SGP Cloud and Land Surface Interaction Campaign (CLASIC)
Land Surface States and Fluxes Experiment Plan

June 4, 2007

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1. Introduction

Cumulus convection is an important component of the atmospheric radiation budget and hydrologic cycle of the Southern Great Plains (SGP) region of the U.S., particularly during the summertime growing season. Continental cumulus convection is strongly modulated by land surface conditions; while at the same time influencing the land surface through rain- induced changes in soil moisture and through its impact on photosynthesis. Land surface conditions determine whether the partitioning of surface available energy is dominated by the sensible heat flux or by the latent heat flux, which is an important factor in the evolution of the convective boundary layer. Consequently, land surface characteristics can influence the timing and evolution of cumulus convection, in particular the cloud base height, cloud depth, and convective available potential energy.

A project called Cloud and Land Surface Interaction Campaign (CLASIC) will be conducted in this region to better understand these issues. This was initiated by the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) proposal led by Mark Miller. This is a broad project that focuses on the ARM Climate Research Facility (ACRF) located in the Southern Great Plains (SGP) of the U.S. It will include an Intensive Observing Period (IOP) that will cover a period of several months centering on June 2007. The purpose of this IOP is to advance our understanding of cumulus convection and its controls, particularly those associated with land surface processes. The study period will straddle the winter wheat harvest when dramatic changes in the land surface occur that could lead to large changes in the surface albedo, latent heat flux, and sensible heat flux.

The CLASIC Land Team was formed from interested groups and will attempt to characterize land surface states and fluxes throughout the IOP. These include surface soil moisture, water and energy fluxes, carbon flux, surface temperature, land cover and vegetation indices. These will be provided through a combination of insitu, aircraft and satellite observations.

1.1. CLASIC goals and objectives

CLASIC is led by the DOE ARM Program. A primary objective of the program is improved scientific understanding of the fundamental physics related to interactions between clouds and radiative feedback processes in the atmosphere. ARM focuses on obtaining continuous field measurements and providing data products that promote the advancement of climate models. The program has included the development of several highly instrumented ground stations for studying cloud formation processes and their influence on radiative transfer, and for measuring other parameters that determine the radiative properties of the atmosphere. The ARM Climate Research Facility (ACRF) manages these sites, which includes the SGP site located in Oklahoma and Kansas (Figure 1).

It has been observed that land surface characteristics influence the timing and evolution of cumulus convection, in particular the cloud base height, cloud depth, and convective available potential energy (Golaz et al. 2001). It is hypothesized that the land surface properties in the SGP that influence cumulus convection are modulated by human activities, particularly agriculture. Human induced changes in the land surface structure associated with harvesting, plowing, crop rotation, and irrigation induce changes in the surface latent heat flux, sensible heat flux, albedo, and carbon flux.

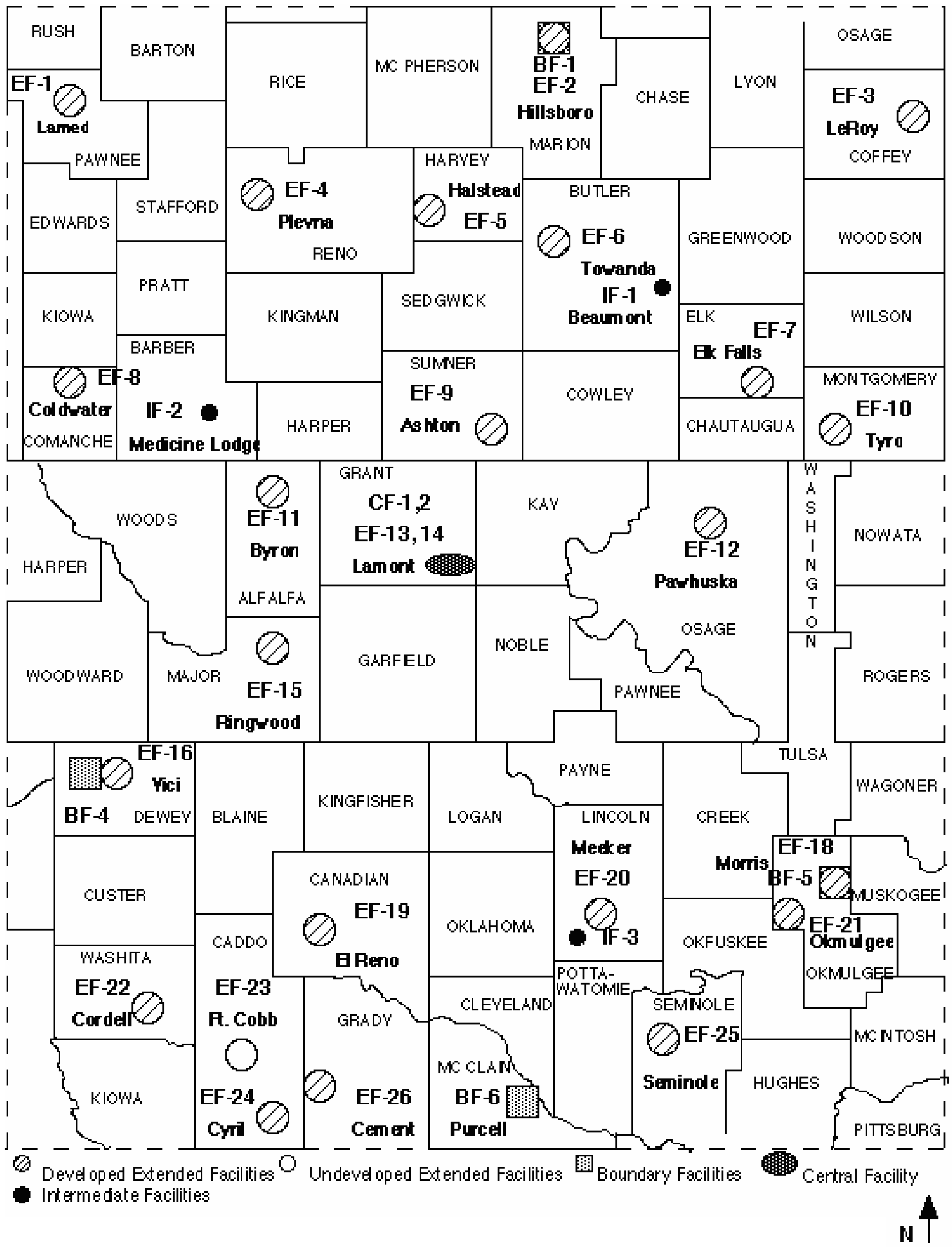


Figure 1. The ARCF Southern Great Plains Site and Instrument Locations (From the ARM website)

For the SGP, the harvest of winter wheat is particularly interesting. This occurs within a short period in early June. The timing of this harvest depends upon the seasonal climate, recent precipitation, and to the availability of migrating harvesting equipment. During the harvest, the land in the vicinity of the SGP Central Facility is converted from waist- high winter wheat to bare soil in a matter of hours. This impulse-like perturbation in the land surface state likely has important implications for the structure and occurrence of cumulus convection.

Models of all varieties struggle to accurately simulate continental cumulus convection, particularly the early and middle stages. In some models, this is due, in part, to inadequate horizontal and vertical resolution. Even cloud system-resolving models with resolution on the scale of 1-km struggle to accurately simulate continental cumulus.

A particularly acute problem with simulations of continental cumulus convection in climate models is the parameterization of land surface interactions. To date, these interactions are either not parameterized, or parameterized in an extremely simplistic manner. It is known that clouds strongly influence the net ecosystem exchanges of carbon dioxide (Gu et al. 1999, Min and Duan 2005). Many factors can play a role in this process. They include changes in the amount, diffuse to direct ratio, and fraction of photosynthetically active solar radiation and modifications of air temperature and vapor pressure deficit. Clouds also introduce large fluctuations in surface solar radiation, including the cloud focusing effect. Recent research in the Harvard Research Forest suggests that feedbacks between carbon uptake by plants and water use efficiency are strongly dependent on cloud cover (Min and Duan 2005). More specifically, carbon uptake efficiency is generally larger under partly cloudy skies and cloudy skies than it is under clear skies because plants are strongly influenced by diffuse radiation due to the details of leaf illumination. The details of the spectrum of incident radiation are also known to be important, though they are generally neglected in models. All these factors influence ecosystem carbon processes and surface energy balance and interact with stomatal dynamics through which photosynthesis and transpiration are coupled.

Changes in surface energy balance and moisture transport to the boundary layer will influence cloud processes, thus potentially creating a feedback loop. Cumulus convection is among the most critical cloud systems to accurately simulate due to the potential impacts of climate change on agricultural concerns. It is known, for example, that certain crops tend to decrease their stomatal resistance when presented with rising amounts of carbon dioxide, thereby increasing their contribution to the latent heat flux through increased evapotranspiration. Other plants respond by increasing their stomatal resistance under these conditions, which may decrease the latent heat flux. Hence, the feedback processes suggested above may be an important component of climate change.

The ARCF in the SGP has developed improved capabilities in order to make detailed observations of cumulus convection. These include the capability to observe the early and middle stages of cumulus convection using cloud radar and for sampling sky radiance more rapidly. Also important in this system are new satellite capabilities that have recently become available. Satellites carrying active sensors, such as Cloudsat and

Calipso, are expected to provide spaceborne measurements that will significantly eclipse current capabilities.

Characterizing the land surface of the SGP site will be a challenge. There have been satellite analyses of surface albedo, scattered measurements of the surface fluxes at the boundary facilities, carbon flux measurements at the now defunct Atmospheric Boundary Layer Experiment (ABLE) site in the northeastern part of the SGP Site, hydrologic studies in the Walnut River Watershed (Miller et al. 2005), and ongoing hydrologic measurements in the Little Washita and Fort Cobb Watersheds on the Southern Boundary of the SGP site by the United States Department of Agriculture (USDA). The Oklahoma Mesonet maintains a soil moisture network throughout the region (Basara and Crawford 2000). Several field experiments have focused on soil moisture within the SGP domain (Jackson et al. 1999, 2002, 2005). These have included both aircraft and satellite product development and validation. There have been few efforts to characterize evapotranspiration at the SGP site and even fewer to understand ground water. Hence, the true nature of the land surface of the SGP Site remains partially characterized.

Once cumulus convection has been initiated, precipitation may result. Precipitation is a critical component of the liquid water budget and, through inference, the radiation budget. Precipitation measurements in the SGP are of variable quality, depending on the location of a specific area relative to the WSR-88D network, but radar coverage at the ARM Central facility is poor and precipitation estimates are typically unreliable. Because the horizontal resolution of the WSR-88D is 1-km and the ARM cloud radars are not at the ideal wavelength for such measurements, precipitation from early and middle stage cumulus is difficult to measure routinely. Yet, the precipitation produced by these clouds is a central issue because it depletes cloud water, dries the lower troposphere, impacts the surface latent heat flux, changes soil moisture, and alters the albedo of plowed fields.

As noted earlier, CLASIC will be conducted at the ARCF SGP during the summer of 2007. The purpose of this IOP is to advance our understanding of cumulus convection and its controls, particularly those associated with land surface processes. The field campaign component of the IOP will cover a period of 1 month (June 2007) and attempt to include the winter wheat harvest when large changes in the land surface lead to large changes in the surface albedo, latent heat flux, and sensible heat flux.

There will be several crosscutting missions as part of CLASIC. Some of the major goals of these will be to:

1. *Improve model parameterizations of land surface and atmosphere interactions during the summer period, with particular emphasis on moist periods containing typical summertime convection.*
2. Evaluate new measurements of summertime cloud properties from cloud radars and formulate a detailed climatology of the properties of small convective elements, which have been previously undetected by radar due to insect contamination.
3. Measure the 3-D cloud microphysical structure and its radiative forcing.

4. Determine the radiative impact of small cumulus elements with low optical and liquid water path and their heating rate profiles.
5. Quantify aerosol indirect effects in early stage cumulus convection.
6. *Quantify the various pathways that link local hydrologic structure to cloud properties.*
7. *Make continuous CO2 measurements to assist in the quantification of evapotranspiration and to act as a tracer for measurements of vertical advection of water vapor into clouds.*

Of these goals, the Land Team efforts will contribute primarily numbers 1, 6 and 7.

There are five primary science questions that will be addressed during CLASIC:

1. What is the role of cumulus convection and spatial variations in land cover in depleting low-level water vapor as it is advected to the SGP from the Gulf of Mexico?
2. How do cumulus clouds and aerosols impact the carbon flux and evapotranspiration and the coupling between the carbon flux and transpiration, and how does this impact feed back to cloud processes?
3. How does the winter wheat harvest at the SGP impact the surface fluxes, boundary layer structure, cloud structure, and aerosol loading?
4. What is the role of aerosol loading and chemistry in varying the microphysical and macrophysical properties of cumulus cloud fields, and how is this loading related to land surface processes?
5. What roles do soil moisture and ground water play in influencing the latent heat flux and cloud formation, either through increased transpiration by plants or by direct conduction?

All of these questions will require the Land Team products. In addition to addressing the main objectives of CLASIC, these investigations will utilize new instruments for soil moisture remote sensing and evaluate satellite derived terrestrial hydrology products in support of NASA programs.

1.2. The Role of the Land Surface and Requirements

Addressing the overall goals of CLASIC and the identified science questions will require flux and state measurements obtained over the dominant land covers and distributed over the geographic domain. The Land Team contributions will include these measurements and will specifically design the investigation to determine the level of up-scaling/aggregation required in order to understand the impact of landscape changes affecting energy balance/flux partitioning and impact on cloud/atmospheric dynamics. From the investigation it may then be possible to determine the critical factors (canopy temperature, vapor pressure deficit, soil moisture availability, etc.) that need to be monitored in order to predict the sensible and latent heat fluxes at an acceptable accuracy for predicting the onset of cloud formation. We also hope to establish the parameters necessary for accurate modeling of both energy and CO_2 fluxes.

The approach that will be used involves a combination of intensive point/tower observations, higher resolution aircraft tracks and maps, and satellite derived products. The cornerstones will be four locations (super sites) distributed over the SGP domain, selected to represent the dominant land covers, optimize resources, and satisfy larger scale objectives. Standardization of measurements and protocols at each location is highly desirable but may not be possible.

The specific contributions that will be made by the Land Team include:

1. Tower observations of surface fluxes including sensible, latent, and CO2 fluxes at three super sites and supporting observations at a fourth site.
2. Regional satellite-based flux products and intermediate-scale aircraft-based flux studies.
3. Photo records at the super sites of surface conditions and sky conditions to detect the type and onset of cloud formation.
4. Surface soil moisture characterization of each super site.
5. Intensive soil moisture in specific regions for evaluating a new active-passive microwave aircraft instrument and high spatial resolution satellite synthetic aperture radar.
6. High resolution regional soil moisture maps from the aircraft-based Polarimetric Scanning Radiometer that will be part of the CLASIC P-3 instrument package.
7. Regional soil moisture from the NASA Aqua Advanced Microwave Scanning Radiometer (AMSR-E) satellite.
8. Development of geographic resources including land cover, vegetation indices, and soil properties.

1.3. NASA Related Programs

The Land Team will contribute to the CLASIC science objectives described above. In addition to these, it will also address science priorities of at least two NASA programs related to land surface hydrology; the Terrestrial Hydrology Program (THP) and the Aqua AMSR-E.

The soil moisture research priorities of the THP Soil Moisture Mission Working Group (SMMWG) support the development of future dedicated soil moisture satellite missions and include science objectives that are complementary to CLASIC:

- Participate in field experiment opportunities that address key mission or application issues through cooperative efforts with other programs and agencies
- Develop more robust radar soil moisture retrieval algorithms
- Improve multiple resolution retrieval algorithms that integrate active/passive measurements

CLASIC will provide us the opportunity to evaluate a new aircraft based passive and active L band (PALS) microwave sensor that could be the prototype of a next generation satellite instrument. Intensive sampling within limited domains is critical to this effort.

The other key program is the NASA Aqua Advanced Microwave Scanning Radiometer (AMSR-E), which is attempting to develop a robust soil moisture algorithm and reliable products. Scaling and validation are important components of these efforts. The Little Washita Watershed is one of the primary validation sites and has been the focus of previous validation activities. One issue with previous campaigns was the unfortunate limited range of conditions observed (mostly very dry). A recently established insitu network in the Fort Cobb Watershed will also be evaluated a part of CLASIC.

Aircraft observations provided by the Polarimetric Scanning Radiometer (PSR) will also contribute to AMSR-E scaling and validation. The multiple sub-bands and frequencies of the PSR also contribute to risk-reduction for CMIS. Implementing retrieval algorithms for the PSR is critical to both CLASIC and scaling/validation research. The additional support that NASA would provide would insure success.

The support of these activities will require ground sampling and post processing, including aircraft data sets, as implemented in previous SMEX. We will deploy teams, composed primarily of students at universities currently supported by NASA THP and related programs, to collect soil moisture and vegetation information over an approximately 30 day period in June 2007. This is an intensive learning experience for the students and has proven valuable in attracting them to this field of research.

1.4. Campaign Overview

For CLASIC, what we hope to achieve is an extensive description of the water and energy fluxes and states at a few carefully selected locations, to then link these points to local and regional scales using aircraft and satellite data, and ultimately to tie spatial/temporal products to the cloud and atmosphere investigations.

The starting point for experiment design is a consideration of the dominant land cover features and their spatial distribution over the SGP. The best way to capture this is using high resolution multispectral imagery from the time period that represents the expected vegetation conditions. A composite of several Landsat Thematic Mapper images from April/May 2005 was made for this purpose (Figure 2). This is a traditional false color composite. The dominant land uses/covers will be winter wheat/stubble (white to light blue), grassland (pink to red), and forest (red/deep red). Each of these dominates a specific geographic area; winter wheat in the East and North, Forest in the East, and grasslands in the South and West. The primary super sites were selected to include the geographic/land use distribution, considering existing resources. These sites are listed in Table 1.

Tower-Based Surface Fluxes: The priority of this component of the Land Team campaign is to collect high quality flux data for the dominant land cover conditions in the experimental domain: winter wheat, grassland and forest. In addition, the SGP is a large domain and some consideration must be given to geographical distribution. The resources of four different groups will be coordinated to achieve this. These are Lawrence Berkeley National Laboratory-LBNL (Margaret Torn and Marc Fischer), ARS (Bill Kustas and John Prueger), NOAA (Tilden Meyers), and Los Alamos National Laboratory-LANL (Mavendra Dubey and Thom Rahn).

The groups will attempt to establish standard methods and protocols. The general locations of the super sites were selected in order to form a triangle that would facilitate aircraft scaling analyses.

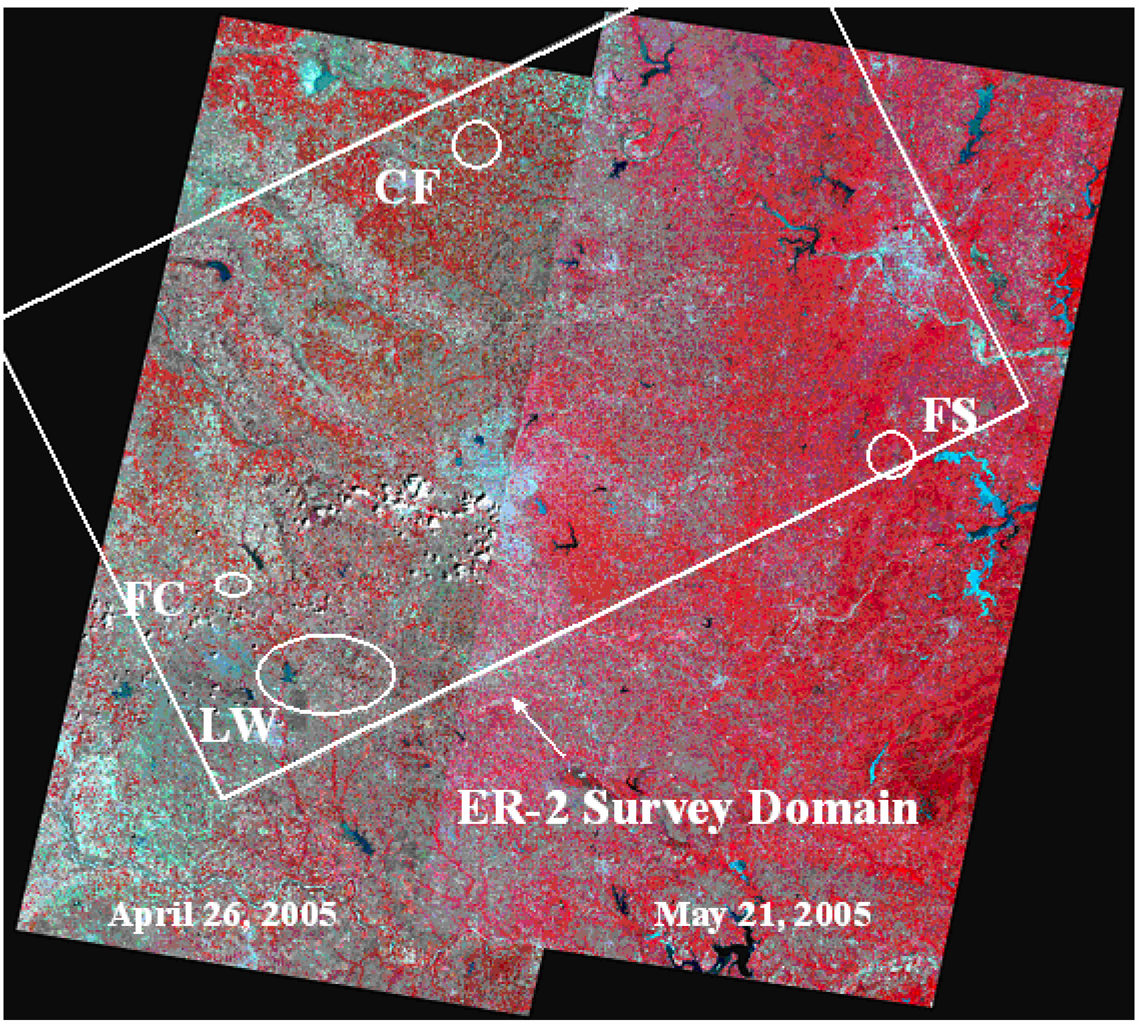


Figure 2. Landsat False Color Composite Image of the Oklahoma Portion of the ARM SGP showing Potential Super Sites. The left portion of the composite was obtained in April and the right in May. Between these dates wheat would senesce and grass would green up, assuming adequate moisture

The choice of the CF as a super site was obvious. It has extensive instrumentation, a long period of record, and is highly representative of its particular area of the SGP region (Figure 3). Data collection here will be led by LBNL. Three tower sites will be installed.

Table 1. CLASIC Land Super Sites

Site	Code	Land Use	Flux Towers	Soil Moisture Network
Central Facility	CF	Winter Wheat	Replication	Temporary Network
Little Washita	LW	Winter Wheat and Grassland	Three locations	Micronet and intensive sampling
Forest	FS	Forest	Replication	Temporary Network
Fort Cobb	FC	Irrigated Agriculture	None	Micronet and intensive sampling

Figure 3. Typical winter wheat field condition near the CF in late June

LW was selected as a focal area because of the extensive hydrologic information available from the ARS Micronet and stream flow gages. It has also been the focus of numerous surface flux and soil moisture studies and includes two of the ARM EFs. It is also a mixed land use area. Here we have decided to establish three separate tower sites, one in winter wheat and two in grasslands. The two grassland sites will be selected to represent the diverse soil types found in the area. One of these sites will be the EF26, which has very sandy soils (Figure 4). The other two sites will be selected from a small number of fields that were visited in September. The general locations of the three sites were chosen to form a triangle that could be flown by the Duke University Helicopter flux system for the scaling studies. ARS will lead the efforts in LW.

Figure 4. Grassland conditions during the summer at EF26 located in the Little Washita Watershed

The third location will be located in the vicinity of ARCF site EF21 (FS), which is a forest dominated area (Figure 5). One additional tower will be installed in this region. NOAA will lead activities at this site.

Figure 5. Forest canopy and tower at the EF21 site

A fourth site at Ft. Cobb was recently added. This will be supported by LANL and coordinated with the Tethersonde activity described later.

Regional Flux Products: It would be extremely beneficial (possibly essential) to incorporate aircraft-based flux monitoring during critical periods of the campaign in order to obtain landscape/regional information to interpret other ancillary atmospheric observations and model results. To address this problem a new helicopter based flux measurement system developed by Duke University (http://www.cee.duke.edu/research/hop/index.php) will be used. Additional details are described in a later section.

Imagery collected with the MODIS Airborne Simulator (MAS) (http://mas.arc.nasa.gov/), to be flown on the ER-2 aircraft, will be used to supplement satellite-based flux products – extending the spatial resolution of these products to the sub-field scale. It is important to note that we are working under the assumption that the data will be fully processed by the provider. If this is not the case, additional time and resources will be required in order to complete this task. Centering overpass times near midmorning (i.e., ~1030 CST) over the super site under intensive observation provides the most useful information for thermal remote sensing-based flux modeling.

Regional Soil Moisture: It is well known that the location of the soil moisture influencing the flux observations, boundary layer development, and cloud formation may originate at some distance from a tower or point location. General patterns can provide some guidance but it is impossible to know the exact location a priori. Therefore, it is of great importance that spatially distributed map products of soil moisture be available. The only observational technique that can provide these at acceptable spatial resolutions and temporal frequencies is aircraft-based microwave remote sensing. Over larger scales it may be possible to provide the information with satellite products but this remains a research question. Currently available satellite soil moisture products are available at a nominal spatial resolution of 25 km from NASA. These will be of some value to CLASIC but we would like to explore two improvements to these as part of CLASIC. These include enhanced spatial resolution approaches utilizing higher resolution sensors and improved, regionally optimized, soil moisture retrieval algorithms

Aircraft observations provide the critical bridge for scaling and integrating the point observations to the coarse satellite footprints. In addition, the higher resolution aircraft soil moisture products are of value in more intensive hydrologic investigations. The Polarimetric Scanning Radiometer (PSR) will be the key sensor in providing the required soil moisture product. There are, however, several steps involved in translating the sensor data into soil moisture (Bindlish et al. 2006). These require some level of ground based sampling for calibration and some lower altitude/higher spatial resolution flights for both calibration and scaling. Frequent coverage of both the domain (high altitude) and LW (low altitude) are needed.

As originally conceived the PSR was to be part of the ER-2 instrument package. However, last moment issues resulted in shifting the PSR to a NASA P-3 aircraft. The flightlines for the P-3 will cover most of the ER-2 survey domain and all super sites. This change improved the spatial resolution of the potential soil moisture product.

Our sources of ground based calibration/validation data will include intensive studies and existing networks in the LW and FC that will be described in following sections. For the CF and FS we will deploy a temporary network of automated insitu sensors, described in a later section, during the IOP.

Intensive Soil Moisture Studies: NASA will be supporting a project that will utilize a new aircraft instrument (PALS) that combines both active and passive technologies for soil moisture applications. This instrument, in its current state, is not designed for regional mapping and would be used in intensive soil moisture studies for specific regions within the domain. Intensive soil moisture and temperature would be used to support the instrument. Ground based sampling to support this instrument will require sampling large fields, typically a quarter section in size, that include diverse cover/use types. Fields must be co-located within smaller domains in order to optimize aircraft resources.

In previous experiments we have utilized these studies to validate the performance of our insitu network and to understand scaling in the domain. In SMEX03 (Jackson et al. 2005) we did not capture an adequate range of soil moisture conditions during the campaign, therefore, CLASIC may provide a valuable addition to the LW validation. We will also include validation tests of a new soil moisture network installed in the FC area. We will also arrange for the irrigation of one or more fields in FC and use this for the PALS research.

Land Cover and Vegetation Products: Land cover and vegetation products for the entire CLASIC domain are one of the most critical pieces of information needed for the suite of objectives/science questions being addressed. These will be developed from multidate imagery collected by several satellites and the MAS on the ER-2. In the past we have found the Landsat TM products to be very valuable because of the minimal processing, low cost, and adequate spatial resolution. However, it is uncertain whether the Landsat platforms will still be in operation next summer. There are a variety of other sensors/satellites available and will be described in later sections.

Accurate land cover and vegetation index data will require ground based surveys, reflectance measurements, and biomass sampling during the IOP. The Land Team will include these in its planning. Other databases are available but require access, reformatting and integration (i.e. soils).

Organization of this Experiment Plan: Infrastructure, related activities, satellite observations, aircraft plans, flux tower component, soil moisture component.

2. Relevant Networks and Infrastructure

The region in Oklahoma selected for investigation is exceptionally well instrumented for surface soil moisture, hydrology and meteorology research. USDA ARS, the Oklahoma Mesonet, and ARM operate observing networks. The overall character of the SGP region is reflected in the false color composite image created from a Landsat TM data shown in Figure 2. The climate of region is classified as sub-humid with an average annual rainfall of 75 cm. The topography of the region is moderately rolling with a maximum relief less than 200 m. Soils include a wide range of textures with large regions of both coarse and fine textures.

2.1. The ARCF SGP Site

The Southern Great Plains (SGP) site was the first field measurement site established by DOE's Atmospheric Radiation Measurement (ARM) Program. Scientists are using the information obtained from the SGP to improve cloud and radiative models and parameterizations and, thereby, the performance of atmospheric general circulation models used for climate research. Deployment of the first instrumentation to the SGP site occurred in the spring of 1992. Additional instrumentation and data processing capabilities have been incrementally added in the succeeding years.

The SGP was chosen as the first ARM field measurement site for several reasons including its relatively homogeneous geography and easy accessibility, wide variability of climate cloud type and surface flux properties, and large seasonal variation in temperature and specific humidity. It also already had a large, existing network of weather and climate research and instrumentation.

The SGP site consists of in situ and remote-sensing instrument clusters arrayed across approximately 55,000 square miles (143,000 square kilometers) in north-central Oklahoma (Figure 1). The heart of the SGP site is the heavily instrumented central facility located on 160 acres of cattle pasture and wheat fields southeast of Lamont, Oklahoma.

More than 30 instrument clusters have been placed around the SGP site (Table 2), at the central facility (CF) and at boundary (BF), extended (EF), and intermediate facilities (IF). The locations for the instruments were chosen so that the measurements reflect conditions over the typical distribution of land uses within the site. The instruments throughout the site automatically collect data on surface and atmospheric properties, routinely providing data to the Site Data System, which is linked by high-speed communications to the ARM Archive and Data Center. (http://www.arm.gov/sites/site_inst.php?loc=sgp&facility=E)

The SGP Extended Facility instruments are:

- Aerosols
  - Multifilter Rotating Shadowband Radiometer (MFRSR)
  - Normal Incidence Multifilter Radiometer (NIMFR)

- Radiometric
  - Infrared Thermometer (IRT)
  - Multifilter Rotating Shadowband Radiometer (MFRSR)
  - Normal Incidence Multifilter Radiometer (NIMFR)
  - Solar and Infrared Radiation Station (SIRS)
- Surface Meteorology
  - Meteorological Observation System Instruments for SGP (SMOS)
- Surface/Subsurface Properties
  - Eddy Correlation Flux Measurement System (ECOR)
  - Energy Balance Bowen Ratio Station (EBBR)
  - Soil Water and Temperatures System (SWATS)

Table 2. General Characteristics of the ARCF SGP Sites

Site ID	Name	Latitude (Degrees)	Longitude (Degrees)	Surface Type	Soil Moisture/ Energy Balance System Type
EF-9	Ashton, KS	37.1330	-97.2660	Pasture	Y/B
IF-1	Beaumont, KS	37.6260	-96.5380	Rangeland	-
EF-11	Byron, OK	36.8810	-98.2850	Alfalfa	Y
EF-26	Cement, OK	34.9570	-98.0760	Pasture	N/B
EF-8	Coldwater, KS	37.3330	-99.3090	Rangeland (grazed)	Y/B
EF-22	Cordell, OK	35.3540	-98.9770	Rangeland (grazed)	Y/B
EF-24	Cyril, OK	34.8830	-98.2050	Wheat (gypsum hill)	Y/E
EF-27	Earlsboro, OK	35.2690	-96.7400	Pasture	Y/B
EF-19	El Reno, OK	37.3830	-96.1800	Pasture	N/B
EF-7	Elk Falls, OK	35.5570	-98.0170	Pasture (ungrazed)	Y/B
EF-5	Halstead, KS	38.1140	-97.5130	Wheat	Y/E
BF-1	Hillsboro, KS	38.3050	-97.3010	Grass	-
EF-2	Hillsboro, KS	38.3050	-97.3010	Grass	Y/B
EF-13	Lamont, OK	36.6050	-97.4850	Pasture and wheat	Y/B
EF-14	Lamont, OK	36.6070	-97.4880	Pasture and wheat	Y/E
EF-1	Larned, KS	38.2020	-99.3160	Wheat	Y/E
EF-3	LeRoy, KS	38.2010	-95.5970	Wheat or soybeans)	Y/E
IF-2	Medicine Lodge, KS	37.2800	-98.9330	Rangeland	-
EF-20	Meeker, OK	35.5640	-96.9880	Pasture	Y/B
IF-3	Meeker, OK	35.5510	-96.8640	Grass	-
BF-5	Morris, OK	35.6880	-95.8560	Grass	-
EF-18	Morris, OK	35.6870	-95.8560	Pasture (ungrazed)	Y/B
EF-21	Okmulgee, OK	35.6150	-96.0650	Forest	N/E
EF-12	Pawhuska, OK	36.8410	-96.4270	Native prairie	Y/B
EF-4	Plevna, KS	37.9530	-98.3290	Range (ungrazed)	Y/B
BF-6	Purcell, OK	34.9850	-97.5220	Grass	-
EF-15	Ringwood, OK	36.4310	-98.2840	Pasture	Y/B
EF-6	Towanda, KS	37.8420	-97.0200	Alfalfa	Y
EF-10	Tyro, KS	37.0680	-95.7880	Alfalfa	Y
BF-4	Vici, OK	36.0710	-99.2040	Grass	-
EF-16	Vici, OK	36.0610	-99.1340	Wheat	Y

Many of the EFs collect soil moisture measurements, obtained with Soil Water and Temperature Systems, or SWATS. These utilize the same heat dissipation sensors employed in the Oklahoma Mesonet. The SWATS take observations once every hour, with data transmitted automatically via phone line every 8 hours. Data is also stored locally, and manually downloaded during biweekly maintenance checks. The final design consists of electronics in a surface-mounted enclosure (data logger, multiplexor, constant-current source, power supply, storage module, and telecommunications equipment) supporting 16 CSI 229-L sensors, deployed in two profiles of 8 sensors each. Sensors are located at depths of 5, 15, 25, 35, 60, 85, 125, and 175 cm, rock permitting.

The CF will play an important role in the project. Figure 6 is a Landsat TM image showing the CF and the area surrounding it.

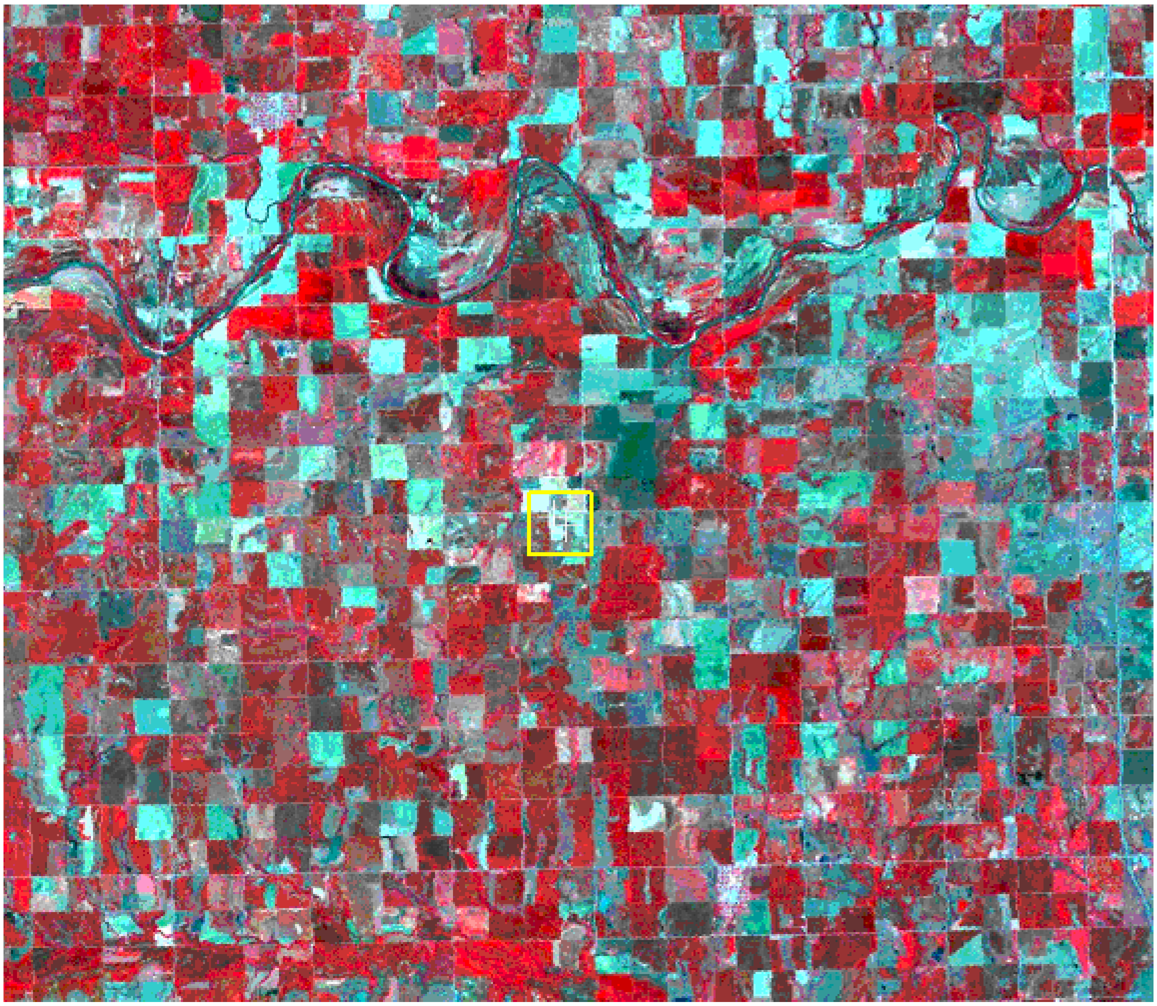


Figure 6. Landsat False Color Composite Image of the ARCF Central Facility Area obtained in April 2005

2.2. LW Measurement Network

The Little Washita Experimental Watershed (LW) is located in southwest Oklahoma in the Southern Great Plains region of the United States and covers an area of 611 sq. km. (Figure 7). The USDA ARS Grazinglands Research Lab operates meteorological and hydrological observing systems throughout the watershed.

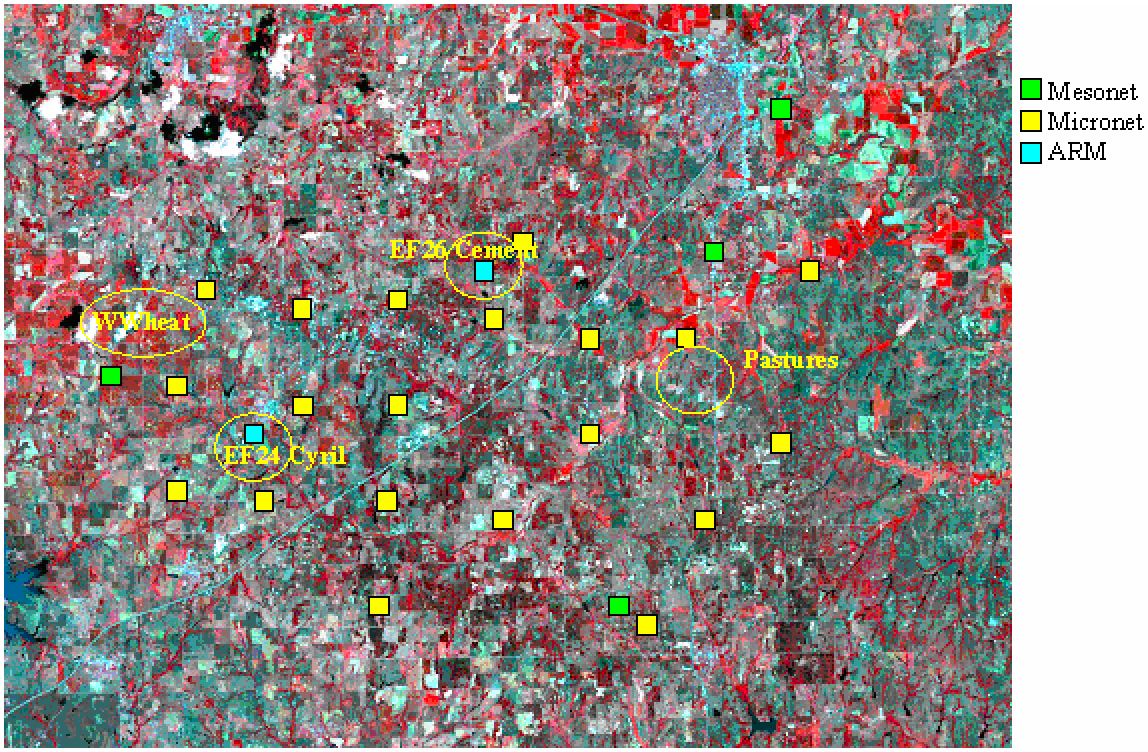


Figure 7. Landsat False Color Composite Image of the LW showing locations of instrumentation and potential tower sites. Image was obtained in April 2005

Within the LW, summers are typically long, hot, and relatively dry. The average daily high temperature for July is 34°C, and the average accumulative rainfall for July is 5.6 cm. Winter is typically short, temperate, and dry but usually is very cold for a few weeks. The average daily low temperature for January is –4°C, and the average accumulative precipitation for January is 2.7 cm. Much of the annual precipitation and most of the large floods occur in the spring and fall.

The topography of the LW is moderately rolling with a maximum relief less than 200 m. Except for a few rocky, steep hills near Cement, OK; the upland topography is gently to moderately rolling. The flatter upland soils are those developed from the finer textured Dog Creek Shale and Blaine Formations near the eastern end of the watershed and those developed from the Cloud Chief Formation in the western portion of the watershed. The alluvial areas have the flattest slopes, usually 1 percent or less. The channel system is well developed throughout the watershed and extends practically to the drainage divide in most areas, so the watershed is well drained except for a few alluvial areas. Drainage ways in the western third of the watershed have eroded through the Cloud Chief Formation into the less erosion resistant, underlying Rush Springs Sandstone. Incised channels in the Rush Springs Sandstone are up to 18 to 21 m deep.

Soils include a wide range of textures with large regions of both coarse and fine textures. Surveys of the soils in the watershed have been made by the NRCS. In these surveys 64 different soil series were defined for the watershed, and 162 soil phases were mapped within these soil series to reflect differences in surface soil textures, slopes, stoniness, degree of erosion, and other characteristics that affect land use. Generally, silt and loam textured soils occur in the western and eastern portions of the watershed, with about the center 1/3 of the watershed in sandy textured soils.

Land use is dominated by rangeland and pasture (63%) with significant areas of winter wheat and other crops concentrated in the floodplain and western portions of the watershed area. Figure 7 illustrates typical conditions using a false color composite derived from Landsat TM data obtained in April 2005. Bright reds are winter wheat fields and deep reds are trees. Grass lands are pink or green and white is bare soil. Additional background information on the watershed can be found in Allen and Naney (1991).

The USDA Agricultural Research Service, Grazinglands Research Laboratory at El Reno, OK operates a meteorological network within LW (http://ars.ocs.ou.edu/overview/). There are currently 20 ARS Micronet stations that measure accumulated rainfall, relative humidity and air temperature at 1.5 m, incoming solar radiation, surface temperature, and soil temperature and soil moisture at depths of 5, 25 and 45 cm. Soil temperature is also measured at depths of 5, 10, 15 and 30 cm. These sites are shown in Figure 7 and coordinates are listed in Table 3. Vitel Hydraprobes provide both soil moisture and temperature. The installations are centered on the depths referenced. Cosh et al. (2006a) demonstrated that this network was able to accurately predict the large-scale soil moisture mean with an RMSE of less than 1% volumetric soil moisture. Figure 8 shows the close relationship between the network mean and an intensive soil moisture campaign average (SMEX03).

The meteorological data are provided in 5-minute increments. One set of the soil temperature are measured every 15 min. Surface temperature is averaged over a reporting period but the Vitel soil temperature and moisture are instantaneous values reported every 30 minutes. The data are telemetered by radio every 15 minutes to a central archiving facility located at the Oklahoma Climate Survey, University of Oklahoma, Norman, OK. There the data are quality controlled, and a data quality indicator is provided for each data entry.

The Little Washita watershed has been a valuable resource in soil moisture remote sensing for 25 years. Most recent efforts have included SGP97 (Jackson et al. 1999) and SGP99 (Jackson et al. 2002) and AMSR-E validation in SMEX03 (Jackson et al. 2005).

