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Light scattering properties of quartz particles in seawater

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Abstract — Existing models of seawater optical properties [1] usually do not explicitly include quartz particles. These models are good for open ocean waters and biologically stable coastal waters but fail to adequately predict optical properties of coastal waters with shallow sandy bottoms. In this paper we try to fill this gap by extending our previous optical model of quartz suspensions in seawater [2] by including calculations of all inherent optical properties.

INTRODUCTION

In our model we consider quartz to be a non-absorbing scattering matter with a relative refraction index equal to 1.25. The calculations of scattering coefficient for quartz particles with the size parameters ranging from 48 to 20,000 have been performed and published earlier [2]. Here we calculate all inherent optical properties of quartz particles with size parameters ranging from 17.6 to 61,000. To accomplish this task a special Mie scattering program was written in Pascal [3]. This program is capable of computing Mie scattering coefficients on spherical particles with size parameters up to one billion.

CALCULATIONS

To simplify the algorithm we pre-calculated all optical properties of quartz particles for bin sizes given in Tab. 1 and wavelengths corresponding to the AC-9 probe [4]. The calculations were made for 201 particle sizes evenly distributed over bin at 363 scattering angles. The backscattering probability B was obtained by direct numerical integration of the phase function. All results obtained for each bin were averaged. The results of these calculations are presented in Figs. 1-5. Because the spectral dependence of phase functions and other parameters was relatively weak (see Figures 1-5) we averaged all results over all spectral bands and presented them in the form of Tables 2 and 3. These tables give us the following simple algorithm to compute scattering properties of quartz particles suspended in seawater. The input parameters to this algorithm are five concentrations of quartz particles $\{N_i, i=1,..,5\}$ corresponding to five size bins given in Table 1.

Probability of backscattering is calculated according to:

$$B = N_0^{-1} \sum_{i=1}^{5} N_i \langle B \rangle_i , \qquad N_0 = \sum_{i=1}^{5} N_i , \qquad (1)$$

Here N_i is a concentration of quartz particles in i-nth bin and N_0 is a total concentration of particles (in m^{-3}).

Table 1. Bin sizes in μm adopted from [2, 5].

Bin #	Bottom, μm	top, μm	middle, μm
1	2.0	9.0	4.2
2	9.0	41.2	19.2
3	41.2	189.5	88.4
4	189.5	870.6	406.1
5	870.6	4000.0	1866.1

Table 2. Optical properties [6] of quartz suspensions in chosen bins averaged over AC-9 wavelengths.

i	$\langle B \rangle_i$	σ_i, m^2	$\langle Q_{sca} \rangle_i$	$\langle \overline{\cos\theta}\, Q_{sca} \rangle_i$
1	1.2e-3	2.3e-10	2.146	0.880
2	8.5e-5	4.6e-9	2.051	0.904
3	3.8e-6	9.6e-8	2.018	0.912
4	1.7e-7	2.0e-6	2.006	0.914
5	8.2e-9	4.2e-5	2.001	0.915

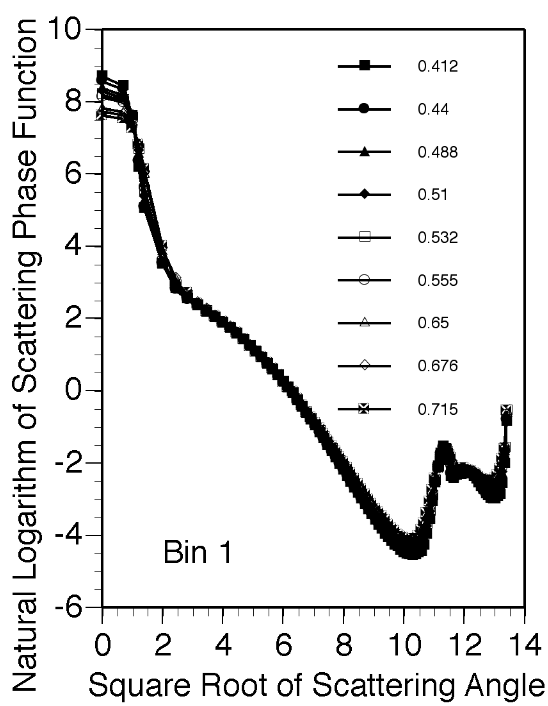

Fig. 1. Light scattering phase functions of quartz particles averaged over sizes in bin 1.

