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INTERNATIONAL ENERGY AGENCY
program
to develop and test
solar heating
and cooling systems

task III
performance testing
of solar collectors

RESULTS OF AN OUTDOOR AND INDOOR PYRANOMETER COMPARISON

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task III: Performance Testing of Solar Collectors,
subtask A: Development and Application of Standard Test Procedures for Determining Thermal Performance

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ABSTRACT

The performance of a representative number of pyranometers which are commonly being used for solar collector testing or similar applications was investigated. Experiments were conducted both indoors and outdoors. Laboratory investigations from different places were compared. The results allow an assessment to be made of the overall accuracy of global irradiance measurements associated with the comparison of thermal performance data in solar energy applications.

Practical guidance is provided for the selection of pyranometers.

The present laboratory measurement techniques for determining the directional response of pyranometers were shown to be characterized by great uncertainties. The day-long variability of the pyranometer performance during a typical calibration day was found to be most indicative of the instrument's quality.

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PREFACE

INTERNATIONAL ENERGY AGENCY

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organization for Economic Cooperation and Development (OECD) to administer that agreement. Twenty countries are currently members of the IEA, with the Commission of the European Communities participating under a special agreement.

As one element of the International Energy Program, the participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat, coordinates the energy research, development, and demonstrations program.

SOLAR HEATING AND COOLING PROGRAM

Solar Heating and Cooling was one of the technologies selected by the IEA for a collaborative effort. The objective was to undertake cooperative research, development, demonstrations and exchanges of information in order to advance the activities of all Participants in the field of solar heating and cooling systems. Several tasks were developed in key areas of solar heating and cooling. A formal Implementing Agreement for this Program, covering the contributions, obligations and rights of the Participants, as well as the scope of each task, was prepared and signed by 15 countries and the Commission of the European Communities. The overall program is managed by an Executive Committee, while the management of the sub-projects is the responsibility of Operating Agents who act on behalf of the other Participants.

The tasks of the IEA Solar Heating and Cooling Program and their respective Operating Agents are:

II. Coordination of R&D on Solar Heating and Cooling Components -
Agency of Industrial Science and Technology, Japan
III. Performance Testing of Solar Collectors -
Kernforschungsanlage Jülich, Federal Republic of Germany
VI. Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors -
United States Department of Energy
VII. Central Solar Heating with Seasonal Storage -
Swedish Council for Building Research
VIII. Passive and Hybrid Solar Low Energy Buildings -
U.S. Department of Energy
IX. Solar Radiation and Pyranometry Studies -
Canadian Atmospheric Environment Service

Collaboration in additional areas is likely to be considered as projects are completed or fruitful topics for cooperation identified.

This report documents work carried out under Task III of this project. The cooperative work and resulting report is described in the following section.

ACKNOWLEDGEMENTS

This report is the result of international cooperative work within Task III. Many Task participants have made significant contributions to this work and several manufacturers supported the experimental work by a loan of instruments. The authors are thankful for the support of the Executive Committee of the IEA Solar Heating and Cooling Project. In particular they wish to acknowledge the encouragement given by Paul Kesselring.

The International Energy Agency was fortunate to receive the generous support of the authors' home institutions. Two laboratories provided the means and tools for the experimental investigations:

> The Physikalisch-Meteorologisches Observatorium, Davos,
> The Swedish National Testing Institute, Boras.

Two governmental bodies have made these investigations possible by their outstanding support:

> This work was supported by the Swiss National Fund for Energy Research coordinated by the Swiss Federal Energy Office, Berne, Switzerland.
>
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The authors are grateful to their colleague Bill Gillett whose help made the English text fluent and elegant.

1. INTRODUCTION

The development of solar energy technology has put new emphasis on the measurement of meteorological parameters and on the measurement of solar radiation in particular. The established concepts and expertise for these types of measurement are largely housed in classical meteorological science. However, since the needs of the solar energy technologists with respect to data differ markedly from those of meteorologists, it was not simply a matter of transferring know-how, but rather a challenge for a true interdisciplinary dialogue.

The activities and the publications of the World Meteorological Organisation (WMO) and many national meteorological laboratories over the recent years have demonstrated the importance of their expertise for the development of solar energy technology, and we have readily communicated on a broad spectrum of subjects. Pyranometry certainly is a field of common interest and the investigations reported here should be seen as part of an on-going dialogue. The collaborative activities of the IEA Solar Heating and Cooling Project have provided the resources and a much welcomed framework in which to conduct both outdoor and laboratory experiments.

Why did we do it?

Experience from an intercomparison of thermal performance test results and of the global radiation instruments themselves has shown that the required accuracy was not established /1, 2, 3/. Therefore, in close collaboration with meteorologists an experimental investigation was designed and the objectives were stated as follows:

- Quantification of the accuracy of global radiation measurements in solar energy applications (especially in testing and monitoring).
- Establishment of a data base of comparative pyranometer performance (restricted to the most widely used types).
- Preparatory work for a standard code of practice for pyranometry in solar energy applications.
- Identification of possible measures to improve the accuracy of measurements and recommendations for the selection of useful instruments.

How we did it?

Intercomparisons of pyranometers had been done elsewhere /4, 5/. One major concern in the design of the new investigative scheme was, therefore, to overcome some of the shortcomings of earlier investigations. Among those shortcomings the following aspects were identified to be most relevant:

- investigations were confined to a single type of instrument,
- if conducted for different types of instrument, the number of instruments was too small to be representative for a particular type and brand,
- if comparative testing was done outdoors, a complete indoor characterization was lacking.

Secondly, our investigations were designed by the experimentalists and test engineers very much from a user's point of view. The product in question was the pyranometer and the guideline for the experiments and the evaluation of data was to make them meaningful with respect to the usual situation found in solar energy application studies.

Thirdly, it was decided to cooperate with the manufacturers of pyranometers which was felt to be vital for the experiment and possible future impacts thereof. The manufacturers readily provided the instruments on a loan basis. Any bias by a possible pre-selection of instruments was considered not relevant.

Last not least, an immediate reference to the WRR (World Radiometric Reference) was felt to be an essential requirement for the outdoor testing. The World Radiation Center in Davos, Switzerland, was, therefore, selected to perform outdoor measurements.

2. OUTDOOR TESTS

The design of the experiments reflects many typical applications of pyranometry for testing and monitoring of engineered solar energy systems and components, where measurements are usually required for an inclined receiving surface. However, for most outdoor tests the horizontal position was preferred because, in this position, identical albedo conditions could easily be provided. The methodology adopted in this outdoor investigation may not have been perfect, but it is thought to have produced results which are meaningful for the intercomparison of thermal performance test data in solar energy applications.

The accuracy of global irradiance measurements (especially short term) has been an item of some controversy for many years, so it is hoped that the data presented here may be useful to other workers for reference purposes. A great number of comparative studies are possible, and only a few could be elaborated in this report. The reader is, therefore, encouraged to use the performance data (Appendix A) according to his gusto.

Performing the outdoor experiment in Davos at the World Radiation Center had several advantages:

- The absolute cavity radiometer PMO2 could be used as a very accurate reference. This instrument - one of the World Standard Group - is traditionally used as reference for the calibration of the other radiometers and in international pyrheliometer intercomparisons.

- The center is well equipped, its infrastructure is often used for pyrheliometer comparisons, the data acquisition system is very accurate and well designed for such a task. Part of the software was already available.

- The staff is highly skilled and was of great support during the experiment.

2.1 Test Conditions

The outdoor tests were conducted at the World Radiation Center (WRC) in Davos, Switzerland. The coordinates of the location are:

Latitude: 46.8145 °N
Longitude: 9.8459 °E
Altitude: 1,598 m

Two types of pyranometer, both "thermo-electric", were tested:

- black and white surfaces arranged in a star pattern (hot and cold junctions are near the surface)
- thermopile with a black receiving surface (hot junction) and the instrument's body as a heat sink (cold junction).

A total of 6 groups of instruments and three WRC pyranometers were investigated:

6 Eppley PSP
5 Kipp & Zonen CM 10
5 Kipp & Zonen CM 5
5 Schenk star
6 EKO star
3 Swissteco
1 PMOD (WRC)
2 PMOD Cavity

During the tests all the pyranometers were aligned on a bench. The mechanical support consisted of two bars of 5 m length. The construction allowed for accurate levelling and tilting of the instruments. Four of the instruments were continuously shaded which required a special mount for the step motors. The shading disks had a view angle of about 5^{o}. The absolute radiometer had an independent tracking mount with accurate active pointing system. Direct radiation was recorded with the absolute radiometer reference of the WRC (PMO2). This instrument gives a very accurate absolute value (about 0.4% /6/). An auxiliary pyranometer was used to monitor the reflected irradiance. This instrument was installed 2 m above the ground level facing downwards. These measurements were most important during winter time when the instruments viewed a snow-covered slope. In between the two bars for the pyranometers additional sensors were located to measure wind velocity and direction, ambient air temperature and the pyranometer body (PMOD 6703-A) temperature.

All instrument readings were sampled 10 times every minute and the arithmetic mean values of these 10 values were stored as 1 minute mean values on tape. The central unit of the data acquisition system was a PDP8 computer. Figure 1 displays a scheme of the data acquisition system and Figure 2 a flow chart of the data acquisition logic.

The measured and computed data were stored on magnetic tape. Evaluation work was done on the CDC mainframe computer of the Swiss Federal Institute of Technology in Zürich.

The comprehensive outdoor data is presented in the Appendix A. The data plots allow the performance of each individual instrument to be identified and provide a summary of the solar radiation data, other meteorological data and relevant geometrical parameters. For the calibration days, the reference was the sum of diffuse radiation measured with a shaded pyranometer and the direct radiation measured with the WRC absolute cavity radiometer. For those days where an absolute reference was not available we have chosen a group of 4 pyranometers as the reference. This choice was made after the experimental studies, during the evaluation. The criteria for our choice were the instruments' performance with respect to tilt, irradiance, temperature and incident angle on calibration days. The group of four instruments that served as a reference consists of:

Eppley PSP	20523
Eppley PSP	20644
Kipp & Zonen CM10	790059
Kipp & Zonen CM10	810120

Later in this investigation, the indoor characterization endorsed this choice. This method of choosing a reference could introduce a bias which is unavoidable for non-clear sky conditions, but the error is believed to be negligible for clear days.

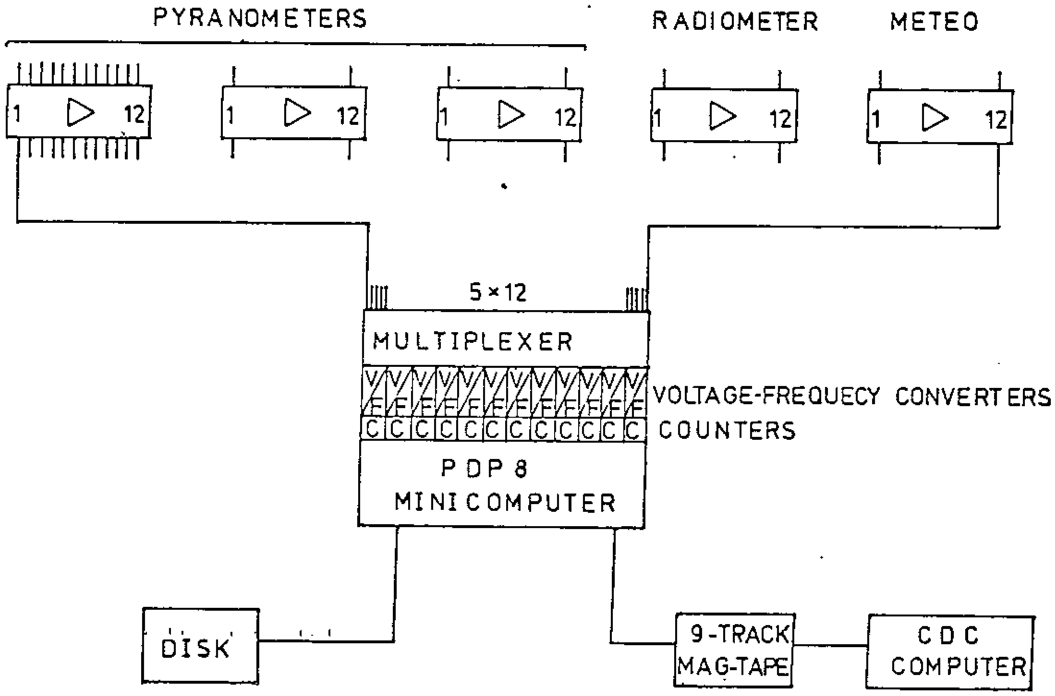


Figure 1: Scheme of the data acquisition system

The data acquisition system consists of 12 voltage-to-frequency (V/F) converters whose output pulses are fed to 12 counters that can be started simultaneously. Each V/F input is multiplexed to 16 levels, three of them are connected to reference voltages and used periodically for calibration. The remaining 13 levels of 12 analog channels are connected to amplifiers with different sensitivity. These amplifiers are calibrated by connecting a programmable voltage source to their inputs and measuring this stimulus with a system DVM of high accuracy. At the same time, their outputs are measured by the V/F. Using a set of voltages appropriate for each amplifier, its gain and offset are determined and stored for later evaluation of the actual measurements. During instrument comparison the reference instrument is connected to the first channel of each level, so that at each simultaneous reading of the channels of a level the reference is also read.

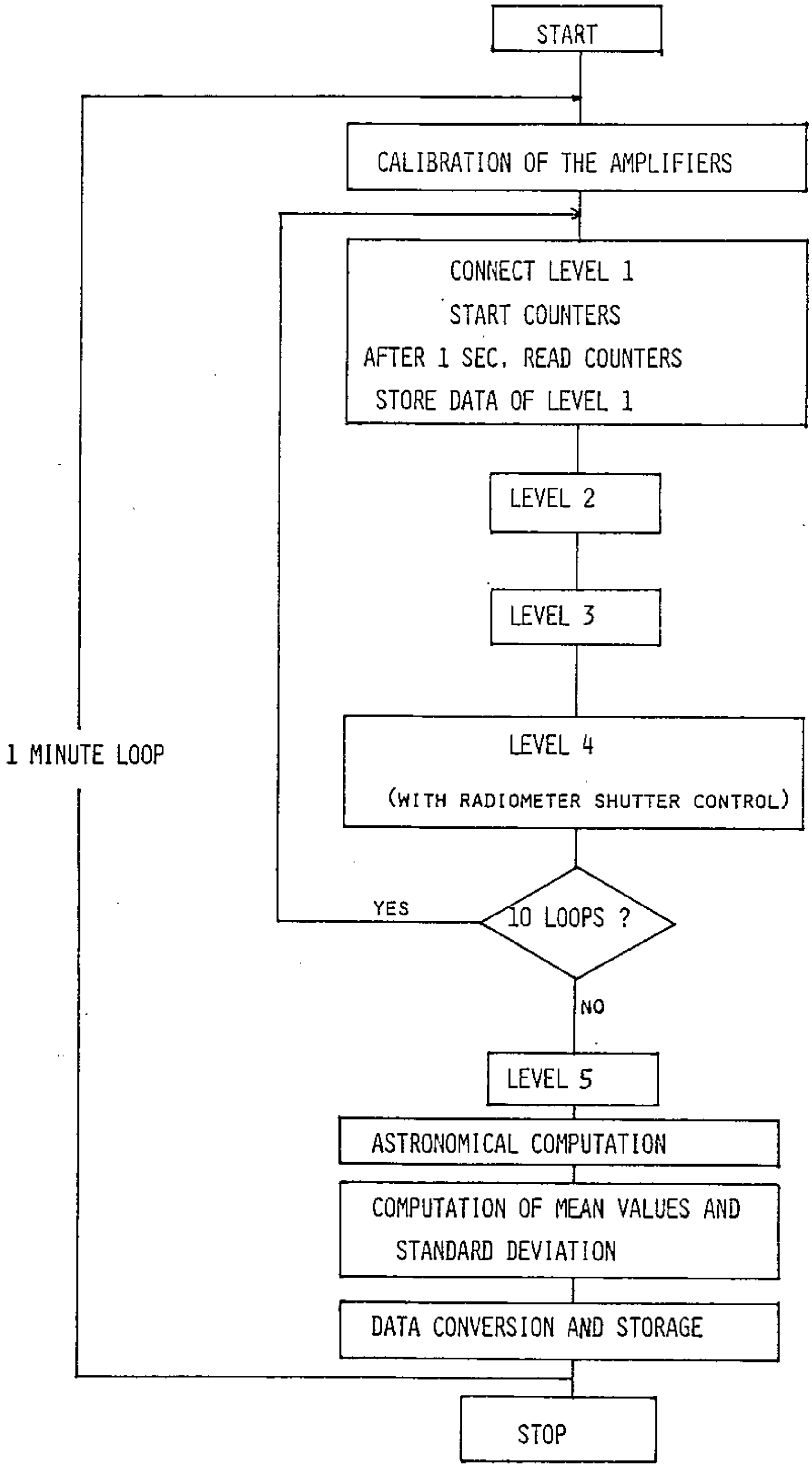


Fig. 2: Flow Chart of the Data Acquisition Program

Performance data were recorded on a wide range of weather and seasonal conditions: winter and summer; clear, cloudy and overcast skys. A total of 26 test days with a variety of weather and test conditions make the complete set of outdoor data:

Day	Weather	Tilt
29 July 1981	clear	0^{o}
30 July 1981	clear	0^{o}
5 August 1981	clear	0^{o}
18 August 1981	clear	0^{o}
19 August 1981	clear	0^{o}
13 August 1981	clear	30^{o}
13 January 1982	clear	30^{o}
14 January 1982	clear	0^{o}
18 January 1982	clear	0^{o}
26 April 1982	clear	Tracking
3 May 1982	clear	Tracking
14 August 1981	clear	45^{o}
27 August 1981	cloudy	0^{o}
28 August 1981	cloudy	0^{o}
31 July 1981	cloudy	30^{o}
31 July 1981	cloudy	60^{o}
6 August 1981	cloudy	30^{o}
12 August 1981	cloudy	45^{o}
21 December 1981	cloudy	30^{o}
3 December 1981	cloudy	0^{o}
8 December 1981	cloudy	0^{o}
24 November 1981	overcast	0^{o}
26 November 1981	overcast	0^{o}
27 November 1981	overcast	0^{o}
9 December 1981	overcast	0^{o}
11 December 1981	overcast	30^{o}

2.2 Participating Instruments

The basic approach in this investigation was to use to a large extent new instruments. The selection was conducted with the assistance of the experts from solar test laboratories participating in Task III. While it is well recognized that there are other manufacturers of pyranometers which were not considered, it is hoped that this selection of instruments serves the needs of most test laboratories. On request, the manufacturers provided a number of instruments on a loan basis. The Swissteco instruments should be considered as "under development"; they were included on special request by the Swiss Participants.

The Kipp & Zonen CM5 instruments were included to provide information on a retrospective basis for a number of laboratories in the European Community, which had been using them for some years in their solar testing work.

After completion of the investigations, the instruments were shipped to the destinations indicated on the list of participating instruments. The greater part of the instruments were shipped to the National Atmospheric Radiation Center (NARC), in Canada. Contact person: Dave Wardle, NARC, 4905, Dufferin St., Downsview, Ont. M3M5T4, Canada.

Postal addresses of manufacturers involved in this investigation:

The Eppley Laboratory, Inc.
12 Sheffield Ave.,
Newport, R.I. 02840, U.S.A.

Kipp & Zonen
P.O.Box 507
NL-2600 AM Delft
Netherlands

Philipp Schenk
Postfach 3
A-1212 Vienna, Austria

EKO Instruments Trading Co.Ltd.
21-8, Hatagaya 1 Chome
Shibuya-Ku, 151 Tokyo, Japan

Swissteco Instruments
Stegweg, Eichenwies
CH-9463 Oberriet SG

The complete list of the pyranometers that were tested is given in Table 1.

Table 1: List of Pyranometers

Identification of instrument		Owner	Destination/Remark
EKO	81901	manufacturer	transfer to NARC
star	81902	"	donation/damaged in transit
	81903	"	donation
	81906	"	"
	81907	"	transfer to NARC
	81908	"	" " "
	81909	"	" " "
Eppley	14806	NBS, Washington	returned to owner
PSP	17750	NRC, Toronto	transfer to NARC
	18135	manufacturer	" " "
	20523	"	" " "
	20524	"	" " "
	20655	PMOD, Davos	returned to owner
Kipp & Zonen			
CM 5	773656	Met. Office, Bracknell	transfer to NARC
	773992	DFVLR, Cologne	" " "
	774120	KFA, Jülich	" " "
	785017	PMOD, Davos	returned to owner
	785047	EPFL, Lausanne	transfer to NARC
CM 10	790059	Met. Obs., Hamburg	returned to owner
	810119	manufacturer	transfer to NARC
	810120	"	" " "
	810121	KFA, Jülich	" " "
	810122	manufacturer	" " "
Schenk	1626	Met. & Geodyn., Vienna	transfer to NARC
star	2186	manufacturer	" " "
	2209	"	" " "
	2217	"	" " "
	2221	"	returned to owner
Swissteco			
	113	manufacturer	transfer to NARC
	114	"	" " "
	115	"	returned to owner
PMOD	6703-A	PMOD, Davos	Davos
	CAV-1	"	"
	CAV-2	"	"

These instruments took part in the intercomparison of pyranometers during 1981 and 1982 at the World Radiation Center in Davos, Switzerland, and were characterized by the Statens Provningsanstalt, Boras, Sweden, during summer 1982. After completion of these investigations the instruments were shipped to the NARC (National Atmospheric Radiation Center, Canada). Since the performance of these instruments has been thoroughly characterized, they may serve as a reference for supplementary investigations in the future.

2.3 Reference calibration

Since there is no absolute standard available for global radiation instruments, calibration practices are related to an absolute standard for beam irradiance. This standard is represented by a group of instruments (absolute radiometers), known as the World Radiometric Reference (WRR). The only direct method by which global radiation instruments can be referenced to an absolute or primary standard of beam radiation is the classical sun-shade method: the pyranometer undergoes a sequence of shaded and unshaded exposures and the difference in signal is referenced to the readings of the direct irradiance instrument /7, 8/.

Although the generic basis of pyranometer calibration is straight-forward, the details of the calibration procedure differ from laboratory to laboratory: e.g. different shading geometry, different durations of the shaded-unshaded sequences, horizontal or tracking mount, pre-selected solar elevations etc. Alternatively, a second pyranometer - with known characteristics - to measure the diffuse part of the radiation can be used, which makes the shading and unshading sequence obsolete. The main advantage of this latter method is that transient conditions of the pyranometer are avoided. Since several time constants are involved in the transient response of pyranometers, there is some uncertainty concerning the accuracy and reproducibility of the sun and shade method.

Meteorological services and manufacturers tend to use indoor calibrations (artificial light source), because such calibrations can be performed on a regular basis. The reference instrument in this case is a pyranometer of the same type which has been previously calibrated outdoors.

With the awareness of these differences in calibration methods, but without a chance to correct for them, the methodology adopted for the outdoor investigations involved a two stage "entry check" of all instruments:

- The first step in our investigation (recalibration of all instruments) reflects very much the procedural step of a potential user. After procurement of a pyranometer that is thought to serve as reference instrument for a test laboratory, the user will certainly tend to get a confirmation of the instrument constant provided by the manufacturer. (Independent measurement)
- The second step was to establish a common reference for all the instruments in the test. By using this, intercomparisons of instruments discussed in this report could be referenced to the instrument constants derived during the "entry check", and the peculiarities of the manufacturers' methods of calibration were eliminated.

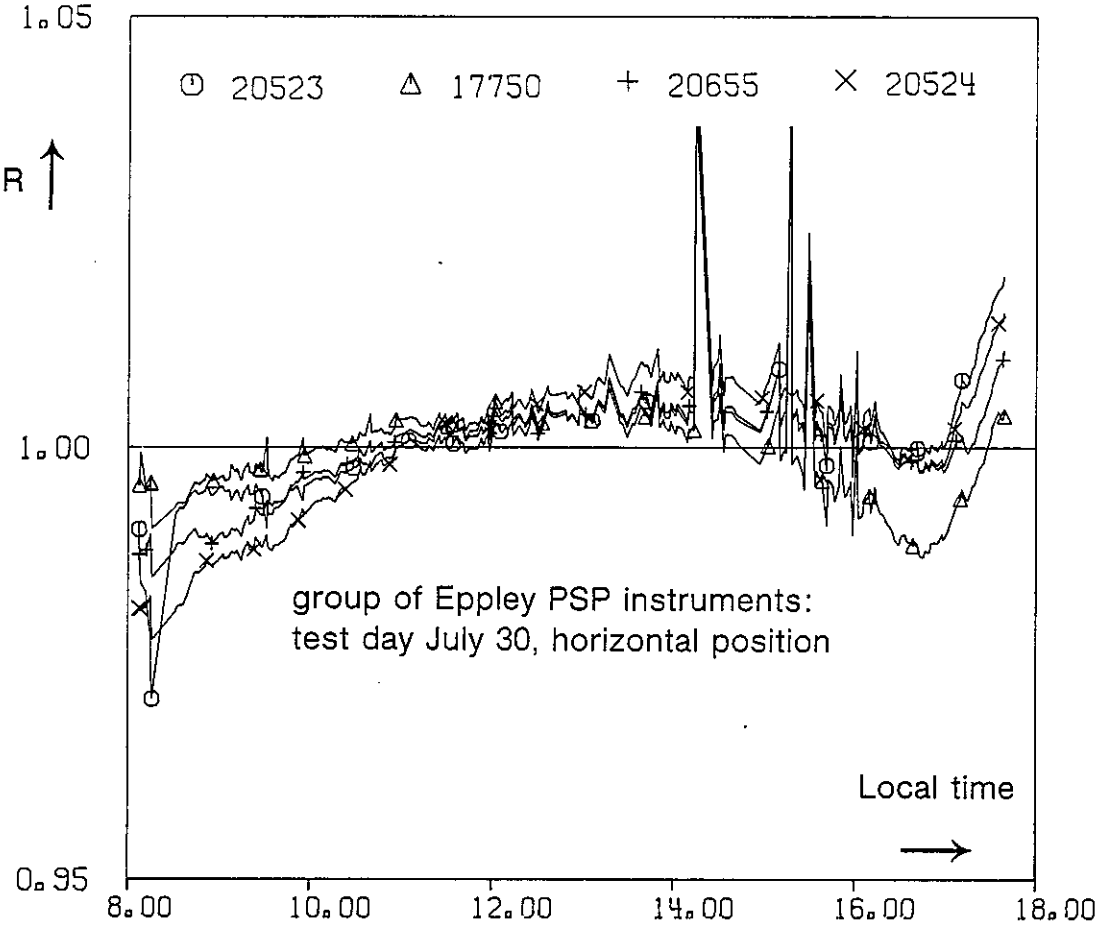
A major practical constraint on the choice of a calibration procedure for this test was the great member of instruments which had to be handled. The shading method requires individual handling of the instruments, which would have made it impossible to calibrate 30 instruments simultaneously. Therefore, the pyranometer readings were compared with the reference global irradiance derived from the vertical component of the direct irradiance and the diffuse irradiance (using the PMO2 and an Eppley PSP 18135 F3 as the respective instruments). The requirements for a high angle of incidence (solar elevation - 35^{o}), and an irradiance level (global) - 650 W/m^2 resulted in a data base of pyranometer readings of 4-5 hours. The calibration constants derived in the "entry check" were determined using the mean value of pyranometer readings over this time period on July 30, the day on which the reference calibration was performed.

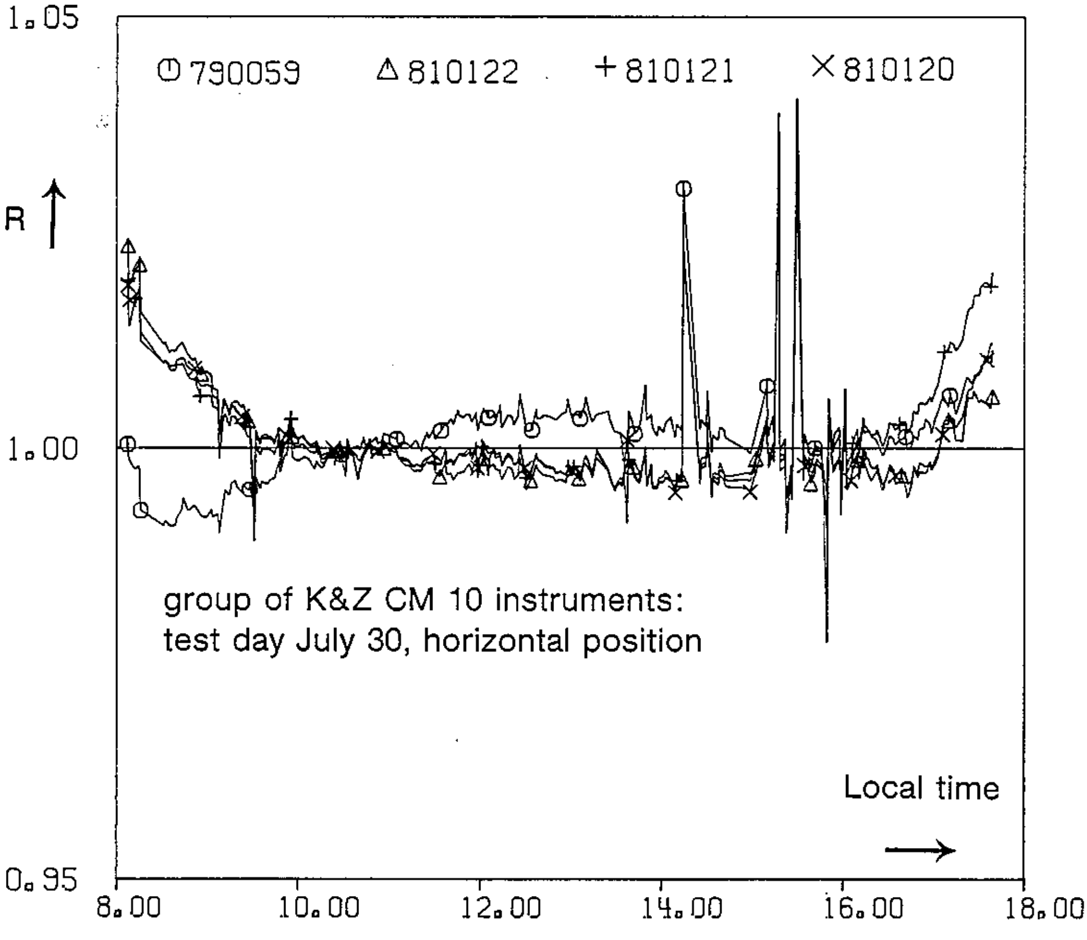
2.3.1 Day-long variability

The day-long performance of pyranometers is affected by the gradual changes of environmental and radiation conditions. The levels of irradiance increase, and decrease during the course of a day. The angle of incidence and the ambient air temperature change likewise. The response of a pyranometer is expected to follow the level of irradiance linearly and to be insensitive to environmental parameters. However, deviations from this ideal response are common, and these are usually of the order of a few percent. For convenience of presentation, we have plotted in Figures 3a - 3f, the ratio R against the time where,

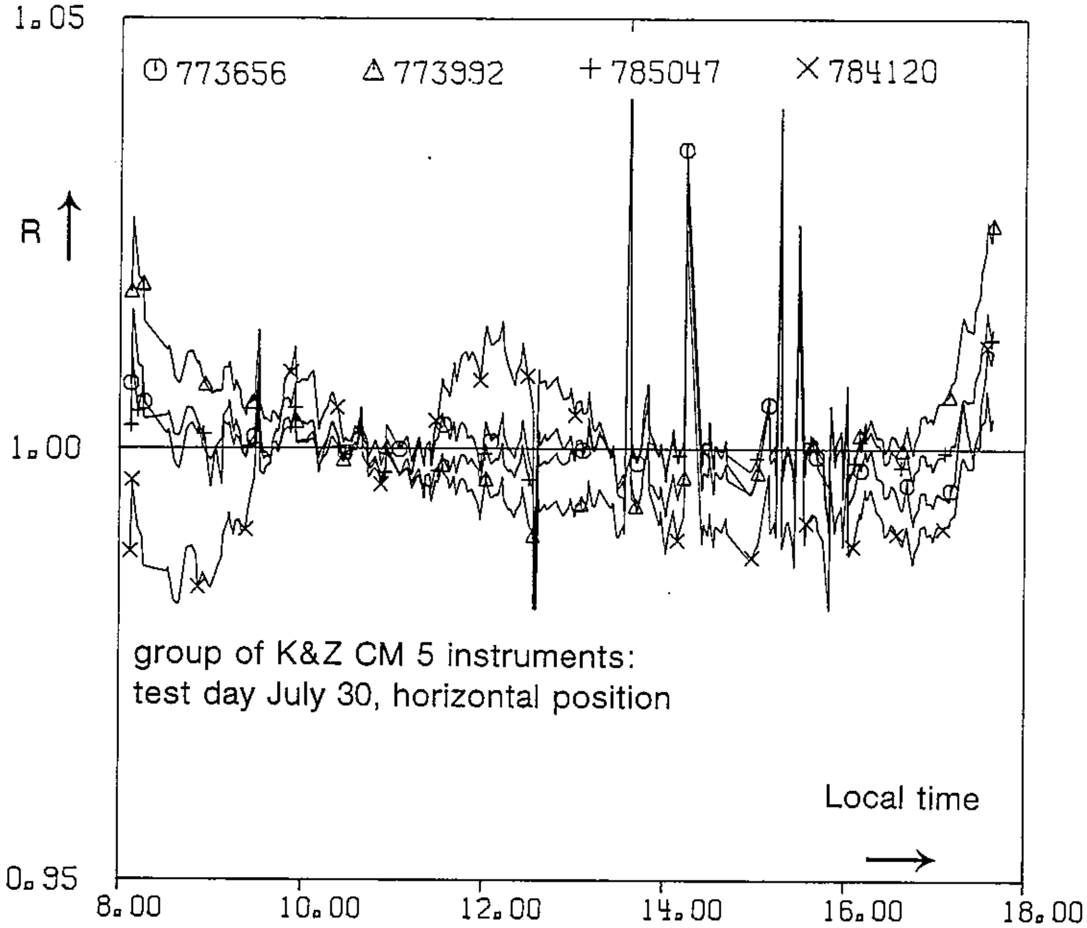
$$R = \frac{\text{10-min. mean reading of the pyranometer}}{\text{10-min. mean value of reference instrument}}$$

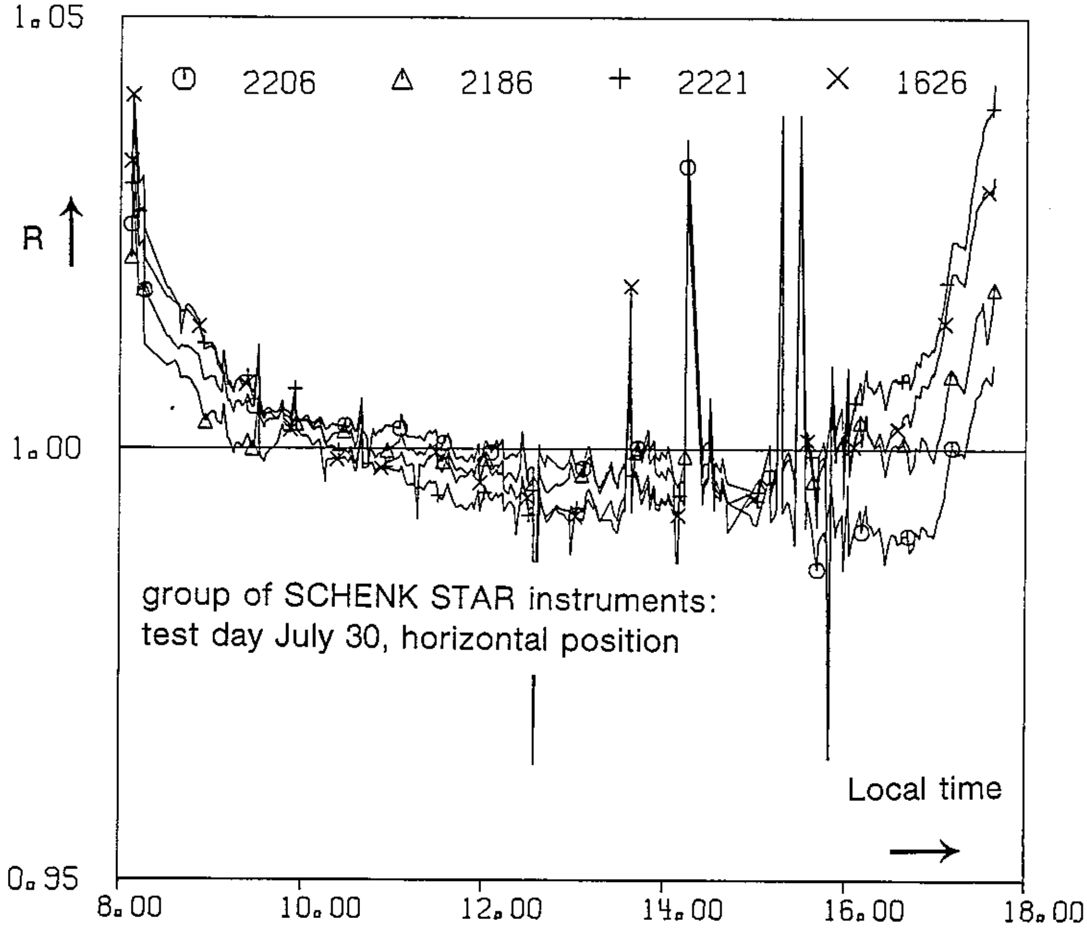
On a clear day, a sequence of the values of R around solar noon do not show much variation. However, a distinct variation of the instruments' sensitivity can be seen if the period of observation is extended to a full day. For the horizontal position and clear sky condition (test day: July 30) a typical curvature of R is found for all instruments. A few instruments exhibit extreme deviations in the early morning and late afternoon. This can be understood as it is caused by deviations from the ideal cosine law for the respective angles of incidence.



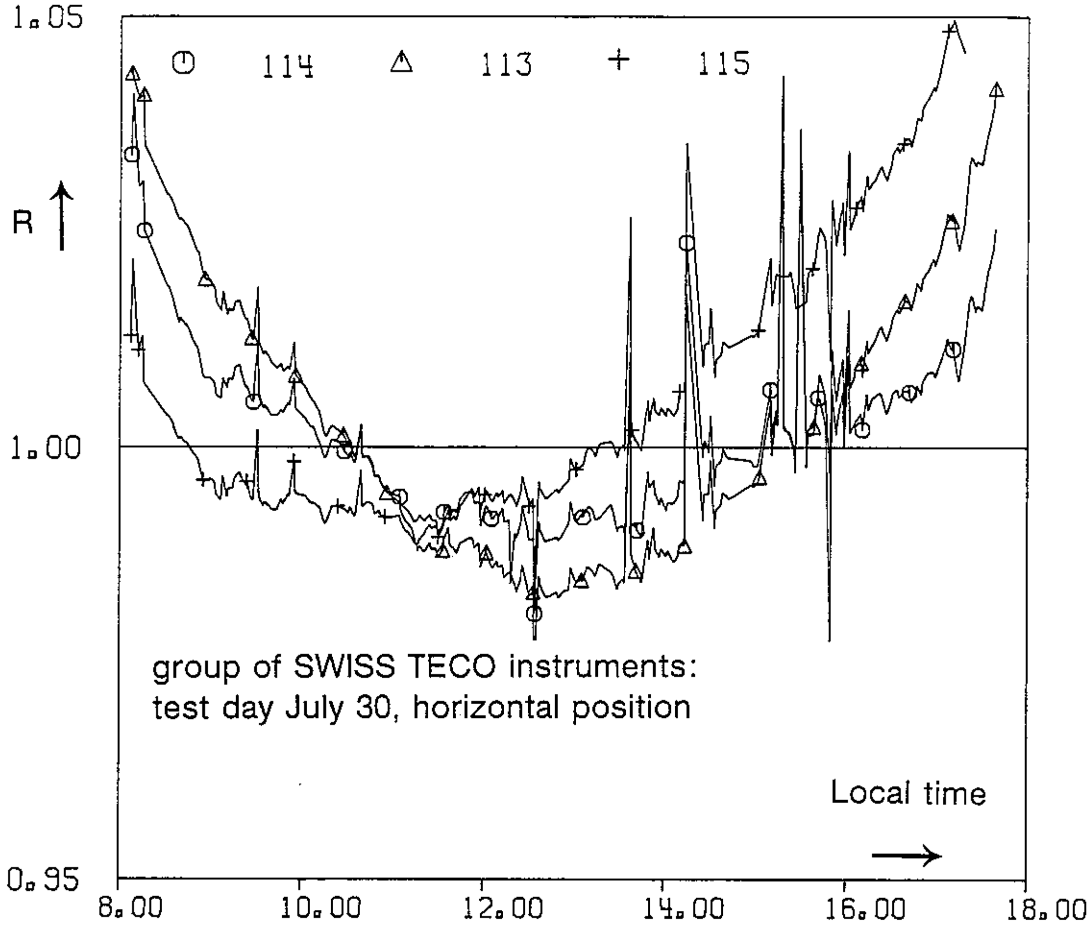


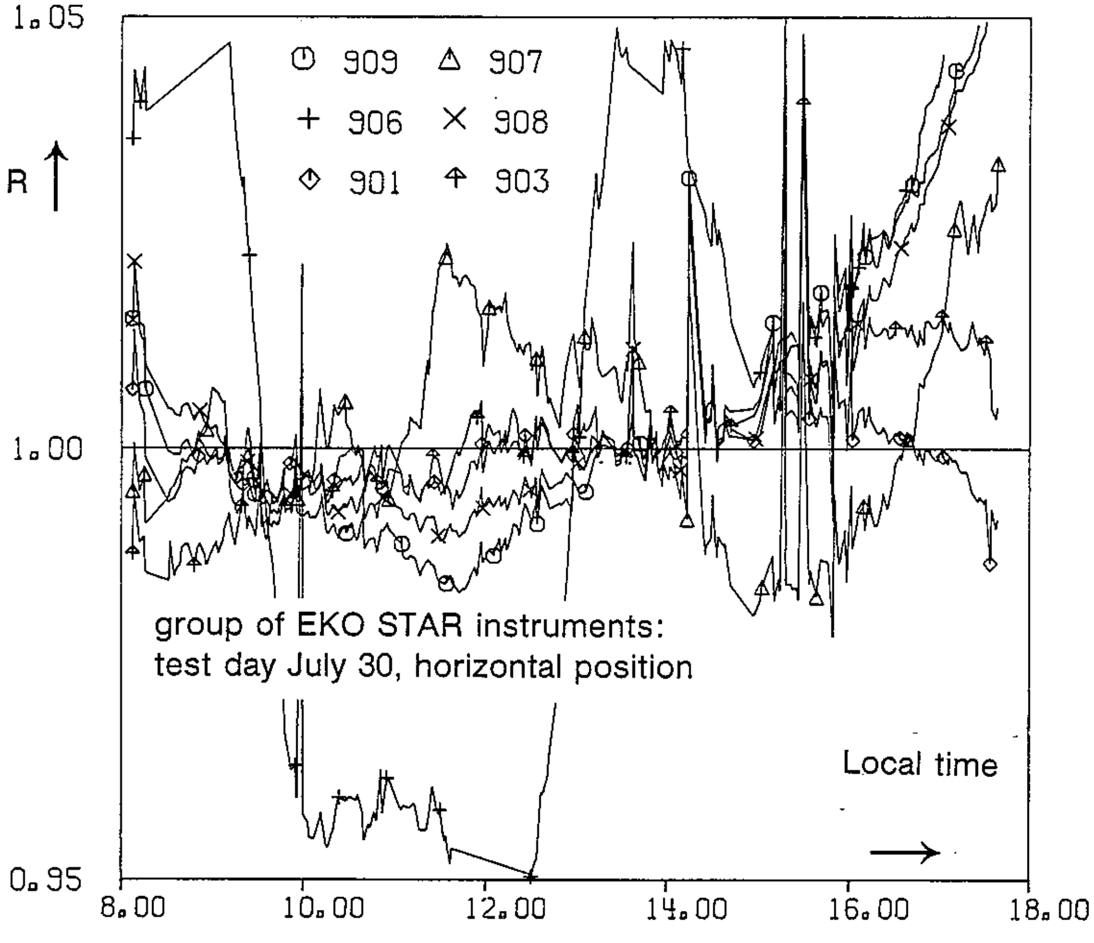
Figures 3a and 3b





Figures 3c and 3d





Figures 3e and 3f

2.3.2 Results of a recalibration

As already stated, there were two reasons to recalibrate all the instruments. Apart from establishing a common reference for the outdoor investigations, we made an "entry check" of the manufacturer's calibration constants in order to reflect the usual situation of a test laboratory for solar energy applications, and as an attempt to verify the accuracy of the global irradiance measurements. The calibration was conducted as described in section 2.3 based on an instruments' performance over several hours (day-long performance on July 30).

The comparison of calibration constants for this "entry check" yielded the figures given in Table 2. In order to allow the results to be analysed at a glance, the ratios of the instrument constants are also shown in a histogram.

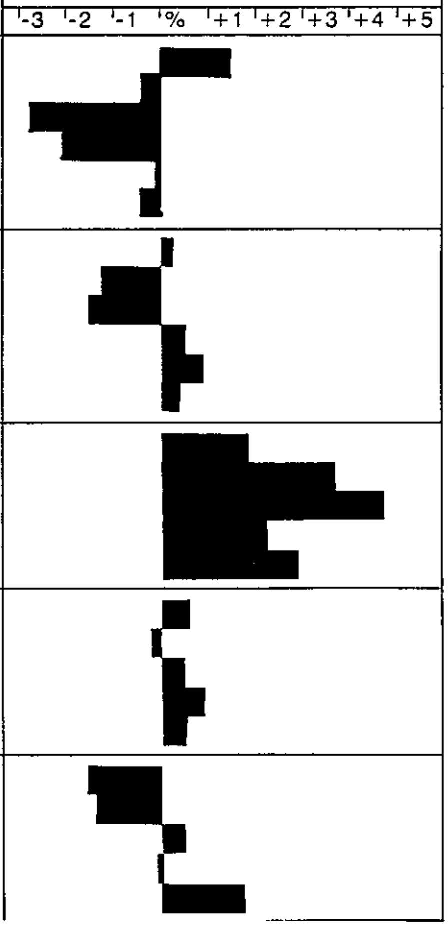
Pyranometer Manufacturer	Type	Instrument Number	Calibration Constants		% - Deviation = $\frac{\text{Manuf. Calibration}}{\text{WRC Calibration}} - 1$
			(mV/kWm^{-2}) (Manufacturer)	(mV/kWm^{-2}) (WRC Davos 81)	
EKO	STAR	81901	8.24	8.12	
EKO	STAR	81903	7.85	7.88	
EKO	STAR	81906	6.89	7.09	
EKO	STAR	81907	7.25	7.40	
EKO	STAR	81908	9.61	9.62	
EKO	STAR	81909	7.42	7.45	
EPPLEY	PSP	14806F3*	9.81	9.78	
EPPLEY	PSP	17750F3*	9.15	9.27	
EPPLEY	PSP	18135F3	8.78	8.92	
EPPLEY	PSP	20523F3	9.95	9.90	
EPPLEY	PSP	20524F3	10.10	10.01	
EPPLEY	PSP	20655F3	10.28	10.24	
KIPP & ZONEN	CM5	773656*	11.94	11.72	
KIPP & ZONEN	CM5	773992*	12.62	12.16	
KIPP & ZONEN	CM5	774120*	13.41	12.80	
KIPP & ZONEN	CM5	785017	10.59	10.35	
KIPP & ZONEN	CM5	785047*	12.23	11.87	
KIPP & ZONEN	CM10	790059	5.68	5.65	
KIPP & ZONEN	CM10	810119	4.58	4.59	
KIPP & ZONEN	CM10	810120	4.54	4.52	
KIPP & ZONEN	CM10	810121	4.66	4.62	
KIPP & ZONEN	CM10	810122	4.24	4.22	
SCHENK	STAR	1626	14.26	14.49	
SCHENK	STAR	2186	14.94	15.15	
SCHENK	STAR	2209	15.36	15.29	
SCHENK	STAR	2217	14.16	14.17	
SCHENK	STAR	2221	15.24	14.97	

Table 2: Comparison of calibration constants (mV/kWm^{-2})

The Swissteco instruments are not included in Table 2 because the manufacturer did not provide calibration constants. If the instrument number is marked with a star, then a correction of 2.2% has been made to the manufacturer's constant for the WRR.

We found close agreement (better than ± 1%) for the manufacturers' calibrations of the three new Eppley PSP and the K&Z CM10 instruments. A distinct bias in the manufacturer's calibrations was indicated for the K&Z CM5, and a scatter of instrument constants was found for the black and white instruments (EKO star and Schenk star).

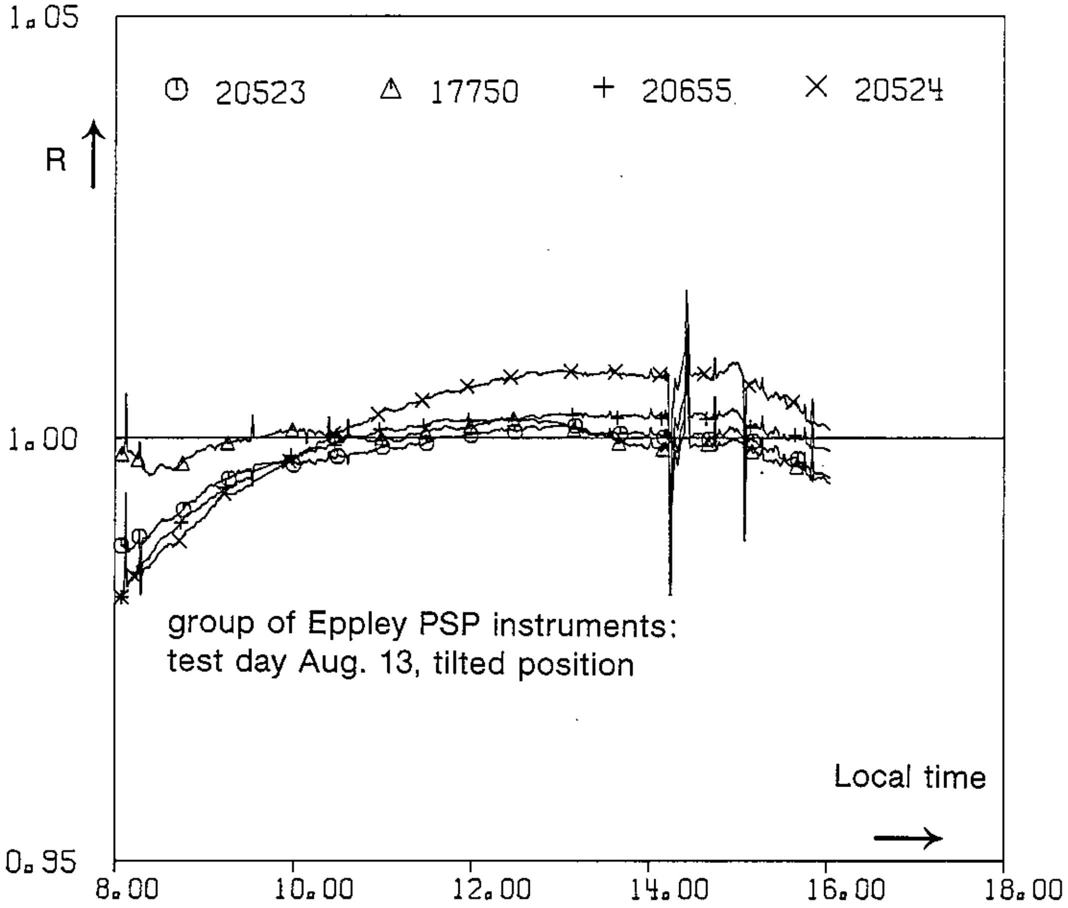
2.4 Applications to collector testing

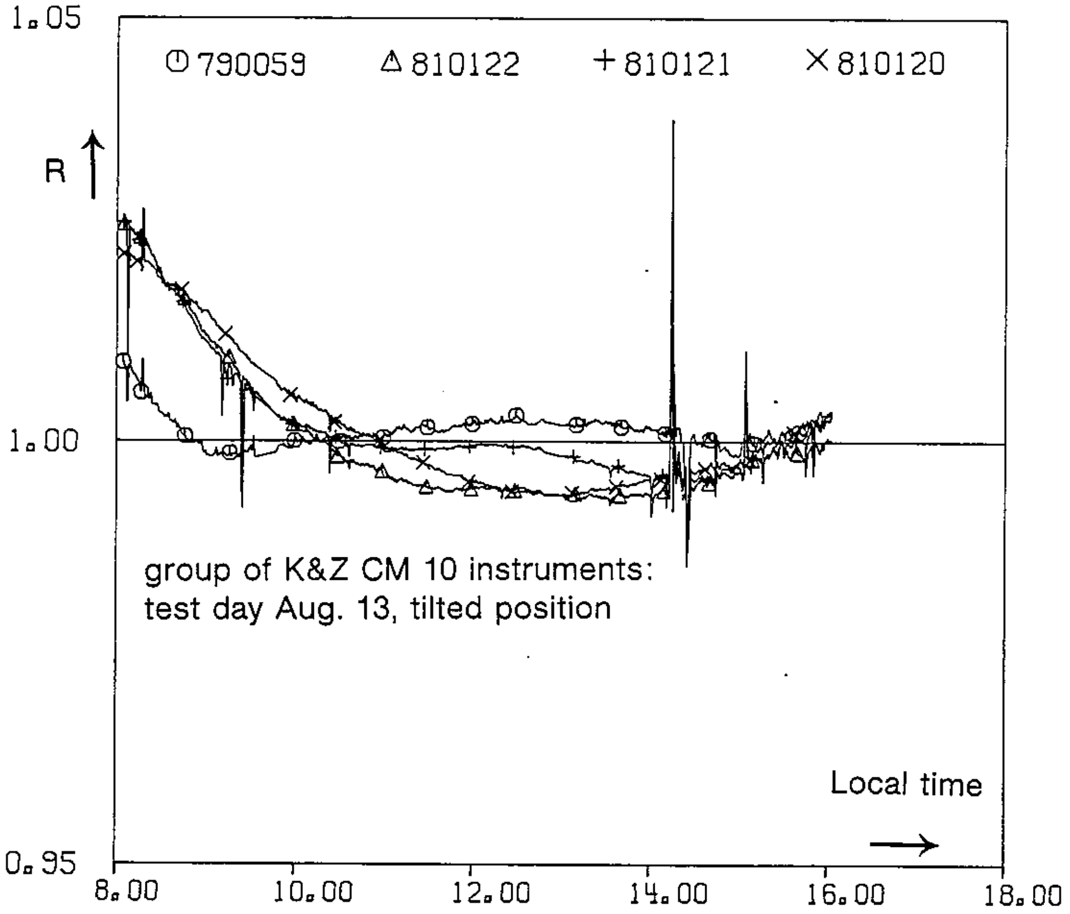
The standard methods of testing the thermal performance of collectors require quasi steady state conditions, and the required levels of irradiance are high ($G \geq 630\ W/m^{-2}$). The collector is tilted and the pyranometer is mounted parallel to the aperture plane of the collector. Typical angles of tilt with respect to the horizontal are close to the location's angle of latitude, which implies that the pyranometer is exposed to direct radiation at near normal incidence. The test procedures for collectors require the angle of incidence to be less than 30^0. High levels of irradiance are usually associated with clear sky conditions (low portion of diffuse radiation) and as a consequence the collector test conditions differ only with respect to tilt from the conditions during the calibration of pyranometers. A possible change of sensitivity of the pyranometer with inclination is, therefore, of major concern in collector testing applications. Therefore, we have looked at tilt effects.

2.4.1 Performance in an inclined (tilted) position

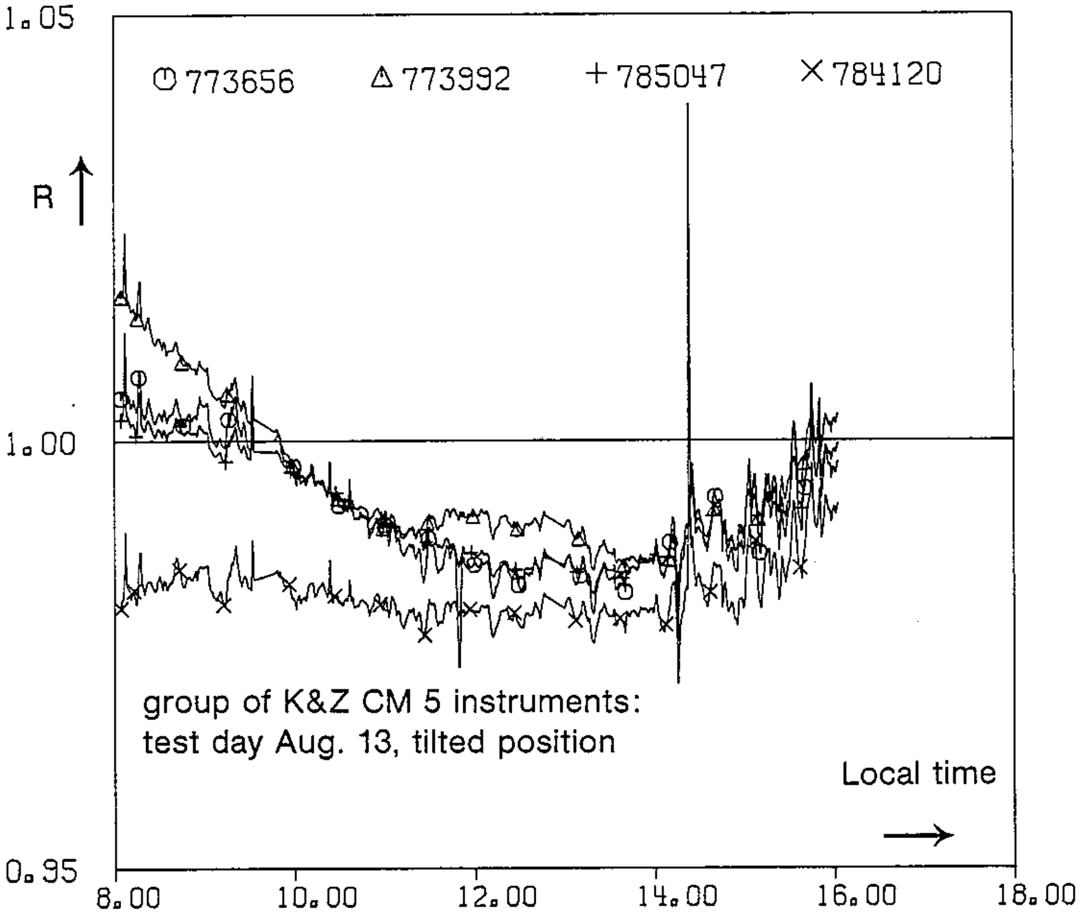
We chose two clear days in the summer to look at possible tilt effects, when the ambient air temperature, wind speed and sky conditions were very similar. It was expected that the greater variations in the angle of incidence which occured during day-long performance in the tilted position would also reveal errors caused by poor cosine response. By comparing the day-long performance of instruments in the horizontal position on July 30 (Figs. 3a - 3f), with the performance under 30^0 tilt on August 13 (Figs. 4a - 4f), we could see clearly which of the instrument groups were sensitive to tilt.

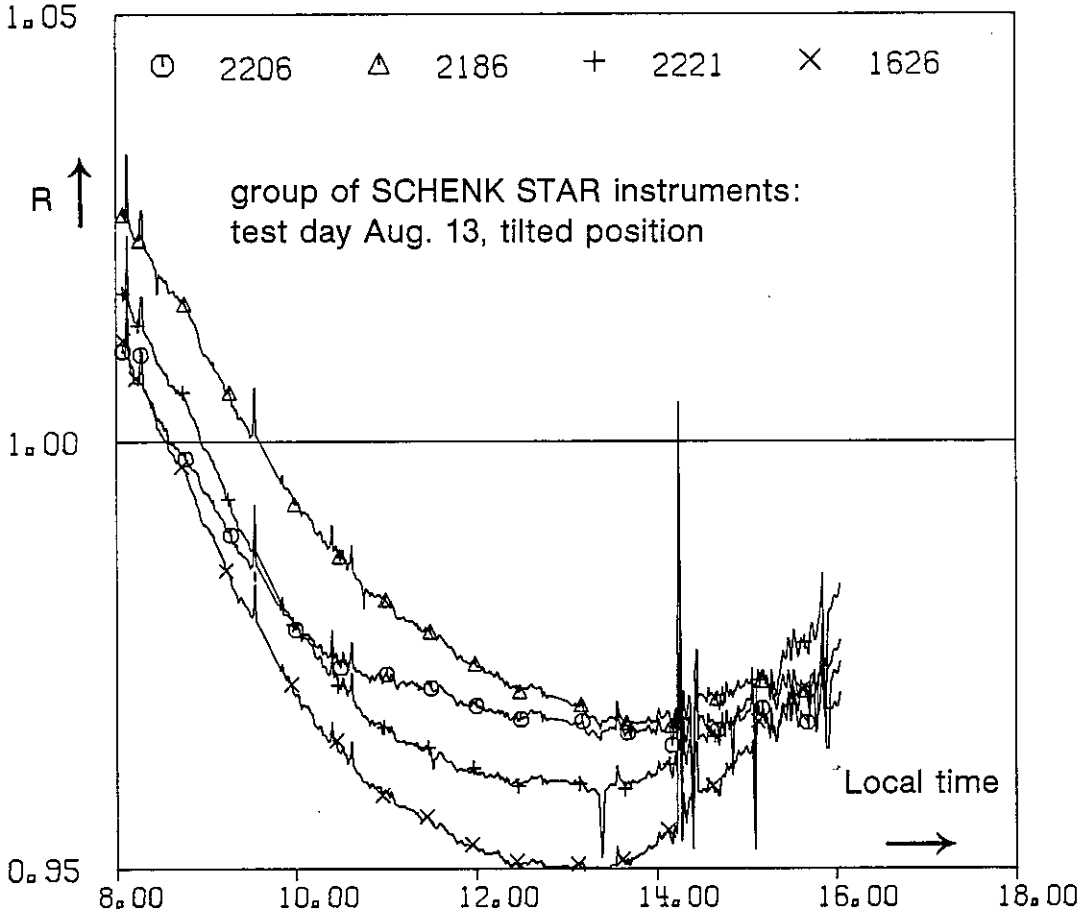
Note: On August 13 no direct radiation reference was available. all data were, therefore, referenced to the reference group of pyranometers, and a possible bias for the group of CM 10 and PSP instruments cannot be excluded a priori. However, as it turned out later, outdoor



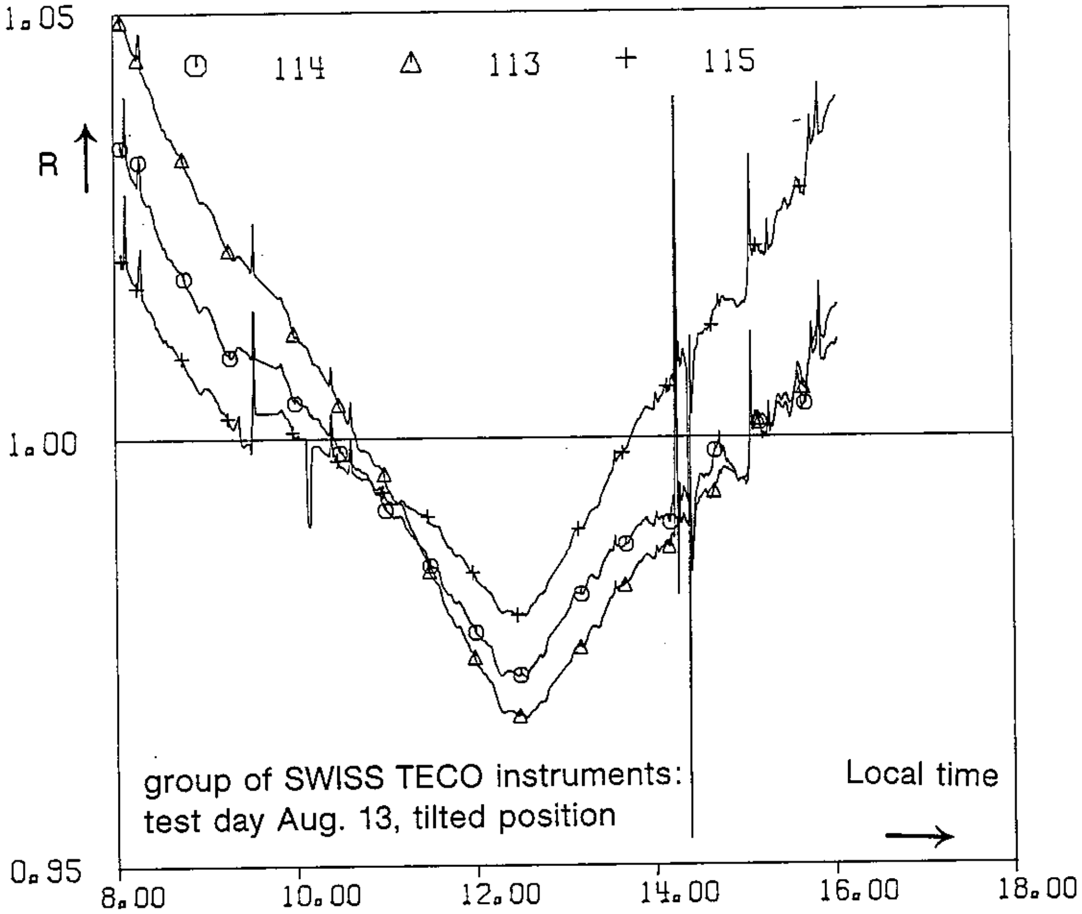


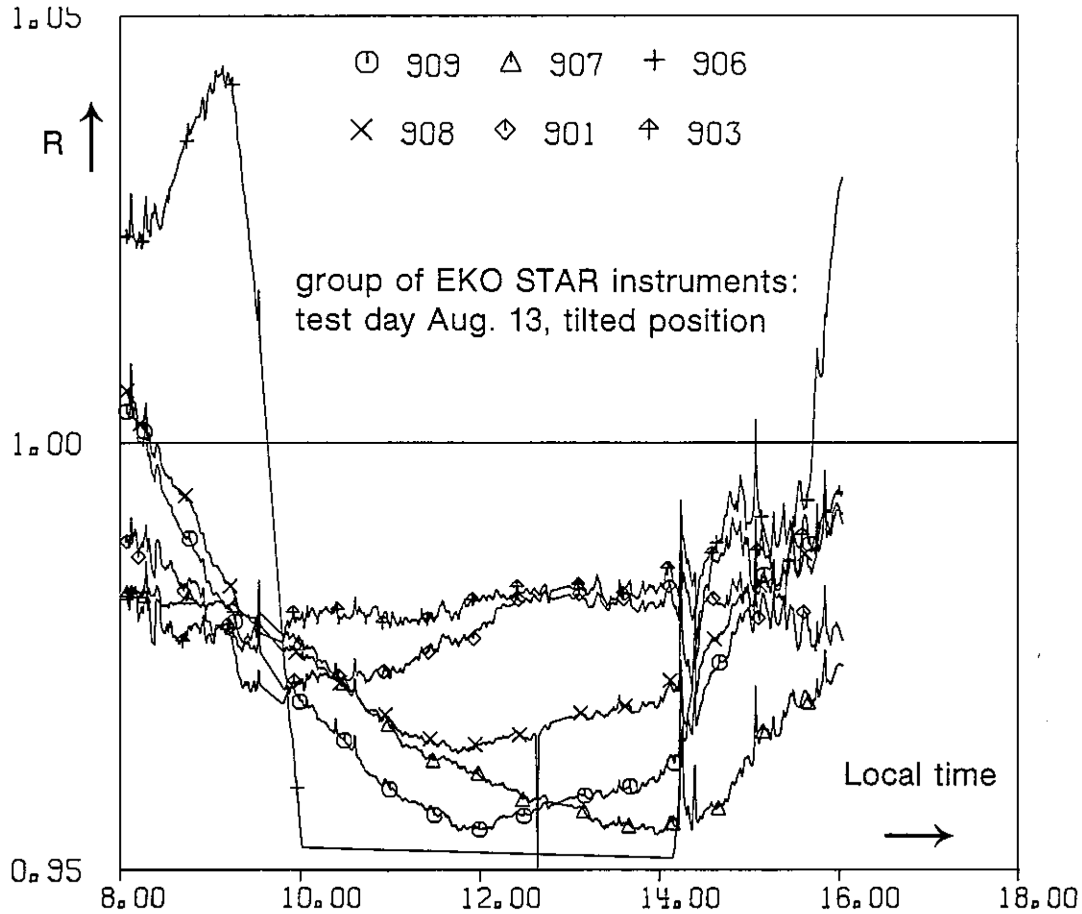
Figures 4a and 4b





Figures 4c and 4d





Figures 4e and 4f

Note (continued): findings with regard to tilt effects were fully in accordance with the indoor measurements.

The typical day-long curvature in Figures 4a - 4f and what is more important, the mean daily values of the ratios for the PSP and CM 10 instruments were found to be unaffected by tilt. The variations of performance within this group of instruments were also found to be small. The group of Kipp & Zonen CM 5 instruments exhibits a shift, which indicates a decrease in sensitivity. The largest changes in sensitivity due to tilt are shown by the EKO star and Schenk star instruments, which for a 30^0 angle of inclination exhibit a decrease in sensitivity of roughly 3%.

The day-long calibration curves for the Swissteco instruments have a different shape in the tilted position. This indicates an effect of the angle of incidence. The mean daily value of the calibration, however, is not changed. Our conclusion is that no tilt effect can be detected for the Swissteco instruments.

A small tilt effect is displayed by the group of CM 5 instruments.

2.4.2 Aspects of pyranometer performance and accuracy

To put our findings concerning the comparative performance of pyranometers in perspective for field applications, it is helpful to consider three aspects of pyranometry which affect the comparability of thermal performance test results:

- the accuracy of calibrations
- the day-long variability
- the impact of tilt and environmental effects

Table 2 indicates that the calibration procedures practised at the present time by the manufacturers are in good agreement with each other. However, it is possible that, for example thermal performance collector test results derived from new K&Z CM 10 and old K&Z CM 5 instruments may be intercompared without any special note. In this special case a bias of 3% should be taken into account. Apart from this, the results of the outdoor tests indicate that, for certain groups of instruments, agreement can be expected to be as close as ± 1%.

The day-long variability indicates the accuracy of the "instantaneous" readings required for collector testing. Several test runs are usually done around solar noon, possibly on several consecutive days, and the results are correlated by the efficiency curves of the collector.

The variation of short term readings (10-min. mean values) over a period of two hours before and after solar noon is 1% for the Eppley PSP and K&Z CM 10, between 1% and 2% for the Schenk star and K&Z CM 5 instruments, and is greater than 2% for the EKO and Swissteco groups of instruments.
The day-long variability of an instrument is inherently connected with the achievable calibration accuracy. However, for the purposes of collector testing and assessments of accuracy, it is reasonable to consider these two effects as independent.
The comparative performance measurements for pyranometers in a tilted position have clearly revealed which of the instruments are sensitive to tilt.
If the instrument constants are derived from calibrations in a horizontal position with rigour, then only those instruments which exhibit negligible change of sensitivity with tilt should be used for collector testing purposes.

Collector testing can be conducted in ambient air temperatures which may vary in the range from -5 °C to +30 °C. Although it is well known that some instrument constants apply only for a particular temperature, a correction for the temperature prevailing during testing is seldom applied. The pyranometer performance which we measured on a clear winter day gives some insight into the accuracy of pyranometry for the situation where pyranometer constants are derived from a calibration in a horizontal position during summer time and the instruments are used for collector testing on a clear day in winter. Performance data for the tilted pyranometers on a clear winter day (January 13) are shown in Appendix A. The pyranometer readings for this day were referenced to the sum of direct and diffuse irradiance using the absolute radiometer at WRC.

Comparing the performance of pyranometers on a winter day with a summer day, we can derive a number of conclusions which typify the groups of instruments: The winter outdoor performance of all instruments indicates that the changes in sensitivity with temperature are a feature of the group rather than of a particular instrument. (The EKO instruments being an exception where each individual instrument has its own temperature coefficient.) The Schenk star instruments gain significantly in sensitivity when the temperature is decreased. The effect of seasonal changes of environmental parameters on the performance of the Eppley PSP and K&Z CM 10 instruments was also demonstrated by our measurements: Both groups of instruments showed an increase in sensitivity of 1%-2%. This means that for the purposes of collector testing an additional uncertainty is introduced if the testing is not restricted to a particular season of the year.

2.5 Application to solar system monitoring

A pyranometer calibration is usually made during favourable conditions of insolation (e.g. low incidence angle, high intensity, moderate ambient temperature). These conditions are also suitable for testing solar devices but they are met only during a small part of the year. A wide range of meteorological conditions may occur for other applications of pyranometers: e.g. for the monitoring of solar systems, long term performance studies, and for biomass and agricultural research.

For these reasons, we also investigated the performance of pyranometers over very different meteorological conditions. Measurements were made in summer and winter, during clear, cloudy and overcast days, from sunrise to sunset, over a wide range of temperature and with horizontal, tilted and sun tracking instruments. Over 130 hours of recording are available in one-minute means of 10 one-second integrated values.

We have compared the daily sum measured by a reference group of instruments (the integrated reading of the irradiance measured by the four reference pyranometers for a whole day) with the daily sums derived for the individual instruments. Since deviations are dependant on seasonal and sky conditions, the maximum deviations of daily irradiation are given in Table 3 for days of different types.

Some effects like tilt, temperature, and irradiance level, may typically show either an increase or a decrease in sensitivity. Table 3 provides an indication of the accuracy of daily sums of global radiation measurements. The table shows that the Eppley PSP and K&Z CM10 can be used in all the conditions studies with a fair degree of accuracy. The PMOD instrument gives very reproducible results under standard calibration conditions, and for this reason is suitable as reference but not as field instrument. All other pyranometers show greater deviations if they are tilted, if the incidence angle is low, or if the temperature is low. Hence, the range of conditions in which these instruments can be used with a given degree of accuracy is limited, and each instrument needs to be tested individually to determine its characteristics.

A related study /9/ on 18 CM5 pyranometers has shown that integral values over a 18 day period in summer have a scattering range of only ± 0.5% with respect to the reference, even though the daily sums can vary by up to 5.5%.

Type of Pyranometer	Number of Instrument	Clear Summer Horizontal		Clear Winter Horizontal		Clear Summer Tilted	
PMOD	1	+0.1		- 0.7	+ 0.3	-1.5	
EKO	6	-6.9	+0.4	-11.2	+ 9.4	-6.3	- 3.3
Eppley (new)	3	-0.5	+0.3	- 2.4	+ 0.8	-0.6	+ 0.4
K&Z CM5	4	-2.2	-0.3	- 5.7	- 3.5	-1.6	- 0.9
K&Z CM10	4	-0.2	+0.7	- 0.7	+ 1.8	-0.4	+ 0.8
Schenk	4	+0.4	+2.2	+ 7.7	+10.4	-5.9	- 2.9
Swissteco	3	-0.5	+4.0	+ 1.7	+13.0	-3.7	+ 3.0
		Cloudy Summer Horizontal		Cloudy Winter Horizontal		Overcast Winter Horizontal	
PMOD	1	-1.5	+1.0	+ 2.2		+1.7	+ 3.8
EKO	6	-2.7	+1.6	- 3.5	+ 7.5	-0.7	+10.0
Eppley (new)	3	-0.5	+0.1	- 3.0	- 1.2	-1.3	+ 0.6
K&Z CM5	4	-1.7	+0.5	- 1.8	+ 0.7	+0.6	+ 3.9
K&Z CM10	4	+0.2	+0.5	+ 1.1	+ 2.0	+1.2	+ 2.0
Schenk	4	+0.8	+1.9	+ 4.4	+ 8.2	+3.0	+ 3.8
Swissteco	3	+1.6	+5.5	+ 2.0	+ 6.2	+5.9	+ 6.2

Table 3: The maximum deviation of daily sums (percent)

For monitoring applications the user often wishes to check the calibration constant of a field instrument against a reference pyranometer. The calibration constant derived for monitoring applications may differ from that used for collector testing because a reasonable accuracy is required over a wide range of meteorological conditions. This can be established if the calibration constant is evaluated from long-term comparisons with a reference instrument. To provide some guidance we have compared the calibration constant for July 30 with a user-orientated calibration constant derived from an all year comparison of 10-min. mean values. Since this was done on the basis of our complete outdoor performance data set, the statistical basis is quite large. The ratios of the 10-min. values for each instrument to those of the reference set of pyranometers, and the percentage deviations in terms of a standard deviation are listed in Table 4. This comparison suggests that for monitoring applications it is possible to derive a calibration constant for a field instrument from long-term performance comparisons with a useful accuracy.

Type of instrument		No.	Ratio	St. Dev.(%)
WRC	PMOD	6703-A	1.008	2.43
EKO	Star	81901	0.987	2.03
EKO	Star	81903	0.942	11.33
EKO	Star	81906	1.009	6.18
EKO	Star	81907	0.985	2.49
EKO	Star	81908	1.006	4.10
EKO	Star	82909	1.005	2.77
Eppley	PSP	14806F3	0.990	1.76
Eppley	PSP	17750F3	0.999	1.22
Eppley	PSP	18135F3	-	-
+ Eppley	PSP	20523F3	0.995	1.07
Eppley	PSP	20524F3	0.994	1.31
+ Eppley	PSP	20655F3	0.994	1.36
Kipp & Zonen	CM5	773656	0.994	1.75
Kipp & Zonen	CM5	773992	1.001	1.57
Kipp & Zonen	CM5	774120	0.988	1.81
Kipp & Zonen	CM5	785017	-	-
Kipp & Zonen	CM5	785047	0.998	1.47
+ Kipp & Zonen	CM10	790059	1.007	1.28
Kipp & Zonen	CM10	810119	-	-
+ Kipp & Zonen	CM10	810120	1.003	0.96
Kipp & Zonen	CM10	810121	1.007	1.14
Kipp & Zonen	CM10	810122	1.001	1.02
Schenk	Star	1626	1.013	4.35
Schenk	Star	2186	1.017	3.53
Schenk	Star	2209	1.008	3.45
Schenk	Star	2217	-	-
Schenk	Star	2221	1.019	4.49
Swissteco	SS-25	113	1.021	3.13
Swissteco	SS-25	114	1.018	2.83
Swissteco	SS-25	115	1.082	9.41

- shaded instrument, + reference instrument

Table 4: Ratio of user-orientated calibration constant to reference calibration constant

3. CHARACTERIZATION OF PYRANOMETERS

Pyranometers of the thermoelectric type are designed to respond to short wave radiation. Their sensitivity to this is cross correlated with sensitivities to a number of other parameters which are assumed to have a small accumulative effect on the instruments' performance. Some of these sensitivities can be separately investigated by laboratory experiments which are designed to isolate a particular feature.

