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Empirical model of multiple-scattering effect on single-wavelength lidar data of aerosols and clouds

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Figure S1 shows examples of the multiple-scattering relative contributions to lidar signals, i.e., the ratios R_{2to1} and R_{MSto1}. The ground-based lidar is at the altitude h=0 km, the layer is within the altitude h range of [8 – 11] km. The optical thickness of the layer is $\tau = 3.0$, that is, the extinction coefficient is of 1.0 km^{-1}. The distance to the layer base is of 8 km. The number of photons emitted by the lidar was of $4 \cdot 10^{10}$. Figures S1(a – d), i.e., the left hand column, correspond to the full RFOV of the lidar of 1.0 mrad. The right hand column, i.e., Figs. S1(e – h) corresponds to the full RFOV of 0.25 mrad. The red and black points represent the MC data, computed for double and multiple scattering, respectively. The MC data were fitted by the $V(d, \boldsymbol{a})$ function, that is, we computed the values of the free parameters $\boldsymbol{a} = \{a_1, a_2, a_3\}$ using the ordinary least squares approach. The blue and green lines in Fig. S1 show the fitting curves. It is seen that the empirical model fits well not only the multiple scattering contribution, but also the double-scattering part.

Tables S1 – S8 provide the values of the fitting parameters $\boldsymbol{a} = \{a_1, a_2, a_3\}$ for the cases discussed in the paper.

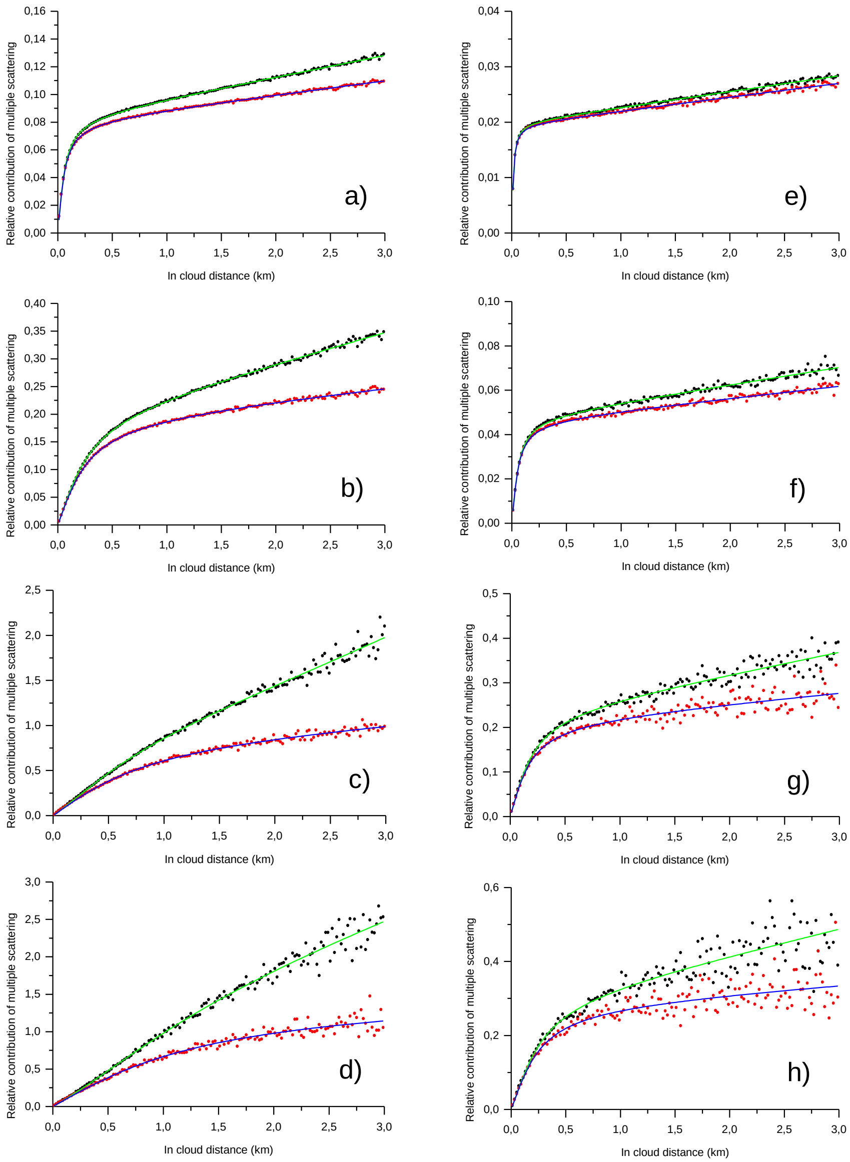

Figure S1. Double (red points and blue lines) and multiple (black points and green lines) scattering contributions to lidar signals. Full RFOV is of 1.0 mrad (a – d) and of 0.25 mrad (e – h). Coarse-aerosol (a, e), water cloud (b, f), JS cirrus (c, g), Ci cirrus (d, h). Extinction coefficient is of 1.0 km^{-1}.

