Notice to Data Users:
The documentation for this data set was provided solely by the Principal Investigator(s) and was not further developed, thoroughly reviewed, or edited by NSIDC. Thus, support for this data set may be limited.

SMEX04 Walnut Gulch Experimental Watershed Soil Moisture Data: Arizona

Summary

This data set contains several parameters measured in the Walnut Gulch Experimental Watershed for the Soil Moisture Experiment 2004 (SMEX04). The parameters include volumetric soil moisture, soil temperature, soil conductivity, soil salinity, and surface temperature. SMEX04 was conducted during August of 2004 to coincide with the North American Monsoon Experiment in the Southwestern U.S. and Northwestern Mexico. Data provided here were collected from July 1, 2004 through September 30th, 2004 using in-situ soil moisture sensors and radiometric surface temperature sensors.

Data are provided in ASCII text files, and are available via FTP.

The Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) is a mission instrument launched aboard NASA's Aqua Satellite on 4 May 2002. AMSR-E validation studies linked to SMEX are designed to evaluate the accuracy of AMSR-E soil moisture data. Specific validation objectives include assessing and refining soil moisture algorithm performance, verifying soil moisture estimation accuracy, investigating the effects of vegetation, surface temperature, topography, and soil texture on soil moisture accuracy, and determining the regions that are useful for AMSR-E soil moisture measurements.

Citing These Data:

Jackson, T. J., M. H. Cosh, D. Goodrich, S. Moran, and T. Keefer. 2009. *SMEX04 Walnut Gulch Experimental Watershed Soil Moisture Data: Arizona.* Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.

Overview Table

Category	Description
Data format	ASCII tab-delimited text
Spatial coverage	31.422° N to 31.112° N, 109.718° W to 110.239° W
Temporal coverage	1 June 2004 to 30 September, 2004
File naming convention	"RG###_05cm.txt" where ### identifies the Raingage ID.
File size	650 KB per file
Parameter(s)	Soil moisture, soil salinity, soil temperature
Procedures for obtaining data	Data are available via FTP.

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1. Contacts and Acknowledgments:

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Acknowledgements:

The USDA ARS Southwest Watershed Research Center and the many graduate students and volunteers collected the field data.

2. Detailed Data Description:

Format:

Data consist of ASCII tab-delimited text files.

File Naming Convention:

File Naming Convention: Each hydra probe was located at 5 cm below the surface near a Walnut Gulch Experimental Watershed Raingage in the WG study region. Location information is based on the WGS84 datum.

Table 1: Soil Moisture Sensor Locations

Site	Latitude	Longitude	Northing in m	Easting in m	Depths of sensors
RG003	31.72044	-110.14294	3509769	581200	5
RG013	31.72380	-110.09110	3510181	586108	5
RG014	31.69683	-110.09869	3507185	585414	5
RG018	31.70487	-110.08492	3508087	586712	5
RG020	31.67610	-110.07712	3504905	587478	5
RG028	31.72201	-110.04340	3510021	590629	5
RG034	31.69886	-110.04030	3507458	590946	5
RG037	31.68613	-110.01556	3506067	593303	5
RG040	31.72429	-110.01431	3510298	593383	5
RG046	31.70931	-109.99436	3508655	595289	5,15,30
RG057	31.72842	-109.98571	3510781	596089	5
RG069	31.76997	-109.90260	3515463	603916	5
RG070	31.75861	-109.89881	3514207	604288	5
RG076	31.71956	-110.12815	3509682	582602	5
RG082	31.73618	-109.94271	3511680	600154	5,15,30

RG083	31.74377	-110.05292	3512425	589706	5
RG089	31.75682	-109.98308	3513931	596308	5
RG092	31.73860	-110.13545	3511787	581894	5
RG100	31.67398	-110.01608	3504720	593266	5
RG400	31.80210	-110.13240	3518828	582126	5
RG600	31.66375	-110.17775	3503460	577949	5

File Size:

File sizes range from 600 KB to 2.8 MB.

