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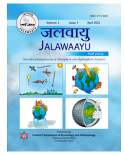

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Research Article

# Identification of Summer Monsoon Onset over Nepal by using Satellite-Derived OLR Data

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**Abstract:** Summer monsoon onset is considered as the beginning of the rainy season in South Asia. In Nepal, summer monsoon onsets from eastern part and ~80% of the annual rainfall occurs during summer monsoon season (i.e., June to September). The monsoon onset is one of the crucial elements for the socio-economic development as the majority of the population depends primarily on rain fed agriculture systems for their livelihood. For identification of the monsoon onset date over eastern Nepal, daily mean satellite-derived Outgoing Long-wave Radiation (OLR) data ($1^0 \times 1^0$ spatial resolution) obtained from National Environmental Satellite Data and Information Service (NESDIS), NOAA is used. Long term OLR data from 1979 to 2019 for March to June is analyzed to study monsoon progression towards eastern Nepal. The rainfall amount obtained from rain gauge stations is compared with the OLR data, which depicts a higher correlation in the southern part of Eastern and Central Nepal than in the northern regions. A

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convective episode signifies the drop in OLR by about 45 $Wm^{-2}$ from 10 May to 10 June. Further, the relation between the date of characteristic fall of OLR below 250$Wm^{-2}$ and monsoon onset date announced by MFD (Meteorological Forecasting Division) for the study period is evaluated to predict new onset dates over the region. The predicted onset date is found as 13$^{th}$ of June on average and its correlation with the MFD onset date is 0.6 ($p<0.01$). The study highlights the potential application of the satellite-derived OLR based method for the early prediction of onset of summer monsoon over eastern Nepal.

## 1. Introduction

The South Asian summer monsoon (SASM) is one of the prominent seasonal weather systems in the world. SASM affects the Indian subcontinent and lasts from June to September. During the SASM, an elongated zone of low pressure develops along the Indo-Gangetic plains of North India, extending from southeast to northwest. This low-pressure area is known as the monsoon trough or equatorial trough and resides in this region for four monsoon months (Ramaswamy 1962). Monsoon trough advances northwards from the Equator in the summer monsoon months and retreats southwards in the post-monsoon period. Therefore, the onset and withdrawal of monsoons are associated with the northward and southward movement of the equatorial trough (Ananthakrishnan and Rajagopalachari 1964). Further, Tamura et.al. (Tamura, Taniguchi et al. 2010) showed that convective heating around the Bay of Bengal is crucial for the onset of the Indian summer monsoon and has two major roles, first is to induce upper tropospheric warming to the southwest of the Tibetan Plateau, and the second is to extend monsoon trough westward from the Bay of Bengal to the Arabian Sea. Similarly, Devkota (Devkota 1983) has suggested that the advancement of summer monsoon toward north is accelerated by the formation of a depression over the Bay of Bengal.

The economy of Nepal is dominated by the agriculture sector which assure about 27 % of GDP and 65% of people's livelihood (G.o.N. 2019) . Out of 2.7 million hectares of total agricultural land, only 1.3 million hectares is irrigated(Pradhan, Parajuli et al. 2017), and the rest is heavily dependent on monsoon rainfall, which accounts for 80% of the annual precipitation (Shrestha 2000, Hamal, Sharma et al. 2020). Irrigation water availability depends upon rainfall as it recharges the groundwater aquifers and provides stable flow in the rivers for the dry season (Nayava 1980). The nature of the rainfall and its spatio-temporal variability are the major factors affecting the agricultural potential (Nayava 1980). Nayava et al. (Nayava 2017)has revealed the impact of rainfall on rice yield and production. Similarly, Malla et al. (Malla 2008) has also identified that deficit rainfall over the Eastern Terai in 2005 was due to shorter monsoon duration because of late-onset, which caused nearly 10% of agricultural lands to remain fallow and the crop production decreased by 12.5% on a national basis. Hence monsoon and its onset date are vital for food security in Nepal. Thus, it is worth having an idea of the monsoon onset date in advance so that farmers get enough lead time for preparedness.

Devkota has also revealed that the onset in Nepal is possible only when monsoon trough extends upto 700 mb level and easterly Jet stream lies over Madras area, India. The summer monsoon typically begins in Eastern Nepal on 10 June, and covers the entire country within a week, whereas it retreats on 23 September from Western Nepal spanning the 105 days in average (DHM 2010). Generally, the onset date of monsoon is determined by a sharp increase and characteristic persistency in rainfall. But in Nepal, thunderstorm activities are highly pronounced and cumulative precipitation shows a sudden increase making the onset quite confusing (Gautam and Regmi 2013). Thus, the Meteorological Forecasting Division (MFD) of the Department of Hydrology and Meteorology (DHM) decides the onset date by studying the atmospheric pattern over the region based on synoptic chart analysis, including various model output from international institutes.

