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FINAL REPORT

The Surface Radiation Budget and Cloud Climate Interactions as a Part of CERES

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Work that has been completed under NASA Grant number NAG11264 is described in the attached reprints and preprints, and summaries in terms of broad categories are given as follows.

The Relationship between Surface and Satellite Shortwave Radiative Fluxes

Considerable effort was devoted towards understanding the relationship between shortwave (SW) radiative fluxes measured at the surface by pyranometers, and at the top-of-the-atmosphere (TOA) by satellites as part of the Earth Radiation Budget Experiment (ERBE). The initial focus was upon understanding how CERES measurements could be used to infer the surface SW radiation budget. This was later expanded to investigate satellite cloud scene-identification algorithms for various underlying surfaces.

Cloud-Climate Interactions in Atmospheric General Circulation Models

To better understand cloud-climate interactions in atmospheric general circulation models, with the goal towards addressing cloud feedback, we compared seasonal changes in cloud-radiative forcing (CRF) at the top of the atmosphere from 18 atmospheric general circulation models and observations from the Earth Radiation Budget Experiment (ERBE). To enhance the CRF signal and suppress interannual variability, we consider only zonal-mean quantities for which the extreme months (January and July) have been differenced as well as differencing the Northern and Southern Hemispheres. Since seasonal variations of the shortwave component of cloud-radiative forcing are caused by both seasonal changes in cloudiness and in solar irradiance, the latter was removed. In the Earth Radiation Budget Experiment data, seasonal changes in cloud-radiative forcing are primarily driven by changes in cloud amount. The same conclusion applies to the general circulation models. The shortwave component of seasonal cloud-radiative forcing is a measure of changes in cloud amount at all altitudes, while the longwave component is more a measure of upper-level clouds. Thus, important insights into seasonal cloud-amount variations of the models have been obtained by comparing both components, as generated by the models, to the satellite data. For example, in ten of the eighteen models the seasonal oscillations of zonal cloud patterns extend too far poleward by one latitudinal grid.

Absorption of SW Radiation by Clouds

To investigate the absorption of shortwave radiation by clouds, we collocated satellite and surface measurements of shortwave radiation at several locations. Considerable effort was directed towards understanding and minimizing sampling errors caused by the satellite measurements being instantaneous and over a grid that is much larger than the field of view of an upward facing surface pyranometer. The collocated data indicate that clouds absorb considerably more shortwave radiation than is predicted by theoretical models. This is consistent with the finding, from both satellite and aircraft measurements, that observed clouds are darker than model clouds. In the limit of thick clouds, observed top-of-the-atmosphere albedos do not exceed a value of 0.7, whereas in models the maximum albedo can be 0.8. Interpretations were further made of aircraft measurements of shortwave radiation measurements that were obtained as part of the Atmospheric Radiation Measurements (ARM) Enhanced Shortwave Experiments (ARESE). These interpretations use the 500 nm (10 nm bandwidth) measurements to minimize sampling errors in the broadband measurements. It is indicated that the clouds present during this experiment absorb more shortwave radiation than predicted by clear skies and thus by theoretical models, that at least some ($\leq 20\%$) of this enhanced cloud absorption occurs at wavelengths less than 680 nm, and that the observed cloud absorption does not appear to be an artifact of sampling errors nor of instrument calibration errors.

Clear-Sky Atmospheres Shortwave Radiation

To address a recent issue of whether contemporary clear-sky shortwave radiative transfer models do or do not portray reality, we have collocated satellite measurements of reflected shortwave radiation at the top-of-the-atmosphere, made as part of the Earth Radiation Budget Experiment, with measurements of surface insolation made at 24 stations located throughout southern Canada. From this a clear-sky data set has been constructed by using both the satellite and the surface measurements to identify clear days, and the data set extends over a 4-year period (1985 through 1988). Two quite different types of shortwave radiative transfer models were employed, one a model-derived algorithm that converts the top-of the-atmosphere measurements to surface insolation, and the other a stand-alone column model which computes the surface insolation independently of the satellite measurements. Both models incorporate prescribed aerosols, and they were compared to the clear-sky data by using satellite-measured atmospheric water vapor as model input. The models are in excellent agreement with the clear-sky measurements when averaging is performed over all stations and over all seasons. The relative bias error in surface insolation is roughly 1% for both models, despite the fact that one model is constrained to the top-of-the-atmosphere measurements and the other is not. Thus the models' incorporation of tropospheric aerosols seems quite realistic when compared to the averaged data. For daily means and individual stations, however, the models' relative bias errors in surface insolation are observed to range from -6% to 10%, and it is demonstrated that this is caused by temporal and geographical variability in tropospheric aerosol loading. Because the models incorporate prescribed aerosols, they produce a relative bias error of roughly -6% for aerosol-free conditions. The opposite limit of 10% corresponds to aerosol loading in excess of that prescribed in the models. There is no evidence that the models incorrectly portray any important physical processes, and we find no support for a suggestion that there is an unknown and substantial source of shortwave absorption by water vapor. Our comparisons do not, however, rule out recently suggested minor absorbers of shortwave radiation. Also, since a very stringent clear-sky identification procedure was used with the goal of removing forest fire smoke as well as clouds, our study does not rule out possible atmospheric absorbers resulting from urban pollution.

Surface Shortwave Radiation Measurements

Motivated by the appearance of several recent studies that suggest significant deficiencies in our knowledge of atmospheric clear-sky shortwave radiation, we have performed some rather straightforward consistency tests on the types of data used to arrive at these conclusions. Specifically, the data consist of broadband measurements of shortwave irradiances to the surface (total, direct and diffuse) taken in Oklahoma. To place these data in perspective, we have also examined similar data taken at 8 stations located throughout Canada. With the exception of a single station, the Canadian data show no apparent inconsistencies. The Oklahoma data, on the other hand, exhibit some very troubling inconsistencies, suggesting that these data not be used for the purpose of testing atmospheric radiation models until these inconsistencies are either understood or rectified.

There are no inventions to report