P4.23 THE CHESAPEAKE LIGHTHOUSE AND AIRCRAFT MEASUREMENTS FOR SATELLITES (CLAMS) EXPERIMENT

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1. INTRODUCTION

NASA has developed an Earth Observing System (EOS) consisting of a series of satellites designed to study global change from space. The EOS “flagship” is the EOS TERRA satellite, launched in December 1999, equipped with five unique sensors to monitor and study the Earth’s heat budget and many of the key controlling variables governing the Earth’s climate system. CLAMS, the Chesapeake Lighthouse and Aircraft Measurements for Satellites field campaign was conducted from NASA Wallops Flight Facility and successfully executed over the middle Atlantic eastern seaboard from July 10 – August 2, 2001. CLAMS is primarily a shortwave closure experiment designed to validate and improve EOS TERRA satellite data products being derived from three sensors: CERES (Clouds and Earth’s Radiant Energy System), MISR (Multi-angle Imaging Spectro-Radiometer) and MODIS (MODerate Resolution Imaging Spectroradiometer). CLAMS is jointly sponsored by the CERES, MISR and MODIS instrument teams and the NASA GEWEX Global Aerosol Climatology Project (GACP). CLAMS primary objectives are to validate satellite-based retrievals of aerosol properties and vertical profiles of radiative flux, temperature and water vapor. Central to CLAMS measurement strategy is the Chesapeake Lighthouse, a stable sea platform located in the Atlantic Ocean, 13 miles east of Virginia Beach near the mouth of the Chesapeake Bay and the site of an ongoing CERES Ocean Validation Experiment (COVE). Six research aircraft were deployed to make detailed measurements of the atmosphere and ocean surface in the vicinity of COVE, over the surrounding ocean, over nearby NOAA buoys and over a few land sites. The measurements are used to validate and provide “ground truth” for simultaneous products being derived from TERRA data, a key step toward an improved understanding and ability to predict changes in the Earth’s climate. One of the two CERES instruments on-board TERRA was programmed for Rotating Azimuth Plane Scans (RAPS) during CLAMS, increasing the CERES coverage over COVE by a factor of 10. Nine coordinated aircraft missions and numerous additional sorties were flown under a variety of atmospheric conditions and aerosol loadings. On one “golden day”, July 17, all six aircraft flew coordinated patterns, vertically stacked between 100 ft and 65,000 ft over the COVE site as the TERRA satellite orbited overhead. A summary of CLAMS measurement campaign and a description of the platforms and measurements is given below.

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2. PLATFORMS

2.1 Surface Sites

An important component of the CERES program is to improve estimates of the Surface and Atmospheric Radiation Budget (SARB) over the globe (Charlock et al.,1997). COVE is a critical validation site for CERES SARB flux profiles and is the only continuously operating oceanic radiometric measurement station in the world meeting BSRN (Baseline Surface Radiation Network) calibration protocols. Validation of upwelling and net fluxes are less problematic at COVE than over land sites owing to the relative uniformity of the ocean surface. NASA LaRC has a 20 year agreement with the United States

Coast Guard for continuous access to this platform. CERES has installed and maintains a BSRN measurement station at COVE since August 1999 for broadband fluxes, supplemented with an MFRSR photometer and an AERONET (Cimel) sunphotometer for spectral aerosol optical thickness. A SP1A spectralphotometer scans downward to measure the angular distribution of reflected radiation by the sea or BRDF (bi-directional reflectance distribution function), an important boundary condition for satellite remote sensing. Additionally, numerous other radiometers are operating at COVE including Eppley pyranometers specially modified to account for thermal offset phenomena (Haeffelin, 2001), Kipp & Zonen radiometers, pyrgeometers, shadowband radiometers and a downward looking MFRSR. NOAA maintains a basic meteorology station at the lighhouse that includes wind and wave information.

