TRIQUETRA

DLR

Analyzing Climate Change Impacts on European Cultural Heritage Sites Using High-Temporal-Resolution Satellite Time Series

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Background

The TRIQUETRA project is an EU-funded initiative that develops a technological toolbox and methodological framework for identifying and mitigating climate change and natural hazards at cultural heritage sites [1]. As part of the project's mission, databases related to hazards in the context of extreme water, snow, and ice are developed based on satellite time series data.

Snow, Drought, and Coastal Changes: EO Insights for Cultural Heritage Sites

As climate change increasingly threatens historical and archaeological sites, monitoring environmental changes becomes crucial. This study leverages Earth observation datasets and high-resolution satellite time series to analyze long-term trends and assess their impacts on selected European cultural heritage sites (Fig.1). It focuses on variables such as snow cover, drought, and coastal changes, demonstrating how remote sensing techniques offer essential information for climate change adaptation and preservation efforts. Key archaeological sites analyzed include:

Fig. 1: Selected cultural heritage (CH) sites.

Trends of Snow Cover

At the Kalapodi archaeological site in Greece, snow cover extent from 2000 to 2022 was analyzed using binary masks from the Global SnowPack daily products [2], based on the MODIS sensors (500 m resolution). Monthly composites were created to track trends and multi-decadal means (Fig.3 and Fig.4).

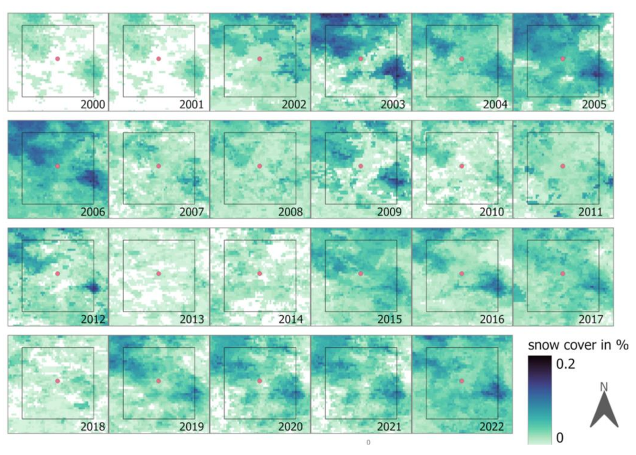


Fig. 2: Mean annual snow cover area for the period 2000–2022 for the CH site Kalapodi.

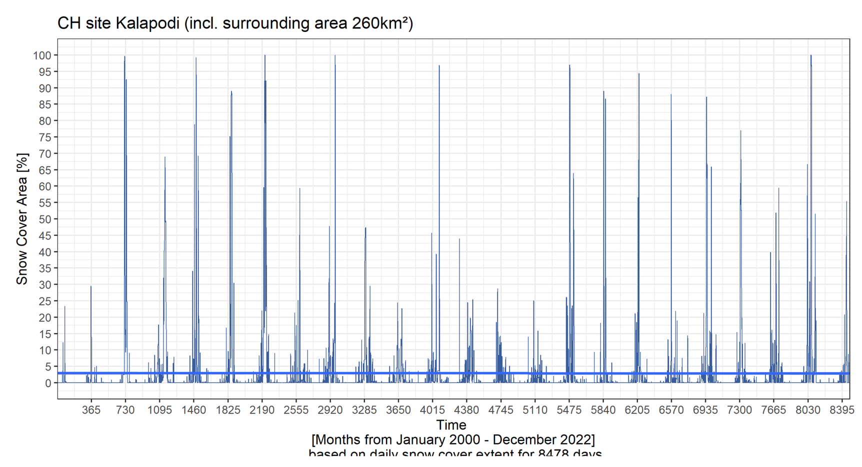


Fig. 3: Mean monthly snow cover area (%) from daily snow cover extent for 2000–2022 (1=Jan to 12=Dec).

