IJIST
P ISSN : 2618-1630
E ISSN : 2909-6130

Frontal System Track Variation and Its Impact on Water Availability in Northern Pakistan Using Remote Sensing and Ground Data During Monsoon Season- 2019

Original Article

J. Qureshi[1], S.A. Mahmood[1], A. Amin[1], T. Mahmood[1]
[1]Department of Space Science, University of the Punjab, Lahore, Pakistan.
***Correspondence**: Jahanzeb Qureshi; Email: jzebqureshipu@gmail.com

Citation | J. Qureshi, S. A. Mahmood, A. Amin, and T. Mahmood, "Frontal System Track Variation and Its Impact on Water Availability in Northern Pakistan Using Remote Sensing and Ground Data During Monsoon Season- 2019", IJIST, Vol. 5, No. 1, pp. 56-67, Jan. 2023.
DOI: https://doi.org/10.33411/IJIST/2023050104
Received | Nov 16,2022 ;**Revised** | Dec 23,2022 ;**Accepted** | Dec 28,2022 ;**Published** | Jan 02,2023.

Pakistan, which is positioned in the South Asian sub-continent, occupies a significant climatological location. It is included among the world's few countries which experience a comprehensive transformation from summer all the way to winter season. The variation in precipitation has direct and significant consequences on society. In this ongoing research, the latitudinal variation in the track of the frontal system and trends in Pakistan during the monsoon period have been examined. Meteorological data (monthly rainfall, maximum temperature, satellite images, upstream data for Tarbela, Mangla, Rasool, and Marala) has been taken to conduct the ongoing research. Consequently, the focus of the study is the frontal weather system that moves North of Pakistan and energizes the monsoon rainfall over the Indus Basin which makes it a source of flooding. The rainfall is the cause of flooding downstream of rivers in the plains of Punjab and Sindh. Varying trends in rainfall were observed across the selected stations in Pakistan. The ongoing research is conducted across Pakistan with Gilgit and Skardu being the cities in Northern Pakistan. Among all the water reservoirs, Tarbela exhibited an increased upstream flow due to the snow melt factor over glaciers in Gilgit and Skardu because of an increase in maximum temperature.

Keywords: Climatological, Precipitation, Latitudinal, Meteorological, Flooding.

Project details.
The current research is a result of Punjab for the Fiscal year 2019-20.of the research project grant awarded by the University of the Punjab.

Conflict of interest.
The authors declare that there exists no conflict of interest for publishing this manuscript in IJIST.

Acknowledgments
The authors are thankful to the University of Punjab (Lahore, Pakistan) for providing financial assistance. The author also acknowledges Pakistan Meteorological Department (PMD) for providing valuable meteorological data for the current research.

Author's Contribution.
The corresponding author (J. Qureshi) has hypothesized, processed, and formulated the data. Co-author (S. A. Mahmood) contributed to organizing and formulating the data while the rest co-authors (A. Amin and T. Mahmood) contributed to data collection.

Introduction

Pakistan occupies a distinctive position in the world. It receives extensive monsoonal rainfall as well as winter rainfall because of western disturbances. In meteorology, floods are considered one of the most devastating hazards. Many countries in the world experience this chaos primarily due to extensive rainfall in the catchments of any specific river [1] [2][3]. In the past, Pakistan encountered devastating floods during the years 1958, 1974, 1988, 1992, etc. and all these floods happened during the period of summer monsoon [4][5]. Pakistan's climate widely varies from one location to another. Generally, its climate is arid to semiarid categorized by blistering summers as well as chill cold winters. It has extreme temperature variations at various locations, apart from the southern Himalayas slopes and in the sub-mountain zone, where the yearly rainfall varies from 760 mm to 2000 mm [6][7][8]. Occasionally, it experiences a lot of rainfall in the area when cold air advection aloft occurs because of westerly waves in the summer season [9][10]. Northern Pakistan receives more heavy rainfall episodes than the rest of the country [11][12][13] while it abruptly reduces towards the southern half of the country[10][14]. The reason for it is because of the elevated topography in northern Pakistan. It receives moisture from the Bay of Bengal (BoB) along the Arabian Sea and hence becomes cooler as it moves on to the northern parts of the country resulting in precipitation [14].

In summer Low-Pressure Systems (LPS) originate over the Arabian Sea and BoB and these are the chief moisture source contributors resulting in rainfall over Pakistan [15]. These LPS which develop over BoB move Northwest (NW) causing heavy rainfall in Kashmir and upper Punjab finally resulting in the flood disaster in the country. Pakistan's upstream and downstream hydrological regime is extremely interrelated. If Northern parts of the country receive excess water either by heavy rainfall or by the melting of snow/glaciers, it instantly moves down to the lower elevation plains of Punjab and Sindh not only flooding the cultivated lands but destroying standing field crops as well [16]. The frontal weather system (atmospheric fronts) not only plays a key role in the weather variability in the mid-latitudes but is regularly linked with high-impact weather episodes e.g., wind, gusts, hail, or precipitation [17]. Procedures for automatic objective frontal analysis [18][19] frequently depend on the definition of a thermal frontal parameter. Several regional and global climatology depend on the processed thermal front parameter approach [20][21] along with trend analyses for the past, recent, and future forecasts e.g., [22][23]. A front is regarded as a transition area between two air masses of distinct densities. As density variations are normally caused by temperature changes, fronts generally split air masses with differing temperatures (Figure.1). They generally separate air masses with varying humidities also [24][25][26]. Air masses exhibit both vertical and horizontal extension. Accordingly, the upward extension of a front is described as a frontal zone or can be regarded as a frontal surface [27].

The primary objective of this study is to track the frontal system North of Pakistan between latitudes (35°N to 50°N). The frontal system in the monsoon period brings rainfall and flooding and when there is the presence of westerly waves it accentuates and energizes the monsoon system. It can condense the available moisture over plains as well.

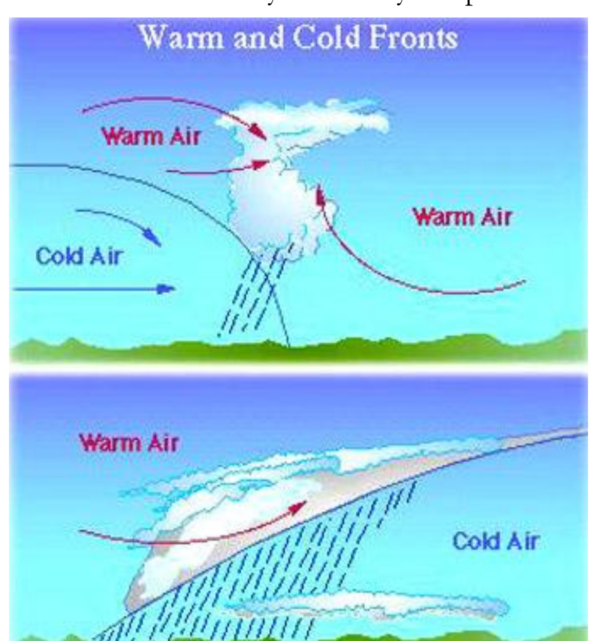


Figure 1. The formation of warm and cold fronts [3]

Material and Methods.