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Scattering b and backscattering b_B coefficients are calculated using the following equations:

$$b = N_0^{-1} \sum_{i=1}^{5} N_i \sigma_i , \quad \sigma_i = \left\langle \pi r^2 Q_{sca} \right\rangle_i , \quad b_B = b B, \quad (2)$$

here σ_i is a cross-section of scattering by one quartz particle (see Tab. 2) averaged inside each bin size and over AC-9 wavelengths.

The phase function of light scattering by quartz particles with the size distribution $\{N_i\}$ is given by

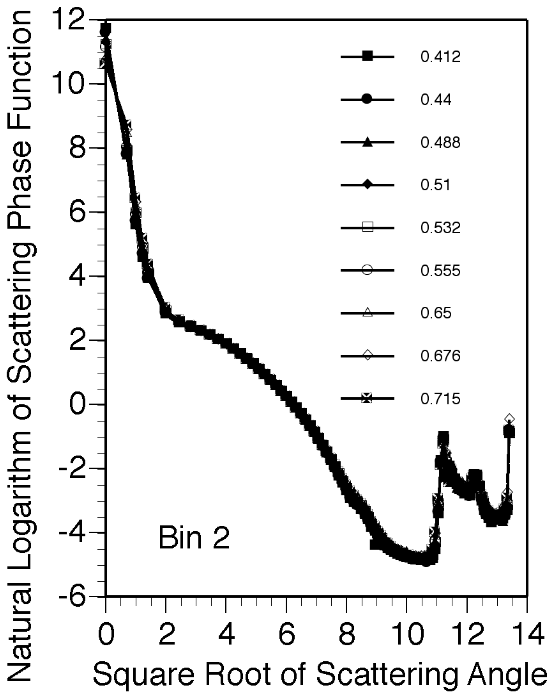

Fig. 2. Light scattering phase functions of quartz particles averaged over sizes in bin 2.

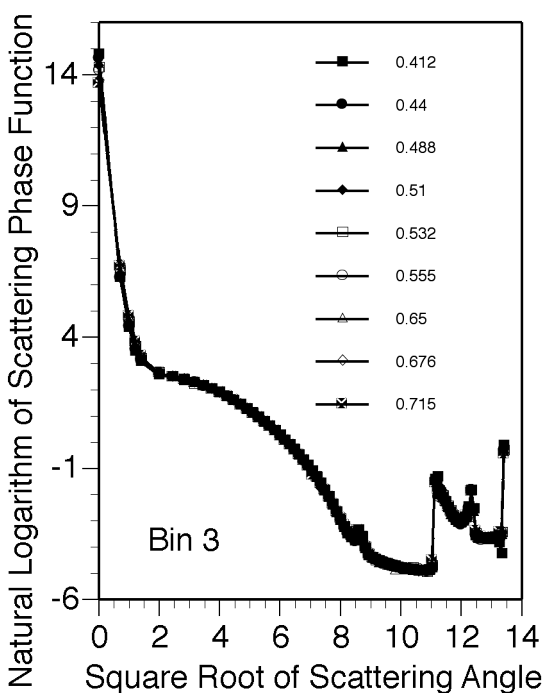

Fig. 3. Light scattering phase functions of quartz particles averaged over sizes in bin 3.

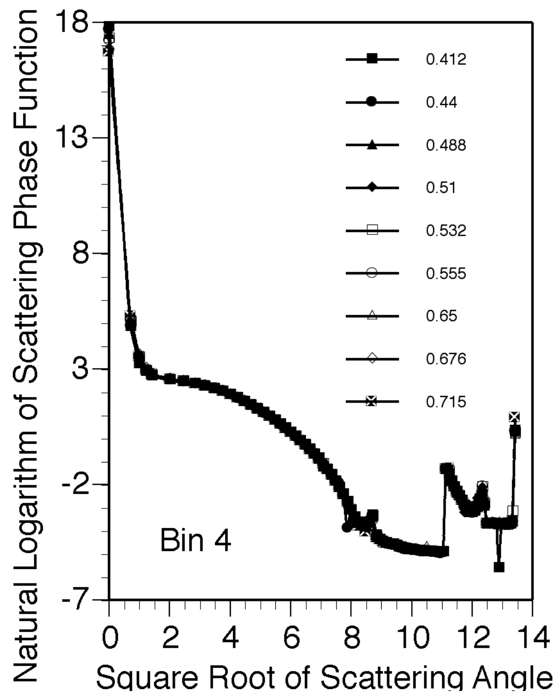

Fig. 4. Light scattering phase functions of quartz particles averaged over sizes in bin 4.

