Radiative Cloud Fraction: Determination by high resolution photography from the surface looking upward

Stephen E. Schwartz
Brookhaven National Laboratory
ses@bnl.gov

Clouds greatly affect short- and longwave radiation transfer in the atmosphere and consequently climate. Hence it is essential that the amount and radiative influences of clouds be accurately represented in climate models. The conventional measure of the amount of cloud in a grid cell is cloud fraction, CF, the fraction of the surface area covered by cloud. CF is a commonly reported meteorological quantity, with a long record of surface observations, greatly augmented in the past several decades by satellite observations. Global cloud fraction determined from satellite measurements has systematically increased with time, a consequence not of secular increase in cloud fraction but of an increase with time in the sensitivity of active and passive satellite instruments. Such a situation raises the question of whether CF can be defined and how well it can be measured.

Commercially available digital cameras provide an unprecedented opportunity for detailed study of cloud structure from the surface, looking upward. Key attributes of such cameras include large number of pixels, (e.g., 3456 x 4608; 16 M pixel) yielding rich detail of spatial structure, high spatial resolution, and high dynamic range (16 bit in each of three color channels at visible wavelengths). In the work reported here two cameras were pointed vertically, typically with field of view FOV 21 × 29 mrad and 120 × 160 mrad, respectively, denoted here narrow field of view, NFOV, and wide field of view WFOV, corresponding, for cloud base at 1 km, to 21 × 29 m (NFOV) and 120 × 160 m (WFOV). For perspective, the FOV for the NFOV camera is 2 × 3 sun diameters and for the WFOV camera 11 × 15 sun diameters. Nominal angular dimension of a single pixel is 6 µrad for the NFOV camera and 34 µrad for the WFOV camera, corresponding, again for cloud height 1 km, to 6 mm and 34 mm, respectively. Such single-pixel resolution is some 3 to 5 orders of magnitude finer than that available in satellite imagery. Photography of clouds from the surface looking upwards affords the further advantage, relative to satellite imagery looking downward, that the background is black (space) with contributions to path radiance only from blue sky (Rayleigh scattering), aerosols, and clouds, without complication of surface-leaving radiance.

Here results are presented from measurements at the Department of Energy ARM site in north central Oklahoma in summer 2015. Even over the short distance scales examined, cloudiness within a single image is frequently highly variable. CF for a given image is frequently highly dependent (several tens of percent) on the quantity used as a discriminant (e.g., optical depth or color ratio), threshold, and resolution. This situation results ultimately from CF being determined based on a binary decision (cloud or no cloud) in individual pixels. To circumvent this problem an alternative, continuous color-based measure of cloud influence on downwelling radiance is proposed. This radiative cloud fraction, which is determined on a pixel-by-pixel basis and thus is presented as a two-dimensional image of a continuously varying quantity is insensitive to resolution and hence may be a much more useful measure of cloud radiative influence than conventional cloud area fraction.

Reference: Schwartz S. E., Huang D. and Vladutescu D. V. (2017). High-Resolution Photography of Clouds from the Surface: Retrieval of Optical Depth of Thin Clouds down to Centimeter Scales. *J. Geophys. Res. - Atmos.*, 2017. http://onlinelibrary.wiley.com/doi/10.1002/2016JD025384/abstract