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Comparison of Ground Based Measurements of Solar UV Index with Satellite Estimation at Four Sites of Nepal

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Abstract: The main objective of this study is to compare the ground based measurements and satellite estimation of solar UV index in four sites namely, Kathmandu, Pokhara, Biratnagar and Lukla. Kathmandu (27.72°N, 85.32°E), Pokhara (28.22°N, 83.32°E) Biratnagar (26.45°N, 87.27° E) and Lukla (27.69°N, 86.73°E) and are located at an elevation of 1350m, 800m, 72m and 2850m respectively from the sea level. The ground based measurements and satellite estimation were performed by NILUUV irradiance meter and EOS Aura OMI satellite. The NILUUV irradiance meter is a six channel radiometer designed to measure hemispherical irradiances on a flat surface. The Ozone Monitoring Instrument (OMI) on board, the NASA EOS Aura space craft is a nadir viewing spectrometer that measures solar reflected and back scattered light in ultraviolet and visible spectrum. The study shows that OMI overestimate the ground based data before monsoon by 71.28%, 47.29%, 27.92% and 35.83% respectively at Kathmandu, Pokhara, Biratnagar and Lukla. However during the monsoon period the same comes down to 8.55%, 15.63%, 10.74%, and 11.33% respectively. The main reason behind these discrepancies might be due to the spatial resolution of the satellite which estimates the UV Index on the basis of 13×24 km^2 in nadir where as the ground measurement is for a single point. The correlation between satellite derived and ground measured ozone column was found to be 91 % and 89% for Kathmandu and Lukla respectively.

Key words: OMI, NILUUV, Ultraviolet, Ozone, UV Index.

1. Introduction

Ultraviolet radiation is an important environmental factor that has received much attention in recent years. Besides causing human health problems, UV radiation may cause accelerated wear of both natural and synthetic materials and have harmful effects on water ecosystems, soil, and vegetation. In view of the decline in the total ozone-column amount it is important to be able to monitor accurately and reliably the amount of UV radiation reaching Earth's surface (Hoiskar et al., 2003). The study of ultraviolet (UV) solar radiation reaching the Earth's surface has achieved a notable interest in the last decades. This is due to concerns related to the well-known ozone depletion (WMO, 2006). Thus, it is of great importance to continue high accuracy UV radiation measurements at different locations. Satellite UV data complement ground-based measurements providing global daily maps with uniform geographical coverage from a single instrument. The continuous validation of satellite UV data with ground-based measurements from well-calibrated and well-maintained instruments is an essential task for assessing the quality and accuracy of satellite data and to identify local to regional specific sources of uncertainty (Arola et al., 2005; Tanskanen et al., 2007).

Ozone monitoring instrument (OMI) (Levelt et al., 2006), launched in July 2004, and is the successor to the Total Ozone Mapping Spectrometer (TOMS) instruments. The work of Anton et al. (2007) compared the erythemal UV irradiance (UVER) derived from TOMS with Brewer measurements at EI Arenosillo (South Spain) under different sky conditions. This work showed that TOMS overestimates the UVER data by 12% during cloud-free days, and the bias increases with the aerosol load.

The first comprehensive validation of the OMI UV products can be found in Tanskanen et al. (2007), which shows good agreement between OMI-derived daily erythemal doses and the daily doses calculated from the ground-based spectral UV measurements from 18 reference stations in Europe, Canada, Japan, USA and Antarctic. However, the bias increased up to 50% for sites affected by absorbing aerosols or trace gases. In addition Buchard et al. (2008) compared the UV irradiance products from OMI with ground-based measurements recorded at two French locations, showing that the bias is less than 15% for clear sky conditions. Ialongo et al. (2008) showed that OMI UV data overestimate ground-based UVER values measured from both Brewer spectrophotometer and YES broadband radiometer (biases about 20%) at Rome (Italy). Weihs et al. (2008) showed that OMI-Brewer differences can reach +50% under overcast conditions during a validation campaign in the region of Vienna (Austria). Kazadzis et al. (2009) compare UV irradiance products from OMI against ground-based Brewer measurements at Thessaloniki (Greece), showing that OMI overestimates UV spectral irradiances by 30%, 17% and 13% for 305nm , 324 nm, and 380 nm, respectively.

Kathmandu, Pokhara, Biratnagar and Lukla are the measurements sites of this study. Kathmandu is the capital and largest metropolitan city of Nepal. The city is the urban core of Kathmandu valley which contains two sister cities namely Patan 5 km to its southeast and Bhaktapur 14 km to its east and is a touristic destination centre. Pokhara is a sub- metropolitan city in the western part of Nepal enriched with beautiful lakes and mountains scenarios. Biratnagar is the second largest industrial sub-metropolitan city in the south eastern part of Nepal and is familiar for agriculture, commerce and industry. Lukla is the place at middle altitude in the Khumbu area and is situated in north eastern Nepal. It is a most popular touristic point for trekking into Mount Everest. These four measurement sites cover low altitude to mid altitude region and tropical to Himalayan climatology of Nepal. The study basically provides information regarding the level of UV index in the sites.

