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Article

GIS-Based Dashboards as Advanced Geospatial Applications for Climate Change Education and Teaching the Future

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Abstract: ArcGIS Dashboard technology allows for the integration and visualization of various maps, charts, and indicators within a single interface, using databases underneath a geographic information system. The two dashboards of the European project Teaching the Future address the dual objective of (i) cartographically displaying the evolution in four phases of climate change data experienced across the entire planet from 1954 to 2021 in vectorial cells measuring one degree of latitude by one degree of longitude and (ii) spatially representing three scenarios (low, medium, and high greenhouse gas emissions) up to the year 2100, showing potential temperature increases in those same cells. In addition to the maps, the different data and charts contribute to the understanding of anomalies relative to the average, the global increase in each selected area by zooming in on the map, and the evolution of both observed and projected data. Both dashboards represent an accurate and reliable treatment of the data, as well as a cartographic expression that is easy for map readers to understand, making them powerful resources for teaching climate change at any educational level, whether in higher education or schools and for a general audience.

Keywords: ArcGIS Dashboard; geospatial competences; geographical education; climate change

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1. Introduction

Educators and scientists are deeply concerned about the climate crisis. Teaching the Future (https://teachingthefuture.eu) is a European Union-funded project aimed at enhancing climate change education, embedded within the European Commission's "Education for Climate Coalition" as a flagship initiative of the European Education Area and a horizontal priority in the Erasmus Plus program to develop green competences for lifelong learning [1]. This project, led by the EUROGEO (European Association of Geographers) [2], seeks to provide easy access to scientific data and climate information through a comprehensive climate data dashboard and maps. These tools support a teacher training program designed to disseminate effective knowledge on climate education. The project also focuses on equipping young people with the skills to work with high-quality scientific data and reliable information sources to address the challenges posed by climate change. The skills are related to the EU competence frameworks DigComp (skills in data literacy, communication, content creation, safety, and problem-solving) and the GreenComp (skills in embodying sustainability values, embracing complexity, envisioning sustainable futures, and acting for sustainability). Consequently, these maps become powerful resources for promoting active citizenship, encouraging young people to engage with their local communities using inquiry-based approaches to citizen science to examine and tackle climate issues.

The project is grounded in an analysis of secondary education curricula across several European countries, with a particular focus on geography. This analysis highlights both the deficiencies and the potential of climate education within national standards. As a result, an online climate data dashboard, primarily composed of maps, has been developed as a teaching resource for educators in both school and higher education. This resource adopts an interdisciplinary approach that extends beyond geographical science. The maps are based on open data initiatives, utilizing geospatial information from European sources, such as the European Environment Agency Climate Data Centre, the European Space Agency Climate Initiative, and the EU Open Data Portal. These resources can be further enriched with global datasets from organizations like NASA and the Intergovernmental Panel on Climate Change (IPCC).

Integrating these reliable data sources, accessible to the public and produced by leading scientists, into climate education represents a highly innovative approach. Currently, there is little to no awareness in most European schools of the availability of open data or related scientific resources, such as data visualization and presentation tools that are freely available through maps and dashboards. These tools have the potential to enhance education and lifelong learning at all levels, including school education, higher education, and adult education.

2. Climate Change Education with Geoinformation and Dashboards: Context

Climate change education is a topic of growing interest in scientific research [3], with nearly 1000 references currently available on the Web of Science related to this topic, many of them in geographic education or natural sciences education. However, very few of these bibliographic references explicitly mention the importance of maps and geoinformation as essential teaching resources for the instruction and learning of climate change. When mentioned, it is often indirectly, focusing on issues such as prior knowledge and misconceptions (what the student and teacher know), curricular content (what the student needs to know), teacher training (what the teacher needs to know), learning methods (particularly inquiry-based learning), the assessment of learning outcomes, and technological approaches through audiovisual resources and communication strategies that can foster comprehensive climate change education (knowing, doing, and being), as well as a personal and collective commitment to climate change adaptation and mitigation measures [4–8].

If references to maps are scarce, those maps and cartographic resources created with geospatial technologies and GIS are even rarer unless they are local case studies [9]. This contrasts with the recent dominance of geoinformation as an essential element for acquiring geographic and geospatial competencies in geographic education, both in school education and higher education [10–14], and particularly to achieve meaningful learning, spatial and geographical thinking, and powerful knowledge in geographical issues like climate change [15–20].