Among those parameters which affect sensitivity we find a number which are amenable to indoor measurements:

- the effect of tilt from the horizontal position (tilt effect)
- the effect of the intensity of solar radiation (deviation from the expected linear response, linearity)
- spectral distribution of the light source and the response of the instrument (spectral response)
- the temperature of the instrument body or the ambient air (temperature coefficient)
- the effect of transient irradiance and thermal shock (time constant)
- the effect of the angle of the incident solar radiation (azimuth and altitude, cosine error)

If measurements are conducted to investigate these dependencies, the pyranometer is said to be "characterized". If the data that is yielded meets the specification of the WMO it can be classified accordingly (see Appendix B). It is important to note that any classification is not a natural gift of a particular brand but has to be proven by indoor investigations. Unfortunately, much confusion and notable inaccuracies have been introduced into global irradiance measurements by a neglect of this vital recommendation. Traditionally the meteorological laboratories are capable of undertaking this selective screening. The experimentalists in thermal applications of solar energy generally do not have the means to perform the required tests and inspections.

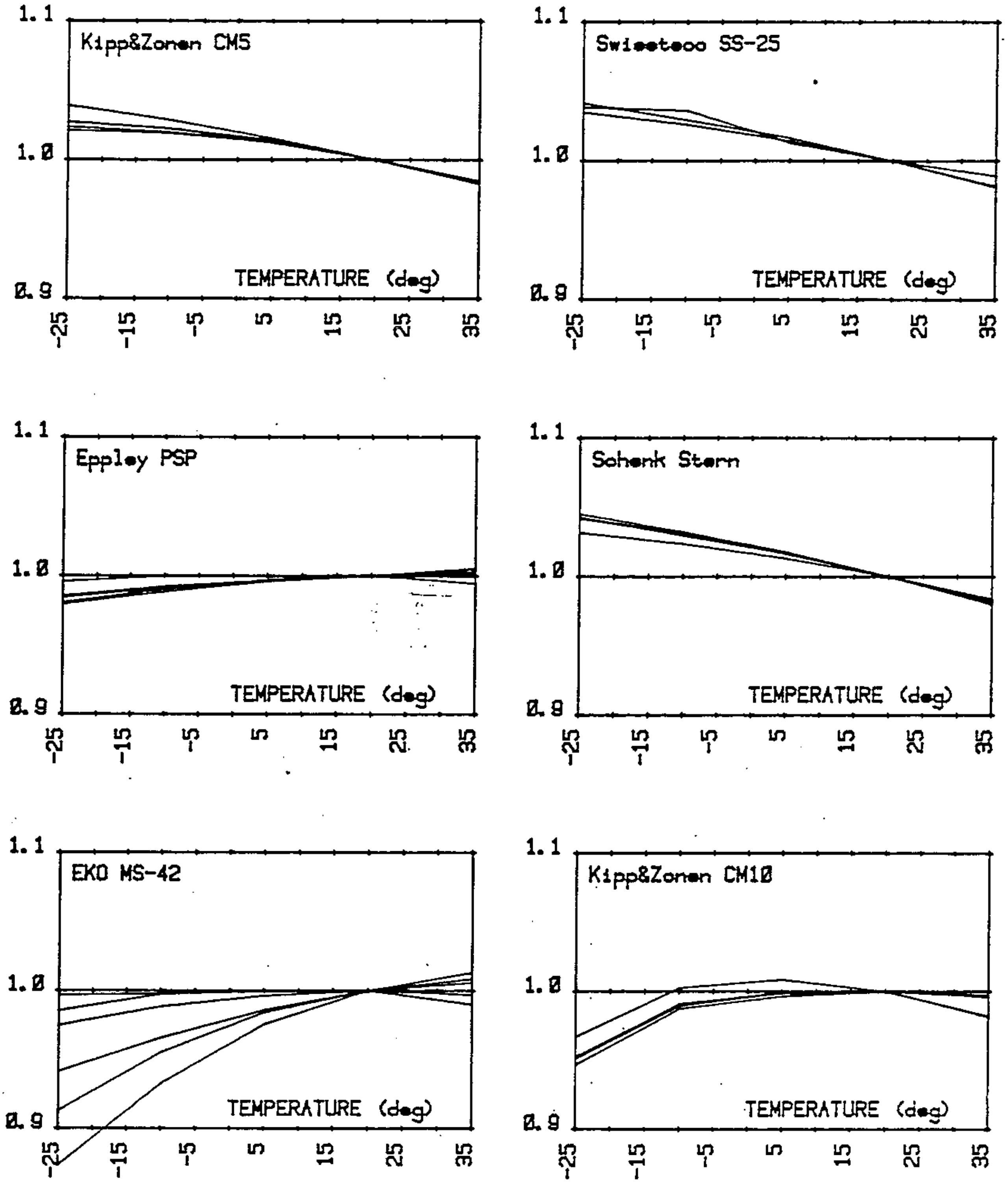
As it turns out, the experimental set-up which is needed to test pyranometer performance with respect to a particular parameter is quite sophisticated. The user should pay attention to the dependencies which are a characteristic of an individual instrument, and those which are specific for a brand. The indoor measurements have inherent limitations. For example: the deviation from the ideal cosine response is always cross-correlated with the response to the level of irradiance /10/.

3.1 Experimental methods for laboratory investigations at Boras and Davos

The indoor investigations were confined to four parameters. Table 5 gives an overview indicating which test method and test set-up was applied. A fundamental consideration in the experimental procedure was to minimize or even avoid cross correlations /11/.

Effect	Physical Causes	Test Set-up or Test Method	Important Interacting Parameter
time response	heat transfer in a heterogeneous body	not investigated	not investigated
temperature	thermoelectrical effect (mismatched compensation	climatic chamber, external light source	temperature distribution over body and glass domes
linearity	properties of heat transfer mechanism change with temperature	outdoors and indoors: rotating sector disk, grey filter indoors: superposition of irradiances from two sources	temperature of the instrument's body
tilt	convection currents inside the instrument (between dome and thermopile)	indoors: tilted beam arrangement between source and sensor or fixed source turning box or drums with reflection surface or mirror arrangements	irradiance level and ambient air temperature
directional response	geometrical optics and symmetry of dome and sensor, reflectance of paints, levelling of support parallel to the sensor	pyranometer and source can change their directional relation, leaving one of them fixed	tilt, temperature field across the instrument, irradiance level

Table 5: Characterization of pyranometers
Test set-up and methods applied



Figures 5a-5f: Relative detector responsivity versus ambient air temperature
(All pyranometers of the same type are in one diagram)

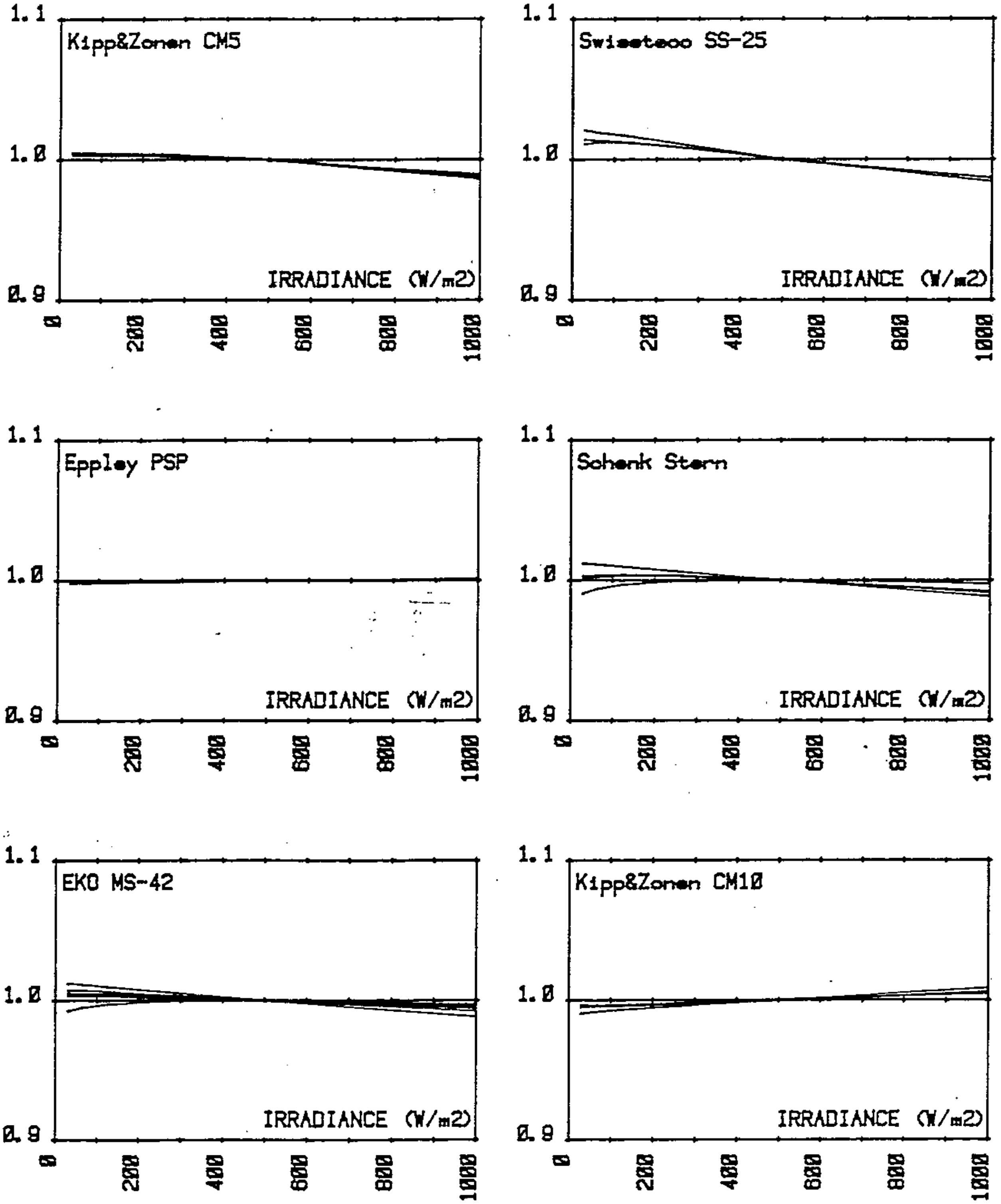
3.1.1 Temperature effect (Boras)

A temperature stabilized chamber was used. Its inner dimensions were 0.4 x 0.4 x 0.3 m^3. The pyranometer was mounted horizontally in the middle of the chamber and irradiated at normal incidence through a hole at the top of the chamber, the irradiance being about 1000 W/m^2 as measured by the pyranometer. The light source was a 250 W tungsten halogen lamp without heat filter and energy was supplied by a stabilized power source, the electrical power being measured continuously. The level of irradiance produced by the projector was sufficiently stable that its variations did not affect the measured results. A thermo-couple junction was fixed to the base of the instrument and in good thermal contact with it. This enabled the temperature of the base to be controlled to within 0.1 ^{o}C of the desired value.

The detector signal was measured every 30 seconds until it changed less than 0.1% over a 20-minute period. When this stability had been reached, the value was recorded.
The temperature was changed from -25 ^{o}C to +35 ^{o}C in steps of 15 ^{o}C. The +5 ^{o}C point was used as a reference and the chamber was set to this temperature before and after each other temperature setting. Using these reference values, corrections for drift could be performed.
The relative responsitivity was normalized to 1.0 at +20 ^{o}C. The whole set up was controlled by a computer once the pyranometer was mounted and the program started. The testing procedure was completed within about 4 hours. The results are shown in figures 5a - 5f.

3.1.2 Level of irradiance (linearity)

The test procedure used was first introduced almost 90 years ago /12/ and later developed by the National Physical Laboratory in London for use on photometric detectors /13/. The detector is irradiated by two projectors via a mirror system. The detector is irradiated first by one of the projectors and then by the second projector and finally by the two detectors superimposed. The sum of the two first signals is compared with the third signal, giving the deviation from ideal linearity when the irradiance is doubled. This procedure is repeated and the irradiance is, in this way, reduced stepwise by a factor of 2 from 1000 W/m^2 to 31 W/m^2.
The irradiance was varied by varying the voltage to the projector lamps.



Figures 6a-6f: Relative detector responsivity versus level of irradiance
(All pyranometers of the same type are in one diagram)

Because of the heat removing filter, the radiation spectrum is not significantly changed by this procedure. The procedure is described as follows:

1. Both projectors open, the lamp voltages are adjusted until the pyranometer reads 1000 W/m^2.

2. A number of readings are taken:
   both projectors closed: U_{01}
   projector A open: U'_A
   both projectors closed: U_{02}
   both projectors open: U'_{AB}
   both projectors closed: U_{03}
   projector B open: U'_B
   both projectors closed: U_{04}

Corrections for offsets:

$$U_A = U'_A - (U_{01} + U_{02})/2$$

$$U_{AB} = U'_{AB} - (U_{02} + U_{03})/2$$

$$U_B = U'_B - (U_{04} + U_{03})/2$$

Any voltage reading is a linear function of the irradiance G: $U = c \cdot G$ where the responsivity c is ideally a constant value. However, the experimental investigation is designed to reveal the dependency $c = c(G)$. The procedure yields relative values like

$$r_{AB} = U_{AB}/(U_A + U_B)$$

$$r_{AB} = \frac{c(A+B) \cdot G_{AB}}{c(A) \cdot G_A + c(B) \cdot G_B} \approx \frac{c(A + B)}{c(\frac{A + B}{2})}$$

The procedure is repeated for the levels of irradiances G = 1000, 500, 250, 125 and 62.5 W/m^2. Normalizing the responsivity c(500 W/m^2) = 1.0 allows a recursive formulation of the responsivity c(G):

$$\begin{aligned}
c(1000) &= r(1000) \\
c(500) &= 1 \\
c(250) &= 1/r(500) \\
c(125) &= c(250)/r(250) \\
c(62.5) &= c(125)/r(125) \\
c(31.25) &= c(62.5)/r(62.5)
\end{aligned}$$

The whole procedure was controlled by a computer and takes about 2 hours. The results of this investigation are given in figures 6a - 6f.

3.1.3 Tilt effect (Boras)

The test method used agrees essentially with that used by Flowers /5/. The pyranometer was mounted together with a projector, on a swivelling optical bench. The cable connection to the pyranometer was pointing away from the bench (upwards for horizontal bench).

The projector had a 250 W tungsten halogen lamp, a condensor lens and a heat filter. The objective lens of the projector was replaced by a 80/f250 lens placed outside the projector. The irradiance at the pyranometer was adjusted to 1000 W/m^2. The direction of the beam was adjusted to give normal incidence at the pyranometer.

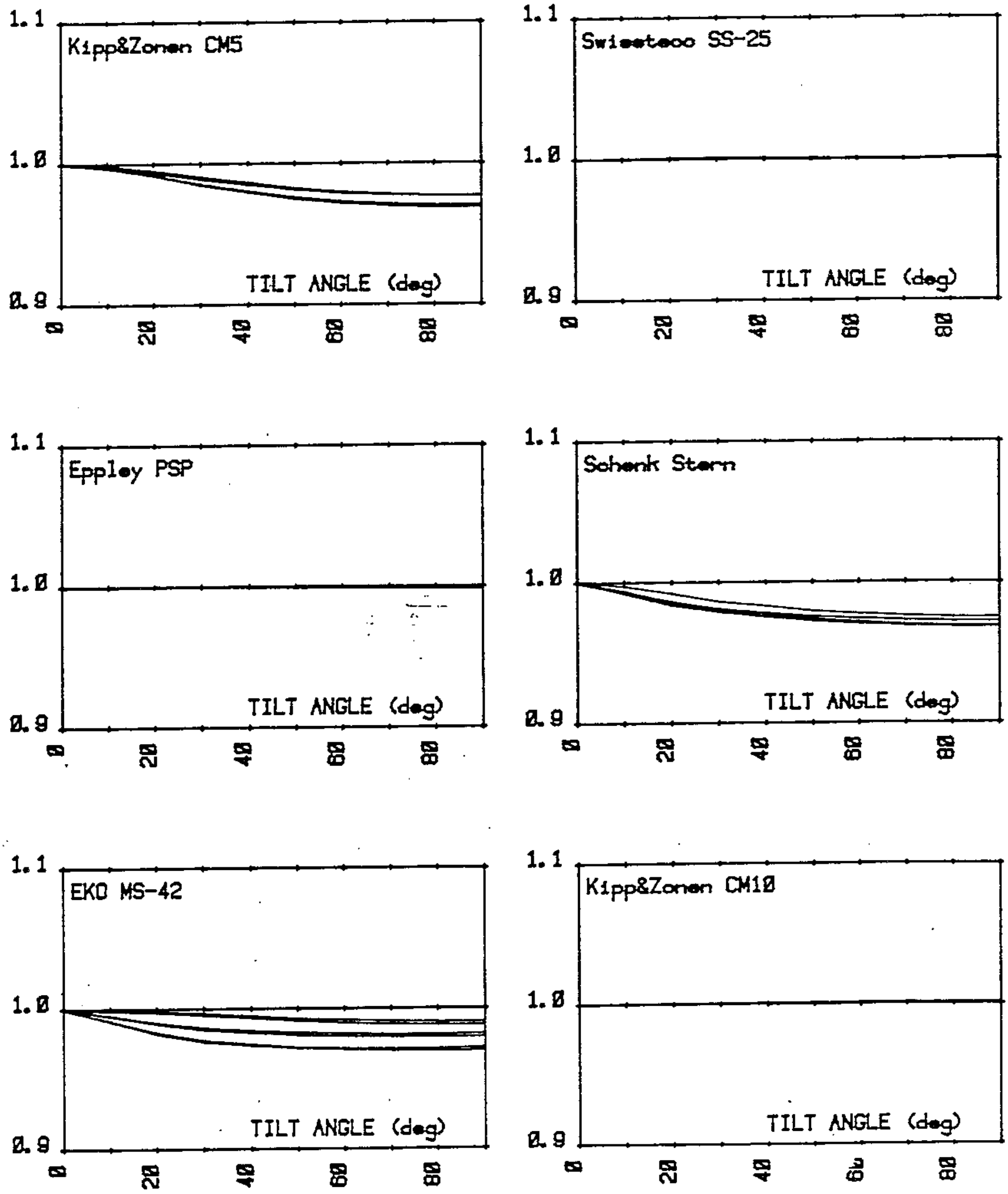
A beam splitter (glass without coatings) was mounted on the bench between the lens and the pyranometer. A silicon detector (UDT 1 cm^2) fitted with a radiometric filter (flat spectral response) was placed in the reflected radiation in such a position as to see the same part of the radiation source as did the pyranometer. This detector was used as a reference detector.

The measurements started with the optical bench in a horizontal position. Readings were then taken both on the pyranometer and on the silicon cell at each 10^o from horizontal to vertical and back to horizontal, in all 19 positions. The ratio of the pyranometer reading to the silicon detector readings was recorded and mean values of the two readings at each tilt angle were computed.

Before each series of measurements the pyranometer was allowed to stabilize for at least 5 minutes at the full irradiance level, 1000 W/m^2. The stabilization time needed at each tilt angle was 10 - 20 s.
The readings were normalized to 1.0 at 0^o tilt angle.

3.1.4 Directional response (Boras)

The test method used was an improved version of a method used in an earlier investigation /11/. Two rotational stages were mounted on top of each other, the lower one (table A) was mounted horizontally (vertical axis), and the upper one (table B) vertically (horizontal axis).



Figures 7a - 7f: Relative detector responsivity versus angle of tilt (irradiance level = 1000 W/m^2)

For mounting the pyranometer the following procedure was used.
The pyranometer was first placed on a horizontal table and adjusted to the horizontal position by using its spirit level. It was then mounted on table B, which in turn was carefully adjusted to bring the detector surface coincident with the vertical rotational axis of table A. During this operation a microscope was used.

The optical axis of the radiation source passed through the centre of the detector sensitive area, and at 0^0 polar angle it coincided with the horizontal rotational axis of table B.

The radiation source was a projector having a 250 W tungsten halogen lamp and fitted with a heat filter, cutting off the infrared radiation. Maximum spectral irradiance occurred at 590 nm wavelength.

The projector was operated without its objective lens, giving an irradiance inhomogeneity of only 0.5% peak to peak across the pyranometer glass dome. The irradiance level was only 100 W/m^2 at normal irradiance to the pyranometer.

The distance between the radiation source and the detector surface was about 90 cm.
At that distance the divergence angle of the beam was about 5^0.

An aperture was placed close to the pyranometer to limit the radiation cone so that only the glass dome area was irradiated. This was used to reduce the stray light. Two more apertures were placed between the pyranometer and the projector. In front of one of these was placed a shutter for taking zero readings from the pyranometer.

The inhomogeneity of the irradiance across the sensitive area of the detector was very small, 0.1% for small area detectors (Eppley, Kipp & Zonen, Swissteco, PMOD) and 0.5% for large area detectors (Schenk, EKO), all values peak to peak.

When measuring cosine response the pyranometer was mounted vertically and irradiated by a horizontal beam, the irradiance being about 100 W/m^2 at normal incidence. The pyranometer could be rotated around a horizontal axis through the centre of its sensitive surface, and turned around a vertical axis in the plane of the sensitive surface. Readings were taken at every second degree from -90^0 to $+90^0$ in six planes representing six azimuth angles, giving in all 540 readings. Each reading was the difference between open shutter reading and closed shutter reading.

The angular repeatability of the rotational feed mechanism was better than 0.05^0.

The cable connection to the pyranometer body was used to define the north direction, i.e. 0^0 azimuth angle.

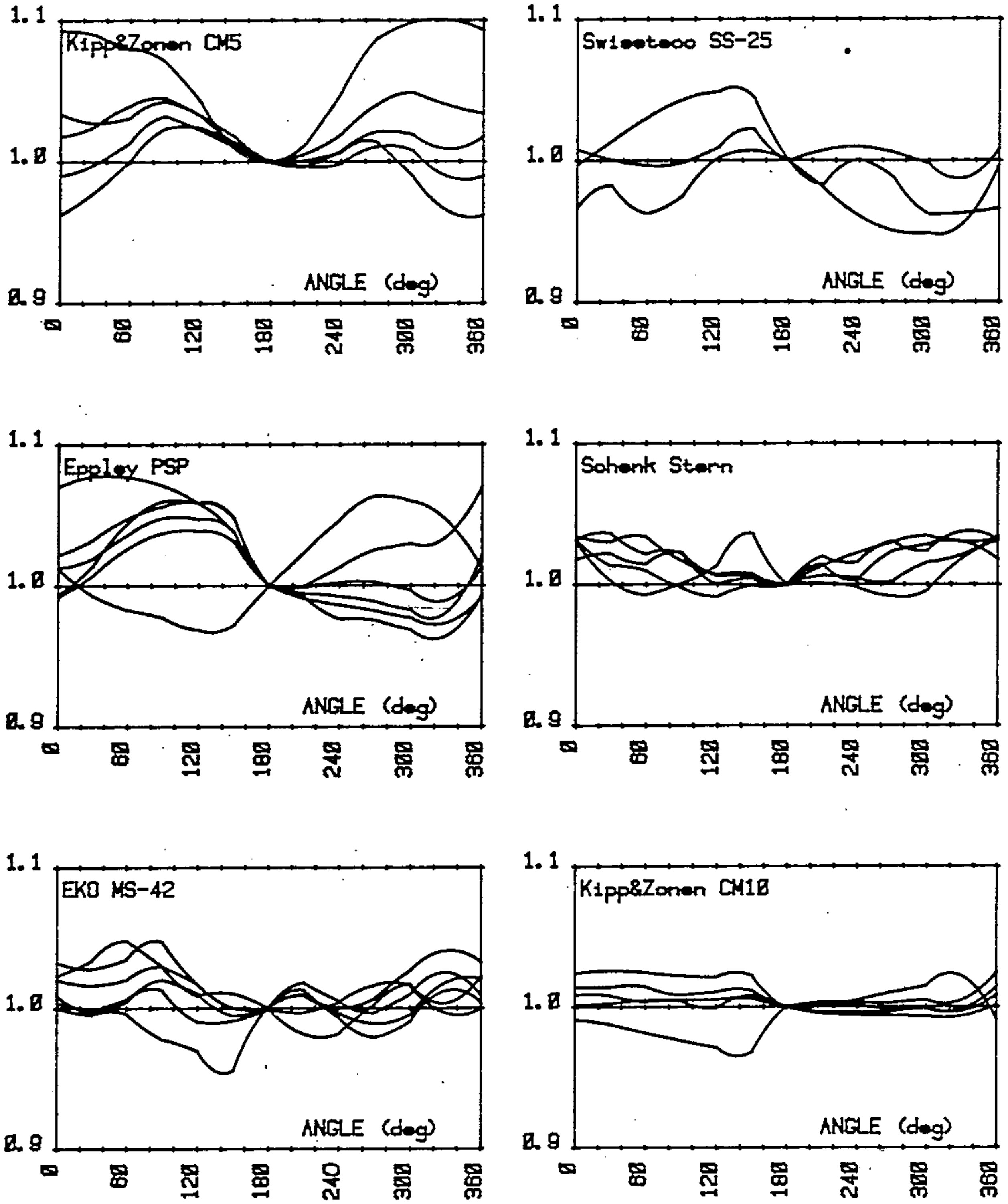
The output voltage from the pyranometer was measured using a Keithley 180 nanovolt meter as a preamplifier to a conventional digital voltmeter.

The following measurement procedure was used. Table B was rotated so that the 0^0 - 180^0 azimuth line of the pyranometer was horizontal. After taking an initial reading at 0^0 polar angle, table A was rotated from -90^0 to $+90^0$ polar angle, readings being taken at each second degree. A zero reading was taken at each angle and subtracted from the reading taken with open shutter. Before each reading, the pyranometer was allowed to stabilize during 30 - 60 seconds. This waiting time was chosen individually for each pyranometer type.

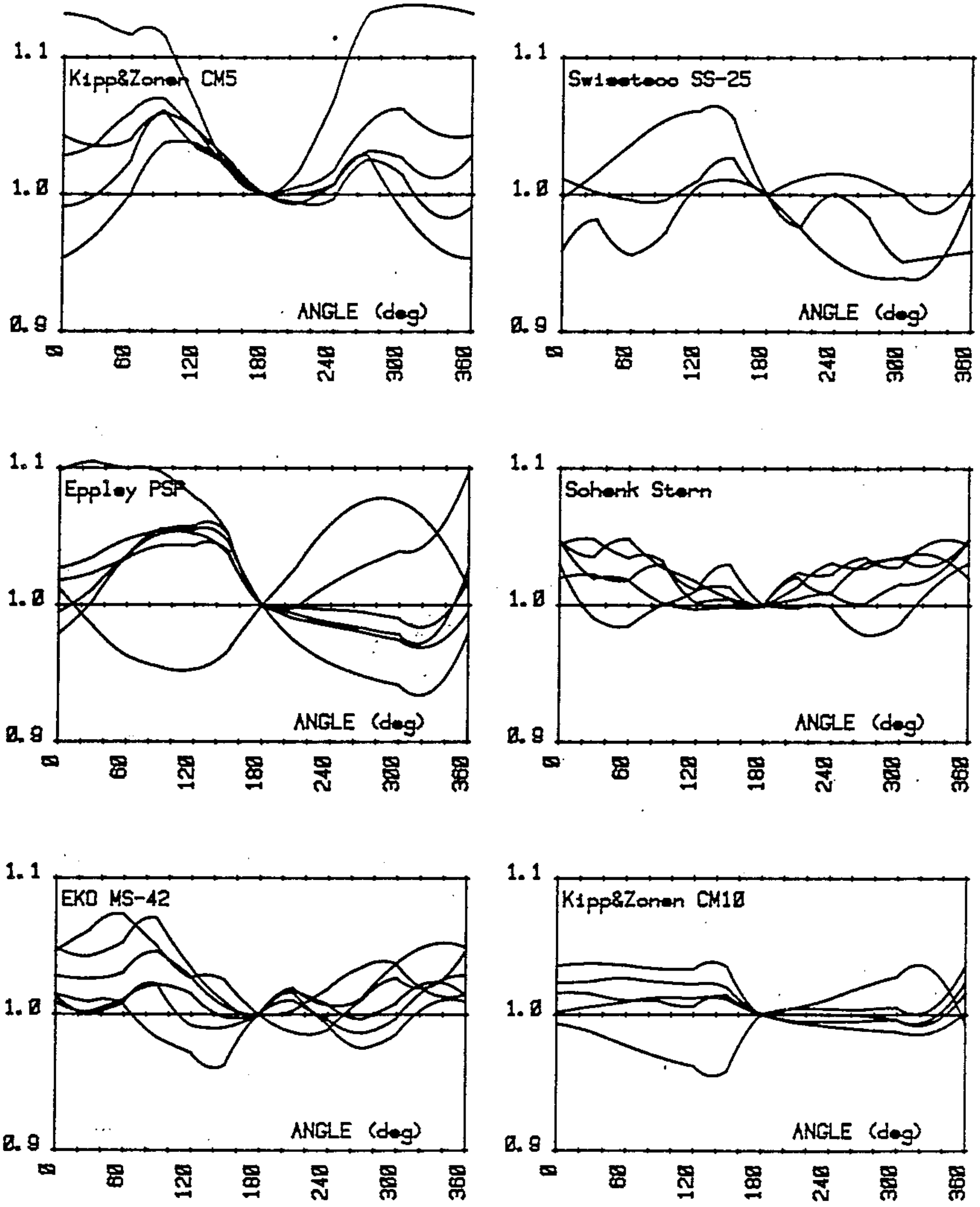
This sequence of readings was repeated at the six azimuth planes 0^0-180^0, 30^0-240^0, 90^0-270^0, 120^0-300^0 and 150^0-330^0 by rotating table B in steps of 30^0. An extra reading at 0^0 polar angle was taken between each sweep.

The whole procedure was controlled by a computer and took from 9 to 18 hours depending on the type of pyranometer. The projector lamp was very stable, but a slight correction for drift during the 9-18 h period was made by using the readings at 0^0 polar angle.

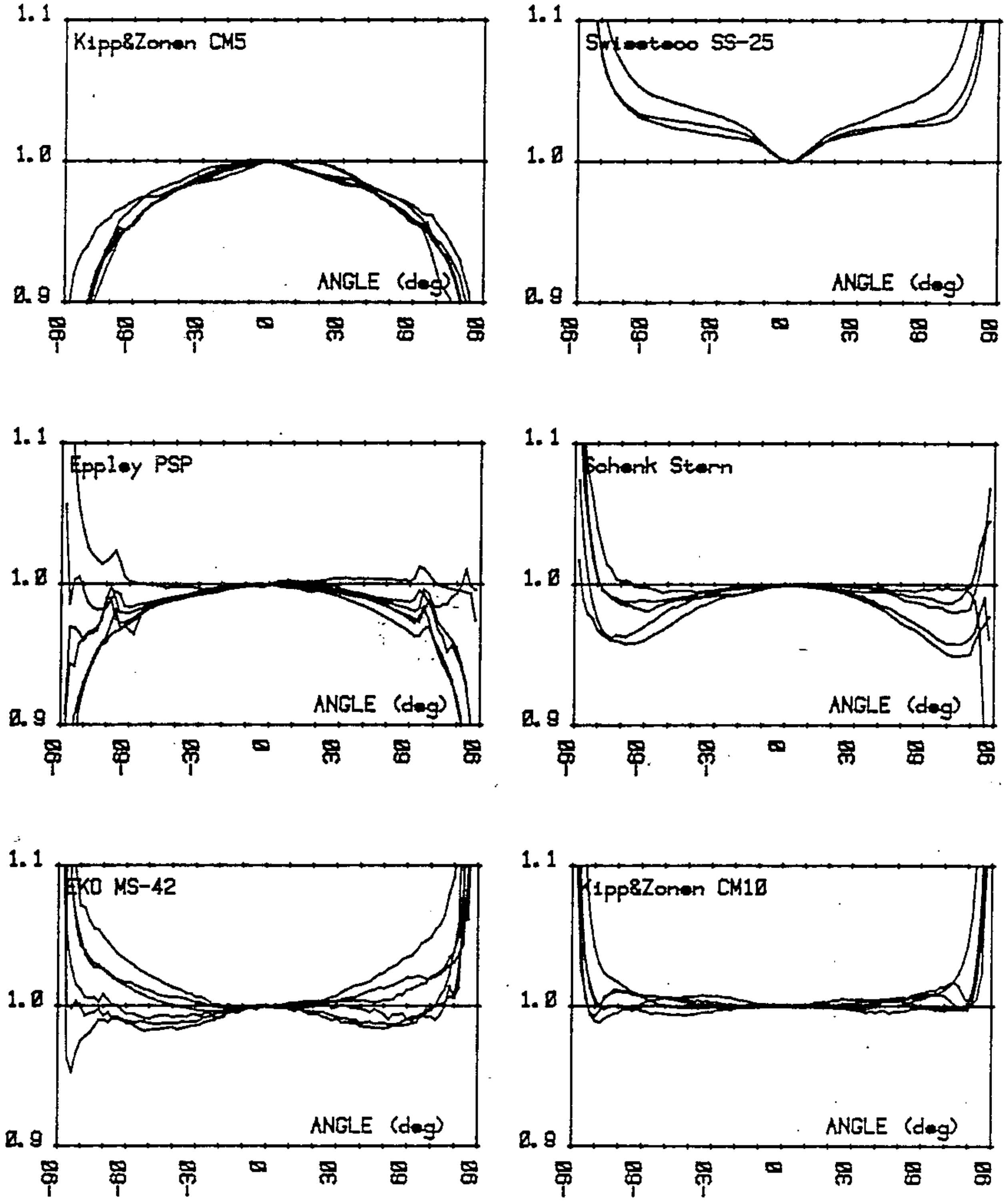
When presenting the results, an offset angle of up to 1^0 was introduced to make the results symmetric for the following reason. To obtain reliable cosine measurements the pyranometer must be mounted with an angular accuracy of better than $\pm 0.1^0$. This is difficult to achieve for practical reasons. Besides, imperfections in the pyranometer itself may make this accuracy impossible. It might be imperfections in the spirit level fixture or a tilt of the detector plane relative to the pyranometer body.



Figures 8a - 8f: Relative detector responsivity versus azimuth angle for a fixed incidence angle of 70°



Figures 9a - 9f: Relative detector responsivity versus azimuth angle for a fixed incidence angle of 75°



Figures 10a - 10f: Relative detector responsivity versus angle of incidence (cosine response). Data are taken in the reference plane defined by the azimuth angles of 0° and 180°.

Therefore, the readings were made symmetric between +70° and -70° by introducing a small offset angle and controlling the result by using a least square fitting procedure. The introduction of this offset angle sometimes had a drastic effect on the presented cosine deviation at angles greater than 70°.

In Figs. 8 and 9 a summary of measurements is shown. Each diagram shows the results from one type of pyranometer. Fig. 10 shows the cosine response for the 0°-180° plane, in which the cable connection is pointing north (0°). Complete data tables for the effects of tilt, irradiance and temperature are given in Appendix B. For ease of handling this report, the cosine responsivity data tables are not included in the report.

3.1.5 Discussion of results

Generally speaking, a good quality pyranometer should reveal only small dependencies on tilt and ambient air temperature, a linear dependency on the level of irradiance, and an ideal cosine response with respect to the angle of the incident radiation. If additionally a group of instruments of the same type display the same dependencies both quantitatively and qualitatively, then it is very likely that the instruments were manufactured with great care and expertise.

- Temperature effect:
  The groups of K&Z CM5, Schenk Star and Swissteco instruments show a "natural" temperature coefficient while the other groups of instruments might be classified as slightly overcompensated. The sign of the temperature coefficient was found to be typical for each brand or group of instruments, the only exception being the EKO Star instruments where each instrument has its individual temperature coefficient. These findings are consistent with those of Dirmhirn /4/ for the Schenk Star pyranometers.

- Linearity:
  The response of the instruments with respect to varying levels of irradiance was linear to a very good degree. This was true for all types of instruments studied. For the group of Eppley PSP pyranometers deviations from a linear response could not be resolved.

- Tilt effect:

The effect of tilt is most relevant for solar energy equipment testing and monitoring purposes. The tilt effect is obviously cross-correlated with the level of irradiance, and the figures show the effect for a 1000 W/m^2 level of irradiance. Three groups of instruments, Eppley PSP, K&Z CM 10 and Swissteco, did not show any tilt effect. Three other groups of instruments, K&Z CM 5, the Schenk Star and EKO Star did show a tilt effect of comparable magnitude. It should be pointed out that these findings are consistent with the findings from the comparative outdoor performance measurements.

- Directional response:

The pyranometers exhibited a distinct individualism in their deviations from the ideal cosine response. However, all instruments showed a marked deviation from the ideal response for angles of incidence greater than 60^0. The uncertainties associated with the measurements for large angles of incidence should be stressed once more. The similarity of results shown in figures 8 and 9 suggests that the precision of the directional response measurements is excellent. According to the method used for this investigation we would expect a cross correlation with the level of irradiance.

3.2 Directional response, Davos laboratory investigations

- Goniometer:

During the indoor tests the instrument was mounted on a goniometric table and exposed to radiation from a solar simulator. The goniometer had a vertical cosine axis and a horizontal tilt axis. A turntable that swung around the tilt axis provided the azimuth movement of the pyranometer. For a tilt angle of zero the azimuth axis coincided with the cosine axis, while for tilt angle 90^0 all three axes were perpendicular to each other. All axes were driven under computer control by stepping motors and worm gears.

- Mounting of the instrument:

The instrument was mounted on the goniometer with its detector horizontal for a tilt angle of zero, and with the tilt axis through its detector surface. The cable or connector was oriented northwards, e.g. in the direction opposite to the source. When the goniometer swung to a tilt position of 90^0 all three axes met at the detector, whose normal axis then pointed towards the solar simulator. A ventilator with a hose directed a stream of ambient air onto the upper part of the instrument to keep its dome at room temperature.

- Solar simulator:

A 1 kW Xenon high pressure lamp was chosen as source for its high power, high luminance and sun-like spectrum. A simple planar convex condensing lens of focal length 150 mm and with a diameter of 110 mm concentrated the light into a parallel beam. The pyranometer was mounted at a distance of 250 mm from the lens. Between them was a glass disc as beamsplitter for the lamp control, a filter wheel and a 75 mm aperture. The filters allowed an attenuation of the beam by approximately one, two and three thirds. The maximum irradiance at the detector was close to 2 kWm^{-2}. The central part of the beam reflected from the glass disc was focused onto a silicon radiometer which stabilized the current in the Xenon lamp and the intensity at the pyranometer detector to better than 1%. The irradiance of the beam was homogeneous to within a few percent in the central part and increased by about 10% at a distance of 35 mm, but was rotationally symmetric to better than 1 - 2%. The increase towards the outside of the beam was mainly due to the relatively thick condensing lens. -

- Measurement sequence:

The response of the instrument was measured at tilt angles of 90^{o} and 45^{o} at seven cosine positions with $\cos\theta$ = 1.0, 0.85, 0.70, 0.55, 0.40, 0.25, 0.10. The corresponding angles of incidence were 0.0, 31.8, 45.6, 56.6, 66.4, 75.5 and 84.3 degrees. At each of these positions 8 or 4 readings were taken with different azimuth angles separated by 45 degrees. At the tilt angles of 60^{o} and 30^{o}, a reduced measuring sequence was used in order to reduce the total measurement time. For each measurement the output of the instrument was sampled five times at intervals of 1 second by a microprocessor controlled A/D converter with an accuracy of better than 0.1%. The mean value of these samples was accepted only if the first and the last sample were within 0.4% of the mean signal. Thus the response time of the instrument under test was always correctly taken into account. A total sequence consisted of 124 positions and it took about 80 minutes to complete one sequence. Nine times within a sequence the beam was blocked using the filter wheel to allow a reading of the zero of the detector.

- Data evaluation:

  The measured voltages were converted to irradiance using the calibration factor determined during the outdoor comparisons and taking into account the zero readings. These irradiance values were compared to the normal incidence value at tilt angle 90^0 and the same azimuth angle. The results in the form of deviations from the ideal cosine response are tabulated in Appendix B. For each type of instrument a typical representative was chosen and the results are plotted to illustrate the behaviour of each instrument type.

3.3 Comparison of results from different laboratories

Directional response measurements were conducted at Boras and at Davos for all instruments. For some of the old instruments, which participated in an earlier round robin investigation, a characterization from other laboratories was also available showing the directional response and the temperature dependency.

The Kipp & Zonen company had sent complete data sheets along with the instruments. Therefore, it was possible to compare data from different laboratories. Appendix B contains data of directional response and temperature dependencies from four different laboratories:

SP	Statens Provningsanstalt, Boras, Sweden,
WRC	World Radiation Center, Davos, Switzerland,
NARC	National Atmospheric Radiation Center, Downsview, Canada,
K&Z	Kipp & Zonen, Delft, Netherlands.

Two laboratories, WRC and NARC, used irradiance levels of about 700 W/m^2 at normal incidence while SP and K&Z used a low intensity light source of about 100 W/m^2. Data from WRC and NARC has been normalized to low irradiance (compensation of non-linearity effects). The results of this comparison indicates that there is no consistency between measurements of directional response from different laboratories. The closest agreement is found between measurements from SP and K&Z which both use low level irradiance. The discrepancies could not be explained. It is felt that a separate investigation is needed to clarify the methodological uncertainties associated with the directional response measurements. Somewhat encouraging is, however, the agreement of data on the effect of temperature from different laboratories (see Appendix B).

4. COMPARISON OF OUTDOOR AND INDOOR DATA

It might be expected that some correspondance between outdoor performance data and indoor test data should be detectable. However, not all of the dependencies investigated indoors can be observed directly outdoors: e.g. an effect of non-linear responsivity is not directly accessible. Further, any comparative analysis of the outdoor and indoor data should take into account that cross-correlations always affect the outdoor data. However, a remarkable correspondence between the indoor characterization of pyranometers and the outdoor performance was found. A qualitative correspondence could be identified for the effects of tilt, ambient temperature and to some extent for the directional response. Comparing the outdoor performance data on July 30 with that on August 13 (tilt 30^0), we found no tilt effect for the Eppley PSP and K&Z CM 10 instruments as confirmed by the indoor tests. The other instruments did reveal some effect of tilt which was again confirmed by the indoor tests. (Compare Figures 3, 4 and 7.)

The effect of ambient temperature on the performance can be seen by a comparison of summer and winter outdoor data with the indoor test data. In particular, the EKO instruments with their different temperature coefficients show an increase of the relative spread and scatter in their winter performance.

If the directional response closely follows the ideal response a correspondence between indoor and outdoor data can hardly be verified. An instrument like the Swissteco type of pyranometer was proven indoors to be highly sensitive to the angle of incident radiation. The day-long variability (Figures 3 and 4) corresponds fully with the indoor data. Although it is hard to account for the deviations quantitatively if they tend to be small as for

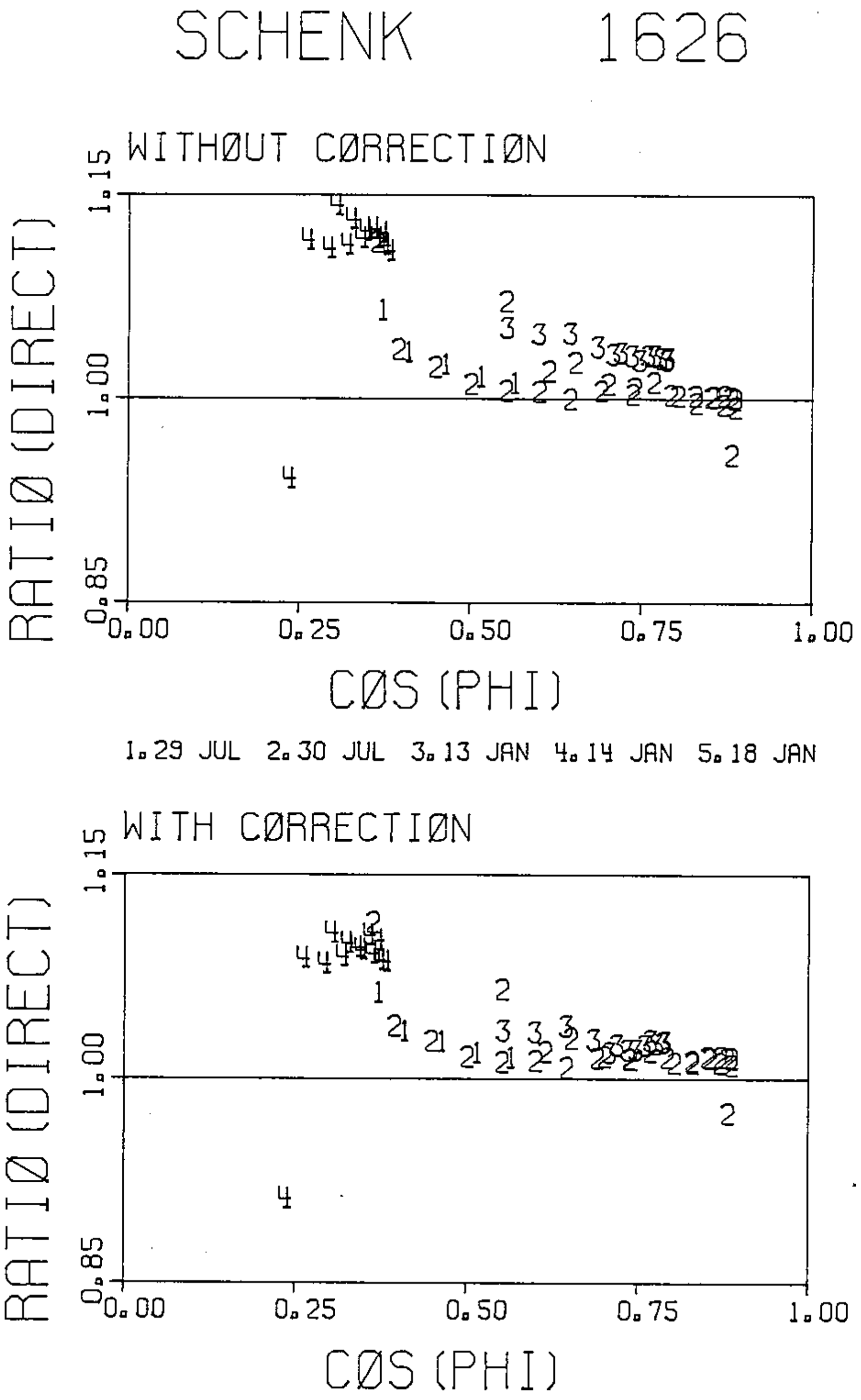


Figure 11: Synthesis of outdoor and indoor data
Instrument: Schenk Star 1626

the Eppley PSP and K&Z CM 10, it is felt that the day-long variability is an excellent over all check of the instruments' quality.
A synthesis of outdoor and indoor data could also be of practical relevance for pyranometry in solar energy applications. It is conceivable that some of the test data available for a particular instrument could be used to correct pyranometer readings to enhance the accuracy of the measurements. We have adopted such a view and have conducted a case study investigation.

The outdoor performance data of 5 days:

1. July 29
2. July 30
3. January 13 (tilt 30^{o})
4. January 14
5. January 18

was normalized to G = 650 W/m^2, T_e = 15 ^{o}C and 0^{o} tilt on the basis of the indoor data obtained from the characterization effort. The deviations from an ideal directional response were not corrected for. Tilt, level of irradiance and ambient temperature are easily amenable to correction.

Typical results are shown in Figure 11 and Figure 12. The raw data and the corrected (normalized) data are plotted in two diagrams:

x-Axis: cosine of the incident angle PHI

$$\text{y-Axis: ratio } \frac{\text{(global-diffuse)/cos(PHI)}}{\text{direct irradiance (PMO2)}}$$

Obviously as shown by Figure 11 the corrections applied for tilt, temperature and level of irradiance tighten the cluster of performance data. The improvement, however, is moderate. As shown by Figure 13 and Figure 14 the corrections themselves become very small and accordingly the effect of corrections is negligible. It seems that either the directional response, some cross-correlated dependencies and (or) other parameters (not accounted for) produce a "noise level" which can not be effectively reduced by the corrections applied.

The conclusion from this excercise is, therefore, that for well behaved instruments the effect of corrections is negligibly small and that for instruments - which do not behave well - corrections can not cure the problems.

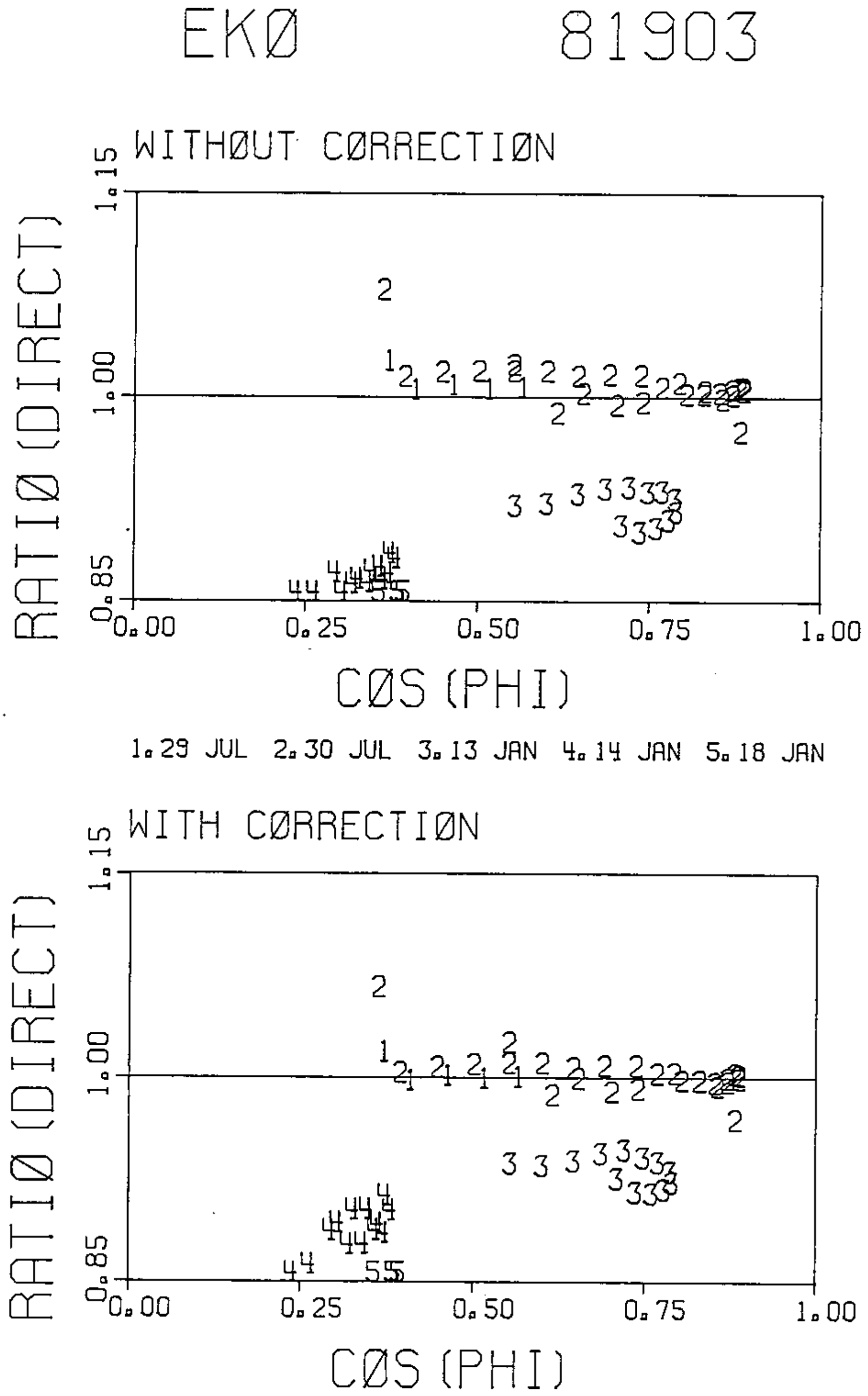


Figure 12: Synthesis of outdoor and indoor data
Instrument: EKO Star 81903

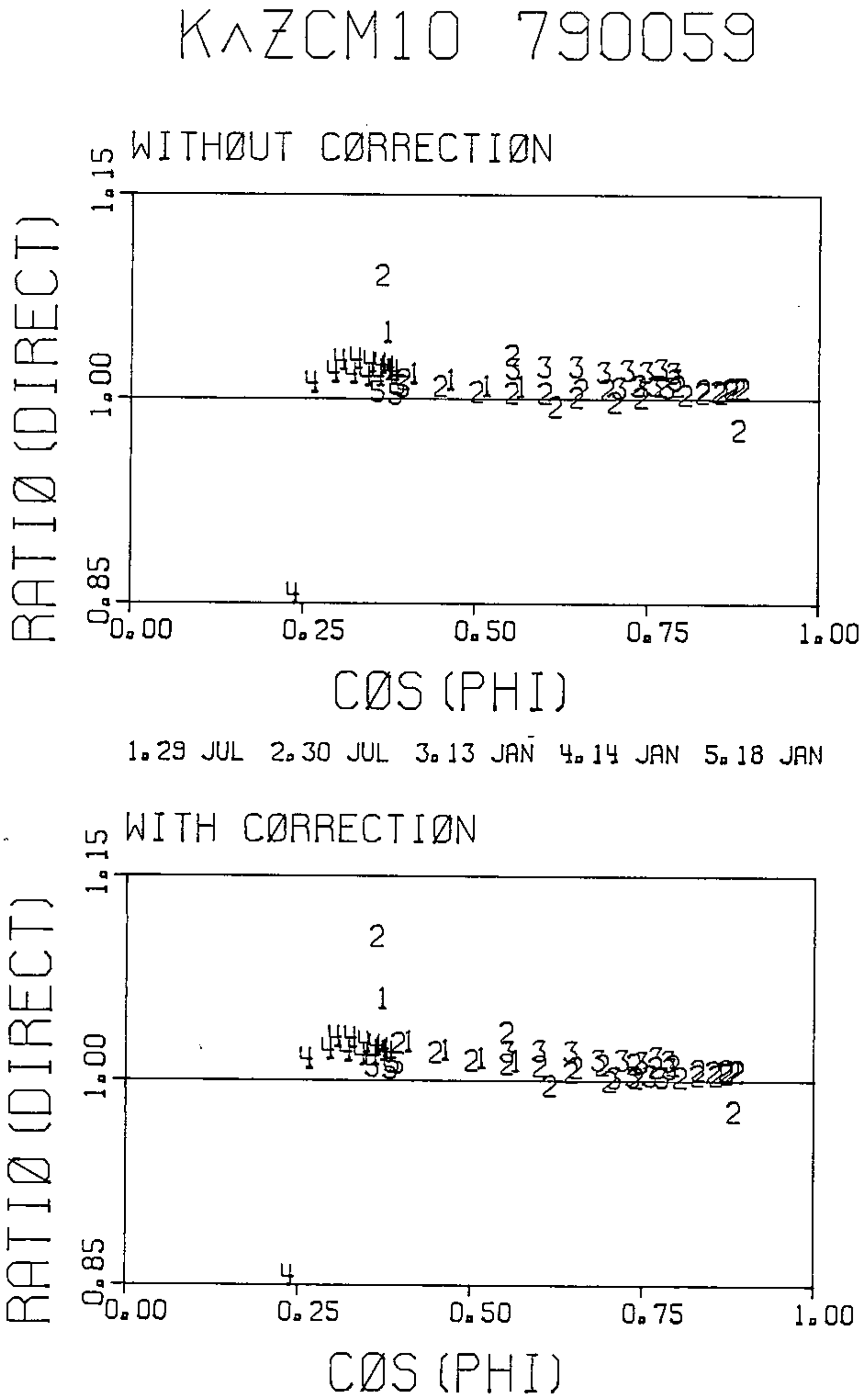


Figure 13: Synthesis of outdoor and indoor data
Instrument: Kipp & Zonen CM 10 - 790059

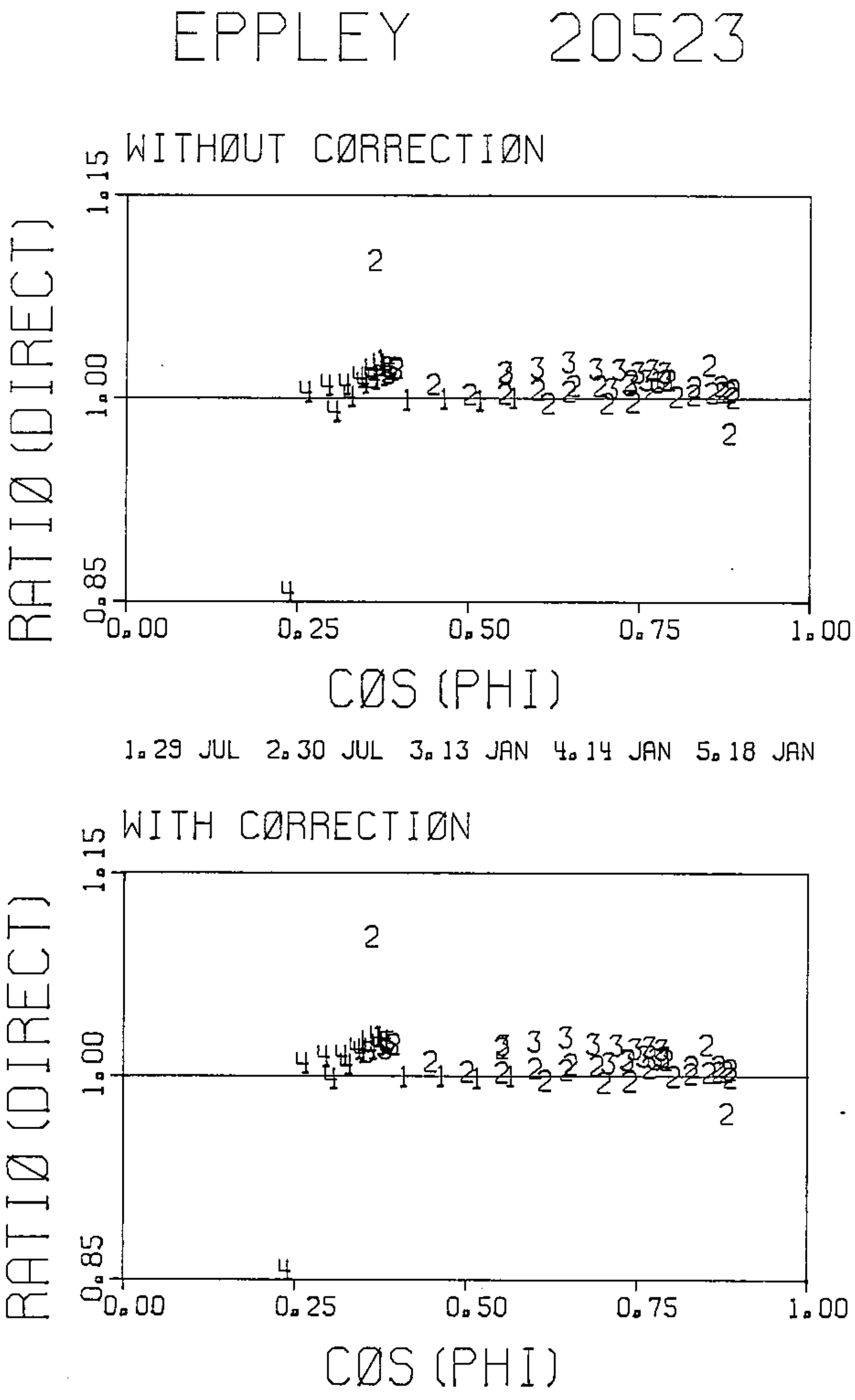


Figure 14: Synthesis of outdoor and indoor data
Instrument: Eppley PSP - 20523

5. RECOMMENDATIONS

- From our results we would recommend that the Eppley PSP and the K&Z CM 10 instruments be used for solar collector testing or similar applications. Accounting for the uncertainties of the calibration procedure and the day-long variability we can then expect an overall accuracy of ± 2.5% to 3% for the measurement of global irradiance in solar energy applications.

- We would not recommend the use of pyranometers which exhibit a tilt dependence. An in-situ calibration is required for tilt dependent pyranometers under test conditions, and their calibration factors in a tilted condition may be expected to vary with irradiance level.

- When buying a pyranometer, the purchaser should also obtain data sheets about the following features of his instrument:
  - temperature coefficient
  - tilt effect (high level of irradiance)
  - linearity

  We would recommend that the manufacturers make such data sheets available on request from the buyer.

- The present uncertainty associated with the measurement techniques for determining the directional response of pyranometers makes further investigation necessary. We feel that the day-long variability during a typical calibration day can be an excellent passport of an instrument's quality. (Referenced to independent measurements of direct and diffuse irradiance.) This could be considered as a substitute for cosine response measurements.

- It has been shown that to make corrections for environmental and geometrical conditions is not a viable option for improving the accuracy of pyranometer measurements.

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APPENDIX A

OUTDOOR DATA (DAVOS EXPERIMENTS)

- Meteorological parameters for all test days
- Performance of pyranometers for all test days
- Performance of groups of instruments on Jan. 13, tilted position
- Data tape description and format

METEOROLOGICAL PARAMETERS FOR ALL TEST DAYS

Arrangement of data plots: **Meteorological and geometrical parameters**

direct irradiance
diffuse irradiance
global irradiance
sun elevation
sun azimuth
incident angle
wind velocity
air temperature
albedo

for 8 groups of test days

summer, clear, horizontal
summer, clear, tilted
summer, cloudy, horizontal
summeer, cloudy, tilted

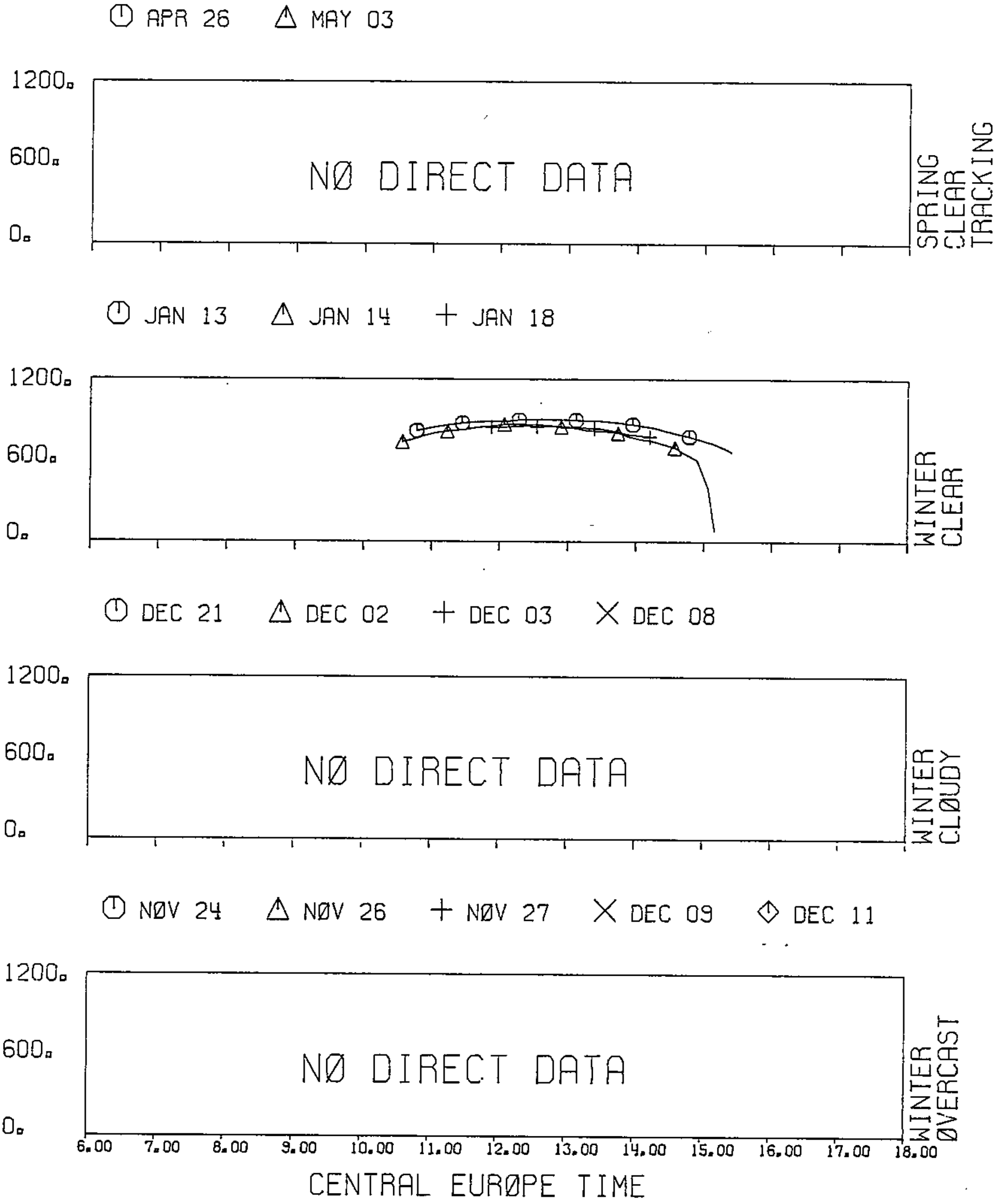
spring, clear, tracking
winter, clear
winter, cloudy
winter, overcast

Comments:

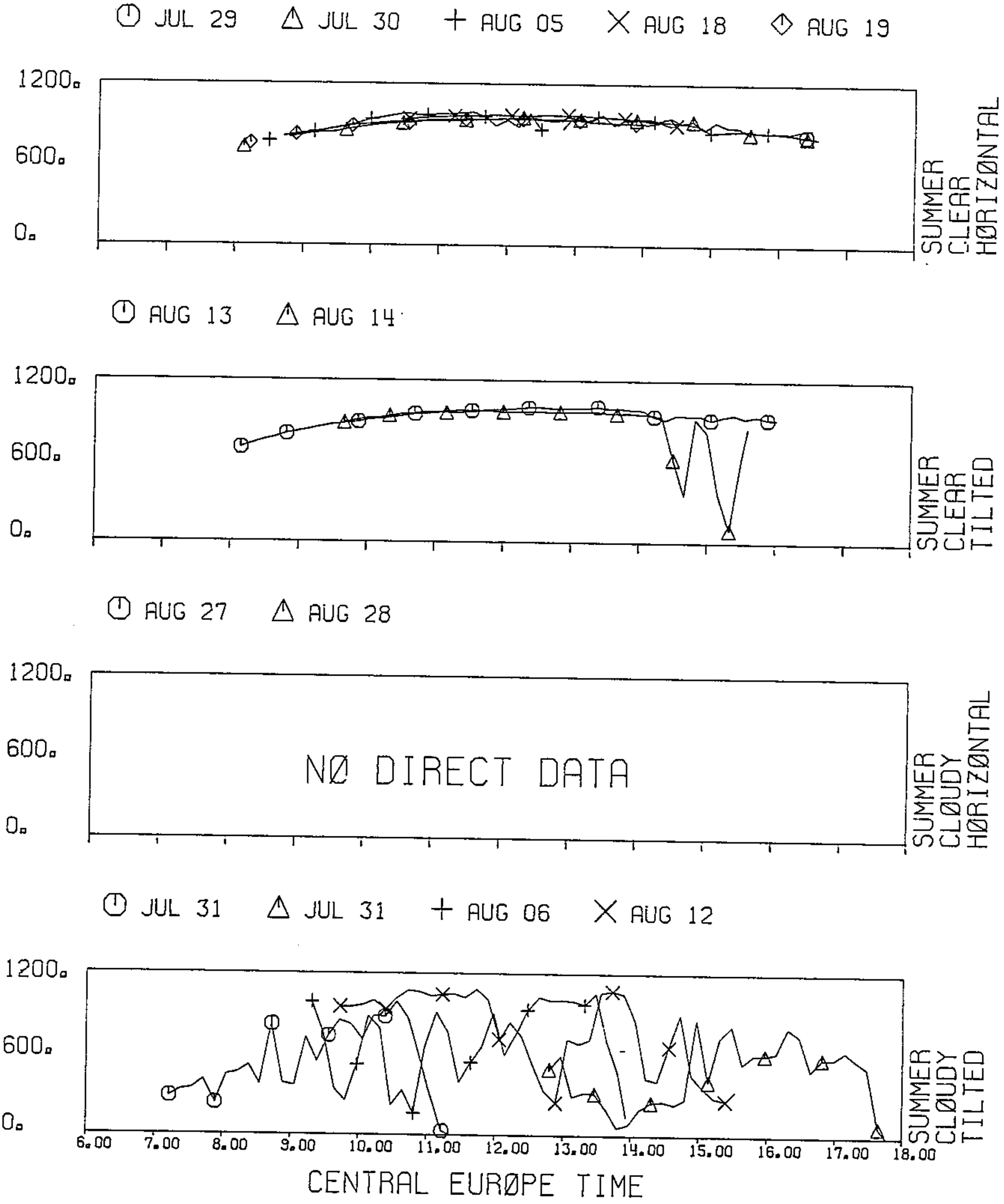
Albedo is defined as the ration between reflected and global irradiance. Interpretation of data has to be done with some care, especially for the winter time data, because the reflecting surface was not horizontal. This explains the albedo values greater than 1.0 for a snow-covered surface. Global irradiance is defined as the mean value of the four reference pyranometers.

Instrument temperature refers to the temperature sensed within the PMOD 6703-A instrument.