Outgoing longwave radiation (OLR) is a key component of the earth's radiation budget and one of the essential climatic variables. OLR strongly depends on cloud coverage in the sky along with the incoming solar radiation. So that higher (lower) values of OLR may be due to the higher (lower) amount of incoming short-wave radiation from the sun or may be because of less (more) cloud cover in the sky (Prasad and Bansod 2000). Monsoon onset can be investigated considering several parameters such as; precipitation, lower level zonal wind, upper-level zonal wind, vertical profile of water vapor and OLR etc (Gadgil 2003). Puri et al.(Puri and Miller 1990) has used OLR to identify the region of deep convection associated with monsoon onset over South India. In extra tropics, OLR cannot signify the rainfall because of the chances of its non-convective nature, but can signify rainfall in tropical regions because most of the rainfall is of convective nature (Puri and Miller 1990). Romatschke et al. (Romatschke and Houze Jr 2011) also revealed that convective systems with enormous stratiform precipitation occur in the eastern Himalayan region and over the Bay of Bengal. Since OLR is feedback of many other climatic parameters in tropics, OLR can be considered as a single parameter in predicting monsoon onset date and rainfall characteristics. Ghanekar et al. (Ghanekar, Puranik et al. 2010) analyzed OLR data for the months from March to June, and revealed a characteristic fall in OLR over the Kerala region about 5 to 9 weeks prior to the onset of Indian summer monsoon. Same study identified an indirect non-linear relationship between the time of occurrence of the pre-monsoon convective peak and the onset date.

With the advancing technology and a better understanding of the system, there are improved skills in predicting monsoon onset. However, DHM is still unable to predict reliable monsoon onset date as earlier as it has to be because of the subjective ways that have been used so far to identify the onset of monsoon. So, it is necessary to define objective criteria to determine the onset of summer monsoon in Nepal. This study aims to identify the monsoon onset date in Nepal by using OLR as a single parameter, and this could be a milestone as it is the first attempt to predict monsoon onset date on OLR basis over such a complex topography.

## 2. Materials and Methods

### 2.1. Study area

Monsoon enters in Nepal after the monsoon depressions formed over Bay of Bengal propagate north-westward heading to eastern Nepal (Lang and Barros 2002). The effect of monsoon is more prominent in the eastern half of the country (Marahatta, Dangol et al. 2009), hence the present research has attempted to cover $25^0$ N to $28^0$ N latitude and $87^0$ E to $89.5^0$ E longitude (Figure 1), which is considered as the gateway of summer monsoon over Nepal.

### 2.2. Data

In this study, OLR data was assessed from NOAA's National Centers for Environmental Information (NCEI), National Environmental Satellite Data and Information Service (NESDIS), Physical Science Division. The dataset is freely available on https://www.ncei.noaa.gov/data/outgoing-longwave-radiation-daily/access/, which has daily mean OLR flux at the top of the atmosphere with spatial resolution $1^0 \times 1^0$ available from 1979 to 2019, however 178 days of data in 1985 were missing.

Similarly, for detecting the relationship between rainfall and OLR, gauge observed rainfall data from the stations which are well distributed over the study area were obtained from DHM. However only seven stations were selected for the study because of significant data gaps in the remaining stations. Kathmandu aero-synoptic station (1030) and Simara aero-synoptic station (0909) are also taken to make east-west and north-south comparative study of OLR with respect to time. Monsoon onset date announced by DHM were obtained for the years 1979 to 2020 from the official website of DHM.