Spatial Coverage:

Southernmost Latitude: 31.112° N
Northernmost Latitude: 31.422° N
Westernmost Longitude: 110.239° W
Easternmost Longitude: 109.718° W

Temporal Coverage:

1 June 2004 to 30 September 2004

Temporal Resolution:

Hydra Probe recorded every 20 minutes though 3 sites were recorded every 5 minutes for intensive study.

Parameter or Variable:

Raw Data Format ASCII text table - Column Headings

Header Key
Site: Site #
Depth: Depth cm
Soil_Type: Vitel soil type (sand=1, silt=2, and clay=3)
Year: Year
Day: Day of Year
Hour: Hour (Mountain Standard Time)
Minute: Minute
V1: Vitel Voltage 1
V2: Vitel Voltage 2
V3: Vitel Voltage 3
V4: Vitel Voltage 4
Real Diel: Real Dielectric Constant
Imag Diel: Imaginary Dielectric Content

Temp: Temperature C calculated from Vitel algorithm using Voltage 4
TcorRD: Real Dielectric Constant (Temperature Corrected)
TcorIDorr: Imaginary Dielectric Content (Temperature Corrected)
VWC: Soil Moisture VWC calculated by Vitel Calibration
Salinity: Soil Salinity
Soil_Cond: Soil Conductivity
TcorSC: Soil Conductivity (Temperature Corrected)
Water_Cond: Soil Water Conductivity (Temperature Corrected)
VSM_RFC: Volumetric Soil Moisture with Rock Fraction Correction

This data has been quality controlled and suspect or missing data has been removed. Consequently, this data is not continuous.

3. Data Access and Tools:

Data Access:

The U.S.D.A. Agricultural Research Service (ARS) measures hydrologic conditions in the Walnut Gulch Experimental Watershed in southeastern Arizona, near the historic cowboy town of Tombstone.

Twenty-one stations were operational during SMEX04. In the future, these data sets will be available for public use, but in the meantime, three months of data are being made available for the SMEX04 experiment.

Software and Tools:

No special tools are required to view these data. A word-processing program or Web browser will display the data.

Related Data Collections:

See related information on the Soil Moisture Experiment (SMEX) Web site.

4. Data Acquisition and Processing:

Hydra Probes

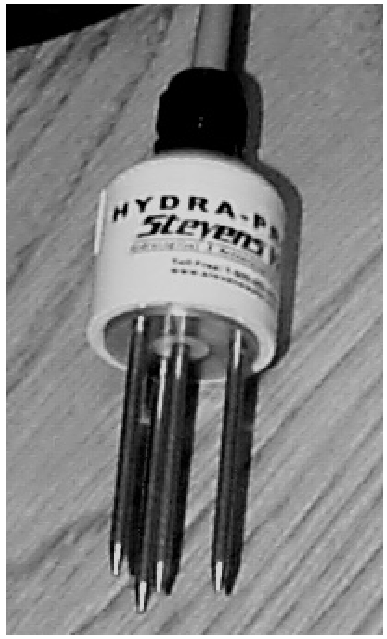

Figure 1: Hydra Probe by Stevens Water Inc.

Soil moisture and temperature for the surface layer were measured using Vitel Type A Hydra Probes (HP). This version is compatible with Campbell CR-10 data loggers; the temperature output voltage never exceeds 2.5 V.

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

The HP has three main structural components: a multiconductor cable, a probe head, and sensing tines. The probes were installed horizontally in the soil, with the center tine at a depth of 5 cm.

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

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

The output data from an HP consists of a time stamp and four voltages (V1-V4), which are converted to estimate the soil moisture and soil temperature through a program provided by Stevens-Vitel. The program requires the four voltages and a soil classification (sand=1, silt=2, and clay=3). The quality control of these data was limited to removing samples for which the program returned erroneous data because of corrupted voltages. These voltages may be a result of several things, including faulty installation, lightning strikes, and rodent impact. Erroneous samples were removed, so the data are not continuous for every HP.

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

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

The 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.

