Temporal Observations of Surface Soil
Moisture Using A Passive Microwave Sensor

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A series of 10 aircraft flights was conducted over agricultural fields to evaluate relationships between observed surface soil moisture and soil moisture predicted using passive microwave sensor observations. An a priori approach was used to predict values of surface soil moisture for three types of fields: tilled corn, no-till corn with soybean stubble, and idle fields with corn stubble. Acceptable predictions were obtained for the tilled corn fields, while poor results were obtained for the others. The source of error is suspected to be the density and orientation of the surface stubble layer; however, further research is needed to verify this explanation. Temporal comparisons between observed, microwave predicted, and soil water-simulated moisture values showed similar patterns for tilled well-drained fields. Divergences between the observed and simulated measurements were apparent on poorly drained fields. This result may be of value in locating and mapping hydrologic contributing areas.

Introduction

A principal goal of soil moisture remote sensing research is the evaluation and development of remote sensing technology for measuring and/or monitoring soil moisture. A secondary goal is to improve existing water management procedures through the use of this technology. In some cases, a change in existing procedures is necessary because conventional soil moisture surveys are impractical and current water management procedures have developed under the assumption that this type of data could not be obtained.

Research on passive microwave remote sensing utilizes both theoretical models and truck, aircraft, and satellite sensors. Each of these methods has an important and unique role in the program. Truck and modeling experiments focus on the problems of defining optimal sensor systems and developing soil moisture estimation algorithms based on remotely sensed data. These studies allow evaluation of factors such as vegetation and soil type under well controlled conditions.

Achieving the two primary goals of soil moisture research hinges on extrapolating the truck and modeling experiments to airborne systems, which are prototypes of future operational satellite systems. Significant research questions, such as the effects of scene heterogeneity and instrument sensitivity at the lower resolutions, typical of space sensors, can only be addressed using airborne sensors.

Another important role of aircraft systems is in evaluating the application of new research technology to large-area concerns. Based on these considerations, the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) cooper-
ated in the development of an optimal sensor aircraft system that would be available for extended dedicated periods and would include a multibeam L band microwave radiometer developed by NASA Langley Research Center, a scanning thermal infrared system, and a multispectral scanner. The principal objectives of the study described in this report were to evaluate the performance of this sensor system and evaluate the utility of repetitive observations in soil moisture and hydrologic studies. Data collected in time series over agricultural test sites in Maryland from 10 flights during the period from 12 May to 27 June, 1983 were used to compare the sensor measurements to predictions of surface soil moisture based on theory. A soil water simulation model was used in a limited evaluation of what kind of temporal information could be extracted from the data.

Site Descriptions

Fourteen agricultural fields along three flightlines near Carmichael, MD, were selected for study in this experiment. These flightlines were located on or near the facilities of the Wye Research Center operated by the University of Maryland’s Agricultural Experiment Station and are shown in Fig. 1. The predominant crops in this study area are corn and soybeans. Corn is planted in early to mid May and soybeans in late May, although due to wet field conditions the soybean planting was delayed at least a month in 1983.

At the time of the first flight in early May, most of the fields covered by the flightlines were planted in corn with the plants just beginning to emerge. By the beginning of June, the corn was between 10 and 30 cm in height with less than 10% ground cover (estimated by field observation), as shown in Fig. 2. Heavy rains during this period made the soil surfaces fairly smooth in the tilled fields. At the end of June, some of the corn fields had close to 100% ground cover while other fields were just being planted with soybeans.

Several of the corn fields were planted using a no-till procedure and as a result had a heavy soybean residue cover. Figure 3 illustrates the ground cover in a corn field with dense soybean stubble. Other fields had a weed and stubble cover for most of the study. Figure 4 illustrates the typical cover conditions in an idle field. Table 1 summarized the temporal land cover conditions of each field used in this study.