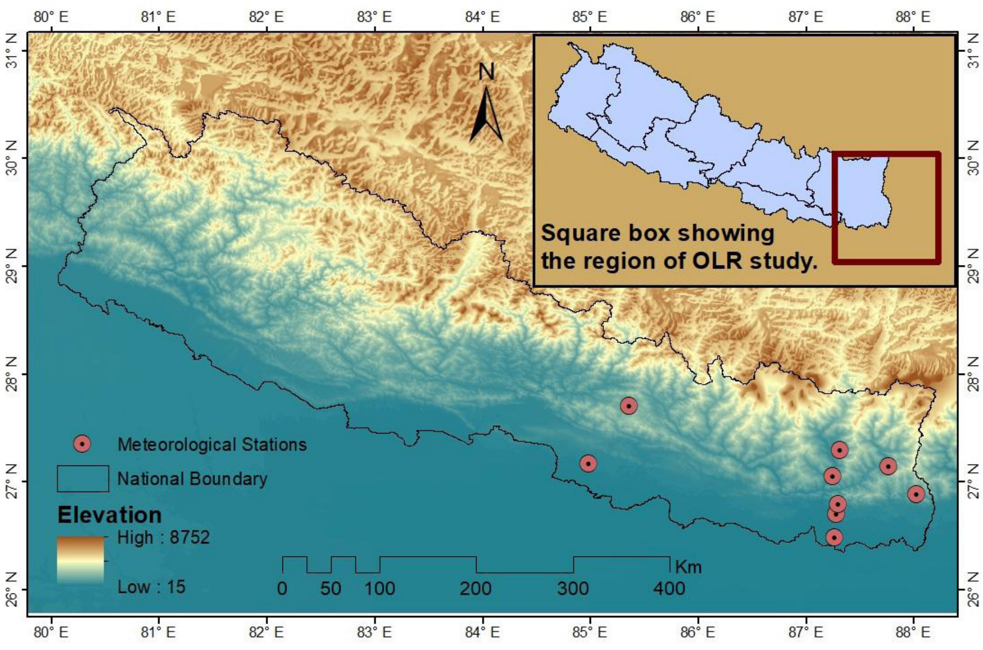


**Figure 1**: Map showing the study area of OLR by the square box and climatic stations by the small dots.

## 2.3. Methodology

In order to identify the Summer Monsoon Onset date, methodology adapted by Ghanekar (Ghanekar, Puranik et al. 2010) has been followed. Daily average OLR from March starts falling due to increasing dense cloud cover during pre-monsoonal convective peak and reach below 250 $wm^{-2}$ which is known as characteristic fall of OLR (Ghanekar, Puranik et al. 2010). The characteristic fall of OLR is studied by taking 7 days moving average of daily OLR. The date in which OLR falls below 250 $wm^{-2}$ is the date of characteristic fall for the year. After comparing the dates of characteristic fall of OLR with monsoon onset dates published by DHM for all years, the duration between monsoon onset date (DHM) and the date of characteristic fall are computed for the study period. Then the duration are averaged and are further analyzed to establish an empirical relationship for the prediction of the onset date of each years (Equation 1).

$$D_{OM} = D_{CF} + d_{OC} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where, $D_{OM}$= Predicted monsoon onset date for a year,

$D_{CF}$= Date of characteristic fall of that year and

$d_{OC}$= Average duration between monsoon onset date (DHM) and the date of characteristic fall

Based on the newly developed empirical relationship, monsoon onset dates are predicted for the study period from 1979 to 2019.

## 3. Result

### 3.1. Trend of summer monsoon onset date

Figure 2 shows the monsoon onset dates announced by MFD for the year 1979 to 2020. The mean summer monsoon onset date is observed as 13 June, which is three days later than the normal onset date declared by MFD and is the same as revealed by Gautam and Regmi (Gautam and Regmi 2013).

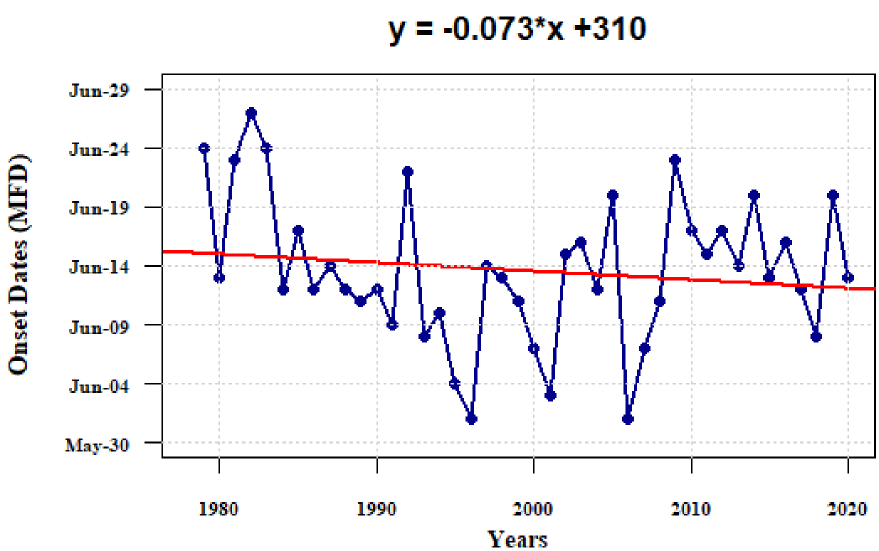


**Figure 2**: Trend of monsoon onset date announced by MFD

During the study period, the earliest onset date is found on 31 May in 1996 (14 days early) and the latest on 27 June in 1982 (13 days delay). The linear trend of the monsoon onset date is found slightly negative (early-onset), i.e., 0.07 day per year. It is observed that 50% and 45.2 % of monsoon onset dates are later and earlier than the mean onset date, respectively. Only 4.76 % of onset dates are the same as the mean onset date.

