4. RADIATION MODELING

4.1 INTRODUCTION

In guiding the discussions of the Working Group on Radiation Modeling, it was recognized that the possibilities and existing activity in the field of radiation modeling are extremely broad and that it would not be feasible to include them all for discussion in a brief period. Thus, it was decided that the scope of the discussions should be limited to those applications of radiation modeling that are directly pertinent to the ERBSS. It was noted also that because of the low resolution nature of the ERBSS measurements, both spectrally and spatially, there would be relatively limited utility of the ERBSS data for radiation modeling, but that, on the other hand, radiation modeling could be very useful in the analysis and interpretation of the ERBSS data. Thus, radiation modeling activities would play mainly a supporting role for the ERBSS. There will, of course, be aspects of ERBSS investigations which will be useful for radiation modeling studies (e.g., measurements of atmospheric or surface properties), but these are auxiliary to the main ERBSS mission.

The discussions in the working sessions were further concentrated mainly on the determination of fluxes of radiant energy at the "top of the atmosphere" from measurements of intensity in a given direction to be obtained from the scanning channels of the ERBSS radiometers. The radiation budgets on regional or planetary scales are determined by total radiant fluxes, and measurements of directional intensities are most useful for climatological studies as indicators of the total fluxes. In order to derive fluxes from individual intensity measurements, it is necessary to utilize an angular model of the hemispheric intensity distribution for the flux computations. Considerations of the effect of various surface and atmospheric parameters on the indicatrix describing the radiation field under different conditions constituted the core of the discussions of the Working Group.

Another major problem discussed by the Working Group concerned the requirements for data validation in the ERBSS. Experience on previous systems has shown that in spite of some progress in data validation efforts, serious problems persist in fulfilling the requirements of assuring that a given output from the measurement system can be interpreted to yield a unique and accurate representation of the radiation stream to which the sensor was subjected. The obvious utility of radiation modeling in the data validation problem accounts for the inclusion of the subject in the agenda for this Working Group.

In summary, the discussions of the Radiation Modeling Working Group were concentrated on modeling of atmospheric effects in solar and terrestrial radiation regimes, radiative effects of surfaces, and the problem of data validation. In addition, a small amount of attention was given to the effects of clouds, but it was agreed that a more thorough treatment of the cloud problem would be on the agenda of the Cloudiness and the Radiation Budget Working Group. The main points developed in the discussions of the Radiation Modeling Working Group are given here.

4.2 MODELING OF ATMOSPHERIC EFFECTS

As mentioned previously, the most important task of radiation modeling in conjunction with the ERBSS is that of converting satellite-observed intensity (or radiance) to the flux density (or irradiance), from which reflected and emitted radiant energy components can be defined. This conversion involves the development of theoretical or empirical angular models of the radiation field. The development of these indicatrices is a particularly difficult problem for the solar radiation regime.

4.2.1 Modeling in the Solar Radiation Regime

In modeling of atmospheric effects in the solar wavelength regime, the most important atmospheric constituents are aerosols, water vapor, carbon dioxide, and ozone. While it was recognized that cloud effects are dominant in many atmospheric radiation fields, the subject of clouds was left to be discussed in another working group. Carbon dioxide and ozone are most significant in the stratosphere, whereas water vapor effects are more nearly confined to the troposphere. Aerosol parameters of most importance for the modeling of aerosol effects are the size-frequency distribution, number concentration, and complex refractive index of the aerosol particles.

It is known that atmospheric aerosols have significant effects on the angular distribution of the intensity of solar radiation in the atmosphere, and are, therefore, of direct importance for the ERBSS. Unfortunately, data on aerosol characteristics in the atmosphere are still relatively sparse. Thus a comprehensive program of aerosol measurements should be initiated, the measurements to be concentrated on determinations of the large-scale variability of the aforementioned aerosol characteristics. These measurements should be accompanied by simultaneous measurements of the radiation indicatrices resulting from aerosol scattering.

It is not necessary to await improved data on aerosols and gaseous constituents of the atmosphere for the performance of a sensitivity analysis of atmospheric effects on intensity indicatrices at satellite altitude. Atmospheric models of assumed properties could suffice very well for the purpose. Such a sensitivity analysis is of particular importance in the case of the ERBSS, as it is thought likely that the indicatrices in the broad spectral ranges encompassed by radiometers on the ERBSS will be less sensitive to atmospheric effects than those in more restricted spectral ranges. This is not a certainty, however, and should be verified or refuted by model calculations. If such a simplification is found to be real, it will have obvious effects on the data analysis procedures of the ERBSS. If, on the other hand, such a simplification does not appear realistic, a recommendation *for increased efforts in atmospheric modeling and measurements would be justified.* In any case, the spectral sensitivity characteristics of the ERBSS instruments should be of prime consideration in these activities.