Being located at high altitude, UV Index and UV dose in Kathmandu and Lukla is expected to be higher. UV Index is an indicator that helps to measure the effect of solar ultraviolet radiation on human skin. It is an important indicator and is useful to raise public awareness for skin damage. The higher the Index, the greater the risk of skin damage due to UV radiation. According to World Health Organization, the UV Index is classified as “low”, “moderate”, “high”, “very high”, and “extreme” based on UV Index values. UV index gives us the valuable information about the level of skin damaging ultraviolet radiation. There are several UV networks in different parts of the world such as, USA, Europe and Australia. Bhattarai et al., 2007 has reported that relatively few measurements on UV radiation have been performed in South East Asian subcontinent. Ground based measurement of UV radiation is lacking in developing countries in the lower latitude region. Comparison of ground based measurement and satellite estimation of UV radiation has not been performed in Nepal. Thus the comparison of ground based UV Index measurement with satellite estimation at Kathmandu, Pokhara, Biratnagar and Lukla done in this study. UV index differs from place to place and depends upon different factors such as ozone, clouds, aerosols, solar zenith angle and albedo.

The paper aims to compare UV index derived from OMI with UV index measured by the NILUUV irradiance meter. The study is technically based on the data from 2010. Monthly mean variation, spring and summer season variation of ground based and OMI estimation of UV index are carried out during the study period. The correlation between the ground based and OMI estimate of UV index for the whole year is studied. A typical diurnal pattern of Aerosol Optical Depth (AOD) is studied to characterize its effect on UV radiation.

2. Instrumentation and Methodology

2.1 Ground based measurement

Kathmandu (27.72°N, 85.32°E), Pokhara (28.22°N, 83.32°E), Biratnagar (26.45°N 87.27° E) and Lukla (27.69°N, 86.73°E) are located at an elevation of 1350m, 800m , 72m and 2850m respectively from the sea level. The instrument used during the measurement periods were the NILUUV irradiance meter. NILU-UV is a six-channel moderate-bandwidth filter instrument. Five of the channels are in the UV with centre wavelengths at 305, 312, 320, 340, and 380 nm and a bandwidth 10 nm at FWHM. The sixth channel measures the so-called photo synthetically active radiation. It covers wavelengths between 400 and 700 nm with a bandwidth of 300 nm at FWHM. The front optics consists of a flat Teflon diffuser followed by custom-made interference filters from Barr Associates, Inc., Westford, Mass. To minimize stray-light problems the five UV channels in addition have UG-11 and read leak filters. For the same reason the 305, 312, and 320 nm channels are equipped with individual specified short-pass filters. For all channels the radiation is recorded by S1226-8BQ silicium detectors from Hamamatsu. The instrument is the temperature stabilized at 50°C. It records data in a built in data logger within a minute time resolution. The data logger has the capacity to store 3 weeks of 1 min averages. By interfacing the instrument to a computer using a RS-232 port, data with 1-sec time resolution may be recorded. The total weight of the instrument ready for operation is 3.3 kg. The instrument is weatherproof and designed to operate in harsh environments (Hoiskar et al., 2003).

2.2 Satellite observation

The OMI satellite instrument is a contribution of the Netherland's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorology Institute (FMI). It is on board the NASA EOS/Aura platform launched in July 2004 (Schoeberl et al., 2006). The OMI instrument is a nadir viewing spectrometer that measures solar reflected and backscattered radiation in the wavelength range from 270 nm to 500 nm with a spectral resolution of 0.55 nm in the ultraviolet and 0.63 in the visible. The instrument has a 2600 km wide viewing swath and it is capable of daily global contiguous mapping.

In this study the following OMUVB products are used: OPEDRate (Overpass Erythemal Dose Rate), and OPIrd305, 310 nm and 324 nm, respectively. In addition, OMUVB dataset contains LambEquRef (Lambertain Equivalent Reflectivity at 360 nm) which is used for cloud characterization. All these OMUVB products are obtained using the new version of the OMI level 1 (radiance and irradiance) and level 2 (atmospheric data products) data set named collection 3. This new version takes advantage of a coherent calibration and revised dark current correction for OMI level 2 data and Aura Validation data center for the OMI station overpass data (http://disc.gsfc.nasa.gov/Aura/OMI/, http://avdc.gsfc.nasa.gov).

