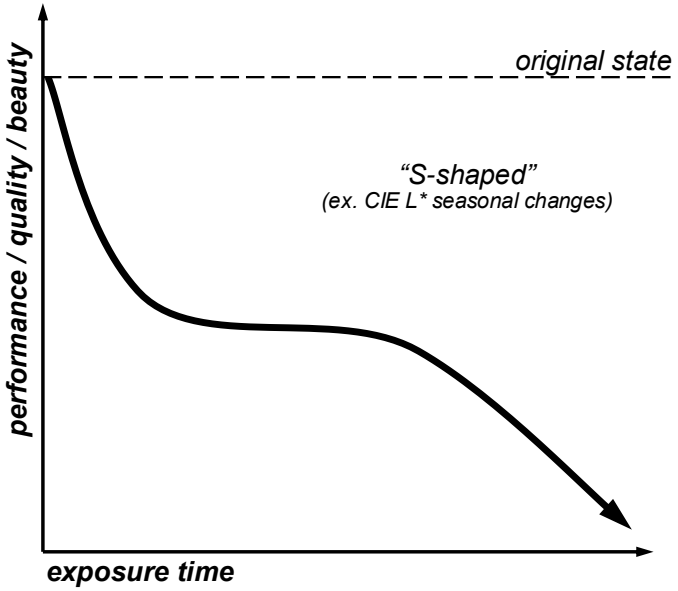
- Is a function **linking material state with the weather dose** *D*
- The model curve is computed on the base of **experimental data**
- The horizontal axis corresponds to the normalized weathering progress in the range of 0 (not weathered surface) to 1000 (state of the common reference weathering)
- 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



