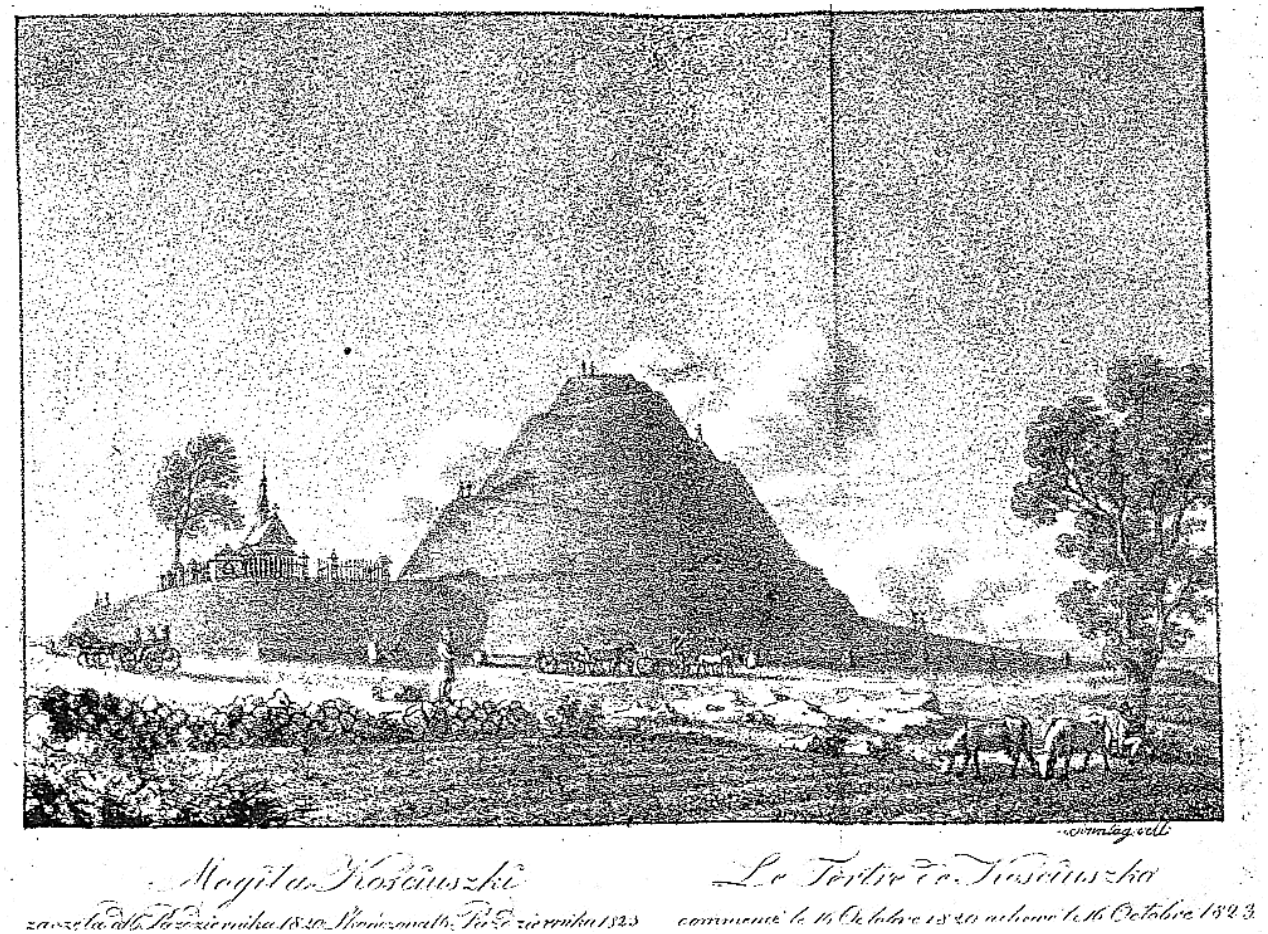
Structural Health Monitoring for Kościuszko Mound in Cracow

Mariusz Maślak, PhD, DSc
Michał Pazdanowski, PhD
Rafał Sieńko, PhD
Tomasz Howiacki, MSc

Tadeusz Kościuszko
Cracow University of Technology
Faculty of Civil Engineering

Table of contents

- History
- Reasons for measuring
- Our purposes
- Surveyor system
- Current results
- Conclusions



Important dates

1820 – mounding began

1823 – structure completed

1850 – fortification began

1854 – Fort V finished

1939 – entered in the registry of monuments

Geometry

80m – base diameter

8m – diameter of viewing platform

34m – height of the mound

40 – 60° - the angle of slopes

Damage in 1997

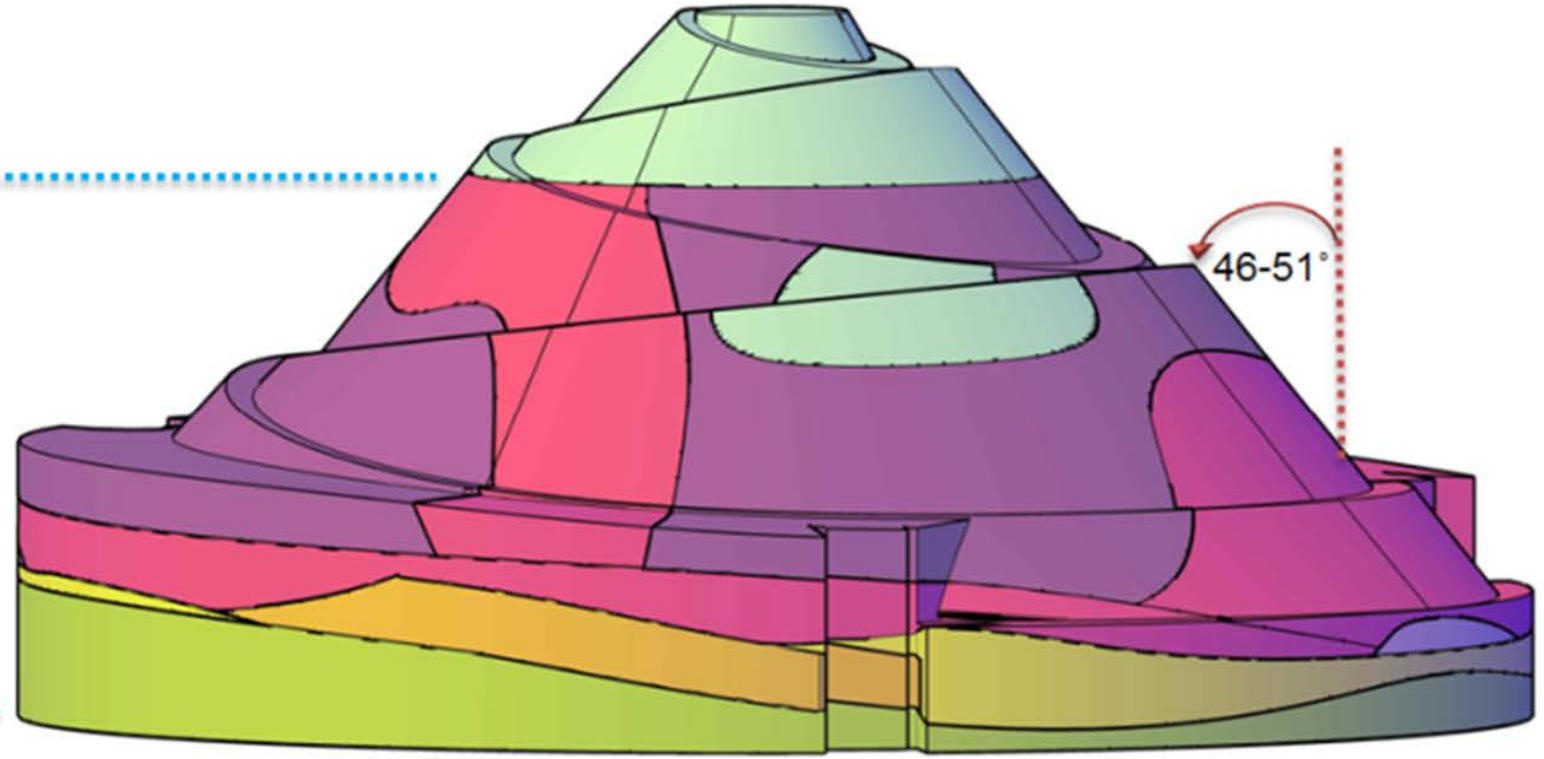
Geology

non-cohesive soil (9m)
(sands and gravels)

silts and clays (12-20m)
(with highly plastic areas)

subsoil layer (2-4m)
(silts and clays)

limestone



Reasons for measuring

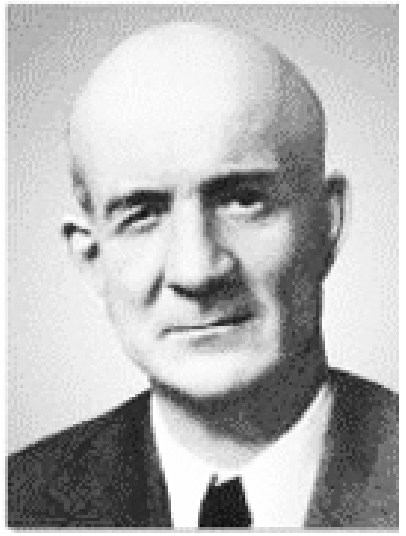
- **<u>continuous degradation</u>**
- difficult conditions (material, slopes)
- not fully effective repairs
- lack of full geotechnical documentation until 2012
- surface observations until 2012

Our purposes

- ✓ understand the phenomena occuring over time
- ✓ diagnose the mechanism of ground layers work
- ✓ improve future designs

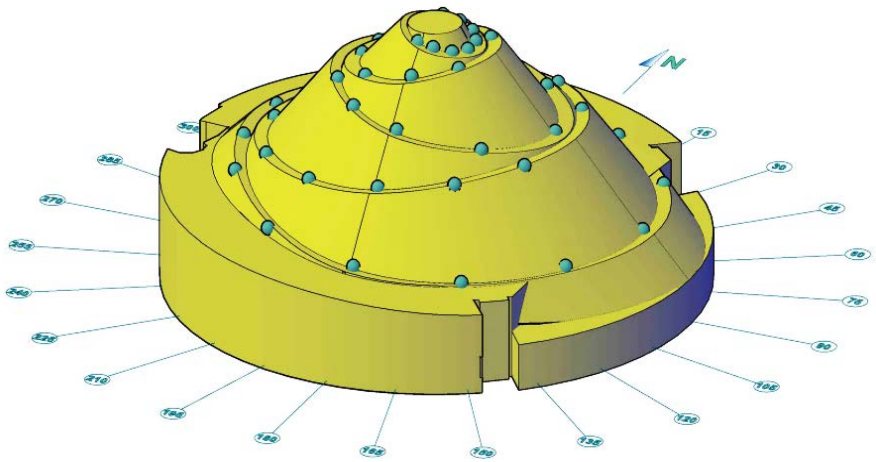
It is easier and better to understand phenomena
by experimental way,
than analyse theoretical schemes, which are never
able to accurately reflect phenomena.