It is a fortunate circumstance that radiative transfer models adequate for determining intensity distributions for the ERBSS are well in hand. Computer programs based on different approaches to the radiative transfer problem have been developed by several research groups around the country, and the scientists involved with the research are certainly capable of performing the sensitivity analyses outlined above. The main requirement remaining for the task is that of providing improved data on the constituents of the real atmosphere. In this regard, the members of the Radiation Modeling Working Group unanimously *endorsed present and proposed efforts by NASA and other agencies in determinations of atmospheric properties, and particularly aerosol properties, of most value in radiation modeling.*

In many atmospheric modeling problems, the limitations inherent in the plane-parallel atmospheric assumption cause serious deficiencies in the final results. This, however, does not appear to be the case for the ERBSS. Only for the very low sun elevation situation existing in high latitude regions does the sphericity of the atmosphere assume significance in modeling calculations for the ERBSS, and for those cases a simple correction to the plane-parallel geometry should be sufficient.

Finally, a sustained effort should be made for deducing intensity indicatrices from satellite data before the launch of the ERBSS. Of particular importance for this purpose are the *measurements from the ERB experiments on NIMBUS-6 and NIMBUS-7, but other types of satellite data should be included where applicable.*

4.2.2 Modeling in the Terrestrial Radiation Regime

The angular distributions of longwave radiation are probably simpler than those of solar radiation and, therefore, easier to model. Because of the lack of essential azimuthal dependence in emitted radiation, the only significant angular dependence is that with respect to zenith or nadir angle. In addition, the effects of atmospheric aerosols are much less important at the longer wavelengths, and for many purposes may be neglected. Clouds, of course, are of dominating importance in both wavelength ranges, but their effects on intensity angular distribution appear to be less important in the longwave regime than at shorter wavelengths. Absorbing gases, principally water vapor, carbon dioxide, and ozone, play a very important role in the terrestrial radiation regime and probably have significant effects on the angular distribution of longwave radiant intensities. However, their overall effects on intensity indicatrices, particularly the effects of changing vertical profiles and the overlapping of bands, are not well determined and a sensitivity analysis applicable to the ERBSS should be performed.

One problem which was emphasized in discussions of this Working Group is that of the radiative properties of cirrus clouds. As an outcome of those discussions, the recommendations made were that: *(1) distributions of intensities over cirrus clouds in different wavelengths be measured by aircraft, (2) radiative transfer models for cirrus clouds be developed to supplement the aircraft measurements, and (3) a sensitivity analysis of the effects of the variability of cirrus clouds and uncertainties of their radiation indicatrices on final flux determinations be performed by the ERBSS configurations.*

4.2.3 Effects of Polarization for the ERBSS

The effects of polarization were discussed only in private meetings, so no consensus of the members of this Working Group on the problem was possible. However, all available evidence indicates that the effects of polarization on the indicatrices of both shortwave and longwave radiation in spectral bands of interest in the ERBSS are of minor significance, if not completely negligible. There probably are, however, polarization effects in the instrument systems of the ERBSS which have to be accounted for, but this subject was not germane to discussions of this Working Group.

4.3 MODELING OF SURFACE EFFECTS

In this case also, as in atmospheric effects, the important feature of the radiation field to be considered by modeling of surface effects is the intensity indicatrix at the top of the atmosphere. Surface reflection of solar radiation in cloud-free areas is probably more important for the ERBSS than for most other satellite sensors because of the great width of the spectral bands to which the ERBSS instruments are sensitive. The atmosphere is more transparent at some wavelengths than others, and the ERBSS responds to essentially all wavelengths.

As pointed out above, the inclusion of surface effects in radiation models can be handled well by existing methods if the surface properties are known. Unfortunately, this is not generally the case, particularly for the large areas encompassed by the field of view of the ERBSS instruments. There is comparatively little information on the reflection and emission properties of natural surfaces, including angular dependence, spectral dependence, and even total albedo for most surfaces. Even less information on the radiative properties of clouds is available.

The first recommendation developed in the discussions of surface effects is that *an analysis for determining the sensitivity of the intensity indicatrix at the top of the atmosphere to surface properties should be conducted.* Perhaps the effects are sufficiently minor that relatively gross characteristics of surface properties will suffice for purposes of the ERBSS. However, this is probably not the case in general. In the absence of definite information on the subject, the analysis should be used to evaluate the magnitude of the problem and should include all surfaces which are of climatological significance. The most important of these are bare sands and soils, vegetated areas, wind-roughened sea surface, snow and ice, and, of course, the different categories of clouds. It is thought likely that contours of terrain features may have significant effects which should be included.

The analysis will probably require an integrated theoretical study and measurement program. The data from the ERB experiments of NIMBUS-6 and NIMBUS-7 will be especially valuable for model verification, but measurements of surface properties at surface level or from low altitude aircraft would be very valuable in establishing a reasonable confidence level in the modeling results and improving the algorithms for flux calculations.