Sun Photometer

The instrument used to monitor aerosol optical depth (AOD) is MicroTops II sun photometer, manufactured by solar light Inc, USA. It works on the method of differential optical absorption and scattering. It is a portable multi band instrument, comprising of five different collimators working in ultraviolet (340 nm), visible (440, 500, 675nm) and infrared (870 nm) wavelengths. The bandwidth for channel 340 is 2nm and for the rest of the channels are about 10nm. The sun photometer consists of an interference filter, photodiode and necessary electronic devices. The field of view of the input optics is about 2.5°. During measurement the window of the instrument is directed towards the sun and it measures direct solar irradiance. Data were recorded from sunrise to sunset throughout the day at an interval of about half an hour. The data were monitored in UT which is 5:45 hours behind the local time.

3. Results and Discussion

In this study noon time ground based measurements and satellite estimation of solar UV index for 2010 at Kathmandu, Pokhara, Biratnagar and Lukla is analyzed and reported. The ground based measurement and satellite estimation are summarized in terms of monthly variation of UV index.

The variation of monthly mean ground based and satellite estimated UV index are shown in figure1. It is found that OMI overestimate the monthly mean ground based UV index in June by 72.02 % at Kathmandu, 59.89 % at Pokhara, 51.43 % at Biratnagar and 172.31 % respectively at Lukla for all sky conditions. The reason of overestimation in Lukla might be due to frequent events of clouds in the atmosphere than other sites. The satellite overestimation of the monthly UV index in four measurements sites might be due to aerosols and clouds. The average difference between OMI and ground based measurements in Nepal are comparable to that during overcast conditions at Strebersdorf (16°23’E, 48°18’N) (Weihs et al., 2008).

Figure 2 shows the ground based and satellite estimated UV index in March, April and May in Kathmandu, Pokhara, Biratnagar and Lukla while figure 3 represents the same for June, July and August. The study showed that OMI overestimate the ground based measurement before monsoon by 71.28 % at Kathmandu, 47.29 % at Pokhara, 27.92 % at Biratnagar and 35.83% respectively at Lukla. However during the monsoon period the same comes down to 8.55 % at Kathmandu, 15.63% at Pokhara, 10.74% at Biratnagar, and 11.33% at Lukla respectively. This overestimation values are less than that observed in Strebersdorf (Weihs et al., 2008). A difference between ground based and satellite UV irradiance is that ground based instrument measure the irradiance at a single point while satellite products are an average over a given area (satellite pixel) (Ialongo et al., 2008). The OMI over estimation of ground based measurements may partly be explained with the fact that satellite instrument do not probe well the lower atmospheric layers of urban sites where aerosols play an important role (Krotkov et al., 1998: Kazantzidis et al., 2006).

Figure 4 shows the scatter plot of OMI and Ground based (GB) UV indices in all sky conditions. The study showed that UV Index from ground based measurement and satellite estimation are almost equal with a correlation coefficient of 63% for Kathmandu,47% for Pokhara, 70% for Biratnagar and 48% for Lukla. The correlation coefficient(r) is obtained by using Karl Pearson's formula.

Validation of satellite UV estimates with ground based measurements is a complicated task, since the spatial distribution of solar UV irradiance received at the ground is mainly controlled by the variability of the total ozone and clouds and therefore may vary strongly from place to place. Parameters such as aerosols and air pollution in four measurements sites also play a dominant role for the variation in UV radiation. The gradual increasing deviations are due to the continuous buildup of the aerosols (Kazadzis et al., 2009).

Figure 5 shows OMI and Ground based daily total ozone column. The OMI ozone data was retrieved from NASA and ground-based ozone column was obtained using the principle described by Hoiskar et al., 2003. The correlation coefficient(r) between OMI based daily ozone column and ground based measurement was found to be equal to 91% in Kathmandu, 85% in Pokhara, 88% in Biratnagar and 89% in Lukla. The coefficient of determination (R^2) between OMI daily total ozone column data and ground based daily total ozone column data was found to be 0.82 at Kathmandu, 0.71 at Pokhara, 0.77 at Biratnagar and 0.79 at Lukla in all sky conditions. This is an agreement as shown by (Ialongo et al., 2008) for Rome (41.9°N, 12.5°E).

The relative percentage deviation between OMI and ground based ozone showed 2.62% in Kathmandu and 3.61% in Lukla for January to April as shown in figure 6. As the day number increases percentage deviation decreases because of smaller Solar Zenith Angle (SZA). Aerosols play an influencing role to attenuate solar radiation reaching the earth's surface. The higher the quantity of aerosols present in the atmosphere, the lesser will be the UV transmission. Figure 7 indicates a plot between solar UV index and AOD at 340nm measured with Microtops II Sun-photometer for Kathmandu during January. The figure reveals that an UV index of 2.70 is achieved with an AOD of 0.93 while 3.62 for an AOD of 0.49. It is observed that a negative correlation between UVI and AOD is obtained with a coefficient of 0.67. The mean AOD at 340nm over Thessaloniki during summer time was found to be 0.55 (Kazadzis et al., 2007).

