Response to Reviewer#2

Sincerest thanks for the comments on our manuscript entitled "Improving Cloud Type Classification of Ground-Based Images Using Region Covariance Descriptors" (amt-2020-189). These comments are very valuable and helpful for revising and improving our paper, and they also have important guiding significance to our researches. We have studied comments carefully and made revisions which we hope meet with approval.

The main revisions in the paper and the responses to the reviewer's comments are as following:

Reviewer #2:

Summary:

Apply region covariance descriptor (RCovD) computations to features and then use the output from the RCovD computations as input to a Bag-of-Features approach to create histograms. The histograms are classified using a support vector machine (SVM) method. The approach is applied to labelled cloud images, with some images serving as training data and the remaining images as testing data. Results of the classification are given.

1. The Abstract contains the sentences "Cloud types are important indicators of cloud characteristics and short-term weather forecasting. The meteorological researchers can benefit from the automatic cloud type recognition of massive images captured by the ground-based imagers. However, by far it is still of huge challenge to design a powerful discriminative classifier for cloud categorization." and the first few sentences of the Introduction are as follows: "Clouds have a strong impact on climate modeling, weather prediction and the Earth's energy budget balance. In recent years, the growing appeal on renewable solar energy pushes additional interest on cloud coverage measurement and cloud classification (Heinemann et al., 2006; J. Huertas, 2017; Martínez-Chico et al., 2011). Therefore, accurate cloud type classification is in great need."
Just how cloud classification as pursued in this study is applicable to climate modeling, weather prediction, Earth's energy balance, and surface solar irradiance is never made. Advancing our knowledge on these topics requires three-dimensional fields of optical depth, water content, and hydrometeor numbers, shapes, sizes, phase, and fall speeds. How results of the classification scheme have a bearing on these quantities is never made. Related to this issue is that the physical significance of the five cloud types in the 784 images of the SWIMCAT dataset and the 500 images of the Zenithal dataset is never made. For example, what is the physical significance of "patterned clouds, thick-dark clouds, thick-white clouds" and how will knowledge of their occurrence provide information on improving climate and forecast models and studies? Not clear.

Reply: Many thanks for your concern. Motivated by the comments, we have detailed the impact of cloud classification on climate modeling, weather prediction, Earth's energy balance, and surface solar irradiance in the revised manuscript. The sentences at the beginning of the Introduction section have been replaced as following:

"Clouds have a strong impact on the Earth's energy budget balance, climate modeling and weather prediction. Cloud type variations (e.g., variations in cloud-top height and water content) may affect both shortwave and longwave radiative fluxes. During climate variations, the distribution and frequency of different cloud types may change (Chen et al., 2000). Additionally, accurate cloud classification, especially convective cloud identification, are essential to Hazardous weather monitoring (Zhang et al., 2018a)."

In this paper, we extend our previous work[1], which has been published in AMT. Currently, ground-based cloud observation equipment can only estimate cloud types and cloud cover, other cloud characteristics like optical depth, water content, and hydrometeor numbers, shapes, sizes, phase, and fall speeds, etc., need to be acquired by other detection equipment, which is not the focus of this paper. The main contribution of our work is to propose a new automatic cloud type classification method with better performance as compared to state-of-the-art approaches, especially for the small training dataset. The physical significance of cloud type classification results on improving climate and forecast models may beyond the scope of our current paper, and we will explore this topic in the future work.

[1] Luo, Q., Meng, Y., Liu, L., Zhao, X., and Zhou, Z.: Cloud classification of ground-based infrared images combining manifold and texture features, Atmos. Meas. Tech., 11, 5351-5361, 10.5194/amt-11-5351-2018, 2018.

2. This study is similar to those that occurred in the late 1980s and 1990s during the first wave of artificial intelligence/machine learning methods into the atmospheric sciences. Many studies were devoted to classifying cloud types, cloud textures, etc..., similar to the current study, but these studies never really went anywhere because of lack of quantitative information relative to cloud optical depths, water contents, etc... How this paper will escape this same fate is not addressed.

