Erythemal Exposure Data Product

The Erythemal Exposure data product is an estimate of the daily integrated ultraviolet irradiance, calculated using a model for the susceptibility of caucasian skin to sunburn (erythema). This can be interpreted as an index of the potential for biological damage due to solar irradiation, given the column ozone amount and cloud conditions on each day.

The Erythemal Exposure is defined by the integral

$$\text{Exp.} = \frac{1}{d_{\text{es}}^2} \int_{280\text{nm}}^{400\text{nm}} d\lambda\, S(\lambda) W(\lambda) \int_{t_{\text{sr}}}^{t_{\text{ss}}} dt\, C(\lambda, \vartheta, \tau_{\text{cl}}) F(\lambda, \vartheta, \Omega)$$

where

$$\begin{aligned}
d_{\text{es}} &= \text{Earth-Sun distance, in A.U.} \\
S &= \text{Solar irradiance incident on the top of the atmosphere at 1 A.U.} \\
W &= \text{Biological action spectrum for erythemal damage (see below).} \\
t_{\text{sr}}, t_{\text{ss}} &= \text{Time of sunrise, time of sunset.} \\
C &= \text{Cloud attenuation factor.} \\
\tau_{\text{cl}} &= \text{Cloud optical thickness.} \\
\vartheta &= \text{Solar zenith angle (function of time, } t\text{).} \\
F &= \text{Spectral irradiance at the surface under clear skies, normalized to unit solar} \\
&\quad\ \text{spectral irradiance at the top of the atmosphere.} \\
\Omega &= \text{Total column ozone.}
\end{aligned}$$

The Earth-Sun distance and sunrise and sunset times, as well as the dependence of the solar zenith angle on time during a day depend on the latitude and time of the year, and are calculated from standard formulæ [*USNO, 1992; Smart, 1977*].

The extraterrestrial solar irradiance incident at the top of the atmosphere when the Earth is at a distance of 1 A.U. from the Sun was measured over the wavelength interval of interest by the UARS/SOLSTICE instrument [*Woods et al., 1996*].

The weighting function used to approximate the wavelength-dependent sensitivity of caucasian skin to erythema-causing radiation is the model proposed by McKinlay and Diffey [*McKinlay and Diffey, 1987*], and adopted as a standard by the *Commission Internationale de l'Éclairage* (CIE). This model is given by the equations (wavelengths λ in nm):

$$W(\lambda) = \begin{cases} 1, & \text{if } \lambda < 298 \\ 10^{-0.094(\lambda-298)}, & \text{if } 298 \leq \lambda < 328 \\ 10^{-0.015(\lambda-139)}, & \text{if } 328 \leq \lambda \end{cases}$$

The function F is the normalized global (direct plus diffuse) irradiance incident on a horizontal surface at the terrain altitude of a given location, given the total column ozone measured by TOMS, the wavelength, and solar zenith angle. The value of F is computed using the table of solutions of the radiative transfer equation, which are used in the TOMS ozone retrievals. The actual incident global spectral irradiance under cloud-free skies is the product $S \cdot F$.

The cloud factor C is obtained in two steps: The 380 nm (Nimbus-7) or 360 nm (Adeos, EarthProbe) radiances, solar and viewing angles, terrain height, and climatological surface albedos [*Herman and Celarier, 1997*] are used to derive a model cloud optical thickness ($\tau_{\rm cl}$) using tables of solutions of the radiative transfer equation at these wavelengths. In the second step, the attenuation of the global irradiance due to a model uniform cloud of that optical thickness is computed. In both these steps, the cloud is modeled as a homogeneous Mie-scattering layer, located between 500 mbar and 350 mbar. The scattering phase function is the C-1 model of Deirmendjian [*Deirmendjian, 1969*].

Because most locations on the Earth are viewed by the TOMS instrument only once per day, the model cloud optical thickness is presumed to be valid throughout the day. This can lead to large discrepancies between TOMS-estimated exposures and ground-based measurements. In regions where there is substantial diurnal variability in cloud cover, averaging over periods of at least a week is recommended when comparing the TOMS-based estimates and ground-based measurements of erythemal exposure.

The algorithm uses the same database as the TOMS ozone retrieval algorithm to determine the probability of presence of snow/ice in the instrument's field of view. In the presence of snow/ice, the algorithm assumes a surface albedo of 40%. While this albedo is typical of snow cover over midlatitude and subpolar regions, it may give rise to an overestimate of the erythemal exposure in urban or rugged areas, where the actual albedo is generally less than 40%. In conditions of freshly-fallen snow, or snow on a flat terrain, the actual albedo is generally greater than 40%, and the algorithm will tend to underestimate the erythemal exposures. The algorithm assumes that any excess upward radiance, above what would be due to the 40% reflective surface, is due to clouds, and the appropriate correction is made.

In high-altitude regions having high surface reflectivity, the algorithm tends to overestimate the UV exposure. In the high Andes region of Peru, and in the Himalayas TOMS-based exposures may be overestimated by up to 20%.