The results showed that Satellite overestimate the ground based UV index in different sites of Nepal. This is due to the fact that the GB measurements are representative of the local position, where as satellite measurements are representative for a large region. This further arises uncertainties from the cloud or aerosol variability parameters that both affect UV irradiance, inside the satellite pixel area according to Weihs et al., (2008).

Conclusions

The ground based and satellite estimation of solar UV index in Kathmandu, Pokhara, Biratnagar and Lukla were analyzed. The satellite overestimates the ground based UV index by 8.55% at Kathmandu, 15.63% at Pokhara, 10.74% at Biratnagar and 11.33 % at Lukla during monsoon period. The correlation coefficient(r) between satellites estimated ozone column and ground based ozone was found to be 91% in Kathmandu, 85% in Pokhara, 88% in Biratnagar and 89% in Lukla. The correlation coefficient (r) between OMI retrieved daily ozone data with the daily ozone data from the NILUUV showed a good agreement. The Satellite overestimation is due to its wide field of view while ground based measurement is representative only for a single point. The aerosols and clouds content in different sites of Nepal plays an influencing role in ground based measurement. In case of recently used OMI surface algorithm for UV index there is no provision for aerosols correction. This might be another reason of satellite overestimation. The OMI overestimation with respect to ground based NILU-UV measurements might also be due to different atmospheric conditions between solar noon and satellite overpass time.

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Figures

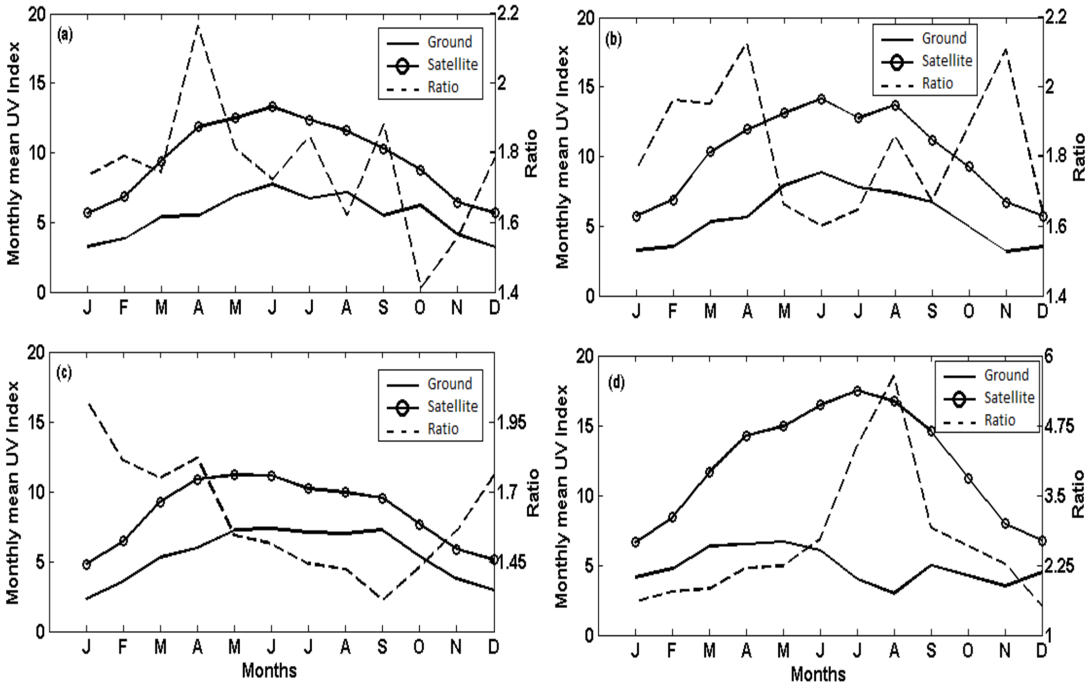

Figure 1: Variation of Monthly mean ground based and satellite estimated UV index in (a) Kathmandu (b) Pokhara (c) Biratnagar and (d) Lukla. The solid line represents ground based measurement while the solid line with marker for satellite based UV index (left y axis). The dashed line represents the ratio of satellite and ground based UV index (right y axis).