Soils in the study area are mostly silt loams with laboratory texture analyses confirming the existing soil survey maps. Average texture percentages for the test fields were sand = 30%, silt = 57%, and clay = 13%. Pressure plate tensiometer measurements indicated that the −15 bar moisture (sometimes referred to as the wilting point) contents ranged from 7 to 15% by volume and the −0.33 bar values (sometimes referred to as the field capacity) ranged from 17 to 34%. Additional details concerning the sites can be found in Jackson et al. (1984).

Gravimetric soil moisture samples were collected coincident with the aircraft overflights using a 5 cm deep scoop with a total volume of approximately 85 cm³. The greatest number of samples were obtained for the 0–5 cm soil layer, with fewer samples for both the 5–10 and 10–15 cm soil layer. An effort was made to collect the samples within ±2 h of the aircraft flights. The number of gravimet-
FIGURE 1. Flightlines and field locations.
ric samples per field varied from 6 to 18, depending on the field size, which averaged approximately 3 ha. Data were obtained using a grid centered on the flightline with a surface sample every 150 m both along and across track. The gravimetric soil moisture values were averaged for each field on each date. This average was multiplied by the independently sampled and/or estimated bulk density to obtain the field average volumetric soil moisture values.

Determination of soil bulk density for the 0–5 cm soil layer was based on a volumetric displacement procedure, and four density samples in each field were collected several times over the study period. All of the bulk density data collected over the experimental period were evaluated in terms of timeliness, tillage, cover, soils, and rainfall to estimate a bulk density value for every gravimetric sampling date. The values used were: recently plowed = 1.11 g/cm³, tilled after rainfall = 1.34 g/cm³, and no till or idle = 1.48 g/cm³.

In addition to soil moisture measurements, soil temperature data were collected at depths of 5 and 15 cm. The 5 cm values were obtained at almost all soil moisture sampling points. The 15 cm soil temperature measurements were obtained at all 15 cm soil moisture sampling locations, which usually numbered 3 or 4 sites near each field center line. Observed within-field temperature variations were typically less than 1°C at both depths.

During the course of the study, a limited number of corn biomass samples were gathered. These values for an immature corn crop are summarized in Table 2 and can be compared to data presented by O’Neill et al. (1984) for a mature canopy which had wet biomass values.
TABLE 1  Cover-Tillage Conditions during the Aircraft Experiments in 1983a

<table>
<thead>
<tr>
<th>FIELD</th>
<th>05/12</th>
<th>05/24</th>
<th>05/31</th>
<th>06/02</th>
<th>06/09</th>
<th>06/10</th>
<th>06/13</th>
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</table>

aCodes: 1 = bare soil, tilled; 2 = corn, tilled; 3 = soybeans tilled; 4 = no-till corn, soybean stubble; 5 = weeds, corn stubble.

TABLE 2  Corn Biomass Sample Data

<table>
<thead>
<tr>
<th>FIELD</th>
<th>DATE</th>
<th>PLANT HEIGHT (cm)</th>
<th>WET BIOMASS (g/m²)</th>
<th>DRY BIOMASS (g/m²)</th>
<th>WATER CONTENT (g/m²)</th>
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<tbody>
<tr>
<td>1</td>
<td>6/15/83</td>
<td>90</td>
<td>871</td>
<td>59</td>
<td>812</td>
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<td>1</td>
<td>6/22/83</td>
<td>120</td>
<td>2218</td>
<td>178</td>
<td>2040</td>
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<td>6/15/83</td>
<td>45</td>
<td>502</td>
<td>33</td>
<td>469</td>
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<tr>
<td>13</td>
<td>6/22/83</td>
<td>60</td>
<td>1855</td>
<td>185</td>
<td>1670</td>
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<tr>
<td>16</td>
<td>6/15/83</td>
<td>15</td>
<td>86</td>
<td>7</td>
<td>79</td>
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</table>

ranging from 5 to 7 kg/m². The soybeans were planted very late in the study period, and their biomass was judged to be insignificant.