There are three main types of rainfall: orographic, frontal, and convective. Pakistan experiences all three types of rainfall depending upon the location and season of the year. It may also be emphasized that precipitation is the most variable parameter of all-weather factors over the temporal and spatial scales [28]. Meteorological data (monthly rainfall, maximum temperature, satellite images, upstream data for Tarbela, Mangla, Rasool, and Marala) was collected from Pakistan Meteorological Department, Lahore, Pakistan for the monsoon months (July-September 2019). For monthly rainfall assessment stations were selected from central and northern Pakistan having variations in their latitudinal locations. Graphs were plotted for these parameters to analyze the rainfall trends for the said stations (Islamabad, Murree, Jhelum, Mangla, Gilgit, Skardu, and Kotli). Tarbela Reservoir is quite vital for Pakistan's economy due to its hydrological setting. It has a regular pattern of inflow, with the annual hydrograph that is dominated by snow meltwater, which usually starts to build up at the start of May, peaks in July and has virtually finished by the September end [29][30]. To assess this fact graphs were plotted between Tarbela upstream flow and maximum temperature for Gilgit and Skardu in Northern Pakistan. Satellite images from European Meteorological Satellite (EUMETSAT) were used to identify the frontal system and cloud top temperature for the said period. The adopted research methodology adopted in the ongoing research is shown by the flow chart (Figure.2).

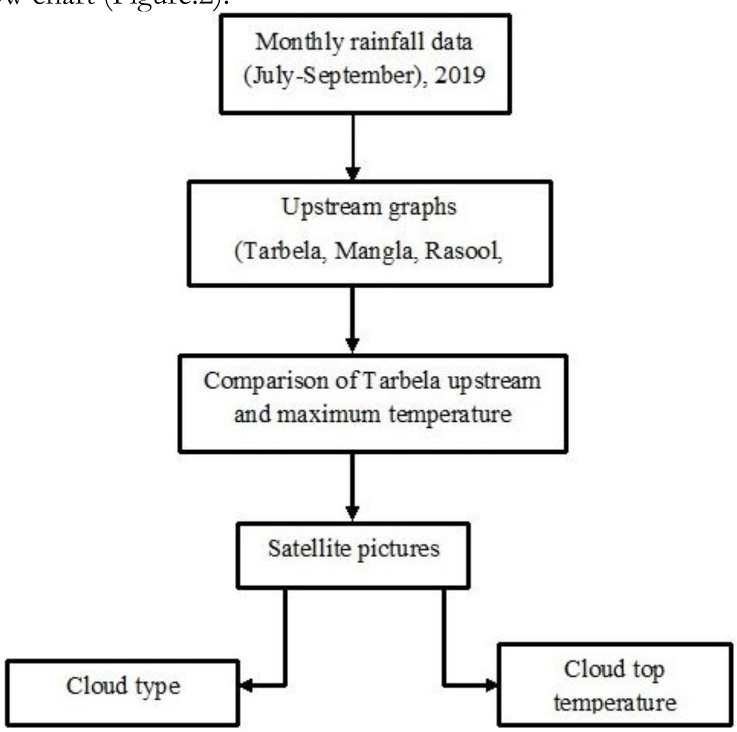


Figure 2. Flow chart of the methodology adopted for research

Result and Discussion.

Monthly Rainfall Analysis from (July-September), 2019

In the month of July pronounced rainfall (1004 mm) over the Islamabad, Jhelum, Mangla, and Murree areas was due to the monsoon system, and lesser rainfall over Gilgit, Skardu, and Kotli areas is due to the absence of western disturbances. In August there is more rainfall than in July over the Islamabad-Murree area due to the strong monsoon effect but in the Gilgit-Skardu area, it's due to weak western disturbances. In September strong monsoon is contributing more rainfall over Islamabad, Jhelum, Mangla, and Murree areas whereas due to the absence of western disturbance there is one odd occasion of rainfall in the Gilgit-Skardu area (Tables 1-3, Figures. 3-5).

Table 1: Rainfall data for July 2019

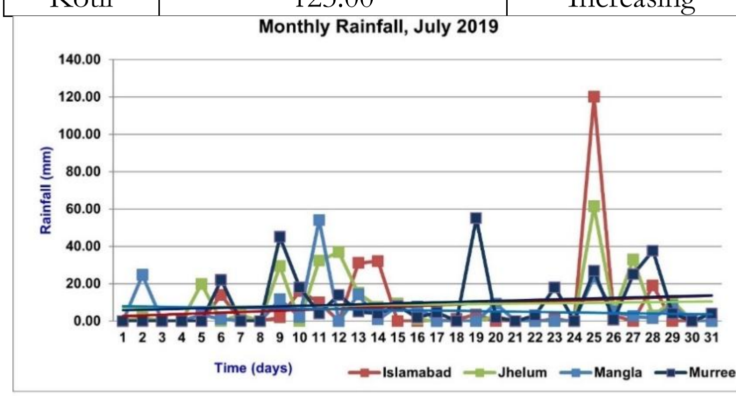
City	Monthly Rainfall (mm)	Rainfall Trend
Islamabad	252.44	Increasing
Jhelum	271.42	Decreasing
Mangla	177.91	Decreasing
Murree	302.61	Increasing
Gilgit	4.63	Very low rainfall
Skardu	1.23	Very low rainfall
Kotli	147.62	Increasing

Table 2: Rainfall data for August 2019

City	Monthly Rainfall (mm)	Rainfall Trend
Islamabad	494.51	Decreasing
Jhelum	196.51	Decreasing
Mangla	187.13	Decreasing
Murree	233.31	Decreasing
Gilgit	15.45	Decreasing
Skardu	32.55	Decreasing
Kotli	268.20	Decreasing

Table 3: Rainfall data for September 2019

City	Monthly Rainfall (mm)	Rainfall Trend
Islamabad	97.63	Increasing
Jhelum	131.53	Increasing
Mangla	183.54	Increasing
Murree	62.30	Increasing
Gilgit	0.03	Very low rainfall
Skardu	0.21	Very low rainfall
Kotli	123.00	Increasing



