NASA'S EARTH VENTURE-1 (EV-1) AIRBORNE SCIENCE INVESTIGATIONS

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Abstract - In 2010, NASA announced the first Earth Venture (EV-1) selections in response to a recommendation made by the National Research Council for low-cost investigations fostering innovation in Earth science. The five EV-1 investigations span the Earth science focus areas of atmosphere, weather, climate, water and energy and, carbon and represent earth science researchers from NASA as well as other government agencies, academia and industry from around the world. The EV-1 missions are: 1) Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS), 2) Airborne Tropical Tropopause Experiment (ATTREX), 3) Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), 4) Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), and 5) Hurricane And Severe Storm Sentinel (HS3). The Earth Venture missions are managed out of the Earth System Science Pathfinder (ESSP) Program Office (Allen, et. al. 2010b)

Index Terms— Ecology, Climate, Meteorology, Hydrology, Atmosphere

1. INTRODUCTION

Last year, NASA's Science Mission Directorate (SMD) announced the selection of five airborne science investigations resulting from the first Earth Venture (EV) call for proposals, EV-1. The Earth Venture program was initiated in response to a recommendation made by the National Research Council (NRC) in the 2007 Decadal Survey (NRC, 2007) for low-cost research and application investigations fostering innovation in Earth Science. The EV-1 solicitation (ROSES, 2009) targeted technically mature suborbital (airborne) Earth science investigations with temporally sustained data acquisition over a life cycle of less than or equal to five years and total investigation cost not to exceed $30 million each.

The awarded investigations were selected based on scientific and technical merit with consideration for NASA's programmatic aim to contribute to as many Earth science focus areas as possible. The EV-1 investigations span the Earth science focus areas of atmospheric composition, weather, climate variability and change, water and energy cycles, and carbon cycle and ecosystems and represent Earth science researchers from NASA as well as other government agencies, academia and industry from around the world. The EV-1 Principal Investigators (PIs) and investigations are Mahta Moghaddam, University of Michigan (AirMOSS); Eric Jensen, NASA Ames (ATTREX); Charles Miller, NASA JPL (CARVE); James Crawford, NASA Langley (DISCOVER-AQ); and Scott Braun, NASA Goddard (HS3).

The EV-1 missions are managed out of the Earth System Science Pathfinder (ESSP) Program Office (Allen, et. al., 2010b). This paper serves to update Allen, et. al., 2010a.

2.1. AirMOSS — Airborne Microwave Observatory of Subcanopy and Subsurface

The goal of the AirMOSS investigation is to minimize one of the largest components of uncertainty in net ecosystem exchange (NEE) estimates of carbon over North America, namely the component arising from the lack of knowledge of root zone soil moisture (RZSM) and its spatial heterogeneity. AirMOSS will reach this goal by addressing the following objectives: (1) providing high-resolution regional observations of RZSM over the major North American biomes, (2) quantifying the impact of RZSM on estimation of regional carbon fluxes contributing to NEE, and (3) upscaling the reduced-uncertainty regional estimates of carbon fluxes to the continental scale of North America. RZSM, the average volumetric moisture (m^3/m^3 in %) in the soil column from surface to the rooting depth of plants, can describe as much as 60%–80% of the variability in NEE carbon flux components, yet remains an unobserved quantity except at few point locations.
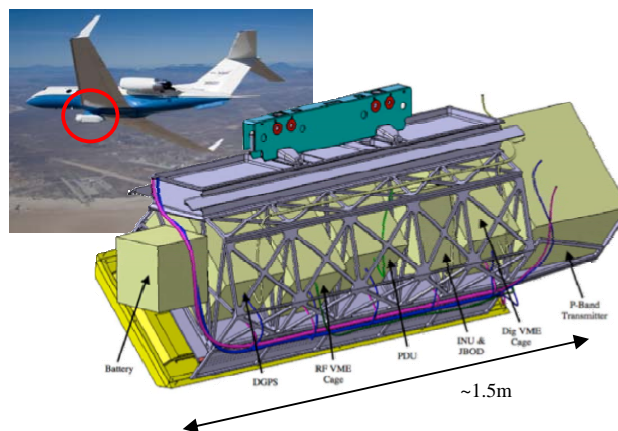

Figure 1: The G-III aircraft during flight (top) and the UAVSAR pod (circled in red) that will house the AirMOSS UHF radar (bottom).

