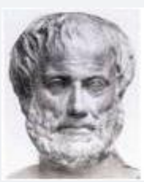
CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE:
FACING THE CHALLENGE

International Conference
June 21-22, 2019
Athens, Greece



The contribution of Hellenic National Meteorological Service for the protection of Greek cultural heritage

Brigadier General (HAF)
Nikolaos Vogiatzis
Director General of HNMS

P. Skrimizeas, Director of Forecasting (NWP) and Research Division/HNMS
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Major Ch. Karvelis, Head of Remote Sensing Department/ HNMS
A. Mamara, Head of Climatology Department /HNMS

Climate Change

- *According to the World Meteorological Organization (WMO)*
  - Continuation of long-term warming trend in 2018
  - The average global temperature of 2018 was the fourth highest on record, while the 20 warmest years on record have been in the past 22 years, with the top four in the past four years
  - The global average temperature in 2018, for the first ten months of the year was nearly 1°C above the pre-industrial baseline (1850-1900)
  - Increasing trend of greenhouse gases concentrations (at record levels nowadays), if continues - may see temperature increases 3-5 °C by the end of the century

- *According to IPCC Special report on Global Warming of 1.5°C*
  - Increasing trend of global temperature per recent decades above the pre-industrial baseline (for the decades: 2006-2015 / 0.86°C, 2009-2018 / 0.93°C, 2014-2018 / 1.04°C)

IPCC Special Report

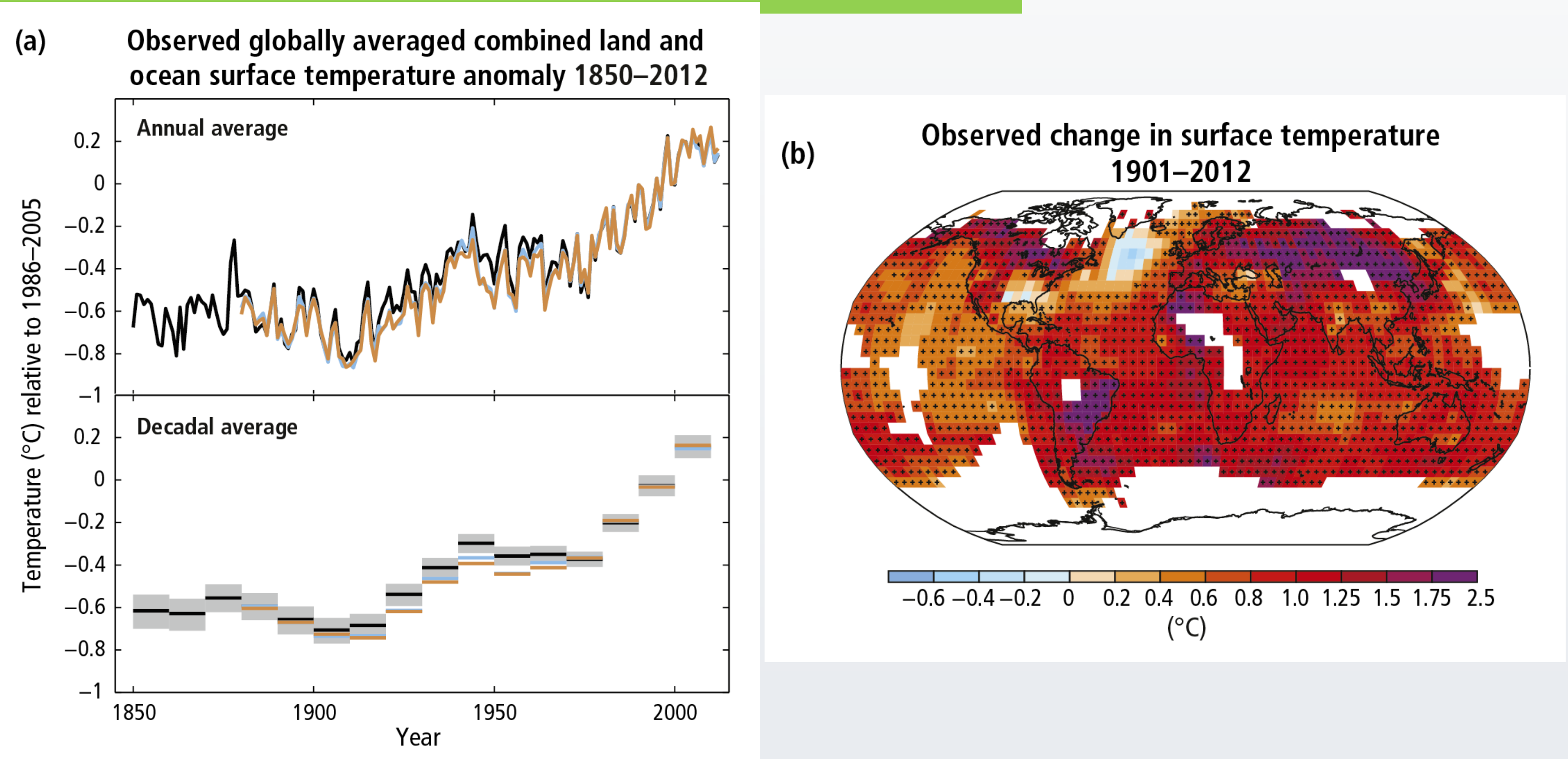

Figure from IPCC AR5 Synthesis Report | Multiple observed indicators of a changing global climate system. **(a)** Observed globally averaged combined land and ocean surface temperature anomalies (relative to the mean of 1986 to 2005 period, as annual and decadal averages) with an estimate of decadal mean uncertainty included for one data set (grey shading). {WGI Figure SPM.1} **(b)** Map of the observed surface temperature change, from 1901 to 2012, derived from temperature trends determined by linear regression from one data set (orange line in Panel a).

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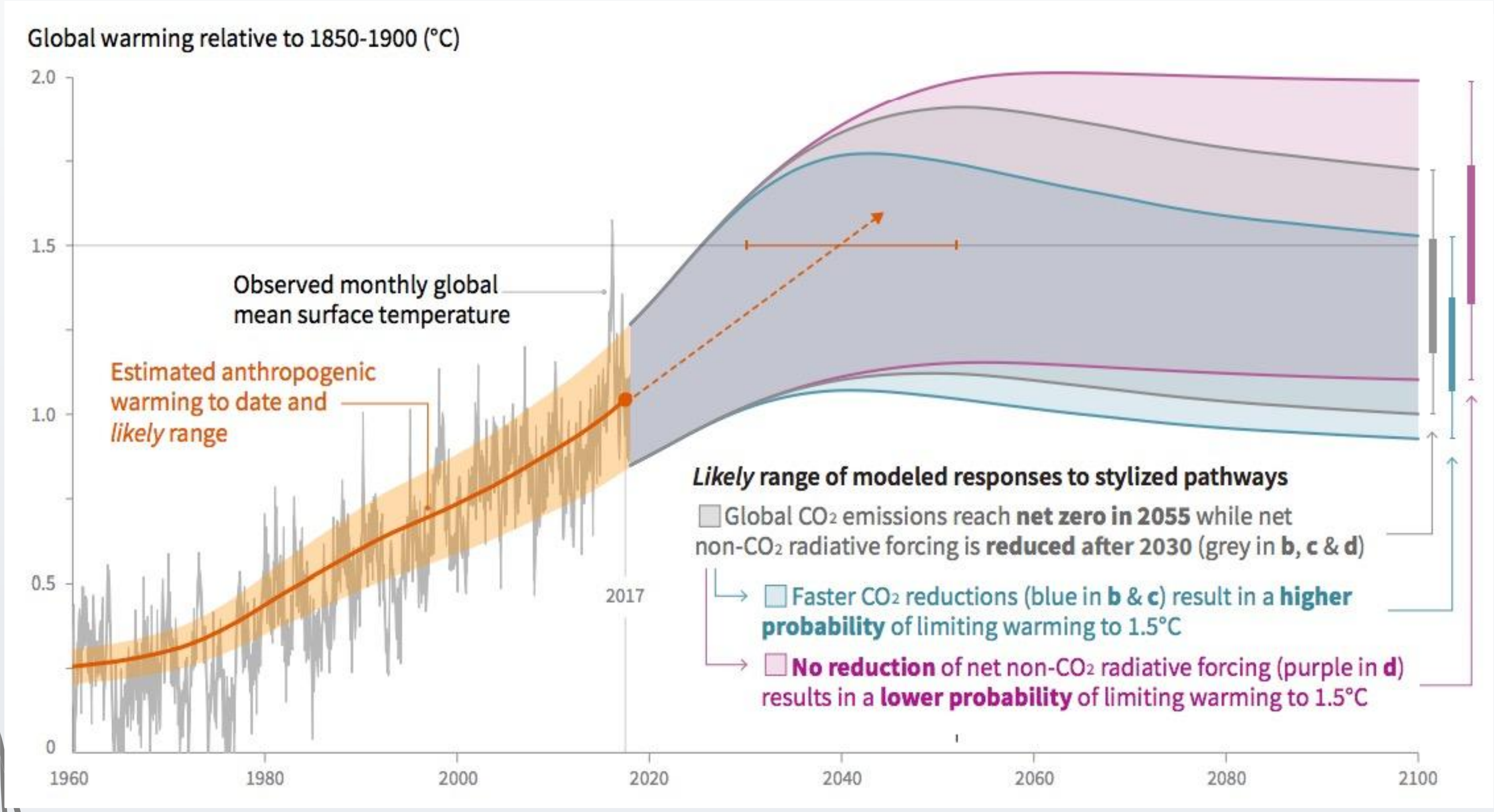
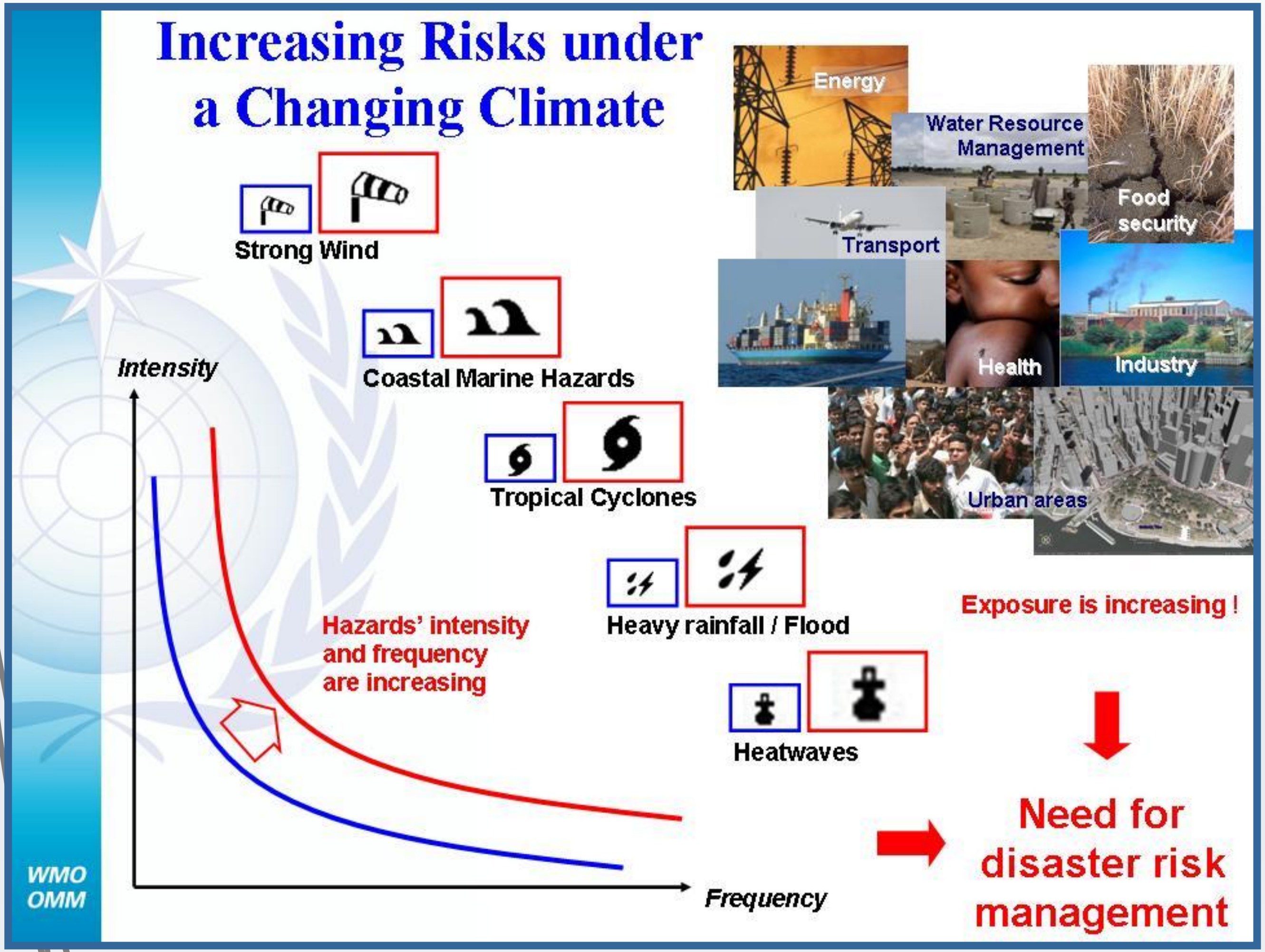
IPCC Special Report
Global warming of 1.5°C