A second type of analysis will be required to establish the magnitude of surface effects in integrations over large areas of varying surface properties and time scales of weeks, months, or seasons. In this case, both atmospheric and cloud properties would have to be considered. Present models are not adequate to handle this larger problem and the required data are not available for it. Thus, the climatic scale analysis will demand a large and continuing effort encompassing both experimental and theoretical components. It was considered by this Working Group to be an extremely important activity for the ERBSS to pursue.

4.4 DATA VALIDATION REQUIREMENTS FOR THE ERBSS

There are two aspects to the data validation problem. First, it is necessary to obtain periodic checks of the calibration of the ERBSS shortwave scanning radiometer while the instrument is in orbit. It is assumed that a complete calibration will be obtained before launch, in which case checks of the calibration are the only requirement during the postlaunch period. The method of checking against an on-board diffuser plate is not considered sufficient for the purpose of data validation. The second task in data validation is that of assuring the validity of flux density determinations at the top of the atmosphere from intensity measurements at the satellite. This latter aspect, involving the validation of indicatrix algorithms, was considered to be beyond the scope of the charge of this Working Group.

There are at least six different methods of checking the response of the shortwave scanning channels while in orbit which will now be discussed.

1. Transfer of calibration constants from other satellite instruments, for which the response is known, to the ERBSS instrument, by comparisons of system output while the instruments are viewing the same scene from orbit. There are likely to be problems of spectral response and field of view matching between the instruments by this method.

2. Checking system output at the time the instrument is viewing a uniform area on the surface, for which reflective properties and illumination are known and atmospheric transfer functions can be computed. This method would probably require a ground station in a uniform desert area (such as in Australia or the Middle East) for providing radiative data at ground level.

3. Underflight measurements by properly instrumented aircraft. This is likely to be the most cost effective method if proper instrumentation is available.

4. Measurements from the shuttle. The highest accuracy of calibration checks could be obtained by this method, but scheduling and other operational problems tend to decrease its attractiveness for practical purposes.

5. Direct viewing of the Sun. Although the possibility of viewing the Sun directly by the scanning channels is not presently in the operational scheme, it should be considered for calibration checks on an infrequent basis. Obviously, some method of attenuating the beam or changing the gain of the channels would be required for accommodating the high intensities of the solar beam, but this should not present an insolvable problem. The necessary maneuvers of the spacecraft might be difficult but, because of the high accuracy attainable by the method, it should at least be considered.

6. Combinations of the above, or other methods not yet thought of.

At the present time, there is not enough information to make a final choice among the various methods. In order to resolve the problem, the Radiation Modeling Working Group made the following recommendations:

1. An error analysis of the accuracies attainable, as well as the operational constraints, in each of the methods should be performed. Parameters to be considered are relative spectral responses, fields of view, and simultaneity of measurements for interinstrument transfers, surface reflection and atmospheric corrections, effects of inhomogeneities of the radiation field for aircraft measurements, and any sources of error in measurements from the shuttle.

2. A cost analysis of each of the methods, or combinations of methods, should be performed. Tight budgets will undoubtedly demand that the methods finally selected should be cost effective.

3. The spare instrument system as nearly a duplicate of flight systems as possible should be made available on a continuing basis after launch for performing calibration checks of the instruments in orbit. Only by such a spare instrument can sufficient commonality of spectral and angular responses between calibration and operational instruments be ensured.

A final recommendation from this Working Group is *that a method should be developed for validating the data products which the ERBSS will yield. Such products are expected to be in the form of maps, tables, tapes, etc. Past experience indicates* *the need for a comprehensive data validation scheme to become operable as soon after launch as possible. The development of an adequate method should be considered early in the program.*

4.5 ADDITIONAL FINDINGS IN RADIATION MODELING

The following additional points were developed in the discussions of the Working Group on Radiation Modeling:

The data from a large number of experiments, both satellite and other types, are available now. Although certain of the data are not in a form conducive to modeling activities, many would be useful for development and verification of radiation models. *Every effort should be made to ensure the fullest utilization of data now existing, as well as those to be taken before launch of the ERBSS, for radiation modeling necessary to support the ERBSS program.*

In order to promote radiation modeling in support of the ERBSS, *teams of scientists interested in the subject should be established and properly supported for carrying out the necessary modeling research projects.* It is likely that the value of such modeling projects would be maximized by scheduling them early in the ERBSS program.

Data packages from various combinations of satellite (and perhaps other) experiments should be made available at moderate cost for use in modeling activities. Of particular value will be data taken simultaneously from instruments on a single spacecraft, but other types of data packages should be developed for special purposes as well. Information on the availability of such packages should be disseminated widely through the scientific community to ensure their maximum utilization.