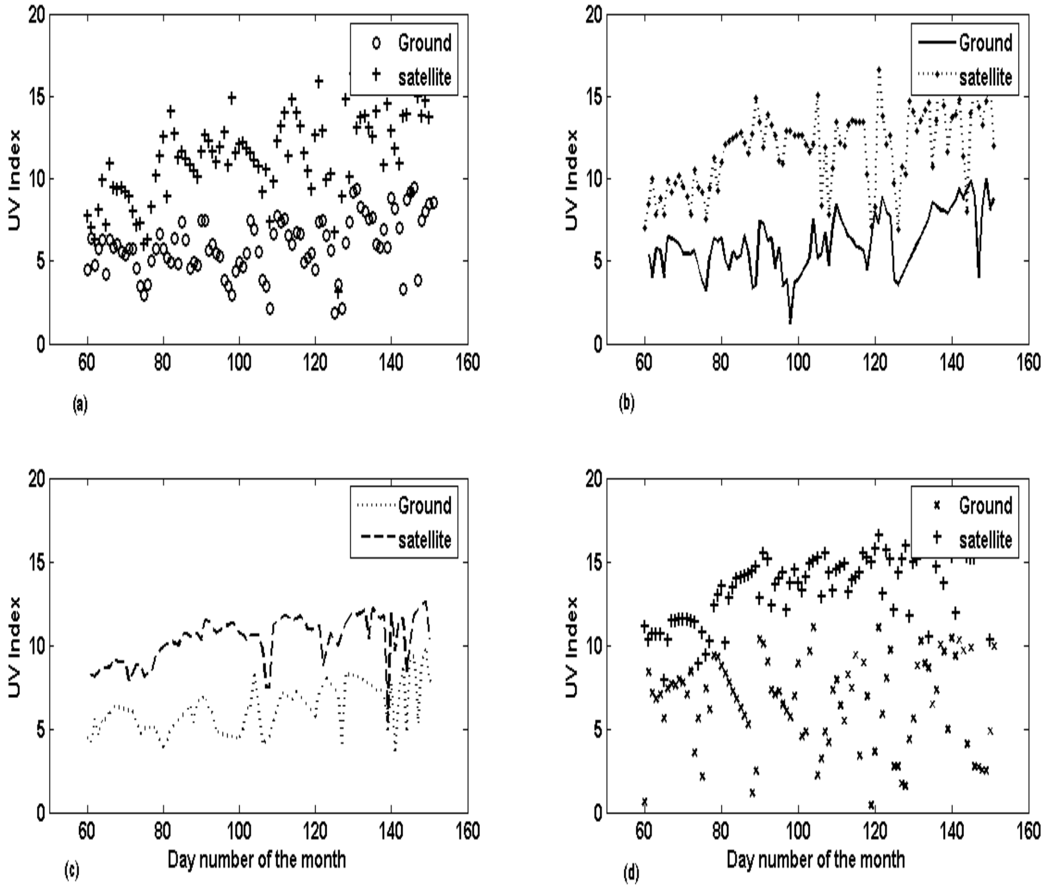

Figure 2: Variation of ground based and satellite estimated solar UV Index in March, April, and May in (a) Kathmandu (b) Pokhara (c) Biratnagar and (d) Lukla before monsoon