Data Processing

The output data from a Hydra probe consists of a time stamp and four voltages (V1-V4). These voltages are converted to estimate the soil moisture and soil temperature through a program provided by Stevens-Vitel (contact www.stevenswater.com) [either Hydra.exe, hyd-file.exe]. These programs require the four voltages and a soil classification (Sand=1, Silt=2, and Clay=3). The quality control of this data was limited to removing samples for which the program returned erroneous data because of corrupted voltages. These voltages may be a result of several things, including for example, faulty installation, lightening strikes, and rodent impact. Erroneous samples were removed, therefore, the data is not continuous for every Hydra Probe. All sites were considered to be located in 'sand' with the exception of RG046 which is located in a 'clay' area.

Calibration and Rock Fraction Correction

As part of the Soil Moisture Experiment in 2004 (SMEX04), gravimetric and dielectric probe samples were taken daily throughout the WGEW to coincide with aircraft overflights. A gravimetric sample was taken at 64 sites within the watershed. These were all co-located with in situ soil moisture sensors and rain gages. Five dielectric probe samples were also taken at each of the 64 sites. In a manner similar to Cosh et al. (2005), the dielectric probes were calibrated using the co-located gravimetric samples to create a site-specific calibration equation for volumetric soil moisture.

The first step in the process is the calculation of the Gravimetric Soil Moisture, GSM, as follows

$$\frac{WetWgt - DryWgt}{DryWgt - CanWgt} = GSM \qquad (1)$$

where WetWgt is the sample weight before drying, DryWgt is the sample weight after 24 hours of drying at 100 F, and CanWgt is the weight on an empty can and lid. From this Gravimetric Soil Moisture, in g/g, the (Gravimetrically-based) Volumetric Soil Moisture of the Sample ($GVSM_{SAMP}$) is calculated with

$$GSM * BD_{SAMP} = GVSM_{SAMP} \qquad (2)$$

where BD_{SAMP} is the bulk density of the sample volume. Field samples of bulk density and rock fraction, $RF_{SAMP,}$ were taken independently near the raingages and soil moisture sampling sites while making sure not to disturb the installations. One of the 5 dielectric samples was taken at the exact same location as the gravimetric sample. This is the dielectric measure used in the calibration. Using the following equation

$$\theta = \frac{\left[1.07 + 6.4V - 6.4V^2 + 4.7V^3\right] - a_0}{a_1} \qquad (3)$$

where V is the voltage reading from the probe, and a_0 and a_1 are calibration constants, the root mean square error between the $GVSM_{SAMP}$ and θ is minimized by changing a_0 and a_1. The overall root mean square error (RMSE) associated with the calibration for the WGEW dielectric probe sampling as compared to the gravimetric sampling was 0.024 m^3/m^3.

There is a degree of bias in the location of ground sampling, because there is a large amount of rock at the surface. People obtained samples at locations with fewer surface rocks. This sample represents the soil (plus small rocks) rock fraction. However, for remote sensing and grid based modeling, the volumetric moisture of the surface layer is required. A procedure was developed for converting the point observations, which is referred to as the Rock Fraction Correction.

The bulk density (and rock fraction) samples were approximately 300 cm^3 in volume, which is comparable to the ground sampling protocols for soil moisture (100 cm^3). This sample is a combination of rock and soil, however, it will be somewhat biased to a sample with more soil than if we were able to obtain a very large sample (>10,000 cm^3). There is a need to 'correct' this ground sample to a large-scale estimate, which would incorporate a more accurate rock fraction. The first step in this correction is to calculate the volumetric soil moisture of the soil only, $GVSM_{SOIL}$. This is accomplished by using the rock fraction of the sample at the surface, RF_{SAMP}, with

$$GVSM_{SOIL} * (1 - RF_{SAMP}) = GVSM_{SAMP} . \quad (4)$$

In order to provide a more area representative estimate of rock fraction, we used the data provided in the NRCS. SSURGO (http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/) data base. These values are also available at coarser scales from using the VSM_{SOIL} and the rock fraction estimate from the SSURGO database, the rock fraction corrected volumetric soil moisture, VSM_{RFC}, is calculated by

