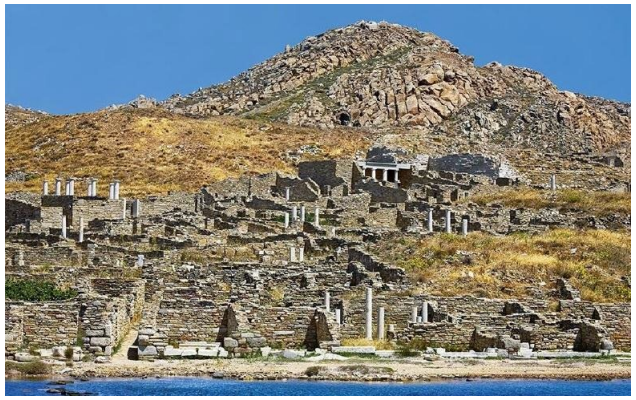


An Integrated System for Monitoring the Effects of Climate Change on the Monuments of Delos

Fountoulakis I.[1], Kapsomenakis I.[1], Melis N.[2], Poupkou A.[1], Solomos S.[1], Athanasoulis D.[3], Boukouras K.[2], Douvis K.[1], Garlaouni C.[2], Gkikas A.[1], Kalabokas P.[1], Kalligeris N.[2], Kalogeras I.[2], Lentas K.[2], Liadopoulos E.[2], Maris C.[3,4], Spyrou C.[1], Stavraka T.[1], Synolakis C.[5,6], Zerefos C.[1,7,8,9]

[1]Research Centre for Atmospheric Physics and Climatology, Academy of Athens, 79 Vasilissis Sofias str, 11521, Athens, Greece

[2]Institute of Geodynamics, National Observatory of Athens, Lofos Nimfon, Thissio,118 10, Athens, Greece

[3]Ephorate of Antiquities of the Cyclades, Ministry of Culture, Greece

[4]University of West Attica, Attica, Greece

[5]Research Center for Natural Disasters, Academy of Athens, 10680, Athens, Greece

[6]Department of Civil and Environmental Engineering, University of Southern California, Los Angeles, CA90089, USA

[7]Biomedical Research Foundation, Academy of Athens, Athens, Greece

[8]Mariolopoulos-Kanaginis Foundation for the Environmental Sciences, Athens, Greece

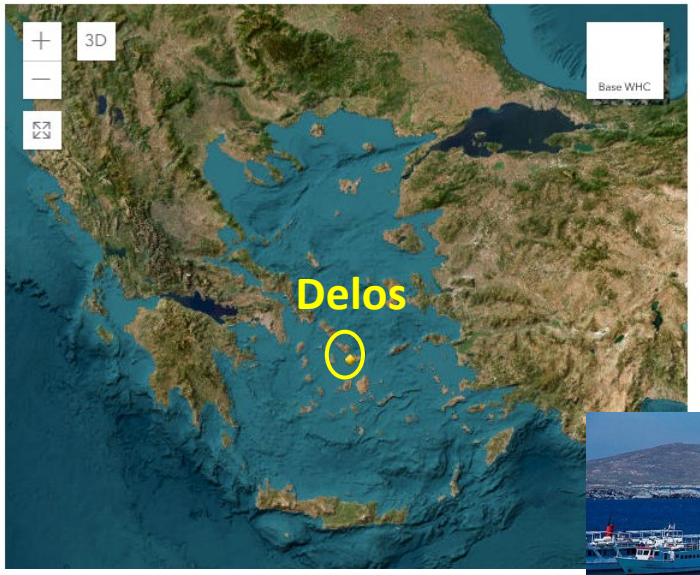
[9]Navarino Environmental Observatory (N.E.O), Messenia, Greece

ΑΚΑΔΗΜΙΑ ΑΘΗΝΩΝ

21 πρωτοβουλία

UNESCO WH Site of Delos: Location and Characteristics

- **One of the most important parts of the ancient Greek world** including temples in the honor of Gods Apollo and Artemis.
- Example of **exceptional combination of cultural, architectural and natural beauty**.
- The island of Delos located in a **vulnerable landscape (complex coastline)** and characterized by local weather conditions in the center of the Aegean Sea (**unique microclimate**).
- **Ancient monuments built with different materials** (e.g. stone, marble) and **different architectural features**.



