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ROLE OF SCENE RADIATION MODELS IN REMOTE SENSING

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I. ABSTRACT

Scene radiation modeling will likely play an important part in total system simulation studies in the analysis of sensor and algorithm design tradeoffs for future satellite based information delivery systems. While the direct application of crop canopy reflectance models to crop inventory and monitoring may be limited, their indirect use, particularly when combined with well-structured experimental programs will lead to practical assessment techniques. Finally, scene radiation modeling provides a unifying perspective of electromagnetic interactions with terrain materials.

II. INTRODUCTION

Perhaps the most important role of scene radiation modeling in remote sensing is indicated by the juxtaposition of this presentation between that of Holmes, "Advanced Sensor Systems" and Nagy's "Advances in Information Extraction Techniques". In the 1980's and 1990's it is evident that technological advances will permit us to measure earth surface features at varying spatial, spectral, and temporal scales under a variety of sensor/source viewing geometries. These advances will also permit us to manipulate these measurements or combine them with other information sources in tractible fashions. The limiting factors during the next two decades or so for remote sensing, therefore, are not likely to be "how to implement an algorithm or build a sensor system" but rather "what to build or implement". The possibilities are virtually limitless; our intellectual and financial resources are more bounded. Common sense dictates that intelligent choices be made conditioned on both economic payback and on a means to investigate information attributes "extractable" from measured features. One tool for evaluating the efficacy of a proposed satellite information delivery system is the concept of a total system simulation. Our ability to perform such analyses will improve with iteration. Scene radiation modeling will form one component of such an overall simulation when linked with sensor and analysis modules.

A definitive way to preview the future role of scene radiation modeling in remote sensing is not known to the author. It is instructive, however to review the past two decades of remote sensing development. During the decade of the 1960's, scene radiation and atmospheric effects research gave strong support to the belief that satellite multispectral sensors could gather Earth scene radiance measurements that would provide, upon analysis, valuable information for crop inventory and monitoring. Concurrent machine data analysis research supported the belief that such analysis would be a most efficient means of providing such information.

The decade of the 1970's saw widespread experimentation with LANDSAT and TIROS data. Machine data analysis and information extraction techniques of the 1970's were based largely, however, on pattern recognition methods which ignore cause and effect in a giant step from gross ground truth descriptions or knowledgeable analyst estimations directly to satellite data labeling.

In truth, satellite sensor designs of the 1970's were based largely on a sparse data set of laboratory, field and aircraft multispectral observations. The success of these designs is indicated by the numerous application papers given in symposia such as the present one.

Nevertheless, the greater flexibility that technology offers us in the next two decades and the level of information desired indicates that "further advancement of remote sensing technology in both components and systems, hardware and software, and widespread user acceptance and adoption require increased understanding of the characteristics of scene radiation and atmospheric effect"[22].

III. VALUE OF MODELING

To obtain a perspective of the role of scene radiation models in remote sensing recall for a moment the airplane flight you probably took to reach W. Lafayette, Indiana, in my case, from Denver, Colorado. There were undoubtedly a kalidoscope of change scenes. Even concentrating on crops you probably observed changes in type, condition, planting densities, cultural practices, development stage and different soil types and underlying topography. Further, you were probably aware of changes in atmospheric state although the spatial and temporal variations relative to your observation scale could only generally be guessed.

To guide the development of analysis algorithms for LANDSAT in this situation, an extensive experimental program was implemented in conjunction with mathematical pattern recognition research. Canopy reflectance modeling played a minor role in these efforts although modeling was helpful in the interpretation of the tasselled cap transformation[15]. Similarly, canopy modeling is likely to be useful in relating Badhwar coefficients to crop biophysical attributes[2].

As we begin to ask questions about future sensor design tradeoffs including spectral regions, spatial and temporal sampling scales, and impact of directional considerations and, further, address the monitoring of other resource classes, reflectance modeling will more likely play a stronger role. Our manpower resources are simply too limited in order to perform all possible experiments without the use of models to bridge between them and to extrapolate results.

Another role of scene radiation modeling is the perspective and insight it can provide to the interpretation of the remote sensing problem. While the emphasis of this symposium is on crop inventory and monitoring, we are more generally interested in the monitoring of all resources. Strictly experimental programs focusing on crops or any one resource may well miss more general properties. Modeling approaches, per se, are more general; they become resource specific when the electromagnetic parameters are related to the media under study.

