Review of Ylivinkka et al. “Clouds over Hyytiälä, Finland: an algorithm to classify clouds based on solar radiation and cloud base height measurements” by Anonymous Referee #1

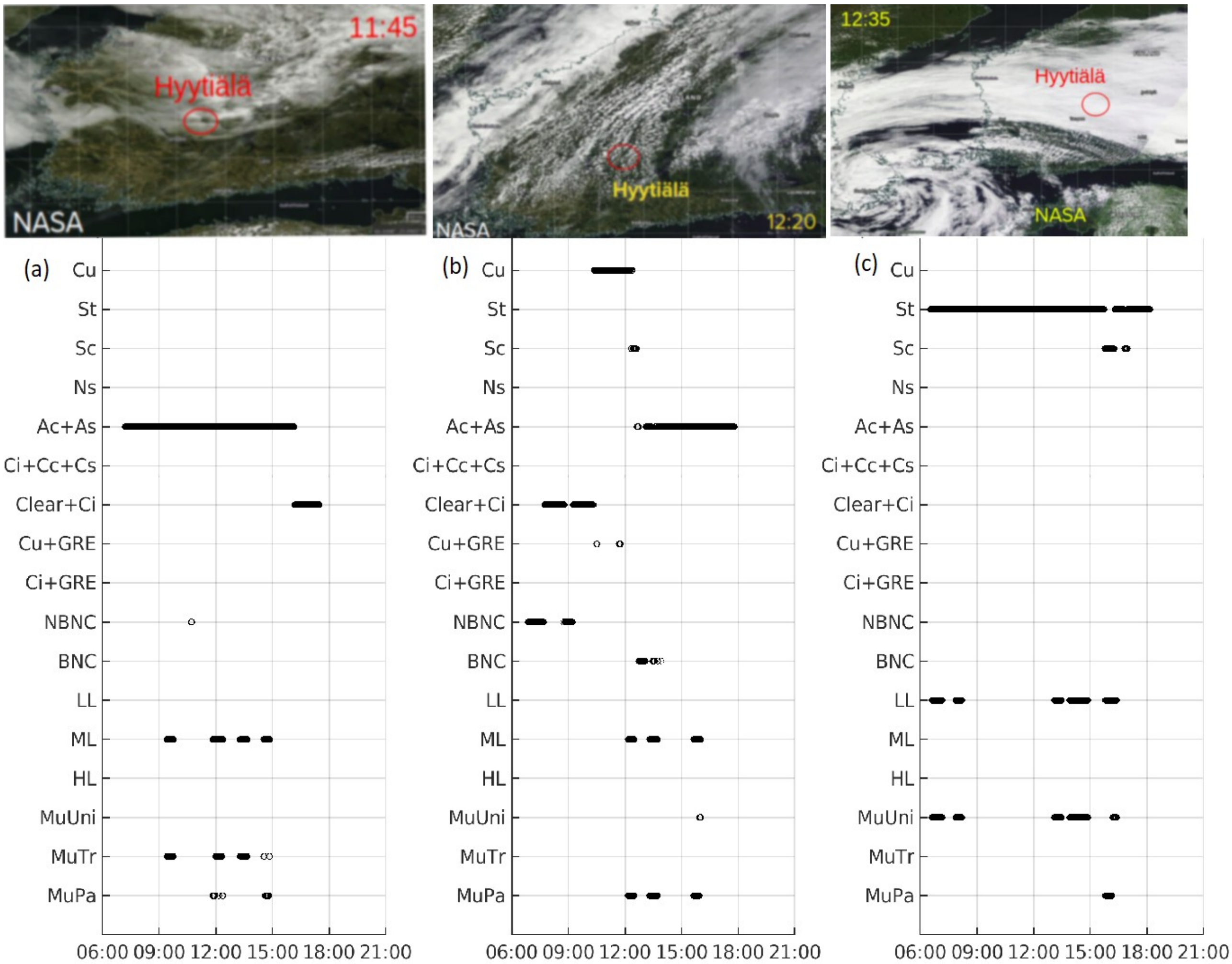
We thank Referee 1 for the valuable comments and improvements to our manuscript. We have revised our manuscript, and provide below a point-by-point answers to the comments, which are repeated in italic.