An Extremely Endangered WH Site in the Mediterranean (*Kapsomenakis et al, 2022*)

ΑΚΑΔΗΜΙΑ ΑΘΗΝΩΝ

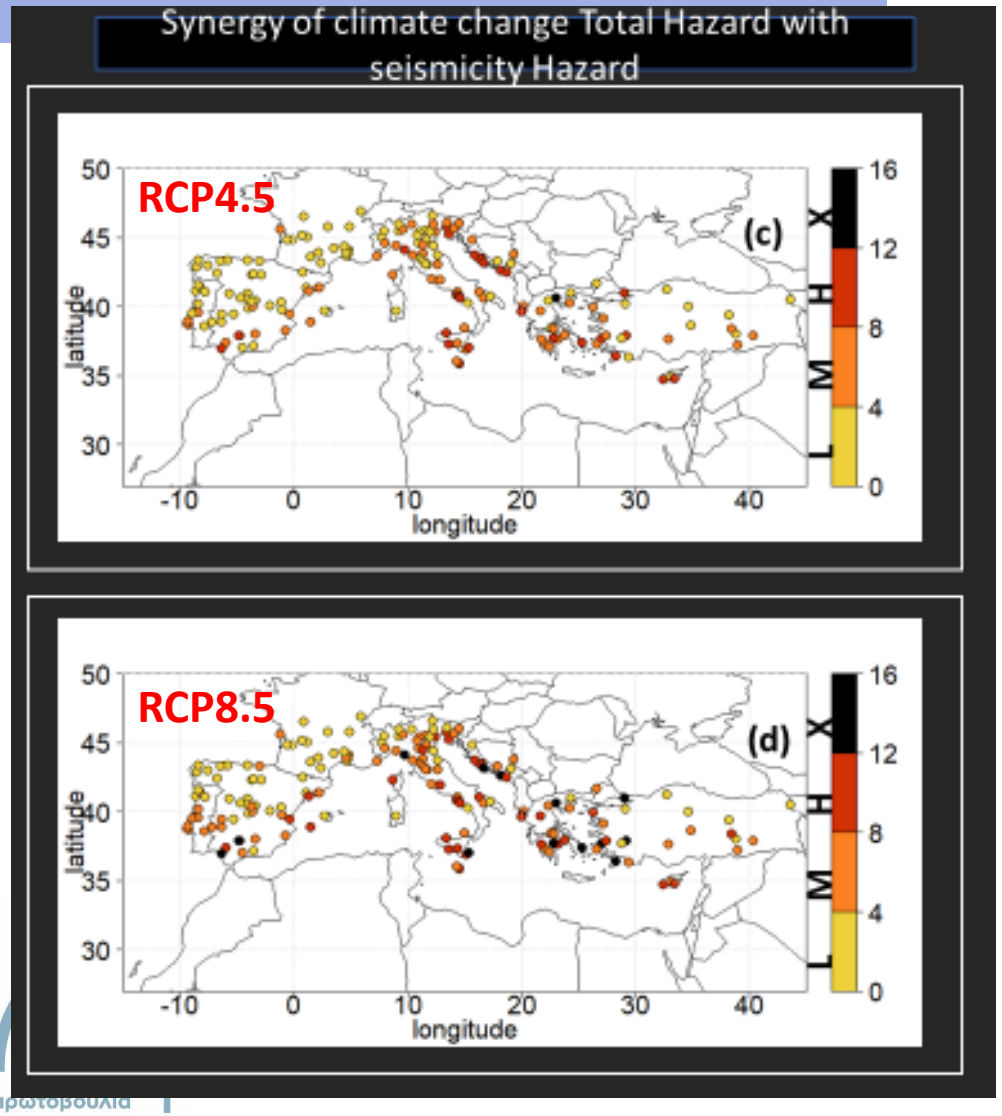
Climatic and Geophysical Hazards of Delos

According to the Heritage Hazard Index (HHI)

- Extreme heat
- Extreme Fire Weather
- Extreme precipitation/ flooding/ landslides
- Aridity
- Frost
- Sea level rise

+

- Seismic Hazard



Open Access | Published: 01 October 2022

Climate change threats to cultural and natural heritage UNESCO sites in the Mediterranean

J. Kapsomenakis, C. Douvis, A. Poupkou, S. Zerefos, S. Solomos, T. Stavraka, N. S. Melis, E. Kyriakidis, G. Kremlis & C. Zerefos

