

THE ALTUS CUMULUS ELECTRIFICATION STUDY (ACES): A UAV-BASED SCIENCE DEMONSTRATION

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ABSTRACT: The Altus Cumulus Electrification Study (ACES) is an unmanned aerial vehicle (UAV)-based project that investigated thunderstorms in the vicinity of the Florida Everglades in August 2002. ACES was conducted to investigate storm electrical activity and its relationship to storm morphology, and to validate satellite-based lightning measurements. In addition, as part of the NASA sponsored UAV-based science demonstration program, this project provided a scientifically useful demonstration of the utility and promise of UAV platforms for Earth science and applications observations. ACES employed the Altus II aircraft, built by General Atomics – Aeronautical Systems, Inc. Key science objectives simultaneously addressed by ACES are to: (1) investigate lightning-storm relationships, (2) study storm electrical budgets, and (3) provide Lightning Imaging Sensor validation. The ACES payload included electrical, magnetic, and optical sensors to remotely characterize the lightning activity and the electrical environment within and around thunderstorms. ACES contributed important electrical and optical measurements not available from other sources. Also, the high altitude vantage point of the UAV observing platform (up to 55,000 feet) provided “cloud-top” perspective. By taking advantage of its slow flight speed (70 to 100 knots), long endurance, and high altitude flight, the Altus was flown near, and when possible, over (but never into) thunderstorms for long periods of time that allowed investigations to be conducted over entire storm life cycles. An innovative real time weather system was used to identify and vector the aircraft to selected thunderstorms and safely fly around these storms, while, at the same time monitor the weather near our base of operations. In addition, concurrent ground-based observations that included radar (Miami and Key West WSR88D, NASA NPOL), satellite imagery, and lightning (NALDN and Los Alamos EDOT) enable the UAV measurements to be more completely interpreted and evaluated in the context of the thunderstorm structure, evolution, and environment.

INTRODUCTION

The Altus Cumulus Electrification Study (ACES) is an end-to-end science experiment to investigate thunderstorms in the vicinity of the Florida Everglades using an unmanned aerial vehicle (UAV). Based out of the Naval Air Facility Key West (NAFKW), the field campaign phase of this project was successfully conducted during the month of August 2002. The UAV represents an exciting new technology that can contribute in significant and unique ways to lightning and storm observations. In turn, these measurements can be linked to global scale processes (e.g., global water and energy cycle, climate variability and prediction, atmospheric chemistry) to provide an improved understanding of the total Earth system.

The primary science objective of ACES was to investigate the lightning activity and its relationship to the microphysical and dynamical properties of summertime thunderstorms. Using a complement of electrical, magnetic, and optical sensors, ACES has the potential to increase our knowledge of storm processes, which will lead to advancements in weather forecasting and the field of atmospheric electricity. The information obtained from this mission will serve to validate observations provided by space-borne lightning sensors, characterize the electromagnetic interaction between thunderstorms and the ionosphere, improve rainfall algorithms, and diagnose and forecast severe weather events. As part of the NASA sponsored UAV-based science demonstration program, the ACES project was highly successful in meeting stated program objectives to:

- Conduct high-quality research that exploits the unique capabilities of the Altus aircraft.
- Demonstrate the utility and promise of UAV platforms for Earth science observations.
- Build confidence in UAV platforms through a scientifically useful demonstration.

AIRCRAFT AND PAYLOAD HERITAGE

Figure 1 shows the Altus II UAV integrated with the ACES payload. The Altus is manufactured by General Atomics – Aeronautical Systems, Inc. (GA-ASI). The decision to select Altus was based on a number of factors including the maturity level of this aircraft system, its performance capabilities and proven flight record, and the successful integration and flights of a developmental version of the ACES payload on Altus in September 2000 under an activity managed by R. Goldberg. These flights established the physical and functional compatibility of the ACES payload with the Altus platform and showed the Altus to be an electrically quiet platform ensuring that the thunderstorm measurements could be readily achieved, as was verified during the August 2002 campaign. The ACES payload used flight-proven sensors that all had a solid heritage derived from previous aircraft or rocket investigations, and thus were very reliable and low risk.

The performance characteristics of the Altus, including some very unique capabilities, made this UAV ideally suited for thunderstorm studies. The performance characteristics include high altitude flight, long-duration missions with long “on station” time, slow flight speed, and quick response time. No other aircraft platform has this combination of capabilities, essential for acquiring complete storm lifecycle observations.

KEY SCIENCE

Three important science objectives simultaneously addressed by the UAV investigation include (1) validating satellite-based lightning detectors, (2) strengthening lightning-storm relationships, and (3) gaining improved understanding of the Global electric circuit and storm electric budget.

