Modelling solar UV radiation in the past:
Comparison of algorithms and input data

P. Koepke (1), H. De Backer (2), A. Bais (3), A. Curylo (4), K. Eerme (5), U. Feister (6), B. Johnsen (7), J. Junk (8), A. Kazantzidis (3), J. Krzyscin (9), A. Lindfors (10), J. A. Olseth (11), P. den Outer (12), A. Pribullova (13), A. W. Schmalwieser (14), H. Slaper (12), H. Staiger (15), J. Verdebout (16), L. Vuilleumier (17), P. Weihs (18)

(1) Meteorol. Instit., L-M-Univ., Munich, Germany, peter.koepke@lrz.uni-muenchen.de; (2) Royal Meteorol. Inst. Belgium, Brussels, Belgium, Hugo.DeBacker@kmi-irm.be; (3) Aristoteles Univ., Thessaloniki, Greece; (4) Inst. Meteorol. Water Manag., Legionowo, Poland; (5) Tartu Obs., Toravere, Estonia; (6) German Meteorol. Service, Richard Aßmann Obs., Lindenberg, Germany; (7) Norwegian Rad. Prot. Auth., Oesteraas, Norway; (8) Dep. Climat., Univ. Trier, Trier, Germany; (9) Inst. Geophys., Polish Acad. Sciences, Warsaw, Poland; (10) Finnish Meteorol. Inst., Helsinki, Finland; (11) Geophys. Inst., Univ. Bergen, Bergen, Norway; (12) Nat. Inst. Public Health Environ., Bilthoven, The Netherlands; (13) Geophys. Inst., Slovak Acad. Sciences, Bratislava, Slovakia; (14) Inst. Med. Phys.Biostatistics, Univ. Vet. Med., Vienna, Austria; (15) German Meteorol. Service, Dep. "Climat. Environ.", Freiburg, Germany; (16) Europ. Com. - Joint Res. Centre, Ispra, Italy; (17) Fed. Off. Meteorol. Climatol. MeteoSwiss, Payerne, Switzerland; (18) Inst. Meteorol., BOKU, Vienna, Austria.

ABSTRACT

The objectives of the COST action 726 are to establish long-term changes of UV-radiation in the past, which can only be derived by modelling with good and available proxy data. To find the best available models and input data, 16 models have been tested by modelling daily doses for two years of data measured at four stations distributed over Europe. The modelled data have been compared with the measured data, using different statistical methods. Models that use Cloud Modification Factors for the UV spectral range, derived from co-located measured global irradiance, give the best results.

Keywords: UV-radiation; UV-modelling; UV-climatology; UV data base; UV proxy data

1. INTRODUCTION

The variation of UV-irradiance during the last decades is of interest for skin cancer development and other long-term studies of UV effects. Thus, to determine the geographical distribution of the UV-daily dose for whole Europe during the last 50 years, the COST action 726 "Long term changes and climatology of UV radiation over Europe" has been established (1). UV-radiation in the past can only be obtained by using adequate models running with the correct input data, i.e. values of the parameters that affect the solar UV radiation at the surface. Consequently, available numerical models and algorithms have been recorded, and the availability has been tested, both of the meteorological data, which are needed to run these models for different places in Europe, and of measured UV data that can be used to check the model results.

2. METHOD

To test the model quality, erythemal weighted daily dose have been calculated by each model and compared with measured values.
The reason for erythemal weighting was its relevancy for human health damage and it is the quantity that has been measured most frequently. The daily dose has been chosen as a compromise between the temporal resolution that is available for the input data and what is needed to investigate biological UV-processes. To check the widest range of meteorological conditions, two complete years have been chosen as time interval, 1999 and 2002, and four stations distributed over Europe:
Bergen (Norway, 60,4° N, 5.3° E, 45 m a.s.l.),
Davos (Switzerland, 46.8° N, 9.8° E, 1590 m a.s.l.)
Potsdam (Germany, 52.4° N, 13.1° E, 107 m a.s.l.)
Thessaloniki (Greece, 40.6°N, 23.0°E, 60 m a.s.l.)

The modelled daily doses have been compared with the measured data with absolute differences for each day. To get a final estimation of the model quality, a combination of model-measurement correlation together with equality of root mean square values of the modelled and the measured data has been used, as proposed by Taylor (2).

3. OBSERVATIONAL DATA

For the four stations and two years that should be modelled, observational data have been made available by working group 1 of the COST-action (1), which should be used by all modellers. An overview of the measured data is listed in the Table 1. The way how to use these data and to derive the needed input data, e.g. surface albedo from snow information or cloud impact on UV from solar radiation or cloud cover, was decided by the modellers as part of their algorithm.

