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

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ABSTRACT

The Altus Cumulus Electrification Study (ACES) is an uninhabited aerial vehicle (UAV)-based project that will investigate thunderstorms in the vicinity of the Florida Everglades in July 2002. ACES is being conducted to both investigate storm electrical activity and its relationship to storm morphology, and validate Tropical Rainfall Measurement Mission (TRMM) satellite measurements. In addition, as part of NASA's UAV-based science demonstration program, this project will provide a scientifically useful demonstration of the utility and promise of UAV platforms for Earth science and applications observations. ACES will employ 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, already developed and flown on Altus, includes electrical, magnetic, and optical sensors to remotely characterize the lightning activity and the electrical environment within and around thunderstorms. ACES will contribute 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) offers a useful "cloud-top" perspective. By taking advantage of its slow flight speed (70 to 100 knots), long endurance, and high altitude flight, the Altus will be flown near, and when possible, above (but never into) thunderstorms for long periods of time, allowing investigations to be conducted over entire storm life cycles. In addition, concurrent ground-based observations will enable the UAV measurements to be more completed interpreted and evaluated in the context of the thunderstorm structure, evolution, and environment.

INTRODUCTION

The Altus Cumulus Electrification Study (ACES) is a scientific field experiment to investigate thunderstorms in the vicinity of the Florida Everglades using an uninhabited aerial vehicle (UAV). 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 will be to investigate the lightning activity and its relationship to the microphysical and dynamical properties of summertime thunderstorm. Using a complement of electrical and optical sensors, we expect our investigation 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 NASA's UAV-based science demonstration program we will:

- 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 though a scientifically useful demonstration

AIRCRAFT SELECTION

Figure 1 shows the ALTUS II UAV, manufactured by General Atomics – Aeronautical Systems, Inc. (GA-ASI), that will be used for this study. 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 flight of the ACES payload on ALTUS in September 2000 under a Small Business Innovation Research (SBIR) activity with IDEA managed by R. Goldberg.

The performance characteristics of the ALTUS, including some very unique capabilities, make this UAV ideally suited for pursuing the proposed 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 will be simultaneously addressed by this UAV investigation: (1) validation of satellite-based lightning detectors, (2) lightning-storm relationships, and (3) 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. 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). The ALTUS, having a slow flight speed, and thereby able to stay in continual proximity to a storm, will be better able than the U–2 to acquire a large sample

***Figure 1**. The ALTUS II aircraft shown in flight over the California desert.*

optical pulse measurements needed for ongoing validation efforts.

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 ALTUS 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. Scatter plots of lightning rates versus the cloud parameters will help identify and statistically validate relationships between these parameters. The relationship between storm electrical and kinematic properties is of particular interest as they might be used to discriminate severe from non-severe storms. How mesoscale boundaries (e.g., land/ocean) affect the development and evolution of these properties will also be explored.

Global Electric Circuit and Storm Electric Budget

Finally, 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. 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 now being 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 are two primary demonstration goals in the ACES project. First, by exploiting the unique capabilities of ALTUS, we will demonstrate the utility and promise of UAV platforms for investigating thunderstorm and other weather phenomena. Slow flight speed, coupled with long endurance and high-altitude flight give the ALTUS aircraft the ability to be maintained continuously near thunderstorms for long periods of time and enable investigations to be conducted over entire storm life cycles. This overcomes 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, can remain within measurement range (i.e., ~5 km) even while making turns. Presently, only the ALTUS has this combination of capabilities, essential for conducting complete storm life cycle investigations (i.e., no gaps). This demonstration goal supports a principal objective of NASA's UAV science demonstration.

A second goal, also supportive of the UAV science demonstration objectives, is to provide a demonstration of real-time monitoring and control of the UAV science payload and data. During flights, selected instrument output (e.g., electric field) will be sent to the ground via the ALTUS telemetry link enabling us to monitor target storms in real time. In fact, we have proposed to monitor the ambient electric field environment in real time to avoid high electric field (>11-16 kV/m depending on altitude) regions, and thus reduce to a low probability the threat of incurring a lightning strike to the aircraft. Output from the ALTUS video camera and a real time weather display that includes lightning, radar, and satellite imagery will also help monitor storm conditions during flights.

EDUCATION AND PUBLIC OUTREACH

Our overall outreach goals are to increase public awareness and inform the public of the purpose and benefits of the ACES project and the NASA Earth Science Enterprise (ESE). The outreach will create a positive image of NASA and the ESE.

We will adopt a three-fold approach to generate effective education and public outreach. First, access to traditional news services with the aid of the MSFC public affairs office (PAO) will create immediate coverage in the form of good press. Second, comprehensive treatments and information about the project will be made education project designed to inspire the next generation of scientists and engineers through a "hands-on" application employing actual ACES data sets.

EXPERIMENT DESIGN

We propose to base the flight operations from Naval Air Station Key West (NASKW), located on Boca Chica Key, Florida. From this location, we will be able to investigate thunderstorms occurring over the sparsely populated Florida Everglades and nearby ocean as shown in Fig. 2. Basing operations from Key West also allowed ACES to take advantage of significant cost and resource sharing with the NASA sponsored Cirrus Regional Study of Tropical Anvils and Cirrus Layers–Florida Area Cirrus Experiment (Crystal-Face).