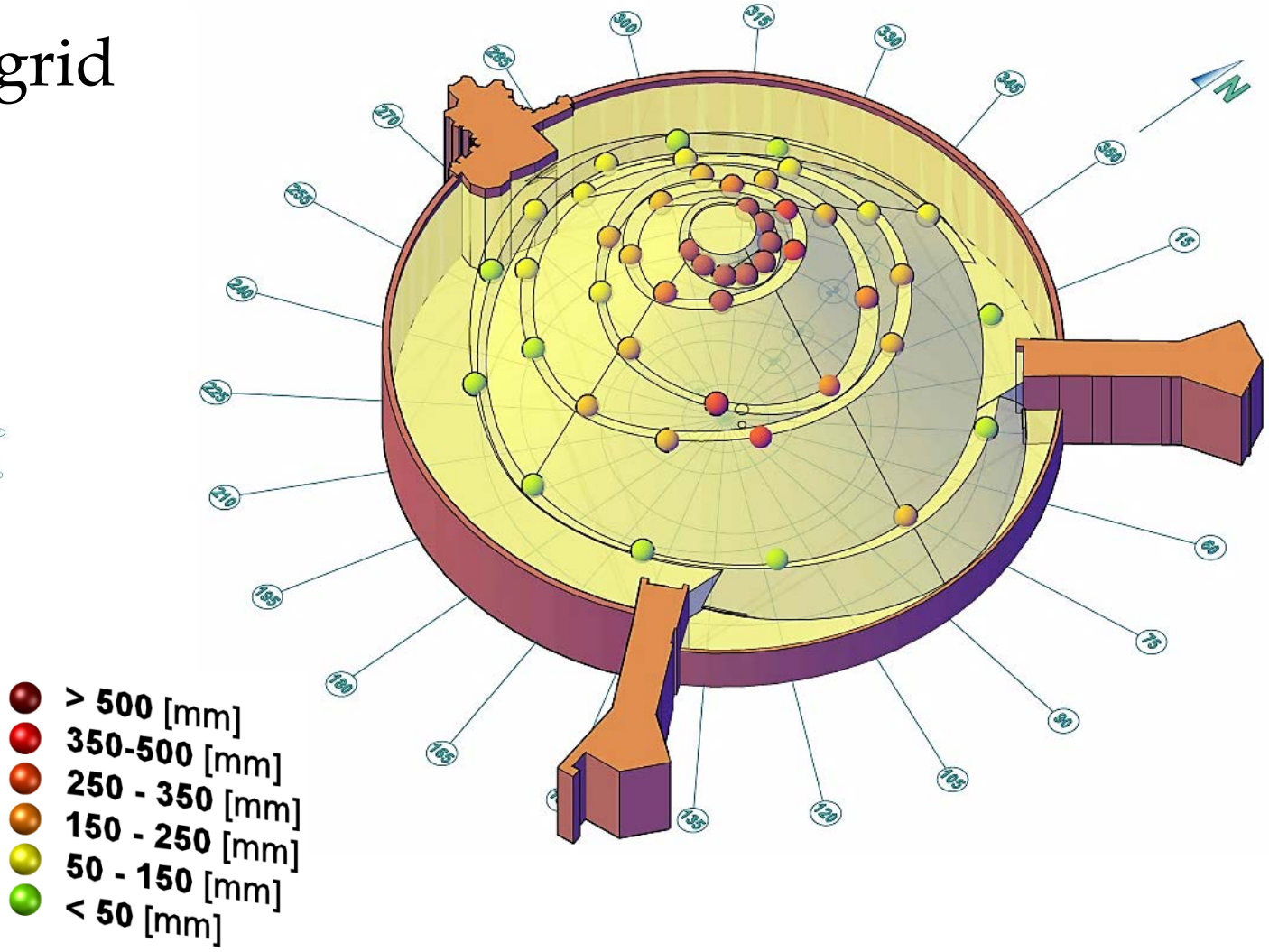
prof. Zbigniew Wasiutyński



Displacement history

surveying - benchmarks grid

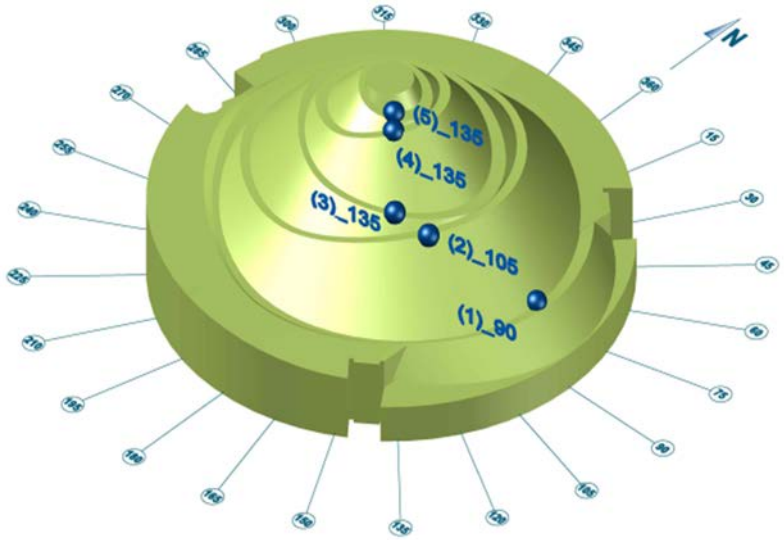


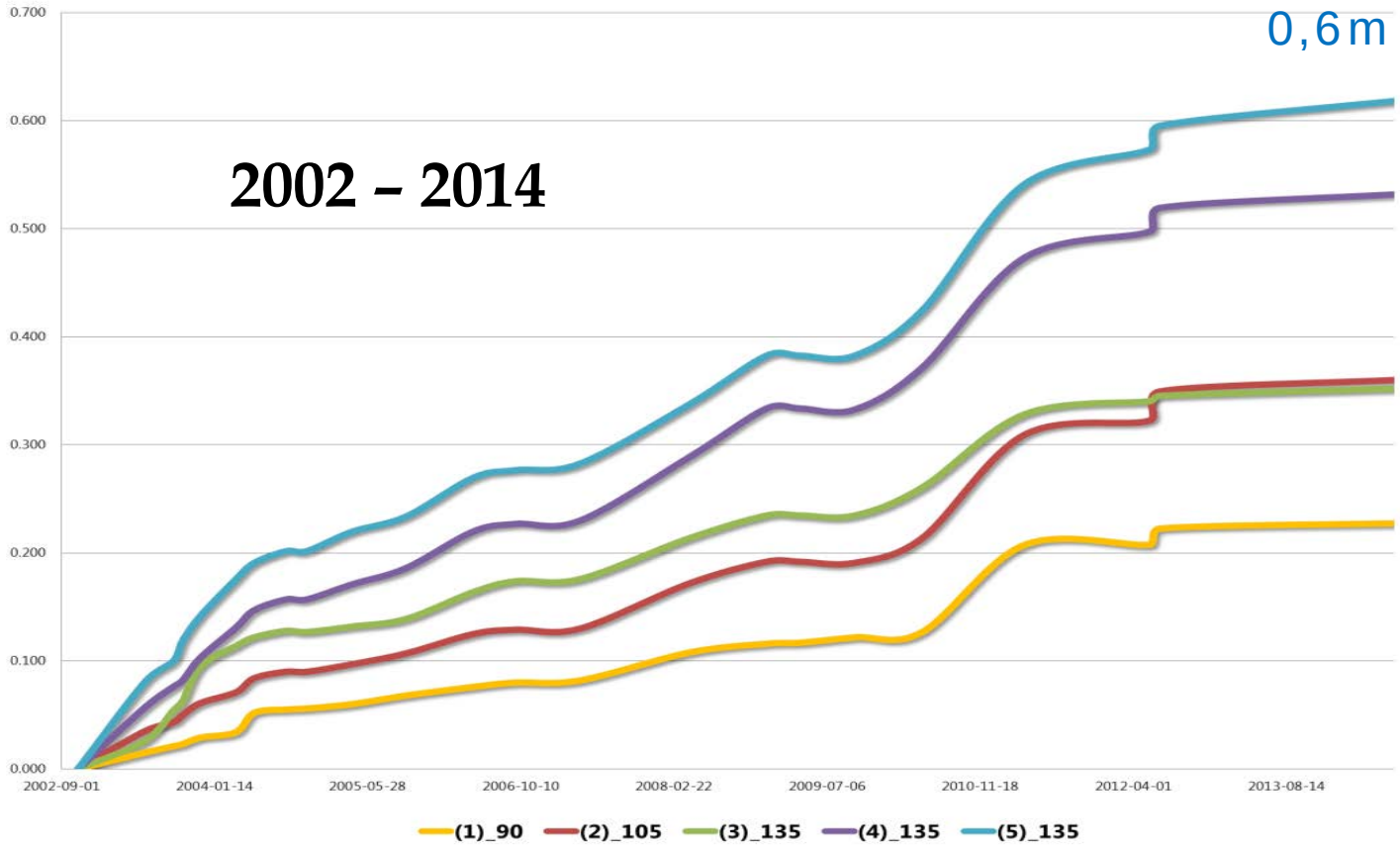


2002 – 2014

Displacement history

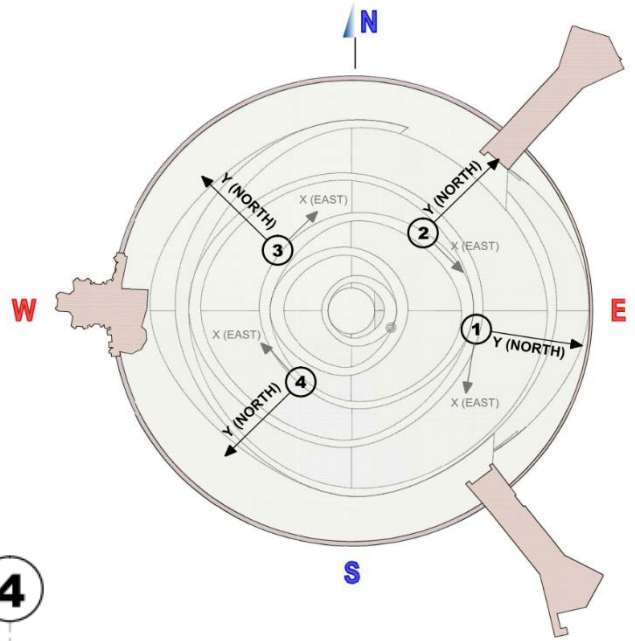
surveys – grid of benchmarks

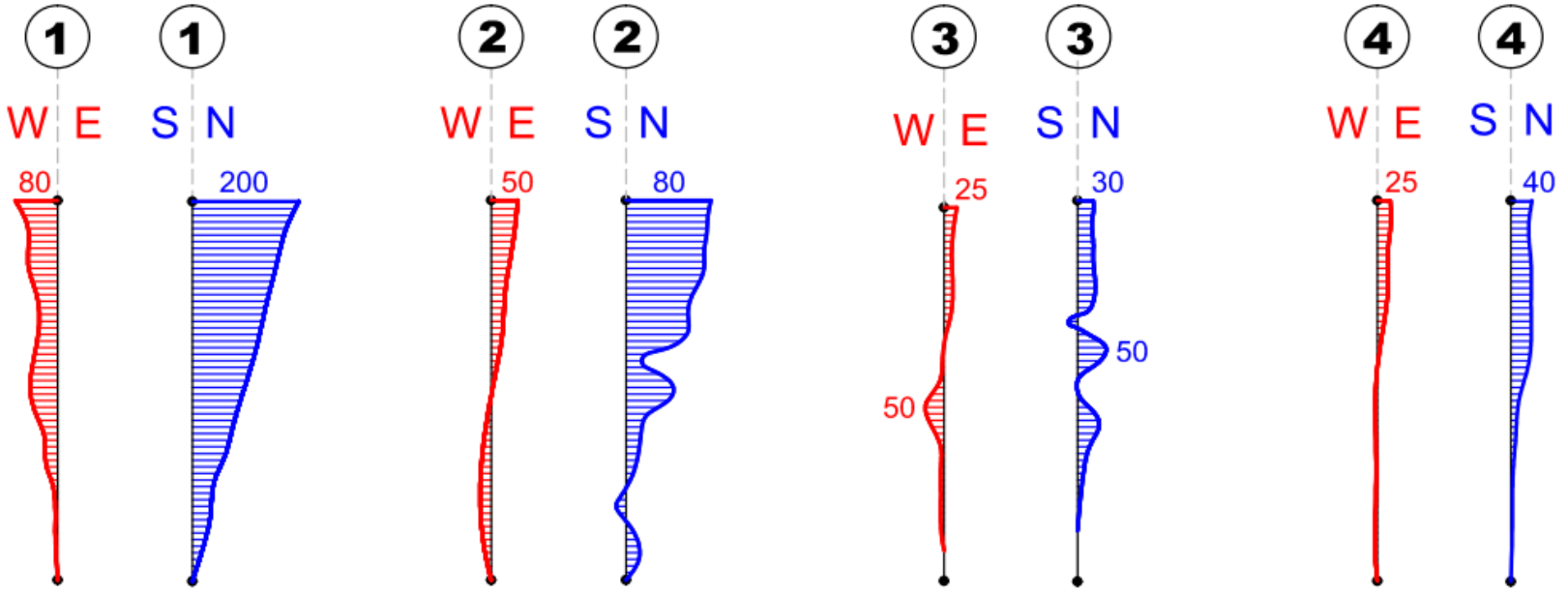




Previous measurements

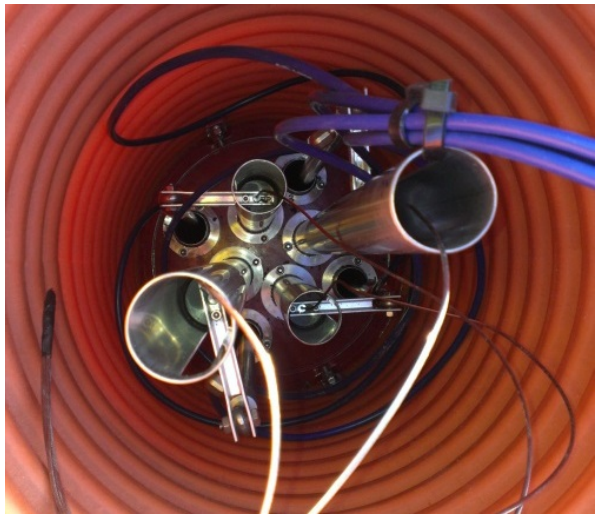
Inclinometer measurements





Structural Healh Monitoring System (SHM)

A number of sensors connected to datalogger, and used to continously measure selected physical values, important from the structural point of view.



