Experimental Design Overview (EDO)

for a

Deep Convective Clouds and Chemistry (DC3)

Field Campaign

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I. Executive Summary

The Deep Convective Clouds and Chemistry (DC3) field campaign makes use of two instrumented aircraft platforms and extensive ground-based observations to characterize the impact of deep convective systems on the composition and chemistry of the mid-latitude upper troposphere and lower stratosphere. The NSF/NCAR Gulfstream-V aircraft, instrumented to measure a variety of gas-phase species, radiation, and some information on condensed phase species as they relate in particular to the budgets of HOx radicals, is the primary platform to study the high altitude outflow of the storms. The NASA DC-8 aircraft provides remote sensing to aid in flight planning and column characterization, and in situ observations to characterize the convective storm inflow and to assess the perturbation of air mass composition by the storm itself. Ground-based radar networks are used to characterize the phys-ical and dynamical characteristics of storms as well as to provide information that helps guide the re-search aircraft as storms evolve. The impact of lightning on outflow composition is constrained through detailed measurements from VHF lightning mapping arrays. The forecasting and analysis is improved through other ground-based observations such as balloon sondes for thermodynamic and limited chemical information, as well as precipitation collection and analysis. Satellite data are used to place the airborne and ground-based measurements in the context of the wider geographical regions and help guide sampling strategies. At the same time, DC3 measurements help satellite retrievals of atmospheric constituents such as NO_2 near storms.

The observations are conducted in three locations: 1) northeastern Colorado, 2) central and western Oklahoma, and 3) northern Alabama in order to gather data on different types of storms and with different boundary layer compositions and convective environments and to improve the odds of suitable storms for study. Significant ground-based infrastructure already exists in these three locations. Possible bases of operation for the aircraft have been assessed, and it is concluded that a single base in Kansas or Oklahoma would allow access to storms in Colorado, Oklahoma and Alabama. While a single base will use more flight time transiting to the observation regions, it will result in significant savings compared to staging multiple bases for aircraft and PI operations, and will provide flexibility in selecting storms for study. A single base will also facilitate collaborative first-cut analyses of data. The locations for observations are guided by state-of-the-art forecasting tools used along with in situ, radar, and satellite observations. The data collected during DC3 are analyzed using models over a range of scales from 0-D box models and cloud-scale models to global models. The needs of these models have been carefully considered in the design of the experiments.

The DC3 project provides broader impacts to society via extensive education and outreach activities, and through improved understanding of sources of UT ozone, an important constituent to climate and air quality, for assessment reports and resulting policy decisions. Further, DC3 measurements are instrumental in improving model parameterizations of convective transport, production of NO by lightning, and wet deposition of chemical species. Undergraduate and graduate students are participating in DC3 in a variety of ways including airborne and ground-based observations, design and construction of instruments, operation and improvement of numerical models, precipitation collection and analysis, and reporting of the results to the scientific community through presentations and publications. Outreach days for the public and media provide a valuable means to engage the public in atmospheric science as well as on-line social networking sites and movies.

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II. Program Rationale, Scientific Objectives, and Scientific Hypotheses

The composition of the upper troposphere and lower stratosphere is influenced by many factors including exchange of air between the stratosphere and troposphere, aircraft emissions, transport of boundary layer constituents by deep convection, cloud processing of species during transport, injection of odd nitrogen gases produced by lightning, and formation of secondary species through photochemistry. The cumulative influence of all of these processes makes separating out the influence of any one of them difficult. Nevertheless, there is convincing evidence that such processes, for example, change the concentration of ozone and the oxidizing capacity in the upper troposphere. Water vapor concentrations are also influenced, thus impacting the heat energy balance affecting cirrus cloud formation and photochemistry.

There have been many theoretical and experimental studies of the influence of deep convection on the composition of the upper troposphere (e.g. Chatfield and Crutzen, 1984; Dickerson et al., 1987; Pickering et al., 1990; Jaeglé et al., 1997; Winterrath et al., 1999; Huntrieser et al., 2002; Ridley et al., 2004; Huntrieser et al., 2008; Ancellet et al., 2008; Fried et al., 2008) Several of the experimental studies focused on the perturbations to NO_x (e.g. STERAO, CRYSTAL-FACE, EULINOX) by individual storms or inferred the influence by uncharacterized storms upwind of the measurement locations (e.g PEM-Tropics B and. INTEX-NA). Numerical modeling studies have hypothesized that convective storms likely influence the balance of peroxides because of gas-to-condensed phase partitioning and condensed phase chemistry (Barth et al., 2001; 2007), and impact upper tropospheric HO_x and O_3 budgets by the transport of HO_x precursors such as peroxides and formaldehyde (e.g. Ravetta et al., 2001; DeCaria et al., 2005). Ozone photochemistry is also impacted by transported and storm-produced NO_x (e.g. Pickering et al., 1990; 1991; 1996; DeCaria et al., 2005). Scavenging of other species can further influence the composition of convectively-influenced air masses.

Missing from previous observational studies are direct observations of a suite of important gas-phase radicals, inorganic, organic and oxygenated compounds, and particle-phase properties in the outflow of individual convective storms or systems, connection to evolving composition downwind of the convective event, and relating the measured species to the storm dynamics. Since these earlier studies, airborne instruments have improved dramatically in terms of expanded capabilities, such as faster response speeds, lower detection limits, and improved measurement accuracy. New studies of convection employing such instruments would thus significantly enhance our knowledge of the influences of those processes operative in convective transport. The ideal experiment would deploy instruments for a wide variety of measurements (e.g. including actinic radiation, aerosol surface area density, and hydrometeor phase, in addition to those mentioned earlier) in the inflow and entrainment regions of an isolated storm, would follow these species within the core and into the outflow of storm, and would include subsequent measurements of the evolution of primary and secondary effects 12-48 hours after the initial convective event. A variety of logistical and platform restrictions limit the practicality of this approach. Most aircraft cannot penetrate or even closely approach severe convective storms due to lightning, hail and extreme winds. Research aircraft typically have limitations on deployments of 8-12 hours depending on payloads and base airport altitude, temperature and runway limitations (NASA, 2002; NCAR 2003, 2006). Air masses can be subject to multiple impacts by convection, making the attribution to individual events problematic. The experimental plan described here addresses these issues and outlines an experimental approach that will provide unprecedented information on the impact of deep convective clouds and chemistry on the composition of the upper troposphere and lower stratosphere, and the resulting impact on HO_x and O_3 photochemistry. These observations, when combined with other data (e.g. from ground-based systems and satellite platforms) and various types of numerical models, will allow us to pursue two primary goals and to address the following scientific hypotheses (see the DC3 Scientific Program Overview document for a detailed discussion).

The primary goals of DC3 are to:

1) *Quantify and characterize the convective transport of fresh emissions and water to the upper troposphere within the first few hours of active convection, investigating storm dynamics and*

physics, lightning and its production of nitrogen oxides, cloud hydrometeors effects on scavenging of species, surface emission variability, and chemistry in the anvil.

2) *Quantify the changes in chemistry and composition in the upper troposphere after active convection, focusing on 12-48 hours after convection and the seasonal transition of the chemical composition of the UT.*

Ancillary goals include examining the influence of aerosols on droplet/storm formation, secondary aerosol formation, and the transport of halogens to the upper troposphere.

These goals will be accomplished through coordinated, research-grade observations from a variety of platforms combined with numerical modeling tools on a range of scales and over the full spectrum of complexity (box models, cloud-scale models, lightning discharge models, regional models, and global models), making use of data assimilation approaches where feasible. These goals are designed to fill gaps in our understanding at the process level and then will allow us to test and adjust parameterizations describing the influence of convection on chemical constituents in regional and global atmospheric models.

Hypotheses related to Goal 1.

Hypothesis 1. Inert tracers are transported primarily to the upper troposphere within 3-5 km of the tropopause in shear-driven storms, such as those found in Colorado and Oklahoma, and can be used to determine the maximum outflow altitude, which will be different than cloud top height, the level of neutral buoyancy, and the maximum ice content altitude. These same inert tracers are transported throughout the free troposphere in airmass thunderstorms, more common in the southeastern U.S. This implies that shear-driven thunderstorms contribute more to UTLS chemistry, ozone production, and cross tropopause transport than airmass thunderstorms.

Hypothesis 2. In the anvil and near the convective cores, soluble species, e.g. HNO_3*,* H_2O_2 *and* CH_2O*, will be depleted compared to their background UT mixing ratios because ice scavenges the dissolved species in cloud water within the convective core. Furthermore, because of the short time an air parcel is in contact with liquid water and the high updraft speeds, transport of soluble species to the UT will be more efficient in the high plains (Colorado) storms compared to the storms in northern Alabama. The warmer cloud bases and greater moisture contents in Oklahoma and Alabama have larger liquid water regions resulting in more efficient scavenging of soluble species.*

Hypothesis 3. The contribution of lightning to NO_x *concentrations in the anvil, and subsequently in the upper troposphere, depends on overall flash rates and aggregate channel lengths at heights extending from just above the melting level to the uppermost region of the convective core. The amount of* NO_x *produced by a cloud-to-ground flash is on average roughly equivalent to that produced by an intracloud flash.*

Hypothesis 4. The flash rates of a storm are proportional to the volume of updrafts greater than $10\ m\ s^{-1}$ *in the -10˚C to -40˚C layer and to storm graupel echo volume. Cloud-to-ground lightning occurrence usually follows the occurrence of precipitation in the 0˚C to -10˚C layer after graupel has appeared in this region or higher regions. Conversely, cloud-to-ground lightning occurrence is inhibited in storms that produce little precipitation.*

Hypothesis 5. Storms that produce inverted-polarity IC flashes in the upper part of storms and inverted-polarity CG flashes are those in which a large fraction of the adiabatic liquid water profile is realized as cloud liquid in the mixed phase region.

Hypothesis 6. The chemical composition of the convective outflow within and near the visible anvil will be stratified into a top layer with high radiation fluxes accelerating radical chemistry, and a lower layer with low radiation fluxes and near nighttime-like radical chemistry.

Hypotheses related to Goal 2.

Hypothesis 7. In sampling the convective plume 12-48 hours after convection, we expect to find that 8-12 ppbv ozone will be produced per day due to high NO_x *and enhanced concentrations of* HO_x *precursor species. The ozone production will vary in a complex nonlinear fashion depending on the* NO_x *and VOC abundance transported to the anvil from the boundary layer and the amount of* NO_x *produced by lightning.*

Hypothesis 8. Survey flights at the end of June from the central U.S. to the northern Caribbean will find the greatest UT ozone and NO_x *mixing ratios above the Gulf of Mexico and Florida. Daily ozonesonde/LIDAR profiles from Huntsville, Alabama will document the seasonal build up and decay of the UT ozone enhancement from May to September.*

In addition to these primary hypotheses, several secondary hypotheses will be addressed using the DC3 data related to influences of aerosols on droplet/storm formation, secondary aerosol formation, and transport of halogens.

III. Experimental design and observational requirements

III.a. Overview

In order to accomplish the goals and test the hypotheses, DC3 will make use of state-of-the-art ground-based dual Doppler and polarimetric radar and three-dimensional lightning mapping facilities, and two extensively instrumented aircraft platforms to observe the impacts of convection on UTLS composition. Each instrument and facility is selected to specifically address one or more DC3 goals. The two primary aircraft platforms are: the NSF/NCAR Gulfstream-V (HIAPER), and the NASA DC-8. There also may be other aircraft platforms that could contribute to this project, potentially including the DOE G-1, the DLR Falcon or HALO Gulfstream-V, the NASA WB-57, the UK BAe-146 and the University of North Dakota Citation II. Addressing the goals and hypotheses of DC3 is focused on the use of the G-V and DC-8. The ground based facilities are tailored to each measurement region. It is the extensive infrastructure that is already in place on the ground that leads, in part, to the choice of observation regions. Other sites could have some advantages, but the complete build-up of the needed facilities would be prohibitively expensive.

It is envisioned that DC3 will involve observations in the following regions:

1. <u>Northeast Colorado</u> centered on the CSU-CHILL and Pawnee national radar facilities operated by Colorado State University;
2. <u>Central Oklahoma</u> using surface facilities maintained by the National Severe Storms Laboratory and University of Oklahoma, including SMART-Rs, KOUN polarimetric radar and the Oklahoma Lightning Mapping Array; and
3. <u>Northern Alabama</u> utilizing surface facilities operated by the University of Alabama-Huntsville and NASA Marshall Space Flight Center, including the ARMOR polarimetric radar, the MAX X-band radar, northern Alabama lightning mapping array, and the MIPS mobile sounding facility.

Having three study regions also improves the probability of suitable storms for study. These three groups of ground facilities, described below, offer unique opportunities to study convection across a diverse spectrum of climatologies, ranging from subtropical-like systems in the southeast U.S. to multicellular and super-cellular convection in Oklahoma to high-cloud-base deep convection in Colorado. Not only will DC3 sample a wide variety of storm types, but each of these environments is also characterized by somewhat different background chemistry. In all three regions, multiple Doppler and polarimetric radars will be used to provide air flow and hydrometeor information. For these same regions, three-dimensional lightning mapping observations will be supplemented with cloud-to-ground lightning data from the National Lightning Detection Network (NLDN) to provide ground strike points, peak currents, flash polarity, intracloud and cloud-to-ground flash rates and total flash rates. These measurements are central to the DC3 hypotheses that relate to lightning-generated NO_x.

In a general sense, DC3 will attempt to characterize the flow of air into, around, through and out of isolated deep convective clouds. The deployment of the facilities and aircraft platforms will depend on the forecasting of the timing and location of the development of convective storms in the areas under study. State-of-the-art forecasting tools and near real-time radar observations will be used to help manage the deployments. This follows on the lessons learned during PRESTORM (1985), STERAO (1996), STRAT (1996), PEM West A (1991), PEM West B (1994), PEM Tropics A (1996), EULINOX (1998), CRYSTAL-FACE (2002), INTEX-NA (2004), AMMA (2008), and many other studies.

A representative situation is described in the following scenario.

A probable operation period begins with meteorological forecasts on previous days indicating the likelihood of deep convective events within one of the study areas. As conditions for storms appear to become favorable, radar data will be used with models to help finalize the decision to study convection at one of the three locations (relevant communication and decision-making issues are discussed later). The two aircraft will be made available to instrument PIs to get instruments warmed up and ready for flight, usually two to three hours before takeoff. At an appropriate time, probably in the early afternoon, the aircraft will takeoff and transit to the study region during which common instruments will be compared. In the study region, the G-V will fly mostly at middle to high altitudes to characterize the air surrounding the storm. The DC-8 will fly at low-to-middle altitudes measuring the composition of cloud inflow. Sondes will be released to characterize the vertical structure of temperature, humidity and other quantities in the region of the storm. As the storm matures and an anvil develops, the G-V will begin sampling the outflow including flying as close to the core within the anvil as possible (limitations are discussed later). The DC-8 will sample the lower anvil region to quantify ice particle settling and the impact on the composition of the outflow. As the storm dissipates, the aircraft will fly in the UT following the convective outflow until the return to base to sample the chemical evolution of the outflow region and provide forecasters with information to guide the aircraft the following day. Available satellite data will also be used to place the *in situ* measurements in the context of the wider geographical region and help guide sampling strategies. On selected occasions, the next morning (12 or more hours later), the aircraft will be deployed to quantify the composition and evolution of the convectively impacted air mass. This will again require a two to three hour instrument warm up period before takeoff. For northeastern Colorado storms, this will likely be over Iowa or Illinois; for central Oklahoma storms, it could be Tennessee or Kentucky. It could be difficult to locate such air masses, and particularly to ascribe their composition to impact by a specific convective event, but the attempts will be valuable. For several hours (4-5) the vertical, cross-wind and along-wind structure of the convectively impacted air mass will be observed with flight plans that are similar to the prototypes described later. These measurements will be conducted during the photochemically active part of the day (late morning to mid-afternoon) when radical concentrations and ozone perturbations will likely be maximized. On occasion, if the particular situation warrants (e.g. weak winds at the outflow altitude) flights may be conducted to attempt to study the same air mass the following day (i.e. 36 or more hours after the end of the storm). Such examination of long range transport of convectively influenced air has been done before, including during three NASA studies: INTEX-NA, INTEX-B, and ARCTAS. . The timelines for Goal 1 and Goal 2 scenarios are portrayed graphically in Table 1.

We envision that most of the flights will be to address Goal 1 (Table 1a), with occasional flights to address Goal 2 the day after, and rare Goal 2 flights 2 days later. There will be combinations of day 1-2 and day 1-3 flights, but we don't envision attempting a day 1-2-3 combination. The meteorological situations encountered will dictate the exact apportionment of the various types.

We recognize that conducting a two aircraft experiment in the congested air space over the continental United States presents many logistical challenges. Decisions on where to fly require rapid digesting of radar observations and model results, as well as considerations of safety. Requests to change course or altitude from ATC may be delayed because of the need to divert regular air traffic around the storm. We will make use of expertise within EOL and the rest of the airborne science community to enhance our chances of success.

