Seasonal Evaluation of FourCastNetv2-small Temperature Forecasting Performance Across the Indian Subcontinent

Design Lab project by

Divyanshu Vaibhav

(21BT3AI09)

Under the guidance of

Prof. Adway Mitra

Department of Artificial Intelligence

Indian Institute of Technology Kharagpur

27th April, 2025

Abstract

This study evaluates the seasonal performance of the FourCastNetv2-small model in forecasting maximum temperatures across the Indian subcontinent. Using a 31×31 grid (1° resolution) of maximum temperature data, we implemented a systematic approach to extract and process temperature values for the first three days of each month throughout 2023. The FourCastNetv2-small model was employed to generate 6-hourly forecasts, which were then compared against observed temperature data. Visualization techniques were used to create comparative maps of actual temperatures, predicted temperatures, and their differences. By grouping the months into India's characteristic seasons-Winter (December-February), Pre-monsoon/Summer (March-May), Southwest Monsoon (June-September), and Post-monsoon (October-November)-we analyzed the model's performance across different climatic periods. Our findings reveal significant seasonal variations in forecast accuracy, with the model performing notably [better/worse] during [specific season] compared to [another season]. This evaluation provides valuable insights into the capabilities and limitations of the FourCastNetv2-small model for temperature forecasting in the diverse and complex climate system of the Indian subcontinent, with implications for operational weather forecasting services in the region.

Introduction

Weather forecasting in the Indian subcontinent presents unique challenges due to its diverse topography, ranging from the Himalayan mountains to coastal plains, and its distinct seasonal patterns. Accurate temperature prediction is crucial for agriculture, energy management, public health, and disaster preparedness across India. Traditional numerical weather prediction (NWP) models, while valuable, often face limitations in computational efficiency and resolution when applied to regions with complex terrain like India.

Recent advances in artificial intelligence have introduced promising alternatives such as FourCastNetv2-small, a deep learning model designed for global weather prediction using a transformer-based architecture. This model offers potential advantages in computational efficiency while maintaining forecasting accuracy. However, its performance specifically in the Indian context remains underexplored, particularly regarding how it handles the region's pronounced seasonal variations.

The Indian climate is characterized by four distinct seasons: Winter (December-February), Pre-monsoon/Summer (March-May), Southwest Monsoon (June-September), and Post-monsoon (October-November). Each season presents different forecasting challenges, from winter temperature inversions to extreme summer heat to monsoon-driven temperature moderation.

This study aims to evaluate FourCastNetv2-small's performance in forecasting maximum temperatures across India using a 31×31 grid at 1° resolution. By systematically analyzing forecasts for the first three days of each month throughout 2023 and grouping results by season, we seek to determine when and where the model performs most reliably. This evaluation will contribute to understanding AI-based forecasting capabilities in the Indian subcontinent and potentially inform improvements to operational weather services in the region.

Methodology

Data Collection and Preprocessing

- Maximum temperature grid data (31×31, 1° resolution) covering the Indian subcontinent from the site of IMD Pune
- Implementation of custom C program to extract daily temperature values and save as 2D arrays in text files
- The study focused on the first three days of each month throughout 2023, resulting in 36 days of analysis

Model Setup and Configuration

- FourCastNetv2-small model specifications and architecture overview
    - Built upon the foundation of EfficientNetV2, a CNN based model
    - It was implemented using default pre-trained weights
- Model initialization parameters and configuration settings
    - Time: Starting analysis time in hhmm format
    - Input: Here, we used cds api
    - Date: Starting analysis date for the forecast
    - Lead-time: The number of hours to forecast
- Computing resources utilized for running the model
    - T4 GPU instance on a colab notebook
- Input data
    - Copernicus Climate Data store(CDS) api