For example, consider three resource classes: vegetation, snow, and soil. The theoretical analysis of the reflectance from these classes has followed a similar pattern. In vegetation, first an abstraction of a canopy as a diffusing medium, using a Kubelka Munk type approximation was made[1]. Next attempts to relate the scattering coefficient to biophysical parameters occurred[24]. Monte Carlo methods[20] and finally more general radiative transfer calculations were performed[8,19].

A similar pattern is evident in the analysis of snow. First an abstraction of the snow layer as a diffusing medium[9]; then attempts to empirically relate scattering coefficients to snow density and grain size[4], Monte Carlo techniques[13], and finally more complete radiative transfer treatments[4,6,30]. Again, a similar pattern for soils is evident: Diffusing medium approximation[27], Monte Carlo10, and more general treatments[7,12].

An impetus for the development of soil models was the lunar exploration program. LANDSAT and TIROS spurred the development of snow models. LANDSAT has also been an impetus for vegetation modeling.

A detailed comparison of the treatment of these three resource categories is instructive not only in their similarities but also their differences. For example, the fact that snow and soil generally correspond to optically thick media leads to simpler approximation formula for parameter estimation. In general, more complex relationships are required for vegetation.

IV. STATUS OF CROP REFLECTANCE MODELS

The status of canopy reflectance modeling may be summarized as follows:

1. Radiative transfer theory appears applicable to the canopy reflectance problem. Fundamentally, this means that characterization of the canopy medium in terms of such constructs as leaf facets leads to a self-consistent interpretation of overall reflectance.

2. The plane-parallel canopy case is well-studied.

A variety of computational procedures have been implemented by various investigators. Allen, et al[1], Park and Deering16, and Suits[21] used a Duntley differential equation approach. Ross and Nilson[19] employed first order scattering theory, Weinman and Guetter[28] used the method of discrete ordinates, Cooper et al[8] the adding method and Smith and Oliver the Monte Carlo technique[20]. It should be noted, however, that there is a major dichotomy in the abstraction of a plant canopy in terms of whether or not the complete leaf slope distribution is required in order to calculate the electromagnetic parameters.

3. An operational interpretation of the plane-parallel canopy case does not exist.

Pragmatically, this means that limited testing and intercomparison of the models have been performed. The models have not been applied to a wide spectrum of canopy cover and conditions. The model predictions typically differ between

0 and 70 percent from one another and with field measurements.

4. Few complete experimental determinations have been made for modeling applications.

Unfortunately, the greatest uncertainty in model predictions occurs in data sparse regions, e.g. off nadir sun and view angles.

5. Multi-dimenstional models are being developed.

Two fundamental approaches to row crop modeling are being pursued. The earliest models employ primarily geometric optics. That is, geometric form factors for the rows and an analysis of shadowing play a dominant part. Multiple scattering is ignored. Richardson, et al[18], Jackson[14], Egbert [11], and Strahler 23 are examples. Extensions of this approch which combine geometric optics analysis for interactions between rows but still incorporate multiple scattering within rows are being studied by several authors. Norman and Welles [29] and Kimes (personal communication) have attacked the problem from first principles. Bunnik[26], and Suits [25] have investigated the extension of the Suits model.

From the discussion above it is evident tha- as we enter the decades of the 1980's and 1990's that reasonable theoretical approaches, at least, for the plane parallel case are available. There are certainly several conceptual and pragmatic questions still to be addressed in the comparison of these approaches, but at least the broad outline is clear. The next three to five years will likely see a similar pattern appear in the development of multi-dimensional models which are now underway. The fruition of these efforts will be helpful in the analysis of SPOT, TM and possibly MLA type sensor data and in the combination of multi-sensor data.

In the near future, a major issue is likely to be how to acquire the parameters required to run the models and, conversely, how to use the models to infer parameters. While this discussion has been limited to reflectance modeling, it should also be noted that a major opportunity exists for comparison of modeling approaches accross the optical and microwave regime and this is likely to also be an issue in the next few years.

V. SUMMARY

Scene radiation modeling should assume increasing proimance in both applied and basic remote sensing studies. At a fundamental level the study of electromagnetic radiation interactions, from a remote sensing perspective, is an intriging problem. The treatment of multidimensional canopies is just beginning but is expected to have relevance to the "mixed pixel" problem which has been evident in LANDSAT studies and which will be present in TM and SPOT observations.

The evaluation of crop reflectance models requires a symbiotic relationship with field studies. It is also possible that estimation of spatially distributed and highly variable biophysical crop attributes may more easily be inferred by indirect inferrence, through models, rather then by direct measurement.

An important role for scene radiation modeling will be to generate simulated data sets useful for sensor design and information extraction studies using both user-directed deterministic parameter variations and estimated realistic parameter distributions occuring for application areas of interest.

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