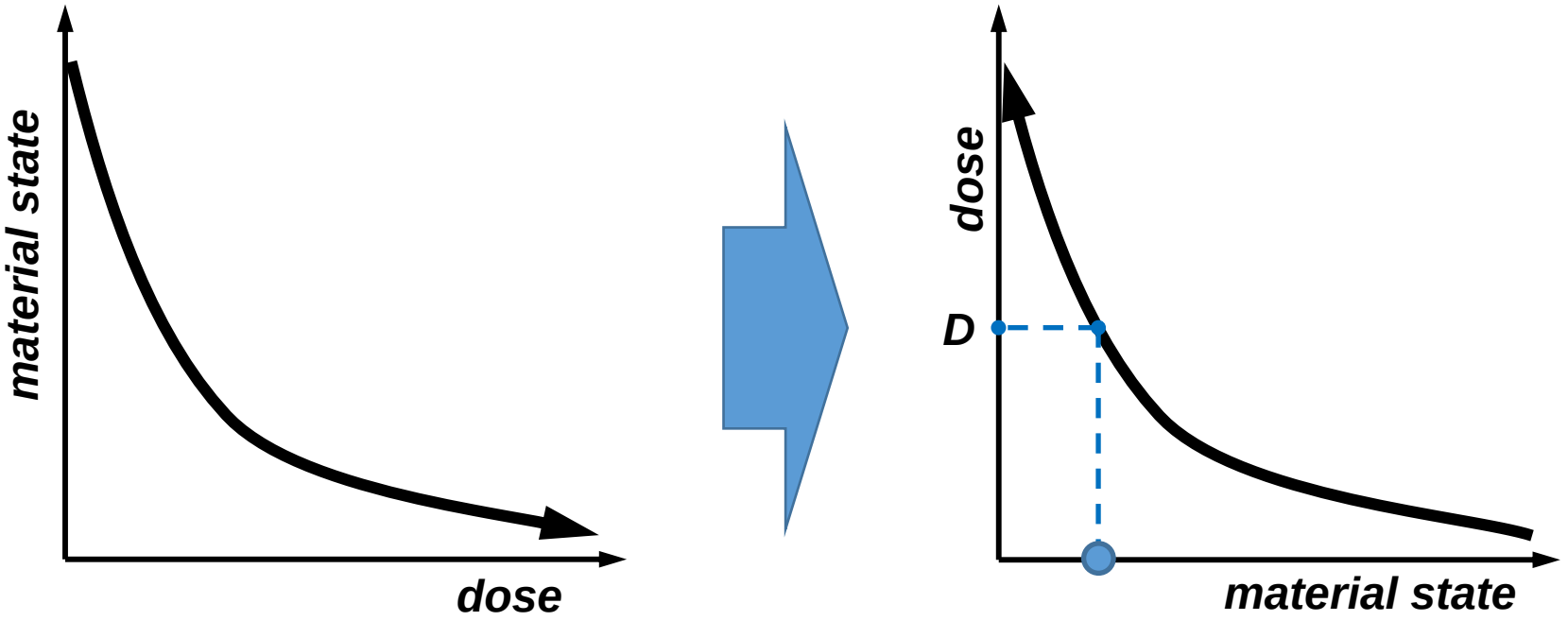




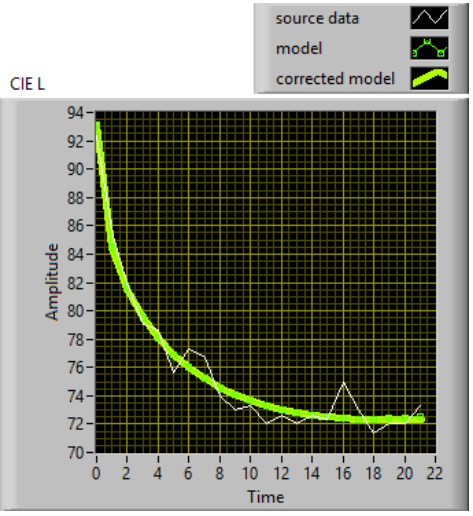


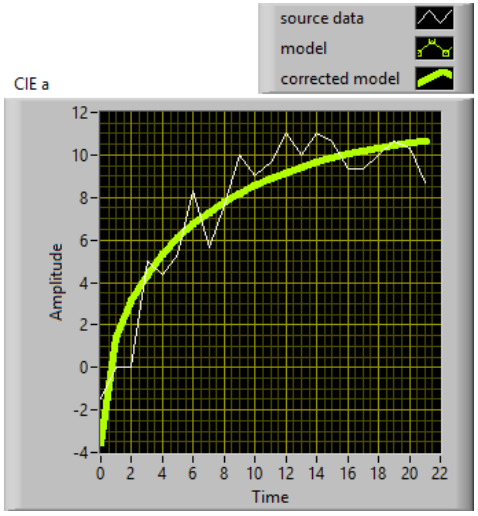
DEFINITIONS: Inversed model curve of weathering

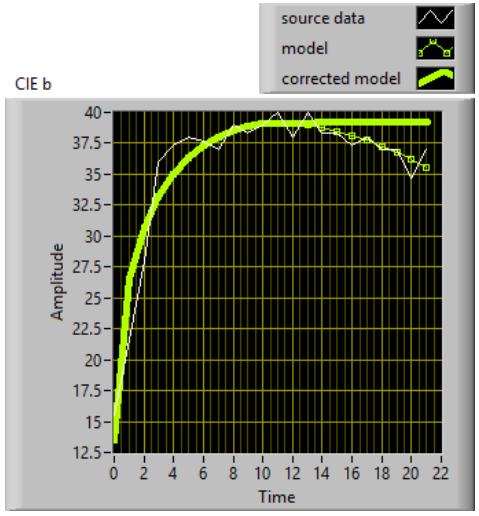
- It is a **variation of the Model curve of weathering**, where X and Y axis are inversed
- It is used for determination of the **total accumulated weather dose *D*** along the (time independent) weathering.
- The value of dose *D* is directly computed by the algorithm on the base of the given material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

