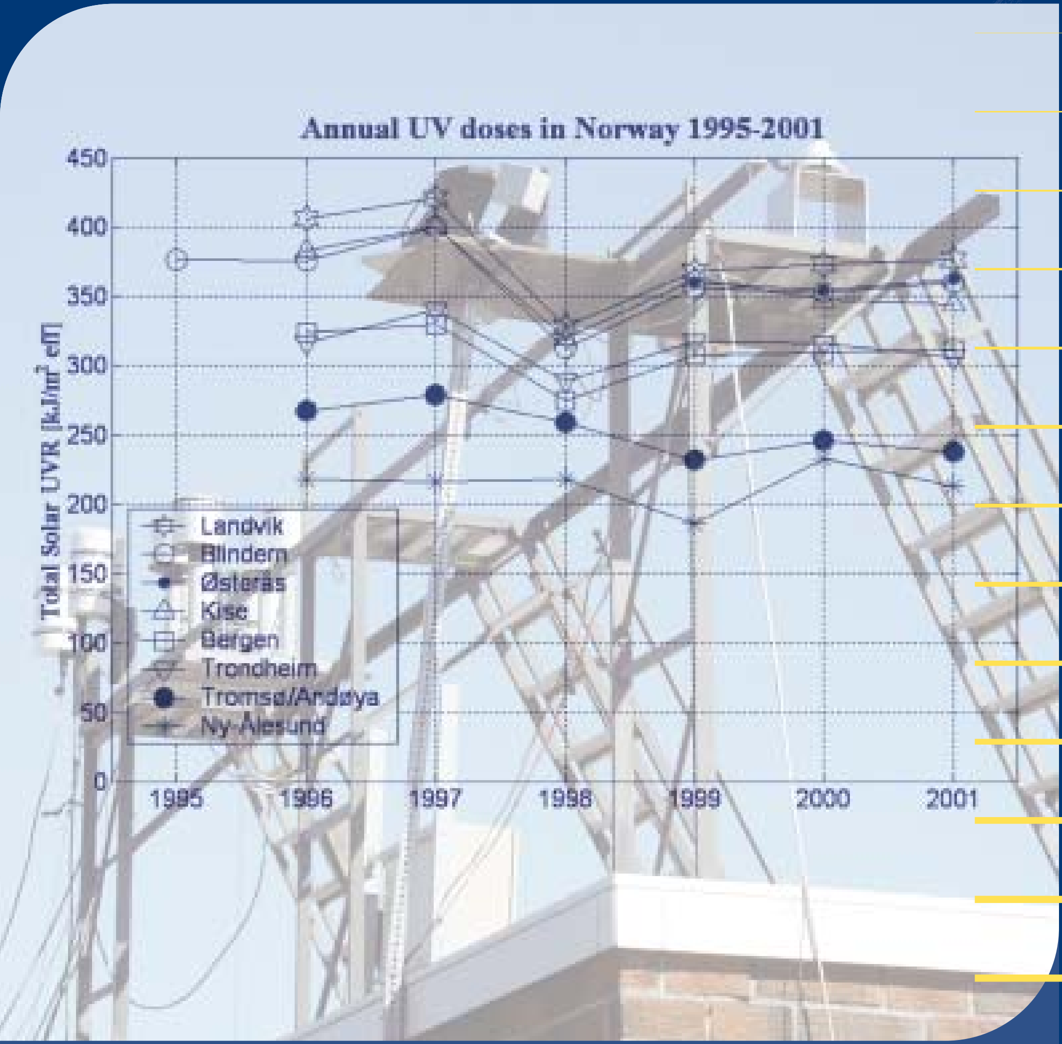
Strålevern Rapport 2002:4

The Norwegian UV-monitoring program

Period 1995/96 to 2001



Bjørn Johnsen, Oddbjørn Mikkelborg,
Merete Hannevik, Lill Tove Nilsen,
Gunnar Saxebøl, Karl Gerhard Blaasaas

Statens
strålevern

**Norwegian Radiation
Protection Authority**
Postboks 55
N-1332 Østerås
Norway

Reference:
Johnsen BJ, Mikkelborg O, Hannevik M, Nilsen LT, Saxebøl G, Blaasaas KG. The Norwegian UV monitoring program. Perid 1995/96 to 2001. StrålevernRapport 2002:4. Østerås: Norwegian Radiation Protection Authority, 2002.

Key words:
Ultraviolet radiation. UV. Solar UV. Solar UV-index. UV-dose. UV monitoring. UV trend. Alpine UV. CIE. Erythema. GUV. Multiband radiometer. UV-Biometer. Bentham spectroradiometer. Calibration. Quality control. Cloud transmittance. Ozone.

Abstract:
The implementation, operation and quality control program for the national UV monitoring network are presented. Final results of UV-indices and UV-doses for the period 1995/96 to 2001.

Referanse:
Johnsen B et al. The Norwegian UV monitoring program. Perid 1995/96 to 2001. StrålevernRapport 2002:4. Østerås: Statens strålevern, 2002. Språk: engelsk.

Emneord:
Ultrafiolett stråling. UV. Naturlig UV. UV-indeks. UV-dose. UV overvåking. UV trend. Alpin UV. CIE. Erythem. GUV. Flerbåndsradiometer. UV-Biometer. Bentham spektralradiometer. Kalibrering. Kvalitetskontroll. Skytransmittans. Ozon.

Resymé:
Oppbyggingen, driften og kvalitetskontrollen av et nasjonalt UV overvåkingsprogram presenteres. Endelige resultater for UV indeks og UV doser for perioden 1995/96 til 2001 vises.

Head of project: Merete Hannevik.

Approved:

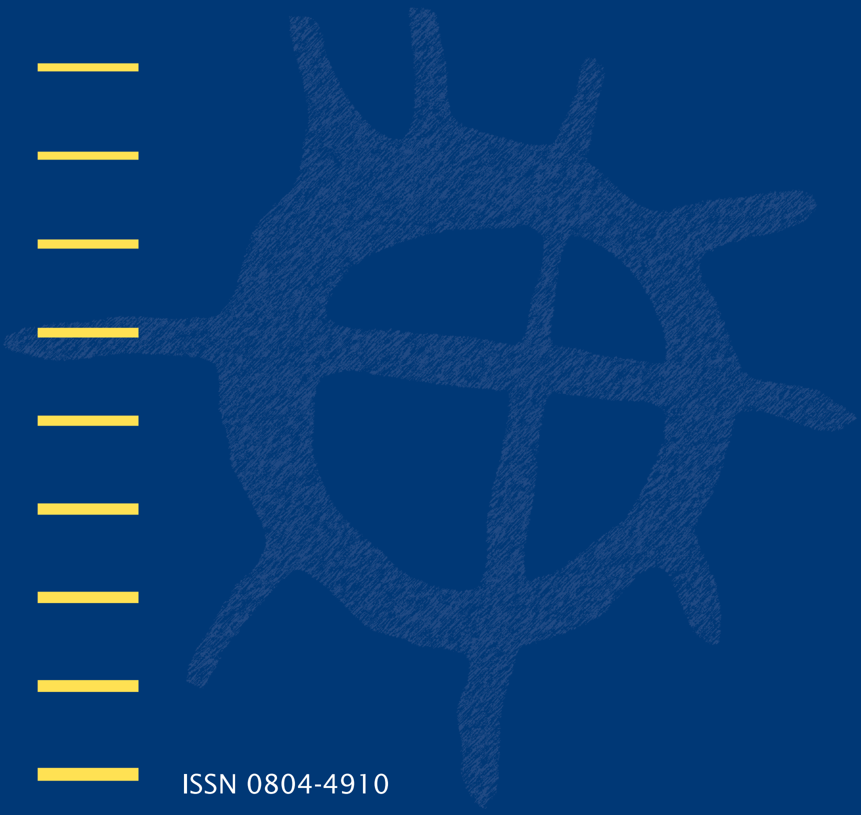
Ole Harbitz, Director General, NRPA.

40 pages.
Published 2002-09-15.
Printed number 400
Cover design: Lobo Media as, Oslo.
Printed by Lobo Media as, Oslo
Orders to:
Norwegian Radiation Protection Authority, P.O. Box 55, N-1332 Østerås, Norway.
Telephone +47 67 16 25 00, fax + 47 67 14 74 07.
www.nrpa.no
ISSN 0804-4910

StrålevernRapport 2002:1
Virksomhetsplan for 2002

StrålevernRapport 2002:2
Helsebekymringer relatert til
virksomheten ved IFA/IFE – Kjeller
En studie blant lokalbefolkningen

StrålevernRapport 2002:3
The Norwegian Assistance Program for Increased
Reactor Safety in Eastern Europe



ISSN 0804-4910

Lobo Media 10813

Content

1 Sammendrag

Hovedpunkter:

- UV-overvåking i Norge gjennomføres 8 steder, fordelt mellom 58°N og 79°N
- Erfaringene med gjennomføring og drift av nettverket er svært gode.
- Kalibreringer er sporbare til flere europeiske UV-nettverk, gjennom deltakelsen i den nordiske målekampanjen som ble arrangert i Sverige i juni 2000 (NOGIC2000)
- Kvaliteten på måleresultatene er blitt kontrollert for alle år og stasjoner og funnet samstemte for hele perioden nettverket har vært operativt.
- Seks års komplette serier med daglig integrert, erythem-vektet UV (heretter benevnt UV-dose) og daglig maksimal UV-indeks er tilgjengelig for forsknings- og informasjons formål. UV-indeks gir et mål på intensiteten av UV-stråling og benyttes for publikumsinformasjon i de fleste land med målenettverk.
- Måleseriene er foreløpig for korte til å vurdere om det har vært en langtids endring i UV-strålingen.
- Resultatene presenteres i nær sanntid på Strålevernets websider *http://uvnett.nrpa.no/*
- UV-prognoser, basert på data fra målenettverket, utføres av Norsk institutt for luftforskning (NILU) og presenteres på http://www.luftkvalitet.info/uv/.

Et landsdekkende målenettverk bestående av flerbånds filterradiometre har vært operativt ved 7, senere 8 stasjoner, siden 1995/1996. Stasjonene er lokalisert fra Grimstad i sør (58°N) til Ny-Ålesund i nord (79°N). Hensikten er å framskaffe UV-data som er relevante for vurderingen av de helse- og miljømessige effektene av UV-strålingen, samt å følge utviklingen i UV-klimaet over flere tiår. Overvåkingsprogrammet er et samarbeid mellom Helsedepartementet og Miljøverndepartementet og administreres av Statens strålevern (NRPA) og Statens forurensningstilsyn (SFT) ved Norsk institutt for luftforskning (NILU).

Seks års serier med UV-data er nå tilgjengelig for forsknings- og informasjonsformål. Kalibreringene som inntil 2000 var sporbare til Biospherical Instruments UV-nettverk i Amerika og Antarktis, er nå sporbare til målekampanjen NOGIC2000 i Sverige. Endringen ble gjort fordi foregående målekampanje (NOGIC96) og målinger på Strålevernet tydet på at original kalibrering av nettverksinstrumentene gav for lave verdier. Forut for deltakelsen i NOGIC2000 ble 3 av referanseinstrumentene rekalibrert mot våre egne standarder. Kalibreringene ble så testet gjennom blindtester mot andre lands instrumenter. I målekampanjen deltok fagmiljøer fra de nordiske landene, samt Polen, Østerrike og Kanada. Testene bekreftet meget godt samsvar (-1%±2%) med referansedata, som i praksis førte til at det norske UV-nettverket heretter er relatert til en felles nordisk kalibrerings-standard. Overgangen til en nordisk basert kalibreringsstandard innebar en økning i tidligere rapporterte dagsdoser på ca. 10%, samt at kvaliteten på måle-resultatene nå er bedre ved lave solhøyder og høye breddegrader. Rapporten inkluderer en reevaluering av måledata for hele perioden 1995/1996 til 2001.

Sikring av høy kvalitet og kontinuitet i UV målingene gis høy prioritet. Daglige eller ukentlige inspeksjoner av instrumentene i tillegg til sanntids presentasjon av samtlige stasjoners resultater på internet (*http://uvnett.nrpa.no/*) sikrer rask varsling i tilfelle problemer med datainnsamlingen. Avbruddsfrie strømforsyninger er installert ved 5 av stasjonene. Svakheter som førte til at temperaturkontrollerne sluttet å virke etter noen år er nå utbedret etter anvisninger fra NILU.

Hvert år foretas en kalibreringskontroll av samtlige instrumenter ved at 1-2 referanseinstrumenter settes opp ved siden av de faste for en kortere periode. Dette sikrer kontroll med endringer i instrumentenes følsomhet slik at nettverket kan opprettholde en stabil kalibrering over tid. Etter 6 års drift er endring i følsomhet i kanalene til det mest stabile instrumentet –2% til +5% i forhold til original versjon, mens det eldste og minst stabile instrumentet har hatt en endring i følsomhet på opptil 23%.

Nøyaktig kontroll av drift i referanseinstrumentene utføres ved bruk av stabile lamper ved kalibreringslaboratoriet på Strålevernet. To av lampene er detetektorstabiliserte og er særdeles godt egnet for å opprettholde en stabil standard over mange år. I tillegg sikrer årlige kalibreringskontroller, utført av leverandøren i USA, en uavhengig evaluering av langtidsstabiliteten til ett av referanse instrumentene. Spektralresponsene til hvert enkelt instrument er kartlagt av Strålevernet. Disse responsdata er nøkkelen til å beregne en rekke størrelser, slik som biologisk effektiv eller fysikalsk uvektet UV-stråling, totalozon og skysvekningsgrad. Seks av instrumentene er også karakterisert med hensyn til vinkelrespons og disse data er brukt til å beregne korreksjonsfaktorer som funksjon av solhøyde. Kartlegging av disse responsfunksjonene bidrar til at måleresultatene har høy kvalitet også ved lave solhøyder.

Kalibrering av instrumentene er gjort av Strålevernet, ved bruk av fasilitetene og referanseinstrumentene som finnes her. Usikkerheten i kalibrering av nettverksinstrumenter anslås til ±5% (2 sigma). En egen plattform på taket av bygningen er avsatt for solkalibreringer, hvor 2 instrumenter er i kontinuerlig aktivitet. Et spektralradiometer, Bentham DM150BC, utstyrt med en nærmest ideell frontoptikk sikrer nøyaktige spektralmålinger for bølgelengde-området 290-450 nm. Kvalitetssikringen av solspektra er i tråd med anbefalinger fra WMO. Deltakelsen i NOGIC2000, hvor resultatene ble rapportert uten kjennskap til de andre gruppenes resultater, bekreftet at Strålevernets målinger samsvarte innenfor –1% ±2 % med kampanjens referansedata for alle solvinkler og dager. To av filterradiometrene som brukes som mobile sekundærstandarder for resten av nettverket er kalibrert mot dette spektralradiometeret. Sammenligninger viser at den erythemeffektive UV-strålingen basert på målinger med disse instrumentene samsvarer med spektralradiometeret innenfor ±2% for solhøyder over 10°. De lokale nettverksinstrumentene er i sin tur kalibrert mot disse mobile referanseinstrumentene. Dagsdoser målt på stasjonene samsvarer innenfor ±1% for 6 års kalibreringskontroller. Nettverket har på denne måten en enhetlig kalibreringskjede som starter med blindtester mellom vårt nasjonale og andre lands spektralradiometre, kalibrering av mobile referanseinstrumenter mot dette spektralradiometeret, og overføring av kalibrering til lokale instrumenter.

Av forskjellige grunner, slik som svikt i PC'er og instrumenter, strømbrudd, bygningsrelaterte forhold og kalibreringer av instrumentene, mangler det måledata i deler av tiden instrumentene har vært operative. Antallet dager med betydelige brudd i måleseriene varierer mellom 0 og 10 per år for de fleste stasjonene. Instrumentet i Tromsø som i 2000 ble flyttet til Andøya har de siste par årene hatt mer enn 70 dager med helt eller delvis tapte data. Kalkyler viser at samlede dagsdoser som er gått tapt siden 1996 utgjør 5% til 20% av en årsdose for alle stasjonene, med unntak av Tromsø/Andøya hvor 63% er gått tapt.

Hull i serier av dagsdoser og daglig maksimale UV-indekser er komplettert ved beregninger basert på skysvekningsdata fra totalstrålingsinstrumenter. Med unntak av Andøya, hvor det per utgangen av 2001 ikke fins andre filterradiometre som kan gi skyinformasjon, fins det for hver UV stasjon pyranometre med totalstrålingsdata registrert som timesmiddelverdier. Beregninger av teoretiske dagsdoser og midlere UV-indeks er basert på strålingstransport beregninger av timesvis irradianser vektet med den faktiske skysvekningen for hvert sted. Teoretiske og faktiske dagdoser samsvarer typisk innenfor ±15% for hver stasjon, selv under variable skyforhold. Metoden har vist at kombinasjonen av pyranometer- og totalozondata gir brukbare estimater for tapte UV-data. Estimatene for tapte dagsdoser øker usikkerheten i beregnede årsdoser. Dette usikkerhetsbidraget er mindre enn ±1.5% for alle stasjoner, med unntak av Andøya hvor usikkerheten er inntil ±6%.

De kompletterte måleseriene viser ulike årlige variasjonsmønstre for stasjoner i Sør- og Nord-Norge. Stasjoner fra Trondheim og sørover viser variasjoner på opptil ±12% i årsdoser i perioden 1996-1998, med et maksimum i 1997 og et minimum i 1998, etterfulgt av en mer stabil periode (±3%) for de siste 3 årene. Data fra pyranometere viser at skysvekningen var 10% til 15% mindre for sommermånedene i 1997 enn i 1998. Mengden av totalozon var også omtrent 10% lavere i sommermånedene i 1997 enn i 1998. Kombinasjonen av ulik skysvekning og ozonmengde kan sannsynligvis forklare forskjellene i årsdosene for disse to årene. For de to nordligste stasjonene ble det målt lavest årsdose i 1999, men ikke så uttalt som for stasjonene i sør-Norge i 1998. I likhet med de sørligste stasjonene hadde Tromsø et maksimum i 1997, etterfulgt av en mer stabil (±3%) periode de 3 senere årene. Sommeren 1997 huskes av mange som en periode med uvanlig godt vær i Troms og Nordland. Årsdosene i Ny-Ålesund var stabile (±1.5%) i 1996-1998 og 2001. Årsdoseminimum i 1999 (-12%) er sterkt påvirket av skyer i juni og juli denne sommeren. Den korte sommersesongen gjør at årsdosene her er mer preget av sommerværet enn for stasjoner i sør.

Alt i alt har årsdosene vært lavere i perioden 1999-2001 enn i 1996-1997. De årlige variasjonene er imidlertid for store og observasjonsperioden for kort til å vurdere om nedgangen er statistisk signifikant.

