

## Comparison of ground based, satellite estimated and modeled solar UV Index in three major cities of Nepal

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### ABSTRACT

This paper presents the comparison of solar UV Index (UVI) at three major cities of Nepal (Kathmandu, Pokhara and Biratnagar). Kathmandu (27.72° N, 85.32° E), Pokhara (28.22° N, 83.22° E) and Biratnagar (26.45° N, 87.27° E) are located at an elevation of 1350m, 800m and 72m respectively from the sea level. The NILUUV irradiance meter is used to record UV radiation on these stations. The Ozone Monitoring Instrument (OMI) on board, NASA EOS Aura space craft, is a nadir viewing spectrometer that measures solar reflected and back-scattered light in ultraviolet and visible spectrum. The UVSPEC model from the LibRadtran package version 1.01 is also used to reconstruct the global spectral irradiance from 290 to 450nm at 0.5nm resolution. The study is based on one year (2009) data for Kathmandu (KTM), Pokhara (PKR) and Biratnagar (BRT). OMI overestimates the ground based data (June- September) by 50.7 - 93.9 % in KTM, 48.8 - 70.4 % in PKR and 33.3 - 62.0 % in BRT. Radiative transfer (RT) clear sky calculation with ground based (GB) measurement was used to determine the influence of clouds and aerosols on the surface UV radiation. On common clear day in March 1, 2009 the relative difference between calculated clear sky UVI and ground based UVI was found to be 44.7 % at KTM, 41.8 % at PKR and 42.3 % at BRT at 7 UT. The correlation coefficient ( $r$ ) between GB and OMI noon time ozone showed a good agreement and were found to be 0.92 at KTM, 0.91 at PKR and 0.91 at BRT respectively from January to April, 2009.

**Keywords:** UV index, OMI, Ozone, Clouds, Radiative.

### 1. Introduction

Sun is the ultimate source of energy and its emission includes Ultraviolet (UV), visible and infrared radiation. UV radiation is a part of electromagnetic spectrum and is divided into three regions: UV-C (200-280 nm), UV-B (280-315 nm) and UV-A (315-400 nm). Solar UV radiation possesses strong biological effect on ecosystem. Atmospheric oxygen and ozone absorb most of UV-C radiation and prevent it from reaching the earth's surface. However, a small part of UV-B radiation and a relatively greater amount of UV-A radiation can reach the earth's surface.

Solar UV radiation reaching the earth's surface has a wide range of effects on humans, aquatic and terrestrial ecosystems (ACIA, 2005). For humans, exposure to UV radiation has been linked to sunburn, skin cancer, corneal damage and cataracts (Gruijil et al., 2003). The important beneficial effect of UV radiation is the photochemical production of vitamin D in the skin (Lehmann, 2005). Vitamin D is essential for the formation and strengthening of the bones (Holick, 1996) and it may also protect from internal cancers (Grant, 2002). On one hand, reflections from snow covered surfaces and the long hours of sunshine during summer months can lead to considerable UV exposure (Cockell et al., 2001). On the other hand, the

virtual absence of UV-B radiation during winter months may result in vitamin D deficiency (Webb et al., 1988; Engelsens et al., 2005) and is associated with diseases such as rickets (Stokstad, 2003)

Stratospheric ozone content influences solar UV irradiance received at the Earth's surface in immensely varying amounts through the UV range; for example the effective absorption cross-section is 20 times less at 340 nm than at 300 nm (Molina and Molina, 1986). As a consequence, ground UV-B irradiance is only a fraction as low as 5%, of the whole ultraviolet irradiance. Total UV irradiance shows daily and yearly cycles that strongly depend on the geographic latitude and on other local conditions such as altitude above the mean sea level, cloudiness, ground albedo, etc. The UV climatology at a specific site depends primarily on the time of day and day of the year, secondly, on cloudiness and thereafter on the type and amount of aerosols (Foyo et al., 2003). Clouds have strong influence on surface UV attenuation both in the UV-A and the UV-B regions and the wavelength dependence is weak. Radiation in the UV-A region however, is nearly insensitive to ozone.

