THE TARRAWARRA DATA SET: SOIL MOISTURE PATTERNS, SOIL CHARACTERISTICS AND HYDROLOGICAL FLUX MEASUREMENTS

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ABSTRACT

Experiments investigating the spatial variability of soil moisture conducted in the 10.5 ha Tarrawarra catchment, south-eastern Australia are described. The resulting data include high resolution soil moisture maps (over 10,000 point measurements at up to 2,060 sites), information from 125 soil cores, over 1,000 soil moisture profiles from 20 sites, 2,500 water level measurements from 74 piezometers, surface roughness and vegetation measurements, meteorological and hydrological flux measurements, and topographic survey data. These experiments required a major commitment of resources including 250 person days in the field, with a further 100 person days in the laboratory preparing for field trips and checking and collating data. These data are available on the World Wide Web (http://www.civag.unimelb.edu.au/data/).

INTRODUCTION

Soil moisture is a key variable in a wide range of processes important in the terrestrial phase of the hydrologic cycle [Georgakakos, 1996], in land-atmosphere interaction [Entekhabi, 1996] and in many other environmental processes. Soil moisture is highly variable in space and a knowledge of the characteristics of that variability is important for understanding and predicting the above processes. This spatial variability results from many processes acting over scales ranging from cm to thousands of km. A significant impediment to progress in understanding the spatial dynamics of soil moisture has been the limited availability of detailed spatial measurements.

This data note describes data from a series of field experiments investigating the spatial variability of soil moisture. The aim of these experiments was to collect data at a scale that could capture organised spatial behaviour of soil moisture from the 10 m^2 scale up to the small catchment scale (10^5 m^2). This required data with high spatial resolution [Williams, 1988]. The resulting data set includes high resolution soil moisture and soils maps and a range of other supporting information, including meteorological and runoff data. These experiments required a major commitment of resources including 250 person days in the field, with a further 100 person days in the laboratory preparing for field trips and checking and collating data. While we have conducted (and continue to conduct) our own analyses of this data set, we are making it available to the wider research community so that it may be used to its fullest potential.

Due to the importance of soil moisture in a range of processes, these data have a variety of potential uses. Specific analyses we are conducting include: investigation of the spatial and temporal soil moisture variation [Grayson et al., 1997]; development and testing of process-based distributed hydrologic models [Western et al., 1997]; estimation of spatially distributed water balances; investigation of relationships between terrain position and soil moisture [Western, et al., 1998a]; evaluation of Synthetic Aperture Radar data for surface soil moisture estimation [Troch et al., 1997]; analysis of the geostatistics of the soil moisture patterns [Western et al., 1998b, 1998c; Western and Blöschl, 1998]; and development of methods for estimating catchment average soil moisture from limited point measurements [Grayson and Western, 1998].

CATCHMENT DESCRIPTION

The Tarrawarra Catchment is located in southern Victoria, Australia (37° 39' south, 145° 26' east) (Figure 1). The climate is temperate, the mean annual rainfall is 1000 mm and the class A pan evaporation is 1200 mm. Compared with evapotranspiration, there is a significant rainfall deficit in summer, and excess in winter.

The geology is lower Devonian siltstone with interbedded thin sandstone and local bedded limestone (the Humevale formation) [Garratt and Spencer Jones, 1981]. The soils in the Tarrawarra catchment consist of three units. On the upper slopes is a texture contrast soil with a silty loam A horizon (15-25 cm deep) and a heavy yellow-grey clay B horizon. The midslope soils have a silty loam A horizon (15-30 cm deep) with a silty loam or silty clay B1 horizon and a silty clay or clay B2 horizon. The soils in the depressions have a deeper 25-40 cm silty loam or silty clay loam A horizon, and a silty clay loam or clay B horizon. Solum depth varies from 40 cm at some points on the ridge-tops to over 2 m in the depressions. Water tables form in the A horizon during the wetter months of the year. The surface soils crack during dry periods.

The terrain consists of smoothly undulating hills (Figure 1). There are no perennial streams and no channels within the catchment. The landuse is cattle grazing and the vegetation consists of perennial improved pastures. Wind breaks exist along two-thirds of the northern boundary (10 m Cypress trees) and a small part of the southern boundary (5 m mixed Australian native trees) and there are two Eucalyptus sp. trees located in the south eastern corner of the catchment. A sealed road follows the northern boundary of the catchment and an access laneway follows the southern boundary. Runoff from the road does not flow into the catchment.