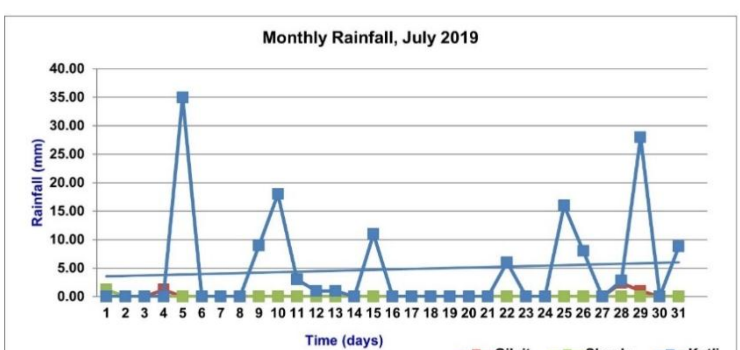


Figure 3. Graph showing monthly rainfall for selected stations in July 2019

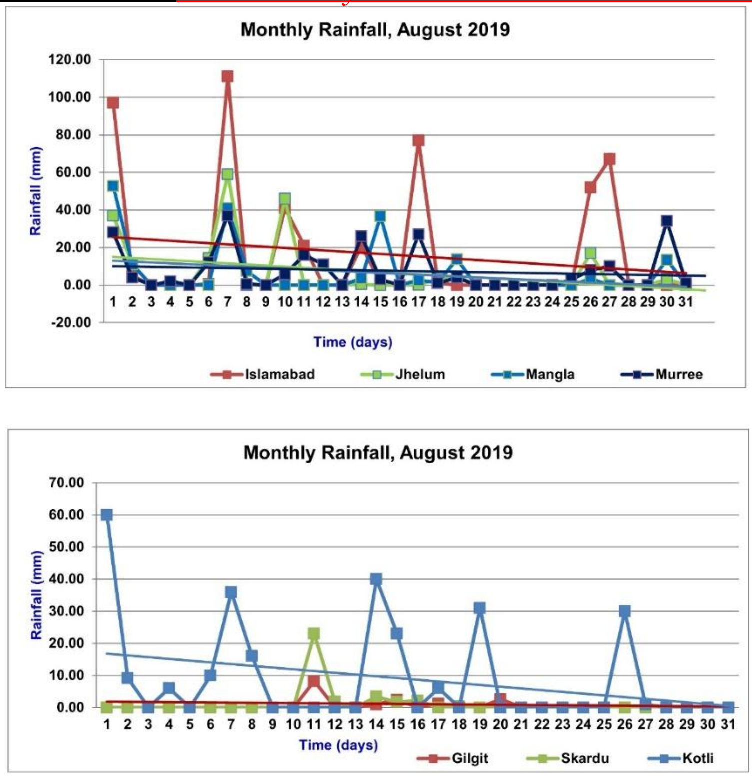


Figure 4. Graph showing monthly rainfall for selected stations in August 2019

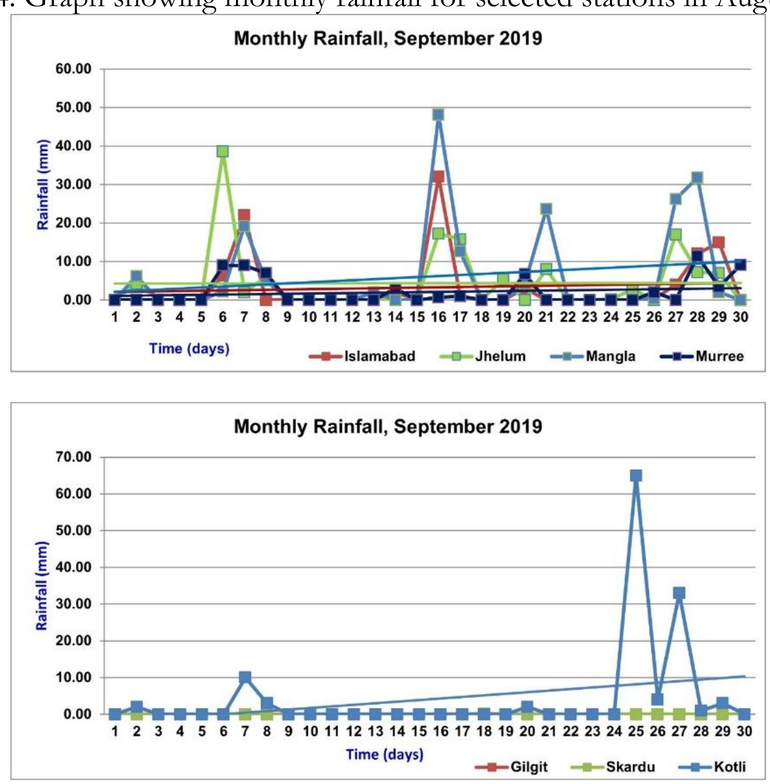


Figure 5. Graph showing monthly rainfall for selected stations in September 2019

Upstream Graphs

Upstream graphs were plotted for Tarbela, Mangla, Rasool, and Marala water reservoirs. All the water reservoirs except Tarbela exhibited almost the same trend. The rainfall patterns clearly show an increase and decrease in upstream inflows at Tarbela which is the first water availability monitoring station over the Indus River (Figure. 6).

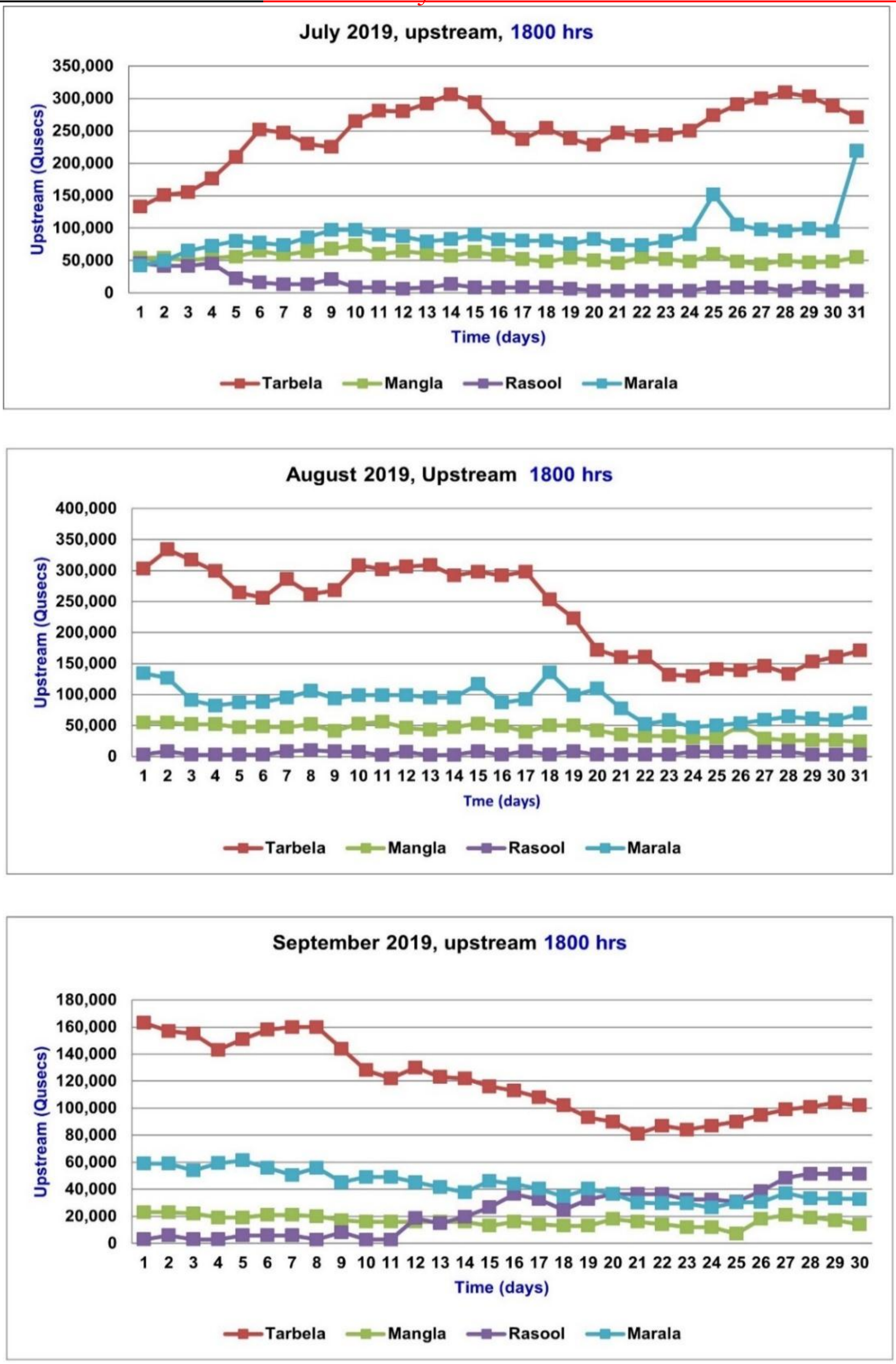


Figure 6. Graphs showing upstream patterns for water reservoirs (July-September) 2019

