REPORT OF THE WMO MEETING OF EXPERTS
ON UV-B MEASUREMENTS, DATA QUALITY AND
STANDARDIZATION OF UV INDICES

(Les Diablerets, Switzerland, 25 - 28 July 1994)

Co-sponsored by
The UV Monitoring and Assessment Program Panel
and WMO
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A Contribution to the Global Environment Monitoring System (GEMS)
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1. OPENING OF THE MEETING

The representative of the World Meteorological Organization (WMO) Dr. John M. Miller opened the meeting and welcomed all participants on behalf of the Secretary-General Professor G.O.P. Obasi (see Appendix B for the list of participants). Dr. Miller also introduced the representatives of the co-sponsor of the meeting Lane Bishop, Jean-Marie Libre and Thomas Werkema from the UV Monitoring and Assessment Programme Panel (UMAP), an organization sponsored by an international group of chemical companies. He further thanked the international organizing committee for their help.

Dr. Miller briefly outlined the Global Atmosphere Watch (GAW) programme, which is a world-wide effort to co-ordinate atmospheric chemistry measurements and related parameters. One of the major measurement programmes of GAW has been the tracking of stratospheric ozone decline especially over the last five years. The relationship between the decrease of ozone and the increase of UV radiation reaching the ground has become a major public and scientific issue. In response to this problem, a number of UV monitoring stations have recently been put into operation or are currently proposed and in few countries diagnostic and/or predictive indices have been designed as a public health warning.

Within the framework of GAW, the WMO organized with co-sponsorship by UMAP the four day meeting of experts to discuss harmonization of present activities and to define future programme objectives of UV monitoring and index calculation.

During the first two days, discussions included describing on-going monitoring programmes, defining a quality assurance protocol to harmonize the measurements internationally and specifying techniques of data archiving. Specific recommendations that were made during this session will be outlined later.

During the second part, the participants discussed what procedures should be followed to establish guidelines for a standard UV index that can be used world-wide.

2. GLOBAL UV MONITORING

(a) The Need for Global Monitoring

The ozone decline during the past 25 years has been well documented in the International Ozone Assessments (e.g., WMO Ozone Reports 18, 20, 25). The relationships between ozone decreases, clouds and tropospheric pollutants, and changes in solar UV-B radiation reaching the ground have been established in the literature, both by theoretical models and observations taken by high resolution spectral measurements in Antarctica, Ushuaia, Argentina and Toronto, Canada. Furthermore, relationships between UV radiation and biological effects on humans, animals and plants are also being established (WHO Report No. 160) Therefore, a number of nationally sponsored UV stations or networks have recently been put into operation or are currently proposed, and in a few countries, diagnostic and/or predictive levels of UV-B reaching the ground have been initiated.

Most countries are interested in a programme to achieve one or more of the following objectives:

- to develop a UV climatology, i.e., a knowledge of average levels of UV and common UV variations at specific locations;
- to understand the cause-effect relationship between factors that influence UV levels;
- to develop a reliable data base of UV observations to evaluate possible UV trends;
- to increase public awareness of UV changes and potential effects of UV.

To some extent, the goals of a national or particular station monitoring programme will determine the key aspects of the programme, e.g., type of instrumentation (e.g., broad-band or spectral radiometers, selection of sites for observing stations, observation nature and frequency,
perspective, it is important that individual networks co-ordinate the methods of observation, and quality control and systematic calibration, so that a global picture of UV climatology can be formed and possible changes in UV can be evaluated. Although a number of meetings of international groups of scientists have been conducted to discuss these issues, as yet there has been no formal mechanism created for the necessary harmonization of the various regional networks and individual stations.

In the first part of this meeting, after introductory remarks were made on the need for global monitoring, representatives of a variety of monitoring programmes reported on their efforts. A summary of the key elements of these talks appears below. This is followed by a summary of plenary sessions in which the participants evaluated the aspects of global co-ordination of UV networks, and discussed instrumentation, quality assurance and data archiving issues. These sessions led to the presentation by WMO of a proposal for formation of an international Scientific Steering Committee (SSC) under the auspices of the WMO, to guide the harmonization of national networks and propose standards for compatible observations, quality assurance and common calibration systems, and data archiving at the WMO World UV Data Centre in Toronto, Canada. The mechanism for the formation of the Scientific Steering Committee is discussed at the end of this Chapter.

(b) Summary of Existing/Proposed Networks

**UV Monitoring Networks Using Spectral Instruments**

It should be noted that many UV monitoring networks were planned which comprise both spectral and broad-band instruments. The following is a summary of the spectral instruments presented at this conference. It should be noted that this does not represent a comprehensive list of all spectral instruments in operation.

**North America:**

**United States:** The US Department of Agriculture (USDA) is developing a three tiered network: broad band instruments at roughly ten sites, quasi-spectral filter instruments at an additional twenty sites and a research network of ten spectral instruments with a wavelength range of 285 to 400 nm. Ten broadband instruments are already operating; the first spectral instrument should be installed in 1995.

- The US Environmental Protection Agency has a project for 15 UV monitoring sites equipped with spectral instruments. 8 Brewers have already been acquired and 4 established. 11 sites will be located in urban areas and the remaining sites will be located in less polluted areas.

**Canada:**

- The Canadian programme for UV monitoring is constituted of 12 Brewer instruments with the reference instrument located in Toronto and 20 broad-band instruments.

**Europe:**

- Several spectral instruments developed or maintained in Europe (UK, Belgium, Germany, Norway, Denmark, The Netherlands, Austria and Greece) have been involved in an intercomparison process since 1990 with the purpose of establishing the standard of a future network.

- In Greece, the University of Thessaloniki started a UV network (LAPNET) which is comprised of a main station with 2 spectral instruments and 6 peripheral stations equipped with broad-band instruments.

- In Germany a network of four stations with spectral instruments was developed in 1993 by the Federal Office for Radiation Protection and the Federal Environmental Office: two stations are located at high altitudes (493 and 1205m).

- A network was started in Finland in 1989 by the Finnish Meteorological Institute and Center for Radiative and Nuclear Safety which is comprised of one Brewer
spectrometer and should be upgraded with a second Brewer in 1994. Several
broad-band meters are also in operation. The total number of monitoring sites
should be about 6.

Asia and Oceania

New Zealand - The New Zealand Weather Agency has established a UV monitoring network
with two spectral instruments in Lauder (also a NDSC station) and 9 broad-band
instruments.

Polar Regions - Spectral instruments developed by Biospherical Instrument Inc. have been
funded by NSF (US) for 4 stations in Antarctica and one in Point Barrow
(Alaska).

Japan - Four UV monitoring sites with Brewers have been established by the Japan
Meteorological Agency.

Russia - UV flux measurements with Brewers are in development.

China - UVB flux measurements are done with a Brewer spectrometer since 1991 at
Mt. Waliguan GAW station.

International Programmes:

- The NDSC (Network for the Detection of Stratospheric Change) is looking to
  include UVB flux measurements in its stations. Lauder and Garmisch-
  Partenkirchen (IFU) are already in place. The future plan is to have measurements
  in Hawaii, Antarctica and the Arctic.

- The SPARC project (Stratospheric Processes and their Role in Climate) has been
  approved by WCRP (World Climate Research Programme). Among its objectives
  is the establishment of a NDUV (Network for Detection of UV).

(c) Summary of Issues Raised in Monitoring and Network Issues

Monday Discussions

The Monday afternoon discussion period began by M. McFarland with an introduction to
the issue of global co-ordination of monitoring networks. Dr. McFarland sketched the reasons for
national networks and desirability of global co-ordination as mentioned in the Introduction section
to Chapter II, and then suggested several topics to guide the ensuing discussion: (1) what do you
want from international co-ordination ?; (2) co-ordination tasks; (3) issues requiring protocols;
(4) structure of a steering committee; (5) action plan. These topics were subsequently led by
several individuals, as discussed below.

T. Werkema, chairman of UMAP, gave some information on the UV Monitoring and
Assessment Programme Panel (UMAP), a relatively new organization of nine industrial companies,
with a goal of fostering activities in monitoring UV, and to some extent, assessing the effects of
UV changes. As well as partial sponsorship of this meeting, UMAP has reserved some funds to
gain an effort started toward international co-operation in monitoring, and is prepared to support
some of the operational and meeting expenses involved in the activities of the Scientific Steering
Committee.

John Miller, Chief of the Environment Division, WMO, told the participants that WMO has
been given a charge to help lead activities in global monitoring, and presented an initial map of a
proposal for a Science Steering Committee (SSC).

A. Webb led a discussion on the first of Dr. McFarland’s suggested topics: what do you
want from international co-ordination ?. Suggested activities and issues raised and discussed
included:

- An assessment and information database of existing and beginning networks would be
  a desirable co-ordination activity (Note (E. C. Weatherhead): an existing effort in this
months);
- Quality Assurance (QA) and Quality Control (QC) are critical issues, and a necessary co-ordinating activity. Data of unknown quality are not useful to the scientific community;
- Issue: should SSC activities lead to some sort of seal of approval to participating networks when they comply with SSC suggested protocols?
- Examples of analogous groups which have been successful are the World Radiometric Reference led by C. Fröhlick in the early 1970's, and the Network for Detection of Stratospheric Change (NDSC), which was created in the late 1980's to support a small number of very high quality observing stations;
- The user community needs to be involved in the activities of the SSC, not just those responsible for implementation of the networks.

P. Simon followed with a discussion of co-ordination tasks. His suggestions included an inventory of sites and instrumentation, guidelines or standards for calibration, co-located complementary measurements, the possibility of primary and secondary site classification as in the NDSC, data protocols, evaluation and acceptance criteria for data, intercomparisons, trend studies (e.g., UNEP/WMO Science Assessments for the Parties to the Montreal Protocol), data assimilation from satellite, and evaluation of radiation transfer models. A few issues were raised in discussion:

- It is unclear what influence the SSC may have in the design or operation of networks. In practice, we face several networks designed for different reasons. Co-ordination goals would be to gather and harmonize the information from existing networks;
- A key need is the ability to combine data sets, make sure they are comparable, to make a larger pool for analyses;
- The SSC should co-ordinate QA/QC and data availability.

R. Booth led a discussion on issues which may require protocols, for example, broad-band vs. spectral radiometer vs. narrow-band, scan range and increment, bandwidth, sample rates, comparison to reference instruments of reference standards, ancillary measurements. Additionally:

- Standards for uncertainty calculations;
- Data rights protocol. Researchers would like to have time to evaluate their data, and for publications, before others have access. R. Bojkov: it is a WMO principle that data collected from network monitoring (as opposed to limited, special purpose campaigns), have unrestricted exchange;
- Protocols for intercomparisons.

R. McKenzie led discussions on the structure of a committee (SSC) to resolve the stated issues. Using J. Miller's chart as a strawman, several issues were raised:

- Instrument experimenters should be included;
- Different communities have different requirements - representatives should be included from the various user groups;
- So many people are interested, how do we keep the committee size within reasonable bounds?
- Must reflect international interests, not just the U.S.A. and Europe;
- Needs credibility - membership should be of the highest quality science people, those we respect.

Finally, J. Miller presented a proposed action plan for the formation by the WMO of a SSC; this is discussed in the last section of this chapter.
Tuesday Discussions

P. Simon led the first discussion on Network Compatibility Recommendations. For data to be of known quality, documentation must be provided for the instrument, the measurement, and observing conditions. Regardless of instrument type (spectral, filter, broad-band), the instrument response must be well characterized, calibrations frequent and well defined, participations in intercomparisons, and documented proof of long-term stability. We need tools to make measurements with different models of instruments compatible, e.g., for different slit functions. Attention must be paid to on-site calibration (quality control) and intercomparisons or use of travelling standard instruments. An assessment of data quality includes site description, and information on albedo. Discussion points:

- We need both travelling standard instruments and intercomparison campaigns;
- Users must accept that results are tied to the explicit response functions of particular instruments;
- Even if all these things were done perfectly, would UV measurements made with different instruments at different sites be comparable?

A. Webb led a discussion on data archiving and access. Important issues brought out included:

- Data rights and access - you are "giving up your data to who knows who."
- Data format from both broad-band and spectral instruments. (D. Wardle: there already exists a written protocol for the World UV Data Centre);
- Metadata needs to be archived as well - details on the instrumentation, calibrations, etc.
- Do we still want or need centralized databases, in an era of Internet and CD-ROMs?
- Access must be protected over long periods of time, so archiving should be a responsibility at least at the country level;
- Data should become available on CD-ROM (especially for large spectral archives);
- Should raw data be archived? Con: sheer volume may make the raw data difficult to store. Pro: with raw data stored, the central archive can recompute as necessary for everyone at once (as an example, the change from Vigroux to Bass-Paur coefficients for the Dobson spectrophotometers);
- Summary data (erythemal dose, daily max., etc.) should be stored as well as high resolution spectral data.

A general discussion on all monitoring issues was led by V. Mohnen:

- Efforts must be accelerated for global coordination, because the networks will soon be in place;
- UV-A should be included in the monitoring and data archiving, not just UV-B;
- Long-term time series are important for calculations of trends, and the value of long-term time series can be destroyed by changes of calibration, unless all such changes are documented and tracked;
- Different data products should be made available, for example, raw data, integrated, index;
- There was some discussion of the possible use of standards in the type of ISO 9000, i.e., guidelines for procedures and for documentation of those procedures that would detail the level of quality control performed.

(d) Action Plan

The need for a global coordination of UVR flux measurement programmes and networks worldwide has been established. To achieve that goal an action plan was developed as follows:

(i) WMO will take the leadership to establish a global UVB monitoring network. A consensus was reached on this approach which is also supported by UMAP.
responsible for the following aspects:

- define the requirements for the UVR flux measurements and data in order to meet the requirements of the user community needs;
- co-ordinate UVR flux measurements programmes;
- set a QA/QC programme;
- organize the data archiving system;

(iii) The SSC will have to be approved by the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry. Its structure should be such that each important topic be covered by a specific subgroup, i.e. Instruments, QA/QC, Modelling, Data Archiving and Users community needs.

(iv) WMO will establish as soon as possible an AD HOC committee with the following duties:

- develop criteria for selecting members of the SSC;
- obtain informal review of the criteria from the scientific community involved in UVR flux measurements;
- present nominations and selection criteria to WMO-EC Panel as soon as possible and preferably before April 1995;
- the formation of the SSC will then be notified.

(v) Once formed the SSC will have to properly define its own structure in the following way:

- elect or confirm a chairman;
- develop operational structure including the creation of working groups for each topic listed in section 3;
- establish relationships with other agencies, user communities and scientific programmes;
- develop the plan and mechanism for implementation of the Global UVR-Network.

Figure 1: Organization of Scientific Steering Committee
ULTRAVIOLET INDICES

a) Summary of Indexes

Ten reports of UV index programmes from eight different countries were presented at this meeting. The countries represented were Canada, Finland, Germany, New Zealand, Sweden, UK, JS, and the Netherlands. Three separate indexes from the U.S. were reported on including one by the National Weather Service. This was not a comprehensive representation of all of the existing indexes, with some notable exceptions absent including Australia which is one of the oldest, however representatives from Australia were present to comment on their programme. The methods of production, scales and philosophies differed among the indexes presented. Almost all of the indexes\(^1\) implemented one day forecasts using CIE weighted irradiance. Five of the countries specifically used a CIE weighted irradiance scale such that one unit was equal to 25 mW/m\(^2\); this results in a system with a scale of between 0 and roughly 16 on a global scale. The individual systems were discussed. All present agreed that a single uniform scale used throughout the world would be best to present a consistent message to the public. A consensus was reached on the basic details for a uniform scale with the suggestion that this be presented to both WMO and WHO for approval.

Canada

The Canadian index system includes both an ozone and UV information system. An ozone watch is issued once a week for 10-12 locations in Canada. The two week average local ozone level is compared to the pre-1980 average from Dobson measurements for each location. A yearly report of monthly ozone deviations is also reported as part of this programme. The UV advisory programme is a one day forecast for the different regions of Canada using ozone levels and clouds as relevant parameters in their forecast. The ozone field is predicted by a regression output using the present day’s ozone values. The prior day’s forecast errors are incorporated in the present day’s prediction. Ozone, solar elevation and an empirical model give the clear sky UV index. This clear sky value is then augmented by a correction factor which incorporates cloud information. The correction factors are 1.0 for clear or scattered skies, 0.7 for overcast skies without rain and 0.4 for overcast skies with rain. The final index is produced with an additional digit after the decimal point. Extensive networks of Brewers and RB meters are available for ground truthing of their index. Dissemination takes place through a variety of outlets including Weather offices and the wire service. Contour plots of the UV level in Canada are available. One of the private weather services produces hourly UV levels for dissemination throughout the day. Recent research in the UV index shows that 72% of the population was aware of the UV index; 59% claim to have changed exposure habits because of the index with sunscreen, sun avoidance, clothing and sun glasses. 88% of those surveyed were satisfied with the UV index.

Germany

The Federal Office for Radiation Protection is currently using a sunburn index. The scale is determined by dividing the CIE weighted dose in a six hour period divided by 250 J/m\(^2\), which was considered to be the minimal effective dose for sensitive skin. The scale is displayed only in integer values. These numbers are not presently released to the public, but dissemination is planned.

New Zealand

The New Zealand index is one of the oldest UV index programmes in existence. It began in 1987 by the NZ Met. Service (now with NIWA) to estimate clear sky burn times. Erythemally weighted levels are computed using ozone values from TOVS. Predictions for the next day UV level are provided on a daily basis. Burn times are also produced from a network of broad-band

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\(^1\)The plural of index is used in two contexts. For this draft the common convention of referring to the different systems as indexes and the actual numbers produced from any one index as indices.
significantly different. This may be due to incorrect O₃ levels in the model estimations, errors in calculation or a difference in the definition of burn times. A comparison of the burn times from the two systems was presented.

**Sweden**

SMHI (the Swedish Radiation Protection Institute) began producing daily forecasts of UV intensity in the summer of 1993. They present ACGIH weighted intensity normalizing the values so that roughly a value of 100 is at the equator. The scaling was chosen for ease of interpretation. During the summer they present UV levels representing the weighted irradiance on a horizontal surface. The model calculations include the season, weather, ground reflectance, clouds and ozone. During Winter in spring, UV irradiance on a tilted surface is calculated. The angle of the tilt is determined to maximize the day’s UV dose. UV predictions are made for seven regions in Sweden, plus the Alps, the Mediterranean and the Canary Islands. The largest public interest was in 1993 when low ozone values were frequently reported to the public.

**UK**

The UK began producing daily UV clear-sky warnings on April 1, 1994. Clear sky levels of CIE based erythemally weighted UV are calculated and converted into times to burn for skin type 1 as well as skin types 2&3. The ozone is forecasted using a linear regression model between TOVS, temperature and geopotential models. Clear sky calculations are based on the predicted ozone levels. Weekly summaries are produced showing the diurnal cycles and actual UV levels from ground-based measurements.

**U.S. - NWS**

The National Weather Service (NWS) in collaboration with the US Environmental Protection Agency (EPA) initiated an Experimental Ultraviolet (UVI) Index forecast on June 28, 1994. The UVI is a mechanism by which the American public is forewarned of tomorrow’s noontime intensity of UV radiation at 58 locations within the US. The EPA’s role in this effort is to alert the public of the health aspects resulting from overexposure to, and the accumulative effects of UV radiation. The National Weather Service first calculates an ozone forecast for the next day using existing meteorological and satellite ozone measurements and the global forecast model. Then, utilizing an advanced radiative transfer model the clear-sky values of the C.I.E. -weighted exposure is calculated for solar noon. Next, operational cloud forecasts (in four categories) developed from a forecast model are utilized to calculate the effect of the clouds in diminishing the UVI.

**U.S. - Ray-Ban**

Bausch & Lomb launched the Ray-Ban UV index in the spring of 1994, producing daily UV forecasts. As with the US National Weather Service, the Ray-Ban UV index is based on the Frederick radiative transfer model incorporating ozone and sun angle and represents a one hour dose around local solar noon. The Ray-Ban UV index is further based on a network of ground-based quasi-spectral instruments to provide immediate ground-truthing and now-reports. The UV index is presented with regional contour maps, diurnal plots with measured and clear sky levels. The emphasis of the network is on the effect of UV to eyes and is part of a research and marketing campaign by Bausch & Lomb.

**U.S. - Suncast**

Suncast currently provides one day forecasts for 527 cities around the U.S. Three daily numbers are provided representing the CIE weighted dose rate at solar noon, three hours before noon and three hours after noon. Clear sky calculations from the Frederick model are used with adjustments for four different sky conditions. O₃, clouds, surface albedo and solar elevation are used for the initial calculations. A ground based validation factor is added to correct for local effects. Their primary products are colour maps of the U.S. with six additional regional maps.
Denmark

The Danish Meteorological Service and the Danish Cancer Society and the National Board of Health began producing a daily UV index in the spring of 1992. The index is based on measurements from a Brewer. The Danish High Resolution Weather Model is used to calculate clear sky CIE weighted UV levels. A minimum burn time for a typical Dane is calculated from the clear sky CIE weighted doses. The typical Dane burn time is determined by examining the sensitivity of 40 Danish citizens on a monthly basis to allow for changes throughout the year. The maximum time to stay in the sun at the noon communicated to the public. A survey of indices in the Western Europe was presented.

(b) Summary of Issues Raised

Discussions focused on the following topics with the discussion leaders noted:

- Action Spectra - S. Madronich
- Clear-Sky Versus Clouds - F. Frederick
- Predictions Versus Reports - U. Wester
- Time-Scales - J. Austin
- Exposure on Eyes - D. Sliney
- WHO Activities - R. Schmidt
- Public Response - A. Kricker
- Validation Procedures - D. Wardle
- Normalization of Scale - S. Madronich

Action Spectra

Several issues were raised concerning the selection of a uniform action spectrum that resulted in considerable discussion amongst the participants. These deliberations centred on the sensitivity of the measurements to ozone changes, the ease of direct measurement, the general applicability to human health and the ultimate impact on the scaling factors that effect the message to the public. Several action spectra were proposed and considered, including the standards for DNA, ACGIH, and C.I.E. as well as several additional ones proposed by Madronich based on the ozone cross-section or uniform with wavelength.

The major discussion centred on the general applicability of one spectrum to the general issues of both skin and eye effects. While it was recognized that no one spectrum was appropriate for all effects, it was, ultimately, recognized that the C.I.E. (1987) normalized to 1.0 at 297 nm appeared to serve the atmospheric science community best at this time.

It was recommended that the C.I.E. (1987) action spectrum be adopted as the standard for the ultraviolet indices, but that this recommendation be forwarded to the World Health Organization for review and possible endorsement.

Clear-Sky Versus Clouds

The discussion was initiated by J. Frederick describing recent measurements of ultraviolet radiation at the ground (weighted to the UV-A portion of the spectrum) that showed the dependence of surface UV on fractional sky coverage, visibility, and cloud ceiling (as a proxy for optical thickness). Overall discussion focused on the question of the opacity of clouds in the UV-B portion of the spectrum as well as the relationship of cloud cover to angular distribution of radiation. It was stressed that we require focused studies of transmittance of clouds in the UV-B as a function of solar zenith angle.

After considerable debate, it was decided that some provision for clouds should be incorporated, but that no specific recommendation could be made at this time for uniform cloud consideration. One specific recommendation to have each country present both clear-sky and
Prediction Versus Reports

The discussion was introduced by U. Wester in the form of a caution sign placed in front of a train-crossing versus a sign placed at the back of the crossing. With respect to the UV index, debate included the notion of the relative accuracy, but generally limited spatial extent of the measurements versus those available from the model outputs. Although no official recommendation was made it was recognized that there appears to be value in both measured reports and forecast indices.