Some of the references that highlight the role of maps in climate change education showcase the learning opportunities provided by interactive maps and Story Maps [21,22] or the vast amount of information offered by raster maps generated with data from remote sensing for climate change education [23,24]. Other contributions also demonstrate the massive climate educational potential of geospatial information through MOOCs [25] or emphasize its contribution to education on the SDGs, one of which (number 13) focuses on climate action [26].

Finally, there are not many studies that analyze dashboards that include maps despite the fact that at the recent Esri User Conference 2024, the Governor of Minnesota, Tim

Walz, stated that the COVID-19 Map created by Johns Hopkins University using ArcGIS Dashboard technology has become the most viewed map in the history of geography. He made this statement with the agreement of his presenter, Esri President Jack Dangermond. The recent selection of Tim Walz as a candidate for Vice President of the United States in the 2024 elections, along with his self-description as a “GIS nerd”, has led to more discussion of this dashboard-based example in the international press than in academic circles.

In fact, the main references that analyze and highlight the cartographic power of maps included in dashboards are related to the COVID-19 Map [27–29] or other disciplines within geography, such as urban geography [30] or mobility [31]. In geographic education, some good teaching practices with dashboards and maps have also been published [2,32]. Two recent specific publications are relevant: one that cited climate as one of the topics for innovative instruction in geography using dashboards [33] and another that disseminates a specific example of ArcGIS Dashboard for data climate data visualization [34]. In this way, the climate dashboard developed in the *Teaching the Future project* aims to contribute to increasing mapping references in climate change education.

3. Materials and Methods

The design of the thematic maps and their time series, along with the accompanying charts, involved using various data sources and types depending on the variables analyzed and the time range. The initial stage included a quality control check of the original dataset to eliminate the most obvious errors, following the methodology previously implemented [35]. A paleoclimatic perspective was incorporated by comparing recent instrumental data with previously published proxy-based temperature reconstructions and future-modeled climate data layers based on representative concentration pathways (RCPs 2.6, 4.5, and 8.5). The climate projections are based on Representative Concentration Pathway (RCP)/Shared Socioeconomic Pathway (SSP) scenarios. The ensemble (and some single-model) datasets were harmonized using regular latitude–longitude grids with horizontal resolutions of 2° (CMIP5), 1° (CMIP6), 0.5° (ORAS5), 0.25° (CORDEX-CORE and ERA5), 0.125° (CORDEX-EUR-11, E-OBS), and 0.1° (ERA5-Land).

3.1. Copernicus Data Source

The use of dashboards alongside spatial and cartographic information offers the unique advantage of enabling interactive and dynamic visualization of geospatial data. Users can interact with maps and charts by zooming in and out, filtering, and exploring the data in various ways. These dashboards are accessible from any device with an internet connection, allowing users to access information from anywhere. However, a notable limitation is that ArcGIS Dashboards have a limited capacity to handle raster data natively. Although raster data formats, such as GeoTIFF, can be used as background or reference layers, analyzing and interacting directly with these data often requires conversion to vector formats (shapefile and feature class) for better integration and functionality within the dashboard.

For this reason, the data obtained from the Copernicus Climate Change Service in NetCDF format [36–38], which were used to develop the climate dashboard for the Teaching the Future project, required conversion through Python, followed by processing in ArcGIS Pro and ArcGIS Online, to be integrated into the ArcGIS Dashboard. Along with the spatial dimension, the creation of this climate dashboard has allowed the cartographic visualization of the temporal variable, as expressed in Table 1, which details the metadata used in the spatial modeling of the data.

Table 1. Data source for Teaching the Future climate dashboard.

	Study Area	Typology of Climate Data	Spatial Resolution	Temporary Coverage
1	World	Observed average annual temperatures	1° latitude and longitude	1954–2019
2	World	Average annual temperatures modeled according to RCP scenarios	1° latitude and longitude	2006–2100
3	Europe	Observed average annual temperatures (average, maximum, and minimum) and rainfall	0.2° latitude and Longitude	1950–2021

Source: Copernicus Climate Change Service (2018).

The temperature in both the observed and projected dashboards is generated at 2 m above the surface. On the other hand, the precipitation data were provided in the datasets as mean precipitation flux (kg m^{-2} s^{-1}). This is the amount of water per unit area and time, and it was converted to annual rainfall (mm/year).

In this paper, 1 kg $m^{-2}s^{-1}$ is equivalent to 1 mm/s^1 because 1 kg m^{-2} corresponds to 1 mm of water depth. As a year has 31,536,000 s, the precipitation flux value should be multiplied by this constant.

