P5.17 MULTI-YEAR OBSERVATIONS OF OCEAN ALBEDO FROM A RIGID MARINE OCEAN PLATFORM

Charles Kendall Rutledge[1], Gregory L. Schuster[2]
[1] Analytical Services & Materials Inc., Hampton VA
[2] NASA Langley Research Center, Hampton, VA

1 INTRODUCTION

The ocean/atmosphere interface is the planet's most ubiquitous surface type. Covering nearly 70% of the Earth, the ocean's surface is the location of an important boundary condition necessary for accurately understanding the Earth's energy budget. The shortwave ocean albedo (defined as the ratio of the upwelling shortwave irradiance to the downwelling shortwave irradiance measured near the surface) can be used to characterize this boundary condition for radiative transfer calculations.

NASA's Clouds and the Earth's Radiant Energy System (CERES) project (Wielicki et.al., 1996) seeks an accurate knowledge of the ocean's shortwave albedo for Earth radiation budget studies. A component of the CERES project (the Surface and Atmosphere Radiation Budget, Charlock et.al., 2002) uses radiative transfer models to estimate radiation quantities at the surface and at several pressure altitudes within the atmosphere for the entire planet. CERES/SARB specifically requires accurate ocean albedo as inputs into the radiative transfer calculations. To this end, CERES established a radiation measurement program on an ocean platform to obtain long term observations for the radiation components necessary to characterize the ocean/atmosphere radiation boundary condition.

2 OBSERVATION PROGRAM

The radiation observation program, the CERES Ocean Validation Experiment (COVE), operates on the Chesapeake Lighthouse that is located 25 kilometers from the Virginia, USA coastline. The project has operated for approximately four years beginning in September of 2000. The COVE ocean platform is located in 11 meters of water which is influenced periodically by the freshwater buoyant plume which exits the mouth of the Chesapeake Bay. The optical quality of the waters in the vicinity of the site have been determined to be case 2 (optically complex). During the four year period of operation, features associated with the sandy bottom have only been observed twice by the crew working at the site.

The rigid structure (Figure 1) allows the deployment of various types of sensors well above the sea spray associated with breaking waves. Optical surfaces of the instruments are cleaned daily by an automated washing system.

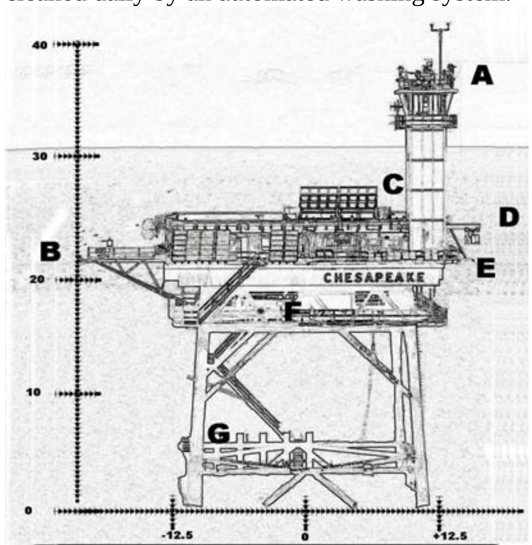

Figure 1 Schematic of the Chesapeake Lighthouse ocean platform with dimensions (meters) and letters representing locations of various sensors. A- downwelling radiation sensors, B- upwelling radiation sensors, C- Micropulse LIDAR, D- Fourier transform interferometric radiometer (periodically), E- wave energy spectra sensor, F- scanning spectroradiometer (periodically), G. in-water temperature sensor.

Corresponding Author:
C. Kendall Rutledge
(C.K.RUTLEDGE@LARC.NASA.GOV)
NASA Langley Research Center, Mail Stop 936
Hampton, Virginia 23681-2199

Here we limit the discussion to passive shortwave sensors (pyranometers and pyrheliometers) used for measuring the components required for the ocean albedo determination. The instruments for measuring downwelling irradiance include a pyranometer (KZ CM31) measuring diffuse irradiance and a pyrheliometer (KZ CH1) measuring direct normal irradiance. The downwelling irradiance (I_D) is computed as:

$$I_D = \cos \Theta I_{DIR} + I_{DIF} \ ,$$

where Θ represents the solar zenith angle, I_{DIR} represents the direct normal irradiance and I_{DIF} represents the downwelling diffuse irradiance. These instruments are mounted on a solar tracker (KZ AP1) which provides accurate pointing for the pyrheliometer and accurate shading for the diffuse pyranometer. Each of these sensors integrate radiances between the wavelengths of 280 to 4000 nm. A single pyranometer (KZ CM31) is used to measure the upwelling irradiance from the ocean's surface.

