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Recent Progress in Atmospheric Radiation[1]

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Cochairpersons, Fifth Conference on Atmospheric Radiation

Abstract

This report contains summaries and highlights of the papers presented at the Fifth Conference on Atmospheric Radiation. The scope and content of these papers represent recent applied research and scientific progress in atmospheric radiation and related fields. Papers spanning the subjects of satellite remote sensing, interactions of radiation and general circulation, effects of clouds and aerosols on climate, radiation budget studies from satellites, some aspects of radiative transfer and radiation measurements, and solar energy applications were presented.

1. Introduction

The AMS Fifth Conference on Atmospheric Radiation was held in the Baltimore Hilton Hotel from 31 October through 4 November 1983. The scientific program of the conference was organized by the AMS Radiation Energy Committee. The atmospheric radiation conference also included two special programs: clouds and climate, and solar energy applications, that were cosponsored by the AMS Climate Variations Committee and the Solar Radiation Division of the American Solar Energy Society, respectively. The program committee received approximately 180 invited and contributed abstracts for presentation. In order to provide a reasonable amount of time for the presentation and discussion of each paper and to limit the need for multiple sessions, a large number of potentially good papers had to be placed on reserve status.

The final program included about 110 invited and contributed papers that were presented during a period of four and a half days. In addition, about 20 papers were displayed in the poster session. More than 250 scientists in the atmospheric radiation and related fields, representing about 80 academic, research, and government institutions, actively participated in the conference. High-quality papers with clear visual displays were presented within the allowed time limit. Due to the author's adherence to time limitations and the work of the session chairpersons, the program proceeded smoothly. There were many questions and comments from the general audience.

The entire conference was organized into eight primary sessions, including remote sensing, radiation and GCM, radiation and climate, clouds and climate, aerosols and climate, radiation budget, radiative transfer and radiation measurements, and solar energy applications. Each session was chaired and cochaired by leading and active scientists in their respective fields, who were extremely cooperative in providing summaries and highlights of the papers presented. Using these summaries and highlights, a review of recent progress in atmospheric radiation and related fields as reported at the Fifth Conference on Atmospheric Radiation is presented.

2. Remote sensing (R. McClatchey, H. E. Fleming, S. R. Drayson, R. J. Curran)

The conference began with papers dealing with remote sensing of atmospheric temperature and atmospheric constituents from orbiting meteorological satellites. Three invited papers, by Smith of the University of Wisconsin/NOAA, Chahine of the Jet Propulsion Laboratory (JPL), and Gille of NCAR, were presented first in the overview session. This session was highlighted by two important notions: 1) that, in the future, researchers in remote sensing from satellites must seek ways to deal with the high spatial resolution requirement of mesoscale phenomena; and 2) that there is much that can be inferred from existing observations to provide a more complete set of atmospheric and surface parameters for global forecasting and climate studies.

Smith *et al.* proposed that high spectral resolution interferometry in the infrared holds the key to providing high spatial resolution observations for mesoscale numerical modeling. He argued that interferometry offers the only possibility of extracting the required data, depending on the horizontal resolution requirements. He envisioned such a system on a geostationary satellite, together with some microwave observations to deal with totally cloudy regions. The presentation by Chahine *et al.* emphasized the analysis of existing satellite-sounding observations. They have used available infrared and microwave data to infer a wide variety of atmospheric and surface properties, including atmospheric temperature and humidity, cloud cover, cloud height and cloud

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temperature, and a number of surface properties. Chahine pointed out the need to perform this kind of complete analysis in order to define the boundary conditions necessary for a more accurate set of atmospheric interpretations. The results obtained provide necessary input for forecasting models and potential verification for climate studies. In his paper, Gille described the results and potential of limb sounding for the observation of temperature and ozone above the troposphere. High vertical resolution is possible with this technique, but there are a variety of corrections necessary to account for asymmetries in the long tangent paths along which the radiation originates. He showed the accuracies of the temperature observations and a number of minor gases that could be derived using the limb-sounding technique. Of particular interest was the temperature accuracy, which was shown to be about 0.7 K. The question of whether his instrument could be used to detect the stratospheric cooling due to the increase of CO_2 was asked. The final paper in the overview session was given by King, who described a concept of radiative entropy in the form of a kind of unifying theory providing guidance regarding the accuracy and smoothness of radiance observations as related to the smoothness of the related weighting functions. This theory explains the requirement for the smoothing and conditioning of matrices found necessary in matrix inversion procedures. It may provide guidance as we move toward the further development of techniques aimed at higher-resolution observations to gather data pertinent to the mesoscale.

The five talks that followed dealt with the temperature remote-sensing problem. One of the talks described a retrieval system, one a hardware system, and the remaining three were concerned with methods for improving temperature retrieval accuracies. Physical retrievals of temperature profiles suffer from incomplete knowledge of the atmospheric transmittances. This error propagates into the solution, in large part, as a bias error. A method was presented by Fleming *et al.* for eliminating the bias component of the solution error. In addition, the algorithms and procedures developed at the Goddard Laboratory for Atmospheric Sciences (GLAS) and JPL for processing TIROS-N satellite data described by Chahine were described further by Susskind *et al.*, who also described the possibility of deriving the sea ice extent and snow cover over land.

