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# Light scattering coefficient by quartz particles suspended in seawater

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**Abstract** — A fast algorithm to compute scattering coefficient of quartz particles is presented. The algorithm is based on a regression between scattering efficiency and size parameter. This regression relationship was obtained by analyzing results of extensive Mie calculations in the range of size parameters between 48 to 40,000. A FORTRAN subroutine to compute scattering and backscattering coefficients of quartz suspensions is released for public use.

## INTRODUCTION

Existing models of seawater optical properties [1, 2] usually do not explicitly include quartz particles. These models are good for open ocean waters but fail to adequately predict optical properties of coastal waters with shallow sandy bottom. In this presentation we try to fill this gap by proposing an optical model of quartz suspensions in seawater.

In this work we consider quartz as an nonabsorbing scattering matter. The extensive Mie scattering calculations for quartz particles with the size parameters ranging from 48 to 40,000 were performed [3-5]. By analyzing computed material we succeeded in obtaining two regression relationships that connect an efficiency factor and a backscattering probability with the size parameter for any monodisperse quartz particle size distribution. These regression relationships were used to create an extremely fast algorithm to compute spectral light scattering and backscattering coefficients for any polidisperse system consisting of quartz particles. A comparison with an independently derived data shows that the precision of this algorithm is adequate for model calculations.

## APPROACH

The scattering coefficient $b_q$ by a polidisperse ensemble of quartz particles may be expressed in the following form [6]:

$$b_q(\lambda) = \pi \int_0^\infty r^2 Q_{sca}^q (2\pi r / \lambda)\, N_q(r)\, dr, \quad \int_0^\infty N_q(r)\, dr = N_q^0, \quad (1)$$

here $r$ is a particle size, $N_q(r)$ is theparticle size distribution, $N_q^0$ is a total amount of quartz particle in a unity volume, $\lambda$ is a wavelength of light, and $Q_{sca}^q$ is the scattering efficiency for quartz particles [6]. The scattering efficiency $Q_{sca}^q(x)$ (here $x = 2\pi r / \lambda$ is a size parameter) in Eq. (1) is usually calculated with Mie scattering code. In numeric calculations, size distributions $N_q(r)$ are represented by the number of size bins. In order to be realistic we have chosen a system of five bins adopted by T. R. Keen [7]. The bottom, top, and middle sizes of these bins in µm are given in Tab. 1.

In order to calculate the quartz scattering efficiency as a function of size parameter $x$ we estimated the range of variability of $x$ for all 5 bins in the range of wavelengths $\lambda$ characteristic to visible spectrum. In order to effectively eliminate "ripples" in $Q_{sca}^q$ reported by Dave [8] we divided every bin's interval of $x$'s into 100 parts, calculated efficiencies at 101 points inside each bin and averaged them. The result was assigned to an average bin's size parameter. The first four bins were processed using Wiscomb's code [4]. Unfortunately, this popular code [4] fails at a majority of size parameters characteristic to bin 5. From the literature [9] it is known that the problem of stability of Mie calculations at large values of Mie size parameter $x$ may be successfully resolved. Because we have no access to the code reported in Ref. [9], one of the authors (Shybanov) created his own Mie

Table 1. Bin sizes in µm adopted by T. R. Keen in his hydrodynamic model [7].

| 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 |

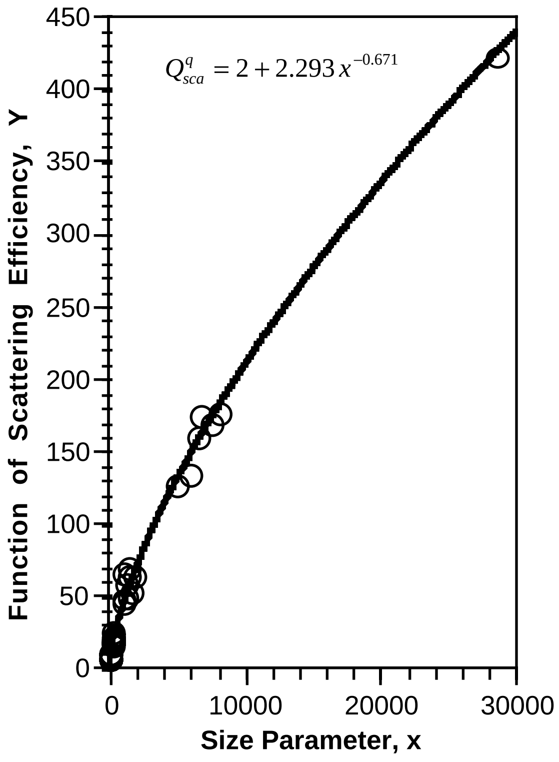

Figure 1. Function $Y = \left(\overline{Q^q_{sca}} - 2\right)^{-1}$ of averaged scattering efficiency as a function of size parameter $x$.

code which is stable up to the values of $x$ close to one billion [5]. Using Shybanov's program MBP we calculated the scattering efficiencies for the largest fifth bin. The results of all averaged calculations are displayed in Fig. 1.