Climatological Data

Rainfall data were available at several weather station locations near the flightlines. The most complete and detailed record was from the class A station maintained by the Wye Agricultural Experiment Station. This station included a tipping bucket raingage, evaporation pan, and sensors for temperature, dew point, solar radiation, and wind speed. Data from the instruments, excluding the raingage, were recorded in analog form and can be evaluated at 1-min intervals.

To illustrate the general meteorological conditions in a form that will be useful in the analysis of the remotely sensed data, Fig. 5 was developed using the daily evaporation pan readings. This is a cumulative plot of evaporation minus rainfall, where positive values indicate more evaporation than rainfall. Figure 5 also includes a bar graph of the daily
precipitation at the Wye site. May had started off with some very large rainfalls, while the first few weeks of June were dry and at the end of June there were a few large storms.

The validity of the pan evaporation readings was evaluated using the relationship between pan and potential evaporation described by Jensen (1983). Daily potential evapotranspiration for grass was computed using available daily air and dew point temperatures, wind speed, and solar radiation. These values were compared to the pan values to obtain the pan coefficient of 0.65. This result is in the range of 0.6–0.75 reported by Jensen (1983).

Aircraft Sensor Systems

The sensor system consists of a 1.4 Ghz three-beam pushbroom microwave radiometer, a thermal infrared scanner, a multispectral scanner, a photographic camera, a video camera and recorder, and a LORAN-C navigational system. All of these systems were mounted on a NASA Skyvan aircraft. Details on the pushbroom microwave radiometer (PBMR) are presented in Fig. 6. The PBMR measures the
SOIL MOISTURE SENSING

FREQUENCY - 1.41 GHz
POLARIZATION - H
BEAMWIDTH - 20°(3db)
BEAM CENTERS - 0°,±30°

PBMR

RESOLUTION (CROSS TRACK)
BEAM 2 - 0.35 Altitude
BEAMS 1,3 - 0.53 Altitude

FIGURE 6. Characteristics of the pushbroom microwave radiometer.

brightness temperature of a target. Its configuration in this study was a three-beam L band system centered at 0° and ±30°, with the 3 db (half power) points of the beams located at roughly ±10° of the beam center position. For the center beam this configuration results in a swath (ground resolution) of 0.35 times the altitude. The two side beams have swaths about 0.53 times the altitude while the beam centers for the side beams are ±0.58 times the altitude. During the experiment all flightlines were flown at a height of 150 m, and one flightline was also flown at 300 m. Total coverage for the three beams is a swath equal to 1.68 times the altitude.

Calibrated radiometer data were available at 0.5-s intervals during the aircraft overflights. Coverage for each field and run were extracted using the video camera record to compute the average and standard deviation for the brightness temperature in each field. Brightness temperatures were normalized for thermal variations using ground samples of temperature as described in Choudhury and Schmugge (1982). Under the assumptions of this procedure, the normalized brightness temperature is equivalent to the microwave emissivity.

Predicting Surface Soil Moisture Using Remotely Sensed Data

The intention of this study was not to develop a new algorithm for interpreting microwave emission data but rather to evaluate and verify previously developed algorithms for estimating soil moisture using data collected for a larger heterogeneous sensor footprint. Based upon current knowledge, it is necessary to account for the following factors when predicting soil moisture from emissivity data: soil texture, bulk density, tillage and surface roughness, and vegetation water content.

Due to the nonlinear and complex nature of the relationship between soil moisture and emissivity and its associated parameters, the first step is to establish the theoretical relationship for emissivity as a function of soil moisture, texture, and bulk density. These relationships were used to simulate pairs of emissivity and soil moisture for different conditions. The simulated values were then used to fit a simple polynomial function that would predict soil moisture from emissivity.

