

Abstract

NASA's Terra satellite has transformed Earth observation over 25 years, providing continuous, high-resolution insights into climate dynamics, environmental change, and human impacts through daily data streams from its instruments, including MODIS and CERES. Terra's data enables scientists and emergency managers to monitor global temperature trends, wildfire intensity, vegetation health, and atmospheric phenomena, supporting real-time responses and long-term climate modeling.

Terra integrates observations from five instruments to measure Earth's atmosphere, land, oceans, snow, ice, and energy fluxes. MODIS, with its wide spatial coverage and multi-spectral bands, tracks clouds, aerosols, vegetation, and surface temperatures, informing understanding of the carbon cycle, ecosystem shifts, and sources of greenhouse gases. CERES measures the energy radiated from Earth's surface and clouds, helping quantify the planet's energy budget and climate change drivers.

Recent projects using Terra data have developed animated narratives visualizing the impacts of heatwaves and wildfires. These visualizations combine satellite images and environmental measurements to highlight how extreme events stress communities, damage ecosystems, and contribute to rising temperatures and air pollution. Increased frequency and severity of fires—detected by MODIS and confirmed by aerosol trends—show tangible effects of climate change and regional vulnerability.

Simple machine learning models built with Terra's historical data can predict global mean temperature trends for 2010–2030, revealing a modest but significant warming pattern. These models leverage MODIS and CERES outputs, using variables such as surface temperature, cloud cover, and radiative flux to make accessible, data-driven forecasts. The findings reinforce concerns about future climate risks and the need for adaptive policies.

By combining satellite analysis, visualization, and AI-generated storytelling, these projects translate complex scientific evidence into engaging, understandable content. This approach highlights environmental stressors, impacts on communities, and long-term risks like global warming and sea-level rise, making the science relevant to daily life and policy decisions. Terra's legacy emphasizes how sustained Earth observation is essential for informed climate action, education, and resilience planning.

In summary, NASA's Terra satellite exemplifies how advanced Earth observation delivers actionable data, innovative storytelling, and predictive power, building robust links between climate science and society's response to environmental challenges.

Problem Statement

The problem is to transform the vast and complex data collected by NASA's Terra satellite over 25 years—captured by its five instruments—into an engaging animated product that effectively communicates an Earth science story. The focus is on showcasing the impacts of heat extremes and wildfires on the environment, ecosystems, human communities, and climate change in a way that is accessible and meaningful to individuals and communities. This involves converting scientific satellite data into visual narratives that highlight real-world environmental challenges and their consequences.

Objectives

The objectives of this project are:

1. Utilize Terra's Long-Term Datasets:

Leverage the extensive, multi-decadal datasets collected by Terra's five instruments to visualize climate-related impacts such as heat extremes and wildfires. This involves analyzing changes over time in temperature, vegetation, atmospheric conditions, and fire activity to reveal both immediate and cumulative environmental effects.

2. Create Engaging Animations:

Develop dynamic, visually compelling animations that transform complex satellite data into understandable stories. These animations will help communicate scientific findings clearly to diverse audiences by illustrating phenomena like wildfire spread, heatwave intensity, and their consequences on ecosystems and communities.

3. Implement Predictive Climate Modeling:

Apply predictive machine learning models using Terra's historical and current data to forecast future climate trends, especially global temperature changes. This predictive insight aims to inform understanding of how climate extremes may evolve and their potential impact in the coming decades.

4. Raise Awareness on Climate Resilience and Action:

Through the combination of data, visualization, and predictive analytics, the project aims to increase public awareness about the urgency of climate change. By linking scientific evidence to tangible impacts on human health, ecosystems, and future climate risks, the project encourages informed decision-making and proactive resilience strategies.

Together, these objectives focus on converting scientific satellite observations into actionable knowledge and engaging narratives that connect global climate processes to local and personal relevance.

Terra Satellite Background and Research

NASA's Terra satellite, launched in December 1999, has been operational for over 25 years and hosts five key scientific instruments: MODIS, CERES, MOPITT, MISR, and ASTER. Each instrument serves a unique purpose, collectively providing a comprehensive dataset on Earth's atmosphere, land surface, oceans, snow and ice, and energy balance. For example, ASTER captures high-resolution multispectral imagery useful for detailed land surface and terrain mapping, while CERES measures Earth's radiation budget, essential for understanding the climate system. MODIS offers broad multispectral imaging for vegetation, clouds, and surface temperature, and MOPITT tracks air pollution such as carbon monoxide. These instruments operate simultaneously on Terra's sun-synchronous polar orbit, enabling consistent, global-scale Earth observations over the last two and a half decades.