The pyrheliometer has a 1 degree (full angle) field of view. The pyranometers have 2π steradian fields of view. Initial measurements for these sensors were taken once per second and averaged to one minute intervals. Thirty minute averages were obtained from the CERES ARM Validation Experiment website, obtain these data at http://www-cave.larc.nasa.gov/cave/.

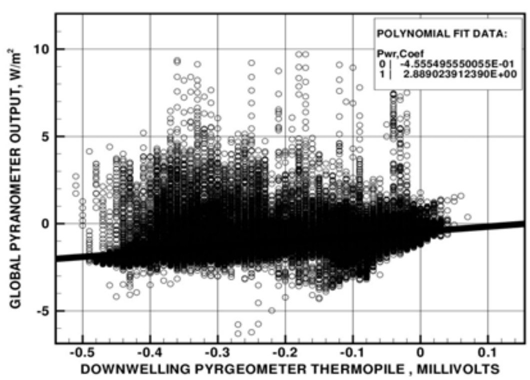

Figure 2 Example nighttime relationship between pyrgeometer thermopile signal and pyranometer signal. Year 2000 nighttime allsky data.

Calibration procedures for each of the sensors are based on those prescribed by the Baseline Surface Radiation Network (Ohmura et.al., 1998) using an active cavity radiometer calibrated at the World Radiation Center, Davos, Switzerland. Calibration details can be found at http://cove.larc.nasa.gov/cal/index.html.

The pyranometer measuring the upwelling irradiances is located on the west side of the ocean platform structure at the end of a catwalk (6 m from the main structure). Prior to solar noon, shadows from the lighthouse structure fall directly below the pyranometer measuring upwelling irradiance. Only after solar noon observations are used for albedo determinations.

A correction for the bias of "nighttime offset" for the pyranometers as demonstrated by Haeffelin et.al. (2001) was determined (for example, see Figure 2). Corrections were applied to the signals of each of the pyranometers used in the albedo calculations.

3 OCEAN ALBEDO RESULTS

Thirty minute mean shortwave ocean albedo results from the entire four year sampling period (n = 11,082) for allsky, all windspeeds and all optical depth conditions are presented below (Figure 3).

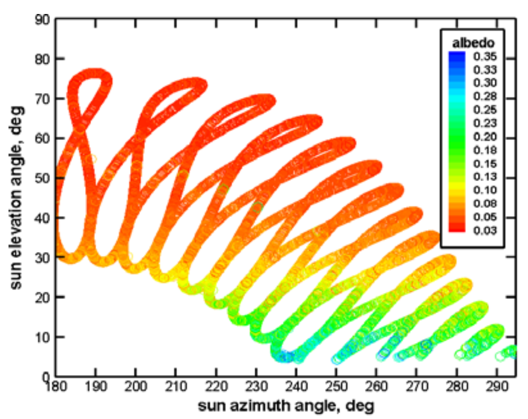

Figure 3 Multi-year shortwave ocean albedo results from observations made between August 2000 and July 2004. Allsky data are included.

After solar noon, the ocean albedo ranges from approximately 0.03 to 0.35. The magnitudes of the albedo show a strong dependence to the sun elevation angle. Lower albedo is associated with higher sun elevation angles and higher albedo is associated with lower sun elevation angles.

The Long-Ackerman cloudiness index was used to partition the albedo results into clear and cloudy conditions (Figure 4).