During CLAMS a shortwave spectrometer measured downwelling irradiance from 350-2200 nm with 10 nm resolution and an MPLnet micro pulse lidar provided information on the vertical distribution of aerosols and clouds. A compliment of in-situ instruments including a nephelometer, an aphelometer, a condensation nuclei counter and a nucleopore filter collection system were deployed at COVE to measure aerosol radiative properties and chemical composition. In-situ oceanographic instruments were deployed by a team from the Old Dominion University (ODU) Ocean, Earth and Atmospheric Sciences Department to measure chlorophyll, color dissolved organic matter (CDOM), water column profiles of temperature and salinity. Spectral measurements of in-water absorption, attenuation and backscatter were obtained and water leaving radiance was measured with a SeaWIFS Airborne Simulator (SAS). At Wallops Flight Facility, the University of Wisconsin deployed an Atmospheric Emitted Radiance Interferometer (AERI) measuring longwave spectra from 3-25 μm to derive boundary layer temperature and humidity structure. A filter collection system similar to the one at COVE was deployed on top of a building on Wallops Island and an AERONET station was deployed in Oyster, Virginia near the lower end of Virginia's eastern shore. Wind and wave information from several NOAA ocean buoys are being used to help interpret CLAMS ocean optics measurements. Figure 1 depicts CLAMS operating area and the locations of the key surface sites. Radiosondes were launched daily from Wallops and COVE at 0 and 1200 UTC, near TERRA overpass time at roughly 1600 UTC and at other times coinciding with the aircraft measurements.

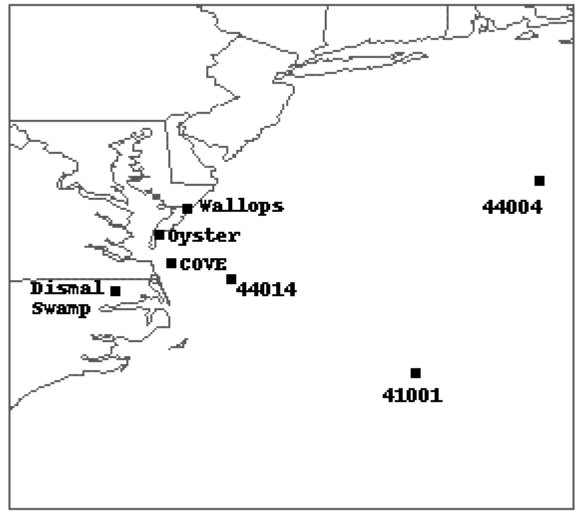

Fig. 1. CLAMS primary operating area depicting location of surface sites and NOAA buoys

2.2 Aircraft

Six research aircraft participated in CLAMS including NASA's ER-2 and OV-10, the University of Washington CV-580, the Proteus, a Cessna 210 and a Lear Jet. Figure 2 shows an altitude timeline for the aircraft operations conducted over COVE on July 17, 2001. All six aircraft participated on this day. The flight scenario shown in Fig. 2 is typical of most of CLAMS aircraft operations, although not all aircraft participated in every flight, the target area was moved to include offshore buoys or adjacent cloud free areas, and the timing of some of the profiles was altered for various reasons, mainly cloud avoidance.

The NASA ER-2 serving as a surrogate satellite, flew at 65 kft with airborne versions of MODIS (MAS: MODIS Airborne Simulator) and MISR (AirMISR). The Scanning High-resolution Interferometer Sounder (S-HIS) and the Advanced Visible/Infrared Imaging Spectrometer (AVIRIS) measured longwave and shortwave spectra, respectively. Typical flight patterns included a series of adjacent legs parallel to the solar plane to test new aerosol retrieval algorithms for sun-glint from MAS, daisy patterns for AirMISR BRDF and a single track parallel to the TERRA orbit track and centered over one of the surface sites (typically COVE or one of the NOAA Buoys). The latter track also provided multi-angle measurements of the target area with airMISR.