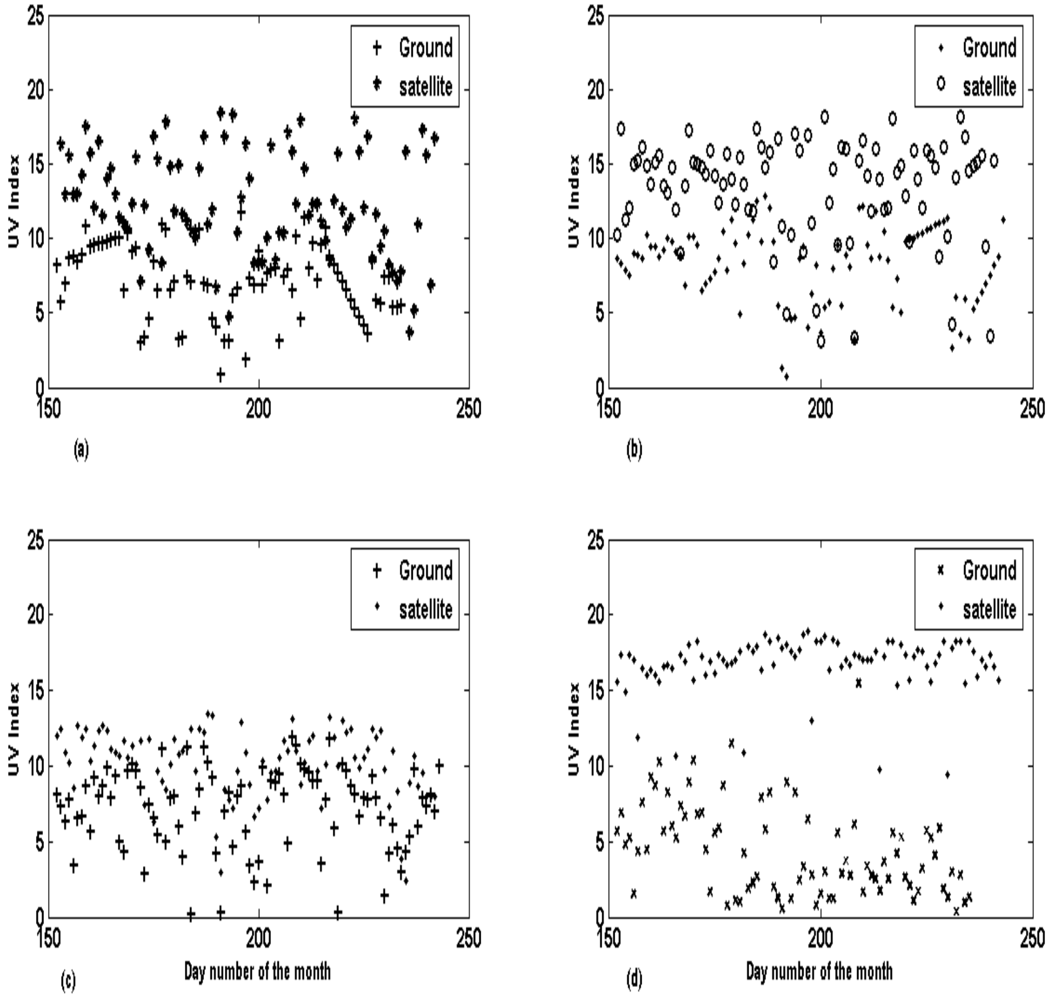

Figure 3: Variation of ground based and satellite estimated solar UV Index in June, July, and August in (a) Kathmandu (b) Pokhara (c) Biratnagar and (d) Lukla during monsoon.

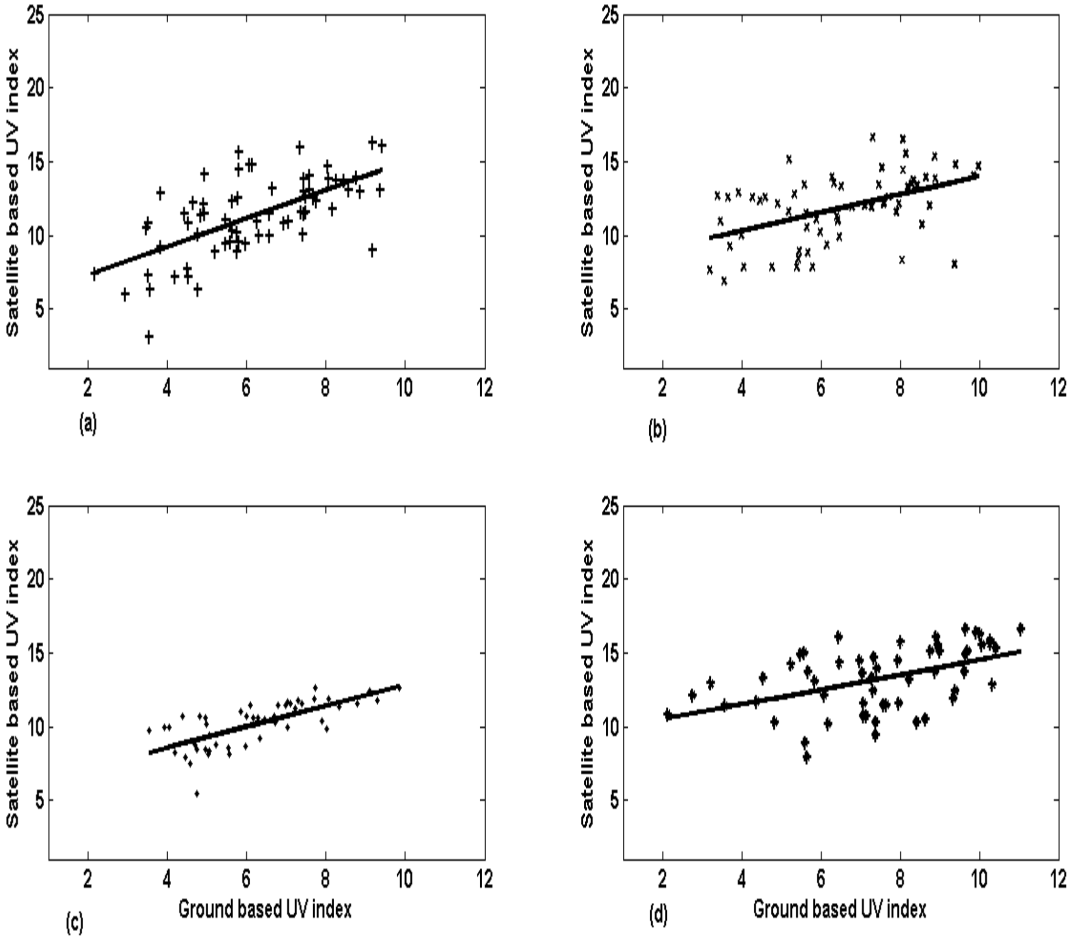

Figure 4: Satellite and ground based UV index scatter plot in March, April, and May in all sky conditions in (a) Kathmandu (b) Pokhara (c) Biratnagar and (d) Lukla. The solid black line represents the linear fit.

