Determination of the Effect of Dew on Passive Microwave Observations from Space

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ABSTRACT

Recent field experiments showed that dew has a significant effect on L-band (1.4 GHz) microwave observations. At an experimental grass site in the Netherlands (ELBARA2003), and at an experimental fallow site in France (SMOSREX) several dew events were able to increase the horizontal polarized brightness temperature up to 10 K. The Microwave Polarization Difference Index (MPDI) was shown to be a powerful index to describe the effect of dew.
Current satellite missions (*i.e.* TRMM and SSM/I) but also future missions (*i.e.* HYDROS and SMOS) observe the Earth surface when dew is likely, between 6-8 AM. These observations are used in soil moisture retrieval methodologies, and ignoring of the dew effect may lead to a significant underestimation of soil moisture.
Therefore we started, as a follow up of the previous field studies, an investigation of the effect of dew on microwave observations at satellite scale.
Two months of TRMM data were selected to study the diurnal variations of the microwave signal and their relation to morning dew. Between February and March 1998 distinct diurnal MPDI patterns were detected from space. The MPDI values at X band (~10 GHz) were significantly higher in the afternoon, compared to the morning for several agricultural regions in the northern part of the state of Oklahoma in the United States. These diurnal MPDI variations from space were similar as the patterns as detected by the dew affected field observations at L-band, leading us to conclude that TRMM data at X-band is as well affected by dew.

Keywords: Passive microwave remote sensing, dew, soil moisture, TRMM

1. INTRODUCTION

NASA and ESA are currently preparing new passive microwave missions for large scale soil moisture studies. ESA's Soil Moisture and Ocean Salinity Mission (SMOS) is planned to be launched in 2007 and NASA's Hydros in 2010. Both satellites have an L-band radiometer onboard and they will scan the Earth surface between 6-8 AM and 6-8 PM.

As reported in earlier studies[1,2] dew can have a significant effect on L-band observations on grassland. Based on results from field experiments above short grass sites in the Netherlands these studies showed that the several dew events were able to increase the horizontal brightness temperature up to 10 K. A long term L-band experiment in France (SMOSREX; see `www.cesbio.ups-tlse.fr/us/indexsmos.html` for more detailed information about this experiment) on a fallow site showed similar effects (Pers. Comm. P. de Rosnay).

If the presence of dew has the same effect on microwave observations from space, this may have significant consequences for these future satellite missions, because they will scan the earth surface when dew is most likely, early in the morning.

The observed brightness temperatures from space will be used in models to retrieve soil moisture, and when the effect of dew is neglected this will result in wrong soil moisture estimates. Therefore, these field observations led us to two

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main questions; will dew has an effect on passive microwave observation from space with an L-band radiometer, and are current space radiometers from other frequencies, like C-band and X-band, as well affected by dew. The first question is hard to address because there is still not an L-band radiometer in orbit. Therefore, this study will focus on the latter question.

In this paper, background information about the physical basics of microwave remote sensing is presented first. Then, shortly the effects of dew on field observations are described, followed by a study to detect dew from space using TRMM-MI observations. In addition, the effect of dew on current soil moisture retrieval methodologies will be discussed.

2. THEORETICAL BACKGROUND

The upwelling radiation as observed above a vegetation canopy may be expressed in terms of brightness temperature, T_b, and is given as a simple radiative transfer equation[3]:

$$T_{bH} = T_s e_H \Gamma + (1-\Gamma)T_c(1-\omega) + (1-e_H)(1-\omega)T_c(1-\Gamma)\Gamma \tag{1}$$

$$T_{bV} = T_s e_V \Gamma + (1-\Gamma)T_c(1-\omega) + (1-e_V)(1-\omega)T_c(1-\Gamma)\Gamma \tag{2}$$

where the subscripts H and V indicate polarization, T_s and T_c are the thermodynamic temperatures of the soil and canopy, respectively, and ω is the single scattering albedo. The emissivities e_H and e_V are functions of the soil dielectric constant (k), and the incidence angle (u) and can be estimated with simple Fresnel relations, or with coherent models[4]. Emissivities can be affected by surface roughness and emissivity models that include roughness[5,6] can also be used. The soil dielectric constant (k) is a function of soil moisture and soil properties and can be estimated with a soil mixing model[7]. The canopy transmissivity, Γ, is defined as

