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RASTA

Radiometer for Automatic Stations

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Summary

In order to improve the understanding of the atmosphere in general and of the radiation field in particular, routine direct radiation measurements represent a powerful tool to monitor changes of the atmospheric transparency, for example due to an increase of the aerosol load. All-weather automatic measuring devices are needed for that purpose. The RASTA systems, consisting of a sun-tracker, an absolute radiometer and up to three sunphotometers, have been developed in the recent years within a joint venture between a research institute, two private companies and a governmental institution. A complete description of the systems and preliminary results are presented, especially concerning the effects of the aerosol cloud injected in the stratosphere by the Pinatubo volcanic eruption in 1991.

Résumé

Dans le but d'améliorer nos connaissances de l'atmosphère en général et du champ de rayonnement en particulier, les mesures routinières du rayonnement direct représentent un outil puissant pour la surveillance des variations de la transparence atmosphérique, par exemple dues aux changements du contenu en aérosols de l'atmosphère. Des instruments de mesure automatiques, supportant toutes les conditions météorologiques, sont nécessaires pour obtenir cette information. Les systèmes de mesure RASTA - une poursuite du soleil, un radiomètre absolu et jusqu'à trois photomètres solaires - ont été développés dans le cadre d'une collaboration entre un institut de recherche, deux compagnies privées et une institution gouvernementale. Une description du système de mesure ainsi que des résultats préliminaires sont présentés, en particulier concernant les effets de l'éruption volcanique du Pinatubo en 1991.

Zusammenfassung

Mit dem generellen Ziel, den allgemeinen Wissensstand über die Atmosphäre zu verbessern und im Speziellen das Strahlungsfeld noch besser zu ergründen, sind routinemässig durchgeführte Messungen der direkten Sonnenstrahlung ein hervorragend geeignetes Mittel, die Veränderungen der atmosphärischen Transparenz, hervorgerufen durch die variable Belastung der Atmosphäre durch Aerosole, zu überwachen. Zu diesem Zweck sind allwettertaugliche, automatische Messeinrichtungen notwendig. Um diese Aufgabe erfüllen zu können, wurde in den letzten Jahren an der SAP in einer "joint venture" mit einem Forschungsinstitut, zwei privaten Herstellern von Messgeräten und einem staatlichen Institut, die RASTA- Messplatform, die aus einer Sonnennachführung, einem Absolutradiometer und bis zu drei Sonnenphotometer- Einheiten besteht, entwickelt. Eine Beschreibung des Systems sowie erste Resultate der Messungen werden im Bericht präsentiert. Speziell werden Messungen der atmosphärischen Trübung, hervorgerufen durch die Eruption des Vulkans Pinatubo vom Jahre 1991, vorgestellt.

Riassunto

Allo scopo di migliorare le nostre conoscenze dell'atmosfera in generale e del campo della radiazione in particolare, le misure sistematiche della radiazione diretta rappresentano un valido mezzo per sorvegliare le variazioni della trasparenza atmosferica, dovute per esempio ai cambiamenti del contenuto degli aerosoli nell'atmosfera. Degli strumenti di misura automatici, che siano in grado di funzionare in tutte le condizioni meteorologiche, sono necessari per ottenere queste informazioni. I sistemi di misura RASTA - un sistema d'inseguimento del sole, un radiometro assoluto e fino a tre fotometri solari - sono stati sviluppati nell'ambito di una collaborazione tra un istituto di ricerca, due compagnie private e un'istituto governativo. Una descrizione del sistema di misura e dei risultati preliminari sono qui presentati, in particolare per quel che riguarda gli effetti dell'eruzione volcanica del Pinatubo nel 1991.

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1. Introduction

Direct solar radiation measurements are used not only to monitor the radiation fluxes in the atmosphere, but also to determine the amount and type of aerosols (turbidity) as well as the amount of water vapor, ozone and other trace gases present in it. The instruments used for this purpose measure either the whole spectrum of the incoming solar radiation (pyrheliometer, absolute radiometer) or only at selected wavelengths by using interference filters (spectroradiometer or sunphotometer). The measured quantities describe extinction processes due to the interaction of the radiation with the atmospheric constituents.

The influence of the depletion of stratospheric ozone on possible climate changes is today a very actual topic. Massive aerosol emission blown directly in the stratosphere during volcanic eruptions such as from the El Chichon (1981) and more recently from the Pinatubo (1991) seem to play also an important role, if not more important, in the problem area of climate changes.

In order to monitor these possible changes of the atmospheric transmittance due to the variability of the amount and distribution of the aerosols in the atmosphere, the Swiss Meteorological Institute SMI has set up a program for the measurement of the background turbidity with absolute cavity radiometers as well as sunphotometers. Six stations have been equiped with such systems (RASTA: Radiometer for Automatic STAtion) in Switzerland at different altitudes and at locations representing best the climatic variability of this country.

The expected results will contribute to the development of a reliable climatology which would allow to predict the influence of possible long-term changes of the amount and type of aerosols.

2. Historical review

On January 1,1979, the World Radiation Center at Davos, Switzerland, (PMOD/ WRC) overtook the task to develop 2 prototype units of a new automatic system for the measurement of the direct solar irradiance, consisting of:

- an automatic all-weather sun-tracker, designed to be operated on networks under all possible weather conditions and at all possible altitudes,
- an absolute radiometer equiped with a robust and efficient protection against harsh environment conditions.

At that time, all-weather sun-tracking systems were not available on the market so that a new instrument had to be designed. Many difficulties appeared during the development phase of the whole system, especially concerning the sun-tracker module. These technical problems could however be solved and the first prototype of the new system called RASTA (Radiometer for Automatic STAtions) was put into operation on the 1.1.1982 at Davos and connected to the automatic meteorological network ANETZ of the SMI. This first prototype worked with a few interruptions until 1985 [1] and the data were used, among other applications, to monitor the influence of the El Chichon volcanic eruption in 1982-1983 [2].

Renewed interest in all-weather solar trackers rose in 1985 among the solar energy community in order to perform direct irradiance measurements in the Alps for the determination of the potential of solar power plants at high altitude (consortium SOTEL). Considering the experience gathered with the first RASTA prototype, it was then decided to start the second phase of this project under a new organization. A joint venture agreement was signed in 1986 between the SMI, the PMOD/WRC, the Paul Sherrer Institute (PSI) and the Centre Suisse d'Electronique et de Microtechnique at Neuchâtel (CSEM) in order to build industrially produced all-weather sun trackers. A first prototype unit was ordered by the SMI on December 5,1986.

