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MAPPING THE DOWNWELLING ATMOSPHERIC RADIATION AT THE EARTH'S SURFACE - A RESEARCH STRATEGY

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MAPPING THE DOWNWELLING ATMOSPHERIC RADIATION AT THE EARTH'S SURFACE

-A RESEARCH STRATEGY-

by

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ABSTRACT: A strategy is presented along with background material for determining downward atmospheric radiation at the Earth's surface on a regional scale but over the entire globe, using available information on the temperature and humidity of the air near the ground and at cloud base altitudes. Most of these parameters can be inferred from satellite radiance measurements. Careful validation of the derived radiances will be required using ground-based direct measurements of radiances, to avoid systematic biases of these derived field quantities.

1. INTRODUCTION:

The radiation fields at the Earth's surface force circulations within the atmosphere (e.g. convection, etc.) and in the oceans as well. They also reflect the dynamics of the atmosphere with associated phenomena themselves. Therefore, modern climate research is echoing the "old" call for thorough mapping of the radiation fields at the Earth's surface. The importance of this quantity on the heat storage in oceans has been formally recognized recently (WCP92). Detailed discussions were held recently at a "Workshop on SURFACE RADIATION BUDGET FOR CLIMATE APPLICATIONS" to assess current and future use of satellite data for the determination of all four components of the radiation budget of the surface.

We will concentrate here on only one of these components, the downward infrared radiation. This quantity might vary within a reasonable range between about 100 and 400 Wm^{-2}, depending on the climate region on the Earth. As with the other three (3) components it is desired to determine the downward infrared radiation within an uncertainty limit of ± 10-20 Wm^{-2}, to permit evaluation of diagnostics of climate fluctuations and reliable energy transfer estimates.

In the tropics, the infrared net radiation at ground, which is the difference between emissions from the surface and the atmosphere, assumes values between 20-40 Wm^{-2}, with small variations.

Various methods have been developed in the past, primarily for agricultural applications, to estimate the downward atmospheric radiation from easily accessible parameters, such as shelter temperature, moisture and cloud cover.

We will keep in mind in all further considerations that the downward atmospheric radiation will not be determined here for a single isolated location, but for areas of the size of grid regions of circulation models

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or climate models. The time resolution should be of the order of 1 month averages. This data set should cover the entire globe and be obtained with minimum costs, thus computer routines and data access must be rather simple.

2. THE ORIGIN OF DOWNWARD ATMOSPHERIC RADIATION AT GROUND:

The downward atmospheric radiation at ground, hereafter named with the symbol M_a, originates from thermal emission by atmospheric water vapor, carbon dioxide, a few minor gases and aerosols and from cloud bases. Typical spectra of M_a, or of its radiances, are shown for example by Berdahl and Fromberg (1982). They demonstrate the dominance of emission within the 6.3 micron-band of atmospheric water-vapor and within the continuum and rotational bands.

The relative contribution of emission from each layer can be demonstrated using radiative transfer calculations for prescribed atmospheric conditions. The source for the emission within the entire range of infrared radiation (from about 4 to 50 μm) has to be calculated separately for each layer before integration over the atmospheric column. Examples are given in Fig. 1 and 2 (from P. Schmetz, 1984). They show that for clear skies about 75 percent of M_a originates from the lowest 200-300 meters of the atmosphere, depending on the amount of water vapor present. The latter also controls the contribution from cloud base emissions. The M_a is furthermore affected by cloud base heights and the emittance of cloud sheets. Fig. 3 shows the increase of M_a due to a black cloud layer at different altitudes. Furthermore, the cloud contribution is small, or even negligible, in tropical moist air, but its contribution can be relatively high in the dry polar and subpolar regions.

Since in further analyses it is envisaged to determine M_a as a spatial average for each grid region, the fractional coverage of the lowest level cloud layers, and of any equivalent value which may describe, for instance, the emission of cloud layers, must be used.

The above-mentioned facts have been known already by many investigators, who derived empirical relations between M_a and the ambient air temperature, moisture and cloud fields but very few systematic investigations are published yet in the literature. Figs. 1-3 illustrate the nature of our problem.

3. THE RETRIEVAL PROBLEM:

The above described relations between M_a and atmospheric properties make it difficult to "retrieve" M_a directly or even solely from spectral radiance measurements made at satellite altitudes, even when the latter are highly correlated to the temperature of air near ground levels. Cloud bases can seldom be seen from space, unless they will be measured in the future with high-powered laser systems. Rather, they must be inferred from cloud-top heights and cloud species and other atmospheric properties, such as stability and divergence fields and/or the condensation levels. One may also attribute to each retrieved cloud layer an effective thickness or assume in case of multilayered clouds within a grid layer that they may overlap randomly. Guidance in this respect could be provided by the statistics of Hahn et al. (1983).

A direct retrieval of M_a is difficult; however, several authors (Darnell et al., 1983; W. L. Smith et al., 1983) have tried to compute M_a from satellite-borne spectral radiance data which are measured in order to retrieve the vertical temperature profile. Their methods make more or less use of the fact that M_a is highly correlated with the temperature in the lower levels. The lower level temperature determines to some degree the outgoing radiance in some of the spectral intervals. However, it is known that the temperature in the lowest layers is subject to large errors, even for clear-sky retrievals. Therefore, global-scale or even mesoscale fields of M_a would be "retrieved" better from operational grid-point analyses of temperatures and moisture fields in the lowest layers of the atmosphere. Over many areas of the world, these analyses are based overwhelmingly on information which originates from satellite data as well as the required information on clouds, but are supplemented in many cases with direct radiosonde readouts.

As an illustration, Fig. 4 shows vertical profiles of the upward and downward longwave radiation, and of the net flux, which have been derived from VAS soundings over Madison, Wisconsin at conditions of low and high clouds (W.L. Smith et al., 1983, private communication). Also shown are simultaneous radiometersonde data. Unfortunately no comparison has been reported with direct measurements at ground. It is beyond the scope of this paper to discuss the agreement or disagreement between their radiometersonde and retrieval data.

