VORTEX2 2009–2010

Second Verification of the Origins of Rotation in Tornadoes Experiment

Operations Plan

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Chapter 1

Experiment overview

1.1 Introduction

The Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) is a multi-agency field program to investigate tornado genesis, maintenance, and demise; tornado structure and near-ground winds; relationships between tornadic storms and their environments; and numerical prediction of supercells and tornadoes. The first field phase of VORTEX occurred in 1994 and 1995 (`www.eol.ucar.edu/projects/vortex` and `www.eol.ucar.edu/projects/vortex95`). The second field phase of VORTEX—*VORTEX2*—will occur in the United States Great Plains region (Fig. 1.1) during spring of 2009 and 2010. The field experiment will be conducted with mobile facilities, without a "home base" per se. This "fully mobile" strategy is necessary to obtain the needed high-resolution observations in the limited time available for the field phase. VORTEX2 will also benefit from data collection by the fixed observing network in the Great Plains, particularly the rich observing network in Oklahoma.

The VORTEX2 field phases will occur **10 May–13 June 2009** and **1 May–15 June 2010**. The selected time period for operations tends to cover the part of the spring storm season that has slower-moving storms, thereby presenting a better opportunity to obtain the high-resolution observations needed in support of the science objectives summarized in section 1.3.

The observational domain for VORTEX2 (Fig. 1.1) is restricted to those areas in "Tornado Alley" with favorable terrain, road availability, and land use to enable mobility as well as unobstructed radar and visual viewing from vantage points on the ground. Both the anticipated weather and logistical constraints will determine where within the large domain that VORTEX2 field teams operate on a given day. When choosing target areas, the value of the extensive network of stationary instrumentation in central Oklahoma, including the NWRT Multifunction Phased Array Radar, the KOUN dual-polarization radar, and the CASA radar network will be considered. In addition, the value of observations above the surface provided by Unmanned Aircraft Systems (UAS) will be considered; UAS operations/testing is likely to occur in eastern CO, northwestern KS, and southwestern NE. All else being equal, operations will be preferred in these central Oklahoma and High Plains subdomains (shaded in green and purple in Fig. 1.1).

Our experience shows that full mobility is essential because, in any given year, the large-scale pattern tends to favor smaller regions for repeated supercell activity. For example, some years have frequent supercell activity on the dryline in western Texas, whereas other years have activity focused in the central Plains. Sometimes, several-day episodes of supercells shift from one part of the Plains to another. The overall cost of the experiment is probably less than that for an experiment of comparable duration having a fixed home base, because travel miles (vehicle wear, fuel expenses, and participant fatigue) will be reduced compared to the previous paradigm in which long ferries to and from a base site occurred frequently.

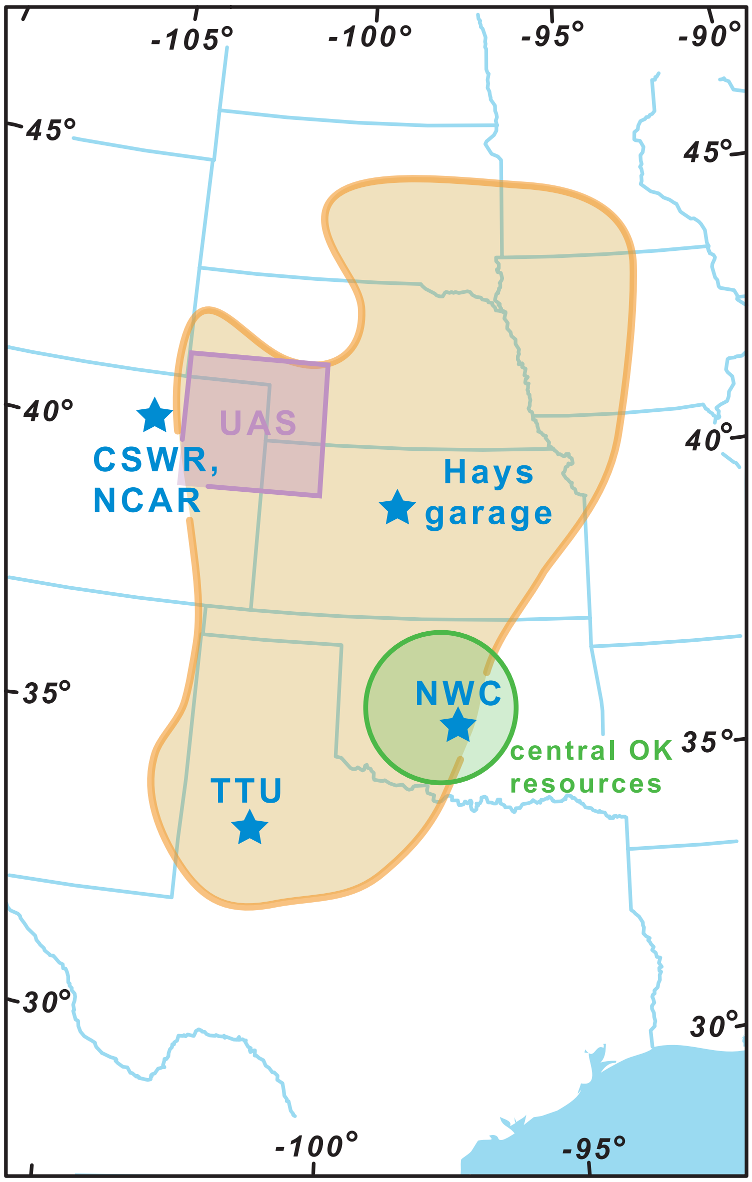

Figure 1.1. VORTEX2 domain (red outline) and other key locations: subdomain of central Oklahoma resources (including the NWRT Multifunction Phased Array Radar); National Weather Center (NWC, including National Severe Storms Laboratory and University of Oklahoma); Lubbock, Texas (Texas Tech University); rented garage in Hays, Kansas; UAS demonstration subdomain; and Boulder, Colorado (Center for Severe Weather Research, National Center for Atmospheric Research, and University of Colorado).

1.2 Instrumentation overview

VORTEX2 will send approximately 40 vehicles to the field. Classes of instruments that will be available are summarized below. More details about the instruments are provided in Appendix B.

Mobile radars:

- Shared Mobile Atmospheric Research and Teaching (SMART) Radar 1: C-band / 5 cm
- SMART Radar 2: C-band / 5 cm
- Doppler on Wheels 6 (DOW6): X-band / 3 cm
- DOW7: X-band / 3 cm
- Rapid-Scan DOW (DOW5): X-band / 3 cm, 6 simultaneous beams
- CIRPAS MWR-05XP: X-band (3 cm), phased array
- NSSL and OU X-band (3 cm) dual-polarization (NOXP) radar
- University of Massachusetts X-band (3 cm) dual-polarization radar
- University of Massachusetts W-band (3 mm) radar: 0.2° beamwidth
- Texas Tech University Ka-band radar (TTU-Ka): 1 cm, 0.5° beamwidth

Surface observing systems:

- mobile mesonet (6 or 7 vehicles)
- StickNet, a rapidly-deployable surface sensor network (24 probes)
- tornado in situ pods (12)
- OTT Parsivel laser disdrometers (4)
- 2DP video particle probes (2)

Tropospheric in situ observing systems:

- Mobile GPS Advanced Upper Air Systems (MGAUS) (4 systems nominally, 5 systems 25 May–9 June 2009)
- Unmanned Aircraft Systems (UAS)

Photography:

- digital single-lens reflex (DSLR) cameras
- HD video cameras

In addition, the rich observing network in Oklahoma will benefit VORTEX2 research significantly. The resources that are available in and near Oklahoma include the following:

- NWRT Multifunction Phased Array Radar (MPAR)
- KOUN† and KICT dual-polarization radars
- Collaborative Adaptive Sampling of the Atmosphere (CASA) radar network
- WSR-88D network (specifically the KTLX, KFDR, KVNX, and KINX sites)
- Oklahoma City Terminal Doppler Weather Radar (TDWR)
- Oklahoma Mesonet
- NOAA wind profilers
- Atmospheric Radiation Measurement (ARM) observing systems.

†The KOUN radar is scheduled to be down (unavailable) for retrofit and new dual-polarization upgrade throughout the period of 2009 VORTEX2 operations. If the current schedule holds, both the KOUN and KICT radars will be upgraded to have dual-polarization capability before VORTEX2 operations in 2010. Beta testing with this new capability is currently (as of March 2009) scheduled for 15 April–9 July 2010.

1.3 Scientific objectives

The primary target of the VORTEX2 observing facilities will be supercell thunderstorms. Most strong tornadoes (EF2–EF3) and virtually all violent tornadoes (EF4–EF5), which account for a disproportionate fraction of tornado damage and casualties, are associated with supercell thunderstorms. Although it is recognized that many tornadoes are associated with nonsupercellular parent convection, nonsupercell tornadogenesis intercepts will only be attempted on a "target-of-opportunity" basis, i.e., when such an event appears imminent and VORTEX2 facilities are at relatively close range.

The scientific objectives of VORTEX2 are discussed in detail in the separate Scientific Program Overview (SPO, available at `www.eol.ucar.edu/projects/vortex2/documents/index.html`). To summarize briefly here, the VORTEX2 **tornadogenesis focus** encompasses scientific objectives regarding processes of vorticity generation, redistribution, and amplification. Vorticity with a quasi-horizontal orientation is generated through the action of buoyancy gradients and synoptic-scale processes (environmental vorticity). When possible, VORTEX2 will observe vorticity generation by buoyancy gradients associated with mesoscale boundaries independent of the supercell and produce comprehensive documentation of the distribution of vorticity in the boundary layer during the pre-storm and storm stages. The vorticity will be characterized through observations obtained by mobile and fixed Doppler radars. Buoyancy gradients will be quantified by targeted mobile soundings, surface observations (mobile mesonet, StickNet, and fixed surface networks), and (when possible) UAS traverses.

Much larger buoyancy gradients typify supercell storms, where updraft cores can sometimes be more than 10°C warmer than the storm environment, and cool and hydrometeor-laden downdrafts can have effective negative buoyancy just as large. he buoyancy contrasts are associated with localized shading by the thunderstorm anvil, storm-generated boundaries in and near clouds and precipitation owing to precipitation loading, warming by condensation/freezing, and cooling by evaporation/sublimation. These intra-storm buoyancy gradients will be studied using targeted soundings, the mobile mesonet, the StickNet, and (when possible) UAS transects. Microphysical observations, which are necessary to estimate variations in buoyancy owing to precipitation loading and phase change, will be obtained by mobile and deployable disdrometers and particle probes, as well as inferred from mobile dual-polarization radar. Dual-polarization radar also will be useful for studying rear-flank descending precipitation cores, which in some cases appear to serve as catalysts in the tornadogenesis process.

Vertical-velocity gradients and convergence are responsible for reorienting horizontal vorticity into the vertical and for amplifying vertical vorticity, respectively. Both updrafts and downdrafts are involved in the reorientation and amplification of vorticity, and rear-flank downdrafts, gust fronts, and updrafts near the ground are believed to be particularly important. VORTEX2 will observe the wind field throughout the depth of the target storm, with particular emphasis near the ground at spatial intervals of O(100 m) and temporal intervals of O(1 min). Such resolution was not attainable during VORTEX1 due to the lack of mobile, ground-based radars. Because some VORTEX2 hypotheses concerning why tornadoes do or do not develop within the mesocyclone involve relative buoyancy in the low-level mesocyclone, these radar observations will be complemented with thermodynamic observations obtained by surface probes deployed directly in the path of mesocyclones and tornadoes.

The second VORTEX2 focus, on **near-ground winds in tornadoes**, concerns profiles of radial, tangential, and vertical motion in a variety of tornadoes (strong vs. weak, wide vs. narrow, single vortex vs. multiple vortex) and relationships between damage and wind speed, acceleration, and duration. The challenge of obtaining wind measurements in the lowest few tens of meters AGL will be met through “targets of opportunity,” in which tornadoes cross or pass near roads where narrow-beam and rapidly-scanning radars, tornado in situ probes, and photogrammetry cameras are deployed. When tornadoes are well observed by these instruments, detailed ground and aerial damage surveys will be conducted soon after tornado occurrence.

The VORTEX2 focus on **supercells and their environments** concerns environmental heterogeneity and influences on supercell evolution, and how interactions among multiple storms affect tornado formation and dissipation. The scientific questions will be evaluated using wind analyses from the mobile multiple-Doppler radar network, surface observations (deployable and fixed), targeted mobile soundings, and UAS observations (when available). These adaptable network observations will also provide the base data to be used in extensive experiments designed to assess and improve the **numerical prediction of supercells and tornadoes**, which is the fourth VORTEX2 focus. This focus also will include the assessment of parameterization errors for storm-scale models and data assimilation at the storm scale. Additional topics of interest are optimal use of observations and analysis and prediction of the prestorm environment.

1.4 Funding and support

VORTEX2 is sponsored by the **National Science Foundation** and the **National Oceanic and Atmospheric Administration.** Participating organizations include the Center for Severe Weather Research, Center for Interdisciplinary Remotely-Piloted Aircraft Studies, Cooperative Institute for Mesoscale Meteorological Studies, Environment Canada, Lyndon State College, National Center for Atmospheric Research, National Severe Storms Laboratory, North Carolina State University, Penn State University, Purdue University, Rasmussen Systems, State University of New York (SUNY) at Oswego, Texas Tech University, University of Colorado, University of Illinois, University of Massachusetts, University of Nebraska, and University of Oklahoma.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation and National Oceanic and Atmospheric Administration.

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Table 1.1. VORTEX2 Principal Investigators. Additional contact information is provided in Appendix A.

Chapter 2

Deployment strategy

2.1 Autonomy, coordination, and the scientific mission

The coordination and operation philosophy (chapter 3) is fairly simple and relies largely on field teams carrying out their missions based upon the information assimilated and distributed by the coordination team. During the duration of a deployment, the mobile C-band Doppler radars will collect observations of the entire storm to provide contextual dual-Doppler wind syntheses and precipitation observations (Fig. 2.1). To the extent possible (allowing for redeployment, setup, takedown) coordinated dual-Doppler scanning will be done with these radars. The aim will be to maximize the duration of the dual-Doppler observation periods. Most other mobile observing assets will be focused on the updraft/rear-flank region of the supercell, with a few specialized teams on standby beneath the updraft for tornado observations. The intent will be to observe the supercell updraft, mesocyclone, and rear-flank processes from about the time of the onset of the mesocyclone and/or weak echo region until the storm is no longer observable because of safety or logistical considerations.

A fairly robust communications infrastructure (chapter 4) will be utilized by VORTEX2, but *teams must expect that there will be times that they have no ability to communicate with other teams, or to receive situational awareness data.* Hence it is imperative that each team have a complete understanding of their mission to collect scientific data, and how to perform their missions based on visual clues. Even when communications are available, it is expected that teams should operate autonomously, using the information available through the situational awareness software. Only when there are questions about how to best conduct a mission should the coordinator be contacted. On the other hand, teams should monitor communications channels and their situational awareness displays for guidance from their coordinator.

The exception to the concept of maximum autonomy is the operation of mobile radars. Many scientific objectives require radar data to be collected simultaneously in a coordinated fashion. This is particularly true and necessary for multiple-Doppler data collection and retrievals. In some contexts, the network of mobile radars could be thought of as one instrument. Therefore, the mobile radars will rely much more heavily on a central coordinator who plans activities in real-time with operators of the mobile radar platforms.

Obviously, deployment strategies depend on many factors that cannot be anticipated in an operations plan, such as road networks, road accessibility, storm evolution, and others. That is why we focus on mission. However, in each platform-focused section below, scenarios for fast-moving and slow-moving storms are discussed to provide examples for the platform operators to

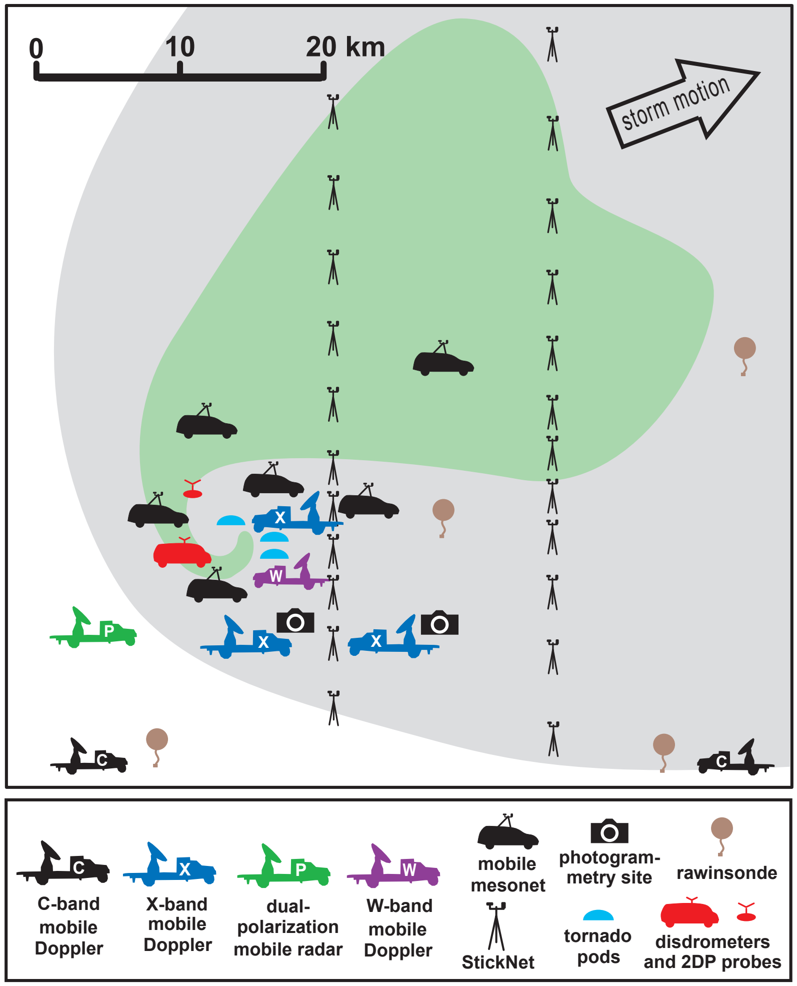

Figure 2.1. An idealized deployment of VORTEX2 facilities targeting a slow-moving supercell. Green shading represents the precipitation region of a supercell thunderstorm and gray shading indicates the approximate cloud boundary as viewed by satellite. The deployment depicted above serves only as an example to acquaint the reader with how instruments might be deployed to gather data needed to answer the science questions summarized in section 1.3. More detailed deployment maps for each instrument appear in subsequent sections.

ponder in advance of operations. It is essential that all participants study these plans in advance for the platforms they will be involved with, and discuss contingencies and scenarios with their respective coordinators in advance of operations.

2.2 Mobile radar observations

VORTEX2 will employ a heterogeneous network of mobile radars. Different radars have substantially different capabilities and limitations. Some radars need to operate in tight coordination with some other radars, while some can operate semi-autonomously within a target area. The radars and their general capabilities are listed in Table 2.1. This is meant to be an overview rather than a complete listing of radar specifications.

Radar	Wavelength	Peak Power	Beamwidth	Primary Mission
SR1 (SMART Radar 1)	C-band/5 cm	250 kW	1.5°	Storm-scale surveillance dual-Doppler with SR2
SR2 (SMART Radar 2)	C-band/5 cm	250 kW	1.5°	Storm-scale surveillance dual-Doppler with SR1
DOW6	X-band/3 cm	250 kW	0.9°	Hook/mesocyclone-scale dual-Doppler with DOW7
DOW7	X-band/3 cm	250 kW	0.9°	Hook/mesocyclone-scale dual-Doppler with DOW6; radar and tornado pod coordination
Rapid-Scan DOW	X-band/3 cm	40 kW	0.8° (6 beams)	Rapid-updates of low-level winds
NOXP (dual-pol)	X-band/3 cm	250 kW	0.9°	Microphysics in hook and RFD regions
UMASS-X (dual-pol)	X-band/3 cm	50 kW	0.9°	Microphysics in hook and RFD regions
UMASS-W	W-band/3 mm	1 kW	0.2°	High-resolution low-level winds
TTU-Ka	Ka-band/10 mm	0.2 kW	0.5°	High-resolution low-level winds
CIRPAS MWR-05XP	X-band/3 cm	19 kW	1.8°	Rapid-updates of low-level winds

Table 2.1. Listing of mobile radars and overview of their missions

By using these various radars in a coordinated fashion, multiple VORTEX2 scientific goals can be achieved simultaneously during one event. Broadly speaking, storm-scale surveillance, mesocyclone-scale surveillance, tornado-resolving low level wind surveillance, and dual-polarization surveillance can all be achieved in concert. Since several science objectives require dual-Doppler wind field retrievals, and these can only be achieved through the actions of multiple radars, acting together, scanning synchronously, placed in a coordinated array, the strategies for radar coordination are different than those of the other VORTEX2 instrumentation. Radars who are part of a multi-Doppler network will not be deploying "autonomously," but will be directed to tightly defined deployment areas by a radar coordinator, acting in close consultation with the individual radar PIs and operators. In VORTEX2, individual radars will be deployed to satisfy both the individual needs of the radar PIs, and the key science objectives of the VORTEX2 project overall. Sometimes this will require PIs to deploy their radar differently than they might have done to solely serve their individual science need. So, for example, a DOW may, from time to time, depending on many factors, including logistical, mission priority decisions, etc., engage in storm-scale scanning. This might occur if a SMART radar is in transit. Similarly, a SMART-Radar may need to engage in non-storm-topping, fine temporal resolution scanning if they and an X-band system are close to an ongoing tornado and high resolution dual-Doppler at low levels is a priority. These decisions will be made by VORTEX2 coordinators in consultation with the individual radar PIs with the goal of balancing overall VORTEX2 objectives and individual PI objectives.

2.2.1 Broad science goals and deployment philosophies

Very generalized schematics are shown below and illustrate the goals of different mission modes as well as the complexity of establishing overlapping multiple-Doppler storm scale, mesocyclone scale, dual-polarization, and low level wind radar networks. Precise deployment maps for all scenarios cannot be produced owing to the high sensitivity of the details of these deployments to storm motion, errors in forecast of storm motion, storm evolution, storm type (HP, classsic, etc.), storm/mesocyclone propagation complexities (i.e. cyclic/discrete propagation), road networks, terrain, foliage, urban blockage, storm interactions, and other factors.

2.2.2 Slow-moving, isolated storm: pulsed mesocyclone-scale dual-Doppler IOPs

In the simplest case, a slow moving, isolated, slowly-evolving, classic supercell is moving at a steady speed in a constant direction, parallel to a paved road network, over non-hilly, non-forested terrain, with little human habitation. For the purposes of illustration, we will assume the storm is moving due east. One goal of the constant storm-scale, pulsed mesocyclone-scale IOP (intensive observing period) strategy is to obtain O(5000 s) of dual-Doppler storm-scale coverage, at levels ranging from 1–15 km AGL, at 150 s intervals. These data are obtained by two SMART-Radars deployed parallel and south of the predicted path of the supercell, at a range of about 20 km to the southern edge of the supercell, and with a baseline of 35 km. The scales retained in a dual-Doppler synthesis are often dictated by the spatial resolution of the data collected at the greatest range (i.e, that with the poorest resolution). In the current deployment scenario, a nominal range to the mesocyclone by the most distant SMART-Radar is approximately 35 km, resulting in a beamwidth of approximately 1 km (ignoring both integration-time smearing and oversampling). Assuming at least four samples across a feature are necessary in order to consider it properly resolved, scales larger than 4 km will be resolved.

Another goal of this deployment mode is to obtain continuous dual-Doppler coverage at the mesocyclone scale. This is achieved with the DOW6, DOW7, NOXP, and UMASS-X radars. These are deployed parallel to and about 5 km south of the predicted path of the mesocyclone/hook, with a 10 km baseline. Assuming a nominal range of 12 km from the most distant DOW to the mesocyclone, the simple (i.e., ignoring integration-time smearing and oversampling), beamwidth is about 200 m, permitting resolution of features of 4Δ = 800 m. Owing to the proximity of the mesocyclone-scale radars to the mesocyclone, the vertical extent of coverage will range from about 200 m AGL to about 5000 m AGL, but not to storm top.

The challenge in VORTEX2 will be to establish and maintain these nested dual-Doppler arrays to achieve the idealized scenario described above. Some radars require substantial time to deploy and undeploy, and all radars require substantial time to cover tens of kilometers to get to deployment sites, or to redeploy to new sites. The following illustrated narrative is brief because it is necessarily schematic for an idealized case. Radars will proceed to preliminary deployment locations approximately 5500 s (1.5 h) before multiple-Doppler data collection begins. Figure 2.2 illustrates the initial deployment of the storm-scale SR radars well before a storm is near other VORTEX2 instrumentation. 5500 seconds later, at IOP time t = 0, the idealized storm has matured into a nearly tornadic supercell (Fig. 2.3). The SR radars are deployed with a 35 km baseline about 15–20 km southeast of the projected path of the tip of the hook. The CIRPAS radar is also deployed at this distance. The four X-band radars, DOW6, DOW7, NOXP, and UMASSX, are deployed in a line southeast and east southeast and 5–10 km south of the projected path of the tip of the hook. In a dual-Doppler IOP, the two DOWs are adjacent and the NOXP and UMASSX are adjacent. The tornado scale radars, the Rapid-Scan DOW, the UMASS-W, and the TTU-Ka are deployed or maneuvering in front of the hook. When the hook passes the rearward X-band radar, in this illustration this would be DOW6, that radar undeploys at t = 1500 and moves east, passing the other X-band radars (Fig. 2.4). DOW6 will finally redeploy at the front of the X-band line at t = 2900 (Fig. 2.5). When the hook passes the new rearmost X-band radar, DOW7, that radar undeploys at t = 2500 and begins moving eastward. The tornado-scale radars either deploy to collect data in tornadoes or keep moving gradually eastward for positioning. This pattern of X-band moving/hopscotching is repeated (Figs. 2.6–2.8) until at least t = 6000 or until logistical or meteorological conditions require change. Note that the SR radars are still collecting storm scale

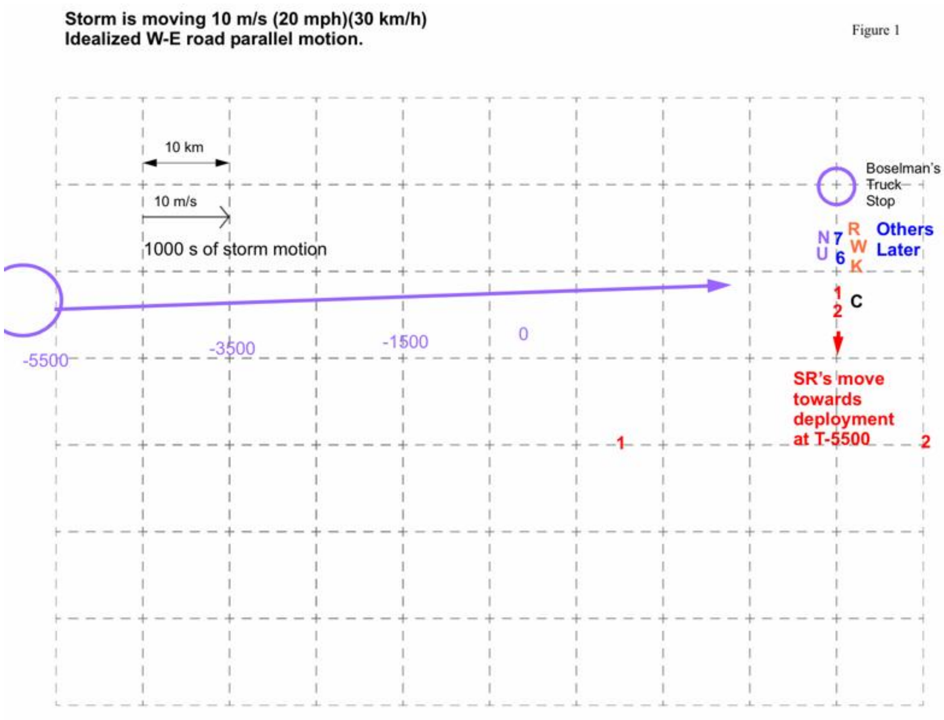

Figure 2.2. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of an approaching slow-moving storm, depicting the initial deployment of the storm-scale SR radars well before a storm is near other VORTEX2 instrumentation.

data through t = 6000. After t = 6000, the SR radars would have to redeploy to catch this storm with the remaining radars, or the SRs and all other radars would redeploy to intercept a new storm.

