Appendix A

Mission Summaries

The following sections provide brief descriptions of the potential missions documented by the authors to date. These missions are a direct result of the workshops held during 2004 and 2005. A complete description of each mission along with platform and communication requirements may be found in Appendix D of the Assessment draft document located on the Civil UAV Assessment website.

Missions have been separated into the following mission categories: Earth Science, Homeland Security, and Land Management. Additional workshops are being planned to include commercial applications.

A1. Earth Science

The following missions have been documented primarily through the Suborbital Science Missions of the Future Workshop and personal interviews. Missions involve both *in situ* and remote sensing applications. The unanimous consensus among scientists however, was that UAV missions would augment rather than replace satellite observations. Inclusion in this report does not imply that these missions have been funded or otherwise validated by any government agency.

Repeat Pass Interferometry for Surface Deformation
This mission would allow measurement of the geophysical processes associated with natural hazards such as earthquakes, landslide, and volcanoes as they are manifested by deformations in the Earth's crust. Measurements of the crustal deformation would be made by an interferometric synthetic aperture radar (SAR) carried by the UAV platform.

Cloud and Aerosol Measurements
This suborbital mission would study transformations of aerosols and gases in cloud systems in the following domains:

- Convective systems: to include areas of Costa Rica, Southern Florida, and Central United States
- Sea breeze cloud formation – wide areas of coastal U.S.
- Marine stratiform – primarily the California coastal areas
- Contrails in the Central U.S. in air traffic regions and ship tracks in oceans
- Synoptic scale systems & Fronts – in the Central U.S. region
- Cirrus outflow – large areas of the tropics, Southern Florida, and Central U.S.

Stratospheric Ozone Chemistry
The purpose of this mission is to observe changes in the stratospheric ozone chemistry by the profiling of source gases, water, aerosols, and temperatures in the mid-latitudes and Polar Regions in the upper troposphere/lower stratosphere. In addition to source gases, tracers as well as reservoir species and radicals are to be measured. The mission will make simultaneous measurements of water vapor, total water temperature, pressure, winds, ozone, aerosols, and polar stratospheric clouds (PSC).

Tropospheric Pollution and Air Quality
The objective of this suborbital mission is to study the sources, evolution, and distribution of tropospheric pollutants. The pollutants and particles and their source

emissions would be profiled on regional to hemispheric scales from near the surface to the tropopause region. This profiling would cause determination of where plumes of pollution are transported and how they evolve.

Water Vapor and Total Water Measurements
The objective of this mission is to study water vapor and total water in the tropical tropopause layer. The focus will be to profile water from the mid-troposphere to the lower stratosphere and from the tropics into the mid-latitudes. This study will try to determine what controls upper troposphere/lower stratosphere water and how it impacts climate change feedbacks.

Coastal Ocean Observations
This suborbital mission would help scientists understand further coastal bloom compositions and the changes over time and space. In addition, the science data will help scientists quantify the submerged aquatic vegetation and coral reefs, measure an estuarine condition, and evaluate how nutrients are consumed and released into the coastal zone and the impact on the carbon cycle. The science data gathered would reduce the uncertainties in the fluxes and coastal sea dynamics by resolving horizontal and vertical resolution (improved spatial and temporal resolution) and multiple sensor integration.

Active Fire, Emissions, and Plume Assessment
This suborbital mission would help Earth Science scientists further understand the influence of disturbance on carbon cycle dynamics by observing and measuring: the atmospheric chemistry; the thermal intensity time-series; the plume composition, including the volume, albedo, particle size distribution; and, the fuel type and quality. The measurements would also provide the atmospheric composition focus area a better understanding of fire plume chemical constituents resulting from different fuels under different intensities of fire.

O2 and CO2 Flux Measurements
This suborbital mission would help scientists further understand the flux of O_2 and CO_2 and other trace gases between the surface (land and sea) and atmosphere and how it changes with space and time. Diurnal time series measurements of surface to atmosphere gas flux are critical. Specifically the mission must provide science data that contains CO_2 and O_2 measurements, separating out land from ocean fluxes, to less than 0.1 parts per million.