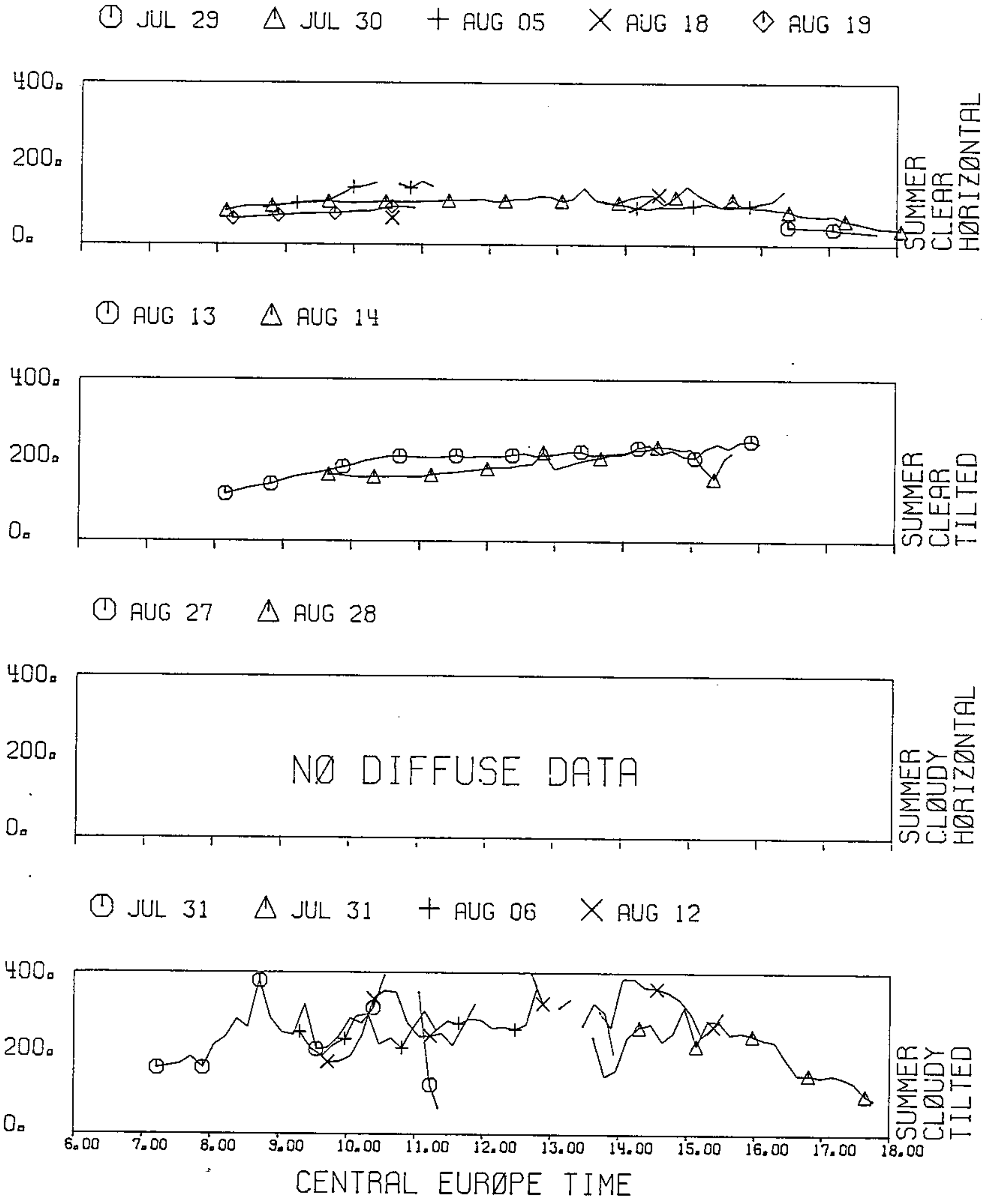
DIRECT RADIATION (WM-2)



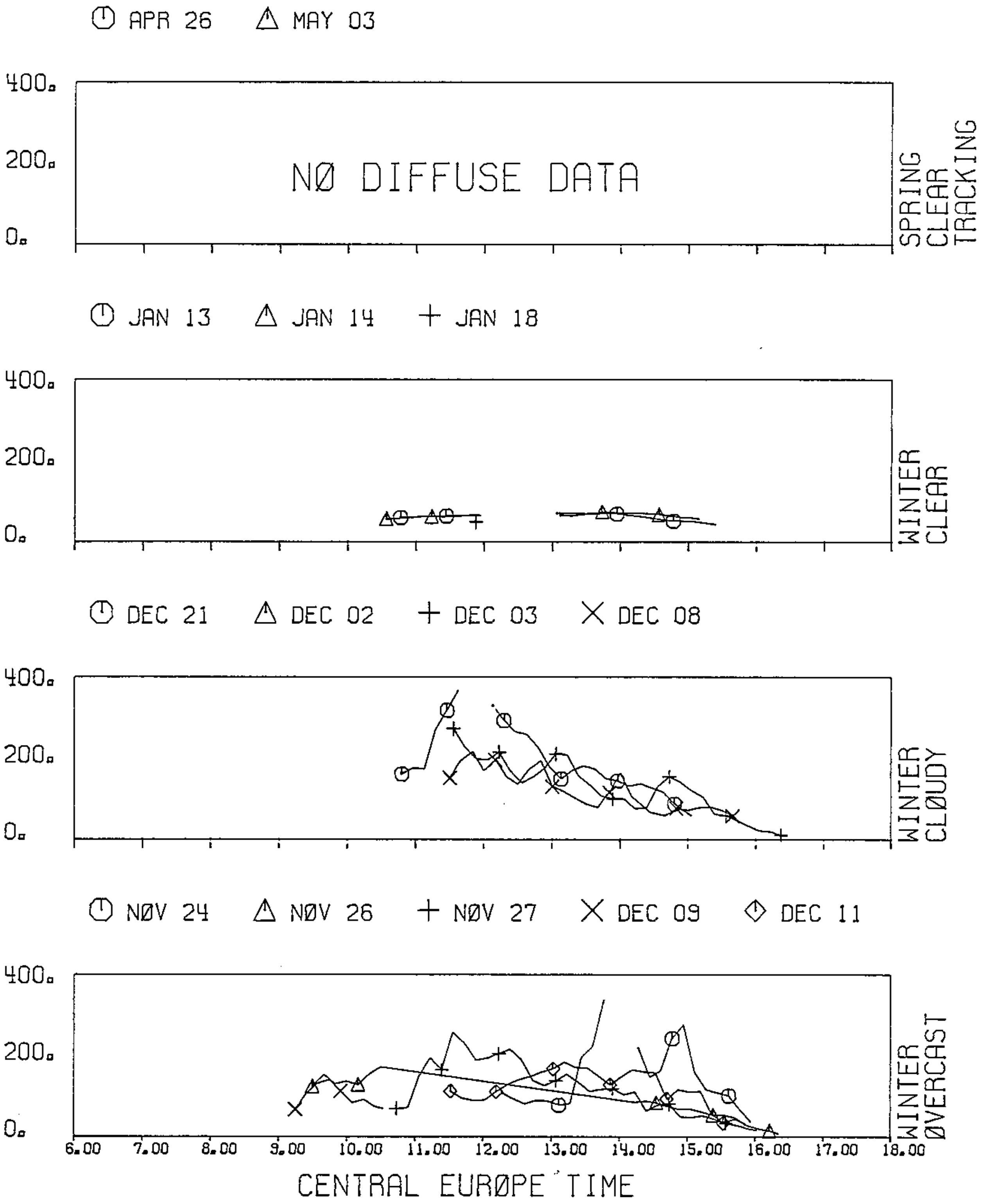
DIRECT RADIATIØN (WM-2)



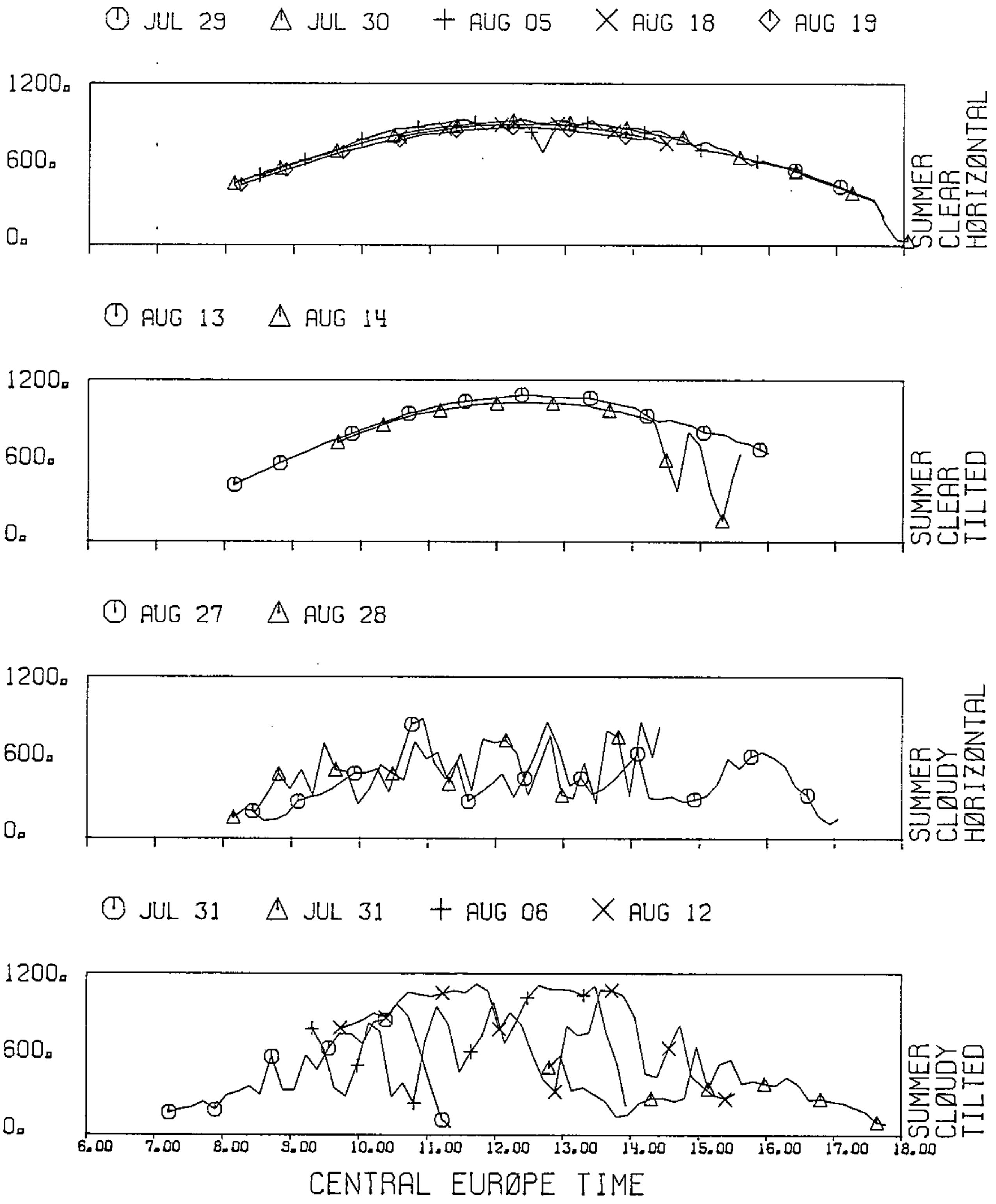
DIFFUSE RADIATION (WM-2)



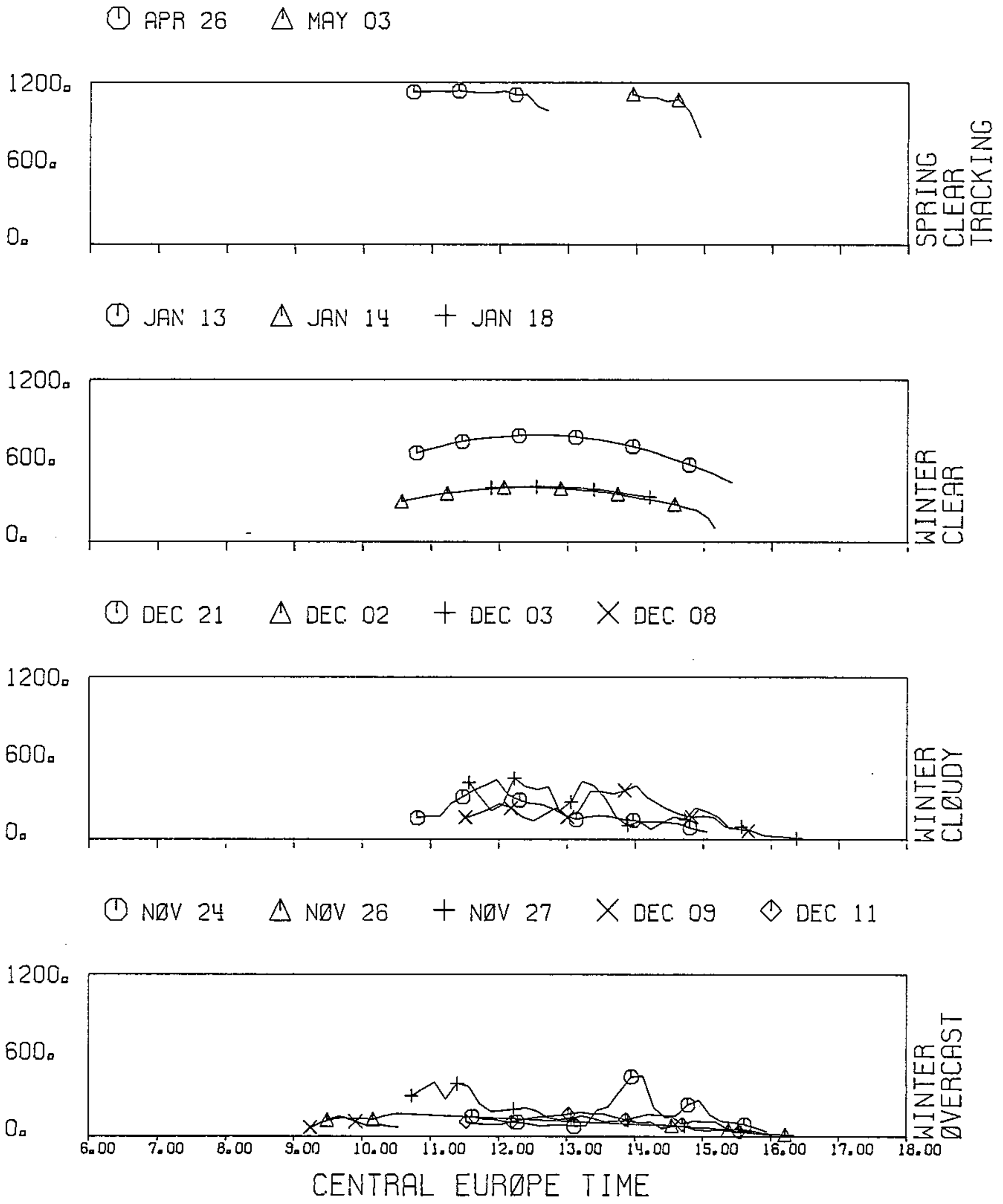
DIFFUSE RADIATIØN (WM-2)



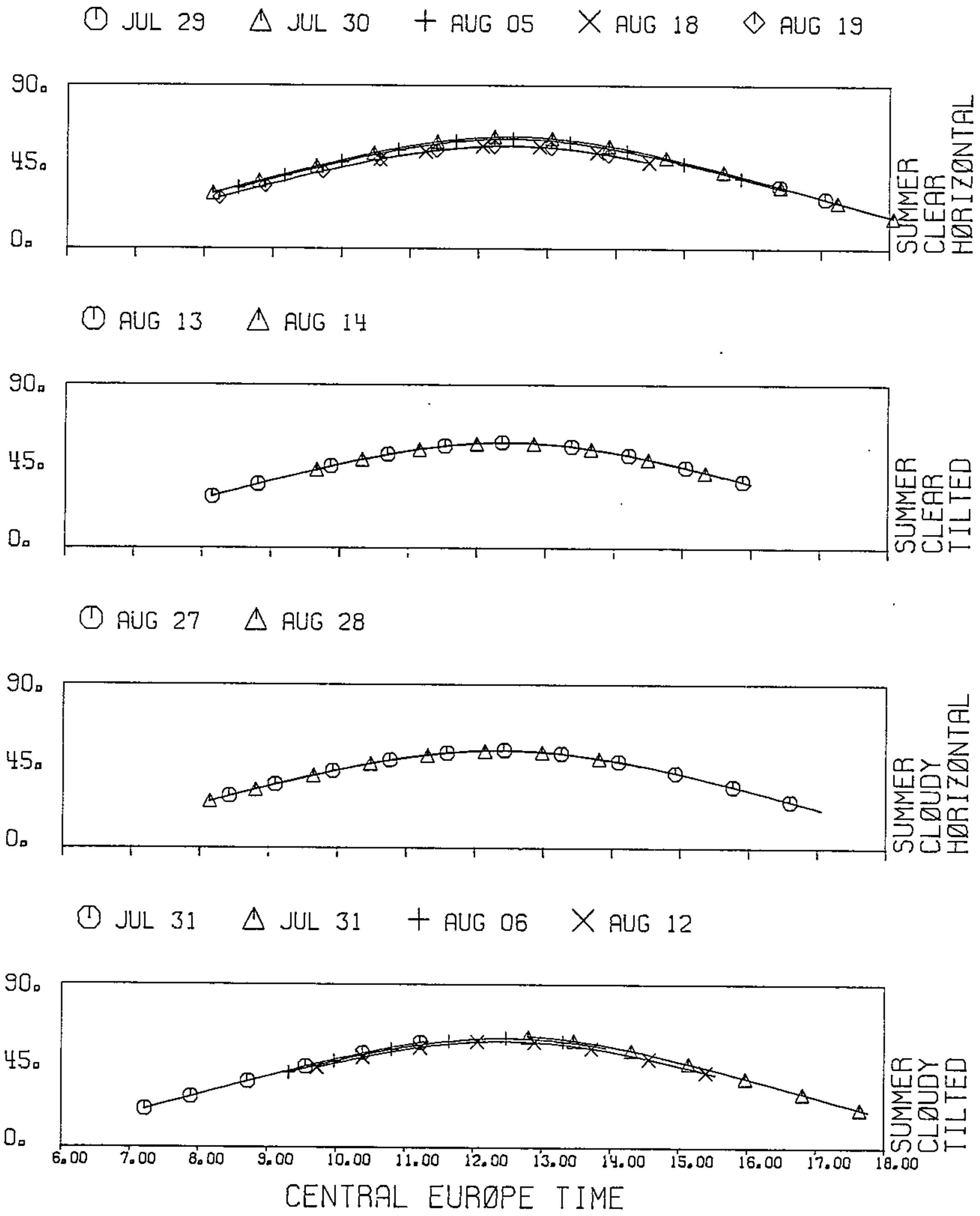
GLØBAL RADIATIØN (WM-2)



GLOBAL RADIATION (WM-2)



SUN ELEVATIØN (DEGREE)



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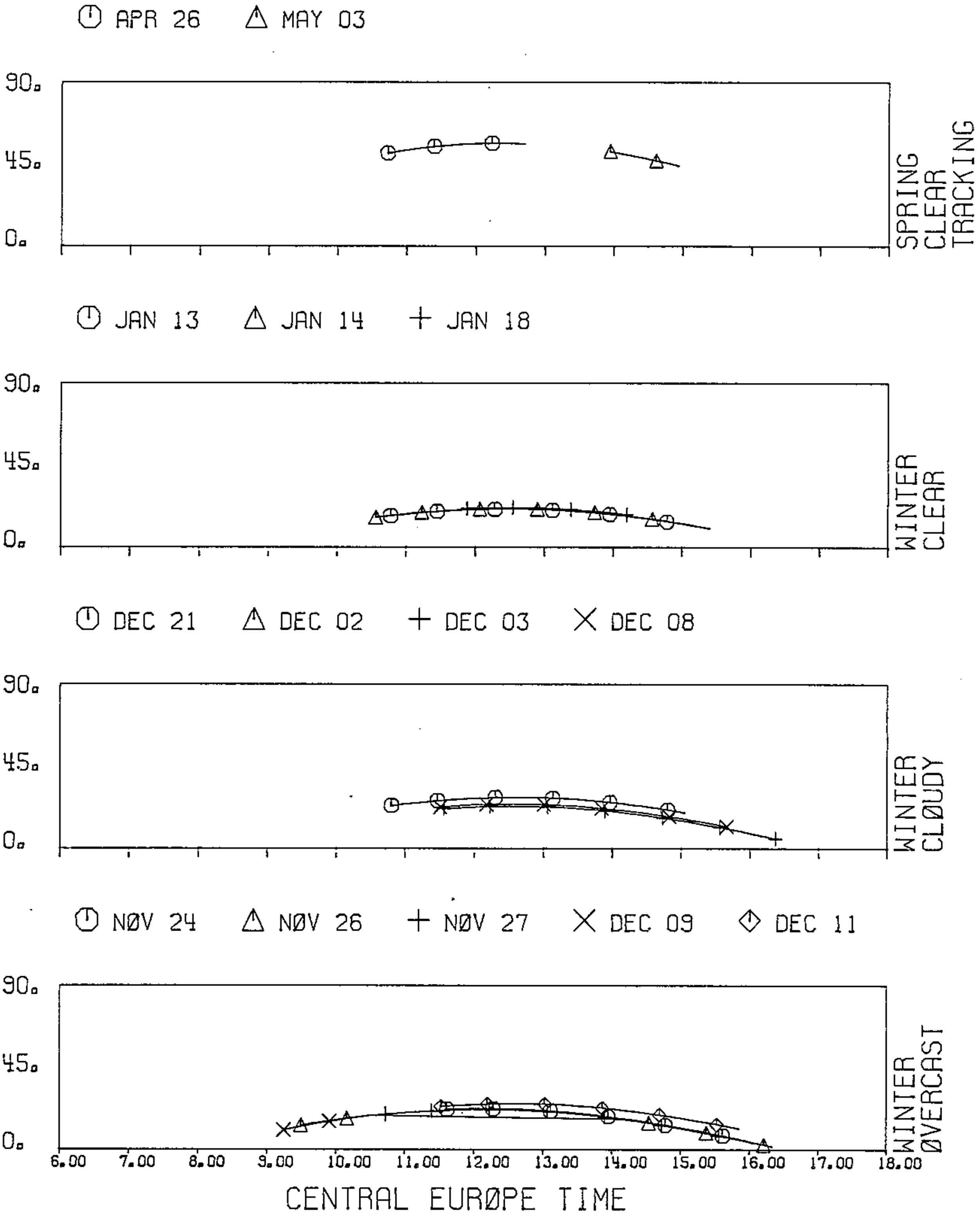
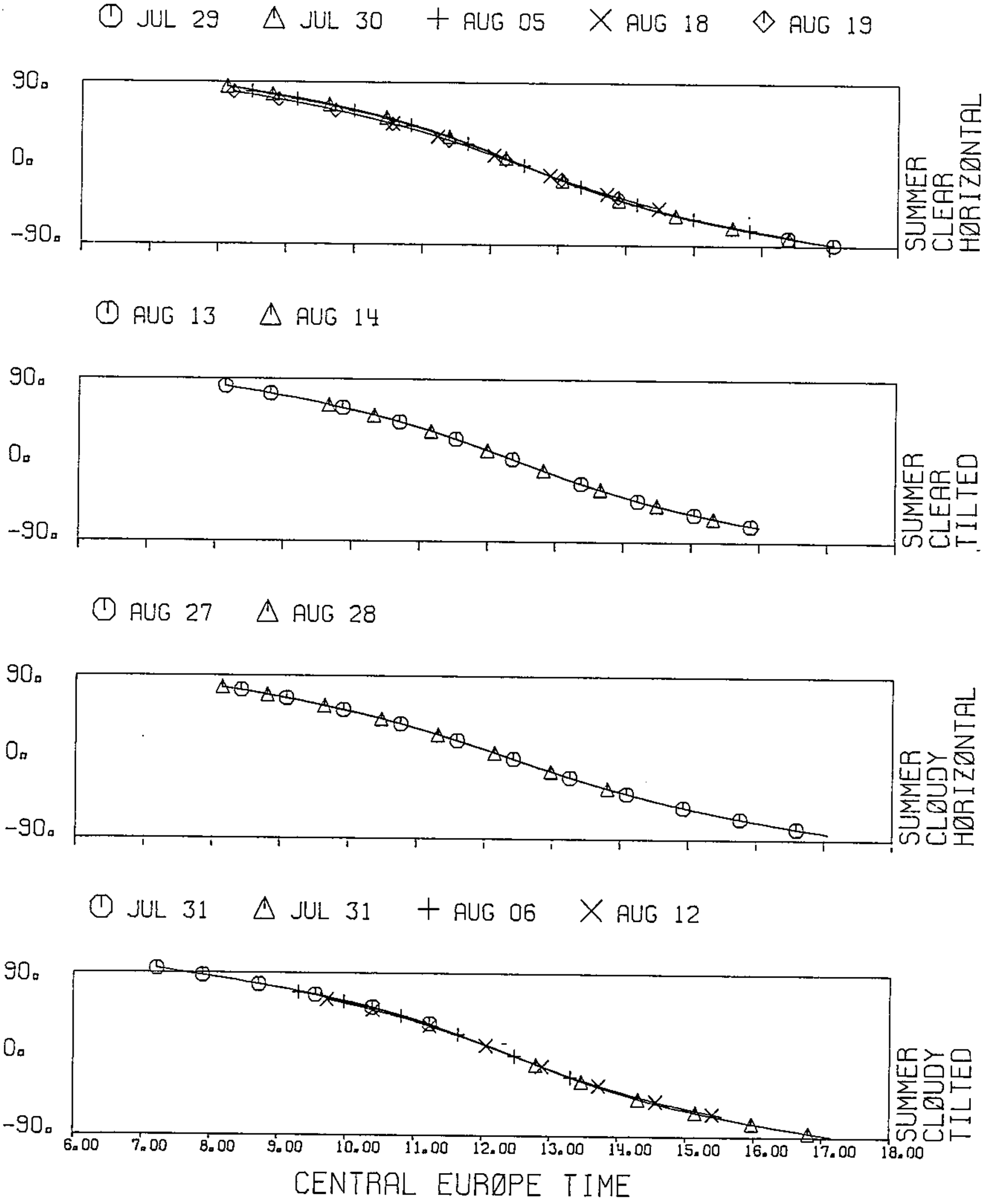


SUN AZIMUTH (DEGREE)



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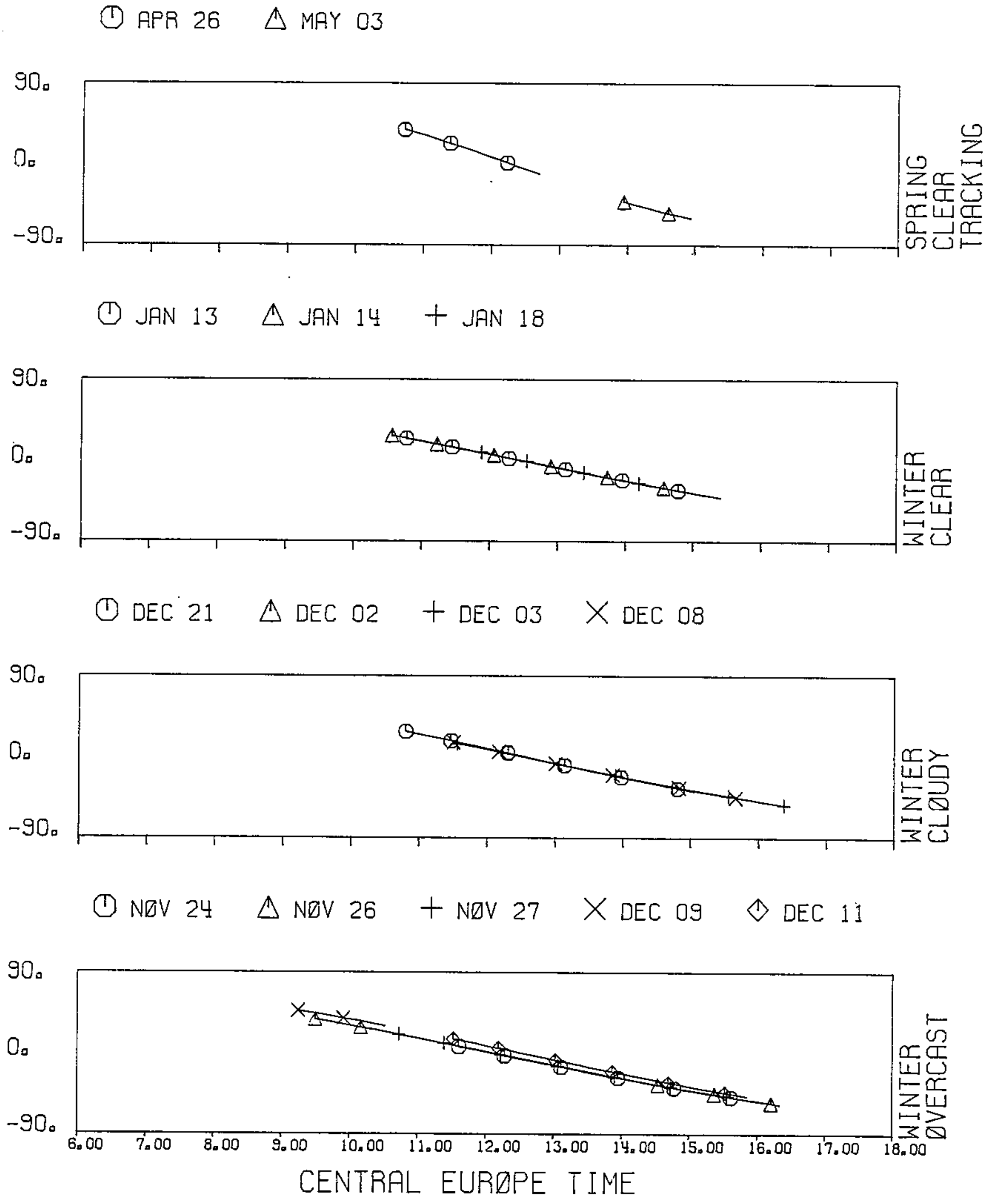

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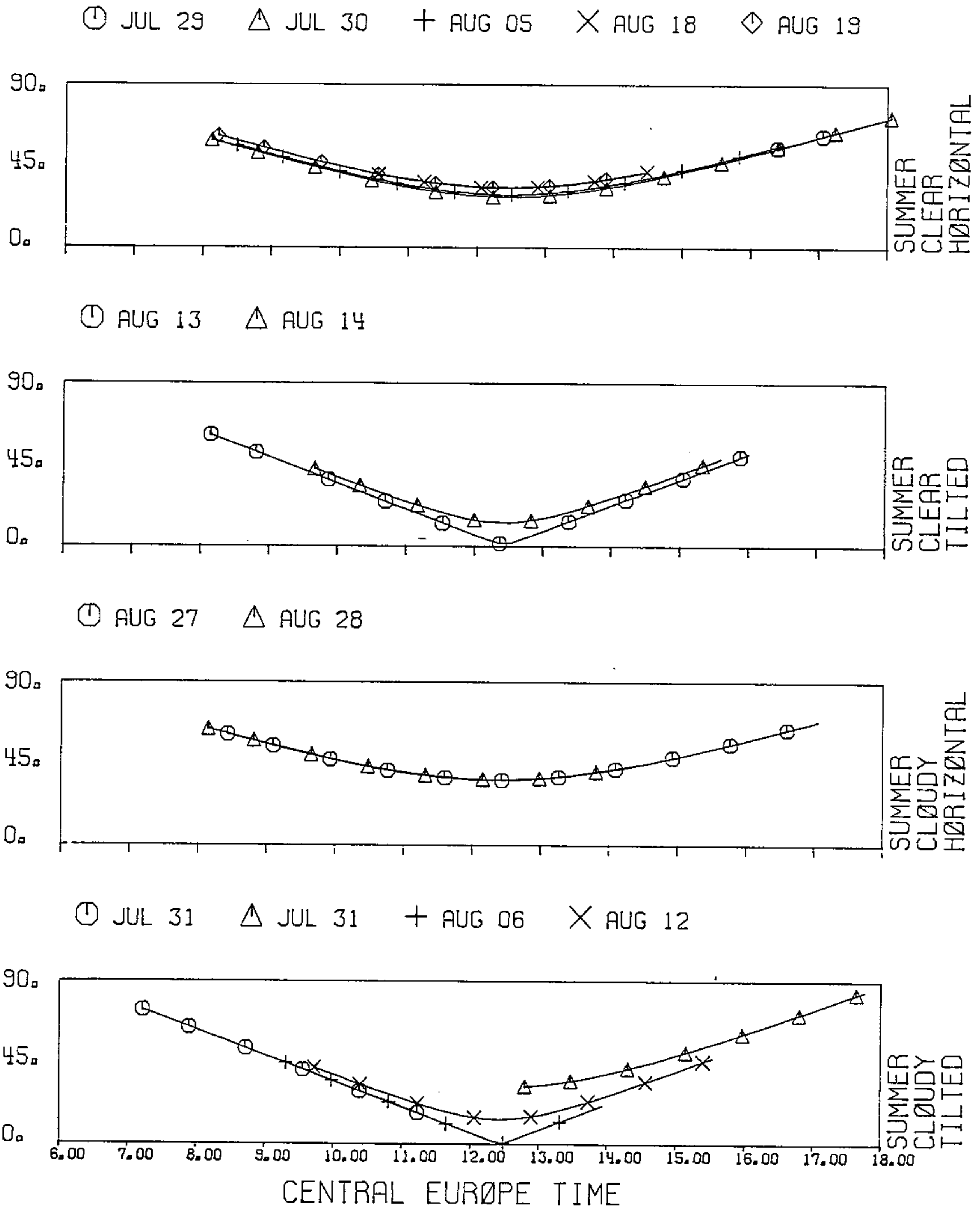

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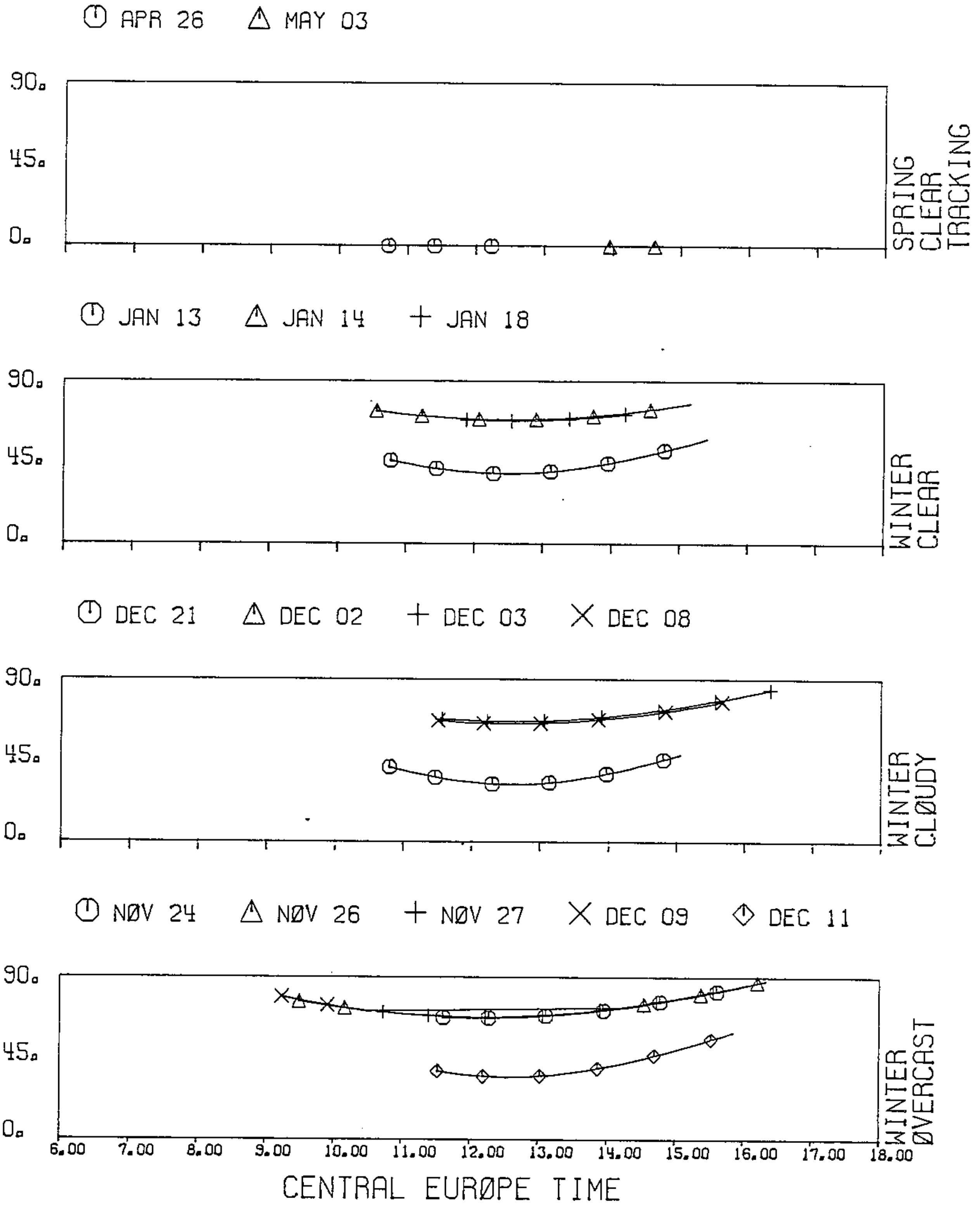

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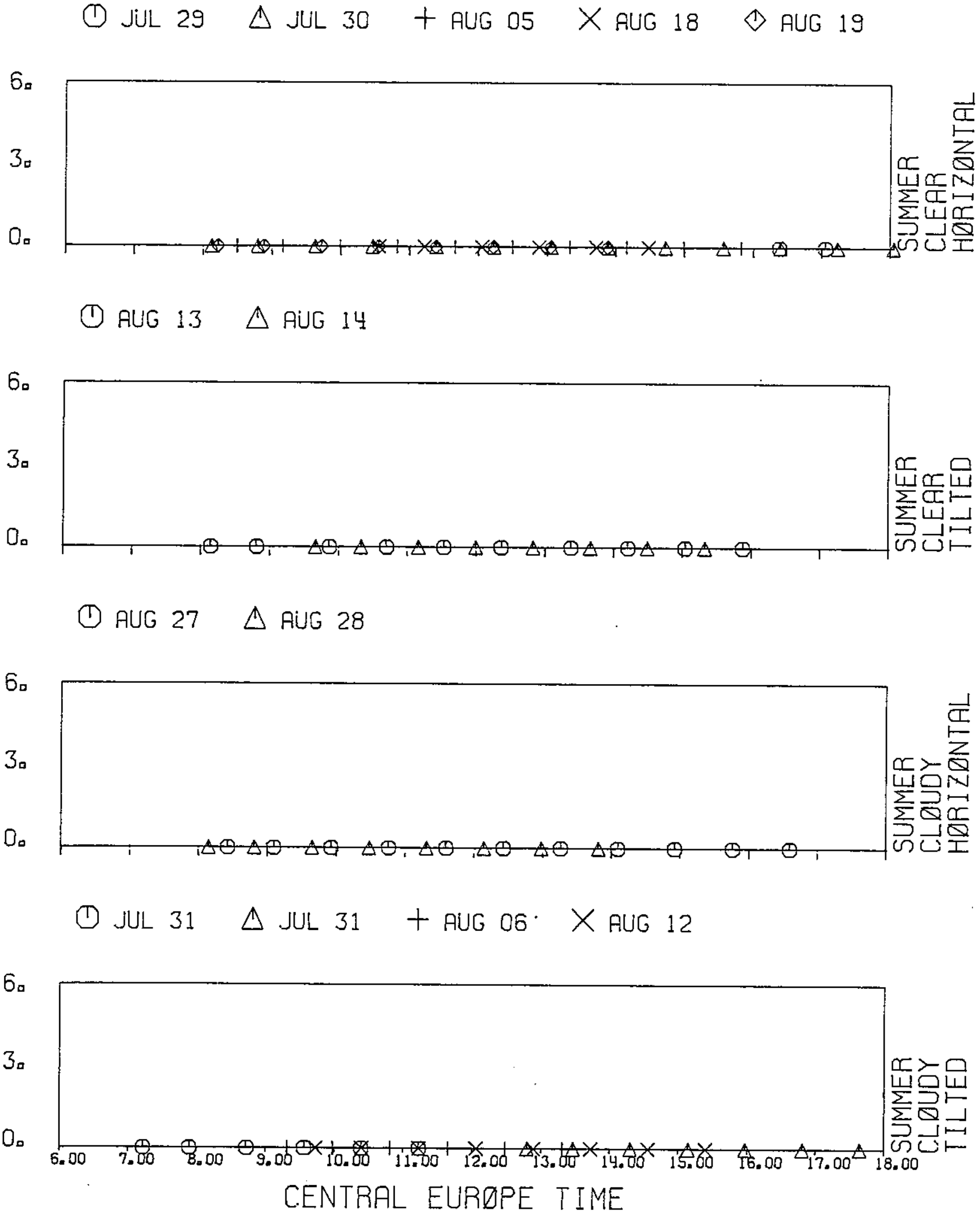
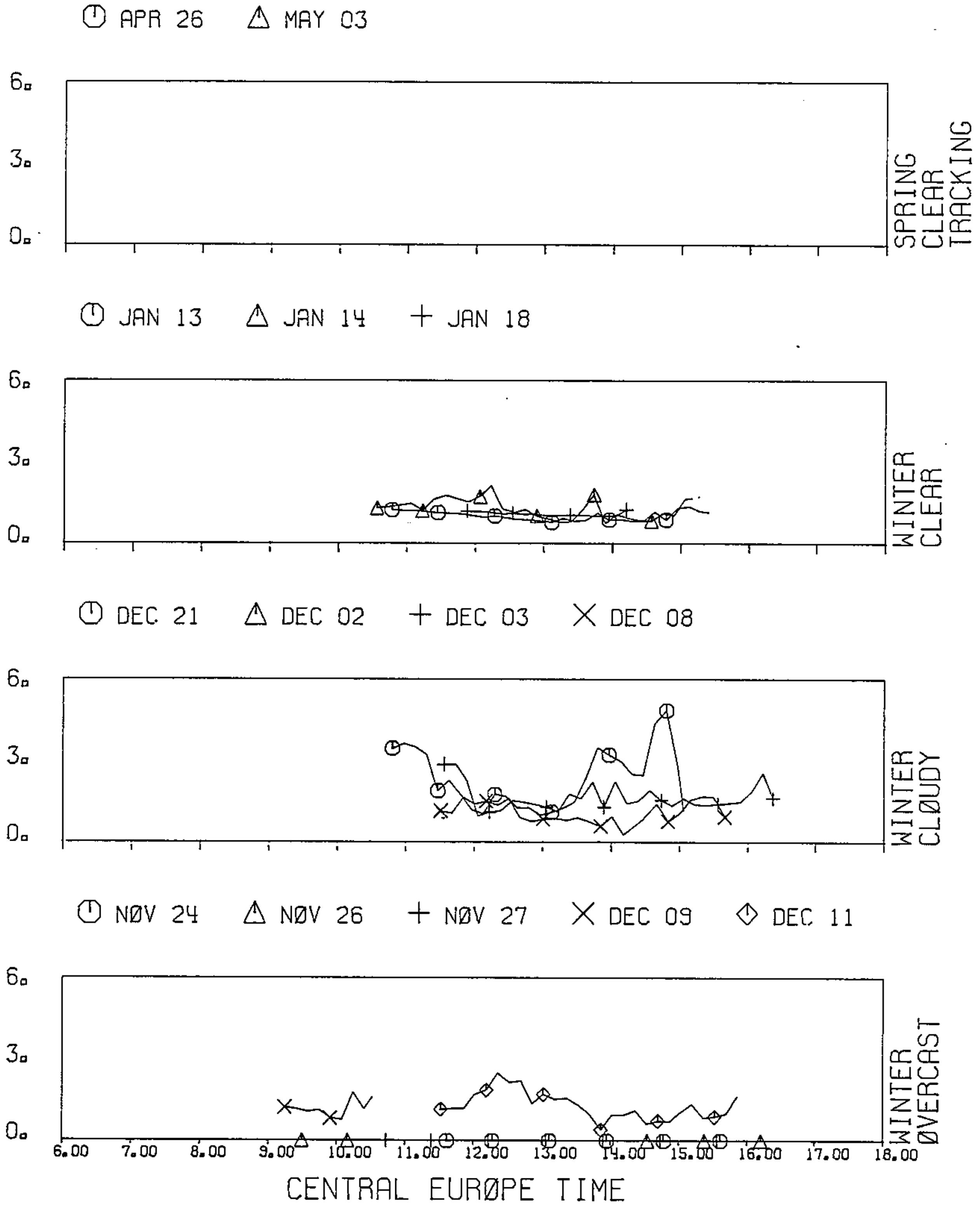


WIND VELØCITY (M/S)



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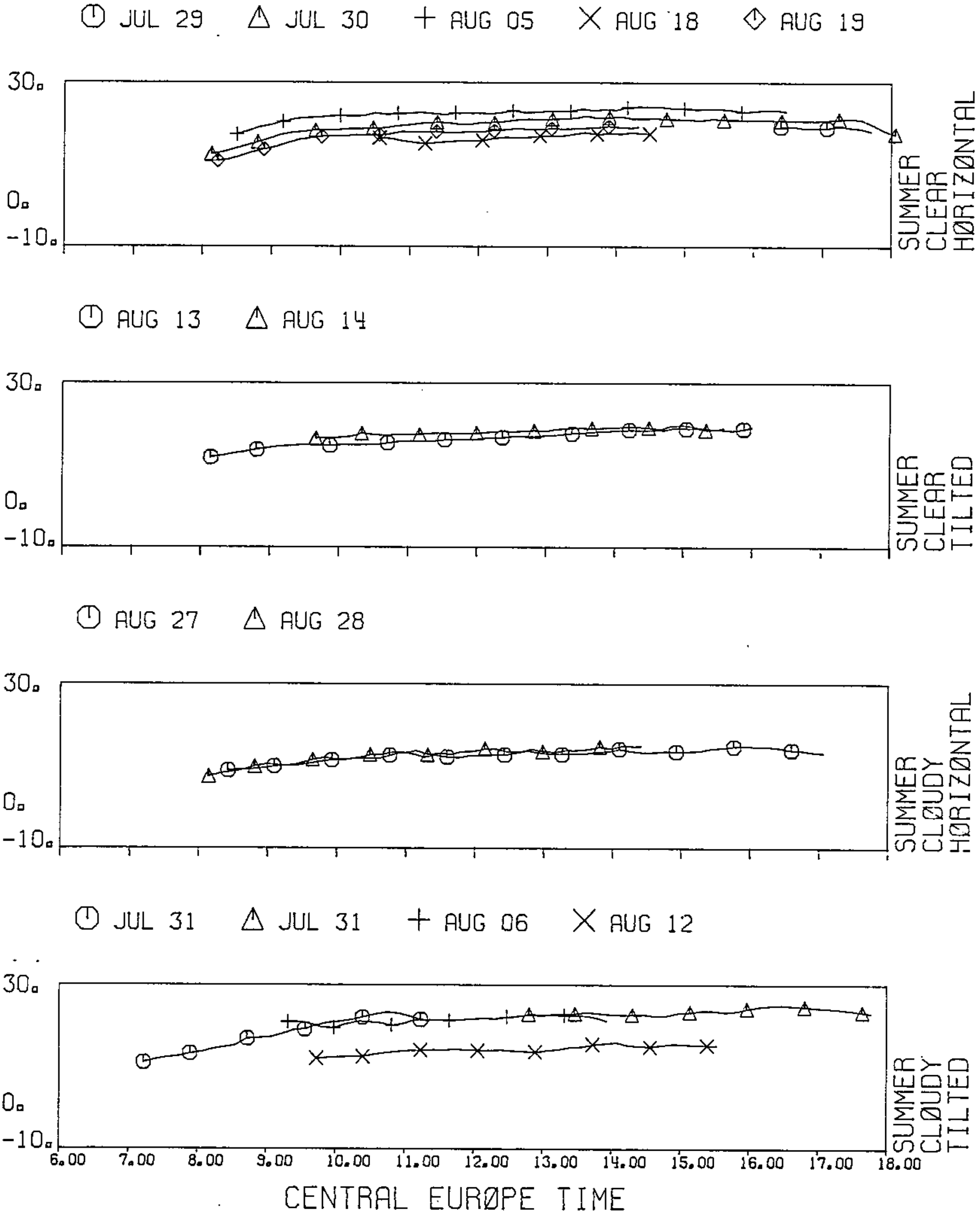

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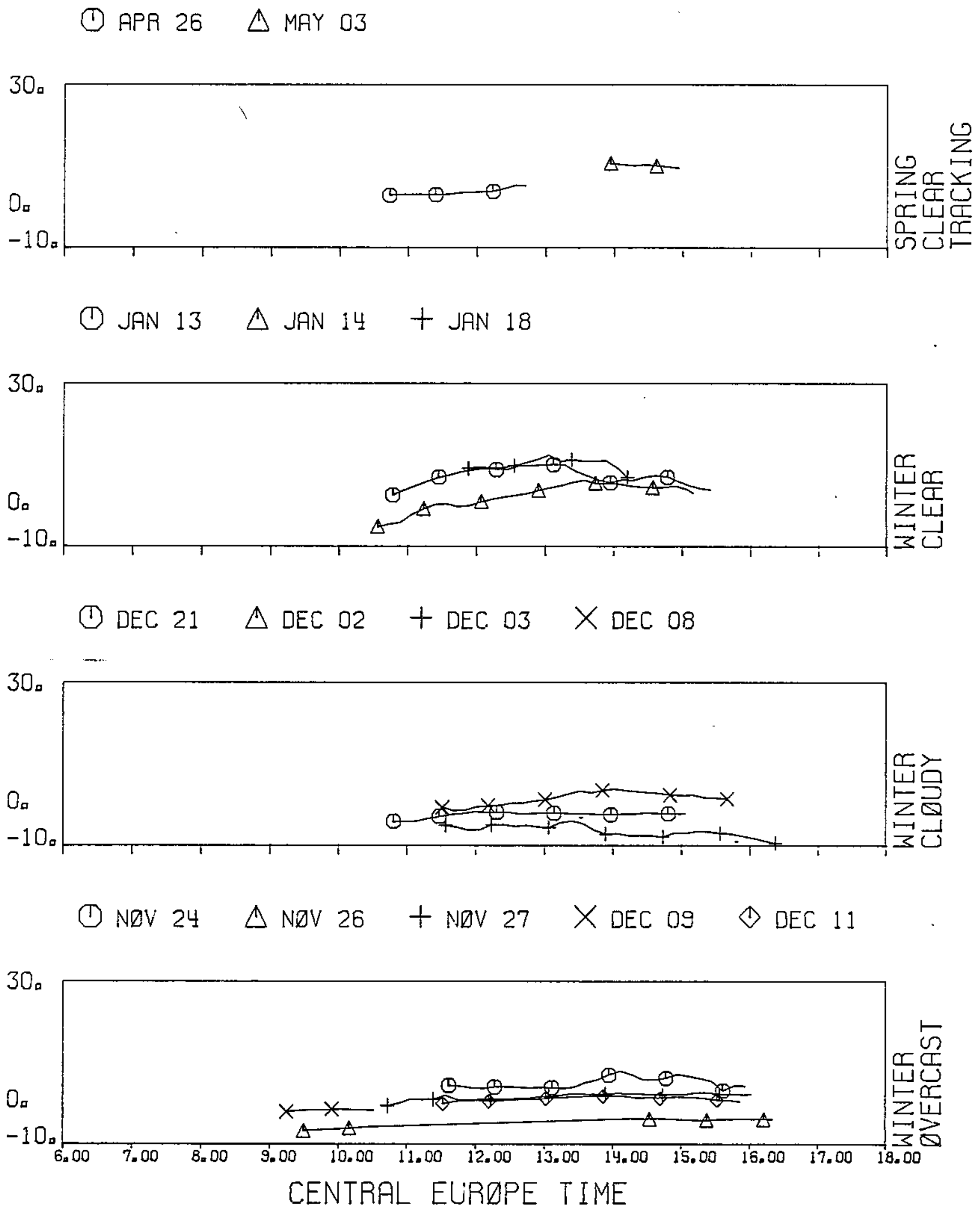

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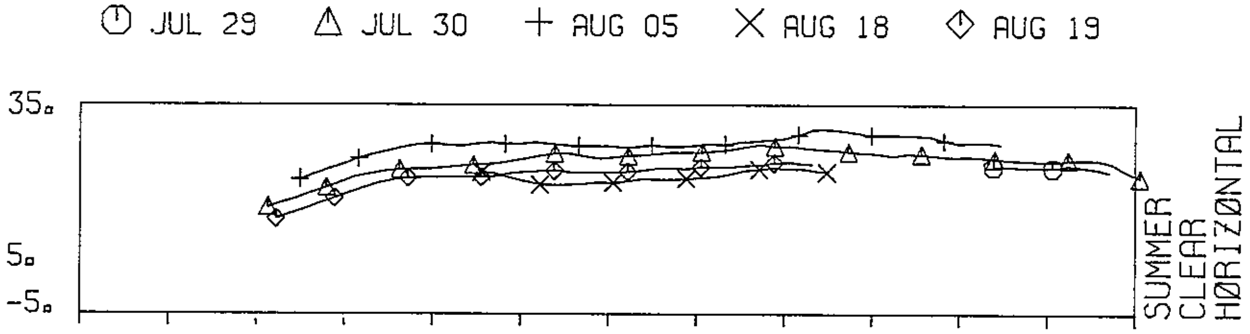

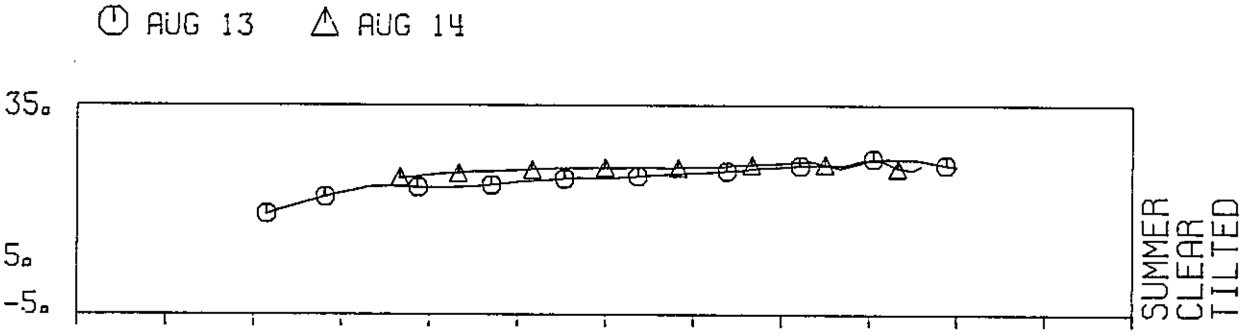

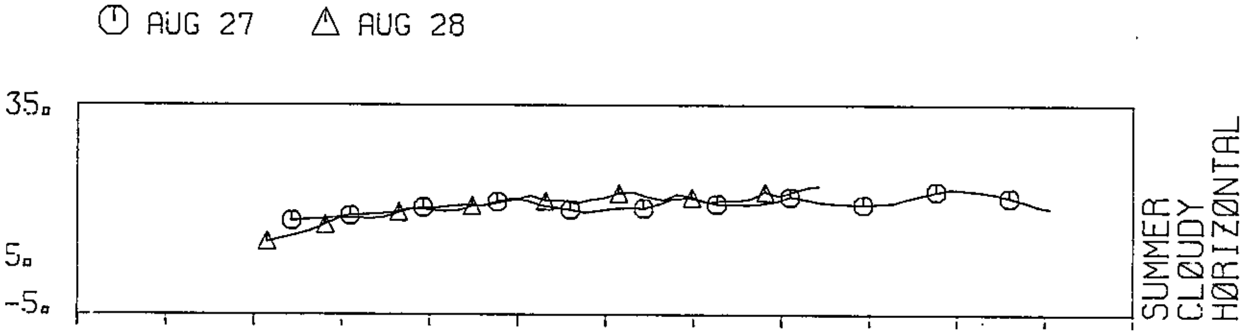

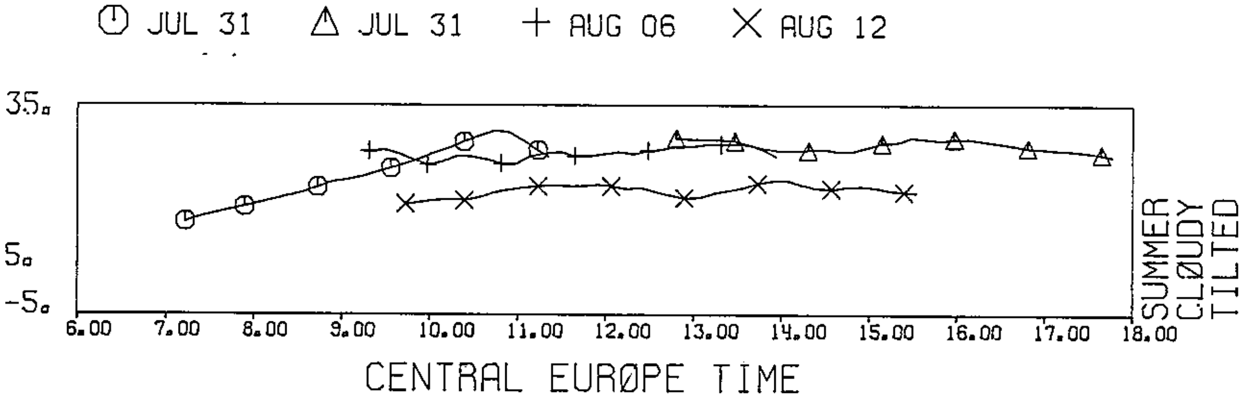

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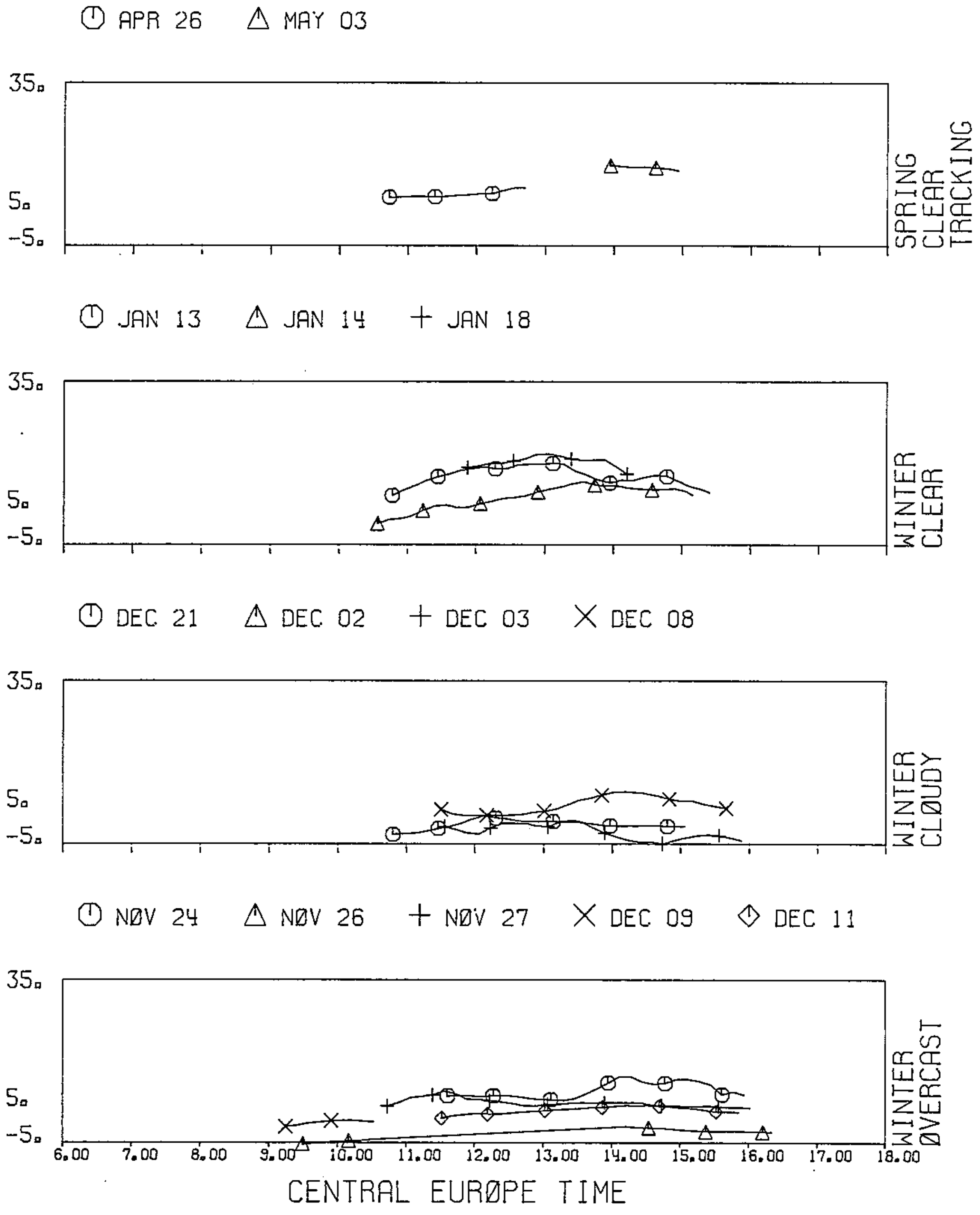
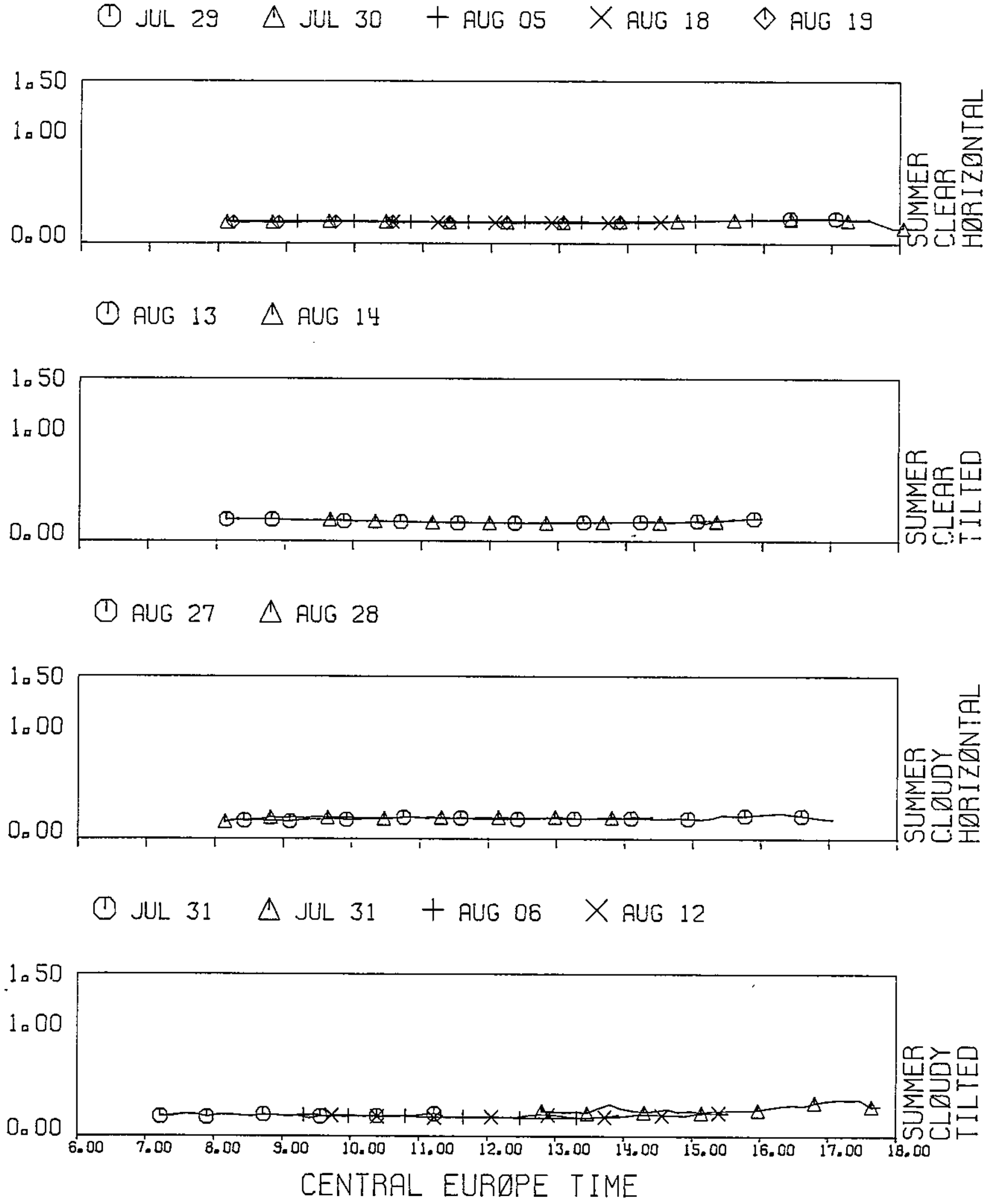


ALBEDØ


○ JUL 29 △ JUL 30 + AUG 05 × AUG 18 ◇ AUG 19
1.50
1.00
0.00
SUMMER
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SUMMER
CLEAR
TILTED
○ AUG 27 △ AUG 28
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SUMMER
CLØUDY
HØRIZØNTAL
○ JUL 31 △ JUL 31 + AUG 06 × AUG 12
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SUMMER
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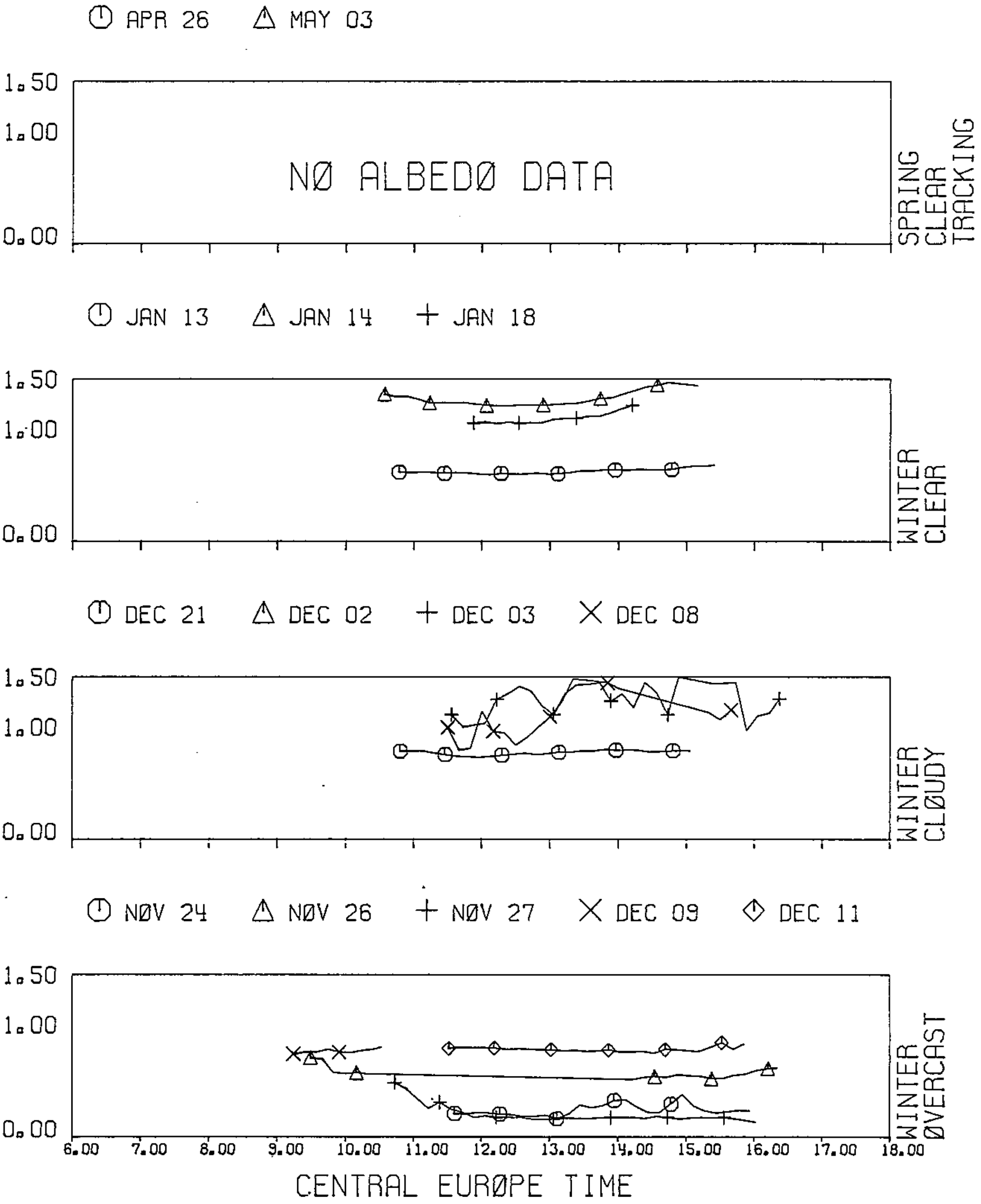
CENTRAL EURØPE TIME

ALBEDO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0.00
WINTER CLEAR
DEC 21
DEC 02
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WINTER CLOUDY
NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
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WINTER OVERCAST
6.00
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10.00
11.00
12.00
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14.00
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18.00
CENTRAL EUROPE TIME

PERFORMANCE OF PYRANOMETERS FOR ALL TEST DAYS

Arrangement of data plots: **Ratio of pyranometer reading and reference reading**

Pyranometer identification

(1) summer, clear horizontal
(2) summer, clear, tilted
(3) summer, cloudy, horizontal
(4) summer, cloudy, tilted
(5) winter, clear, horizontal/tilted
(6) winter, cloudy, horizontal/tilted
(7) winter, overcast, horizontal/tilted
(8) spring, clear, tracking
(9) ratio during calibration days
(10) ratio against temperature
(11) ratio against irradiance
(12) ratio against incidence angle

Comments:

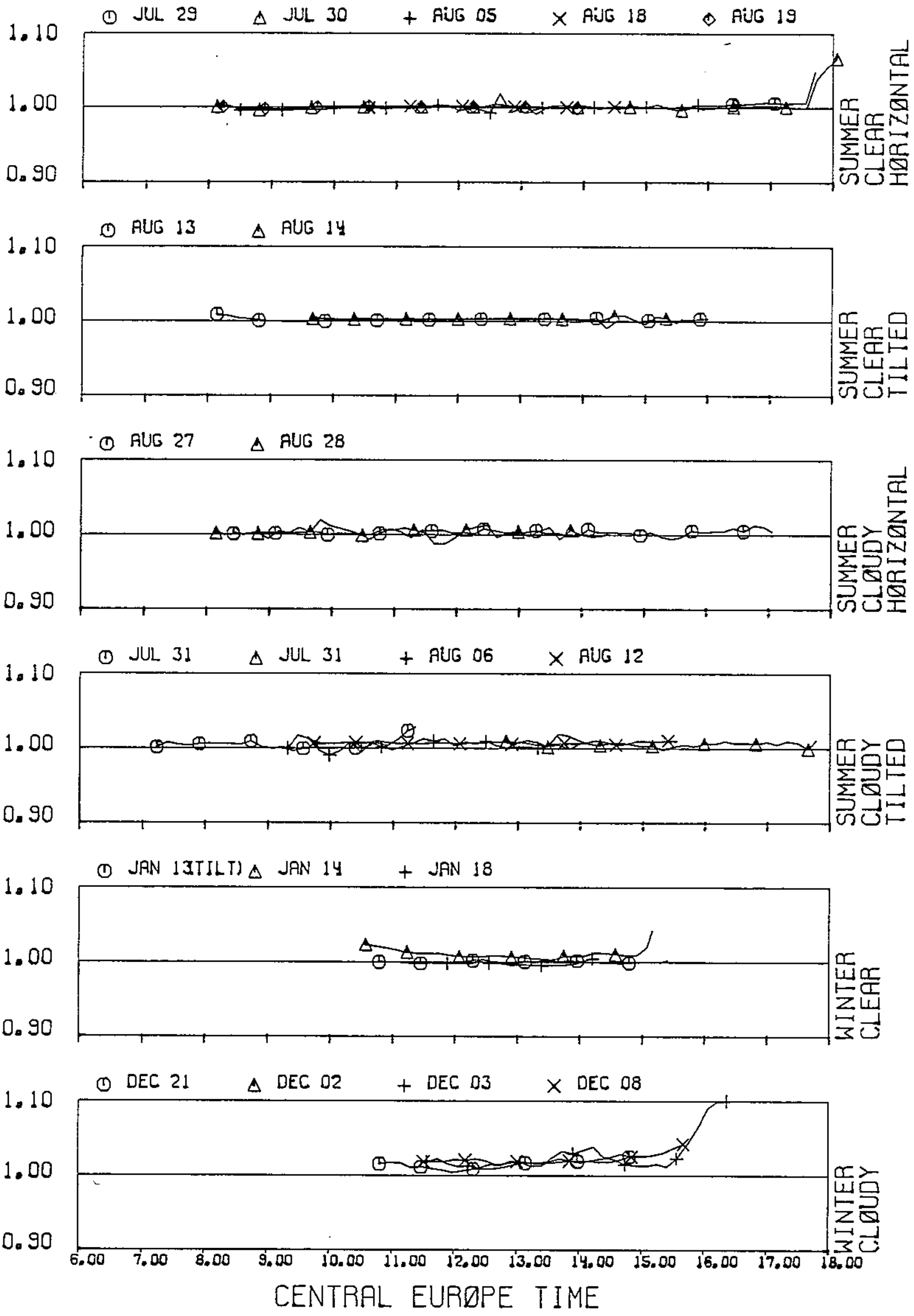
For plots Nos 1.-.8 the reference consists of the mean reading of the reference group of instuments:

PSP	20523
PSP	20655
CM10	790059
CM10	810120

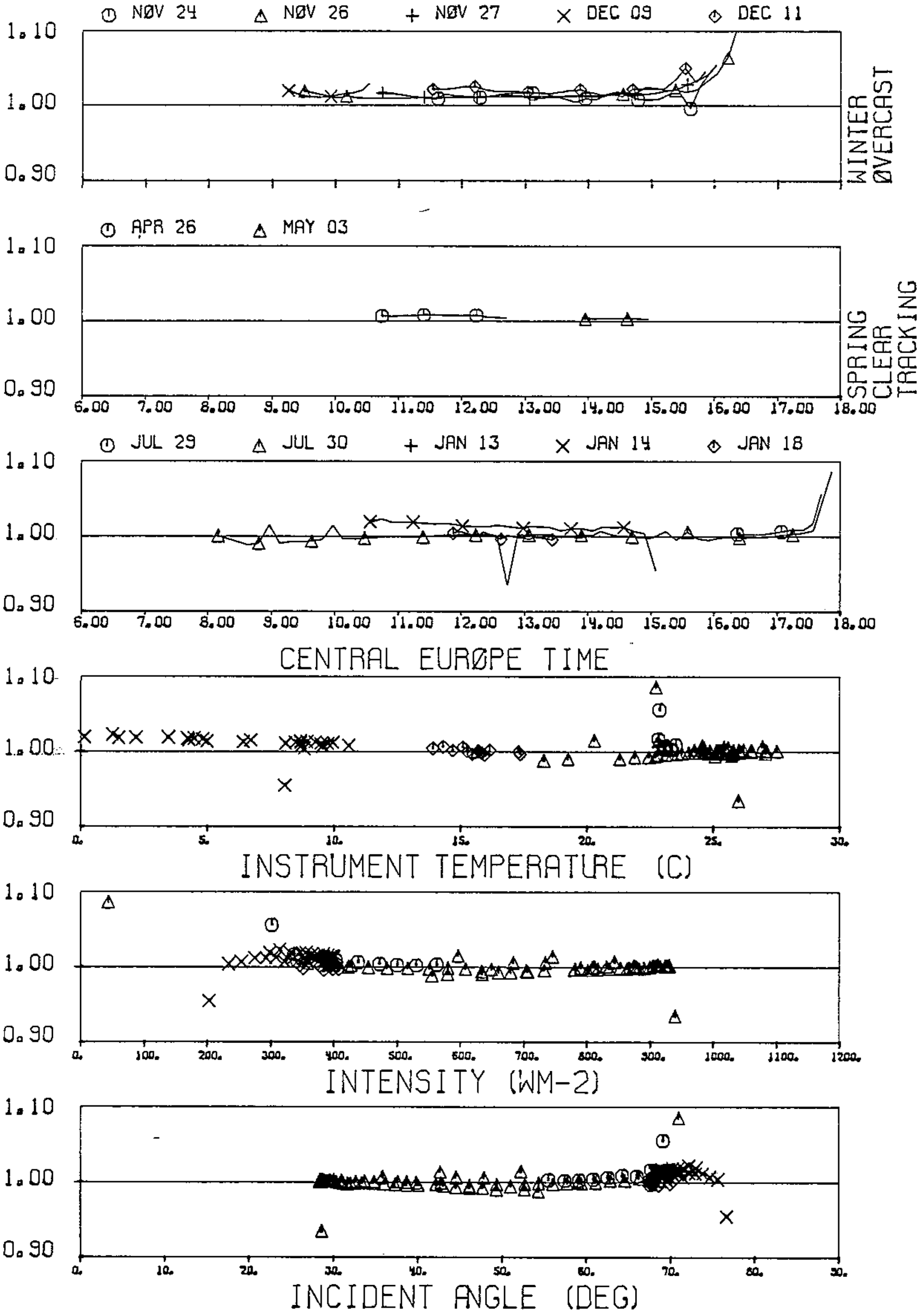
For plots Nos. 9 - 12 the reference consists of an absolute radiometer reading and a reading of a pyranometer for the diffuse component.

The performance of some instruments listed in Table 1 (page 10) are not plotted because they were operated in a special mode (e.g. shaded mode).

