Mount Everest’s photogenic weather during the post-monsoon

Logan Grey1, Alexandria V. Johnson2, Tom Matthews3, L. Baker Perry4, Aurora C. Elmore5,6, Arbindra Khadka7,8,9, Dibas Shrestha9, Subash Tuladhar10, Saraju K. Baidya10, Deepak Aryal9 and Ananta P. Gajurel11

1Department of Physics & Astronomy, Purdue University, West Lafayette, Indiana, USA
2Department of Earth, Atmospheric, & Planetary Sciences, Purdue University, West Lafayette, Indiana, USA
3Department of Geography, King’s College London, London, UK
4Department of Geography & Planning, Appalachian State University, Boone, North Carolina, USA
5National Geographic Society, Washington, District of Columbia, USA
6National Oceanic & Atmospheric Administration, Washington, District of Columbia, USA
7University of Grenoble Alpes, CNRS, IRD, IGE, Grenoble, France
8International Centre of Integrated Meteorology Development, Lalitpur, Nepal
9Central Department of Hydrology & Meteorology, Tribhuvan University, Kirtipur, Nepal
10Department of Hydrology & Meteorology, Kathmandu, Nepal
11Department of Geology, Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal

Mount Everest, known locally as Sagarmatha or Qomolangma, is the world’s highest (8849m) and arguably most iconic, peak. That allure draws large numbers of tourists to Nepal every year with hopes of seeing or climbing the famed mountain. Importantly, the large tourist presence has wide ranging environmental (Napper et al., 2020; Aubriot et al., 2019; Semple et al., 2016; Faulon and Sacareau, 2020; Miner et al., 2021; Byers, 2005), cultural (Rai, 2017; Nepal et al., 2020), societal (Pallathadka, 2020; MOFA, 2021) and economic (Nyaupane, 2015; Mu, 2019) implications for the Khumbu Region of Nepal. Using data from a new array of automatic weather stations (AWSs) installed as part of the 2019 National Geographic and Rolex Perpetual Planet Everest Expedition (Matthews et al., 2020a,b) shows that seasonal variations in the weather on Mt. Everest modulates the timing of optimum climbing conditions for mountaineers. However, the influence of seasonality on the likelihood of visitors’ ability to view the famed summit from Mt. Everest’s (Nepalese) Base Camp has not been assessed. Here, we utilize previously unpublished photos taken twice-daily by an automatic camera at the Base Camp AWS (Figure 1), alongside meteorological data, to examine the impacts of weather on the visibility of this iconic peak that draws visitors from all over the world.

Using the seasonal timing identified by Matthews et al. (2020a), we investigate the conditions of both the 2019 and 2020 post-monsoon seasons (1 October to 30 November) using hourly measurements from five AWSs, at varying altitudes, along the Mt. Everest summit route (Figure 2a): Phortse (3810m), Everest Base Camp (5315m), Camp II (6464m), South Col (7945m) and Balcony (8430m). Here, we examine data encompassing two post-monsoonal seasons, spanning 1 August 2019 to 31 January 2021, the time periods when the upper slopes of Mt. Everest are least obscured by clouds. In addition to the numerical data recorded by the AWSs, a Campbell Scientific Canada CCFC Field Camera looking eastward toward the summit of Mt. Everest was also installed at Everest Base Camp during the 2019 Everest Expedition (Figure 1). As shown in Figure 2(a), the camera’s viewshed from left to right (north to south, respectively) primarily shows Mt. Everest’s West Ridge (~7000–7200m), Mt. Everest’s summit (8849m) and Nuptse’s sub-peak (~7400m). The camera takes two photographs daily at 0937 Nepal time (NPT) (0352 utc) and at 1437 NPT (0852 utc), respectively.

According to meteorological data, the summer monsoon brings significant changes to the Nepal Himalaya (Khadka et al., 2021), and herein, we show that the monsoon’s departure brings equally significant changes once more. One noticeable difference is the absence of cloud cover during the post-monsoon season, as suggested by AWS measurements of incoming shortwave radiation and downward
Mount Everest’s photogenic weather

157

Weather – May 2022, Vol. 77, No. 5

longwave radiation measured by the Camp II AWS (Figures 3a,b). Using the mean daily values for incoming shortwave and downward longwave radiation with a three-day running mean (Figures 3a,b), we can assess trends across seasonal changes for both 2019 and 2020. The transition from the monsoon to post-monsoon season shows an increase in incoming shortwave radiation accompanied by a decrease in downward longwave radiation.

