Algorithm for the Determination of the Optical Depth and Lidar Ratio of Cirrus Clouds by Elastic Lidar Measurements

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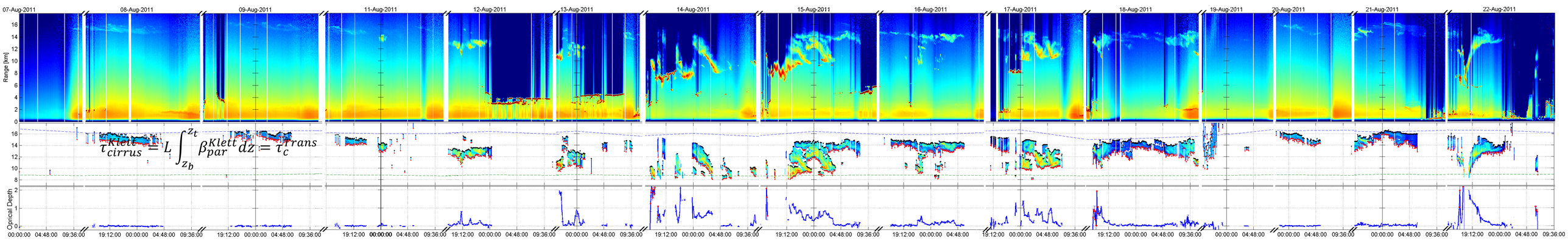


ABSTRACT

We present an algorithm for determination of cloud optical depth and average extinction-to-backscattering ratio (lidar ratio) of cirrus clouds from the elastic backscatter vertical profiles measured by lidar systems. The cirrus optical depth can be obtained from the transmission factor of the lidar equation for elastic backscattering by the evaluation of the attenuation caused in the lidar signal due to cirrus cloud. This method is known as the transmittance method, and requires no previous information of the lidar ratio of the cirrus cloud. An average value for the lidar ratio of this cloud can then be estimated by comparing the optical depth obtained by the transmittance method and the optical depth obtained by integrating the cloud extinction coefficient profile obtained by Klett-Fernald method, assuming that the optical depth by the two methods are equal when the true value of the lidar ratio of the cirrus cloud is used as input to the Klett-Fernald method. In order to validate the methodology, we performed computer simulations os cirrus clouds with COD varying from 0.01 to 0.4, and LR varying from 10sr to 40sr. The RMS error of the retrived COD and LR depends mostly on the lidar signal-to-noise ratio. As an application, we will present and discuss COD and LR obtained when applying the algorithm to cirrus clouds measured by a ground based lidar system in the Amazon forest region.

Theory: Cirrus Optical Depth and Lidar Ratio definitions

Rayleigh-Mie Lidar Equations:

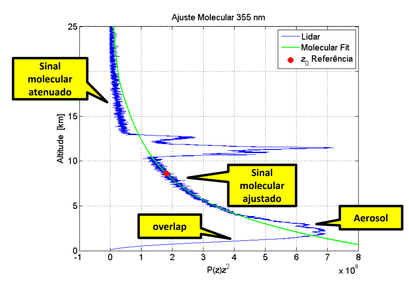
$$P(\lambda_0, z) = P_0 \frac{c\Delta_t}{2} A_{tel} \epsilon_{ef}(\lambda_0) \frac{O(z)}{z^2} \beta(\lambda_0, z) \exp\left[-2\int_0^z \alpha(\lambda_0, \zeta) d\zeta\right]$$

$$\beta(z) = \beta_{mol}(z) + \beta_{par}(z) \qquad L_{mol}(\lambda, z) = \frac{\alpha_{mol}(\lambda, z)}{\beta_{mol}(\lambda, z)}$$

$$\alpha(z) = \alpha_{mol}(z) + \alpha_{par}(z) \qquad L_{par}(\lambda, z) = \frac{\alpha_{par}(\lambda, z)}{\beta_{par}(\lambda, z)}$$

$$P(\lambda_0, z_0 + \Delta z) = CP_{mol}(\lambda_0, z_0 + \Delta z) + BG$$

$$\tau_c = \int_{z_b}^{z_t} \alpha_{par}(z') dz'$$

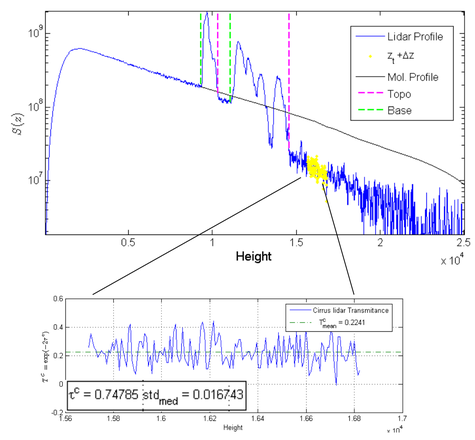


Lidar Inversion Technique: Cirrus Optical Depth and Extinction-to-Backscattering Ratio