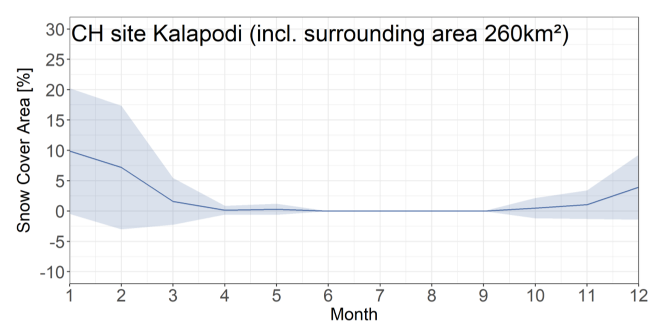
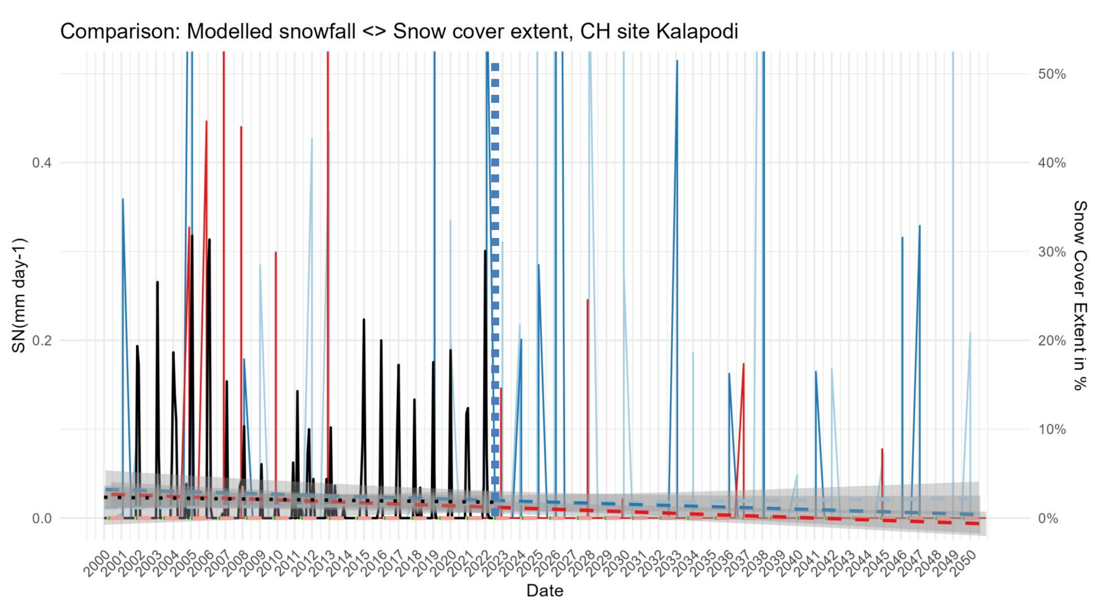


Fig. 4: Mean monthly snow cover area (%) for 2000–2022 (1=Jan to 12=Dec).

Comparing these data with global climate model snowfall data (Fig.5) revealed valuable links between snow cover dynamics and climate variability [1].

Both RCP4.5 and RCP8.5 project substantial snowfall declines by 2050/2100, especially under RCP8.5 due to higher temperatures.



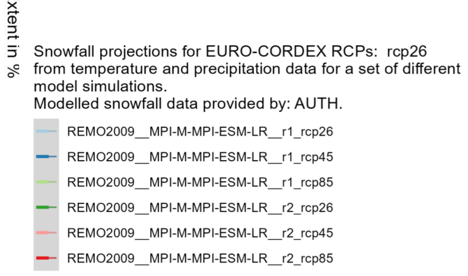


Fig. 5: Snow cover extent in % (black dotted line) and modelled snowfall data for the CH site Kalapodi.

Drought Analyses

Vegetation anomalies were detected at Roseninsel, Lake Starnberg, Germany, using Terra MODIS Enhanced Vegetation Index (EVI) time series from 2000 to 2022 (Fig.6). Drought-induced stress was particularly evident during the summers and autumns of 2003, 2004, and 2008, providing valuable insights into vegetation response and supporting measures to mitigate erosion risks.