The classification and quantification of clouds from routine surface and remote-sense measurements remains essential information from studies that range from weather, atmospheric chemistry and the interaction between land and atmosphere. In this research, the authors present an algorithm that enables a cloud classification based on global radiation (observed with a pyranometer) and cloud base height (measured with a ceilometer). The algorithm is based on the calculation of three variables related to the cloud characteristics: transparency, patchiness and the measured CBH. By combining these metrics they are able to identify and classify low, middle and high clouds. To evaluate the performance of the algorithm thy compare with an observed who use total sky images. The agreement is 70 %. The paper explained and discussed very interesting findings that can help the SMEAR II site -a referent site in the boreal ecosystem due to its completeness in measurements and other sites. The article is very well written with a very complete introduction that stresses the relevance to have this sort of classification and quantification as a routine product for meteorological/atmospheric chemistry sites. The paper discussed interesting histograms of the cloud types monthly and daily averages, and as the authors mentioned in the conclusions, it will become a valuable tool to study the interactions between surface and the cloudy-boundary layer at boreal ecosystems. I agree with them. My comments to the article are the following:

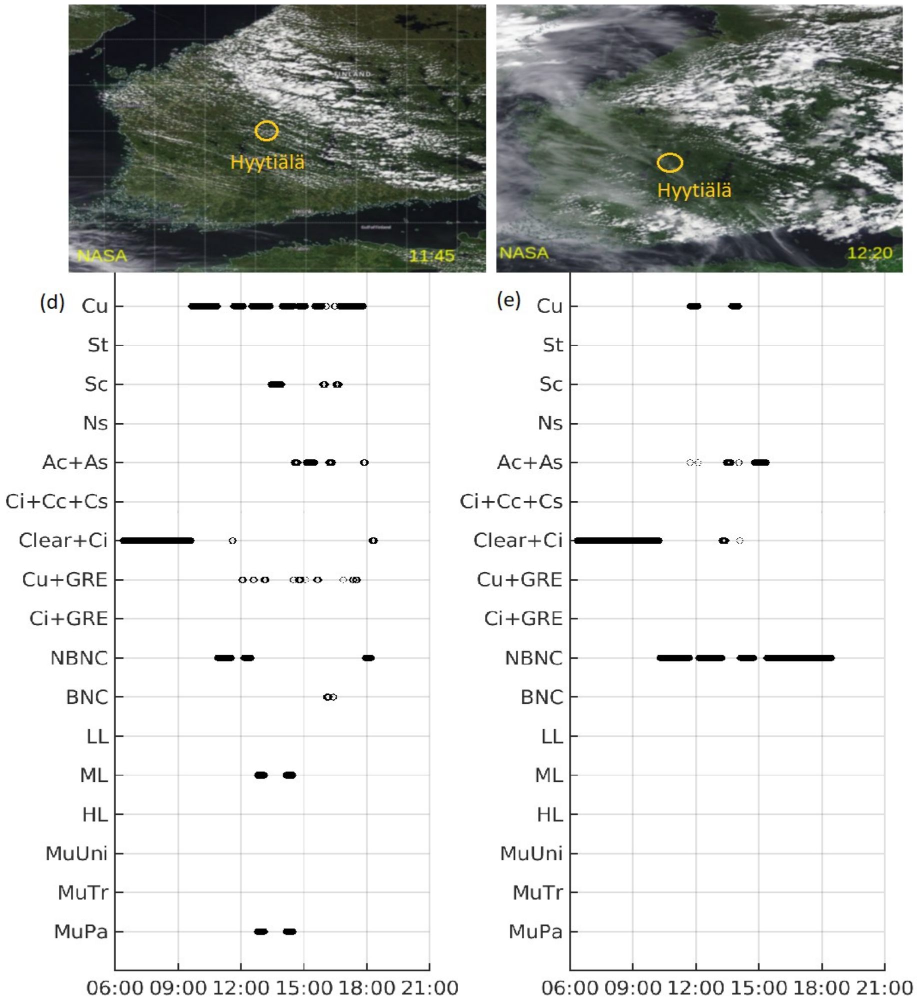
We are grateful for the positive viewing of our manuscript and helpful comments to improve it.