Environment, Development and Sustainability (2022) | Cite this article

Evident Impacts ….Necessity for Monitoring

Εφορεία Αρχαιοτήτων Κυκλάδων

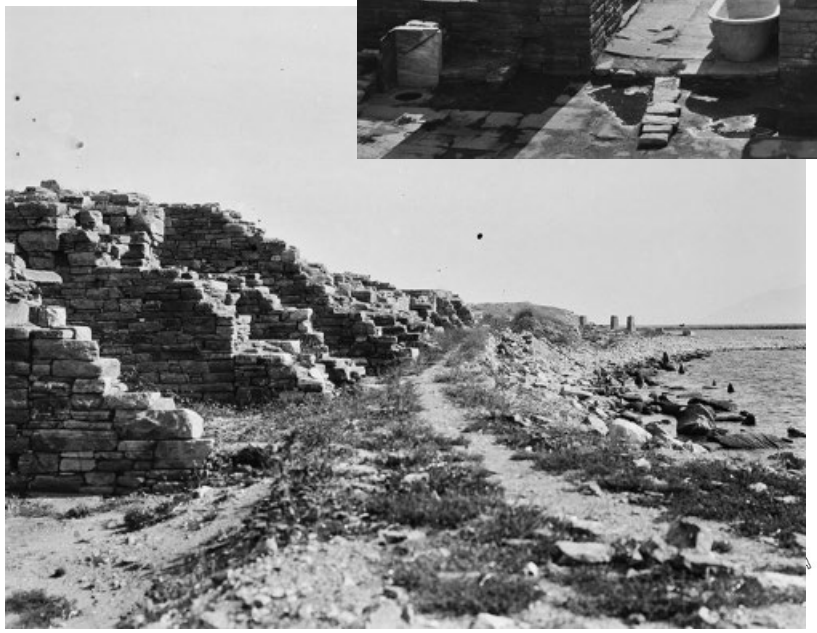
Ephorate of Antiquities of Cyclades

1905

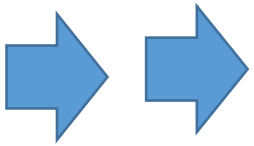
Εφορεία Αρχαιοτήτων Κυκλάδων

Ephorate of Antiquities of Cyclades

2015



Sea Level Rise

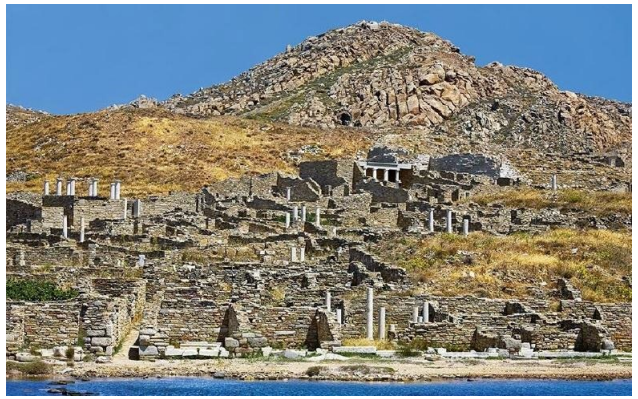


Photos Credit: Demetrios Athanasoulis
(Hellenic Ministry of Culture
Ephorate of Antiquities of the Cyclades)

Integrated System for Monitoring the Environmental Effects on the Monuments of Delos

Geo-environmental Hazards:

- Climate Change.
- Air Pollution.
- Seismic Activity.



Scientific Tools:

- Climate Change Analysis.
- In-situ Atmospheric and Sea Level Monitoring.
- Satellite Monitoring.
- Seismicity monitoring.
- Environmental Modeling.

