SCATTERING OF LIGHT BY SAND GRAINS SUSPENDED IN SEAWATER

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Abstract

Existing models of sea water optical properties usually do not explicitly include sand or 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 [1] to include sand suspensions in sea water.

Introduction

In our model we consider sand (quartz) grains to be a non-absorbing scattering matter with a relative to water refraction index equal to 1.157. The calculations of scattering coefficient for 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, 4]. This program is capable of computing Mie scattering coefficients by spherical particles with size parameters up to one billion.

Calculations and Algorithm

To simplify the algorithm we pre-calculated all optical properties of quartz particles for the five bin sizes given in Table 1 and nine wave lengths corresponding to the widely used AC-9 probe [5]. The calculations have been made for 201 particle sizes evenly distributed over bin at 363 scattering angles. It was found that the spectral dependence of phase functions of sand in visible spectrum is very weak (see, for example, Fig. 1). All results obtained for each bin have been averaged over following wavelengths of AC-9 probe: 412, 440, 488, 510, 532, 555, 650, 676, and 715 nm. The results of these calculations are presented in Fig. 2 and Table 2.

Table 1. Bin sizes in μm adopted from [2, 6].

Bin # i	Bottom, μm	Top, μm	Average $\bar{a}_i$, 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

The analysis of computed results gives us the following simple algorithm to calculate scattering properties of sand grains suspended in sea water. The input parameters to this algorithm are the number of grains in cubic volume $\{N_i, i = 1,..,5\}$ that correspond to the five size bins given in Table 1.

Scattering phase function of sand grains suspended in water is calculated according to:

$$p_{sand}(\vartheta) = \sum_{i=1}^{5} p_i(\vartheta)\bar{a}_i^2 N_i \Big/ \sum_{i=1}^{5} \bar{a}_i^2 N_i, \tag{1}$$

here $p_i(\vartheta)$ is a scattering phase function that corresponds to bin i (see Fig. 2 and Tab. 2*)*, $\bar{a}_i$ is the average size of grains in bin i (see Table 1).

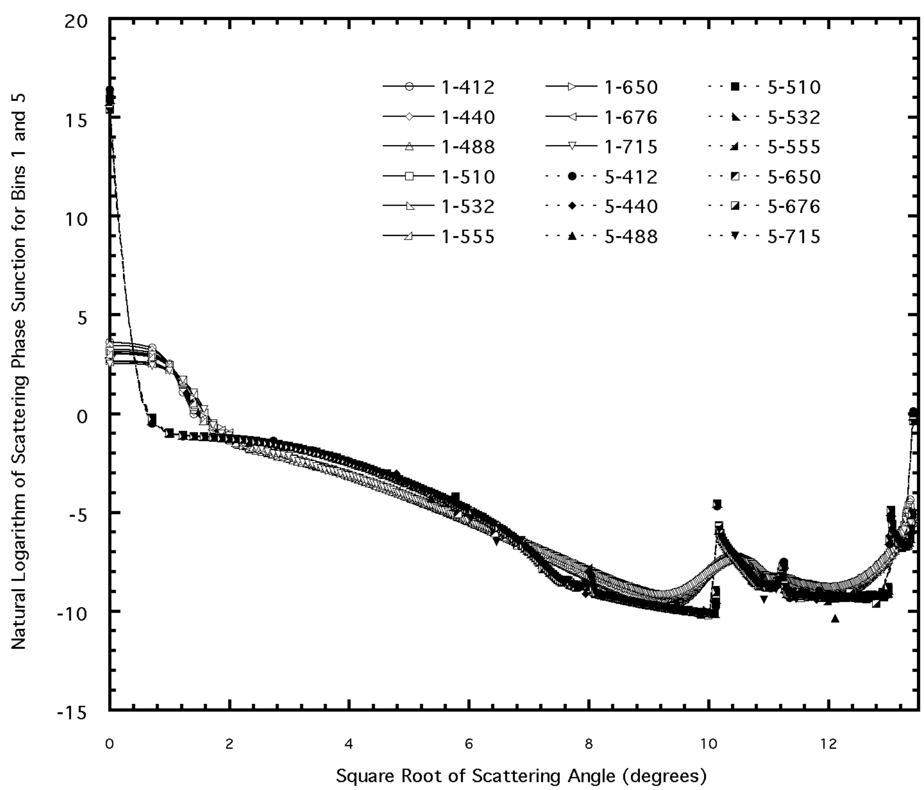

Figure 1. Light scattering phase functions of sand grains for the first and the last bins.