Tarbela Upstream Flow and Maximum Temperature

The increase in temperature in the Gilgit-Skardu region results in glacier melting which contributes towards the increase in upstream inflows at Tarbela; though there is a long-term effect because of which flow of water from the upper Indus catchment region (Gilgit-Skardu) to Tarbela monitoring station takes some 30-40 hours which is depicted as black insets in the graphs (Figures. 7-8). Similarly, a fall in temperature in the upper Indus region (Gilgit-Skardu) is also reflective of decreasing trend of upstream inflows at Tarbela station which is also called the first measuring station (rim station).

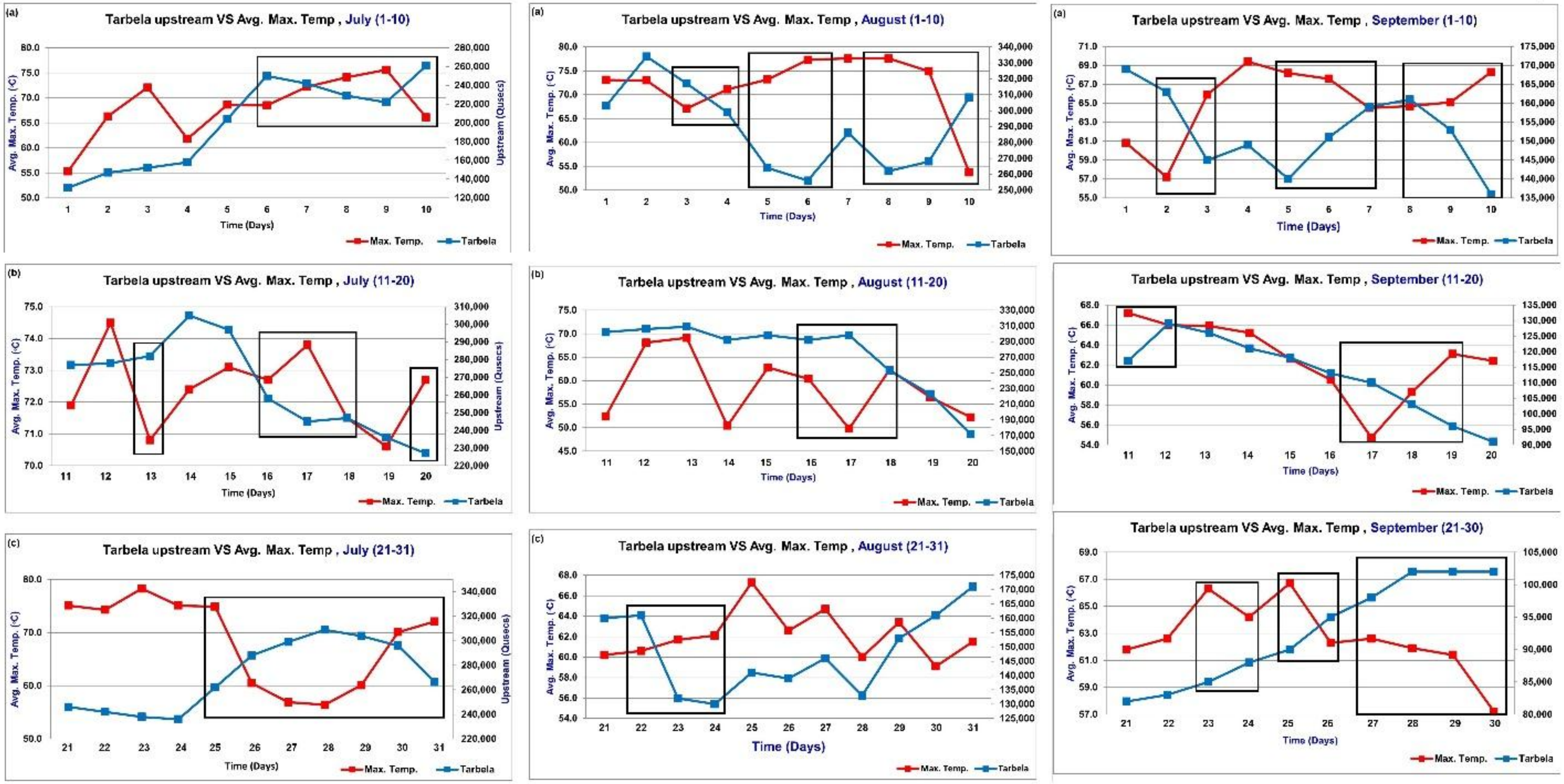


Figure 7. Comparison between Tarbela upstream pressure and average maximum temperature for Gilgit and Skardu(combined), July-September 2019.

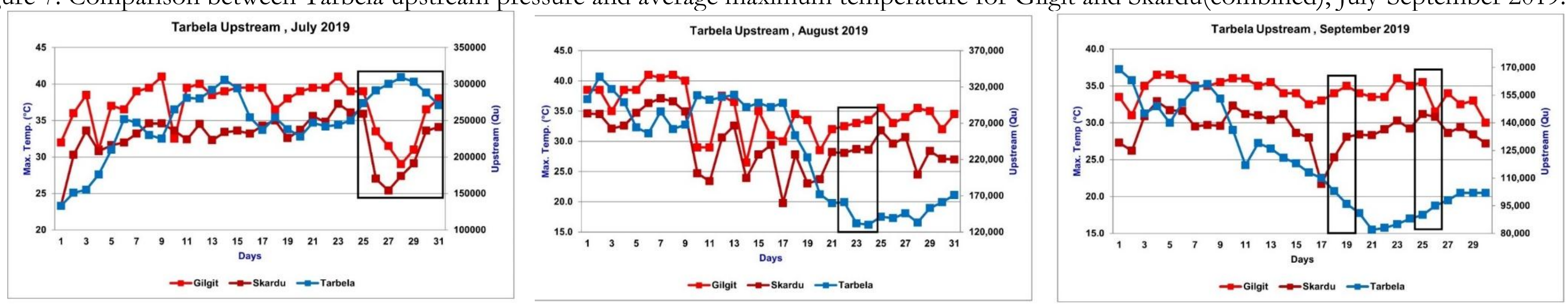


Figure 8. Tarbela upstream vs maximum temperature for Gilgit and Skardu (July-September 2019)

