A parameterization ocean surface albedo

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A parameterization of ocean surface albedo

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[1] Measurements at a sea platform show that the ocean surface albedo is highly variable and is sensitive to four physical parameters: solar zenith angle, wind speed, transmission by atmospheric cloud/aerosol, and ocean chlorophyll concentration. Using a validated coupled ocean-atmosphere radiative transfer model, an ocean albedo look up table is created in terms of these four important parameters. A code to read the table is also provided; it gives spectral albedos for a range of oceanic and atmospheric conditions specified by the user. The result is a fast and accurate parameterization of ocean surface albedo for radiative transfer and climate modeling. *INDEX TERMS:* 3359 Meteorology and Atmospheric Dynamics: Radiative processes; 1620 Global Change: Climate dynamics (3309); 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 4552 Oceanography: Physical: Ocean optics; 1610 Global Change: Atmosphere (0315, 0325). **Citation:** Jin, Z., T. P. Charlock, W. L. Smith Jr., and K. Rutledge (2004), A parameterization of ocean surface albedo, *Geophys. Res. Lett.*, *31*, L22301, doi:10.1029/2004GL021180.

1. Introduction

[2] The oceans cover 70% of the Earth's surface and play a pivotal role in regulating Earth's climate. The ocean surface albedo (OSA) is simply the ratio of the upwelling to downwelling solar irradiance (flux) at the air-sea boundary. OSA must be prescribed in a general circulation model (GCM). An accurate spectral OSA is needed for a determination of the radiation budget of the atmosphere and the penetration of sunlight into the upper ocean. Hence OSA has various applications in satellite remote sensing, as well as in climate modeling.

[3] A simple OSA parameterization was proposed by *Briegleb et al.* [1986]. They parameterized the OSA as a function of solar zenith angle based on the observations by *Payne* [1972]. *Taylor et al.* [1996] also proposed a similar OSA parameterization based on their aircraft measurements. A more sophisticated parameterization was given by *Hansen et al.* [1983], where the OSA is a function of solar zenith angle (SZA) and wind speed. These are broadband parameterizations which generally neglect the effects of ocean hydrosols and spectral dependence.

[4] SZA and wind are not the only geophysical parameters which affect ocean albedo. Atmospheric optical depth (of aerosols or clouds) and bulk ocean scattering (from below the sea surface) can have similar or even larger effects on ocean albedo, depending on SZA and wavelength; but to date they have not been explicitly included in widely used parameterizations for OSA. Today, aerosol and cloud properties and ocean color data are readily available over the globe. We incorporate such information, as well as a spectrally resolved output, in a parameterization for OSA.

[5] We first show, using measurements from a sea platform, the effects of these key parameters on the OSA. Then, a look up table (LUT) for OSA based on the validated Coupled Ocean-Atmosphere Radiative Transfer (COART) model is presented. The purpose is to provide a more accurate and comprehensive OSA parameterization for radiative transfer and climate modeling.

2. Observation and Model

[6] Upwelling and downwelling broadband solar irradiances are measured continuously at the Chesapeake Lighthouse (36.91°N, 75.71°W), located 25 km east of the Virginia Beach. The Chesapeake Lighthouse is also a station for NASA's AERONET [*Holben et al.*, 1998], which measures aerosol optical parameters with a Cimel spectral photometer, and for measurements of meteorological variables and sea state by NOAA.

[7] Figure 1 contrasts the impacts of SZA and aerosol optical depth (AOD) at 500 nm on broadband OSA. The albedos (solid lines) were observed on two clear days from noon to late afternoon. Wind speeds during both days were small and similar, but the AODs (triangles in Figure 1) were very different. These measurements show that increasing AOD increases the albedo when the sun is high, but decreases albedo when the sun is low. The aerosol affects albedo primarily by altering the partition of direct and diffuse beams incident to the surface. Recall that the Fresnel reflection by an ocean wave facet depends on the angle of incidence. The diffuse albedo is thus basically independent of SZA. But the direct albedo increases with SZA; it is smaller than the diffuse albedo at high sun (small SZA) and larger than the diffuse albedo at low sun. Increasing AOD means more scattering, more diffuse radiation, and thus an increase in albedo at high sun (and decrease in albedo at low sun).

[8] Figure 2 shows the effects of wind on OSA. The albedos (solid lines) are from observations on three days having small and similar AODs but very different wind speeds (asterisks). These results indicate that the wind speed has small effect on albedo at high sun, but its effect increases as SZA increases. Wind affects OSA mainly by changing the slopes of wave facets.