Increasing Risks
(Conclusions from IPCC)



Source: "*WMO Approach to Strengthening National Early Warning Systems' Capacities with a Multi-Hazard Approach*" Maryam Golnaraghi, Ph.D. Chief, Disaster Risk Reduction Programme World Meteorological Organization

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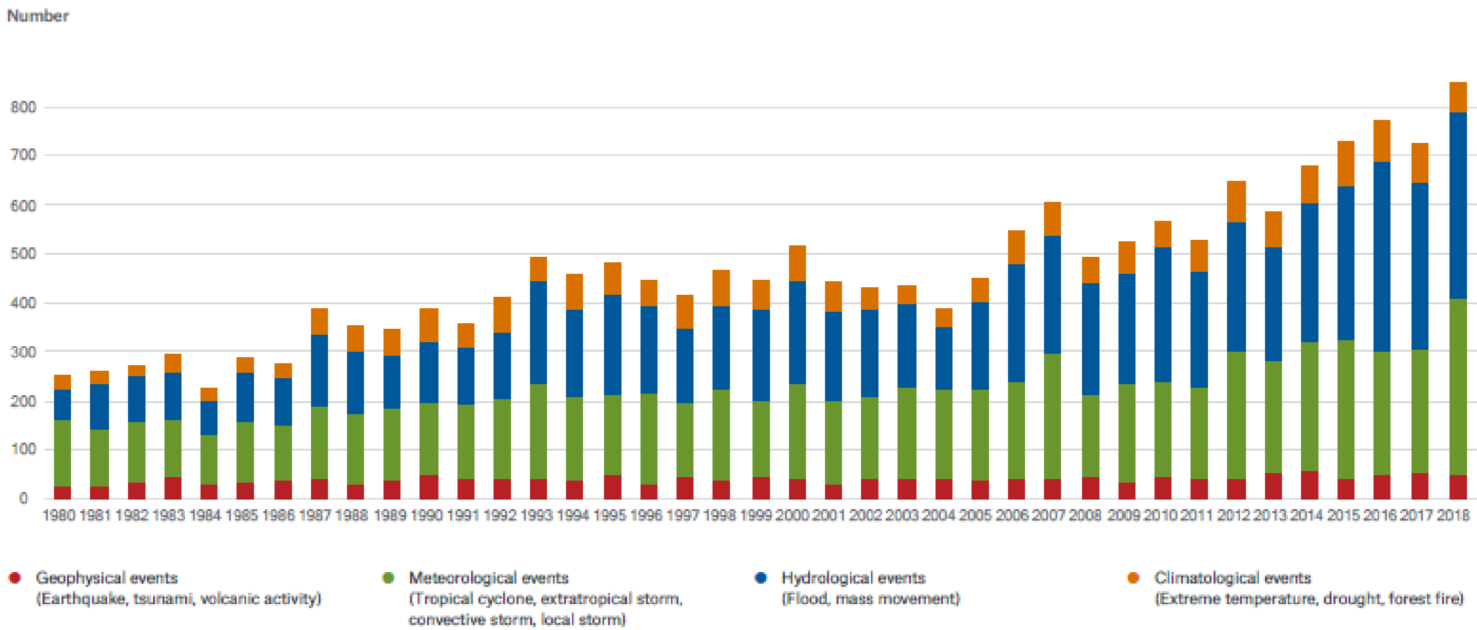
Worldwide Natural Hazards 1980- 2018

NatCatSERVICE

Munich RE

Number of events

Relevant natural loss events worldwide 1980 – 2018



Accounted events have caused at least one fatality and/or produced normalised losses ≥ US$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country).

Cultural Landscapes

Defined by the World Heritage Operational Guidelines as properties that are representative of the ‘combined works of nature and of man’ and illustrate the ‘evolution of human society and settlement over time, under the influence of the physical constraints and/or opportunities presented by their natural environment’ (Intergovernmental Committee for the Protection of the World Cultural and Natural Heritage, 2008).

Cultural landscapes that are identified as archaeological, or are intrinsically associated with archaeological remains, or whose preservation impacts on those remains, are included for consideration here.

Cultural Landscapes

In 1996, Pearson and Williams (Possible Effects of Climate Change on the Cultural National Estate) **wrote:**

‘[. . .] there is a vast amount of information we have to gather about cultural places before we as archaeologists, anthropologists or heritage managers can have a proper input into the discussion about the possible effects of climate change. It will be very difficult to convince governments of the threats to the cultural environment, and of the range of options available to reduce the impact of climate change, if substantial work is not carried out in the next 10 years’

Archaeologists Race Against Time to Save Sites from Climate Change

WASHINGTON (June 28, 2018)
An international group of archaeologists, in a race against time to preserve, or at least document, artifacts and sites threatened by coastal erosion, melting glaciers and permafrost thaw, have published the first synthesis of how climate change is affecting Arctic archaeological sites in the journal Antiquity.

Climate Change Is Coming for Underwater Archaeological Sites

Wrecks stand to see a number of threats in a changing ocean

IMPACTS MATRIX FOR THE PREDICTED EFFECTS OF CLIMATE CHANGE ON ARCHAEOLOGICAL HERITAGE IN TEMPERATE ZONES

Climate effect	Controlling parameters	Potential impact on heritage values
TEMPERATURE • Increased annual temperatures • Reduction in freeze thaw events	Temperature Moisture	Changes in land use Changes in lichen colonies
RAIN • Storms/heavy rain • Prolonged wet periods • Flooding • Altered water table • Prolonged dry periods	Rain intensity and duration Rain volume Catchment hydrology (i.e. flooding can be caused by rain elsewhere) Temperature	Soil erosion Deterioration of water quality Landslides Increased risk of fires Mechanical erosion Dissolution Change in humidity cycles (salts) Increase in time of wetness Subsidence and collapse Lightning activity

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IMPACTS MATRIX FOR THE PREDICTED EFFECTS OF CLIMATE CHANGE ON ARCHAEOLOGICAL HERITAGE IN TEMPERATE ZONES

Climate effect	Controlling parameters	Potential impact on heritage values
WIND • Wind driven rain • Wind pressure • Wind driven particulates • Gusts and changes in wind direction	Wind speed Wind direction Rain intensity and duration	Soil erosion Tree throw Mechanical erosion and abrasion Dissolution Increased penetration of water Physical damage and collapse
COASTAL WINDS • Wind transported salts • Wind driven sand • Increased wave heights • Storm surge	Wind speed Wind direction Surface pressure	Coastal erosion Saline intrusion Flooding Erosion of foundations Increased penetration of salts and salt weathering

IMPACTS MATRIX FOR THE PREDICTED EFFECTS OF CLIMATE CHANGE ON ARCHAEOLOGICAL HERITAGE IN TEMPERATE ZONES

Climate effect	Controlling parameters	Potential impact on heritage values
INCREASED SEA TEMPERATURE • Sea level rise • Cyclones-Low pressure systems	Temperature Ocean currents	Coastal flooding Erosion Salt in soils and water table Migration of human population Coastal protection engineering Increase in salt damage Storm damage Salt water intrusion Submersion

SAMPLE OF VULNERABILITY MODEL FOR CLIMATE CHANGE IMPACTS AT SITE

Climatic factor	Impact	Sensitivity	Exposure	Adaptive capacity	Measure of vulnerability