This continuous, high-resolution, long-term dataset is critically important for monitoring environmental changes over time, from detecting wildfire occurrences, tracking heatwaves, to measuring changes in atmospheric composition tied to climate processes. However, despite the richness and scientific value of Terra's data, it is often inaccessible or difficult to interpret for non-expert audiences. Raw satellite data requires technical knowledge to analyze and visualize effectively, which creates a barrier between complex climate science and the public.

The gap addressed by this project lies precisely in translating this sophisticated scientific data into compelling, understandable storytelling. By converting Terra's multi-instrument datasets into clear visual narratives—such as animations illustrating the progression and impacts of heat extremes and wildfires—we can bridge the divide between advanced climate research and broad public engagement. This approach aims not only to communicate urgent environmental issues but also to enhance awareness, support informed decision-making, and foster community resilience through accessible science.

Satellite remote sensing, particularly through instruments like MODIS onboard NASA's Terra satellite, plays a crucial role in monitoring and managing forest fires globally. It enables near real-time detection of active fires and long-duration fire events, providing vital data for firefighting and environmental management efforts. These satellite systems can detect large fires over extensive areas, generate fire alerts within minutes to hours, and track fire progression over time. This rapid detection capability helps authorities respond swiftly, minimize damage, and allocate resources effectively. Moreover, the data collected aids in understanding fire behavior, assessing environmental impacts, and informing climate and ecological research. Incorporating satellite-based fire monitoring into scientific storytelling enhances public awareness of wildfire severity, their environmental consequences, and the urgent need for proactive fire management strategies.

Wildfires have far-reaching and severe effects beyond the immediate burning of forests. Environmentally, wildfires destroy vast areas of vegetation and wildlife habitats, causing long-term loss of biodiversity and disruption of ecosystems. The loss of forests reduces the planet's capacity to absorb carbon dioxide, thereby accelerating global warming. Burning trees release large amounts of carbon dioxide, methane, and black carbon into the atmosphere, which contribute significantly to climate change and create a feedback loop that worsens future fire risks. Moreover, fires expose soil, increasing susceptibility to erosion and landslides, while altering watershed hydrology by reducing soil's ability to absorb water, leading to increased surface runoff and potential flooding.

Economically, wildfires impose enormous costs on local communities through property destruction, loss of timber and non-timber resources, firefighting expenses, and restoration efforts. The economic burden extends to disruptions in businesses, tourism, and supply chains, hitting especially hard on vulnerable and rural populations.

On human health, wildfire smoke contains particulate matter, carbon monoxide, nitrogen oxides, and other toxic substances that severely degrade air quality. This pollution is linked to elevated rates of respiratory and cardiovascular diseases, strokes, and even premature death. Psychological impacts are also notable, with affected communities suffering stress, anxiety, PTSD, and cognitive disturbances due to displacement and loss.

Recent wildfire seasons have exemplified these effects globally, including record-breaking fires in Canada, the western United States, South America, and Siberia. For instance, Canadian wildfires released more carbon in five months of 2024 than some large industrialized nations do in a year, with huge impacts on air quality and public health. Fires in urban-adjacent regions have caused evacuations, health crises, and widespread economic damage, demonstrating the heightened risks as climate change intensifies heatwaves and drought conditions.

Thus, wildfires contribute not only to environmental degradation and climate change but also impose heavy social, economic, and health costs that require integrated approaches to mitigation, resilience, and recovery.

Recent wildfire incidents in 2024 and 2025 have been among the most severe on record, demonstrating the escalating environmental and social impacts of these disasters. For instance, California experienced devastating fires like the Gifford Fire in San Luis Obispo County, which burned over 130,000 acres in 2025, causing multiple injuries and the destruction of several structures. The Madre Fire in the same region also consumed over 80,000 acres, highlighting the scale of wildfire outbreaks in heavily populated and ecologically sensitive areas.

