DETECTION OF CLOUD TYPE USING GROUND-BASED MEASUREMENTS OF GLOBAL SHORTWAVE RADIATION AND CLOUD BASE HEIGHT

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Keywords: CLOUD TYPE, GLOBAL RADIATION, CLOUD BASE HEIGHT.

INTRODUCTION

Clouds are of key importance for the Earth radiative budget. Besides, they play a relevant role for the physical and chemical processes in the boundary layer. One example is formation and growth of secondary organic aerosol. Plants emit biogenic volatile organic compounds (BVOC) that are further oxidized in the atmosphere. Part of these oxidized BVOC are low-volatility and extremely low volatile organic vapours contributing to aerosol particles formation and growth (Hallquist *et al*., 2009). Among the key atmospheric oxidants are O_3, OH-radicals and NO_3. In the presence of clouds, ultraviolet radiation is limited and OH-radicals production is less effective. The mechanism of oxidation due to OH-radicals is important for monoterpenes, which constitute the biggest fraction of BVOCs in boreal coniferous forests. Therefore, clouds may affect new particle formation and growth in forests imposing a limit on the production of organic vapours. Another important example is clouds effect on photosynthesis. A forest ecosystem can photosynthesise more effectively under diffuse radiation conditions, when more radiation penetrates inside the canopy (Gu *et al*., 2002). Ezhova *et al*. (2018) revealed ecosystem productivity increases of up to 30% under cloudy-sky conditions in boreal forests (as compared to clear sky and clean atmosphere). This increase is supposedly due to thin or patchy clouds; however, the corresponding cloud type and statistics pertaining to different types (i.e. how often different types of clouds can be found) have not been identified.

Our aim was to develop a simple algorithm for estimates of the cloud type using ground-based measurements at SMEAR II. The algorithm is based on the work of Duchon and O'Malley (1999). However, we used a different clear-sky radiation model (Ineichen, 2008), explicitly accounting for aerosol loading in the atmosphere, and in addition, we used the cloud base height (CBH) as a separate parameter in order to distinguish between the clouds on different levels.

METHODS

The algorithm we propose is essentially a simple 2D parallelepiped classifier (Tapakis and Charalambides, 2013). Following Duchon and O'Malley (1999), the clouds are classified based on two parameters: transparency and patchiness. Transparency, T, is the ratio of the measured shortwave global radiation to the modelled clear-sky radiation averaged over a characteristic time interval (we chose 21 min similar to Duchon and O'Malley, 1999). Transparency is equal to 1 if the sky is clear and it is close to 0 for an overcast sky. Patchiness, P, is the standard deviation of radiation measured with 1 min time resolution and scaled with respect to the clear-sky model. Patchiness is calculated for the same time interval of 21 min. To increase the classifier precision, we added CBH as an additional parameter influencing the decision on the cloud type: a running minimum of the lowest CBH was calculated for the same time window as T and P. Tests of the algorithm were performed using total sky images (TSI).

The TSI and ceilometer data were acquired from the Atmospheric Radiation Measurement (ARM) facility of the U.S. Department of Energy. Aerosol optical depth (AOD) and precipitable water (PW) data for the clear-sky model were provided by the Aerosol Robotic Network (AERONET). Another parameter used in the clear-sky model, the solar zenith angle, was calculated with the MIDC SPA calculator from the National Renewable Energy Laboratory (NREL). Global radiation was downloaded from the SMEAR II Hyytiälä forest station through the AVAA open data publishing platform.

First, we constrained rectangular areas in the (T,P)-plane pertaining to different cloud types and compared them to the results obtained by Duchon and O'Malley (1999). For this, we determined the cloud type using selected total sky images (TSI) along with the supplemental information on CBH. The latter was useful, in particular, for separating low-level and midlevel cumuli.

The analysis was performed for the daytime during the period between 1 May and 31 July, 2014. Due to the applications mentioned in the Introduction, we focused on the growing season. TSI/data pairs were randomly sampled. Initially we took a sample of 665 pairs. However, our analysis of CBH showed that low-level clouds prevail at the site. Therefore, another distinct sample of 320 pairs was taken with the condition that the minimum CBH at that time was more than 2 km – to ensure that mid and high level clouds were represented in the analysis. For each TSI/data pair the cloud type was determined primarily through visual inspection, with some consideration given to CBH, as mentioned above. The transparency, patchiness, and cloud base height were recorded along with the cloud type, which was placed into the categories: stratus, stratocumulus, cumulus, nimbostratus, altostratus, altocumulus, cirrus, cirrostratus, cirrocumulus, and clear sky. The results were displayed as scatter plots in (T,P)-plane separately for low, midlevel and high clouds. The cloud type groups were used to create rectangular segmentations of the (T,P)- plane for different cloud levels, giving us the parameter ranges for each cloud type.

The obtained parameter ranges were then implemented in the cloud type classification algorithm. A distinct sample of 204 TSI, including the running minimum and maximum cloud base heights in a 21 min window, was analysed and the cloud type determined through visual inspection. These cloud type classifications were compared to the results obtained with the algorithm in the matrix form, and the parameter ranges were further refined based on the matrix values. The classifications were compared in a new matrix after refining the algorithm.

CONCLUSIONS

We developed an algorithm for the detection of a cloud type based on measured shortwave radiation and cloud base height. Our algorithm allows distinguishing between seven classes of clouds, with some of them being separate conventional cloud types and others being clusters of cloud types, because it was not possible to separate their point locations in the (T,P)-plane. The seven classes we used were 1) stratus, 2) stratocumulus, 3) cumulus, 4) nimbostratus, 5) altostratus/altocumulus, 6) cirrus/cirrostratus/cirrocumulus and 7) cirrus/clear sky. Due to the additional parameter, CBH, we were able to distinguish between more cloud types as compared to the study by Duchon and O'Malley (1999), mainly because clouds at the different levels often correspond to the same area in (T,P)-plane. Our algorithm gives the correct cloud class in approximately 70% of the time as compared to 45% reported by Duchon and O'Malley (1999) and provides a good basis for the studies of cloud-related processes in the atmospheric boundary layer.

ACKNOWLEDGEMENTS

This work was supported by the Academy of Finland Centre of Excellence under grant 307331.

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