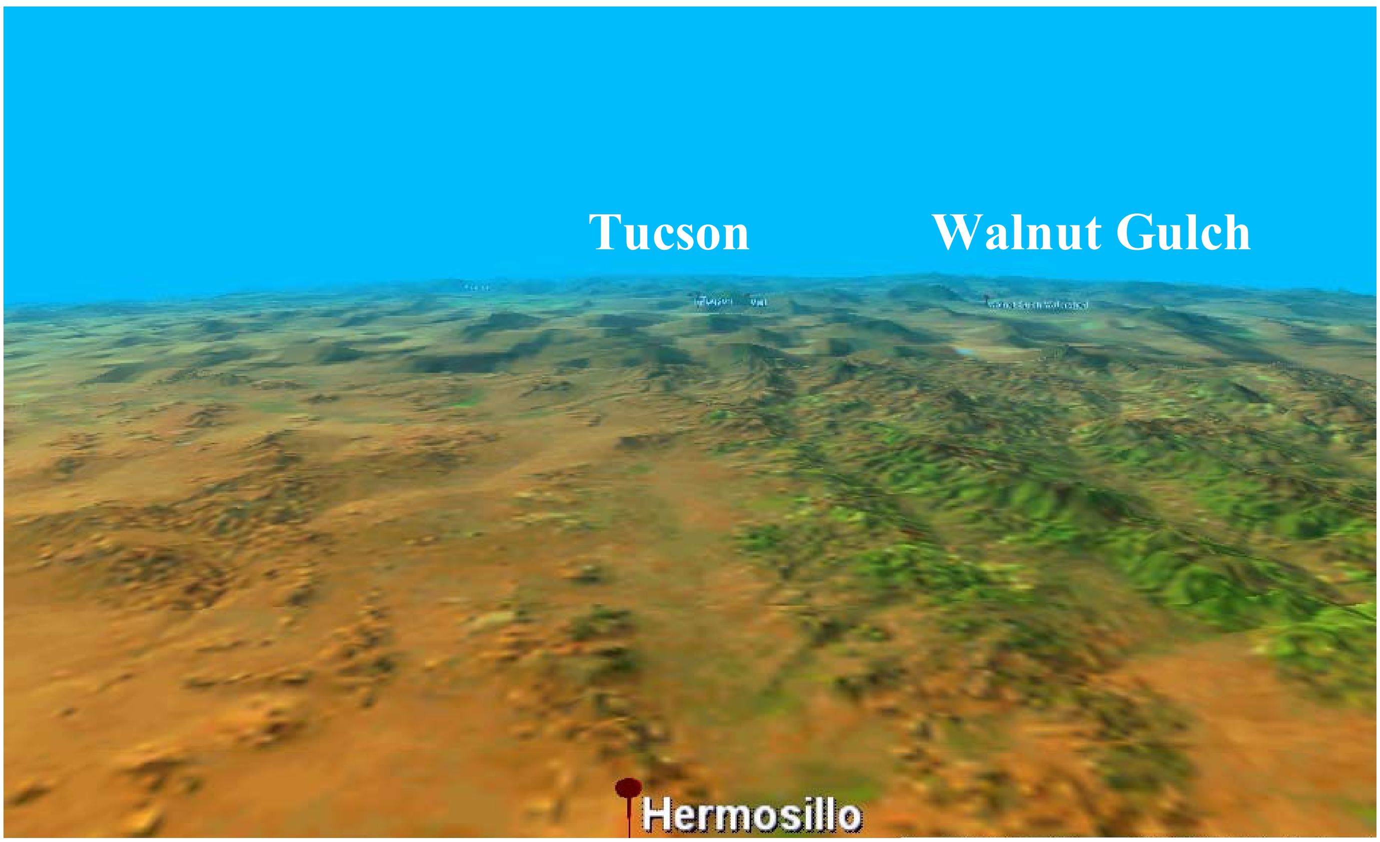
Soil Moisture Experiment 2004 (SMEX04) And the North American Monsoon Experiment (NAME)



Preliminary Experiment Plan

November 2003

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1 OVERVIEW AND SCIENTIFIC OBJECTIVES

1.1 Introduction

In much of the interior of the North American continent, summer precipitation is a dominant feature of the annual cycle. Surface boundary conditions play an important role in initiation and maintenance of the North American Monsoon System (NAMS), which controls summer precipitation over much of this region. The most important surface boundary conditions are sea surface temperature and land surface wetness and temperature. The NAMS has important practical as well as scientific implications. Figure 1 shows annual streamflow into the Rio Bravo (known as the Rio Grande in the U.S.) reservoir system since the early 1950s. A prolonged drought over the last 10 years, including two of the lowest yearly discharges in the gauge record, is attributable to reduced summer monsoon rainfall over northern Mexico. The associated drastic reductions in agricultural water supply allocations have resulted in abandonment of agricultural lands in Mexico, international tensions resulting from inability of Mexico to meet treaty obligations relating to inflows to international reservoirs, and additional pressure on Mexican immigration to the U.S.

Two of the four general science questions of the North American Monsoon Experiment (NAME) (http://www.cpc.ncep.noaa.gov/products/precip/monsoon/) relate directly to land surface boundary conditions, specifically:

(1) How is the evolution of the warm season (May-October) atmospheric circulation and precipitation regimes over North America related to the seasonal evolution of oceanic and continental boundary conditions?

(3) What are the significant features of and interrelationships between the anomaly-sustaining atmospheric circulation and the boundary conditions that characterize large-scale long-lasting continental precipitation (and temperature) anomaly regimes?

A working hypothesis of NAME is that among the land surface antecedent boundary conditions that control the onset and intensity of the NAMS are soil moisture and snow extent in the southwestern U.S. and northern Mexico and those in the northwestern U.S. (these usually being out of phase), while the concurrent conditions that typify NAMS are out of phase surface wetness and temperature in the southwestern U.S. and northern Mexico, on the one hand, and in the U.S. Great Plains, on the other. The influence of the land surface is relayed through surface evaporation and associated surface cooling (dependent on soil moisture), terrain, and vegetation cover. Soil moisture and, in particular, surface wetness, can change dramatically after heavy rain events. Increased soil moisture after precipitation promotes evapotranspiration between storm events. This may contribute to enhanced convection and further precipitation. Soil moisture can vary both spatially, due to topography, soil, vegetation and precipitation variability, and temporally, due to differences in soil physical characteristics that control drainage and accumulated evapotranspiration.

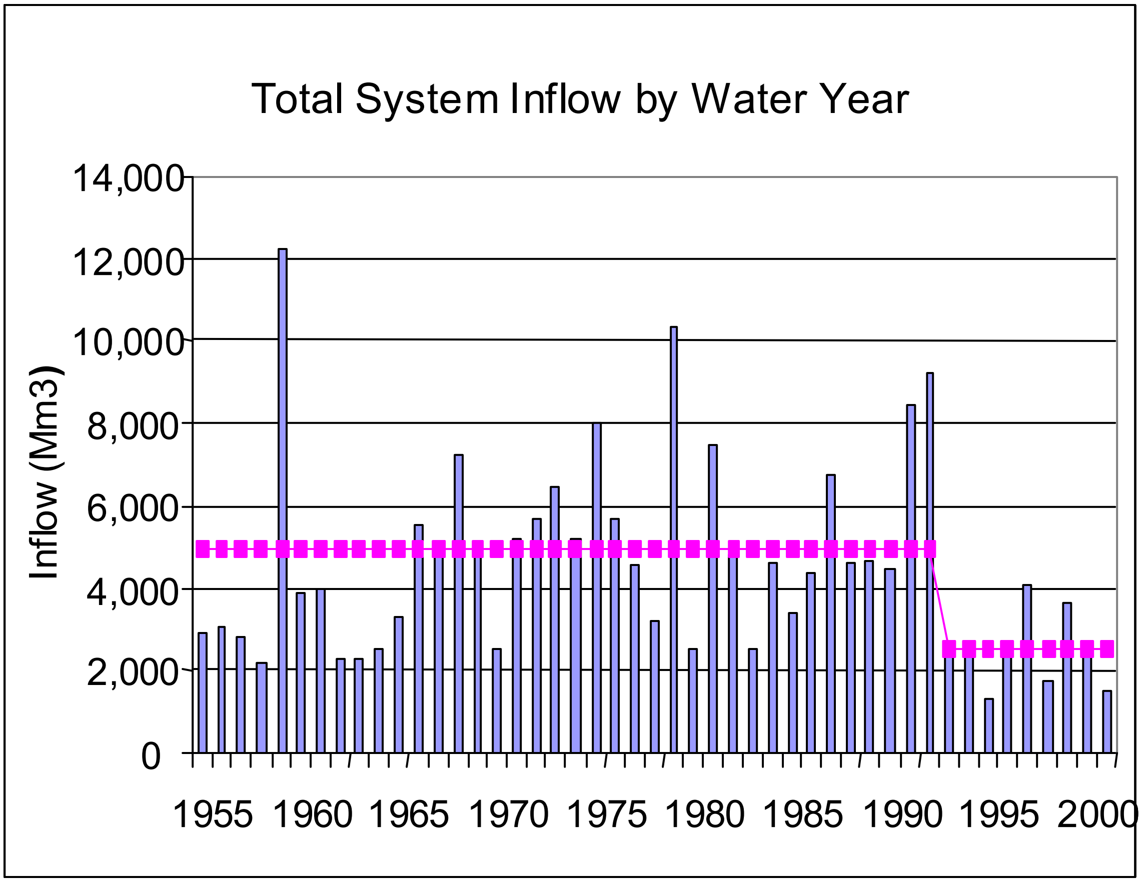


Figure 1: Total annual inflow to the Rio Bravo reservoir system, 1954-2001. [Note that three years during the drought period starting in 1993 have lower flows than any previously observed in the 48-year record. Figure from Vigerstol (2002).

Over much of the NAME region soil moisture observations are sparse and even precipitation observations that might be used to derive estimates of surface wetness are inadequate, especially in the region of northern Mexico that seems to be critical in initiating NAMS convective activity (Carbone 2002). The Soil Moisture Experiment 2004 (SMEX04) described here will focus on providing these critical soil moisture products using the new generation of satellite sensors. It will at the same time contribute to the validation of these products and expand our knowledge of the effects of key land surface features and the potential of new technologies for soil moisture mapping.

Remote sensing provides an alternative means of observing spatial and temporal variations in surface wetness over the region. Frequent derived estimates of soil moisture over much of the NAME region should be made possible through recently launched satellite microwave sensors, including the Advanced Microwave Scanning Radiometer (AMSR-E) on Aqua as well as the TRMM Microwave Imager (TMI). Figure 2 shows a sequence of TMI brightness temperature images for a few days in July of 2002 over the general NAME Tier 1 region (Figure 3). There is spatial structure and temporal consistency of some features. We also can observe a very large range of brightness temperatures, which suggests a high probability of success in deriving soil moisture.

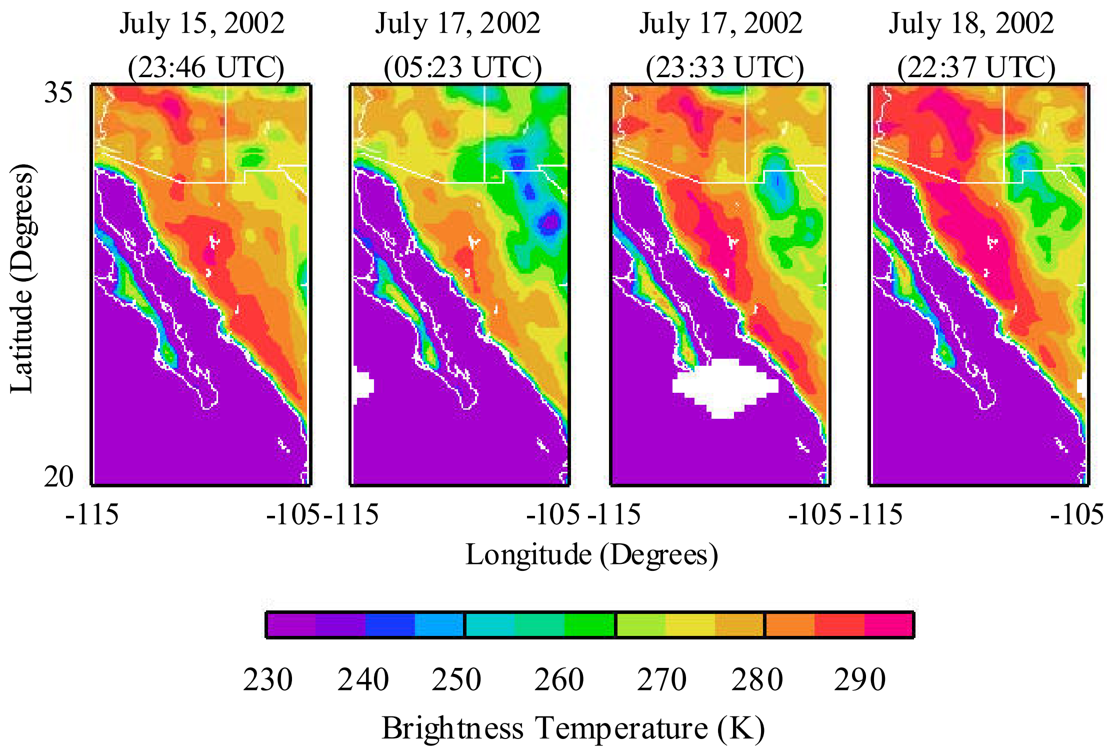


Figure 2. TRMM Microwave Imager 10.7 GHz H polarization maps of brightness temperature for the NAME Tier 1 region.

SMEX04 provides an excellent opportunity to evaluate AMSR products because much of the region has relatively sparse vegetation, which is important given the relatively short sensor wavelength (for soil moisture applications). Herein we propose to use high spatial resolution aircraft-borne passive microwave instruments with frequencies similar to AMSR and future L-band soil moisture missions, along with strategically located and designed automated and manual surface observations, to verify and extend the satellite observations over portions of the NAME region with sparse vegetation (here roughly delimited as areas with 3 kg/m^2 total vegetation biomass).

As outlined at http://www.cpc.ncep.noaa.gov/products/precip/monsoon/ in the NAME Science and Implementation Plan, hydrology and soil moisture are fundamental components of NAME research. At present, however, there are no provisions for collecting soil moisture observations. The U.S. CLIVAR Panel, in its review of the NAME Science and Implementation Plan, specifically pointed out that the land activities within NAME should be enhanced. Moreover, a soil moisture field component of NAME will provide an opportunity for the NASA Terrestrial Hydrology, Global Water Cycle, and Aqua AMSR-E Programs to become involved in a problem that has important scientific and practical implications while simultaneously addressing key NASA science priorities.

1.2 North American Monsoon Experiment (NAME)

The physical domain of the NAME comprises three tiers (see Figure 3). Field activities, high-resolution modeling, and the focus of most observation activities will be on Tier 1. However, it is recognized that the implications to and of the NAMS extend beyond the Tier 1 core region and, for this reason, larger Tier 2 and 3 domains are defined within which supporting modeling and other activities will be conducted, as necessary. It is worth noting that most of Tier 1 lies within the domain of the Land Data Assimilation System (LDAS) (Mitchell et al. in review) (which extends south to 25 N), and LDAS will therefore be able to provide some key information, such as historic precipitation and derived (modeled) soil moisture that will be important for comparison with satellite and aircraft observations.

The scientific objectives of NAME outlined in the Science and Implementation Plan (*http://www.cpc.ncep.noaa.gov/products/precip/monsoon/*) are to promote a better understanding and more realistic simulation of:

(1) Warm season convective processes in complex terrain (Tier 1);
(2) Intraseasonal variability of the monsoon (Tier 2);
(3) The response of the warm season atmospheric circulation and precipitation patterns to slowly varying, potentially predictable oceanic and continental surface boundary conditions (Tier 3);
(4) The evolution of the North American monsoon system and its variability.

In addition to these scientific objectives, NAME researchers will:
(5) interact with applications, assessment, and human dimensions researchers on the potential use of NAME science by end users.

The NAME Science and Implementation Plan specifically targets:

(1) Empirical and modeling studies, data set development, and enhanced monitoring activities that carry on some elements of the existing PACS program and the US CLIVAR/GEWEX Warm Season Precipitation Initiative (2000 onward) while initiating new elements to provide the spatial and temporal context for the NAME;
(2) *Field activities in the core region of the North American monsoon during the summers of 2004, including build-up, field, analysis and modeling phases (2003-2008);*
(3) Strong links between the VAMOS element of CLIVAR, US CLIVAR Pan American research, and the GEWEX America Prediction Project (GAPP).

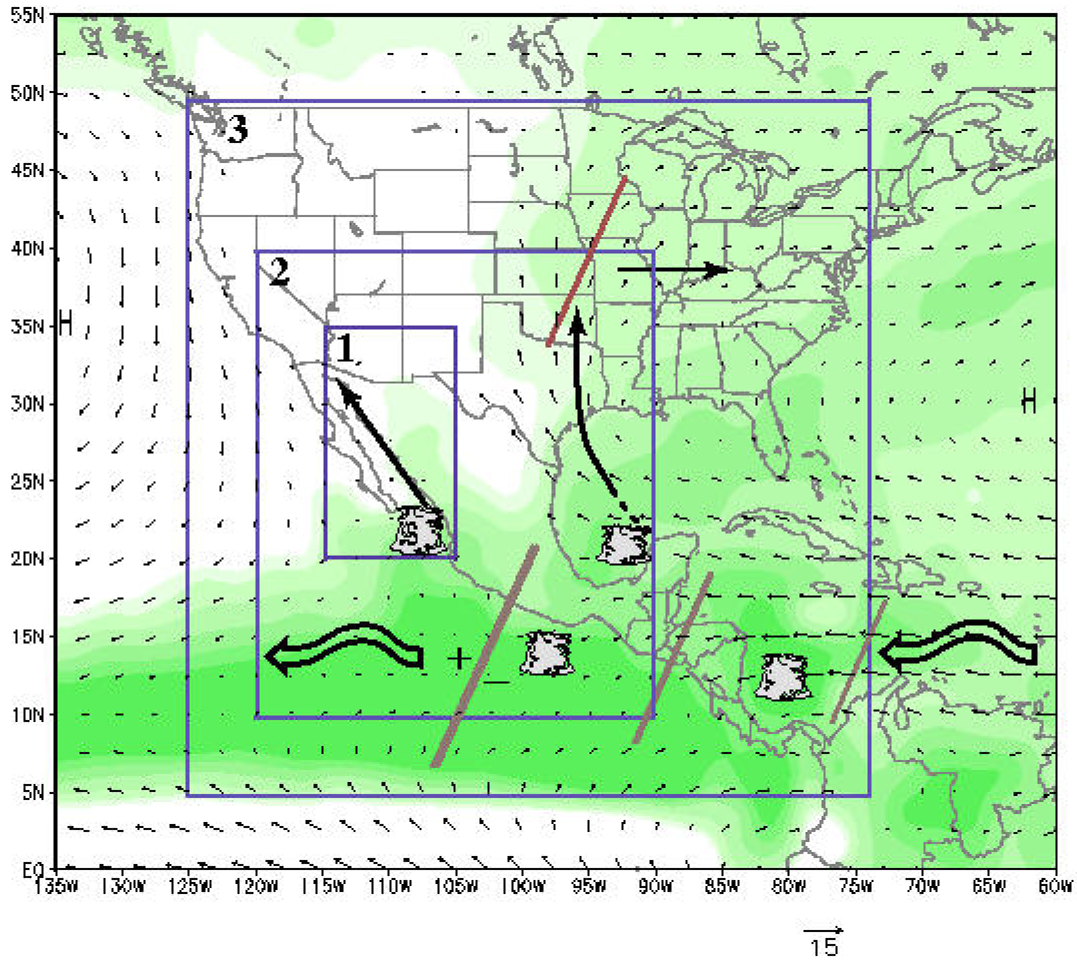


Figure 3. Scheme illustrating the multi-tiered approach of the North American Monsoon Experiment (from the NAME Implementation Plan).

