Reply to referee #1

We thank Referee #1 for reviewing the manuscript and the valuable comments and suggestions which we address below. The responses to the referee comments are given in blue italic letters.

General comments:

This paper does more than what is described in its title. A whole new approximation to 3D radiative transfer (RT) in clouds at solar wavelengths is introduced, going by the whimsical name of IDEFAX (InDEpendent column local halF-sphere ApproXimation). It is an alternative to the well-known ICA (Independent Column Approximation) with 3 extra parameters to accomodate broken cloud fields. However, even these approximate 3D RT models are too cumbersome to use operationally due to their large parameter spaces, hence look-up tables (LUTs), with 11 and 14 dimensions, respectively, for ICA and IDEFAX. Therefore, the authors invoke a neural net (NN) model trained to accelerate either ICA or IDEFAX.

Both the new (IDEFAX) and old (ICA) approximations are tested against synthetic clouds and observations using the NCAR Weather Research and Forecasting (WRF) model followed by detailed computational 3D RT using the LMU MYSTIC code to estimate the intensity (Stokes I) and polarized (Stokes U and Q) radiances. The present application is for low-level mixed-phase Arctic clouds and the simulated observations are for LMU's airborne specMACS sensor.

The research is new and timely, and the paper is well-written. In this reviewer's opinion, it can be published in AMT after a revision that addresses the following questions.

Specific comments:

The most innovative part of this work is the IDEFAX model described in Section 4 and validated against high-fidelity (WRF+MYSTIC) vector 3D RT simulations in Section 6. That should be emphasized rather than the (more and more common) NN implementations in the revised title.

We completely see your point and changed the title to focus more on the parameterization than the neural networks. In addition, we slightly adapted the introduction. The title reads now: Parameterization of 3D cloud geometry and a neural-network-based fast forward operator for polarized radiative transfer in low-level Arctic mixed-phase clouds

Also, we hear about the ~5 orders-of-magnitude speedup of the NN models compared to MYSTIC. However, the more relevant speedup factors are IDEFAX or ICA vs MYSTIC and the NN implementations vs (LUT-based) IDEFAX and ICA. Please provide.

Thank you very much for noting that. We added approximate times for the different options. The final computations were performed on our cluster which consists of a number of different machines with unfortunately quite different computation times for the same tasks. Thus, only approximate computation times are given.

I may have missed this, but we'd like to know exactly how many WRF realizations of the Arctic clouds were used in the NN training. It feels like there is only one, which I doubt.

We used only one realization of WRF for the validation of the IDEFAX and plane-parallel ICA against full 3D radiative transfer simulations. The neural networks were not trained with WRF simulations, but by randomly sampling all input parameters (summarized in Table 1) within their boundaries. Otherwise, the generation of training data would have been very computationally expensive.

Lastly, does the new cloud fraction parameter not have an upper limit that is less than unity? 78.5% for hemispheres on a square cartesian grid, or 81.4% for closely packed hemispheres.

Yes, this is true, the cloud fraction has an upper limit less than unity. We added an additional sentence about this to Section 4.

Technical corrections:

p. 1, l. 9: Remove 2nd coma.

Changed as suggested.

p. 1, l. 25: either roughening and smoothing --> both roughening and smoothing
or --> either roughening or smoothing

Changed as suggested.

l. 30: most retrievals --> most operational retrievals

Changed as suggested.

l. 75: Word "used" is unnecessary.

Changed as suggested.

l. 111, and many times after this: 1000m --> 1000 m, with unbreakable space before unit

We added a space between numbers and units throughout the paper.

Fig. 2: Would be beneficial to show lines of equal scattering angle here and in similar figures.

We added scattering angles to Figures 2, 6, and 8 as suggested.

l. 146: Need either comas or parentheses or both in "radiances respectively Stokes vectors".

Changed as suggested.

l. 271: Remove first "the".
Changed as suggested.

l. 300, 1st sentence: Best to separate clauses with a coma. Elsewhere too, e.g., often before "which" (unless it should be "that").

Changed as suggested. Still missing comas will hopefully be corrected during typesetting.

l. 325, and elsewhere: Referring to "real" clouds is misleading, better to use "realistic" or "WRF".

Changed as suggested.