### 3.2. Variation of OLR

The daily OLR for the study period shows the variation throughout the year (Figure 3). OLR values start to fall from pre-monsoon, become less during monsoon, and increase during the winter season. It is seen that the highest value of OLR is 271.6 $wm^{-2}$ on 25 October. Similarly, the lowest value is seen on 24 July as 206.9 $wm^{-2}$ indicating the high cloud coverage on the day. With the reduced solar radition during the winter season, average OLR is still maximum.

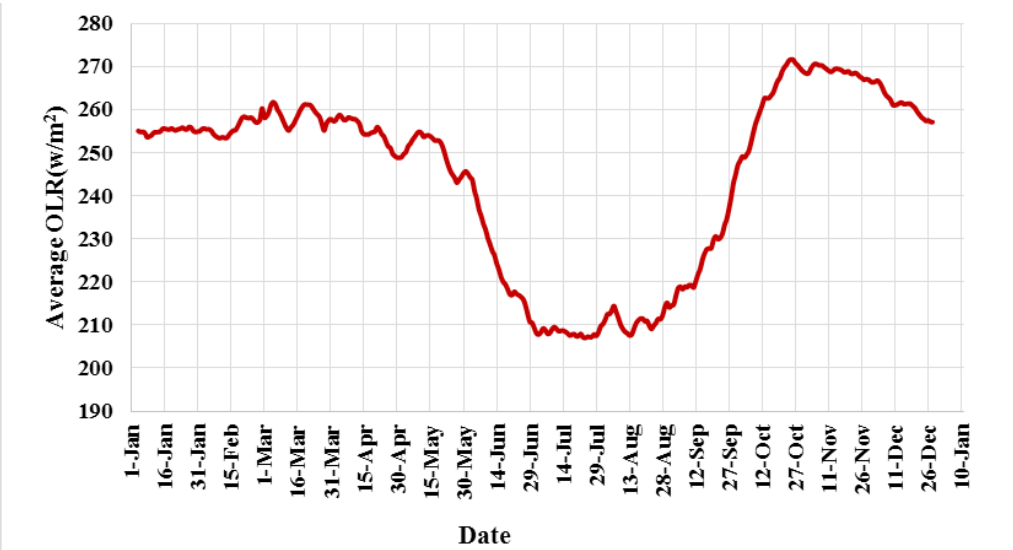


**Figure 3**: Average OLR vs. time

### 3.3. Comparison of OLR values with the rainfall amounts

A comparison of long-term average gauge observed daily rainfall and OLR is shown in Figure 4. It is observed that rainfall over various stations of eastern Nepal and the spatially-averaged OLR values over the area are interconnected with each other. The correlation between the average gauge observed rainfall and OLR over the study area is -0.9 ($p<0.01$), which implies that the lower values of OLR are associated with high amounts of rainfall. This result agrees with the previous study of Puri et al.(Puri and Miller 1990), who shows the application of OLR to provide information about convective heating.

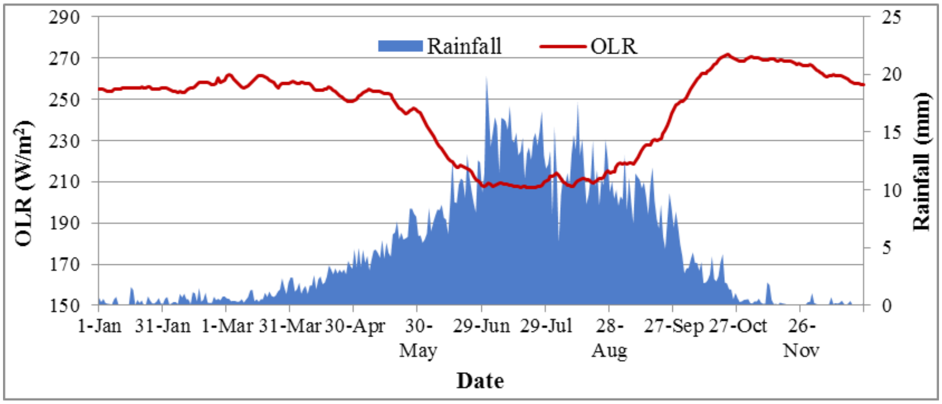


**Figure 4**: Average gauge observed daily rainfall (mm/d) vs. spatial average OLR (w/m²)

For this study, OLR data at each station were extracted using station-to-grid methods (Sharma, Chen et al. 2020) and it is found that Biratnagar has a better correlation between OLR and rainfall amounts than in Muga. Similarly, there is a better correlation in Simara than in Kathmandu, with the same p-value less than 0.01.