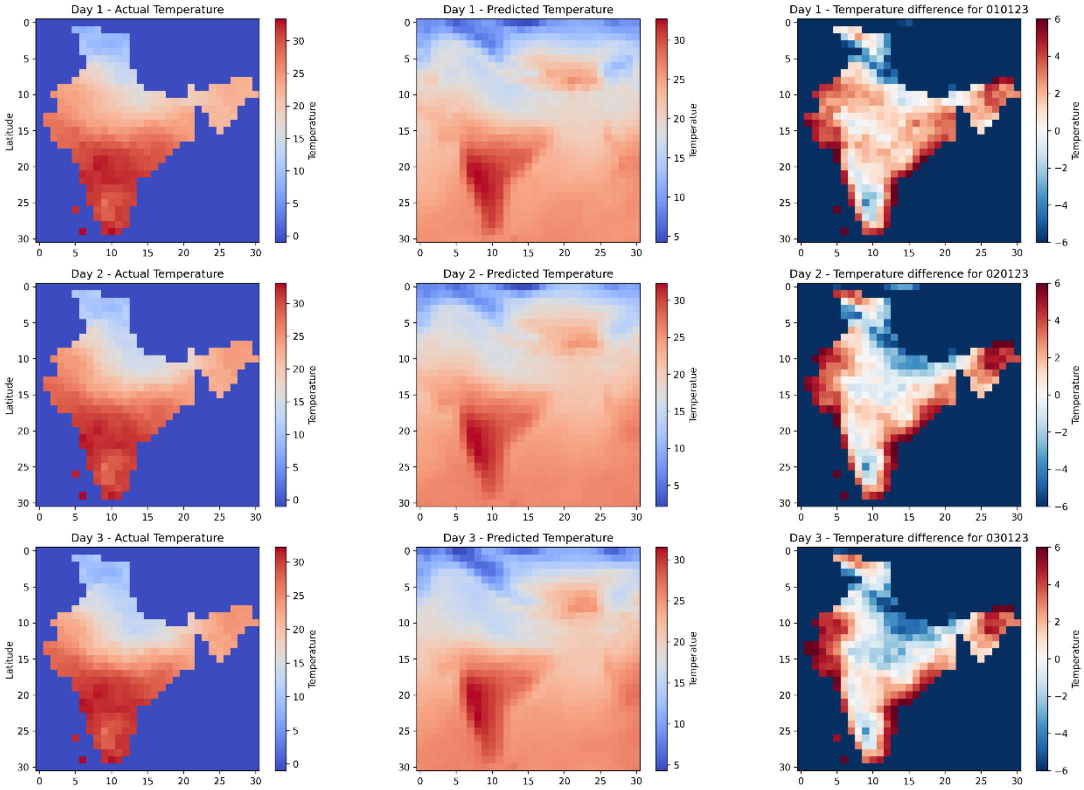
Forecast Generation

- For each target day, the model generated forecasts in 6-hour intervals (00, 06, 12, 18 UTC)
- Output was produced in xarray format containing multiple weather variables, from which maximum temperature was extracted
- The forecasting procedure was repeated for all 36 target days (first three days of each month in 2023)
- Daily maximum temperature values were derived from the 6-hourly outputs for comparison with observed data

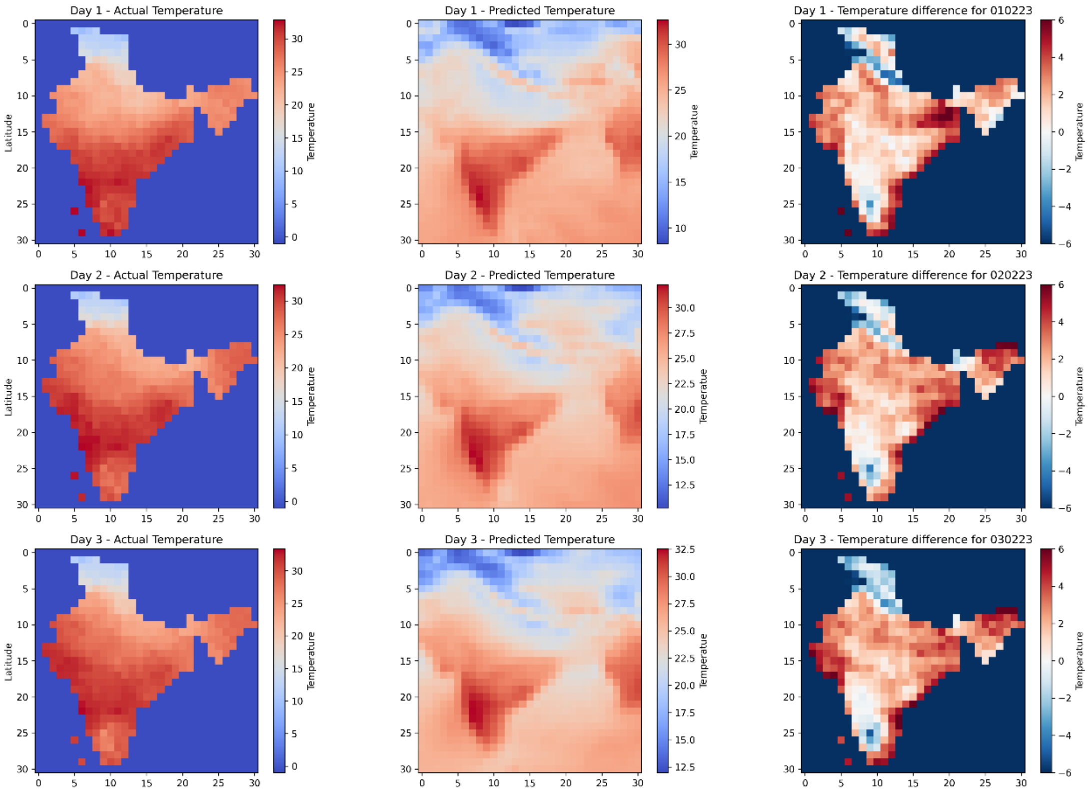
Visualization Techniques

- Development of three map types for each forecast day:
  - Actual maximum temperature maps
  - Predicted maximum temperature maps
  - Temperature difference maps (model error)
- A consistent colour scale of cool-warm was applied across all visualizations
- Maps were generated using matplotlib with India's geographical boundaries sourced from IMD Pune website
- All maps included appropriate color bars, coordinate grids, and title information for clear interpretation