III.b. Study Regions

Described here are the ground-based facilities that will be used for research of convective storms in the three study regions. The locations of the proposed regions are defined by the fixed facilities (such as radars), are complemented with mobile facilities, and are set in the context of storm climatology. Northeast Colorado can experience a clean or polluted boundary layer, depending on the direction of the prevailing winds. Winds from the northeast can be quite clean, while winds that pass over the Denver metropolitan area (pop. 2.4 million, 59 million vehicle-miles/day) can be quite polluted. The emissions come not only from vehicle traffic, but from industrial activities and energy production. In this region, the convective storms are characterized by high cloud base heights. The central Oklahoma area can also be subject to pollution from the Oklahoma City metropolitan area (pop. 1.2 million, 30 million vehicle-miles/day), the Dallas-Ft. Worth metropolitan area (pop. 6.1 million, 151 million vehicle-miles/day) and emissions from oil production, but also can include biogenic emissions, particularly in the eastern part of Oklahoma. In northern Alabama, biogenic emissions will be significant, but fresh urban emissions will likely be less (12 county pop. one million; Huntsville pop. 360 thousand). Oklahoma and Alabama storms have lower cloud base heights than Colorado, and typically have storms with different CAPE levels. These three regions will allow contrast in a number of the controlling variables that affect the ability of storms to transport species to the upper troposphere, thus testing our understanding and leading to improved parameterizations.

III.b.1. Northeast Colorado

This region is situated adjacent to the major metropolitan area of Denver and surrounding suburbs. Figure 1 illustrates the locations of key ground-based observational facilities available to DC3 in this area. The centerpiece of the observational suite is the advanced, CSU-CHILL S-band Doppler and polarimetric radar maintained by Colorado State University under a cooperative agreement with the National Science Foundation. The CHILL facility will serve as an operational center for DC3 when DC3 aircraft are operating in the vicinity. Located 45 km to the north of CHILL is the CSU-PAWNEE radar, which is an S-band Doppler radar. These two radars form a dual-Doppler pair providing characterization of 3-D winds in precipitation. Two NEXRAD radars, one near Denver (KFTG) and the second at Cheyenne, WY (KCYS), complement this dual-Doppler pair. Additional dual-Doppler coverage is afforded by a KFTG-CHILL pair, and a KCYS-Pawnee pair, thus providing extended dual-Doppler coverage over a large domain. Software is already in place at the CHILL facility to ingest radar data from the other three radars and derive near real-time dual-Doppler wind estimates, overlain with precipitation and hydrometeor identification fields derived from CHILL. This software will provide a rich environment for real time decision-making and aircraft guidance during DC3, and will also provide invaluable information for the post-analysis of the storms.

These radar platforms will be embedded within a network of 10-12 VHF receivers forming a 3-D lightning-mapping array (LMA). It is expected that this LMA will be developed and deployed by personnel from the New Mexico Institute of Mining and Technology. This network will provide estimates of lightning locations and lightning channel geometries throughout the region mapped by the dual-Doppler radar pairs. Collectively these measurements will provide detailed maps of storm kinematics, microphysics (derived from the CHILL polarimetric data over a smaller region compared to the full dual-Doppler coverage), flash rates and flash locations in deep convection, thus addressing central goals of DC3.

Additional resources that are required for Colorado include expendables for thermodynamic sounding releases from the CSU-CHILL site (utilizing a Vaisala GPS sounding unit recently purchased by CSU), and rainwater samples for subsequent chemical analysis. CoCoRaHS (Community Collaborative Rain, Hail & Snow network – www.cocorahs.org) volunteers in the region could be trained to collect and preserve rainwater. DC3 will also benefit from profiler, raingauge and disdrometer measurements at the Platteville Atmospheric Observatory (operated by NOAA) for characterizing wind profiles. Support for a mobile hail and rainwater collection platform will be requested from NCAR. The Mobile Integrated Sounding System (MISS) will be used to characterize the vertical profiles of temperature, pressure, relative humidity, and winds.

III.b.2. Central Oklahoma

This region includes both extensive agricultural areas and major metropolitan cities of Oklahoma City and Dallas-Ft. Worth. Figure 2 illustrates the key observational platforms available to DC3 in this area. Three dimensional lightning mapping is provided by the existing Oklahoma Lightning Mapping Array (OKLMA), operated by the University of Oklahoma (OU) and the NOAA/National Severe Storms[80] Laboratory (NSSL). It is also expected that DC3 lightning coverage will be extended well in the Texas Panhandle region through a new LMA network being installed around Texas Tech University in Lubbock, TX (E. Bruning, PI). This network will be supplemented by 3-6 deployable LMA stations, to extend the region of three-dimensional lightning mapping to within the region of two-dimensional coverage on a daily basis. The fixed S-band radars available within this region are the KOUN Doppler polarimetric radar and the phased array radar (PAR), both operated by NSSL, and five Doppler radars in the national WSR-88D network: Oklahoma City (KTLX), Tulsa, Vance Air Force Base (Enid), Frederick (SW Oklahoma), and Fort Worth. The only pair of these radars which provides dual-Doppler three-dimensional winds is KOUN and KTLX in central Oklahoma, with a baseline of only 20 km. Therefore, it is essential to use both of the mobile SMART-R (Shared Mobile Atmospheric Research and Teaching Radar) C-Band Doppler radars operated by a consortium that includes OU and NSSL. With two SMART-R radars and 3-6 deployable LMA stations (the preferred configuration), the Doppler radar data and lightning mapping data required by DC3 can be acquired anywhere within the purple circled regions shown in Figure 2. In 2009, mobile X-band and C-band polarimetric radars also will become available. The OU PRIME radar, a narrow beamwidth, C-band Doppler and polarimetric radar is also expected to be available for DC3 operations.

NSSL's experimental forecast center will provide now-casting and coordinate field operations in this region. NSSL also operates a mobile ballooning facility that uses Vaisala GPS radiosondes to track balloons and provide soundings of wind and standard thermodynamic parameters for the environment in which storms occur, an essential data set for storm modeling. This system also is used for larger balloons carrying instruments inside storms to measure the vector electric field and to provide precipitation imaging along the balloon track. Balloons for *in situ* storm measurements are typically launched into updrafts, but after ascending may descend through the rainy downdraft.

Also available are the extensive measurements at the two Oklahoma ARM sites: the Central Facility near Lamont in northern Oklahoma, and the Kessler Farm near Washington in central Oklahoma. The central facility has several radiometric measurements, two radar wind profilers (50 MHz and 915 MHz), CO_2 flux and aerosol measurements, two cloud radars, two LIDARs, raingauges, a disdrometer, surface wind and thermodynamic measurements, and atmospheric sounding systems. A 3 radar X-band network and a C-band polarimetric radar are planned for the ARM site and will be operational in the DC3 timeframe. Instrumentation at the Kessler Farm is less extensive, but includes surface wind and thermodynamic measurements, a radiometer, a disdrometer, a rain gauge, and a 915 MHz profiler (some instruments are not from ARM). A detailed list of available instruments is provided on the web site, www.arm.gov/instruments/location.php. These facilities are supported by the Department of Energy and will be requested from the DOE/ARM program. No funding is requested for the ARM and Kessler farm facilities, rather, these sites serve to provide supplementary data to the DC3 field campaign.

Surface observations of the background wind field and thermodynamics will be provided throughout Oklahoma by the extensive grid of Oklahoma Mesonet (http://www.mesonet.org/) stations operated by the Oklahoma Climatological Survey (OCS). These surface data are supplemented in south-central Oklahoma by a network of four CASA X-band radars that scan low elevation angles.

Additional resources required for DC3 include expendables for thermodynamic soundings from the NSSL mobile ballooning platform and for supplemental soundings from the National Weather Service in Norman to provide environmental data required for storm modeling, and rainwater sampling for subsequent chemical analysis. Local CoCoRAHS volunteers could be trained to collect and preserve rainwater for analysis.

III.b.3. Northern Alabama

Key facilities envisioned to operate for DC3 in the Huntsville area are shown in Figure 3. Radar facilities maintained by the National Space Science and Technology Center (UAH/NASA-MSFC) include the ARMOR, a 5-cm Doppler and polarimetric radar located at the Huntsville airport. This is a 1-degree beamwidth system, with advanced signal processing and excellent data quality. Dual-Doppler opportunities exist with three other radars, the KHTX (Hytop, AL) NEXRAD situated 68 km to the northeast, the UAH Mobile Alabama X-band dual-polarimetric radar (MAX; variable baseline), and the recently upgraded Redstone Arsenal S-band radar located on a 15 km baseline extending southeast of ARMOR. The most flexible dual-Doppler baseline can be realized by using the mobile capabilities of the UAH MAX radar with any of the other aforementioned radars. For example, the MAX radar can be located 30-40 km southeast of ARMOR to provide dual-Doppler coverage over a portion of the NASA LMA lightning mapping area not observed by the ARMOR-KHTX dual-Doppler pair. Alternatively, to enhance Doppler sampling, the radar can be located 42 km north-northeast of ARMOR and 35 km west of KHTX to facilitate triple Doppler sampling, or located 50 km west of ARMOR to provide extended dual-Doppler lobe coverage to the west of the ARMOR-KHTX pair.

Within the northern Alabama LMA coverage region, a 10-station electric field mill and field change meter network will also be available for use. Data from this network will provide important information on the electric field changes associated with individual lightning flashes and enable lightning flash energetics and physics to be addressed for those signatures detected in coincident VHF LMA data. Note that lightning energetics, and particularly the flash energy per unit channel length are important parameters for modeling *in situ* cloud chemistry.

Hence, by combining the four radars with the LMA field change network and associated NLDN observations, storm kinematic, microphysical and lightning properties can be observed around Huntsville. An additional vertically-pointing X-band system is also expected to be operational at UAH in time for DC3, to provide high resolution information on radar reflectivity and Doppler velocities in the vertical. Other facilities at UAH that will provide important observations for DC3 include the UAH mobile MIPS system and M3V (instrumented vehicle) directed by Dr. Kevin Knupp. MIPS includes a 915 MHz profiler for measuring storm inflow winds, a scanning multi-frequency radiometer for estimating water vapor and cloud water, a SODAR for deriving estimates of virtual temperature, and an electric field mill (providing information on local electric fields). As is the case for the other two DC3 ground based networks, the HSV-area observations will need to be supplemented by a mobile mesonet, and sounding releases. Both UAH and Redstone Arsenal (UAH collaborator) support sounding equipment. Redstone Arsenal also has one mobile Vaisala sounding unit that will be used by UAH in coordination with Redstone Arsenal in northern Alabama (cost of expendables an done Redstone Arsenal technician). Rain water samples will be collected throughout the HSV region for subsequent chemical analysis, and the M3V will be used to collect these samples within the raining cores of sampled thunderstorms. It is also expected that several portable VHF (LMA) receivers will be available in the HSV region to extend the optimal LMA coverage area on a day-to-day basis.

It is important to note that observational components of DC3 related to the sampling of convection, lightning and air chemistry are highly complementary to GOES-R Global Lightning Mapper (GLM) Risk Reduction (R3) activities currently underway at NASA MSFC and UAH. Current R3 activities at NASA-MSFC/UAH are focused on GLM data collection, data assurance, and product development for a diverse set of applications including severe weather now-casting, studies of global climate change, and assimilation of lightning flash information into numerical weather prediction and cloud/global chemistry models. The R3 activities also rely heavily on the use of existing ground validation “test-bed” activities associated with polarimetric radar and lightning mapping array studies of convection and lightning in and around Huntsville Alabama. Of course, variability in convection and lightning behavior convolved with the necessary global application of satellite algorithms demands the synthesis of observational results from a much broader variety of convective environments. To this end, the intensive observations proposed for DC3 are synergistic with NASA-MSFC/UAH R3 because they provide a means to examine convection, lightning and chemistry in three very distinct chemical backgrounds and convective regimes. This programmatic synergy will provide one mechanism for infusing DC3 results directly into operational satellite algorithms.

III.b.4. Regional Summary of Ground Facilities

The ground-based facilities discussed above are summarized in Table 2. They are separated by study region for clarity. To the extent possible, we have sought to choose and instrument all three study areas with the same minimum capabilities. All have (1) significant regions of dual-Doppler, polarimetric, research-grade radar coverage, including the ability to make use of the WSR-88D (NEXRAD) network, (2) large areas of three-dimensional lightning mapping that overlap the dual-Doppler regions, (3) networks of meteorological observations, and (4) regular sonde launching within the study regions. Some regions require supplementing the available infrastructure with mobile radars, and lightning mapping stations. The infrastructure in some areas is superior to others, either in coverage or range or other quality, but for DC3, all will brought up to a sufficient level to accomplish the scientific goals of the mission. For the mobile facilities to provide the most value, close communication between the forecasting teams, the facility deployment teams and the PIs will be an absolute necessity, and is an important element of our communication and management plan.

III.c. Communications and Decision-Making

For DC3 to successful collect the data needed to address the goals and hypotheses, it is imperative that rapid and effective communication channels be available between forecasting/now-casting teams, radar scientists, lightning scientists, aircraft science and operation teams, and the DC3 PIs. We will work closely with those selected to provide data services to come up with systems that provide data, images, and voice channels between the needed parties. Figure 4 summarizes a concept for such a network. With the appropriate information and recommendations, we envision the primary decision-makers before aircraft takeoff to be the DC3 PIs. Once the aircraft are in the study region, we will transfer decision making to a radar scientist in the local radar operations center who will consult with the aircraft mission scientists and others on detailed flight decisions. The pilots will be in communication with FAA centers, who will have been briefed on the types of flight patterns desired and the needs of the project.

III.d. Aircraft Base of Operation

There are a number of issues in considering possible bases of operation for aircraft. These have been extensively discussed by a focused working group and DC3 workshop attendees, and the results of those discussions are summarized here. The main physical issues are the length, altitude and weight-bearing capability of the runways, the ambient temperature, and the flying time to and from the study regions. There are other considerations related to conducting airborne research over the continental United States and providing needed information to those making decisions. These include advanced communication with FAA centers, advanced planning of communication and data exchange procedures between ground sites, the main base, and the aircraft, and coordination of the project facilities during intensive measurement periods.

From a physical and logistical standpoint, a single base of operation for studying storms in all 3 locations is possible and preferred, with Salina (Salina Municipal), Wichita (Mid-Continent or McConnell AFB), or near Oklahoma City (Clinton-Sherman, Vance AFB, Altus AFB, Tinker AFB, or Will Rogers) recommended (Figure 5). A common base will provide flexibility in studying storms in any of the regions. Each airport has long runways with large weight-bearing capability. They are at low enough altitudes so take-offs of heavily loaded aircraft are possible even with high afternoon temperatures. The Kansas airports are about 45 minutes flying time for the G-V to Greeley, and 20-45 minutes to Oklahoma City. Transit time from Oklahoma City to Greeley is about 60 minutes. Flight times from the possible bases to northern Alabama are 70-80 minutes. The times are similar for the DC-8. For downwind outflow evolution studies, the G-V could fly from Salina to the central Illinois in about 60 minutes and western Pennsylvania in about 120 minutes. Airborne instruments will be operated whenever the aircraft are flying, and thus these ferry flights (from the main base to the study regions) will provide additional information on the composition and properties of regional air masses where target storms develop, and also will be used to compare common measurements on the airborne platforms. It is estimated that 14 flight hours (for the G-V) will be used to transit to and from storms. A single base of operations is also preferred for the convenience and reduced costs for the PIs and the aircraft support teams.

Travel expenditures for NCAR staff could be reduced by making use of the Rocky Mountain Municipal (formerly Jeffco) Airport (RMMA) in Broomfield, Colorado for at least part of DC3. We propose to stage test flights from RMMA, probably during the first week of May. The test flights will be of limited extent (4-5 hours) because of the weight-bearing limitations of RMMA runways. We will then move the aircraft operations to the main base.

The aircraft base of operation obviously must also be acceptable to NCAR / EOL / RAF and it must have sufficient infrastructure to support the aircraft deployments. In addition, for researchers to keep their instruments operational, easy access to consumables such as dry ice, liquid nitrogen, and compressed gases is required. It is convenient if support personnel can easily travel to the bases via commercial airlines. Availability of overnight shipping is also important. None of these are issues at any of the proposed locations.

If airborne platforms other than the two primary ones participate in DC3 (discussed later), we would like them to be staged at the same location, if possible. The NASA DC-8 cannot be staged out of RMMA, but could be at the other airports under consideration. If we find ourselves using more than one airport, we will need to expand our communications and data exchange plans (discussed later) accordingly.

III.e. Aircraft Platforms and Instruments

We carefully considered the identification and number of aircraft platforms that would be most suitable to addressing the DC3 goals. For example, one could conceive a campaign using only the G-V platform. It certainly has the performance characteristics to measure both the inflow and outflow composition, and, in principle, to rapidly switch between the two regions. It was felt (and other studies have shown), however, that air traffic control limitations over the continental United States would likely preclude easy movement between the boundary layer and the outflow altitude. On the other hand, two aircraft instrumented similarly, allow simultaneous and nearly continuous observation of both the inflow and outflow regions. This does not completely obviate air traffic issues, but does make them easier to deal with. It was the overwhelming opinion of attendees at DC3 workshops that the G-V (for outflow measurements) and the NASA DC-8 (for inflow, entrainment, and remote sensing) would be the best combination of airborne platforms for DC3. Such an arrangement would require interagency collaboration that, while possible and with precedent (e.g. MILAGRO), could not be assumed at the present planning stage. As we currently understand it, several NASA programs are planning to pool their resources to undertake a detailed study of tropical convection in 2012. This could provide the opportunity for the DC-8, instrumented for the NASA mission, to participate in DC3, and perhaps for the G-V, instrumented for DC3, to participate in the NASA mission. We will leave this to the relevant program officers to see if such a scenario is possible.