	Bergen	Potsdam	Davos	Thessaloniki
Cloud cover	X	X	X	X
(relative) sunshine duration	X	X	X	X
Diffuse solar radiation	X	X	X	
Global solar radiation	X	X	X	X
Visibility	X	X	X	X
Snow height	X	X	X	
Snow age			X	
Ozone	TOMS	Dobson or Brewer	Dobson (Arosa)	Brewer

Tab. 1. List of meteorological, radiation and ozone data made available for the modelling exercise. Meteorological and radiation data are from meteorological or synoptic observations.

The UV-index data, which have been used to get the UV-daily doses used for the comparisons, are from measurements with broadband Instruments or derived from spectral measurements as specified for the stations in the following.
The UV-measurements for Bergen are based on a GUV multiband filter radiometer from Biospherical Instruments Inc with 5 detector channels in the UV. A linear combination of the output from different detector channels forms the basis for deriving CIE-effective doses. The absolute calibration is traceable to the Nordic Ozone Group international intercomparison of global sky instruments in Tyløsand, Sweden, 2000.
Erythemally weighted UV irradiance at Potsdam was integrated from UV spectra measured by a Bentham DM150 double monochromator. Calibration has been based on standard lamps of the FEL1000W type cali-

brated by the Physikalisch-Technische Bundesanstalt (PTB) in Germany. Due to a wrong data file for 1999, only UV-measurement for 2002 have been used for the comparison.

The daily UV data for Davos are integrated from 2-minute broadband instrument (Solar light 501) observations. The instrument is operational since 1995.

The UV data for Thessaloniki were produced by an erythemal detector of type YES UVB-1 with temporal resolution of 1 min. The detector is regularly calibrated against two Brewer spectroradiometers, and hence its stability in time is sufficiently controlled to within about ±7%.

4. MODELS

Sixteen models and algorithms took part in the modelling exercise. The way, how to use the available information from the observational meteorological data, is decided individually by each modeller.

All models firstly calculate the UV irradiance for cloud free conditions with one of the high quality radiation transfer models in the UV. These models from the mathematical point of view all give good results (3). The uncertainties mainly come from the uncertainty of the used input parameters to describe the atmosphere.

Using the UV-irradiance for cloud free conditions, the cloud effects are taken into account in a second step, which results in additional and variable uncertainty.

The albedo values used for UV-modelling are taken individually by the modellers. They are fixed to low values for summer conditions and to values depending on snow age and snow height for snow conditions.

Measured aerosol information was only visibility and very few dates with measured optical depth. It is known that visibility is only weakly correlated to the aerosol optical depth in the UV and, moreover, besides optical depth also the absorption properties of the aerosol have to be taken into account. Thus many of the modellers used climatolgical vales of optical depth and single scattering albedo, typical for the site, or even fixed values for all stations.

To consider the influence of clouds, generally so called Cloud Modification Factors (CMF) have been used, but with different methods to get their values. CMFs are defined as the ratio between the irradiance under cloudy conditions against that resulting from the atmosphere with the same conditions, but with no clouds.

The CMFs are connected with the cloud conditions either by cloud amount (4, 5), or by cloud amount in different cloud layers (6, 7) or by the correlation of a CMF_{sol} , valid for the complete solar spectral range, to the needed CMF_{UV} , valid for the erythemally weighted UV (8). The latter takes the global solar irradiance as input information, which more often is available as measured quantity than UV irradiance, with the advantage that the actual conditions of the sky really are taken into account. This includes the position of a cloud against the sun, resulting in shadow or even enhancement of irradiance, considers the optical thickness of the clouds in all layers, resulting in change of transmittance, and even includes aerosol effects on the irradiance to a certain amount. To get proper CMF_{UV} the differences of the cloud effects in solar and in UV-spectral range, depending on solar elevation, have to be taken into account (8).

If only the cloud amount is taken to get a CMF_{UV}, the detailed actual information mentioned above is lost and the description of the cloud effects by the CMF is more general, valid only in average (7). On the other hand this description of the CMF_{UV} has the advantage that information on cloud amount more often is available than solar irradiance, especially in the past.

A third method to describe the reduction of UV-daily dose due to clouds is the use of sunshine duration. It is based on the assumption that direct sun is the most important factor for UV daily dose. Consequently, for conditions with the sun not obscured, the irradiance has been modelled as a sky with no clouds at all. For the opposite condition, when the sun is blocked by clouds, overcast conditions have been modelled. These two results have been weighted by sun shine duration. Here again no detailed information on sky properties and their effects have been considered.

With help of a neural network also additional information on the atmospheric conditions besides solar global radiation, like sun shine duration and diffuse irradiance, can be used to describe cloud effects in the UV.

The UV doses can be modelled on hourly values and added to the daily dose, if the measured input data are available, or directly be modelled as daily values. The latter often results in reduced quality, due to daily varia-

tions in cloudiness. The way how to interpolate the measured data, which are available with different temporal resolution and at different time, belongs to the modellers.
Since the modelling exercise is going on, and not all reasons for discrepancies have been analysed, the models are described with alphabetic characters and only their basic properties are given (Tab.2). Detailed description of all models and of the final results of modelling-measuring comparison will be presented in a COST booklet (9).

