Project title	Aerosol Inherent optical properties
Title	Introducing the IOP in the 6S code
Deliverable	D11: Software on L_TOA computation, SLTOA
Version	0.5
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Modification history	8/10/2006, first draft
Distribution	Internal

1. Objectives

6S is a generic radiatif transfer tool to be used for calval activities over the ocean. Within the frame of this contract, one requirement is to input the aerosol IOPs into 6S. We develop in section two how to do it.

Over ocean, in 6S the water body contribution corresponds to ocean case 1 water with as input the chlorophylle concentration.It is relevant to input as well the marine reflectance as well as the remote sensing reflectance (RSR, the MERIS level 2 parameter). One easy evaluation of the improvement brings by the use of the CIMEL derived IOPs is:

(i) To have simultaneous CIMEL and MERIS measurements.
(ii) To derive the aerosol IOP from CIMEL
(iii) To run 6S with as input this IOPs and the level 2 RSR.
(iv) To compare this predicted MERIS TOA radiance with the measured one.

If simulated and measured MERIS TOA radiances are close, we then validate the current atmospheric correction algorithm implemented into the MERIS ground segment.

This approach was used by .

2. Introducing the aerosol IOPs into 6S

2.1 The output file from WOPAER

The standard output from the phase function retrieval program (WOPAER) is attached. The retrieval is only for one CIMEL spectral band.

2.2. The 6S option to input MIE files

In the aerosol model section of the 6S main program, it is possible to select specific user models as for example the Junge model *(iaer=10)*. One example of input file is given in annex 1. It is also possible to read a file with the aerosol inherent optical properties *(iaer=12)*. One example of such a file is given in annex 1. Therefore, the nex task is to prepare this input file.

```
c***********************************************************************c
c                                                                       c
c       iaer       aerosol model(type)                                  c
c                  --------------                                       c
c  you select one of the following standard aerosol models:             c
c         0  no aerosols
c        10 Junge Power-Law distribution
c  or you can use results computed and previously saved              c
c        12  Reading of data previously saved into FILE              c
c             you have to enter the identification name FILE in the    c
c             next line of inputs.                                c
c                                                         c
c                                                         c
c  iaerp and FILE  aerosol model(type)-Printing of results            c
c                  --------------------------------------           c
c                                                         c
c For iaer=8,9,10,and 11:                                          c
c    results from the MIE subroutine may be saved into the file        c
c    FILE.mie (Extinction and scattering coefficients, single        c
c    scattering albedo, Asymmetry parameter, phase function at         c
c    predefined wavelengths) and then can be re-used with the          c
c    option iaer=12 where FILE is an identification name you           c
c    have to enter.                                         c
c                                                         c
c    So, if you select iaer=8,9,10,or 11, next line following the      c
c    requested inputs by the options 8,9,10, or 11 you have to enter   c
c    iaerp                                                  c
c                                                         c
c        iaerp=0    results will not be saved                      c
c        iaerp=1    results will be saved into the file FILE.mie       c
c                   next line enter FILE                          c
c                                                         c
                                                         c
c***********************************************************************c
        read(iread,*) iaer
        goto(49,40,41,42,49,49,49,49,43,44,45,46,47),iaer+1
```

```
 47 read(5,'(A80)')FILE2
    i2=index(FILE2,' ')-1
    go to 49

 49 continue
    if (iaer.ge.8.and.iaer.le.11)then
     read(5,*)iaerp
     if (iaerp.eq.1)read(5,'(A80)')FILE
        i1=index(FILE,' ')-1
        FILE2=FILE(1:I1)//'.mie'
        i2=index(FILE2,' ')-1
      endif
```

2.3. Prepare the input file for 6S

Playing with the WOPAER outputs

When allowed by defined criteria, WOPAER will be simultaneously run for the three CIMEL bands: 440 nm, 670 nm and 870 nm. The three outputs files will be use as input in a preparation module doing:

(i) A quality check in each band. First the single scattering albedo should be between 0.6 and 1. Second, the convergence of the iterative process is juged on the multiple/single scattering factor *f* provides at 83 angles (80 Gaussian angles+ 0°+ 90°+180°). The maximum value of:

$$\Delta f / f(\Theta) = 100.abs(f_N(\Theta) - f_{N-1}(\Theta)) / f_N(\Theta)$$

can be not above 5% (TBC) and the mean value not above 2% (TBC).
If the quality check is not reach the process stop.

(ii) Compute the asymmetry parameter g, as required as 6S inputs

$$g(\lambda) = \int_{-1}^{1} P(\lambda, \mu)\mu \, d\mu$$

(iii) Normalize the aerosol phase function.

(iv) make a new output file with the three CIMEL bands with for each band, $\tau_a, \varpi_0, g, P(83\Theta)$.

Compution the IOPs at the 5S wavelengths

A preparation module should interpolate the above values in the 10 reference wavelengths of 6S (0.400,0.488,0.515,0.550,0.633,0.694,0.860,1.536,2.250,3.750).
Single scattering albedo and phase functions at 1.536, 2.250, 3.750 µm are those derived by WOPAER at 870 nm. Single scattering albedo and phase functions at 400 nm are those derived by WOPAER at 440 nm. Linear interpolations are done at 0.488, 0.515, 0.550, 0.633, 0.694 and 865 nm for WOPAER at 440 nm, 670 nm and 870 nm.

Making the 6S input file

The 6S input file (see annex 1) contents:

(i) The normalized extinction coefficient defined as: $\sigma_{ext}^{\lambda} = \tau_a(\lambda)/\tau_a(0.55\mu m)$.

(ii) The normalized scattering coefficient defined as: $\sigma_{scat}^{\lambda} = \sigma_{ext}^{\lambda} * \varpi_0^{\lambda}$

(iii) The single scattering albedo, already computed.

