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NEAR REAL TIME VARIABILITY OF SOIL MOISTURE AND TEMPERATURE UNDER DIFFERENT LAND USE AND COVER: THE ALABAMA MESONET

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The Alabama Mesonet (ALMNet) has been established to provide near-real-time data to conduct research that aims to ensure the security, quality, and quantity of the Nation's natural resources. The ALMNet is made up of eleven combination meteorological/soil profile stations and twelve soil profile stations positioned at 23 locations in eight counties. The stations are included in the USDA NRCS SCAN network. Meteorological and soil profile data collected by ALMNet include temperature (air and soil), humidity, solar radiation, wind (speed and direction), soil heat flux, soil moisture and precipitation. The objectives of the ALMNet are to: (i) serve as a validation site for current and future satellite missions of monitoring soil moisture (e.g. the Aqua satellite) and archive both atmospheric and hydrologic related data: (ii) study soil moisture and temperature variability at different time scales and under different land use and land cover: (iii) model soil water content and temperature from observable climate data and compare model estimates in terms of energy partitioning: (iv) strengthen outdoor research and training facilities for both undergraduate and graduate students: and (v) establish an Online Internet Service for extension agents, farmers and interested individuals to visualize climate related data. Our long-term vision is to complete detailed hydrological and meteorological process analyses for northern Alabama and southern Tennessee in collaboration with scientists from NASA, USDA and other Universities. We also hope to expand the recording sites throughout Alabama as our resources permit.

INTRODUCTION

Spatial variability of soil and plant properties presents many measurement and modeling challenges (Tsegaye et al. 1998). Unfortunately, long-term, spatially and temporally distributed near-real-time data sets are rare (Tsegaye et al. 2003). In the past it was difficult and time consuming to obtain soil moisture validation data sets to test energy balance models and compare intra-seasonal and inter-annual variation of soil water condition and corresponding impacts on energy partitioning (Famiglietti et al. 1999). The deployment of automated sensors within a watershed allows us to collect near-real-time data which in turn helps researchers and farmers to assess the temporal and spatial variability of climate forcing variables, soil water and temperature conditions, crop growth, and determine the frequency of irrigation (Seyfried et al. 2001).

The main objectives of the ALMNet are to: serve as a validation site for future satellite mission of soil moisture mapping e.g. AMSR/AMSR-E, AQUA and others and archive both atmospheric and hydrologic process related data; study soil moisture and temperature variability at different time scales and under different land use and land cover; model soil water content and temperature from observable climate data and compare model estimates in terms of energy partitioning; strengthen outdoor training activities and collection of data by undergraduate and graduate students; and establish an Online Internet Service for extension agents, farmers and interested individuals to visualize climate related data.

OVERVIEW OF MEASUREMENT PROGRAM

The Alabama Mesonet (ALMNet) a comprehensive outdoor research and teaching laboratory established in 2002 was equipped with state-of-the-art *in situ* soil, meteorological, atmospheric, and environmental sensors (Table 1) that continuously record fluxes in soil temperature, soil moisture, relative humidity, radiation, rainfall, etc. (Figure 1). The data recorded at the eleven SCAN sites may be obtained from the following USDA web sites: http://www.wcc.nrcs.usda.gov/scan/Alabama/alabama.html and http://www.wcc.nrcs.usda.gov/scan/Tennessee/tennessee.html. Additional numerical tabular data and graphic displays of the instrumented sites can be viewed at the HSCaRS web site: http://wx.aamu.edu/ALMNet.php.

These field sites will be maintained and monitored constantly and collect field data to build a long-term climatic data for Alabama and southern Tennessee. ALMNet serves as a validation site for evaluating data recorded by satellite and aircraft sensors that monitor the Earth’s surface. The data is being used to develop better prediction and modeling equations for accurate weather forecasting, improved severe weather and flood warnings, more effective emergency management and disaster mitigation planning, more efficient use of water resources, and accurate records to quantify drought severity. Farmers and land owners are getting more access to reliable, comprehensive, and timely weather data as they conduct agriculture activities including plowing, planting, irrigation, pesticide application, and harvesting. Other benefits of ALMNet also include: providing weather data for K-12 classrooms to stimulate science literacy; enhance undergraduate and graduate instruction research programs at Universities, state and federal agencies. In short, the ALMNet is benefiting all scientists, teachers, landowners and consumers. ALMNet further affords us opportunity to make better decisions based on timely and accurate environmental information. This ALMNet will also provide an integrated database for temporal analyses, inter-

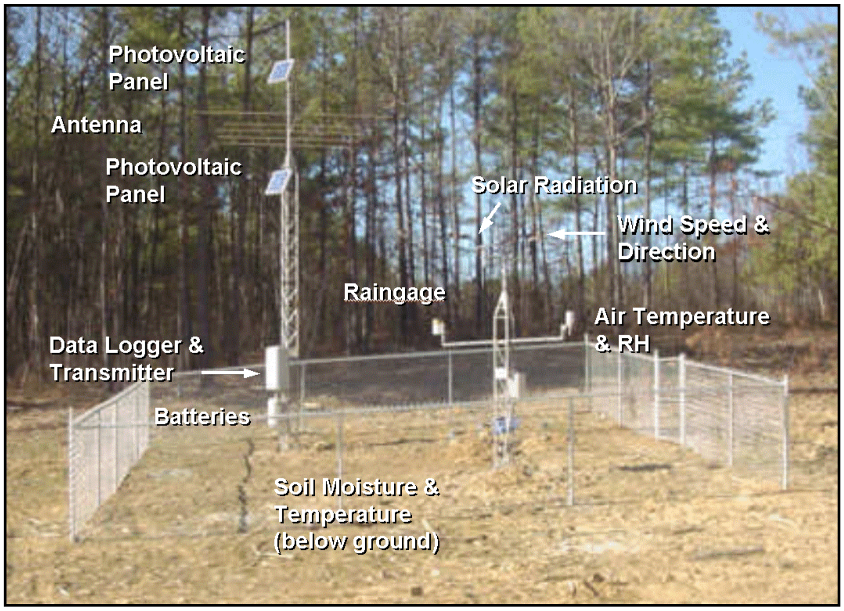

Figure 1. ALMNet station that integrates meteorological and soil profile instrumentation into a single automated system.

comparisons between sites, and spatial comparisons across environmental gradients. Our long-term vision is to complete detailed hydrological and meteorological process analyses for Alabama in collaboration with scientists from NASA, USDA and other Universities. We also hope to expand the recording sites throughout Alabama as our resources permit.

Using ALMNet, data simulation can be performed to investigate heat and water movement through plant cover, residue and soil. Robust spatial and temporal characteristics of these data should provide important insights into current and future farm management planning. The Mesonet data has been used for satellite and aircraft multispectral sensor calibration and validation, faculty research and graduate and undergraduate training. It also played a key role in HSCaRS Summer Enrichment Program (SEP) that occurs each summer. This program introduces undergraduates to research activities involving Earth Science. The outdoor laboratory will also provide a continuous flow of data to serve as a validation site for research performed in the soil moisture remote sensing area by other research groups.

REGIONAL DESCRIPTION

The northern Alabama study area spans the Alabama-Tennessee border in the Tennessee River Valley (Figure 2). The eastern third of the study area is comprised of remnants of the Cumberland Plateau and is characterized by significant relief (Figure 3). The remaining part of the study area is a smooth or gently rolling plain that is part of the Highland Rim of the Interior Low Plateau.