$$\Gamma = \exp\left(\frac{-\tau}{\cos u}\right) \tag{3}$$

where τ is the vegetation optical depth. The optical depth is a measure of how opaque a medium (in this case the canopy) is to radiation passing through it. The optical depth is related to vegetation water, and is also a function of the incidence angle, the radiometric frequency and its polarization dependence.
According to De Jeu et al.[2] the optical depth may be defined as

$$\tau = bVWC_{\text{int}} + gVWC_{ext} \tag{4}$$

where b and g are constant values that depend on the vegetation structure and frequency. Values of b and g are variable and needs to be estimated on a case by case study. VWC_{int} is the internal vegetation water content which is a direct function of biomass and VWC_{ext} the external water content, both in kg m^{-2}. VWC_{ext} can be explained as water outside de vegetation, like dew, and VWC_{int} as water inside the vegetation.

A recent study of Meesters et al.[8] showed that the optical depth can be solved analytically if we assume that we have an isotropic vegetation cover ($\tau_H=\tau_V$).
They showed that the optical depth may be equal to

$$\tau = \cos u \ln\left(ad + \sqrt{(ad)^2 + a + 1}\right) \tag{5}$$

where

$$a(k,u) = \frac{1}{2}\left[\frac{e_V(k,u) - e_H(k,u)}{MPDI} - e_V(k,u) - e_H(k,u)\right] \tag{6}$$

and

$$d = \frac{1}{2}\frac{\omega}{(1-\omega)} \tag{7}$$

The used Microwave Polarization Difference Index (MPDI) is a ratio function between horizontal polarized brightness temperature and vertical polarized temperature and is defined as:

$$MPDI = \frac{T_{b[V]} - T_{b[H]}}{T_{b[V]} + T_{b[H]}} \tag{8}$$

The MPDI is an important parameter in microwave studies because it is insensitive to surface temperature fluctuations and mainly a function of vegetation water content and soil moisture.
Figure 1 shows the theoretical relationship between MPDI and vegetation optical depth using the analytical model of Meesters et al. as described above.
The figure clearly shows the tandem effect of the MPDI; the MPDI increases when soil moisture increases, but the MPDI decreases when the vegetation water content (VWC) increases. In addition the sensitivity of the MPDI measurements to variations in soil moisture decreases with increasing optical depth. This is because the soil emission is attenuated by the canopy and emission from the vegetation canopy tends to saturate the signal with increasing optical depth.

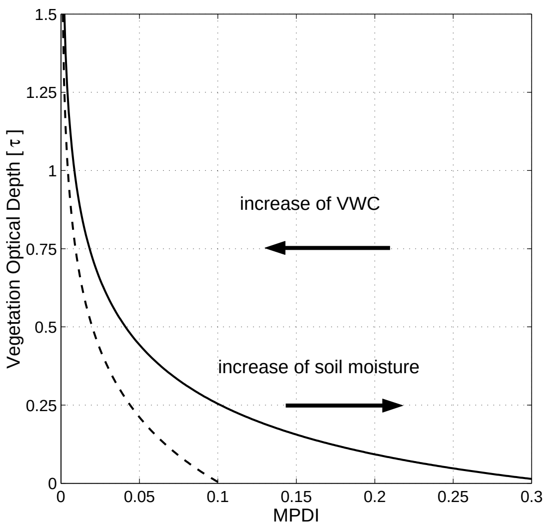

Figure 1. The theoretical relationship betweeen MPDI and the vegetation optical depth (τ) for a dry soil (dashed line) and a wet soil (solid line). For this model simulation we used no surface roughness (*h*), a single scattering albedo (*ω*) of 0.06, and the incidence angle of the TRMM-TMI radiometer (u = 52.8°). The two arrows show in which direction MPDI will change when soil moisture or VWC changes.

3. FIELD OBSERVATIONS; WAGENINGEN CASE STUDY

From April to October 2003 a field study was carried out on three different sites in Wageningen (NL) using an L-band Radiometer (ELBARA). This experiment is described in more detail by de Jeu et al in the previous SPIE proceedings[1].

One of the major findings of this study was the significant effect of dew on microwave observations. The figure below shows the striking resemblance between dew, estimated with the atmospheric dew model of Jacobs[9] and the L-band microwave observations, expressed as MPDI values. Both react similar to large and small dew events. During this period the soil moisture content of the first 5 cm was very low (~ 0.1 m^3 m^{-3}), and had hardly any diurnal variation. The grass above the soil surface had a height of about 15 cm and a VWC_{int} of approximately 0.2 kg m^{-2}.