The italic items above indicate the specific land activities of the NAME to which SMEX04 would address. The broader 2004 intensive observing period and associated field campaign is central to the NAME. It will consist primarily of oceanographic and near-surface atmospheric data collection from a research vessel, mostly near the mouth of the Gulf of California and along transects up the gulf, and aircraft micrometeorological and cloud physics data collected from flight lines of the NOAA P3, probably mostly over the coastal and Sierra Madre massif in the southern portion of Tier 1, the latter, to the extent possible, connecting with the Ron Brown transects. Land surface observations would be limited mainly to supplemental rain gauge transects (some of which have already been installed) along several major mainland roads from the coast inland to (and in some cases over) the Sierra Madre crest. NOAA is currently reviewing proposals that include additional observation activities. We intend to integrate these with SMEX04.

Although the supplemental precipitation gage network is expected to provide much higher quality data than are currently available, especially in areas of complex terrain, and will help to understand the interaction of topography and the diurnal cycle of precipitation during the monsoon period, it is not logistically feasible to provide a spatial context for variations in soil moisture from the transects alone. For this reason, we are proposing a soil moisture field activity that, in combination with LDAS and related supplemental products from the enhanced rain gauge network, will allow estimation of surface wetness over the NAME Tier 1 domain.

1.3 Relevance to NASA Hydrology Programs

The current research priorities of the NASA Terrestrial Hydrology Program (THP) related to soil moisture include science objectives that are complementary to the NAME project. These are (see Roadmap for Water Cycle for specifics):

(1) The development and validation of soil moisture retrieval algorithms using microwave remote sensing in regions with moderate to significant topographic variation;
(2) Validation of soil moisture products from the Aqua and ADEOS-II AMSR (Advanced Microwave Scanning Radiometer) instruments;
(3) Establishing long-term in situ soil moisture validation sites for satellite based retrievals;
(4) Evaluation of new sensor technologies and algorithms for future soil moisture missions including HYDROS and SMOS;
(5) Understanding the feedback mechanisms of surface soil moisture on weather and climate;
(6) Development of methods to assimilate surface soil moisture observations in models.

The NAME region includes a wide range of arid to semi-arid conditions and heterogeneous topography that would allow us to address objective 1. Between Hermosillo Mexico and Tombstone Arizona (Figure 4) the topography varies from flat deserts to mountains with elevations of more than 2500 m.

As part of ongoing efforts to validate soil moisture products from AMSR-E, several watershed sites in the U.S. have been instrumented to provide continuous long-term observations of surface soil moisture and temperature. The Aqua calibration/validation plan includes intensive experiments to calibrate and validate these sites using ground and aircraft observations. One of the sites is the Walnut Gulch Watershed near Tombstone Arizona. This site is in the NAME Tier 1 region and is hydrologically dominated by the NAMS. Integrating Walnut Gulch into the SMEX04 and NAME soil moisture field activities provides a bridge to the Aqua AMSR-E program and to the soil moisture remote sensing and summer Monsoon rainfall studies conducted there in the past. A second target site, which will also include in situ observations, is being established in the Sonora region of Mexico. The Sonora area is linked to the northern (Walnut Gulch) site by a major highway and has surface characteristics (topography, soils, and vegetation) that would complement but not duplicate those of the Walnut Gulch site with increased vegetation and topographic variability. The soil moisture activity would address objectives 2 and 3 of the NASA Terrestrial Hydrology Program.

The instruments providing soil moisture information to be flown on aircraft during the SMEX04 would include the L-Band passive microwave Two Dimensional Synthetic Aperture Radiometer (2DSTAR) and the NOAA Polarimetric Scanning Radiometer (PSR) with C and X band. If feasible, a Global Positioning System (GPS) based reflectometer used in previous experiments will also be included. Of these, the 2DSTAR and GPS represent new technology that is currently under development, and would therefore address THP’s objective 4.

THP's objectives 5 and 6 are central to the NAME science questions and objectives laid out in the Science and Implementation Plan. Consequently, the proposed soil moisture activity of SMEX04 in particular, and NAME, in general, is highly complementary with the Terrestrial Hydrology Program's soil moisture priorities.

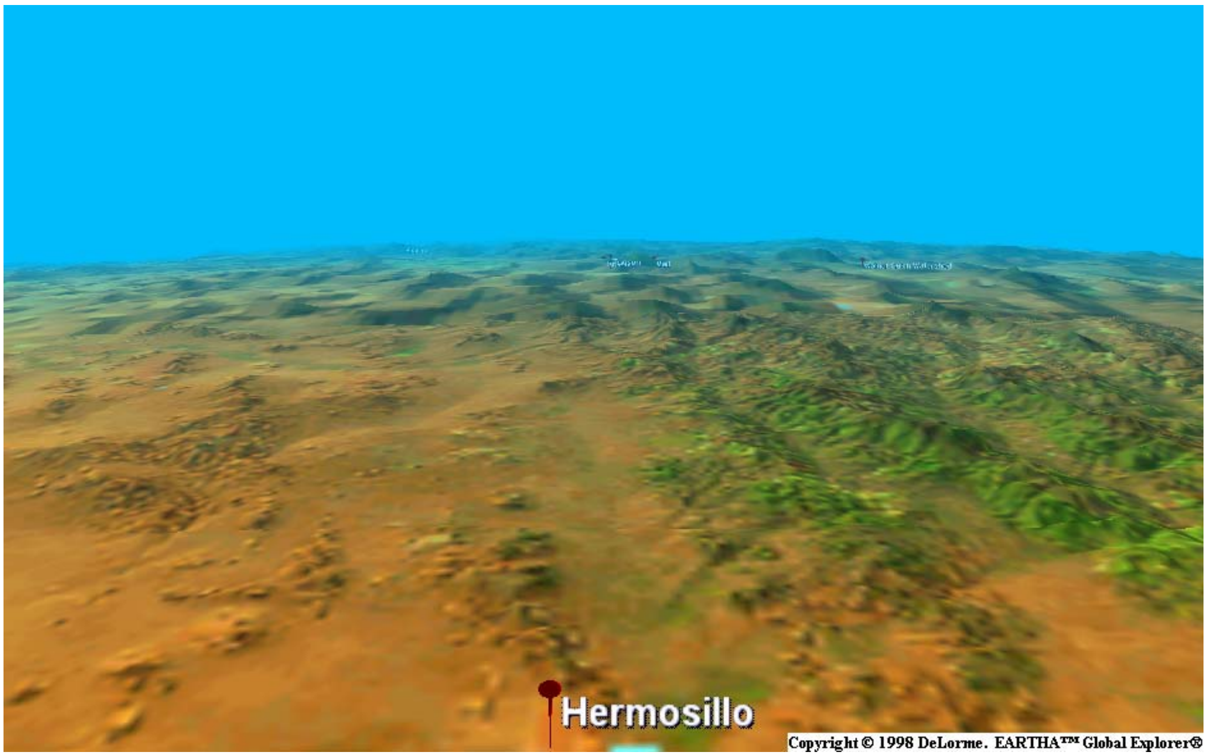


Figure 4. Three-dimensional perspective of the SMEX04 and NAME region looking north from Hermosillo to Tucson.

1.4 Elements of Soil Moisture Experiments in 2004 (SMEX04)

Field experiments in support of remote sensing, hydrology and climate have included catchments throughout North America (Little Washita, Oklahoma: SGP97, SGP99, SMEX03; Little River, Georgia: 2000, SMEX03; Walnut River, Iowa: SMEX02). These experiments have been intensive efforts ranging from one to six weeks in duration. The basic approach used in these experiments has been to collect ground-based samples of soil moisture in conjunction with aircraft flights at the same time as satellite overpasses. The aircraft instruments operate in low frequency microwave wavebands that are well suited for the measurement of soil moisture. The aims of these experiments have been:

(1) Validation of remotely sensed data from aircraft and/or space-borne microwave sensors, including validation of the retrieval algorithm and/or calibration of certain non-physical parameters in these algorithms

(2) The mapping of spatial and temporal variability of soil moisture, specifically, the spatial and temporal patterns after a dry-down.
(3) The relationship of soil moisture to vegetation and the near-surface atmospheric characteristics, as well as land-atmosphere interaction variables such as evapotranspiration and latent heat fluxes.
(4) The collection of in-situ gravimetric data for soil moisture for validation of the land surface hydrological models used to simulate the watershed at pre-specified spatial and temporal resolutions.

One of the main objectives of NAME is to improve prediction of warm season precipitation. Warm season precipitation is highly dependent on convection, which, in turn, is controlled, at least in part, by soil moisture and surface temperature. Therefore, an accurate characterization of spatial and temporal variability of soil moisture is critical to NAME in three ways, viz.,

(1) The spatial and temporal patterns of soil moisture estimated from remote sensing (by aircraft so as to provide high spatial resolutions) can be used for initialization and/or updating of the boundary conditions for the land surface component of land-atmosphere models.
(2) The spatial and temporal patterns of soil moisture can be used for validation of land surface model outputs, and to discern the relationship between soil moisture and warm season precipitation and associated feedback mechanisms.
(3) Aircraft-based soil moisture mapping can provide a basis for model-based extrapolation over Tier 1, using methods developed under LDAS and AMSR validation studies. For the larger Tier 2 and 3 regions, satellite retrievals using AMSR will be most appropriate, and will be validated using AMSR data as well as in-situ measurements from networks like the Oklahoma Mesonet.

The timing of SMEX04 and the NAME EOP are driven by the NAMS. Table 1 shows the number of rainy days in the NAME area for the Hermosillo Mexico region for 1965-2001. This table also gives the average monthly rainfall in Hermosillo. These statistics illustrate interesting aspects of the regional precipitation. First, the number of rainy days in June is very small, i.e.1-4 days whereas the number of rainy days in July/August is much larger, viz., 6-18 days. Secondly, the average rainfall in June is 7.3 mm whereas the average rainfall in July/August is 90.7/94.7 mm (greater by a factor of 10). About half of the annual precipitation falls in July and August.

These statistics demonstrate quite clearly that the field experiment should be centered around the period roughly mid-July to mid-August, when the number of rainy days is large and the possibility of having a having flights prior-to and subsequent to heavy rainfall is high.

SMEX04 will involve four complementary elements;

- In-situ soil moisture networks
- Aircraft mapping of soil moisture
- Intensive sampling concurrent with aircraft mission
- Satellite products

Table 1. Rainfall (1965-2000) Characteristics by Month for Hermosillo Mexico

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Number of days with Rainfall	2.5	2.1	1.3	0.7	0.4	0.9	9.4	8.5	4.5	1.9	1.6	3.1
Maximum Number of days with Rainfall	8	7	5	3	4	5	18	14	11	9	5	9
Average Monthly Rainfall (mm)	18.2	18.6	7.2	3.9	3.7	7.3	90.7	94.7	53.2	17.5	15.1	27.1

Ground based observations will include a combination of in-situ and mobile soil moisture data collection. A network of continuous point observations of surface soil moisture will be established within two regions of the study domain. One of these will be the Walnut Gulch Watershed in Arizona. The other will be within northern Mexico. Each region will utilize the same soil moisture instrumentation (Vitel sensors HYD-50A). Each network will include 15 or more sites distributed over a nominal AMSR-E low frequency footprint. Data will be collected continuously over an extended time period, longer than the EOP. The Walnut Gulch network is currently operating.

The sparse network described above would be supplemented with more intensive observations by mobile teams during the intensive observing period on specific days with either aircraft and/or satellite observations. The soil moisture sampling teams would use more traditional gravimetric methods. Data would be collected by teams from the participating U.S and Mexican institutions.

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. A NASA aircraft (P-3B) will be used with a X, C, and L band microwave radiometers. Missions will be flown approximately every other day and timed to coincide with satellite coverage.

By the time of SMEX04, both U.S. and Japanese AMSR-E algorithm science teams will be producing standard soil moisture products for areas of low vegetation cover. The experiment team will facilitate the analysis and distribution of these products to the broader NAME science and forecast team for evaluation. This will be continued beyond the IOP and may be expanded to the entire Tier 1 area or larger domain.

2 REGIONAL SOIL MOISTURE NETWORKS

Two regional study sites will be used, Walnut Gulch Arizona (AZ) and Sonora Mexico (SO). The general vegetation conditions for the two sites are shown in Figure 5. Vegetation in AZ will be less than SO as will be the topographic variability. The following sections describe these sites and the regional networks.

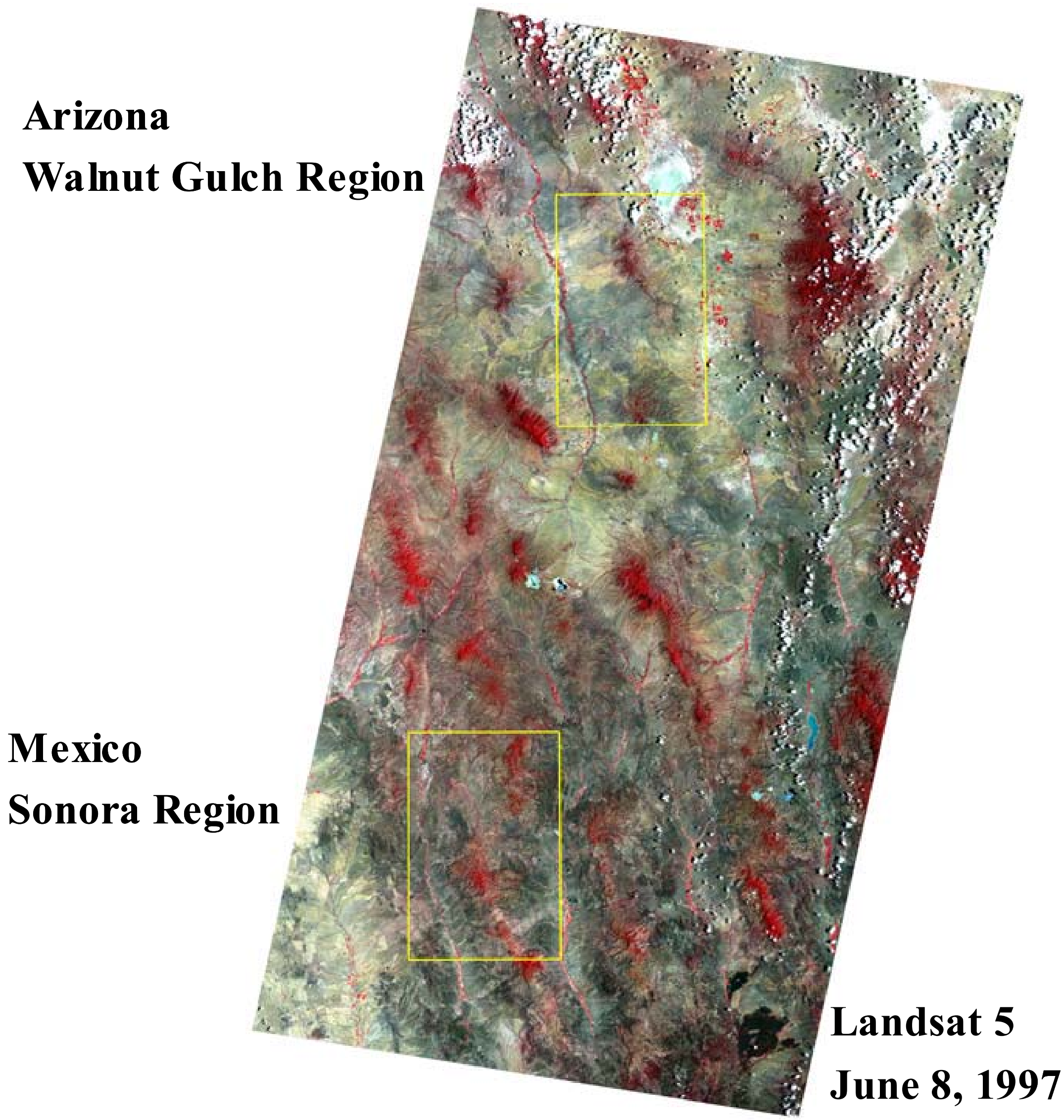


Figure 5. Landsat image with regional study areas.

2.1 Arizona Region

2.1.1 Region Description

The core of the Arizona region (AZ) is the USDA-ARS Walnut Gulch Experimental Watershed (http://tucson.ars.ag.gov/unit/Watersheds/WGEW.htm. The Walnut Gulch Experimental Watershed encompasses the 150 square kilometers in southeastern Arizona, U.S.A. (31^o 43'N, 110^o 41'W) that surrounds the historical western town of Tombstone. The watershed is contained within the upper San Pedro River Basin, which encompasses 7600 square kilometers in Sonora, Mexico and Arizona (Figure 6). The watershed is representative of approximately 60 million hectares of brush and grass covered rangeland found throughout the semi-arid southwest and is a transition zone between the Chihuahuan and Sonoran Deserts. Elevation of the watershed ranges from 1250 m to 1585 m MSL. Cattle grazing is the primary land use with mining, limited urbanization, and recreation making up the remaining uses. Walnut Gulch, being dry about 99% of the time, is an ephemeral tributary of the San Pedro River.