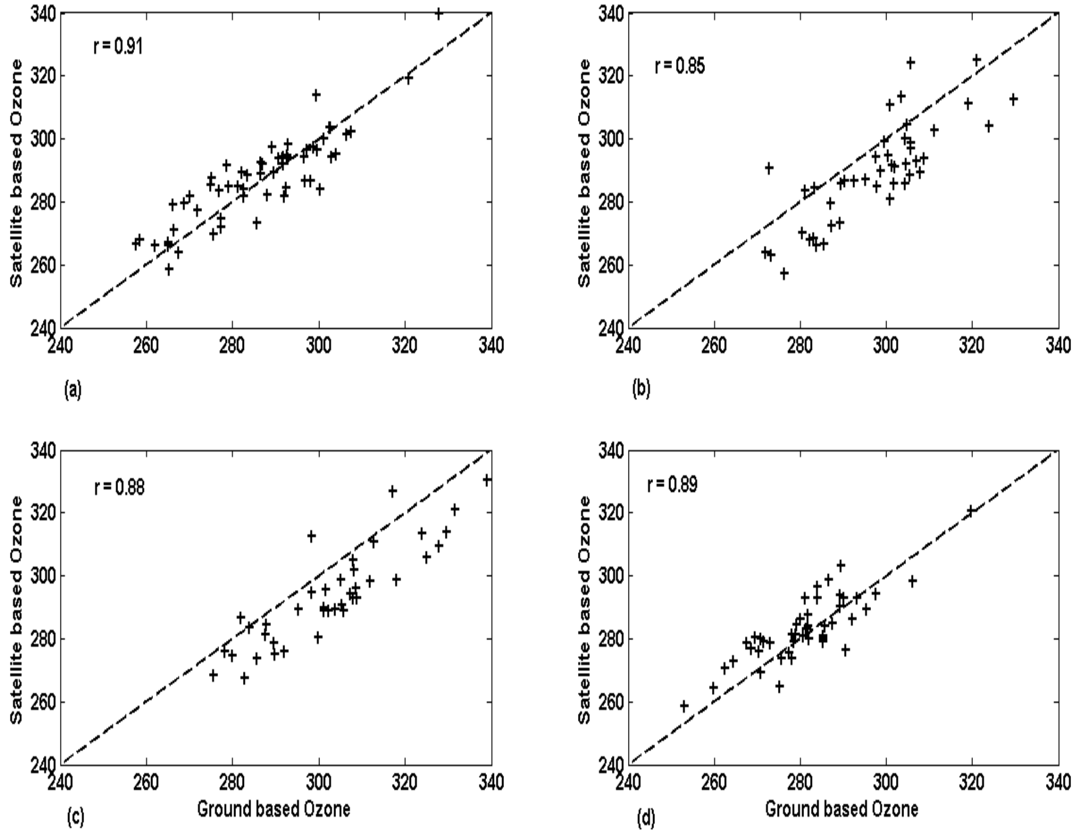

Figure 5: Scatter plots of satellite and ground based daily ozone scatter plot in March, April and May in (a) Kathmandu (b) Pokhara (c) Biratnagar and (d) Lukla. The solid dash line is the bisectrix.