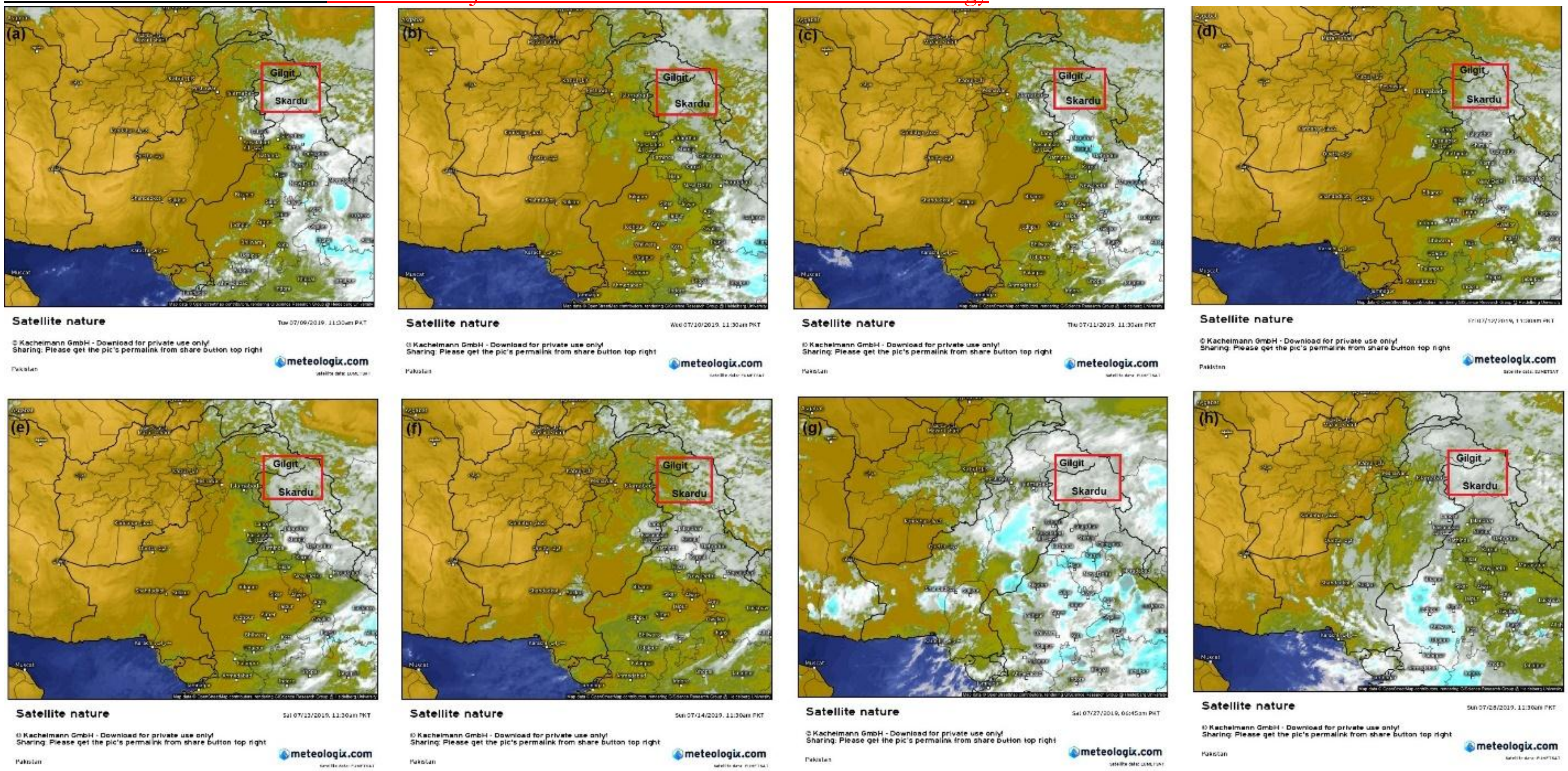


Figure 9. Satellite pictures across Pakistan for July 2019

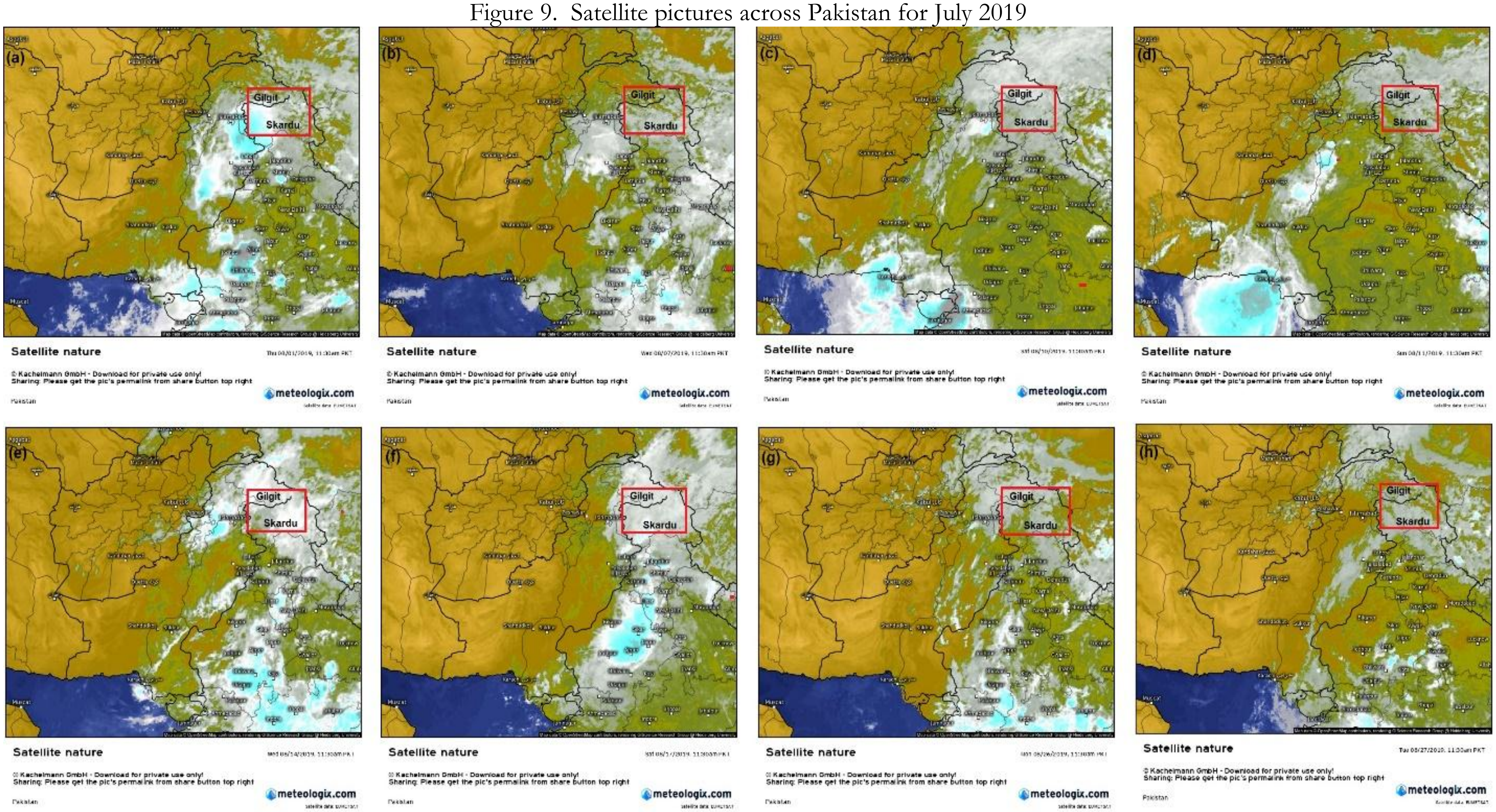


Figure 10. Satellite pictures across Pakistan for August 2019

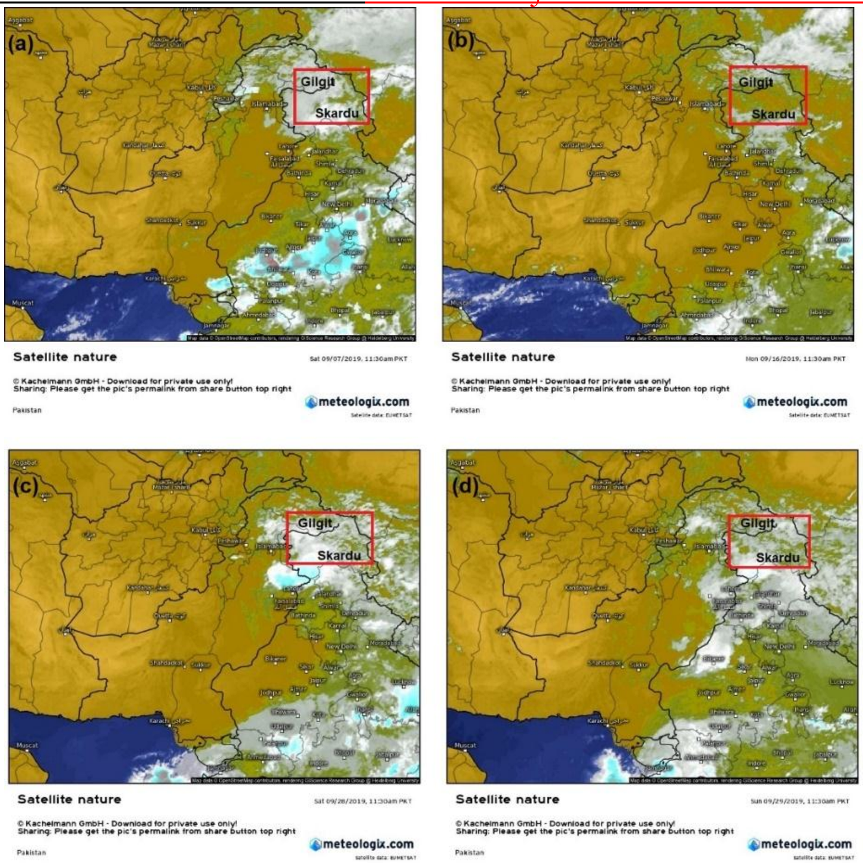


Figure 11. Satellite pictures across Pakistan for September 2019

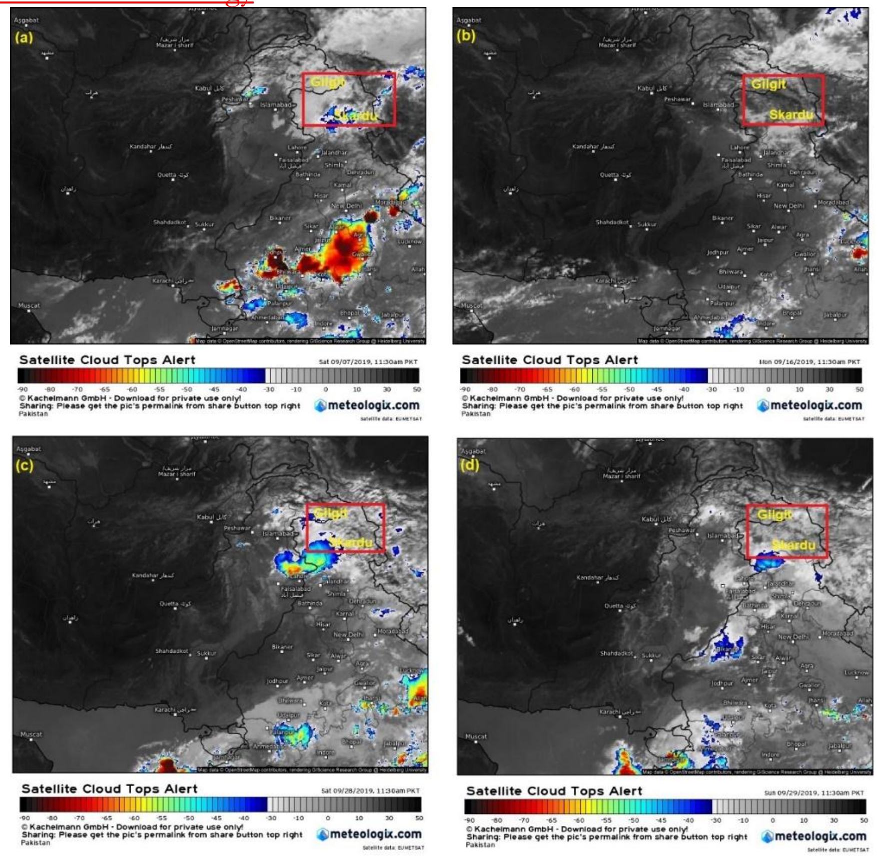


Figure 12. Satellite pictures for cloud top temperature for September 2019

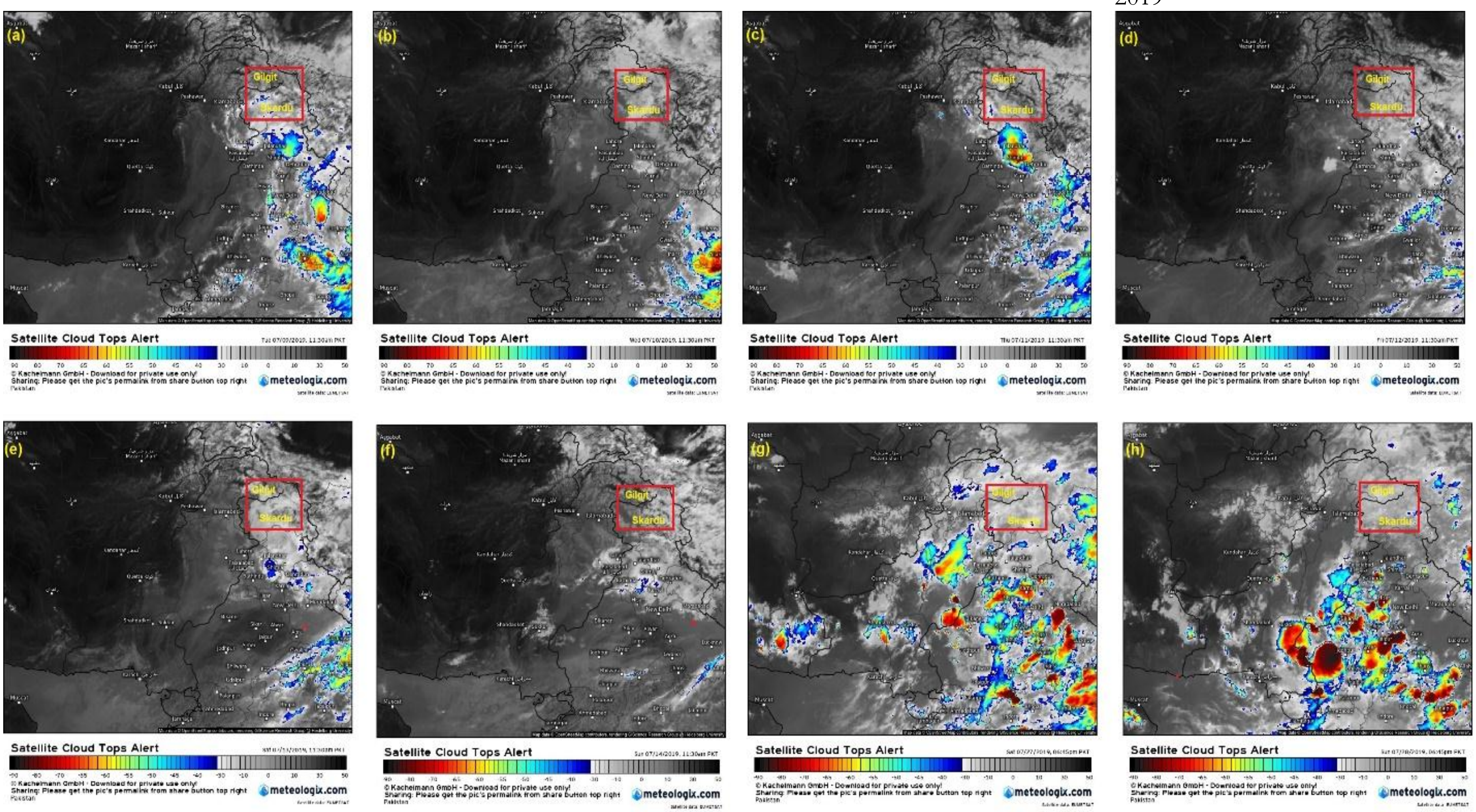


Figure 13. Satellite pictures for cloud top temperature for July 2019

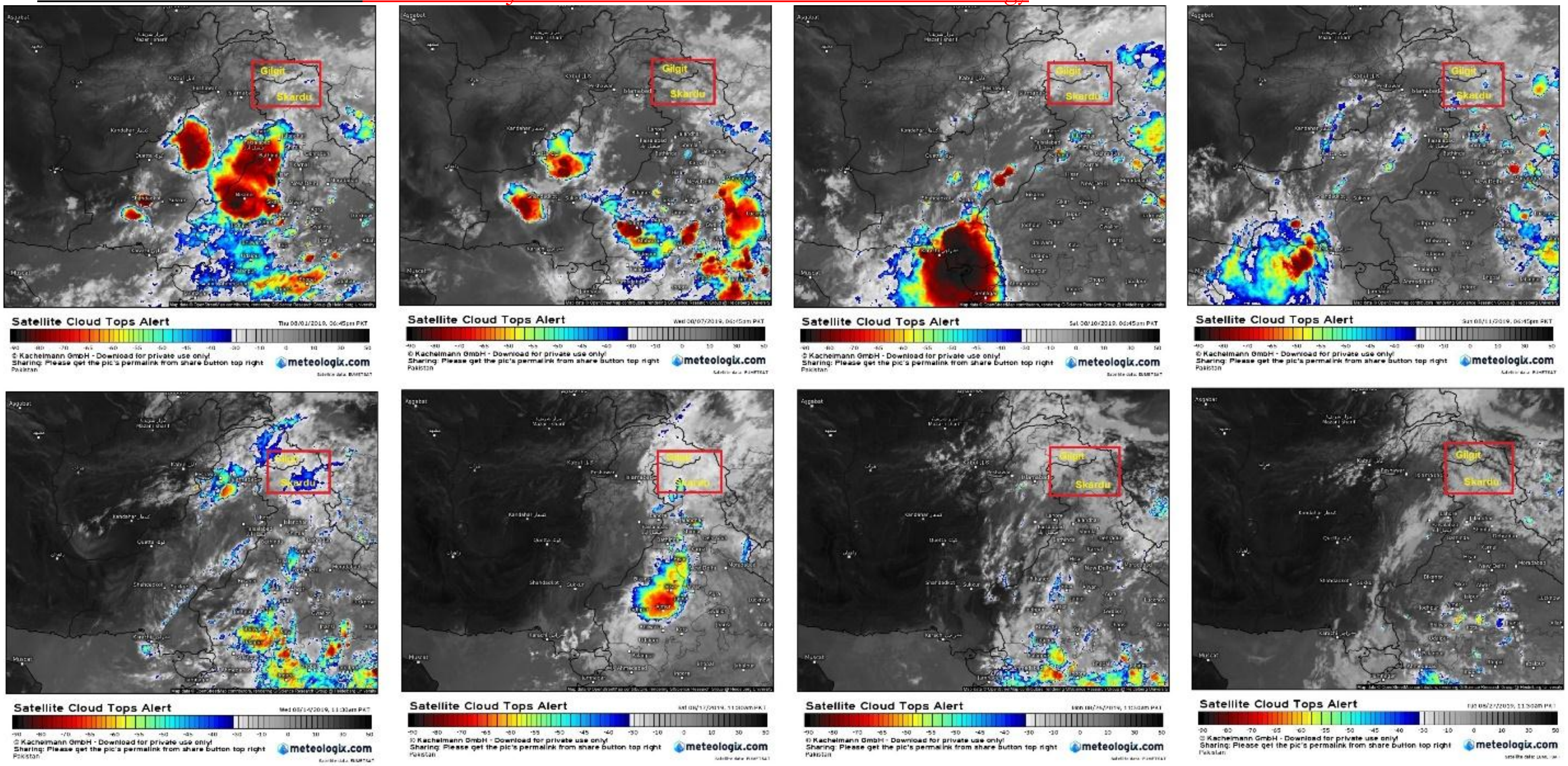


Figure 14. Satellite pictures for cloud top temperature for August 2019

Satellite Pictures