Time-Scales

The issue of what time scales to utilize for the calculation was presented with several options offered. These ranged from the basic irradiance (or dose rate) at local solar noon to integrated doses over hour periods (dose).

After debate amongst the participants of the strengths and weaknesses of each system from the atmospheric community, it was stressed by those of the medical community that they strongly preferred dose rate as the basic report. On the basis of this stated preference, it was recommended that we adopt a minimum requirement to report the irradiance (dose rate) value at local solar noon. This allows those that wish to report more frequently to do so.

Exposure on Eyes

D. Sliney presented extensive information on the aspect of ultraviolet exposure and eye damage, stressing the dependence of the effects on solar zenith angle and local albedo. It was emphasized that the current UV indices do not directly apply to the eye and that the message to the public is critical.

While no formal recommendation was proposed, it was suggested that an action item be adopted by the optical community to develop an algorithm (including an action spectrum) that might be appropriate for consideration by those producing and disseminating the operational ultraviolet indices.

WHO Activities

R. Schmidt presented an overview of the World Health Organization’s INTERSUN programme. Amongst the efforts, those related to the UV index programmes include the task to enhance the understanding of the relationship between personal risk from UV radiation, constitutional sensitivity and sun-related behaviour. In addition, he presented several general WHO principles for the UV index programmes. These include that the index should be simple and on a direct linear scale, adaptable to local conditions, include the range or two values (cloudy and clear skies), uniformly used throughout the world, amenable for inclusion in weather forecasts, and introduced as soon as possible.

Public Response

A. Kricker presented elements of the SunSmart campaign in Australia and indicated that the efforts seem to show a significant effect on human behaviour in the amount of time spent outside around noon, the wearing of hats etc. A major point made was that significant differences exist between the public’s attitude and change in behaviour and that they must first alter their attitude and perception of risk before they will alter their response. The three main points for a public response programme are attitude, knowledge, and behaviour.
Validation Procedures

D. Wardle presented a brief summary of the importance of the validation process, stressing the themes of accountability, credibility and the what-and-how of validation. The discussions amongst the participants indicated that a requirement existed to develop a consistent method of statistical validation of the product. However, as evidenced in the discussion of the cloud considerations, this area is still in an evolutionary state and will have to be reconsidered at a later time.

Index Scale

Discussion in this area focused on the index scale to be utilized for public dissemination with several options offered by S. Madronich. These included the following:

- Normalizing the action spectrum to a wavelength other than the current standard of 297 nm;
- Utilizing a public information unit of time for 1 MED or MED per unit time;
- Standard energy or power units;
- A relative standard reference to provide a scale from 0 to 10 or to 100;

Debate amongst the participants quickly removed consideration of the first two and last options, focusing attention on the third as the most viable for universal acceptance.

It was noted that the accepted standard of local solar noon irradiance, together with the choice of the C.I.E. action spectrum dictated a general maximum value of about 350 mW/m² which would, in standard energy units result in maximum index values of 0.35, 3.5, 35 or 350 depending on the choice of units. Debate centred on the issues of continuity from current scales, the fact that the accepted C.I.E. action spectrum is normalized to 297 nm (which is by itself somewhat arbitrary), the number of countries already using any particular scale, and the public acceptance of various numbers. After due debate the recommendation was unanimously accepted that we adopt the current scale used in Canada whereby the index is expressed by multiplying the weighted irradiance in W/m² by 40.0. (This will lead to an open-ended index which is normally between 0 and 16).

4. CONCLUSIONS

Because of stratospheric ozone decline, especially over the last five years, the relationship between the decrease of ozone and the increase of UV radiation reaching the ground has become a major public and scientific issue for many WMO Members. In response to this problem, a number of UV monitoring stations have recently been put into operation or are currently proposed and in a few countries diagnostic and/or predictive indices have been designed as a public health warning.

Within the framework of the WMO Global Atmosphere Watch, the WMO organized, in collaboration with the UV Monitoring and Assessment Programme (UMAP), sponsored by an international group of chemical companies, a four-day meeting held in Les Diablerets, Switzerland (25 to 29 July) to discuss harmonization of present activities and to define future programme objectives of UV monitoring and index calculation.

During the first two days, discussions included describing on-going monitoring programmes, defining a quality assurance protocol to harmonize the measurements internationally and specifying techniques of data archiving. Specific recommendations that were made during this session were:

- Publish a catalogue/inventory of UV monitoring activities;
- Develop an international instrument calibration facility;
- Produce a QA protocol and coordinate data availability;
scientific steering committee. Under this committee, an action plan for implementation will be designed. An organizing committee has been established and has begun its work.

During the second half of the meeting recommendations concerning UV indices were made. These results are particularly important to Meteorological Services or other organizations that have, or are considering establishing an UV index for public dissemination. The technical details will be given in a report of the meeting that is now in preparation, briefly the guidelines for index calculation as recommended for world-wide use unanimously by the participants are as follows:

- Utilization of the C.I.E. (1987) action spectrum normalized to 1.0 at 297 nm;
- A minimum requirement is to report irradiance values at local solar noon;
- The index is expressed by multiplying the weighted irradiance in W/m² by 40.0 (this will lead to an open-ended index which is normally between 0 and 16).

Using the technical information gathered at the Les Diablerets meeting the WMO organized its first regional workshop on UV-B for the Americas in Buenos Aires from 22 to 26 August. The workshop was supported by Canada and the USA through the WMO Special Climate Fund.

The workshop provided basic information on UV radiation and on its biological and health effects. Countries reported on their existing UV research and monitoring, as well as on their UV education programmes and information services. Fourteen countries were reported to use different types of UV indices.

The workshop gave its full support to the recommendations from the Les Diablerets meeting and endorsed strongly the need for standardization in monitoring and in the use of UV indices.

Thus important steps have been made to recommended a set of basic rules by which, if accepted by all countries, UV measurements and indices can be harmonized around the world.

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WMO MEETING OF EXPERTS ON UV-B MEASUREMENTS, DATA QUALITY
AND STANDARDIZATION OF UV INDICES
(called in collaboration with UMAP and IOC)

LES DIABLERTS, SWITZERLAND
25-28 July 1994

AGENDA

PART 1. GLOBAL UV MONITORING

Monday, July 25

Introduction

08:30 - 08:50  John Miller: Welcome on behalf of WMO and Overview of the WMO Global
               Atmospheric Watch.

Session I: Existing and Proposed Monitoring Programmes
           B. Weatherhead, Chair

08:50 - 09:10  S. Madronich: The Need for Global UV Monitoring

09:10 - 10:30  Monitoring programme presentations

09:10 - 09:35  J.H. Gibson: U.S. Department of Agriculture UV-B Monitoring Programme

09:35 - 10:00  W. F. Barnard (with L.T. Cupitt): The UV Monitoring Programme at the U.S. EPA

10:00 - 10:30  M-L. Chanin: Stratospheric Processes and their Role in Climate (SPARC)

10:30 - 10:50  Break

10:50 - 11:15  M. Nimon: Co-ordination and Global UV Monitoring

11:15 - 11:40  R. L. McKenzie: UV Measurements in New Zealand

11:40 - 12:05  S.P. Perov: Operative (Near-real time) UV-B Monitoring System in Russia

12:05 - 12:30  D. Wardle: Spectral Ultraviolet Radiation Measurements in Canada: The
               Environment Canada Brewer Network

12:30 - 14:00  Lunch

14:00 - 14:25  C.R. Booth: NSF Monitoring Network for Polar Regions

14:25 - 14:50  B. Forgan: UV Monitoring in Australia

14:50 - 15:15  C. Zerefos: The Observed Changes of Spectral UV-B during the Past 3 Years:
                Climatology of UV Measurements from the LAP-NET at High and Middle Latitudes

15:15 - 15:40  K. Dehne: Spectral solar UV-B monitoring as planned by Deutscher Wetterdienst
               (DWD)
15:40 - 16:00  Break

16:00 - 16:25  S. Guo: UV-B measurement in China at Mount Waliguan GAW station and Antarctic Zhongshan Station

16:25 - 16:50  R. Philipona: UV-B Monitoring: the Swiss approach


19:30 - 20:00 Dinner

20:30 - 22:30 Poster Sessions

1. M. Beaubien: A New Low-Cost Narrow Band, 2nm Band-Pass Automated Shadowband Radiometer for UV-B Measurements

2. D. Berger and M. Morys: Comparison of Spectroradiometers in radiometers for UV radiation


7. C. Driscoll: Solar UV measurements and indices in the U.K.


9. M. Janouch: Measurements of UV Radiation at the Solar and Ozone Observatory at Hradec Kralove and Building up of Robertson-Berger Network in Central Europe.

10. J.H. Kinsey: A Dual Channel System for Continuous Monitoring of Biologically Weighted Solar UV-B

11. Z. Litynska: First results of UV-B monitoring network of the Institute of Meteorology and Water Management

12. E. Obermeier: Fast measurement of the UV-spectrum and ozone at high resolution and dynamic range using novel double-monochromator design.


15. C. Varotzos: The activities of the Athens University on the SUVR Issue.

Posters should remain in place throughout the meeting.
Tuesday, July 26

**Session II:** Instrumentation and Network Issues
Miller - Chair

*IIa: (Inter)calibration and Long-term Stability*


08:55 - 09:20 W. Josefsson (with T. Koskela): The Nordic Intercomparison of UV Instruments and Calibration Lamps at Izaña in 1993

09:20 - 09:45 G.J. Seckmeyer: The German Reference Instrument for the Measurement of Solar UV-Radiation

09:45 - 10.10 A.R. Webb: The European Spectroradiometer Intercomparisons: An Overview

10.10 - 10.30 Break

10.30 - 10.55 P. Simon: Development of a portable calibration unit for UV spectroradiometer

10.55 - 11.20 D. Berger (with M. Morys): Factors Affecting the Accuracy of Long-term UV Radiation Monitoring

11.20 - 11.45 T. Ito: Solar UV-B Observation and Data Quality in Japan Meteorological Agency

11.45 - 12.00 P. Disterhof: U.S. National UV Radiometric Calibration Facility operated by NOAA/ERL

12.00 - 12.25 H. Reinen: Monitoring the Biologically Relevant UV Radiation in the Netherlands

12.25 - 14.00 Lunch

14.00 - 14.45 Discussion II: Network compatibility recommendations (P. Simon)

*IIb: Quality Assurance and Data Processing/Data Management*

14.45 - 15.10 A. Bais: UV Monitoring and Quality Assurance of "LAPNET" in Greece


15.35 - 16.00 B. Baker: UV Data Archiving and Information Delivery Systems

16.00 - 16.20 Break

16.20 - 16.45 D. Wardle: The WMO World Ultraviolet Radiation Data Centre (WUDC)

16.45 - 17.10 Discussion III Data Archiving and access (A. Webb)

17.10 - 17.30 General discussion of Part I and preparation of recommendations (Mohnen)

End of Part I
PART II:  ULCRAVIOLET INDICES
Libre - Chair

08:30 - 08:45  A.J. Miller: Introduction
Presentation of UV index programmes

08:45 - 09:15  D. Wardle: The Canadian UV-Index Programme 1992-1994

09:15 - 09:45  P. Taalas: North European UVB Research Co-operation.

09:45 - 10:15  K. Dehne: First steps of DWD forecasting routine

10:15 - 10:35  BREAK

10:35 - 11:05  R. McKenzie: The UV Index Programme in New Zealand


11:35 - 12:05  J. Austin: The UK Meteorological office UV Forecasting Method

12:05 - 12:35  A.J. Miller: The NOAA-EPA Programme to Provide Experimental Forecast
Guidance of an Index of UV Radiation at the Ground Experimental Ultraviolet
Index (EVI)

12:35 - 14:00  LUNCH

14:00 - 14:30  D. Vander Schaaf: North American UV Index and the Need for Global
Standardization

14:30 - 15:00  M. Pastrone: SUNCAST™ Ultraviolet Radiation Prediction Service Overview and
Index Comparison

15:00 - 15:30  S. Andersen: European Survey of UV-B forecast and warning systems

15:30 - 16:00  R. Matthes: UV Monitoring in Germany and Public Education

16:00 - 16:30  BREAK

16:30 - 17:15  S. Madronich: Discussion on Action Spectra

19:00 - 20:30  DINNER

20.30 - 22.00  Review draft of recommendations from Part I

Thursday, July 28

Bishop - Chair

08:30 - 09:20  J. Frederick: The Treatment of Clouds in Estimates of Ground-Level Solar
Ultraviolet Irradiance

09:20 - 10:10  J. Wester: Discussion of prediction vs reports
10:10 - 10:30  BREAK
10:30 - 11:20  J. Austin: Discussion of time scales
11:50 - 12:10  R. Schmidt: Brief Overview of WHO Activities on UV
12:10 - 14:00  LUNCH
14:00 - 14:50  A. Kricker: Assessing Public Response
14:50 - 15:40  D. Wardle: Validation Procedures
15:40 - 16:00  BREAK
16:00 - 16:50  B. Weatherhead: Message to public
16:50 - 17:30  A.J. Miller: Summary and where do we go from here
19:00 - 20:30  DINNER
20:30 - 22:00  Informal discussions

Friday, July 29

Organizing committee will prepare draft meeting report

Ad Hoc Presentations

P. Taalas.  UV Research and Forecasts in Finland

B. Andersen.  Summary: Public UV Forecasting in Denmark
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SELECTED SPEAKER'S SUMMARIES

The Need for Global UV Monitoring
Sasha Madronich
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Several different purposes of UV monitoring should be distinguished, as each has specific user communities and required experimental strategies:

(1) UV process studies are aimed at understanding and quantifying the factors that control the amount of UV radiation reaching the surface. These include solar zenith angle, earth-sun distance, stratospheric ozone, tropospheric gases (O_3, SO_2, NO_2, ...), surface elevation and albedo, clouds, aerosols, the angular distribution of the radiation in relation to the geometry of the target (e.g., human skin or eyes), and possibly other factors. The user community is largely limited to atmospheric radiation modelers, because the measurements provide critical tests of our ability to calculate surface radiation levels, given detailed specification of the atmospheric composition. Such experimental studies are carried out most easily with spectroradiometers, supplemented by independent measurements of atmospheric quantities of ozone profiles, turbidity, etc. Relatively few well-instrumented sites can provide most of the required information.

(2) UV climatology monitoring is needed to establish the geographical and seasonal distributions of both averages and variabilities of UV radiation at the earth's surface. The potential user community for such data is large and spans many disciplines, including human health (epidemiology, public education), terrestrial ecology (animals, crops, forests), aquatic ecosystems (marine food chain, water photochemistry), atmospheric sciences (tropospheric chemistry, climate and biogeochemical fluxes), material damage (e.g., plastics). Furthermore, the development of satellite-based UV climatology models will require validation using corresponding climatological surface UV observations. The most stringent requirement for developing a climatology is high temporal and spatial coverage. Spatial correlation distances for UV are expected to be relatively short due to the large geographical variations of cloud cover, pollution, surface albedo and elevations, etc. Special design factors (such as high population density, or presence of particularly susceptible crops) may require even higher spatial coverage. Clearly, numerous instruments are required to achieve useful
geographical representativeness, and serious consideration should be given to the development of low-cost instrumentation.

(3) UV trends must be detected over periods of decades, together with UV anomalies occurring over a few months to a few years. Large changes have implications for the climatology, and are therefore of general interest. Such information is also critical to environmental policy, as for example the possible amendments and adjustments to the Montreal Protocol for the protection of the ozone layer. The requirements of wide geographical coverage are less stringent than for UV climatology studies, and, in principle at least, trend detection is possible with either spectroradiometers or low-cost instruments such as filter/broad-band meters, subject of course to the requirement of excellent long term stability. However, the causes of trends (e.g., ozone change vs. cloud changes) are most easily identified from spectral data. A key concern is the detection of statistically significant trends due to ozone reductions, given that the natural fluctuations of UV radiation can be quite large because of clouds and tropospheric pollution. This problem can be alleviated somewhat by use of spectroradiometers, where the ozone spectral signature can be separated from other causes of variation, and by data stratification according to different conditions of cloudiness and other tropospheric pollution.
The U.S. Department of Agriculture (USDA) has a responsibility to agriculture to assess the potential effects of UV-B radiation on agricultural crops and forests. To meet this responsibility, data on surface UV-B radiation is essential to establish both the climatology and long-term trends. In the broader sense, this information is necessary to support programs related to assessment of UV-B effects on human health, ecosystems, and materials, as well as supporting atmospheric science research and model development and providing ground truth for satellite measurements. To meet these objectives, it has been determined that two networks will be necessary - research and climatology. The climatology network will require a large number of sites deployed across the U.S. but will not require the sophisticated instrumentation deployed at the research sites. This will greatly reduce both initial installation as well as operational costs. This two phase approach will meet the need for spectral data, and at the same time provide UV-B climatology over broad geographic regions to support biological effects research and to provide a basis for a regional assessment of the potential impacts on agriculture and forests.

**Research Network:** The research network will be instrumented with a small number (6-14) of high resolution spectral radiometers. The high resolution spectral data is required to:

- Support research aimed at understanding of the factors controlling surface UV-B irradiance (tropospheric O$_3$, SO$_2$, NO$_x$, aerosols etc.)
- Provide highest precision for detecting trends
- Provide ground truth measurements for satellite based calculations of UV-B irradiance to aid in model related regional interpolations.
- Provide comparison and calibration for other instruments (example - broad-band, multi-band spectral, etc.).

Sites in the research network will be chosen to represent different latitudes and elevations and different meteorological and air quality conditions - all factors which effect the flux of UV-B radiation. Other parameters will be measured at these sites which are necessary to interpret the UV-B measurements (absorbing gasses, aerosols, cloud cover, etc.) and thus determine the role of changes in stratospheric ozone.

**Climatological Network:** In order to provide an adequate density of measurement sites to establish the climatology of UV-B irradiance, a larger network of sites (30-40) will be necessary. The climatology network will be instrumented with lower cost multi-wavelength spectral instruments (initially broadband) and designed to:

- Provide information to Agriculture and others about the climatological and geographical distribution of UV-B irradiance
- Provide ground truth for satellite-model interpolations of UV-B irradiance
- Provide information on trends in UV-B irradiance
These sites will be located in primarily rural areas, with particular consideration given to agricultural and forested regions. The initial 10 or 11 sites have been chosen for the climatological network and are indicated on the attached map. In addition to selecting these sites on the basis of their relationship to forestry and agriculture, locations were chosen which will likely be established as research sites when the high resolution spectrometers become available.

Data Quality and Comparability: The USDA monitoring effort is coordinated with the National Oceanic and Atmospheric Administration (NOAA), the U. S. Environmental Protection Agency (USEPA), the Department of Energy (DOE), and the National Science Foundation (NSF) in the location of sites to assure adequate collocation to establish data comparability and at the same time reduce unnecessary redundancy. To provide long-term instrument calibration, the USDA, USEPA, NSF, and NOAA are jointly supporting a calibration facility which will be administered by NOAA at their Boulder, CO laboratories. Overview of the operation of this facility as well as radiation standards will provided by NIST.
THE UV MONITORING PROGRAM AT THE U.S. EPA. William F. Barnard
and Larry T. Cupitt, Atmospheric Research and Exposure
Assessment Laboratory, U.S. EPA, Research Triangle Park, NC.

The U.S. Environmental Protection Agency (EPA) has initiated a
program to develop and operate a monitoring network to measure
ultraviolet (UV) radiation flux at the earth's surface and to
provide for public awareness of exposure to UV radiation through
adaptation and publication of a predictive UV "exposure Index."
This "Index," similar to the one developed and publicized by
Canada in 1992, was developed in conjunction with the National
Weather Service, and was initiated on June 29, 1994 in 58 cities
across the US.

The monitoring program, designed to provide "ground-truthing" for
the Index and for epidemiological studies, calls for 15 sites
employing spectrophotometers to be installed over the next 3
years. Currently 4 urban sites have been installed and plans
call for an additional 4 background sites and 7 more urban sites
to measure UV intensities on a spectrally-resolved basis. Other
parameters to be measured include total column ozone, cloud
cover, interfering tropospheric pollutants, and other factors
that are suspected to effect UV flux. The eleven urban sites
will provide data to validate the "Index" predictions in
proximity to ~25% of the U.S. population. The information
gathered at the two types of sites, urban (polluted) and rural
(less polluted) will enable EPA to improve the algorithms upon
which the "index" predictions are based. Experiments are also
being conducted to determine other factors such as cloud type and
aerosols, which may effect the UV flux. A series of instrumental
intercomparisons with other agencies are also planned to ensure
comparability of data and good quality assurance/quality control.
The first of these is scheduled for September, 1994 in Boulder,
CO. EPA's intent is to coordinate its efforts with other Federal
Agencies and with the international community. In accomplishing
this goal, EPA is one of 4 government agencies that is funding a
UV central calibration laboratory to be operated by NOAA in
Boulder, Colorado. EPA has also been heavily involved in the
development of a government wide UV monitoring plan which has
recently been critiqued by over 100 external reviewers. The
final version should be available by the end of September, 1994.
Stratospheric Processes and their Role in Climate (SPARC)

by Marie-Lise CHANIN,

Until recently, the World Climatic Research Programme (WCRP) had emphasized the ocean-troposphere system in its studies of climate, but in implementing the Stratospheric Processes and their Role in Climate (SPARC) project in March 1992, the Joint Scientific Committee (JSC) has recognized that one must understand stratospheric behaviour in order to take it into account in many studies of the troposphere-stratosphere climate. The recent eruption of Mt Pinatubo in the Philippines has once again illustrated how volcanically induced changes in the stratospheric aerosol content can influence the climate, both by the induced ozone change and by the direct radiative effect of aerosols down to the surface. It is finally becoming clearer that the stratospheric changes resulting from the ozone depletion and the increasing concentration of greenhouse gases must be considered both in identifying and evaluating greenhouse influences on the troposphere. One of the potential impact of the ozone decrease which has always been considered quite seriously relates to the consequences of the penetration of UV-B solar flux into the troposphere, where it could modify the tropospheric chemistry, and the increase of available UV-B at the surface and its consequences on human health and terrestrial and oceanic ecosystems.

