Manual for the 2013 computations

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June 26th, 2014

1 Content of the database

This database includes results of scattering computations for dry and pristine single ice crystals and their aggregates at microwave frequencies between 3 GHz (S band) and 220 GHz (G band). The particles are oriented according to the maximum moment of inertia mimicking actual freefall. All particles have their orientation fixed for the scattering computations, which means that the scattering properties have not been averaged in any way and therefore include all phase-related features of the incident and scattered wave. I recommend averaging over the random samples and orientations, when using these particle properties.

2 Use of the database

I provide this database 'as is' and freely to use and experiment. If the results are used in a scientific paper, the only thing I ask is to refer to our paper (*Tyynelä et al.* (2013)), which introduces the computations.

Any bug reports or questions about database can be emailed to janityynela(at)gmail.com.

3 Data structure

The data arrays in the database have been produced with Matlab and the output format is NetCDF (version 4.1.3). There are individual NetCDF files for each frequency band, each snowflake type, and each type of property. For the frequency, possible values are: `'003'` (3 GHz), `'014'`(14 GHz), `'036'` (36 GHz), `'060'` (60 GHz), `'090'` (90 GHz), `'120'` (120 GHz), `'150'` (150.0 GHz), `'180'` (180 GHz), and `'220'` (220.0 GHz). For the snow types, values are: `'hexcolum'` (hexagonal column), `'hexplate'` (thin hexagonal plate), `'hexplate2'` (thick hexagonal plate), `'steldend'` (stellar dendrite), and `'rosette6'` (six-bullet rosette). For the particle properties, values are `'cross'` (cross sections), `'phys'` (physical properties), and `'phase'` (phase function).

The naming format of the files is:

```
[author name and year] _ [creation date] _ [particle property] _ [frequency] _ [snow type].nc
```

3.1 Cross sections

For the cross sectional data, we have `'chh'` and `'cvv'` as the linearly co-polarized horizontal and vertical backscattering cross sections, respectively, `'cvh'` as the linearly cross-polarized backscattering cross section, `'csca'`, `'cabs'`, and `'cext'` as the total scattering, absorption, and extinction cross sections for unpolarized incident wave, respectively, `'ssa'` as the single-scattering albedo, and `'asym'` as the asymmetry parameter for unpolarized incident wave. The units are square meters m^2 for all cross sections. Single-scattering albedo and asymmetry parameter are dimensionless.

The dimensions of the arrays are the number of ice crystals `'ncr'`, the number of sample particles `'nsmpl'`, and number of azimuthal orientations `'nori'`.

3.2 Physical properties

For the physical properties, we have `'ncryst'` as the number of crystals in the aggregates, `'ndip'` as the number of dipoles, `'dmax'` as the maximum diameter in units of meters m, `'area'` as the geometric cross section in units of square meters m^2, `'ar'` as the aspect ratio, `'mass'` as the mass in units of kilograms kg, and `'round'` as the roundness.

The dimension of the arrays are the number of ice crystals `'ncr'`, and the number of sample particles `'nsmpl'`.

3.3 Phase functions

The phase functions are stored as `'phase'`. The dimension of the arrays are the number of ice crystals `'ncr'`, the number of sample particles `'nsmpl'`, the number of azimuthal orientations `'nori'`, and the number scattering angles `'nang'`. The number of scattering angles is 181 in 1 degree intervals between 0 and 180.

Note that the phase function p is normalized as

$$\int_0^{\pi} \int_0^{2\pi} p(\theta, \phi) sin(\theta) d\theta d\phi = 1, \tag{1}$$

where θ is the scattering angle and ϕ the azimuth angle. For an unpolarized incident wave, $p = P_{11}/(\sigma_{\text{sca}} k^2)$, where P_{11} is an element in the scattering matrix, σ_{sca} the scattering cross section, and k the wavenumber of the incident wave.

Due to the fixed orientation for each sample particle, the ADDA program outputs the scattering matrices between 0 and 360 degrees for the scattering angle. However, since the phase function is defined only between 0 and 180 degrees for the scattering angle, I have averaged over these two hemispheres.

4 Modeling

4.1 Shape modeling

There are five single crystal types: hexagonal column, thin hexagonal plate, thick hexagonal plate, stellar dendrite, and six-bullet rosette. The thickness-to-diameter and length-to-diameter ratio is fixed at 100 for both the stellar dendrites and the thin hexagonal plates and at 10 for the thick hexagonal plates, while the length-to-thickness ratio is fixed at 10 for the hexagonal columns. These values correspond to the more extreme cases reported by *Takahashi et al.* (1991), but are used to get the maximum variability between shapes. For the bullet rosettes, I use symmetric six-bullet rosettes with the shapes of individual bullets adopted from *Um and McFarquhar* (2007).

For the dendrites, I use the crystal growth algorithm by *Reiter* (2005). It is based on a 2-D cellular automaton using two parameters that control the amount of water available for the cells both locally and globally.

For the a use the physically-based aggregation model by *Westbrook* (2004). It mimics the aggregation process in a stochastic way by iteratively determining the probability of collision between randomly chosen ice crystals, which depends on the size and fall speed of the candidates. Due to the lack of observations, I assume random orientation and a narrow Gaussian size distribution for the ice crystals in an aggregate because of the complex flow around the snowflakes. The ice crystals are attached without overlapping to their nearest neighbour. For the number of crystals in each aggregate we use 1, 2, 10, and 100.

The size of the individual ice crystals vary according to the exponential probability density function *Mitchell* (1991). The diameter is truncated at 0.5 mm in the lower end and at 2.0 mm at the higher end. The average diameter of the ice crystals is fixed to 1 mm.

4.2 Scattering modeling

The scattering properties are computed using the discrete-dipole approximation (DDA), which is a method where the particle is divided into small volume elements (dipoles) that are placed into a regular cubic lattice (*Purcell and Pennypacker* (1973)). This allows a high degree of detail in the particle shape,

which can be controlled by the number of volume elements used in the shape model. The accuracy of DDA is determined both by the number of dipoles and the dipole spacing kd relative to the wavelength (k is the wavenumber of the incident wave). It is usually required that $|m|kd < 1.0$, where m is the refractive index of the material (*Draine* (2000)). In the computations, $|m|kd$ is 0.4 at maximum for all shapes and frequencies. The refractive index of solid ice is taken from *Jiang and Wu* (2004). The ADDA program by *Yurkin et al.* (2011) is used to compute all the scattering properties in this database.

I have generated 50 random ice crystals for each aggregate and snow type and 5 uniformly distributed azimuthal orientations. The total number of different snowflakes used in the computations is therefore 5000.

References

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