Table 2. Averaged over nine AC-9 wavelengths phase function of light scattering by sand grains for size bins given in Tab. 1.

$\sqrt{\vartheta^\circ}$	ϑ°	$Ln(p_1(\vartheta))$	$Ln(p_2(\vartheta))$	$Ln(p_3(\vartheta))$	$Ln(p_4(\vartheta))$	$Ln(p_5(\vartheta))$
0.0000	0.0000	3.0343	6.4171	9.6793	12.773	15.830
0.70515	0.49724	2.8714	3.3531	2.0051	0.66604	-0.36950
0.99723	0.99448	2.3679	1.2800	0.18396	-0.63459	-1.0072
1.2214	1.4917	1.5026	0.18604	-0.57074	-0.97354	-1.1166
1.4103	1.9889	0.49354	-0.44923	-0.89687	-1.0935	-1.1539
1.5768	2.4862	-0.17937	-0.83814	-1.0516	-1.1530	-1.1761
1.7273	2.9834	-0.62185	-1.0653	-1.1525	-1.1881	-1.2077
1.8657	3.4807	-0.94940	-1.2263	-1.2166	-1.1837	-1.2321
1.9945	3.9779	-1.1977	-1.3351	-1.2689	-1.2591	-1.2642
2.6384	6.9613	-1.9543	-1.7138	-1.5248	-1.4829	-1.4706
3.2314	10.442	-2.4401	-2.0909	-1.8668	-1.8241	-1.8162
3.6641	13.425	-2.8225	-2.4369	-2.2138	-2.1630	-2.1515
4.0508	16.409	-3.1844	-2.7985	-2.5662	-2.5285	-2.5087
4.6240	21.381	-3.7817	-3.4081	-3.1936	-3.1273	-3.1064
5.0358	25.359	-4.2599	-3.8909	-3.6614	-3.6093	-3.5989
5.2295	27.348	-4.4869	-4.1310	-3.9018	-3.8494	-3.8417
5.5970	31.326	-4.9306	-4.6076	-4.3860	-4.3355	-4.3252
6.0248	36.298	-5.4605	-5.2100	-5.0269	-4.9628	-5.0095
6.6149	43.757	-6.2438	-6.1570	-6.0560	-6.0317	-6.0500
7.0162	49.227	-6.7809	-6.8862	-6.9507	-7.0016	-6.9900
7.6274	58.177	-7.6303	-7.9920	-8.2843	-8.4802	-8.4567
8.0090	64.144	-8.1703	-8.5987	-8.6292	-8.4932	-8.2580
8.6075	74.088	-8.9322	-9.4364	-9.4768	-9.4598	-9.4536
8.8073	77.569	-9.1550	-9.6338	-9.6147	-9.5852	-9.5773
9.0028	81.050	-9.3099	-9.7960	-9.7319	-9.6959	-9.6919
9.2210	85.028	-9.4206	-9.9325	-9.8480	-9.8152	-9.8035
9.4079	88.508	-9.3845	-10.020	-9.9450	-9.9035	-9.8914
9.6170	92.486	-9.1067	-10.066	-10.029	-9.9848	-9.9828
9.8216	96.464	-8.6039	-9.7655	-10.095	-10.066	-10.055
10.022	100.44	-8.0031	-8.1412	-9.6411	-10.125	-10.114
10.219	104.42	-7.5084	-6.4856	-6.1157	-6.3846	-6.3219
10.411	108.40	-7.2795	-7.5497	-7.1787	-7.1929	-7.1678
10.601	112.38	-7.4782	-7.7407	-7.7787	-7.8573	-7.8664
10.810	116.85	-8.1281	-8.0863	-8.2946	-8.4747	-8.5896
11.015	121.33	-8.2984	-8.2904	-8.5674	-8.6579	-8.7895
11.216	125.80	-8.4437	-8.5045	-8.2522	-7.8788	-8.2026
11.414	130.28	-8.6185	-8.8694	-9.0655	-9.1867	-9.2002
11.608	134.75	-8.7541	-9.1354	-9.2585	-9.2512	-9.2381
11.820	139.72	-8.8880	-9.3288	-9.3087	-9.2833	-9.2686
12.008	144.20	-8.9389	-9.4165	-9.3223	-9.2928	-9.2970
12.214	149.17	-8.9122	-9.4610	-9.3364	-9.3028	-9.2951
12.395	153.65	-8.7625	-9.3922	-9.3408	-9.3055	-9.2823
12.594	158.62	-8.4134	-9.2111	-9.3182	-9.2886	-9.2715
12.790	163.59	-7.9624	-8.5460	-9.2103	-9.2197	-9.2733
12.983	168.56	-7.3193	-7.2281	-7.3770	-8.5304	-9.1078
13.192	174.03	-6.3652	-6.0109	-6.6160	-6.5027	-6.5610
13.416	180.00	-5.2226	-4.2644	-2.8859	-1.6434	-0.18220