The afternoon remote-sensing sessions focused on the retrieval of constituents. Determination of the distribution of water in all its phases—solid, liquid, and vapor—utilizing observations in the microwave, infrared, visible, and ultraviolet, with both passive and active devices, was discussed first. The inference of the vertical profile of water vapor in the troposphere from satellite observations remains too inaccurate for operational purposes, although progress is being made in improving these remote-sensing techniques.

The session continued with investigations of tropospheric aerosols, including their relationship with water vapor. Aerosols are important in their own right, and also inasmuch as they interfere with the sensing of surface parameters such as sea surface temperatures.

Three papers on remote sensing of ozone were presented. Of particular interest was a comparison by Fleig *et al.* of profiles derived from the Limb Infrared Monitor of the Stratosphere (LIMS), the Stratospheric Aerosol and Gas Experiment (SAGE), and the Solar Backscattered Ultraviolet (SBUV), which showed remarkably close agreement between instruments operating in three different spectral regions. Proposed changes in UV scattering cross sections will enhance the agreement even further.

The wide range of remote-sensing techniques presented in the papers served to emphasize the point that no single method can provide a comprehensive understanding of global conditions, but that our knowledge is being expanded by diverse instruments scanning the spectral range from the ultraviolet to the microwave region.

In addition to the aforementioned presentations, during a luncheon on Wednesday, Suomi of the University of Wisconsin gave a lively and enlightening lecture on the feasibility of deriving the hydrological cycle from satellite measurements. He indicated that the present configuration of satellites does not provide sufficient information to obtain this cycle. The polar-orbiting satellites that have microwave sensors do not have the required temporal resolution. An extremely large antenna would be required to obtain the desired resolution with a microwave sensor on a geostationary satellite system. Suomi suggested a new satellite system that would consist of satellite(s) in a nearly circular orbit, similar to that of the present geostationary system, but with a smaller orbital radius. The motion of the satellite relative to the earth would be such that the same geographical area would be viewed once every 6 h. In addition, the lower orbit would permit the use of a smaller flexible antenna to obtain the desired resolution for the microwave sensor. This system could be used to determine the wind fields in the boundary layer that would be used to estimate evaporation. A knowledge of the evaporation is essential for the determination of the hydrological cycle. The advantages of this system are that it provides microwave information with a spatial resolution that is not possible from geostationary satellites, and temporal resolution that is not possible from polar-orbiting satellites. In addition, if sensors with spectral channels in the visible and IR also are flown aboard, the information provided by this system will be as comprehensive as that provided by the present satellite systems. The main disadvantage of the system would be the lack of satellite information for polar regions. Suomi believes that it might become an economical necessity to convert to a single satellite system that can perform many functions, rather than maintain multiple satellite systems.

3. Radiation and GCM (A. Arakawa, L. D. Kaplan)

Three invited papers (by Wetherald and Manabe of the Geophysical Fluid Dynamics Laboratory (GFDL), Ramanathan of NCAR, and Kuo *et al.* of the University of Chicago) were presented first. Wetherald discussed the role of cloud feedback in climate sensitivity experiments. He pointed out that cloud cover, on the one hand, increases the planetary albedo and cools the earth-atmosphere system and, on the other, reduces outgoing long-wave radiation and warms the earth-atmosphere system. In their model experiments regarding quadrupling of CO_2, it was found that in all cases considered, clouds were reduced in the convectively active regions such as the tropical and middle latitude rainbelts, but increased in the stable layer near the earth's surface from middle to high latitudes. It is likely, he asserted, that the former would produce a net warming or positive feedback, whereas the latter would lead to a net cooling or negative feedback. However, the quantitative effects of the increase of high clouds and decrease of middle clouds on the warming, a positive feedback, depend upon the degree of "blackness" chosen for cirrus. He also pointed out that the prediction of low stratiform clouds in the arctic and subtropical regions is of great importance in climate sensitivity investigations. Unfortunately, none of the models developed so far satisfactorily simulate low stratiform clouds.

Ramanathan presented a review of the relative importance of long-wave radiative processes on the general circulation of the lower atmosphere. Cloud/radiation coupling, H_2O continuum effects, and stratospheric processes were identified as several of the most significant mechanisms affecting the meridional gradients of longwave radiative cooling rates, which in turn play an active and important role in determining the atmospheric zonal mean circulation. In a numerical experiment using the NCAR community climate model, he showed the influence of the blackness of cirrus on the IR cooling rates and the consequence to zonal mean wind and temperature field. The temperature changes induced by the cirrus radiative heating were found to be as important as moist convection and dynamical transport of sensible heat in his model simulations. He pointed out the need for a better physical and quantitative knowledge of the time and spatial variations of IR heating rates caused by H_2O, O_3, and clouds in order to improve our understanding of the lower stratospheric general circulation. In the final part of his talk, Ramanathan utilized the GARP Atlantic Tropical Experiment (GATE) cloud and radiation data sets to show the spatial inhomogeneity of IR cooling rates induced by clouds.