About 60 percent of the study area is covered by soils with moderate infiltration rates (Figure 3 and 4). These soils overlie primarily Paleozoic carbonate rocks that are predominant in the eastern part of the study area. These soils are very deep, clayey soils on gently sloping uplands. Typically, they have dark-reddish brown silt loam topsoil and a dark red silty clay loam and clay subsoil. Soils with slow infiltration rates cover about 38 percent of the study area. These soils primarily overlie sandstone and unconsolidated sand, but also overlie carbonate rocks. These soils are moderately deep, loam soils on gently sloping uplands. Typically, they have dark-grayish brown fine sandy loam surface layer and brownish sandy clay loam sub-soils overlying hard sandstone bedrock at a depth of 20 to 40 inches. Other locations of the study region have a mixture of soils with moderate to slow infiltration rates, and in some places very slow infiltration rates, which cover about two percent of the area. Soils with high infiltration rates are present in less than one percent of the area and are located at the northern and eastern parts of the area.

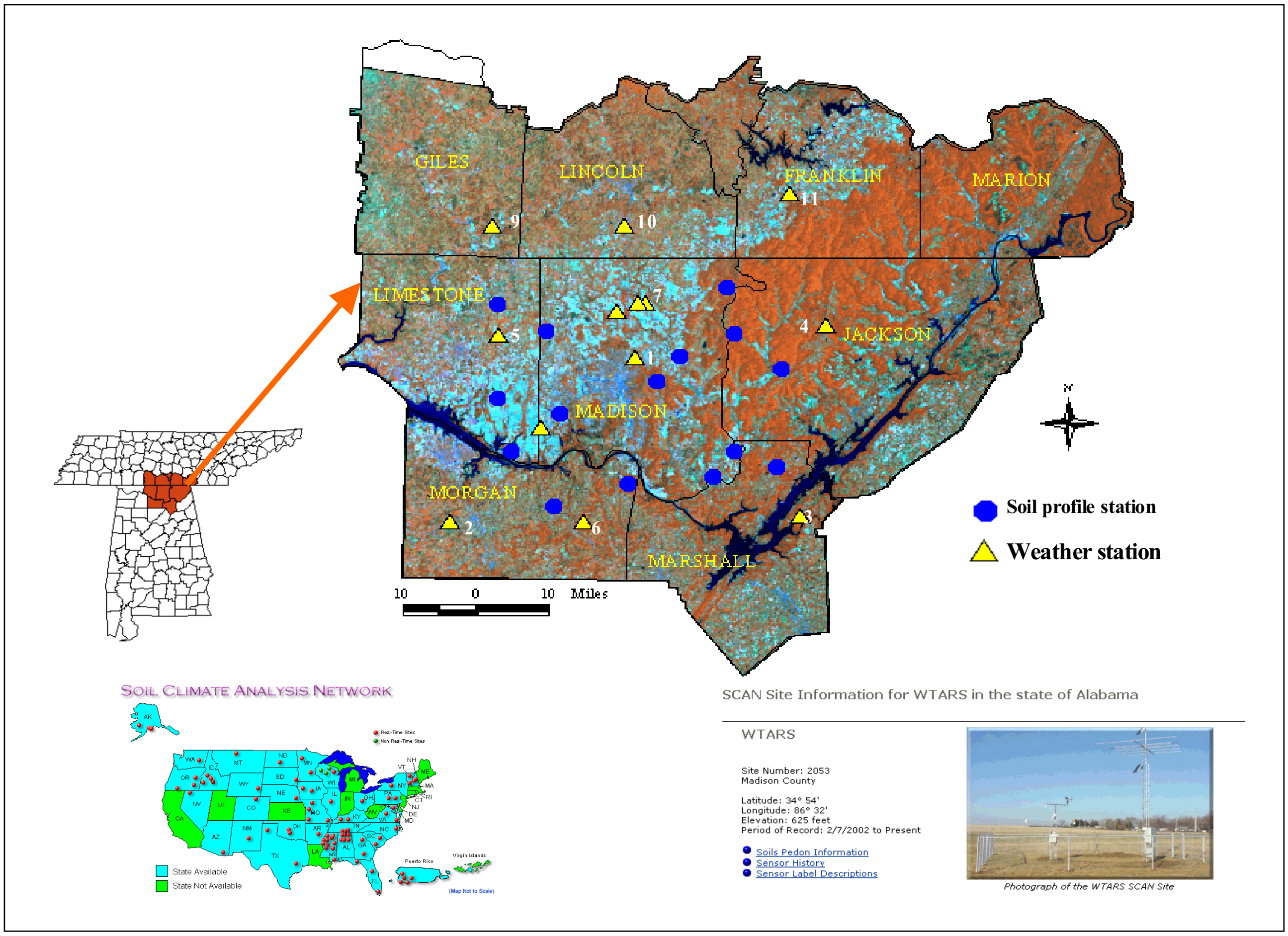

Figure 2. Coverage and location of the Alabama Mesonet (ALMNet) soil profile and weather stations.

Most of this area consists of small and medium-sized farms. Agricultural land-(pasture and cultivated land) accounts for about 40 percent of land use. Pasture accounts for about 72 percent of all agricultural land throughout the study area. Cultivated land generally is located in the central and southwestern part of the study area, where relief is lowest (Figure 3). The western region contains the largest percentage of cultivated land (16 percent). Corn, soybeans, cotton, and wheat are the predominant crops grown in this area. Corn acreage was the largest of the crop areas in 1992 and accounted for about 34 percent of the total harvested acreage of these crops (U.S. Department of Commerce, 1994). Soybean acreage accounted for about 32 percent, cotton about 23 percent, and wheat about 11 percent of the total harvested acreage of all four crops in 1992. The amount of forested land ranges from about 27 percent in the western part to 68 percent in the eastern part of the study region where topographic relief is greatest. The plateau and remnant “mountains” support a mixed oak-pine forest. Shortleaf pine, *loblolly* pine, sweetgum, yellow-poplar, red oaks, and white oaks are the major overstory species. Dogwood and redbud are major midstory species. Japanese honeysuckle, greenbrier, low panicums, bluestems .and native lespedezas are understory species.