The SRs will scan with 3-minute update intervals, with sweeps up to storm top. DOW6 and DOW7 will scan with either 1-minute intervals, or a staggered 90-/30-second interval with the 2nd volume only including low-level sweeps. NOXP and UMASS-X would scan at 2-minute intervals, scanning to 5 km AGL. If possible, DOW6 and DOW7 will conduct additional interleaved sweeps at low levels to better quantify the boundary layer divergence field.

In an ideal case where a slow-moving tornado is established, the tornado-scale radar platforms (Rapid-Scan DOW, TTU-Ka, UMass-W) will coordinate in such a manner to establish dual- or triple-Doppler lobes encompassing the tornado cyclone. For an eastward storm motion, as depicted in Figs. 2.2–2.12, two radars would establish a north-south baseline ($\sim$5 km) to the east of the mesocyclone. The ideal range to target for these platforms is $\sim$3 km. In an effort to resolve the inflow boundary layer and corner-flow region of the tornado, quasihorizontal sweeps will be repeated rapidly at elevation angles as close to the surface as possible without contamination from the ground. The tornado-scale radars will attempt similar coordinated scans of the pre-tornadic near-mesocyclone environment. Individually, RHIs will be obtained through the tornado cyclone when possible.

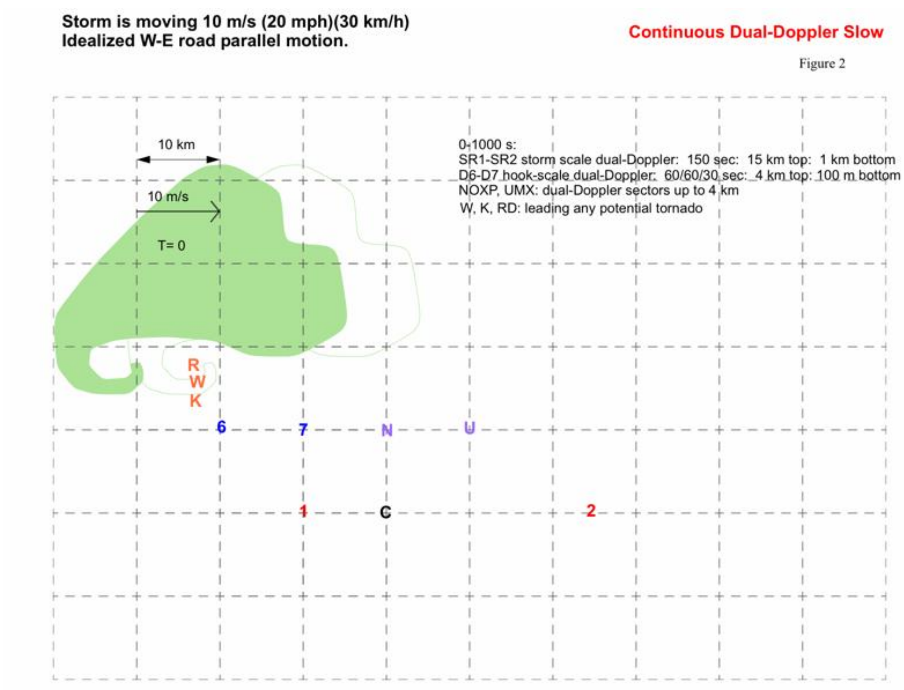

Figure 2.3. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of a slow-moving storm at a time when all of the radars have deployed (∼1.5 h after the time shown in Fig. 2.2). This time is referred to as t = 0 s.

2.2.3 Slow-moving, isolated storm: pulsed mesocyclone-scale dual-polarimetric IOPs

A variant of the dual-Doppler IOP is an IOP focused on gathering continuous dual-polarization observations while maintaining as much dual-Doppler coverage as possible. In this case, radars will be deployed well ahead of the storm as in Fig. 2.2, with the SRs establishing storm-scale dual-Doppler coverage. The main difference is that the dual-polarization X-band radars will not be adjacent in the X-band hopscotching line so that at least one of them is always collecting dual-polarimetric data. This can be seen schematically in Fig. 2.9. The X-band radars and the tornado-scale radars redeploy to maintain coverage of the hook echo and mesocyclone region as illustrated in Figs. 2.10–2.12. In this mode, update rates would be 3 min for SRs, 90 s for DOW6, DOW 7, and UMASS-X, and 3 min for NOXP. The DOW6 and DOW7 radars will extend their surveillance range so that they can get 90-s mutual dual-Doppler-compatible sweeps.

2.2.4 Fast-moving storms or no clear supercell target

If no obvious supercellular target storm is available, and storm motion is fast and/or not orthogonal to the local road network, our strategy will be to establish an array of mobile radars capable of either/both storm-scale and mesocyclone-scale surveillance. Because the storms may not be fully mature, storm motion and interactions may be difficult to predict. Thus, depending on the evolution and motion of the storms, radars may or may not be able to be redeployed into more optimal placements, so the intent of this deployment mode is to cast a wide net, retaining a substantial

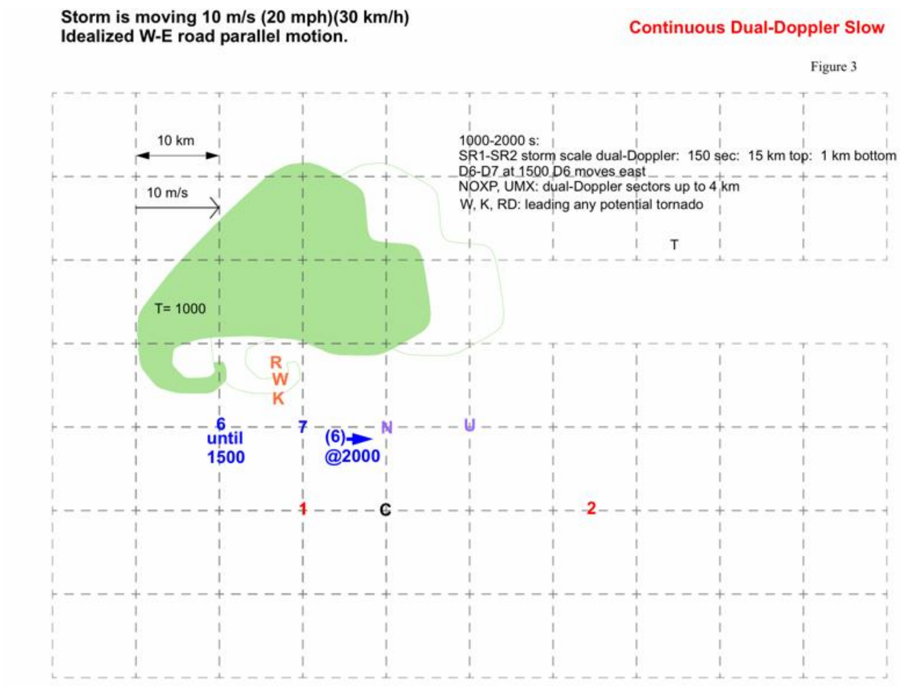

Figure 2.4. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of a slow-moving storm at t = 1000 s.

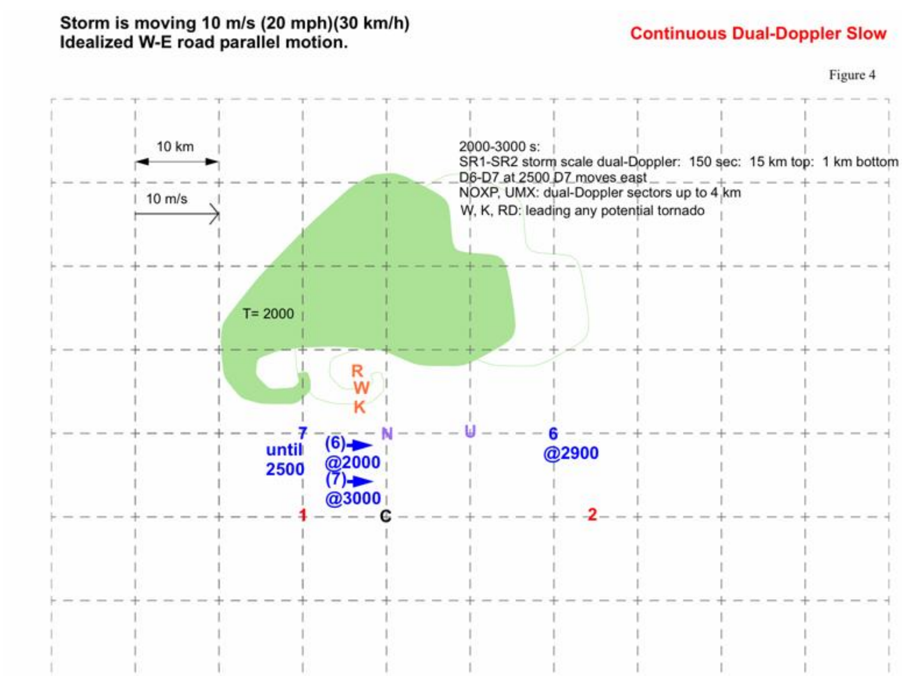

Figure 2.5. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of a slow-moving storm at t = 2000 s.

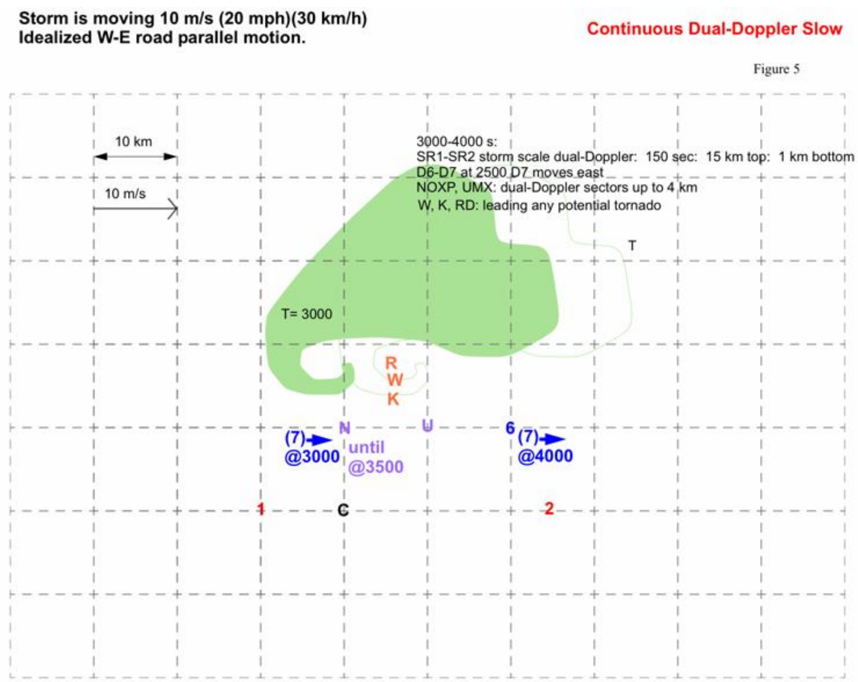

Figure 2.6. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of a slow-moving storm at t = 3000 s.

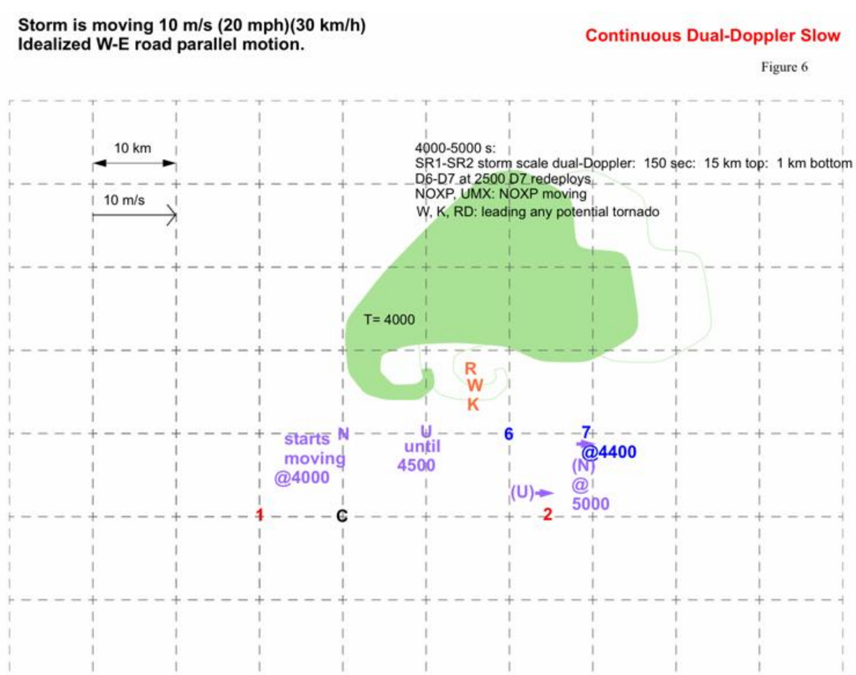

Figure 2.7. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of a slow-moving storm at t = 4000 s.

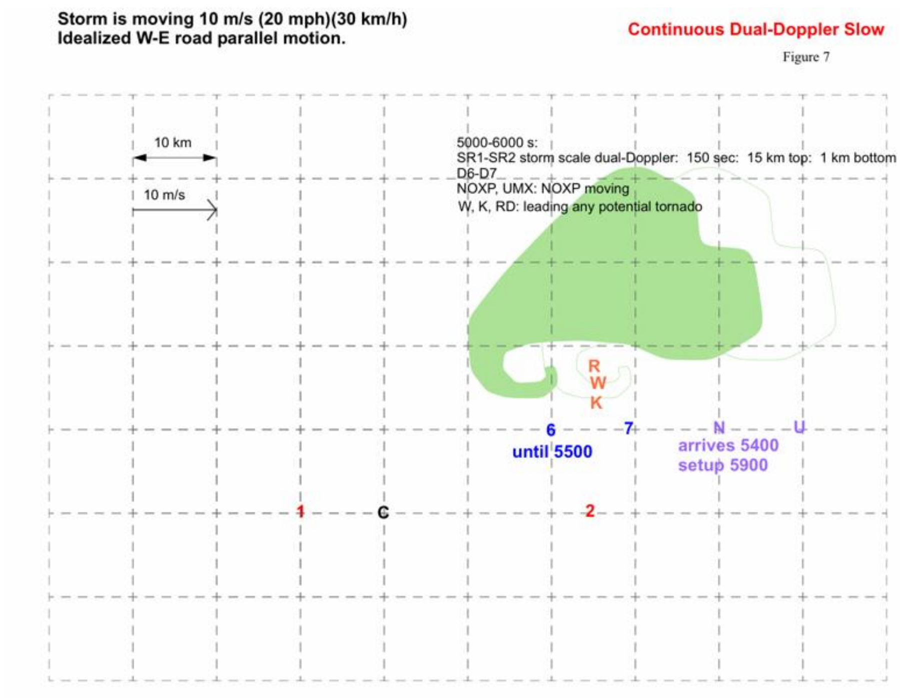

Figure 2.8. Idealized mobile radar deployment strategy that emphasizes continuous dual-Doppler sampling in the case of a slow-moving storm at t = 5000 s.

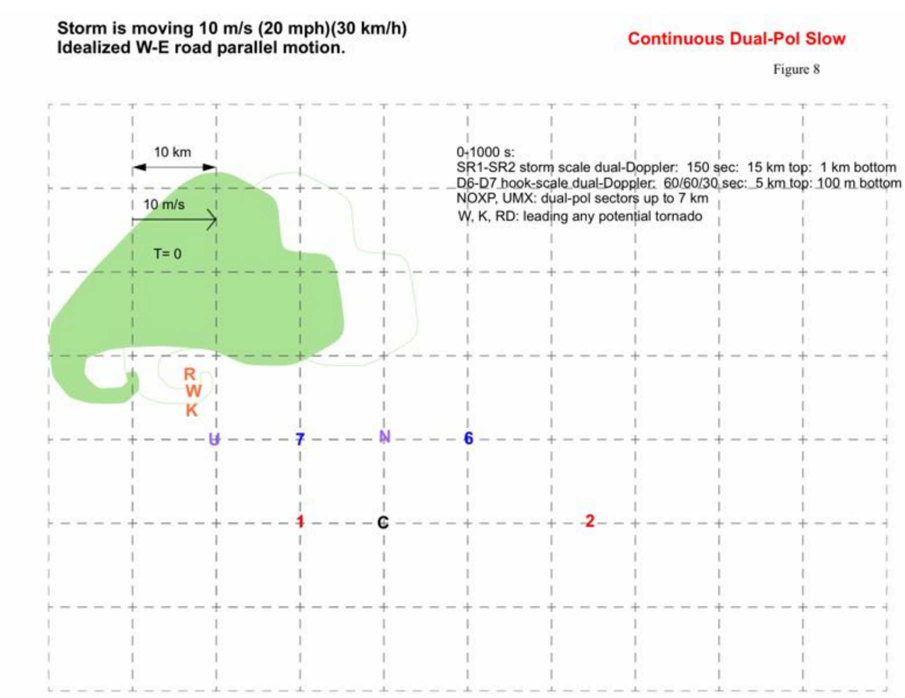

Figure 2.9. Idealized mobile radar deployment strategy that emphasizes continuous dual-polarimetric sampling in the case of a slow-moving storm at t = 0 s.

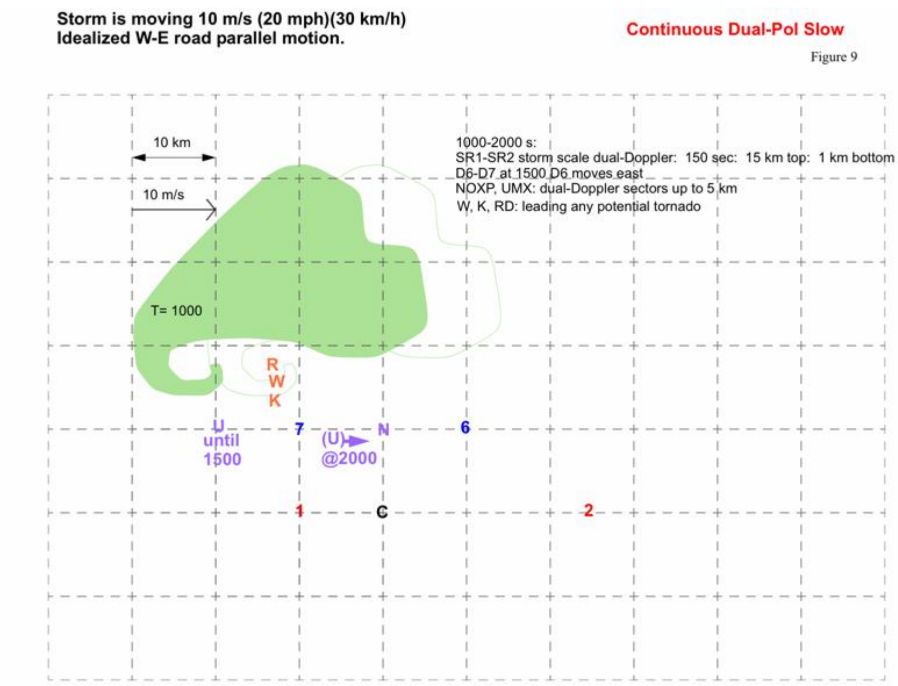

Figure 2.10. Idealized mobile radar deployment strategy that emphasizes continuous dual-polarimetric sampling in the case of a slow-moving storm at t = 1000 s.

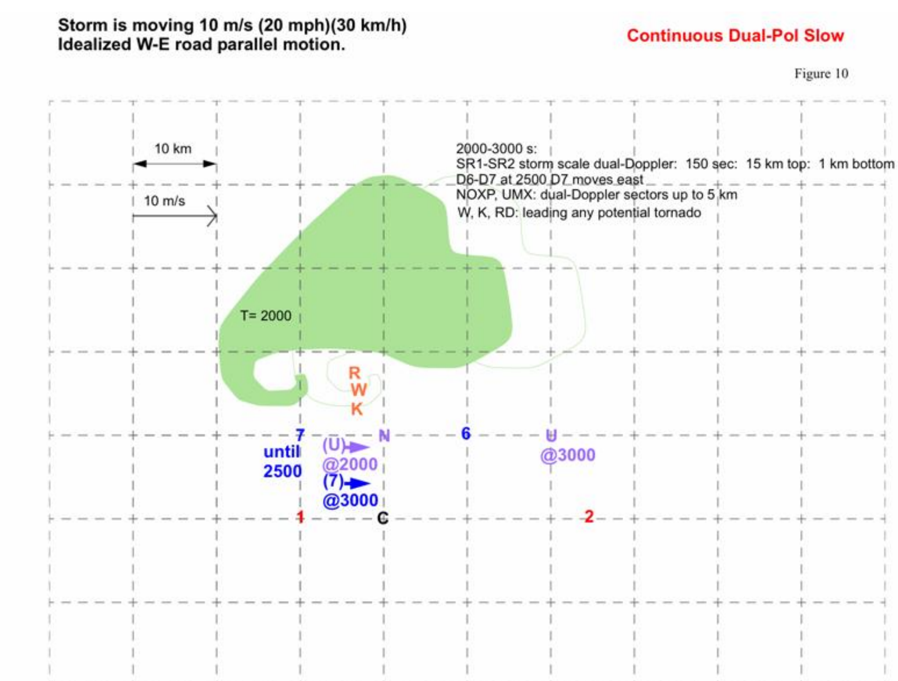

Figure 2.11. Idealized mobile radar deployment strategy that emphasizes continuous dual-polarimetric sampling in the case of a slow-moving storm at t = 2000 s.

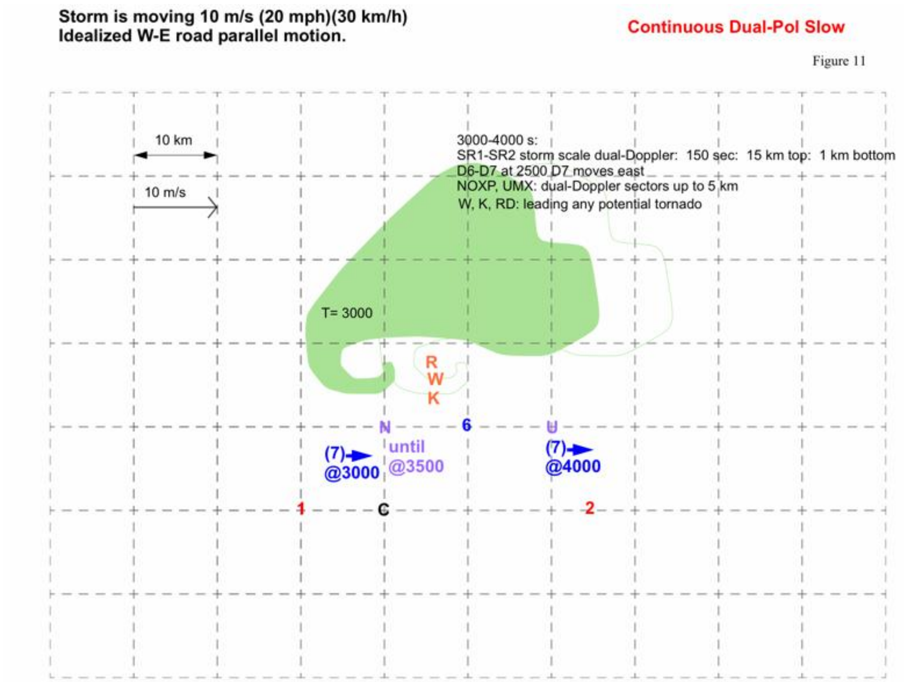

Figure 2.12. Idealized mobile radar deployment strategy that emphasizes continuous dual-polarimetric sampling in the case of a slow-moving storm at t = 3000 s.

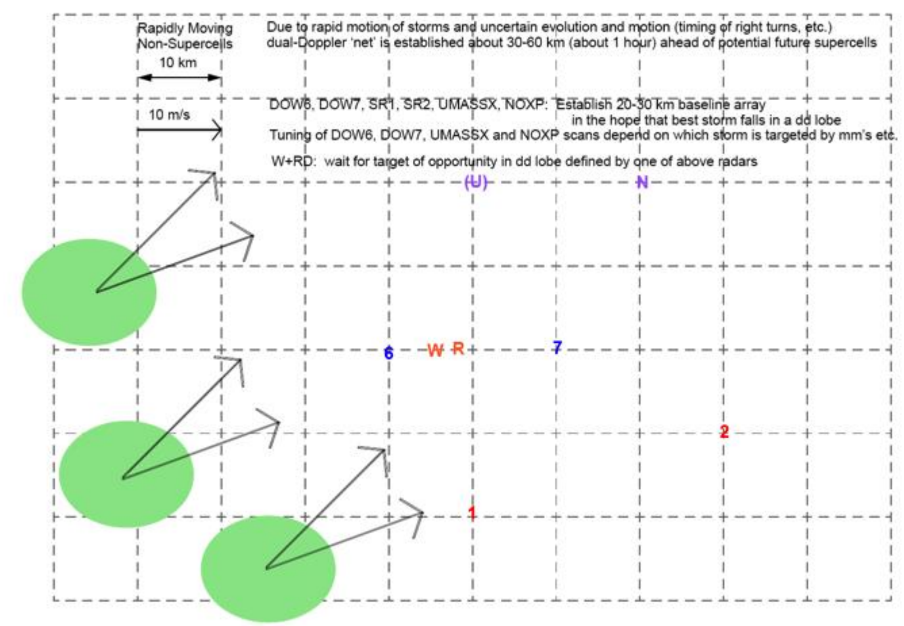

Figure 2.13. Idealized mobile radar deployment for fast-moving supercells or nonsupercells.

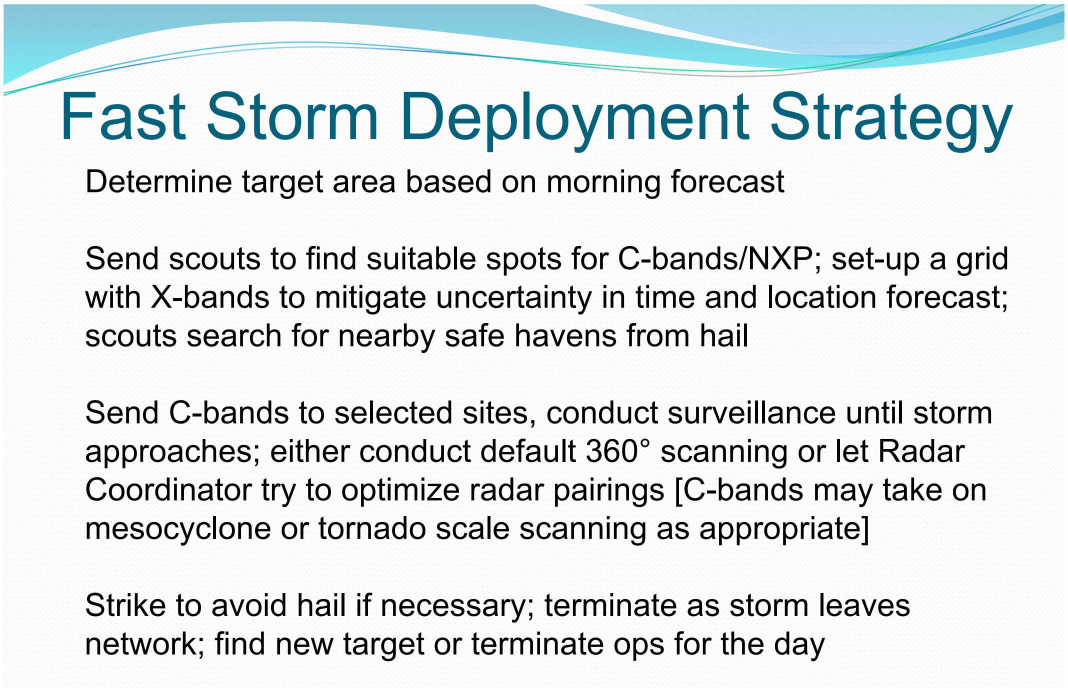

Figure 2.14. Strategy for mobile radar deployment for fast-moving supercells or nonsupercells.

probability of obtaining medium to fine-scale dual-Doppler and dual-polarimetric data, using some combination (unknown a priori) of the various radars. The tornado-scale radars will remain mobile inside the net, waiting for a favorable storm to evolve. However, owing to rapid storm motion, they may or may not be able to keep up with the storm for long periods.