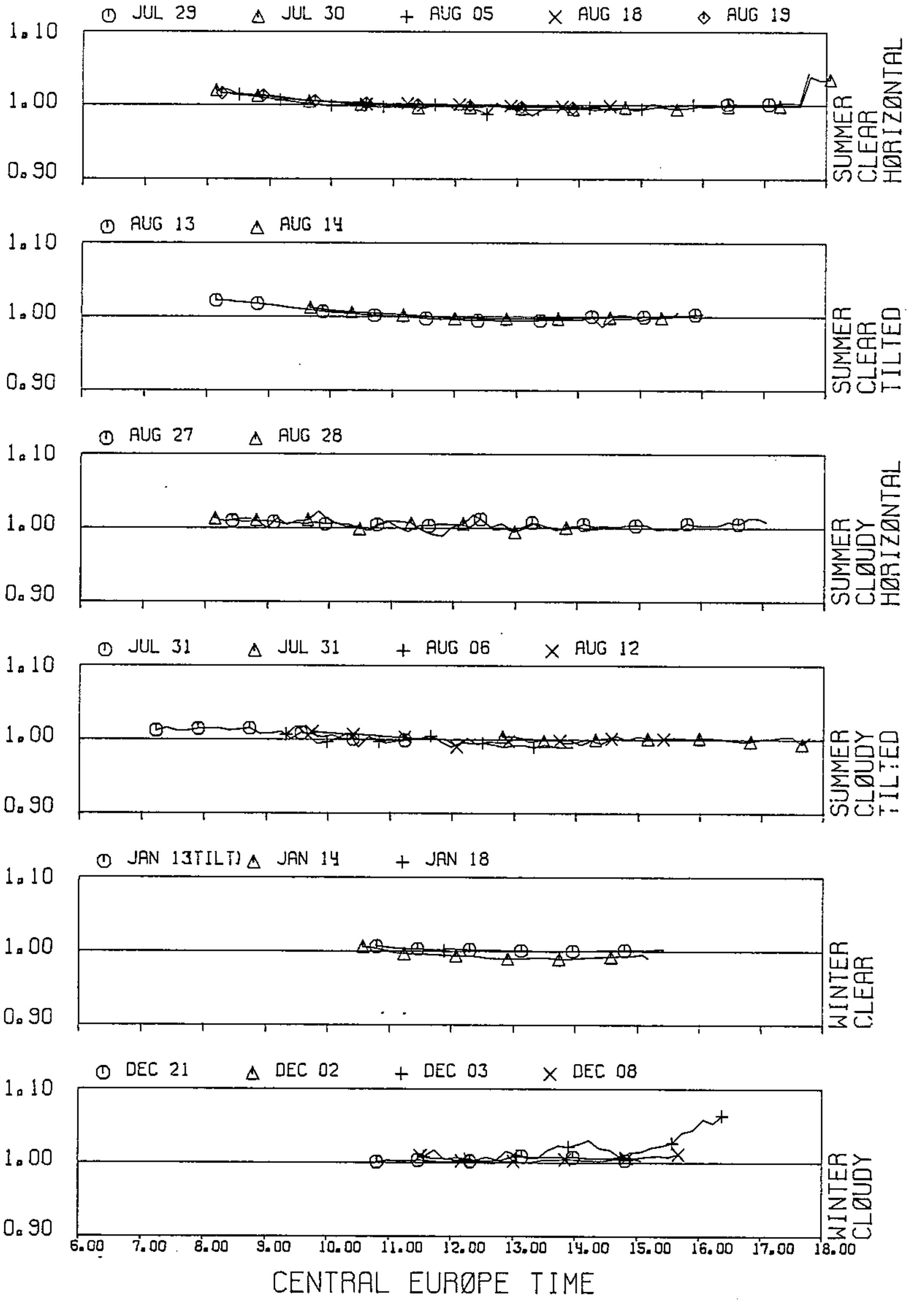
K∧ZCM10 790059



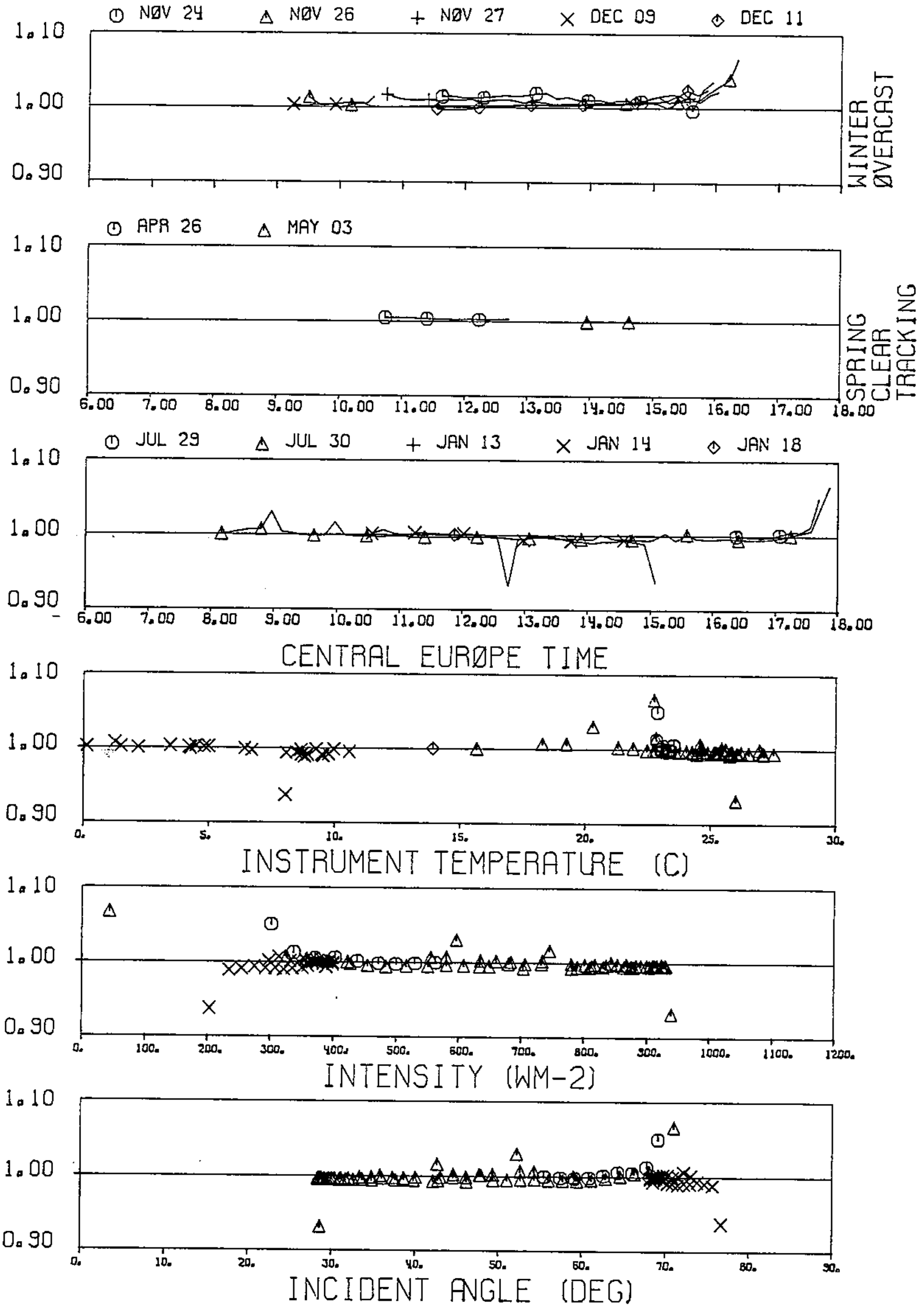
KΛZCM10 790059



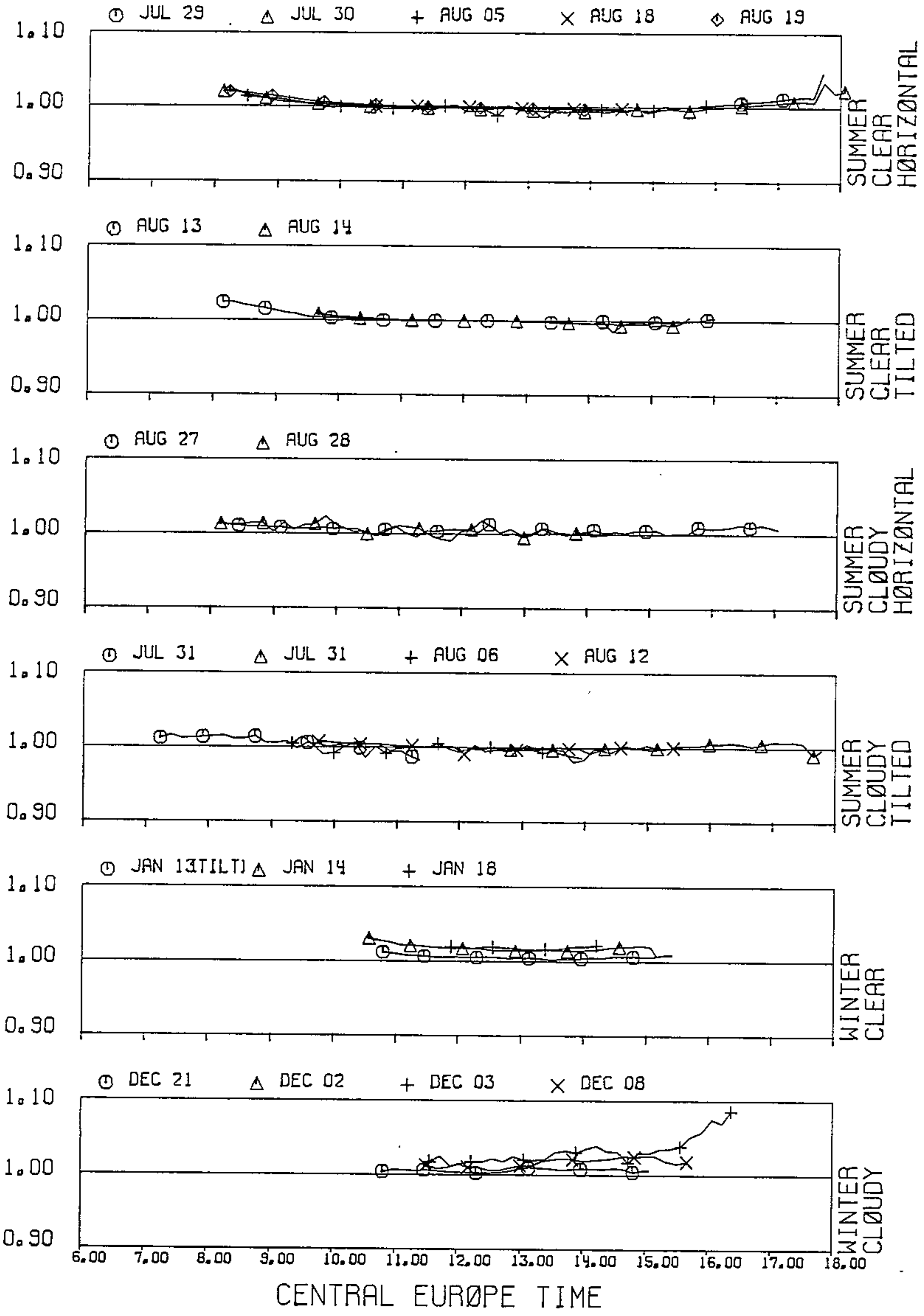
K∧ZCM10 810120



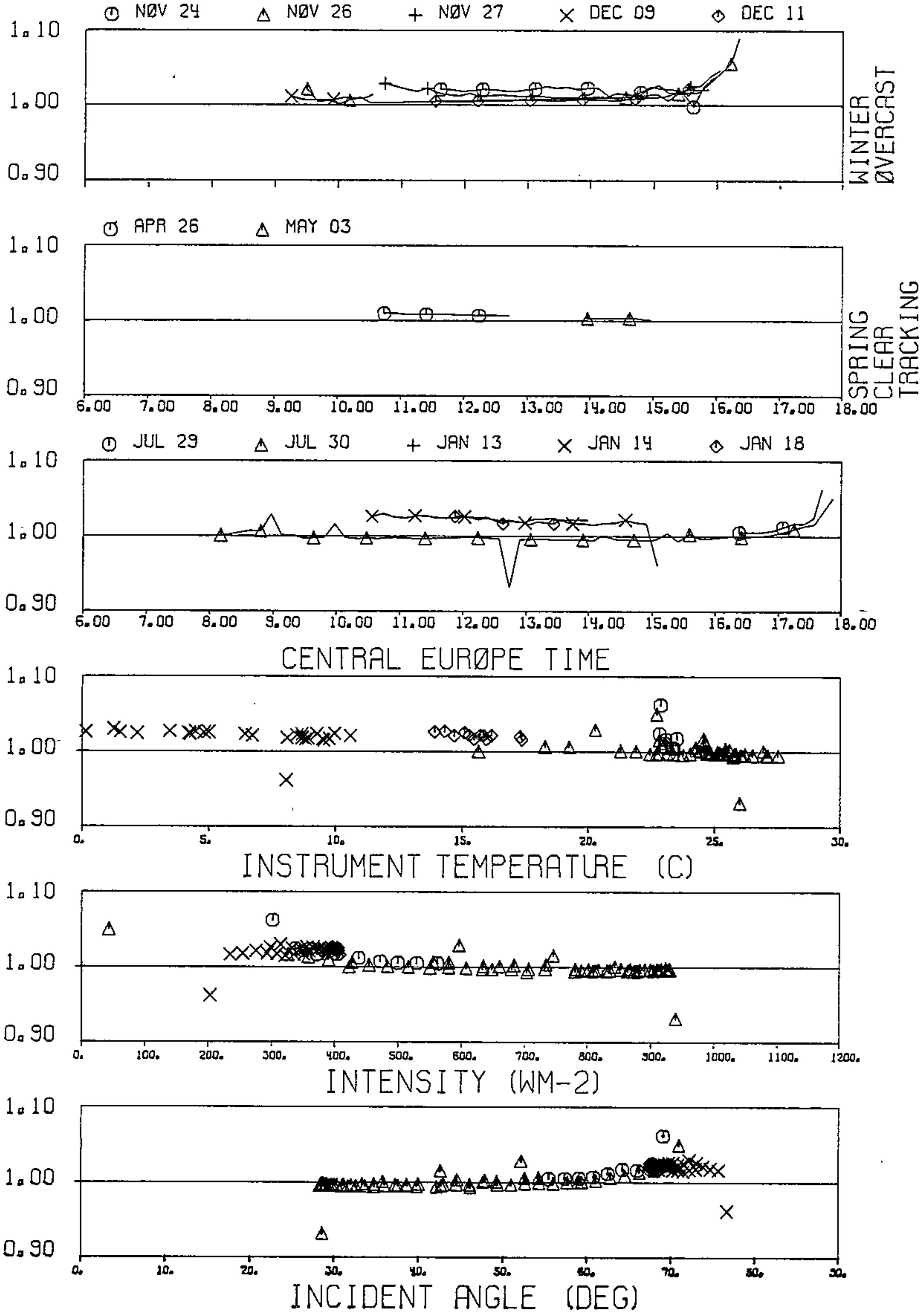
K∧ZCM10 810120



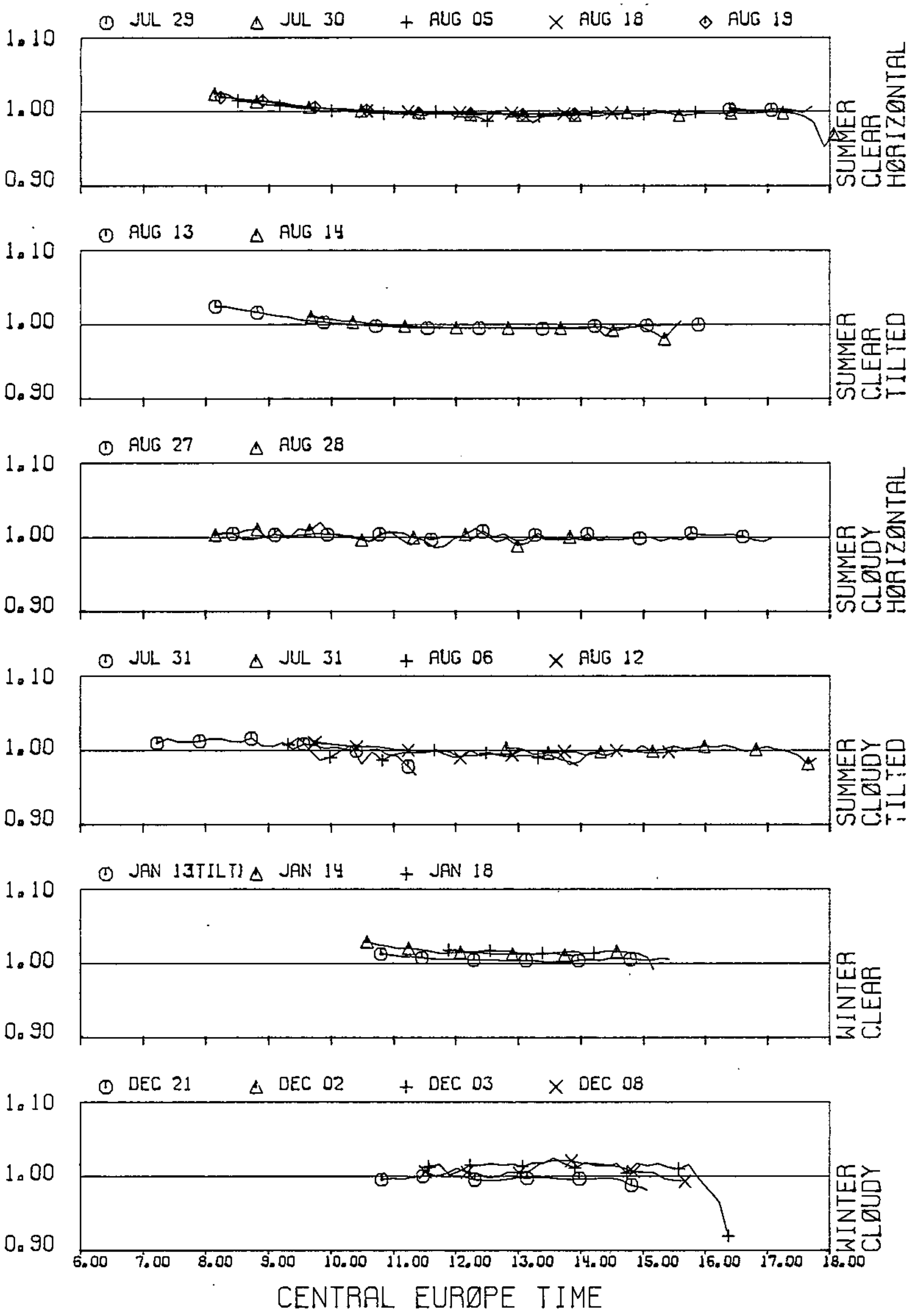
K∧ZCM10 810121



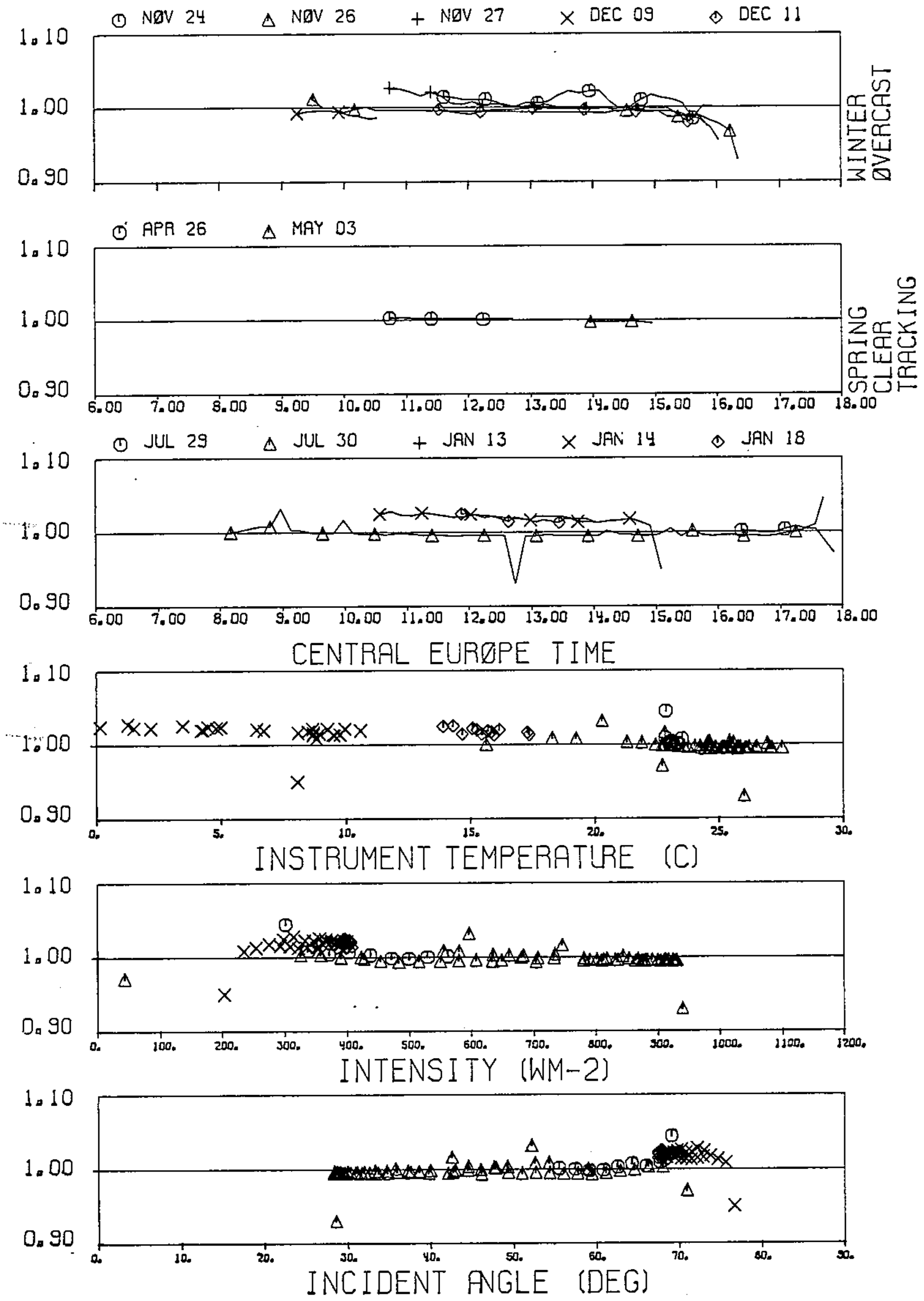
K∧ZCM10 810121



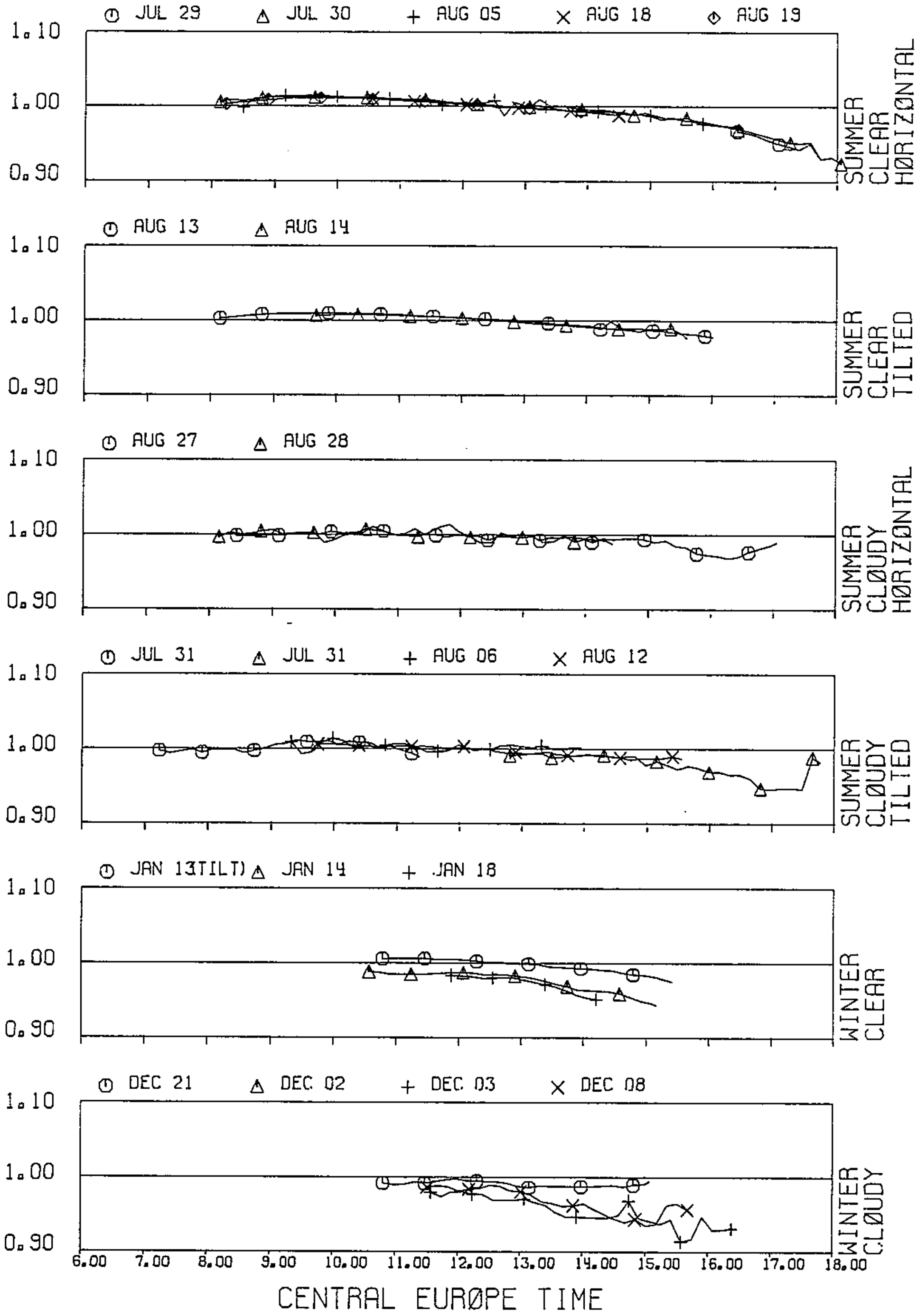
K∧ZCM10 810122



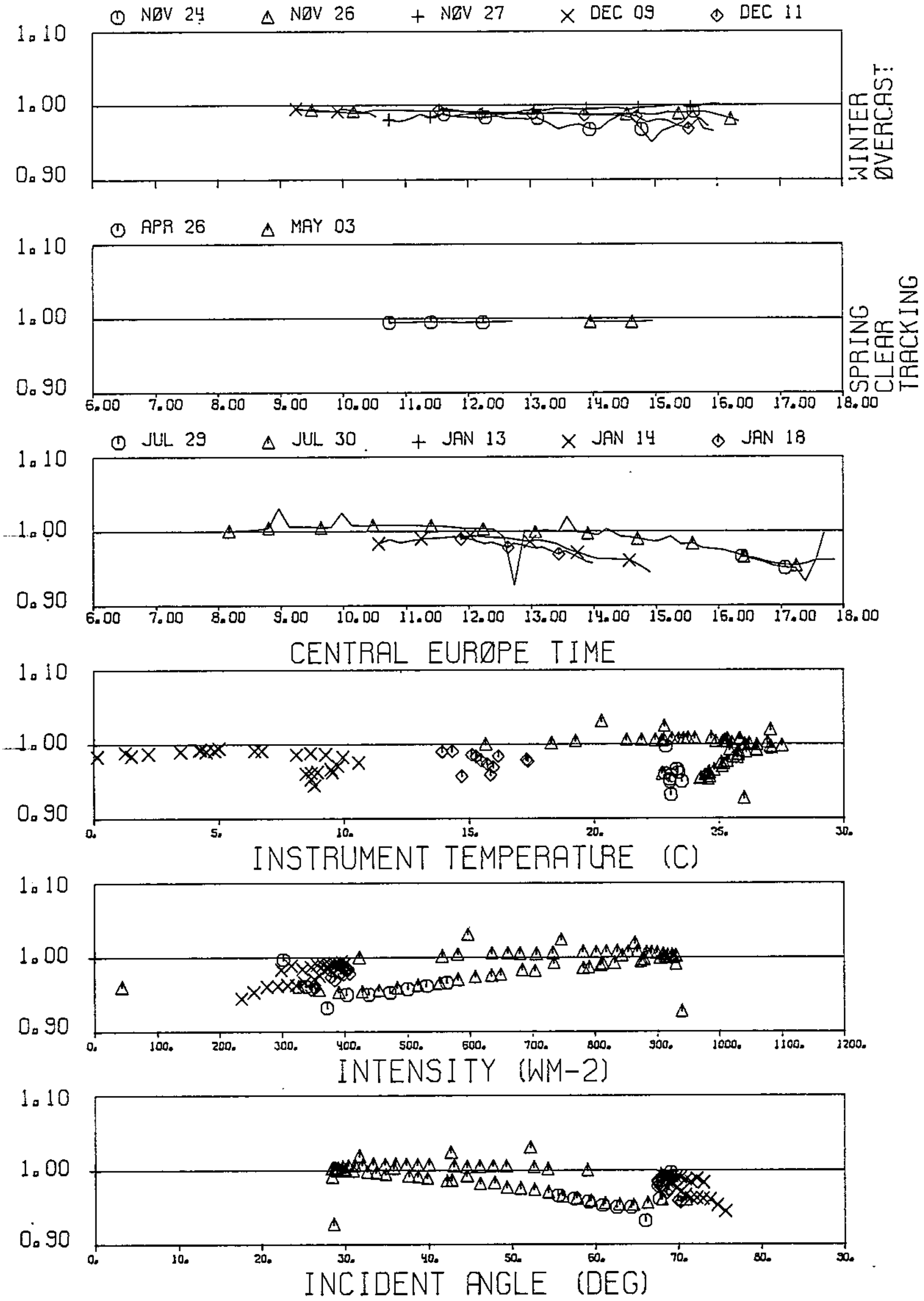
KAZCM10 810122



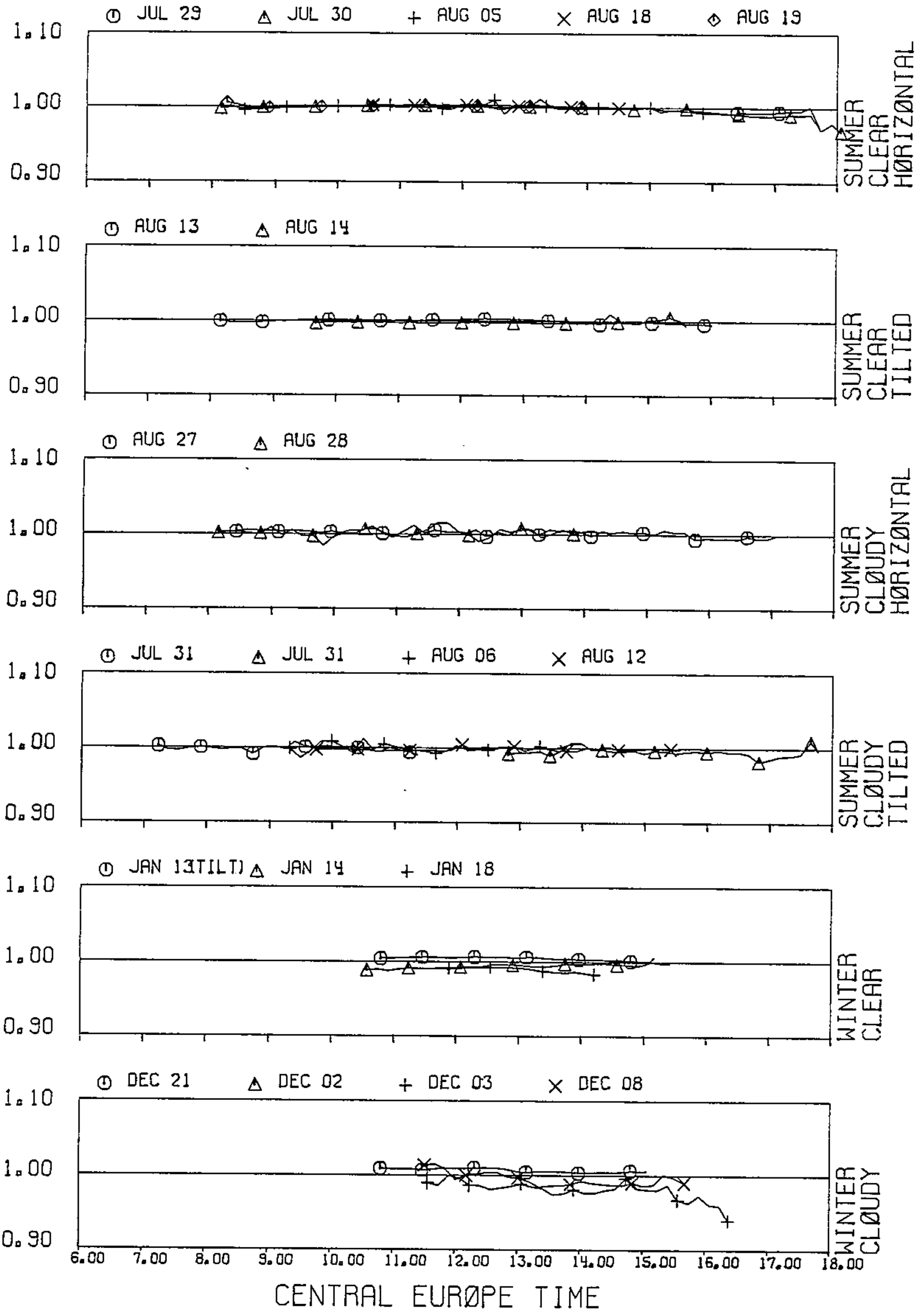
EPPLEY 14806



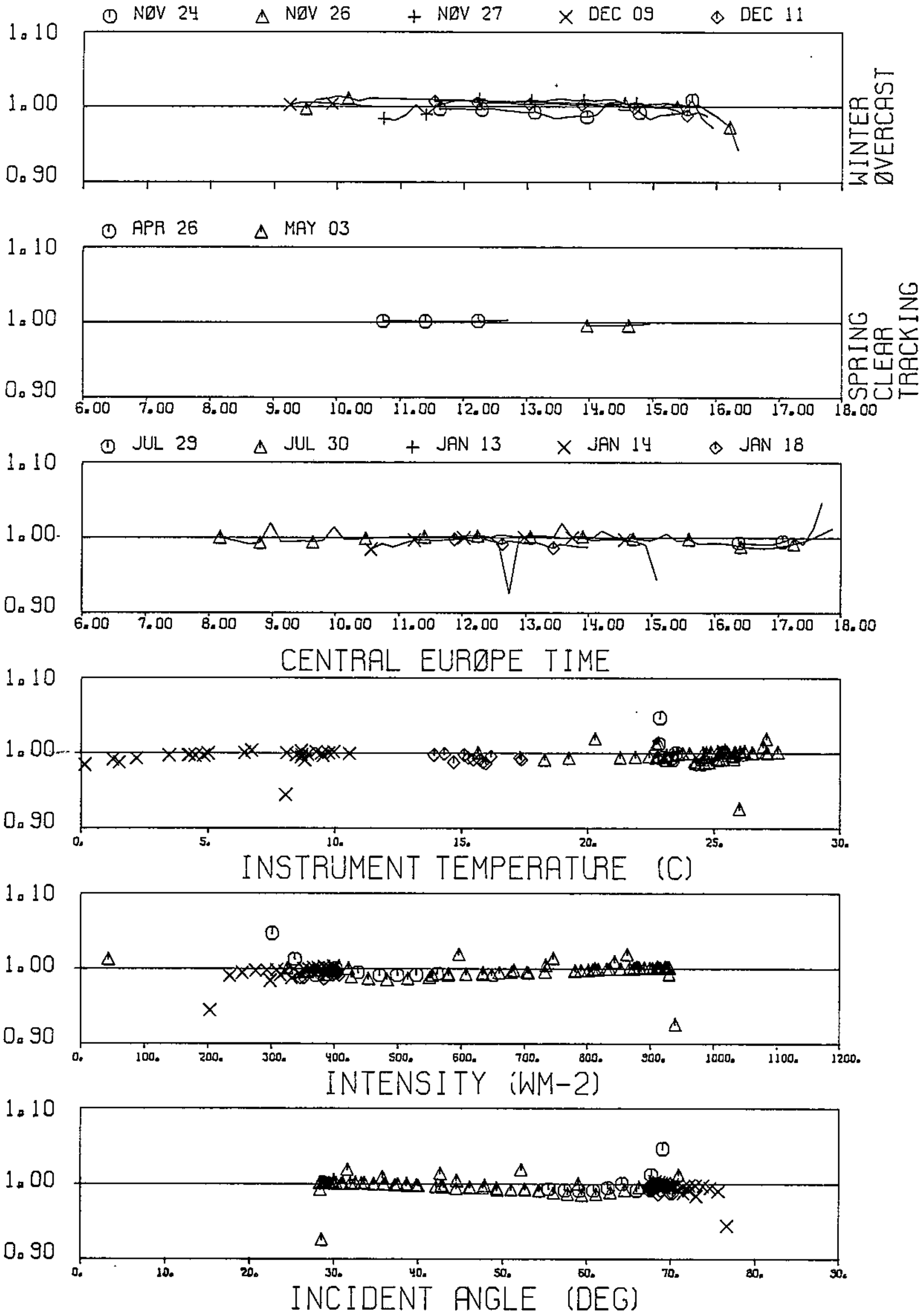
EPPLEY 14806



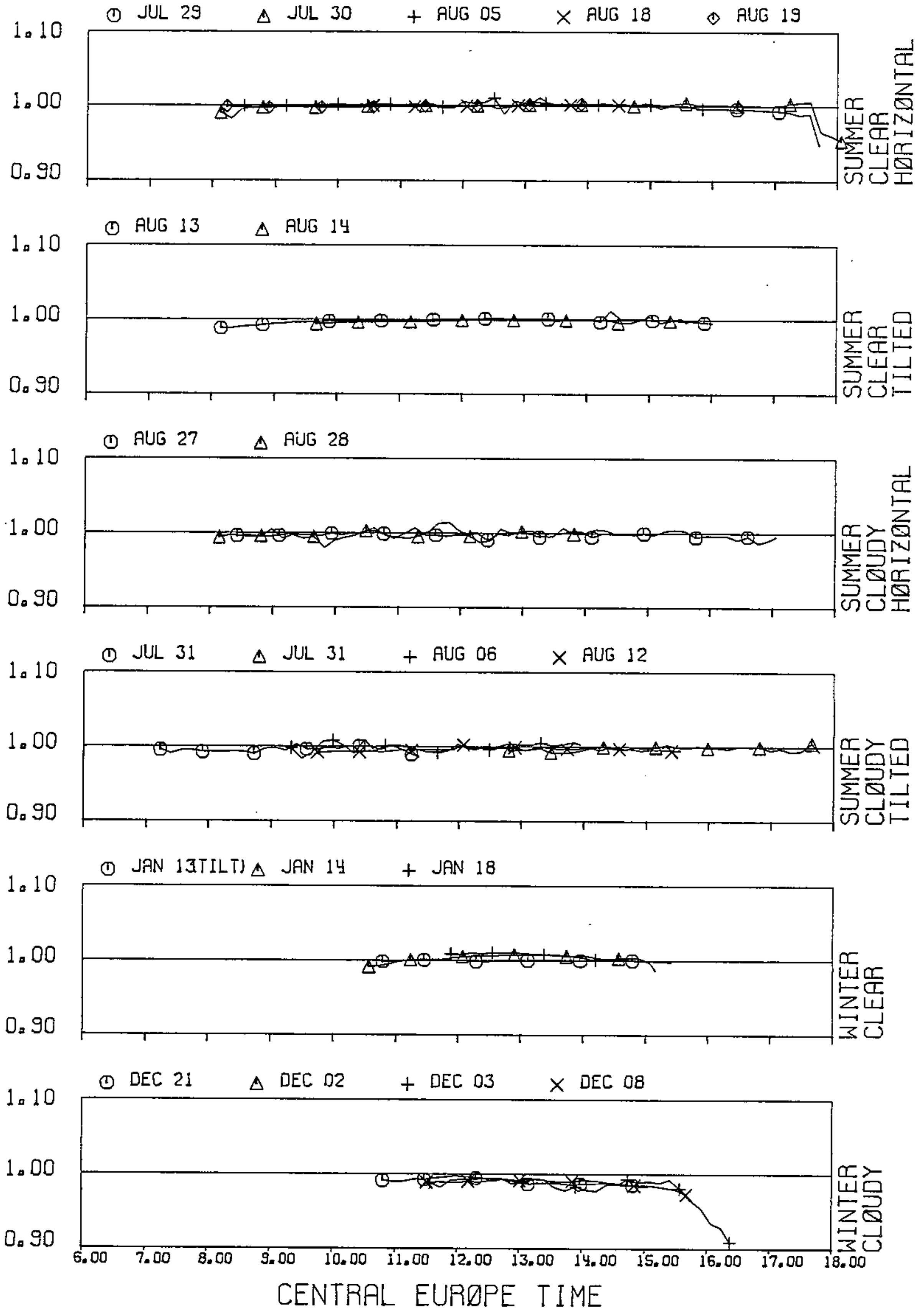
EPPLEY 17750



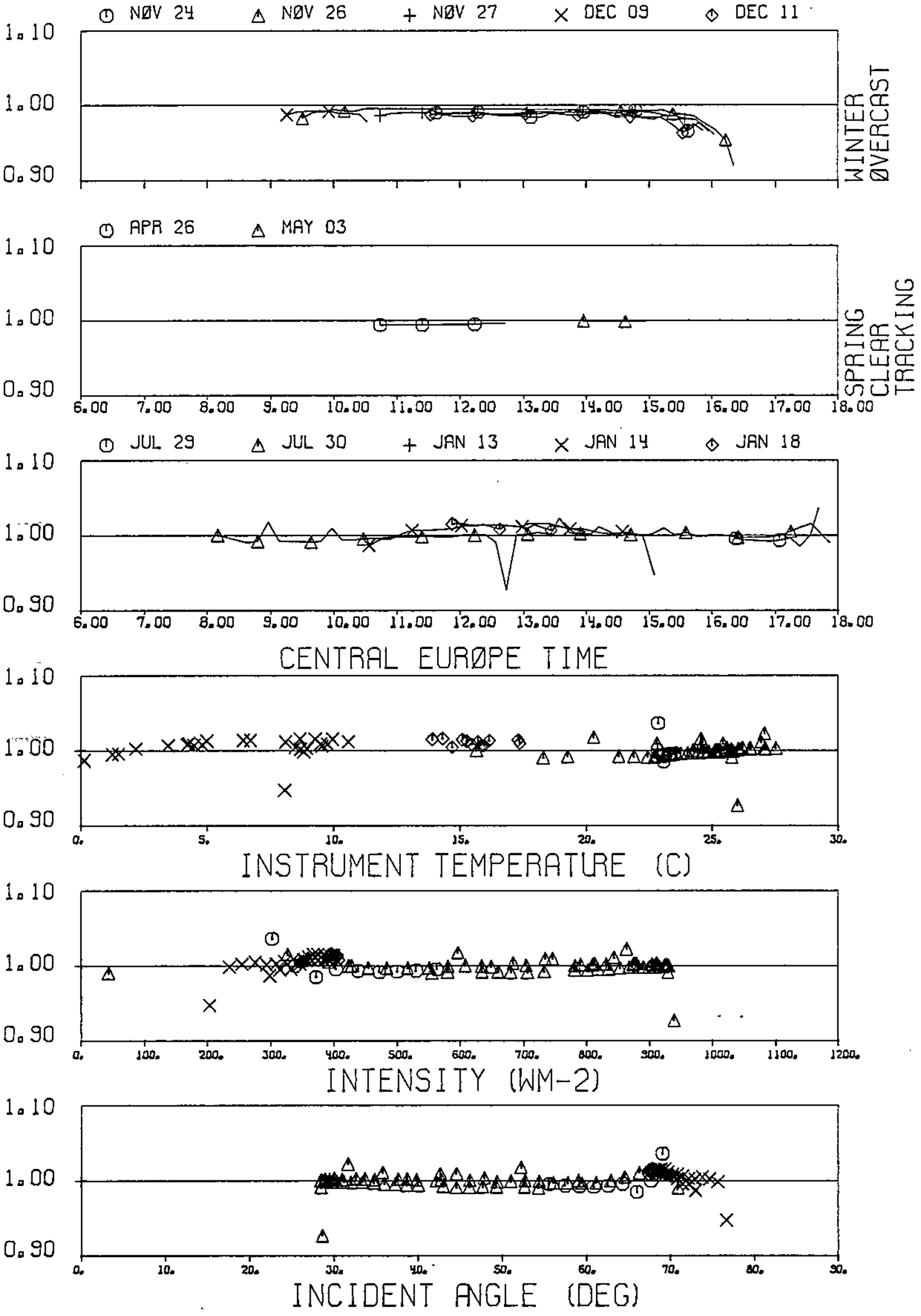
EPPLEY 17750



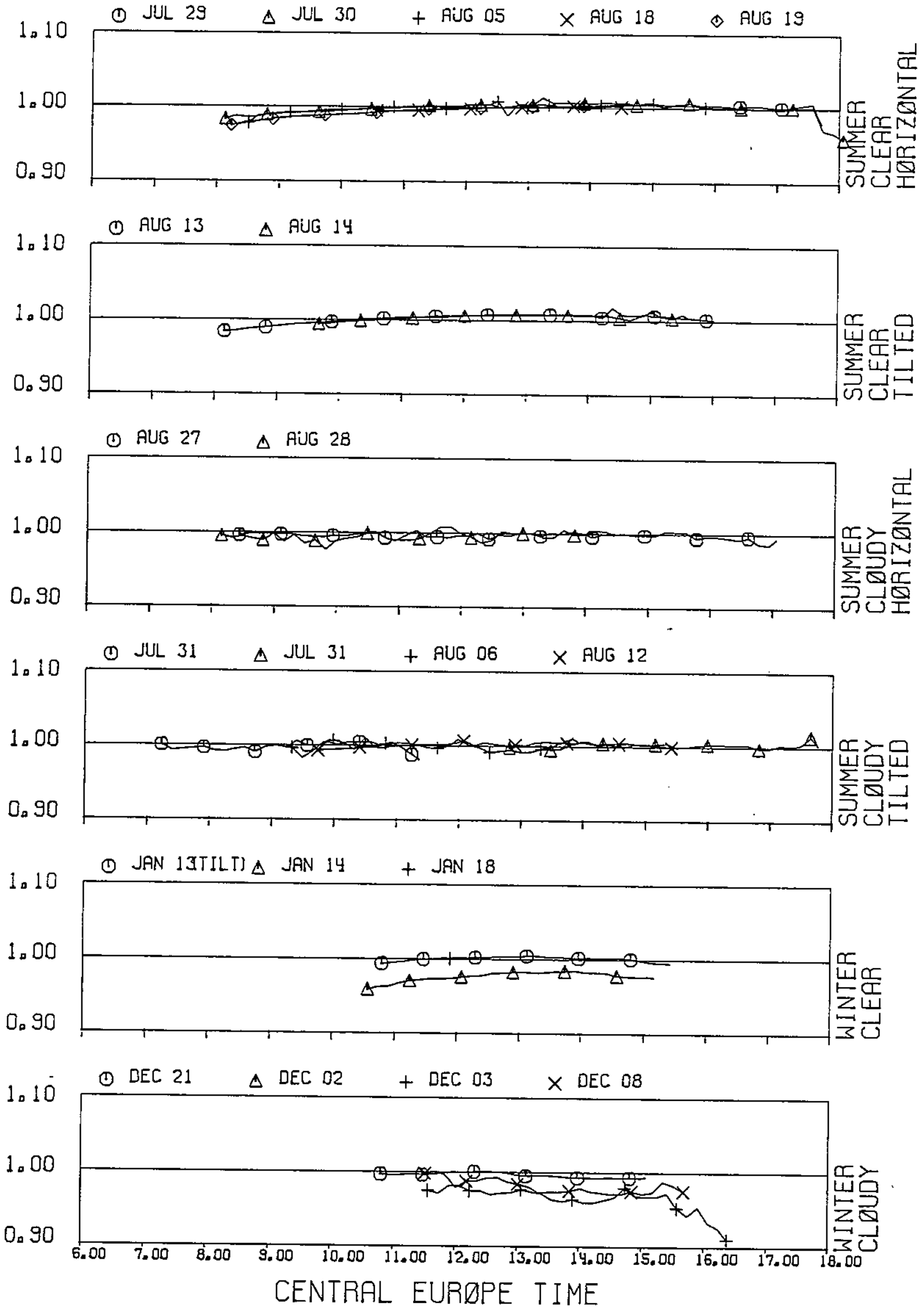
EPPLEY 20523



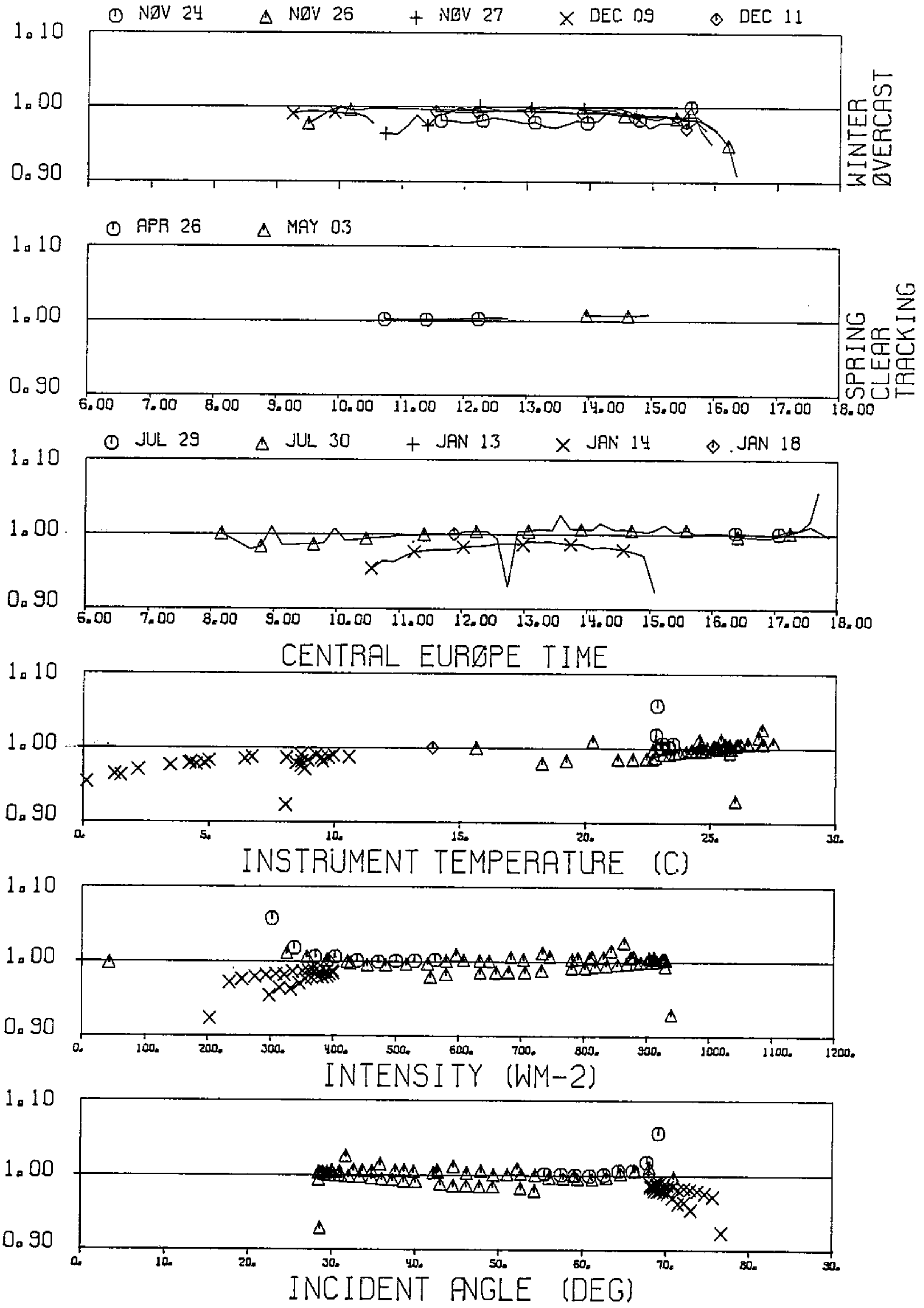
EPPLEY 20523



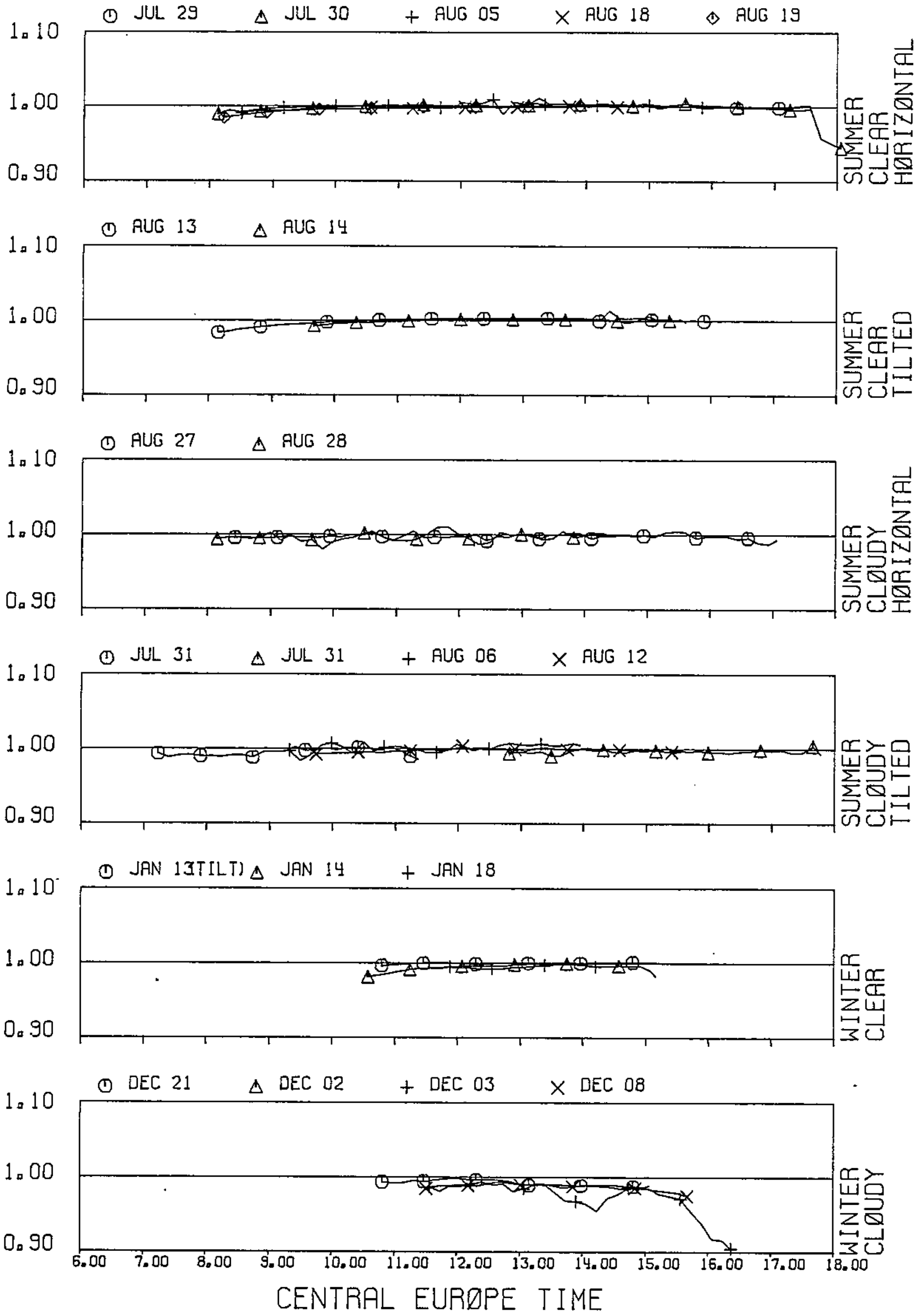
EPPLEY 20524



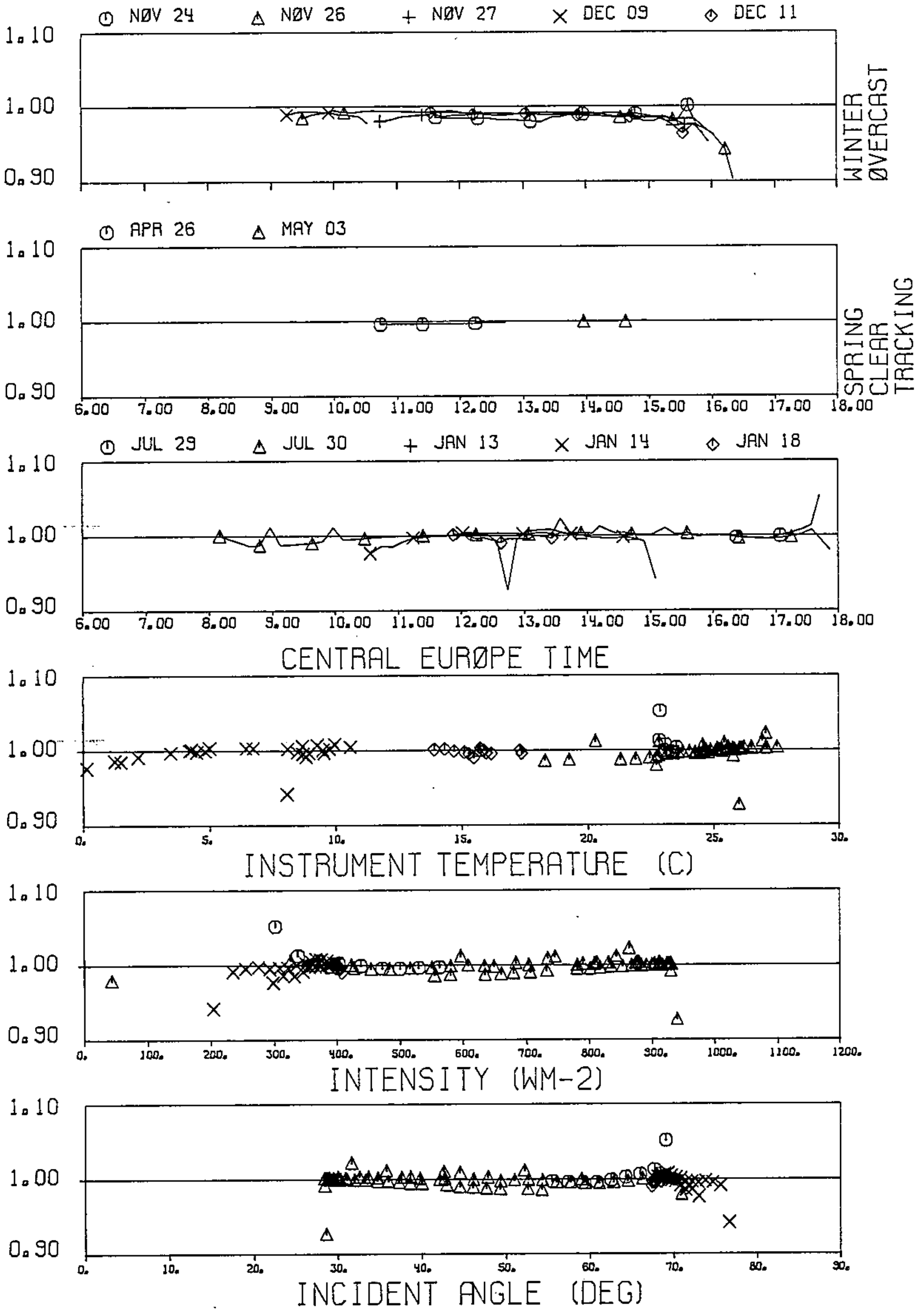
EPPLEY 20524



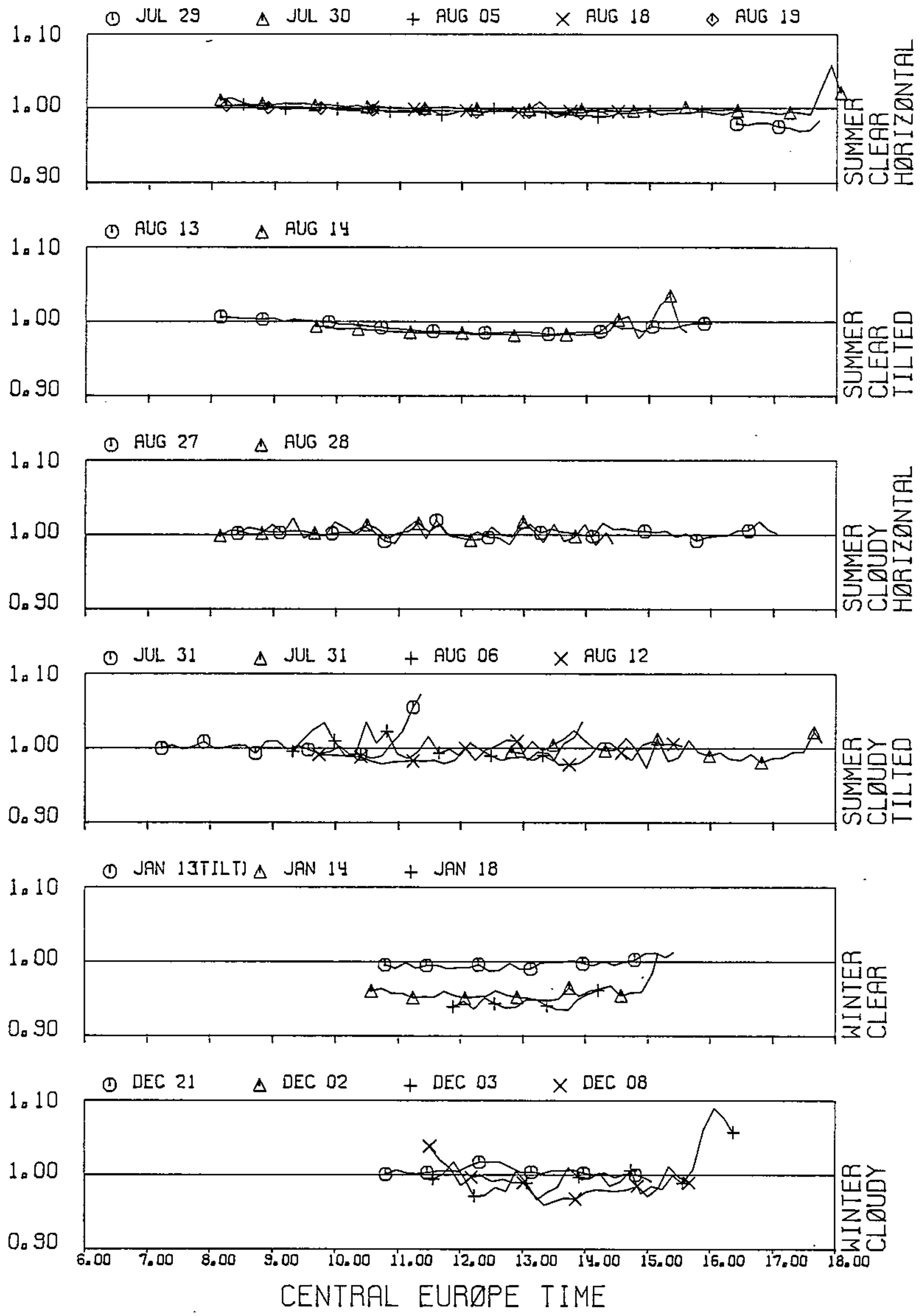
EPPLEY 20655



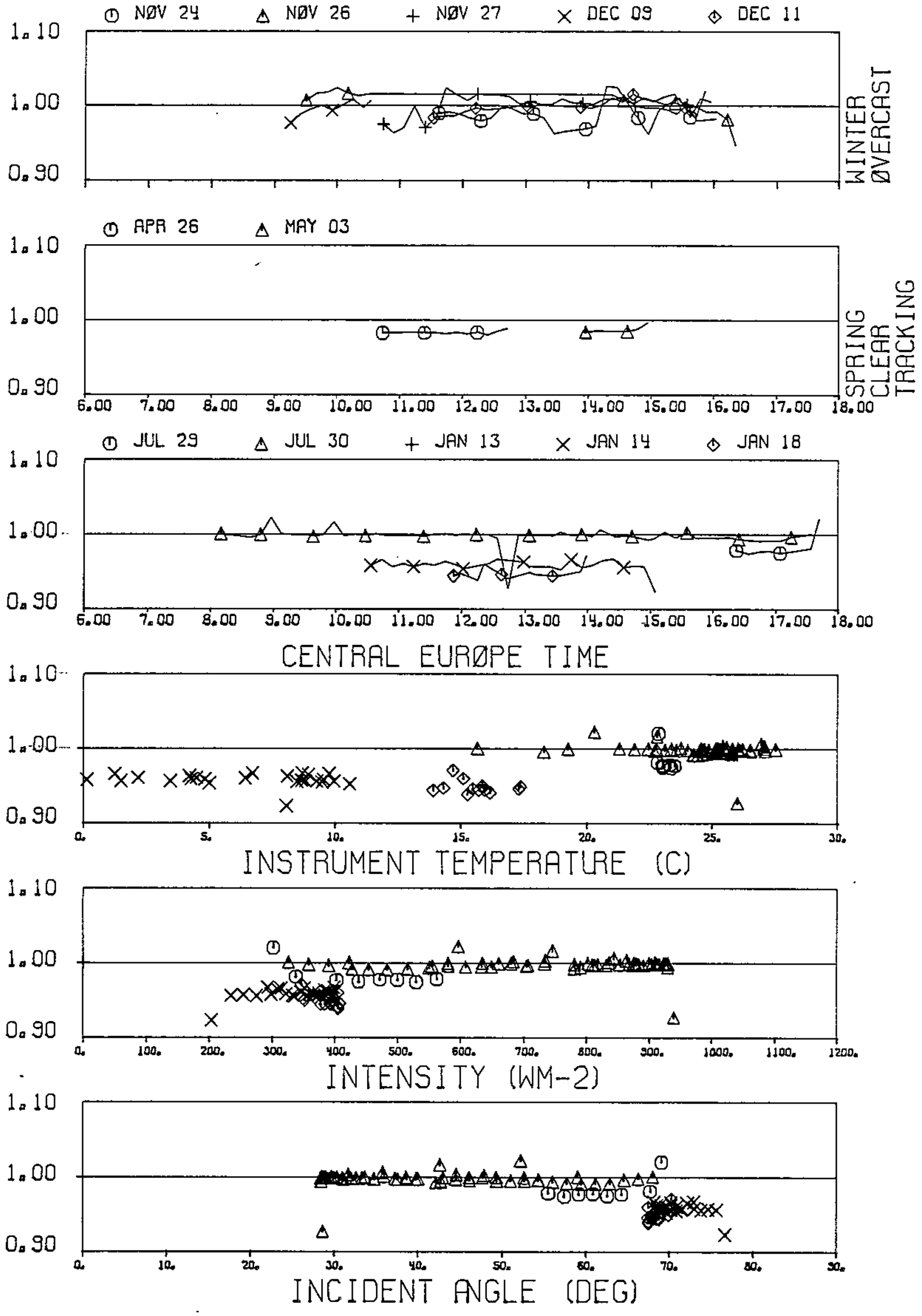
EPPLEY 20655



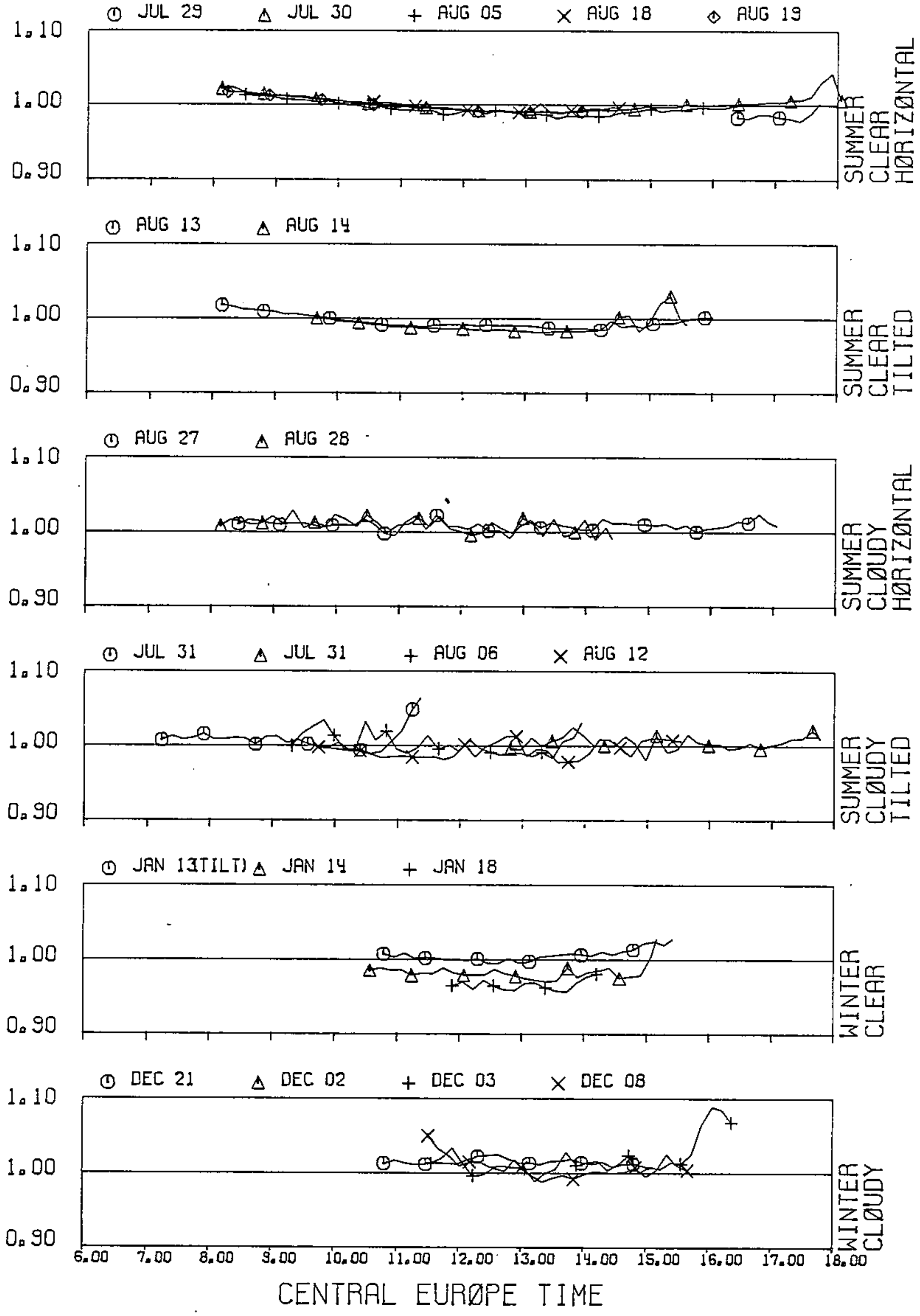
K∧ZCM5 773656



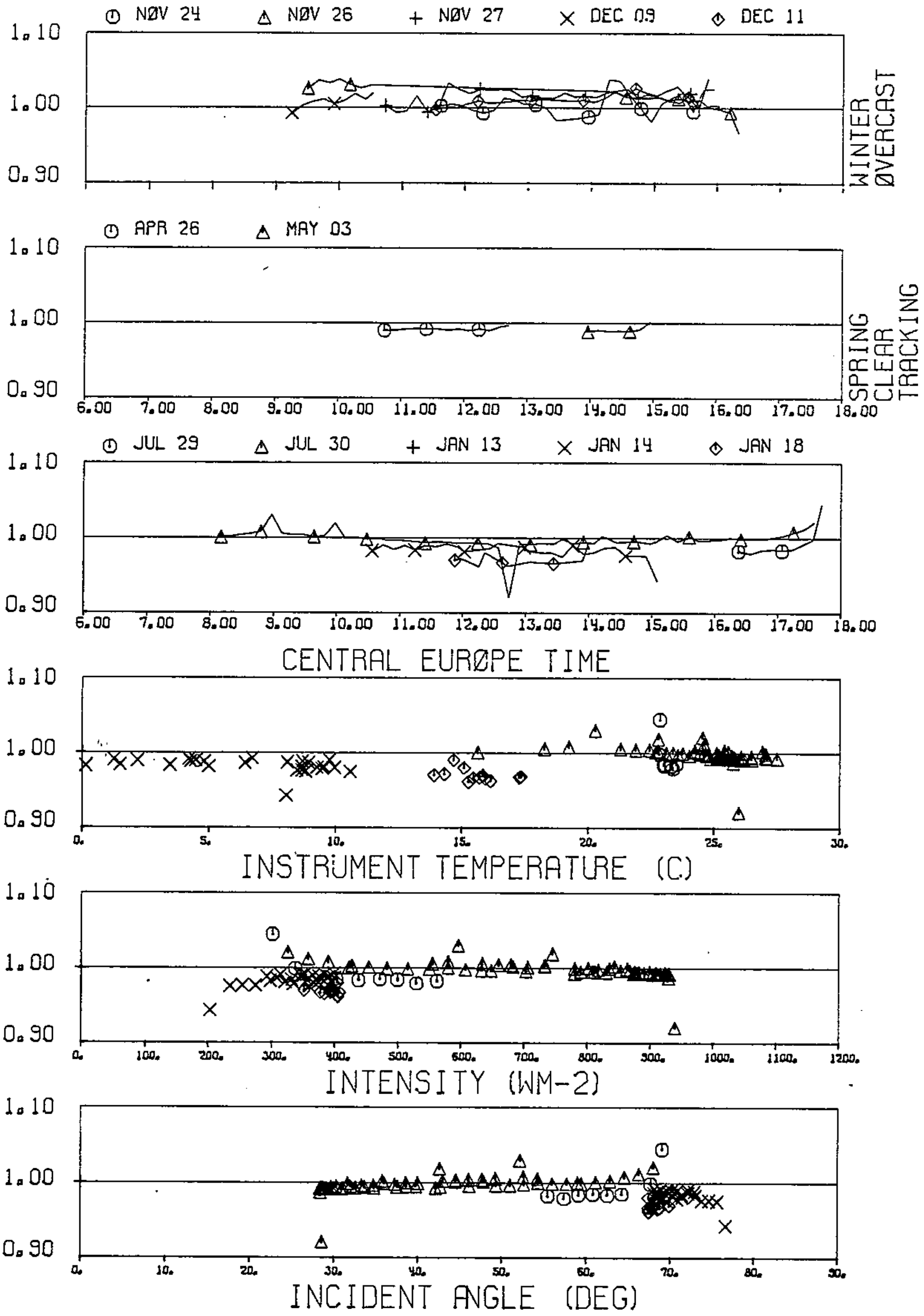
K&ZCM5 773656



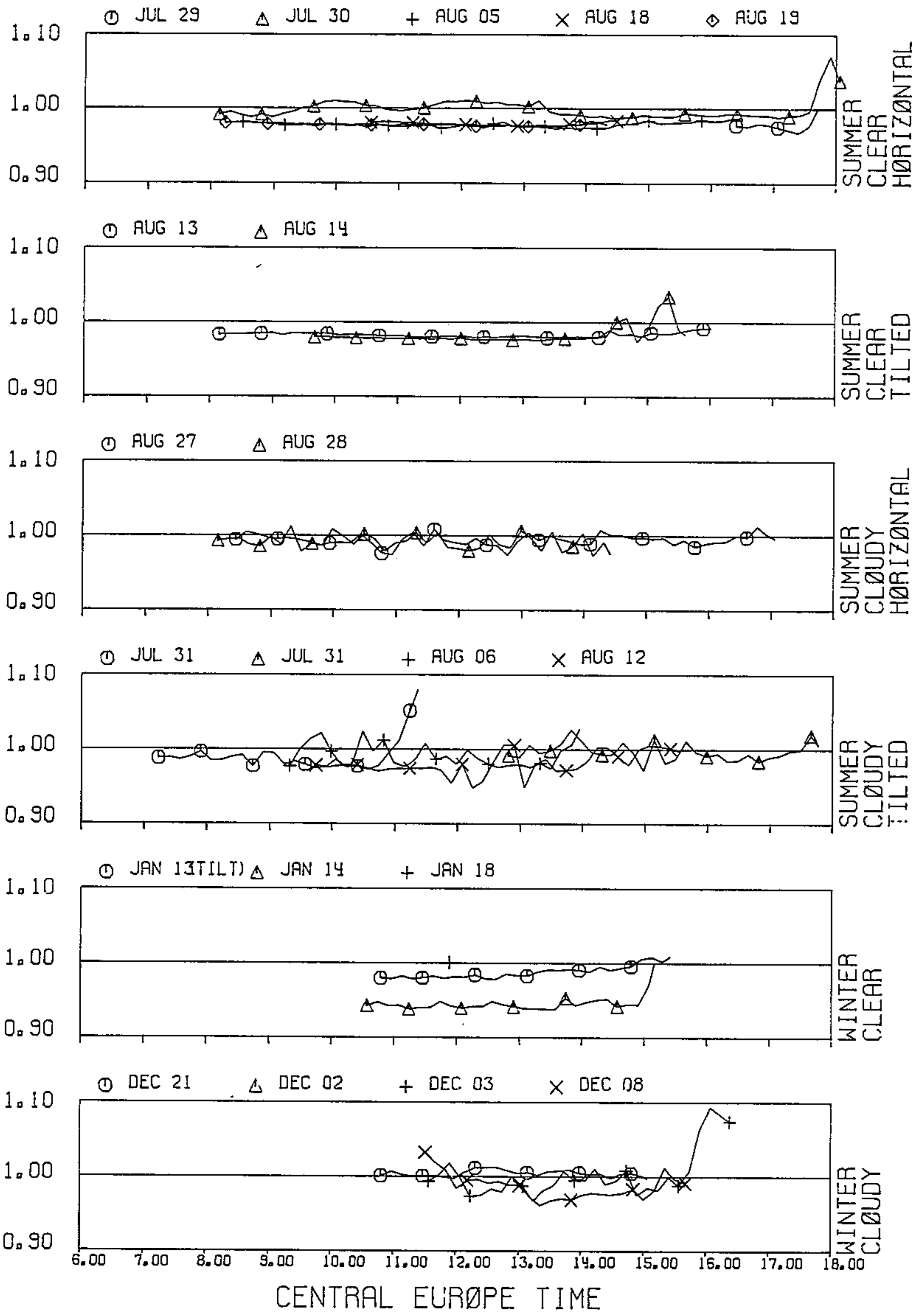
KAZCM5 773992



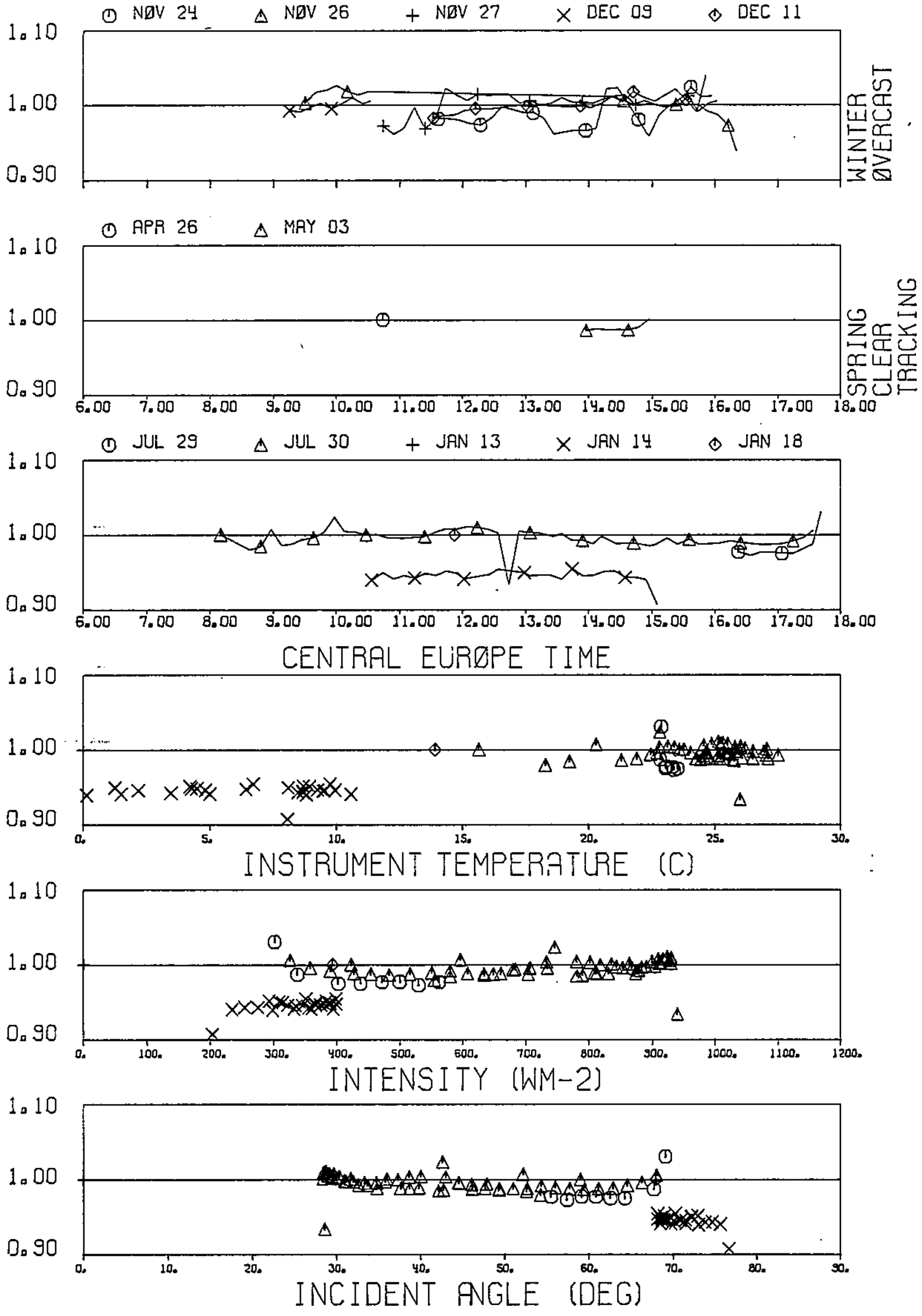
K&ZCM5 773992



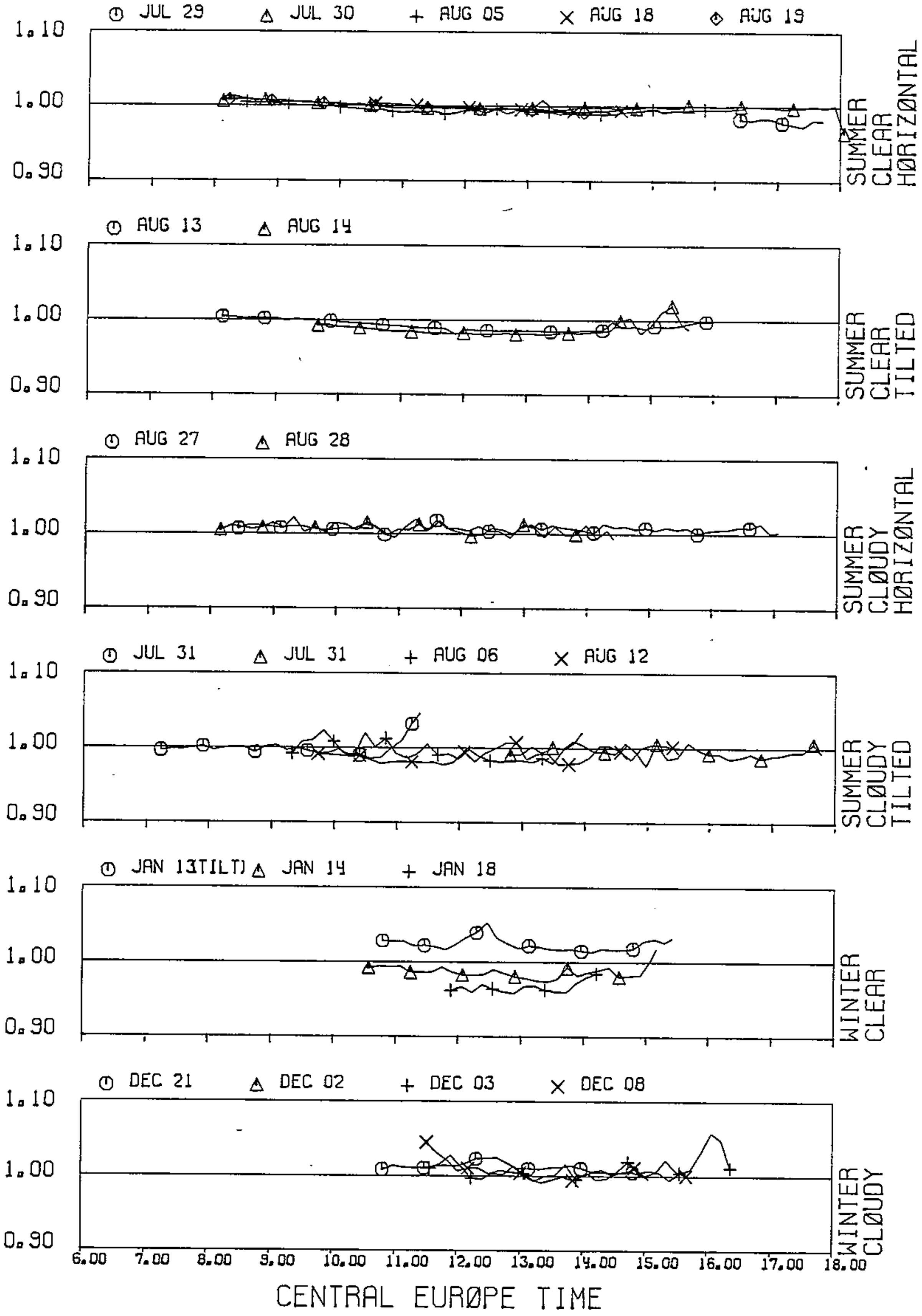
K^ZCM5 784120



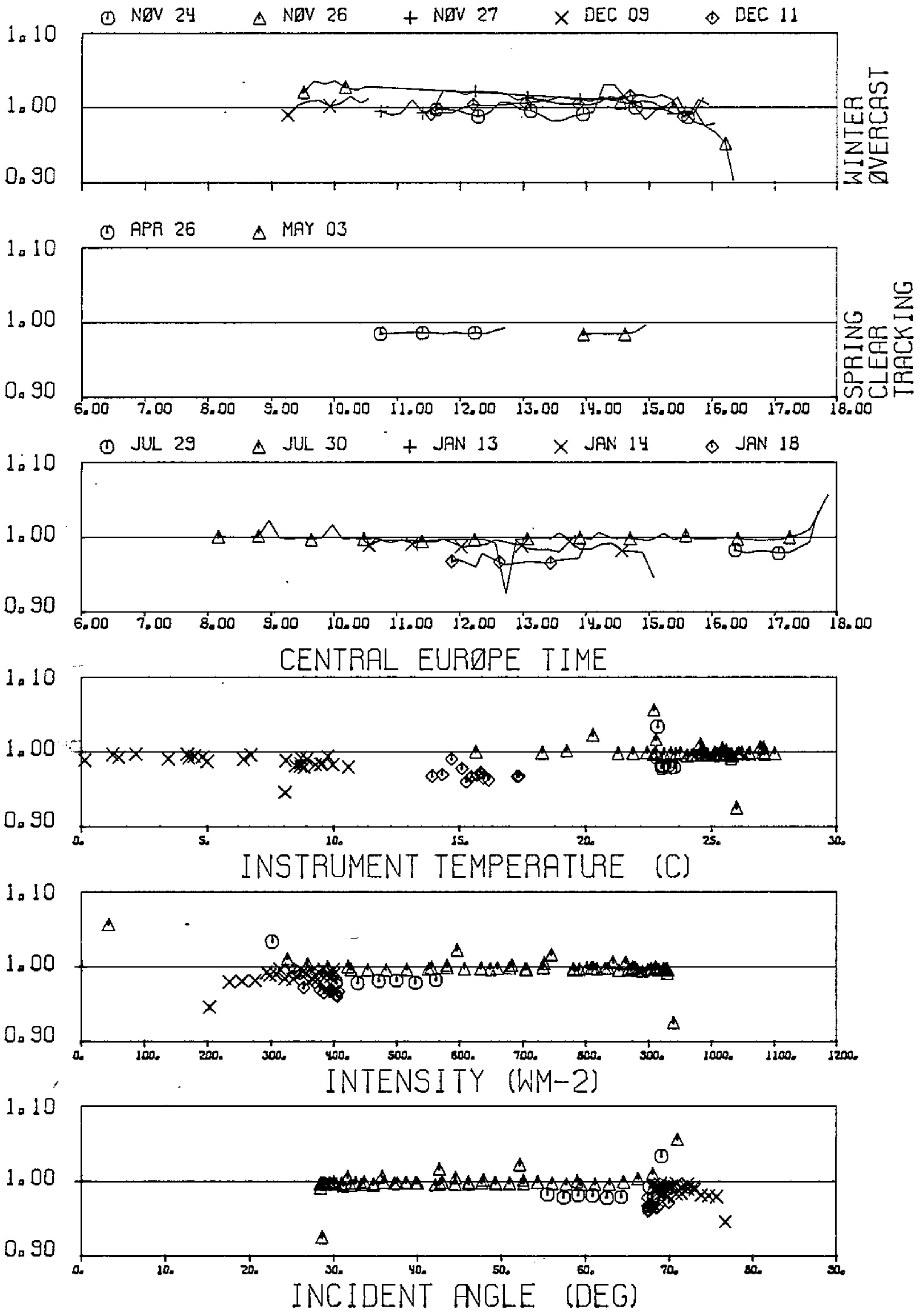
K&ZCM5 784120



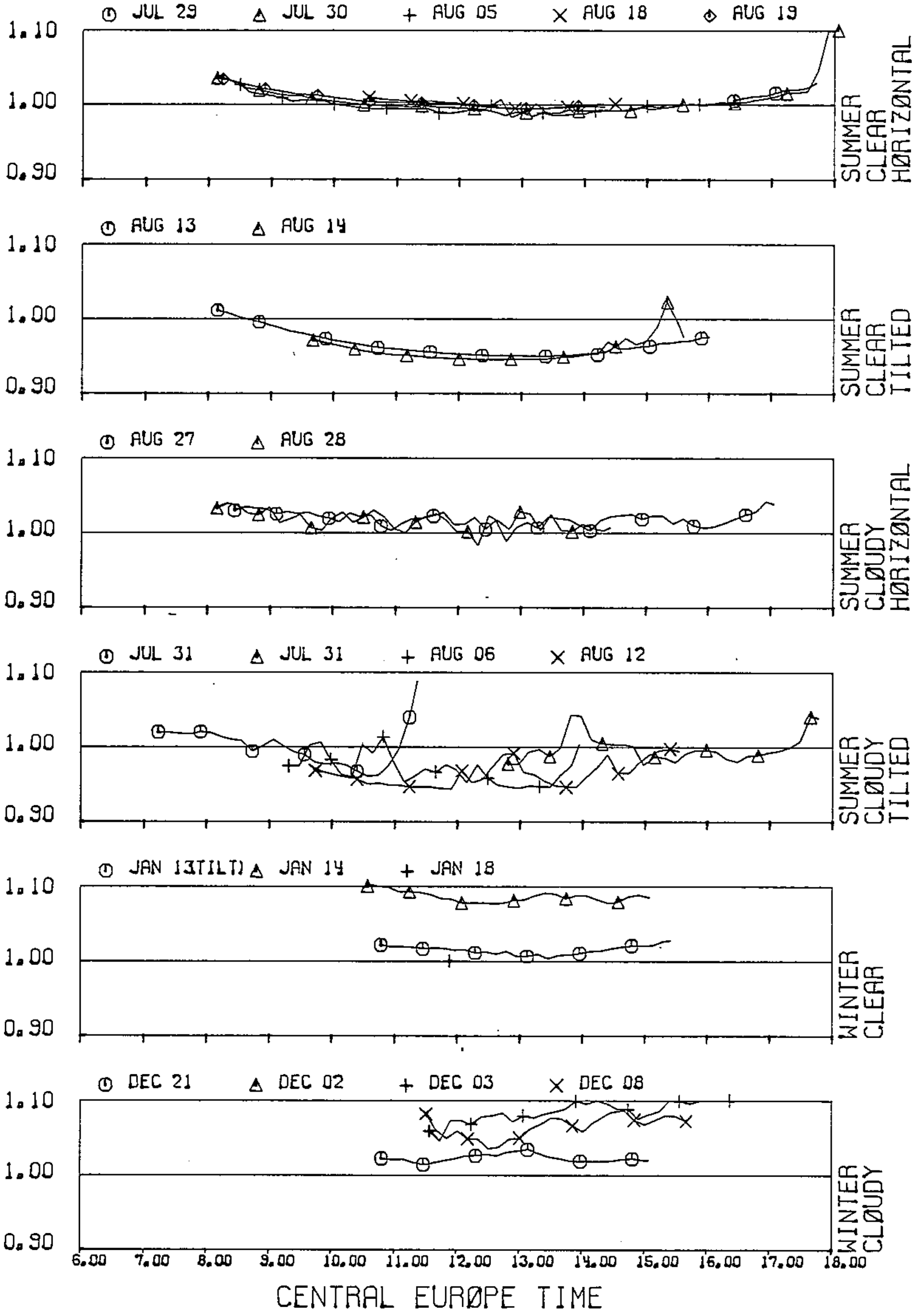
K^ZCM5 785047



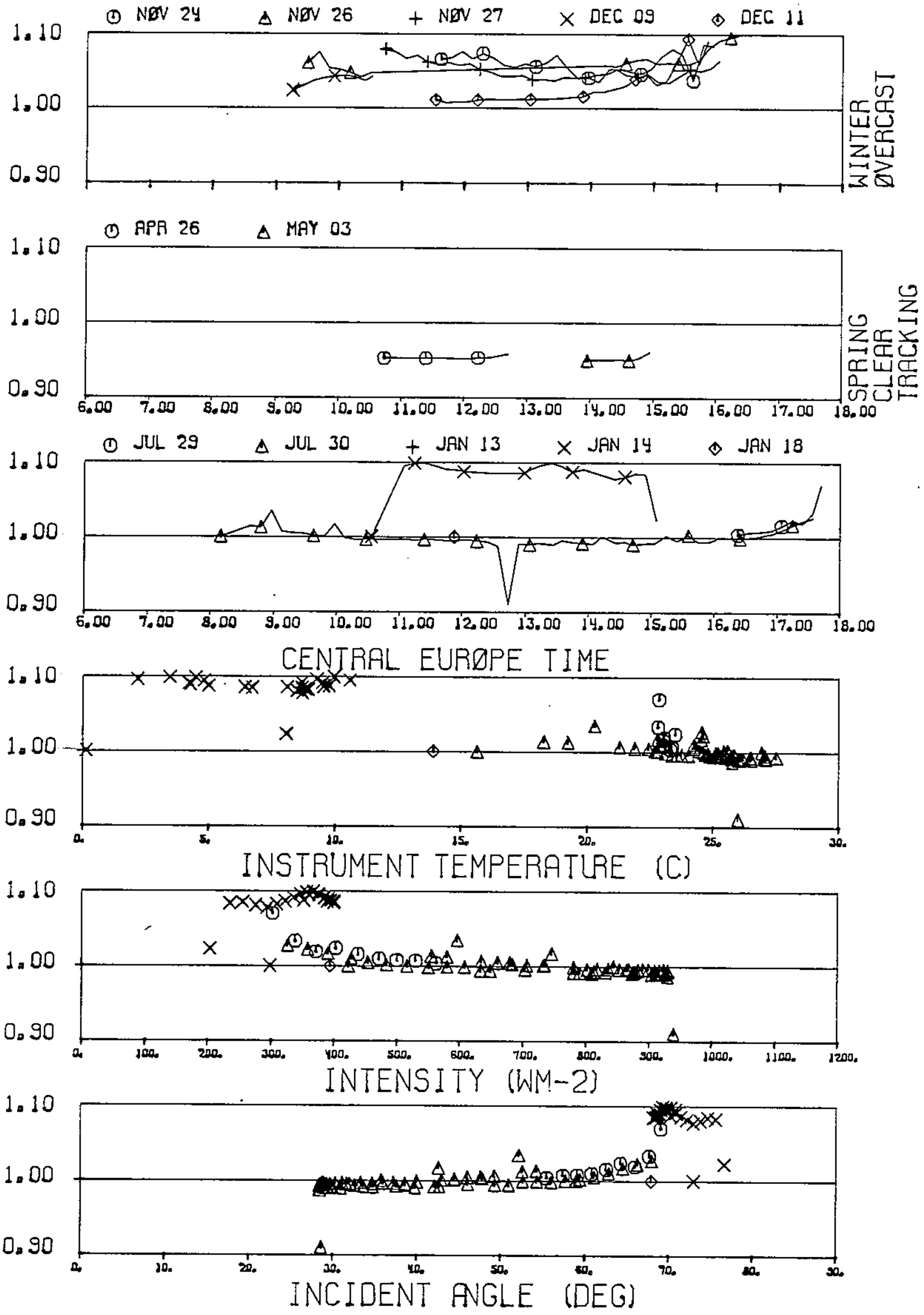
K&ZCM5 785047



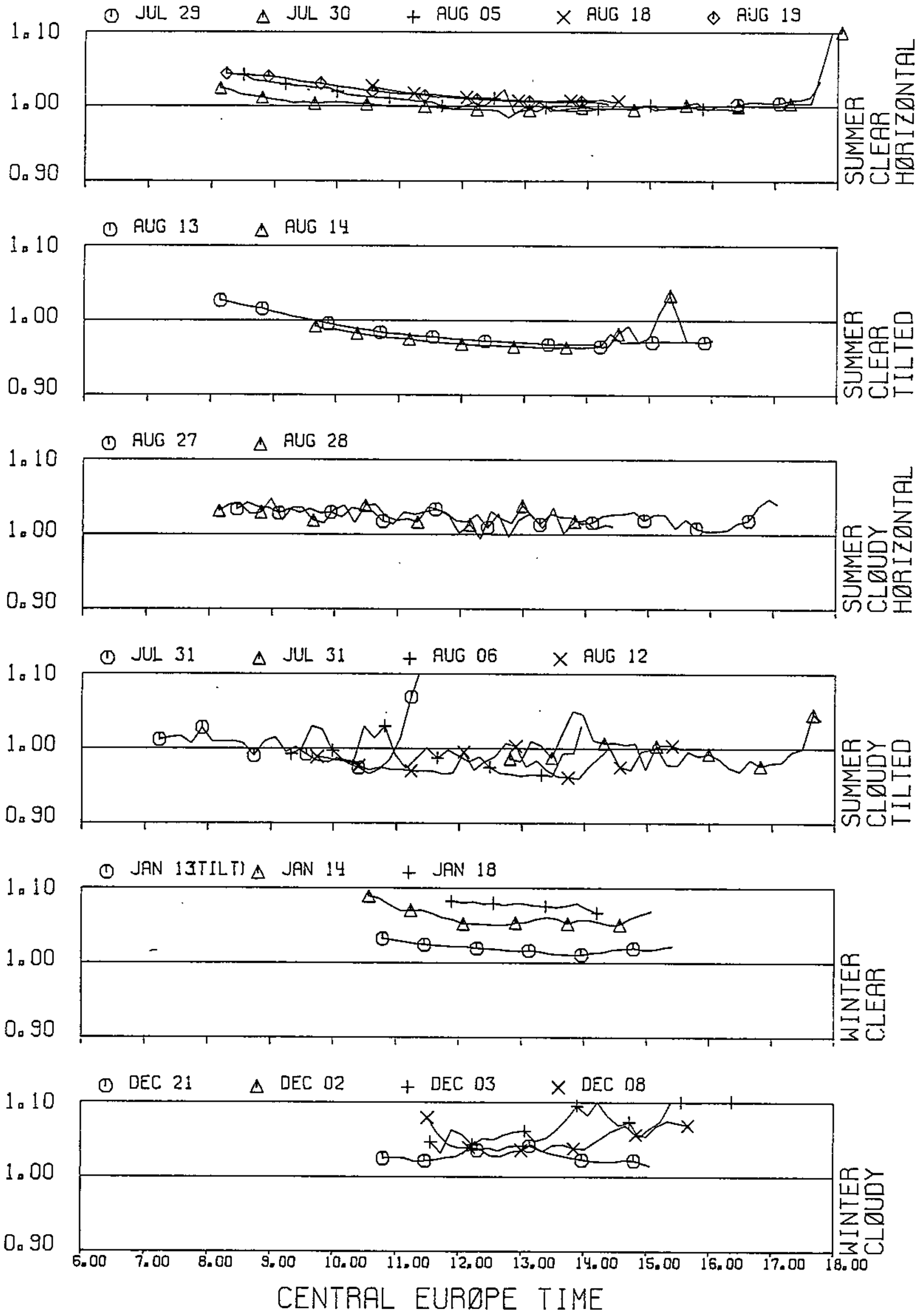
SCHENK 1626


⊕ JUL 29 △ JUL 30 + AUG 05 × AUG 18 ◇ AUG 19
SUMMER CLEAR HORIZONTAL
⊕ AUG 13 △ AUG 14
SUMMER CLEAR TILTED
⊕ AUG 27 △ AUG 28
SUMMER CLOUDY HORIZONTAL
⊕ JUL 31 △ JUL 31 + AUG 06 × AUG 12
SUMMER CLOUDY TILTED
⊕ JAN 13(TILT) △ JAN 14 + JAN 18
WINTER CLEAR
⊕ DEC 21 △ DEC 02 + DEC 03 × DEC 08
WINTER CLOUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

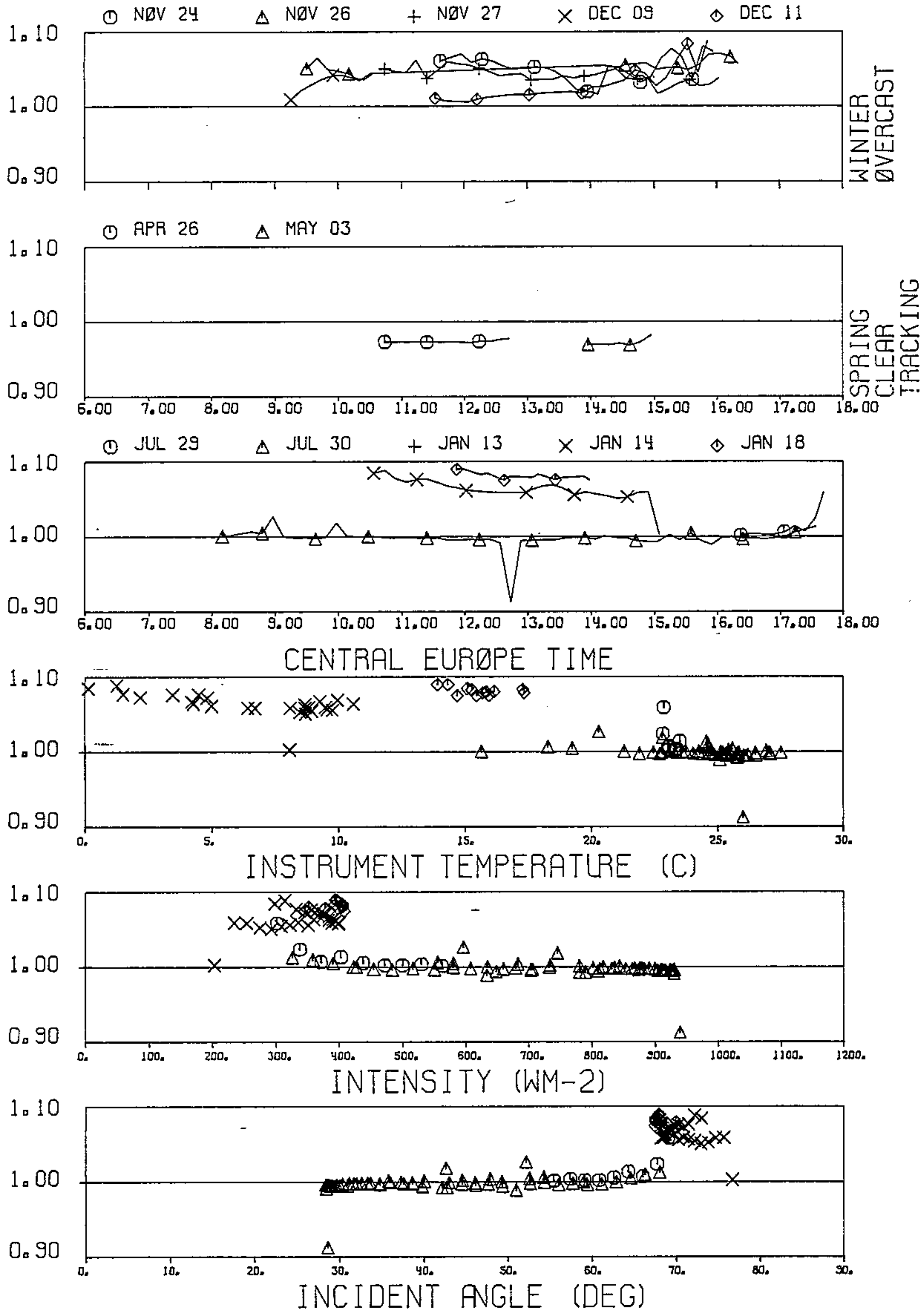
SCHENK 1626


⦶ NØV 24
△ NØV 26
+ NØV 27
× DEC 09
◇ DEC 11
1.10
1.00
0.90
WINTER ØVERCAST
⦶ APR 26
△ MAY 03
1.10
1.00
0.90
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
⦶ JUL 29
△ JUL 30
+ JAN 13
× JAN 14
◇ JAN 18
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EURØPE TIME
1.10
1.00
0.90
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
1.10
1.00
0.90
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
1.10
1.00
0.90
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

SCHENK 2186

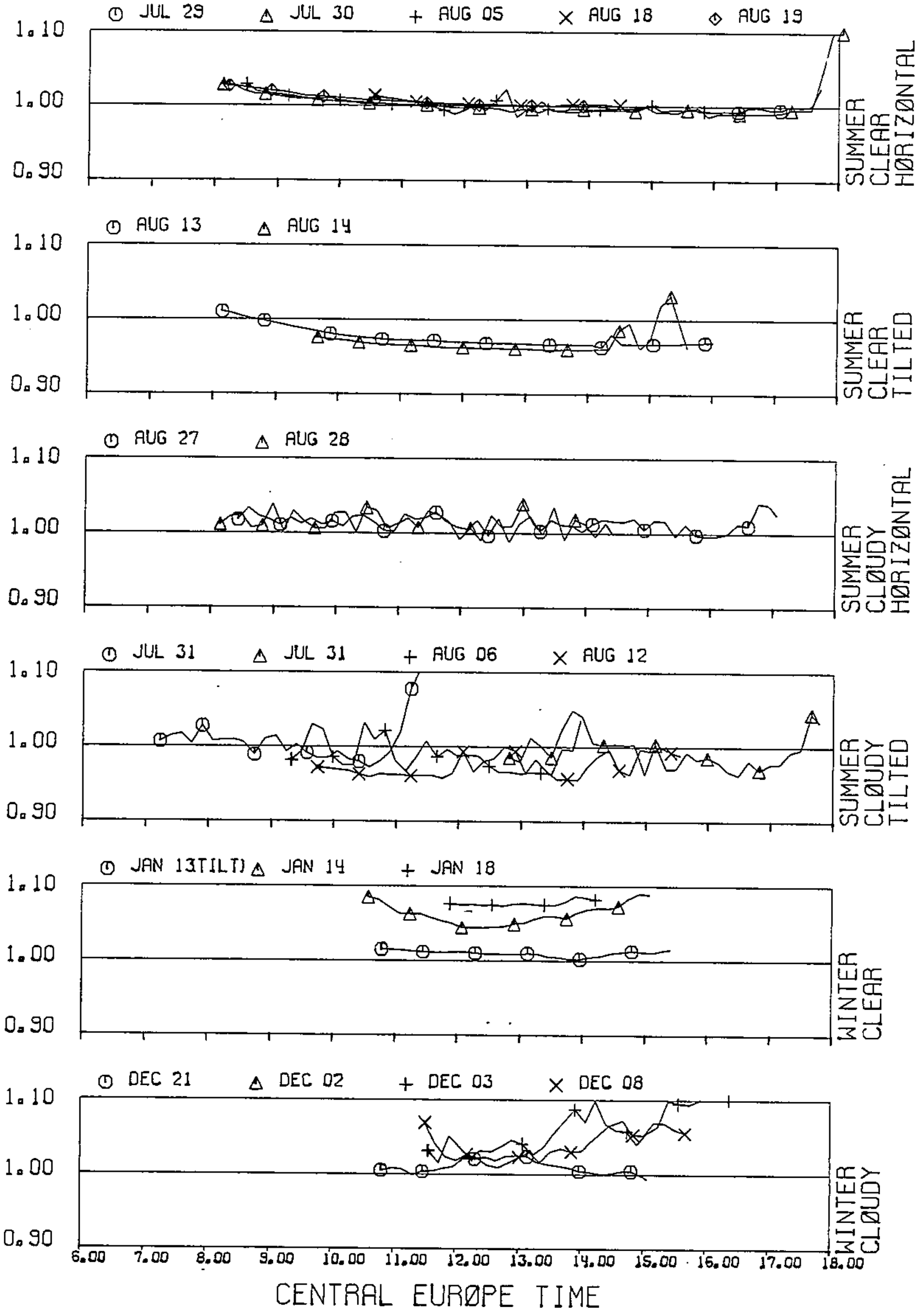

⦶ JUL 29
△ JUL 30
+ AUG 05
× AUG 18
◇ AUG 19
SUMMER CLEAR HØRIZØNTAL
⦶ AUG 13
△ AUG 14
SUMMER CLEAR TILTED
⦶ AUG 27
△ AUG 28
SUMMER CLØUDY HØRIZØNTAL
⦶ JUL 31
△ JUL 31
+ AUG 06
× AUG 12
SUMMER CLØUDY TILTED
⦶ JAN 13TILT)
△ JAN 14
+ JAN 18
WINTER CLEAR
⦶ DEC 21
△ DEC 02
+ DEC 03
× DEC 08
WINTER CLØUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EURØPE TIME

SCHENK 2186

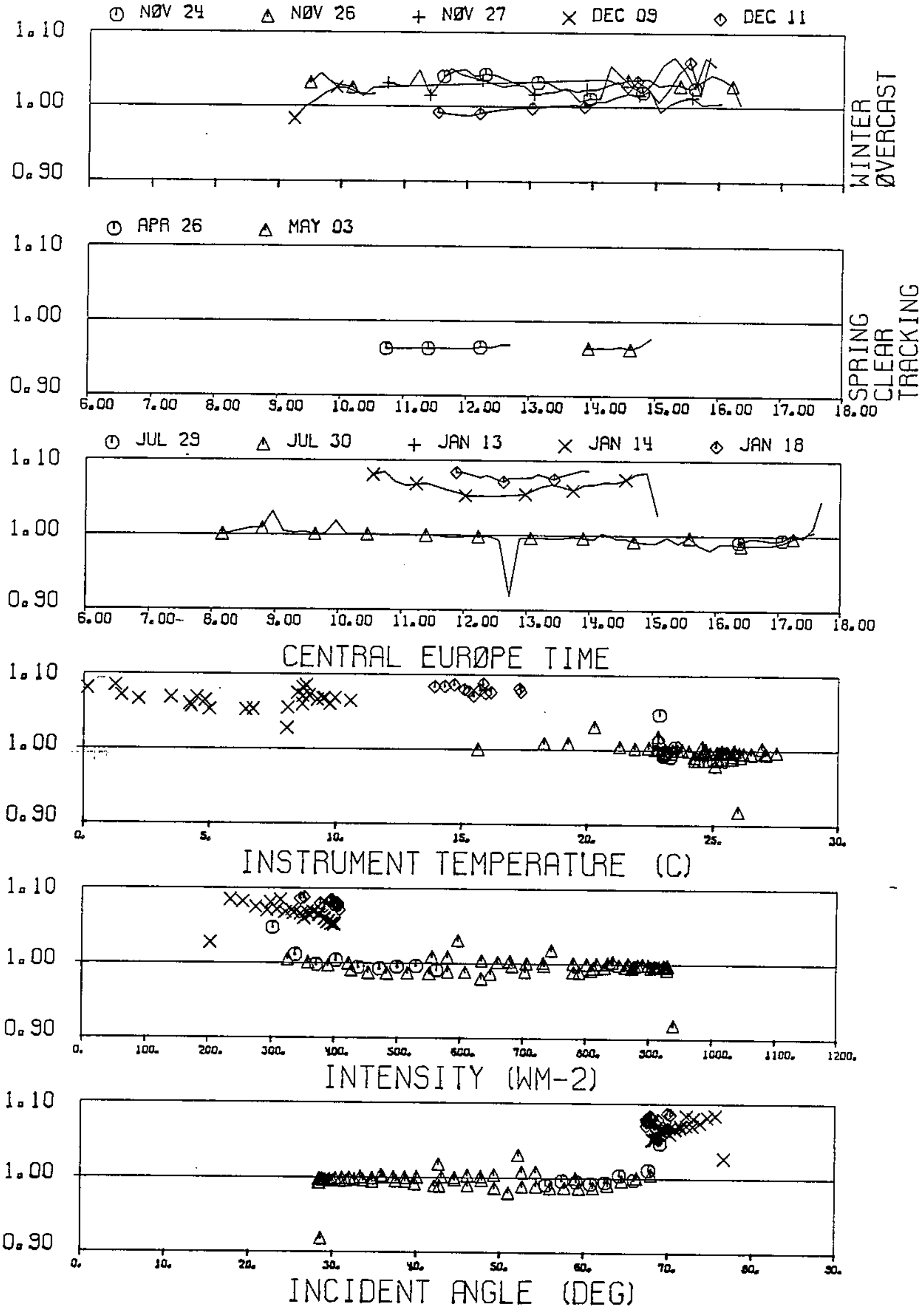


NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
WINTER OVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

SCHENK 2208

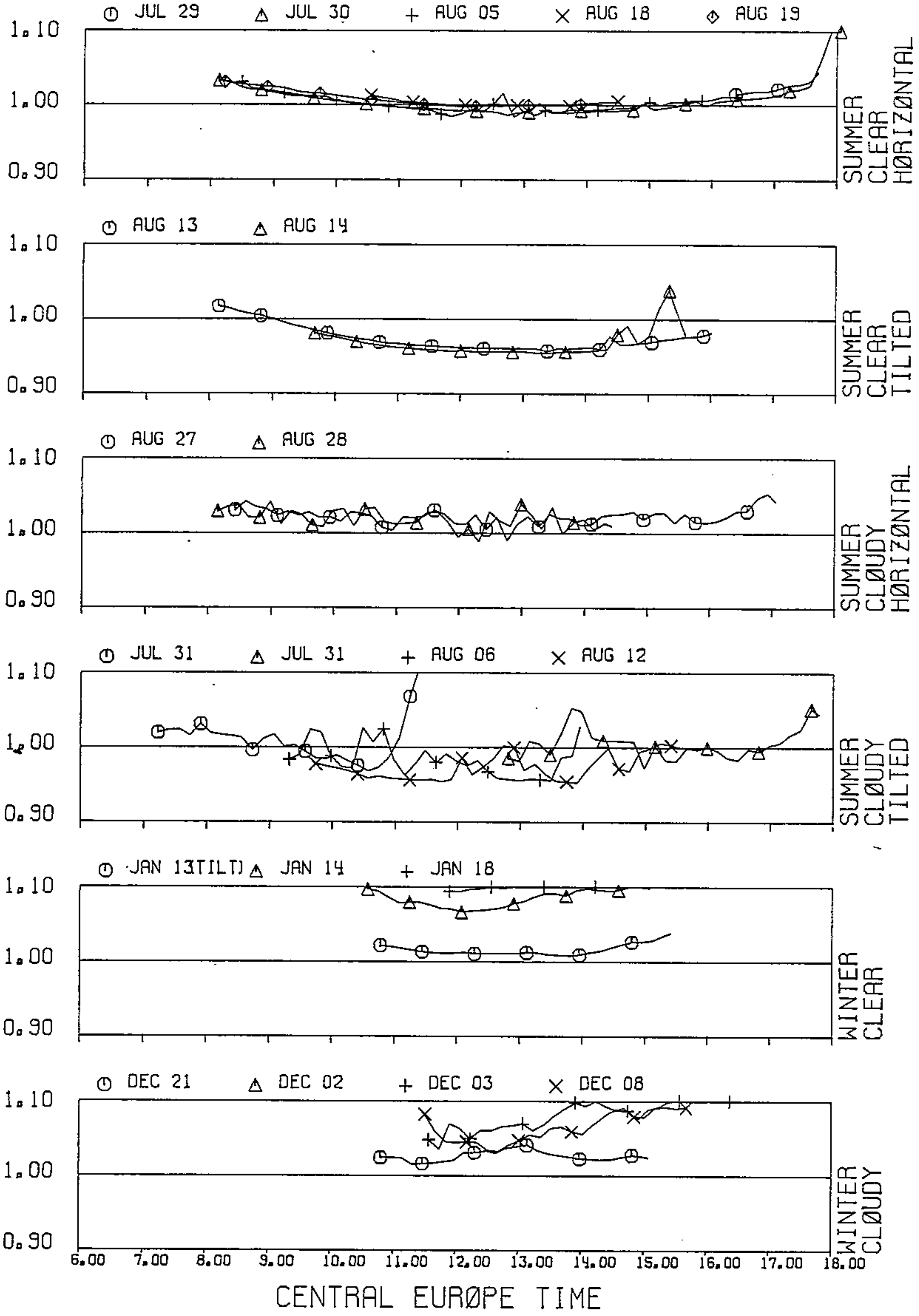

⦶ JUL 29
△ JUL 30
+ AUG 05
× AUG 18
◇ AUG 19
1.10
1.00
0.90
SUMMER CLEAR HORIZONTAL
⦶ AUG 13
△ AUG 14
1.10
1.00
0.90
SUMMER CLEAR TILTED
⦶ AUG 27
△ AUG 28
1.10
1.00
0.90
SUMMER CLOUDY HORIZONTAL
⦶ JUL 31
△ JUL 31
+ AUG 06
× AUG 12
1.10
1.00
0.90
SUMMER CLOUDY TILTED
⦶ JAN 13TILT)
△ JAN 14
+ JAN 18
1.10
1.00
0.90
WINTER CLEAR
⦶ DEC 21
△ DEC 02
+ DEC 03
× DEC 08
1.10
1.00
0.90
WINTER CLOUDY
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

SCHENK 2208

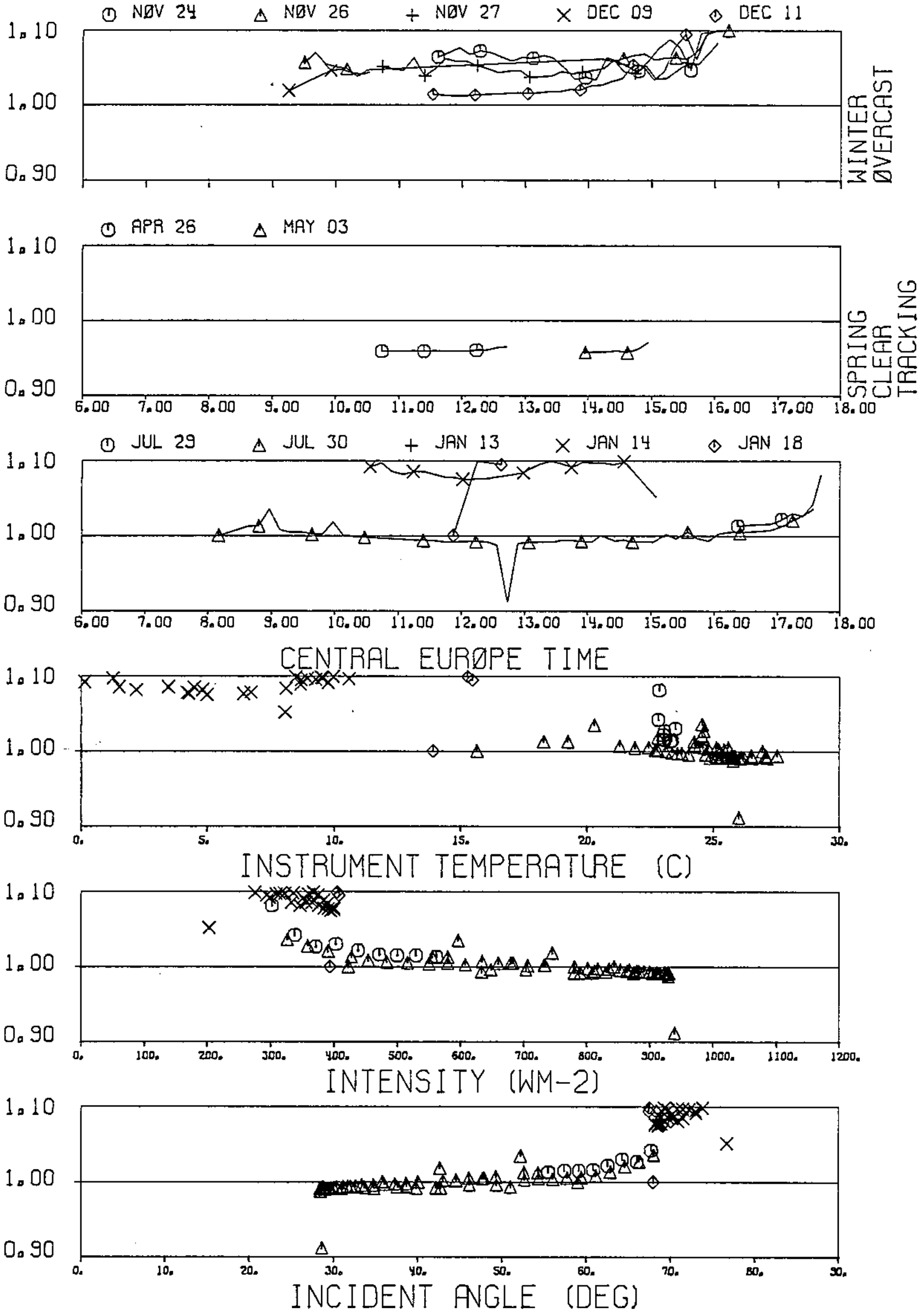


NØV 24
NØV 26
NØV 27
DEC 09
DEC 11
1.10
1.00
0.90
WINTER ØVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
CENTRAL EURØPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

