1.2 AN OVERVIEW OF THE SOIL-MOISTURE-ATMOSPHERIC-COUPLING -EXPERIMENT (SMACEX) IN CENTRAL IOWA

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1. INTRODUCTION

The Soil Moisture-Atmospheric Coupling Experiment (SMACEX) was conducted in the Walnut Creek Watershed near Ames, Iowa over the period from June 15-July 8, 2002. The study area is representative of a much larger agricultural region in the upper Midwest involved primarily in corn and soybean production. This field campaign was conducted in concert with the Soil Moisture Experiment 2002 (SMEX02) where the primary objective was to investigate the utility of microwave remote sensing for estimating soil moisture under rapidly changing crop biomass in support of the NASA Aqua satellite mission. SMACEX is an interdisciplinary investigation involving a diverse set of field measurements and modeling activities funded by the NASA Terrestrial Hydrology Program. Measurements of the coupled exchange of water, carbon and energy between the soil, vegetation and atmosphere included: tower and aircraft-based water, energy and carbon fluxes, atmospheric radiosoundings and acoustic sodar soundings, ground-based Lidar observations of atmospheric boundary layer water vapor densities and heights, and cloud cover, vegetation biomass and cover, remote sensing in the visible, near-IR, thermal and microwave wavelengths from aircraft and satellite platforms. The complementary scale inherent in these measurements will provide the necessary range to investigate local to regional scale impacts of landscape heterogeneity on water, carbon and energy exchanges. This paper will provide a description of the hydrometeorological conditions that existed during the field campaign, an overview of the measurements and some preliminary measurement and modeling results, which provide a synopsis of the range in soil moisture, vegetation cover and atmospheric states observed during the study.

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2. EXPERIMENT DESCRIPTION

The SMACEX study area encompassed the Walnut Creek (WC) Watershed which was part of the SMEX02 watershed-scale mapping mission (see http://hydrolab.arsusda.gov/smex02/ for details of the experiment). The location of the soil moisture sampling fields, the boundary of the WC watershed, flight tracks for the microwave mission and field sites containing flux towers are illustrated. The WC study area encompassed a rectangular region of ~10 km north-south x 35 km east-west. There were 14 eddy covariance (EC) flux stations in operation during the one month field campaign and were deployed over the WC Watershed and study area (Fig. 1). All 14 EC towers had a Campbell Scientific Inc.(CSI) CSAT3 3-D sonic anemometer with 10 having LiCor-7500 water vapor/CO_2 sensor and the remaining 4 having the CSI Krypton Hygrometer (KH20) **[Trade and company names are given for the benefit of the reader and imply no endorsement by USDA]**. Of the 14 towers, 12 were operating in “time series” mode (i.e., the raw 20 Hz data from the EC system were recorded), while 2 other sites were run in “flux mode” where initial processing of the raw 20 Hz is preformed by the data logger and 30-min average EC fluxes and associated statistics are stored. In addition, ancillary data involving the continuous measurement of soil heat flux and temperature, and moisture for the 0-6 cm layer, net radiation, air temperature and relative humidity, and radiometric surface temperature were recorded on a separate logger with 10-min averages being stored. For more details see Prueger *et al.* (2003).