The Scientific Steering Group (SSG) named by the Joint Scientific Committee (JSC) of WCRP prepared a document on the Scientific Objectives of SPARC, document published in 1994 by WCRP as Report No 83, and entitled "Initial Review of Objectives and Scientific Issues". It described the contents of the 4 main identified themes

Themes of the SPARC Project:
• The Influence of the Stratosphere on Climate, with the following objectives:
  Study the Influence of the Stratosphere on Tropospheric Climate
  Assess the Potential Role of Stratosphere/Troposphere Interactions in Climate Change
• Physics and Chemistry associated with Stratospheric Ozone Decrease
  With 3 objectives:
  Chemical and Aerosol Processes,
  Dynamical Transport of Chemical Constituents,
  Radiative-Dynamical-Chemical Interactions
• Stratospheric Variability and Monitoring:
  Objective: Understand the Variability of Long-Term Trends in the Stratosphere
• Monitoring and Modelling of UV Irradiation Changes
  With 2 Objectives:
  Model and Measure UV Penetration,
  Establish Global UV Climatology and Prediction

SPARC Initiatives
At its first formal meeting, the SSG decided to place a special emphasis on 6 initiatives, and, to achieve that goal, Working and Study Groups were created on the following topics:
• Troposphere-Stratosphere Modelling
  with Dr. S. Pawson, and Dr. K. Kodera as Co-Chairmen
  - In order to assess the present state of troposphere-stratosphere general
circulation modelling, strategies for model intercomparisons, and plans to improve
their capability for studying problems related to SPARC.
• Gravity wave climatology and parameterisation
  with Dr. K. Hamilton and Dr. R. Vincent as Co-Chairmen
  With the purpose to produce a climatology of gravity waves for a better
parameterisation of gravity waves in atmospheric models and to assess the needs in
terms of instrumentation, data analysis, and modelling.
• Assessment of Stratospheric Temperature Trends
  Under the chairmanship of Dr. V. Ramaswamy
  The objective is to assess stratospheric temperature trends in the middle
atmosphere using and intercomparing all available sources of data. This should
include a study of the consistency of temperature trends with the observed ozone
trends and comparison with model predictions.
• Water vapour instrumentation and climatology
  Under the chairmanship of Dr John Gille
  To review the available measurement techniques for monitoring H2O from the
troposphere to the lower stratosphere and to suggest a monitoring programme for
the establishment of water vapour climatology.
• Stratosphere / Troposphere Exchange
  With Dr. Ivar Isaksen, Chairman and Dr Mark Schoeberl & Dr Peter Hess, Co-
Chairmen
  With 2 objectives
  1. To identify a measurement strategy to produce the needed understanding
and the quantification of ST exchange as well as for other problems involving the
complex interplay of lower stratosphere chemistry and dynamics.
  2. To define a framework for international co-operation so that the relatively
disconnected existing national and international programmes can best mount a co-
ordinated effort to advance progress in this area.

The SSG also suggested the formation of a Joint Advisory Committee on UV-B
To assess the situation of the UV-B monitoring system and to make
recommendations to satisfy the needs of the users community.

However the concern for UV-B data being common to several WRCP and IGBP
programmes, this advisory committee should include representatives of SPARC,
IGAC, JGOFS, GCTE, LOICZ, SCOPE.....and obviously GAW which should assume
their responsibility in the coordination of the network.

Dr. P. Simon has been named as the representative of SPARC.

In order to receive more informations from the SPARC Office and to be put on
the SPARC Newsletter, please write to:
SPARC Office,
Service d’Aéronomie, CNRS, BP3,
91371 VERRIERES-LE-BUISSON, FRANCE
Tel: (33) 1 64 47 43 15
Fax: (33) 1 69 20 29 99
e-mail: sparc.office@aerov.jussieu.fr

The 3rd SPARC Newsletter in in press and should be distributed in 2000
samples during August 1994. If you wish to receive it together with the 2 first ones,
please write to the SPARC Office
UV measurements in New Zealand

R. L. McKenzie

NIWA, Lauder, Central Otago, New Zealand

Introduction

After it became apparent that global ozone reductions were occurring, a UV radiation programme was initiated by NIWA, NZ. It aims are to build a climatology of the spectrum of UV in the New Zealand region, to relate these to other regions, to understand and quantify the factors that influence UV, and to monitor long term trends.

A measurement system based on a commercially available double monochromator was developed to measure cosine-weighted spectral irradiances between 290 and 450 nm at 1 nm resolution. The spectrum is oversampled (800 samples) to ensure accurate wavelength calibration. Since the end of 1989, measurements have been made daily at 5 degree increments in solar zenith angle and at midday (3 scans), whenever weather permits. Measurements of the diffuse component are also made during clear-sky conditions near noon.

Quality assurance includes daily comparisons with calculated spectra, regular (7-10 day) Hg and tungsten lamp calibrations, and on-site 1000 W absolute calibrations as required. A log of weather conditions and instrument changes and tests is maintained. The instrument details, calibration and quality control procedures are described in McKenzie et al., (1992).

Correlative Measurements

An important aspect of the measurements at Lauder is the availability of correlative measurements which are helpful both for quality control (e.g. other UV monitoring instruments), and for understanding the causes of the differences in UV. Useful measurements include ozone, clouds, aerosols, air pressure. For rigorous comparisons between measurements and radiative transfer models, it is desirable that altitude profiles of these are available.

Lauder is one of five global sites which comprise the Network for the Detection of Stratospheric Change (NDSC). A wide range of state-of-the-art measurements are available at these sites. Recently it was decided to broaden the scope of this network to include UV measurements. A UV sub-group has been formed (initially comprising R. McKenzie (NIWA, NZ) and G. Seckmeyer (IFU, Germany), others may be added) and has been asked to specify the NDSC requirements for UV spectro-radiometers, including instrument specifications and data quality assurance.

Results

Measurements from Lauder to date have investigated the relationship between UV changes and several atmospheric parameters, including ozone column changes. Scattering by aerosols from the eruption of Mt. Pinatubo were found to have only a minor effect on the total UV, but they did increase the diffuse/direct ratio appreciably. Over the 4 year period (5 summers) for which UV measurements have been made, ozone changes at this site have been relatively small and any long term trends are below the detection threshold.

This contrasts strongly with the situation in the Northern Hemisphere, where large UV enhancements were seen in 1992/93 associated with anomalously low ozone at those latitudes.
Measurement Difficulties

The large intensity variations in the UV-B region mean that instruments to measure in this region must have a wide dynamic range (>10^6), very good stray light rejection, and accurate wavelength alignment. With the technologies presently available, scanning monochromators are required for reliable measurements at 300 nm and below. However, if the technical difficulties can be overcome, there would be significant advantages in using diode array or CCD systems. These would enable more continuous sampling, and the spectral shape could be preserved even when cloud variability causes intensity changes during the sampling period.

Other difficulties include the need to have accurately calibrated lamps, traceable to a common standard. Transferring the lamp calibration to the instrument also requires very careful procedures, because variations in lamp current typically cause variations in UV irradiance a factor of ten larger. Very stable power supplies, and precision monitoring equipment are required. We are currently assessing the suitability of optical feedback to improve long term stability of lamp output. A further uncertainty arises from the geometric configuration of solar UV spectro-radiometers. Most lamps are calibrated horizontal viewing whereas, the measurements of interest are usually made with vertical viewing. Changing the orientation of either can lead to errors. Excellent linearity in gain is required because the spectrum from typical calibration lamps differs widely from the solar UV spectra of interest. There are wide variations in the literature regarding the extra terrestrial solar spectrum.

A second instrument was developed in 1992 to provide continuity during process studies and intercomparison periods at other locations. Differences included: integrating sphere instead of diffuser, fibre optic connector, higher resolution, higher throughput, and automatic unattended scans throughout the day including the twilight period (and midnight). Cosine response errors were improved significantly with the integrating sphere, but further improvements are desirable.

Calibration results between the two Lauder instruments, and between instruments from other groups show that is difficult to achieve absolute accuracies better than 5%. However, it is possible that with careful procedures, long term stability (which excludes cosine response differences, for example) could be better than absolute accuracy. Comparisons between UV spectro-radiometers and complementary broad band instruments are also in progress.

Reference

Spectral Ultraviolet Radiation Measurements in Canada: The Environment Canada Brewer Network.

94 07 20.

Spectrally resolved measurements of ultraviolet horizontal irradiance are made by Environment Canada (EC) at twelve locations with Brewer spectrophotometers (Fig 1). In addition, there are two networks of broadband UV radiometers in Canada. EC operates an experimental network using Vital Technologies’ BW100 instruments. Télémedia, the company that provides 24-hour television weather programming in Canada, operates a network of twenty Robertson-Berger meters.

The UV measurements at the Brewer sites were started at various times between 1988 and 1993. Three of the sites are in cities and two are within 50km of cities; the remainder are isolated. The Brewer is a grating spectrometer with an F/6 aperture ratio and a focal length of 160mm. Its features are shown in Fig 2. It is designed for ultra-stable wavelength setting and high spectral purity in the 305-330nm region (achieved with a NiSO₄·6H₂O crystal filter which attenuates progressively above 315 nm and blocks above 330nm). There are 7 or 8 motorized controls. The controls are effected by simple commands from a host personal computer via an RS232 interface. The operation is normally programmed to be completely automatic. About seven observing routines have been developed. These and five self-test routines are used in the observing schedule.

The two most important routines used in Canada are the Ozone Direct Sun Observation (DS) and the UV scan routine. These are outlined in Fig 3. In the DS routine, only the radiation from within 3 degrees of the sun’s centre is measured. Five wavelengths are sampled with 0.8 seconds, using five of the six exit slits, and the signals are co-added for about 30 seconds; the five co-added signals are recorded and four more 30-second sub-observations are made. The column ozone and SO₂ values are computed for each sub-observation and corresponding means and standard deviations of the two sets of five values are calculated. If the ozone standard deviation is less than 2.5 DU, the observation is considered good and is used to compute the daily mean ozone. Fig 4 contains the results of several DS observations during a period when the ozone was steady. UV-Index measurements are also shown in Fig 4.

The standard UV scan is made with just one slit is open, and the horizontal irradiance, incident on a teflon diffuser on top of the instrument, is measured. A series of 71 measurements are made while the wavelength is scanned from 290 to 325 to 290nm at 0.5nm intervals. This takes about eight minutes. (Some double-monochromator Brewers scan over the range 290-360 nm). Since the bandwidth is only 0.55nm fwhm, the spectrum is slightly undersampled. All the spectral measurements are recorded; as well, the spectrum is weighted by the CIE erythemal spectrum, integrated and divided by 25mW.m⁻² to yeild a value of the UV-Index. Regular calibration is done by making observations with a variety of internal and external radiation sources listed in Fig 5. Instruments generally remain at their respective sites. A travelling standard instrument and standard lamps are
taken to each site every year in order to calibrate the local instrument. Our estimate of the current overall uncertainty in the measurements is about 7%. We hope to improve the calibration by using our newly developed 1000W transportable lamp and lamp housing. This can easily be mounted on a Brewer in its operating location, day or night.

It is important to note that any user can programme a new observing routine for some specific requirements. A new routine now in operation in Canada measures the horizontal irradiance at the five wavelength of the DS routine with the same sampling technique (i.e. every 0.8 seconds). This is providing data which is good for studying the spectral effects of clouds, which are not well reflected in slow spectral scans. We are also starting to analyze the DS data for the UV optical depth which is equivalent to studying the direct solar UV.

Each Brewer in the Canadian network produces about 250Kbytes of raw data each day. Currently, a small summary of these, of which Fig 4 is an example, is transmitted every hour or so as a bulletin on the EC Wide Area Net. These summaries are immediately available in Toronto, or elsewhere in Canada, for examination. The ozone values from the summaries are read automatically in Montreal for use in the operational forecast of ozone and UV. The raw data are archived in the Brewer Data Management System which is a relational database in Toronto. The transfer is currently by mail on floppy discs. A new mode of operation is being developed. In this all the data transfer will be in near real time and all the programs in the local host computers will be instantly modifiable from Toronto. With this new arrangement, it will be easy to effect special measurements or diagnostic routines at any of the twelve sites.

The UV data from Toronto during the period May 1989 to Sept 1993 have been used in an analysis of spectral UV changes which suggests there have been significant changes in UV irradiation due to ozone depletion (Kerr & McElroy, Science 262, 1032-1034, 1993). Fig 6 is an extension of this study which includes preliminary data for the winter of 1993-94. The UV data shown for 300 nm and 324 nm are not just for clear skies; they reflect the total UV irradiation during the 4-month periods. This figure shows that the four mean measurements of the 324 nm irradiation, which is not significantly affected by ozone, vary over a range of about 10%. Meanwhile, the 300nm irradiation, changes by more than a factor three, clearly in response to the changes in the mean ozone. The main ozone change was between 1993 and the other three years. The difference between the mean ozone of the 1990's, excluding 1993, and the pre-1980 mean is about the same as the 1993 anomaly. We believe therefore that these data demonstrate conclusively that the ozone-induced winter enhancement at 300nm of pre-1980 radiation is much larger than the variability due to clouds and other factors. The summer data also show enhancement.
Fig 2  BREWER SPECTROMETER - Overview

1. Modified Ebert Grating Spectrometer with Photon counting detection and SIX exit slits. HEXACHROMATOR slit widths 0.55nm fwhi

2. 7-8, computer-set, motorised controls
   *1 Azimuth
   *2 Elevation / mode (solar, zenith, irradiance, internal lamps)
   3 Field of view
   4 ND filters
   5 Polarizations / diffuser
   *6 Grating angle (wavelength)
   7 Exit slit openings (wavelengths)
   8 (Extra filters) **"continuous controls".**

3. Basic design to measure ozone (precision ~ 1:500)
   1 ULTRA-Stable Wavelength (.01nm ; .006nm steps; .0006nm finding)
   2 Spectral Purity
   3 Stable Spectral Responsivity.

4. LIVES OUTSIDE. ( ~ 250 instrument years to date)
Fig 3  BREWER ROUTINES

OZONE DS  Measure the direct solar beam at FIVE wavelengths in
RAPID cycle (~1.6 seconds up - down)

Centre wavelengths: 306.3 310.0 313.4 316.7 320.0 nm
Co-add for a total of ~3 minutes.

UV-B SCAN  OPEN ONE SLIT
Scan up then down 290 - 325 - 290nm, in 0.5nm steps
Co-add up and down scans
71 spectral elements ~8 minutes

Many other observing and diagnostic routines are used.
New routines can be programmed. UV-B codevelopers GREECE, SWEDEN, JAPAN

Fig 4: Bulletin: SXCN10 CWTO 161522
TORONTO OZONE - BREWER # 014

PRELIMINARY DATA - LOCAL DATE SEP 16/93
LATITUDE - 43.782 : LONGITUDE - 79.47
ETC'S - O3/SO2 - 3243 / 3229 : ABSORPTION - .3408 / 1.1452

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cont.
Fig 4 cont. Bulletin sxcn10- continued

SUMMARY OF BREWER UVB SCAN MEASUREMENTS FOR SEP 16/93

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An example of the near real time data that are put onto the Environment Canada Wide Area Net from the 12 stations in the Canadian Brewer Ozone and UV-B observing network.

Fig 5 Brewer calibration for UV-B

TOOLS
Reference Instruments
Reference Brewers reside at Toronto
Travelling Standard Brewers travel to and from Toronto

Internal lamps
Spectral lamp  Hg
20 watt quartz halogen lamp

External lamps
Small 200W lamp + housing...
can be used in-situ but is not good between instruments.
1000W Optronics/NIST...
indoor use mainly.
1000W lamp housing for outdoor use...
being tested.

SITE CALIBRATION (ANNUAL)
Take 1000W Optronics lamp AND
Standard Brewer to the site.

Performance 1992-1994:
Lamp and Standard agree within 2-3%.

OVERALL UNCERTAINTY  ? 5% ? + NIST (2σ)
Fig 6

Mean Dec-Mar daily UV irradiation and ozone at Toronto

KJ/sq m, (300nm x 1000), Ozone 300-370DU
The United States National Science Foundation's Monitoring Network for
Polar Regions

Charles R. Booth, Tanya Mestrechkina, Timothy Lucas,
John Tusson IV and John H. Morrow

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Abstract:

High latitude ozone depletion has resulted in elevated levels of UV irradiance in
Antarctica. To monitor and verify this, in late 1987 the United States National Science
Foundation, Division of Polar Programs, decided to establish a network of high spectral
resolution (0.7nm) UV spectroradiometers in Antarctica. This network is the first
automated, high resolution UV scanning spectroradiometer network installed in the
world. It has been successful in being operated in the harshest environments of
Antarctica and the Arctic and is currently returning data to researchers studying the
effects of ozone depletion on terrestrial and marine biological systems. The data is also
being used to develop and verify models of atmospheric light transmission and the
impact of ozone depletion. Biospherical Instruments, Inc., under contract to Antarctica
Support Associates, directed by the National Science Foundation, is responsible for the
network and for distributing data to the scientific community. This presentation outlines
the instrumentation and operation of the monitoring network.

I. INTRODUCTION

To monitor and verify elevated levels of UV irradiance in Antarctica due to high
latitude ozone depletion, in late 1987 the United States National Science Foundation,
Office of Polar Programs, decided to establish a network of high spectral resolution
(0.7nm) UV spectroradiometers in Antarctica. In 1988 instruments were installed at the
UV-B Measurement in China Mt. Waliguan GAW Station and Antarctic Zhongshan Station

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UV-B Measurement in China Mt. Waliguan GAW Station:

Brewer Ozone Spectrophotometcr No. 54 has been used since August 1991 to take the measurement of Ozone and UV-B Irradiance. For UV-B measurement, it has been calibrated by External standard lamps, which have been calibrated by standard lamp of NIST in U.S.A., every 3-5 times a year. Mt. Waliguan GAW Station is an inland plateau WMO GAW Station (Lat. = 36.387N, Long. = 100.898E, Alt. = 3816m).

a. UV-B and Damage UV-B Radiation is somewhat inverse to total column ozone and its seasonal variation is inverse to total column ozone. Together with decrease of total column amount of ozone in Winter and Spring time of 92-93, UV-B Radiation has great increase. (See Figure 1, 2, 3.)

b. For the UV-B Irradiance, its amount increase with the solar angle and arrive at its highest value around noon time and decrease with the solar angle (see Fig. 4). The Short wavelength UV-B irradiance is more sensitive to Ozone than the longer wavelength. And 300.5nm/323.5nm Ratio is most sensitive to the total column amount of ozone of all. (See Fig. 5, 6, 7)

UV-B measurement in Chinese Antarctic Zhongshan Station during 1993 "Ozone Hole":

Brewer Ozone Spectrophotometcr No. 74 has been used since March 1993 to take the measurement of Ozone and UV-B Irradiance. For UV-B measurement, it has been calibrated by External standard lamps, which has been calibrated by standard lamp of NIST in U.S.A., every month. The
Chinese Antarctic Zhongshan Station is located in southeast part of Antarctic(Lat.=69.37S,Long.=76.368E).

a. The Damage UV-B Radiation is somewhat inverse to the slant column ozone during 1993 Antarctic Ozone hole. The DUV-B increase greatly with the decrease of total column amount of ozone. The UV-B Radiation has great relation to cloudy cover and solar angle as well as ozone. (See Fig. 8,9)

b. For the UV-B Irradiance, the short wavelength irradiance is more sensitive to the change of ozone than the longer wavelength and the 300.5nm/323.5nm Ratio is also most sensitive the the change of total column amount of ozone of all.

Future Plan:

Both our Mt. Waliguan GAW Station and Antarctic Zhongshan station will continue our measurement of UV-B and Ozone. And the two station will use UV-B Radiometer in the future. We also will add the UV-B measurement project to our other ozone station in China.
UV-B Monitoring: the Swiss Approach

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Measurement campaign in collaboration with: Swiss Meteorological Institute
Approach

- Precision UV-Photometers continuously measure direct solar and sky radiance at three defined directions at three wavelength of the UV spectrum.

- Global UV-B irradiance spectra are determined by combining experimental measurements made during clear days and theoretical model calculations.

- Robertson-Berger type instruments installed at same stations are compared during clear days and continuously measure direct, diffuse and global UV-B.

- Continuous measurements at six stations at different altitudes, together with theoretical calculations allow to perform a UV-B climatology of Switzerland.

Combination of experimental measurements and theoretical calculations.
A New Low-Cost Narrow-Band, 2 nm Band-Pass Automated Shadowband Radiometer for UV-B Measurements

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Introduction
This paper describes a new hybrid-technology UVB narrow-band instrument that provides the atmospheric researcher with four Brewer lines yet costs approximately an order of magnitude less than conventional Brewer spectral scanning instruments. Although the instrument employs interference filters, it eliminates the serious solarization problems that all interference filters suffer from by providing the user with a direct-beam measurement verified via Langley analysis. It also measures in 2 nm FWHM band-pass, eliminating the “steep slope” problem that other filter radiometers such as the wide-band Biospherical GUV-511 suffers from. The steep extinction of UVB in the biologically important 300 nm region of the UVB necessitates that the instrument have very narrow band pass, approaching 1 nm. Unfortunately, the lack of photons in this region, coupled with the inherent loss in diffusers and interference filters makes this measurement extremely difficult, ultimately limiting the practical band-pass of this instrument to 2 nm.

History and Background of Practical Field Instrumentation for the UVB
Historically, UVB instruments have fallen into two technological categories: broad-band and narrow-band. Widely used instruments in the broadband category include the Yankee UVB-1 instrument as well as the Solar Light 501 UV-Biometer. Both of these instruments employ thermally regulated optics that eliminates the well-known temperature dependent wavelength drift problems of the earlier RB-meter designs. Furthermore, their reliance on chemically inert phosphor provides excellent long-term calibration stability. While these broadband radiometers provide a stable and low-cost UVB dose measurement, their output cannot be expressed truly in terms of a unit of radiometric power, as is required by certain applications in the climatological research. Nevertheless, the widespread diurnal variations in average UVB necessitates the deployment of a spatially dense network of ground measurements. Largely due to simple economics, even with their limitations, broadband radiometers have been widely deployed around the world for use in governmental public health monitoring networks.

Narrow band spectral-radiometers based on mechanically tuned optical gratings provide a true radiometric power since they measure in narrow bandwidths approaching 0.5 nm. These instruments employ photo-multiplier detectors and due to their complexity generally require highly skilled personnel to operate them over the extended period of time required in trends analysis. In addition, unlike broadband instruments that produce a simple dose value, the scanning instruments produce much more data that must be telemetered, analyzed and archived, further exacerbating operations. Finally, the sheer cost of these complex instruments puts them in the economic realm of “big science,” making them unreachable for many researchers. Nevertheless, grating instruments are required in limited numbers to act as secondary calibration references to backup the lower sophistication instruments.

Problems of Traditional Filter Radiometers
The application of fixed wavelength narrow-band interference filters to the measurement of atmospheric radiation is a well-known technology. By filtering out unwanted wavelengths and measuring the optical power that transmitted in the region of interest with a detector, these instruments can measure radiometric power at a fixed wavelength, as long as they are of narrow-band design. Although interference filters have cost benefits over traditional scanning instruments, they are relatively expensive, and must be carefully handled during manufacture. In addition, they must be kept thermally regulated and maintained in a dry environment in the field since their center wavelength shifts with temperature. Although these problems can and have been overcome through engineering, a more significant drawback is that interference filters will change their transmission based upon exposure to light. This systemic shift makes constant calibrations against radiometric
New “Hard-Coat” Filter Technology Unfortunately Has Unproved Benefits

Recent introduction by several manufacturers of interference filters of so-called “hard-coat” filters have prompted several manufacturers to introduce radiometer products based on this untested technology. Several commercial instrument manufacturers have been testing these filters in high flux environments. Unfortunately, although these new oxide coatings clearly make the surface of these filters more rugged mechanically, there is no published evidence to show that it retards solarization, which is the major source of calibration drift in any filter based instrument. In some cases this drift is filter dependent, that is, the drift cannot be predicted. The solarization drift rate often changes from instrument to instrument, even when they are co-located and the filters are from the same production batch. Until a long term study (5-10 years) of the stability of this new filter technology can conducted and the results are published, the trust in, and ultimately the deployment of these instruments will be delayed. Finally, the additional mechanical resistance to scratching that the oxide coating provides is of limited use, since these filters already must be kept in thermally regulated and desiccated enclosure to protect them from moisture exposure and variations in ambient temperature. It is therefore questionable to design in these more expensive filters and pass the costs along to users if evidence of their benefits are not proven.