Validation

The ACES validation effort will provide detailed characterization of lightning type, cloud top optical energy, and power statistics that is needed to better interpret the global lightning database collected by Lightning Imaging Sensor (LIS) and other satellite-based optical lightning detectors [Christian, 1992; 2003]. Cloud-top measurements were last collected using a NASA U-2 aircraft in the early 1980s but provided only a small data set for validation activities (i.e., <350 total discharges, <25 cloud-to-ground lightning discharges) [Christian, 1987; Goodman, 1988]. The Altus, with its slow flight speed, was able to stay in continual proximity to storms to acquire a large sample optical pulse measurements needed for ongoing validation efforts [Mach, 2003].

Lightning-Storm Relationships

While it is widely recognized that strong relationships exist between lightning, updraft strength, ice mass aloft, storm height, and precipitable water, the observed connections remain essentially qualitative. The ACES measurements and the ancillary ground- and satellite-based observations will contribute to the effort to develop a functional description between lightning and many of the above storm parameters throughout the thunderstorm life cycle [Buechler, 2003]. The relationship between storm electrical and kinematic properties is of particular interest as they might be used to discriminate severe from non-severe storms.

Global Electric Circuit and Storm Electric Budget

ACES electrical measurements will enable us to uniquely address important questions about the electrical budget of thunderstorms, the global electric circuit, and the electrodynamic interaction with the upper atmosphere [Farrell, 2003]. The relationship between storm current output and total flash rate will be investigated. Then, using this relationship, the current output from worldwide thunderstorm activity will be estimated from the global observations of lightning acquired by the LIS and the Optical Transient Detector (OTD) satellites. This result will provide an independent measure of the current flowing in the global electric circuit.

DEMONSTRATION GOALS

There were two primary demonstration goals in the ACES project that were successfully addressed. First, by exploiting the unique capabilities of Altus, the ACES project demonstrated the utility and promise of UAV platforms for investigating



Figure 1. The Altus taking off with the ACES payload to go monitor thunderstorms

thunderstorm and other weather phenomena. Slow flight speed, coupled with long endurance and high altitude flight gave the Altus aircraft the ability to be maintained continuously near thunderstorms for long periods of time and enabled investigations to be conducted over entire storm life cycles. This overcame the limitations of conventional aircraft that, as a result of much faster flight speeds, provide only a few brief “snapshots” of storm activity sandwiched between long intervening periods with no observations. The Altus, with its lower flight speed, remained within measurement range (e.g., within 5 km) even while making turns.

A second demonstration goal was to provide a demonstration of real-time monitoring and control of the UAV science payload and data. During flights, selected instrument outputs (e.g., electric field) were sent to the ground via the Altus telemetry link enabling the scientists to monitor target storms in real time. In fact, for safety concerns, the ambient electric field environment was monitored in real time to avoid high electric field (>11-16 kV/m depending on altitude) regions, and thus reduced to a low probability the threat of incurring a lightning strike to the aircraft. Also, in support of ACES, an innovative Web-based real time weather display system was developed that included lightning, radar, and satellite imagery along with aircraft track information. Proving to be an invaluable tool in the conduct of ACES, the real time weather system was used to identify and vector the aircraft to selected thunderstorms and safely fly around these storms, while, at the same time monitor the weather near our base of operations. Figure 2 shows actual examples from the mission of the aircraft/weather displays to illustrate how these data were used in real time during mission execution. During post-deployment, this system – in a playback mode – is aiding in the science analyses and the education and public outreach.

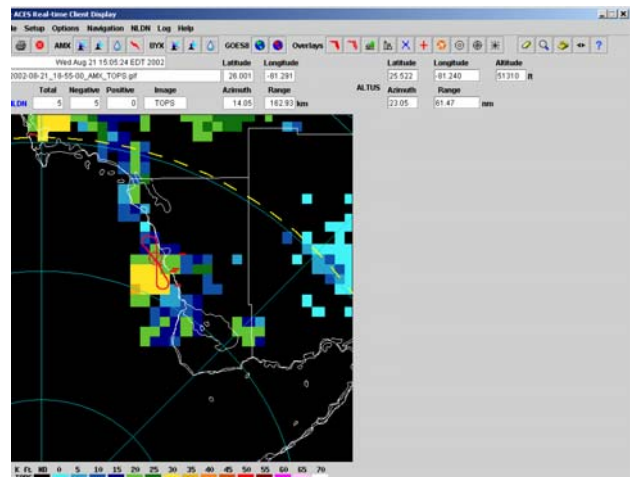


Figure 2. This is a zoomed in view of the Altus aircraft at 51,910 ft executing a figure eight pattern over the top of an Everglade thunderstorm.