ΑΚΑΔΗΜΙΑ ΑΘΗΝΩΝ

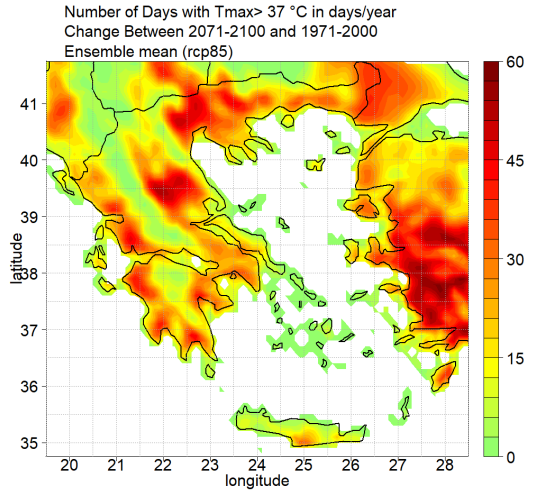
ΕΘΝΙΚΟΝ ΑΣΤΕΡΟΣΚΟΠΕΙΟΝ ΑΘΗΝΩΝ
NATIONAL OBSERVATORY ATHENS

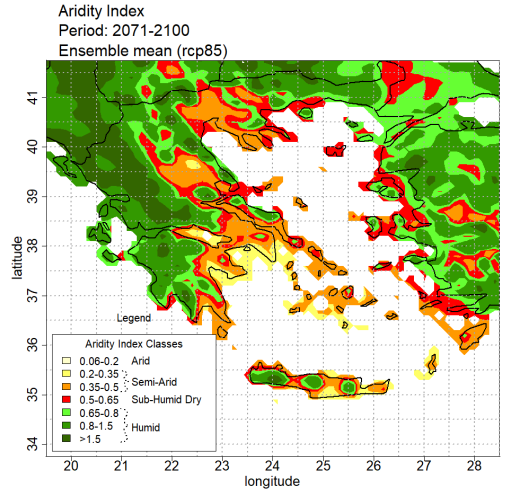
21 πρωτοβουλία

Climate Change Analysis and Hazard Identification

- **Climate change analysis** based on the ensemble of regional climate model results (10×10km^2, CORDEX program) to be **statistically downscaled at 250 x 250m^2 over Delos**.
- Reference period (**1971-2000**), Near (**2031-2060**) and Far (**2071-2100**) future.
- Emission scenarios: **Moderate mitigation** (RCP4.5), **Business as usual** (RCP8.5).
- Estimation of **indices to identify climate hazards** (e.g. Extreme heat, High thermal discomfort (for visitors), Extreme Precipitation/Flooding, Drought, Strong winds).
- **Determining vulnerability** and risk taking into account the: a) **Climate hazard indicators**, b) **Specific properties of the monuments and surrounding landscape** (e.g. coastline), c) **Geological features** (e.g. earthquakes and erosion).

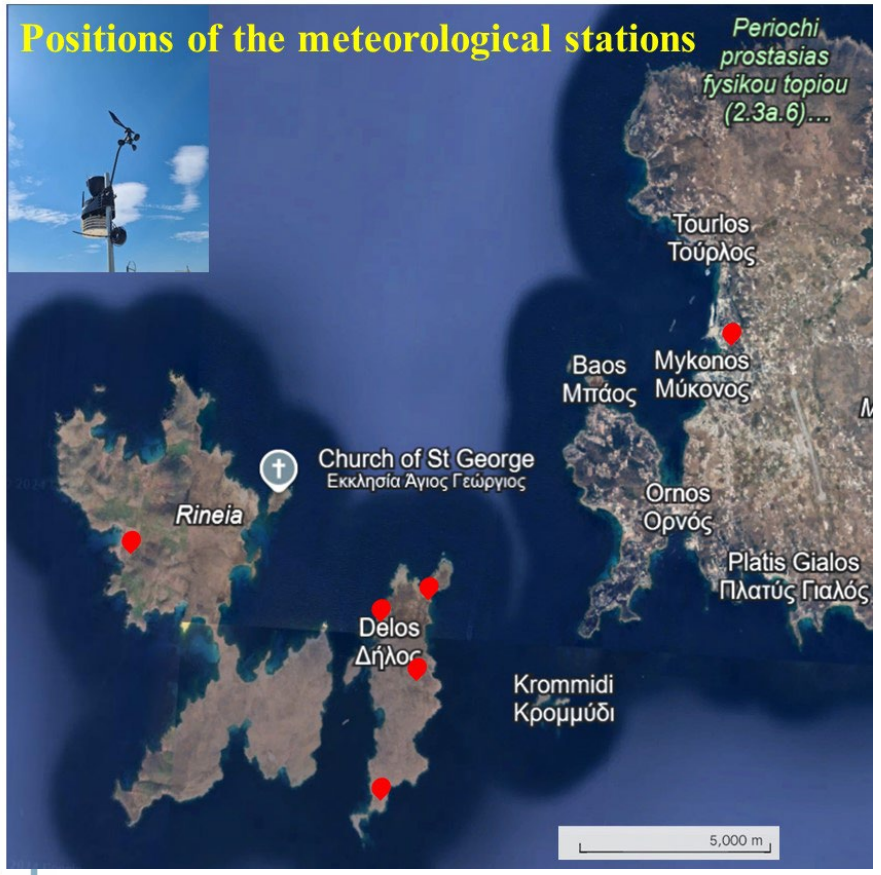
✓ **Contribution to the preparation of a management plan including climate change adaptation solutions for Delos.**





In-situ Atmospheric Monitoring (1)