Table 3. Little Washita Micronet Locations		
LW Micronet	Latitude (Degrees)	Longitude (Degrees)
121	34.9586	-97.8986
124	34.9728	-98.0581
131	34.9503	-98.2336
132	34.9428	-98.1819
133	34.9492	-98.1281
134	34.9367	-98.0753
135	34.9272	-98.0197
136	34.9278	-97.9656
144	34.8789	-97.9172
146	34.8853	-98.0231
148	34.8992	-98.1281
149	34.8983	-98.1808
150	34.9061	-98.2511
152	34.8611	-98.2511
153	34.8553	-98.2000
154	34.8553	-98.1369
156	34.8431	-97.9583
159	34.7967	-97.9933
162	34.8075	-98.1414
182	34.845	-98.0731
LW-SCAN	34.9500	-97.9831

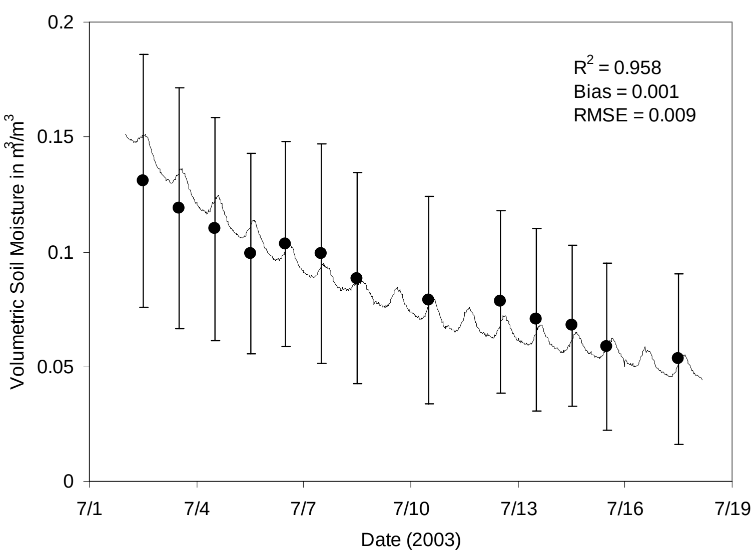


Figure 8: Average soil moisture value from the LW soil moisture network (line) versus the SMEX03 sampling estimated average soil moisture with 1 standard deviation error bars. Diurnal patterns in the LW average are a result of water vapor fluxes at the surface

2.3. FC Measurement Network

The USDA Agricultural Research Service, Grazinglands Research Laboratory at El Reno, OK recently installed a new meteorological and soil moisture network in the Fort Cobb Watershed (FC). It is 813 km^2 and has rolling topography. Land use is a mix of agriculture (cropland, rangeland, and pasture), forest, water, and urban areas. Fort Cobb is primarily an agricultural crop watershed with a significant number of fields with center pivot irrigation. Winter wheat, corn, peanuts, and soybeans are just some of the crops grown in this watershed. Figure 9 clearly illustrates the difference in the field structure and land cover as compared to LW.

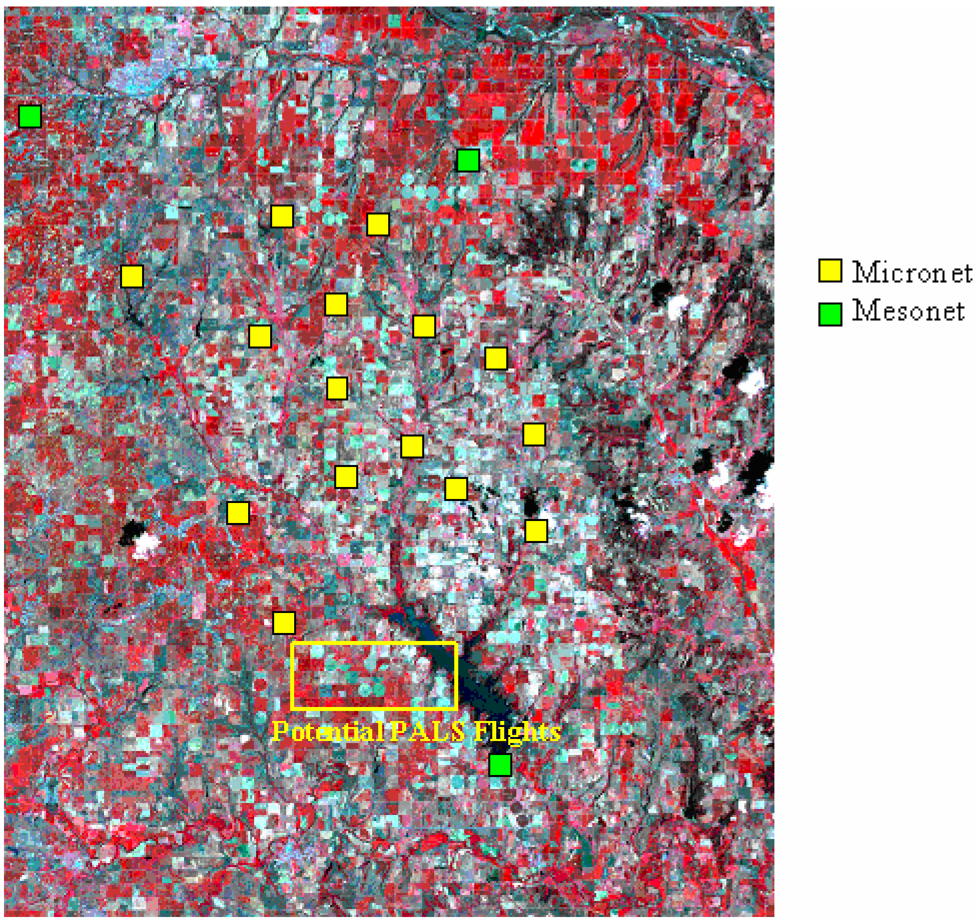


Figure 9. Landsat false color composite image of the FC showing locations of instrumentation. Image was obtained in April 2005

There are 15 ARS Micronet stations that measure accumulated rainfall, relative humidity and air temperature at 1.5 m, incoming solar radiation, and soil temperature at 5, 10, 15 and 30 cm below ground surface. The meteorological data are provided in 5-minute increments and the soil temperature data are provided in 15-minute increments. The data are telemetered by radio every 15 minutes to a central archiving facility located at the Oklahoma Climate Survey, University of Oklahoma, Norman, OK. There the data are quality controlled, and a data quality indicator is provided for each data entry.

As in the case of the LW, these stations include Vitel Hydraprobes at depths of 5, 25, and 45 cm, which provide soil moisture and temperature. Locations of the FC Micronet stations are shown in Figure 9 and coordinates are listed in Table 4.

Table 4. Fort Cobb Micronet Locations		
FC Micronet	Latitude (Degrees)	Longitude (Degrees)
F101	35.4551	-98.6064
F102	35.4504	-98.5443
F103	35.4237	-98.7087
F104	35.3923	-98.6233
F105	35.4072	-98.571
F106	35.3915	-98.5138
F107	35.3764	-98.465
F108	35.3611	-98.5712
F109	35.3123	-98.5675
F110	35.3303	-98.5202
F111	35.3343	-98.4383
F112	35.3051	-98.4914
F113	35.291	-98.6357
F114	35.283	-98.4371
F115	35.2294	-98.6063

2.4. The Oklahoma Mesonet

The Oklahoma Mesonet is an automated network of over 110 remote, meteorological stations across Oklahoma (Figure 10). Each station measures nine core parameters: air temperature and relative humidity at 1.5 m, wind speed and direction at 10 m, atmospheric pressure, incoming solar radiation, rainfall, and bare and vegetated soil temperatures at 10 cm below ground level. Data are collected and transmitted to a central point every 15 minutes where they are quality controlled, distributed and archived. For additional information about the Oklahoma Mesonet, see Brock et al. (1995) and http://okmesonet.ocs.ou.edu/.

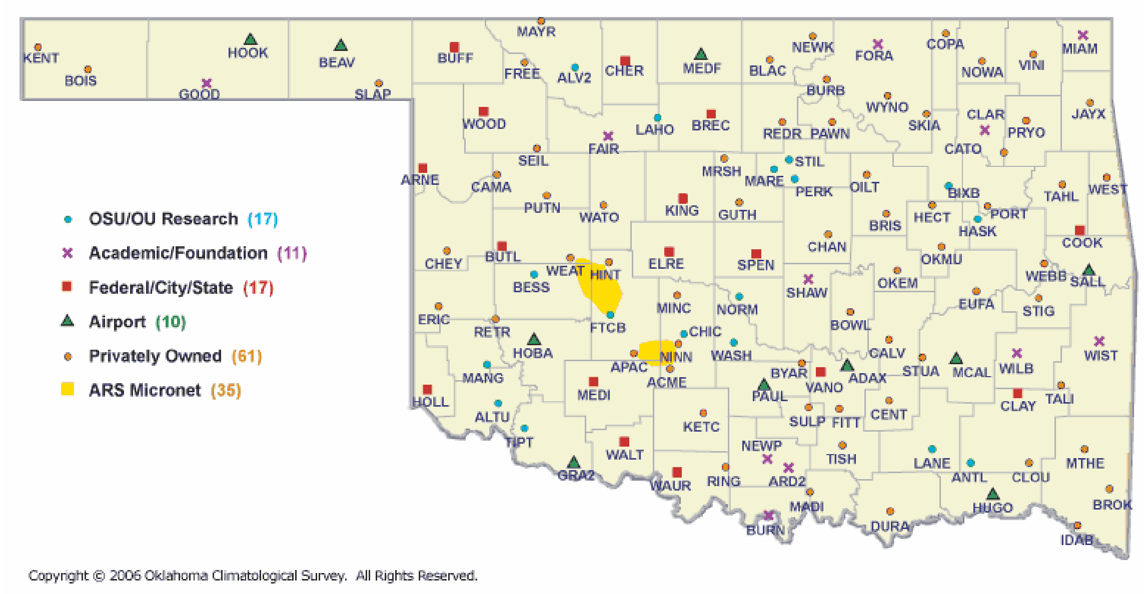


Figure 10. Locations of the Oklahoma Mesonet Sites

During 1996 matric potential sensors (the Campbell Scientific 229-L) were installed at 60 sites in the Oklahoma Mesonet. The sensors were installed at depths of 5, 25, 60, and 75 cm. Based upon the initial success in using data from this initial deployment of soil moisture sensors, 229-L sensors were installed at an additional 43 Mesonet sites during 1998 and 1999. The network of 229-L sensors is unique in that they provide an estimate of both soil-water potential *and* water content every 30 minutes (Basara and Crawford 2000). As a result, the soil moisture sensors installed at more than 101 Mesonet sites are now providing a continuous record of soil moisture conditions.

In 1998, the National Science Foundation provided funds to upgrade Oklahoma Mesonet with a suite of instruments capable of measuring latent and sensible heat fluxes. Thus, sensors were installed at 89 Mesonet sites during 1999 as part of the Oklahoma Atmospheric Surface-layer Instrumentation System Project (Brotzge et al. 1999). Currently 10 site locations measure surface energy fluxes using the eddy correlation method. These sites are referred to as OASIS Super Sites. The sensors at OASIS Super Sites allow these stations to measure net radiation, sensible, latent, and ground heat fluxes. Surface skin temperature is also measured at Super Sites using an infrared temperature sensor (IRT) manufactured by Apogee and mounted at 2 m. In addition, surface skin temperature is measured at an additional 79 sites designated as OASIS Standard sites. Instrumentation features at each site are summarized in Table 5.

Table 5. Oklahoma Mesonet Sites and Characteristics					
Identifier	Name	Latitude (Degrees)	Longitude (Degrees)	Station Type	Soil Moisture
ACME	Acme	34.8056	-98.0056	Oasis	Y
ADAX	Ada	34.7989	-96.6692	Oasis	Y
ALTU	Altus	34.5872	-99.3378	Standard	Y
ALV2	Alva	36.7083	-98.7075	Super	Y
ANTL	Antlers	34.2242	-95.7006	Standard	Y
APAC	Apache	34.9139	-98.2917	Oasis	Y
ARD2	Ardmore	34.1926	-97.0857	Oasis	Y
ARNE	Arnett	36.0728	-99.9014	Oasis	Y
BEAV	Beaver	36.8022	-100.5300	Oasis	Y
BEEX	Bee	34.1905	-96.6435	Standard	N
BESS	Bessie	35.4017	-99.0589	Oasis	Y
BIXB	Bixby	35.9625	-95.8661	Oasis	Y
BLAC	Blackwell	36.7544	-97.2539	Oasis	Y
BOIS	Boise City	36.6925	-102.4970	Super	Y
BOWL	Bowlegs	35.1717	-96.6314	Standard	Y
BREC	Breckinridge	36.4119	-97.6942	Oasis	Y
BRIS	Bristow	35.7808	-96.3539	Oasis	Y
BROK	Broken Bow	34.0433	-94.6244	Standard	N
BUFF	Buffalo	36.8314	-99.6408	Standard	Y
BURB	Burbank	36.6342	-96.8111	Standard	N
BURN	Burneyville	33.8939	-97.2692	Super	Y
BUTL	Butler	35.5914	-99.2706	Oasis	Y
BYAR	Byars	34.8497	-97.0033	Oasis	Y
CALV	Calvin	34.9925	-96.3342	Oasis	Y
CAMA	Camargo	36.0283	-99.3464	Oasis	Y
CENT	Centrahoma	34.6086	-96.3331	Oasis	Y
CHAN	Chandler	35.6528	-96.8042	Oasis	Y
CHER	Cherokee	36.7481	-98.3628	Oasis	Y
CHEY	Cheyenne	35.5458	-99.7275	Oasis	Y
CHIC	Chickasha	35.0319	-97.9144	Standard	N
CLAY	Clayton	34.6556	-95.3261	Standard	N
CLOU	Cloudy	34.2231	-95.2494	Oasis	Y
CLRM	Claremore	36.3213	-95.6461	Standard	N
COOK	Cookson	35.6794	-94.8486	Oasis	Y
COPA	Copan	36.9097	-95.8853	Oasis	Y
DURA	Durant	33.9206	-96.3200	Oasis	Y
ELRE	El Reno	35.5481	-98.0358	Oasis	Y
ERIC	Erick	35.2047	-99.8033	Oasis	Y
EUFA	Eufaula	35.3000	-95.6583	Oasis	Y
FAIR	Fairview	36.2636	-98.4978	Standard	Y
FITT	Fittstown	34.5520	-96.7178	Standard	Y
FORA	Foraker	36.8403	-96.4278	Super	Y
FREE	Freedom	36.7256	-99.1422	Oasis	Y

FTCB	Fort Cobb	35.1492	-98.4667	Oasis	Y
GOOD	Goodwell	36.6017	-101.6010	Oasis	Y
GRA2	Grandfield	34.2392	-98.7444	Super	Y
GUTH	Guthrie	35.8489	-97.4800	Oasis	Y
HASK	Haskell	35.7475	-95.6400	Standard	Y
HECT	Hectorville	35.8436	-96.0056	Standard	Y
HINT	Hinton	35.4844	-98.4822	Oasis	Y
HOBA	Hobart	34.9897	-99.0525	Oasis	Y
HOLL	Hollis	34.6861	-99.8339	Oasis	Y
HOOK	Hooker	36.8553	-101.2250	Oasis	Y
HUGO	Hugo	34.0308	-95.5400	Oasis	Y
IDAB	Idabel	33.8303	-94.8806	Super	Y
INOL	Inola	36.1422	-95.4505	Standard	N
JAYX	Jay	36.4817	-94.7831	Oasis	Y
KENT	Kenton	36.8297	-102.8780	Oasis	Y
KETC	Ketchum Ranch	34.5289	-97.7647	Oasis	Y
KING	Kingfisher	35.8806	-97.9111	Oasis	Y
LAHO	Lahoma	36.3844	-98.1114	Oasis	Y
LANE	Lane	34.3086	-95.9975	Oasis	Y
MADI	Madill	34.0361	-96.9431	Standard	Y
MANG	Mangum	34.8361	-99.4239	Oasis	Y
MARE	Marena	36.0644	-97.2128	Super	Y
MAYR	May Ranch	36.9869	-99.0111	Oasis	Y
MCAL	McAlester	34.8819	-95.7808	Oasis	Y
MEDF	Medford	36.7922	-97.7456	Standard	N
MEDI	Medicine Park	34.7292	-98.5667	Oasis	Y
MIAM	Miami	36.8886	-94.8447	Oasis	Y
MINC	Minco	35.2722	-97.9556	Oasis	Y
MRSH	Marshall	36.1168	-97.6068	Standard	Y
MTHE	Mt Herman	34.3108	-94.8228	Standard	N
NEWK	Newkirk	36.8981	-96.9106	Oasis	Y
NEWP	Newport	34.2282	-97.2007	Standard	N
NINN	Ninnekah	34.9678	-97.9514	Standard	N
NOWA	Nowata	36.7436	-95.6078	Oasis	Y
NRMN	Norman	35.2361	-97.4649	Super	Y
OILT	Oilton	36.0314	-96.4972	Oasis	Y
OKEM	Okemah	35.4317	-96.2628	Oasis	Y
OKMU	Okmulgee	35.5811	-95.9150	Oasis	Y
PAUL	Pauls Valley	34.7156	-97.2294	Oasis	Y
PAWN	Pawnee	36.3611	-96.7697	Oasis	Y
PERK	Perkins	35.9983	-97.0481	Standard	Y
PORT	Porter	35.8258	-95.5600	Oasis	Y
PRYO	Pryor	36.3689	-95.2717	Oasis	Y
PUTN	Putnam	35.8992	-98.9603	Oasis	Y
REDR	Red Rock	36.3556	-97.1531	Oasis	Y
RETR	Retrop	35.1231	-99.3597	Standard	N
RING	Ringling	34.1939	-97.5883	Oasis	Y

SALL	Sallisaw	35.4381	-94.7978	Standard	Y
SEIL	Seiling	36.1903	-99.0406	Oasis	Y
SHAW	Shawnee	35.3650	-96.9483	Oasis	Y
SKIA	Skiatook	36.4147	-96.0372	Oasis	Y
SLAP	Slapout	36.5969	-100.2620	Oasis	Y
SPEN	Spencer	35.5422	-97.3411	Oasis	Y
STIG	Stigler	35.2653	-95.1814	Super	Y
STIL	Stillwater	36.1211	-97.0950	Standard	Y
STUA	Stuart	34.8764	-96.0700	Oasis	Y
SULP	Sulphur	34.5661	-96.9506	Standard	N
TAHL	Tahlequah	35.9728	-94.9869	Oasis	Y
TALI	Talihina	34.7106	-95.0117	Oasis	Y
TIPT	Tipton	34.4394	-99.1375	Oasis	Y
TISH	Tishomingo	34.3328	-96.6794	Oasis	Y
VANO	Vanoss	34.789	-96.8430	Standard	Y
VINI	Vinita	36.7753	-95.2211	Oasis	Y
WALT	Walters	34.3647	-98.3206	Oasis	Y
WASH	Washington	34.9817	-97.5208	Super	Y
WATO	Watonga	35.8422	-98.5261	Oasis	Y
WAUR	Waurika	34.1678	-97.9878	Oasis	Y
WEAT	Weatherford	35.5081	-98.7753	Oasis	Y
WEBB	Webbers Falls	35.4728	-95.1322	Standard	N
WEST	Westville	36.0111	-94.6450	Oasis	Y
WILB	Wilburton	34.9008	-95.3478	Oasis	Y
WIST	Wister	34.9847	-94.6881	Oasis	Y
WOOD	Woodward	36.4233	-99.4169	Oasis	Y
WYNO	Wynona	36.5172	-96.3422	Oasis	Y

2.5. Forest Site (FS)

Located west of the town of Okmulgee, OK, the Forest Site (FS) is a forested region near Lake Okmulgee and Dripping Springs State Park. Figure 11 shows the forested region between Okmulgee (east) and Lake Okmulgee (to the west). There are a variety of trees including pin oak, black jack oak, and along the riparian area, water oak and willow oak. Currently, surface flux investigations are being conducted in and around this region by various groups including an ARM site (EF-21) and a Mesonet site near the town of Okmulgee.

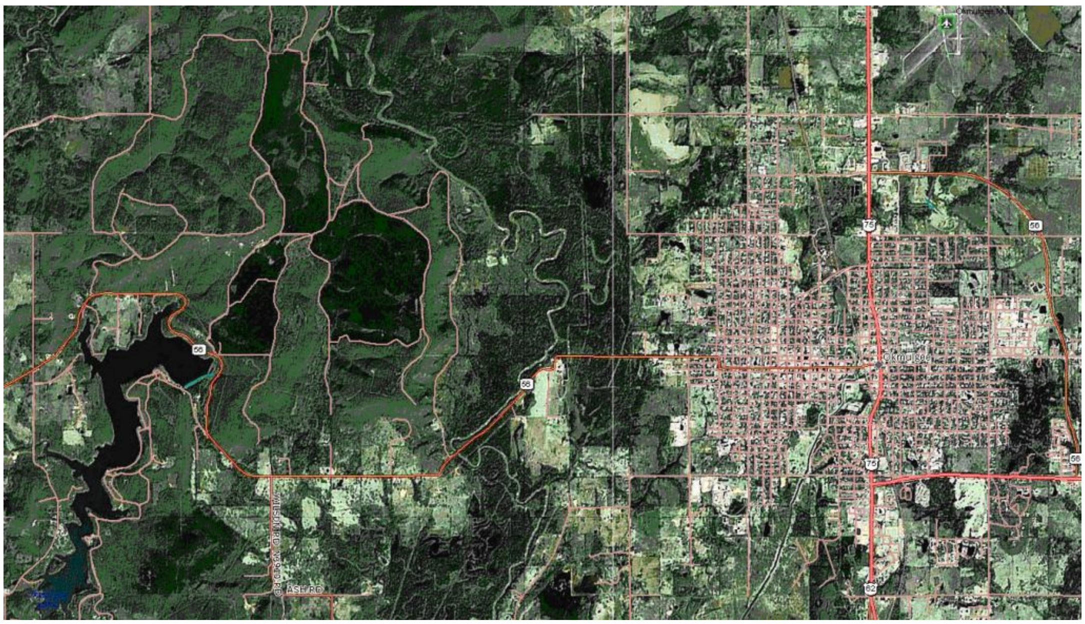


Figure 11: Forest Site near Okmulgee, shown to the east

3. Land Surface Satellite Remote Sensing Data

3.1. Advanced Microwave Scanning Radiometer (AMSR-E)

AMSR-E on Aqua (http://wwwghcc.msfc.nasa.gov/AMSR/) was launched in May 2002. Algorithm development and validations of AMSR-E soil moisture products are very important components of the SMEX program (Njoku et al. 2003).

As shown in Table 6, the lowest frequency of AMSR-E is 6.9 GHz (C band). However, studies indicate that there is widespread radio frequency interference (RFI) in the C band channels (Li et al. 2004). Therefore, it is likely that the most useful channels for soil moisture will be those operating at the slightly higher X band. The viewing angle of AMSR is a constant 55°. Details on AMSR-E can be found at http://wwwghcc.msfc.nasa.gov/AMSR/. The average local overpass times in the CLASIC region at this time of the year are 3:22 and 14:35. Aqua afternoon overpasses for the CLASIC region are summarized in Table 7.

Table 6. AMSR-E Characteristics

Frequency (GHz)	Polarization	Horizontal Resolution (km)	Swath (km)
6.925	V, H	75	1445
10.65	V, H	48	1445
18.7	V, H	27	1445
23.8	V, H	31	1445
36.5	V, H	14	1445
89.0	V, H	6	1445

Aqua includes several other instruments of potential value:

- The Atmospheric Infrared Sounder (AIRS) is a high-resolution instrument, which measures upwelling infrared (IR) radiances at 2378 frequencies ranging from 3.74 and 15.4 micrometers.
- The Advanced Microwave Sounding Unit (AMSU) is a passive scanning microwave radiometer consisting of two sensor units, A1 and A2, with a total of 15 discrete channels operating over the frequency range of 50 to 89 GHZ. The AMSU operates in conjunction with the AIRS and HSB instruments to provide atmospheric temperature and water vapor data both in cloudy and cloud-free areas.
- Clouds and the Earth's Radiant Energy System (CERES) is a broadband scanning radiometer, with three detector channels, 0.3 to 5.0 micrometers, 8.0 to 12.0 micrometers and 0.3 to 50 micrometers.
- Moderate Resolution Imaging Spectroradiometer (MODIS) is a passive imaging spectroradiometer. The instrument scans a cross-track swath of 2330 km using 36 discrete spectral bands between 0.41 and 14.2 micrometers.

Table 7. Aqua AMSR-E Coverage Dates and Times During CLASIC (afternoon)					
Month	Day	LW	FC	FS	CF
6	9			X	
6	10	X	X	X	X
6	11				
6	12	X	X	X	X
6	13				
6	14	X	X	X	X
6	15				
6	16			X	X
6	17	X	X		
6	18				
6	19	X	X	X	X
6	20				
6	21	X	X	X	X
6	22				
6	23	X	X	X	X
6	24				
6	25			X	
6	26	X	X		X
6	27				
6	28	X	X	X	X
6	29				
6	30	X	X	X	X
7	2			X	X

It should also be pointed out that Aqua is part of the NASA A-Train of satellites that includes CloudSat, Calipso, and Aura. A focus of CLASIC is combined validation of these instrument suites. Unlike AMSR-E and MODIS that have wide swaths, CloudSat and Calipso have very narrow swaths.

3.2. WindSat

WindSat is a satellite-based multi-frequency polarimetric microwave radiometer developed by the Naval Research Laboratory for the U.S. Navy and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) (Gaiser et al., 2004). It is one of the two primary instruments on the Coriolis satellite. The Coriolis satellite was successfully launched on January 6, 2003 with an expected life cycle of three years.

The WindSat radiometer operates at nominal frequencies of 6.8, 10.7, 18.7, 23.8, and 37 GHz. Using a conically-scanned 1.83 m offset parabolic reflector with multiple feeds, the WindSat covers a 1025 km active swath (based on an altitude of 830 km) and provides two looks at both fore (1025 km) and aft (350 km) views of the swath. The nominal earth incidence angle (EIA) is in the range of 50 – 55 degrees. The inclination of the WindSat orbit is 98.7 degrees. It has a sun synchronous polar orbit with an ascending node at 6:00 PM and a descending node at 6:00 AM.

The WindSat has similar frequencies to the Advanced Microwave Scanning Radiometers on the Earth Observing System (AMSR-E), with the addition of full polarization for 10.7, 18.7 and 37.0 GHz and the lack of an 89.0 GHz channel. The characteristics of the WindSat radiometer are listed in Table 8. Initially, the methods developed for algorithm development and validations for AMSR-E may be applied to WindSat with minimal modifications. The coverage dates and times of WindSat during CLASIC are summarized in Table 9. Note that the average morning overpass time is 7:44 am local time (CDT) and the evening is at 6:52 pm (CDT).

Table 8. Characteristics of WindSat

Frequency (GHz)	Polarization	Incidence Angle (Degrees)	Footprint (Km)	Fore/Aft Swath (Km)
6.8	V, H	53.5	40 x 60	1025/350
10.7	V, H, U 4	49.9	25 x 38	1025/350
18.7	V, H, U, 4	55.3	16 x 27	1025/350
23.8	V, H	53.0	12 x 20	1025/350
37.0	V, H, U, 4	53.0	8 x 13	1025/350

3.3. Special Sensor Microwave Imager (SSM/I)

SSM/I satellites have been collecting global observations since 1987. The SSM/I satellite data can only provide soil moisture under very restricted conditions because the frequencies (see Table 10) were not selected for land applications. The viewing angle of the SSM/I is 53.1°.

There may be as many as four satellites with the SSM/I on board in operation during CLASIC. The local ascending equatorial crossing times of the three currently available satellites are F13 (17:54), F14 (20:46), and F15 (21:20). F16 (07:54) was launched in October 2003. SSM/I data are useful in some aspects of algorithm development and provide a cross reference to equivalent channels on the WindSat and AMSR-E instruments. SSM/I data are freely available to users through http://www.saa.noaa.gov/. As in past experiments, the data will be subset and repackaged for this experiment.

Table 9. WindSat Coverage Dates and Times During CLASIC (Morning)					
Month	Day	LW	FC	FS	CF
6	9				
6	10				
6	11	X	X	X	X
6	12	X	X	X	X
6	13				
6	14				
6	15				
6	16				
6	17	X	X	X	X
6	18	X	X	X	X
6	19				
6	20				
6	21				
6	22	X	X		X
6	23	X	X	X	X
6	24	X		X	X
6	25				
6	26				
6	27				
6	28	X	X		X
6	29	X	X	X	X

Table 10. SSM/I Characteristics			
Frequency (GHz)	Polarization	Spatial Resolution (km)	Swath (km)
19.4	H and V	69 x 43	1200
22.2	V	60 x 40	1200
37.0	H and V	37 x 28	1200
85.5	H and V	15 x 13	1200

3.4. Advanced Land Observing System (ALOS)

ALOS is a satellite platform launched by the Japanese Aerospace Exploration Agency (JAXA) in January 2006 into a sun synchronous orbit at an altitude of 700 km. The repeat cycle is 46 days and the local time at descending node is about noon CDT. The data are available to currently selected investigators. There are two instruments of interest for CLASIC, the Phased Array type L-band Synthetic Aperture Radar (PALSAR) and the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2).

PALSAR (http://www.eorc.jaxa.jp/ALOS/about/palsar.htm) is an active microwave sensor aboard ALOS. This radar sensor operates at L-band with HH and VV polarization (HV and VH polarizations are optional). The sensor is beam steerable in elevation and the ScanSAR mode, which allows obtaining a wider swath than conventional SARs. PALSAR has a spatial resolution of 20 m for the fine resolution mode (swath width of 70 km) and 100 m for the ScanSAR mode (swath width of 360 km). ALOS PALSAR data was requested over the selected regions of the CLASIC domain that would include the super sites. However, the allocations of coverage were very sparse (see Table 11).

PALSAR has many operating modes. For most of the year, JAXA sets the mode for a period of time. ScanSAR HH data is collected on all descending passes (morning). For the ascending passes (evening), we anticipate that this will be HH+HV 34.3^{o} during CLASIC.

AVNIR-2 (http://www.eorc.jaxa.jp/ALOS/about/avnir2.htm) is a visible and near infrared radiometer onboard ALOS. AVNIR-2 provides 10 m spatial resolution images. The pointing angle of AVNIR-2 is +44° and -44°. Acquisitions over the U.S. are planed during CLASIC, obviously on the descending passes. However, it is uncertain what will be obtained at this time. Overpass time is approximately 11:30pm CDT for CLASIC.

Table 11. ALOS PALSAR Acquisitions During CLASIC

Month	Day	Mode	Site Center
6	9	FBD34.3	Forest
7	1	FBD34.3	Little Washita
7	13	FBD34.3	Central Facility
7	18	FBD34.3	Fort Cobb

3.5. Envisat Advanced Synthetic Aperture Radar (ASAR)

The Envisat satellite was launched by the European Space Agency in March 2002 (http://envisat.esa.int/). It is designed to provide Earth observations using a suite of remote sensing instruments. Of particular interest to soil moisture and hydrology is the inclusion of the Advanced Synthetic Aperture Radar (ASAR) that will provide both continuity to the ERS-1 and ERS-2 mission SARs and next generation capabilities. Envisat also has a visible and near infrared imaging system called MERIS. Envisat has a sun synchronous polar orbit. The exact repeat cycle for a specific scene and sensor configuration is 35 days.

The ASAR is a C band instrument, which is the same frequency as the ERS instrument. Unlike the ERS satellites that had a fixed angle of incidence (23°) ASAR has a wider range of choices that can provide more frequent coverage and a variety of incidence angles. ASAR Image Mode will provide data acquisition in the seven different swath positions listed in Table 12, giving incidence angles ranging from 15° to 45°. IS1 is closest to the track of the satellite and IS7 is furthest away. When acquired simultaneously, each IS views a different area across track. In order to get all IS positions for the same ground location a series of days is required.

The other new feature of ASAR of interest for soil moisture is the alternating polarization (AP) mode. In this mode two polarization combinations (ERS had only VV) can be obtained (VV and HH, HH and HV, or VV and VH). It is anticipated that this additional information will enhance soil moisture retrieval. Swath width is nominally 100 km and the product pixel size is 30 m.

There are a limited number of data products available in dual polarization mode. Those of interest include: Alternating Polarization Mode Precision Image (APP) and Alternating Polarization Ellipsoid Geocoded Image (APG). Each will be a nominal 100 x 100 km scene with a pixel spacing of 12.5 x 12.5 m and a pixel size of 30 x 30 m. The APG is resampled to a North orientation and georectified.

Table 12. Specifications for ASAR Image Mode Swaths

Image Type	Swath Width (km)	Ground Position from Nadir (km)	Incidence Angle Range (Degrees)
IS1	105	187 - 292	15.0 - 22.9
IS2	105	242 - 347	19.2 - 26.7
IS3	82	337 - 419	26.0 - 31.4
IS4	88	412 - 500	31.0 - 36.3
IS5	64	490 - 555	35.8 - 39.4
IS6	70	550 - 620	39.1 - 42.8
IS7	56	615 - 671	42.5 - 45.2

In general the VV-VH combination is preferred for soil moisture. IS2 provides continuity of the ERS observations. IS1-IS3 may be better for minimizing roughness effects while IS4-IS6 may provide more vegetation information. Data takes must be scheduled and are limited to approved investigations. Coverage of the select CLASIC sites concurrent with ground data collection will be requested. Potential IS2 data sets ordered are listed in Table 13. Note that these are all at approximately 11:30 am local CDT. There are a number of other coverage types available.

There are other approaches that could be used in selecting ASAR data. For instance we could request HH+HV data for IS-4 in order to match the system parameters of PALSAR (except the frequency) during CLASIC. This issue will be resolved prior to the next draft of the experiment plan.

Table 13. Envisat ASAR AP Data Requested for CLASIC			
Location	Month	Day	IS mode
LW+FC	4	26	I2
LW+FC	5	31	I2
LW+FC	6	10	I7
LW	6	13	I4
LW+FC	6	19	I1
LW+FC	6	29	I6
LW+FC	7	5	I2
LW+FC	7	15	I7
LW+FC	8	9	I2
LW+FC	6	16	I3
FC	4	10	I2
FC	5	15	I2
FC	5	25	I6
FC	7	24	I2
FC	8	28	I2
Forest	4	4	I2
Forest	4	23	I2
Forest	5	9	I2
Forest	5	28	I2
Forest	6	7	I6
Forest	6	23	I7
Forest	6	26	I5
Forest	7	2	I2
Forest	7	18	I2
Forest	8	6	I2
Forest	8	22	I2
CF	4	26	I2
CF	5	22	I7
CF	5	31	I2
CF	6	13	I4
CF	6	19	I1
CF	7	5	I2
CF	8	9	I2

Another instrument on Envisat that may be of value is the MEdium Resolution Imaging Spectrometer Instrument (MERIS). This is a 68.5° field-of-view pushbroom imaging spectrometer that measures the solar radiation reflected by the Earth, at a ground spatial resolution of 300 m, in 15 spectral bands (412.5, 442.5, 490, 510, 560, 620, 665, 681.25, 705, 753.75, 760, 775, 865, 890, and 900 nm), programmable in width and position, in the visible and near infra-red. The instrument has a very wide swath, which results in frequent coverage. MERIS allows global coverage of the Earth in 3 days. MERIS data cannot be obtained at the same time as ASAR image products.

3.6. Terra and Aqua Sensors

The NASA Terra and Aqua spacecraft (http://terra.nasa.gov/About/, http://aqua.nasa.gov/about/) include several instruments of value to the investigations of soil moisture and vegetation dynamics proposed here. Of particular interest are the Moderate-resolution Imaging Spectroradiometer (MODIS) and on board both the Terra and Aqua satellites (http://modis.gsfc.nasa.gov/) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on board Terra (http://asterweb.jpl.nasa.gov/). The AMSR-E instrument was described in a previous section.

The Terra satellite has a descending orbit that crosses the equator about 10:30 AM local time (SGP overpasses ~11:30 am CDT) and the Aqua satellite has an ascending equatorial crossing time of 1:30 PM local time (SGP overpasses ~2:50 CDT). Coverage of a single location varies with the orbital path, so coverage can be either daily or every other day. The angle of incidence varies depending on the orbital path from -55º to 55º for a swath of 2330 km. The bands of MODIS are listed in Table 14.

Table 14. MODIS Bands

Primary Use	Band(s)	Wavelength	Pixel Size
Vegetation Index	1	620-670 nm	250 m
Vegetation Index	2	841-876 nm	250 m
	3 459-479 nm	500 m	
	4 545-565 nm	500 m	
Vegetation H_2O	5	1230-1250 nm	500 m
Vegetation H_2O	6	1628-1652 nm	500 m
	7	2105-2155 nm	500 m
Ocean Color	8-16	405-877 nm	1000 m
Atmospheric H_2O	17-19	890-965 nm	1000 m
Thermal	20-36 3.660-	14.385 nm	1000 m

Most of the imagery from MODIS is provided by the NASA GSFC and LP DAAC as 250m, 500m or 1km gridded data products. Surface reflectance for bands 1-7 are provided as product MOD09, which has: (1) an atmospheric transmittance correction; and (2) a cloud mask. These data are not explicitly corrected for topography. A view-angle corrected surface reflectance is supplied every 8-days by product MCD43 in MODIS bands 1-7. This product also provides BRDF model parameters and surface albedo values for bands 1-7 (Figure 12) as well as for three additional shortwave broad bands.

Other MODIS products of interest are land cover type and phenology (MOD12), vegetation indices (MOD13), leaf area index (MOD15), evapotranspiration (MOD16), net primary production (MOD17), and land surface temperature (MOD11), which are produced at daily, 8-day or 16-day intervals.

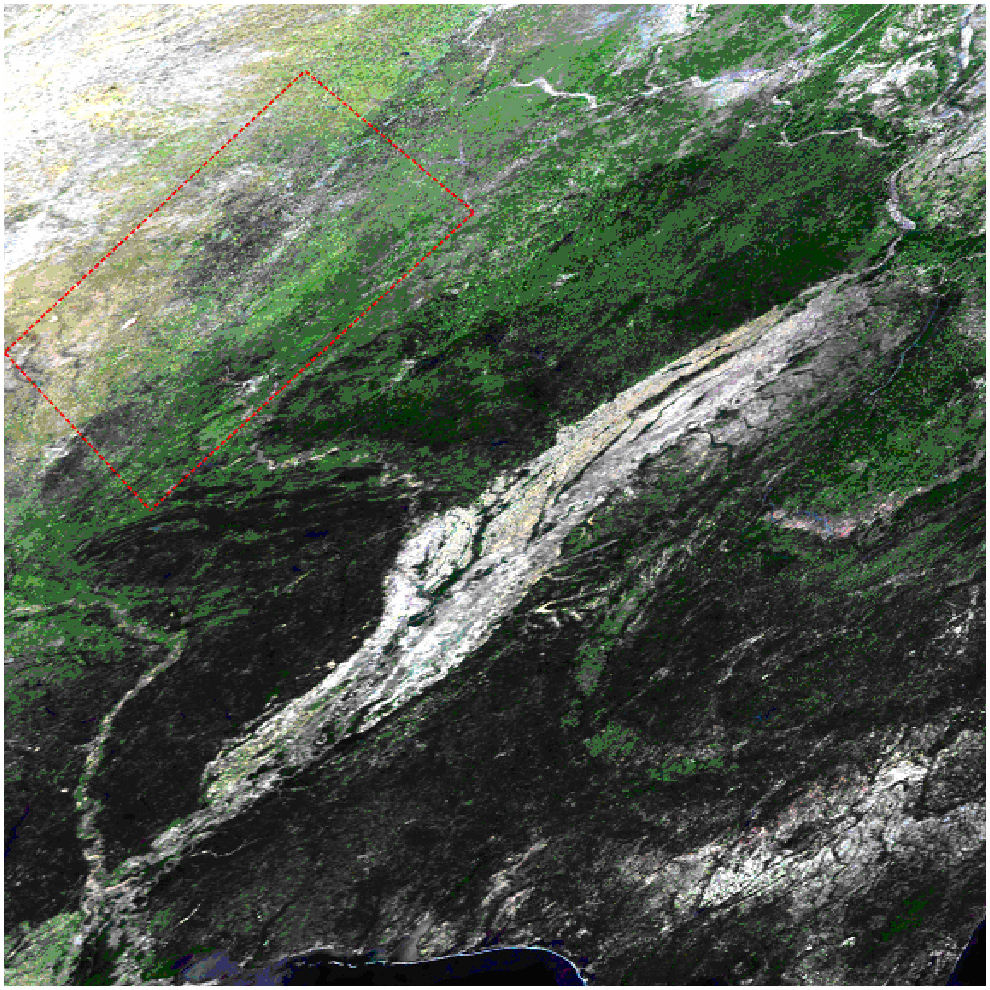


Figure 12. White Sky Albedo from the MODIS 500-m product, MCD43A3, a true-color image in sinusoidal projection, nominal date 5/23/2006.

The MODIS land team is especially interested in CLASIC as a means of supporting CEOS/WGCV/Land Product Validation (LPV) efforts (http://lpvs.gsfc.nasa.gov/) in regards to satellite-derived landcover, biophysical, and radiation parameters. The availability of numerous ground and tower measurements, coupled with both MODIS Airborne Simulator (MAS) imagery and Cloud Airborne Radiometer (CAR) bidirectional reflectance data and high resolution Landsat, Quickbird and ASTER imagery, provide an ideal opportunity to validate the MODIS albedo and leaf area index (LAI) products.

ASTER, another Terra sensor, provides high resolution visible (VIR (15m), shortwave infrared (SWIR - 30m)), and thermal infrared (TIR - 90m)) data (see Table 15). Coverage is only obtained on request and these are prioritized. In general, the data coverage occurs on the same day as Landsat 7 for a 60km swath. A large number of ASTER scenes have been requested by ASTER, MODIS and ARM investigators (Table 16). Due to the large area considered it is not possible to cover the entire CLASIC domain on a given acquisition date. Figure 13 compare Landsat and ASTER images obtained over the SGP region.

Table 15. Characteristics of the ASTER Sensor Systems			
System	Channel	Spectral Range (µm)	Spatial Resolution (m)
VIR	1	0.52-0.60	15
	2	0.63-0.69	
	3N	0.78-0.86	
	3B	0.78-0.86	
SWIR	4	1.60-1.70	30
	5	2.145-2.185	
	6	2.185-2.225	
	7	2.235-2.285	
	8	2.295-2.365	
	9	2.360-2.430	
TIR	10	8.125-8.475	90
	11	8.475-8.825	
	12	8.925-9.275	
	13	10.25-10.95	
	14	10.95-11.65	

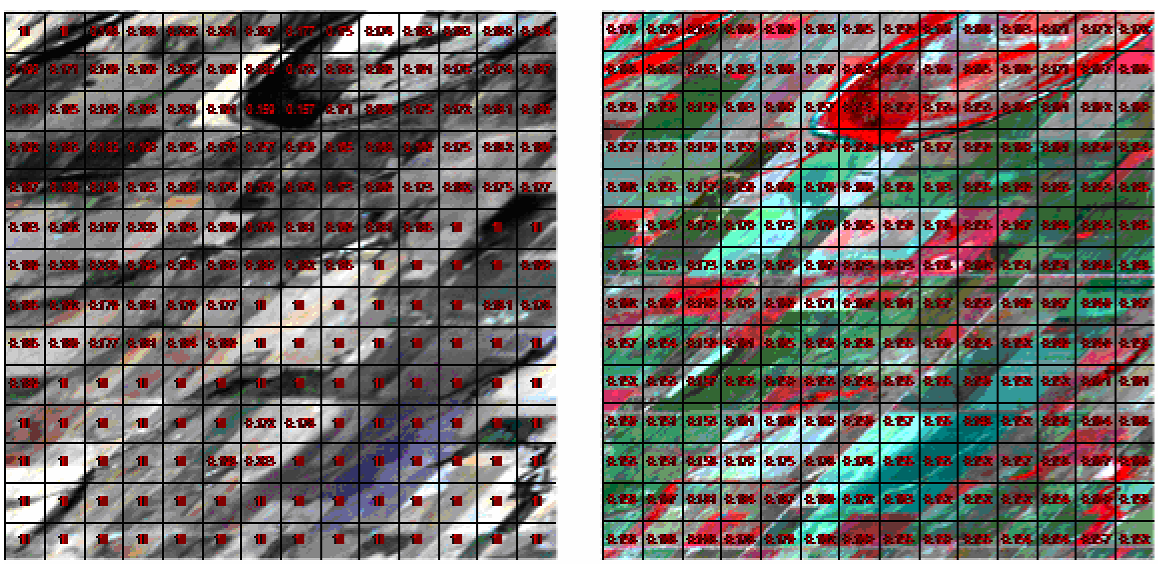


Figure 13. Landsat ETM+ (left) and ASTER (right) scenes collected on 7/12/01 and 5/23/06 (respectively) at the ARM-C01 station. These 7km x 7km scenes have been superimposed against two MODIS ASCII blue-sky albedos subsets at 500m.

Table 16. ASTER Requested Coverage Dates		
Month	Day	Sites (LW, FC, CF, FS)
April	17	FS
April	24	LW, CF
May	3	FS
May	10	LW, CF
May	19	FS
May	26	LW, CF
June	4	FS
June	11	LW, CF
June	20	FS
June	27	LW, CF
July	6	FS
July	13	FC, CF
July	29	FC

3.7. Landsat Thematic Mapper

The Landsat Thematic Mapper (TM) satellites collect data in the visible and infrared regions of the electromagnetic spectrum. Data are high resolution (30 m) and are very valuable in land cover and vegetation parameter mapping. Additional details on the Landsat program and data can be found at http://landsat7.usgs.gov/programdesc.html.