25% increase in storms

35–44% predicted rainfall reduction

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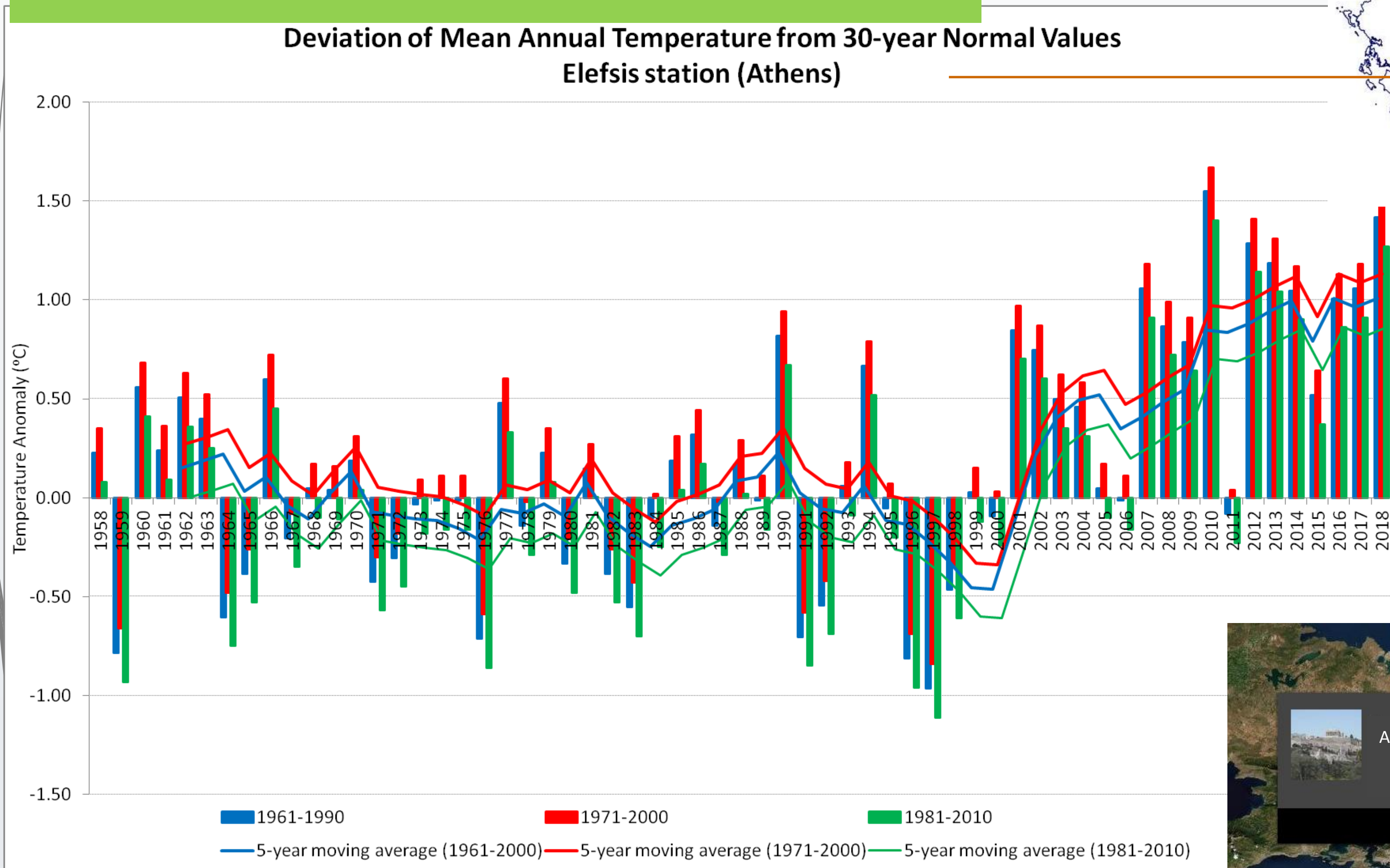
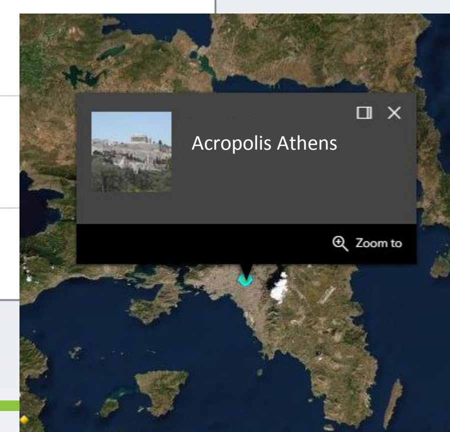
Temperature Anomalies in Greece





UNESCO World Heritage Site

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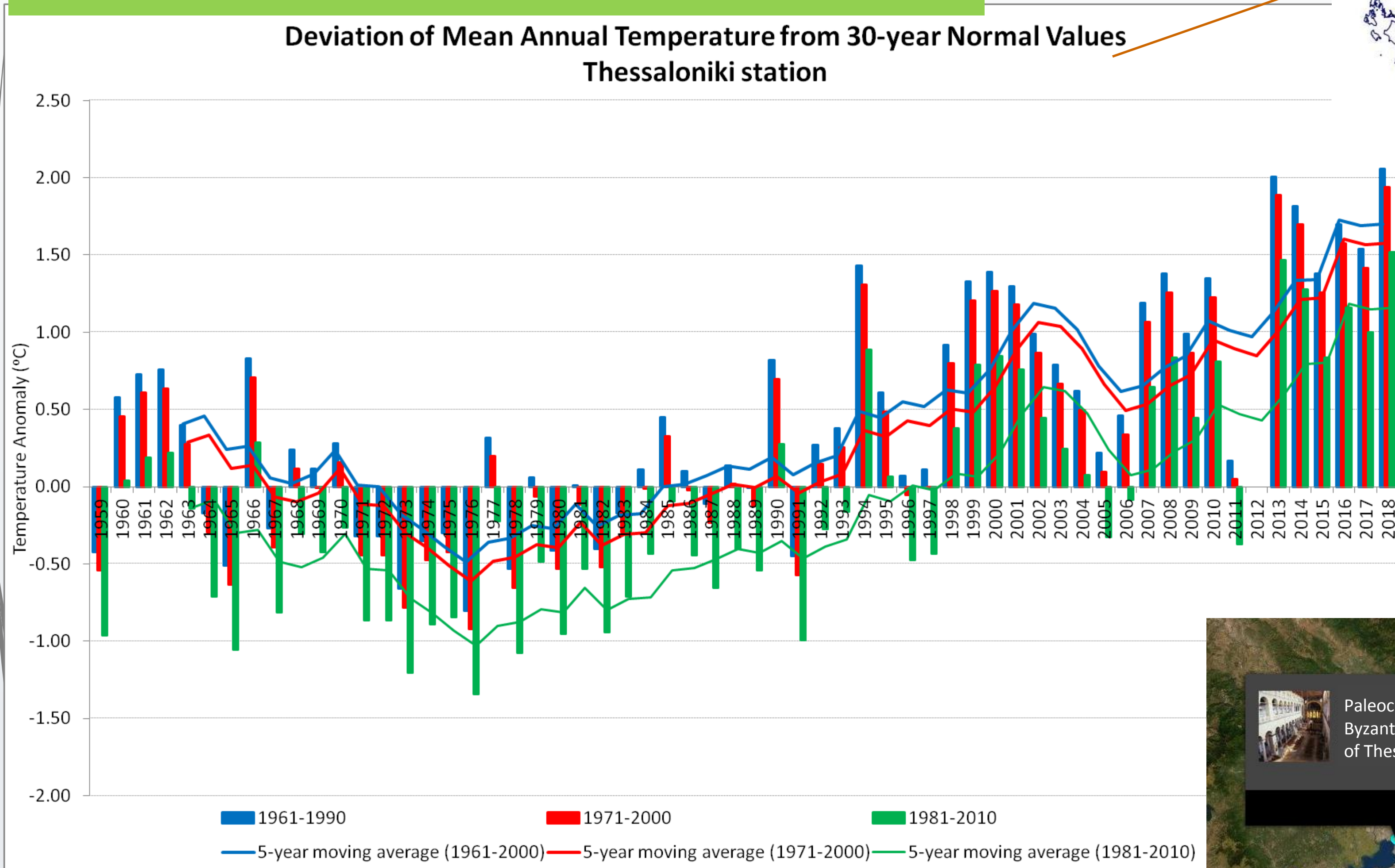
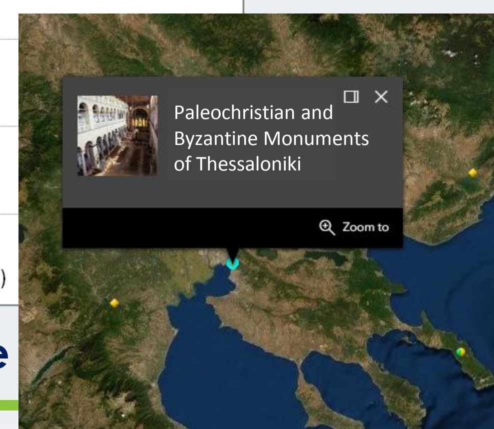
Temperature Anomalies in Greece





UNESCO World Heritage Site

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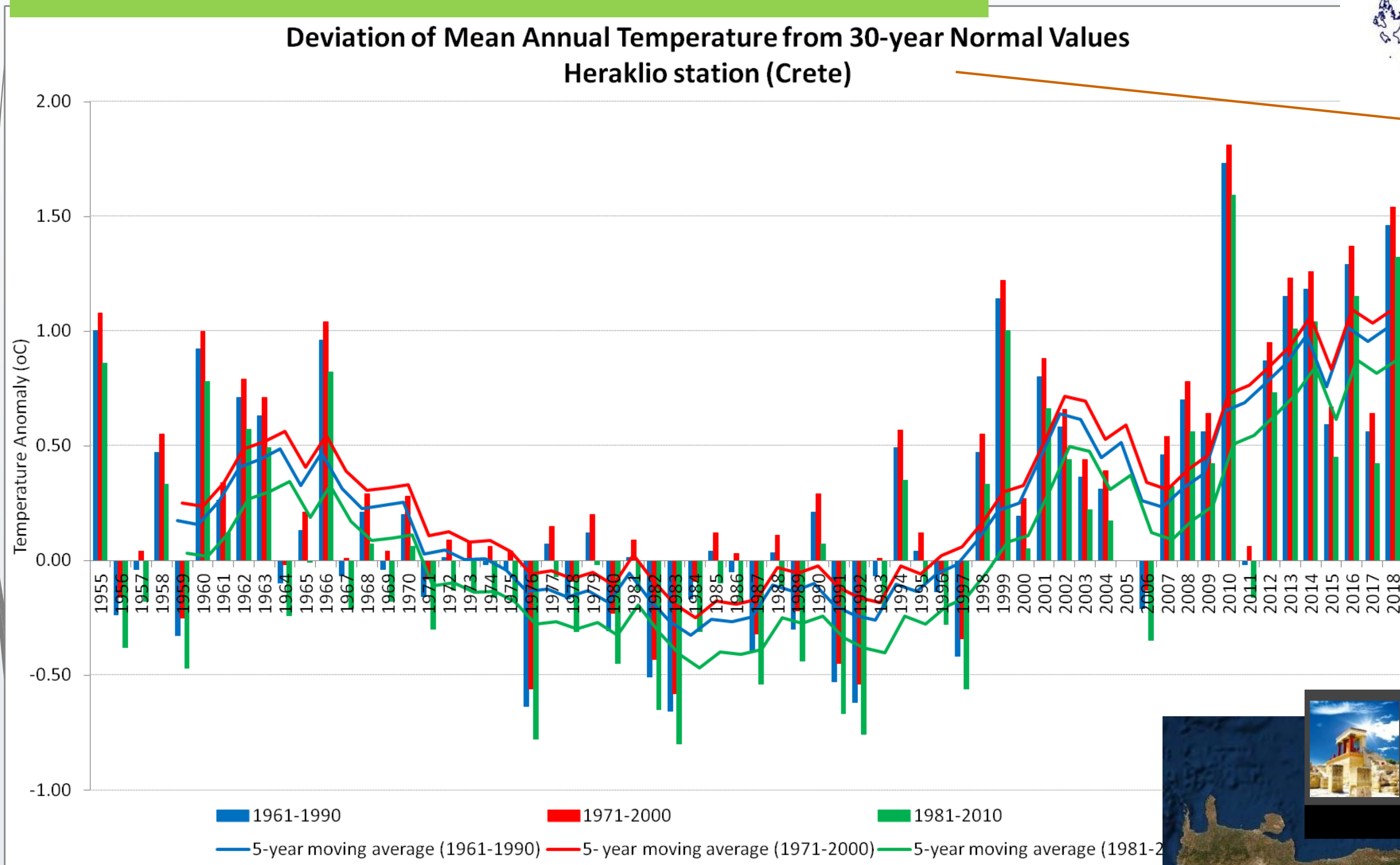

