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Polarimetric Signatures from a Crop Covered Land Surface Measured by an L-Band Polarimetric Radiometer

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Abstract**—This paper describes preliminary results from field measurements of polarimetric azimuth signatures with the EMIRAD L-band polarimetric radiometer, performed over a land test site at the Institut National de la Recherche Agronomique in Avignon, France. Scans of 180 degrees in azimuth were carried out in order to identify an eventual dependence of the Stokes vector on the look-direction. Results indicate a clear signature, for bare soil as well as for the crop-covered surface, and variations of more than 10 K are observed.**

I. INTRODUCTION

A high-resolution L-band (1.4 GHz) radiometer system, based on interferometric techniques, and known under the acronym SMOS (soil moisture ocean salinity), is under phase-B studies as one of ESA's Earth Explorer Opportunity Missions. Measuring the L-band brightness temperature over land surfaces enables a determination of surface soil moisture.

To understand the brightness temperature as a function of the soil moisture, the soil type, and the vegetation on a field, experiments have to be made, and in the spring 2001, the EMIRAD L-band radiometer was used for land observation at the Institut National de la Recherche Agronomique in Avignon, France.

II. THE EXPERIMENTS

The EMIRAD radiometer [1] is based on digital down conversion and detection techniques. The instrument provides simultaneous measurement of the full Stokes vector, and it has a stability within 0.1 K for a one hour run, making it well suited for measurements of signatures, when scanned over a surface. The absolute calibration, however, is the critical parameter for a long experiment campaign, and test measurements indicate a level better than 1 K over the total campaign duration.

The full Avignon experiment consists of a range of measurements over the test site at the Institut National de la Recherche Agronomique, INRA. Available for the experiment was an area of approximately 150 meters by 100 meters, divided in two sub-areas by a rail track. On the rail a crane is mounted in a permanent setup, and it may be moved along all 120 meters of track length. In the height of 20 meters the crane has a carriage mounted under a 20 m boom, which may be turned around 360 degrees. The EMIRAD L-band radiometer is mounted on the crane, 20 m above the ground. It may observe incidence angles from 0 to 60 degrees, and two times 90 degrees azimuth angle. The whole site is illustrated in fig.1. Experiments were carried out in the period from April 24th 2001 to July 26th 2001, reaching a total number of data acquisition days equal to 38.

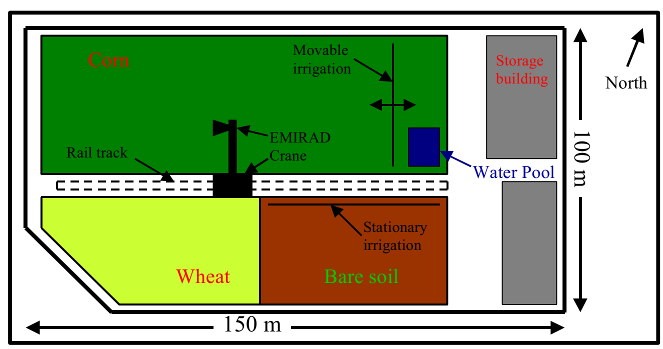

Figure 1. The test site at Institut National de la Recherche Agronomique, Avignon, France. The EMIRAD L-band radiometer is mounted on the crane, 20 m above the ground. It may observe incidence angles from 0 to 60°, and two times 90 degrees azimuth angle.

Three target areas were available. The wheat field, however, was not available for radiometer measurements due to the antenna pattern size, and the campaign focused on the two other targets, using the cornfield as primary target. Two kinds of measurement series were carried out, change of incidence angle with constant look-direction (parallel to the rail or perpendicular to the rail) and change of azimuth look-direction with constant incidence angle. The first series was primarily intended for modeling of the influence from soil moisture on the measured brightness temperature, while the latter is used for identification of eventual azimuth signatures from the field.

This paper will present some of the preliminary results from the 180 degrees azimuth scans, performed approximately once a week. All azimuth look directions are measured relative to a line perpendicular to the rail track. For some days, a full 180 degrees scan was possible, while other scans were limited to 100 degrees due to work in the field, i.e. irrigation etc.

III. Experiment Results

The first measurement was carried out on April 25th (Day Of Year = 115), observing the cornfield, when it was still bare and without any crop. It was plowed and sowed a few days earlier, and the surface formed a wave pattern, with structures of 8 cm height, running parallel to the rail track, i.e. perpendicular to the 0 degree look direction.

The polarimetric result from April 25th, is shown in fig.2, where the 1st Stokes parameter is plotted with a zero mean to fit in the diagram. As it is known from sea surface wave patterns at higher frequencies [2] the signature seems to have some 1st and 2nd harmonic content in all the Stokes parameters, and a harmonic fit with a 1st and 2nd harmonic is shown in table 1. A plot of the harmonic fit, i.e. a filtered signature, showing only the 1st and 2nd harmonics, is shown in fig.3, and the length of the scan is extrapolated to cover a full circle signature.