DATA SUMMARY

Terrain data

Two grided digital elevation models (DEM) of Tarrawarra are available. These were developed by interpolating point heights from a topographic survey (conducted on a 10 by 10 m paced grid) using thin plate splines [Hutchinson and Gessler, 1994]. The DEM's have an elevation resolution of ±0.01 m and an accuracy of ±0.1 m. They are available in both the local coordinate system and standardised to the Universal Transverse Mercator (Zone 55) (UTM) (using the Australian Geodetic Datum 1966) to an accuracy of ±1 m in plan and ±0.1 m in elevation. The local coordinate system corresponds to the soil moisture sampling grid, which is aligned with the natural axis of the catchment.

Soil moisture data

Thirteen detailed soil moisture maps are available. These are based on Time Domain Reflectometry (TDR) measurements (500 to 2000 points) of soil moisture over the top 30 cm. Measurements are made on regular grids. Measurements were taken within 0.5 m of the sampling grid point. Two-wire TDR probes mounted on an all-terrain vehicle were used. The all-terrain vehicle has low pressure tyres which cause insignificant soil disturbance. The TDR probes were hydraulically inserted into the soil. Probes were inspected regularly to ensure that they had not been damaged, and were replaced if necessary. Calibration of the TDR against gravimetric measurement of soil moisture indicates that error variances for the

TDR derived estimates of soil moisture are ±1.7 $(\%V/V)^2$. European Remote Sensing satellite (ERS1 and ERS2) and NASA AirSAR synthetic aperture radar (SAR) data were collected coincidently with some of our samplings. Note that the SAR signal penetrates the soil to a depth of a few (~5) cm rather than 30 cm. These data are not available as part of the public data set. Table 1 provides dates and summary statistics for the available soil moisture patterns. Example data are included in Figure 2.

Soil moisture profiles were measured using a Neutron Moisture Meter (NMM) at 20 sites (Figure 1) over a 2 year period. Access tubes were installed to depths of between 75 and 150 cm, depending on the depth to bedrock. Measurements were taken approximately biweekly at depths of 15, 30, 45, 60, 90, 120 and 150 cm, or to the bottom of the access tube. Calibration of the NMM was carried out by gravimetric sampling. NMM soil moisture measurements have an error standard deviation of ±2.5% V/V.

Meteorological and flux measurements

Meteorological and flux measurements from an automatic climate station (Figure 1) extend over the study period. The following are measured every 6 minutes (measurement height, ±measurement error): dry bulb air temperature (0.08 and 1.40 m, ±0.2° C); wet bulb air temperature (1.40 m, ±0.2° C); rainfall (0.30 m, 0.2 mm tipping bucket); average wind speed (2.0 m, ±0.1 km/hr); maximum wind speed (2.0 m, ±0.1 km/hr); wind direction (2.0 m, ±10°); global radiation (1.1 m, ±10 kJ/m^2); and net radiation (0.9 m, ±3%). Soil temperature is measured every 30 minutes at depths of 0.02, 0.05, 0.1, 0.2, and 0.5 m with an error of ±0.5° C. There is less than 2% missing data.

Five collecting rain gauges (Figure 1) are read on each site visit. The four rain gauges in the corners of the catchment have similar exposure and the data indicate that there are no significant spatial trends in the rainfall across the catchment at the event time scale.

All rain gauges used have a 203 mm diameter orifice installed 30 cm above the ground surface.

Surface runoff is measured using a flume (Figure 1). A small area (~40 m^2) of the access lane way unavoidably contributes water to the flume. Measurement errors for various flow rates (l/s) are: 1±0.20; 2±0.38; 5±0.54; 10±0.70; 20±1.00; 50±1.53; 100±2.20; and 150±2.74. Water levels are scanned every minute and recorded if they vary by more than 1.5 mm from the previous measurement.

Other data

Data from 74 manually read piezometers (Figure 1) measuring shallow water table elevations are available. The piezometers extend below the boundary between the A and B horizons. Water levels are accurate to ±0.5 cm.

125 soil cores (55 mm diameter) were collected on a 20 by 40 m grid to a depth of 70 cm. Core holes were refilled with a mixture of gravel and bentonite so that high conductivity flow paths were not created. The sampling grid was offset 5 m to the east of the grid used for TDR measurements. Horizon depths from all cores plus particle size analyses from representative cores are available. Field saturated hydraulic conductivities from well permeameter tests are also available.