Vegetation Structure, Composition, and Canopy Chemistry
This suborbital mission would help scientists improve the characterization of terrestrial biomass, leaf level chemistry and canopy water content. The science data will provide vegetation 3-dimensional structure and information on composition and chemistry. In addition, the observations will elucidate functional groups and physiological impacts on the carbon cycle.

Aerosol, Cloud, and Precipitation Distribution
This mission is designed to measure the distribution in space and time of aerosols in regions polluted by industrialized areas. The data collected during this mission will improve the evaluation of climate sensitivity to the forcing of aerosols by:

- Quantifying how urban aerosol sources contribute to global aerosol budgets and loading

- Detecting the indirect effect of anthropogenic aerosol on cloud formation and radiative forcing
- Detecting multi-year to decadal trends in direct and indirect aerosol forcing.
- Developing a statistical data base of pollution impacts downstream of pollution sources

Glacier and Ice Sheet Dynamics
This mission supports measurements of the dynamics of the breakup of polar glacier and polar ice sheets. The measurements enable direct observation of the evolution in time of ice and land topography, iceberg volume, glacier profiles, and glacier channel profiles and provide data for validating simulations of these dynamics and their interaction with the ocean environment.

Radiation - Vertical Profiles of Shortwave Atmospheric Heating Rates
This mission will collect data on the vertical profile of shortwave atmospheric heating rates in polluted and unpolluted clear and cloudy skies. Measurements will take place in mega-cities and industrialized regions in different climatological regimes. The data collected will improve the evaluation of climate sensitivity to the forcing of aerosols by:
- Quantifying how urban aerosol sources contribute to global aerosol forcing
- Detecting the indirect effect of anthropogenic aerosol on cloud radiative forcing

Ice Sheet Thickness and Surface Deformation
The purpose of this mission is the accurate measurement of ice sheet thickness and crustal deformation of underlying surfaces due to ice sheet loading and earth internal activities such as earthquakes. These measurements are important for the study of glaciers and global warming.

Imaging Spectroscopy
The intent of this mission is to collect spectra as images to determine surface composition, change, water vapor and sulfur dioxide in space and time. Specifically, this mission would measure:
- the composition and change at the surface-atmosphere interface
- accurate and precise 3-dimensional water vapor for GPS based derivations
- 3-dimensional SO_2 and other phenomena associated with active volcanology
- earthquake fault optical spectroscopy properties before and after

Topographic Mapping and Topographic Change with LIDAR
The purpose of this mission would be to generate high-resolution topographic mapping and topographic change-detection of targeted ground areas (including those covered by vegetation) using LIDAR measurements. All-terrain topographic change detection by repeat mapping compliments interferometric SAR measurements of sub-centimeter to decimeter surface levels (e.g., observe decimeter to tens of meter near-field surface deformation in the vicinity of ruptured faults and inflating volcanoes to understand earthquake and magmatic processes; observe decimeter to hundreds of meters topographic change associated with landslides, volcanic eruptions and flows, coastal and fluvial erosion and sediment redistribution). Targets of highest priority are narrow, long, quasi-linear features (e.g. fault zones, coastal zones) amenable to targeted mapping or point features (e.g. volcanoes) amenable to station-keeping monitoring.

Gravitational Acceleration Measurements

This mission would accurately measure gravitational acceleration that varies spatially and temporally near Earth, as a consequence of the inhomogeneity and the dynamics of Earth's mass density structure. This spatial variation occurs at all scales, from thousands of kilometers, due to core/mantle boundary anomalies, to sub-kilometer and smaller, due to local topographic (or bathymetric) masses. Earth's gravitational field defines satellite orbits, affects inertial navigation, reflects oil and mineral deposits, and characterizes crustal geologic structure. The equipotential surface, known as the geoid, defines a reference for sea surface topography (leading to oceanographic current determination through satellite ocean altimetry), and it defines the conventional reference of heights for national vertical geodetic control.