(iv) The asymmetry factor g, already computed.

(v) The extinction coefficient set to normalized extinction coefficient value.

(vi) The scattering coefficient set to normalized sattering coefficient value.

(vii) The phase function at 83 angles, already computed.

The format of the file is given in the 6S subroutine "aero":

```
       if (iaer.ge.8.and.iaer.le.11) then
        open(10,file=FILE)
         write(10,'(3x,A5,1x,5(1x,A10,1x),1x,A10)')'Wlgth',
     s'Nor_Ext_Co','Nor_Sca_Co','Sg_Sca_Alb',
     s'Asymm_Para','Extinct_Co','Scatter_Co'
         do 79 l=1,10
          write(10,'(2x,f6.4,4(3x,f6.4,3x),2(2x,e10.4))')
     s wldis(l),ext(l),sca(l),ome(l),gasym(l),ext(l)/nis,sca(l)/nis
 79      continue
          write(10,'(//,T20,A16,/,3x,A4,1x,10(3x,f6.4,2x))')
     s    ' Phase Function ','TETA',(wldis(l),l=1,10)
         do 76 k=1,83
          write(10,'(2x,f6.2,10(1x,e10.4))')180.*acos(cgaus(k))/pi,
     s                    (phasel(l,k),l=1,10)
 76      continue
         close(10)
```

3. 6S over oceanic sites

6S simulates the signal over the open ocean in an option where the BRDF is accounted for: The Fresnel reflection is convoluted by the wave slope distribution function of Cox and Muck and depends upon the wind speed and direction. The major limitation is that the chlorophyll concentration is the input to compute the water leaving signal. Instead, we can think about modifying the code to directly enter the remote sensing water reflectance (or water leaving radiance)

```
c          idirec=1 ( directional effect)             c
c                 select one of the selected model from the  c
c                 ibrdf value (see note2).
c note2: values of the directional reflectance is assumed spectrally   c
c       independent, so you have to specify, the brdf at the          c
c       wavelength for monochromatic condition of the mean value      c
c       over the spectral band                           c
c                                                 c
```

```
c         6  Ocean                                         c
c            the parameter are: pws,phi_wind,xsal,pcl                 c
c                pws=wind speed (in m/s)                          c
c                phi_wind=azim. of the wind (in degres)               c
c                xsal=salinity (in ppt) xsal=34.3ppt if xsal<0        c
c                pcl=pigment concentration (in mg/m3)                 c
```

The nominal 6S code only allows computing the water body contribution for ocean case 1 with as input the chlorophyll content. Annex 2 indicates how to select this value if no in situ measurements are available.

Annex 2 also proposes how to input measurement at sea of the marine reflectance and/or of the so-called remote sensing reflectance. In this last case, we suppose that the user is able to convert the usual water leaving radiance into this remote sensing reflectance.

4. 6S for MERIS

5. Looping on MERIS images

6. Example of applications

7. References

Project acronym	IOPA
Project title	Aerosol Inherant Optical Properties
Annex	1
Title	6S aerosol IOP
Version	0.1
Author(s) and affiliation(s)	R. Santer, Université du Littoral, France
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Distribution	Internal

The following input file allows to generate the Mie file which describes the aerosol IOPs.

```
0                             (specific user observation)
  30.0 0.0 0.0 0.0 6 21        (sza, saa, vza, vaa, month, day)
 2                             (MLS profile)
 10                             ([0] no aerosols, [10] Junge model)
0.1 10
4
1.44 1.44 1.44 1.44 1.44 1.44 1.44 1.44 1.44 1.44
0 0 0 0 0 0 0 0 0 0
1
"Junge"
23.0                           (visibility [km], [-1.] case no aerosol)
 0.0                           (surface altitude [km])
-1000.0                        (sensor altitude  [km])
 1                             (user's filter function)
  0.4550 0.5325                (wvl_inf,wvl_sup [mic.], and filter f(wvl) by
step of 0.0025mic.)
  0.157302067126 0.237884418760 0.266192487219 0.263898644143
0.258501889309 0.264289842187 0.308899755501 0.349606579240 0.409157590576
0.461146921538 0.467481662592 0.569851078017 0.642831740387 0.664147588353
0.703356301400 0.755318959769 0.815150033341 0.825516781507 0.852220493443
0.881266948211 0.895310068904 0.881093576350 0.855416759280 0.831549233163
0.836470326739 0.887441653701 0.952949544343  0.965543454101 0.684583240720
0.352076461436 0.133044232051 0.071970215603
 0                             (homogeneous surface)
  1                            (directional effect)
  6                            (ibrdf=ocean)
  3. 0. 0. -1.                 (wind-speed, phi_wind, salinity, pigment
concentration)
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
-10                           (no atmospheric correction)
```

6S outputs this MIE file as:

Wlgth	Nor_Ext_Co	Nor_Sca_Co	Sg_Sca_Alb	Asymm_Para	Extinct_Co	Scatter_Co
0.4000	1.2923	1.2923	1.0000	0.7245	0.2083E-03	0.2083E-03
0.4880	1.1061	1.1061	1.0000	0.7114	0.1783E-03	0.1783E-03
0.5150	1.0582	1.0582	1.0000	0.7072	0.1706E-03	0.1706E-03

0.5500	1.0000	1.0000	1.0000	0.7028	0.1612E-03	0.1612E-03
0.6330	0.8833	0.8833	1.0000	0.6938	0.1424E-03	0.1424E-03
0.6940	0.8099	0.8099	1.0000	0.6906	0.1305E-03	0.1305E-03
0.8600	0.6606	0.6606	1.0000	0.6819	0.1065E-03	0.1065E-03
1.5360	0.3689	0.3689	1.0000	0.6725	0.5946E-04	0.5946E-04
2.2500	0.2483	0.2483	1.0000	0.6694	0.4003E-04	0.4003E-04
3.7500	0.1438	0.1438	1.0000	0.6653	0.2317E-04	0.2317E-04