Based on the striking similarity between dew and MPDI we expect that the diurnal variation of the MPDI could only be explained by the diurnal variation of the VWC_{ext}, in this case the dew.

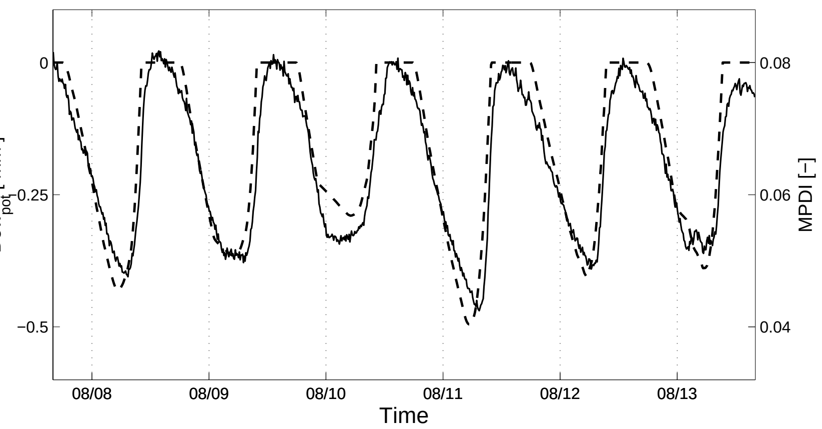

Figure 2. Diurnal variation of potential dew (dashed line) and L-band MPDI (solid line) above a short grass site during a dry period in August 2003.

4. SPACE OBSERVATIONS; OKLAHOMA CASE STUDY

To study the effect of dew at satellite scale two months of TRMM-TMI data of the region of Oklahoma between 33.5-37 N latitude and 103-94 W longitude (See Figure 3.) were selected. We selected the brightness temperature data at X-band (10.7 GHz), both horizontal and vertical polarized for February and March 1998. For this study we converted the brightness temperatures into MPDI values.

Beside the brightness temperature, FASIR-NDVI data[10] of this period and the 1/8 degree LDAS predominant Adjusted UMD land cover map, as derived from the land data assimilation systems (LDAS) database (`ldas.gsfc.nasa.gov`), were selected for comparison.

Micrometeorological and hydrological information was taken from the Oklahoma Mesonet network (`www.mesonet.ou.edu/`). The temperature in the period between February and March 1998 of the study region was on average 8 ˚C with values of about ˚5 C at night and 14 ˚C during the day. A total of approximately 200 mm rainfall was recorded during the two month period. Most rainfall (~150 mm) occurred in the last two weeks of March. The soil moisture amounts as measured at 5 cm depth at the Oklahoma Mesonet network stations varied between 0.2 and 0.5 m^3 m^{-3}, but the temporal variability of the soil moisture for the two month period was low.

The dominant vegetation type of the study area in this period is winter wheat. This crop is easy to recognize on the NDVI image (Figure 5 B) as the region with the high NDVI values (0.5-0.6) in the center of the state. The south east part of the state is forested, which also has high NDVI values.

To study the effect of dew we selected three 0.5 degree grids in the study region and plotted the diurnal variation of the MPDI for the entire study period (See Figure 4). Two grids were selected from agricultural regions (A and B) and one

(C) from a forested region. The location of these two grids can be found in Figure 5. The grids of the agricultural regions showed a distinct diurnal pattern with low MPDI values in the morning and high values in the afternoon. The forested grid gave no diurnal variation. The MDPI reached its lowest point round 6:00 hr local time and its highest point at 17:00 hr.