Subsequent detailed studies of the project led to the conclusion that the addition of sunphotometers on the RASTA systems would represent a major increase of the information potential of the whole setup. Also at that time, a new company BRUSAG was created under the direction of one of the former leading participant in the development of absolute radiometers and of the first RASTA prototype (Dr. R. W. Brusa) at PMOD/WRC. Taking into account the experience of the company BRUSAG in the field of radiation measurements, electronics and software, CSEM decided then to subcontract the development/update of the sun-tracker processing unit to this company. At the same time, and in order to increase the synergy between the involved companies to this project, the SMI took the decision to entrust BRUSAG with the development of:

- the control electronics of the absolute radiometer PMO6,
- the interface electronics for the absolute radiometer PMO6 and for the sunphotometer SPM-2000,
- the data acquisition system,
- the mechanical design of the instruments' protection box.

Problems mainly due to difficulties encountered in the development of the sun-tracker and the sunphotometers led to important delays of the project, so that the first complete RASTA unit of the new type was put into operation only in 1989.

First experiences gathered in the field with this newest version of the sun-tracker immediately showed that important problems remained to be solved, especially concerning the shaft drive motors which showed a life expectancy of only a few months outdoors. A modified design of the sun-tracker was then developed by CSEM in collaboration with the SMI, which allowed at the same time for easier maintenance of the system.

In 1991, in view of this situation and of the Pinatubo volcanic eruption, the SMI and the WRC/PMOD decided to install the instrument platform as prepared for the RASTA unit on an existing sun-tracker at Davos which was originally built for clear day operation. This provisory setup was put into operation at the beginning of 1991 and allowed thus to measure the influence of the Pinatubo eruption over Davos in 1991-1992 [3].

After solving many minor problems and performing many tests at the SMI-Aerological Station at Payerne, the installation of the remaining of the RASTA units and the update of the Davos unit could be performed in 1993 and 1994. At present date, five stations are in operation and the remaining sixth unit is due to be installed at the beginning of 1995. The RASTA installation project will then be completed and the RASTA units fully integrated in the ANETZ.

3. Technical description

3.1 System overview

The RASTA system consists of the instrument platform with one PMO6-type absolute radiometer and one triple SPM-2000 sunphotometer, the data acquisition system, the sun-tracker and the controller. A block diagram of the RASTA is shown on fig. 1 while fig. 2 displays more details about the instrument platform.

Sun tracker with controller:

The sun-tracker is an altitude-azimut mount controlled by microprocessor. Based on the system time transmitted by the automatic network and the geographical coordinates of the station, the position of the sun is computed and the tracker is oriented towards the sun. An automatic rewind is performed after the astronomical sunset.

Instrument platform and data acquisition:

The instrument platform shown on fig. 2 has been designed to accommodate up to four instruments. Data acquisition and control of the instruments is performed with a serial party line (RS232-C). The platform includes a four quadrant sensor which allows to detect possible mispointing of the tracker e. g. due to a drive blocked by ice. The same microprocessor system as for the tracker is designed to control for instruments and data acquisition. The electronics meet the harsh outdoor environmental conditions.All the measurement electronics is integrated into the instrument platform.

Instruments:

One triple SPM-2000- type sun photometer and one PMO6- type absolute radiometer are incorporated.

3.2 Description of the subsystems

3.2.1 Tracker and Controller

The tracker - an altitude-azimut mount - consists of two almost identical drives. Both axis are built as weatherproof cast aluminium housings. Each drive includes a DC-motor, a gear with no backlash, position encoders and end-of-course switches. The azimut angle drive is attached to the base plate and the altitude drive interfaces to the azimut drive.The control unit is designed for unattended outdoor operation. The core of the tracker controller is a commercially available microprocessor board (GESSBS5 of GESPAC). The card includes a real-time-clock with calendar. A custom-made interface with power drivers, encoder circuits, end-switch logic and a dual serial interface completes the controller. The controller is equipped with a full lightning protection, which means that all lines to or from the controller are equipped with surge arresters and protection filters.