Alle rådata og bearbeidede data fra nettverket, og kalibrerings- og korreksjonsfaktorer er lagret i en relasjonsdatabase utviklet på Strålevernet. Databasen er et kraftig verktøy for lagring og uthenting av data. Websidene på Strålevernet, *http://uvnett.nrpa.no/*, er koplet opp mot denne databasen, som gir tilgang på oppdaterte måleresultater og generell informasjon om UV-stråling og helseeffekter. Måledata og informasjon om UV nettverket finnes på websider både ved Strålevernet, NILU og Fysisk institutt ved Universitet i Oslo (*http://www.nrpa.no og http://uvnett.nrpa.no*, *http://www.luftkvalitet.info/uv/* og *http://www.fys.uio.no/plasma/ozone/*). Prognoser for UV-indekser i ulike landsdeler foretas av NILU. Disse prognosene er også tilgjengelige på NILUs websider.

2 Abstract

Highlights:

- UV-monitoring is performed at 8 locations between 58°N and 79°N
- The experiences with the network implementation and operation are very good.
- Calibrations are traceable to several European UV networks, through the Nordic Intercomparison of UV and total ozone instruments in Sweden 2000.
- The measurements have been validated and found consistent.
- Six years of complete series of daily-integrated erythemally effective UV radiation (denoted UV-doses for short) and UV-indices are available for public and scientific use.
- The measurements are relevant for the assessments of health- and environmental aspects of UV-radiation.
- The measurement series are yet too short to infer any trend in the UV-radiation.
- Measurements are presented on-line on *http://uvnett.nrpa.no/*.
- The Norwegian Institute provides UV-forecasts for Air Research on *http://www.luftkvalitet.info/uv/*.

A Norwegian UV-monitoring network of GUV multiband radiometers has been operating at locations between 58°N and 79°N since 1995-96. The purpose is to obtain long-term series of UV-data of high quality, to be used in further

assessments related to health- and environmental issues. The Ministry of Health and The Ministry of Environment finance the network. The network is administered by The Norwegian Radiation Protection Authority (NRPA) and The Norwegian Pollution Control Authority (SFT), the latter through The Norwegian Institute for Air Research (NILU).

Six years of UV measurements are now available for research and information purposes. The calibrations, which until 2000 were traceable to the manufacturer Biospherical Instruments, are now traceable to the Nordic intercomparison of UV radiometers held in Sweden in June 2000 (NOGIC2000). The change of scale was effectuated because the previous intercomparison (NOGIC96), as well as solar measurements at NRPA, indicated too low measurements. Before participating in NOGIC2000, the 3 instruments brought by NRPA were recalibrated towards our own standards. The calibrations were then tested through participations in the NOGIC2000's blind-tests with reference instruments from other countries. The campaign had participants from the Nordic countries, as well as from Poland, Austria and Canada. The tests confirmed good agreement (-1%±2%) with the campaigns reference data, implying that the Norwegian UV-network is verified traceable to a common Nordic calibration scale. The new standard results in a step in daily UV-doses and UV-indices by about 10% compared to the previously reported results. The change implies improved accuracy for large solar zenith angles as well. The present report comprises a presentation of the UV-network and the characterizations- and quality assurance work, and implies a re-evaluation of measurements for the period 1995/1996 to 2001.

Maintenance of measurement quality and continuity in measurements are given priority. Daily or weekly inspections of instruments and online graphical display of UV measurements on the internet (*http://uvnett.nrpa.no/*) provide early warning in case of instrument failure. Power backup systems have been installed at five locations to improve the continuity in measurements. Frequently occurring failures of detector controllers have been eliminated, following a modification scheme designed by NILU.

Calibrations have been a main issue since the start of the network. Once a year the instruments are calibrated to mobile transfer standard instruments. This enables determination of the long-term change in instrument responses for the purpose of maintaining a stable calibration scale over many years. For the six years period of operation, the changes in spectral responses of the detector channels of the best instrument are –2% to +5% relative to the original version, whereas for the oldest and least stable instrument the corresponding changes are up to –23%.

Accurate monitoring of response changes for the mobile transfer standard instruments is performed at the optical laboratory at NRPA. Optical feedback regulated lamps as well as conventional current-stabilised lamps are used for this purpose. Annual calibration controls by the manufacturer enable an independent evaluation of one of these transfer standards. The agreement between the manufacturer's and NRPA's results for lamp measurements is good.

Spectral response functions have been measured for all instruments, using the facilities of NRPA. The response functions enable calculation of physically unweighted or biologically weighted UV irradiances. Angular response functions have been characterized for six instruments and cosine errors calculated for different sky conditions and solar zenith angles. This enables means for correcting for errors at large solar zenith angles.

The calibrations of instruments are performed by NRPA, using our calibration facilities and reference instruments. The uncertainty in calibrations of network filterradiometers is estimated to ±5% (2 sigma). A platform at the roof serves the purpose of solar calibration of network instruments. A Bentham DM150BC spectroradiometer, fitted with a close to ideal cosine receptor, provides highly accurate spectral measurements for the wavelength region 290-450 nm (optional 500nm). Quality control of spectra follows recommendations from the World Meteorological Organization.

Blindtest intercomparisons performed during the NOGIC2000 showed that the spectroradiometer agreed within –1%±2% with the campaigns reference spectra for all solar zenith angles and days. The mobile transfer standard GUV instruments have been calibrated towards this spectroradiometer. Comparisons between these transfer standards and the spectroradiometer show close agreement in erythemally effective irradiances (± 2%) for solar zenith angles less than 80°. Calibration of the local network instruments is performed applying the transfer standard instruments. The erythemally-effective irradiance measured with the local network instruments match the transfer standards within ±1% for solar zenith angles less than 80°. Daily UV-doses recorded with the local instruments and the transfer standard GUV agree within ±1 % for the 6 years of intercomparisons. Thus there is a consistent chain of calibration steps starting with the reference spectroradiometer participating in the NOGIC2000, the calibration of transfer standard GUVs toward this reference spectroradiometer, and finally the transfer from travelling standards to network instruments.

Failures with the GUV instrument's temperature-controllers and computers, power shutdowns, work related to calibrations and spectral characterisations of instruments etc, have resulted in several gaps in measurement series. The number of days with significant gaps in measurement data varies between 0 and 10 per year for most locations. However, the instrument in Tromsø that in year 2000 was moved to Andøya has had excessive gaps, with more than 70 days with significant gaps in 2000 and 2001. Estimates of the loss of annual UV-doses that have been cumulated since 1996 amount to 5 % to 20 % for all locations, except for the Tromsø/Andøya locations where the loss is 63 %.

Gaps in integrated daily UV-doses and maximum UV-indices have been corrected by using total global irradiance measurements from nearby pyranometers to estimate the UV sky transmittance. With exception of Andøya, pyranometer data exist for all locations. For Andøya, UV sky transmittances have been assumed constant, or taken as an average of the period before and after the gap. Clear-sky UV-indices were calculated with a radiative transfer model and modified according to the hourly mean UV sky transmittances. The agreement between estimated and measured daily UV-doses is generally within ± 15% for variable cloud conditions. The method of retrieving UV-doses from ancillary measurements significantly improve the accuracy of estimates of monthly and annual UV-doses. In addition to the ±5% calibration uncertainty, the estimates for missing doses affect the uncertainty in annual UV-doses by ± 1.5% or less for locations with pyranometers. For the Andøya location, where pyranometer data is non-existing, the corresponding increase in uncertainty is up to ±6%.

Looking at the 6 (7) years measurements, the corrected time series indicate different interannual variations in total UV-doses for the locations in southern and northern Norway. Locations from Trondheim and southwards show large variations (±12%) in the period 1996-1998, with a maximum (12%) in 1997 and a minimum (-12%) in 1998, followed by a fairly stable (±3 %) period in 1999-2001. Pyranometer data show that the UV sky transmittance was about 10-15 % higher during the summer months of 1997 than in 1998, indicating a more sunny summer. The total ozone amount was about 10 % lower in the summer months of 1997, resulting in higher clear sky UV-doses. The combined enhancement and reduction of UVR from variations in cloud and ozone amount may explain the differences seen in 1997 and 1998.

For the two northern locations a minimum in annual UV-doses were observed in 1999, however not as pronounced as in 1998 for the southern locations. Tromsø/Andøya had a maximum in annual UV-doses in 1997, a summer renown for its long period of clear sky conditions, followed by a fairly stable (±3 %) period for the last 3 years. The annual UV-doses for Ny-Ålesund were fairly the same (±1.5 %) in 1996-1998 and in 2001. The minimum (-12 %) in 1999 is largely due to the overcast conditions in June and July. The short summer season implies that the annual UV-doses will be most sensitive to weather conditions in the north.

The annual UV-doses have been non-statistically significantly lower in the period 1999-2001 than in 1996-1997. The interannual variations are however too large and the observation period too short to infer any statistically significant trend in the UV-radiation (UVR).

All raw data and processed data for the GUV instruments, and calibration and correction factors are stored in a SQL database developed at NRPA. The database provides a powerful tool for data storage and retrieval. The website *http://uvnett.nrpa.no/* is linked to this database, enabling access to updated UV information to the public. Measurement data and information about the monitoring network are provided by NRPA, NILU and The University of Oslo (*http://www.nrpa.no* and *http://uvnett.nrpa.no, http://www.luftkvalitet.info/uv/* or *http://www.fys.uio.no/plasma/ozone/*. Forecasts of UV-indices for different regions of Norway are provided by NILU. The service is available on NILU's web site since 2001.

3 Introduction

Great concern is paid to the effects of anthropogenic emissions of greenhouse gases and ozone destructing agents, and to which extent they presently affect the earth's natural radiation climate and biota. There are evidences of long-term decreases in the atmospheric ozone over the past two decades (Zerefos 2002, Høiskar et al. 2000). A decrease in ozone implies enhanced transmittance of short wave UV radiation (UVR). Terrestrial and aquatic ecosystems are highly sensitive to changes in UVR. Increases in the ground level UVR will have deleterious effects for many organisms, either directly, or indirectly by affecting the balance between species. There are evidences that even the present level of UVR is a limiting growth factor for many organisms, particularly under arctic conditions. UVR also causes harmful health effects (WHO 1999, NRPB 2002). WHO estimates 2.2 million cases of skin cancers pro year. Blindness affects annually 12 to 15 million people; of which WHO estimates 20 percent is induced by UVR (WHO/EHG 1995).

UV monitoring has a short history in Europe compared to ozone monitoring. The UV climate is affected also by long-term changes in the cloud cover, surface reflections and air pollutants. The net effect is uncertain because the factors influencing the UV climate are geographically dependent and may operate on different time scales. National UV monitoring networks have been established in several countries (Diffey 1996). In Norway, the UV monitoring network was initiated as a joint program between the health and environmental authorities. The network has been in operation since 1996, and two reports covering the UVR for the periods 1996-1997 and 1998-1999 have been issued (Hannevik et al. 1998, Norvang et al. 2000).

In the next sections a detailed description of the organization of the network, instrumentation and quality assurance follow. Finally, the results for the period 1995/96 to 2001 are presented followed by a discussion of the uncertainties and experiences with the network implementation.

4 Aims & network organisation

At the end of 1994, The Ministry of Enrvironment and The Ministry of Health initiated a national UV monitoring network.

Primary aim:

- Provide UV-data of high scientific quality, to be used in further assessments related to health- and environmental issues.

The monitoring program was stated to last for several decades in order to detect possible long-term changes in the UV climate. This requires internationally accepted quality for all network locations and high stability in measurements, transfer and storage of data.

Secondary aims:

- Documentation of annual and seasonal variation of UV radiation.
- Documentation of geographic and topographic variation.
- Analysis of UV trends, as basis for public warning.
- Public information about sun protection, based on UV measurements.
- Provision of UV-data to the scientific community for effects studies.

The Norwegian Radiation Protection Authority (NRPA) and the Norwegian Pollution Control Authority (SFT) are responsible for the network implementation and administration. Some locations that in 1994 were a part of the national ozone-monitoring program, which the Norwegian Institute for Air Research (NILU) conducts for SFT, were supplemented with UV instruments. NILU is contracted by SFT to perform UV monitoring at these locations (Blindern, Tromsø/Andøya and Ny-Ålesund), as well as to report ozone and UV results for these locations. The 5 new locations (outside the national ozone monitoring program) are operated by NRPA (Landvik, Bergen, Trondheim, Kise and Østerås). NRPA is responsible for reporting health relevant UV-data for the total UV network. In addition NRPA has a superior responsibility for network administration and calibrations. An organizational map is shown in Figure 1.

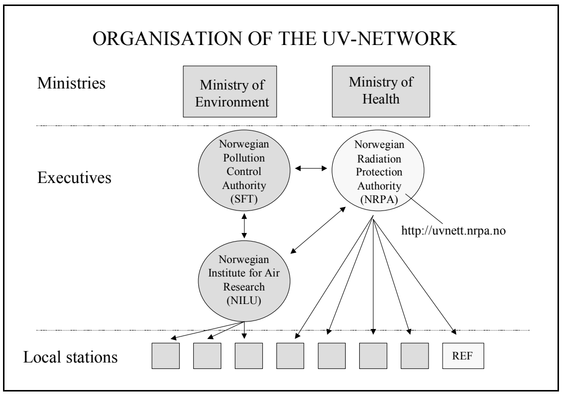


Figure 1 Organization of the national UV monitoring program

5 Description of the UV network.

5.1 Locations

The Norwegian UV network consists of 8 locations from 58°N to 79°N (figure 2). The locations were selected according to the following criteria:

- wide latitude range
- high population density
- high number of sunshine hours in the summer months
- representative for important agricultural districts
- existing infrastructure and competence in solar radiation measurements

Figure 2 Map of network locations

Personnel working at the network locations maintain routines for daily or weekly inspection, as well as giving necessary assistance.

The northernmost UV network instrument is located in Ny-Ålesund (79°N) and has been in continuous operation since the summer 1995. The location is a part of the Large Scale Facility for Arctic Environmental Research. The location is normally inside the polar vortex and represents a test chamber for climate change studies. The Norwegian Polar Institute operates the network instrument, and SFT via NILU is responsible for it. More information can be found on *http://www.npolar.no/nyaa-lsf/.*

Ny-Ålesund (79 °N). Photo: Jon Børre Ørbæk, Norwegian Polar Institute.

The second location in the UV network was originally the Auroral Observatory at the University of Tromsø (70°N). The instrument was operating here from the summer 1995 until end of 1999. SFT via NILU is responsible also for this UV instrument. In 2000 all UV and ozone activities in Tromsø were moved to the Andøya Rocketrange. More information about the UV activities can be found on *http://www.rocketrange.no/alomar/.*

Andøya (70 °N). Photo: Anette Jensen, Andøya RocketRange.

The Department of Physics at the Norwegian University of Science and Technology in Trondheim (63°N) houses the third network instrument, operating since 1996. The location also has instrumentation for measuring spectral and total solar radiation from the ultraviolet to the infrared. NRPA is responsible for the network instrument. More information about the UV activities can be found on *http://phys.ntnu/instdef/grupper/miljofysikk/uv/html.*

The Norwegian University of Science and Technology in Trondheim (63 °N). Photo:NRPA

The fourth network instrument is located at the Geophysics Institute at the University of Bergen (60°N), operating since 1996. The location also houses instrumentation for solar radiation monitoring and has the longest records of radiation measurements in Norway. NRPA is responsible also for this network instrument. More information can be found on *http://www.gfi.uib.no/index_e.html.*

Geophysics Institute, University of Bergen (60°N) Photo: The Photosection at the University.

The fifth UV network instrument, operating since 1996 is located at the Crop Research Station at Kise (61°N), situated by Mjøsa, the largest lake in Norway. The location conducts agricultural development studies on soils, berries, fruits, vegetables and herbs and also has meteorological facilities. NRPA is responsible also for this instrument. More information can be found on *http://www.planteforsk.no/.*

The Crop Research Location at Kise (61°N). Photo: NRPA.

The sixt and southernmost UV network instrument is located at the Crop Research Station at Landvik (58°N), near Grimstad. The location conducts agricultural development studies on seeds, vegetables, potatoes and grains and also has meteorological facilities. NRPA is also responsible for this instrument, which has been in operation since 1996. More information can be found on *http://www.planteforsk.no/.*

The Crop Research Location at Landvik (58°N). Photo: NRPA.

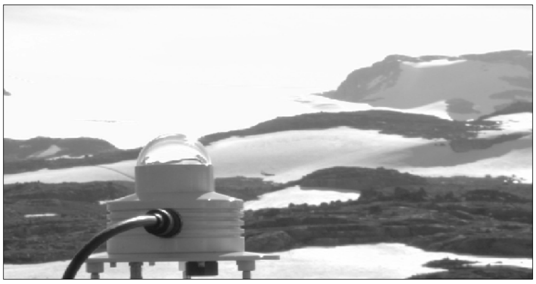
The Department of Physics at the University of Oslo (60°N) houses the seventh UV network instrument, which has been in operation since 1994. Ozone-monitoring has been performed since 1979. The University of Oslo operates the instrument, which SFT via NILU is responsible for. More information can be found on *http://www.fys.uio.no/plasma/ozone/.*

Physics Institute, The University of Oslo (60°N). Photo: Arne Dahlback at the University.

The solar calibration facilities of NRPA at Østerås, near Oslo, form the eight' location in the network. The location has been in continuous operation since 1999, when a new instrument was purchased. NRPA is responsible for this location. More information can be found on *http://uvnett.nrpa.no/uv/.*

The Norwegian Radiation Protection Authority (60°N). Photo: NRPA.

In addition, although yet not formally included in the UV network, a UV broadband instrument is opeating at the Finse Alpine Research location (60°N). Finse is located at Hardangervidda, a mountaineous plateau 1200 meter above sealevel. The instrument has been in operation periodically from 1992 to 1994 and continuously from 1996. More information can be found on *http://www.admin.uio.no/ia/uniforum/1998/uniforum06-98/08.html.*



The Finse Alpine Research Location (60°N). Photo: NRPA.

5.2 Instrumentation

The UV network consists of 11 multiband filterradiometers, model GUV from Biospherical Instruments Inc. and one double grating spectroradiometer model DM150BC from Bentham Instruments Inc. Eight of the GUV instruments are in continuous operation at the network locations, two serve calibration purposes and one is a backup. The GUV instruments (figure 3) are weatherproof and temperature stabilized. Temperature stabilization improves the accuracy of UV measurements and keeps the front optic dry. The instruments record spectral irradiance within 5 wavelength bands with bandwiths approximately 10nm. The nominal center wavelengths for the detector channels are 305nm, 313nm, 320nm, 340nm and 380nm, with exception of an older instrument with a channel in the visible part of the spectrum instead of at 313nm. The oldest instrument was purchased in 1992/1993, whereas the next 7 instruments, having optical components from the same production batches were purchased in May 1995. The last 3 instruments, having improved cosine response, were purchased in 1998, 1999 and 2001. Typical response functions, as measured by NRPA, are shown in Appendix A. The response functions may deviate significantly, even for instruments manufactured with components from the same production batches.

