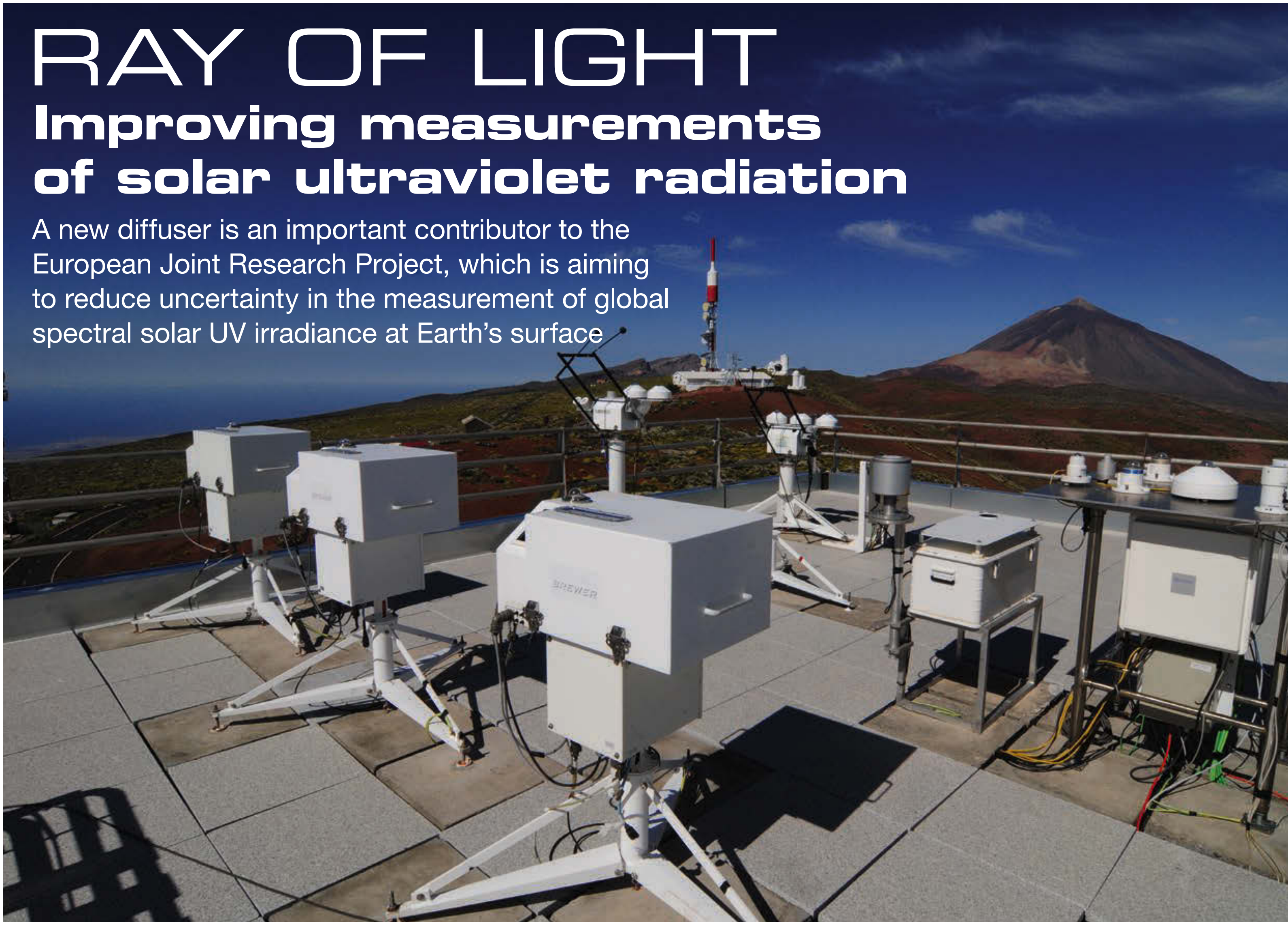
by Allard Partosoebroto

RAY OF LIGHT

Improving measurements of solar ultraviolet radiation

A new diffuser is an important contributor to the European Joint Research Project, which is aiming to reduce uncertainty in the measurement of global spectral solar UV irradiance at Earth's surface



A major concern in many parts of the world is the amount of harmful ultraviolet (UV) radiation from the sun and sky. The ultraviolet (UV) part of the solar spectrum has several beneficial effects for human biology, but too much can be very harmful. The UV region covers the wavelength ranges 100-280nm (UVC), 280-315nm (UVB) and 315-400nm (UVA). Almost all UVC and approximately 90% of UVB from the sun is absorbed by the earth's atmosphere. UVA radiation at the earth's surface is normally 15-20 times greater than UVB.