The new instrument described here does not rely on the stability of its interference filters. It instead provides a mechanism for measuring the filter drift accurately, thus allowing the user to be able to know about and compensate for it. This operational verification takes place continuously in the field, greatly reducing the need to send the instrument back to a lab for re-calibration, or to co-locate it with an expensive Brewer instrument. The verification relies on the ability to take direct and diffuse measurements with the same set of detectors in the UVB region of 300 to 340 nm. With the data from the direct and diffuse measurements the instrument automatically conducts automatic Langley analysis and check for calibration drifts. All data is archived in raw form and the calibration constants can be applied at any time. The ability to conduct this automatic data quality check in the field on a daily basis is important, since operational experience with hundreds of filter instruments has shown that the interference filter solarization behavior can be a highly non-linear, sudden and random problem. This fact is important to consider when deploying a large network of the same instrument. Without this ability to calibrate in the field the instrument to instrument calibration drift will be unknown.

Optical Configuration of the Instrument

The new instrument employs the field-proven optical configuration, data acquisition and software architecture as the widely used MFR-6 Automated Multi-Filter Shadowband Radiometer developed by Drs. Lee Harrison and Joe Michalsky for the Department of Energy’s Atmospheric Radiation Measurements program [see 1,2,3]. The shadowband, data acquisition system and control unit are standard products, as is the software analysis package, which through economies of scale helps to keep down the cost of manufacture.

The major difference between the new UVB instrument and the MFR-6 is in the instrument head, where the optical openings have been increased to allow more light gathering capability. Four interference filters look up into an integrating chamber that is covered by a Teflon diffuser that provides an excellent cosine response. An early prototype showed that the original MFR optical design did not provide enough light to provide adequate signal-to-noise ratio on all channels, thus a new design was produced with larger optics. The entire head is thermally regulated, and environmentally sealed with a field-replaceable desiccant. The four wavelengths have been chosen to match closely four standard Brewer-pairs in the UVB region of 300-320 nm so that data can be inter-compared and checked against these popular instruments. Furthermore, the entire instrument can be converted for use in the visible by adding a second standard MFR-6 head with filters at 415, 500, 615, 673, 870 and 940 nm.

New Detector Technology Required

Due to the limited amount of photons available in the UVB region of 300-320 nm signal-to-noise ratio is a major problem. Although it is possible to build amplifiers with extraordinarily high trans-
impedance gains, these gains are ultimately limited by the shunt impedance of the detector. We have evaluated several non-silicon technologies including GaP detectors as the sensor, similar to the technology used in the YES SPUV-10 direct beam UV sun-photometer. To evaluate these technologies we developed a global filter radiometer instrument to allow us to conduct long-term testing of batches of filters and various optical configurations and amplifiers [4]. This test bed evolved into the seventeen channel global UVB (2 nm FWHM) and visible (10 nm FWHM) instrument is now currently produced as the GFR-17.

A fundamental problem remains with filter radiometers in the UVB region. Although interference filters can be manufactured to have excellent (10E-4 to 10E-5) out of band stray light rejection, there is still more than enough light leakage in the visible region that a silicon detector is highly responsive to it. The user sees this leakage as noise, and it is impossible to extract the UVB signal from the leakage. The gains employed necessarily require filters with out-of-band specifications that are unattainable with present technology. Note that the new oxide coated filters also do nothing to help this out-of-band rejection problem.

What is required is a truly solar-blind solid-state detector that rejects light in the visible range. Due to price versus performance requirements of network users that often are forced to run on solar power in remote locations, solar-blind photo-multiplier tubes have been ruled out as a detection solution. We are currently evaluating several new semiconductor technologies. Unfortunately, a lack of a reliable commercial manufacturer of these currently exotic devices has limited their practical use on a commercial basis.

**Instrument Performance and Conclusions**

Several prototypes have been built and are currently being tested at our calibration facility and are about to be deployed at other independent scientific facilities equipped with Brewers. Signal-to-noise ratio (SNR) is not equal on all four channels and varies from about 2.5 orders of magnitude SNR at 300 nm to 4 orders of magnitude at 340 nm. Since the levels of 300 nm UVB falls off rapidly at extreme latitudes the 300 nm channel may be of limited use for these sites. In this case another slightly longer wavelength filter can be substituted.

The long term stability of the instrument will be tested in exhaustive field testing, to begin in mid-1994 against spectral-radiometers on several continents. Nevertheless, the instrument provides a cost effective solution to narrow band UVB measurements that relies on physics rather than filter technology that has not shown long term stability for its calibration.

**References**

applied to the determination of the altitude effect

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In order to measure the increase of solar irradiance with increasing altitude it is essential to measure global solar UV irradiances simultaneously at both sites. For the first time simultaneous spectral UV measurements were carried out in July and August 1993 near Garmisch-Partenkirchen, Southern Germany, with 4 different doublemonochromator spectralradiometers (instruments 1, 2, 3 and 4 were a Bentham DM150, an Optronic 742, a Double Brewer and a Bentham DM300). The instruments had a halfbandwidth between 0.6 nm and 1.6 nm, and spectra were taken between 290 nm and 370 nm simultaneously every 3 seconds for each step of 0.5 nm. In order to establish the relation between the instruments, comparative measurements in Garmisch-Partenkirchen were performed first (Fig. 1 and 2). Then two of the instruments were brought to the nearby mountain station Wank, 5 km away and vertically separated by 1000 m (Fig. 3 and 4). These measurements allow to determine the increase of UV irradiance with altitude in dependence on wavelength and solar elevation. The invariability of the ratios between the instruments is the limiting factor for the accuracy of the determination of the altitude effect, therefore two instruments were operated at each site simultaneously.

The altitude effect amounts to 9%, 11% and 24% at the wavelengths 370 nm, 320 nm and 300 nm, expressed as increase per 1000 m difference in altitude and related to the valley station. These results are valid when local albedo was similar at both sites (meadow and woodland). Within the measurement accuracy of about ±4% no dependence on solar elevation in the range of 20° to 60° could be observed. The results are in good qualitative agreement with model calculations.

Further measurements in April 1994 showed the influence of different albedo. When the mountain station was snow covered and the valley station was still snow free, the altitude effect was about 10% higher for all wavelengths.
**Figure 1:** Wavelength dependency of the ratio of solar spectra measured by instrument 3 and instrument 1 for two different times (top and middle) and ratio of these two curves (bottom). The relatively high structure in the ratios of the two instruments is mainly a consequence of the different slit width (0.6 nm and 0.9 nm) and therefore very constant with time. This structure disappears almost completely in the ratio of these ratios (bottom). The remaining small structure is mainly caused by random small wavelength shifts less than 0.05 nm.

**Figure 2:** Diurnal variation of the ratios of measurements by instruments 2 and 3 relative to instrument 1 at the wavelengths 307, 323, 350 and 404 nm, each calculated relative to the ratio at 11:30 UT. The error bars indicate the standard deviation of the relative ratios in the wavelength interval ±4 nm. The absolute irradiances at each wavelength, measured with instrument 1, are shown as the smooth curves (scale on the right). At 307 nm the ratio instrument 2 / instrument 1 is higher and has a strong diurnal variation. This is caused by the large slit width of 1.6 nm of instrument 2, which therefore overestimates the irradiance at wavelengths, where the spectrum is steeply increasing, which occurs for 307 nm especially at low solar elevations in the morning and in the evening. Instrument 3 can measure only up to 370 nm. The slightly increasing tendency of the ratios during the day of about 5% is mainly a consequence of the inadequate temperature stabilisation of the controlling electronics of instrument 1. For the ratios at the higher wavelengths no variation symmetric to the diurnal course of solar elevation is found, thus indicating that all three instruments have about the same cosine response.

**Figure 3:** Spectra of global solar UV irradiance measured simultaneously in Garmisch-Partenkirchen by instrument 3 and on Wank by instrument 1 on 02.08.1993 at 8:00 UT in a logarithmic (left) and a linear scale (right). The small slit width of instrument 3 of 0.6 nm is responsible for the higher structure of the spectrum measured by instrument 3. The logarithmic scale shows clearly the lower detection limit of both instruments.

**Figure 4:** Spectral dependency of the altitude effect, expressed as the ratio of the intensities at the mountain station and at the valley station, vertically separated by 1000 m, on 02.08.1993 at 8:00 UT. To eliminate systematic differences of the two instruments, the ratio of the two scans at different altitudes is divided by the ratio when the two instruments were collocated. This is done for all four possible permutations of instrument pairs (1/3, 1/4, 2/3, 2/4). The solid line gives the mean altitude effect, the dotted lines the range ±1 STD. The smooth lines give the altitude effect calculated with a discrete ordinate model with urban (top) and continental (bottom) type aerosols.
Fig. 3
INTRODUCTION

Daily measurements of UV-B radiation at Belsk (Poland, 52°50'N, 20°47'E) started in May 1975 in the Central Geophysical Observatory of the Institute of Geophysics of the Polish Academy of Sciences. The measurements have been made by means of the Robertson-Berger meter (detector no 36, recorder no 40). In order to eliminate dependance of the RB-meter readings on temperature a new version of instrument (thermostated detector) was developed (Blumthaler et al. 1989).

Since March 1992 a new model of RB-meter UV-Biometer Mod.501A (Solar Light Co. Philadelphia) has been used and in February 1991 Brewer spectrophotometer with UV-B monitor was installed.

At the Observatory total ozone content (by means of Dobson spectrophotometer) and global solar radiation are also measured.

CALIBRATION PROCEDURE

For the period 1976-84 calibrations have been done through field intercomparisons of the Belsk RB meter with reference instrument provided by the Photobiology Center, Philadelphia University. The differences between readings of the instruments were within 3-8% range.

Since 1985 a different approach to the calibration problem has been applied because the standard meter was not available. Data for several cloud free days were compared to calculated solar erythemal UV-B radiation. Calculations were based on Dave-Halpern radiation model weighted by the DIN action spectrum (Slomka, Slomka 1985). Comparison of the ratio of number of counts to calculated UV erythemal dose for two periods; one when we assumed that the instrument was properly calibrated, and for sample period, made possible determination of adjustment coefficient. According to this procedure sensitivity of the instrument dropped down in 1992 to 81% of the value for 1985. Inspection of the fractional deviations of UV-B mean monthly values from long term mean, suggests that such
a procedure could introduce some errors, due to nonlinear behavior of the ratio of number of counts to calculated UV dose as function of zenith angle. We believe that a reevaluation of the data set with the method described by Zheng and Basher (1993) would remove inhomogeneity of the data.

Comparison of the indications of the old RB meter with the new UV-biometer shows that new instrument reads relatively higher by 40% in summer time to 70% in winter season. Readings of the new instrument are very well correlated with the Damaging Ultraviolet measurements with the Brewer spectrophotometer (correlation coefficient 0.99).

DATA ANALYSIS

Three sets of monthly mean values have been analyzed; UV-B radiation, global solar radiation, and total ozone content for the period 1976-1992. To eliminate annual variations normalized deviations from long term average values were calculated and regression analysis was applied to detect trends. All analyzed series show negative trend; UV radiation 0.51+.20 % per year, global radiation 0.3+.21 % per year, total ozone 0.32+.07 % per year. The negative trend in UV series is inconsistent with very distinct negative trend in total ozone and can not be explained by small negative trend in global radiation. If UV data are divided into two sets corresponding to different calibration procedure, we get insignificant trend for the 1976-85 period and large positive trend 1.2 +.6 % per year for 1986-92 period. The results of trend analysis should be treated with caution, and the analysis will be done again after data reevaluation.

REFERENCES


UV Radiation in Antarctic and Sub-Antarctic Regions

Susana B. Diaz *

Summary

The National Science Foundation UV Monitoring Network was established in 1988. Originally three systems were installed at Antarctica (South Pole, McMurdo and Palmer) and one in Ushuaia (Argentina). Lately one system in Barrow (Alaska) and one in San Diego (California) were added. This equipment are high resolution spectroradiometers, and were described in many publications.

In this presentation irradiances measured by the mentioned spectroradiometers and ozone concentrations measured by TOMS were considered. Instantaneous and hourly mean monthly values of irradiance and monthly accumulated energies were analyzed for all sites and for all available data in the CD Roms edited by Biospherical Instruments Inc. Daily and mean monthly ozone concentrations, provided by TOMS (NASA courtesy) are also analyzed.

It was observed that each year the "Ozone Hole" affected spring and summer irradiances for all Antarctic and Sub-Antarctic sites of the National Science Foundation UV Monitoring Network. Although the characteristics varied strongly from year to year. On one side Palmer and Ushuaia showed similar characteristics in most of the analysis, but in Ushuaia the effects were always less pronounced. While South Pole and Mc Murdo showed similarities one with the other too.

The study of instantaneous values showed that absolute maximum irradiance and absolute minimum ozone concentrations did not occur at the same day. It also showed that maximum irradiance for Palmer exceeded the maximum for San Diego for the analyzed periods, while the maximum for Ushuaia was slightly lower. Nevertheless mean monthly values and monthly accumulated energies were considerably lower than for San Diego.

When analyzing the effect of an ozone depletion on the irradiance, the influence of daylength and solar zenith angle and cloudiness should be considered. In this study only the first two parameters were taken into account and the effect of cloudiness will be discussed in a future analysis.

Measurements of UV radiation at the Solar and Ozone Observatory in Hradec Kralove and building up of Robertson-Berger network in Central Europe

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Long-term monitoring of A+B ultraviolet radiation

Monitoring of ultraviolet radiation A+B had been carried out at the Solar and Ozone Observatory (SOO) by means of Eppley ultraviolet radiometers (TUVR) No. 10976, 10975 since 1971 to 1990. Measurements were recorded into hourly, daily and monthly sums. About 6360 of daily files were made in Hradec Kralove. Nowadays Eppley ultraviolet database is studied and complete results will be published in the near future.

Spectral measurements of UV-B radiation by means of Brewer Spectrophotometer

The Brewer Spectrophotometer was installed at our Observatory in December 1993. Regular measurements at (SOO) are made in Hradec Kralove (50°11' N, 15°50' E') since January 1, 1994. Our measurements are from Brewer No.98. Nowadays we have two separate automatic schedule which are designed to observe the UV-B radiation at the specific Zenith Angles (SZA) of 70, 60, 50, 40 and 30 degrees both in the morning and afternoon. Each schedule is to do UV-B measurement each day at Local Noon.

Building up of Robertson-Berger network in Central Europe

In May 1994 the meeting on the topic of "Atmospheric Radiation and Ozone Measurements", Central Initiative, category of meteorology was organized within the framework of long-term cooperation of Central European meteorological services at the SOO in Hradec Kralove. Urgent need of creation of national network for monitoring of UV-B radiation was declared by all delegates. The participants emphasized importance of close cooperation in this activities. The details will be specified with respect to the recommendations of the "WMO Meeting on UV-B Monitoring in July 1994". Nowadays Czech Hydrometeorological Institute plans to build up the network for measurements of UV-radiation in the Czech Republic. Therefore Robertson-Berger UV-Biometer is installed for 4 month at SOO. We have very preliminary results comparing measurements from the Brewer No.98 with UV-Biometer. They indicate that differences exceed exceptionally ± 7 % and are mostly smaller than ±4% during all days. In general, detailed comparison of both instruments will be made in the fall in this year. Nevertheless, it seems that UV-Biometer can be successfully used to monitoring the biological effectiveness of solar ultraviolet radiation.

Conclusions

The primary objective of this paper is to get information about measurements of UV radiation at the SOO in Hradec Kralove. The changes of total ozone have a great important influence on UV-B radiation. Further study is needed toward the establish the relationship between solar UV-radiation and SO2, clouds and solar cut off wavelength reaching the surface and amount of total ozone.
A Dual Channel System
for
Continuous Monitoring of Biologically Weighted Solar UV-B

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Abstract: It is shown that a one channel detector system is not capable of measuring biologically-weighted irradiance directly because of the variable shape of the UV portion of the solar spectrum at ground level. A two channel detector system is both necessary and sufficient to determine the biological action of the solar UV-B at the earth's surface. On the basis of calculations performed on the values of solar irradiance from an atmospheric radiative transfer model, it is shown that erythemally-weighted irradiance can be expressed as a function of the UV irradiance measured by a solar-blind detector, corrected by a term containing short wavelength visible irradiance measured by a second detector.

I. Rationale

Solar radiation entering the top of the earth's atmosphere is attenuated by various gases and aerosols before reaching the earth's surface. Two of the most important agents in this process are clouds and ozone. Water droplets in the form of clouds produce wavelength-independent attenuation across a wide spectral range. The reduction in UV radiation due to ozone, however, is a decreasing function of wavelength for UV-B (290 to 320 nm).

The response of an entity sensitive to a spectral wavelength region, such as a detector or living organism, may be represented by an integral of the incident radiation, weighted by an appropriate response function, to give a total response. If \( F(\lambda) \) represents the incident radiation and \( s(\lambda) \) is the spectral sensitivity of a detector, then the overall response of that detector is given by

\[ S = \int_{\lambda_1}^{\lambda_2} F(\lambda) s(\lambda) d\lambda \quad (1) \]

where integration is over the range of sensitivity. Similarly, if the weighting function used is a biological action spectrum, such as that for erythema, \( b(\lambda) \), the action can be written as

\[ B = \int_{\lambda_1}^{\lambda_2} F(\lambda) b(\lambda) d\lambda \quad (2) \].
First results of UV-B monitoring network of the Institute of Meteorology and Water Management.

Zenobia Lityńska, IMWM, Centre of Aerology.

In July 1993 a network of UV-B Biometers (model 501 Solar Light) was established. The three sites, as seen in the above figure are situated along N-S cross-section through Poland, representing the climate at Baltic coast (Leba), in midland (Legionowo) and in Tatra Mountains (Kasprowy Wierch). The sites are standard meteorological stations with global solar irradiation measurements (Kipp & Zonen pyranometer).

The network works semi-operationally. The UV-B data base is located in the Centre of Aerology in Legionowo, where every morning the daily and midday (10-14h) UV-B values are sent by telex. Every month the disquettes with all UV-B data (MED/0.5 hour) are transferred to Legionowo.

The total ozone measurements are performed only at Belsk*, ca 50 km from Legionowo, so the research on relation of total ozone versus UV-B is reliable by now only for midland of Poland.

The results of measurements from July 1993 to June 1994 give all months observations and allow to present the diurnal, monthly and yearly cycles of UV-B values. As it is well known, the main factors limiting the UV-B irradiation to earth surface are the solar zenith angle, total ozone, clouds and aerosols. The influence of the 1, 3 and 4 th factors is evidently seen in the average UV-B diurnal cycles for different months at all sites (fig.1). At each site there are seasonal differences, the highest values in warm months (V, VI, VII, VIII), the lowest in cold months (the relation ca 20:1), and the well marked diurnal cycles, symmetric against the local noon, with highest values at it. In some months the symmetry is spoiled by the influence of clouds.

The latitudinal effect can be best seen in fig.2, which represents the all data diurnal cycles for the seasons of the year. The clear day values are the highest at Kasprowy Wierch, but to some extent the less amount of aerosols in the atmosphere at ca 2000 m could have an impact. In all seasons the influence of cloudiness upon UV-B can be very well observed. The differences between the clear and cloudy day values are in summer months of the same order as the seasonal differences.

In fig.3 the yearly cycles of UV-B broad band irradiation (provided 1MED=2.1mJcm⁻²), solar irradiation and total ozone are presented. The envelopes of UV-B and global irradiation define the highest clear sky diurnal values. The dispersion of the values inside the envelopes is mainly due to clouds and perhaps to total ozone. The good symmetry of UV-B irradiation against the summer solstice, compared to the yearly cycle of total ozone diurnal values, gives the evidence that the main factor limiting UV-B irradiation is the solar zenith angle.

Nevertheless we can find the evidence upon the correlation between the UV-B and total ozone after elimination of clouds influence. In fig.4 the comparison of the relation UV-B/global solar irradiation versus total ozone is presented, where we can observe an evident negative correlation.

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* Geophysical Observatory of Polish Academy of Sciences.
UV-B measurements in India were initiated around 1980 at the National Physical Laboratory (NPL), New Delhi and the Centre for Earth Sciences Studies (CESS), Trivandrum. These were initiatives by individual scientists as part of their own/institutional research programmes. With the formulation of the Indian Middle Atmospheric Programme (IMAP) in 1982-83, an attempt was made towards establishing a co-ordinated network of the UV-B stations in India comprising of Jodhpur, Pune, Visakhapatnam and Mysore, in addition to the already existing New Delhi and Trivandrum station. Dr. B.N. Srivastava of NPL was nominated as Co-ordinator for this network. Identical instruments were fabricated and installed at each of these stations (except Pune which built its own unit) and network observations began around 1986. The instrument, a four wavelength broadband (±10nm) filter photometer with centre wavelengths generally at 280nm, 290nm, 300nm and 310nm respectively was designed for measurement of Global UV-B irradiance at ground eventhough some stations measured direct solar radiation also. Even after completion of the IMAP programme in 1989, the University stations are being funded under an ISRO-UGC agreement and except for Jodhpur where observations could not be continued for operational reasons, all other stations continue to make observations. New Delhi and Trinandrum stations have a data record for about 12 years now.

With the available data, a few studies have been conducted on the diurnal and seasonal variations at the individual stations. The New Delhi and Trivandrum data has been examined for possible UV-B trend at these stations. Attempts have also been made to estimate from this data as well as from model calculations the erythemal dosage at some locations in India.
An attempt is being made to compile the data from these stations and make a consolidated report. This has brought to light some anomalies in some of the data sets and the current effort is to come up with a recommendation on the observation procedure, calibration and intercomparison programme which can ensure a reliable data set.

Until this exercise is completed and a new co-ordinator is named, the contact person for additional information would be Dr. S.C. Chakravarty, Space Science Office, ISRO Headquarters, Bangalore. or The present authov.

SOME REFERENCES:

An intercomparison of thirteen ultraviolet (UV) spectroradiometers and eight filter radiometers was arranged in the autumn 1993 at the Observatory of Izaña (INM) on the island of Tenerife, Spain. The experiment, named NOGIC-93, was arranged by the Nordic Ozone Group (NOG) and joined by other nations, too. The purpose of the experiment was to produce information on the comparability of the ozone and ultraviolet measurements currently made in different countries.

The intercomparison consisted of spectral measurements of laboratory lamps, laboratory equipment tests, spectral as well as moderate and broadband measurements under natural sun, total ozone column determinations, ozone soundings and experiments with radiative transfer models. The methods and the results of the intercomparison are analyzed and suggestions for future work are presented in the ten independent papers of this report.

The main results of NOGIC-93 are the following:

- The agreement between the standard ozone instruments was generally excellent.
- The secondary UV lamp standards were able to transfer a calibration within ±3% in most cases.
- Most spectroradiometer UV calibrations agreed in laboratory within ±4 to 7%.
- Deviation in measuring the electric current caused an uncertainty of ±1% on lamp irradiance.
- The outdoor spectral measurements agreed at least within ±15% at wavelengths longer than 310 nm but deviated more at the shorter wavelengths.
- The integrated outdoor dose rates of most of the spectroradiometers agreed generally within ±10% and those of the other instruments within ±15%.
- The consistency of the UV measurements can be increased by the use of a travelling lamp unit.
- A radiative transfer model responds logically to changes in its parameters and yields useful information on the behaviour of radiation in the atmosphere.
The German Reference Instrument for the Measurement of solar UV-radiation

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A high accuracy spectroradiometer for the measurement of UV-radiation was developed and installed in Garmisch-Partenkirchen (latitude 47.48° N, longitude 11.06°, altitude 730m) to serve as a stationary weatherproof reference instrument in Germany. It is part of the NDSC (network for the detection of stratospheric change) alpine station. A second spectroradiometer is currently installed at the nearby Zugspitze (altitude 3000 m). Another NDSC station that performs UV-measurements is situated in Lauder, New Zealand (latitude 45° S, longitude 169° E). Both global and direct sun and sky irradiance are measured with 0.5 nm resolution. Weekly calibrations are performed to check the continuous measurement of spectral irradiance.