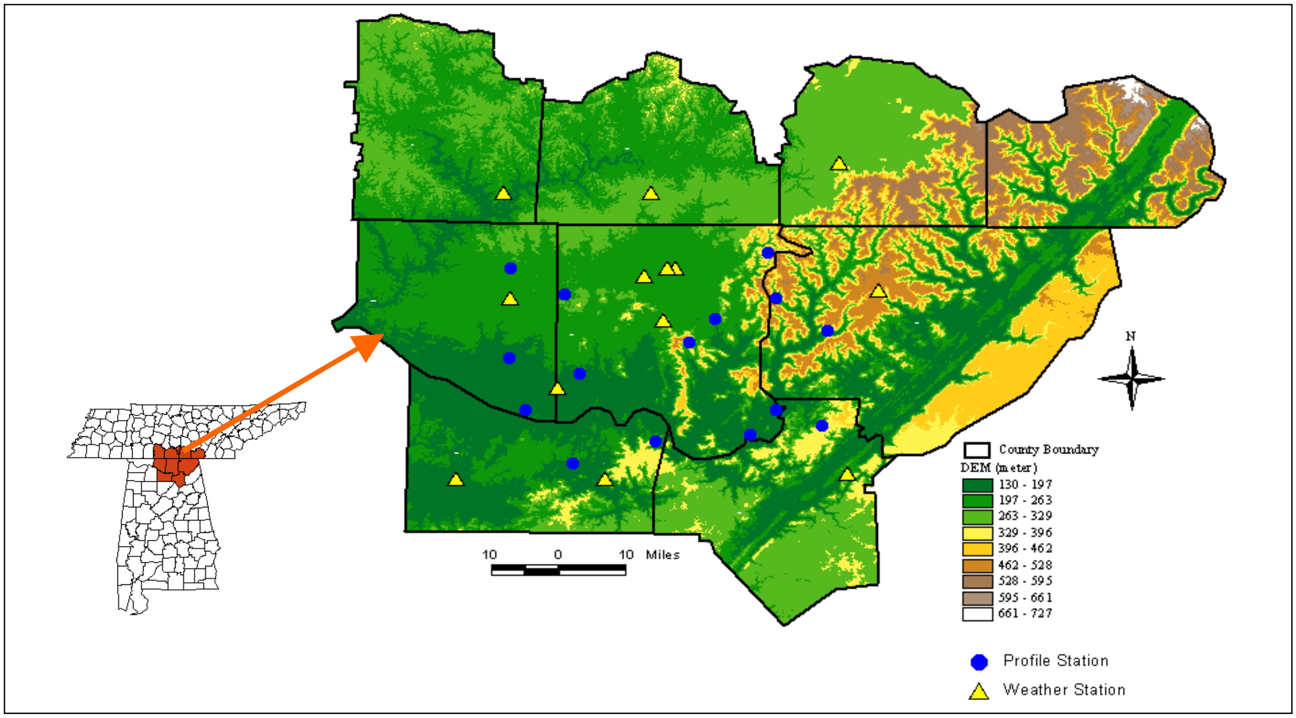

Figure 3. Digital elevation model (DEM) for the Alabama Mesonet (ALMNet) study sites.

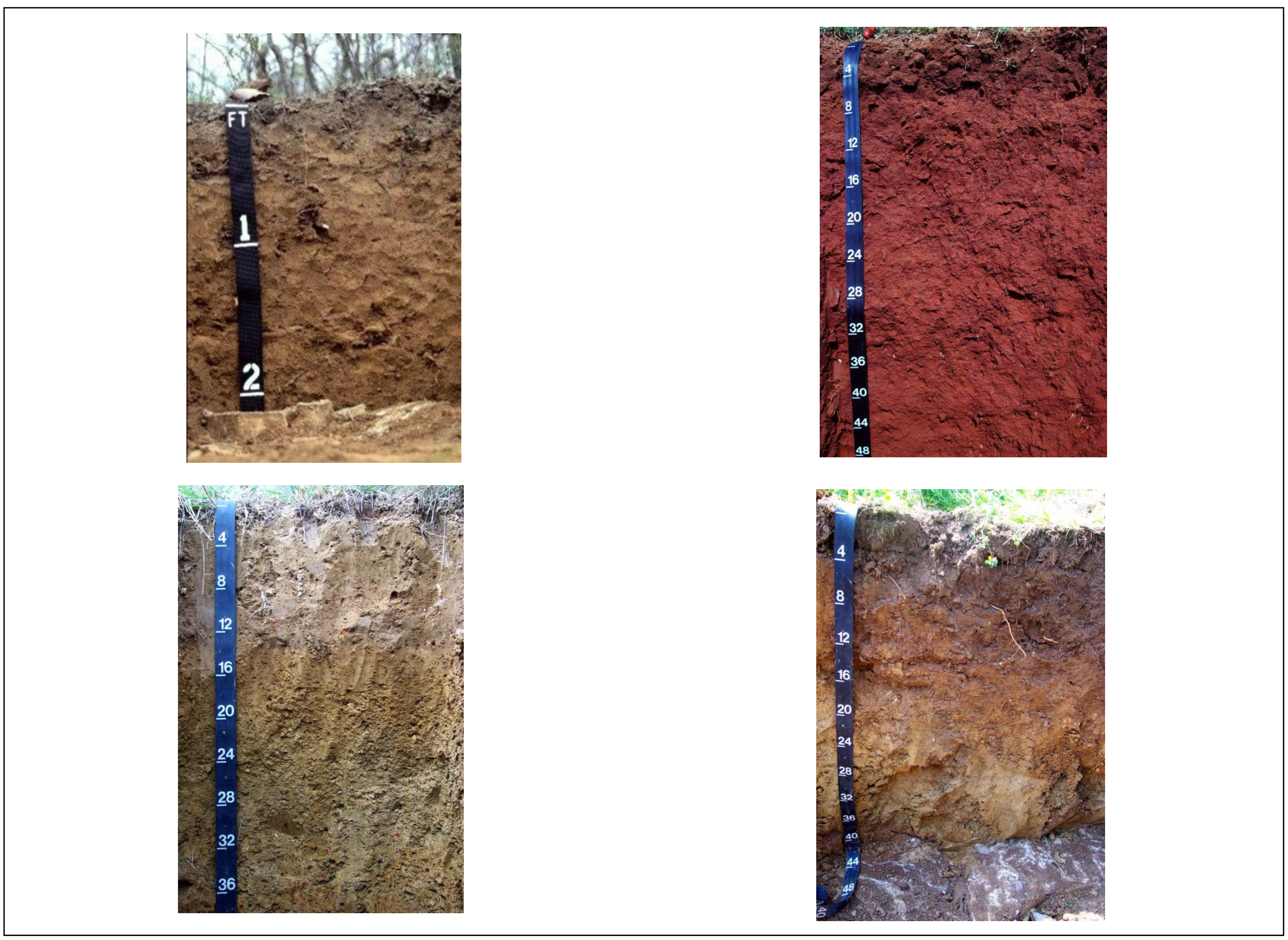

Figure 4. Soil profile for the Hartsell (a), Decatur (b), Dickson (c), and Mimosa (d) Series for the Cumberland Plateau (MLRA 125 & 129), Tennessee Valley (MLRA 128), the Highland Rim (MLRA 122), and the Outer Nashville Basin (MLRA 123) within the ALMNet study site.

The study region has a temperate and warm, humid climate. Average temperature across the region ranges from 56 to 61°F with an average annual temperature of about 59°F. The warmest months are July and August and the coolest month is January. Average annual precipitation is about 56 inches. The average amount of precipitation for individual sites in the study area ranges from about 50 inches in the western part of the study area to about 60 inches in the eastern part of the study area. The increase in precipitation from west to east generally corresponds to the increase in elevation. Average rainfall amounts are highest during November through May, with March generally being the wettest month. Average rainfall amounts are lowest from June through October. August through October is usually the driest part of the year.

METEOROLOGICAL AND SOIL MOISTURE NETWORKS

The Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS) developed an outdoor research and teaching laboratory equipped with permanent sensors that continuously record environmental and meteorological data. The ALMNet is located in north central Alabama and southern Tennessee covering an area of approximately 8100 km^2 (Figure 1). The network covers Madison county and portions of Jackson, Limestone, Marshall, and Morgan Counties in north Alabama and Franklin, Giles, and Lincoln counties in southern Tennessee (Table 1).