## 3.4. Characteristic of pre-monsoon fall of OLR

Daily OLR values are smoothened by computing 7-day moving averages of OLR data, and sub-synoptic scale variations are filtered out. Figure 5 represents the average weekly running mean OLR for the months from March to June over the study region. This graph shows the variability of convective activities observed on long-term mean during pre-monsoon season over the study area.

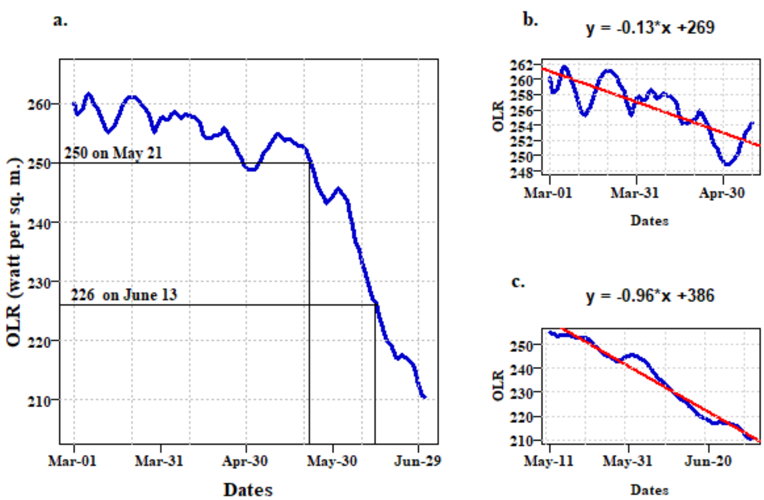


**Figure 5**: Climatological weekly running mean OLR for the months from March to June over the study region.

Just after the vernal equinox in the northern hemisphere, OLR value is seen as maximum (260 $wm^{-2}$) on 23 March (Figure 5a and 5b). Advancing to summer solstice, inspite of increasing solar radiation, OLR begins to fall continuously due to more convective activities. Figure 5b indicates the falling OLR values from March onwards, but a marked declining trend is not observed until the third week of May. In contrast, the study of Ghanekar et al. (Ghanekar, Puranik et al. 2010), who was focused over the Kerela region, revealed a characteristic fall of OLR below 250$wm^{-2}$ about 5 to 9 weeks before the onset of the Indian summer monsoon. Therefore, the falling trend of OLR is studied by breaking the falling pattern into two sections, i.e., from early March to 9 May (Figure 5b) and from 10 May to the onset of monsoon over Nepal (Figure 5c).

OLR from early March to 9 May shows a decreased OLR value by 10 $Wm^{-2}$ with the slope 0.13 and $R^2$ value 0.63, which does not reflect a clear falling trend (Figure 5a). Even though values after 28 April indicate the fall below 250 $Wm^{-2}$, it does not hold consistent enough as it again rises above 250 $Wm^{-2}$ after 4 May. However, the analysis of average OLR from 10 May indicates a clear falling trend with slope 0.96 and higher $R^2$ value (0.96). During the period between 10 May to 10 June, the OLR value was dropped by 45 $Wm^{-2}$. The OLR falls below 250 $Wm^{-2}$ after 22 May and didn't rise above it until the monsoon onset on 13th June over eastern Nepal. So, 250 $Wm^{-2}$ is defined as the characteristic (threshold) value of OLR. In addition to the criteria adapted by Ghanekar, following two additional criteria have been defined to detect the date of characteristic fall of OLR below 250 $Wm^{-2}$ for each year:

OLR value should be dropped below 250 $Wm^{-2}$ for at least 3 consecutive days in such a way that $OLR_1 \geq OLR_2 \geq OLR_3$. Difference in first and third value of OLR should be at least 5 $Wm^{-2}$, i.e. $OLR_1 - OLR_3 \geq 5$ $Wm^{-2}$

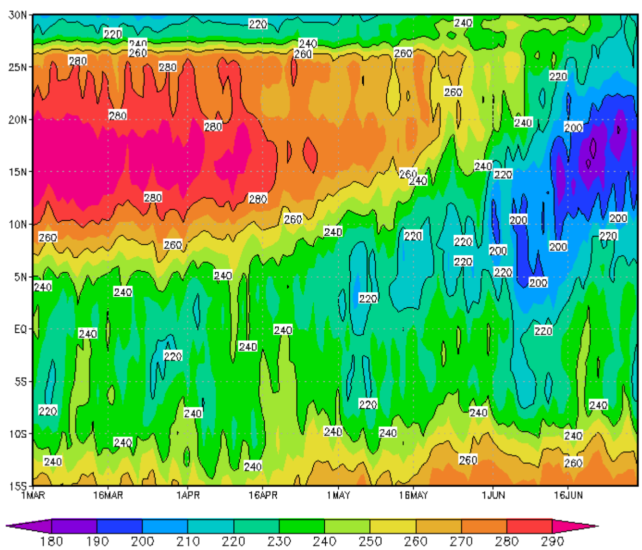


**Figure 6**: Meridional time section of climatological weekly running mean OLR over 15°S-30°N (88$^0$E is taken as a fixed longitude) for the months March to June.