Using a regional model, Kuo discussed the relative importance of diurnal variation of solar radiation and large-scale and deep cumulus condensation on the development of the mean monsoon circulation in summer. The model included solar and infrared parameterizations coupled with the effects of dry and deep cumulus convection based on Kuo's scheme. Resulting simulations showed that the large-scale features of the mean July circulation in the tropics were created chiefly by the differential diabatic heating influenced by the specific topography and were almost independent of the initial state. Kuo also demonstrated that the time requirement for the atmosphere to establish the large-scale features of the mean monsoon circulation under the combined radiative/convective heating effects was only about five days when the diurnal variation of solar radiation was included. However, it took much longer when only the daily mean solar heating was used. Kuo pointed out that the physical reason for these differences is the increase of dry and moist convective activities produced by strong insolation during the day over the large continent and plateau regions.

The next two papers, by Coakley and Cess and by Randall and Carlson, were concerned with the effects of aerosols on the general circulation models. Coakley found that lowering of the NCAR Community Climate Model's equilibrium surface temperature due to radiative forcing by the naturally occurring tropospheric aerosol was an order of magnitude less than that predicted by an energy balance model because of a lack of feedback in the NCAR model due to a fixed ice line and a fixed sea surface temperature. In a simply parameterized study of the sensitivity of the GLAS Climate Model to Saharan dust heating, Carlson found that the dust seems to produce a southward shift and intensification of the tropical rainbelt, a marked reduction of the easterlies, and a shifting of the zone of maximum convergence of the meridional wind. Carlson concluded that the experiment should be continued with more detailed aerosol physics, improved radiation parameterizations, and, eventually, inclusion of dust transport and a parameterization of its sources and sinks.

Three papers, by Liou and Zheng, Ellingson and Looper, and Morcrette and Laval, dealt with the interactions of radiative processes with the general circulation of the atmosphere. Liou discussed the complexity and importance of interactions among radiation, clouds, and dynamic processes in a General Circulation Model (GCM), with illustrations from results of a cloud-predictive, interactive model developed at the University of Utah. Ellingson discussed results of tests of radiative effects on a medium-range numerical weather prediction (NWP) model. Morcrette presented GCM results with different radiation schemes and with and without interactive clouds and humidity.

Gannon and Dias presented results of cloud water and precipitation predictions in a 10×10 km grid over the island of Hawaii by the Environmental Research Laboratories' (ERL) 3-dimensional model modified by the addition of a detailed surface solar flux calculation, a simple longwave surface flux parameterization, and surface energy budget algorithms, including ground surface and canopy parameterizations. In a numerical investigation of the effects of cloudiness on mesoscale atmospheric circulation, Wong *et al.* showed that effective modeling of cloud modulation of ground heating by solar radiation can improve significantly their model prediction of cloudiness and precipitation, as well as cyclone development, presumably through better latent heat release. Finally, Wobus *et al.* gave a new, improved parameterization of radiative transfer at 15 μm for the GLAS GCM, which uses model-produced temperature and pressure variations with height to calculate transmittances, rather than those of a standard atmosphere.

4. Radiation and climate (R. E. Dickinson, J. A. Coakley, Jr.)

This session began with two invited papers presented by North of GLAS/NASA and Cess of SUNY at Stonybrook. North gave a review of energy balance climate models in general, and more specifically, recent studies with his energy balance climate models. They have now been "pushed to the limit" with the introduction of realistic land-sea-ice geographic distribution. The model as tuned gives a good large-scale simulation of the seasonal cycle of surface temperature. Its many applications include ice ages, CO_2 transience, solar variability, and ancient climates. Another experiment discussed was the determination of the climate at 50 000 000 B.P. when Antarctica and Australia were attached.

Cess and Potter discussed the question of the global climate equilibrium response to the doubling of CO_2. Idso and Newell both recently applied surface energy balance arguments to infer that the temperature change due to a doubling of CO_2 would be quite small. Cess presented a surface energy balance model that replicates the conventional warming of about 2°C for doubling CO_2, but, by making approximations equivalent to those made by Idso and by Newell, also reproduced their low values. Likewise, by making approximations such as those by Möller in an earlier study, they reproduced Möller's results. All of these approximations made by Idso, Newell, and Möller are in violation of the first law of thermodynamics! In a CO_2-related paper, Luther discussed the change of radiative fluxes due to increasing CO_2. The fluxes most sensitive to changing CO_2 are downward fluxes at wavenumbers of around 750 μm and a few kilometers above the surface. The idea is to develop a strategy for monitoring CO_2 radiative changes that gives the earliest statistically significant indications of a radiative effect due to increased CO_2.

Development of broad-band infrared transmission functions for use in climate studies then was presented by Chou, using empirical fits to accurate line-by-line computations. Results for surface temperature change due to various forcing terms were reported. It was found that the response of their climate model depends primarily on changes in the radiative fluxes at the tropopause and not on changes in fluxes at the surface. The following four papers, by Starr, Ramaswamy and Detwiler, Ou and Liou, and Wang and Kaplan, investigated cirrus and climate problems. Starr presented a 2-dimensional hydrodynamic model involving cirrus with parameterized cloud microphysics and interacting solar and longwave radiative programs. Ramaswamy and Detwiler discussed optical properties of nonspherical particles and a physical model of cirrus clouds with prescribed atmospheric velocity. Ou and Liou presented a 2-dimensional climate model based on radiation and turbulence parameterizations and its dependence on cirrus clouds. The model includes relative humidity, surface albedo, and parameterized dynamic feedbacks. It was found that the existence of net heating by IR greenhouse effects or cooling by excess solar albedo by the cirrus depends on the magnitude of cirrus emissivity. The high latitudes are much more sensitive to the value of cirrus emissivity than are low latitudes. Wang and Kaplan discussed the role of cirrus on climate. In particular, some GCM sensitivity studies with a 10-day simulation were reported in which the effects of transparent or black cirrus to longwave radiation were investigated. The transparent treatment produces a cooler troposphere and warmer stratosphere.

