MULTI-YEAR OBSERVATIONS OF SHORTWAVE AND LONGWAVE RADIATION AT THE CERES OCEAN VALIDATION SITE

C. Kendall Rutledge
Analytical Services and Materials, Inc.
Hampton, VA. USA
c.k.rutledge@larc.nasa.gov

William L. Smith Jr.
Radiation and Aerosols Branch
NASA Langley Research Center
Hampton, VA. USA
william.l.smith@nasa.gov

***Abstract*—A long-term surface-based measurement program has been established at an oceanic site to validate new products being derived globally as part of NASA's Earth Observing System for global change studies. This unique site, located at the Chesapeake Lighthouse in the Atlantic Ocean is completely surrounded by water offering a uniform background with well-known physical properties ideal for validating space-based retrievals of climatologically important parameters such as radiative fluxes and aerosol properties. A description of the site and synergy among current and future measurement programs established at the Chesapeake Lighthouse along with radiation and aerosol data from the first three years of measurements are presented.**

I. INTRODUCTION

One of the highest priority satellite instruments in NASA's Earth Observing System (EOS) is CERES (Clouds and the Earth's Radiant Energy System), an experiment to examine the role of cloud/radiation feedback in the Earth's climate system [1]. CERES products include the longwave (LW) and shortwave (SW) radiation budget from the top of the atmosphere to the Earth's surface. CERES also produces a comprehensive set of cloud properties determined using simultaneous imager data [2] and convolved to match the CERES flux footprint. Radiative flux profiles, including surface fluxes are derived with a radiative transfer model using CERES cloud properties, ECMWF temperature and humidity profiles, NCEP ozone products, aerosol properties derived from satellite or from an assimilation model and using CERES well calibrated TOA flux estimates to constrain the calculations [3]. A key component of CERES validation plan is to utilize high quality, long term measurements of radiative fluxes, aerosol and cloud properties from surface sites located in as many climatological regimes as possible. This strategy provides the best approach for obtaining the necessary statistical sampling required to adequately determine errors and uncertainties in CERES surface fluxes. This strategy is critical for determining the algorithm and data product improvements needed to meet climate accuracy requirements. The Department of Energy's Atmospheric Radiation Measurement (ARM) program, the Baseline Surface Radiation Network (BSRN), a program initiated by the World Meteorological Organization (WMO) and the SURFRAD program are working to provide such accurate long-term surface measurements from sites established across the globe. A critical problem in satellite-based retrieval of both aerosols and surface fluxes is separating the effects of the surface and the atmosphere; and accounting for the spatial variability of both. This can be particularly problematic in the shortwave (SW) over land surfaces where the surface albedo can be highly variable spatially and also of significant magnitude, particularly in the near infrared. Consider the checkerboard reflectance pattern in a Landsat image taken over the ARM central facility (CF) site in Lamont, Oklahoma depicted in Fig. 1. It is unlikely that a tower measurement of surface albedo at the CF will represent the surface albedo even at the scale of a few satellite imager pixels much less the 20 km CERES footprint. Furthermore, the area mean surface albedo impacts the solar insolation at the surface thru multiple scattering processes. In clear skies the relevant area mean albedo scale is about 10 km. The impact of uncertainties in surface albedo is small but comparable to uncertainties in aerosol properties and atmospheric state and needs to be considered in direct aerosol radiative forcing studies. In cloudy skies, the relevant area mean albedo scale is twice the cloud base height and the impact of surface albedo on insolation is significant. For a cloud with a base 2 km above the surface, an albedo uncertainty of 0.1 yields a calculated insolation discrepancy of nearly 30 W/m^2 [4]. These surface properties affect our ability to use land sites to validate CERES products and algorithms.

Figure 1. LANDSAT 10km x 10 km color composite over the ARM CF site.