The meteorological stations and associated soil profile systems are part of the USDA NRCS NWCC Soil Climate Analysis Network (SCAN). They are fully automated and provide near real-time observations at five-minute intervals that are averaged over 60 minutes and transmitted to the NWCC and HSCaRS laboratories every hour through the USDA SCAN system for quality control and dissemination.

Soil profile systems are collocated with each of the eleven meteorological stations. There are 12 additional soil profile stations located throughout the Mesonet area (Figure 2). The soil profile stations are equipped with soil moisture and temperature sensors, soil heat flux plates, and a tipping bucket rain gauge (Table 2). The soil moisture sensors record soil moisture fluxes at five depths, 5, 10, 20, 50 and 100 cm, using RF measurements of dielectric constant. Soil temperature is measured at 5, 10 and 20 cm with thermistor probes and soil heat flux is measured between 5 and 10 cm with thermistor temperature differential readings. These data are measured at one minute intervals, averaged and recorded at 15-minute intervals on data loggers, which are downloaded every two weeks for quality control and dissemination.

EXAMPLES OF DATA USA

These data allow a variety of analyses of processes related to hydrological and meteorological

Table 1. Site Description for the ALMNet Weather Stations

ID #	Site name	County	State	Elevation (m)	Latitude	Longitude
1	AAMU Campus	Madison	AL	262.1	34^0 47' N	86^0 33' W
2	Hartselle USDA	Morgan	AL	192.9	34^0 26' N	87^0 00' W
3	Hodges Farm	Marshall	AL	222.5	34^0 27' N	86^0 09' W
4	Hytop	Jackson	AL	544.1	34^0 52' N	86^0 06' W
5	Newby Farm	Limestone	AL	192.9	34^0 51' N	86^0 53' W
6	Stanley Farm	Morgan	AL	193.5	34^0 26' N	86^0 41' W
7	WTARS	Madison	AL	190.5	34^0 54' N	86^0 32' W
8	Braggs Farm Co-OP	Madison	AL	243.2	34^0 53' N	86^0 36' W
9	Allen Farms	Giles	TN	214.9	35^0 04' N	86^0 54' W
10	McAlister Farm	Lincoln	TN	278.3	35^0 04' N	86^0 35' W
11	East View Farms	Franklin	TN	321.3	35^0 08' N	86^0 11' W

variations over time under different land use and cover types. The Alabama A & M University Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS) and the NASA's National Space Science and Technology Center (NSSTC) Global Hydrology and Climate Center (GHCC) have been involved with the Alabama portion of the Soil Moisture Experiment 2003 (SMEX '03). The Huntsville, Alabama, activities serve to ground truth the microwave remote sensors on the NASA P3B aircraft (NASA's 2D STAR, a.k.a. ESTAR 2D, and NOAA's PSR-CX) and the spaceborne platforms AMSR/AMSR-E, TRMM-TMI, etc. The ground-truthing activities included soil sampling (cores, theta probe) and vegetation sampling. The Huntsville portion of SMEX '03 was conducted from June 21st to July 3rd 2003 (Jackson et al., 2004).

Table 2. Instrumentation Used in the ALMNet Systems

Variable	Sensor/Equipment	Vendor	Model	Height/Depth
Solar radiation	Pyranometer	Licor	LI-200SZ	15 or 30ft.
Wind speed and direction	Anemometer, vane	R. M. Young	03001-5	15 or 30 ft.
Air temperature and relative humidity	Thermometer, probe	CSI/Vaisala	CS500	9 or 10 ft.
Rainfall	Tipping Bucket	Campbell Sci.	TE525	5 or 9 ft.
Soil moisture	Probe	Stevens-Vitel	Hydra-Probe	2, 4, 8, 20 and 40 in.
Soil moisture	Probe	Delta-T	PR1/6w-L10	2, 4, 8, 12, 20 and 40 in.
Soil moisture	Probe	Delta-T	ML2x	4 and 8 in.
Soil temperature	Probe	Stevens-Vitel	Hydra-Probe	2, 4, 8, 20 and 40 in.
Soil temperature	Probe	Dynamax	TM-L35	2, 4, 8 and 20 in.
Soil heat flux	Plate	Campbell Sci.	HFT	2 and 4 in.
	Data logger	Campbell Sci.	CR10x	
	Transmitter	Meteor	545B	

Although there was a high level of variability in volumetric soil moisture data between all weather stations, patterns regarding precipitation, measurement depths, and soil types were observable by looking at figures 5 through 9 below. Due to sub surface flow, the deeper profiles were expected to have a higher volumetric soil moisture percentage, which was the case for most sites. Elevation and soil type were obvious parameters that varied considerably from one site to another. When looking at the data for site #4 (Figure 9), the 100 cm depth had more variability than all other depths, most likely due to its elevation of over 544 meters. In addition, the soil at site #4 had high sand and low clay content, causing water to leave the soil quickly and flow to lower elevations. The 20 cm soil depth the water retention was by far better than all other depths, because it had a higher clay percentage than the soil of other depths. At all other sites, the 100 cm depth had the highest and most stable moisture content readings. On the other hand, the 5 cm soil depth had a high level of variability after each rainfall event at all seven sites. The mid-slope location of site #3 (Figure 8) and the high elevation at site #4 contributed to the immediate loss of moisture at 5 cm, where runoff was common. The low soil moisture readings for the 50 cm depth at site #7 (Figure 12) were due to a lower clay percentage than the layers above and below it, as seen in Table 3. The high clay content at site #6 (Figure 11) was responsible for increased water retention at the 20 cm soil depth when compared to the 5 and 10 cm soil depths, as seen in Figure 11.

In addition to higher overall volumetric soil moisture readings, more stable moisture readings were also expected for the deeper depths. For site #6, the volumetric soil moisture readings at the fifth depth of 100 cm were nearly constant at about 40% over the entire year, while the soil moisture readings at site #5 and #6 at the 100 cm soil depth had more variability. The significant water loss at these two sites between October and January were most likely due to lower

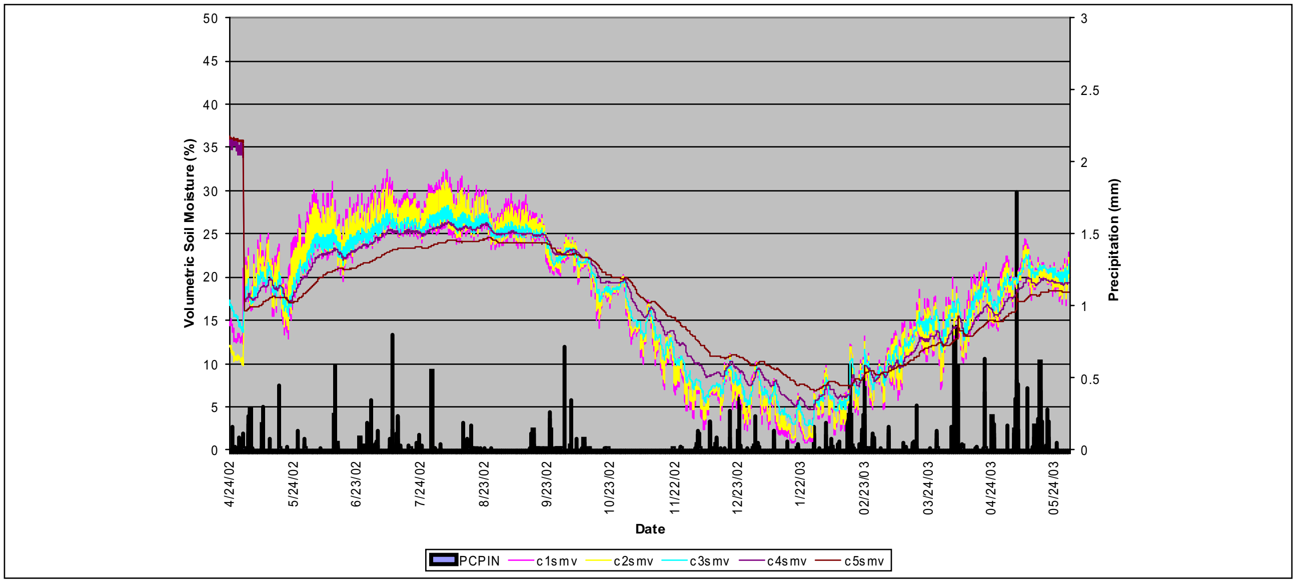

Figure 5. Precipitation and soil moisture distribution at site #1.