Antarctic Exploration Surveyor
This mission would provide coordinated magnetometer, gravity, and LIDAR measurements from a small, easily deployed autonomous low-cost aircraft platform. These measurements would allow basic mapping to determine ice sheet bed characteristics and ice sheet elevation. This data would allow scientists to examine the geologic controls on ice sheet dynamics.

Magnetic Fields Measurements
The purpose of this mission would be to measure vector and tensor magnetic fields to support comprehensive magnetic field source models and isolate time-varying crustal field components. The magnetic field spectrum is under-sampled in the spatial wavelengths intermediate between the near-surface (up to 1.1 nm (2 km)) and satellite altitude (190 nm to 380 nm) (350 to 700 km). These measurements are critical to producing models that account for all sources of magnetic fields from crust to core.

Cloud Properties
This mission is designed to collect *in situ* data on cloud microphysics. The data will allow better understanding of cloud dynamics and lead to improved weather and climate models. Weather, climate, and atmospheric composition focus areas will also benefit from the data collected in this mission.

River Discharge
This mission will collect data on the volume of water flowing in a river at multiple points. The data is critical for global and regional water balance studies. Other beneficiaries of this data include USGS, EPA, coastal zone studies, and floodplain mapping efforts.

Snow – Liquid Water Equivalents
This mission was conceived to measure the amount of water stored in the snowpack at very high spatial resolution (≈ 165 ft (50m)). Also, snowpack characteristics such as depth, density, wetness, age, emissivity, albedo, etc will be measured. Measuring the snow characteristics has significant application for decision makers and is important for water budget. It would allow for improvements in snow prediction as well as understanding the climate data record.

Soil Moisture and Freeze/Thaw States
This mission was envisioned for measuring surface soil moisture, deep soil moisture, and the freeze or thaw state of surface soil in the presence of vegetation. Benefits include improved water budgets and better modeling of the carbon cycle.

Cloud Microphysics/Properties

The purpose of this mission is to observe the microphysics and properties of clouds. Specifically this entails measurements of:

- Turbulence, vertical velocity
- Particle size distributions, habit, phases
- Liquid/ice contents
- Highly-accurate thermodynamic information
- Electrical and radiation characteristics

These data would provide better understanding of tropical rainfall and energy release, rain particle growth, and stratospheric water exchange enabling the improvement of satellite algorithms.

Focused Observations – Extreme Weather

The purpose of this mission would be to accomplish process studies involving severe and hazardous weather events to improve the physics in mesoscale models (parameterizations). This approach would use high altitude remote sensing to gather data on precipitation, clouds, electrical phenomenon, and microphysics. These data would improve models used to predict winter storm hazards and provide accurate regional forecasting of rain and snow for economic decisions.

Forecast Initialization

The intent of this mission is to gather data that will improve weather forecasting and augment data available from satellites. This includes both a research element such as determining data sensitive regions (e.g. THORPEX, atmospheric rivers) and an operational element (e.g. NOAA/NCEP winter storms program). Missions would include observations would be made for short term (24 hour) initialization where observable events were already formed, and longer term (3 to 7 days). Additional benefits would include satellite validation (e.g. GPM and GIFTS) and the improved use of satellites for forecasting. Missions would be event oriented with the Eastern Pacific, Northern Atlantic, and Arctic/Antarctic as probable target areas.

Hurricane Genesis, Evolution, and Landfall

The purpose of this mission would be to accomplish observations of hurricanes to improve predictions of hurricane paths and landfall. This approach would use high altitude remote sensing to gather data on precipitation, clouds, electrical phenomenon, microphysics, and dust. Daughter ships or drop-sondes would gather data (four-dimensional cubes of thermodynamic variables and winds) at lower altitudes. Additional data would be gathered in the boundary layer (sea surface temperature and surface winds, surface imaging, turbulent fluxes, water surface state). Measurements of this type would improve hurricane modeling capability to increase human safety.