2.2.5 Special cases and other notes

When operating in central Oklahoma, operations will be normal for slow-moving storms. But, for fast-storm deployments, consideration will be given to anchoring the radar "net" to the NWRT Phased Array Radar. Consideration also will be given to anchoring near other fixed assets (e.g., CASA radars, TDWRs, WSR-88Ds) within the VORTEX2 domain.

Operations will be considered, with the consent of individual radar PIs, in nontornadic targets of opportunity. These might include bow echoes, squall lines, convection initiation cases, boundary layer studies, etc. During a nontornadic day, an effort will be made to obtain a multiple-frequency observation of a single storm with W, K, X, and C band radars for a four-frequency intercomparison.

Tornado-scale observations with DOWs: The primary mission of the DOWs is to collect dual-Doppler observations. However, in some rare cases, a tornado may pass near a DOW, offering the opportunity for unique tornado-scale observations. The DOWs may consider breaking off from dual-Doppler mesocyclone-scale scans if dual-Doppler tornado-scale observations are possible in conjunction with the Rapid-Scan DOW, TTU-Ka or UMASS-W. The DOWs may collect tornado-scale observations if a tornado is crossing through a town or if the tornado pod array is deployed in a tornado.

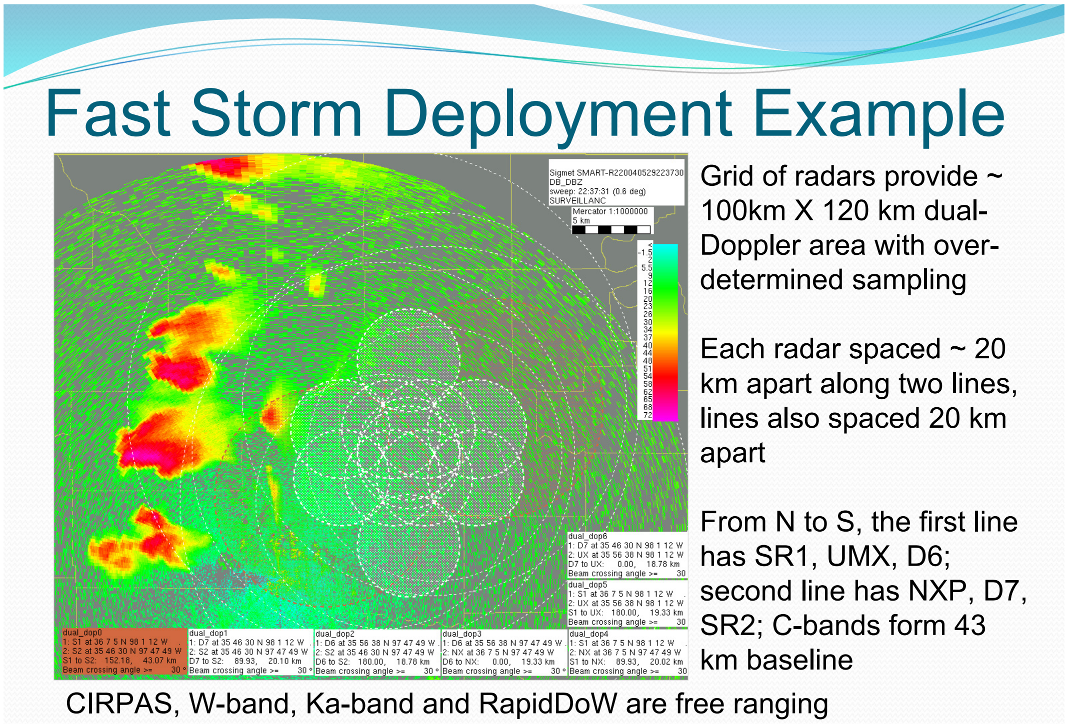

Figure 2.15. An example of mobile radar deployment for fast-moving supercells or nonsupercells.

HP Storms: High precipitation storms pose additional logistical complications and safety risks. Radar baselines and ranges to targets may be expanded for HP storms.

Cyclically Tornadic Storms: Dual-Doppler X-band deployments will be the highest priority.

Mergers: Deployment strategies for mergers will be considered on a case-by-case basis since there is no archetypical merger scenario for which deployments can be pre-planned. Some mobile assets would be redeployed to the merging storm with a goal of characterizing the cold pools and low-level wind fields of both storms prior to and during the merger process.

2.3 Surface in situ observations

2.3.1 Mobile mesonet

Described below are the team missions of the six “probe” vehicles that comprise the mobile mesonet (Figs. 2.16 and 2.17). Each of the probes will work in pre-determined locations of a storm. Although guidance will be provided by the mobile mesonet coordinator (residing in Probe 1), each mobile mesonet team must be able to perform their tasks autonomously. Some of the probes may work in potentially dangerous locations of a storm. Therefore it is of utmost importance that all safety precautions, as described in section 6.1, be followed. Although the mobile mesonet coordinator may request a team to move into a particular position or location in a storm, the team leader of each probe has the ultimate responsibility in determining whether his or her

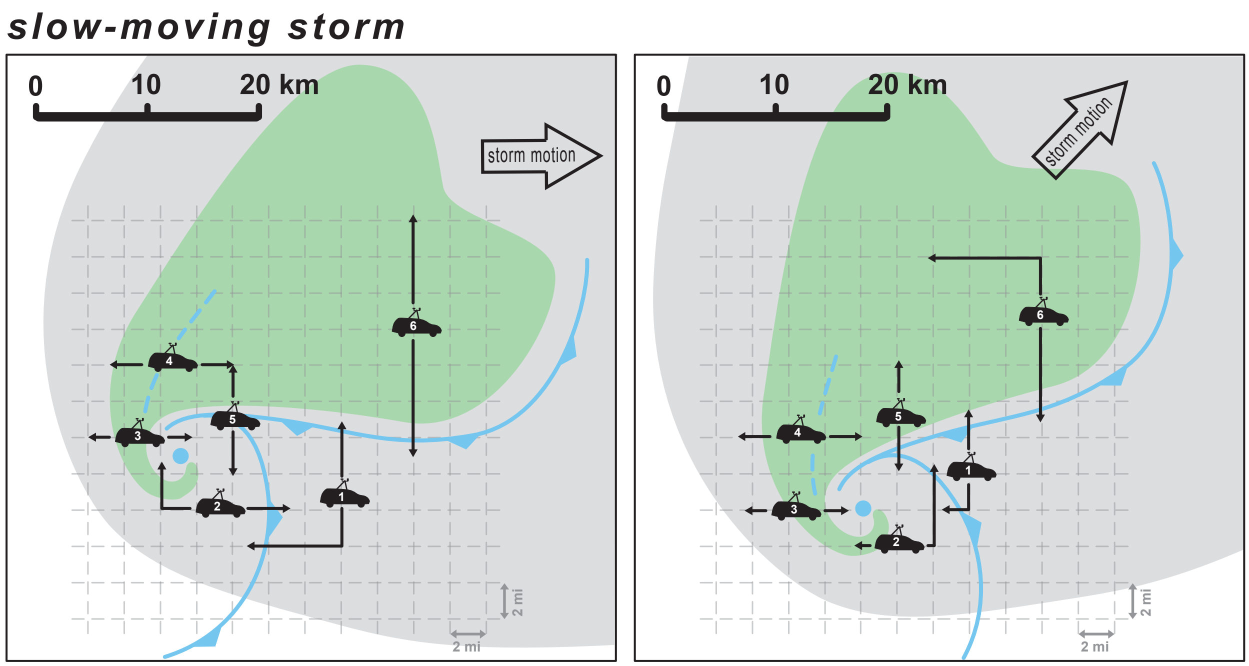

Figure 2.16. Idealized mobile mesonet deployment for a slow-moving supercell for two different storm motions relative to an idealized road grid. Mobile mesonets are indicated with numerals 1–6 (see text for a more detailed textual discussion of the missions). Idealized transects are indicated with black arrows. The road network is indicated with gray dashed lines. The precipitation region of the supercell is green. The anvil is indicated with gray shading. Gust fronts are blue, barbed lines. The blue circle indicates center of maximum rotation at the surface (e.g., tornado location in a tornadic supercell).

crew can proceed safely.

With the exception of the mobile mesonet coordination vehicle (Probe 1), probes will largely be sampling storm outflow. In general, probe transects lengthen with increasing distance from the mesocyclone as a result of faster vehicle speeds permitted by better visibility and road conditions at increasing distances from the mesocyclone. Furthermore, meteorological fields probably vary less rapidly in time and space with increasing distance from the mesocyclone. Most probe transects include a turn-around after crossing a gust front (Fig. 2.16). It is believed that an accurate mapping of gust front (and thus surface wind shift) locations will greatly benefit storm-scale analyses.

In the event that the road network requires that multiple probes collect data on the same road, probes should maintain a separation of at least a half-mile ($\sim$1 km). When vehicles fail to maintain separation, one vehicle's data is effectively lost. Moreover, vehicles should never stop and park at the same location, no matter how good the view is. Vehicle accelerations also should be minimized, as these affect the quality of the wind observations. Team leaders are encouraged to take it upon themselves to make sure these rules are observed.

In case of relatively fast storm motion (storm speed exceeding $\sim$30 mph, or perhaps even a lesser threshold if the direction of storm motion is at a large angle to the road grid), a "picket-fence" deployment strategy will be utilized (Fig. 2.17).

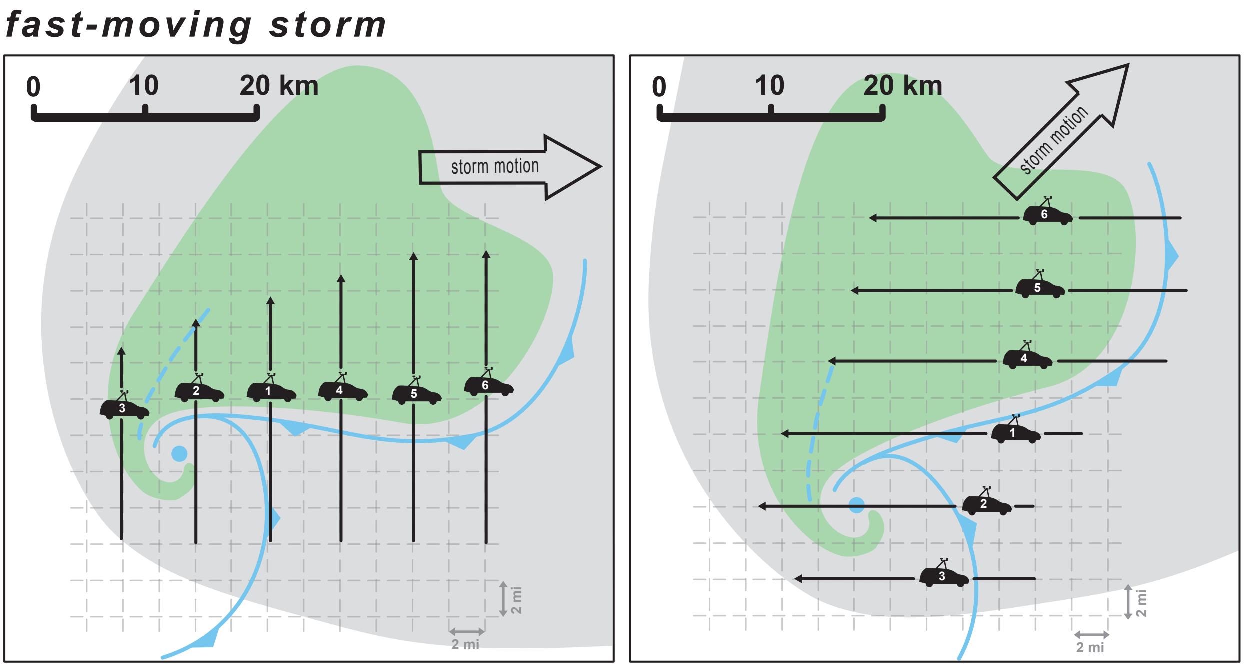

Figure 2.17. Idealized mobile mesonet deployment for a fast-moving supercell for two different storm motions relative to an idealized road grid. Mobile mesonets are indicated with numerals 1–6 (see text for a more detailed textual discussion of the missions). Idealized transects are indicated with black arrows. The road network is indicated with gray dashed lines. The precipitation region of the supercell is green. The anvil is indicated with gray shading. Gust fronts are blue, barbed lines. The blue circle indicates center of maximum rotation at the surface (e.g., tornado location in a tornadic supercell).

Probe 1 Probe 1, which also serves as the mobile mesonet coordination vehicle (P. Markowski and Y. Richardson are the Mobile Mesonet Coordinators), will be somewhat centrally located so that VHF radio communications can be maintained with the other probes during data collection. Probe 1 will sample the near-storm inflow and will continuously perform both zonal and meridional transects, turning around upon encountering a gust front (Fig. 2.16). It is anticipated that Probe 1 will experience relatively good visibility and driving conditions, and will be able to operate at a speed of 50–60 mph. For deployments targeting fast-moving storms, Probe 1 will be near the middle of the "picket fence" (Fig. 2.17), also for communications reasons.

Probe 2 Probe 2 will generally operate in the southeastern quadrant of the mesocyclone region (Fig. 2.16), performing transects between the rear-flank gust front and hook-echo precipitation immediately south of the circulation center. Probe 2 should not end up significantly west of the circulation center; westbound transects should be terminated at or shortly after passing the longitude of the mesocyclone center. Eastbound transects should be terminated at the gust front, although if it is found that the gust front is situated more than $\sim$5 km east of the longitude of the circulation center, then the eastbound transect should be terminated and it will be the mission of Probe 1 to locate the gust front. Probe 2 will document potentially important baroclinic zones, or lack thereof, in the hook echo region of the RFD. It is important that the Probe 2 staff make precipitation observations as well, noting precipitation intensity and qualitative information about hydrometeor species when possible (e.g., small/large hail, small/large raindrops).

Visibility could be significantly reduced along the western portion of the transects where the hook echo is penetrated. It will be crucial for the team to stay abreast of the location of the mesocyclone center, both for safety reasons as well as for the purpose of knowing where to terminate the westbound transect. It is anticipated that vehicle speeds outside of the hook echo within the outflow may safely approach 50–60 mph, but that speeds within the southern part of the hook echo may have to be reduced to as low as 25–30 mph.

Probe 3 Probe 3 will be conducting relatively short ($<$5 km) zonal transects through the hook echo near or just north of the latitude of the mesocyclone center (Fig. 2.16). It is anticipated that the transects will only need to be approximately 3–4 km long. These transects will obtain critical thermodynamic observations (e.g., buoyancy, buoyancy gradients) of the air than very likely is just upstream of the near-ground mesocyclone center. As was the case for Probe 2, it is important that the Probe 3 staff make precipitation observations during their transects, noting precipitation intensity as well as qualitative information about hydrometeor species when possible (e.g., small/large hail, small/large raindrops). Visibility is anticipated to be very low in the region sampled by Probe 3; thus, vehicle speeds will seldom exceed 25 mph. More importantly, it will be of utmost importance for the Probe 3 team leader to keep abreast of radar updates of the mesocyclone center (or tornado position) provided by the mobile mesonet coordinator (these would likely be given relative to the probes), as well as keep a close eye to the sky.

Probe 4 Like Probe 3, Probe 4 also will perform zonal transects upwind of the near-ground mesocyclone, but a bit farther upwind, i.e., near the “top” of the hook echo, where the hook echo is joined to the main precipitation echo associated with the storm (Fig. 2.16). It is anticipated that the transects will be approximately 5 km long. The observations of Probe 4 also will be vital to documenting surface thermodynamic conditions (e.g., buoyancy, buoyancy gradients) upstream of the circulation center. Precipitation observations (e.g., intensity, hydrometeor species) also should be recorded at regular intervals. Visibility is anticipated to be very low in the region sampled by Probe 4; thus, vehicle speeds will seldom exceed 25 mph. As is the case for Probe 3, it will be of utmost importance for the Probe 4 team leader to keep abreast of radar updates of the mesocyclone center (or tornado position) provided by the mobile mesonet coordinator (these would likely be given relative to the probes), as well as keep a close eye to the sky.

Probe 5 Probe 5 will conduct $\sim$5-km long meridional transects just ahead of the circulation center, sampling any wind shifts or baroclinity that might be present immediately northeast of the circulation center (Fig. 2.16). Part of the transects will likely be in precipitation, especially large hail, and part of the transects will likely be in precipitation-free conditions. Obviously, given the circulation-relative location of the transects and the accompanying dangers, it will be of critical importance for the team leader to pay attention to signs of imminent tornadogenesis or the location of of an ongoing tornado, as well as keep abreast of radar updates passed along from the mobile mesonet coordinator. Depending on visibility, vehicle speeds might range from 25–50 mph. In the event of a high-precipitation (HP) supercell, it is likely that the Probe 5 mission will not be attempted; an alternative mission will be dictated as conditions warrant.

Probe 6 Probe 6 will conduct long (10–15 km) transects within the forward-flank precipitation region, fairly far upwind ($\sim$10 km) of the updraft (Fig. 2.16). Probe 6 will document forward-flank buoyancy and buoyancy gradients, as well as look for a forward-flank wind shift, if there is one. It is anticipated that precipitation rates will be light enough to permit moderately fast vehicle speeds of 30–45 mph, such that a transect can be completed roughly every 10 min. Precipitation observations (e.g., intensity, hydrometeor species) also should be recorded by Probe 6 at regular intervals.

2.3.2 StickNet

The StickNet is an array of instrument packages on tripods that will collect storm-scale observations of temperature, humidity, pressure, wind speed, wind direction, and precipitation (rain and hail). These observations will be used to document near-surface thermodynamic and kinematic gradients in supercell thunderstorms. Storm-scale low-level baroclinity is believed to play a significant role in the formation of horizontal vorticity and ultimately the formation of the low-level mesocyclone, but it is unclear what the typical patterns of baroclinity are in supercells and how much variability there is from storm to storm. Multi-storm interactions through low-level outflows are also hypothesized to play a role in supercell mesocyclogenesis and tornadogenesis, and the StickNet will be deployed such that observations of these interactions will be obtained when they occur. After the VORTEX2 field phase, StickNet observations will also support thermodynamic retrieval and numerical simulation efforts.

The StickNet and Mobile Mesonet observations complement each other, and the planned deployment strategies take into account the advantages (and disadvantages) of each platform. The main advantages of the StickNet are the large number of independent observation points (up to 24 StickNet probes will be deployed at a time) and the ability to obtain measurements in locations that are unsafe for manned platforms (e.g., in the mesocyclone of HP storms). In some situations, the StickNet and Mobile Mesonet arrays might also be augmented by CSWR tornado in-situ pods deployed for the purpose of storm-scale observations, rather than the typical deployment of these pods for tornado measurements.

The lead time of the StickNet deployment is significant—beginning nearly an hour before the updraft starts to pass over the array—and is similar to the lead time required for setting up the storm-scale surveillance (SMART Radar) dual-Doppler deployment. Therefore, the FC must work with the StickNet and SMART Radar team leaders to ensure that the deployments begin early enough and that the StickNet probes are within the dual-Doppler lobe.

Compass directions (north, south, east, and west) are used for convenience in the discussion below. The discussion assumes a typical east-northeasterly storm motion; the deployment would be adjusted for atypical storm motions.

Four vehicles are used for all deployment strategies which, in the default case, will be divided between two available north-south roads downstream of the target storm. The design of the strategy is such that the two deployment vehicles that are towing trailers (responsible for the coarse array) are not required to make U-turns. Therefore, all deployments are made from north to south to minimize as best as possible the exposure to forward-flank precipitation and ensure a direct escape route. Ideally, the two vehicles not towing trailers (responsible for the fine array) will similarly deploy from north to south, but more flexibility is permitted for these shorter-fuse drops.

All StickNet arrays should be deployed within the SR dual-Doppler lobe. Ideally, X-band multiple-Doppler lobes will also be positioned above these arrays.

The StickNet deployment begins approximately 55 minutes before the updraft is predicted to cross the westernmost N-S oriented road (time $t-55$ min; Fig. 2.18). The first probe in the coarse array will be deployed $\sim$10–15 km to the north of the (evolving) position where the updraft is forecasted to cross the road, followed by deployments every 5 km to the south.

At time $t-35$ min, the deployment of the fine-scale array will begin on the westernmost road, starting at a position $\sim$2 km to the north of the anticipated updraft-road crossing, then deploying every 1 km to the south. Additionally, the coarse-array deployment will begin on the eastern road, following the same strategy as above.

At time $t-15$ min, the fine scale array will be deployed on the easternmost road. All deployments should be complete on the westernmost road by this time. By time t+5 min, all StickNet drops should be finished.

Four additional probes will be available for deployment, if desired. Probes from either fine-scale array may also be retained to supplement this total. Scenarios where these probes could be used include where:

- an east-west road is available that is forecasted to be near and to the left of the updraft track, or
- a third north-south road is within reasonable range ($\sim$20 km) of the original deployment roads.

In the event that storm motion is too rapid to carry out the default deployment plan, probes will be deployed approximately 3 km apart in a leapfrog fashion from north to south along each of the two roads (Fig. 2.19). No fine-scale array will be attempted.

2.3.3 Disdrometers and particle probes

In situ microphysical measurements at the surface will be collected using a variety of instrument types and platforms. Four laser optical disdrometers will be deployed using one vehicle-based platform and three unmanned platforms each collecting data at fixed sites along a line as the storm passes overhead. Two 2DP optical particle probes also will be used on a pair of vehicle-mounted platforms. The particle probes need a headwind of 15 m s^{-1} across the sensor plane for adequate sample volumes, and so will be collected on a mobile, vehicle-borne platform. The representativeness of samples from these platforms in a supercell environment remains relatively unknown to date. Collectively, these platforms will gather particle size distribution (PSD) data across significant sectors of the storm, biased toward the right flank. These microphysical measurements will supplement thermodynamic observations, provide comparison data for single- and dual-polarization radar observations, and provide verification data for microphysical parameterizations and physical processes (e.g., evaporative cooling rates). Each sampling platform includes a

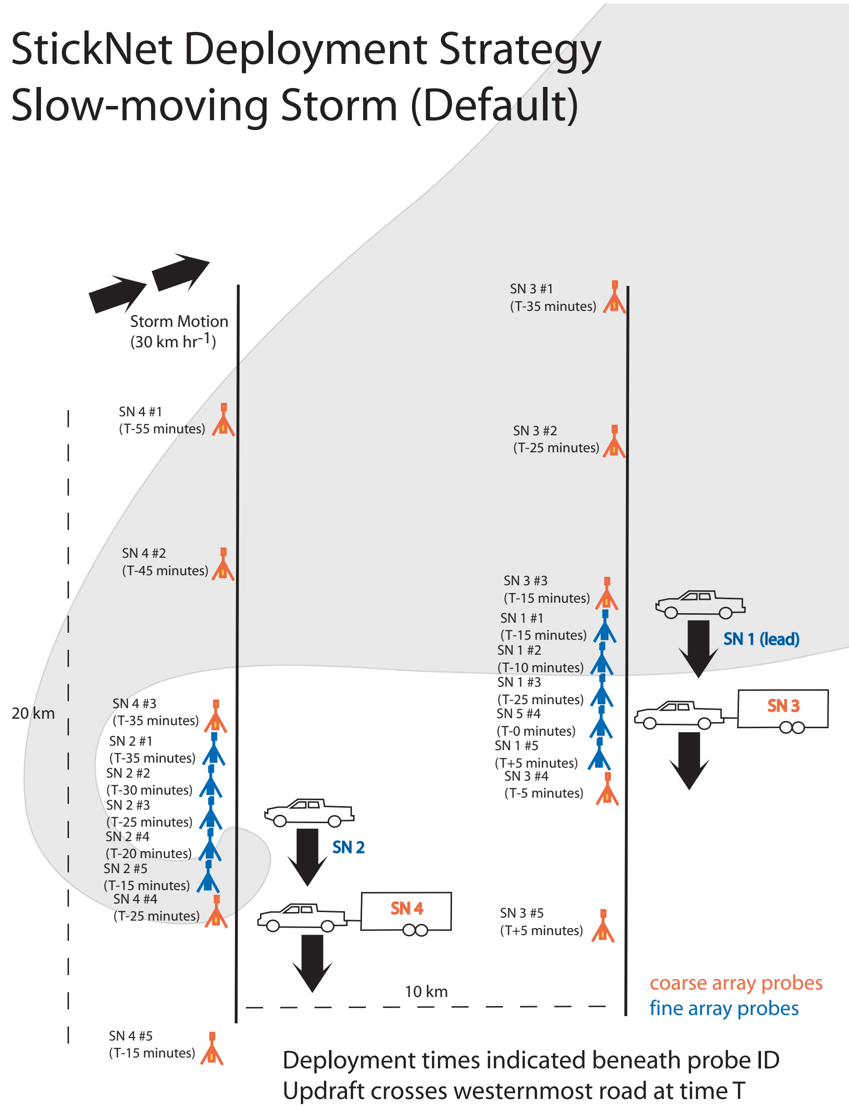

Figure 2.18. Idealized deployment of StickNet for a slow-moving storm. The supercell's precipitation core is indicated by gray shading. Solid lines are N-S oriented roads. The probes for the coarse-scale array, which are deployed at intervals of approximately 5 km from two trailers, are shown in red. The probes for the fine-scale arrays, which are deployed at intervals of approximately 1 km from two pickup trucks, are shown in blue.

local surface mesonet station, while an additional mobile mesonet equipped vehicle will conduct transects along the line of deployed laser disdrometer platforms. Fixed platforms will favor sampling in storm regions where modest surface wind conditions are expected, whereas the particle probes will preferentially target regions where significant surface wind speeds are expected (such as nearer to the tip of the hook echo).