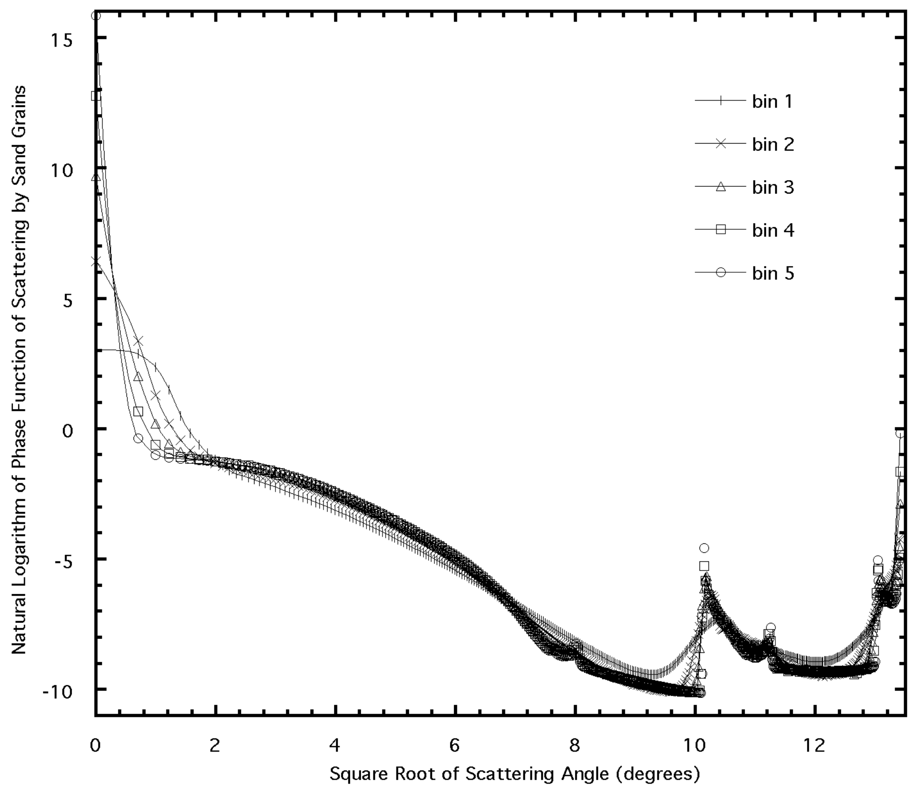

Figure 2. Light scattering phase functions of sand for five size bins given in Tab. 1. averaged over nine AC-9 wavelengths.[5]

The beam scattering coefficient due to the sand grains is expressed through the following equation:

$$b = \sum_{i=1}^{5} Q_{si}\,\bar{a}_i^2 N_i, \quad Q_{si} = 2.1182(\bar{a}_i / a_0)^{-0.008773}, \quad N_0 = \sum_{i=1}^{5} N_i. \tag{2}$$

Here N_0 is the total number of grains (in m^{-3}), and $a_0 = 1$ in units used to represent $\bar{a}_i$.

Conclusion

Analysis of computed results shows that the sand grain suspensions in sea water scatter light almost non-selectively adding gray component to the light ascending from the sea. The proposed simple equations (1) and (2) together with Tab. 2 allow us to expressly estimate the input of sand component into inherent properties of sea water.

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