Model	Cloud effects	Temp res.	Aerosol	Albedo
A	CMF_{UV} via CMF_{sol}	hourly	fix SSA, local fix AOD	snow effects
B	CMF_{UV} via CMF_{sol}	daily	climat SSA, climat AOD	snow effects
C	CMF_{UV} via CMF_{sol}	hourly	climat SSA, climat AOD	snow effects
D	broad avail. info	hourly	in cloud effects	in cloud effects
E	CMF_{UV} via CMF_{sol}			
F	CMF_{UV} via CMF_{sol}	hourly	AOD from visibility	snow effects
G	broad avail. info	hourly	fix SSA, fix AOD	snow effects
H	CMF_{UV} via CMF_{sol}	hourly	climat alpha,climat AOD	snow effects
I	CMF_{UV} via CMF_{sol}	hourly	in cloud effects	clim value visible
J	CMF_{UV} using GR_{sol}	hourly	AOD from visibility	snow effects
K	CMF_{UV} via CMF_{sol}	daily	fix SSA, fix AOD	snow effects
L	CMF_{UV} using GR_{sol}	hourly	AOD from direct meas	snow effects
M	sun shine duration	daily	local fix AOD	fix no snow, snow
N	cloud amount	hourly	AOD from visibility	snow effects
O	sun shine duration	hourly	AOD from visibility	snow effects
P	sun shine duration	daily	no aerosol	

Tab. 2. General properties of models

The different methods to get CMF_{UV} can be applied by using data that are individually adapted for each of the sites to be modelled. These “local” models have the advantage to take into account the climatological conditions of the site, but have the disadvantage that they cannot be applied directly for the whole of Europe as they have to be trained first with data from very many positions, which often are not available or even do not exist. The “general” models that use one parameterization for all sites easily can be used to produce UV-maps. The sunshine duration models, of course, are general.

5. RESULTS

The agreement between measured and modelled data is shown as differences, modelled minus measured daily dose, as function of the day in the year. Presented are two examples, namely Bergen 2000 (Fig.1) and Thessaloniki 2000 (Fig.2), two stations with very different latitude to show effects of different climate and solar elevation. Absolute differences are shown for the comparison, since the absolute doses are relevant for human health.
Measured daily UV-doses do not exist for all days, and also not all modellers calculated UV-doses for all days, especially if one of the meteorological quantities used as input parameter was not available. To perform the comparison of the modelled results on the basis of equal days, only those days have been used, which were available from all modellers.