A simple model was constructed by assuming that conditions involved a bare soil with a smooth surface and uniform dielectric properties in both the horizon-
tal and vertical dimensions. Under these assumptions for a nadir viewing angle, the Fresnel relationship for reflectance can be reduced to a very simple form to yield an estimate of emissivity \( e \)

\[
e = 1 - \left| \frac{\sqrt{k} - 1}{\sqrt{k} + 1} \right|^2 
\]

for both horizontal and vertical polarizations. \( k \) is the dielectric constant and is a measure of the response of the material to an applied electric field. It is composed of real \( (k') \) and imaginary \( (k'') \) components. Values of \( k \) for dry soil are very small \((< 4)\) while values for water are much larger \((\sim 80)\). It is this large contrast in \( k \) that makes microwave techniques promising as a tool for soil moisture sensing.

There are several different approaches that are currently used for estimating \( k' \) and \( k'' \) for a given set of soil parameters. The approach used here was one presented by Dobson et al. (1985). In this approach, the dielectric properties of the soil–water mixture depend upon the soil texture, bulk density, and volumetric soil moisture. Using representative soil texture values for the silt loam soils at the study site and the three bulk density values mentioned previously, the soil water dielectric model was used with Eq. (1) to generate the relationships between microwave emissivity \( e \) and volumetric soil moisture. Two of these relationships are shown in Fig. 7. Since the computations involved in obtaining \( e \) for a given volumetric soil moisture do not lend themselves to a simple inversion, it is easier to approximate these relationships with a polynomial function. Predicted data pairs were used to fit a polynomial regression equation and the resulting regression

![Figure 7. Emissivity vs. soil moisture based on Dobson et al. (1985) dielectric model](image)

coefficients and coefficient of multiple determination \( (R^2) \) for the three relationships are summarized in Table 3.

The equations described by the parameters listed in Table 3 are for a bare smooth soil. If the field conditions involve rough soil surface conditions and/or vegetation cover, these factors must be accounted for in predicting soil moisture from emissivity.

A simple model for correcting for the effects of surface roughness was developed by Choudhury et al. (1979) and was adapted for this study for use at nadir look angles. The equation used is

\[
e = 1 - (1 - e_R) \exp(-h), 
\]

where \( e \) is the emissivity of a bare smooth surface, \( e_R \) is the emissivity of a rough surface, and \( h \) is an empirical roughness parameter. Choudhury et al. showed that \( h \) is generally related to measurable field characteristics, although the current understanding of this relationship is inadequate. In general, few agricultural fields will have \( h \) values of 0. A typical value of
**TABLE 3** Regression Coefficients and $R^2$ Values Obtained for Predicting Volumetric Soil Moisture from Microwave Emissivity

<table>
<thead>
<tr>
<th>Bulk Density (g/cm$^3$)</th>
<th>Intercept</th>
<th>$e$</th>
<th>$e^2$</th>
<th>$e^3$</th>
<th>$e^4$</th>
<th>$R^2$</th>
</tr>
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<tbody>
<tr>
<td>1.10</td>
<td>-2.33</td>
<td>18.72</td>
<td>-42.11</td>
<td>38.35</td>
<td>-12.60</td>
<td>0.9990</td>
</tr>
<tr>
<td>1.34</td>
<td>-3.26</td>
<td>23.60</td>
<td>-52.23</td>
<td>47.78</td>
<td>-15.92</td>
<td>0.9998</td>
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<td>1.48</td>
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<td>14.59</td>
<td>-34.80</td>
<td>33.00</td>
<td>-11.31</td>
<td>0.9990</td>
</tr>
</tbody>
</table>

$h$ might be between 0 and 0.1. Right after tillage a value of 0.5 is possible (Wang et al., 1983). In this investigation it was assumed that no-till or idle fields had a value of $h = 0$, and that settled or consolidated tilled fields had a value of $h = 0.1$. Recently tilled fields were assigned a value of $h = 0.5$ until a significant rainfall had occurred which smoothed the soil surface.