Physical Oceanography, Meteorology, and Atmospheric Chemistry

During seasonal storms in the North Pacific, North Atlantic, and the Southern Ocean small scale but relatively intense exchanges of mass and energy occur between the ocean surface and the lower atmosphere. This mission would allow scientists to study these exchanges in turbulent, high energy density environments in or near storm systems and will help them understand their broader implications for larger scale phenomena such as:

- Understanding break-up or development of the thermocline and surface mixed layer during high winds

- Understanding transition between disorganized and coherent wave patterns that transit whole ocean basins
- Understanding vertical transport of oceanic aerosols to the marine boundary layer inversion where they participate in the Earth's radiation balance by acting as cloud condensation nuclei
- Understanding the transport of oceanic gases to the free troposphere and stratosphere where they are photo-oxidized and participate in gas-particle conversion and atmospheric processes involving heterogeneous chemistry

Tracking Long Distance Transport and Evolution of Pollution
The purpose of this mission is to observe over long distances, time periods, and multiple altitudes, the progression and movement of pollutants, by measuring the composition of the gases and aerosols. Part of this study is to analyze the impact of pollution on climate and chemistry. The mission will utilize inert tracers to identify plume position, reactive tracers to interpret chemical evolution, and other products to determine ozone formation, oxidizing potential, and aerosol interaction. With the long duration capability of suborbital platform, Lagrangian sampling can be achieved.

Cloud Systems- Clouds/ Aerosol/ Gas/ Radiation Interactions
This mission will perform in-depth analysis of cloud microphysics, chemistry and optical properties during formation, evolution, precipitation and dissipation. Clouds are the chemical processing factory of the atmosphere, affecting the hydrologic cycle and the radiative balance of the planet. The results of this project will help to:
- establish the link between the clouds, hydrologic cycle, radiative balance of the planet, weather, aerosol geochemical cycles, and other cycles
- provide better understanding of natural and anthropogenic aerosol/gas constituents upon cloud properties.

Long Time Scale Vertical Profiling of Atmosphere
This mission was envisioned for observing and making measurements of high resolution vertical chemical structure of the atmosphere. Once these measurements are combined with ground based and satellite measurements, a map showing the vertical structural composition can be generated.

Global 3D Continuous Measurement of Environmentally
The purpose of this mission is to collect 3D continuous measurements for environmentally important species for assimilation in global models. Specifically, this mission would measure:
- global evolution of atmospheric composition on time scales from synoptic to decadal
- regional emission and continental outflow
- resolution of fine vertical structures inaccessible from satellite observations

With these observations, improved emission estimates, more accurate global trends, and better model descriptions of processes can be made and continuous monitoring of plumes is possible. Areas impacted by these observations consist of numerical weather prediction, carbon cycle science, and climate variability.

Transport and Chemical Evolution in the Troposphere
This suborbital mission would help scientists improve process-based understanding to guide chemical transport models and knowledge of global-scale transport. Critical

observations will be gathered on processes of transport and chemical evolution in the troposphere, such as intercontinental transport of plumes, convective processing, and lightning effects. Specifically, the mission must provide science data on chemical evolution and movement in scales ranging from convective to global. Information will also be collected on ozone, aerosols, and related species affecting their evolution.

A2. Homeland Security

The following missions have been documented from the DHS workshop and personal interview. Inclusion in this report does not imply that this mission has been funded or otherwise validated by any government agency.

Marine Interdiction, Monitoring, Detection, Tracking
The purpose of this mission is to monitor, detect, track, and interdict targets of interest to the DHS, specifically 'go-fast' vessels used by drug smugglers.

Tunnel Detection and Monitoring
The purpose of this mission is to monitor the areas around the border for tunnels used for smuggling and unauthorized entry. Currently, if intelligence indicates there is a tunnel, the military is called. Investigating the tunnel scares the smugglers away. Utilizing UAVs in this mission will allow faster response times and a more efficient investigation and interdiction process.