The subsequent papers presented by Crane (Shine *et al.*), Short, Fouquart (Bonnel *et al.*), and Albrecht discussed, respectively, arctic cloud cover and its coupling to arctic ice cover; the IR parameterization, A+BT, as used in energy balance climate models; the NEPHOS program, intended to validate cloud models for GCM and to develop a cloud data set; and the relation of moist convection to cloud cover using the NCAR community climate model.

5. Clouds and climate (J. London, M. C. MacCracken, F. P. Bretherton, A. Arking)

The clouds and climate sessions were cosponsored by the AMS Climate Variations Committee and were organized by Jim Coakley of NCAR. The morning session included five invited and two contributed papers that covered aspects of cloud-climate interactions ranging from a review of cloud data bases to an investigation of the sensitivity of climate models to clouds.

Rossow *et al.* of the Goddard Institute of Space Studies (GISS)/NASA provided a review of cloud satellite data bases and their limitations as a basis for illustrating the need for the International Satellite Cloud Climatology Project (ISCCP). He identified three steps to follow in using satellite radiance data for cloud studies, namely: use detailed spectral data to derive cloud microphysical properties directly, study the sensitivity of model-calculated fluxes to various cloud inversion algorithms and microphysical parameters, and compare model-calculated broad-band fluxes with measurements. Rossow used global cloud distribution maps to report on one approach for following these steps in order to derive cloud cover, cloud top temperature (and altitude), and cloud optical thickness. The study found that relatively low global coverage of cirrus and deep convective clouds predominate in winter storms, with additional complexities making evaluation of possible feedback effects difficult to estimate.

Bretherton of NCAR reviewed the advantages and disadvantages of five basic approaches to inverting satellite radiance data for cloud properties. In his review he pointed out that it is necessary to rid the data of clouds so that an accurate profile can be created, derive summary data for comparison with GCMs, or just understand better what is going on. In undertaking these inversions, he reminded us, each algorithm depends on an underlying conceptual model, and so it is essential to carefully compare derived results with observations to assure consistency. The threshold technique (of assuming a pixel, which is either filled with clouds or cloud-free based on some criteria), is a widely used technique. However, when aggregating high-resolution estimates onto a GCM grid, very large errors may result. Tests of data for spatial coherence provide a second approach based on the assumption that all variations in the scene are due to variations in the fraction of cloud cover. A clustering technique then is used to distinguish cloud layer and surface temperatures. The third variant dealt with a multichannel, multifield-of-view approach that attempts to derive additional data about cloud properties. The fourth approach involved searching histograms of cloud albedo vs. cloud brightness temperature for clusters characteristic of particular cloud types. The fifth, and relatively new, approach was to use stereo views of the same cloud scene to determine optical properties. He warned that one should not be surprised when different retrievals give different results, and that these differences deserve careful attention. Bretherton offered hope by pointing out that multiple radiance sets and additional information in the data stream have yet to be used in estimating cloud fractions.

Hansen of GISS/NASA presented an analysis of the role of cloud feedback in determining climate sensitivity. By viewing feedback as an analog to electrical gain, he separated the effects of various feedbacks that led to a sensitivity of 4°C for the GISS GCM, to a doubling of CO_2 and a sensitivity of −4°C when the Climate: Long-Range Investigation, Mapping, and Prediction Project (CLIMAP) boundary conditions for 18 000 B.P. were imposed. He identified several positive cloud feedback mechanisms that profoundly affect the sensitivity of model climate experiments. Hansen pointed out the importance of this finding in estimating the time-dependent warming due to CO_2 because the effect of the ocean's heat capacity on delaying the warming is dependent on the magnitude of the sensitivity.

Randall of GLAS/NASA reported on attempts to simulate stratocumulus clouds in GCMs. Such clouds are important because of their effects on latent heat release, radiative fluxes, and air-sea exchange. Randall pointed out the particular need to consider the relationship of tubulence and stratocumulus prediction. The parameterization worked better in predicting winter stratocumulus off the east coast of the United States in winter than off the west coast in summer. Arctic stratocumulus also were not well represented. Incorporation of radiation flux interactions with predicted clouds in the present parameterization model is physically impossible, since the predicted liquid water content is too high. Cahalan of GLAS/NASA described cloud fluctuations on various space and time scales, pointing out that the diverse types of fluctuations would make searching for trends exceedingly difficult. He showed analyses of observations, down to the limits of satellite resolution (of about 100 m), which indicate that as one looks on finer and finer scales, the number of clouds continues to increase. Consequently, it is unlikely that any GCM grid cell is ever cloud-free.