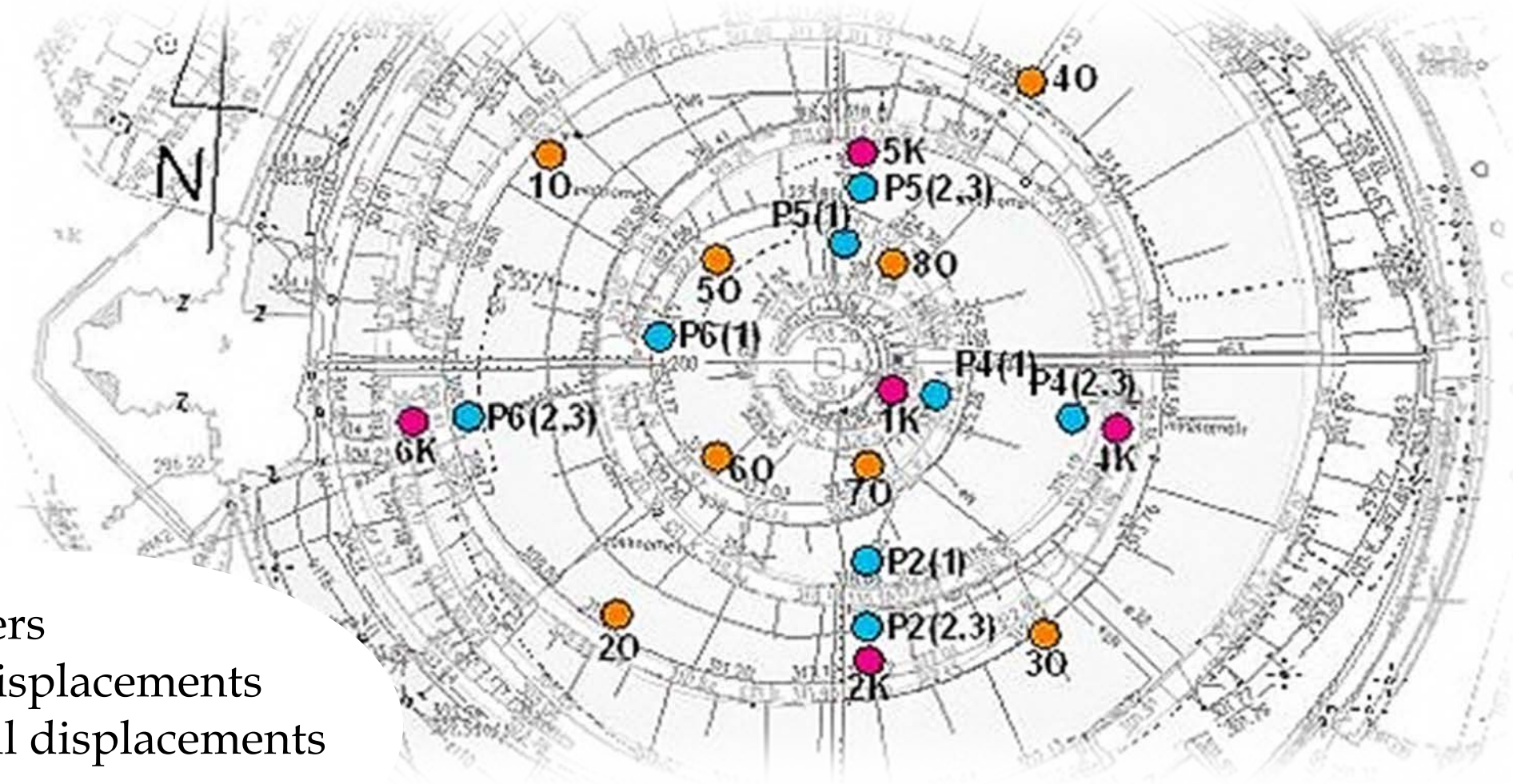
1. Humidity and temperature

2. Water pressure and temperature

3. Horizontal displacements

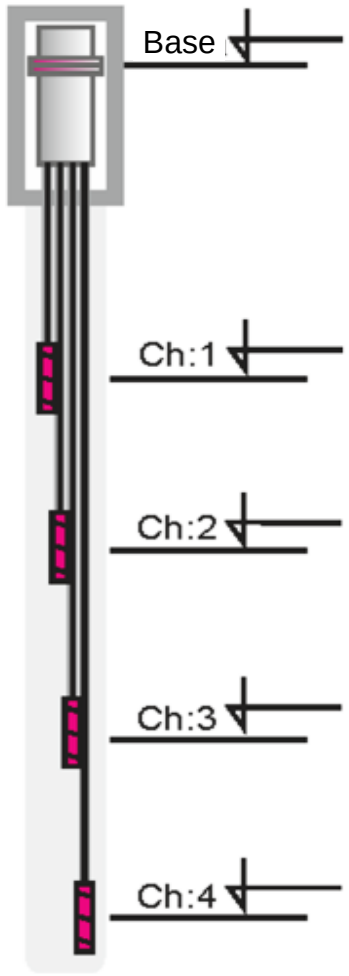
4. Vertical displacements

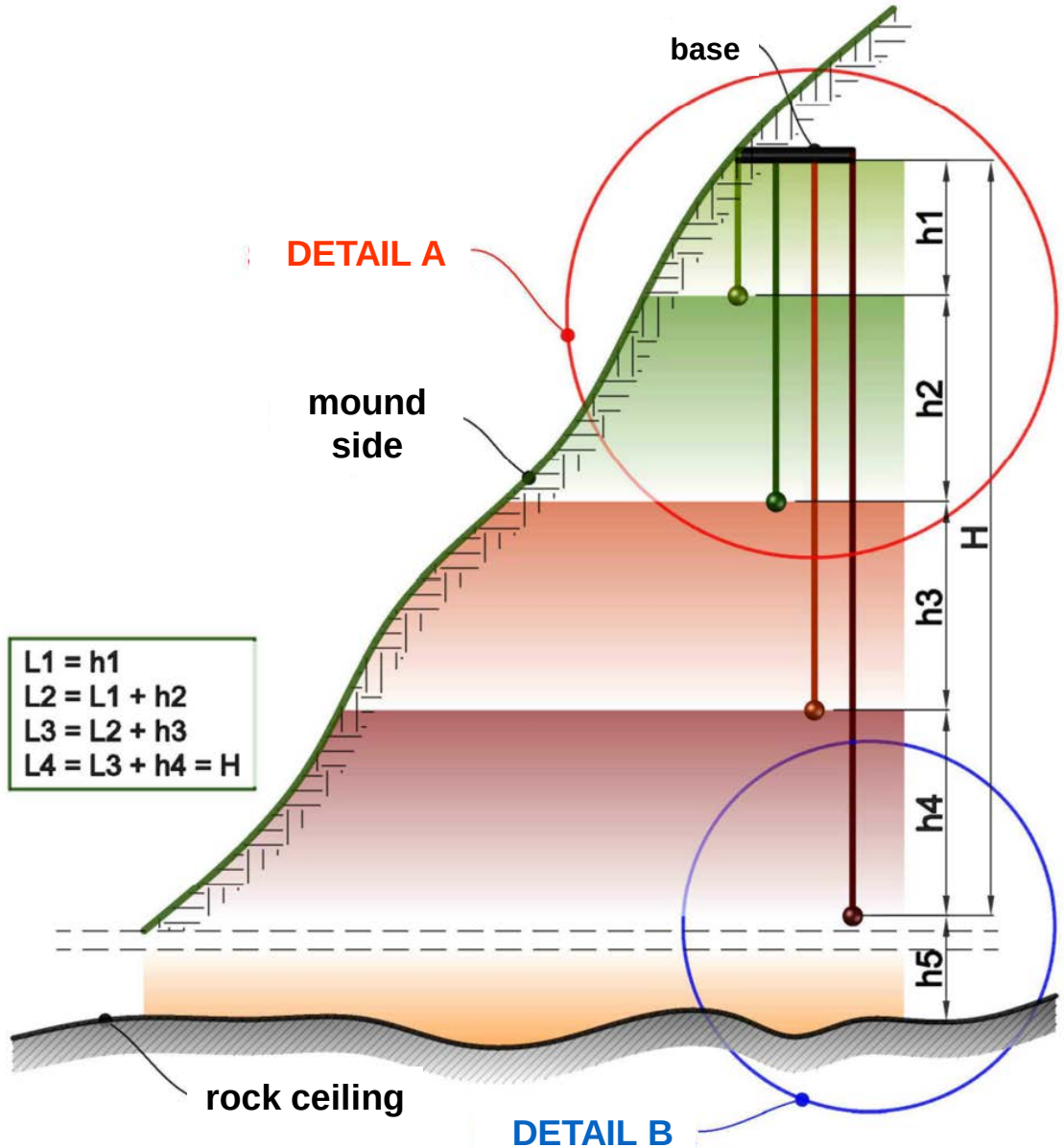
SHM system

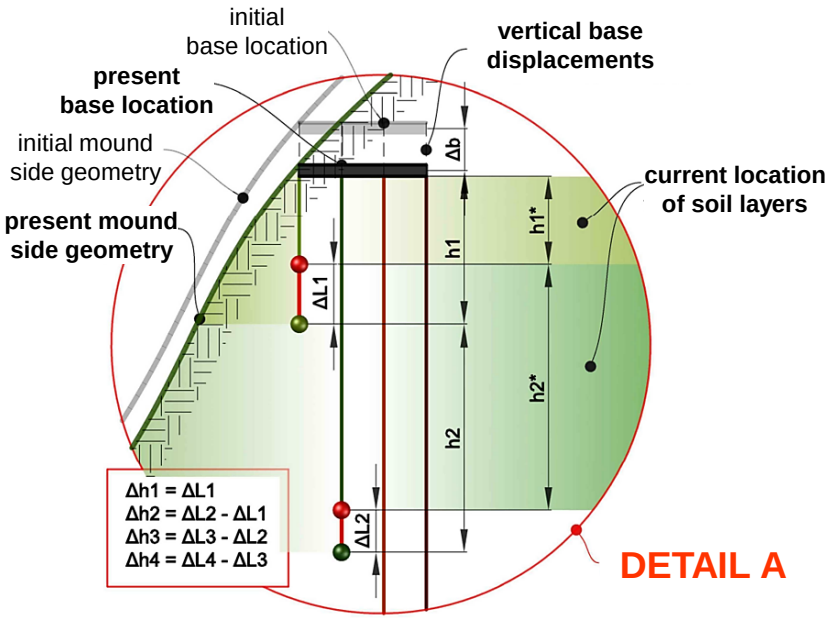


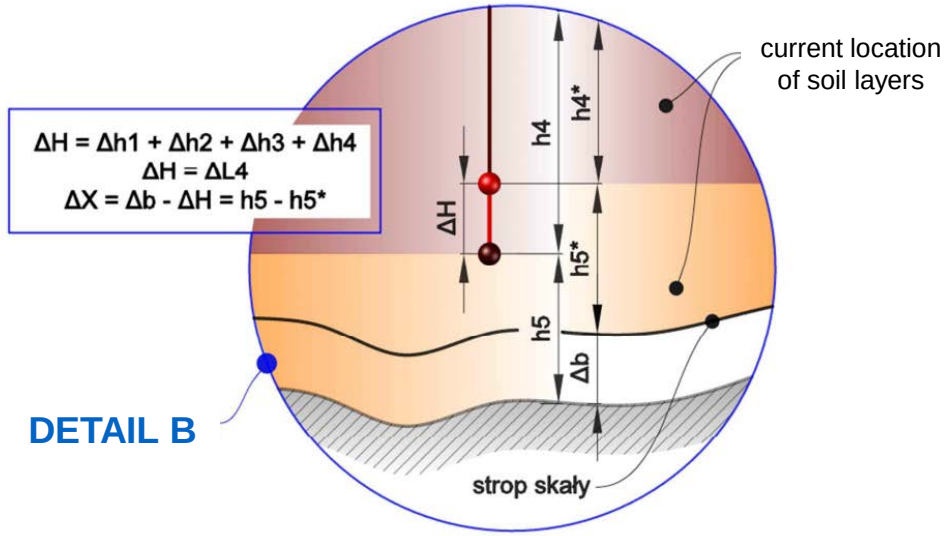
- Piezometers
- Vertical displacements
- Horizontal displacements

Vertical displacements

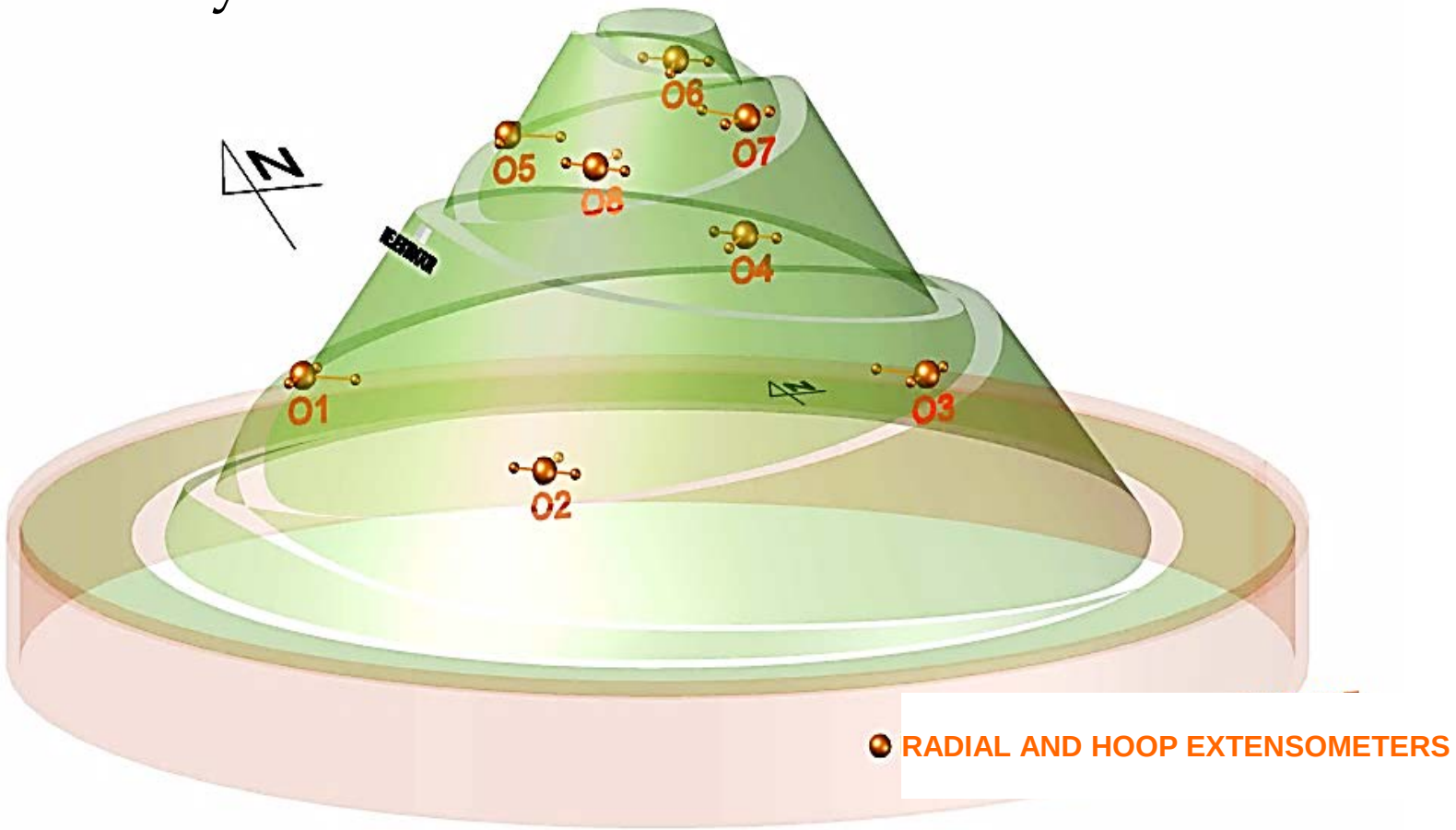


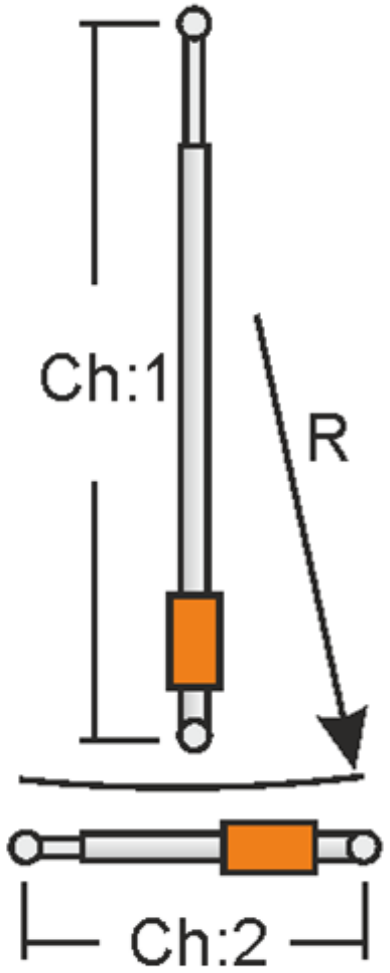

base
DETAIL A