The DC-8 can be outfitted with the needed suite of instruments and can be used to study the storm at lower altitudes. Table 3 shows our intent to request flight hours for instrument testing and flight pattern practice in 2011, as well as payload flight tests immediately before the DC3 intensive phase.

The aircraft platforms will be configured with instruments for measurement of a wide array of gas-phase and condensed-phase species, radiation and meteorology, and remotely sensed quantities. The design of the observational suite will allow characterization of the chemical and physical properties of deep convective systems in the active stage and after dissipation, when the perturbations on the chemistry and composition on the upper troposphere and lower stratosphere continue. Several of the newly-developed HAIS instruments for the G-V platform will be deployed as indicated in Table 4a; HAIS refers to HIAPER Aircraft Instrumentation Solicitation, which is a group of instruments developed through NSF support specifically for the G-V aircraft. Other instruments are either under development with partial or full funding, or are waiting for funding.

III.e.1. Instruments on Aircraft

Payloads for the aircraft have been designed to complement each other and contribute directly to the primary and ancillary goals of DC3, and to test the hypotheses put forward. The observations are also selected with the needs of numerical modeling in mind. The proposed instruments for the G-V are shown in Table 4a and for the DC-8 in Table 5. Included are gas-phase species related to HO_x radical and ozone formation, measurements of aerosol size, and cloud hydrometeor size and composition. The DC-8 payload also includes remote sensing and radiation measurements (SEAC4RS planning document, Crawford et al.) These observations will allow us to constrain models that predict the movement of species through the convective storm, including dissolution into liquid droplets and adsorption onto ice, removal through rainout, snow and hail, and appearance in the outflow. Additional desired but optional instruments are shown in Table 4b.

To help determine if the maximum altitude of the G-V is suitable for studying storms in the three proposed regions, an analysis of tropopause heights coincident with lightning flashes, as a measure of maximum storm outflow height, in the study regions was conducted (Cooper, 2007) using ECMWF data for April, May and June 2004 and 2006. The results are shown in Figure 6. In April and May, observations up to 14 km (45,900 ft) will capture nearly 100% of the occurrences in Colorado and 80-95% or more in Oklahoma and Alabama. In June, the tropopause is higher. Flights to 14 km will capture about 85% of the events in Colorado and about 65% in the other regions. While the G-V will probably do a reasonable job of capturing the outflow based on this analysis, addition of a high-flying platform such as the WB-57 would provide additional information to DC3.

The species listed in Tables 4a and 5 were identified in a DC3 community planning workshop (April 2006) and by a DC3 working group as highest priority (including some medium priority species that are included with the proposed methods) for linking models and observations and for addressing the DC3 scientific objectives. These species will be used for a variety of purposes including tracers of convective transport, testing wet scavenging schemes in models, estimating NO production by lightning, assessing transport of water vapor and other species to the UTLS, testing of photochemical mechanisms, testing processes for formation of new particles in cloud outflow, testing schemes for calculating photolysis rates in and around clouds, evaluation of the NO_x budget, verification of microphysics in cloud-resolving models, setting initial conditions for models, estimating fluxes of trace gases, and verification of cloud electrification models. While the proposed payloads cannot include every species one would like to measure (because of weight and space limitations), the highest priority items are covered. More comprehensive payloads for experiments such as DC3 will have to wait for further reduction in size and weight of instruments, and perhaps development of new techniques that provide more species per unit volume and weight. The measurements of species aboard the aircraft platforms will also need to have reasonably high sampling rates, at least 0.03 Hz (30 s avgs), but 0.1 to 1 Hz (10 to1 s avgs) or greater are preferred, and are available with many measurements.

Not all of the instruments for measurement of the critical species are currently available (as of the writing of this document). While none involve major new method development, investigator-provided instruments for the G-V will need modifications to be made smaller, as automated as possible, and designed to meet stringent flight worthiness requirements. In order to meet these needs, these instruments will need funding. While PIs are actively seeking funds for these instruments, it is possible that the rate of funding availability could impact the deployment date for DC3. This situation is discussed below. In addition, these instruments must be tested aboard their respective platforms. While we have set aside a modest number of flight hours for testing at the beginning of DC3, we expect that these instruments will also participate in focused flight testing opportunities in advance of DC3.

The G-V, with its relatively limited payload carrying capability (3400 - 8300 lbs; NCAR, 2006; compared to heavy lifting aircraft such as the DC-8), will be configured primarily to study HO_x radicals, their precursors, and NO_x and O_3 sources and sinks above, below and within the outflow region of convective storms. The payload will include facility instruments, HAIS instruments, and user-supplied instruments. Most of these will operate autonomously, thus minimizing the number of operators required and maximizing the number of instruments that can be staged. It is vitally important to have real-time communication between PIs on the ground and personnel on the aircraft and/or ability to examine instrument parameters directly. This capability has been successfully demonstrated through Satcom data and chat links on many airborne platforms. Remote control of airborne instruments would be a useful addition and is under development for the G-V at this time. In order to reduce the number of scientific personnel on the G-V, instrument operators will be trained to manage several instruments. Without this capability, additional instruments may require onboard operators, thereby reducing the instrument payload. Communication requirements include aircraft-to-aircraft, aircraft-to-radar operations base, and aircraft-to-forecasting/nowcasting teams.

The DC-8 with its large payload carrying capability (up to 20,000 lbs), will be configured as both a remote sensing platform for the region around the storms and as an *in situ* platform for inflow and entrainment regions. The primary remote sensing instrument is an O_3/aerosol LIDAR, but aerosol profile instrumentation is also likely.

A schematic diagram of a generic convective cloud with the proposed DC3 observational platforms and facilities superimposed is shown in Figure 7. The *in situ* and remote measurements on the aircraft platforms will allow us to follow the evolution of important species as they move from the boundary layer into the cloud base or are entrained at higher altitudes, potentially undergo condensed phase chemistry within the cloud, are directly or indirectly impacted by lightning, move into the anvil region where they can be removed by hydrometeor settling or are exported at high altitude. Some soluble species might be returned to the gas-phase as the cloud evaporates. Others might remain in the aerosol due to cloud chemistry (such as oxidation of SO_2 by H_2O_2 or O_3 within liquid droplets leading to sulfate). Over the life of a storm, the size of the convective outflow could be quite large, perhaps hundreds of miles long. Initially, the perturbed layer might have plume characteristics with a vertical dimension of 5-6 km and a horizontal dimension of tens of kilometers, but vertical shear could rapidly convert it to many separate, very thin layered plumes. This may make quantitative studies of the downwind evolution challenging. Remote sensing guidance will be valuable for detecting and following such plumes. Tracer releases have been employed in other studies and will be evaluated for DC3.

To link observations from the various platforms, a detailed series of comparison flights will be conducted, along with ground-based comparisons to harmonize all the common observations. These will not be "formal" comparisons, but could be called "semi-formal" to help lead to data of the highest possible quality. At the beginning and end of several flights (at least 3), aircraft will fly side-by-side in pairs at two or three altitudes (about 10 minutes per altitude). These comparison data will be submitted to an impartial referee within 24 hours of the end of the flight, who will prepare correlation and time-series comparisons of the common species. The results will be reported back to the PIs of the appropriate instruments in a timely manner so that instrumental problems can be resolved. On selected no-fly maintenance days, comparisons of ambient concentrations and standards will be organized. The data will be treated the same as the in-flight comparisons. Each species common to multiple aircraft will take part in at least two of these exercises. Comparisons will also be made between similar observations, for example between NO_y species (PAN, HNO_3) and NO_y itself, or between *in situ* and remote O_3. All aircraft taking part in DC3 will participate in the comparison exercises. Atmospheric profiles of thermodynamics and winds will be compared between sondes and aircraft observations collected in the vicinity. When practical, the transit flight periods from the bases of operation to the study areas will be used for these comparisons. Successful implementation of the envisioned multiple aircraft program mandates rigorous, regular and thorough testing of common observations.

III.e.2. G-V Aircraft

The G-V aircraft will make use of two basic flight patterns. For both flight patterns the transit to the sample region will include time spent in coordination with the DC-8 to compare instrument measurements. The flight patterns will be adjusted for the particular situation using information from model forecasts and now-casts, and observations from ground-based radars, which will be transmitted to the mission scientist in near-real-time. These flight patterns are shown schematically in the diagrams, and described below. All altitudes are AGL. The patterns are: GV-1) to characterize the surrounding composition at high altitude, penetrate and characterize the anvil; to characterize outflow composition and spatial distribution; and GV-2) to locate and to survey 1-2 day old outflow. In addition, one flight will focus on ozone amounts in the upper troposphere over the southeastern US and Gulf of Mexico to assess the seasonal evolution of ozone (GV-3).

G-V Flight Pattern GV-1. The aircraft will transit to the study area (20-50 minutes), and then perform a 1000 ft/min profile (30 minutes). It will then sample upwind of the forecast outflow region (30 minutes) and fly a wall consisting of a series of stacked legs at several altitudes upwind of the forecast outflow region at fixed or drifting ground positions (as appropriate) covering altitudes above and below the expected main outflow altitude range (120 minutes). It will then fly a wall pattern above, within and below the anvil as close as safely possible to the storm core region with legs shorter than previous pattern (60 minutes). The wall pattern will be repeated near the anvil outer extent, but still within the anvil (60 minutes). This will be followed by a repeat of the wall 30-60 km downwind of visible anvil (60 minutes). The G-V will then transit back to the base of operations (20-50 minutes) for an estimated total flight time of 7.5 hours. The estimated maximum altitude range is 42,000 to 45,000 ft.

G-V Flight Pattern GV-2. The aircraft will transit to the study area (60-90 minutes), as in GV-1. As the forecast target area is approached, it will begin a series of saw-tooth profiles (2000 ft/min) to and from aircraft ceiling to 30,000 ft (30-60 minutes). It will fly three or four walls consisting of a series of legs (about 5) at several altitudes bracketing the forecast (and/or LIDAR observed) plume at several downwind distances. Each wall is estimated to take 60-80 minutes for a total of 180-320 minutes. The G-V will transit back to the base of operations after following convective outflow at 42,000 to 45,000 ft (60-90 minutes) for an estimated total flight time of 7.5 hours. The estimated maximum altitude range is 42,000 to 46,000 ft.

G-V Flight Pattern GV-3. The aircraft will climb to UT altitudes heading toward the central U.S. then transit to the Caribbean (90-150 minutes) flying over Huntsville and Miami. The observations over the Caribbean will focus on profiles of ozone in the upper troposphere, from about 35,000 ft to the aircraft ceiling via ascents and descents (vertical zigzags). By providing real-time NO, NO_2, and O_3 measurements to the Mission Scientist, the flight pattern can be modified to remain in O_3-rich layers. The Gulf of Mexico region will be studied for 4-5 hours. The aircraft will then transit back to the base of operations (90-120 minutes) for an estimated total flight time of 8 hours.

The plan is to study 4 storms in each of the three study areas (12 flights), using GV-1 sometimes followed by GV-2 the next day or 2 days later (6 flights). Twelve flights of 7.5 flight hours each of pattern GV-1, 6 flights of 7.5 flights hours each of GV-2, and 1 flight of 8 hours of GV-3, leading to a total of 143 hours over 19 flight days, plus 10-20 test flight hours before the deployment. Sponsorship of the G-V is being requested from the NSF ATM facility deployment pool. Deployment of the G-V configured as described above will address all of the DC3 goals.

III.e.3. DC-8 Aircraft

The second aircraft will make use of three basic flight patterns, which will incorporate instrument comparisons as described above. This aircraft will characterize the inflow and measure fluxes in the lower part of the storm. Remote sensing instruments on board will be used to help guide the location of G-V flights and help place *in situ* measurements in a wider context. It will characterize the location and makeup of downdrafts. It will be used to characterize the middle troposphere and provide remote sensing to help the G-V locate the aged outflow. All altitudes are AGL. The patterns are: DC8-1) to characterize convective inflow and the location and composition of downdrafts; to use remote sensing to locate and characterize the outflow, and DC8-2) to help locate aged outflow and to sample the middle troposphere and the lower part of the outflow. These patterns are shown schematically in the diagrams and described below.

DC-8 Flight Pattern DC8-1. The aircraft will transit to the study area, performing comparisons or transiting at middle to upper troposphere altitudes (10,000 – 33,000 ft) (20-50 minutes). Then it will perform a 1000 ft/min profile from 33,000 ft to 200 ft AGL in the storm vicinity (30 minutes), followed by surveys horizontally and vertically of the storm inflow region. The aircraft will provide remote sensing information to the G-V to help define its flight plans (60-120 minutes). Next it will horizontally and vertically survey the storm downdraft regions (60-90 minutes). This will be followed by repeat surveys of the inflow region (300-330 minutes), and providing remote sensing information for the G-V. The aircraft will transit back to the base of operation after following the convective outflow at UT altitudes (20-50 minutes) for an estimated total flight time of 7.5 hours. The estimated maximum altitude range is 39,000 ft.

DC-8 Flight Pattern DC8-2. The aircraft will transit to the study area (120-180 minutes) as in C130-1. As the target area is approached, it will begin a series of horizontal zigzag patterns at middle to upper troposphere altitude (30-60 minutes). It will sample the lower outflow region at the aircraft altitude ceiling while remaining in the region below the G-V. The aircraft will transit back to base of operation (60-90 minutes) for an estimated total flight time of 7.5 hours. The estimated maximum altitude range is 39,000 ft.

The plan is to study 4 storms in each of the three study areas (12 flights), using DC8-1, sometimes followed by DC8-2 the next or following day (4 flights). Twelve flights of 7.5 flight hours each plus 6 flights of 7.5 flight hours each, leads to a total of 140 hours over 16 flight days, plus 10-20 test flight hours before the deployment. Deployment of the DC-8 configured as described above will help address all of the DC3 goals.

III.e.4. Instrument Testing and Logistic Practice Flights

With all airborne studies, it is important to test the performance of instruments in a few flights immediately before the inception of the intensive campaign. We request 10-20 hours for each platform for this purpose. In addition, we would like dedicated pre-DC3 test flights, also 20 hours or so, for instrument testing (we understand these are currently scheduled for May 2011). We propose to use these flights not only to test instrumentation, but also for practice forecasting, communication, testing of flight patterns, and working out the details of interactions with air traffic control. We believe that such testing will lead to the best use of the airborne hours during the DC3 intensive phase, and will help us improve the performance of the planning process required for this campaign to be successful.

III.e.5. Flight Plan Contingencies

Given the potentially difficult weather conditions, it is possible that the aircraft will not be able to return to the base of operations after a specific flight is completed. We will work with the Research Aviation Facility, NASA pilots, and the FAA to locate potential alternate landing locations in such a situation. Detailed surveys of airports throughout and outside the three study regions have been conducted for the purpose of identifying the primary base of operations. These data can also be used to identify alternate airport(s) should the need arise. It makes sense that at least three alternate locations be identified corresponding to the three DC3 study regions, with additional alternates in the vicinity of the base of operations. Assuming a central Oklahoma base, alternate airport candidates are Salina KS, Wichita KS, Denver International, Buckley AFB, Clinton OK, Lubbock TX, Roswell NM, Albuquerque NM, Huntsville AL, and Memphis TN. All are within 90 minutes flight time of central Oklahoma.

Our intent to base operations for all of DC3 at one location will make logistics easier for the overall project and for individual aircraft PIs in terms of spare parts, expendables, and other types of support. Diverting the aircraft to an alternate location will remove access to those items. In addition, to maximize weight and space availability aboard the G-V aircraft, instruments will be configured with the minimum of compressed gases and other expendables. Given the likelihood that both the G-V and the DC-8 would be required to divert to an alternate location, it is conceivable that the DC-8 could carry some expendables needed by G-V instruments (e.g. nitrogen gas cylinders). This, in principle, could allow a flight with scientific focus following a landing diversion.

The other factor for DC3 flights is the need for a suitable storm or the suitability of outflow from a previous storm. While conceivable that such a situation could arise after needing to land an alternate airport, it is more likely that the situation will not be ideal for study. It is therefore probable that after diverting to an alternate airport, the aircraft will take a short transit to home base the following day without scientific focus.

III.e.6. Benefits of Proposed Aircraft Platforms and Instruments

Making airborne observations of convective storms that are continually evolving presents many difficulties. The dangers inherent from high winds, lightning and hail add to this complexity. The approach with the greatest probability of success makes use of high flying jet aircraft like the G-V, and the DC-8. The G-V can reach developing storms relatively quickly, can perform detailed flight maneuvers rapidly, and the G-V can access nearly the entire vertical extent of even rather large storms. In order to connect the inflow and outflow compositions, two aircraft platforms are imperative. It would be ideal if the two aircraft had the same research air speeds, but this is probably the least important characteristic. =

There are tradeoffs between loading the platform with instrumentation, carrying sufficient fuel for fairly long flights, and being able to reach the altitudes needed to make *in situ* observations. For most of the candidate flight patterns described above, the G-V can reach 45,000 ft altitude 2-3 hours into the flight. The G-V can always reach 42,000 ft altitude for the conditions proposed. These parameters should allow many, even very tall storms to be well-characterized.