Most of the recent scientific studies have been devoted to the effects of UV-B radiation on humans, ecosystems and materials. Numerous investigations also emphasize the role of UV-A radiation. The location of the DNA damage in human skin suggests that long-wave UV radiation is an important carcinogen for the stem cells in the skin (Bachelor and Bowden, 2004). Also photosensitivity reactions in human skin are promoted by UV-A radiation. Not only UV-B but also UV-A radiation cause severe damage in some animal species in sub-arctic climate (Zellmer, 1998), and both UV-B and UV-A radiation are potent modulators of the immune defense in fish (Salo et al., 2000).

Forecasting the UV is a usual practice in the developed world (WHO, 2002). At present UV is monitored in different parts of the world like USA, Europe, Australia and some parts of Asia. Continuous UV monitoring was lacking in Nepal before October 2008. However, a few case studies have been documented (Bhattarai et al., 2007). This is the first time UV monitoring is being carried out in Nepal. The need for measurement can also be highlighted by the fact that thousands of tourists take Nepal as their destination. The consequent data thus aids the visitors to identify the places that are safe from a radiation point of view.

At higher altitude the strength of UV radiation is relatively higher. People residing at these altitudes may not be aware and familiar with solar UV radiation and its effects. Hence, scientists developed UV Index to provide information about UV radiation to the public. UVI is related with erythral effects of UV radiation on human skin and it is standardized under the umbrella of several international institutions (Vanicek, 1999). The UV index is an estimation of UV levels that are important to determine the effects on human skin, where 1 unit equals  $25\text{mW/m}^2$ . It is usually given for local solar noon, when the sun is highest in the sky, and it is valid for clear-sky conditions (<http://www.temis.nl/uvradiation/info/uvindex.html>). The UVI presented in this paper is based on worldwide used CIE action spectrum (McKinlay and Diffey, 1987). UV index differs from place to place and depends upon different factors. Thus the presentation of UV level at three major cities is an important part of the study.

The main aim of this paper is to present the level of UVI in Kathmandu, Pokhara and Biratnagar. The monthly mean variation of ground based and satellite based UVI is analyzed. The correlation coefficient (r) between noon time ground and satellite based ozone from January to April is also analyzed. Radiative transfer (RT) model is used to show the effects of clouds and aerosol. Estimated model UVI is compared with ground based UVI for

common clear day (March 1). Relative difference between calculated clear sky and ground based UVI for March is also analyzed. Section 1 represents the introductory part of UV radiation. Methodology is given in section 2. Results and discussion of the UV measurement is presented in section 3. Conclusions of the measurement are included in section 4.

## **2. Methodology**

Kathmandu (27.72° N, 85.32° E), Pokhara (28.22° N, 83.32° E) and Biratnagar (26.45° N 87.27° E) are located at an elevation of 1350m, 800m and 72m respectively. The instruments used during measurement were NILU-UV irradiance meters. The NILU-UV is a six channel radiometer designed to measure hemispherical irradiances on a flat surface. UV doses with various action spectra and total ozone column amounts can be derived from the measured irradiance by using a technique described by Dahlback, 1996. The NILU-UV comprises of 5 different channels with center wavelengths at 305±2.5 nm, 312±2.5 nm, 320±2.5 nm, 340±2.5nm and 380±2.5 nm. The bandwidth of each channel is 10 nm FWHM (Full Width at Half Maximum). The sixth channel measures the visible radiation between 400-700 nm. The instrument has a built-in data logger and temperature stabilized at 50°C. The data logger automatically records one minute averages every minute for each of the channels. The instrument has a Teflon diffuser designed to obtain a good cosine response for the angular sensitivity. After passing the diffuser, the incoming radiation is passed through band pass filters with a very low cut-off-band transmittance. The filtered light is converted into electric currents by photo detectors, one for each channel. The photo detector consists of a conduction band and valence band. Photons move electrons from the valence band on to the conduction band and forms currents ( $C_i$ ). The currents are subsequently amplified, digitized and converted to absolute irradiances for each channel. The instruments were calibrated against a Bentham DM50 high-wavelength resolution spectroradiometer (bandwidth 0.8nm at FWHM) at the Norwegian Radiation Protection Authority (NRPA) in Oslo, Norway using a technique described by Dahlback (1996).

