Informal Final Report for Grant NAG 1 1263

Characterization of Clouds and the Anisotropy of Emitted and Reflected Radiances for the Purpose of Obtaining the Radiative Heating of the Atmosphere

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1. Introduction

The goal of the work supported through this grant was to assess the validity of the assumptions underlying the CERES strategy for determining radiative fluxes. Specifically, the work focused on the determination of scene type and the use of anisotropic factors to derive radiative fluxes from observed broadband radiances. The work revealed a dependence of the anisotropy of reflected and emitted broadband radiances on the spatial resolution of the observations that had been overlooked in the formulation of the CERES strategy. This dependence on spatial resolution coupled with errors in scene identification led to view zenith angle dependent biases in the ERBE derived radiative fluxes. Scene identification will be greatly improved in CERES thereby alleviating somewhat the biases arising from the dependence of the anisotropy of the radiances on spatial resolution.

Attention was then focused on the validity of plane-parallel radiative transfer theory which is relied on to characterize the scene types viewed by the CERES scanner. Again, viewing geometry dependent biases were found even for single-layered, overcast cloud systems. Such systems are taken to be the closest examples of plane-parallel clouds. At least some of the departures from plane-parallel behavior were evidently due to relatively small bumps on the tops

of extensive stratus layers. The bumps cannot be resolved in the imagery that will be used to characterize the scenes viewed by the CERES scanner. As part of this investigation, the ice sheets of Greenland and Antarctica were shown to provide radiometrically stable targets for determining the visible and near infrared calibrations of radiometers. These targets were used to calibrate the reflected sunlight at visible wavelengths used in this study.

Finally, the limitations of plane-parallel theory notwithstanding, the common practice of ignoring fractional cloud cover within the fields of view of imaging radiometers was shown to lead to biases in the retrieved cloud properties. The development of retrievals for pixel-scale cloud cover fraction is an attempt to reduce such biases. Work on these retrievals continues.

2. Anisotropy of Observed Radiances

The approach employed by CERES to obtain radiative fluxes is to first determine the physical properties of the scenes being viewed. The physical properties are associated with the angular dependence of reflected sunlight and emitted thermal radiation. The angular dependence is deduced from many observations made with as many viewing geometries as possible for scenes with like physical properties. Then for the scene being viewed, the angular dependence of the broadband radiances associated with the scene's physical properties is used to estimate the radiative fluxes from the observed broadband radiances.

The difficulty encountered with this approach is that the angular dependence, or anisotropy, is a nonlinear function of the physical properties. Since the physical properties vary on scales that are much smaller than those of the observing instruments, the relationship between the observed anisotropy and the physical properties is a function of the spatial scale of the observations. Evidence for this dependence was demonstrated by Ye and Coakley (1996a) using ERBE scanner observations. They showed that the anisotropy of reflected and emitted radiances for the four ocean scene types: clear, partly cloudy, mostly cloudy, and overcast, depended on the spatial resolution of the observations used to determine the anisotropy. As the spatial scale of the observations increased, sunlight reflected by scenes identified as being clear-sky became more strongly dependent on view zenith angle, i.e. more anisotropic, as the spatial scale of the scene increased. Ye and Coakley attributed this dependence to a decrease in the cloud contamination of the clear-sky scenes as the spatial scale of the scenes increased. In like manner, the anisotropy of radiances associated with overcast scenes should have decreased with increasing spatial scale, but Ye and Coakley demonstrated that for observations with fixed spatial scale, the frequency of overcast scenes obtained by ERBE grew from nadir to limb. This growth in frequency indicated that serious errors existed with the identification of the partly cloudy, mostly cloudy, and overcast cloud categories. As a result, no conclusions could be drawn for the anisotropy of the scenes for the three cloud categories. Ye and Coakley (1996b) developed a new scene identification scheme which, for observations with fixed spatial scale, kept the frequencies of scene type constant from nadir to limb. They derived anisotropic factors for the new identification scheme and demonstrated that the fluxes derived by ERBE had view zenith angle dependent biases. The biases arose from a combination of scene identification errors, the spatial scale dependence of the anisotropy, and the growth of the ERBE scanner field of view size from nadir to limb.

3. Validity of Plane-Parallel Radiative Transfer Theory

One approach to characterizing scene type is to use plane-parallel radiative transfer theory to derive cloud hydrometeor size, liquid/ice water amount, and cloud top altitude. Loeb and Coakley (1997 and 1998) used 4-km AVHRR observations of marine stratus to show that the optical depths derived for the stratus, which are as close to plane-parallel as nature provides, grow with increasing solar zenith angle and depend on view zenith angle, at least for sunlight reflected in the direction of forward scattering. The results indicate that the properties of clouds retrieved using plane-parallel theory have viewing geometry dependent biases. Loeb et al. (1998) went on to demonstrate that the view zenith angle dependence of the retrieved optical depths was consistent with the existence of subpixel scale (< 4 km) bumps on top of the stratus clouds. Thus, 3-D effects are evident even for flat, layered clouds.

As part of the investigation of plane-parallel theory, Loeb (1997) developed a new method for using Earth targets to calibrate the visible and near infrared observations of instruments like the AVHRR. He demonstrated that the permanent ice sheets of Greenland and Antarctica were radiometrically stable, and he developed models for the narrow-band reflectances of these ice sheets using observations from the NOAA-9 AVHRR, for which there was an independent radiometric calibration. Loeb used the ice sheets to calibrate the radiances used in the assessment of the plane-parallel radiative transfer model.

4. Retrievals of Cloud Properties

Owing to the complexity of 3-D radiative transfer calculations for realistic cloud systems, plane parallel radiative transfer theory, despite its shortcomings, will continue to be used to retrieve the physical properties of clouds. As pointed out by Coakley (1997), however, the common practice of applying the theory to the ~1-km scale observations available from imaging radiometers in the CERES time-frame will lead to gross biases in the retrieved cloud properties if allowance is not made for partial coverage within the imager's field of view. Work continues on developing a retrieval scheme that allows for fractional cloud cover within an imager's field of view. Hopefully, by accounting for the fractional cloud cover, biases in the retrieved properties will be reduced.

Publications from NAG 1 1263

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