Precipitation (mm/year) = Precipitation flux (kg $m^{-2}s^{-1}$) $\times$ 31,536,000

The ensemble (and some single-model) datasets were harmonized using regular latitude–longitude grids with horizontal resolutions of 2° (CMIP5), 1° (CMIP6), 0.5° (ORAS5), 0.25° (CORDEX-CORE and ERA5), 0.125° (CORDEX-EUR-11 and E-OBS), and 0.1° (ERA5-Land).

3.2. Dashboard Generation Process

Teaching the Future consists of six different dashboards. However, the cartographic and methodological process for designing these dashboards follows the same phases and procedures, which include (i) processing the raw NetCDF data with Python, (ii) further processing with ArcGIS Pro, and (iii) the design of climate maps and dashboards through various ArcGIS Online applications (Figure 1).

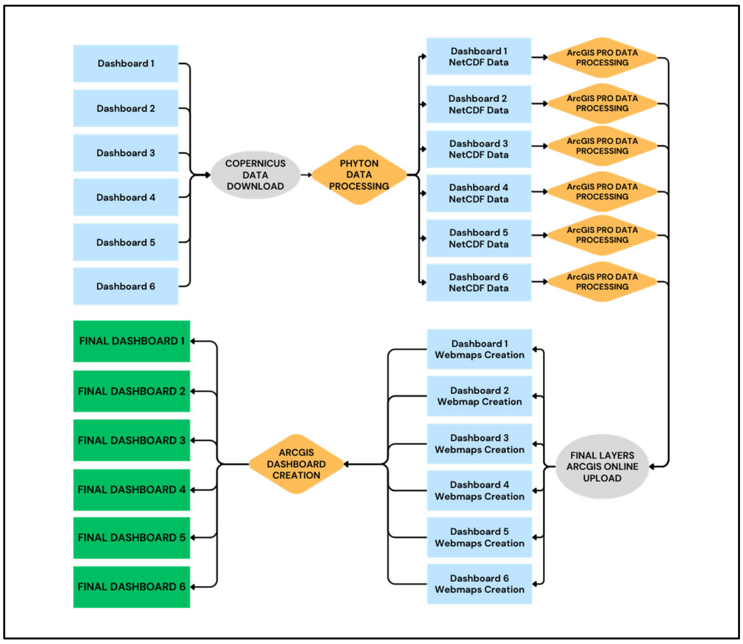

Figure 1. From NetCDF data to ArcGIS Dashboard.

3.3. Data Processing with Python

The data, downloaded from the official Copernicus portal of the EU (Climate Data Store), were processed using Python to consolidate the vast amount of data from each dataset into a single NetCDF file. This was necessary because the nature and arrangement of the data—sometimes daily or even at smaller temporal scales, other times monthly or annually—made them impossible to handle due to their size and volume. The Python script in Figure 2 was used for this process.

```
import os
import numpy as np
import xarray as xr
import rioxarray as rio
from netCDF4 import Dataset
def nc_to_geotiff(input_nc: str, output_tiff: str = None) -> str:
    """ Converts a NetCDF file to GeoTIFF by computing the average of all
relevant layers.

    Parameters:
        input_nc (str): Path to the input NetCDF file.
        output_tiff (str, optional): Path to the output GeoTIFF file. If
not provided,
                             the input filename will be used with a
.tif extension.
        Returns:
        str: 'ok' if the conversion was successful, 'error' otherwise.
    """    variables = ['tas', 'tasmax', 'tasmin', 'tasavg', 'tassum',
'pr',            'prmin', 'prmax', 'pravg', 'prsum', 'rr',          'rrmin',
'rrmax', 'rravg', 'rrsum']

    try:
        with Dataset(input_nc, mode='r') as nc:
            nc.set_auto_mask(False)

            for var in variables:
                if var in nc.variables:
              data = nc[var][:]
              avg_data = np.mean(data, axis=0)

                    lat = nc['lat'][:]
                    lon = nc['lon'][:]

                    data_xr = xr.DataArray(avg_data, coords={'y': lat, 'x':
lon}, dims=["y", "x"])
                                  output_tiff = output_tiff or
f"{os.path.splitext(input_nc)[0]}.tif"
                    data_xr.rio.to_raster(output_tiff)
    return 'ok'
    except Exception as e:
        print(f"Error processing {input_nc}: {e}")
        return 'error'
        return 'error'
def process_nc_directory(directory: str):
        Processes all NetCDF files in a directory and converts them to Geo-
TIFF.
        Parameters:
        directory (str): Path to the directory containing NetCDF files.
       for filename in os.listdir(directory):
       if filename.endswith(".nc"):
            input_path = os.path.join(directory, filename)
            print(f"Processing: {input_path}")
            result = nc_to_geotiff(input_path)
            print(f"Result: {result}")
# Input directory configuration
nc_directory = r'C:/Users/ ' process_nc_directory(nc_direc-
tory)
```

Figure 2. Python script.