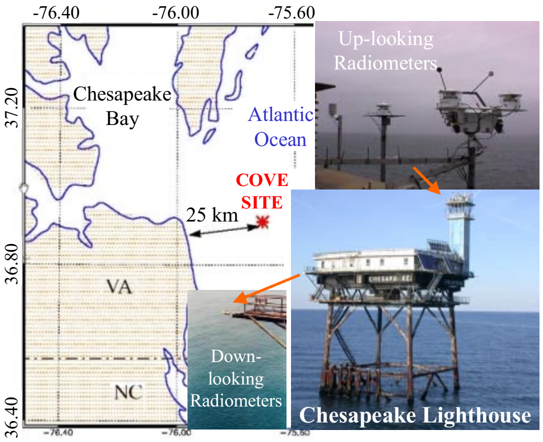

Figure 2. CERES Ocean Validation Experiment at the Chesapeake Lighthouse.

II. CERES OCEAN VALIDATION EXPERIMENT (COVE)

To address the issues described above, CERES has developed an oceanic surface remote sensing platform referred to as COVE (CERES Ocean Validation Experiment), at the U.S Coast Guard's (USCG) Chesapeake Lighthouse, 25 km east of coastal southern Virginia (Fig 2). Since late-1999, we maintain a high quality BSRN radiometric station that includes upwelling and downwelling broadband SW (direct and diffuse) and LW fluxes that adhere to the calibration protocols established by the BSRN. At COVE, the ocean provides a uniform background compared to that at most land sites, the albedo is low and well known (Fig. 3 adapted from [5]). This unique aspect is not found at other long-term radiation measurement sites. Also operating at COVE is an AERONET Cimel sunphotometer for aerosol properties, a NOAA GPSMet receiver for continuous integrated water vapor, a Licor photosynthetically active radiation (PAR) sensor, and up- and down-welling multi-filter rotating shadowband radiometers (MFRSR) to measure spectral albedo and aerosol optical thickness. NOAA maintains a basic meteorology station including ocean temperature and wave spectra measurements. A Micro-Pulse Lidar network (MPLnet) [6] lidar system is expected to be operating continuously by the end of 2003. Data is transferred to/from the site using a TCP/IP based computer network using 256 kbps spread spectrum transceivers. This system offers the ability for direct worldwide computer access and control. The power system consists of two battery banks (12 and 24 VDC), solar panels, wind generators and software controlled 7.5 KW diesel generator for battery recharging when needed at night. An inverter offers 110 VAC using the 12 VDC battery bank. The battery storage capacities allow the 12 and 24 VDC systems to deliver 1 KW for 4.1 and 2.6 days respectively, during overcast conditions.

III. THREE YEAR MEASUREMENT SUMMARY

A brief summary of the key measurements obtained at COVE from April 2000 until May 2003 is presented. A more complete description of the measurements, cloud and aerosol forcings, ocean properties and meteorology will be presented at the conference.

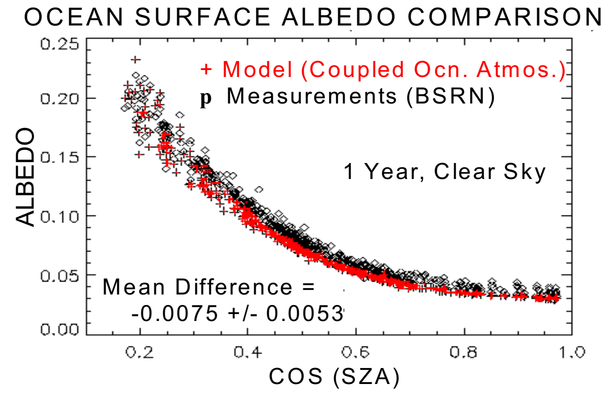

Fig 3. COVE measured Albedo vs. theory. Adapted from [5]

