INVESTIGATION OF CLIMATE CHANGE IMPACTS ON THE BUILDING MATERIALS OF ARCHEOLOGICAL MONUMENTS

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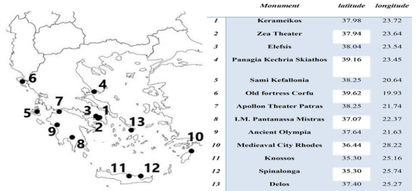
Abstract: Weather conditions affect the microclimate of architectural monuments. The alteration of microclimate conditions may create risks for monuments, accelerating their weathering process. For Greece, hosting with numerous monuments, the identification of the risks that climate change possess is essential for planning mitigation actions. The main soluble salts that affect archaeological materials are halite and the system of thenardite/mirabilite. The thermodynamics of the salts' equilibrium are affected by atmospheric conditions. We study the climatology of these conditions, adopting modeled data produced by high-resolution simulations. Possible Climate Change impacts are investigated aiming the mapping of monuments vulnerability in Greece.

Data and Methodology:

- Use of **gridded** dataset developed in EREL(INRASTES) with 5 km spatial resolution.
- 6 hours values of **Relative Humidity (RH)** and **Temperature (T)** at 2 meters above ground.
- Calculation of daily minimum **(RHmin)** and maximum **(RHmax)** RH.
- Calculation of daily mean T **(TM).**
- **2** processes occurrences calculated in **1980-2004** period in the past and two future periods in **2025-2049** and **2075-2099** and two future emission scenarios **RCP4.5** and **RCP8.5**.
  - **1st Crystallization of halite**
  - **2nd Crystallization and hydration of thenardite to mirabilite**



	Monument	latitude	longitude
1	Kerameikos	37.98	23.72
2	Zea Theater	37.94	23.64
3	Elefsis	38.04	23.54
4	Panagia Kechria Skiathos	39.16	23.45
5	Sami Kefallonia	38.25	20.64
6	Old fortress Corfu	39.62	19.93
7	Apollon Theater Patras	38.25	21.74
8	I.M. Pantanassa Mistras	37.07	22.37
9	Ancient Olympia	37.64	21.63
10	Medieaval City Rhodes	36.44	28.22
11	Knossos	35.30	25.16
12	Spinalonga	35.30	25.74
13	Delos	37.40	25.27

Figure 1. Map of the 13 monuments with the information of the name, the latitude and the longitude

Process 1

Count of days with **RHmin<75.3%** and **RHmax >75.3%.**

Process 2

Count of days that RH is between two limits (Eq 1, 2) as in Figure 2.

RHup = -0.0122*TM^2 + 0.1218*TM + 98.2847 **(1)**

RHlow = 0.73*TM+60.58 **(2)**

RHlow<RH<RHup

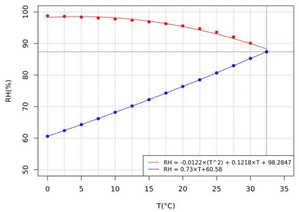


Figure 2. Stability diagram (RH vs T) for the sodium sulfate system. Eq 1 describes red line, while Eq. 2 the blue line. The two lines cross each other at T=32.38^{o}C and RH=87.4% (point where the dotted lines meet).

RESULTS PROCESS 1

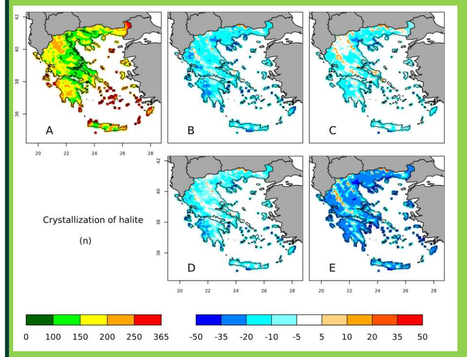


Figure 3. Average number of crystallization events of for halite, events per year. (A) refers to 1980-2004 period. (B-E) show the difference between the historic and the future periods and scenarios. (B) depicts the 2025-2049 period and RCP4.5, (C) 2075-2099 and RCP4.5, (D) the 2025-2049 period and RCP8.5 and (E) refers to 2075-2099 period and RCP8.5.

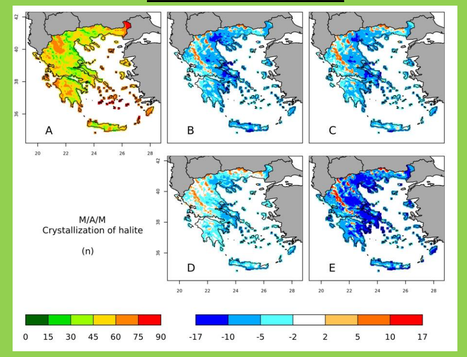


Figure 4. Average number of crystallization of halite events per M/A/M season. (A) refers to 1980-2004 period. (B-E) show the difference between the historic and the future periods. (B) depicts 2025-2049 and RCP4.5, (C) 2075-2099 and RCP4.5, (D) 2025-2049 and RCP8.5 and (E) refers to 2075-2099 and RCP8.5.