The script's objective is to unify multiple NetCDF files from a directory into a single *xarray* data structure and perform annual resampling. From this resampling, several statistics are derived: mean, maximum, minimum, standard deviation, median, sum, and product. Additionally, given that months and leap years have different durations, the script also calculates the time-weighted average and weighted sum.

The script is designed to work with dimensions set as indexes, as long as they are numeric (coordinates) or date-type values. The statistics are calculated for all numeric columns, excluding the indexes, to avoid issues related to variables with different names. Each derived statistic is saved in a separate file to facilitate management and take advantage of Esri software's visualization options. This allows the sequence of data to be visualized using the "play" functionality in ArcGIS Pro.

Running the script automates the data preparation work, which is typically time-consuming and labor-intensive. Although developing the script required significant effort, testing has proven its effectiveness. Once opened, the NetCDF files can be handled, like a *pandas dataframe* or an *xarray*, making them easier to edit and analyze and enabling the preparation of more complex functions or simulations.

3.4. From ArcGIS Pro to ArcGIS Online

Once the necessary processing of the Copernicus climate files was completed using Python (with NetCDF data homogenized to annual temporal scales), the data were processed using ArcGIS Pro, following the cartographic design shown in Figure 3. One of the peculiarities of ArcGIS Online Dashboards is that they only accept spatial data in a shapefile format, relegating raster data (such as TIFF files) to visual support elements, similar to base maps.

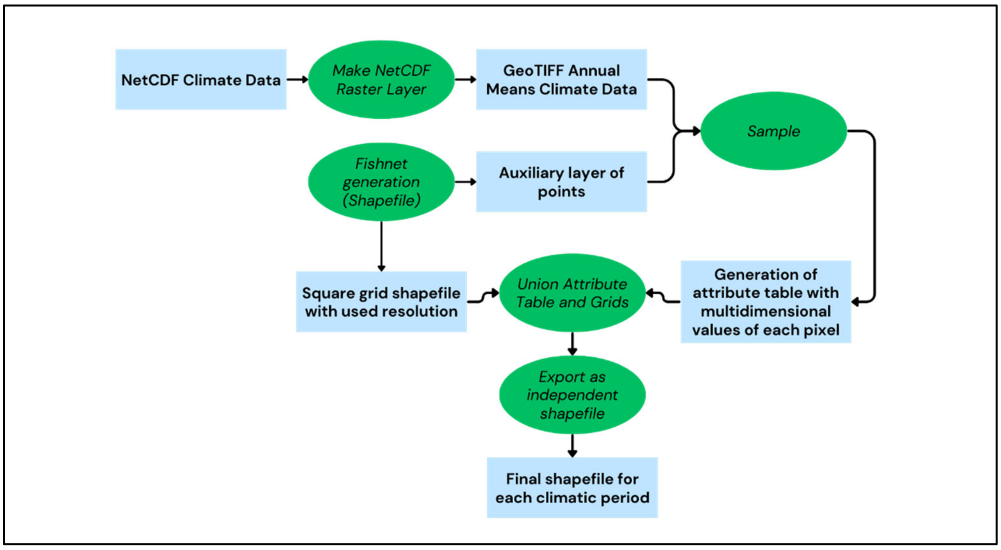

Figure 3. Shapefile creation process.

Therefore, with ArcGIS Pro, prior to uploading the information to ArcGIS Online, the data were processed to generate vector format layers (shapefiles). Additionally, ArcGIS Pro was used to create extra thematic information from the raw data, such as calculating the means of the standard 30-year climatic periods (1961–1990; 1971–2000; 1981–2010; and 1991–2020) or the annual thermal or precipitation anomalies relative to the reference climatic period (1961–1990). The same approach was applied to the future modeled climate data layers based on Representative Concentration Pathways (RCPs 2.6, 4.5, and 8.5). These RCPs are climate change scenarios that project future greenhouse gas concentrations. They describe future greenhouse gas concentrations and have been formally adopted by the IPCC.