The final factor that must be considered is the effect of vegetation on interpreting microwave emission data for soil moisture. In general, a vegetation canopy increases the observed emission and the amount of the increase depends upon the soil emission and vegetation biomass or water content. A simple model developed by Jackson et al. (1982) describes the effect

$$e = 1 + (e_v - 1) \exp(bW),$$  

where $e$ is the bare soil emissivity and $e_v$ is the microwave emission observed above a vegetation canopy with vegetation water content $W$ (g/m$^2$). The parameter $b$ is a proportionality factor which depends upon several variables, including the sensor wavelength, the viewing angle, and the vegetation shape. For L band, $b$ is approximately 0.0002 (Jackson et al., 1982). Typical values of $W$ for immature corn were presented in Table 2. These values were used to estimate a value of $W$ for each field on each date. Although actual vegetation measurements were used in this experiment, in principle remotely sensed data at other wavelengths could be used to estimate $W$ (Tucker et al., 1980).

To compute surface soil moisture from aircraft microwave data, the estimated value of $W$ and the observed emissivity for each test field were used in Eq. (3) to extract the vegetation effects and derive what the bare soil emissivity would be in the absence of the vegetation. Next, this corrected emissivity and the estimated roughness parameter $h$ were used with Eq. (2) to compute the emissivity of a bare smooth soil. This emissivity was then used with the appropriate polynomial regression equation from Table 3 to compute the volumetric soil moisture.

**Results and Discussion**

**Comparison of observed and emissivity predicted surface soil moisture**

Using the procedure described in the previous section, a soil moisture value was predicted for each of a total of 246 emissivity observations, obtained over the 14 test fields on the 10 flight days. Since there were multiple runs on each flight-line, there are some replications in the data set. Using this *a priori* approach for the entire data set, the standard error of estimate, based on comparing field average observed soil moisture with the predicted values, was 12.1% with an under-
TABLE 4  Standard Error and Bias Based on Tillage Treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. Samples</th>
<th>Mean Volumetric Soil Moisture (%)</th>
<th>Standard Error of Estimate (%)</th>
<th>Bias (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilled</td>
<td>128</td>
<td>24.1</td>
<td>6.5</td>
<td>-2.7</td>
</tr>
<tr>
<td>No-till</td>
<td>78</td>
<td>33.5</td>
<td>14.6</td>
<td>-14.0</td>
</tr>
<tr>
<td>Idle</td>
<td>40</td>
<td>36.0</td>
<td>18.5</td>
<td>-15.5</td>
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</table>

prediction bias of 8.4%. These values can be compared to the overall observed mean soil moisture which was 28.9%.

The standard error is too large for the estimates of soil moisture to be considered reliable. If a prediction procedure for this particular area was desired without regard for cause and effect, the bias could be adjusted for, which would reduce the standard error of estimate to 8.5%, which is better but not acceptable for many applications.

In an effort to improve the prediction accuracy, several factors of the data set were considered in terms of their effect on microwave emissivity or surface soil moisture. The first factor considered was the tillage treatments of the various fields. These fell into three general categories: tilled, no-till with soybean stubble, and idle fields with corn stubble. When the observed and predicted soil moisture values of each category were compared, the results listed in Table 4 were obtained for the three types of tillage.

Results for the tilled fields, which were primarily corn, are reasonable considering the observed mean soil moisture. Jackson et al. (1982) reported a standard error of estimate of 4.3% in estimating soil moisture for tilled vegetated fields. Their results were based on using the same data for calibration and prediction and are therefore optimistic. In addition, Jackson et al. (1982) were working with data collected over small plots using a truck-mounted sensor. Considering these factors, the standard error observed for tilled fields in the current study seems appropriate.

In contrast, the standard errors and biases computed for the no-till and idle fields are extremely high. Identifying the cause of these errors is not a simple task. The following factors could cause under-prediction errors of soil moisture:

1. Rougher soil surface than considered.
2. A loose unconsolidated soil structure.
3. A lower bulk density.
4. More vegetation than considered.
5. An effect caused by stubble.