Downwelling longwave is a function of the emissivity and temperature of the atmosphere. We separate these by computing the thermal emissivity of the surrounding air, $\varepsilon$ is the Stefan-Boltzmann constant approximated to 5.67E-8 W m$^{-2}$ K$^{-4}$ and $T$ is the mean daily air temperature (Kelvin) recorded at the Camp II AWS. Without an airborne device to record air temperature at cloud level, the 2m air temperature serves as an approximation for this. The three-day running mean of emissivity in Figures 3(c) and (d) shows a post-monsoonal drop in both years assessed. In 2019, the decline in emissivity was from 0.87 (±0.09, where uncertainty is one standard deviation) to 0.68 (±0.11); in 2020, the decline was from 0.82 (±0.11) to 0.62 (±0.07). Accompanied by the uptick in shortwave radiation, this drop suggests a lack of cloud, which would normally re- radiate longwave radiation back down towards the surface.

In support of the meteorological data, images collected from Base Camp looking towards the summit, which first became available on 11 October 2019, confirm an absence of post-monsoonal cloud cover. Figures 4 and 5 each contain five 32-day photo arrays depicting the seasonal changes in morning and afternoon cloud cover, respectively. Throughout manual assessment, these arrays show that the clouds enshrouding Mt. Everest during the monsoon season are replaced with clearer skies as the post-monsoon progresses. Of note, cloud coverage tends to increase into the afternoon when compared with the morning, especially during the monsoon season as shown by the differences between Figures 4(e) and 5(e). During the post-monsoon, afternoons also tend to be cloudier than mornings, but the diurnal variation is less pronounced than during the monsoon (Figures 4c and f; 5c and f). More photographic data from future years are needed to confirm this. Depending on the season, trekkers and climbers may want to be in line of sight of the peak earlier in the day should their goal be to see Mt. Everest’s summit.

We also monitored the changes in relative humidity (RH) at the Phortse, Base Camp, Camp II, South Col and Balcony AWSs for 2019 and the lower four stations for 2020 using the mean daily RH with a three-day running mean shown in Figures 3(e) and (f). The change in season from the monsoon to post-monsoon is accompanied by a significant drop in RH (Figures 3e and f) as the regional winds shift direction from off the Bay of Bengal and the Arabian Sea to more westerly continental trajectories (Perry et al., 2020). The drop in RH is most noticeable for the higher stations of Camp II and South Col located at 6464 and 7945m asl, respectively. In the 2019 post-monsoon, these stations experience a decrease from an average of around 90% RH to 20% RH over the course of 15 days, with a similar decrease from 80% to 20% observed in 2020, staying below 50% for the majority of the season. While data at the South Col station are missing during the transition to the post-monsoon, the RH is initially close to that at Camp II, so we expect it to have similar values up to and through the monsoon/post-monsoon transition, after which it begins to diverge slightly. Lower humidity post-monsoon is consistent with a decrease in cloud cover at that time.

Another quantity of interest is the specific humidity calculated for each station in both years with a three-day running mean (Figures 3g,h). Of the five stations, the Phortse and Base Camp AWSs see the largest decreases in specific humidity over a short period, from 8.8 to 4.0 and 6.1 to 2.0 g kg$^{-1}$, respectively, occurring at the same time as the similarly large decrease.
in RH. For both years, the specific humidity approaches its minimum towards the end of the post-monsoon for all stations.

The post-monsoon is also accompanied by a significant decrease in precipitation at Phortse (the only AWS for which precipitation data are currently available), shown by the plateauing of cumulative precipitation at the start of the season (Figures 3(i) and (j)). While a lack of precipitation at lower elevations alone may not directly indicate a lack of cloud coverage near the summit, the clear conditions along the lower section of the Nepali route will benefit climbers looking to catch an early glimpse of Mt. Everest.

Compared to the transition from the monsoon to the post-monsoon, the continuation into winter currently provides much smaller but still noteworthy changes in atmospheric conditions. RH shown in Figures 3(e) and (f) continues to decrease and reaches a minimum for the observed time period. The mean emissivity in Figures 3(c) and (d) sees little change, falling from 0.68 (±0.11) to 0.67 (±0.14) for 2019, and for 2020, from 0.62 (±0.07) to 0.61 (±0.09). Specific humid-
secondary climbing window. Due to the significantly higher burden of supporting staff and resources required by prospective summit climbers, the pressure of the mountain’s workers and the environment during the pre-monsoon climbing season could be significantly reduced if even more trekkers who are seeking to view Mt. Everest, rather than summit, travelled there during the post-monsoon.

Acknowledgements
This research was conducted in partnership with National Geographic Society, Rolex and Tribhuvan University, with approval from all relevant agencies of the Government of Nepal. We gratefully acknowledge the communities of the Khumbu Region and the Sherpa climbing team for their efforts in aiding the setup and maintenance of the AWSs, as this work would not be possible without them. We also thank the reviewers for their time and their helpful feedback which improved this manuscript.