This thorough process ensured that the data were appropriately formatted and enhanced for effective visualization and analysis within the ArcGIS Online Dashboard environment.

4. Results

Once all the adjustments and processing of each layer to be used in the dashboards were completed and uploaded to the ArcGIS Online servers, the final process of creating the dashboards was divided into two phases: (i) the design of the web maps to be included in each dashboard and (ii) the final generation of each dashboard with its widgets and unique elements.

Regarding the creation of each web map, decisions were made on the value range for the legend and color scale and the values and type of cartographic representation, as well as other aesthetic values and parameters typical of thematic cartography [39]. Additionally, unlike conventional cartographic elements, being dynamic maps, other utilities were developed, such as pop-ups with extra thematic information within each cell. These pop-ups present elements from the attribute table in a more user-friendly way for the intended audience of the dashboards, using different fonts, colors, or graphics instead of standard cells. Once the cartography was processed from the ArcGIS online server, the different dashboards were generated.

In total, six dashboards were carried out, as shown in Figure 4: two main ones that cover the entire world and four complementary dashboards that map climate change in Europe with greater detail, which are all available at the webpage of the project https://teachingthefuture.eu/climate-dashboards/ (accessed on 14 February 2025).

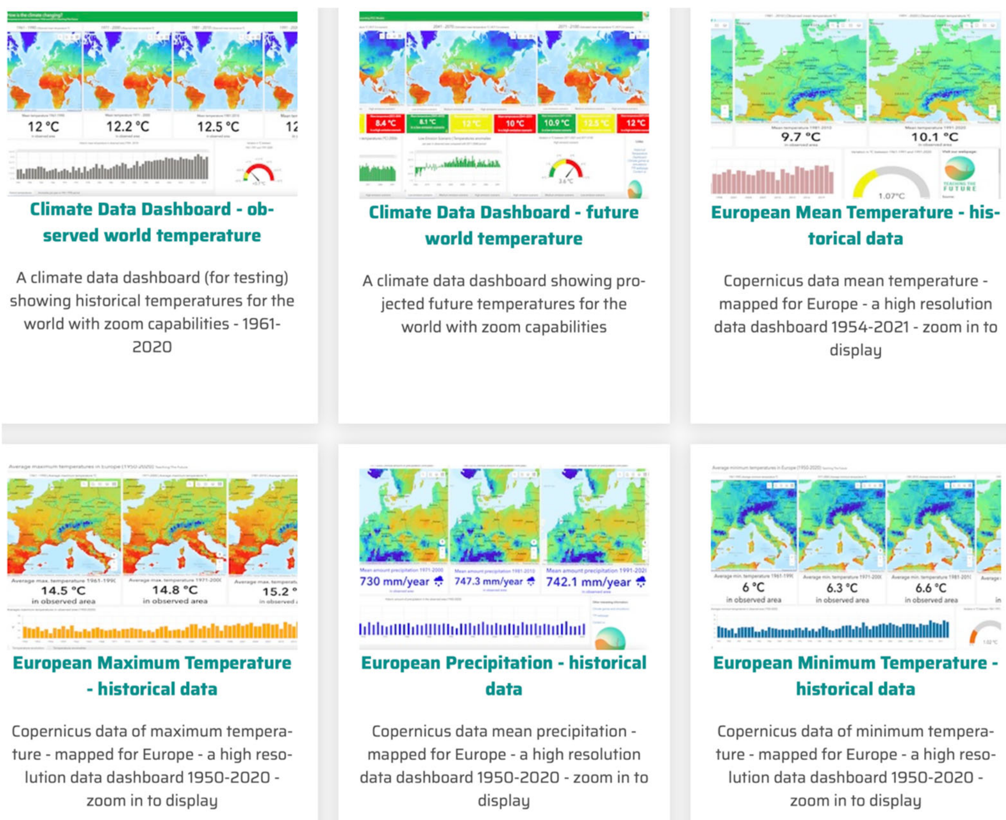

Figure 4. Teaching the Future climate dashboards.

- Climate data dashboard: observed mean temperature, world, 1961;
- Climate data dashboard: estimated mean temperature, world, 2011–2100;

- Climate data dashboard: observed mean temperature, Europe, 1961–2020;
- Climate data dashboard: observed average maximum temperature, Europe, 1961–2020;
- Climate data dashboard: observed average minimum temperature, Europe, 1961–2020;
- Climate data dashboard: observed annual precipitations, Europe, 1961–2020.