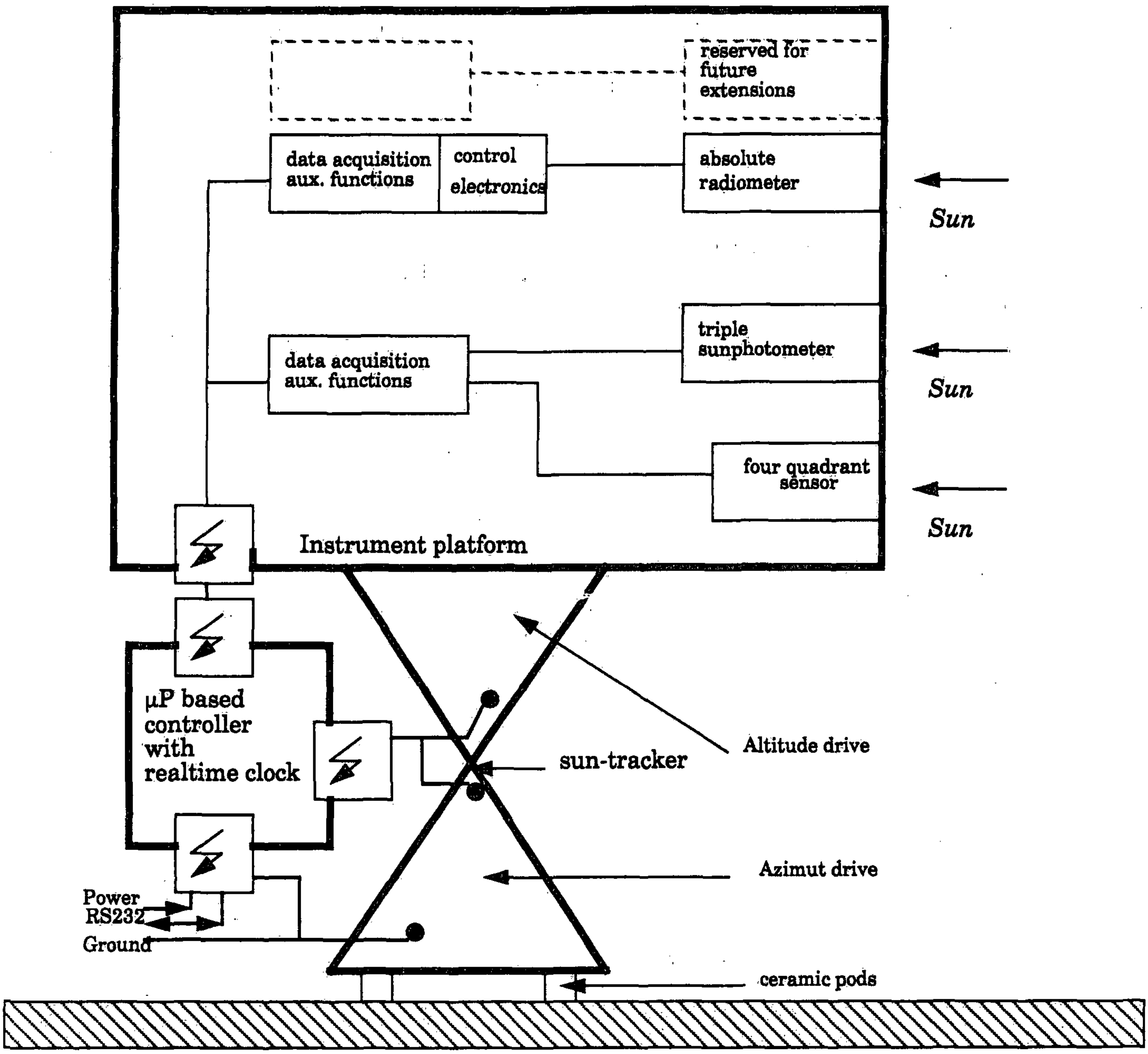


Fig 1: Block diagram of the RASTA units designed for autonomous operation and equipped with an integral lightning protection.

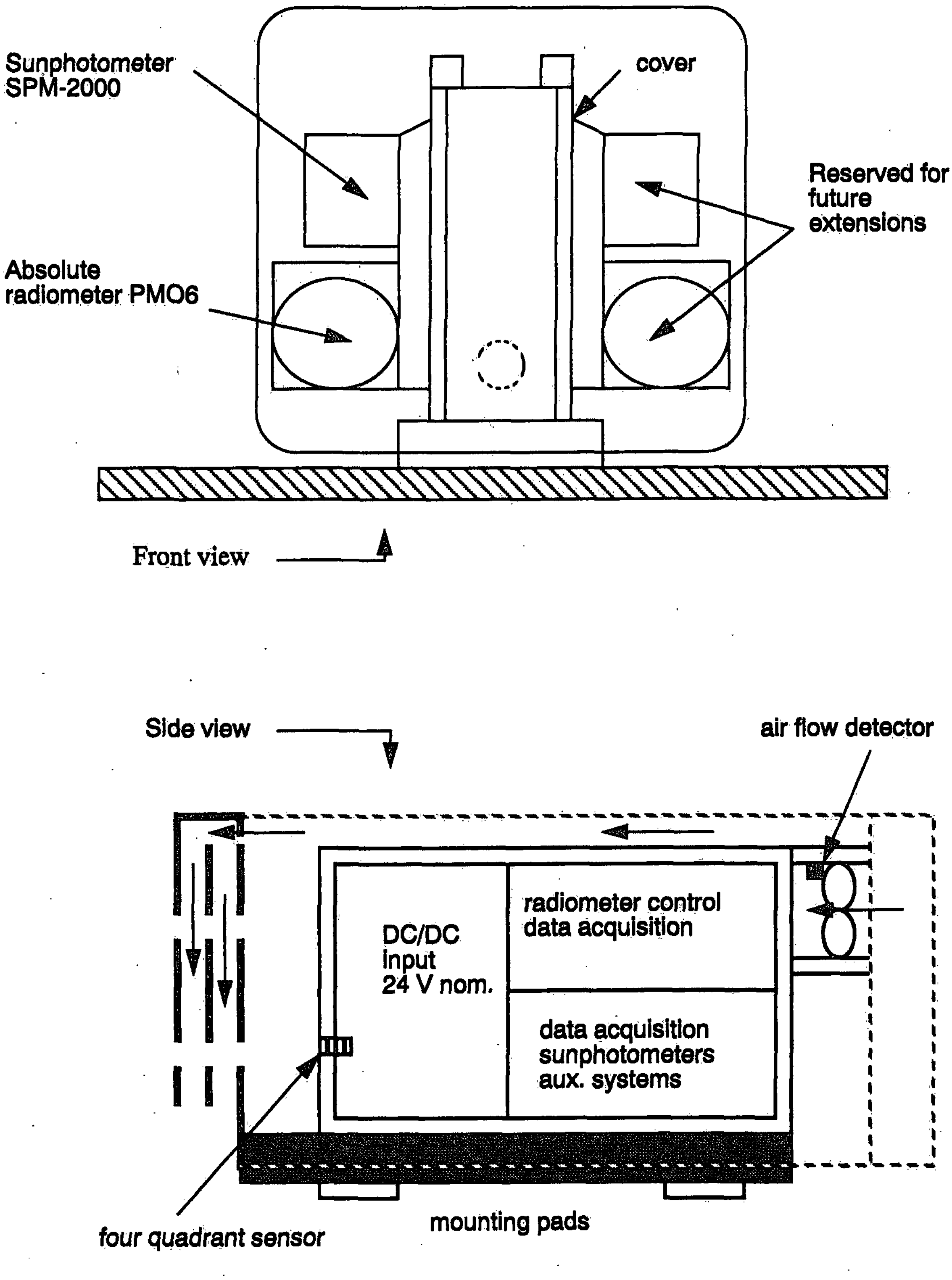


Fig. 2 Concept of the instrument platform of the RASTA. The precision required prohibits the use of optical windows (rain, dust, etc.). A ventilation system prevents rain, snow, etc. from entering the instrument. The control electronics of the radiometer and the data acquisition electronics are located in the center part of the RASTA housing. The electronics is easely accessible by lifting the left or the right cover. The instruments then move with the cover but keep their line of sight.

The ROM resident software points the tracker towards the sun during daytime and performs a rewind during the night. The control program computes the position of the sun from the time and date information it reads from the system clock and the co-ordinates of the site. Site parameters must be entered at system start-up. The software includes utilities to ease installation and servicing of the tracker.

The tracker is available now as a commercial product. Table I contains further technical details.

Table I: Fact sheet for the CSEM-2000 tracker
Mechanical Mount: -Altitude-Azimut configuration -Weatherproof aluminium construction -Altitude and Azimut- angle axis drive (DC- motors) with position encoders, in hermetically sealed boxes -No gear backlash -End- of- course security switches -Levelling instrument for horizontal alignment Control Unit: -Weatherproof enclosure, easily accessible for set-up or servicing -Microprocessor- based tracking control using ROM- resident software -Real- time- clock with calendar for tracking control -Automatic rewind during the night -Software includes a "manual" mode to ease installation and servicing -standard serial link (RS232- C) for remote control or data transfer -Standard G - 64 bus system allows addition of user experiment modules (3 single+ 3 double card slots) -All components for extended temperature range operation (-25 °C/-40 °C...+80 °C) -24 V DC operation, battery backup for RAM and RTC Options: -Lightning- protection for all lines to and from the tracker -Power modules for AC operation -Four quadrant sun sensor -Modifications for sites at low (<35 deg) or high (>60 deg) latitudes -Thermostat heater (for automatic de-freeze)

3.2.2 Instruments

3.2.2.1 Photometers

The photometer used in the RASTA allows to measure the spectral irradiance at three wavelengths. The three channels are independent and allow simultaneous measurements. Each channel consists of an interference filter, a Si-photodiode and a high precision current-to-voltage converter. The filters and the photo diodes are assembled into a temperature controlled enclosure, which is kept at about 45 C. The development of these instruments was initially started at thePMOD/WRC in Davos. They are now commercially available from CSEM. Table II gives the essentials about these instruments while table III lists the wavelengths which are recommended to monitor aerosols and other atmospheric constituents.