References
Aubriot O, Faulon M, Sacareau I et al. 2019. Reconfiguration of the water–energy–food nexus in the Everest tourist region of Solukhumbu, Nepal. Mt Res Dev. 39: R47–R59.
Baral N, Kaul S, Heinen J et al. 2017. Estimating the value of the World Heritage Site designation: a case study from Sagarmatha (Mount Everest) National Park, Nepal. J. Sustainable Tour. 25: 1776–1791.
Byers A. 2005. Contemporary human impacts on Alpine ecosystems in the Sagarmatha (Mt. Everest) national park, Khumbu, Nepal. Ann. Assoc. Am. Geogr. 95: 112–140.
Faulon M, Sacareau I. 2020. ‘Tourism, social management of water and climate change in an area of high altitude: The Everest massif in Nepal. J. Alp. Res. 108(1): rga.6779.
Khadka A, Matthews T, Perry LB et al. 2021. Weather on Mount Everest during the 2019 summer monsoon. Weather 76: 205–207.
Matthews T, Perry LB, Abernathy K et al. 2020a. Going to extremes: installing the world’s highest weather stations on Mount Everest. Bull. Am. Meteorol. Soc. 101(11): E1880–E1890.
Matthews T, Perry LB, Lane TP et al. 2020b. Into Thicker(e) Air? Oxygen Availability at Humans’ Physiological Frontier on Mount Everest. Science 331(6017): 101718.
Miner KR, Clifford H, Taruscio T et al. 2021. Deposition of PFAS ‘forever chemicals’ on Mt. Everest. Sci. Total Environ. 759: 144421.
MOCTCA. 2020. Nepal tourism statistics–2019. Singha Durbar, Nepal. Government of Nepal - Ministry of Culture, Tourism & Civil Aviation, Planning & Evaluation Division Statistical Section. https://www.tourism.gov.np/files/NOTICE%20MANAGER_FILES/Nepal_%20tourism_statistics_2019.pdf [Accessed 22 September 2021].
MOFA. 2021. Tourism in Nepal. Government of Nepal - Ministry of Foreign Affairs: Kathmandu, Nepal. https://mofa.gov.np/about-nepal/tourism-in-nepal/ [Accessed 3 August 2021].
Mu Y, Nepal SK, Lai P-H. 2019. Tourism and sacred landscape in Sagarmatha (Mt. Everest) National Park, Nepal. Tourism Geographies 21(5): 442–459.
Napper IE, Davies BFR, Clifford H et al. 2020. Reaching new heights in plastic pollution—preliminary findings of microplastics on Mount Everest. One Earth 3: 621–630.
Weather radar in Nepal: opportunities and challenges in a mountainous region

Rocky Talchabhadel1, Ganesh R. Ghimire2, Sanjib Sharma3, Piyush Dahal4, Jeeban Panthi5, Rupesh Baniya6, Jayaram Pudashine7, Bhes Raj Thapa8,9, Shakti P.C.10 and Binod Parajuli11

1Texas A&M AgriLife Research, Texas A&M University, El Paso, Texas, USA
2Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37381, USA
3Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, Pennsylvania, USA
4The Small Earth Nepal, Kathmandu, Nepal
5Department of Geosciences, University of Rhode Island, Kingston, Rhode Island, USA
6Institute of Engineering, Pulchowk Campus, Tribhuvan University, Lalitpur, Nepal
7Bureau of Meteorology, Melbourne, Australia
8Universal Engineering and Science College, Lalitpur, Nepal
9Nepal Academy of Science and Technology (NAST), Lalitpur, Nepal
10National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan
11Department of Hydrology and Meteorology, Ministry of Energy, Water Resources and Irrigation, Kathmandu, Nepal

Extreme rainfall is one of the major causes of natural hazards in the central Himalayan region, including Nepal. The performance of strategies to manage hazards and related risks relies on the accuracy of quantitative hydro-meteorological prediction. Rain gauges have traditionally been used to measure the rainfall amount. However, point measurements with limited gauge coverage cannot accurately represent spatial precipitation variability in complex topography. Weather radar have shown potential for useful information on accurate area rainfall estimates. The Department of Hydrology and Meteorology (DHM) in Nepal installed their first weather radar in 2019 in the western region of the country. Two more radars will be added to the planned radar network in the near future, in the country’s central and eastern regions, respectively. We highlight both the opportunities and challenges with radar installation and observation in the mountainous regions. Radar-rainfall estimates across the Himalayas can be useful to inform decision-making in a broad range of infrastructure sectors, including water, energy, construction, transportation, and agriculture.

Introduction

Extreme rainfall-driven hazards such as flash-floods, debris flows, and landslides pose a major risk to life and property in the Himalayan region, including Nepal. Himalayan river basins are characterized by steep slopes and fast runoff processes (DWDIP, 2014). Hence timely and accurate hydrometeorological predictions are sensitive to the spatiotemporal variability of rainfall. Also, numerical modelling of extreme hydrometeorological events is challenging because of observational constraints. Nepal has a diverse climate, ranging from tropical in the southern lowlands to polar across northern mountain peaks and temperate in the mid-hills (Talchabhadel and Karki, 2019). It is national that approximately 8400 weather-related deaths are recorded in Nepal from 1983 to 2013, with an average of 269