While the G-V payload capacity has size and weight limitations, with the instrument developments envisioned a fairly complete photochemistry payload can be accommodated along with some aerosol and cloud information. The payload will be complex and challenging, but the years before the proposed campaign will give time for incremental steps toward such complexity, as well as time for several flight tests of individual instruments (in other campaigns, such as START08 and HIPPO, and in focused flight tests offered at least once per year). We do not envision that DC3 will provide the maiden flights for any of the proposed instrumentation; they will all have either participated in previous campaigns or test flight opportunities well before DC3. The value of the proposed remote sensing capability onboard the DC-8 cannot be overstated. It will help greatly in the coordination of the aircraft flights. The overlap of species measured on the two platforms, if properly harmonized, will also lead to valuable information that would be difficult or impossible to collect with a single platform.

We recognize that conducting a two aircraft experiment in the congested air space over the continental United States presents many significant challenges. Decisions on where to fly require rapid ingesting of a wide variety of data. Air traffic control can limit the freedom with which the aircraft can move horizontally and vertically. It is our intent to bring a current or retired air traffic controller onto the DC3 team to help with ATC communications and flight planning. We will also brief the relevant ATC centers of the desired flight patterns and airborne platform needs for the success of DC3. Practice flights are proposed to be conducted well in advance of the DC3 intensive period to test communications, potential proximity to storms, ATC limitations, and unexpected factors. We would like 3 or 4 flights in mid-2011 of 4-5 hours each to work out the issues needed to make such flights succeed.

The valuable infrastructure of the proposed ground-based facilities has been discussed. DC3 will bring together the unique combination of two well-instrumented aircraft, research-grade dual-Doppler radars, and 3-D lightning mapping, along with other facilities.

Instrumentation and platform issues related to the timing of the DC3 campaign are discussed later.

III.e.7. Roles of Other Aircraft

The DC3 experiment is designed as a two-aircraft study with comprehensive ground-based radar, lightning mapping and other facilities. The scientific questions of DC3 can be fully addressed with these assets. The DC3 PIs have been approached with the possibility of addition of other aircraft to the study. None of these are yet supported by their relevant funding agencies, so they are not a certainty. Many of these aircraft are outfitted to provide added value to DC3. We will work with the appropriate PIs and RAF to seek ways to incorporate them into the experiment in a safe and sensible manner that enhances the science of the project. Any additional aircraft will be asked to conform to the policies and procedures of the DC3 campaign (e.g. data format, submittal and sharing, decision-making, etc.). These other aircraft include the DLR Falcon, the UK BAe-146, the UND Citation, and the NOAA WP-3D.

The details of the roles of potential other aircraft in DC3 has not been fully defined because of the uncertainty of their participation. As their plans are developed, we will gather more detailed information from the PIs describing their scientific goals and the limitations of the aircraft. We envision the other aircraft contributing to understanding the inflow and outflow composition, contributing remote sensing if available, and generally coordinating with the goals of DC3 while not interfering with the flight patterns of the two primary aircraft (the G-V and DC-8). As we firm up commitments from these aircraft, we will clarify their role in the DC3 observational science. Here is the information we currently have regarding these platforms and their flight strategies as part of DC3.

The DLR Falcon has flown in several previous thunderstorm-chemistry field experiments such as EULINOX, TROCCINOX, and SCOUT-O3. The aircraft can fly up to 42 kft (12.8 km) and has a maximum endurance of 5 hours. For DC3 it could fly either in local convection or can refuel when sampling further from the operations base. While no percentage was given for the likelihood of the DLR Falcon joining DC3, it is the intention of DLR investigators (contact is Dr. Heidi Huntrieser) to join in (therefore likely). A decision on financial support for the deployment of the Falcon to DC3 will be made by summer 2011. The Falcon would likely join DC3 for a 4-week period and would fly in the 10-12 km altitude anvil region capturing fresh outflow from the convective cores.

The UK BAe-146 aircraft has a maximum altitude of 28 kft (8-9 km) and has a 5 hour endurance. For DC3 it could fly either in local convection or can refuel when sampling further from the operations base. There is probably about 20% likelihood that the BAe-146 will join DC3; decision on its support will be made by July 2011 (the contact is Mat Evans). The aircraft will fly near the storms sampling gas-phase, aerosol physical and composition characteristics, and actinic flux to improve understanding of how clouds affect the composition and chemistry in the lower troposphere region near storms.

The UND Citation has a maximum altitude of 12 km and endurance of 3-4 hours. Like the Falcon and BAe-146, it could fly either in local convection or can refuel when sampling further from the operations base. Dr. Tony Grainger and colleagues are submitting a proposal to NSF and decision is expected by January 2011. The Citation aircraft would focus on addressing the convective cloud electrical fields with respect to its microphysical characteristics (e.g. the liquid water content), and would sample developing cumulus. This flight strategy, explained more below, is being encouraged for the other aircraft as well.

The NOAA WP-3D aircraft flies in the low to middle troposphere to examine air quality and climate questions related to gas and aerosol composition and chemistry. There is a possibility (<50%) that they will conduct a field campaign in the southeast U.S. to study secondary organic aerosols (i.e. which is less relevant to DC3 goals). A decision on the WP-3D deployment should be made by January 2011 (the contact is Dr. Joost DeGauw). If NOAA conducts a field experiment in the southeast U.S., then it would be beneficial to coordinate flights between NOAA and the DC3 field experiment for the northern Alabama region. The flight strategy could likely follow the strategy in which the NOAA aircraft flies earlier in the day than the G-V and DC-8. Because the NOAA aircraft will be only in the Alabama region, their flights will be of a looser coordination than a synchronized affair.

One important aspect of DC3 is the regular comparison of common measurements between the two primary aircraft. It should be relatively straightforward, because of their flight speeds, to incorporate the Falcon and Citation into the measurement comparisons. Measurement comparisons between the faster platforms and the slower BAe-146 and WP-3D are possible but more difficult.

Following the philosophy that the DC3 experimental design is fundamental and that the other aircraft would add to DC3 but not change its strategy, we do not want to complicate the DC3 flight strategy by having all the aircraft that are participating in DC3 flying in the same location and time. Here, we propose some scenarios of how the flights could be coordinated. Any scenarios that are adopted would have to pass through the DC3 decision-making process and address the DC3 risk assessment procedures.

One strategy would be to use two additional aircraft, e.g. the UK BAe-146 and UND Citation, to sample developing storms. Thus, they would deploy to the sample region 2-3 hours before the G-V and DC-8 aircraft and would have minimal overlap with the two primary aircraft. This type of scenario would need to be reviewed thoroughly during the preparation for DC3 to be sure it is acceptable with Air Traffic Control. At this point, this strategy is the most favored one.

A second strategy is to fly the additional aircraft on days when the G-V and DC-8 are not flying. The benefit of this scenario is that additional storms would be sampled providing more data and statistics for analysis. The flights of the 2-3 aircraft would be tightly coordinated to sample both inflow and outflow regions of the storms.

A third strategy is to fly the aircraft near active convection while the G-V and DC-8 are sampling air further downwind (i.e. either flying GV-2 and DC8-2 flight patterns as described, or flying a similar flight patter but closer to the active convection). The benefit of this scenario is that stronger connections between active convection and aged convective outflow could be made. This strategy would require very good coordination between the aircraft.

An issue to be discussed with EOL is the level of the logistical support provided for the G-V and DC-8 being extended to these other aircraft. We are currently still discussing with EOL/RAF the risks and likelihood of coordinating with aircraft other than the G-V and DC-8.

We want to emphasize that the addition of other aircraft will not impact nor detract from the basic DC3 science and experimental plan. They will only participate under the control and guidance of the DC3 decision-making process.

III.f. Forecasting

Forecasting for DC3 operations will be accomplished through the use of guidance from both operational and research numerical models. Operational models, such as the NAM (formerly ETA) and GFS, run with resolutions of order 12 km or larger with convective parameterization, will be used to identify regions with a potential for producing significant convective activity out to 72 h in advance. However, to get better guidance as to the specific character of the anticipated convection and its transport properties, experimental forecast models will be used, such as WRF-ARW, which can be run at grid resolutions of 1-10 km and can treat convective processes explicitly. Such forecasts have been generated successfully at NCAR in real time for the past several warm seasons using 4 km resolution over most of the US and have demonstrated an ability to predict convective system mode, propagation, and evolution out to 36 h. These simulations can be run overnight (using 00 UTC observation), with a 36 h forecast available by roughly 8:00 am the next morning to help guide the next afternoon's and evening's observations. For DC3, it may be possible to extend these forecasts to 48 h, to help guide the next day's planning as well. In previous studies, 18 h forecasts were generated by initializing with 12 UTC observations which were available by early afternoon. Thus, the potential value and practicality of such update forecasts for DC3 will be considered. Model data will be interpreted by a team of forecasting groups situated at NCAR, CSU, the University of Oklahoma/NSSLO and the University of Alabama, Huntsville and the Marshall Space Flight Center. These local forecast teams will be available to DC3 at no cost. Therefore, local forecasting expertise will be used for DC3 in order to develop the best possible forecasts for operations in each of the three DC3 operational domains. A conference call will be held each morning with NCAR forecasters, the PI team, and local forecasters at each of the three domains. Based on these discussions, a plan for the day will be developed that includes where we will target operations, aircraft take-off times, development of a back-up plan, and outlook for the next day's operations. Forecast information will be provided to the Science Team through appropriate figures, movies, and text at regular briefings.

One of the specific needs for DC3 is forecast guidance as to subsequent transport of chemical species by the convection, and, in particular, the projected locations and extent of the downwind chemical plumes within convective anvils. This type of forecast guidance can be achieved by adding passive tracers to the boundary layer at various times and then following their progression through the remaining simulation. This technique was used successfully to help guide observations of potential chemical transport in the 2006 MIRAGE field program held in Mexico. Forecasts of potential plume locations would be made available along with the forecasts of anticipated convection. High time resolution WRF output will also be used to produce real time trajectory analyses, using software such as Flex-part.

Resolutions used for these forecasts will depend on results from an ongoing study of retrospective cases from the proposed DC3 core study areas. At 4 km resolution, our experience suggests that convective system properties are reasonably well reproduced, but cell scale properties are still highly suspect. Resolutions of 2 km may be sufficient to reproduce some cell scale properties (e.g., super-cells can be reasonably represented at 2 km), but it is unclear at what resolution cell scale transport properties can be reasonably reproduced for the full range of convection likely to be encountered in DC3. This retrospective testing will be used to clarify the potential capabilities of the various resolutions as well as the amount of resources that would be necessary to operate various model configurations in real time.

Also, our forecast exercises to date have all used the initial cold-start analyses and boundary conditions from the operational NAM models. Thus, convection that should be present in the initial state is not represented and must subsequently be spun up over a several hour period. This does not appear to have a significant impact at longer forecast time scales (e.g., greater than 12 h), but is still a point of on-going concern that might limit the accuracy of some of the forecasts. However, advanced data assimilation techniques for WRF-ARW, such as 4DVAR or EnKF are actively under development and should be available in time for DC3. As such capability becomes available its potential value for DC3 will be tested.

III.g. Post-Mission Numerical Modeling and Analysis

Post-mission modeling efforts will include cloud-resolving numerical models and model that utilize parameterized convection (e.g., regional models). Within the cloud-resolving category, some models contain explicit cloud electrification and generate lightning flashes, while others use observed lightning flash rates as input and parameterize the lightning placement within the model. Regional models typically use model-predicted meteorological and cloud variables to parameterize flash rates. Some observations will be used in constraining the models and others used in evaluating their performance. The cloud-resolving models will be most useful for studies of convective transport, lightning NO_x production, fate of soluble species, and photochemistry within a storm and anvil. Regional models will be best for evaluating the effects of convection and lightning on downwind chemistry in the UTLS.

Cloud-resolving modeling with chemistry and lightning NO production has been performed for several previous experiments (e.g., STERAO, EULINOX, CRYSTAL-FACE). These modeling experiments identified the types of data lacking. One of the most serious problems with previous experiments was lack of sufficient anvil sampling. As a result, DC3 plans to perform anvil measurements over a range of altitudes and distances downwind of the convective core. Models have often shown downward mixing of higher O_3 air around the edges of the anvil. Aircraft measurements in these locations are needed. Also missing in previous experiments were measurements of soluble chemical species and will command high priority during DC3. In order to investigate the fate of soluble species during the freezing process and to obtain observations of NO in the region of greatest lightning flash channel generation, measurements in or near the core of the storm would be necessary. Thus, use of a storm-penetrating aircraft would be beneficial for studies of specie transport and processing, and as many species as possible should be measured at rates as high as 1 Hz or better. With horizontal resolution of 1 km typical of cloud-resolving models, it will be necessary to average the airborne observations over 5 or 6 seconds to be comparable to the models, given typical aircraft speeds. It is planned for the majority of species to be averaged over times no greater than 30 seconds. Averaging over longer periods will be necessary for comparisons with regional models (typical horizontal resolution of 10-20 km).

III.h. Use of Satellite Data

Satellite data will also be used to examine the influence of convection on the UTLS composition and chemistry. These spaceborne data will be used before the DC3 field deployment to better prepare for the operating period. Case studies from previous years will bring together chemical measurements, e.g. NO_2 and HCHO from OMI, CO and O3 from TES, and O3 and water vapor fro AIRS, and meteorological parameters, e.g. radar reflectivity from the NWS Nexrad radar network, cloud-to-ground lightning strikes from the NLDN, GOES images, lidar data from the CALIPSO satellite, and radar data from CloudSat.

During the DC3 deployment, the satellite data will place the *in situ* measurements in a wider geographical context and should be able to give some guidance to the location of downwind convective outflow plumes. Validation exercises such as comparing *in situ* observations with satellite observations have been conducted frequently in the past (i.e. TRACE-P, INTEX-NA and B). They are valuable for testing inversion algorithms and for examination of particular situations (e.g. measurements near clouds). They can also help to harmonize the datasets as they are combined for particular scientific purposes.

The potential in using satellite observations is much greater than that given above. Consider the measurement of the column abundance of NO_2 by OMI on the Aura satellite. Because the signal can be adjusted to give tropospheric column NO_2, relatively large tropospheric NO_2 sources (e.g. urban areas, fires) can be examined. Analysis of long terms records of such data reveals a consistent background level of NO_2 in the column. The location of tropospheric NO_2 in such analysis is presumed to be primarily near the surface, but NO_2 could be located at higher altitudes resulting from convective outflow. Such signals could also be due to errors in subtraction of the middle atmospheric column amounts. Examination of NO_2 data in the outflow of deep convective storms in DC3 will allow such alternative explanations to be tested. The satellite records will also place the relatively local and short time aircraft and ground based observations in wider context and provide constraints for large scale (regional to global) models.

Two other particularly exciting satellite based instruments are CALIOP aboard the CALIPSO satellite and CPR aboard Cloudsat. CALIOP is a LIDAR instrument that provides profiles of aerosols and clouds with high vertical (120-360 m) and 40 by 40 km horizontal resolution. CPR is a radar instrument that measures the 3-dimensional structure of clouds with 0.5 km vertical and 1.4 by 2.5 km horizontal resolution. The combination of these two instruments with the planned DC3 airborne and ground based assets provides opportunities for redundancy in characterization of clouds and aerosol layers, comparisons between the space-based and other platforms, and extension of the view of clouds and aerosols beyond that possible by the aircraft and ground-based systems alone. CALIOP could also be very useful in locating perturbed air downwind of the initial convective event, if aerosols or clouds are present.

Additional satellite platforms with synergistic benefit to DC3 include geostationary satellite images from the GOES-EAST and GOES-WEST platforms, TRMM/LIS data measuring lightning flashes, Aura/TES CO and O_3 profiles, Aura OMI O_3, NO_2, CH_2O, SO_2 and aerosol columns, Terra and Aqua/MODIS data of aerosol optical depth, Terra/MOPITT CO data, and Aqua/AIRS CO data.

III.i. Time Period of the Field Campaign

There are a number of issues constraining the optimum time for the DC3 campaign. These include the probable occurrence of storms in the three study regions and the readiness of instrumentation and facilities critical to addressing the projects goals and hypotheses.

III.i.1. Storm Climatology.

The recommendation is based upon climatological analyses of: 1) cloud-to-ground lightning flashes from national and local lightning detection networks; 2) a 10-year convective precipitation climatology; 3) tracer studies of anthropogenic NO_x emissions; and 4) storm frequency climatologies above the three study sites. All of these products can be viewed at: http://www.al.noaa.gov/metproducts/dc3/ .

The best time period for the DC3 experiment is May 8 – June 30. This 6-week period has several advantages: 1) The month of June is a good “intersection” month that yields relatively high precipitation often driven by daytime convection at all three sites (Figure 10). This month also provides a high incidence of air mass thunderstorms, with the additional occurrence of frontal driven convection during the first half of the month. 2) The last half of May provides a high incidence of frontal driven convection at all three sites. 3) While MCS and MCC storms occur in this time frame they do not dominate convective activity. 4) This is the best time period for deep, isolated convection within the range of the CHILL radar in northeast Colorado. 5) Including the month of June provides the most daylight hours allowing aircraft missions to extend into the early evening, plus ample daylight for photochemistry studies.

This study period precludes the best time to sample convection associated with the North American Monsoon that dominates during July and August. But this time frame is not recommended because the convection that begins in the afternoon along the Rocky Mountains advects into Kansas and Oklahoma during the night making research flights difficult. These nighttime storms often become very large MCS or MCC storms that are potentially dangerous for aircraft missions.

The chosen time frame should allow DC3 investigators to sample both air mass and shear driven convection at all three sites, permitting exploration of the wide range of hypotheses that we have proposed. A one-week “shake down” period in the field between about May 1 and May 7 is also recommended to work out the instrument, aircraft, forecast model, and communication issues that inevitably arise at the beginning of large-scale field missions.