$$GVSM_{SOIL} * \left(1 - RF_{SSURGO}\right) = GVSM_{RFC} . \quad (5)$$

More simply, this equation can be rewritten as

$$GVSM_{SAMP} * \left(\frac{1 - RF_{SSURGO}}{1 - RF_{SAMP}}\right) = GVSM_{RFC} \quad (6)$$

which clearly shows how the rock fraction correction is a scaling value, referred to as the Rock Fraction Correction. This correction should also be applied to the dielectric probe samples, because the dielectric probes are inserted in the ground with the same bias of sampling location (more soil than rock). The $GVSM_{SAMP}$ can be replaced with $\overline{\theta}$, which is the average volumetric soil moisture from the site specific calibrated dielectric probes. This is based on five sampling points compared to the single gravimetric sample.

$$\overline{\theta} * \left(\frac{1 - RF_{SSURGO}}{1 - RF_{SAMP}}\right) = \overline{\theta}_{RFC} \quad (7)$$

It is also necessary to apply a correction to the WGEW soil moisture sensor network (SMSN). Since the SMSN sensors were installed in the same soil (locally) that was sampled during SMEX04, it is logically to apply the same RFC to the sensor data per site, resulting in an $SMSN_{RFC}$ for each sensor.

Table 2 shows the rock fractions and the correction constants. This also lists the RMSE values for comparison of the $SMSN_{RFC}$ with ($\overline{\theta}$) and ($\overline{\theta}_{RFC}$) as well as the R^2 values (this value is the same for both comparisons because one is a linear combination of the other). RMSE values decreased from 6.4% to 4.2 % error on average. R^2 values were generally high indicating a moderate to strong relationship between the ground sampling and the local soil moisture sensor. The RMSE of the $SMSN_{RFC}$ average to the $\overline{\theta}_{RFC}$ (which is based on 69 sampling points) is approximately 1% for the SMEX04 time period.

Figure 2 is a plot of the two SMSN time series (uncorrected and corrected) during the SMEX04 experiment. Using the Rock Fraction Correction on the soil moisture sensor network lowers the estimated soil moisture for the WGEW by approximately 0.023 m^3/m^3. Also plotted are the uncorrected (Theta) and corrected ($Theta_{RFC}$) soil moisture averages from the dielectric probe sampling during SMEX04. The average difference between these measurements is 0.02 m^3/m^3.

Table 2: Rock Fractions and the Rock Fraction Correction. '*' indicates no sampled rock fraction and the Rock Fraction Correction is estimated from nearby similar RF_{SSURGO} site. RMSE values and R^2 were calculated between the dielectric probe soil moisture ($\overline{\theta}$ or $\overline{\theta}_{RFC}$) and $SMSN_{RFC}$.

Site	Sample Rock Fraction	SSURGO Rock Fraction	RF Correction	RMSE, $\overline{\theta}$ m^3/m^3	RMSE, $\overline{\theta}_{RFC}$ m^3/m^3	R^2
RG003	0.11	0.1400	0.96629	0.017	0.017	0.695
RG013	0.23	0.1600	1.09091	0.130	0.155	0.446
RG014	0.24	0.3713	0.82730	0.018	0.016	0.599
RG018	0.20	0.1600	1.05000	0.024	0.024	0.680
RG020	0.42	0.3713	1.08405	0.082	0.073	0.626
RG028	0.23	0.5175	0.62662	0.046	0.012	0.643
RG034	*	0.4163	0.71429	*	*	*
RG037	*	0.5313	0.67958	*	*	*
RG040	0.08	0.3825	0.67120	0.054	0.018	0.701
RG046	0.15	0.5175	0.56765	0.126	0.072	0.000
RG057	0.29	0.5625	0.61620	0.062	0.024	0.060
RG069	0.17	0.5438	0.54970	0.093	0.024	0.600
RG070	0.31	0.5438	0.66123	0.038	0.013	0.345
RG076	0.18	0.2413	0.92530	0.112	0.102	0.006
RG082	0.13	0.5850	0.47701	0.080	0.022	0.763
RG083	0.21	0.5175	0.62076	0.046	0.009	0.707
RG089	0.41	0.3825	1.04661	0.091	0.090	0.122
RG092	0.07	0.5175	0.51882	0.053	0.017	0.430
RG100	0.34	0.4163	0.88447	0.045	0.033	0.662
RG400	0.05	0.0813	0.96711	0.035	0.033	0.229
RG600	*	0.2770	0.51882	*	*	*

