Response to Interactive Reviewer 2's comments on "Microphysics of Summer Clouds in Central West Antarctica Simulated by Polar WRF and AMPS" by Hines et al.

Response to General Comments

Thank you for these comments. We have changed the wording describing the microphysics schemes. We might add though that we believe our previous words are not "promotional" as much as they are accurate descriptions of the current thought in the cloud modelling community. The one-moment WSM5C scheme represents an older approach to cloud modeling with a prognostic treatment of several hydrometers in terms of the mixing ratio, while the other schemes are from more recent generations of cloud modelling and include elements of two-moment microphysics schemes. Thus, the newer schemes predict both the mixing ratio and some measure of the cloud size distribution. Accordingly, they allow for a greater degree of freedom in the cloud hydrometers. We have had extensive discussions with Hugh Morrison and Greg Thompson on these microphysics schemes.

Here is some text we included from the discussion with Reviewer 1:

We believe the comparison of the WSM5C microphysics schemes to the other schemes – which we refer to as more advanced schemes – is well founded. The WSM5C microphysics scheme is well-known in WRF modeling community to have difficulty simulating supercooled liquid water. More generally, representing supercooled liquid water is known to be difficult in numerical modeling studies. We have added the reference of Morrison and Pinto (2006) in this regard. Hugh Morrison's microphysics scheme, which was developed with the Arctic in mind is relatively successful in representing Arctic cloud water (Hines and Bromwich 2017 and references therein). This is known in the polar climate modeling community. So we believe the comparison of the WSM5C scheme – a one-moment microphysics scheme which is a relatively older generation algorithm – to newer generation schemes is a reasonable thing to do.

AMPS is considering changing microphysics schemes for better cloud representation. Other schemes, however, are more computationally expensive (Jordan Powers, personal communication, 2018), so the cpu cost must be weighed versus the gain in results. Our research is relevant to this decision.

Since the role of the different boundary conditions and initial conditions has been discussed by both reviewers, we added analysis of a simulation with WSM5C microphysics scheme that has forcing by the GFS final analysis rather than ERA-Interim. The new simulation is called WRF GFS. The results of this simulation show a 2 m temperature cold bias (-1.5 °C) similar to that of AMPS (-1.6 °C). The longwave and shortwave radiation for WRF GFS have biases of the same sign and slightly larger magnitude than those of WSM5C simulation. For longwave, the bias for WSM5C is -14.8 W m^{-2} and -17.0 W m^{-2} for WRF GFS. The results of the new simulation supports the conclusion that the WSM5C microphysics has biases in the representation of clouds leading to too much downwelling shortwave and too little downwelling longwave radiation at the surface of West Antarctica.

We have done what we could to improve the figures. We recognize that the reduction in size to the manuscript specifications in the initial submission reduces the visibility of figures. We have attached selected larger figures to this response. We will see to it that high quality figures are sent to the journal for final publication.

Observations of clouds by surface observers or by remote sensing techniques differentiate between “cloud fraction” and “cloud frequency”. For comparison to the model, the distinction is not so important since model cloud fraction tends to be zero or one (either by the vertically-integrated hydrometer method taken from Fogt and Bromwich [2008] or by a local threshold value set at a hydrometer mixing ratio of 10^{-6}). We have sought to make the manuscript more clear on this point.

Specific Comments:

Page 2, Line 8, Page 3, Line 29, Page 4, Line 10, Page 5 Line 13, Page 7 Line 18, Page 8 Line 18, Page 11 Line 4, Page 11 Line 30-35, Page 12 Line 14 and Page 12 Line 26. The text has been modified to address these comments.

Page 3, Line 30, Page 15, Line 6 and Page 19, Line 5-11. The text has been rearranged based upon these comments.

Page 4, Line 12. The field site locations are added to Figures 1b and 2b.

Page 13, Line 12. The new simulation WRF GFS helps here in that it shows the radiation biases do not greatly change between forcing by GFS or ERA-Interim. The results are consistent with simulations with the WSM5C scheme showing too little liquid water, too little downwelling longwave radiation and too much downwelling shortwave radiation. This scheme is rather well known among WRF users in the polar regions for simulating too little liquid water. We have added the reference to Morrison and Pinto (2006) about the known difficulty of models simulating liquid water in polar regions. Our simulations with the more recent microphysics schemes produce more liquid water and greater cloud radiative effect.

Page 16, Line 4. The observations that could be taken at WAIS Divide during December 2015 and January 2016 were limited, due to the remoteness of the location. The main observational location for AWARE was at the McMurdo station that is a major freight transit point in Antarctica. We must use what observations are available for WAIS. Fortunately, lidar observations were available at WAIS, and the observations can be processed into cloud fraction following Sibler et al. (2018). We are making use of the available observations for comparisons to the modeling results.

