DERIVATION OF THE RADIATION BUDGET AT GROUND LEVEL FROM SATELLITE MEASUREMENTS

Ehrhard Raschke
University of Cologne
Cologne, Germany

INTRODUCTION

The radiation budget at the ground, consisting of two components, plays an important role in atmospheric and climatic energetics. Knowledge of the Earth radiation budget over spatial and temporal scales can be used for several purposes and applications, e.g.,

Radiation budget of the atmosphere

Heat input to the ocean

Convective activity over the ground

Energy budget at the surface

Climatological investigations and modeling

Use of solar energy

Agriculture and forestry

Ocean biology

Sufficiently dense and well-organized networks of measurement ground stations exist only in a few countries. These measurements are affected by the local environment. The data from many such stations have limited availability for scientific research. Therefore, methods must be developed and tested to determine the radiation budget at ground level from satellite measurements. Now and later, the basic data sets will be measurements of the planetary radiation budget components and/or the imaging multi-optical data of operational satellites. Future work at the University of Cologne will be directed toward solving individual problems inherent to this subject.

THE PROBLEM

Keep in mind that radiation budget values will be determined for areas approximately 100 km × 100 km. The two components of the radiation budget at the ground consist of upward and downward fluxes of solar and thermal radiation. They are discussed here separately.

Solar Radiation

The net radiation at the ground $M_{N,S}$ can be expressed as

$$M_{N,S} = G(1 - \alpha)$$

where

G downward global radiation consisting of a diffuse and a direct component

α surface albedo or reflectance

Although α, due to angular and spectral dependences, changes slightly with respect to cloud cover, humidity, and solar incidence, it can be estimated and mapped over most land surfaces rather accurately with satellite measurements. Atmospheric effects on measurements can be corrected with models. Its values over oceans are well known.

The global radiation G may also be determined with empirical relations. Some authors use simple regressions between satellite (e.g., GOES data) and ground-based network measurements, while we, along with others, consider clouds as perturbations in the field of clear sky radiation. We either parameterize the cloudiness in fractional units of optically dense clouds or assign specific radiative transfer characteristics to clouds such as those detected in sky photographs or from operational observers.

Thermal Radiation[1]

The net heat radiation at the ground $M_{N,t}$ can be expressed as

$$M_{N,t} = A\downarrow - \varepsilon\sigma T_S^4$$

where

$A\downarrow$ downward atmospheric radiation which is a function of the ambient temperature and moisture profile and of the cloudiness and cloud ceiling heights

ε emissivity (≈0.98 for most surfaces)

σ Stefan-Boltzmann constant

T_S surface temperature, itself a complex dependent of the heat (radiation and other heat fluxes) budget at the ground

---

[1] The symbols used here do not always correspond to those recommended for publication in the official literature.

C-2

No attempt has yet been made to parameterize this quantity. The cloud ceiling height, possibly the most critical quantity, can only be estimated from stereo techniques and/or condensation level calculations. Future laser techniques may improve the accuracy for thin cloud layers, e.g., cirrus.

SOME RESULTS OF OUR RESEARCH AT THE UNIVERSITY OF COLOGNE

Calculations of the Radiation Budget in a Circulation Model

We have developed an economic delta-two stream approximation; clouds had previously been treated with a random distribution in each layer. Therefore, we overestimated the albedo as seen from space and the global radiation at the ground.

Figure 1 shows a comparison of preliminary results of the global radiation calculated for the period February 15-25, 1976, using three methods: (1) the long-range forecasting model of the European Center of Medium Range Weather Forecast (ECMWF), (2) University of Cologne method, and (3) daily planetary radiation budget calculated from data from the National Oceanographic and Atmospheric Administration (NOAA) archives. These satellite data may contain systematic errors due to their method of calculation.

In table I, global averages of radiation budget components are compared. Table II shows a comparison with concurrent pyranometer measurements available from the rather crude World Meteorological Organization (WMO) network. Such comparisons require more careful design and maintenance of ground-Earth networks. As of March 31, 1980, our routine has been improved, and with the improved routine, further tests with the ECMWF will include recalculation for the same periods and calculation of the energetics for the special observing periods during the First Global Group Experiment (FGGE), e.g., January 1979. In the latter case, we intend to use Nimbus 7 Earth Radiation Budget Experiment (ERBE) data for comparison with calculated radiation budget components.