There are five dashboards featuring observed data, each consisting of four maps, one for each standard 30-year climatic period (1961–1990, 1971–2000, 1981–2010, and 1991–2020). One dashboard for projected future data consists of three maps corresponding to the three mentioned IPCC RCP scenarios (2.6, 4.5, and 8.5) for the periods 2011–2040, 2041–2070, and 2070–2100, making a total of twenty-three maps.

These maps include pop-up elements, where clicking on a specific area of the map provides detailed information about that area, such as the average temperature for the observed period, a chart showing the variation in annual average temperatures across periods, and the thermal variation between periods (Figure 5). Additionally, the dashboards offer features like a geographic search tool, spatial bookmarks, a legend, and the ability to toggle layers on and off (Figure 6).

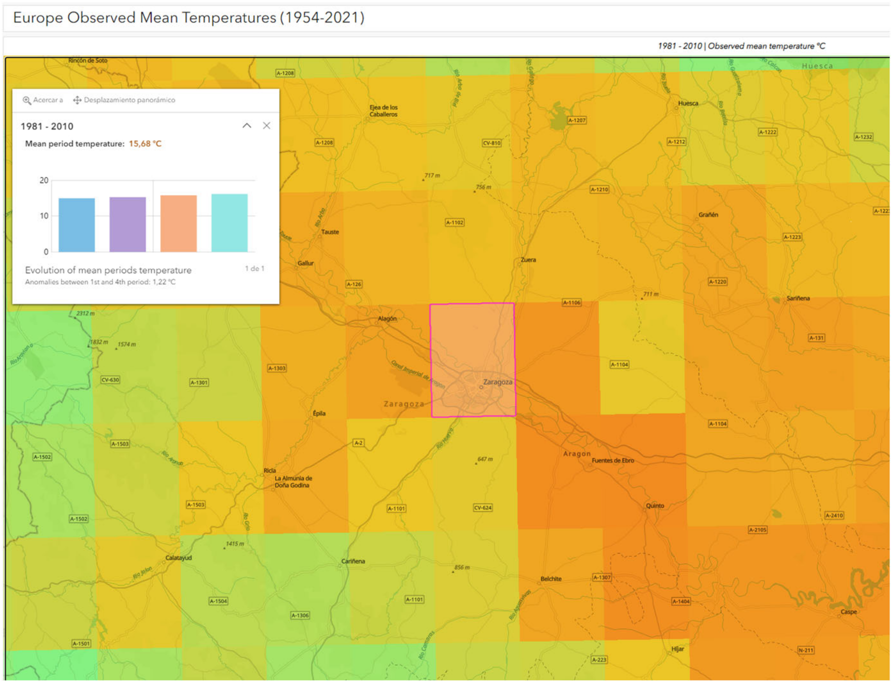

Figure 5. Detailed data of a cell raster with pop-up window: average temperature and chart.

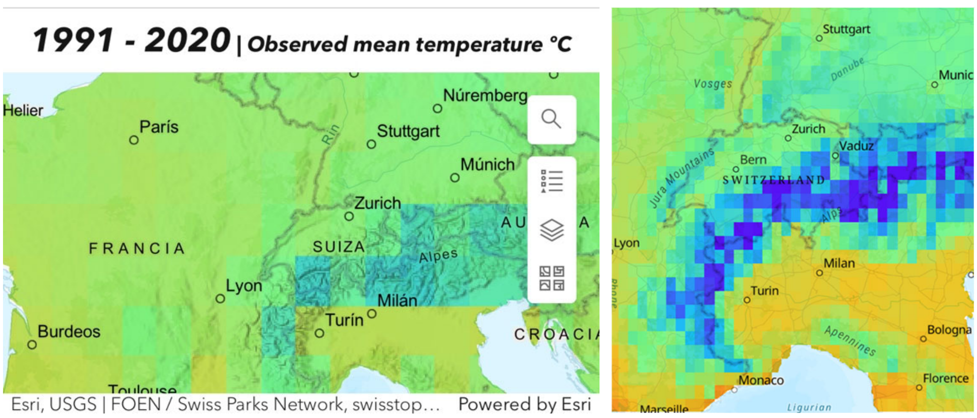

Figure 6. Difference in raster cell size between the world map (**left**) and the European map (**right**).