Page 16, Line 16. Observations of clouds by surface observers or by remote sensing techniques differentiate between “cloud fraction” and “cloud frequency”. For comparison to the model, the distinction is not so important since model cloud fraction tends to be zero or one (either by the vertically-integrated hydrometer method taken from Fogt and Bromwich [2008] or by a local threshold value set at a hydrometer mixing ratio of 10^{-6}). We have sought to make the manuscript more clear on this point.

Table 1. We have added the driving source of the meteorological fields to Table 1. We believe the detailed description of the microphysics schemes is best shown in Section 3.2.

Figures 8-12. Unfortunately, the similarity of the time series makes it difficult to differentiate some of the lines. Larger size versions of Figures 8-10 (old ordering according to the previous submission) are attached here for better clarity. Figures 11 and 12 have been replaced due to the introduction of the lidar simulator.

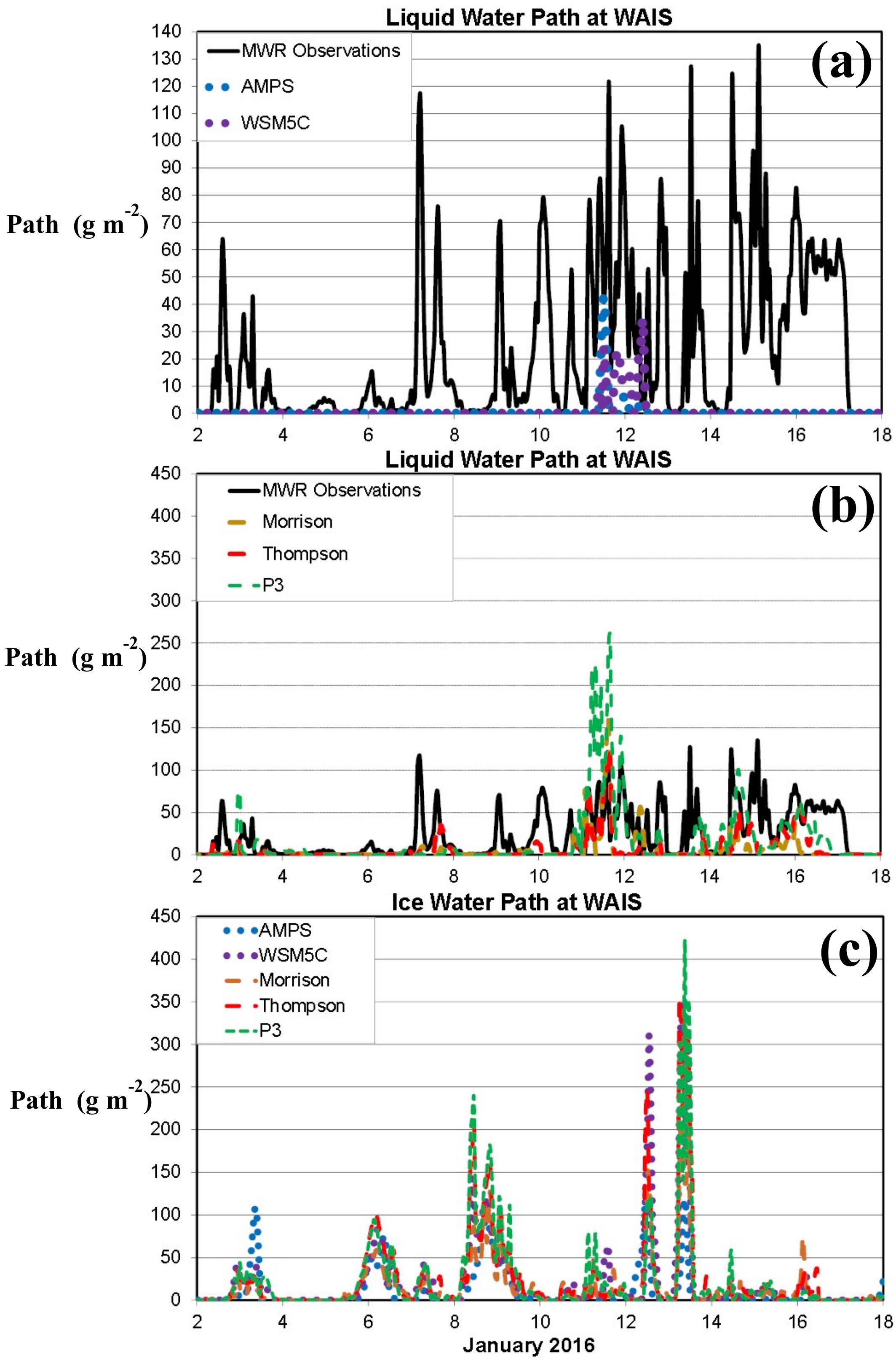

Figure 8: Time series of (a) and (b) liquid water path (mm) and (c) ice water path (mm) over 0000 UTC 2 January–0000 UTC 18 January 2016. Microwave radiometer (MWR) observations are available for liquid water path and are shown by solid curves in (a) and (b). Values for AMPS and the WSM5C simulation are shown in (a) and (c), while values for the three simulations with advanced microphysics schemes are shown in (b) and (c).

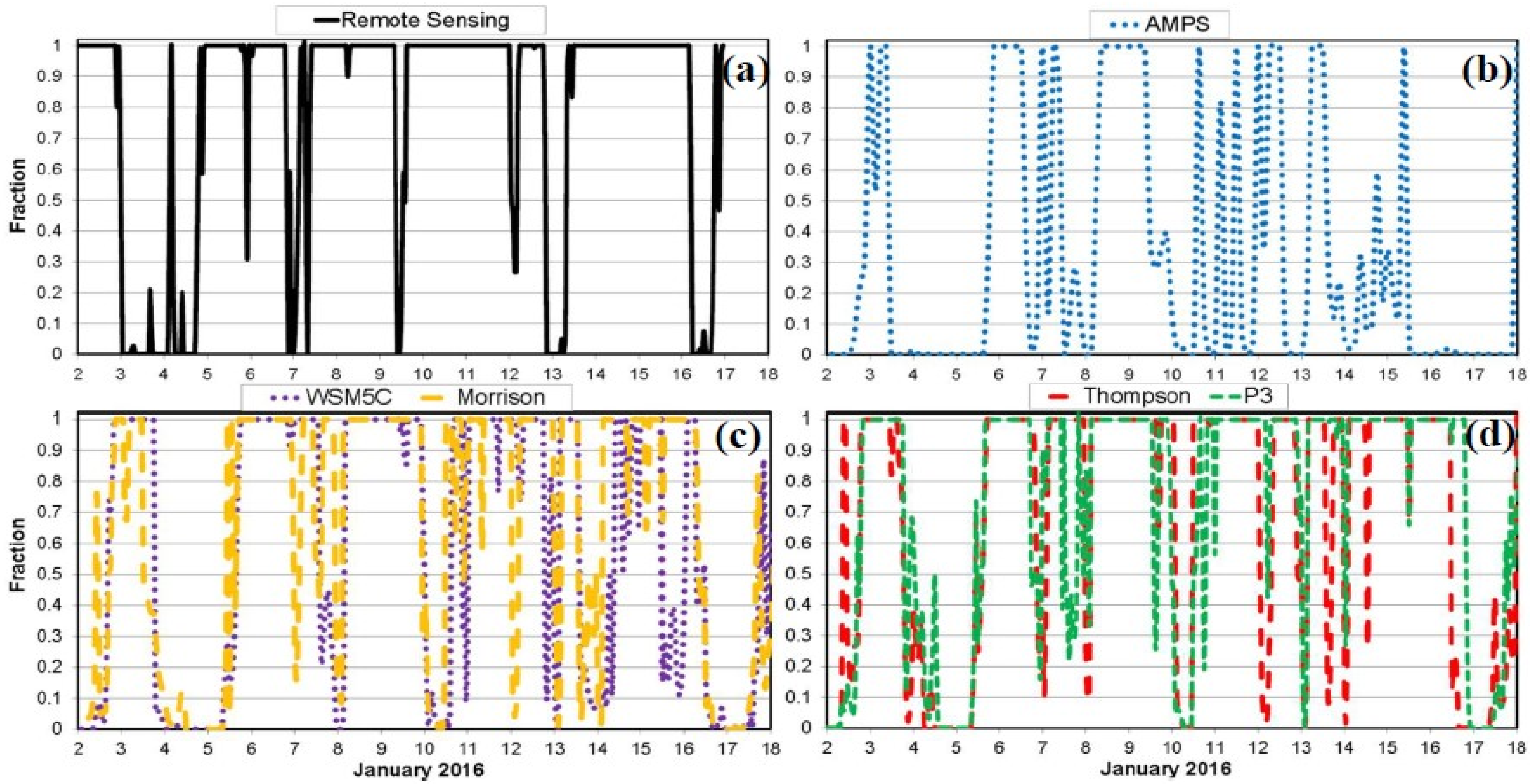

Figure 9: Time series of cloud fraction for (a) remote sensing observations, (b) AMPS, (c) the WSM5C and Morrison simulations, and (d) the Thompson and P3 simulations. Model values of cloud fraction are based upon the Fogt and Bromwich (2008) algorithm using liquid water path and ice water path.