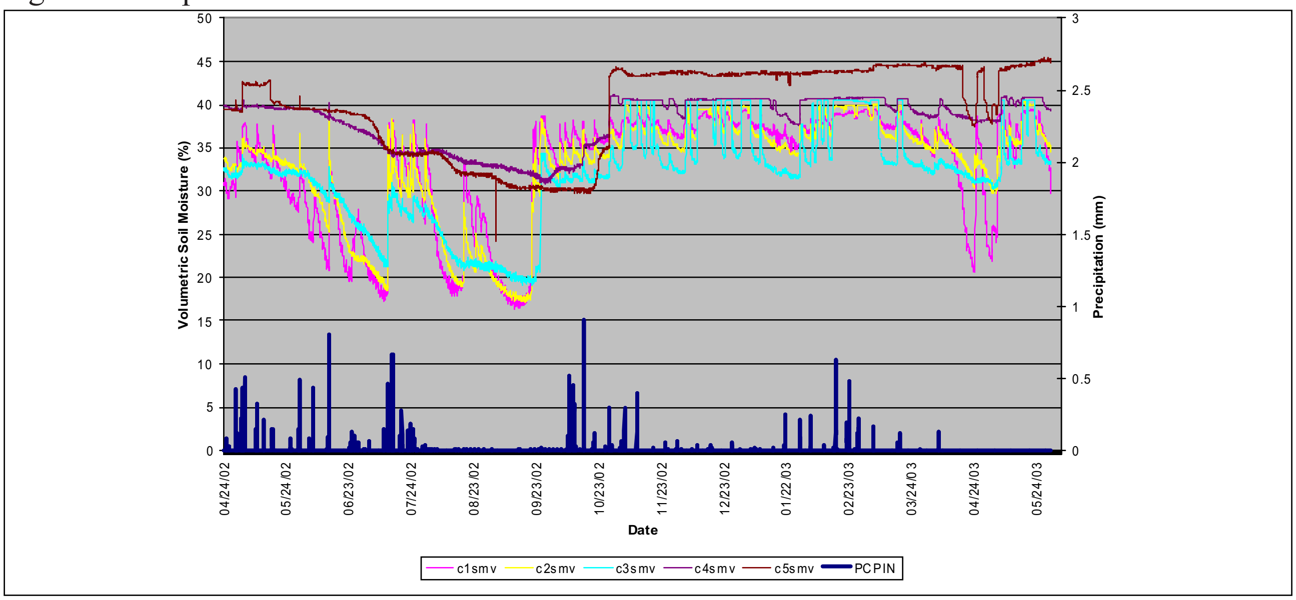

Figure 6. Precipitation and soil moisture distribution at site #2.

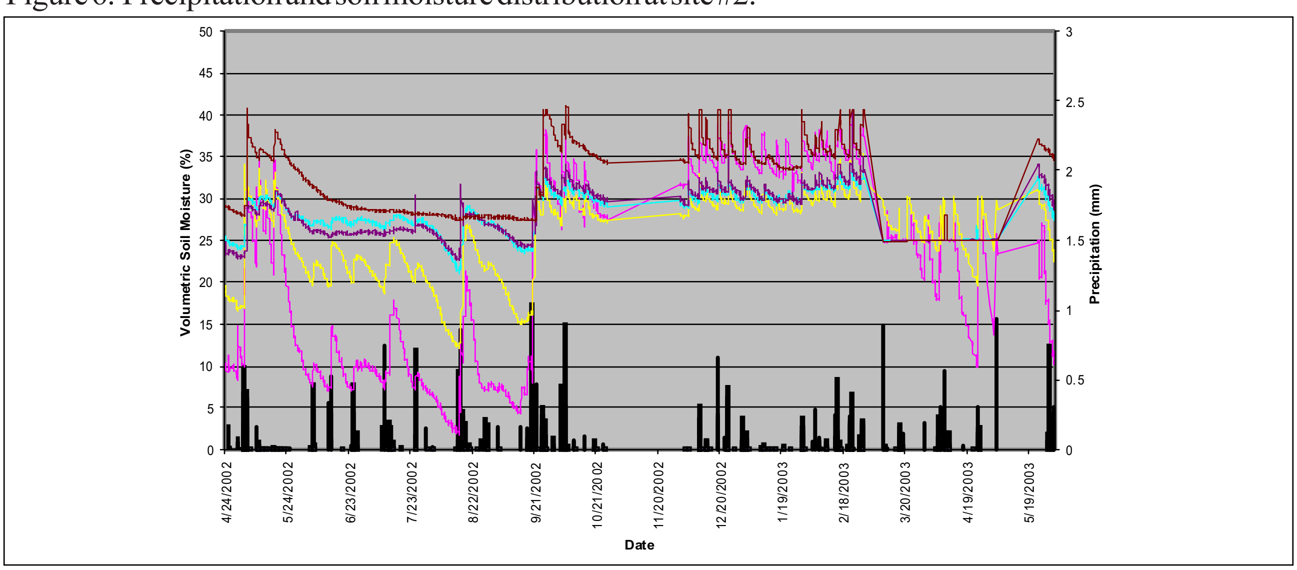

Figure 7. Precipitation and soil moisture distribution at site #3.

