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LONG-TERM THERMAL ANOMALY DETECTION AND MAPPING AT PIXEL LEVEL USING A GOOGLE EARTH ENGINE TOOL

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ABSTRACT:

Frequency of extreme weather events such as cloudbursts, heatwaves etc. have increased as an outcome of changing climate. Identification of the pattern of extreme temperature events is important since it governs various events such as heatwaves, wildfires, droughts, storms, coldwaves etc. Moderate Resolution Imaging Spectroradiometer (MODIS) provides Land Surface Temperature (LST) data at 1 kilometre of spatial resolution at daily interval that can help in the identification and mapping of the anomalies in the temperature at pixel level. This study proposes a global-scale daily long-term thermal anomaly detection tool made using Google Earth Engine (GEE) App. This open source tool with the name of 'Deviation from Mean' uses the MODIS LST data available from 2000 till date to detect temperature anomaly based on the deviation of temperature of any day (chosen by the user) from the long-term climatological mean. It also generates a time-series plot of temperature values of any pixel for any date for last 24 years i.e. 2000-2023 in the graphical form to analyze the variation in the temperature over the time. A case study has also been done using the tool to highlight the thermal anomaly experienced over the Indian sub-continent during March-April, 2022 and 2023. This tool is capable of providing thermal anomaly information at global, regional as well as local level that can help in taking region-specific mitigation measures.

1. INTRODUCTION

Extreme events have been increasing in terms of frequency as well as intensity (Bevacqua et al., 2023; Seneviratne et al., 2012), and can be estimated as those events that occur outside of the lower or upper bounds of the statistical lower or upper bounds of evidently characteristic climate events (Jia et al., 2019). This anomaly of extremeness can be attributed to the human-induced climate change (Wei et al., 2023). Extreme weather events like floods, droughts, heatwaves, cyclones etc. generally occur due to the extreme temperature and precipitation conditions and they cause a lot of damage to the people and environment (Lehmann et al., 2015). Researchers from all around the world are interested in and focused on the effects of extreme climate and weather events on diverse environmental components, such as terrestrial ecosystems (Flach et al., 2018; Wei et al., 2023) and its impact on vegetation growth etc. (Liang et al., 2023).

Mean global temperature has been rising since the onset of 20th century with an enhanced rate of warming in past thirty years (Allan et al., 2021). This necessitates the identification and understanding of the pattern of extreme temperature events (Herrera-Estrada & Sheffield, 2017). With the advancement of geospatial technology and availability of the long-term Land Surface Temperature (LST) datasets, it has now become feasible to assess the pattern of changing environmental conditions over a large area for a long period of time. Understanding the pattern of daily temperature to detect the thermal anomaly requires global satellite data from a common source to avoid any kind of discrepancy in data.

A number of studies have been done to analyze the impacts of climate change on the frequency and intensity of extreme events, and the impact of extreme weather events on phenology (Inouye, 2008), vegetation dynamics (Baumbach et al., 2017; Jiang et al., 2017; Seddon et al., 2016) and terrestrial carbon cycle (Piao et al., 2019). Genzano et al., (2020) proposed a Google Earth Engine (GEE) App to analyze, map out, and keep track of volcanic thermal anomalies on a worldwide scale using images from Sentinel-2 MSI and Landsat-8 OLI based on the Normalised Hot spot Indices (NHI) technique that can investigate more than 1400 active volcanoes with very quick processing times.

But it is more vital to analyze the spatio-temporal pattern of extreme weather events in order to characterize their frequency and intensity. Alexander et al., (2006) have computed and analyzed multiple climate change indicators based on daily temperature and precipitation data with a focus on extreme occurrences. As per their findings, more than 70% of the sampled land area worldwide had a considerable decrease in the

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frequency of cold nights and an increase in the frequency of warm nights annually.

There is a lack of a robust method to detect and monitor thermal anomalies over long-term at regional or global scale at high temporal frequency. To fill this gap, the present study proposes a thermal anomaly detection tool that can detect, map and monitor thermal anomaly at daily interval globally. This tool can be used to understand the pattern of extreme events. In this study, Moderate Resolution Imaging Spectroradiometer (MODIS) Terra LST data, available at 1 km spatial resolution globally has been used to detect the long-term thermal anomaly at global scale. Thermal anomaly detection is based on the deviation from long-term mean approach. The developed tool uses the potential of Google Earth Engine (GEE) App that allows utilising its vast geospatial data catalogue and computational ability. This tool developed automates the process of thermal anomaly detection at per-pixel level based on the deviation of LST provided by MODIS from climatological mean of last 23 years (2000-22).