Figure 3 GUV multiband filterradiometers from Biospherical Instruments Inc. (left), beside NILUV multiband filterradiometers (right). Photo: NRPA.

The spectroradiometer is the primary reference instrument for the national UV network (figure 4). It serves as link to international UV monitoring networks through Nordic intercomparisons in 1996 (Kjeldstad et al., 1997) and 2000 (unpublished). Electronics and wavelength dispersive optics are housed in a temperature stable box inside the building. A lightguide connects the spectroradiometer with the input optic at the solar platform. In spring of 1999, the spectroradiometer was upgraded. Problems with temperature stabilization and large hysteresis effects in detector response were resolved with new electronics and a new type of photomultiplier tube. The front optic was redesigned to improve the cosine response; applying a spherically shaped diffusor and a quartz dome purchased via Gigahertz Optik. Optimisations have resulted in a close to perfect cosine response. This means that spectral irradiance can be accurately monitored for all sky conditions and solar zenith angles. Temperature stabilization of front optic and continuous flushing with dry nitrogen inside eliminates effectively any humidity problems. Global scan spectra are recorded every 10 minutes for the wavelength range 290nm to 450nm (optionally 500nm) in steps of 0.5nm. Spectral bandwidth, defined as full width at half maximum (FWHM), is 0.89nm.

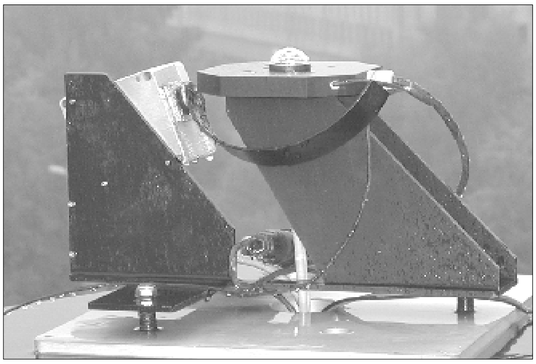
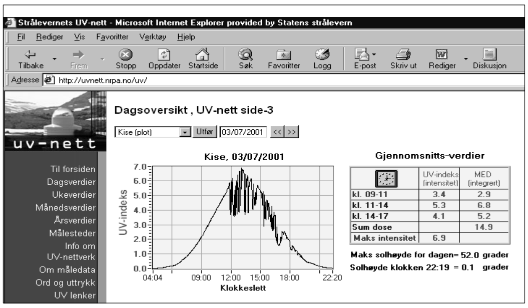


Figure 4 Front optic of Bentham DM150BC spectroradiometer. Photo: NRPA.

6 Remote access and processing of UV-data

PCs connected to the local GUV instruments record spectral irradiance for each detector channel at one-minute intervals. Several times a day, measurement data is transferred automatically to and between fileservers at NILU and NRPA. In the same operation, the local PC clocks get synchronised with a timeserver. The locations are connected to central servers through internet and modems. Measurement data is stored as uncorrected data. A database developed at NRPA stores data in a structured and easily accessible form, keeping hold of instrument-specific calibration and weighting factors for each network location and instrument. Calibration factors are listed in Appendix B. The database is updated automatically and corrected UV-doses and UV-indices processed as soon as raw data has been transferred to NRPA. The database allows manual insertion of estimates where data is missing in order to keep complete records of UV-data for all days since the start of the UV monitoring program. The database is connected to a website *http://uvnett.nrpa.no/*, providing online graphical display of daily, weekly, monthly and annual UV-indices and UV-doses for each location (figure 5, Mikkelborg et al., 1999). The user community as well as public and media have shown increasing interest for UV-data and information about the health and environmental aspects of UV radiation. Health relevant UV-data may also be found by visiting websites at NILU and the University of Oslo, who also provides ozone and sky optical depth data from GUV measurements; *www.luftkvalitet.info* and *http://fys.uio.no/plasma/ozone*. UV forecasts provided by NILU are available on the internet and media and have similarly triggered great interest for UV-data



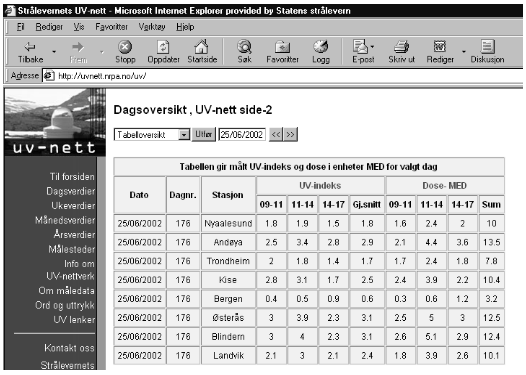
Dagsoversikt , UV-nett side-3

Gjennomsnitts-verdier

	UV-indeks (intensitet)	MED (integrert)
kl. 09-11	3.4	2.9
kl. 11-14	5.3	6.8
kl. 14-17	4.1	5.2
Sum dose		14.9
Maks intensitet	6.9	

Maks solhøyde for dagen= 52.0 grader
Solhøyde klokken 22:19 = 0.1 grader

Figure 5a Online display of UV-index at a selected location (Kise), http://uvnett.nrpa.no/.



Dagsoversikt , UV-nett side-2

Tabellen gir målt UV-indeks og dose i enheter MED for valgt dag

Dato	Dagnr.	Stasjon	UV-indeks				Dose- MED			
			09-11	11-14	14-17	Gj.snitt	09-11	11-14	14-17	Sum
25/06/2002	176	Nyaalesund	1.8	1.9	1.5	1.8	1.6	2.4	2	10
25/06/2002	176	Andøya	2.5	3.4	2.8	2.9	2.1	4.4	3.6	13.5
25/06/2002	176	Trondheim	2	1.8	1.4	1.7	1.7	2.4	1.8	7.8
25/06/2002	176	Kise	2.8	3.1	1.7	2.5	2.4	3.9	2.2	10.4
25/06/2002	176	Bergen	0.4	0.5	0.9	0.6	0.3	0.6	1.2	3.2
25/06/2002	176	Østerås	3	3.9	2.3	3.1	2.5	5	3	12.5
25/06/2002	176	Blindern	3	4	2.3	3.1	2.6	5.1	2.9	12.4
25/06/2002	176	Landvik	2.1	3	2.1	2.4	1.8	3.9	2.6	10.1

Figure 5b Online display of mean and total UV-index and UV-doses on a selected day, http://uvnett.nrpa.no/.

7 Continuity in UV measurements

GUV instruments operate automatically and are only dependent on a local computer for storing to disc. The instruments are robust and require normally only routine maintenance, like daily inspections and cleaning. The continuity in UV measurements has generally been good for the period 1996 to 2001. However, stops in measurements happen and routines for daily checks of data transfer and actions to restore UV monitoring are required. Online display of UV measurements on the internet (*http://uvnett.nrpa.no/*) provides a tool where loss of measurement data quickly can be detected.

Gaps in measurement series are defined as number of days with more than 2 hours break in measurements and where the gaps have occurred during daylight periods (Figure 6). Five locations have moderate losses, about 60 days for the 6 years period, whereas the instruments in Bergen and Tromsø/Andøya have up to 275 days with significant gaps. Instruments operated by NRPA at Landvik, Kise, Bergen and Trondheim had several gaps in 1996, mainly because UV monitoring did not start before late January or February. These instruments and the first transfer standard instrument were spectrally characterised before deployment in order to obtain reference data for later comparisons. In addition, software for communication via modems, computer controlled set-ups for calibrations and characterisations had to be developed. Instruments operated by NILU at Blindern, Tromsø/Andøya and Ny-Ålesund had gaps because of calibrations, characterisations and repair of one detector controller. Characterisations were always made during the winter period in order to keep the losses in UV-doses low. The excessive gaps during the autumn and winter seasons of 1998/1999 in Bergen were due to shipments to NRPA and to the manufacturer in USA for examinations and repair. The end cap had developed starshaped fractures and was replaced in order to avoid water entering the optics. In the near future, other GUV instruments will need the same repair. Gaps in measurement series were also caused by shutdowns in mains, which du to thunderstorms happened at Kise and Landvik. Battery power backup systems were installed in 1998 at all locations operated by NRPA. Electronic protection of mains and phone lines from lightning-generated spikes will be installed at Kise and Landvik in 2002. All detector controllers have had failures with power supplies. During the year 2000, one controller from NRPA and two controllers from NILU had failures in the same period. NILU invented a modified design for the temperature regulating circuit, which eliminates future malfunctions. NILU's modification scheme has been implemented on all detector controllers in the network, and two more spare detector controllers have been purchased. Further, there have been gaps in measurements due to computer failure. In autumn 2000 there was also a period with gap due to construction works on the solar platform in Bergen.

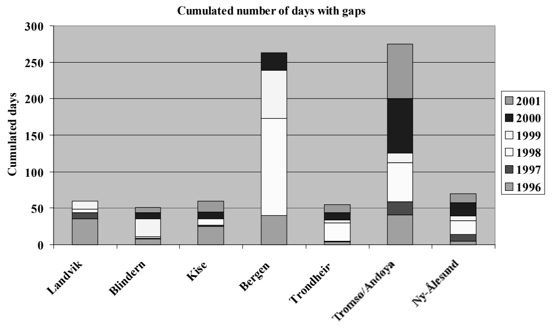


Figure 6 Number of days with significant loss of UV measurements since 1996.

Subtracting the number of days related to late deployment in 1996, repair, calibrations and building construction works from the total number of days with gaps, a more relevant picture of the discontinuity in measurements appears (Figure 7). The cumulated number of days with gaps are 40 or less for 5 locations, 59 days for Ny-Ålesund and 222 days for Tromsø/Andøya. Clearly, the continuity in UV measurements is anomalous for Tromsø/Andøya compared to the other locations. It must be concluded that there has been degradation in continuity for this instrument after deployment at Andøya in 2000.

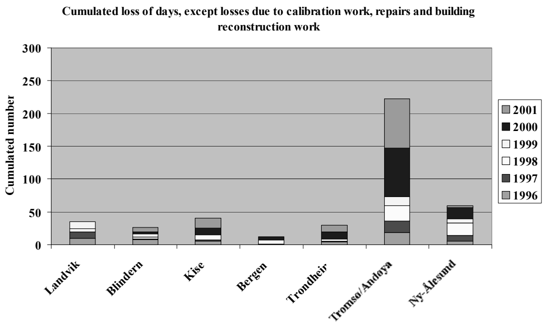


Figure 7 Number of days with significant loss of UV measurements, excluding gaps that are caused by calibrations, repairs and building construction works.

8 Estimates of missing UV-doses and UV indices

Daily UV-doses and UV-indices can be estimated from measurements of total solar radiation, reflecting the attenuation of radiation caused by clouds, and calculations of the theoretical clear sky radiation. With exception of Andøya, pyranometers measuring total hourly radiation are located in proximity to every location in the UV network. The institutes responsible for these pyranometers have kindly provided data for the locations of interest. The Geophysical Institute in Bergen also provided daily hourly reference data for clear sky conditions at each location. The ratio between actual measured total radiation, corrected for calibration errors, and clear sky modelled data, is the total sky transmittance. An empirical fit has been derived between the total sky transmittance and the UV sky transmittance, which shows approximately a linear relation. Combined with estimates of the albedo and ozone data derived from satellites or ground instruments, real sky UV-doses and UV-indices may be estimated. We have applied the radiative transfer model libRadtran (Kylling and Mayer 2000) to generate UV-spectra needed for the calculation of hourly clear sky UV irradiances. The clear sky UV irradiances were then modified according to the UV sky transmittances for calculating daily UV-doses and maximum UV-indices.

An example of how well the method works is shown for the UV instrument in Bergen, which had no gaps in 1997. In Figure 8 the input data is the daily total ozone amount and the estimated noon UV sky transmittance. Daily total ozone amounts have been derived from GUV measurements where existing, using software made by Dahlback at the University of Oslo (zardoz.nilu.no), and from the earth probe Total Ozone Mapping Spectrometer TOMS (*http://toms.gsfc.nasa.gov/fltmodel/spacecr.html*). The albedo is assumed to be 5% for the whole year.

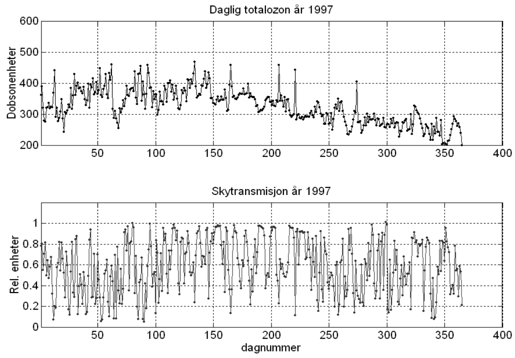


Figure 8 Daily total ozone (upper panel) and daily UV sky transmittance (lower panel) in Bergen, 1997.

Figure 9 shows daily UV-doses, theoretical estimates of UV-doses, where estimates have been normalised to the actual annual UV dose, and the ratio between theoretical and actual UV-doses. The ratios are approximately flat for the whole year, with standard deviations less than ±15%. For the Andøya location, the same method has been applied, except there was no ancillary data available for the estimation of UV sky transmittance. The uncertainty in estimated UV-doses is here assumed to be twice as high as for locations with pyranometer data.

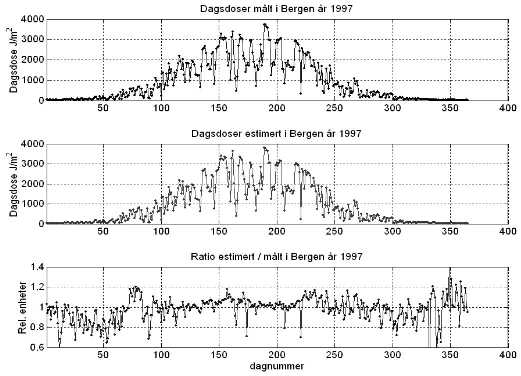


Figure 9 Daily UV-doses in Bergen 1997, measurements (upper panel), theoretical estimates (mid panel) and ratio between estimates and measurements (lower panel).

Reviewing the days with significant gaps in measurement series (Figure 6), the cumulated loss in annual UV-doses is shown in Figure 10. For the 6 years period, Bergen and Tromsø/Andøya had the largest gaps, affecting in total 19% and 63% of an annual UV dose.

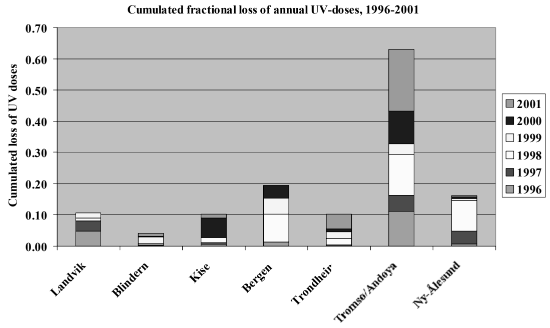


Figure 10 Cumulated loss in annually integrated UV-doses from days with gaps in UV measurements.

By excluding the gaps caused by late deployment in 1996, repair, calibration and building construction works (Figure 7), the effective cumulative losses in annual UV-doses become as shown in Figure 11. The cumulated losses amount 11% or less for 5 locations, 16% for Ny-Ålesund and 63% for Tromsø/Andøya. Assuming respectively +/-15% and +/-30% uncertainty in the estimates of daily UV-doses for locations with and without pyranometer data, the uncertainties in annual UV-doses from estimates of missing data are respectively less than ±1.5% and up to ±6% in addition to the calibration uncertainty.

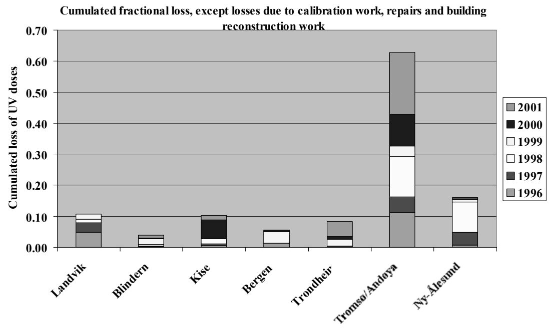


Figure11 Cumulated loss in annually integrated UV-doses, excluding gaps caused by calibrations, repairs and building construction works.

9 Quality control and calibrations

The quality control starts at the local locations. Instruments are daily or weekly inspected and have the front optics cleaned. The importance of regular inspections is illustrated in Figure 12, showing bird excrements left on the front optic. Local PC clocks are synchronised every day and data is downloaded to fileservers at NILU and NRPA. The website providing online display of measurement results (*http://uvnett.nrpa.no/*) is a powerful tool for early detection of problems with operation or data transfer or storage and has improved the continuity in measurements for several locations. When it comes to measurement quality, a spectroradiometer located at NRPA is in continuous operation, providing a reference for solar comparisons with other instruments, including the two travelling transfer standard instruments. Once a year the spectroradiometer is brought down to the optical lab at NRPA for calibrations towards standard lamps. During the normal operation outdoor, deviations from the initial irradiance calibrations are measured and corrected for with a set of portable lamps, performed once or twice a month. Errors in the wavelength scale are corrected for, applying a wavelength shift detection technique, where the measured sky spectra are correlated with a reference spectrum (Slaper et al. 1995). A close to perfect angular response of the front optic provides automatic cosine correction. Recommendations for quality control of spectra, provided by the World Meteorological Organization (WMO), are thus fulfilled.

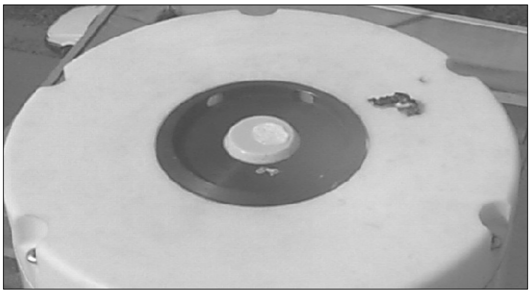


Figure 12 Bird excrements on the front optic of a GUV instrument.

9.1 Assessments of longterm stability in instruments

Once a year one or both of the networks transfer standard instruments are shipped to the local sites, providing on-site solar comparison of measurement results. Longterm changes in detector responses may then be quantified and corrected for, without disturbing the continuity in UV monitoring at the location.