Considering the fact that the fields were no-till or idle and the fact that bulk density was sampled, it is unlikely that factors 1, 2, or 3 could be the source of the errors. It is also unlikely that error in estimating the level of the vegetation water content could have produced a significant effect. The vegetation level on the idle fields was very low, and the estimates used for the no-till corn fields were conservative.

At the present time it is most likely that the error is related to factors 5 and 6. Vegetation experiments over standing corn and soybeans (Jackson et al., 1982) canopies have shown that as the water content of the vegetation decreases, its
effect on emission becomes negligible. Therefore, based solely on this argument, it is expected that dry stubble would have no effect. On the other hand, experiments conducted by O’Neill et al. (1984) showed that the orientation of cut corn stalks had a significant effect on emission which varied with polarization. They found for stalks with a relatively high water content that stalks oriented parallel to the H polarization increased emission and stalks perpendicular decreased emission (as compared to a bare soil). Other experiments showed that even dry stalks could increase emission slightly. The problem with these studies is that they were conducted for relatively low background soil moisture values, 12–14%, and at off-nadir look angles. The average soil moisture values observed in the current study for no-till and idle fields were 33–36%. The effects of vegetation are more significant as the background emissivity decreases. A recent study by Brunfeldt and Ulaby (1986) involved radiometer observations over standing soybeans with metal screens placed between the rows. The use of the screens results in a very low background emissivity (< 0.3). Their observations near nadir indicated that there was a difference in the emission of a given polarization depending upon whether the crop was viewed parallel or perpendicular to the row directions. Brunfeldt and Ulaby (1986) note that there is no acceptable theory to explain this phenomena at the present time. Therefore, based on these limited results, it is possible the dry stubble (especially if it has a preferential orientation) could increase the observed emissivity above the value expected for bare soil conditions. Over prediction of emissivity would result in underprediction of soil moisture. Further controlled experiments to evaluate the effects of stubble are necessary before a conclusion can be reached.

The final source of error might be spatial variability of soil moisture. Gravimetric samples from the entire field were used to compute the observed soil moisture. These were compared to a soil moisture computed from emissivity collected over a single swath of the field. If the soil moisture within these swaths tended to be lower than the field average, it would result in consistent underpredictions. Based upon the samples and observed conditions in aerial photographs under low vegetation, it does not appear that this situation is likely. However, sampling variability could still be a factor.

Based upon the analyses described above, the soil moisture prediction algorithm appears to perform within acceptable and expected error limits for tilled field conditions. The errors encountered in predicting soil moisture from microwave measurements over no-till and idle fields containing stubble were unacceptable. It seems that the stubble layer or soil moisture variability may be the source of the error.

**Temporal comparisons of observed and predicted soil moisture using a soil water simulation model**

A major projected use of surface soil moisture observations is in determining water balance at a desirable resolution over geographically large regions. This information in turn would be used in water management activities of agriculture and hydrology and in the forecasting activities of these same areas plus meteorology. It must be recognized that the value of a remote sensing system is
FIGURE 8. Schematic of the Soil Plant Atmosphere Water (SPAW) model (Saxton et al., 1974).

not entirely in producing a single one-time soil moisture map, but also in the temporal information that can be derived from a frequent series of these observations.

In the previous section it was shown that surface soil moisture could be derived from microwave emissivity in tilled corn fields. In this section the relationships between time series of these surface
data and soil water modeling simulations are evaluated. The model that was used is one developed by Saxton et al. (1974) called the Soil–Plant–Atmosphere–Water (SPAW) model.

The basic components of the SPAW model are shown in Fig. 8. Some processes are physically based, and others utilize the most reliable semiempirical techniques. The model simulates daily water balance in a layered soil column utilizing meteorological inputs consisting, in this case, of pan evaporation and rainfall. Rainfall was used with the Soil Conservation Service Runoff Curve Number technique to compute infiltration and runoff. Soil and plant functions are then used to redistribute moisture within the soil profile.