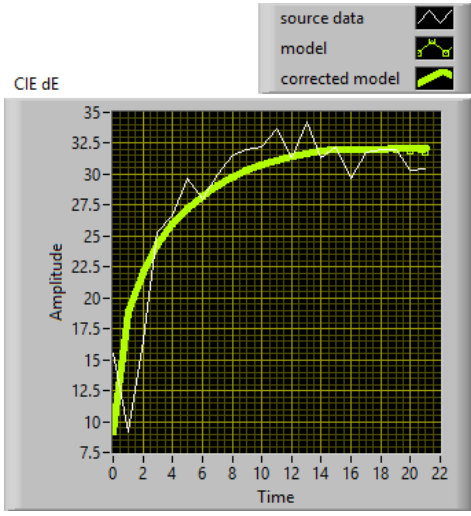


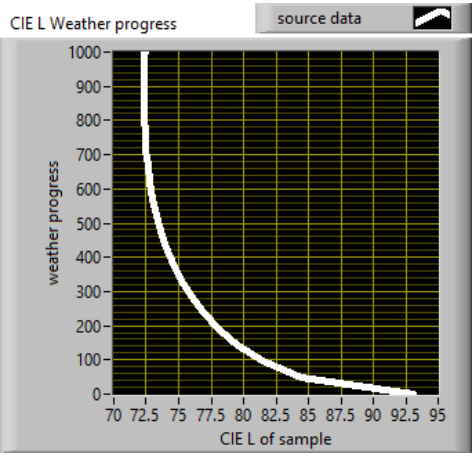
model curves of real weathering data

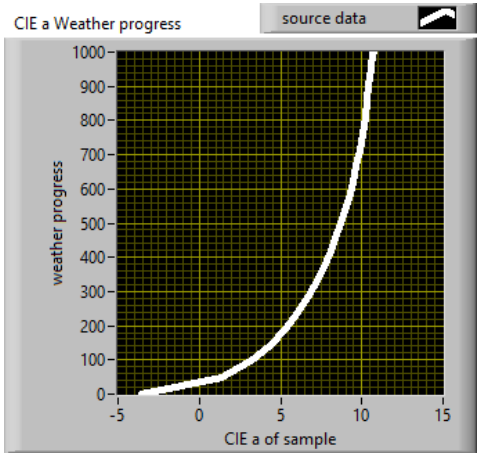


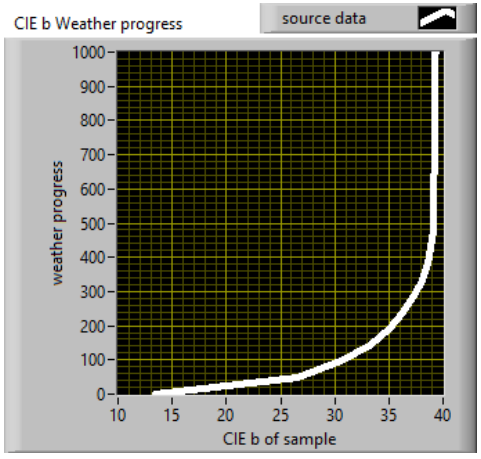


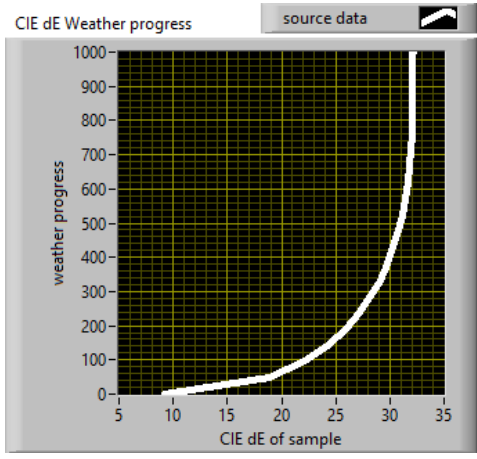