1) For the completeness of the article, I would have appreciated a short section discussing the evaluation of the algorithm against satellite measurements. For instance the Meteosat Second Generation provides information on cloud classification. Please note that I am not asking a full comparison of the three years under analysis, but perhaps some case examples, for instance related to the diurnal variability or the more demanding and difficult to classify multi-layer clouds. Would it be possible to include this information?

We thank Referee for a valuable comment. Data from satellite products could surely be used as an optional parameter to improve the algorithm, and especially its ability to detect and classify multilayered and high clouds. Additionally, we could test how well satellite cloud classification and satellite-derived parameters with clearness index and patchiness compare with the results of our algorithm. This is, however, something that we must investigate further in the future. Now, we tested five random case examples of satellite images taken over southern Finland against the classification made by the algorithm. The results are shown below. The selected days were (a) 03 May 2016, (b) 13 May 2016, (c) 27 May 2016, (d) 07 June 2017 and (e) 17 June 2017. BNC refers to the “Base, no class” and NBNC to the “No base, no class”. We used satellite data provided by NASA Worldview (https://worldview.earthdata.nasa.gov/, last access: 27 August 2020). We can see that mostly the algorithm was able to produce similar clouds as seen in the satellite image.



11:45
Hyytiälä
NASA
Hyytiälä
NASA
12:20
12:35
Hyytiälä
NASA
(a)
(b)
(c)
Cu
St
Sc
Ns
Ac+As
Ci+Cc+Cs
Clear+Ci
Cu+GRE
Ci+GRE
NBNC
BNC
LL
ML
HL
MuUni
MuTr
MuPa
06:00 09:00 12:00 15:00 18:00 21:00



2) Section 2.2 The length of the time interval (21 minutes) to calculate the transparency needs to be better justified. There is not a clear explanation on why it is used (only a reference to the work of Duchon and O'Malley (1999)). Is it related to a life time of clouds? More important, What is the sensitive of the algorithm to this value to the proposed classification? At the discussion, there is a short discussion on these values(lines 383-389), but it does not include the sensitivity to it.

We added a new paragraph to better describe the use of 21 min interval. The text now reads (L. 157):

"The chosen time interval in this work was 21 min, similar to Duchon and O'Malley (1999) to be able the compare our results. However, the length of the time interval is based on empirical experience of the time span of cloud variability in the sky and the life time of clouds. Cumulus clouds are the largest patchy clouds, and hence they are used as a reference for the time span of clouds. The representative size of typical cumulus clouds is 1 km and if assuming that the average wind speed is about 3–6 m s^{-1} (Stull, 2000), then during 21 min the clouds can move 3.8–7.6 km, meaning that roughly 4–8 clouds can pass the measurement beam of the instruments. Capturing several clouds is necessary for the calculation of standard deviation, which is employed when calculating patchiness as described below. Hence, decreasing the 21 min time interval can be problematic due to insufficient number of passing clouds, needed for the calculation. Moreover, a study by Rodts et al. (2003) show that ca. 1 km sized clouds dominate the vertical mass and buoyancy fluxes. Thus, they can be expected to be optically thicker than smaller or larger clouds, and thereby they cause the largest decrease in solar radiation which contributes to the standard deviation the most. Rodts et al. (2003) also showed that the cloud cover density is dominated by intermediate clouds with linear sizes of 0.7–1 km. This means that they give the largest contribution to the cloud cover, determined as a ratio of the 2D projection of the area occupied by clouds to the total image area. Another time constraint is related to the life time of clouds. A typical life time of cumulus cloud is 20 min, so 21 min is a reasonable to capture one life cycle of cumulus clouds (Lohmann et al., 2016). Other clouds have longer life times (Lohmann et al., 2016). Therefore, we can expect that 20–30 min would give the same results but considerably shorter time intervals would not give the best representation of the overall cloudiness conditions and longer time interval will increase the number of poorly defined cases when there is a transition from one type of cloudiness to another."