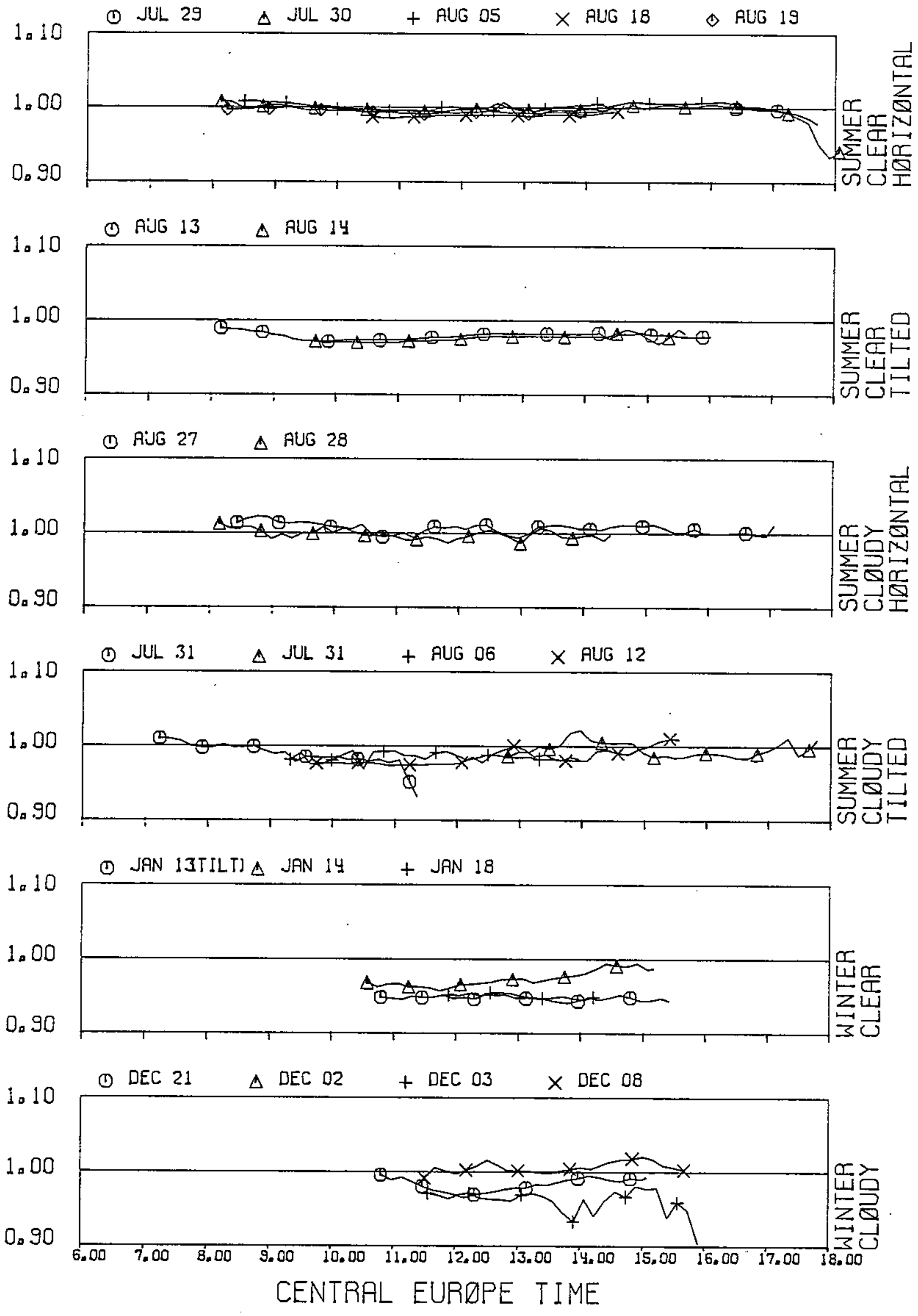
SCHENK 2221


⦶ JUL 29 △ JUL 30 + AUG 05 × AUG 18 ◇ AUG 19
SUMMER CLEAR HORIZONTAL
⦶ AUG 13 △ AUG 14
SUMMER CLEAR TILTED
⦶ AUG 27 △ AUG 28
SUMMER CLOUDY HORIZONTAL
⦶ JUL 31 △ JUL 31 + AUG 06 × AUG 12
SUMMER CLOUDY TILTED
⦶ JAN 13TILT) △ JAN 14 + JAN 18
WINTER CLEAR
⦶ DEC 21 △ DEC 02 + DEC 03 × DEC 08
WINTER CLOUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

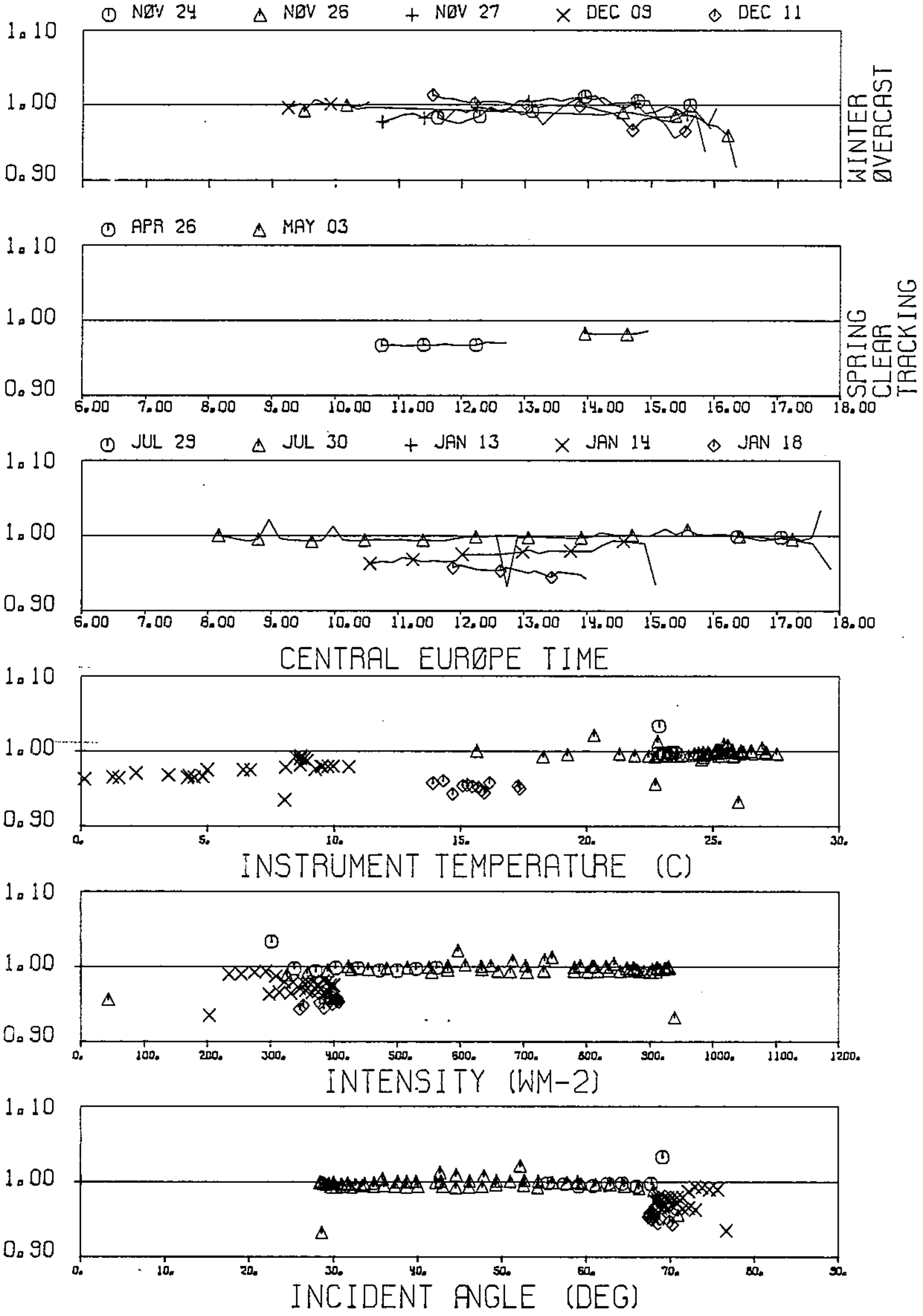
SCHENK 2221


⊕ NØV 24
△ NØV 26
+ NØV 27
× DEC 09
◇ DEC 11
1.10
1.00
0.90
WINTER ØVERCAST
⊕ APR 26
△ MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
⊕ JUL 29
△ JUL 30
+ JAN 13
× JAN 14
◇ JAN 18
CENTRAL EURØPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

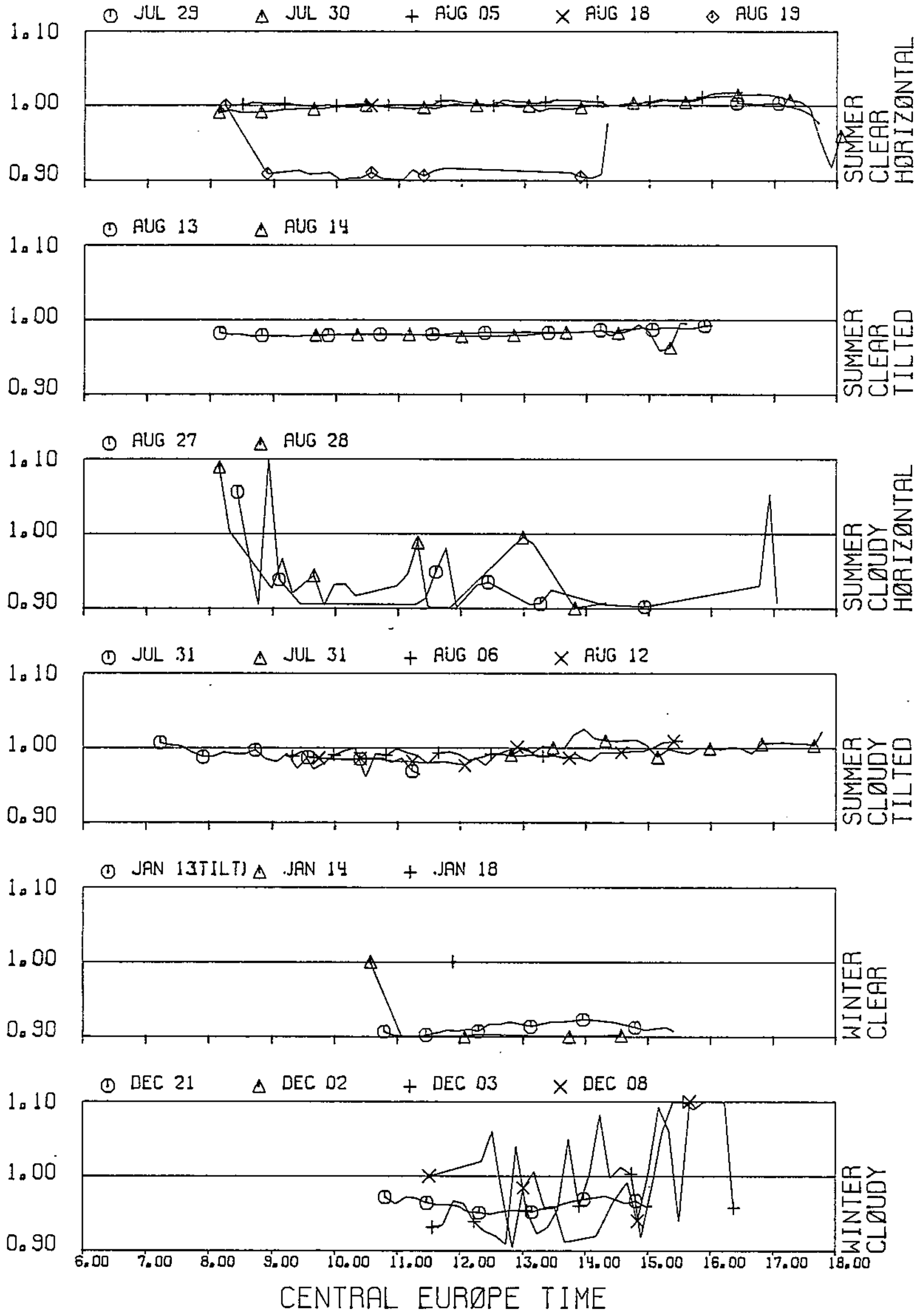
EKO 81901


⦶ JUL 29
△ JUL 30
+ AUG 05
× AUG 18
◇ AUG 19
SUMMER CLEAR HORIZONTAL
⦶ AUG 13
△ AUG 14
SUMMER CLEAR TILTED
⦶ AUG 27
△ AUG 28
SUMMER CLOUDY HORIZONTAL
⦶ JUL 31
△ JUL 31
+ AUG 06
× AUG 12
SUMMER CLOUDY TILTED
⦶ JAN 13TILT)
△ JAN 14
+ JAN 18
WINTER CLEAR
⦶ DEC 21
△ DEC 02
+ DEC 03
× DEC 08
WINTER CLOUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

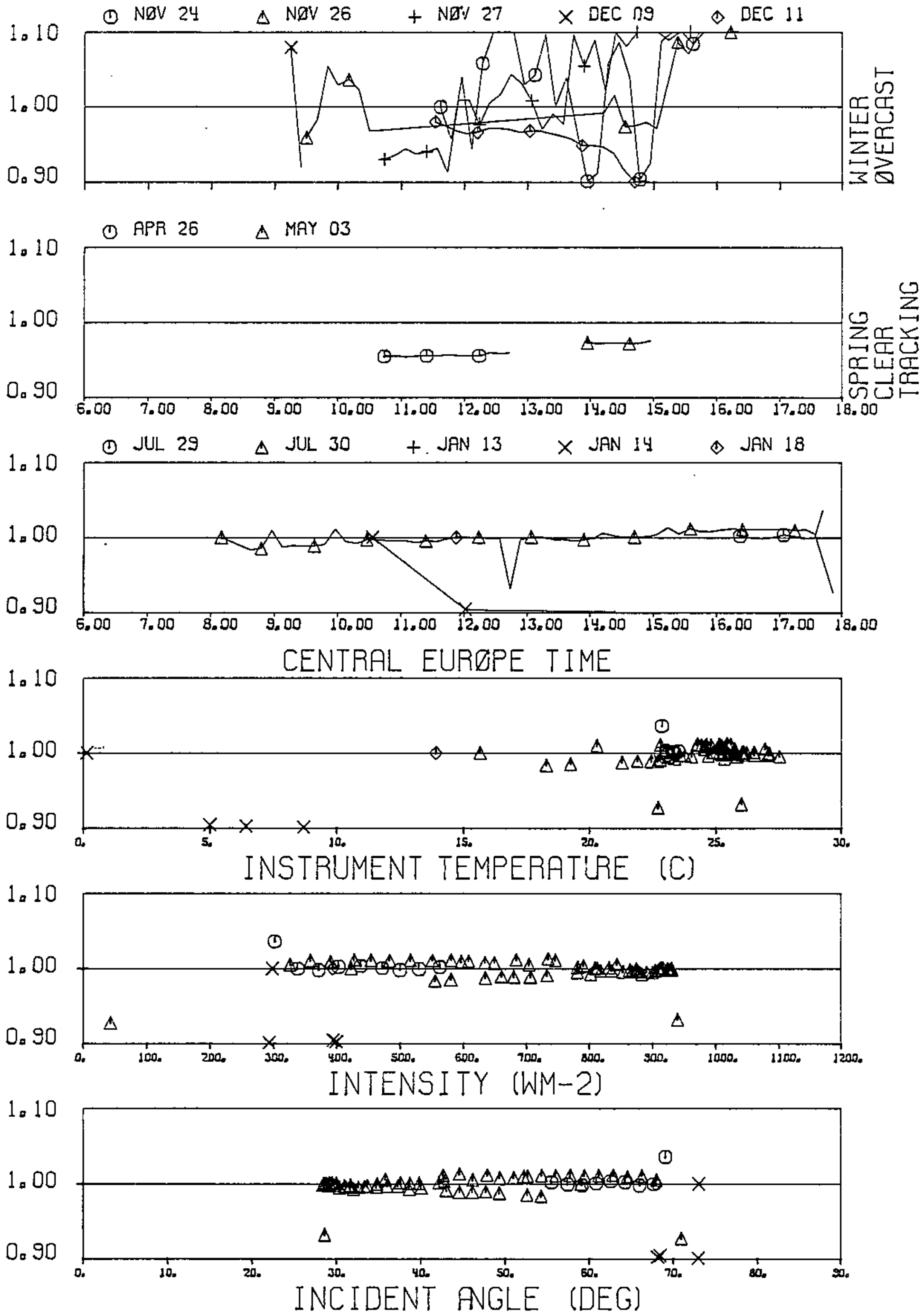
EKØ 81901


⊕ NØV 24
△ NØV 26
+ NØV 27
× DEC 09
◇ DEC 11
1.10
1.00
0.90
WINTER ØVERCAST
⊕ APR 26
△ MAY 03
1.10
1.00
0.90
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
⊕ JUL 29
△ JUL 30
+ JAN 13
× JAN 14
◇ JAN 18
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EURØPE TIME
1.10
1.00
0.90
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
1.10
1.00
0.90
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
1.10
1.00
0.90
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

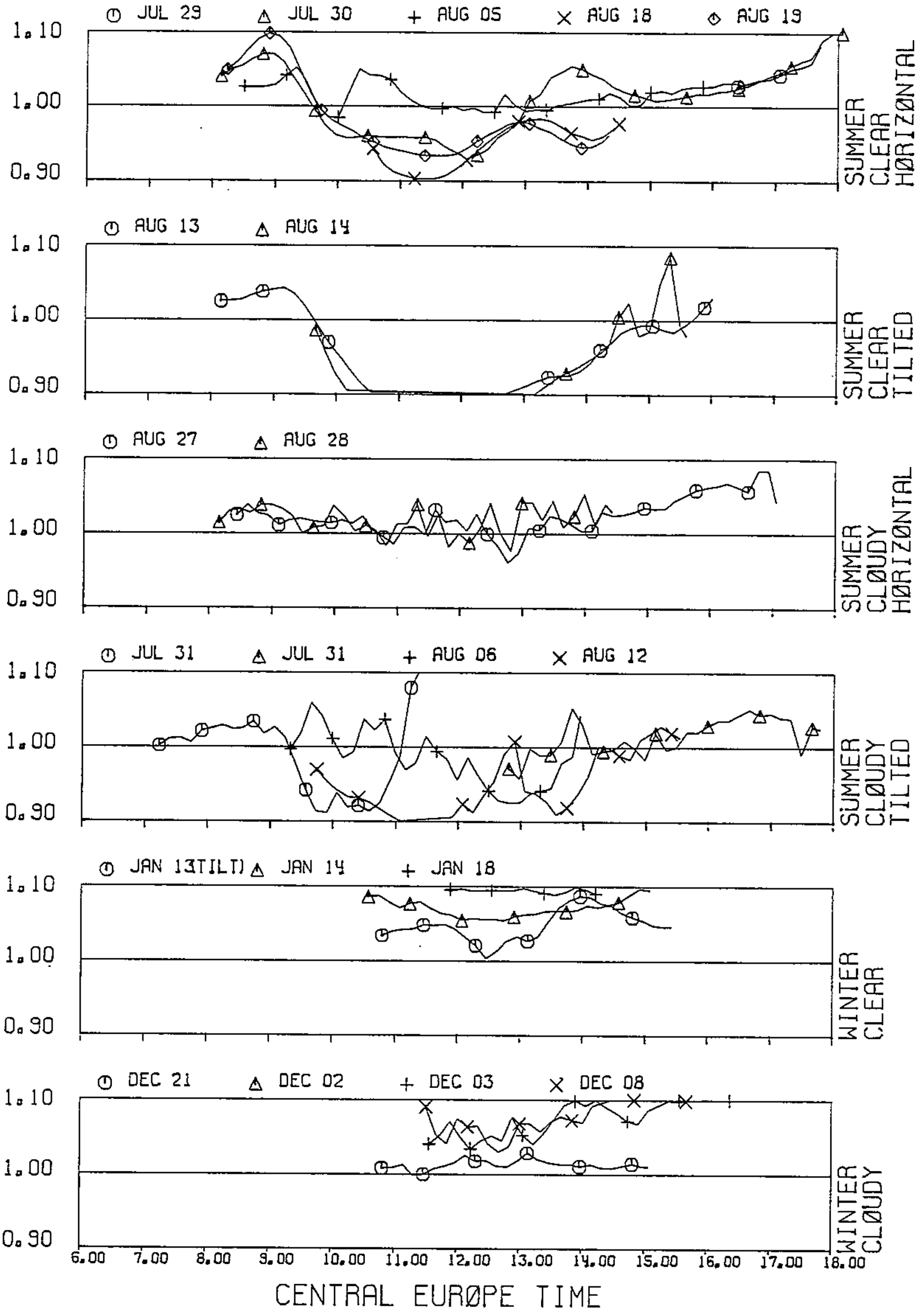
EKØ 81903


⊕ JUL 29 △ JUL 30 + AUG 05 × AUG 18 ◇ AUG 19
SUMMER CLEAR HØRIZØNTAL
⊕ AUG 13 △ AUG 14
SUMMER CLEAR TILTED
⊕ AUG 27 △ AUG 28
SUMMER CLØUDY HØRIZØNTAL
⊕ JUL 31 △ JUL 31 + AUG 06 × AUG 12
SUMMER CLØUDY TILTED
⊕ JAN 13TILT) △ JAN 14 + JAN 18
WINTER CLEAR
⊕ DEC 21 △ DEC 02 + DEC 03 × DEC 08
WINTER CLØUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EURØPE TIME

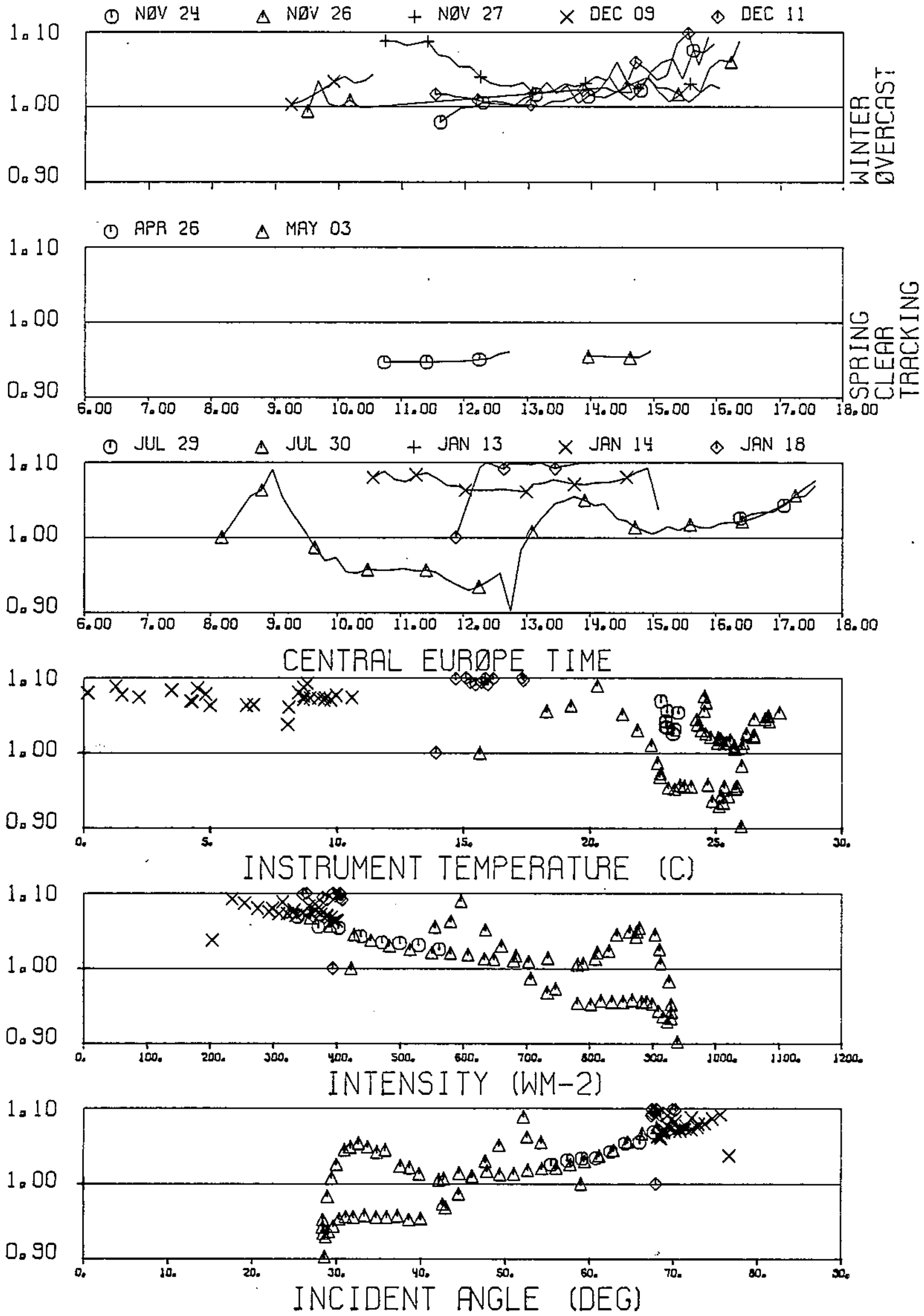
EKO 81903


NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
1.10
1.00
0.90
WINTER OVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
CENTRAL EUROPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

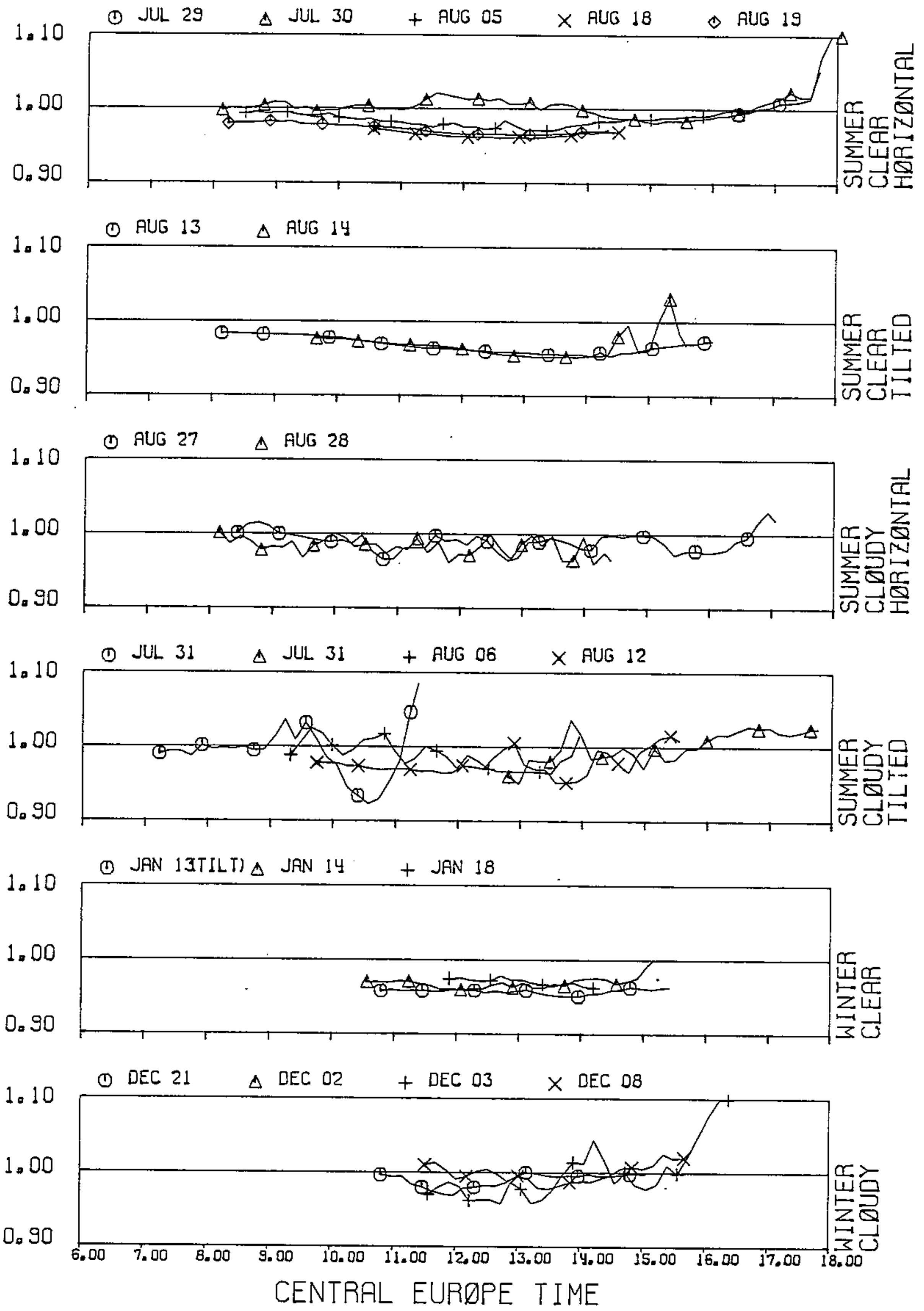
EKØ 81906


JUL 29
JUL 30
AUG 05
AUG 18
AUG 19
1.10
1.00
0.90
SUMMER CLEAR HØRIZØNTAL
AUG 13
AUG 14
1.10
1.00
0.90
SUMMER CLEAR TILTED
AUG 27
AUG 28
1.10
1.00
0.90
SUMMER CLØUDY HØRIZØNTAL
JUL 31
JUL 31
AUG 06
AUG 12
1.10
1.00
0.90
SUMMER CLØUDY TILTED
JAN 13TILT)
JAN 14
JAN 18
1.10
1.00
0.90
WINTER CLEAR
DEC 21
DEC 02
DEC 03
DEC 08
1.10
1.00
0.90
WINTER CLØUDY
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EURØPE TIME

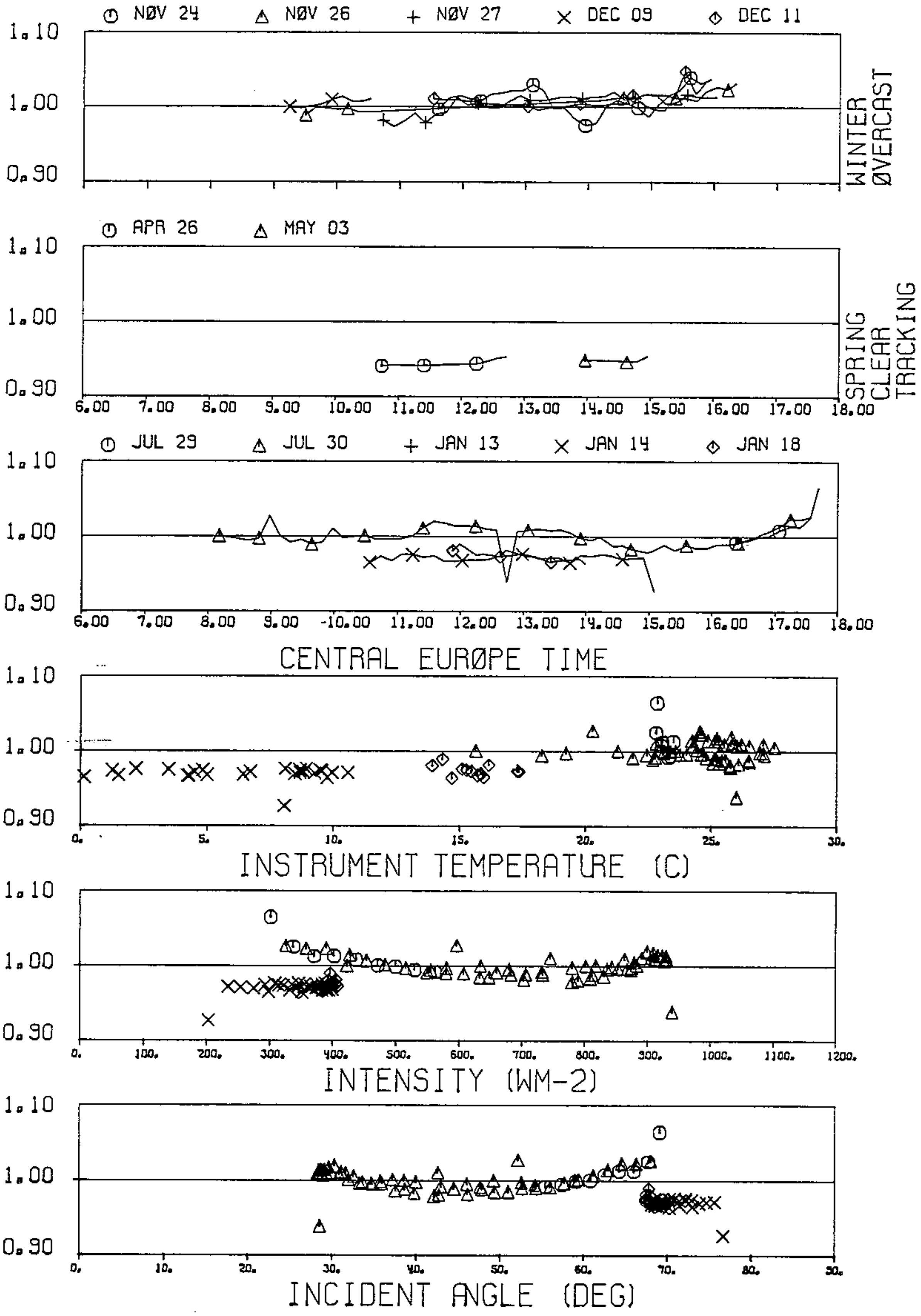
EKO 81906


NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
1.10
1.00
0.90
WINTER OVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
CENTRAL EUROPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

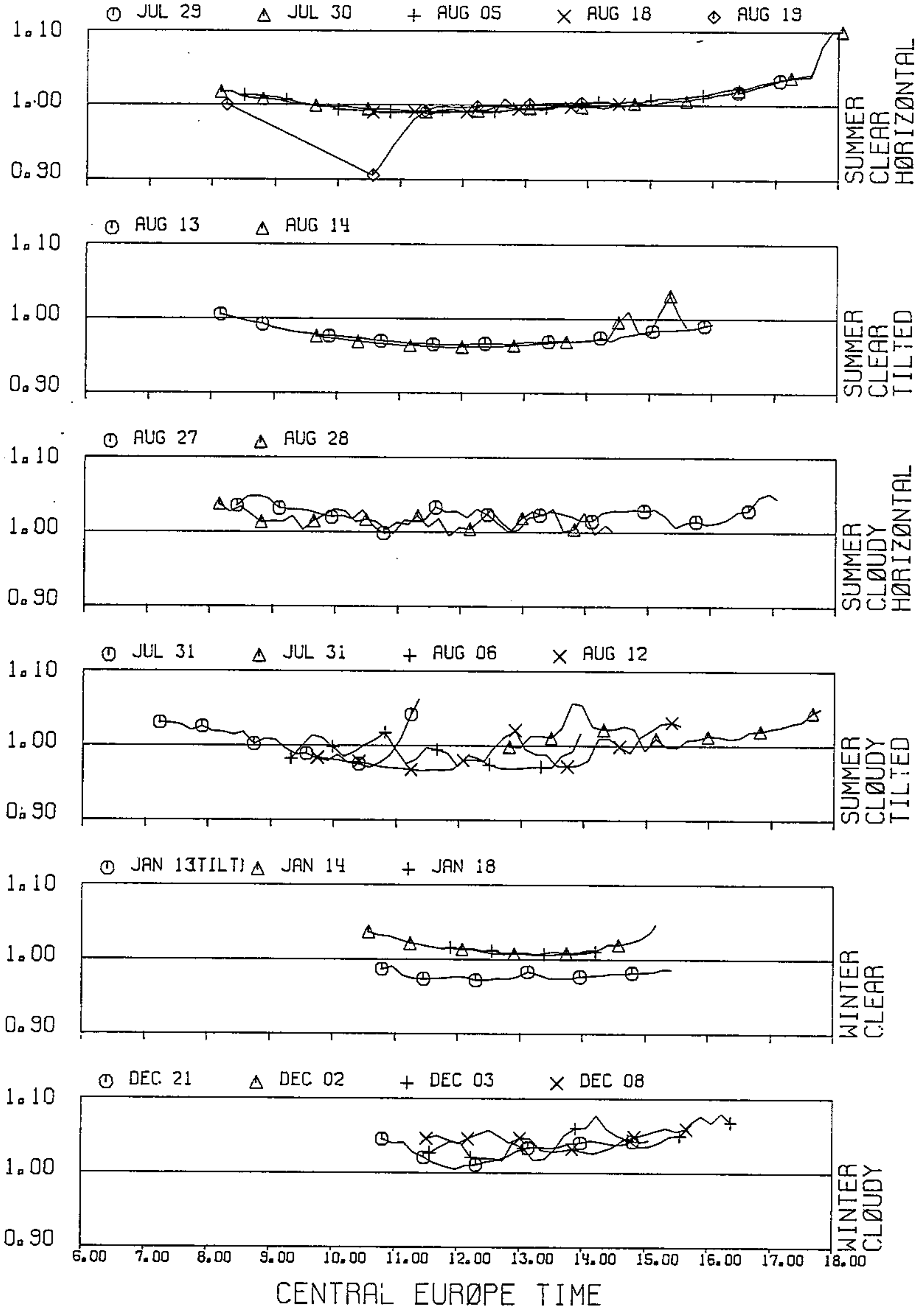
EKØ 81907


⊕ JUL 29 △ JUL 30 + AUG 05 × AUG 18 ◇ AUG 19
SUMMER CLEAR HØRIZØNTAL
⊕ AUG 13 △ AUG 14
SUMMER CLEAR TILTED
⊕ AUG 27 △ AUG 28
SUMMER CLØUDY HØRIZØNTAL
⊕ JUL 31 △ JUL 31 + AUG 06 × AUG 12
SUMMER CLØUDY TILTED
⊕ JAN 13TILT) △ JAN 14 + JAN 18
WINTER CLEAR
⊕ DEC 21 △ DEC 02 + DEC 03 × DEC 08
WINTER CLØUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EURØPE TIME

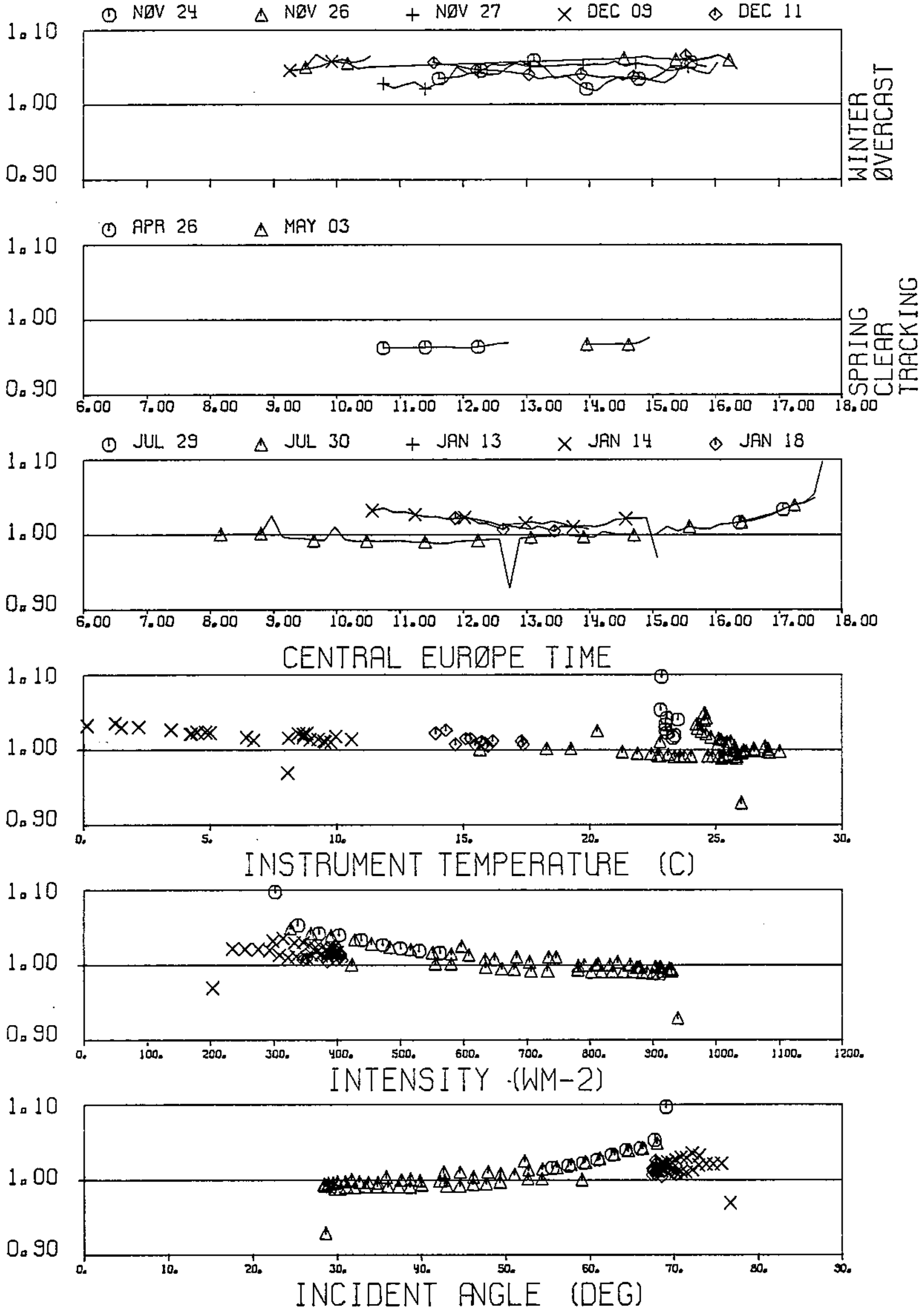
EKO 81907


NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
1.10
1.00
0.90
WINTER OVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
CENTRAL EUROPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