In Canada, the 2025 wildfire season has been alarming, with over 200 fires burning uncontrolled across provinces such as Alberta, Saskatchewan, and Manitoba. These fires have led to massive evacuations—tens of thousands of people displaced—and have severely degraded air quality across North America due to the pervasive smoke plumes. More than 490,000 acres burned in Manitoba alone, with numerous fires still uncontained, posing ongoing threats to ecosystems and communities.

Additionally, the rapid spread of the Dragon Bravo fire in the Grand Canyon region destroyed historic structures and forced extensive evacuations in the summer of 2025.

Similarly, in Minnesota, wildfires in May 2025 burned around 30,000 acres, damaging homes and infrastructure, underscoring that wildfire impacts are now seen even in traditionally less fire-prone regions.

These events illustrate the broad-ranging effects of wildfires, including loss of life, destruction of property, ecosystem damage, deteriorated air quality affecting human health, and amplified carbon emissions exacerbating climate change. They also demonstrate the urgent need for clear and accessible communication of these climate-related impacts through data-driven storytelling, such as that enabled by Terra satellite observations.

Incorporating such recent incidents into Earth science narratives highlights the tangible, real-time consequences of warming climates and environmental stress, reinforcing calls for increased resilience and proactive mitigation strategies.

Data Sources

- **MODIS (Moderate Resolution Imaging Spectroradiometer):** Heat-affected regions, wildfire scars, and surface observations.
- **CERES (Clouds and the Earth's Radiant Energy System):** Energy balance, radiation fluxes, and climate forcing.
- **NASA Earth Observatory Maps:**
 - Fire Data: [MOD14A1_M_FIRE](#)
 - Land Surface Temperature: [MOD_LSTD_M](#)

Methodology & Workflow

The project methodology consists of several well-defined stages to transform satellite data into impactful animated storytelling and predictions:

Data Collection & Processing

- Extracted datasets from NASA's Terra satellite instruments MODIS and CERES, which provide critical measurements on surface temperature, vegetation, clouds, and Earth's radiation budget.
- Data processing was performed using Python libraries such as NumPy and Pandas for data manipulation, Matplotlib and OpenCV for visualization and image processing, ensuring standardized, clean datasets ready for analysis.

Visualization & Impact Analysis

- Visualized the percentage of global land area affected by wildfires and extreme heat events using spatiotemporal plots.
- Correlated CERES radiation imbalance data with observed climate changes to illustrate how energy flux anomalies drive warming trends and ecosystem stress.
- Generated comprehensive charts and maps to highlight the environmental and human impacts of these extremes.

Machine Learning Model

- Built a predictive model using historical MODIS and CERES data as input features.
- Employed regression techniques to forecast global temperature trends from 2010 to 2030, revealing ongoing warming patterns driven by climate stressors.