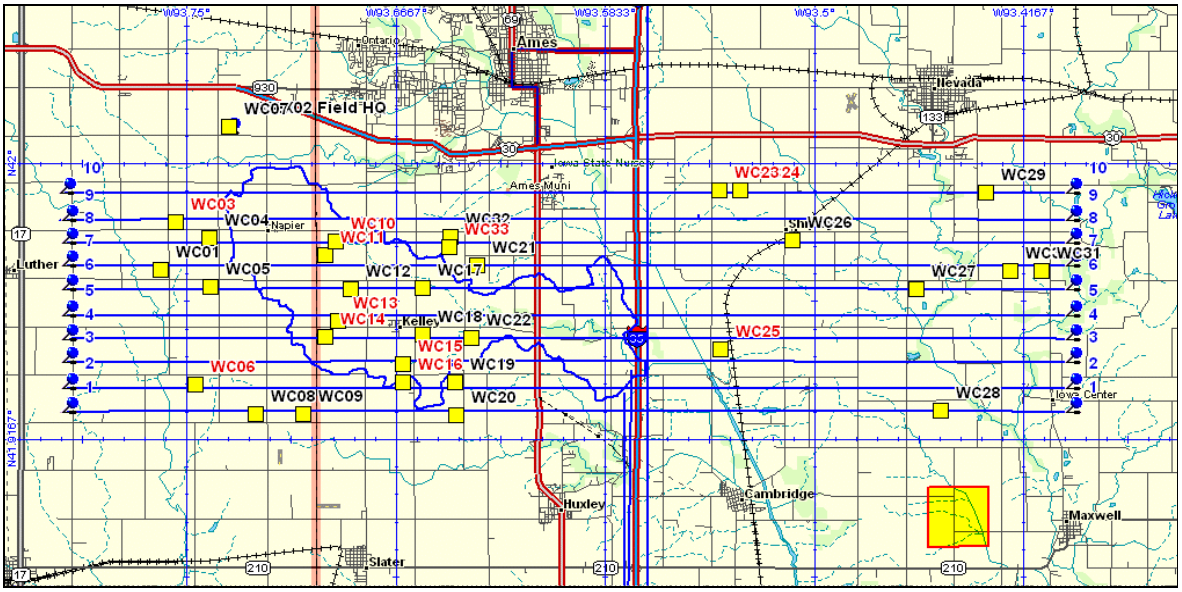


Figure 1. WC study area defined by the Walnut Creek Watershed boundary and microwave aircraft flight lines (blue). The yellow squares and associated number are soil moisture sampling sites with those with red text also being EC tower sites. The large yellow square is 2 km by 2 km and is used to illustrate scale.

The NRC Twin Otter atmospheric research aircraft flew transects over the WC study area designed to intersect several of the tower EC stations and to be used as a means of estimating WC-scale momentum, water, energy, and carbon fluxes. In addition to instruments providing turbulent fluxes of heat, water, CO_2, and momentum, remote-sensing instruments acquired surface temperature and a vegetation greenness index. The Twin Otter flew missions in the period June 15 to July 6, 2002. Fluxes were measured at an altitude of approximately 40 m on repeated passes over 6 tracks ranging in length from 6 to 12 km. Most flights included at least two soundings, which provided atmospheric profiles from about 20 m above the surface to about 300 m above the top of the mixed layer. Details of the aircraft-based measurements are given by MacPherson *et. al.* (2003).

High-resolution airborne multispectral imagery was acquired with the Utah State University airborne (Piper Seneca) digital system. Short-wave imagery was acquired over the WC study area using Nikon digital cameras with Thematic Mapper filters and a thermal infrared Inframetrics camera. Missions involved systematic coverage of the WC research area with a combination of short wave (~1.5 m resolution) and thermal-IR (~5 m resolution) measurements to coincide with airborne microwave flights (Figure 1). Flights were also conducted over the Twin Otter transects coincident with Twin Otter missions (Neale *et al*., 2003). Higher pixel resolution (~0.5 m short wave, ~1 m thermal-IR) imagery were collected over the fields containing the flux stations and the Lidar system (Eichinger *et al*., 2003). The optical images provide distributed surface cover characterizations that allow calculation of water and energy exchange rates at very high resolution. Due to the high spatial resolution of the imagery, the system lends itself well to monitor sparse or incomplete cover crops, as it can resolve the soil background and vegetation canopy. The highest resolution imagery will support the ground measurements of LAI and fractional vegetation cover in certain cropped fields. These data add significant value to high resolution satellite observations.

The Raman scanning Lidar from Los Alamos National Lab (LANL) provided water vapor concentration fields in the lower boundary layer, and a scanning wind Lidar from the University of Iowa (UI) provided horizontal winds throughout the boundary layer. A scanning elastic Lidar also from UI mapped winds in the area, boundary layer height, entrainment zone properties and cloud information. A sodar and radar/RASS system from LANL was used to measure meso-synoptic scale atmospheric conditions. The Lidar measurements were coordinated with tower-based flux measurements conducted over adjacent corn and soybean fields (WC15 and WC16) which had significant differences in roughness and fractional vegetative cover due to differences in planting dates and crop type. The Lidar data provide distributed water vapor and wind fields, which are used to compute evaporative fluxes over the remotely sensed fields. This would be the first time that such detailed data are collected simultaneously, and will provide the basis for assessing the injection of spatial heterogeneity form the land surface and into the lower atmosphere.

3. FIELD CONDITIONS

The start of SMACEX coincided with a Landsat 7 and Terra-ASTER overpass on June 15, (Day 166) with airborne observations ending on July 8 (Day 189) with another Landsat 7 overpass. The EC tower measurements continued through the SMEX02 study, which started June 25 (Day 176) and ended July 12 (Day 193), up until the end of August.

During the SMACEX study period the corn and soybeans crops grew rapidly. Observations near EC towers indicated canopy heights starting at nominally 15 and 50 cm, for the soybean and corn, respectively and reaching heights ~50 and 250 cm by Day 193 (see Figure 2).