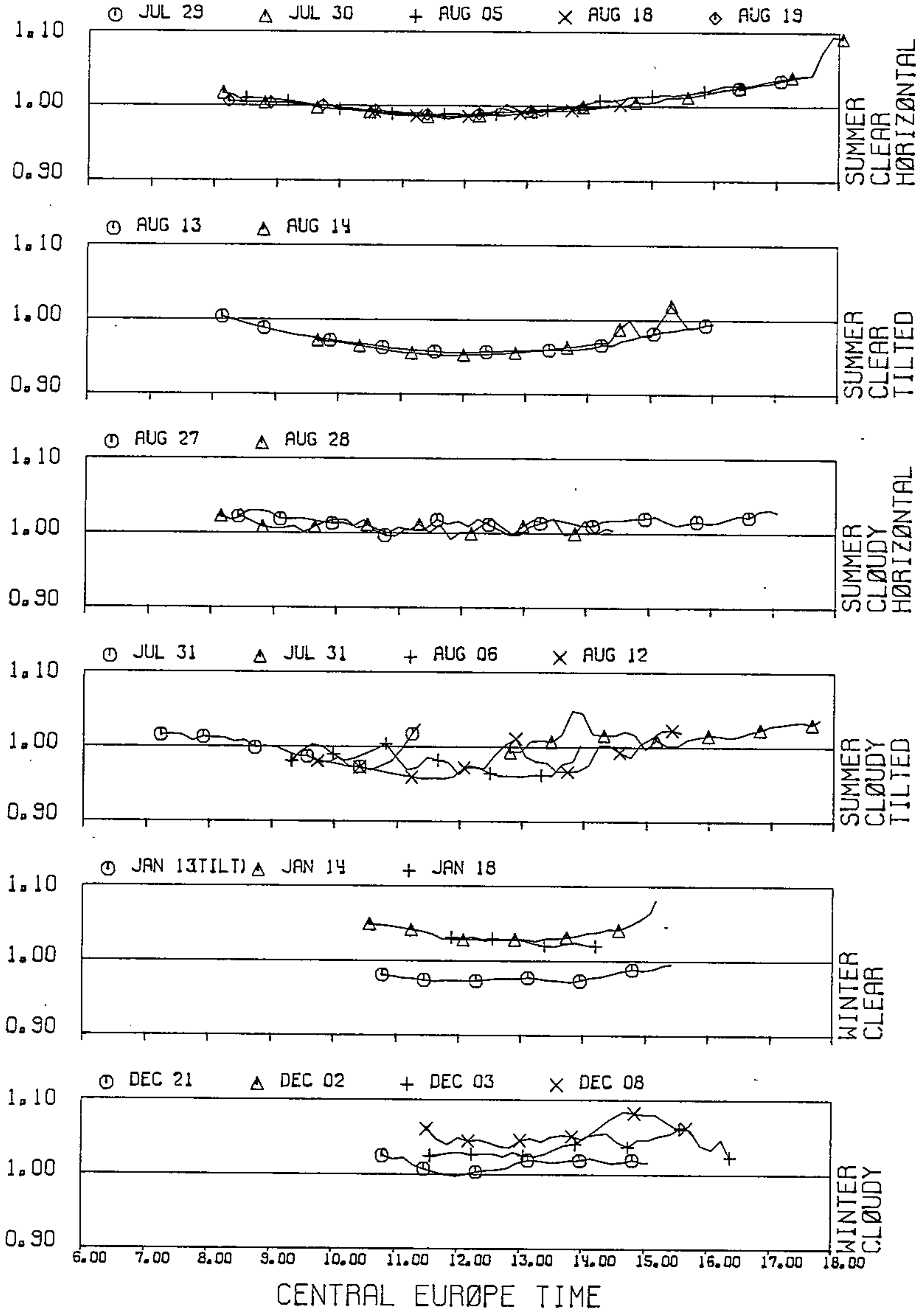
EKO 81908


JUL 29
JUL 30
AUG 05
AUG 18
AUG 19
1.10
1.00
0.90
SUMMER CLEAR HORIZONTAL
AUG 13
AUG 14
1.10
1.00
0.90
SUMMER CLEAR TILTED
AUG 27
AUG 28
1.10
1.00
0.90
SUMMER CLOUDY HORIZONTAL
JUL 31
JUL 31
AUG 06
AUG 12
1.10
1.00
0.90
SUMMER CLOUDY TILTED
JAN 13(TILT)
JAN 14
JAN 18
1.10
1.00
0.90
WINTER CLEAR
DEC 21
DEC 02
DEC 03
DEC 08
1.10
1.00
0.90
WINTER CLOUDY
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

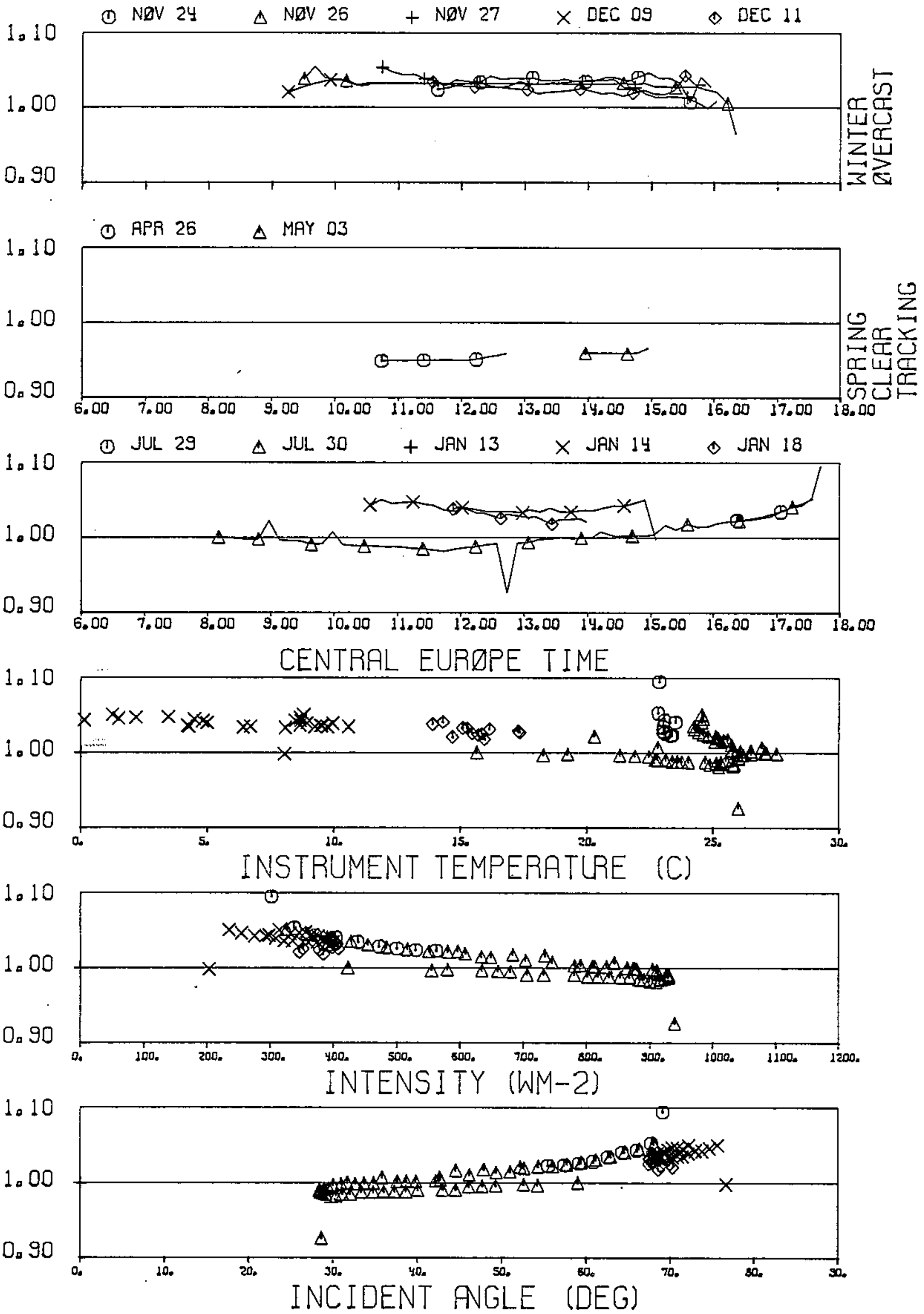
EKO 81908


NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
1.10
1.00
0.90
WINTER OVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
CENTRAL EUROPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

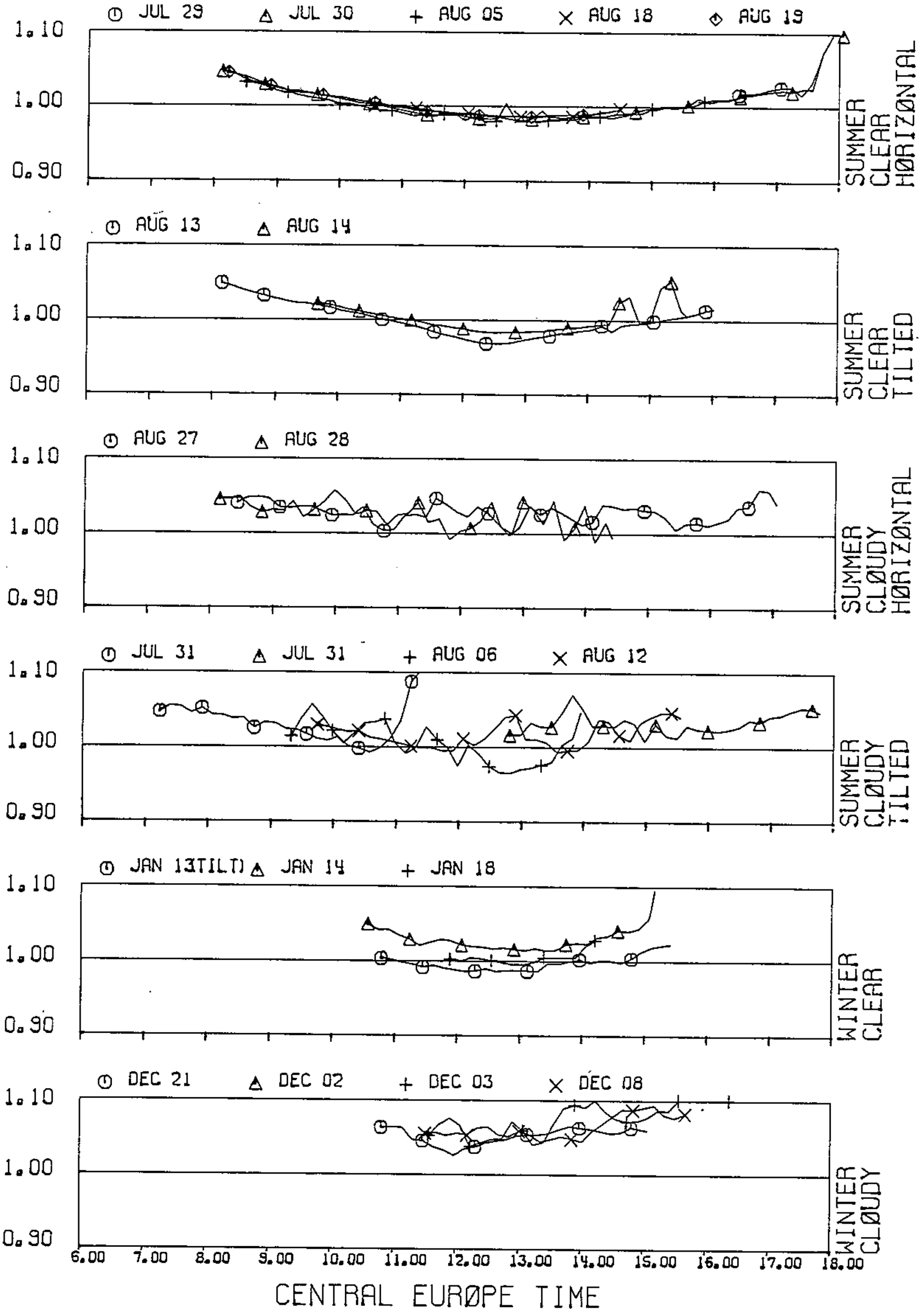
EKO 81909


JUL 29
JUL 30
AUG 05
AUG 18
AUG 19
SUMMER CLEAR HORIZONTAL
AUG 13
AUG 14
SUMMER CLEAR TILTED
AUG 27
AUG 28
SUMMER CLOUDY HORIZONTAL
JUL 31
JUL 31
AUG 06
AUG 12
SUMMER CLOUDY TILTED
JAN 13(TILT)
JAN 14
JAN 18
WINTER CLEAR
DEC 21
DEC 02
DEC 03
DEC 08
WINTER CLOUDY
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

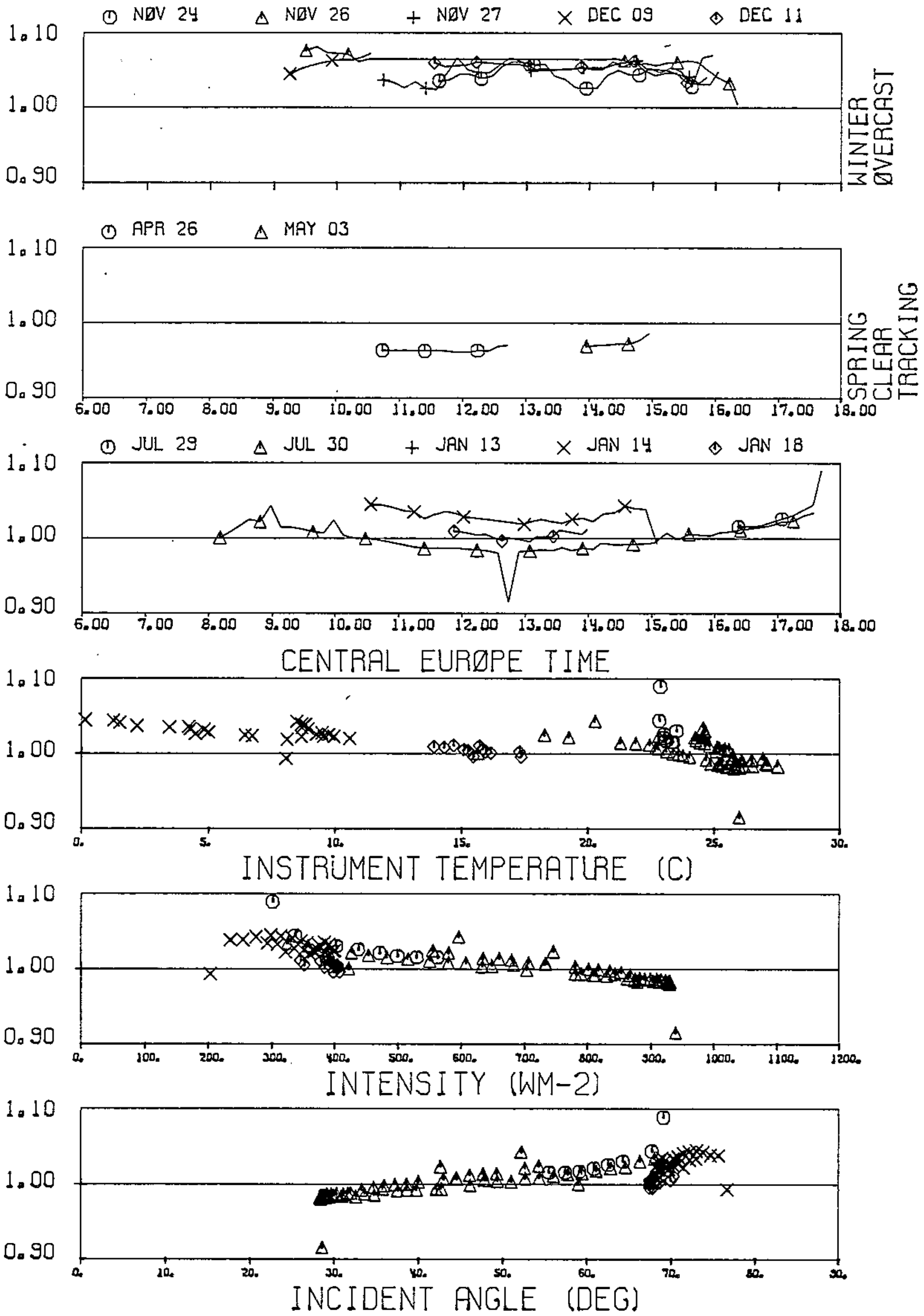
EKO 81909


NOV 24
NOV 26
NOV 27
DEC 09
DEC 11
1.10
1.00
0.90
WINTER OVERCAST
APR 26
MAY 03
SPRING CLEAR TRACKING
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
JUL 29
JUL 30
JAN 13
JAN 14
JAN 18
CENTRAL EUROPE TIME
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

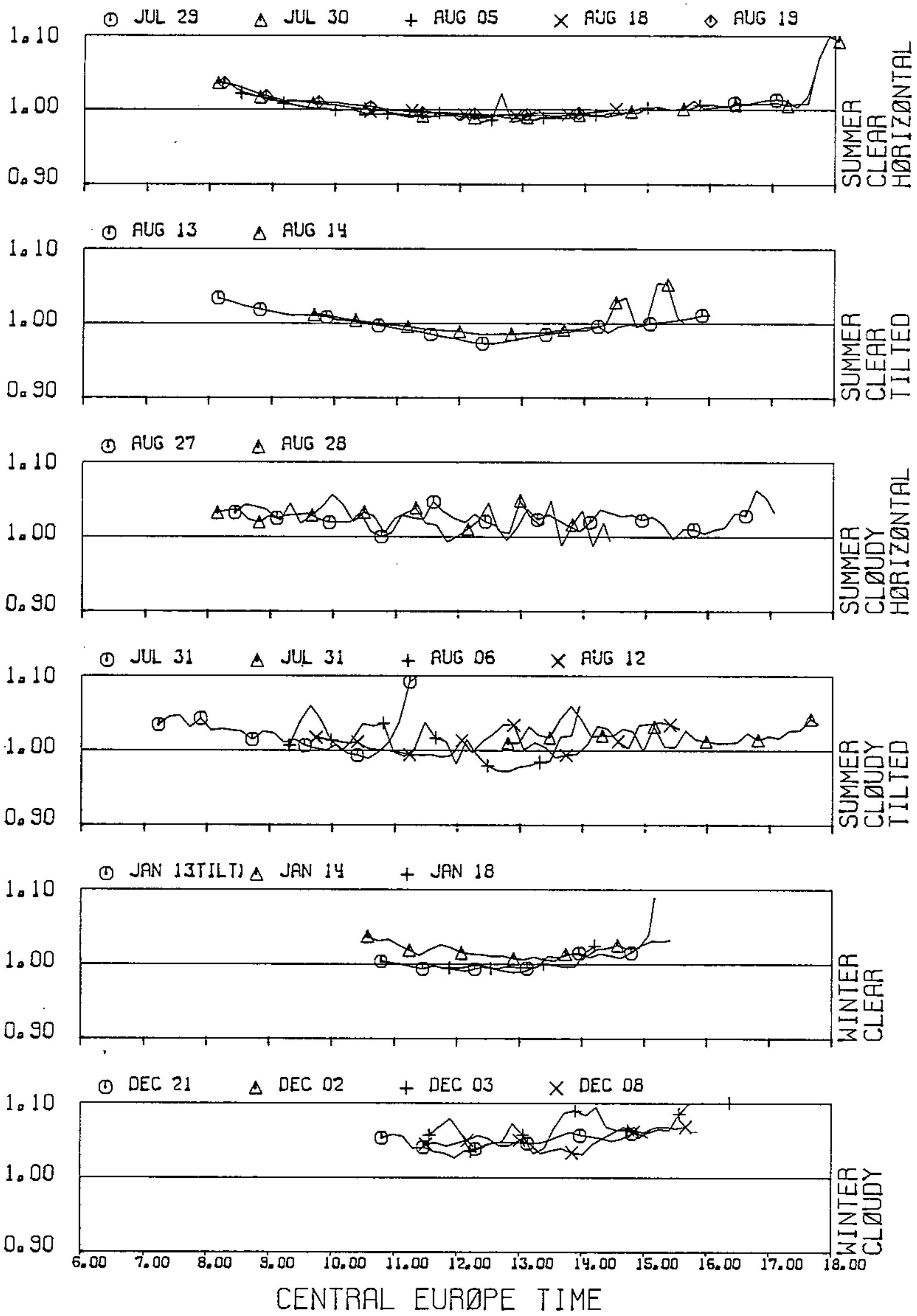
SWISSTECO 113



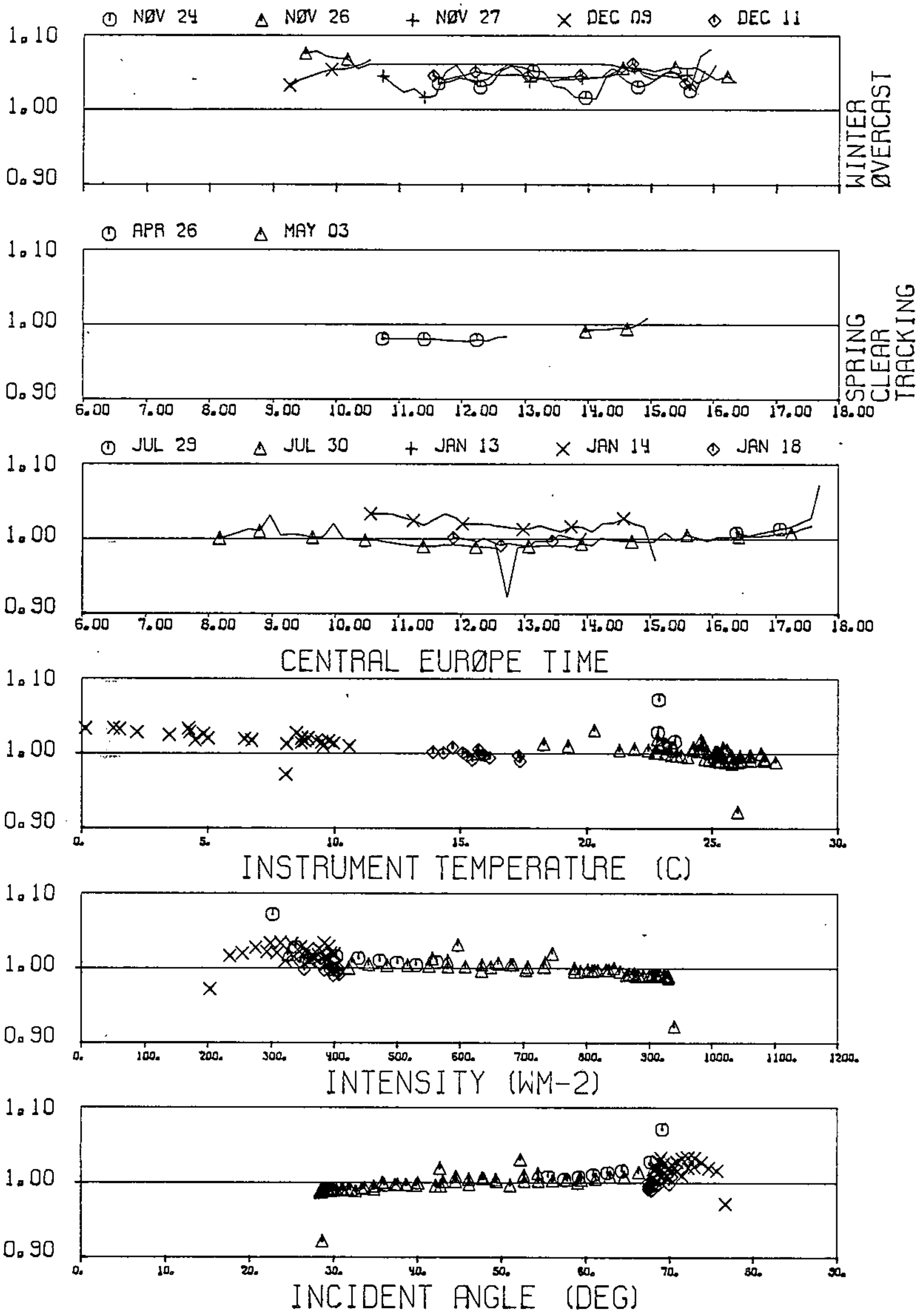
SWISSTECO 113



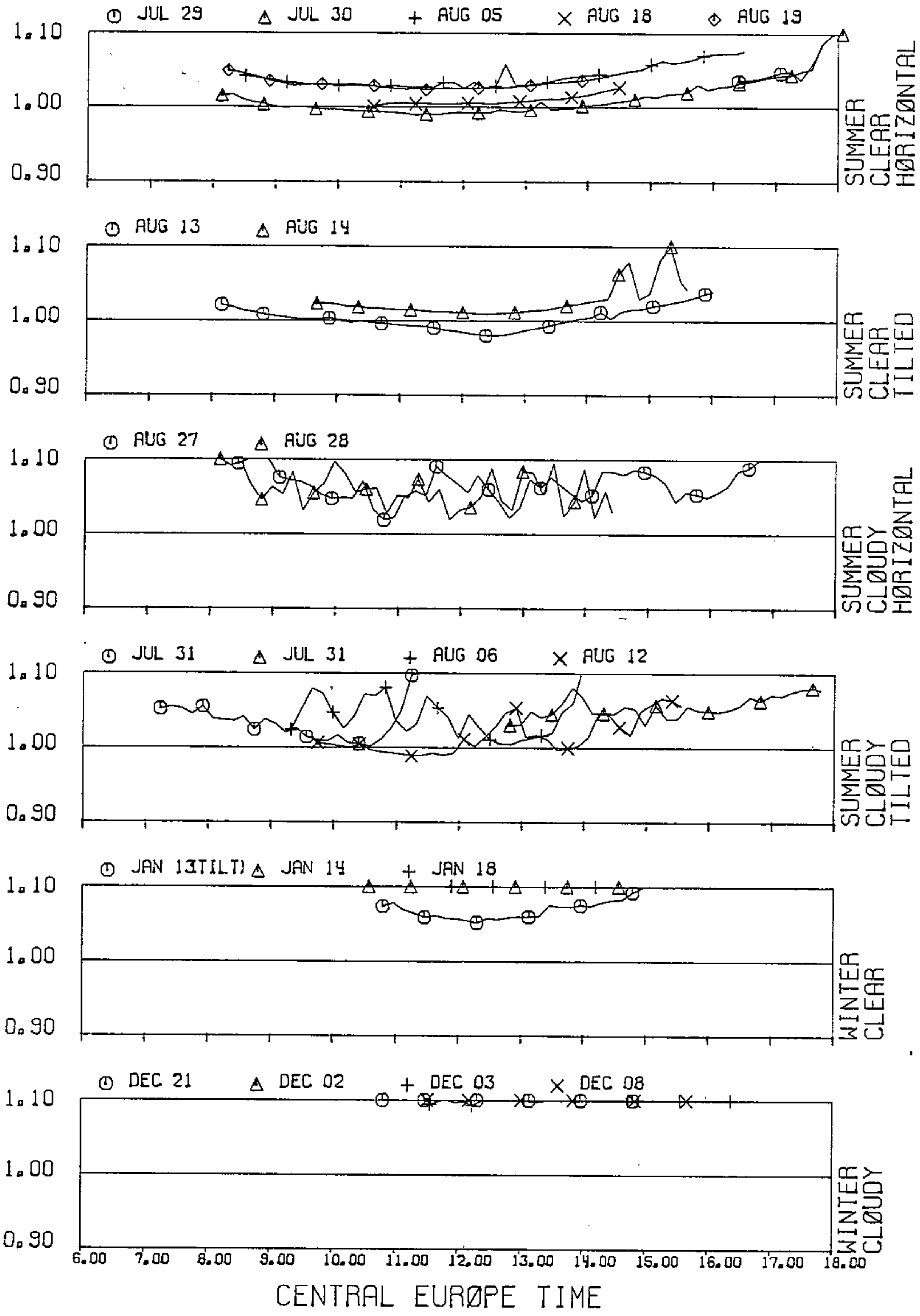
SWISSTECO 114



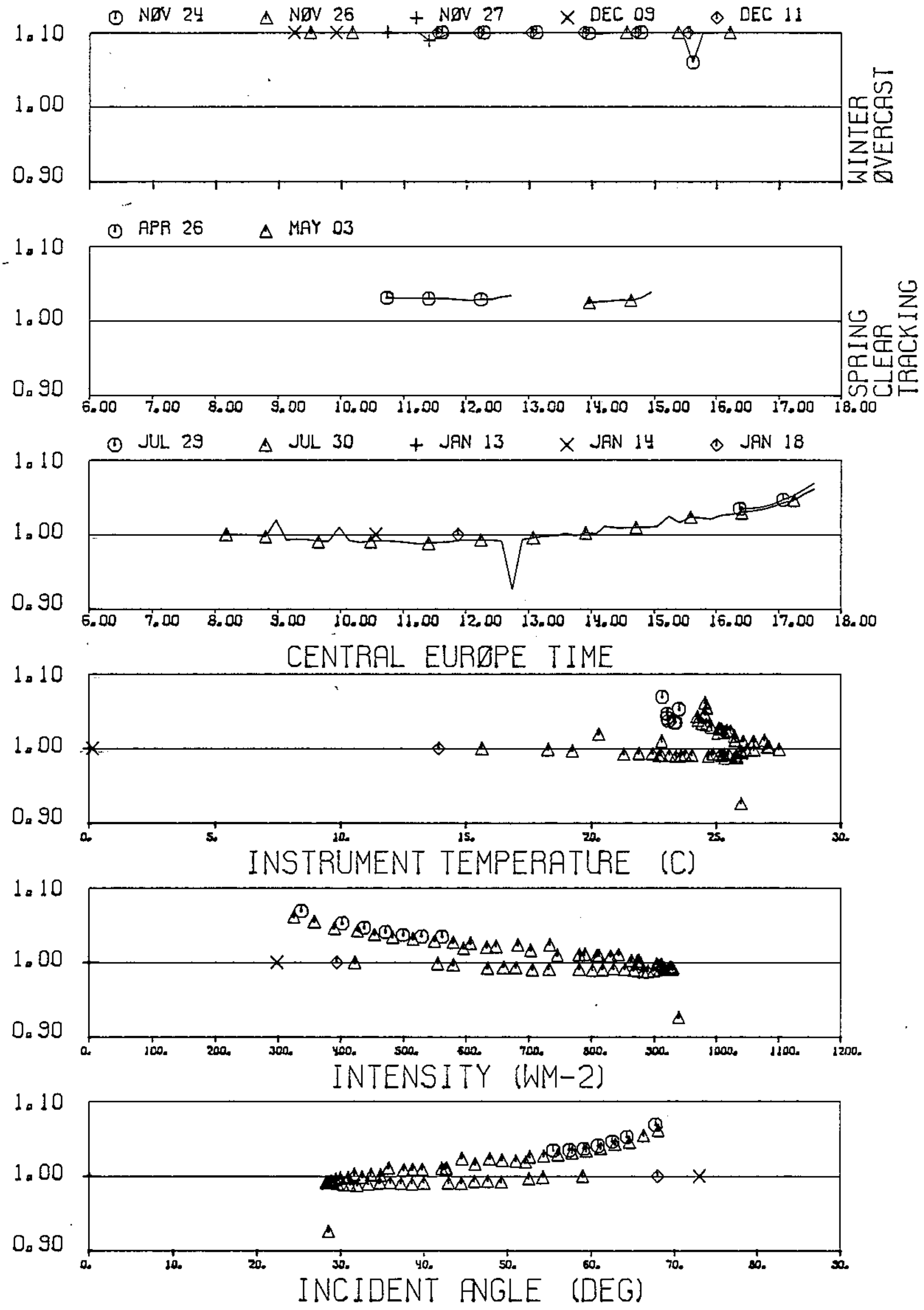
SWISSTECO 114



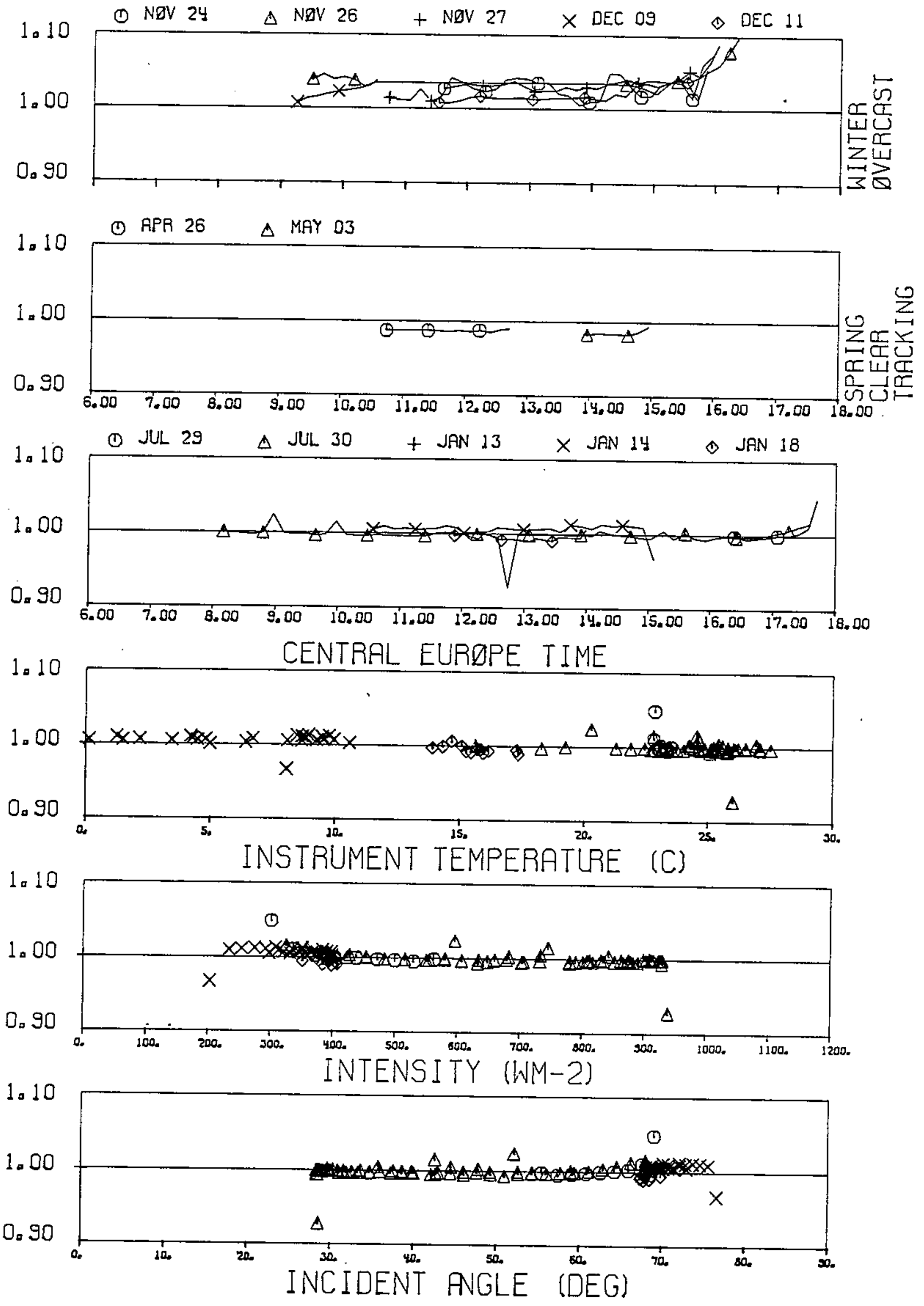
SWISSTECØ 115



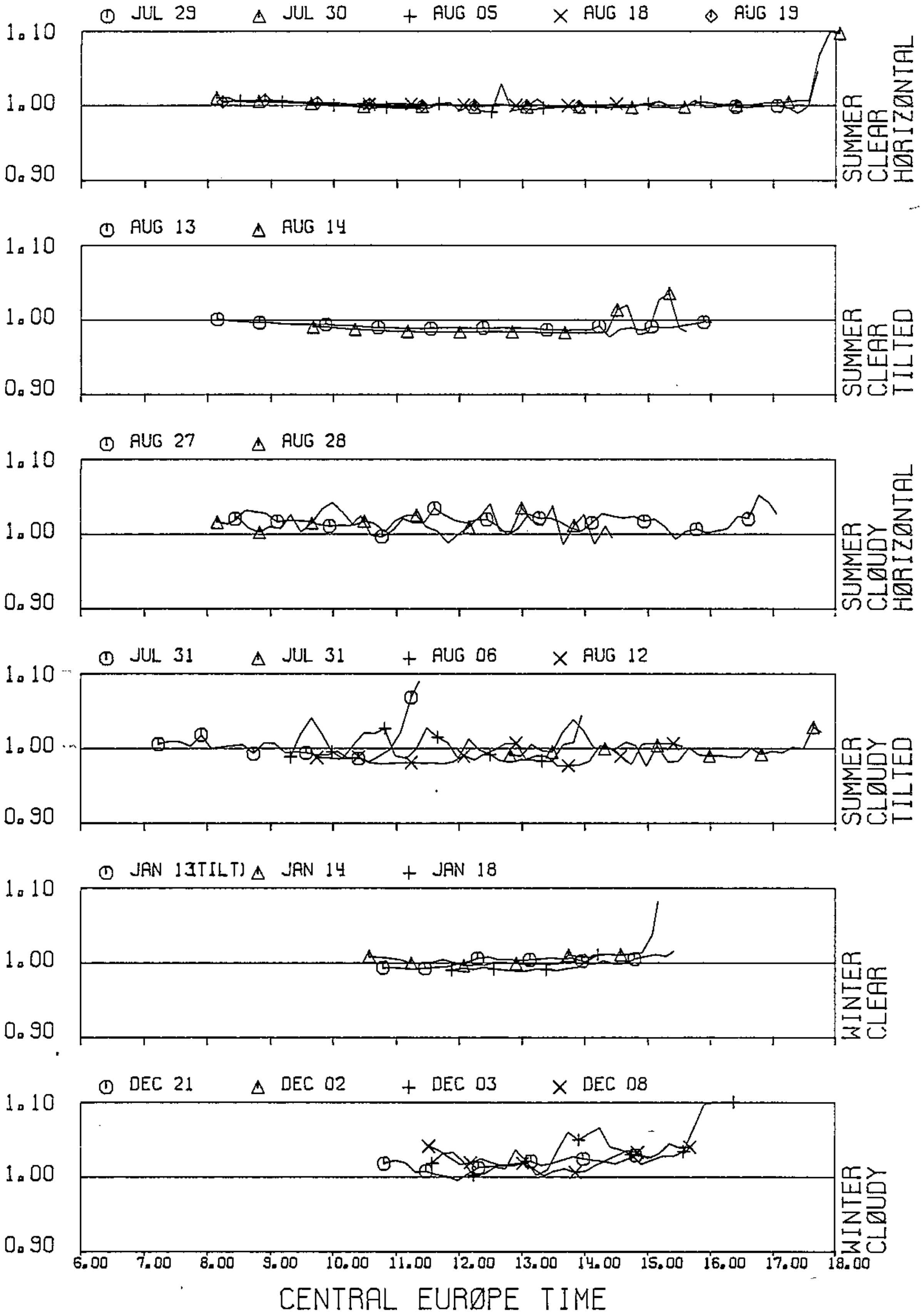
SWISSTECO 115



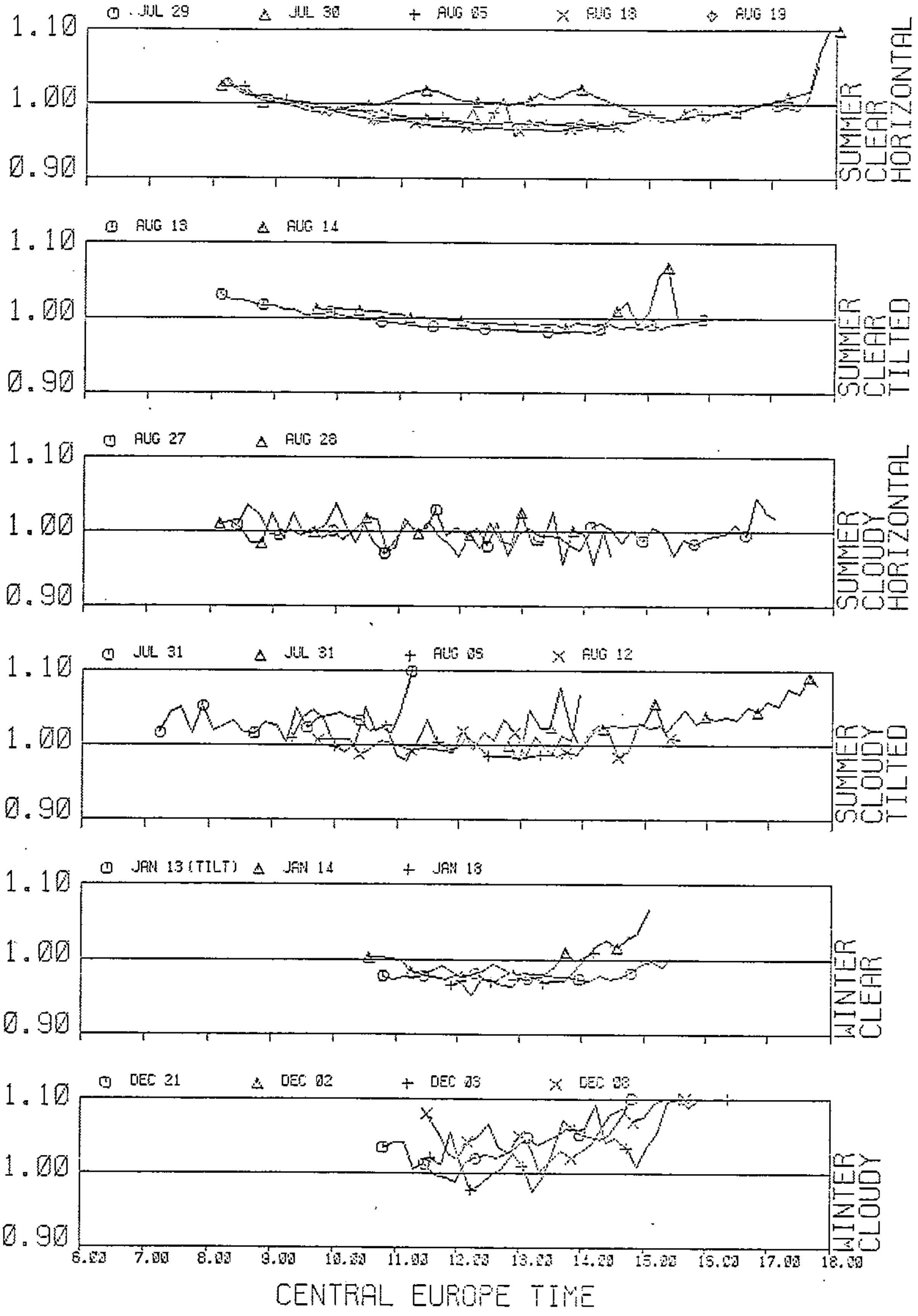
PMOD 6703-A


○ NOV 24
△ NOV 26
+ NOV 27
× DEC 09
◇ DEC 11
1.10
1.00
0.90
WINTER OVERCAST
○ APR 26
△ MAY 03
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
SPRING CLEAR TRACKING
○ JUL 29
△ JUL 30
+ JAN 13
× JAN 14
◇ JAN 18
1.10
1.00
0.90
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME
1.10
1.00
0.90
0.
5.
10.
15.
20.
25.
30.
INSTRUMENT TEMPERATURE (C)
1.10
1.00
0.90
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
1000.
1100.
1200.
INTENSITY (WM-2)
1.10
1.00
0.90
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
INCIDENT ANGLE (DEG)

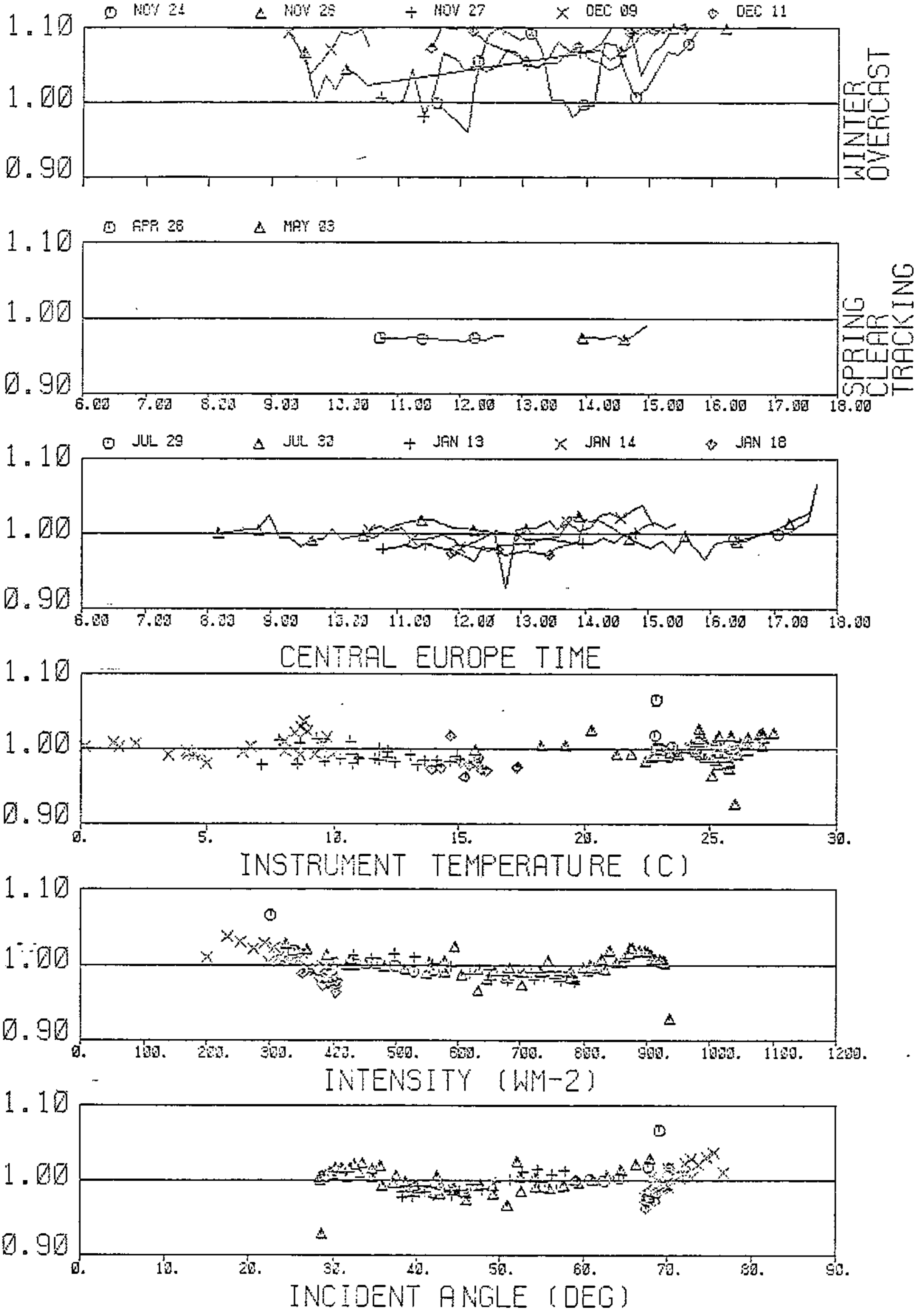
PMOD 6703-A


⊕ JUL 29 △ JUL 30 + AUG 05 × AUG 18 ◇ AUG 19
1.10
1.00
0.90
SUMMER CLEAR HORIZONTAL
⊕ AUG 13 △ AUG 14
SUMMER CLEAR TILTED
⊕ AUG 27 △ AUG 28
SUMMER CLOUDY HORIZONTAL
⊕ JUL 31 △ JUL 31 + AUG 06 × AUG 12
SUMMER CLOUDY TILTED
⊕ JAN 13TILT) △ JAN 14 + JAN 18
WINTER CLEAR
⊕ DEC 21 △ DEC 02 + DEC 03 × DEC 08
WINTER CLOUDY
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
CENTRAL EUROPE TIME

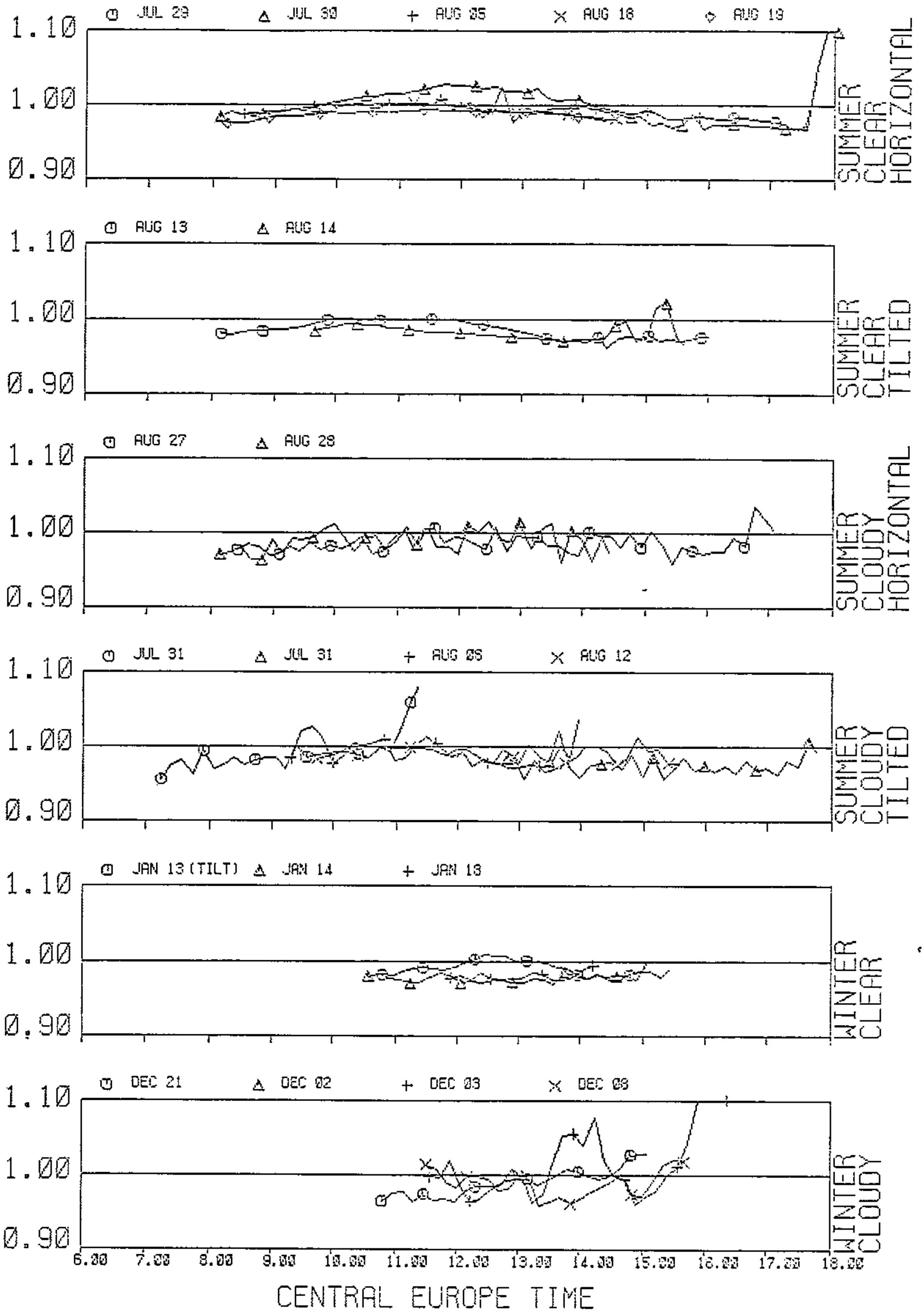
PMOD-CAVITY 1



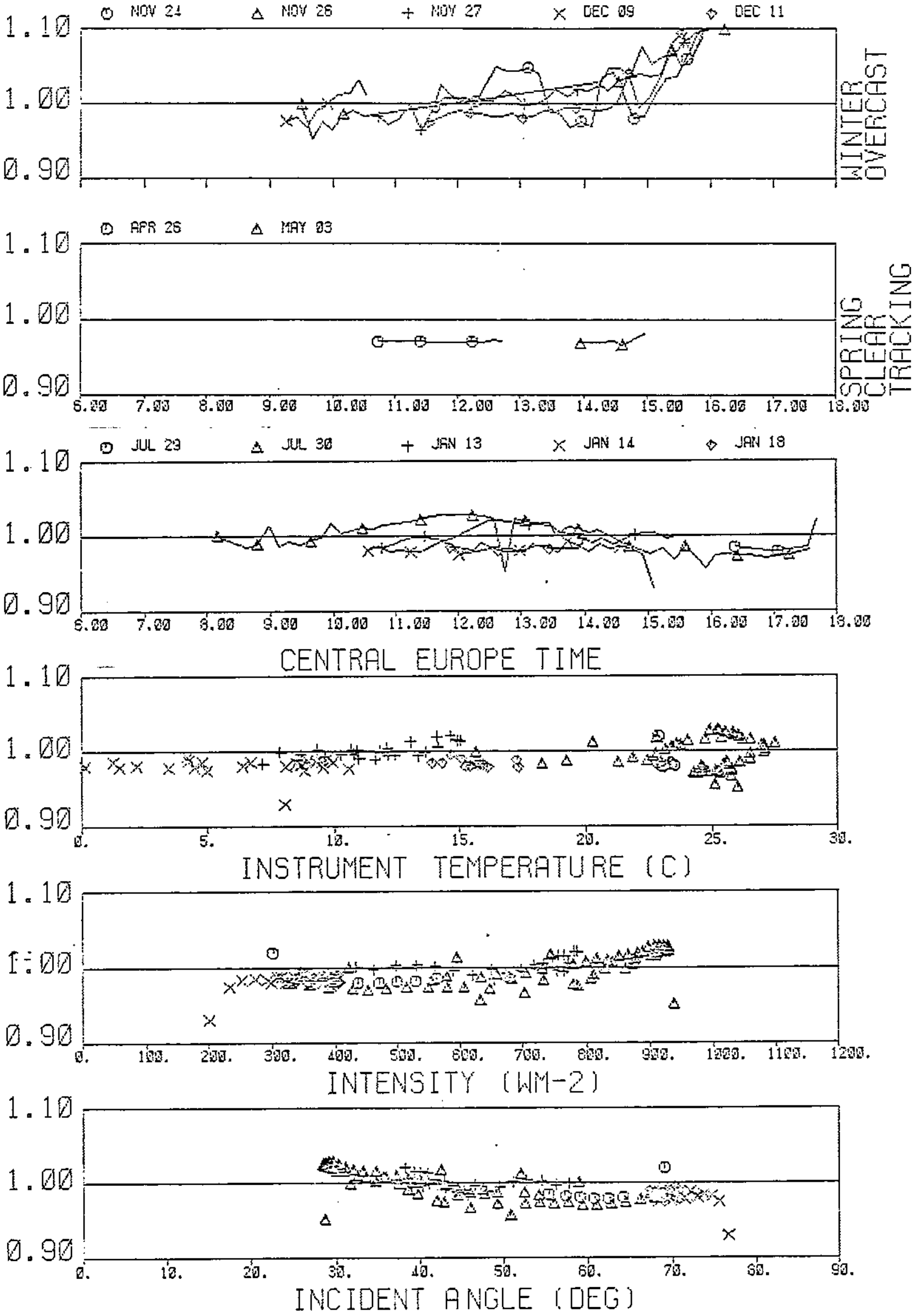
PMOD-CAVITY 1



PMOD-CAVITY 2



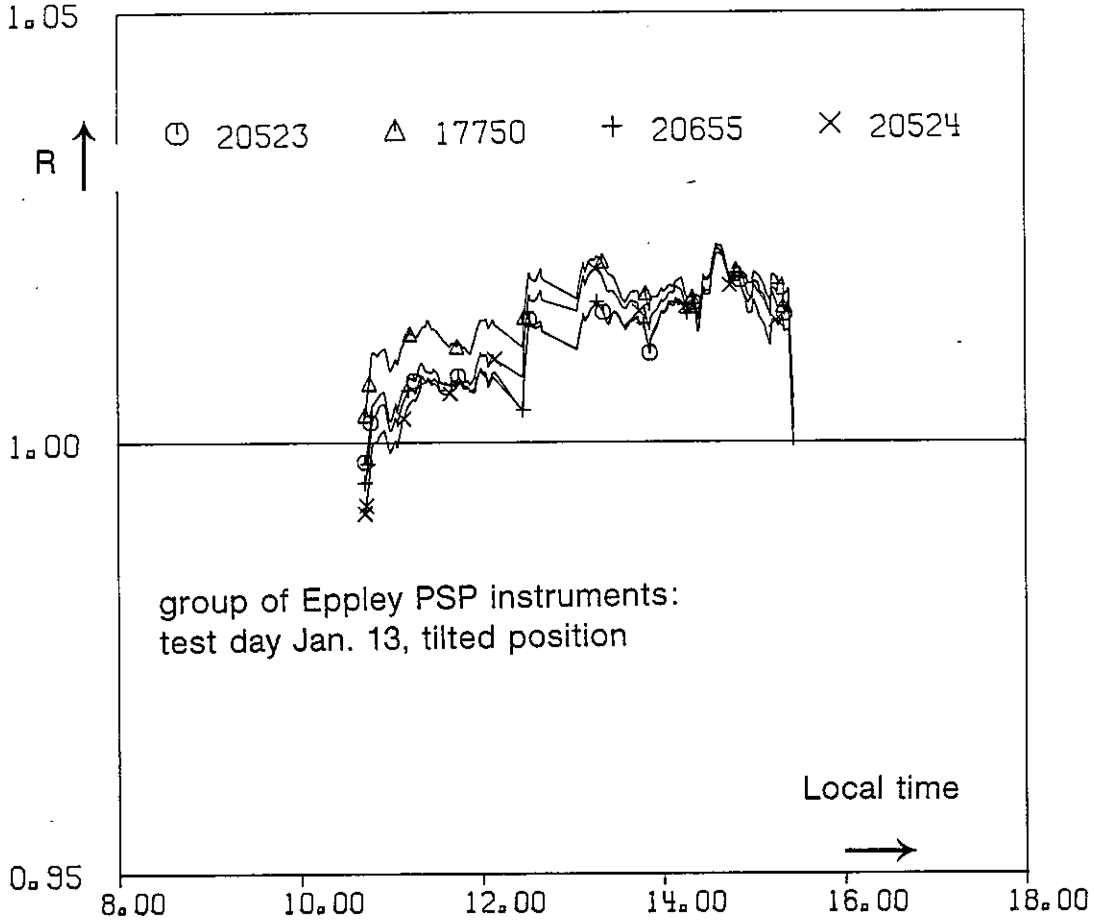
PMOD-CAVITY 2

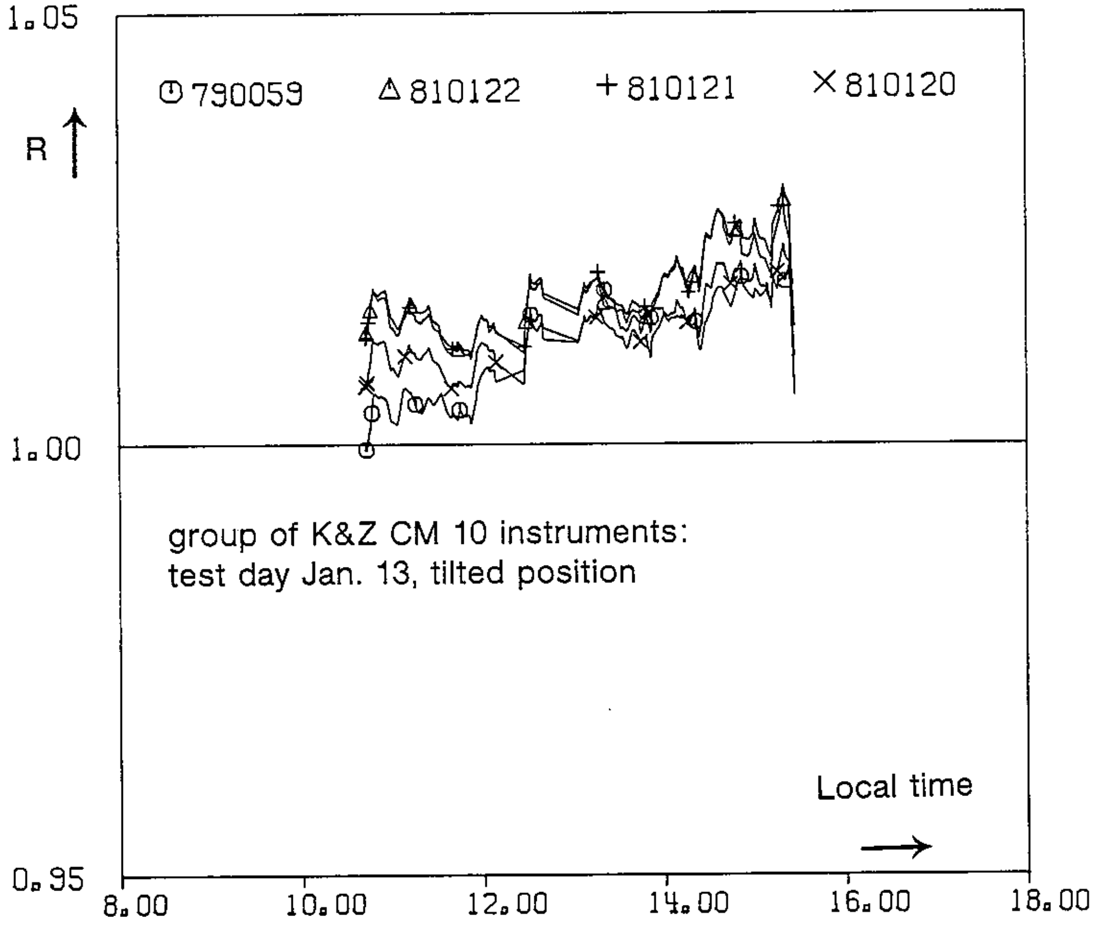


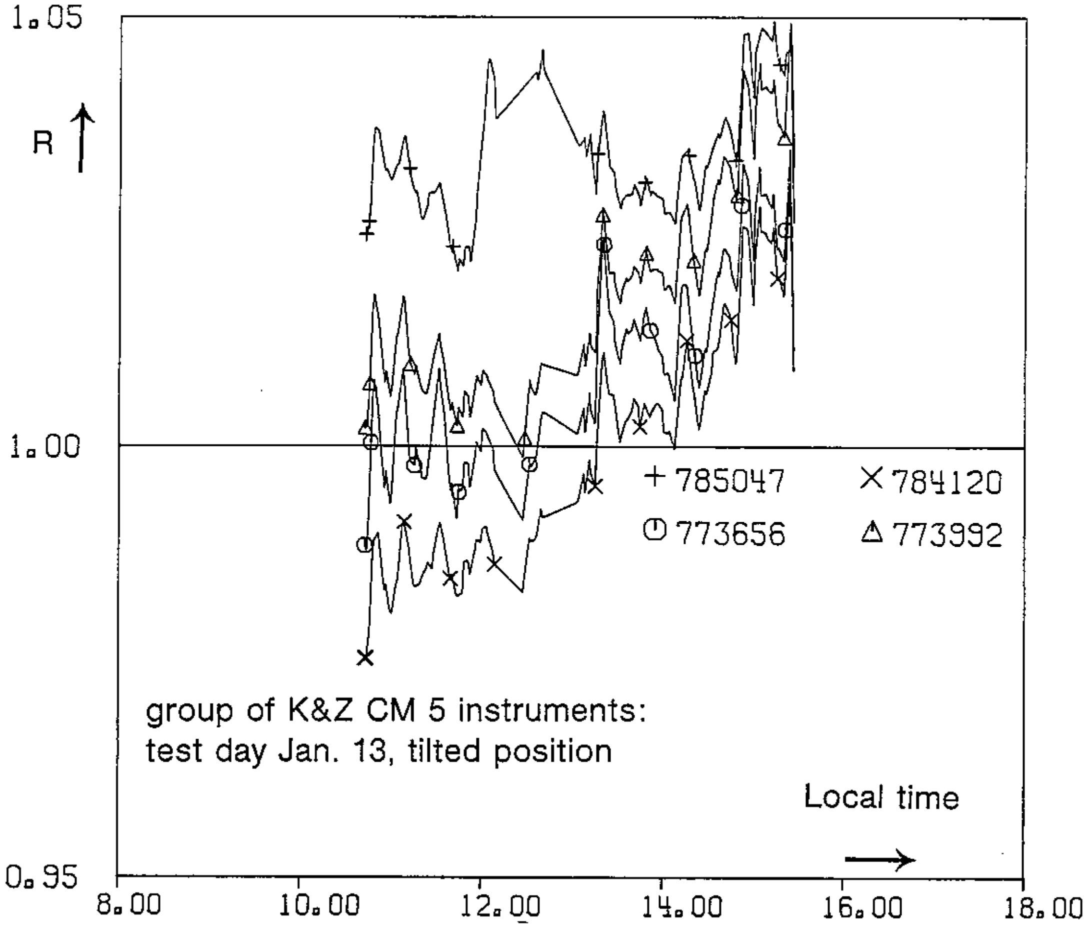
PERFORMANCE OF GROUPS OF INSTRUMENTS ON JAN, 13, TILTED POSITION

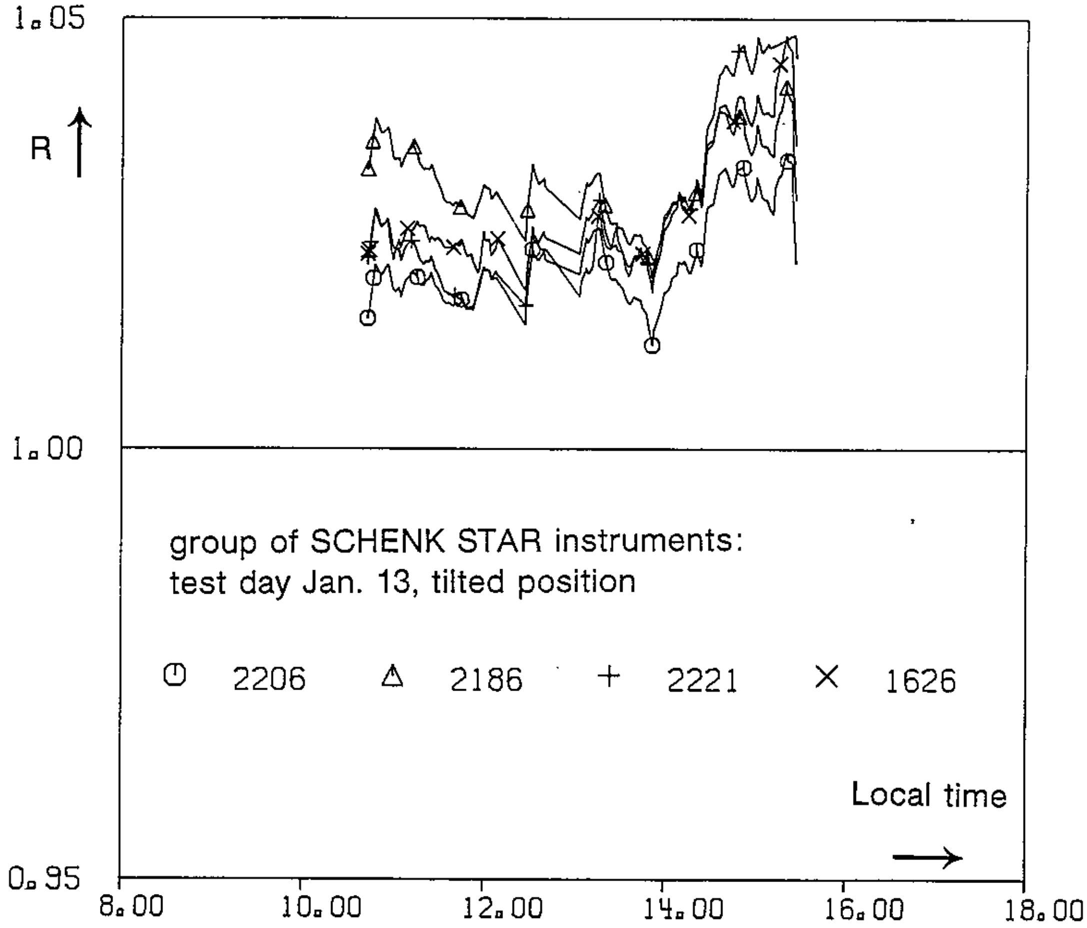
Arrangement of data plots: **Ratio of pyranometer reading and reference reading**

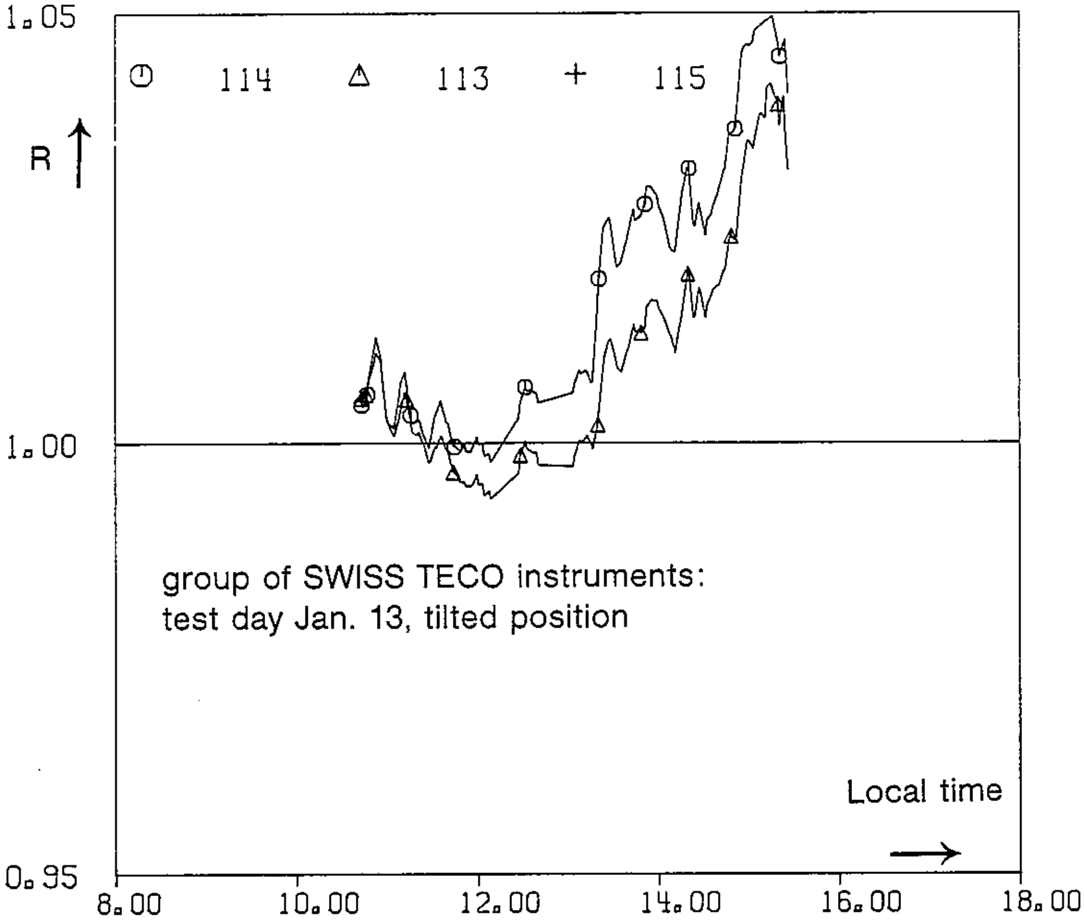
group of Eppley PSP instruments
group of Kipp & Zonen CM 10 instruments
group of Kipp & Zonen CM 5 instruments
group of Schenk Star instruments
group of Swiss Teco instruments
group of EKO Star instruments

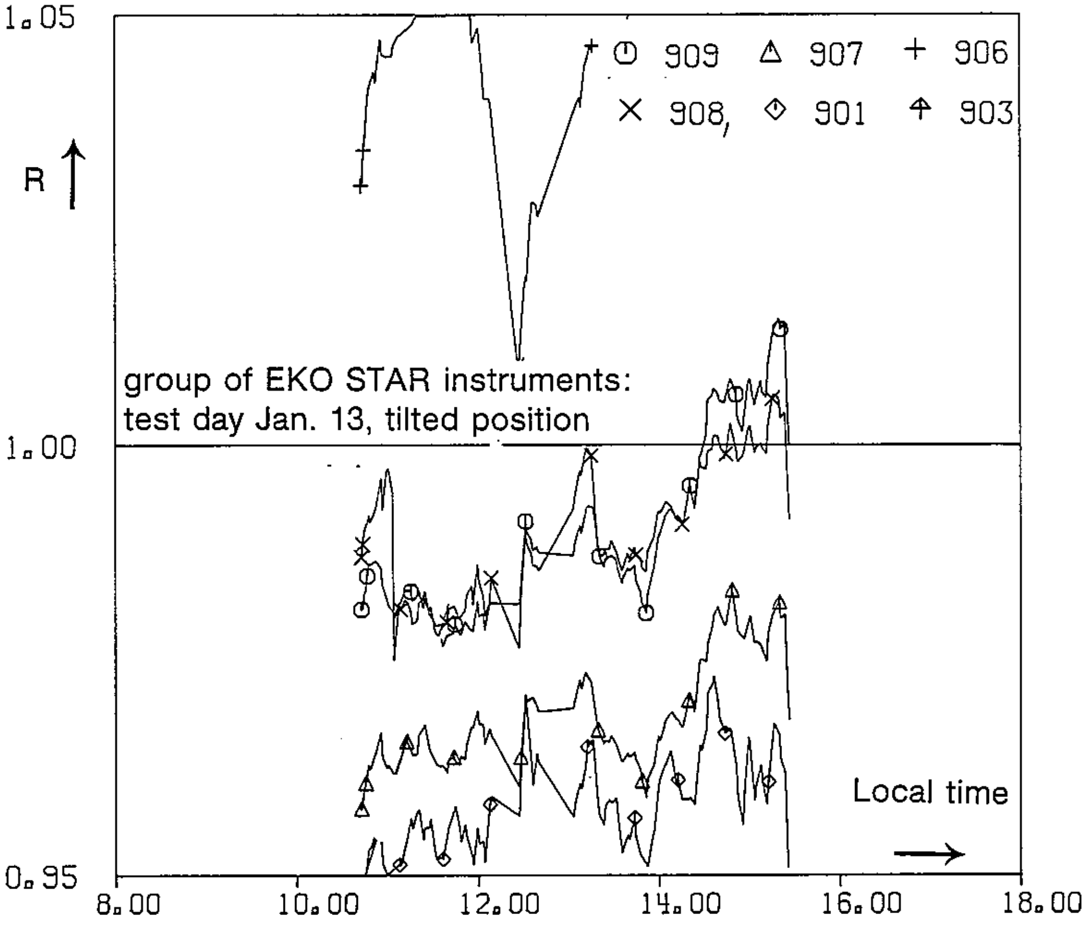

1.05
R
○ 20523
△ 17750
+ 20655
× 20524
1.00
group of Eppley PSP instruments:
test day Jan. 13, tilted position
Local time
0.95
8.00
10.00
12.00
14.00
16.00
18.00


1.05
○ 790059
△ 810122
+ 810121
× 810120
R
1.00
group of K&Z CM 10 instruments:
test day Jan. 13, tilted position
Local time
0.95
8.00
10.00
12.00
14.00
16.00
18.00


1.05
R
1.00
0.95
8.00
10.00
12.00
14.00
16.00
18.00
+ 785047
× 784120
○ 773656
△ 773992
group of K&Z CM 5 instruments:
test day Jan. 13, tilted position
Local time


1.05
R
1.00
0.95
8.00
10.00
12.00
14.00
16.00
18.00
group of SCHENK STAR instruments:
test day Jan. 13, tilted position
○ 2206
△ 2186
+ 2221
× 1626
Local time


1.05
1.00
0.95
R
114
113
115
group of SWISS TECO instruments:
test day Jan. 13, tilted position
Local time
8.00
10.00
12.00
14.00
16.00
18.00


1.05
1.00
0.95
R
909
907
906
908,
901
903
group of EKO STAR instruments:
test day Jan. 13, tilted position
Local time
8.00
10.00
12.00
14.00
16.00
18.00

DATA TAPE DESCRIPTION AND FORMAT

Arrangement of pages:
- Tape description
- Sequence of test days
- Information and key for the data items

Comment:

The data tape can be obtained on request from

Dr. Claus Fröhlich
World Radiation Center
P.O.B. 173
CH-7260 Davos Dorf
Switzerland

Tape Description:

The whole set of outdoor data consists of 130 hours of data recording of three types:

- pyranometer outputs
- meteorological parameters
- description of test arrangement

The time resolution for the time-dependent parameters is one minute. (Based on a sampling rate of ten measurements per minute.)

The recorded data is available on a 9-track, 2400 ft. tape. The density is 1600 BPI and the tape is written in ASCII format:

80 characters per line
10 lines per block
1 file

For ease of logical handling each date line begins with a letter to identify the data (3 identifiers):

```
I = Information, key for data items (20 A4)
S = Description of the test day (20 A4)
D = Data FORMAT(4(1HD, 12.2, F7.3, 7(13.2,F7.3),/), 1HD, I2.2, F7.1,
         1      2(13.2,F7.1),/, 1HD,I2.2, F7.1/ 5(I13.2,F7.1),/.1HD,
         2      12.2, F7.2, 13.2, F7.2)
```

The sequential order of the data lines is:

45 lines of type I (informations lines)

Then, for all 26 measurement days the following sequence:

1 line of type S (day information)
N groups of 7 lines, for each 1 minute recording.
All data are arranged with an identifier and the value itself.
For the data sequence and identification see the preceding page.