Lau and Chan examined changes in cloudiness on the monthly and interannual time scales, attempting to determine if global-scale cloud anomaly patterns are comparable to global sea surface temperature (SST) anomaly patterns. Lau's analysis showed both monthly and interannual oscillations and an apparent longitudinal dipole oscillation across the central Pacific, indicating fluctuations in reasonable accord with other more usual measures of tropical oscillations. The final paper in the morning, by Minnis and Harrison, examined diurnal variations of cloud amount on an 8 km grid using visible and IR radiances from GOES for two several-week periods, using a hybrid, bispectral threshold method to distinguish low, middle, and high clouds. They pointed out that both diurnal and monthly variations in cloud amount and height should be included in cloud climatologies.

The afternoon session was notable for the recognition given to the effects of small-scale variability on satellite-based estimates of cloudiness. Of the 11 papers presented, seven were concerned primarily with methodology and four with the analysis and interpretation of observations. Four of the methodology papers were concerned specifically with extracting cloud cover parameters for situations recognized as difficult: semitransparent clouds, multilayered clouds, and nonfilling of the field of view (FOV).

Cloud retrieval algorithms based on Advanced Very High Resolution Radiometer (AVHRR) data were presented by Arking and Childs and by Desbois *et al.*, both using an approach combining visible-infrared histograms to classify cloud type with a microphysical model that takes into account fractional cloudiness within a pixel. Further developments along these lines may be anticipated. A paper by Wielecki, complimentary to that of Cahalan described previously, presented cloud size distributions from Land Monitoring Satellite (LANDSAT) data. Within the cloud populations examined (boundary layer cumulus), the number density of cloud elements increases down to the smallest detectable scales, and any inferences based on coarser resolution cannot presume that the clouds are plane-parallel and completely fill a pixel. Fortunately, it may be possible to extrapolate statistical structure downwards from larger scales. In discussion, it was suggested that, interesting though these fractional cloud cover effects may be, the cases discussed do not account for much of the total climatological cloud cover.

Cloud retrievals based on spatial coherence approaches were presented by Molnar, who described an ingenious technique for estimating cirrus when there are no solid or opaque clouds, and by Baldwin and Coakley, who described climatological features of stratus and stratocumulus over the Pacific ocean. Gordon was concerned with cloudiness retrievals in order to compare them with output from a GCM. Gordon basically summarized the visible and infrared radiances in terms that were model-dependent, but undistorted by the ambiguities in the conceptual models that underly other retrieval schemes. The emphasis was on consistency of the radiance fields with GCM, rather than on faithfully reproducing the real cloud populations. Warren *et al.*, on the other hand, described cloudiness statistics over the oceans, including frequency distributions for individual cloud types, based on routine reports from volunteer observers onboard ships. Of particular interest was evidence of 30-year trends in cloud cover, trends that were different over different ocean basins. Furthermore, a reduction in cumulus and an increase in stratus and stratocumulus over most ocean areas were shown from long-term trends. They expect to publish an atlas giving details during 1984.

The other methodology papers were presented by Bunting *et al.*, who discussed means of improving the cloud parameter extraction algorithms used in the Air Force RT-Nephanalysis (formerly called 3D-Nephanalysis), and by Stowe *et al.*, who showed an improvement in cloud cover estimates by adding measurements made at 380 nm to Nimbus 7 THIR data. The remaining papers, by Chen and Ohring, and by Smith, dealt with the interpretation and analysis of data involving clouds, as well as the sensitivity of radiation fluxes at the top of the atmosphere to cloud amounts.

6. Aerosols, radiation, and climate (J. J. DeLuisi, M. P. McCormick)

Twomey of the University of Arizona and Pollack of Ames/NASA each gave an invited paper in this session. Twomey's presentation described a three-part research program involving field measurements of cloud nucleus concentrations and particulate absorption, satellite-inferred global distribution of cloud optical thickness, and computations predicting resulting global reflectants for present-day and other levels of pollution. The conclusion was a positive planetary albedo sensitivity to pollution levels. An increase in cloud condensation nuclei would tend to increase the planetary albedo by modifying the droplet-size concentration.

The first part of Pollack's talk was concerned with the climatic implications of volcanic aerosols, polar stratospheric clouds, and arctic haze. On the basis of recent research on volcanic aerosol optical properties, it was found that volcanic aerosols are likely to cause a warming of the lower stratosphere and a cooling of the troposphere. For polar stratospheric clouds that are thought to consist mostly of ice crystals, the resulting radiative heating or cooling rates in the lower stratosphere will depend strongly on the temperature contrast between the altitude levels where they exist and the effective emitting level in the troposphere. However, arctic haze, a springtime phenomenon, appears to be relatively highly absorbing because of the high soot content. Absorption of solar radiation could affect the heat balance and might even affect the seasonal thawing of sea ice. For the remainder of his talk, Pollack introduced a new and provocative concept, namely, the climatic effects of tremendous amounts of crustal aerosols and aerosols from burning nuclear bomb targets lofted into the upper troposphere and lower stratosphere. Given specific scenarios, a drastic rapid cooling was predicted. The radiative properties of aerosols are still lacking in sufficient precision for climatic assessment. Pollack recommended more experiments aimed at satisfying these needs.