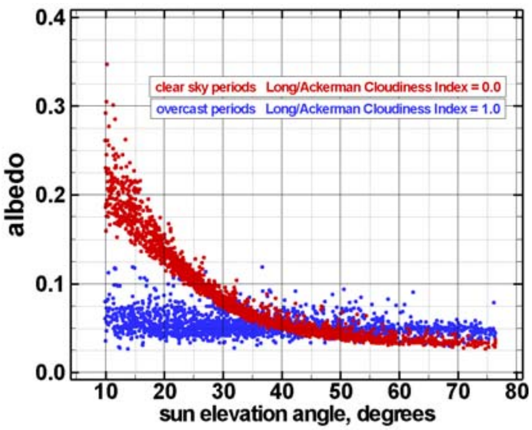

Figure 4 Ocean albedo for clear (red) and overcast (blue) sky conditions for observations made between August 2000 and July 2004.

During clearsky conditions, the albedo is highest when the sun's position in the sky approaches the horizon. The change in radiance associated with the sunglint specular reflections from the oceans surface is an important contributor to the change in albedo in the clearsky case. During overcast conditions, the change in radiance associated with the specular glint does not develop with changing sun positions in the sky. This results in a near constant albedo under clearsky conditions with a mean ocean albedo of 0.053.

4 TOWER EFFECT ON ALBEDO

Accurately measuring upwelling ocean surface irradiance from a large structure is complicated by unknown effects of the ocean platform structure on the radiometric observations. Several mechanisms likely cause the upwelling observations to be problematic. The obscured ocean surface radiance is not sampled completely. The COVE ocean platform structure which accounts for approximately 20% of the hemispherical upwelling field of view of the pyranometer used for measuring upwelling irradiance also reflects shortwave radiation directly into the sensor. The scattered light fields within the sky and ocean in the near vicinity of the structure are also likely altered by its presence. Each of these mechanisms produce biases which are likely effected by the sun's position in the sky, the cloudiness of the sky, the nature and quantity of particulates within the ocean and sky, the wind effects on the ocean's capillary wave structure and the angular dependence of scattered radiances from the materials which make up the ocean platform structure, to name a few.

We have initiated measurements to understand/quantify some these bias mechanisms (not presented here). Until these biases are better understood, the ocean albedo observations have uncertainties whose magnitudes are not easily summarized.

5 COMPARISON TO EARLIER WORK

The work of Payne (1972) is reconsidered because of its wide acceptance for ocean albedo parameterizations used for remote sensing studies. Payne's observations were taken from a similar ocean platform as is used for the COVE observations. The optical quality of the waters at Payne's observation site (Buzzard's Bay, Mass, USA) were representative of case 1 oceanic waters (Payne, personal communica-tion).

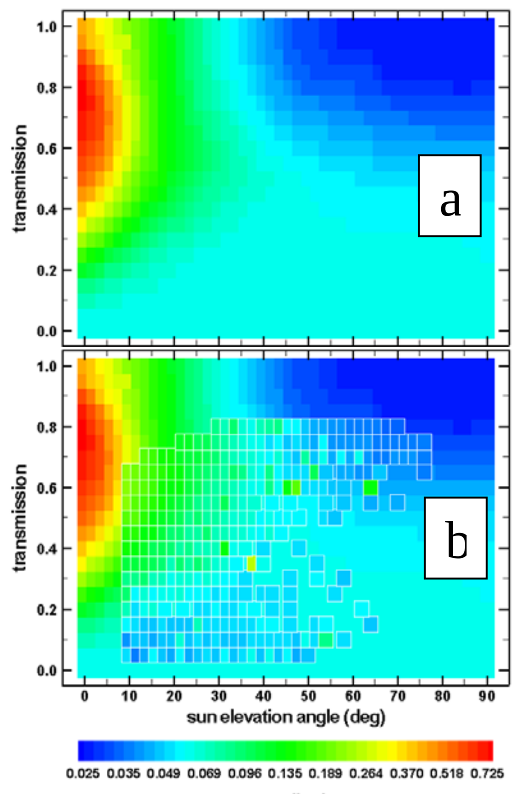

Figure 5 a) Contour of ocean albedo as a function of sun elevation and shortwave transmission. (Table 1 from Payne, 1972). b) Contour of albedo from 4 years of observations at the COVE site superimposed on the Payne (Table 1) parameterization.