During the proposed study period, the G-V will be able to reach the lower stratosphere, or at least the tropopause layer. This will allow us to directly contrast the background UT and LS, and the convectively perturbed composition of those regions. Later in the summer, this becomes more difficult, at least from a climatological standpoint (see Figure 6).

III.i.2. Instrument and Platform Issues; Timing of Campaign.

As discussed earlier, the year of the campaign has some constraints. DC3 should not be attempted until all the critical instruments are completed and well-tested. Successful deployment requires that the crucial HAIS instruments are ready. The present request is to conduct DC3 in 2012.

Seasonal timing of the experiment requires a reasonable probability of development of convective storms. Making use of climatology and using three operational regions improves the chances, but does not guarantee success. Fall or winter seasons are not suitable because of the low probability of deep convective storms with extensive lightning activity. Recognizing the complexity of this experiment, it makes sense to conduct it during a time when isolated, deep convective storms have the highest probability. This is also a time when there will be reasonably high photochemical activity, allowing assessment of the impact of chemistry on the production of secondary products such as ozone. The requested timing could shift perhaps a few weeks at most without serious loss of scientific return.

IV. Project management including management in the field

The DC3 Scientific Steering Committee has requested specific assistance from NCAR's Earth Observing Laboratory (EOL) in areas related to project planning, field operations support and data management. The NASA Earth Science Project Office (ESPO – www.espo.nasa.gov) has also been contacted. Both entities have considerable experience in providing such support. To keep costs down, some of the project management will be handled by NCAR-ACD personnel.

IV.a. Project planning and coordination

DC3 involves the study of convective processes occurring in three areas of the Central US: northeastern Colorado, central Oklahoma, and northern Alabama. Several acceptable candidate locations for a single, centrally located base of operations from which all project activities will be directed have been identified. A project of this complexity will require an extensive support network and well-considered plan for effective communications and operations implementation. The Principal Investigators will invite EOL and ESPO to work with them to develop optimum support strategies. . It is envisioned that ESPO will provide input and advice regarding the needs of the NASA DC-8 and data management, where needed, while EOL will provide the bulk of the logistical support for DC3. To facilitate this EOL and ESPO will be invited to participate in planning discussions and meetings and to assist with preparation of Operations and Data Management Plans.

These responsibilities will also include coordinating NSF ground-based facilities, coordinating project aircraft activities and FAA/ATC interactions, project communication, in-field and post-project data management, and collaborative development of a mission planning process. Appropriate EOL and ESPO staff will be invited to participate in aircraft base site selection and logistics planning to help ensure maximum and efficient scientific return with a reasonable cost. The issues associated with selecting an aircraft base of operations for DC3 are discussed in the EDO document and include airports with runways of sufficient length for the altitude and expected temperatures, proximity to the proposed study areas, access to fuel, available commercial air travel, sources of supplies (such as gases, liquid nitrogen, and dry ice) for aircraft and instrument PIs, proximity to other forecasting centers (such as NSSL), overnight parcel delivery, hotels and restaurants in the proximity of the airport, and facilities for a DC3 operations center. Airports in Salina, Kansas, Wichita, Kansas, or near Oklahoma City should be acceptable for these issues. Discussions with field project support and aircraft personnel will help to refine the selection of an operations base.

IV.b. Field coordination and support

The project will require advance planning and coordination for all aircraft missions in order to operate on a non-interference basis with local and regional FAA air traffic patterns and Military Operations Areas. This will begin with meetings and briefings at affected FAA Air Traffic Centers and military districts in advance of the field deployment and will involve project personnel and platform pilots. Flight operations conducted over ground sites will fall within the domain of the following FAA Air Route Traffic Control Centers: 1) Denver (Northeastern Colorado); 2) Fort Worth, Kansas City and Memphis (central Oklahoma); and 3) Atlanta, Memphis and Jacksonville (northern Alabama). Briefings with additional centers in areas of anticipated outflow will also be needed. Procedures will be established to describe how the FAA would like to receive proposed project flight operations alerts and requests. This will involve advanced notifications, graphical depictions of affected areas, aircraft flight plans, and consideration of the timing of each facility's flight operations. For maximum probability of success, we want to be able to update flight plan details based on changing weather conditions. DC3 anticipates having to be flexible about the location and maneuverability of project aircraft, especially as proposed flight plans are highly likely to intersect known operational airways and restricted military operations areas. The project will rely on the experience of platform pilots to assist in this planning. We intend to bring a current or retired air traffic controller onto the DC3 team to help with planning and communications.

During the intensive field phase of the experiment, EOL will be asked to provide a field operations center near the aircraft main base of operations and will assist in real-time coordination of DC3 research activities during field operations. These include daily project planning meetings (with many attendees interacting remotely) and preparation and implementation of a field catalog. For example, the EOL Field Catalog is a web-based central repository of project planning documents, mission reports, facility status updates, field data, satellite, and model products, and other information useful for in-field decision making and post-project reference. Communication and display capabilities such as the EOL RDCC, internet chat-rooms, and components of the next generation EOL Virtual Operations Center may also be implemented as part of the field operations center. When the aircraft are deployed, the primary aircraft-to-ground communication channel and decision pathway will be through the local radar operations center. Information will still flow between the main operations center and the local radar operations center, but real-time aircraft guidance will come from the radar operations center.

EOL has implemented a new requirement for airborne missions at risk of encountering hazardous weather. A Mission Coordinator will be required to be aboard the G-V to provide information to the crew and the mission scientist. This person will relay meteorological information to help guide the flights as well. We also hope that the data display requirements for the Mission Coordinator will be minimized to the degree possible.

IV.c. General Project Management Issues

The DC3 Principal Investigators are primarily responsible for the organization and oversight of DC3. Together they make the decisions concerning the platforms and facilities requested for the campaign, and decisions in the field regarding the day-to-day actions of the science team when studying a specific storm. These decisions are not made in a vacuum. The PIs have been and will continue to be advised by the DC3 Scientific Steering Committee via regular meetings and communications, and by interested members of the scientific community through focused workshops. The workshops tend to yield general recommendations, the steering committee makes more specific recommendations with pros and cons of each side, and the PIs make the decisions and take the actions necessary to carry them out. The PI has expertise in storm research (Barth), airborne research and instrumentation (Cantrell, Brune), and ground-based storm research (Rutledge). This expertise lead to the primary roles of the PIs in development and execution of DC3. The PIs and DC3 Steering Committee Members are listed on the cover page of the Experiment Design Overview document.

In a project such as DC3, there will be many requests from the community to become involved. In some cases the involvement is tangential (e.g. use of data in a model) and, if within the financial limitations of the sponsors, many parties can be involved in this way. In other cases (e.g. an instrument on an aircraft), space, weight or other constraints may limit the number of possible persons involved. The Science Team will be a mixture of representatives from government-sponsored laboratories, private companies, and universities. We expect, and indeed will cultivate a rich relationship among members of these institutions, using strengths of each for the betterment of the project. For example, it is our expectation that university team members will involve graduate students and post-doctoral fellows as has been the case in past missions. It is also our expectation that government-sponsored laboratories involved in this study will use Education and Outreach programs within their organizations to help provide some support for the educational and training aspects of DC3.

In the field, on a daily basis it must be decided which location has a reasonable probability of developing storms that can be studied. It must also be decided whether to study the storm itself, or study the aged outflow from a previous storm. These decisions are to be based on evaluation of weather forecasts (presented on behalf of the forecasting team by a representative), evaluation of information from radars using feedback from the radar scientists, evaluation of the readiness of the aircraft in consultation with the facility managers, and evaluation of the balance between the various types of studies needed to address the goals and hypotheses of the experiment. During the intensive field phase of the experiment, a deployment team consisting of PIs, forecasters, facility managers, and instrument representatives will meet 24-36 hours before a possible deployment to assess the latest forecast. Alternative deployment goals will also be placed on the table for consideration. As the forecasts are updated, the deployment team will meet as needed to assess the changes. Eighteen hours before possible deployment, this group will make a recommendation for aircraft and ground based operations. The alternative deployment plans are narrowed to one or two choices. The Mission Scientists will meet with the pilots to finalize candidate flight plans, and approximate takeoff times will be selected. On the previous evening, the recommendations will be reviewed and the probability of deployment assessed. At 6 hours or so, an essentially final decision will be made to deploy or not. At 3 hours, some aircraft instruments will require power and access to prepare for the deployment. A final decision is made at this time. If we had planned to study a specific storm development in a specific region, and a storm suitable for study doesn't develop, we will make a decision to go to our alternate target (another storm, aged outflow, or other) or abort the flight.

While the aircraft are deployed, there will be continual communication between the Mission Scientists for each aircraft, the local ground-based radar scientists, and the other ground-based members of the deployment team (i.e. everyone involved in the field phase of the project). They will regularly review the status of the deployment and make recommendations for the optimum observation strategy. During this time, however, the individual aircraft through consultation between the mission scientist and pilots will be responsible for their own flight tracks and safety.

An Operations Planning Team, consisting of a representative of the PIs, EOL representatives, and logistics support personnel, will begin their work well before the campaign intensive period begins by informing relevant Air Traffic Control and FAA representatives of the plans and goals of the campaign. We will inform them of the chain of command for decision making for the project, and contact information for each of the important issues and facilities. This type of background work can make the actual deployment go much smoother, although we recognize that there is a significant amount of air traffic over the continental US that could interfere with our plans.

RAF and FAA rules limit the amount of time aircraft crews can work per day, per week and per month. These limitations will be part of the consideration in planning upcoming missions. EOL will provide a project manager to help interface between the science team and the aircraft crew. We also recognize that non-eye-safe lasers that are part of the LIDAR instrument are restricted at low aircraft altitudes, over cities and under other circumstances. We do envision primarily operating the LIDAR in the zenith direction, and utilizing the nadir direction when allowed.

IV.d. Risk Management

A complex mission such as DC3 making use of airborne platforms with state of art instrumentation, coordinating ground-based facilities, and undertaking the difficult study of convective storms is inherently subject to some risk. The time period of the campaign could be particularly inactive or storms suitable for study might be rare. Key instruments might not perform as desired for a variety of reasons. Limitations of forecasts could lead to sorties that are minimally successful through timing and/or location of storm development. The desired flight patterns of DC3 aircraft will be difficult within the crowded flight corridors over the continental US. Communications with the ground and between aircraft could be interrupted at critical times.

Given these potential difficulties, we believe the probability of successfully addressing the scientific goals of DC3 through the plans we have developed. We are making use of the vast experience of EOL and NASA to conduct airborne research campaigns, and the considerable expertise of the PIs of the airborne instruments and the ground-based facilities. We will also incorporate the experience of previous complex missions to develop methods for optimum decision-making and reduction of risk of failure. These include:

- Making use of multiple state-of-the-art forecasting models to help predict the timing and location of storms suitable for study,
- Formally polling instrument and facility PIs of readiness and using that information as part of the deployment decision-making process. If significant needs arise that can be addressed by financial and/or staff support resources, we will work with the PI to provide those.
- Establishing a chain of command for decision-making during storm probability assessment, pre-storm preparation, transiting to the study region, and storm or outflow observation periods. This time and location division recognizes that the decision-maker(s) will be different under these various circumstances. The person in charge will be clearly defined and well-known to all involved. Obviously, there will be times when needs of the science will be overridden by the pilots for safety or other air traffic reasons.

We will incorporate an air traffic control expert (perhaps a retired controller) into our team to serve as liaison with ATC in the study regions and the transit corridors. This person will help us in advance of the campaign period to educate personnel at relevant ATCs of the nature of the DC3 flight plans and needs of the study. During the campaign, they will serve as spokesperson for the team with ATC in collaboration and consultation with the aircraft pilots. They will also help the team understand the constraints of ATC and help us plan our experiment accordingly. This resource will obviously supplement the considerable expertise of the aircraft facility teams (pilots, managers, technicians, mechanics).

We will make use of new decision-making tools to optimize the use of the resources awarded to DC3. These include application of the decision algorithm reported by Small et al. (Monthly Weather Review, submitted, 2010). While such tools remain new to the airborne science community, they appear to have demonstrated higher yields of desired conditions and thus increased data applicable to the science questions of the study. Given the difficulty in predicting location, timing and severity of convective storms, we will make use of all resources that show promise at improving the predictive skill of the forecast team.

Planning and decision-making will be optimized by exploiting the considerable expertise of those involved in this project. This includes EOL and NASA for operational and logistical issues, the DC3 Scientific Steering Committee and the DC3 Science Team for scientific and observational strategies, the DC3 Data Steering Committee for data assembly, processing, merging and archiving issues, and other committees that will be established as needed to address important ongoing DC3 needs.

An efficient, reliable, high-speed communication system between DC3 team members at the various locations is a critical aspect of the success of DC3 and the reduction of risk. The DC3 PIs will work with EOL, NASA, and the various ground-based components of DC3 to establish needs for such communications, protocols for using the communication tools, and backup systems in the event of failure of the primary ones. We have outlined such a plan in the DC3 EDO, and will refine it in consultation with all the relevant parties.

Some factors are out of the control of the DC3 team. We believe, though, that a fully fleshed out plan of operation and communication using the concepts described above, will enhance the chances of success and reduce the risk of failure.

V. Data management plan

This describes a preliminary data management plan that the PIs, DC3 Scientific Steering Committee, and facility managers will review and refine closer to the observation period. It follows the pattern of recent large, complex aircraft missions.

Each facility will have its own Data Manager (including satellite instruments), and the entire DC3 project will have an overall DC3 Data Manager. They will be advised by the DC3 Data Steering Committee that will include some members of the DC3 Scientific Steering Committee, instrument PIs, EOL staff, and others. This group will examine the needs of data sources and data users to make recommendations to develop the specifics of the DC3 Data Policy, which will include items such as the format of data, testing of data to meet format requirements, data submittal deadlines, and developing of products (such as merges) from the submitted data. They will also make recommendations on the use of data by researchers other than those who collected it. Based on recommendations, the Data Managers and the DC3 Data Manager will develop submittal procedures, security methods to limit access in the early stages, methods for production of various merges, and archives of data, and will communicate these to DC3 Science Team members.

We anticipate four types of data that will be submitted from aircraft and ground observations. Similar data will be submitted from the output of forecasting and analysis models, satellite instruments, and other observing systems.

1) Field data – quick turnaround data (<24 hours) with preliminary calibration factors;

2) Preliminary data submitted a few months after the campaign completion;

3) Final data submitted 9-12 months after the end of the campaign; and

4) Comparison data submitted as described above but treated separately to enable blind comparisons. A DC3 Comparison Referee will be selected who will process the comparison data according to procedures developed by the DC3 Data Steering Committee, and present them to the DC3 Science Team. This analysis and presentation will be done quickly (particularly for field data) to help instrument PIs detect problems they may have with their instruments or data reduction procedures.

Composite Datasets will be created that will bring together data from different observing networks. The data will be converted to a common format and will undergo uniform quality control. Composites will be made for all three stages of data (field, preliminary, and final).

About one year after the final data has been submitted, they will be made available to the public. This policy is different from the routine EOL data policy, and thus we will request a waiver of that policy for DC3. The data archive will include raw data from individual instruments and platforms, composite datasets including merges of instrument data to common time base(s), as well as other data discussed earlier. Users of the data will be informed about restrictions in the use and publication of data, as developed by the DC3 Data Steering Committee and in accordance with funding agency policies. Text to acknowledge those using DC3 data will be developed and included in the DC3 Data Policy.

DC3 will have comprehensive website that is overseen by a single DC3 Website Manager, with contributions from webmasters from various entities at NCAR, universities, and other institutions. The intent is that from a single virtual location interested parties will be able to access planning documents, preliminary data presentations, data archives, aircraft status, vendor contact information, PI contact information, education and outreach activities, and an array of other links and facts relevant to the campaign including links to all of the facility websites. Parts of the website will be password protected and access restricted, as appropriate.