Radiative Transfer Characteristics of Clouds

In field experiments during the Joint Air-Sea Interaction project (1978 over the North-Atlantic Ocean), we measured radiation fields from aircraft and ships and also cloud structures (see, e.g., Schmetz and Raschke, 1980). Figure 2 shows a comparison between calculated and measured upward and downward solar radiation. Solid cloud decks, such as stratus, can satisfactorily be parameterized. Further work will be done for broken cloud fields. An experiment is planned for the fall of 1981.

Solar Radiation at Ground From Meteorological Data

A geostationary satellite, such as Meteosat, provides information on the cloud fields with a high spatial and temporal resolution. Thus, valuable information on the available solar energy can be derived for direct application.

Considering clouds as perturbations in the clear sky radiation field, we formulated the map of Germany shown in figure 3 (global radiation at 12:00 noon, average for June 1-15, 1979). Figure 4 shows a comparison with some simple pyranometer stations which is still not satisfactory.

Planetary Radiation Budget

The University of Cologne participates in preparations for the ERB satellite system, but we also intend to contribute actively to a European project. Therefore, a 10-channel radiometer is under study (breadboard model being built). Figure 5 shows a sketch.

The conical scan of this instrument (constant pixel size at all zenith angles of about 50-60 km) allows more accurate studies of the angular dependence of outgoing radiances and also stereo-analysis (with some limited accuracy) of cloud fields. The 10 channels are sensitive to the global radiation budget components, but also to variation of internal components, such as cloudiness, aerosols, water vapor, ozone, surface temperatures, and mean stratospheric temperatures. No spacecraft has yet been conceived as a platform.

REFERENCE

Schmetz, J.; and Raschke, E. 1980: Radiative Properties of Boundary Layer Clouds as Measured by an Aircraft. Univ. of Cologne paper presented at the International Radiation Symposium 1980 (Fort Collins, Colorado).

TABLE I.- RADIATION BUDGET GLOBAL AVERAGES

	ECMWF	Cologne	NOAA
Energy balance:			
Global, W/m^2	4.59	6.3	-5.56
Global mean of zonal variances, (W/m^2)^2	517.3	1827	493.9
Infrared emission:			
Global, W/m^2	240.45	239.6	241.6
Global mean of zonal variances, (W/m^2)^2	109.0	125.7	281.0
Planetary albedo:			
Global, percent	31.5	30.1	34.1
Global mean of zonal variances, (percent)^2	52.9	23.9	75.0
Infrared radiation balance:			
Global, surface, W/m^2	-55.84	-58.0	
Global mean of zonal variances, (W/m^2)^2	176.4	283.5	
Global radiation:			
Surface, W/m^2	174.24	179.6	173.7
Global mean of zonal variances, (W/m^2)^2	833.3	1630.3	5.70
Cloud cover:			
Global, percent	59.30	58.30	
Global mean of zonal variances, (percent)^2	320	370	

TABLE II.- COMPARISON OF VALUES OF

GLOBAL RADIATION (W/m^2)

Period	Region	Ground measurements	ECMWF (a)	Cologne (a)	NOAA
August 25 to September 4, 1975	Africa I	161.1	218.9	132.5	205.3
	Africa II	239.2	218.5	174.6	227.7
	USA I	290.2	258.2	233.2	246.7
	USA II	229.2	220.8	192.5	217.0
	USA	259.7	239.5	212.9	231.9
	Western Europe	196.8	202.1	149.5	179.5
February 15 to 25, 1976	Africa I	238.5	202.6	148.0	220.7
	Africa II	273.8	179.8	162.5	227.8
	USA I	176.4	140.3	148.6	124.9
	USA II	158.8	132.0	131.8	108.7
	USA	167.6	136.2	140.2	116.8
	Western Europe	92.9	88.3	85.6	72.0

[a] Calculated in a circulation model.