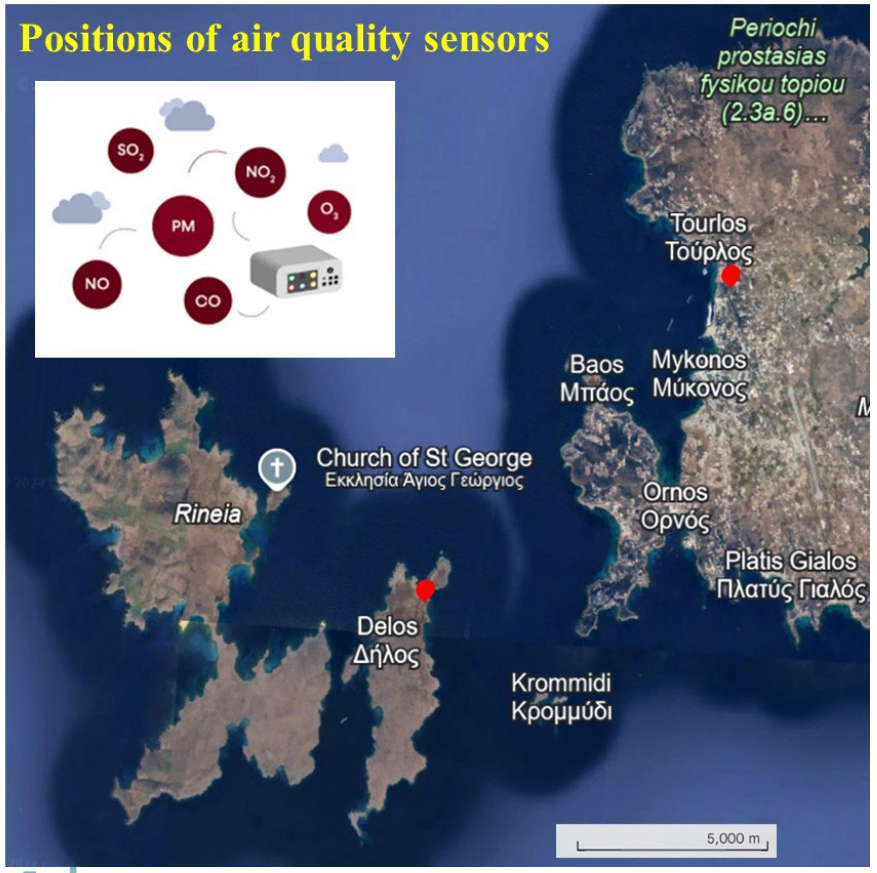
- **Temperature, Relative Humidity, Wind Speed, Wind Direction** (multiple sites)
- **Rainfall** (two sites: Delos and Mykonos)



- **Cloudiness** monitored by a sky camera.

In-situ Atmospheric Monitoring (2)

- Surface concentration of **SO_2, O_3, NO_x, CO, PM_1, $PM_{2.5}$, PM_{10}, Radon** (two sites: Delos and Mykonos)



Pollutant emissions from intense passenger and cruise ship traffic during summertime since Mykonos is a top touristic destination.

ΑΚΑΔΗΜΙΑ ΑΘΗΝΩΝ

ΕΘΝΙΚΟΝ ΑΣΤΕΡΟΣΚΟΠΕΙΟΝ ΑΘΗΝΩΝ
NATIONAL OBSERVATORY ATHENS

21 πρωτοβουλία

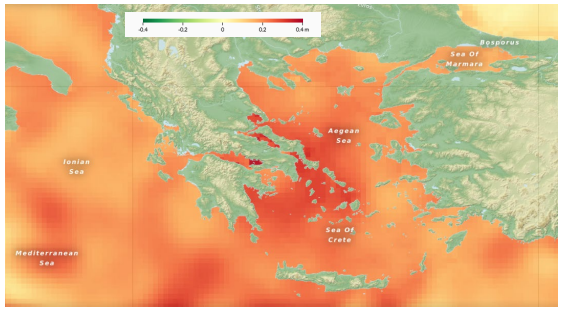
Real-time Sea Level Monitoring

- **Piezoelectric tide gauge + Global Navigation Satellite System station in the harbor of Delos** to measure absolute sea level changes.
- **Radar-type tide gauge in the port of Mykonos** for complimentary sea level monitoring.

- **Monitor sea and ground level changes, tidal, storm surge** and other meteorologically-induced sea level fluctuations.
- **Estimation of rate of sea level change**.