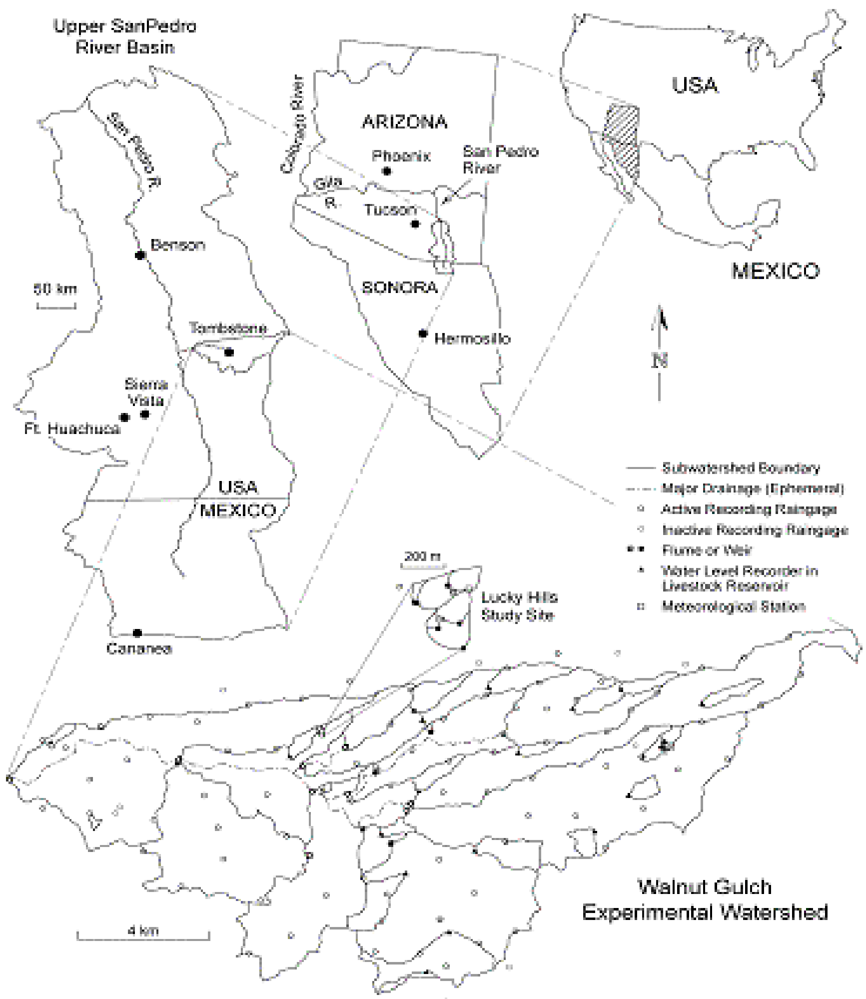


Figure 6. Arizona-Walnut Gulch region.

Walnut Gulch was the focus of the Monsoon'90 experiment (Kustas et al. 1991) that included extensive microwave remote sensing (Jackson et al. 1992, Goodrich et al. 1994, Schmugge et al. 1994) and subsequent modeling efforts (Houser et al. 1998). In 1991 it was the first soil moisture study conducted with the ESTAR (Jackson et al. 1994).

This region has been the focus of a long term project by USDA and NASA called SALSA (http://www.tucson.ars.ag.gov/salsa/archive/archive.html and http://www.tucson.ars.ag.gov/salsa/archive/documents/background/salsa_fact_sheet_apr98.html.

Climate. Walnut Gulch Experimental Watershed lies in the transition zone between the Sonoran and the Chihuahuan Deserts. The climate is classified as semi-arid, with mean annual temperature at Tombstone of 17.7°C and mean annual precipitation of 350 mm. On average there are 53 days of precipitation per year and most accumulation is as rainfall. The precipitation regime is dominated by the North American Monsoon with slightly more than 60% of the annual total coming during July, August and September; about 1/3 coming during the six months October through March (Figure 7). Summer events are localized short-duration, high-intensity convective thunderstorms driven by the intense solar heating of the land surface and moisture inputs from the Gulf of Mexico and Gulf of California. Winter storms are generally slower moving, frontal systems from the Pacific Ocean. These frontal systems generate longer duration and lower intensity precipitation that covers larger areas. The two opposite phases of the ocean-atmosphere phenomenon El Nino-Southern Oscillation (ENSO), referred to as El Nino and La Nina, affect winter precipitation with greater than normal precipitation during El Nino periods and less than normal precipitation during La Nina episodes. Virtually all runoff is generated by summer thunderstorm precipitation and runoff volumes and peak flow rates vary greatly with area and on an annual basis.

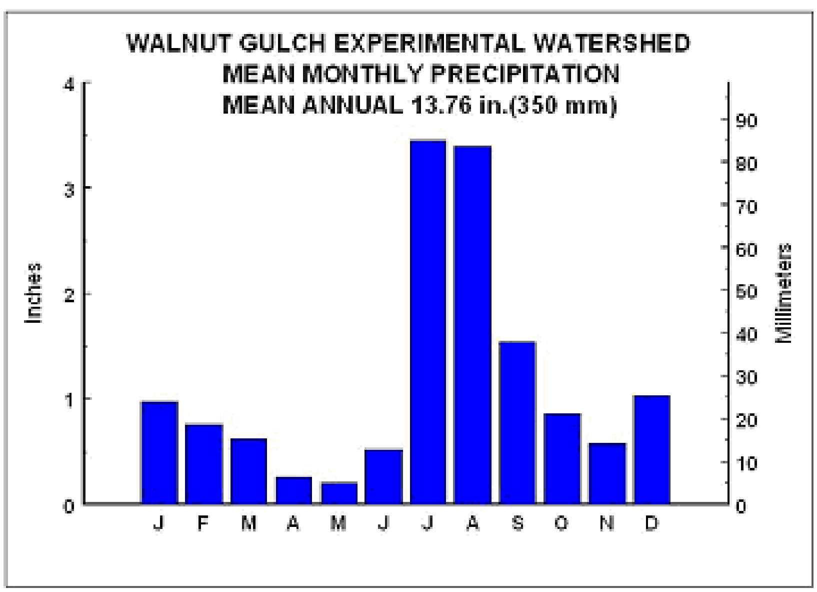


Figure 7. Average monthly precipitation in the Walnut Gulch Watershed.

Soils. Soils on the Walnut Gulch Experimental Watershed reflect the geologic parent material from which they developed (Figure 8). The limestone influenced alluvial fill parent material is dominant on the watershed. The soils that developed from this material are generally well-drained, calcareous, gravelly loams with large percentages of rock and gravel at the soil surface. Soil surface rock fragment cover (erosion pavement) can range from nearly 0% on shallow slopes to over 70% on the very steep slopes. NRCS has mapped 27 soil series on the watershed. The major soil series presently defined on this area are Blacktail (fine, mixed, thermic, Aridic Argistolls), McAllister (fine-loamy, mixed, thermic, Ustollic Haplargids), Elgin (fine, mixed, thermic, Ustollic Paleargids), Sutherland (loamy-skeletal, carbonatic, thermic, shallow Ustollic Paleorthids), Monterosa (loamy-skeletal, mixed, thermic, shallow Ustollic Paleorthids), Stronghold (coarse-loamy, mixed, thermic, Ustollic Calciorthids), Luckyhills(coarse-loamy, mixed, thermic, Ustochreptic Calciorthids). The uppermost 10 cm of the soil profiles contain up to 60% gravel, and the underlying horizons usually contain less than 40% gravel. The remaining soils developed from igneous intrusive materials and are generally cobbly, fine textured, shallow soils.

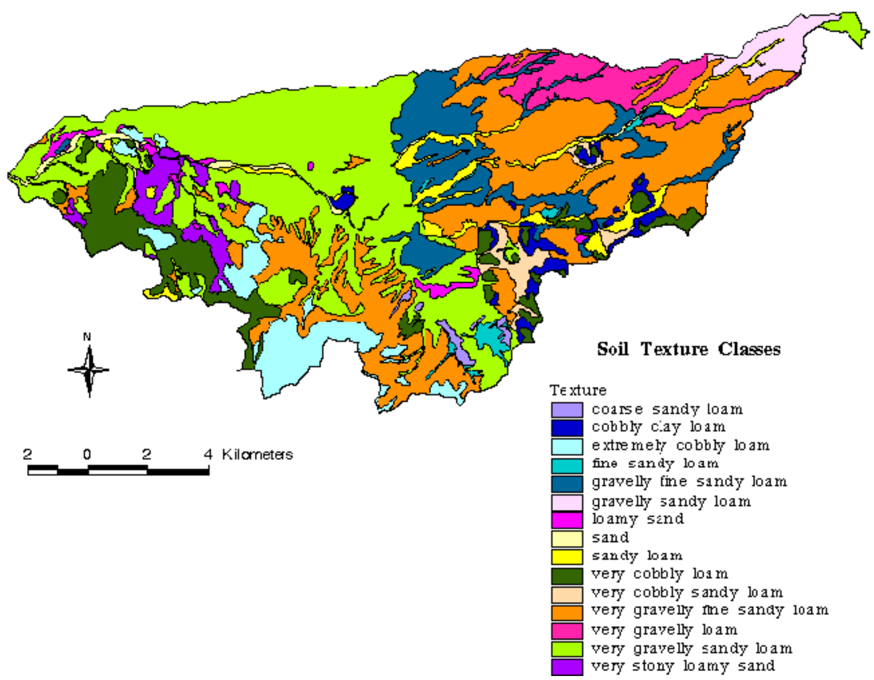


Figure 8. Soil texture map of the Walnut Gulch Watershed**.**

Vegetation. Although historical records indicate that most of the Walnut Gulch Experimental Watershed was grassland approximately 100 years ago, shrubs now dominate the lower two-thirds of the watershed (Figure 9). Major watershed vegetation includes the shrub species of creosote bush (Larrea tridentata), white-thorn (Acacia constricta), tarbush (Flourensia cernua), snakeweed (Gutierrezia sarothrae), and burroweed (Aplopappus tenuisectus); and grass species of black grama (Bouteloua eriopoda), blue grama (B. gracilis), sideoats grama (B. curtipendula), bush muhly (Muhlenbergia porteri), and Lehmann lovegrass (Eragrostis lehmanniana). Shrub canopy cover ranges from 30 to 40% and grass canopy cover ranges from 10 to 80%. Average annual herbaceous forage production is approximately 1200 kg/ha. Figures 10 and 11 illustrate the general features of the vegetation cover in the watershed.

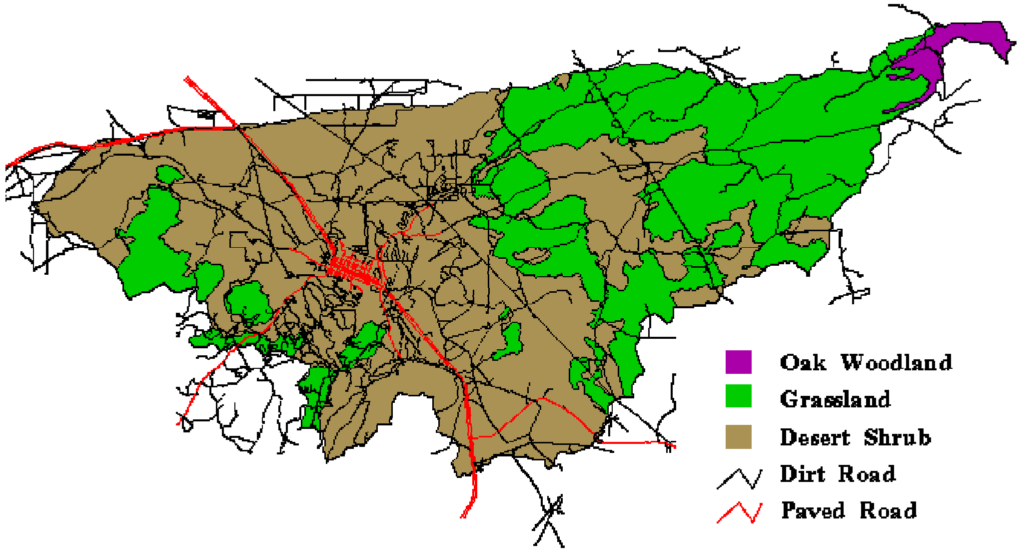


Figure 9. Vegetation map of the Walnut Gulch Watershed.

Figure 10. Shrub dominated lower part of watershed.

Figure 11. Grass dominated upper part of watershed.

Instrumentation. The Walnut Gulch Experimental Watershed is one of the most densely instrumented semi-arid watersheds in the world. Rainfall is currently recorded on a continuous basis at 88 locations using digital recording weighing rain gauges (Figure 12). Runoff is measured using a variety of methods from 29 nested watersheds whose drainage areas range in scale from 0.2 to 14,800 hectares. On a daily basis, all locations are automatically and sequentially queried and data are transmitted to a dedicated computer at the Tombstone field office. Data are archived, used to generate daily reports and written to the Tucson SWRC network server using a 56K phone line.

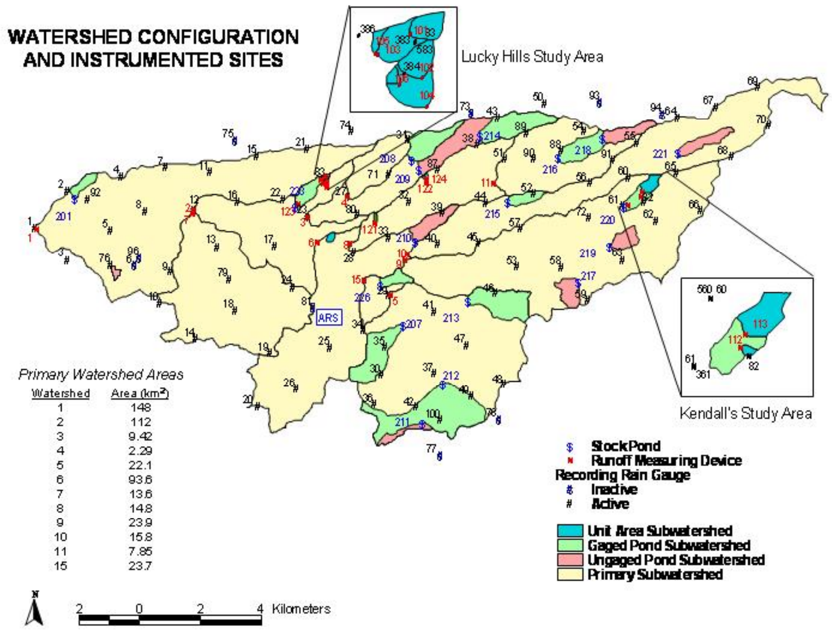


Figure 12. Walnut Gulch raingage sites.

Two intensive study areas of particular interest are the Lucky Hills (brush dominated) and Kendall (grass dominated) unit source watershed areas (nested micro-watersheds ranging in area from 0.2 to 60 ha). At these two sites near continuous energy and water balance measurements have been made since 1990 and since 1996 carbon fluxes have also been measured at these sites. Long term soil moisture and temperature measurements in multiple depth profiles (to roughly 80 cm in depth) have been made since 1990 at the Lucky Hills and Kendall micro-watersheds. Soil moisture has been measured using time domain reflectometry and electrical resistance sensors.

2.1.2 Network Description

The raingage network in the Walnut Gulch Watershed was mentioned above. Recently, as part of a project sponsored by the NASA Aqua Calibration/Validation Program surface soil moisture sensors have been installed at a number of locations in the Walnut Gulch Watershed and surrounding region.

Twenty-seven Vitel soil moisture probes have been installed at twenty-one locations on or near the 150 km^2 the watershed in the vicinity of Tombstone AZ. Nineteen locations are on the watershed, all of which are co-located with electronic-measuring digital-recording raingages;

sixteen of these have a single sensor at 5 cm depth, the other three sites on WGEW have a shallow profile array of 3 sensors at 5, 15 and 30 cm. Two sites, both sensors installed at 5 cm, are within about 10 km of WGEW, one north co-located with a recording raingage, one west co-located with a meteorological/flux station. All data are recorded at 30-minute intervals. All three shallow profile sites, all 16 single sensor sites on the watershed and one of the off-watershed single sensor sites have been integrated into the existing radio-telemetry data-acquisition network. Data from this network are automatically downloaded from Campbell Scientific CR10X data loggers daily. The remaining off-watershed sensor is recorded to a Campbell Scientific 21X data logger and manually downloaded every week.

The selected subset of raingage sites (Table 2) provide watershed-area coverage, a range of soil types and accessibility. The sites selected are RG's 3, 13, 14, 18, 20, 28, 34, 37, 40, 46, 57, 69, 70, 76, 82, 83, 89, 92 and 100 (see map and coordinate table). The 19 raingage sites (16 single and 3 profile) are located on 16 different soil types.

RG 83 (Lucky Hills), RG82 (Kendall) and near RG 46 (clay site) each has 3 Vitel probes at 5, 15 and 30 cm depth. The Lucky Hills raingage 83 site is about 100 m west of the NRCS SCAN site (Figure 13), which has Vitel soil moisture probes at 5, 10, 20, 50 and 100 cm. Also nearby the SCAN site is a meteorological station with Dynamax Thetaprobes at 5, 15 and 30 cm, and a proposed soil moisture trench (to be installed 10/02) with TDR probes at 5, 15, 30, 50, 100, 150 and 200 cm. Near the Kendall raingage 82 is a meteorological station with Dynamax Thetaprobes at 5, 15 and 30 cm.

Figure 13. The NRCS SCAN site in the Walnut Gulch Watershed.

RG 400 (Windmill) is located approximately 15 km north of the center of Tombstone, is accessible from the highway and has radio telemetry. The San Pedro site is located in a mesquite bosque about 100 m east of the San Pedro River, approximately 15 km WSW from the center of Tombstone. The sensor is installed at a highly instrumented meteorological/flux/soil research site operated by SWRC. Other soil moisture measurements are made with Campbell Scientific Water Content Reflectometer (WCR) probes (CSI-615).

Table 2. Locations of Arizona Network Sites.				
RG#	Easting (m)	Northing (m)	Elev. (m)	Soil Type
3	581265	3509566	1253	Off watershed but 'sandy'
13	586181	3509986	1327	Monterosa very gravelly fine sandy loam
14	585495	3506970	1373	Chiricahua very gravelly clay loam
18	586778	3507884	1358	Shiefflin very stony loamy sand
20	587543	3504739	1519	Mabray-Chiricahua-Rock-Outcrop complex
28	590669	3509803	1369	Graham cobbly clay loam
34	591018	3507252	1420	Sutherland very gravelly fine sandy loam
37	593354	3505864	1407	Monterosa very gravelly fine sandy loam
40	593449	3510092	1392	Baboquivari-Combate complex
57	596162	3512115	1462	Tombstone very gravelly fine sandy loam
69	603982	3515260	1640	Blacktail gravelly sandy loam
70	604327	3514015	1632	Woodcutter gravelly sandy loam
76	582707	3509391	1312	Lampshire-Rock Outcrop complex
89	596373	3513731	1483	Stronghold-Bernardino complex
92	581955	3511576	1251	McAllister Stronghold complex
100	593548	3504309	1436	Mabray Rock Outcrop complex
Profile Sites				
46	595346	3508470	1440	clay
82	600225	3511469	1521	Elgin Stronghold complex
83	589765	3512232	1367	Luckyhills McNeal complex
Off Watershed Sites				
400	582120	3518828	1266	off watershed but sandy
SP	577947	3503457	1215	more organic material than other

2.2 Sonora Region

2.2.1 Region Description

Some of the regional characteristics presented for the Arizona region apply to the Sonora. There is more significant topographic variation and a greater amount and mixture of vegetation within the area of Sonora that has been selected.