The AirMOSS RZSM benchmark dataset, the first of its kind, will be a major breakthrough over current point-scale RZSM measurements and will provide a critical input parameter to carbon flux models. Through the use of hydrologic data assimilation and ecosystem demography models, AirMOSS will be able to quantify the impact of RZSM on NEE at local, regional, and continental scales. Without this measurement and modeling framework, large uncertainties in NEE estimation will always remain.

To measure RZSM, AirMOSS will use an airborne ultra-high frequency (UHF) synthetic aperture radar (SAR) that has the capability to penetrate through substantial vegetation canopies and soil to depths down to approximately 1.2 meters. The AirMOSS instrument will be housed in a pod, and will be deployed on a Gulfstream-III (G-III) aircraft. Extensive ground, tower, and aircraft in-situ measurements are planned to validate RZSM and carbon flux model estimates. Figure 1 shows the G-III aircraft during flight, including the pod that will house the AirMOSS UHF radar and the major radar building blocks.

AirMOSS will conduct field operations in 2012, 2013 and 2014, flying four campaigns each year starting in the spring and ending in the fall. Flights each year will focuses on sites in Canada and the United States, including the boreal BERMS flux site in Saskatchewan, as well as study sites in Oklahoma (Little Washita), Massachusetts (Harvard Forest), North Carolina (Duke Forest), Oregon (Metolius), California (Tonzi Ranch), and Arizona (Walnut Gulch), Mexico (Chamela), and Costa Rica (La Selva).

2.2. ATTREX — Airborne Tropical TRopopause EXperiment

The goal of ATTREX is to improve our understanding of how deep convection, slow large-scale ascent, waves, and cloud microphyiscs control the humidity and chemical composition of air entering the stratosphere. This knowledge will improve global-model predictions of feedbacks associated with future changes in Tropical Tropopause Layer (TTL) cirrus, stratospheric humidity, and stratospheric ozone in a changing climate.

Despite its low concentration, small changes in stratospheric humidity may have climate impacts that are significant compared to those of decadal increases in greenhouse gases. While the tropospheric water vapor climate feedback is well represented in global models, predictions of future changes in stratospheric humidity are highly uncertain because of gaps in our understanding of physical processes occurring in the TTL (~13-18 km). Uncertainties in the TTL chemical composition also limit our ability to predict future changes in stratospheric ozone. Poorly understood processes affecting TTL composition and stratospheric humidity include deep convection, thin cirrus, large-scale transport, atmospheric waves, and the chemistry of short-lived trace gases. Science questions that will be addressed by ATTREX include the following:

- What processes control the tropical tropopause temperature and the humidity of air entering the stratosphere?
- What are the dominant pathways for vertical transport from convective detrainment altitudes in the TTL up to the tropical tropopause in different seasons?
- What are the formation processes, microphysical properties, and climate impact of TTL cirrus, and how do these clouds regulate the humidity of air entering the stratosphere?
- What are the chemical and transport processes that drive the budgets of precursors of ozone-destroying substances such as short-lived halogen compounds?
- How will TTL cirrus, stratospheric humidity, and stratospheric ozone respond to a changing climate, and what are the resulting feedback effects?

ATTREX addresses these science questions with Global Hawk (GH) Unmanned Aircraft System (UAS) campaigns based at NASA Dryden and other locations surrounding the Pacific Ocean. The campaigns will take place in Boreal summer, winter, fall, and summer as shown in Figure 2. Instruments comprising the GH payload include Cloud Physics Lidar, Advanced Whole Air Sampler, Chromatograph for Tracers, multiple hygrometers, radiometers, and temperature profilers.

This instrument suite will provide measurements of TTL tracers with a broad range of lifetimes, cloud microphysical properties, dynamic and thermodynamic variables, radiative fluxes, water vapor, and bromine containing gases. By providing measurements at high spatial resolution over large geographical regions, ATTREX will fill the gap between coarser-resolution satellite data and single, limited-domain conventional high-altitude aircraft campaigns.
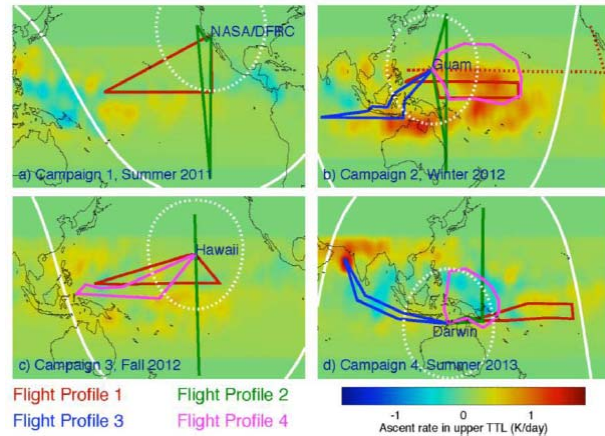