In order to achieve our objectives, we plan to observe thunderstorms during the August 2002. It is anticipated that this campaign will last approximately 4 weeks with a goal of performing 8 to 10 UAV flights of 6 to 8 hours duration. Each mission will require about 4 to 5 hours on station at altitudes from 40,000 feet to 55,000 feet. For the missions, we will direct the ALTUS to fly close to, and when possible, above (but never into) thunderstorms using safe operational procedures.

Access to a large variety of meteorological data products will be available to the ACES project via the Internet. During the missions these data provided to ACES will be employed in real time to aid mission planning and execution. During post-deployment, these data will aid in the science analyses and in the education and public outreach.

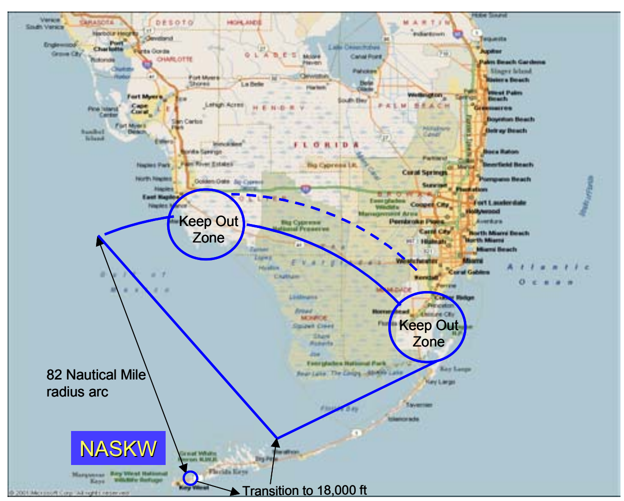

***Figure 2.** Location of the ACES field campaign. The 82 nautical mile radius represents the allowed range at 50,000 ft altitude. With favorable winds the range may be extended (e.g., dashed line on map).*

Expected 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. This means that on average, there will be thunderstorms every 2–3 days. Figure 3 is an example of the lightning statistics for the ACES domain during a representative year, characterized here by August 1999.

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).

Payload and Aircraft Heritage

The ACES payload uses existing flight-proven sensors from MSFC and GSFC. The sensors all have a solid heritage derived from previous aircraft or rocket investigations, and thus are very reliable and low risk. Previous platforms include the high-and medium altitude aircraft and sounding rockets. In September 2000, the payload was successfully flown on the ALTUS at the GA–ASI El Mirage, California flight test center under an aforementioned SBIR activity. These test flights established the physical and functional compatibility of the ACES payload with the ALTUS platform. In addition, ALTUS was found to be an electrically quiet platform ensuring that the planned thunderstorm measurements can be readily achieved.

The ALTUS also has considerable heritage. The ALTUS is a derivative of the Predator system, now proven with over 40,000 hours of fleet experience worldwide. The ALTUS itself now has flown 70 missions/209 hours without incident. In addition, the ALTUS has demonstrated that it can meet the ACES operational mission requirements to fly altitudes of 40,000–55,000 feet.

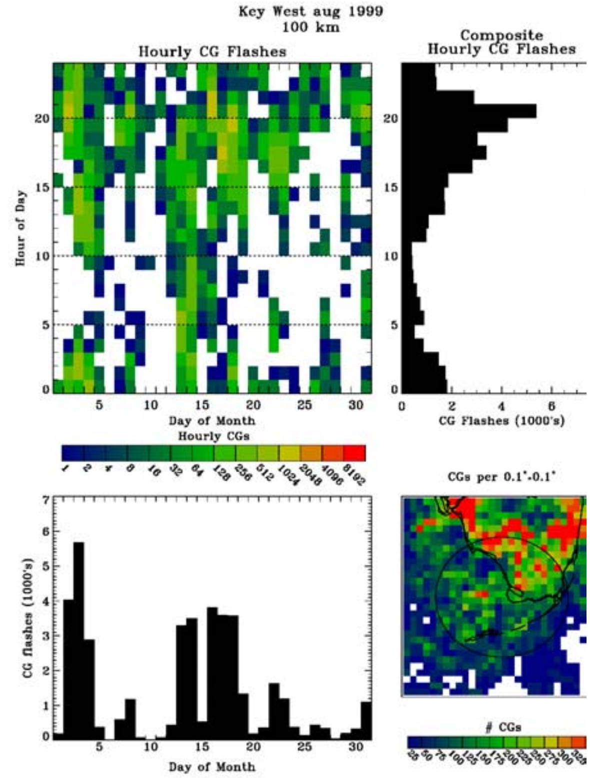

Figure 3. *Cloud-to-ground lightning statistics for the ACES domain (i.e., Everglades and nearby ocean). The hourly and daily graphs include only lightning within the 100 km circle in lower right hand plot.*

Concluding Remarks

The ACES team is comprised of scientists at the NASA Marshall Space Flight Center and NASA Goddard Space Flight Center partnered with GA–ASI and IDEA, LLC. The ACES team brings considerable experience to the planned effort, including aircraft operations (GA–ASI); sensor development; and thunderstorm and other science investigations using aircraft, spacecraft, and rocket platforms. This combined investigator experience makes the ACES team very unique and capable of quickly developing and successfully flying a payload that will meet all the near-term science and demonstration objectives of NASA's UAV science demonstration program.

Our combined experience means that the ACES team can deploy instruments that possess substantial heritage, are of low risk, and can be successfully delivered in the required time. ACES, with its campaign planned for the summer 2002 timeframe, will quickly demonstrate the usefulness of UAVs for Earth science and applications observations.