2. STUDY AREA

The thermal anomaly tool developed in this study is capable of generating deviation from mean maps globally and thus detecting the thermal anomaly for the entire globe on a single click. The extent of the layer generated is based on the coverage and data availability of the input dataset i.e. MODIS Terra LST. Figure 1 shows the global climatological mean LST for 15th May for the years 2000-2022, calculated using the tool for the thermal anomaly detection.

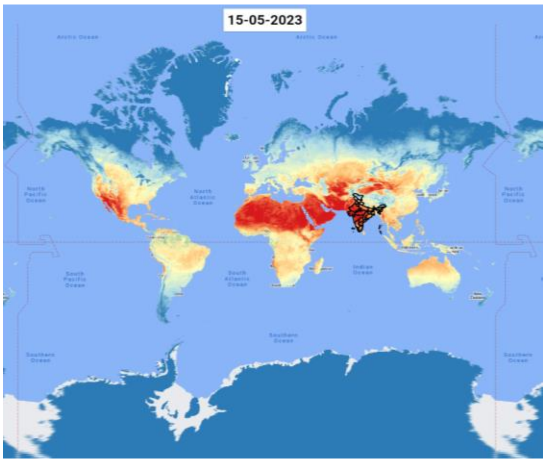

Figure 1. Climatological mean LST (2000-2022) for 15th May calculated using the tool shown in the GEE interface

3. MATERIAL AND METHOD

3.1 Satellite dataset

The present study uses Moderate Resolution Imaging Spectroradiometer (MODIS) Terra LST and emissivity data for detecting the long-term thermal anomaly for the entire globe. The generalized split-window approach is used to obtain MODIS LST data, and it estimates the emissivity from channels 31 and 32 based on the types of land cover, atmospheric column water vapor, and lower boundary air surface temperature. MODIS Terra LST provides the geospatial data of temperature of land surface daily for day time as well as night time at 10:30.

Data Name:	MOD11A1
Platform:	Terra
Instrument:	MODIS
Spatial Resolution:	1 Kilometre
Temporal Resolution:	Daily
Spatial Coverage:	Global
Temporal Coverage:	2000-till date

Table 1. Specification of the input satellite data used

Currently, the tool provides thermal anomaly based on MODIS Terra only, since it has more temporal coverage than MODIS Aqua LST, which is from 2002 and comparatively less amount of missing pixel data. The specification of the input data used in the current study is given in Table 1.

3.2 Methodology

Analysis of the long-term satellite data is necessary for thermal anomaly detection and monitoring. To handle this huge volume of data and perform analysis requires a platform with high computational facility. GEE provides such platform to perform high-end data analytics as well as it provides a vast catalogue of geospatial database globally (Gorelick et al., 2017). The entire study has been carried out using the GEE platform. In the present work, daily deviation from long-term climatological mean has been calculated for each date in order to identify the thermal anomalies and understand their spatio-temporal pattern.

MODIS Terra LST dataset has been retrieved from GEE for the entire globe. For the detection of thermal anomaly, standard deviation of the land surface temperature from the long-term climatological mean has been calculated. Extreme events or anomalies can be daily phenomenon, so in order to catch the anomalies at daily interval; deviation from mean has been calculated for each day as shown in Figure 2. The deviation of land surface temperature of a particular day in any year, let's say 2023, has been calculated from the climatological mean of the LST of that particular day for last 23 years i.e. from 2000-2022. While for any date selected before 2023, deviation has been estimated from the climatological mean of the day from 2000 to the previous year's LST i.e. for 2022; mean is calculated from 2000 to 2021 and so on.

Monitoring and detection of thermal anomaly over the entire globe at the spatial resolution of 1 kilometre has been made convenient by developing an application in GEE with the name 'Deviation from mean' tool. The interface and other features of the app or tool developed in the present study have been explained in further sections.