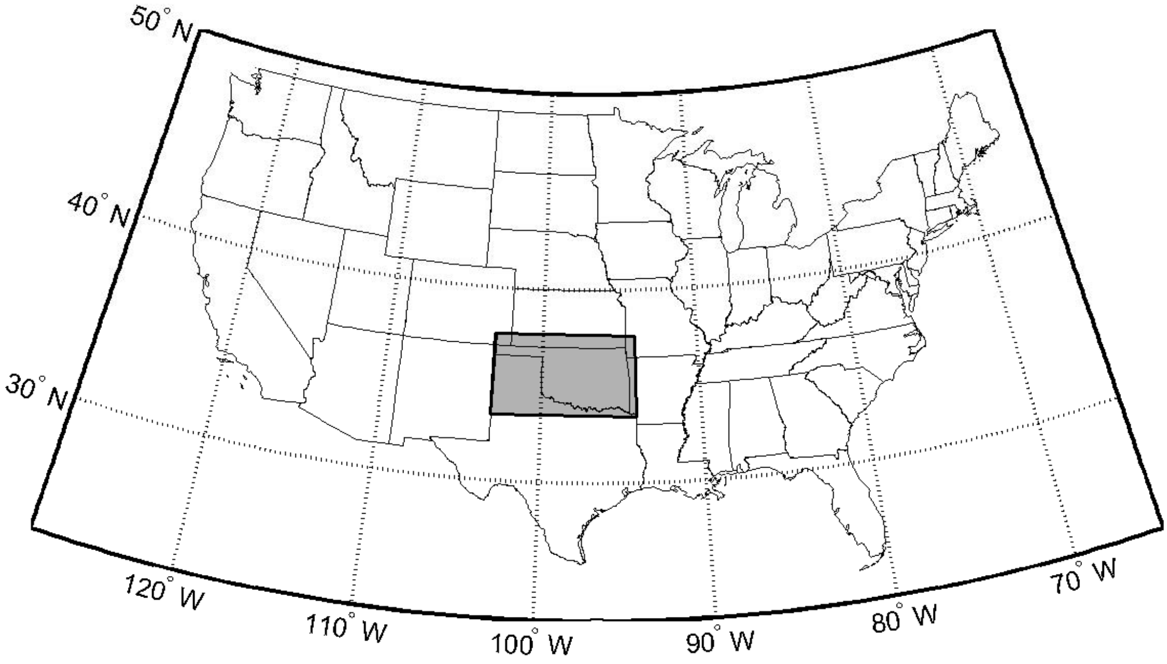

Figure 3. Location map of the selected Oklahoma study area (gray box).

The diurnal variation of the satellite derived MPDI can be driven by either dew or soil moisture. The dew hypothesis is the most likely, because (A) the diurnal variation of the satellite derived MPDI at the agricultural regions looks similar to the dew affected diurnal patterns as measured in the field (Figure 2) and (B) we don't see any of such diurnal variations in the top soil moisture field observations at the Oklahoma Mesonet stations.

Now a procedure was started to study the spatial variability of the dew-affected MPDI data. The MPDI data were stored in a 0.5 degree grid and from every grid we calculated the average MPDI value between 5:30 hr and 6:30 hr (morning map, Figure 5 C) and between 16:30 and 17:30 local time (afternoon map, Figure 5 D).

The morning MPDI image (Figure 5 C) showed rather low values in the northern part of the study region with MPDI values of approximately 0.02, and the forested region in the southeast, with values close to 0.01. The afternoon image (Figure 5 D) showed much more spatial variability and the MPDI values in the north were much higher (up to 0.05).
A simple subtraction of the morning image from the afternoon image gives us a clear view of the regions with a high diurnal variability. Figure 5 E is a result of such a subtraction and it seems that northern agricultural regions have the highest diurnal variability. These regions were probably most affected by dew, during the period February-March 1998.