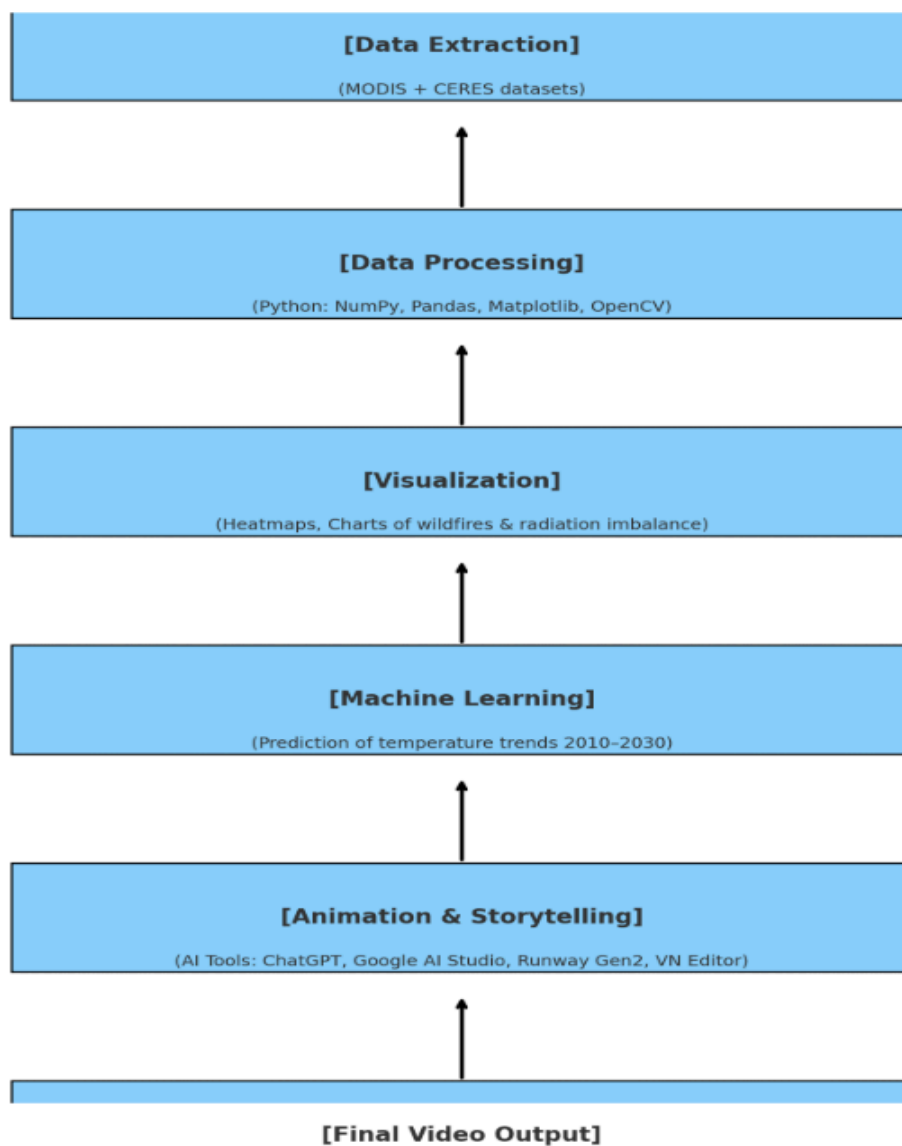
Animation & Storytelling

- Developed a detailed script for each animation scene, focusing on narrative flow to engage diverse audiences.
- Used AI-powered tools such as ChatGPT for script refinement, Google AI Studio and Runway Gen2 for generating animations, and VN Editor for video editing and narration integration.

- The resulting animated video combines scientific visualization with accessible storytelling to communicate climate impacts intuitively.

Demo Video

- The full project, including datasets, code, animations, and a demo video, is available at - [GitHub Project & Demo Link](#)



Archeitecture

This workflow enabled an integrated approach from raw satellite data through analysis, prediction, and engaging communication, effectively linking Earth observation science with public understanding and climate action.

Results

The results of the project reveal significant findings and predictions drawn from the analysis of Terra satellite data combined with machine learning techniques:

Findings

1. Increased Frequency of Heat Extremes and Wildfires:

The analysis confirms a rise in the occurrence and intensity of heatwaves and wildfires across multiple regions globally. Recent years, especially 2023 and 2024, recorded record-breaking wildfire seasons, including severe events in Canada, California, Europe, and South America. These extremes are closely linked to prolonged periods of elevated temperatures, drought, and climate change-driven environmental stress.

2. Environmental Stress:

Data show extensive vegetation loss and land degradation resulting from repeated heat extremes and widespread wildfires. Burned areas have expanded sharply, contributing to soil erosion, habitat destruction, and reduced carbon sequestration capacity. This leads to a feedback loop that exacerbates warming trends.

3. Human Impact:

Communities face increased health risks due to poor air quality from wildfire smoke, heat-related illnesses, and mental health challenges resulting from displacement and economic losses. The economic damages from property destruction, firefighting efforts, and interrupted livelihoods have grown substantially, with multi-billion-dollar impacts in some wildfire-prone regions.

4. Climate Linkage:

Thermal radiation imbalances measured by CERES and temperature anomalies captured by MODIS confirm that heatwaves and wildfires significantly contribute to global warming acceleration. This warming drives glacier melt and sea-level rise, linking local extreme events to broader climate change consequences.

Predictions

Using machine learning models trained on historical MODIS and CERES data, the project predicts a continuing warming trend from 2010 to 2030. While this rise is modest in absolute terms, it is statistically significant and represents ongoing climatic shifts resulting from accumulated greenhouse gases and ecosystem feedback. The predictions underscore the urgency of climate mitigation and adaptation measures.