ORIGINAL PAGE IS
OF POOR QUALITY

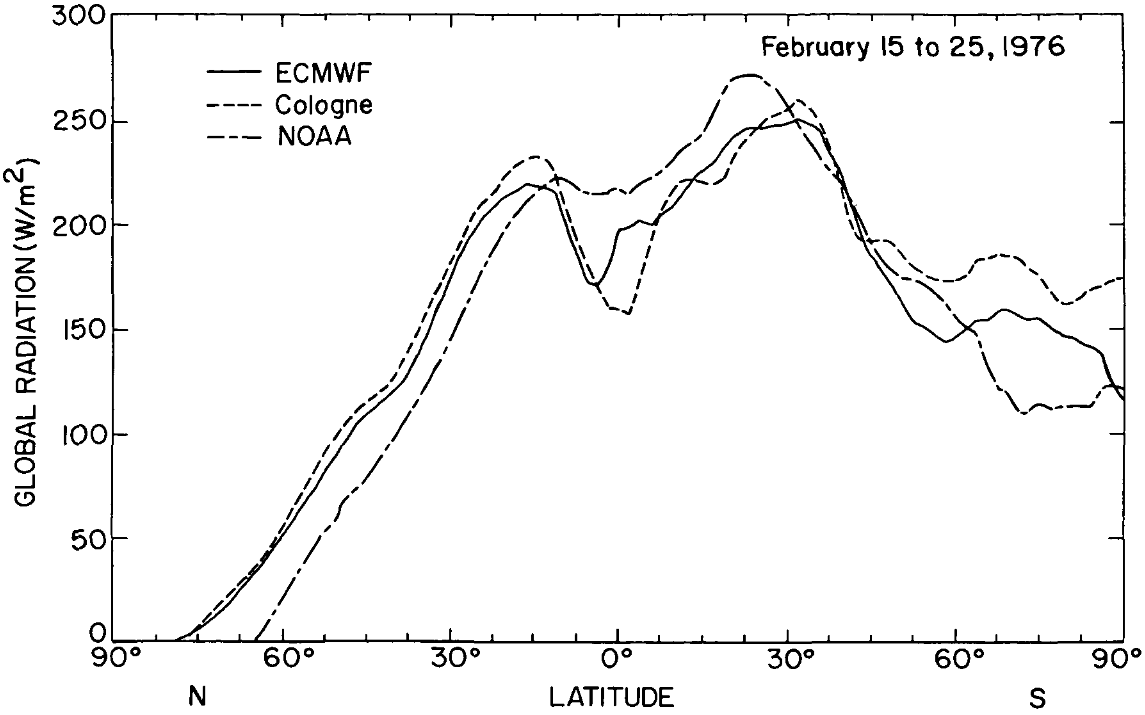


Figure 1.- Comparisons of global radiation calculated for the period of February 15-25, 1976.