At the present time Landsat 5 is still in operation and, following a problem, Landsat 7 is now providing modified products. An instrument malfunction occurred onboard Landsat 7 on May 31, 2003. The problem was caused by failure of the Scan Line Corrector (SLC), which compensates for the forward motion of the satellite. The problem is permanent and results in an up to 25 % data loss per scene. The Landsat 7 Enhanced Thematic Mapper Plus (ETM+) is still capable of acquiring useful image data with the SLC turned off, particularly within the central portion of any given scene (about 22 km). These data are still acquired and are referred to as "SLC-off" mode. SLC Enhanced products are also now available that use interpolation schemes to fill missing data gaps. These can be based on pre-loss of SLC scenes or other dates.

The CLASIC domain is located on rows 35 and 36 of both paths 27 and 28. Coverage dates for Landsat 5 and 7 are listed in Table 17. The super sites fall in LW (Path 28 Row 36), FC (Path 28 Row 36), FS (Path 27 Row 35) and CF (Path 28 Row 35). Figure 2 illustrates the scene coverage.

Table 17. Landsat TM Coverage			
Landsat 5		Landsat 7	
Path 28	Path 27	Path 28	Path 27
15-Mar	8-Mar	7-Mar	16-Mar
31-Mar	24-Mar	23-Mar	1-Apr
16-Apr	9-Apr	8-Apr	17-Apr
2-May	25-Apr	24-Apr	3-May
18-May	11-May	10-May	19-May
3-Jun	27-May	26-May	4-Jun
19-Jun	12-Jun	11-Jun	20-Jun
5-Jul	28-Jun	27-Jun	6-Jul
21-Jul	14-Jul	13-Jul	22-Jul
6-Aug	30-Jul	29-Jul	7-Aug

3.8. Advanced Wide Field Sensor (AWiFS)

AWiFS is a moderate-spatial resolution sensor on board the Resourcesat-1 satellite from the Indian Remote Sensing Program (launched October 17, 2003). Data are available from Space Imaging (Thornton, Colorado). AWiFS has a swath of 740 km, which gives it a higher temporal repeat frequency than Landsat or Aster, but less than MODIS on Terra and Aqua. The pixel size for AWiFS data is 56 m. Quarter scenes (or quads, 370 km by 370 km) will be ordered for CLASIC, which are within 55 ° zenith angle of the study area center point, to provide the potential for weekly coverage. Characteristics of AWiFS are presented in Table 18.

Based upon paths, acquisitions have been requested for June 7, 8, 12, 16, 17, 21, 22, 26, 27, July 1 and 2. However, these are not guaranteed if there are other priorities that conflict.

Table 18. Characteristics of the AWiFS System	
Equatorial crossing	10:30 AM
Orbit height	817 km
Swath width (km)	740 km
Orbit Inclination	98.7°
Number of orbits per day	14
Spatial Resolution (m)	56
Spectral Bands (micron)	0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70

4. Aircraft Based Microwave Remote Sensing of Soil Moisture

4.1. PSR

The PSR is an airborne microwave imaging radiometer developed by NOAA for the purpose of obtaining polarimetric microwave emission. It has been successfully used in several major experiments. Its first major soil moisture experiment was SGP99, which was conducted in the CLASIC domain (Jackson et al. 2002). It has also been used in SMEX02 (Bindlish et al. 2006), SMEX03 (also in the SGP, Jackson et al. (2005), and SMEX04 (Bindlish et al. 2007). Figure 14 shows the results of mapping brightness temperature data from SGP99 in Oklahoma.

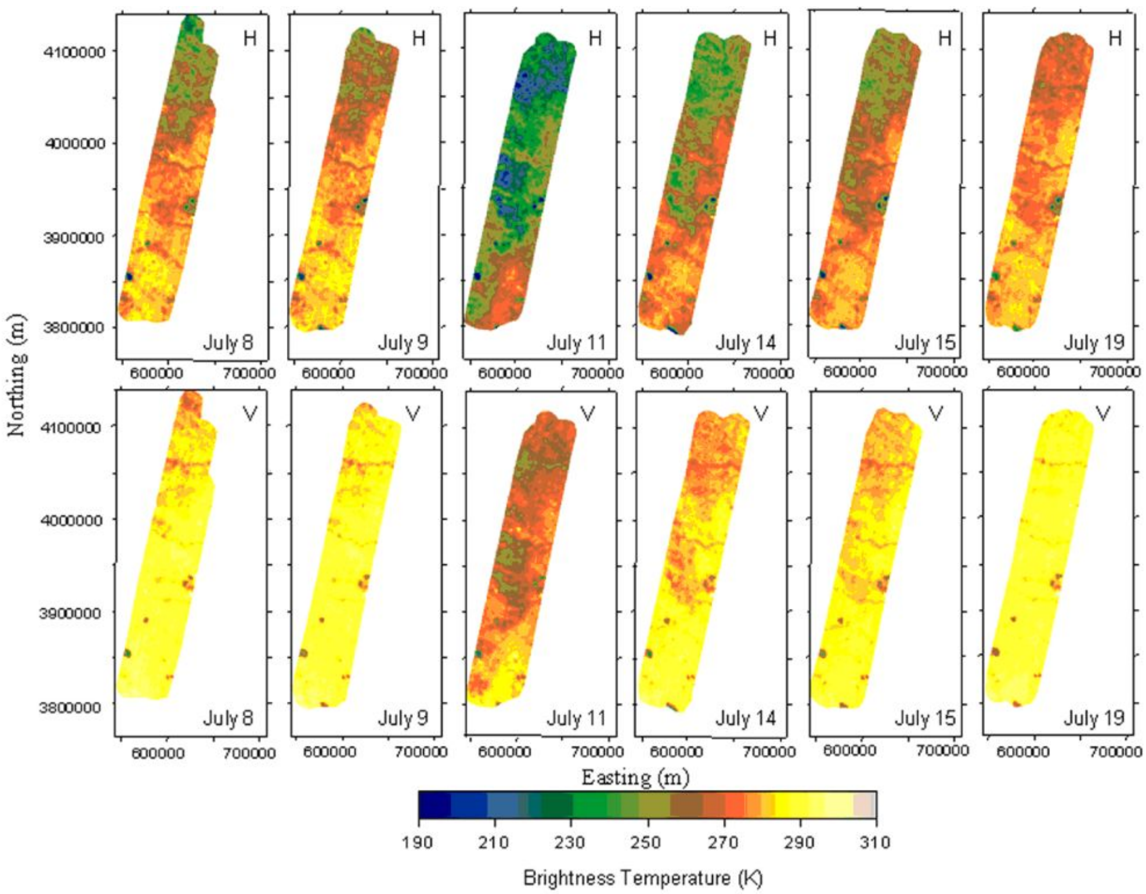


Figure 14. PSR H and V brightness temperature maps of the SGP99 study area (Jackson et al. 2002)

A typical PSR aircraft installation is comprised of four primary components: 1) scanhead, 2) positioner, 3) data acquisition system, and 4) software for instrument control and operation. The scanhead houses the PSR radiometers, antennas, video and IR sensors, A/D sampling system, and associated supporting electronics. The scanhead can be rotated in azimuth and elevation to any arbitrary angle. It can be programmed to scan in one of several modes, including conical, cross-track, along-track, and spotlight. The positioner supports the scanhead and provides mechanical actuation, including views of ambient and hot calibration targets. The PSR data acquisition system consists of a network of four computers that record several asynchronously sampled data streams, including navigation data, aircraft attitude, scanhead position, radiometric voltage, and calibration target temperatures. These streams are available in-flight for quick-look processing.

During CLASIC, the PSR/CX scanhead will be integrated onto a NASA P-3 aircraft. The PSR/CX scanhead will have the polarimetric channels listed in Table 19. The system will be operated using conical scanning at an incidence angle of 55 degrees. Mapping characteristics in the expected aircraft altitude range are described in Table 20. Additional details on the PSR not presented here can be found at http://www1.etl.noaa.gov/radiom/psr/

Table 19. PSR/CX Channels

Frequency (GHz)	Polarizations	Beamwidth
5.82-6.15	v,h	10°
6.32-6.65	v,h	10°
6.75-7.10	v,h,U,V	10°
7.15-7.50	v,h	10°
10.6-10.8	v,h,U,V	7°
10.68-10.70	v,h	7°
9.6-11.5 um IR	-	7°

Table 20. PSR Flight line and Mapping Options for CLASIC

Altitude (AGL) in m	C Band 3–db Footprint (m)	X Band 3–db Footprint (m)	Swath (m)
7620	3060	2140	21790

Collecting the raw brightness temperature is the first step in soil moisture retrieval. Additional steps in pre-processing include calibration, georegistration, temporal normalization, and radio frequency interference removal. Following these adjustments a locally optimized soil moisture retrieval algorithm is applied. This requires up to date data bases of land cover, vegetation water content and soil properties. Each of these will be acquired as part of CLASIC. An example of the soil moisture products from a previous experiment in the SGP is shown in Figure 15.

Some constraints on mission design were:

- Map as much of the entire CLASIC domain as possible during Survey flights
- Keep mapping period to <5 hours
- Sequence of flight lines should be consistent day to day
- Coverage time should be consistent day to day
- During a dry down (following a rain event), fly every possible day
- Biasing the flights to the morning is advantageous in avoiding pattern disruptions due to storms
- Maintain adequate overlap of adjacent lines for temporal corrections

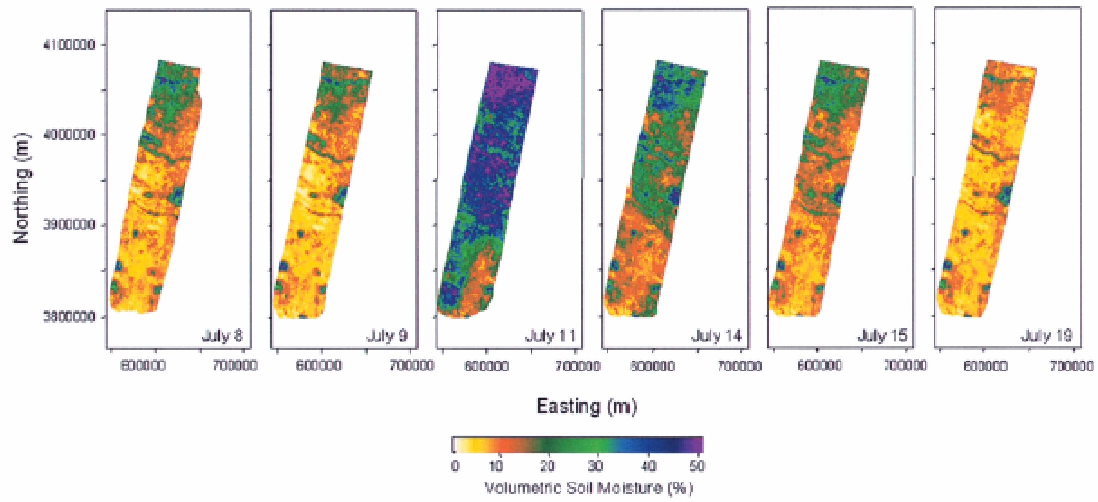


Figure 15. PSR based soil moisture images from SGP99 (Jackson et al. 2002)

The P-3/PSR flightlines were designed to satisfy the CLASIC objectives and to support and complement the activities of the multiple instrument ER-2 platform described in a later section of this plan. The ER-2 mapping domain is shown in Figure 16. The ER-2 will fly at least four different missions. After considering aircraft logistics it was decide that the P-3/PSR would attempt to support only two of these:

- Survey – to study cloud formation and land surface interaction. Synoptic coverage of a large spatial domain at acceptable spatial resolution
- Evolution – to study cloud development over an area. A rectangle will be flown either continuously or at intervals. The focus will likely be a super site (most likely CF or LW). Details of these missions will be determined after a period of time on-site to assess conditions and timing.

Figure 16 shows the P-3 survey and evolution flightlines. Table 21 lists the coordinates of these lines. Note that only one type of mission will be flown on a given day. The P-3 will require a total of ~7.2 hours to conduct the survey mission (~5.8 hours on the lines). After considering the ER-2 plans and typical flight conditions the take off will likely be 0830 am CDT (time on lines ~0900 – 1540 CDT). The aircraft will base in Oklahoma City, which minimizes transit time. Note that the southwest corner of coverage, specifically lines P01 and P02, had to be truncated due to a conflict with restricted airspace (10-18 km). These portions may become available at flight time if there are no conflicts.

Table 21. P-3 Survey and Evolution Flightlines				
Line	Start		End	
	Latitude (Deg.)	Longitude (Deg.)	Latitude (Deg.)	Longitude (Deg.)
Survey				
P01	34.683	-98.232	35.606	-95.887
P02	35.753	-95.972	34.793	-98.403
P03	34.898	-98.592	35.900	-96.056
P04	36.047	-96.142	35.043	-98.680
P05	35.188	-98.769	36.193	-96.227
P06	36.340	-96.313	35.332	-98.859
P07	35.477	-98.948	36.486	-96.399
P08	36.633	-96.485	35.622	-99.038
P09	35.766	-99.129	36.779	-96.572
P10	36.926	-96.659	35.911	-99.219
Evolution				
EN1	36.608	-97.888	36.608	-97.088
EN2	36.771	-97.088	36.771	-97.888
ES1	34.894	-97.650	34.894	-98.450
ES2	35.054	-98.450	35.054	-97.650

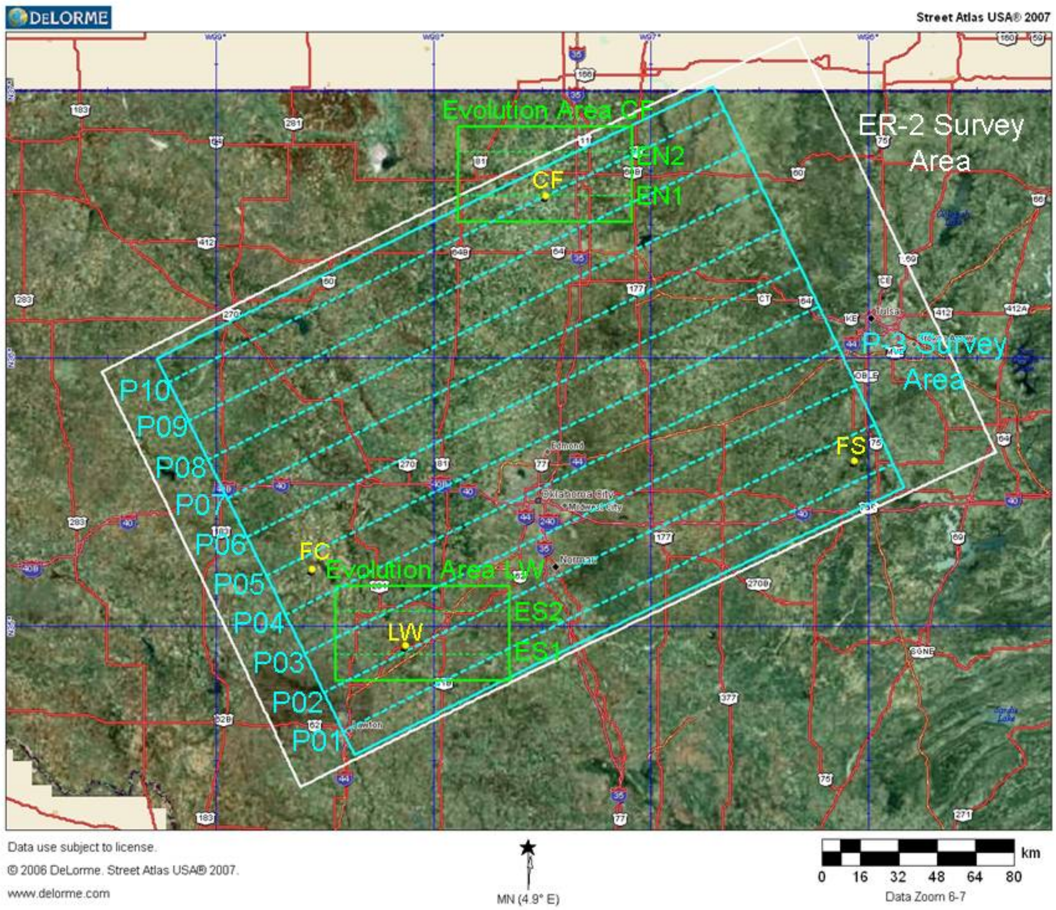


Figure 16. P-3 flight lines. Also shown are the general locations of the four super sites. The ER-2 mapping domain corresponds to the MAS coverage. The boxes enclosing the P-3 lines define the total PSR mapping domain of those lines. The background is true color satellite imagery.

4.2. PALS

Current microwave models and retrieval algorithms have significant limitations in their treatment of different vegetation types and heterogeneous scenes (mixtures of grass, crops, trees, streams, lakes) and quantitative treatment of algorithm scaling and error analysis for such heterogeneous scenes. Measurements over wide varieties of terrain are needed, with joint active and passive sensors, to develop algorithms and parameterizations that can work across all terrain types, and extract optimum information from the combined data. This will have direct impact on the design of dedicated soil moisture missions and development of methods to assimilate such data into land surface models.

Microwave radiometry and radar are well-established techniques for surface remote sensing. Combining passive and active sensors provides complementary information contained in the surface emissivity and backscatter signatures, which can improve the accuracy of retrieval of geophysical parameters. Over land, it has been demonstrated that the radiometer and the radar both provide information for estimating soil moisture and vegetation water content (Bolten et al. 2003, Njoku et al. 2002, Narayan et al. 2004).

To investigate the benefits of combining passive and active microwave sensors, the Jet Propulsion Laboratory (JPL), with NASA support, designed, built and tested a precision Passive/Active L/S-band (PALS) microwave aircraft instrument for measurements of soil moisture and ocean salinity (Wilson et al. 2001). The PALS instrument had dual-frequency (L- and S-band), dual polarization radiometer and polarimetric radar. The original design incorporated massive antennas that could only be operated on a limited set of aircraft platforms (C-130s). This was a single beam system and it was not feasible to operate it in a mapping mode.

The capability and scientific potential of PALS have been demonstrated through past field programs and associated research results for both soil moisture and ocean salinity applications (Bolten et al. 2003, Limaye et al. 2004, Njoku et al. 2002, Narayan et al. 2004). The PALS instrument acquired data during SGP99 for field-averaged vegetation water contents (VWC) mainly in the 0-2.5 kg/m2 range, while the SMEX02 experiment covered various stages of soybean and corn fields for VWC up to 5 kg/m2. The PALS/SGP99 data showed that vegetation significantly degraded the direct correlation between radar backscatter and soil moisture for the combined field data. This suggests that soil moisture estimates may not be feasible using current bare soil radar algorithms, which are expected to be accurate for regions of vegetation water content up to only about 0.5 kg/m2, i.e., significantly less than the capability of the passive (radiometer) L-band algorithms. A major goal of the SMEX02 experiment was to develop and demonstrate the capability of soil moisture retrieval algorithms under higher vegetation water content conditions (0-5 kg/m2). The PALS/SMEX02 active and passive microwave measurements were analyzed, indicating soil moisture retrieval errors of approximately 0.04 g/g gravimetric soil moisture. The retrieval errors were higher for the corn than for the soybean fields due to the higher vegetation water content for the corn crops.

To extend the radar-based soil moisture retrieval capability to vegetation water content above 0.5 kg/m2, the PALS SGP99 and SMEX02 data were used to investigate a change-detection algorithm approach for Hydros (Entekhabi et al. 2004). The change detection approach is illustrated in Figure 17. The investigated vegetation conditions in SGP99 are primarily pasture and agricultural crop fields. The upper panels of Figure 17 show temporal sequences of L-band horizontally polarized brightness temperature (Tb_H) and backscatter (σ^o_{vv}) images.

There was no precipitation prior to July 10 for over a week, and the conditions were dry on July 9. The precipitation on July 10 had greatest intensity towards the west (left portions of the image). The increased soil moisture resulted in a decrease in Tb_H and an increase in σ^o_{vv}. Successive drying took place from July 11 to July 14. Landscape features (vegetation, roughness, topography) have different influences and impose different spatial patterns on the passive and active data. The bottom panels show the relative changes in Tb_H and σ^o_{vv} (difference from July 9), indicating similar temporal and spatial responses to soil moisture in the passive and active data, independent of the landscape spatial patterns. This indicates that soil moisture is the dominant influence on radar backscatter over daily time-scales, over a significant range of vegetation cover. The key questions are if this apparent correlation of temporal Tb_H and σ^o changes can be extended to a wide variety of surface and vegetation conditions and how the signatures can be translated into robust soil moisture retrieval algorithms for Hydros or other future combined active and passive microwave sensors.

As noted previously, a key limitation of the PALS (PALS-I) system was the use of a conical horn for the antenna. The conical horn is large (about 3 meters long), prohibiting operation on smaller aircraft. The large PALS-I antenna could only be operated in flight on the lowered ramp of a C-130 aircraft. In addition, the large horns are bulky and cannot be mechanically rotated for image scanning in flight. The size of the PALS-I system made it unsuitable for deployment at short notice to targets of opportunity.

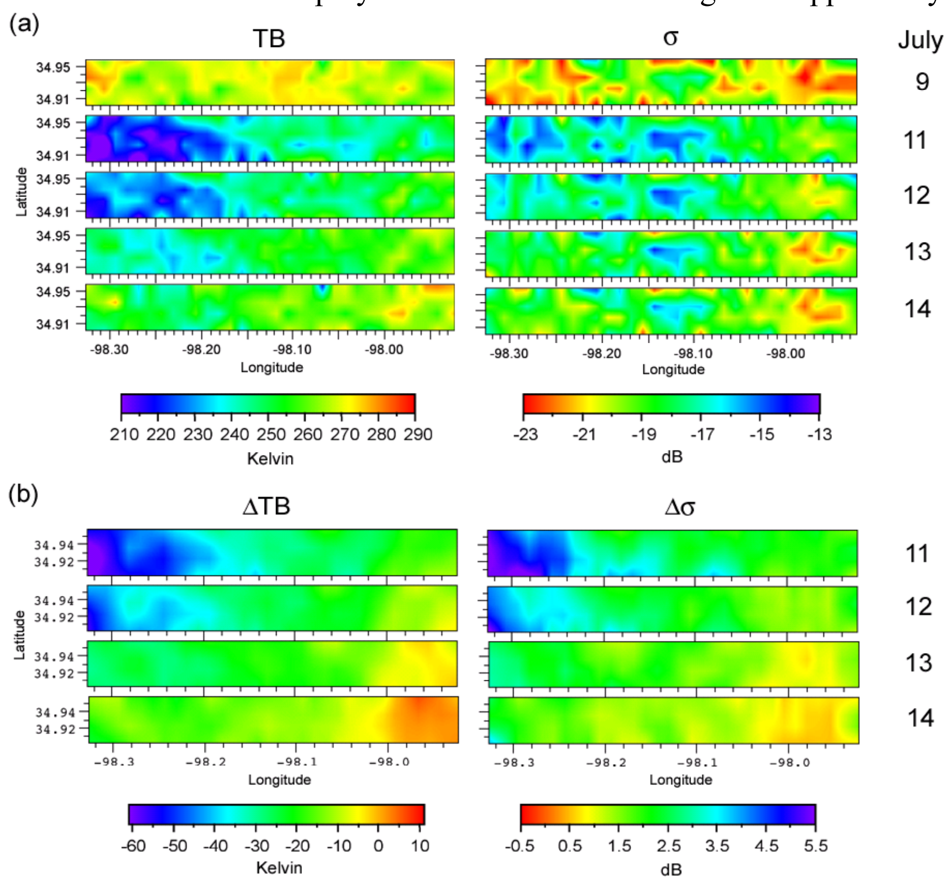


Figure 17. (a) Time series of PALS T_b and σ^o_{vv} data images show responses of L-band data to soil moisture changes in Little Washita, Oklahoma during the SGP99 experiment. A rain event occurred on July 10. (b) Changes of T_b and σ^o_{vv} from July 9 show the similar spatial patterns of wetting and drying, independent of the landscape spatial patterns (influenced by vegetation, roughness and topography).

To overcome these limitations the PALS (PALS-II) instrument has been modified for operation on a Twin Otter aircraft by replacing the antenna with an alternate design. This project leveraged off a flat-panel antenna array being developed under the support of the NASA Earth Science Technology Office (ESTO) Advanced Component Technology (ACT) program. The scope and intent of the ACT development task was to develop a lightweight flat-panel antenna technology with dual-frequency (for radar and radiometer) and dual-polarization capabilities for future spaceborne soil moisture and sea surface salinity missions. The planar antenna will consist of 16 stacked-patch microstrip elements arranged in a four-by-four array configuration (Figure 18). The design, fabrication and testing of the stacked-patch elements have been completed. To ensure excellent radiometric calibration performance, we will apply temperature control (±0.1ºC stability) to the antenna assembly. An imaging capability will be added in the future. The new version of PALS is only L band.

The PALS-II antenna will be mounted on the belly of the Twin Otter (DHC-6) with a custom-made fairing (Figure 18). The fairing will be designed to accommodate the antenna as well as an antenna positioner to scan the flat-panel antenna in azimuth. The cable connection from the antenna will be routed through the nadir port to the PALS-II electronics box inside the fuselage. The size of the nadir port, about 20 inches by 40 inches, is large enough to accommodate a nominal motor assembly for the antenna positioner. The antenna will be mounted at a fixed staring direction with boresight pointing at 40 degree off nadir, matching the incidence angle of Hydros (Entekhabi et al. 2004).

For previous field experiments on the C-130, the PALS backend receiver and data acquisition system were mounted on two double-bay 19-inch-wide racks. We will repackage the rack-mounted equipment on four single-bay 19-inch racks to fit in the fuselage of the Twin Otter, and will rebuild the cables for inter-connections. Following completion of the re-racking, tests will be performed to ensure the integrity of the system prior to shipping the racks to the aircraft facility for integration with the Twin Otter.

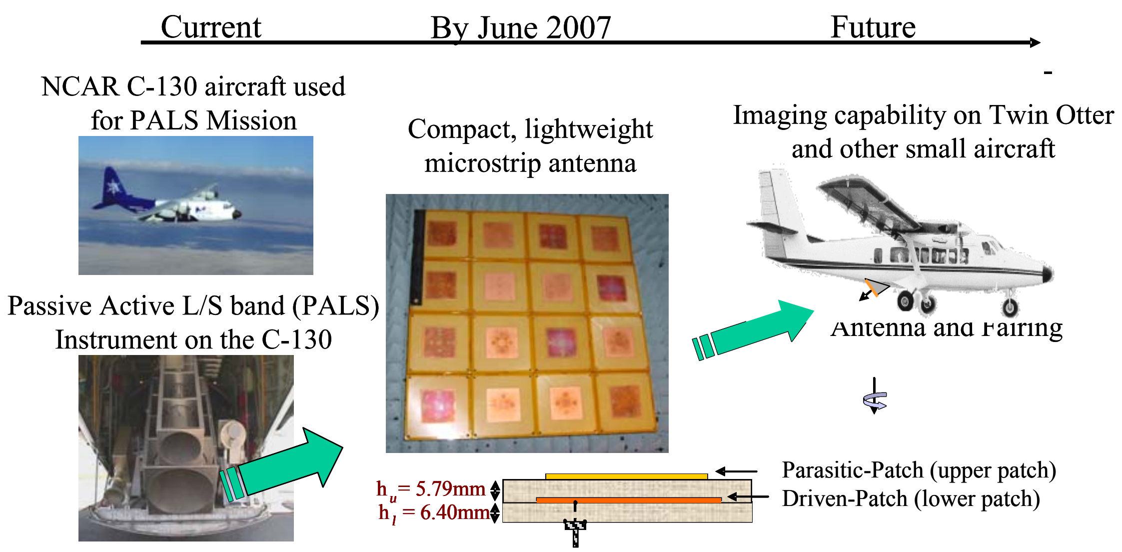


Figure 18. PALS antenna configurations on the NCAR-C130 and Twin Otter (PALS-II). The bottom left panel illustrates the PALS horn antenna on the ramp of the C-130. The flat panel antenna for PALS-II will be less than 3 inches thick.

The goals for the PALS-II in CLASIC will include 1) the demonstration of the new antenna, 2) additional data sets for active-passive algorithm development and validation, 3) polarimetric analyses, 4) diurnal analyses, and 5) combined flights with the Duke HOP.

For the most part we have designed the missions to include a set of flight lines over intensively sampled fields. Fields are located close together and with general locations that minimize the number of flight lines. An altitude of 1100 m AGL was selected, which results in an instantaneous footprint size of approximately 400 m. In much of Oklahoma the fields are laid out in quarter sections aligned on a regular grid. To facilitate mapping, the lines in the LW and FC super sites are offset by 800 m resulting in a ladder pattern.

At this time we are planning flight lines in both the LW and FC areas (Figure 19 and 20). The LW lines will link to the super sites and the previous experiments in this domain. The FC lines are being added to increase the potential range of both land cover and soil moisture conditions. The FC area selected includes numerous fields with the potential to provide irrigation (center pivot). It is unlikely that the farmers would be irrigating at this time of year, however, they would be willing to irrigate if they were reimbursed for their costs. Preliminary discussions indicate that if full profile irrigation is not required (which it is not) it is possible to complete the irrigation in 6-12 hours. We consider this to be an important part of the CLASIC experiments because it guarantees that we will be able to observe wet conditions, which are critical for PALS-II, and that there would be the possibility of observing a dry down time sequence, which is critical for many of the algorithm science questions.

Based upon available information, the Twin Otter ground speed would be between 150 and 300 km/hour. Using 200 km/hour, each of the LW lines would require about 15 minutes with turns and the FC about 10 minutes. Coverage time for LW would be ~ 2 hours and ~1 hour for FC if lines are flown in alternating directions. If both directions are needed to identify or mitigate RFI the times would double. Transit time to the sites would be about 0.5 hours. Total daily mission duration of ~4 hours has been set as a limit. At this time it is anticipated that the flighlines will be covered between 8:30 am and 11:30 am CDT.

The PALS flightlines are coded as follows:

- W-Little Washita
- C-Fort Cobb
- F-Forest Site
- T-Helicopter Triangle

A three character code will be used for flightlines and a four character code for ground sites. Coordinates for the lines are summarized in Table 22 and plotted in Figures 19 (Little Washita), 20 (Fort Cobb), 21 (Forest), and 22 (Triangle).

Table 22. PALS Flightlines

Line	Start		End	
	Latitude (Deg.)	Longitude (Deg.)	Latitude (Deg.)	Longitude (Deg.)
W01	34.960	-98.350	34.960	-97.850
W02	34.953	-98.350	34.953	-97.850
W03	34.945	-98.350	34.945	-97.850
W04	34.938	-98.350	34.938	-97.850
W05	34.931	-98.350	34.931	-97.850
W06	34.924	-98.350	34.924	-97.850
W07	34.916	-98.350	34.916	-97.850
W08	34.909	-98.350	34.909	-97.850
W09	34.790	-98.350	34.860	-98.365
C01	35.208	-98.650	35.208	-98.400
C02	35.201	-98.650	35.201	-98.400
C03	35.193	-98.650	35.193	-98.400
C04	35.186	-98.650	35.186	-98.400
C05	35.235	-98.524	35.159	-98.447
F01	35.600	-96.060	35.700	-96.060
F02	35.600	-96.036	35.700	-96.036
T01	34.900	-98.150	35.631	-96.004
T02	35.631	-96.004	36.605	-97.485
T03	36.605	-97.485	34.900	-98.150

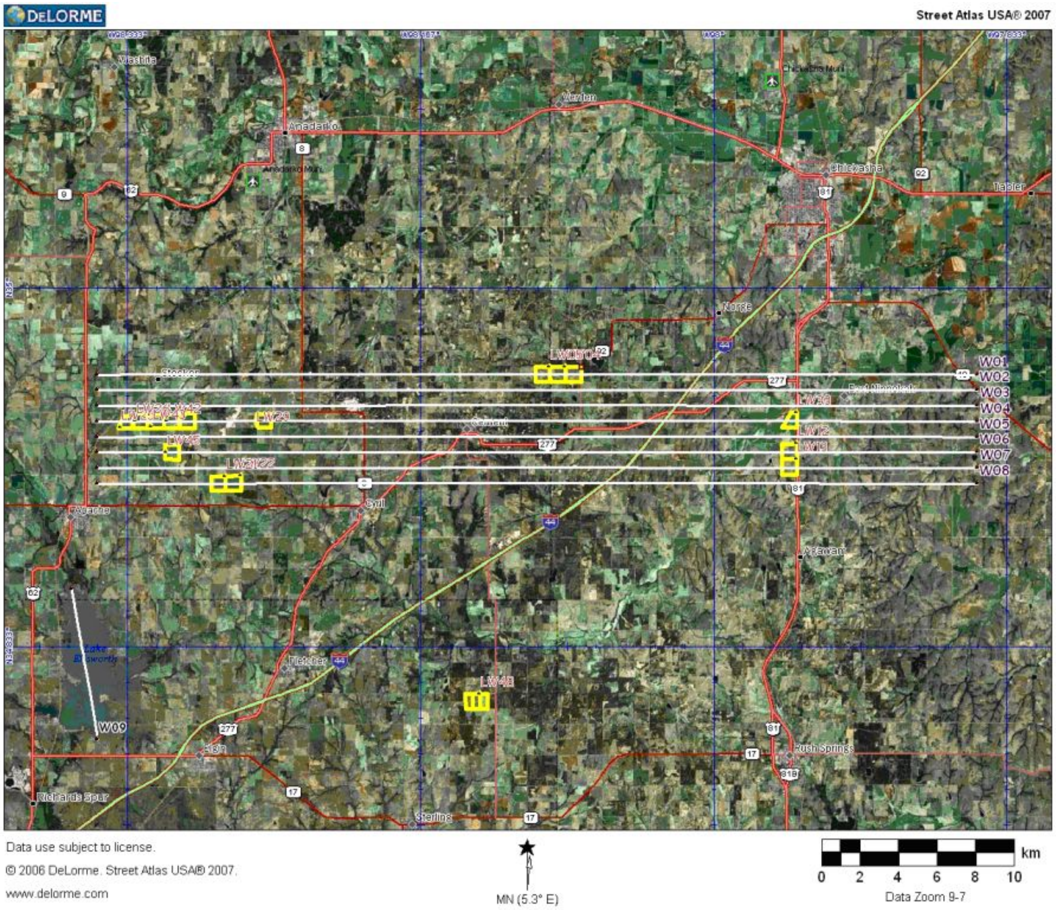


Figure 19. PALS Little Washita flightlines.

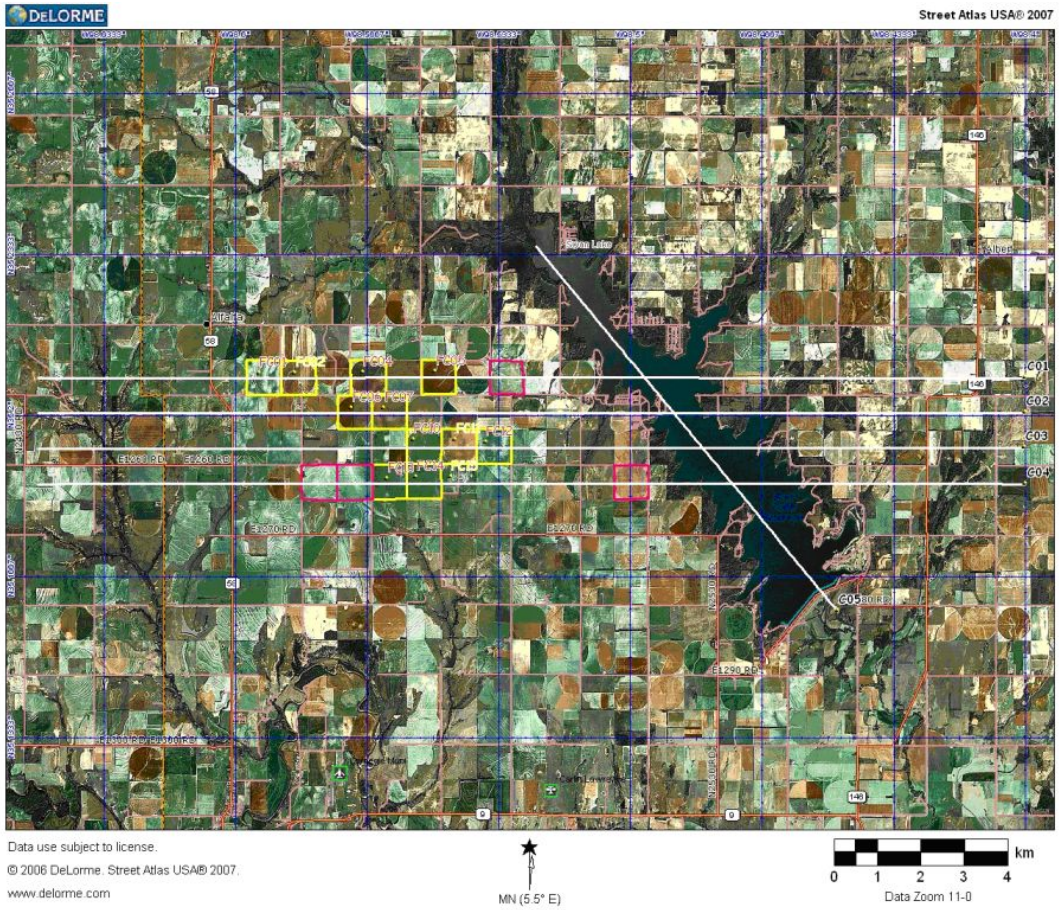


Figure 20. PALS Fort Cobb flightlines.

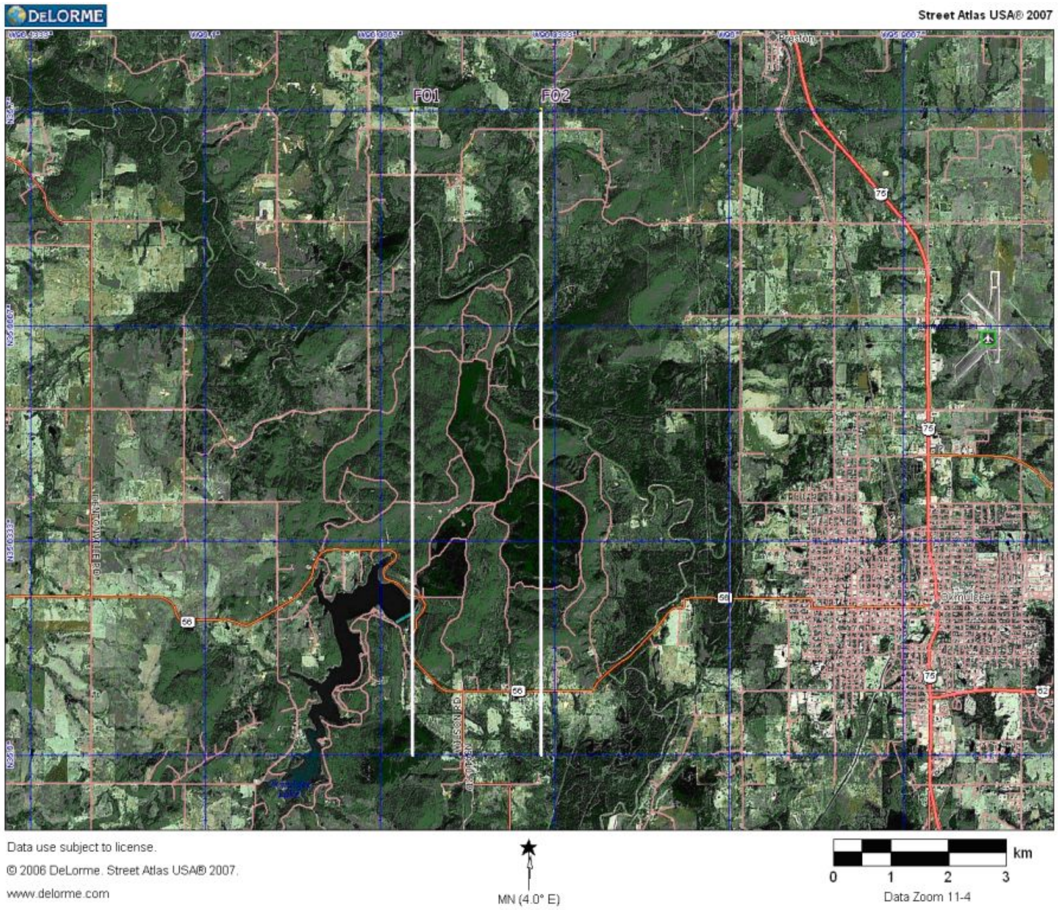


Figure 21. PALS Forest Site flightlines.

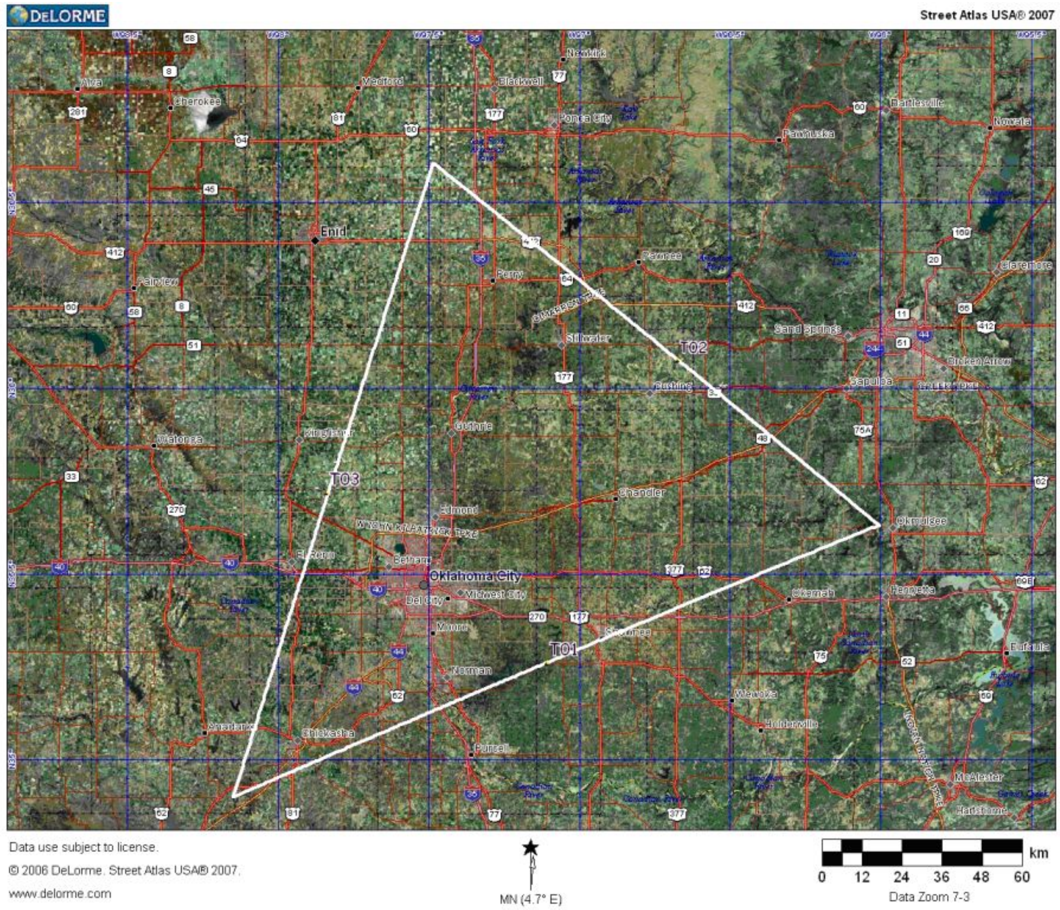


Figure 22. PALS Triangle Pattern flightlines.

The data from the field experiments will be radiometrically calibrated and geolocated for distribution to hydrology research community. We will also conduct data analysis to correlate the PALS-II data with the insitu measurements to explore the utility of the polarimetric measurements.

5. Observations of the Land Surface Fluxes and Atmospheric Boundary Layer and Other Studies

5.1. Tower-Based

5.1.1 Measurement Description

Through this project and collaborative relationships we will deploy a number of eddy covariance systems throughout the study areas, with each system consisting primarily of Campbell Scientific CSAT3 3-D sonic anemometer and KH20 krypton hygrometer, measuring momentum flux and sensible and latent heat fluxes between the land and the atmosphere across the watershed. These observations will be representative at the "patch" or local scale (i.e., length scales ~ 10^2 m). These systems will also provide a picture of the complete energy balance by including net radiation, soil heat flux, and radiometric surface temperature measurements. In addition, there will be several systems, which will also be measuring net carbon exchange by eddy covariance with the 3D sonic and LiCor LI-7500 open path CO_2/H_20 sensors. This will permit a very detailed assessment of water-energy-carbon fluxes and controls as a function of crop type and amount of cover and tillage practices. For selected sites with a significant fractional bare soil component, there are also plans to make measurements of soil respiration using LiCor LI-6200 sensors.