Table II: Fact sheet for CSEM sun-photometer SPM-2000
Type of Detector: 3- channel, Si- photodiodes with built-in precision interference filters, all in a temperature controlled assembly. Wavelengths: 368, 500 and 778 nm with 5nm FWHM View angle: 3° full angle Slope angle: 0.9° Measurement electronics: high precision signal amplifier Temperature controller: temperature of detectors/filters stabilized at approx. +45 °C with 0.005 °C stability Signal output (Si- diodes): ~5V full scale Signal output (temperature): approx. 4V @ +20°C (13 mV/K) Component grades: for extended range (-40° C...+85° C) Power requirements: +5 V/5 mA, +9 V/27 mA, -9 V/17 mA,+24 V...+28 V Housing (not used for RASTA): Construction: weatherproof, leak-tight aluminium housing Instrument storage: purging system for N_2- storage Dimensions: a) approx. 320 x 75 x 75 mm (for 1 single instrument) b) approx. 320 x165 x 165 mm (for up to 4 instruments (dimensions without mounting flanges) Weight: a) approx. 2 kg (incl. 1 instrument) b) approx. 5 kg (incl. 4 instruments) Power supply: +24 V DC (19- 35 V) Options: -Housings for 1 single or up to 4 instruments (see above) -Filters with specific characteristics (broad or narrow bandpass, etc.) -Ge- photodiodes for NIR/IR- measurements

Table III: WMO recommendations for Sunphotometers

	Wavelenghts channels (nm)											
Application	368	412	450	500	610	675	719	778	817	862	946	1024
Aerosol minimum	x			x				x				
Aerosol extended	x	x		x		x		x		x		
Ozone		x		x	x	x		x				
Water vapor weak						x	x	x	x	x		
Water vapor strong										x	x	x
Nitrous oxide	x	x	x									
standard channels	SPM-2000-1: 368/500/778 nm											
optional channels	SPM-2000-2: 412/610/862 nm											
	SPM-2000-3: 675/719/817 nm											
	SPM-2000-4: 450/946/1024 nm											

3.2.2.2 Radiometer

The PMO6-type absolute radiometer is based on the measurement of a heat flux using an electrically calibrated heat flux transducer. Brusa and Fröhlich [4] have demonstrated, that this type of radiometers allows to achieve an absolute accuracy of better than 0.17% against the WRR. The PMO6-type radiometers - originally developed at the PMOD/WRC - are now commercially available from CIR.

A schematic drawing of the receiver unit of a PMO6-type radiometer may be seen on fig. 3. Two such units are combined to form a differential heat flux transducer. The front cavity is alternatively shaded and irradiated. A servo loop keeps the temperature between the cavities constant by controlling the electrical power dissipated in the front cavity. The amount of radiative power in the irradiated cavity is obtained as the difference of the (steady state) electrical power fed to the shaded and irradiated cavity respectively.