Phase Function

TETA	0.4000	0.4880	0.5150	0.5500	0.6330	0.6940	0.8600	1.5360	2.2500	3.7500
180.00	0.3321E+00	0.3152E+00	0.3315E+00	0.3394E+00	0.3523E+00	0.3308E+00	0.3601E+00	0.3531E+00	0.3462E+00	0.3188E+00
178.38	0.3136E+00	0.3062E+00	0.3164E+00	0.3148E+00	0.3259E+00	0.3114E+00	0.3339E+00	0.3360E+00	0.3330E+00	0.3115E+00
176.03	0.2866E+00	0.2792E+00	0.2897E+00	0.2868E+00	0.3029E+00	0.2964E+00	0.3171E+00	0.3127E+00	0.2981E+00	0.2846E+00
173.83	0.2628E+00	0.2639E+00	0.2674E+00	0.2712E+00	0.2824E+00	0.2821E+00	0.2991E+00	0.3050E+00	0.2918E+00	0.2649E+00
171.61	0.2560E+00	0.2517E+00	0.2625E+00	0.2642E+00	0.2765E+00	0.2717E+00	0.2882E+00	0.2986E+00	0.2996E+00	0.2670E+00
169.36	0.2552E+00	0.2497E+00	0.2592E+00	0.2607E+00	0.2815E+00	0.2718E+00	0.2947E+00	0.3066E+00	0.3033E+00	0.2860E+00
167.14	0.2584E+00	0.2576E+00	0.2640E+00	0.2661E+00	0.2861E+00	0.2789E+00	0.3011E+00	0.3098E+00	0.3092E+00	0.3035E+00
164.91	0.2638E+00	0.2647E+00	0.2691E+00	0.2758E+00	0.2837E+00	0.2839E+00	0.2997E+00	0.3087E+00	0.3114E+00	0.3080E+00
162.67	0.2626E+00	0.2665E+00	0.2689E+00	0.2731E+00	0.2804E+00	0.2857E+00	0.2954E+00	0.3057E+00	0.3054E+00	0.3012E+00
160.42	0.2593E+00	0.2586E+00	0.2646E+00	0.2650E+00	0.2784E+00	0.2784E+00	0.2911E+00	0.3024E+00	0.3000E+00	0.2906E+00
158.20	0.2485E+00	0.2475E+00	0.2549E+00	0.2549E+00	0.2711E+00	0.2678E+00	0.2847E+00	0.2928E+00	0.2914E+00	0.2801E+00
155.97	0.2337E+00	0.2359E+00	0.2401E+00	0.2441E+00	0.2544E+00	0.2560E+00	0.2680E+00	0.2755E+00	0.2741E+00	0.2685E+00
153.73	0.2144E+00	0.2187E+00	0.2210E+00	0.2272E+00	0.2347E+00	0.2391E+00	0.2486E+00	0.2564E+00	0.2559E+00	0.2548E+00
151.49	0.1927E+00	0.1980E+00	0.2017E+00	0.2070E+00	0.2158E+00	0.2201E+00	0.2309E+00	0.2396E+00	0.2409E+00	0.2401E+00
149.25	0.1745E+00	0.1799E+00	0.1849E+00	0.1878E+00	0.1987E+00	0.2033E+00	0.2131E+00	0.2250E+00	0.2267E+00	0.2266E+00
147.01	0.1585E+00	0.1649E+00	0.1693E+00	0.1720E+00	0.1845E+00	0.1881E+00	0.1987E+00	0.2125E+00	0.2139E+00	0.2152E+00
144.79	0.1446E+00	0.1516E+00	0.1564E+00	0.1595E+00	0.1723E+00	0.1753E+00	0.1875E+00	0.2004E+00	0.2029E+00	0.2056E+00
142.54	0.1324E+00	0.1413E+00	0.1452E+00	0.1501E+00	0.1608E+00	0.1660E+00	0.1769E+00	0.1890E+00	0.1930E+00	0.1967E+00
140.31	0.1236E+00	0.1334E+00	0.1370E+00	0.1424E+00	0.1522E+00	0.1581E+00	0.1681E+00	0.1802E+00	0.1843E+00	0.1885E+00
138.07	0.1170E+00	0.1270E+00	0.1307E+00	0.1357E+00	0.1459E+00	0.1514E+00	0.1610E+00	0.1733E+00	0.1770E+00	0.1814E+00
135.84	0.1113E+00	0.1215E+00	0.1254E+00	0.1305E+00	0.1403E+00	0.1457E+00	0.1552E+00	0.1674E+00	0.1710E+00	0.1758E+00
133.60	0.1067E+00	0.1170E+00	0.1210E+00	0.1265E+00	0.1359E+00	0.1413E+00	0.1514E+00	0.1625E+00	0.1665E+00	0.1716E+00
131.37	0.1034E+00	0.1139E+00	0.1181E+00	0.1231E+00	0.1329E+00	0.1381E+00	0.1483E+00	0.1590E+00	0.1630E+00	0.1679E+00
129.13	0.1011E+00	0.1122E+00	0.1161E+00	0.1209E+00	0.1306E+00	0.1360E+00	0.1454E+00	0.1561E+00	0.1599E+00	0.1647E+00
126.89	0.9952E-01	0.1109E+00	0.1148E+00	0.1197E+00	0.1292E+00	0.1346E+00	0.1435E+00	0.1542E+00	0.1577E+00	0.1625E+00
124.66	0.9875E-01	0.1100E+00	0.1143E+00	0.1195E+00	0.1287E+00	0.1336E+00	0.1428E+00	0.1533E+00	0.1566E+00	0.1613E+00
122.42	0.9875E-01	0.1105E+00	0.1144E+00	0.1195E+00	0.1289E+00	0.1337E+00	0.1426E+00	0.1529E+00	0.1562E+00	0.1609E+00