UV radiation produces vitamin D, but it can also burn the skin and cause cancers, melanoma and cataracts. UVB is of great biological importance because photons in this region may damage deoxyribonucleic acid (DNA) molecules and some proteins of living organisms, and cause other cell damage. A 10% increase in surface UV radiation could cause an additional 4,500 melanoma and 300,000 non-melanoma skin cancers worldwide every year, and between 1.6 and 1.75 million more annual cases of cataracts globally.

UV radiation measured with a similar response to the human skin is termed erythemally active UV irradiance (UVE) and is used to calculate the Global Solar UV Index (UVI) for public health information. UV radiation also affects terrestrial and aquatic ecosystems, agriculture, air quality, materials degradation and atmospheric chemistry.

Reductions in stratospheric ozone allow more harmful UV to reach the ground. Although the Montreal Protocol of 1989 has succeeded in controlling the worst ozone depleting substances, the ozone layer still remains under threat and future surface UVB radiation is still a matter of concern. Antarctic 'holes' in the ozone layer are well known (areas where stratospheric ozone is depleted by 25% or more), but 2011 saw the first Arctic ozone hole.

There is an increasing need for widely distributed, near real-time, high accuracy, spectral UV measurements and a key instrument for this is the Brewer Spectrophotometer. The global network provides measurements to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC).

The need for improvement

The Brewer MkIII is an automated instrument with a unique design of two ultraviolet spectrometers in series that are

Dome on Brewer cover with the new diffuser inside

self-compensating for the expansion and contraction of components caused by changes in temperature. This means that it can be used around the world outdoors without the need for complex temperature stabilization.

It measures the total column of ozone in the atmosphere from the intensity of the direct beam from the sun at six wavelengths. It can also make UV spectral scans of the direct beam, or of the whole sky, to measure UVA, UVB and UVE (and hence, the UV Index). Of most importance to us is the 'global' sky measurement. The input optics of the Brewer incorporates a prism controlled by a microprocessor that can rotate to look directly at the sun, at internal calibration lamps, or at the sky through a diffuser and a quartz dome.

Climate change is a slow process, with small changes. Long-term trends in surface solar radiation, 'global dimming' and 'global brightening', have demonstrated changes in the order of 2% per decade over Europe. These are currently explained by changing transparency of the atmosphere (aerosols), cloud cover and cloud opacity.

Trends in solar UV radiation are expected to be of the same order of magnitude. In order to project into the future changes due to climate issues (ozone column, aerosols and cloud) requires measurements of the global spectral solar UV irradiance at the earth's surface with much lower uncertainties than presently achieved. The current typical measurement uncertainty in the order of 5% must be significantly improved.

The international measurement improvement program

The European Joint Research Project, 'Traceability for surface spectral solar ultraviolet radiation' started in August 2011 and is a collaboration between National Metrology Institutes (NMIs), the research community in Europe, and partners from industry. The aim of the project is to improve the calibration and measurement uncertainty with a target of 1% to 2%, and to shorten the traceability chain to the fundamental SI unit.

The National Metrological Institutes of the Netherlands, Germany and Switzerland (VSL, PTB and METAS) worked on developing new standard lamps for irradiance and wavelength calibrations to reduce the calibration uncertainty. A Brewer MkIII spectrophotometer provided and operated by the manufacturer, Kipp & Zonen of the Netherlands, was used to test these light sources.

A significant source of measurement uncertainty in radiometers is the directional response. The research and development Brewer was used to evaluate improved diffuser materials and designs, together with Aalto University, Helsinki, Finland and CMS-Schreder of Austria.

The project ended with several days of inter-comparison of ultraviolet spectroradiometers in July 2014 at the World Radiation Center, Davos, Switzerland.

Brewer system

The Brewer is equipped with a precision-machined and polished hemispherical dome made from synthetic quartz with excellent UV transmission from below the UVB to beyond the visible spectrum. It is necessary to measure UV coming directly from the sun's beam, and also scattered from the sky and clouds, at all angles. To achieve this, it uses a diffuser. Non-spectral, broadband, UV radiometers also use domes and diffusers.