In a follow-up paper by MacCracken and Luther, the discussion concerned the climatic effects of the El Chichón eruption. MacCracken briefly described the radiative forcing included in a zonal, statistical-dynamic climate model to calculate the seasonal climatic response to El Chichón volcanic aerosols. He stressed the need for a more detailed time-dependent representation of the global characteristics of the El Chichón cloud to improve the precision of the model analysis. The second part of his talk was on the climatic consequences of an intensive nuclear bomb exchange between the U.S. and the U.S.S.R. The conclusions were similar to those of Pollack's presentation. It was acknowledged that large uncertainties exist in the atmosphere cleansing rate and aerosol loading feedback processes. In an attempt to study the effects of volcanic aerosols on the IR radiation budget, Charlock discussed relationships between the altitudes of the stratospheric aerosol cloud and the tropospheric cloud and the warming or cooling of the stratospheric cloud.

The following eight papers were concerned with the determination of El Chichón aerosols from remote measurements. DeLuisi and Dutton presented optically effective size distributions of El Chichón aerosols deduced from spectral extinction measurements made in December 1982 from the NASA-990 and indicated that the maximum particle concentration was within a radius of 0.2 μm. Schwedfeger *et al.* discussed aerosol optical depth measurements using AVHRR data and showed optical depth enhancements due to El Chichón. The AVHRR optical depth data was found to agree well with Mauna Loa optical depth measurements. In another satellite study, Bhartia *et al.* illustrated that two types of anomalous UV backscatter were observed with the Nimbus 7 SBUV instrument. Dutton and DeLuisi then presented a summary of stratospheric aerosol optical thickness observations made from surface-based and aircraft platforms. These measurements illustrated the spatial and optical inhomogeneity of the El Chichón cloud, and will be useful for climatic sensitivity studies. The other optical depth study was reported by Spinhirne and King, who discussed airborne photometer measurements of the spectral optical thickness of the El Chichón cloud. Coulson presented measurements of the degree of polarization. At Mauna Loa Observatory, dramatic changes in the degree of polarization of zenith skylight (λ = 700 nm) were observed. The angular distances of the Babinet and Arago points from the sun as a function of sun elevation were shown. To interpret Coulson's polarization measurements, King and Fraser carried out radiative transfer calculations using El Chichón stratospheric aerosol-size distributions deduced from Mauna Loa spectral optical depth measurements. These calculations compared very favorably with actual observations made at Mauna Loa. The final paper was presented by Ryznar and Baker, who discussed atmospheric solar irradiances and turbidity measurements in southeastern Michigan due to the presence of the El Chichón stratospheric aerosol cloud. In addition, in a poster paper, DeLuisi *et al.* showed lidar observations of the El Chichón aerosol cloud for 1982 and displayed time series isopleths of optical thickness increments and integrated optical depth vs. time.

7. Radiation budget (T. Vonder Haar, H. Jacobowitz, W. Wiscombe)

Vonder Haar of Colorado State University (CSU) began the session with a brief review of the availability of radiation budget data in the past and its prospect for the future. The first presentation in this session was an invited paper by Hartmann of the University of Washington, who discussed the relevance and importance of radiation budget data on various temporal and spatial scales to the understanding of the dynamics of climate variability and change. Subjects included in his presentation were regional energy budgets, interannual variability, and mean seasonal and nonseasonal variations. He pointed out the need for long homogeneous records of earth radiation budget (ERB) data with good spatial and temporal resolution, which are essential for testing and improving climate models and for trying to understand how the earth's climate varies.

Jacobowitz then presented the time-latitude cross sections for the outgoing longwave flux and albedo derived from the wide field-of-view (WFOV) channels of the Nimbus-7 satellite. Randel and Vonder Haar attempted to correlate a number of synoptic events with daily radiation budget results from the Nimbus-7 scanning radiometer. Wiegner discussed the radiation budget over the Sahara based on measurements from Meteosat and Nimbus-7 satellites. The next two papers, by Ohring *et al.* and by Wydick and Davis, discussed the accuracy of radiation budget components derived from Scanning Radiometer (SR) and AVHRR narrow channels on NOAA satellites. Ohring showed that a high correlation between the observed total flux and the observed radiance of the IR window exists in terms of their equivalent brightness temperatures; however, a positive bias of ~13 $W \cdot m^{-2}$ should be removed.

The influence of clouds on both regional and zonal earth radiation budgets was the subject of the paper by Harrison and Minnis. Measurements obtained from the GOES-East geosynchronous satellite for November 1978 showed the albedo effect was greater than the greenhouse effect, causing a decrease in the net radiation flux from the clear-sky value. It also was found that the change in the radiation balance was related closely to the amount of insolation and the vertical distribution of the clouds. The following paper, by Green, discussed the application of numerical filtering to medium- and wide-angle radiation measurements. It was shown that medium-angle observations yielded better estimates of the albedo than the wide-angle observations if errors in the bidirectional models were ignored. The next two papers, by Stuhlmann *et al.* and by Taylor *et al.*, were concerned with angular models of the reflection and emission. The first one, presented by Smith of Langley, showed that the experimentally derived bidirectional reflectance models from the Nimbus-7 ERB compared favorably with those derived from radiative transfer theory. Models derived from GOES data also compared well with the ERB models. Taylor presented the emission models derived from ERB and showed that limb-darkening increases from pole to equator and decreases with increases in cloud height.