Table S1. Fitting coefficients of the empirical model. The distance to the cloud base is of 8 km. RFOV = 1.0 mrad

$\varepsilon_p(h)$ (km^{-1})	Coarse aerosol			Water cloud			Jet-stream cirrus			Ci cirrus		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.06							3.47E-02	1.44	4.62E-03	4.19E-02	1.10	6.92E-03
0.20	1.04E-02	18.32	2.08E-03	2.59E-02	4.19	4.42E-03	1.30E-01	1.26	8.77E-03	1.78E-01	0.90	6.10E-03
0.50	2.59E-02	18.11	5.60E-03	6.25E-02	4.27	1.36E-02	2.42E-01	1.60	6.22E-02	3.20E-01	1.11	6.82E-02
1.00	5.13E-02	18.36	1.36E-02	1.20E-01	4.42	3.96E-02	4.53E-01	1.62	1.58E-01	7.54E-01	0.96	1.04E-01

Table S2. Fitting coefficients of the empirical model. The distance to the cloud base is of 8 km. RFOV = 0.25 mrad

$\varepsilon_p(h)$ (km^{-1})	Coarse aerosol			Water cloud			Jet-stream cirrus			Ci cirrus		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.06							8.05E-03	7.11	1.59E-03	1.10E-02	5.12	1.58E-03
0.20	2.54E-03	71.96	4.87E-04	6.16E-03	18.70	1.08E-03	2.90E-02	5.64	3.98E-03	3.78E-02	4.35	4.12E-03
0.50	6.29E-03	71.53	1.29E-03	1.52E-02	17.89	2.83E-03	6.67E-02	6.83	1.50E-02	9.13E-02	4.53	1.38E-02
1.00	1.26E-02	69.76	2.74E-03	2.99E-02	18.55	7.18E-03	1.38E-01	6.11	3.49E-02	1.74E-01	4.50	4.55E-02

Table S3. Fitting coefficients of the empirical model. The distance to the cloud base is of 1 km. RFOV = 1.0 mrad

$\varepsilon_p(h)$ (km^{-1})	Coarse aerosol			Water cloud			Jet-stream cirrus			Ci cirrus		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.06							4.26E-03	10.70	5.35E-03	5.21E-03	8.83	6.52E-03
0.20	1.28E-03	128.70	2.03E-03	3.08E-03	40.07	4.65E-03	1.20E-02	16.22	1.96E-02	1.54E-02	12.14	2.28E-02
0.50	3.19E-03	134.31	5.13E-03	7.18E-03	43.85	1.21E-02	3.03E-02	14.19	4.90E-02	3.87E-02	9.55	5.85E-02
1.00	6.28E-03	150.74	1.05E-02	1.38E-02	49.96	2.56E-02	5.69E-02	16.70	1.07E-01	6.62E-02	13.28	1.35E-01

Table S4. Fitting coefficients of the empirical model. The distance to the cloud base is of 1 km. RFOV = 0.25 mrad

$\varepsilon_p(h)$ (km^{-1})	Coarse aerosol			Water cloud			Jet-stream cirrus			Ci cirrus		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.06							1.20E-03	23.16	1.38E-03	1.53E-03	37.31	1.68E-03
0.20	3.26E-04	357.31	4.77E-04	7.57E-04	171.33	1.13E-03	2.87E-03	124.84	5.42E-03	3.87E-03	63.90	6.37E-03
0.50	7.85E-04	282.96	1.25E-03	1.77E-03	161.66	2.97E-03	8.38E-03	49.51	1.29E-02	1.09E-02	31.88	1.58E-02
1.00	1.54E-03	592.47	2.52E-03	3.53E-03	172.87	5.92E-03	1.61E-02	70.99	2.69E-02	1.88E-02	71.42	3.58E-02

Table S5. Fitting coefficients of the empirical model. The CALIOP configuration.

$\varepsilon_p(h)$ (km^{-1})	Coarse aerosol			Water cloud			Jet-stream cirrus			Ci cirrus		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.06							1.01E-02	2.925	4.76E-02	7.50E-03	3.310	4.87E-02
0.20	8.73E-02	2.156	6.51E-03	1.24E-01	0.602	4.17E-02	4.30E-02	1.931	1.51E-01	2.70E-02	3.148	1.56E-01
0.50	2.19E-01	2.087	3.81E-02	3.17E-01	0.524	1.26E-01	8.74E-02	2.234	3.96E-01	5.03E-02	3.382	4.10E-01
1.00	3.63E-01	2.426	1.52E-01	3.94E-01	0.543	4.01E-01	1.47E-01	2.518	8.32E-01	7.40E-02	4.836	8.70E-01

Table S6. Fitting coefficients of the empirical model. The ATLID configuration.

$\varepsilon_p(h)$ (km^{-1})	Coarse aerosol			Water cloud			Jet-stream cirrus			Ci cirrus		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.06							5.45E-02	0.665	2.31E-02	3.38E-02	0.696	3.48E-02
0.20	4.69E-02	4.380	2.34E-03	9.95E-02	1.068	1.05E-02	1.08E-01	0.956	9.47E-02	7.71E-02	0.906	1.24E-01
0.50	1.15E-01	4.319	9.28E-03	2.35E-01	0.995	2.94E-02	4.46E-01	0.628	1.84E-01	2.38E-01	0.708	2.92E-01
1.00	2.14E-01	4.603	4.26E-02	3.60E-01	1.097	1.32E-01	7.24E-01	0.692	4.37E-01	3.70E-01	0.831	6.29E-01

Table S7. Fitting coefficients of the empirical model. The CALIOP configuration.

$\varepsilon_p(h)$ (km^{-1})	Water cloud		
	a_1	a_2	a_3
1.0	0.3094	0.6269	0.4269
2.0	-0.1754	0.5236	1.4309
5.0	-1.7236	1.1859	5.9731
10.0	-1.7160	2.6726	13.7002

Table S8. Fitting coefficients of the empirical model. The distance to the cloud base is of 8 km.

RFOV (mrad)	Water cloud		
	a_1	a_2	a_3
5	0.4198	0.8536	0.2192
10	0.4795	0.4268	0.4021
20	-0.0441	0.6590	0.6863
50	-1.2715	0.2620	1.1000