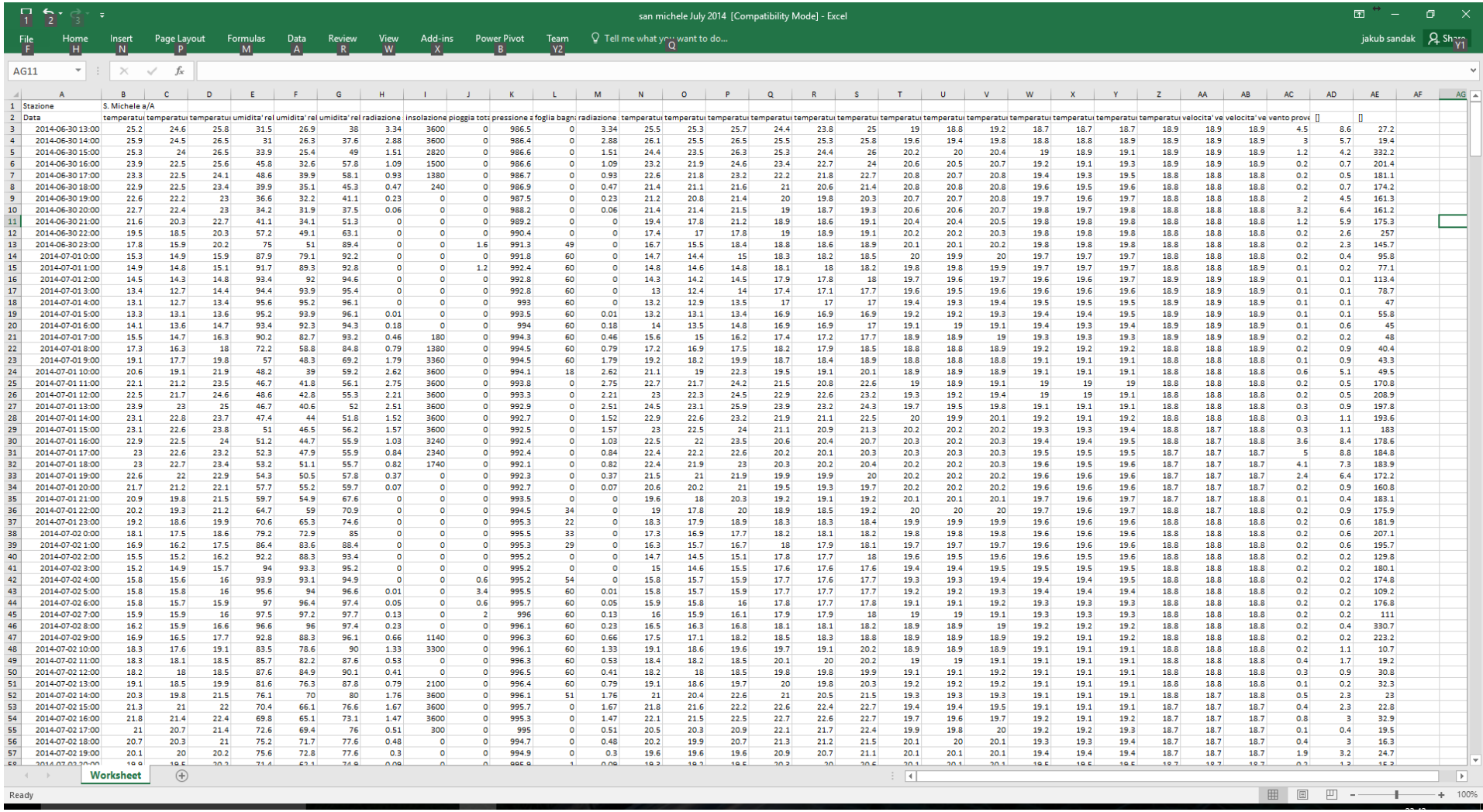


Presentation of the climat data to the numerical model

… a key result of the STSM is development of the alternative way(s) for presentation of the weather data and computation of the weather dose