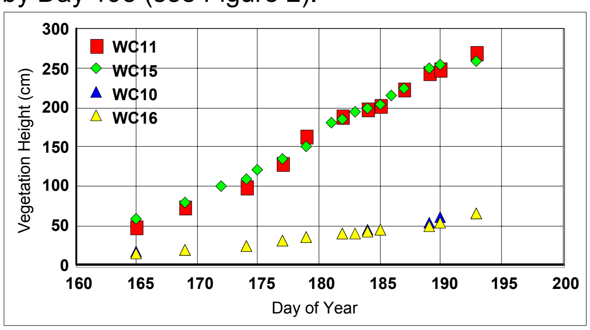


Figure 2. Vegetation height near EC towers in corn (fields WC11 and WC15) and soybean (WC10 and WC16).

With such dramatic increases in vegetation height there was also significant increases in vegetation biomass and leaf area index. Detailed vegetation sampling data were collected on a weekly basis for EC tower and soil moisture sampling sites and are currently being analyzed and processed.

Precipitation events during SMACEX mainly occurred a few days prior to Day 165 and then stayed mostly rain free for most of the WC area until Day 185 with a significant event on Day 191 where over 60 mm was recorded by the rain gage network over the WC region (Figure 3). This resulted in surface soil moisture (0-5 cm depth) decreasing from near field capacity ~25-30% on Day 165 to ~5-10% before the rains, particularly the one on Day 191.

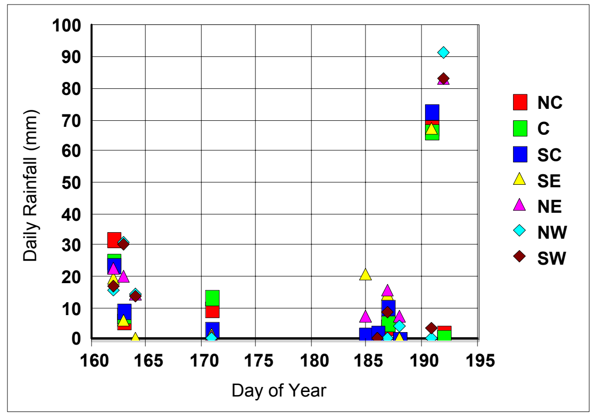


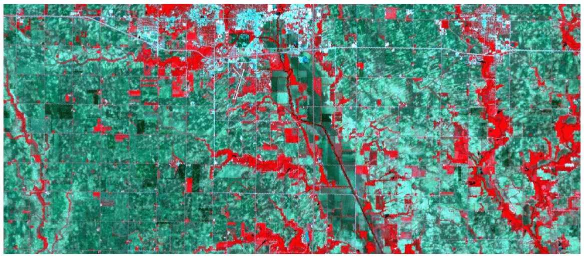
Figure 3. Rainfall totals (mm) over the SMACEX period from several of the rain gages in the WC watershed. The acronyms indicate rain gage location in the watershed: NC=north central, C=central, SC=south central, SE=southeast, NE=northeast, NW=northwest, SW=southwest.

Although the surface moisture dried out considerably, the EC tower measurements indicated latent heat flux (*LE*) and CO_2 flux generally increased while sensible heat flux (*H*) decreased resulting in the Bowen ratio (*BR*=*H*/*LE*) decreasing from ~1 for both corn and soybean at the start of SMACEX to ~0.5 for soybean to ~0.25 for corn before the rains near the end of the study period (Prueger *et al.* 2003). A similar result was obtained with the aircraft-based flux observations. In addition, there was a significant reduction in soil heat flux as the canopy cover increased from ~50% to nearly 100% by the end of SMACEX. However, near the end of the dry down there were visual signs of water stress at some field sites. This stressed condition was significant enough to have an impact at the WC-scale since aircraft-based measurements showed a slight rise in *BR* before the rains (MacPherson *et al.* 2003).

4. REMOTE SENSING DATA

Landsat 7 imagery collected before SMACEX on June 6, 2002 and then in the middle of the experiment on July 1, 2002 shows the dramatic change in green vegetation cover (Figure 4). Note that soybean fields are not as red as the corn, indicating less than full vegetation cover. These data along with the very high resolution data from Neale *et. al* (2003) will be used in concert with the vegetation sampling data to derive accurate vegetation cover and land use conditions over the course of the experiment.

(a)



(b)

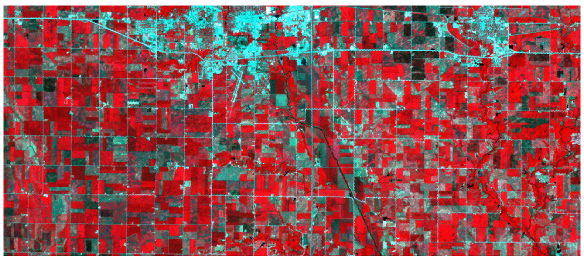


Figure 4. Landsat-7 false color images from a) June 6, 2002 (Day 157) and b) July 1, 2002 (Day 182). Red tones indicate green vegetation.