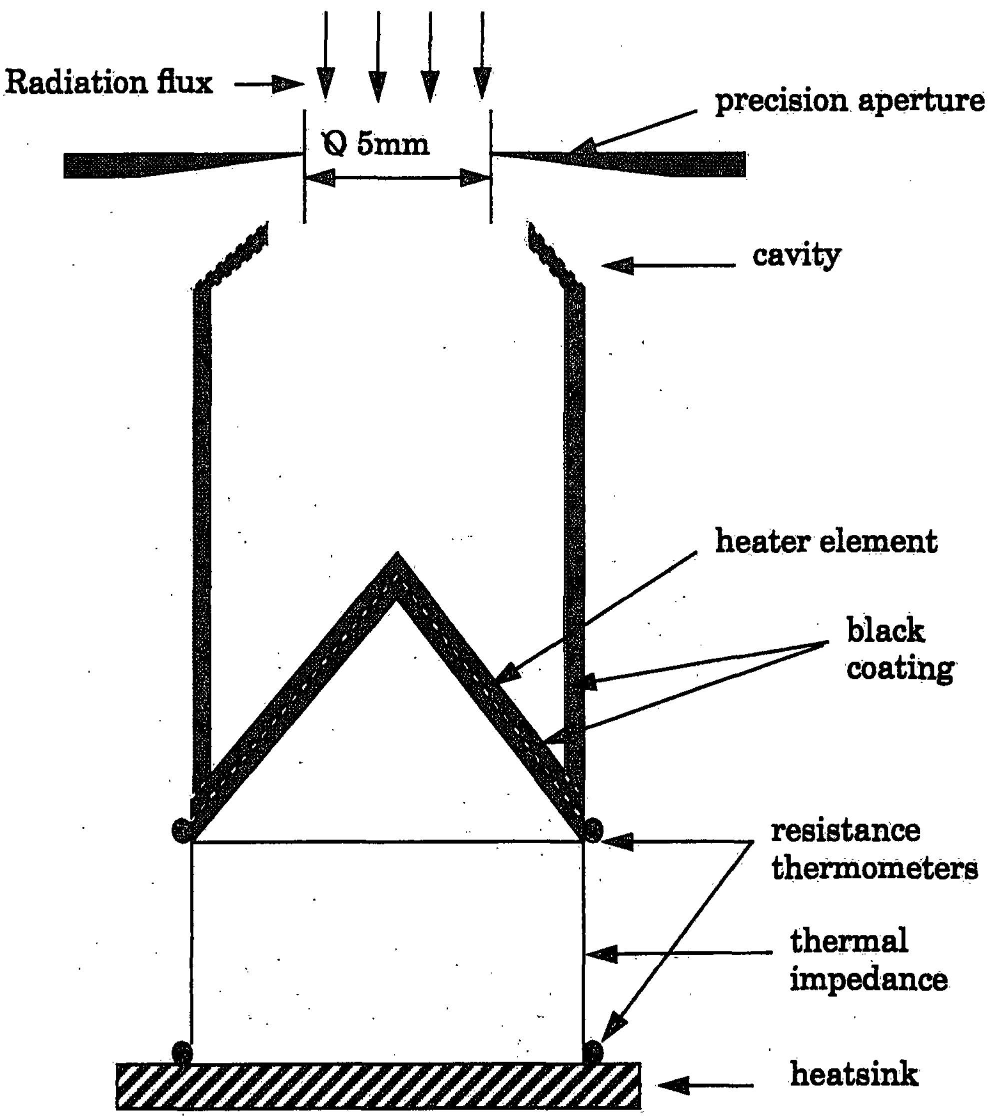


Fig. 3: Schematic drawing of the cavity units of the PMO6-type radiometer

3.2.3 Instrument Platform and Data Acquisition System

3.2.3.1 Mechanical and optical aspects

The design of the instrument's platform (fig. 2) is based on two requirements which are in contradiction with each other. On one hand, it has to be all weather resistant - hence tight - and on the other hand, the precision required prohibits the use of optical windows. The solution is a ventilated system where a stream of filtered air prevents rain and snow - as well as any other contamination - to enter the apertures of the instruments. The platform may accommodate up to four instruments and their control and data acquisition electronics. At present time, an absolute radiometer and a triple sunphotometer are installed.

3.2.3.2 Radiometer Controller and Data Acquisition System

The data acquisition for the radiometer is located on the same printed circuit, together with the radiometer controller. Basically it is an analogue to digital conversion unit with two parallel, simultaneous channels. It is based on voltage to frequency converters. The gate time for the (1 MHz max) V-f signals is selectable in the range from 100 ms to 12800 ms. The calibration sources built into the circuit allow to achieve a system accuracy of 0.01 per cent of full scale in the temperature range from -30° C to +30° C.

3.2.3.3 Photometer Controller and Data Acquisition System

The data acquisition for one triple sun photometer and the four quadrant sensor is on a second board of the same size as the radiometer control/data acquisition. Its principle of analogue to digital conversion is the same as for the radiometer electronics. It is designed to meet a system accuracy of 0.04 per cent in the temperature interval from -30° C to + 30° C. This board may be used as a general A/D converter offering a total of 24 channels for signals with (differential) voltages between 0 to 10 V full scale. The board includes 3 digital outputs for general control and 6 digital inputs.

Both boards - as well as future extensions - are connected to an RS232-C party line. Addressed commands invoke one board at a time and allow control of the system by only 3 wires. Two other additional wires are required to feed the 24 V power to the DC/DC converter inside the electronic box of the instrument platform. Each of these interconnections between controller and instrument platform is equipped with filters for lightning protection.

3.2.3.4 Characterization of the data-acquisition system

Prior to installation, each system will be characterized in a temperature chamber. The purpose of these tests is to demonstrate and assure that the system meets its design goals under the temperature conditions that will occur during its outdoor operation.

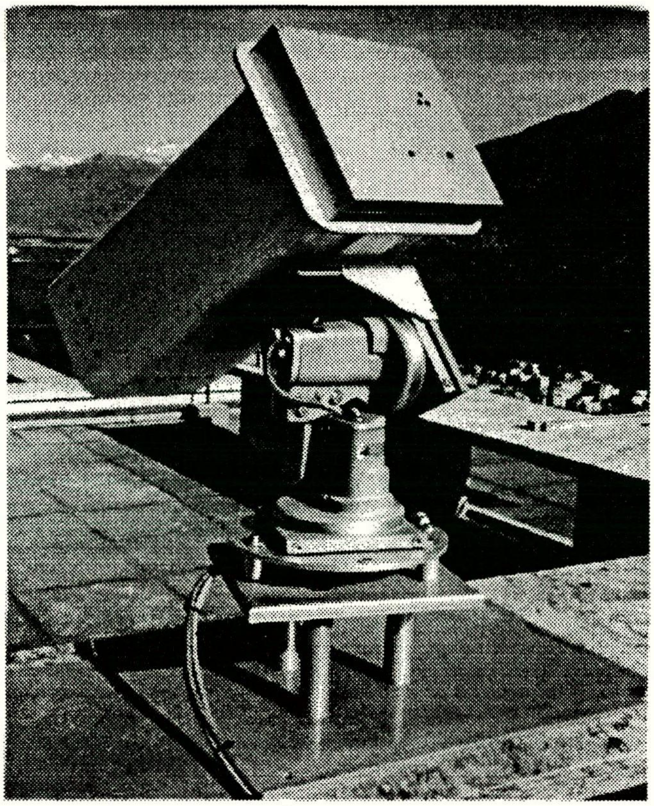
3.3 Data transmission

The program controlling the RASTA determines 10 minute-mean values of the total solar irradiance and reads the three channels of the sunphotometers every 10 minutes. These data - together with quality information about the data - will be transmitted by an RS232-C link to a corresponding interface in the SMI-ANETZ automatic weather station (ASTA). All the ANETZ stations are connected by leased lines to the central computer of the SMI which reads out all the values of a station every 10 minutes. A local data storage at the site of the RASTA is presently not envisaged.

The quality information about the RASTA-data include data on the pointing accuracy and flags which indicate that shutters or the fan do work properly.

3.4 Development

- Tracker + Controller:	commercial product by CSEM, Neuchâtel
- Instrument Platform + DAS:	BRUSAG, Stäfa
- Sunphotometers:	commercial product by CSEM, Neuchâtel
- Radiometers:	commercial product by C. I. R., Bern
- Software:	BRUSAG, Stäfa
- System Integration:	BRUSAG, Stäfa
- Tests and field installation:	SMI, Payerne



Picture 1: View of the RASTA unit installed at Locarno-Monti.

4. Present state and preliminary results

Measurements with the RASTA systems began officially on the 1.1.1991 at Davos (DAV: 46.817 N, -9.850 E, 1590 m.a.s.l.) and in June 1994 at three other stations: Changins (CGI: 46.4 N, -6.233 E, 430 m.a.s.l.), Payerne (PAY: 46.817 N, -6.95 E, 490 m.a.s.l.) and Locarno-Monti (OTL: 46.18 N, -8.783 E, 366 m.a.s.l.; see picture 1). A fifth station was installed at the end of 1994 at the Jungfraujoch (JUN: 46.55 N, -7.98 E, 3580 m.a.s.l.). The last unit is due to be put into operation at La Dôle (DOL: 46.43 N, -6.1 E, 1670 m.a.s.l.) at the beginning of 1995.

Figure 4 displays the variations of the direct solar irradiance as measured by the absolute radiometer at the 4 stations in operation during November 1994. The patterns found at Payerne and Changins are strikingly similar, indicating a strong correlation between the two stations.