The research strategy of the IFU is to combine different measurements of atmospheric parameters in order to evaluate and validate radiative transfer models (including their parametrization) for predicting future UV levels. The measurements of UV-irradiance are complemented by a number of other measurements such as air temperature, relative humidity, air pressure, visibility and total (global) irradiance and other chemical substances. Additional information is available through other collocated projects using LIDAR systems to evaluate ozone profiles and aerosols in the troposphere.

Specifications of the instruments:

Double monochromator: TDM300, Bentham Instruments
focal length: 300 mm
Gratings: 2400 Lines/mm
Detector: Bialkali-Photomultiplier, Type 9205QB(EMI)
Lock-In-amplifier with Chopper Technique

wavelength reproducibility: better than ± 0.02 nm
wavelength accuracy: better than ± 0.1 nm

entrance optics: quartz-cosine-diffusor

detection limit: 10^{-6} W m^{-2} nm^{-1} with 1 nm Halfbandwidth
is Integrationtime and Cosinediffusor

minimal Scantime: 7 sec (low accuracy)

actual Parameters:

wavelength range: 285-410 nm
Half band width: 0.5 nm (nominal)
adventure duration: 6 minutes

calibration: 100 W Quartz-Halogen-Lamps, calibrated at National Physical Laboratories (NPL), UK intercompared with 1000 W FEL lamps, calibrated at PTB
Introduction

In the years 1991-93 the Commission of the European Communities supported a research programme entitled ‘Determination of Standards for a UV Monitoring Network’. As part of this programme three intercomparisons of spectroradiometers were held, one in the summer of each year, to assess the relative performances of the different instruments used for UV measurements in Europe. By working together to identify and understand differences between the disparate instrument designs many improvements in individual instruments have been made, better techniques for comparison measurements have been developed, and the absolute level of agreement between systems has increased markedly.

Sites and Instruments

Two sites were used for the intercomparisons: a school outside the village of Panorama in northern Greece (1991 and 1992), and the Fraunhofer Institute outside Garmisch-Portenkirchen, Germany (1993). In each case the flat roof of the building was used as an instrument platform and the general horizon, while not planar, was uniform for all spectroradiometers. A dark room for calibration and lamp investigations was several storeys below the roof site at both locations.

Six instruments took part in the 1991 intercomparison, increasing to eight in 1992 (plus 2 visitors from other continents), and 12 in 1993. Four instrument-operator pairs took part in all three intercomparisons and a fifth operator was present each year, but with a new model of instrument in 1993. A great diversity of instruments was represented which allowed investigation of many facets of instrument performance, but also posed some challenges for obtaining directly comparable results, both in the field and the dark room. Improvements in instrument characterisation, operating procedure, temperature stabilisation and automation of many of the instruments during the three years allowed new comparison techniques to be employed in 1993, removing some sources of uncertainty encountered in previous years, and enabling other differences to be investigated in more detail.

Methods

The 1991 intercomparison was very much an exploratory exercise with each instrument scanning in its usual mode, beginning at a pre-determined time, followed by immediate comparison of results after a measurement. This allowed swift identification of major problems with instruments operating in a strange environment, and no longer in isolation, for the first time, and was a beneficial learning process for all involved.

However, the pertinent question to ask is ‘How good is the agreement between independent instruments operated in isolation when measuring the same source in the field or the laboratory?’ By 1993 the techniques and protocol to address this question more rigorously had been established. Instruments arriving in Garmisch were set up on the roof platform and prepared for measuring solar radiation. Any tests or calibrations the operator deemed necessary were made solely with equipment brought from the home institute. A measurement schedule was defined for a pre-determined scan regime: a scan was to begin at 280nm at the scheduled time and proceed in steps of 0.5nm
every 3 seconds, ending at 420nm for those instruments with sufficient range. This synchronised scanning ensured that data was compatible over the whole wavelength range and not subject to uncertainties due to changing weather conditions and variable scanning speeds. The diode array instruments measure spectra instantaneously, and took their spectra at the beginning and end of the synchronised periods, and after 4 minutes when the scanning instruments reached 320nm. There was no discussion or exchange of data until the end of the outdoor campaign when all data had been submitted for analysis.

In the dark room all instruments measured a single 1000W standard lamp operated by the Fraunhofer Institute with current supply to, and voltage across, the lamp being continuously monitored. After completion of this second set of isolated measurements some of the operators' own calibration lamps and supporting equipment were investigated.

Results

The most rigorous test of the spectroradiometers is the simultaneous measurement of global solar radiation. This tests all aspects of instrument performance: absolute spectral irradiance calibration, optical features, mechanical stability, recording and control procedures. In 1991 the participating instruments showed that they could accurately and repeatably resolve and record the shape of the solar spectrum, but absolute values of irradiance differed by tens of percent. Between pairs of instruments the ratios were inconsistent with time, and changed from dark room to field measurements. By 1993 absolute agreement between some of the instruments was consistently better than 10% across the full wavelength range, and better instrument characterisation enabled an understanding of some of the remaining discrepancies. Two of the features of an instrument which can be characterised and hence assessed for their affect on a measurement are the slit function and cosine response. Slit functions of all instruments were measured in Garmisch by scanning across a number of emission lines from a mercury lamp, and varied from FWHM of 0.32 to 1.6nm. A radiative transfer model was used to approximate and then remove the slit function effect from the ratios between two instruments, and much reduced the characteristic structure seen in the original measurements. The best agreement between a large number of instruments was achieved when the solar zenith angle was small and most cosine responses satisfactory. At larger solar zenith angles cosine responses tend to become progressively worse, and may be asymmetrical in the azimuthal plane. This leads to diurnal variation in the relative measurements of two instruments, even assuming that all other components of the measurement procedure remain stable. Cosine responses measured by some of the instruments at their home laboratory were used to calculate errors due to an imperfect cosine response and applied to the measured spectra. This process improved the diurnal consistency of the results slightly. A well designed and equipped dark room enabled the absolute spectral irradiance calibrations of each instrument to be tested, with the encouraging result that several instruments were within 5% of the PTB calibration certificate of a 1000W lamp at UVB and UVA wavelengths even after travel and recalibration, often with a secondary "field" standard.

Further improvement in the absolute spectral measurement of solar radiation will depend upon improved calibration facilities and procedures, good stabilisation of power supply to, and temperature of, the spectroradiometer, improved cosine responses of the input optics, and care levelling the receiving surface, plus attention to other sources of residual error such as stray light, amplifier noise and dark current.
Solar UV–B Observation and Data Quality in Japan Meteorological Agency

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ABSTRACT

The Japan Meteorological Agency started the observation of spectral irradiance of global solar ultraviolet–B (UV–B) in Tsukuba January 1, 1990 and in Sapporo, Kagoshima, and Naha January 1, 1991 by using Brewer spectrophotometer. The main objective of the observation is to detect long–term trends of UV–B irradiance on the ground. Details of the procedure for assuring the data quality are described. Some results of analysis of observations obtained up to present are shown. At present the Japanese data is not enough in time length after the commencement of the observation to detect long–term trends in UV–B irradiance on the ground because of their large temporal variability caused by clouds and turbidity effects, although episodes of intensified UV–B irradiance due to low total ozone can be demonstrated based on the observations.

1. Introduction

Increases of solar ultraviolet–B (UV–B; 280–315 nm) irradiance due to ozone layer depletion have become of great concern in the world. Theoretical studies on UV–B increases due to ozone layer depletion have been made extensively since 1970's (e.g., Cutchis, 1974; Venkateswaran, 1974; Dave and Halpern, 1976; Pyle and Derwent, 1980; Gelstl et al., 1981), whereas a limited number of studies based on observations has been made so far (Josefsson, 1986; Frederick et al., 1991; McKenzie et al., 1991; Correll et al., 1992; Ito, 1993; Kerr and McElroy 1993).

In the total ozone observation with Dobson spectrophotometer, decreases in total ozone are measured as increases in monochromatic irradiance at a wavelength in UV–B relative to monochromatic irradiance at a wavelength in ultraviolet–A (Dobson, 1957). In other words, Dobson spectrophotometer detects, in principle, decreases in total ozone in terms of increases in UV–B irradiance under cloud–free and aerosol–free conditions. Thus, it should be noted that the long–term decreasing trends in total ozone, as have been detected from ground based observations (WMO, 1992), evidence the existence of the
long-term increasing trends in UV-B irradiance on the ground under cloud-free and aerosol-free conditions. Moreover, Ito (1993) determined the quantitative relation between UV-B increases and total ozone decreases as a function of solar zenith angle and wavelength through a careful analysis of simultaneous observations of total ozone and UV-B spectral irradiance. Further efforts to detect long-term trends in UV-B irradiance on the ground under cloud-free and aerosol-free conditions will not bring additional important knowledge to us. There is no rational reason to insist urgent needs for evidencing UV-B increases on the ground due to total ozone decreases under cloud-free and aerosol-free conditions. The most urgent need is to detect the quantitative long-term trends of UV-B spectral irradiance containing effects of aerosols, clouds and so on to assess possible adverse effects of increased UV-B irradiance.

The Japan Meteorological Agency (JMA) started the observation of spectral irradiance of solar ultraviolet in Tsukuba (36.05°N, 140.00°E) January 1, 1990 by using Brewer spectrophotometer (SCI-TEC Inc.). Solar ultraviolet irradiance on a horizontal surface on the ground (called global irradiance) is measured at wavelengths between 290 and 325 nm with a wavelength interval of 0.5 nm. The wavelength range covers over that of UV-B almost completely. The observation is made every hour from 30 minutes before sunrise to 30 minutes after sunset every day. The observation was also started in Sapporo (43.05°N, 141.33°E), Kagoshima (31.63°N, 130.60°E) and Naha (26.20°N, 127.68°E) January 1, 1991 to constitute the JMA UV-B Observation Network. Figure 1 shows the location of the total ozone and UV-B observation sites operated by JMA. Details of the observation methods and the analysis of spectral data obtained through the observation have been presented elsewhere (Ito, 1993; Ito et al., 1991, 1992, 1993). This paper aims to discuss the data quality in the JMA UV-B Observation Network and to describe further results of the observation.

2. Quality Assurance

2.1. Calibration of Spectrophotometers

The initial calibration of each Brewer spectrophotometer was performed at Aerological Observatory in Tsukuba before installing them in each observation site. The halogen-quartz standard lamp (EPI-1783; 1000 watt) was used in the calibration. The standard lamp has the table of spectral irradiance which is certificated to be traceable to the standard of National Institute of Standard and Technology (NIST, USA). Through the calibration, the spectral responsivity of each Brewer spectrophotometer was determined.
In the United States there are several federal agency UV-B monitoring programs. These agencies, the United States Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the National Science Foundation (NSF) in a collaborative effort, have established a multi-agency sponsorship of a national calibration facility. The facility has been created to assure consistent calibrations between the various national UV monitoring networks.

The USDA is presently monitoring UV radiation with broad-band meters and is in the process of developing a high-end spectral instrument. The USDA is emphasizing monitoring in remote and agricultural areas which will be most useful for detecting background trends in UV radiation. The EPA is starting a monitoring network using Brewer spectral radiometers. The EPA is emphasizing high population areas which will be most useful for assessing health risks and in epidemiological studies. NSF has sustained the longest running US spectral UV monitoring effort. NSF has emphasized monitoring in the polar regions which will be useful in detecting changes in UV as a result of severe ozone depletion. NOAA has the longest running national effort to monitor UV radiation with the RB network.

In order to meet the calibration needs of the networks, Ambler Thompson from NIST along with John Deluysi and Patrick Disterhoft from NOAA are working to establish a highly precise national calibration facility. The facility is located on the campus of the University of Colorado-Boulder, East Campus in Building RL3. The facility is presently under design and development. Our plan calls for the facility to be fully operational in two years. Although as needs and goals change, as well as the technology and art of radiometry develop, we will continually upgrade the facility.

The ultimate goal of the facility is to provide stable calibration for the detection of trends on a 5-30 year basis. The facility will not replace NIST as a comprehensive testing facility, but will relieve NIST of the duties of routine calibration. The calibration facility will provide a limited number of NIST qualified tests both in the laboratory and in field conditions. These tests will include angular response measurements, linearity measurements, and spectral responsibility for broad-band meters. Also there will be irradiance calibrations for spectral instruments. A further role of the facility will be to host and oversee instrument intercomparisons. The facility will maintain monitoring standards where we presently have three Yankee Environmental Systems UVB-1 Pyranometers running as reference standards.

Following is a general description of how the calibration facility will operate. We will be using NIST traceable standard lamps, NIST procedures for controlling current to the lamps, and computer control of both the angular response measuring system and the spectral responsivity system. Data acquisition boards will be used to record test results and monitor equipment operations. This will minimize human error and monitor variable conditions during measurement sequences.
Located just north of Boulder is a fully maintained field monitoring site which is used for atmospheric testing. This will be important for field comparisons of various instruments, as well as for generating Langley calibrations. We also have access to a high altitude test site maintained by the NOAA Aeronomy Laboratory which is 25 miles from Boulder.

Current plans are to hold an instrument intercomparison at the permanent UV field calibration facility which is located just north of Boulder. The site is in a fairly remote area with very little immediate pollution sources. The site is such that the highest obstruction is less than five degrees above the horizon. Boulder is an excellent location for an instrument intercomparison because we have direct sunshine for at least part of the day almost every day of the year. A special permanent facility is presently under construction for this purpose. It will consist of concrete slabs for the spectral radiometers, a large wooden deck area to host a variety of broad-band and ancillary instruments, and a variety of atmospheric monitoring instruments. The facility is being constructed by the NIST technical services division and will be completed by September 1, 1994. Since this is our first time hosting a NIST/NOAA intercomparison we plan to start in a limited way with 6 to 7 instruments from the USDA, USEPA, NSF, and AES networks. We hope that if we have a second intercomparison we can open up the field to include instruments from international efforts. The emphasis at this intercomparison will be on spectral radiometers from the national programs. The focus will be to compare the field and laboratory response of the spectral radiometers under a variety of conditions. Broad-band meters from the national programs will also be present.

As mentioned at the beginning of the talk, the calibration facility is under design and development. We are currently finishing the design and construction of the automated angular response measurement system. We will be working closely with Ambler Thompson and Chris Cromer form NIST on the design and construction of our spectral responsivity system. As these aspects of the facility develop, other facets of calibration techniques and experimental setups will evolve until it is complete. It is hoped that the milestones that we have set for ourselves can be met and that the UV calibration facility will be fully operational within two years.
At the RIVM, a project has started at the beginning of 1989 to collect information on the current UV climatic conditions and changes. The goals of the monitoring project are 1) knowledge of the present biologically relevant UV climate and its dependence on atmospheric conditions 2) validation of atmospheric UV transfer models and 3) determination of long-term trends in the biologically relevant UV climate using measurements and model calculations.

For this purpose a UV spectrometer system is developed consisting of a highly accurate scanning double monochromator especially for the biologically relevant UV-B wavelength range and a multichannel detection system (diode array) for UV-A radiation measurements from 300 to 450 nm. Measurements of the solar spectrum are performed every 12 minutes from sunrise to sunset. Integrated global radiation is monitored continuously using a pyranometer. The operation of the combined system is fully automatic. The system is mounted in a light-tight and temperature stabilized mobile container. The system is described in more detail elsewhere [RE93].

The advantage of the combination of the two spectrometers is a reduction of the duration of a measurement cycle and the possibility to study systematic measurement errors by combining the output of both systems. In addition differences in global irradiance can be detected by a series of multichannel measurements during the scan of the shorter wavelengths. This provides a certain correlation between the irradiance measurements for different wavelengths.

Monitoring has started at the beginning of april 1993. With the monitoring system RIVM participates in an EC project entitled 'Calibration and maintenance of standards for spectral UV measurements'.

In the monitoring routine, the single spectra are summed to obtain daily, weekly, monthly and yearly totals of spectral UV. To determine the biologically relevant UV, the spectra are weighted with action spectra for various effects to calculate the effective UV dose. For the analysis of the 1993 data an action spectrum is used for skin cancer induction in the hairless mouse [SL87]. Since monitoring started in april 1993, the monthly totals of the first three months of 1993 are determined by model calculations and the experimentally determined relationship between the effective UV and the integrated radiation measured by a pyranometer [RE94]. This was also done for missing data in 1993 due to calibration and maintenance of the system and the participation in the international intercomparison in Germany, which was organized within an EC project.

Figure 1: Comparison of daily sums obtained by measurements and model calculations with the method described in the text.
The model used in the analysis [LE88] was validated by comparing it to the measurements showing good results for clear sky conditions. The pyranometer data are used to take into account the influence of clouds on the effective UV and to scale the clear sky model results. Figure 1 shows the comparison between the daily sums of effective UV; measured and modelled with the above described method. The accuracy to fill in gaps in the monitoring data with this method is 10 to 15%.

Figure 2: Monthly totals of effective UV-doses for 1993 obtained from measurements and model calculations. The open bars show the reduction by clouds and aerosols.

Figure 2 shows the monthly totals of effective UV-doses at ground level in Bilthoven for 1993. The open bars on top show the reduction in effective UV by clouds and aerosols.

Although measurements started in 1993, the method described above enabled us to determine and compare the yearly totals of effective UV for the years '91, '92, '93 in the Netherlands, when ozone amounts were reduced considerably.

Figure 3: Yearly totals for '91, '92 and '93 obtained by measurements and model calculations. The top bars show the reduction by clouds and aerosols.

Figure 3 shows that, applying the method, 1992 was estimated to have 14% higher doses than 1991 and 1993 11% higher doses. The main reason for the increase in 1992 and 1993 are differences in the ozone layer, explaining a 9% increase in 1992 and a 15% increase in 1993. Compared to 1991 the reduction by clouds was estimated to be smaller in 1992 and larger in 1993. Thus the real UV-burden was higher in 1992 than in 1993, although higher doses were expected in 1993 based on ozone measurements only. The accuracy of this comparison of yearly totals of effective UV based on measurements and model calculations is about 10%.


Ultraviolet radiation measurements in Finland

Solar ultraviolet irradiance has been measured in Finland since 1989 by the Finnish Meteorological Institute (FMI) at the Meteorological Observatory of Sodankylä (67.4°N, 26.6°E) and by the Finnish Centre for Radiation and Nuclear Safety (STUK) in Helsinki (60.2°N, 25.0°E). Three erythemally weighted broadband Solar Light Model 500 (denoted SL 500) radiometers have been continuously monitoring solar ultraviolet radiation since 1991 at the Meteorological Observatories of Sodankylä, Tikkakoski (62.4°N, 25.6°E) and Jokioinen (60.8°N, 23.5°E). In Sodankylä, solar UVB irradiance is measured with the Brewer Mk II spectroradiometer. In 1994, another Brewer spectroradiometer will be deployed in Jokioinen and the SL 500 radiometers will be replaced with the newer model SL 501 meters. Besides the measuring sites listed above, FMI will install two more SL 501 meters for continuous monitoring, one in Helsinki and another on the island of Utö off the southcoast of Finland. The solar measurements by STUK are not carried out on regular basis, but rather for calibration and testing purposes and for collecting solar UV data for research and UV climatology purposes (Jokela et al. 1993a and 1993b). All the broadband meters are tested by STUK with respect of spectral and cosine responses and temperature sensitivity before they are put into use (Leszczynski et al. 1993, Leszczynski 1994a).

Radiometric tests and calibrations

The measurement instrumentation for solar UV radiation measurements, testings and calibration of the STUK includes an Optronic 742 spectroradiometer together with the broadband SL 500 and SL 501 radiometers, 1000 W FEL and 200 W DXW quartz halogen standard lamps, an irradiance monochromator consisting of a 1000 W xenon lamp Oriel 6271 and a monochromator Oriel 77200 and a solar radiation simulating filtered metal halide lamp Philips HPA 400 W. The irradiance monochromator is utilized for the spectral response measurements and the solar simulator is used for the cosine response measurements of the broadband meters.

The Optronic 742 spectroradiometer is calibrated against a 1000 W FEL lamp the calibration of which is traceable to the National Institute of Standards and Technology (NIST) in the U.S. The spectroradiometer has been thoroughly characterized and the measurement results are numerically corrected with respect of the most significant sources of error, e.g. the non-ideal cosine response (± 5%), inaccuracy of the wavelength scale (± 3%) and the temperature sensitivity of the optics head (± 3%). By these corrections the overall uncertainty of ± 8% (2σ) at 310 nm in solar measurements has been achieved (Leszczynski et al. 1993, Leszczynski 1994a and 1994b). This is also the uncertainty of the erythemally effective dose rate values derived from the spectral solar measurements. In future, efforts to decrease the uncertainty associated with the lamp based calibration will be carried out by performing comparisons with a cryogenic absolute radiometer.

STUK calibrates the SL radiometers of FMI annually at the observatories, and an intercomparison between the Brewer and Optronic 742 spectroradiometers is carried out on yearly basis, too. The calibrations and intercomparisons are carried out in solar radiation on clear weather during the period from May to September.
The broadband radiometers of FMI are calibrated in solar radiation by comparing the dose rate values [MED/h] indicated by these instruments with the CIE weighted dose rate values derived from the spectral measurements by the Optronic 742 spectroradiometer. In our studies, a value of 200 J/m² is adopted for one MED. The uncertainties of the spectroradiometric solar calibrations of the temperature monitored SL 500 meters and temperature stabilized SL 501 meters are estimated to be ± 14% and ± 11%, respectively (Leszczynski et al. 1993).

References


There is an opportunity to link via the Internet data and information as it relates to the UV-B community. Keep in mind in this discussion that the tools used are free or in the public domain and can be utilized on different platforms that include personal computers, Macintosh and unix based machines. First we must start by providing an appreciation for the tools available. The primary tool is MOSAIC. MOSAIC was developed by the National Center for Supercomputing Applications at the University of Illinois. This client/server software provides a mouse driven interface along with a hypertext-hypermedia environment to the Internet. As a result one can now link data and information about the data and internet nodes seamlessly together. As with any other measurement program methodologies for documenting the quality control procedures and metadata need to be incorporated into the database. The software interface simply allows one to examine the quality control procedures, metadata or data in a non-linear fashion and assimilate this information to assess if there is enough information to answer a particular scientific issue.

The paradigm can be best explained by examining figure 4. This figure illustrates the non-linear fashion in which data and information may be explored. Notice the cross links between the data (anonymous ftp and subsetting the data) and the information (interactive time series and journal articles). Now any or all of that information can be explored by anyone that has this software on the Internet. The way that the Internet nodes can be linked are shown in figure 5. MOSAIC allows for someone to "connect" to another internet node in a variety of ways. In this instance there is an interactive organizational chart, interactive map and text. Each one of these methods allow for the connection to a node by simply "clicking" on a box in the case of the organizational chart, a star on the map or an individual line of text.

The next issue is examining the organization of information and data for a particular node. In this example we will use the National Climatic Data Center internet node and discuss the climatological datasets used to examine climate change over different spatial and temporal scales. Figure 6 is an example of the datasets used for research. Notice it is like reading a book with a table of contents. Each line of text is an active pointer to different areas on the server. This is an example of what as meant by examining the data and information in a non-linear fashion. One could immediately examine the database by clicking on one of the climatological datasets or go to the published articles about that dataset which are further cross linked to the interactive display. Thus one may start their query in one particular area but as questions arise may navigate to another area without starting at the beginning.

