Simulations of the Optical Properties of Dirty Snow

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Abstract

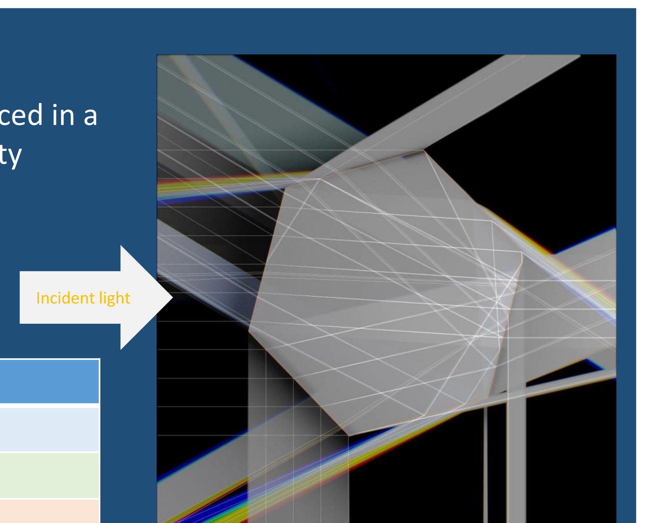
We present simulation results on backscattered, transmitted, and absorbed intensity of shortwave radiation by a dirty snow layer. A two-dimensional geometric ray-tracing algorithm was developed to study the scattering of light in a snow layer. The snow model is comprised of randomized cross-sections of plate and column ice crystals. Periodic boundary conditions allow for a large horizontal extension of the snow layer. Incident light is subject to reflection, refraction, and absorption in those particles. Each incident ray is traced until it either leaves one of the surfaces or has decreased in intensity below a threshold. We present our findings on the influence of light-absorbing particles (LAPs) in various depths and densities on the reflection and transmission properties of the snow layer.

Cross sections of hexagonal prisms include triangles, squares, pentagons, and hexagons. When generating the snow layer, these shapes were randomly chosen, rotated, stretched, and placed as to emulate an experimentally observed particle density and packing of snow. The system contains between 200 and 500 ice particles with periodic boundary conditions, corresponding to a depth between 20 and 50 monolayers of ice particles between top and bottom surface of the model. Three wavelength-dependent indices of light were considered allowing some degree of spectral resolution in the scattering processes. The backscattered, transmitted, and absorbed intensities were collected for an assessment of the radiative behavior of the snow layer. One of the questions of interest targeted the influence of using geometrically realistic shapes versus spherical particles in such a simulation. We present a comparison of the two types of snow systems. To track how LAP's depth and density impact albedo, the snowpack was divided into ten layers with varying depth and number of LAPs.

Optical Ray-Tracing

Based on laws of refraction and reflection, light rays are traced in a two-dimensional model. Fresnel coefficients govern intensity changes at surface points, resolved by red, blue, and green channels.

Program: Caustic (S. Boyd and J. Stagg)



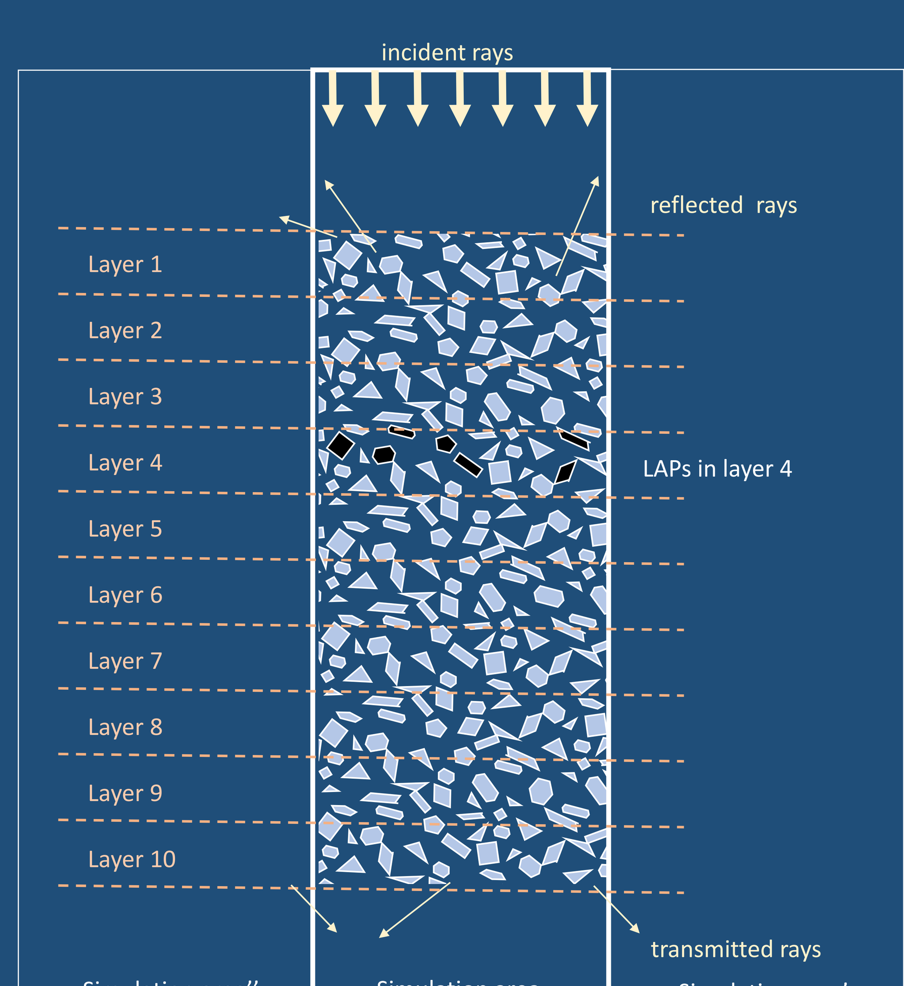
Refractice indices	Air	Ice
400 nm (B)	1.000283	1.3194
550 nm (G)	1.000278	1.3110
700 nm (R)	1.000276	1.3069