Careful error and sensitivity analyses are required to study the effects of uncertainties in the input data on the estimated values of M_a.

4. RESULTS OF A SENSITIVITY ANALYSIS:

Several authors have studied changes in M_a due to changes in the input parameters. Some of these analyses are presented here. Chou (1985) presents a table (see Table 1) where he determines changes in the solar and infrared radiation at the surface due to changes in temperature, moisture, cloud heights (pressure), cloud cover, and optical thickness of the clouds for the tropical Pacific Ocean. All these quantities have been increased by values given in the left column of this table. Variations of the downward solar and infrared radiation reached values of up to 11.8 W m^{-2}. The change of downward infrared radiation is shown to be sensitive to change of temperature and moisture. These examples may not be representative of a full treatment of the errors.

Darnell et al. (1983) used the probable errors in TOVS data products (from Kidwell 1981) to compute the sensitivity of the downward atmospheric radiation. Their results are reproduced in Table 2. Here again temperature and moisture uncertainties produced the largest errors in M_a, while cloud-base heights are less influential.

P. Schmetz (1984) applied a radiative transfer code to temperature, moisture and cloud data which are representative for several climate regions. Table 3 explains the models and their mean specific humidity at the ground. This has been changed by .3 g m^{-3} and $\pm$ 1.0 g m^{-3}, respectively, with a shift of the entire humidity profile. The results are given in Tables 4 to 8, where the last table contains the overall errors. Here it is assumed that the individual errors are totally uncorrelated, which in fact is not always the case. This moisture content of the air is to some degree controlled by the temperature, and thus affects also the cloud fields.

We can summarize from this study:

(a) In all geographical regions studied here, the largest uncertainties are due to those in the temperature for clear skies.

(b) The contribution of the clouds increases from almost negligible in the Intertropical Convergence Zone to high values in subpolar climates-according to the decrease of the water vapor content within the atmosphere.

(c) Uncertainties of low level cloud parameters (altitude and fractional coverage) cause somewhat higher errors than those of higher clouds.

(d) The overall errors in these model cases cause uncertainties in M_a of up to 10 Wm^{-2} (RMS).

Although these are crude model studies we can conclude that uncertainties of at least 10-15 Wm^{-2} (RMS) should be expected. The magnitudes of the errors may also vary for each climate region. Larger errors would occur where cloud base altitude variabilities are large. Further analyses are required to identify geographic regions of highest uncertainties and specify required validation procedures. These require without doubt ground-based measurements, where instrumental networks must be specified according to spatial and temporal scales of temperature and cloud-base variations.

5. A SHORT SUMMARY OF ALREADY EXISTING METHODOLOGIES:

5.1 REGRESSION EQUATIONS

Possibly Å. Angstrom (1916) was the first to relate M_a to the ambient temperatures and moisture:

$$M_a = \sigma T_a 4 * [A - B.\exp(-C.e_a)]$$

where: T_a, e_a = shelter temperature and water vapor pressure
A, B, C = empirical constants

All empirical relations which have been proposed by many authors (for one summary see e.g. Martin and Berdahl) can be considered as derivations from this simple equation. They have usually one property in common: that they are tested only against values of a few stations. Some authors included the cloud coverage and cloud base heights (temperatures) as a further quantity. Idso's and others' parameter families belong to this same category. Various authors used also the concept of an effective sky-emittance (e.g. Yamanuchi, 1984).

5.2 RADIATION TRANSFER METHODS:

These make use not only of detailed profiles of the temperatures and moisture, but also of observed clouds. Most prominent examples used the data sets which were obtained during the GATE field phases (Atwater and Ball, 1983; Cox and Griffith, 1979 a and b). Here, however the radiative transfer properties of clouds have been specified according to mean climatological properties. The differences as reported by Atwater and Ball (1983), between calculated values of M_a and those measured at four ships during GATE ranged between 2 and 3 percent for daily sums and about 4-5 percent for hourly sums. This good agreement is possibly due to the dominant temperature and moisture effects in this area. In their study the cloud types were specified according to their patterns in GOES images.

6. METHODS BASED PRIMARILY ON SATELLITE DATA:

It is attractive to make use of unique data sets such as provided by satellite systems. The ISCCP data set will at the end cover the entire globe. It should provide the urgently needed information on clouds.

6.1 USE OF SATELLITE SOUNDING DATA

Darnell et al., 1983 (and also Gupta et al., 1982; Gupta, 1984) used directly the temperature and humidity profiles and cloud top heights as derived from the operational TOVS data. With the assumption of a mean cloud thickness of about 50 mb and a detailed radiative transfer model, they calculated the M_a. Comparison has been made with simultaneous measurements of one station, but with 41 satellite overpasses.

M_a ranged between about 220 and 400 Wm^{-2}, and the mean standard error of estimate was 20 Wm^{-2}. One major error source identified by these authors is the poor knowledge of the lower cloud base, in particular during fog condition. Fog and low clouds are difficult to identify in the TOVS-data, but may be observable in correlative AVHRR data (at least during night: e.g. Eyre. et al., 1983). Another version of this methodology has been reported in an unpublished paper by Frouin (1985- during the Workshop on Surface Radiation Budget for Climate Applications).

W. L. Smith (1983 - extract given in WCP-70) has developed multiple regression equations relating VAS channel radiances to downward longwave flux profiles within the atmosphere as well as M_a, as discussed with Figure 4.

6.2 USE OF OPERATIONAL TEMPERATURE FIELDS AND CLOUDS FROM METEOSAT IMAGERY:

P. Schmetz (1984) was the only investigator to date who tried to make use of the operational analysis temperature fields, which are available each day as grid point values on an global scale. These are based on ground-based and direct radiosonde observations, and TOVS analyses over data-sparse regions. The low level moisture data needed for M_a computaation are not available in operational analyses, except for very limited regions.