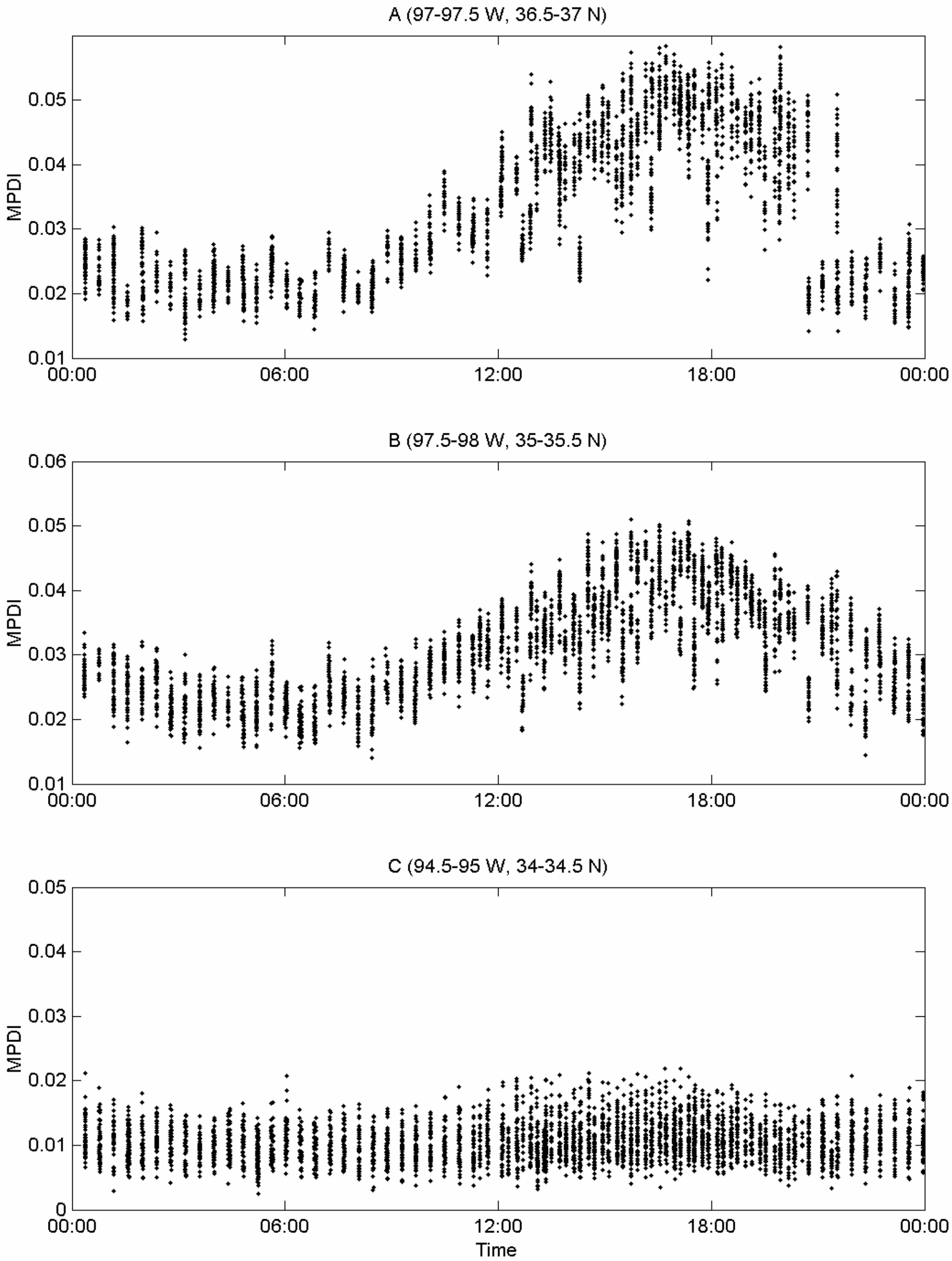

Figure 4. Diurnal variations of TRMM MPDI at X-band for three selected 0.5 degree grids. Grid A and B were taken from an agricultural region and grid C from a forested region. The location of these grids can be found in Figure 4.