The method for quantifying changes in the network instruments involves 3 steps. In the first step, the longterm changes in the transfer standard instrument itself are determined. First we apply a set of stable conventional as well as optical feedback regulated 1000-Watt quartz tungsten halogen lamps for this purpose (figure 13). Exposed to the radiation from the lamps, the detector signals may be related to the signals that were measured before the deployment in 1995. The 5 detector channels of the transfer standard have been observed to be stable within –2% to +5% for the years since 1995 (Appendix B). This is the smallest drift detected among all GUV instruments, which could be related to the fact that it has been less exposed to solar UV radiation than the instruments in continuous operation. Once a year the instrument is shipped to the manufacturer for an independent evaluation of the long-term stability. Finally, once a year the change in solar calibration factors derived from comparisons between the reference spectroradiometer and the transfer standard GUV are compared with the lamp based changes in order to verify that they are consistent. So far, the most consistent reference scale appears to be our own laboratory lamps. Thus, the corrections for longterm changes in the reference GUV are based on these lamp standards. Having established correction factors for the transfer standard, the correction factors for the local instruments may be derived from on-site solar comparisons (step 2). Ratios of corresponding detector channel readings are calculated for the local instrument and the transfer standard. Differences in spectral response functions may show up as ratio curves being increasingly convex as function of the SZA. The SZA-dependency is removed in the third step, whereby observed ratio curves are normalised to ratio curves simulated for the same sky conditions and SZAs with knowledge of the spectral response functions of each instrument and detector channel. In this step, the spectral response function of either instrument is convolved with solar spectra generated for a set of SZAs and the actual ozone amount. The result is a flat curve, where the actual change in detector responsivity is the offset from 1.00.

The relative change in the spectral responsivity of each instrument's channels is shown in Appendix B. Some instruments demonstrate a gradual increase or decrease in responsivities over the years, whereas others demonstrate a sudden recovery after some years. Generally the responsivity of the 305-channels have increased, whereas the responsivity of the 320-channels have decreased over time. The 340- and 380-channels appear to be the most stable, whereas there is no specific trend for the 313-channels. Comparing instruments from different production series, the 7 instruments with optical components from the same production batches (s/no. 9270 to 9276) are more stable than instruments purchased one by one. The 320-channels are less stable than other channels, and possibly this channel may limit the lifetime of the instruments in the network. The responsivity of the 320-channel of the oldest instrument has dropped by 23% over 6 years. This instrument also shows a diurnal hysteresis in the dark current, which disturbs mesurements above 80° SZA. We recommend that a new instrument soon be purchased for permanent installation beside this older instrument. This will allow a gradual exchange of deficit instruments, maintaining overlap in timeseries.

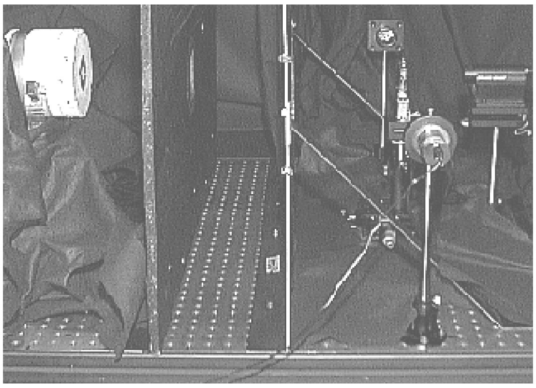


Figure 13 Set-up for monitoring of the long-term stability of a transfer standard GUV, applying a calibration lamp and laser-based alignment tools

9.2 Calibration scale

The calibrations and maintenance of a calibration scale stable over many years are crucial for the accuracy of climate change assessments and effects studies. The calibrations are based on a high-resolution spectroradiometer and lamp standards, and comparions with other spectroradiometers. Applying the spectroradiometer as reference, the absolute spectral response of filterradiometers may be derived by relating the signals from detector channels to the absolute spectral irradiance. In the next step, biologically weighted irradiances may be derived from a combined sum of spectral measurements (Dahlback, 1996). Originally, the calibrations of the UV-network were based on the manufacturers SUV-spectroradiometer. Intercomparisons performed in Oslo during the summer 1995 (Johnsen and Hannevik, 1997) showed that the internal agreement in spectral irradiances was good for all detector channels and instruments, within ±2% for SZA less then 50°. For SZA above 50° the shortwave detector channels showed increasingly departure, up to 50% at 80°, indicating differences in the instruments spectral response functions. On the basis of SUV spectra and spectral response functions measured at NRPA, Dahlback calculated instrument specific weighting factors, which form the basis for the previous annual reports (Hannevik et al. 1998, Norvang et al., 2000). From 2000 the calibration scale and weighting factors for the UV network has been adapted to the lamp standards and the spectroradiometer of NRPA. The spectroradiometer has implemented a front optic, which enables close to ideal cosine response for all SZAs, verified during the latest Nordic intercomparison of spectroradiometers (NOGIC2000). The recalibrations imply an increase of about 10% in the calibration scale, as well as improved accuracy for large SZAs. Absolute calibrations of the UV-network transfer standards are based on the clear sky spectral sky measurements performed at NRPA on days 127 in 2000 and 128 in 2001. The repeatability in lamp spectral measurements with a GUV instrument has shown to be better than the repeatability in solar spectral measurements with a spectroradiometer. Thus the maintenance of the UV networks calibration scale has been based on relative lamp measurements with absolute solar calibrations in 2000 and 2001 as fixed points, rather than annually adapting the absolute solar calibrations to the spectroradiometer.

9.3 Participation in Nordic intercomparisons

The spectroradiometer of NRPA participated in the Nordic intercomparisons of UV and total ozone instruments in 1996 (Kjeldstad et al., 1997) and 2000 (unpublished). The agreement was very good both years. For the latest intercomparisons the agreement was within –1%±2% for all days and SZAs (figure 14), indicating excellent match with reference instruments from other national UV networks. In addition to the spectroradiometer, NRPA participated with one of the network transfer standard GUV instruments and a broadband UV-Biometer instrument from Solar Light Company. With our own calibrations the UV-doses obtained for the blindtest comparisons agreed with the references by respectively +0.3%±1.5% and –0.5%±1.5% for 4 out of 6 days (personal communication L. Ylianttila 2002).

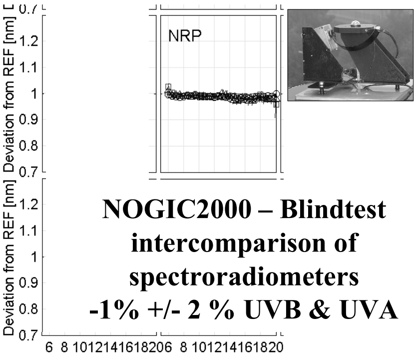


Figure 14 Agreement between the spectroradiometer of NRPA and the NOGIC2000 reference data for the wavelength intervals305-315 nm, 355 - 365 nm and 380 to 390nm. Time period is 06 to 20 UTC, day 162 (personal communication T. M. Thorseth 2001).

9.4 Revised dose assessments

Based on the principle that the effective time-integrated UVR (UV irradiances) can be derived as a weigthed sum of simultaneous measurements of spectral irradiance, we have calculated a set of new weighting factors for each GUV instrument. By optimising the weigthing factors, the result is a close to perfect match between irradiances obtained for the GUV instruments and the spectroradiometer. In Figure 15, measurements of the diurnal irradiance for a summer day with periods of cloud cover are shown for 3 GUV instruments and the spectroradiometer. Plotted as function of the SZA, the ratio between measurements obtained for each GUV instrument and the spectroradiometer are shown to be within ±2% for SZAs up to 80° (figure 16). The high consistency for large SZAs demonstrates that the GUV instruments are particularly well suited for UV monitoring at high latitudes.

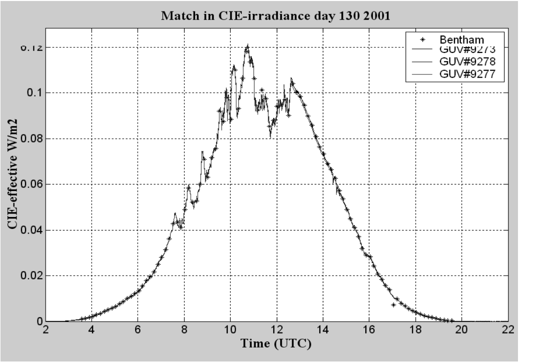


Figure 15 Erythemally effective irradiances measured with the spectroradiometer (crosses) and 3 GUV instruments (continuous lines). NRPA, day 130 2001. Serial numbers for the GUV instruments are 9273, 29222 (called 9277) and 29229 (called 9278).

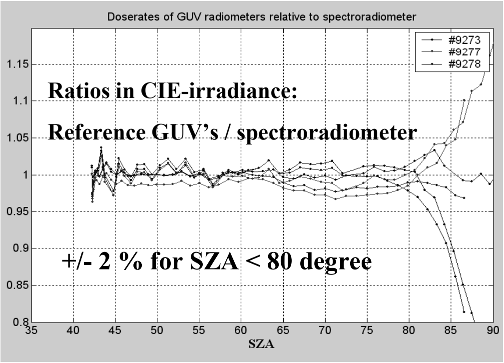


Figure 16 Ratios between GUV instruments and the spectroradiometer, as function of SZA. NRPA, day 130 2001.

A re-evaluation of the complete measurement period 1996-2001 has been conducted. Local GUV instruments have been absolute calibrated towards the transfer standards. Weighting factors have been optimised for each instrument. Irradiances agree within ±1% for SZAs up to 80° for all locations, as demonstrated for the location in Bergen (figure 17), Andøya (figure 18) and Ny-Ålesund (figure 19). The consistency in daily UV-doses is within ±2% for the six years of local comparisons. The excellent internal agreement among locations and the agreement over time imply that trend detections may be achievable with high significance.

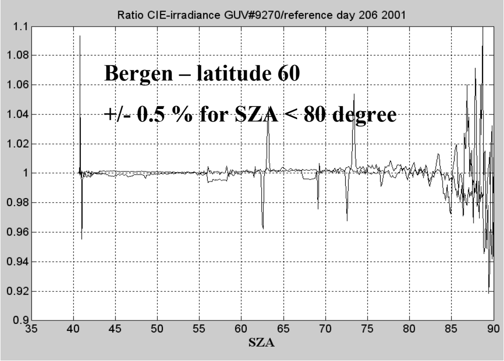


Figure 17 Ratios of irradiances measured with the GUV instrument in Bergen and the transfer standard, as function of SZA. Results from day 206 in 2001.

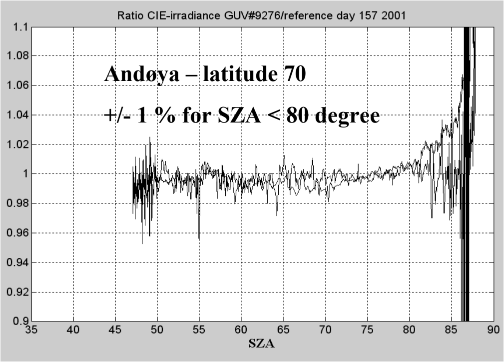


Figure 18 Ratios of irradiances at midnight sun conditions, measured with the GUV instrument at Andøya and the transfer standard. Spikes in ratio curve are resulting from drifting clouds and small synchronisation errors. Results from day 157 in 2001.

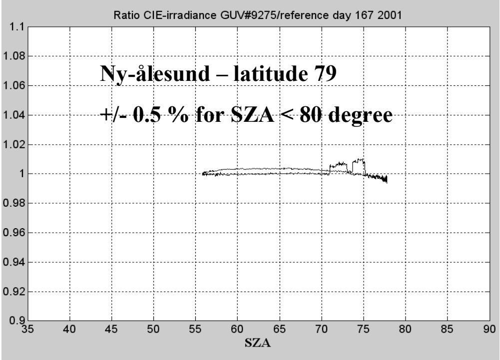


Figure 19 Ratios of irradiances at midnight sun conditions, measured with the GUV instrument in Ny-Ålesund and the transfer standard. Results from day 167 in 2001.

10 Measurement uncertainties

The uncertainty budget for the spectroradiometer of NRPA is shown in Appendix C, Table C1. The most significant error source is the primary calibration lamps, calibrated at the Swedish Testing and Research Instiute in Borås 1996. Other signifiant sources are an azimuthally dependent cosine error, estimated to within ±1.6% for all SZA and sky conditions, and an intensity hysteris effect of about ±1.5%. The hysteresis effect is manifested as a diurnal increase in the signal for increasing exposure of the instrument, and can be separeted from the azimuthal effects. In total the errors amount to ±4% at 2-sigma level for the wavelength region 300-400nm.

During the NOGIC2000, the agreement with reference spectroradiometers was –1%±2%. The consistency with other European UV monitoring networks is thus much better than the absolute uncertainty in the calibration scale.

An uncertainty budget for the daily UV-doses from GUV instruments is shown in Appendix C, Table C2. The main contributors are the uncertainty in the primary calibration from comparisons with the spectroradiometer (±4%), and the uncertainty in maintaining a stable scale from relative measurements towards a transfer standard instrument (±2%). In total, the uncertainty in UV-doses is estimated to ±5% at 2-sigma level. For the annual UV-doses, additional errors resulting from estimating gaps in measurement series are within ±1.5% for all locations and years, except Andøya, where the uncertainty amounts up to ±3% in 2000 and ±6% in 2001.

11 Results

UV measurement data is presented for the period 1995/1996 to 2001 for eight UV monitoring locations in Norway. The results are provided as erythemally effective UV radiation based on the International Commission on Illumination action spectrum for induction of erythema in Caucasian skin types (CIE 1999). The UV irradiances are reported in units of Global Solar UV-index (WHO/ICNIRP 1995, WHO 1999). The UV-index corresponds to the instantaneous CIE-effective irradiance [W/m2] times 40, and is usually reported for the maximum at noon. The concept UV-index is widely used for public information concerning sunburn potential of solar UV radiation. UV radiation at the earth surface corresponds typically to UV-indices between 0 and 10, but can range up to 20 at Equatorial regions and high altitudes (WHO 1998).

11.1 UV index

Daily maximum UV-indices at each network location are shown in figure 20 to 27. The UV-indices follow annual cycles varying from 0 to 6.5 for the southernmost lowland locations, 0 to 4.5 in Tromsø/Andøya and 0 to 3 in Ny-Ålesund. The UV-index corresponding to sunburn risk is highly dependent on the skin type. People with a skin type that easily get sunburned may pose low sunburn risk for UV-indices below 3, moderate risk for UV-indices 3-4, high risk for UV-indices 5-6, very high risk for UV-indices 7-8 and extreme risk for UV-indices above 9 (WHO 1998).

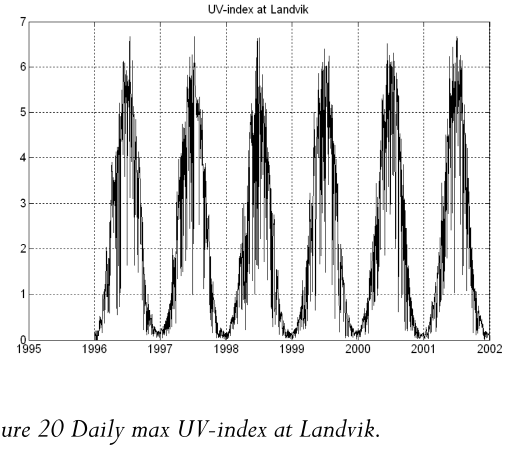


Figure 20 Daily max UV-index at Landvik.

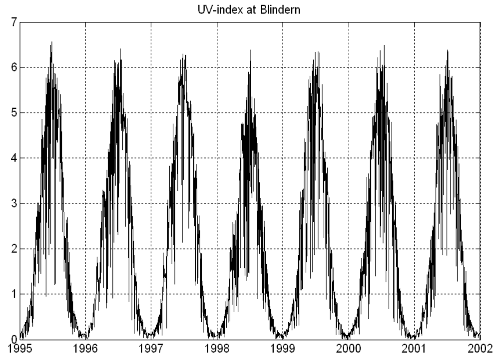


Figure 21 Daily max UV-index at Blindern.

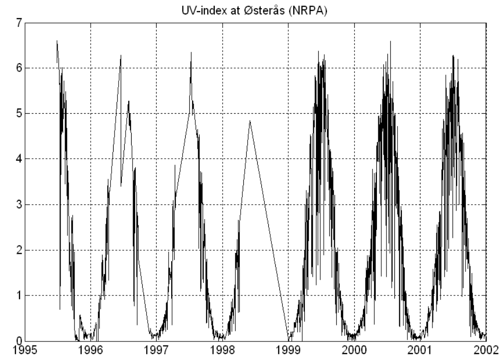


Figure 22 Daily max UV-index at Østerås (NRPA).

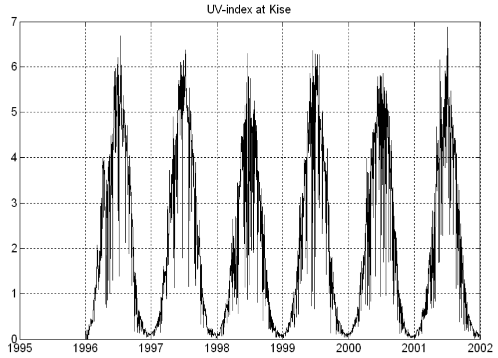


Figure 23 Daily max UV-index at Kise.

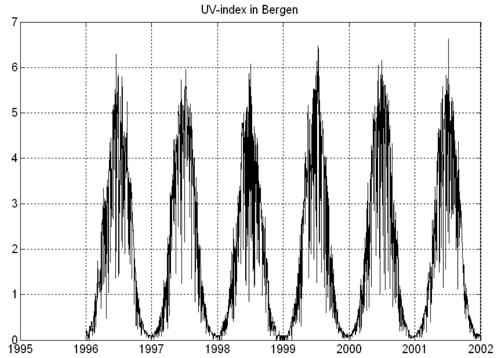


Figure 24 Daily max UV-index in Bergen.

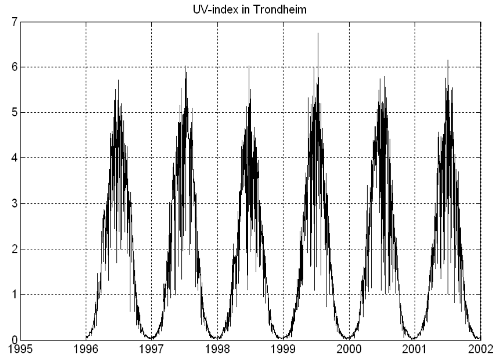


Figure 25 Daily max UV-index in Trondheim.

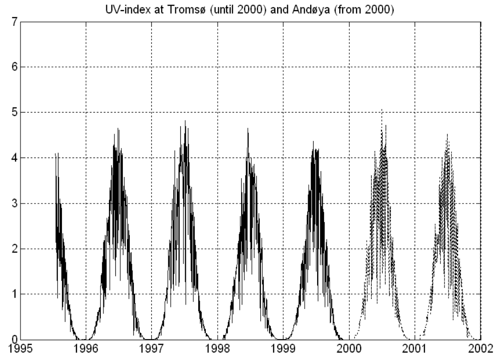


Figure 26 Daily max UV-index in Tromsø (1995-1999) amd Andøya (2000-2001).