The two papers, by Guptal *et al.* and by Staylor *et al.*, which followed, dealt with estimates of surface radiation parameters. These papers were concerned, respectively, with a parameterization of the downward longwave flux from operational satellite data in terms of the water vapor burden and the water vapor-weighted average temperature in the layer from the surface to 700 mb, and with how TIROS-N data were used to estimate the clear-sky insolation using a semiempirical modeling approach. Hickey *et al.* described the record of the total extraterrestrial solar irradiance from the Nimbus-7 ERB observations. It was shown that dips in the record of 0.2–0.4% for periods of a few days always corresponded to peaks in standard solar variability indicators. Also, a downward trend of 0.02% a year was present in the long-term data, and it seemed to lessen with time. The last paper of the session, presented by Baker-Blocker, was an examination of received ultraviolet radiation data for possible solar influences.

In addition, a number of papers were presented in the poster session. The analysis of Nimbus-7 ERB data was the theme of four of them: inflight calibration of the wide field-of-view radiometer, the derivation of solar reflectance angular models, the determination of interannual global and regional climatic changes of the radiation budget, and the spectral nature of the solar irradiance variability of its phase relationship to solar activity. Two papers described the variation of the outgoing longwave radiation; one was concerned with the zonal and hemispherical variability, while the other dealt with the diurnal variability. Another paper in the poster session presented the earth-radiation budget derived from the TIROS-N satellites.

Six papers were presented in the Radiation Budget (General) session held on the last day of the conference. Barkstrom emphasized the importance of viewing satellite experiment design as a systems problem in which all the elements that normally are treated separately—orbit selection, instrument design, sampling strategy, final data analysis, and so on—are optimized in unison in order to provide the maximum information with the least error. This can be done using techniques from information theory. Ruff and Gruber discussed the possibility and limitations of utilizing the presence of various types of earth surface and clouds from AVHRR. Pinker developed theoretical models aimed at inferring components of the surface radiation budget from satellites. While this obviously is a hopeless quest on a minute-by-minute basis, she was able to demonstrate considerable skill on a diurnal and monthly average basis. Because we have allowed our surface radiation network to erode (and even at its best, the coverage was poor), such techniques are going to be vital in the future.

The influence of desert dust layers on the tropical meteorology remains a subject of considerable interest. A French field experiment in Niger, led by Estournel, established that such dust may alter dramatically the nocturnal boundary layer. The dust counteracted the radiative cooling of the surface by causing 20–30 W/m^2 more downward longwave flux, and it augmented the radiative cooling higher up in the planetary boundary layer (PBL) by 2–3 K/day. Ackerman *et al.* made similar but more extensive analyses of the radiative situation over the Arabian Desert in connection with MONEX. They found a substantial shortwave effect of dust, but no discernable longwave effect. Among other things, they converted GOES measurements to broad-band radiation budget values, something that is becoming increasingly popular. The final paper, by Leaitch *et al.* and presented by Leighton, discussed the effects of large concentrations of pollutants on solar radiation transfer and the consequence of temperature structure near the surface, based on aircraft and surface observations together with radiative transfer calculations.

8. Radiative transfer and radiation measurements (M. D. King, J. A. Weinman)

The radiative transfer session began with a stimulating presentation by Davies on the relative contribution of water vapor and cloud droplets to the absorption of solar radiation by clouds. Davies made use of the distribution of photon path lengths for conservative scattering within a cloud layer, together with composite vapor-liquid transmission functions as a function of path length, to derive the spectral distribution of absorption due to water vapor above the cloud, water vapor within the cloud, and cloud droplets. Davies's paper was followed by two theoretical papers dealing with hypotheses to explain discrepancies between aircraft observations and theoretical computations of the absorption of solar radiation by clouds. Wiscombe demonstrated that the presence of a small number of very large droplets in the cloud droplet size distribution is sufficient to produce an increase in cloud absorptivity of 2–4%. Welch, who collaborated on the paper presented by Wiscombe, followed with an interesting paper suggesting yet another explanation for the apparent anomalous absorption by clouds. Welch suggested that inhomogeneities in cloud microphysics would contribute to reduced cloud reflectivity and increased cloud transmissivity, especially in the visible wavelength region. In particular, he cautioned cloud radiation experimenters to avoid neglecting cloud "spikes" in reflected and transmitted radiation along the flight path, for neglecting these regions in averaging cloud radiation measurements will lead to biased values of cloud absorption. The final cloud radiation paper, by Kuo and Vonder Haar, described the vertical distribution of upward and downward flux densities as measured within maritime stratocumulus clouds off the California coast. This paper, presented by Kuo, compared radiative transfer calculations with measurements of the vertical distribution of net flux. Ackerman of NASA/Ames presented a paper on an efficient method for determining absorption in spectral regions where absorption by atmospheric gases is highly structured and significant. He based his method on converting line-by-line absorption coefficients into a cumulative probability distribution of absorption coefficients. His application to the 9.6 μm band of O_3 was quite clear and of interest to many scientists in the audience. The final paper was given by Otterman, who discussed the effect of a thin scattering layer over the surface on the reduction of solar radiation.