To read the data we give an example of a FORTRAN code to read the tape.

```
      PROGRAM READDATA
C
C     INPUT : FILE 99
C     OUTPUT: FILE 06
C
      LOGICAL+1 DAY(80),X(80)
      DIMENSION TITEL(20),ID(43),PYR(31),PAR(11)
 10   FORMAT(20A4)
 11   FORMAT(1X,i2.2,F7.3,7(I3.2,F7.3))
 20   FORMAT(3(1X,I2.2,F7.3,7(I3.2,F7.3),/),1X,I2.2,F7.1,
     1 2(I3.2,F7.1),/,1X,I2.2,F7.1,5(I3.2,F7.1),/,1X,I2.2,F7.2,
     2 I3.2,F7.2)
 30   FORMAT(80A1)
      DO 100 I=1,45
      READ (99,10)TITEL
      WRITE (6,10)TITEL
 100  CONTINUE
      DO 200 IDAY=1,26
 300  READ(99,30)X
      IF (X(1).EQ.'S')THEN
              DECODE(80,30,X)DAY
              WRITE(6,30)DAY
      ELSE IF(X(1).EQ.'D')THEN
              DECODE(80,11,X)ID(1),TIME,(ID(K+1),PYR(K),K=1,7)
              READ(99,20)(ID(K+1),PYR(K),K=8,31),
     1        (ID(J+32),PAR(J),J=1,11)
              WRITE (6,11)ID(1),TIME,(ID(K+1),PYR(K),K=1,7)
              WRITE(6,20)(ID(K+1),PYR(K),K=8,31),
     1        (ID(J+32),PAR(J),J=1,11)
      ELSE
              STOP
      END IF
      GOTO 300
 200  CONTINUE
      END
```

Sequence of test days:

Day	Weather	Tilt
29 July 1981	clear	0°
30 July 1981	clear	0°
5 August 1981	clear	0°
18 August 1981	clear	0°
19 August 1981	clear	0°
13 August 1981	clear	30°
13 January 1982	clear	30°
14 January 1982	clear	0°
18 January 1982	clear	0°
26 April 1982	clear	Tracking
3 May 1982	clear	Tracking
14 August 1981	clear	45°
27 August 1981	cloudy	0°
28 August 1981	cloudy	0°
31 July 1981	cloudy	30°
31 July 1981	cloudy	60°
6 August 1981	cloudy	30°
12 August 1981	cloudy	45°
21 December 1981	cloudy	30°
3 December 1981	cloudy	0°
8 December 1981	cloudy	0°
24 November 1981	overcast	0°
26 November 1981	overcast	0°
27 November 1981	overcast	0°
9 December 1981	overcast	0°
11 December 1981	overcast	30°

Information and key for the data items:

I00 time (Central Europe Time)

I##	Manufact	Type	Number	Calib.Manuf.	Unit	Default Value
I01	WRC	PMOD	6703-A	24.82	MICROV/WM-2	99,999
I02	EKO	-	81901	8.24	MICROV/WM-2	99,999
I03	EKO	-	81903	7.85	MICROV/WM-2	99,999
I04	EKO	-	81906	6.89	MICROV/WM-2	99,999
I05	EKO	-	81907	7.25	MICROV/WM-2	99,999
I06	EKO	-	81908	9.61	MICROV/WM-2	99,999
I07	EKO	-	81909	7.42	MICROV/WM-2	99,999
I08	EPPLEY	PSP	14806F3	9.81	MICROV/WM-2	99,999
I10	EPPLEY	PSP	17750F3	9.15	MICROV/WM-2	99,999
I10	EPPLEY	PSP	18135F3	8.78	MICROV/WM-2	99,999
I11	EPPLEY	PSP	20523F3	9.95	MICROV/WM-2	99,999
I12	EPPLEY	PSP	20524F3	10.10	MICROV/WM-2	99,999
I13	EPPLEY	PSP	20655F3	10.28	MICROV/WM-2	99,999
I14	KIPP&ZONEN	CM5	773656	11.94	MICROV/WM-2	99,999
I15	KIPP&ZONEN	CM5	773992	12.62	MICROV/WM-2	99,999
I16	KIPP&ZONEN	CM5	774120	13.41	MICROV/WM-2	99,999
I17	KIPP&ZONEN	CM5	785017	10.59	MICROV/WM-2	99,999
I18	KIPP&ZONEN	CM5	785047	12.23	MICROV/WM-2	99,999
I19	KIPP&ZONEN	CM10	790059	5.68	MICROV/WM-2	99,999
I20	KIPP&ZONEN	CM10	810119	4.58	MICROV/WM-2	99,999
I21	KIPP&ZONEN	CM10	810120	4.54	MICROV/WM-2	99,999
I22	KIPP&ZONEN	CM10	810121	4.66	MICROV/WM-2	99,999
I23	KIPP&ZONEN	CM10	810122	4.24	MICROV/WM-2	99,999
I24	SCHENK	STERN	1626	14.32	MICROV/WM-2	99,999
I25	SCHENK	STERN	2186	14.94	MICROV/WM-2	99,999
I26	SCHENK	STERN	2209	15.36	MICROV/WM-2	99,999
I27	SCHENK	STERN	2217	14.16	MICROV/WM-2	99,999
I28	SCHENK	STERN	2221	15.24	MICROV/WM-2	99,999
I29	SWISSTECO	SS-25	113	-	MICROV/WM-2	99,999
I30	SWISSTECO	SS-25	114	-	MICROV/WM-2	99,999
I31	SWISSTECO	SS-25	115	-	MICROV/WM-2	99,999

I All Pyranometer Data are the Instrument Outputs in Millivolt

I50	Normal Direct Radiation	(W/M2)	9999,9
I51	Diffuse Radiation	(W/M2)	9999,9
I52	Reflex Radiation (Horizontal)	(W/M2)	9999,9
I60	Air Temperature	(DEG C)	9999,9
I61	Reference Instrument Temperature	(DEG C)	9999,9
I62	Relative Humidity	(PER CENT)	9999,9
I63	Air Pressure	(MILLIBAR)	9999,9
I64	Wind Velocity	(M/S)	9999,9
I65	Wind Direction	(DEG)	9999,9
I70	Solar Altitude	(DEG)	9999,9
I71	Solar Azimuth	(DEG)	9999,9

APPENDIX B

INDOOR DATA (BORÅS AND DAVOS INVESTIGATIONS)

- Classification of pyranometers
- Tables of responsitivity data; SP, Borås
  tilt, level of irradiance, temperature coefficient
- Results of cosine response determination at PMOD/WRC, Davos
- Comparison of characterization data from different laboratories

CLASSIFICATION OF PYRANOMETERS

Arrangement: 1 table

Comment:

Excerpt from chapter 9 of the WMO-Guide Meteorological Instruments and Observing Practices.

Classification of pyranometers

(Excerpt from Chapter 9 of the WMO-Guide
Meteorological Instrument and Observing
Practices)

Characteristic	Secondary standard	First class	Second class
Resolution (smallest detectable change in W m^{-2})	± 1	± 5	± 10
Stability (percentage of full scale, change/year)	± 1	± 2	± 5
Cosine response (percentage deviation from the mean at 10^{o} solar elevation on a clear day)	< ± 3	< ± 7	< ± 15
Azimuth response (percentage deviation from the mean at 10^{o} solar elevation on a clear day	< ± 3	< ± 5	< ± 10
Temperature response (percentage maximum error due to change of ambient temperature within the operating range)	± 1	± 2	± 5
Non-linearity (percentage of full scale)	± 0.5	± 2	± 5
Spectral sensitivity (percentage deviation from mean absorptance 0.3 to 3 μm)	± 2	± 5	± 10
Response time (99% response)	< 25 s	< 1 min	< 4 min

TABLES OF RESPONSIVITY DATA; STATENS PROVNINGSANSTALT, BORAS

Arrangement of tables: **Responsivity variation with respect to**

- tilt
- level of irradiance
- ambient air temperature

RESPONSIVITY VARIATION WITH TILT ANGLE IN PARTS PER THOUSAND

Cable connection upwards (north)

Pyranometer	0	10	20	30	40	50	60	70	80	90
WRC AV-1/1	0	-1	-1	-1	-0	-0	-0	-1	-1	-0
WRC AV-2/2	0	-1	-1	-1	-1	-1	-0	-1	-1	-1
PMOD 6703-A/3	0	-7	-12	-17	-20	-23	-25	-26	-26	-26
EKO 81901/4	0	-0	-1	-3	-5	-7	-8	-9	-9	-9
EKO 81903/5	0	-1	-2	-4	-6	-9	-10	-11	-12	-11
EKO 81906/6	0	-8	-18	-23	-26	-28	-28	-28	-28	-27
EKO 81907/7	0	-8	-16	-22	-25	-28	-29	-30	-30	-30
EKO 81908/8	0	-5	-10	-15	-17	-19	-20	-20	-20	-20
EKO 81909/9	0	-5	-10	-13	-15	-17	-18	-18	-18	-18
Eppley PSP 14806F3/10	0	0	0	0	-0	-0	-1	-1	-1	-2
Eppley PSP 17750F3/11	0	0	0	0	0	-0	-0	-1	-1	-2
Eppley PSP 18135F3/12	0	0	0	0	0	1	0	-0	-1	-1
Eppley PSP 20523F3/13	0	0	0	0	-0	-0	-1	-1	-1	-2
Eppley PSP 20524F3/14	0	0	0	0	0	0	0	-0	-1	-2
Eppley PSP 20655F3/15	0	0	0	0	1	0	1	0	0	0
K&Z CM5-773656/16	0	-2	-6	-11	-15	-18	-21	-22	-23	-23
K&Z CM5-773992/17	0	-3	-8	-15	-20	-25	-28	-30	-31	-31
K&Z CM5-774120/18	0	-3	-8	-14	-19	-24	-27	-29	-29	-29
K&Z CM5-785017/19	0	-2	-5	-10	-14	-18	-20	-22	-23	-23
K&Z CM5-785047/20	0	-1	-4	-9	-13	-17	-20	-22	-23	-23
K&Z CM10-790059/21	0	0	1	1	1	1	1	1	1	1
K&Z CM10-810119/22	0	0	0	0	1	1	1	1	1	1
K&Z CM10-810120/23	0	0	0	1	1	1	1	1	1	1
K&Z CM10-810121/24	0	0	0	0	1	1	1	1	1	1
K&Z CM10-810122/25	0	0	0	0	0	0	1	1	1	1
Schenk Stern 1626/26	0	-3	-8	-14	-17	-20	-22	-24	-25	-25
Schenk Stern 2186/27	0	-6	-14	-20	-24	-27	-29	-31	-31	-32
Schenk Stern 2209/28	0	-6	-14	-19	-22	-24	-26	-27	-28	-28
Schenk Stern 2217/29	0	-8	-16	-21	-25	-27	-30	-31	-32	-32
Schenk Stern 2221/30	0	-7	-14	-19	-22	-26	-29	-31	-32	-32
Swissteco SS-25/31	0	0	1	1	1	1	1	0	1	2
Swissteco SS-25/32	0	-0	0	0	0	-0	-0	-0	0	1
Swissteco SS-25/33	0	0	1	1	0	0	0	0	1	2
EKO 81909/9:500	0	-2	-5	-8	-9	-10	-11	-12	-11	-11
EKO 81909/9:750	0	-3	-7	-10	-13	-13	-14	-15	-15	-14
EKO 81909/9:1000	0	-5	-10	-13	-15	-17	-18	-18	-18	-18
EKO 81909/9:1250	0	-5	-11	-14	-17	-19	-20	-21	-21	-20
K&Z CM5-785047/20:500	0	-1	1	0	-3	-3	-6	-7	-8	-9
K&Z CM5-785047/20:750	0	-1	-3	-5	-10	-13	-15	-17	-18	-19
K&Z CM5-785047/20:1000	0	-1	-4	-9	-13	-17	-20	-22	-23	-23
K&Z CM5-785047/20:1250	0	-2	-6	-11	-16	-21	-24	-26	-28	-27
Schenk Stern 2221/30:500	0	-4	-7	-10	-13	-16	-19	-21	-22	-22
Schenk Stern 2221/30:750	0	-6	-10	-15	-19	-23	-25	-27	-28	-28
Schenk Stern 2221/30:1000	0	-7	-14	-19	-22	-26	-29	-31	-32	-32
Schenk Stern 2221/30:1250	0	-8	-16	-21	-25	-29	-31	-33	-34	-34

Note: EKO 81901 and 81903 have a black field upwards
EKO 81906-9 and all Schenk Star pyranometers
have a black/white border upwards

RESPONSIVITY TEMPERATURE DEPENDANCE

Pyranometer	-35 deg	-10 deg	5 deg	20 deg	35 deg
1 WRC AV-1	0.978	0.987	0.994	1.000	1.002
2 WRC AV-2	0.984	0.990	0.995	1.000	1.002
3 PMOD 6703-A	0.994	0.997	0.998	1.000	0.998
4 EKO 81901	0.913	0.955	0.984	1.000	1.006
5 EKO 81903	0.873	0.933	0.976	1.000	1.013
6 EKO 81906	0.975	0.989	0.996	1.000	1.000
7 EKO 81907	0.941	0.966	0.986	1.000	1.009
8 EKO 81908	0.997	0.998	1.000	1.000	0.990
9 EKO 81909	0.986	0.998	1.000	1.000	0.997
10 Eppley PSP 14806F3	0.980	0.989	0.996	1.000	1.003
11 Eppley PSP 17750F3	0.996	1.000	1.000	1.000	0.994
12 Eppley PSP 18135F3	0.981	0.991	0.997	1.000	1.006
13 Eppley PSP 20523F3	0.985	0.992	0.997	1.000	0.999
14 Eppley PSP 20524F3	0.986	0.993	0.997	1.000	1.005
15 Eppley PSP 20655F3	0.985	0.992	0.997	1.000	1.001
16 K&Z CM5-773656	1.021	1.019	1.013	1.000	0.985
17 K&Z CM5-773992	1.024	1.020	1.012	1.000	0.984
18 K&Z CM5-774120	1.028	1.023	1.014	1.000	0.983
19 K&Z CM5-785017	1.039	1.029	1.016	1.000	0.983
20 K&Z CM5-785047	1.027	1.023	1.014	1.000	0.984
21 K&Z CM11-790059	0.967	1.003	1.009	1.000	0.996
22 K&Z CM11-810119	0.947	0.988	0.997	1.000	0.997
23 K&Z CM11-810120	0.952	0.991	0.999	1.000	0.982
24 K&Z CM11-810121	0.952	0.991	0.999	1.000	0.982
25 K&Z CM11-810122	0.951	0.990	0.999	1.000	1.001
26 Schenk Stern 1626	1.045	1.032	1.018	1.000	0.980
27 Schenk Stern 2186	1.042	1.030	1.017	1.000	0.983
28 Schenk Stern 2209	1.032	1.024	1.013	1.000	0.984
29 Schenk Stern 2217	1.042	1.031	1.017	1.000	0.983
30 Schenk Stern 2221	1.042	1.029	1.017	1.000	0.982
31 Swissteco SS-25 113	1.035	1.026	1.014	1.000	0.982
32 Swissteco SS-25 114	1.042	1.029	1.017	1.000	0.981
33 Swissteco SS-25 115	1.039	1.036	1.013	1.000	0.989

RESPONSIVITY VARIATION WITH IRRADIANCE LEVEL IN PARTS PER THOUSAND

Responsivity normalized to one at 500 W/m^2.

Pyranometer		32.2	62.5	125	250	500	1000
1	WRC AV-1/1	-9	-7	-6	-3	0	3
2	WRC AV-2/2	-12	-9	-6	-3	0	3
3	WRC AV-3/3	18	18	17	11	0	-14
4	EKO MS-42 A81901/4	4	3	3	2	0	-4
5	EKO MS-42 A81903/5	5	5	5	3	0	-4
6	EKO MS-42 81906/6	-7	-5	-3	-1	0	-3
7	EKO MS-42 A81902/7	13	12	10	7	0	-12
8	EKO A81908/8	7	8	7	4	0	-8
9	EKO A81909/9	3	4	4	3	0	-6
10	Eppley PSP 14305F3/10	-1	-1	-1	-1	0	1
11	Eppley PSP 17750F3/11	-0	-1	-1	-0	0	1
12	Eppley PSP 18135F3/12	-2	-2	-1	-1	0	1
13	Eppley PSP 20523F3/13	-1	-1	-1	-1	0	1
14	Eppley PSP 20524F3/14	-1	-1	-1	-1	0	1
15	Eppley PSP 20655F3/15	-0	-1	-1	-1	0	1
16	K&Z CM5-773656/16	5	5	5	4	0	-13
17	K&Z CM5-773992/17	4	4	4	4	0	-13
18	K&Z CM5-774120/18	4	5	5	4	0	-14
19	K&Z CM5-785017	3	3	3	3	0	-10
20	K&Z CM5-785047/20	4	4	4	3	0	-12
21	K&Z CM11-790059/21	-9	-8	-7	-5	0	9
22	K&Z CM11-810119/22	-3	-4	-4	-3	0	5
23	K&Z CM11-810120/23	-4	-4	-4	-2	0	5
24	K&Z CM11-810121/24	-4	-4	-4	-3	0	6
25	K&Z CM11-810122/25	-5	-4	-4	-3	0	6
26	Schenk Stern 1626/26	12	11	10	6	0	-12
27	Schenk Stern 2186/27	3	4	4	3	0	-8
28	Schenk Stern 2209/28	-9	-6	-3	-1	0	-3
29	Schenk Stern 2217/29	2	3	4	3	0	-8
30	Schenk Stern 2221/30	1	2	3	3	0	-9
31	Swissteco SS-25 113/31	21	19	17	11	0	-16
32	Swissteco SS-25 114/32	11	12	12	9	0	-13
33	Swissteco SS-25 116/33	14	14	12	9	0	-13

RESULTS OF COSINE RESPONSE DETERMINATION AT PMOD/WRC, DAVOS

Arrangement of data: 31 tables; one table for each instrument ordered alphabetically and with ascending serial numbers

7 graphical representations for one instrument of each type

Comments with respect to tables:

The first column in the four tables is the azimuth angle in degrees. Azimuth zero means cable pointing north e.g. upwards at tilt angle of 90°.

The second column in the first table (tilt angle 90°) shows normal incidence intensities in Wm^{-2}. These intensities are the reference values for the evaluation of the deviations.

All other columns are 4 deviations from the reference value at the corresponding azimuth angle.

The mean and standard deviations summarize the deviations for each $\cos\Theta$ in %. The only exception is column one in table one, where the mean is in Wm^{-2}.

Obvious outliers are excluded from the calculations of the mean and standard deviation. The values are flagged with parentheses.

The last line summarizes the tilt error calculated from the results of the cosine deviation at different tilt. As the measurement at tilt is a combination of cosine and tilt, the corresponding cosine deviation for e.g. $\cos\Theta = 0.71$ (corresponding to an incident and tilt angle of 45°) is taken from the measurements at 90° tilt and subtracted from the value measured at the corresponding tilt. (C. Fröhlich)

Comments with respect to graphs:

The first two graphs show the deviations from cosine at 90° and 45° tilt. The letters indicate the corresponding azimuth angle as in the tables. The full line connects the azimuthal means at each cosine angle. For comparison the mean line at 90° tilt is repeated in the graph for the 45° tilt.

The third graph displays the azimuthal variation at normal incidence and 90° tilt. This variation is mainly due to sensitivity changes of the detector due to its orientation relative to the gravity field.

The forth graph summarizes the results of the tilt measurements. The data labelled "corrected" are corrected for the cosine effect as the tabulated values, that is they represent the deviations due to tilt only. The data "uncorrected" are plotted as they are measured, that is the deviations from the normal incidence value at 90° tilt. (C. Fröhlich)

```
Date:    9- 4-82      CM5 773656      Cal.fact. 11.53 µV/W/m²
Tilt     90.
            1.00      0.85      0.70      0.55      0.40      0.25      0.10
------------------------------------------------------------------------------
  0.A     563.7                          -1.14    (-7.62)    -5.55     -0.42
 45.B     502.1                           2.81      4.38      0.52    -20.30
 90.C     506.0                           1.75      2.94     -1.54    -15.90
135.D     509.1                           1.49      3.09      0.27    -14.03
180.E     512.6       1.29      1.73      1.21                          -9.28
225.F     513.2       0.16      1.04      0.43                         -16.62
270.G     510.8       0.07      0.82      0.34                         -19.67
315.H     512.5       0.37      0.95      0.93                         -17.53
------------------------------------------------------------------------------
Mean      516.3       0.47      1.13      0.98      3.47     -1.57    -14.22
Stdev      3.79       0.56      0.41      1.16      0.79      2.80      6.56

Tilt     45.
            0.71      0.60      0.49      0.39      0.28      0.18      0.07
------------------------------------------------------------------------------
  0.A      (0.49)   (-3.95)   (-7.71)   (-3.73)                         (0.92)
 45.B       8.68      8.09      6.53      4.94                        -31.31
 90.C       9.35      6.82      4.95      3.10                        -20.76
135.D       8.90      5.80      4.41      2.66                        -18.61
180.E       8.18                          2.77     -1.43     -6.56    (-9.29)
225.F       7.70                          1.65     -2.41    -12.60    -17.23
270.G       8.62                          0.87     -4.40    -13.91    -21.52
315.H       7.61                          0.53     -3.82    -15.04   (-69.18)
------------------------------------------------------------------------------
Mean        8.43      6.90      5.30      2.36     -3.02    -12.03    -21.89
Stdev       0.64      1.15      1.10      1.50      1.35      3.78      5.54

Tilt     30.
            0.50      0.43      0.35      0.28      0.20      0.12      0.05
------------------------------------------------------------------------------
  0.A     (-1.92)
 45.B       4.73
 90.C       6.36
135.D       5.44
180.E    (-27.73)
225.F       4.36
270.G       5.16
315.H       4.34
------------------------------------------------------------------------------
Mean        5.07
Stdev       0.77

Tilt     60.
            0.87      0.74      0.61      0.48      0.35      0.22      0.09
------------------------------------------------------------------------------
  0.A      (2.69)
 45.B      12.35
 90.C      11.44
135.D      10.86
180.E      10.40
225.F      (9.71)
270.G      10.05
315.H       9.42
------------------------------------------------------------------------------
Mean       10.60
Stdev       1.03

Tilt Angle            90.0     45.00     30.00     60.00
Tilt Error                      7.33      4.29     10.17
```

```
Date: 13- 4-82        CM5 773992          Cal.fact.  12.10 µV/W/m²
Tilt   90.
            1.00     0.85     0.70     0.55     0.40     0.25     0.10
----------------------------------------------------------------------
  0.A      579.4                      -1.09    -6.44    -5.54     2.73
 45.B      558.5                      -0.35    -1.79    -4.73   -16.31
 90.C      560.8                      -1.53    -3.19    -5.80   -12.60
135.D      562.3                      -1.61    -3.80    -4.91   -14.40
180.E      563.9    -1.16    -0.57    -1.81                      -7.35
225.F      565.2    -1.62    -1.77    -2.69                     -13.94
270.G      563.2    -1.42    -1.96    -2.48                     -17.86
315.H      564.4    -0.62    -1.50    -1.21                     -15.59
----------------------------------------------------------------------
Mean       564.7    -1.20    -1.45    -1.60    -3.80    -5.25   -11.92
Stdev       1.12     0.43     0.62     0.75     1.95     0.51     6.70

Tilt    45.
            0.71     0.60     0.49     0.39     0.28     0.18     0.07
----------------------------------------------------------------------
  0.A      -2.73    -6.44    -9.21    -5.01                     (3.49)
 45.B      -3.67    -2.72    -3.86    -3.93                     -25.37
 90.C      -2.26    -3.33    -4.58    -5.06                     -18.09
135.D      -2.10    -4.32    -5.14    -5.52                     -19.52
180.E      -2.71                      -5.58    -8.98   -10.70   -10.33
225.F      -3.25                      -6.78    -9.41   -17.43   -16.48
270.G   (-22.54)                      -7.49   -11.02   -18.08   -22.05
315.H      -3.73                      -8.27   -10.49   -19.28   -19.54
----------------------------------------------------------------------
Mean       -2.92    -4.20    -5.70    -5.95    -9.98   -16.37   -18.77
Stdev       0.65     1.63     2.40     1.44     0.94     3.86     4.70

Tilt    30.
            0.50     0.43     0.35     0.28     0.20     0.12     0.05
----------------------------------------------------------------------
  0.A      -4.06
 45.B      -5.50
 90.C      -3.70
135.D      -3.47
180.E      -4.13
225.F      -4.90
270.G      -4.97
315.H      -5.39
----------------------------------------------------------------------
Mean       -4.52
Stdev       0.77

Tilt    60.
            0.87     0.74     0.61     0.48     0.35     0.22     0.09
----------------------------------------------------------------------
  0.A      -1.40
 45.B   (-54.15)
 90.C      -0.62
135.D      -0.70
180.E      -1.21
225.F      -1.77
270.G      -1.89
315.H      -2.39
----------------------------------------------------------------------
Mean       -1.43
Stdev       0.63

Tilt Angle           90.0    45.00    30.00    60.00
Tilt Error                   -1.48    -2.18    -0.35
```

```
Date: 27- 2-82         CM5 774120          Cal.fact. 12.61 µV/W/m²
Tilt     90.
                 1.00      0.85      0.70      0.55      0.40      0.25      0.10
------------------------------------------------------------------------------
   0.A    1023.6                              -3.01     -6.17     -6.55     -6.47
  45.B    1015.8                              -2.36     -4.39     -7.71    -19.32
  90.C    1019.4                              -1.91     -4.62     -6.84    -15.42
 135.D    1020.0                              -1.26     -3.62     -4.07    -13.45
 180.E    1021.1     -0.56     -0.34          -1.03                          -7.95
 225.F    1021.9     -1.00     -1.10          -1.94                         -15.36
 270.G    1020.1     -1.06     -1.82          -2.66                         -22.28
 315.H    1020.5     -0.79     -2.07          -1.94                         -24.69
------------------------------------------------------------------------------
Mean      1020.3     -0.85     -1.33          -2.01     -4.70     -6.29    -15.62
Stdev       0.22      0.22      0.78           0.66      1.07      1.56      6.41

Tilt     45.
                 0.71      0.60      0.49      0.39      0.28      0.18      0.07
------------------------------------------------------------------------------
   0.A     -2.90     -5.05     -8.27     -7.55                         -12.20
  45.B     -4.09     -4.60     -6.40     -6.80                         -24.30
  90.C     -3.61     -4.96     -6.36     -6.95                         -22.11
 135.D     -3.13     -4.75     -5.62     -6.06                         -18.35
 180.E     -3.28                         -5.62     -8.52    -12.70    -10.81
 225.F     -2.87                         -7.01     -8.94  (-74.87)(-90.56)
 270.G     -2.60                      (-95.49)(-81.81     -18.91    -27.97
 315.H     -2.89                         -6.02     -9.41    -18.28    -21.56
------------------------------------------------------------------------------
Mean       -3.17     -4.84     -6.66   - 6.57    - 8.96    -16.63    -19.61
Stdev       0.48      0.20      1.13      0.69      0.45      3.42      6.27

Tilt     30.
                 0.50      0.43      0.35      0.28      0.20      0.12      0.05
------------------------------------------------------------------------------
   0.A     -4.75
  45.B     -6.71
  90.C     -6.16
 135.D     -6.16
 180.E     -5.01
 225.F     -4.70
 270.G     -4.16
 315.H     -4.69
------------------------------------------------------------------------------
Mean       -5.29
Stdev       0.92

Tilt     60.
                 0.87      0.74      0.61      0.48      0.35      0.22      0.09
------------------------------------------------------------------------------
   0.A     -1.62
  45.B     -1.35
  90.C     -1.63
 135.D     -1.95
 180.E     -1.89
 225.F     -1.84
 270.G     -1.62
 315.H     -2.25
------------------------------------------------------------------------------
Mean       -1.77
Stdev       0.27

Tilt Angle                 90.0     45.00     30.00     60.00
Tilt Error                          -1.86     -2.38     -1.01
```

```
Date:   9- 4-82      CM5 784472       Cal.fact. 11.00 µV/W/m²
Tilt    90.
            1.00      0.85      0.70      0.55      0.40      0.25      0.10
-----------------------------------------------------------------------------
  0.A    1020.8                          -0.37     -1.65     -1.52      2.78
 45.B    1005.9                           0.74     -0.19     -2.78     -6.64
 90.C    1004.0                           0.04     -1.37     -3.39     -7.23
135.D     999.2                          -0.16     -1.78     -2.40     -8.67
180.E     999.3     0.03     -0.05       -0.83                          -3.29
225.F    1005.0    -0.82     -1.60       -2.46                         -19.47
270.G    1011.2    -0.69     -1.97       -3.11                         -26.06
315.H    1017.7     0.18     -1.12       -1.74                         -21.64
-----------------------------------------------------------------------------
Mean     1007.9    -0.33     -1.18       -0.99     -1.25     -2.52    -11.28
Stdev       0.80    0.50      0.83        1.33      0.73      0.78      9.99

Tilt    45.
            0.71      0.60      0.49      0.39      0.28      0.18      0.07
-----------------------------------------------------------------------------
  0.A    -2.94     -4.19     -6.04     -5.96                          -2.71
 45.B    -1.98     -1.53     -2.29     -2.66                         -13.05
 90.C    -0.83     -1.63     -2.58     -3.51                         -12.64
135.D    -0.05     -2.01     -2.58     -3.43                         -13.83
180.E    -1.17                         -3.64     -5.15     -7.05      -6.81
225.F    -1.32                         -6.53     -9.87    -18.72     -23.49
270.G    -1.86                         -8.60    -13.04    -22.04     -31.71
315.H    -3.35                         -8.67    -12.75    -20.87     -25.95
-----------------------------------------------------------------------------
Mean     -1.69     -2.34     -3.37     -5.38    -10.20    -17.17     -16.27
Stdev     1.09      1.25      1.78      2.41      3.66      6.88       9.91

Tilt    30.
            0.50      0.43      0.35      0.28      0.20      0.12      0.05
-----------------------------------------------------------------------------
  0.A    -5.47
 45.B    -4.52
 90.C    -1.73
135.D    -1.54
180.E    -1.76
225.F    -2.69
270.G    -3.96
315.H    -5.90
-----------------------------------------------------------------------------
Mean     -3.45
Stdev     1.75

Tilt    60.
            0.87      0.74      0.61      0.48      0.35      0.22      0.09
-----------------------------------------------------------------------------
  0.A    -1.07
 45.B     0.10
 90.C     0.14
135.D     0.21
180.E    -0.07
225.F    -0.63
270.G    -0.95
315.H    -2.05
-----------------------------------------------------------------------------
Mean     -0.54
Stdev     0.79

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -0.55     -2.37     -0.25
```

```
Date: 27- 2-82       CM5 785017       Cal.fact. 10.30 µV/W/m²
Tilt    90.
           1.00      0.85      0.70      0.55      0.40      0.25      0.10
-------------------------------------------------------------------------------
  0.A    1050.8                         -0.84     -2.47     -1.90     -2.13
 45.B    1045.4                         -1.83     -2.96     -6.33    -14.00
 90.C    1044.1                         -3.06     -4.84     -7.35    -16.32
135.D    1042.9                         -2.75     -4.81     -6.60    -16.58
180.E    1044.7     -1.02     -1.33     -2.09                         -5.22
225.F    1047.4     -0.75     -1.06     -1.97                        -15.91
270.G    1048.8     -0.58     -1.36     -1.98                        -19.21
315.H    1049.5     -0.39     -1.21     -1.35                        -17.21
-------------------------------------------------------------------------------
Mean     1046.7     -0.68     -1.24     -1.98     -3.77     -5.54    -13.32
Stdev      0.27      0.27      0.14      0.71      1.23      2.47      6.18

Tilt    45.
           0.71      0.60      0.49      0.39      0.28      0.18      0.07
-------------------------------------------------------------------------------
  0.A     -1.83     -3.46     -5.47     -5.88                         -4.60
 45.B     -2.60     -2.82     -4.17     -5.13                        -21.44
 90.C     -1.72     -3.36     -4.88     -6.86                        -23.33
135.D     -2.09     -4.51     -5.76     -7.18                        -23.07
180.E     -3.08                         -6.48     -8.68    -10.53     -9.36
225.F     -2.85                         -6.68     -9.85    -18.05    -20.01
270.G     -2.60                         -7.03    -10.66    -18.45    -25.02
315.H     -2.41                         -6.81    -10.16    -17.77    -22.52
-------------------------------------------------------------------------------
Mean      -2.39     -3.54     -5.07     -6.51     -9.84    -16.20    -18.67
Stdev      0.48      0.71      0.71      0.68      0.84      3.79      7.47

Tilt    30.
           0.50      0.43      0.35      0.28      0.20      0.12      0.05
-------------------------------------------------------------------------------
  0.A     -3.70
 45.B     -4.63
 90.C     -3.41
135.D     -3.82
180.E   (-24.89)
225.F     -5.47
270.G     -4.79
315.H     -4.69
-------------------------------------------------------------------------------
Mean      -4.36
Stdev      0.73

Tilt    60.
           0.87      0.74      0.61      0.48      0.35      0.22      0.09
-------------------------------------------------------------------------------
  0.A     -1.10
 45.B     -1.28
 90.C     -0.92
135.D     -1.15
180.E     -1.68
225.F     -1.70
270.G     -2.14
315.H     -1.91
-------------------------------------------------------------------------------
Mean      -1.48
Stdev      0.43

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -1.18     -1.78     -0.87
```

Date: 8- 4-82 **CM5 785047** Cal.fact. 11.83 μV/W/m^2

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
0.A	783.4			-0.07	-1.46	-0.75	3.90
45.B	772.1			1.84	0.75	-0.93	-3.91
90.C	773.8			1.01	-0.51	-1.62	-3.16
135.D	775.9			0.24	-1.69	-2.81	-7.93
180.E	777.9	-0.44	-0.35	-1.03			-8.37
225.F	779.2	-1.41	-2.21	-3.17			-25.48
270.G	779.4	-1.72	-4.17	-3.88			-32.18
315.H	782.2	-0.73	-1.55	-1.94			-22.68
Mean	778.0	-1.08	-2.07	-0.87	-0.73	-1.53	-12.48
Stdev	0.50	0.59	1.60	2.01	1.11	0.93	12.69

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
0.A	-3.93	-4.89	-6.80	-6.40			-0.33
45.B	-2.99	-1.89	-2.48	-2.20			-7.11
90.C	-1.23	-1.30	-2.05	-2.50			-7.66
135.D	-0.60	-1.76	-2.62	-3.28			-11.96
180.E	-0.95			-4.86	-8.93	-10.77	-11.17
225.F	-1.79			-7.63	-11.65	-21.83	-28.68
270.G	-2.31			-10.58	-16.08	-26.37	-40.08
315.H	-4.02			-10.87	-14.34	-24.36	-29.08
Mean	-2.23	-2.46	-3.49	-6.04	-12.75	-20.83	-17.01
Stdev	1.32	1.64	2.22	3.44	3.13	6.96	13.82

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
0.A	-7.27						
45.B	-5.54						
90.C	-2.40						
135.D	-1.71						
180.E	-2.09						
225.F	-3.23						
270.G	-4.15						
315.H	-7.00						
Mean	-4.18						
Stdev	2.20						

Tilt 60.

	0.87	0.74	0.61	0.48	0.35	0.22	0.09
0.A	-1.99						
45.B	-0.22						
90.C	0.13						
135.D	0.27						
180.E	-0.04						
225.F	-0.68						
270.G	-1.36						
315.H	-2.45						
Mean	-0.79						
Stdev	1.03						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		-0.21	-3.35	0.17

```
Date:   5- 4-82      CM10 790059      Cal.fact.   5.69 µV/W/m^2
Tilt    90.
              1.00      0.85      0.70      0.55      0.40      0.25      0.10
------------------------------------------------------------------------------
  45.A     660.6                         -2.31     -3.28     -2.77      8.17
  90.B     656.7                         -1.17     -2.47     -3.40      1.55
 135.C     658.9                         -1.95     -3.78     -5.44     -0.79
 180.D     658.9                         -2.57     -4.84     -5.62     -5.42
 225.E     659.4     -1.10     -1.67     -2.76                         -6.50
 270.F     659.6     -1.09     -1.94     -2.57                         -2.13
 315.G     659.9     -1.12     -1.71     -2.16                          2.41
   0.H     660.1     -0.81     -1.70     -1.42                          5.98
------------------------------------------------------------------------------
Mean       659.3     -1.03     -1.75     -2.11     -3.59     -4.31      0.41
Stdev       0.18      0.15      0.13      0.57      0.99      1.43      5.16

Tilt    45.
              0.71      0.60      0.49      0.39      0.28      0.18      0.07
------------------------------------------------------------------------------
  45.A     -2.38     -3.68     -4.86     -5.33                         10.71
  90.B     -2.59     -2.85     -3.60     -3.87                          2.62
 135.C     -2.26     -2.90     -3.98     -5.07                         -0.80
 180.D     -1.96     -3.55     -4.76     -6.10                         -6.11
 225.E     -2.41                         -6.85    -11.40    -15.66     -7.10
 270.F     -2.84                         -7.17    -10.73    -13.96     -1.99
 315.G     -3.32                         -6.28     -8.99    -10.66      3.95
   0.H     -2.81                         -5.94     -7.40     -9.59      8.49
------------------------------------------------------------------------------
Mean       -2.57     -3.24     -4.30     -5.83     -9.63    -12.47      1.22
Stdev       0.42      0.43      0.61      1.06      1.80      2.83      6.43

Tilt    30.
              0.50      0.43      0.35      0.28      0.20      0.12      0.05
------------------------------------------------------------------------------
  45.A     -3.88
  90.B     -3.54
 135.C     -3.37
 180.D     -3.21
 225.E     -3.85
 270.F     -4.77
 315.G     -4.88
   0.H     -5.01
------------------------------------------------------------------------------
Mean       -4.06
Stdev       0.72

Tilt    60.
              0.87      0.74      0.61      0.48      0.35      0.22      0.09
------------------------------------------------------------------------------
  45.A     -1.05
  90.B     -0.38
 135.C     -0.63
 180.D     -0.37
 225.E     -0.51
 270.F     -0.85
 315.G     -1.06
   0.H     -1.64
------------------------------------------------------------------------------
Mean       -0.81
Stdev       0.43

Tilt Angle                90.0     45.00     30.00     60.00
Tilt Error                         -0.85     -1.46      0.11
```

```
Date: 23- 4-82        CM10-810119       Cal.fact.  4.61 µV/W/m²
Tilt   90.
           1.00      0.85      0.70      0.55      0.40      0.25      0.10
-------------------------------------------------------------------------
-30.A     785.7                         -0.75     -2.26     -3.49     -1.05
 15.B     782.8                         -0.92     -2.05     -4.18     -4.90
 60.C     783.2                         -1.54     -2.96     -5.34     -6.41
105.D     783.5                         -1.39     -2.96     -5.66     -7.90
150.E     784.0     -0.59     -0.66     -1.28                         -6.30
195.F     785.0     -0.49     -0.61     -0.84                         -4.06
240.G     784.8     -0.23     -0.32     -0.43                         -2.13
285.H     784.6     -0.10     -0.31     -0.25                         -0.94
-------------------------------------------------------------------------
Mean      784.2     -0.35     -0.48     -0.93     -2.56     -4.67     -4.21
Stdev      0.14      0.23      0.18      0.46      0.48      1.01      2.63

Tilt   45.
           0.71      0.60      0.49      0.39      0.28      0.18      0.07
-------------------------------------------------------------------------
-30.A     -0.69     -1.85     -3.58     -4.22                         -2.91
 15.B     -1.12     -1.63     -2.77     -4.28                         -6.68
 60.C     -0.98     -2.17     -3.27     -5.26                         -8.56
105.D     -1.60     -2.60     -4.04     -5.64                        -10.42
150.E     -1.61                         -5.81     -9.37    -14.11     -8.83
195.F     -1.71                         -5.47     -8.25    -12.59     -7.13
240.G     -1.57                         -4.89     -7.11    -11.72     -5.99
285.H     -1.18                         -4.54     -6.78    -10.77     -4.26
-------------------------------------------------------------------------
Mean      -1.31     -2.06     -3.41     -5.01     -7.88    -12.30     -6.85
Stdev      0.37      0.42      0.54      0.62      1.18      1.42      2.47

Tilt   30.
           0.50      0.43      0.35      0.28      0.20      0.12      0.05
-------------------------------------------------------------------------
-30.A     -2.03
 15.B     -2.53
 60.C     -2.35
105.D     -2.81
150.E     -3.59
195.F     -3.53
240.G     -3.40
285.H     -2.63
-------------------------------------------------------------------------
Mean      -2.86
Stdev      0.58

Tilt   60.
           0.87      0.74      0.61      0.48      0.35      0.22      0.09
-------------------------------------------------------------------------
-30.A     -0.19
 15.B     -0.13
 60.C     -0.63
105.D     -0.89
150.E     -0.75
195.F     -0.88
240.G     -1.04
285.H    (-7.23)
-------------------------------------------------------------------------
Mean      -0.72
Stdev      0.32

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -0.84     -1.39     -0.40
```

```
Date:    5- 4-82       CM10 810120       Cal.fact.  4.54 µV/W/m²
Tilt     90.
            1.00      0.85      0.70      0.55      0.40      0.25      0.10
-----------------------------------------------------------------------------
-45.A    677.6                           -1.21     -3.03     -4.02     -3.02
  0.B    675.8                           -1.61     -2.64     -4.16     -5.17
 45.C    676.7                           -1.88     -3.18     -4.68     -5.82
 90.D    677.1                           -2.12     -3.56     -4.88     -6.24
135.E    677.3     -0.54     -1.13       -2.12                         -5.62
180.F    676.9     -0.40     -1.05       -1.83                         -3.73
225.G    676.5     -0.18     -0.84       -1.56                         -3.03
270.H    675.8     -0.05     -0.64       -1.17                         -2.98
-----------------------------------------------------------------------------
Mean     676.7     -0.29     -0.92       -1.69     -3.10     -4.43     -4.45
Stdev     0.09      0.22      0.22        0.37      0.38      0.41      1.40

Tilt     45.
            0.71      0.60      0.49      0.39      0.28      0.18      0.07
-----------------------------------------------------------------------------
-45.A    -1.13     -2.41     -4.09       -5.08                         -7.81
  0.B    -1.42     -1.99     -3.39       -4.58                        -10.17
 45.C    -1.07     -2.28     -3.81       -5.16                        -11.01
 90.D    -1.22     -2.71     -4.27       -5.71                        -11.45
135.E    -1.42                           -6.08     -9.46    -13.94    -10.11
180.F    -1.50                           -5.94     -8.93    -13.03     -7.77
225.G    -1.48                           -5.64     -8.44    -12.46     -7.42
270.H    -1.35                           -5.30     -7.81    -12.03     -6.63
-----------------------------------------------------------------------------
Mean     -1.32     -2.35     -3.89       -5.44     -8.66    -12.86     -9.05
Stdev     0.16      0.30      0.38        0.50      0.71      0.83      1.84

Tilt     30.
            0.50      0.43      0.35      0.28      0.20      0.12      0.05
-----------------------------------------------------------------------------
-45.A    -3.28
  0.B    -3.36
 45.C    -3.11
 90.D    -3.44
135.E    -3.80
180.F    -3.97
225.G    -3.91
270.H    -3.76
-----------------------------------------------------------------------------
Mean     -3.58
Stdev     0.32

Tilt     60.
            0.87      0.74      0.61      0.48      0.35      0.22      0.09
-----------------------------------------------------------------------------
-45.A    -0.09
  0.B     0.09
 45.C    -0.02
 90.D    -0.19
135.E    -0.23
180.F    -0.40
225.G    -0.42
270.H    -0.39
-----------------------------------------------------------------------------
Mean     -0.21
Stdev     0.19

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -0.44     -1.42      0.05
```

```
Date:   5- 4-82      CM10 810121      Cal.fact.  4.54 µV/W/m²
Tilt    90.
           1.00       0.85      0.70      0.55      0.40      0.25      0.10
--------------------------------------------------------------------------------
-45.A   697.2                           -1.74     -2.87     -3.35     -2.09
  0.B   696.5                           -1.12     -2.45     -3.79     -5.15
 45.C   697.8                           -1.31     -2.80     -4.33     -6.05
 90.D   698.6                           -1.42     -2.92     -4.20     -6.45
135.E   699.2     -0.86     -1.28       -1.59                         -5.65
180.F   699.8     -0.99     -1.41       -1.59                         -4.42
225.G   699.6     -1.01     -1.42       -1.53                         -3.10
270.H   698.5     -0.89     -1.39       -1.35                         -2.33
--------------------------------------------------------------------------------
Mean    698.4     -0.94     -1.37       -1.46     -2.76     -3.92     -4.40
Stdev     0.17     0.07      0.07        0.20      0.21      0.44      1.71

Tilt    45.
          0.71       0.60      0.49      0.39      0.28      0.18      0.07
--------------------------------------------------------------------------------
-45.A   -1.52     -2.62     -3.99       -4.69                         -6.42
  0.B   -2.17     -2.45     -3.44       -3.90                         -8.88
 45.C   -1.93     -2.68     -3.76       -4.45                        -11.51
 90.D   -1.88     -2.82     -3.96       -4.78                        -11.98
135.E   -1.95                           -4.94     -7.91    -12.09     -9.30
180.F   -2.00                           -4.93     -7.51    -11.66     -7.55
225.G   -2.07                           -4.71     -7.07    -10.77     -5.21
270.H   -2.01                           -4.80     -6.72    -10.51     -3.82
--------------------------------------------------------------------------------
Mean    -1.94     -2.64     -3.79       -4.65     -7.30    -11.26     -8.08
Stdev    0.19      0.15      0.25        0.34      0.52      0.74      2.89

Tilt    30.
          0.50       0.43      0.35      0.28      0.20      0.12      0.05
--------------------------------------------------------------------------------
-45.A   -2.76
  0.B   -3.31
 45.C   -3.06
 90.D   -3.21
135.E   -3.41
180.F   -3.46
225.G   -3.44
270.H   -3.24
--------------------------------------------------------------------------------
Mean    -3.24
Stdev    0.23

Tilt    60.
          0.87       0.74      0.61      0.48      0.35      0.22      0.09
--------------------------------------------------------------------------------
-45.A   -0.56
  0.B   -0.59
 45.C   -0.77
 90.D   -0.85
135.E   -0.85
180.F   -0.89
225.G   -0.96
270.H   -1.01
--------------------------------------------------------------------------------
Mean    -0.81
Stdev    0.16

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -0.59     -1.35      0.03
```

Date: 5- 4-82 **CM10 810122** Cal.fact. 4.27 $\mu V/W/m^2$

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
-45.A	676.2			-0.95	-2.21	-2.98	-3.24
0.B	674.3				-1.92	-3.35	-6.69
45.C	675.7			-0.71	-2.33	-4.29	-7.49
90.D	676.4			-1.12	-2.55	-4.33	-8.47
135.E	676.7	-0.52	-0.78	-1.32			-8.40
180.F	676.5	-0.40	-0.71	-1.31			-8.35
225.G	676.4	-0.32	-0.67	-1.15			-8.23
270.H	675.8	-0.21	-0.57	-0.69			-8.23
Mean	676.0	-0.36	-0.68	-1.03	-2.25	-3.74	-7.39
Stdev	0.11	0.13	0.09	0.26	0.26	0.68	1.78

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
-45.A	-1.10	-2.09	-3.72	-4.27			-6.08
0.B	-1.12	-1.82	-3.03	-3.59			-8.90
45.C	-1.22	-2.36	-3.55	-4.49			-10.17
90.D	-1.51	-2.65	-3.77	-4.96			-11.68
135.E	-1.71			-5.24	-8.87	-14.34	-11.35
180.F	-1.76			-5.11	-8.51	-13.96	-12.82
225.G	-1.71			-4.87	-7.79	-13.55	-11.06
270.H	-1.40			-4.55	-6.90	-12.32	-6.78
Mean	-1.44	-2.23	-3.52	-4.64	-8.02	-13.54	-9.85
Stdev	0.27	0.36	0.34	0.53	0.87	0.88	2.41

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
-45.A	-2.58						
0.B	-2.89						
45.C	-2.63						
90.D	-3.06						
135.E	-3.22						
180.F	-3.33						
225.G	-3.39						
270.H	-3.11						
Mean	-3.02						
Stdev	0.30						

Tilt 60.

	0.87	0.74	0.61	0.48	0.35	0.22	0.09
-45.A	-0.53						
0.B	-0.48						
45.C	-0.74						
90.D	-0.89						
135.E	-0.97						
180.F	-1.05						
225.G	-1.06						
270.H	-1.01						
Mean	-0.84						
Stdev	0.23						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		-0.78	-1.58	-0.52

Date: 20- 4-82 **EKO 81901** Cal.fact. 7.97 μV/W/m²

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
0.A	721.3			-3.99	-6.61	-6.90	-0.72
45.B	716.6			-5.83	-4.69	-6.35	-3.40
90.C	717.6			-7.55	-7.57	-9.93	-9.75
135.D	710.3			-6.67	-7.19	-8.88	-11.38
180.E	717.9	-2.63	-4.64	-7.16			-12.89
225.F	715.4	-2.84	-5.19	-7.66			-16.48
270.G	713.4	-2.35	-4.41	-5.33			-9.87
315.H	719.5	-1.70	-3.98	-4.94			-4.95
Mean	716.5	-2.38	-4.56	-6.14	-6.52	-8.01	-8.68
Stdev	0.49	0.49	0.50	1.33	1.28	1.68	5.26

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
0.A	-1.21	-3.22	-5.75	-5.32			-6.03
45.B	-1.91	-2.49	-3.80	-4.50			-2.98
90.C	-1.44	-3.11	-5.09	-7.69			-14.87
135.D	-1.63	-4.69	-6.11	-8.13			-4.64
180.E	-3.18			-12.55	-40.63	-79.67	-69.37
225.F	(-19.26)			-50.24	-70.34	-57.02	-32.53
270.G	-2.44			-43.23	-18.92	-15.29	-9.25
315.H	-2.49			-10.56	-7.78	-12.37	-4.73
Mean	-2.04	-3.38	-5.19	-17.78	-34.42	-41.08	-18.05
Stdev	0.69	0.93	1.02	18.16	27.56	32.83	22.86

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
0.A	-1.79						
45.B	-3.03						
90.C	-1.75						
135.D	-1.98						
180.E	-4.78						
225.F	-3.52						
270.G	-4.28						
315.H	-4.82						
Mean	-3.24						
Stdev	1.31						

Tilt 60.

	0.87	0.74	0.61	0.48	0.35	0.22	0.09
0.A	-0.62						
45.B	-0.38						
90.C	-0.57						
135.D	-0.43						
180.E	-1.09						
225.F	-0.98						
270.G	-0.62						
315.H	-0.98						
Mean	-0.71						
Stdev	0.27						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		-2.04	3.02	1.42

```
Date: 20- 4-82      EKO 81902       Cal.fact.  7.50 µV/W/m²
Tilt   90.
          1.00     0.85     0.70     0.55     0.40     0.25     0.10
--------------------------------------------------------------------
  0.A    682.1                      -4.04    -6.60    -6.82     0.01
 45.B    677.6                      -8.46    -5.02    -7.43    -5.29
 90.C    678.6                      -9.91    -7.58    -9.74    -9.36
135.D    669.6                      -9.20    -7.81   -10.05   -10.40
180.E    675.9    -3.55    -5.80    -9.28                     -10.17
225.F    675.0    -2.63    -5.98    -9.21                     -10.81
270.G    675.2    -1.92    -4.68    -7.15                      -1.69
315.H    680.7    -1.77    -4.96    -6.88                      -0.26
--------------------------------------------------------------------
Mean     676.8    -2.47    -5.36    -8.02    -6.75    -8.51    -6.00
Stdev     0.57     0.81     0.63     1.93     1.27     1.63     4.77

Tilt   45.
          0.71     0.60     0.49     0.39     0.28     0.18     0.07
--------------------------------------------------------------------
  0.A    -0.45    -3.28    -5.39    -5.00                      -2.03
 45.B    -1.14    -3.10    -4.37    -4.79                      -7.55
 90.C    -1.22    -3.33    -5.09    -7.54                     -12.44
135.D    -0.82    -4.12    -6.37    -8.26                     -14.28
180.E    -2.20                      -6.70   -10.25   -14.90   -14.33
225.F    -2.11                      -8.45   -11.75   -16.20   -16.02
270.G    -2.24                      -6.12    -9.12   -11.21    11.59
315.H    -1.73                      -5.13    -7.02   -10.58     0.23
--------------------------------------------------------------------
Mean     -1.49    -3.46    -5.30    -6.50    -9.53   -13.22    -6.85
Stdev     0.68     0.45     0.83     1.47     1.99     2.75     9.56

Tilt   30.
          0.50     0.43     0.35     0.28     0.20     0.12     0.05
--------------------------------------------------------------------
  0.A    -1.66
 45.B    -2.42
 90.C    -2.04
135.D    -1.49
180.E    -4.20
225.F    -3.66
270.G    -4.16
315.H    -4.18
--------------------------------------------------------------------
Mean     -2.98
Stdev     1.19

Tilt   60.
          0.87     0.74     0.61     0.48     0.35     0.22     0.09
--------------------------------------------------------------------
  0.A    -0.04
 45.B     0.02
 90.C    -0.24
135.D    -0.03
180.E    -0.56
225.F    -0.82
270.G    -0.63
315.H    -0.06
--------------------------------------------------------------------
Mean     -0.30
Stdev     0.33

Tilt Angle         90.0    45.00    30.00    60.00
Tilt Error                  3.73     4.62     1.91
```

Date: 20- 4-82 EKO 81903 Cal.fact. 7.47 μV/W/m²

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
0.A	754.0			-3.77	-6.32	-9.56	0.63
45.B	750.9			-7.45	-4.80	-7.61	-3.02
90.C	752.4			-8.63	-7.28	-10.16	-10.00
135.D	741.2			-7.26	-6.33	-8.88	-10.04
180.E	748.6	-2.57	-4.36	-7.54			-12.10
225.F	748.2	-2.78	-5.28	-8.55			-14.51
270.G	748.6	-2.61	-5.34	-7.60			-13.20
315.H	750.5	-1.56	-4.57	-6.89			-10.26
Mean	749.3	-2.38	-4.89	-7.21	-6.18	-9.05	-9.06
Stdev	0.51	0.55	0.50	1.52	1.03	1.10	5.21

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
0.A	-1.75	-4.11	-7.03	-6.59			-3.34
45.B	-2.35	-2.82	-3.76	-5.09			8.74
90.C	-1.37	-3.15	-4.67	-7.88			-17.05
135.D	-0.99	-3.47	-4.95	-7.13			-2.85
180.E	-1.77			-5.95	-11.92	-14.60	-4.19
225.F	(-22.89)			-8:35	-11.89	-20.19	-47.58
270.G	-2.21			-10.45	(-36.37)	(-78.83)	-51.66
315.H	-1.89			(-59.87)	(-63.60)	-18.38	-11.24
Mean	-1.76	-3.39	-5.10	- 7.31	-11.91	-17.72	-16.15
Stdev	0.47	0.55	1.38	1.76	0.02	2.85	21.97

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
0.A	-2.22						
45.B	-5.02						
90.C	-2.61						
135.D	-2.13						
180.E	-3.82						
225.F	-3.79						
270.G	-2.88						
315.H	-3.76						
Mean	-3.28						
Stdev	0.99						

Tilt 60.

	0.87	0.74	0.61	0.48	0.35	0.22	0.09
0.A	-1.09						
45.B	-0.85						
90.C	-0.90						
135.D	-0.77						
180.E	-0.11						
225.F	-0.37						
270.G	-0.19						
315.H	-0.39						
Mean	-0:58						
Stdev	0.36						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		3.01	3.59	1.54

Date: 24- 4-82 EKO 81906 Cal.fact. 7.49 µV/W/m²

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
0.A	639.3			-0.67	-4.11	-3.79	3.77
45.B	613.1			2.75	1.29	1.76	1.07
90.C	626.4			1.11	-0.50	-1.21	1.70
135.D	625.7			-0.54	-2.73	-0.57	-2.63
180.E	625.9	-0.46	0.16	-0.74			-3.18
225.F	633.6	-0.69	-0.72	-1.62			-7.07
270.G	624.4	-0.65	-0.93	-1.00			-5.79
315.H	627.2	0.48	-0.54	0.96			0.78
Mean	626.9	-0.33	-0.51	0.03	-1.51	-0.95	-1.42
Stdev	1.20	0.55	0.47	1.44	2.39	2.28	3.84

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
0.A	-0.70	-1.83	-3.91	-2.30			-2.15
45.B	1.44	2.44	1.25	(-15.69)			2.52
90.C	0.99	1.42	0.92	0.63			5.83
135.D	2.03	0.77	-0.10	-2.04			-9.42
180.E	1.42			-2.46	-3.97	-6.94	(-42.79)
225.F	-0.31			-4.12	-5.21	-11.91	-18.78
270.G	1.25			-4.27	-6.33	-11.78	-12.28
315.H	-0.48			-3.99	-4.72	-14.37	3.73
Mean	0.71	0.70	-0.46	-2.65	-5.06	-11.25	-4.36
Stdev	1.04	1.82	2.37	1.73	0.99	3.11	9.29

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
0.A	-0.13						
45.B	2.06						
90.C	0.42						
135.D	2.59						
180.E	1.26						
225.F	-1.75						
270.G	1.11						
315.H	-1.54						
Mean	0.50						
Stdev	1.58						

Tilt 60.

	0.87	0.74	0.61	0.48	0.35	0.22	0.09
0.A	-0.60						
45.B	2.18						
90.C	1.03						
135.D	1.53						
180.E	1.51						
225.F	0.49						
270.G	0.22						
315.H	-1.34						
Mean	0.63						
Stdev	1.18						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		1.21	0.98	0.92

```
Date: 19- 4-82        EKO 81907          Cal.fact.  7.31 µV/W/m²
Tilt   90.
           1.00    0.85    0.70    0.55    0.40    0.25    0.10
----------------------------------------------------------------------
   0.A   681.9                   -1.75   -3.93   -3.85    0.49
  45.B   675.5                   -2.47   -2.89   -3.25   -0.26
  90.C   685.9                   -3.78   -4.46   -5.78   -3.34
 135.D   686.2                   -5.10   -7.16   -9.08  -12.67
 180.E   685.6   -2.94   -3.86   -4.56                   -9.70
 225.F   693.6   -2.76   -3.86   -5.07                  -11.69
 270.G   685.0   -2.02   -2.67   -3.43                   -4.04
 315.H   685.3   -0.25   -1.20   -1.81                    5.12
----------------------------------------------------------------------
Mean     684.9   -1.99   -2.90   -3.50   -4.61   -5.49   -4.51
Stdev     0.73    1.23    1.26    1.37    1.82    2.62    6.35

Tilt   45.
           0.71    0.60    0.49    0.39    0.28    0.18    0.07
----------------------------------------------------------------------
   0.A   -0.51   -0.65   -1.83   -2.80                   -3.24
  45.B    0.87   -0.19   -2.19   -3.44                   11.73
  90.C    0.59   -1.52   -2.75   -2.77                   11.29
 135.D    0.47   -2.83   -4.83   -6.63                  -18.34
 180.E   -1.46                   -5.76   -9.10  -12.52    5.90
 225.F (-17.00)                  -6.73  -10.13  -15.28  -17.17
 270.G   -1.75                   -6.04   -8.08  -11.20  -11.16
 315.H   -2.51                   -2.24   -3.39   -5.24   19.28
----------------------------------------------------------------------
Mean     -0.61   -1.30   -2.90   -4.55   -7.67  -11.06   -0.21
Stdev     1.32    1.16    1.34    1.91    2.98    4.24   14.33

Tilt   30.
           0.50    0.43    0.35    0.28    0.20    0.12    0.05
----------------------------------------------------------------------
   0.A   -0.28
  45.B    1.32
  90.C   -0.85
 135.D   -0.01
 180.E   -2.03
 225.F (-10.78)
 270.G   -1.63
 315.H   -3.63
----------------------------------------------------------------------
Mean     -1.02
Stdev     1.60

Tilt   60.
           0.87    0.74    0.61    0.48    0.35    0.22    0.09
----------------------------------------------------------------------
   0.A   -0.64
  45.B    0.99
  90.C    1.61
 135.D    1.03
 180.E   -0.41
 225.F   -1.67
 270.G   -1.62
 315.H   -1.58
----------------------------------------------------------------------
Mean     -0.29
Stdev     1.34

Tilt Angle        90.0   45.00   30.00   60.00
Tilt Error                3.46    2.84    1.49
```

```
Date: 20- 4-82      EKO 81908        Cal.fact.  9.73 µV/W/m²
Tilt  90.
               1.00    0.85    0.70    0.55    0.40    0.25    0.10
--------------------------------------------------------------
  0.A   683.0                   -2.99   -6.24   -6.54   -3.09
 45.B   667.2                   -4.31   -3.02   -3.98   -1.39
 90.C   675.5                   -4.90   -4.38   -6.18    1.27
135.D   670.4                   -5.56   -5.60   -6.21   -9.49
180.E   666.3   -1.99   -2.95   -4.57                   -3.22
225.F   672.4   -1.32   -3.01   -4.73                   -5.42
270.G   665.0   -1.40   -2.49   -3.36                   -1.35
315.H   670.6   -1.02   -2.55   -2.45                    0.97
--------------------------------------------------------------
Mean    671.3   -1.43   -2.75   -4.11   -4.81   -5.73   -2.71
Stdev    0.87    0.41    0.27    1.07    1.42    1.18    3.52

Tilt  45.
               0.71    0.60    0.49    0.39    0.28    0.18    0.07
--------------------------------------------------------------
  0.A   -0.57   -2.27   -4.19   -3.59                   -7.66
 45.B   -0.13   -1.25   -2.87   -4.14                   13.36
 90.C   -1.06   -2.19   -3.02   -4.32                   14.42
135.D   -0.02   -2.48   -3.87   -6.22                  -15.38
180.E   -0.78                   -4.78   -8.74  -10.28   10.95
225.F (-16.06)                  -5.22   -9.32  -13.84   -7.27
270.G   -0.76                   -5.41   -7.87  -68.75 (-79.60)
315.H   -1.06                 (-32.35)(-70.24) -29.05    1.90
--------------------------------------------------------------
Mean    -0.63   -2.05   -3.49   -4.81  - 8.64  -30.48   -1.47
Stdev    0.42    0.55    0.65    0.88    0.73   26.78   11.85

Tilt  30.
               0.50    0.43    0.35    0.28    0.20    0.12    0.05
--------------------------------------------------------------
  0.A   -0.72
 45.B    0.36
 90.C   -2.02
135.D    0.04
180.E   -1.38
225.F   -4.63
270.G    0.10
315.H   -1.81
--------------------------------------------------------------
Mean    -1.26
Stdev    1.63

Tilt  60.
               0.87    0.74    0.61    0.48    0.35    0.22    0.09
--------------------------------------------------------------
  0.A   -0.80
 45.B    0.50
 90.C    0.20
135.D    0.24
180.E    0.12
225.F   -0.07
270.G    0.06
315.H   -0.24
--------------------------------------------------------------
Mean     0.00
Stdev    0.39

Tilt Angle          90.0   45.00   30.00   60.00
Tilt Error                  2.05    3.09    1.28
```

```
Date: 19- 4-82       EKO 81909         Cal.fact.  7.59 µV/W/m²
Tilt   90.
            1.00      0.85      0.70      0.55      0.40      0.25      0.10
-----------------------------------------------------------------------------
  0.A     704.4                          -1.32     -4.05     -3.78     -0.30
 45.B     690.2                           0.19      0.07     -0.09      3.37
 90.C     700.5                          -0.74     -0.99     -1.52      8.92
135.D     694.1                          -1.11     -1.76     -1.28     -1.82
180.E     690.1     -0.21      0.36      -0.14                           0.19
225.F     698.3      0.05     -0.35      -1.01                          -4.79
270.G     691.6     -0.24     -0.39      -0.61                           0.60
315.H     696.5     -0.19     -0.64      -0.17                           3.92
-----------------------------------------------------------------------------
Mean      695.7     -0.15     -0.26      -0.61     -1.68     -1.67      1.26
Stdev       0.74     0.13      0.43       0.53      1.75      1.54      4.15

Tilt   45.
            0.71      0.60      0.49      0.39      0.28      0.18      0.07
-----------------------------------------------------------------------------
  0.A       1.46    -0.47     -2.32      -1.41                          -1.67
 45.B       1.24     0.17     -0.67      -1.15                          15.43
 90.C      -0.39     0.04      0.19      -0.45                          32.28
135.D       1.85     0.58     -0.21      -1.86                          -5.91
180.E       1.41                         -2.41     -9.80    -49.83    -18.01
225.F  (-25.51)                         -29.77    -66.41    -58.46    -23.89
270.G       1.69                        -58.96    -46.92    -12.87     -6.92
315.H       0.75                        -37.85    -11.36     -6.13     15.49
-----------------------------------------------------------------------------
Mean       -1.14     0.08     -0.75     -16.73    -33.62    -31.82      0.85
Stdev       0.76     0.44      1.10      22.58     27.78     26.16     18.88

Tilt   30.
            0.50      0.43      0.35      0.28      0.20      0.12      0.05
-----------------------------------------------------------------------------
  0.A       1.95
 45.B       2.29
 90.C      -0.10
135.D       3.56
180.E       2.30
225.F       0.38
270.G       3.59
315.H       0.90
-----------------------------------------------------------------------------
Mean        1.86
Stdev       1.38

Tilt   60.
            0.87      0.74      0.61      0.48      0.35      0.22      0.09
-----------------------------------------------------------------------------
  0.A       0.79
 45.B       1.11
 90.C       0.39
135.D       0.39
180.E       1.34
225.F       1.20
270.G       1.11
315.H       0.68
-----------------------------------------------------------------------------
Mean        0.88
Stdev       0.37

Tilt Angle          90.0      45.00     30.00     60.00
Tilt Error                     1.40      2.83      1.01
```

```
Date: 29- 3-82        PSP-14806.F     Cal.fact.  9.64 µV/W/m²
Tilt   90.
          1.00       0.85      0.70      0.55      0.40      0.25      0.10
--------------------------------------------------------------------------
  0.A    686.3                          -1.95     -3.80     -6.89     -8.08
 45.B    688.1                          -1.77     -3.92     -8.12    -11.04
 90.C    691.6                          -3.61     -6.20    -12.07    -19.48
135.D    694.0                          -5.57     -8.86    -15.83    -28.25
180.E    695.1      -2.07     -4.32     -6.93                        -33.38
225.F    694.2      -1.96     -4.29     -6.73                        -32.59
270.G    695.7      -1.60     -3.34     -5.39                        -26.70
315.H    695.1      -0.43     -1.66     -2.89                        -16.78
--------------------------------------------------------------------------
Mean     692.5      -1.52     -3.40     -4.36     -5.70    -10.73    -22.04
Stdev     0.51       0.75      1.25      2.07      2.38      4.05      9.64

Tilt   45.
          0.71       0.60      0.49      0.39      0.28      0.18      0.07
--------------------------------------------------------------------------
  0.A    -3.38      -4.27     -6.24     -7.06                        -14.73
 45.B    -2.96      -3.23     -4.94     -5.47                        -16.89
 90.C    -1.94      -4.05     -6.10     -7.74                        -26.14
135.D    -2.41      -5.64     -8.44    -10.76                        -35.94
180.E    -3.71                         -12.94    -20.63    -29.81    -40.80
225.F    -5.07                         -13.40    -20.18    -29.85    -38.81
270.G    -6.17                         -12.70    -17.94    -25.74    -32.42
315.H    -5.91                         -10.02    -14.17    -20.18    -21.43
--------------------------------------------------------------------------
Mean     -3.94      -4.30     -6.43    -10.01    -18.23    -26.39    -28.40
Stdev     1.60       1.00      1.46      2.98      2.95      4.57     10.06

Tilt   30.
          0.50       0.43      0.35      0.28      0.20      0.12      0.05
--------------------------------------------------------------------------
  0.A    -7.54
 45.B    -6.02
 90.C    -4.64
135.D    -5.34
180.E    -7.50
225.F    -9.14
270.G   -10.64
315.H   -10.31
--------------------------------------------------------------------------
Mean     -7.64
Stdev     2.25

Tilt   60.
          0.87       0.74      0.61      0.48      0.35      0.22      0.09
--------------------------------------------------------------------------
  0.A    -0.79
 45.B    -0.25
 90.C     0.13
135.D    -0.22
180.E    -1.15
225.F    -1.97
270.G    -2.61
315.H    -2.45
--------------------------------------------------------------------------
Mean     -1.16
Stdev     1.06

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -0.63     -2.84      0.19
```

```
Date: 30- 3-82        PSP-20524        Cal.fact. 10.00 µV/W/m²
Tilt   90.
           1.00     0.85     0.70     0.55     0.40     0.25     0.10
------------------------------------------------------------------------
  0.A     696.3                        -5.69    -8.74   -13.48   -25.44
 45.B     694.8                        -5.52    -9.14   -15.05   -29.45
 90.C     697.5                        -5.76    -9.18   -15.12   -28.53
135.D     699.0                        -4.45    -7.70   -12.11   -23.55
180.E     698.6    -0.53    -1.62      -3.14                     -15.44
225.F     697.2    -0.54    -1.63      -3.13                     -14.53
270.G     698.1    -0.81    -2.16      -3.79                     -19.09
315.H     700.7    -1.32    -2.86      -4.29                     -20.67
------------------------------------------------------------------------
Mean      697.8    -0.80    -2.07      -4.47    -8.69   -13.94   -22.09
Stdev      0.25     0.37     0.58       1.09     0.69     1.43     5.62

Tilt   45.
           0.71     0.60     0.49     0.39     0.28     0.18     0.07
------------------------------------------------------------------------
  0.A     -3.76    -6.63    -9.73   -11.68                       -32.24
 45.B     -4.88    -7.14    -9.68   -10.78                       -36.04
 90.C     -5.44    -8.11   -10.37   -11.45                       -36.26
135.D     -6.07    -8.09   -10.22   -10.79                       -31.14
180.E     -5.97                      -9.02   -13.29   -18.94     -20.95
225.F   (-67.26)                     -8.31   -11.73   -17.86     -19.84
270.G     -4.29                      -7.99   -12.47   -19.13     -24.00
315.H     -4.22                      -9.60   -13.81   -21.90     -27.42
------------------------------------------------------------------------
Mean     - 4.35    -7.49   -10.00    -9.95   -12.82   -19.46     -28.48
Stdev      0.91     0.73     0.35     1.42     0.91     1.72       6.45

Tilt   30.
           0.50     0.43     0.35     0.28     0.20     0.12     0.05
------------------------------------------------------------------------
  0.A     -7.09
 45.B     -8.68
 90.C     -9.06
135.D     -9.97
180.E    -13.57
225.F     -8.34
270.G     -6.75
315.H     -6.87
------------------------------------------------------------------------
Mean      -8.79
Stdev      2.25

Tilt   60.
           0.87     0.74     0.61     0.48     0.35     0.22     0.09
------------------------------------------------------------------------
  0.A     -1.34
 45.B     -1.71
 90.C     -2.22
135.D     -2.52
180.E     -2.61
225.F     -2.11
270.G     -1.54
315.H     -1.81
------------------------------------------------------------------------
Mean      -1.98
Stdev      0.46

Tilt Angle         90.0    45.00    30.00    60.00
Tilt Error                - 2.95    -2.91    -1.27
```

```
Date: 29- 3-82         PSP-20655         Cal.fact. 10.25 µV/W/m²
Tilt    90.
          1.00      0.85      0.70      0.55      0.40      0.25      0.10
-----------------------------------------------------------------------------
  0.A    688.0                         -4.58     -6.69    -10.59    -15.69
 45.B    686.3                         -4.78     -6.47    -11.40    -19.86
 90.C    689.4                         -5.47     -6.84    -11.67    -19.77
135.D    690.3                         -4.39     -6.20     -9.78    -16.07
180.E    690.0     -0.93     -2.04     -3.43                        -12.20
225.F    688.7     -1.02     -2.35     -3.68                        -12.46
270.G    688.9     -1.23     -3.00     -4.42                        -15.47
315.H    689.3     -0.93     -2.85     -4.33                        -16.79
-----------------------------------------------------------------------------
Mean     688.9     -1.03     -2.56     -4.39     -6.55    -10.86    -16.04
Stdev     0.18      0.14      0.45      0.63      0.28      0.85      2.86

Tilt    45.
          0.71      0.60      0.49      0.39      0.28      0.18      0.07
-----------------------------------------------------------------------------
  0.A    -4.17     -6.69     -9.15     -9.99                        -24.07
 45.B    -4.64     -6.54     -8.39     -8.72                        -27.31
 90.C    -4.88     -6.86     -8.73     -9.08                        -27.23
135.D    -5.08     -7.07     -8.67     -8.71                        -23.20
180.E    -5.16                         -7.99    -11.75    -16.80    -17.90
225.F    -4.73                         -7.48    -10.85    -16.49    -18.02
270.G    -4.18                         -8.18    -11.86    -18.32    -20.74
315.H    -4.30                         -8.93    -12.79    -19.77    -22.88
-----------------------------------------------------------------------------
Mean     -4.64     -6.79     -8.73     -8.64    -11.82    -17.85    -22.67
Stdev     0.39      0.23      0.31      0.76      0.79      1.51      3.64

Tilt    30.
          0.50      0.43      0.35      0.28      0.20      0.12      0.05
-----------------------------------------------------------------------------
  0.A    -7.18
 45.B    -8.27
 90.C    -7.98
135.D    -8.28
180.E    -8.35
225.F    -7.43
270.G    -6.53
315.H    -6.81
-----------------------------------------------------------------------------
Mean     -7.60
Stdev     0.72

Tilt    60.
          0.87      0.74      0.61      0.48      0.35      0.22      0.09
-----------------------------------------------------------------------------
  0.A    -1.72
 45.B    -1.70
 90.C    -2.12
135.D    -2.18
180.E    -2.31
225.F    -2.11
270.G    -1.68
315.H    -1.80
-----------------------------------------------------------------------------
Mean     -1.95
Stdev     0.25

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -2.16     -2.50     -1.04
```

Date: 14- 4-82 SCHENK 1626 Cal.fact. 14.95 μV/W/m²

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
-30.A	751.5			-0.31	-2.28	-0.56	-1.18
15.B	731.6			0.51	2.67	5.13	0.10
60.C	729.5			3.25	5.77	10.74	14.23
105.D	726.7			1.41	5.59	10.22	12.76
150.E	725.2	-1.04	-0.63	-2.18			-2.30
195.F	723.4	-0.94	-1.02	-2.95			-5.95
240.G	718.1	-0.89	-1.19	-2.13			-8.66
285.H	723.3	-1.27	-2.62	-2.49			-9.89
Mean	728.7	-1.03	-1.36	-0.61	2.94	6.39	-0.11
Stdev	1.39	0.17	0.87	2.21	3.76	5.27	9.11

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
-30.A	2.32	-0.93	-2.73	-1.38			-10.25
15.B	1.73	2.91	2.47	3.61			-8.44
60.C	3.09	4.36	4.02	6.09			8.67
105.D	4.57	6.20	6.60	6.77			5.56
150.E	(-11.38)			2.25	-1.03	-6.80	-20.02
195.F	4.44			-0.09	-1.53	-11.15	-26.92
240.G	4.86			0.77	-1.73	-10.95	-23.79
285.H	3.92			-1.82	-4.09	-10.00	-17.09
Mean	3.56	3.13	2.59	2.02	-2.10	-9.73	-11.54
Stdev	1.21	3.03	3.93	3.25	1.36	2.01	13.10

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
-30.A	2.20						
15.B	2.43						
60.C	4.29						
105.D	6.62						
150.E	0.90						
195.F	8.72						
240.G	6.66						
285.H	5.02						
Mean	4.60						
Stdev	2.67						

Tilt 60.