Final Output

The culmination of this work is an animated science story video that synthesizes complex data into an accessible, engaging narrative suitable for diverse audiences. By combining clear visuals of wildfire and heatwave impacts, data-driven climate forecasts, and compelling AI-generated storytelling, the video enhances public understanding and awareness. It serves as a bridge between satellite science and socio-environmental realities, empowering viewers with knowledge on the causes, impacts, and future trajectories of climate extremes.

This integrated approach demonstrates how long-term satellite observations combined with modern analytical tools can effectively communicate urgent environmental challenges and inspire informed resilience and policy action.

Land Surface Temperature

- Code:

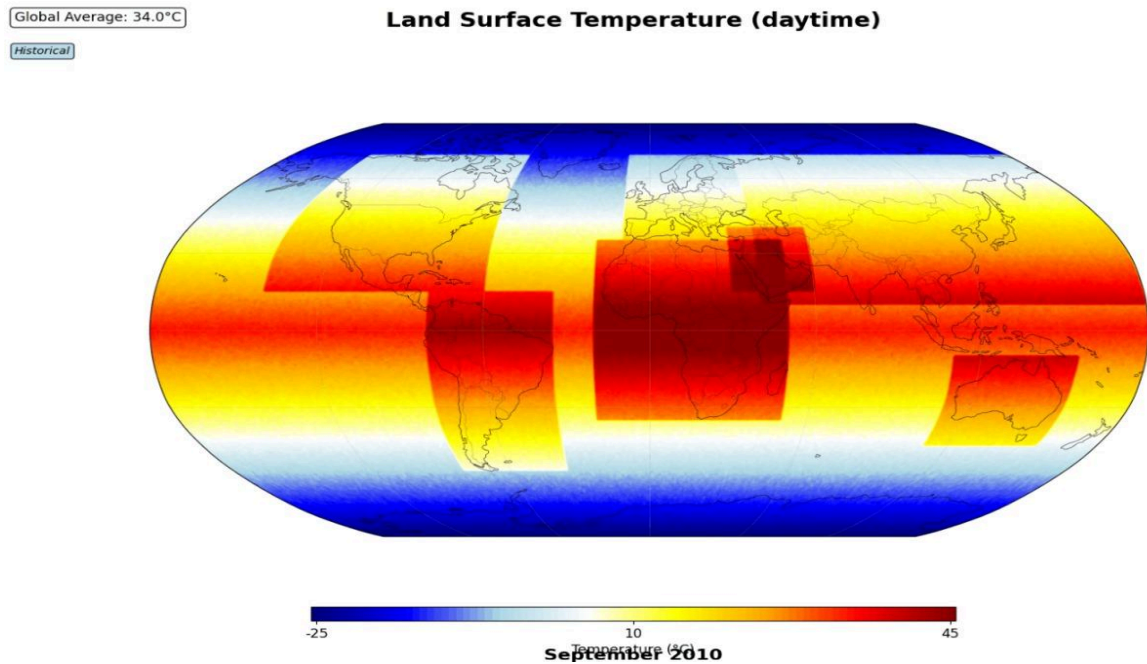
```
import cv2
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import matplotlib.animation as animation
from matplotlib.colors import LinearSegmentedColormap
import cartopy.crs as ccrs
import cartopy.feature as cfeature
from PIL import Image
import os
import webbrowser

# ----- USER CONFIG -----
VIDEO_PATH = r"C:\Users\farah\Downloads\vid1.mp4"
OUTPUT_GIF = r"C:\Users\farah\PycharmProjects\PythonProject4\temperature_world_map.gif"
OUTPUT_CSV = r"C:\Users\farah\PycharmProjects\PythonProject4\predictions.csv"

start_year = 2010
frames_per_year = 20
sample_rate = 1
calib_min_temp = 0.0
calib_max_temp = 60.0
hot_temp_threshold = 35.0
poly_degree = 2
target_year = 2030

# ----- Helper functions -----
def frame_to_temperature_map(frame):
    """usage
    b = frame[:, :, 0].astype(np.float32)
    g = frame[:, :, 1].astype(np.float32)
    r = frame[:, :, 2].astype(np.float32)"""
```

- Output:



Fire Prediction Evolution

- Code:

```
# -----
# Fire Prediction with 3D Globe Visualization - Using Actual Data
# -----

# Step 1: Import Libraries
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from prophet import Prophet
import plotly.express as px
import plotly.graph_objects as go
import numpy as np
import os
from datetime import datetime, timedelta

# Step 2: Load YOUR CSV data
file_path = r"C:\Users\farah\PycharmProjects\PythonProject4\fire_data.csv"

if not os.path.exists(file_path):
    raise FileNotFoundError(f"CSV file not found at {file_path}")

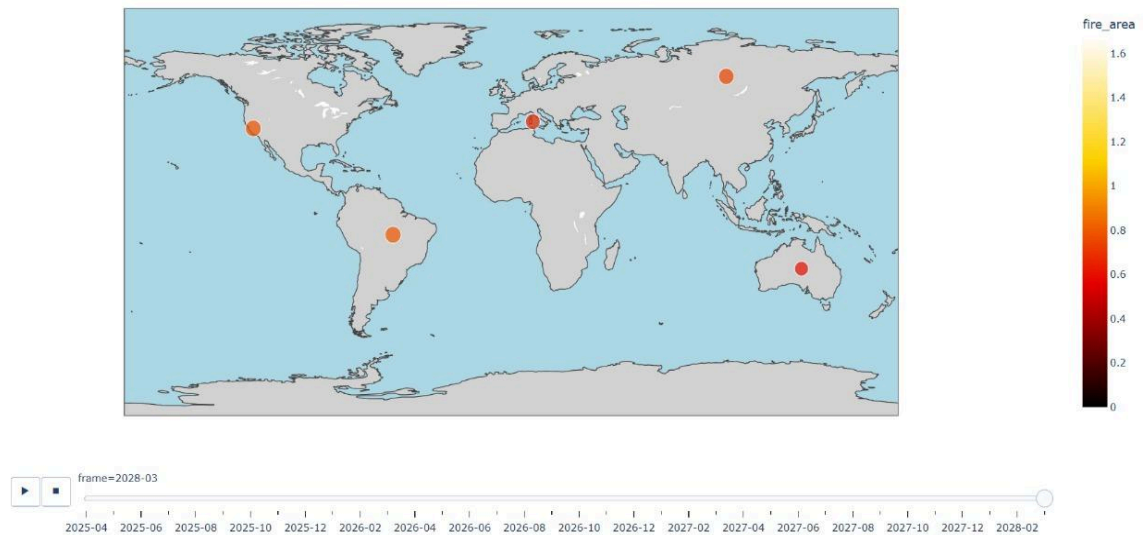
df = pd.read_csv(file_path)

# Step 3: Preprocess YOUR data
df['date'] = pd.to_datetime(df['year_month'])
df = df.rename(columns={"fire_area_percent": "fire_area_percentage"})
df = df.sort_values('date')
df = df[['date', 'fire_intensity', 'fire_area_percentage']]

print("Your dataset columns:", df.columns.tolist())
```

- Output:

Monthly Fire Prediction Evolution - YOUR Data



Impact & Applications

The impact and applications of this project are multifaceted and crucial for advancing climate understanding and action:

Scientific Communication

The project translates complex, large-scale climate data from Terra satellite instruments into engaging visual stories. By using animations and data visualizations, it transforms technical satellite measurements of heatwaves, wildfires, and radiation imbalances into intuitive narratives. This enhances communication among scientists, policymakers, and the public, making critical climate information more accessible and meaningful. Visual storytelling is essential for conveying temporal and spatial complexities of climate change that static charts or raw data cannot effectively express.

Educational Tool

The animated climate science story serves as an excellent resource for education at multiple levels, from schools to universities. It provides learners with concrete, visually rich examples of environmental phenomena, climate impacts, and data-driven predictions. Such tools are invaluable for climate literacy, helping students and communities grasp the urgency of climate issues through relatable and structured storytelling. Moreover, it can be used in public awareness campaigns, workshops, and training programs to foster deeper engagement with climate science.

Policy & Planning

Data-driven animations and forecasts generated from Terra datasets can inform disaster preparedness, emergency response, and climate adaptation strategies. Policymakers and planners can visualize trends in heat extremes and wildfire risks, helping to prioritize resource allocation and mitigation measures. By translating raw data into actionable insights, this project supports evidence-based decision-making aimed at reducing vulnerabilities, protecting ecosystems, and safeguarding public health in a changing climate.