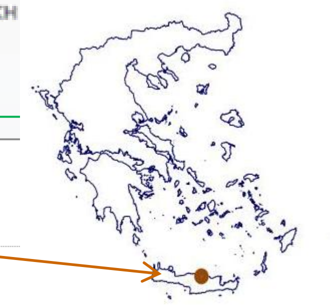

Archaeological Site

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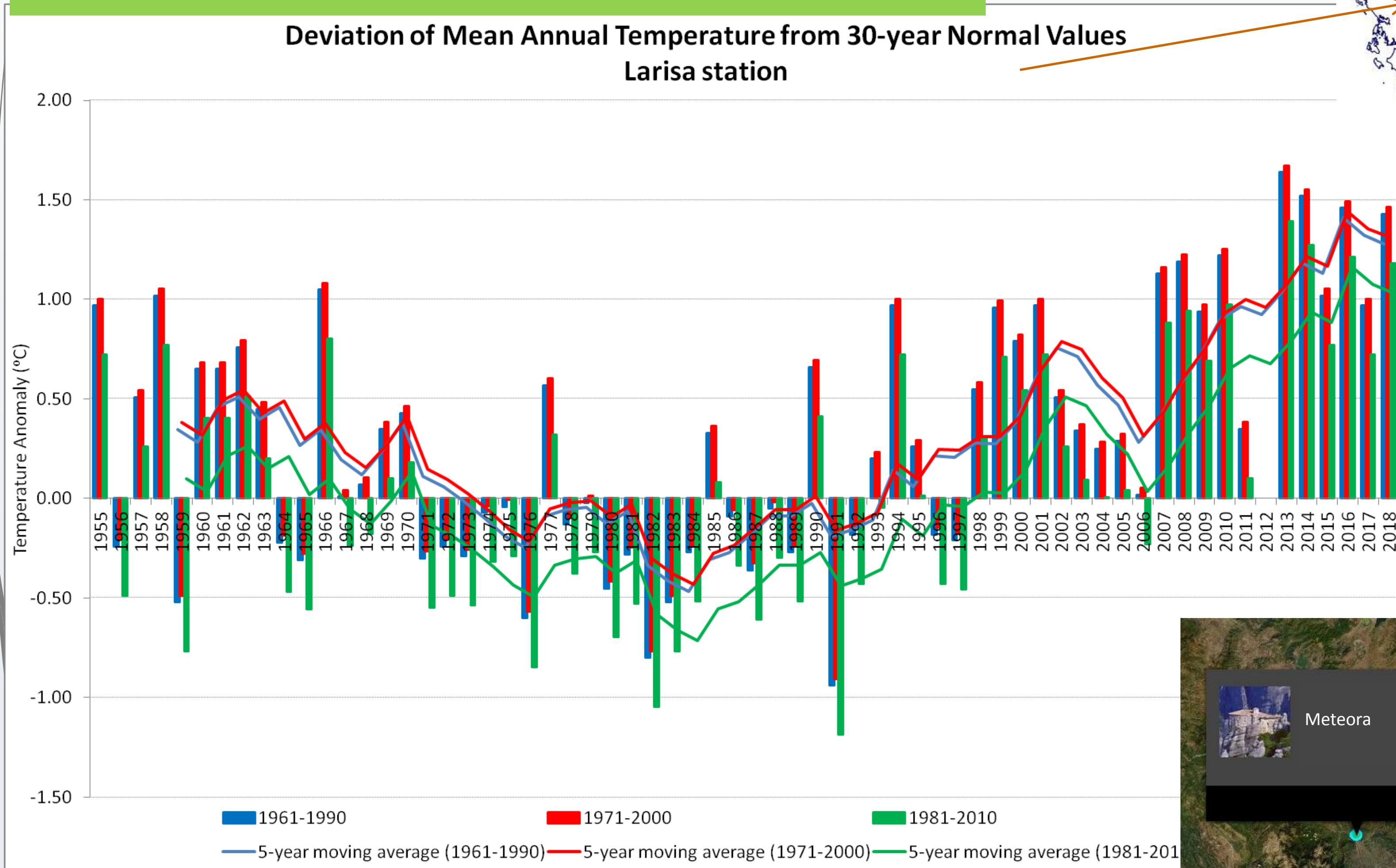

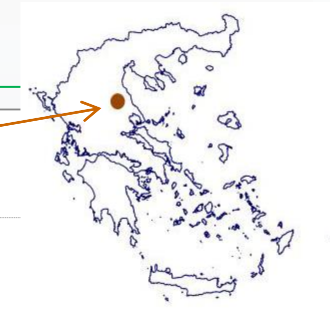

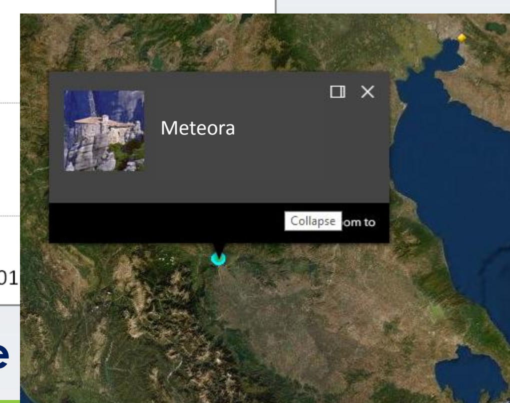

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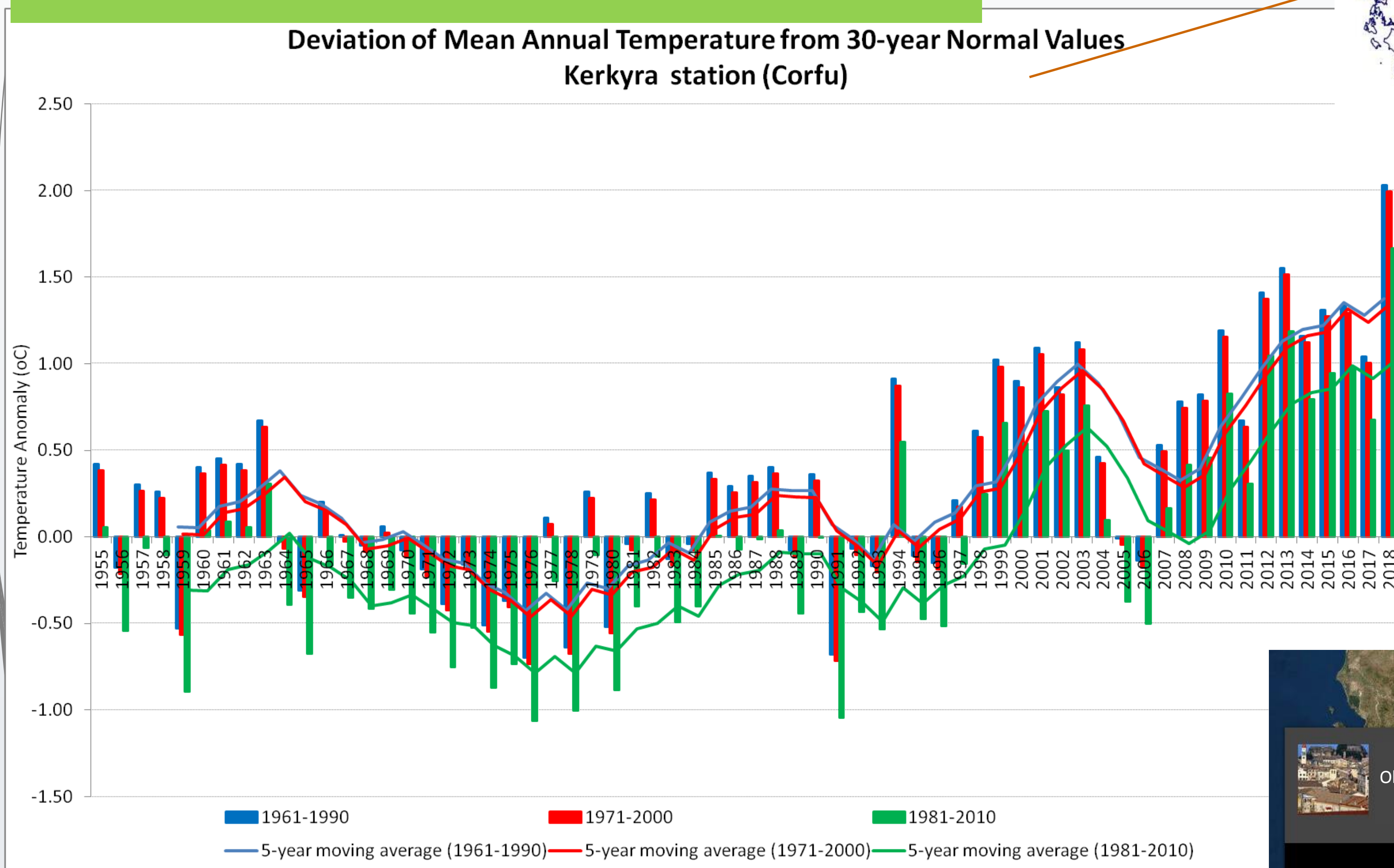
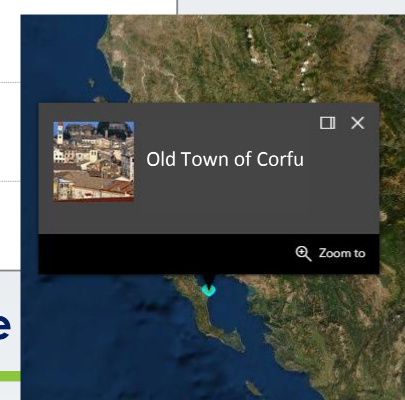
Temperature Anomalies in Greece