	0.87	0.74	0.61	0.48	0.35	0.22	0.09
-30.A	0.47						
15.B	1.46						
60.C	1.93						
105.D	2.89						
150.E	3.48						
195.F	3.46						
240.G	3.30						
285.H	2.92						
Mean	2.49						
Stdev	1.09						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		3.04	5.90	3.41

```
Date: 16- 4-82        SCHENK 2186       Cal.fact. 15.65 µV/W/m²
Tilt   90.
     -      1.00    0.85    0.70    0.55    0.40    0.25    0.10
------------------------------------------------------------------
-30.A      730.8                   -1.28   -4.01   -2.24    7.93
 15.B      717.4                   -0.53   -0.66   -0.76   -4.81
 60.C      719.3                   -1.25   -1.59   -2.82   -1.30
105.D      718.3                   -3.52   -3.52   -3.08   -4.09
150.E      717.5   -1.75   -2.30   -5.19                   -8.56
195.F      714.1   -1.36   -2.99   -5.25                  -10.58
240.G      710.5   -0.93   -2.65   -3.79                   -8.20
285.H      710.9    0.06   -2.01   -2.07                    0.85
------------------------------------------------------------------
Mean       717.4   -1.00   -2.49   -2.86   -2.44   -2.23   -3.59
Stdev       0.89    0.78    0.43    1.84    1.58    1.04    6.03

Tilt   45.
            0.71    0.60    0.49    0.39    0.28    0.18    0.07
------------------------------------------------------------------
-30.A       0.64   -0.46   -3.18   -0.65                    5.44
 15.B       1.74    2.83    1.75    0.65                   -8.25
 60.C       3.02    2.66    1.41   -0.10                   -4.99
105.D       3.77    1.20    0.05   -2.74                   -9.28
150.E       3.17                   -5.05  -10.26  -12.41  -15.93
195.F       1.72                   -5.01   -8.01  -14.40  -17.50
240.G       1.13                   -4.10   -6.68  -11.68  -14.61
285.H       0.77                   -4.03   -4.78   -9.74  -12.41
------------------------------------------------------------------
Mean        1.99    1.56    0.01   -2.63   -7.43  -12.06   -9.69
Stdev       1.18    1.53    2.25    2.29    2.31    1.93    7.41

Tilt   30.
            0.50    0.43    0.35    0.28    0.20    0.12    0.05
------------------------------------------------------------------
-30.A       0.04
 15.B       1.37
 60.C       3.79
105.D       4.53
150.E   (-11.88)
195.F       1.21
240.G       0.89
285.H       0.18
------------------------------------------------------------------
Mean        1.72
Stdev       1.75

Tilt   60.
            0.87    0.74    0.61    0.48    0.35    0.22    0.09
------------------------------------------------------------------
-30.A       0.17
 15.B       1.97
 60.C       2.92
105.D       2.51
150.E       1.94
195.F       1.69
240.G       1.27
285.H       0.70
------------------------------------------------------------------
Mean        1.65
Stdev       0.91

Tilt Angle          90.0   45.00   30.00   60.00
Tilt Error                  4.41    2.74    2.54
```

```
Date: 16- 4-82      SCHENK 2209      Cal.fact. 15.76 µV/W/m²
Tilt   90.
             1.00      0.85      0.70      0.55      0.40      0.25      0.10
-----------------------------------------------------------------------------
-30.A       723.7                         -3.51     -7.04     -5.39      2.40
 15.B       702.6                          0.24     -1.93     -1.23     -4.91
 60.C       705.4                          0.15     -1.80     -1.20      3.88
105.D       708.2                         -1.94     -3.68     -0.81      2.09
150.E       711.9     -0.94     -1.45     -3.64                         -5.10
195.F       712.1     -1.14     -2.88     -4.23                        -12.71
240.G       708.8     -1.09     -3.07     -3.88                        -17.33
285.H       709.2     -0.45     -2.80     -2.54                        -11.95
-----------------------------------------------------------------------------
Mean        710.3     -0.91     -2.55     -2.42     -3.61     -2.16     -5.45
Stdev        0.88      0.31      0.74      1.77      2.44      2.16      7.94

Tilt   45.
             0.71      0.60      0.49      0.39      0.28      0.18      0.07
-----------------------------------------------------------------------------
-30.A       -1.39     -3.41     -5.94     -3.36                         -3.59
 15.B       -0.39      0.06     -1.00     -0.17                         -7.45
 60.C        0.47      0.80     -0.23      0.05                          3.19
105.D        1.50      0.14      0.03     -1.77                          1.31
150.E        1.94                         -3.87     -9.86    -10.35     -7.24
195.F        0.77                         -5.89     -8.58    -16.79    -14.98
240.G        0.36                         -7.36    -10.23    -20.14    -21.35
285.H       -0.82                         -8.45     -9.31    -47.68    -61.09
-----------------------------------------------------------------------------
Mean         0.31     -0.60     -1.79     -3.85     -9.49    -23.74    -13.90
Stdev        1.13      1.90      2.80      3.18      0.72     16.47     20.70

Tilt   30.
             0.50      0.43      0.35      0.28      0.20      0.12      0.05
-----------------------------------------------------------------------------
-30.A       -2.65
 15.B       -0.86
 60.C        0.61
105.D        2.23
150.E        1.79
195.F        1.04
240.G       -0.11
285.H       -1.66
-----------------------------------------------------------------------------
Mean         0.05
Stdev        1.70

Tilt   60.
             0.87      0.74      0.61      0.48      0.35      0.22      0.09
-----------------------------------------------------------------------------
-30.A       -1.08
 15.B        0.45
 60.C        0.41
105.D        0.67
150.E        0.64
195.F        0.42
240.G       -0.24
285.H       -1.42
-----------------------------------------------------------------------------
Mean        -0.02
Stdev        0.81

Tilt Angle                 90.0     45.00     30.00     60.00
Tilt Error                           2.78      2.87      0.79
```

```
Date: 16- 4-82          SCHENK 2217      Cal.fact. 14.20 µV/W/m²
Tilt    90.
            1.00     0.85     0.70     0.55     0.40     0.25     0.10
----------------------------------------------------------------------
-30. A     725.1                      -0.95    -2.79     1.38    14.51
 15. B     710.8                       0.49     1.05     3.55     9.54
 60. C     715.6                      -0.45    -0.27     0.85    10.98
105. D     721.4                      -2.62    -2.28    -0.55     1.30
150. E     725.3    -1.59    -1.39    -3.79                      -2.91
195. F     719.1    -1.27    -1.66    -3.56                       1.10
240. G     710.8    -1.03    -1.55    -2.80                       3.20
285. H     708.7     0.16    -1.21    -0.28                      10.85
----------------------------------------------------------------------
Mean       717.1    -0.93    -1.45    -1.75    -1.07     1.31     6.07
Stdev        0.9     0.76     0.20     1.64     1.79     1.70     6.17

Tilt    45.
            0.71     0.60     0.49     0.39     0.28     0.18     0.07
----------------------------------------------------------------------
-30. A       1.6     0.87    -1.01     1.20                      14.25
 15. B       2.4     3.32     2.72     3.72                      11.78
 60. C       3.3     3.54     2.92     2.79                      11.05
105. D       4.1     2.19     1.30    -0.77                      -2.91
150. E    (-7.2)                      -2.80    -7.46    -9.01    -8.82
195. F       2.1                      -2.30    -3.76    -8.30    -2.53
240. G       3.2                      -1.70    -2.48    -6.49    -0.31
285. H       2.9                      -1.27    -1.00 (-23.75)(-43.46)
----------------------------------------------------------------------
Mean         1.6     2.48     1.48    -0.14    -3.68     7.93     3.22
Stdev        3.6     1.23     1.81     2.42     2.77     1.30     8.98

Tilt    30.
            0.50     0.43     0.35     0.28     0.20     0.12     0.05
----------------------------------------------------------------------
-30. A       1.9
 15. B       3.7
 60. C       5.0
105. D       6.2
150. E    (-8.5)
195. F       2.3
240. G       3.5
285. H       3.4
----------------------------------------------------------------------
Mean         3.7
Stdev        1.5

Tilt    60.
            0.87     0.74     0.61     0.48     0.35     0.22     0.09
----------------------------------------------------------------------
-30. A       0.5
 15. B       1.9
 60. C       2.2
105. D       2.3
150. E       1.7
195. F       1.6
240. G       2.2
285. H       2.0
----------------------------------------------------------------------
Mean         1.8
Stdev        0.6

Tiltangle 90.0        45.0        30.0        60.0
Tilterror  0.0         4.2         5.2         2.6
```

```
Date: 14- 4-82          SCHENK 2221      Cal.fact. 15.65 µV/W/m²
Tilt    90.
             1.00      0.85      0.70      0.55      0.40      0.25      0.10
------------------------------------------------------------------------------
-30. A      726.4                         -1.65     -4.35     -3.10      4.04
 15. B      710.0                         -0.46     -1.07     -0.79     -7.41
 60. C      711.2                          0.27     -0.19      0.17     -0.65
105. D      711.2                         -0.48      0.50      2.67      4.15
150. E      711.7     -1.05     -0.60     -1.69                          3.94
195. F      710.5     -0.78     -1.12     -1.90                          2.04
240. G      706.6     -0.72     -1.46     -1.64                          0.09
285. H      705.4     -0.19     -1.75     -0.83                          1.33
------------------------------------------------------------------------------
Mean        711.6     -0.69     -1.23     -1.05     -1.28     -0.26      0.94
Stdev        0.90      0.36      0.50      0.78      2.14      2.39      3.84

Tilt    45.
             0.71      0.60      0.49      0.39      0.28      0.18      0.07
------------------------------------------------------------------------------
-30. A        1.8     -0.21     -2.37     -0.08                          0.05
 15. B        2.1      2.28      1.23     -0.12                        -11.27
 60. C        3.0      2.50      1.61      1.29                         -4.82
105. D        3.5      2.64      2.21      0.82                         -0.07
150. E        3.8                          2.64      1.32     -0.59    -10.01
195. F     (-10.2)                         1.02      2.11     -4.83     -5.60
240. G        2.5                          0.15     -0.54     -6.21     -2.67
285. H        3.0                         -1.50     -1.87     -7.91     -4.53
------------------------------------------------------------------------------
Mean          2.8      1.80      0.67      0.53      0.25     -4.89     -4.87
Stdev         0.7      1.35      2.07      1.22      1.80      3.13      4.14

Tilt    30.
             0.50      0.43      0.35      0.28      0.20      0.12      0.05
------------------------------------------------------------------------------
-30. A        2.2
 15. B        2.5
 60. C        3.6
105. D        3.9
150. E        4.8
195. F      (-8.3)
240. G        4.4
285. H        4.4
------------------------------------------------------------------------------
Mean          3.7
Stdev         1.0

Tilt    60.
             0.87      0.74      0.61      0.48      0.35      0.22      0.09
------------------------------------------------------------------------------
-30. A        0.8
 15. B        1.8
 60. C        1.8
105. D        1.8
150. E        1.9
195. F        3.0
240. G        2.3
285. H        1.8
------------------------------------------------------------------------------
Mean          1.9
Stdev         0.6

Tiltangle  90.0           45.0           30.0           60.0
Tilterror   0.0            4.0            4.8            2.5
```

```
Date: 28- 4-82        SWISSTC 113       Cal.fact. 16.41 µV/W/m²
Tilt    90.
            1.00       0.85      0.70      0.55      0.40      0.25      0.10
----------------------------------------------------------------------------
-135.A    704.1                            1.80      0.22      2.54     18.18
 -90.B    702.4                            3.29      2.43      3.92     16.60
 -45.C    703.9                            3.29      2.26      3.23     15.26
   0.D    704.3                            2.70      1.22      2.15     11.22
  45.E    704.1      2.52      2.49        1.68                          8.20
  90.F     704.3    1.65       1.50       0.89                         (-6.19)
 135.G    704.4      1.49      1.29       0.84                           9.10
 180.H    704.9      1.95      1.71       1.54                           9.86
----------------------------------------------------------------------------
Mean      704.0      1.90      1.75       2.00      1.53      2.96       9.15
Stdev       0.11     0.45      0.52       0.98      1.03      0.78       6.48

Tilt    45.
            0.71       0.60      0.49      0.39      0.28      0.18      0.07
----------------------------------------------------------------------------
-135.A      1.47     0.67     -0.28       0.56                          21.45
 -90.B      1.73     1.94      1.44       1.66                          21.94
 -45.C      2.49     2.67      2.13       1.97                          19.33
   0.D      3.20     2.74      1.99       1.16                          16.24
  45.E      3.42                         -0.14     -2.27     -2.84      13.34
  90.F      3.12                         -1.70     -3.27     -5.72      11.36
 135.G      2.22                       (-27.58)(-48.71)      -3.47      10.59
 180.H      1.38                         -1.52     -2.50     -2.21      16.39
----------------------------------------------------------------------------
Mean        2.38     2.01      1.32      -0.28     -2.69     -3.56      16.33
Stdev       0.81     0.96      1.11       1.47      0.53      1.53       4.36

Tilt    30.
            0.50       0.43      0.35      0.28      0.20      0.12      0.05
----------------------------------------------------------------------------
-135.A      0.69
 -90.B      0.85
 -45.C      2.10
   0.D      3.10
  45.E      3.19
  90.F      2.42
 135.G      1.17
 180.H      0.11
----------------------------------------------------------------------------
Mean        1.70
Stdev       1.16

Tilt    60.
            0.87       0.74      0.61      0.48      0.35      0.22      0.09
----------------------------------------------------------------------------
-135.A      1.51
 -90.B      1.67
 -45.C      2.03
   0.D      2.49
  45.E      2.71
  90.F      2.45
 135.G      1.77
 180.H      1.01
----------------------------------------------------------------------------
Mean        1.95
Stdev       0.57

Tilt Angle          90.0      45.00     30.00     60.00
Tilt Error                     0.62     -0.14      0.26
```

```
Date: 28- 4-82        SWISSTC 114      Cal.fact. 18.06 µV/W/m²
Tilt   90.
            1.00      0.85      0.70      0.55      0.40      0.25      0.10
---------------------------------------------------------------------------
180.A     720.4                           0.29     -2.18     -2.85      6.24
225.B     714.7                           1.66     -1.75     -3.24     -1.16
270.C     719.2                           0.83     -2.61     -4.14     -2.33
315.D     720.8                           0.52     -3.06     -2.90     -2.17
  0.E     722.1     1.67      1.88        0.83                         -0.77
 45.F     723.1     1.66      1.50        1.34                          2.75
 90.G     723.0     2.01      1.82        1.98                          4.85
135.H     723.3     2.46      2.08        2.76                          4.66
---------------------------------------------------------------------------
Mean      720.8     1.95      1.82        1.28     -2.40     -3.28      1.51
Stdev       0.40    0.38      0.24        0.83      0.56      0.60      3.50

Tilt   45.
            0.71      0.60      0.49      0.39      0.28      0.18      0.07
---------------------------------------------------------------------------
180.A       1.97    0.96     -1.29     -1.25                            8.20
225.B       1.90    1.42     -0.51     -1.17                            1.17
270.C       1.74    0.39     -1.24     -1.91                           -0.81
315.D       1.45   -0.40     -1.62     -2.48                           -0.72
  0.E       0.72                       -2.71     -6.83     -7.94      2.38
 45.F       0.29                       -2.21     -4.44     -5.50      7.05
 90.G       0.44                       -1.65     -3.21     -4.29      9.94
135.H       0.53                       -2.05     -2.61     -5.57     10.21
---------------------------------------------------------------------------
Mean        1.13    0.59     -1.16     -1.93     -4.28     -5.82      4.68
Stdev       0.71    0.79      0.47      0.55      1.87      1.53      4.68

Tilt   30.
            0.50      0.43      0.35      0.28      0.20      0.12      0.05
---------------------------------------------------------------------------
180.A       1.38
225.B      -0.17
270.C      -0.26
315.D      -0.19
  0.E      -0.46
 45.F      -0.86
 90.G      -0.64
135.H      -0.25
---------------------------------------------------------------------------
Mean       -0.18
Stdev       0.68

Tilt   60.
            0.87      0.74      0.61      0.48      0.35      0.22      0.09
---------------------------------------------------------------------------
180.A      -3.80
225.B       2.68
270.C       2.07
315.D       1.71
  0.E       0.90
 45.F       0.43
 90.G       0.40
135.H      -0.21
---------------------------------------------------------------------------
Mean        0.52
Stdev       1.99

Tilt Angle           90.0     45.00     30.00     60.00
Tilt Error                    -0.70     -0.23     -1.22
```

```
Date:  29- 4-82       SWISSTC 115      Cal.fact. 17.11 µV/W/m²
Tilt    90.
              1.00     0.85     0.70     0.55     0.40     0.25     0.10
-------------------------------------------------------------------------
   0.A     711.0     1.28              -0.76    -3.37    -3.95    -0.66
  45.B     710.5                       -0.65    -3.20    -4.30    -5.71
  90.C     712.5                        0.02    -2.49    -2.99    -1.62
 135.D     713.1                        1.43    -0.77    -0.39     3.25
 180.E     713.0     2.92     3.07      2.97                       5.67
 225.F     712.5     3.36     3.59      3.78                       6.59
 270.G     711.7              3.34      3.32                       7.75
 315.H     711.5     0.81     2.22      2.05                       2.95
-------------------------------------------------------------------------
Mean       712.0     2.09     3.05      1.52    -2.46    -2.91     2.28
Stdev       0.15     1.24     0.60      1.81     1.19     1.77     4.61

Tilt    45.
              0.71     0.60     0.49     0.39     0.28     0.18     0.07
-------------------------------------------------------------------------
   0.A      3.57     1.15    -0.76     -1.46                      -1.02
  45.B      2.14    -0.12    -2.07     -3.19                      -6.43
  90.C      1.03    -1.02    -2.52     -3.03                      -1.98
 135.D      0.35    -0.57    -1.51     -1.66                       6.45
 180.E      0.76                       -0.17    -2.30    -2.95     8.98
 225.F      1.84                        0.94    -0.47    -1.72     5.09
 270.G      2.38                        1.17    -0.25    -1.75    10.56
 315.H      3.27                       -0.23    -1.80    -4.83     5.87
-------------------------------------------------------------------------
Mean        1.92    -0.14    -1.71     -0.95    -1.21    -2.81     3.44
Stdev       1.16     0.93     0.76      1.66     1.00     1.46     5.92

Tilt    30.
              0.50     0.43     0.35     0.28     0.20     0.12     0.05
-------------------------------------------------------------------------
   0.A      2.94
  45.B      0.89
  90.C     -0.91
 135.D     -1.68
 180.E     -0.85
 225.F      0.53
 270.G  (-25.25)
 315.H      2.65
-------------------------------------------------------------------------
Mean       -0.51
Stdev       1.79

Tilt    60.
              0.87     0.74     0.61     0.48     0.35     0.22     0.09
-------------------------------------------------------------------------
   0.A      3.26
  45.B      2.30
  90.C      1.44
 135.D      0.94
 180.E      1.04
 225.F      1.44
 270.G      2.61
 315.H      2.74
-------------------------------------------------------------------------
Mean        1.97
Stdev       0.87

Tilt Angle           90.0    45.00    30.00    60.00
Tilt Error                   -1.09     0.32     0.10
```

Date: 27- 4-82 **SWISSTC 116** Cal.fact. 16.00 $\mu V/W/m^2$

Tilt 90.

	1.00	0.85	0.70	0.55	0.40	0.25	0.10
0.A	715.4			3.05	1.13	2.73	15.81
45.B	711.9			5.83	3.55	4.70	15.42
90.C	715.1			5.22	2.34	2.98	13.46
135.D	715.3			3.90	-0.05	0.60	6.03
180.E	715.8	2.04	2.26	2.11			-1.89
225.F	716.8	1.97	1.78	1.24			-5.70
270.G	717.6	2.36	1.97	1.82			-2.98
315.H	717.8	2.91	2.81	3.45			4.31
Mean	715.7	2.32	2.21	3.33	1.74	2.75	5.56
Stdev	0.26	0.43	0.45	1.62	1.55	1.68	8.63

Tilt 45.

	0.71	0.60	0.49	0.39	0.28	0.18	0.07
0.A	1.27	1.26	-0.05	1.10			19.21
45.B	1.81	2.85	2.04	2.83			20.40
90.C	2.47	2.56	1.82	1.98			17.53
135.D	2.56	1.46	0.64	-0.16			8.98
180.E	1.82			-2.73	-6.54	-9.21	-0.30
225.F	0.59			-4.36	-7.56	-11.49	-4.65
270.G	-0.27			-4.03	-6.80	-9.82	-2.15
315.H	-0.35			-2.77	-3.93	-6.64	6.54
Mean	1.24	2.03	1.11	-1.02	-6.21	-9.29	8.20
Stdev	1.14	0.79	0.99	2.81	1.58	2.01	10.03

Tilt 30.

	0.50	0.43	0.35	0.28	0.20	0.12	0.05
0.A	-0.48						
45.B	0.69						
90.C	1.80						
135.D	2.26						
180.E	1.30						
225.F	-0.52						
270.G	-2.12						
315.H	-2.54						
Mean	0.05						
Stdev	1.77						

Tilt 60.

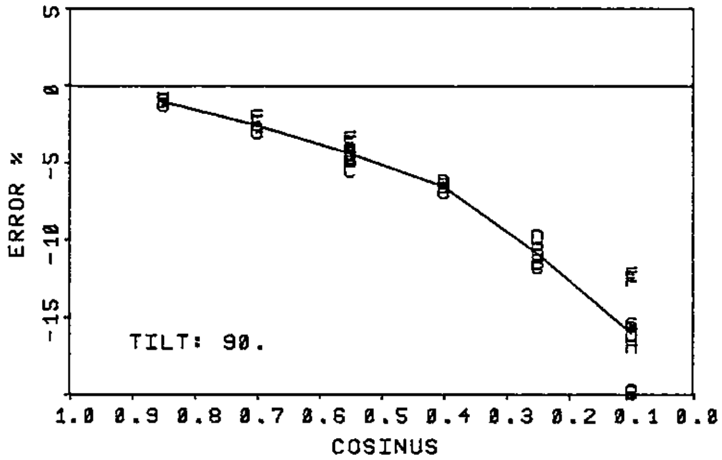
	0.87	0.74	0.61	0.48	0.35	0.22	0.09
0.A	2.08						
45.B	2.86						
90.C	2.81						
135.D	2.57						
180.E	1.73						
225.F	0.91						
270.G	0.50						
315.H	0.25						
Mean	1.71						
Stdev	1.04						

Tilt Angle	90.0	45.00	30.00	60.00
Tilt Error		-0.97	-2.75	-0.36

```
Date: 12- 4-82          WRC CAVITAET       Cal.fact.   1.80 µV/W/m²
Tilt    90.
              1.00     0.85     0.70     0.55     0.40     0.25     0.10
------------------------------------------------------------------------
  0. A      1143.9                      -3.29    -6.87    -7.67    -5.71
 45. B      1134.6                      -2.02    -4.15    -4.81    -9.06
 90. C      1140.6                      -0.86    -2.60    -2.96    -4.19
135. D      1142.1                          -    -1.33    -0.27    -1.63
180. E      1142.1     1.21     0.98    -0.20                      -0.84
225. F      1141.8     0.36    -0.96    -1.36                      -2.26
270. G      1141.3    -0.76    -2.46    -2.61                      -4.80
315. H      1140.7    -0.80    -3.01    -2.58                      -8.17
------------------------------------------------------------------------
Mean        1140.9     0.00    -1.36    -1.61    -3.74    -3.93    -4.58
Stdev          0.2     0.97     1.79     1.20     2.39     3.11     2.99

Tilt    45.
              0.71     0.60     0.49     0.39     0.28     0.18     0.07
------------------------------------------------------------------------
  0. A        -3.2    -5.15    -7.82    -7.75                      -8.96
 45. B        -3.6    -4.18    -5.95    -7.37                     -16.27
 90. C        -3.5    -4.02    -5.17    -6.19                      -9.43
135. D        -2.7    -3.23    -3.47    -4.60                      -6.24
180. E        -1.1                      -4.10    -7.67    -9.83    -4.87
225. F        -0.1                      -4.92    -7.42   -11.27    -5.66
270. G        -0.5                      -6.50    -8.96   -13.83    -8.31
315. H        -1.9                      -8.54   -10.58   -16.84   -12.28
------------------------------------------------------------------------
Mean          -2.1    -4.15    -5.60    -6.25    -8.66   -12.95    -9.00
Stdev          1.4     0.79     1.81     1.60     1.45     3.08     3.78

Tilt    30.
              0.50     0.43     0.35     0.28     0.20     0.12     0.05
------------------------------------------------------------------------
  0. A        -4.9
 45. B        -6.4
 90. C        -6.0
135. D        -5.2
180. E        -3.4
225. F        -2.3
270. G        -2.5
315. H        -3.7
------------------------------------------------------------------------
Mean          -4.3
Stdev          1.5

Tilt    60.
              0.87     0.74     0.61     0.48     0.35     0.22     0.09
------------------------------------------------------------------------
  0. A        -1.1
 45. B        -0.6
 90. C        -0.9
135. D        -0.1
180. E         0.7
225. F         1.0
270. G         0.7
315. H        -0.5
------------------------------------------------------------------------
Mean          -0.1
Stdev          0.8

Tiltangle  90.0         45.0          30.0          60.0
Tilterror   0.0         -0.8          -2.0          -0.1
```

```
Date: 23- 4-82        WRC PD6703         Cal.fact. 25.20 µV/W/m²
Tilt    90.
            1.00      0.85      0.70      0.55      0.40      0.25      0.10
-----------------------------------------------------------------------------
  0.A     747.4                          -1.59     -4.73     -6.29    -10.71
 45.B     740.4                           0.03     -2.67     -4.67    -10.43
 90.C     743.1                          -0.88     -3.52     -5.40    -10.36
135.D     747.2                          -1.93     -5.05     -6.32    -14.45
180.E     758.6    -1.15     -1.64       -3.14                        -19.65
225.F     769.9    -1.09     -2.09       -3.33                        -22.38
270.G     768.5    -0.46     -1.40       -2.39                        -22.01
315.H     756.7     0.29     -0.52       -0.63                        -18.76
-----------------------------------------------------------------------------
Mean      754.0    -0.60     -1.41       -1.73     -3.99     -5.67    -16.09
Stdev       1.49    0.67      0.66        1.20      1.10      0.79      5.22

Tilt    45.
            0.71      0.60      0.49      0.39      0.28      0.18      0.07
-----------------------------------------------------------------------------
  0.A     -1.55    -2.64     -4.78       -4.60                        -14.27
 45.B     -1.44    -1.64     -3.16       -3.85                        -18.91
 90.C     -1.16    -2.40     -3.82       -4.57                        -14.88
135.D     -1.25    -3.11     -4.37       -5.74                        -18.87
180.E     -1.94                          -7.60    -12.32    -18.39    -24.19
225.F     -3.05                          -9.01    -13.22    -20.65    -27.28
270.G     -3.41                          -8.81    -12.77    -20.20    -26.88
315.H  (-48.61)                          -7.73    -10.75    -19.25    -23.18
-----------------------------------------------------------------------------
Mean      -1.97    -2.45     -4.03       -6.49    -12.27    -19.62    -21.06
Stdev      0.90     0.62      0.70        2.04      1.07      1.01      5.08

Tilt    30.
            0.50      0.43      0.35      0.28      0.20      0.12      0.05
-----------------------------------------------------------------------------
  0.A     -3.63
 45.B     -3.17
 90.C     -2.59
135.D     -2.71
180.E     -3.87
225.F     -5.59
270.G     -6.77
315.H     -6.06
-----------------------------------------------------------------------------
Mean      -4.30
Stdev      1.61

Tilt    60.
            0.87      0.74      0.61      0.48      0.35      0.22      0.09
-----------------------------------------------------------------------------
  0.A     -0.57
 45.B      0.13
 90.C     -0.17
135.D     -0.26
180.E     -0.67
225.F     -1.55
270.G     -5.98
315.H     -2.08
-----------------------------------------------------------------------------
Mean      -1.39
Stdev      1.99

Tilt Angle          90.0     45.00     30.00     60.00
Tilt Error                   -0.60     -1.81     -0.85
```

EPPLEY PSP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-5
-10
-15
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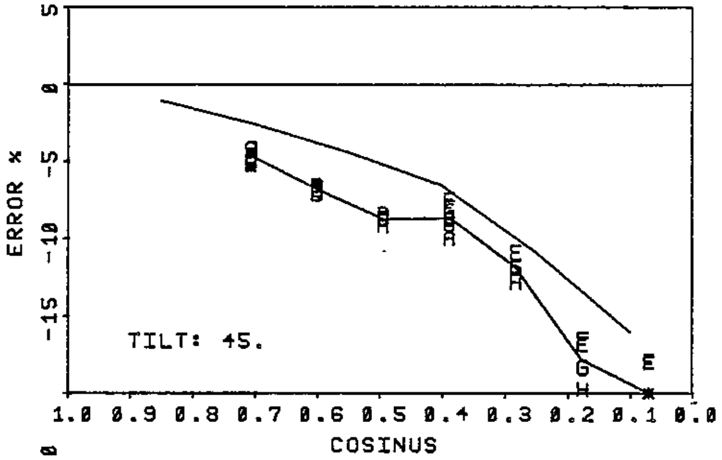
COSINUS


ERROR %
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0
-5
-10
-15
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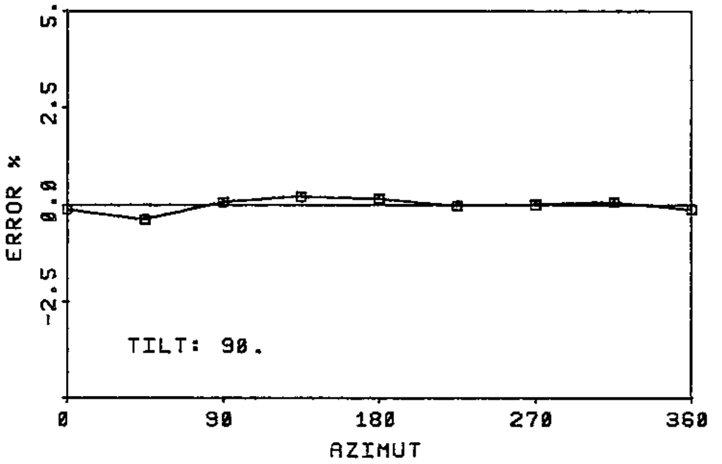
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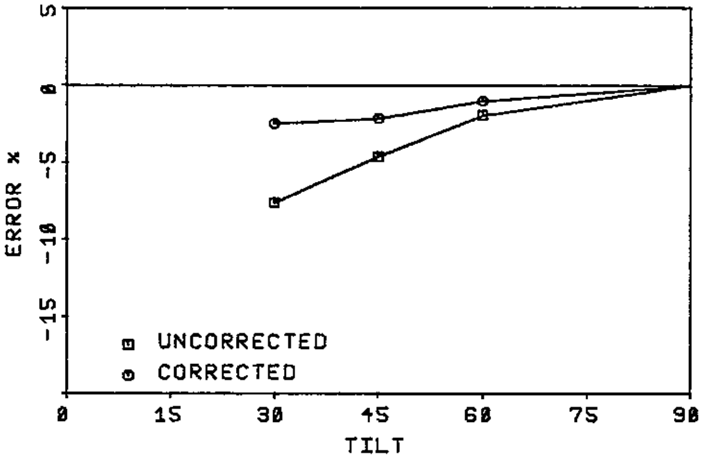
0.0
-2.5
TILT: 90.
0
90
180
270
360
AZIMUT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-5
-10
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UNCORRECTED
CORRECTED
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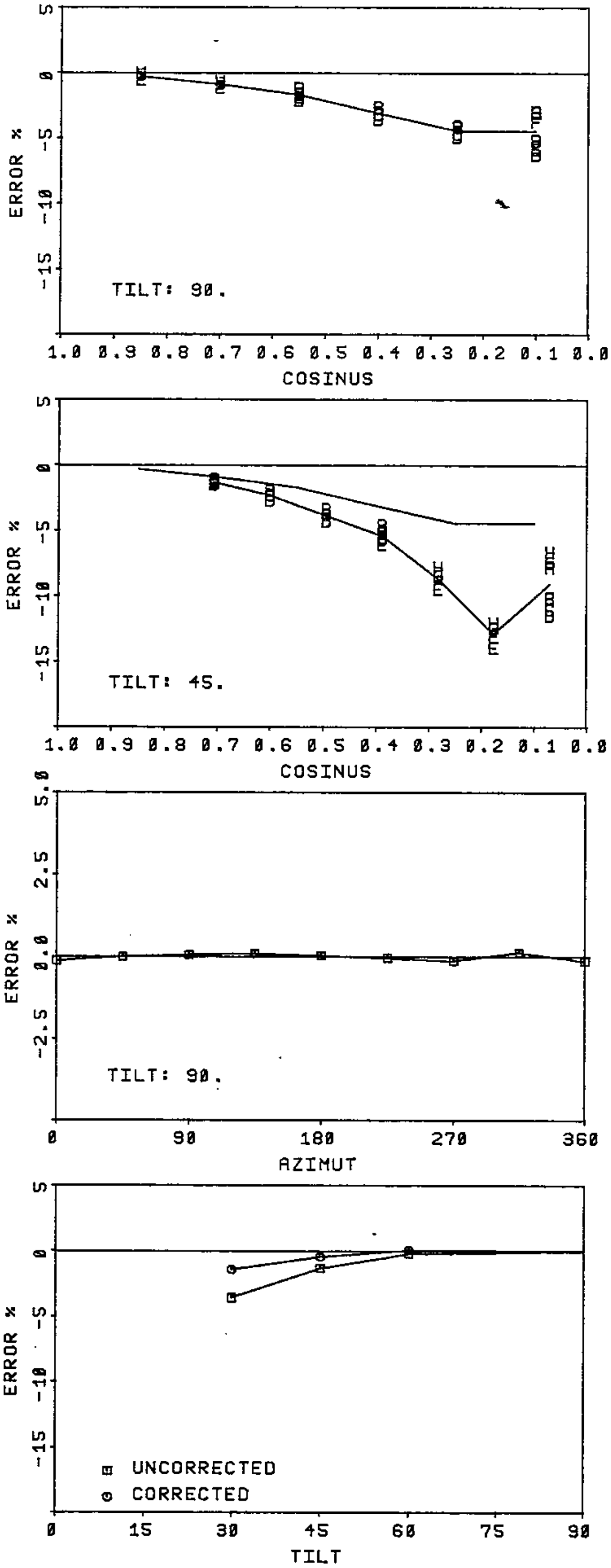
15
30
45
60
75
90
TILT

K+Z CM10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0
-5
-10
-15
ERROR %
TILT: 90.
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
COSINUS
5
0
-5
-10
-15
ERROR %
TILT: 45.
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
COSINUS
5.0
2.5
0.0
-2.5
ERROR %
TILT: 90.
0
90
180
270
360
AZIMUT
5
0
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-10
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ERROR %
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CORRECTED
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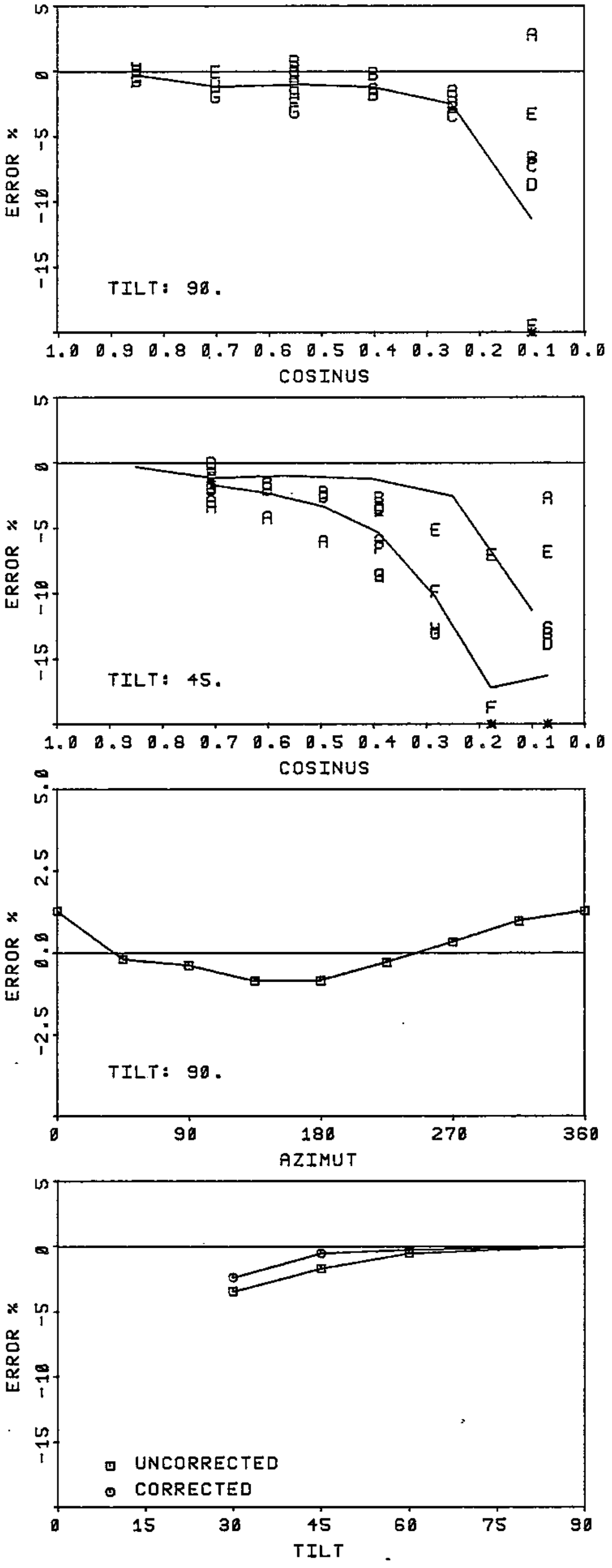
TILT

K+Z CMS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-5
-10
-15
TILT: 90.
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
COSINUS
A
E
B
C
D
F
ERROR %
TILT: 45.
COSINUS
ERROR %
5.0
2.5
0.0
-2.5
TILT: 90.
0
90
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270
360
AZIMUT
ERROR %
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CORRECTED
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30
45
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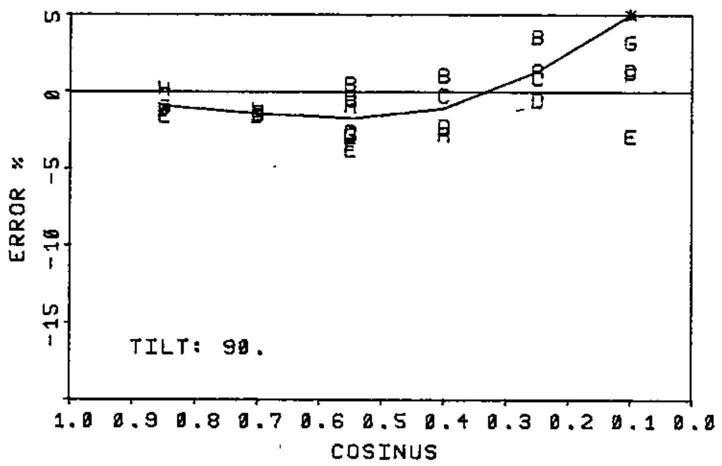
90
TILT

SCHENK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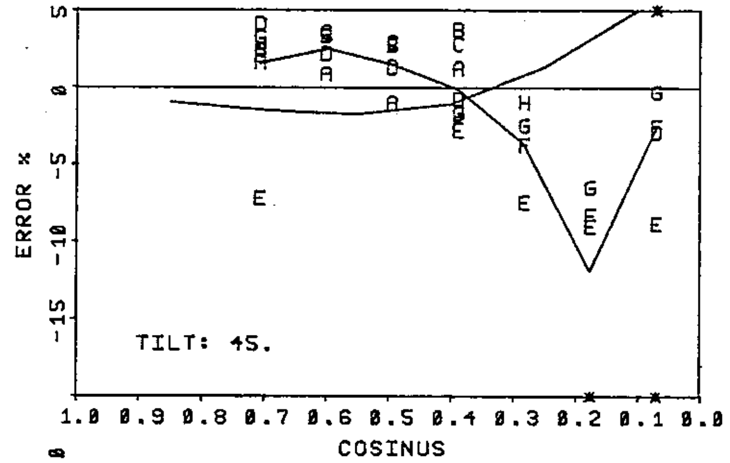
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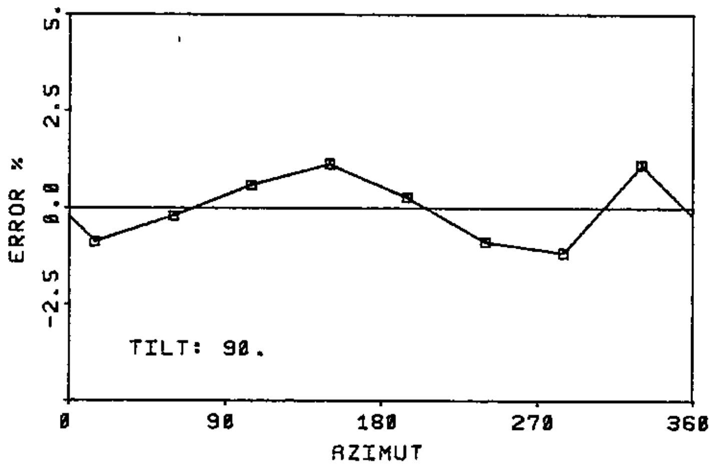
COSINUS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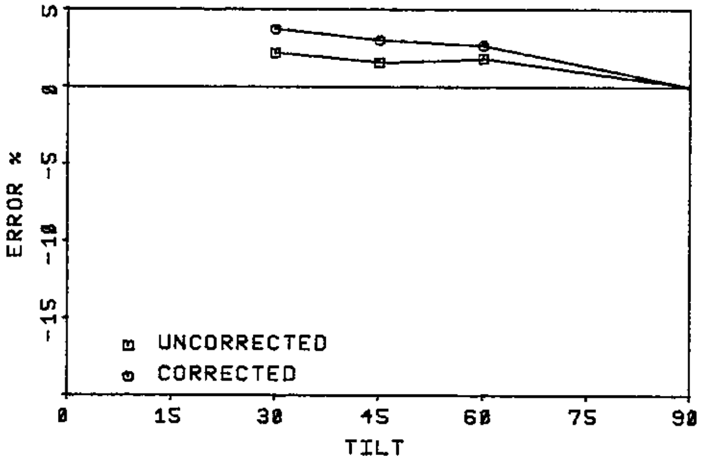
AZIMUT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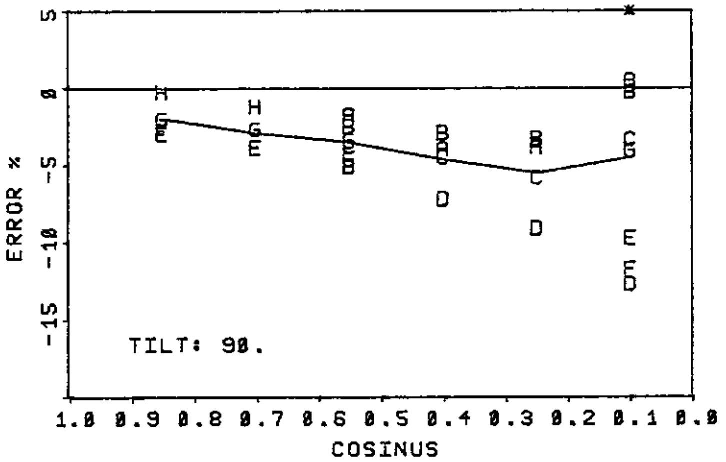
UNCORRECTED
CORRECTED
0
15
30
45
60
75
90
TILT

EKO STAR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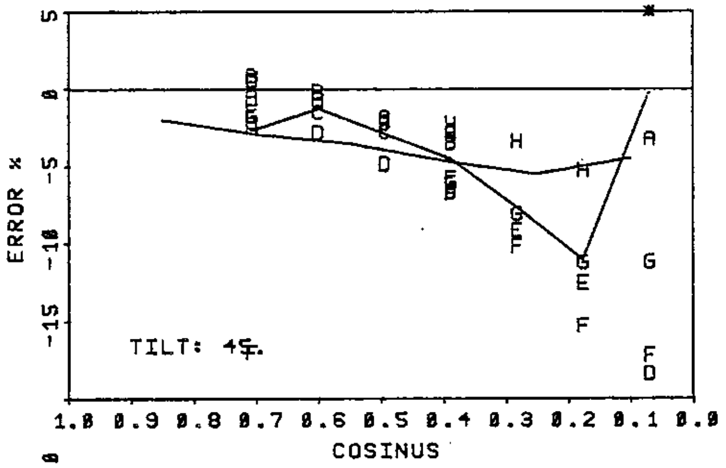
COSINUS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TILT: 45.
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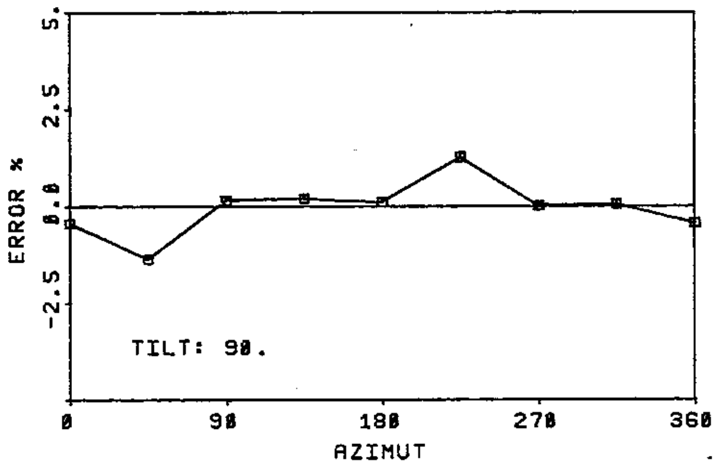
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0.0
-2.5
ERROR %
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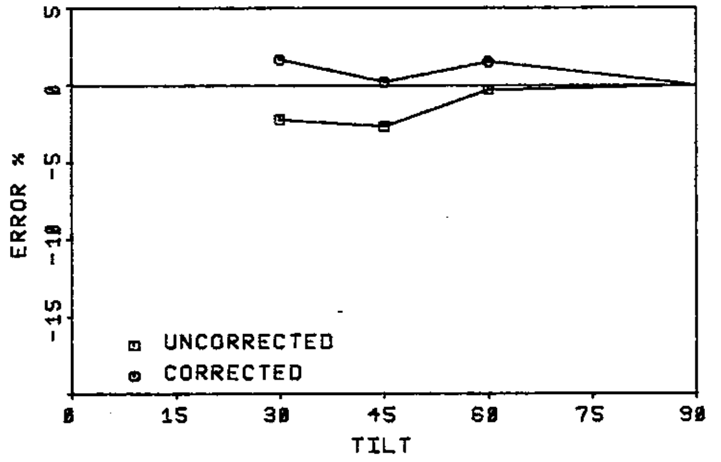
AZIMUT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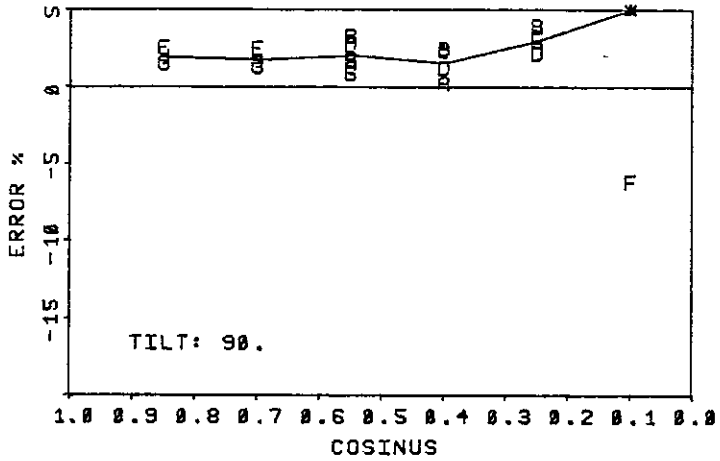
TILT

SWISSTECO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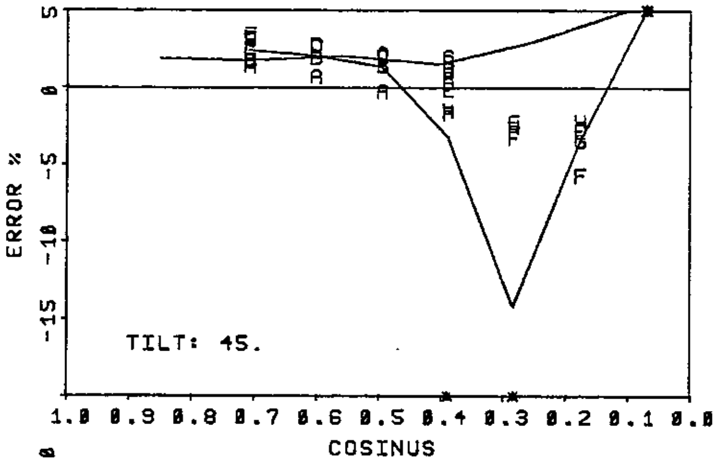
COSINUS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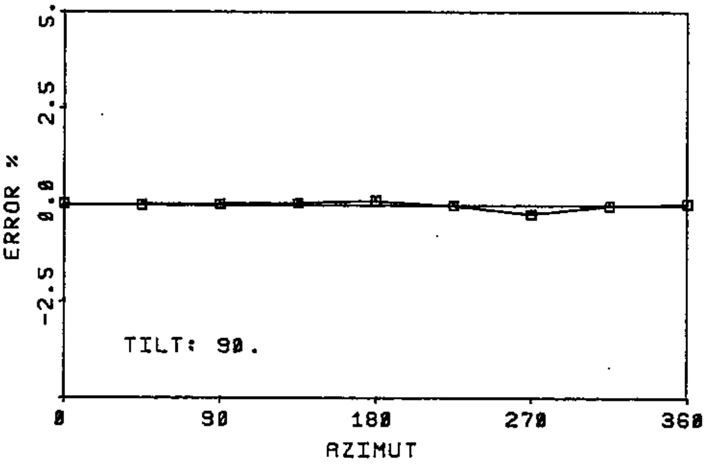
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2.5
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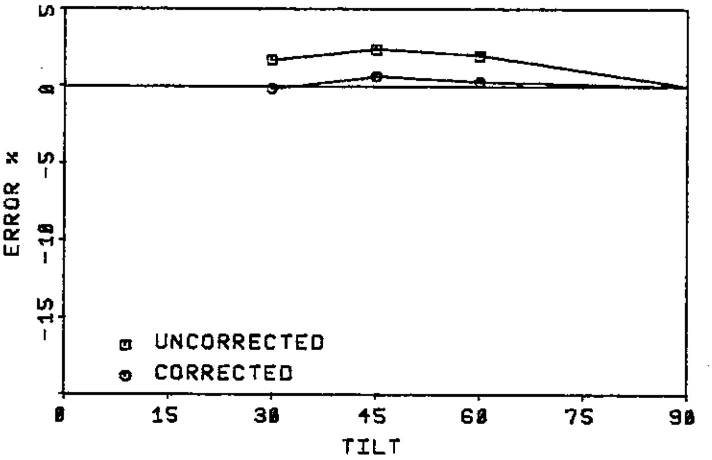
AZIMUT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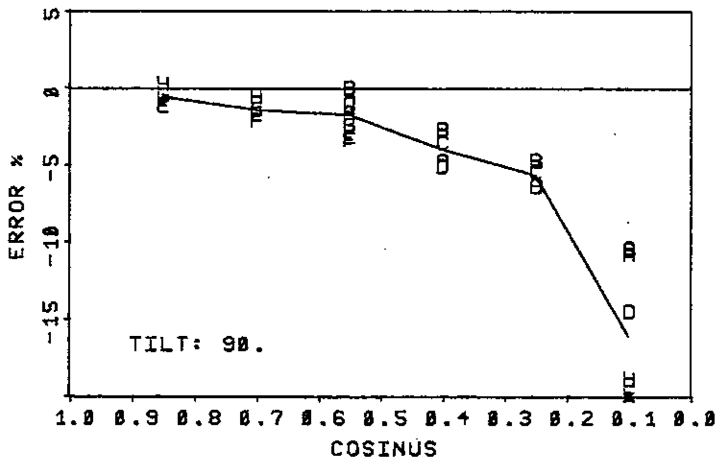
TILT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ERROR %
TILT: 90.
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0.7
0.6
0.5
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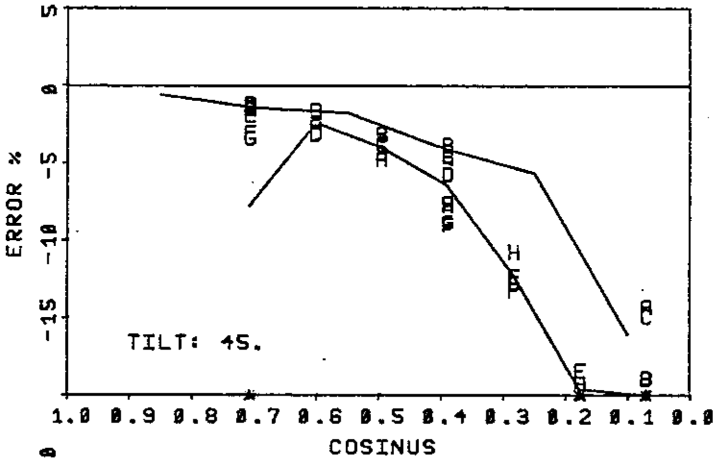
COSINUS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ERROR %
TILT: 45.
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0.6
0.5
0.4
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0.2
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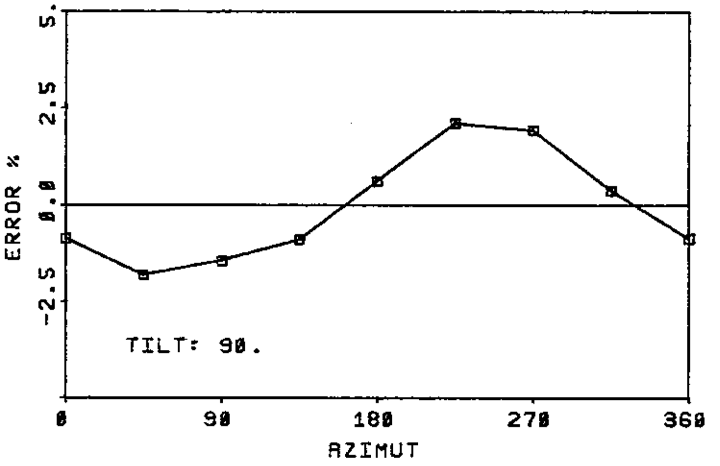
0.0
COSINUS

PD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2.5
0.0
-2.5
ERROR %
TILT: 90.
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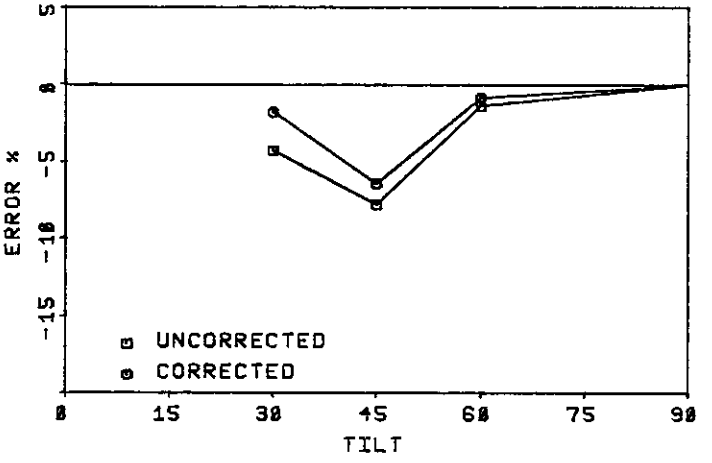
360
AZIMUT


5
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ERROR %
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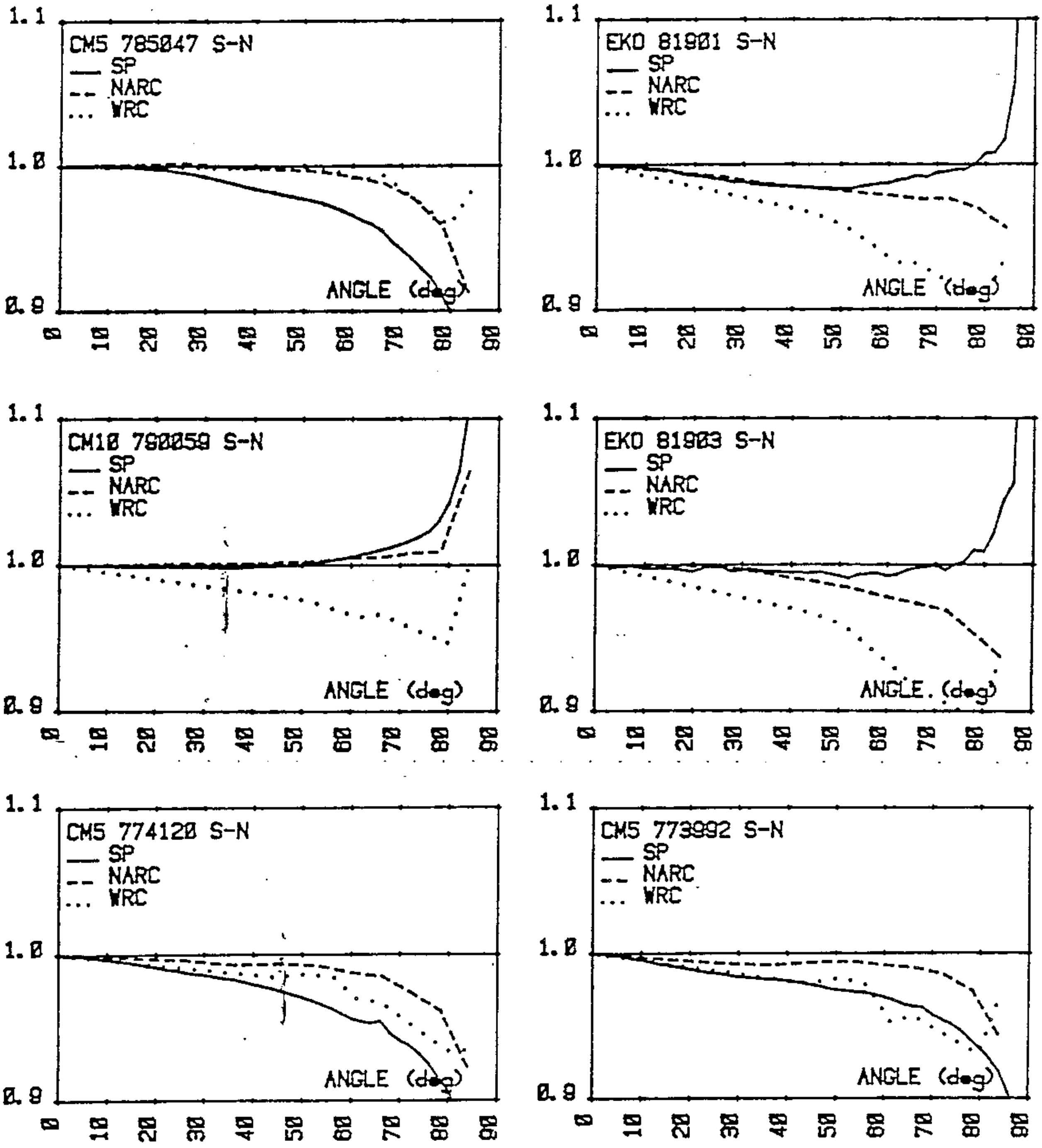
90
TILT

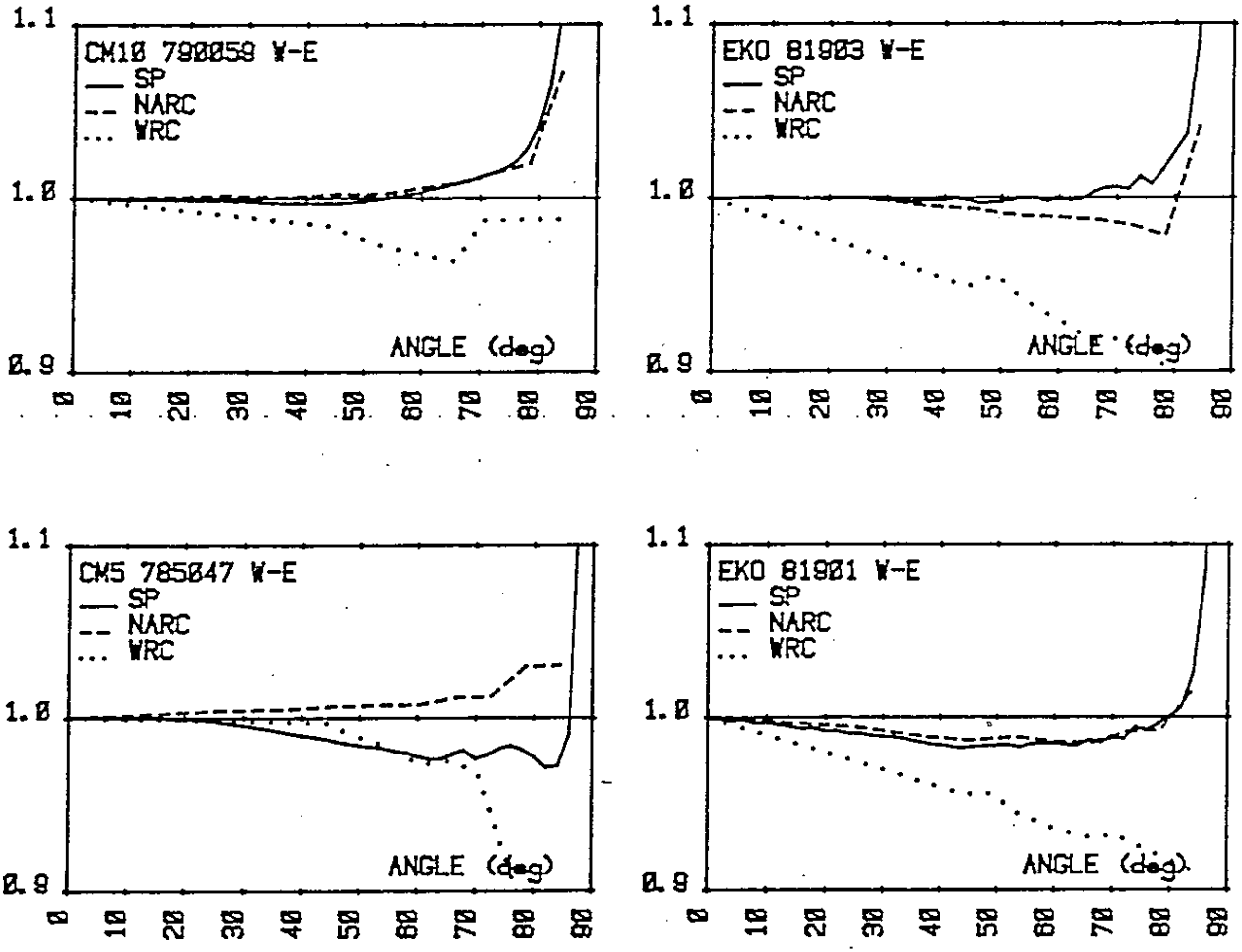
COMPARISON OF CHARACTERIZATION DATA FROM DIFFERENT LABORATORIES

Arrangement of data plots: **Cosine responsivity and temperature coefficient**
directional responsivity 24 plots, 5 pages
temperature coefficient 10 plots, 2 pages



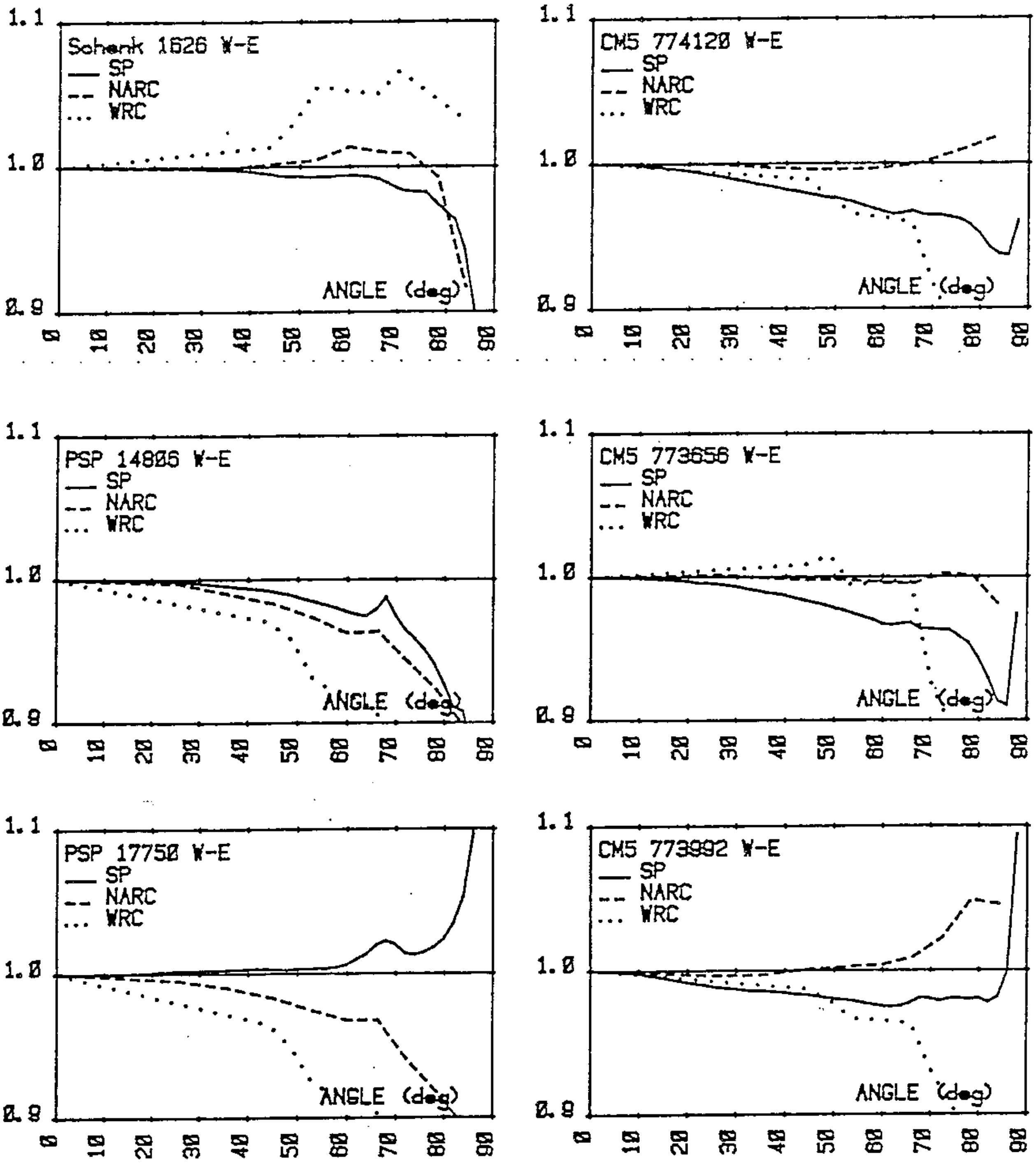
Comparison between measurements of cosine response from SP, WRC and NARC. Sections in the south-north direction. The cable connection pointing north. All curves are mean values at data from the two directions zenith-north and zenith-south.

SP	Statens Provningsanstalt, Boras, Sweden
WRC	World Radiation Center, Davos, Switzerland
NARC	National Atmospheric Radiation Center, Downsview, Canada



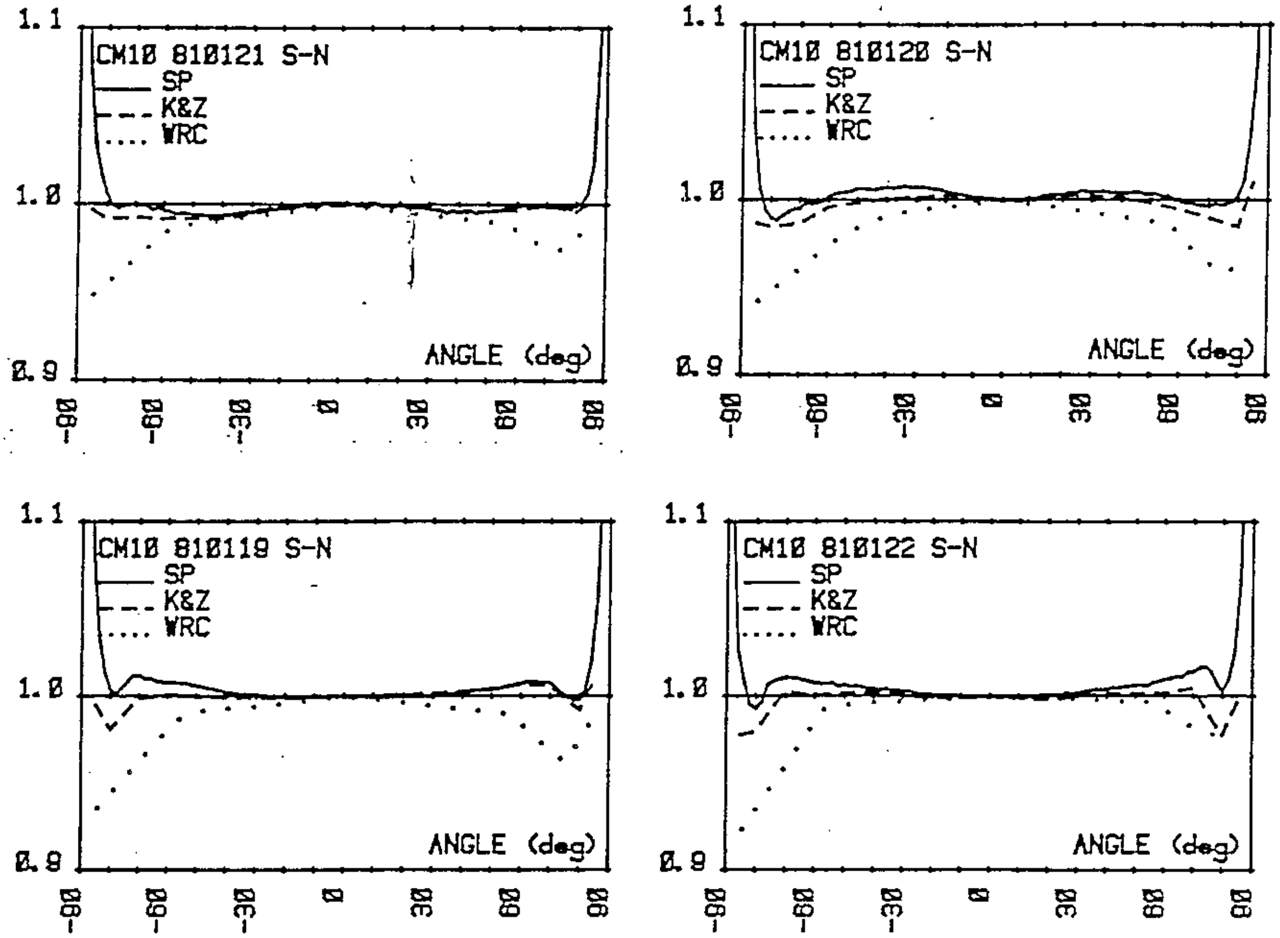
Comparison between measurements of cosine response from SP, WRC and NARC. Sections in the west-east direction. The cable connection pointing north. All curves are mean values of data from the two directions zenith-west and zenith-east.

SP	Statens Provningsanstalt, Boras, Sweden
WRC	World Radiation Center, Davos, Switzerland
NARC	National Atmospheric Radiation Center, Downsview, Canada



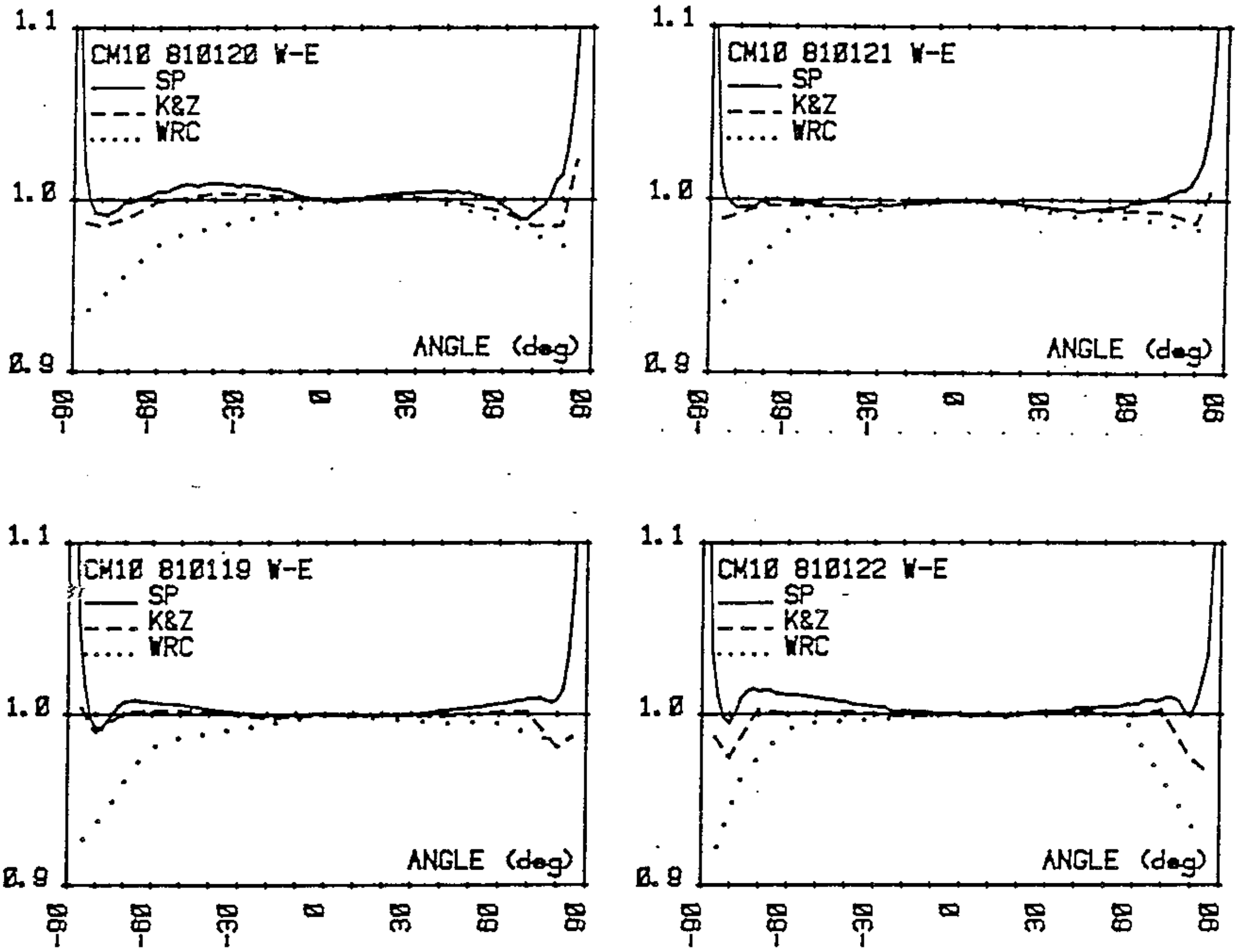
Comparison between measurements of cosine response from SP, WRC and NARC. Sections in the west-east direction. The cable connection pointing north. All curves are mean values of data from the two directions zenith-west and zenith-east.

SP	Statens Provningsanstalt, Boras, Sweden
WRC	World Radiation Center, Davos, Switzerland
NARC	National Atmospheric Radiation Center, Downsview, Canada



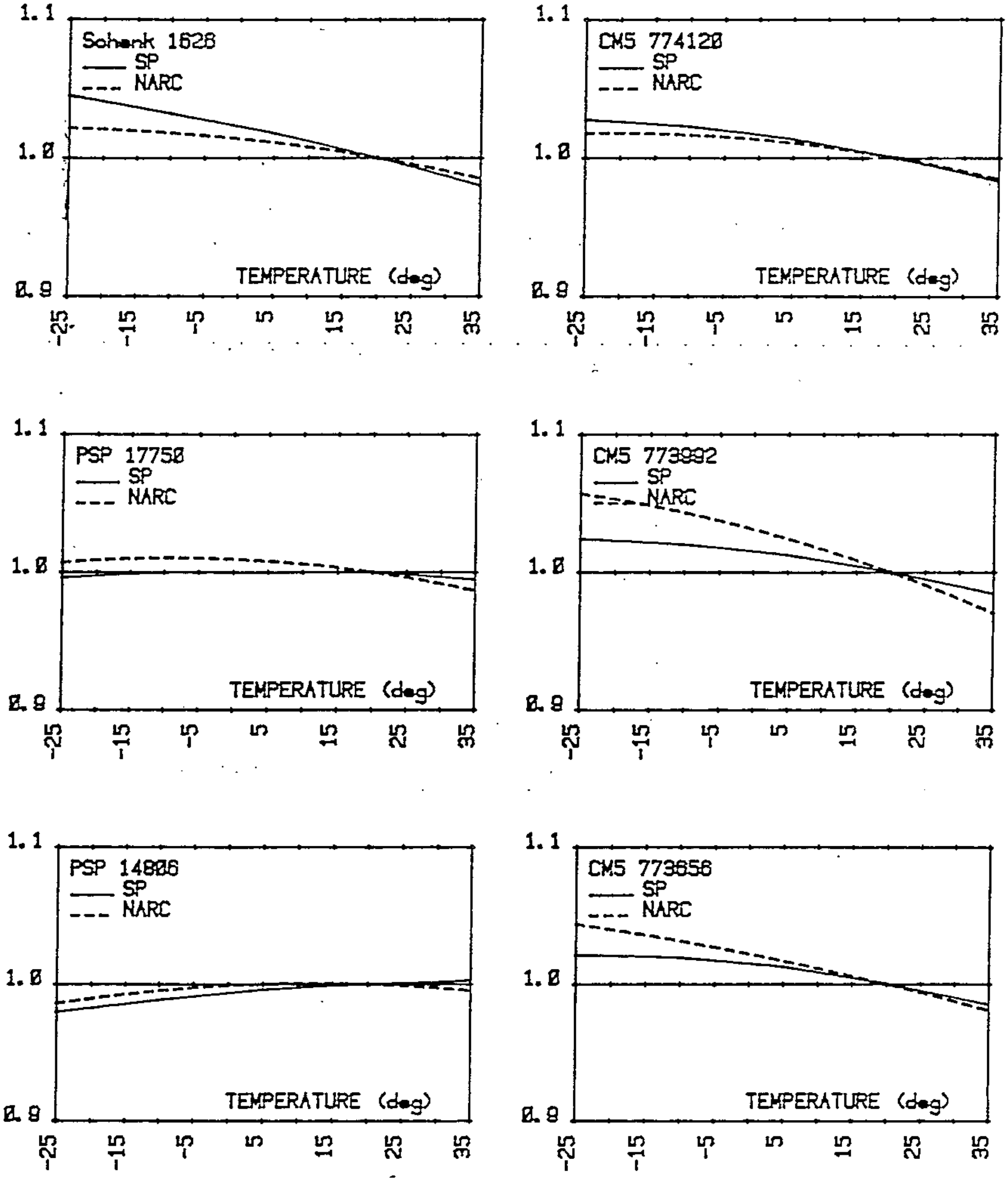
Comparison between measurements of cosine response from SP, WRC and K&Z. Sections in the south-north direction. The cable connection pointing north.

SP	Statens Provningsanstalt, Boras, Sweden
WRC	World Radiation Center, Davos, Switzerland
K&Z	Kipp & Zonen, Delft, Netherlands



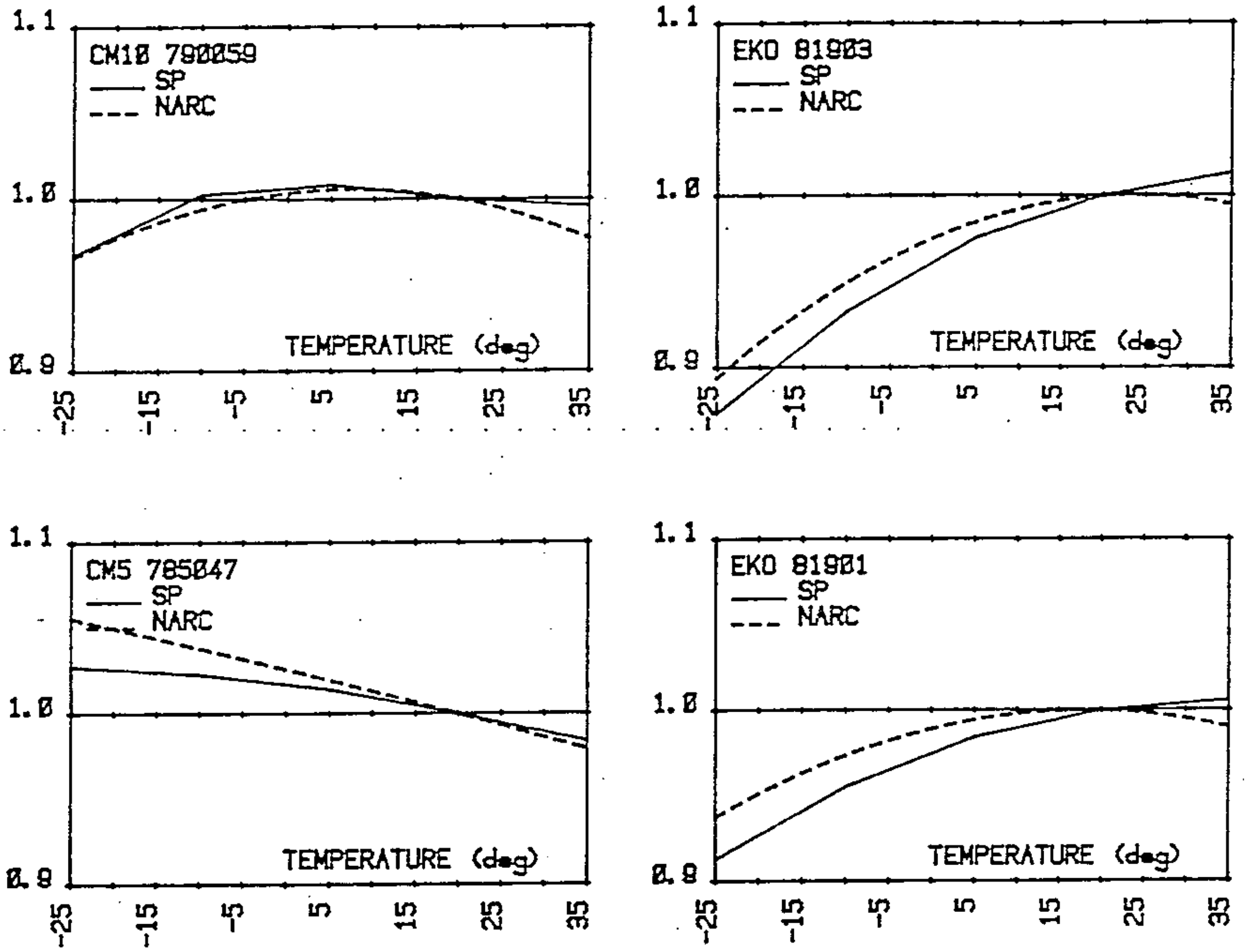
Comparison between measurements of cosine response from SP, WRC and K&Z. Sections in the west-east direction. The cable connection pointing north.

SP	Statens Provningsanstalt, Boras, Sweden
WRC	World Radiation Center, Davos, Switzerland
K&Z	Kipp & Zonen, Delft, Netherlands



Comparison between measurements of temperature dependence from SP and NARC.

SP Statens Provningsanstalt, Boras, Sweden.
NARC National Atmospheric Radiation Center, Downsview, Canada



Comparison between measurements of temperature dependence from SP and NARC.

SP Statens Provningsanstalt, Boras, Sweden
NARC National Atmospheric Radiation Center, Downsview, Canada