Comparing fig.3 to a wave signature from the sea surface at higher frequencies, e.g. 34 GHz, shows some similarities. The presence of the 1st and 2nd harmonics is expected, and the cosine nature of the 2nd harmonic as well as the sine nature of the 3rd harmonic is similar. The 3rd and 4th Stokes parameters are observed to be 180 degrees out of phase, which also

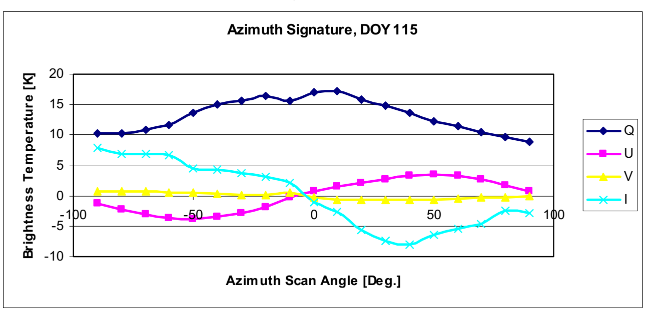

Figure 2. Azimuth signature from the April 25th 2001 measurement. The 1st Stokes parameter is offset to zero mean, and all azimuth angles are measured relative to a line, perpendicular to the rail track.

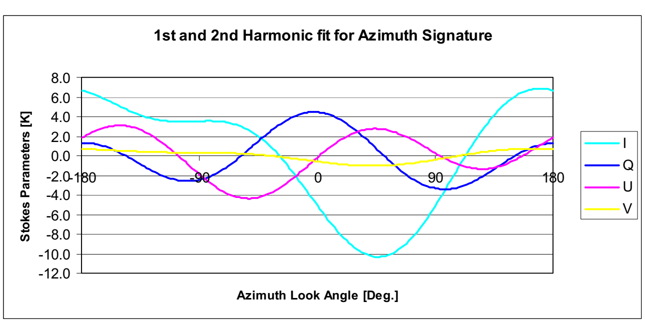

Figure 3. Azimuth signature from the April 25th 2001 measurement, based on the fit of the 1st and 2nd harmonic for each Stokes parameter. The signature is extrapolated to cover a full 360° scan

TABLE I. HARMONIC STOKES PARAMETER FIT.

Harmonic	I, Mag.	I, Phase	Q, Mag.	Q, Phase
1	7.31	-143.47	1.64	-15.37
2	3.18	-75.29	2.89	-1.12
Harmonic	U, Mag.	U, Phase	V, Mag.	V, Phase
1	1.51	132.80	0.74	-150.44
2	2.84	73.17	0.31	-80.59

1st and 2nd harmonic fit for the full polarimetric azimuth signature from the April 25th measurement. No crop was visible on the field, and the soil had an obvious plowing/sowing signature, parallel to the rail track, i.e. perpendicular to the 0° direction.

confirms the similarity to well known azimuth signatures from the sea surface. In the present case, the 0 degrees look direction is comparable to the upwind look direction for a sea surface signature, which corresponds to the wave pattern, running perpendicular to the 0 degrees look direction. The magnitude of the patterns show approximately 8 K from peak-to-peak in the 2nd and 3rd Stokes parameters, while the 4th Stoke parameter is smaller than 2 K peak-to-peak. The relation between the magnitudes of the 3rd and the 4th parameters is likewise comparable to the sea surface situation.

During the growth season the sowing pattern decreased due to weather and irrigation, and already after a few days, the height was reduced by 50 % due to irrigation. The polarimetric signature for April 27th (Day Of Year = 117) is seen in fig.4, and it is noticed, that all Stokes parameters show the same basic behavior. Comparing fig.4 to fig.2 it is seen that signatures in the 2nd, 3rd, and 4th Stokes parameters have been decreased to about 50 % size, corresponding to the reduced wave height.

June 27th (Day Of Yeay = 178), the sowing pattern had completely disappeared, and the crop had reached a height of 55 cm. The polarimetric signature, shown in fig.5, shows a significantly increased polarimetric signature. A peak-to-peak variation of 15 K is observed in the 2nd Stokes parameter in the reduced angular range, and the 3rd Stokes parameter is estimated to have a similar peak-to-peak variation over the full 360 degrees range. The variation of the 4th Stokes parameter is again ¼ of the variation of Q and U, but due to the small magnitude and the reduced angular space, the uncertainty on the parameter estimation is large.

The signature from July 26th (Day Of Year = 207), the last day of the campaign, is almost similar to the June 27th pattern, and all phases are identical within a few degrees. Magnitudes of the signatures are also similar, although a shift in the level of the 2nd Stokes parameter is observed. It may be due to the increased leaf structures of the crop as well as by a change in the soil moisture.