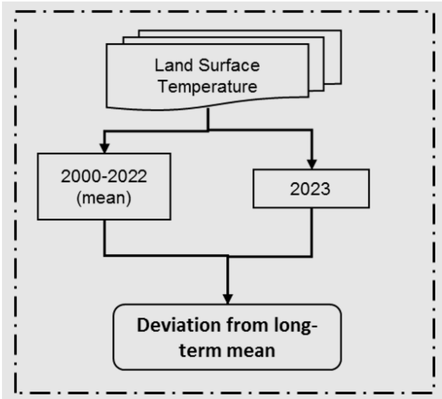

Figure 2. Flow diagram showing the basic steps involved in detecting thermal anomaly

4. RESULTS AND DISCUSSION

Long-term thermal anomaly detection and mapping at per-pixel level at global scale has been done in this study by developing a GEE tool. It provides a homogenous approach to detect the thermal anomaly all over the world and its continuous monitoring over long-term.

Interface of the tool- Deviation from mean

Along with various advantageous features of GEE, it also allows to make the user interface in the form of GEE application. ‘Deviation from Mean’ is one such application having a user-friendly interface having different features and showing the state boundary of India by default. This tool gives an option to the user to choose a date to analyze the thermal anomaly either from the calendar or from the date slider for narrow date range as shown in Figure 3. As soon as the user chooses any date, the deviation from mean layer gets created. Figure 4 shows the deviation from mean for 15th may 2023 that has been calculated using the tool.

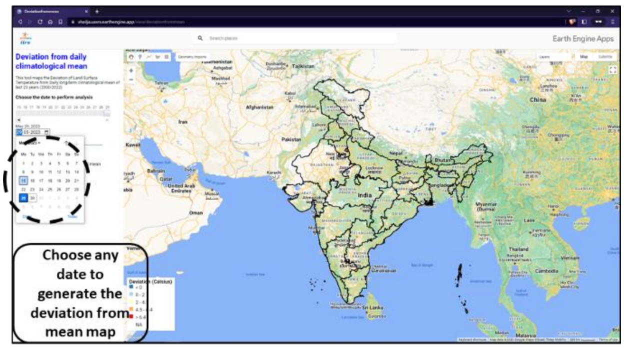

Figure 3. Interface of the app showing the India's state boundary

This tool has another feature of generating a time-series graph of the LST values at any particular location for last 24 years i.e. from 2000-2023. The year-range for the plots is common for all the pixels and it utilizes the entire database of MODIS day-time Terra LST available in GEE. Value of LST in the graphical form is shown in ºCelsius and is based on the availability of the data at that particular pixel over the years. The graphs get generated on the left panel when the user clicks on any location on the map. Multiple graphs can be generated for a single date.

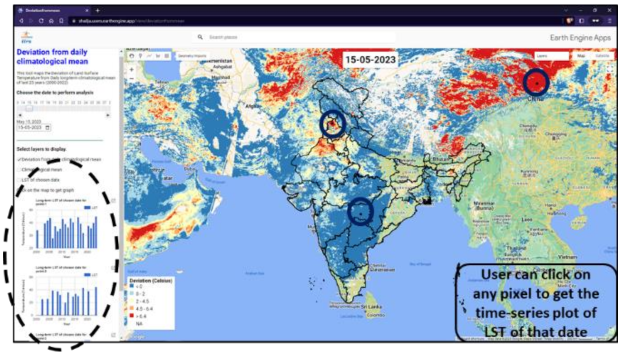

Figure 4. Multiple graphs shown on the left panel

In Figure 4, the graphs for three locations have been shown. These locations also get added on map as a point to highlight the locations for the graphs have been generated. For the 3 locations chosen, time-series plots have been generated that shows the variation of LST from 2000-2023. These graphs can be exported as Comma Separated Value (CSV), Scalable Vector Graphic (SVG) and/or Portable Network Graphic (PNG) file for further analysis as shown in Figure 5.

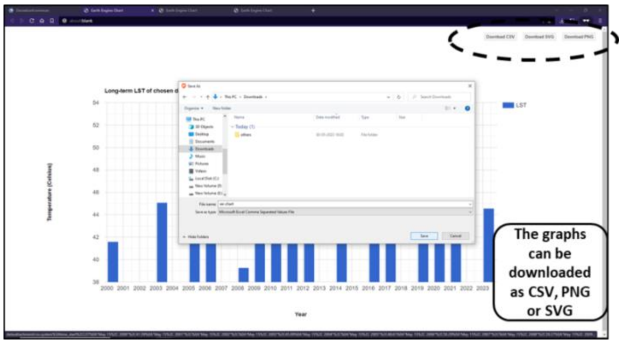

Figure 5. Time-series plot of the selected points shows the variation of LST from 2000-2023

The climatological mean and LST of the chosen date, which have been used to calculate the deviation from mean can also be visualized using the buttons on the left side panel (Figure 6). It utilizes the high computational resources of GEE to provide the continuous monitoring of thermal anomaly using high temporal resolution MODIS data globally at pixel-level.

