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Diagnosis of clear sky ultraviolet radiation for Mexico

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RESUMEN

Utilizando un modelo de transferencia de radiación de ordenadas discretas se desarrolla un sistema para el diagnóstico de la distribución de radiación ultravioleta para cielo despejado en la República Mexicana. La radiación para cielo despejado se obtiene utilizando la respuesta espectral de la piel humana y los datos de satélite de ozono total registrados por el espectrómetro TOMS. Se presentan ejemplos del Índice de radiación ultravioleta (UV Index) calculados con el modelo y se comparan con las mediciones en superficie obtenidas en la Universidad de Colima durante 1999.

Palabras clave: Radiación ultravioleta, ultravioleta, UV Index, diagnóstico de ultravioleta.

ABSTRACT

A discrete-ordinate radiative transfer model is employed to develop a regional clear sky ultraviolet (UV) diagnosis system. The clear sky UV radiation, weighted by the spectral sensitivity of human skin is calculated using the Total Ozone Mapping Spectrometer (TOMS) data sets. Examples of the geographical clear sky UV Index distributions are presented and the model results are compared with surface UV measurements from the University of Colima for 1999.

Key words: Ultraviolet radiation, ultraviolet, UV Indice, ultraviolet diagnosis.

1. Introduction

Colima city (19.02°N, 104.4°W) is located at the western part of Mexico, 45 km inland from the Pacific coast and 30 km SW from the "Volcán de Fuego de Colima" volcano. Its main activities are highly sophisticated agriculture and fishery industries. Surface measurements performed in the Centro Universitario de Investigaciones en Ciencias del Ambiente (CUICA) at the University of Colima, have shown high irradiance fluxes, particularly in the UV spectral region (Galindo *et al.*, 1995; Galindo *et al.*, 1999; Galindo *et al.*, 2000). These radiation levels are of concern because even relatively small increases in UV radiation can have important impacts on the biosphere and on human health (UNEP, 1998). In Colima medical statistics show that skin cancer incidence ranks in the second place, just after uterine cancer (Galindo, *et al.*, 2000). Therefore a joint UV research project between the Southern Hemisphere of Meteorology Cooperative Research Centre (Australia), the Bureau of Meteorology Research Centre (Australia) and CUICA at the University of Colima (Mexico) (hereinafter referred to as CUICA) was undertaken. As a result, a regional clear sky UV system "AMEX" was implemented at CUICA for research purposes. The system was developed considering the computing limitations and previous experience using the discrete-ordinate method at CUICA. The system uses the discrete-ordinates radiative transfer model libRadtran (Killyng and Mayer, 1997).

The amount of UV radiation that reaches the Earth's surface is a function of the solar irradiance, the solar zenith angle, ozone amount, surface albedo, altitude, clouds and aerosols. The maximum surface clear sky UV radiation occurs at local solar noon, when the solar zenith angle is at its minimum and the optical path length through which radiation travels is shortest. As the altitude increases the optical path length decreases and the amount of clear sky UV radiation increases. Ozone, clouds and aerosols in general reduce the amount of UV radiation reaching the surface. However reflecting surfaces (e.g. sand or snow) and scattering from the edges of the clouds can increase the surface UV radiation (Madronich, 1993).

The direct and diffuse radiation are calculated in libRadtran by solving the radiative transfer equation (which describes the transfer of radiation through and absorbing and scattering media) using the discrete-ordinates method described in Stamnes *et al.* (1988). Inputs to the model are solar zenith angle, ozone, and surface albedo as well as the optical depths, single scattering albedo and phase function for each atmospheric layer.

The libRadtran model (for 6-streams) has been adapted at CUICA to compute UV radiation over the Mexican region between latitudes 13-34°N and longitudes 116-86°W (details of the software can be found in Solano, 2000). The latitude, the day of the year and time of the solar day are used to determine the solar zenith angles (Iqbal, 1983) throughout the year for the Mexican region. The total ozone amounts required by the model are obtained from the Total Ozone Mapping Spectrometer (TOMS) data sets. Additionally a variable broad-band UV surface albedo derived from the Earth Radiation Budged Experiment (ERBE) clear sky surface albedo data sets, UV surface albedo observations (Doda and Green, 1981; Cess and Vulis, 1989; Li and Garand, 1994), and a modified approximation to the Briegleb *et al.* (1986) surface albedo was also used in the model. The system (AMEX) is being run in a HP Apollo 9000 workstation. In this paper the UV radiation is calculated for local solar noon and clear skies. Examples of the geographical distribution of surface clear sky UV radiation for the Mexican region are shown and the comparison of clear sky UV with measurements from CUICA for 1999 is presented.