Micrometeorological and eddy covariance (MicroEC) instrumentation will be mounted on towers several meters above the canopy to measure the surface energy balance components of radiation (Rn), sensible heat flux (H), and latent heat flux (λE) densities (W m-2), carbon (CO2) flux (g m-2) and hydrometeorological observations. Soil heat flux (G) is measured with soil heat flow transducers and soil thermcoples buried several centimeters below the soil surface. Net radiation will be measured with Kipp & Zonen, Inc. (U.S.A.) CNR-1 net radiometers. The CNR-1 net radiometer measures separately the incoming and outgoing shortwave and long-wave radiation components. A set of at least three REBS soil heat flow transducers (HFT-1) will buried ~0.08 m below the soil surface. Above each soil heat flux plate at 0.02 and 0.06 m depth will be two Type-T (copper-constantan) soil thermocouples. The soil temperature data are used to compute the storage component of the soil heat energy above the flux plates. A 3-D sonic anemometer manufactured by Campbell Scientific, Inc. (CSI-U.S.A.) or other manufacturer and a LICOR, Inc. (U.S.A.) LI7500 infrared hygrometer will be positioned ~ 2x the canopy height (to minimize roughness sublayer effects) for measuring H, λE and CO2 flux densities using the covariance of the vertical wind velocity (w) with air temperature (Ta), water vapor density (q), and CO2 concentration. Friction velocity (u*) and the standard deviation of vertical velocity (σ_w) are computed from the sonic anemometer. Standard hydrometeorological instrumentation will also be mounted on the tower to measure Ta and relative humidity (RH) using CSI HMP 45C sensor and precipitation using Texas Instruments TE-525. In addition photosynthetically active radiation (PAR) will be measured using LI-190SB quantum sensor and surface radiometric temperature observation using Apogee Inc. (U.S.A.) IRTS-P3 infrared thermocouple sensors viewing the surface at approximately a 45^o viewing angle. The sampling frequency is 10 Hz for the eddy covariance and 10 s for the energy balance and meteorological instrumentation. The raw 10 Hz data will be stored as well as 30-minute averages on a Campbell CR5000 logger.

5.1.2 Site Locations

A network of MicroEC systems will be set up at the LW, FC, FS and CF locations. Table 23 lists the anticipated locations and their features. An attempt will be made to set up the towers in each super site in a triangular design with the distances between the legs ~10-30 km. This will provide enough sampling time/distance for proper averaging of the helicopter flux transects and the triangular design will permit landscape scale atmospheric water/energy budget calculations. The CF site will be operated and maintained by M. Torn and colleagues who currently have a 30 m tower located within the facility for making MicroEC measurements over a mixed land use of winter wheat and pasture. Additional MicroEC systems will be located over winter wheat and pasture fields. At LW, HRSL, NSTL and NOAA-Ok Ridge instrumentation will be deployed at four locations along with existing CART-ARM extended facilities (EF) flux towers already operating within the LW study area (EF-24 and EF-26). The sites will likely include two grassland sites under significantly different soil texture regimes, and two in winter wheat fields, differing in management practices (i.e., one remaining wheat stubble after harvesting, while the other tilled and raked bare soil). At the FS site, one additional tower will be installed to complement the existing ARM-CART site (EF-21).

Table 23. Flux Tower Installations during CLASIC

SuperSite	Field	Latitude (Deg.)	Longitude (Deg.)	Land Cover
LW	LW13	34.91814	-97.95462	Rangeland
LW	LW52	34.79311	-98.11577	Rangeland
LW	LW21	34.91181	-98.27880	Winter Wheat (no-till)
LW	LW45	34.92690	-98.31146	Winter Wheat (conv. till)
FC	FC01	35.21069	-98.58952	Wheat stubble
FC	FC05	35.21060	-98.54538	Corn/Irrigated*
FS	EF21	35.61834	-96.06555	Forest
FS	FS02	35.63898	-96.04349	Forest
CF	EF13	36.60500	-97.48500	Pasture
CF	EF14	36.60500	-97.48800	Winter Wheat / Pasture
CF	CF01	36.56740	-97.46630	Pasture
CF	CF12	36.58950	-97.56470	Milo

*FC05 was harvested winter wheat on June 7. It is expected that it will be planted as corn.

5.1.3 Okmulgee Forest Flux Tower

The Cloud and Land Surface Interaction Campaign (CLASIC) will be conducted in the Oklahoma region to better understand issues of the interaction of land surface fluxes and cloud formation and development. The Intensive Observing Period (IOP) that will cover a period of several months centering on June 2007. The purpose of this IOP is to advance our understanding of cumulus convection and its controls, particularly those associated with land surface processes. The study period will straddle the winter wheat harvest when dramatic changes in the land surface occur that could lead to large changes in the surface albedo, latent heat flux, and sensible heat flux. The CLASIC Land Team was formed from interested groups and will attempt to characterize land surface states and fluxes throughout the IOP. These include surface soil moisture, water and energy fluxes, carbon flux, surface temperature, land cover and vegetation indices. These will be provided through a combination of insitu, aircraft and satellite observations. This particular discussion will describe in detail the measurements that will be taken at the FS location, located within the Okmulgee Wildlife Manage Area (WMA). The Okmulgee Wildlife Management Area covers 10,900 acres of west central Okmulgee County. Located 5 miles west of the city of Okmulgee, Oklahoma, the area is heavily wooded in post oak blackjack timber and bisected by seven miles of the Deep Fork of the Canadian River. The area is approximately 95% wooded, with elevations ranging from about 600 ft. near the river to over 950 ft. on wooded ridges. Post oaks, blackjack oaks, and hickories dominate the poor, rocky upland soils. Canopy heights range from 10 – 15 m, and there is no immediate A/C power.

Access to most of the area is via unpaved roads and trails. A site visit was conducted on April 17, 2007 and a suitable location for a tower was found within the WMA. Security is not believed to be problem since the area is used mostly for hunting in autumn. Nearly all of the area is wooded, and initially, by inspection, the LAI was estimated to be between 3 and 4. Since fluxes measured above the canopy will consist of contributions from both the trees and forest floor, it would be appropriate to adequately characterize both of these fluxes, with the available instruments, tower hardware, and resources for remote power generation, rather than spread the sensors over more sites. Most of the models used today are at least two layer models (canopy soil). At times, the soil/litter layer may constitute a significant portion of either the energy and/or CO_2 flux from the ecosystem. The following observations will be made (or are available); eddy covariance measurements (H, LE, CO_2, u*, 2 sonic anemometers, 2 LI7500), above canopy and forest floor radiation measurements (incoming and outgoing shortwave, longwave and photosynthetically active radiation), meteorological data (Tair, RH, pressure, precipitation), Soil Measurements (soil temperature at 2, 4, 8, 16, 32, 64 cm, ground heat flux sensors, soil moisture sensors at 5x3, 10x3, 20x2, 50, 100 cm), and plant measurements (LAI, tree bole temperatures (0, 2, 4, 8, 16 cm -3 reps, DBH, conductance)

5.1.4 Data Provided

The eddy covariance data will processed with temperature and relative humidity measurements used to correct for oxygen and density effects on the evaporative and CO_2

fluxes (Webb-Pearman-Leuning-WPL correction; Webb et al. 1980). Further processing included applying a 2-D coordinate transformation (coordinate rotation-CR) forcing v = w = 0. In addition to the fluxes, mean wind speed (u) and wind direction (WD) were computed from the CSAT3 measurements.

The soil surface heat flux (G) which includes soil heat flux across the heat flow transducer (GT), and heat transfer of the soil layer above the transducers, the storage term (S), so that G=GT + S (see e.g., Campbell and Norman, 1998). Estimated moisture for the storage layer will come from an automated moisture sensor system (Stevens Water Hydra Probe I) near the tower. The raw 10 Hz EC data will be corrected and processed as summarized above with 30-minute average heat and carbon fluxes, H, λE and CO2 being reported as well as the remaining energy balance components Rn and G. In addition, 30-min average u* and σ_w which are metrics of the surface layer turbulent intensity will be provided. Hydrometeorological data (30-min averages) will include Ta, RH, u, WD, PAR, rainfall (30-min totals), and incoming and outgoing shortwave and longwave radiation components.

5.2. Duke Helicopter

A goal of CLASIC is to decipher the respective roles of local and regional forcing on the observed cloud structure. The spatial and temporal observation of turbulent fluxes in the ABL is essential for the overall success of this experiment. The Duke University Helicopter Observation Platform (HOP) is a new system that can measure turbulent fluxes at a slower airspeed and lower to the ground than other aircraft, thus increasing the resolution of observations and measuring where it greatly matters, namely in the atmospheric surface layer near the ground surface. HOP bridges the gap between ground measurements and airplane observations

The main objective of HOP is to observe the spatial and temporal variation of fluxes of momentum, heat, moisture and carbon dioxide in the ABL over the different types of land cover found at the experimental site in Oklahoma, under the different meteorological conditions that will be encountered during the IOP.

The HOP is based on a Bell 206B-3 “Jet Ranger” (Figure 23) (Avissar et al. 2007). Fully fueled and with pilot and co-pilot/scientist on board, the HOP can carry ~600 lbs of equipment and sensors and it can fly for a period of ~3.5 hours. Moreover, helicopters can typically land at almost any experimental site where a fuel truck can be stationed and, as a result, the commuting (down) time to airports can be completely eliminated. If needed, refueling can be completed within a few minutes and, as a result, observations can be carried out almost uninterruptedly. From a payload point of view, this aircraft is comparable to small-to-medium size airplanes. Yet it has the unequaled capability of flying at slow speeds and at altitudes ranging from just above tree top (or sea surface) up to 3,000 – 4,000 m, i.e., well above the top of the atmospheric planetary boundary layer (PBL). This provides a unique opportunity for measuring aerosols properties as well as fluxes of heat, moisture and trace gases where it greatly matters, namely within the atmospheric surface layer. Slow airspeeds yield an observation resolution superior to that of any airplanes carrying the exact same sensors. Indeed, for a given sampling frequency, the HOP flying at an airspeed 1/3 that of an airplane (as is likely to be the case in most experiments) provides a measurement resolution that is three times better that of the airplane. While very small airplanes (e.g., the Sky Arrow) are designed to fly relatively slowly, their payload capability is extremely limited and they typically cannot fly safely at as low altitudes as helicopters can.

The HOP has a modular design and, therefore, sensors and instruments can be mounted on it for specific experiments and dismounted afterward. Some of the instruments/sensors are useful for almost any field experiment and are mounted permanently on the HOP. These sensors provide high-frequency measurements of turbulence (40 Hz with the Aventech AIMMS-20, 20Hz with the R.M.Young sonic anemometer, and 40 Hz with the new Kaijo- JAXA sonic anemometers) and, using the eddy-correlation technique, fluxes of heat, water and carbon dioxide (40 Hz). Note, the new Kaijo-JAXA sonic was designed specifically for aviation to measure high frequency turbulence at airspeeds of 0 – 60 m/s. Only two prototypes are currently available worldwide, including the one provided to us. Its resolution is 0.005 m/s and 0.025^{o}C, which is twice better that of the R.M. Young anemometer. Installations are shown in Figure 23.

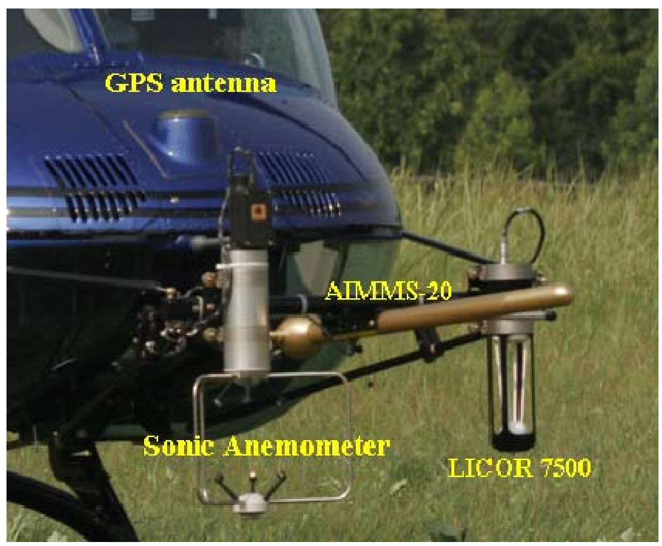


Figure 23. The Duke University Helicopter Observation Platform (HOP).

The on-board data acquisition system includes a differential (dual antenna) GPS and 3D electronic accelerometers that provide the exact location and attitude (pitch, yaw, and rolling angles) of the HOP at a frequency of 240 Hz. The HOP navigation and communications systems include two each SL-30 Nav/Comm's, Garmin GMA-340 Audio Control and the SKY-497 Skywatch System. Also included is the Chelton Synthetic Vision EFIS System, which comes standard with integrated moving map and terrain awareness and warning system. This system, known as "Highway-In-The-Sky (HITS)," helps perform very precise flights. This is a quite new, state-of-the-art technology that is not available on other research aircraft.

It is typically (yet wrongly) believed that atmospheric sampling in helicopters is unpractical due to the "…considerable airflow disturbance created by the main-rotor wake downwash…" This assumption, however, is based on a misunderstanding of the aerodynamic envelope of helicopters in forward flights. Holder and Avissar (2006) demonstrated that the volume of air in front of the Duke HOP nose is clear of any of the interferences created by the aircraft, as long as it flies at airspeeds larger than about 10 m/s. Thus, not surprisingly, at moderate airspeeds, most of the atmospheric disturbance created by the main rotor is obtained behind the forward flying helicopter. On the other hand, as the airspeed of the aircraft increases, the pressure front generated by its frame propagates further ahead of its nose. Thus, there is an optimal airspeed range at which the volume of air ahead of the helicopter nose is unaffected by either the main rotor wake or the frame-generated pressure front.

We intend to perform 15 days of flight observations distributed between these three sites during the IOP (i.e., June 5 to June 29, 2007). Thus, we will operate at each site five days, but we will move every day to another site and we will come back to the same site every 3-5 days. With this approach, we will be able to characterize land-atmosphere interactions as impacted by both the change of meteorological conditions and the change of vegetation cover that is typically taking place during June as a result of crop harvesting.

A day of observations at each one of the three sites will consist of five, one-hour flights. For each of them, we will fly the perimeter of a 10 x 10 x 10 km triangle pattern defined by the towers at the site at three different altitudes: (1) near the ground surface; (2) near the top of the ABL; and (3) near the middle of the ABL. Flying at a speed of 25 m/s, each altitude of the 30-km triangle perimeter can be executed in 20 minutes, and the three altitudes can be completed in just above one hour (including the few minutes needed to climb or descend from one altitude to the next). On a typical day, we will perform an early morning flight (right after sunrise), another one in mid morning, next one around noon time, then one in mid afternoon, and the last one in late afternoon (right before sunset). Thus, using this strategy, we expect to be able to characterize the diurnal variation of the ABL flux profiles at each one of these three sites.

Assuming that at a time scale of one hour the ABL does not change significantly (a well-accepted assumption in boundary-layer dynamics that is mostly questionable in mid morning but probably reasonable at any other times), this specific pattern will furthermore allow us to calculate the balance of moisture, heat and carbon dioxide for the volume of atmosphere that is typically used in a single grid point of a mesoscale (regional) climate or weather forecasting models. Indeed, an equilateral triangle with a 10-km base has an area that is roughly 43 km^2, thus corresponding to a square grid resolution of ~6.5 km. While this was not a factor in our decision for selecting this specific pattern, it is nevertheless interesting to note that there is a growing interest in the atmospheric modeling community to switch from a rectangular grid structure to a triangular structure, which is much better suited to simulate the spherical Earth. According to this plan, a total of 75 flight-hours (five, one-hour flights per day, at three sites, five times during the IOP) will be conducted for this part of the project.

In addition, we also intend to observe the ABL along the perimeter of the large triangle connecting between the three sites (see Fig. 22). Each side of this triangle is ~160 to ~200-km long. Thus, at a speed of 25 m/s, they can be flown in 100-140 minutes (i.e., an average of ~2 hrs). We anticipate flying each such side four times during the period of the IOP at the lowest altitude (i.e., near the ground surface) while we commute from site to site. A total of 25 flight-hours will be dedicated for this part of the project. Obviously, the data collected during these long flight legs will not have the same use as those collected at the three sites. Yet, it is reasonable to assume that the CLASIC research team (and others in the future) will be interested to simulate the entire domain experimented in CLASIC. These "between-sites" legs will then be very useful to evaluate at least the models performance in simulating atmospheric-surface fluxes there. Because of the heterogeneity of land-cover type found between the sites, this dataset is expected to be quite valuable. It will particularly and clearly contribute to our capability to simulate the entire experimental region, which will be required by various components of the CLASIC research team.

5.3. Vertical Elastic Lidar Measurements

The University of Iowa (UI) lidar group is interested in the dynamics at the top of the boundary layer. During the SMACEX experiment during SMEX02 they developed a method to measure the areal average sensible heat flux (H) from detailed knowledge of the height of the boundary layer and the vertical temperature profile (Eichinger et al. 2005). The UI elastic lidars can measure to 1.2 m resolution, and can make high spatial and temporal (resolution < 1 s) measurements of the boundary layer. From these, the instantaneous height of the boundary layer can be determined. Knowing the fluctuations of the boundary layer height allow us to estimate the ratio of the virtual potential heat flux at the top of the boundary layer to that at the bottom (also known as the boundary layer A parameter). A model developed by Batchvarova and Gryning (1991, 1994) allows estimation of the surface heat flux using these types of measurements. We propose to implement this technique and test it against the array of surface flux measurements. It is generally assumed that the boundary layer integrates over a large area. Using the array of surface measurements we may be able to estimate the size of this area.

The height of the boundary layer is governed not only by inputs from the bottom of the atmosphere, but also by the amount of energy entrained from above. The fraction of energy entrained from above (the A parameter) is commonly assumed to be 0.2, but is acknowledged to deviate from this value. Our measurements during SMEX02 found values between 0.08 and 2.0 and indicated that they were strongly related to the slope of the temperature profile.

The derivation of the A parameter is made from the geometry of the top of the boundary layer, particularly the average height of the boundary layer and the size of the fluctuations above and below. The size of the fluctuations is in turn related to the amount of kinetic energy accumulated as the plume rises, which is a function of the temperature difference between the plume and the ambient air.

Collaborating with the Duke helicopter group will allow the measurement of temperature in the boundary layer at times when we also know the dynamics of the boundary layer. This will in turn allow the development of a model of the relationship between the surface heat fluxes, the temperature differences in the plumes, and the A parameter. A theory of this nature will allow the closing of the energy fluxes in the boundary layer with a complete, predictive model.

The UI lidar team will field two lidar systems, one stationary and one mobile. The stationary system will make continuous high resolution measurements of the boundary layer and cloud cover. The mobile system will be used to:

- Support the mission of the Duke Helicopter system
- Make measurements of the spatial variability of the boundary layer
- Provide column aerosol measurements via the solar photometers.

The lidars will operate and collect data from approximately 9 June to 29 June, 2007, subject to weather. We anticipate the following products:

- Continuous boundary layer height, entrainment zone width at the stationary lidar location.
- Continuous cloud height, thickness, opacity and reflectivity measurements at the stationary lidar location.
- Estimates of the areal sensible heat flux.
- Measurements of the variability of the boundary layer height with position.
- Measurements of aerosol properties from the solar photometers.
- Estimates of the boundary layer A parameter.

The lidars will provide high resolution boundary layer depth and dynamics information to the study group. They will also provide cloud coverage, height, thickness, opacity and reflectivity information from the lidars. The mobile lidar is also equipped with solar photometers of several types that can work when stationary. The systems can measure total downwelling solar energy, and also make almucanter measurements and measurements of the solar spectrum between 270 and 1100 nm. These measurements allow estimation of the total aerosol loading, particulate size distribution, and aerosol phase function. The capability also exists to measure the total column water content. While this has not done this previously, it is the intent to attempt this measurement. The availability of nearby measurements from the ARM site for comparison makes this an ideal time to test the method. The mobile lidar will be used to make transects of the area measuring the height of the boundary layer. The mobile lidar has GPS capability and records the location of each set of laser pulses. In as much as the CLASIC experiment postulates changes in the boundary layer and cloud cover with changes in surface conditions, the lidar should be able to observe and document these changes. Since the boundary layer changes relatively slowly, it is conceivable that multiple runs could be made of lengths approaching 5 miles.

Note that there are some safety concerns regarding the lidar that are described in the Safety section of this plan.

5.4. Tethersondes - Linking Cumulus Formation to the Diurnal Cycle of Surface Fluxes Across Surface Wetness Contrasts

The development of land-breeze type circulations across landscape gradients (e.g. bare/vegetated surfaces, dry/wet surfaces) and the role of the upward branch of such circulations in the formation of clouds, triggering of convective activity, and enhancing rainfall processes has long been viewed as one key mechanism of land-atmosphere interactions and a pro-active mediator in rainfall recycling (Mahouf et al. 1987, Segal et al. 1988, and many others). Early studies relied mostly on the use of regional mesoscale models (often hydrostatic) to examine the intensity and extent of the land-breeze as a function of landscape layout (the characteristic size of wet-dry patches and land-cover contrasts), and to determine the influence of synoptic-scale winds (Bechtold et al. 1991). Observational evidence of such phenomena and associated symptoms are often of an anedoctal nature (e.g. comparing the morphology of cloud fields over heterogeneous landscapes) and lack the continuum of state variables that is needed to track the mechanisms by which surface moisture contrasts translate into low level thermodynamic gradients in the boundary layer, changes in moist stability conditions in the lower troposphere, development of breeze circulations, and the formation of cumulus clouds.

Over the last fifteen years, as model resolution improved, and more physically-based land hydrology models were coupled to atmospheric models, much effort has been directed at using such models to demonstrate that the parameterization of land-atmosphere interactions is necessary to improve both weather and climate simulations, and in particular model simulations/forecasts of surface temperature and rainfall. However with the current-generation non-hydrostatic cloud-resolving models, the challenge is no longer to establish whether land-atmosphere interactions matter on some average sense, but rather to simulate their organization and intensity and their impact on cloud formation at the field scale (Bushan and Barros 2007). A critical obstacle to obtaining continuous observations for model evaluation is the fact that in order to achieve significant moisture gradients, rainfall is needed. However, it is difficult to plan ahead where rain will fall and how the surface wetness gradients will develop, and it is virtually impossible to monitor boundary-layer evolution before, during, and even shortly after rainfall events using tethersondes due to safety concerns. Irrigated agriculture on the other hand can provide the appropriate gradients on a consistent basis across pre-determined lines.

We propose to take advantage of the contrasts that can be created by managing existing irrigation systems in the Fort Cobb area to obtain a statistically robust portrait of the diurnal cycle of boundary layer evolution (potential temperature, specific humidity and relative humidity, wind direction and wind magnitude) and the surface energy budget. Specifically, we propose to deploy two tethersonde systems and two hydrometeorological towers, across a dry-wet transition on a transect normal to the predominant regional-scale flow. We will place the transect within the confines of the planned PALS flights described in the PALS section of this experiment plan.

The overall objective of the field campaign is to obtain concurrent and physically integrated observations of land-surface and boundary layer moisture and temperature states, including surface fluxes and boundary layer profiles of temperature, moisture and winds to be used for estimating atmospheric correction and for calibration of soil moisture retrieval from the PALS instrument (Jackson and Barros), and for the validation of coupled cloud-land models (Barros and Peters-Liddard). The geographic location of the experiment is shown in Figure 24. A schematic of the observational setup is provided in Figure 25. The wet field will be maintained wet throughout the experiment via the application of irrigation during the night in order to restore early morning surface moisture conditions on a daily basis. The dry field will be wetted only by the natural occurrence of rainfall during the experiment. The scope of this proposal concerns the deployment of two tethersonde systems and two field-scale arrays of raingauges at the Fort Cobb site during CLASIC. The raingauge arrays and one of the tethersonde systems will be provided by Duke University (Dr. Barros). The second tethersonde system will be provided by Goddard (Dr. Peters-Liddard). The two flux-towers will be provided, maintained and operated by Dr. Thom Rahn from Los Alamos National Laboratory, Earth and Environmental Sciences Division. Dr. Nathaniel Brunsell from Kansas University will participate with a large aperture scintillometer. In addition, an array of short towers (2m height) will be placed along the wet-dry transition to establish with detail the near-surface thermodynamic gradients. Instruments for this purpose will be provided by Duke University. The specific measurements to be conducted in the context of this proposal are as follows:

(1) Hourly tethersonde launches to obtain profiles of temperature, humidity and winds up to 500 m AGL from sunrise to sunset for the duration of the experiment.

(2) Sub-hourly (every fifteen minutes) tethersonde launches during three days to capture the evolution of early morning collapse of the nocturnal boundary layer and late-morning/mid-afternoon growth of the daytime boundary layer.

(3) Sub-hourly measurements of rainfall at a minimum of twelve distinct locations, seven in the wet field and five in the dry field. The raingauges will collect rainfall during naturally occurring storms, and in the wet field they will be used to monitor the spatial distribution of irrigation intensity.

(4) Sub-hourly measurements of pressure, air temperature and relative humidity gradients along the wet-dry transect using 2 m height stands to describe the low-level thermodynamic gradients in detail.

The entire suite of measurements will be submitted to baseline quality control and made available to other investigators at the latest within three months of the experiment. We will provide measurement uncertainty estimates for these observations which we refer to as Level 1 data. Processed and derived products such as the diurnal cycle of CAPE and precipitable water in the boundary layer will be made available as they are derived and verified. We refer to these as level 2 data. Our objective is to have both level 1 and level 2 data publicly available by June 2008.

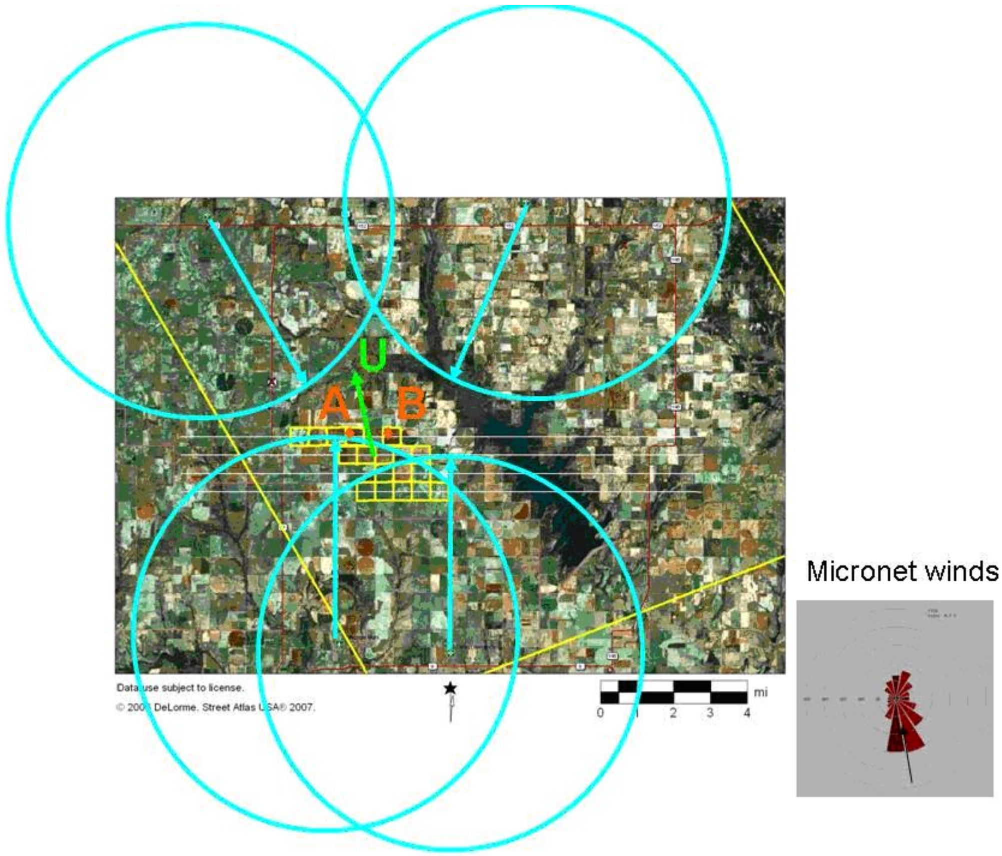


Figure 24. Fort Cobb field site. White horizontal lines indicate planned PALS flights; Cyan circles indicate the regions where tethersonde flights are not allowed as per the FAA 5-mile radius requirement away from airports; Yellow squares indicate fields that are under consideration for ground sampling; Green arrows show the prevailing wind direction in the surface layer. A and B indicate the proposed locations for the two tethersondes. One of the fields will be irrigated; the other one will not.

On June 7 the anticipated launch locations for the tethersondes were the southwest corners of FC01 (wheat stubble) and FC05 (corn-irrigated).

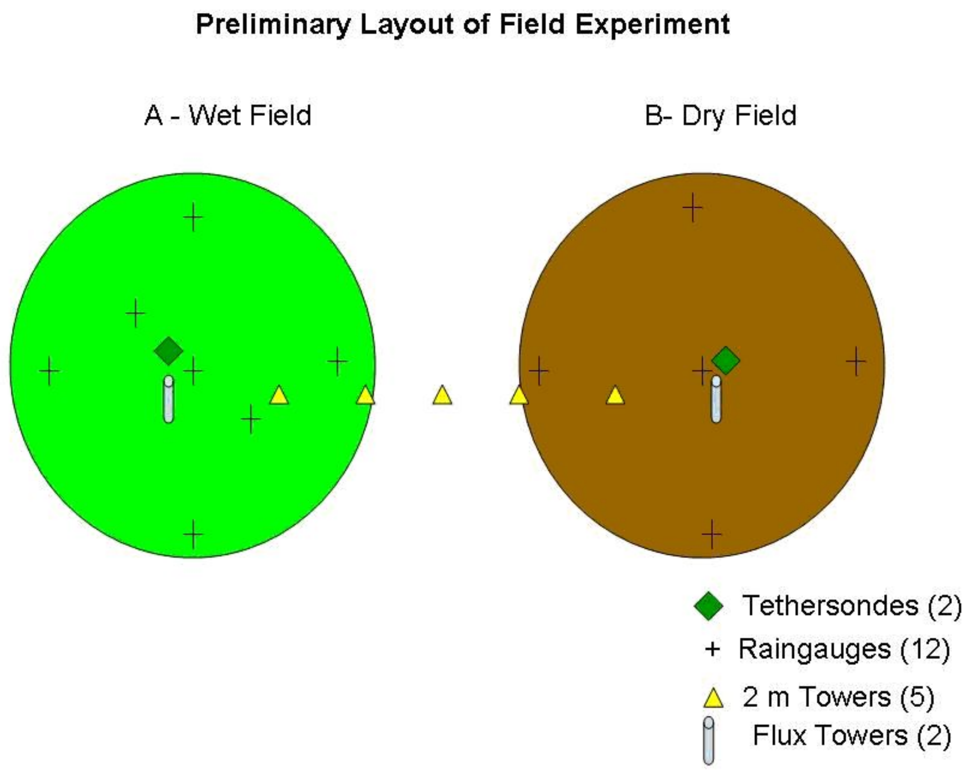


Figure 25. Preliminary layout of field experiment covered by this proposal (tethersondes, raingauges and short towers). The two flux towers from the Los Alamos group are marked to provide context.

5.5. Radiosonde Deployment

As part of the overall CLASIC field campaign, five radiosonde locations will be launching balloons throughout the experiment. These locations are listed in Table 24.

Table 24: Radiosonde Locations for the CLASIC Campaign			
Name	ID	Latitude	Longitude
Hillsboro	BF-1	38.305	-97.301
Vici	BF-4	36.071	-99.204
Chickasha	BF-6	35.044	-97.914
Morris	BF-5	36.688	-95.856
Central Facility	CF	36.605	-97.488

5.6. Satellite/Aircraft-based Surface Flux Mapping

To effectively link the temporal and spatial variability in land-surface conditions over the CLASIC experiment domain to fluxes measured at tower sites and by aircraft, and to forces driving cumulus convection, an upscaling mechanism must be employed to fill temporal and spatial gaps that remain unsampled by the deployed flux instrumentation set. One approach to flux upscaling uses land-atmosphere-transfer-schemes (LATS) linked to remotely-sensed boundary conditions as an intermediary between the sensor footprint and regional scales. Modeled flux fields provide a basis for connecting point-like tower data and linear aircraft transect measurements made at height with the two-dimensional patterns of fluxes diagnosed at the land surface. The tower and aircraft fluxes can be back-projected onto the surface source/sink distribution through inversion of an appropriate advection-dispersion model, defining the effective "source weighting" or "flux footprint" function. If the comparisons are reasonable within the segment of the experimental domain sampled by the measurement sets, gridded model fluxes can be aggregated with some degree of confidence to larger spatiotemporal scales with similar characteristics.

In this capacity, we will examine the utility of a multi-scale LATS framework that uses thermal and visible/near infrared remote sensing imagery from multiple satellites to partition surface temperature and fluxes between the soil and canopy. Surface temperature, derived from thermal remote sensing, is a valuable metric for constraining models of regional evapotranspiration (ET) because varying soil moisture conditions yield a distinctive thermal signature. Moisture deficiencies in the root zone lead to vegetation stress and elevated canopy temperatures, while depletion of water from the soil surface layer causes the soil component of the scene to heat up rapidly. The Atmosphere-Land Exchange Inverse (ALEXI; Anderson et al. 1997) model uses thermal data from the GOES satellite to map water and energy fluxes across the continental U.S. at 5-10km resolution. Gap-filling procedures have been developed to provide full hourly coverage under both clear and cloudy conditions at the continental scale. An associated flux disaggregation technique (DisALEXI; Norman et al. 2003) can be applied to map fluxes at finer scales for comparison with ground observations, integrating higher resolution thermal information from polar orbiting or airborne imaging systems. Because vegetation stress similarly affects both transpiration and carbon assimilation fluxes, a thermal-based canopy resistance submodule has been adapted for the ALEXI/DisALEXI system to additionally facilitate CO_2 flux mapping (Anderson et al. 2000).

ALEXI/DisALEXI have been previously validated over the CLASIC domain in comparison with tower data from the Mesonet OASIS network, and with tower and aircraft fluxes collected over the El Reno study areas during SGP97. Figure 26 shows an example of disaggregated ET flux fields in 5-km boxes surrounding 7 OASIS sites spanning the east-west vegetation cover gradient that exists across Oklahoma. Mean absolute differences (MAD) between footprint-weighted DisALEXI estimates and tower measurements from these combined experiments is 30 Wm^{-2}, or about 10% of the mean observed flux (Anderson et al. 2007).

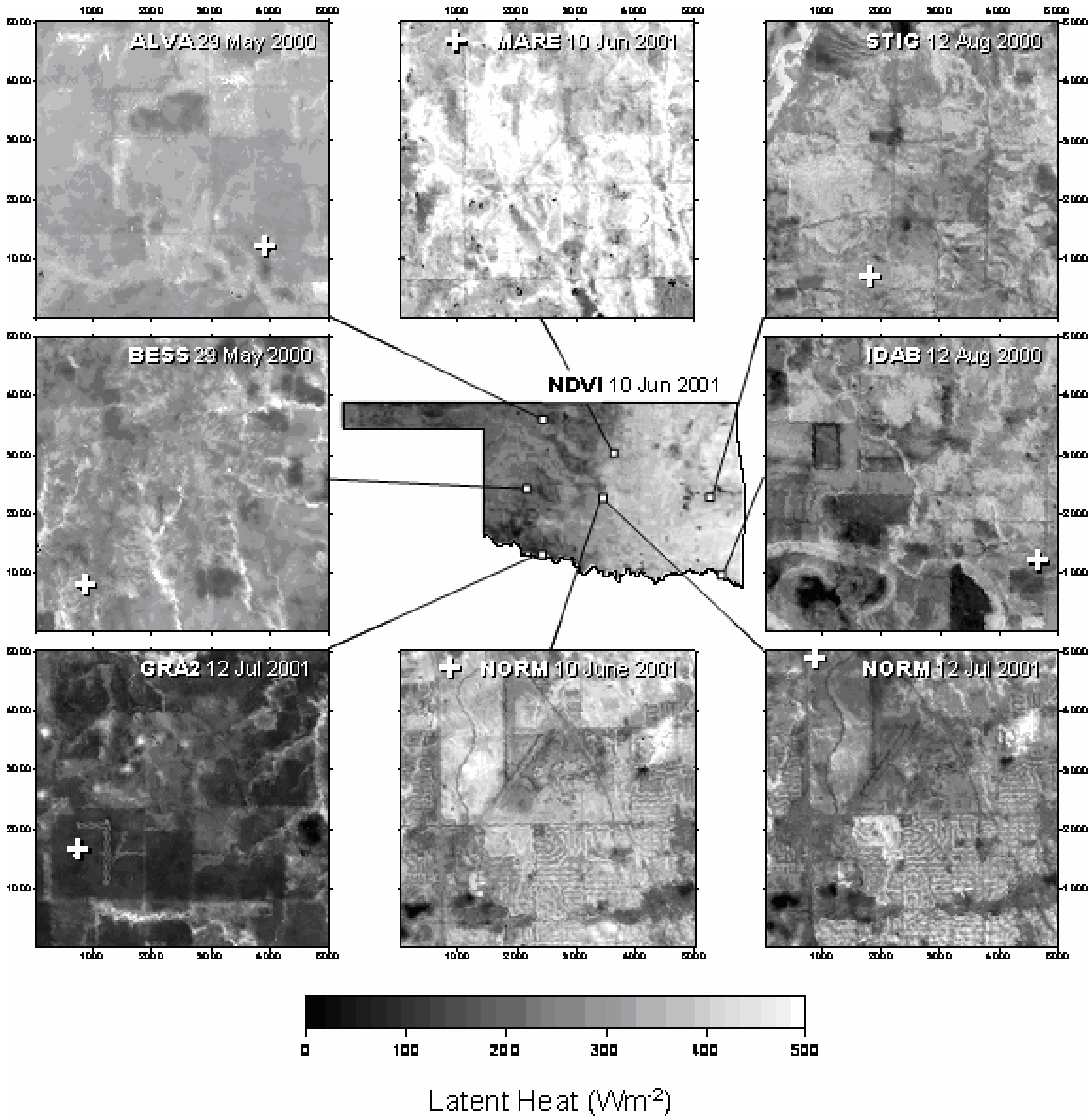


Figure 26: Disaggregated maps of latent heating (30-m resolution) in 5-km ALEXI grid cells around flux towers in the OASIS network. Crosses indicate the location of the towers. Axes are labeled as distance in meters.

For the El Reno study, the footprint-weighted model output also reproduced the spatial distribution of fluxes sampled along the aircraft transect, showing a broad decrease in evaporative flux as the aircraft moved over the area of lower vegetation cover near the center of the transect (Fig. 27, left). The sensible heat profile is more poorly reconstructed using this weighting function (Fig. 27, right) - an average of a swath of pixels directly underneath the transect does a better job at capturing feature (Fig. 27, right). This suggests that the source areas for heat and water fluxes measured at height may be very different in this case, with the footprint for sensible heat peaking much closer to the aircraft transect (Kustas et al. 2006). This may be due to the fact that sensible heat is an active flux, buoyantly driving its own vertical transport and therefore constrained to smaller scales, while water vapor is more passively transported by the mean wind field and subject to horizontal mixing – a phenomenon that may be important to understanding the linkage of cumulus convection with land-surface conditions

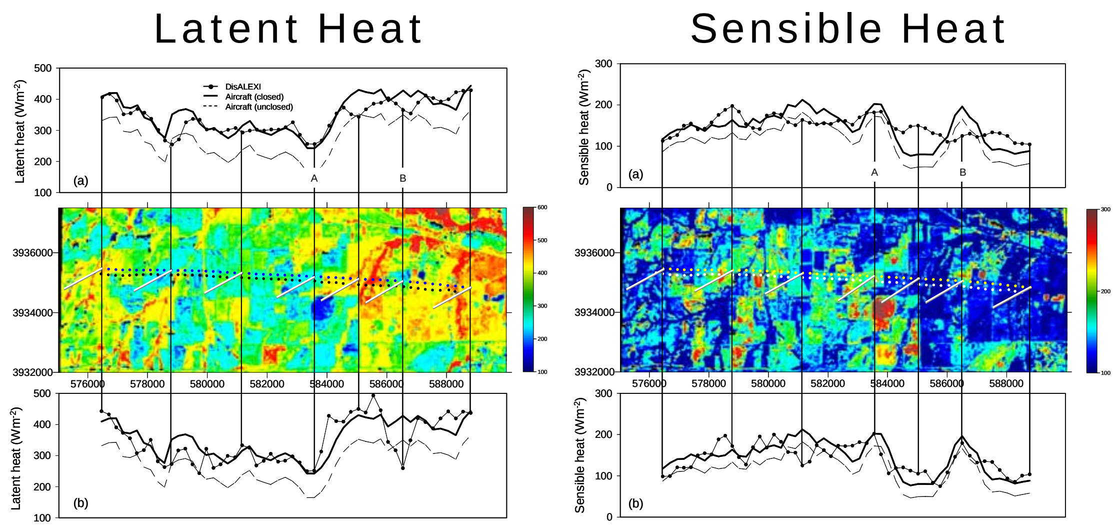


Figure 27: Comparison of aircraft latent heat (left) and sensible heat (right) profiles acquired over El Reno transect (SGP97) on 2 July 1997 with model predictions from DisALEXI. Uncorrected and closure-corrected aircraft fluxes as a function of position (Easting UTM, zone 14) along transect, with DisALEXI estimates integrated over the aircraft source area footprint (a) and over a swath directly beneath the aircraft (b). Middle panel shows DisALEXI flux map of with aircraft transect (upper dotted line) and maxima of footprint function (lower dotted line) indicated. White lines represent axis of footprint function (in upwind direction).

For the CLASIC experiment timeframe, hourly ALEXI energy and water flux maps will be generated over the continental U.S. at 10-km resolution, and at 5-km resolution over the SGP. *Optimal output for disaggregation is generated at ~10:30-11:00 LST.* DisALEXI will be applied to mid-morning MODIS thermal imagery at 1-km resolution, Landsat 5 at 120 m (if operable), and ASTER at 90 m, creating periodic high-resolution instantaneous flux maps over the experiment site under clear-sky conditions.

To help bridge the gap between the tower footprint and satellite pixel scale, *DisALEXI will also be applied to MAS imagery collected with the ER-2 aircraft.* Relevant features of the MAS as installed on the ER-2 are

- 50 multispectral bands from 445 nanometers to 14.428 micrometers.
- FOV 2.5 mrad (50 m @ 20 km, 25 m @ 10 km.)
- Swath Width 85.92^{o} (37.5 km @ 20 km, 18.75 @ 10 km)
- Level-1B data (calibrated and geolocated radiances).
- Level-0 quick-look imagery are available in-field and nadir surface temperature plots (1 km cell along flight track).

- HDF format files delivered within 60 days of end of mission. Calibrated and geolocated spectral radiances MAS Channels (50) are listed at this URL; http://mas.arc.nasa.gov/reference/mas_summ.html

An overpass time of 10:30 CST will be optimal. We are requesting that for this flux-mapping experiment that thermal and shortwave (visible/NIR) MAS imagery be processed, atmospherically corrected, georegistered and mosaicked to a final form prior to delivery. If this is not possible it will be necessary to seek additional support and introduce delays into the analyses.

The flux images will be compared with tower, helicopter, and Twin Otter flux measurements using an analytical source area modeling scheme. The patchwork pattern of cover/moisture conditions over the SGP landscape, particularly during the wheat harvest, should provide discrete sources of heat and water vapor that may give us additional insight into turbulent flux footprint incompatibilities in comparison with airborne flux observations.

5.7. ER-2 Aircraft Studies

The ER-2 is a very important element of CLASIC. Originally the PSR was part of the ER-2 payload, however, last minute issues resulted in the PSR being moved to the P-3 aircraft. The ER-2 payload includes the following instruments:

- CPL (Cloud Physics LIDAR)
- MAS (MODIS Airborne Simulator)
- CRS (94 GHz cloud radar system)-
- EDOP (9.6 GHz doppler, precipitation, radar system)

The flight altitude selected (~20 km) was specified based on aircraft operations. The aircraft was designed for high altitude flights. Lower altitudes are much more difficult and changes in altitude are time consuming. Therefore, lower altitude requests for the MAS were rejected.

The higher altitude does facilitate mapping a large domain efficiently. For the Survey missions described below, the domain size (line length and number of lines) and time required were carefully balanced.

Some constraints that were requested were:

- Map entire CLASIC domain during Survey flights
- Keep mapping period to <4 hours
- Sequence of flight lines should be consistent day to day
- Coverage time should be consistent day to day
- Maintain adequate overlap of MAS data from adjacent lines (spacing < 30 km)

The ER-2 will fly at least four different missions, which may be combined if time constraints do not create problems. These are

- Survey – to study cloud formation and land surface interaction. Synoptic coverage of a large spatial domain at acceptable spatial resolution
- Evolution – to study cloud development over an area. A rectangle will be flown either continuously or at intervals. The focus will likely be a super site (most likely CF or LW). Details of these missions will be determined after a period of time on-site to assess conditions and timing.
- Gulf Trajectory – to study role of cumulus convection and land cover in depleting low-level vapor advected from the Gulf of Mexico. Fly a pattern (line) from the Gulf to the CLASIC domain. It will be easy to combine this with either the Evolution or Survey patterns.
- A-Train Validation – the ER-2 includes several of the instrument types on the A-Train satellites. Since the Cloudsat/Calipso satellites have narrow swaths, the proximity of the tracks relative to the CLASIC domain will have to be considered. Dates that appear to fall into that category are June 12, 19, and 26.

These flightlines are plotted in Figure 28 (note that the exact lines that will be used for the Gulf Trajectory and Evolution have not been defined but will fall in the general locations shown. The Evolution box could move to the LW area or elsewhere. Coordinates of the Survey lines and bounding box are listed in Table 25.