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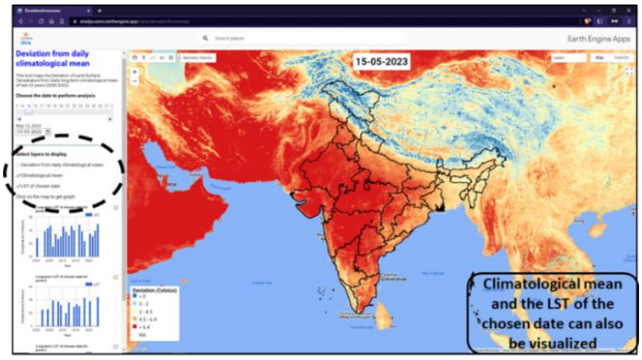

Figure 6. Climatological mean and LST of the selected date

Case study: Thermal anomaly detection for Indian Subcontinent

To showcase the potential applications of the tool, a case study has been conducted for the thermal anomaly detection over the Indian sub-continent for the months of March-April, 2022 and 2023. The deviation from long-term mean layers have been classified into five classes to highlight the increase in temperature in ºCelsius as per the criteria of heatwaves given by India Meteorological Department (IMD) (Bhadram et al., 2003; Pai et al., 2004) that has been kept constant for the entire globe.

The deviation from mean maps generated using the tool developed in the study, shown in Figure 7 for 11-20 March, 2022 shows the very high deviation of LST i.e. more than 6.4 ºC in the Tibetan region as well as in the Pakistan region along with the southern and central Indian part. While for the same dates in 2023, the deviation has been lowered.

Similar pattern can be observed while comparing for 1-10 April of 2022 and 2023 in Figure A1 in appendix. This shows the unusual warming of the Tibetan region and the central and southern part of India during March and April, 2022 which is lowered during the same months of 2023 due to precipitation resulted from the western disturbance (Wei et al., 2023).