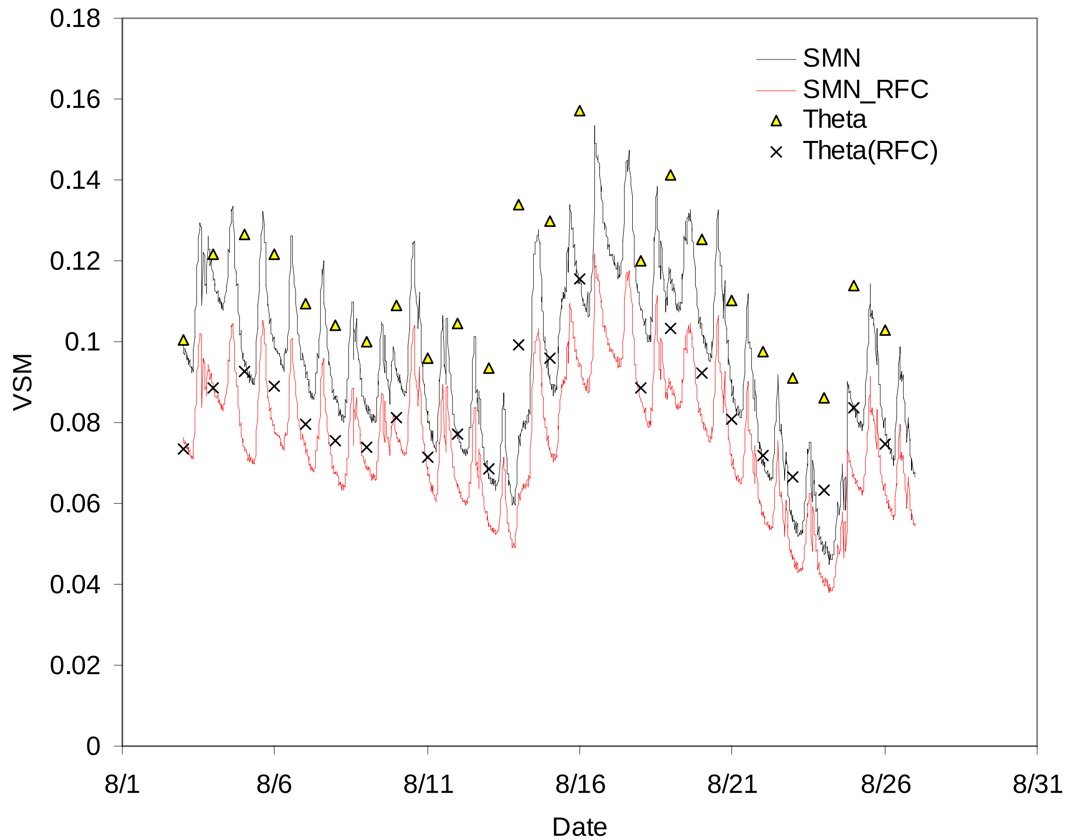

Figure 1: Time series of soil moisture network and rock corrected soil moisture network and the dielectric average and rock fraction corrected dielectric average.

5. References and Related Publications:

Cosh, M. H., T. J. Jackson, R. Bindlish, J. Famiglietti, and D. Ryu (2005). Calibration of an impedance probe for estimation of surface soil water content over large regions. Journal of Hydrology **311**(1-4): 49-58.

Please see the SMEX04 site for more information, and the NSIDC SMEX site to access data.

6. Document Information:

Glossary and Acronyms:

Please see the EOSDIS Glossary of Terms for a general list of terms.

List of Acronyms

Please see the EOSDIS Acronyms list for a general list of Acronyms. The following acronyms are used in this document:
AMSR-E - Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)
FTP - File Transfer Protocol
HP - Hydra Probe
SMEX - Soil Moisture Experiment
UTM - Universal Transverse Mercator

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