2. Model and measurements results

The UV system AMEX is being run for the Mexican region using standard tropical atmosphere conditions (McClatchey *et al.*, 1972), for 1nm wavelength intervals over the 290 to 400nm wavelength-band and a spatial resolution of $1^\circ \times 1.25^\circ$ in latitude and longitude. The clear sky surface UV irradiance is weighted by the erythemal action spectrum CIE (Commision Internationale d'Eclairage, 1987) and integrated over wavelength to derived clear sky UV Indices. The CIE represents the spectral sensitivity of "average" human skin to UV radiation and one UV Index unit is equal to 25 W/m^2 (WMO, 1995).

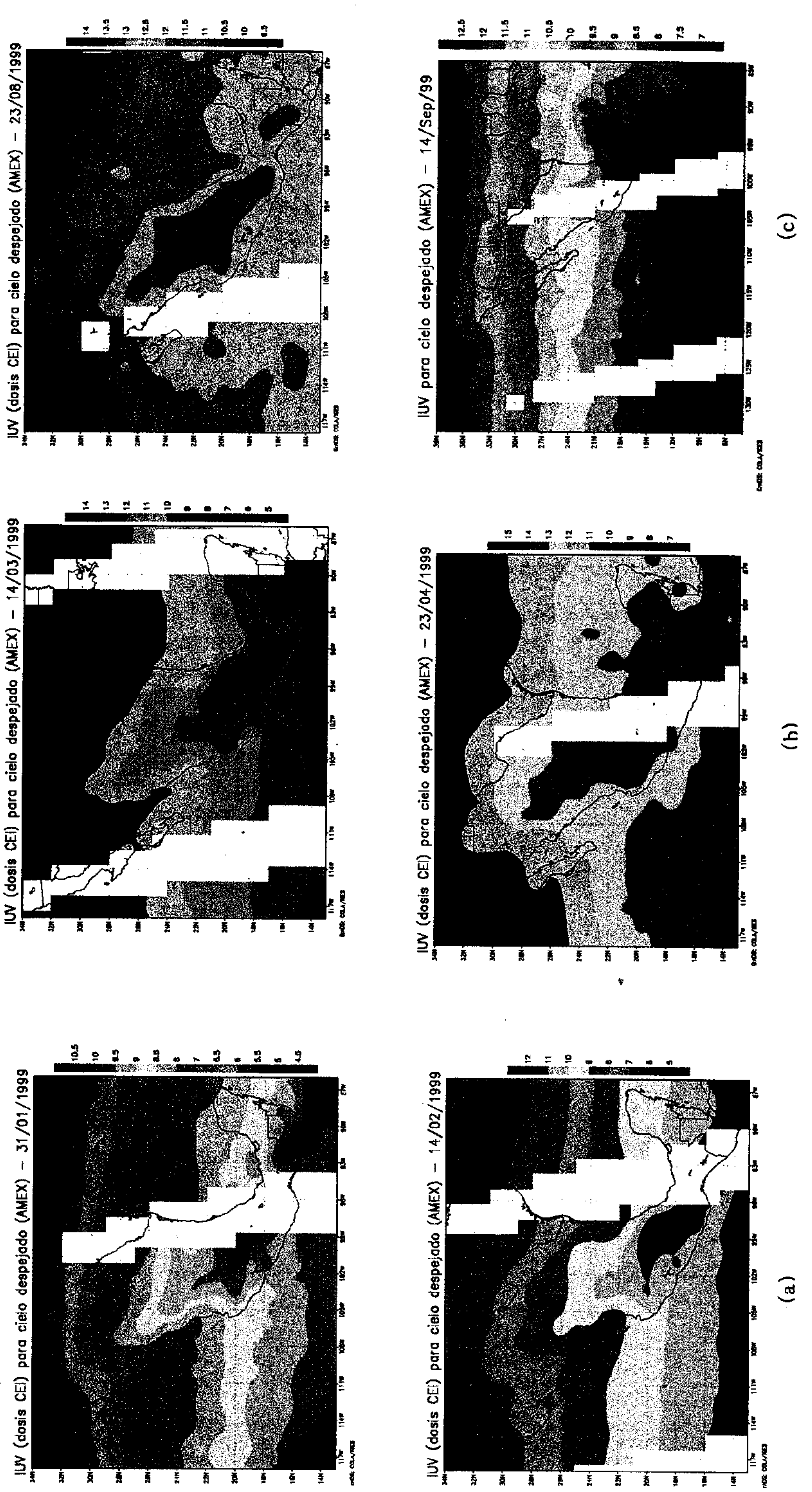

Fig. 1. Clear sky UV Index for the Mexican Region (13-34EN and longitudes 116-86EW) for a) January and February, b) March and April and c) August and September, 1999.

The seasonal variation of the geographical distribution of the clear sky UV Index over the Mexican region is shown in Figures 1a to 1c where examples for January, February, March, April, August and September 1999 are presented. The results show that the clear sky UV Index increases towards the equator, with values from 9 up to 15 UV Index units to the South of Mexico. Lower values are obtained for the North of Mexico (between 6 and 12). The Mexico clear sky UV Index for the west coast shows the impact of the high altitude of the mountain chain "Sierra Madre Occidental" with increased UV Index being observed in this area. In these regions the altitude and the decrease in solar zenith angle towards the equator are the main causes of the increase in the UV radiation field. A similar effect is observed for the east coast along the ranges of the "Sierra Madre Oriental". The white areas in the Figures 1a-1c are due to no data from TOMS. During spring (Fig. 1b), when the solar zenith angle is small and the sun is over to northern latitudes and the atmospheric scattering and absorption of UV radiation is small (small optical paths compared with winter situations Fig. 1a), the UV reaches its maximum values.