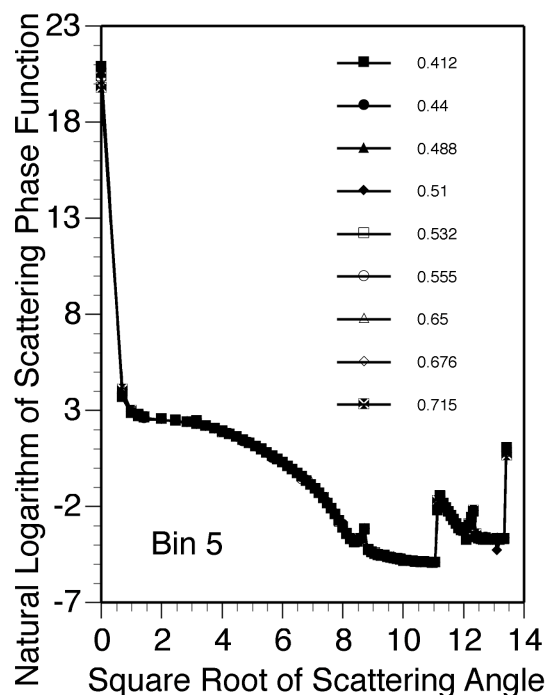

Fig. 5. Light scattering phase functions of quartz particles averaged over sizes in bin 5.

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Table 3. Natural logarithms of averaged phase functions of light scattering by quartz particles in seawater.