Ideally, the diffuser would have a high throughput of radiation, with a flat spectral response from below 280nm (UVB) to beyond 400nm (UVA), and would be equally efficient for radiation incident from all angles. It must be dimensionally stable and the properties should not change with temperature, time, or exposure to solar radiation – particularly UV!

When the sun is exactly overhead (solar zenith angle = 0°) the beam is at direct normal incidence (DNI) to a horizontal surface below and makes a circle on the ground of a certain irradiance, measured in W/m^2. As the sun moves lower in the sky and strikes the surface obliquely, the direct beam is spread out into an ellipse, so the energy density is reduced. Up to zenith angle about 85° (sun 5° above the horizon), this follows a cosine function and the diffuser should reproduce this directional response.

Suitable diffuser materials are very limited and currently the most commonly used is polytetrafluoroethylene (PTFE). This is largely because it is easily available, although not all 'grades' have the same optical properties, and it can be molded or machined to make shaped diffusers.

All Brewers made to date have a flat diffuser made from a thin sheet of PTFE stretched and clamped over a former, and mounted on the top of the instrument cover under the quartz dome. This arrangement under-reads by 10% at 65° solar zenith angle, and 30% at 80°, and is therefore a key area for improvement. Correction methods do not reduce the uncertainty substantially due to the unknown atmospheric radiance field impinging on the detector.

UV radiation and ozone measurement inter-comparison of Brewer spectrophotometers at the Lichtklimatisches Observatorium of MeteoSwiss in Arosa, Switzerland

Designing a better diffuser

The work under the Joint Research Project addressed the above issues, consisting of material characterization, ray trace modeling and testing of prototypes. The outcome is a diffuser with a significantly improved directional response.

A number of potential UV diffuser materials were identified, obtained and characterized, including the transmittance and directional response of flat samples of each material. Good overall transmission, especially in the UVB, is essential to ensure sufficient signal strength at the Brewer photo-multiplier tube detector.

The measured properties were input to a Monte Carlo ray tracing program that was especially developed for this project by Aalto University of Finland. The ray tracing software was used to determine the optimal geometry for each diffuser material.

Ray tracing parameters

The directional responses of the optimized diffusers were characterized with a very stable quartz halogen lamp, rotated around the diffuser at a constant distance in steps of 5°. Multiple measurements were performed and statistically analyzed.

The clear winner as a material was sintered quartz, which consists of numerous air bubbles formed within the synthetic quartz crystal. Since this material does not absorb any UV radiation, it is not sensitive to solarization. The characteristics do not change with temperature or humidity. It can be manufactured with suitable transmission and scattering properties, depending on the bubble size and bubble density. If this can be reliably controlled, it makes an ideal material for diffusors of UV radiometers.

The diffuser can be made relatively thick, so that there is an 'edge' to catch radiation close to the horizon. Another advantage is that sintered quartz can be glued onto a holder, whereas PTFE must be clamped for reliability and stability. The prototype holder is a tube of adjustable height and is mounted internally onto the Brewer fore-optics, unlike the standard diffuser that is part of the weather cover. This allows the diffuser position to be optimized for both the spectrometer and the quartz dome, which must remain mounted on the cover.

The new diffuser material has no temperature dependence or change in structure at normal operational temperatures, no effect of humidity, no effect of solarization, is easier to mount reliably, and will be more stable and repeatable in production.

The optimization of the geometry and location of the diffuser greatly improve the directional response of the Brewer for measurements of global ultraviolet radiation.

The standard and new diffusers differ significantly in directional (cosine) response at solar zenith angles above 45°. The errors of 10% at 65°, and 30% at 80°, are reduced to 2% and 8% respectively. At any solar zenith angle between 0° and 60°, the error of the new diffuser is less than 1%. Many Brewers are located above 45° latitude and, in the winter, the sun may be very low, and often the solar zenith angle is in the range of 70° to 90°. This means that most of the time, the spectrophotometers are operating in the least favorable part of their directional characteristic and the effect of the new diffuser will be very significant.

Although the main benefit is in improving the measurement of the direct component of the global solar UV irradiance, there will also be a benefit to the measurement of the diffused UV radiation from the sky. ∎

Allard Partosoebroto is a project engineer at Kipp & Zonen, the Netherlands