[9] Phytoplankton and associated products influence the optics of both the open ocean and coastal waters. Chlorophyll concentration (Chl, the phytoplankton biomass) is the principal parameter widely used in bio-optical models to parameterize the ocean optical properties [*Morel and Maritorena*, 2001]. Chl values are readily available

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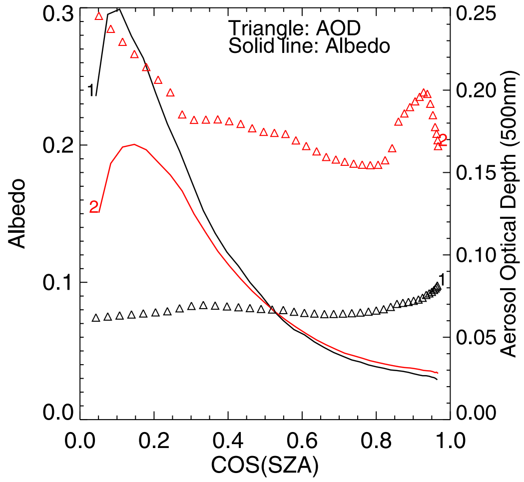

Figure 1. Measured ocean broadband albedo (lines) and AOD at 500 nm (triangles) on two clear afternoons (distinguished by color).

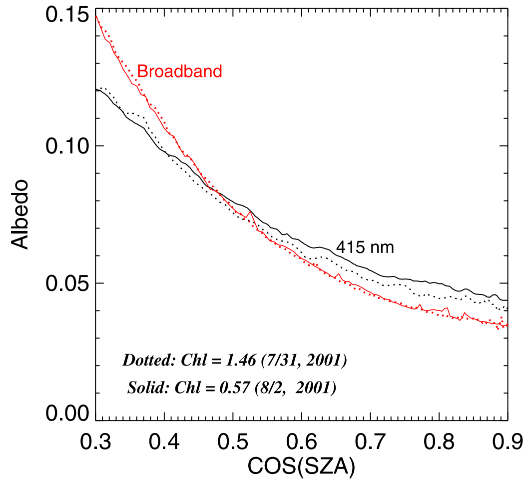

Figure 3. Measured 415 nm albedo (black) and broadband albedo (red) on two clear afternoons with different values of Chl. Dotted lines for Chl of 1.46 mg/m^3 on 7/31/01. Solid lines for Chl of 0.57 mg/m3 on 8/2/01.

over the global ocean today. Chl affects albedo mainly in the visible; it may increase or decrease the albedo at a particular wavelength, depending on the absorption and scattering of the phytoplankton particles and associated materials. Figure 3 shows albedos for broadband and for 415 nm measured on two days; both days have small (and similar) wind speeds and AODs, as well as similar absorptions for dissolved organic matters in the waters sampled by the Lighthouse, but the Chl (in mg/m^3) differ. The 415 nm albedo was measured by the Multi-Filter Rotating Shadow band Radiometer (MFRSR). With small SZA, the spectral albedo at 415 nm is smaller for the day with higher Chl, because high Chl causes more absorption. As SZA increases, the Chl effect on 415 nm albedo diminishes because the sub-surface contribution falls, while the effect of Fresnel reflection from wave facets becomes dominant. The differences in broadband albedos between the two days are much smaller, however, because phytoplankton particles increase albedo in the green-yellow and decrease it in the blue.

[10] Concurrent COVE measurements of radiation and related parameters, in both atmosphere and ocean at the same site, provide a comprehensive database for testing a radiative transfer model. Figure 4 shows the measured and modeled spectral albedo in two MFRSR channels (415 nm and 868 nm) on July 31, 2001 from local noon to late afternoon. The calculations are done by COART, which treats the scattering and absorption in the atmosphere and ocean consistently; a special boundary condition accounts for differences in the refractive indices of both media at the surface, as well wind-blown surface roughness. COART can calculate the radiation at any level in the atmosphere and ocean (and hence the OSA). A detailed model description is given by *Jin et al.* [2002] and *Jin and Stamnes* [1994]. The results in Figure 4 indicate that the OSA varies greatly with wavelength. The albedos at 415 nm and 868 nm also change with SZA quite differently. OSA at 415 nm is larger at small SZA because of larger sub-surface scattering and smaller water absorption. OSA at 868 nm increases more sharply