EXPERIMENTAL DESIGN AND CONDUCT

The ACES flight operations were based from NAFKW, located on Boca Chica Key, Florida during the month of August 2002 as shown in Fig. 3. From this location, the ACES scientists were able to investigate thunderstorms occurring over the sparsely populated Florida Everglades and nearby ocean.

The ACES flight campaign lasted approximately 4 weeks with the first science flight flown on August 4, 2002 and the last mission flown on August 30. During the campaign we flew 13 sorties for a total of 37.8 hours. The longest flight duration was on August 21 for a period of 6.7 hours. All missions were conducted at an altitude above 40,000 feet with typical storm observation made between about 48,000 to 52,000 feet. For the missions, we flew close to, and when possible, above (but never into) thunderstorms using safe operational procedures.

EXPECTED AND ACTUAL WEATHER

Thunderstorm activity in Florida near the Everglades peaks during the summer months. Not unexpectedly, the greatest frequency of thunderstorm occurrence is in summer afternoons between 13–18 local standard time (LST). The climatological number of thunderstorm days for the Everglades area is about 12-15 days for August. Figure 4 shows the actual lightning statistics for the ACES domain during the August 2002 campaign. These data also show that during this period thunderstorms occurred on more than 20 days during the month, which is better than the climatologic mean.



Figure 3. Location of the ACES field campaign. The 82 nautical mile radius represents the range at 50,000 ft altitude allowed by GA-ASI. With favorable winds the range could be extended at the pilot’s discretion (e.g., dashed line on map)

Summer thunderstorms in the Everglades are generally of the small air mass “pulse-type” variety. They are usually slow moving with typical lifetimes of 0.5–1.0 hour or less. The typical dimension of the thunderstorms is around 10 km in diameter with heights around 12 km. Since synoptic-scale forcing is quite weak in the summer season, the thunderstorm formation is dominated by weak interacting boundaries, often initiated by differential heating and classic sea breeze convergence. Other mechanisms, although weak, can produce boundaries and boundary interactions sufficient to contribute to summer thunderstorm development. These include convective outflows, river and lake breezes, cloud shadow and soil moisture temperature discontinuities, washed out frontal zones/shear lines, and remnants of boundaries from previous day(s).

CONCLUDING REMARKS

The ACES team, comprised of scientists and engineers at the NASA Marshall Space Flight Center and NASA Goddard Space Flight Center partnered with GA-ASI and Idea, LLC. brought considerable experience to the project, including aircraft operations (GA-ASI); sensor development; and thunderstorm and other science investigations using aircraft, spacecraft, and rocket platforms. This combined investigator experience with comprehensive project management and system engineering made the ACES team capable of quickly developing and successfully flying a payload that achieved all the near-term science and demonstration objectives of NASA’s UAV science demonstration program. The Altus proved to be an excellent platform to study thunderstorms. The electrically quiet environment of the Altus aircraft and its demonstrated ability to remain within measurement range of storms and other weather phenomena strongly supports the application of this aircraft and its successors to future NASA Earth Science missions.

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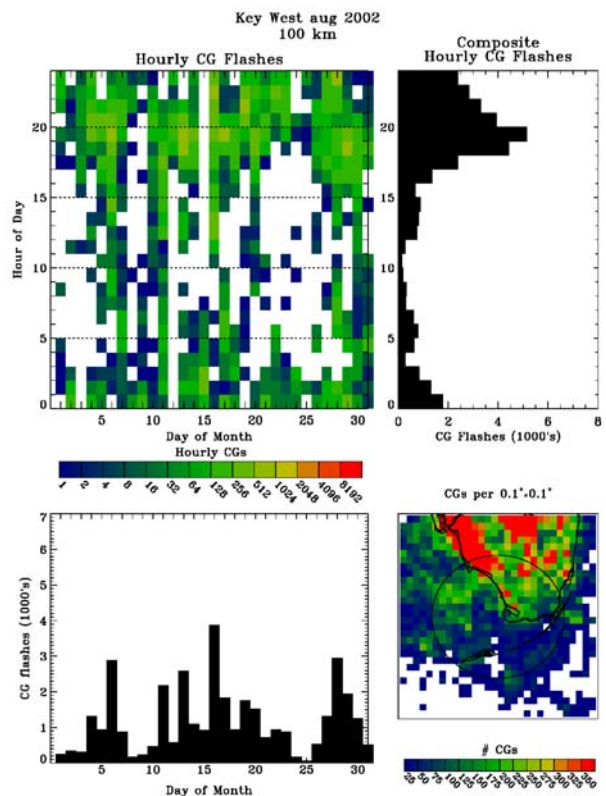


Figure 4. Cloud-to-ground lightning statistics for the ACES domain (i.e., Everglades and nearby ocean). The hourly and daily graphs include only lightning within the 100 km circle in lower right hand plot.