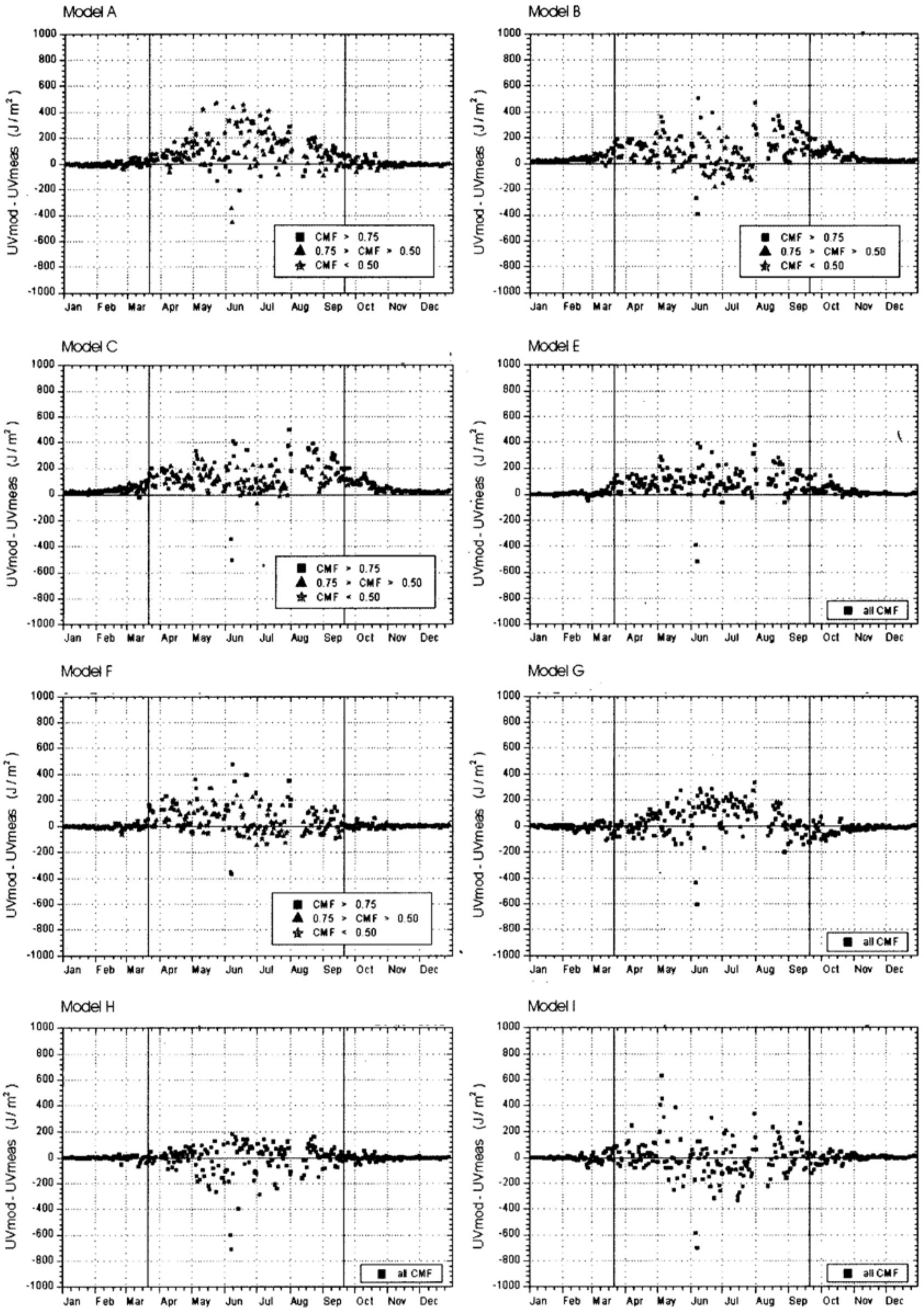

Fig. 1a Differences between modelled and measured daily UV dose for Bergen 2002
Models as shown on the separated figures with the letter given in Tab.2.