Figure 6 present the meridional time section of climatological weekly running long-term mean OLR. 88° E is taken a fixed longitudinal belt to represent eastern Nepal. Therefore, OLR is calculated at 88°E along the latitudinal belt between 15° N and 30° N to analyze the progression of monsoon from low latitudes towards Nepal for four months from March to June. During the first week of March, despite intense heating, 220 $Wm^{-2}$ contour is found slightly south to the Equator. At that time, ITCZ also lies around the Equator and is shifted northward from the Equator as time passes. ITCZ reached around $20^0$ N near the southern plain of Eastern Nepal by early June, resulting frequent convective activities followed by the maximum cloud coverage which implies the least OLR value contour (190 $Wm^{-2}$) in the region.

## 3.5. Characteristic pre-monsoon fall in OLR for individual years and the onset date

As explained earlier, the date of characteristic fall of OLR below 250 $Wm^{-2}$ after 21 May is identified for each year by examining the 7 days moving average OLR (Table 1). The earliest date of characteristic fall is 22 May, reported in the years 1984, 1989, 2000 and 2018, whereas the most delayed date (12 June) is reported in 1981 and 2011. The values of the difference between these two dates are given in column 3 of Table 1. Such value indicates the time period between the dates of characteristic fall in the pre-monsoon and monsoon onset. The periodicity is found to be lowest as 3 days in 2007 while highest as 28 in 2014. The mean periodicity is observed to be 15 days and the mean date of characteristics fall is observed as 29 May. The onset has occurred as earliest on 6 June in four years 1984, 1989, 2000 & 2018 and the latest by 27 June in two years 1981 and 2011. Based on the 41 years analysis, the mean onset date is observed as 13 June, which is exactly the same date as depicted by MFD.

**Table 1**: The list of characteristic fall dates, a time period between the dates of characteristic fall and the MFD onset dates & predicted onset dates.

| Years | Date of Characteristic fall | Time periods | MFD onset | Predicted Onset | Differences (Days) |
|---|---|---|---|---|---|
| 1979 | 9-Jun | 15 | 24-Jun | 24-Jun | 0 |
| 1980 | 27-May | 16 | 12-Jun | 11-Jun | 1 |
| 1981 | 12-Jun | 11 | 23-Jun | 27-Jun | -4 |
| 1982 | 3-Jun | 24 | 27-Jun | 18-Jun | 9 |
| 1983 | 31-May | 24 | 24-Jun | 15-Jun | 9 |
| 1984 | 22-May | 20 | 11-Jun | 6-Jun | 5 |
| 1985 | | | 17-Jun | | |
| 1986 | 8-Jun | 4 | 12-Jun | 23-Jun | -11 |
| 1987 | 27-May | 18 | 14-Jun | 11-Jun | 3 |
| 1988 | 23-May | 19 | 11-Jun | 7-Jun | 4 |
| 1989 | 22-May | 20 | 11-Jun | 6-Jun | 5 |
| 1990 | 28-May | 15 | 12-Jun | 12-Jun | 0 |
| 1991 | 24-May | 16 | 9-Jun | 8-Jun | 1 |
| 1992 | 7-Jun | 14 | 21-Jun | 22-Jun | -1 |