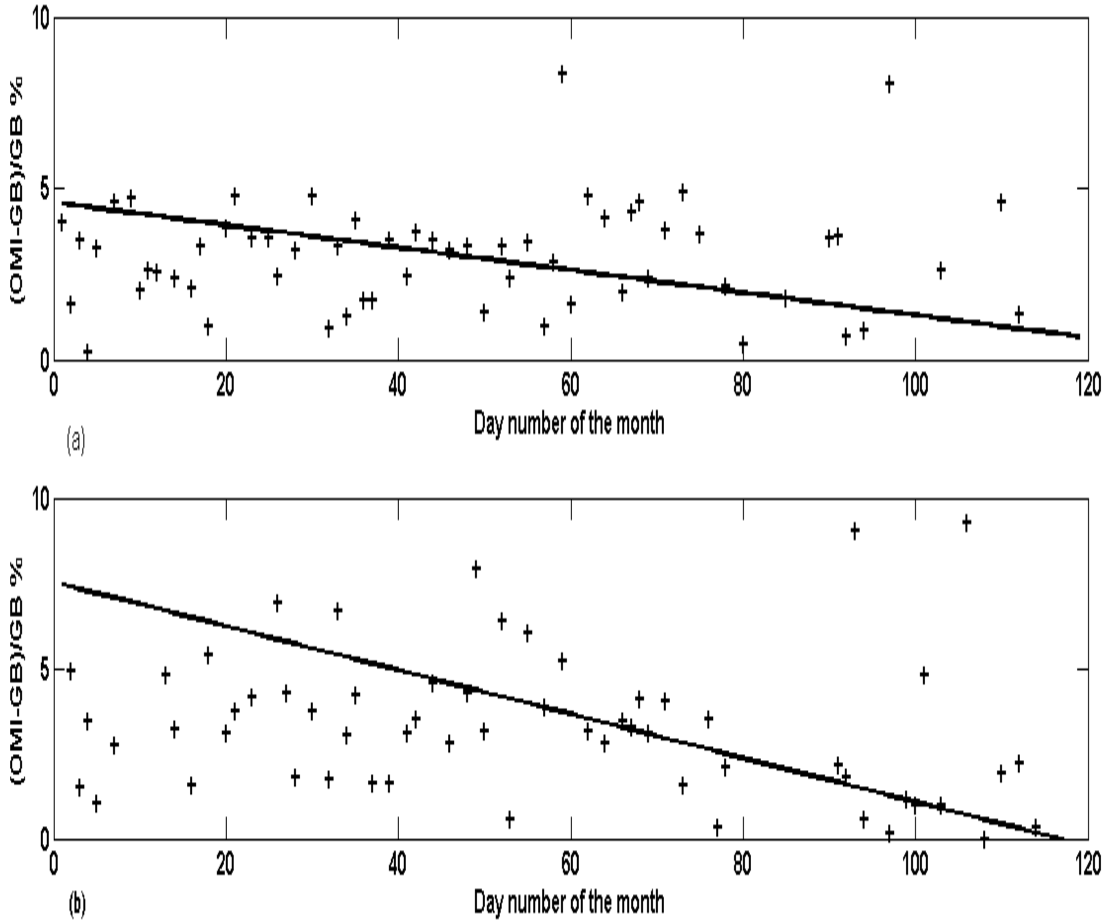

Figure 6: Relative percentage deviation of satellite and ground measured ozone in (a) Kathmandu and (b) Lukla for January to April.

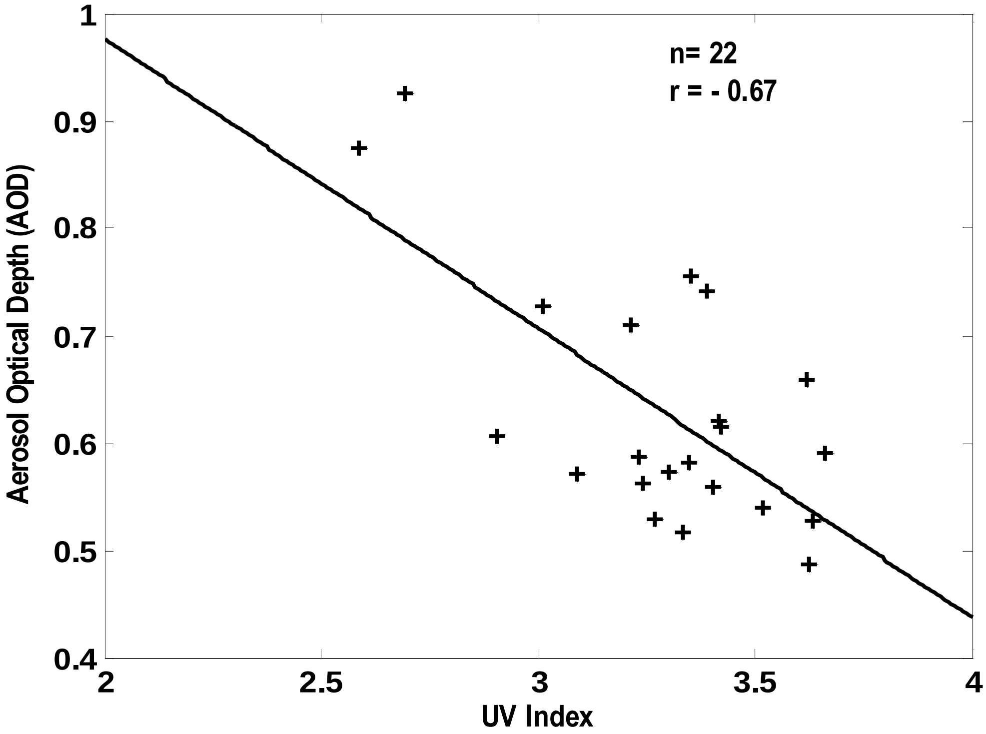

Figure 7: A scatter plot of UV index with AOD at 340nm in January at Kathmandu.