**Bhutan Water Resources**

*Comparing Precipitation, Temperature, and Phenology Data Trends in Bhutan to Assist the Himalayan Environmental Rhythm Observation and Evaluation System (HEROES) Project*

**Project Team**

***Project Team: Bhutan Water Resources***

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**Project Overview**

***Project Synopsis:*** The Bhutan Water Resources team analyzed phenological and meteorological data for Bhutan from 1996 to 2017. This is one of the first NASA DEVELOP projects analyzing Bhutan’s climate using Earth observations to assess trends in precipitation, temperature, and vegetation phenology to examine how the country had been affected by climate variability. The project’s main goal was to help end users including the Bhutan Foundation and the Himalayan Environmental Rhythm Observation and Evaluation System (HEROES) project use the outcomes of this work to support actions taken to mitigate climate variability.

***Abstract:***

Himalayan countries, including Bhutan, have become vulnerable to warming trends which result in increasing temperature and variable rainfall and snowfall. By combining phenological and meteorological data, Earth observation platforms and sensors were used to assess trends in precipitation, temperature, and vegetation phenology in Bhutan from 1996 through 2017. This project studied precipitation using Climate Hazards Center Infrared Precipitation with Station data, analyzed temperature using the Famine Early Warning System Network Land Data Assimilation System, incorporated elevation data from the Shuttle Radar Topography Mission, and assessed vegetation phenology using Aqua and Terra Moderate Resolution Imaging Spectroradiometer (MODIS) to evaluate climate variability and its effects on Bhutan. *In situ* temperature and precipitation data were also collected from the Himalayan Environmental Rhythm Observation and Evaluation System (HEROES) project and Bhutan’s National Center for Hydrology and Meterology. Modeled and *in situ* data showed similar trends in precipitation and temperature for the Thimpu, Chhukha, and Gasa regions. Aqua and Terra MODIS phenology data were variable from year to year. However, the data suggested a late onset of spring green up. Partners at the Bhutan Foundation and locally in Bhutan can use this information to better understand and monitor climate variability and replicate these methods for future analysis.

***Key Terms:***

climate trends, elevation, precipitation, temperature, vegetation phenology, FLDAS, CHIRPS, MCD 12

***National Application Area Addressed:*** Water Resources

***Study Location:*** Bhutan

***Study Period:*** 1996 to 2017 (June – August)

***Community Concerns:***

* Bhutan currently faces the risk of glacial lake outburst floods and this threat could increase due to a warming climate.
* Over the years, Bhutan has observed increasing potential snow melt and decreasing likelihood of precipitation falling as snow.
* Local farmers have expressed concerns over delayed growing seasons.
* The evaluation of fluctuations in precipitation is crucial to inform the agricultural community of trends that might impact productivity.

***Project Objectives:***

* Combine phenological and meteorological data to assess trends in climate variability in Bhutan from 1996 to 2017
* Provide temperature and precipitation trend analysis using CHIRPS estimates and FLDAS modelled data
* Compare modelled satellite and *in situ* data for climate variables such as precipitation, temperature, and land surface vegetation phenology
* Lay foundation for future research based on the results from the project to replicate similar studies or further develop existing work to monitor climate variability in Bhutan

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Bhutan Foundation** | Tshewang Wangchuk, Executive Director | End User | Yes |
| **Ugyen Wangchuk Institute for Conservation and Environmental Research (Bhutan)** | Sangay Pelzang, Information and Communication Technology Officer | Collaborator | No |

***Decision-Making Practices & Policies:***

The Bhutan Foundation bases its project support decisions and priorities as outlined in the Bhutan 12th Five Year Plan (FYP), which is a series of national economic plans created by the government since 1961. This plan has been inspired by the Royal Addresses and is anchored on the provisions of the Constitution, lessons from the review of the 11th FYP, extensive stakeholder consultations (including Civil Society Organizations (CSOs) and political parties), and regional and internal commitments, including the Sustainable Development Goals (SDG). One of the main priorities within the plan is to create a harmonious society in order to maintain a healthy ecosystem with carbon neutral and climate resilient development, which aligns with the goals of this project. The Bhutan Foundation does not currently use Earth observations in their research or project planning activities, but they are interested to learn how these data products can be used in their work.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Terra MODIS** | Phenology (MCD12), NDVI | A land surface phenology product (MCD12) was used to create a time series for ~40 years to calculate phenological trends. |
| **Aqua MODIS** | Phenology (MCD12), NDVI | A phenology product (MCD12) was used to create a time series for ~40 years to calculate phenological trends. |
| **SRTM** | Elevation | SRTM elevation was used to threshold modelled temperature and precipitation data for comparison to *in situ* point data. |

***Ancillary Datasets:***

* University of California, Santa Barbara Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) – Gridded rainfall estimates from rain gauge and satellite observations were used to create a time series from 1996 to 2017 to identify climate variability
* NASA Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) Noah air temperature – Analyze temperature change from 1996 to 2017
* Himalayan Environmental Rhythm Observation and Evaluation Systems (HEROES) data – *In situ* data for phenology, temperature, and precipitation were used to compare with Earth observations
* NASA Shuttle Radar Topography Mission (SRTM) – Variation in elevations and slopes for mountainous regions were resolved using SRTM

***Software & Scripting:***

* Google Earth Engine API – Data visualization and raster manipulation
* ArcGIS Pro 2.5 – Data visualization, raster analysis, and zonal statistics
* Panoply 4.11.1 – Climate data visual inspection

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Climate Trend Analysis** | Terra MODIS  Aqua MODIS  SRTM | This analysis will provide partners with timely, objective, and spatially explicit meteorological data for land surface temperature, precipitation, and phenology. | N/A |
| **Climate Data Acquisition and Display Tutorial** | N/A | The modelled satellite data acquisition tutorial will help the partners to fill in for any missing *in situ* data and perform a comparative analysis for the modelled and ground data. | N/A |

***Product Benefit to End User:***

Results from the project will assist the Bhutan Foundation and the Ugyen Wangchuk Institute for Conservation and Environmental Research in bolstering the efforts of the HEROES project in recognizing and assessing changes to land surface vegetation phenology and climatology over the last few decades. Earth observations provide objective, timely, and spatially explicit information and can serve as another monitoring tool for promoting better understanding and appreciation of climate trends in Bhutan. This project can serve as a prototype for our partners to replicate similar studies in the future and apply the same process to other geographical districts within the country.

***Project Continuation Plan:***

The project is expected to continue next summer. For future work, it is crucial to place more emphasis on how variation in climate trends affect Bhutan's agricultural lifestyle and the implications for local farmers in the country. More research can be done to examine how climatic variables influence the blooming of plants and other phenological trends. Because MODIS data are only available from 2000 on, it would be advisable to look into NOAA’s Advanced Very High Resolution Radiometer (AVHRR) for a longer-term phenology dataset.

**References**

Bhutan Foundation: https://bhutanfound.org/

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