$$\frac{S(z_t)}{S(z_b)} = \frac{\beta(z_t)}{\beta(z_b)} e^{-2\int_{z_b}^{z_t} \alpha_{par}(z')dz'} e^{-2\int_{z_b}^{z_t} \alpha_{mol}(z')dz'} \qquad z < z_b \text{ e } z > z_t \Rightarrow \alpha_p(z) \approx 0 \text{ e } \beta_p(z) \approx 0.$$

$$T_{cirrus} = e^{-2\int_{z_b}^{z_t} \alpha_{par}(z')dz'} = \frac{S(z_t)}{S(z_b)} \frac{\beta_{mol}(z_b)}{\beta_{mol}(z_t)} e^{-2\int_{z_b}^{z_t} \alpha_{mol}(z')dz'}$$

$$\tau_{cirrus} = \int_{z_b}^{z_t} \alpha_{par}(z')dz' = -\frac{1}{2}\ln(T_{cirrus})$$

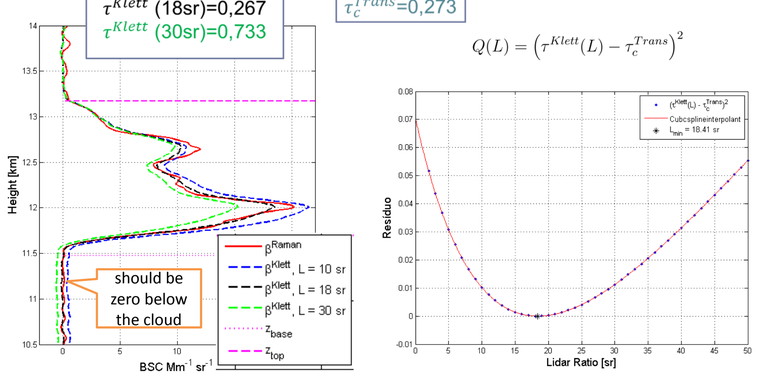


$$\tau_{cirrus}^{Klett} = L\int_{z_b}^{z_t} \beta_{par}^{Klett} dz = \tau_c^{Trans}$$

τ^{Klett} (10sr)=0,167
τ^{Klett} (18sr)=0,267
τ^{Klett} (30sr)=0,733

τ_c^{Trans}=0,273

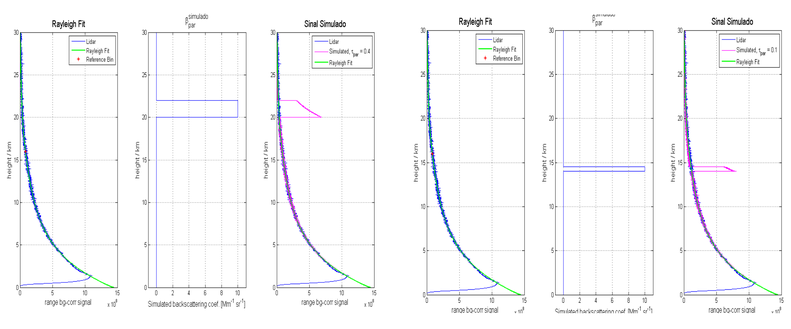
$$Q(L) = \left(\tau^{Klett}(L) - \tau_c^{Trans}\right)^2$$

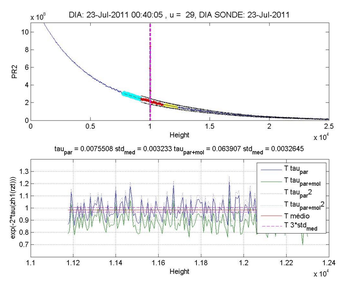


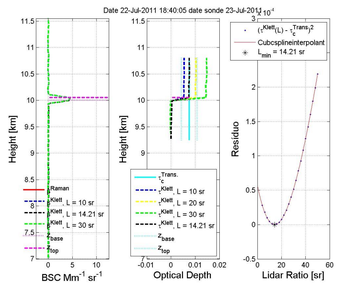
Cloud Simulation

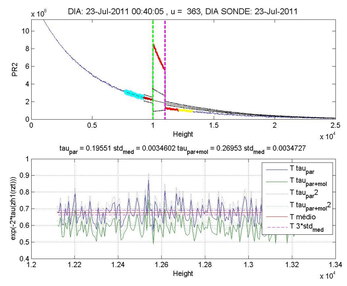
$$\beta^{simulado} = \beta + \beta_{par}^{simulado}$$

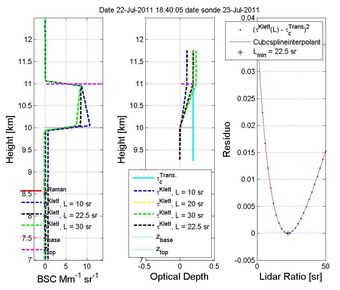
$$a^{simulado} = \alpha + \alpha_{par}^{simulado}$$

