Geosci. Model Dev. Discuss.,
https://doi.org/10.5194/gmd-2018-99-AC2, 2018

Geoscientific
Model Development
Discussions

Interactive comment on “(GO)^2-SIM: A GCM-Oriented Ground-Observation Forward-Simulator Framework for Objective Evaluation of Cloud and Precipitation Phase” *by* Katia Lamer et al.

Katia Lamer et al.

kxl5431@psu.edu

Received and published: 6 September 2018

The authors would like to thank the reviewer for their insightful comments. A point by point response to the reviewer’s comments, along with changes made to the manuscript as a result, are included below. (Please see the pdf document attached at the end of this document for a better rendering of the mathematical equations)

R1. Although it is frequently stressed in the manuscript that the radar is very sensible to particle size none of the empirical equations takes the particle size into account.

A1. The following manuscript changes have been made to address the reviewer’s comment:

“(GO)2-SIM relies on water content-based empirical relationships to estimate cloud liquid water (cl), cloud ice (ci), precipitating liquid water (pl) and precipitating ice (pi) radar reflectivity. Different relationships are used for each species to account for the fact that hydrometeor mass and size both affect radar reflectivity.”

“Figure 3b illustrates the fact that for all these empirical relationships increasing water content leads to increasing radar reflectivity. As already mentioned, radar reflectivity is approximately related to the sixth power of the particle size, which explains why, for the same water content, precipitating hydrometeors are associated with greater reflectivity than cloud hydrometeors.”

R2. The motivation for the ice lidar ratio of 25.7 sr (Eq. 7) is not motivated. Additionally the lidar ratio is often dependent on the particle size which is not addressed in the manuscript.

A2. The following manuscript changes have been made to address the reviewer’s comment:

“Lidar co-polar backscattered power (β_(copol,species) [mˆ(-1) srˆ(-1)]) generated by each hydrometeor species is related to lidar extinction ãĂŰ(σãĂŮ_(copol,species) [m-1]) through the lidar ratio (Sspecies [sr]):

β_(copol,cl)= ((1)/(S_cl) σ_(copol,cl)). (6) β_(copol,ci)= ((1)/(S_ci) σ_(copol,ci)). (7)

While constant values are used for the lidar ratios of liquid and ice clouds in this version of the forward-simulator, we acknowledge that in reality they depend on particle size. O’Connor et al. (2004) suggest that a liquid cloud lidar ratio (Scl) of 18.6 sr is valid for cloud liquid droplets smaller than 25 μm, which encompasses the median diameter expected in the stratiform clouds simulated here. Kuehn et al. (2016) observed layer-averaged lidar ratios in ice clouds (Sci) ranging from 15.1 to 36.3 sr. Sensitivity tests indicate that adjusting the ice cloud lidar ratio to either of these extreme values in the forward-simulator increases the number of detectable hydrometeors by no more than 0.6 %, changes the hydrometeor phase frequency of occurrence statistics by less than 0.4% and causes less than a 0.1% change in phase-classification errors (not shown). Given these results, the ice cloud lidar ratio is set to the constant value of 25.7 sr, which corresponds to the mean value observed by Kuehn et al. (2016)"

R3. No multiple scattering is simulated even for water clouds or thick ice clouds.

A3. The following manuscript changes have been made to address the reviewer's comment:

"Lidar attenuation is exponential and two-way as it affects the lidar power on its way out and back:

β_(copol,total,att)=β_(copol,total) eˆ(-2$\eta\tau$). (22)

Note that in some instances multiple scattering occurs before the lidar signal returns to the sensor, thus amplifying the returned signal. In theory, the multiple scattering coefficient (η) varies from 0 to 1. Sensors with large fields of view, such as satellite-based lidars, are more likely to be impacted by multiple scattering than others (Winker, 2003). In the current study, for which a ground-based lidar is simulated, a multiple scattering coefficient of unity is used. A sensitivity test in which this coefficient was varied from 0.7, such as that implemented in the CALIPSO satellite lidar simulator of Chepfer et al. (2008), to 0.3, representing an extreme case, indicated that multiple scattering had a negligible impact (less than 1%) on the number of hydrometeors detected, the hydrometeor phase frequency of occurrence statistics, and in phase classification error (not shown)."