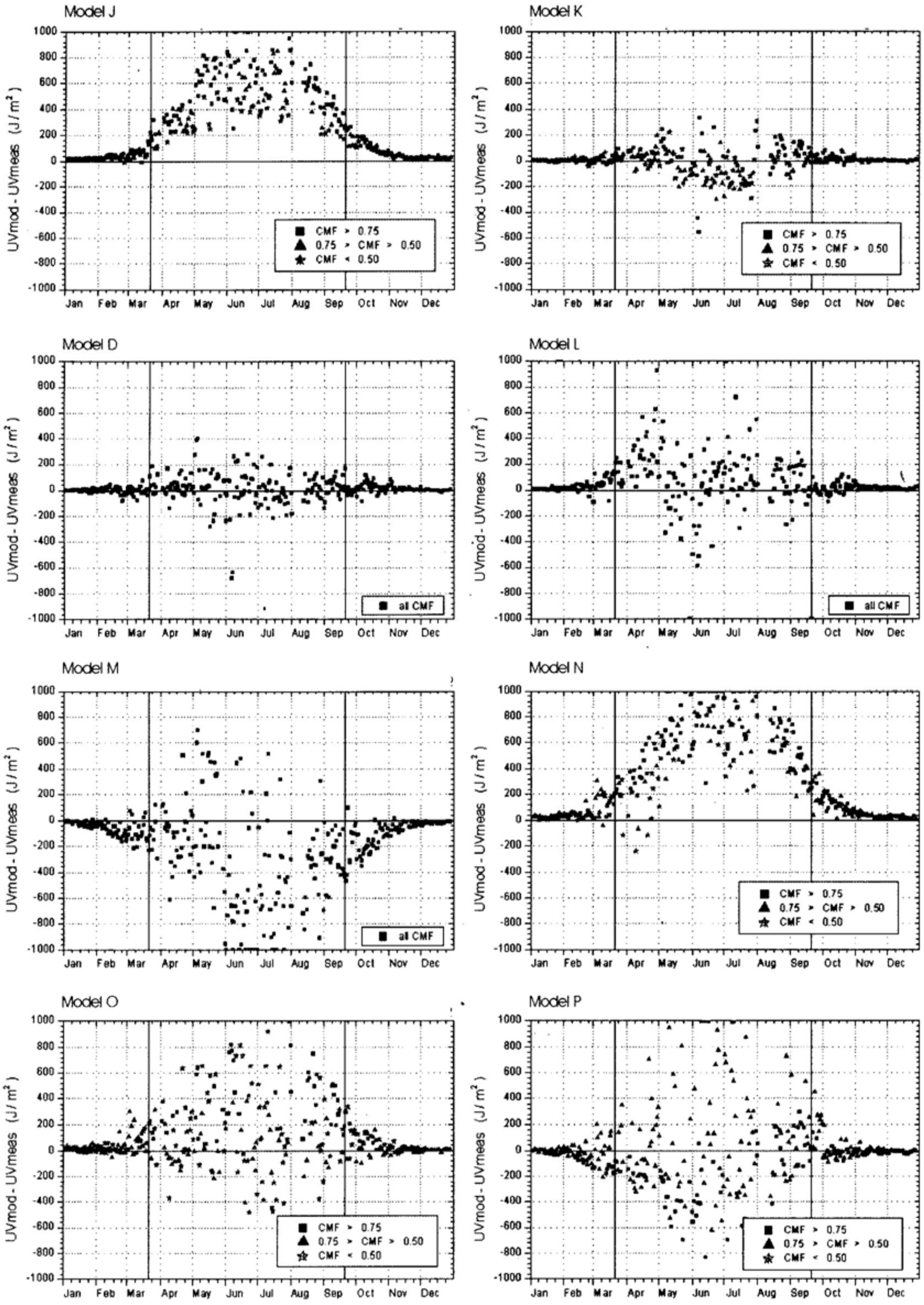

Fig. 1b Differences between modelled and measured daily UV dose for Bergen 2002
Models as shown on the separated figures with the letter given in Tab. 2

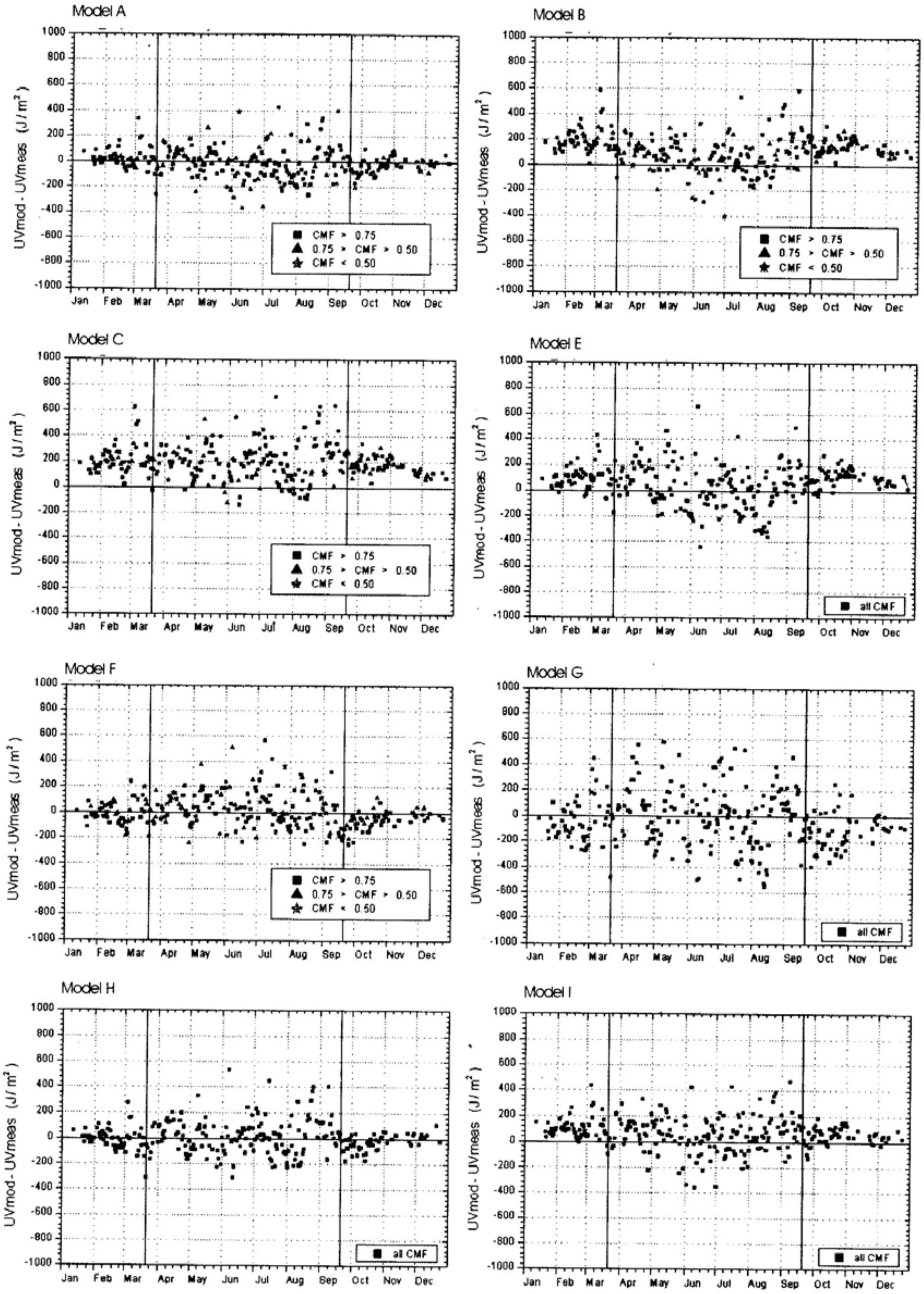

Fig. 2a Differences between modelled and measured daily UV dose for Thessaloniki 2002
Models as shown on the separated figures with the letter given in Tab. 2