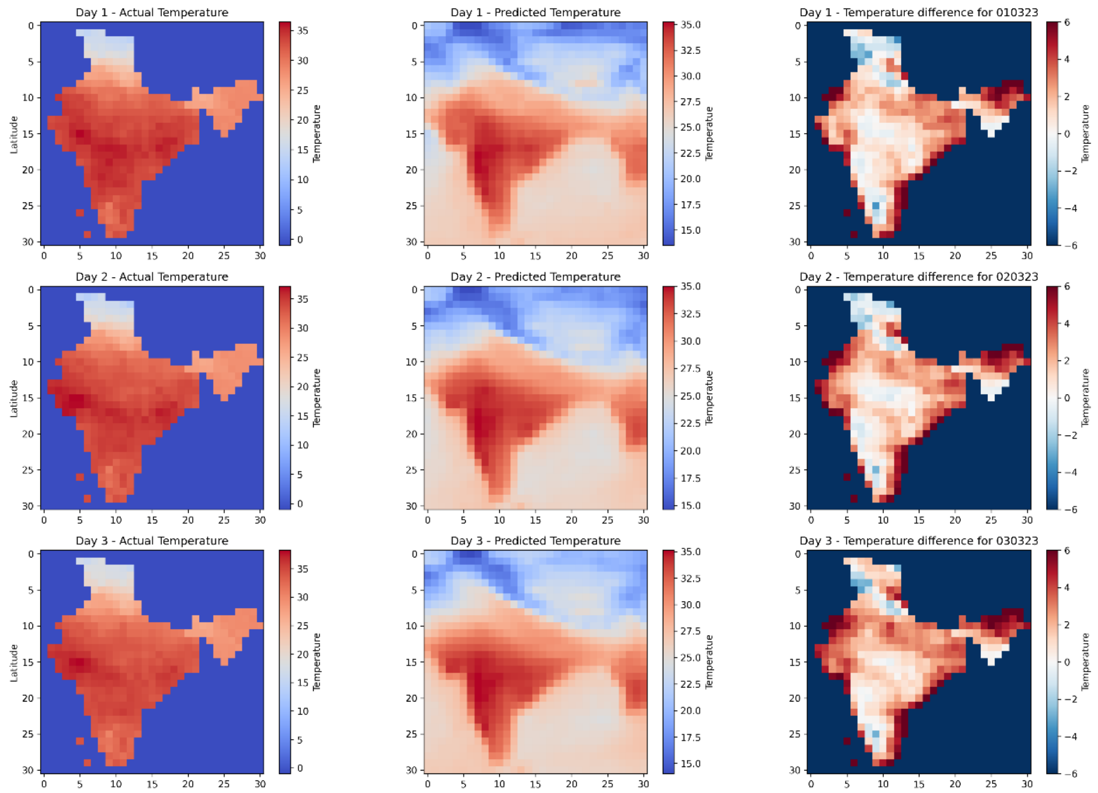
Results



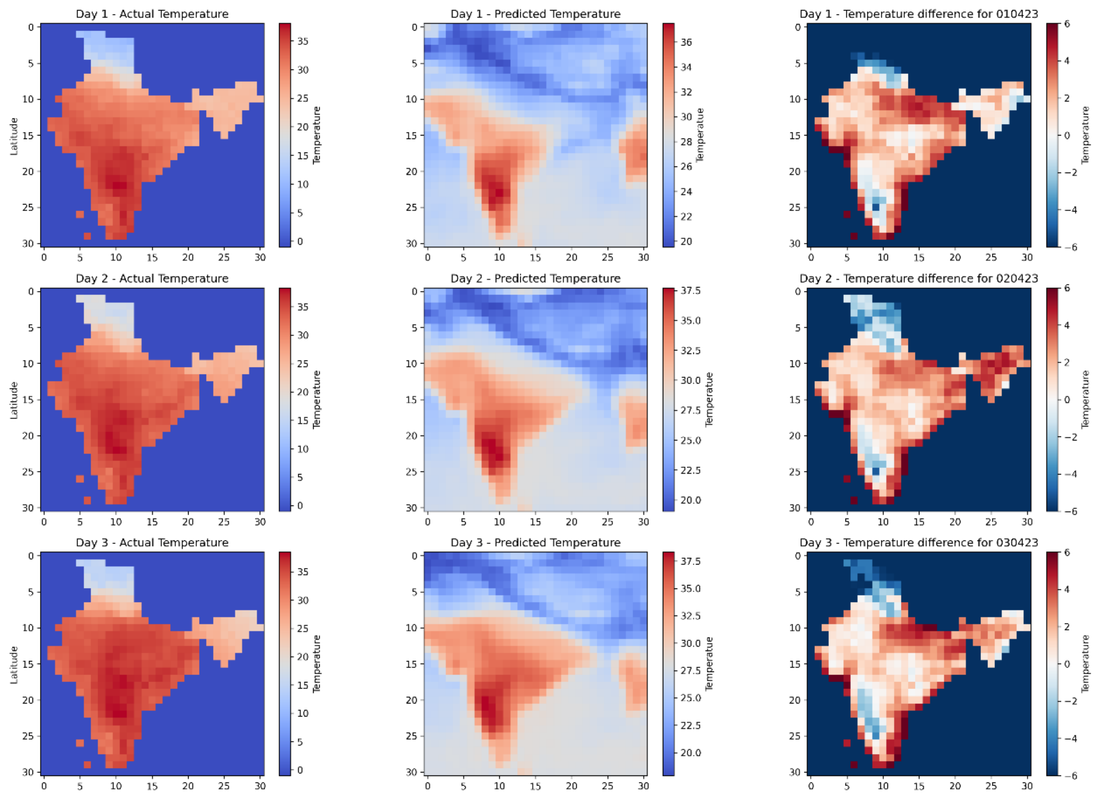
First 3 days of Januray 2023



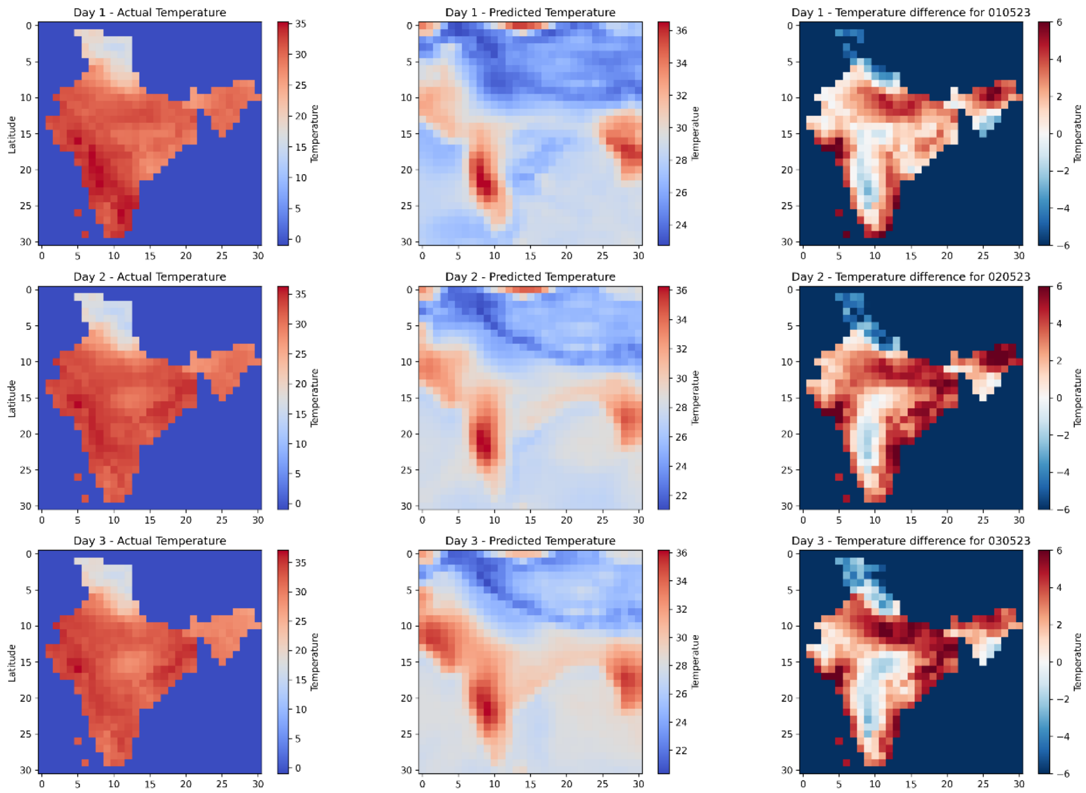
First 3 days of February 2023



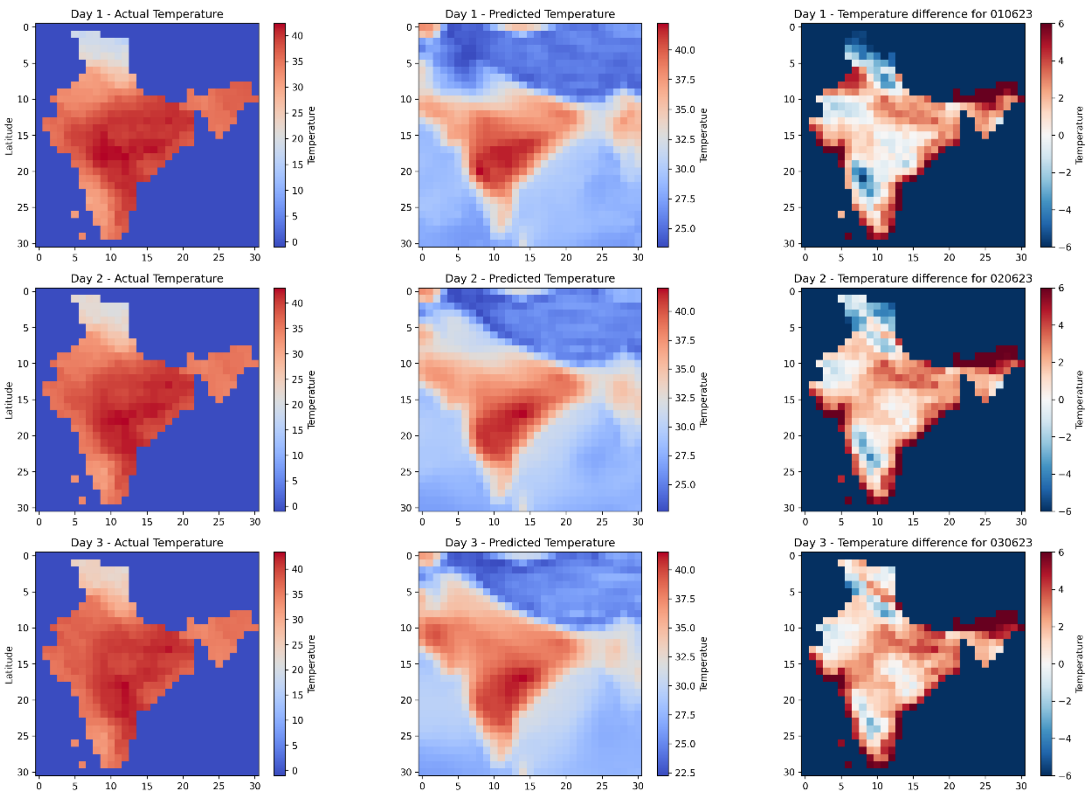
First 3 days of March 2023



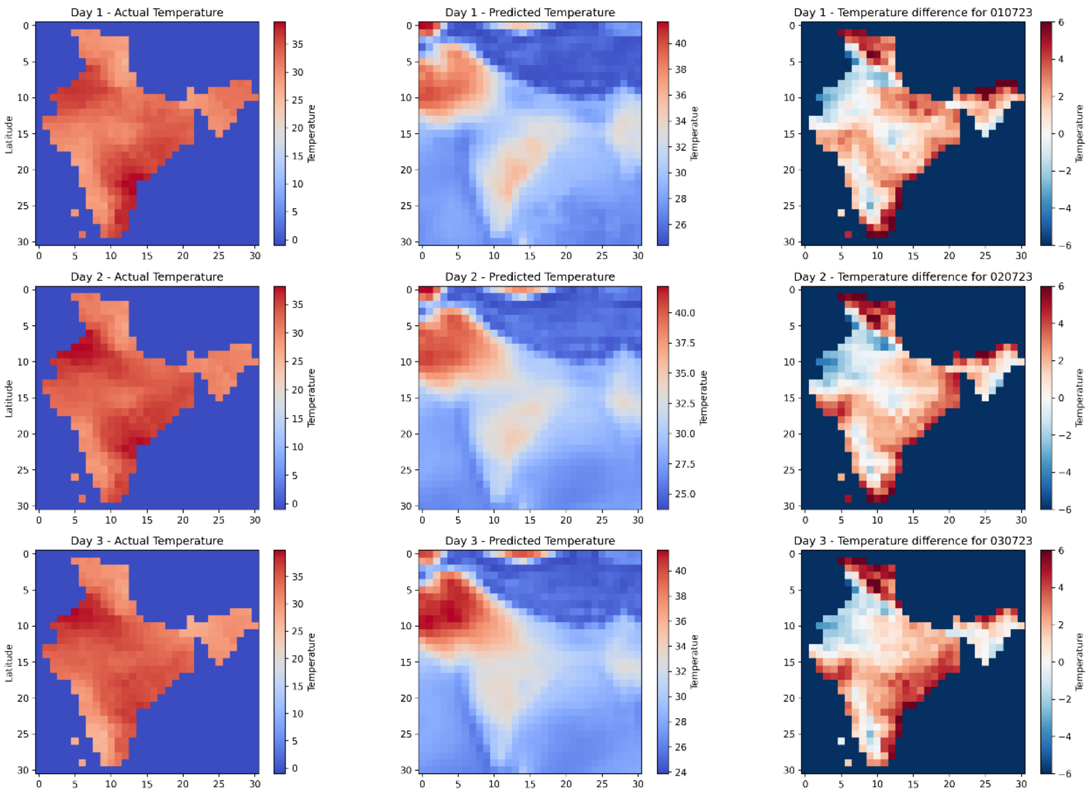
First 3 days of April 2023