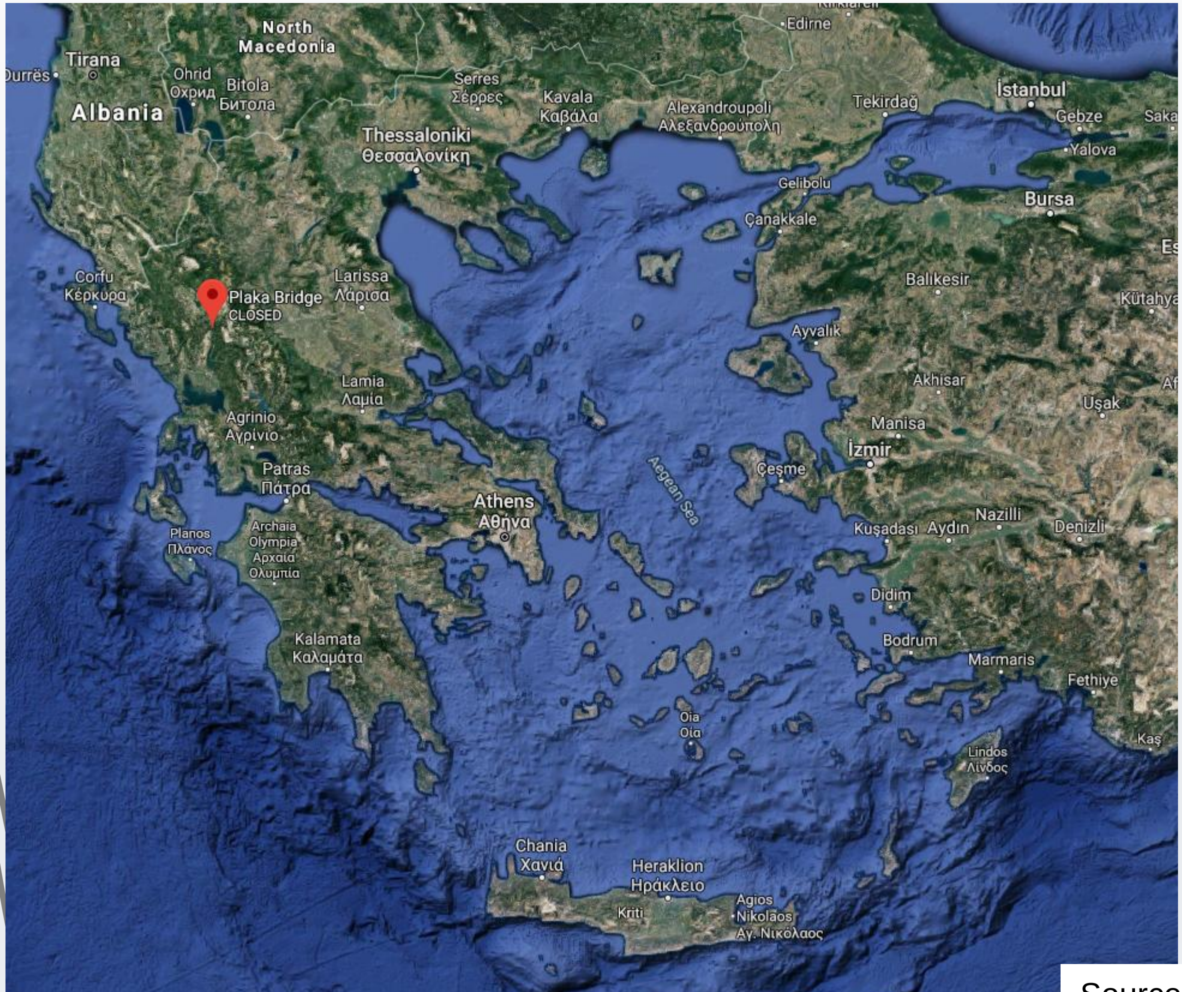
UNESCO World Heritage Site

Temperature Anomalies in Greece

Based on the previous graphs depicting the deviations of Mean Annual Temperature from three successive 30-year Normal values (1961-1990, 1971-2000, 1981-2010) the following conclusions are driven:

- Increasing trend of mean annual temperature is unequivocal.
- Mean annual temperature records, since 1998 indicate warming.
- Deviations of mean annual temperature from normal values (a 30-year period 1961-1990, 1971-2000, 1981-2010) are positive during the last 20 years, and since 2007 approximately were nearly or exceeded 0.8 ^{o}C.
- In general, five year moving averages calculating with different based periods (1961-1990, 1971-2000, 1981-2010), shown in the previous figures, indicate a gradual temperature increase beginning by the middle of ‘80s or early ‘90s.

Climate change and Cultural Heritage



Plaka Bridge is a stone one-arch bridge.
It is located at the borders of Arta and Ioannina prefectures, above the waters of Arachthos River.
It was the largest one-arch bridge in Greece and the Balkans, and the third largest one-arch stone bridge in Europe. It was considered "one of the most difficult, single-arch bridges to construct."
The bridge was completed in 1866.

Source: https://en.wikipedia.org/wiki/Plaka_Bridge

Climate change and Cultural Heritage

Plaka Bridge before…

Climate change and Cultural Heritage

Plaka Bridge after…

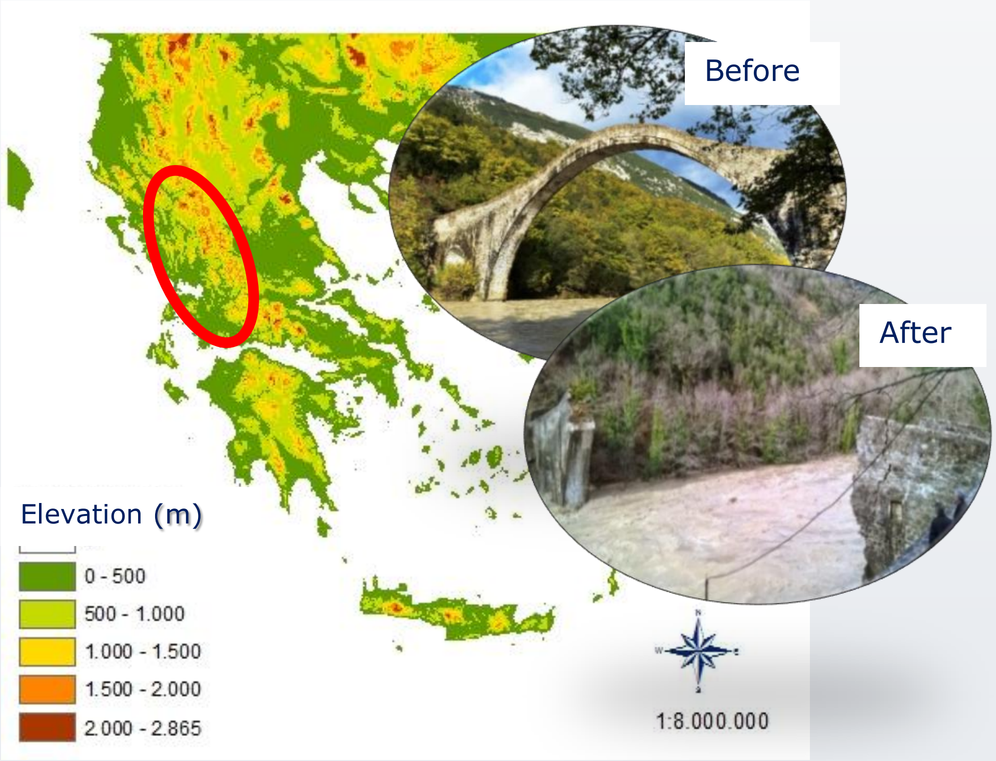
The bridge, which was one of the most impressive examples of Greek popular architecture, collapsed on 1 February 2015.
A flash flood caused by heavy rainfall caused the Arachthos River to rip the bridge's foundations from the riverbanks leading the central section of the bridge to collapse and be washed away.
The reconstruction is in progress

Source: https://en.wikipedia.org/wiki/Plaka_Bridge

Stochastic forecasts and extreme weather events.

The case study of intense and devastating rains over NW Greece during 30/1-1/2/2015 - Skrimizeas P. and A. Papakrivou - Using ECMWF's Forecasts (UEF) Workshop, ECMWF, Reading UK, 8-10/6/2015.

In 2015 and during the January 30 to February 1 period, the extended territory of Arta (NW Greece) experienced intense and devastating rains which caused huge disasters. But nor floods or landslides or crop damage or evacuations of villages caused so much anger and sadness as much as the collapse of the historic bridge of Plaka in Tzoumerka Mountains.



In this work, we test the effectiveness of the ECMWF stochastic weather forecasts and demonstrate their utility in decision-making, under the supervision of an experienced weather forecaster. To do so, we use as case study the region of Arta in northwest Greece, which experienced intense and devastating rains during the period January 30 - February 1 2015.

Probabilistic approach (ensemble forecasts)

The probability of the 12hr accumulated precipitation to exceed 50mm, are thought to be a useful tool in the phase of preparedness. In addition, considering an apparent increase of the region vulnerability, due to the significant rainfall observed during the previous days, we decided the parallel use of charts with the probability of the 12hr accumulated precipitation to exceed 30mm, a significant lower height. Using ecCharts, we synthesized forecasting maps showing the probability of the 12hr accumulated precipitation to exceed the defined thresholds (three runs: 30/01 00UTC, 30/01 12UTC, 31/01 00UTC).

	P(%) > 30mm			P(%) > 50mm		
	Time before the event					
Forecast valid	36hr	24hr	12hr	36hr	24hr	12hr
31/1- 18UTC	35-65	65-95	100	0-35	0-35	0-35
31/1- 21UTC	65-95	100	100	35-65	0-35	35-65
1/2- 00UTC	100	100	100	35-65	35-65	65-95
1/2- 03UTC	100	100	100	65-95	65-95	100
1/2- 06UTC	100	100	100	35-65	35-65	65-95
1/2- 09UTC	65-95	100	100	35-65	35-65	35-65
1/2- 12UTC	65-95	65-95	65-95	0-35	0-35	0-35
run based on	30/00UTC	30/12UTC	31/00UTC	30/00UTC	30/12UTC	31/00UTC

e.g. Run 30/01 1200 UTC

65-95% chance the 12hr accumulated precipitation (31/01 06UTC - 31/01 18UTC) to exceed 30mm, in the region of interest.

0-35% chance the 12hr accumulated precipitation (31/01 06UTC - 31/01 18UTC) to exceed 50mm, in the region of interest.

This information was operationally available about 24 hours before the event to be completed.