P. Schmetz, J. Schmetz and E. Raschke (private communication) determined first a clear-sky emission to ground, where they related the temperature fields to M_a (clear) with a regression formula as first proposed by Idso (1969)- but with new coefficients. In a second step the cloud contribution has been estimated on the basis of cloud-top heights, as visible in Meteosat IR-imagery, a variable and altitude dependent cloud thickness and an emittance of the cloud field, which is related to the transmittance for solar radiation. This latter assumption might be applicable to day-time data only.
This method has been applied to temperature fields, which have been prepared especially for the ALPEX- analyses. Comparison with only four stations have been possible yielding an RMS error on 11.6 Wm^{-2} which corresponds to about 4% of the downward longwave radiation flux (Fig. 5).

6.3 SOME CONCLUSIONS ON BOTH METHODOLOGIES:

These few attempts do not cover all climate regions, thus they should be considered as first studies. They, however, have shed some light on problems which are involved in mapping globally M_a. In particular they showed that the basic data, i.e. the temperatures and moisture near the surface, require more improvements to increase their reliability, in particular over all oceans, but also over mountainous regions.

These studies also emphasize the urgent need for adequately designed ground-based networks. These do not need to cover the entire globe, but should be available at some areas which are critical to climate fluctuations and also calculations of the downward atmospheric radiation. Additional use is encouraged of measurements made of various experimental sites, in particular the anchor-station set up for the ISLSCP.

7. A POSSIBLE RESEARCH STRATEGY FOR THE FUTURE:

7.1 DEFINED GOALS:

(a) It is envisaged to map globally the downward atmospheric radiation M_a with a space and time resolution which corresponds to that of GCM's or climate model. In certain locations, finer details may be required in studies of climate processess which must be resolved at the mesoscale or even smaller spatial resolution.

(b) In order to minimize costs, the data should be operationally available over the entire globe.

(c) The accuracy should be better than 20 Wm^{-2} (RMS) for monthly averages and should show interannual trends of more than 5 Wm^{-2}/year.

7.2 REQUIRED STUDIES:

(1) Since M_a depends on air temperatures and moistures of the lowest layers (0 to 1000 meters above ground) and on cloud base emission, one needs the following:

- ° information on the operational measurement uncertainties of T_a and q_a (Kidwell, 1981, provide such numbers for TOVS products; see Darnell et al., 1983).
- ° investigation of the possiblity of inferring cloud-base heights and emittances from data bases (e.g. ISCCP- data bases, climatology of observations)

(2) Sensitivity studies must follow and show for all climate regions the possible ranges of uncertainties in M_a due to those in T, q and cloud properties. These sensitivity studies require a reliable and speedy radiative transfer model, a data base and some peturbations of data. Perhaps about 1-2000 profiles need to be considered.

(3) An error propagation study must follow to
- ° identify interrelated errors (e.g.: q vs. T, q vs. clouds)
- ° observe time propagation of errors (Do monthly averages of the input fields yield the same results in M_a?).
- ° identify errors associated with various systems.

(4) A study on possible time and space variations of M_a must be made to derive recommendation for the design of ground-base methods.

(5) Study the utility of the ISCCP data products in connection with global field analyses.

7.3 URGENT DEVELOPMENTS AND STUDIES:

These are considered to be prerequisites for the final design of an operational algorithm:

(a) Study the use of TOVS-temperatures vs. operational temperature analyses, which are available from ECMWF or NMC.
(b) Study the need of accurate knowledge of moisture field q_a or a replacement by mean or seasonal climatology of water vapor content.
(c) Study the possibility of using the ISCCP results for low, middle and high clouds in the same area.
(d) Study need for additional assumptions on the presence of low level clouds, when not seen from space due to higher cloud covers. The analyses of the ISCCP might yield to fractional cloud covers as seen from space. Do we need to supplement them with statistics by Warren, Hahn and London?
(e) Study of cloud-base altitudes as a function of top heights/and transmittance for solar radiation.
(f) Study the need for separate calculation of both infrared fluxes in favor of an infrared net flux as a function of cloud height, cover and climate region?
(g) Determine proper areas and configurations for deployment of surface-based pyrgeometers or pyrradiometers.
(h) Investigate the quality of operational temperature analyses for grid areas.

8. APPROACH:

This stategy can be considered to be part of the surface radiation budget pilot study on deriving parameters using the ISCCP data products. This pilot study will firstly concentrate on the determination of the downward solar radiation from the B2 data. One obtains in principle results on the transmittance of the atmosphere for solar radiation which, in turn, could be used to estimate the emittance of the atmosphere for M_a.

Several research groups should participate, which in particular take care of the data validation over particular regions of the globe. A study may also show that careful validation using ground-truth may already replace additional efforts over oceans. However, all ship-borne data should be kept at a data base.

A specific workshop might be necessary to define the project in terms of workpackages. Possible contributors are:

Darnell (LaRC), Deluisi (NOAA), Gautier (Scripps), Hay (Vancouver), Herman (Madison), Pinker (College Park), Raschke (Köln), Rossow (GISS), W. L. Smith (Madison), Yamanuchi (Japan)

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Table 1. (from Chou, 1985)

Sensitivity of surface radiation (W m^{-2}) to atmospheric and cloud parameters at four locations in the tropical Pacific. The changes in air temperature ΔT and humidity ΔQ are set to be uniform with height. Computations are performed for the January and July 1970 conditions. Results are then averaged. S signifies solar radiation; IR thermal infrared radiation; T air temperature; Q specific humidity; p_c cloud height; C fractional cloud cover; τ signifies cloud optical thickness.