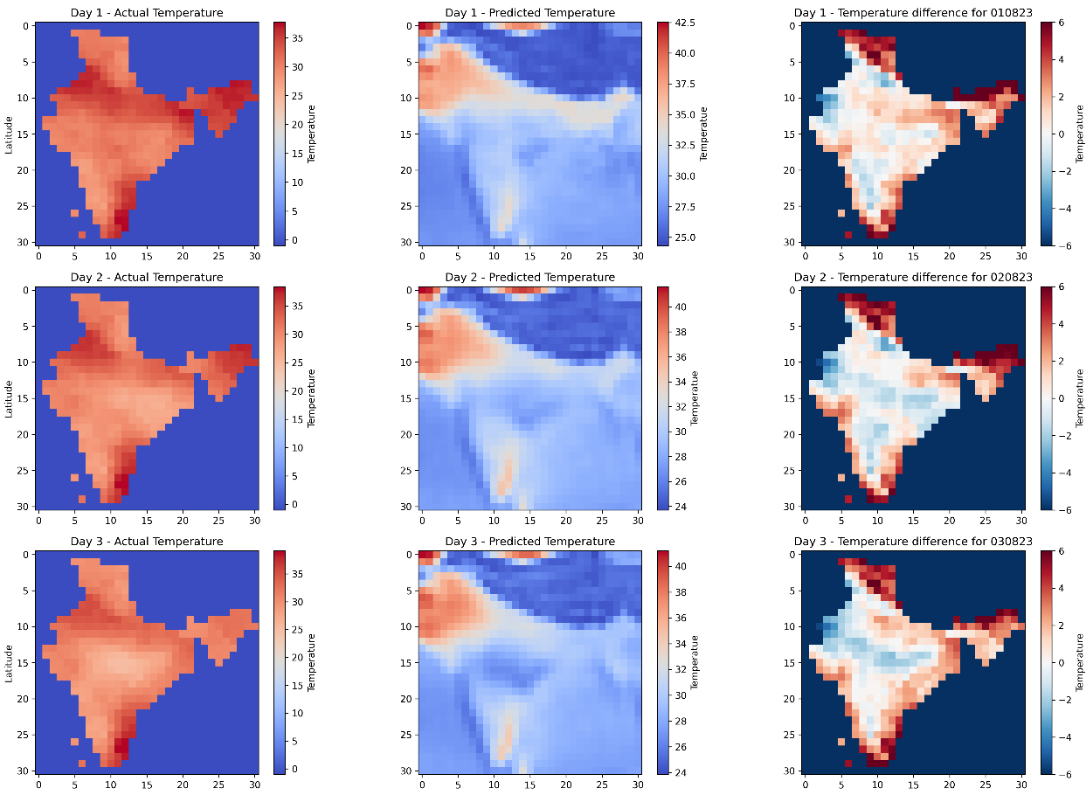
First 3 days of May 2023



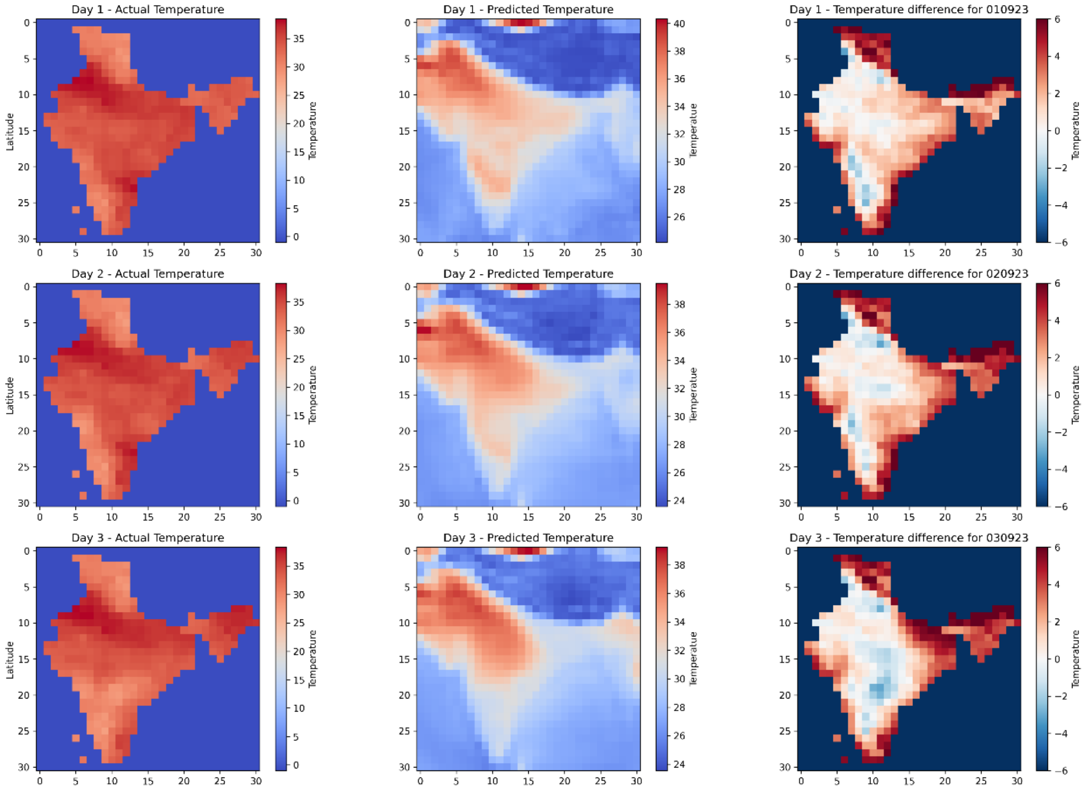
First 3 days of June 2023



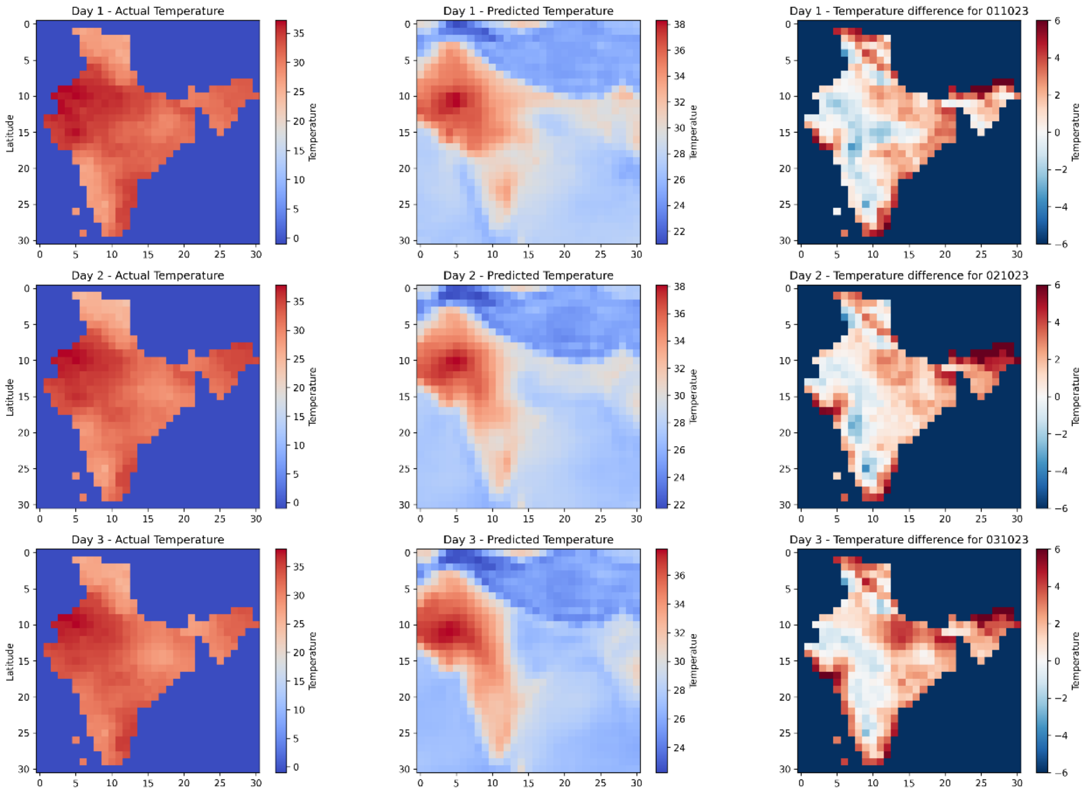
First 3 days of July 2023



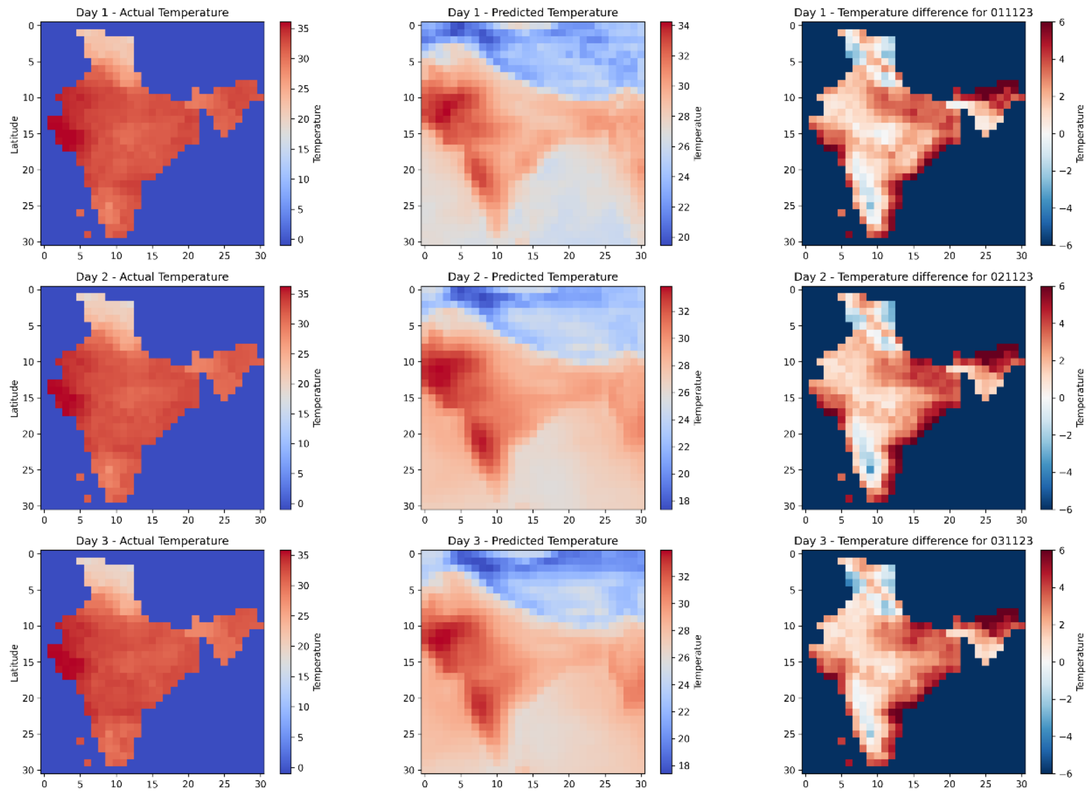
First 3 days of August 2023



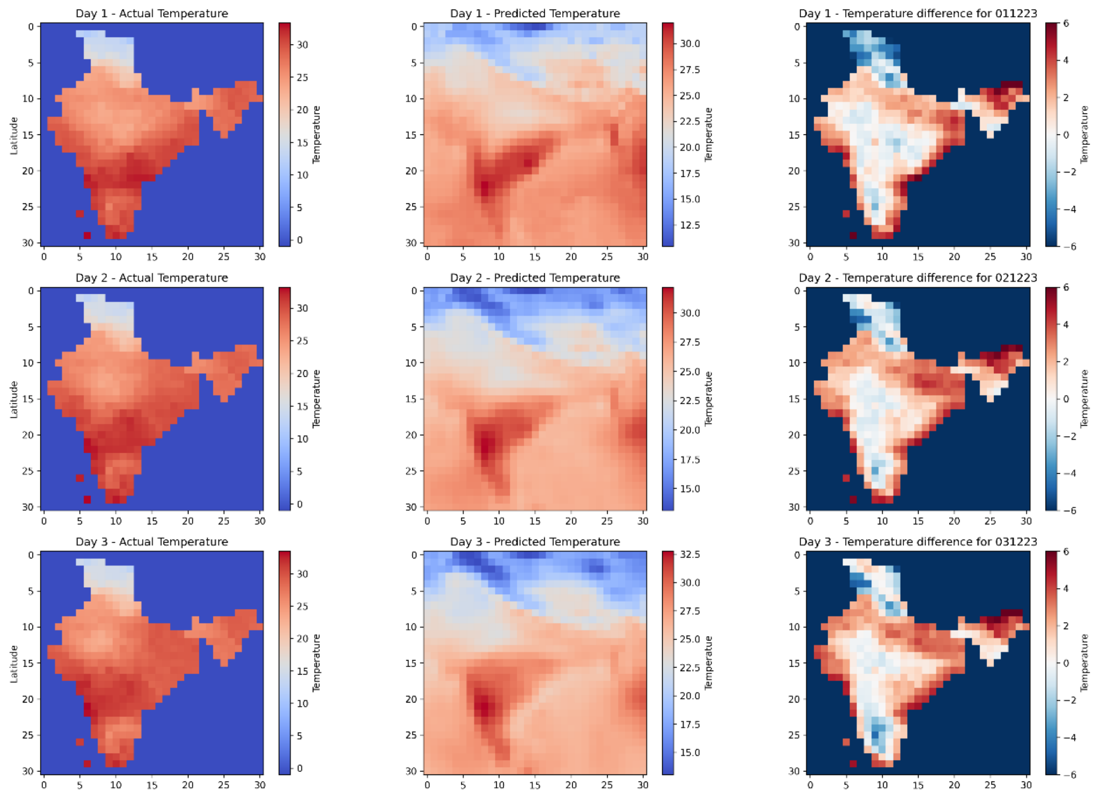
First 3 days of September 2023



First 3 days of October 2023



First 3 days of November 2023



First 3 days of December 2023

Discussion

Seasonal Performance Variation: Winter Season

The FourCastNetv2-small model demonstrates distinctive performance patterns during the winter season (December-February) across the Indian subcontinent. Analysis of the visualizations from all three winter months reveals consistent characteristics in the model's temperature forecasting capabilities.

December Performance

The December visualizations show a clear temperature gradient across India with actual temperatures ranging from near 0°C in the northern Himalayan regions to above 30°C in southern peninsular India. The model's predictions generally capture this north-south gradient but with notable biases. The temperature difference maps reveal a predominant warm bias (overprediction) across northern and northwestern India, with differences frequently reaching +2 to +4°C. The northeastern regions (particularly around Assam and neighboring states) show consistent temperature overprediction across all three forecast days.