A qualitative "danger category" to exposure of UV radiation can been associated with the UV Index value. In the Australian UV Index analysis and forecast system (Lemus-Deschamps *et al.*, 1999), for example, values below 3 units are considered moderate, between 3 and 6 are high, between 7-9 are very high and larger than 9 are considered extreme. The seasonal geographical distributions presented in this work show that for Mexico the UV Index values are in the "high" category and above, reaching extreme values over a large part of the country during most of the year. Colima (19.02°N, 104.4°W), in particular, shows clear sky values above 8 UV Index units for most of the year.

The values of clear sky UV Index obtained with the AMEX system were compared with UV measurements from the meteorological station CUICA for the year 1999. The UV measurements were obtained using a calibrated Eppley total ultraviolet radiometer (TUVR). The TUVR radiometer is installed on the roof of a 4m high building. It is regularly calibrated against the Eppley H-F cavity radiometer No. 28965 which is one of the regional radiometer instruments of the Regional Radiation Center of Mexico for the Regional Association IV of the World Meteorological Organization. Previous results show (Galindo *et al.*, 1999) that the instrument calibration is important since significant loss of the instrument's sensitivity has been observed suggesting that the TUVR instrument mean life time under tropical conditions is about 4 years. This problem and the measurement's accuracy need to be kept in mind for the data analysis. For UV measurements (290-385nm) between 20 and 35 W/m^2, a 2-3% relative error has been estimated.