	140–145°E			170–175°W		
	ΔS	Δ IR	Net	ΔS	Δ IR	Net
			0–5°S Latitude			
ΔT (+1°C)	0.0	5.5	5.5	0.0	5.2	5.2
ΔQ (+15%)	−0.9	11.6	10.7	−1.1	11.2	10.1
Δp_c (+66 mb)	0.0	2.2	2.2	0.0	2.0	2.0
ΔC (+0.05)	−9.6	1.4	−8.2	−11.8	1.8	−10.0
$\Delta\tau_{scat}$ (+20%)	−5.8	0.0	−5.8	−4.2	0.0	−4.2
$\Delta\tau_{abs}$ (+20%)	−1.2	0.0	−1.2	−0.8	0.0	−0.8
			25–30°N Latitude			
ΔT (+1°C)	0.0	5.0	5.0	0.0	5.0	5.0
ΔQ (+15%)	−0.8	8.8	8.0	−0.9	7.8	6.9
Δp_c (+66 mb)	0.0	2.4	2.4	0.0	1.8	1.8
ΔC (+0.05)	−9.8	2.2	−7.6	−10.2	2.5	−7.7
$\Delta\tau_{scat}$ (+20%)	−4.4	0.0	−4.4	−3.8	0.0	−3.8
$\Delta\tau_{abs}$ (+20%)	−0.9	0.0	−0.9	−0.8	0.0	−0.8

Table 2. Sensitivities of computed flux to probable errors of TOVS data (from Darnell et al., 1983).

Sensitivity of computed flux to probable errors of TOVS data.

TOVS parameter	Probable error	Error in S_i (%)
Surface & tropospheric temperature	±2.5 K	±3.0
Water vapor burden of the atmosphere	±30%	±4.6
Cloud cover	±20%	±3.1
Cloud base height:		
650 mb	±100 mb	±1.29
800 mb	±100 mb	±1.35

Table 3. Absolute humidity values for seven atmospheric models, which are either standard models (McClatchey et al., 1977) or taken from World Climate Data.

Atmospheric model	abbr.	absolute humidity, q ($g\ H_2O\ m^{-3}$)
Antarctic Summer	AS	3.4
Subarctic Winter	SAW	1.2
Subarctic Summer	SAS	9.1
Mid Latitude Winter	MLW	3.5
Mid Latitude Summer	MLS	14.2
Subtropic Desert	W	5.4
Tropics	T	19.

Table 4. Changes of downward radiation M_a due to changes in the moisture at cloudless, low cloud (cloud base height = 1 km) and high cloud (cloud base height = 5 km). All values are in Wm^{-2} (from P. Schmetz, 1984). The change is listed under the downwelling radiation.

	cloudless					cloud base 1 km					cloud base 5 km				
Atmos.	q	q+0.3	q+1.	q-1.	q-0.3	q	q+0.3	q+1.	q-1.	q-0.3	q	q+0.3	q+1.	q-1.	q-0.3
AS	219.	224.7 +5.7	236.3 +17.3	199.2 -19.8	213.8 -5.2	303.	303.3 +0.3	303.9 +0.9	301.7 -1.3	302.7 -0.3	269.6	270.9 +1.3	273.6 +4.	263.2 -6.4	268. -1.6
SAW	174.4	180.4 +6.	191.6 +17.2	— —	168. -6.4	250.4	250.3 +0.1	250.2 +0.2	— —	250.5 -0.1	225.4	226.4 +1.	228.1 +2.7	— --	224.2 -1.2
SAS	296.8	300.3 +3.5	309.5 +12.7	286.6 -10.2	293.6 -3.2	370.3	370.4 +0.1	370.7 +0.4	369.8 -0.5	370.1 -0.1	343.5	344.4 +0.9	346.5 +3.	340.5 -3.	342.6 -0.9
MLW	248.1	255.3 +7.2	267.5 +19.4	219.4 -28.8	239.1 -9.	301.3	301.5 +0.2	301.7 +0.4	300.9 -0.4	301.2 -0.2	279.2	280.6 +1.4	283.4 +4.2	273.3 -5.9	277.6 -1.6
MLS	346.5	349.6 +3.1	357.7 +11.2	336.9 -9.6	343.6 -2.9	412.	412.1 +0.1	412.3 +0.3	411.6 -0.4	411.9 -0.1	388.4	389.2 +0.8	391.1 +2.7	385.5 -2.9	387.5 -0.9
W	340.8	345. +4.2	355.9 +15.1	329.1 -11.7	337.1 -3.7	441.6	441.8 +0.2	442.2 +0.6	440.8 -0.6	441.4 -0.2	408.5	409.5 +1.	411.8 +3.3	405.2 -3.3	407.5 1.
T	395.2	397.8 +2.5	403.9 +8.7	387.1 -8.1	392.8 -2.1	443.8	443.9 +0.1	444.2 +0.4	443.3 -0.5	443.6 -0.2	425.4	426.1 +0.7	427.9 +2.5	422.7 -2.7	424.6 -0.8

Table 5. Effect on downward radiation M_a of changes in the temperature profile (changes by ±1.5 K) for clear and cloudy conditions. All values are in Wm^{-2} (from P. Schmetz, 1984). The change is listed under the downwelling radiation.

atmosphere	cloudless			cloud base 1 km			cloud base 5 km		
	T	T+1.5	T-1.5	T	T+1.5	T-1.5	T	T+1.5	T-1.5
AS	219.	223.3 +4.3	214.7 -4.2	303.	309.7 +6.7	296.4 -6.6	269.6	275.6 +6.	263.7 -5.9
SAW	174.4	178. +3.6	170.9 -3.6	250.4	256.3 +5.9	244.6 -5.8	225.4	230.7 +5.3	220.2 -5.2
SAS	296.8	302.2 +5.4	291.5 -5.3	370.3	378.1 +7.8	362.6 -7.7	343.5	350.7 +7.15	336.5 -7.
MLW	248.1	252.8 +4.7	243.5 -4.6	301.3	308. +6.7	294.7 -6.6	279.2	285.3 +6.2	273.1 -6.
MLS	346.5	352.6 +6.	340.5 -6.	412.	420.4 +8.4	403.7 -8.3	388.4	396.1 +7.8	380.7 -7.7
W	340.8	346.8 +6.	334.9 -5.9	441.6	450.5 +8.9	432.8 -8.8	408.5	416.8 +8.2	400.7 -7.8
T	395.2	402. +6.8	388.5 -6.7	443.8	452.7 +8.9	435. -8.7	425.4	433.6 +8.3	417.1 -8.2