2.2.2 Network Description

Based upon previous experiences we anticipate that the soil moisture instruments will be installed at 15 locations distributed over a 50 by 75 km domain. Figure 14 shows the sites and land cover characteristics. Table 3 lists the geographic information for the network sites. We will install Vitel sensors (HYD-50A) along with raingages. All sites will have a 5 cm depth sensor and three or four will be profile with surface infrared measurement also. All instruments will be connected to Campbell Scientific (e.g., CR10X) recorders and reporting at a fixed interval such as 15 minutes. The probes provide soil moisture and temperature. The network should be established as soon as possible and could be left in place for an extended period.

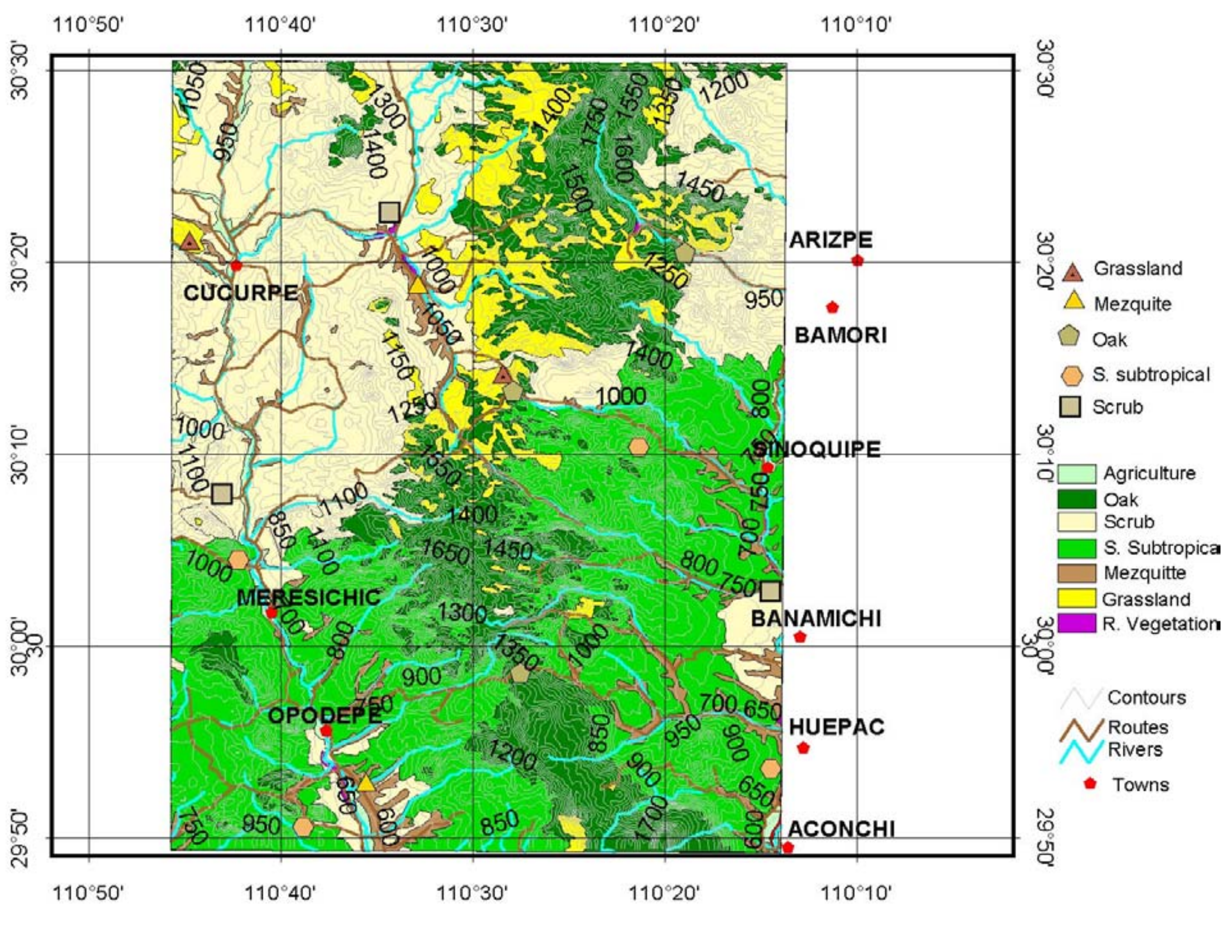


Figure 14. Locations of Sonora Network Sites.

Table 3. Sonora Network Site Geolocation Information							
Site	Vegetation Type	Location	X(m)	Y(m)	Lon (W)	Lat (N)	Altitude (m)
1	S. subtropical	Sinoquipe-M. kino	562041	3337916	-110.35566	30.17267	950
2	Oak	Bamori	565800	3356695	-110.31545	30.34193	1200
3	Grassland	Bamori	566566	3357370	-110.30744	30.34798	1200
4	mezquite	Rayon-Opodepe	539316	3305536	-110.59287	29.88139	650
5	mezquite	Sinoquipe-Cucurpe	543486	3353463	-110.54773	30.31378	1000
6	Grassland	Sinoquipe-Cucurpe	550600	3344844	-110.47415	30.23572	1200
7	Grassland	Cucurpe-M. kino	524402	3357605	-110.74612	30.35169	950
8	Oak	Opedepe-Huepac	552253	3316144	-110.45838	29.97664	1300
9	Oak	Sinoquipe-Cucurpe	551494	3343320	-110.46494	30.22193	1200
10	S. subtropical	Aconchi-Huepac	573241	3307027	-110.24147	29.89329	700
11	S. subtropical	Rayon-Opodepe	534088	3301228	-110.64714	29.84267	750
12	S. subtropical	Opodepe-Cucurpe	528618	3326883	-110.70308	30.07434	750
13	Scrub	Opodepe-Cucurpe	527197	3333190	-110.71767	30.13129	850
14	Scrub	Sinoquipe-Cucurpe	541101	3360356	-110.57226	30.37606	1000
15	Scrub	Banamichi-Sinoquipe	573105	3324121	-110.24171	30.04756	700

note: LON/LAT, spheroide clarke 1866, datum NAD27
UTM, spheroide clarke 1866, zone 12, datum NAD27

3 AIRCRAFT REMOTE SENSING CAMPAIGN

3.1 Flightlines and Mission Profile

Considerations and constraints on mission design (based on SMEX04 specific objectives, and past experience with similar campaigns) include:

- The intensive observing period will be approximately July 15 – August 15, 2004
- The NASA WFF P-3B will be the aircraft platform. The anticipated base of operations will Tucson International Airport in Tucson, AZ
- Daily mission duration should be limited to no more than six hours, but four is preferred
- All data must be normalized for physical temperature in order to produce synoptic maps. (Note: this becomes more difficult to achieve, as mission duration gets longer. In the past the duration has been restricted to about 3 hours.)
- Coverage will be timed to bracket the afternoon AMSR-E overpass time of 1:30 pm
- Since the rainfall may be localized, including as large a spatial domain as possible will increase the probability of observing a wide range of conditions
- A water body in the U.S. will be added to the flightline list at a later time
- Flightlines will be flown at an altitude of approximately 7300 m above sea level

The two areas chosen for aircraft mapping include the insitu networks previously described and will provide coverage of boxes approximately 50 km by 75 km in size. As shown in Figure 15 and 16 this includes six Ease-grid cells. Geolocation information is provided in Table 4. Four flightlines would be used to achieve a 60 km swath.

Table 4. Geolocation Information for NAME Soil Moisture Project

Region or Site	Line	Latitude (Deg.)	Longitude (Deg.)
Tucson Airport		32.115	-110.941
Walnut Gulch Watershed		31.737	-110.032
Hermosillo, Mexico		29.050	-110.950
AZ Region	AZ1	30.51	-110.68
		29.84	-110.68
	AZ2	29.84	-110.58
		30.51	-110.58
	AZ3	30.51	-110.47
		29.84	-110.47
	AZ4	29.84	-110.37
		30.51	-110.37
Sonora Region	SO1	30.505	-110.7
		29.837	-110.7
	SO2	29.837	-110.6
		30.505	-110.6
	SO3	30.505	-110.5
		29.837	-110.5
	SO4	29.837	-110.4
		30.505	-110.4

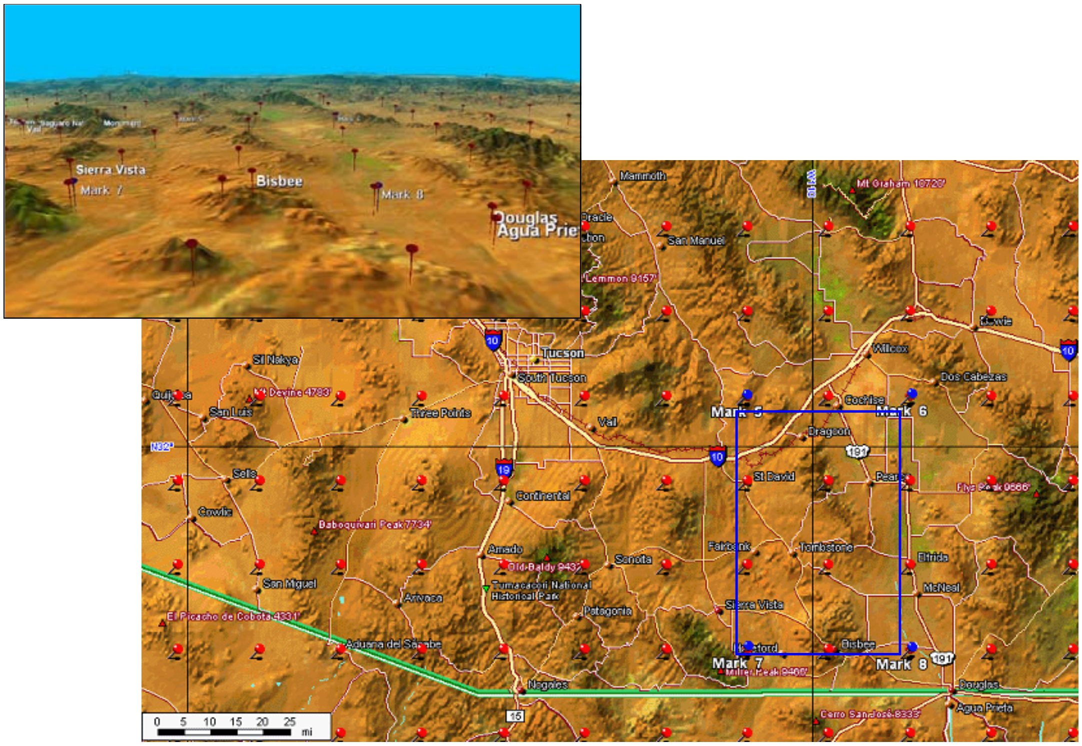


Figure 15. The AZ aircraft mapping area.

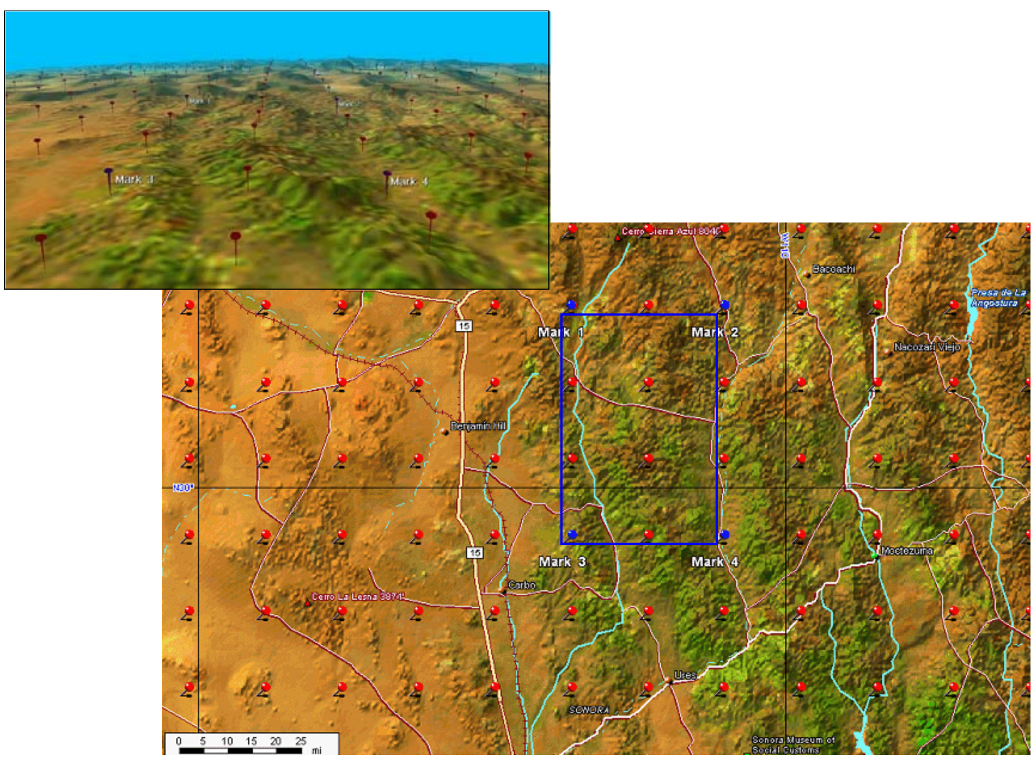


Figure 16. The SO aircraft mapping area.

3.2 P-3B Aircraft

The P-3B (Figure 17) operates from the NASA Wallops Flight Facility in Wallops Island, VA. Details on the aircraft can be found at http://www.wff.nasa.gov/. It will have the PSR, 2DSTAR, and GPS sensor systems on board. The primary mission of the P3-B is to collect high altitude data over the study regions with the PSR instrument. Another very important objective is to collect data with the 2DSTAR over the regions. Mission design and operations are dependent on the PSR and not the 2DSTAR.

Figure 17. The NASA WFF P-3B aircraft.

3.3 Instruments

3.3.1 Polarimetric Scanning Radiometer (PSR)

The PSR is an airborne microwave imaging radiometer operated by the NOAA Environmental Technology Laboratory (Piepmeier and Gasiewski 2001) for the purpose of obtaining polarimetric microwave emission. It has been successfully used in several major experiments including SGP99 and SMEX02 (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 SMEX04, the PSR/CX scanhead will be integrated onto the NASA WFF P-3B aircraft in the aft portion of the bomb bay. The PSR/CX scanhead is an upgraded version of the previously successful PSR/C scanhead used during SGP99 and was used in SMEX02 and SMEX03 (Figure 18 and Table 5).

The PSR/CX scanhead will have the polarimetric channels listed in Table 5 for SMEX04. The system will be operated in two imaging modes, both using conical scanning. Mapping characteristics are described in Table 6. Figure 19 shows the results of one day of mapping brightness temperature using the PSR in SGP99.

At the end of a each set of flight lines a steep (~60 degree) port roll will be requested for the purpose of calibrating the PSR radiometers using cold sky looks. Additional details on the PSR not presented here can be found at http://www1.etl.noaa.gov/radiom/psr/.

Figure 18. PSR/C scanhead installed on the NASA P3-B aircraft during the SGP99 experiment.

Table 5. PSR/CX Channels for SMEX04		
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	V+h	7°

* Indicates close to an AMSR-E channel.

Table 6. PSR Flightline and Mapping Specifications for SMEX04		
	Wide Area Imaging	High-Resolution Imaging
Altitude (AGL) in m	7300	1800
Number of parallel flight lines	4	4
Flight line length (km)	150	50
Flight line spacing (km)	19	4.75
Scan period (seconds)	8	3
Incidence angle (deg)	55	55
3-dB footprint resolution	3.0 km at 6 GHz 2.0 km at 10 GHz	750 m at 6 GHz 500 m at 10 GHz
Sampling	Oversampling above Nyquist	Nyquist

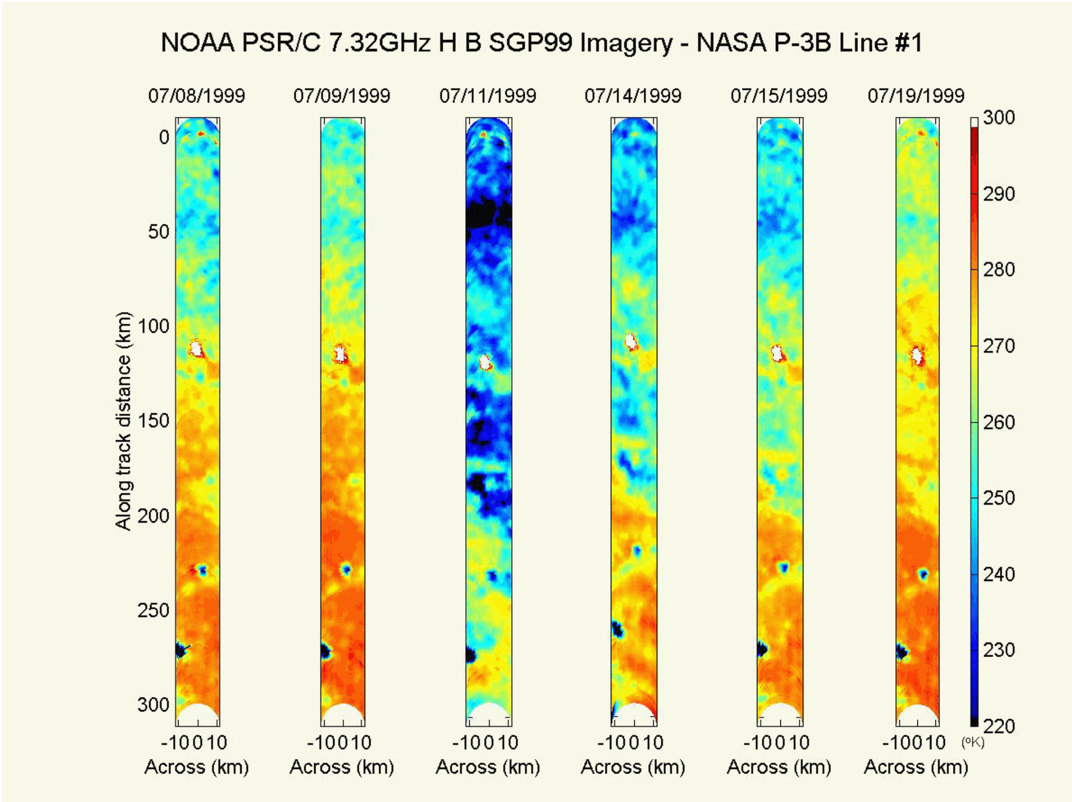


Figure 19. SGP99 PSR/C conically-scanned brightness temperature imagery 7.325 GHz channel, H-polarization, North looking.