Table 25. ER-2 Survey Flightlines

Line	Start		End	
	Latitude (Deg.)	Longitude (Deg.)	Latitude (Deg.)	Longitude (Deg.)
S01	35.800	-95.535	34.550	-98.735
S02	34.800	-98.870	36.050	-95.670
S03	36.300	-95.805	35.050	-99.005
S04	35.300	-99.140	36.550	-95.940
S05	36.800	-96.075	35.550	-99.275
S06	35.800	-99.410	37.050	-96.210

The ER-2 planners estimate that it will take 3.25 hours to fly the survey lines. Combined with a transit to and from the base in Houston, they estimate the total mission time as 5.75 hours. Based on a request by the flux group, the southern lines will be flown first and if possible LW will be covered at approximately 11:30 am CDT.

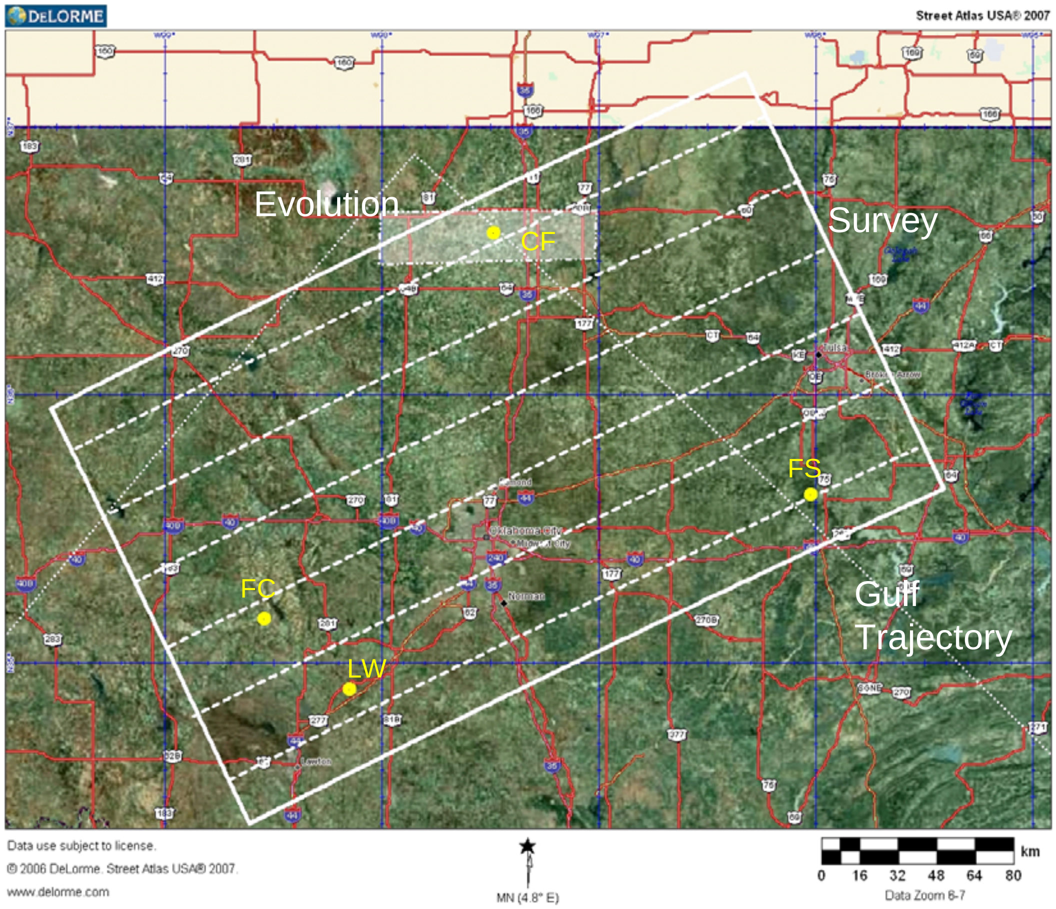


Figure 28. ER-2 flight lines and super sites. The background is true color satellite imagery.

5.8. University of Tokyo Upward Looking Microwave Radiometer

Passive microwave radiometers can provide information on atmospheric parameters. The AMSR-E instrument on Aqua includes several higher frequencies that are used for this purpose. The University of Tokyo (T. Koike) is planning to deploy a ground based upward looking simulator of the higher frequency AMSR-E channels that will be used to better understand the atmospheric and land contributions to the satellite observations. The instrument will be deployed near the Chickasha field headquarters, indoors but looking at the sky at the AMSR-E incidence angle.

5.9. Image-Based Retrieval of Leaf Biochemical and Canopy Biophysical Parameters

Accurate quantitative estimates of leaf biochemical and canopy biophysical variables are important for land surface models quantifying the exchange of energy and matter between the land surface and the lower atmosphere. Key variables include the leaf area index (LAI) that exhibits a major control on transpiration and uptake of CO_2 by the canopy, and leaf chlorophyll content (C_{ab}) that can assist in determining photosynthetic capacity and productivity.

20 m resolution maps of LAI and leaf chlorophyll content will be generated for Little Washita and Fort Cobb using inverse and forward canopy reflectance modeling techniques and SPOT reflectance observations as described in Houborg and Boegh (2007). The scheme is completely automated and image-based and also solves for the soil background reflectance signal, leaf mesophyll structure, specific dry matter content and Markov clumping characteristics. Since the retrieval scheme is independent of in-situ measurements, it can in principle be directly implemented and run for any agricultural region as long as the model input requirements are met (see below).

The biophysical parameter retrieval approach is described by Houborg & Boegh (2007). Aerosol data from MODIS and profiles of air temperature, humidity and ozone from the Atmospheric Infrared Sounder (AIRS) are used for the atmospheric correction of SPOT radiances to surface spectral reflectances. A canopy reflectance model (ACRM – PROSPECT) is used for the inverse model estimation of 2 soil-specific and 3 vegetation-specific parameters. For this purpose only 'bare soil' (LAI < 0.5) and dense vegetation pixels are selected. Subsequently, a family of land cover and site-specific simplified relationships are established to build look-up tables allowing pixelwise calculation of C_{ab} from green reflectance and LAI-calculation from NDVI (for sparse vegetation) or near-infrared reflectance (for dense vegetation). An unsupervised land cover classification approach is used for the separation of spectrally homogeneous land cover classes. The methodology requires at least two clear-sky SPOT scenes to represent conditions of dense green vegetation and 'bare soil' respectively for each of the agricultural land cover classes of interest. Improvements to the modeling scheme are ongoing, and the retrieval of leaf equivalent water thickness has now been made feasible by the inclusion of the water sensitive mid-infrared band available on SPOT-4.

Reflectance data in the green, red, near-infrared and mid-infrared wavelength regions will be obtained in April, June and August by the SPOT 4 high resolution visible and infrared (HRVIR) instrument for the LW and FC watersheds. Aqua/Terra MODIS aerosol data and Aqua AIRS profile retrievals of air temperature, humidity and ozone will be acquired at the time of the SPOT-4 acquisitions for atmospheric correction purposes using MODTRAN.

Field data of leaf chlorophyll and LAI will be collected on representative field plots (i.e. wheat, barley, maize, rye and grass) in LW and FC in April, June and August for validation purposes. A portable SPAD-502 chlorophyll meter (Minolta) will be used for non-destructive measurements of leaf chlorophyll.

5.10. Soil Heat Flux Experimental Design

The objective is to determine optimal measurement design for assessing soil heat flux at flux-tower sites. While very detailed guidelines are provided by the various flux-tower networks (e.g., AmeriFlux and EuroFlux) for measurement designs of the radiative, as well as the sensible and latent heat, flux components of the energy-balance, no guidelines are provided for soil heat flux (SHF) measurements. Different designs are therefore applied at different sites, most of which consist of the combined method (see below), but some restrict measurements to soil heat flux plates only. Although the SHF is a relatively small component in the energy budget, it has a significant contribution in various conditions, and determination of uniform guidelines for SHF measurements may contribute to the reliability and completeness of the flux-tower networks.

Since the relative contribution of SHF to the energy budget is largest over bare soils (compared to vegetated areas), general guidelines can be determined based on the measurement setup design that will be found adequate enough to assess SHF in bare soils (with the restriction that spatial variability is site specific and will have to be carefully considered for each site separately in order to determine the required minimum number of replicates). In addition, with no-till becoming more widely used for water and soil conservation and for reducing environmental impacts on water quality, the affect of this thatch layer/barrier on the soil heat flux and resulting surface energy balance needs to be quantified.

Measurement of soil heat flux – background:

Soil heat flux can be measured directly by means of calibrated heat flux plates, be deduced from temperature and moisture content measurements (soil calorimetric method) or by a combination of these two (the combination method).
Soil Heat Flux Plates – Although heat flux plates are simple to use, their construction, calibration and installation require great care. The thermal properties of the plates are likely to be different from those of the soil, which vary with water content. If this difference is large, or if the plate is placed too close to the surface, the pattern of G may be distorted significantly. Therefore, soil heat flux plates should probably be placed at least 5 to 10 cm below the soil surface.
Soil Calorimetry – Provided that the thermal conductivity of the soil is known, *G* at a given depth can be calculated according to:

$$G = -K\frac{\partial T}{\partial z} \tag{1}$$

where *G* [W m^{-2}] is the vertical downward flux, K [W m^{-1} K^{-1}] is the soil's thermal conductivity, T [K] is the soil temperature and z [m] is the depth (pointing down).
Substituting (2) in the equation of conservation of heat yields eq. (3), upon which the calorimetric method is based:

$$C_v\frac{\partial T}{\partial z} = \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right) \tag{2}$$

C_V [J m^{-3} K^{-1}] – the volumetric heat capacity of the soil determined by the volume fraction of mineral soil θ_m, organic matter θ_o, water θ_w and air θ_a.
Integrating eq. (2) and combining it with eq. (1) yields

$$G_1 - G_2 = \int_{z_1}^{z_2} C_v(z)\frac{\partial T}{\partial t}dz \tag{3}$$

where G_1 and G_2 are the heat flux densities at levels z_1 and z_2 respectively.

Numerical integration of eq. (3) over the entire soil layer down to the depth at which SHF equals zero results in the following:

$$G_{j+\frac{1}{2}} = C_{v_{j+\frac{1}{2}}} \frac{\left(T_{j+1}^{i} + T_{j+1}^{i+1}\right) - \left(T_{j}^{i} + T_{j}^{i+1}\right)}{2} \frac{dz}{dt}$$
$$G = \sum_{j=1}^{n} G_{j+\frac{1}{2}} \qquad (4)$$

in which $G_{j+\frac{1}{2}}$ is the mean heat gain/loss for a soil layer of thickness dZ [m] between depths j and j+1 for time interval dt (between i and i+1) and n is the number of soil layers.

The main drawbacks of this method are: 1. it requires measurements of the temperature profiles down to the depth at which the diurnal temperature is constant; and 2. it requires continuous measurement of the soil water content, which is not always available.

The combination method – it has been suggested to measure G at a depth of 5 to 10 cm by a soil heat flux plate and to use eq. (4) to determine the heat storage above the plate from successive temperature profiles. This combination eliminates some of the drawbacks of both methods: the plate is installed deep enough to eliminate interference with the heat and moisture flow near the surface while there is no longer need for temperature measurements to the depth of constant temperature (that for short periods can exceed 1 m).

5.10.1 Suggested experimental design

It is suggested to have minimum three replicates of this design around the tower, preferably – of the entire set, and if not possible – at least to the depth of 10cm. The number of towers around which to install this setup will be determined by instrumentation availability. In the following – the required instrumentation for a complete one set of measurements is detailed.

Soil temperature:

13 thermocouples connected differentially installed at depths of 0-5 cm in 1 cm increments, 7.5, 10, 15 cm and 20-50 cm in 10 cm increments. It is assumed that at 50 cm depth there is no diurnal variation in soil temperature.

An absolute thermocouple will be installed at depth of 50 cm as a reference.

Thermocouples should be ~2.5mm in diameter to allow installation close to the soil surface.

Number of differential channels (it is preferable that they will be differential and not single-ended): 13

Soil heat flux plates:

3 SHFP will be installed at depths of 3, 5, and 7.5 cm (reflecting the commonly applied depths).

Number of channels (these measurements are less sensitive to type of connection, can be connected single-ended if needed).

Soil moisture:

The most detailed measurements of soil moisture we can obtain, the more accurate the SHF computation will be. Depending on available sensors continuous measurement of soil moisture at the uppermost soil layer and two additional depths is ideal.
In addition it is suggested to take soil samples at 2-3 hour intervals for 24 hours at least 3 times during the experiment for gravimetric soil moisture and bulk density measurements. Samples will potentially be of the uppermost 10 cm of the soil, of which the upper 5 cm divided into 1 cm layers.

5.10.2 Setup design

Site: Little Washita – 1 setup in conventional tilled winter wheat and another in no-till/wheat stubble

Measurement design:
Set up at several locations within the flux tower footprint and near soil moisture hydroprobes a soil heat flux measurement system for looking at with-in field spatial variability. In addition, collect gravimetric soil samples multiple times over a 24-h measuring period for evaluating the importance of temporal variations in surface soil moisture and resulting impacts on soil heat flux estimates.

Methodology:
Sample for gravimetric water content every 2 hours for 24-hours, 3-6 times during CLASIC.
In each sampling event: take 3 replicates of 0-8 cm soil samples. From 0 to 5 cm - slice the samples to 1-cm layers. The remaining 3 cm will be measured as a bulk layer.

6. Soil Moisture Sampling

Ground based soil moisture measurements will be made using multiple scenarios. The four primary objectives are:

- Provide field (~800 m) average surface volumetric soil moisture for the development and validation of microwave remote sensing soil moisture retrieval algorithms at a range of frequencies primarily from aircraft platforms. This will be called *Watershed sampling*.
- Provide an estimate of the representative character of the Micronet facilities in the Fort Cobb watershed by sampling adjacent fields for comparison to the *Micronet* soil moisture record during the CLASIC campaign.
- Provide continuous soil moisture for water and energy balance investigations. This will be called *Tower sampling*.
- Supplement existing instrumentation with smaller more mobile in situ soil moisture probes for a continuous data record using *Mini-stations*.

6.1. Watershed Sampling

The goal of soil moisture sampling in the Watershed sites is to provide a reliable estimate of the mean and variance of the volumetric soil moisture for fields that are approximately 800 m by 800 m. These measurements are used primarily to support the aircraft based microwave investigations, which will be conducted between 8:30am and 12:30pm CDT. This determines the time window for the Watershed site sampling.

The primary measurement made will be the 0-6 cm dielectric constant (voltage) at eight locations in each field using the Theta Probe (TP). These locations will be co-located with any flux tower/instrument installed in the field, when present. Additional details will be provided in the Protocols section of the experiment plan. Dielectric constant is converted to volumetric soil moisture using a calibration equation. There are built in calibration equations and, as the result of SMEX02 and SMEX03 studies (Cosh et al. 2005), site specific calibrations have proven more reliable. Therefore, at two standard locations within each field the 0-6 cm gravimetric soil moisture (GSM) will be sampled on each day of sampling using a scoop tool. GSM is converted to volumetric soil moisture (VSM) by multiplying gravimetric soil moisture by the bulk density of the soil. Bulk density will be sampled one time at each of these four locations using an extraction technique. These coincident gravimetric samples will provided a ground truth for Theta Probe calibration activities. It is anticipated that individual investigators may conduct more detailed supplemental studies in specific sites.

TPs consist of a waterproof housing which contains the electronics, and, attached to it at one end, four sharpened stainless steel rods that are inserted into the soil. The probe generates a 100 MHz sinusoidal signal, which is applied to a specially designed internal transmission line that extends into the soil by means of the array of four rods. The impedance of this array varies with the impedance of the soil, which has two components - the apparent dielectric constant and the ionic conductivity. Because the dielectric of water (~81) is very much higher than soil (typically 3 to 5) and air (1), the dielectric constant of soil is determined primarily by its water content. The output signal is 0 to1V DC for a range of soil dielectric constant, ε, between 1 and 32, which corresponds to approximately 0.5 $m^3 m^{-3}$ volumetric soil moisture content for mineral soils. More details on the probe are provided in the sampling protocol section of the plan.

Watershed sampling will only be performed on days with aircraft coverage of the watershed. However, due to timing of activities it may happen that ground sampling will be ongoing before the scheduled aircraft mission is cancelled.

Sites were identified within the Little Washita watershed (Table 26) and Fort Cobb (Table 27). Not all locations listed will be sampled. Sites were identified based on the following criteria.

- At least 800 m in the NS direction
- At least 800 m in the EW direction
- Centered on one of the low altitude flight lines
- Single cover condition
- Single management unit
- Permission to use

Figure 29, 30, 31, and 32 show the distribution of the watershed fields within LW and Figure 33 applies to the FC watershed.

Table 26. Soil moisture sampling fields within the Little Washita River Watershed.						
Fields	Corner	Section	Township Range	County	NE corner Latitude (Deg.)	NE corner longitude (Deg.)
LW03	SE 1/4	30	06N08W	Grady	34.964	-98.076
LW04	SW 1/4	30	06N08W	Grady	34.964	-98.084
LW05	SE 1/4	25	06N09W	Caddo	34.964	-98.093
LW12	NE 1/4	8	05N07W	Grady	34.928	-97.953
LW13	SE 1/4	8	05N07W	Grady	34.921	-97.953
LW21	NW 1/4	17	05N10W	Caddo	34.913	-98.278
LW25	NW 1/4	2	05N11W	Caddo	34.941	-98.330
LW26	NE 1/4	2	05N11W	Caddo	34.942	-98.322
LW29	SW 1/4	4	05N10W	Caddo	34.934	-98.260
LW33	NE 1/4	5	05N07W	Grady	34.942	-97.953
LW42	NE 1/4	1	05N11W	Caddo	34.942	-98.304
LW43	NW 1/4	1	05N11W	Caddo	34.941	-98.312
LW44	SE 1/4	6	05N10W	Caddo	34.935	-98.287
LW45	NE 1/4	12	05N11W	Caddo	34.927	-98.304
LW50	NE 1/4	4	05N10W	Caddo	34.941	-98.252

Table 27. Soil moisture sampling fields within the Fort Cobb Experimental Watershed.						
Fields	Township Range	Section	Corner	County	NE corner latitude	NE corner longitude
FC01	09N13W	32	SE 1/4	Caddo	35.211368	-98.588422
FC03	09N13W	33	SE 1/4	Caddo	35.211523	-98.570853
FC04	09N13W	34	SW 1/4	Caddo	35.211381	-98.561894
FC05	09N13W	35	SW 1/4	Caddo	35.211462	-98.544281
FC06	08N13W	4	NE 1/4	Caddo	35.204102	-98.565427
FC10	08N13W	3	SE 1/4	Caddo	35.197241	-98.547834
FC13	08N13W	10	NW 1/4	Caddo	35.190015	-98.556557
FC14	08N13W	10	NE 1/4	Caddo	35.190073	-98.547932
FC15	08N13W	11	NW 1/4	Caddo	35.190081	-98.538985
FC22	08N13W	4	NW ¼	Caddo	35.204010	-98.574340
FC23	08N13W	5	SE ¼	Caddo	35.197150	-98.583370

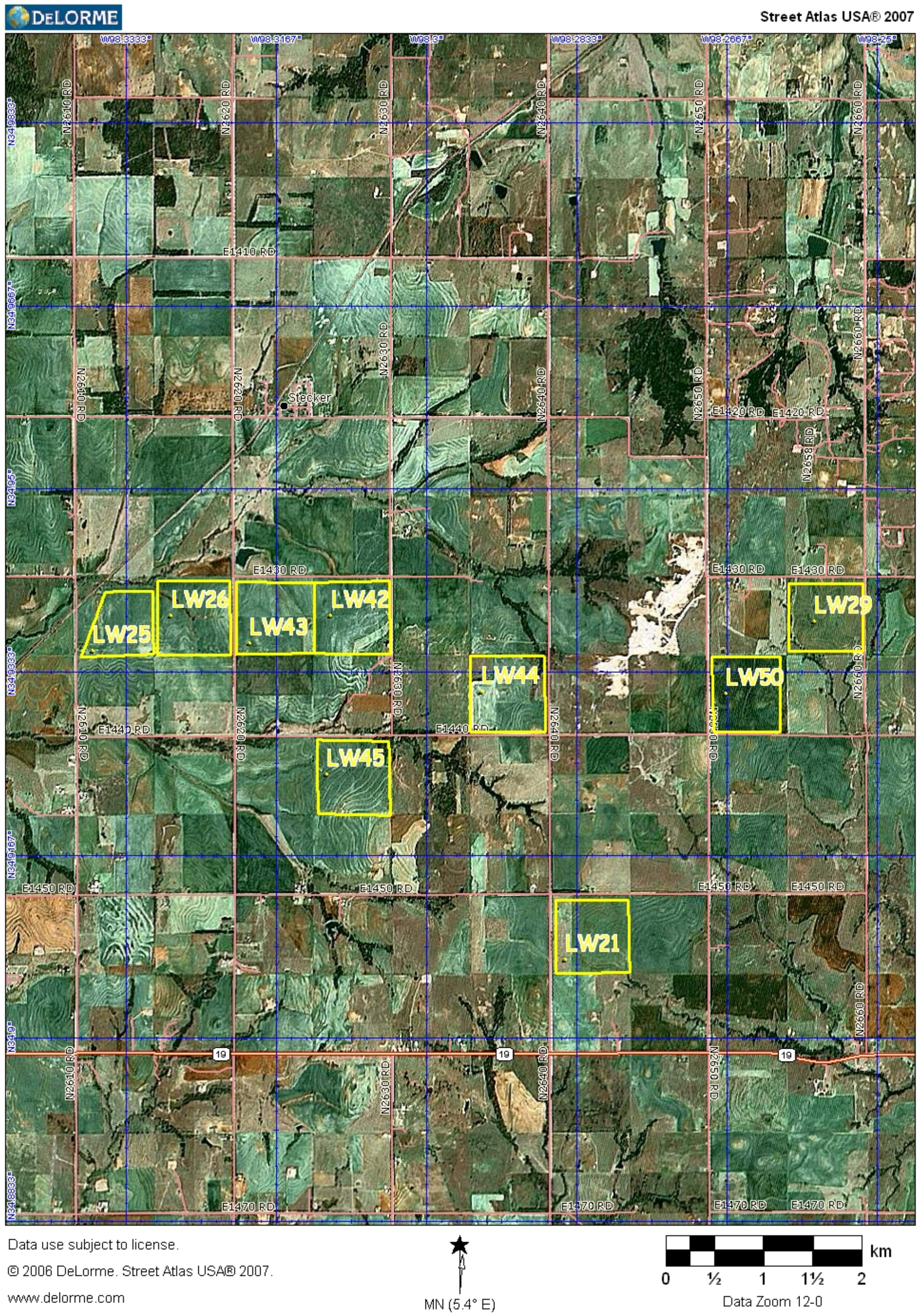


Figure 29. LW sampling sites (Part 1).

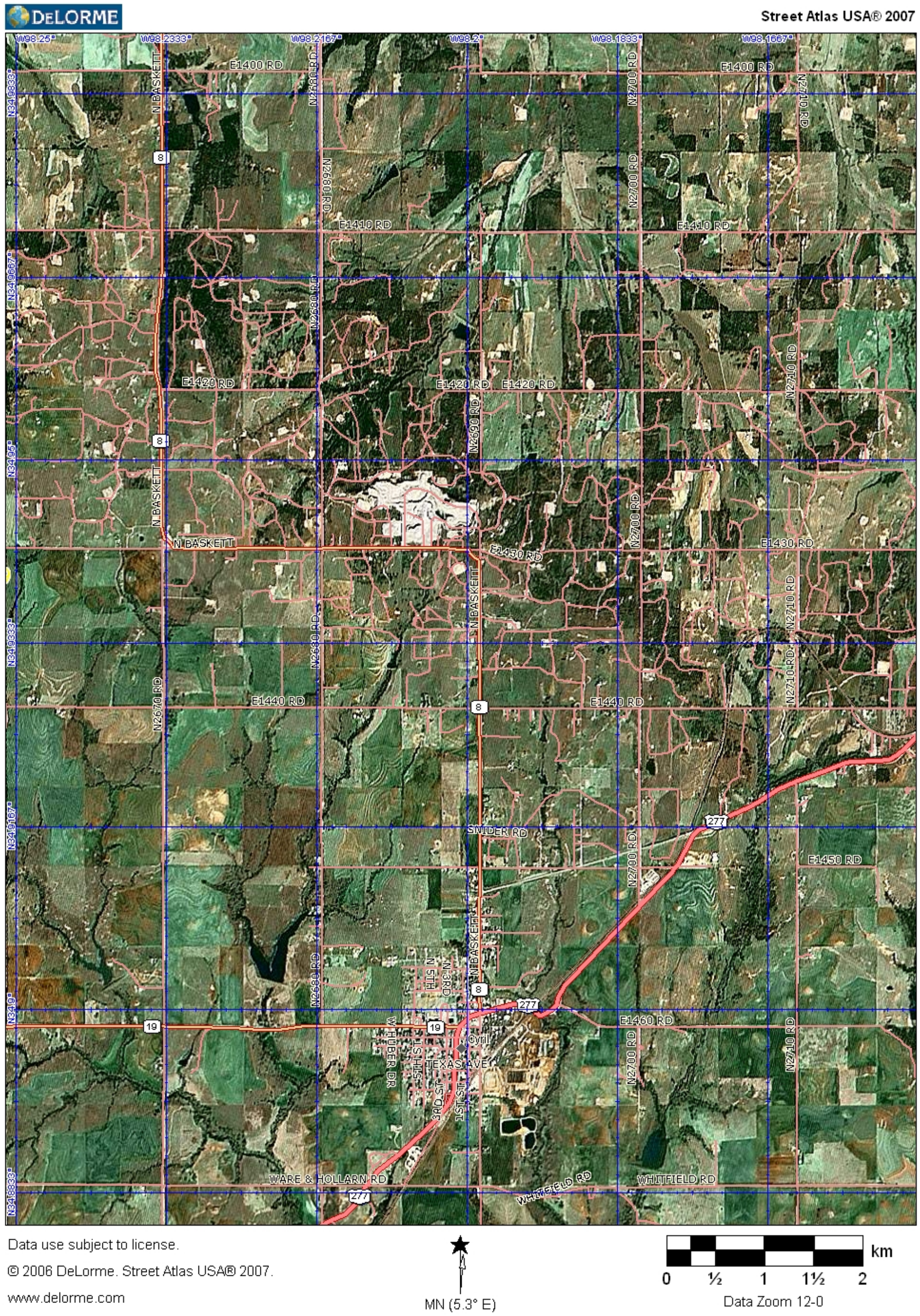


Figure 30. LW sampling sites (Part 2).

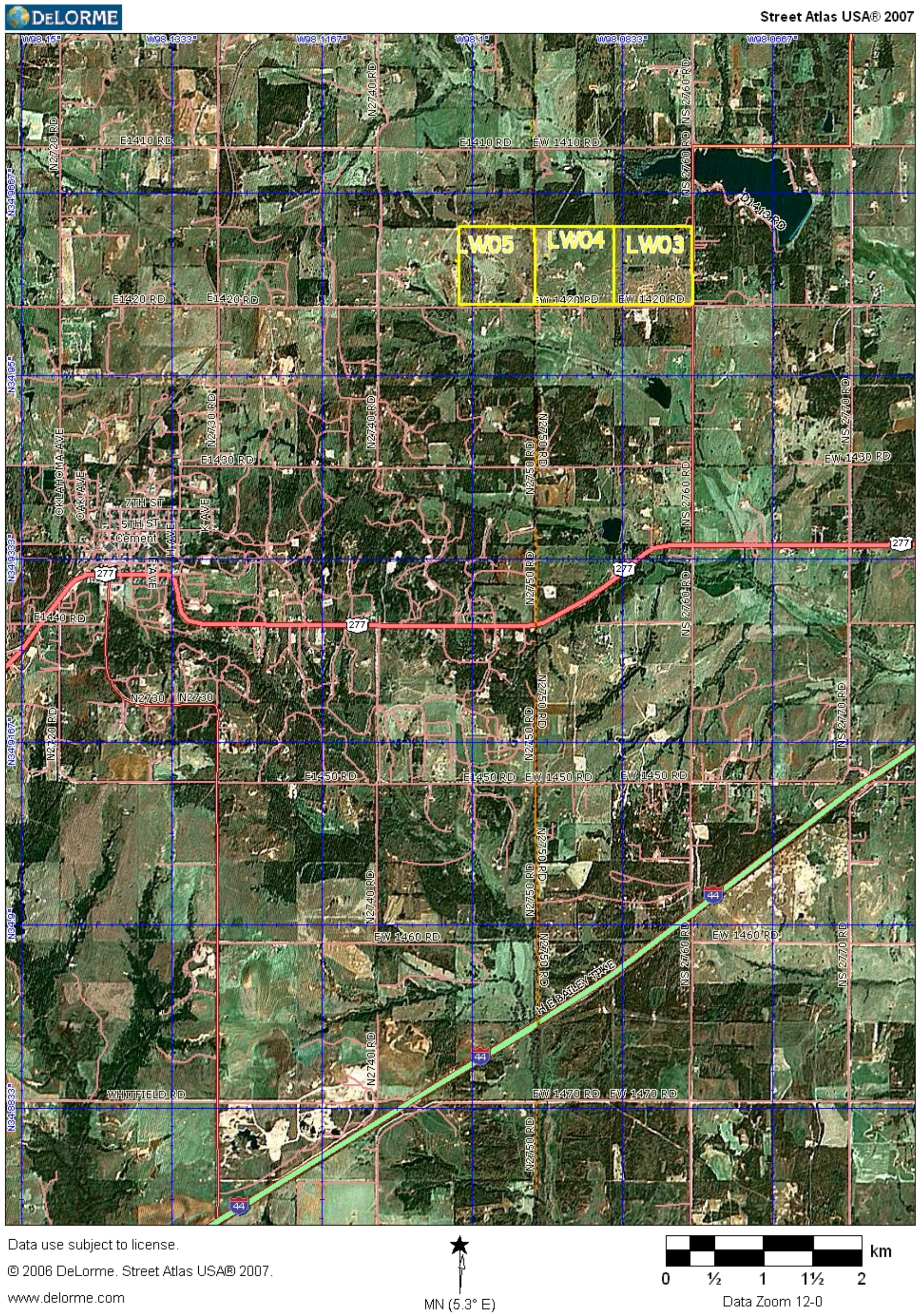


Figure 31. LW sampling sites (Part 3).

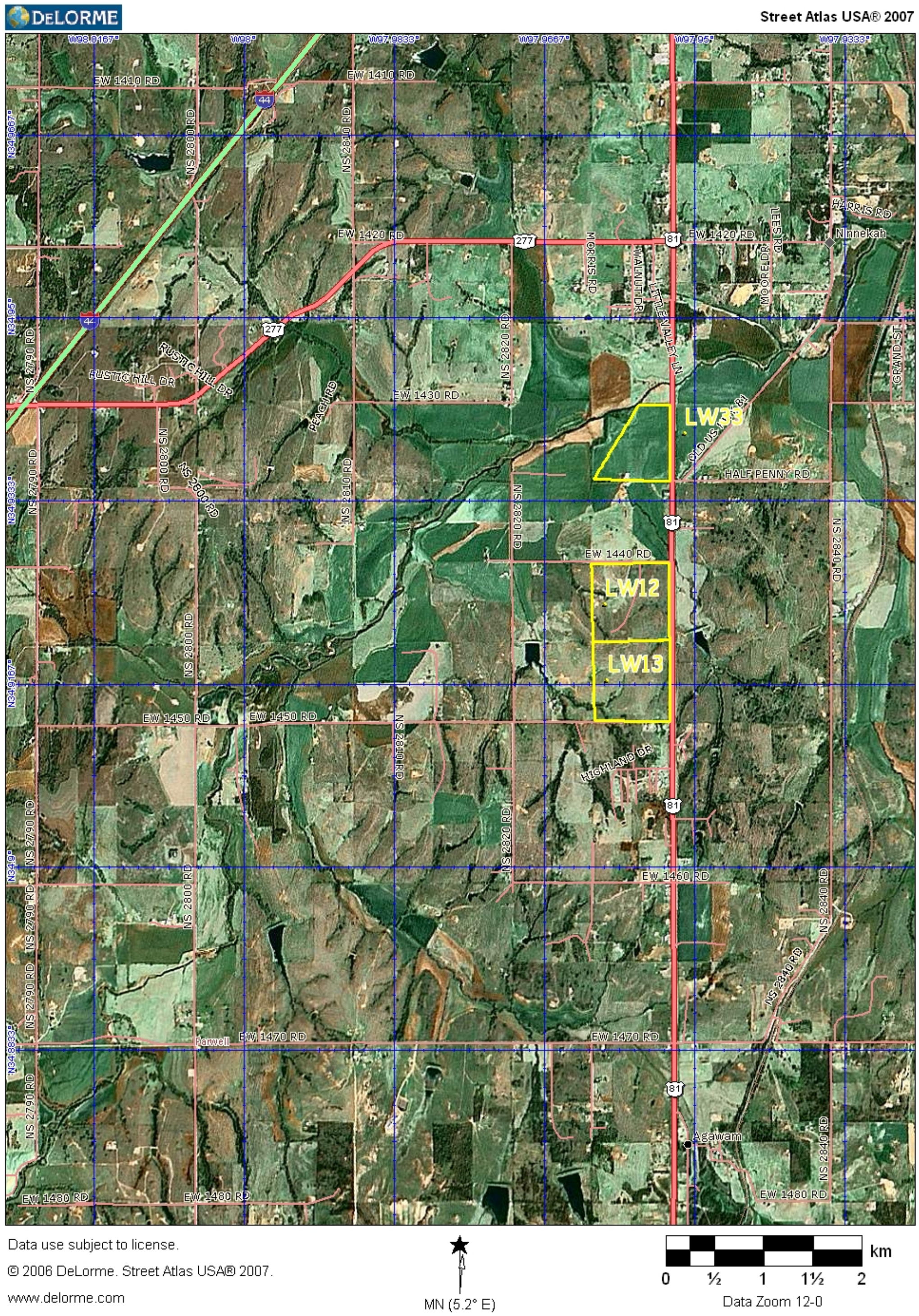


Figure 32. LW sampling sites (Part 4).

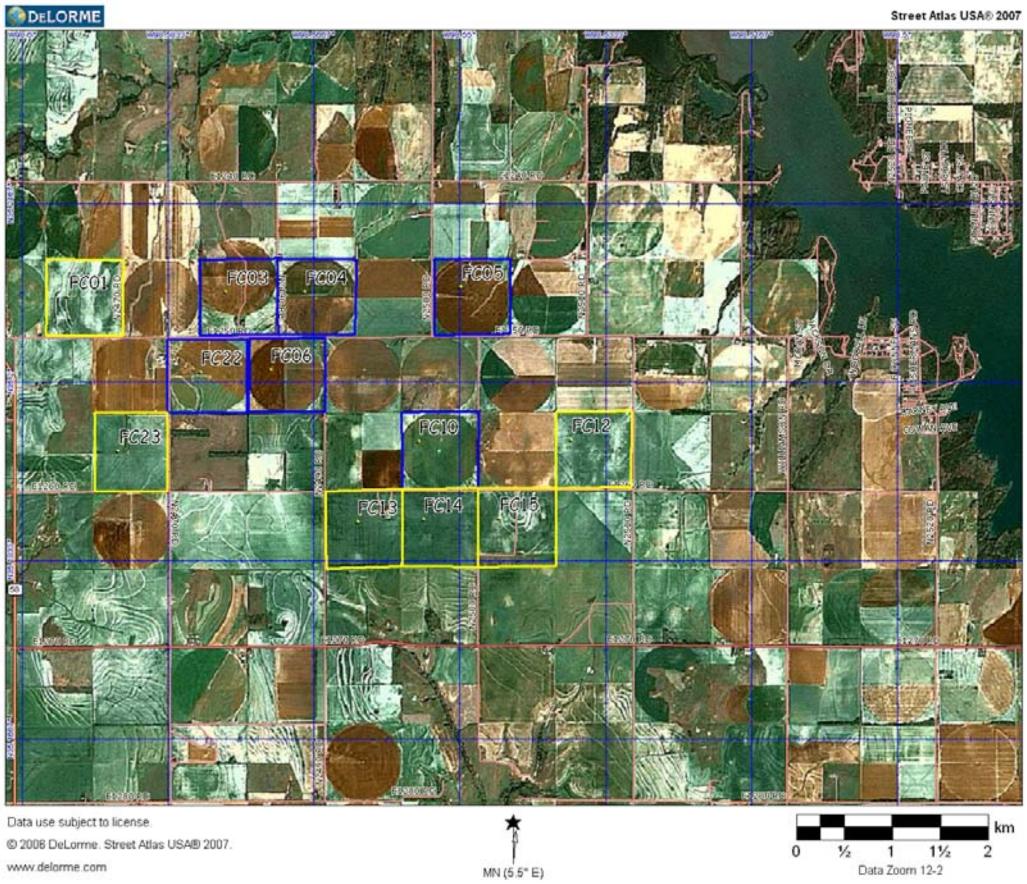


Figure 33. FC sampling sites (Blue boxes are irrigated and yellow are dryland).

6.2. Micronet Sampling

The goal of soil moisture sampling over the Oklahoma region is to provide a reliable estimate of the VSM mean within a single satellite passive microwave footprint (~50 km) at the nominal time of the WindSat and AMSR-E overpasses (possibly four in a day). In order to satisfy this requirement we will be using insitu sensors (Stevens Water Hydra Probes) with data loggers. These sensors will be installed at a depth of 5 cm and provide the soil moisture and temperature. A single location in each of sites is queried each hour. The sampling team will download the soil moisture and soil temperature data from the dataloggers. Because of the variability introduced by the installation and maintenance of these sensors, it is necessary to verify how these point measurements relate to the surrounding area. In this regard, soil moisture samples and soil temperature observations will be made to calibrate the in-situ observations. Micronet locations were previously listed in the site description section (Tables 3 and 4).

6.3. Tower Sampling

Tower sampling is intended to provide continuous measurements of the surface soil moisture at the locations of the surface flux towers. A single Hydra Probe will be installed at a depth of 5 cm. To insure accurate calibration of these devices, the TP and GSM measurements will be made near these locations on each sampling date.

Soil moisture and temperature for the surface layer will be measured using Type A Hydra Probes. This version is compatible with Campbell CR-206 data loggers along with many other Campbell loggers; the temperature output voltage never exceeds 2.5 volts.

The Hydra Probe (HP) soil moisture probe determines soil moisture and salinity by making a high frequency (50 MHz) complex dielectric constant measurement. A complex dielectric constant measurement resolves simultaneously the capacitive and conductive parts of a soil's electrical response. The capacitive part of the response is most indicative of soil moisture while the conductive part reflects predominantly soil salinity. Temperature is determined from a calibrated thermistor incorporated into the probe head.

As a soil is wetted, the low dielectric constant component, air, is replaced by water with its much higher dielectric constant. Thus as a soil is wetted, the capacitive response (which depends upon the real dielectric constant) increases steadily. Through the use of appropriate calibration curves, the dielectric constant measurement can be directly related to soil moisture.

The dielectric constant of moist soil has a small, but significant, dependence on soil temperature. The soil temperature measurement that the Hydra probe makes can be used to remove most of the temperature effects.

The Hydra Probe has three main structural components, a multiconductor cable, a probe head, and probe sensing tines. The probes will be installed horizontally in the soil with the center tine at a depth of 5 cm. Additional details on the Hydra Probe are provided in the sampling protocol section of this plan.

The measured raw electrical parameters determined by the HP are the real and imaginary dielectric constants. These two parameters serve to fully characterize the electrical response of the soil (at the frequency of operation, 50 MHz). These are both dimensionless quantities.

Because both the real and imaginary dielectric constants will vary somewhat with temperature, a temperature correction using the measured soil temperature is applied to produce temperature corrected values for the real and imaginary dielectric constant. The temperature correction amounts to calculating what the dielectric constants should be at 25^{o}C.

The dielectric constants are used to calculate soil moisture with conversion equations. The manufacturer provides these, however, through the ground sampling component it should be possible to refine these for each site.

Tower sampling will be conducted at the locations listed in Table 23.

6.4. Mini-station based soil moisture measurements

Small scale stations will be deployed in several regions to assist in the calibration of aircraft datasets as well as monitor the localized soil moisture conditions for local surface flux work. These networks will vary in size and distribution, but will be composed of similar mini-stations.

Each station will consist of a soil moisture/soil temperature sensor recording at 30 minute intervals. The Stevens Water Hydra Probe (I) will be the sensor of choice, as it has proven reliable and robust in previous experiments as well as long term networks such as the USDA-NRCS SCAN. The datalogger is a Campbell Scientific CR206 datalogger with integrated 915MHz Radio. This will allow for small scale networking of sensors in some locations. Power will be provided by small solar panels designed specifically for the CR206 datalogger.

Stations

- Forest Flux Study Region – A mini-net will be established in the forested region near the Okmulgee Mesonet location in Eastern Oklahoma. Covering a region approximately 1 km by 1 km in scale, a network of 6 Mini-stations will be deployed with a predominance in the local wind direction for measurements within the fetch of the local flux stations, beneath the forest canopy.

- Central Facility Study Region – A mini-net will be established around the DOE SGP ARM CART Central Facility with approximately 3 stations. The scale of the study region for this site is approximately 2 km by 2 km. The goal of this sampling will be a combination of fetch monitoring to the local flux tower and spatial estimation.

- Fort Cobb Study Region – In support of low altitude flights in the southern Fort Cobb watershed, 6 mini-stations will be deployed in a variety of fields, including 4 fields with central pivot irrigation rigs. These installations will be located near gravimetric sampling points within the fields.

- Little Washita Study Region – The intensive soil moisture and flux studies within the Little Washita watershed will necessitate approximately 5 mini-stations within the watershed to supplement the Micronet with is currently deployed in this region. Also, a concentration of sensors will be located in the northwestern portion of the watershed in the winter wheat fields.

The exact locations of these sensor packages will not be determined until just before the CLASIC IOP.

There is no regular ground sampling schedule for soil moisture in the Forest Site or Central Facility super sites, however, at least once during the experiment, some soil moisture sampling will be conducted in coordination with the mini-station deployment to verify the accuracy and representativeness of the installations.

6.5 Vadose Zone Characterization and Monitoring During CLASIC

This project will be conducted by teams from Texas A&M (Binayak Mohanty, Raghavendra Jana, Champa Joshi, Dipankar Dwivedi, Susi Chairani), the USDA-ARS National Soil Erosion Lab (Gary Heathman, Scott McAfee, Myriam Larose), and the USDA-ARS Hydrology and Remote Sensing Lab.

The vadose zone (between the land surface and ground water table) lies in the heart of soil moisture and land-atmosphere interaction studies. Partially-saturated water flow (infiltration and evaporation) through the vadose zone dictates the dynamics of soil moisture as well as the related biogeochemical process status in the biosphere across different space and time scales. Proper characterization and up/downscaling of the water retention, hydraulic conductivity, and thermal properties of soil as well as the monitoring of profile water content and soil water pressure head across the vadose zone are critical for better hydrologic process understanding and accurate soil-vegetation-atmosphere-transfer modeling to close the water and energy budget at different scales.

During CLASIC field campaign, we propose to study the dominant control mechanisms for soil moisture variability and resultant vadose zone fluxes at different space-time scales in Oklahoma. Our hypotheses includes: 1) soil moisture variability is dominated by soil properties at the field scale, topographic features at the catchment/watershed scale, and vegetation characteristics and precipitation patterns at the regional scale and beyond, and 2) ensemble hydrologic fluxes (evapotranspiration (ET), infiltration (I), and shallow ground water recharge (GWR)) across the vadose zone at the corresponding scale can be effectively represented by one or more scale factors relating soil, topography, vegetation, or climate. Our work fits to the CLASIC goal of *improving model parameterizations for land surface and atmosphere interactions.*

While our past field and numerical studies showed the significance of variations in soil hydraulic properties on soil moisture dynamics and hydrologic fluxes across the land-atmosphere boundary, in CLASIC campaign we will design experiments to focus on the physical controls including topography, vegetation, and agricultural management (irrigated/non-irrigated; tilled/no-tilled). Topography is one of the control factors that play an important role in the evolution of effective hydrologic parameters at landscape to watershed scales. Inclusion of the effect of topography into up/downscaling schemes would greatly enhance the accuracy of the up/downscaled soil hydraulic parameters. This in turn would ensure better accuracy in the predictions of hydrologic fluxes in the land surface and vadose zone models. Two complementary studies are designed to address vadose zone characterization, fluxes, and scale issues during the CLASIC field campaign.

6.5.1 Study I

As part of the CLASIC 2007 remote sensing campaign in Oklahoma, we propose to measure the variation in soil hydraulic parameters in topographically complex terrain. Coupled with the CLASIC airborne and satellite-based measurements, along with other proposed studies during the same time, this study will provide base-line data for developing and validating soil moisture and soil hydraulic parameter upscaling schemes.

The relationship between soil moisture and topography, and the effect of fine scale variation in topography on soil hydraulic parameters at the field scale as well as watershed scale will be studied. Data from this sampling project will be used to derive relationships between topographic attributes (such as slope, relative elevation, flow contributing area) and soil hydraulic parameters. These relationships will subsequently be used in developing scaling algorithms at the hill-slope, landscape, to watershed scale. Also, the new data will be used jointly with the data sets from the previous field campaigns (SGP97, SGP99, SMEX03) in the same region to analyze the time stability features of the soil moisture and other soil properties over time.

Field Measurements

Nested sampling design (across hill slope, field, to watershed) will be adopted. Intensive soil moisture measurements (during a 3-hour window in the afternoon) will be made in two extreme field locations within the Little Washita river watershed (LWRW). One location will represent topographically complex terrain, while the other will represent relatively uniform flat terrain. Based on available information from previous studies in the Little Washita watershed (SGP97, SGP99, SMEX03), we propose LW13 and LW21 as the two study sites. Figure 34 shows the location of the two sites within the Little Washita watershed and Figure 35 shows the detail soil, vegetation, and topographic attributes of the two fields. LW13 has complex topography while LW21 is relatively flat.