The regression of data presented in Fig. 1 gives us the following formula for the scattering efficiency by quartz particles:

$$Q^q_{sca} = 2 + 2.293\,x^{-0.671}, \qquad 48 \le x \le 4\cdot 10^4,\ \ r^2 = 0.9875. \tag{2}$$

Table 2. Comparison of methods to calculate the total scattering coefficient of quartz-like material [10].

| Station number | Elevation from bottom | $b_q(532), m^{-1}$ this appr. | $b_q(532), m^{-1}$ Mie polydis. |
|---|---|---|---|
| SCM2 | 0.05 | 2.84 | 2.82 |
| SCM2 | 0.53 | 0.0799 | 0.0771 |
| SCM2 | 1.21 | 0.413 | 0.412 |
| OS15 | 0.05 | 3.078 | 3.082 |
| OS14 | 1.27 | 0.327 | 0.328 |
| OS8 | 8.14 | 0.002014 | 0.002018 |

Equations (1) and (2) constitute an algorithm to calculate the scattering coefficient for an ensemble of quartz scattering particles. This algorithm is implemented as a FORTRAN subroutine `quartzopt` given in APPENDIX.

## VALIDATION

The algorithm `quartzopt` was validated [10] by comparing direct Mie scattering calculations on an ensemble of experimentally measured quartz particle size distributions to the results of this algorithm. The comparison of two methods is given in Table 1. It is clearly seen that the discrepancy between our fast algorithm and conventional calculations is very small and practically insignificant.

## CONCLUSION

It is shown that the algorithm to compute scattering coefficient of quartz particles based on precalculated results of Mie scattering gives acceptable results and significantly (about 10,000 times) decreases time of modeling calculations.

The results presented here may be used in radiative transfer [11-14] and predictive visibility [7, 10] calculations.

## ACKNOWLEDGMENT

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## APPENDIX: A FORTRAN SUBROUTINE TO CALCULATE SCATTERING AND BACKSCATTERING COEFFICIENTS OF QUARTZ SUSPENSIONS

```
c ***************************************
      subroutine quartzopt(Nq, b, bB)
c ***************************************
c     written by Vladimir I. Haltrin
c       <haltrin@nrlssc.navy.mil>
c =======================================
c     Input: Size distribution of quartz
c     particles at 5 bins, Nq(1:5).
c     Output: Scattering and backscat-
c     tering coefficients b(1:9) and
c     bB(1:9) [in 1/m] for quartz
c     particles (nRfq/nRfw = 1.25) at 9
c     wavelengths which correspond to an
c     AC-9 meter.
c =======================================
```

```
c =======================================
c     Nq(i) a number of quartz particles
c     in bin i [in m^(-3)]
c     Qsca scattering efficiency for a
c     size parameter xx precalculated
c     with W. Wiscombe's and
c     E. Shybanov’s Mie codes and
c     regressed to a simple equation.
c     ar(i) average quartz particle radi-
c     us in bin (i) [in m] (see Table 1)
c     lm(1:9) wavelength of light for 9
c     channels of an AC-9 meter [in m].
c     b(i) scattering coefficient at
c     wavelength lm(i) [in 1/m].
c     bB(i) backscattering coefficient
c     at wavelength lm(i) [in 1/m].
c     precalculated for each size
c     parameter and regressed.
c =======================================
      implicit   none
      integer*2  i,j
      real*8     Nq(5),b(9),bB(9)
      real*8     ar(5),lm(9)
      real*8     bt,g,xx,Qsca,y,lam
      real*8     Pi,twoPi,ra
      data       ar /4.2e-6, 1.92e-5,
     &      8.84e-5, 4.061e-4, 1.8661e-3/
      data       lm /4.12e-7, 4.40e-7,
     &              4.88e-7, 5.10e-7,
     &              5.32e-7, 5.55e-7,
     &              6.5e-7, 6.76e-7,
     &              7.15e-7/

      Pi = 2.*ASIN(1.)
      twoPi = Pi+Pi
      do i = 1, 9
         lam = lm(i)
         bt = 0.
         g  = 0.
         do j = 1, 5
            ra = ar(j)
            xx = twoPi*ra/lam
          Qsca = 2.+ 2.293*(xx**(-0.671))
            bt = bt + Pi*ra*ra*Qsca*Nq(j)
            g = g + 1746.781 + xx*
     &          (-3.632333+0.01548126*xx)
         end do
          b(i)  = bt
         bB(i) = bt/g
      end do

      return
      end
c ***************************************
```

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