3.3.2 L Band Two Dimensional Synthetic Aperture Radiometers (2DSTAR)

Aperture synthesis is an interferometric technique that has the potential to break through the barrier on resolution set by antenna size on future passive microwave instruments in space. The technique has been applied successfully to earth remote sensing using synthesis in one dimension (the L-band radiometer, ESTAR) (Le Vine et al. 1990 and 1994). New research is being conducted at the Goddard Space Flight Center and University of Massachusetts to go the next step and demonstrate the potential of aperture synthesis in both dimensions for meeting future remote sensing goals. An aircraft prototype instrument operating at L-band is being built by this team with ProSensing Inc. This prototype uses digital correlation and employs a configurable antenna that can be arranged into several thinned array configurations.

2DSTAR consists of three major subsystems, the antenna array, the RF receiver and the digital processor. The antenna array consists of a rectangular array of dual polarized, patch antennas tuned to L-band (1.413 GHz). In the 2DSTAR instrument, the digital processor averages for a minimum time (on the order of 0.1 second, but adjustable) and then hands the products over to the data system, which stores them and does further averaging as desired. Figure 20 shows the detail of the antenna array. A fully populated, rectangular array of patches is being built. However, only some of the patches will be connected to a receiver. For example, the instrument could operate as a thinned array in the shape of a cross, "+", as shown in Figure 20. A fully populated array is being built so that different configurations can be tried and to minimize effects of mutual coupling by providing a common environment for each patch.

The 2DSTAR instrument has been designed to operate from an aircraft (the NASA P-3) in a nadir looking orientation as shown in Figure 21. Using aperture synthesis, one obtains a map of the entire field-of-view of each individual antenna in each integration cycle. This allows for a number of processing options. For example, it allows one to arrange the pixels in the equivalent of a conical scan as illustrated in Figure 21 or to use the multiple looks that one obtains with each pixel as it moves through the field-of-view to reduce noise by averaging or to retrieve additional data. In the later case, because a given pixel is viewed at different incidence angles as it moves through the field of view, it may be possible to retrieve parameters such as attenuation in the canopy in the case of a soil covered with a layer of vegetation.

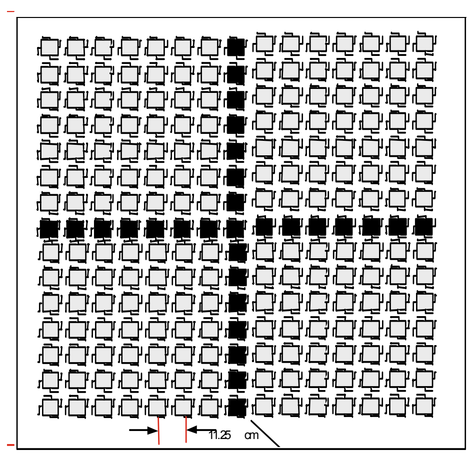


Figure 20. Antenna patch array shown configured for measuring using a cross "+" configuration.

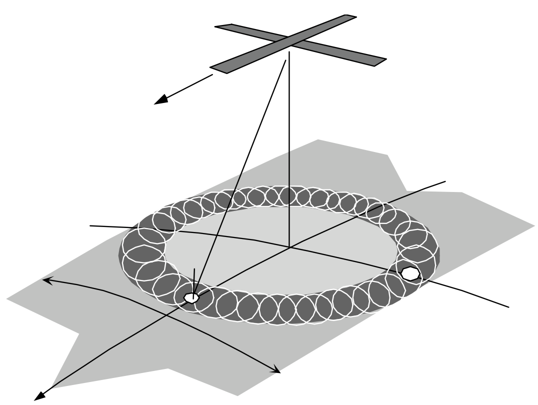


Figure 21. A thinned array in a nadir-pointing mode illustrating the potential for conical scanning.

3.3.3 Global Positioning System (GPS) Bistatic Radar

Use of Global Positioning System (GPS) signals reflecting off of land and ocean surfaces is under research as a new, potentially inexpensive remote sensing tool [Armatys et al., 2000, Masters et al., 2000, 2001]. The GPS Bistatic Radar instrument measures L-band GPS satellite signals reflecting from the land surface to estimate soil moisture. Simultaneous measurement of both direct and surface-reflected GPS signals constitutes a bistatic radar system, with transmitters located at GPS satellites and a separate receiver located on an aircraft platform. Land surface bistatic radar cross sections are estimated using relative measurements of the reflected signal power and measurements of the direct, line-of-sight signal power. Surface soil moisture can subsequently be inferred from the bistatic cross section estimates along with information on the surface roughness characteristics and soil properties. A general illustration of how this is used for remote sensing is shown in Figure 22.

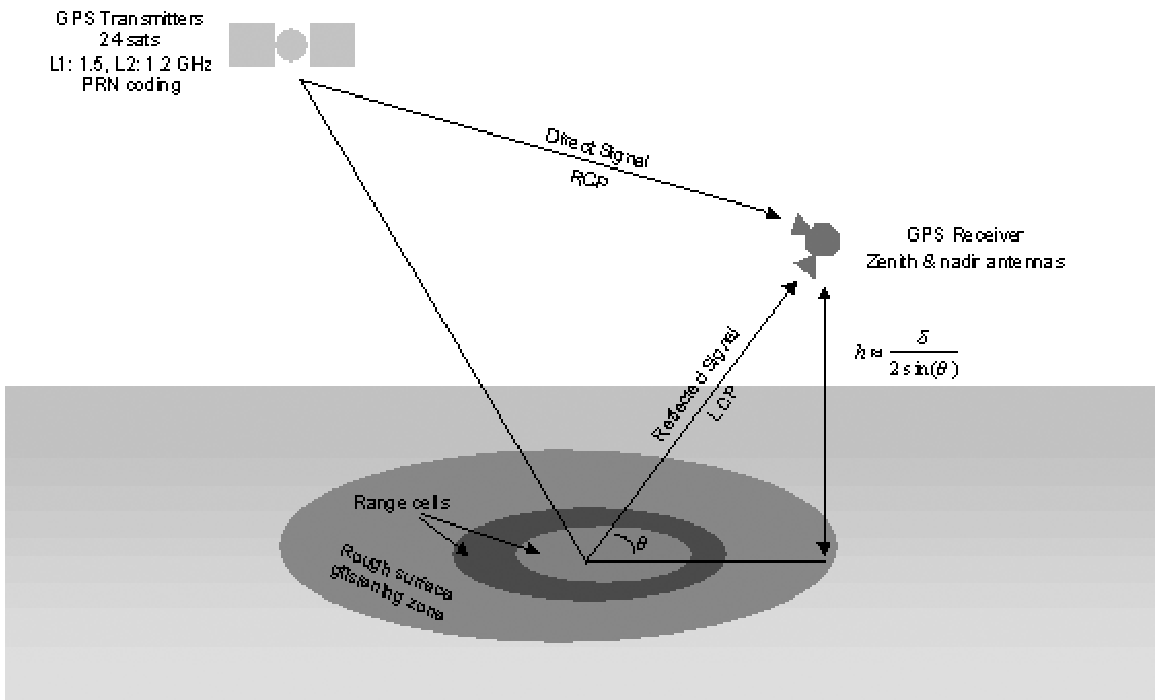


Figure 22. Bistatic radar configuration of reflected GPS signals.

The GPS satellite constellation currently broadcasts a civilian-use carrier signal at 1.57542 GHz, which is bi-phase modulated by satellite-specific pseudorandom noise codes. The signals are encoded with timing and navigation information so that the receiver can calculate the positions of the transmitting satellites and solve for its own position and time by measurement of pseudoranges from at least four satellites. These direct signals are normally received by a low-gain, hemispherical, zenith antenna. These same GPS signal transmissions also reflect off of the Earth's surface and can be measured with a nadir-viewing antenna at longer delays than the direct signal. The reflected signal is modified by the roughness and dielectric properties of the scattering surface. If the roughness is known a priori or is assumed constant over time, the ratio of reflected signal power to the direct signal power is an indicator of the dielectric constant of the surface. Therefore, this ratio can be used to temporally sense changes in soil moisture in the top 5 cm of the surface. Additionally, the polarization of the RCP direct signal is predominantly LCP upon surface reflection for most incidence angles. Because the geometry is variable depending upon the slowly changing transmitter and receiver positions, a hemispherical nadir antenna is used.

The received signals are cross-correlated with a replica signal (1 ms code length) to produce a narrower, approximate 1 μs correlation pulse. This procedure is similar in design to pulse compression radar receivers. Previous efforts have been focused on the distribution or spreading of the reflected signal power over time delay, which is an indicator of the roughness of the reflecting surface. For soil moisture sensing, the observable is the ratio of the magnitudes of the reflected and direct signal powers.

In bistatic radar systems, scattering is mainly forward, and the radar cross section is expressed as a normalized bistatic cross section. For the specific case of an aircraft receiving direct and land-reflected GPS signals, we use an analytical scattering model [Zavorotny and Voronovich, 2000]. The model is based upon physical optics and will employ a rough surface estimated from the SMEX04 terrain.

The current GPS Bistatic Radar receiver is based upon a modified Plessey 12-channel C/A code receiver built by NASA Langley Research Center. New receivers, such as the APL sampling receiver, are currently being developed for GPS bistatic radar applications, and their use in SMEX04 is possible. The Plessey receiver is comprised of a single board containing two RF front-ends and a correlator, which is connected to a PC/104 computer in a small, lightweight chassis (20x15x15 cm). The RF front-ends perform automatic gain control, down conversion, and IF sampling. The PC/104 computer serves as the controller and data logger for both GPS navigation functions and recording the reflected and direct signal powers.

In the Delay Mapping Receiver (DMR) mode of operation, five channels track direct signals in a conventional, closed-loop fashion. The pseudorange and Doppler measurements made by these channels are used to form navigation solutions. The other 14 correlators (two for each of seven channels) are controlled in an open-loop mode to measure reflected signal power at specific delays relative to one or more of the direct signal channels. For each of the slaved reflection correlators, one hundred 1 ms correlator samples are averaged to produce an estimate of reflected signal power at a rate of 10 Hz. The reflected signal power is sampled in discrete bins around the time delay corresponding to the arrival of the signal from the specular reflection point. The direct and reflected signal power measurements are stored on internal disk for later analysis. In the DMR mode of operation, the bistatic radar receiver can operate for long periods without user intervention.

The radar footprint is nominally 20 m diameter at 1 km altitude and varies as a function of the surface roughness and aircraft altitude.

The GPS-based measurements will be evaluated in conjunction with the observations made by the NOAA PSR and NASA instruments and the ground sampling of soil moisture. The GPS Bistatic Radar measurement parameters are presented in Table 7. These tests will guide future development of optimized receivers and processing algorithms to retrieve soil moisture and surface roughness information from GPS Bistatic Radar measurements.

The University of Colorado at Boulder and NOAA/ETL will operate the GPS Bistatic Radar instruments. For more information on GPS Bistatic Radar remote sensing, visit http://ccar.colorado.edu/~dmr.

Table 7. GPS Bistatic Radar Parameters	
Frequency	1.575 GHz
Polarization	LCP
Incidence Angle	0-60 deg (predicted by satellite geometry)
Spatial Resolution	Variable w/ height & angle (20 m @ 1 km alt.)
Footprints	Up to 12 simultaneous footprint zones

3.4 Other Potential Aircraft and Instruments

Two additional/aircraft systems have been requested for participation in SMEX04. the NASA ER-2 with the Advanced Very Imaging System (AVIRIS) and the NASA DC-8 with a synthetic aperture radar (AIRSAR). AVIRIS would provide additional vegetation information, which is important in accounting for attenuation. AIRSAR would provide additional measurements necessary for HYDROS algorithm design and development.

AIRSAR is a side-looking radar instrument developed by the Jet Propulsion Lab http://airsar.jpl.nasa.gov/. It has several operating modes. In SMEX03 the polarimetric (POLSAR) will be used. In POLSAR mode, fully polarimetric data are acquired at all three frequencies C-, L-, and P-band. Fully polarimetric means that radar waves are alternatively transmitted in horizontal (H) and vertical (V) polarization, while every pulse is received in both H and V polarizations. Therefore, there are four combinations; HH, VV, HV and VH. Basic parameters of the AIRSAR are listed in Table 8. It is anticipated that the 20 MHz bandwidth data will be requested. Data will be collected only in Oklahoma.

Table 8. AIRSAR Parameters			
Channel	C	L	P
Frequency GHz	5.29875	1.2375	0.4275
Pixel Spacing 20 MHz Bandwidth (m)	10 x 10		
Swath Width 20 MHz Bandwidth m	15		

4 SATELLITE OBSERVING SYSTEMS

4.1 Advanced Microwave Scanning Radiometer (AMSR-E)

Two versions of the AMSR instrument were launched in 2002, AMSR-E on Aqua (http://wwwghcc.msfc.nasa.gov/AMSR/) in May and AMSR on ADEOS-II (http://adeos2.hq.nasda.go.jp/default_e.htm) in December. The ADEOS-II instrument ceased operations in October 2003. Algorithm development and validations of AMSR-E soil moisture products are very important components of SMEX04.

As shown in Table 9, the lowest frequency is 6.9 GHz (C band). However, preliminary studies indicate that there is widespread radio frequency interference (RFI) in the C band channels. 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^o. Details on AMSR-E can be found at http://wwwghcc.msfc.nasa.gov/AMSR/. Figure 23 illustrates the type of coverage provided by AMSR-E. Aqua is has an overpass time of 1:30 am and pm local time.

Based on the results of SMMR and supporting theory (Wang, 1985, Ahmed, 1995, and Njoku and Li, 1999, Njoku et al. 2003), we anticipate that this instrument will be able to provide soil moisture information in regions of low vegetation cover, less than 1 kg/m^2 vegetation water content. There are very few data sets that have been obtained that include the low frequencies of the AMSR instruments, especially dual polarization at off nadir viewing angles. Early research efforts did examine these frequencies in limited ground and aircraft experiments (Wang et al. 1983 and Jackson et al. 1984). Several of these data sets can be found at the following web site http://hydrolab.arsusda.gov/. Recent experiments have incorporated X and C band observations (Jackson and Hsu 2001, Jackson et al. 2002).

Table 9. 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 to investigators in the 2004 experiment:

- 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.

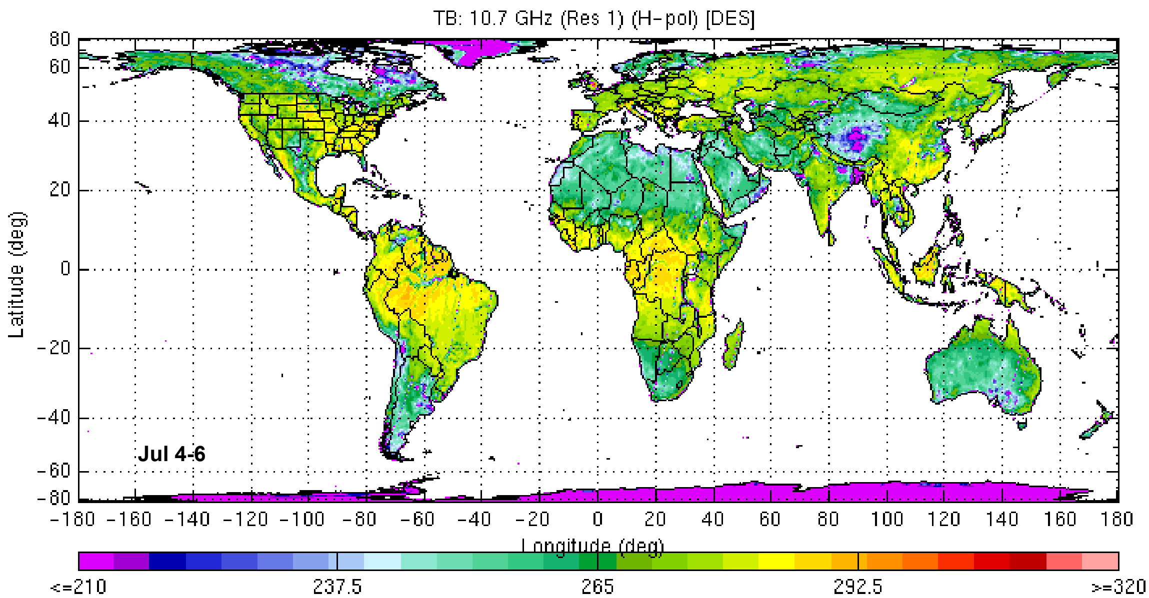


Figure 23. Example of AMSR-E brightness temperature image, three day global composite.

4.2 Tropical Rainfall Mapping Mission (TRMM) Microwave Imager (TMI)

All of the study areas in SMEX04 fall within the coverage domain of the Tropical Rainfall Mapping Mission (TRMM) Microwave Imager (TMI). It is a five-channel, dual-polarized, passive microwave radiometer with a viewing angle of 52.75^{o} (see Table 10). Coverage is available between + and - 38 degrees latitude. The lowest frequency of the TMI is about half that of the SSM/I. Other interesting features of the TMI are its significantly higher spatial resolution (at 19 GHz the TMI is 18 km as opposed to the SSM/I 60 km). For most of the southern U.S. it is possible to obtain coverage every day. Details on this satellite can be found by starting at the following web site http://trmm.gsfc.nasa.gov/data/. There are several sources for these data and products. TMI data have been used in previous soil moisture mapping applications (Jackson and Hsu 2001).

Table 10. TMI Characteristics			
Frequency (GHz)	Polarization	Horizontal Resolution (km)	Swath (km)
10.7	V, H	38	790
19.4	V, H	18	790
21.3	H	16	790
37.0	V, H	10	790
85.5	V, H	4	790

4.3 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 11) were not selected for land applications (Jackson 1997, Jackson et al. 2002, Teng et al. 1993). 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 SMEX04. The ascending equatorial crossing times (UTC) of the three currently available satellites are F13 (17:54), F14 (20:46), and F15 (21:20). F16 (????) 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 TMI and AMSR 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 11. 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

4.4 Coriolis WindSat

WindSat is a multi-frequency polarimetric microwave radiometer developed by the U.S. Navy and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) (http://www.pxi.com/windsat). It is one of the two primary instruments on the DoD Space Test Program's Coriolis Mission. 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 89.0 GHz. The characteristics of the WindSat radiometer are listed in Table 12. The methods developed for algorithm development and validations for AMSR-E during SMEX04 may be applied to WindSat with minimal modifications.

Table 12. Characteristics of WindSat.

