A FAST TANGENT-LINEAR FORWARD RADIATIVE TRANSFER MODEL FOR MICROWAVE RADIANCE ASSIMILATION

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Microwave radiometric data from satellite- and ground-based sensors is an extremely valuable source of information for weather prediction systems. Of importance in the use of microwave radiances is the numerical solution of the radiative transfer equation which governs the response of the sensor to changes in cloud content, rain rate, surface conditions, etc. [1]. Statistically optimal radiance assimilation requires, among other components, fast calculation of the incremental response functions for various environmental parameters [e.g., 2,3]. Currently, the fraction of data from polar orbiting microwave sensors that can be assimilated into numerical weather models remains limited due to an inability to compute these incremental functions over heavy clouds and precipitation. In such environments the radiative transfer equation includes a scattering term which complicates the solution. The use of the satellite data in steering the state of the numerical weather model through direct radiance assimilation is thus hindered by the lack of a means to rapidly compute small changes in the model state associated with microwave radiance variations.

This study addresses the problem of efficient numerical calculation of the incremental brightness temperature profiles for a layered scattering atmosphere. The form of the radiative transfer equation considered accounts for both absorption by gases and absorption and scattering by hydrometeors. The atmosphere is represented as a stack of horizontal layers with constant properties within each layer. To obtain a numerically stable solution of the problem the “adding layer” procedure using discrete ordinate angles is used. In this approach a stack of layers is characterized by a reflectance operator describing reflection of the external radiation incident on the stack from above and self-radiation of the stack. Recursion relations are developed for calculating these values. This scheme generally requires only matrix multiplications along with inversion of well-conditioned matrices.

A non-trivial aspect of this procedure is stable calculation of the reflectance and transmittance operators for both highly scattering and nearly-transparent individual layers. In general this task requires the calculation of exponential matrix functions which are carried out in a diagonal representation of appropriate operators. These operators are represented as the product of a pair of symmetric matrices, one of which is positive definite. Accordingly, the diagonalization involves only symmetric matrices for which standard numerical procedures exist. Even still, direct application of the appropriate explicit analytic expressions for the reflectance and transmittance operators of individual layer requires inversion of a particular ill-conditioned matrix. To be able to accomplish this we have performed an analytic factorization of the matrix to be inverted first. Using the factored matrix the inversion no longer results in numerical divergences.

Since the solution of the direct problem is represented in the form of explicit recurrent relations, differentiation of the solution with respect to any governing geophysical parameter is straightforward. Thus, the Jacobian of the transformation between geophysical parameters and radiances can be efficiently and precisely computed. Initial tests yield calculation times for an atmospheric model consisting of fifty layers in less then five seconds on a standard 500 MHz PC. Concrete numerical examples illustrating the work of the appropriate algorithm (realized in FORTRAN-90 code) will be presented. The present version of the algorithm neglects coupling between polarizations, however generalization of the approach to incorporate polarization effects is straightforward.

REFERENCES

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