Now let's go through an example. Figure 7 is the anonymous ftp archive and each line of text is an active pointer. Figure 8 illustrates the descriptive information about a dataset. The top part shows the geographic distribution of stations for that particular dataset and can be magnified to examine more closely by simply clicking on it. Next each dataset is treated as a book with a table of contents. This area allows one to point to anonymous ftp to download the dataset, an interactive document.
that explains the quality control or peer reviewed results from
the dataset or further explore this dataset interactively.
Figure 9 shows the page that that would appear if one decided to
examine the dataset in space and time in an interactive fashion.
The options are to choose a contour or timeseries plot. Next,
one would choose a space domain. In this case the choices are
various geographical regions or a user defined region. Finally,
the time domain is chosen. These can be changed as long as they
are not "submitted" (at the bottom of the form). Once submitted
this information is sent back to the "server" and a program is
started to to generate a postscript file that is sent back to the
"client". Generally within 1 1/2 minutes the image will appear
on the screen.

At this juncture an investigator has had the opportunity to
download the entire dataset, read the documentation and/or
journal article pertaining to the research conducted with this
dataset and visually examine the the data via contour maps or
timeseries plots. It may be that only a subset of the data is
desired. Figure 10 illustrates the method in which one may
obtain a subset of a particular dataset in the time and space
domain. The top part is a listing of all datasets. Once chosen
the time and space domain are selected either by typing them in
or defining a box using the mouse inside the map of the world.
Once chosen the geographic distribution of the stations are shown
for the particular query and any metadata associated with the
selected stations can be examined (Figure 11). The final step
is the extraction of the data. Prior to extraction the
investigator may choose the format of the data (Figure 12).
Figure 13 shows how a file of data may look after extraction.

This paradigm used for climate data certainly could be
useful for UV-B data. Figure 14 is a prototype of a MOSAIC page
for an arbitrary UV-B database. At the top is the geographic
distribution of stations. These can be magnified and each
station could be an active link. This link would provide the
first level of information that would be station location,
elevation, type of instrument(s), period of record, contact and
ancillary measurements. Further down one could then choose a
particular station obtain all of the data via anonymous ftp, or
generate a time series of the data. The type of data to be
stored and the medium is shown in figure 15.

The technology to organize a global UV-B distributed
database is certainly available today. It only requires the
coordination with the WMO World Ozone and UV data center (WUVDC)
and the cooperation from each data center or national program
that wishes to participate.
Canada has operated the World Ozone Data Centre (WODC) for WMO for more than 30 years. During the last few years there has been a great proliferation of ultraviolet measurement programs and a consequent need for a world data centre. The profound effect of ozone on atmospheric ultraviolet radiation argues for the collocation of UV data with ozone data. With this background in June 1992, the Permanent Representative of Canada accepted the invitation from the President of the WMO to expand the scope of the WODC to include UV radiation data. The new centre is called the World Ozone and Ultraviolet Radiation Data Centre (WUDC); its two components are the WODC and the WUDC. The core activity of WUDC is that of a distribution centre for UV data, but there will also be measurement, modelling and applications research carried out in conjunction with the data management. These research activities should enhance the quality of the core WUDC operation and strengthen the connections to user communities.

A WMO/Environment Canada sponsored Expert meeting on UV data was held in Toronto in December 1992. The subjects covered included user requirements, data type (spectral and/or broad-band), co-data, format, submission protocol, relational structure, raw versus processed data. An important conclusion was that data submission must be accompanied by a sponsorship statement by a responsible involved scientist. The statement must include descriptions of the calibration hierarchy, the frequency of instrument calibration, instrument characterization, what quality control has been used and the scientist’s estimate of the accuracy. In addition the statement may include what special factors the potential user should be informed about and any restrictions and accreditation requirements pertaining to the use of the data. This information will always be made available with the data. The statement of data quality will be subject to review by WUDC and may, at any time, be changed by the submitting scientist. The ultimate scientific authority of WUDC should be an international group of experts meeting as an advisory committee, essentially the same as December 1992 group.

The development of the WUDC has been taking place against a general declining resource scenario in Environment Canada. This has resulted in a concentration of effort on the core WUDC activities. It is anticipated that a staff of three will be dedicated to the WUDC, supplemented by in-house scientists already involved in ozone and UV research. Research partnerships, for example in doing epidemiology studies, and cooperative arrangements with other agencies involved in UV data studies will be sought by Environment Canada.

The operation of WUDC was initiated with the request for data submission made to the Permanent Representatives to WMO in March 1994. The user interface, which is shared with WODC, is an ftp server on the Internet; the address and other information are shown in Figure 1. Detailed instructions for submission, formats and data availability are contained in text files on the server. Four years of spectral data from Toronto and four years of spectral data from four stations in Japan, a
total of about 40Mbytes, are now available for output.

The Brewer Data Management System (BDMS) is a relational database for raw data from Brewer spectrometers. It greatly facilitates the production of ozone and UV data from Canadian Brewer measurements. By virtue of the BDMS, WOUDC can accept and process raw Brewer data (c200Kbytes/day). This type of submission is encouraged but is not meant to supersede the processing of Brewer data either locally or by national agencies.

The development of the WUDEC will continue to be concentrated in the core activities involving data and information on ultraviolet radiation. The possibility of accepting raw data from instruments other than the Brewer is being studied. It is expected that a second meeting of a WMO Advisory Committee of Experts will be convened early in 1995.

Figure 1: Ozone and UV data transfer in Environment Canada and the World Ozone and Ultraviolet Radiation Data Centre (WOUDC), (boxed items are computers or spectrometers).
Publicly disseminated forecasts of UV radiation were started in Canada in June 1992. The development of forecasts or warnings about UV radiation was in the government agenda for the environment, called the Green Plan, but implementation was scheduled for 1993. It was brought forward in response to wide-spread and understandable public concern resulting from media reaction to the NASA announcement, in February 1992, of measurements of large concentrations of chlorine oxide in the arctic stratosphere. Another public information program addressing that concern, Ozone Watch, was put in place in March 1992. The purpose was to help the public put into perspective the many media statements about ozone depletion that occur today by releasing suitably condensed ozone measurements. Ozone Watch is issued weekly and comprises the averages of the last two weeks of measurements at the Canadian ozone stations compared with the pre-1980 averages, defined implicitly as "normal". Figure 1 is the usual form as distributed on weather television. The numbers are put on the wire service and published by some newspapers. Ozone Watch also compiles seasonal and annual data summaries shown in Figures 2&3. The scientific basis is described in reference 1.

The objectives of the Index program were formulated as to, increase public awareness of the variations in UV values, support health agency goals of educating the public on UV risks and to assist individuals in making healthy life-style choices. The vehicle is a credible forecast of maximum UV radiation to be broadcast either in the morning or the previous evening. The means of expressing the UV radiation was the subject of extensive discussions in the spring of 1992, within Environment Canada, with National Stakeholders especially in health agencies and in blind focus groups. Accepting the CIE erythema spectrum was a consensus that was reached fairly easily. (The change in radiometric amplification from 2, which had previously been accepted, to "about 1.2" was, inevitably, the source of some confusion.) The majority of stakeholders felt that minutes-to-burn have an advantage of being easy to understand but that the advantage is more than offset by the implicit and wrong messages that they can be accurately forecast and that it is acceptable to stay in the sun for 19 minutes when the forecast says 20 minutes to burn. It was considered that the SI unit of mW.m\(^2\) would entail numbers that were too large (eg 300) and the final choice was to normalize the radiation so that 10 would be a very high values for Canada (lowest latitude 42 N). Correspondingly, a typical sea-level tropical value would be 12. This is achieved by dividing the irradiance by 25 mW.m\(^2\). Also four categories were defined: extreme-greater than 9, high-between 7 and 9, moderate-between 4 and 7, low-less than 4. Although minutes-to-burn are not forecast, they are used in some cases to help explain index values or categories; e.g. "extreme ... average time to burn is less than 15 minutes".

The method used for the UV forecast in 1993 is described in Reference 2 and shown in Figure 4. The 1992 method was simpler but slightly less accurate. The 1993 method has been used on 1992 data in order to extend the range of validation. The first stage is to produce a regression forecast of column ozone from the output of the Canadian Meteorological Centre’s numerical prediction model. The parameters of the regression were determined from TOMS ozone data during 1988-1991 and corresponding data for pressure temperature and winds over the Northern Hemisphere. A correction field, based on real-time measurements at the 12 Canadian ozone stations, is added to the regression forecast. The correction field is adjusted, with a feed-back ratio of 0.6, by the discrepancies between yesterday’s forecast of today and today’s observed ozone values.
Modified inverse linear weighting is used to compute the correction field from the data at the 12 (or fewer) sites of observation. The method works primarily because the error of the regression forecast is not random. Figure 5 shows the autocorrelation of this error and that the 1-day lag value is approximately 0.6, which, by good fortune, is the same as the chosen value for the feedback. The results of the ozone forecast are shown in Figure 6. The key point is that in both years, the overall ozone rms error is about 11 DU for 18-hour forecasts and 13 DU for the, not used, 42-hour forecasts. These are significantly better than persistence and regression alone, especially in 1993.

The clear-sky noon UV irradiance is computed from the ozone with the algorithm given in Figure 7. It is derived from clear-sky data between 1989 and 1991 in Toronto, and fits the measured data with an rms error of about 8%. Since May 1993, the output has been modified according to cloud forecasts, essentially as follows: overcast with precipitation x0.4, overcast without precipitation x0.7, all other conditions x1.0. This is a cautious or safe, scheme, in the sense that it is more likely to overestimate than underestimate the UV. The output for Toronto in 1993 is shown in Figure 8, which also shows measurements and values that were calculated from pre-1980 data and from the 1978-1991 TOMS average.

The dissemination of the UV forecast is by wire service, graphics on a bulletin board, Environment Canada weather offices and thence to media and public, automatic telephone answering service and weather radio. An example of FPCN48, the twice-daily bulletin put on the Environment Canada Wide Area Net is shown in Figure 9; this is edited and used by most major newspapers in Canada. It includes the times when the UV is moderate or higher as well as the maximum index. A very effective presentation of the forecast is made by Hydro-média, shown in Figure 10. This is shown every half-hour on cable television in Canadian cities. The continuous graph is generated locally from the Environment Canada noon clear-sky forecast, and the histogram comes from local measurements made with Robertson-Berger Meters. This presentation combines a real forecast which shows how much stronger the radiation is near noon, with validating measurements. The purist may object to the upper-left panel which shows standard minutes to burn.

Through involvement in the program development, many of the Environment Canada meteorologists have become experts in communicating UV information to the public. A measure of the influence of the program and of their influence is indicated in the results of a national survey taken in December 1992. 73% of Canadians had then heard of the program and, of those, 59% said they had altered their lifestyle to some degree.


Figure 1. Ozone Watch, the normal weekly graphical product.

Figure 2. Ozone Watch, year-end monthly station summary.
Fig. 4 ENVIRONMENT CANADA FORECAST OF OZONE & UV-B

METHOD:
FORECAST OF TOMORROW'S OZONE =

REGRESSION FIELD + CORRECTION FIELD

<table>
<thead>
<tr>
<th>NWP FORECAST DATA</th>
<th>adjust each day with a feedback ratio of 0.6, using:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBSERVED ERRORS</td>
</tr>
<tr>
<td></td>
<td>YESTERDAY'S FORECAST OF TODAY'S OZONE</td>
</tr>
<tr>
<td></td>
<td>TODAY'S MEASUREMENTS BY (12) BREWERS</td>
</tr>
</tbody>
</table>

TIMING: The Numerical Weather Prediction Model of the Canadian Meteorological Centre runs twice daily at 0000Z and 1200Z. All other times shown below are Eastern Standard. (EST = CUT(2) - 5 hours)

00Z 12Z NWP runs (twice per day)

<table>
<thead>
<tr>
<th>day 1</th>
<th>day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>ozone</td>
<td></td>
</tr>
<tr>
<td>measurements</td>
<td></td>
</tr>
<tr>
<td>(1400h)</td>
<td></td>
</tr>
<tr>
<td>18h</td>
<td>(42h, under test)</td>
</tr>
</tbody>
</table>

tv, radio
c2100h\note: the calculation of ozone and UV fields is shown thus: ---a---
c1500h
FIG 6  OZONE FORECAST ERRORS IN DOBSON UNITS

<table>
<thead>
<tr>
<th>Model</th>
<th>Bias</th>
<th>Sigma</th>
<th>RMSE</th>
<th>Bias</th>
<th>Sigma</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>regression</td>
<td>7.7</td>
<td>13.7</td>
<td>15.7</td>
<td>17.4</td>
<td>15.2</td>
<td>23.0</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>0.1</td>
<td>10.7</td>
<td><strong>10.7</strong></td>
<td>-0.1</td>
<td>11.0</td>
<td><strong>11.0</strong></td>
</tr>
<tr>
<td>persistence</td>
<td>2.3</td>
<td>14.2</td>
<td>14.4</td>
<td>1.2</td>
<td>14.6</td>
<td>14.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Bias</th>
<th>Sigma</th>
<th>RMSE</th>
<th>Bias</th>
<th>Sigma</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>regression</td>
<td>7.8</td>
<td>13.7</td>
<td>15.7</td>
<td>17.1</td>
<td>15.9</td>
<td>23.3</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>-0.1</td>
<td>12.3</td>
<td><strong>12.3</strong></td>
<td>-0.3</td>
<td>13.2</td>
<td><strong>13.2</strong></td>
</tr>
<tr>
<td>persistence</td>
<td>1.5</td>
<td>18.0</td>
<td>18.0</td>
<td>1.2</td>
<td>19.9</td>
<td>19.9</td>
</tr>
</tbody>
</table>

FIG 7  CLEAR SKY IRRADIANCE ALGORITHM

\[
F = C_d \cdot \cos \Theta \cdot \exp[ a + b \mu x + c \mu + d(\mu x)^2 + e \mu^2 ]
\]

\[
F = \text{CIE erythemally weighted horizontal irradiance in mW.m}^{-2}
\]

\[
\Theta = \text{solar zenith distance}
\]

\[
\mu = \sec(\sin^{-1}((6371/6393)\sin \Theta)) \quad \text{air mass}
\]

\[
x = \text{column ozone amount (DU)}.
\]

\[
a = 7.178 \quad b = -3.842 \quad c = -0.731 \quad d = 1.574 \quad e = 0.1279
\]

\[
C_d = 1.000110 + .034221 \cos y + .001280 \sin y + .000719 \cos 2y + .000077 \sin 2y
\]

\[
= \text{Earth-sun distance correction}
\]

\[
y = 2 \pi ((\text{Julian date} - 1)/365)
\]

\[
\text{CANADIAN UV-INDEX} = F / 25
\]
Figure 5. Autocorrelation of errors in the regression forecast.

Serial Correlation of Daily Error Residual

![Graph showing serial correlation of daily error residuals with different symbols for various locations including Canada, Saturna, Alert, Halifax, Resolute Bay, Edmonton, Saskatoon, Churchill, Goose Bay, Toronto, Montreal, and Winnipeg.

Figure 8. Index measurements and forecasts at Toronto, 1993.

![Graph showing UV index over Julian Day 1993 with lines representing CMC 18-h Forecast, Brewer Observed, Calculated from TOMS Ozone 1978-91 Average, and Calculated from pre-1980 Ground-based Ozone Data.

Operational UV Forecasts, Brewer Measurements, and Climatological Calculations
Fig 9 TYPICAL EXAMPLE OF THE fpcn48 INTERNAL ENVIRONMENT CANADA UV BULLETIN

The forecast UV index generally indicates the UV intensity in full sunlight at midday. Ultraviolet intensities are lower under thick cloud cover and/or precipitation.

VARIABLE CLOUD DAYS ALLOW FULL ULTRAVIOLET EXPOSURE DURING THE SUNNY PERIODS.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>WEATHER</th>
<th>FCST UV INDEX</th>
<th>CATEGORY</th>
<th>TIMES UV ABOVE 4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGALUIT</td>
<td>SHOWERS</td>
<td><em>2</em> LOW DUE CLOUD/PRECIP</td>
<td>NIL</td>
<td></td>
</tr>
<tr>
<td>RESOLUTE</td>
<td>CLOUDY</td>
<td>2.0 LOW</td>
<td>NIL</td>
<td></td>
</tr>
<tr>
<td>INUVIK</td>
<td>MAINLY SUNNY</td>
<td>3.6 LOW</td>
<td>NIL</td>
<td></td>
</tr>
<tr>
<td>RANKIN INLET</td>
<td>CLOUDY PERIODS</td>
<td>3.9 LOW</td>
<td>NIL</td>
<td></td>
</tr>
<tr>
<td>YELLOWKNIFE</td>
<td>MAINLY SUNNY</td>
<td>4.3 MODERATE</td>
<td>1 TO 3</td>
<td></td>
</tr>
<tr>
<td>WHITEHORSE</td>
<td>SUNNY</td>
<td>5.0 MODERATE</td>
<td>12 TO 4</td>
<td></td>
</tr>
<tr>
<td>VANCOUVER</td>
<td>SUNNY PERIODS</td>
<td>5.8 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>VICTORIA</td>
<td>SUNNY PERIODS</td>
<td>5.8 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>KAMLOOPS</td>
<td>PARTLY CLOUDY</td>
<td>5.9 MODERATE</td>
<td>11 TO 3</td>
<td></td>
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<tr>
<td>NIKINING</td>
<td>SUNNY PERIODS</td>
<td>5.7 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>PORT HARDY</td>
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<td>5.8 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>SANDSPIT</td>
<td>CLEARING</td>
<td>5.9 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>PRINCE RUPERT</td>
<td>MAINLY SUNNY</td>
<td>5.7 MODERATE</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>KELLOMA</td>
<td>PARTLY CLOUDY</td>
<td>6.1 MODERATE</td>
<td>10 TO 3</td>
<td></td>
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<tr>
<td>PRINCE GEORGE</td>
<td>MAINLY CLOUDY</td>
<td>5.7 MODERATE</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>CRANBROOK</td>
<td>MAINLY CLOUDY</td>
<td>6.6 MODERATE</td>
<td>10 TO 3</td>
<td></td>
</tr>
<tr>
<td>CASTLEGAR</td>
<td>AFTERNOON CLOUD</td>
<td>6.5 MODERATE</td>
<td>10 TO 4</td>
<td></td>
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<tr>
<td>EDMONTON</td>
<td>MORNING CLOUD</td>
<td>5.8 MODERATE</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>CALGARY</td>
<td>SHOWERS</td>
<td><em>4</em> LOW DUE CLOUD/PRECIP</td>
<td>NIL</td>
<td></td>
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<tr>
<td>LETHBRIDGE</td>
<td>ISOLATED SHOWERS</td>
<td>6.7 MODERATE</td>
<td>11 TO 4</td>
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<td>GRANDE PRAIRIE</td>
<td>MORNING CLOUD</td>
<td>5.6 MODERATE</td>
<td>12 TO 4</td>
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<tr>
<td>SASKATOON</td>
<td>MAINLY CLOUDY</td>
<td>5.8 MODERATE</td>
<td>11 TO 4</td>
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<tr>
<td>REGINA</td>
<td>MAINLY CLOUDY</td>
<td>6.2 MODERATE</td>
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<tr>
<td>YORKTON</td>
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<td>10 TO 3</td>
<td></td>
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<tr>
<td>THOMPSON</td>
<td>VARIABLE CLOUD</td>
<td>4.9 MODERATE</td>
<td>12 TO 3</td>
<td></td>
</tr>
<tr>
<td>WINNIPEG</td>
<td>FEW SHOWERS</td>
<td>6.3 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>THUNDER BAY</td>
<td>THUNDER SHOWERS</td>
<td>6.7 MODERATE</td>
<td>11 TO 5</td>
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<tr>
<td>SUBURY</td>
<td>MAINLY SUNNY</td>
<td>6.9 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>WINDSOR</td>
<td>SUNNY</td>
<td>7.5 HIGH</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>TORONTO</td>
<td>SUNNY</td>
<td>7.4 HIGH</td>
<td>10 TO 4</td>
<td></td>
</tr>
<tr>
<td>BARRIE</td>
<td>SUNNY</td>
<td>7.3 HIGH</td>
<td>10 TO 4</td>
<td></td>
</tr>
<tr>
<td>LONDON</td>
<td>SUNNY</td>
<td>7.4 HIGH</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>OTTAWA</td>
<td>SUNNY</td>
<td>7.1 HIGH</td>
<td>10 TO 4</td>
<td></td>
</tr>
<tr>
<td>MONTREAL</td>
<td>SUNNY</td>
<td>7.0 HIGH</td>
<td>10 TO 4</td>
<td></td>
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<tr>
<td>SHERBROKE</td>
<td>MAINLY SUNNY</td>
<td>6.8 MODERATE</td>
<td>10 TO 4</td>
<td></td>
</tr>
<tr>
<td>QUEBEC</td>
<td>SUNNY</td>
<td>6.7 MODERATE</td>
<td>10 TO 3</td>
<td></td>
</tr>
<tr>
<td>ST-ADÉLE</td>
<td>MAINLY SUNNY</td>
<td>6.9 MODERATE</td>
<td>10 TO 4</td>
<td></td>
</tr>
<tr>
<td>FREDERICTON</td>
<td>SUNNY</td>
<td>6.6 MODERATE</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>SAINT JOHN NB</td>
<td>SUNNY</td>
<td>6.7 MODERATE</td>
<td>11 TO 4</td>
<td></td>
</tr>
<tr>
<td>HALIFAX</td>
<td>CLEARING</td>
<td>7.0 HIGH</td>
<td>10 TO 4</td>
<td></td>
</tr>
<tr>
<td>CHARLOTTETOWN</td>
<td>CLEARING</td>
<td>6.7 MODERATE</td>
<td>11 TO 4</td>
<td></td>
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<tr>
<td>ST. JOHN'S NF</td>
<td>SHOWERS</td>
<td><em>5</em> MODERATE DUE CLO/PRECIP</td>
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<td>GOOSE BAY</td>
<td>SUNNY</td>
<td>5.5 MODERATE</td>
<td>11 TO 3</td>
<td></td>
</tr>
</tbody>
</table>

* ESTIMATE OF UV UNDER CLOUD AND/OR PRECIPITATION * ALL TIMES MENTIONED IN THIS BULLETIN ARE IN LOCAL TIME.

SUN TIP: BEMARE OF REFLECTED LIGHT FROM SNOW, SAND, CONCRETE OR WATER. BE SMART - USE A SUNSCREEN.

UV CATEGORIES | UV INDEX RANGE | AVERAGE TIME TO BURN |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTREME</td>
<td>9.0 OR HIGHER</td>
<td>LESS THAN 15 MINUTES</td>
</tr>
<tr>
<td>HIGH</td>
<td>7.0 TO 8.9</td>
<td>AROUND 20 MINUTES</td>
</tr>
<tr>
<td>MODERATE</td>
<td>4.0 TO 6.9</td>
<td>AROUND 30 MINUTES</td>
</tr>
<tr>
<td>LOW</td>
<td>LESS THAN 4.0</td>
<td>ONE HOUR OR MORE</td>
</tr>
</tbody>
</table>

NOTE: AVERAGE TIME TO BURN ONLY ADDRESSES UV EFFECTS ON THE SKIN. UV ALSO AFFECTS THE EYES. THIS BULLETIN WILL NOT BE AMENDED. CONTACT YOUR LOCAL ENVIRONMENT CANADA WEATHER OFFICE TO OBTAIN THE MOST UP-TO-DATE WEATHER AND UV INDEX INFORMATION. (bullfp48)
Figure 10. Example of the Hétéromédia UV display of forecast and measurements for July 12, 1994
The directors of meteorological institutes in the Nordic Countries established a working group for ozone and UV research in 1988 (NOG). The first chairman of the NOG was prof. Seppo Huovila, and from 1992 on Dr. Petteri Taalas. Today instutes with ozone or UV measurements and research from Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Russia and Sweden form the basis of the NOG. Scientists from Germany, Netherlands, Poland and UK have also been participating in the NOG work. The NOG has established a climatological ozone database to follow the long-term behaviour of total ozone and the vertical distribution of ozone in the Northern Europe. The database is running in Unix workstation environment with Oracle relational database facilities. The NOG database offers its users also SAS statistical and graphical software package, real-time TOVS total ozone images and an access through Internet. For further information please contact: Juhani.Damski@fmi.fi.