VI. Acronyms

2D-S –particle imager at 2 orthogonal views

ARCTAS – Arctic Research of the Composition of the Troposphere from Aircraft and Satellites, 2008 (http://www.nasa.gov/mission_pages/arctas/)

ARM – Atmospheric Radiation Measurement network

ARMOR – Advanced Radar for Meteorological and Operational Research, located at Huntsville International Airport (http://nsstc.uah.edu/ARMOR/index.html)

AWAS – Advanced Whole Air Sampler

CALIOP – Cloud-Aerosol LIdar with Orthogonal Polarization aboard the CALIPSO platform

CALIPSO – Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (http://www-calipso.larc.nasa.gov/)

CASA - Center for Collaborative Adaptive Sensing of the Atmosphere

CPI – particle imager at 8-bit gray levels

CRYSTAL-FACE – Cirrus Regional Study of Tropical Anvils and Cirrus Layers – Florida Area Cirrus Experiment, 2002 (http://www.espo.nasa.gov/crystalface/index.html)

CSU-CHILL – Colorado State University advanced transportable dual-polarized S0-band weather radar system (http://www.chill.colostate.edu)

CSU-Pawnee – Colorado State University single-polarization radar system (http://www.chill.colostate.edu)

DFW – Dallas – Ft. Worth International Airport

DIA or DEN – Denver International Airport

DLR – German Aerospace Center (Deuches Zentrum fuer Luft- und Raumfahrt) (www.dlr.de/en/)

DOE – Department of Energy (http://www.energy.gov/)

EOL – NCAR Earth Observing Laboratory (http://www.eol.ucar.edu/)

ESPO – Earth Science Project Office (http://www.espo.nasa.gov/)

EULINOX – European Lightning Nitrogen Oxides Project, 1998 (http://www.pa.op.dlr.de/eulinox/)

FAA – Federal Aviation Administration

FPS – Field Project Services (http://www.eol.ucar.edu/fps.html)

GTCIMS – Georgia Tech Chemical Ionization Mass Spectrometer

HAIS – HIAPER Aircraft Instrumentation Solicitation

HALO – High Altitude and LOng range research aircraft (http://www.halo.dlr.de/)

HARP – HIAPER Atmospheric Radiation Package

HIAPER – High-performance Instrumented Airborne Platform for Environmental Research (http://www.hiaper.ucar.edu)

HSV – Huntsville International Airport (http://www.hsvairport.org)

INTEX-NA – Intercontinental Chemical Transport Experiment – North America (http://www.espo.nasa.gov/intex-na/)

KCYS – NEXRAD radar near Cheyenne, Wyoming

KFTG – NEXRAD radar near Denver, Colorado

KOUN – NSSL NEXRAD radar near Norman, Oklahoma

KTLX – NEXRAD radar near Oklahoma City, Oklahoma

LDAR II – Lightning Detection and Ranging system in the Dallas-Ft. Worth area

LIDAR – Light Detection and Ranging

LMA – Lightning Mapping Array

M3V – Mobile Meteorological Measurements Vehicle

MAX – Mobile Alabama X-band polarimetric radar

MC3E – ARM-GPM Midlatitude Continental Convection Experiment (http://adabs.harvard.edu/abs/2008AGUFM.H41D0907J)

MIPS – Mobile Integrated Profiling System (http://ghrc.msfc.nasa.gov:5721/dataset_documents/c4gmipwp_dataset.html)

MSFC – Marshall Space Flight Center (http://www.nasa.gov/centers/marshall/home/index.html)

MTP – Microwave Temperature Profiler (http://mtp.jpl.nasa.gov)

NASA – National Aeronautics and Space Administration (http://www.nasa.gov)

NCAR – National Center for Atmospheric Research (http://www.ncar.ucar.edu/)

NEXRAD – Next Generation Radar network operated by National Weather Service, technically termed WSR-88D (http://www.roc.noaa.gov/)

NLDN – National Lightning Detection Network (http://www.lightningstorm.com/)

NOAA – National Oceanic and Atmospheric Administration (http://www.noaa.gov/)

NPOESS – National Polar-orbiting Operational Environmental Satellite System (http://www.ipo.noaa.gov/)

NSF – National Science Foundation (http://www.nsf.gov)

NSSL – National Severe Storms Laboratory operated by NOAA (http://www.nssl.noaa.gov)

NWS – National Weather Service (http://www.weather.gov/)

OCO – Orbiting Carbon Observatory satellite (http://oco.jpl.nasa.gov/)

OCS – Oklahoma Climatological Survey (http://climate.ok.gov/)

OKLMA – Oklahoma Lightning Mapping Array network (http://www.nssl.noaa.gov/observations/ltmap.php)

OU – University of Oklahoma;

PAR – Phased Array Radar located near Norman, Oklahoma

PEM-Tropics B – Pacific Exploratory Mission in the Tropics Phase B (http://www-gte.larc.nasa.gov/pem/pemtb_hmpg.htm)

QCLSH – Quantum Cascade Laser Spectrometer for HIAPER

RAF – NCAR/EOL's Research Aviation Facility (http://www.eol.ucar.edu/about/our-organization/raf)

RDCC – Real-time Display and Coordination Center (http://www.eol.ucar.edu/rdp/services/RDCC_whitepaper.htm)

SID-2H – Small Ice Detector, Version 2

SMART-R – Shared Mobile Atmospheric Research and Teaching Radar (http://www.nssl.noaa.gov/smartradars/)

START08 – Stratosphere-Troposphere Analysis of Regional Transport, 2008 (http://www.acd.ucar.edu/start/)

STERAO – Stratosphere-Troposphere Experiments: Radiation, Aerosols and Ozone, 1996 (http://box.mmm.ucar.edu/science/sterao/sterao.html)

TOGA – Trace Organic Gas Analyzer

TRACE-P – TRAnsport and Chemical Evolution over the Pacific,2001 (http://hyperion.gsfc.nasa.gov/Missions/TRACEP)

UAH – University of Alabama, Huntsville

WSR-88D – Weather Surveillance Radar, 1988, Doppler; the technical name for NEXRAD network

VII. Figures

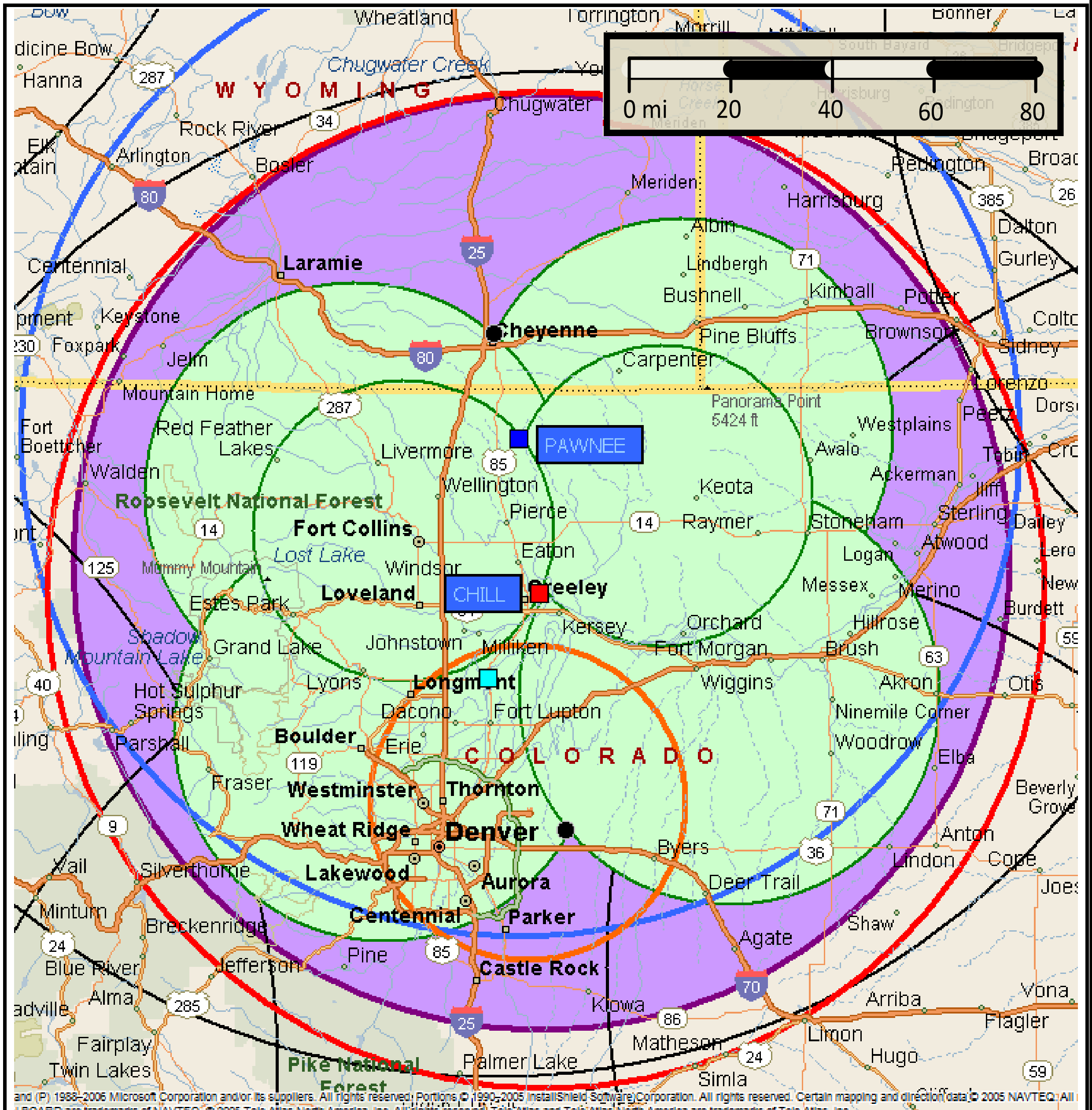

Figure 1. Ground based facilities for DC3 in northeastern Colorado. Radar coverage is provided by the CSU-CHILL facility near Greeley (red square), the PAWNEE radar (blue square), and the NEXRAD radars near Denver and Cheyenne (black circles). The polarimetric coverage for CHILL is indicated by the red circle and the non-polarimetric coverage for PAWNEE is indicated by the blue circle. Dual-Doppler coverage by combinations of these radars is shown by the filled green circles. The filled purple circle shows the coverage of the lightning mapping array network. The orange circle shows the Class B controlled airspace for Denver International Airport. The NOAA facility at Platteville is indicated by the light blue square.

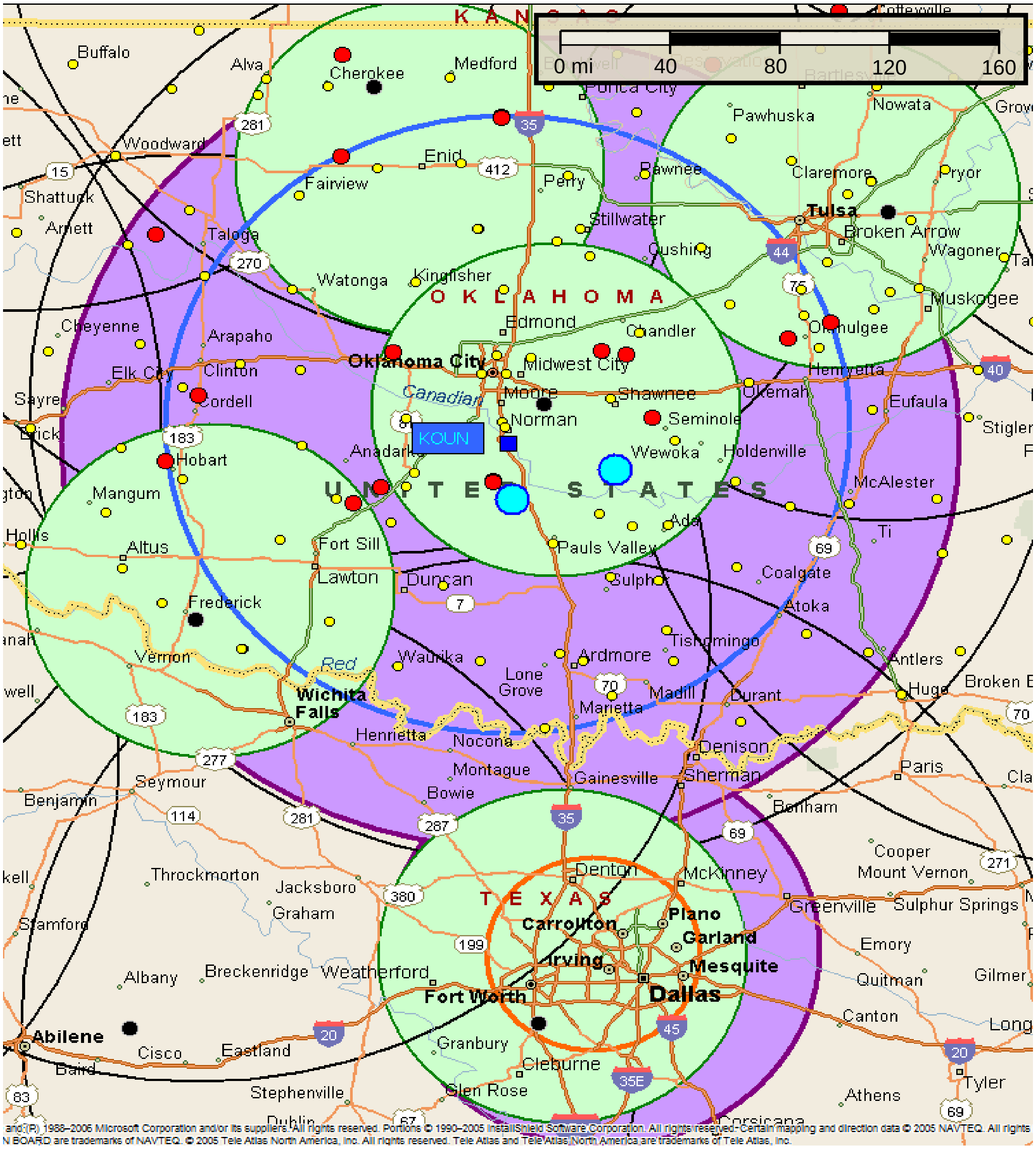

Figure 2. Map of fixed facilities available to DC3 in Oklahoma. The blue circle delineates the region for polarimetric radar measurements by the KOUN radar in Norman (blue square), where the fast-scanning phased array radar (PAR) also is located. The purple circles are the regions of three-dimensional lightning mapping possible by supplementing the OKLMA and the LDARII in northern Texas fixed arrays with mobile lightning mapping stations. Black circles show the extent of short range base reflectivity products for the WSR-88D NEXRAD radars, whose locations are shown by small black-filled circles. The small light green circles show the region of dual-Doppler coverage when one mobile radar (SMART-R) is paired with a NEXRAD radar. Supplementing with two mobile radars (preferred) extends coverage throughout the study region. An example configuration of two SMART-Rs is shown by the teal circles. The two mobile radars would be moved to provide optimum dual-Doppler coverage while overlapping with the polarimetric coverage of KOUN. Small red-filled circles show ARM sites, some of which are configured with instruments of value to DC3. Yellow filled circles are Oklahoma Mesonet sites. The orange circle is the Dallas-Ft. Worth Airport Class B controlled airspace.

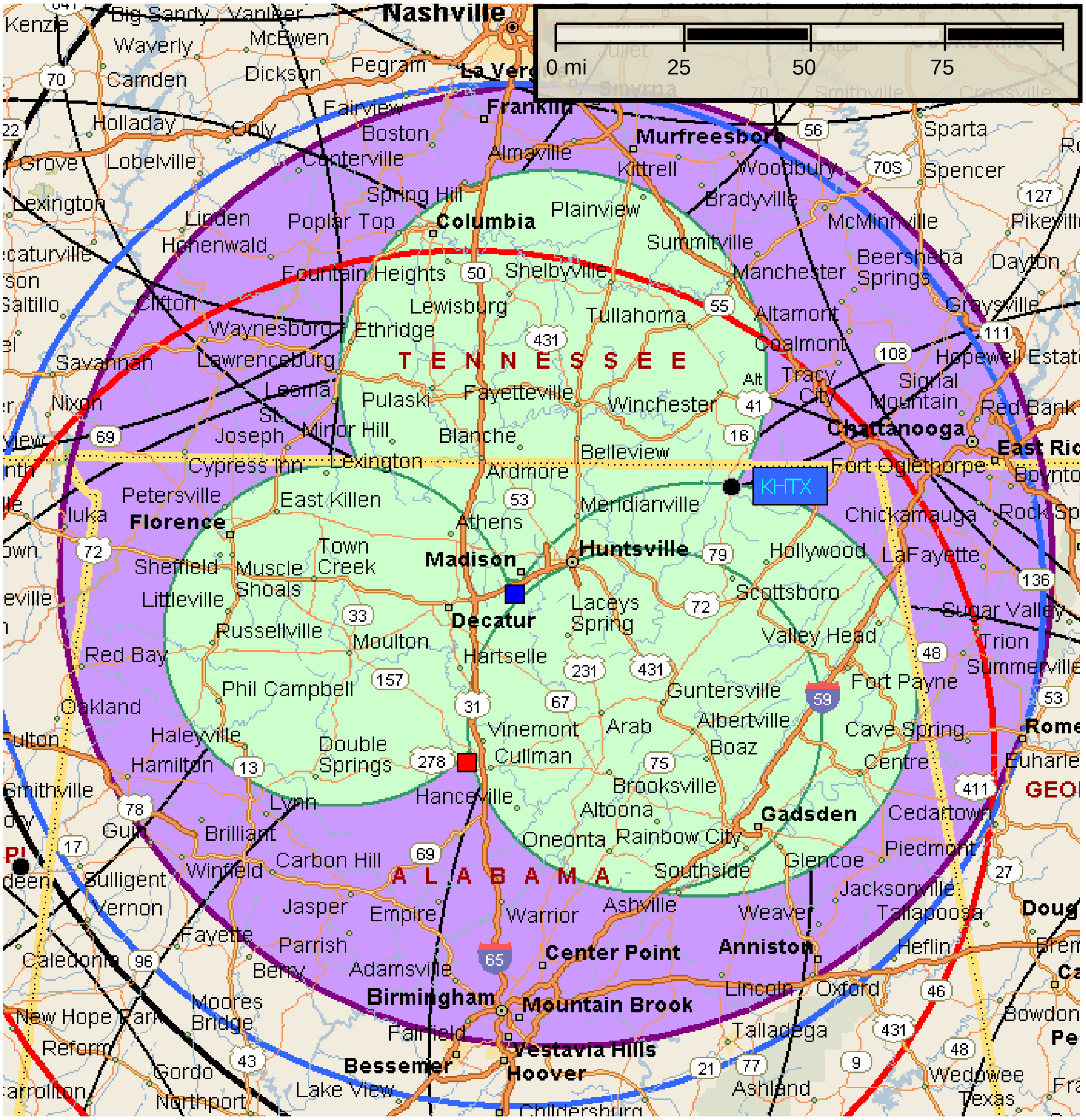

Figure 3. Map of fixed facilities available for DC3 in northern Alabama. The blue circle shows the range of polarimetric measurements by the ARMOR radar (blue square). The red circle shows the range for the mobile MAX radar (red square in this example). These two radars combined with the KHTX NEXRAD radar northeast of Huntsville (black filled circle) provide dual Doppler cover over the green region shown. The filled purple circle shows the range of the lightning mapping array. The black filled circles show other NEXRAD radars in the region with their base reflectivity shown in black circles.