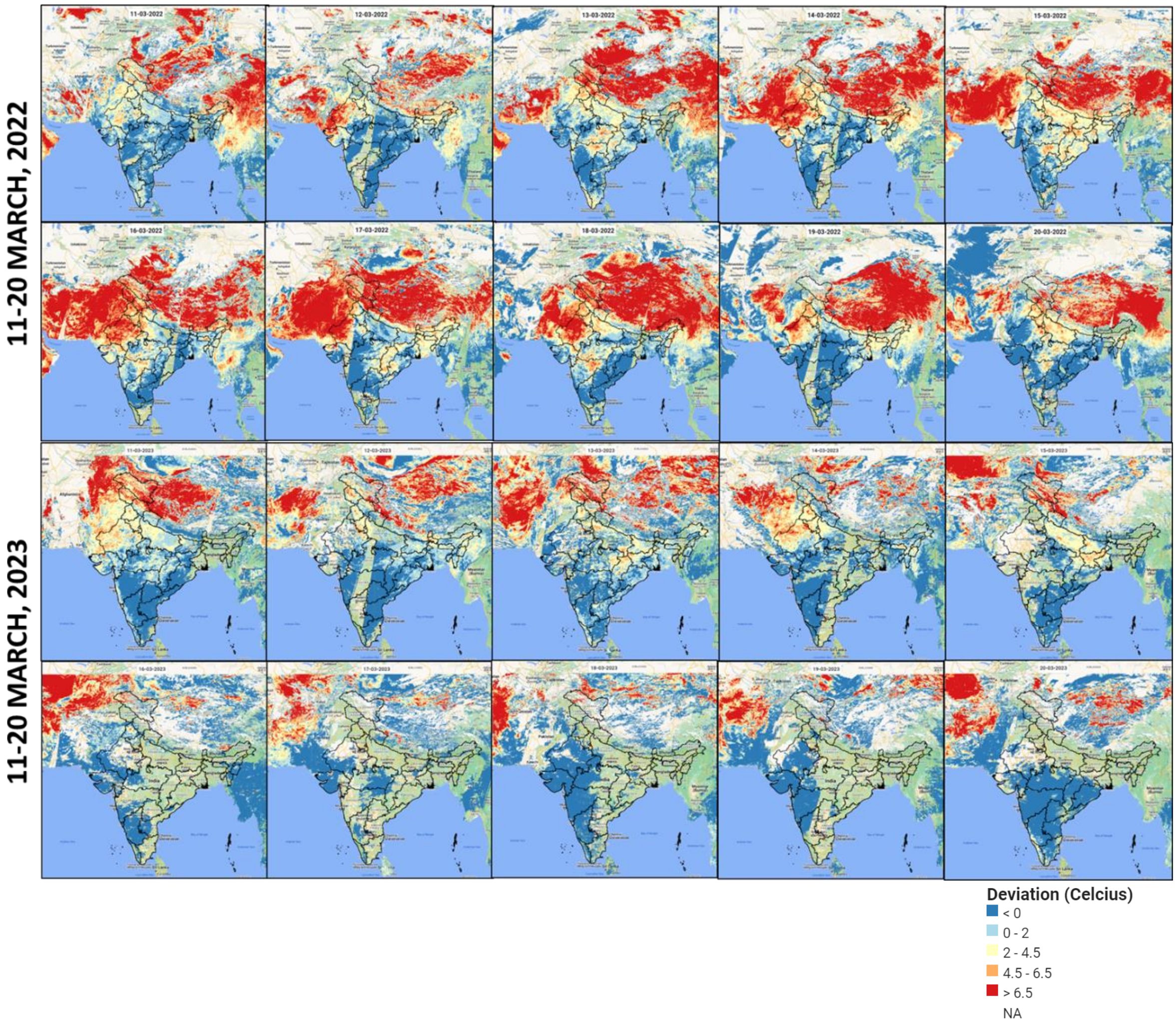

Figure 7. Deviation from mean maps generated from the tool for 11-20 March, 2022 and 2023

Time-series plot of the random points generated for the areas having high deviation values from the long-term mean LST from 2000-2023 for 15th May, 2023 over the Amritsar area is shown in Figure 8. The time-series plots showing the variation of LST from 2000-2023 states the anomalous warming of these locations on 15th May, 2023. LST values shows the sharp rise for the same date in 2005, 2010 and 2013. By utilizing the information from these graphs, thermal anomaly over a region can be detected, monitored and analyzed.

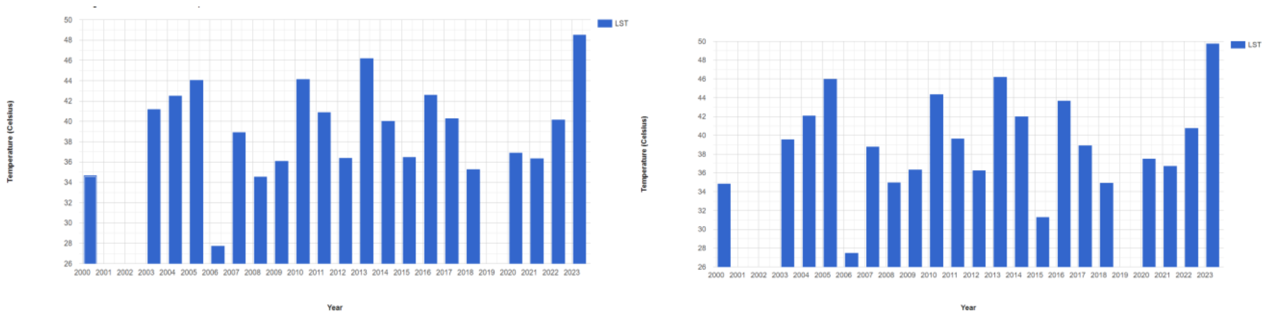

Figure 8. Time-series plot of LST for 15th May, 2023 of the random locations from Amritsar, India

5. CONCLUSION

The study concludes that the thermal anomaly detection and monitoring tool developed in the study can be proved to be extremely helpful in doing the global, regional as well as local level studies of detecting thermal anomalies whether leading to heat wave or cold wave which can help in taking region-specific mitigation measures. Future scope of this study aims at improving the user-friendly experience and performance of the tool to include the analysis part and also include other variables such as precipitation which can help in investigating the extreme events.