mound
side
h1
h2
h3
h4
h5
H
L1 = h1
L2 = L1 + h2
L3 = L2 + h3
L4 = L3 + h4 = H
rock ceiling
DETAIL B


initial
base location
present
base location
initial mound
side geometry
present mound
side geometry
vertical base
displacements
current location
of soil layers
Δb
h1
h1*
ΔL1
h2
h2*
ΔL2
Δh1 = ΔL1
Δh2 = ΔL2 - ΔL1
Δh3 = ΔL3 - ΔL2
Δh4 = ΔL4 - ΔL3
DETAIL A

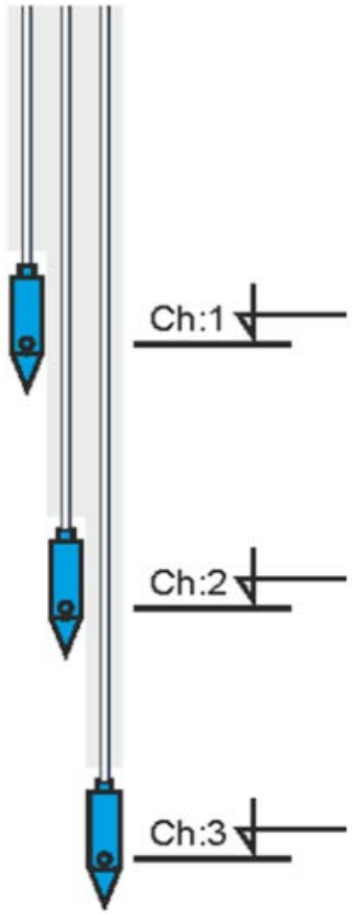

ΔH = Δh1 + Δh2 + Δh3 + Δh4
ΔH = ΔL4
ΔX = Δb - ΔH = h5 - h5*
current location
of soil layers
h4
h4*
ΔH
h5*
h5
Δb
DETAIL B
strop skały