Satellite pictures of selected days were chosen for the summer monsoon months of July, August, and September 2019. The days were chosen based on the amount of rainfall recorded over the Gilgit and Skardu areas (Northern Pakistan). The average height of Gilgit and Skardu is 1550 m and 2150 m respectively above the Mean Sea Level (MSL). The satellite pictures clearly show the clouds in three different colors (white, grey, and blue) based on varying cloud temperatures. Mostly Gilgit and Skardu regions are covered by grey clouds as shown in the red inset (Figures. 9-11). Grey clouds in the satellite pictures show mountainous areas have cloud temperatures between 0 to -10°C (Figures. 12-14). These clouds either have no or very low precipitable water which is also clear from the rainfall amount over Gilgit and Skardu during monsoon months (Tables 1-3). The Lapse rate of temperature is 1.8°C per 300 m.

White clouds in the satellite pictures which are cumulus and altocumulus clouds show cloud temperatures between (-25 to -30°C) while blue clouds which are large Cumulus and Cumulonimbus exhibit cloud temperatures of -35°C (Figures. 9-11). The freezing level at 0°C is 3700 m whereas cloud temperature at -10°C means a further 1550 m. above 3700 m makes 5250 m in total. As mentioned earlier the average height of Gilgit is approx. 1500 m. above MSL, hence subtracting this height from 5250 m makes it 3700 m which is the cloud height over Gilgit from the ground level. Likewise, for Skardu with an average height of 2150 m above MSL, the cloud height is 3100 m ft. from the ground level.