3) Due to the completeness of the SMEAR II data set, I think it will be nice to attempt to connect the proposed metrics to other variables that are very relevant in the modelling of the clouds, but remain difficult to be measured. For example, Have the authors compared the transparency with an estimation of the cloud optical depth?

We thank Referee for pointing out this important question related to connection of modeling and measurement results. In Hyytiälä cloud optical depth (COD) has been measured with Three-Waveband Spectrally-agile Technique (TWST) sensor (Niple and Scott, 2016) during the BAECC campaign. Transmittance is related with COD with a theoretical formula (Sena et al., 2016, Eq. (6)). We plotted the transmittance against measured COD along with the theoretical relation curve, and hence compared the results. We could conclude that COD for non-patchy clouds can be estimated utilizing transmittance during daytime. We added new sections 2.4 and 3.4.2 to describe the theory and results related to COD.

4) Equations (1) and (2). How do they model the clear sky radiation?

We clarified the behavior of transmittance and patchiness in clear sky and cloudy conditions (L. 151):
"Transmittance is the ratio of the measured global radiation (I_meas) to the modeled clear sky radiation (I_gh), given by Eq. (5), averaged over a running time interval: ...", (L. 155):
"Transmittance describes how effectively clouds block solar radiation. It is equal to 1 in clear sky conditions and approaches 0 for an overcast sky.", and (L. 177):
"The modeled clear sky radiation is calculated using Eq. (5). Patchiness determines the variability of the cloud layer. The value is smallest both for uniform and overcasting, and clear sky conditions, and increases in partly cloudy conditions."

Besides the comments by Referee, we changed term "transparency" to more generally used "transmittance". We additionally removed parameter "TR_max" as in the further examination of the algorithm it was found to be redundant. Because the data availability of AERONET data was low during March, April and September of 2016 and 2017, we calculated median values of the available data separately for spring (March and April) and September, and applied those when data was missing in those months. Lastly, we changed the upper limit of transmittance for stratus clouds from 0.4 to 0.6. This was done because we could see that many St clouds fall into this area but were previously not classified. These latter two changes to the algorithm decreased the number of cases falling into the class “Base, no class”. Now also the frequency of occurrence of stratus clouds is better in accordance with observations in *Climatic Atlas of Clouds Over Land and Ocean* (available online at https://atmos.uw.edu/CloudMap/, last access: 10 January 2020). We additionally changed the upper transmittance limit of Ns from 0.4 to 0.3 and lower transmittance limit of Ac+As clouds from 0.4 to 0.3. This was done because we could see that especially in springtime Ac+As clouds were previously falsely classified as Ns. The overall occurrence of Ns clouds decreased (from 1.4 % to 0.6 %) and occurrence of Ac+As increased (from 9.0 % to 10.3 %) but otherwise the change did not affect our results.

References

Duchon, C. E. and O’Malley, M. S.: Estimating cloud type from pyranometer observations, Journal of Applied Meteorology, 38, 132–141, 1999.

Lohmann, U., Lüönd, F., and Mahrt, F.: An introduction to clouds: From the microscale to climate, Cambridge University Press, 2016.

Niple, E. R. and Scott, H. E.: Biogenic Aerosols – Effects on Climate and Clouds. Cloud Optical Depth (COD) Sensor Three-Waveband Spectrally-Agile Technique (TWST) Field Campaign Report, Tech. rep., United States, https://doi.org/10.2172/1248494, 2016.

Rodts, S. M. A., Duynkerke, P. G., and Jonker, H. J. J.: Size Distributions and Dynamical Properties of Shallow Cumulus Clouds from Aircraft Observations and Satellite Data, Journal of the Atmospheric Sciences, 60, 1895–1912, https://doi.org/10.1175/1520-0469(2003)060<1895:SDADPO>2.0.CO;2, 2003.

Sena, E. T., McComiskey, A., and Feingold, G.: A long-term study of aerosol–cloud interactions and their radiative effect at the Southern Great Plains using ground-based measurements, Atmospheric Chemistry and Physics, 16, 11 301–11 318, https://doi.org/10.5194/acp-16-11301-2016, 2016.

Stull, R. B.: Meteorology for scientists and engineers, Brooks/Cole, 2nd edn., 2000.