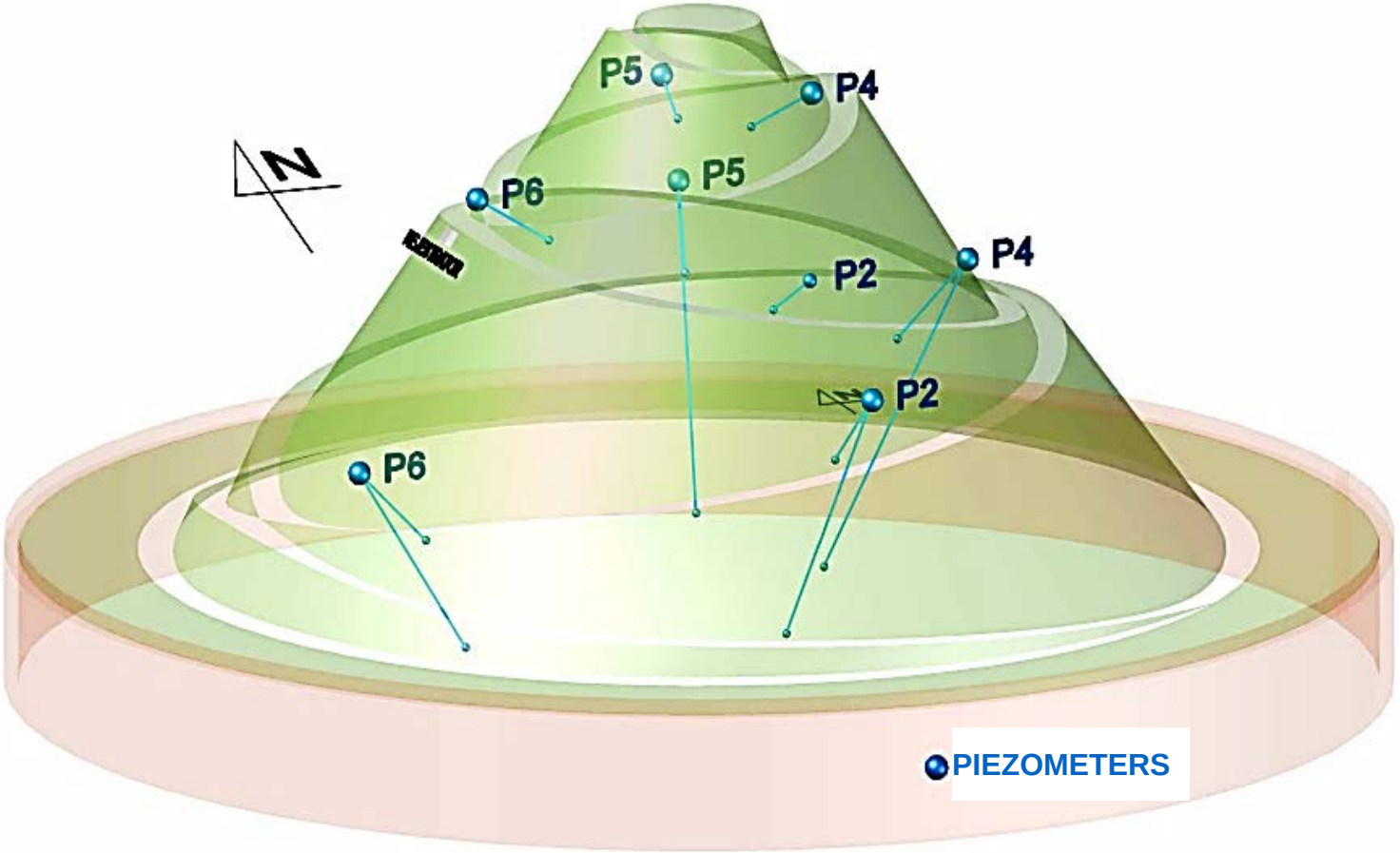
Horizontal displacements
+ temperature
+ humidity





Water pressure in the ground pores

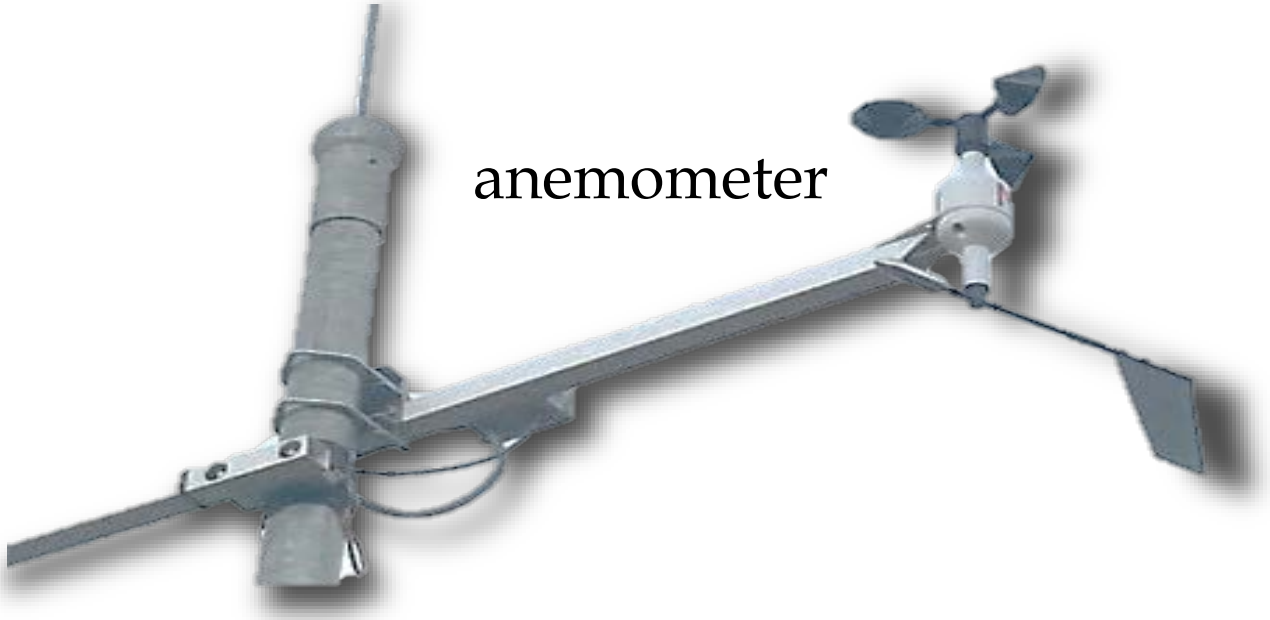




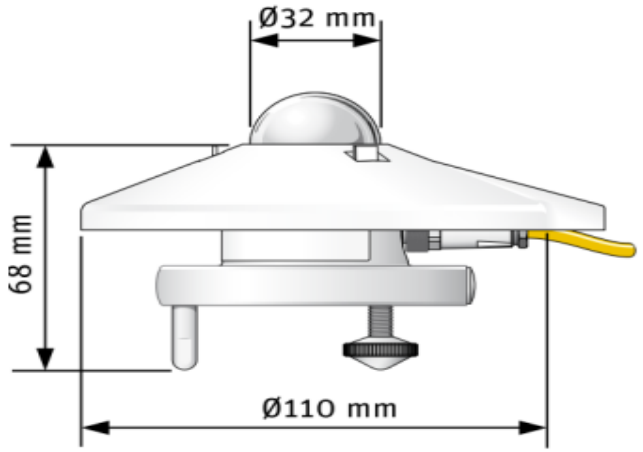
Meteorological monitoring

rain gage

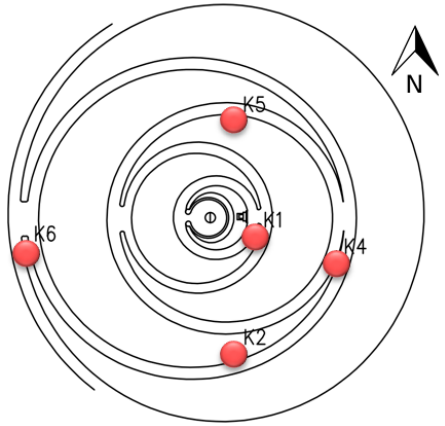
anemometer

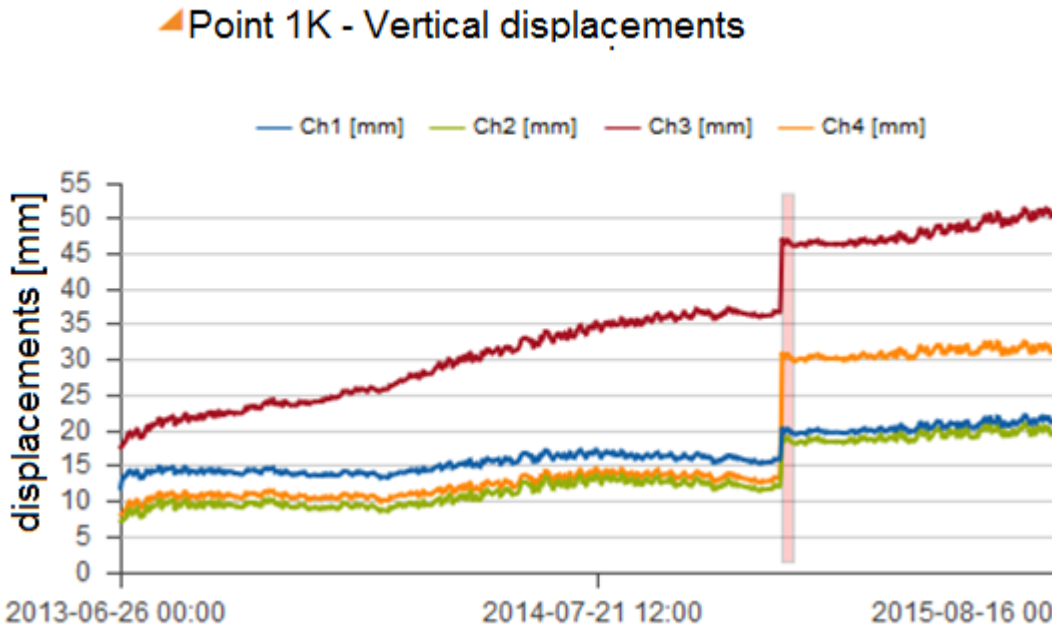


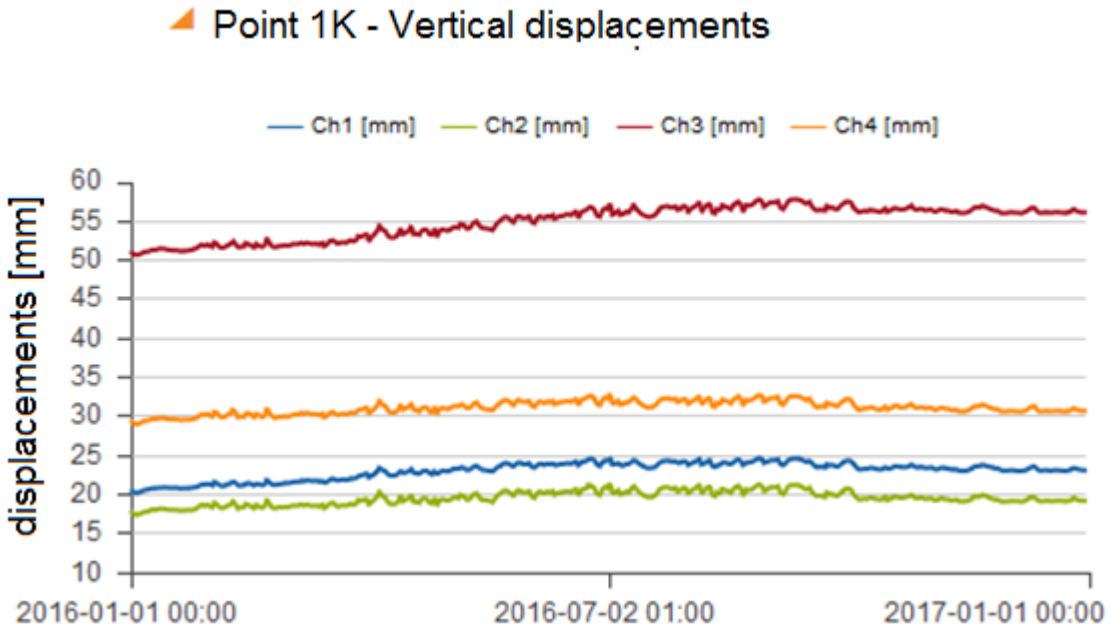
pyranometer



the changes in layer thickness (sample plots – point 1K)