The algorithm does not take account of the effects of absorbing aerosols, *e.g.* under smoke plumes from biomass burning, and in the great deserts during seasons when the desert dust is lofted by winds. Under these conditions, the UV attenuation can exceed 80%.

A note on the units of the exposure.

In the above expression for the exposure, the quantity $S/d_{\rm se}^2$ has units of [nW m^{-2} nm^{-1}]. The functions F and C are dimensionless. It is common in the literature to also regard W as being dimensionless, and hence the exposure as having units of [J m^{-2}]. However, the biological response to radiation should be expressed in units that relate the biological damage to the incident energy, thus giving the exposure units of [B.D. m^{-2}], where B.D.= Biological Damage, expressed in biologically significant units. The normalization of the McKinlay and Diffey (CIE) action spectrum for erythema is chosen to be such that the function is equal to unity at 298 nm. Because the normalization of W is arbitrary, the units of exposure should also be considered to be arbitrary.

Calculated exposure values will be found generally in the range $[0, 10^4]$, though values upward of about $8,000$ occur only at very high altitudes in the tropics and subtropics. The median exposure value at the subsolar latitude usually falls in the range $[6000, 8000]$.

Format of the data file

Each file consists of 3 header records, followed by 2160 data records. The data records are organized in 180 groups of 12 records. The first 11 records in each group contain 25 three-digit value codes; the 12th record contains 13 value codes, followed by the numerical value of the center latitude of the band. Each group corresponds to a single 1° wide latitude band, and each value code corresponds to a cell of dimensions $1^\circ \times 1.25^\circ$ (latitude × longitude).

Each value code consists of three digits: a 1 digit exponent (E), and a 2 digit mantissa (M). A decimal point is implied between the two digits of the mantissa. Together, E and M encode a value of $M \times 10^E$. For example, the value code `342` represents the value 4.2×10^3. Note that a value code of `999` is a fill-value, where TOMS data were unavailable.

The following format specifications are recommended for reading the data records (all at once) from an Erythemal Exposure data file.

To read into a single integer array of dimensions (288,180) (using the FORTRAN or IDL subscripting convention), the recommended format specification is

```
(179(11(1X,25I3,/),1X,13I3,/),11(1X,25I3,/),1X,13I3)
```

To read into a single integer array of dimensions (2,288,180), the recommended format specification is

```
(179(11(1X,25(I1,I2),/),1X,13(I1,I2),/),11(1X,25(I1,I2),/),1X,13(I1,I2))
```

Code and data samples

Samples of code that can read the erythemal data files are provided in the following files.

`codestubs`	Segments of FORTRAN and IDL code that can be integrated into one's own code. These use arithmetic methods to unpack the code values. Some require more memory than others.
`read_ery.fc`	FORTRAN-77 subroutine that opens and reads an erythemal exposure data file, unpacks the code values, and returns the real data in an array. Uses some tricks, and may not work on all compilers, but the code is very fast and makes efficient use of memory.
`read_ery.fp`	FORTRAN-77 subroutine that opens and reads an erythemal exposure data file, unpacks the code values, and returns the real data in an array. Similar to `read_ery.fc`, but should be reliably platform-independent.
`read_ery.c`	C function that opens, reads, and unpacks the data values from a specified file. This file also contains a `main` program that uses the `read_ery` function and produces a test file.
`test_re.f`	Program to read the sample input data file `ga999999.n7e` and write the output file `ery.tst`. If `ery.tst` is found to be identical to `ery.ref`, then the program and its subroutines have compiled and run correctly.
`ga999999.n7e`	Sample input data file for use by `test_re.f` or the `main` program in `read_ery.c`.
`ery.ref`	Reference output file. See above, under `test_re.f`.

References

Deirmendjian, D (1969), "Electromagnetic scattering of spherical polydispersions," Elsevier, NY.

Herman, J.R. and E.A. Celarier (1997), Earth Surface Reflectivity Climatology at 340 nm to 380 nm from TOMS data, *J. Geophys. Res.*, **102**, 28,003–28,011.

McKinlay, A.F. and B.L. Diffey, (1987) A reference spectrum for ultraviolet induced erythema in human skin, in *Human Exposure to Ultraviolet Radiation: Risks and Regulations*, edited by W.R. Passchler and B.F.M. Bosnajokovic, Elsevier, Amsterdam.

Smart, W.M., Textbook on Spherical Astronomy, (6/e, 1977) Cambridge University Press, Cambridge.

USNO (United States Naval Observatory) (1992), Explanatory supplement to the Astronomical Almanac, edited by P.K. Seidelmann, University Science Books, Mill Valley, CA.

Woods, T.N., *et al.* (1996), Validation of the UARS solar ultraviolet irradiances: comparison with the ATLAS 1 and 2 measurements, *J. Geophys. Res.*, **101,** 9541–9569.

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