DATA AVAILABILITY

The study utilizes publicly available MODIS LST data which can be found in the GEE data catalogue on the link- https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD11A1. The link for the long-term thermal anomaly detection tool called 'Deviation from mean' that can detect, map and monitor thermal anomalies at daily interval globally can be provided upon request.

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REFERENCES

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Tank, A. M. G. K., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Kumar, K. R., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D. B., Burn, J., Aguilar, E., Brunet, M., … Vazquez-Aguirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, *111*, D05109. https://doi.org/10.1029/2005JD006290

Allan, R. P., Hawkins, E., Bellouin, N., & Collins, B. (2021). *IPCC, 2021: summary for Policymakers*.

Baumbach, L., Siegmund, J. F., Mittermeier, M., & Donner, R. V. (2017). Impacts of temperature extremes on European vegetation during the growing season. *Biogeosciences*, *14*, 4891–4903.

Bevacqua, E., Suarez-Gutierrez, L., Jézéquel, A., Lehner, F., Vrac, M., Yiou, P., & Zscheischler, J. (2023). Advancing research on compound weather and climate events via large ensemble model simulations. *Nature Communications*, *14*, 2145. https://doi.org/10.1038/s41467-023-37847-5

Bhadram, C. V. V., Amatya, B. V. S., Pant, G. B., & Kumar, K. K. (2003). Heat waves over Andhra Pradesh: A case study of summer of 2003. *Mausam*, *56*, 385–394.

Flach, M., Sippel, S., Gans, F., Bastos, A., Brenning, A., Reichstein, M., & Mahecha, M. D. (2018). Contrasting biosphere responses to hydrometeorological extremes: Revisiting the 2010 western Russian heatwave. *Biogeosciences*, *15*, 6067–6085.

Genzano, N., Pergola, N., & Marchese, F. A. (2020). Google Earth Engine Tool to Investigate, Map and Monitor Volcanic Thermal Anomalies at Global Scale by Means of Mid-High Spatial Resolution Satellite Data. *Remote Sensing*, *12*, 3232. https://doi.org/10.3390/rs12193232

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*.

Herrera-Estrada, J. E., & Sheffield, J. (2017). Uncertainties in Future Projections of Summer Droughts and Heat Waves over the Contiguous United States. *Journal of Climate*, *30*, 6225–6246.

Inouye, D. . (2008). Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology*, *89*, 353–362.

Jia, G., Shevliakova, E., Artaxo, P., Noblet-Ducoudré, D., Houghton, R., House, J., Kitajima, K., Lennard, C., Popp, A., Sirin, A., & Sukumar, R. (2019). Land-climate interactions. In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (pp. 131–248).

Jiang, L., Guli·jiapaer, G., Bao, A., Guo, H., & Ndayisaba, F. (2017). Vegetation dynamics and responses to climate change and human activities in Central Asia. *Science of The Total Environment*, *599–600*, 967–980.

Lehmann, J., Coumou, D., & Frieler, K. (2015). Increased record-breaking precipitation events under global warming. *Climate Change*, *132*, 501–515.

Liang, H., Jianbin, G., Wenbin, Y., Qunou, J., Lin, C., & Kexin, T. (2023). Multifaceted responses of vegetation to average and extreme climate change over global drylands. *Science of The Total Environment*, *858*(2). https://doi.org/10.1016/j.scitotenv.2022.159942

Pai, D. S., Thapliyal, V., & Kokate, P. D. (2004). Decadal variation in the heat and cold waves over India during 1971–2000. *Mausam*, *55*, 281–292.

Piao, S., Zhang, X., Chen, A., Liu, Q., Lian, X., Wang, X., Peng, S., & Wu, X. (2019). The impacts of climate extremes on the terrestrial carbon cycle: A review. *Science China Earth Sciences*, *62*, 1551–1563.

Seddon, A. W. R., Macias-Fauria, M., Long, P. R., Benz, D., & Willis, K. J. (2016). Sensitivity of global terrestrial ecosystems to climate variability. *Nature*, *531*, 229–232.