Frequency (GHz)	Polarization	Incidence Angle (Deg.)	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

4.5 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 that is of interest in SMEX04. 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^o) 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 13, 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 is viewing a different area across track. In order to get all IS positions for the same ground location a series of days is required.

Table 13. Specifications for ASAR Image Mode Swaths.

Image Swath	Swath Width (km)	Ground, position from nadir (km)	Incidence Angle Range
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

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)
- 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.

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. Figure 24 is a color composite image of IS2 data collected over the Walnut Gulch watershed in September 2003.

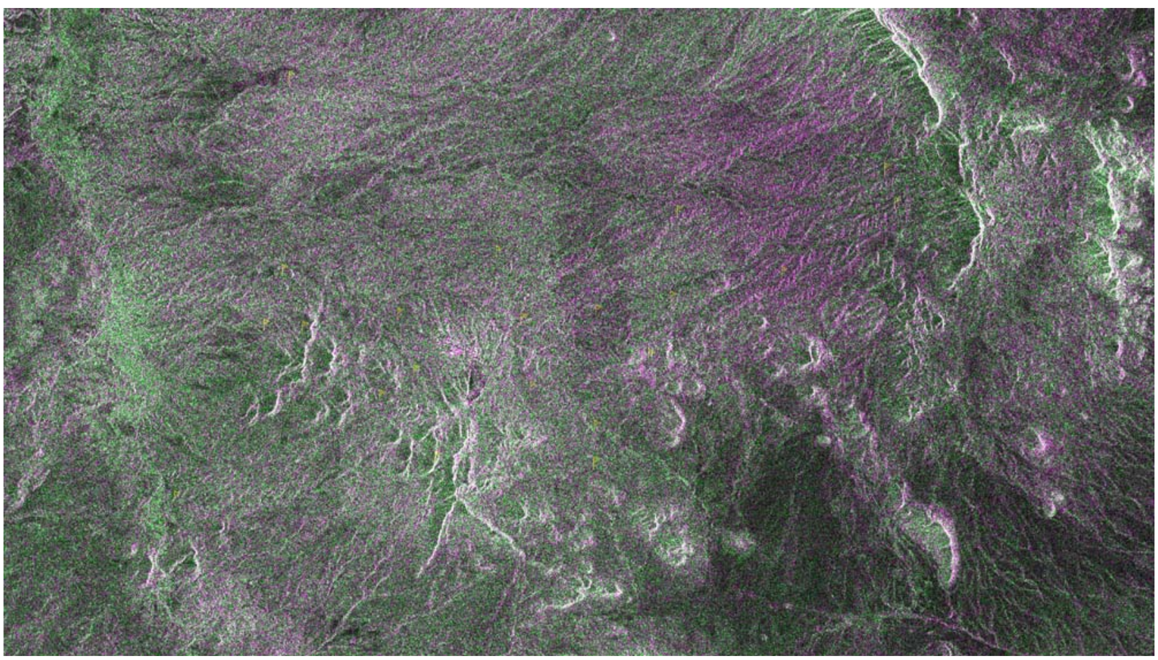


Figure 24. ASAR image of the Walnut Gulch Watershed on September 9, 2003. VV was assigned green and VH purple.

Data takes must be scheduled and are limited to approved investigations. Coverage of all SMEX04 sites concurrent with ground data collection will be requested. Data set selection will be reviewed a few months prior to the field campaign.

Another instrument on Envisat that may be of value in SMEX04 is the MEdium Resolution Imaging Spectrometer Instrument (MERIS). This is a 68.5^o 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. MERIS data have been requested for daytime passes on June 29, July 2, 5, 8, 12, 15,18, 21, and 24 at a nominal time of 11:00 am CDT.

4.6 Terra Sensors

The NASA Terra spacecraft (http://terra.nasa.gov/About/) includes several instruments of value to the soil moisture investigations proposed here. Of particular interest are the Moderate-resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

MODIS can view the entire surface of the Earth every 1-2 days. MODIS is a whisk broom scanning imaging radiometer consisting of across-track scan mirror, collecting optics, and a set of linear arrays with spectral interference filters located in four focal planes. MODIS has a viewing swath width of 2330 km (the field of view sweeps ± 55° cross-track) and will provide high-radiometric resolution images of daylight-reflected solar radiation and day/night thermal emissions over all regions of the globe. Its spatial resolution ranges from 250 m to 1 km at nadir, and the broad spectral coverage of the instrument (0.4 - 14.4 µm) is divided into 36 bands of various bandwidths optimized for imaging specific surface and atmospheric features. The observational requirements also lead to a need for very high radiometric sensitivity, precise spectral band and geometric registration, and high calibration accuracy and precision. Coverage time is about 16:15 UTC. MODIS data for SMEX04 regions of interest will be acquired by CODIAC.

ASTER coverage will be requested for the regional study areas for several dates during the planned study period.

4.7 SeaWinds QuikSCAT

SeaWinds is a radar scatterometer on QuikSCAT. It was launched in 1999 and was designed to measure near-surface wind speed over the Earth's oceans. SeaWinds uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna spins at a rate of 18 rpm, scanning two pencil-beam footprint paths at incidence angles of 46^o (H-pol) and 54^o (V-pol). The antenna radiates microwave pulses at a frequency of 13.4 GHz across broad regions on Earth's surface with an 1800 km swath.

QuikSCAT is in a sun-synchronous, 803-kilometer, circular orbit with a local equator crossing time at the ascending node of 6:00 A.M. +/- 30 minutes. The SeaWinds antenna footprint is an ellipse approximately 25-km in azimuth by 37-km in the look (or range) direction. There is considerably overlap of these footprints, with approximately 8-20 of these ellipses with centers in a 25x25 km box on the surface. Signal processing provides commandable variable range resolution of approximately 2- to 10-km. The nominal resolution is approximately 6 km—an effective range gate of 0.5 msec. Additional information is available at http://podaac.jpl.nasa.gov/quikscat/qscat_doc.html.

Gridded (0.2x0.2 degree) daily observations are available. Documentation is available at http://podaac.jpl.nasa.gov:2031/DATASET_DOCS/dLongSigBrw.html, and data orders can be placed through linked pages. Non-binned data are available, on tapes and through FTP, from the PO.DAAC (http://podaac.jpl.nasa.gov/quikscat/qscat_data.html).

5 Field Campaign Design

Ground based soil moisture measurements will be made for a variety of investigations. How these will be integrated for each of the study regions will vary but should be based upon the general model shown in Figure 25.

The goal of Regional soil moisture sampling is to provide a reliable estimate of the VSM mean and variance within a single satellite passive microwave footprint (~50 km) and multiple EASE-grid 25 km cells at the nominal time of the Aqua AMSR-E overpass (1330 local standard time). The exact center location and orientation of the satellite footprint will vary with each overpass. A grid of sites will be sampled each day that covers a domain of approximately 50 km by 100. The exact size and layout will vary at each of the Regional study areas. Spacing will be nominally 8-10 km between sites. The layout should attempt to provide a minimum of six sites within each 25 km square EASE-grid cell. A single location within each of these sites will be sampled. As noted, these measurements are used primarily to support the AMSR based microwave investigations; therefore, the Regional sampling will be conducted within one to two hour time window of the satellite overpass.

The primary measurement made will be the 0-6 cm dielectric constant at a single location in each site using the Theta Probes (TP). Dielectric constant is converted to volumetric soil moisture using a calibration equation. There are built in calibration equations, however, we will develop field and site specific relationships using supplemental either volumetric soil moisture or gravimetric soil moisture and bulk density sampling. Each sampling day, a coring tool will be used to extract a single VSM sample of the 0-3 cm and 3-6 cm soil layers. The composite set of VSM samples and TP dielectric constants will be used to calibrate the TP for each site. Figure 26 illustrates how regional sampling was performed in SMEX02.

An integral part of the Regional sampling will be the existing continuous soil moisture sampling sites (Towers). Each of these will be sampled to contribute to the calibration of the insitu sensors.

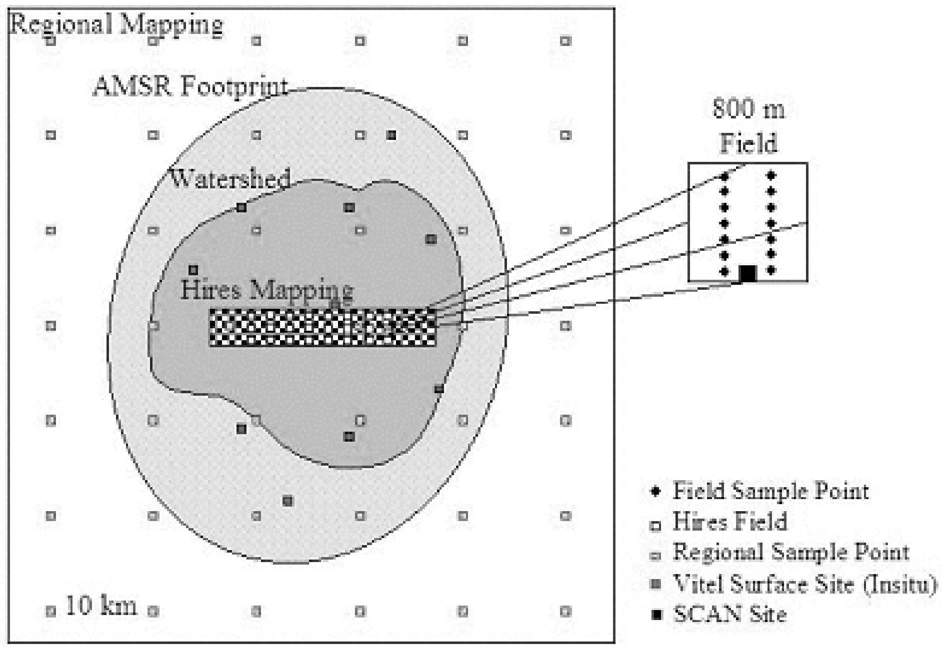


Figure 25. The general approach used in SMEX04 soil moisture sampling.

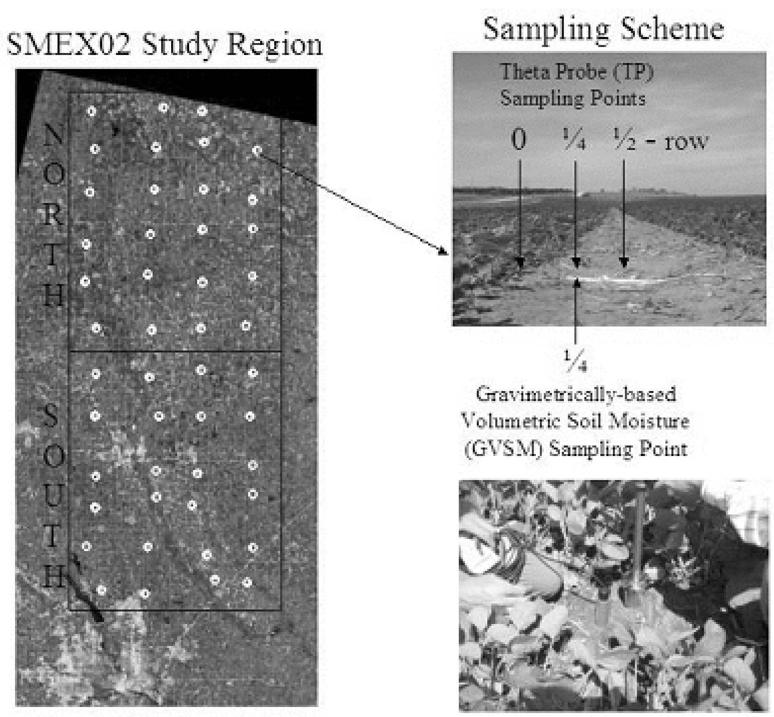


Figure 26. Regional soil moisture sampling in SMEX02.

5.1 Ground Sampling Arizona

This section will describe the sites selected for ground sampling and describe specific protocols that will be used.

5.2 Ground Sampling Sonora

This section will describe the sites selected for ground sampling and describe specific protocols that will be used.

6 OTHER ACTIVITIES

This section will describe other investigations and data sets that should or will be coordinated with the SMEX04 activities. For instance Figure 27 shows information on existing and supplemental raingages in Mexico (Shuttleworth Project). More information will be available after the NOAA proposal reviews and February Workshop.

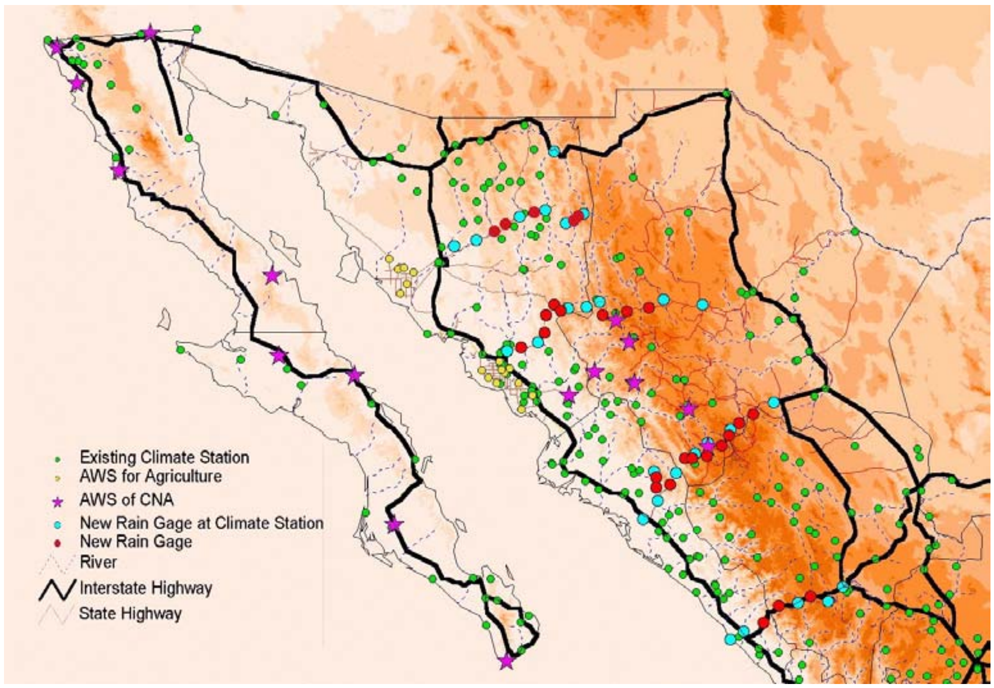


Figure 27 Existing and NAME supplemental climate, weather stations and raingages in the Hermosillo and Culiacan areas

7 SAMPLING PROTOCOLS

This section describes various sampling protocols that have been used in previous experiments. It is anticipated that these will be modified for conditions in these regions at a later time.

7.1 General Guidance on All Types of Sampling

- Sampling is conducted **every day**. It may be 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 or IMADES 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.
- 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.
- Some of the sampling sites may have livestock. Please be considerate towards the cattle and **do not try to scare them** away.
- Work in **teams of two. Carry a cell phone.**

7.2 Regional Site Surface Soil Moisture and Temperature

Regional sampling will take place within approximately 90 minutes of a satellite overpass. The first sample will be taken around 11:30 am. The sampling will be done between 11:30 am and 2:30pm.

Soil moisture and temperature sampling of the selected regions is intended to estimate the site average and standard deviation at the scale of passive microwave satellite footprints and grid cells. The variables that will be measured or characterized are:

- 0-6 cm soil moisture using the Theta Probe (TP) instrument
- 0-3 and 3-6 cm gravimetric soil moistures and bulk density using the coring tool
- Surface temperature using a hand held infrared thermometer **(IF ASSIGNED)**
- 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)
    - Coring tool and coring tool hammer
    - Scoop tool
    - Soil Moisture Insertion Tool (SMITY)
    - 10 cm spatula
    - 4 cm spatula
    - Funnel
    - Bottle brush
    - Notebook
    - Pens
    - Box of cans (see note below)
    - Soil thermometer
    - Handheld infrared thermometer (IF ASSIGNED)
    - Extra batteries
    - Screwdriver
    - Camera
    - First aid kit (per car)
    - Phone

- Verify that your TP, data logger, infrared instrument, and soil thermometer are working.
- For the regional sites, each team should take one box of 18 cans. The cans will be numbered XX01-XX18.
- The first time you sample, it will help to use flags or paint to mark the field entry point and sample point location. Use only plastic flags and mark with the site ID. Do not place flags in a field with grazing or potential tillage. For these conditions use paint.
- All sample points should be located with a GPS once during the experiment. Points will be referenced by Site.
- Check weather

Procedure

- Upon arrival at a site, note site id, your name(s), TP ID, 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).
- Assemble 2 sequential cans. ***Odd numbered cans are used for the 0 – 3 cm sample and even numbered cans are used for the 3 – 6 cm sample.***
- Go to the pre-established sampling location.
    - The sampling sites should be at least 100 m inside the field boundaries.
    - Sample in the row adjacent to the row you are working in, it is suggested that this be the row to your right (If no rows choose a random location within 1 meter of the selected location).

- Using the coring tool collect one gravimetric soil moisture sample for 0-3 cm and 3-6 cm following the Coring Tool Sampling protocol, enter can numbers in book. This sample should be done coincident with the second TP sample, in either row crop or non-row crop fields.
- One soil temperature (Degrees C) for 1 cm, 5 cm and 10 cm using the probe, enter values in book
- At all Apogee sites, one averaged surface thermal infrared temperature (Degrees C) using infrared thermometer, enter value in book. All teams may not collect this.
- Record your stop time and place cans in box. Try to keep them cool.

Sample Data Processing

- Return to the field headquarters immediately upon finishing sampling.
- Weigh the gravimetric samples and record on the data sheets that will be provided. Use a separate sheet for each date and record cans sequentially. (see Figure P1)
- Transfer temperature and other requested data to data sheets (same sheet used for GSM).
- Place cans in oven 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.

SMEX03 Regional
Gravimetric Soil Moisture Sampling

Dates: ____________________ Team: ____________________

Time: ____________________ Observers: ____________________

Site ID	Local Sample Time	IRT in C	Soil Temp in C			Theta Probe (%)			Can ID	Depth in cm	Wet Weight (grams)	Dry Weight (grams)
			1 cm	5 cm	10 cm	A	B	C				

Figure P1. Example of the gravimetric soil moisture sampling data sheet.

7.3 Theta Probe Soil Moisture Sampling and Processing

There are two types of TP configurations; Type 1 (Rod) (Figure P2) and Type 2 (Handheld) (Figure P3). They are identical except that Type 1 is permanently attached to the extension rod. 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 P4. 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 SMEX02, all observations will be recorded as mV and processed later to soil moisture.