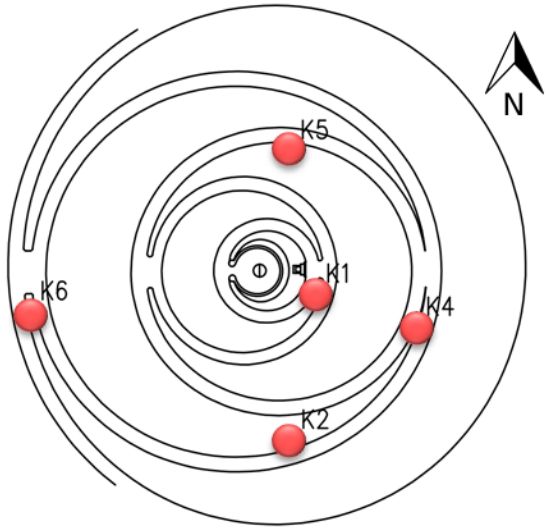






Changes in base heights [mm]

point name	Height [m] 26.06.2013	Height [m] 04.03.2014	Height [m] 10.09.2014	difference Δ1 [mm]	difference Δ2 [mm]
[1]	[2]	[3]	[4]	[3] – [2]	[4] – [2]
1K	325,483	325,472	325,457	- 11	**- 26**
2K	311,853	311,853	311,846	0	**-7**
4K	314,028	314,024	314,015	- 4	**- 13**
5K	317,518	317,515	317,505	- 3	**- 13**
6K	308,066	308,065	308,059	- 1	**- 7**

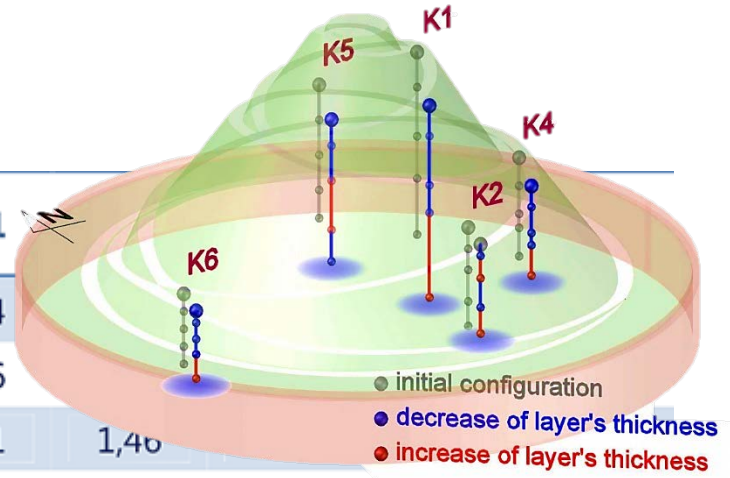


Changes in measurement section lengths [mm]

point name	8 months (26.06.2013 -04.03.2014)		6 months (04.03.2014 - 10.09.2014)		14 months (26.06.2013 - 10.09.2014)
1K	3,01		2,84		**5,85**
2K	1,74		2,93		**4,67**
4K	3,72	+	4,81	=	**8,53**
5K	-0,90		-0,15		**-1,05**
6K	1,39		1,92		**3,31**

Changes in layer thicknesses in time [mm]

point name	Δh1	Δh2	Δh3	Δh4	Σ = ΔH
1K	2,67	-0,32	8,23	-7,56	**3,01**
2K	2,82	-0,47	0,75	-1,36	**1,74**
4K	3,68	1,29	-1,05	-0,20	**3,72**
5K	0,48	0,69	-1,54	-0,53	**-0,90**
6K	1,48	0,18	0,33	-0,59	**1,39**



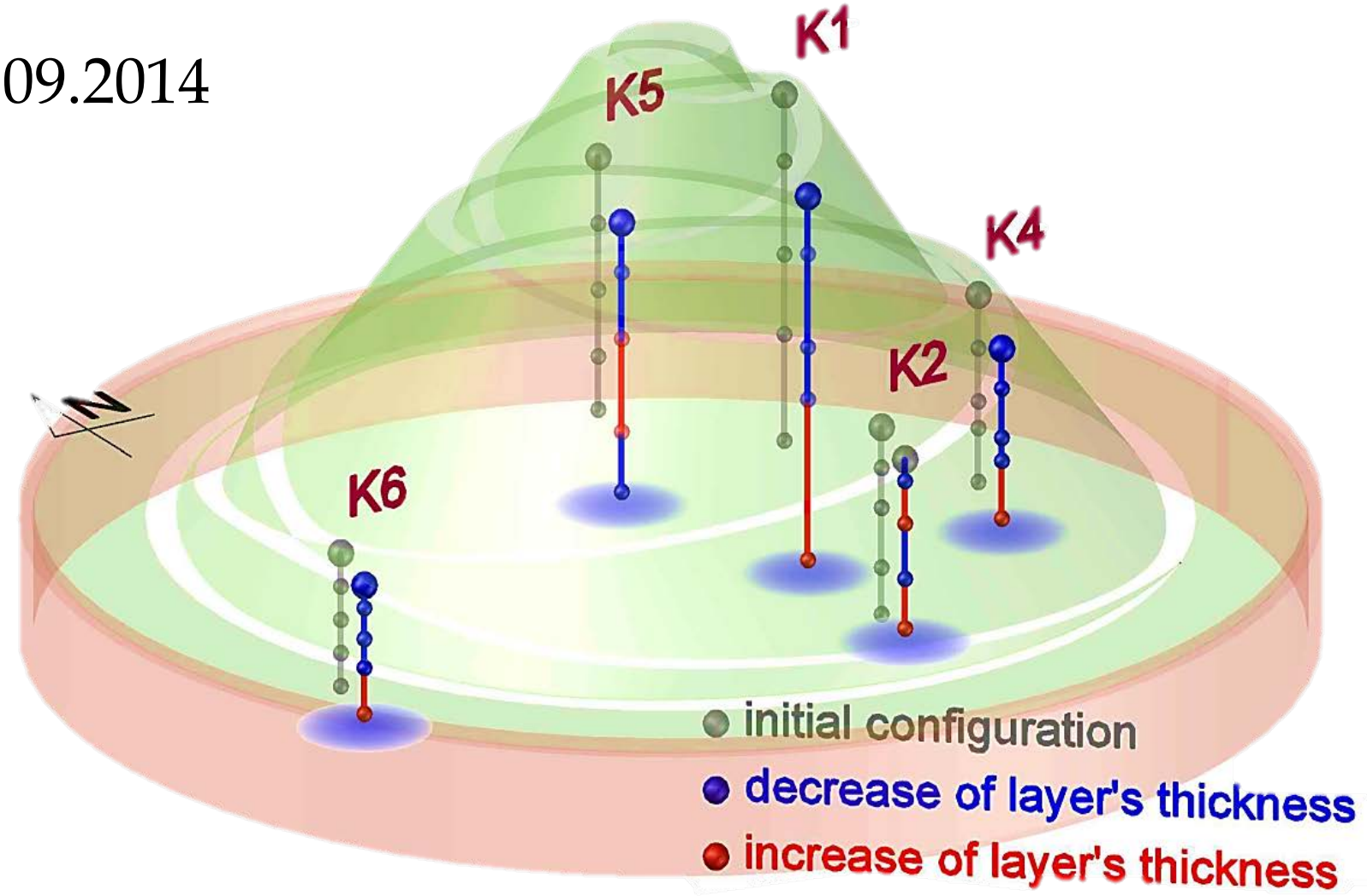
point name	Δh1				
1K	4,84				
2K	4,96				
4K	6,91	1,46			
5K	1,32	0,52	-2,96	0,07	-1,05
6K	3,06	0,70	0,44	-0,90	**3,31**

Changes in the lowest layer thickness in time [mm]

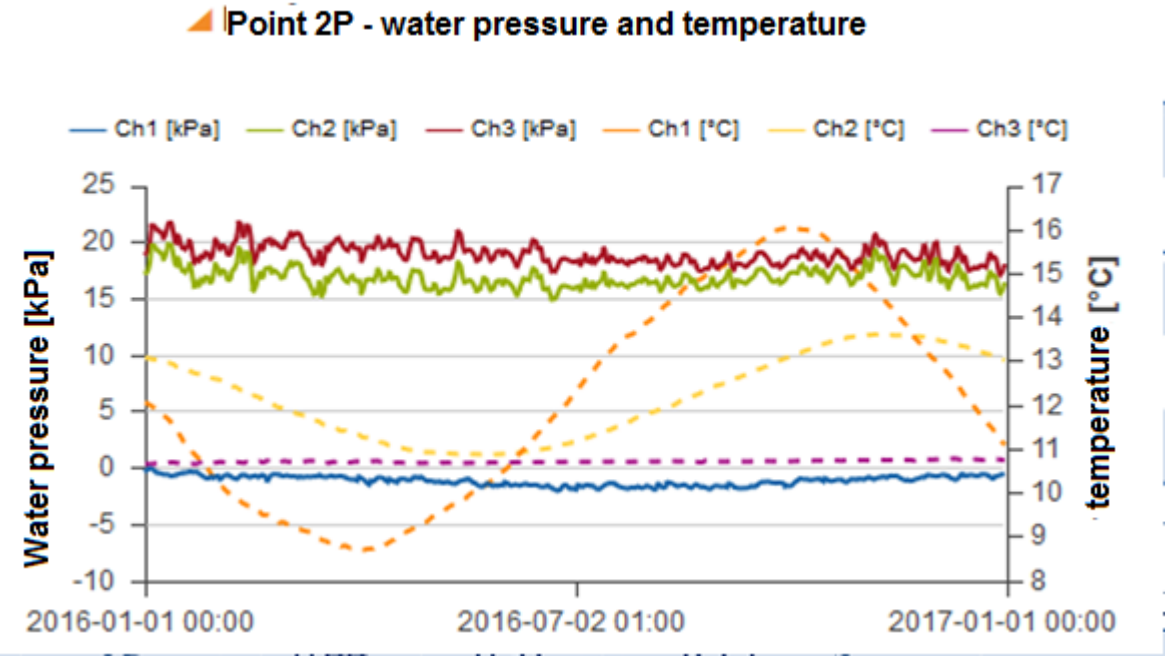
point name	ΔH	Δb	ΔX = Δb – ΔH
1K	3,01	11	**7,99**
2K	1,74	0	**-1,74**
4K	3,72	4	**0,28**
5K	-0,90	3	**3,90**
6K	1,39	1	**-0,39**