The Nordic Council of Ministers has been funging the work of NOG through its environmental programmes. In October-November a NOG ozone and UV instrument intercomparison was organized at Tenerife, Izana. Operational and laboratory spectroradiometers and broadband UVB radiometers from Denmark, Finland, Greece, Norway, Spain and Sweden were compared in laboratory and outdoor conditions. The intercomparison was also the first step towards unified calibration system in the Nordic Countries. The NOG has also decided to establish a North-European database for UV records. The software development for a relational database has already been started. The database, which allows mapping of UV radiation, will be operational in 1995.

The NOG co-operation includes also UV modelling. The models have been developed at the Universities of Fairbanks and Tromso, the Norwegian Institute for Air Research and the Finnish Meteorological Institute. Models are used to study the interactions between ozone, aerosols, surface properties and cloudiness. By using long ozone records and ozone scenarios one can construct estimates of UVB changes so far and in the future. One of the most important aspects of the Arctic UV research are the influence of the snow/ice-covered surfaces on UVB irradiance on different geometrical surfaces and the future changes of the polar vortex dynamics related to atmospheric CO₂ increases.
The UV Index Programme in New Zealand

R. McKenzie

Burn Times

A brief history of "burn time" information in NZ.

In the 1987 Dr Reid Basher of the NZ Met Service (now with NIWA) implemented a method to provide estimates of clear-sky "burn times" in New Zealand. The information was provided (at a cost) to Television NZ, who required these burn times as forecasts for the following day on the weather forecast at 6:30 pm.

The burn times are based on the following:

The spectral distribution of UV radiation is calculated using the Green model.

Inputs to the model include the day-of-year, location, time, and an estimate of the ozone column.

The spectrum is multiplied by an erythemal weighting function to give the erythemally weighted UV.

This model was calibrated using the working definition that at the equator (sza=0, 260 DU ozone) the calculated irradiance is equivalent to a burn time of 12 minutes (Berger and Urbach, 1982)

Initially, the ozone column was from climatological zonal monthly means. The method is summarized by Basher (1987).

Around 1991, Dr R. G. (Don) Grainger at NZ Met Service modified the algorithm to use estimates of ozone from the TOVS instrument. This was based on the algorithm developed by A. Neuendorffer at NOAA/NESDIS, but with modifications to cope with observation-angle dependent errors. The ozone retrievals were ground-truthed against Dobson observations at Lauder. Grainger left NZ about the same time as an organizational change in the Met Service (mid 1992).

Burn times are also derived from a network of broad band UV monitors distributed at population centres in New Zealand (G. Smith, Industrial Research Ltd), and are made available to the public by means of Telecom pagers which are located at local radio stations.

The burn times derived from UV measurements at Lauder are significantly shorter than those currently being broadcast on TV. We are still investigating the reason for this discrepancy. There are several possibilities:

1. The ozone fields being used are incorrect.

2. There are differences in the definition of burn time.

   We use the criterion: 1 MED = 21 mj cm-2 of energy erythemally weighted according to McKinlay and Diffey, 1987. This weighting function is normalized to 1 at 297 nm. This definition seems to be the same as that used by Solar Light Co for the biometers. With this definition, burn times less than 12 mins can occur even at mid latitudes (eg at sza=25, ozone=260 DU).
The TV burn time algorithm is equivalent to: 1 MED = 20.7 mJ cm^-2, with a different approximation to the erythema action spectrum, which is normalized to 1 at 300 nm. (Note that at 300 nm, McKinlay and Diffey's action spectrum has reduced to 0.65).

3. There are errors in the model calculations

   The measurements we make at Lauder are accurate to within 10%, and self-consistent between several instruments. The discrepancies in the models can be from:
   - errors in the approximation to the extra-terrestrial spectrum used as an input
   - errors in ozone cross sections used
   - inadequate treatment of scattering
   - differences in weighting function used (shape and normalization point).

We hope to cross calibrate our UV measurements against the calculated burn times to resolve these differences.

An internationally-agreed definition of an MED, in terms of a energy weighted by a well-defined weighting function, is urgently required.

References.


R. L. McKenzie
18 Feb 1994
File: Burn.doc
UV-index in Sweden 1993-1994
Ulf Wester (SSI), Weine Josefsson (SMHI) and Johan Nissen (SSI)

As a service to news media and the public in Sweden, the Swedish Radiation Protection Institute (SSI) and the Swedish Meteorological and Hydrological Institute (SMHI) in the summer of 1993 introduced daily forecasts of the intensity of the sun's ultraviolet radiation. The forecasts have continued 1994 and are intended to help media and the public judge solar UV strength.

Too much solar UV is harmful to life on earth. In man UV-rays can cause acute biological damage to an unprotected eye or skin - photokeratitis or erythema. Years of frequent UV-exposure increase skin cancer risks. Excessive sun exposure and repeated sunburns - especially in childhood - is a causative factor for malignant melanoma of the skin, annually increasing by 5-6 percent.

1. Reasons to introduce UV-index forecasts
Awareness of risks of sun overexposure and of the depletion of the protective stratospheric ozonelayer, has caused newmedia and the public in Sweden to ask for simple and up-to-date information on solar UV-radiation and its practical consequences. In late winter and spring of 1993 SSI's and SMHI's burden of information to news media and the public multiplied due to reported low ozone values in combination with a large number of sunny days. That was a contributing factor that caused us to initiate a quick project to get a pedagogical and to the layman simple and easily understood UV-forecast service in Sweden - UVindex - that also could serve as a tool to prevent UV-induced adverse health effects. In order to get the UV-forecast service ready as quickly as possible we chose techniques and methods for UV prognoses that we already had available. Ten years earlier SMHI as a result of a SSI funded research project had developed methods to calculate "ACGIH-weighted" UVB-irradiance and exposure at ground level with regard to measured ozone and weather parameters [Josefsson 1986]. That calculation model was combined with prognoses of ozone and weather parameters.

2. Choice of index presentation
For pedagogical reasons, we chose intensity based UV-forecasts rather than prognoses of "time in minutes to receive an erythemal dose (MED)" or "minutes to burn". We thought prognoses of "MED-minutes" would be perceived as unjustified precise because of the relatively wide span of "suntolerance" of human skin and would be of little pedagogical comparison value at different latitudes on earth or at different seasons - or may be felt irrelevant among people from or at southern latitudes. UV-forecasts with an "index presentation" with its maximum related to equatorial areas had been introduced in Canada 1992. The Swedish UVindex is designed with a 0-100 scale. Although it is an absolute and open-ended scale, it may be perceived by the public as "percentage of UV at the equator".

3. Physical basis of UV-index
In summer 1993 the Swedish UV-index was a forecast of direct and diffuse UV-irradiance on a horizontal surface at the time of the day when the UV was to be at maximum intensity - usually around noon. Forecasted cloud cover was taken into account. A "winter version" of the Swedish UV-index was introduced March 31 and during spring of 1994 and was based on weekly forecasts of direct and diffuse UV-irradiance (from a clear sky at noon) on a surface oriented to receive maximum exposure. During winter and early spring at Nordic latitudes with low sun and snowcovered ground that means an almost vertical south-oriented surface that towards summer becomes more and more horizontally oriented. Forecasts were made for seven regions in Sweden and three regions abroad (the Alps, the Mediterranean and the Canary Islands). Since
June 1 there are daily forecasts for eleven regions in Sweden which take cloudiness and weather into account and are calculated for a horizontal surface and a time of the day with maximum intensity. Forecasts for the Mediterranean and the Canary Islands assume clear sky and normal ozone of the season. The forecasts are distributed to subscribing media via a news agency (TT). Data affecting UV-index forecasts are: latitude, season, cloudiness, ground reflection, and the total column of ozone measured at Norrköping 58.6°N. The measured ozone data are used by SMHI for a prognosis of next day's ozone using a meteorological forecast of stratospheric temperatures (derived from HIRLAM-data = High Resolution Limited Area Model).

4. Action spectrum
The choice of action spectrum may not be critical but any reported large ozone changes have to show up in the forecasted UV-index - or the public will distrust the forecasts. The UV-prognoses in Sweden are forecasts of UVB weighted with the ACGIH and IRPA/INIRC's -action spectrum for UV-hazard analysis (expressed in Swedish legislation as "Recommendations from the Swedish Radiation Protection Institute concerning UV-radiation - SSI FS 1990:1"). The ACGIH and IRPA/INIRC action spectrum is relevant for evaluating both skin and eye hazards - the latter is of particular interest for UV-forecasts in winter and spring during the skiing season. In the spectral region 304-310 nm where the weighted solar irradiance peaks, the ACGIH & IRPA/INIRC action spectrum has a steeper slope than the CIE skin erythema action spectrum and consequently a higher radiation amplification factor with respect to ozone changes. However, weighted irradiance calculated with one action spectrum can for a given UV-source (solar spectral distribution) be transformed into weighted irradiance of another action spectrum with accuracy enough for the purpose of a UV-index scale. With the UV-index concept any moderate change of action spectrum will probably not affect forecasted UV-index values in a way noticeable to the public. This may be relevant if new action spectra appear in the future.

5. Normalization
The UV-index in Sweden is normalized to a value = 100 for 82 mW/m² IRPA/INIRC weighted solar UVB-irradiance estimated from mathematical model calculations to be typical of clear sky conditions with a zenith sun at equatorial areas. If UVA-influence is included in the weighting, the UV-index value 100 can be set to equate 100 mW/m² at the equator - and the UV-index scale becomes a scale of weighted irradiance.

6. MED-time information
Sensitivity to the sun varies considerably among different individuals and skin types and therefore forecasts or recommendations of sunexposure time do not have general or universal relevance - but may be essential locally for individuals with high skin sensitivity. In order to make the Swedish UV-index useful for persons with the highest types of skin sensitivity, UV-index values can be transformed to estimates of safe sun exposure time. Recommendations are available in leaflet information that is distributed to media with the UV-index. Detailed sunexposure time information for individuals with high skin sensitivity is available with a "sundisk" that can be used to "dial" safe sun time.

7. UV-forecasts and standardization
UV-forecast data should be simple, easy to understand, universally acceptable for the public, and be relevant for both eyes and skin. Intensity based UV-index forecasts for tilted surfaces meet that requirement and may also be used for skin type information locally or individually.


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THE UK METEOROLOGICAL OFFICE UV FORECASTING METHOD by John Austin.

The primary concern of the forecasting system is to address the problem of increasing malignant melanoma due to the increase in travel to more southerly locations. In this respect although ozone change is of concern it is considered small relative to the effects of social change for northern hemisphere mid-latitudes.

In this talk I shall first present a total ozone climatology based on TOMS data for the years 1981-1991. This shows the well known high ozone in northern hemisphere high latitude spring and the Antarctic ozone hole. From this clear sky UV levels have been calculated for noon based on the empirical formula of AES Canada. The figure shows the high tropical values exceeding 11 during some parts of the year decreasing to zero in the polar night. Further analysis of these theoretical UV index values shows a wide spread of values due to observed variations in total ozone during the 11 year period. For example the UV index occasionally exceeds 9 but at other times is lower than 6 in midsummer at 45 deg. N. Similar behaviour occurs in the southern hemisphere mid-latitudes except that the effects of the Antarctic ozone hole appear as an accentuated maximum UV level occurring several weeks before solstice as far equatorwards as 55 deg. S.

To forecast ozone simple linear regression model is applied between observed ozone from TOVS observations and temperatures and geopotentials from the Met. Office numerical weather prediction model. Ozone forecasts over Europe and the East Atlantic for a single day, chosen at random, earlier this summer show general agreement with TOVS ozone, although a general increase in the errors towards higher latitudes are seen. The calculated UV index shows the expected strong dependence on latitude with slightly enhanced values corresponding to the ozone trough situated over continental Europe. While a detailed forecast of this sort is sent to our local forecasters the information released to the public is converted into a "time to burn", based on skin type 1 for Fair skin and skin type 2/3 for "average" UK skin.

In order to verify the results of the forecast method there are four questions to be addressed. 1. Is the regressed ozone accurate? Comparisons between the Camborne (50 deg. N) Dobson instrument the TOVS ozone and the regressed ozone for the month of September 1993 showed good agreement at a time when the ozone is changing to the winter circulation leading to enhanced ozone columns. The mean and RMS difference between the regressed ozone and the Camborne measurement were 3.8% and 7.6% respectively. A similar level of agreement between TOVS observations and regressed ozone occurred providing confidence in the statistical model. 2. If the ozone is accurate, is the UV index accurate? Comparisons between spectrally resolved data at Reading (51 deg. N) for sample clear skies in June of 1992, 1993 and 1994 provide generally good results in comparison with the theoretical UV index. Typical RMS errors are about 8%. However, for one day during August 1993, UV levels were significantly (40%) higher than expectation, possibly due to edge effects from cumulus clouds present on that day. 3. Is the ozone forecast accurate? Comparisons between TOVS, climatology and the forecast values are presented for the summer 1994 interpolated to the position of Chilton (51.5 deg. N). During April, the forecast values are an
improvement on climatology but still significantly in error with mean and RMS differences of about 7 and 10% respectively. During May and June the RMS difference improved to just 5-6%. The day to day variation of the ozone column was very well represented and the forecast was a substantial improvement on climatology.

4. Is the UV forecast accurate? Comparisons with NRPB broad band measurements produced mixed results and are still being analysed. While good agreement was obtained during a sunny period in late June the poor weather during the early part of the summer makes direct comparisons difficult. However it does appear that the forecast UV levels are too high. This appears to contradict the apparent good forecast of ozone values during May and further analysis is required to resolve this issue.

In summary it would appear that the results have established the general accuracy of the forecasting procedures especially during our rare sunny summer days. Future work may investigate the role of cloud aerosol and reflections from the sea surface depending on feedback from the public.

Many scientists have contributed to the work including B. Barwell, S.J. cox, P.A. Highes, J.R. Knight, G. Ross, P. Sinclair (all Met. Office), A.R. Webb (Reading University) and C. Driscoll (NRPB). We are especially indebted to AES, Canada, for their helpful advice in the development of our forecasting service.
NOAA - EPA Program to Provide Experimental Forecast

Guidance of an Index of UV Radiation at the Ground

EXPERIMENTAL ULTRAVIOLET INDEX
(UVI)

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June 22, 1994

The basic methodology developed for production of the daily index follows the outline listed below:

1. At about 1000 am Eastern Standard Time (EST), a global analysis of total column ozone based on the SBUV/2 data for the previous day (t0-1) as measured in Greenwich time (e.g. 00-24 UTC) is produced. As the SBUV/2 measures ozone only in the sunlit portion of the earth, it requires 24 hours of data to fill out the hemisphere for a complete map. The analysis is accomplished on the standard NMC 65x65 rectangular grid on a polar stereographic projection. This 65x65 grid is interpolated to a 10x10 latitude/longitude array for compatibility with the NMC global model fields.

2. The model forecast fields for 0000 and 1200 UTC are available such that the ozone forecast for tomorrow (t0+1) and the associated ultraviolet index will, generally, be available by about 1300 EST.

3. As the SBUV/2 measures ozone on a sun-synchronous system, about 1400 local time, it is not truly applicable to associate the ozone field with any one synoptic field for the hemisphere. However, in previous work (e.g., Miller et al. 1979) we have demonstrated the usefulness of comparing the SBUV ozone maps with the standard-time meteorological fields. Therefore, as the SBUV/2 data are compiled over a 24 hour UTC day, we have selected the 1200 UTC analyses for the initialization process.

4. Physically, our method of ozone forecast is based on the paradigm that the ozone map for tomorrow is equal to yesterday's map plus a delta that is related to the changes in the meteorological fields. Statistically, the method utilizes multiple regression of the measured ozone changes over each hemisphere for the previous two days (t0 -1 minus t0-2) with changes in the 500 mb height, the 100 mb height, and the 50 mb temperature. The calculated coefficients are then applied to the forecast model parameter changes (t0+1 minus t0-1) and added to the initial ozone values at t0-1.
As a test of the methodology, we have examined the results of the ozone forecast system for the specific period of December 25, 1993 - February 5, 1994. The daily Root Mean Square (RMS) error over the Northern Hemisphere, Southern Hemisphere (Summer) and over the continental United States are generally less than about 6% and in the vast majority of cases, the forecast value RMS results are lower than those of persistence.

5. To ensure continuity of index availability, we have developed a decision tree within the computer code to account for days with no SBUV/2 observations, missing meteorological analyses, or missing forecasts. Basically, this methodology utilizes persistence of the ozone-meteorological relationship and extends the forecast from the closest available time with an upper limitation of four days. Tests have indicated that the forecasts provide considerable skill over persistence up to four days. In the event of SBUV/2 instrument failure, the plan is to migrate to the TOVS ozone data. We should add that the current plan is for the SBUV/2 instrument to fly on the afternoon satellites which results in one designated "operational" instrument with several possible backups. As part of the implementation, we continually compare daily results from both SBUV/2 and TOVS. Also, we note that the TOVS is an infrared sounder on-board both the morning and afternoon satellite series. As such, there are several backup instruments available to the current instrument of choice.

6. With the ozone forecast accomplished, we compute the ultraviolet radiation reaching the earth's surface for solar noon utilizing a radiation code provided by Professor John Frederick of the University of Chicago. This radiation code (Frederick and Lubin 1988) calculates the ultraviolet irradiance in 1 nm intervals from 290-330 nm and in 2 nm intervals from 330-400 nm. The resultant irradiances are then integrated over the 290-400 nm domain with a weighting function (McKinlay-Diffey 1987) applied that matches the general performance characteristics of the surface-based sensors. The resultant forecasts are for the clear sky condition. Within the radiation code a generalized term for aerosol contamination is included with the optical thickness set at 0.2 (unitless). Surface albedo is set at 5%. This integrated irradiance value, in mWatts/m², is then integrated over the one hour time period centered on solar noon to provide an ultraviolet dose. Examination of the integration procedure has indicated that multiplying the solar noon irradiance values by 3600 seconds provides a solar noon 1-hour dose that is accurate to well within 2%. This one-hour dose centered about solar noon is the precursor for the Experimental Ultraviolet Index. As the values calculated in this manner are of the order of 106, we simply scale the resultant numbers by a factor of 10-5 to produce the Index. The units of the Experimental Index, thus, are 102 joules/m² and have the range from zero to about 14.
7. Cloudiness is accounted for by incorporating the NWS operational Model Output Statistics (MOS) of the probability of opaque clouds within 4 categories; clear, scattered, broken, and overcast (Erickson 1988). Utilizing the available broad-band meter database (Berger 1976; Frederick et al. 1993) available from the NOAA Air Resources Laboratory for 1992, we have developed a simple multiple-regression method to determine the appropriate scaling factor for the 30-hour forecast cloud probabilities.

For the cloud regressions, we utilize the ratio of the broad-band observations to the clear-sky forecast as the basic dependent variable as this removes the seasonal and spatial variations between sites. In addition to the cloud forecasts, we also examined the effect of including the forecast temperature dew point and dew point depression to possibly account for local haze, but the statistics for these parameters were not significant. For the 1320 observations the correlation coefficient was 0.66 resulting in an explained variance of about 44%. Note also that for the simplistic case of 100% probable forecast within each category our results indicate the following coefficients; clear: 0.992, scattered: 0.896, broken: 0.726, and overcast: 0.316.

The experimental forecast index is computed for an initial set of 58 cities.

REFERENCES


SUNCAST™ Ultraviolet Radiation Prediction Service
Overview and Index Comparison

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SunCast Overview
Orbital Sciences Corporation (OSC) in cooperation with WSI Corporation has developed and is now operating the SunCast Ultraviolet Radiation Prediction Service. The SunCast service currently issues one-day UV-B level forecasts for 527 cities within the United States. Each daily forecast includes three time periods, solar noon, three hours before solar noon and three hours after solar noon. The estimated UV-B level for each time period is given for four sky conditions: clear, scattered, broken and overcast.

In addition to the actual forecasts, a historical average UV-B level is given for solar noon values using climatological ozone data. This climatological ozone data is an average of satellite-based measurements taken from 1978 through 1990 by the Nimbus-7 spacecraft using the Total Ozone Mapping Spectrometer (TOMS).

SunCast uses a radiative transfer model to determine the surface UV-B level. Inputs to the radiative transfer model include forecasted ozone, cloud condition, latitude, longitude, elevation, surface reflectivity, time-of-day, day-of-year and a ground-based validation factor. The ozone forecast is calculated by first determining the correlation of ozone measurements from the Meteor-3 TOMS instrument with general circulation model data and then applying this correlation to general circulation model forecasts for the time period of interest. The SunCast UV-B level is directly proportional to the erythermal dose rate using the McKinlay-Diffey erythermal action spectrum.

North American UV-B Index Comparison
A comparison of the SunCast scale with the United States National Weather Service and the Canadian scales is given below.

The SunCast scale is directly proportional to erythermal dose rate and uses two reference points, zero and 100. Zero represents the absence of ultraviolet radiation and 100 represents the maximum ultraviolet radiation experienced at sea level on the face of the Earth. This maximum value occurs at the Equator when the Sun is directly overhead (the 21st of September and the 21st of March). The SunCast scale is "open ended" so values greater than 100 are possible. Greater than 100 readings will be observed in tropical regions at elevations above sea level. This scale yields clear-sky UV index values that range from 50 to approximately 80 in the United States during the summer season.
The NWS scale is also directly proportional to erythermal dose rate. The scale was derived by multiplying the erythermal dose rate by 3,600 seconds to reflect a one hour dose at a constant dose rate. The final numbers are derived by dividing by 100 to make the numbers more user-friendly. This scale yields clear-sky UV values that range from approximately 6 to 10 in the United States during the summer season.

The Canadian scale is also directly proportional to erythermal dose rate. The Canadian Scale is designed to produce clear-sky UV values that reach a maximum level of approximately 10 in Canada.

Although the rationale that drove the design of the scales under discussion is quite different, the actual differences between the scales in terms of how they are derived is quite small, as illustrated below:

\[
\text{SunCast UV Index} = \text{Erythermal Dose Rate (W/m}^2\text{)} \times 312
\]

\[
\text{United States NWS UV Index} = \text{Erythermal Dose Rate (W/m}^2\text{)} \times 36
\]

\[
\text{Canadian UV Index} = \text{Erythermal Dose Rate (W/m}^2\text{)} \times 40
\]
UV-MONITORING IN GERMANY AND PUBLIC EDUCATION

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Since 1993, the Federal Office for Radiation Protection BfS together with the Federal Environmental Office UBA has developed a monitoring network for the continuous spectral measurement of solar ultraviolet radiation. The network encloses 4 stations (table 1).