Broad Area Surveillance
The purpose of this mission is to monitor border areas between ports of entry to detect unauthorized entry by immigration and customs violators. These areas include both land and maritime/coastal borders and their associated airspace. Currently, it is not possible to detect, identify, and track 100% of border crossings. Due to the lack of 24/7 airborne border coverage, unspecified amounts of weapons, drugs, and unidentified individuals enter the United States illegally. The use of UAVs will enable the border patrol to conduct greater covert and overt surveillance of the border. In addition, they will aid ground agents by enhancing their situational awareness. Specific examples include performing vehicle/target identification, identifying friend vs. foe and high priority targets via facial recognition software, determining whether individuals are armed, and serving as a communications node.

BORTAC Situational Awareness
The purpose of this mission is to enhance situational awareness of Border Patrol Tactical Team (BORTAC) agents during operations through a hand launched tactical UAV platform.

Coastal Patrol
This is a U.S. Coast Guard mission. It is a surveillance mission of maritime traffic off the shores of the USA (east & west coast, Alaska & Hawaii). Flights would launch and recover from one to three locations within 100 miles (213 km) of the coast for each of the four regions listed above. Missions would traverse our coastal waters 50 to 500 miles (106.5 to 1065 km) off shore.

A3. Land Management

The following missions have been documented from the Land Management and Coastal Zone Dynamics Workshop. Inclusion in this report does not imply that these missions have been funded or otherwise validated by any government agency.

Wildlife Management Population Count
The goal of this mission is to collect data for population counts of wildlife species to enable effective management of the population of that species. The species of interest ranges from birds, to herds of wild horses or burros, to bears, who operate independently.

Wildlife Management Telemetry Mission
The goal of this mission is to identify the location of animals with pre-tagged RF transmitters to enable effective management of species population.

Wildlife Habitat Change Mission
The objective of this mission is to document, with more spatial and temporal completeness than is currently available, the change in the habitat environment of various species of animals. This knowledge would enhance dynamic decision support systems designed to facilitate adaptive management policies.

Precision Agriculture
The goal of this mission is to collect data which enhances crop productivity and resource efficiency. Observations of crop status, surface temperature, canopy and soil moisture are critical for this mission. Weed and pest infiltration monitoring is also desired.

Water Reservoir Management
The goal of this mission is to promote sustainable use of water resources located in regions of inaccessible terrain or which are prohibited by other means, such as scale. To support the mission, observations or measurements of the chemical composition (in-situ sampling), temperature, surface area, and depth of the water resource are necessary. Time critical measurements of sediment, soil moisture, and algae content are required. In addition satellite calibration and validation of snow pack characteristics are also desired.

Range Management
The objective of this mission is to assess and improve range land management. Broad coverage observations of vegetation species and their condition, biomass, and soil moisture are specific goals for the mission. Identification of spatial and temporal patterns and gaps are desired. This data can be used for state and transition, and ecosystem modeling, and supports land management policy decision making.

Urban Management
The goal for this mission is to provide small governments effective tools for land management. As urban regions expand wild life, range land, forest, and coastal regions are affected. In addition, storm run-off can be modified creating localized flooding in certain areas. Effects of heat islands can also be examined. A UAV provides an effective tool to help manage these effects by measuring or observing land usage, pavement quality and coverage, population density, and changes in topography. This data supports urban hydrology models, development plans, and traffic monitoring.

High Resolution Sampling of Coastal Water Quality
The purpose of this mission is to perform high resolution sampling of coastal water quality. After a storm occurs, storm water discharge is often laden with oils and agricultural sediment. Currently, it is not possible to monitor coastal water qualities on a regular basis due to cloud cover. Information on plumes, such as their boundaries, shape, size, direction of propagation, and persistence are highly desired. Other phenomena of interest include Harmful Algal Blooms (HAB), and color dissolved organic matter (CDOM). Observations required to support the mission are sea state reflectance, temperature, sea state roughness, fluorescence, imagery, and water quality samples.