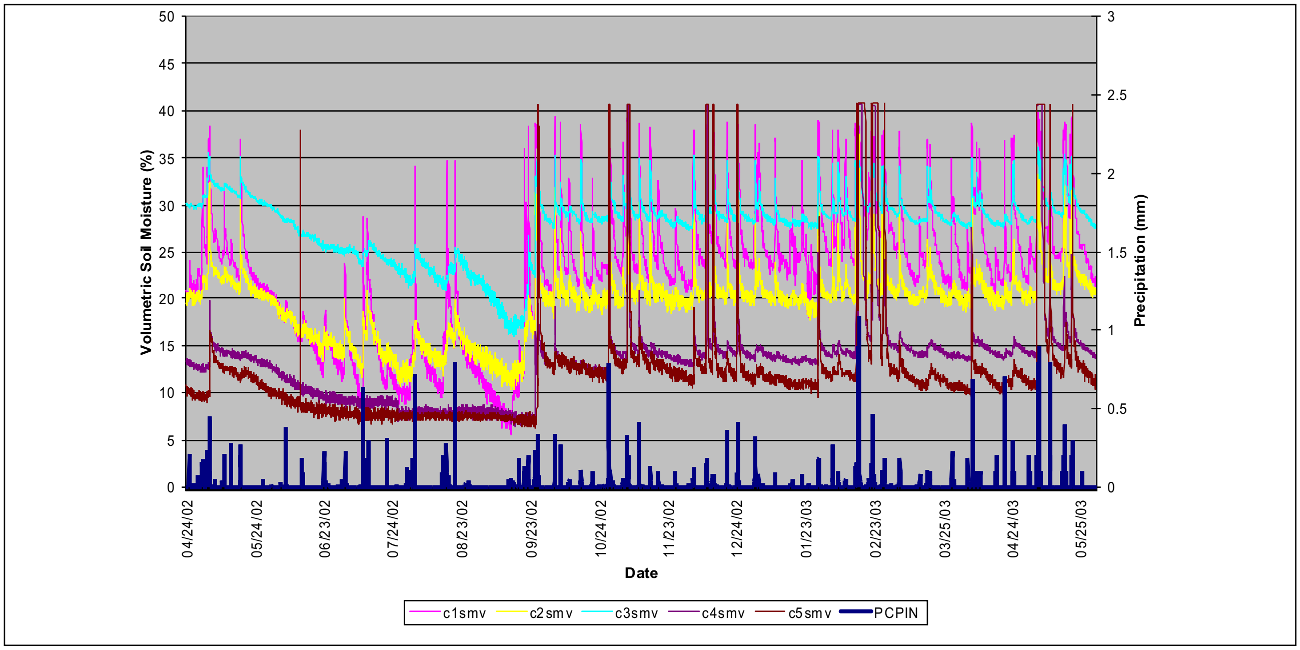

Figure 8. Precipitation and soil moisture distribution at site #4.

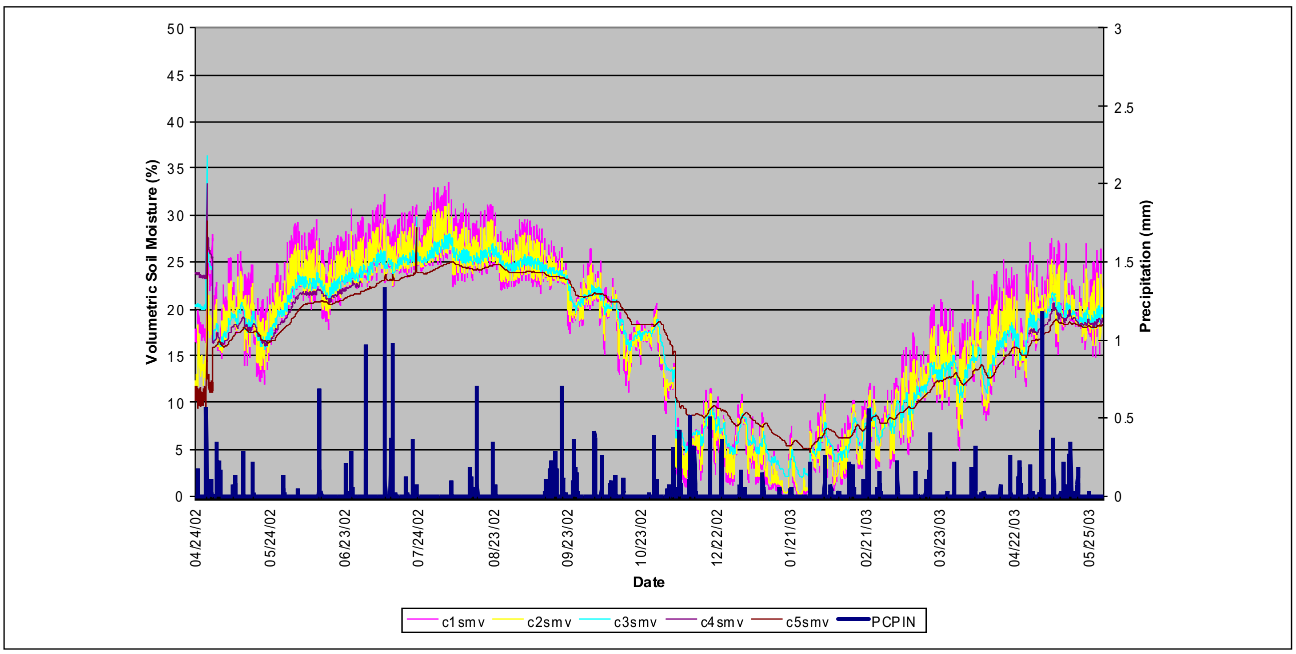

Figure 9. Precipitation and soil moisture distribution at site #5.

amounts of precipitation during these months. The high percentage of silt in the soil at site #5 (Figure 10) and the presence of rocks in the site #1 (Figure 6) also decreased the soils' ability to retain moisture. The shallow depth to ground water at site #6, site #2 (Figure 7), and site #7 were due to their low elevations of less than 200 meters. In addition, site #2 was located at the edge of wetlands, further contributing to the high amount volumetric soil moisture content over time. At site #3, it can be observed that at 100 cm the VWC likewise remained relatively stable, never decreasing below 25 percent.

Seasonal changes were also expected to create variability in soil moisture and precipitation. More rainfall occurred between March and the beginning of June at site #7, causing the top four depths to be wetter during that time, as seen in Figure 12. Contrarily, warmer air temperatures during the summer months decreased soil moisture readings at site #5 and site #1. No

Table 3. Particle Size and Soil Textural Classes for ALMNet Soil Profiles

Site #1				**Site #2**			
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	**Depth (cm)**	Clay (%)	Silt (%)	Sand (%)
0 – 20	22.9	47.9	29.2	0 – 15	15.2	56.2	28.6
20 – 46	32.3	43.4	24.3	15 – 30	16.3	59.6	24.1
46 – 69	41.3	37.8	20.9	30 – 61	23.2	66.6	10.2
69 – 97	47.5	33.9	18.6	61 – 91	28.5	61.2	10.3
97 – 152	54.8	28.9	16.3	91 – 107	33.5	55.7	10.8
				107 -152	37.7	51.3	11.2
Site #3				**Site #4**			
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	**Depth (cm)**	Clay (%)	Silt (%)	Sand (%)
0 – 15	16.4	59.6	24.0	0 – 8	11.8	32.7	55.5
15 – 28	26.1	56.3	17.6	8 – 56	16.6	32.4	51.0
28 – 48	46.8	43.3	9.9	56 – 76	12.8	26.2	61.0
48 – 71	61.6	32.2	6.2	76 – 89	15.0	19.6	65.4
71 – 102	64.2	30.8	5.0				
102 -152	64.5	28.4	7.1				
Site #5				**Site #6**			
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	**Depth (cm)**	Clay (%)	Silt (%)	Sand (%)
0 – 25	15.9	73.7	10.4	0 – 15	17.4	42.6	40.0
25 – 51	18.3	71.9	9.8	15 – 25	21.9	41.3	36.8
51 – 91	22.9	65.8	11.3	25 – 41	25.7	38.8	35.5
91 – 122	22.9	66.7	10.4	41 – 107	24.2	37.2	38.6
122 – 127	28.1	60.9	11.0				
Site #7				**Site #8**			
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	**Depth (cm)**	Clay (%)	Silt (%)	Sand (%)
0 – 10	31.5	61.5	7.0	0 – 5	31.1	56.2	12.7
10 – 23	26.3	67.9	5.8	5 – 20	36.7	50.2	13.1
23 – 48	38.6	57.1	4.3	20 – 46	48.9	43.1	8.0
48 – 69	36.0	58.6	5.4	46 – 104	54.1	38.4	7.5
69 – 86	43.3	48.8	7.9	104 – 132	56.5	34.6	8.9
86 - 122	46.6	43.0	10.4	132 -152	56.2	33.8	10.0
122 - 152	42.9	39.2	17.9				
Site #9				**Site #10**			
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Depth (cm)	Clay (%)	Silt (%)	Sand (%)
0 – 10	25.0	51.9	23.1	0 – 10	19.1	66.1	14.8
10 – 20	28.0	50.9	21.1	10 – 23	23.4	63.7	12.9
20 – 46	35.5	42.9	21.6	23 – 43	25.5	62.0	12.5
46 – 60	56.7	27.0	16.3	43 – 71	36.0	51.1	12.9
60 – 90	62.3	20.2	17.5	71 – 102	47.8	30.8	21.4
90 - 107	61.8	24.0	14.2	102 - 152	53.0	31.7	15.3
Site #11							
Depth (cm)	Clay (%)	Silt (%)	Sand (%)				
0 – 20	26.6	67.0	6.4				
20 – 56	37.2	57.1	5.7				
56 – 86	34.6	55.7	9.7				
86 – 114	33.0	56.2	10.8				
114 – 152	48.7	43.7	7.6				