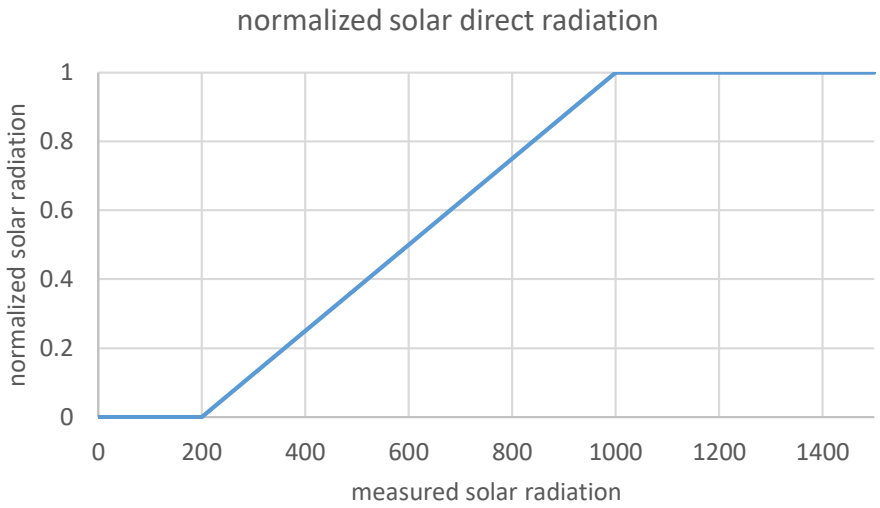
Climate in Europe

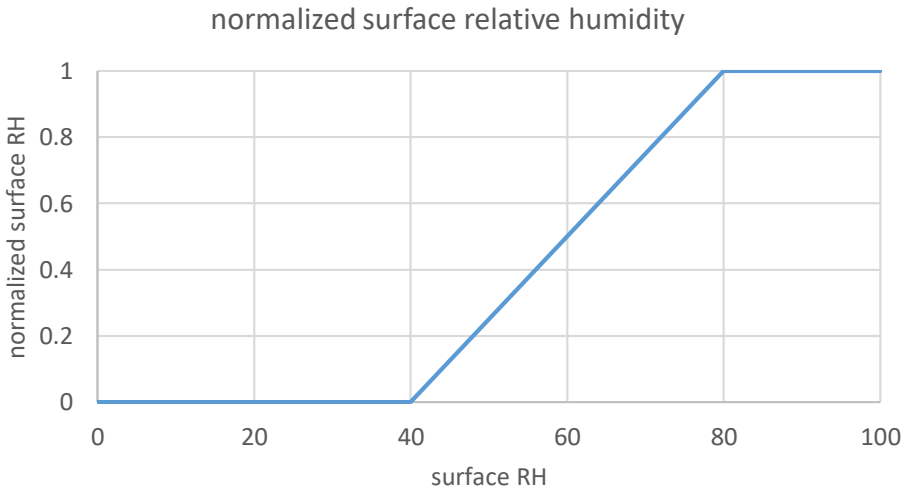
Weather data: starting point

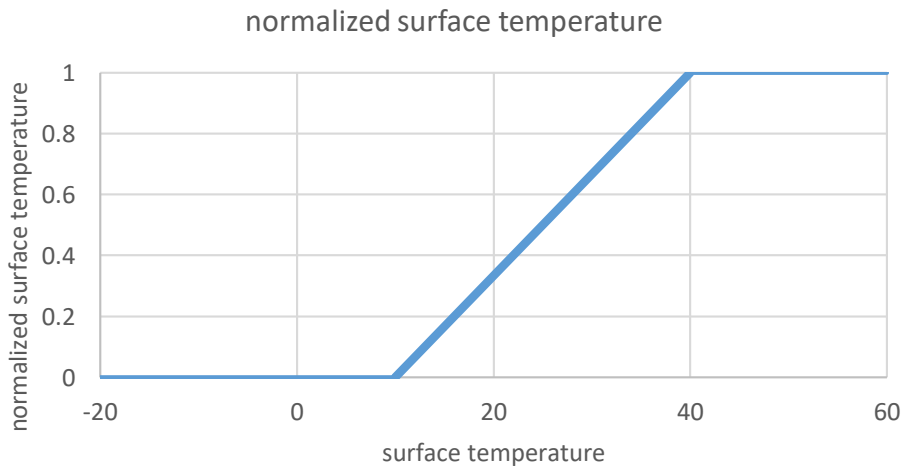


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	Stazione	S. Michele a/A																													
2	Data	temperatu	temperatu	temperatu	umidita' rel	umidita' rel	umidita' rel	radiazione	insolazione	pioggia tot	pressione a	foglia bagn	radiazione	temperatu	temperatu	temperatu	temperatu	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	17.8	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
58	2014-07-02 20:00	19.9	19.5	20.2	71.4	67.1	74.9	0.09	0	0	995.9	1	0.09	19.3	19.2	19.5	20.3	20	20.5	20.1	20.1	20.1	19.5	19.5	19.5	18.7	18.7	18.7	0.2	1.3	15.2