Multiple-year cloud screened AERONET aerosol optical thicknesses at 500 nm (Fig. 4) are seen to vary nearly an order of magnitude from winter (0.07) to summer (0.50). The inter-annual variability can be significant depending on the synoptic weather patterns and owing to the sites proximity to the coast and subsequent competition between the eastward propagation of pollution from the continent versus the cleaner marine environment to the east. The region has been the focus of several major field campaigns to study aerosol properties and effects, including most recently the CLAMS experiment [7]. Though the lower atmosphere at COVE is mainly influenced by industrial pollution (sulfates, organic and elemental carbon), and sea salt, a dust event resulting from long-range trans-Atlantic transport was observed at COVE during CLAMS (July 2001). Figure 5 depicts the monthly average cloud fraction at COVE for the three-year period. Cloud fraction was determined from the downwelling measurements of broadband shortwave radiation [7]. The monthly summaries show the means for the cloud fraction and their distribution shapes to change noticeably between seasons. During the summer period, higher cloud fractions with distributions tending toward symmetry are observed. The winter periods are characterized as having highly skewed cloud fraction distributions with the means close to 0.1. The month of August produces the highest cloud fraction average (near 0.5). The month of February is

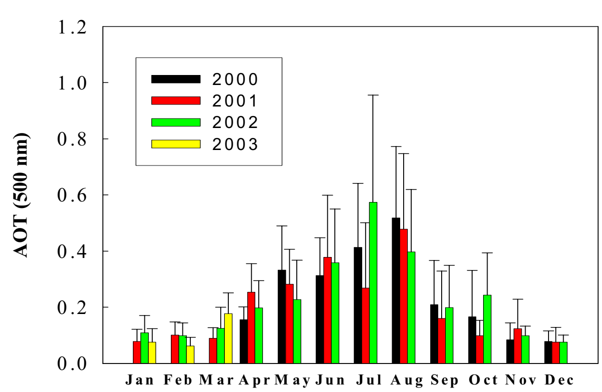

Figure 4. AERONET 500 nm aerosol optical thickness means and standard deviations at COVE.

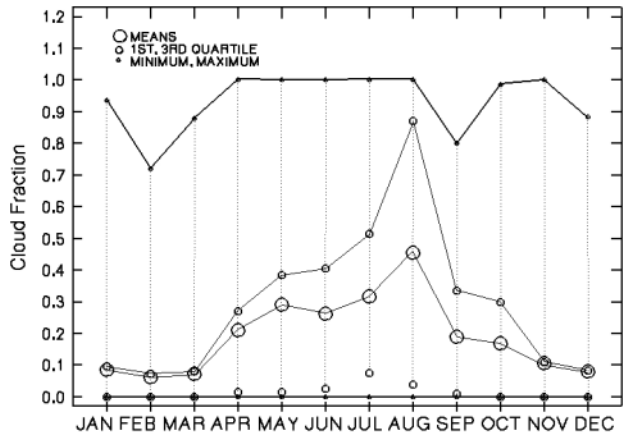

Figure 5. Monthly distribution statistics for cloud fraction from three years.

most cloud-free based on its mean cloud fraction of 0.08 and its maximum of about 0.7 (both parameters being the lowest for all the months).

The monthly upwelling and downwelling LW fluxes observed at COVE are displayed in Fig. 6. The distribution shapes of these data are generally symmetric with the upwelling fluxes demonstrating about half the dispersion of the downwelling fluxes. The upwelling LW fluxes follow the expected seasonal warming and cooling of the ocean surface temperature. During August, the maximum downwelling LW emission is evident (approximately 450 W/m^2). This feature is likely associated with the increased cloudiness observed during this month. The general dispersion differences observed between the upwelling and downwelling LW emissions are likely associated with the variability associated with cloud and water vapor (data not shown) within the atmosphere (higher variability) versus the less dynamic sea surface temperature (data not shown).