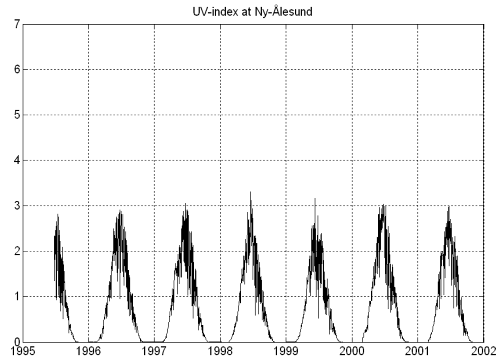


Figure 27 Daily max UV-index in Ny-Ålesund.

UV-indices above 6.5 might happen, the most prominent peaks observed for a few days at Kise in July 2001 and in Bergen and Trondheim in July 1999. The total ozone amount recorded by TOMS was 290 to 300 Dobson units (DU) for these days and locations. Plots of the daily variation in UV-index at Kise (figure 28) indicate that the day before and after the peak had almost clear sky conditions and UV-index 5.9 at noon. The day between had drifting clouds, causing large and rapid modulations of the UV-index. For these days the total ozone amounts recorded by TOMS were respectively 314DU, 300DU and 306DU. The enhancement in UV-index by 14DU less total ozone corresponds to theoretically 5% increase in UV-index, whereas 15% increase was observed. The observations demonstrate that clouds may also significantly amplify the UV radiation if they are partially covering the sky without occluding the sun.

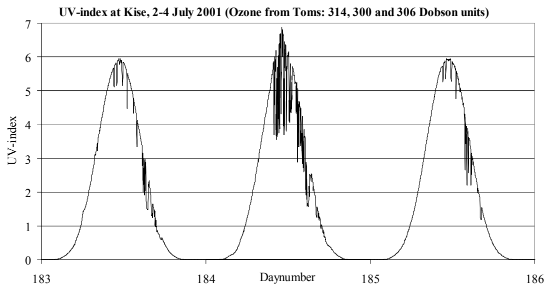


Figure 28 UV-index at Kise, 2-4 July 2001.

Monthly mean daily UV-indices are shown in figure 29-36 and tabulated in Appendix D. For the six years summer means, there is one year for each location that separates from the other years. In Tromsø the summer means were significantly higher (11%) in 1997, in southern Norway significantly lower (9-12%) in 1998 and in Ny-Ålesund significantly lower (12%) in 1999. The 8 sites are located from 58°N to 79°N. The differences in latitudes correspond to different magnitude, as well as length of period with UV-index above 1.0. Locations in southern Norway generally achieve the highest UV-indices in July, whereas June for the two northern locations. At Landvik the mean UV-index exceeds 1.0 for 7.5 months (March-September/October), corresponding to 5 months (April-August) in Ny-Ålesund. Blindern and Østerås, located 5 km apart in respectively urban and rural areas, correspond within ±2% for 7 monthly means for the period 1999-2001.

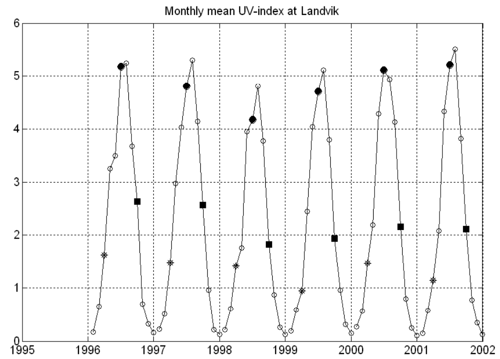


Figure 29 Monthly mean daily UV-index at Landvik.

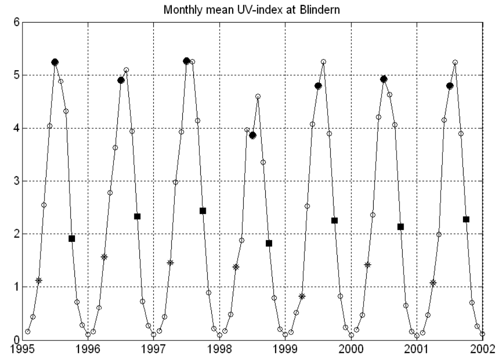


Figure30 Monthly mean daily UV-index at Blindern.

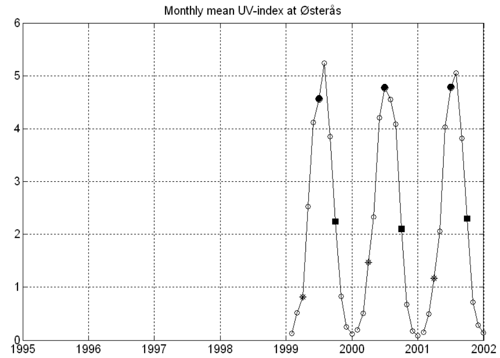


Figure 31 Monthly mean daily UV-index at Østerås (NRPA).

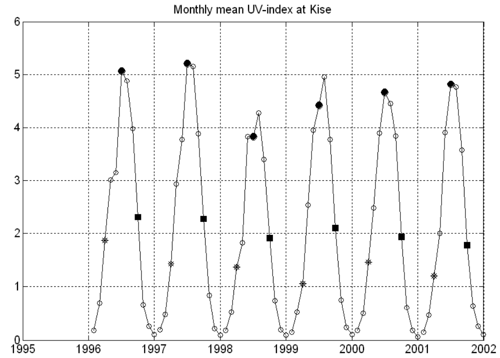


Figure 32 Monthly mean daily UV-index at Kise.

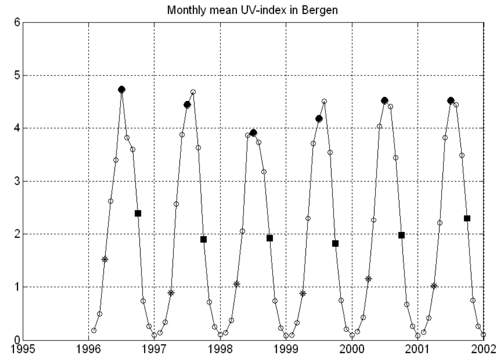


Figure 33 Monthly mean daily UV-index in Bergen.

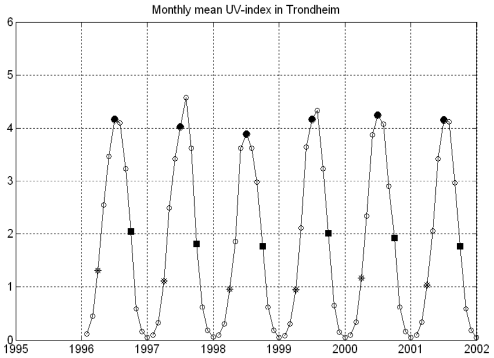


Figure 34 Monthly mean daily UV-index in Trondheim.

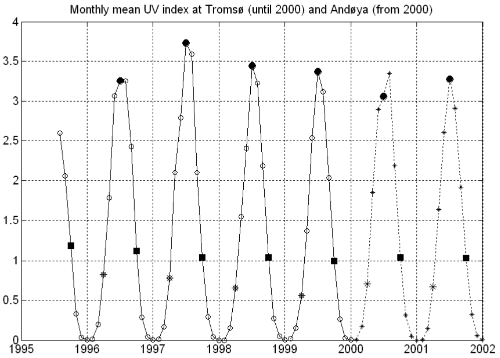


Figure 35 Monthly mean daily UV-index in Tromsø (1995-1999) and Andøya (2000-2001).

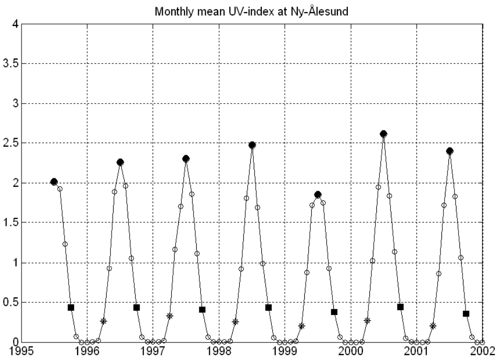


Figure36 Monthly mean daily UV-index in Ny-Ålesund.

11.2 Daily UV-doses

Daily, CIE-effective UV-doses are shown in figure 37-44. The annual summer maximum is typically 2800J/m^2 in Ny-Ålesund and increases gradually with decreasing latitudes to 4000J/m^2 at Landvik. For the 6 years period, the largest variations in summer maxima are seen for Landvik in 1998 (-10%) and 2001 (+12%), and in Ny-Ålesund in 1999 (-15%). The exceptional high daily dose at Landvik on 3 July 2001 corresponds to clear sky conditions and a fairly low total ozone amount of 306DU (TOMS). The maximum UV-index was however not significantly different from other years, as well as neither the daily UV-doses at other locations in southern Norway.

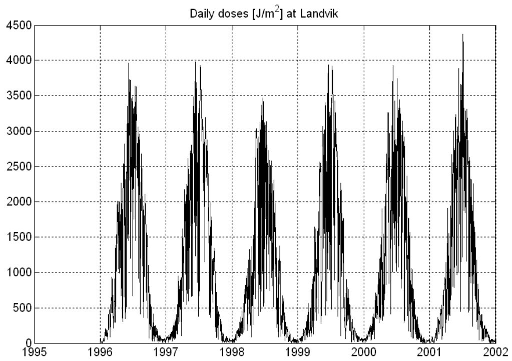


Figure 37 Daily effective UV-doses (Jm^2) at Landvik.

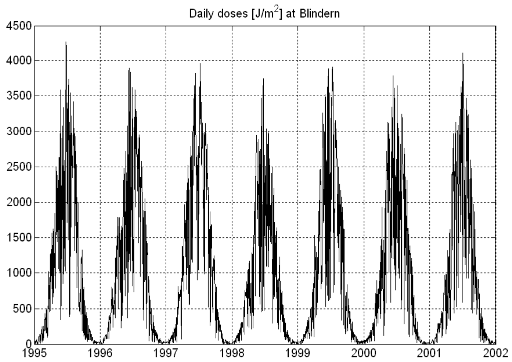


Figure 38 Daily effective UV-doses (Jm^2) at Blindern.

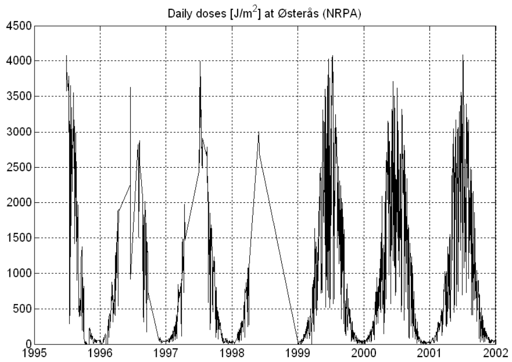


Figure 39 Daily effective UV-doses (Jm^2) at Østerås (NRPA).

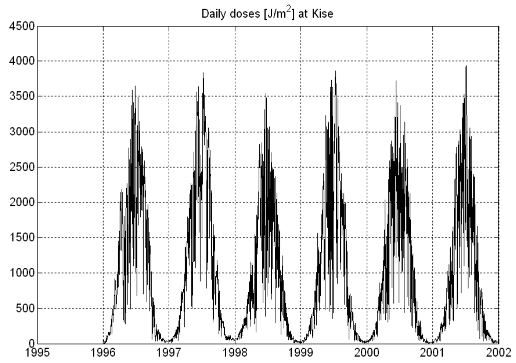


Figure 40 Daily effective UV-doses (Jm^2) at Kise.

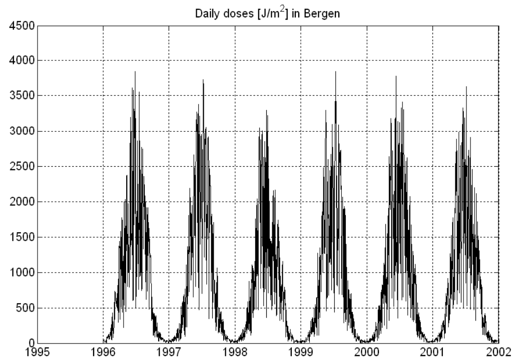


Figure 41 Daily effective UV-doses (Jm^2) in Bergen.

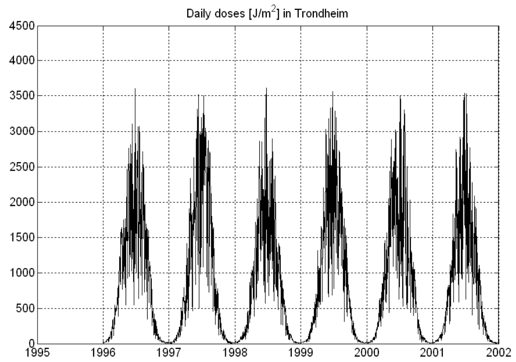


Figure 42 Daily effective UV-doses (Jm^2) in Trondheim.

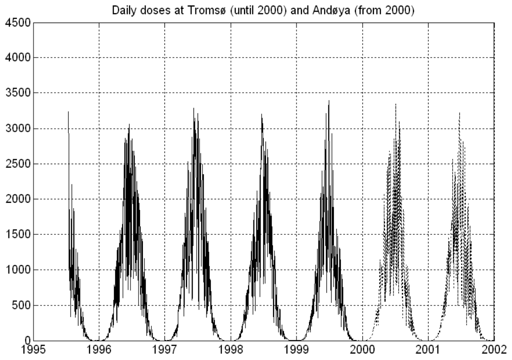


Figure 43 Daily effective UV-doses (Jm^2) in Tromsø (1995-1999) and Andøya (2000-2001).

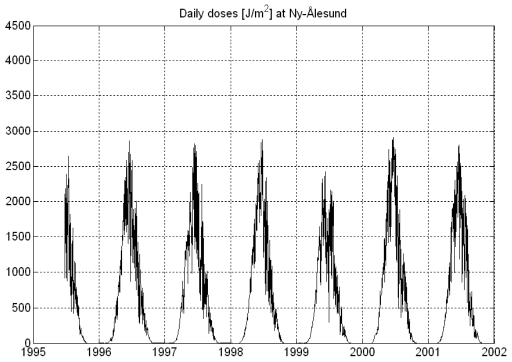


Figure 44 Daily effective UV-doses (Jm^2) in Ny-Ålesund.

Monthly mean daily UV-doses are shown in figure 45-52 and tabulated in Appendix D. The inter-annual variations follow the pattern seen for UV-indices, however, more accentuated. Summer means are significantly lower (-15%) in 1998 for the locations in southern Norway and in 1999 (-14%) in Ny-Ålesund. The summer means are also outstandingly higher in 1997 (+15%) for all locations except Ny-Ålesund. The period of the year corresponding to sunburn risk may be defined as the period with monthly means exceeding 2 minimal erythema doses (MED) per day. The MED of Caucasians with skin type II (burns moderately, tans minimally) is typically 210 J/m^2 (Parrish 1982). The period with significant sunburn risk corresponds to mid March to mid October (7 months) at Landvik and early April to mid September (5.5 months) in Ny-Ålesund.

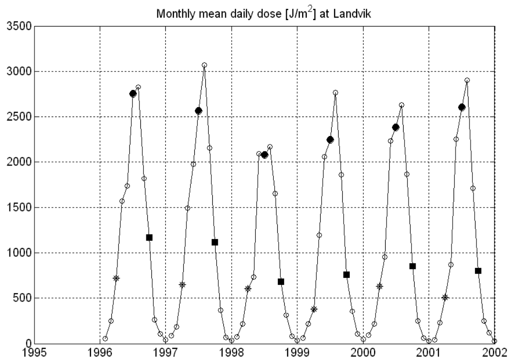


Figure 45 Monthly mean daily UV-doses at Landvik.

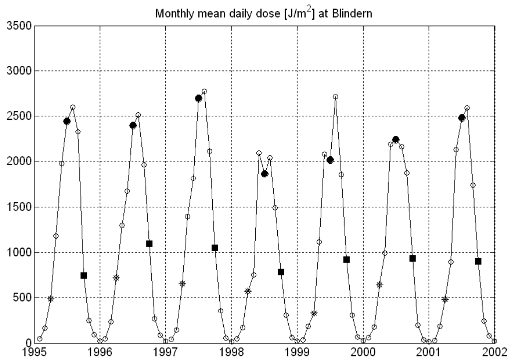


Figure 46 Monthly mean daily UV-doses at Blindern.

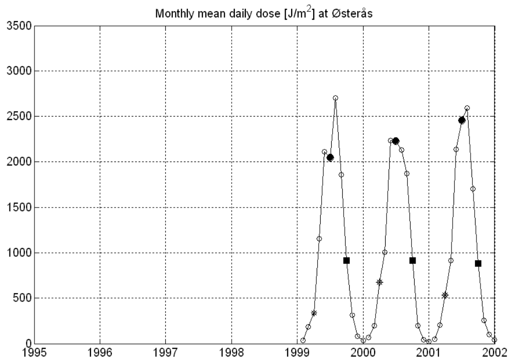


Figure 47 Monthly mean daily UV-doses at Østerås (NRPA).

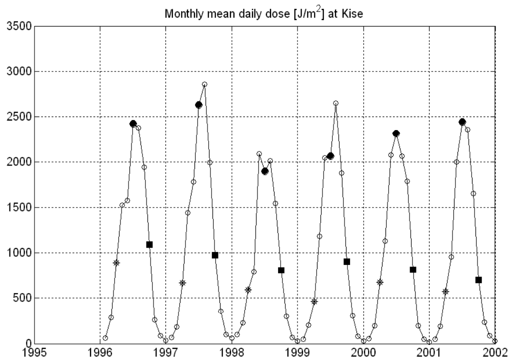


Figure 48 Monthly mean daily UV-doses at Kise.

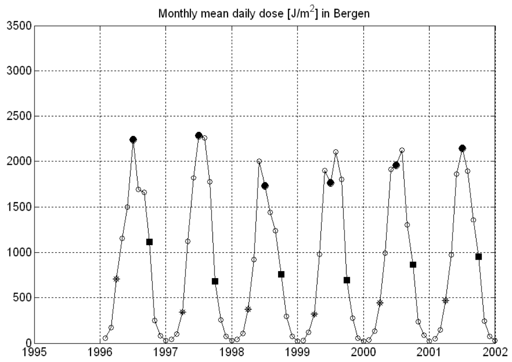


Figure 49 Monthly mean daily UV-doses in Bergen.