Figure 2: Representative Global Hawk flight profiles for the four phases of ATTREX. Solid and dotted white lines represent maximum roundtrip range for the Global Hawk and ER-2, respectively.

2.3. CARVE — Carbon in Arctic Reservoirs Vulnerability Experiment

The goal of CARVE it to bridge critical gaps in our knowledge and understanding of Arctic ecosystems, linkages between the Arctic hydrologic and terrestrial carbon cycles, and the feedbacks from fires and thawing permafrost. CARVE will quantify correlations between atmospheric and surface state variables for the Alaskan terrestrial ecosystems through intensive seasonal aircraft campaigns, ground-based observations, analysis, and modeling. Key unanswered science questions that drive the CARVE science investigation are:

- What are the sensitivities of the Arctic carbon cycle and ecosystems to climate change?
- How does interannual variability in surface controls affect landscape-scale atmospheric concentrations and surface-atmosphere fluxes of carbon?
- What are the impacts of fire and thawing permafrost on the Arctic carbon cycle and ecosystems?

The CARVE science objectives bridge these critical gaps in current knowledge by:

- Directly testing hypotheses attributing the mobilization of vulnerable Arctic carbon reservoirs to climate change;
- Delivering the first direct measurements of CO_2 and CH_4 on local to regional scales in the critical Arctic ecozone; and
- Demonstrating new remote sensing and improved modeling capabilities to quantify Arctic carbon fluxes and carbon cycle-climate processes.

CARVE achieves its science objectives by integrating seasonal aircraft deployments using a De Havilland DHC-6 Twin Otter with continuous measurements from strategically located ground-based sites. CARVE's payload includes Passive-Active L-band System (PALS) and a nadir-viewing Fourier transform spectrometer (FTS) to deliver the first simultaneous measurements of surface controls on emissions (soil moisture, inundation state, freeze/thaw state, surface temperature) and

total atmospheric columns of CO_2, CH_4, and CO. The aircraft payload also includes an In Situ Gas Analyzer which links the FTS-based total column measurements directly to WMO standards.

Initial engineering test flights will occur in 2011 in Alaska and Oklahoma. With science deployments out of Fairbanks, AK occurring during the spring, summer and early fall of each year from 2012–2014 when Arctic carbon fluxes are changing rapidly and the sensitivities of ecosystems to external forcings are maximized. CARVE flight paths (Figure 3) sample multiple permafrost domains and ecosystems, and deliver detailed measurements over ground-based measurement sites, fires, and burn-recovery chronosequences and will concentrate observations on three study domains: the North Slope, the interior, and the Yukon River valley. North Slope flights (gold path) are anchored by the flux towers in Barrow, Atqasuk, and Ivotuk, regions of tundra and continuous permafrost. Continuous ground-based measurements from CO_2 and CH_4 flux towers, Alaska Ecological Transect surface control sites, the NOAA/ESRL global network and Total Column Carbon Observing Network provide temporal and regional context as well as calibration for CARVE airborne measurements.
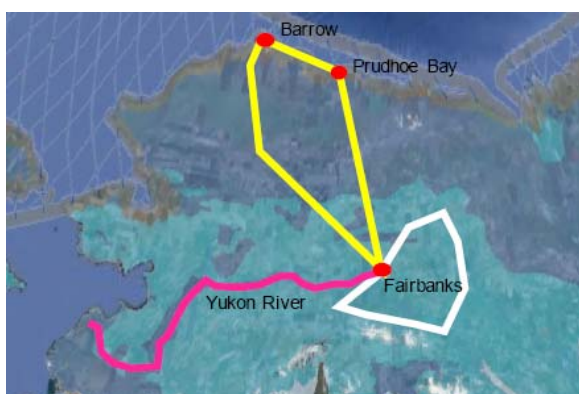

Figure 3: CARVE flight plans deliver measurements over continuous (dark blue), discontinuous (light blue), sporadic (gray) and subsea (hatched) permafrost regimes. Each colored loop represents a single day's flight path.