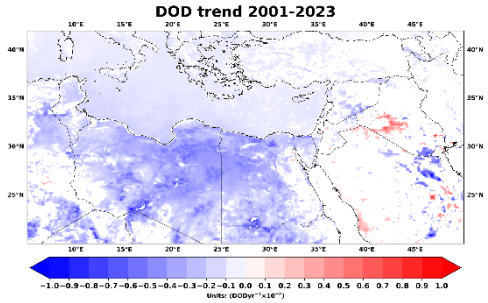
NRT and Long-term Monitoring from Spaceborne Instruments

Sea Level



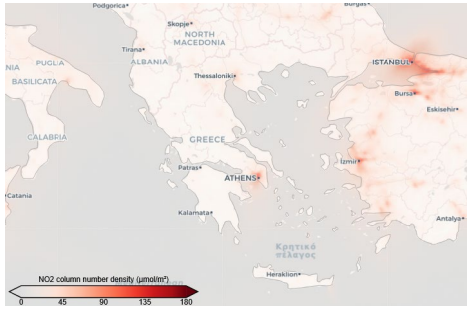
Copernicus altimetry missions
Spatial resolution: 0.125° x 0.125°
Temporal resolution: Daily
Temporal coverage: 1993 - present

Dust optical depth



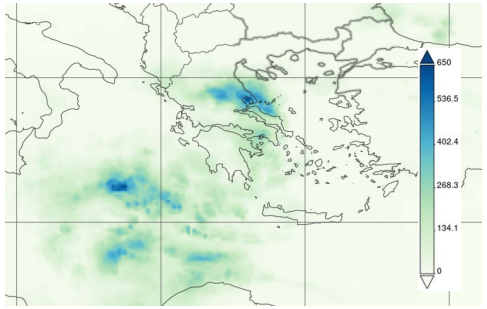
ModIs Dust AeroSol (MIDAS)
Spatial resolution: 0.1° x 0.1°
Temporal resolution: Daily
Temporal coverage: 2001 - present

Air Quality



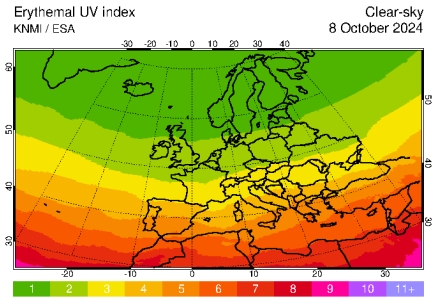
TROPOspheric Monitoring Instrument (TROPOMI)
Spatial resolution: 5.5 km x 3.5 km /7 km x 3.5 km
Temporal resolution: Daily
Temporal coverage: 2017 - present

Precipitation



Integrated Multi-satellitE Retrievals (IMERG)
Spatial resolution: 0.1° x 0.1°
Temporal resolution: Hourly
Temporal coverage: 2000 - present

UV radiation



Tropospheric Emission Monitoring Internet Service (TEMIS)
Spatial resolution: 0.25° x 0.25°
Temporal resolution: Daily
Temporal coverage: 2002 - present

Atmospheric and Sea Level Monitoring for….

- ✓ **Long-time measurement records and observations** for the complete study of the *spatiotemporal variation of micrometeorological and atmospheric chemical conditions, and sea level fluctuations* and **for the better understanding** of ***how the monuments of Delos are affected in long-term***.
- ✓ **(Near) Real-time evaluation** of the ***atmospheric conditions and those at sea for monuments protection at short-term***.
- ✓ **Joint analysis** of *in-situ with satellite monitoring*.
- ✓ **Validation** of *high resolution environmental modeling with measurements*.

ΑΚΑΔΗΜΙΑ ΑΘΗΝΩΝ

ΕΘΝΙΚΟΝ ΑΣΤΕΡΟΣΚΟΠΕΙΟΝ ΑΘΗΝΩΝ
NATIONAL OBSERVATORY ATHENS

21 πρωτοβουλία

Real-time Seismic Monitoring

- **Two model seismic stations**: Delos (Archaeological Museum) and Mykonos (Archaeological Museum).

✓ **Improved monitoring for better estimation** of seismic effects on monuments.