Additionally, each dashboard's set of maps includes a three-part complement, thus increasing the interactivity of the map reader with the map and the graphical and numerical spatial information:

- Indicators: The observed annual mean temperature for each period within the observed area;
- Calipers: They display the thermal variation (°C) between the 1961–1991 climate period and the 1991–2020 climate period. Depending on the degree of temperature increase, it is displayed using a traffic light system (green, yellow, and red);
- Charts: Two graphs are provided in each dashboard, according to the maps. These charts show the annual evolution of mean temperatures per year, as well as the thermal anomalies for each year relative to the reference climate period. The data observed in the charts (Figure 7), dependent on the observable scale, can be downloaded as a ".csv" file in accordance with the interoperability requirements of the project.

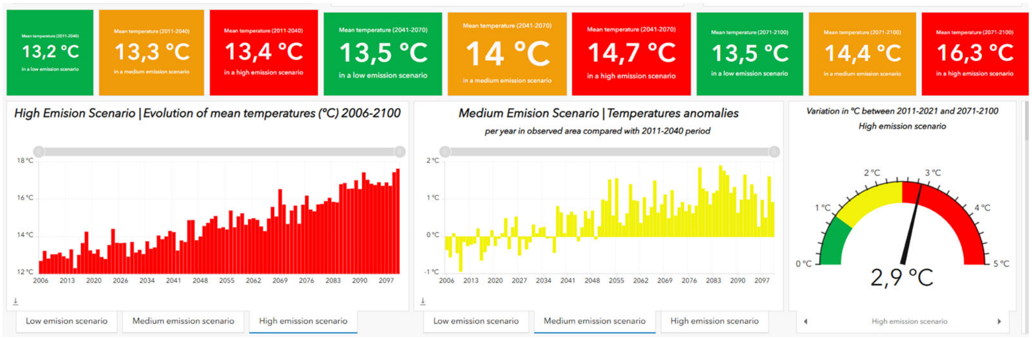

Figure 7. Data and charts associated with the maps in the climate dashboard.

5. Discussion

Once the six dashboards were developed, the discussion focused on validating these cartographic resources based on geoinformation as educational materials that effectively contribute to climate education in real school contexts. This discussion has been extensively addressed in the report on curriculum and digital teaching resources, which was developed within the framework of the *Teaching the Future* project, as well as in some of the previously cited references [2–5,14,16,33,34] and others [40,41], which have highlighted the benefits of Web_GIS in addressing key challenges—such as climate education—in geography education while also emphasizing essential strategies to develop geospatial, digital, and sustainability-related skills. This debate has been further reinforced by the recent publication of the *Handbook of Geography Education* [42], which, in several of its chapters, highlights the comparative advantage of GIS (and even GIS dashboards) over other climate education studies or resources.

Following the previous discussion, a second debate arises regarding the selection of the best approach to integrate project-based learning with problem-based learning in geospatial education. In this regard, the academic literature [43] concludes that the geo-inquiry approach is capable of integrating three fundamental dimensions for meaningful learning: geo-instructional, geo-progressions, and geo-capabilities.

As a result, the dashboards have led to the development of a lesson plan on climate change and a proposed geo-inquiry scaffolded in five steps—engage → explore → explain → elaborate → evaluate—following the 5E instructional model [44] for science education. The materials, alongside others, like climate simulations, to implement experiential learning activities, are available on the project's website (https://teachingthefuture.eu/module-4/ (accessed on 14 February 2025)) and have been widely disseminated through geography teacher training programs in secondary education, as well as in 53 schools across Europe, particularly in Belgium, Spain, Greece, and Italy.

6. Concluding Remarks

This study demonstrates the value of climate dashboards as a powerful educational resource for climate change teaching and learning. By integrating spatial and temporal data visualization, the *Teaching the Future* climate dashboards provide an interactive, data-driven approach to understanding climate change at multiple scales. These tools bridge the gap between scientific climate data and classroom instruction, making complex climate trends more accessible and fostering critical thinking in students and the general public.

Climate action, as outlined in SDG 13—and specifically target 13.3, which promotes climate education, awareness-raising, and the enhancement of human and institutional capacity for climate change mitigation, adaptation, impact reduction, and early warning—is a key focus aligned with the UN Sustainable Development Goals. This initiative supports countries in adopting the Paris Agreement, with the goal of limiting global temperature rise to well below 2 degrees Celsius and addressing the global impacts, whether they be environmental, economic, or social.