The dominant soil type in both the fields is silt loam. These two field sites are selected for vadose zone characterization to supplement the complementary studies including flux towers measurements to obtain auxiliary data.

Theta probes will be used to measure soil moisture every 20 meters (three replicates each) along three transects at LW13, with finer spacings on steeper slopes. Two transects will be used across the DEM contours at the field site, and the third transect will be parallel to a contour. This will allow for evaluation of topographic and non-topographic influences on soil moisture. A schematic of the sampling transects is shown in Figure 34. In the flat LW21 field, soil moisture measurements will be made at 20 meter intervals along two perpendicular transects.

In addition to soil moisture measurements, near-surface soil cores will be extracted at approximately 40 points matching the soil moisture measurement sites within the two fields. These cores will be used to conduct lab experiments for measuring soil hydraulic conductivity, water retention and texture analyses (Figure 36). Besides the two fields, we will collect replicated soil moisture and few soil core samples in 2-3 other fields across the watershed to capture any gradient across LW21 (upstream) to LW13 (downstream) sides of the Little Washita watershed (Figure 34).

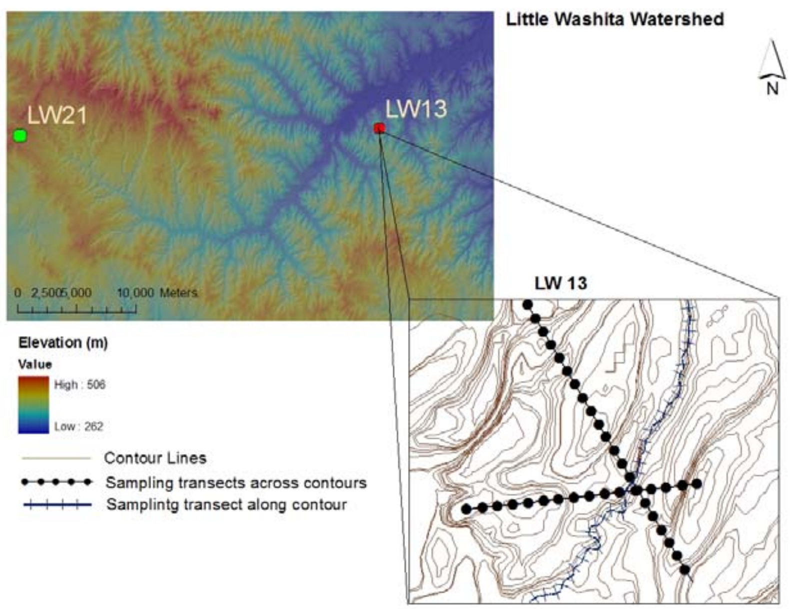


Figure 34. Little Washita Watershed and selected topographically flat (LW21) and complex (LW13) fields for vadose zone characterization and soil moisture physical control studies.

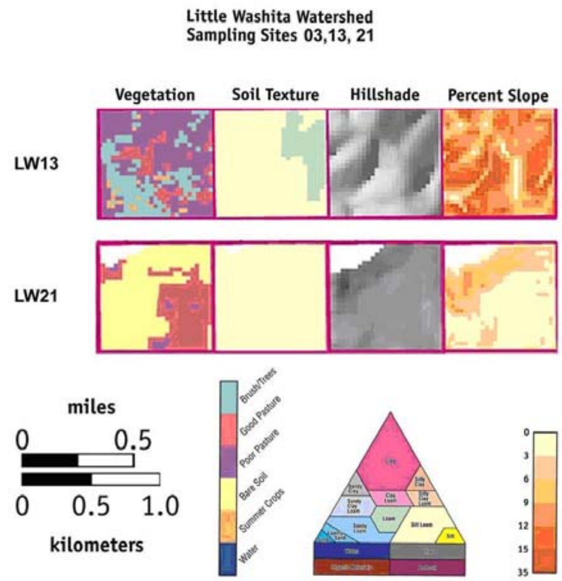


Figure 35. Physical attributes of selected field sites (LW13 and LW21) for the vadose zone characterization and soil moisture physical control studies.

Figure 36. Example of experimental setup for water retention curves from soil cores using Tempe cells.

6.5.2 Study II

The status of profile soil water content and pressure head in the root zone are key parameters for estimating vadose zone fluxes. As an extension of Study I, the aim of Study II is to improve model parameterization for estimating vadose zone fluxes and evapotranspiration (ET) using hydrologic modeling with data assimilation of surface soil moisture from point to field scale under different management practices, soil types, and vegetative covers. The study will involve the use of TDR probes to obtain profile soil moisture in 15cm intervals to a depth of 60cm and tensiometers to measure pressure head at 15, 30 and 60cm across various fields within the CLASIC study watersheds.

The approach will integrate data assimilation, scaling theory, pedotransfer functions, remote sensing of surface soil moisture, and modeling vadose zone soil moisture dynamics and ET with the USDA-ARS Root Zone Water Quality Model (RZWQM), and Texas A&M University Soil Moisture Assessment Tool (SMAT). This effort will help address, in part, CLASIC 2007 science question #5 and objective #1. The specific objectives of Study II are:

1. Determine rank stable sites for surface (0-5cm) and profile soil moisture (0-60cm) in two fields within the Little Washita River Watershed (LWRW) and two fields within the Upper Washita River Watershed (UWRW) under different land management practices and for various soil types.
2. Determine the correlation between soil surface and soil profile rank stability soil moisture analysis. Are the rank stable sites (RSS) determined in each field for surface and profile soil moisture the same?
3. Determine the correlation between the RSS for surface soil moisture in each field with remotely sensed soil moisture pixel values during the study period and evaluate the use of the RSS for sensor calibration/validation and model data assimilation input.
4. Determine the practical application of using data assimilation of remotely sensed surface soil moisture with the EnKF technique for estimating the spatial mean profile soil moisture at the 800 m X 800 m pixel scale in layered soils using the RZWQM and SMAT.
5. Determine the vadose zone fluxes using the data assimilation tools at the land surface and ground water boundaries (i.e., I, ET, GWR) for the selected (monitored) fields and develop scaling schemes for extrapolating the fluxes to larger land areas.

Field Measurements

Upper Washita and Little Washita River Watersheds

TDR probes will be installed and co-located with CLASIC 2007 surface soil moisture sampling points (8) in 800 m x 800 m fields, including one irrigated and one non-irrigated agricultural field in the UWRW, and one winter wheat field (LW21) and one rangeland field (LW13) in the LWRW totaling 32 TDR profile sampling sites. In each field two locations will be selected to install tensiometers at 15, 30 and 60 cm depths. Data will be collected on a daily time scale concurrent with CLASIC soil moisture sampling times.

As conditions and time permits, additional soil profile samples will be collected for TDR calibration and for texture and bulk density determinations. At representative sites within each field, soil cores will be obtained across root zone profiles to match TDR and tensiometric measurements for soil hydraulic property measurements.

7. Soil and Surface Temperature

The objectives of the soil and surface temperature are nearly identical to those of soil moisture. There are a few differences related to the spatial and temporal variability of temperature versus soil moisture. Typically the soil temperature exhibits lower spatial variability, especially at depth. On the other hand surface temperature can change rapidly with changes in radiation associated with clouds. In addition, it can be difficult to correctly characterize surface temperature at satellite footprint scales (30 m – 1 km) using high resolution ground instruments. This is especially true when there is partial canopy cover.

7.1. Watershed Sampling

Temperature sampling will be conducted at the two locations selected for gravimetic sampling. These will be distributed over the site. The soil temperatures will be obtained using a temperature probe inserted to depths of 1 cm, 5 cm, and 10 cm depths at th ¼ row position. The surface temperature will be sampled using handheld infrared thermometers (IRT) at the two gravimetric locations. At each of these locations surface temperature of exposed and shadow ground and vegetation will be measured. Details about the location of these measurements are provided in the protocol section of the plan.

7.2. Micronet Sampling

The Stevens Water Hydra Probe provides soil temperature at 5 cm. In addition to the in-situ observations, soil temperature observations will be made couple of times during the experiment to calibrate the in-situ sensors. The soil temperatures will be obtained using a temperature probe inserted to depths of 1 cm, 5 cm, and 10 cm depths. The surface temperature will be sampled using handheld infrared thermometers (IRT) coincident with any Infrared sensors that are a part of the Micronet. At each of these locations surface temperature of exposed and shadow ground and vegetation will be measured. Details about the location of these measurements are provided in the protocol section of the plan.

7.3. Tower Sampling

The Hydra Probe provides soil temperature at 5 cm. An Apogee infrared sensor will be installed on each tower and will provide surface observations. This device provides the measured surface temperature and the sensor housing temperature. This second observation can be used to adjust for diurnal effects. These will be installed at a height of 2 m on the tower at an angle of 30 degrees. More information can be found in the protocols section of the plan.

8. Vegetation and Land Cover

Vegetation biomass and soil moisture sampling will be performed for all watershed sites. The primary measurements during CLASIC from the Vegetation Sampling Team are: 1) plant density, 2) Leaf Area Index (LAI), 3) stem water content per plant, 4) foliage water content per plant, and 5) leaf Equivalent Water Thickness (leaf EWT). Vegetated fields will be sampled during week 1 (June 9-16) and resampled during week 3 (June 22-June 29) of CLASIC. The Vegetation Sampling Team will also make other important measurements at cropped sites such as 6) plant height, 7) plant cover, 8) digital photographs, and 9) number of leaves per plant (for determination of plant growth stage. In addition, multispectral observations will be made with a Cropscan instrument, described in the protocol sections.

Sampling will take place in two segments each day. In the morning, a group of three people will go to one to three sites and make measurements, return and process the samples at the work area. In the afternoon, one or two more sites will be visited by the team with an additional team deployed to characterize the surface roughness of each of the watershed sites. Some of the Vegetation Sampling Team will need to make leaf reflectance measurements in the afternoon. Each site will have 3 plots, two coincident with the GSM sampling points and the other a VSM sampling point.

Land cover maps of the watershed and region will be developed using procedures described in Doriaswamy et al. (2004). This will require the acquisition of several satellite images. In addition, a detailed survey of the low altitude mapping will be performed that includes the crop row direction where applicable.

8.1. Surface Roughness

Each Watershed site will be characterized one time during the time frame. The grid board photography method employed in previous experiments will be used. A total of three locations will be selected in a field, including two gravimetric sampling points. Between two and four pictures will be taken at each location to insure data capture and one pair of images will be processed for xy directions.

8.2. Crop Residue Cover and Soil Tillage Intensity Mapping

Plant litter or crop residues on the soil surface play significant roles in the surface energy balance, net primary productivity, nutrient cycling, and carbon sequestration. Tillage reduces crop residue cover, alters surface energy fluxes, and accelerates soil erosion by increasing the soil exposure to wind and rain. As a result, accurate assessments of surface energy balance in agricultural regions must account for the spatial and temporal changes in crop residue cover.

The standard technique used by the USDA Natural Resources Conservation Service (NRCS) for measuring crop residue cover in individual fields is visual estimation along a line-transect. This technique is time-consuming and prone to operator bias. Rapid and accurate methods are needed for objectively monitoring crop residue cover or tillage intensity over broad areas.

Remote sensing could provide an efficient and objective method of obtaining information about crop residue cover and tillage intensity over large areas. Numerous spectral indices exploit the characteristic shape of the green vegetation spectrum by combining the low reflectance of the visible with the high reflectance of the near infrared to identify and quantify green vegetation. However, because crop residues lack the unique spectral signature of green vegetation in the 400 nm to 1200 nm wavelength region, discrimination between crop residues and soils is difficult using spectral vegetation indices (Streck et al., 2002).

Alternative approaches for discriminating plant litter from soils are based on three broad absorption bands near 1730 nm, 2100 nm, and 2300 nm that are primarily associated with nitrogen, cellulose, and lignin, respectively (Elvidge, 1990). The strong absorption at 2100 nm appeared in all compounds possessing alcoholic -OH groups, such as sugars, starch, and cellulose (Murray and Williams, 1988), and was clearly evident in the reflectance spectra of the dry crop residues (Daughtry, 2001). The cellulose absorption index (CAI), which is an adaptation of the continuum-removal method (Kokaly and Clark, 1999), quantifies the relative intensity of this absorption feature and is linearly related to crop residue cover in laboratory, field, and regional studies (Daughtry et al., 2004; 2006).

Our objectives are 1) to evaluate several spectral indices for estimating crop residue cover using MAS and Hyperion imagery and 2) to classify soil tillage intensity in agricultural fields based on spectral measures of crop residue cover. Crop residue cover images will be compared to ground measurements of residue cover in selected fields. We will provide maps of crop residue cover and soil tillage intensity for the Fort Cobb and Little Washita sites.

We are requesting that for this crop residue cover mapping experiment that shortwave (400-2400 nm) and thermal MAS imagery be processed atmospherically corrected, georegistered, and mosaicked to a final form prior to delivery. If this is not possible, it will be necessary to seek additional support and will delay the analyses.

8.3. Sun Photometer

The NASA Aeronet, which is led by Brent Holben, will provide CLASIC with an eight channel (Cimel) sun photometer. The sun photometer is designed to view the sun and sky at preprogrammed intervals for the retrieval of aerosol optical thickness and water vapor amounts, particle size distribution, aerosol scattering, phase function, and single scattering albedo. It measures the intensity of sunlight arriving directly from the Sun. Although some Sun photometers respond to a wide range of colors or wavelengths of sunlight, most include special filters that admit only a very narrow band of wavelengths. These measurements are used to radiometrically correct satellite imagery in the visible and infrared bands. By radiometrically correcting these images it is then possible to quantitatively extract physical parameters and compare multiple dates. The instrument will be installed at a central location to provide data appropriate for the intensive site and for the regional area studies. During CLASIC, a sun photometer will be stationed at the LW Chickasha Headquarters at approximately N35.044 W97.914.

8.4. Cloud Absorption Radiometer (CAR) Measurements for CLASIC

Another aircraft participating in CLASIC that carries an instrument pertinent to the land studies is the Jetstream-31. Onboard this aircraft the NASA Cloud Absorption Radiometer (CAR) will be used to acquire multiangular and multispectral observations suitable for satellite validation. Flights will be designed to cover three super sites located in the US Department of Energy Southern Great Plains (Central Facility, Little Washita and Forest site) in Oklahoma. These measurements will help to improve model parameterization of land surface reflectance and address up-scaling needs for comparison with satellite measurements.

The CAR is an airborne multi-wavelength scanning radiometer that can perform several functions including: determining the single scattering albedo of clouds at selected wavelengths in the visible and near-infrared; measuring the angular distribution of scattered radiation; measuring bidirectional reflectance of various surface types; and acquiring imagery of cloud and Earth surface features. The instantaneous field of view is 1° and 382 pixels are sampled over 190°. It spatially scans in a plane orthogonal to the flight vector from the zenith to nadir at 1.7 revolutions per second fourteen spectral channels between 0.3 and 2.3 microns are sampled. The Cloud Absorption Radiometer (King et al. 1986) has been used in the past to acquire BRDF measurements of the ocean, sea ice, snow, tundra, savanna (cerrado, mopane, miombo), smoke, vegetation, desert (Saudi Arabia, salt pans in Botswana and Namibia), and clouds.

Figure 37 shows the Jetstream-31 (J-31; N22746 registered to Sky Research Inc.) in Veracruz, Mexico with radiation sensors that were used during the Intercontinental Chemical Transport Experiment: Ames Airborne Tracking Sunphotometer (AATS), CAR, Solar Spectral Flux Radiometer (SSFR), and Research Scanning Polarimeter (RSP), not shown, but located on the bottom tail end of the aircraft.

Figure 38 shows a typical flight pattern whereby the aircraft, with the CAR in the nose cone, flies a clockwise circular pattern above the surface or cloud repeatedly, drifting with the wind, and scans the underlying surface and much of the transmitted solar radiation from above, and makes radiometric observations about every 1° in azimuth and better than 1° in zenith angle with an instantaneous field-of-view of 1°. Often, multiple circular orbits are averaged together to smooth out the reflected solar radiation signal. From an altitude of 200 m above ground the CAR has a spatial resolution of 4 m at nadir.

Figure 37. The J-31 Configuration during a past experiment

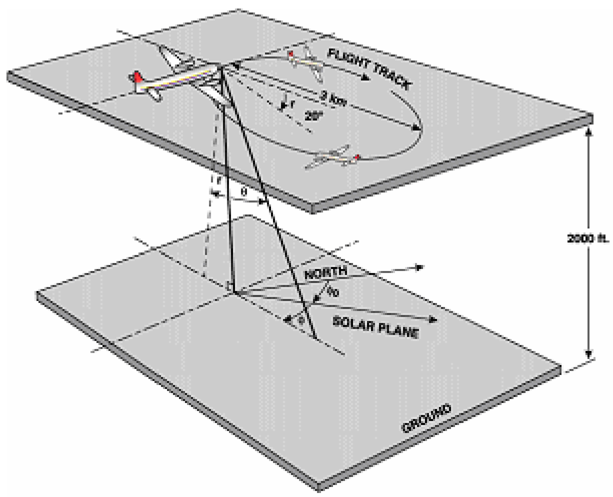


Figure 38. CAR BRDF flight track

Figure 39 shows selected examples of the bidirectional reflectance observed over selected terrestrial surfaces, including Namibian stratus with a rainbow and glory, the Etosha Pan, Namibia, and savanna vegetation at Skukuza, South Africa (Gatebe et al. 2003), and ocean reflectance with sunglint off the Virginia coast in the western Atlantic (Gatebe et al. 2005). Similar results are expected for the upcoming CLASIC.

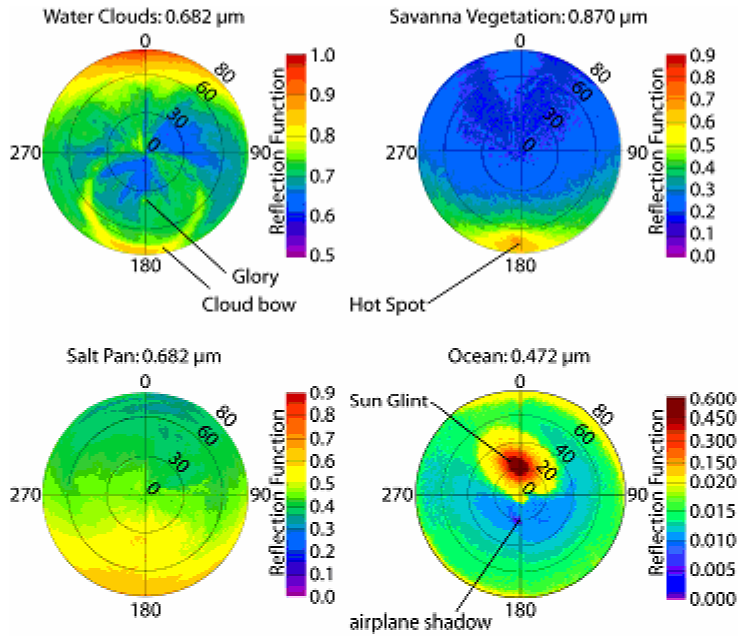


Figure 39. CAR BRDF of various natural surfaces

9. Logistics

9.1. Security/Access to Fields

Do not enter any field that you do not have permission to enter. If questioned, politely identify yourself and explain that you are with the USDA/NASA experiment. Flyers will be available that provide a general overview of the experiment. In case of any trouble, leave the field and contact your CLASIC supervisor. At the time of sampling, if the farmer is working in the field, DO NOT sample and contact your CLASIC supervisor. Prior to the experiment all requests for field access are to be directed to Mike Cosh (Micahel.Cosh@ars.usda.gov). Do not assume that you can use a field without permission. Requests for installations and unplanned sampling made during the experiment will not be easy to satisfy. Tracking down a landowner and getting permission can take up to a half-day of time by our most valuable people. These people will be extremely busy during the experiment. Therefore, if you think you will have specific needs that have not been addressed, you did not spend enough time planning…so learn for the next time.

- Access to field headquarters: Open 8am until 4pm everyday. For periods of time during the day the lab may be unattended and locked. In this circumstance contact a CLASIC supervisor for entry.

9.2. Safety

General Field Safety

There are a number of potential hazards in doing field work. The following page has some good suggestions. Common sense can avoid most problems. Remember to:

- When possible, work in teams of two
- Carry a phone
- Know where you are. All roads have street signs. Make a note of your closest intersection.
- Do not touch or approach any unidentified objects in the field. Notify your CLASIC supervisor after returning to the field headquarters
- Dress correctly; long pants, long sleeves, boots, hat
- Contact with corn leaves can cause a skin irritation
- Use sunscreen.
- Protective eyewear is strongly encouraged because corn leaves can be very sharp on their edges and can be hazardous to your eyes.
- Carry plenty of water for hydration.
- Notify your teammate and supervisors of any preexisting conditions or allergies before going into the field.

Lynn McKee, CLASIC Safety Officer, 202-679-3654

Beltsville Area

SAFETY NEWS RELEASE

WE WANT YOU TO KNOW

Release 00-01

SUMMERTIME SAFETY FOR OUTSIDE WORKERS

PREVENTING HEAT-RELATED ILLNESS

When your body is unable to keep itself cool, illnesses such as "heat exhaustion" and "heatstroke" can occur. As the air temperature rises, your body stays cool when your sweat evaporates. When sweating is not enough to cool your body, your body temperature rises, that is when you may become ill with a heat-related illness.

Tips to stay cool:

1. Supervisors should encourage workers to drink plenty of water (approximately one cup of cool water every 15-20 minutes). Avoid caffeinated drinks such as coffee and tea which can contribute to dehydration.

2. Supervisors should encourage workers to wear light-colored, lightweight, loose-fitting clothing. Workers should change if their clothing becomes completely saturated.

3. Supervisors should have employees alternate work and rest periods, with longer rest periods in a cooler area. Shorter, but frequent, work-rest cycles are best. Schedule heavy work for cooler parts of the day and use appropriate protective clothing.

4. Supervisors should consider an employee's physical condition when determining fitness to work in a hot environment. Obesity, lack of conditioning, pregnancy and inadequate rest can increase susceptibility to heat stress illnesses.

5. Supervisors and employees should learn to spot the symptoms of heat illnesses and what should be done to help:

    HEAT EXHAUSTION: The person will be sweating profusely, lightheaded, and suffer dizziness. Have the victim rest in a cool place and drink some fluids. The condition should clear in a few minutes.

    HEAT STROKE: This is a medical emergency. A Person may faint and become unconscious. Their skin will be dry and hot, possibly red in color. A person exhibiting these symptoms should be moved to a cool place, do **not** give the victim anything to drink, wet the persons skin with cool wet cloths, and CALL 911.

PREVENTING SUN-RELATED ILLNESSES

Exposure to ultraviolet radiation may lead to skin cancer. One million new cases of skin cancer are diagnosed each year. Cumulative sun exposure is a major factor in the development of skin cancer. The back of the neck, ears, face and eyes are sensitive to sun exposure. Luckily these and other body parts can be easily protected by wearing proper clothing, sunscreen, or sunglasses. By taking precautions and avoiding the sun's most damaging rays, you may be able to reduce your risk.

Tips to prevent sun exposure:

1. Avoid the sun at midday, between the hours of 10:00 a.m. and 3:00 p.m., when the ultraviolet rays are the strongest. If possible, schedule outside work for early in the morning.

2. Protective apparel should be worn.
    HATS provide protection for the face and other parts of the head. When selecting a hat consider how much of your face, ears and neck will be shaded.
    SUNGLASSES protect your eyes from serious problems. Ultraviolet rays from the sun can lead to eye problems, such as cataracts. Make sure your sunglasses provide 100% UV protection. This rating should be on the label when purchasing new ones.
    CLOTHING will protect against the sun and minimize heat stress. For maximum benefit, lightweight, light-colored, long-sleeves, and long pants that are 100% cotton fiber is preferred to provide both comfort and protection.

3. Use Sunscreen: Any skin that may possibly be exposed should be protected by sunscreen. One million new cases of skin cancer are diagnosed each year. The American Academy of Dermatology recommends wearing sunscreen with an SPF of at least 15 every day, year-round. As an added benefit, Some sunscreens now come formulated with insect deterrents in them to prevent bites from insects such as mosquitoes, deer ticks, etc.

Released July 3, 2000

SAFETY NEWS RELEASE is published by the Beltsville Area Safety, Occupational Health and Environmental Staff. Comments or questions, please contact M. Winkler at winklerm@ba.ars.usda.gov.

Ticks

Ticks are flat, gray or brownish and about an eighth of an inch long. When they are filled with their victim's blood they can grow to be about a quarter of an inch around. If a tick bites you, you won't feel any pain. In fact you probably won't even know it until you find the tick clamped on tightly to your body. There may be some redness around the area, and in the case of a deer tick bite, the kind that carries Lyme Disease, a red "bulls-eye" may develop around the area. This pattern could spread over several inches of your body.

When you find a tick on you body, soak a cotton ball with alcohol and swab the tick. This will make it loosen its grip and fall off. Be patient, and don't try to pull the tick off. If you pull it off and it leaves its mouth-parts in you, you might develop an irritation around these remaining pieces of tick. You can also kill ticks on you by swabbing them with a drop of hot wax (ouch!) or fingernail polish. After you've removed the tick, wash the area with soap and water and swab it with an antiseptic such as iodine.

Ticks are very common outdoors during warm weather. When you are outdoors in fields and in the woods, wear long pants and boots. Also spray yourself before you go out with insect repellent containing DEET.

(Source: www.kidshealth.org/cgi-bin/print_hit_bold.pl/kid/games/tick.html?ticks#first_hit)

Drying Ovens

The temperature used for the soil drying ovens is 105°C. Touching the metal sample cans or the inside of the oven may result in burns. Use the safety gloves provided when placing cans in or removing cans from a hot oven. Vegetation drying is conducted at lower temperatures that pose no hazard.

Driving

- Observe speed limits and try to keep the dust minimal (slow down) around houses.
- Watch for loose gravel, sand, and farm animals
- Road intersections are often unsigned, use caution, and watch for cross traffic.
- Do not leave car unlocked (theft)
- Do not leave all windows sealed when car is unattended (heat buildup can break a window)

Lightning

- Lightning can be a deadly force, watch the skies for sudden cloud development.
- Do not leave your vehicle in a thunderstorm.

Tornados

- Be aware of the weather at all times, have a plan where to seek shelter in case of a tornado

- If a tornado approaches, do not get into the car but find the lowest spot on the ground and lay flat**.**
- For Tornado warnings, you will be in either Grady County (Western LW) or Caddo county (Eastern LW and FC). Comanche County is to the south.

Medical

For medical emergencies call 911 or go to:

Hospitals

In Chickasha: call 911 or go to:

Grady Memorial Hospital
2220 W Iowa Ave
Chickasha, OK 73018
(405) 224-2300

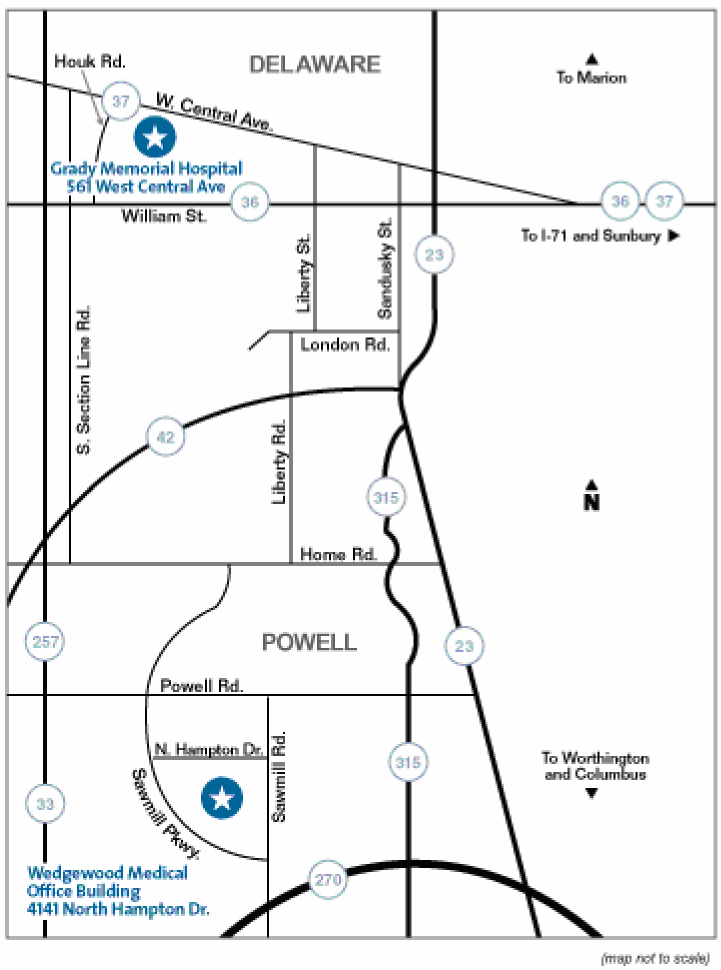


Figure 40. Chickasha's Grady Memorial Hospital

If you are near Fort Cobb Sampling Locations call 911 or go to:
Carnegie Hospital
102 N Broadway St,
Carnegie, OK
(580) 654-10501002

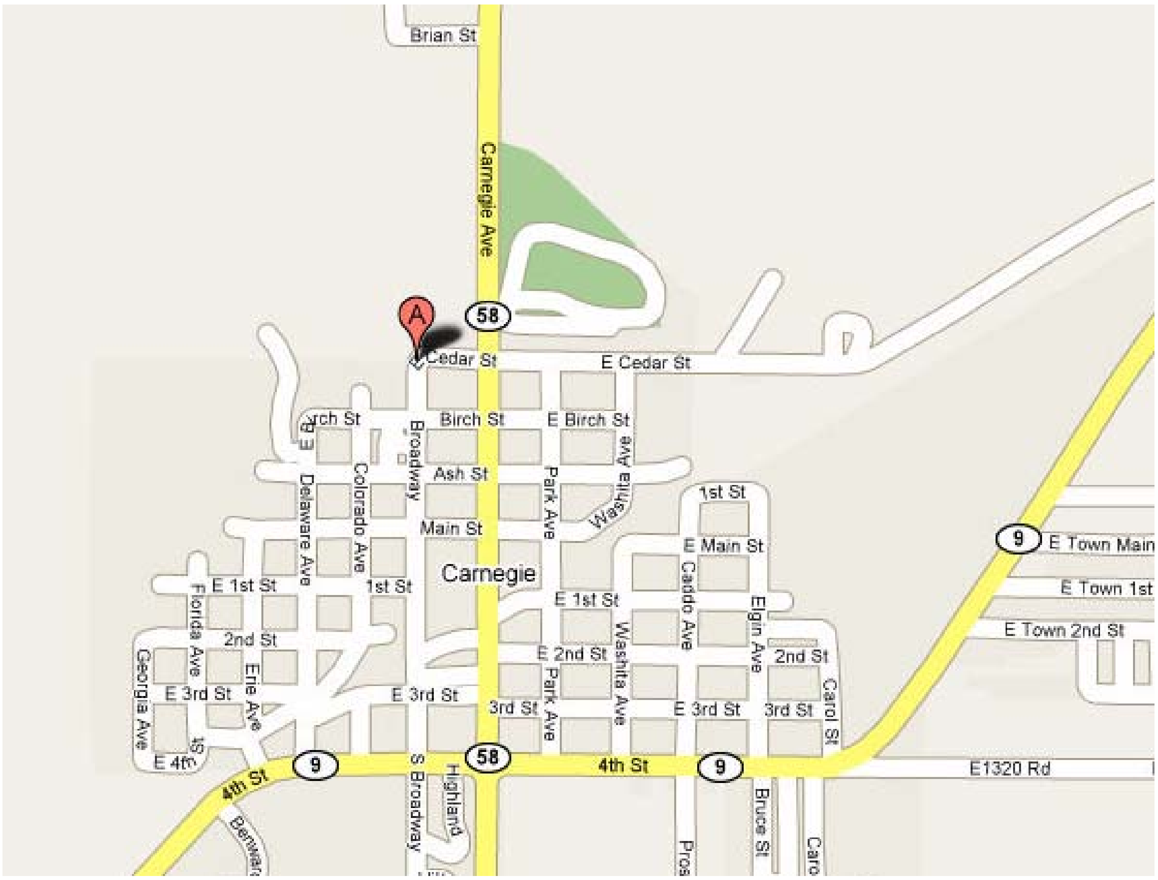


Figure 41. Carnegie Hospital

Another local Hospital is in Anadarko:
Physician's Hospital
E Central Blvd
Anadarko, OK 73005
(405) 247-2551

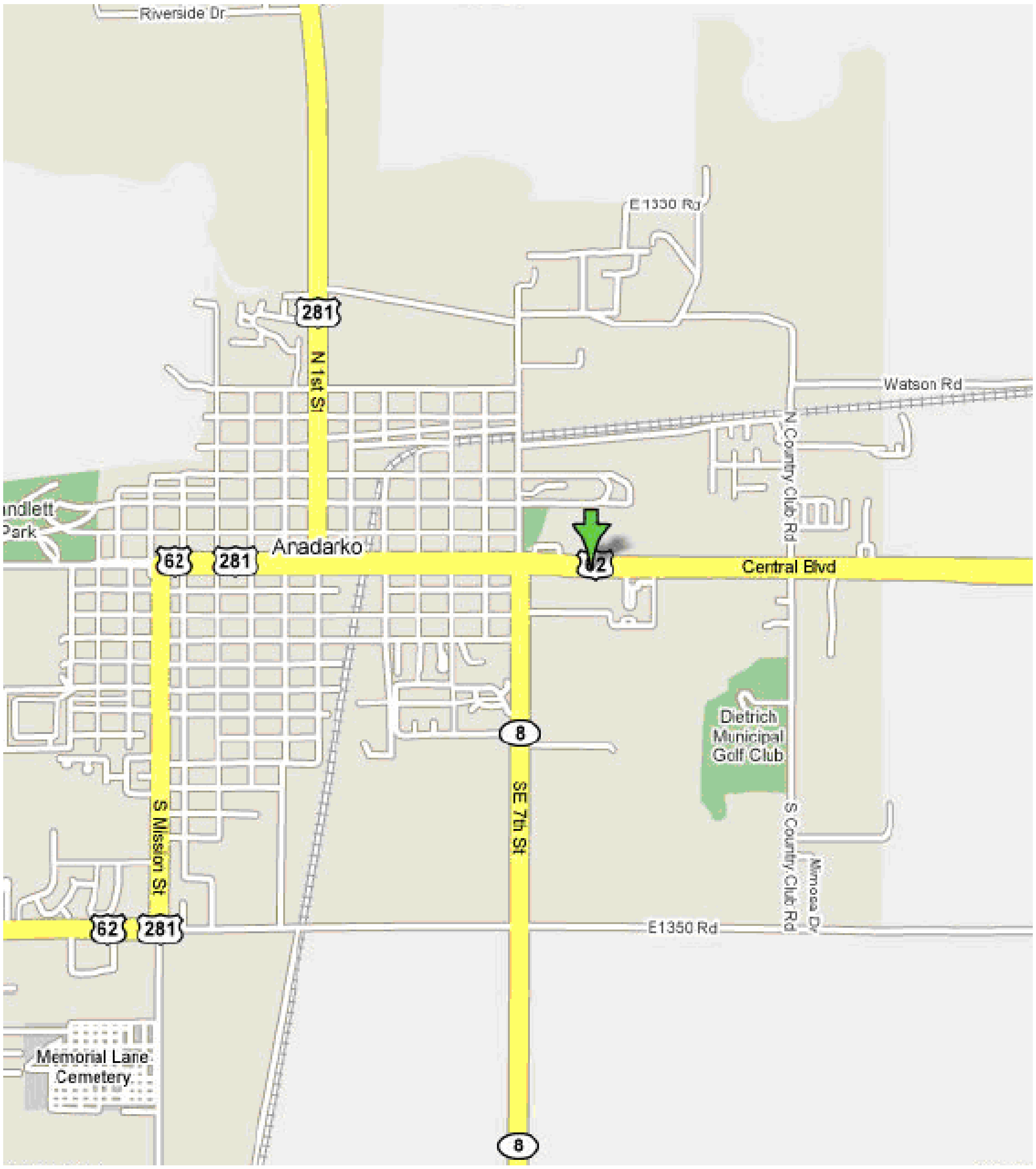


Figure 42. Anadarko's Physician's Hospital

Eye Safety: University of Iowa Elastic Lidar Systems

The following table contains nominal ocular hazard distances as a function of laser pulse energy for the Big Sky ND:YAG Laser.

		BIG SKY ND:YAG LASER						
		1.064 UM, 50HZ						
GIVEN VALUES								
	wavelength	lambda=	1.064	um				
	rep rate	f=	50	Hz				
	pulse width	w=	1.00E-08	sec				
	exposure time	T=	10	sec				
	divergence	phi=	3	mr				
	beam dia	a=	0.6	cm				
	atm atten coeff	mu=	0.00E+00	cm^-1	(1.14e-6 is typical for Los Alamos)			
	Max. Perm. Exp.	MPE=	5.00E-06	J/cm^2	for single pulse laser			
	max pulse energy	Q=	0.14	J				
	diffuse tgt reflectivity	rho=	1.00					
	diffuse viewing angle	thetav=	0.00	radians		0.384845		
		MPEskin=	0.10	J/cm^2		0.002353		
CALCULATED VALUES								
	MPE/pls	MPEpls=	1.06E-06	J/cm^2	for repetitive pulse laser			
	max radiant exposure	H0=	0.50	J/cm^2				
	Hazard Distance	Rnohd=	1,369	m				
		OD intrabeam=	6.09					
	Diffuse reflection NHZ	NHZdif=	2.05	m				
	rad. exp. diff. @1m	H0dif=	4.5E-06					
	diffuse OD @ 1m	ODdif=	0.62					
	energy		NOHD					
	mJ		meters					
	50		818					
	75		1,002					
	100		1,157					
	150		1,417					

This is the output of one of the commercially available programs for laser eye safety. The bottom of the chart is the nominal hazard distance for a given laser energy per pulse. Other considerations are;

- We normally operate at ~25 mJ per pulse energy, which puts the eyesafe distance well below 700 m.
- Both lidars look straight up. This is significant in that it is quite difficult to look straight down from an aircraft (it can be done, but you have to try; anything more than a quarter of a degree from vertical and you won't see it). So accidental viewing is unlikely.
- We have the capability to talk to aircraft via radio. During SMEX02, when we had a scanning lidar, the pilots that were concerned with this would call us on the radio when they were near and we would shut it down. Some provision would have to be made for what frequency we need to monitor.

Additional Information

William Eichinger, The University of Iowa
(319) 358-1053
william-eichinger@uiowa.edu

9.3. Hotels

If you will be participating in ground sampling in the Little Washita/Fort Cobb area of Oklahoma, the base of operations will be Chickasha, OK. This is located about 45 minutes southwest of Oklahoma City.

http://www.chickasha.org/

More logistics info will be provided later but for your planning, we anticipate the following:

Thursday June 7 – Arrive in Oklahoma
Friday June 8 at 8 am - All hands meeting for ground sampling in Chickasha
Saturday June 9 - First sampling day
Friday June 29 - Last sampling date for regular watershed sampling
Saturday June 30 – Departure date for Regular Samplers
Sunday July 1 – Select Little Washita Sampling for PALSAR overpass

The suggested motel is the Holiday Inn Express:

Holiday Inn Express Hotel & Suites
Chickasha
2610 South 4th Street
Chickasha, Ok 73018
Hotel Front Desk: 1-405-224-8883 Hotel Fax: 1-405-224-8884

Deluxe Continental Breakfast
http://www.ichotelsgroup.com/h/d/ex/1/en/hotel/CHKOK/welcome

There is a block of 20 rooms under the code "USDA" at the government rate of $60/night for a single or a double. You need to call the hotel directly to make reservations. If you have problems, talk to the hotel manager Sherry. Please make reservations by May 15th.

An alternative motel is Days Inn:

Days Inn
2701 S 4th Street
Chickasha, OK 73018
(405) 222-5800
Full breakfast
http://www.daysinn.com/DaysInn/control/Booking/property_info?propertyId=02341&brandInfo=DI&cid=%EAid!

There is a block of 8 rooms under the code "USDA" at government rate of $40.49/night singles & $44.99/night doubles. You need to call the hotel directly to make reservations. If you have problems, talk to the hotel manager Lila.

9.4. Directions and Maps

From Oklahoma City Airport to Chickasha

Turn right at S Meridian Ave 0.5 mi
Turn right at SW 54th St 0.6 mi
Continue on SW 59th St 0.5 mi
Turn right to merge onto I-44 W/OK-3 E/OK-74 S 0.6 mi
Take exit 1A for I-44 W/US-62 W toward Lawton 0.4 mi
Merge onto I-44 W (Partial toll road
Take exit 80 for US-81 toward Chickasha/Duncan 0.2 mi
Turn left at S. 4th street

Holiday Inn Express is on the Left.

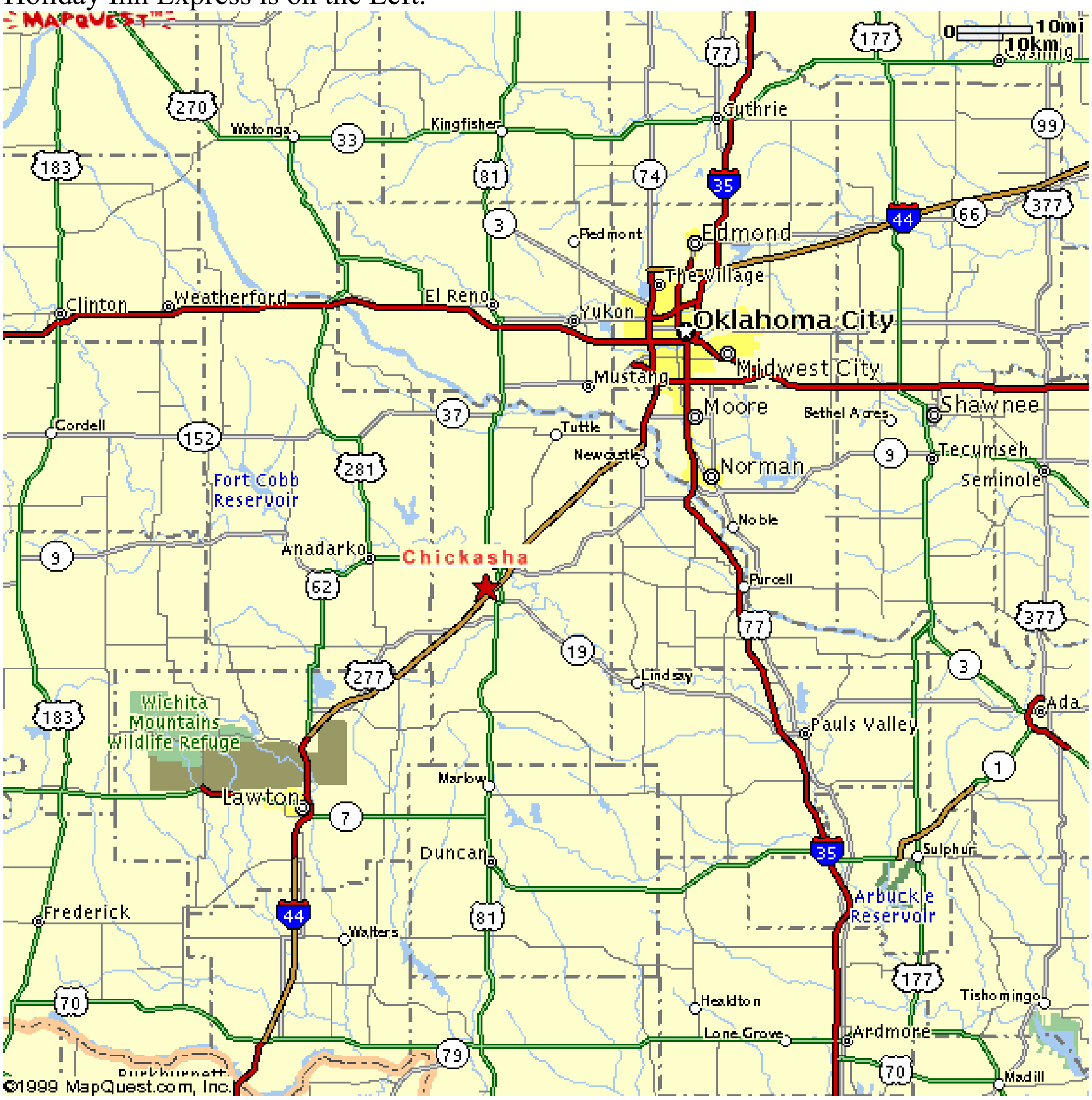


Figure 43 Southwestern Oklahoma Regional Map

Chickasha Field Headquarters

The location of the Field Headquarters for CLASIC is in an old ARS building currently owned by the Oklahoma State University on . To get there from the hotels, Take S. 4th St. North to W. Grand Ave. and turn right. Follow W. Grand Ave. Turn right onto Iowa St. and 1000' down on the right is the HQ.