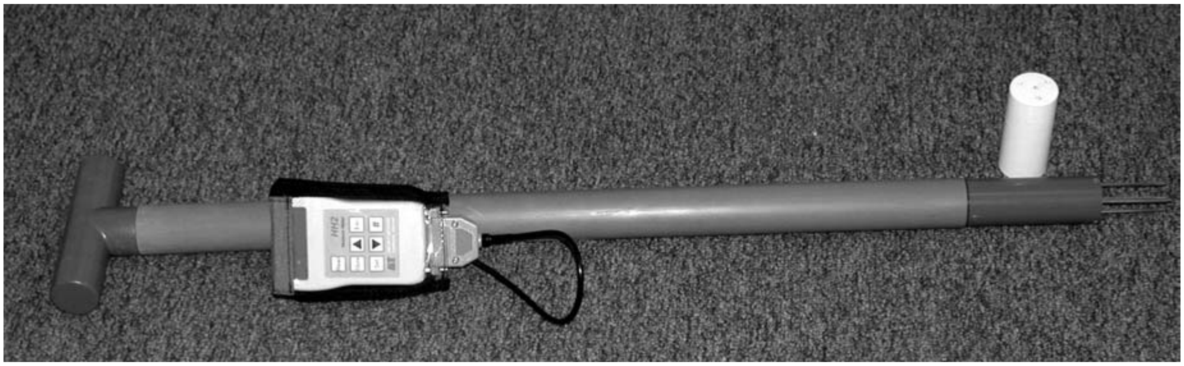


Figure P2. Theta Probe Type 1 (with extension rod).

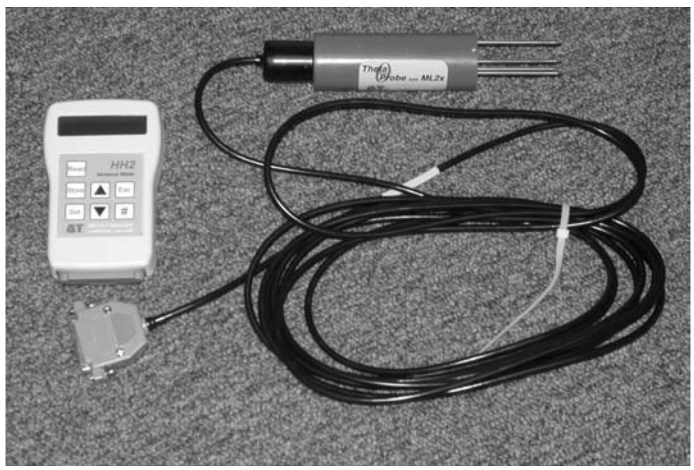


Figure P3. Theta Probe Type 2.

Figure P4. 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 P5. 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 P6) 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.

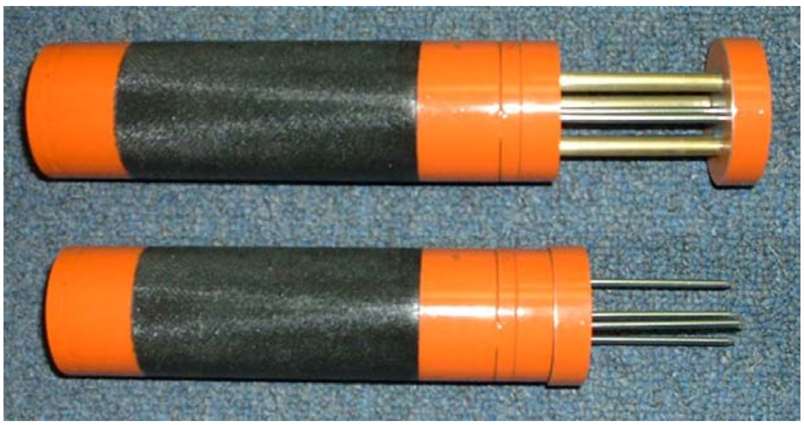


Figure P5: SMITY, Soil Moisture Insertion Tool, with slider extended and retracted.

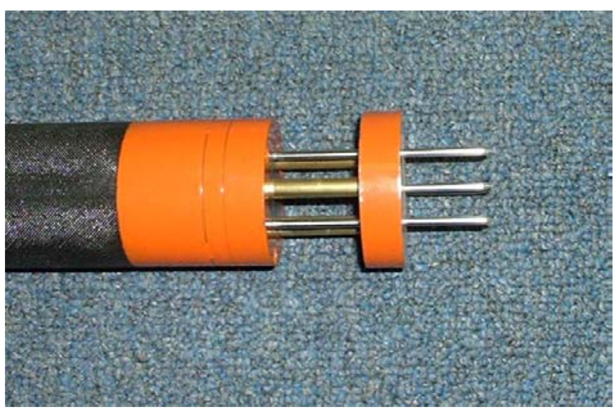


Figure P6: Close-up of the SMITY slider.

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.

<u>Before Taking Readings for the Day Check and configure the HH2 settings</u>

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**.**

<u>Check Date and Time</u>

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.

7.4 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 P7a).
- Push the GSM tool into this vertical face. The top of the scoop should be parallel with the soil surface. (Figure P7b).
- Use the large spatula to cut a vertical face on the front edge of the scoop (Figure P7c).
- Use the small spatula to cut the sample into a 0-3 and a 3-6 cm depth sample.
- Place each sample depth in a separate can, the small spatula aids extraction (Figure P7d). Remember that the odd numbered cans are for the top layer and the even are for the deeper layer (remember to use cans sequentially and odd numbers for the 0-3 and even for 3-6 cm samples).
- Record these can numbers in the field notebooks at the point location on the map.
- 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 temperature. Record these values in degrees C to one decimal point in the field notebooks at the point location on the map.

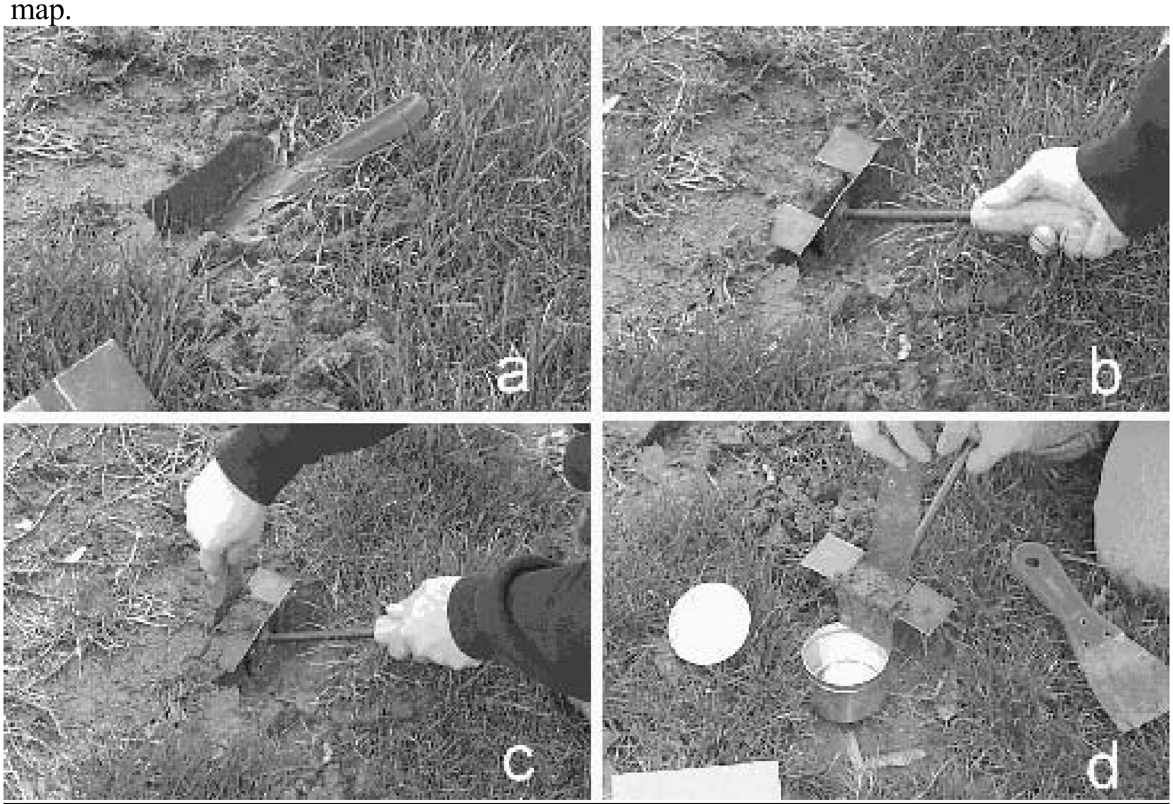


Figure P7. How to take a gravimetric soil moisture sample.

7.5 Gravimetric Soil Moisture and Bulk Density Sampling with the Coring Tool

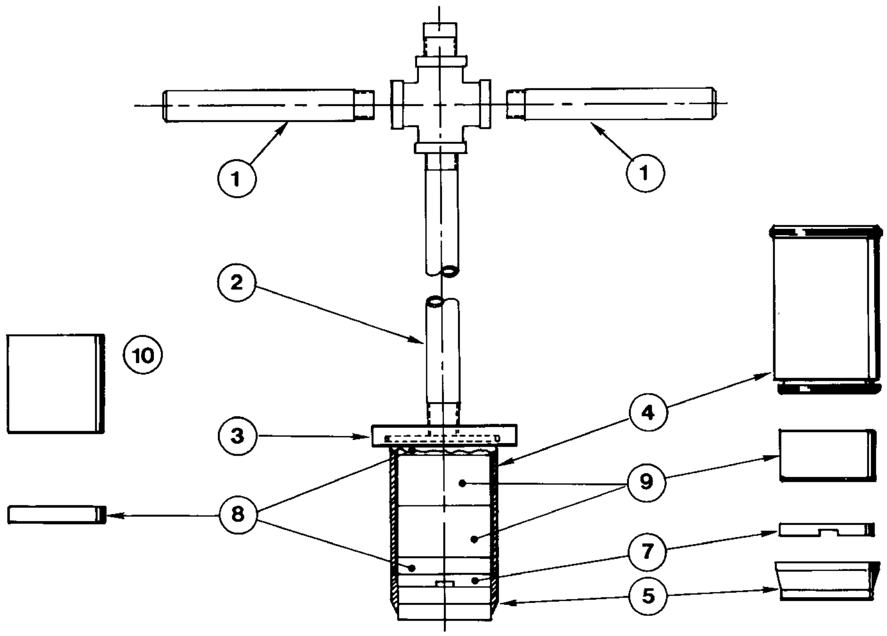
- The tool is called a 200-A soil core sampler.
- Figure P8 shows the parts of the apparatus.
- The thin cutting tip was used in SMEX03 because the soils will be uniform and rock-free. This can be replaced using a spanner tool to unscrew it from the barrel.
- The cap is unscrewed to insert or remove rings.
- The ring volumes are 3 cm=>68.7 cm^3. (diameter of the ring is 5.4 cm)

Procedure for Taking a Sample

- Insert five sample rings and the extractor ring in the following order starting from the cutting end
    - Extractor
    - 1 cm
    - 1 cm
    - 3 cm
    - 3 cm
- Replace cap with handle
- Insert the coring tool into the soil. If necessary, the hammer tool can be used. The hammer rod is inserted into the handle.
- Stop when the lip of the cap reaches the surface, try not to compact the sample.
- Remove the core and inspect the tip to make sure the notches on the extractor ring are clear. Use the extractor tool (Figure P8) to assist in cleaning these notches. Also inspect for separation within the coring tool by looking for protruding soil at the bottom of the tool. If there is separation, dispose of this sample and start again.
- Remove the cap.
- Use the extractor tool (from the bottom or cutting edge) to push the rings out the top or cap end.
- Using a wide spatula, cut the rings apart into the soil moisture cans using the soil funnel to insure capture of the entire sample..
- Place the 0-3 cm and 3-6 cm samples in cans (Remember odd-0-3 cm and even-3-6 cm).
- It can be difficult to extract a perfect surface 3 cm sample for bulk density. However, it s still useful as a GSM sample. Please make a note on the sample quality in your notebook.
- Clean all rings.

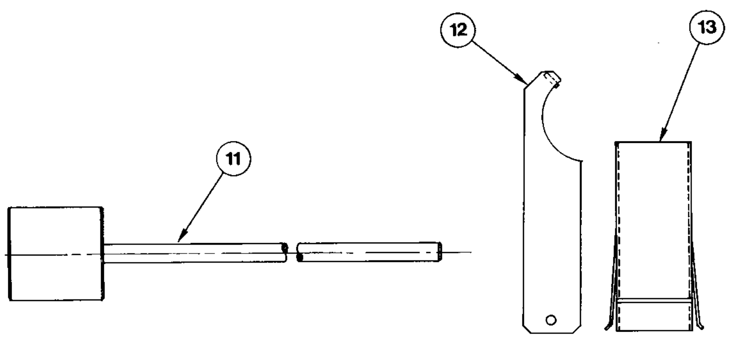
Computing the Volumetric Soil Moisture and Bulk Density

- Compute the sample GSM and dry mass
- Divide the mass of the soil by the volume of the cylinder (3 cm) hole to obtain the sample bulk density
- Compute VSM=GSM*BD



PARTS BREAKDOWN

ITEM NO.	PART NO.	DESCRIPTION	ITEM NO.	PART NO.	DESCRIPTION
1	201-6	HANDLE			
2	201-100	STEM ASSEMBLY	7	201-9	NOTCHED EXTRACTOR RING
3	201-4	CAP	8	208	CYLINDER 1 CM. LONG
4	201-3	BARREL	9	207	CYLINDER 3 CM. LONG
5	201-1	BLADE CORING TIP	10	206	CYLINDER 6 CM. LONG



PARTS BREAKDOWN (CONTINUED)

ITEM NO.	PART NO.	DESCRIPTION
11	202	DRIVE HAMMER
12	203	SPANNER WRENCH
13	204	SLOTTED CORE EXTRACTOR

Figure P8. Coring tool parts.

7.6 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 can, fill out a sample set sheet, and record a wet weight at the field headquarters. A lab team will place the samples 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 in late afternoon or early the following morning. These samples will remain in the ovens until the morning of the second day (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 before 8:00 am the following day.

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

7.7 Soil Bulk Density and Surface Roughness

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

The Bulk Density Apparatus

The Bulk Density Apparatus itself consists of a 12" diameter plexiglass piece with a 6" 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 three inches high and two inches thick. The foam is attached so that it follows the circle of the plexiglass. Figure P9 shows the basic components.

Other Materials Required for Operation:

- Three 12" 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 and 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 gas can 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 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 rocks or roots in the actual area, which will be tested and has soil which has not been disturbed.
2. Ready the site for the test. Remove all vegetation, rocks and other debris from the surface prior to beginning the test. Remove little or no soil when removing the debris.

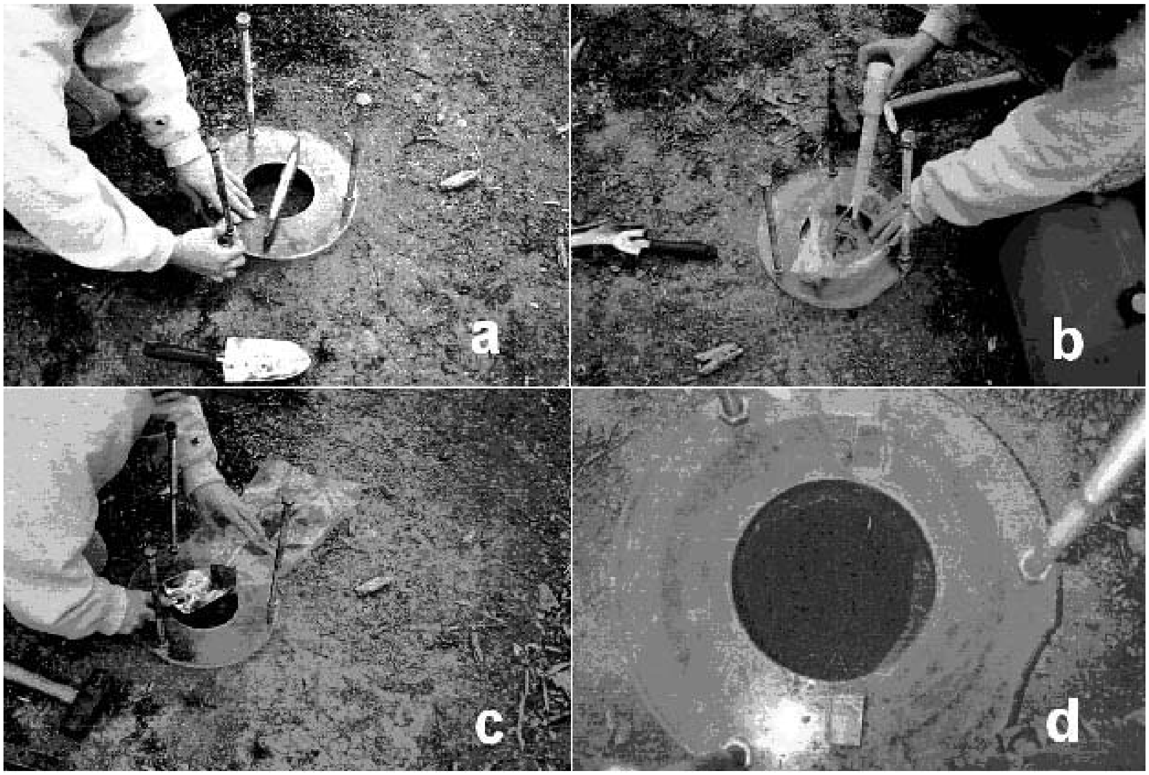


Figure P9. How to take a bulk density sample.

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 P9a)

Leveling the Apparatus Horizontally to the Ground

1. Tighten each of the bolts until the apparatus appears level and the foam is compressed to 1-1/2" to 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 P9b)
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. 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. (The hole should be a cylinder: with surface area the size of the hole of the apparatus and height of six inches.)
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 P9c and d)
4. Continue to remove the soil until the hole fits the qualifications.

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**. 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 Density of the Soil

1. Dry the soil in an oven for at least 24 hours.
2. Determine the mass the soil.
3. Divide the mass of the soil by the volume of the hole. The answer is the density of the soil.

Potential Problems and Solutions

After I started digging I hit a 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, corn cobs, 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

- Take a photo along and across the rows at each BD location with the grid board.
- The site and sample ID should be indicated in the photo.

7.8 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 P10).