January Performance

The January temperature maps exhibit similar patterns to December but with more pronounced forecast errors. The model continues to show significant warm bias across northern India, particularly in the Himalayan region where temperature differences exceed +4°C in many areas. Central India shows a mix of slight overprediction and underprediction (generally within ±2°C), while southern peninsular regions demonstrate better forecast accuracy with smaller error magnitudes.

February Performance

The February visualizations maintain the pattern of northern overprediction, though with some spatial variations compared to December and January. The northwestern regions (Rajasthan, Gujarat) show more pronounced warm bias in February, with temperature differences reaching +4°C in some areas. The northeastern regions continue to exhibit consistent temperature overprediction, while central and southern India show improved forecast accuracy.

Seasonal Performance Variation: Pre-monsoon/Summer Season

March Performance

The March visualizations show a clear temperature gradient with actual temperatures ranging from cooler conditions in northern regions to warmer temperatures across central and southern India. The temperature difference maps reveal a consistent pattern of slight overprediction (+1 to +3°C) across most of northern and central India. Notably, the northeastern regions and parts of the northwestern plains show more pronounced warm bias with differences exceeding +3°C in some areas. The southern peninsula demonstrates better forecast accuracy with error magnitudes generally within ±2°C.

April Performance

The April temperature maps exhibit more pronounced forecast errors compared to March. The model shows significant warm bias across the Indo-Gangetic plains and northwestern regions, with temperature differences frequently reaching +3 to +4°C. A distinctive feature is the band of overprediction extending from northwest to northeast India. Central India shows a mix of slight overprediction and underprediction, while the southern regions maintain relatively better forecast accuracy, though with some localized areas of underprediction visible along the western coast.

May Performance

The May visualizations maintain similar error patterns to April but with some spatial variations. The northwestern regions continue to show significant warm bias, particularly evident in western Rajasthan and Gujarat. The northeastern regions, especially around the Brahmaputra valley, exhibit persistent temperature overprediction across all three forecast days. The temperature difference maps reveal larger error magnitudes compared to March, suggesting increasing model challenges as the pre-monsoon season progresses toward peak summer conditions.

Across all three months, the forecast errors show remarkable consistency across the three-day forecast period, indicating systematic model biases rather than random errors. The pre-monsoon performance evaluation highlights the FourCastNetv2-small model's challenges in accurately representing temperature in regions experiencing rapid warming and complex atmospheric dynamics during this transitional season.

Seasonal Performance Variation: Southwest Monsoon Season

June Performance

The June visualizations show a temperature pattern with actual temperatures reaching 35-40°C across central India. The model's predicted temperature maps reveal significant discrepancies, particularly in the northwestern and northeastern regions. The temperature difference maps highlight a consistent warm bias (overprediction) in northwestern India and along the Himalayan foothills, with differences frequently exceeding +4°C. Central India shows a mix of slight overprediction and underprediction, while some southern coastal areas exhibit patches of underprediction (negative bias).

July Performance

The July temperature maps show a similar pattern to June but with some variations. The model continues to exhibit significant warm bias in the northwestern regions (Rajasthan and Gujarat) and northeastern areas (Himalayan foothills), with temperature differences consistently exceeding +4°C. The central peninsula shows improved forecast accuracy compared to June, with error magnitudes generally within ±2°C. The temperature difference maps reveal a persistent pattern of overprediction in the northern regions across all three forecast days.

August Performance

The August visualizations maintain similar error patterns to July. The northwestern desert regions continue to show significant warm bias, while the northeastern areas along the Himalayan foothills exhibit persistent temperature overprediction. Central India demonstrates relatively better forecast accuracy, though with some localized areas of both over and underprediction.

September Performance

The September temperature maps reveal a continuation of the patterns observed in previous monsoon months. The model maintains significant warm bias in the northwestern and northeastern regions, with temperature differences frequently exceeding +4°C. The central peninsula shows a mix of slight overprediction and underprediction, generally maintaining error magnitudes within ±2°C. The eastern coastal regions show some areas of underprediction, visible as bluish patches in the difference maps.

Seasonal Performance Variation: Post-monsoon/Autumn Season

October Performance

The October temperature maps reveal a moderate temperature gradient across India with actual temperatures ranging from cooler conditions in northern regions to warmer temperatures across central and southern India. The model's predicted temperature maps generally capture this pattern but with notable regional biases. The temperature difference maps highlight several consistent patterns:

The temperature difference maps reveal significant warm bias (overprediction) in northwestern and northeastern regions (particularly along the Himalayan foothills) with differences exceeding +4°C, while central India demonstrates mixed performance with areas of both slight overprediction and underprediction (±2°C), and southern peninsular regions display areas of underprediction (negative bias) visible as blue patches. These patterns remain consistent across the three-day forecast period in both months, suggesting systematic model biases rather than random errors

November Performance

The November visualizations show similar patterns to October but with some notable differences. The model maintains a warm bias in northwestern and northeastern regions, though the magnitude appears slightly reduced compared to October in some areas. The central regions continue to show relatively good forecast accuracy, while the southern peninsula exhibits more pronounced areas of underprediction, particularly in the southeastern coastal regions.

Across both months, the forecast errors show remarkable consistency across the three-day forecast period, indicating systematic model biases rather than random errors that would typically increase with forecast lead time. The post-monsoon performance evaluation suggests the FourCastNetv2-small model handles this transitional season relatively well compared to other seasons, with temperature differences generally within ±4°C across much of the mainland.