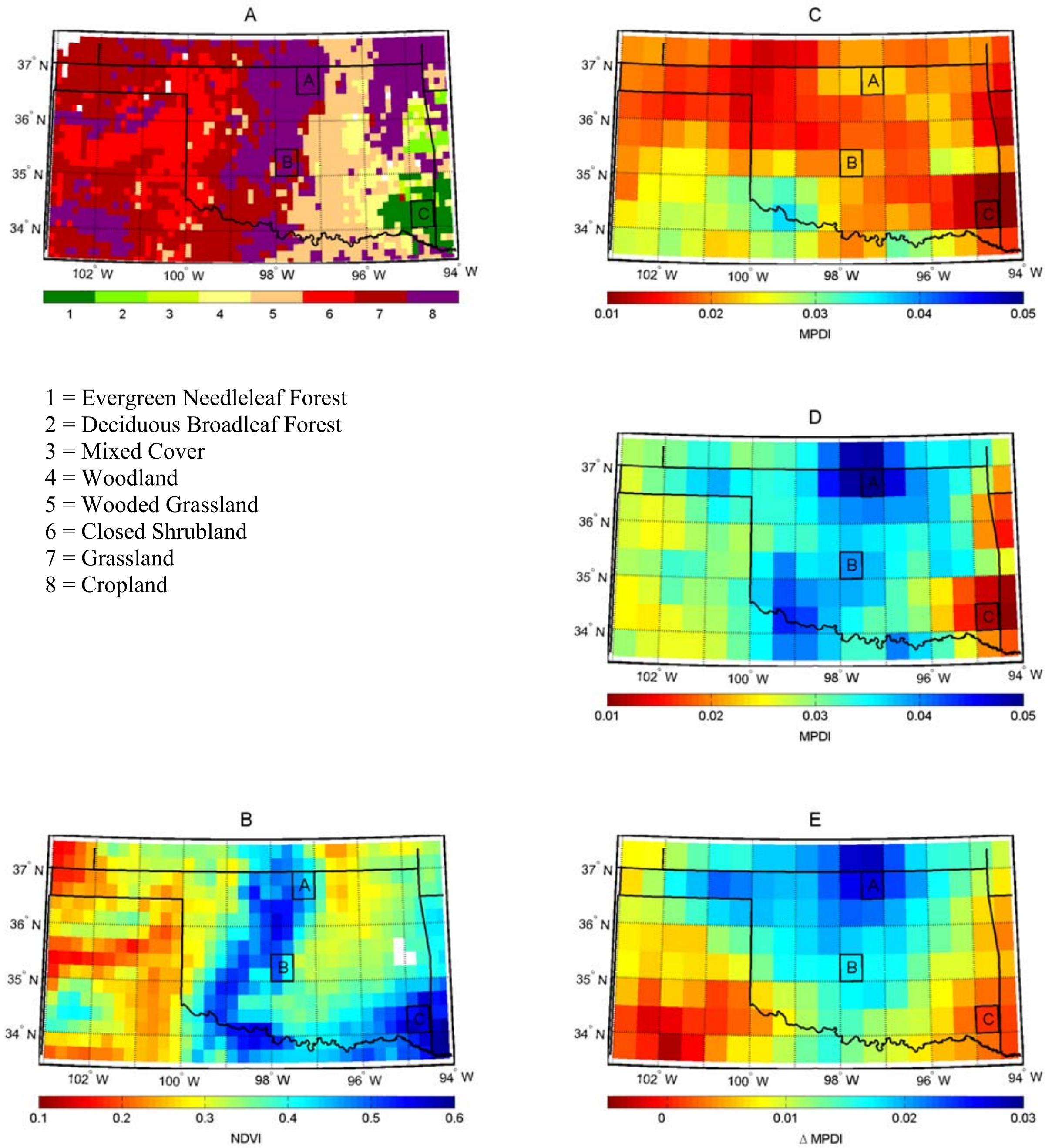

Figure 5. (A) land use classification map of the study area, (B) average FASIR-NDVI image of the study period, (C) average morning image of TRMM MPDI at X-band (between 5:30-6:30 AM, local time), (D) average afternoon image of TRMM MPDI at X-band (between 4:30 and 5:30 PM, local time), (E) Absolute difference in MPDI between the afternoon image (D) and morning image (C).

5. CONCLUSIONS AND DISCUSSION

Dew has an effect on passive microwave observations and at L-band it can easily increase the horizontal brightness temperature up to 10 K.[1,2] Till now these effect were only studied at field scale and not at satellite scale. The current study showed that dew can also affect satellite observations.

TRMM-TMI data at X-band were selected for the Oklahoma region for the period between February and March 1998 and converted to MPDI values. The MPDI values were used to study the effect of dew, because this parameter is insensitive to temperature fluctuations and is mainly a function of soil moisture, dew and internal vegetation water.

The MPDI showed a distinct diurnal pattern in the agricultural regions of Oklahoma. These temporal variations could only be explained by dew because top soil moisture field observations did not register such diurnal variations. In addition, these diurnal variations showed many similarities with the dew affected MPDI field observations at L-band. Both had low values early in the morning and high values in the afternoon.

Current passive microwave satellite observations like DMSP-SMM/I, AQUA-AMSR/E and TRMM-TMI, but also future missions like SMOS and HYDROS, will observe the Earth surface when dew is most likely, in the morning hours. And many of these satellite observations over land are used or will be used in emission models to estimate important land surface parameters like soil moisture. Most emission models still neglect the effect of dew[11,12,13]. Ignoring of dew in an emission model will result in an underestimation of soil moisture. Furthermore, dew decreases the vegetation transmissivity (and increases of the vegetation optical depth) resulting in a significant decrease of sensitivity for soil moisture retrieval. De Jeu et al.[2] detected a decrease in soil moisture sensitivity of about 25 % when a grass site was affected by 0.1 mm (~0.1 kg m^{-2}) of dew.

Although the importance of the effect of dew on microwave observations above land starts to become visible, the research part is still not mature yet, and further research on the effect of dew on microwave observations is necessary to fully understand the consequences of this natural phenomenon on the reliability of land surface parameters as derived from microwave signals from space.

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