Table 1: STATIONS OF THE BfS/UBA UVR MONITORING NETWORK

<table>
<thead>
<tr>
<th>Station</th>
<th>Distance</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neuherberg</td>
<td>493 m</td>
<td>48° 13' N</td>
<td>11° 35' E</td>
</tr>
<tr>
<td>Offenbach</td>
<td>110 m</td>
<td>50° 06' N</td>
<td>8° 45' E</td>
</tr>
<tr>
<td>Schauinsland</td>
<td>1205 m</td>
<td>47° 55' N</td>
<td>7° 55' E</td>
</tr>
<tr>
<td>Zingst</td>
<td>1 m</td>
<td>54° 38' N</td>
<td>12° 70' E</td>
</tr>
</tbody>
</table>

This stations should represent the main geographical situations in Germany. In contrast to some other monitoring systems in our network all spectroradiometers and all the electronic measurement and control devices are operated inside the laboratories under stable conditions. UVR is coupled to the radiometer via a 4 m fibre optic from the roof mounted Teflon diffuser. The stations are calibrated routinely every 2 months. A wavelength check by scanning some Fraunhofer lines with high (0.075 nm) resolution is included in the measurements every 6 minutes. The network is currently running in a quasi routine mode. Obviously there is a continuous effort to increase the technical and operational performance of the system. Some technical parameters of the modified Bentham DM 150 double grating spectroradiometer used and the mode of operation is shown in table 2, a more comprehensive description of the network characteristics can be found elsewhere (Steinmetz M. UV monitoring in Germany, Bundesamt für Strahlenschutz, Salzgitter, Germany, 1993).

Table 2: CHARACTERISTICS OF THE UVR MONITORING SYSTEM

<table>
<thead>
<tr>
<th>WAVELENGTH</th>
<th>1 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>bandwidth</td>
<td></td>
</tr>
<tr>
<td>linearity</td>
<td>&lt; 0.1 nm</td>
</tr>
<tr>
<td>repeatability</td>
<td>0.075 nm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IRRADIATION</th>
<th>10^-7 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>straylight</td>
<td></td>
</tr>
<tr>
<td>dark current</td>
<td>&lt; 10^-4 nm</td>
</tr>
<tr>
<td>sensitivity</td>
<td>10^4 W/m^2/nm</td>
</tr>
<tr>
<td>accuracy</td>
<td>≈ 10 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>every 6 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>scan</td>
<td></td>
</tr>
<tr>
<td>start</td>
<td>≈ 30 min after sunrise</td>
</tr>
<tr>
<td>stop</td>
<td>≈ 30 min before sunset</td>
</tr>
<tr>
<td>scan time</td>
<td>60 sec</td>
</tr>
<tr>
<td>scan band</td>
<td>290 - 450 nm</td>
</tr>
<tr>
<td>scan step</td>
<td>0.5 nm (290 - 320 nm)</td>
</tr>
<tr>
<td></td>
<td>5 nm (320 - 450 nm)</td>
</tr>
</tbody>
</table>
The main objectives for that network arise from the viewpoint of radiation and environmental protection. Those include the monitoring of solar UVR to provide data for research, radiation protection purposes and policy. The aims are to examine longtime trends in biologically effective UV irradiance at ground level and to assess health hazards from solar exposure with regard to different groups and different habits of people from the general public. Furthermore the data could be used in public information and education if provided in an appropriate format.

Independent from UV monitoring, there is an urgent need for an offensive against the evident increasing incidence of skin cancer. One possibility to decrease mortality and morbidity from skin cancers is public education. Therefore it is essential for information about health hazards from excessive exposure to UVR to be made available to the general public. Such information should be based on sound medical and scientific data and should be presented in a positive manner; thus enabling people to enjoy the sun safely. Changes in people’s behaviour towards sun exposure and the current societal view associating a tan with good health are unlikely to come about in the short term and therefore a long term strategy may be required.

The aims should be that people are aware of the need to avoid excessive UVR exposure and are cognisant of the ways in which they can achieve this. The single most important objective is the avoidance of sunburning exposure. Emphasis should be placed on the protection provided by clothing, sun glasses and the use of sun blocks and sunscreens. It is important to target UVR health information at specific groups of people most at risk. In this respect children are particularly important. It should also be emphasised that the risk of adverse health effects from UVR exposure is not limited to vacation exposure abroad but can also result from exposure in one’s own country. Solar UVR monitoring data can be used in public information and a UV index communicated to the media in a straightforward manner would be an excellent tool for educating people. However, it is important that solar indexes used by different agencies are compatible and should not cause confusion to the public. Therefore a UV index should be internationally harmonized.

From the viewpoint of radiation protection a solar index should be a measure for the health risk associated with UVR exposure. It should therefore reflect the radiant exposure (dose). It should be based on the sunburning and/or carcinogenic potential. It should match sun protection factors, for example those for sunscreens or for fabrics. For public use the index scale should be arbitrary and displaying only integer values. Moreover the scale should be open ended to prevent undue public alarm from out of range values. For some scientific purposes there could be the wish to use UV indexes as a rough dosimetric estimate. Therefore the should be easily convertible to physical units.

The BfS is currently using a sunburn index (SBI). It is based on measurements of UVR and reflects the biologically effective dose per day accumulated during 6 hours centred around noon time. The standard biological effectiveness curve from CIE is used. The scale is generated by dividing the daily effective dose by a minimal effective dose which reflects sensitive skin (set to 250 J/m²). The scale only displays integer values and is not limited on the upper end. As this scale directly reflects measured biologically effective exposure, it could also be used as an approximative dose in some scientific investigations. The Federal Office for Radiation Protection strongly supports the development of an internationally harmonized UV index. It would appreciate guidelines on that issue from international bodies like the World Meteorological Organization, the World Health Organization, the United Nations Environmental Programme and the International Commission on Non-Ionizing Radiation Protection.
The Treatment of Clouds in Estimates of Ground-Level Solar Ultraviolet Irradiance

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Three major processes are involved in the transmission of solar ultraviolet radiation to the earth's surface. These are absorption by ozone, multiple Rayleigh scattering, and scattering by clouds and other particulates. Although absorption by ozone is extremely important, it is also well-understood and easy to include in numerical models of radiative transfer. The same is true of Rayleigh scattering. The treatment of clouds, however, poses a number of formidable problems. In principle one can compute the optical thickness and phase function for scattering by a cloud from knowledge of its physical properties (ice or water content, particle size distributions). In practice the geometrical complexity and temporal variability displayed by cloudy skies pose major problems to rigorous numerical modeling.

For purposes of producing ultraviolet indices on an operational basis it is not feasible to attempt a rigorous theoretical treatment of radiative transfer through clouds. Rather, a statistical approach that relates the attenuation provided by a cloudy sky to standard meteorological parameters appears more practical. The central question of this effort is: To what extent can one characterize the attenuation of ultraviolet irradiance using three routinely available quantities, being fractional cloud cover (f), visibility (V), and cloud ceiling altitude (C)?

We describe the attenuation of sunlight under a cloudy or hazy sky by the "normalized irradiance", defined as \( T(uv) = \frac{E(\text{measured})}{E(\text{clear})} \). Here \( E(\text{measured}) \) is the noontime irradiance measured by an Eppley ultraviolet sensor and \( E(\text{clear}) \) is the irradiance that would have existed under a clear sky with unlimited visibility. Use of a ratio removes the strong dependence on solar elevation. We then develop regression models to relate \( T(uv) \) to various combinations of \( f \), \( V \), and \( C \). The data sets were obtained in Chicago, IL over the period April through October 1993.

A statistically significant negative correlation exists between \( T(uv) \) and \( f \) in the aggregate, although on any given day fractional cloud cover alone is insufficient to estimate the ground-level irradiance. The irradiance may equal its clear-sky value for any value of fractional cloud cover. This simply

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reflects the fact that fractional cloud cover does not contain explicit information on the optical thickness of the clouds. A thick stratus deck that covers the entire sky will backscatter most of the incident sunlight, while a thin layer of cirrus may have little influence on the surface irradiance. However, both of these situations will be described by \( f = 1 \). A regression based on fractional cloudiness alone explains 39% of the variance in the normalized irradiances.

The inclusion of visibility in the regression model improves the overall agreement with the normalized irradiances, explaining 52% of the variance. Finally, a model based on all three parameters \( f, V, \) and \( C \) shows a substantial improvement and explains 65% of the variance in \( T(\text{uv}) \). The cloud ceiling altitude is likely correlated with cloud optical thickness. Use of this parameter allows the model to discriminate between skies that are totally covered by high, thin clouds and low, thick clouds.

Unfortunately, even the most sophisticated of the regression models can produce sizeable errors when applied to any specific day. We compared the predictions of the regression model using \( f, V, \) and \( C \) with the measured \( T(\text{uv}) \) for each day of the data set. The error in the regression model’s estimate was 20% or greater on 32% of the days (69 out of 214 days). This level of agreement may be the best one can expect to achieve from a simple statistical approach.

The use of satellite-based data may allow improvements in the treatment of clouds. Measurements of backscattered sunlight from the Total Ozone Mapping Spectrometer contain useful information on the reflecting properties of clouds at a wavelength of 360 nm. Interpretation of the effective reflectivities derived from these radiances allows one to estimate fractional cloud cover and cloud albedos. This information can then be meshed with models of radiative transfer to predict the full spectrum of solar ultraviolet irradiance at the earth’s surface including the effects of both absorption by ozone and scattering by clouds.
Depletion of stratospheric ozone partly due to the reactions with certain chemicals released from civilization, has become a major concern of the world community and the subject of many conferences and action programmes. The United Nations Conference of Environment and Development in Rio de Janeiro in 1992 emphasized the understanding and proposed corrective actions in several areas of global environmental change, among them the effects from the changes in the ozone level of the stratosphere. National governments, private enterprise, NGOs, international organizations were asked in this conference to act and/or coordinate corresponding efforts. Major programmes include counter measures on causes of depletion of ozone as well as understanding of mitigation of its effects. Among those, most importantly, increased UV radiation requires emphasis on understanding of health effects and appropriate protective measures.

By its constitution, which largely dates back to its foundation, WHO is responsible, among others:

- to act as the directing and coordinating authority on international health work
- to promote and conduct research in the field of health
- to provide information, counsel and assistance in the field of health
- to assist in developing an informed public opinion among all peoples on matters of health.

Accordingly the following Rio Conference recommendation is particularly relevant for WHO; nationally determined action programmes, with international assistance, support and coordination, where necessary, should undertake, as a matter of urgency, research on the effects on human health of the increasing ultraviolet radiation reaching the earth’s surface as a consequence of depletion of the stratospheric ozone layer."

The International Research Programme on Health, Solar UV Radiation and Environmental Change is a collaborative project of the International Agency for research on Cancer (IARC), the Division of Environmental Health of the World Health Organization (WHO) and the United Nations Environment Programme (UNEP). Its general objectives are to evaluate accurately the quantitative relationship between solar ultra violet (UV) radiation at the surface of the earth and human health effects, develop reliable predictions of the health consequences of changes in UV, provide baseline estimates of the incidence of health effects of UV in representative populations around the world, and develop practical ways of monitoring change in these effects over time in relation to environmental and behavioural change. It will provide essential input into environmental and public health policy responses to depletion of stratospheric ozone and a means of monitoring the effects of these policies.
In addition to the limited resources of WHO, at the outset of the INTERSUN programme, major collaborating centres have been engaged in supporting INTERSUN work through contributions in kind and in cash. Besides the founding partners of INTERSUN, significant support is coming from the United States Environmental Protection Agency, Environment Agency of Japan, United States Army Environmental Hygiene Agency, Institute of Ophthalmology, London and Bundesamt Fur Strahlenschutz, Oberschleissheim, Germany.

In detail amended and expanded objectives of the INTERSUN Programme include most importantly:

- To evaluate accurately the quantitative relationship between solar UV at the earth's surface and human health effects

- To provide baseline estimates of the incidence of health effects in representative populations

- To develop reliable predictions of the health consequences of changes in UV

- To develop a network of centres monitoring the occurrence of health effects of UV radiation

- To support the development of practical ways of monitoring human exposure to UV radiation

- To enhance the understanding of the relationship between personal risk from UV radiation, constitutional sensitivity and sun-related behaviour

- To provide a basis for development and evaluation of interventions or reduce the occurrence of adverse health effects of solar UV radiation

- To interpret and ameliorate, as far as possible, the trends in relation to environmental change, changes in human behaviour and implementation of public policies

In its first two years of operation INTERSUN activities have been centred around the definition and coordination of programmes with the collaborating centres, setting of priorities and identifying additional research areas. A major output, largely supported by the programme and including many of its findings is the new WHO publication of the "WHO ENVIRONMENTAL HEALTH CRITERIA 160, ULTRA VIOLET RADIATION".

Much interest has been shown for INTERSUN and many suggestions have been made, however, the implementation will largely depend on more rapid support from international and national institutions around the world and contributions in kind and in cash. Such expanded and internationally coordinated efforts would involve intensified work on bio-markers identification and validation, intensified work on the relationship between cataracts and UV radiation and the investigation of the relationship between UV radiation and the function of the immune system. Research on non-malignant melanoma and cancer as well as harmonization of algorithms on UV effectiveness will also be included.

Solid, confirmed knowledge from the INTERSUN programme and related
programmes around the world will form an excellent basis to inform the public truthfully, intelligently and effectively. Such public information, to enhance protection against UV radiation can be derived, as has been shown in some countries, from state of the art knowledge and could then be updated step by step, when additional knowledge becomes available. The international organizations could accelerate and support such efforts and collect and evaluate important existing public information, and develop internationally valid recommendations based on their effectiveness, provide advice and training to local authorities and organizations and devise follow-up measures to sample for changes in perception, attitudes and health of the public.

Already now it appears feasible to reach a consensus on widespread and more uniform warnings via UV indices, in the meteorological forecasts by applying, for example, the following principles:

- Index should be simple, relative figure
- Direct, linear scale (0-10)
- Scaled to presently credible danger threshold, which may be refined later
- Adaptable to local conditions, habits, e.g. via locally adapted danger thresholds
- Should indicate range or two values, for cloudy and clear skies
- Amenable for inclusion in weather forecasts
- Uniformly used throughout the world, i.e. understandable for travellers, everywhere
- Must be introduced as soon as possible

In summary, it can be said, that the effects of UV radiation, their causes and their mitigation should be investigated/clarified expeditiously, that international organizations should take a lead in required coordination functions (according to their mandates and/or jointly).

INTERSUN is an authorized and broadly-based WHO programme devoted to health and environmental effects of UV radiation. Additional members, contributions in kind and in cash are highly welcome and needed to accelerate the programme.
UV research and forecasts in Finland

Petteri Taalas, Tapani Koskela, Juhani Damski,
Esko Kyro, Annakaisa Sarkanan and Kari Hurtta
Finnish Meteorological Institute
Helsinki

UV measurements & models

A Brewer spectrometer was installed at Sodankyla, 67 N in 1988. In 1990 the Brewer was equipped with a UV calibration lamp to allow spectral UV measurements. In 1991 three broadband SL500 erythema radiometers were installed to Sodankyla, Tikkakoski (62 N) and Jokioinen (61 N) observatories. The instruments were later equipped with temperature stabilizing and defrosting units. In 1994 new SL501 sensors will replace the older sensors, and new stations Helsinki (60 N) and Uto (59 N) will be established. The former represent urban environment with 1 milj. inhabitants around, and the latter an isolated rocky island in the Baltic Sea. The Institute of Nuclear and Radiation Safety in Finland has been responsible for testing and calibrating the sensors.

The Jokioinen observatory will be equipped with a double monochromator Brewer (Mk. III) in September 1994. The in-house calibration facilities will be developed to Jokioinen as well. Besides pure UV measurements total ozone (satellites, Brewers, SAOZ spectrometer), ozone soundings, other solar radiation measurements, aerosol and albedo measurements are available at FMI for UV research.

FMI is using a sophisticated spectral UVSPEC model, developed by Knut Stamnes and Arve Kylling at the Univ. of Fairbanks. Also simpler UVDOS model by Arne Dahlback from NILU and the Green's model are in use.

UV research at FMI

The UV research at FMI is highly linked to North-European co-operation. The first stage of FMI UV research has been the mapping of UV radiation to find out the variability and levels of UV radiation in different parts of Finland. To be able to use the broadband data before the temperature stabilizing unit was available a temperature sensor was installed under the green filter of SL500 instrument. The sensor temperature error correction method has been developed. That method is also useful for correcting the old RB-records against the sensor temperature errors.

FMI has used old total ozone records of Northern Europe to model the possible changes in the UVB radiation in Northern Europe so far. Austin et al. (1992) have calculated that the doubling of atmospheric CO₂ content in the next century may lead to a more stable and longer persisting Arctic polar vortex. This might lead to a serious Arctic ozone loss during some years. It has been calculated that this ozone loss might enhance the clear-sky UVB doses in the Arctic springtime considerably, e.g. about 65 % locally in April. Need for additional ozone scenarios are highly needed.

The interaction between UVB radiation, cloudiness and the profiles of O₃, SO₂, NO₂ and
aerosols will be studied by using field measurements and models. The effect of snow/icecover on UVB albedo is of high interest in Northern Europe.

**UV forecasts in Finland**

FMI has created its UV forecast system in late 1993. The system is based on the method developed by AES in Canada. The regression equation for Finland has been made by using the total ozone measurements of Sodankyla for 1988-94 and the ECMWF stratospheric analysis fields. The ozone forecast is made by using the total ozone measurements of Sodankyla and Jokioinen and the stratospheric forecast fields as produced by the North-European HIRLAM fine-mesh model. The clear-sky erythemal UV doses are further calculated by Green's model. Observed albedos are also used.

The doses are calculated for morning, noon and afternoon hours for skin type II (the MED is defined by 210 J/m²). So far the newspapers and TV channels have published minutes for erythem. The calculation is made for Europe by using long-term normals of total ozone outside Finland. Erythema minutes for popular holiday resorts in the Alps, in the Mediterranean region and for Canary Islands is also calculated.

The planning of the forecast product and related general information package has been created in co-operation with the Cancer Society and the Institute of Nuclear and Radiation Safety in Finland. The erythema minutes or intensity units are favoured instead of index. It has been found out that a index has to be interpreted as erythema minutes anyway. The representatives of mass media is interested in as simple and easy output products as possible.

The inclusion of clouds to the forecast system will be done as soon as the quality of cloud forecasts is high enough.
Summary: Public UV forecasting in Denmark
Signe B. Andersen and Paul Eriksen

UV forecasts have been made in Denmark by the Danish Meteorological service together with the Danish Cancer Society and the National Board of Health since spring 1992. They are based on measurements of ozone by a Brewer, forecasting of ozone by use of HIRLAM (Danish high resolution weather model), calculation of clear sky UV spectrum weighted with the McKinley-Diffey action spectrum.

The minimum burntime is calculated and updated through the summer. For this purpose a pool of 40 people are tested each month at the state hospital in Copenhagen.

The ozone value and in summer the maximin time an average dane can stay in the sun at noon is then communicated to the public via text TV, radio and newspapers.

Summary: Survey on indices used in western europe

Survey initiated at a meeting in spring 1994 for Research Directors at Western European Meteorological Services.
ENVIROMENTAL POLLUTION MONITORING AND RESEARCH PROGRAMME REPORT SERIES


7. Fourth Analysis on Reference Precipitation Samples by the Participating World Meteorological Organization Laboratories by Robert L. Lampe and John C. Puzak, December 1981*

8. Review of the Chemical Composition of Precipitation as Measured by the WMO BAPMoN by Prof. Dr. Hans-Walter Georgii, February 1982


11. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1982

12. Report on the Mount Kenya Baseline Station Feasibility Study edited by Dr. Russell C. Schnell


14. Effects of Sulphur Compounds and Other Pollutants on Visibility by Dr. R.F. Pueschel, April 1983

15. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1981, May 1983


17. General Consideration and Examples of Data Evaluation and Quality Assurance Procedures Applicable to BAPMoN Precipitation Chemistry Observations by Dr. Charles Hakkarinen, July 1983
19. Forecasting of Air Pollution with Emphasis on Research in the USSR by M.E. Berlyand, August 1983

20. Extended Abstracts of Papers to be Presented at the WMO Technical Conference on Observation and Measurement of Atmospheric Contaminants (TECOMAC), Vienna, 17-21 October 1983


23. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1982. November 1984


26. Sulphur and Nitrogen in Precipitation: An Attempt to Use BAPMoN and Other Data to Show Regional and Global Distribution by Dr. C.C. Wallén. April 1986


29. Recommendations on Sunphotometer Measurements in BAPMoN Based on the Experience of a Dust Transport Study in Africa by Dr. Guillaume A. d'Almeida. September 1985


35. Provisional Daily Atmospheric CO₂ Concentrations as Measured at BAPMoN Sites for the Year 1983. December 1985


43. Recent progress in sunphotometry (determination of the aerosol optical depth). November 1986


46. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1984. December 1986


50. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1985. December 1987


53. WMO Meeting of Experts on Strategy for the Monitoring of Suspended Particulate Matter in BAPMoN - Reports and papers presented at the meeting (Xiamen, China, 13-17 October 1986). October 1988


55. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at 31 December 1987

58. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the years 1986 and 1987


62. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the year 1988


64. Report of the consultation to consider desirable locations and observational practices for BAPMoN stations of global importance (Bermuda Research Station, 27-30 November 1989)


68. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data For 1989, Volume I: Atmospheric Aerosol Optical Depth

69. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1989


72. Integrated Background Monitoring of Environmental Pollution in Mid-Latitude Eurasia by Yu.A. Izrael and F.Ya. Rovinsky, USSR

73. Report of the Experts Meeting on Global Aerosol Data System (GADS) (Hampton, Virginia, 11-12 September 1990)

75. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1990

76. The International Global Aerosol Programme (IGAP) Plan: Overview

77. Report of the WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques (Lake Arrowhead, California, 14-19 October 1990)

78. Global Atmospheric Background Monitoring for Selected Environmental Parameters BAPMoN Data for 1990, Volume I: Atmospheric Aerosol Optical Depth


80. Report of the WMO Meeting of Experts on the Quality Assurance Plan for the GAW (Garmisch-Partenkirchen, Germany, 26-30 March 1992)


83. Report on the Global Precipitation Chemistry Programme of BAPMoN

84. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at GAW-BAPMoN sites for the year 1991

85. Chemical Analysis of Precipitation for GAW: Laboratory Analytical Methods and Sample Collection Standards by Dr. Jaroslav Santroch


88. Guide to the observations by E. Meszaros

89. 4th International Conference on CO₂ (Carqueiranne, France, 13-17 September 1993)


91. Extended Abstracts of Papers Presented at the WMO Region VI Conference on the Measurement and Modelling of Atmospheric Composition Changes Including Pollution Transport (Sofia, 4-8 October 1993)


94. Report on the Measurements of Atmospheric Turbidity in BAPMoN
Our ref.: R/UV-B/1

Annex: 1 (available in English only)

Subject: Distribution of a WMO report in the Global Atmosphere Watch (GAW) publication series

Action required: For information

Dear Sir/Madam,

With continuous depletion of the global ozone layer, the question of increasing UV-B radiation has become one of the leading research interests among the atmospheric science community and the public. Consequently, national authorities have requested reliable information on UV radiation from WMO. For gathering such information, WMO organized a meeting of UV experts in Les Diablerets, Switzerland.

I am pleased to send, under separate cover, for your information and that of interested scientists and technicians inside and outside the Meteorological Service, one copy of the following report of the WMO meeting, recently produced under the above-mentioned publication series, namely:

No. 95: Report of the WMO Meeting of Experts on UV-B Measurements, Data Quality and Standardization of UV Indices
(Les Diablerets, Switzerland, 25-28 July 1994)

Additional copies are available from the Secretariat upon request.

Yours faithfully,

(G.O.P. Obasi)
Secretary-General

To: Permanent Representatives (or Directors of Meteorological or Hydrometeorological Services) of Members of WMO (PR-5129)

cc: Participants of the meeting
President of CAS
EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry
(for information)