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. The UVSPEC model (Mayer et al., 1997; Kylling et al., 1998) from the LibRadtran package (<http://www.libradtran.org>) version 1.01 is used to reconstruct the global spectral irradiance from 290 to 450nm resolution. UVSPEC radiative transfer (RT) model is based on the discrete transfer algorithm by Stamnes et al. (1998).

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 (340nm), visible (440, 500, 675nm) and infrared (870 nm) wavelengths. The bandwidth for channel 340 nm is 2nm and for the rest of the channels is about 10 nm. 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 under clear sky in Kathmandu.

The cosine response and the spectral response are the two important characteristics of NILU-UV instrument. The input optics of instrument is designed to obtain a good cosine response. The deviations are less than  $\pm 5\%$  from the ideal cosine response for incidence angles less than  $75^\circ$ . The spectral response is the ratio of the output of each channel to the input determined over the range of wavelength to which the channel is sensitive. Accurate determination of the spectral response is needed in order to calibrate the individual channels (www.nilu.no/products).

### 3. Results and discussion

This paper analyzes and presents the UVI levels at three major cities of Nepal in Kathmandu, Pokhara and Biratnagar as shown in figure 1. Radiative transfer (RT) calculations and ground based measurements are used for this analysis.



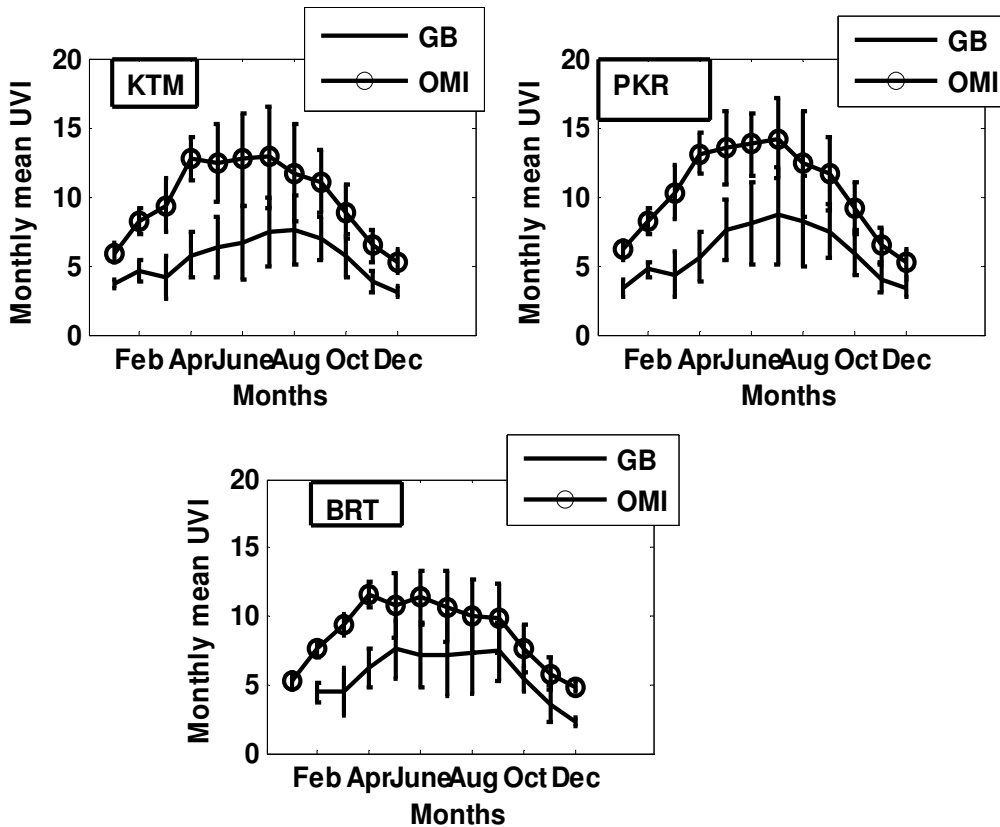
**Figure 1:** Measurement sites

The monthly mean values of noon time ground based UVI were found to be  $7.5 \pm 2.5$  at KTM,  $8.6 \pm 3.5$  at PKR and  $7.2 \pm 3.1$  at Biratnagar in July as shown in figure 2 (a), (b) and (c). The corresponding OMI UVI in July was  $12.7 \pm 3.6$  at KTM,  $14.4 \pm 2.6$  at PKR and  $10.3 \pm 2.7$  at BRT. Further analysis of these data revealed that the OMI values overestimated the GB values. In fact, during monsoon (June –September), OMI data were greater than the GB data by 50.7 to 93.9 % in KTM, 48.8 to 70.4 % in PKR and 33.3 to 62.0 % in BRT. This fact is confirmed by Kazantizidis et al. (2006) which states that TOMS UV data overestimates ground based measurements by almost 20 % under high aerosol load. Likewise, Krotkov et al. (1998) also showed that absorbing aerosols can lead to an overestimation in the satellite derived UV flux ranging from a few percent to 50 %. And Weihs et al. (2008) further strengthened this fact by stating that in polluted areas satellite UV was up to 50 % higher than ground based measurements.

Observations also revealed that the ground based UVI values were closer to 10 in KTM, 12 in PKR and 8 in BRT during most of the days in July. It could also be verified by Dahlback et al. (2007), which states that on clear sky UV index above 10 may occur frequently between 1 March and 1 October in Lhasa ( $29.63^\circ$  N,  $91.11^\circ$  E). In fact, the average value of UV Index in June-July at Lhasa was  $12.2 \pm 2.8$  (Dahlback et al., 2007). This comparison with Lhasa is made because of the fact that it lies close to our stations in latitude. Now, the main reason for

the high value of UVI in July is due to the position of the sun which lies in the northern hemisphere and the angle made by it with the zenith which is small.

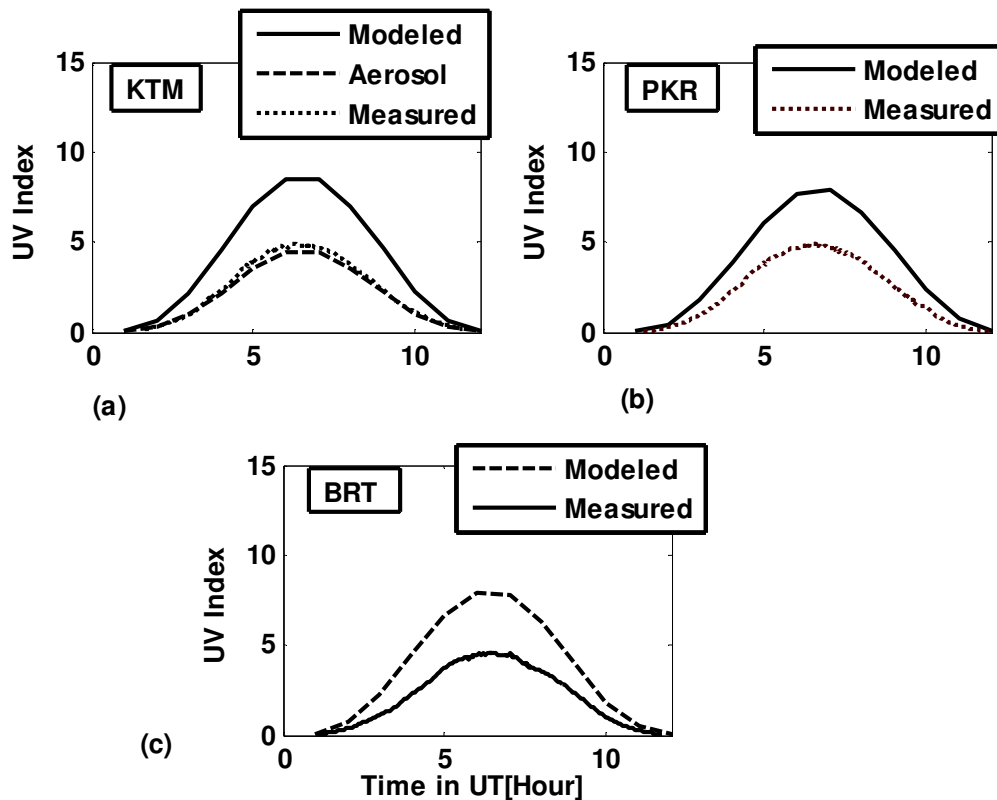
Meanwhile the analysis also revealed that the UVI at PKR was higher than in other sites. It is because of the higher rainfall that is observed at PKR. According to Nazrul (2007), the annual average rainfall in PKR is 3951.5 mm. As a consequence the aerosols and pollutants present in the atmosphere are washed out which results in UVI to increase.