All of the input data required were assembled, and the SPAW model was run for the period of the aircraft experiment. Local climatological data collected by the Wye Agricultural Experiment Station were used to drive the model. Simulations were generated for the three general field conditions that were present during the study: tilled corn, no-till corn with heavy stubble, and idle land with weeds and stubble.

Figure 9 summarizes the soil moisture for tilled corn. These data are for the 0–15 cm soil layer, the shallowest layer that SPAW predicts. Also included in this figure are the observed 0–5 and 0–15 cm soil moisture data and the 0–5 cm soil moisture predicted from microwave emissivity. Several features of Fig. 9 are of

![Figure 9](image-url)
interest. First, there is a close relationship between the observed 0–5 and 0–15 cm soil moisture values on a given day in this field. Therefore, the 0–15 cm soil moisture could be predicted from the 0–5 cm value in these fields. Second, the emissivity procedure tends to underpredict the observed soil moisture. It does, however, exhibit a similar temporal pattern. Finally, the SPAW simulation model does a good job of reproducing the temporal variations and moisture levels of the 0–15 cm soil layer. Based on these data it would appear that the model would be the best approach to estimating surface moisture, if all necessary data were available. The emissivity procedure provides information on surface moisture but does not require the extensive supporting data.

SPAW simulation results for most of the other fields that remained under a constant treatment throughout the study period were also very good. However, a few of the fields, particularly the no-till, showed large discrepancies between the SPAW simulated and the observed soil moisture. Figure 10 summarizes the simulated and observed data for Field 9, which was no-till corn with soybean stubble. Here, as in other no-till fields, the observed soil moisture is consistently larger than the SPAW simulated values. The reason for the difference is that this field has very poor drainage and a high water table which was ignored when the SPAW model was used. As a result, the soil moisture depleted by evapotranspiration is easily replenished and infiltration.
can raise the moisture above field capacity.

Once it is known that the soil moisture always remains high, components and parameters of the SPAW model can be adjusted to account for the observed patterns. Without the observations of surface soil moisture to indicate the need for corrective action, the model would have continued to produce erroneous results. Discrepancies between the observed and emissivity predicted soil moisture were discussed in a previous section.

Conclusions

Passive microwave remote sensing has the potential for providing frequent coverage of soil moisture over large areas if implemented on a high altitude platform. Practical problems of implementation dealing with interpretation algorithms, the extrapolation of small scale theory and field observations to larger resolution cells, and the value of these data in applications must be evaluated before such a system is implemented.

In order to investigate these questions, a multibeam microwave L band radiometer was installed along with ancillary sensors as part of a dedicated aircraft system. A time series of observations was collected over test fields and compared to ground observations and model predictions and simulations of soil moisture.

Using a simple theoretical a priori approach, soil moisture was predicted from microwave emissivity for all the fields and dates. Results showed that this approach worked well for previously studied conditions such as tilled corn fields. However, significant prediction errors occurred for fields with dense stubble. Follow-up investigations are necessary to understand this problem.

Surface soil moisture observations alone cannot provide all the information necessary for dealing with some agricultural and hydrologic problems. Although simulation models provide a greater range of information, these models are only as good as their input data and parameters, and how accurately they depict the physical processes involved. Often the analyst must guess at values for some model parameters. In this investigation it was shown that if frequent surface soil moisture data were available, they would be valuable in the calibration and verification of simulation models.

The analysis of temporal soil moisture information has another potential hydrologic application in partial area hydrology (Engman, 1986). As illustrated in the analysis of the no-till corn fields, discrepancies between the simulated and observed surface soil moisture indicated that the model was not accounting for some aspect of the true field conditions. Here this meant that the fields were wetter than other areas due to drainage and water table conditions. In partial area hydrology, the identification and mapping of such areas are critical to the modeling process.

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