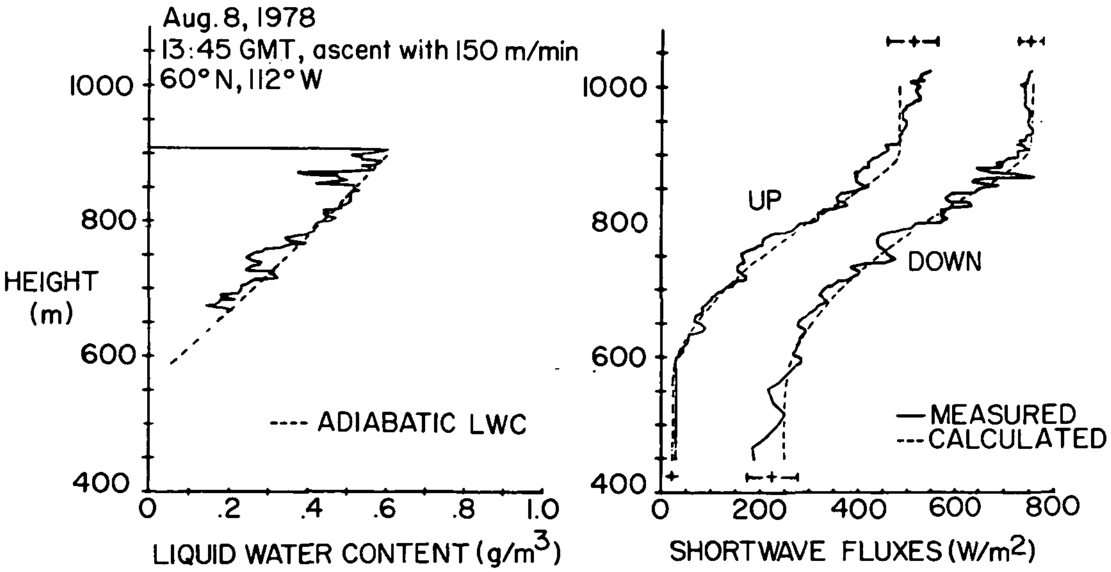


Figure 2.- Comparison of measured and calculated solar radiation components. (Schmetz and Raschke, 1980)

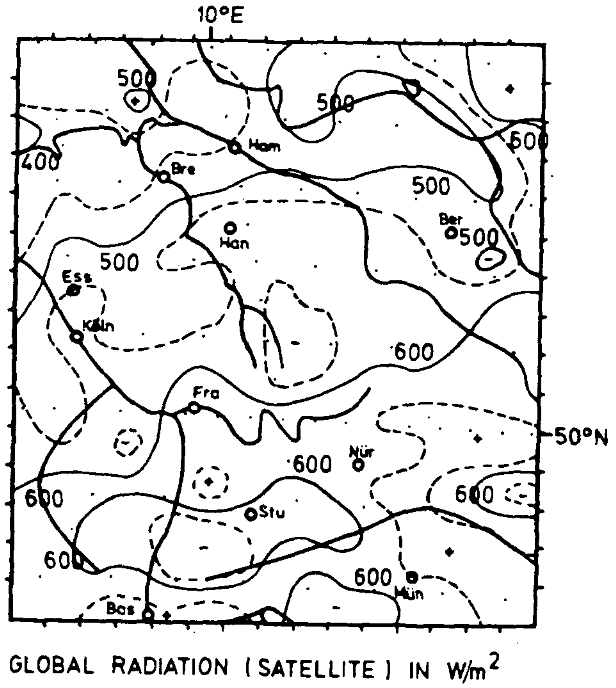


Figure 3.- Global radiation at 12:00 p.m. (average for June 1-15, 1979) over Germany as obtained from Meteosat.