**Figure 2:** Monthly mean variation of ground based and satellite estimation of solar UV Index in (a) Kathmandu (b) Pokhara and (c) Biratnagar.

The overall picture of these data provided us with a sense of understanding that the higher UVI are observed during the clear sky condition. It is because a uniform cloud layer reflects parts of radiation into the space. However, Mims and Frederick (1994) and Nack and Green (1974) slightly contradicted this fact by stating that the local surface UV irradiance can be increased if clouds are not obstructing the disk of the sun and additional radiation is reflected from the side of a broken cloud field toward the ground.

According to Eck et al. (1995) surface albedo ranges from around 0.02 to 0.07 in most of the land surfaces. Alongside, Taskanen et al. (2007) concludes that selecting a threshold of 0.1 is reasonably good to distinguish snowy and non-snowy surface. Since the measurement sites under consideration are snow free for most of the time in a year, the surface albedo of less than 0.1 is considered in this study. Meanwhile, the cloudy and cloud free days are selected by observing the daily oval shaped pattern of UVI. This pattern of UVI showing several kinks indicates the presence of clouds. Likewise the influence of aerosol is determined by using Microtops II Sunphotometer and the wavelength exponent  $\alpha$  and Angstrom coefficient  $\beta$  was calculated by using least square fit method for Angstrom power law.



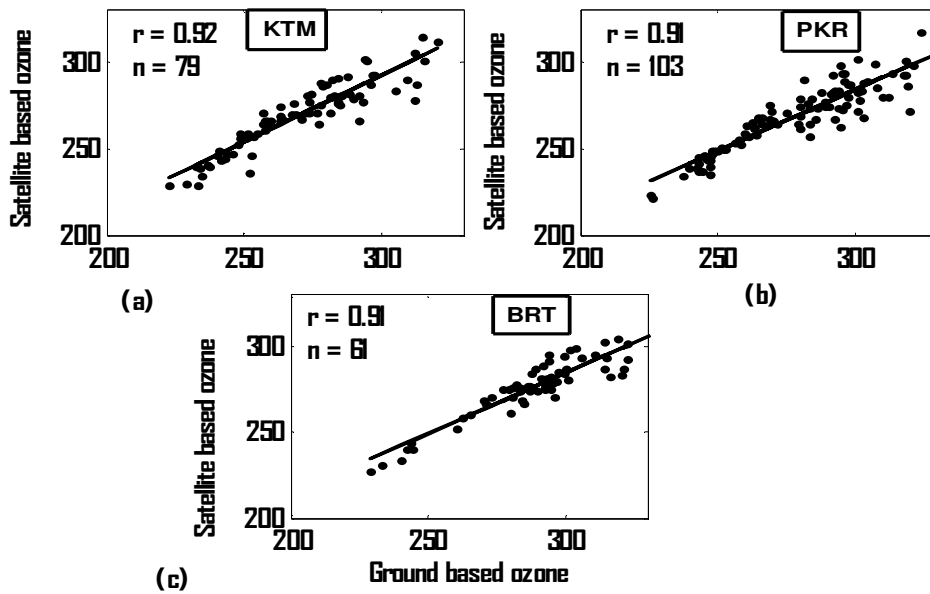
**Figure 3:** Diurnal variation of UVI using calculated clear sky model and ground based measurement in (a) Kathmandu (b) Pokhara and (c) Biratnagar