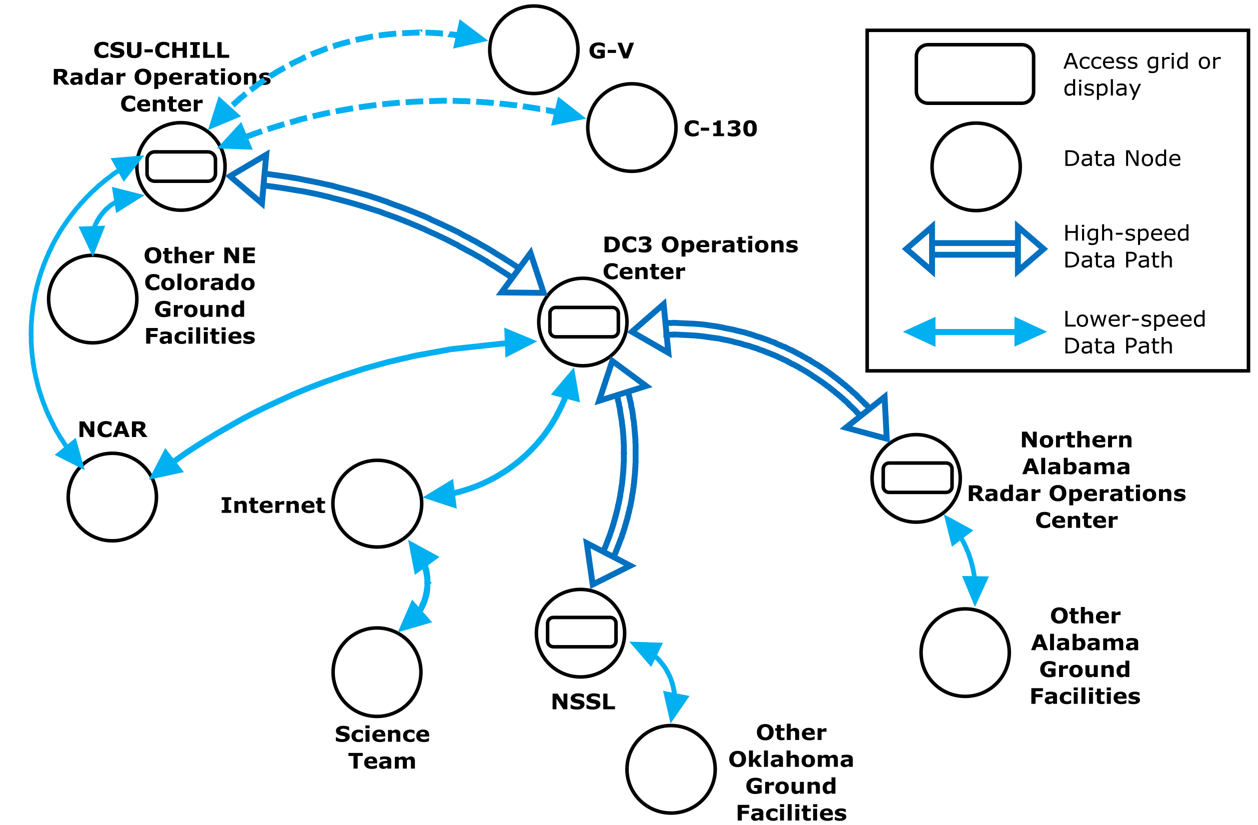

Figure 4. Schematic diagram of data and communications pathways for DC3. Communication pathways to and from aircraft are linked to the regional radar operations center (shown as an example for NE Colorado).

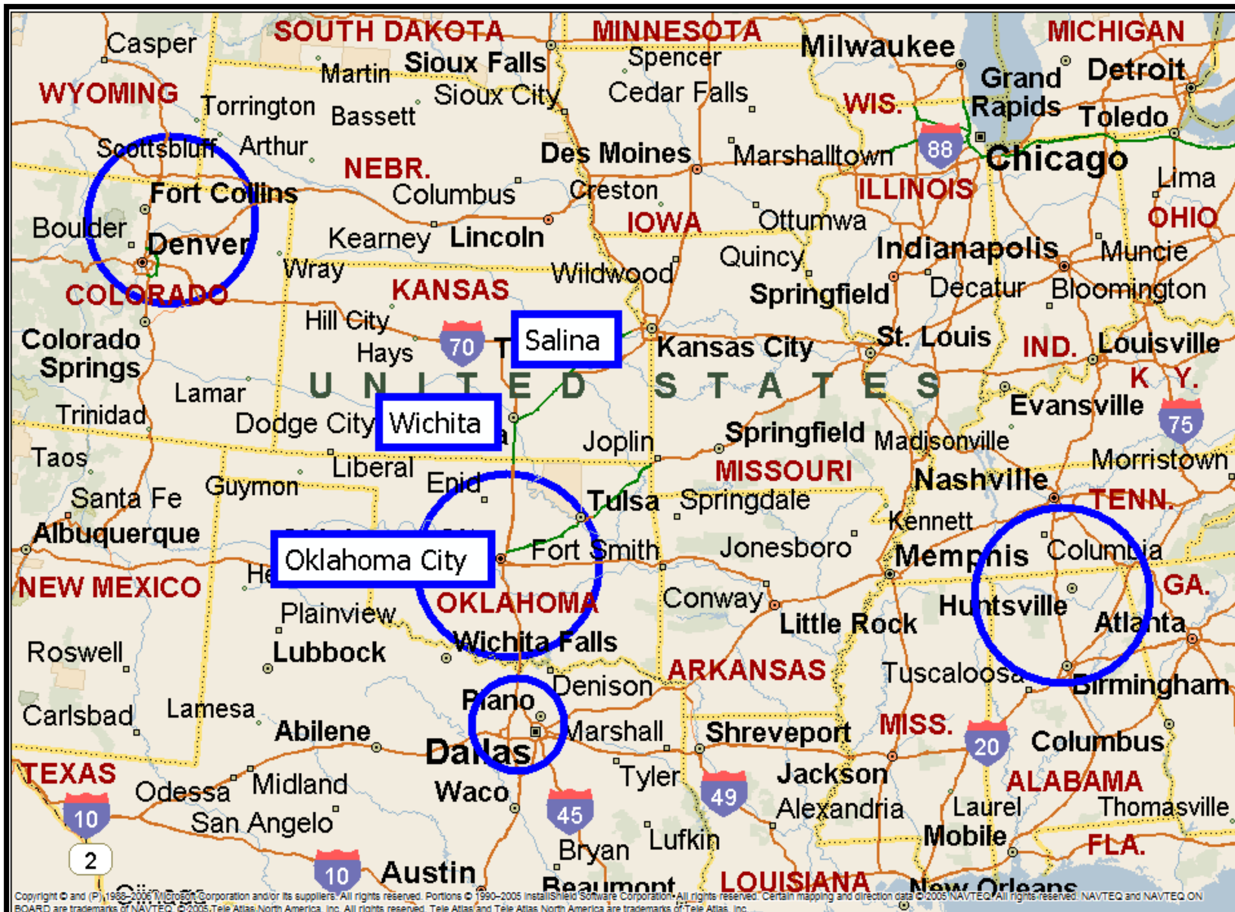

Figure 5. Airports that could serve as bases of operation for DC3 (Salina, Wichita, Oklahoma City). The proposed study areas for which there is coverage by the ground-based facilities are encircled.

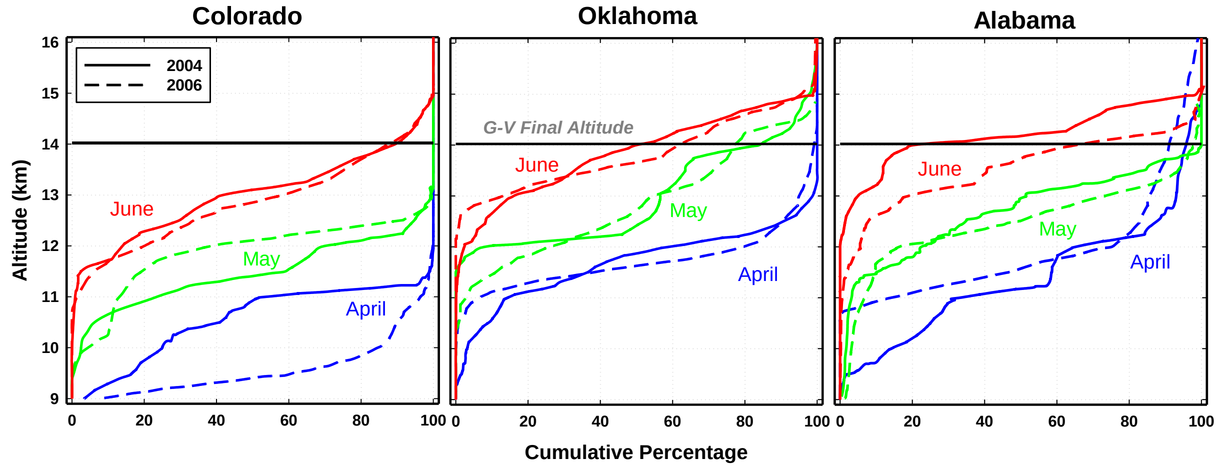

Figure 6. Tropopause heights observed in conjunction with lightning flashes from the analysis of Owen Cooper (Cooper, 2007) during April (blue), May (green) and June (red) for 2004 (solid lines) and 2006 (dashed lines). Cumulative probabilities are shown as a function of altitude for the three proposed DC3 study regions. The estimated final altitude of the fully configured G-V aircraft is shown for comparison.

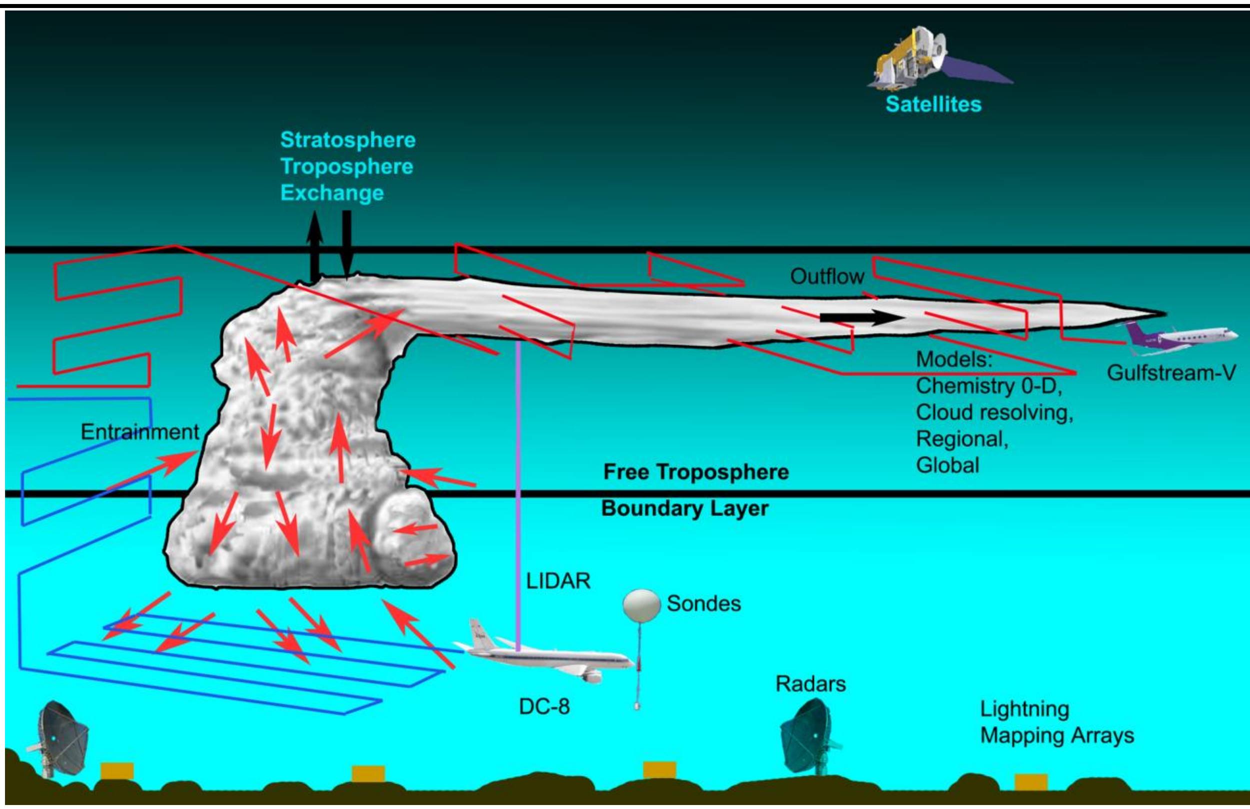

Figure 7. Schematic diagram of DC3 facilities and their relation to a generic deep convective storm.

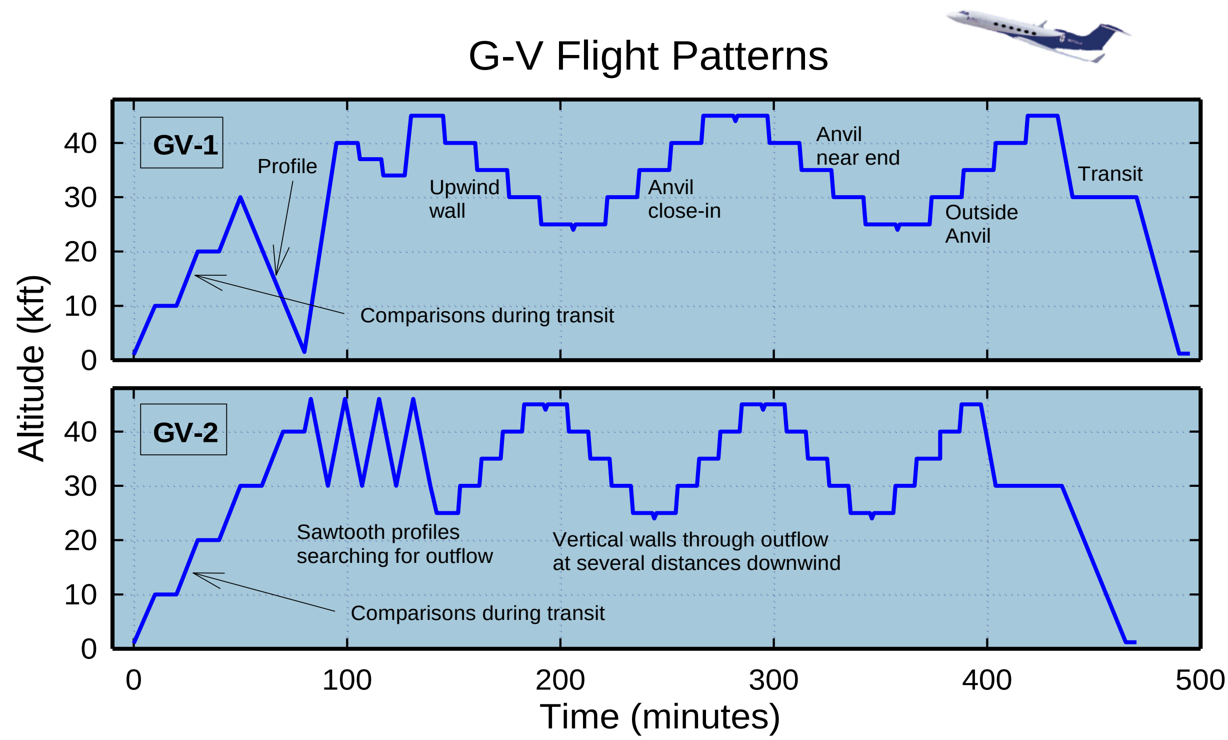

Figure 8. Typical flight patterns proposed for the G-V platform.