Global Relevance

Linking space-based Earth observations to tangible human experiences broadens the relevance of satellite data worldwide. The project helps bridge the gap between global scientific monitoring and local realities, reinforcing that climate change is a shared challenge affecting diverse communities. This global-to-local connection fosters international cooperation and empowers individuals to understand their role within the planetary system, encouraging collective climate resilience and sustainability efforts.

In summary, by combining satellite data, machine learning, and AI-driven storytelling, the project enhances climate communication, education, policy formation, and global awareness, acting as a model for how advanced Earth observation can promote informed climate action.

Challenges Faced

The main challenges faced during the project were as follows:

1. **Large Dataset Handling and Preprocessing:**
The Terra satellite generates massive volumes of high-resolution data from multiple instruments like MODIS and CERES, spanning over 25 years. Managing this extensive dataset required significant computational resources and careful preprocessing to make it “analysis-ready.” Preprocessing involved cleaning, filtering, correcting for sensor and atmospheric distortions, and aligning diverse data formats. This process was time-consuming and technically demanding due to the scale, heterogeneity, and complexity of Earth observation data.
2. **Ensuring Animations Align with Real Data:**
Translating complex scientific datasets into accurate and visually compelling animations posed a creative and technical challenge. It was essential that the visual output faithfully represented real-world phenomena captured by satellites, such as the spread and intensity of wildfires or surface temperature changes during heatwaves. Balancing scientific accuracy with clarity and engagement required repeated refinement of visualizations and close attention to data integrity.
3. **Time Limitations in Refining Machine Learning Predictions:**
While the machine learning model successfully predicted a warming trend from 2010 to 2030, the available timeframe constrained iterative tuning, validation, and exploration of advanced predictive techniques. Additional time would have enabled improving model robustness, addressing uncertainties more comprehensively, and incorporating more diverse environmental variables.

Overall, these challenges reflect the inherent difficulties of working with large-scale Earth observation data, combining rigorous science with creative communication, and leveraging emerging technologies under project constraints. Overcoming them was vital to delivering a reliable and impactful climate storytelling product.

Future Work

Future work on this project aims to build upon the current achievements by expanding the use of additional Terra satellite datasets such as MISR, ASTER, and MOPITT, which

provide complementary information on aerosols, high-resolution land surface details, and atmospheric pollutants respectively. Incorporating these datasets will enrich environmental analyses and enhance the robustness of climate impact assessments.

Advancing the machine learning and AI components will be a priority, focusing on integrating more sophisticated algorithms and broader environmental variables to improve predictive accuracy and better capture complex climate dynamics. This will help refine temperature trend forecasts and anticipate extreme event patterns more reliably.

Developing interactive, user-friendly dashboards for real-time visualization of Terra data and model outputs is planned to facilitate timely access for researchers, policymakers, and the public. Such platforms could enable dynamic exploration of wildfire spread, heatwave intensity, and radiation imbalances, thereby supporting immediate decision-making and awareness.

Collaboration with educators, climate communicators, and policymakers will be strengthened to ensure that the scientific storytelling outputs and data tools effectively meet educational needs and inform policy formulation. Engaging with these stakeholders will maximize the outreach and impact of the project, fostering greater climate literacy and resilience planning globally.

Together, these future directions will transform the project from a static analysis and animation effort into a versatile, interactive system for climate monitoring, education, and policy support, leveraging the full potential of Terra satellite observations and modern AI technologies.

Conclusion

This project showcases the power of NASA's Terra satellite data in understanding the climate impacts of heat extremes and wildfires. By blending cutting-edge science, advanced technology, and compelling storytelling, it transforms complex satellite datasets into an engaging and accessible animated product. This approach bridges the gap between sophisticated Earth observation data and public understanding, making the urgent realities of climate change tangible to diverse audiences. The project highlights critical environmental stresses, health risks, and economic damages linked to heatwaves and wildfires, while connecting these phenomena to global warming and

sea-level rise. Ultimately, it promotes informed action and resilience strategies, emphasizing the need for a sustainable future grounded in science-based awareness and policy. This confluence of science communication and data visualization sets a precedent for how ongoing satellite missions like Terra can actively contribute to climate education and decision-making worldwide.

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