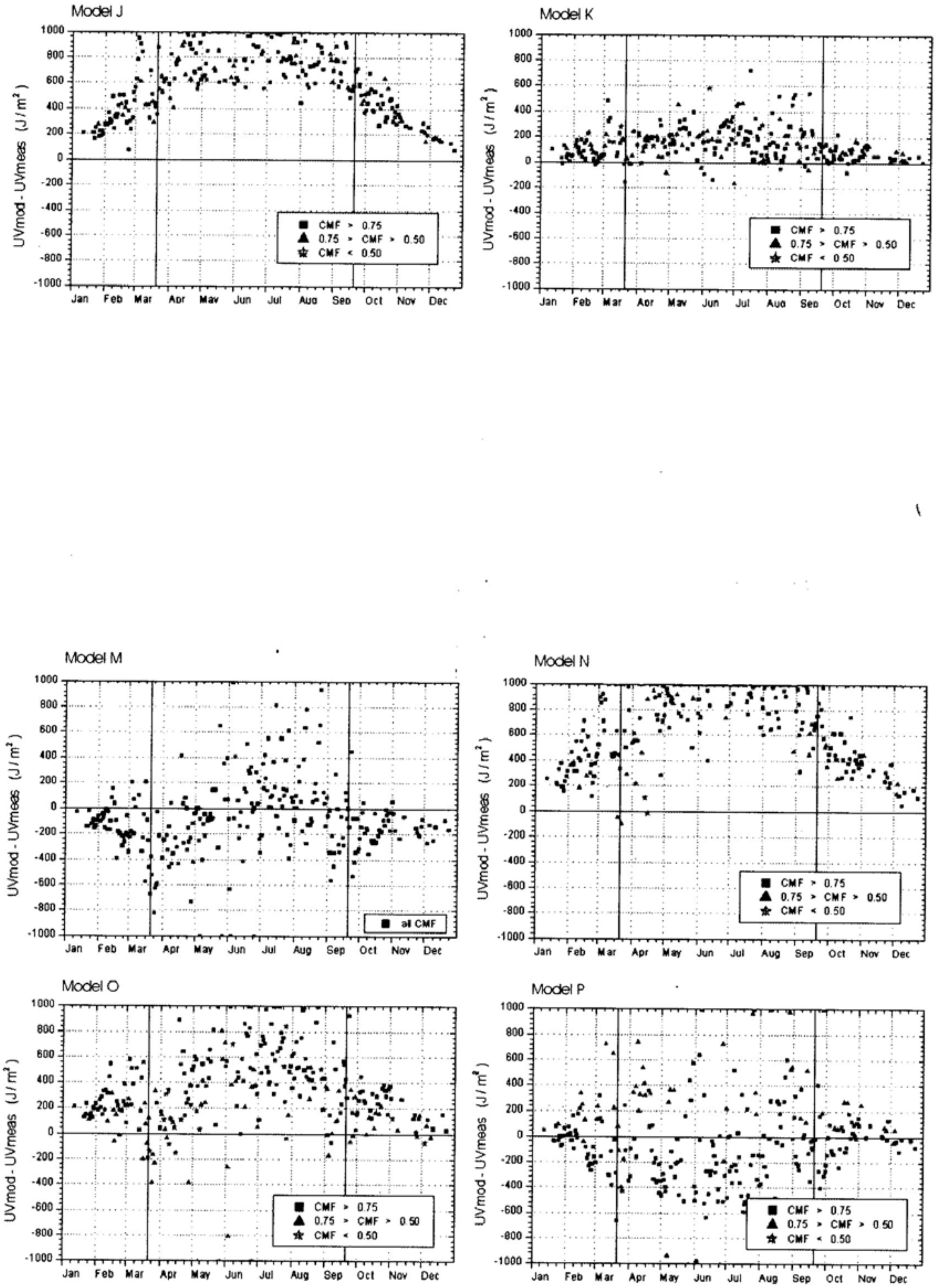

Fig. 2b Differences between modelled and measured daily UV dose for Thessaloniki 2002
Models as shown on the separated figures with the letter given in Tab. 2.

Within Figs. 1 and 2 each graph shows the result for one model, denoted with the character from Tab. 2. Model D is not between C and E, but on the second page due to technical reasons. For Thessaloniki, data from models D and L are not available. If the value of the CMF is known, the data are separated by symbol for conditions with low (CMF > 0.75), medium (0.75 >= CMF > 0.50) and large attenuation due to clouds (CMF<0.50). Values exeeding 1000 J/m² are clipped to the 1 kJ/m² line and negative values accordingly, to have the same range in all figures. The days 21 March and 21 September are shown with vertical lines, to separate the summer time.