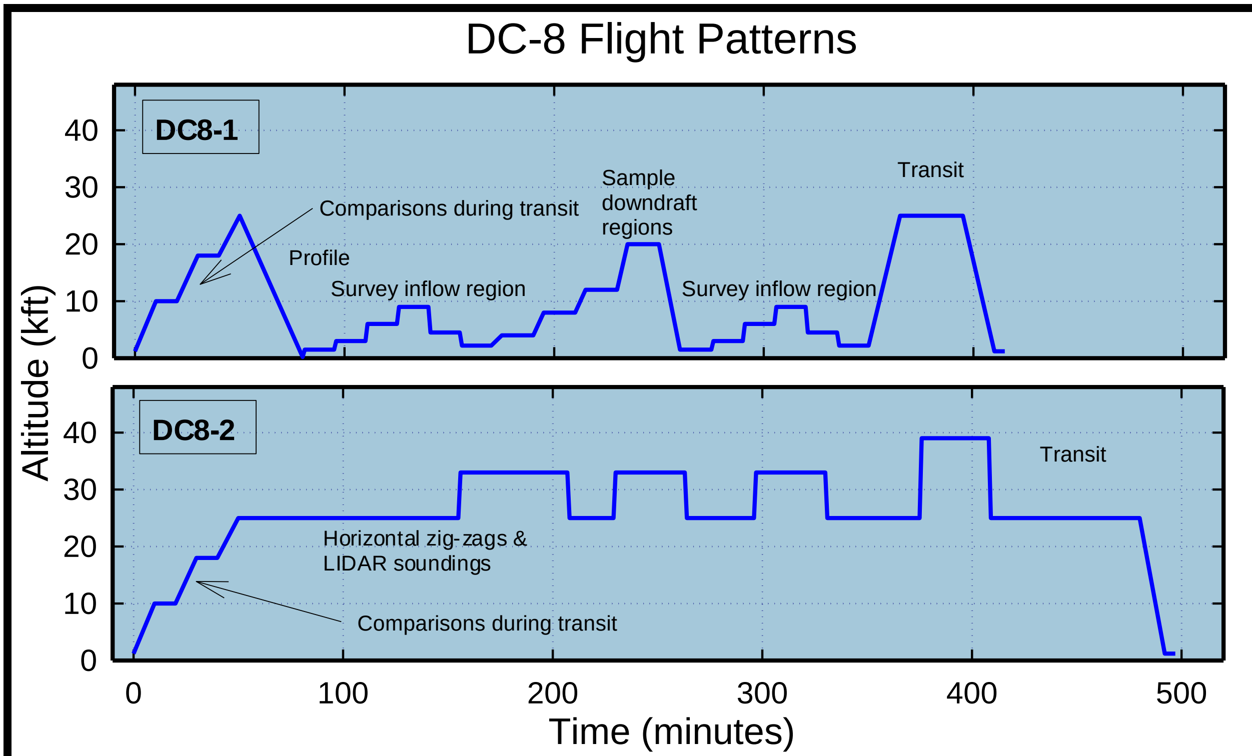

Figure 9. Typical flight patterns proposed for the DC-8 aircraft.

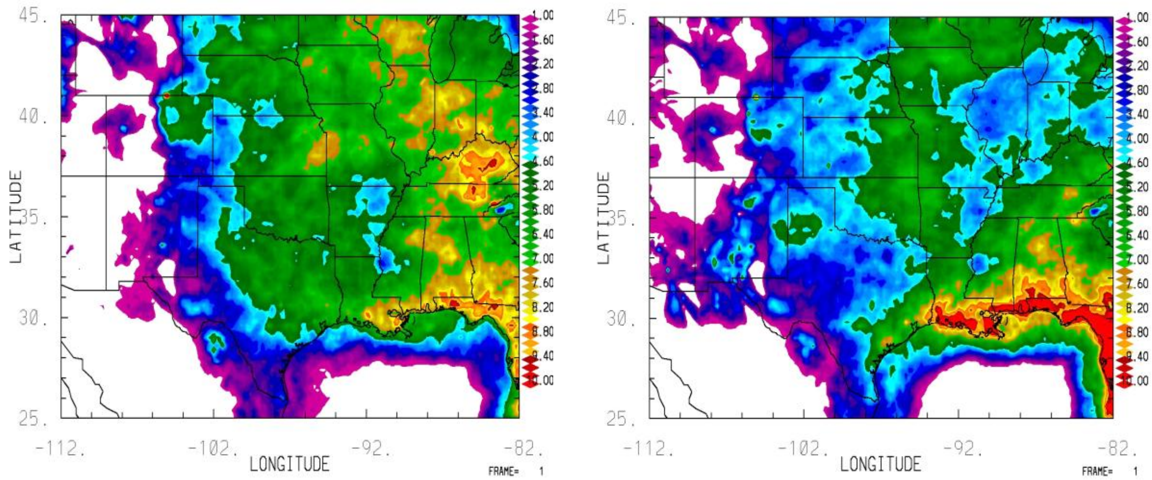

Figure 10. Percent of time (color scale, purple = 1% and red=10%) that rainfall is present during June 1-15 (left panel) and June 16-30 (right panel) as a climatological average over the years 1996-2005.

VIII. Tables

Table 1a. Conceptual Timeline for Decision-making and facility activity during DC3 related to Goal 1 (study of active deep convection)

Facility or Activity	DD1-2 days	DD1-1 day		*Day of Deployment-Goal 1 (DD1)			
	0-24 hrs	0-12	12-24	0-6	6-12	12-18	18-24
Model Forecasts							
Radar observations							
Lightning observations							
G-V instrument warmup							
G-V deployment							
DC-8 instrument warmup							
DC-8 deployment							
Sondes							
PI assessment							

* storm suitable for study from 1500-2000 hours on DD.
[#] daylight from about 0500-1900 hours.
+ colored regions indicate times of facility operation or other activity

Table 1b. Conceptual Timeline for Decision-making and facility activity during DC3 related to Goal 2 (study of evolution of outflow)

Facility or Data	DD2-1		*Day of Deployment-Goal 2 (DD2)			
	0-12 hrs	12-24 hrs	0-6	6-12	12-18	18-24
Model Forecasts						
Radar observations						
Lightning observations						
G-V instrument warmup						
G-V deployment						
DC-8 instrument warmup						
DC-8 deployment						
Sondes						
PI assessment						

* Storm studied on DD2-1 or DD2-2

Table 2. Ground-based platforms and facilities to be used in DC3.

Facility	Product	Sponsor	Required for Goals:
NE Colorado			
CSU-CHILL, Pawnee, NEXRAD radars	Winds, precipitation, hydrometeor identification	♦NSF, NOAA	1
3-D lightning mapping array (LMA) (fixed and mobile)	Lightning location, geometry	NSF	1
Sondes & profiling (MISS)	T, P, RH	NSF	1
Rainwater samples	Rainwater composition	NSF	1
NOAA Platteville observations	Rainfall, wind profiles	NOAA	1
Mobile hail & rainwater collector	Hydrometeor amount and composition	NCAR	1
Central Oklahoma			
Oklahoma LMA (plus mobile)	Lightning location, geometry	OU, NSSL	1
KOUN, PAR, NEXRAD, SMART-R and X-band mobile radars	Wind, precipitation, hydrometeor identification	OU, NSSL, NOAA	1
Sondes	Winds, T, P, RH, electric field, precipitation	NSSL, NSF	1
ARM sites	Solar radiation, wind profiles, CO_2 flux, aerosols, cloud properties, aerosol profiles, surface winds, sondes	DOE	1
Oklahoma Mesonet	Wind field & thermodynamic grid	OCS	1
Rainwater samples	Rainwater composition	NSF	1
Northern Alabama			
Radars (ARMOR, KHTX, MAX, Redstone)	Winds, precipitation, hydrometeor identification	UAH, NASA, NOAA, Redstone	1
MIPS mobile	Wind profiles, water vapor, cloud water, virtual T, electric field	UAH	1
Sondes	Winds, T, P, RH, O_3, precipitation	UAH, Redstone, NSF	1
M3V vehicle	Surface meteorology, rain water samples	UAH	
Mobile sounding unit	Winds, T, P, RH, O_3, electric field, precipitation	UAH (Redstone), NSF	1
Rainwater samples	Rainwater composition	NSF	1
Alabama LMA (plus mobile)	Lightning location, geometry	NASA-MSFC	1
Northern Alabama Electric Field Change Network	Lightning physics, energetics	UAH	1

♦ Sponsor acronyms: NSF: National Science Foundation; NOAA: National Oceanic and Atmospheric Administration; NCAR: National Center for Atmospheric Research; OU: University of Oklahoma; NSSL: National Severe Storms Laboratory; DOE: Department of Energy; OCS: Oklahoma Climatological Survey; UAH: University of Alabama-Huntsville; MSFC: Marshall Space Flight Center.

Table 3. Summary of airborne platforms and flights hours for DC3.

Scenario	Aircraft #1	Flight Hours	Aircraft #2	Flight Hours
~~1~~	~~NSF/NCAR G-V~~	~~143*~~	~~NSF/NCAR C-130~~	~~122#~~
2	**NSF/NCAR G-V**	**143***	**NASA DC-8**	**143***
Pre-Test & Practice Flights (mid-2011)		20		20
Test Flights (Late April-early May 2012)		20		20

* For type 1 flights, 7.5 hours on station and transit times for 4 flights to each study region (12 flights total). Outflow evolution flights are assumed 7.5 hours each (6 flights). In addition, the G-V will fly 1 flight (8 hours) to the Gulf of Mexico region to evaluate seasonal ozone changes.

~~# For type 1 flights, 7.5 hours on station and transit times for 4 flights to each study region (12 flights total). Participation in 4 outflow evolution studies (8 hours each).~~

Table 4. High priority measurements and RAF required payload items for the G-V during DC3.

Instrument/ Species	Possible PI	Method	☼ Avail-able	♦ G-V Rcks	Oper-ators Reqd	Estd Wgt (lbs)	Inlet re-quired ?	Re-quired for Goals:
RAF ADS	--	--	A	1	1	90	N	All
RAF Routine (winds, T, CN, DP, diff GPS)	--	various	A	0.25	0	200	Y	All
Mission Scientist	C. Cantrell, NCAR	--	-	0.1	1	10	N	--
Mission Coordinator	RAF, NCAR	--	-	0.5	1	90	N	--
CH_4, CO_2, H_2O	F. Flocke, NCAR	PICARRO	UC	0.5		100	Y	1,2
CO	T. Campos, NCAR	UV fluor	A			100	Y	1,2
NO, NO_2	A. Weinheimer, NCAR	CL $^{\Delta}$	A	2.0		471	Y	1,2
Fast O_3	T. Campos, NCAR	CL	A			100	Y	1,2
HNO_3, HNO_4, SO_2, BrO	G. Huey, GA Tech	GTCIMS $^{\Delta}$	HAIS-UC	1		396	Y	1,2
OH, H_2SO_4,HO_2,RO_2	C. Cantrell, NCAR L. Mauldin, NCAR	HOxCIMS	UC	0.1		600	wing-pod	1,2
H_2O vapor	T. Campos, NCAR M. Zondlo, Princeton	VCSEL	HAIS	0		12	N	1,2
H_2O vapor	T. Campos, NCAR	TDL	A	0		30	N	1,2
H_2CO, HCOOH	A. Fried, NCAR	DFGAS $^{\Delta}$	UC	1		400	Y	1,2
Actinic radiation	S. Hall, NCAR	HARP	HAIS	0.5	3	50	N	1,2
Peroxides	D. O'Sullivan, USNA B. Heikes, URI	P-CIMS	UC	0.5		300	Y	1,2
NMHCs, OVOCs	E. Apel, NCAR	TOGA	HAIS-UC	1.0		350	Y	1,2
Total H_2O	Linnea Avallone, CU	CLH	A	0		21	wing-pod	1
Cloud particle size distributions	D. Rogers, NCAR A. Heymsfield, NCAR	3VCPI	A	0.5		786	wing-pod	1
		CDP	A	0.1				
		2D-C	A	0				
		SID2H	A	0.1				
Aerosol particle size distributions	D. Rogers, NCAR J. Smith, NCAR	UHSAS	A	0.1		100	wing-pod	1,2
		SMPS	UC	0.25		100	Y	
Totals				**9.5**	**6**	**4306**		
Maxima				16		8300		

☼ Availability acronyms: A = available or will soon be available; HAIS = available or to be available under the HAIS program; UC = under construction; P = proposed, NA = nothing currently available or proposed.

♦ The sum of G-V racks and operators with a seat cannot exceed 16 (instruments in wing pods not counted in this total, but are included in weight total estimates).

$^{\Delta}$ Instrument includes an external pump or cylinder.

Table 4b. Other instruments "Desired but Optional" for the G-V during DC3.

Priority	Instrument/ Species	Possible PI	Method	☼ Avail-able	♦ G-V Rcks	Opera-tor re-quired	Estd Wgt (lbs)	Inlet re-quired ?	Contri-butes to Goals:
1	Photometric O_3	P. Romashkin, NCAR	UV abs.	UC	0.25		50	Y	1,2
	NOAA photometric O_3	R. Gao, NOAA	UV abs.	A	0.25		50	Y	1,2
2	Cloud Radar	J. Vivekanandan, NCAR	HCR	HAIS, UC	0.45		300	N	1
3	Cloud condensate mass & particle resi-duals	TBD	CVI	A	0.9	1	300	Y	1
4	NMHCs, other trcrs	E. Atlas, Miami	AWAS	HAIS	1		271	Y	1,2
5	Irradiance	S. Schmidt, CU	HARP	A	0.5		100	N	
6	Microwave Temper-ature Profiler	J. Haggarty, NCAR	MTP	HAIS	0.25		50	N	1
	Totals				**3.6**	**1**	**1121**		

Table 5. Priority of species and parameters to be measured aboard the NASA DC-8 during DC3.

Required Measurements	Desired Measurements	Useful Measurements
Gas Phase In Situ Species		
O_3, H_2O, CO, CO2, NO, $OH/HO_2/RO_2$, HCHO, H_2O_2, CH_3OOH, NMHCs, OVOCs	BrO, halocarbons, NO_y, CH_4, NO_2, HNO_3, PANs, HO_2NO_2, HCN, CH_3CN, SO_2	N_2O, HOBr, ClO, HOCl, $RONO_2$, NH_3, organic Acids, speciated mercury
Aerosol and Cloud In Situ		
Aerosol number, aerosol size distribution, optical properties (scattering/absorption, aerosol hygroscopicity, f(RH), aerosol composition, inorganic, aerosol composition, organic, CCN, aerosol composition, BC, condensed water content	Aerosol gravimetric mass, Size-resolved aerosol composition, Hydrometer size distribution	Aerosol volatility, cloud water chemistry, radionuclides (Rn222, Be7, Pb210)
Remote Sensing and Radiation		
UV spectral actinic flux, O_3 lidar (nadir/zenith), hyperspectral solar flux, broadband flux (Nadir/Zenith Solar and IR), multi-spectral optical depth profiles, aerosol extinction profile (nadir/zenith), aerosol backscatter (nadir/zenith), aerosol depolarization (nadir/zenith)	Multi-wavelength imager for combined land, ocean and cloud use	Multi-angle, multi-wavelength, polarized radiances
Meteorology		
Vertical State	Vertical Wind, SST	

Section I of SPO (facility cost estimates)

Estimates of the costs of the DC3 facilities and the various agencies and programs expected to be supposed those facilities are shown in Table 6.

Table 6. Preliminary cost estimates for DC3 facilities (January 2009).

	Agency/Program Costs (thousands $)						
Facility	**NSF ATM Depl. Pool**	**NSF/ ATC**	**NSF/ PDM**	**NCAR**	**NASA/ TCP**	**UAH**	**NOAA**
Gulfstream V	820						
DC-8					2000		
UND Citation			*425*				
DOE G-1							
DLR HALO							
UK BAe-146							
CSU-CHILL, CSU-Pawnee	15						
MISS	40						
CO LMA			325				
CO hail/rain collector				20			
OK SMART-Rs			52				
Oklahoma mobile LMA			50				
OK sondes			127				
AL radars (MAX, ARMOR)			32			30	
AL Lightning obs.			30				
AL sondes, LIDAR			166				46
AL MIPS profiler			46				
Subtotals	**855**	**0**	**1041**	**20**	**2000**	**30**	**46**
Field Project Support (EOL)		300-600					
ESPO		X					

* Items in italics add value but not required for DC3 goals. If funding source not listed, they will come with their own funding. "X" indicates amount unknown.

Section J of SPO (partial - potential investigators and cost estimates)

Table 7. Summary of Potential Investors for DC3 and estimated costs in addition to facility costs shown in Table 6 (January 2009).

	Agency/Program Costs (thousands $)								
Principal Investigator	NSF		NCAR			NASA	NOAA	UAH	Vaisala
	ATC	PDM	ACD	MMM	EOL				
S. Rutledge (CSU)		630							
P. Krehbiel (NMIMT)									
D. MacGorman (OU)		580					250		
M. Biggerstaff (OU)		600							
W. Peterson (MSFC)						X*			
L. Carey (UAH)		360							
K. Knupp (UAH)		X					X		
H. Christian (UAH)		360							
M. Newchurch / O. Cooper (UAH / NOAA,CU)	166						X	X	
N. Demetriades (Vaisala)									X
J. Collett (CSU)		450							
M Zondlo (Princeton)	250								
A. Weinheimer (NCAR)									
F. Flocke (NCAR)			125						
G. Huey/D. Tanner (GT)	420								
C. Cantrell (NCAR)			500						
E. Atlas (U-Miami)	670								
D. Blake (UCI)	550								
E. Apel (NCAR)			350						
S. Hall (NCAR)			600						
A. Fried (NCAR)					X				
D. O'Sullivan (USNA)	685								
B. Heikes (URI)	300								
W. Brune (PSU)	550								
J. Hair/S. Ismail (NASA)	474					247			
D. Rogers (NCAR)					X				
J. Helsdon (SDSMT)	*600*								
A. Heymsfield (NCAR)				X					
M. Weisman (NCAR)				X					
O. Cooper (CU)									
K. Pickering (NASA)						X			
L. Pan (NCAR)			X						
J. Stith (NCAR)					X				
L. Emmons (NCAR)			X						
G. Mullendore (UND)		33							
Totals	**4665**	**2980**	**1575**	**0**	**0**	**247**	**250**	**0**	**0**

* "X" indicates amount unknown.

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