Coordination with polarimetric radar platforms will be sought to maximize microphysical data collection efforts. Missions may be adjusted during events with exceptionally large hail to protect our small pool of instrumentation and deployment vehicles. When practical, deployments will be sought in the vicinity of Sticknet fine arrays while taking care to avoid redundancy in station

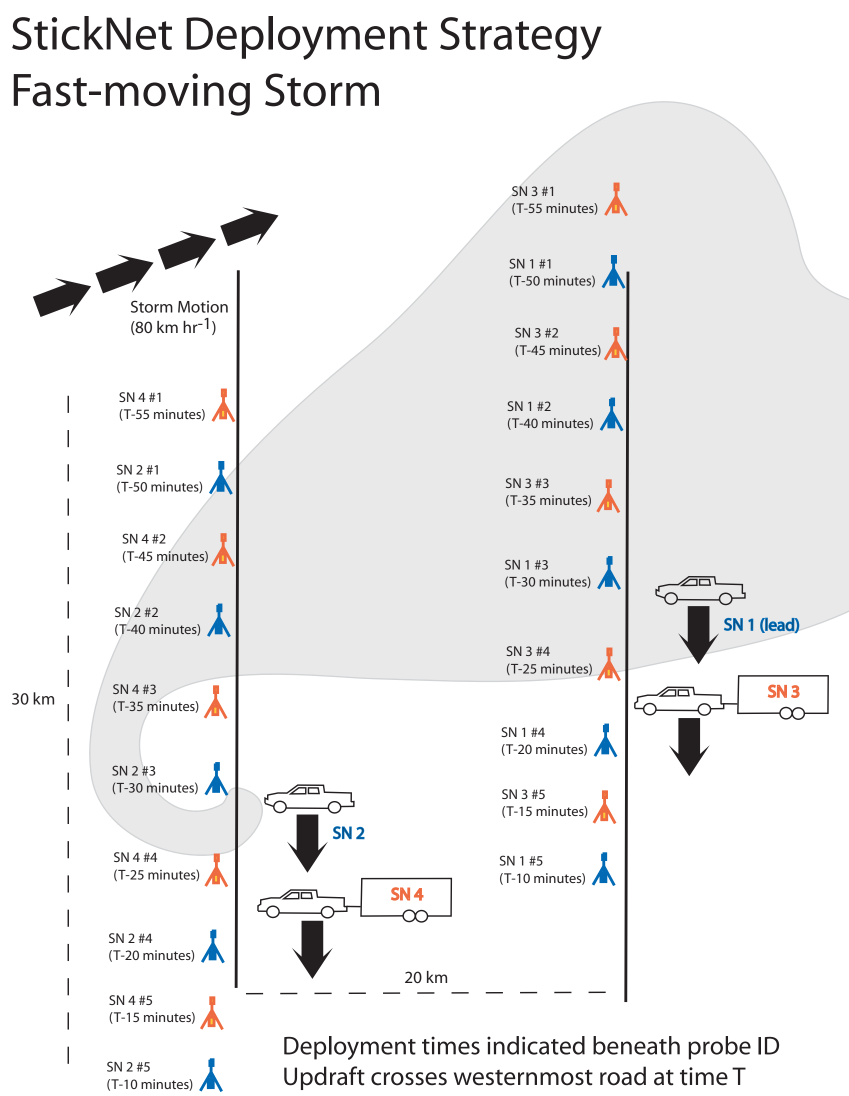

Figure 2.19. Idealized deployment of StickNet for a fast-moving storm. No fine-scale deployment is attempted. Instead, all teams work together to deploy a coarse-scale array, consisting of probes spaced approximately 3 km apart.

spacing. Deployment strategies will vary based on storm motion and also differs between fixed and mobile resources.

For slow-moving storms, the unmanned platforms will be relatively closely spaced and deployed in order to sample the connecting region between the hook appendage and the storm core (Fig. 2.20). The mobile disdrometer and particle probes will focus on east-west transects through the hook appendage, where practical both just north and just south of the low-level mesocyclone, with the expectation of data collection during westbound transects only (eastbound transects may often lack adequate probe-relative winds for useful measurements). Fixed site deployment lines aligned with the storm motion will also be considered on a case-by-case basis (as road networks and storm motion allows) to sample hook appendage DSD temporal evolution characteristics (not

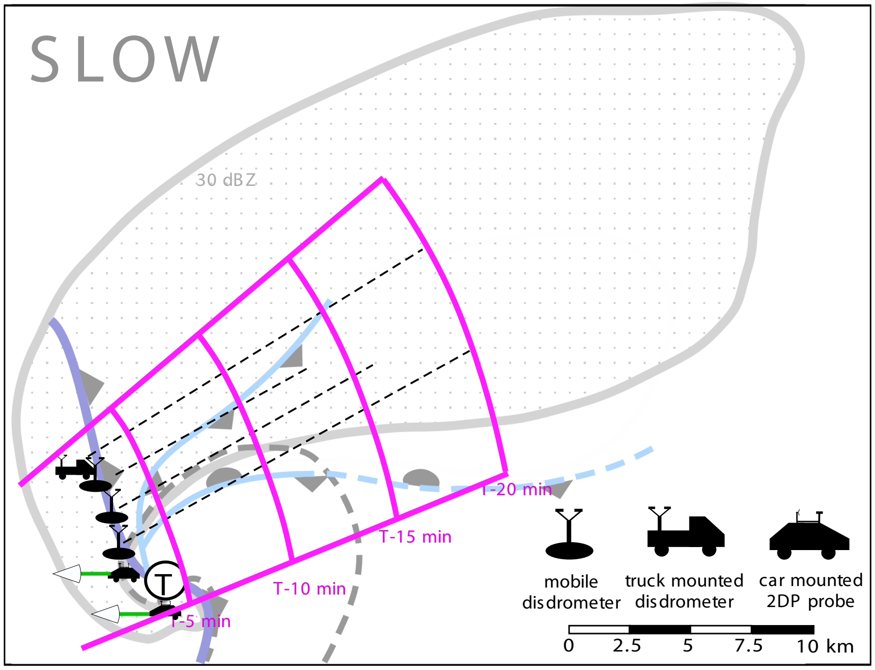

Figure 2.20. Idealized deployment of microphysical probes for a slow-moving storm.

shown).

For fast-moving storms, the fixed laser disdrometer teams will deploy in a picket fence strategy perpendicular to the storm motion in advance of approaching storms (Fig. 2.21). Vehicle borne particle probes will operate in alternating transects across the forward flank region, traveling down the hook appendage as the RFD approaches.

2.3.4 Tornado pods

Twelve tornado pods will be deployed by four vehicles in the path of tornadoes. These vehicles are guided by the radar coordinator. The pods will be dropped in tightly spaced arrays, either in single or double lines, depending on the projected path of the tornado, road conditions and other factors. Deployment time for each pod is approximately 45 s, and driving time between deployments is about 30 s; thus, it requires approximately 200–250 s for a vehicle to deploy all of its pods. Deployments must be completed well before tornadic winds impinge on the deployment vehicles. The preferred direction of deployment is north to south, so that the vehicles can wait south of the tornado. After the tornado crosses the line(s) of pods, they will be collected and the vehicles will proceed south, then east, then north again, to flank the tornado and be in position ahead of the tornado's path.

Tornado pod deployment vehicles may coordinate with the mobile mesonets after they have deployed their pods and are waiting for the tornadic region to cross the arrays.

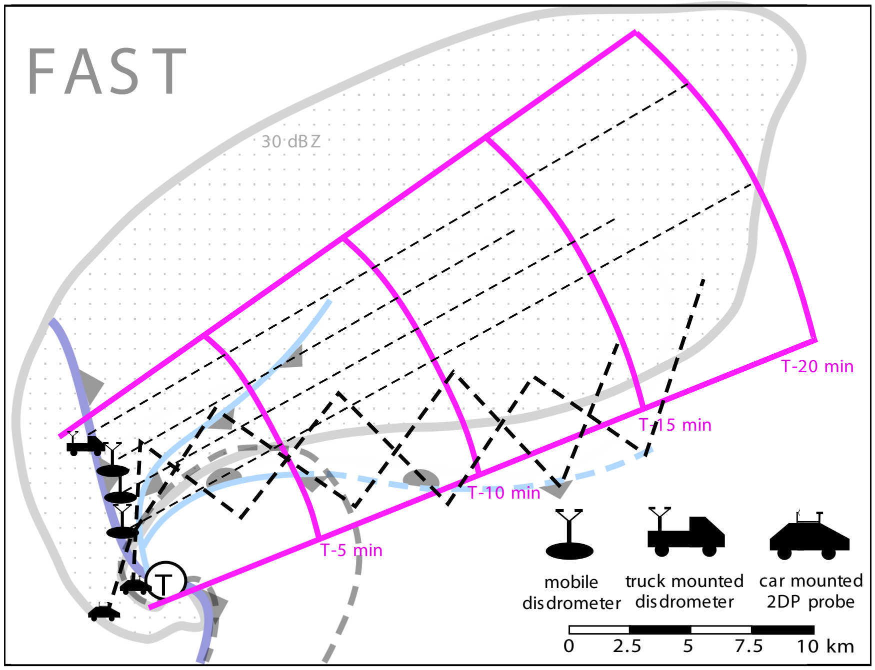

Figure 2.21. Idealized deployment of microphysical probes for a fast-moving storm. The goal is to maximize number of collected samples across storm, with spacing of ∼2 km between fixed sites.

2.4 Unmanned Aircraft Systems (UAS)

Operations of the UAS are limited to the areas defined by the Certificates of Authorization (CoA) approved by the FAA. This restricts operation to only a portion of the VORTEX2 domain (Fig. 1.1). As such, the UAS crew may operate independently of the armada, but will continue to provide vehicle status and science data through SASSI. If at any point the armada will be conducting operations within an area available for UA operations, the UA crew will at that time coordinate participation.

The UAS operations will consist of one aircraft, a command trailer and two tracker vehicles. The trailer is the center for operations, and will remain stationary so long as flights are occurring. The tracker vehicles will be mobile during operations, and have the primary job of transporting UA spotters and providing first person meteorological observations back to the command trailer. UA flights are restricted to being within one mile of a qualified spotter, therefore any sensing will be performed above a tracker vehicle.

The primary focus of UAS deployments will be on collecting in-situ observations within the RFD. The secondary focus will be on collecting in-situ observations across preexisting airmass boundaries in the vicinity of ongoing supercells.

An electronic tethering strategy is assumed in the following scenarios. During electronic tethering the UA is tasked with following the GPS position of one of the trackers. This approach simplifies UA and tracker coordination, facilitates easier spotting, and should provide a more robust communication network between the trackers and the command trailer.

2.4.1 RFD sampling (slow-moving storms only)

Slow-moving storm: Ingress from the east

The objective of the RFD flights is to make stacked traverses through the RFD and across the rear-flank gust front (RFGF) (Fig. 2.22). The control trailer will reach a position right of the storm trajectory ∼10–15 min prior to launch ∼10–15 km from the low-level circulation. The UA will be launched when the RFGF is ∼2–3 km from the control trailer. The UA will head westward at low altitudes (∼500 ft AGL). After passing across the RFGF and through the southern fringes of the hook, the UA will reverse its path and climbs to 1500 ft AGL. The height may be reduced in the event of low visibility due to precipitation in the first pass through the hook. The UA will then travel back across the RFGF into the warm sector while roughly paralleling the storm trajectory. Once having flown several kilometers into the warm sector, the UA will reverse direction and ascend to 2000–2500 ft. As before, the UA height could be modulated based on visibility. The UA will then attempt to make one more pass across the RFGF, reverse direction, and descend to ∼1500 ft, after which the UA will return to the control trailer.

Slow-moving storm: Ingress from the west

Launching from behind the RFGF yields a more cautious entry into the hook because the storm is generally moving away from the control trailer. Thus, if the precipitation is too heavy, the UA can be redirected towards a more southerly flight plan that avoids the heavier precipitation (Fig. 2.23). By launching east of the storm (Fig. 2.22), the egress will be shorter because the control trailer is farther east; thus, more flight time can be devoted to observing the RFD.

The command trailer will take up a position right of the storm trajectory ∼10–15 min prior to launch ∼5–6 km from the low-level circulation. The UA will be launched shortly after the RFGF passes over the control trailer. The UA will head northward toward the low-level circulation and hook at low altitudes (∼500 ft AGL). After reaching the hook the UA will head east towards the RFGF roughly paralleling the storm trajectory. After passing across the RFGF approximately 1–2 km into the warm sector, the UA will reverse its path and climb to 1500 ft AGL. The height may be reduced in the event of low visibility owing to precipitation in the first pass through the hook. The UA will then travel back across the RFGF into the southern fringes of the hook. After passing across the hook, the UA will reverse direction again and ascend to 2000–2500 ft. As before, the UA height could be modulated based on visibility. The UA will then attempt to make one more pass across the RFGF, reverse direction, and descend to ∼1500 ft, after which the UA will return to the control trailer.

2.4.2 Preexisting boundary sampling (slow- or fast-moving storms)

The objective of these flights is to make stacked passes across a preexisting airmass boundary ahead of a storm (Fig. 2.24). The control trailer will reach a position near the preexisting boundary approximately 50 km from the location of the low-level circulation. The UA will be launched perpendicular to the boundary at a low altitude (∼500 ft), and the UA will proceed to execute repeated

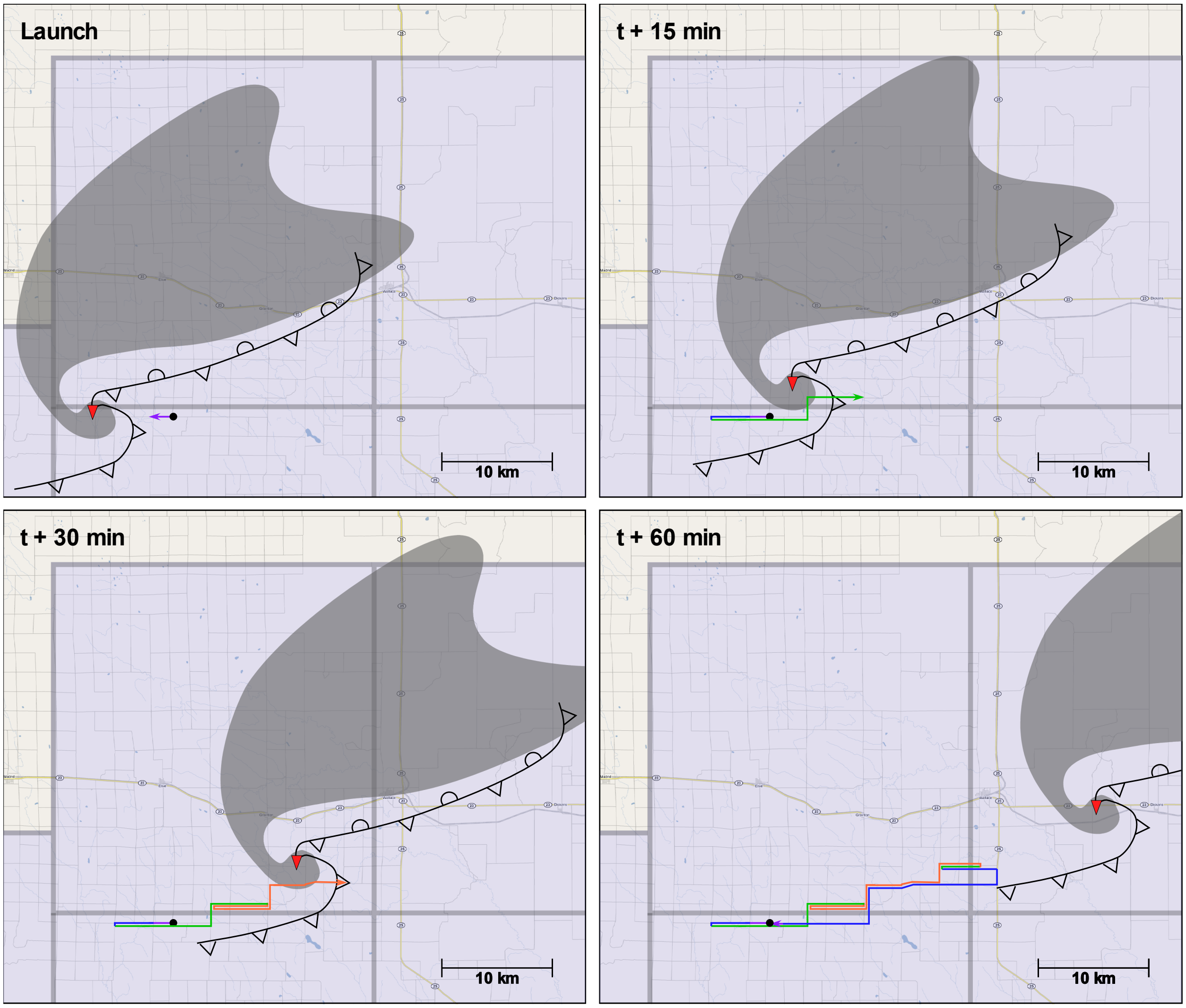

Figure 2.22. Idealized deployment of UAS to sample the RFD of a slow-moving storm from the east.

passes extending from roughly 10–15 km on the cool side to 5–10 km on the warm side. Each reversal of the trajectory is to be associated with a ∼500 ft increase in elevation. The distance of the flights into the cool air may need to be reduced as the precipitation from the storm approaches, and the flight should be completed with enough time to redeploy in the RFD, if feasible.

The distance from the launch location to the storm should be based on the distance the storm will travel in 1 hour plus approximately 15–20 km in order to allow the UA to be redeployed in the RFD following completion of the preexisting boundary deployment. It also means that preexisting boundary deployments can be accomplished regardless of storm motion.

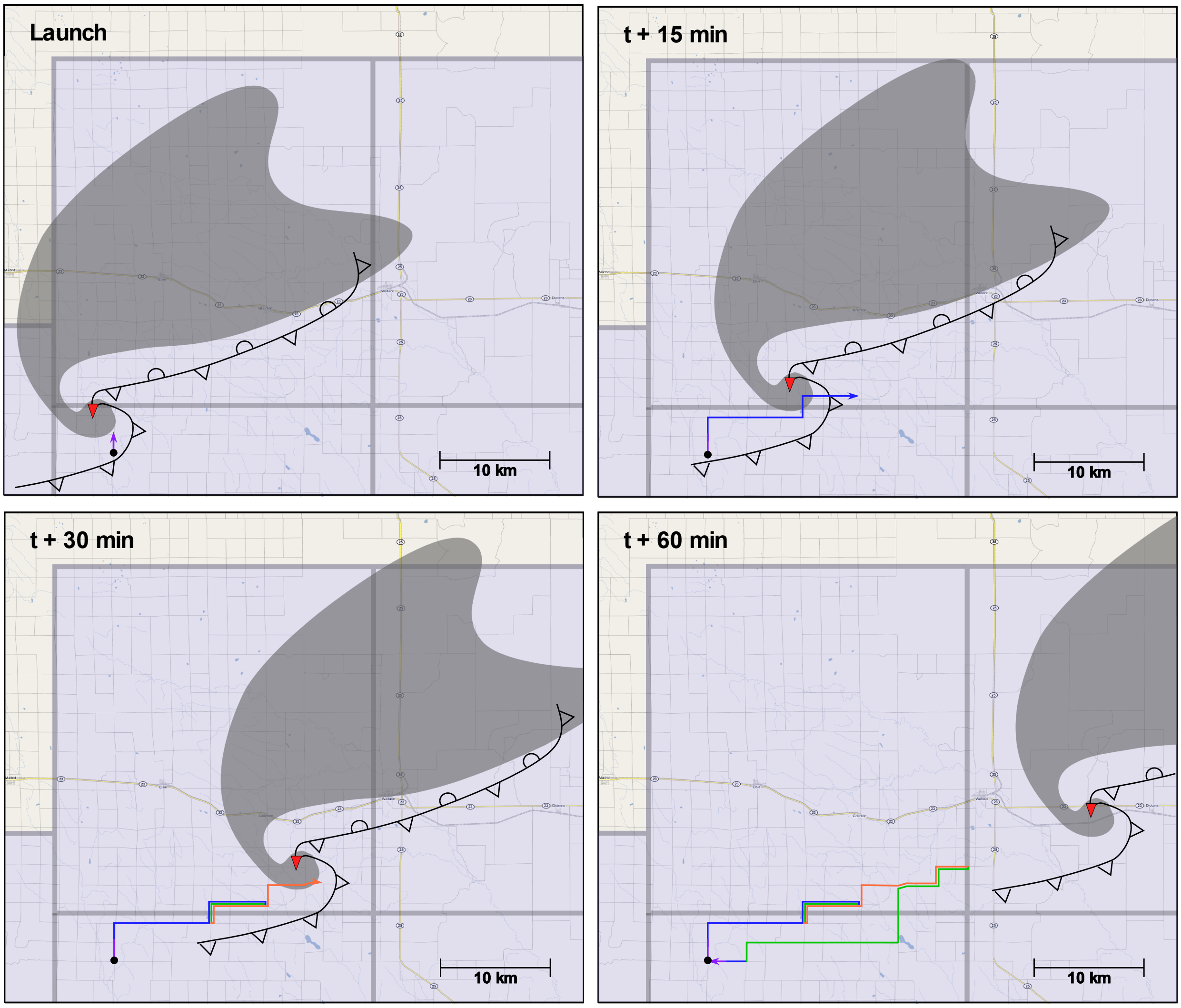

Figure 2.23. Idealized deployment of UAS to sample the RFD of a slow-moving storm from the west.

2.5 Mobile soundings

2.5.1 Overview

NCAR EOL and NOAA NSSL will each field two Mobile GPS Advanced Upper Air Systems (MGAUS; see Appendix B for details), for a total of four mobile sounding systems. The mobile soundings will enhance the observations of the pre- and during-storm mesoscale environments of tornadic storms, with emphasis on documenting both the larger scale forcing features that may be critical to storm formation and the smaller scale environmental heterogeneities (e.g., pre-existing boundaries and baroclinic zones near anvil edges) that may be important for tornadogenesis. Mobile sounding data also will be used along with other field observations and standard operational observations to initialize cloud and mesoscale models, to enhance analyses and diagnostic studies of mesoscale processes, and to establish better the predictability of tornadic and other severe convective events.

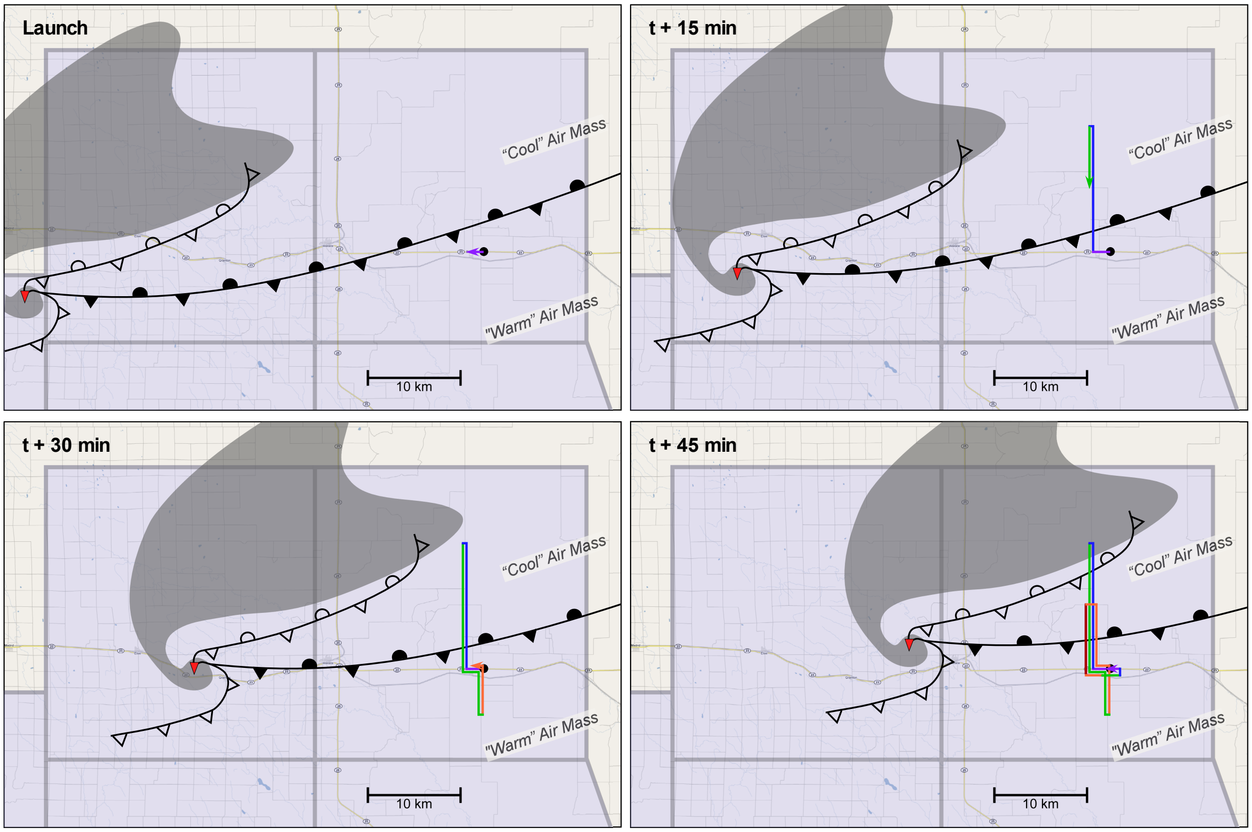

Figure 2.24. Idealized deployment of UAS to sample a preexisting mesoscale boundary.

The mobile sounding systems will be staffed by 2 NCAR-EOL MGAUS specialists, 2 Upsonde Coordinators (M. Parker and G. Bryan), and 5 students from North Carolina State University. The nominal daily schedule for mobile sounding data collection is as follows:

9:00 am – 10:00 am CDT Prepare vehicles and equipment for operations.

10:00 am – 2:00 pm CDT If the VORTEX2 target area is nearby, position the four soundings systems in/near the target area and obtain pre-storm soundings (Fig. 2.25). Otherwise, if the target is far away, drive to the target area in anticipation of operations later in the afternoon.

2:00 pm – 7:00 pm CDT Collect sounding data in the environment near supercells, employing either the strategy for slow-moving storms (Fig. 2.26) or fast-moving storms (Figs. 2.27 and 2.28).

7:00 pm – 9:00 pm CDT Drive to hotel.

The Upsonde Coordinators, in consultation with the Field Coordinator, will set the daily schedule. They could make changes of up to 2 hours to the nominal schedule, depending on the expected and observed weather. On some days, the sounding teams will leave the hotel in the morning 1-2 hours earlier than the other mobile teams in order to obtain pre-storm data. Therefore, the Upsonde Coordinators must stay in contact with the Field Coordinator as the target area is refined. This communication will continue during operations, with the Upsonde Coordinators discussing overall strategy with the Field Coordinator; the Upsonde Coordinators will then plan and implement the specific deployments. Operations will end before dark. During the drive to the hotel after operations, the Upsonde Coordinators will keep the other sounding team members informed about weather hazards and notify them about the schedule for the following day.

The MGAUS units will be deployed on every "go" day. However, the nature of the pre-storm data collection will be situation-dependent.

On days when the VORTEX2 target area is well defined and is close to where the mobile teams spent the night, the MGAUS units will be deployed in the late morning and early afternoon to sample the local pre-convective environment (Fig. 2.25). Three MGAUS units will be deployed roughly 50–100 km from each other, centered on the VORTEX2 target. This target is where mature storms are expected later in the day, not where storms are first expected to form. One MGAUS unit will be deployed closer to the location where storms are first expected to form (e.g., the dryline). An exception will be made if fast storm motions are expected; in this case, the fourth MGAUS unit will join the other three in the target for mature storms.

The purpose of the pre-storm soundings is to give a fuller characterization of the mesoscale environment at times and sites that fall between the operational rawinsonde observations. The soundings will be used both for real-time refinement of the day's forecast, and for retrospective research. Whenever possible, pre-storm upsonde launches will be coordinated (in time and in terms of spatial coverage) with operational NWS/NOAA/ARM soundings and wind profilers. A process is currently under discussion whereby the upsonde coordinators can request supplemental NWS/NOAA/ARM soundings (e.g., at 18 UTC or 21 UTC) in order to supplement the mobile soundings.

The VOC would be responsible for coordinating requests for special soundings. With respect to ARM soundings, ARM will continue to launch four soundings per day, but there is ongoing discussion about whether some supplemental soundings might be possible (per Brad Orr at ARM). Requests for NWS/NOAA special soundings will be through the SPC. The Upsonde Coordinators will communicate their preferred time and location to the VOC, who will then discuss with SPC. These soundings are typically ordered around 8 am CDT, therefore contact with the VOC must be established in the early morning hours. Supplemental NWS soundings can be expected on perhaps a dozen days during the field phase (they are almost a certainty on days with a MDT risk or higher from SPC). SPC can request 18 UTC soundings, or some later time, at their discretion. Additional special sounding requests might be considered by the Texas Mesonet (such requests would be via Chris Weiss). Finally, regarding possible launches at Fort Sill (Oklahoma), VORTEX2 will not have the ability to request special soundings there.

We anticipate that the "all out" strategy depicted in Fig. 2.25 will be implemented on roughly one third of the "go" mission days. On other days, it will be too difficult during the morning to define the target area and/or the teams will need to travel a significant distance to reach the target area. On these days, fewer pre-storm soundings will be obtained and only when feasible. For example, if the VORTEX2 armada is stationary, one or more MGAUS units will obtain pre-storm soundings in the vicinity. If the armada is traveling and nearing the target area, then one or more MGAUS units may stop for $\sim$1 hour to obtain a sounding. If the schedule for reaching the target area does not allow time for significant stops, then it is possible that no pre-storm soundings will be obtained.