120.19	0.9971E-01	0.1118E+00	0.1155E+00	0.1205E+00	0.1299E+00	0.1347E+00	0.1429E+00	0.1533E+00	0.1563E+00	0.1608E+00
117.95	0.1013E+00	0.1134E+00	0.1178E+00	0.1223E+00	0.1313E+00	0.1361E+00	0.1442E+00	0.1543E+00	0.1573E+00	0.1615E+00
115.72	0.1031E+00	0.1157E+00	0.1197E+00	0.1243E+00	0.1339E+00	0.1382E+00	0.1467E+00	0.1565E+00	0.1596E+00	0.1634E+00
113.48	0.1057E+00	0.1186E+00	0.1225E+00	0.1271E+00	0.1374E+00	0.1407E+00	0.1502E+00	0.1595E+00	0.1626E+00	0.1662E+00
111.24	0.1093E+00	0.1220E+00	0.1265E+00	0.1317E+00	0.1409E+00	0.1443E+00	0.1536E+00	0.1625E+00	0.1656E+00	0.1697E+00
109.01	0.1132E+00	0.1267E+00	0.1310E+00	0.1366E+00	0.1455E+00	0.1490E+00	0.1575E+00	0.1665E+00	0.1692E+00	0.1737E+00
106.77	0.1189E+00	0.1328E+00	0.1370E+00	0.1417E+00	0.1508E+00	0.1546E+00	0.1632E+00	0.1716E+00	0.1746E+00	0.1785E+00
104.54	0.1244E+00	0.1392E+00	0.1433E+00	0.1480E+00	0.1574E+00	0.1612E+00	0.1701E+00	0.1777E+00	0.1813E+00	0.1845E+00
102.30	0.1311E+00	0.1463E+00	0.1503E+00	0.1560E+00	0.1647E+00	0.1683E+00	0.1770E+00	0.1847E+00	0.1880E+00	0.1917E+00
100.06	0.1392E+00	0.1549E+00	0.1592E+00	0.1645E+00	0.1726E+00	0.1766E+00	0.1843E+00	0.1927E+00	0.1957E+00	0.2001E+00
97.83	0.1480E+00	0.1642E+00	0.1690E+00	0.1746E+00	0.1824E+00	0.1862E+00	0.1938E+00	0.2019E+00	0.2051E+00	0.2097E+00
95.59	0.1570E+00	0.1748E+00	0.1788E+00	0.1855E+00	0.1926E+00	0.1972E+00	0.2048E+00	0.2121E+00	0.2157E+00	0.2206E+00
93.35	0.1690E+00	0.1868E+00	0.1914E+00	0.1967E+00	0.2053E+00	0.2095E+00	0.2171E+00	0.2245E+00	0.2280E+00	0.2326E+00
91.12	0.1833E+00	0.2010E+00	0.2068E+00	0.2092E+00	0.2201E+00	0.2228E+00	0.2307E+00	0.2394E+00	0.2424E+00	0.2462E+00
90.00	0.1896E+00	0.2084E+00	0.2138E+00	0.2169E+00	0.2275E+00	0.2299E+00	0.2386E+00	0.2470E+00	0.2500E+00	0.2538E+00
88.88	0.1963E+00	0.2163E+00	0.2211E+00	0.2253E+00	0.2352E+00	0.2385E+00	0.2462E+00	0.2546E+00	0.2578E+00	0.2620E+00
86.65	0.2113E+00	0.2324E+00	0.2370E+00	0.2439E+00	0.2517E+00	0.2562E+00	0.2630E+00	0.2714E+00	0.2747E+00	0.2802E+00
84.41	0.2302E+00	0.2516E+00	0.2568E+00	0.2633E+00	0.2715E+00	0.2755E+00	0.2830E+00	0.2911E+00	0.2947E+00	0.3004E+00
82.17	0.2520E+00	0.2738E+00	0.2801E+00	0.2843E+00	0.2944E+00	0.2969E+00	0.3054E+00	0.3139E+00	0.3174E+00	0.3228E+00
79.94	0.2749E+00	0.2985E+00	0.3040E+00	0.3095E+00	0.3195E+00	0.3223E+00	0.3305E+00	0.3393E+00	0.3426E+00	0.3482E+00
77.70	0.3017E+00	0.3259E+00	0.3321E+00	0.3378E+00	0.3480E+00	0.3502E+00	0.3591E+00	0.3676E+00	0.3717E+00	0.3770E+00
75.46	0.3328E+00	0.3576E+00	0.3644E+00	0.3681E+00	0.3801E+00	0.3815E+00	0.3914E+00	0.3994E+00	0.4038E+00	0.4094E+00
73.23	0.3665E+00	0.3928E+00	0.3991E+00	0.4049E+00	0.4154E+00	0.4172E+00	0.4259E+00	0.4352E+00	0.4383E+00	0.4454E+00
70.99	0.4039E+00	0.4320E+00	0.4383E+00	0.4474E+00	0.4553E+00	0.4578E+00	0.4659E+00	0.4747E+00	0.4784E+00	0.4862E+00
68.76	0.4496E+00	0.4784E+00	0.4850E+00	0.4925E+00	0.5007E+00	0.5042E+00	0.5121E+00	0.5198E+00	0.5247E+00	0.5324E+00
66.52	0.5004E+00	0.5311E+00	0.5368E+00	0.5418E+00	0.5533E+00	0.5555E+00	0.5644E+00	0.5722E+00	0.5767E+00	0.5847E+00
64.28	0.5585E+00	0.5882E+00	0.5958E+00	0.6002E+00	0.6123E+00	0.6123E+00	0.6218E+00	0.6308E+00	0.6347E+00	0.6429E+00
62.05	0.6246E+00	0.6545E+00	0.6626E+00	0.6667E+00	0.6776E+00	0.6782E+00	0.6863E+00	0.6950E+00	0.6994E+00	0.7083E+00