The University of Washington Convair 580 was the workhorse of CLAMS, instrumented to measure the physical and chemical properties of aerosols in-situ. The CV-580's instrument compliment included several nephelometers, an aphelometer, two FSSP's for small and large

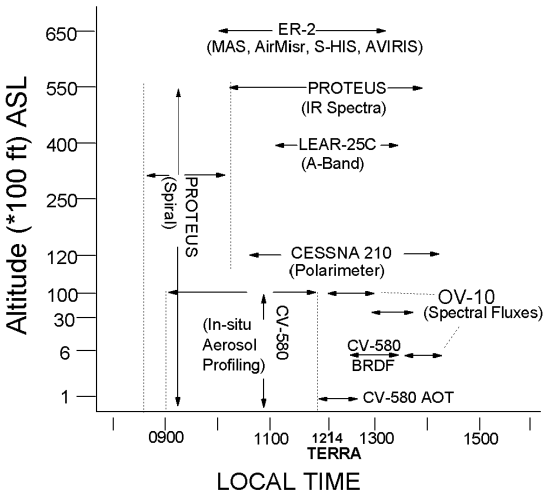

Fig. 2. Altitude timeline for CLAMS aircraft on July 17, 2001. The Terra overpass was at 1214 EDT.

particles, CN counters, an aerosol spectroreflectometer with a nucleopore filter collection system to measure aerosol absorption, teflon and quartz filter collection systems for measuring ionic and carbonaceous species. The CV-580 also deployed several radiometric instruments to measure spectral and broadband shortwave radiation, including the NASA Ames 14 channel Automated Airborne Tracking Sunphotometer (AATS-14) and the NASA Goddard Cloud Absorption Radiometer (CAR). The AATS-14 (Schmid et al., 2000) provides the aerosol optical thickness profiles while the CAR (King et al., 1986) provides the important lower boundary condition (BRDF), both critical for radiative closure studies and validation of AOT derived from the TERRA satellite and ER-2 airborne data. Although the CAR measurements are limited to the wind and sea conditions and solar geometries encountered during CLAMS, they will be useful for checking the validity of the long-term measurements of ocean BRDF being made at COVE under a much wider range and variety of conditions. The typical flight scenario for the CV-580 included BRDF patterns near the beginning and end of each mission, a 30-minute leg flown at 100ft centered at satellite overpass time to characterize the total column AOT and a detailed characterization of two to four aerosol layers. Each layer was sampled for 45 minutes alongwind and crosswind to ensure sufficient aerosol mass was collected on the filters. A quick ascent from the surface to 12 kft prior to the detailed characterization provided the flight scientist the information needed to determine what altitude and how many layers to characterize and also provide an AOT profile for closure studies.

A third key aircraft for CLAMS is the NASA LaRC OV-10 configured to measure upwelling and downwelling longwave (broadband) and shortwave (broadband and spectral) irradiances. The broadbands are manufactured by Eppley Laboratories, Inc. The spectral shortwave measurements are obtained with Analytical Spectral Devices Full Range (ASD-FR) spectrometers which measured irradiance from 350-2500 nm at 3-10 nm resolution (Kindel et al., 2001). The primary objectives of the OV-10 were to conduct low-altitude (100 and 600 ft) surveys of spectral and broadband flux to measure the spatial variability of ocean optics within the scale of a MODIS and MISR pixel; to help understand platform effects on the measurement of upwelling radiation at COVE; to determine how well COVE measurements represent the sea in general; and to determine the shortwave flux profile below 10 kft.