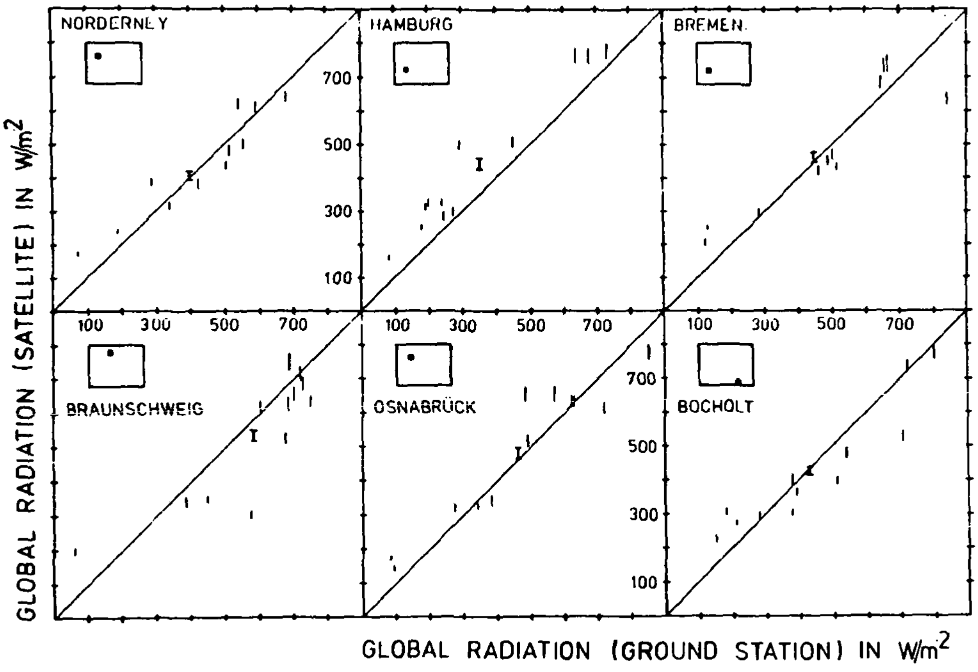
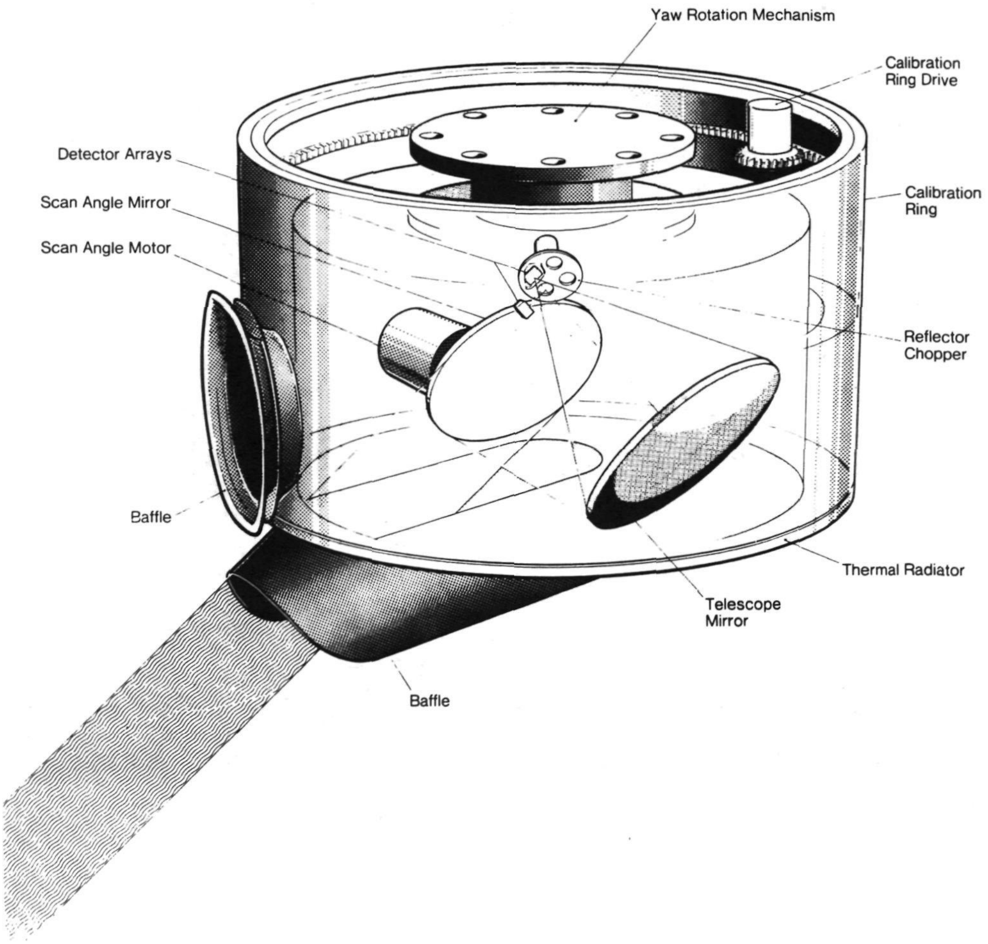


Figure 4.- Comparison between Meteosat and ground station global radiation at the ground. The inserted boxes show the location of each station relative to the grid center.



Channel no.	Spectral range, λ (μm)	Virtual target temperature, T (K)	Radiometric accuracy, (percent)	Objectives
A_1	0.25 - 4.0		1 - 2	Planetary and ground albedo
A_2	0.2 - 0.3		5	
A_3	0.35 - 0.7	Corresponding to 0.8 solar-constant	5	Aerosols, clouds
A_4	0.7 - 1.0		5	Vegetation
A_5	1.0 - 2.0		5	
B_1	4.0 - 70.0	200 - 300	1 - 2	Planetary emission
B_2	5.4 - 7.2	200 - 270	5	Water vapor
B_3	10.0 - 12.0	200 - 280	1 - 2	Surface temperature
B_4	9.3 - 9.8	200 - 280	5	Ozone
B_5	14.0 - 16.0	200 - 270	5	Stratospheric temperature

Figure 5.- Ten-channel conical scan radiometer.