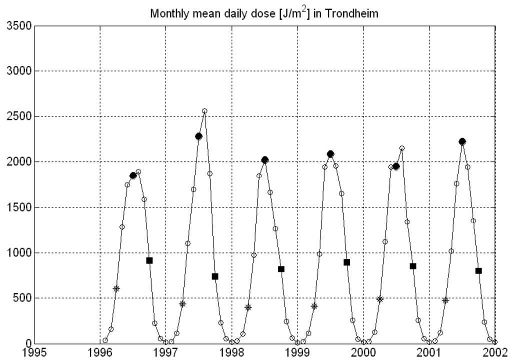


Figure 50 Monthly mean daily UV-doses in Trondheim.

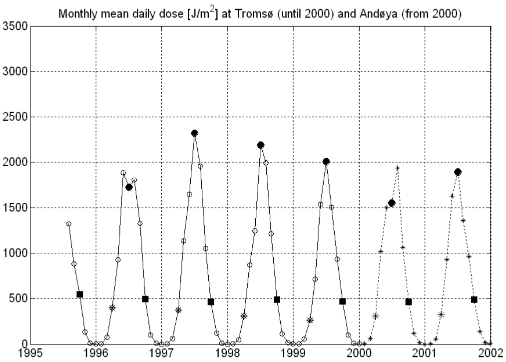


Figure 51 Monthly mean daily UV-doses in Tromsø (1995-1999) and Andøya (2000-2001).

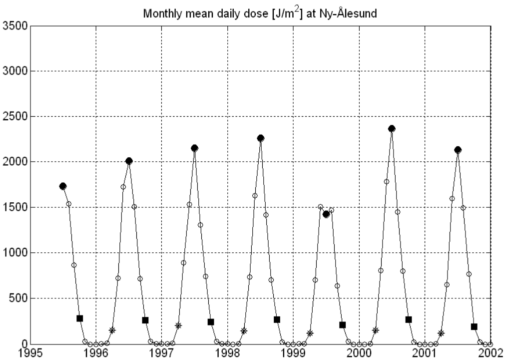
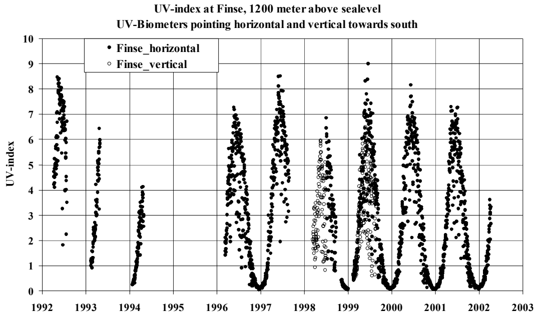


Figure 52 Monthly mean daily UV-doses in Ny-Ålesund.

11.3 High- and low altitude UV-locations

Two Solar Light SL-501 UV-Biometers have been partially in operation since 1992 at the Finse Alpine Research Location. Situated near the glacier Hardanger Jøkulen at an altitude of 1200 meter, the measurements facilitate a comparison between high- and low-altitude environments at approximately the same latitude. Time-series with daily maximum UV-indices and UV-doses are shown in Figure 53 and 54. Note that the y-axis for the alpine measurements has been expanded compared to the lowland measurements shown in the previous sections. UV-indices above 8.0, corresponding to very high or extreme exposure, have been recorded in 1992, 1997, 1999 and 2000, with a peak of 9.0 on 18 June 1999. The highest daily UV-dose recorded is 5600 J/m^2 and occurred on 11 June 1997.



Figur 53 Maximum daily UV-index at Finse (1200 meter above sea level).Note that the y-axis is different from previous graphs.

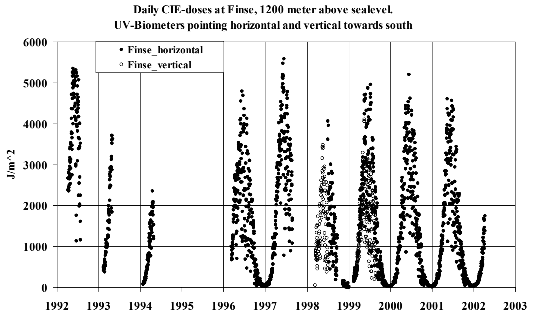


Figure 54 Maximum daily UV-dose(J/m^2) at Finse (1200 meter above sea level). Note that the y-axis is different from previous graphs.

The effect of different altitudes is shown in Figure 55 and 56. Here the peak daily UV-index and UV-dose for the period 1996-2001 have been selected for the mountain location and a combination of 2 locations representing south-eastern Norway (Blindern and Kise). In the early spring, when snow is present at both locations, or in the autumn when there are bare ground conditions, the differences in UVR are small. However, as the snow starts melting in the lowland, the UVR is 30% to 40% higher in the mountain. Evidences of clear-sky conditions after snowfall are seen as spikes on the curves. The largest differences are observed around Easter time in April. In Norway this period is particularly attractive for skiing and outdoor activities in the mountains. The UVR in the Easter period is observed to be up to a factor 2 higher when the Eastern is late, compared to early. The UV-exposure may thus be significantly different, depending on the start of the Easter period and the snow conditions.

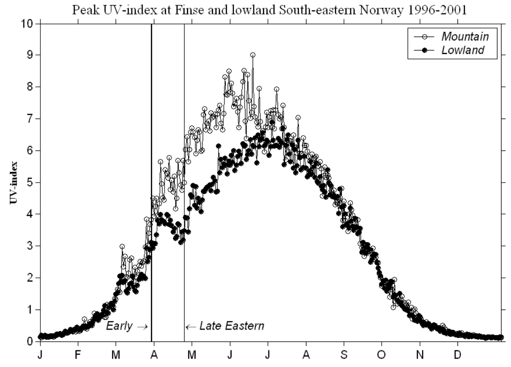


Figure 55 Peak daily UV-index for the mountain- and lowland locations, period 1996-2001.

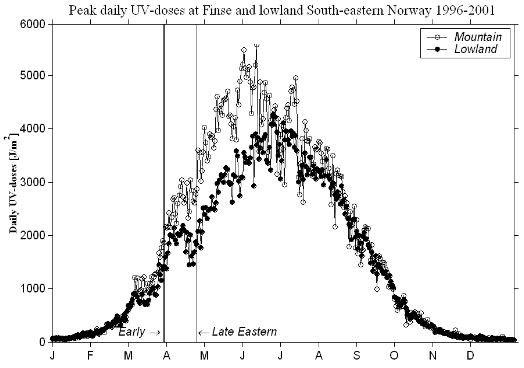


Figure 26 Peak daily UV-dose for the mountain- and lowland locations, period 1996-2001.

11.4 Annual UV-doses

Annual UV-doses for the period 1995/96 to 2001 is shown in Figure 57 and tabulated in Appendix D. The mean annual UV-dose for the period 1996-2001 is 379 kJ/m^2 at Landvik and 214 kJ/m^2 in Ny-Ålesund. The time-series indicate different patterns in annual UV-doses for the locations in southern and northern Norway. Locations from Trondheim and southwards show large variations (±12%) in the period 1996-1998, followed by fairly stable doses (±3 %) in the period 1999-2001. Pyranometer data from Bergen (Appendix E) showed a UV sky transmittance about 10-15 % higher during the summer months of 1997 than in 1998. The total ozone amount (Appendix E) was also about 10 % lower in the summer months of 1997 than in 1998, resulting in higher clear sky UV-doses. The combined enhancement and reduction of UV radiation from variations in the cloud and ozone amount may explain most of the differences seen in 1997 and 1998.

For the two northern locations a minimum in annual UV-doses were observed in 1999, however not as pronounced as in 1998 for the southern locations. Tromsø/Andøya had a maximum in annual UV-doses in 1997, a summer renown for its long period of clear sky conditions, followed by a fairly stable (±3 %) period for the last 3 years. The annual UV-doses for Ny-Ålesund were fairly the same (±1.5 %) in 1996-1998 and in 2001. The minimum (-12 %) in 1999 is largely affected by the overcast conditions of June and July that summer. The short summer season implies that the annual UV-doses are most sensitive to the cloud conditions in the north.

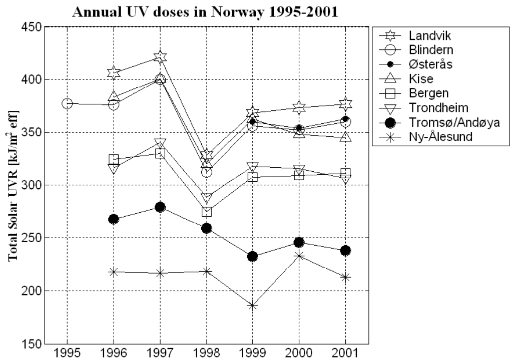


Figure 57 Annual integrated UV-doses for the period 1995/96 to 2001.

11.5 UV-trends

With the exception of Ny-Ålesund, the annual UV-doses have been higher in 1996-1997 than in 1998-2001. A linear regression analysis of the monthly mean daily UV-indices and UV-doses was performed after having normalised monthly means to year 2000. Changes in UV-index and UV-doses show good correlation, but changes in the daily doses are more pronounced than the UV-indices. For all locations the period March-April have downward, non-statistically significant trends by -3% to -5% and up to -10% (Landvik) per year. The period September-October has also negative trends for all locations but Bergen and Trondheim, but less pronounced (0% to –5% per year) than for the spring period. For the location in Bergen and Trondheim the changes are very small for the spring and autumn and within ±1.5% per year. For the summer period June-August the changes are more ambiguous among the locations. The changes in UV-indices are smaller, within ±2% per year for most locations, whereas the UV-doses indicate slightly negative trends (+2 to –5% per year). The changes in monthly means of May differ notably from other months. In May there is a non-statistically significant upward trend by 0% (Ny-Ålesund) to +4% per year for all locations except Tromsø/Andøya. The latter location has downward trends also for this month. A statistical F-test for the winter, spring, summer and autumn means confirms declining gradients for the 6-year period, but the results are not statistically significant at a 5% level. Measurements performed over the past two decades indicate however a longterm decrease in total-ozone with an expected increase in shortwave UVR (Zerefos 2002, Høiskar et al. 2000), although being smaller for the last decade (Zerefos 2002). When analyzing the data from the Norwegian UV-network we have to keep in mind that 6-7 years is still a short period, where the inter-annual variations in UVR still are much larger than the expected longterm change. It remains thus vital to continue the UV-monitoring activities for a long period.

12 Discussions

The spectral information provided by the GUV instruments enables the calculation of numerous data of relevance for the assessments of health and environmental impacts of UVR. Only erythemally effective UVR is presented in this report, but, in principle, any biologically action spectrum may be applied. The results from 6 years monitoring demonstrate large daily and annual variations in UVR. The most significant factor controlling the UV-radiation is the SZA, seen as a decrease in UVR with increasing latitudes. A comparison of UV-measurements at Landvik (58°N) and Ny-Ålesund (79°N), shows that the annual UV-doses are about 70% higher in the south. For clear sky summer days the noon UV-index is about 2 times higher in the south. The daily UV-doses are however only 30% larger in the south, due to the significant contribution of UVR under midnight sun conditions in the north. The second most significant factor is the variability in cloud conditions. From Pyranometer data, the daily UV attenuation from clouds is typically 10% to 70%, but may attenuate up to 100% during thunderstorms or even amplify the UVR by up to 10% under partially broken cloud cover. The maximum UV-index and daily UV-doses correlate well, but days with spikes in UV-indices caused by cloud reflections have generally lower daily UV-doses than days with clear sky conditions. The significance of variations in the total ozone amount is high, but is out of the scope in the present report. Readers may instead consult NILU's annual reports (Høiskar et al. 2000). Finally, the comparison of UV-measurements at snow-covered Finse and lowland bare-ground locations in southeastern Norway has shown that snow enhances the UVR by typically a factor 30%.

The highest annual UV-doses were measured in 1997 for 7 locations and in 2000 for the location in Ny-Ålesund. The highest daily UV-dose recorded in the lowland is 4400 J/m^2 (21 MED), which was measured at Landvik in July 2001. For the other locations the maximum daily UV-doses or UV-indices in July 2001 were not significantly different from other years. The highest daily UV-dose recorded is 5600J/m^2 (27 MED), measured at the Finse mountain location in June 1997. The maximum daily UV-doses in southern Norway may thus exceed 20 MED, which is hazardous for unprotected skin. The maximum UV-index recorded is 6.9 in the lowland and 9.0 at the Finse mountain location. Corresponding numbers for clear sky summer days at Palma de Mallorca are 8 and 9 (Intersun 2002). Thus the snow-covered alpine regions of southern Norway may reach the same levels as lowland in southern Europe or high altitudes in central or southern Europe.

The instruments have performed reasonably stable for the 6 years in operation. The changes in spectral responses appear to be gradual and monotonic for most instruments, which show that calibration controls performed once a year are sufficient. Two instruments have shown hysteresis effects, where the responses after a few years approach the initial sensitivities. The reason for this is unknown, but is likely related to the fractures appearing in the detector unit's end cap, where water may have entered. Experiences demonstrate that regular calibration controls are crucial for quality maintenance of UV-data.

The instruments operate automatically and normally require minimal maintenance. However, daily inspections and routines are required to maintain continuity and quality of UV measurements. The continuity in UV measurements has been satisfactorily for most instruments and locations. The use of ancillary data for estimating missing daily UV-doses and maximum UV-indices has limited the uncertainty in annual UV-doses from gaps in measurement series to less than ±1.5% for most locations. The instrument in Tromsø, later moved to Andøya, has excessive gaps in measurement series, which has worsened after the removal to the new site. The uncertainty in annual UV-doses from gaps is here up to ±6%, but could be significantly reduced with ancillary data for the estimation of UV cloud attenuation.

13 Conclusions and recommendations

The experiences with the network implementation, operation and the quality of UV-data are very good. The network has provided UV climatology for Norway, with information of the daily and seasonal variability of UV radiation at 8 locations. The data is available for the scientific and public user communities. There has been an increasing interest for these data and actual measurements are presented online on the internet. The user community has expressed wishes that more biologically relevant UV-data become available from the network. The use of alternative action spectra will be a topic for the near future. When it comes to trend analysis the time period is yet too short to infer any statistically significant change. Maintenance of the quality and continuity in measurements will still be given priority.

Recommendations for the future:

- Implementation of auto-message systems via the internet for detection of loss of measurement data.
- Implementation of power backup systems at each network location.
- Implementation of lightning protection units.
- Replacement of fractured end caps on GUV instruments.
- Implementation of ancillary radiometers needed to estimate UV-data that has been lost due to instrument failure.
- Purchase of a new GUV instrument in replacement of the instrument at Blindern, as this instrument has had excessive drift over the last years.
- Implementation of a GUV instrument at Finse, representing high-altitude locations of Southern Norway.
- Derivation of alternative units of biologically effective UVR.

14 Acknowledgements

We would like to thank the people providing global total radiation measurements from different UV-network locations: Jan-Asle Olseth at the University of Bergen, Halvard Hole at the Norwegian Crop Research Institute, Jon Børre Ørbæk at the Norwegian Polar Institute, Berit Kjeldstad at the Norwegian University of Science and Technology and

Merete Halvorsen Larre at the Norwegian Meteorological Institute. Jan-Asle Olseth's calculations of clear sky global total radiation have been of great value for the derivation of hourly UV-sky transmittances at the network locations. The radiation transfer model libRadtran from Arve Kylling at the Norwegian Institute for Air Research and Bernhard Mayer at the Deutsches Zentrum für Luft und Raumfart is highly appreciated. We also acknowledge Arne Dahlback at the University of Oslo for giving access to his computer program for calculation of total ozone from measurements with GUV instruments. Rune Søndenaa, student at the Norwegian University of Science and Technology, made a valuable job with UV calculations during his stay at NRPA in June and July 2001. Finally we like to thank the personnel at the network locations, the collegues at SFT and NILU and the ministries for their continued support.

15 References

1. Dahlback A. Measurements of biologically effective UV-doses, total ozone abundances and cloud effects with multichannel, moderate bandwith filter instruments. Applied Optics 1996; 35: 6514-6521.
2. Diffey B. Measurement and trends of terrestrial UVB radiation in Europe. Milano: OEMF, 1996.
3. Hannevik M et al. Monitoring natural radiation in Norway: Annual report for 1996 and 1997. StrålevernRapport 1998:10. Østerås: Norwegian Radiation Protection Authority / Statens strålevern, 1998. (In Norwegian).
4. Høiskar BA et al. Overvåking av atmosfærens ozonlag og naturlig ultrafiolett stråling: Årsrapport 2000. NILU OR 35/2001. Kjeller: Norwegian Institute for Air Research / Norsk institutt for luftforskning, 2001. (In Norwegian – no English title) http://www.nilu.no/niluweb/leverfil.cfm/35-2001-bak.pdf?id=2378&type=6 (22.08.02).
5. Intersun 2002: http://www.who.int/peh-uv/UVIpublic.htm (22.08.02).
6. ISO/CIE. Erythema reference action spectrum and standards erythema dose. ISO/CIE 17166:1999 / CIE S 007/E 1998. Geneva: International Organization for Standardization / International Commission on Illumination, 1999.
7. Johnsen B, Hannevik M. (eds.) The 1995 intercomparison of UV- and PAR instruments at the University of Oslo. StrålevernRapport 1997:7. Østerås: Norwegian Radiation Protection Authority, 1997.
8. Kjeldstad B, Johnsen B, Koskela T. (eds.). The Nordic intercomparison of ultraviolet and total ozone instruments at Izaña October 1996. Final report. Meteorological Publications No. 36, FMI-MET-36. Helsinki: Finnish Meteorological Institute, 1997.
9. Kylling A, Mayer B. libRadtran. Library for radiative transfer calculations. Edition 1.0 for libRadtran version 0.15, 2000. *http://www.libradtran.org/*
10. Mikkelborg O, Saxebøl G, Johnsen B. UV-monitoring in Norway on the WEB. Radiation Protection Dosimetry 2000; 91: 165-167.
11. Norvang LT et al. Monitoring natural ultraviolet radiation in Norway: Annual report for 1998 and 1999. StrålevernRapport 2000:4. Østerås: Norwegian Radiation Protection Authority / Statens strålevern, 2000. (In Norwegian).
12. NRPB. Health effects from ultraviolet radiation. Report of an Advisory Group on Non-ionising Radiation. Documents of the NRPB, Volume 13 No. 1 2002. Chilton, Didcot: National Radiological

Protection Board, 2002. *http://www.nrpb.org/publications/documents_of_nrpb/pdfs/doc_13_1.pdf* (22.08.02)

13. Parrish JA, Jaenicke KF, Anderson RR. Erythema and melanogenesis action Spectra of normal human skin. Photochemistry and Photobiology 1982; 36: 187-191.
14. Slaper H et al. Comparing ground-level spectrally resolved solar UV measurements using various instruments: A technique resolving effects of wavelength shift and slit width. Geophysical Research Letters 1995; 22: 2721-2724.
15. Vanicek K. et al. UV-index for the public. COST-713 Action. EUR 19226. Luxembourg: Office for Official Publications of the European Communities, 2000.
16. WHO. Health and environmental effects of ultraviolet radiation: A scientific summary of Environmental Health Criteria 160 Ultraviolet radiation. (WHO/EHG/95.16) http://www.who.int/peh-uv/publications/english/who-ehg-95-16.htm (21.08.02).
17. WHO. Global solar UV index. World Health Organization. Revised Fact Sheet No. 133, 1998. http://www.who.int/inf-fs/en/fact133.html (22.08.02).
18. WHO. Solar radiation and human health: Too much sun is dangerous. World Health Organization. Revised Fact Sheet No. 227, 1999. Geneva: WHO, 1999. http://www.who.int/inf-fs/en/fact227.html (21.08.02).
19. WMO, Seckemeyer G. et al. Instruments to measure solar ultraviolet radiation. Part 1: Spectral instruments. World Meteorological Organization. Global Atmosphere Watch, Report series No. 125, WMO TD No. 1066. Geneva: WMO, 1999.
20. Zerefos CS. Long-term ozone and update through 2001 of UV variations at Thessaloniki, Greece. Submitted to Physics and Chemistry of the Earth, in 2002.