If any of these soundings are obtained early enough so that they could complement the 18 UTC

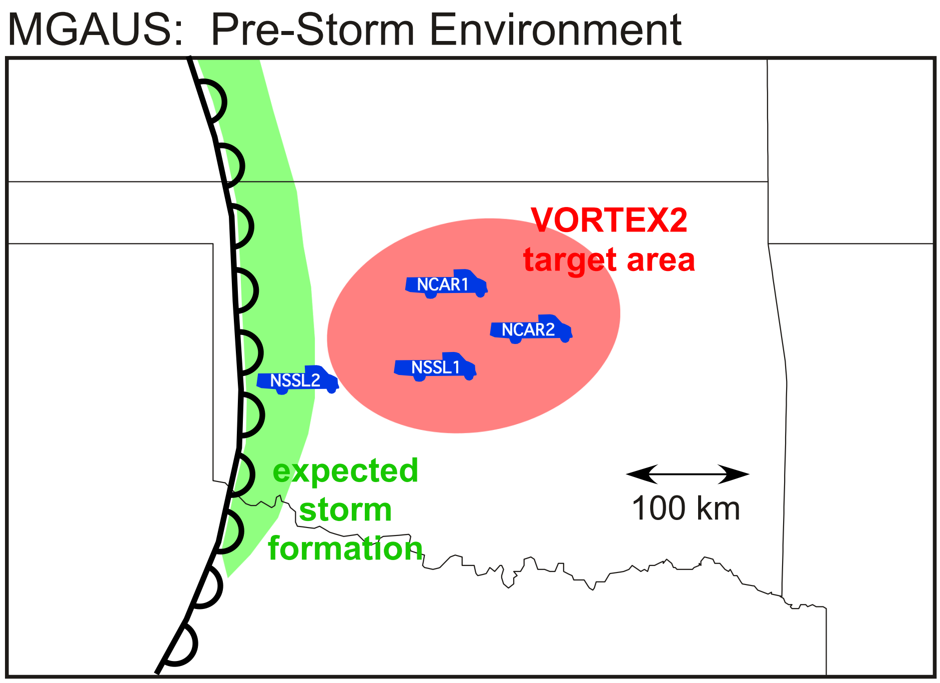

Figure 2.25. Example deployment of 4 MGAUS units in the late morning and early afternoon in and near the VORTEX2 target area.

(1:00 pm CDT) NWS special soundings typically obtained on severe weather days, then these sounding data will be uploaded to the GTS / NOAAPORT data stream that is used to initialize the 18 UTC operational models. Otherwise, sounding data will be uploaded whenever possible to the VORTEX2 Field Catalog in image form so that they can be viewed by the Field Coordinator, the VORTEX2 forecasting and nowcasting team, and NOAA (NWS and SPC) forecasters.

When the Field Coordinator has selected a specific deployment region for coordinated supercell sampling, the MGAUS teams will end pre-storm sampling and move to locations that complement the sampling by other VORTEX2 mobile teams. As determined by the Field Coordinator, the deployment strategy will be based on an expectation of either slow-moving (less than 30 kts; Fig. 2.26) or fast-moving (greater than 30 kts; Figs. 2.27 and 2.28) supercells. One Upsonde Coordinator will be designated for each deployment day and will direct the details of the day's upsonde deployments according to the paradigms appearing in the subsections below. When choosing launch locations, the priorities for upsonde teams will be (in order) (1) safety, (2) solid communications connections (i.e. mobile internet or, minimally, cell phone coverage), (3) launch site free of impediments to balloon preparation and release, and (4) optimal comformity to the deployment patterns above. Apart from some higher-stress forward-flank launches, these four priorities should always be satisfied.

2.5.2 Deployment strategy for slow-moving storms

If a slow-moving supercell is targeted, MGAUS observations will be collected on the right and rear sides of the storm (Fig. 2.26). NSSL1, which is the "lead" unit staffed by the Upsonde Coordinators, will be located 30–50 km to the right of the expected updraft path, obtaining observations through the entire depth of the troposphere. Although no one sounding represents the mean conditions near a supercell, it is expected that these soundings 30–50 km to the right of the storm path will be, in idealized situations, the closest to what might be considered "environmental inflow" soundings.

Two MGAUS units (NCAR1 and NCAR2) will be deployed 10–20 km to the right of the expected storm path. Observations of the lower troposphere are particularly needed in these locations. These observations, together with the observations from NSSL1, will document some of the influences that the storm has on its environment, including forward-flank baroclinity associated with the anvil-shadow edge and the edge of the precipitation core.

NCAR1 and NCAR2 will obtain soundings as frequently as is possible. The nominal sonde cutoff height for the these soundings closest to the storm will be 8000 m AGL. For an upsonde ascent rate of roughly 4 m s^{-1}, a 30-min flight time will be required for each sonde. Assuming that another 30–45 minutes are needed for the vehicles to properly reposition themselves with respect to the storm, and allowing 15 minutes to prepare and release the next sounding, each MGAUS team could release one balloon every 60–90 minutes.

Simultaneous soundings from NCAR1 and NCAR2 would help document the forward-flank low-level baroclinity. However, the mission of NCAR1 and NCAR2 is difficult owing to wind, light precipitation (typically widely-spaced but large raindrops), and the possibility of lightning. Allocating two MGAUS units to this portion of the storm increases the chance that at least one successful sounding will be obtained every hour.

The fourth MGAUS unit, NSSL2, will be deployed roughly 30–60 km behind the updraft. Because the primary purpose of this unit is to sample the upshear environment at mid and upper levels, full-tropospheric soundings are required.

Typically, each MGAUS unit will have to move at least once to maintain its storm-relative position. Therefore, at times mobile data recording will be required. The data-collection strategy will be continued as long as the other VORTEX2 teams are making coordinated measurements.

Upsonde operations will cease at/near sundown owing to safety concerns related to the close proximity to the severe storms.

2.5.3 Deployment strategy for fast-moving storms

When the Field Coordinator has selected a target region for fast-moving supercells, the MGAUS units will be deployed farther apart (Fig. 2.27) than in a deployment for slow-moving supercells. MGAUS teams will be unable to follow individual storms. Instead, teams will typically remain fixed, casting a wide enough net to obtain observations near multiple storms as they move through the target area. MGAUS teams will only move when necessary to avoid severe weather. Ideally, the eventual VORTEX2 target storm would pass through the array of soundings.

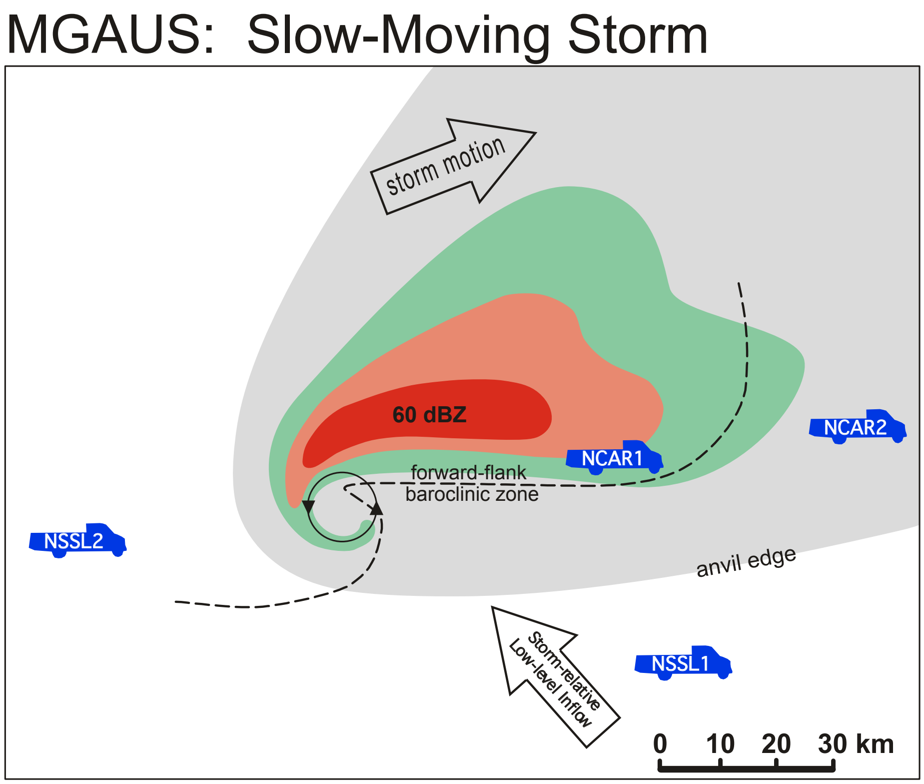

Figure 2.26. MGAUS sampling in the environment of a slow-moving supercell. One MGAUS unit (NSSL1) is deployed 30–50 km to the right of the expected updraft path, on the sunny side of the anvil edge. Two MGAUS units (NCAR1 and NCAR2) are deployed downshear of the updraft, 10–20 km to the right of the projected updraft path, in the shade of the anvil, and in light anvil precipitation. One MGAUS unit (NSSL2) is deployed 30–60 km behind the updraft, in order to sample the upshear environment at mid and upper levels.

The MGAUS units are deployed such that variability both parallel and perpendicular to storm motion is documented. Nominally, soundings will be obtained through the entire depth of the troposphere.

Upsonde operations will cease at/near sundown due to safety concerns related to the close proximity to the severe storms.

When a fast-moving target storm is expected to interact with a well-defined boundary, the Upsonde Coordinators may slightly reconfigure vehicles from the arrangement in Fig. 2.27 into a “boundary deployment” (Fig. 2.28). The goal of this deployment will be to create a three-vehicle “cross-section” through the baroclinic zone so that the gradients in CAPE, CIN, and SRH can be measured (and so that generation of horizontal vorticity can be computed). The themes of the fast-moving storm deployment will remain the same, except that the vehicles will target the boundary as follows: NSSL1 in the warm air, NCAR2 in the cool air, and NCAR1 in the cold air. More frequent soundings that cover only the low and mid troposphere will likely be collected when MGAUS units are properly positioned on both sides of such a boundary.

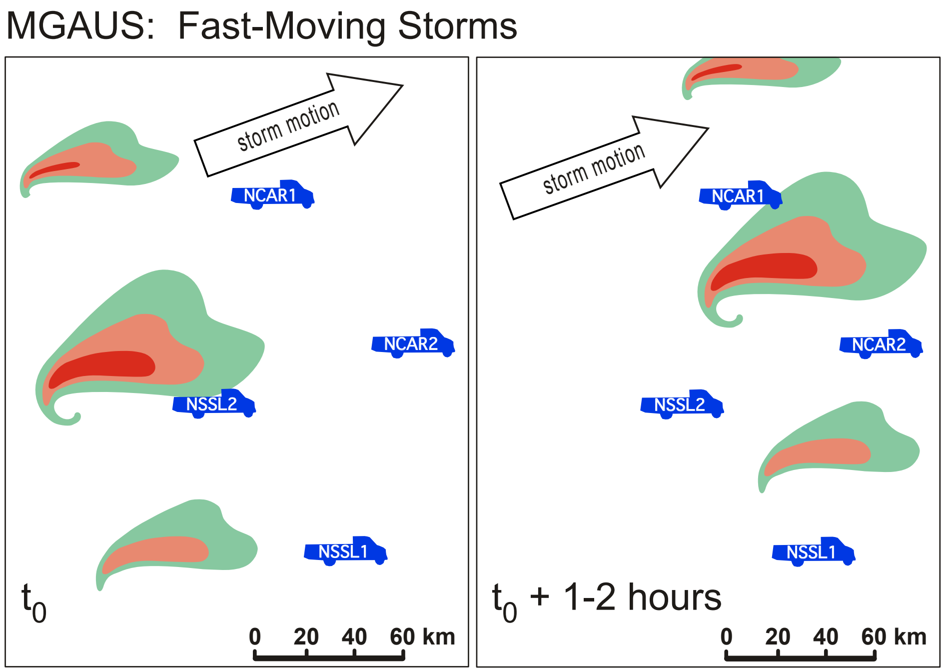

Figure 2.27. MGAUS sampling in the environment of fast-moving supercells. The MGAUS units are spread relatively far apart (50-100 km), in order to obtain environmental soundings near multiple storms. The vehicles generally remain stationary as the storms move through the region.

2.5.4 Redeployment

In all of the above strategies, it is anticipated that it will be quite difficult to continually relocate the sounding vehicles between launches. Nominally, once a particular storm has been targeted, MGAUS vehicles will move no more than once. The reason is that the MGAUS units cannot launch while moving, and require time to find a suitable launch site, set up, launch, and then tear down and receive data. The priority will be to launch sondes more frequently from a variety of storm-relative locations (as the storm moves past) rather than for the upsonde vehicles to be constantly moving (and therefore launching much less frequently). Vehicles will be moved when (a) safety of the participants is threatened, (b) the target storm or deployment plan changes, or (c) we are sampling a slow-moving storm for which redeployment times can be kept small. We can receive data while moving, so when participants' safety is threatened, they should not hesitate to flee the launch site. There is some interest from Parker's group and other PIs in measuring squall line environments and storm interactions. When appropriate, for fast-moving storms, sounding units may stay in place in the post-storm environment and continue to make measurements if additional upstream convection is approaching.

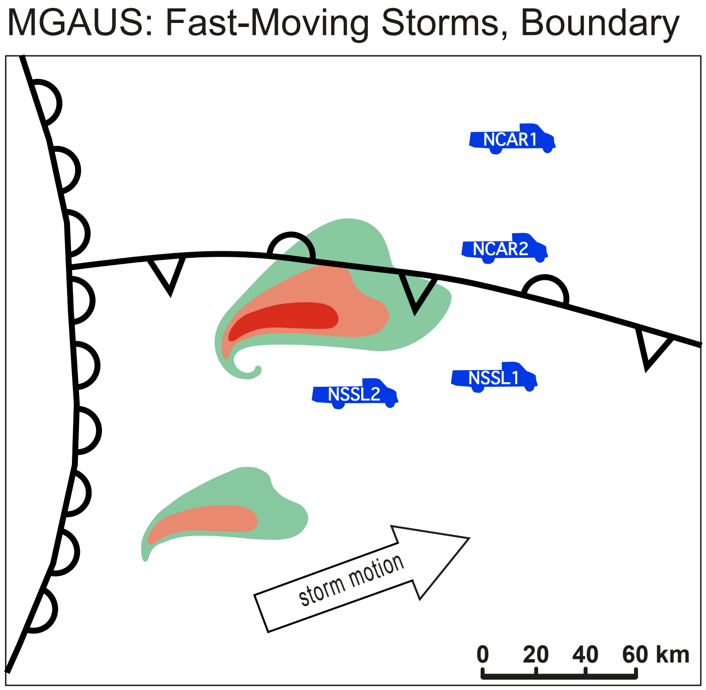

Figure 2.28. MGAUS sampling in the environment of fast-moving supercells, when a significant low-level boundary is expected to influence storm evolution. Three MGAUS units (NSSL1, NCAR1, and NCAR2) focus on documenting the characteristics of the low-level boundary. The fourth MGAUS unit (NSSL2) is positioned where it can obtain one or more soundings to the right of the target storm.

2.6 Oklahoma resources

2.6.1 NWRT-MPAR

The National Weather Radar Testbed–Multifunction Phased Array Radar (NWRT-MPAR) is an electronically steered, S-band radar located on the north campus of the University of Oklahoma. This radar system has the capability to provide targeted electronic scanning of storms within a user-chosen sector size of 90 degrees or less. In spring 2009, targeted scanning of storms will be accomplished using new adaptive scanning software, ADAPTS, developed by NSSL. The ADAPTS periodically (∼5 min) completes a volumetric surveillance scan, which is used to determine where weather echoes are located. Following a surveillance scan, data collection continues contiguously at low elevation angles (e.g., 0.5–2.5°) and is then limited to areas with weather echoes and a limited region around them. Between surveillance scans, ADAPTS (Adaptive DSP Algorithm for PAR Timely Scans), allows the data collection footprint for a given storm to advect and also to expand or shrink in response to storm growth or decay. The surveillance scanning strategy will provide ∼1-min volumetric updates. A scanning strategy developed for specifically for supercells will be employed when these types of storms occur. The supercell-scanning strategy collects high-quality, super-resolution, volumetric data, with finely spaced low-to-midlevel tilts. The temporal resolution varies with height, with the fastest updates occurring at the lowest two tilts. When VORTEX2 missions are near the NWRT-MPAR, the ADAPTS will provide targeted scanning of supercells using the supercell-scanning strategy described above.

2.6.2 WSR-88D dual-polarization radars

There is a good chance that the KOUN dual-polarization radar will be collecting observations during the VORTEX2 field phase in 2010 (but not in 2009). More details will be added closer to the time of the 2010 field phase.

2.6.3 CASA

The Collaborative Adaptive Sensing of the Atmosphere (CASA) radar testbed in Oklahoma is a network of four X-band (3-cm), polarimetric radars near Chickasha, southwest of Oklahoma City (`http://www.casa.umass.edu`). These radars, spaced approximately 25 km from each other, are focused on improving lower tropospheric wind analyses for purposes of prediction and warning of hazardous weather. The CASA radars will be operating throughout the periods in 2009 and 2010 when VORTEX2 will be in the field (`http://wdssii.nssl.noaa.gov/web/wdss2/products/radar/casart.shtml`). When severe weather is within the CASA network, the typical scan strategy includes sector scanning on target storms, plus occasional (roughly every 3 minutes) RHIs and a full 360° scan at one elevation angle.

When VORTEX2 is operating in a fast-moving storm mode in central/southwestern Oklahoma, the project will seek opportunities to collect a combined dataset with the CASA network. Essentially, the CASA fixed network and VORTEX2 mobile network could be combined into a larger network. Since both projects include X-band radars, and thus we would expect possible interference among the radars, the VORTEX2 radars would be placed outside the CASA network, far enough away to avoid interference, but close enough so that the same target storms are observed at low levels by multiple radars.

2.7 Photogrammetry and damage surveys

2.7.1 Storm-scale photogrammetry

In VORTEX2, stereo photogrammetry techniques will be used to create 3D maps of clouds. A pair of teams will trail the storm, photographing the rear side of the updraft when sufficiently free of obstructions to visibility. Mapping of the rear side of the cumulonimbus with respect to radar-derived precipitation and velocity fields will provide new information regarding the location of hook echo precipitation with respect to the updraft and “clear slot.” Perhaps more importantly, we hope to determine if the descending reflectivity core occurs inside the cumulonimbus, straddles the cloud/clear boundary, or occurs significantly outside the cumulonimbus. This information will give us some new clues about the possible thermodynamic forcings of the rear-flank downdraft, and the role of the descending reflectivity core in the RFD. Further, it will be interesting to learn if the streamers of precipitation sometimes seen below the trailing supercell anvil are perhaps the initiators of the descending reflectivity core and RFD. Alternatively, if merging cells are the source of descending reflectivity cores or somehow play a role in the RFD, the rear-side photography should capture this process.

In order to meet these scientific objectives, we require simultaneous photography of the updraft region from the rear. The field of view should contain just the cumulonimbus; the regions to the sides of the CB are not of much scientific interest. The angle subtended from the target to the team baseline should be optimally 90° provided both teams are able to view the same updraft features. The teams will be located approximately 15 km apart and aim to keep the target cumulonimbus within 20 km of their position (Fig. 2.29). They will be initially setting up their baseline to the immediate rear of the hook echo and then allow the supercell to move away from the baseline while still filming. Once the distance to the storm exceeds 20 km, the team will reposition to a point immediately behind the hook echo (Fig. 2.30). In the event of an HP supercell or a cell with obstructed rear view (Fig. 2.31), the photography teams will image the storm from the front side.

High-resolution DSLR cameras will be used with wide-angle lenses set to record at fixed intervals of 1–10 s. The required 0.1° accuracy in azimuth will be met by using two surveyor's quality GPS devices, one (the base) mounted with the camera, the other (the rover) mounted on a tripod approximately 5 to 30 m away within the camera's field of view. The rover will act as a reference point. The GPS devices will require 3–7 minutes to lock into the required positional accuracy, however the camera mount design should allow shooting to commence within that time window. Post-processing of the GPS datastreams should allow for millimeter accuracy of each GPS position. Roll and pitch accuracy will also be measured to 0.1° accuracy with digital protractors mounted on the camera base. This information should be sufficient for cloud mapping photogrammetry without requiring any pre-photogrammetry survey work. The expense and time required for pre-photogrammetry surveys in the past has been one of the main issues preventing the use of cloud mapping photogrammetry for severe storms science.

The teams will synchronize their shooting by cell phone, and possibly VHF radio as a backup. Cell phone coverage should be adequate to be in contact most of the time, however some protocol to carry out the mission will be established if cell phone coverage is poor. Each team will log on a notebook for each static site, photography starting time, GPS location of the base, roll, tilt, focal length, and file names of the base and rover logs. If any of the GPS units, or the camera position moves, a new entry will be made.

Each team will have one member set up the base involving the GPS and the camera, start shooting while communicating with the second photogrammetry team. A second person will set up the rover in the field of view of the camera at least 3 m away from the base, and preferably more. Another person will be monitoring communications with the rest of the VORTEX2 armada, and reporting the activities of the photogrammetry team. A fourth person could help the first person set up the base and rover. At least one team member will continuously document the team's activities.

2.7.2 Tornado-scale photogrammetry and damage surveys

The scientific objectives that will be met by combining detailed damage survey data with the high-resolution mobile ground-based radar and cloud photogrammetry data include the following:

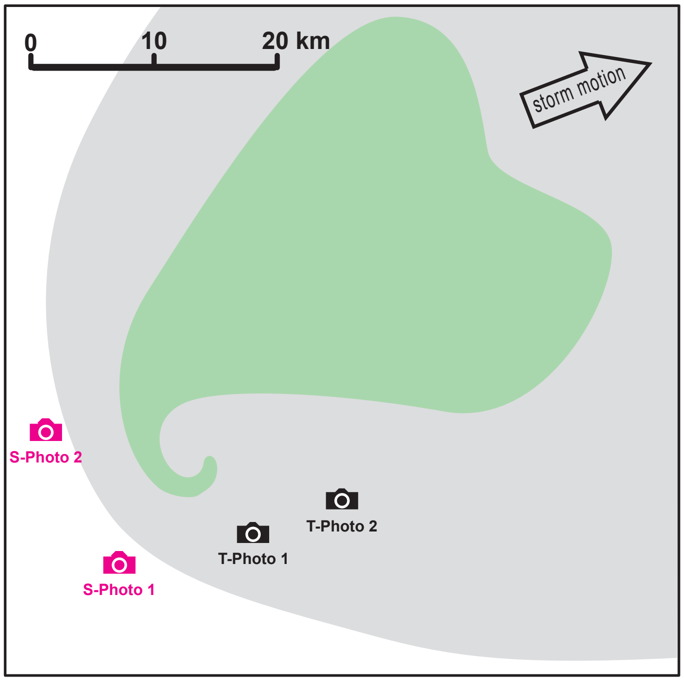

Figure 2.29. The locations of the storm-scale (S-Photo 1 and 2) and tornado-scale (T-Photo 1 and 2) photogrammetry teams in an idealized deployment.

- Investigating the relationship between the tornado and its parent circulation, more specifically:
  - To examine the relationship between the intensities of the mesocyclone and tornado and attendant surface damage intensity.
  - To examine the causes of nonlinear surface damage patterns such as trochoidal and scalloping marks, left and right turns, and sinusoidal patterns.
- Understanding better the structural relationships among the visual characteristics of the tornado, associated damage, and high-resolution radar-detected features within the hook echo such as single-Doppler velocity features, multi-parameter signatures, weak echo eyes, and debris rings.
- Examining the relationship between radar-detected wind speeds with observed damage estimates based on the EF scale.

Following a tornadic event, detailed ground and aerial surveys of the damage path will be conducted using techniques that are well-documented in the literature. The damaged area initially will be located using NWS storm reports, information from VORTEX2 personnel, and radar data. Once the damaged area has been identified, two survey teams led by PIs Atkins and Wakimoto will be deployed for the smaller events. One will perform an aerial survey by flying at altitudes of 500–2000 feet above ground level (AGL). A Cessna 172-RG aircraft will be rented for this purpose. Damage markings such as cusps and scalloping marks are generally only visible in aerial photographs. Owing to the fully mobile nature of VORTEX2, it will be necessary to rent Cessna

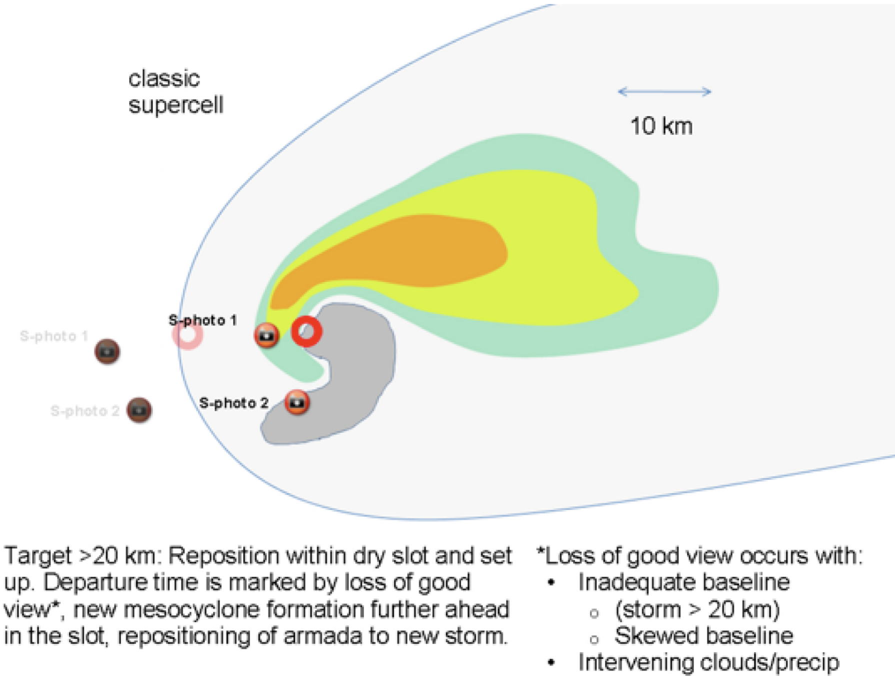

Figure 2.30. Relative locations of the storm-scale photogrammetry teams when repositioning is needed, and then the new deployment locations. The open red circle represents the low-level mesocyclone center. The faded mesocyclone center and photogrammetry teams represent a past location from the start of the previous deployment.

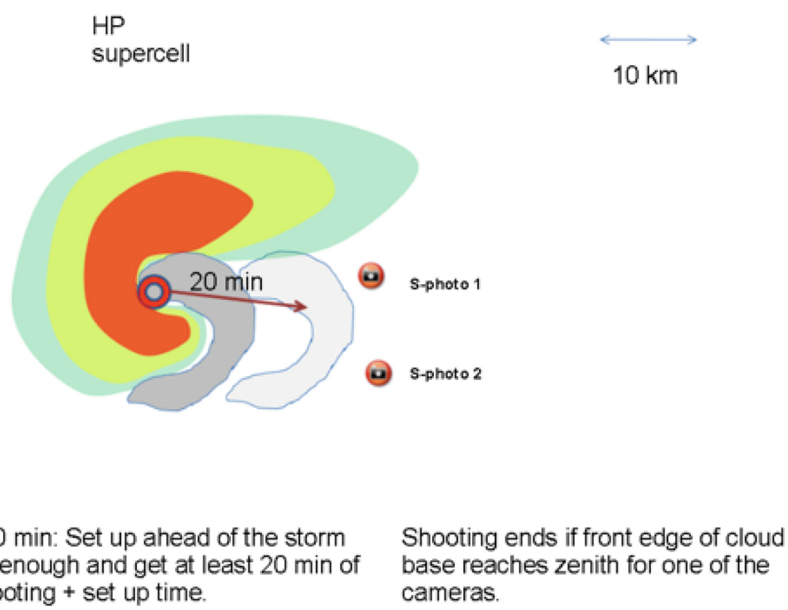

Figure 2.31. Relative locations of the storm-scale photogrammetry teams in the event of an HP supercell.

aircraft from a number of different locations. Rental companies are typically found at the smaller airports within a given region and may be found at `http://www.airnav.com`. The aerial survey team will photo document the damage path with high-resolution digital cameras. Vectors indicating tree fall and structural damage will be drawn on USGS topographic maps. While 1:250000 scale maps will be used to help locate the damaged area, detailed analysis will be placed on 1:25000 scale maps. The ground team will carefully traverse the damaged area photo documenting the damage, mapping out damage vectors, assess the structural integrity of structures, and interview eye witnesses. A preliminary assessment of the EF scale rating will be made in the field. However, it will require detailed analysis of the damage survey data to determine the final EF-scale rating for a given event. Larger tornadic events or a tornado outbreak will require additional survey teams. In this situation, two aerial survey teams may be required. Additional ground survey teams may comprise other VORTEX2 and/or NWS personnel who have experience using the EF scale for damage assessment. The overall damage survey effort will be coordinated by PIs Atkins and Wakimoto.