Atmospheric spectral extinction can be expressed as:

$$I(\lambda) = I_0(\lambda) e^{-\tau_\lambda m}$$

where $I_0(\lambda)$ is the extraterrestrial intensity corrected for the sun-earth distance, $I(\lambda)$ the measured intensity at the earth's surface, τ_λ the spectral total optical depth and m the relative airmass. The spectral total optical depth can be expressed as function of the scattering due to air molecules $\tau_{\lambda R}$, of the ozone absorption $\tau_{\lambda o3}$ and of the aerosol scattering $\tau_{\lambda\alpha}$:

$$\tau_\lambda = \tau_{\lambda R} + \tau_{\lambda o3} + \tau_{\lambda a}$$

Measurements performed with sunphotometers at the three WMO standard wavelengths (368, 500 and 778 nm) are used to compute total optical depths for these channels. The Rayleigh optical depth may be obtained by simple calculation with values of the air pressure at the site measured routinely by the nearby automatic weather station of the national meteorological network ANETZ. The ozone optical depth at 500 nm may be computed by using the total ozone amount for the particular day measured at the ozone station located at the Licht Klimatisches Observatorium LKO at Arosa. Substracting the Rayleigh optical depth and the ozone optical depth (for the 500 nm channel only) from the total optical depth yields the aerosol optical depth at the three wavelengths. The formula defined by Angström [5] gives the aerosol extinction as function of the wavelength:

$$\tau_a(\lambda) = \beta\lambda^{\alpha}$$

where β is the turbidity and α the wavelength exponent. These two parameters are usually used in a first approach to characterize in a broad way the extinction properties of the atmosphere.

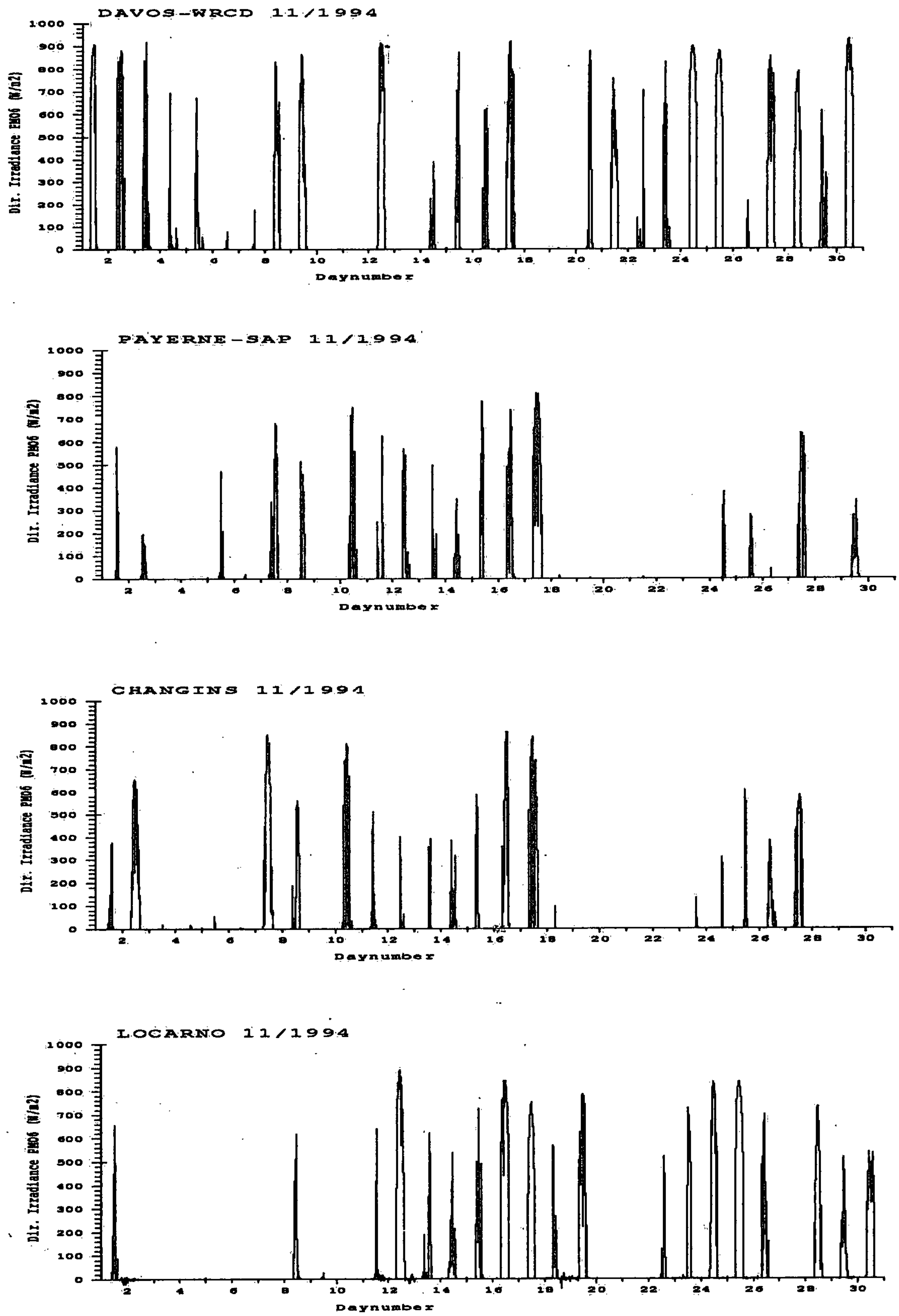
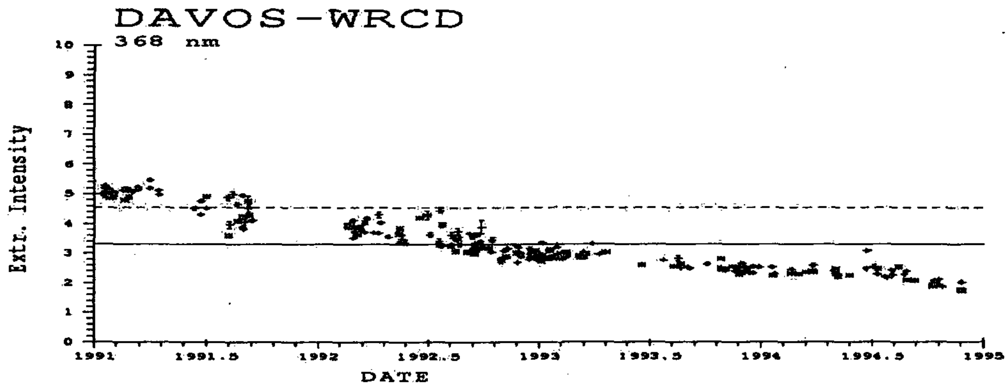
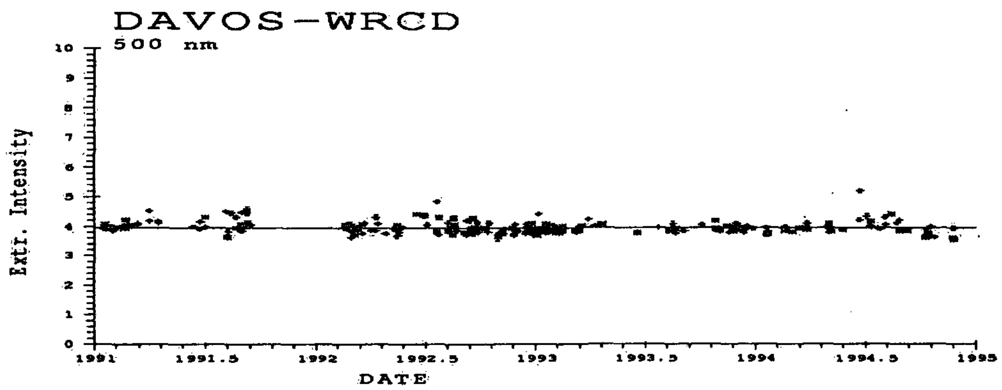