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



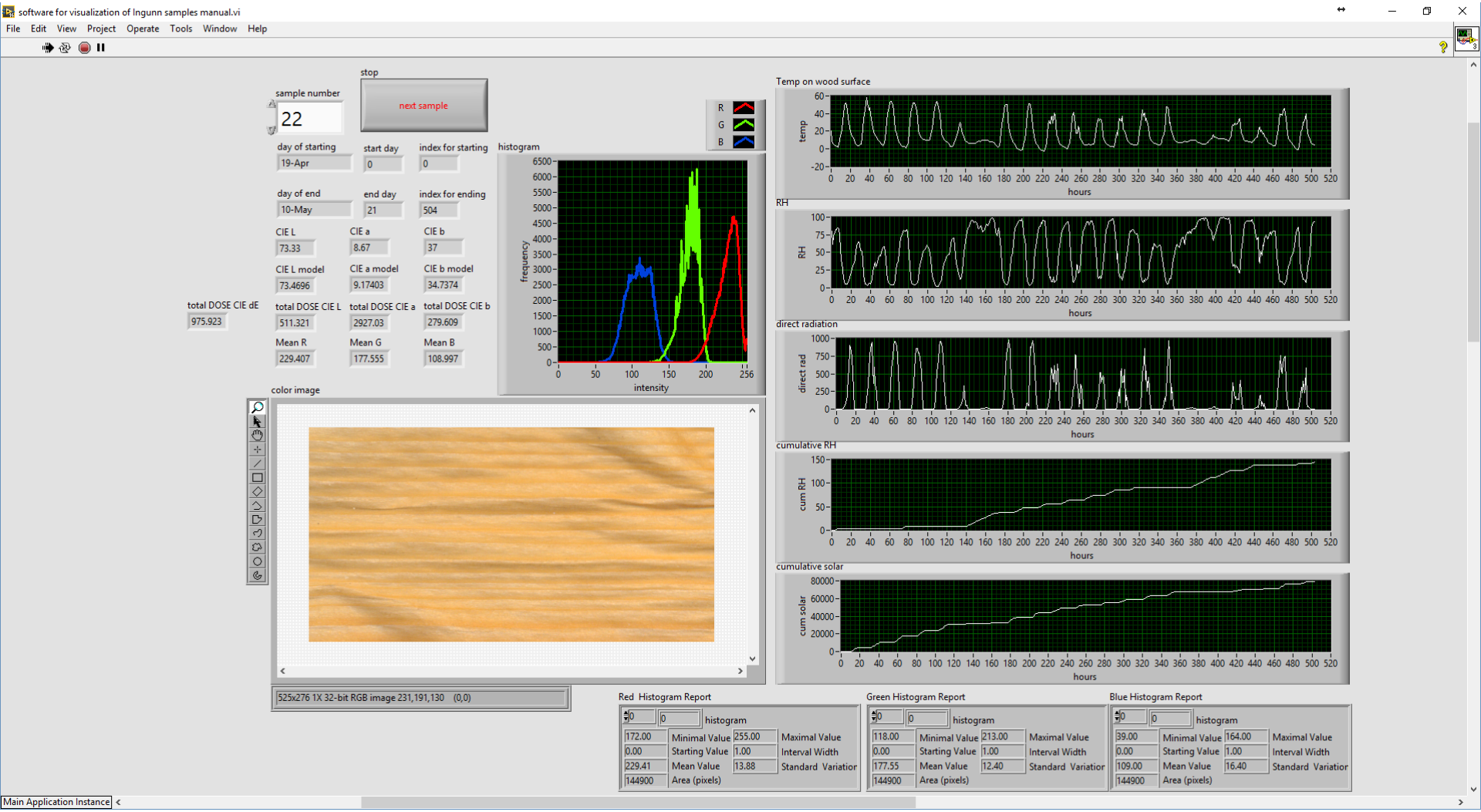




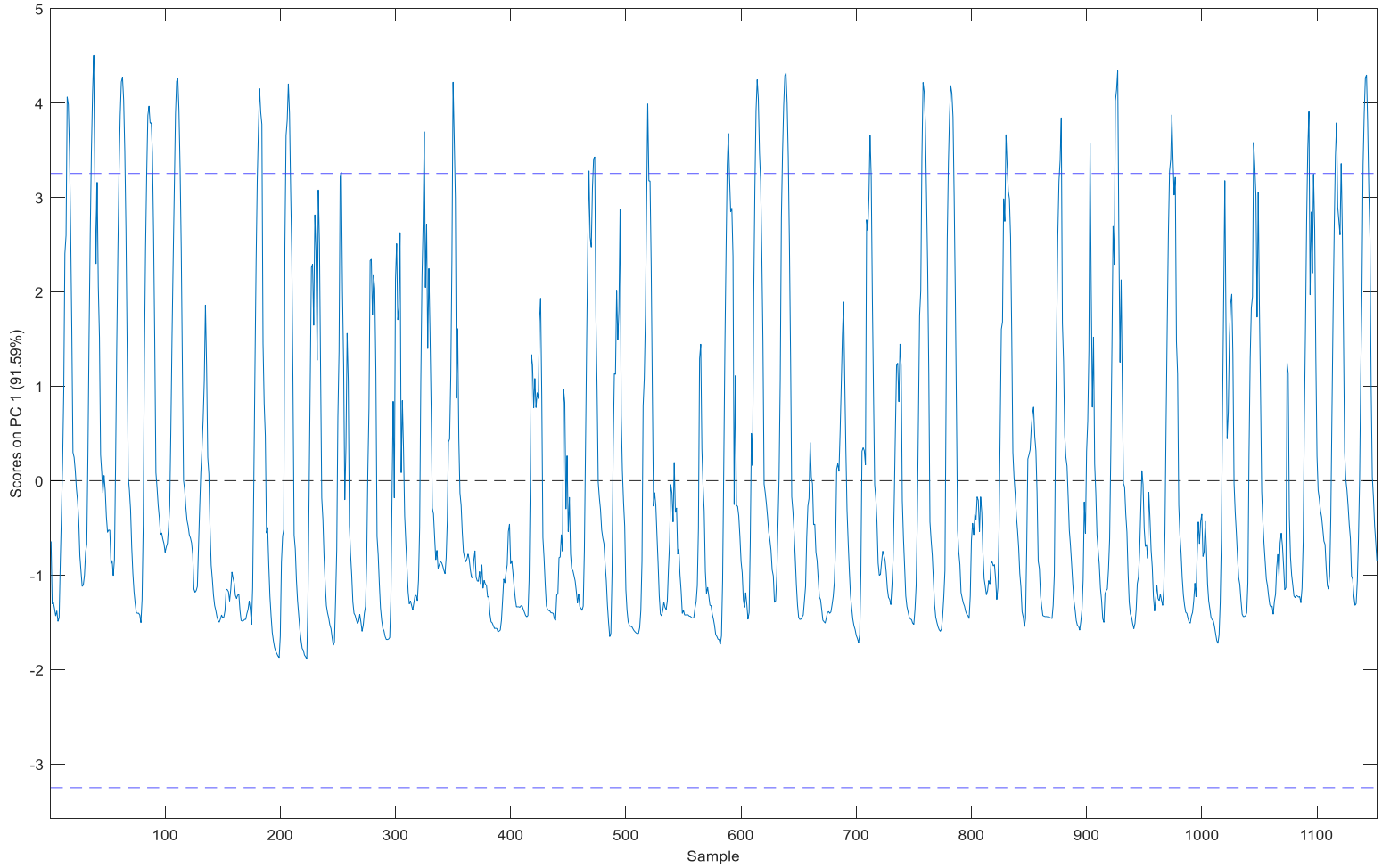
+ weighted average

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.