relationships could be observed regarding time and soil moisture between all seven sites. Data collected over a longer period of time will enable further analysis of temporal soil moisture variability. However, it must be noted that a high amount of cumulative precipitation at one site did not make it wetter than another site with less cumulative precipitation. Although site #4 received 161.54 cm of rainfall between April 24, 2002 and May 31, 2003, the highest volumetric soil moisture reading at any depth never exceeded 42%. Site #2, Site #3, and site #7 received less rainfall but easily reached similar soil moisture readings. Although the site #2 and site #3 were missing data, by looking at the existing data, it was assumed that the total precipitation measurements would not have been as high as that of site #4.

Soil temperature distribution is shown in Figures 12 through 17, showing Sites #1 through #6.

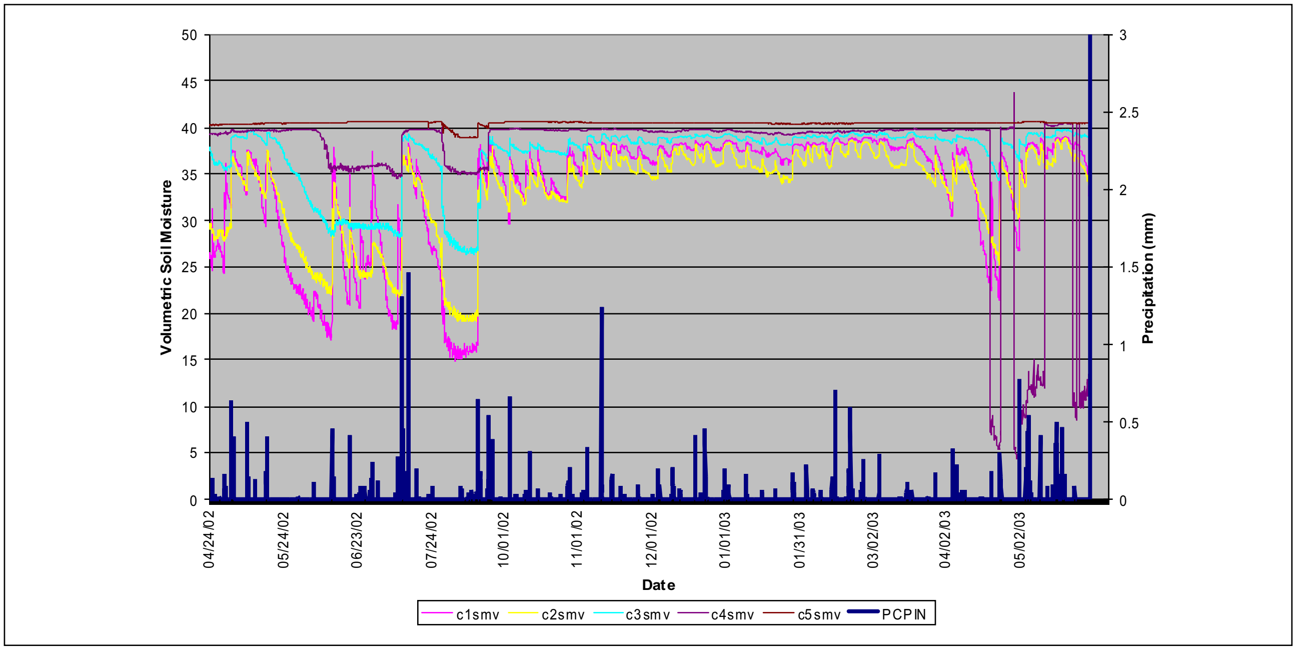

Figure 10. Precipitation and soil moisture distribution at site #6.

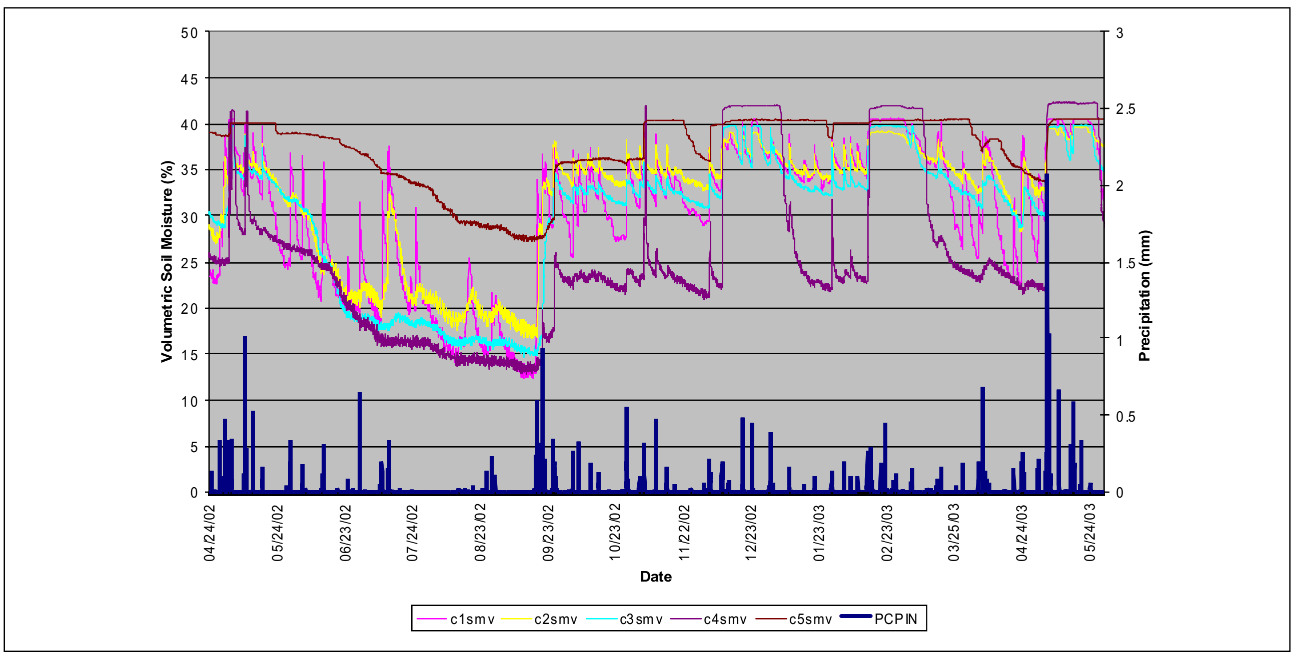

Figure 11. Precipitation and soil moisture distribution at site #7.