The crucial twelve hours: 31/1 15UTC – 01/02 03UTC

For this time period, the maps on the next slide show the spatial distribution of the probabilities for the three consecutive runs (30/00UTC-30/12UTC-31/00UTC). The following parameters are evident:

a. the spatial consistency
b. the certainty for exceeding the 30mm threshold, in all three runs, in the area of interest
c. the significant probability for exceeding the 50mm threshold in the first two runs turns to certainty in the last one

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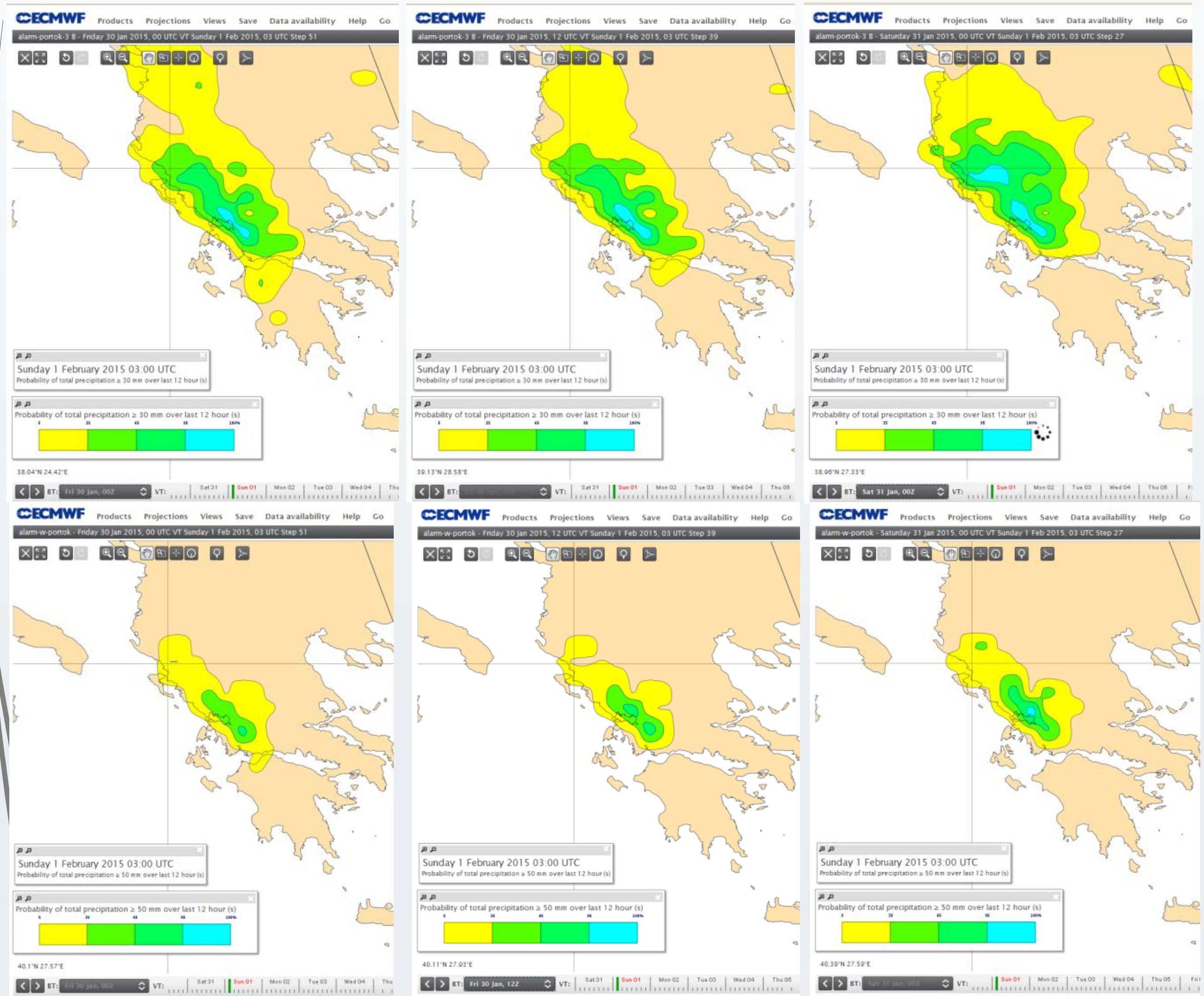
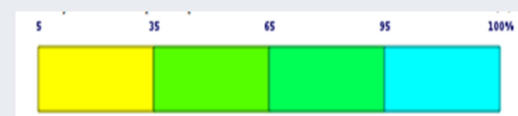
Probabilistic approach (ensemble forecasts)



Spatial distribution % chance the 12hr accumulated precipitation:

- to exceed 30mm, in the region of interest (Up)
- to exceed 50mm, in the region of interest (Down)



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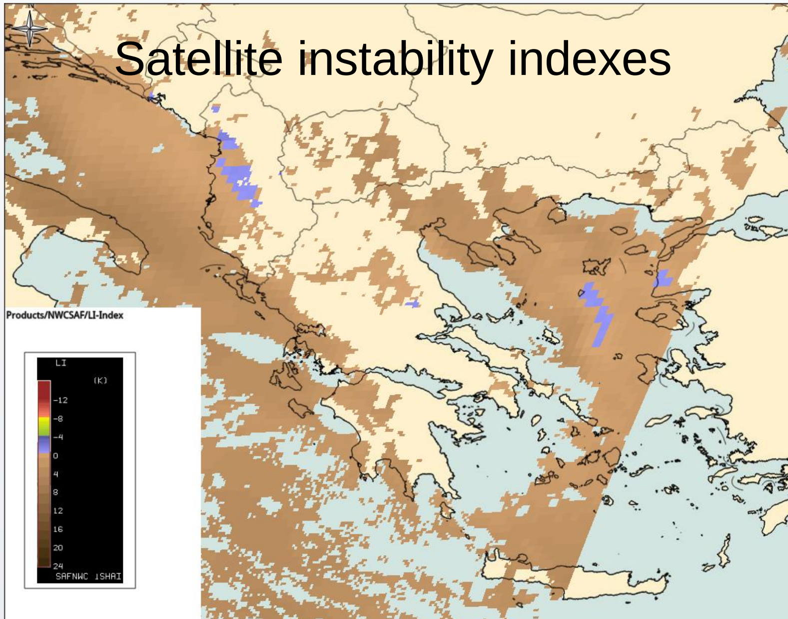
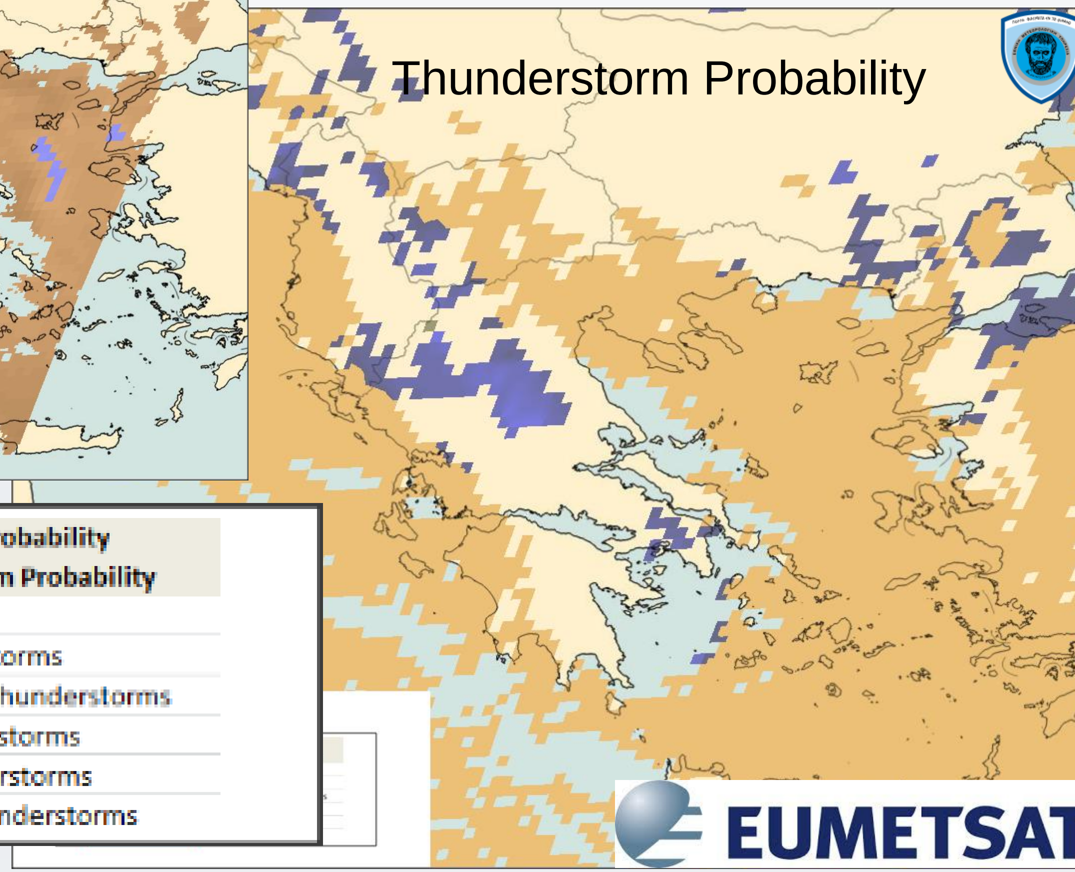
Weather Forecasting - Extreme Weather Events

Weather Forecasting - Extreme Weather Events

New products for **accurate** forecasts.





K-index values vs. Thunderstorm Probability	
K-index value [°C]	Thunderstorm Probability
Less than 20	None
20 to 25	Isolated thunderstorms
26 to 30	Widely scattered thunderstorms
31 to 35	Scattered thunderstorms
36 to 40	Numerous thunderstorms
Above 40	Multitudinous thunderstorms