59.81	0.6986E+00	0.7301E+00	0.7361E+00	0.7428E+00	0.7514E+00	0.7533E+00	0.7598E+00	0.7687E+00	0.7728E+00	0.7830E+00
57.58	0.7835E+00	0.8155E+00	0.8215E+00	0.8262E+00	0.8365E+00	0.8373E+00	0.8444E+00	0.8517E+00	0.8568E+00	0.8681E+00
55.34	0.8808E+00	0.9130E+00	0.9195E+00	0.9225E+00	0.9301E+00	0.9328E+00	0.9382E+00	0.9453E+00	0.9516E+00	0.9642E+00
53.11	0.9915E+00	0.1024E+01	0.1028E+01	0.1032E+01	0.1038E+01	0.1041E+01	0.1044E+01	0.1051E+01	0.1057E+01	0.1071E+01
50.87	0.1120E+01	0.1149E+01	0.1154E+01	0.1156E+01	0.1162E+01	0.1164E+01	0.1164E+01	0.1173E+01	0.1177E+01	0.1192E+01
48.63	0.1265E+01	0.1291E+01	0.1297E+01	0.1296E+01	0.1303E+01	0.1303E+01	0.1302E+01	0.1312E+01	0.1316E+01	0.1331E+01
46.40	0.1429E+01	0.1454E+01	0.1457E+01	0.1454E+01	0.1460E+01	0.1460E+01	0.1460E+01	0.1466E+01	0.1474E+01	0.1490E+01
44.16	0.1614E+01	0.1637E+01	0.1638E+01	0.1640E+01	0.1637E+01	0.1640E+01	0.1638E+01	0.1640E+01	0.1649E+01	0.1673E+01
41.93	0.1831E+01	0.1849E+01	0.1848E+01	0.1849E+01	0.1840E+01	0.1846E+01	0.1836E+01	0.1839E+01	0.1848E+01	0.1877E+01
39.69	0.2078E+01	0.2090E+01	0.2088E+01	0.2084E+01	0.2076E+01	0.2079E+01	0.2065E+01	0.2070E+01	0.2079E+01	0.2106E+01
37.46	0.2360E+01	0.2365E+01	0.2361E+01	0.2349E+01	0.2343E+01	0.2345E+01	0.2328E+01	0.2333E+01	0.2342E+01	0.2367E+01
35.21	0.2684E+01	0.2678E+01	0.2671E+01	0.2660E+01	0.2645E+01	0.2647E+01	0.2629E+01	0.2629E+01	0.2640E+01	0.2672E+01
32.99	0.3046E+01	0.3034E+01	0.3020E+01	0.3014E+01	0.2986E+01	0.2991E+01	0.2968E+01	0.2962E+01	0.2979E+01	0.3022E+01
30.75	0.3466E+01	0.3441E+01	0.3423E+01	0.3418E+01	0.3379E+01	0.3386E+01	0.3355E+01	0.3347E+01	0.3366E+01	0.3422E+01
28.51	0.3952E+01	0.3908E+01	0.3888E+01	0.3876E+01	0.3836E+01	0.3836E+01	0.3801E+01	0.3794E+01	0.3810E+01	0.3872E+01
26.27	0.4508E+01	0.4441E+01	0.4418E+01	0.4399E+01	0.4361E+01	0.4350E+01	0.4318E+01	0.4307E+01	0.4327E+01	0.4385E+01
24.03	0.5146E+01	0.5057E+01	0.5028E+01	0.5008E+01	0.4956E+01	0.4940E+01	0.4903E+01	0.4892E+01	0.4920E+01	0.4982E+01
21.80	0.5881E+01	0.5767E+01	0.5730E+01	0.5709E+01	0.5637E+01	0.5624E+01	0.5576E+01	0.5556E+01	0.5590E+01	0.5684E+01
19.58	0.6733E+01	0.6590E+01	0.6543E+01	0.6518E+01	0.6423E+01	0.6418E+01	0.6355E+01	0.6328E+01	0.6368E+01	0.6497E+01
17.33	0.7769E+01	0.7571E+01	0.7523E+01	0.7469E+01	0.7380E+01	0.7356E+01	0.7280E+01	0.7264E+01	0.7306E+01	0.7440E+01
15.09	0.8994E+01	0.8736E+01	0.8682E+01	0.8610E+01	0.8525E+01	0.8473E+01	0.8395E+01	0.8381E+01	0.8421E+01	0.8542E+01
12.86	0.1049E+02	0.1017E+02	0.1010E+02	0.1002E+02	0.9907E+01	0.9853E+01	0.9759E+01	0.9743E+01	0.9782E+01	0.9905E+01
10.64	0.1240E+02	0.1203E+02	0.1193E+02	0.1183E+02	0.1167E+02	0.1162E+02	0.1150E+02	0.1146E+02	0.1149E+02	0.1166E+02
8.39	0.1508E+02	0.1459E+02	0.1446E+02	0.1438E+02	0.1416E+02	0.1409E+02	0.1396E+02	0.1388E+02	0.1388E+02	0.1391E+02
6.17	0.1924E+02	0.1849E+02	0.1839E+02	0.1821E+02	0.1801E+02	0.1782E+02	0.1771E+02	0.1754E+02	0.1765E+02	0.1643E+02
3.97	0.2706E+02	0.2597E+02	0.2580E+02	0.2551E+02	0.2526E+02	0.2493E+02	0.2469E+02	0.2441E+02	0.2303E+02	0.1879E+02
1.62	0.5470E+02	0.5230E+02	0.5196E+02	0.5149E+02	0.5023E+02	0.4928E+02	0.4651E+02	0.3533E+02	0.2837E+02	0.2050E+02
0.00	0.1299E+03	0.1042E+03	0.9857E+02	0.9266E+02	0.8111E+02	0.7446E+02	0.6207E+02	0.3887E+02	0.2973E+02	0.2087E+02