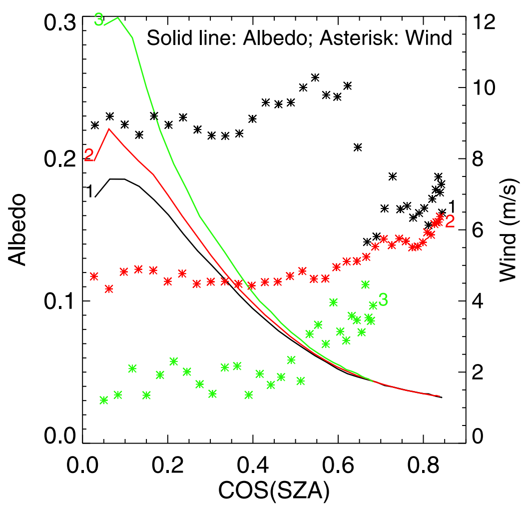

Figure 2. Measured ocean broadband albedo (lines) and wind speed (asterisks) on three clear afternoons.

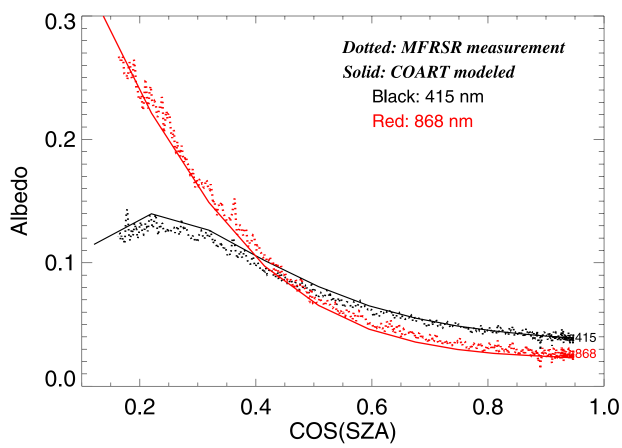

Figure 4. A model-observation comparison of spectral albedo (415 nm and 868 nm) on a single clear afternoon. MFRSR observations dotted and COART model solid. 415 nm in black and 868 nm in red.

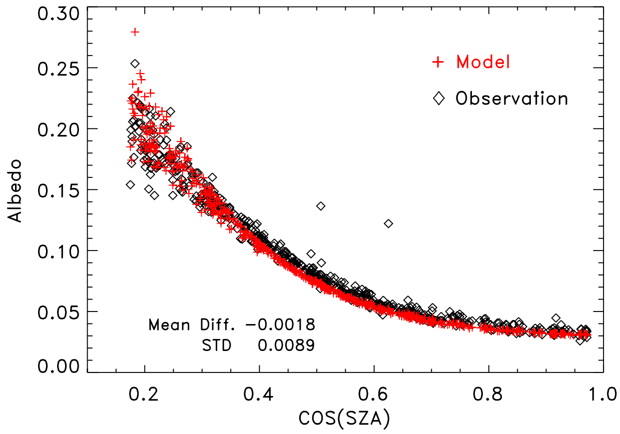

Figure 5. Comparison of modeled (red crosses) and observed (black diamonds) clear-sky broadband ocean albedo for two years (2000–2001).

with SZA because atmospheric scattering is smaller at longer wavelengths, yielding a larger fraction of direct radiation with more Fresnel reflection at large SZA. The model, which uses observed in-atmosphere and in-ocean inputs (none from MFRSR), matches the MFRSR measurements in both channels. Figure 5 shows the observed and modeled clear-sky broadband OSA for two full years (2000–2001). The data are 30 minute averages; each was screened as cloud free with minute by minute measurements. The model captures the albedo variations very well.

[11] The good model-observation agreements in Figures 4 and 5 indicate that both observations and model are robust and that spectral and broadband OSA can be modeled accurately. More comprehensive validation of COART using in situ, airborne, and satellite measurements are referred to by *Jin et al.* [2004].

3. The Ocean Albedo Table

[12] Different applications require OSA for various atmospheric and oceanic conditions throughout the solar spectrum. While broadband measurements of OSA are available, spectral measurements cover only a few channels. Our strategy is to use the model, validated for the broadband and for those few channels, to create an albedo LUT for various atmospheric and oceanic conditions; and span the whole spectrum having significant solar insolation at coarse but appropriate resolution.