the software for analysis of the weathered wood samples developed during STSM

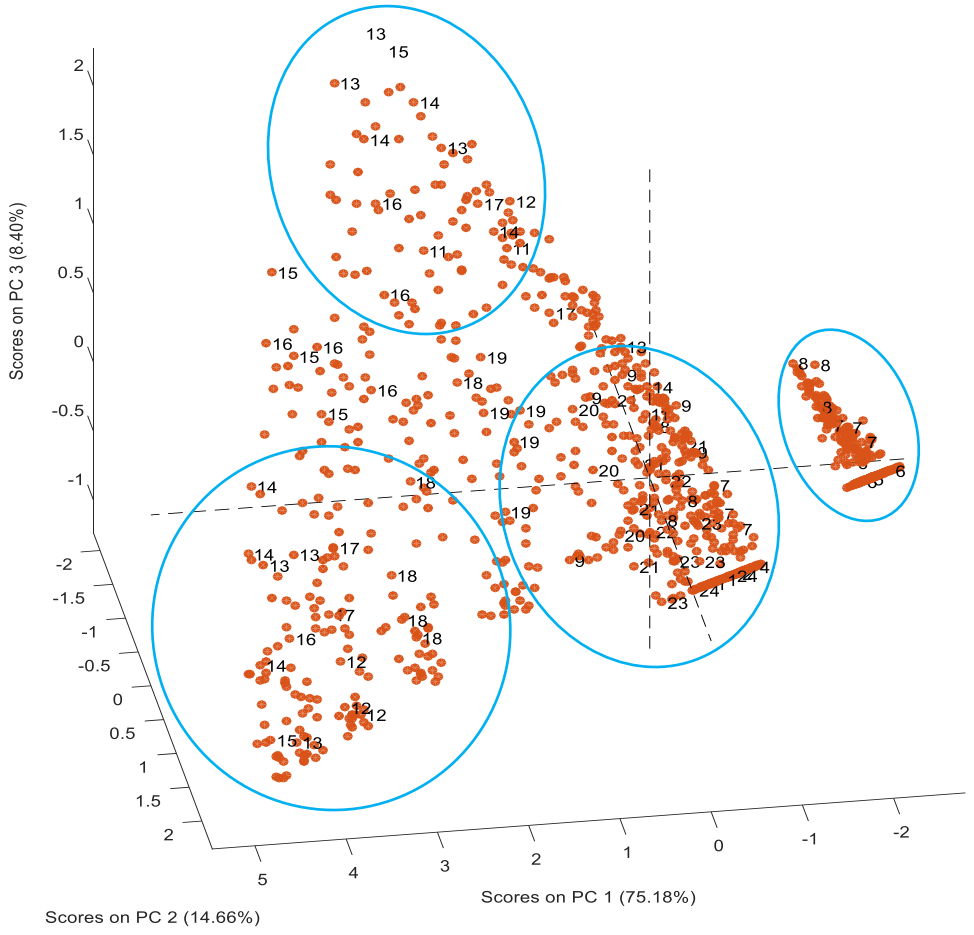


#2: Determination of the single PCA component describing hourly weather conditions