Simulation Parameters/Limitations

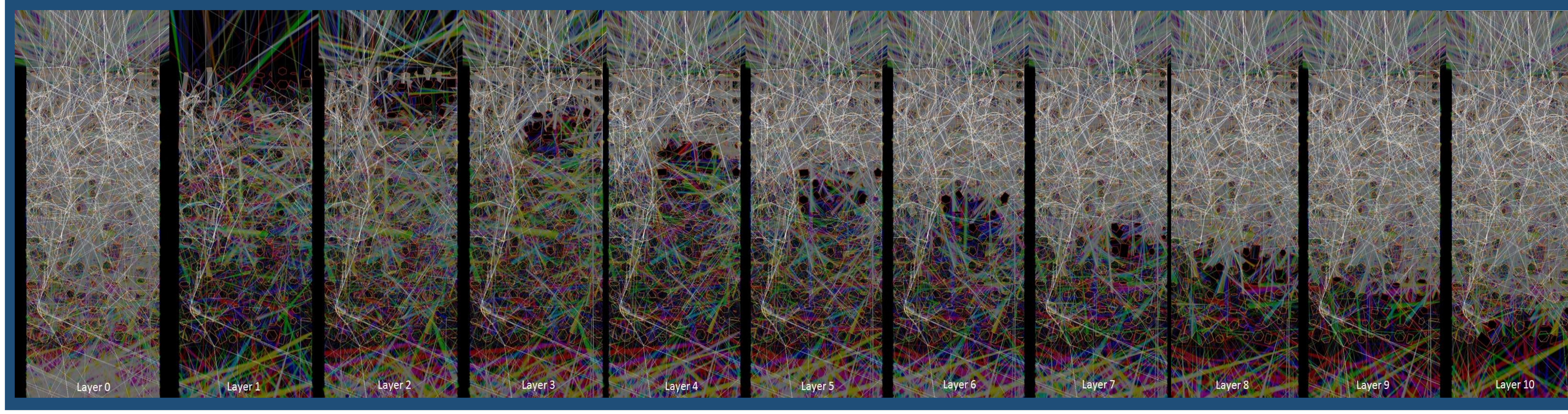
- The number of rays in incoming is confined to the number of pixels in the image, typically 2800 rays.
- Ray segments are ignored once intensity dips below 1/255 of incident intensity.
- Periodic boundary conditions in one dimension are applied.

