Responses to Reviewer RC1

The authors provide a very comprehensive description of TARTES model, which serves as a very good technical documentation for the model. They also compared the TARTES model results with a few other widely-used snow radiative transfer models (AART, DISORT-Mie, SNICAR-ADv3), which generally show reasonable agreement (within 0.02 for snow albedo). Overall, the manuscript is well written. I have a few minor comments for the authors to address.

We thank the reviewer for the supportive comment. We have taken into account all the detailed corrections listed below, almost as proposed.

Minor comments:

1. It is not clear what the specific improvements in TARTES version 2 are compared to version 1, which needs to be clarified.

We propose to add a paragraph describing the scientific and the coding changes between version 2 and the previous version.

"Compared to the previous version, TARTES v2.0 proposes several options to compute diffuse radiation and to compute the semi-infinite layer albedo that appears in the two-stream equation. The default values for the grain shape parameters are changed based on recent advances (Robledano et al., 2023) and likewise for the black carbon properties to match SNICAR-ADv3.
The code has also been improved with the factorization of the impurities calculations (all types are now using MAE, either tabulated or calculated from the refractive index), type hinting, automatic strict formatting, modern packaging, and continuous integration for automatic publication on PyPI. The documentation has been improved and the conformity between the equations presented in this paper and the code carefully checked. In addition the SnowTARTES web application has been enhanced to calculate the irradiance profile."

2. It would be good to also summarize/discuss some underlying assumptions that may limit the TARTES model applications or the cautions users need to take when applying the model.

We propose to add more limitations in the dedicated paragraph of the discussion:

"Despite this advantage, TARTES presents some limitations owing to its simplicity. **It uses the conventional un-polarized radiative transfer, neglecting interferences, near-field and packing effects, as well as polarization effects. As a plane parallel model, the surface is supposed to be perfectly flat, surface roughness is neglected, which may impact simulations on rough terrain, especially at grazing angles. Likewise, the layers are perfectly smooth and horizontally semi-infinite. In practice, in areas where horizontal heterogeneity is strong, for instance as a result of snowdrift, this assumption might be inappropriate to simulate snow optical properties. Also, TARTES only considers snow excluding any other material that might be present in the snowpack, and models its optical behavior as a homogeneous scattering medium. It means that**

the layers must be much thicker than the grain size (i.e. the free photon path). Regarding impurities, only their absorption is considered, and they are randomly distributed. Consistent with the choice of only using the asymmetry factor g instead of requiring the full phase function, the two-stream approximation was selected to solve the radiative transfer equation in TARTES instead of a multi-stream approach as in DISORT-based models. As a direct consequence, TARTES can not calculate the bi-directional reflectance (BRDF) which is essential for instance for satellite remote sensing applications. TARTES was initially designed for energy balance computations and only provides hemispherically averaged quantities, namely surface albedo, absorption in each layer, and profiles of upwelling and downwelling radiation flux."

3. Lines 53-78: These widely-used snow albedo/radiative transfer models have been reviewed and described in details in He and Flanner (2020; https://doi.org/10.1007/978-3-030-38696-2_3), which would be a resource to mention and refer the interested readers to.

We propose to add the reference. Note however that this resource is under a paywall for us.

4. Equation (4): please introduce the delta function and F0 variable.

The definitions will be added: "where F_0 is the intensity of the solar beam at the surface and δ the Dirac function"

5. It would be good to have a table listing all the input and output variables (with units) for TARTES.

The table with symbols (used in the text), parameter names, description and unit will be added.

6. Equations (36-37): please give the mathematical expressions of "A" and "B".

They are unknowns to be determined from the boundary conditions later. We propose to add "where A and B are unknowns that will be determined according to the boundary conditions."

7. Line 244: "… we incorporate the exponential terms in the vector X". This sentence is not very clear to me.

The sentence is indeed not clear, we propose to remove it as the explicit expression for X, M and V are sufficient.

8. Equations (53-55): It seems that B is not included in these equations, which however should be, right?

The expression of X had indeed an error, it will be corrected by including B.

9. Line 300: For the negative albedo case, did the authors also reset other relevant quantities (e.g., internal light absorption energy, actinic flux, etc.)? If so, reset to what values?

We propose to add the following sentence to reply to this comment and stress that this option is only here for demonstrating a problem “The other quantities calculated by TARTES are not corrected, and we discourage to use the 2S option in general.”