The results of Payne's observations and associated analyses are presented in figure 5a. Transmission (T) according to Payne's definition:

$$T = I_D /(S\cos\Theta/\gamma^2),$$

where S represents the solar constant and γ represents the ratio of actual to mean earth-sun separation was followed for these comparisons. During the four months of Payne's observations, the range of transmissions and solar elevation angles did not range the full parameter space presented in the table. To determine albedos for the unobserved parameter space, modeled results were used to extrapolate to the transmission and solar elevation parameter limits used in the table.

The four year COVE albedo dataset was averaged and superimposed upon the Payne-Table 1 data (Figure 5b). Only bins having 10 or more data points are presented (note two-dimensional binning results highlighted by light lines). The binning parameters as defined by Payne were used for both datasets (transmission binwidth: 0.1, elevation angle binwidth: 2 degrees).

Three main differences exist between the two sets of observations. As suggested by the BSRN, we have used the component summation method (employing the direct and diffuse irradiances) to determine the downwelling global irradiance, while Payne used a single global pyranometer. Payne used 15 minute integration periods while 30 minute integration periods have been used for the COVE albedo dataset. A simple correction (a maximum effect of 3%) designed to accommodate the missing northern sky radiance caused by the presence of the ocean platform was used by Payne (but not for the COVE dataset).

Figure 5b indicates a strong similarity between the two albedo datasets for the prominent features of Payne's parameterization. This observation is notable since the parameterization process of Payne has the effect of an efficient spatial smoothing on the contour of his results.

A region of difference is evident when comparing the two datasets. Lower albedo is indicated by the four year dataset in the sun elevation angle range of 8-65 degrees and transmission from 0.05 to approximately 0.3 (relative to the data of Payne).

7 SUMMARY

A four-year time series of ocean albedo results measured in a coastal ocean region of the Atlantic ocean have been presented. Comparisons of the four year albedo dataset to the parameterization of ocean albedo presented by Payne (1972) were performed. For the parameter space of sun elevation angle and transmission considered, the data agree well in all but a single region (sun elevation angle range of 8-65 degrees and transmission from 0.05 to approximately 0.3). Differences in measurement location (and consequently the optical nature of the ocean water) and techniques used to determine the downwelling irradiance were identified possible sources to explain these differences. The completion of measurements to quantify the COVE tower's effect on upwelling radiation measurements remain to be completed.

8 REFERENCES

Charlock, T. P., F. G. Rose, D. A. Rutan, C. K. Rutledge, L. Larman, Y. Hu, S. Kato, and M. Haeffelin, 2000: Surface and Atmospheric Radiation Budget (SARB) Validation Plan for CERES Subsystem 5.0. 52 pp. See http://asd-www.larc.nasa.gov/validation/valid_doc.html.

Haeffelin, M., S. Kato, A. M. Smith, K. Rutledge, T. Charlock, and J. R. Mahan, 2001: Determination of the thermal offset of the Eppley Precision Spectral Pyranometer. Appl. Opt., 40, 472-484.

Jin, Z., T. P. Charlock, and K. Rutledge, 2002: Analysis of broadband solar radiation and albedo over the ocean surface at COVE. J. Ocean. Atmos. Tech., 19, 1585-1601.

Long, C. N. and T. P. Ackerman, 2000: Identification of Clear Skies from Broadband Pyranometer Measurements and Calculation of Downwelling Shortwave Cloud Effects, JGR, 105, No. D12, 15609-15626.

Ohmura, A., H. Gilgen, H. Gegner, G. Muller, M. Wild, E. G. Dutton, B. Forgan, C. Frohlich, R. Philipona, A. Heimo, G. Konig-Langlo, B. McArthur,

R. Pinker, C. H. Whitlock, K. Dehne, 1998: BaselineSurface Radiation Network (BSRN/WCRP): New precision radiometry for climate research. Bull. Amer. Meteoro. Soc., 79, 2115-2136.

Payne, R.E., 1972: Albedo of the Sea Surface. J. of the Atmospheric Sciences, 29, 959-970.

Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee, G. L. Smith, and J. E. Cooper, 1996: Cloudsand the Earth's Radiant Energy System (CERES): An Earth Observing System Experiment. Bull. Amer. Meteor. Soc., 77, 853-868.