Seneviratne, S., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., & Reichstein, M. (2012). Changes in climate extremes and their impacts on the natural physical environment. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 109–230). Cambridge University Press. https://doi.org/10.7916/d8-6nbt-s431

Wei, H., Chen, B., Wu, S., & Xu, B. (2023). Impact of early heat anomalies on urban tree cooling efficiency: Evidence from spring heatwave events in India. *International Journal of Applied Earth Observation and Geoinformation*, *120*, 103334. https://doi.org/10.1016/j.jag.2023.103334

Wei, Y., Yu, M., Wei, J., & Zhou, B. (2023). Impacts of Extreme Climates on Vegetation at Middle-to-High Latitudes in Asia. *Remote Sensing*, *15*, 1251. https://doi.org/10.3390/rs15051251

APPENDIX

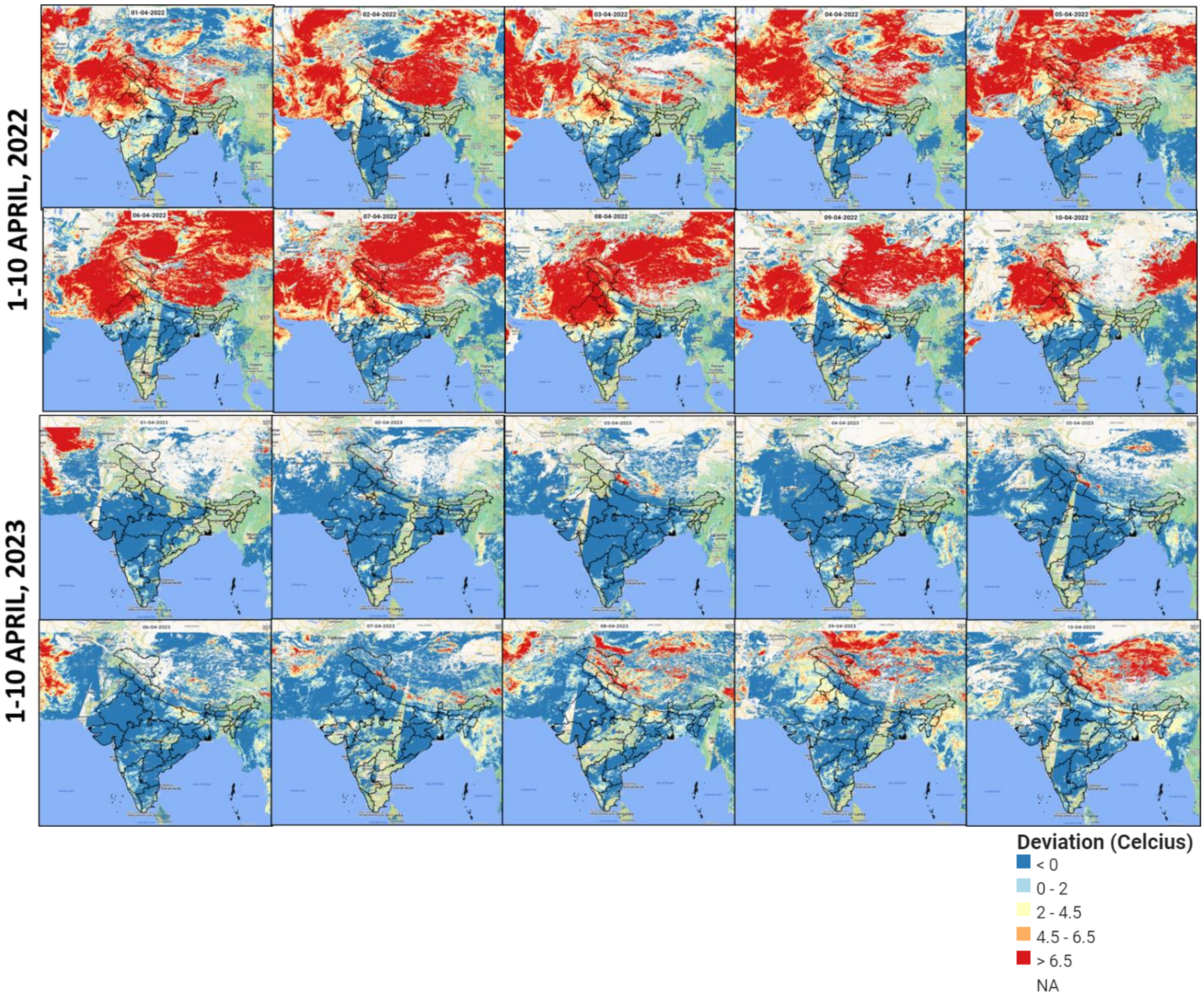

Figure A1. Deviation from mean maps generated from the tool for 1-10 April, 2022 and 2023

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