[13] Based on model calculations and measurements presented above, OSA is most sensitive to four parameters: SZA, wind speed, atmospheric transmission (represented by aerosol/cloud optical depth), and Chl. Other parameters, such as ozone, water vapor, and cloud height, have much smaller impacts on OSA under most conditions. Ocean sediments may also be important for OSA, but significant sediment loadings are confined to some coastal regions. We tabulate OSA as a function of the aforementioned four parameters only.

[14] The LUT has 8400 records ($16 \times 15 \times 7 \times 5$) representing 16 aerosol/cloud optical depths, 15 SZAs, 7 wind speeds, and 5 ocean chlorophyll concentrations. Each record contains albedo values in 24 spectral bands from 0.25 μm to 4.0 μm. The aerosol/cloud optical depth is specified by the user at only one wavelength (0.50 μm or 500 nm). For 500 nm optical depths not exceeding 1.0, the LUT assumes a variation of optical depth with wavelength as per maritime aerosols [*Hess et al.*, 1998]; at larger optical depths, a much flatter variation with wavelength for cloud droplets is assumed. The albedo table is available online at http://www-cave.larc.nasa.gov/cave/ which also has a "point and click" version of COART. For convenience, an interpolation code for the LUT is also attached. The code obtains the albedo using any combination of the four variables, for any discrete band within 0.25–4.0 μm specified by the user (even for the integrated 0.25–4.0 μm broadband OSA as a single value).

[15] The LUT do not include the effect of foam, which may be significant at high wind speeds. Users may choose to add a correction (i.e., the empirical foam parameterization of *Frouin et al.* [2001]) to our LUT for OSA. A robust theoretical formulation for foam is not available.

[16] Figure 6 displays color contours of LUT values for broadband OSA versus the cosine of SZA (horizontal axis) and wind speed (vertical axis); with panels for a pristine atmosphere (AOD of 0.0), for a marine AOD of 1.0, and for

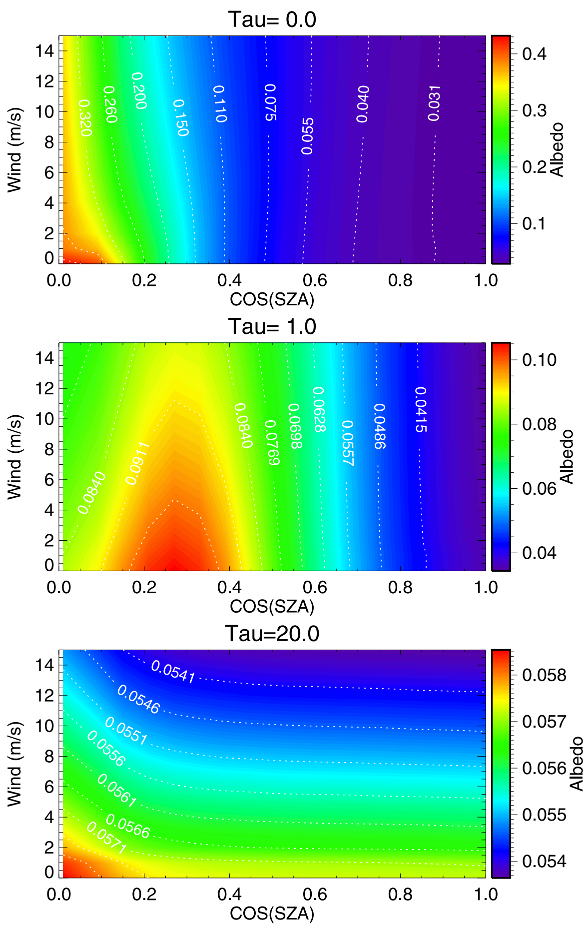

Figure 6. Broadband ocean albedo (color contours and dashed lines with numbers) versus wind speed (vertical axes) and cosSZA (horizontal axes) using the LUT for Chl of 0.2 mg/m^3. Panels for pristine (no aerosol or cloud), maritime AOD of 1.0, and cloud optical depth of 20. Different color scale for each panel.

a cloud optical depth of 20.0. All panels in Figure 6 assume Chl of 0.2 mg/m^3, which is about the average for the global ocean. Moving down the panels of Figure 6, the sensitivity of albedo to SZA decreases quickly as aerosol/cloud optical depth increases. The broadband OSA for a pristine sky (top panel) has a smaller minium, and a larger maximum, than any other sky condition. The incident radiation is diffuse with a large optical depth (bottom panel), so the albedo is then barely sensitive to SZA and slightly sensitive to wind speed. Note that for the moderate optical depth of 1.0 (middle panel), albedo does not vary monotonically with SZA. With no foam effect included, albedo decreases as wind increases (except for small SZA under very clear skies). The wind effect on albedo is more significant for large SZA, but the SZA corresponding to the maximum wind effect depends on aerosol/cloud optical depth or atmospheric transmission. These theoretical results are consistent with observations shown in Figures 1 and 2.