θ, °	$\mathrm{Ln}(\tilde{p}_1)$	$\mathrm{Ln}(\tilde{p}_2)$	$\mathrm{Ln}(\tilde{p}_3)$	$\mathrm{Ln}(\tilde{p}_4)$	$\mathrm{Ln}(\tilde{p}_5)$
0	8.150	11.157	14.197	17.243	20.291
2	5.540	4.066	3.157	2.720	2.586
4	3.654	2.885	2.604	2.529	2.501
6	2.914	2.561	2.467	2.440	2.430
8	2.573	2.403	2.351	2.346	2.347
10	2.360	2.270	2.245	2.245	2.264
12	2.190	2.141	2.129	2.129	2.132
14	2.025	2.003	2.001	2.006	2.008
16	1.864	1.863	1.867	1.867	1.863
18	1.715	1.713	1.718	1.720	1.723
20	1.561	1.559	1.568	1.574	1.570
22	1.394	1.400	1.406	1.414	1.407
24	1.223	1.238	1.244	1.251	1.256
26	1.055	1.074	1.081	1.084	1.086
28	0.891	0.904	0.915	0.920	0.922
30	0.727	0.736	0.746	0.756	0.753
32	0.559	0.567	0.578	0.578	0.573
34	0.395	0.394	0.407	0.411	0.408
36	0.230	0.221	0.232	0.233	0.235
38	0.064	0.044	0.050	0.057	0.055
40	-0.100	-0.136	-0.132	-0.126	-0.126
42	-0.270	-0.318	-0.314	-0.312	-0.312
44	-0.441	-0.504	-0.503	-0.505	-0.514
46	-0.614	-0.694	-0.709	-0.704	-0.706
48	-0.784	-0.898	-0.914	-0.913	-0.896
50	-0.953	-1.101	-1.148	-1.144	-1.127
52	-1.122	-1.306	-1.362	-1.367	-1.363
54	-1.289	-1.522	-1.618	-1.605	-1.611
56	-1.459	-1.741	-1.858	-1.872	-1.874
58	-1.620	-1.965	-2.111	-2.131	-2.160
60	-1.783	-2.187	-2.398	-2.448	-2.450
62	-1.948	-2.419	-2.678	-2.899	-2.801
64	-2.104	-2.635	-2.963	-3.103	-3.122
66	-2.266	-2.842	-3.225	-3.457	-3.474
68	-2.427	-2.984	-3.451	-3.682	-3.746
70	-2.581	-3.088	-3.612	-3.782	-3.888
72	-2.729	-3.215	-3.703	-3.857	-3.881
74	-2.871	-3.361	-3.386	-3.719	-3.725
76	-3.014	-3.550	-3.642	-3.439	-3.230
78	-3.156	-3.747	-4.043	-4.309	-4.316
80	-3.299	-3.979	-4.306	-4.398	-4.431
82	-3.444	-4.104	-4.436	-4.490	-4.506
84	-3.563	-4.234	-4.499	-4.557	-4.572
86	-3.672	-4.366	-4.557	-4.598	-4.616
88	-3.787	-4.452	-4.612	-4.617	-4.596
90	-3.912	-4.525	-4.652	-4.667	-4.685
92	-4.008	-4.602	-4.686	-4.723	-4.733
94	-4.100	-4.629	-4.727	-4.759	-4.752
96	-4.166	-4.693	-4.783	-4.793	-4.790
98	-4.244	-4.726	-4.797	-4.814	-4.801
100	-4.305	-4.745	-4.821	-4.834	-4.847
102	-4.346	-4.783	-4.849	-4.862	-4.874
104	-4.356	-4.811	-4.865	-4.882	-4.888
106	-4.359	-4.829	-4.880	-4.898	-4.902
108	-4.353	-4.844	-4.886	-4.913	-4.921
110	-4.298	-4.849	-4.908	-4.902	-4.932
112	-4.151	-4.848	-4.926	-4.934	-4.949
114	-3.975	-4.851	-4.928	-4.936	-4.943
116	-3.699	-4.814	-4.927	-4.948	-4.955
118	-3.336	-4.732	-4.934	-4.961	-4.964
120	-2.913	-4.293	-4.916	-4.960	-4.967
122	-2.494	-3.184	-4.707	-4.939	-4.956
124	-2.125	-1.836	-1.503	-1.361	-1.974
126	-1.832	-1.144	-1.839	-1.489	-1.508
128	-1.657	-1.862	-1.890	-1.881	-1.878
130	-1.644	-2.145	-2.094	-2.125	-2.123
132	-1.803	-2.221	-2.304	-2.334	-2.327
134	-2.104	-2.377	-2.501	-2.512	-2.516
136	-2.315	-2.495	-2.679	-2.722	-2.736
138	-2.317	-2.573	-2.832	-2.965	-2.951
140	-2.261	-2.645	-2.966	-3.106	-3.152
142	-2.242	-2.705	-3.048	-3.220	-3.285
144	-2.232	-2.757	-3.076	-3.209	-3.304
146	-2.238	-2.761	-2.995	-3.160	-3.258
148	-2.263	-2.461	-2.865	-2.948	-2.989
150	-2.294	-2.239	-2.695	-2.677	-2.642
152	-2.346	-2.298	-1.871	-2.276	-2.277
154	-2.404	-2.579	-2.579	-2.855	-3.579
156	-2.467	-2.933	-3.510	-3.714	-3.736
158	-2.537	-3.215	-3.669	-3.727	-3.739
160	-2.611	-3.384	-3.693	-3.724	-3.750
162	-2.686	-3.475	-3.698	-3.716	-3.697
164	-2.718	-3.538	-3.707	-3.728	-3.753
166	-2.751	-3.563	-3.703	-3.954	-3.767
168	-2.771	-3.566	-3.700	-3.760	-3.766
170	-2.742	-3.575	-3.702	-3.746	-3.768
172	-2.656	-3.527	-3.694	-3.733	-3.794
174	-2.534	-3.517	-3.698	-3.734	-3.761
176	-2.198	-3.381	-3.644	-3.713	-3.757
178	-1.702	-3.137	-3.590	-3.588	-3.716
180	-0.710	-0.856	-0.330	0.313	0.830

$$p_q(\theta) = N_0^{-1} \sum_{i=1}^{5} N_i \, \tilde{p}_i(\theta) \qquad (3)$$

here $\tilde{p}_i(\theta)$ are averaged phase functions of scattering given in Tab. 3.

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