Figure 4: Direct irradiance measurements performed at the 4 operating stations in November 1994 with PMO6-type absolute radiometers (10 mn time step).

The method described above implies that the extraterrestrial intensity must be known either in absolute units or, at least, relative to the instrument. In the latter case, these values may be obtained with the sun as a source by using the well known Langley plot method which requires that the atmosphere remains clear and stable during the measurement periods. Figure 5 displays the variations of the extraterrestrial values relative to the sunphotometer obtained at Davos with the Langley Plot method for the 3 different available wavelengths.





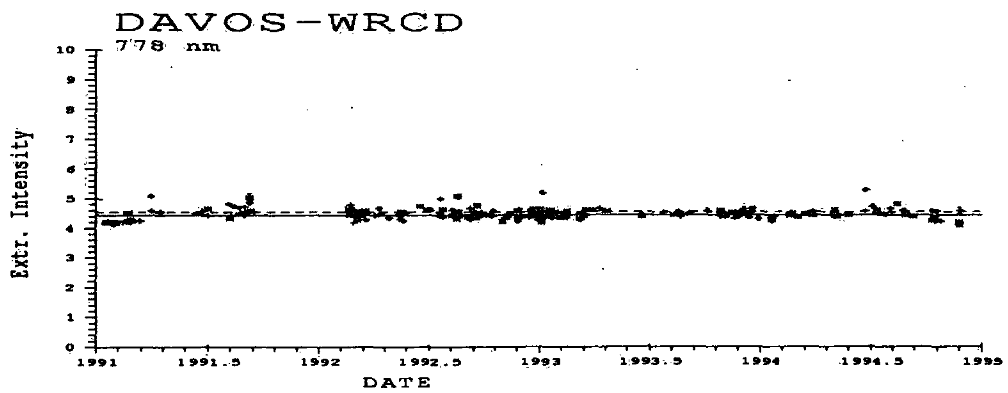


Figure 5: Variations of the spectral extraterrestrial intensities in Volts for the three wavelengths of the sunphotometer in use at Davos for the period 1991-1994

While the extraterrestrial values in the visible and infrared channels remained constant during the whole period, a strong degradation of the ultraviolet channel is evident. The reason of this decrease is not yet completely understood. Figure 5 shows however that the variations of the extraterrestrial value relative to the instrument in the UV channel are smooth, so that the assumption of a stable behavior during one day may be accepted. This means that values of the total optical depths may be extracted from the slope of the regression lines obtained with langley plots without knowing the accurate value of the extraterrestrial intensity of the instrument. Care must be however taken that the weather conditions are clear and stable. A sample of the results is displayed on figure 6 for Davos.

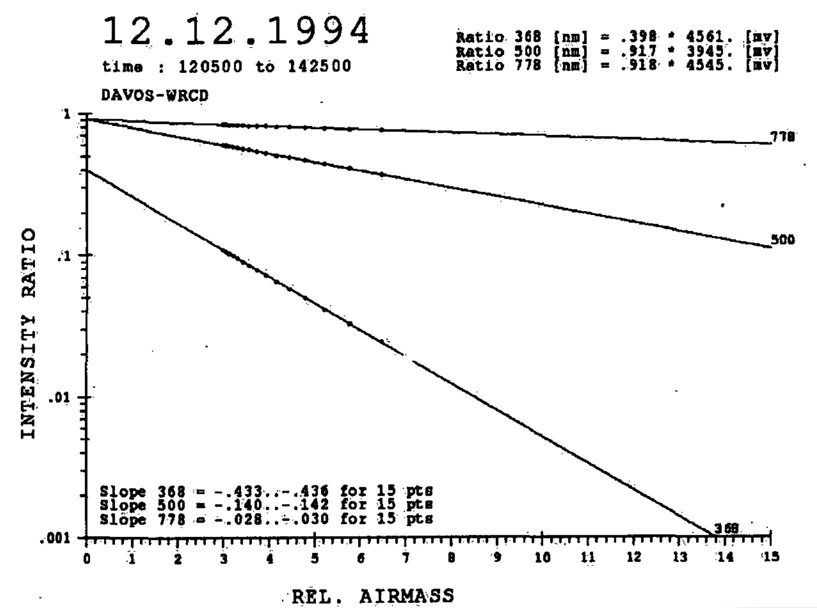


Figure 6: Determination of the extraterrestrial intensities by the Langley plot method on the 12.12.1994 in the afternoon for the 3 wavelengths. The slopes of the regression lines give the spectral total optical depths during the period of measurements.

Once the spectral total optical depths are known, the resulting turbidity and wavelength exponent values can be computed for such cases where the Langley plot method can be applied. Figure 7 displays the monthly mean values of the turbidity factor and of the wavelength exponent obtained at Davos since 1991.