For the Modeled clear sky UVI calculation, 5 % surface albedo and noontime average ground ozone values of 280.8 DU in KTM, 291.1 DU in PKR and 291.4 DU in BRT were used as an input in the RT model. On March 1, 2009 the modeled UVI at 7 UT in KTM, PKR and BRT were found to be 8.5, 7.9 and 7.8 respectively, whereas the ground UVI at the same time were 4.7, 4.6 and 4.5 which are shown in figure 3 (a), (b) (c) and (d). This observation showed the differences between calculated clear sky UVI and ground based UVI to be 44.7 % at KTM, 41.8 % at PKR and 42.3 % at BRT at 7 UT. When assuming constant aerosols as an input, the clear sky model differed by 4.4 % in KTM. This difference in UVI (4.4 %) in clear sky model is due to aerosol whereas 40.3 % might be due to different parameters like cloud, water vapor and gases.

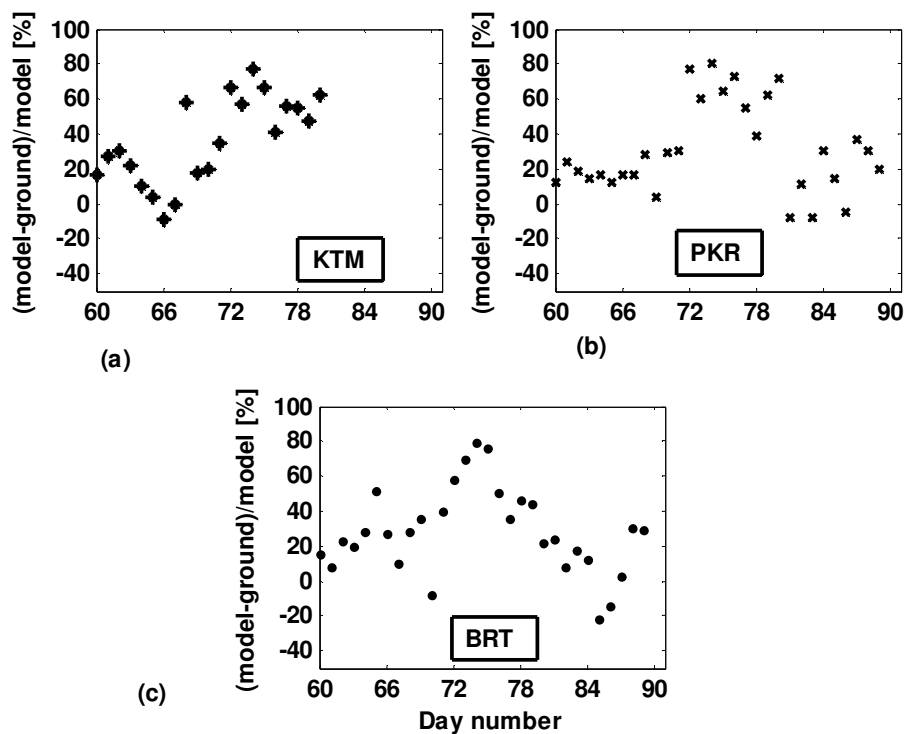
The Modeled clear sky UVI in March differed by 10-50 % in KTM, 10-40 % in PKR and 7-50 % in BRT as shown in figure 4(a), (b) and (c). This type of observation is also performed by Bhattarai et al. (2007) which states that on cloud-free day (25 February), 15 % deviation was found which can be attributed to the effect of aerosols and the effect of non-ideal cosine response of the instrument. In case of PKR and BRT, aerosol as input is not included in the model, because of unavailability of aerosols data.