Table 6. Effect on downward radiation M_a of changes in cloud base height. All values are in Wm^{-2} (from P. Schmetz, 1984). The change is listed under the downwelling radiation.

atmosphere	h=1km	h=2km	h=5km	h=6km	h=4km	h=8km	h=9km	h=7km
AS	303.	293.3 -9.7	269.6	261.7 -7.9	274.5 +4.9	250.2	248.6 -1.6	255.6 +5.4
SAW	250.4	246.2 -4.2	225.4	217.5 -7.9	234.4 +9.	205.1	201.8 -3.3	210.4 +5.3
SAS	370.3	362.7 -7.5	343.5	336.8 -6.7	350. +6.5	325.3	320.6 -4.7	330.7 +5.4
MLW	301.3	296.5 -4.8	279.2	275. -4.2	284.1 +4.9	267.9	264.9 -3.	271.3 +3.4
MLS	412.	407. -5.	388.4	383.4 -5.	393.9 +5.5	374.1	370.1 -3.9	378.5 +4.4
W	441.6	433.3 -8.3	408.5	401.6 -6.9	416. +7.5	386.3	379.8 -6.5	393.6 +7.3
T	443.8	438.5 -5.3	425.4	421.8 -3.6	429.9 +4.5	414.4	412.3 -2.1	418.1 +3.7

Table 7. Effect on downward radiation M_a of change in the cloud coverage, assuming a mean coverage of 4/8 at 1 and 5 km, respectively. All values are in Wm^{-2} (from P. Schmetz, 1984). The change is listed under the downwelling radiation.

atmosphere	cloud base 1 km			cloud base 5 km		
	c_w	$c_w+1/8$	$c_w-1/8$	c_w	$c_w+1/8$	$c_w-1/8$
AS	261.	271.5 +10.5	250.5 -10.5	244.3	250.6 +6.3	238. -6.3
SAW	212.4	221.9 +9.5	202.9 -9.5	199.9	206.3 +6.4	193.5 -6.4
SAS	333.9	343. +9.1	324.8 -9.1	320.6	326. +5.4	314.8 -5.4
MLW	274.9	281.6 +6.7	268.3 -6.7	263.9	268. +4.1	259.1 -4.1
MLS	379.2	387.4 +8.2	371.1 -8.2	367.4	372.7 +5.2	362.1 -5.2
W	391.2	403.8 +12.6	378.6 -12.6	374.7	383.1 +8.4	366.2 -8.4
T	420.	425.8 +5.8	413.9 -5.8	410.6	414.3 +3.7	407. -3.7

Table 8. Net effect on downward radiation of changes in all parameters (T, q, h_w and c_w) as given for cases I, II and III, assuming that they are totally uncorrelated.

h_w = cloud base height
c_w = cloud fractional coverage
q = moisture level
s_i = standard deviation of error of estimate in quantity i

Calculations for this table have been made for the midlatitude summer profile. All values are in Wm^{-2} (from P. Schmetz, 1984).

boundary conditions			net errors in downward radiation, W/m^2		
Δq (g/m^3)	h_w (km)	c_w	s_g (W/m^2) I	s_g (W/m^2) II	s_g (W/m^2) III
0.3	-	-	5.9	4.7	4.7
1.0	-	-	6.5	5.5	5.5
0.3	1	1	8.9	8.2	6.5
0.3	1	0.5	7.5	6.6	6.1
1.0	1	1	9.3	8.6	7.0
0.3	5	1	8.6	7.9	6.1
0.3	5	0.5	7.1	6.2	5.6
1.0	5	1	8.9	8.2	6.5
1.0	5	0.5	7.5	6.6	6.1
0.3	8	1	8.4	7.6	5.7
1.0	8	1	8.8	8.1	6.4
-	1	1	7.7	6.8	4.6
-	1	0.5	6.0	4.9	4.1
-	5	1	7.3	6.4	4.0
-	5	0.5	5.5	4.3	3.4
-	8	1	7.1	6.2	3.7

I : s_T=1K, s_q=0.4g/m^3, s_h=1km, s_c=0.05
II: s_T=0.5K, s_q=0.4g/m^3, s_h=1km, s_c=0.05
III: s_T=0.5K, s_q=0.4g/m^3, s_h=0.5km, s_c=0.05