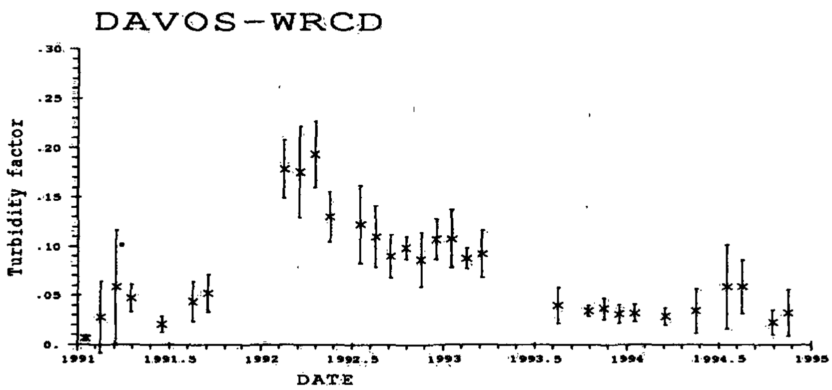
The effect of the presence of the stratospheric cloud produced by the eruption of the Pinatubo volcano in 1991 can be clearly seen at the beginning of 1992 on the upper graph of figure 7. Unfortunately, measurements are missing at the end of 1991 due to mechanical problems with the sun-tracking system. Another smaller turbidity peak may also be spotted at mid 1994, of unknown origin at present time.

The second graph on figure 7 displays the variations of the wavelength exponent.

This parameter gives a rough estimate of the size distribution of the atmospheric aerosols. The basis of the Angström formula is an aerosol size distribution which follows a so-called Junge distribution of the form:

$$\frac{dn(r)}{dr} = Cr^{-(\nu+1)}$$

where C is proportional to the aerosol concentration and υ is related to the wavelength exponent α according to $\alpha=2-\upsilon$. Continental aerosol can be reasonably described with a value of υ equal to 3.3. Values of the wavelength exponent lower than 1.3, as originally assumed by Angström, indicate an overpopulation of relatively large size aerosols while higher values of α are representative of the presence of smaller size aerosols.



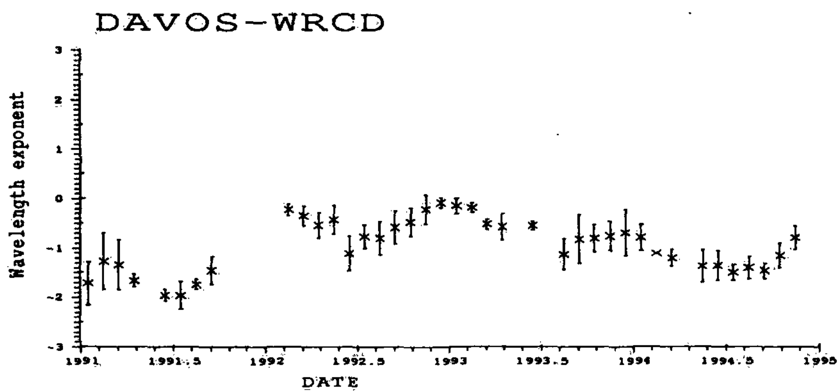


Figure 7: Variations of the monthly mean values of the turbidity factor (upper graph) and of the wavelength exponent (lower graph) measured at Davos. The vertical bars give the standard deviation of the monthly means.

The variations plotted on the second graph of figure 7 seem to indicate some kind of annual trend which will have to be further analyzed when more data are available.

Similar studies can be performed with the total irradiance values measured by the absolute radiometer. Analysis of the effects of the El-Chichon eruption in 1982 have been performed with the first RASTA unit located at Davos [2] and a further publication concerning the effects of the Pinatubo eruption is in preparation [3].

5. Future developments

As mentioned earlier, some difficulties remain to be solved concerning the pointing accuracy of the trackers. A new development is progressing at the SAP in order to correct this by placing the position encoder directly on the axis of the altitude and azimut drives. The software will then directly correct for the misalignment caused by the back lash of the gear, a solution which should bring the tracking errors below 0.1 deg. This new mechanical setup will also allow to incorporate an efficient heating system within the sun-tracker mechanics for operation in harsh environment conditions.

Experience gathered during the summer 1994 has shown that the protection of the instruments is still insufficient, especially in the case of heavy summer rainfalls at high solar elevation. This problem will be solved by adding a rotating shutter system in front of the instrument platform, which will be controlled by a rain detector placed on the front plate. A heating film will be glued on the back of the front plate in order to prevent accumulation of ice during the winter which could hamper the shutter to close when necessary.

Furthermore, the ventilator at the back of the instrument platform will be changed for a more powerful unit and heating resistors will be added in the air flow in order to keep the instrument at normal working temperature under very cold temperature conditions.

Regular inspection of the sunphotometers during calibration have shown that deposition of dust as well as water condensation could be traced on the sensor itself. This problem will be corrected by adding a second shutter mechanism for these instruments, which will be opened only during the measurements (e. g. a few seconds every 10 minutes) and thus prevent as much as possible contamination of the surface of the detector.

6. Conclusion

Scattering and absorption in the atmosphere due to aerosols may affect the climate, the weather, the visibility and in some (cataclysmic) cases the biological equilibrium on earth. Monitoring the atmospheric trends on a world-wide basis is currently an acute problem because of possible future climate changes. Among others, a reliable climatology of the aerosol type and amount is not yet established which would allow to predict the influence of long-term changes.

Ground-based measuring systems such as the RASTA described in the present paper represent a possibility to analyze the influence of aerosols in the atmosphere. Though the development phase of the project took a considerable time, the results obtained until now show the potential of information of such systems integrated in a meteorological network and combined with information concerning the stratospheric aerosol measured by ground-based lidars for example.

The six RASTA units, located at altitudes ranging from 366 to 3580 m.a.s.l. and at longitudes between 6.2° to 9.8° E for practically the same latitude, will ultimately represent a valuable source of information about the climatology of the direct irradiance over the Alps as well as the variations of the aerosol type and amount over the same region. These data should therefore represent also an interesting contribution to the analysis of satellite measurements.

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Acronyms

ANETZ	Automatic meteorological network of the SMI
ASTA	Automatic STation of the ANETZ
BRUSAG	Sensorik & messtechnische Entwicklungen, Chapwiesenstrasse 14, CH-8712 Stäfa
CIR	Compagnie Industrielle Radioélectrique SA, Gals/BE
CSEM	Centre Suisse d'Electronique et de Microtechnique SA, CH-2007 Neuchâtel
DAS	Data Acquisition System
FWHM	Full width at half maximum
IR	Infrared radiation
LKO	Licht Klimatisches Observatorium, Arosa
PMOD/WRC	Physikalisch- Meteorologisches Observatorium Davos / World Radiation Center, CH-7260 Davos Dorf
PSI	Paul Sherrer Institute, CH-5232 Würrenlingen
RAM	Random Access Memory
ROM	Read Only Memory
RTC	Real Time Clock
SAP	Aerological Station of the SMI, CH-1530 Payerne
SMI	Swiss Meteorological Institute
UV	Ultraviolet radiation
WMO	World Meteorological Organization
WRR	World Radiometric Reference