Identification and Tracking of Maritime Species
The purpose of this mission is to locate and track endangered maritime species. For purposes of discussion, the endangered species will be tuna, and the setting is the central/northern Atlantic Ocean. The European species of tuna is currently endangered due to over-fishing. Several fish in a school are tagged to identify their movement and position. However, these markers are visible only when the fish are near the surface of the water. Tuna are visible and relatively stationary when they are feeding. They feed for a few hours, 2-3 times a day, then dive into deeper water where they are undetectable. In addition to population counts and migration tracking, habitat quality is evaluated in this mission.

Shallow Water Benthic Ecosystem
The purpose of this mission is to monitor changes in the shallow water benthic ecosystem. An example mission would take place at Kure Atoll, in the Northern Pacific Ocean. Kure Atoll is located approximately 2200 km from Hawaii. Observations of reflectance, SST, currents, salinity and PH of the water, and rugosity are required to support the mission.

Carbon Dioxide Flux
The primary purpose of this mission is to correlate atmospheric turbulence with carbon dioxide flux. Ancillary phenomena of interest include primary productability (5 m resolution), CDOM (5 m resolution), sea-state (2 m resolution), and winds.

Wildfire/Disaster - Predict, Measure, Monitor, and Manage Events
The wildfire mission shall provide information to the fire fighting agencies and other emergency responders on how to manage their response to the emergency. Specifically, the mission shall encompass the following activities:

- Locate fire hotspots, determine the active fire front, and identify the already burned-out areas.
- Determine the intensity of the fire and its movement and rate of spread shall be measured to help predict the near-term fire behavior.
- Determine local weather and, more specifically, the vertical temperature profile over the fire,
- Measure the fuel moisture levels shall aid in this prediction, and
- Measure the air quality in the fire plume, including particulate levels, to aid in disaster-related evacuation decisions.

Wildfire/Disaster – Real-time Communication

This mission provides a UAV-based voice and RF communications relay between the field command center and personnel in the field fighting the fire or dealing with the natural disaster. Standard line-of-sight communication methods can be rendered inoperative during disaster events; such is the case with Fire fighting, for example, with typically takes place in rugged and mountainous terrain. Such a capability will significantly enhance on-scene command-and-control and could provide life-saving communication to first responders.

Wildfire – Fire Retardant Application
In recent years the US has seen the advent of Mega-Fires, driven by gradual increases in consumable fuels and the continued encroachment of civilization on our wilderness areas. These wildfires and other fire-related disasters are high-risk events for first responders and the public. This mission shall employ a specialized low-altitude UAV's, to replace the role served traditionally by piloted aircraft, for the airborne application of fire retardant. Additional risk reduction is provided by removing the pilot out of harm's way in what is a highly dangerous flight environment.

Wildfire/Disaster – Reducing Risk to Responders and the Public
This mission shall employ a low-altitude UAV's to provide risk reduction to emergency responders and the general public by performing the following tasks:

- Provide information for a rapid, local assessment of a situation by an on-scene responder.
- Provide accurate long-term information regarding the nature, location, and extent (and spreading, in the case of a wildfire) of a disaster event to aid the deployment of first responders, and to aid public safety agencies in their evacuation announcements, as necessary, to the general public.

These capabilities will significantly enhance safety and reduce risk by ensuring that the correct, accurate information – in some ways not available in any other fashion – is available to disaster-event decision makers.

Wildfire/Disaster – Pre-and Post Event Monitoring & Assessment
This is a data-recording mission that is designed to provide non-real-time information to researchers for predictive purposes and to disaster authorities to provide post-event damage assessments. This mission shall observe, measure, and document such things as:

- Vegetation condition – indices, growth, moisture, land cover type.
- Erosion/streams
- Invasive and exotics – presence or absence
- Fuel loading and biomass – tons/acres
- Wild land/urban interface – ingress/egress
- Climatology/trends – weather to supplement Remotely Automated Weather System
- Infrastructure/roads
- Soil conditions
- Terrain

Such observations help predict hazards, mitigate high-risk environmental conditions, help implement post-disaster recovery operations, assist scientific understanding of post-disaster environmental recovery, and help plan for mitigation.