Chapter 3

Mission planning and execution

3.1 Daily schedule

VORTEX2 will be in the field for up to 35 days (10 May–13 June) in 2009. In an average season, one might expect daily activities roughly as follows:

- 12 operations days ("go" status and afternoon/evening data collection)
- 6 travel days (travel toward future target area, no data collection)
- 9 stationary days (mission reviews, vehicle maintenance, and/or "go" days when we never actually leave the motel)
- 8 down days (no official VORTEX2 activities, other than the morning Steering Committee meeting)

VORTEX2 will be staying in different hotels in different towns throughout the project, arriving and departing at different times depending on mission end times and ferry times. Because weather and geography dictate our schedule, it will vary from day to day. However, the nominal daily schedule presented in Table 3.1 provides an overall sense of the timeline of a typical full operations day.

A meeting to discuss instrument readiness, crew status, the previous day's events, and draft the Plan of the Day is nominally scheduled at 9:00 am each day at the hotel housing the Steering Committee. The meeting is open to PIs (PIs also can join via telephone in the event that the meeting room has limited space or if PIs are not located at the same hotel). Independent input from experienced individual forecasters is extremely valuable for identifying possible weather scenarios; PIs who will routinely have the opportunity to examine weather data overnight and/or in the early morning should come to the meeting prepared to present their perspectives. The Plan of the Day will be posted on the VORTEX2 Field Catalog immediately after the 9:00 am meeting. So that the VORTEX2 Logistics Coordinator can begin investigating hotel options, the Plan of the Day will include an initial estimate of the location where the crews will spend the night. The final location and specific hotels will be selected by approximately 3:00 pm.

Nominally starting at 10:00 am, a Weather Overview (lasting approximately 10 minutes) will be followed by a presentation and discussion of the Plan of the Day (lasting approximately 20 minutes). VORTEX2 will carry an LCD projector for presenting information to the group. Hotel facilities for this morning meeting will vary considerably. Sometimes the facilities will be able to

Time (CDT)	Activity	Parallel Activity
8:00 am	Weather analysis by individual forecasters	
9:00 am	PI meeting to discuss instrument readiness, crew status, previous day's events, and draft Plan of the Day	
10:00 am	Weather Overview and discussion of Plan of the Day	Vehicle preparation
11:00 am	Departure from hotel	Refinement of Day 1 target
12:00 pm	Ferry to target area	
1:00 pm	Ferry to target area	
2:00 pm	Ferry to target area	Refinement of Day 1 target
3:00 pm	Arrival at target area	Refinement of Day 2 target, determination of hotel location
4:00 pm	Positioning downstream of developing storms	
5:00 pm	Storm selection, start of deployment	
6:00 pm	Start of data collection	
7:00 pm	Data collection	
8:00 pm	End of data collection, start of ferry to hotel	
9:00 pm	Ferry to hotel	Update on Day 2 schedule and plans
10:00 pm	Arrival at hotel	

Table 3.1. A typical daily schedule.

accommodate all interested and available project personnel. At other times, when limited space is available, top priority for attending the morning meeting will be for PIs and students.

On some days, departure from the hotel might be urgent, so the morning Weather Overview and Plan of the Day discussion would occur on the road via text chat and/or VHF radio on these days. Another way we can promote efficiency is to accomplish tasks in parallel, such as teams splitting up morning tasks between preparing vehicles and participating in the morning meeting, as indicated in the schedule above.

Again, *schedules will vary from day to day*. As soon as possible (typically during the afternoon or evening), the Field Coordinator will communicate the schedule for the next day's activities through the Field Catalog and, when operations are ongoing, through SASSI text chat.

The schedule above does not mention meals. Individual participants and teams are responsible for developing their own routines. On a typical full operations day, we find that it is usually easy to work breakfast and then either a late lunch or a late dinner into the schedule (but not both lunch and dinner). Participants who have special food preferences/schedules should consider preparing non-perishable meals in advance.

3.2 Project leadership and decision making

Throughout the project, the VORTEX2 Steering Committee (Howie Bluestein, Don Burgess, David Dowell, Paul Markowski, Erik Rasmussen, Yvette Richardson, Lou Wicker, and Josh Wurman), with input from team leaders and other PIs, will make decisions related to target choice, mission parameters, etc. These decisions will be communicated to project participants at the morning Plan of the Day discussion, through information posted on the online Field Catalog, and most commonly (i.e., during travel and operations) by the co-Field Coordinators—Erik Rasmussen and David Dowell—through text chat and/or VHF radio. Information flow and communication methods are discussed in more detail in Section 4. Although a hierarchical communication structure is proposed to promote efficient operations, the structure is not completely rigid. When a VORTEX2 participant has important information to convey, he/she should feel comfortable contacting any other VORTEX2 participant.

Decisions affecting overall project operations will be made by consensus of the Steering Committee, while team leaders will make decisions about specific instrument deployments. Within the Steering Committee, a "mission scientist of the day" will be appointed to make final project-wide decisions at times when a timely decision is needed, but no group consensus has been reached. Mission scientists of the day will be appointed in advance as indicated in the schedule below.

Date	Mission Scientist
10–13 May 2009	Erik Rasmussen
14–17 May 2009	Howie Bluestein
18–21 May 2009	Josh Wurman
22–25 May 2009	Paul Markowski
26–29 May 2009	Yvette Richardson
30 May–2 June 2009	David Dowell
3–6 June 2009	Don Burgess
7–10 June 2009	Erik Rasmussen
11–13 June	Lou Wicker

Table 3.2. Mission Scientists.

3.3 Forecasting and nowcasting

The VORTEX2 operations center (VOC) at the National Weather Center in Norman, Oklahoma (location and contact information in Appendix A) will provide forecasting support for potential field operations, and nowcasting and situational support for the field teams on days with field operations. Mike Coniglio, Patrick Marsh, and Lou Wicker are coordinating VOC activities. The VOC will have the lead responsibility for tracking the evolution of the broad target area prior to storm intercepts, and will provide the "mesoscale view" during intercepts to evaluate whether target changes are necessary. During operations, the VOC will communicate primarily with one of the co-Field Coordinators (FC), who will synthesize the information and convey it to mobile teams through updates at regular intervals (at least every 60 minutes). The FC will also provide more urgent updates to the other teams when appropriate. The VOC will communicate with the FC by text chat and phone.

The VOC will be staffed with four volunteers during the morning and early afternoon forecasting periods (the first shift) and three to four volunteers for late afternoon and evenings during operations days (the second shift). The first shift will be from 8:00 am to 4:00 pm and the second shift will be from 3:00 pm until the field teams no longer need support. The end of the second shift will likely vary from 9:00 pm to 12:00 am depending on the needs of the field teams.

The VOC will have access to the suite of observational and modeling data available to SPC operations. These data will include images/loops of output from special model forecasts being produced for VORTEX2 and the Hazardous Weather Testbed Experimental Forecast Program (`hwt.nssl.noaa.gov`). Hard copies of surface and upper-air charts will also be available for hand analysis. In addition to the terminals available for the morning and afternoon forecasting, the VOC will also have machines dedicated to (1) real-time analysis of regional radar data from the Warning Decision Support Systems–Integerated Information (WDSS-II) display and (2) the Situational Awareness for Severe Storms Intercept (SASSI) display that was developed to support VORTEX2 field operations.

3.3.1 VOC first-shift activities

The collective goal of the first shift from 8:00 am to 4:00 pm is to create forecast products to guide potential day-1 and day-2 operations. The products will include 1) the categorical outlook for supercells and 2) the categorical outlook of a targetable storm. The categories for the supercell outlook will follow the familiar SPC convention of “slight,” “moderate,” and “high” risks. If there is at least a slight risk for supercells, the categories for the targetable-storm outlook will be “low” and “good.” The forecasts for supercells will be based on the potential for rotating thunderstorms, regardless of whether they are forecast to be surface-based or elevated or embedded within convective systems. The outlook for targetable storms will reflect other important aspects of our forecasting, such as whether the supercells will be surface-based or elevated, the expected spatial coverage of storms, and the expected motion of the supercells. This last aspect of the targetable-storm forecast is particularly important since there are different field operations plans for slow and fast-moving storms; a storm speed of 25 kt is being used to determine “slow” versus “fast” storms. The graphical outlooks will be disseminated to the field teams through an image that will be sent to the VORTEX2 Field Catalog.

The daily schedule for the first shift is as follows:

8:00 am – 10:30 am Forecasters work individually to form their Day 1 outlooks and form initial thinking on possible Day 2 operations.

9:00 am – 9:30 am A VOC representative participates in the PI conference call.

10:30 am – 11:00 am A consensus Day 1 graphical product along with a brief discussion is generated from the individual forecasts and sent to the VORTEX2 Field Catalog no later than 11:00 am. This forecast will be particularly valuable for refining the target area at the time when teams are departing the hotel.

11:00 am – 4:00 pm Forecasters continue monitoring the morning evolution inside and outside the targeted area. This activity will include interrogation of several convection-allowing model runs initialized with morning observational data (described below). Forecasters will also refine their thinking for possible Day 2 operations and generate individual outlooks (same categories as the Day 1 outlooks). Communication with the FC will be needed periodically during this time.

1:30 pm – 2:00 pm A consensus Day 2 graphical product along with a brief discussion is generated and sent to the VORTEX2 Field Catalog no later than 2:00 pm. A senior forecaster will discuss the Day 2 forecast with the FC. If no Day 1 operations occur, a scientific summary of the daily forecasts will be created for the VORTEX2 Field Catalog.

3.3.2 VOC second-shift activities (operations days only)

In the field, the Field Coordinators (FC) and other teams will monitor the weather through mobile internet connections and will be primarily responsible for choosing the area/storms to target. However, the FC will often not have the capability to monitor the weather situation in as great of detail and over as broad of a region as what is possible in the VOC. Therefore, the VOC will continuously monitor conditions inside and outside the target area to support the field teams when needed. As mentioned previously, the VOC will typically have the best information available for determining if changes to the target area/storm are needed. Once the field teams are targeting a storm, the VOC forecasters will also be focused on the safety of the armada by monitoring the threat of severe straight-line winds, mesocyclones/tornadoes, or significant hail that could impact the armada, from both the targeted storm and other nearby storms.

Once data collection in the field complete, the VOC will support the safe return of the armada to the hotels. The VOC may be especially valuable to the Texas Tech University StickNet crew, who will be recovering their instruments well into the evening. The final task on the second shift will be to create a scientific summary of the daily forecasts for the VORTEX2 Field Catalog.

3.3.3 Experimental forecast guidance

In addition to having full access to operational weather information on several dedicated terminals, the VOC will have access to experimental forecast products that are being produced under the umbrella of the Hazardous Weather Testbed (HWT) Experimental Forecast Program. Links to products will be available on the HWT web page (`hwt.nssl.noaa.gov`), and a subset of these products will also be available in image form on the VORTEX2 Field Catalog. The experimental forecast products include the following:

GOES-CI product This product will be available for testing in real-time in the VOC as part of the "GOES-R Proving Ground" program with SPC. The algorithm uses observations of cloud top cooling and phase change to anticipate initial development of radar echoes and lightning 30–60 minutes in advance.

Convection-allowing models initialized with 00 UTC data

- NSSL 4-km WRF-ARW to 36 h

- NCAR 3-km WRF-ARW to 36 h
- CAPS 4-km WRF-ARW to 36 h
- CAPS 1-km WRF-ARW to 36 h
- CAPS 4-km, 18-member WRF-ARW and WRF-NMM ensemble

Convection-allowing models initialized with morning/early afternoon data

- 12 UTC-initialized NCAR 3-km WRF-ARW to 36 h
- two 12 UTC-initialized CAPS 4-km WRF-ARW runs to 18 h over the VORTEX2 domain, with and without 3DVar data assimilation
- hourly-initialized NOAA/GSD High-Resolution Rapid Refresh (HRRR) forecasts WRF-ARW simulations with 3.1-km grid spacing out to 12 h†

†Because HRRR output will be available for viewing approximately 3 h after the initialization time, HRRR cycles as late as 18 UTC could be used for guidance in Day 1 operations.

Mesoscale models

- 12 UTC-initialized Rapid Refresh (a 13-km WRF-ARW forecast that could be considered the next-generation RUC) out to 48 h. The model run could be used for both Day 1 updates and Day 2 forecasting.
- Hourly 20-km analyses covering the VORTEX2 domain, generated at NSSL by using an ensemble Kalman filter technique to assimilate surface observations into a 30-member WRF-ARW ensemble initialized with the RUC. The focus of this activity is to improve the accuracy of the surface and boundary layer analyses.

3.4 Field coordination

VORTEX2 is too large and too complex of a project to have a "central command" structure. Instead, the coordination paradigm is a "collaboration of semi-autonomous teams." The Field Coordinator and team leaders will work together to select target storms and develop general deployment strategies. Specific instrument deployments will be the responsibility of individual team leaders, who have the necessary expertise to plan and implement such deployments, and who can make decisions on the relevant (usually short) time scales.

Typically 30–60 minutes after the morning Weather Overview and Plan of the Day discussion, the Field Coordinator will start providing guidance through SASSI (section 4). Initially, this guidance will consist of overall weather synopses at regular intervals (at least every 60 minutes), identification of the target area(s), the current destination, limits to how far teams should proceed, and road recommendations (when possible). The SASSI software also provides graphical information such as vehicle locations, so that teams are aware of how they are located relative to other teams and to significant weather.

From the time that a target storm has been selected and continuing into the deployment on the target storm, the Field Coordinator will also provide projections for target storm locations and characteristics, other updates on the target storm when appropriate, information on weather hazards, and road and other logistical information (when possible). The Field Coordinator will facilitate discussions of overall deployment strategy, sometimes including options for switching to another target storm that is more promising for data collection. During storm intercepts, the Field Coordination vehicle will be parked at locations that maximize VHF and digital radio coverage for the mobile teams in the vicinity of the mesocyclone, cell phone coverage, cell data coverage, and on-station time. An ideal location would be a relatively high spot to the right of the projected updraft/mesocyclone path.

The most dangerous part of the mission is often at the end of a full operations day, when it is getting dark, teams have worked a full day already, and, in many cases, severe weather is increasing in areal coverage. VORTEX2 data collection will cease after dark, if not sooner. As teams leave their deployment locations and head to the motel, the Field Coordinator will continue to provide guidance about the weather situation and other logistical issues (e.g., road information, hotel information, Day 2 plans, etc.) through the SASSI software in both graphical and text form. Safety guidelines, which are important all the time but particularly at the end of the day, are provided in section 6.1.

3.5 Logistics of a fully mobile experiment

VORTEX2 will send approximately 40 vehicles and over 100 people to the field. The project has no "home base" and will require about 100 hotel rooms each night. The home institutions that are fielding instruments and personnel are near the edges of the domain (Fig. 1.1), if near the domain at all. The domain is large, and the north-south extent is particularly significant (it is approximately 900 miles, or more than a reasonable one-day drive, from the north to the south end of the domain). For all these reasons, VORTEX2 participants should keep in mind how challenging it is to repeatedly move such a large experiment into position for collecting data on rare, short-lived phenomena. Our moves should be strategic, and participants should do what they can to contribute to an experiment that is efficient, successful, and enjoyable.

A few specific points to keep in mind:

- A 40-vehicle convoy is neither feasible nor desirable. Essentially, we would end up creating our own traffic jams and delaying our arrival to the target area or motel. Furthermore, many of the towns we will visit will be unable to handle 40 vehicles fueling and 100 people eating simultaneously. Instead, staggered departure / arrival / fueling / eating times will promote more efficient travel. Teams can stay aware of other team locations by relying on the SASSI software (section 4).
- Project participants should consider common-sense guidelines for safety (sections 6.1 and 6.2).

- Project participants should consider common-sense guidelines for fueling etiquette and other behavior (section 6.3).

- To reduce wait times significantly for hotel check-in and check-out, hotel reservations and billing are being coordinated by Ling Chan, VORTEX2 Logistics Coordinator (`ling@cswr.org`, 720-304-9100). Individual teams should discuss hotel arrangements with Ling prior to the experiment, and keep her updated when there are changes to the team's nominal hotel requirements.

- Garage space has been rented in Hays, Kansas (at 4820 N. Vine, map provided in Appendix A). This location is rather central in the domain (Fig. 1.1) and has good access via interstates and major highways. The garage will be available as a dry, lighted space for vehicle and instrument repairs, large enough to house several vehicles simultaneously.

Chapter 4

Communications

4.1 Overview

As detailed elsewhere in this Operations Plan, VORTEX2 will rely heavily on nearly autonomous decision making by the participating teams. Information will flow between observing system coordinators and their team members, as well as from one coordinator to another, via VHF radio, chat rooms, and situational awareness displays (to be discussed below; Fig. 4.1).

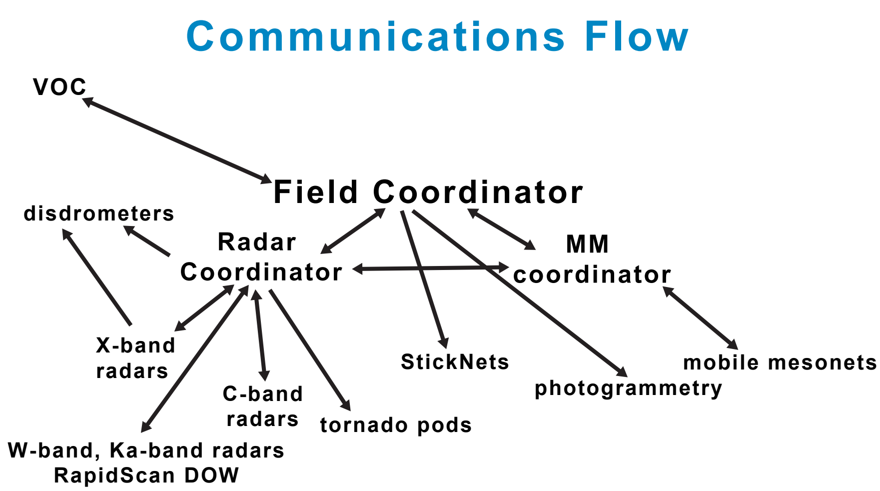

Figure 4.1. Schematic illustrating the flow of information in VORTEX2.

In order for this strategy to be effective, the teams must have the best available real-time situational awareness (SA) information. The requirements motivating the communications and SA design of VORTEX2 are as follows:

- Voice communications must be minimized owing to bandwidth and media constraints.
- Data communications must be as close to real time as possible.
- Data communications must have at least one redundant pathway.
- Situational awareness capabilities should provide enough information for teams to make autonomous decisions whenever possible, while being as simple as possible to use and interpret.

- To the extent possible, communications pathways should be available for use in emergency situations.

4.2 Situational awareness

A situational awareness system has been developed for VORTEX2 by Rasmussen Systems LLC with support from the National Severe Storms Laboratory and the National Science Foundation. For brevity, the software will be called SASSI (Situational Awareness for Severe Storms Intercept) herein. The design goals for this software are as follows:

- Open source
- Cross-platform
- Modern GIS
- Display of state data (mobile mesonet, sounding ob, etc.) using station model symbols
- Display of radar data
- Display of coordinator-generated and nowcaster-generated annotations
- Messaging capability
- Marking capability
- Agnostic as to source of real-time data
- Manage data (e.g. age-off old observations)
- These capabilities are described in more detail below. A separate SASSI User's Guide will be available at `www.rasmsys.com` under the Software and Tools menu category. The User's Guide also will be distributed with the SASSI software and available under the Help menu option of the SASSI software.

4.2.1 Open source

SASSI is an open source software project. At this time, the particular flavor of open source has not been determined. Significant parts of the software system involve the Open Source Qt software framework from Trolltech (`www.trolltech.com`; now Nokia), as well as the open source Quantum GIS (`www.qgis.org`) software framework. The source code for SASSI will be available online from Rasmussen Systems (`www.rasmsys.com`) after the first field phase of VORTEX2. It will be provided with no support, but Rasmussen Systems is contemplating making available support contracts to those who require more than simple source code.

4.2.2 Cross-platform

The software underpinnings of SASSI are cross-platform, and the VORTEX2-specific implementations are written in C++. In theory, SASSI should run under Windows, Mac OS X, and Linux. It is being developed and tested under Ubuntu Linux. As of this writing (1 April 2009), SASSI has been demonstrated under Ubuntu Linux, Windows XP SP3, and Windows Vista. There are no plans for testing and debugging the OS X version, although this port could be done through a contract with Rasmussen Systems. It is recommended that users plan on running SASSI on a Windows XP or Ubuntu Linux laptop, simply because these are the platforms that the author is most experienced with.

4.2.3 Modern GIS

The GIS database contains all roads, public and private, all rivers, streams, lakes, reservoirs, and waterways, all airports, location names, and terrain height. Certain other features are shown, particularly locations likely to have parking areas, in order to help teams select deployment sites. SASSI may provide the ability to view land use data. The primary GIS data source is the U.S. Census Bureau TIGER 2008 database. SASSI will distinguish between limited-access highways, primary highways, secondary roads, private roads, jeep trails, and access roads/ramps. Unfortunately, the TIGER 2008 data do not distinguish between paved and unpaved smaller roads, but SASSI has built-in tools to allow teams to communicate this sort of information.

The GIS database, derived from publicly available sources only, is quite large, and will be distributed on a set of DVDs. Users should set aside at least 20 GB of hard disk space for this dataset. A backup source is a password-protected ftp server at `rasmsys.com` for use by VORTEX2 PIs. Contact `rasm1@rasmsys.com` for further details.

The SASSI GIS provides several resolutions that change as the user zooms in and out. A regional detail provides primary and limited access highways, and will be most useful for viewing annotation information being produced by nowcasters. A state detail adds secondary highways, and will be most useful for selecting routes to target storms. A county detail displays the full suite of GIS data, but no labels on the smaller roads and hydrographic features. This scale is being tailored for storm operations. A local detail shows all roads and their names; this scale will be most useful for finding local route names, shortcuts, deployment locations, etc.

Users are able to turn off GIS layers and/or shuffle them to different heights in the stack of layers being viewed. Road labels can be also be toggled in order to improve map legibility. Beyond this, for the first field phase of VORTEX2, the decision has been made to not allow users to customize the GIS display. There are two reasons. First, support generally is not available to help users who make poor customization decisions and do not understand how to revert to good properties. Second, although each user's SASSI display will generally be different because of zoom level, panning, different types of data arriving at different times, etc., it is felt that common display properties will enhance collaboration and communication.

4.2.4 State data

Various observations are best visualized using conventional station model plotting symbols. Mobile mesonet observations is one example. Similarly, it is feasible to visualize UAV observations and rawinsonde observations using plotting model symbols (this was possible during IHOP in the Field Coordination software, where both balloon observations and research aircraft observations were plotted using station models). The key will be to ensure that these observations are available in the standard ”mm” observation format and transmitted uploaded to the digital communications network.

SASSI has an age-off period for state observations that defaults to five minutes. It is anticipated that each platform will make its state observations available every 30 s or so. Observations will be “dimmed” as they become older so that the user is instantly aware of which data are freshest. At the user’s discretion, the age-off feature can be disabled and only the most recent state observation from each platform is displayed. SASSI has the ability to display derived thermodynamic fields as part of each station model. Derived fields include dewpoint, mixing ratio, potential temperature, wet-bulb and wet-bulb potential temperature, and equivalent potential temperature.

4.2.5 Radar data

SASSI will display full-resolution WSR-88D base scan reflectivity data from all radars proximate to the operations area. There are no immediate plans to make velocity data available, but this can be reconsidered. As of this writing, SASSI will include low-elevation data from the DOW7 mobile Doppler. SASSI has the capability to display DORADE sweep scans, that could be generated by the SMART-Radars. The availability of these scans is not certain.

Based on the position of the team using SASSI, the software will display the lowest-resolution radar data at the bottom of the stack, and successively layer higher-resolution data at higher levels. Thus the most detailed data will obscure the least detailed. Radar data will be replaced when fresher data become available, and data will be removed from the screen if it is older than an age-off period.

4.2.6 Annotations

Certain teams will be allowed to add annotations to their displays that will be disseminated on the MDN. This will include all coordination teams. Annotations will be simple polygons, point markers, arrows, and text. An example might be an annotation that shows expected mesocyclone locations over a certain period of time. Another example would be a forecast from the experiment nowcaster showing the location of imminent convection initiation. The annotations are color coded based on the identity of the coordinator who issues them. Annotations will have a termination time after which they will disappear from all of the SASSI displays. As with all display layers, annotations can be toggled on and off to change the level of clutter and detail in the display.

4.2.7 Messaging

A rudimentary chat system has been built in to SASSI. This system shows messages with backgrounds color-coded to match the icon of the originating team, and an icon matching the one used to depict the team on the map. Messages are time-stamped. If the author requested a message acknowledgment, the message has the abbreviation ACK attached to it, and will not disappear from the unread messages queue until the recipient chooses the message, and presses an ACK button. Upon taking this action, SASSI generates a response along the lines of “ACK your 2312:15 UTC” and sends it back to the author. A more traditional response also serves as an acknowledgment.

Messages that have not been read are shown in bold text at the top of the message queue, grouped with all unread messages from the same team. Messages that have been read are in displayed in plain font, moved toward the bottom of the message display area, and shown in chronological order. If a user clicks on a message in their chat queue, SASSI is ready for the user to begin typing a response. The recipient list is filled out automatically. If a user wants to originate a message, there is a dropdown list of addressees to choose from, including sublists of their own platform type, their own institution, all coordinators, all teams, etc. The final list of recipients can be hand-edited.

If time permits before the VORTEX2 field phase, a means will be developed to notify the recipient of a chat message of its source. For example, the icon of the message author may blink a few times, and if the message requires acknowledgment, the icon may blink until the message is acknowledged. This chat system is fairly similar to many ”IM” systems that are freely available, except that it has been customized to help the user identify the sender in the context of VORTEX2, and to reduce the chance that the user will ignore important messages from other users. At the same time, it does not interfere with or obscure the mission-critical aspects of SASSI. The chat system integration also means that users do not have to switch applications in order to do inter-team chat. The main drawback to SASSI chat will be the latency because SASSI only reads the Incoming data queue every 30 s.

4.2.8 Marker communication

SASSI has a set of markers that can be dropped onto a map, along with hidden annotations. Many of these deal with road hazards, such as paved road, pavement ends, slippery pavement, slow traffic, debris in the road, etc. Others have to do with operational logistics, such as no parking available, parking available, radar parking available, etc. Yet others have to do with hazardous weather, such as small hail occurring, large hail occurring, etc. When a team encounters any of these markable features that other teams ought to be aware of, they simply press the marker button in their toolbar. They are then allowed to add additional text information, and press “Send.” The markers then show up on other user’s maps.

At the sender’s discretion, a marker can be made “permanent” and will not be deleted from the user’s displays. A good example of a permanent marker would be “paved,” “pavement ends,” and “radar parking available” because these conditions are not likely to change over the course of a year or two. Otherwise, the marker expires at a time based on the sender’s best estimate of when the condition might change. The text annotation that is added to a marker becomes visible when the user hovers the mouse cursor over the marker.