Project acronym	IOPA
Project title	Aerosol Inherant Optical Properties
Annex	2
Title	Ocean body contribution
Version	0.1
Author(s) and affiliation(s)	R. Santer, Université du Littoral, France
Modification history	22/07/2005, first draft
Distribution	Internal

1. The climatologic value for ocean case 1 water:

They are no measurement at sea. An example is the so-called Rayleigh calibration which applies at short wavelengths because the Rayleigh scattering dominates. The two residual contributions are the aerosols and the water body signal. The water leaving radiance is estimated from standard values of the marine reflectance which are computed versus the Chla concentration.

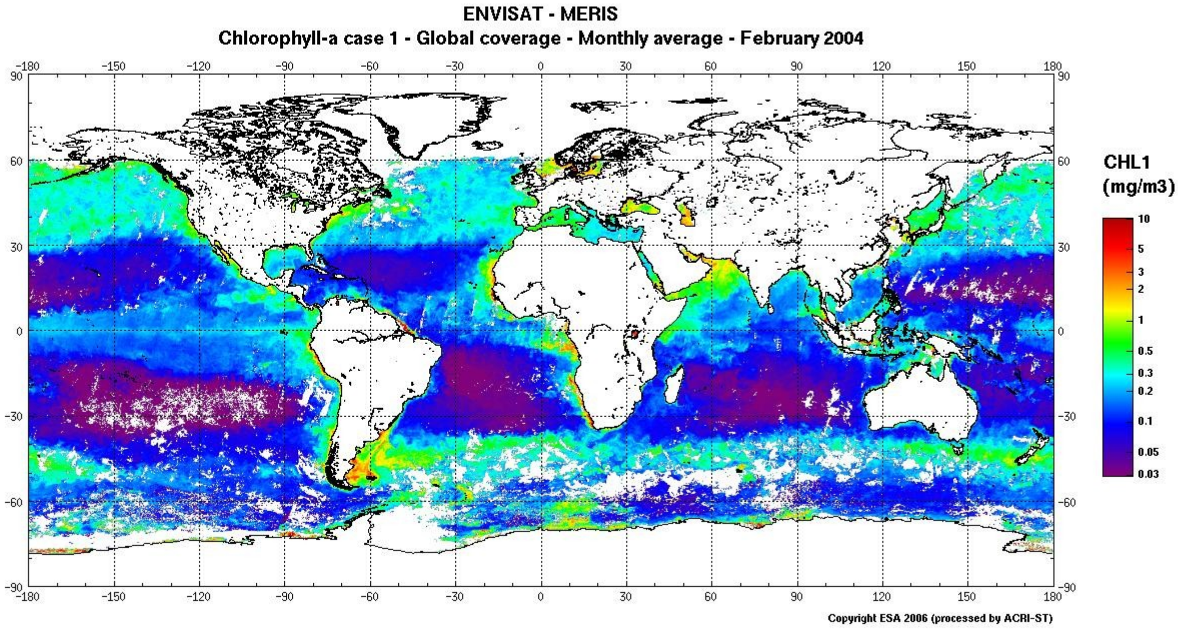
```
c  you consider an homogeneous surface:                         c
c     enter - inhomo=0                                          c

c                idirec=0 (no directional effect)               c
c                        you have to specify the surface reflectance:c
c                        igroun  (see note1) which is uniform and    c
c                        lambertian                             c


c         6  Ocean                                              c
c             the parameter are: pws,phi_wind,xsal,pcl          c
c                 pws=wind speed (in m/s)                       c
c                 phi_wind=azim. of the wind (in degres)        c
c                 xsal=salinity (in ppt) xsal=34.3ppt if xsal<0 c
c                 pcl=pigment concentration (in mg/m3)          c
c                                                               c
```

There are two steps in the subroutine "`oceaalbe`":

(i) The 6S subroutine "MORCASIWAT" , from "`oceaalbe`", is applied to compute the marine reflectance at the fundamental 6S wavelength

(ii) The passage through the air/water dioptre to get the remote sensing reflectance

Climatologic values of CHla can be obtained thanks to "ocean colour" satellite missions such as SeaWiFS, MODIS and MERIS. Level 3 Chla product provide the required input. For MERIS, level 3 images are available at: http://www.enviport.org/meris/lv3_main.htm.



2. In situ measurements of the water body contribution

2.1 Marine reflectance

The marine reflectance RW is the ratio between the upwelling irradiance and the downwelling irradiance just below the surface.

RW has to be provided by the user at in the spectral band of his radiometer.

A preparation module should interpolate these values in the 10 reference wavelengths of 5S (0.400,0.488,0.515,0.550,0.633,0.694,0.860,1.536,2.250,3.750). Default value is zero.

2.2 Remote sensing reflectance

The remote sensing reflectance is the same ratio but above the surface. This value is supposed to be corrected from the Fresnel reflection of the sky dome.

A preparation module should interpolate these values in the 10 reference wavelengths of 5S (0.400,0.488,0.515,0.550,0.633,0.694,0.860,1.536,2.250,3.750). Default value is zero.

2.3 Water leaving radiance

The water leaving radiance has to be transform by the user into remote sensing reflectance.