The correlation coefficient ( $r$ ) between OMI and GB ozone from January to April 2009 were found to be 0.92, 0.91 and 0.91 in KTM, PKR and BRT respectively in all sky conditions. This agrees with the correlation coefficient found by Ialongo et al. (2008) at Rome station (41.9°N, 12.5°E). According to Ialongo et al. (2008) the comparison with OMI using erythemal doses at local noon from YES radiometer shows a correlation coefficient of 0.91 under all sky conditions. Furthermore Bhattarai et al. (2007) also verified this fact by stating that the scatter plot of TOM'S ozone and the ratio between the irradiances at 340 and

305 nm channel of the GUV shows a strong correlation  $r=0.91$ . OMI noon time and NILU-UV one hour noon time ozone values for 7 different days in April, 2009 is shown in Table 1.



**Figure 4:** Relative differences between calculated clear sky modeled and ground based UVI in (a) Kathmandu (b) Pokhara and (c) Biratnagar.



**Figure 5:** Scatter plot between OMI and GB noon time ozone from January to April 2009 in (a) Kathmandu (b) Pokhara and (c) Biratnagar.

**Table 1:** Satellite and ground based ozone in different days of April 2009

Date	Ozone (DU)					
	KTM		PKR		BRT	
	GB	OMI	GB	OMI	GB	OMI
13	289.5	275.2	303	267	295.4	278.8
14	284.4	265.8	295.4	273.6	296.4	270.3
15	276.2	279.2	285.3	274.2	294.7	275.4
16	268.6	266.2	286	271.1	283.9	268.9
17	277.9	269.5	293.9	275.1	283.6	274.6
18	282.5	270.8	290.3	273.8	295.3	
19	291.6	274.7	300.9	276.1	289.6	273.9
<b>Average</b>	<b>281.53± 7.99</b>	<b>271.63± 4.97</b>	<b>293.54± 6.86</b>	<b>272.99± 3.06</b>	<b>291.27± 5.59</b>	<b>273.65± 3.59</b>

Table 1 indicates the satellite and ground based daily averaged ozone values obtained during a period of a week i.e. from 13<sup>th</sup> April to 19<sup>th</sup> April. The average of the these daily averaged ground based ozone was found to be 281±8.0 in KTM, 293.5±7.0 in PKR and 291.3± 6.0 in BRT respectively whereas the corresponding OMI averaged ozone was 271.6±5.0 in KTM, 273.0± 6.0 in PKR and 273.7±4.0 in BRT. Analysis on these data revealed that the relative difference between OMI and GB ozone with respect to the GB measurement were found to be -3.5 % at KTM, -7.0 % at PKR and -6.0 % at BRT. This biasness observed may be due to the presence of cloud in the OMI grid. It may also be due to the wider field of view of OMI and smaller field of view of NILU- UV as well as the changing atmospheric conditions.

#### 4. Conclusions

Based on GB and OMI measurement, one year noon hour UV indices for KTM, PKR and BRT were analyzed. During the monsoon period (June to September), the relative difference in OMI and GB UVI ranged between 50.7 – 93.3 % in KTM, 48.8 – 70.4% in PKR and 33.3 – 62 % in BRT. Most of the days in July the ground based UVI were found to be closer to 10 in KTM, 12 in PKR and 8 in BRT. On one clear day (1 March 2009) the relative difference between calculated clear sky UVI and ground based UVI was found to be 44.7 % at KTM, 41.8 % at PKR and 42.3 % at BRT at 7 UT. From the study it is concluded that higher values of UV indices are observed at Pokhara in comparison to Kathmandu and Biratnagar, although Pokhara is at lower altitude than Kathmandu. The analysis also showed that there is good agreement between satellite estimated and ground based ozone, which was found to be 0.92 in KTM, and 0.91 in PKR and 0.91 in BRT.

#### Acknowledgements

The author acknowledges Solar Radiation and Aerosol in the Himalaya Region for providing necessary data. NPS is also grateful to NASA for satellite data.

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