Conclusion

The snow melt is a dominating factor for an increased inflow due to an increase in maximum temperature over Gilgit and Skardu. Upstream inflow at Tarbela is dependent upon two variables which are rainfall and temperature both increasing and decreasing. It was observed that monsoon rainfall is more in the areas of Islamabad, Jhelum, Mangla, and Murree as compared to the Gilgit-Skardu region that lies in Northern Pakistan either due to the absence or weak western disturbances. Satellite pictures also show the cloud color and varying temperature over the Gilgit-Skardu region which is the main snow-contributing/glaciers factor.

References

[1] Afzaal, M., Haroon, M. A., & Zaman, Q "Interdecadal oscillations and the warming trend in the area-weighted annual mean temperature of Pakistan". "Pakistan Journal of Meteorology", 2009, 6(11), 13-19.

[2] Agha, A "Tarbela Reservoir: towards a sustainable future". "Proceedings of 71st Annual session, 2011", 2006.

[3] Ahmad, N "Characterization of convective rain in Klang Valley, Malaysia" "Doctoral dissertation, Universiti Teknologi Malaysia" 2008.

[4] Ahrens CD "Meteorology today: an introduction to weather, climate, and the environment". "Thomson Brooks/Cole Belmont, CA" 2007.

[5] Ahrens CD. Henson, R "Meteorology today: an introduction to weather, climate, and the environment". "Cengage learning" 2021.

[6] Allaby M "Atmosphere: a scientific history of air, weather, and climate". "Infobase Publishing" 2009.

[7] Anderson K, Bows A "Reframing the climate change challenge in light of post-2000 emission trends". "Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences" 2008, 366(1882): 3863-3882.

[8] Catto JL, Nicholls N, Jakob C, Shelton KL. "Atmospheric fronts in current and future Climates". "Geophysical Research Letters" 2014, 41(21): 7642-7650.

[9] Moazzam MFU, Rahman G, Munawar S, Tariq A, Safdar Q, Lee BG. (2022). "Trends of Rainfall Variability and Drought Monitoring Using Standardized Precipitation Index in a Scarcely Gauged Basin of Northern Pakistan. Water", 2022, 14(7): 1132.

[10] Garg SK, 2002. "Hydrology and Water Resources Engineering", "Khanna Publishers, Delhi" 2002, Twelfth Revised Edition, , 329 pp.

[11] Ghosh S, Luniya V, Gupta A. "Trend analysis of Indian summer monsoon rainfall at different spatial scales" "Atmospheric science letters" 2009, 10(4): 285-290.

[12] Hénin R, Ramos AM, Schemm S, Gouveia CM, Liberato ML "Assigning precipitation to mid- latitudes fronts on sub- daily scales in the North Atlantic and European sector: climatology and trends" "International Journal of Climatology" 2019, 39(1): 317-330.

[13] Jenkner J, Sprenger M, Schwenk I, Schwierz C, Dierer S, Leuenberger D "Detection and climatology of fronts in a high- resolution model reanalysis over the Alps" "Meteorological Applications: A journal of forecasting, practical applications, training techniques and modelling" 2010, 17(1):1-18.

[14] Kitagawa YKL, Nascimento EGS, Souza NBP, Zucatelli PJ, Kumar P, de Almeida Albuquerque, T T, De Moraes MR, Moreira, DM "Evaluation of the WRF-ARW model during an extreme rainfall event: subtropical storm Guará" "Atmósfera" 2022, 35(4): 651-672.

[15] Naheed G, Rasul G "Investigation of rainfall variability for Pakistan". Pakistan Journal of Meteorology, 2011, 7(14), 25-32.

[16] Kripalani RH., Oh, J.H., Kulkarni, A., Sabade, S.S., Chaudhari, H.S "South Asian summer monsoon precipitation variability: coupled climate model simulations and projections under IPCC AR4" "Theoretical and Applied Climatology" 2007, 90(3), 133-159.

[17] Kripalani RH, Kulkarni A "Monsoon rainfall variations and tele-connections over South and East Asia" "International Journal of Climatology: A Journal of the Royal Meteorological Society" 2001, 21(5): 603–616.

[18] Nascimento L, Rodrigues Silvestre M, Sant'anna Neto JL "Trends and rainfall tropicalization in Paraná State, south of Brazil" "Atmósfera" 2020, 33(1): 1-18.

[19] Nilsson ED, Paatero J, Boy M "Effects of air masses and synoptic weather on aerosol formation in the continental boundary layer" "Tellus B" 2001, 53(4):462-478.

[20] Radzka E, Rymuza K "Statistical and geostatistical analysis of spatial variation of precipitation periodicity in the growing season" "Quarterly Journal of the Hungarian Meteorological Service" 2020, 124(1): 129-141.

[21] Rasul, G., and Ahmad, B "Climate change in Pakistan" "Pakistan Meteorological Department", 2012.

[22] Rasul, G, Chaudhry QUZ, Sixiong Z, Qingcun Z, Linlin QI, Gaoying Z "A diagnostic study of heavy rainfall in Karachi due to merging of a mesoscale low and a diffused tropical depression during South Asian summer monsoon" "Advances in Atmospheric Sciences" 2005, 22(3): 375-391.

[23] Schemm S, Rudeva I, Simmonds I "Extratropical fronts in the lower troposphere–global perspectives obtained from two automated methods" "Quarterly Journal of the Royal Meteorological Society" 2015, 141(690): 1686-1698.

[24] Schemm S, Sprenger M, Martius O, Wernli H, Zimmer M "Increase in the number of extremely strong fronts over Europe? A study based on ERA- Interim reanalysis (1979–2014)" "Geophysical Research Letters" 2017, 44(1): 553-561.

[25] Schemm S, Sprenger M, Wernli H "When during their life cycle are extratropical cyclones attended by fronts?" "Bulletin of the American Meteorological Society" 2018, 99(1):149-165.

[26] Sengupta S, Sarkar A "Stable isotope evidence of dual (Arabian Sea and Bay of Bengal) vapour sources in monsoonal precipitation over north India" "Earth and Planetary Science Letters" 2006, 250(3-4): 511-521.

[27] Simmonds I, Keay K, Tristram Bye, JA "Identification and climatology of Southern Hemisphere mobile fronts in a modern reanalysis" "Journal of Climate" 2012, 25(6), 1945-1962.

[28] Stričević L, Pavlović M, Filipović I, Radivojević A, Gocić M, Bursać NM "Statistical analysis of annual and seasonal temperature regime change in Rasina River basin, Serbia" "Quarterly Journal of the Hungarian Meteorological Service" 2022, 126(1): 127-157.

[29] Treydte KS, Schleser GH, Helle G, Frank DC, Winiger M, Haug GH, Esper J "The twentieth century was the wettest period in northern Pakistan over the past millennium" "Nature" 2006, 440(7088): 1179-1182.

[30] Zhang X, Zwiers FW, Hegerl GC, Lambert FH, Gillett NP, Solomon S, Stott A, Nozawa T "Detection of human influence on twentieth-century precipitation trends" "Nature" 2007, 448(7152): 461-465.