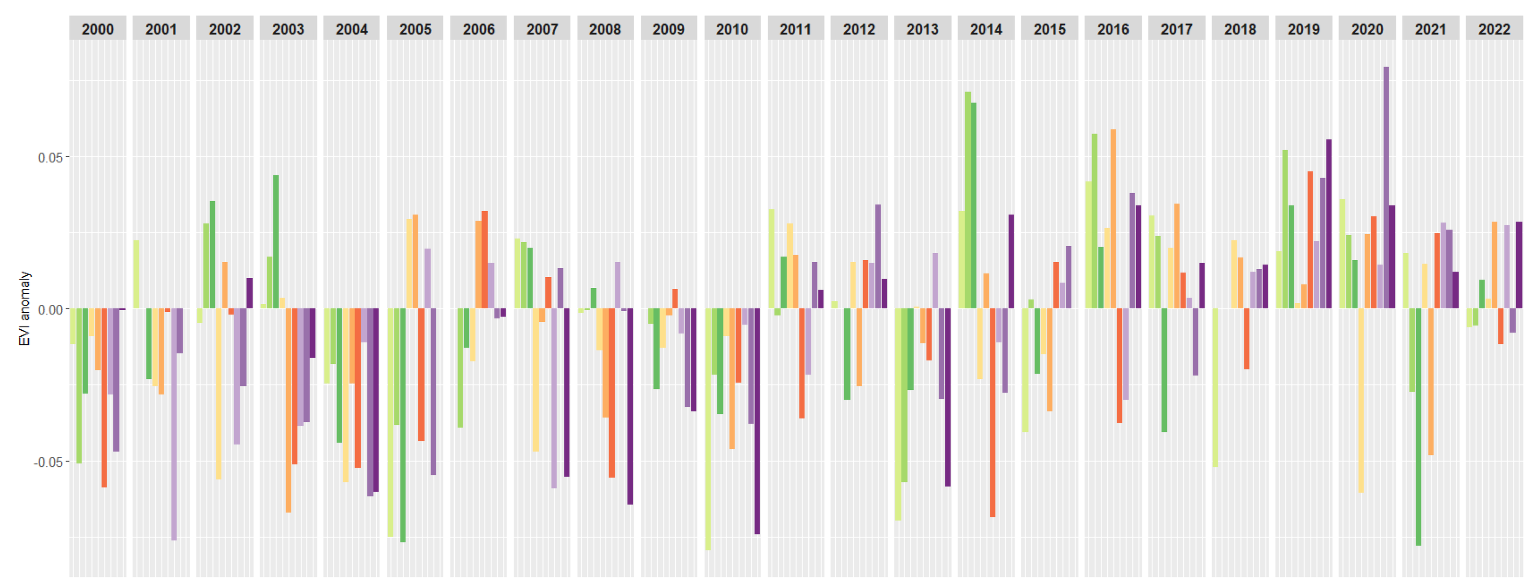


Fig. 6: Temporal patterns of EVI anomalies at Roseninsel CH site – monthly composites.

Coastline Morphology

The coastline detection approach integrates processing of water index images, local coastline extraction, shore-normal transects, and sub-pixel shoreline delineation. To improve detection of small-scale changes and intra-annual dynamics, a very high-resolution PlanetScope optical time series (~3.7 m) was used (2023–2024), enabling consistent identification and mapping of highly variable coastline zones. This dataset improved the ability to detect and quantify small-scale coastal changes. The Interquartile Range (IQR), offering more robustness to outliers than standard deviation, was used as it provides a reliable measure of shoreline position variability.

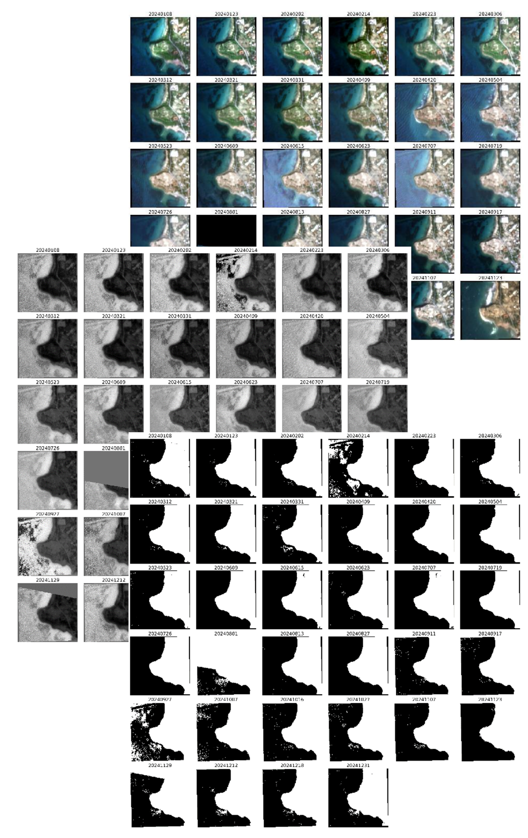


Fig. 7: Top: Optical PlanetScope time series (top); center: water index imagery (NDWI); bottom: water-land boundaries (OTSU threshold).