The possibility for large absolute differences increases with increasing daily doses. Thus the differences for the winter time generally are lower, especially for Bergen, independent of the model. For Thessaloniki even in winter larger deviations occur due to rather high daily doses due to high sun and low cloudiness.
The agreement for the models A to K, which use the information from solar global irradiance, is clearly better, then that for the models M to P which do not. From the rather bad agreement of models J and L it can be seen that solar irradiance should be used as a basis to convert a CMF_{sol} into a CMF_{UV} and not be used directly. The clear overestimation of the UV dose by models J and N results from the fact that they have been trained with local data, but have been used as general models.

To identify a group of models with the best agreement a method proposed by Taylor (2) has been used, which combines in one figure the information on model-measurement correlation and on the equality of root mean square (RMS) values calculated from the modelled and observed data. The results for the absolute deviations are shown in Fig. 3 for 2002 as example for all four stations with the symbol of the model at a point on a polar plot.
The position of this point is given by the correlation coefficient between modelled and measured data (line with increasing slope) and by the ratio of the standard deviation of the model values to that of the observed data (distance from the origin). Using these characteristics to describe the model quality, an ideal model (being in a full agreement with measurements) is marked by the point with coordinates $\varphi=0$ and radius=1. It means the correlation coefficient is equal to 1 and modelled and measured variations have the same amplitude. In case different models have been compared, the quality of the model decreases with increasing distance between its point on the Taylor diagram and the ideal model point (0, 1). Points with the same distance to the point (0,1) are marked as circles.
The analyzed time series of UV daily doses have a strong annual course with the maximum in late spring/early summer and minimum in winter. Thus, any model simulating such behaviour will yield a high correlations coefficient and close RMS value to the observed one. So, to better distinguish between models' performances, the annual pattern has been removed from the analyzed time series. To do this, an annual course is extracted for each year and station for the measured data using the locally weighted scatter (LOWES) smoothing technique and the deviations from the smoothed curves are calculated both for measured and each of the modelled time series.

For the four stations shown in Fig. 3 , the resulting Taylor-points are given in each case for all models, marked by their symbol. The distributions are different for the different stations, but similar patterns can be seen. A group of points, models A, B, C, D, E, F, H, and K, gathers closely to the ideal model point (0,1) and some points appear away from this point. Clearly the models M, N, O, and P, that do not use global radiation as a proxy for the cloud attenuation effects, stay more away than other model points. Models G, J, I, and L, are in between. These are the models that either use the global solar irradiance directly or use a mixture of information to get the $CMF_{UV.}$
To get final insight into the model performance, combination of the results of all four stations and both years have been used. These results confirm the previous finding obtained from individual station and year data. They will be shown in the final report (9), but are not yet given, because firstly detailed discussions between the modellers are necessary.