Reply: We appreciate for your valuable comment. In this manuscript, we provide an improved ground-based cloud images classification method with region covariance descriptors (RCovDs) and Riemannian Bag-of-Feature (BoF). The main perspective of this paper is to solve the problem of cloud categorization automatically with the aid of computer visual technique. Perhaps carrying out deep research on physical properties of clouds might help us understanding the structure of clouds, further help us extracting discriminative features and accomplishing cloud classification tasks. And we will explore this topic in the future work.

3.Perhaps the proposed approach of combining RCovDs, Bag-of-Feature, and SVMs for classification has value relative to existing techniques. To assess this possibility, it would be more convincing to apply the proposed algorithm to large, vetted datasets in the artificial intelligence/machine learning community and to have this community rigorously assess its results.

Along this same line of reasoning, it would strengthen the paper if a case could be made as to why the results presented in this paper using only 784 and 500 images are "impressive" as stated on Line 259 of the paper. Because not much was stated about the diversity of clouds in these few scenes, it is hard to tell if high classification accuracy in regard to them are compelling.

Reply: Thanks for your comment. Unlike the deep learning-based models (e.g., VGGNet, LeNet and ResNet) that designed for general pattern recognition tasks, the proposed algorithm is specifically designed for ground-based cloud image categorization. Although image classification frameworks based on deep learning have achieved huge success, these frameworks all rely on a big pretrained model based on a large-scaled related data set in which the images are finely labelled. However, there is no appropriate public data set large enough to train a deep learning model for cloud classification. In fact, constructing a large data set, including multiple cloud types and finely labelled the cloud images, is much more difficult and expensive because annotating the cloud images needs professional experts with rich observing experience. The advantage of our model is that a very high prediction accuracy can be obtained with a small number of training samples, which is demonstrated in Section 3.2. Furthermore, the proposed method is tested on two datasets captured by different devices (SWIMCAT dataset and *zenithal* dataset). The SWIMCAT dataset is published by the Vision & InterAction Group (part of the School of Computing at the National University of Singapore) and has now been used as benchmark for cloud classification by most researchers. The *zenithal* dataset published by our team is also available to community. In order to exhibit the diversity of clouds, we showed more sample images in Fig. 2 and Fig.3 in the latest manuscript.

4. Overall Weaknesses: The relevance of the paper to outstanding and important issues in weather and climate is not made in a compelling fashion. Along this same line, the output of the classification algorithm does not contain quantitative information on fundamental hydrometeor properties. Rather, it provides classifications of cloud patterns whose fundamental importance are unknown. As a result, the significance of the results to weather and climate problems is not clear. Finally, the datasets used in the study are relatively small and of unknown diversity and significance. From a purely algorithmic development perspective, testing it on accepted datasets for algorithm evaluation would be much more compelling.

Reply: Many thanks for your overall comments. Cloud characteristics like quantitative information and hydrometeor properties need to be acquired by other detection equipment, which is not the focus of this paper. In the last decade, dealing with the problem of cloud classification automatically from the perspective of computer vision has gradually become a trend. A few researchers have been engaged in this field, and almost of them have emphasized the importance of cloud classification for cloud observation [2, 3]. Thus, we believe the categorization of cloud patterns is quite crucial. This manuscript mainly focuses on the cloud image classification algorithm, so the way how the cloud types affect climate and weather is not described in detail. And the reply about the datasets has already been illustrated clearly in the former reply.

[2] Chen, T., Rossow, W. B., and Zhang, Y.: Radiative Effects of Cloud-Type Variations, J. Clim., 13, 264-286, 10.1175/1520-0442(2000)013<0264:reoctv>2.0.co;2, 2000.

[3] Zhang, J., Pu, L., Zhang, F., and Song, Q.: CloudNet: Ground-Based Cloud Classification With Deep Convolutional Neural Network, Geophys. Res. Lett., doi: 10.1029/2018GL077787, 2018a. 10.1029/2018GL077787, 2018

Once again, thank you very much for your creative comments and suggestions.