| | | | | | |
|---|---|---|---|---|---|
| 1993 | 24-May | 15 | 8-Jun | 8-Jun | 0 |
| 1994 | 23-May | 18 | 10-Jun | 7-Jun | 3 |
| 1995 | 30-May | 5 | 4-Jun | 14-Jun | -10 |
| 1996 | 25-May | 6 | 31-May | 9-Jun | -9 |
| 1997 | 23-May | 22 | 14-Jun | 7-Jun | 7 |
| 1998 | 30-May | 14 | 13-Jun | 14-Jun | -1 |
| 1999 | 23-May | 19 | 11-Jun | 7-Jun | 4 |
| 2000 | 22-May | 15 | 6-Jun | 6-Jun | 0 |
| 2001 | 25-May | 9 | 3-Jun | 9-Jun | -6 |
| 2002 | 4-Jun | 11 | 15-Jun | 19-Jun | -4 |
| 2003 | 2-Jun | 14 | 16-Jun | 17-Jun | -1 |
| 2004 | 30-May | 12 | 11-Jun | 14-Jun | -3 |
| 2005 | 9-Jun | 11 | 20-Jun | 24-Jun | -4 |
| 2006 | 23-May | 9 | 1-Jun | 7-Jun | -6 |
| 2007 | 4-Jun | 3 | 7-Jun | 19-Jun | -12 |
| 2008 | 29-May | 12 | 10-Jun | 13-Jun | -3 |
| 2009 | 10-Jun | 13 | 23-Jun | 25-Jun | -2 |
| 2010 | 3-Jun | 14 | 17-Jun | 18-Jun | -1 |
| 2011 | 12-Jun | 3 | 15-Jun | 27-Jun | -12 |
| 2012 | 24-May | 23 | 16-Jun | 8-Jun | 8 |
| 2013 | 23-May | 22 | 14-Jun | 7-Jun | 7 |
| 2014 | 23-May | 28 | 20-Jun | 7-Jun | 13 |
| 2015 | 26-May | 18 | 13-Jun | 10-Jun | 3 |
| 2016 | 7-Jun | 8 | 15-Jun | 22-Jun | -7 |
| 2017 | 23-May | 20 | 12-Jun | 7-Jun | 5 |
| 2018 | 22-May | 17 | 8-Jun | 6-Jun | 2 |
| 2019 | 11-Jun | 9 | 20-Jun | 26-Jun | -6 |
| Average | 29-May | 15 | 13-Jun | 13-Jun | 0 |

## 3.6. Comparison of monsoon onset dates

The inter-annual variations of predicted and MFD onset dates during the studied period is shown in Figure 7. The general pattern of inter-annual variation of predicted onset date is similar to MFD onset dates except for some significant bias in particular years such as 1997 and 2014. The average date Characteristic fall is 29 May, and the average gap between onset date and characteristic fall is 15 days indicating the average onset date on 13 June (Table 1), which is the same as the mean MFD onset date. The dates are found to be perfectly matched in four years (Figure 7). The maximum difference between predicted and MFD onset days is 13 days in 2014. Similarly, 1986, 1995, 2007 and 2011 also have marked differences in onset dates that might be due to the methodological approach. This study attempts to apply an easy and timely objective way for the monsoon onset based on OLR, which is proportional to cloud cover only however the criteria used by MFD is also based on rainfall and winds. Pertaining to this fact, during those years it might been higher cloud coverage but with less moisture supply leading to less rainfall which could be a reason for above mentioned significant bias

