Introduction

One of the most fundamental and crucial quantities for accurate precipitation retrieval is the single-scattering property (SSP) of each individual hydrometeor in the precipitating volume. Thus, an important step in minimizing retrieval uncertainty is to ensure that the particles used for single-scattering calculations resemble those that occur in nature, allowing the SSPs to be computed precisely with numerical techniques.

Hydrometeors with rotational symmetry (axial symmetry) are most efficiently computed using the T-Matrix methods. For hydrometeors with a uniform dielectric, the Extended Boundary Condition Method (EBCM) is the most efficient. However, for mixed-phase hydrometeors with non-uniform dielectrics EBCM is not applicable. In these cases, we can use the Invariant Imbedded T-Matrix (IITM), which we developed for this purpose. It is also noted that hydrometeors with more extreme aspect ratios can be computed with IITM than EBCM and that such hydrometeors are found in precipitating systems. For hydrometeors without any rotational symmetry, however, volume integral methods like Discrete Dipole Approximation (DDA) and the Method of Moments (MoM) must be employed.

Algorithm Flow-Chart for SSPs

Angular Quadrature — Gauss-Legendre

1. Surface discontinuity leads to significant numerical error.
2. Integration must be broken up: \( I = \int_{S_1} \int_{S_2} \)
3. Gauss-quadrature dominates the run time.
4. Functions are cached for each shell to speed up performance.

Numerical Convergence / Precision

Block Structure/Parallelism

Rotational symmetry decouples “m”

Mixed-Phase Hydrometeor Spheroids

To test and study the behavior of our IITM implementation, we study spheroids with an outer shell of melt water. We consider a solid ice core as well as “fluffy” mixed air-ice cores with densities 0.1, 0.2, and 0.3 g/cm\(^3\). Numerical calculations are carried for both prolates and oblates with a semi-minor to semi-major ratio equal to 1/2(2) for frequencies 13.6 GHz, 35.6 GHz, and 94 GHz. The corresponding size parameters are \( -0.25, -0.64, \) and 1.7.

Irregular Hydrometeors

T-Matrix methods are computationally more efficient than Discrete Dipole Approximations (DDAs) for scattering targets that possess a high degree of symmetry. For the case of spheroids shown, it only takes a few minutes on 32 cores to compute the orientation averaged scattering properties. The reason for this is that the T-Matrix becomes sparse and structured, reducing the problem size significantly. Irregular particles incur a substantially larger cost as the maximum allowed angular momentum, \( l_{\text{max}} \), increases, since the block diagonal structure is lost. Specifically, the computational cost for axial and no symmetry:

Conclusions

An efficient C++ parallel IITM code has been developed. This code accurately computes SSPs of non-uniform hydrometeors with rotational symmetry. The code parallelizes by taking advantage of the block structure induced by rotational symmetry about the axis by distributing blocks among MPI processes. Long double precisions was required to achieve satisfactory accuracy. This IITM code will allow the efficient computation of mixed-phase rotationally-symmetric hydrometeors necessary for modeling precipitating systems.

It is challenging to use T-Matrix Methods for irregular hydrometeors, and it is not clear that numerical precision and compute constraints will allow accurate SSPs to be computed using this method. Currently, DDA approaches are employed.

References


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