Figure 44. CLASIC Field Headquarters

9.5. Local information

Several sites offer information about the southwestern Oklahoma region. Ones of note are:

www.chickacha.org

www.chickashachamber.com

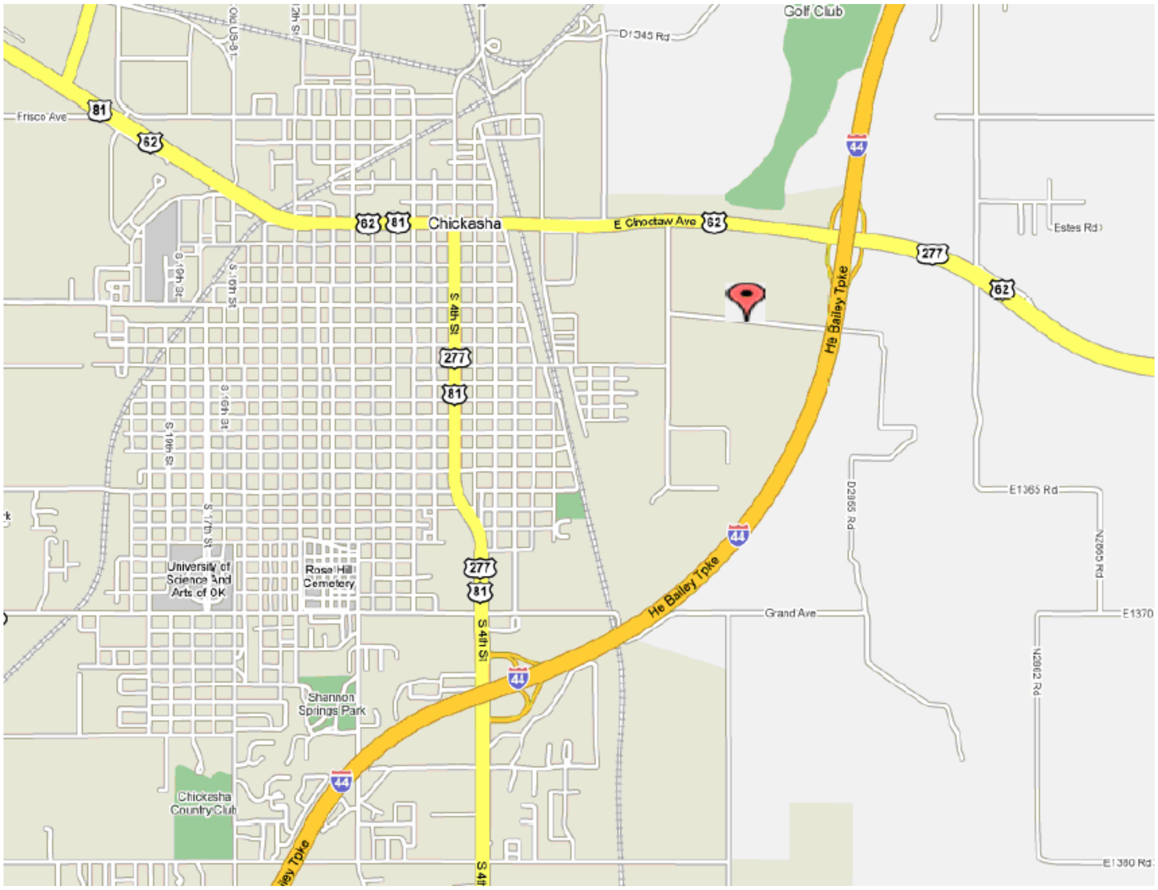


Figure 45. Chickasha CLASIC Field Headquarters

9.6. Local Contacts and Shipping

Pat Starks
USDA/Grazinglands Research Laboratory
7207 W. Cheyenne St.
El Reno, OK, 73036-0000
patrick.starks@ars.usda.gov
Phone: (405) 262-5291
Fax: (405) 262-0133

South Central Research Station
Attn: Don Hooper
1105 East Iowa St
Chickasha, OK 73018
405-224-4476
fax: 405-224-4478
alternative email: scrs_osu@sbcglobal.net

10. SAMPLING PROTOCOLS

10.1. General Guidance on Field Sampling

- Sampling is conducted **every day**. It is canceled by the group leader if it is raining, there are severe weather warnings or a logistic issue arises.
- **Know your pace**. This helps greatly in locating sample points and gives you something to do while walking.
- If anyone questions your presence, politely answer identifying yourself as a scientist working on a NASA/USDA soil moisture study with satellites. If you encounter any difficulties **just leave** and report the problem to the group leader.
- Although gravimetric and vegetation sampling are destructive, try to **minimize your impact** by filling holes. Leave nothing behind.
- Always sample or move through a field along the **row direction** to minimize impact on the canopy.
- Please be considerate of the landowners and our hosts. **Don't** block roads, gates, and driveways. Keep sites, labs and work areas clean of trash and dirt.
- Watch your **driving speed**, especially when entering towns. Be courteous on dirt and gravel roads, lower speed=less dust.
- Avoid parking in tall grass, catalytic converters can be a **fire hazard**.
- **Close any gate** you open as soon as you pass.
- Work in **teams of two. Carry a cell phone.**
- Be aware that increased security at government facilities may limit your access. **Do not assume that YOU are exempt.**

10.2. Watershed Site Surface Soil Moisture and Temperature

Soil moisture and temperature sampling of the watershed area sites is intended to estimate the site average and standard deviation. Watershed site sampling will take place between 8:30 am and 12:30 pm. It is assumed here that most of these sites will be quarter sections (800 m by 800 m), however, there will be a number of variations that may require adaptation of the protocol. The variables that will be measured or characterized are:

- 0-6 cm soil moisture using the Theta Probe (TP) instrument
- 0-6 cm gravimetric soil moistures using the scoop tool
- 0-6 cm soil bulk density (separate team)
- Surface temperature of exposed and in-shadow ground using a hand held infrared thermometer
- Surface temperature of exposed and in-shadow vegetation using a hand held infrared thermometer
- 1 cm soil temperature
- 5 cm soil temperature
- 10 cm soil temperature
- GPS locations of all sample point locations (one time)

Preparation

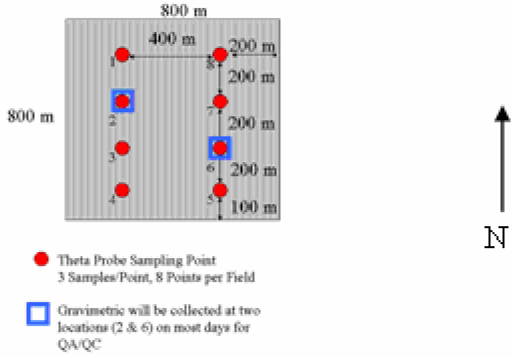
- Arrive at the field headquarters at assigned time. Check in with group leader and review notice board.
- Assemble sampling kit
    - Bucket
    - Theta Probe and data logger (use the same probe each day, it will have an ID)
    - Scoop tool
    - 8 cm spatula
    - 4 cm spatula
    - Notebook
    - Pens
    - Box of cans (see note below)
    - Soil thermometer
    - Handheld infrared thermometer
    - Extra batteries (9v, AA, AAA)
    - Screwdriver
    - First aid kit (per car)
    - Phone (if you have one)
- For the LW/FC sites, each team should take one box of 8 cans.
- Verify that your TP, data logger, infrared instrument, and soil thermometer are working.
- Check weather
- The first time you sample, it will help to use marking tape/spray paint to mark your transect rows and sample point locations. Use only marking tape/spray paint to mark your sites
- All sample points should be located with a GPS once during the experiment. Points will be referenced by Site "LW##" and Point "##".
- Use a new **notebook** page each day. Figure 46 is an example of what your notebook page should look like. Take the time to draw a good map and be legible. These notebooks belong to the experiment, if you want your own copy make a photocopy.

CLASIC Notebook Template

Site: LW01 Date: 6/14/07

Start Time: 9:30 am Stop Time: 10:15 amm

Team: Cleavon Little, Jack McCracken



Field Notes: Conditions were wet today with several puddles visible in the immediate area. Thunderstorms rolled through yesterday.

Site	IRT				Temp Probe			Theta Probe			Can
LW01	A	B	C	D	1	5	10	A	B	C	0-6
1								10.4	17.9	14.3	
2	20	21	23	21	23	23	20	10.3	8.4	13.3	A01
3								20.3	23.1	24.5	
4								13.5	13.7	13.9	
5								14.8	12.9	17.0	
6	31	23	31	23	40	39	36	16.4	18.2	8.4	A02
7								5.5	6.5	8.0	
8								4.7	3.9	4.1	

Figure 46. Notebook Sample template for CLASIC ARS Notebook

Procedure

- Upon arrival at a site, note site id (LW##), your name(s) and time in notebook. Draw a schematic of the field (It might be a good idea to do this before you go out for the day). Indicate the TP ID you are using.
- Assemble 4 sequential cans and indicate on schematic where they will be used.
- **Use cans sequentially**.
- From a reference point for the site (usually a corner), measure 200 m along one side to locate the first transect.
    - Transects should be parallel with the row direction.
    - If possible, select a row that is a tractor row to walk in.
    - IF THERE IS A FLUX TOWER OR MINI-STATION, co-locate a gravimetric site there.
- From this location initiate a sampling transect across the site. Take the first sample at 100 m and repeat every 200 m until you are 100 m from the edge of the site. For a standard quarter section site this will result in 4 samples along the transect.
    - Sample in the row adjacent to the row you are working in, it is suggested that this be the row to your right.
    - At all points collect three TP samples across the row as suggested in Figure 48. **See the Theta Probe protocol for how to use the instrument and data logger.**

- o At points labeled gravimetric in Figure 47 (two per site) collect
    - One gravimetric soil moisture sample for 0-6 cm following the procedures described using the scoop, enter can numbers on diagram in book **(See Gravimetric Sampling with the Scoop Tool protocol)**
    - One soil temperature (Degrees C) for 1 cm, 5 cm and 10 cm using the probe, enter values in book **(See Temperature Sampling protocol)**
    - Four surface thermal infrared temperatures (Degrees C) using infrared thermometer, enter value in book **(See Temperature Sampling protocol)**

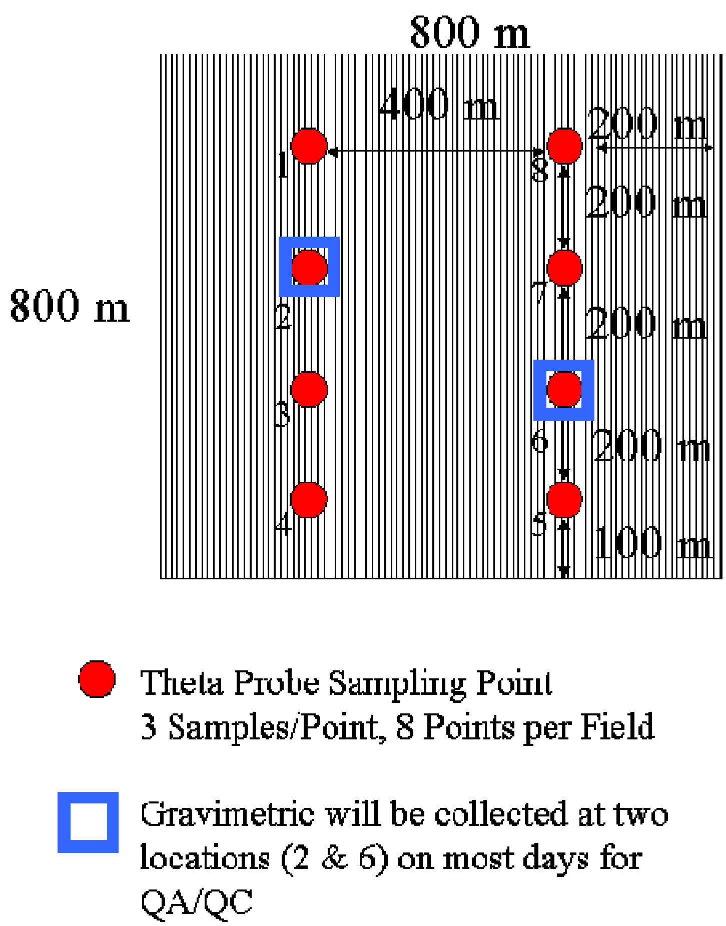


Figure 47. Schematic of layout of samples in a watershed site.

- After completing this transect move 400 m perpendicular into the site and initiate a new transect. This will result in a total of 8 sampling points.
    - o Exit the field before attempting to move to the second transect.
- As you move along the transect note any anomalous conditions on the schematic in your notebook, i.e. standing water.
- Record your stop time and place cans in box. Try to keep them cool.

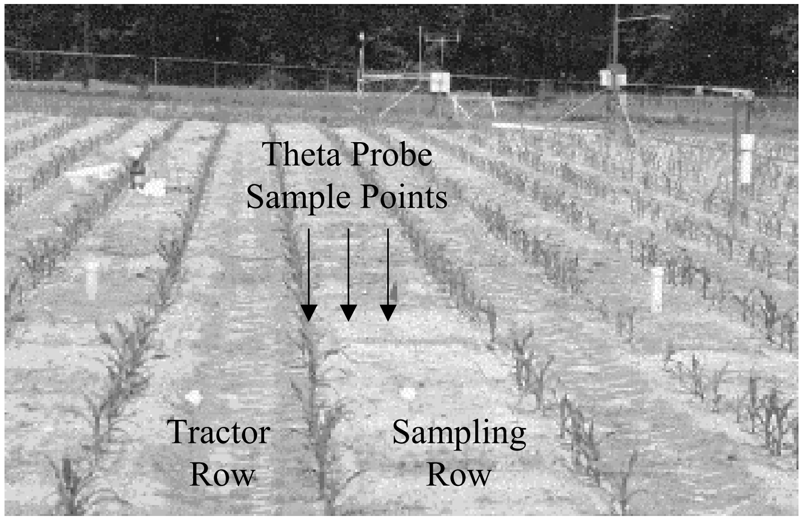


Figure 48. Schematic of layout of Theta Probe sample points.

Sample Data Processing

- Return to the field headquarters immediately upon finishing sampling.
- For each site, weigh the gravimetric samples and record on the data sheets (Figure 49) that will be provided. Use a single data sheet for all your samples for that day and record cans sequentially.
- Transfer temperature and other requested data to data sheets (same sheet used for GSM).
- Place cans in (in box) “TO OVENS” area and data sheet in collection box.
- Turn in your TP and data logger to the person in charge. They will be responsible for downloading data.
- Clean your other equipment.

CLASIC
Gravimetric Soil Moisture Sampling

Dates: __________ Team: __________

Time: __________ Observers: __________

Site ID	Local Sample Time	IRT in C				Soil Temp in C			Theta Probe (%)			0-6 cm		
		A	B	C	D	1 cm	5 cm	10 cm	A	B (GSM Site)	C	Can ID	Wet Wgt	Dry Wgt

Figure 49. Example of Lab Data Sheet

10.3. Theta Probe Soil Moisture Sampling and Processing

There are two types of TP configurations; Type 1 (Rod) (Figure 50) and Type 2 (Handheld) (Figure 51). They are identical except that Type 1 is permanently attached to the extension rod.

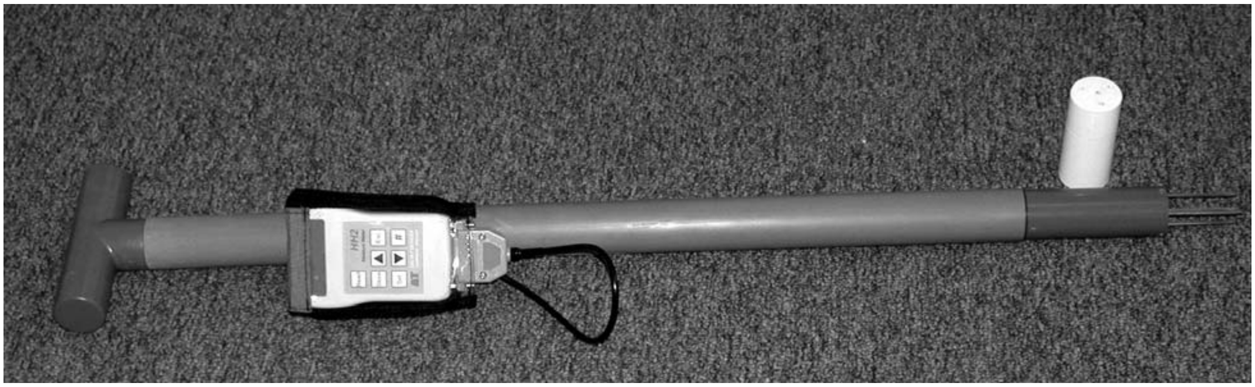


Figure 50. Theta Probe Type 1 (with extension rod).

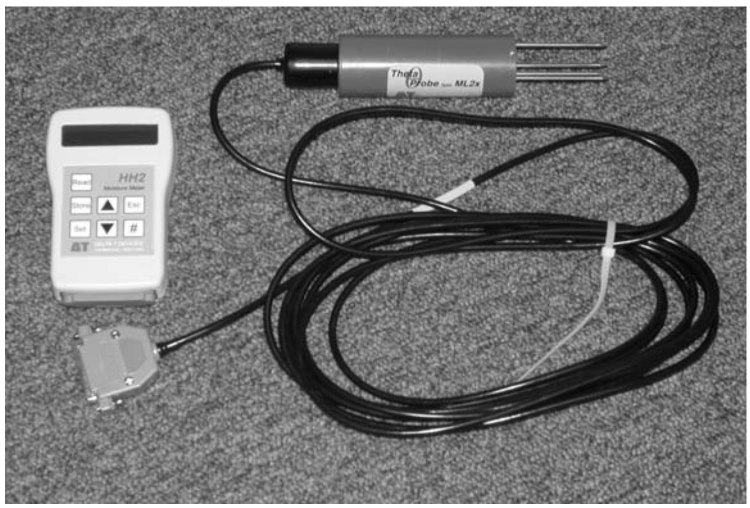


Figure 51. Theta Probe Type 2.

TPs consist of a waterproof housing which contains the electronics, and, attached to it at one end, four sharpened stainless steel rods that are inserted into the soil. The probe generates a 100 MHz sinusoidal signal, which is applied to a specially designed internal transmission line that extends into the soil by means of the array of four rods. The impedance of this array varies with the impedance of the soil, which has two components - the apparent dielectric constant and the ionic conductivity. Because the dielectric of water (~81) is very much higher than soil (typically 3 to 5) and air (1), the dielectric constant of soil is determined primarily by its water content. The output signal is 0 to1V DC for a range of soil dielectric constant, ε, between 1 and 32, which corresponds to approximately 0.5 m^3 m^{-3} volumetric soil moisture content for mineral soils. More details on the probe are provided in the sampling protocol section of the plan.

Each unit consists of the probe (ML2x) and the data logger or moisture meter (HH2). The HH2 reads and stores measurements taken with the ThetaProbe (TP) ML2x soil moisture sensors. It can provide milliVolt readings (mV), soil water (m3.m-3), and other measurements. Readings are saved with the time and date of the reading for later collection from a PC.

The HH2 is shown in Figure 52. It applies power to the TP and measures the output signal voltage returned. This can be displayed directly, in mV, or converted into other units. It can convert the mV reading into soil moisture units using conversion tables and soil-specific parameters. Tables are installed for Organic and Mineral soils, however, greater accuracy is possible by developing site-specific parameters. For CLASIC, all observations will be recorded as % and processed later to mV for calibration.

Use of the TP is very simple - you just push the probe into the soil until the rods are fully covered, then using the HH2 obtain a reading. Some general items on using the probe are:

- One person will be the TP coordinator. If you have problems see that person.
- A copy of the manual for the TP and the HH2 will be available at the field HQ. They are also available online as pdf files at http://www.dynamax.com/#6, http://www.delta-t.co.uk and http://www.mluri.sari.ac.uk/thetaprobe/tprobe.pdf..
- Each TP will have an ID, use the same TP in the same sites each day.
- The measurement is made in the region of the four rods.
- Rods should be straight.
- Rods can be replaced.
- Rods should be clean.
- Be careful of stones or objects that may bend the rods.
- Some types of soils can get very hard as they dry. If you encounter a great deal of resistance, stop using the TP in these fields. Supplemental GSM sampling will be used.
- Check that the date and time are correct and that Plot and Sample numbers have been reset from the previous day.
- Disconnect sensor if you see the low battery warning message.
- Protect the HH2 from heavy rain or immersion.
- The TP is sensitive to the water content of the soil sample held within its array of 4 stainless steel rods, but this sensitivity is biased towards the central rod and falls off towards the outside of this cylindrical sampling volume. The presence of air pockets around the rods, particularly around the central rod, will reduce the value of soil moisture content measured.
- Do not remove the TP from soil by pulling on the cable.
- Do not attempt to straighten the measurement rods while they are still attached to the probe body. Even a small degree of bending in the rods (>1mm out of parallel), although not enough to affect the inherent TP accuracy, will increase the likelihood of air pockets around the rods during insertion, and so should be avoided. See the TP coordinator for replacement.

Figure 52. HH2 display.

Occasionally, the soil is too hard to successfully insert a TP; therefore, a jig (Soil Moisture Insertion Tool – SMITY) has been constructed, shown in Figure 53. This is a tool used to make holes in hard or difficult soils to ease the stress on the TP. To use, place the slider plate (Figure 54) on the surface to be probed. Using pressure or a hammer, drive the SMITY into the ground. Avoid any side-to-side movement, to avoid faulty measurements. Once the SMITY is completely in the ground, hold the slider plate on the surface and pull straight up on the SMITY. Holding the slider plate to the ground should maintain the surface for proper TP insertion. Clean the SMITY and proceed with the TP measurement. Insert the TP probe exactly into the holes created by the SMITY. The TP tines are slightly larger than the holes, but will be much easier to insert than without the SMITY.

Figure 53: SMITY, Soil Moisture Insertion Tool, with slider extended and retracted.

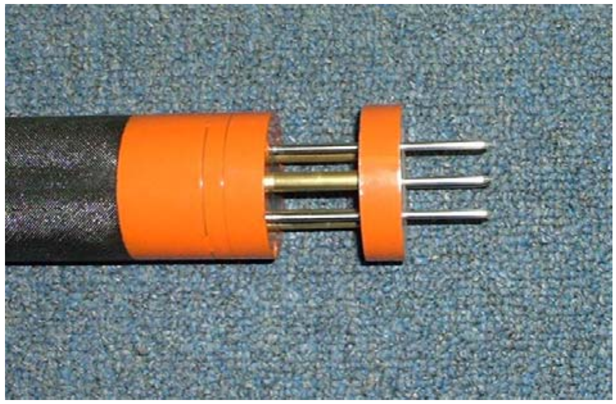


Figure 54: Close-up of the SMITY slider.

Before Taking Readings for the Day Check and configure the HH2 settings

1. Press **Esc** to wake the *HH2.*

Check Battery Status

2. Press **Set** to display the **Options** menu
3. Scroll down to **Status using** the **up** and **down** keys and press **Set.**
4. The display will show the following
   Mem %   Batt %
   Readings #.
   - If Mem is not 0% see the TP coordinator.
   - If Battery is less than 50% see TP coordinator for replacement. *The HH2 can take approximately: 6500 TP readings before needing to replace the battery.*
   - If Readings is not 0 see the TP coordinator
5. Press **Esc** to return to the start-up screen**.**

Check Date and Time

6. Press **Set** to display the **Options** menu
7. Scroll down to **Date and Time using** the **up** and **down** keys and press **Set.**
8. Scroll down to **Date** using the up and down keys and press **Set** to view. It should be in MM/DD/YY format. If incorrect see the TP coordinator or manual.
9. Press **Esc** to return to the start-up screen**.**
10. Press **Set** to display the **Options** menu
11. Scroll down to **Date and Time using** the **up** and **down** keys and press **Set.**
12. Scroll down to **Time** using the up and down keys and press **Set** to view. It should be local (24 hour) time. If incorrect see the TP coordinator or manual.
13. Press **Esc** to return to the start-up screen**.**

Set First Plot and Sample ID

14. Press **Set** at the start up screen to display the **Options** Menu**.**
15. Scroll down to **Data** using the **up** and **down** keys and press **Set.**
16. Select **Plot ID** and press **Set** to display the **Plot ID** options.
17. The default ID should be A. If incorrect scroll through the options, from A to Z, using the **up** and **down** keys, and press **Set** to select one.
18. Press **Esc** to return to the main Options menu**.**
19. Scroll down to **Data** using the **up** and **down** keys and press **Set**
20. Scroll down to **Sample** and press **Set** to display available options. A sample number is automatically assigned to each reading. It automatically increments by one for each readings stored. You may change the sample number. This can be any number between 1 and 2000.
21. The default ID should be 1. If incorrect scroll through the options, using the **up** and **down** keys, and press **Set** to select one.
22. Press **Esc** to return to the main Options menu.

Select Device ID

23. Each HH2 will have a unique ID between 0 and 255. Press **Set** at the start up or readings screen to display the main **Options** menu**.**

24. Scroll down to **Data** using the **up** and **down** keys and press **Set.**
25. Select **Device ID** and press **Set** to display the **Device ID** dialog.
26. Your ID will be on the HH2 battery cover.
27. Scroll through the options, from 0 to 255, and press **Set** to select one.
28. Press **Esc** to return to the main menu.

To take Readings

1. Press **Esc** to wake the *HH2*.
2. Press **Read**
   If successful the meter displays the reading, e.g.-
   ML2 Store?
   32.2%vol
3. Press **Store** to save the reading.
   The display still shows the measured value as follows:
   ML2
   32.2%vol
   Press **Esc** if you do not want to save the reading. It will still show on the display but has not been saved.
   ML2
   32.2%vol
4. Press **Read** to take the next reading or change the optional meter settings first. such as the Plot ID. Version 1 of the Moisture Meter can store up to 863 if two sets of units are selected.

Troubleshooting

Changing the Battery

- The HH2 unit works from a single **9 V PP3** type battery. When the battery reaches 6.6V, (~25%) the HH2 displays :
  ***Please Change**
  Battery
- On receiving the above warning have your data uploaded to the PC next, or replace the battery. Observe the following warnings:
  - ***WARNING 1: Disconnect the TP, immediately on receiving this low battery warning. Failure to heed this warning could result in loss of data.***
  - ***WARNING 2: Allow HH2 to sleep before changing battery.***
  - ***WARNING 3: Once the battery is disconnected you have 30 seconds to replace it before all stored readings are lost.*** If you do not like this prospect, be reassured that your readings are safe indefinitely, (provided that you do disconnect your sensor and you do not disconnect your battery). The meter will, when starting up after a battery change always check the state of its memory and will attempt to recover any readings held. So even if the meter has been without power for more than 30 seconds, the meter may still be able to retain any readings stored.

Display is Blank

The meter will sleep when not used for more than 30 seconds. This means the display will go blank.

- *First check that the meter is not sleeping by pressing the Esc key. The display should become visible instantly.*
- If the display remains blank, then try all the keys in case one key is faulty.
- Try replacing the battery.
- If you are in bright light, then the display may be obscured by the light shining on the display. Try to move to a darker area or shade the display.

Incorrect Readings being obtained

- Check the device is connected to the meter correctly.
- Has the meter been set up with the correct device.

Zero Readings being obtained

- If the soil moisture value is always reading zero, then an additional test to those in the previous section is to check the battery.

Settings Corrupt Error Message

- The configurations such as sensor type, soil parameters, etc. have been found to be corrupt and are lost. This could be caused by electrical interference, ionizing radiation, a low battery or a software error.

Memory Failure Error Message

- The unit has failed a self-test when powering itself on. The Unit's memory has failed a self test, and is faulty. Stop using and return to HQ.

Some Readings Corrupt Error Message

- Some of the stored readings in memory have been found to be corrupt and are lost. Stop using and return to HQ.

Known Problems

- When setting the date and time, an error occurs if the user fails to respond to the time and date dialog within the period the unit takes to return to itself off. (The solution is to always respond before the unit times out and returns to sleep).
- The Unit takes a reading but fails to allow the user to store it. (This can be caused if due to electrical noise, or if calibrations or configurations have become corrupted. An error message will have been displayed at the point this occurred.

10.4. Gravimetric Soil Moisture Sampling with the Scoop Tool

- Remove vegetation and litter.
- Use the large spatula (6 cm) to cut a vertical face at least 6 cm deep (Figure 55a).
- Push the GSM tool into this vertical face. The top of the scoop should be parallel with the soil surface. (Figure 55b).
- Use the large spatula to cut a vertical face on the front edge of the scoop (Figure 55c).
- Use the small spatula to cut the sample into a 0-1cm depth..
- Place the sample the top 0-1 cm in the odd numbered can. The small spatula and a funnel aid extraction of the sample in the can (Figure 55d).
- Take a second sample of 0-6 cm depth and place it in the even numbered can.
- Remember to use cans sequentially and odd numbers for the 0-1 and even for 0-6 cm samples.
- Record these can numbers in the field notebooks at the point location on the map.
- A video clip showing the gravimetric sampling technique can be downloaded from an anonymous ftp site hydrolab.arsusda.gov/pub/sgp99/gsmsamp.avi.
- At the specific sampling points where it is required, measure the soil temperature at 1, 5 and 10 cm depths using the digital thermometer provided. Record these values in degrees C to one decimal point in the field notebooks at the point location on the map.
- At the specific sampling points where it is required, measure the surface temperatures of A) exposed vegetation, B) in-shade vegetation (half the canopy height), C) exposed ground, and D) in-shade ground. If it is not possible to take a measure of any of these four observations at a site, make a note of that in the notebook. This would represent either 0% or 100% vegetation cover. Record these values in degrees C to one decimal point in the field notebooks at the point location on the map.

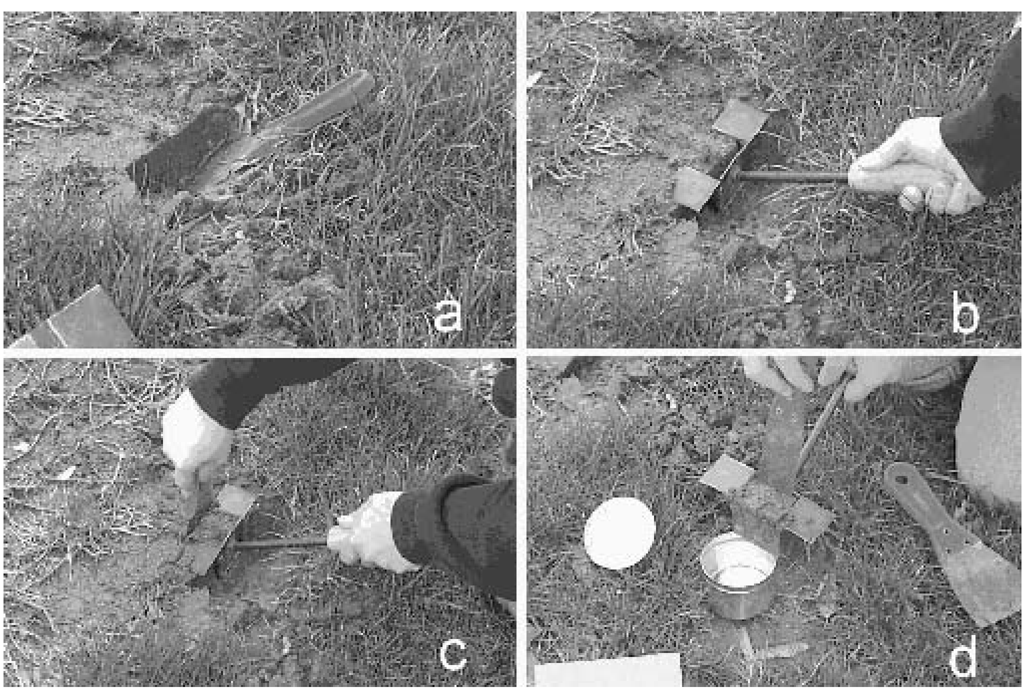


Figure 55. How to take a gravimetric soil moisture sample.

10.5. Gravimetric Soil Moisture Sample Processing

All GSM samples are processed to obtain a wet and dry weight. It is the sampling teams responsibility to deliver the cans, fill out a sample set sheet, and record a wet weight at the field headquarters. A lab team will transport the samples and place them in the drying ovens. They will perform the removal of samples from the oven, dry weighing, and can cleaning.

All gravimetric soil moisture (GSM) samples taken on one day will be collected from the field headquarters each afternoon. These samples will remain in the ovens until the following afternoon (approximately 24 hours).

Wet Weight Procedure

1. Turn on balance.
2. Tare.
3. Obtain wet weight to two decimal places and record on sheet.
4. Process your samples in sample numeric order.
5. Place the CLOSED cans back in the box. Arrange them sequentially.
6. Place box and sheet in assigned locations.

Dry Weight Procedure

1. Each day obtain a balance reference weight on the wet weight balance and the dry weight balance.
2. Pick up all samples from field headquarters.
3. Turn off oven and remove samples for a single data sheet and place on tray.
4. These samples will be hot. Wear the gloves provided
5. Turn on balance.
6. Tare.
7. Obtain dry weight to two decimal places and record on sheet.
8. Process your samples in sample numeric order.
9. All samples should remain in the oven for approximately 20-22 hours at $105^{o}C$.
10. Try to remove samples in the order they were put in.
11. Load new samples into oven.
12. Turn oven on.
13. Clean all cans that were removed from the ovens and place empty cans in boxes. Check that can numbers are readable and replace any damaged or lost cans with spares.
14. Return the clean cans to the field HQ.

Data Processing

1. Enter all data from the sheets into an Excel spreadsheet. One file per day, one worksheet per site.
2. There will be a summary file for each day that will contain the means and standard deviations.
3. All files are backed up with a floppy disk copy.
4. The summary file will be transmitted to a central collection point on a daily basis.
5. You may keep copies of raw data for any site that you actually sample at this stage. You may not take any other data until quality control has been conducted

10.6. Soil Bulk Density and Surface Roughness

All sites involved in gravimetric soil moisture sampling will be characterized for soil bulk density and surface roughness. The bulk density method being used is a volume extraction technique that has been employed in most of the previous experiments and is especially appropriate for the surface layer. Three replications will be made at each field.

The Bulk Density Apparatus -

The Bulk Density Apparatus itself consists of a 12" diameter plexiglass ring with a 5" diameter hole in the center and three 3/4" holes around the perimeter. Foam is attached to the bottom of the plexiglass. The foam is 2 inches high and 1 1/2 inches thick. The foam is attached so that it follows the circle of the plexiglass.

Other Materials Required for Operation:

- Three 12" (or longer) threaded dowel rods and nuts are used to secure the apparatus to the ground.
- A hammer or mallet is used to drive the securing rods into the ground.
- A bubble level is used to insure the surface of the apparatus is horizontal to the ground.
- A trowel is used to break up the soil.
- An ice cream scoop is used to remove the soil from the hole.
- Oven-safe bags are used to hold the soil as it is removed from the ground. The soil is left in the bag when it is dried in the oven.
- Water is used to determine the volume of the hole.
- A plastic jug is used to carry the water to the site.
- One-gallon plastic storage bags are used as liners for the hole and to hold the water.
- A 1000 ml graduated cylinder is used to determine the volume of the water. Plastic is best because glass can be easily broken in the field.
- A turkey baster is used to transfer small amounts of water.
- A hook-gauge is used to insure water fills the apparatus to the same level each time.

Selecting and Preparing an Appropriate Site -

1. Select a site. An ideal site to conduct a bulk density experiment is: relatively flat, does not include any large (>2 cm) rocks or roots in the actual area that will be tested and has soil that has not been disturbed.
2. Ready the site for the test. Remove all vegetation, large (>2 cm) rocks and other debris from the surface prior to beginning the test. Remove little or no soil when removing the debris.

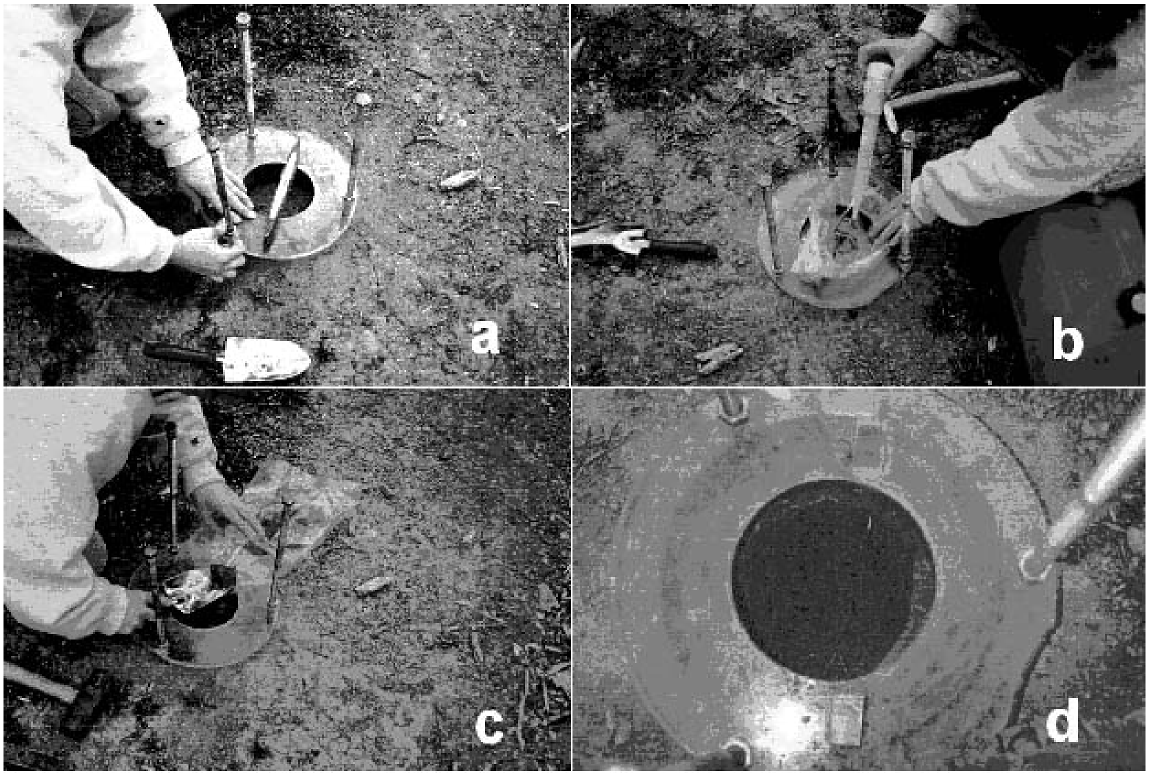


Figure 56. How to take a bulk density sample

Bulk Density Procedure -

Securing the Apparatus to the Ground

1. Place the apparatus foam-side-down on the ground.
2. Place the three securing rods in the 3/4" holes of the apparatus.
3. Drive each dowel into the ground until they do not move easily vertically or horizontally. (Figure 56a)

Leveling the Apparatus Horizontally to the Ground

1. Tighten each of the bolts until the apparatus appears level and the foam is compressed to a height of 1" to 1 1/2".
2. Place the bubble level on the surface of the apparatus and tighten or loosen the bolts in order to make the surface level. Place the level in at least three directions and on three different areas of the surface of the apparatus.

Determining the Volume from the Ground to the Hook Gauge

1. Pour exactly one liter of water into the graduated cylinder.
2. Pour some of the water into a plastic storage bag.
3. Hold the plastic bag so that the water goes to one of the lower corners of the bag.

4. Place the corner of the bag into the hole. Slowly lower the bag into the hole allowing the bag and the water to snugly fill all of the crevasses.
5. Slightly raise and lower the bag in order to eliminate as many air pockets as possible.
6. Lay the remainder of the bag around the hole.
7. Place the hook-gauge on the notches on the surface of the apparatus.
8. Add water to the bag until the surface of the water is just touching the bottom of the hook on the hook-gauge. A turkey-baster works very well to add and subtract small volumes of water. Be sure not to leave any water remaining in the turkey-baster. (Figure 56b)
9. Place the graduated cylinder on a flat surface. Read the cylinder from eye-level. The proper volume is at the bottom of the meniscus. Read the volume of the water remaining in the graduated cylinder. Record this volume. Subtract the remaining volume from the original 1000 ml to find the volume from the ground surface to the hook-gauge.
10. Carefully transfer the water from the bag to the graduated cylinder. Hold the top of the bag shut, except for two inches at either end. Then use the open end as a spout. (It is best to reuse water, especially when doing multiple tests in the field.)

Loosening the Soil and Digging the Hole

1. Label the oven-safe bag with the date and test number and other pertinent information using a permanent marker.
2. Loosen the soil. The hole should be approximately six cm deep and should have vertical sides and a flat bottom. An ice cream scoop is helpful to scrape the bottom of the hole so that it is flat. (The hole should be a cylinder: with surface area the size of the hole of the apparatus and depth of six cm.)
3. Remove the soil from the ground and very carefully place it in the oven-safe bag. (Be careful to lose as little soil as possible.) (Figure 56c and d)
4. Continue to remove the soil until the hole fits the qualifications.
5. Loosely tie the bag so that no soil is lost in transportation.

Finding the Volume of the Hole

1. Determine the volume from the bottom of the hole to the hook-gauge as described in **Determining the Volume from the Ground to the Hook-Gauge**. Record this volume. Reusing the water from the prior measurement presents no potential problems and is necessary when performing numerous experiments in the field.
2. Subtract the volume of the first measurement from the second volume measurement. The answer is the volume of the hole.

Calculating the Bulk Density of the Sample

1. Weigh the sample, and subtract the tare weight of the bag. Record the weight.
2. Dry the soil in an oven at 100°C for at least 24 hours.
3. Reweigh the sample, and subtract the tare weight of the bag. Record the weight.
4. Divide the dry weight of the sample by the volume of the hole. The result is the bulk density of the sample.

Potential Problems and Solutions

After I started digging I hit a large (>2 cm) rock. What should I do?
The best solution is to start over in another location. Also, you can remove the rock from the soil and subtract the volume of the rock from the total volume of the water. You should never include a rock in the density of the soil. Rocks have significantly higher densities than soil and will invalidate the results. Roots, corncobs, ants and even mole holes will also invalidate the results. If you find any of these things the best thing to do is start the test again at another site.

After I began digging the hole I noticed one of the dowels wasn't the apparatus firmly in place. Do I have to start over?
Unfortunately, if you have already started digging you do have to start the experiment again. Replacing the dirt to find the volume between the ground surface and the hook-gauge will give an inaccurate volume and thus an inaccurate soil density.

I noticed that the bag holding the water has a small leak. Is there anything I can do?
If the leak began after you had already found the volume, it is not necessary to start again. The volume is being measured in the graduated cylinder. If you have already removed the appropriate volume of water leaks in the bag, it will not affect the results of the test. However, if you noticed the leak before finding the volume, you will have to start again.

Surface Roughness

Surface roughness photographs will be obtained using the grid board approach. For grasses this should be performed after canopy and thatch removal. Four replications will be made at each site. Two photos are taken at each location, one with the board going North/South, the other with the board going East/West. For row crops, photos will be taken across (c) and along (a) the rows. The soil surface must be visible; therefore it may be necessary to remove plants, but do not damage more plants than you have to. Push the board into the soil surface so that there is no space between the board and the soil surface. Place a card with the site ID on the board and take a photo of the board and the soil surface in front of the board. (see figure 57) Surface roughness photos will be taken once during the experiment unless there is a change in the field conditions (plowing, planting, harvesting …).

Figure 57. Surface Roughness Photo

10.7. Soil Temperature Probes

Several different types of temperature probes may be used to measure soil temperature. These all have a metal rod, plastic top and digital readout. The version used will be the Max/Min Waterproof Digital Thermometer (Figure 58).

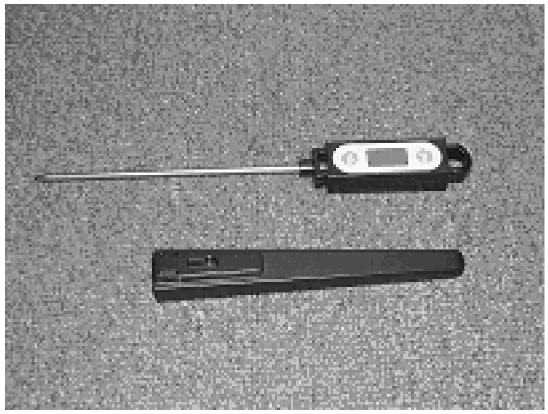


Figure 58. Temperature Probe with Handle/Cover

To Operate:

1. Press On/Off to switch on
2. Verify that the measurement is in Celsius and that the probe is not set to Max or Min
3. Probed into 1 cm of soil at the desired location.
4. Wait for reading to stabilize, and then record the number in the field book.
5. Push the probe to a depth of 5 cm, let it stabilize and record data.
6. Push Probe to a depth of 10 cm, let it stabilize and record data.
7. Turn off probe and cover.

If necessary the cover can be placed on the top of the probe and used as a handle, but do not force the probe into the ground with undue force, as the probe may break.

Normal operation of the probe is simple, but please make sure that neither Max nor Min appear on the LCD. This is a different mode of operation and will not be used for this experiment.

10.8. Infrared Surface Temperature

The infrared surface temperature probe uses 4 AAA batteries that last for a long time.