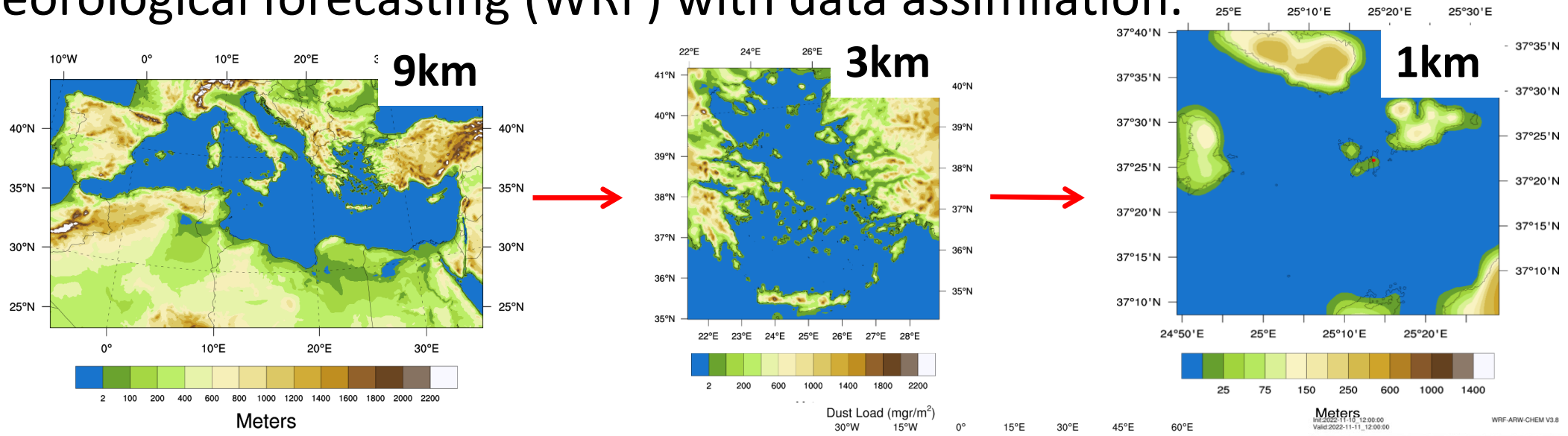
✓ **Micro-seismicity monitoring to improve knowledge** of seismically active fault zones.

✓ Seismic monitoring of natural and human phenomena via **ambient ground noise analysis**.

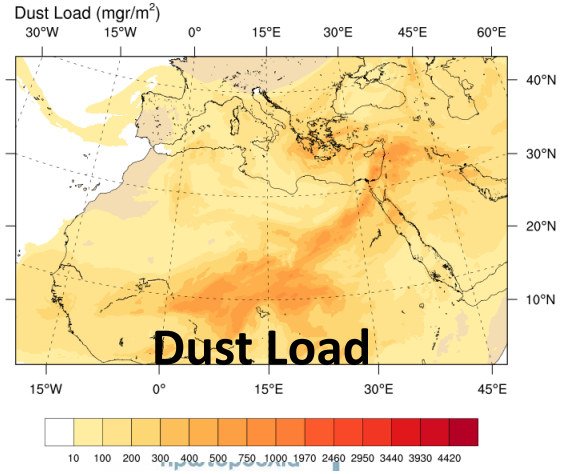
✓ **Estimation of earthquake hazard**.

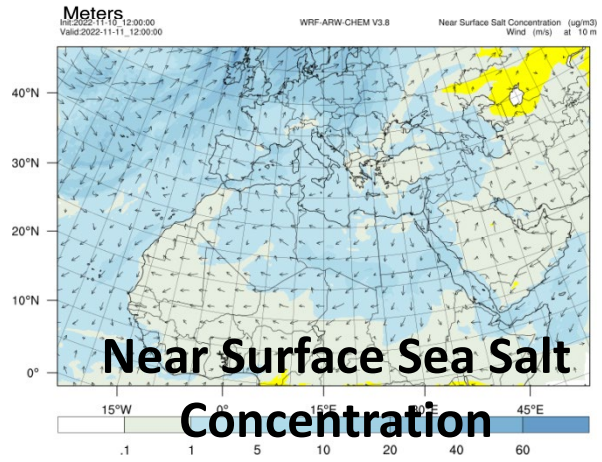
High Resolution Environmental Modeling to Inform Authorities and Community/Visitors for Extreme Events

- Meteorological forecasting (WRF) with data assimilation.