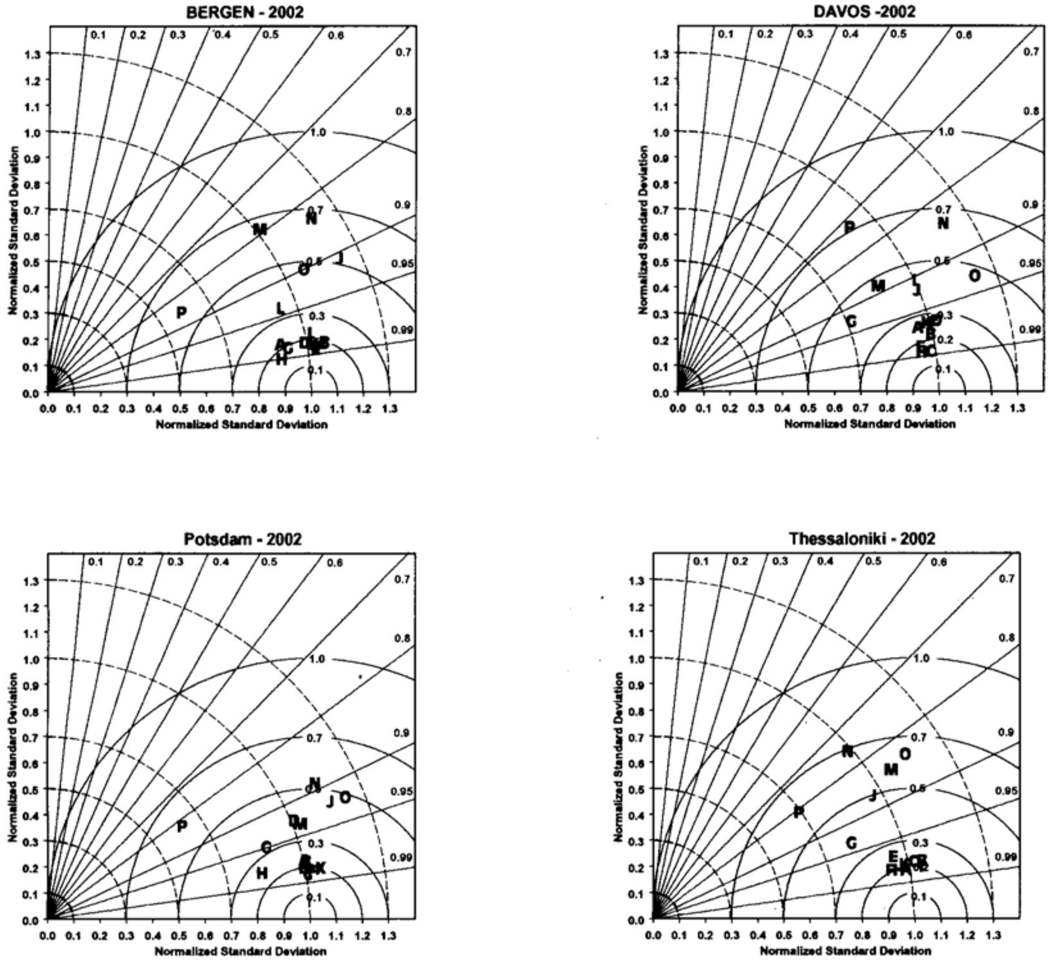

Fig. 3 Taylor diagrams (See text) for absolute deviations between modelled and measured UV doses. The letters stand for the models, as described in Tab.2

6. CONCLUSION

The models with best performance to model erythemal weighted UV daily dose in the past are those that take a CMF_{UV} derived from a measured CMF_{sol} to describe the cloud effects. The reason is that the global solar radiation is affected by the clouds similarly as the UV-radiation. Thus solar irradiance is the most important input parameter to model UV in the past Strong effects of course result from variable ozone, which however is less variable in space and therefore can be taken more easily from old measurements. To determine the quality of the aerosol modelling cloud-free data have to be check independently. As a first result it seems to be better to use climatological aerosol properties with low variability than strong variations inferred from visibility data. In addition, the snow effects should be analysed again, and perhaps can be improved, since the correlation between snow height and age on the one hand, and regional albedo on the other hand, clearly depends on station altitude, longitude and skyline.

The modelling exercise was very successful. Models that are suitable to perform the COST action have been identified. Moreover, a large body of data is available which can be used for many scientific questions, like practical aspects of cloud, aerosol or albedo effects on UV and model improvement.

REFERENCES

(1) COST http://i115srv.vu-wien.ac.at/uv/COST726/Cost726.htm, 2006.
(2) Taylor, K.E. “Summarizing multiple aspects of model performance in a single diagram” *J. Geophys. Res.*, **106 (D7)**, 7183-7192, 2001.
(3) Koepke, P., A. Bais, D. Balis; M. Buchwitz, H. De Backer, X. De Cabo, P. Eckert, P. Eriksen, D. Gillotay, A. Heikkilä, T. Koskela, B. Lapeta, Z. Litynska, J. Lorente, B. Mayer, A. Renaud, A. Ruggaber, G. Schauberger, G. Seckmeyer, P. Seifert, A. Schmalwieser, H. Schwander, K. Vanicek, and M. Weber, “Comparison of Models Used for UV Index Calculations”, *Photochem. Photobiol.*, **67(6)**, 657-662, 1998.
(4) Borkowski, J., A.-T. Chai, T. Mo, and A.E.O. Green “Cloud effects on middle ultraviolet global radiation”, *Acta Geophys. Pol.*, **25(4)** 287-301, 1977.
(5) Blumthaler, M., and W. Ambach “Effects of cloudiness on global and diffuse irradiance in a high-mountain area”, *Theor. Appl. Climatol.*, **50** 23-30, 1994.
(6) Staiger, H., G. Vogel, U. Schubert, R. Kirchner, G. Lux, and G. Jendritzky “UV Index calculation by the Deutscher Wetterdienst and dissemination of UV Index products” In: WMO, 1998: *Report on the WMO-WHO meeting of experts on standardization of UV indices and their dissemination to the public,* WMO/TD-No. 921, 89-92, 1998.
(7) Schwander, H., P. Koepke, A. Kaifel, and G. Seckmeyer “Modification of spectral UV irradiance by clouds” *J. Geophys. Res.*, **107(D16)**, 10.1029/2001JD001297, AAC 7-1 to AAC 7-12, 2002
(8) Den Outer PN, H. Slaper, J. Matthijsen, H.A.J.M. Reinen, and R. Tax “Variability of Ground-Level Ultraviolet: Model and Measurement”, *Radiation Protection Dosimetry*, **91**, 105-110, 2000
(9) COST “Modelling solar UV radiation in the past: Report on the modelling exercise”. To be published 2007.

.