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

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



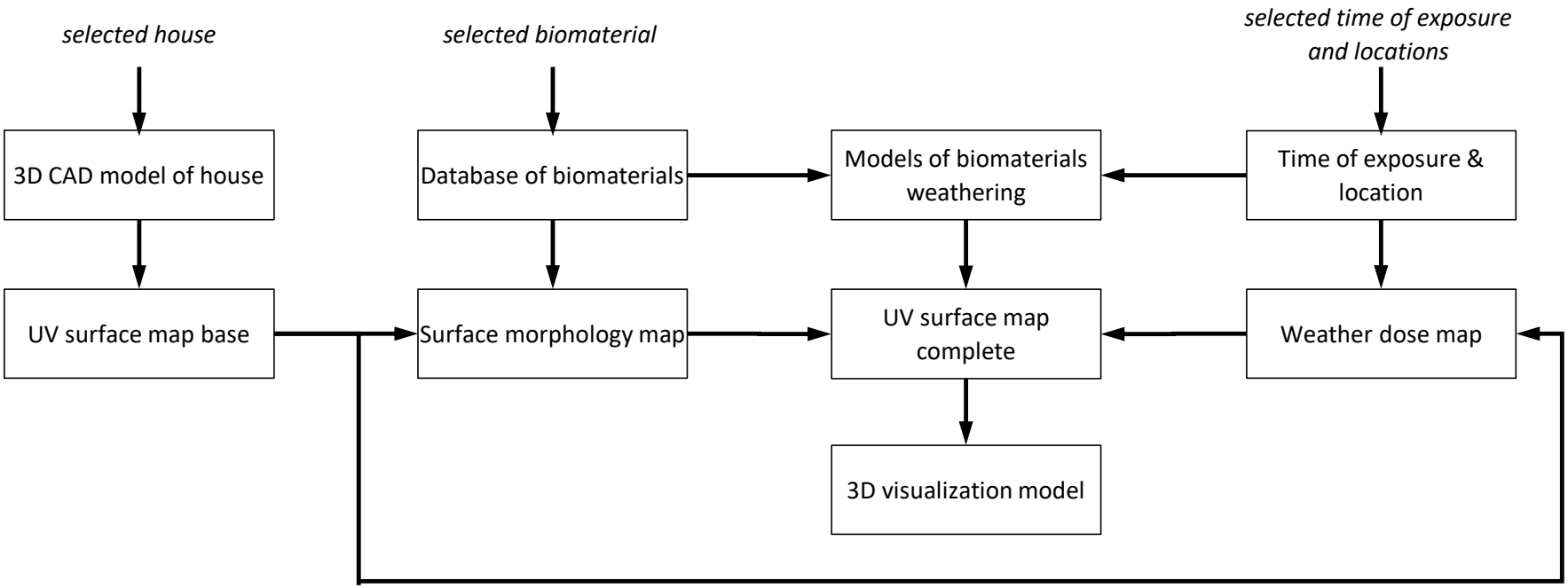
clustering periods of “similar weather”

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

Ongoing work



Concluding remarks

- the **conversion** of the weather data collected during the Round Robin, including its **unification** and determination of the surface temperature, relative humidity close to the surface as well as direct radiation is fundamental for further numerical model development
- STSM was extremely useful for me to develop the core software tools indispensable to modelling of the wood weathering on the base of alternative dose-response approach
- The following work is already ongoing and it is conducted in a close collaboration with COST Action FP1303 participants

Acknowledgments

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- I am very grateful for the greatest hospitality, intensive discussions and openness of my hosts and all Norwegian colleagues. Special thanks to my supervisor, Professor **Ingunn Burud** (with Family), Professor **Thomas Thiis** (with Family), Doctor **Dimitrios Kraniotis** for their time, friendship and numerous debates ending very late. My apologies for frequent changing of ideas and to many monologues ☺.
- I would also like to thank Doctor **Lone Ross Gobakken**, Doctor **Peder Gjedrum**, Doctor **Andreas Treu**, and The Norwegian Institute of Bioeconomy Research (NIBIO) for support of STSM and possibility to visit laboratories.

BIO4ever

Wood performance