During the experiment, the USU aircraft collected optical data for many of the days the Twin Otter had aircraft missions. There was full coverage of the WC study area defined by the microwave mapping mission (see Figure 1) on June 16 (Day 167), June 23 (Day 174), July 1 (Day 182) and July 8 (Day 189).

Satellite data having coarser spatial resolution, but higher temporal resolution, were also collected from the Terra-MODIS and GOES. These data are currently being processed. For the July 1, Landsat 7 overpass time of ~1045 Central Standard Time (CST) the 30 min GOES-8 imager (band 4-thermal-IR) shows a large are of clear skies over Iowa and surrounding region (Figure 5).

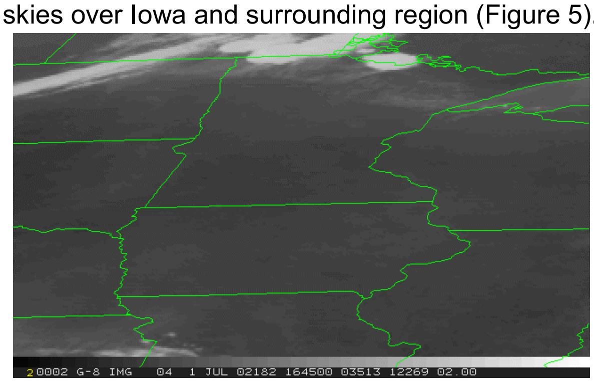


Figure 5. GOES-8 Imager (band 4) for July 1, 2002 (Day 182) at 1045 CST.

4. LAND-ATMOSPHERE MODELING WITH SMACEX DATA

At the time of this writing, only very preliminary surface flux modeling results were available (Anderson *et al.* 2003). There are several land-atmosphere-transfer-schemes (LATS) that will be applied to this data set. One scheme takes the 5-km surface flux estimates based on GOES and disaggregates the fluxes using high spatial resolution satellite imagery such as Landsat-7 and MODIS or aircraft imagery (Norman *et al.*, 2003). Other LATS schemes make use of the high resolution remote sensing data directly (Neale et al., 2003) or utilize the data to define LATS model parameters (e.g., Gillies and Carlson, 1995).

In addition to application of LATS, the Large Eddy Simulation (LES)-remote sensing model recently developed by Albertson et al (2000) will be used. This model couples remotely sensed surface temperature and soil moisture fields (2D) to the dynamic (4D) ABL variables via a LATS model, which includes separate and explicit contributions from soil and vegetation (i.e. two sources) to mass and energy exchanges. This is a merger of active lines of research: the use of remotely-sensed land surface properties to study water and energy fluxes, and the use of LES to study the impacts of surface variability on ABL processes. Typically, LATS are either driven by a network of surface meteorological observations, or use energy conservation principles applied to ABL dynamics to deduce air temperature. However, neither approach considers the resulting impact and feedback of surface heterogeneity on atmospheric turbulence and the resulting spatial features of the mean air properties, particularly at the patch or local scale. LES predictions will provide a benchmark for assessing the impact of a range of surface heterogeneity features on LATS predictions neglecting such coupling.

To validate the results of LES turbulence and flux simulations as the basis for later up-scaling parameterizations, the fields of LES-derived air properties will be compared to Lidar observations (providing multidimensional "snapshots" of the turbulent fields in the ABL), and the LES-derived spatially-distributed heat fluxes will be evaluated in the context of the network of EC tower and aircraft-based flux measurements.

5. FINAL COMMENTS

The first phase of the SMACEX project, the field experiment, was successful in the collection of water-energy-carbon fluxes, remotely sensed data from aircraft and satellite-based sensors, and atmospheric properties over a wide range of vegetation biomass/cover conditions and under both wet and dry surface soil moisture conditions.

This paper was written relatively early in the project analysis period, and therefore can only report on a very limited set of results. A more complete overview of the data will be presented at the time of the symposium.

In the next several years SMACEX will focus on the following research objectives:

1) Investigate several LATS formulations driven by remotely-sensed surface boundary conditions (including surface soil moisture, temperature and vegetation amounts), evaluate their utility in representing the measured water and energy fluxes in the context of the multi-scale flux measurements, and evaluate the effects of sub-pixel heterogeneity on LATS up-scaling and aggregation techniques.

2) Apply the LES-remote sensing model framework, incorporating high-horizontal-resolution remote sensing data, to constrain flux predictions and to test the applicability of these constraints using Lidar, tower and aircraft flux observations.

3) Employ a LATS in a diagnostic mode (utilizing remote sensing and other complementary data to diagnose fluxes at various scales) and also at several resolutions within a mesoscale model (in a prognostic mode incorporating remotely-sensed surface parameters) to assess the impact of remote sensing data and the up-scaling schemes developed in this work on forecast model predictions.

6. ACKNOWLEGEMENTS

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