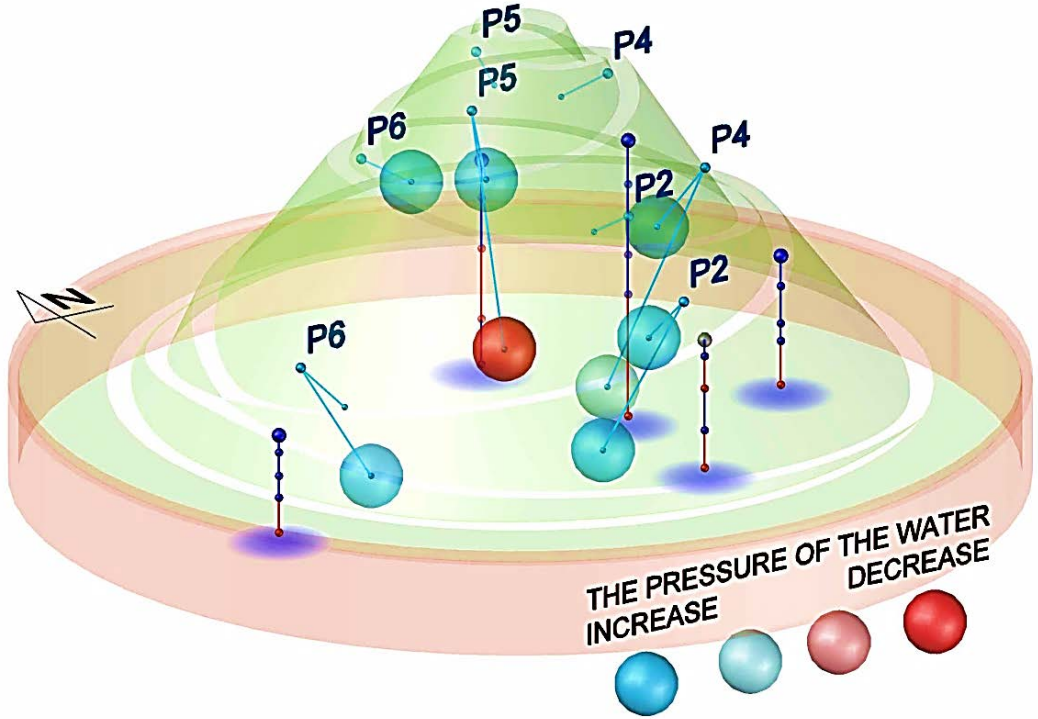
point name	ΔH	Δb	ΔX = Δb – ΔH
1K	5,85	26	**20,15**
2K	4,67	7	**2,33**
4K	8,53	13	**4,47**
5K	-1,05	13	**14,05**
6K	3,31	7	**3,69**

26.06.2013 - 10.09.2014



Water pressure in time[kPa] +temperature

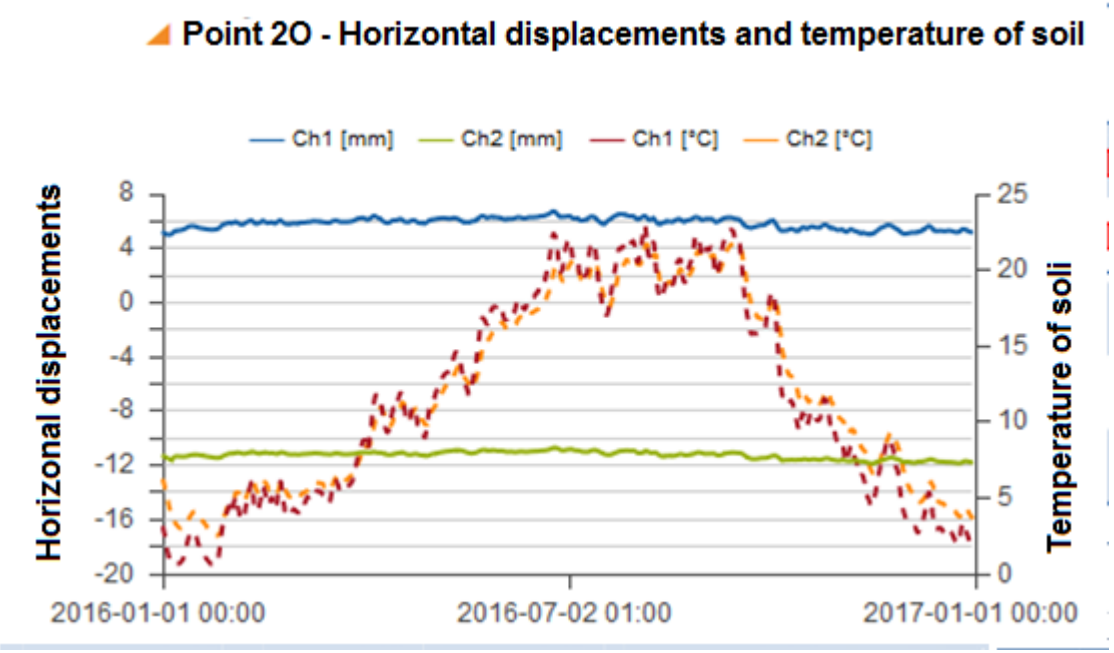


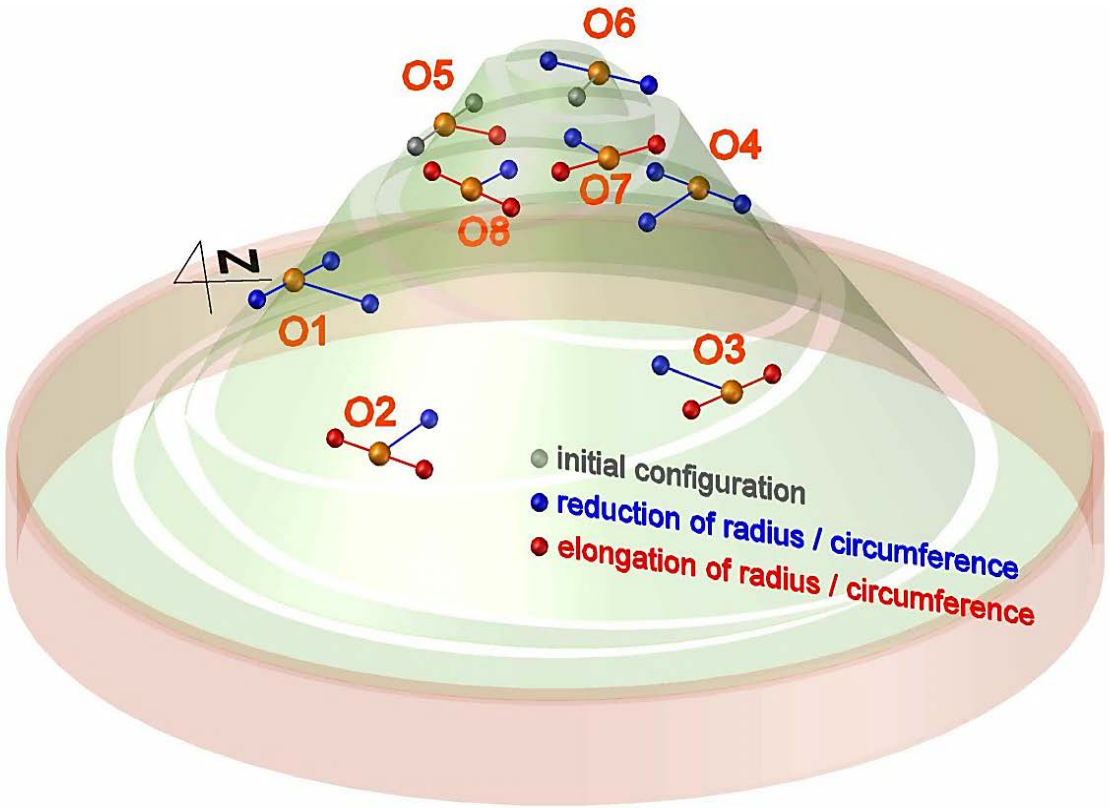


26.06.2013 - 10.09.2014

point name	Ch1	Ch2	Ch3
2P	0,44	6,32	8,25
4p	0,86	8,41	2,80
5p	0,54	19,34	-1,95
6P	11,45	1,65	7,42