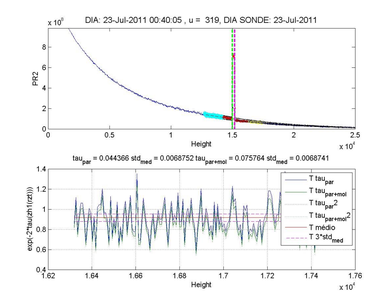


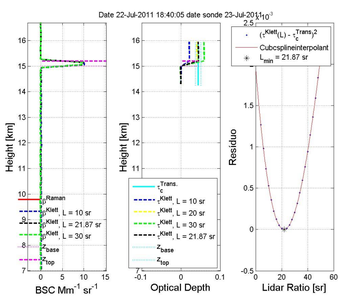




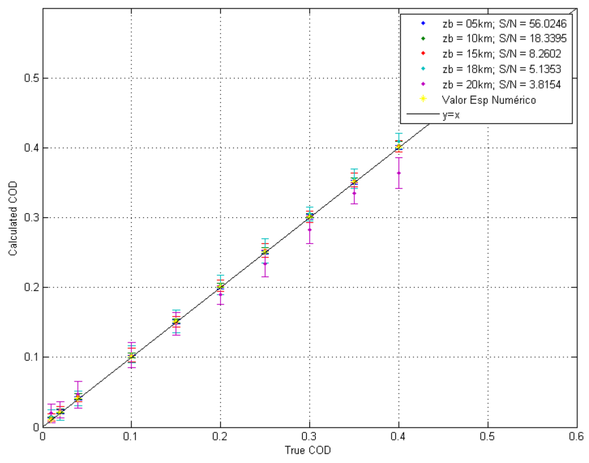


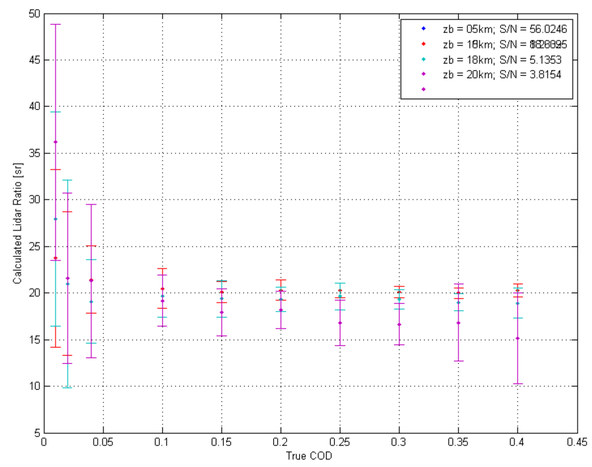


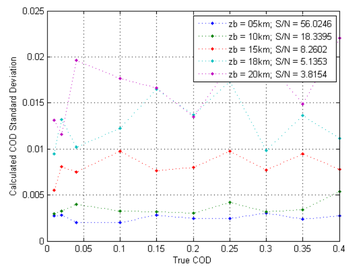


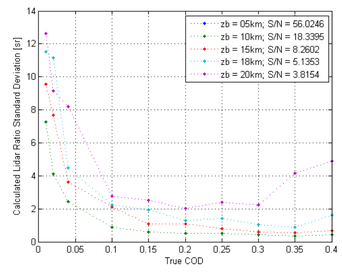


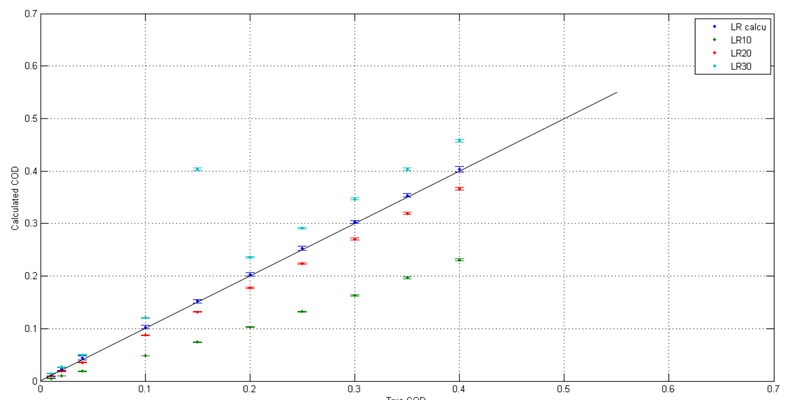
Results

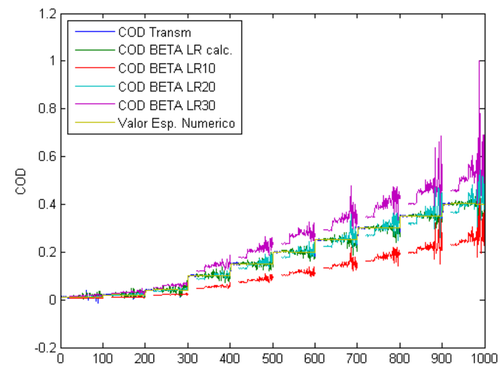












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