2.4 Modify the 6S code

In the main program, we decide to introduce two new subroutines: oceaalbe_RWM (annex 2.2) and oceaalbe_RWRS (annex 2.3):

Annex 2.1: 6S manual, page 152

4-Reflectance emerging from the sea water $\rho_{sw}(\lambda)$ (SUBROUTINE MORCASIWAT for R_w)

The reflectance emerging from sea water (also called remote sensing reflectance of the sea water) $\rho_{sw}(\theta_s,\theta_v,\phi,\lambda)$ is the reflectance as observed just above the sea surface (level 0^+). This reflectance can be related to the reflectance R_w which is the ratio of the upwelling to downwelling radiance just below the sea surface (level 0^-). If we assume the ocean as a Lambertian reflector $\rho_{sw}(\theta_s,\theta_v,\phi,\lambda)$ can be expressed by the relation:

$$\rho_{sw}(\theta_s,\theta_v,\phi,\lambda) = \frac{1}{n^2}\,\frac{R_w(\lambda).t_d(\theta_s).t_u(\theta_v)}{1-a.R_w(\lambda)}$$

where:

•t_d is the transmittance for the downwelling radiance, and is expressed to the Fresnel reflectance coefficient $R_{a\text{-}w}(\theta_s,\theta_d,\phi)$ for the air-water interface by the relation:

$$t_d(\theta_s) = 1 - \int_0^{2\Pi}\int_0^{\Pi/2} R_{a-w}(\theta_s,\theta_d^a,\phi).\cos(\theta_d^a).\sin(\theta_d^a).d\theta_d^a.d\phi$$

The angle θ_d^a represents (see Figure 3) the zenithal angle of the reflected solar beam according to the wave-slopes distribution (*Cox and Munk*'s model, see below).

•t_u is the transmittance for the upwelling radiance, and is expressed to the Fresnel reflectance coefficient $R_{w\text{-}a}(\theta_v,\theta_u,\phi)$ for the water-air interface by

$$t_u(\theta_v) = 1 - \int_0^{2\Pi}\int_0^{\Pi/2} R_{w-a}(\theta_v,\theta_u^w,\phi).\cos(\theta_u^w).\sin(\theta_u^w).d\theta_u^w.d\phi$$

The angle θ_u^w represents (see Figure 3) the zenith angle in the water of the upwelling beam according to the *Fresnel and Snell*'s law: $n_{air}\sin(\theta_{air})=n_{sea}\sin(\theta_{sea})$ and to the wave-slopes distribution.

•a is defined by

$$a = 1 - \int_0^{\Pi/2} t_u(\theta_v).\cos(\theta_v).\sin(\theta_v).d\theta_v$$

In order to minimize computations we adopted a constant value of a=0.485. In theory, the value of a depends on wind speed and water index of refraction. In practice, this value varies very little with wind speed (see table 2 of *Austin*, 1974) and the index of refraction of water in that range of wavelength (0.4µm-0.7µm) is almost constant and taken equal to 1.341.

As described above the irradiance reflectance $R_w(\lambda)$ is the ratio of the upwelling spectral irradiance $E_u(\lambda)$ to the downwelling irradiance $E_d(\lambda)$ just below the surface. This ratio is particularly dependent on the inherent optical properties of the sea water: the total absorption coefficients $a(\lambda)$ [m^{-1}] and the total backscattering coefficient $b_b(\lambda)$ [m^{-1}]. For example, *Morel and Prieur*, 1977, have shown within a good approximation (when $a(\lambda) << 1$) that it can be expressed as:

$$R_w(\lambda) = 0.33 \frac{b_b(\lambda)}{a(\lambda)}$$

According to *Morel*, 1988, "in many situations phytoplankton and their derivative, and detrital products (mainly particulate, but also dissolved) play a predominant role in determining the optical properties of oceanic waters. These waters are classified (by *Morel*) as "case I" waters and are opposed to "case II" waters for which sediments, or dissolved yellow substance, make an important or dominant contribution to the optical properties". Here we use the so called "case I waters" (defined in a range from 0.4 to 0.7 µm) which roughly corresponds to the case I, case IA, case IB, case II, and case III of the *Jerlov*'s chart of optical water type (*Jerlov*, 1951, 1976). For the so called "Case I waters", *Morel* splits the total backscattering coefficient into

$$b_b(\lambda) = \frac{1}{2} b_w(\lambda) + \tilde{b}_b(\lambda).b$$

where:

- $b_w(\lambda)$ is the molecular scattering coefficient of water and is given Figure 4
- $\tilde{b}_b(\lambda)$ is the ratio backscattering/scattering coefficient of the pigments and is related to the pigment concentration C (Chl a + Pheo a, in $mg.m^{-3}$) and the wavelength (in µm) by

$$\tilde{b}_b(\lambda) = 0.002 + 0.02\,(0.5 - 0.25 \log_{10} C)\,\frac{0.550}{\lambda}$$

- b is the scattering coefficient of pigment expressed by

$$b = 0.3C^{0.62}$$

Also according to *Morel*'s "Case I waters", the total absorption coefficient is written as

$$a(\lambda) = u(\lambda).K_d(\lambda)$$

where:

- $u(\lambda)$ is computed as follow

$$u(\lambda) = 0.90 \frac{1 - R_w(\lambda)}{1 + 2.25\, R_w(\lambda)}$$

- $K_d(\lambda)$ is the total diffuse attenuation coefficient for downwelling irradiance and is given by

$$K_d(\lambda) = K_w(\lambda) + \chi_c(\lambda) C^{e(\lambda)}$$

with $K_w(\lambda)$ (the diffuse attenuation coefficient for pure oceanic water), $\chi c(\lambda)$ and $e(\lambda)$ are tabular values. We report Figure 5 the computations of $K_d(\lambda)$ for several pigment concentrations.

Always according to the *Morel*'s model (Case I waters) the computation of the reflectance $R_w(\lambda)$ is only dependent of the pigment concentration C. The Figure 6 shows the computed reflectance R_w in the range from 0.4 to 0.7 µm for different concentrations C.