CARVE observations provide crucial constraints for reconciling top-down (atmospheric concentration inversion) and bottom-up (emission process modeling) carbon flux estimates for the critical Arctic ecozone. CARVE scientists will exploit these observational constraints to develop improved models for key, yet uncertain feedbacks on the Arctic carbon cycle: boreal fires, burn-recovery, emissions from wetlands, and permafrost thaw dynamics. These improved models provide a framework in which to upscale CARVE observations from local to regional scales to augment existing and future space-based observations.

2.4. DISCOVER-AQ — Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality

The goal of DISCOVER-AQ is to improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality. This will be achieved through concurrent, integrated observations of column abundances and surface concentrations for key trace gases and aerosols. These observations will be used to: (1) relate column observations to surface conditions for aerosols and key trace gases O_3, NO_2, and CH_2O; (2) characterize differences in diurnal variation of surface and column observations for key trace gases and

aerosols; and (3) examine horizontal scales of variability affecting satellites and model calculations.

The DISCOVER-AQ observation strategy will employ two aircraft, NASA's P-3B and UC-12B, and a network of ground sites to monitor key trace gases and aerosols throughout the day from multiple perspectives. Flights will be integrated with existing surface sites for research as well as operational monitoring sites that report data to EPA's Air Quality System (AQS) national repository. Remote sensing of the atmospheric column will be accomplished from the NASA B200 with nadir observations of aerosol profiles and trace gas columns using the High Spectral Resolution Lidar (HSRL) and the Airborne Compact Atmospheric Mapper (ACAM), respectively. Concurrently, trace gas and aerosol columns will be monitored from below with 12 Pandora sun-tracking spectrometers, five AERONET sun-photometers, and two aerosol lidars integrated with existing AQS sites. The P-3B will be used to provide in situ profiling of trace gases and aerosols beneath the UC-12B and above selected ground sites. The P-3B instrument suite includes seven instruments providing in situ trace gas and aerosol observations. Additional research-grade surface measurements and ozonesondes will be provided by the NATIVE research trailer as well as research-grade NO_2 measurements at three sites to be furnished by EPA collaborators.
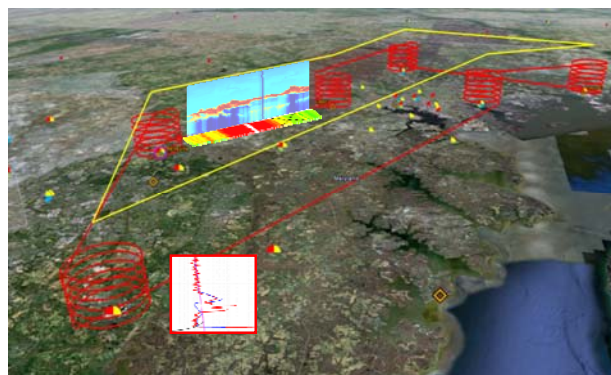

Figure 4: A 3-D perspective on DISCOVER-AQ's nominal flight observation strategy for how the P-3B (red) and UC-12B (yellow) will fly over the Baltimore-Washington focus area.

Four 30-day deployments are planned from 2011 through 2014 to focus on an urban area known for exceeding air quality standards. Baltimore-DC area (Figure 4) will be the focus in 2011. Three additional locations will be determined later based on the science goals but candidate cities include Houston, Sacramento, Los Angeles, Birmingham, and Atlanta. These locations are chosen for the variety in the factors contributing to their local air quality problems (e.g., upwind emissions, transportation, industrial emissions, agriculture), diversity in meteorology and surface conditions, and proximity to NASA deployment sites. Expected outcomes include fundamental improvement in our understanding of the factors governing surface versus column variability, improved understanding of diurnal variability, and improved characterization of variability at scales finer than current models and satellites can resolve. This knowledge will lead to more effective use of current satellite observations, more effective design and observing strategies for future satellites, and improved air quality models.