Surface roughness measurements from a pin profiler (1 m long, 25 mm pin spacing) are available for 6 occasions at 6-9 sites. Profile measurements have an accuracy of ±1 mm, and the pin location at the ground surface is accurate to ±3 mm. Six profiles were measured at each site: two across the slope; two up the slope; and two at 45° to the slope. Most of the surface roughness is due to cow hoof prints.

Vegetation was sampled from $1m^2$ plots on 6 occasions at 3-9 sites. On some occasions the biomass distribution was very patchy. Then plots representative of high and low biomass patches were sampled, and the proportion of each biomass type was estimated visually and used to calculate an average biomass. Dry mass and water contents were determined in the laboratory.

DATA AVAILABILITY

All the data described above (except the SAR data) are available in a database accessible via the World Wide Web (WWW) (http://civag.unimelb.edu.au/data/, click on Tarrawarra). All information needed for interpretation of these data are included in readme files for each data set, along with general information on the site and pictures of the landscape, soils and sampling methods. Due acknowledgment in any publication or presentation arising from use of these data is required. Photographs of the catchment and various installations are also available.

EXAMPLES OF USE OF THE DATA

The data described above allow a wide variety of hydrological analyses. Here characteristic soil moisture patterns, their statistics and the importance of soil moisture as a control on runoff generation at Tarrawarra are considered. Figure 2 shows typical summer and winter soil moisture patterns. During wet conditions the soil moisture pattern is organised by the topography, with wet zones in the drainage lines. During dry conditions the soil moisture pattern is apparently more random. This contrast is due to a change in the processes controlling the spatial pattern between seasons [Grayson et al., 1997].

In summer, soil moisture is low, therefore hydraulic conductivity is very low and lateral redistribution is insignificant. Soil moisture is generally close to the wilting point and is spatially relatively uniform. In winter soil moisture levels are high and lateral redistribution by both surface and subsurface flow paths is important. Note that the wet areas are well connected to the catchment outlet in the wet pattern. Thus any saturation excess runoff generated is unlikely to reinfiltrate before reaching the catchment outlet.

The mean soil moisture and its spatial variability are higher when topographic organisation is present (wet conditions)(Table 1). The variance is highest during spring when the largest moisture contrast between the hillslopes and the drainage lines occurs. The low variance during summer occurs because soil moisture is low and uniform as discussed above.

Figure 3 shows the relationship between catchment average soil moisture (from NMM data) and runoff coefficient (runoff volume/rainfall volume) for days with rainfall greater than 5 mm at Tarrawarra. It is clear that at Tarrawarra surface runoff is a threshold process controlled by soil moisture. The exact moisture threshold varies (between 41 and 46 %V/V) depending on the depth over which soil moisture is averaged. No infiltration excess runoff has been observed at Tarrawarra over two summers.

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FIGURE CAPTIONS

Figure 1: Topography and fixed sampling sites for the Tarrawarra catchment. Narrow dashed lines show fences and wide dashed lines show farm tracks and roads. Trees are indicated by • .

Figure 2: Soil moisture data for Tarrawarra on 27 September, 1995 and 22 February, 1996. Each cell represents a single soil moisture measurement.

Figure 3: Runoff coefficient as a function of soil moisture at Tarrawarra for days with more than 5 mm of rainfall.

TABLES

Table 1: Summary of the 13 soil moisture patterns from Tarrawarra. Statistics include the number of samples, n, the mean volumetric moisture content, $\bar{x}$, the variance, s^2, and the coefficient of variation, C_v.

Date	n	$\bar{x}$	s^2	C_v
27 Sep 95	502	37.7	24.1	0.13
14 Feb 96	498	26.2	10.6	0.12
23 Feb 96	518	20.8	5.3	0.11
28 Mar 96	501	23.8	7.1	0.11
13 Apr 96	507	35.1	12.3	0.10
22 Apr 96	513	40.5	14.6	0.091
2 May 96	2056	41.4	19.4	0.11
3 Jul 96	505	45.0	14.0	0.08
2 Sep 96	515	48.5	13.9	0.08
20 Sep 96	512	47.3	15.2	0.08
25 Oct 96	490	35.0	19.1	0.13
10 Nov 96	1008	29.3	10.8	0.11
29 Nov 96	514	23.9	6.28	0.11