4.2.9 Flexible data source

SASSI cooperates with a data ingest application written by Doug Kennedy of NSSL. That application monitors a server at NSSL and the FreeWave-based Mobile Digital Network, and places any data that the user has not seen into the Incoming directory of SASSI. The data ingest software will manage these connections invisibly and maintain all needed realtime data on the user's system. There will be times when no data are available, which is the reason this Operations Plan emphasizes team decision-making based on science objectives combined with the best available data, which could simply be visual observations.

The realtime clock on the SASSI display has a background color that indicates the amount of time elapsed since the last valid data ingest. If it is green, ingest is operating normally. As it transitions to red, the user has been out of contact with any viable data source for a period of several minutes. If the user has a critical need for new data, it might be necessary to stop on high ground or near a community where either the mobile digital communications with the Field Coordination vehicle, or cell phone internet connectivity with NSSL, can be established.

4.2.10 Miscellaneous tools

SASSI provides a few other tools useful in storm intercept. There is a ruler that measures azimuth and range as the mouse is dragged from one point to another. Readout is in degrees, and both kilometers and miles. Another tool shows dual-Doppler lobes based on the user clicking on one (potential) radar site, and dragging the mouse to the second (potential) radar site.

4.2.11 Data management

SASSI will automatically handle the tasks of making sure the data on the display are current and valid. Either SASSI or another background application will ensure that old data are deleted to prevent problems with memory media. SASSI archives all data that arrive during the course of a mission day, and has a playback mode so that the entire day's data can be played back sequentially at some multiple of realtime.

4.3 Communications hardware

There are a broad set of experiences that many of the VORTEX2 PIs have with communications in the field during the years since VORTEX1. Obviously, cellular and satellite technologies have advanced considerably since VORTEX1. There has been an active discussion of a "hardware communications specification" for VORTEX2 communications within the steering committee, and part of the NSSL and OU spring experiment in 2008 was dedicated to testing several technologies.

The hardware is designed to provide the SASSI display to the end user, and to be able to upload, when possible, information from the platform (e.g., location, radar sweep, mobile mesonet data).

The emerging principle that our combined experiences suggest is (a) multiple cell phone providers, (b) a Mobile Digital Network (MDN) based on 900 MHz IP modems, and (c) VHF radio. The success rate with an individual cell phone service (ATT, Verizon, or Sprint) over any given area appears sporadic at best. Multi-vendor capability (generally, we believe Sprint and ATT, or Sprint and Verizon) seems imperative. The MDN will be critical to providing real-time data feedback to the Field Coordinator (FC) vehicle around the storm, as well as providing a way for each PI to access the SASSI information directly from the FC rather than using cell phone internet to download it from a server at the National Weather Center. Based on our discussions, the NSSL/OU spring tests, and some additional late summer testing, NSSL has come up with a set of equipment that we believe meets these specifications as well as possible. We also designed the system such that PIs and students who already have cell phone data plans could potentially "plug into" this system. Further details are below.

If you will occasionally/frequently operate within 25 km of the FC vehicle typically located near the periphery of the supercell updraft, to the right (south) of the path of the storm you should strongly consider the MDN as your primary data source. The MDN will have lower latency than cell phone internet, and may be available at times/locations when cell phone is unavailable. Receiving/sharing data via the MDN requires all of the equipment in Table 4.1.

Item	Approximate cost	URL
FreeWave 900 MHz radio FGRplus	$1680	`http://www.freewave.com/products/product-187.html`
FreeWave antenna model EAN0905WB	$200	`http://www.freewave.com/subpage.aspx?pageid=165`

Table 4.1. MDN hardware requirements.

NSSL will make available software to capture MDN data to disk, where the SASSI application will read it and display it. NSSL can also provide advice as to how to distribute realtime observations to other times via the MDN.

All teams are strongly advised to have cell phone internet capability. This provides a redundant data I/O system for MDN users, and the only data I/O system for those not able to use the MDN. The following are recommendations of cell phone internet systems based on NSSL's testing and experience.

First, a reliable "high-end" solution requires the items in Table 4.2.

Item	Approximate cost
Internet-In-Motion with Sprint card	$1300 + $60/mon
Cradlepoint MBR1000 router	$250
Wilson cell phone amp & external antenna	$325
ATT cell phone card and plan	$100 + $60/mon

Table 4.2. A "high-end" cell phone internet system.

A cheaper alternative to the internet-in-motion is Autonet's mobile internet system. The hardware is $500, and the service is inexpensive (~$30/mon). They use Verizon/Alltel and are supposed to roam on Sprint. Several commercial chasers have tested these and have been given positive reviews. From NSSL's research, there are questions about using Verizon as the primary provider in VORTEX2 domain, although their purchase of AllTel has likely improved their network.

A less expensive configuration for cell phone internet capability is outlined in Table 4.3. Also see Fig. 4.2.

Item	Approximate cost
Cradlepoint MBR1000 router	$250
Wilson cell phone amp & external antenna	$325
ATT or Sprint cell phone card and plan	$100 + $60/mon

Table 4.3. A less expensive configuration for cell phone internet capability.

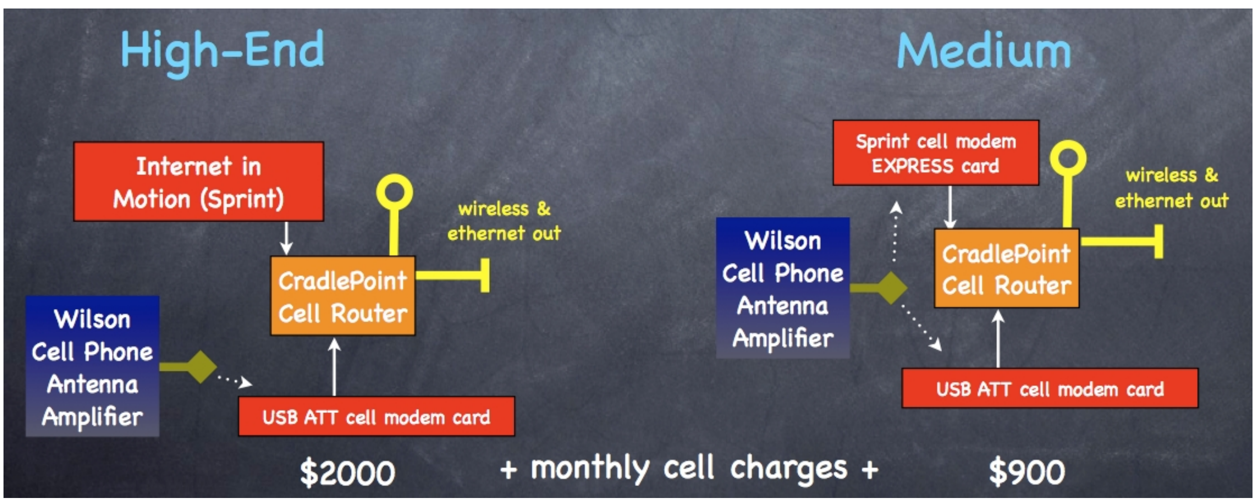

Figure 4.2. Two possible communications hardware configurations.

NSSL will make available software to retrieve situational awareness from an internet server at NSSL. The intent is for the MDN and cell phone data sources to be as redundant as possible, and for the user's SASSI software to utilize whichever data stream is available. In addition to the digital communications capabilities described above, a VHF radio (~$300) is required for all teams requiring voice communications with one of the VORTEX2 coordinators. The VHF voice channels are discussed further in section 4.4. Though the cost of these system may seem large, the success of the program is likely to be determined (aside from the weather) by our ability to transmit and receive information to and from the FC and the individual vehicles, and the costs listed above are rather small relative to the costs of travel, salary, and fuel.

4.4 Radio communications

4.4.1 Frequencies

The following frequencies (MHz) are authorized for mobile use throughout the VORTEX2 domain. They are authorized on a non-interfering basis. This means if we cause interference to another group, we must change frequency. This is accommodated by providing primary and secondary frequencies for each group.

A. Coordination frequency This frequency is so the group coordinators can discuss strategic planning related to storm targeting, storm abandonment, mission design, and other issues. The main vehicles/people talking on this frequency are the following vehicles: Field Coordinators, Radar Coordinator, Mobile Mesonet Coordinator, Sounding Coordinator, Sticknet Coordinator, UAV Coordinator. Since this frequency will be on a repeater, it may be used in urgent situations when a team has lost contact with its coordinators. But, it will be rare that an individual team will need to communicate on this frequency.

Primary Talk: 163.1 Listen: 163.1 and 165.435

Secondary Talk/Listen (no repeater): 161.1

B. Radar frequency This frequency is used for radar coordination. In addition, the Disdrometer and photogrammetry teams that are tightly linked to radar deployments will use this frequency. This frequency will be heard by DOW7 and DOW6 which will be somewhat centrally located and which may have 56 masts erected for additional range, so may be used in urgent situations when a team has lost contact with its coordinators.

Primary Talk/Listen: 161.5

Secondary Talk/Listen: 161.4

C. Mobile mesonet frequency This frequency is used by mobile mesonet communication.

Primary Talk/Listen: 151.7

Secondary Talk/Listen: 151.76

D. Tornado pod team frequency This frequency is used by Tornado Pod Teams (and will be used for TIV-DOW communications). This frequency will be monitored by DOW7, which may have a 56-foot mast extended, so it may be used in urgent situations by teams who have lost contact with their coordinators.

Primary Talk/Listen: 161.3

Secondary Talk/Listen: 161.2

E. Sticknet intra-team frequency, SR and NOXP intra-team frequency, MGAUS intra-team frequency This will be used for intra-team coordination, such as stick placement, SR/NOXP scouting, and similar uses.

Primary Talk/Listen: 161.0

Secondary Talk/Listen: 160.9

F. DOW and tornado pod team tracking This will be used for APRS packets for DOW and tornado pod team tracking. A DOW support vehicle will monitor this channel to listen for conflicting users.

Primary 151.94

Secondary 151.82

G. UAS Frequency / Spare 1

Primary Talk/Listen: 160.85

H. OU-Photogrammetry / Spare 2

Primary Talk/Listen: 160.80

4.4.2 Radio communications protocol

All participants are expected to follow the following rules for VHF radio communication in VORTEX2.

- Keep communications brief, particularly during active mission periods. Your transmitter will be active, and could prevent other teams from communicating. Further, all teams will be able to eavesdrop on the conversations going on in your vehicle.
- No idle chatter until after operations are completed.
- Our communications channels are monitored by outside groups. You are representing public funding agencies, universities, and government laboratories. Be professional.
- There is great temptation to broadcast the existence/formation of tornadoes over the radio. Extra caution has to be exercised in these cases to avoid the “yelling fire in a crowded theater” effect. Unless such a broadcast is necessary for the safety of others in the fleet, unless the tornado has not been otherwise observed, such announcements are to be avoided.
- Cellular phone is the communication medium of choice if you need to speak privately with another participant. Contact numbers can be found in the Appendix. If you can communicate effectively using the chat feature of the SASSI software, please do so. The advantages are minimized radio chatter, and a written record of communications. However, sometimes time is of the essence in communications, and voice is the only suitable method.
- Your radio should be programmed with the channels that you are allowed to use for your team’s communications (section 4.4.1).
- When initiating contact, follow the following to/from protocol example: *“FC, PROBE1.”* (Think: FC, this is PROBE1.) FC will respond with *“PROBE1, go ahead”* or *“PROBE1, stand by.”* You may proceed if you receive the go-ahead for communications.
- If you hear and understand radio conversation directed to you, respond with your ID and the word “copy”, e.g. *“PROBE1, copy.”* If you did not understand, respond with your ID and the message “please repeat”, e.g., *“PROBE1, please repeat.”*

- Keep communications as brief and terse as possible, while at the same time communicating clearly and unambiguously.

Chapter 5

Education and training

The VORTEX2 field project will offer a tremendous opportunity for the education and training of undergraduates, graduate students, and post-docs, many of whom will serve as crew members during the field project. Crew members will receive training specific to their mission from their respective PIs, generally either at their home institution or in Norman prior to the field project. Beyond the training for their specific mission, these young researchers will be exposed to an intellectually rich environment full of high-level discussions regarding severe storm forecasting and dynamics. Students will take part in the daily weather briefing for the VORTEX2 armada during which the Plan of the Day will be presented by the Mission Scientist, such that students are fully informed regarding data collection strategies and goals for the day. Students will lead mission debriefings, where quick-look images summarizing data collection from the previous IOP will be examined to evaluate the effectiveness of deployment strategies and to determine any adjustments that should be made in future IOPs (Table 5.1). Students likely also will be involved in generating these quick-look images and evaluating their own data collection efforts.

We believe the experience of witnessing storms in person and observing their development and evolution is of tremendous educational value. Because students will be paired with more experienced chasers, they will have ample opportunity to ask questions and learn about storm dynamics first-hand. In addition to these informal scientific discussions sure to occur in every vehicle, we also propose more formal learning via a VORTEX2 journal club in which at least one classic journal article per week is read and discussed. Discussions will be led by a PI on down days and may be supplemented with a background lecture/seminar. Topics chosen based on group interest are likely to include supercell dynamics, tornadogenesis, downdrafts, radar basics, polarimetric observations and related fuzzy logic methods for categorizing hydrometeors, and convection initiation.

The media presence expected during VORTEX2 offers an opportunity for educating the general public about research methods and the outstanding questions regarding tornadic storms. Other opportunities for outreach to the general public (local newspapers, schools, etc.) are likely as the armada travels to small towns and cities throughout the Great Plains.

Finally, the data collected during VORTEX2 are sure to serve as an integral part of several masters theses and Ph.D. dissertations and will be shown in university course lectures for years to come, just as observations from IHOP_2002 and BAMEX are now.

Dates	Group
May 10–15	Penn State
May 16–21	Texas Tech
May 22–27	Univ. of Colorado and CSWR
May 28–June 1	Lyndon State and NCAR
June 2–7	North Carolina State
June 8–13	Univ. of Oklahoma

Table 5.1. Schedule of groups responsible for presenting mission debriefings.

Chapter 6

Hazards, mitigation, and etiquette

6.1 Weather, storm intercepts, and personal safety

VORTEX2 is a large government funded project involving universities, government laboratories, and private organizations. VORTEX2 will have a high profile in the areas where it operates and will receive extensive media coverage. It is important that all crew behave safely and are perceived as behaving safely. It is important that they behave and are perceived as behaving in fashions that reflect well on VORTEX2, its sponsors, and all of the participating organizations.

VORTEX2 will send over 40 vehicles and 100 people to the field, and we will drive about 10,000 miles each season. VORTEX2 will operate and ferry through regions experiencing severe weather including heavy rain, hail, lightning, and high winds, not to mention tornadoes. We will be sharing the roads with numerous other vehicles driven by storm chasers, media, local residents, other travelers, and emergency personnel. Traffic jams will occur, particularly during weekends, near metropolitan areas, and when storms are isolated and/or long lived. Driving ability and confidence varies greatly in sub-ideal weather conditions. Many people who are watching our target storms will be only marginally aware of their surroundings. Therefore, we must be aware of them.

So that we complete our mission safely, we ask all VORTEX2 participants to follow these specific guidelines:

- Drive within the speed limit.
- Drive within a reasonable speed given the weather, road and traffic conditions. Hydroplaning on puddles, reduced visibility in rain and hail and dust, cross winds, stalled vehicles, and perhaps downed power lines and other debris in the road are considerable risks and may require reduced driving speeds or even pulling over and waiting until conditions improve. Know your personal limitations.
- Avoid dirt roads, which can quickly become muddy roads if rain begins falling. The probability of getting stuck on a muddy road, or worse yet sliding into a ditch, is greater than the probability of getting a better dataset as a result of having taken such a road.
- Be extraordinarily wary of other drivers, particularly in severe weather conditions. Many drivers are not proficient in severe conditions. Many, including storm chasers, are distracted by the severe weather and might not be paying enough attention to safety themselves.
- Be extraordinarily alert for storm chasers stopped in the road.

- Be extraordinarily alert for storm chasers or other people on the road.
- Be extraordinarily alert for unusual behavior by VORTEX2 radar trucks, balloon launchers, mobile mesonets, tornado pod deployers, sticknet deployers, etc. These vehicles may stop or maneuver unexpectedly. These vehicles may have long braking distances.
- Park safely and off the road, not blocking or partially blocking lanes.
- Don't drive after consuming alcohol or any substance that might impair driving, judgment, coordination, or reaction times.
- Don't provide alcohol to anyone under 21 years old. Some VORTEX2 crew may be under 21.
- Get enough rest and sleep. Don't drive if you are sleepy. Use a relief driver or stop.
- Individual groups will have policies related to driving to restaurants, bars, clubs or parties. But, as a general rule, if you drive to a situation where alcohol may be ingested, have a designated sober driver.
- Watch for traffic when you leave your vehicle. Other drivers may be watching the weather and not the road.
- Wear reflective or bright clothing when outside your vehicle. Individual PIs may have rules for their teams.
- Emergency vehicles always have the right of way. VORTEX2 science is lower priority than law enforcement vehicles, ambulances, fire trucks, etc.
- Stay inside your vehicles or minimize time outside your vehicles when lightning is a risk.
- Stay inside your vehicles or minimize time outside your vehicles when hail is a risk.
- If you are in an accident, first call 911 if necessary. After immediate needs are satisfied, contact your PI. If you can't contact your PI, contact either of two emergency logistics numbers, one at the Norman Operations Center, usually Steering Committee member Lou Wicker (primary: 405.325.2635; backup: 405.325.2669) or, alternately Ling Chan, who is our Logistics Coordinator at (720-304-9100).
- If you are arrested or detained, and can't contact your PI or any other group, contact the Norman Operations Center, Lou Wicker, (primary: 405.325.2635; backup: 405.325.2669), or alternately, Ling Chan at 720-304-9100.
- If you are lost and can't contact your PI or any other group, contact the Norman Operations Center, Lou Wicker, (primary: 405.325.2635; backup: 405.325.2669), or alternately, Ling Chan at 720-304-9100.
- Individual instrument teams have medical kits and procedures. Know what is in your group's kit. Report and treat injuries promptly.
- Inform your team leaders if you are ill. With 100 crew working and living in close quarters, there is a risk of infection.

- Inform your team leaders if you have any physical, mental or medical condition or limitation that might, in your best judgment, affect your ability to perform your duties, or be a risk or concern to others.
- Eat, drink, and sleep reasonably. Five weeks on the road can be taxing on your health. If you have reasonable habits, you are more likely to stay healthy.
- Don't let anyone convince you to do something that you feel is unsafe. You can refuse. Use your best judgment at all times.

To summarize, **no tornado, no data set, no arrival time at a hotel is worth injury. Common sense behavior will go a long way towards keeping you and the rest of VORTEX2 safe. If it doesn't feel safe, dont do it. If it doesn't feel polite, don't do it.** Questions related to safety should be addressed to the PI in charge of your instrument/vehicle/group and/or a member of the VORTEX2 Steering Committee (Howie Bluestein, David Dowell, Don Burgess, Paul Markowski, Erik Rasmussen, Yvette Richardson, Lou Wicker, and Josh Wurman).

Storm and driving hazards are of particular concern after dark. To mitigate such hazards, **VORTEX2 operations will cease after dark.** (In a few circumstances, radars that are actively collecting data might continue operations for a limited time after dark. However, no in situ measurements will be collected after dark.) Though tornadoes can occur after dark, recent experience leads to the conclusion that after-dark operations with large numbers of vehicles are not safe.

To minimize risks when driving to the hotel after data collection, crews should use the Situational Awareness for Severe Storms Intercept (SASSI) software, communicate with their team leader, and use common sense.

6.2 Instruments

The instruments that we will be using during VORTEX2 pose some risk of injury to operators and others in the vicinity. Hazards vary and are instrument-specific. To minimize the risk of injury, teams should receive training from their team leaders before and during the field project.

VORTEX2 participants should also receive training from their team leaders about how to protect instruments from the conditions in which we will be operating. A few specific points to keep in mind are:

- **Dirt roads, which can quickly become muddy roads, should be avoided at all times.** The probability of getting stuck on a muddy road, or worse yet sliding into a ditch, is greater than the probability of getting a better dataset as a result of having taken such a road.
- The vehicles (with their roof-mounted instrument racks) that we will be driving are much taller than the vehicles most of us typically drive. Special attention should be paid to underpasses, low-hanging trees, low-hanging power lines, and canopies/awnings at gas stations, which could easily damage or remove an expensive instrument. When height is a possible concern, one team member should get out of the vehicle to assess the situation and direct the driver.

- Hail is unavoidable during the field project. Participants should receive instructions from their team leaders about how to minimize the damage that hail could cause. Participants should also monitor SASSI, other sources of weather information, and visible storm characteristics to minimize the number of encounters with large hail.

6.3 Etiquette

Wherever we go in May and June of 2009 and 2010, we will be identified as part of VORTEX2. Our behavior will reflect on VORTEX2, its sponsors NSF and NOAA, our home institutions, and the PIs and their home institutions. A little common sense goes a long way in making the project enjoyable for us, and giving others a favorable impression of our project. In addition, VORTEX2 participants should follow these specific guidelines:

- Dont cheer for tornadoes. It is natural to want the thing we are studying to occur. But, tornadoes are a bad thing for people in their path. Remember, local residents may be in earshot and you might be getting filmed.
- Do not go into tornado-damaged areas. We are not tornado tourists. VORTEX2 has two groups that are tasked specifically to conduct damage surveys. These are the LSC/NCAR group led by Nolan Atkins and Roger Wakimoto and the CSWR group led by Joshua Wurman and Karen Kosiba. Coordinate with these PIs if you want to participate in a damage survey. Most VORTEX2 crew will not be participating in damage surveys.
- Be respectful of other drivers on the road. Pass politely. Dont flash lights or sound your horn unless really necessary. Other drivers may be scared by the weather.
- Be respectful of other guests at hotels. Forty or more VORTEX2 crew may stay at any given hotel. After tense and exciting mission days, it is likely that we will want to discuss the day, the weather, what went right or wrong. But, loud parties or hallway discussions that go late into the night could bother other guests.
- Dont do anything on the road, in a restaurant, at a bar or at a club that you, your PI, and the rest of VORTEX2 wouldnt want to appear on TV the next day. There are lots of media around; your dance moves and conversations might be filmed.
- At gas stations, move away from pumps as soon as you are fueled. VORTEX2 will have dozens of vehicles and we need to make these pit stops efficient.
- Be polite on the VHF radios. Our communications are not encrypted so anyone can listen in. If you criticize some other driver, he might hear you on the radio. If you cheer on a tornado, the Sheriff, or a reporter might hear you.
- Be brief on the VHF radios. Different channels will have different rules and these rules may be different during leisurely driving as opposed to busy missions. The different channels and rules are detailed in the operations plan.
- Do not instant message, twitter, blog, or otherwise communicate VORTEX2 target choices, forecasts, or other information outside of VORTEX2. We are concerned about how many

chasers and local residents will be sharing the road with VORTEX2. Individual PIs may have specific rules concerning this issue.

- Local law enforcement personnel or local government staff may be interested in what were doing. Within the constraints of doing your job, go out of your way to explain. Were in their towns and depend on local goodwill for our operations.
- Be polite to the media. You may be indifferent, love, or hate them, but they are doing their jobs too. Some of them have been invited to follow VORTEX2 by various VORTEX2 groups. Some are less integrated. VORTEX2, its sponsoring agencies NSF and NOAA, and the home institutions of the PIs, benefit from a favorable portrayal in the media. Make sure that your actions contribute to such a favorable portrayal.

Chapter 7

Data management

The development and maintenance of a comprehensive and accurate data archive is critical in meeting the scientific objectives of VORTEX2. An archive that allows VORTEX2 investigators to share data with each other and with the rest of the scientific community helps these investigators promptly publish significant findings and transfer new knowledge into operational severe storm prediction. The overall guiding philosophy for VORTEX2 data management is to make datasets available to the scientific community as soon as possible after the field project while at the same time accommodating legitimate interests of investigators who collect the data.

7.1 VORTEX2 data policy

In order to accomplish the goals described in the VORTEX2 Scientific Program Overview (SPO) and in individual proposals, VORTEX2 investigators will use a combination of field observations and operational data. Policies for using the VORTEX2 field observations are described in the current and next sections while procedures for archiving and accessing operational data are described later.

Individual investigators are devoting significant time and resources in preparing to collect, collecting, and analyzing VORTEX2 field observations. After the 2009 and 2010 field phases, investigators will need ample time to identify cases of interest, preprocess observations (data conversion, quality control, etc.), analyze observations, and to begin publishing results. An **initial data-analysis period** is planned to accommodate the needs of individual investigators. The initial data-analysis period lasts 16 months after the data are collected (June 2009–October 2010 for data collected in 2009 and June 2010–October 2011 for data collected in 2010).

VORTEX2 Principal Investigators (PIs) are those who are listed as PIs and/or co-PIs on VORTEX2 grants and/or facility requests that have been funded by NSF and NOAA. The VORTEX2 PIs will participate in **VORTEX2 Research Workshops** in October/November 2009 and 2010 to prioritize cases, discuss research avenues, and develop plans for analyzing VORTEX2 data efficiently in a coordinated and collaborative manner. Having an initial data-analysis period and coordinating research through workshops satisfies the following project needs: (a) significant findings should be published promptly; (b) PIs need time to peruse the data they collected and to prepare them for analysis, sharing, and publication; (c) research niches should be identified for students, who must produce original research and typically require 1–3 years to do so; and (d) research naturally progresses from analyses of data from a single or small number of instruments initially to integrated analyses of multi-platform observations later.

In addition, VORTEX2 PIs will participate in an **End-of-Season Meeting**, which will occur in the field immediately after the last day of operations (i.e., most likely one or two days after the last day of operations). A preliminary discussion of analysis plans will occur, so that PIs can begin analysis and have results in time for summer and fall conferences. The more comprehensive plan for coordinated data analysis will not be developed until the October/November VORTEX2 Research Workshop.

After the VORTEX2 Research Workshops, VORTEX2 PIs shall promptly provide data to other PIs upon request and in accordance with the coordinated analysis plans developed at the workshops. Data sharing can be accomplished either through direct communication among PIs or through the VORTEX2 Data Archive (section 7.4) with the permission of the PI who collected the data.

After the 16-month initial data-analysis period, all VORTEX2 data will be considered public domain. If the team of investigators who collected a dataset wishes to make the dataset available in the public domain before the end of the 16-month period, they may do so. Until a dataset is in the public domain, the dataset may not be provided to a third party (someone who is not a VORTEX2 PI) for journal articles, presentations, research proposals, etc. unless the team of investigators who collected the data provides consent.

Users (including both VORTEX2 PIs and third parties) of VORTEX2 field data should acknowledge and/or offer co-authorship to the investigators who collected the data.

7.2 Data sharing in the field

The VORTEX2 mission depends on coordinated yet somewhat autonomous deployment of multiple vehicles in a rapidly-evolving, complex environment. Because the value of the dataset depends on the degree to which coordination is achieved, it is in the interests of the VORTEX2 community to, as quickly as practical, examine the collected data such that a full understanding of the quality, coverage, scope, duration, and other parameters of data sets collected may be assessed. In this manner, the successes and failures of each mission will be used to strengthen the possibility for success in future missions by enabling us to dynamically adapt observational strategies, to prioritize project goals, and to detect instrument issues or incompatibilities or discrepancies. Furthermore, development of a database containing the known attributes of all cases will allow the earliest possible discussions among PIs concerning analysis collaborations. In order to achieve this goal, the teams that are fielding instruments are strongly encouraged to share their data according to the following guidelines.

It is encouraged strongly that unedited raw and translated data from all platforms will be shared within 24 hours of collection when there are down days between field operations. It is understood that exceptions may occur in unusual circumstances. It is encouraged that in situ measurements (e.g., mobile mesonet, StickNet, tornado in-situ probe, etc.) will be provided in Excel readable ascii spreadsheet format. It is encouraged that radar data will be provided in both raw and commonly readable (dorade sweep, uf, and/or netcdf) formats. It is encouraged that this data sharing be as complete as possible, encompassing the entirety of the collected data.