If the only information you have is the water type following the *Jerlov*'s chart, you can use the approximate C values given by *Morel*, 1988:

0-0.01	0.05	0.1	0.5	1.5-2	$mg.m^{-3}$
I	IA	IB	II	III	

The Parameters are:

1- ws, φ_W, C_{sal}, C

with: ws is the wind speed (in m/s)

φ_W is the direction of the wind (clockwise from the North)

C_{sal} is the salt concentration (in ppt). If $C_{sal} < 0$ then C_{sal}=34.3ppt by default

C is the pigment concentration (Chl a + Pheo a in $mg.m^{-3}$)

```
      program ssssss

      dimension angmu(10),angphi(13),brdfints(-mu_p:mu_p,np_p)
     s     ,brdfdats(10,13),
     s     brdfintv(-mu_p:mu_p,np_p),brdfdatv(10,13),robar(1501),
     s     robarp(1501),robard(1501),xlm1(-mu_p:mu_p,np_p),
     s     xlm2(-mu_p:mu_p,np_p)
c      introduce marine reflectance (or remote sensing reflectance)
c      R. Santer, 31-09-06

      real mwr
      dimension mwr(10)

c                                                                      c
c         6  Ocean                                                     c
c              the parameter are: pws,phi_wind,xsal,pcl                c
c                  pws=wind speed (in m/s)                             c
c                  phi_wind=azim. of the wind (in degres)              c
c                  xsal=salinity (in ppt) xsal=34.3ppt if xsal<0       c
c                  pcl=pigment concentration (in mg/m3)                c
c                                                                      c

c**********************************************************************c
c      brdf from ocean condition
c**********************************************************************c
      if(ibrdf.eq.6) then
        read(iread,*) pws,phi_wind,xsal,pcl
        if (xsal.lt.0.001)xsal=34.3
        paw=phi0-phi_wind
        rm(-mu)=phirad
        rm(mu)=xmuv
        rm(0)=xmus
        call oceabrdf(pws,paw,xsal,pcl,wlmoy,mu,np,rm,rp,
     s           brdfints)
        rm(-mu)=2.*pi-phirad
        rm(mu)=xmus
        rm(0)=xmuv
        call oceabrdf(pws,paw,xsal,pcl,wlmoy,mu,np,rm,rp,
     s           brdfintv)
c      introduce marine reflectance (or remote sensing reflectance)
c      R. Santer, 31-09-06

c Marine or remote sensing reflectances are user inputs
      if(plc.eq.-1.or.plc.eq.-2)then
      read(iread,*)(mwr(i),i=1,10)
      end if
        call oceaalbe(pws,paw,xsal,pcl,wlmoy,
     s         albbrdf,mwr)
        go to 69
      endif
```

Annex 2.2

```
      subroutine oceaalbe(pws,paw,xsal,pcl,pwl,
     s           brdfalbe,mwr)
C INPUT:  pws=speed of wind (in m/s)
C         paw=azim. of sun - azim. of wind (in deg.)
C       xsal=salinity (in ppt)
C       pcl=pigment concentration (in mg.m-3)
C         pwl=wavelength of the computation (in micrometer)
C OUTPUT: brdfalbe=the spherical albedo of the ocean
C
      real Ref(39)
      real pwl,azw,pcl,wl,wspd,C,pws,brdfalbe,w,wlp,paw
      real ref_i,rwc,rw,rogalbe,a,rwb,xsal
      real nr,ni
      integer iwl
      real mwr
      dimension mwr(10)

c effective reflectance of the whitecaps (Koepke, 1984)
      data Ref/
     &0.220,0.220,0.220,0.220,0.220,0.220,0.215,0.210,0.200,0.190,
     &0.175,0.155,0.130,0.080,0.100,0.105,0.100,0.080,0.045,0.055,
     &0.065,0.060,0.055,0.040,0.000,0.000,0.000,0.000,0.000,0.000,
     &0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000/
C conversion of parameter
      C=pcl
      wspd=pws
      azw=paw
      wl=pwl
C compute spectral band index
      iwl=1+int((wl-0.2)/0.1)
      print *, iwl


c if C == -2.0 just pick the measured data and return
      if (C.eq.-2.0) then
        brdfalbe = mwr(iwl)
        return
      endif

C COMPUTE WHITECAPS REFLECTANCE (LAMBERTIAN)
      W=2.95e-06*(wspd**3.52)
      wlp=0.5+(iwl-1)*0.1
      Ref_i=ref(iwl+1)+(wl-wlp)/0.1*(ref(iwl)-ref(iwl+1))
      Rwc=W*Ref_i

C COMPUTE WATER REFRACTION INDEX
      call indwat(wl,xsal,nr,ni)
C COMPUTE BACKSCATTERED REFLECTANCE FROM THE SEA WATER (LAMBERTIAN)
C  water reflectance below the sea surface
c  just compute for C >= 0
      if (C.ge.0.0) then
        call morcasiwat(wl,C,Rw)
      endif
c C == -1.0 pick the right measured marine reflectance
      if (C.eq.-1.0) then
        Rw = mwr(iwl)
      endif
```

```
C SUNGLINT spherical albedo
      call glitalbe(wspd,nr,ni,azw,rogalbe)
C  water reflectance above the sea surface, (albedo re=0.485)
C albedo is a=re is taken from table 2 of Austin,1974,The remote sensing
C of spectral radiance from below the ocean surface, in Optical
C Aspects of Oceanography (N.G. Jerlov and E. Steeman Nielsen,Eds),
C Academic,London,pp. 317-344
      a=0.485
      Rwb=(1.-Rogalbe)*(1.-a)*Rw/(1-a*Rw)
C SPHERICAL ALBEDO OF SEA WATER
      brdfalbe=Rwc+(1-W)*Rogalbe+(1-Rwc)*Rwb
      return
      end
```