The temperature at each level corresponding to the soil moisture measurements above is shown for the year 2003. The sites with higher clay soils (#1, #3 and #5) showed a greater delay in heating and cooling of the lowest measured level (100 cm) than the wetland edge sites (#4 and #6), while the site with sandy soil (#2) showed the least delay. Sites #1, #4 and #5 showed smaller diurnal variation than the other three sites, and the sandy soil site (#2) showed the highest diurnal variation, due to its lower average moisture content. The highest annual range of temperatures was found at Site #6 and the lowest at Site #4, though both are wetland edge sites. Neither of these sites has significant shade, and the difference in total annual temperature variation between all sites is less than 3 ^{o}C.

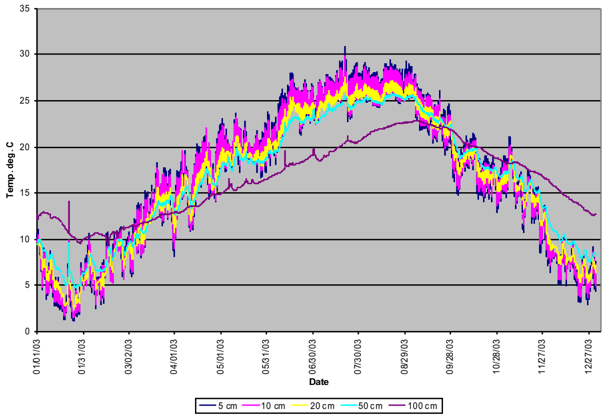

Figure 12. Temperature distribution at site #1.

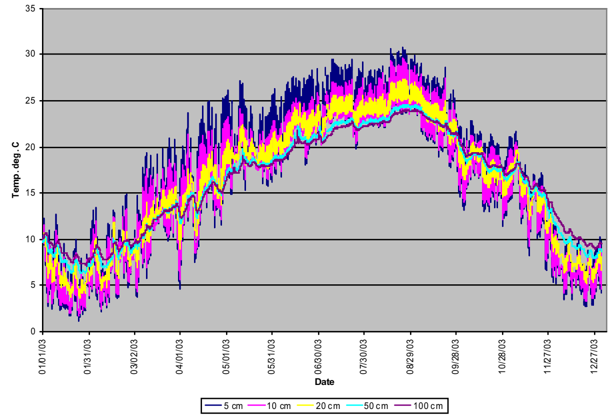

Figure 13. Temperature distribution at site #2.

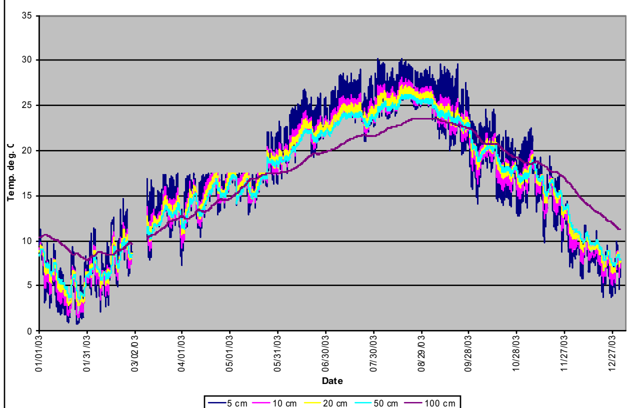

Figure 14. Temperature distribution at site #3.

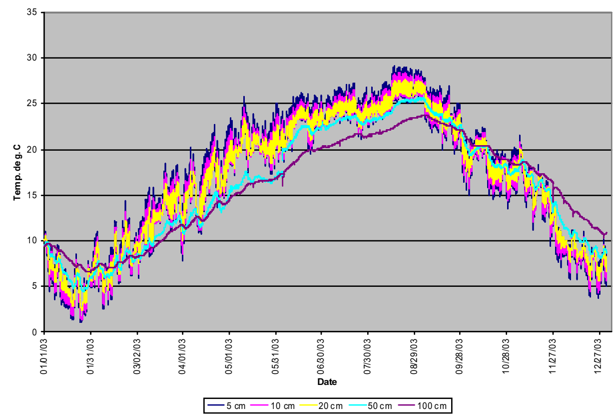

Figure 15. Temperature distribution at site #4.

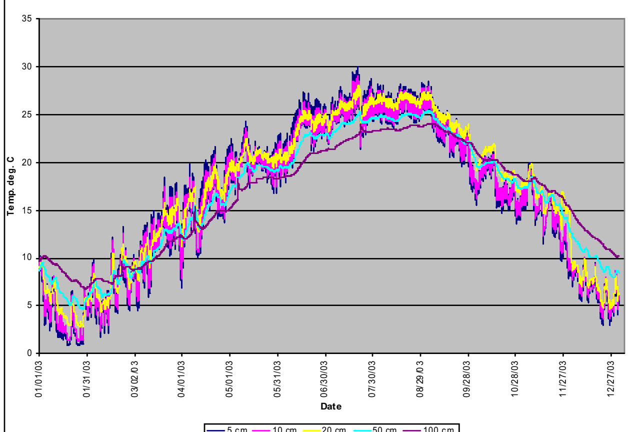

Figure 16. Temperature distribution at site #5.

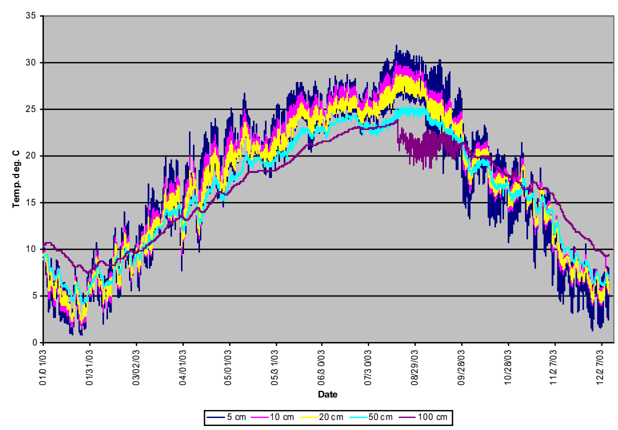

Figure 17. Temperature distribution at site #6.

CONCLUSION

The variability of soil moisture and temperature was evident throughout the study sites within the ALMNet. Variation in rainfall patterns, differences in soil type, and changes in land use and cover types are the main cause for the observed variation in soil moisture and temperature within the study area. The ALMNet data are available to the public viahttp://wx.aamu.edu/ALMNet.html. Our long -term vision is to complete detailed hydrological and meteorological process analyses for northern Alabama and southern Tennessee in collaboration with scientists from the National Aeronautics Space Administration (NASA), USDA and other Universities. We also hope to expand the recording sites throughout Alabama as our resources permit.

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