Horizontal displacements [mm] + soil temperature

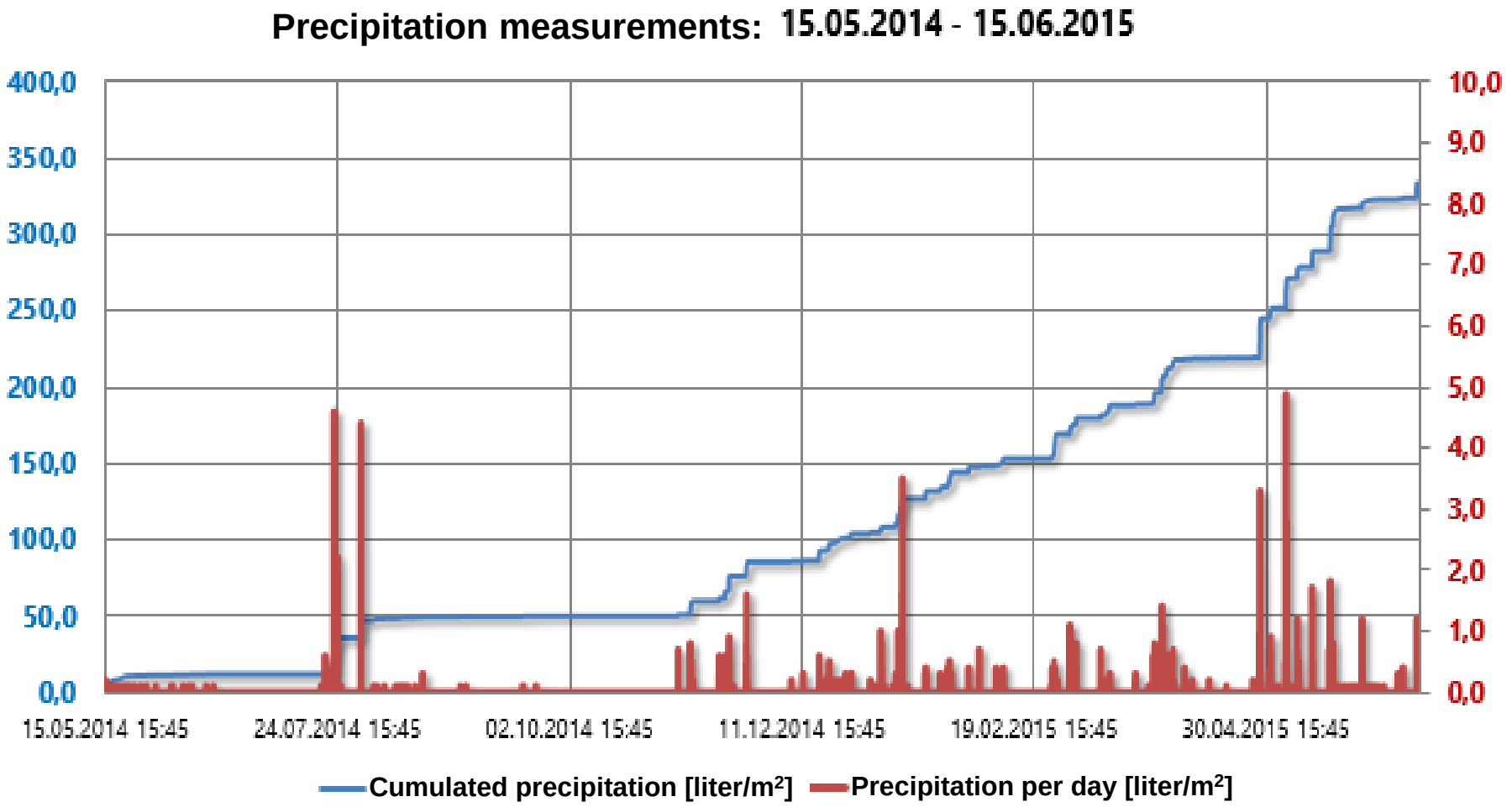




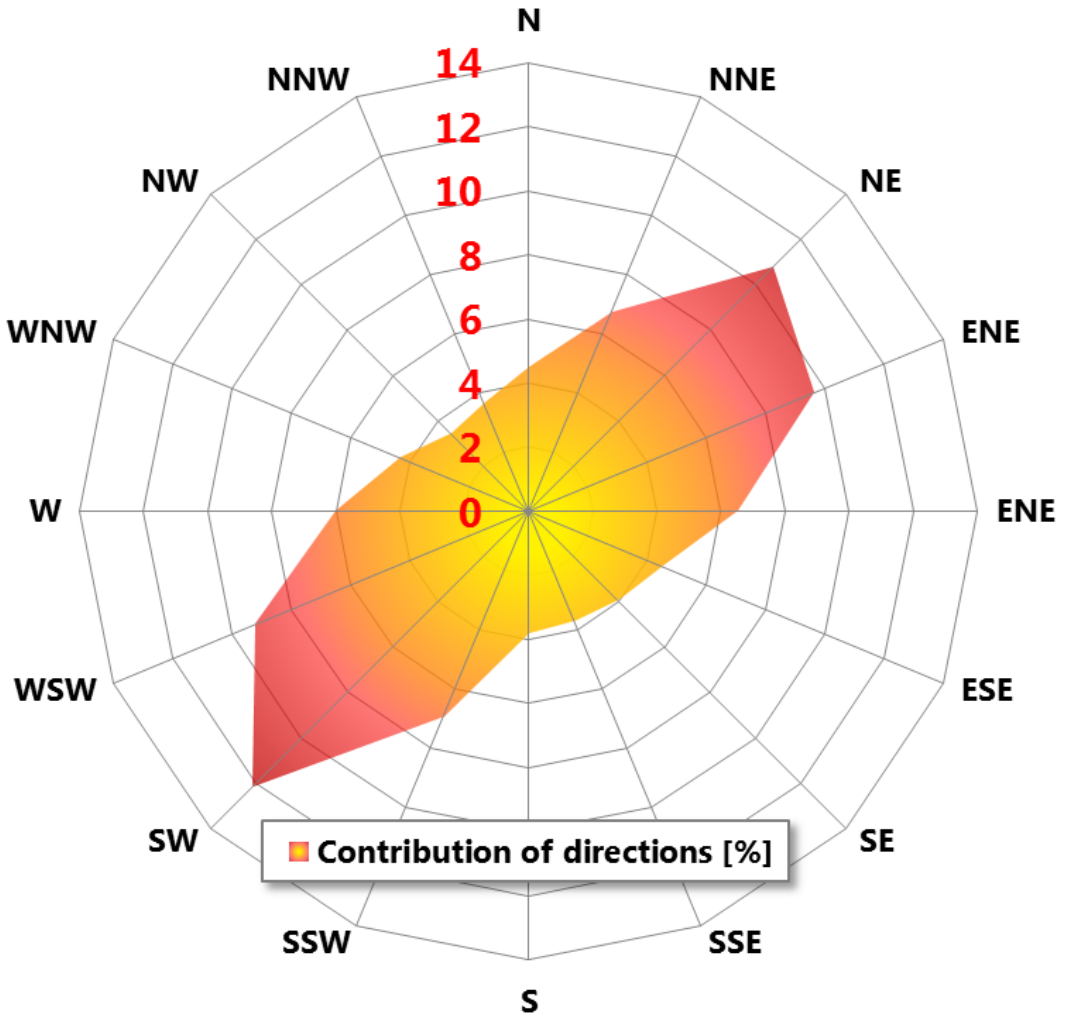
26.06.2013 - 10.09.2014

Point name	O1	O2	O3	O4	O5	O6	O7	O8
Radius	0,84	1,18	0,97	0,93	-0,19	0,47	1,32	1,49
Circumference	-1,24	1,83	1,15	-0,39	-0,14	-0,01	1,31	0,60

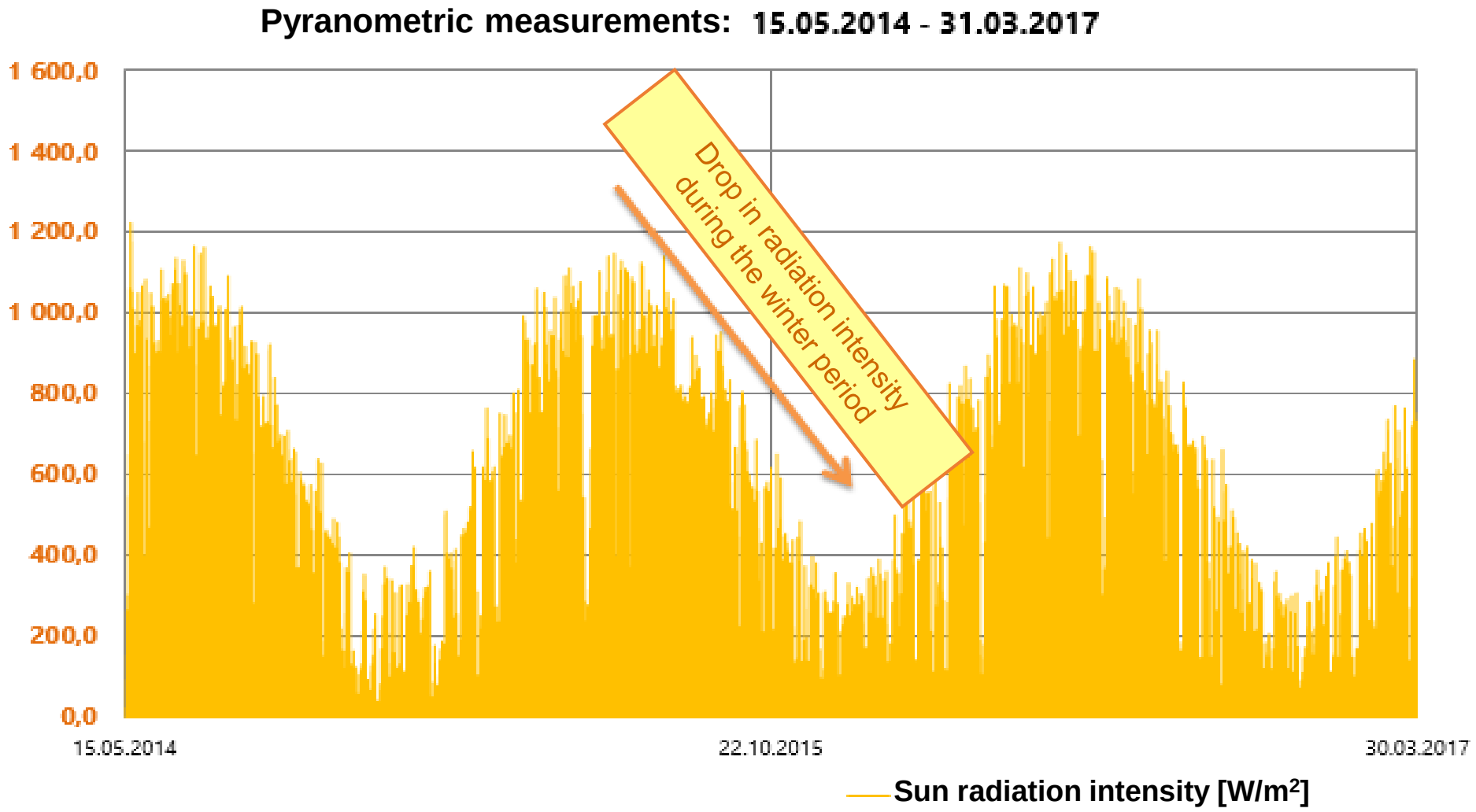
Precipitation (rain, snow, fog)



Wind (direction and velocity)

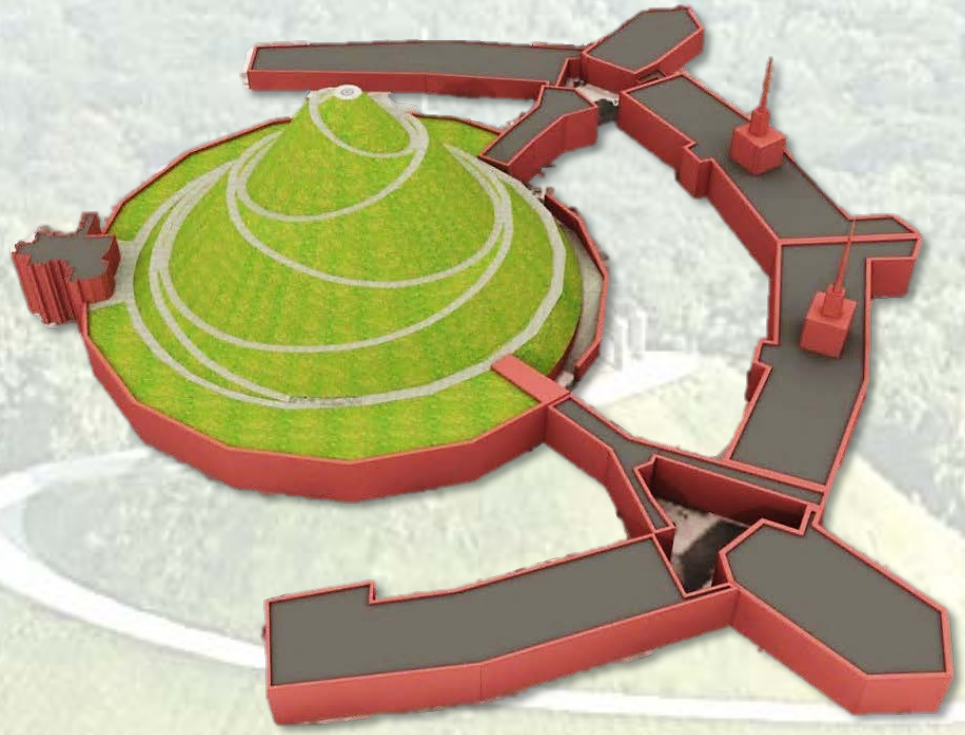


Sun radiation



Conclusions

- The rainfall of long duration or high intensity is the greatest danger;
- The deformation begins at the ceiling of limestone and is very irregular in soillayers;
- The mound tilts mostly in the easterly direction;
- Kościuszko Mound is Polish national monument. Basing on experience, comprehensive documentation, detailed analysis, numerical models and in situ measurements (SHM, inclinometers, surveys, weather station) engineering works must be done in order to preserve it from destruction during the incoming centuries.



Thank You for your attention!