Three additional aircraft participated in CLAMS. The Proteus, owned by Scaled Composites, Inc., flew a payload that included NAST-I, NAST-M and FIRSC adding a longwave component to CLAMS. NAST-I is an interferometer measuring high resolution spectra from 3.3 to 18 μm to map sea surface temperature (SST) and atmospheric profiles of temperature and water vapor. NAST-M is a 17 channel scanning microwave radiometer used for temperature sounding through non-precipitating clouds and for deriving precipitation cell height. FIRSC is the Far-Infrared Spectrometer for Cirrus, a high resolution interferometer measuring from 70 to 1000 μm. Most of the Proteus flight hours were spent mapping at 55 kft but at times the Proteus conducted slow ascending and descending spirals over Wallops and COVE between 55 kft and the surface. A nine channel visible and near infrared Research Scanning Polarimeter (RSP) was flown on a Cessna 210. The Cessna 210 participated in CLAMS from July 10-22 making intensity and polarization measurements at 12 kft to retrieve aerosol properties and 200 ft to retrieve ocean optical properties. Finally, a new NASA Langley Airborne A-Band (765 nm) Spectrometer (LAABS) was flown for the first time during CLAMS on a Lear jet at 40 kft to demonstrate its capability for aerosol optical thickness retrievals. Both the RSP and an oxygen A-band similar to LAABS are being considered for future satellite platforms

3. SUMMARY

Table 1 summarizes the nine most successful CLAMS experiment days, the participating aircraft, flight locations, AOT from the COVE AERONET site, predominant sky conditions and the UTC time and associated wind conditions when the BRDF patterns

Date (2001)	Aircraft	Location	AOT (500nm)	Sky Cond.	BRDF-1 TIME(dir,spd)	BRDF-2 TIME(dir,spd)
10-Jul	1,2,4,5	COVE	0.23	Clear	1810(169,1.5)	2150(156,7.7)
12-Jul	1,2,3,4	COVE, E of Wallops	0.08	Scat. Cirrus		
14-Jul	1,2,4,5	COVE	0.08	few Cu	1605(305,8.2)	
17-Jul	1,2,3,4,5,6	COVE	0.47	Clear	1655(176,6.2)	
23-Jul	1	E of Wallops	0.06	Clear	1510(NA)	
26-Jul	1,2,4	COVE/Bouy 44014	0.17	Mostly Clear	1755(230,8.0)	
30-Jul	1,2,3,4	COVE/Buoy 44014	0.06	Low Clouds	1820(010,9.0)	1910(016,11.3)
31-Jul	1,2,3	Bouy 44004/ D.Swamp	0.08	broken Cu	1700(026,8.2)	1900(NA)
2-Aug	1,2,3	COVE	0.1	Clear	2010(116,3.1)	

Table 1. CLAMS primary experiment days with primary target area, COVE AOT sky conditions and time of BRDF (UTC) with associated wind direction (degrees) and speed (m/s). The participating aircraft are 1:CV-580, 2:OV-10, 3:ER-2, 4:Proteus, 5:Cessna, 6:Lear Jet.

were flown. July 2001 was anomalously cool and dry with lower aerosol amounts than normal. Nevertheless, a variety of aerosol conditions were encountered ranging from very clean (AOT<0.1) to moderate (AOT ~0.5) and a unique set of radiation and in-situ aerosol measurements were obtained to validate MODIS and MISR aerosols and test CERES SARB. Some of CLAMS experimental achievements include:

- Six MISR and MODIS aerosol retrieval validation experiments.
- Three MODIS ‘glint’ experiments.
- Two spatial variability experiments for MISR.
- Measurements of coastal, offshore and deep ocean BRDF(15 total; 8 uncontaminated by cloud) under a variety of sun angles and wind conditions for CERES, MISR and MODIS.
- Twelve OV-10 flights with spectral and broadband shortwave flux measurements under a variety of sun angles and wind conditions.
- Measurements demonstrating several new instrument technologies for future satellite platforms.
- July 17 was “Golden Day” with moderate aerosol and all six aircraft vertically stacked over the Chesapeake Lighthouse at TERRA overpass time.

Preliminary results will be shown at the conference. CLAMS data will be archived at the Atmospheric Sciences Data Center at NASA Langley and should become publicly available by August 2002.

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