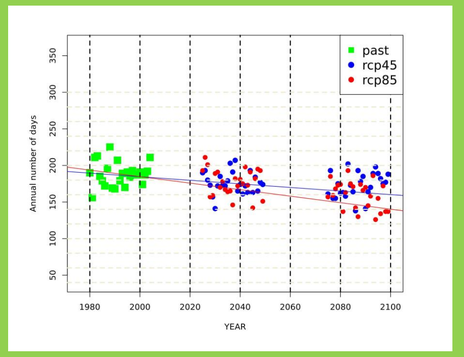


Figure 5. Number of crystallization of halite events per year in **monument number 9 (Ancient Olympia)** with trend lines with blue for RCP4.5 and with red for RCP8.5 scenarios.

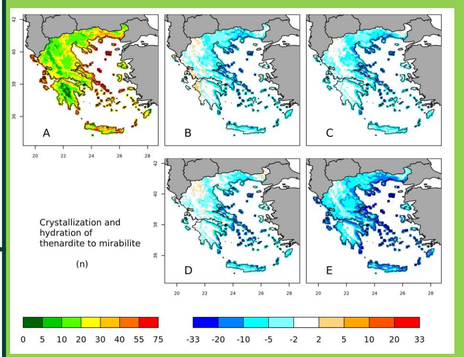


Figure 6. Average number of crystallization of thernadite to mirabilite events per year. (A) refers to the 1980-2004 period. (B-E) show the difference between the historic and the future periods and scenarios. (B) depicts the 2025-2049 period and RCP4.5, (C) the 2075-2099 period and RCP4.5, (D) the 2025-2049 period and RCP8.5 and (E) refers to the 2075-2099 period and RCP8.5.

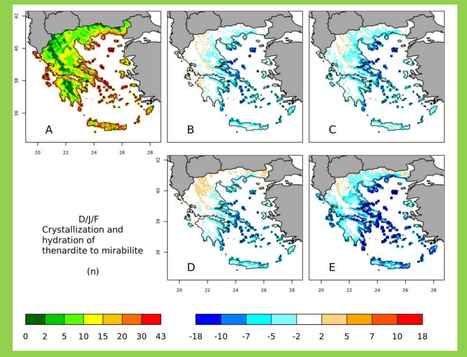


Figure 7. Average number of crystallization of thernadite to mirabilite events per D/J/F season. (A) refers to 1980-2004 period. (B-E) show the difference between the historic and the future periods. (B) depicts 2025-2049 and RCP4.5, (C) 2075-2099 and RCP4.5, (D) 2025-2049 and RCP8.5 and (E) refers to 2075-2099 and RCP8.5.

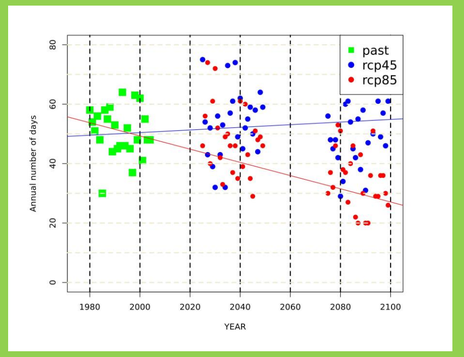


Figure 8. Number of crystallization of thernadite to mirabilite events per year in **monument number 5 (Sami Kefallonia)** with trend lines with blue for RCP4.5 and with red for RCP8.5 scenarios.

CONCLUSIONS

- 1980-2004 period Process 1 : Maximum values **exceed 200 days** in West, Northwest and Northeast mainland and Aegean Islands. Highest values in Spring(March-April-May)
- 1980-2004 period Process 2 : Maximum values reach **75 days** in Aegean Islands and Northeast mainland. Highest values in Winter (December-January-February).
- Future periods Process 1 : Exhibit reduction of number of days in most areas, especially Eastern Greece. Exception are mountainous areas that exhibit increase.
- Future periods Process 2 : Similar to process 2.
- Most areas like Sami Kefallonia (Figure 8) exhibit different trends for RCP4.5 and RCP8.5. RCP8.5 in 2075-2099 yields greater reduction than all scenarios and periods for both processes, meaning **reduction of the risk** for materials from the transition of salts.
- Both processes occur on the **surface** of materials, so further study is needed if we want to quantify the effects of weather conditions on buildings.

Acknowledgments

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