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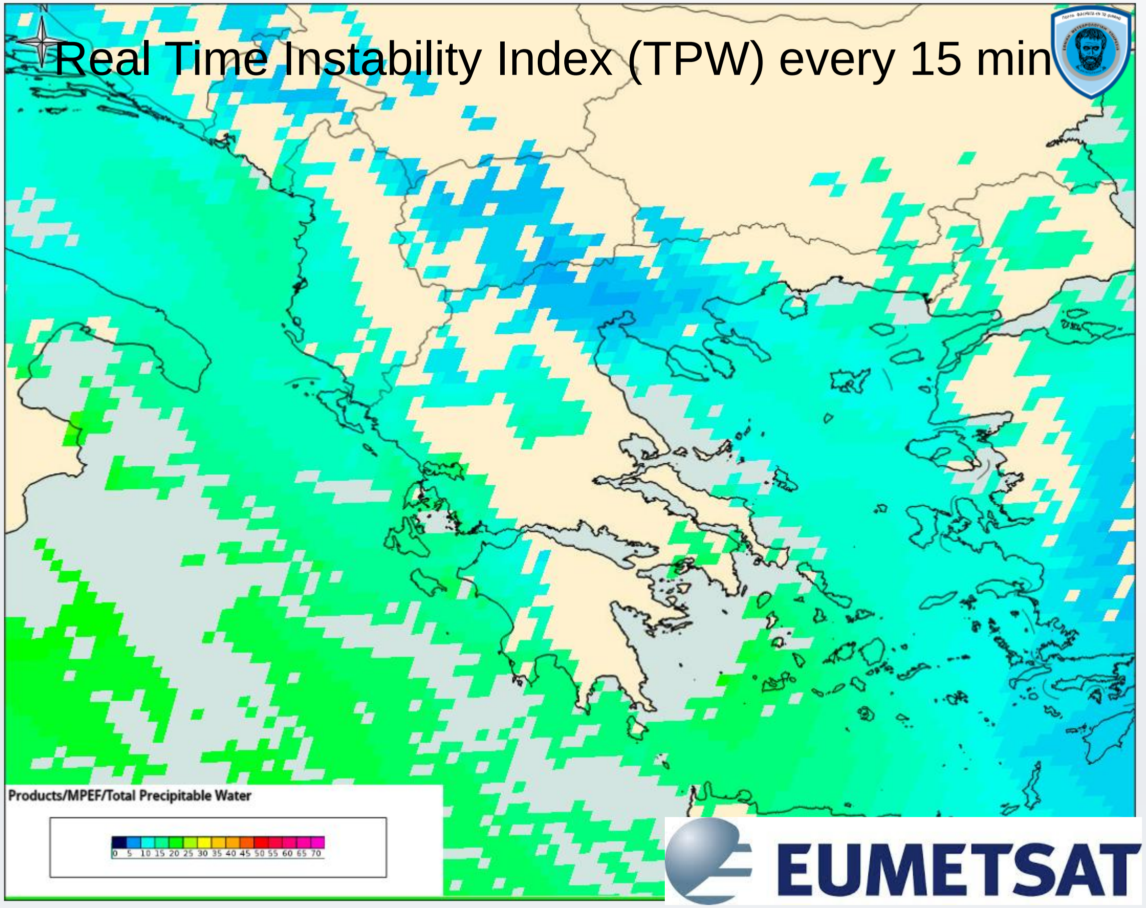
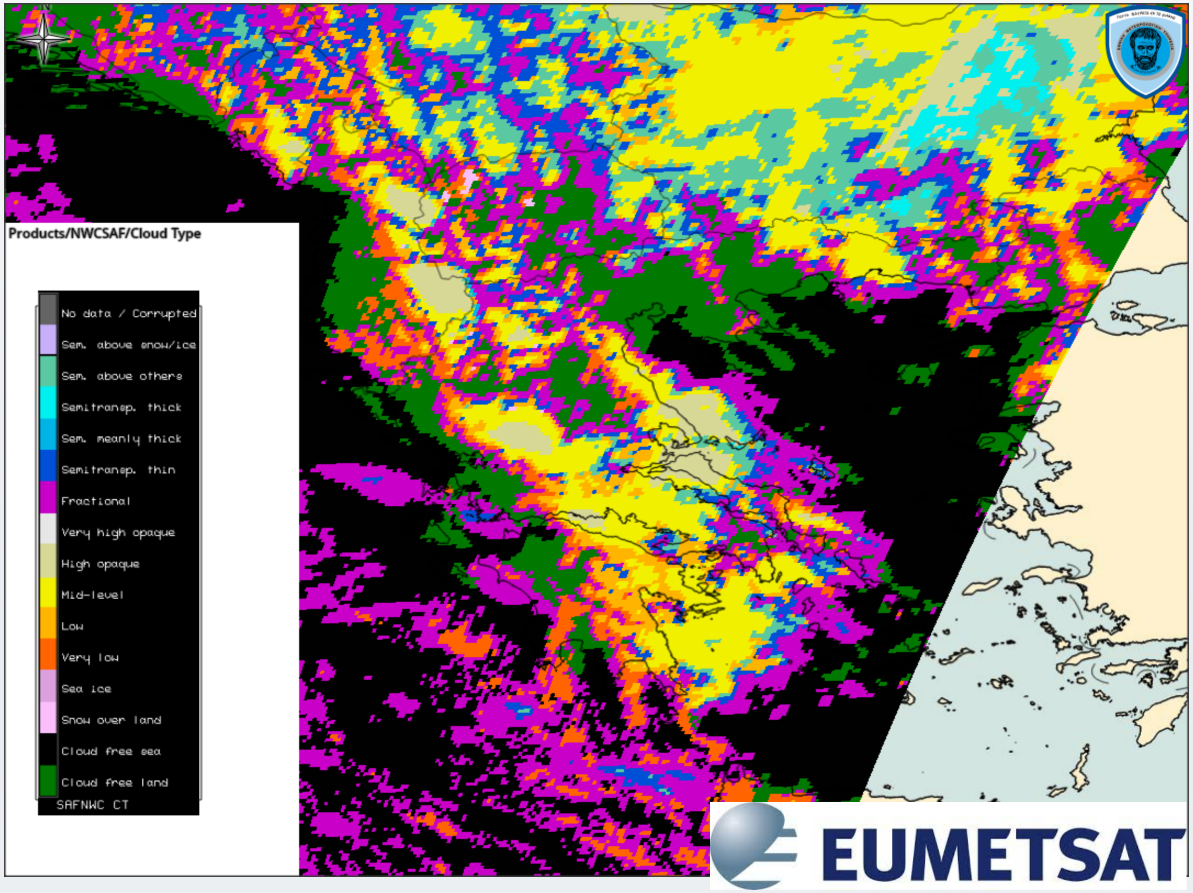


Weather Forecasting - Extreme Weather Events

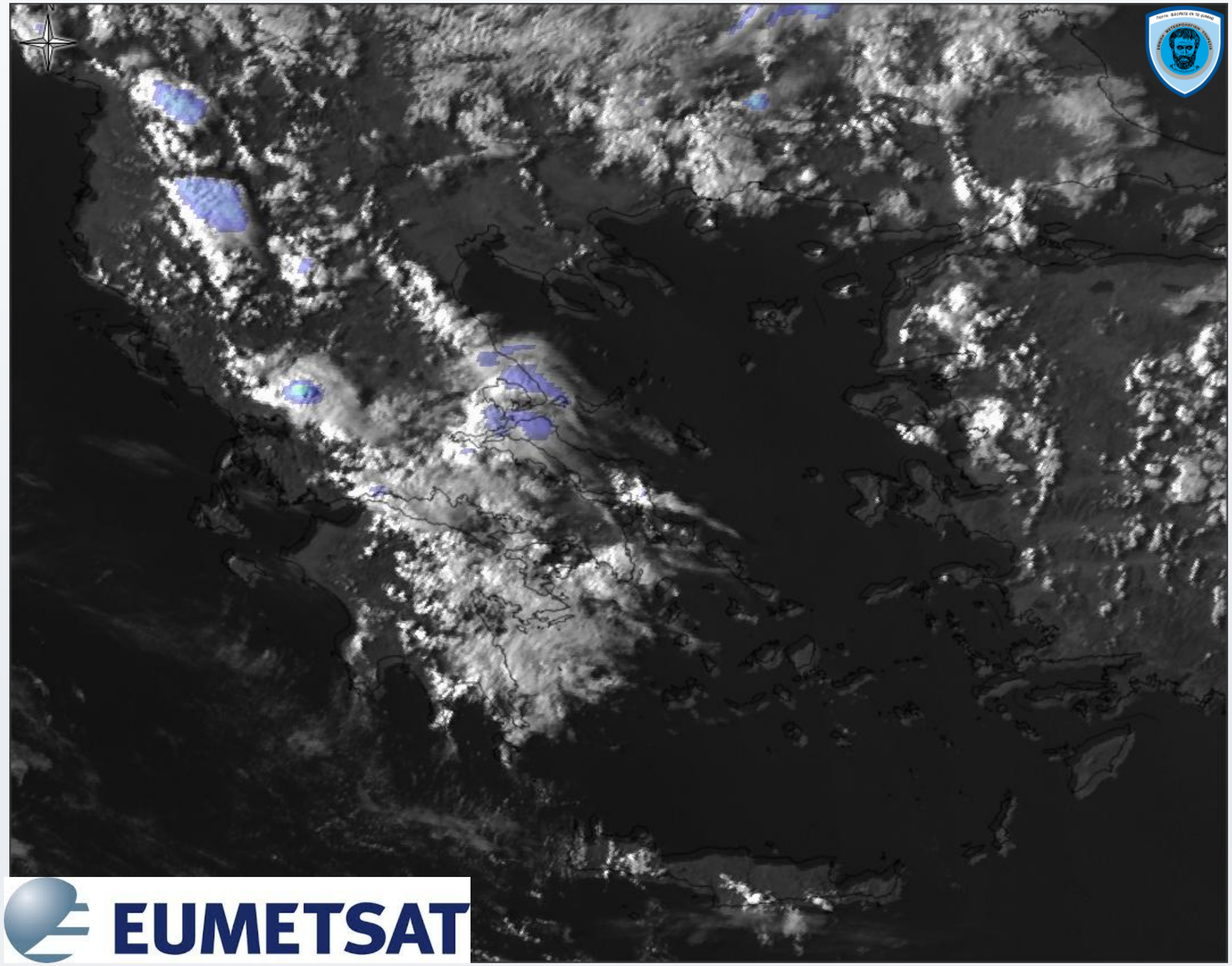
New products for **accurate** forecasts.