2.5. HS3 — Hurricane and Severe Storm Sentinel

The goal of HS3 is to enhance our understanding of the processes that underlie hurricane intensity change in the

Atlantic Ocean basin. HS3 is motivated by hypotheses related to the roles of the large-scale environment and storm internal processes in hurricane intensity change as well as the controversial role of the Saharan Air Layer (SAL) in tropical storm formation and intensification, the role of deep convection in the inner-core region of storms, and the evolution of storm structure and intensity during the process of transition into a more extratropical system. The HS3 objectives are: (1) to obtain critical measurements in the hurricane environment in order to identify the role of key factors such as large-scale wind systems (troughs, jet streams), Saharan air masses, African Easterly Waves and their embedded critical layers and (2) to observe and understand the three-dimensional mesoscale and convective-scale internal structures of tropical disturbances and cyclones and their role in intensity change.

Past hurricane field campaigns have all faced the limitation of a relatively small sample of storms. The small sample is not only a function of tropical cyclone activity in any given year, but also the distance of storms from the base of operations. Addressing the science questions posed by HS3 requires sustained measurements over several years. HS3 will conduct a total of ten 30-hour flights during each of three one-month deployments using two NASA Global Hawk UASs. From mid-August to mid-September during 2012-2014, HS3 will be deployed from the United States east coast, which will provide access to air space and unprecedented access to hurricanes over the Atlantic Ocean. HS3 utilizes a suite of advanced instruments to measure key characteristics of the storm environment and the hurricane's internal structures. The environmental mission (Figure 5) performs a series of north-south transects (numbers indicate the order of the flight way points) to map the SAL and other environmental characteristics. The over-storm flight pattern provides repeated measurements of storm structure, intensity, and evolution.

The environmental payload will provide continuous sampling of temperature and relative humidity in the clear-air environment from the Scanning High-resolution Interferometer Sounder (S-HIS), full tropospheric wind, temperature, and humidity profiles from the Advanced Vertical Atmospheric Profiling System (AVAPS) dropsonde system, continuous wind profiles in clear air from the TWiLiTE Doppler wind lidar, and aerosol and cloud layer vertical structure from the Cloud Physics Lidar (CPL). The over-storm payload measurements include three-dimensional wind and precipitation fields from the HIWRAP conically scanning Doppler radar, surface winds and rainfall from the Hurricane Imaging Radiometer (HIRAD) multi-frequency interferometric radiometer, and measurements of temperature, water vapor, and liquid water profiles, total precipitable water, sea-surface temperature, rain rates, and vertical precipitation profiles from the HAMSR microwave sounder.

HS3 will provide a unique and comprehensive data set on a large number of Atlantic hurricanes to characterize the hurricane environment and internal structures. The HS3 measurements will be used enhance our understanding of hurricane intensification and, by coupling data analysis with both global and mesoscale modeling research, improve current Earth system modeling and prediction capabilities.

3. SUMMARY

The EV-1 investigations will provide new knowledge of:
- the sources and sinks of carbonaceous greenhouse gases in a range of biomes as a function of soil moisture,
- upper atmospheric chemistry and cirrus cloud properties,
- the flux carbonaceous greenhouse gases from thawing permafrost,

- air quality assessment and tropospheric chemistry using satellite remote sensing in conjunction with airborne and ground-based measurements, and air quality models, and
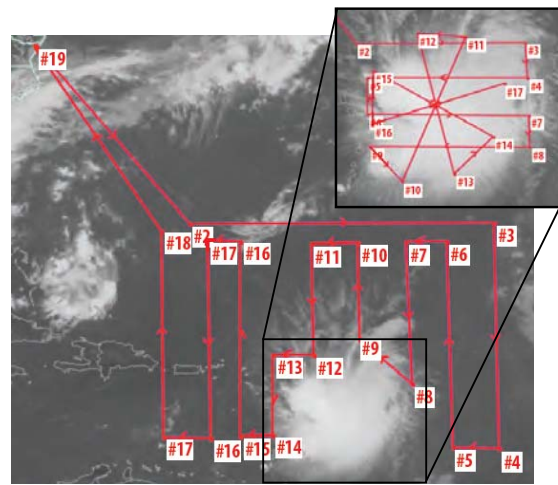- tropical cyclone development and intensification

Figure 5: Example flight patterns for an environmental mission and over-storm mission (inset).

These investigations will contribute to NASA's efforts in Earth system science in the areas of climate, weather, hydrology, carbon cycle and applied science research. Combined with ongoing satellite observations, the EV-1 investigations will significantly enhance NASA Earth Science's goals of developing environmental and climate data records and increasingly refined Earth system models to assist policy makers.

4. REFERENCES

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