standard deviations of temperature, moisture and cloud base height and coverage

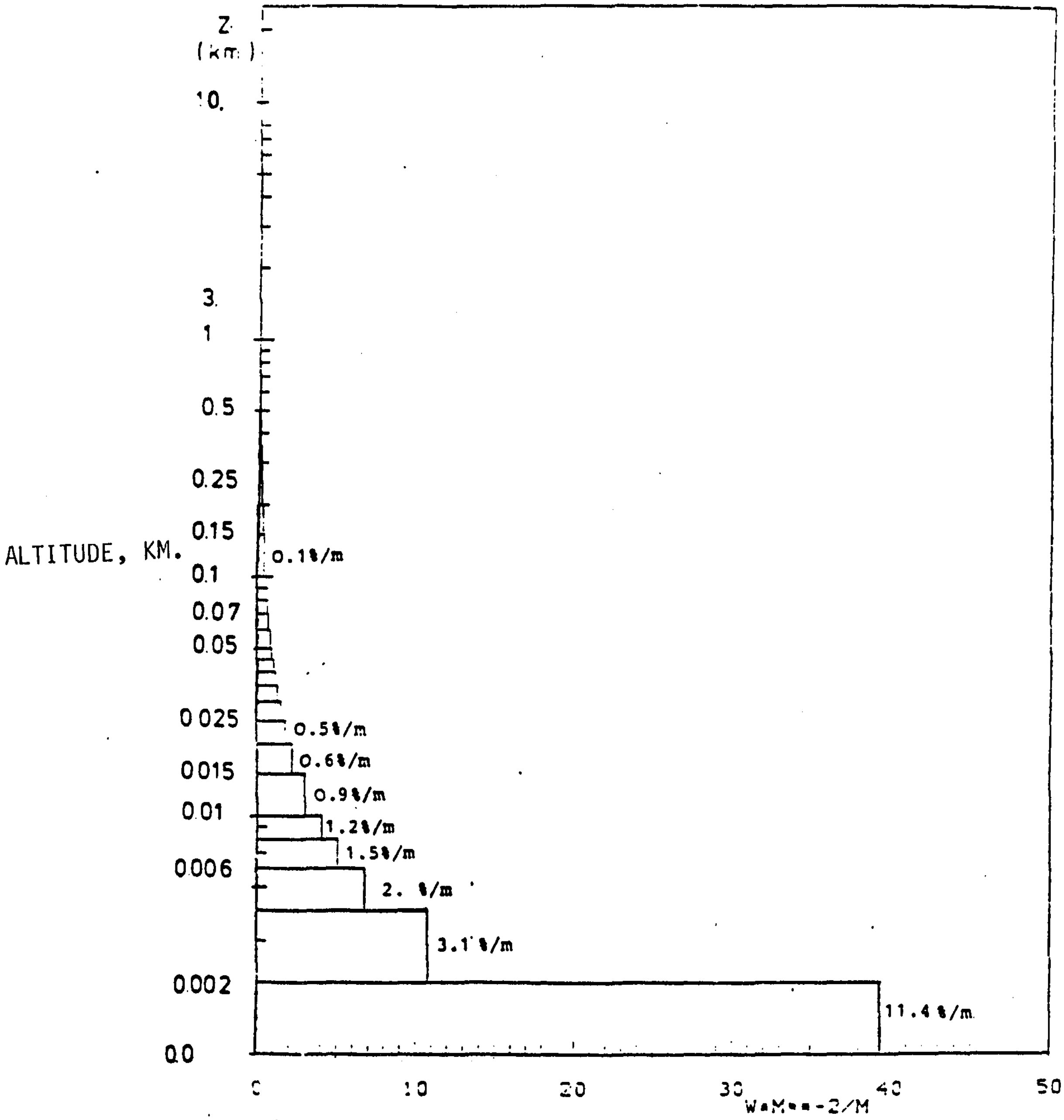

Fig. 1 : Relative contribution (percent per meter layer thickness) of each layer to the downward atmospheric radiation, computed for a mid latitude atmosphere model without clouds (total = 346.2 Wm^{-2}).

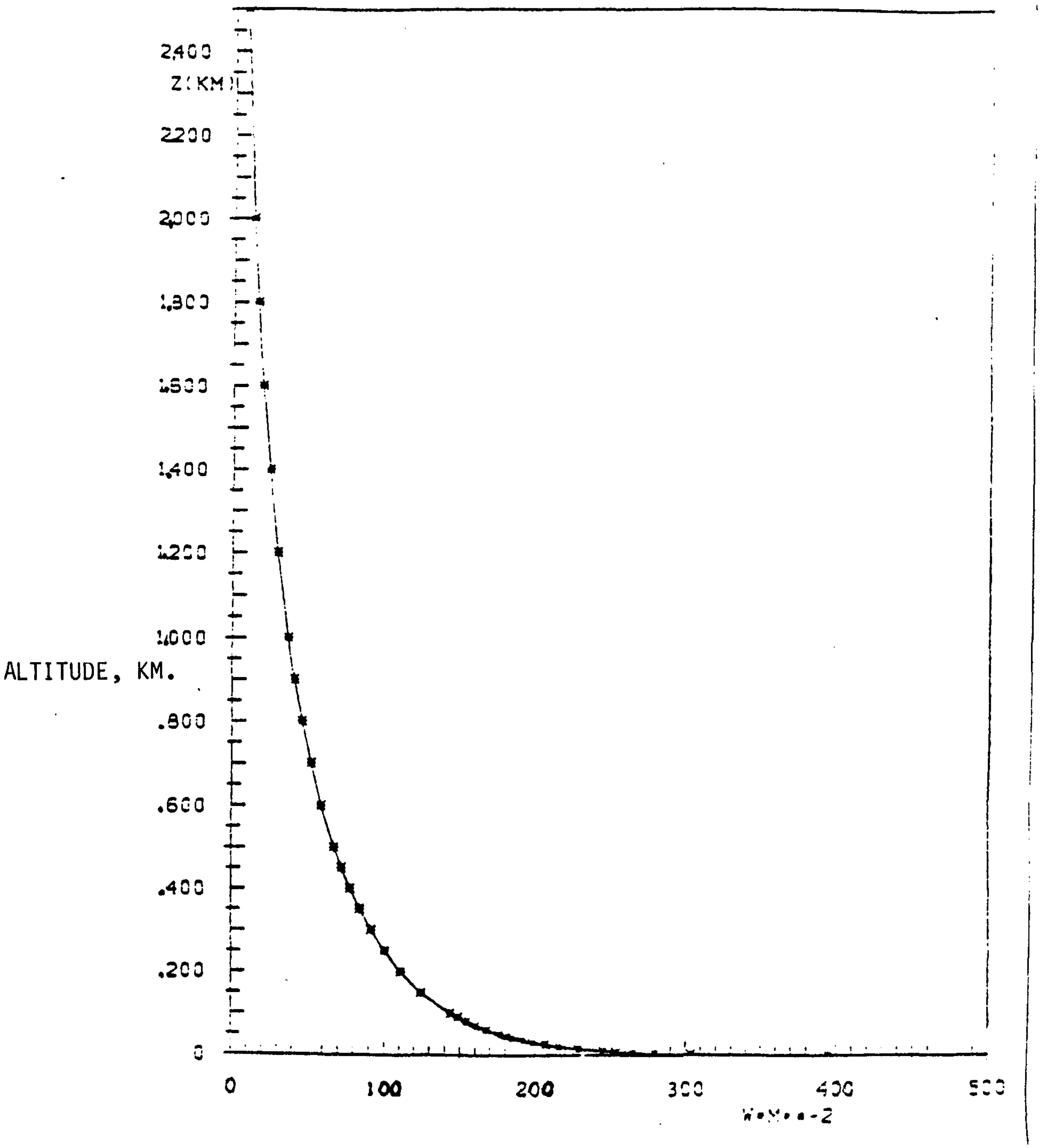

Fig. 2: Cumulative sum of contribution from each layer to the downward atmospheric radiation at ground, computed for a tropical model atmosphere, without clouds (total = 395.2 Wm-2).