16 Relevant websites:

UV-index: Websites per august 2002

Global: *http://www.who.int/peh-uv/index.htm*

Global: *http://www.srrb.noaa.gov/UV/uv1.html*

Argentine: *http://www.conae.gov.ar/caratula.html*

Australia: *http://www.bom.gov.au/info/about_uvb.shtml*

Austria: *http://www-med-physik.vu-wien.ac.at/uv/uv_home.htm*

Canada: *http://www.msc-smc.ec.gc.ca/education/uvindex/*

Czech Republic: *http://www.chmi.cz/meteo/ozon/o3uvb.html*

Denmark: *http://www.dmi.dk/f+u/*

Finland: http://www.ozone.fmi.fi/, *http://www.sateilyturvakeskus.fi/sateilytilanne/uv.html*

Germany: http://www.bfs.de/uvi/index.htm

http://www.dwd.de/services/gfm/uv_index/index.html

Greece: http://lap.physics.auth.gr/uvindex/

Hong Kong: http://www.hko.gov.hk/wxinfo/uvindex/english/uvindex_e.htm

Israel: http://www.weather.co.il/

Italy: http://www.lamma.rete.toscana.it/previ/ita/stazlam.htm

Japan: http://www.shiseido.co.jp/e/e9708uvi/html/index.htm

Luxemburg: *http://www.restena.lu/meteo_lcd/*

Mexico: *http://sima.com.mx/t1msn_valle_de_mexico/southeast.asp*

New Zealand: http://www.niwa.cri.nz/lauder

Norway: *http://uvnett.nrpa.no/uv/*

Portugal: *http://www.meteo.pt/uv/uvindex.htm*

Poland:

http://www.imgw.pl/wl/internet/index.jsp

Slovenia: *http://www.rzs-hm.si/zanimivosti/UV.html*

Spain*: http://www.inm.es/wwz/fijo/estaciones.html*

Sweden*: http://uvindex.ssi.se/uvindex.asp*

http://www.smhi.se/kund_t/uvindex/uv_index.htm

Switzerland*:*

http://www.bag.admin.ch/strahlen/nonionisant/uv/que_sont_uv/d/carte_uv.php

Turkey*: http://www.tubitak.gov.tr/english/*

United Kindgdom*: http://www.met-office.gov.uk/sec3/gsuvi.html*

http://www.nrpb.org/

USA: EPA UV Index:

http://www.epa.gov/ozone/othlinks.html#uvindex

http://www.weather.com/activities/health/skin/?from=healfl

http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/index.html

Other links:

NILU: *http://www.nilu.no/*

The Norwegian Cancer Association: *http://www.kreft.no*

CIESIN (Consortium for International Earth Science Information Network): *http://sedac.ciesin.org/ozone*

17 Appendix A Spectral response functions

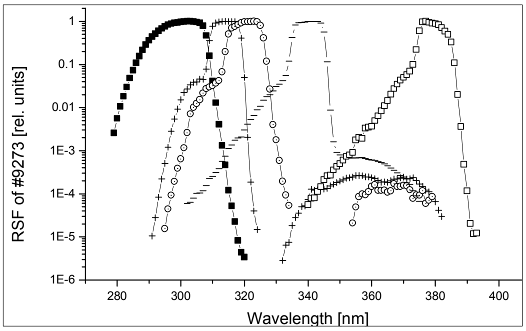


Figure A1 Relative spectral response of GUV s/no. 9273.

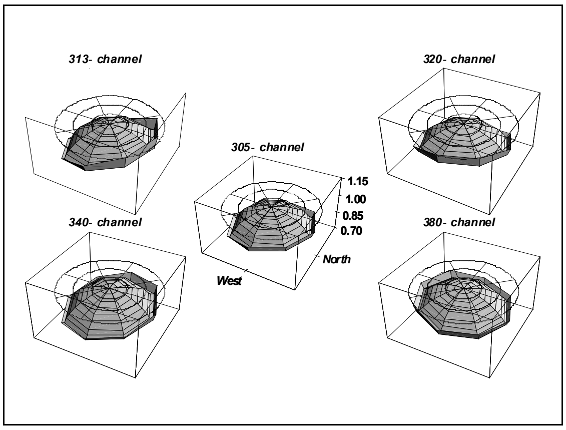


Figure A2 Relative angular response of GUV s/no. 9276.

18 Appendix B Calibration factors

Table B1 CIE-effective weighting factors for GUV instruments in the network. Original data must be in units of $\mu W/cm^2/nm$.

Stasjon	GUV	c1	c2	c3	c4	c5
Bergen	9270	2.3636E-02	0.0000E+00	2.8516E-03	-3.1141E-04	2.0172E-04
Landvik	9271	2.3764E-02	0.0000E+00	2.9567E-03	-3.7551E-04	2.0713E-04
Kise	9272	2.3718E-02	0.0000E+00	2.9882E-03	-3.9254E-04	2.1223E-04
Referanse	9273	2.3805E-02	0.0000E+00	2.8162E-03	-3.0641E-04	2.0228E-04
Trondheim	9274	2.4019E-02	0.0000E+00	2.9517E-03	-3.9204E-04	2.1452E-04
Ny-aalesund	9275	2.3951E-02	0.0000E+00	2.8391E-03	-3.3292E-04	2.0764E-04
Tromso/And	9276	2.4705E-02	0.0000E+00	2.7086E-03	-3.0285E-04	2.0026E-04
Blindern	9222	6.7334E-02	0.0000E+00	2.9309E-03	-2.8966E-04	2.2115E-04
Østerås	9277	1.6305E-02	5.3404E-03	-9.0716E-04	6.4750E-04	0.0000E+00
Reserv-referan	9278	2.2839E-02	1.3556E-03	1.0158E-03	3.9224E-04	0.0000E+00

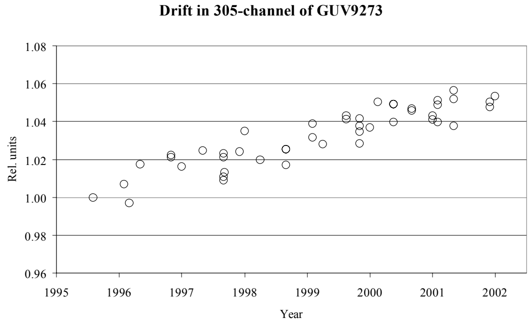


Figure B1 Longterm stability for the 305-channel of the transfer standard GUV9273.

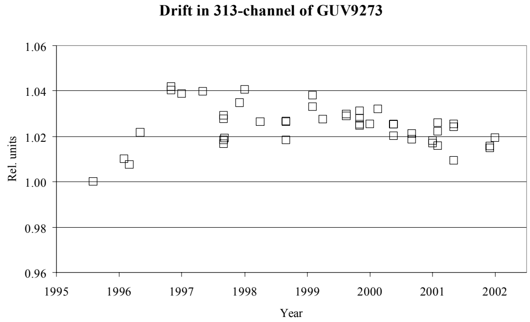


Figure B2 Longterm stability for the 313-channel of the transfer standard GUV9273.

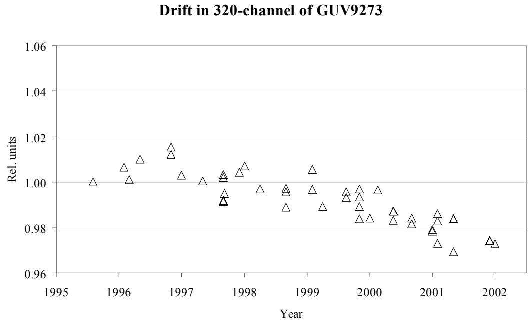


Figure B3 Longterm stability for the 320-channel of the transfer standard GUV9273.

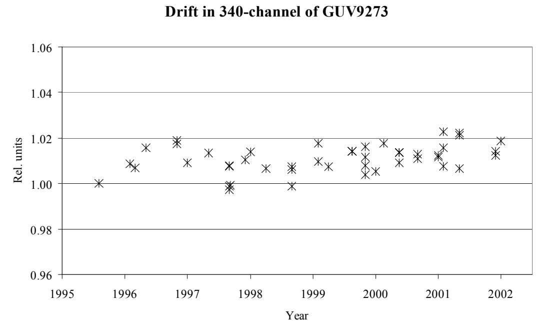


Figure B4 Long-term stability for the 340-channel of the transfer standard GUV9273.

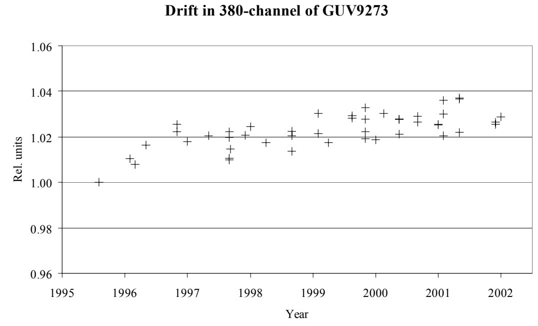


Figure B5 Long-term stability for the 380-channel of the transfer standard GUV9273.

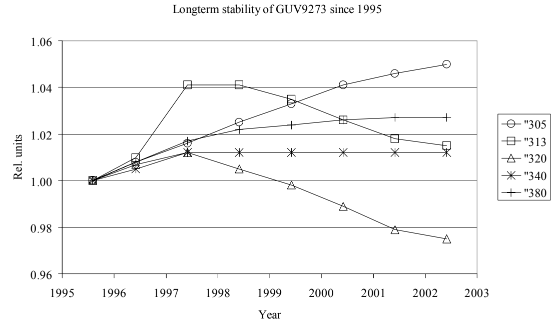


Figure B6 Annual drift factors for the transfer standard GUV9273.

Table B2 Annual drift factors for the transfer standard GUV9273.

Year	"305	"313	"320	"340	"380
1995.6	1.000	1.000	1.000	1.000	1.000
1996.4	1.008	1.010	1.007	1.005	1.008
1997.4	1.016	1.041	1.012	1.012	1.017
1998.4	1.025	1.041	1.005	1.012	1.022
1999.4	1.033	1.035	0.998	1.012	1.024
2000.4	1.041	1.026	0.989	1.012	1.026
2001.4	1.046	1.018	0.979	1.012	1.027
2002.4	1.050	1.015	0.975	1.012	1.027

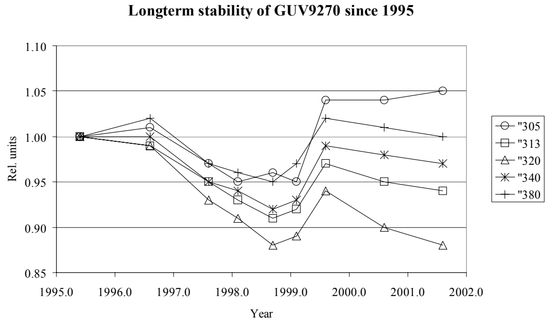


Figure B7 Annual drift factors for the GUV s/no. 9270.

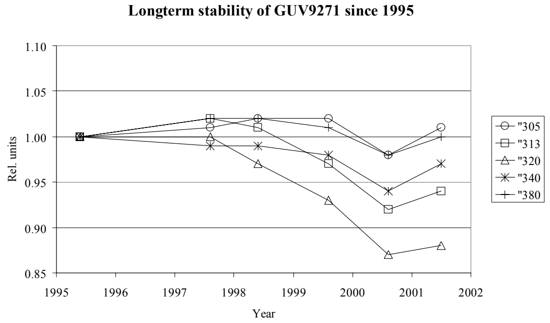


Figure B8 Annual drift factors for the GUV s/no. 9271.

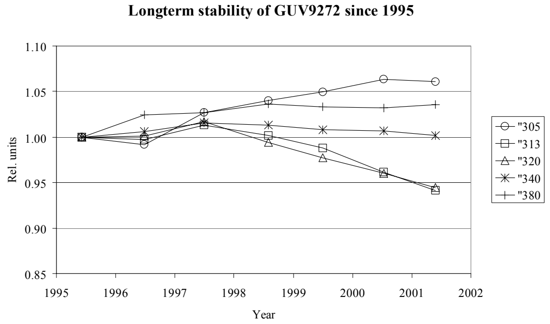


Figure B9 Annual drift factors for the GUV s/no. 9272.

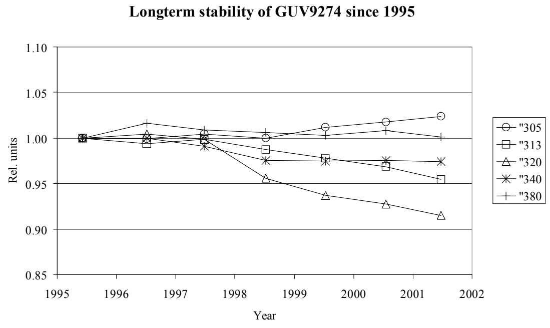


Figure B10 Annual drift factors for the GUV s/no. 9274.

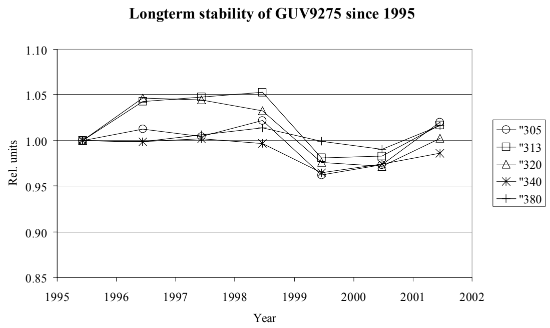


Figure B11 Annual drift factors for the GUV s/no. 9275.

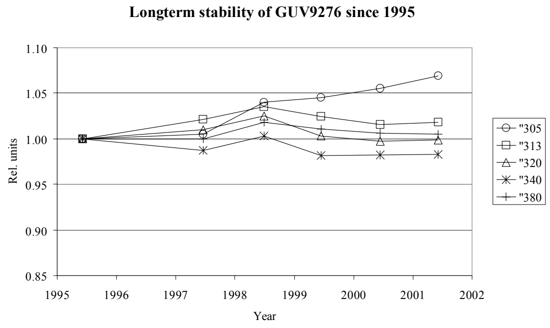


Figure B12 Annual drift factors for the GUV s/no. 9276.

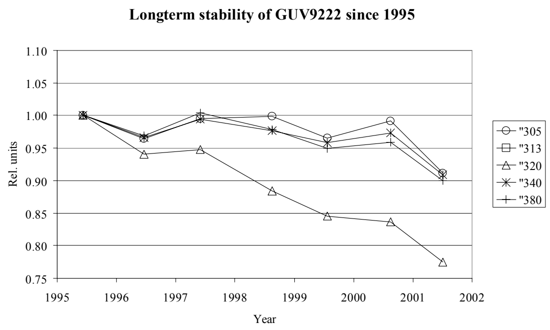


Figure B13 Annual drift factors for the GUV s/no. 9222.

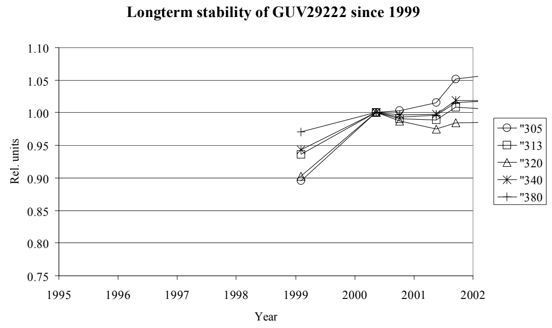


Figure B14 Annual drift factors for the GUV s/no. "9277" (=s/no. 29222).

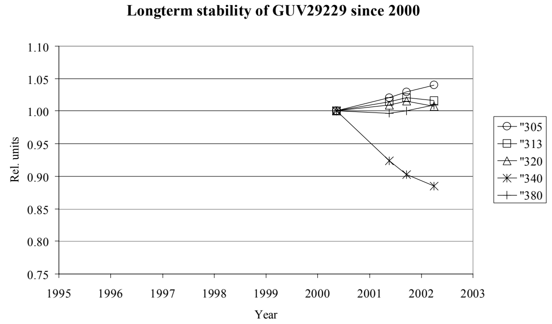


Figure B15 Annual drift factors for the GUV s/no. "9278" (=s/no. 29229).

Table B2 Annual drift factors for the 10 GUV instruments.