The primary goal of creating this climate dashboard was to develop a cartographic tool that simplifies the understanding of a complex phenomenon with multiple consequences. To achieve this, the visual representation of climatic phenomena, particularly the global increase in temperatures, has been crucial in the design of the six dashboards, as well as in each individual map that they comprise. Dashboards are a visual approach that effectively displays climate data, as they clearly communicate information and aid in interpreting spatial climate data.

The dashboards leverage high-quality, authoritative datasets from the European Commission's Copernicus Program and the IPCC, ensuring reliability and scientific rigor. Consequently, the climate dashboard is designed to facilitate climate education using accurate and reliable information not based on biases or fake information that often prevail in denialist or alarmist discourses on climate change. Their user-friendly design facilitates engagement with climate change data, empowering educators, students, and citizens to explore historical trends and future projections based on different emission scenarios. This approach not only strengthens spatial literacy and geographical thinking but also combats misinformation by promoting data-backed climate education.

It offers a scientific perspective grounded in spatial data, which can be replicated in citizen science exercises due to its ease of reading, understanding, and use by school students, university students, and the general public alike. This is further enhanced by the dashboard's combination of spatial and temporal information, observed data with scientifically based forecasts, easy access, and interactive features, allowing for data downloads, information reuse, and map customization. Specifically, it offers cartography that is both local and global, as the zoom-in/out function enables users to understand the phenomenon of climate change at a local to global scale.

In conclusion, the climate dashboard is the primary tool of the European project *Teaching the Future*, which aims to promote climate education and strengthen "green education" as one of the prominent focus areas of the European Education Area. This European Union initiative fosters collaboration between Member States and stakeholders to build more resilient and inclusive national education systems for lifelong learning. Green education seeks to develop green competencies in students, and the climate dashboard aims to implement a comprehensive instructional model based on geographical knowledge, spatial thinking skills, and, most importantly, spatial citizenship, raising awareness of the challenges of global climate change. The *Teaching the Future* climate dashboard encourages its users to move from knowledge to individual and collective action, with measures that contribute to climate change mitigation, adaptation, and impact reduction, thus promoting a powerful resource for powerful and transformative involvement.

Our future work involves promoting teacher training courses and instructional materials based on geospatial inquiry-based learning using the climate dashboard in combination with other resources, such as local case studies, national policies, and global debates on climate change challenges. The open-access user interface, interdisciplinary approach, and transnational nature of this project aim to enhance the impact of these six climate dashboards and maps—which have so far exceeded 13,000 views—in schools, universities, and among stakeholders engaged in climate change education. The EUROGEO's role in the Advisory Group of the European Commission's *Education for Climate Coalition*, as a participatory community supporting teaching and learning for the green transition, will also contribute to this effort.

Additionally, our future research will aim to gather evidence on the implementation and effectiveness of the geo-inquiry approach in climate education, as well as its impact on skills acquisition. This will involve analyzing learning outcomes—through both quantitative and qualitative methods—collected from thousands of users of the climate dashboards. Moreover, we will actively engage in dialogue with users of the *Teaching the Future* climate dashboards and maps to gather feedback, enhance user experience, and further improve the tool's functionality, ensuring the dashboards remain a dynamic and evolving tool for climate education.

Ultimately, the *Teaching the Future* climate dashboards serve as a model for leveraging geospatial technology in education, transforming climate data into actionable knowledge that inspires both awareness and meaningful action toward climate mitigation and adaptation.

Author Contributions: Rafael De Miguel González: conceptualization, visualization, writing—original draft, writing—review and editing, investigation, project administration; Juan Mar-Beguería: data curation, methodology, visualization, investigation, writing—original draft; writing—review and editing; María Sebastián López and Ondrej Kratochvíl: investigation, writing—original draft; writing—review and editing. This paper is part of a doctoral thesis supervised by the first signatory (Rafael De Miguel González) and carried out by the second signatory (Juan Mar-Beguería), financed by the University of Zaragoza (code PI-PRD-001/2023). All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data that support the findings of this study are openly available on Copernicus websites: https://cds.climate.copernicus.eu/datasets/derived-era5-land-daily-statistics?tab=overview, https://cds.climate.copernicus.eu/datasets/insitu-gridded-observations-europe?tab=overview, https://cds.climate.copernicus.eu/datasets/projections-cmip5-monthly-single-levels?tab=overview (all accessed on 14 February 2025).

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