10. Line 320: Some studies (e.g., Peltoniemi, 2007: https://doi.org/10.1016/j.jqsrt.2007.05.009; He et al., 2017: https://doi.org/10.1002/2017GL072916) have quantified the impact of treating snow grains as densely packed medium on snow albedo, which is worth discussing briefly here.

To our understanding this topic is extremely complex as the effect of packing is many-fold. Different studies tend to address very different aspects (e.g. those cited by the reviewer and see also Doicu and Mishchenko. (2019) and Malinka (2023)), make different simplifying assumptions and draw different conclusions. How this applies to natural snow for practical applications is however difficult to assess.

Here, by considering that snow can be represented by the conventional radiative transfer equation applied to a homogeneous media (as done in TARTES, DISORT-Mie, SNICAR) we make a very strong assumption that automatically discards many of these packing effects. However, even within this simple framework, some dense packing effect on albedo has been reported under the geometrical optics approximation and perfectly random media (e.g. Malinka, A. (2023)) but the reason is still unclear to us.

Given the complexity of the topic and our lack of experience, we prefer not to address it at all. Instead we propose to make explicit that TARTES ignores the packing effect (see our response to comment 2).

References:

Doicu, A., & Mishchenko, M. I. (2019). An overview of methods for deriving the radiative transfer theory from the Maxwell equations. III: Effects of random rough boundaries and packing density. Journal of Quantitative Spectroscopy and Radiative Transfer, 224, 154–170. https://doi.org/10.1016/j.jqsrt.2018.11.002

Malinka, A. (2023). Stereological approach to radiative transfer in porous materials. Application to the optics of snow. Journal of Quantitative Spectroscopy and Radiative Transfer, 295, 108410. https://doi.org/10.1016/j.jqsrt.2022.108410

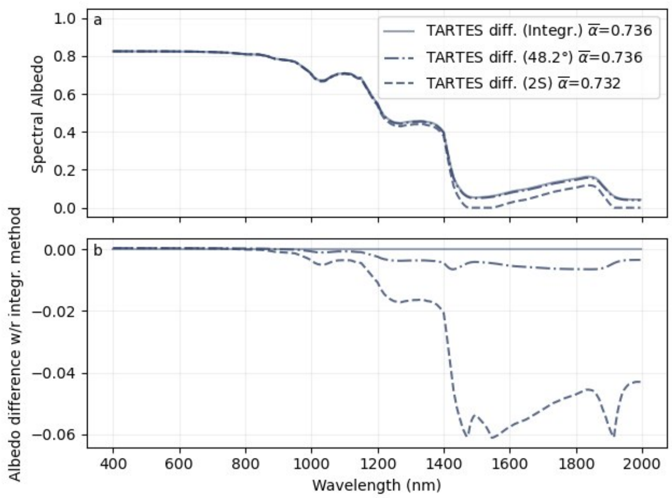
11. Section 3.2: It is not very clear what the key differences in model physics and/or parameters between the Python and Fortran versions, which needs to be clarified.

We propose to add: “TARTES.F was developed in 2014 exactly following the Python version. It contained the same physics and parameters. However it has not been updated since then, and now slightly differs from the most recent Python version. The main difference is the ice refractive database that is based on Warren et al. 2008 only (Picard et al. 2016 is not available). In 2019, impurities were added (Tuzet et al. 2017) using specific MAE values that slightly differ from the Python version (not used here).”

12. Line 506: It should note that this conclusion here is applied to semi-infinite snowpack tested in this study.

We also checked for a shallow snowpack (1 cm snowpack over a perfectly dark surface) and the same conclusion holds (see Figure below). We propose the following updated text:

"Based on these results **and calculations with a shallower snowpack (not shown)**, the direct 48.2° calculation was chosen as the default method to simulate diffuse radiation in TARTES. The integration is in principle more accurate but requires many more computations (solving the linear system for 128 angles instead of 1) even though measuring the execution time (51\,\unit{ms} instead of 34\,\unit{ms}) does not show a difference in the same proportion because only the constant vector of the linear system depends on the angle, not the matrix. In practice, users who prefer the accuracy offered by the integration method can explicitly set this option.



13. It would be good to add a short paragraph to discuss future plans for TARTES model improvements/developments.

We propose to add a list at the end of the Discussion:

“Possible future improvements in TARTES include the inclusion of terrain slopes, bubbly ice and slush layers, extended impurities database and internal mixture impurities.”