"According to an analysis of CALIPSO observations by Cesana and Chepfer (2013), cloud ice particle cross-polar backscattering (β_(crosspol,ci,detect) [mˆ(-1) srˆ(-1)]) and cloud liquid droplet cross-polar backscattering (β_(crosspol,cl,detect) [mˆ(-1) srˆ(-

1)]) can be approximated using the following relationships:

ãĂŰ βãĂŮ_(crosspol,ci,detect)=0.29ãĂŰ (βãĂŮ_(copol,ci,detect)+β_(crosspol,ci,detect)), (26b)

ãĂŰ βãĂŮ_(crosspol,cl,detect)= 1.39ãĂŰ (βãĂŮ_(copol,cl,detect)+β_(crosspol,cl,detect)) +1.76 ãĂŰ10ãĂŮˆ(-2) ãĂŰ (βãĂŮ_(copol,cl,detect)+β_(crosspol,cl,detect)) $\approx$0. (26c)

For reasons mentioned in Sec. 4.1, multiple scattering is considered negligible in the current study such that cloud-liquid droplet cross-polar backscattering is assumed to be zero under all conditions."

R4. Please give a reference for radar attenuation (Eq. 24b).

A4. The manuscript was modified to include a reference to Ellis, S. M., and Vivekanandan, J.: Liquid water content estimates using simultaneous S and Ka band radar measurements, Radio Science, 46, 2011:

"At 8.56 mm (Ka-band) total co-polar attenuated reflectivity (Z_(copol,total,att) [dBZ]) is given by:

Z_(copol,total,att)=Z_(copol,total)-2$\int$_$(z = 0)$ˆ$z[a(WC_pl + WC_cl)]dh, (24)$

where attenuation is controlled by the wavelength-dependent attenuation coefficient a ([dB km-1 (g m-3)-1]) which we take to be 0.6 at Ka-band (Ellis and Vivekanandan, 2011), by the water contents of cloud liquid (WCcl [gãĂŰ mãĂŮˆ(-3)]) and precipitating liquid (WCcl [gãĂŰ mãĂŮˆ(-3)]), and by the thickness of the liquid layer."

R5. The meaning of the terms in Eq. 29 is not completely clear to me. Please give the derivation of Eq. 29.

A5. A reference to Everitt, B., and Hand, D.: Mixtures of normal distributions, in: Finite Mixture Distributions, Springer, 25-57, 1981 was added. A derivation of the first five central moments of a two-component univariate normal mixture is presented in their book. The following manuscript changes were made to improve clarity: "Total mean

Doppler velocity detected (VDcopol,detect [m sˆ(-1)]) is the reflectivity-weighted sum of the mass-weighted fall velocity of each hydrometeor species (Vspecies[m sˆ(-1)]):

VD_(copol,detect)= $\sum\_(species = cl, pl, ci, pi)P\_speciesV\_species, (28)$

where the mass-weighted fall velocity of each hydrometeor species (Vspecies[m sˆ(-1)]) is a model output. Total Doppler spectral width (SWcopol,detect [m sˆ(-1)]) is more complex and can be estimated following a statistical method similar to that described by Everitt and Hand (1981). It takes into consideration the properties of each individual hydrometeor species through their respective fall speed (Vspeies [m sˆ(-1)]) and spectral width (SWspecies [m sˆ(-1)]) in relation to the properties of the hydrometeor population as a whole through the total mean Doppler velocity detected (VD_(copol,detect)) estimated in Eq. 28:

SW_(copol,detect)= $\sum\_(species = cl, pl, ci, pi)P\_species(SW\_species^2 + (V\_species - VD\_$

where the spectral widths of individual species (SWspecies) are assigned climatological values. These climatological values are SW_cl=0.10 m sˆ(-1), SW_ci=0.05 m sˆ(-1), SW_pi=0.15 m sˆ(-1) and SW_pl=2.00 m sˆ(-1) (Kalesse et al., 2016)."

R6. A number of empirical equations are used to estimate the uncertainties. Although each formula is valuable for specific situations I am not sure if their ensemble covers the whole range of variability of ModelE output. A forward model using the modelled effective radius might help.

A6. The authors agree with the reviewer that the 576 forward-simulations performed do not cover the entire range of possible scattering assumptions. The following manuscript changes reflect this reality:

"Additionally empirical relationships are computationally less expensive to implement than direct radiative scattering calculations, thus enabling the estimation of an ensemble of backscattering calculations using a range of assumptions in an effort to quantify part of the backscattering uncertainty (see Sec. 7)."

(GO)2-SIM performs an uncertainty assessment by performing an ensemble of 576 forward simulations based on 18 different empirical relationships (relationships are listed in Table 2). While the relationships used do not cover the entire range of possible backscattering assumptions, they represent an attempt at uncertainty quantification and illustrate a framework for doing so. [. . .] Nevertheless, we suggest using the full range of frequency of occurrences presented in Tables 1b,c for future model evaluation using observations and acknowledge that additional uncertainty is most likely present."

Please also note the supplement to this comment:
https://www.geosci-model-dev-discuss.net/gmd-2018-99/gmd-2018-99-AC2-supplement.pdf

---

Interactive comment on Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-99, 2018.