Operating instructions:

1. Press the Red On/Off button
2. Verify that the measurement is in Celsius and that the probe is not set to Max or Min. If the probe is set to Max/Min, the LCD display will read Max/Min on the bottom right corner.
3. The infrared probe takes an instantaneous measurement (1-2 sec), when you press the red button. The reading will remain on the display after you release the button, till you turn off the device.
4. Point the probe on the exposed canopy (making sure your shadow does not fall on the location where you are pointing the probe). Try to take a measurement at the top of the canopy. This may not be possible for sites that have tall corn canopy and for the forest sites. If possible, take a measurement of the exposed vegetation surface as high as possible at these locations. This is surface temperature measurement A.
5. Point the probe on the shaded canopy. Try to make a measurement at roughly half the canopy height. This is surface temperature measurement B.
6. Point the probe on the exposed ground surface (making sure your shadow does not fall on the location where you are pointing the probe). This may not be possible in dense canopy where the vegetation cover is 100% (make a note in the notebook). This is surface temperature measurement C.
7. Point the probe on the shaded ground surface. This may not be possible for site which have very little vegetation (typically soybean sites at the beginning of the experiment). This is surface temperature measurement D.
8. These four observations are done at the points marked ‘ALL’ and at the tower sites.
9. Turn the probe off by holding on the Red button till the LCD display turns off.

10.9. Hydra Probe Soil Moisture and Apogee Temperature Sensor Installations

Figure 59 shows a close up of the Hydra probe. As with the installation of any soil moisture measuring instrument, there are two prime considerations: the location the probe is to be installed at, and the installation technique. A copy of the instruction manual for the HP will be available at the field HQ and can also be found at http://hydrolab.arsusda.gov.

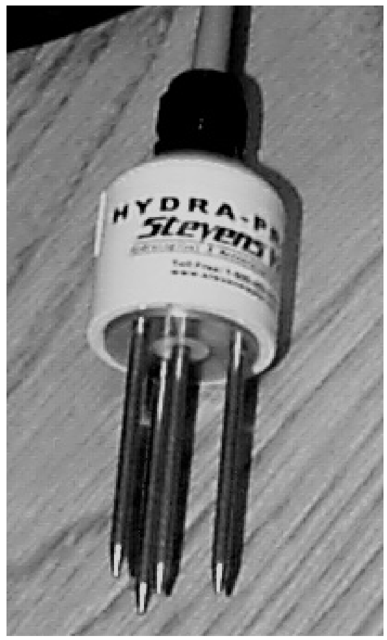


Figure 59. The Hydra probe used at the tower locations**.**

Selecting a Location for the HP

- The probe installation site should be chosen carefully so that the measured soil parameters are "characteristic" of the site.
- Care should be taken that the instrument settles into position before any measurements are considered quality controlled.
- Make sure that the site will be out of foot traffic and is carefully marked and flagged.

Installation of the HP

- The installation technique aims to minimize disruption to the site as much as possible so that the probe measurement reflects the "undisturbed site" as much as possible.
    - o Dig an access hole. This should be as small as possible.
    - o After digging the access hole, a section of the hole wall should be made relatively flat. A spatula works well for this.
    - o The probe should then be carefully inserted into the prepared hole section. The probe should be placed into the soil without any side to side motion

which will result in soil compression and air gaps between the tines and subsequent measurement inaccuracies. The center of the probe head should be at a depth of 5 cm. This will be give a sensing depth of 3-7 cm which will assure a stable signal, less sensitive to surface activity.

  - After placing the probe in the soil, the access hole should be refilled.
  - For a near soil surface installation, one should avoid routing the cable from the probe head directly to the surface. A horizontal cable run of 20 cm between the probe head and the beginning of a vertical cable orientation in near soil surface installations is recommended. Furthermore, sinking the wire deeper than the installation depth is a good method of insuring that the wire will not act as a surface water pathway.
- Other general comments are below.
  - Avoid putting undue mechanical stress on the probe.
  - Do not allow the tines to be bent as this will distort the probe data
  - Pulling on the cable to remove the probe from soil is not recommended.
  - Moderate scratches or nicks to the stainless steel tines or the PVC probe head housing will not affect the probe's performance.

Installation of the Apogee Surface Temperature Sensor

A copy of the instruction manual for the Apogee sensor (Figure 60) will be available at the field HQ

- Height
- Target
- Angle

Figure 60. Apogee thermal infrared sensor.

10.10. Vegetation Sampling

The protocols used in past experiments have been adapted for CLASIC.

Parameters

- Photographs
- Plant height
- Leaf count
- Stand density
- Leaf density
- Green and dry biomass
- Surface reflectance
- Leaf area (LAI)

Sampling Locations

Vegetation sampling will be conducted on all of the soil moisture sampling fields. Three representative locations within each field will be sampled during the course of the study to quantify the full range of vegetative cover. An effort will be made to co-locate these sampling locations with the soil moisture sampling points. GPS coordinates of each location within a field will be recorded. Vegetative sampling is intended to estimate the average site conditions, and data are not intended for footprint averaging.

Sampling Frequency

Each field will be sampled once or twice during the field campaign. If rapid growth is expected in particular fields, the frequency can be increased.

Site Identification

Sites will be identified with their CLASIC field names, followed by a letter to denote the sampling location.

Sampling Scheme

Sampling locations will be selected to provide a representative sample from that area of the field. For row crops (corn and soybeans), 1 plant per row, for 5 rows (a total of 5 plants) will be sampled for green and dry biomass. If the plants are very small, 10 plants may be sampled. These same rows will be sampled for height, stand density, and row cover.

For grasses, weeds, winter wheat and other non-row crops, all vegetation within a 0.44 m by 0.44 m area at a location will be removed. A folding wooden yardstick will be used to define the area. (see Figure 61)

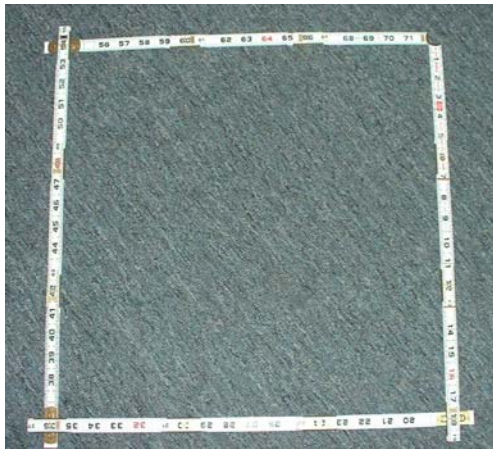


Figure 61. Vegetation Sampling Frame

Data Recording

Data will be recorded onto the sampling sheet illustrated in Figure 62. Data sheets will be maintained as part of the permanent experimental record to verify the data once it is entered into the computer.

Vegetative Sampling

Date: 06/05/2007 Time: 13:47 Observers: Lynn, Iva,

Crop: Pasture

Sample ID	Stand Height (cm)	Row Direction	Row Spacing (cm)	Stand Density	Green Biomass (g)	Dry Biomass (g)
LW04-A	75	na	na	na	112.8	63.3
LW04-B	66	na	na	na	96.2	

Figure 62. Example of the vegetation sampling data sheet

10.10.1 Digital Photographs of Vegetation

Photographs will be taken of plot area at the time of sampling. These will be collected with a digital camera. A marker board will be used to mark the plot, field location, and date. Photographs will be collected at an oblique angle (30-45º from horizontal) and at nadir at a height of a minimum of 1 m above the canopy. Cameras will be fixed to a telescoping pole to allow positioning above the canopy and a remote trigger to collect data. Three photos will be taken in each plot in this order; marker board, oblique, and nadir.

10.10.2 Plant Height

Height will be measured by placing a measuring tape on the soil surface and determining the height of the foliage visually. One person will hold the measuring tape and the other will make the measurement.

10.10.3 Leaf Count

For the first plant that is sampled at each sampling site and plant location, a leaf count will be conducted. Starting from the bottom, each leaf longer than 10 cm (corn) or 3 cm (soy) will be counted and recorded in the data sheet.

10.10.4 Stand Density

First determine the row spacing by placing a meter stick perpendicular to the crop row and measure the distance between the center of one row and the center of the adjacent row. Stand density will be determined by placing a meter stick along the row sampled. The meter stick will be placed at the center of a plant stem and that stem counted as the first plant. All plants within the one-meter length are to be counted. If a plant is at the end of the meter stick and more than half of the stalk extends beyond the end of the meter stick it is not counted. Counts are recorded on the sampling sheet.

10.10.5 Leaf Density

A mature corn plant will develop a total of 20-21 leaves. These are the primary surface to which moisture adheres, therefore, their count and surface area are important to the estimation of total surface wetness.

10.10.6 Green and Dry Biomass

To measure biomass a plant will be cut at the ground surface from each sampling row. The five plants for the sampling site will be placed into a plastic bag with a label for the sampling site. A separate tag with the sampling site id will be placed into the bag as additional insurance against damaged labels. These plants will be transported to the field facility for separation of the plant material into stalks and leaves for corn and stems and leaves for soybean. Corn plants can be separated into leaves and stalks in the field for easier transport to the laboratory. These plant parts will be placed into a bag for drying and marked with sample site id.

Green biomass will be measured for both components (stalks or stems and leaves) by weighing the sample immediately after separation of the components. If the biomass has excess of moisture on the leaves and stalks this will be removed by blotting with a paper towel prior to weighing. Dry biomass will be determined after drying the plant components in ovens at 75C for 48 hours.

10.10.7 Ground Surface Reflectance

Surface reflectance data is valuable in developing methods to estimate the vegetation water content and other canopy variables. Observations made concurrent with biomass sampling provide the essential information needed for larger scale mapping with satellite observations. In addition, reflectance measurements made concurrent with satellite overpasses allow the validation of reflectance estimates based upon correction algorithms.

For CLASIC, we are using instruments developed by CROPSCAN (http://www.cropscan.com). Other instruments may be also be used if available. Most hand-held radiometers, which are used to measure soil and plant reflectance in the field, have one detector that must be calibrated frequently for changing amounts of sunlight. Dual-detector instrument designs measure the amount of sunlight and the reflected light simultaneously; thus, fewer calibrations are required and data may be acquired rapidly. The CROPSCAN Multispectral Radiometer (MSR) is an inexpensive instrument that has up-and-down-looking detectors and the ability to measure sunlight at different wavelengths. The basic instrument is shown in Figure 63.

Figure 63. CROPSCAN Multispectral Radiometer (MSR). (Size is 8 X 8 X 10 cm)

The CROPSCAN multispectral radiometer systems consist of a radiometer, data logger controller (DLC) or A/D converter, terminal, telescoping support pole, connecting cables and operating software. The radiometer uses silicon or germanium photodiodes as light transducers. Matched sets of the transducers with filters to select wavelength bands are oriented in the radiometer housing to measure incident and reflected irradiation. Filters of wavelengths from 450 up to 1720 nm are available.

For CLASIC we will be using a MSR16R unit with the following set of bands:

Satellite	ID	Center Wavelength (Bandwidth)
Thematic Mapper	MSR16R-485TMU	485 nm up sensor (90 nm BW)
	MSR16R-485TMD	485 nm down sensor (90 nm BW)
	MSR16R-560TMU	560 nm up sensor (80 nm BW)
	MSR16R-560TMD	560 nm down sensor (80 nm BW)
	MSR16R-660TMU	660 nm up sensor (60 nm BW)
	MSR16R-660TMD	660 nm down sensor (60 nm BW)
	MSR16R-830TMU	830 nm up sensor (140nm BW)
	MSR16R-830TMD	830 nm down sensor (140nm BW)
	MSR16R-1650TMU	1650 nm up sensor (200nm BW)
	MSR16R-1650TMD	1650 nm down sensor (200nm BW)
MODIS	MSR16R-650U2	650 nm up sensor (40 nm BW)
	MSR16R-650D2	650 nm down sensor (40 nm BW)
	MSR16R-850U2	850 nm up sensor (60 nm BW)
	MSR16R-850D2	850 nm down sensor (60 nm BW)
	MSR16R-1240U	1240 nm up sensor (12 nm BW)
	MSR16R-1240D	1240 nm down sensor (12 nm BW)
	MSR16R-1640U	1640 nm up sensor (16 nm BW)
	MSR16R-1640D	1640 nm down sensor (16 nm BW)

These bands provide data for selected channels of the Landsat Thematic Mapper and MODIS instruments. Channels were chosen to provide NDVI as well as a variety of vegetation water content indices under consideration.

In the field the radiometer is held level by the support pole above the crop canopy. The diameter of the field of view is one half of the height of the radiometer above the canopy. It is assumed that the irradiance flux density incident on the top of the radiometer (upward facing side) is identical to the flux density incident on the target surface. The data acquisition program included with the system facilitates digitizing the voltages and recording percent reflectance for each of the selected wavelengths. The program also allows for averaging multiple samples. Ancillary data such as plot number, time, level of incident radiation and temperature within the radiometer may be recorded with each scan.

Each scan, triggered by a manual switch or by pressing the space key on a terminal or PC, takes about 2 to 4 seconds. An audible beep indicates the beginning of a scan, two beeps indicate the end of scan and 3 beeps indicate the data is recorded in RAM. Data recorded in the RAM file are identified by location, experiment number and date.

The design of the radiometer allows for near simultaneous inputs of voltages representing incident as well as reflected irradiation. This feature permits accurate measurement of reflectance from crop canopies when sun angles or light conditions are less than ideal. Useful measurements of percent reflectance may even be obtained during cloudy conditions. This is a very useful feature, especially when traveling to a remote research site only to find the sun obscured by clouds.

Three methods of calibration are supported for the MSR16R systems:
2-point Up/Down - Uses a diffusing opal glass (included), alternately held over the up and down sensors facing the same incident irradiation to calibrate the up and down sensors relative to each other (http://www.cropscan.com/2ptupdn.html).

Advantages:
- Quick and easy.
- Less equipment required.
- Radiometer may then be used in cloudy or less than ideal sunlight conditions.
- Recalibration required only a couple times per season.
- Assumed radiometer is to be used where radiance flux density is the same between that striking the top surface of the radiometer and that striking the target area, as outside in direct sunlight.

White Standard Up & Down - Uses a white card with known spectral reflectance to calibrate the up and down sensors relative to each other.

Advantages:
- Provides a more lambertian reflective surface for calibrating the longer wavelength (above about 1200 nm) down sensors than does the opal glass diffuser of the 2-point method.
- Radiometer may then be used in cloudy or less than ideal sunlight conditions.
- Recalibration required only a couple times per season.
- Assumed radiometer is to be used where radiance flux density is the same between that striking the top surface of the radiometer and that striking the target area, as outside in direct sunlight.

White Standard Down Only - Uses a white card with known spectral reflectance with which to compare down sensor readings.

Advantages:
- Only down sensors required, saving cost of purchasing up sensors.
- Best method for radiometer use in greenhouse, under forest canopy or whenever irradiance flux density is different between that striking the top of the radiometer and that striking the target area.

Disadvantages:
- White card must be carried in field and recalibration readings must be taken periodically to compensate for sun angle changes.
- Less convenient and takes time away from field readings.

Readings cannot be made in cloudy or less than ideal sunlight conditions, because of likely irradiance change from time of white card reading to time of sample area reading.

There are six major items you need in the field -
- MSR16 (radiometer itself) (Figure 63)
- Data Logger Controller & Cable Adapter Box (carried in the shoulder pack, earphones are to hear beeps) (Figure 64)
- CT100 (hand terminal, connected to the DLC with a serial cable) (Figure 65)
- Calibration stand and opal glass plate

- Memory cards
- Extension pole (with spirit level adjusted so that the top surface of the radiometer and the spirit level are par level)

Figure 64. data logger controller & cable adapter box

Figure 65. CT100 hand terminal

Set Up –

- Mount the radiometer pole bracket on the pole and attach the radiometer.
- Mount the spirit level attachment to the pole at a convenient viewing position.
- Lean the pole against a support and adjust the radiometer so that the top surface of it is level
- Adjust the spirit level to center the bubble (this will insure that the top surface of the radiometer and the spirit level are par level)

- Attach the 9ft cable MSR87C-9 to the radiometer and to the rear of the MSR Cable Adapter Box (CAB)
- Connect ribbon cables IOARC-6 and IODRC-6 from the front of the CAB to the front of the Data Logger Controller (DLC)
- Plug the cable CT9M9M-5 into the RS232 connectors of the CT100 and the DLC (the DLC and CAB may now be placed in the shoulder pack for easy carrying)
- Mount the CT100 on the pole at a convenient position
- Adjust the radiometer to a suitable height over the target (the diameter of the field of view is one half the height of the radiometer over the target)

Configure MSR –

- Perform once at the beginning of the experiment, or if the system completely loses power
- Switch the CT100 power to on
- Press **ENTER** 3 times to get into main menu
- At Command * Press **2** then **ENTER** to get to the Reconfigure MSR menu
- At Command * Press **1** then **ENTER**, input the correct date, Press **ENTER**
- At Command * Press **2** then **ENTER**, input the correct time, Press **ENTER**
- At Command * Press **3** then **ENTER**, input the number of sub samples/plot (5), Press **ENTER**
- At Command * Press **6** then **ENTER**, input a 2 or 3 character name for your sampling location (ex OS for Oklahoma South), Press **ENTER;** input the latitude for your location, Press **ENTER;** input the longitude for your location, Press **ENTER**
- At Command * Press **9** then **ENTER**, input the GMT difference, Press **ENTER**
- At Command * Press **M** then **ENTER** until you return to the main menu

Calibration –

- ***We are using the 2-point up/down calibration method***
- Calibrate everyday before you begin to take readings
- Switch the CT100 power to on
- Press **ENTER** 3 times to get into main menu
- At Command * Press **2** then **ENTER** to get to the Reconfigure MSR menu
- At Command * Press **11** then **ENTER** to get to the Calibration menu
- At Command * Press **3** then **ENTER** to get to the Recalibration menu
- At Command * Press **2** then **ENTER** for the 2-point up/down calibration
- Remove the radiometer from the pole bracket and place on the black side of the calibration stand, point the top surface about 45° away from the sun, press **SPACE** to initiate the scan (1 beep indicates the start of the scan, 2 beeps indicate the end of the scan, and 3 beeps indicate the data was stored)
- Place the separate opal glass plate on top of the upper surface and press **SPACE** to initiate scan
- Turn the radiometer over and place it back in the calibration stand, cover it with the separate opal glass plate and press **SPACE** to initiate scan
- CT100 will acknowledge that the recalibration was stored
- At Command * Press **M** then **ENTER** until you return to the main menu

- Return the radiometer to the pole bracket
- Store configuration onto the memory card

Memory Card Usage –

- Switch the CT100 power to on
- Press **ENTER** 3 times to get into main menu
- At Command * Press **7** then **ENTER** to get to the Memory Card Operations menu
- Memory Card Operations menu is:
    1. Display directory
    2. Store data to memory card (use to save data in the field)
    3. Load data from memory card (use first to download data from memory card)
    4. Save program/configuration to card (use to save after calibrating)
    5. Load program/configuration from card (use when DLC loses power)
    6. Battery check

    M Main menu
- There are 2 memory cards, 64K for storing the program/configuration and 256 for storing data in the field

Taking Readings in the Field –

- Switch the CT100 power to on
- Press **ENTER** 3 times to get to MSR menu
- Press **ENTER** to continue or **M** to return to the main menu
- Enter beginning plot number, **ENTER**
- Enter the ending plot number**, ENTER**, record plot numbers and field ID in field notebook
- Adjust the radiometer to a suitable height (about 2 meters) over the target, point the radiometer towards the sun, center the bubble in the center of the spirit level and make sure that there are no shadows in the sampling area
- **Do not** take measurements if IRR < 300
- Initiate a scan by pushing **SPACE,** the message 'scanning' will appear on the screen and a beep will be heard
- When the scan is complete (about 2 seconds) '**' will be displayed and 2 beeps will be heard
- Now, you can move to the next area
- 3 Beeps will be heard when the data has been stored
- Press **SPACE** to start next scan, **R** to repeat scan, **P** to repeat plot, **S** to suspend/sleep, **M** to return to the MSR main menu, **W** to scan white standard, and **D** to scan Dark reading
- When you are done scanning at that field location, press **M** to return to the MSR main menu, then press **10** to put the DLC to sleep
- Switch the CT100 power off

Downloading Data –

- Plug the cable RS9M9F-5 into the RS232 connectors on the front DLC and the serial port of your PC

- Start the CROPSCAN software on the PC
- Choose RETRIEVE from the menu and press **ENTER**
- Select your PC COM port and press **ENTER**
- Enter your file name (MMDDFL.MV, where MM is month, DD is day, FL is first and last initials of user and MV for raw millivolt data files)
- After the data is downloaded, press **Y** then **ENTER** to clear the data from the DLC

Two types of sampling will be performed as part of CLASIC:

Vegetation Water Content Sampling Location:

Reflectance data will be collected for each vegetation sampling location (Figure 66) just prior to removal using the following sampling scheme.

Making sure that the radiometer is well above the plant canopy; take a reading every meter for 5 meters. Repeat, for a total of 5 replications located 1 meter or 1 row apart.

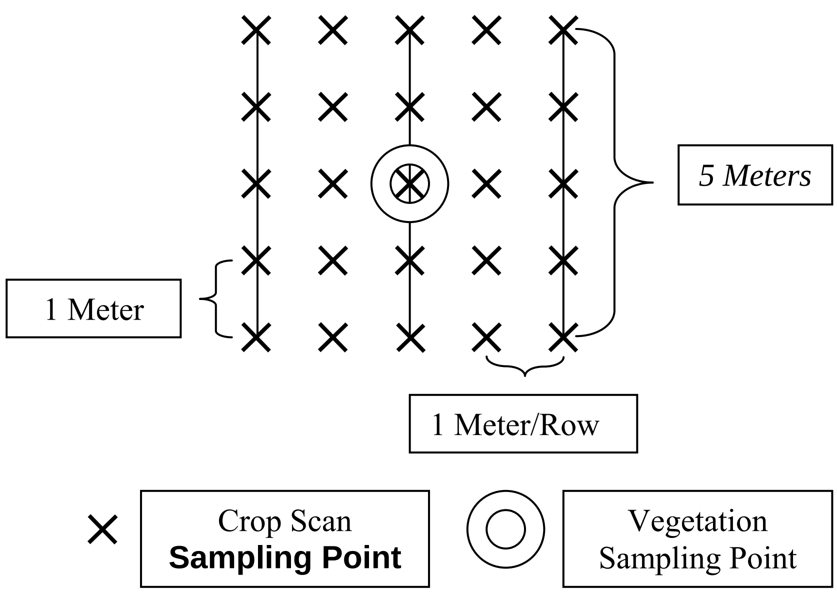


Figure 66. Vegetation sampling scheme

Field Transect:

Each different land use type (Winter Wheat, corn, pasture, etc...) will be characterized by transect sampling. Reflectance will be collected at representative sites (Figures 67 and 68). Reflectance will also be collected over water for calibration purposes. This should be done at least twice, to coincide with the Landsat overpasses. The following sampling scheme will be used for transect sampling.

Making sure that the radiometer is well above the plant canopy, take a reading every 5 meters for 25 meters, walk 75 meters, continue until you have gone 400 meters. Walk over 100 meters. Do another 400 meter transect going in the opposite direction.

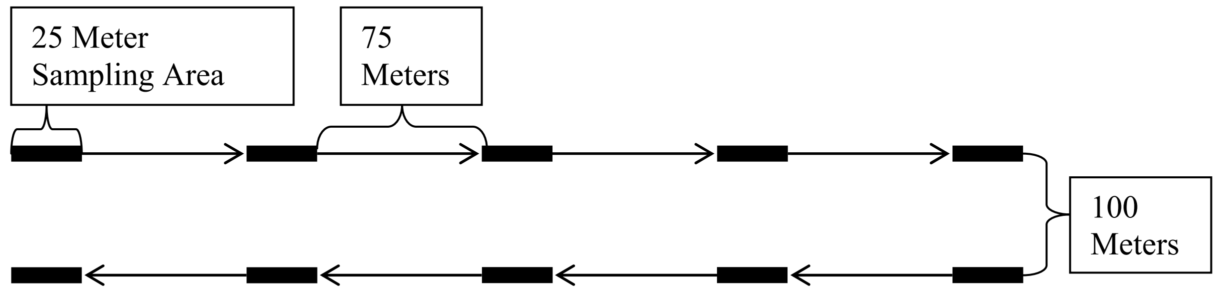


Figure 67. Transect sampling scheme

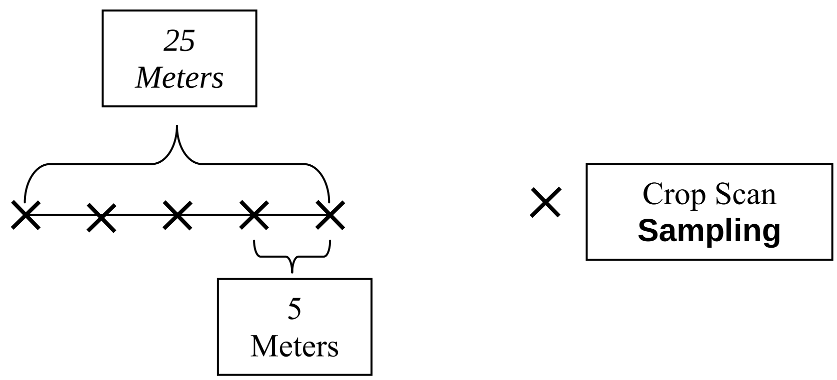


Figure 68. Enlarged transect sampling area

10.10.8 Leaf Area

Leaf area will be measured with a LAI-2000 (Figure 69). The LAI-2000 will be set to average 5 points into a single value so one observation is taken above the canopy and 4 below the canopy. For *grasses and weeds and non-row crops*, five sets of measurements (each set consisting of 1 above the canopy and 4 beneath the canopy) will be made. Measurements will be taken every meter on 5 meter transects. For *row crops*, the 4 beneath canopy measurements will be taken across a plant row (in row, ¼ row, ½ row and ¾ row).

If the sun is shining, the observer needs to stand with their back to the sun and put a black lens cap that blocks ¼ of the sensor view in place and positioned so the **sun and the observer are never in the view of the sensor**. The observer should always note if the sun was obscured during the measurement, whether the sky is overcast or partly cloudy with the sun behind the clouds. If no shadows could be seen during the measurement, then the measurement is marked “shaded”, if shadows could be seen during the measurement then the measurement is marked “sunny”. Conditions should not change from cloudy to sunny or sunny to cloudy in the middle of measurements.

Figure 69. The LAI-2000 Instrument

Operating the LAI-2000 -

Plug the sensor cord into the port labeled “X” and tighten the two screws.

Place a black view-cap over the lens that blocks 1/4 of the sensor view; that 1/4 that contains the operator. Place a piece of tape on the view cap and body of the sensor so if the cap comes loose it will not be lost.

Turn on the logger with the “**ON**” key (The unit is turned off by pressing “**FCT**”, "**0**", "**9**".)

Clear the memory of the logger -
Press “**FILE**”
Use “↑” to place “Clear Ram” on the top line of display
Press “**ENTER**”
Press “↑” to change “NO” to “YES”
Press “**ENTER**”

General items –
When changing something on the display, get desired menu item on the top line of display and then it can be edited.

Use the “↑” and “↓” to move items through the menu and the “**ENTER**” key usually causes the item to be entered into the logger.

When entering letters, look for the desired letter on the keys and if they are on the lower part of the key just press the key for the letter; if the desired letter is on the upper part of the key then press the “↑” and then the key to get that letter.

Press “**BREAK**” anytime to return to the monitor display that contains time, file number or sensor readings on one of the five rings that are sensed by the LAI-2000.

Do not take data with the LAI-2000 if the sensor outputs are less than 1.0 for readings above the canopy.

To Begin -

Press “**SETUP**”

Use “↑” to get “XCAL” on the top line of the display and press “**ENTER**”

Following XS/N is the serial number of the sensor unit, enter appropriate number

Check or put appropriate cal numbers from LICOR cal sheet into the 5 entries.

Final press of “**ENTER**” returns you to “XCAL”

Use “↑” to get to “RESOLUTION”

Set it to “HIGH”

Use “↑” to get to “CLOCK”

Update the clock (set to local time using 24 hr format)

Press “**OPER**”

Use “↑” to get “SET OP MODE” on top line of display

Choose “MODE=1 SENSOR X”

Enter “↑”, “↓”, “↓”, “↓”, “↓” in “SEQ”

Enter "1" in “REPS”

Use “↑” to get to “SET PROMPTS”

Put “SITE” in first prompt

Put “LOC” in second prompt

Use “↑” to get to “BAD READING”

Choose "A/B=1"

Press “**BREAK**”

Display will contain the two monitor lines

Use “↑” and “↓” to control what is displayed on the top line in the monitor mode, time, file number or sensor ring output 1 through 5 for the X sensor. (If FI is selected, then the file number is displayed)

Use the “→” and “←” to control what is displayed on the bottom line of the monitor mode, time, file number or sensor ring output 1 through 5 for the X sensor. (If X2 is selected, then ring #2 output is displayed)

Press “**LOG**” to begin collecting data

Type in the response to the first prompt (if "**ENTER**" is pressed the same entry is kept in response to the prompt).
Type in the response to the second prompt (if "**ENTER**" is pressed the same entry is kept in response to the prompt).
Place the sensor head in the appropriate position above the canopy, level the sensor and press the black log button on the handle of the sensor (a beep will be heard when the black button is pushed). Hold the sensor level until the second beep is heard.

For Row crops –

1. Place the sensor head in the appropriate position above the canopy, level the sensor and press the black log button on the handle of the sensor (a beep will be heard when the black button is pushed). Hold the sensor level until the second beep is heard.
2. Place the sensor below the canopy in the row of plants, level the sensor and press the black log button on the sensor handle and keep level until the second beep.
3. Place the sensor one-quarter (1/4) of the way across the row and record data again.
4. Place the sensor one-half (1/2) of the way across the row and record data again.
5. Place the sensor three-quarters (3/4) of the way across the row and record data again.

   Repeat steps 1-5 so that you have a total of 5 sets of measurements.

For Other Types of Vegetation –

1. At your starting spot, place the sensor head in the appropriate position above the canopy, level the sensor and press the black log button on the handle of the sensor (a beep will be heard when the black button is pushed). Hold the sensor level until the second beep is heard.
2. Place the sensor below the plant canopy in the same place level the sensor and press the black log button on the sensor handle and keep level until the second beep.
3. Repeat step 2 every meter, for a total of 1 up and 4 down measurements.
4. Repeat for a total of 5 transects.

The logger will compute LAI and other values automatically. Using the "↑" you can view the value of the LAI.

NOTE: You will record the "SITE" and "LOC" along with the LAI value on a data sheet.

The LAI-2000 is now ready for measuring the LAI at another location. Begin by pressing "**LOG**" twice. The file number will automatically increment.

When data collection is complete, turn off the logger by pressing "**FCT**", "**0**", "**9**".

The data will be dumped onto a laptop back at the Field Headquarters.

Downloading LAI-2000 files to a PC Using HyperTerminal -

Before beginning use functions 21 (memory status) and 27 (view) to determine which files you want to download. Make a note of their numbers.

1) Connect wire from LAI-2000 (25pin) to PC port (9 pin).

2) Run HyperTerminal on the PC (Start | Programs | Accessories | Communications | HyperTerminal | LAI2000.ht)

3) On the LAI-2000, go to function 31 (config i/o) and configure I/O options. Baud=4800, data bits=8, parity=none, xon/xoff=no.

4) On the LAI-2000, go to function 33 (set format) and setup format options. First we use Spdsheet and take the default for FMT.

5) In HyperTerminal go to Transfer | Capture text. Choose a path and filename (LAIMMDDFL.SPR, where MM is month, DD is day, FL is first and last initials of user and SPR for spreadsheet data files) to store the LAI data. Hit Start. HyperTerminal is now waiting to receive data from the LAI-2000.

6) On the LAI-2000, go to function 32 (print) and print the files. 'Print' means send them to the PC. You will be asked which file sequence you want. Eg. Print files from: 1 thru: 25 will print all files numbered 1-25. Others will not be downloaded.

7) Once you hit enter in function 32, lines of text data will be sent to HyperTerminal. The LAI-2000 readout will say 'Printing file 1, 2, etc'. Check the window in HyperTerminal to ensure the data is flowing to the PC. This may take a few minutes, wait until all the desired files have been sent.

8) In HyperTerminal go to Transfer | Capture text | Stop.

9) On the LAI-2000, go to function 33 (set format) and setup format options. Now set to Standard, Print Obs = yes

10) In HyperTerminal go to Transfer | Capture text Choose a path and filename (LAIMMDDFL.STD, where MM is month, DD is day, FL is first and last initials of user and STD for standard data files) to store the LAI data. Hit Start. HyperTerminal is now waiting to receive data from the LAI-2000.

11) On the LAI-2000, go to function 32 (print) and print the files. ‘Print’ means send them to the PC. You will be asked which file sequence you want. Eg. Print files from: 1 thru: 25 will print all files numbered 1-25. Others will not be downloaded.

12) In HyperTerminal go to Transfer | Capture text | Stop.

13) Using a text editor (like notepad) on the PC, open and check that all the LAI data has been stored in the text file specified in step 3. Make a back up of this file. Once you’re sure the LAI values look reasonable and are stored in a text file on the PC, use function 22 on the LAI-2000 to delete files on the LAI-2000 and free up its storage space.

Note: The above instructions assume that HyperTerminal has been configured to interface with the LAI-2000, i.e. the file LAI2k.ht exists. If not, follow these instructions to set it up.

1) Run HyperTerminal on the PC (Start | Programs | Accessories | Communications | HyperTerminal | Hypertrm

2) Pick a name for the connection and choose the icon you want. Whatever you pick will appear as a choice in the HyperTerminal folder in the start menu later. Hit OK.

3) Connect using com1 or com2. Choose your com port, hit OK. Setup Port settings as follows: Bits per second = 4800, Data Bits = 8, Parity = none, Stop bits = 1, Flow control = Hardware. Say OK.

4) Make sure the wire is connected to the LAI-2000 and the PC and proceed with step 3 in the download instructions above. When finished and leaving HyperTerminal you will be prompted to save this connection.

10.11. Global Positioning System (GPS) Coordinates

The acquisition of geographic coordinates at all sample point locations (e.g., WC and IA points, vegetation sites, and flux towers) is necessary for mapping of data in a Geographic Information System (GIS). A Garmin **e**Trex "sportsman" GPS will be used to collect location data. This unit has the capacity to store up to 500 geographic coordinates or waypoints and it is designed so that all key entries can be performed with the left hand alone. Accurate GPS data can be acquired 24 hours a day under all weather conditions. The only restraint is that the **e**Trex antenna--location determination is made at the site of the internal antenna--must have a clear view of the sky in all directions. Once accurate location data at a particular sample site has been acquired and confirmed, no additional measurements at that site will be needed.

- All sampling points will be located using a handheld GPS.
  - WC points
  - IA points
  - Vegetation samples
  - Flux towers

General Information

Record **e**Trex ID number (etched on back cover), site and point ID, and latitude and longitude coordinates in field notebook.

Watershed and regional sites should be labeled as follows:

Watershed: Site WC## and point ## (e.g., WC05-02)

Regional: Site IA##

Carry at least two (2) extra AA alkaline batteries. The **e**Trex is configured to run in Battery Save mode which automatically turns the GPS receiver on and off to conserve power. In this mode, the **e**Trex should operate for approximately 22 hours. A "Battery Low" message will appear at the bottom of the screen when the unit has ten (10) minutes of battery life remaining.

eTrex GPS Features (see Figure 70)

UP/DOWN ARROW buttons: used to select options.
ENTER button: used to confirm selections or data entry.
PAGE button: switches between display screens (or "pages") and functions as escape key.
POWER button: turns **e**Trex GPS as well as display backlight on and off.

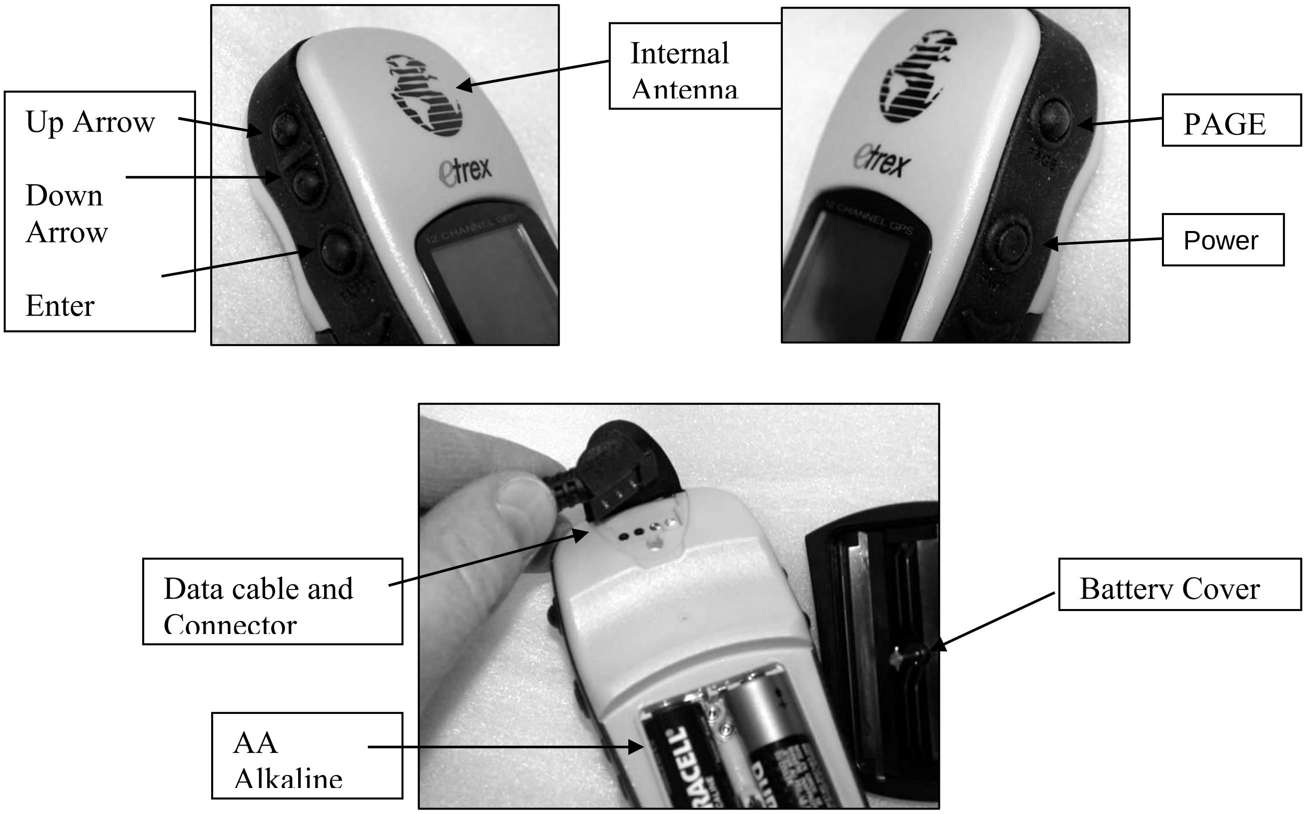


Figure 70. GPS features

All **e**Trex operations are carried out from the four (4) "pages" (or display screens) shown in Figure 71. The PAGE key is used to switch between pages. (The Map and Pointer Pages are used for navigation and will not be discussed further.)

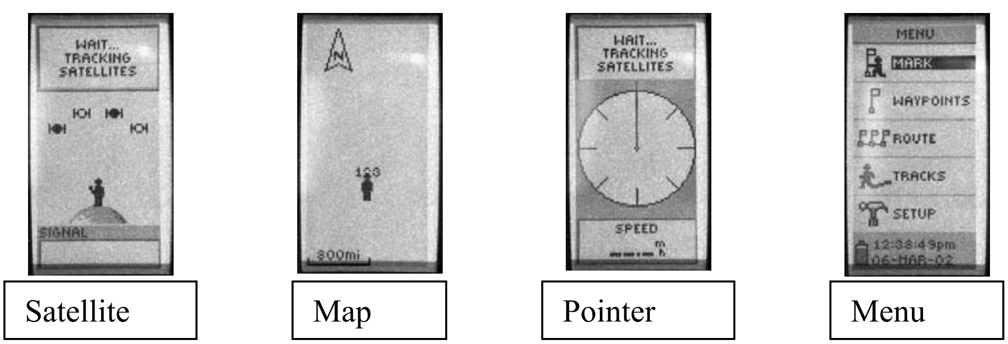


Figure 71. GPS display screens or "pages"

Setup at Headquarters Prior to Data Collection

1. Power unit on: Depress and hold power button until eTrex welcome screen appears and Satellite Page is displayed.

2. Confirm configuration parameters:
   - PAGE to Menu screen; ARROW to Setup; press ENTER (Figure 72)
   - Use the following key sequence to check configuration parameters:
     - ARROW to first parameter; press ENTER;
     - confirm values (see configuration values below);
     - press PAGE to return to Setup menu;
     - ARROW to next parameter, etc.
   - The following are the parameters and required settings;
     - Time = Format: **24 Hour**; Zone: **US-Central**; (UTC Offset: **-6:00**); Daylight Saving: **Auto**
     - Display = Timeout: **15 sec.**
     - Units = Position Format: **hddd.ddddd°**; Map Datum: **WGS 84**; Units: **Metric**; North Reference: **True**
     - Interface = I/O Format: **Garmin**
     - System = Mode: **Battery Save**

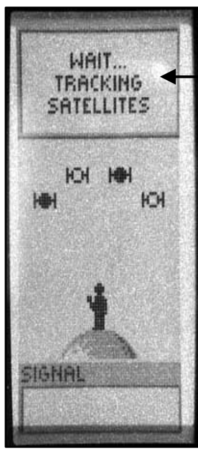
Figure 72. GPS Menu Page

3. Turn **e**Trex off after GPS data collection by depressing and holding POWER button until screen blanks.

Important Note: Geodetic datums mathematically describe the size and shape of the earth and provide the origin and orientation of coordinate systems used in mapping. Hundreds of datums are currently in use and particular attention must be paid to what datum is used during GPS data collection. The Global Positioning System is based on the World Geodetic System of 1984 (WGS84). However, popular map products such as USGS 1:24,000 topo sheets originally used the North American Datum of 1927 (NAD27). Most of the maps in this series have been updated to the North American Datum of 1983 (NAD83). Fortunately, there is virtually no practical difference between WGS84 and NAD83. Yet significant differences exists between NAD27 and NAD83. (In Iowa, a north-south displacement of approximately 215m occurs between NAD27 and NAD83.) *All geographic coordinates collected with the **e**Trex GPS should be acquired* *using the following parameters:* ***latitude/longitude (decimal degrees), WGS84 datum, meters, true north***. Various coordinate conversion software packages such as the Geographic Calculator ($500) or NOAA's Corpscon (free) exist which allow the conversion of geodetic (latitude and longitude) coordinates into planar (UTM or State Plane) coordinates for GIS mapping.

GPS Field Data Collection

1. Power unit on: Depress and hold power button until eTrex welcome screen appears and Satellite Page is displayed (Figure 73). Wait until text box at top of screen reads "READY TO NAVIGATE" before continuing.



Wait until "READY TO NAVIGATE is displayed
<u>AND</u>
Accuracy is <= 10 m
(Up to 5 minutes at a new location;
15-45 seconds on subsequent visits.)

Figure 73. GPS Satellite Page

2. Adjust screen backlight and contrast, <u>if necessary</u>.
   - Turn backlighting on by quickly pressing and releasing POWER button from any screen. (To save power, the backlight remains on for only 30 seconds.); AND/OR,
   - Adjust screen contrast by pressing UP (darker) and DOWN (lighter) buttons from Satellite Page.

3. Initiate GPS point data collection:
   - PAGE to Menu screen (Figure 72); Arrow to Mark; press ENTER. (Shortcut: press and hold ENTER button from any screen to get to Mark Waypoint page below.)
   - ARROW to alphanumeric ID field (Figure 74); press ENTER. Use ENTER and UP/DOWN buttons to edit ID, <u>if necessary</u>. (Waypoint ID increments by one (1) automatically.)
   - Record latitude (North) and longitude (West) coordinates displayed at bottom of screen into field notebook. *Do not rely on electronic data download to save data points!*
   - ARROW to OK prompt; press ENTER to save point coordinates electronically.

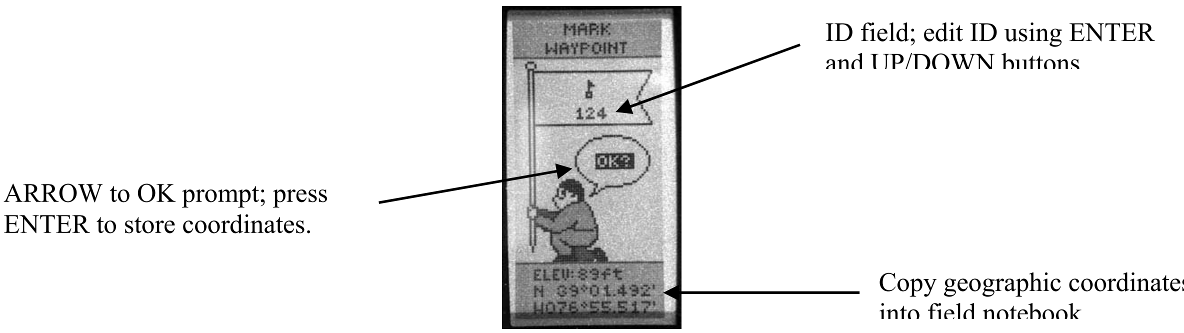


Figure 74. GPS Mark Waypoint Page

4. Turn **e**Trex off after GPS data collection by depressing and holding POWER button until screen blanks.

Electronic Data Downloading

Electronic data downloading will be performed at field headquarters by assigned person.

Connect PC data cable by sliding keyed connector into shoe at top rear of eTrex (under flap); power eTrex on.
Launch Waypoint.exe

GPS => Port => Com?

Waypoints => Download

File => Save => Waypoint

Select Save as type: Comma Delimited Text File

11. References

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