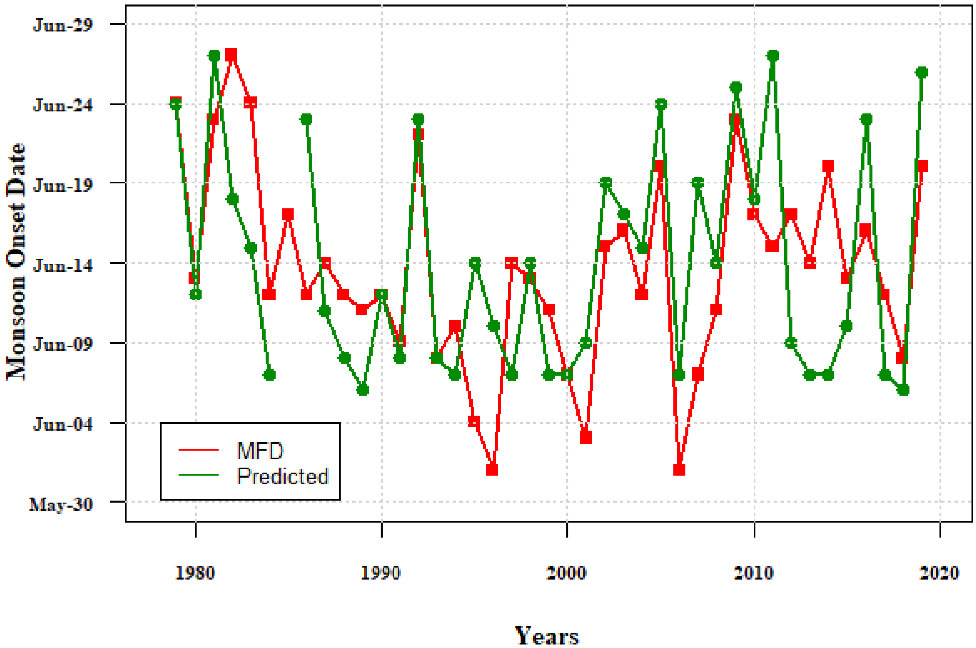


**Figure 7**: Graphical comparisons of onset date announced by MFD and predicted onset date by May fall

## 4. Discussion

SASM is one of the noticeable climatic frameworks on South Asia including Nepal. Out of 2.7 million hectares agrarian place in Nepal, just 1.3 million hectares is irrigated (G.o.N. 2019), and the rest is vigorously reliant on SASM rainfall. Consequently, any adjustment in monsoon onset assumes a vital role on agricultural profitability over Nepal which alone contributes for 27 % of Gross domestic product of the country. The summer monsoon typically starts in Eastern Nepal on 10 June, while it withdraws on 23 September from Western Nepal spreading over the 105 days in normal (G.o.N. 2010). Monsoon onset is dictated by a sharp increment and trademark persistency in precipitation however, in Nepal, thunderstorm activities are profoundly articulated and total precipitation shows an abrupt increment making the onset very confounding (Gautam and Regmi 2013). In this context, MFD decides the onset date by contemplating the atmospheric pattern over the area dependent on SYNOP chart analysis, including different model yield from foreign organizations like Indian Meteorological Department (IMD), European Centre for Medium-Range Weather Forecasts (ECMWF) etc. DHM is yet exploring the methodologies for early prediction of monsoon onset date This study has evaluated the applicability of OLR data on identifying monsoon onset date in Nepal.

OLR value begins to tumble from pre-monsoon, become less during monsoon, and again increment can be seen throughout winter season. With the reduced solar radiation during the winter season, average OLR is still maximum due to reduced cloud coverage indicating a direct dependency of OLR on cloud coverage (Convective activities). A significant negative relationship (0.9, $p < 0.01$) between observed precipitation and the OLR shows OLR shows the dependency of OLR with the amounts of rainfall which agrees with the finding of Puri et al. 16], who shows the utilization of OLR to give information about convective heating. Better correlation between rainfall and OLR extracted at the different gauge locations over most of the station lying in the southern flat terrain of Nepal than stations lying in the hilly areas suggest that regular monitoring of OLR over the Terai region focusing over Eastern Terai would help predict monsoon onset and its proceeding.

During the first week of March, despite intense heating, 220 $Wm^{-2}$ contour is found slightly south to the Equator. At that time, ITCZ also lies around the Equator and is shifted northward from the Equator as time passes. ITCZ reached around 200 N near the southern plain of Eastern Nepal by early June, resulting frequent convective activities followed by the maximum cloud coverage which implies the least OLR value contour (190 $Wm^{-2}$) in the region. The mean onset date predicted by this study is 13 June, which is the same as of MFD. A comparison of predicted and MFD onset dates shows a moderate correlation of 0.6 ($p<0.01$). Although, the OLR based monsoon onset dates matched well with the observed dates, marked difference in some of the years might be due to different methodological approach followed in this study and by MFD. In 2014, continuous rainfall episodes in eastern Nepal from 5 June to 9 June 2014 resulted into the marked drop in OLR values which supports the defined criteria of monsoon onset giving onset date 13 days earlier than that announced by MFD.

## 5. Conclusions

In this study, a possible application of satellite-based OLR data is investigated to define monsoon onset criteria and the onset dates thus predicted is compared with MFD onset dates over Eastern Nepal.

A significant and negative correlation ($r=0.93$, $p < 0.01$) is obtained between OLR and rainfall amount i.e., lesser the value of OLR higher the amount of rainfall. A higher correlation between OLR and rainfall is found in eastern Nepal compared to central Nepal and southern plain than northern hilly region. The linear trend of MFD monsoon onset date during the studied period (1979-2020) shows an earlier onset trend of 0.07 days per year. The mean date of the characteristic fall of OLR below the 250 $wm^{-2}$ is observed on 29 May, and the onset date is identified after 15 days of the characteristics fall date. Average predicted onset date is found to be on 13 June, which is same as the MFD onset date for the study period. The predicted monsoon onset date show neither advancing nor delaying trend of monsoon onset. The correlation between predicted and MFD onset date is 0.6 ($p<0.01$). Consideration of other meteorological parameters with OLR might improve the overall accuracy of the method followed in this study.

**Author Contributions:**

Sanjib Adhikari developed the concept and wrote the original draft. Tek Bahadur Chhetri, Dibas Shrestha, Bikash Nepal and Sadhana Bhattarai contributed to writing, reviewing and improving the manuscript.

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### Data Availability Statement:

Daily OLR data and monsoon onset data used in this manuscript are available freely in online. The daily rainfall data can be purchased from DHM, Nepal.

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### Conflicts of Interest:

The authors declare that they have no conflict of interest.

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