In the radiation measurements session, Ridgway and Davies presented an analysis of a Monte Carlo model of the near-infrared reflectivity of clouds. They showed that the finite horizontal extent or the horizontal inhomogeneity and the gaseous absorption could mask the absorption effect of aerosols and that such absorption may easily be shown to be in excess of 10%. The paper by Kaufman *et al.* described measurements of radiances reflected from a coastline. Aerosol extinction coefficient and relative humidity profiles were measured along with upwelling radiances that were obtained from a model of the ocean color scanner instrument. A simplified radiative transfer model was utilized to compute radiances from the atmospheric data that could be compared to the observed adjacency effect. Nilson presented results from a comparison between the extinction coefficients of aerosols near the surface measured at 0.58 μm and those measured at several wavelengths in IR.

Broad-band spectral measurements of diffuse and direct fluxes were obtained at several solar zenith angles by Spencer and Stewart. Optical thickness of the atmosphere was observed and the effect of El Chichón's dust cloud was evident in the measurements. Shettle *et al.* presented a description of the dual-wavelength polar nephelometer that they fabricated. This apparatus enabled them to measure phase functions for $10° < \theta < 170°$ at 1.06 and 10.6 μm. The last paper of the session, by Volz, showed how information, such as the optical thickness of the El Chichón aerosol cloud, could be obtained from relatively inexpensive instrumentation. The effect of the volcanic aerosol on the measurements of the Arago and Babinet neutral points was discussed.

9. Solar energy applications (K. L. Coulson, P. Berdahl)

Four of the five presentations in the morning session were oriented toward the assessment of solar radiation as an energy resource, and the fifth was devoted to an evaluation of the accuracy requirements for solar radiation data in the design of solar systems. Thus, this session provided a good overview of the practical aspects of the use of solar radiation as a solar energy resource, and at the same time it complemented the more extensive later session.

In the derivation of a method of using data from the GOES meteorological satellite for estimating surface insolation for the United States, Mexico, and part of South America, Justus and Tarpley utilized 7200 coincident satellite images and observations from surface stations for algorithm development. The results obtained from satellite data alone yield root mean square errors of 16% for hourly insolation and about 10% for daily total insolation with respect to the surface measurements. An auxiliary study showed that for the single station of Atlanta, Ga., the National Weather Service daily insolation forecasts were in error by 24, 26, 28, and 30% for 24, 36, 48, and 60 h forecasts, respectively. Also in the area of measurement methods, Brunger *et al.* outlined an automated observation system for measuring four solar radiation components (direct radiation, global and diffuse radiation on a horizontal surface, and global radiation on an inclined surface), visual sky conditions by an all-sky camera, prevailing wind speed, and ambient temperature.

Direct assessment of the solar radiation resources was the subject of papers by Szwarc and by McDaniels and Vignola. From a network of 22 solar radiation stations in northeastern Colorado, Szwarc showed that air pollution in the Denver area decreased the global radiation on a horizontal surface by about 4%. He suggested that this value may be too low because of the spectral response characteristics of the solid-state detectors used in the measurements. The author, however, did not quantitatively evaluate the resulting bias in the measurements. From a 10-station solar network in the Pacific Northwest, McDaniels and Vignola developed a correlation model using the diffuse/global radiation ratio to deduce the direct radiation flux on a horizontal surface. An interesting feature brought out in the data is that the desert area of eastern Oregon compares favorably with the arid Southwest for solar electricity generation. The effects of errors in solar radiation data were evaluated by Grether *et al.* Using models of solar electric generation system performance, it was shown that for systems in which the fraction of energy to be supplied by solar sources (the solar fraction) is relatively small, the cost penalty for data errors is large. They suggested that although this error essentially is negligible for an individual installation, it might be important for a community with numerous solar electric generation systems.

The highlight of the afternoon session was the invited paper given by Hanson of Air Resources Laboratory/NOAA. He discussed the statistics of the variability of the solar energy resource on time scales of days, months, and years, observing that the most significant cause of this variability was cloud cover. He used a movie composed of satellite infrared cloud images to illustrate the dynamics of cloud motions. Berdahl of the University of California/Lawrence Berkeley Laboratory presented results from a program of spectral infrared sky radiation measurements that are applicable to the radiative cooling of buildings. Reviews of technological requirements for solar radiation data were presented for concentrating collectors by Vant-Hall, University of Houston, and for photovoltaic energy conversion by Hulstrom of the Solar Energy Research Institute (SERI).

10. Concluding remarks

Indeed, the invited and contributed papers presented in the conference represented the state of the art in the field of atmospheric radiation and its related disciplines. It should be pointed out that without the cooperation of the chairpersons and cochairpersons of each session and their physical insight into the scope and substance of these papers, this report would not have been possible.

Finally, it is quite evident from these papers that the physical principles of radiative transfer in the atmosphere and their engineering applications have now broadened and been integrated with the fundamental goal of solving climate and weather prediction problems in the atmospheric sciences and meteorology communities.

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