Longterm stability of GUV9270 since May 1995					
Year	"305	"313	"320	"340	"380
1995.4	1.00	1.00	1.00	1.00	1.00
1996.6	1.01	0.99	0.99	1.00	1.02
1997.6	0.97	0.95	0.93	0.95	0.97
1998.1	0.95	0.93	0.91	0.94	0.96
1998.7	0.96	0.91	0.88	0.92	0.95
1999.1	0.95	0.92	0.89	0.93	0.97
1999.6	1.04	0.97	0.94	0.99	1.02
2000.6	1.04	0.95	0.90	0.98	1.01
2001.6	1.05	0.94	0.88	0.97	1.00

Longterm stability of GUV9271 since May 1995					
Year	"305	"313	"320	"340	"380
1995.4	1.00	1.00	1.00	1.00	1.00
1997.6	1.01	1.02	1.00	0.99	1.02
1998.4	1.02	1.01	0.97	0.99	1.02
1999.6	1.02	0.97	0.93	0.98	1.01
2000.6	0.98	0.92	0.87	0.94	0.98
2001.5	1.01	0.94	0.88	0.97	1.00

Longterm stability of GUV9272 since May 1995					
Year	"305	"313	"320	"340	"380
1995.4	1.00	1.00	1.00	1.00	1.00
1996.5	0.99	1.00	1.00	1.01	1.02
1997.5	1.03	1.01	1.02	1.02	1.03
1998.6	1.04	1.00	0.99	1.01	1.04
1999.5	1.05	0.99	0.98	1.01	1.03
2000.5	1.06	0.96	0.96	1.01	1.03
2001.4	1.06	0.94	0.94	1.00	1.04

Longterm stability of GUV9272 since May 1995					
Year	"305	"313	"320	"340	"380
1995.4	1.00	1.00	1.00	1.00	1.00
1996.5	1.00	0.99	1.00	1.00	1.02
1997.5	1.00	1.00	1.00	0.99	1.01
1998.5	1.00	0.99	0.96	0.98	1.01
1999.5	1.01	0.98	0.94	0.97	1.00
2000.5	1.02	0.97	0.93	0.98	1.01
2001.5	1.02	0.95	0.92	0.97	1.00

Longterm stability of GUV9275 since May 1995

Year	"305	"313	"320	"340	"380
1995.4	1.00	1.00	1.00	1.00	1.00
1996.4	1.01	1.04	1.05	1.00	1.00
1997.4	1.00	1.05	1.04	1.00	1.01
1998.5	1.02	1.05	1.03	1.00	1.01
1999.5	0.96	0.98	0.98	0.96	1.00
2000.5	0.97	0.98	0.97	0.97	0.99
2001.5	1.02	1.02	1.00	0.99	1.02

Longterm stability of GUV9276 since May 1995

Year	"305	"313	"320	"340	"380
1995.4	1.00	1.00	1.00	1.00	1.00
1997.5	1.01	1.02	1.01	0.99	1.00
1998.5	1.04	1.04	1.03	1.00	1.02
1999.4	1.05	1.02	1.00	0.98	1.01
2000.4	1.06	1.02	1.00	0.98	1.01
2001.4	1.07	1.02	1.00	0.98	1.01

Longterm stability of GUV9222 since May 1995

Year	"305	"313	"320	"340	"380
1995.4	1.00	-	1.00	1.00	1.00
1996.5	0.96	-	0.94	0.97	0.97
1997.4	0.99	-	0.95	0.99	1.00
1998.6	1.00	-	0.88	0.98	0.98
1999.6	0.96	-	0.85	0.96	0.95
2000.6	0.99	-	0.84	0.97	0.96
2001.5	0.91	-	0.77	0.91	0.90

Longterm stability of "GUV9277" = s/no. 29222

Year	"305	"313	"320	"340	"380
1995.4					
1999.1	0.895	0.936	0.903	0.943	0.970
2000.4	1.000	1.000	1.000	1.000	1.000
2000.8	1.003	0.991	0.987	0.997	0.993
2001.4	1.016	0.989	0.974	0.997	0.996
2001.7	1.052	1.009	0.985	1.019	1.015
2002.3	1.057	1.006	0.985	1.018	1.018
2002.3	1.057	1.006	0.597	1.018	1.018
2002.6	1.061	1.004	0.597	1.018	1.020

Longterm stability of "GUV9278"= s/no. GUV9229

Year	"305	"313	"320	"340	"380
1995.4					
2000.4	1.00	1.00	1.00	1.00	1.00
2001.4	1.02	1.01	1.01	0.92	1.00
2001.7	1.03	1.02	1.02	0.90	1.00
2002.2	1.04	1.02	1.01	0.88	1.01

19 Appendix C – Uncertainty budgets

Table C1 Uncertainty in spectral sky measurement for the wavelength region 300-400nm.

Error sources, 2 sigma level	Uncertainty [%]
Calibration lamps	3
Transfer of calibrations	1
Relative lamp measurements	1
Wavelength shift accuracy, 0.02nm	0.5
Intensity linearity	1
Intensity hysteresis effects	1.5
Repeatability	1
Integrated cosine errors	1.6
Total uncertainty, 2 sigma level	**4**

Table C2 Uncertainty in daily UV-doses for GUV instruments operating in the UV network.

Error sources	Uncertainty [%]
Absolute calibration, NOGIC2000	4
Estimated drift in transfer standard GUVs, from lamp calibrations	1
Estimated drift in local GUVs, from annual solar intercomparisons	2
Intensity linearity	1
Dirt accumulation	2
Temperature	0.1
Total uncertainty in daily UV doses, 2 sigma level	**5**

20 Appendix D1 – monthly means of UV-index.

Landvik	1995	1996	1997	1998	1999	2000	2001
1	NaN	0.17	0.23	0.21	0.19	0.27	0.15
2	NaN	0.65	0.51	0.61	0.59	0.56	0.57
3	NaN	1.63	1.48	1.41	0.95	1.47	1.14
4	NaN	3.26	2.98	1.76	2.45	2.18	2.07
5	NaN	3.50	4.03	3.95	4.05	4.29	4.33
6	NaN	5.18	4.80	4.17	4.70	5.11	5.21
7	NaN	5.24	5.30	4.80	5.11	4.94	5.50
8	NaN	3.67	4.14	3.77	3.80	4.13	3.82
9	NaN	2.63	2.57	1.82	1.93	2.15	2.10
10	NaN	0.70	0.95	0.87	0.96	0.79	0.77
11	NaN	0.32	0.22	0.26	0.31	0.25	0.35
12	NaN	0.16	0.12	0.13	0.15	0.11	0.12

Blindern	1995	1996	1997	1998	1999	2000	2001
1	0.16	0.15	0.17	0.17	0.15	0.19	0.13
2	0.43	0.60	0.43	0.48	0.50	0.47	0.46
3	1.12	1.57	1.47	1.37	0.83	1.42	1.08
4	2.55	2.77	2.97	1.87	2.52	2.36	1.98
5	4.05	3.62	3.93	3.97	4.08	4.21	4.15
6	5.24	4.90	5.26	3.86	4.79	4.92	4.79
7	4.87	5.10	5.25	4.59	5.25	4.63	5.23
8	4.32	3.93	4.15	3.36	3.89	4.07	3.89
9	1.91	2.32	2.44	1.83	2.25	2.13	2.28
10	0.72	0.73	0.89	0.80	0.83	0.66	0.71
11	0.28	0.27	0.21	0.20	0.23	0.16	0.26
12	0.11	0.11	0.09	0.10	0.10	0.08	0.12

Østerås	1995	1996	1997	1998	1999	2000	2001
1	NaN	NaN	NaN	NaN	0.13	0.19	0.15
2	NaN	NaN	NaN	NaN	0.51	0.5	0.49
3	NaN	NaN	NaN	NaN	0.81	1.47	1.17
4	NaN	NaN	NaN	NaN	2.53	2.33	2.05
5	NaN	NaN	NaN	NaN	4.12	4.21	4.03
6	NaN	NaN	NaN	NaN	4.56	4.77	4.78
7	NaN	NaN	NaN	NaN	5.23	4.55	5.06
8	NaN	NaN	NaN	NaN	3.85	4.09	3.82
9	NaN	NaN	NaN	NaN	2.24	2.09	2.29
10	NaN	NaN	NaN	NaN	0.83	0.67	0.71
11	NaN	NaN	NaN	NaN	0.24	0.17	0.27
12	NaN	NaN	NaN	NaN	0.12	0.09	0.13

Kise	1995	1996	1997	1998	1999	2000	2001
1	NaN	0.18	0.19	0.19	0.15	0.18	0.15
2	NaN	0.69	0.48	0.52	0.52	0.49	0.46
3	NaN	1.87	1.43	1.36	1.05	1.47	1.20
4	NaN	3.01	2.93	1.82	2.54	2.48	2.00
5	NaN	3.14	3.77	3.83	3.95	3.90	3.90
6	NaN	5.06	5.21	3.83	4.42	4.66	4.81
7	NaN	4.88	5.16	4.27	4.96	4.46	4.76
8	NaN	3.98	3.88	3.40	3.77	3.83	3.57
9	NaN	2.30	2.27	1.91	2.10	1.93	1.78
10	NaN	0.67	0.83	0.74	0.76	0.61	0.64
11	NaN	0.26	0.21	0.20	0.24	0.18	0.26
12	NaN	0.11	0.09	0.10	0.10	0.06	0.11

Bergen	1995	1996	1997	1998	1999	2000	2001
1	NaN	0.18	0.13	0.14	0.09	0.15	0.15
2	NaN	0.49	0.34	0.36	0.33	0.43	0.41
3	NaN	1.53	0.89	1.06	0.88	1.15	1.03
4	NaN	2.62	2.56	2.05	2.30	2.26	2.21
5	NaN	3.40	3.87	3.86	3.71	4.03	3.82
6	NaN	4.72	4.44	3.90	4.18	4.52	4.52
7	NaN	3.82	4.68	3.72	4.51	4.41	4.44
8	NaN	3.60	3.63	3.18	3.54	3.45	3.49
9	NaN	2.39	1.90	1.93	1.82	1.98	2.30
10	NaN	0.74	0.72	0.74	0.75	0.67	0.75
11	NaN	0.25	0.24	0.23	0.20	0.26	0.25
12	NaN	0.10	0.10	0.08	0.10	0.08	0.10

Trondheim	1995	1996	1997	1998	1999	2000	2001
1	NaN	0.12	0.09	0.10	0.08	0.09	0.10
2	NaN	0.44	0.33	0.30	0.30	0.33	0.34
3	NaN	1.31	1.11	0.96	0.95	1.17	1.04
4	NaN	2.55	2.49	1.86	2.11	2.33	2.06
5	NaN	3.47	3.42	3.62	3.64	3.87	3.43
6	NaN	4.17	4.02	3.88	4.16	4.24	4.16
7	NaN	4.10	4.57	3.61	4.34	4.07	4.12
8	NaN	3.24	3.62	2.98	3.24	2.90	2.96
9	NaN	2.04	1.81	1.77	2.01	1.92	1.77
10	NaN	0.59	0.62	0.62	0.65	0.62	0.59
11	NaN	0.16	0.18	0.18	0.15	0.16	0.18
12	NaN	0.05	0.06	0.05	0.05	0.04	0.05

Tromsø	1995	1996	1997	1998	1999	2000	2001
1	NaN	0.01	0.01	0.00	0.01	0.00	0.01
2	NaN	0.20	0.17	0.15	0.15	0.17	0.14
3	NaN	0.82	0.77	0.66	0.56	0.70	0.67
4	NaN	1.78	2.10	1.55	1.37	1.85	1.64
5	NaN	3.06	2.79	2.40	2.54	2.89	2.60
6	NaN	3.25	3.73	3.44	3.37	3.05	3.27
7	2.60	3.25	3.59	3.22	3.11	3.35	2.91
8	2.05	2.43	2.10	2.19	2.03	2.19	1.92
9	1.18	1.12	1.04	1.04	1.00	1.04	1.03
10	0.32	0.28	0.29	0.26	0.26	0.31	0.31
11	0.03	0.04	0.04	0.05	0.03	0.05	0.05
12	0.00	0.00	0.00	0.00	0.00	0.00	0.01

Ny-Ålesund	1995	1996	1997	1998	1999	2000	2001
1	NaN	0.00	0.00	0.00	0.00	0.00	0.00
2	NaN	0.02	0.02	0.01	0.01	0.00	0.00
3	NaN	0.26	0.33	0.25	0.20	0.26	0.20
4	NaN	0.92	1.16	0.92	0.88	1.03	0.86
5	NaN	1.89	1.71	1.80	1.72	1.95	1.72
6	2.01	2.26	2.31	2.47	1.85	2.61	2.40
7	1.93	1.96	1.86	1.69	1.75	1.83	1.83
8	1.23	1.06	1.11	0.99	0.92	1.13	1.06
9	0.44	0.44	0.41	0.43	0.38	0.44	0.36
10	0.07	0.06	0.06	0.06	0.06	0.05	0.06
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00

21 Appendix D2 – monthly means of UV-doses.

Landvik	1995	1996	1997	1998	1999	2000	2001
1	NaN	55	84	75	59	91	39
2	NaN	249	183	214	215	215	225
3	NaN	716	649	606	381	629	508
4	NaN	1570	1491	732	1189	952	872
5	NaN	1731	1976	2090	2060	2232	2251
6	NaN	2747	2561	2080	2242	2386	2604
7	NaN	2828	3068	2166	2764	2626	2902
8	NaN	1815	2153	1654	1863	1868	1711
9	NaN	1167	1117	680	754	852	803
10	NaN	259	367	310	353	248	248
11	NaN	104	68	82	107	62	117
12	NaN	42	37	36	49	26	31

Blindern	1995	1996	1997	1998	1999	2000	2001
1	49	45	44	48	36	60	26
2	165	234	145	172	184	174	182
3	487	716	652	573	327	644	485
4	1176	1293	1396	750	1112	992	896
5	1976	1672	1812	2089	2076	2185	2133
6	2441	2400	2695	1863	2013	2240	2481
7	2594	2511	2766	2042	2710	2163	2588
8	2325	1966	2108	1494	1856	1877	1732
9	743	1096	1050	782	922	934	901
10	247	264	353	305	303	196	239
11	92	83	54	62	70	36	82
12	23	23	15	23	29	13	22

Østerås	1995	1996	1997	1998	1999	2000	2001
1	NaN	NaN	NaN	NaN	36	65	50
2	NaN	NaN	NaN	NaN	184	192	200
3	NaN	NaN	NaN	NaN	335	672	532
4	NaN	NaN	NaN	NaN	1151	1005	916
5	NaN	NaN	NaN	NaN	2113	2231	2137
6	NaN	NaN	NaN	NaN	2047	2223	2458
7	NaN	NaN	NaN	NaN	2702	2130	2587
8	NaN	NaN	NaN	NaN	1862	1872	1704
9	NaN	NaN	NaN	NaN	914	918	882
10	NaN	NaN	NaN	NaN	311	198	250
11	NaN	NaN	NaN	NaN	83	39	100
12	NaN	NaN	NaN	NaN	37	23	43

Kise	1995	1996	1997	1998	1999	2000	2001
1	NaN	59	65	98	46	54	46
2	NaN	284	181	230	204	193	188
3	NaN	894	664	592	466	674	571
4	NaN	1522	1440	792	1180	1128	952
5	NaN	1572	1777	2092	2048	2079	2003
6	NaN	2422	2627	1903	2064	2314	2445
7	NaN	2378	2858	2015	2649	2064	2360
8	NaN	1942	1998	1540	1884	1788	1649
9	NaN	1090	973	808	905	815	697
10	NaN	257	352	298	301	195	232
11	NaN	86	98	67	80	48	87
12	NaN	37	61	28	29	17	31

Bergen	1995	1996	1997	1998	1999	2000	2001
1	NaN	55	40	41	31	37	46
2	NaN	170	102	107	115	133	144
3	NaN	705	345	371	319	441	472
4	NaN	1151	1121	921	981	993	977
5	NaN	1495	1820	2001	1899	1913	1865
6	NaN	2238	2284	1725	1760	1957	2143
7	NaN	1689	2260	1442	2108	2121	1891
8	NaN	1656	1773	1238	1797	1297	1358
9	NaN	1111	681	754	690	865	955
10	NaN	243	250	290	270	234	238
11	NaN	80	76	74	53	83	74
12	NaN	28	28	24	23	23	30

Trondheim	1995	1996	1997	1998	1999	2000	2001
1	NaN	34	22	31	23	23	30
2	NaN	159	114	103	114	124	119
3	NaN	602	435	401	411	490	475
4	NaN	1278	1102	972	990	1122	1021
5	NaN	1744	1696	1851	1942	1948	1758
6	NaN	1849	2275	2019	2086	1954	2218
7	NaN	1893	2557	1663	1958	2147	1947
8	NaN	1588	1874	1261	1652	1337	1349
9	NaN	917	738	818	900	855	804
10	NaN	221	229	243	249	254	233
11	NaN	53	56	62	48	55	51
12	NaN	15	13	12	16	13	14

Tromsø	1995	1996	1997	1998	1999	2000	2001
1	0	2	3	2	3	3	3
2	NaN	72	61	51	57	59	51
3	NaN	399	373	306	260	306	324
4	NaN	927	1135	871	711	1020	930
5	NaN	1885	1643	1241	1538	1497	1628
6	NaN	1722	2321	2188	2007	1548	1895
7	1320	1804	1959	1997	1507	1938	1355
8	887	1326	1048	1211	939	1062	960
9	545	495	463	486	466	460	487
10	132	100	116	110	100	119	137
11	12	12	12	18	10	15	17
12	1	-1	0	4	0	0	4

Ny-Ålesund	1995	1996	1997	1998	1999	2000	2001
1	NaN	0	0	0	0	0	0
2	NaN	7	7	5	4	5	3
3	NaN	147	200	143	118	151	119
4	NaN	721	892	734	699	798	649
5	NaN	1723	1530	1624	1506	1777	1593
6	1729	2011	2152	2255	1423	2364	2132
7	1535	1504	1302	1416	1463	1445	1492
8	864	714	735	698	637	795	765
9	277	256	236	265	206	262	190
10	28	30	28	20	26	20	25
11	-3	2	2	-6	-2	0	-3
12	-2	2	2	-6	0	0	-3

22 Appendix E – Daily ozone and UV-sky transmittance in Bergen in 1997 and 1998.

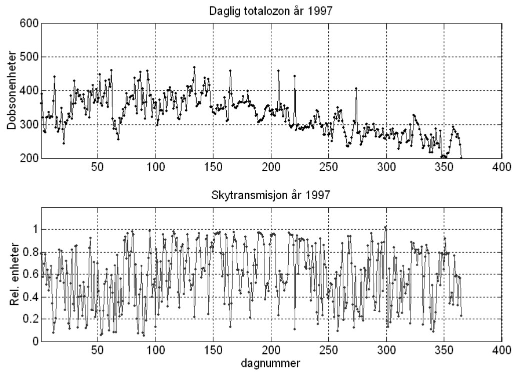


Figure E1 Daily total ozone and UV sky transmittance in 1997 (Annual UV-dose was high).

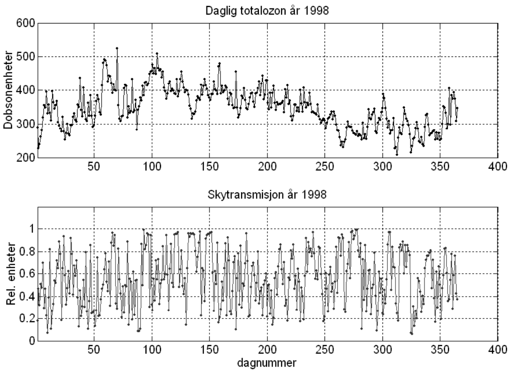


Figure E2 Daily total ozone and UV sky transmittance in 1998 (Annual UV-dose was low).