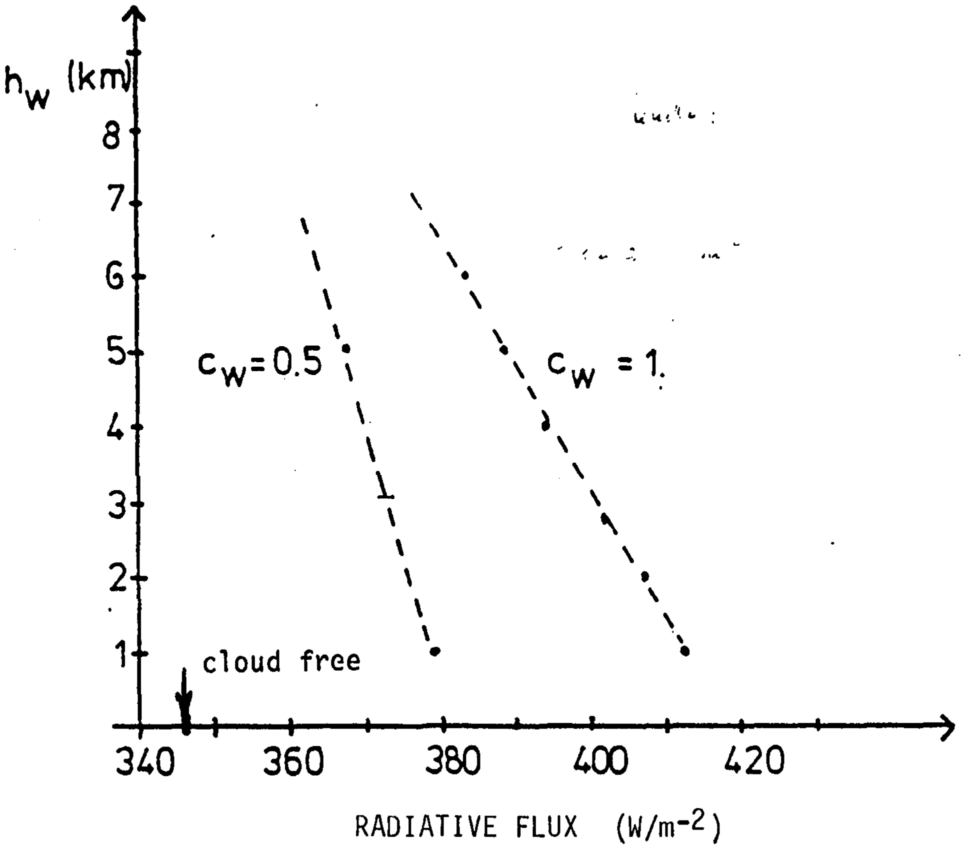

Fig. 3: Contribution of a cloud layer (cover c_w +0.5 and 1.0) at different altitudes to M_a (mid latitude atmosphere profile). The clear-sky value is 346.2 Wm^{-2}.