IV. Conclusion

The polarimetric signatures from the Avignon 2001 experiment show a very similar pattern through all the campaign with respect to shape and phases of the four Stokes parameters. From the bare soil observation the full 360 degrees signature is estimated using a harmonic fit, and it is obvious, that the signal is very similar to the modeled signal from the sea surface. The phase of the signature shows, that observation perpendicular to the sowing waves of the field is similar to the sea surface observation in the upwind direction. This

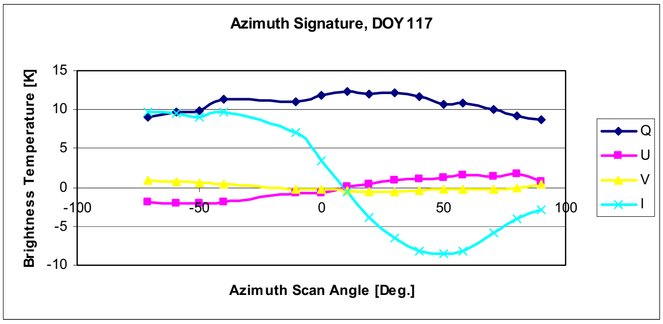

Figure 4. Azimuth signature from the April 27th 2001 measurement. The 1st Stokes parameter is offset to zero mean.

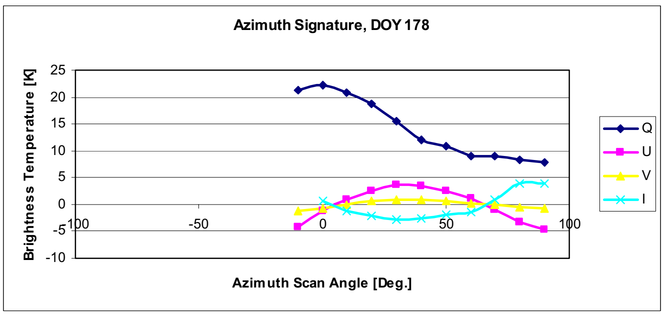

Figure 5. Azimuth signature from the June 27th 2001 measurement. The 1st Stokes parameter is offset to zero mean.

corresponds to the fact that upwind observations on the sea also will be perpendicular to the wave pattern. The difference in upwind/downwind is normally a sea surface specific phenomena, however, and it would be of great interest for the field observation to carry out a full 360 degrees scan in order to exclude the risk, that small uncertainties cause the harmonic fit to show an upwind effect. The effect is present, however, in all harmonic fits done on the data, and a possible explanation for the signal is the asymmetric pattern, created by the plow and the sowing machine, when all soil is turned in the same direction.

The magnitude of the polarimetric signal is seen to depend on the sowing wave height, and for 8 cm waves, variations of 8 K peak-to-peak were observed in the 2nd and 3rd Stokes parameters. The 1st Stokes parameter shows approximately the double signal size, while the 4th Stokes parameter has 2 K peak-to-peak. For the three signatures, measured on the bare soil, the signals were shown to decrease approximately linearly with the wave height, keeping the phase information. Basically this is expectable, and a simple model may be based on table 1, normalizing the wave height to the 8 cm waves, which were present, when the first signature was obtained.

When the sowing pattern decreased and the crop appeared the polarimetric pattern reappeared, reaching a maximum of 15 K peak-to-peak variation for the first three Stokes parameters and 2 K for the 4th. It is noticed, that the maximum signal is reached already when the crop is 0.5 m high, and although it grew to 0.8 m during the following month, adding a large amount of leaf mass, no further signal increase was noticed.

Phases of the signals are seen to be stable during all the series from the first signature from April 25th to the 0.8 m crop on July 26th. The background for this may be the row structure organization of the crop, following the sowing pattern of the field, hence restoring the decreasing sowing structure when the crop begins to form. A simple model for the polarimetric signal from the crop may thus be based on the same basic signature as the bare field, changing only the magnitude to a crop height dependant signal, saturated around the maximum observed signals. The dependence is subject for further investigation, however, and especially the saturation effect must be further analyzed.

Concluding the experiment regarding the polarimetric signatures from the cornfield it is noticed that signal magnitudes up to 15 K are possible from the same field, when observed from different directions. Assuming a large homogenous corn area, it is thus a potential problem for a space borne mission to estimate ground parameters based on the L-band brightness temperatures, if the field has a row structure. For small fields the effect may be averaged out to some extend, as the footprint of the space borne instrument is typically much larger than the size of a single field. For large field areas, e.g. in the central USA, combined with small resolution cells as planed for SMOS, the row structure may be significant, and a potential risk of a systematic error may rise.

Acknowledgment

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