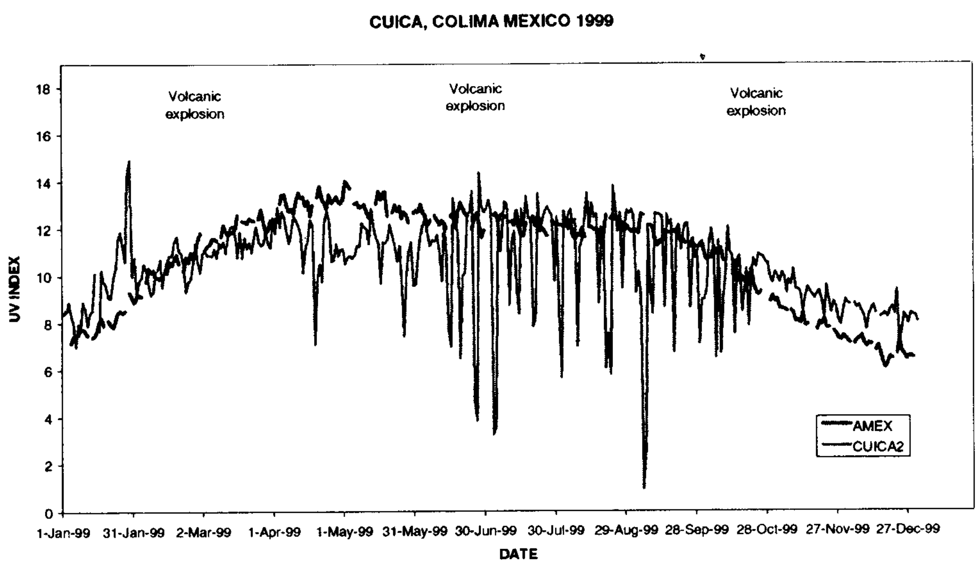

Fig. 2. UV Index derived from measurements (CUICA2) and model clear sky simulations (AMEX) for the meteorological station located in CUICA, University of Colima, Mexico (19.02EN, 104.4EW)

The UV measurements from CUICA were weighted by the erythemal action spectrum (CIE) and expressed in terms of UV Index units to derive the UV Index. In Figure 2 the UV Index derived for 1999 is shown. The model clear sky UV Index derived from the UV system AMEX is also presented in the same figure. The strong decreases in observed UV Index are due to the presence of clouds observed when the UV measurements were performed. The cloud presence was confirmed by satellite images (Galindo and Domínguez, 2001) not shown here. Clouds generally tend to reduce the amount of surface UV radiation, an example of which is observed during August (Fig. 2), when UV Index values of one were measured. It is also noted that the large differences between model and measurements UV Index are mainly due to the presence of clouds during the observations (Fig. 2).

Maximum values of clear sky UV radiation of about 12 units are observed during May and August when the solar zenith angle reaches minimum values. Decreasing to about 8 UV Index units from late May to late June and September to January. From May to early June 1999 the decreases in the UV measurements are thought to be related to the effects of absorbing aerosols due to biomass burning on the UV radiation. During the wet season (June to September) the cloud effects are also seen as a reduction of the measured UV. In contrast, the strong UV increase for 29 January 1999 (Fig. 2) was found to be mainly due to a transient low of total ozone amount (up to 230DU) combined with strong cloud scattering which enhanced the UV radiation measured on that day. The cloud scattering was confirmed from the comparison between the January mean global radiation and the 29 January measurements, which showed an increase of between 35 to about 45%.

The most important volcanic eruptions of the "Volcán de Fuego de Colima" volcano which occurred between 1997 and 1999 (Galindo and Domínguez, 2000) are also indicated in Figure 2. During July the volcano remained very active and one of the strongest explosions took place. There was reduced activity during October where several emissions of steam and ash reached up to 2900 feet. The atmosphere was loaded with volcanic aerosols during this period. Studies have shown that stratospheric aerosols at small solar zenith angle can enhance the UV (Forster and Shine, 1995) and have suggested that marine aerosols, water haze over land and non-absorbing aerosols with low altitude clouds can also cause enhancements (Herman and Celarier, 1997). Therefore the presence of stratospheric volcanic aerosols, marine aerosols and water haze during the observations may be the cause of the higher UV values measured during October-December since they were not included in the model calculations. This will be investigated in a future paper because unfortunately for this work it was not possible to separate the possible effect of the aerosols, haze and low clouds on the UV.

3. Final Remarks

The results of the joint research project between Mexico (the University of Colima) and Australia (the Meteorology CRC and The Bureau of Meteorology) presented here show the first geographical distribution of clear sky UV Index for the Mexican Republic. The UV Index derived from the measurements at the meteorological station CUICA (University of Colima) agree quite well with the UV Index derived from the diagnostic regional clear sky UV model AMEX. The observed differences between model and measured UV Index are due to the presence of clouds during the observations.

From May to June 1999 the decreases are thought to be related to the effects of aerosols due to biomass burning on the UV radiation. The significant UV for 29 January 1999 was found to be mainly due to a transient low of total ozone amount (up to 230DU) and strong cloud scattering which enhanced the UV radiation measured on that day. The UV diagnosis system AMEX is operational and future work will include the development of ozone and UV Index forecasts. The cloud and aerosols effects will also be studied in more detail.

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