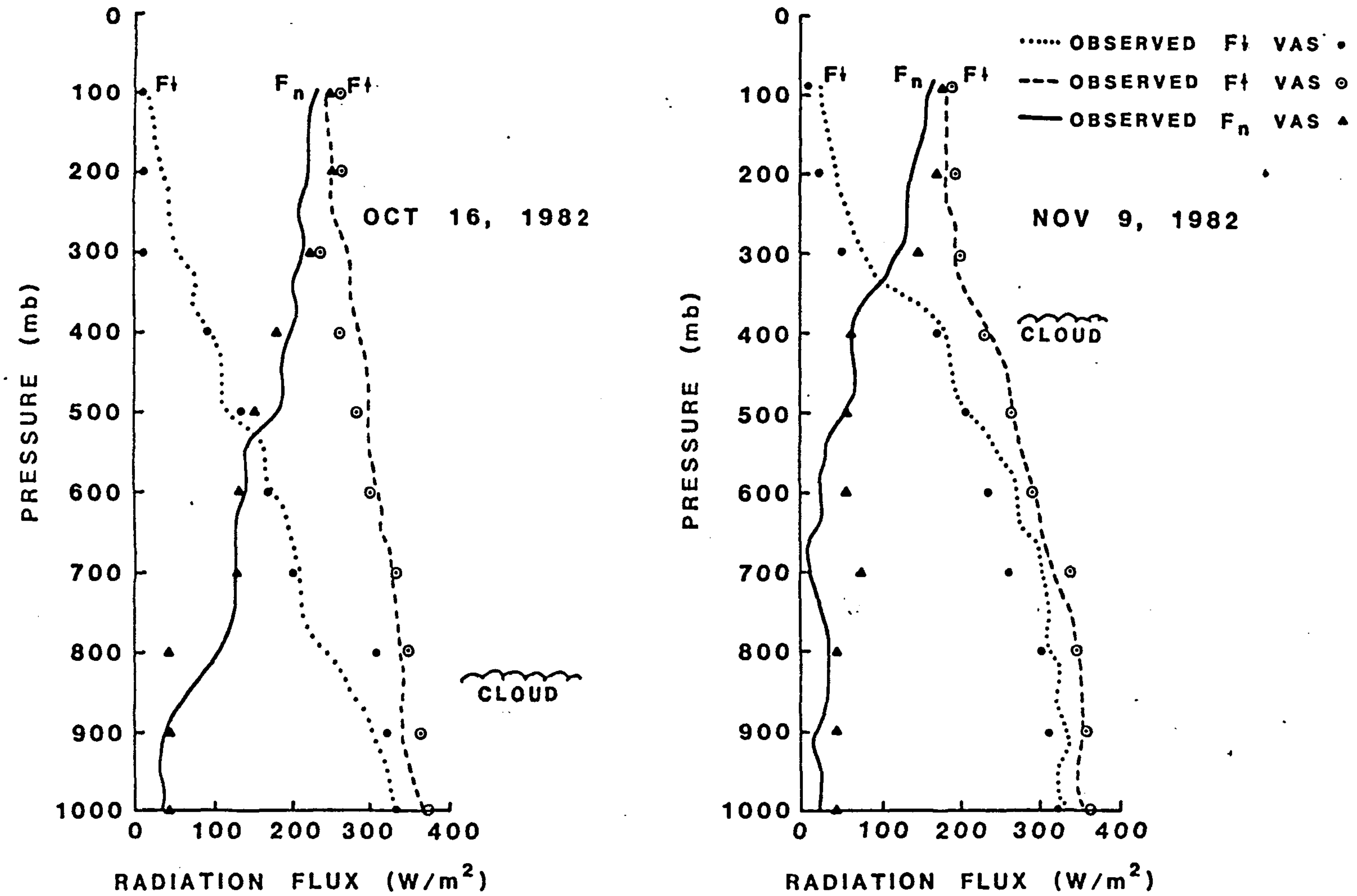

Figure 4. Comparison of upward, downward and net rdiation fluxes observed by radiometersonde (curves) and estimated from simultaneous VAS measurements (points) for Madison, Wisconsin, on a) 16 October 1982, and b) 9 November, 1982.

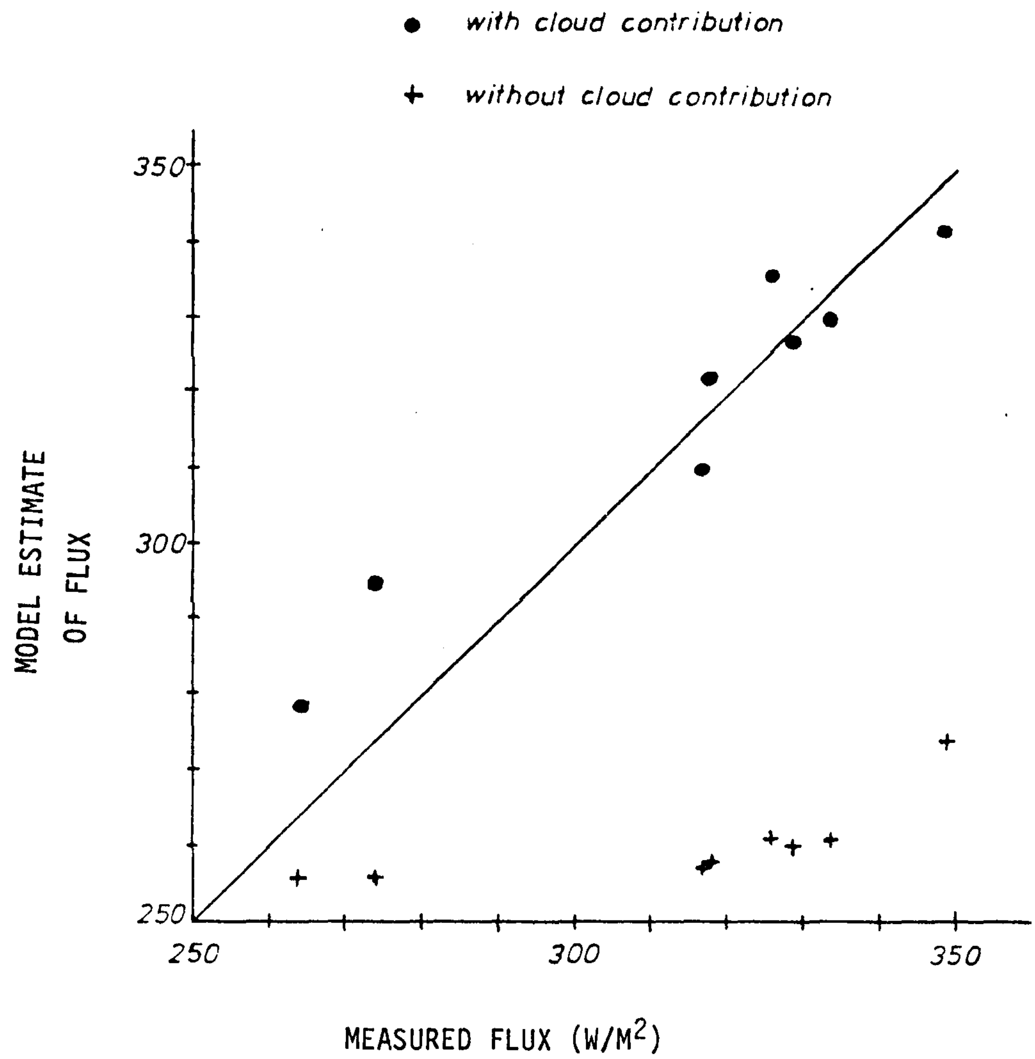

Figure 5. Comparison between measured values of M_a (from four stations in Germany) and the model estimates, based on ALPEX data of 29 and 30 April, 1982 (1200 GMT).
P. Schmetz, J. Schmetz and E. Raschke, unpublished data.

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16. Abstract

A strategy is presented along with background material for determining downward atmospheric radiation at the Earth's surface on a regional scale but over the entire globe, using available information on the temperature and humidity of the air near the ground and at cloud base altitudes. Most of these parameters can be inferred from satellite radiance measurements. Careful validation of the derived radiances will be required using ground-based direct measurements of radiances, to avoid systematic biases of these derived field quantities.

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