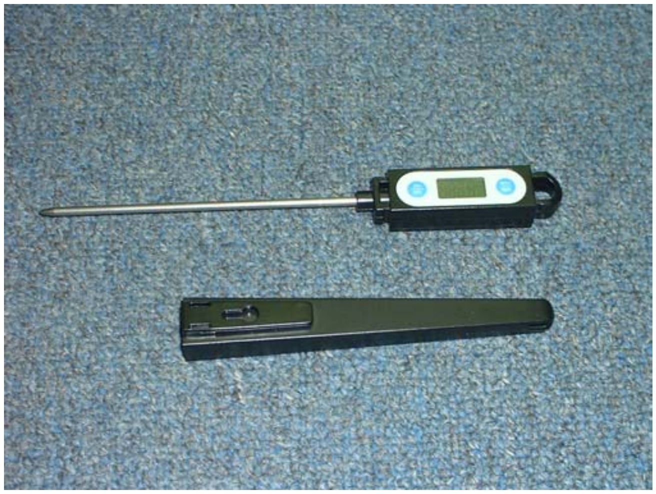


Figure P10. Temperature Probe with Handle/Cover

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.

7.9 Hydra Probe Soil Moisture and Apogee Temperature Sensor Installations

Figure P11 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 he field HQ and can also be found at http://hydrolab.arsusda.gov.

Figure P11. 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.
- 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.
    - Dig an access hole. This should be as small as possible.
    - After digging the access hole, a section of the hole wall should be made relatively flat. A spatula works well for this.
    - 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 probe should be inserted far enough that the plane formed where the tines join the probe head is flush with the soil surface.
    - 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.
- 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.

7.10 Vegetation Sampling

The protocols used in SMEX03 have been adapted for SMEX04. There are different vegetation types in each region that will require protocol modification. Please see the plans for each region on specific procedures.

Parameters

1. Plant height
2. Ground cover
3. Stand density
4. Phenology
5. Green and dry biomass
6. Leaf area (LAI)
7. Surface reflectance

Sampling Locations

Vegetation sampling will be conducted on a subset of the soil moisture sites and will vary by region. Three representative locations within each selected field will be sampled during the course of the study to quantify the full range of vegetative cover. It is important to note that for all sites, even regional, the vegetative sampling is intended to estimate the average site conditions, and data are not intended for footprint averaging. Preliminary site selection will be performed using aerial and satellite imagery. Final selection will be based upon field surveys conducted just prior to the field campaign.

Sampling Frequency

The number of rounds of sampling will be at least twice

Site Identification

Sites will be identified with a unique site id made up of the region id, V for vegetation, site number, and within field location (1-3). For row crops, add an additional final character designating sampling row (sampling rows will be label A-E). For example, Oklahoma South (OS) vegetation (V) site 20 location 1 row A would be OSV201A. The 'V' will denote a vegetative sampling site to avoid any potential confusion with other measurement sites within the same field.

Sampling Layout

Each location will be identified with a flag (or paint if flagging is not allowed) in each corner to aid in locating the site. Sites should be located at least 100 m from roads, farmhouses, etc. For row crops, each sampling location will consist of a 10 row area, 6 m in length. For other types of vegetation (grasses, weeds, etc.) an area 2 m by 2 m will be used. This will provide adequate area for all sampling dates (see Figure P12).

GPS coordinates of each location within a site will be recorded for the corners of the location. The actual sampling will not require the use of GPS. Sampling location will be marked at the edge of the field for assistance. These marks and locations will be compiled in the field notebook. In the case of row crops, the sampling location will be flagged at the end row of the field so the sampling crews can travel down the rows. Flags should include the id, and approximate number of paces to the location.

Row Direction →

Sampling Row E	
Sampling Row D	
Sampling Row C	
Sampling Row B	
Sampling Row A	
3 m First sample	3 m Second sample

Flag

Figure P12. Vegetation sampling layout.

Sampling Scheme

Sampling locations will be selected to provide a representative sample from that area of the field. For row crops, one plant will be sampled from every other row for phenological stage and green and dry biomass (5 plants total). These same rows will be sampled for height, stand density, and row cover. Leaf area will be measured at four locations (in-row, ¼ across row, ½ across row, ¾ across row) using a LAI-2000. The first sampling position will be between the first row (flag location) and the row to the left. The first time sampling, begin on the end next to the flag, the second sampling will begin 3 m down the row from the flag.

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 P13)

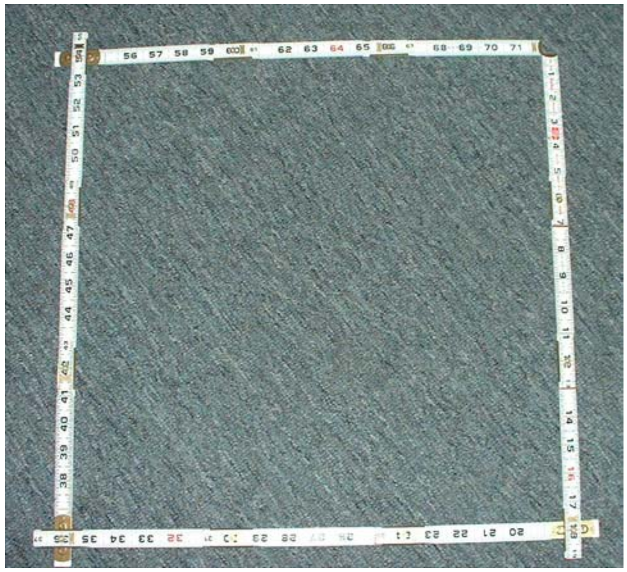


Figure P13. Vegetation sampling frame.

Protocols

7.10.1 Stand density (row crops only)

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 in each of the 5 rows 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.

7.10.2 Height

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

7.10.3 Phenology

Phenological stage for crops will be determined using standard phenological guides.
Grasses: http://www.ag.ndsu.nodak.edu/dickinso/grassland/1022.htm
http://www.caf.wvu.edu/~forage/growth.htm

7.10.4 Green and Dry Biomass

Grasses: All vegetation within the specified area will be cut at ground level. If it is determined that there is a significant thatch layer in grass sites it may be necessary to characterize this as a separate canopy component. Vegetation for the sampling location will be placed into a paper bag with a label for the sampling site. All samples from a location are then placed in a single plastic bag for transport to the lab. A separate tag with the sampling location id will be placed into the bag as additional insurance against damaged labels

Shrubs and Trees: It would be highly desirable to characterize these conditions. However, at this time we do not have a protocol for dealing with these cover conditions.

Green biomass will be measured by weighing the samples immediately. If the biomass has excessive moisture, it 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 (longer if necessary).

7.10.5 Photographs

Photographs will be taken of the 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. Four photos will be taken in each plot in this order: marker board, oblique, and nadir (or as close as possible), and a synoptic field photo.

Surface roughness photographs will be obtained using the grid board approach. For grasses this should be performed after canopy and thatch removal. For row crops, photos will be taken both 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 P14) Surface roughness photos will be taken once during the experiment unless there is a change in the field conditions (plowing, planting, harvesting …).

Figure P14. Surface roughness photo.

7.10.6 Leaf Area

Leaf area will be measured with a LAI-2000 (Figure P15). For *row crops* in the inter-row region at least one meter away from where the biomass sample was taken (5 sets of 4 across-row measurements). The LAI-2000 will be set to average 4 points into a single value so one observation is taken above the canopy and 4 beneath the canopy; in the row, ¼ of the way across the row, ½ of the way across the row and ¾ of the way across the row. This gives a good spatial average for row crops of partial cover. 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. If possible these should be made just before clipping. Protocols for *shrubs and trees* will be developed if necessary.

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 P15. 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 grasslands and shrubs:

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 plant canopy in one corner of your sampling area level the sensor and press the black log button on the sensor handle and keep level until the second beep.
3. Repeat for the other 3 corners

Repeat steps 1-3 so that you have a total of 5 sets of measurements.

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

8. desired files have been sent.

9. In HyperTerminal go to Transfer | Capture text | Stop.

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

11. 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.

12. 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.

13. In HyperTerminal go to Transfer | Capture text | Stop.

14. 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 it's 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 which is 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.

7.10.7 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.

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 basis instrument is shown in Figure P16.

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.

Figure P16. CROPSCAN Multispectral Radiometer (MSR). (Size is 8 X 8 X 10 cm).

For Oklahoma there will be two MSR16R units available with the following set of bands:

Satellite	*ID*	*CenterWavelength (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.

During field data collection 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 P16)
- Data Logger Controller & Cable Adapter Box (carried in the shoulder pack, earphones are to hear beeps) (Figure P17)
- CT100 (hand terminal, connected to the DLC with a serial cable) (Figure P18)
- 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 P17. Data logger controller and cable adapter box.

Figure P18. 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,** to return to the MSR 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 into main menu
- At Command * Press **2** then **ENTER** to get to the Reconfigure MSR menu
- At Command * Press **5** then **ENTER,** input your plot ID (numbers 1-999 only), Press **ENTER**
- Press **M** to return to the MSR main menu
- At Command * Press **8** then **ENTER** to get to the MSR program
- Press **ENTER** to continue or **M** to return to the MSR 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, 5 different areas within 10 m will be scanned at each field location
- 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 were performed as part of SMEX03:

Vegetation Water Content Sampling Location: Reflectance and LAI data will be collected for each vegetation sampling location just prior to removal.

Field Transecst: Several sites will be characterized by transect sampling. Reflectance and LAI measurement will be collected at each of the soil moisture sampling locations (14 total). This should be done at least twice, once to coincide with satellite overpass and the second near the end of the field campaign.

Data Recording

Data will be recorded onto the sampling sheet illustrated in Figure P19. Each field will have a separate notebook and data sheets for each sampling plot within the field. Each blank on the sheet will be filled in during the observation period. 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 ______________Time __________________ Observers _____________________
Row Spacing_______________
Row Direction _____________________
Crop ______________________________
Photographs Taken __________
MSR Done _____________

Sample id	Stand density (plants/m)	Height (m)	Phenology	Green Biomass (g)	Dry Biomass (g)	Leaf Area Index	Sun/shade

Figure P19. Example of the vegetation sampling data sheet.

7.11 Global Positioning System (GPS) Coordinates

The geographic coordinates of all soil, vegetation, and micrometeorological sample sites need to be collected in order to map their locations in a geographic information system (GIS). A Garmin **e**Trex "sportsman" GPS will be used to collect the position data. This unit has the capacity to store up to 500 geographic coordinates or waypoints and 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 GPS measurements at that site will be needed.

- All sampling points will be located using a handheld GPS including
    - Soil samples
    - Vegetation samples
    - Flux towers
    - Met stations

- To the extent possible, a single individual should make all of the readings. This person can be assigned to different teams on different days or use field markings provided by the teams.

General Information

Record site ID, and latitude and longitude coordinates in field notebook. 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 eTrex 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 P20)

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 also functions as escape key.
POWER button: turns **e**Trex GPS as well as display backlight on and off.

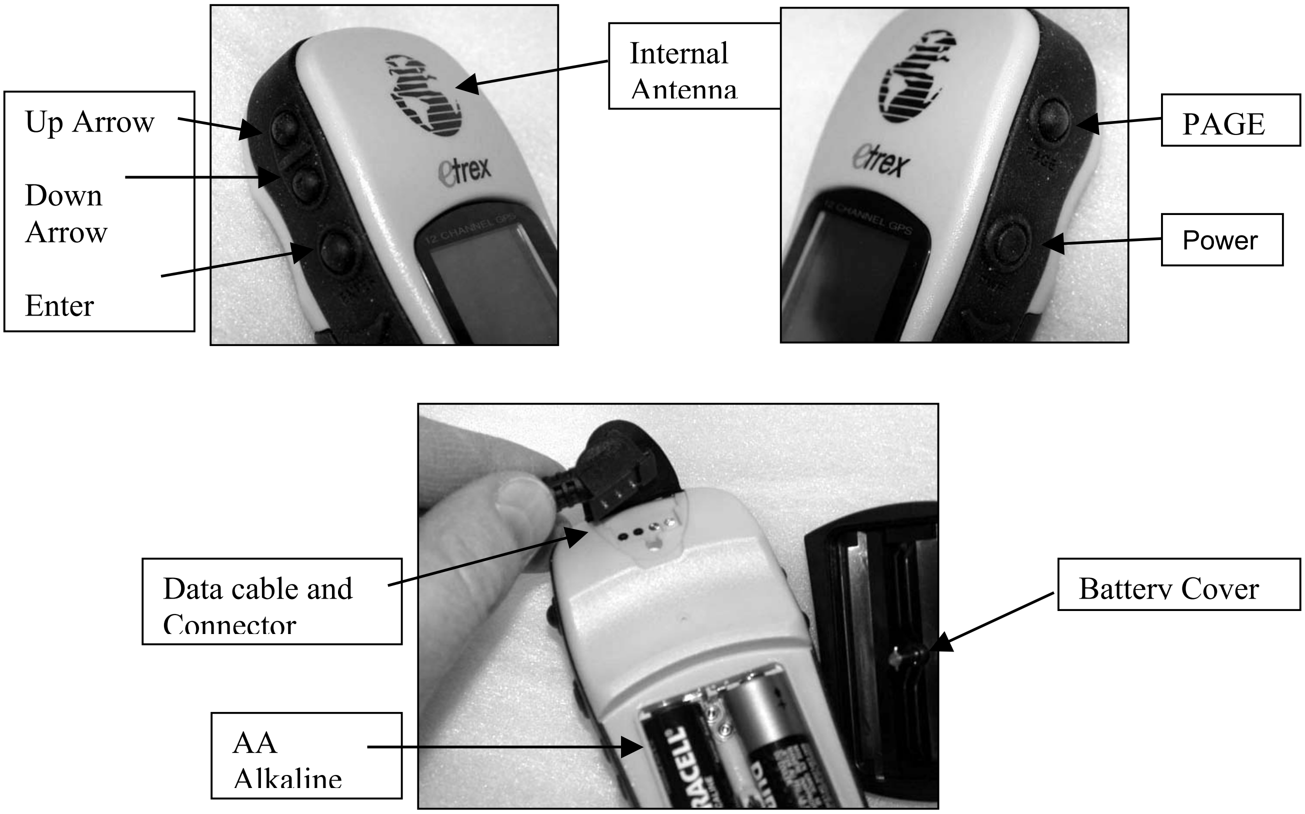


Figure P20. GPS features.

All eTrex operations are carried out from the four (4) “pages” (or display screens) shown in Figure P21. The PAGE key is used to switch between pages. (The Map and Pointer Pages are used for navigation and will not be discussed further.)

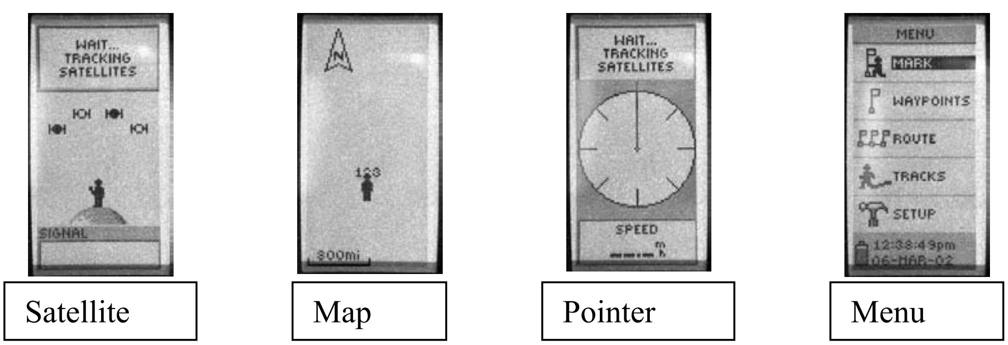


Figure P21. GPS display screens or “pages”.

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 P22)
   - 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; press enter, repeat above steps for all parameters.
   - The following are the parameters and required settings;
     - Time = Format: **24 Hour**;
     - Zone: If Oklahoma, **US-Central**, (UTC Offset: **-6:00**);
If Georgia, **US-Eastern**, (UTC Offset: **-5:00**);
If Alabama, **US Central**, (UTC Offset: **-6:00**);
If Brazil, **Brasilia**, (UTC Offset: **-3:00**)
     - 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**

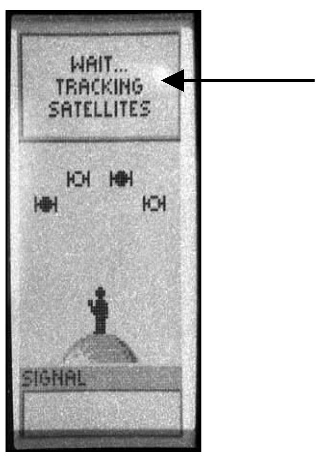
Figure P22. GPS menu page.

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 the 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 exist on the order of hundreds of meters 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***. Coordinate conversion software packages such as NOAA's free Corpscon (http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml) exist which allow for 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 P23). Wait until text box at top of screen reads "READY TO NAVIGATE" before continuing.



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

Figure P23. GPS satellite page.

2. Adjust screen backlight and contrast, if necessary.
   - 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 the Satellite Page.

3. Initiate GPS data collection:
   - PAGE to Menu screen (Figure P22); 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 P24); press ENTER. Use ENTER and UP/DOWN buttons to edit ID, <u>if necessary</u>. (Waypoint ID increments by one (1) automatically.)
   - Record latitude and longitude coordinates displayed at bottom of screen into field notebook. *Do not rely solely on electronic data download to save data points!*
   - ARROW to OK prompt; press ENTER to save point coordinates electronically.

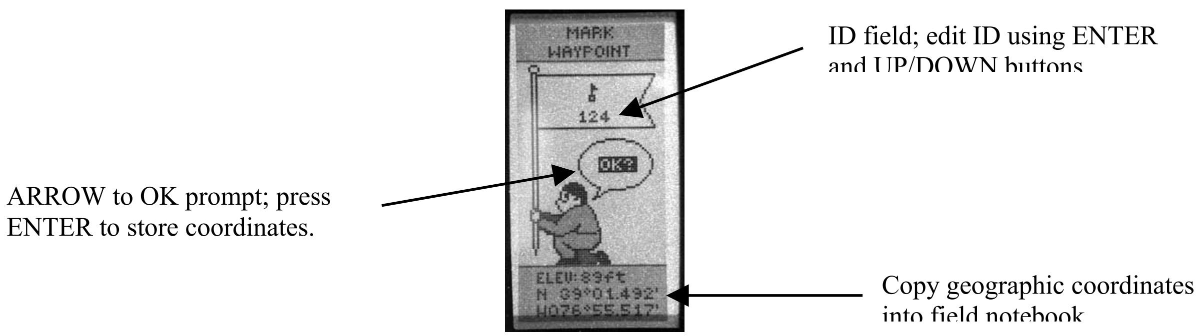


Figure P24. GPS Mark waypoint page.

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<u>?</u>
Waypoints => Download
File => Save => Waypoint
Select Save as type: Comma Delimited Text File

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10 LOGISTICS

This section will include hotel information, shipping information, driving directions, etc.

Figure P24. Walnut Gulch Experimental Watershed Field Office

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Old Bisbee Highway
Tombstone, Arizona 85638
Phone: 520-457-3321

Research Leader
Southwest Watershed Research Center
2000 East Allen Road
Tucson, AZ 85719
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