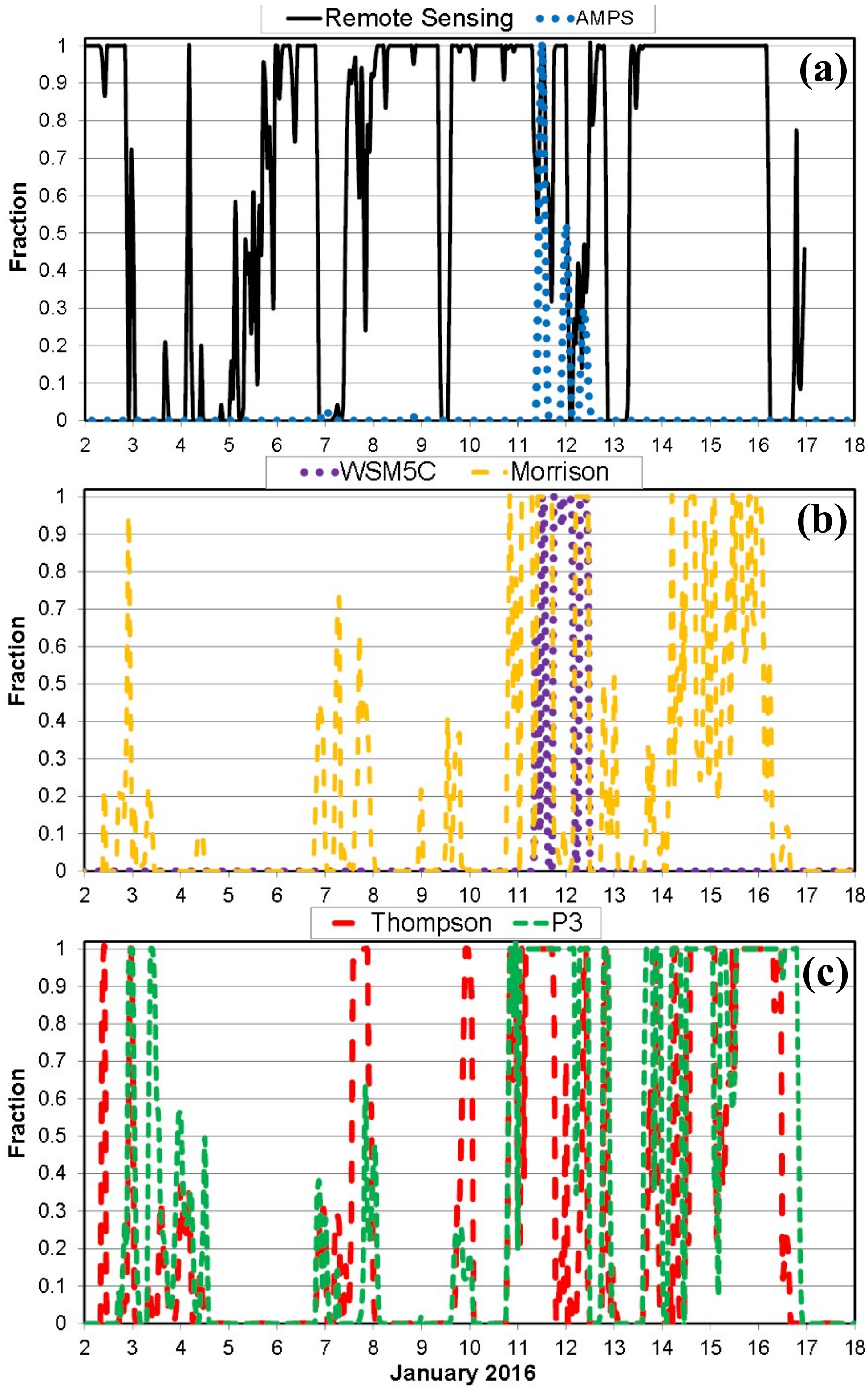

Figure 10: Time series of liquid cloud fraction for (a) remote sensing observations and AMPS, (b) the WSM5C and Morrison simulations, and (c) the Thompson and P3 simulations. Model values of cloud fraction are based upon the Fogt and Bromwich (2008) algorithm.