The ocean's normalized water leaving radiances measured by the SEAWIFS sensor have been used to characterize the ocean water types at the COVE site (not shown). Analysis of these data suggest the COVE coastal location is in a transition zone with respect to less turbid (case 1) oceanic water masses and more turbid (case 2) coastal and bay derived water masses. The water leaving radiances at the site varies continuously between these two types of water masses. This results in a surface that is, at times, more similar to case 1 waters and at other times more similar to case 2 waters.

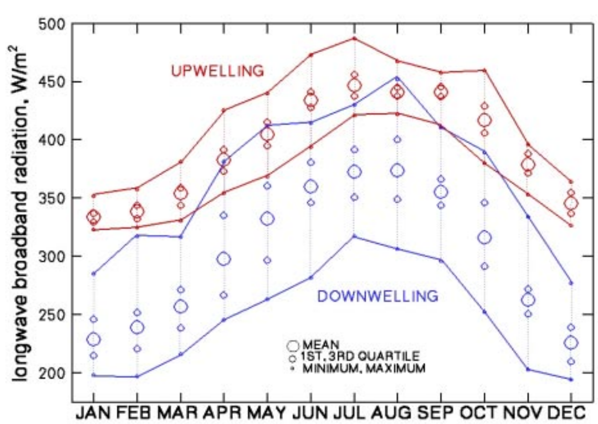

Figure 6. Monthly distribution statistics for upwelling and downwelling longwave radiation from three years.

IV. CONCLUDING REMARKS

COVE surface observations have began contributing to improve our understanding the role clouds and aerosols play in modulating the Earth's energy budget [5]. Surface observations from this site's unique location offer an opportunity to obtain high quality, long-term observations for climate research that is pertinent to nearly 70% of the planet's surface. Recent developments in coupled ocean/atmosphere approaches for studying the complex radiation fields of the environment make the site's development timely. Because of the changing water types that influence the site, both coastal and oceanic research may be addressed. Basic surface observation data from the site are maintained in NASA and WMO climate change research data archives (AERONET, BSRN).

REFERENCES

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

[2] Minnis, P., D. P. Kratz, J. A. Coakley, Jr., M. D. King, D. Garber, P. Heck, S. Mayor, D. F. Young, and R. Arduini, 1995: Cloud Optical Property Retrieval (Subsystem 4.3). "Clouds and the Earth's Radiant Energy System (CERES) Algorithm Theoretical Basis Document, Volume III: Cloud Analyses and Radiance Inversions (Subsystem 4)", NASA RP 1376 Vol. 3, edited by CERES Science Team, pp. 135-176.T. Charlock, personal communication, 2003.

[3] Charlock, T. P., F. G. Rose, D. A. Rutan, T. L. Alberta, D. P. Kratz, L.H. Coleman, G. L. Smith, N. Manalo-Smith, and T. D. Bess, 1997: Compute Surface and Atmospheric Fluxes (System 5.0), CERES Algorithm Theoretical Basis Document. 84 pp. See http://asd-www.larc.nasa.gov/ATBD/.

[4] T. Charlock, personal communication, 2003.

[5] 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.

[6] Welton, E.J., J. R. Campbell, T.A. Berkoff, J.D. Spinhirne, S. Tsay, B. Holben, and M. Shiobara, "The Micro-pulse Lidar Network (MPL-Net)", Int. Laser Radar Conf. 21: Lidar Remote Sensing in Atmospheric and Earth Sciences, 285-288, 2002.M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[7] Long, C. N., and T. P. Ackerman, 2000: Identification of clear skies from broadband pyranometer measurements and calculation of downwelling shortwave cloud effects. J. Geophys. Res., 105, 15,609-15,626.

[8] Smith, W. L., Jr., T. P. Charlock, B. A. Wielicki, R. Kahn, J. V. Martins, C. Gatabe, P. V. Hobbs, G. C. Purgold, J. Redemann, L. Remer, C. K. Rutledge, 2001: The Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) Experiment. Proc. AMS 11th Conf. on Satellite Meteorology and Oceanograph., Madison, WI, Oct. 15-18, 492-496.