To facilitate this process, a standardized metadata log sheet for field logs/notes, navigational information (time, lat/lon, pointing angles, etc.) will be provided to each platform. It is encouraged that crews of platforms use these forms. VORTEX2 will likely provide a hotel room/office that can serve as a data sharing/archiving center during down days. Any hand-written or non-standardized notes can be scanned and uploaded. Community data-archiving Windows and Linux computers will be available so instrument leaders can physically, or through ftp, upload and download datasets. Copies of the data can be uploaded to individual PIs disks/computers and uploaded to their home institutions. The intention is good faith sharing of data as complete as possible to enable preliminary discussions/evaluation of collaborative research, to identify quality control concerns, and to evaluate coordination in the shortest practical time.

Data from instruments that are not included in the 24-hour sharing list above are still expected to be shared freely, in a timely fashion, with all VORTEX2 PIs. Instrument leaders from these latter groups are encouraged to follow the 24-hour policy.

It is understood that quality control will not have been completed.

It is agreed by all PIs who participate in this field sharing of data that analysis teams and collaborations will not be finalized and cases or aspects of cases will not be allocated until the post-field phase meetings (End-of-Season Meeting in June and Research Workshop in October/November) described above. Put in other terms, PIs agree not to begin publication-quality analyses with other instrument data until the distribution of cases is finalized at these meetings.

7.3 On-line field catalog

An on-line **Field Catalog** (`http://catalog.eol.ucar.edu/vortex2_2009/`) will be functional during the VORTEX2 field project to support real-time planning. The real-time Field Catalog will contain data of three basic types: operational (NOAA/NWS, etc.) data, images from experimental real-time numerical weather prediction models, and field reports.

Data-collection information about both operational and field datasets (including metadata and overview documentation) will be entered into the system in near real time beginning on the first day of the field phase in May 2009. The catalog will permit data entry (data-collection details, field-summary notes, certain operational data, etc.), data browsing (listings, plots), and limited catalog information distribution. Designated VORTEX2 participants will prepare daily summaries containing information about operations (sampling times for major instrument systems, weather forecasts and synopses, etc.). These summaries will be entered into the on-line catalog electronically (via WWW interface and/or e-mail). It is important and desirable for the PIs to contribute graphics (e.g., plots in gif, jpg, png, or postScript format) and/or data for retention on the catalog whenever possible. Updates of the status of data collection and instrumentation (on a daily basis or more often depending on the platforms and other operational requirements) will be available. Public access to status information, mission summaries, and selected datasets will be available.

7.4 Distributed data archive

The primary **VORTEX2 Data Archive** will be located at NCAR EOL in Boulder, CO, and data will be accessed through a WWW browser interface. The Data Archive offers scientists access to operational data, field documentation (e.g., situational awareness graphics, daily operations summaries, mission summaries, status reports, and mission scientist reports), and field data. It provides the means to identify datasets of interest and automatically obtain data and metadata via Internet file transfer. The user may browse data to preview selected datasets prior to retrieval. Data displays include time series plots for surface parameters, skew-T/log-P diagrams for soundings, and gif images for model analysis and satellite imagery. Users can download data via the Internet directly to their workstation or personal computer or request delivery of data on magnetic/optical media. Data may be selected by time or location and can be converted to one of several formats before delivery. The Data Archive automatically includes associated documentation concerning the data itself, processing steps, and quality-control procedures.

Some datasets will be archived at the home institutions of the instrument managers rather than in the EOL Data Archive center. These distributed data centers will typically be necessary to manage raw datasets that are too large to be stored in EOL Data Archive center (e.g., datasets from mobile radars and high-resolution model output). Instrument managers who archive data at these distributed centers will provide contact information (name, e-mail address, phone number, and an ftp link to the data archive at the instrument managers home institution) on the Data Archive and must adhere to all policies and guidelines described in this Data-Management Plan.

NCAR EOL Field Project Services will perform any necessary processing for the operational datasets only (e.g., satellite, upper air soundings, surface observations, and model output). Otherwise, individual PIs will be responsible for the final processing, quality control, and submission of their own datasets to the Data Archive since they are best qualified to do so. The time required to prepare “final” observations suitable for analysis depends greatly on the observation type. For example, the quality control of EOL Mobile GPS Advanced Upper-Air System (MGAUS) observations is expected to take 3–6 months after the field phase. Radar datasets particularly require significant preprocessing before a quantitative analysis can be produced, and it is not feasible for instrument managers to prepare quality-controlled radar observations for other PIs. Thus, the standard for exchanging “final” radar data will be raw dorade sweep files, plus sufficient metadata (radar-deployment information, etc.) so that a quantitative analysis such as dual-Doppler analysis could eventually be produced after data-quality control.

All PIs participating in VORTEX2 must promptly (within 16 months after data are collected) submit their “final” data to the VORTEX2 Data Archive. (For most datasets, “final” refers to quality-controlled data; for radar datasets, “final” refers to raw dorade sweep files for the VORTEX2 intensive observing periods.) The requirement for PIs to submit their final data to the Data Archive will facilitate intercomparison of results and an integrated interpretation of the combined VORTEX2 dataset. The PIs will greatly benefit from further collaborative analysis of their datasets within the VORTEX2 community. The scientific community will be interested in VORTEX2 datasets for at least 10 years, probably more, after the field phase ends, so having the data archived in a central location will make it possible to obtain and analyze data for the lifetime of the dataset. Complete metadata (including dataset descriptions, documentation, calibrations, quality assurance results, etc.) must accompany the submitted data. Upon submission, unless otherwise specified by the PI, these data will be available to the general scientific community. The PI does reserve the right to request that the Data Archive provide password protection for these data and/or send notifications when a request for these data is received during the initial 16-month data-analysis period.

7.5 Responsibilities

The VORTEX2 Steering Committee and NCAR EOL Field Project Services are working together to prepare and implement the VORTEX2 Data-Management Plan. Contact information is provided in Appendix A.

Joint responsibilities of both the VORTEX2 Steering Committee and EOL Field Project Services are:

- develop the Data Management Plan
- handle disputes regarding VORTEX2 data.

The following are responsibilities of the VORTEX2 Steering Committee specifically:

- maintain a list of and contact information for VORTEX2 PIs
- coordinate the October/November 2009 and 2010 VORTEX2 Research Workshops.

The following are responsibilities of NCAR EOL Field Project Services specifically:

- survey the VORTEX2 PIs to determine what information will be provided in the Field Catalog and Data Archive
  - operational data and experimental NWP products
  - real-time status reports and other field documentation
  - field data
- develop and maintain the Field Catalog and Data Archive, including processing operational data
- provide in-field support
  - make products needed for real-time planning available through the Field Catalog
  - ensure that VORTEX2 PIs contribute the required operations summaries within a few days after each operations day
- make arrangements for data distribution (e.g., cost, if any, method of distribution, etc.) and coordinate data orders with the requestor
- provide current inventories at least every three months for two years following the field phase so that VORTEX2 data users are aware of new dataset availability

Individual PIs are responsible for providing their “final” field data to the Data Archive, as described earlier in the Data Management Plan.

Appendices

Appendix A

Contact information

Steering Committee

Name	Affiliation	Email
Howie Bluestein	University of Oklahoma	hblue@ou.edu
Don Burgess	University of Oklahoma / CIMMS	Donald.Burgess@noaa.gov
David Dowell	National Center for Atmospheric Research	ddowell@ucar.edu
Paul Markowski	Penn State University	pmarkowski@psu.edu
Erik Rasmussen	Rasmussen Systems	rasm1@rasmsys.com
Yvette Richardson	Penn State University	yrichardson@psu.edu
Lou Wicker	National Severe Storms Laboratory	Louis.Wicker@noaa.gov
Josh Wurman	Center for Severe Weather Research	jwurman@cswr.org

Logistics and emergencies

Name	Email	Phone Number
VORTEX2 Operations Center (VOC) in Norman, OK	voc@noaa.gov	405.325.2635; backup: 405.325.2669
Ling Chan, VORTEX2 Logistics Coordinator	ling@cswr.org	720.304.9100

Coordinators and Team Leaders

Name	Project Component
Brian Argrow, Eric Frew, and Adam Houston	UAS
Nolan Atkins and Roger Wakimoto	Damage Surveys, Tornado Photogrammetry
Mike Biggerstaff	SMART Radars and NOXP
Howie Bluestein, Stephen Frasier, and Ivan Popstefanija	UMass-W, UMass XPOL, MWR-05XP
Mike Coniglio, Patrick Marsh, and Lou Wicker	VOC
Katja Friedrich and Glen Romine	Disdrometers
Jim LaDue and Mike Magsig	Storm-Scale Photogrammetry
Paul Markowski and Yvette Richardson	Mobile Mesonet
Matt Parker and George Bryan	MGAUS
Erik Rasmussen and David Dowell	Field Coordination
Jerry Straka	Particle Probes
Chris Weiss	StickNet, TTU-Ka
Josh Wurman	Radar Coordination, DOWs, Tornado Pods, Damage Surveys

NCAR Earth Observing Laboratory (EOL)

Name	Email	VORTEX2 Role
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Linda Cully	cully@ucar.edu	Data management
Mike Daniels	daniels@ucar.edu	Computing, Data and Software Facility Manager
Tim Lim	tdlim@ucar.edu	MGAUS
Jose Meitin	meitin@ucar.edu	Data management
Jim Moore	jmoore@ucar.edu	Data management
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Steve Williams	sfw@ucar.edu	Data management

VORTEX2 Principal Investigators

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Chris Weiss	Texas Tech University	chris.weiss@ttu.edu
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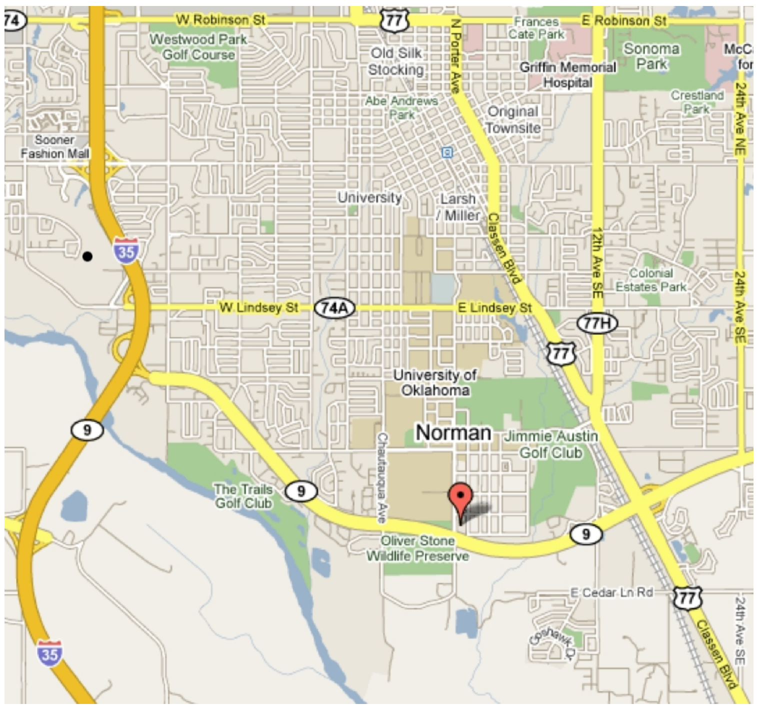
Josh Wurman	Center for Severe Weather Research	jwurman@cswr.org
Ming Xue	University of Oklahoma	mxue@ou.edu
Conrad Ziegler	National Severe Storms Laboratory	Conrad.Ziegler@noaa.gov

National Weather Center and VORTEX2 Operations Center (VOC)

The National Weather Center in Norman, Oklahoma (http://nwc.ou.edu), is the home of the VORTEX2 Operations Center (VOC), described in more detail in section 3.3. Active from 10 May through 13 June 2009 (and approximately 1 May through 15 June 2010), the VOC will provide forecasting support for potential field operations, and nowcasting and situational support for the field teams on days with field operations. The VOC will operate out of the enclosed room (the "media room") on the west side of the Hazardous Weather Testbed (HWT). The HWT is located on the 2nd floor of the National Weather Center, between the Storm Prediction Center (SPC) and the Norman National Weather Service Forecast Office.



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VORTEX2 Operations Center (VOC)
primary (preferred) phone number: 405.325.2635
backup phone number: 405.325.2669
email: voc@noaa.gov

National Weather Center
University of Oklahoma
120 David L. Boren Blvd
NWC Suite 1100
Norman OK 73072
phone: 405.325.3095
fax: 405.325.3072
email: nwc@ou.edu

Media and Public Relations

VORTEX2 Media Day will occur from 10:00 am to noon CDT, Friday, 8 May 2009, at the National Weather Center in Norman, Oklahoma. Interested media will have the opportunity to tour VORTEX2 research vehicles and interview VORTEX2 researchers and teams. Media interactions with VORTEX2 will be coordinated by Keli Tarp and Cheryl Dybas (contact information provided below).

National Oceanic and Atmospheric Administration (NOAA):

Keli Tarp
NOAA Weather Partners
National Weather Center
120 David L. Boren Blvd.
Norman, OK 73072
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National Science Foundation (NSF):

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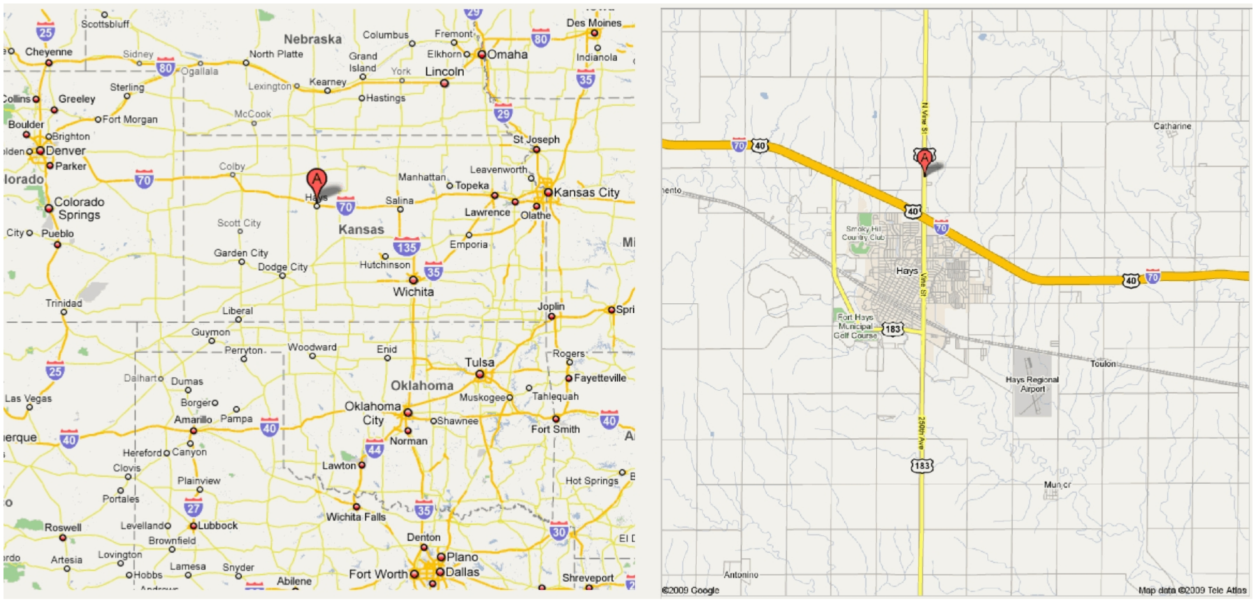
National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230
phone: 703.292.7734
fax: 703.292.9087
email: CDybas@nsf.gov

Garage in Hays, Kansas

VORTEX2 has rented garage space in Hays, Kansas (roughly in the center of the VORTEX2 domain) so that a dry, lighted space is available for vehicle and instrument repairs. The garage is at 4820 N. Vine (also known as Hwy 183). From exit 159 on I-70, take Hwy 183 northbound for less than one mile to the garage.



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Appendix B

Instruments

National Weather Radar Testbed—Multifunction Phased Array Radar (NWRT-MPAR)

Contact: Pam Heinselman (Pam.Heinselman@noaa.gov)
Links: http://www.nssl.noaa.gov/research/radar/mpar.php,
http://www.nssl.noaa.gov/projects/pardemo

CIRPAS MWR-05XP (Meteorological Weather Radar, 2005, X-band, Phased-Array)

Contact: Howie Bluestein (hblue@ou.edu)

Antenna beamwidth: 1.8° (azimuth), 2° (elevation)
Scanning: electronic-mechanical hybrid
Transmitter frequency: 9.37–9.99 GHz (32 steps)
Maximum power: ∼19 kW
Receiver range resolution: 150 m (2007), 75 m (2008)
Maximum unambiguous velocity: ±78.1 m s^{-1}
Maximum PRF: 10 kHz

SMART Radars 1 and 2

Contact: Mike Biggerstaff (drdoppler@ou.edu)

Antenna beamwidth: 1.5°
Scan rate: 30° s^{-1}
Transmitter type: Magnetron
Phase: random
Wavelength: C band (5 cm)
Maximum power: 250 kW
Gate length: 33 m
Polarization: horizontal (in 2009)
PRT: staggered
Signal processor: time series (I & Q)
Deploy time: 10 min
Undeploy time: 3 min

UMASS W-Band Mobile Radar

Contact: Stephen Frasier, Microwave Remote Sensing Laboratory, University of Massachussetts (frasier@ecs.umass.edu)

Antenna type: Cassegrain dish
Antenna diameter: 1.22 m (4 ft)
Antenna beamwidth: 0.18°
Antenna gain: 59 dB
Maximum azimuthal scan rate: 10° s^{-1}
Maximum elevation scan rate: 14° s^{-1}
Pedestal type: elevation-over-azimuth
Transmitter type: Klystron
Transmitter frequency: 95.04 GHz
Power: 1 kW, 1% duty cycle (max)
Transmitter pulse width: 200 ns – 1 μs (200 ns typical)
Polarization: vertical or horizontal
PRF: 5–10 kHz (typical)
Receiver type: Pentek 7631
Receiver dynamic range: 80 dB
Intermediate frequency: 120 MHz
Sample resolution: 30 m
Maximum range: 15 km
Maximum unambiguous velocity: $\pm$40 m s^{-1} (via staggered PRT)
Sensitivity (single pulse, 0 dB SNR): -35 dBZ_e at 1 km
Deploy time: 5 min
Undeploy time: 3–4 min
Other features: bore-sighted digital video

UMASS X-Band Polarimetric (XPOL) Mobile Radar

Contact: Stephen Frasier, Microwave Remote Sensing Laboratory, University of Massachussetts (frasier@ecs.umass.edu)

Antenna type: Parabolic dish
Antenna diameter: 1.82 m (6 ft)
Antenna beamwidth: 1.2°
Antenna gain: 41 dB
Pedestal type: elevation-over-azimuth
Transmitter type: Magnetron
Transmitter frequency: 9.41 GHz
Power: 12.5 kW, 0.1% duty cycle
Transmitter pulse width: 200 ns – 1 μs (200 ns typical)
Polarization: vertical and horizontal (simultaneous)
PRF: 2.4, 1.6 kHz (typical), staggered PRT
Receiver type: Pentek 7631
Receiver dynamic range: 80 dB
Intermediate frequency: 60 MHz
Sample resolution: 30 m
Maximum range: 60 km
Maximum unambiguous velocity: $\pm$38.2 m s^{-1} (via staggered PRT)

NCAR EOL Mobile GPS Advanced Upper Air System (MGAUS)

Contact: Bill Brown (wbrown@ucar.edu)
Link: http://www.eol.ucar.edu/instrumentation/sounding/gaus

Radiosonde manufacturer and type: Vaisala RS-92 SGP
Maximum number of sondes in the air: 4
Launch frequency: every 50 minutes or more, including sending data to ops center
Surface meteorological station: Vaisala WXT 510 (at 2 meters)
Vehicle Information: Type 3/4 ton 4×4 truck
Range: typically 300 miles at normal highway speeds
Capacity: typical load is 15 sondes without reloading helium supply
Crew: 2 (one MGAUS specialist, one student); space for additional crew member possible only for short periods
Communications (mobile): cell phone, VHF radio, satellite phone, wireless internet
Communications (stationary): 0.74 meter satellite communications, enabling 90 kbs upload / 200 kbs download internet access
Total number of sondes for VORTEX2: 137 (2009), 83 (2010) (allowance for 10% failure rate included)

Texas Tech University StickNet

Contact: Chris Weiss (chris.weiss@ttu.edu)
Links: http://www.atmo.ttu.edu/TTUHRT/WEMITE/sticknet.htm,
http://ams.confex.com/ams/88Annual/techprogram/paper_134047.htm

Component	Model	Platform	Output	Accuracy
GPS Receiver	SnyPaQ/E-M12 with SMA-35 antenna	1, 2	Time, lat, lon, altitude	
Compass	KVH C100	1,2	0–360°	±0.5°
All-in-one Sensor	Vaisala WXT510	2	Temp:−52 – +60°C, RH: 0–100%, BP: 600–1100 hPa, WS: 0–60 m s^{-1}, WD: 0–360°, Accum Rainfall: mm, Accum Hailfall: hits/cm^2	Temp: ±0.3°C, RH: ±3%, BP: ±0.5 hPa, WS: ±0.3 m s^{-1}, WD: ±3°, Accum Rainfall: ±5% day^{-1}
Temp/RH	RM Young 41382	1	Temp: −50 – +50°C, RH: 0–100%	Temp: ±0.3°C, RH: ±2%
Pressure	Vaisala PTB101B	1	600–1060 hPa	±1.5 hPa
Wind	RM Young 05103V	1	WS: 0–100 m s^{-1}, WD: 0–360°	WS: ±1%, WD: ±3°

Texas Tech University Ka-band Radar (TTU-Ka)

Contact: Chris Weiss (chris.weiss@ttu.edu)

Antenna beamwidth: 0.49°
Transmitter type: TWTA, up to 50% duty cycle
Transmitter frequency: 34.86 GHz
Power: 200 W (peak), 100 W (average)
PRF: variable, up to 20 kHZ
Receiver minimum detectable signal: −118 dBm
Gate spacing: ∼15 m (using conventional processing mode)
Digital signal processor: Sigmet RVP-8
Other features: computer-assisted hydraulic leveling system

NSSL Mobile Mesonet

Contact: Lou Wicker (Louis.Wicker@noaa.gov)

Measurement	Sensor type	Sensor range	Estimated total inaccuracy	Resolution	Response time
Pressure	Silicon capacitive	600–1100 mb	$< \pm 0.6$ mb	0.01 mb	< 1 s
Temperature (Fast)	Resistance	-30–+50°C	$< \pm 0.3$°C	0.01°C	0.6 s
Temperature (Slow)	Resistance	-30–+50°C	$< \pm 0.5$°C	0.01°C	$\sim$15 s
Relative humidity	Capacitance	0–100%	$<$ 5%	0.03%	15 s
Wind speed	Propeller vane	0–60 m s^{-1}	$<$ 2–4%	0.03 m s^{-1}	< 1 s
Wind direction	Propeller vane	0–360°	$< \pm$3–6°	0.05°	< 1 s
Vehicle heading (stationary)	Flux-gate compass	0–360°	$< \pm 2$°	< 1°	500 ms
Vehicle heading (moving)	GPS	0–360°	$< \pm 2$°	< 1°	< 1 s
Vehicle speed	GPS	unlimited	< 1 m s^{-1}	< 1 m s^{-1}	< 1 s
Vehicle location	GPS	0–$\pm$90° N/S, 0–$\pm$180° E/W	< 100 m	10 m	< 1 s

CSWR Doppler On Wheels (DOW6 and DOW7)

Contact: Josh Wurman (jwurman@cswr.org)

Peak power: 250 kW
Frequency: 9.3–9.4 GHz
Gate length: 25–200 m
PRF: 500–5000 Hz
Truck: 27 ft long, 13.3 ft tall, 8.5 ft wide, 25000 lbs.
Beamwidth: 0.93°
Scan rate: 50° s^{-1}

CSWR RapidScan DOW

Contact: Josh Wurman (jwurman@cswr.org)

Peak power: 40 kW
Frequency: 9.2–9.8 GHz
Gate length: 25–75 m
PRF: 500–7000 Hz
Truck: 20 ft long, 13.0 ft tall, 8.5 ft wide, 16000 lbs.
Beamwidth: 0.8°
Scan rate: 50° s^{-1}

UAS

Contact: Brian Argrow (brian.argrow@colorado.edu)
Links: http://tornadochaser.colorado.edu,
http://recuv.colorado.edu/tempest

Performance Specifications
Length: 5 feet
Wingspan: 10.5 feet
Cruise Speed: 75 kts
Max Take-off Weight: 15 lbs
Endurance: >1 h
Nominal Range: 70 nm

Sensors
Autopilot: Wind Speed and Direction
MIST Sonde (courtesy of NCAR): Pressure, temperature, and relative humidity

Appendix C

Acronyms

ADAPTS Adaptive DSP Algorithm for PAR Timely Scans

AGL Above Ground Level

ARM Atmospheric Radiation Measurement

CAPE Convective Available Potential Energy

CAPS Center for the Analysis and Prediction of Storms

CASA Collaborative Adaptive Sensing of the Atmosphere

CI Convection Initiation

CIMMS Cooperative Institute for Mesoscale Meteorological Studies

CIN Convective Inhibition

CIRPAS Center for Interdisciplinary Remotely-Piloted Aircraft Studies

CoA Certificate of Authorization

DSLR Digital Single-Lens Reflex

DOW Doppler On Wheels

EDO Experiment Design Overview

EOL Earth Observing Laboratory

FAA Federal Aviation Administration

FC Field Coordinator

FCC Federal Communications Commission

FFD Forward-Flank Downdraft

GIS Geographic Information Systems

GOES Geostationary Operational Environmental Satellite

GPS Global Positioning System

GSD Global Systems Division

HP High- or Heavy-Precipitation

HRRR High-Resolution Rapid Refresh

HWT Hazardous Weather Testbed

IOP Intensive Observing Period

KFDR WSR-88D radar at Frederick, Oklahoma

KICT WSR-88D radar at Wichita, Kansas

KINX WSR-88D radar at Tulsa, Oklahoma

KOUN WSR-88D radar at Norman, Oklahoma

KTLX WSR-88D radar at Twin Lakes, Oklahoma

KVNX WSR-88D radar at Vance AFB, Oklahoma

LP Low-Precipitation

LSC Lyndon State College

MDN Mobile Digital Network

MGAUS Mobile GPS Advanced Upper-Air System

MPAR Multifunction Phased Array Radar

NCAR National Center for Atmospheric Research

NCSU North Carolina State University

NOAA National Oceanic and Atmospheric Administration

NOXP NOAA X-band Polarimetric radar

NSF National Science Foundation

NSSL National Severe Storms Laboratory

NWC National Weather Center

NWRT National Weather Radar Testbed

NWS National Weather Service

NWP Numerical Weather Prediction

OU University of Oklahoma

PAR Phased-Array Radar

PI Principal Investigator

PSD Particle Size Distribution

PSU Penn State University

RFD Rear-Flank Downdraft

RFGF Rear-Flank Gust Front

RUC Rapid-Update Cycle

SASSI Situational Awareness for Severe Storms Intercept

SMART-R Shared Mobile Atmospheric Research and Teaching Radar

SPC Storm Prediction Center

SPO Scientific Program Overview

SRH Storm-Relative Helicity

SSDA Storm-Scale Data Assimilation

TDWR Terminal Doppler Weather Radar

TTU Texas Tech University

UA Unmanned Aircraft

UAS Unmanned Aircraft System

UC Upsonde Coordinator

UMASS University of Massachussetts

UTC Coordinated Universal Time

VHF Very High Frequency

VOC VORTEX2 Operations Center

VORTEX Verification of the Origins of Rotation in Tornadoes Experiment

WDSS Warning Decision Support Systems—Integerated Information

WDTB Warning Decision Training Branch

WRF Weather Research and Forecasting system

WRF-ARW Advanced Research WRF

WRF-NMM Nonhydrostatic Mesoscale Model core of WRF

WSR-88D Weather Surveillance Radar–1988 Doppler