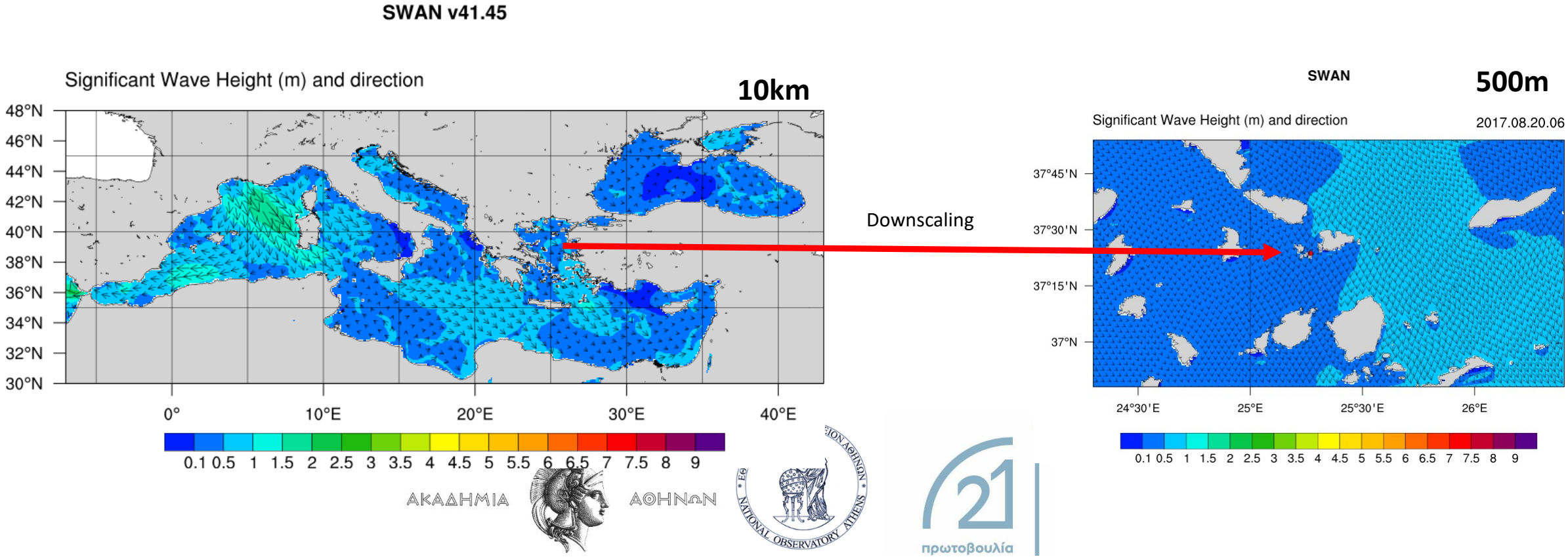
- Air quality forecasting:
  - Dust, Sea salt (WRF-Chem)
  - Forest fire plumes (FLEXPART)





High Resolution Environmental Modeling to Inform Authorities and Community/Visitors for Extreme Events

- Wave forecasting: Simulating Waves Nearshore model (SWAN) driven by WRF meteorological model.



Collaboration with Other Disciplines and Stakeholders

- Combining **monitoring systems and state-of-the-art modelling** will allow the improved identification of current and future geo-environmental effects on the monuments of Delos and the **preparation of a management plan, including also climate change adaptation solutions, to preserve the OUV of Delos and its monuments**.
- This effort calls for multi-disciplinary (e.g. antiquity guards, archaeologists, conservators, architects etc.) and inter-sectoral collaboration involving stakeholders (e.g. archaeological service, local/regional/national authorities, etc) and the society.

Photos Credit: Demetrios Athanasoulis (Hellenic Ministry of Culture Ephorate of Antiquities of the Cyclades)


Results presentation to the international Scientific Community
Dissemination actions, Publications, Conferences
Transferability to other monuments
DELOS
Synergies with National and International Networks (EMEKA, LIFE-IP, CLIMPACT, HARMONIA)
Presentation to Schools, Integration in Postgraduate Programs
Join Greek Initiative at UN Level "Addressing Climate Change Impacts on Cultural and Natural Heritage"

CLIMATE CHANGE IMPACTS ON CULTURAL & NATURAL HERITAGE
FLEXIBLE MECHANISM
Coordination Unit

Initiative : « Addressing climate change impacts on cultural and natural heritage »

Flexible Mechanism

steering committee (Greece, UNESCO, WMO, UNFCCC)

HELLENIC REPUBLIC

United Nations Educational, Scientific and Cultural Organization

WORLD METEOROLOGICAL ORGANIZATION

UNFCCC

Support of:

- More than 100 UN Member States
- International/National Organizations and Institutions

COUNCIL OF EUROPE
CONSEIL DE L'EUROPE

ACADEMY OF ATHENS

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

EUROPA NOSTRA

ICOMOS
international council on monuments and sites

GEO GROUP ON EARTH OBSERVATIONS

WORLD HUMAN FORUM

Union for the Mediterranean
Union pour la Méditerranée
الاتحاد من أجل المتوسط

https://ccich.gr/

Thank you for the attention!

/Delos Kefak

Acknowledgments
This work has been performed in the framework of the project “Development and installation of an integrated system for the monitoring of the impacts of climatic change on the monuments of Delos” that has been funded by benefit foundations of "Protovoulia ‘21“.