Real Time Cloud Type every 15 min



Weather Forecasting - Extreme Weather Events

Improved satellite images



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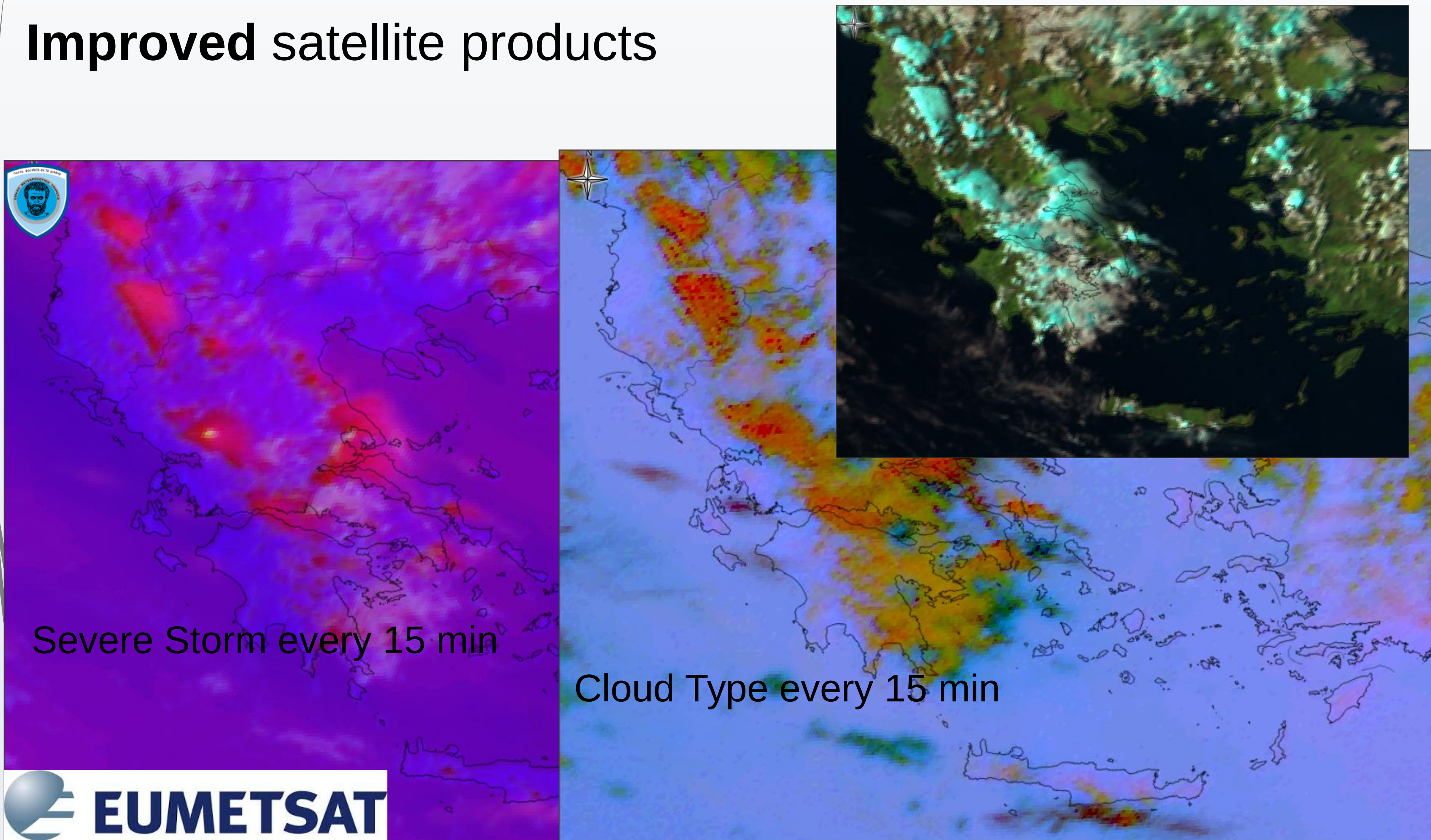


Satellite Tools for Climate Monitoring

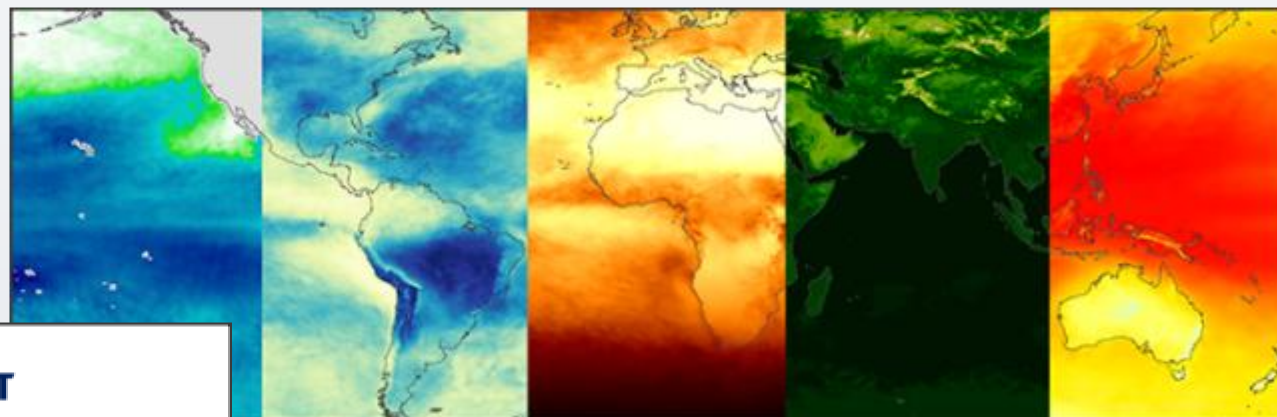
New **satellite** based products to monitoring the climate

The **Satellite Application Facility on Climate Monitoring** develops high-quality satellite-derived products of the global energy & water cycle and related sustained services in support to understand our climate.

EUMETSAT
CM SAF
CLIMATE MONITORING

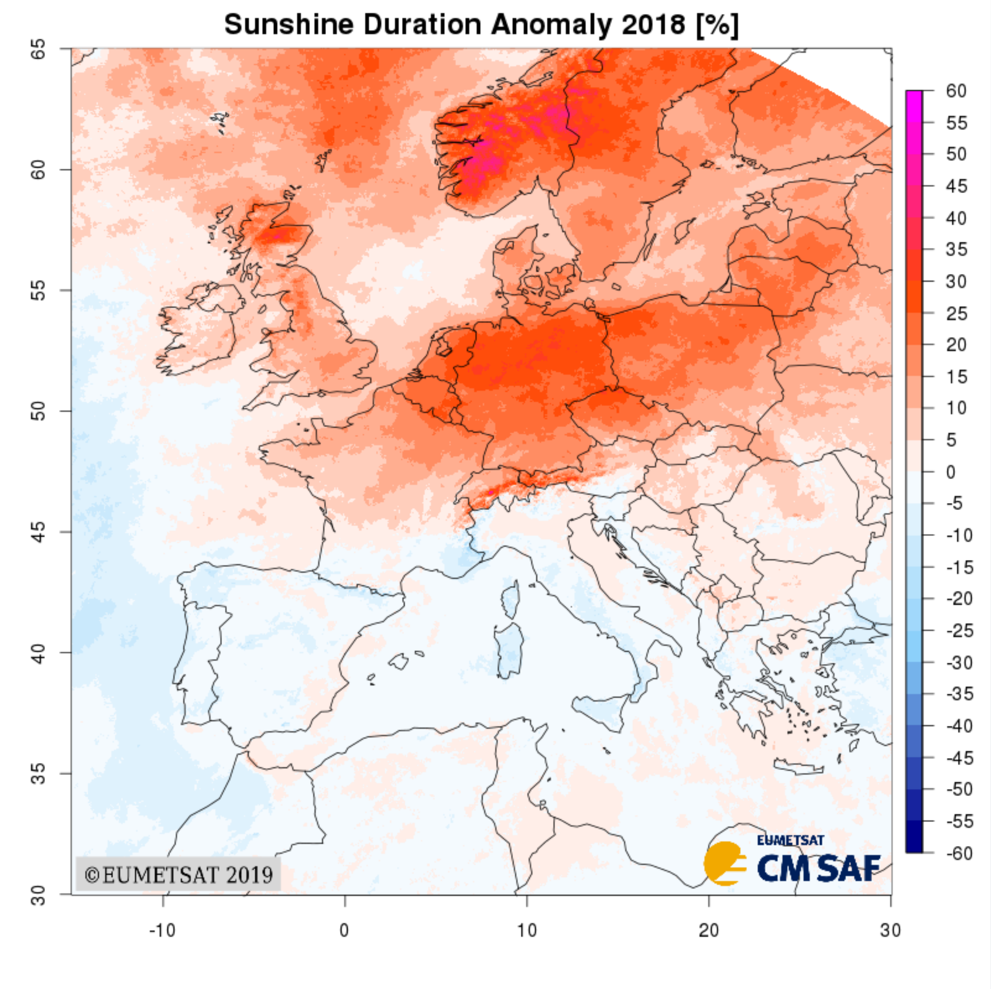
Satellite Tools for Climate Monitoring

CM SAF products describe important components of the Earth's Energy budget and its water cycle, i.e. water vapour, cloud properties, precipitation and surface radiation components.



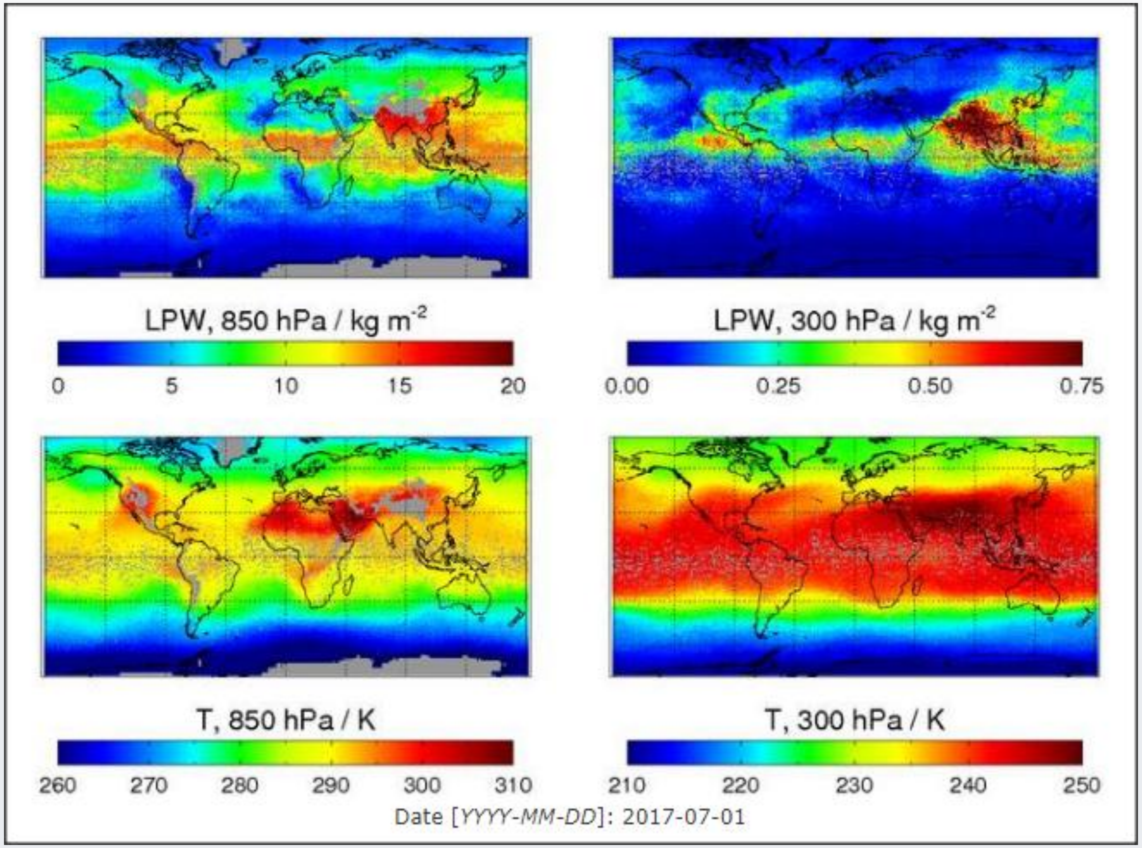
EUMETSAT
CM SAF
CLIMATE MONITORING

Satellite Tools for Climate Monitoring



Satellite Tools for Climate Monitoring

Temperature and specific humidity



Data source: Vertically integrated water vapour from ATOVS (MetOp – NOAA Satellites)