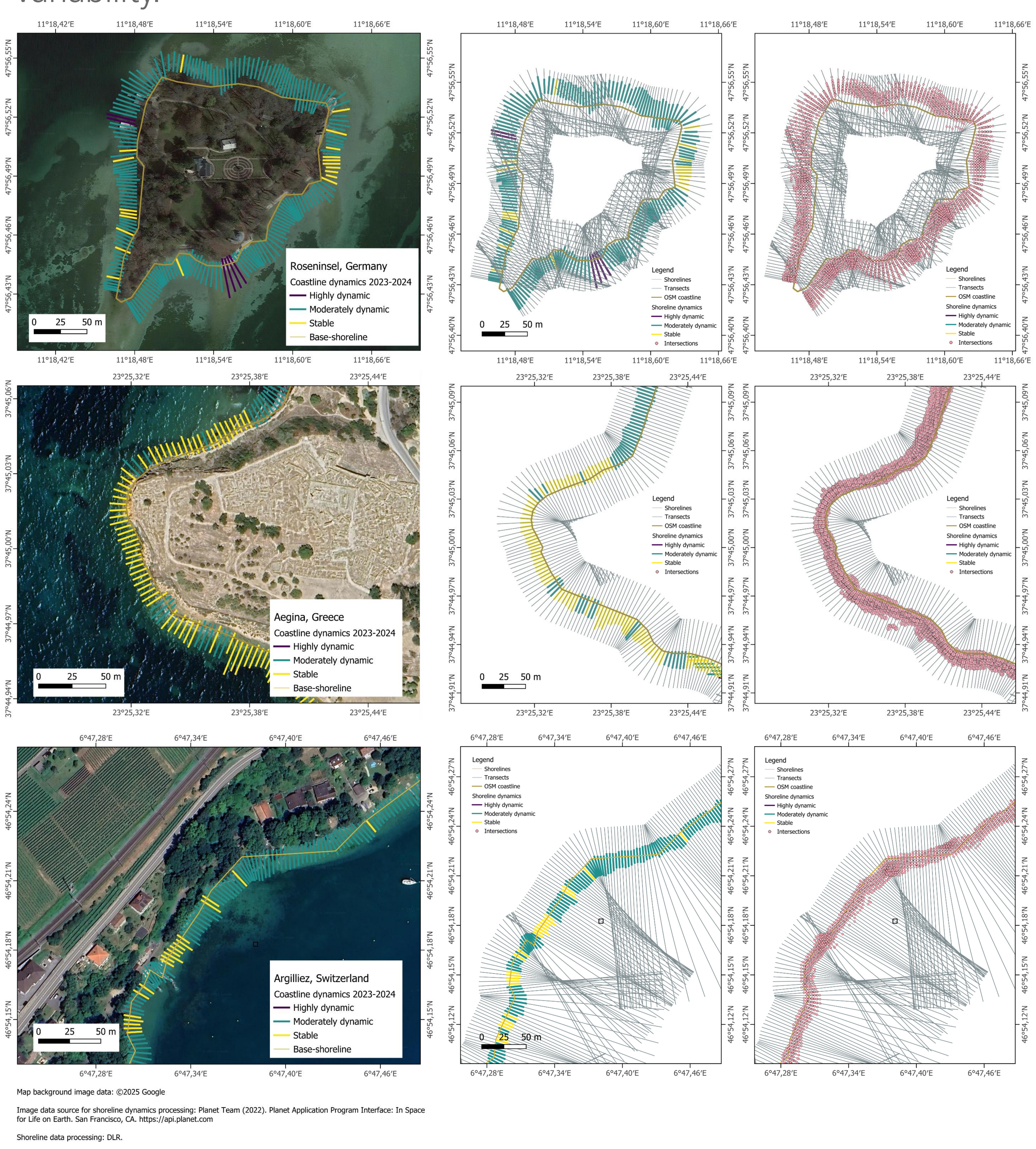


Fig. 6: Coastline dynamics based on PlanetScope time series imagery and extracted intersections and transects generated for the OSM reference shoreline.

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[3] Lappe, R.; Ullmann, T.; Bachofer, F. State of the Vietnamese Coast - Assessing Three Decades (1986 to 2021) of Coastline Dynamics Using the Landsat Archive. *Remote Sensing*. 2022, 14, 2476. https://doi.org/10.3390/rs14102476

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Toolbox for assessing and mitigating Climate Change risks and natural hazards threatening cultural heritage

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