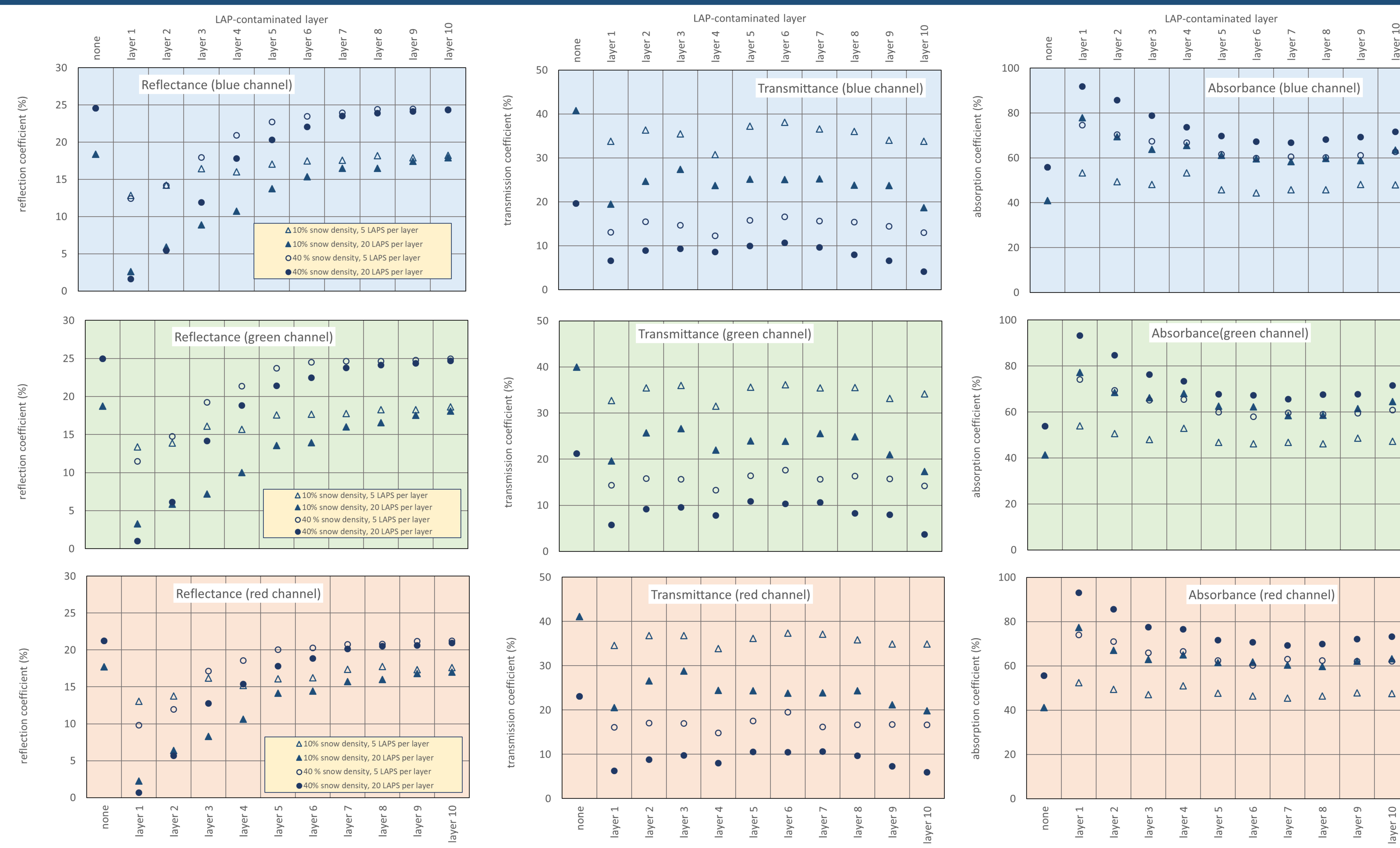
Snowpack Modelling

- Cross sections of hexagonal prisms include triangles, squares, pentagons, and hexagons.
- Shapes were randomly chosen, rotated, stretched, and placed as to emulate an experimentally observed particle density and packing of snow.
- The system contains between 200 and 500 ice particles with periodic boundary conditions, corresponding to a depth between 20 and 50 monolayers of ice particles between top and bottom surface of the model.
- Snowpack density was varied between 5% and 25% areal ice density.
- Light-absorbing particles (LAPs) are perfect absorbers., and placed at varying depths.
- Rays that leave the top layer after scattering were counted as reflected; rays leaving the bottom layer as transmitted.
- Rays leaving the side of the simulation cell re-enter at the opposing side.



Light scattering in snow containing light-absorbing particles (LAPs)





Conclusions

- The ray-tracing program caustic has modified to simulate light scattering in a layer of snow, under inclusion of absorbing particles (LAPs)
- The snowpack was simulated with randomly generated cross-sectional areas of hexagonal prisms.
- We varied the snowpack density, the number of LAPs, and the depth of the LAPs below the top surface, for the case of normal incidence.
- The reflectance of the snow layer is only affected if the LAPs reside in the top four monolayers. Any deeper, and the reflectance resembles clean snow.
- The transmittance is reduced by about 40% due to LAPs, independent on depth.
- Overall, LAPs do not significantly change the reflectance, but block transmitted light from reaching deeper layers.

References

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