[17] The dependence of albedo on Chl in the LUT is also consistent with observations shown in Figure 3. The albedo in the 0.40–0.47 μm band in the LUT shows largest decrease as the Chl increases. The 0.40–0.47 μm band has strong chlorophyll absorption, so its albedo decreases as Chl increases. This contrasts with the 0.52–0.57 μm band, where chlorophyll absorption is much smaller; the albedo in this band increases as the Chl increases, due to increased particle scattering. Due to opposite effects in the blue and green, the overall Chl effect on the broadband albedo is small. It should be noted that the LUT calculations use the bio-optical model of *Morel and Maritorena* [2001] for ocean optical property parameterization. This model was developed for the so-called case 1 waters and may not appliable to the case 2 waters (usually the coastal waters) where the phytoplankton and their associated materials are not the optically primary components as in the case 1 waters.

4. Conclusion

[18] Measurements show that the OSA is dynamic and highly variable. The clear sky ocean albedo varies greatly with solar zenith angle (from about 0.03 to 0.4), but this variation depends on aerosol loading. Increasing AOD will increase albedo at high sun but decrease albedo at low sun. The wind has little impact on the albedo at high sun but has a significant impact at low sun. The ocean phytoplankton, indexed by the Chl, have a small effect on the broadband albedo but may change the spectral shape of ocean reflectance significantly. An OSA LUT is developed with a validated radiative transfer model. The LUT albedo is a function of the four most critical and readily available parameters (SZA, wind speed, aerosol or cloud optical depth, and ocean Chl). The dependences of albedo on these parameters in the table are consistent with observations. With the LUT and attached code, the user can easily obtain the surface albedo in any spectral band for any combination of the four parameters. It can be easily applied to a radiative transfer or climate model.

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References

Briegleb, B. P., P. Minnis, V. Ramanathan, and E. Harrison (1986), Comparison of regional clear-sky albedos inferred from satellite observations and model computations, *J. Clim. Appl. Meteorol.*, *25*, 214–226.
Frouin, R., S. F. Iacobellis, and P.-Y. Deschamps (2001), Influence of oceanic whitecaps on the global radiation budget, *Geophys. Res. Lett.*, *28*, 1523–1526.
Hansen, J., G. Russell, D. Rind, P. Stone, A. Lacis, S. Lebedeff, R. Ruedy, and L. Travis (1983), Efficient three-dimensional global models for climate studies: Models I and II, *Mon. Weather Rev.*, *111*, 609–662.
Hess, M., P. Koepke, and I. Schult (1998), Optical Properties of Aerosols and Clouds: The software package OPAC, *Bull. Am. Meteorol. Soc.*, *79*, 831–844.
Holben, B. N., et al. (1998), AERONET—A federated instrument network and data archive for aerosol characterization, *Remote Sens. Environ.*, *66*, 1–16.
Jin, Z., and K. Stamnes (1994), Radiative transfer in nonuniformly refracting layered media: Atmosphere-ocean system, *Appl. Opt.*, *33*, 431–442.
Jin, Z., T. P. Charlock, and K. Rutledge (2002), Analysis of broadband solar radiation and albedo over the ocean surface at COVE, *J. Atmos. Oceanic Technol.*, *19*, 1585–1601.
Jin, Z., T. P. Charlock, K. Rutledge, G. Cota, R. Kahn, J. Redemann, T. Zhang, D. Rutan, and F. Rose (2004), Radiative transfer modeling for the CLAMS experiment, *J. Atmos. Sci.*, in press.
Morel, A., and S. Maritorena (2001), Bio-optical properties of oceanic waters: A reappraisal, *J. Geophys. Res.*, *106*, 7163–7180.
Payne, R. E. (1972), Albedo of the sea surface, *J. Atmos. Sci.*, *29*, 959–970.
Taylor, J. P., J. M. Edwards, M. D. Glew, P. Hignett, and A. Slingo (1996), Studies with a flexible new radiation code. II: Comparisons with aircraft shortwave observations, *Q. J. R. Metreorol. Soc.*, *122*, 839–861.

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