Investigation of Radio Frequency Interference at L-Band Using Data from Airborne HUT-2D Radiometer and Spaceborne SMOS Radiometer

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Abstract

The launch of the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) satellite in November 2009 opened a new era in monitoring globally and continuously these two environmental parameters. The importance of these measurements to provide information on Earth's climate and its changes has been pointed out by the scientific community in recent years [1]. With SMOS data weather prediction models can be improved and extreme weather phenomena better understood. The SMOS payload radiometer called MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) uses aperture synthesis technique, new to remote sensing, to form an image of the target [2]. The used technique is very effective in producing good quality data with reasonable ground resolution for passive L-band measurements. However, since it is based on having numerous individual receivers, from which the output signals are correlated, the technique is sensitive to artificial or man-made interfering signal sources. It is of great importance to identify the existing sources of RFI (Radio Frequency Interference) to ensure good quality data. This paper describes the work done in Aalto University in this field using available SMOS data and the Aalto University L-band aperture synthesis radiometer (HUT-2D) airborne data collected during the SMOS rehearsal campaigns and other national funded campaigns.

1. Introduction

Data from two satellites carrying microwave radiometers will be available in the near future. European Space Agency (ESA) launched in November 2009 its SMOS satellite in order to provide global soil moisture and ocean salinity data on a regular basis. National Aeronautics and Space Administration (NASA) will soon launch its ocean salinity satellite Aquarius. Both microwave radiometers operate within the protected L-band (1400-1427 MHz). The usefulness of these satellite data may be reduced due to man-made Radio Frequency Interference (RFI) sources emitting radiation within this band.

Some research has been done in the field [4], but it is important to collect a geographically and temporally extensive data set on RFI and develop detection methods to ensure high-quality retrievals from space borne data.

Helsinki University of Technology (TKK), Laboratory of Space Technology (now part of Aalto University) has developed an airborne L-band aperture synthesis radiometer (HUT-2D) [3]. The instrument is accommodated onboard the research aircraft of the University. HUT-2D has the main characteristics similar to those of the SMOS payload radiometer MIRAS, and the instrument has been used e.g. in SMOS Calibration and Validation activities. In April-May 2008 TKK participated in ESA's rehearsal campaign for SMOS satellite validation. TKK was responsible for the coordination of the airborne measurements. The main test sites were the Upper Danube Catchment (UDC) area near Munich and Valencia Anchor Station (VAS) west to Valencia. The campaign included also the transfer flights from Finland to South Germany and Spain in both directions. HUT-2D has also flown in several national campaigns in Finland. The transition flight routes have been selected over cities and industrial areas when possible to provide additional information on possible RFI.

In this paper we give an overview and first results obtained in a research project initiated in late 2009. We discuss the first RFI observations measured by the HUT-2D instrument and present a sample case on the impact of RFI in SMOS data.

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2. Objective of Research

The objective of this research project is to investigate the effect of RFI to the interferometric radiometer data quality. This is done by using the presently available and near-future datasets – both airborne and space-borne, and identifying and classifying the RFI sources in these datasets. In the frame of the project we will study the characteristics of the most common RFI sources with the air- and space borne data and estimate their influence on the data quality. Especially, we study the methods to detect the RFI-contaminated pixels from the data collected with synthetic aperture radiometers, which potentially provide new sensitive means for the purpose, e.g. by making measurements of signal correlations instead of pure total power of the radiation.

Results of the project are also in the interest of authorities, like the Finnish Communications Regulatory Authority, which will benefit from the results in its activities related to compatibility studies between new radio technologies and passive services like Radio Astronomy Service and Earth Exploration Satellite Service.

We use HUT-2D datasets acquired during the various measurement campaigns in Northern and Southern Finland test sites, and especially the data gathered during the transit flights to them, which have been routed over several urban areas. Also, we take the advantage of the data collected during SMOS Cal/Val activities in Germany and Spain in 2008, and during the campaigns in Denmark and Germany in 2010.

3. First Insight into the Impact of RFI

We have compared the influence of a point-like RFI on measurements of HUT-2D and SMOS. The HUT-2D data were acquired over the Finnish town of Seinäjoki, which was measured two times, with a 14 day separation. The brightness temperature swaths composed from the measurements on the two dates are shown in Fig.1. During the second overflight, we note an RFI and its influences in the northern part of the area. Clearly, the RFI is not present during the first flight. In such swath images, which are composed of several two-dimensional snapshots provided by the instrument, the impact of the RFI is spread over a wider area. In order to study it more closely we examine the brightness temperature snapshots provided by the instrument.

We elaborate the impact of the confronted RFI over Seinäjoki in Fig. 2, the top row of which shows three snapshots measured by the instrument, each in 250 milliseconds. The leftmost image in the top row shows a brightness temperature image of a homogenous area at the north end of the test area. The middle and the rightmost image in the top row show the approach of an intense point-like RFI. In the middle part of the figure the peak value of the source is approximately 3000 K. Once the aircraft is directly over the source, in the rightmost figure, its peak value is approximately 2000 K.

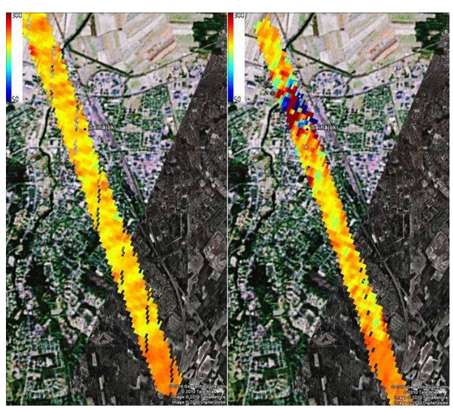

Figure 1. Brightness temperature swaths measured by HUT-2D over the town of Seinäjoki on September 30, 2009 (left) and October 14, 2009 (right). Effects of RFI are seen in the top part of the image acquired in October. The swaths are composed by averaging the measurements in the incidence angle range 0 - 25° off nadir. The northernmost part of the test site is a fairly homogenous agricultural area, followed by an urban area.

In Fig.2, left, we show a difference between two consecutive HUT-2D measurements over a homogenous plain area. This difference shows the normal error level of the images in terms of radiometric resolution. At the right side of the bottom row we show the difference between the RFI-contaminated measurement (top row, middle) and the RFI-free measurement (top row, left); this is the impact of the point-like RFI in the image of HUT-2D. We see that the error induced by the point source is very intense: through the image, we see approximately 400 to 400 K oscillations, which are caused by the finite side-lobe levels of the synthesized antenna patterns, or the Gibbs-effect. Clearly, having RFI intensity as shown is hazardous for any scientific interpretation of the data.

In Fig.3 we show a similar analysis for three snapshots measured by the MIRAS instrument of SMOS. Again, the top row shows three snapshots of MIRAS approximately five minutes from each other. The leftmost snapshot is acquired over Atlantic while heading north, towards Greenland and Baffin Sea. Five minutes later, in the middle snapshot, an intense point-like RFI located in the coastal area of Greenland appears into the instrument's field-of-view. In the bottom row of Fig.3 we show two difference images. The left image shows a difference between two consecutive RFI-free snapshots, and the right image shows the influence of the RFI in the measurement, i.e. the difference between the snapshots shown in the top row, left and middle. From this comparison we see how the nominal error level increased because of the RFI. The ripple level caused by the RFI is of the order of 60 K, peak-to-peak, within the alias-free area of MIRAS. This is a significant increment to the nominal noise level of approximately 10 K peak-to-peak.

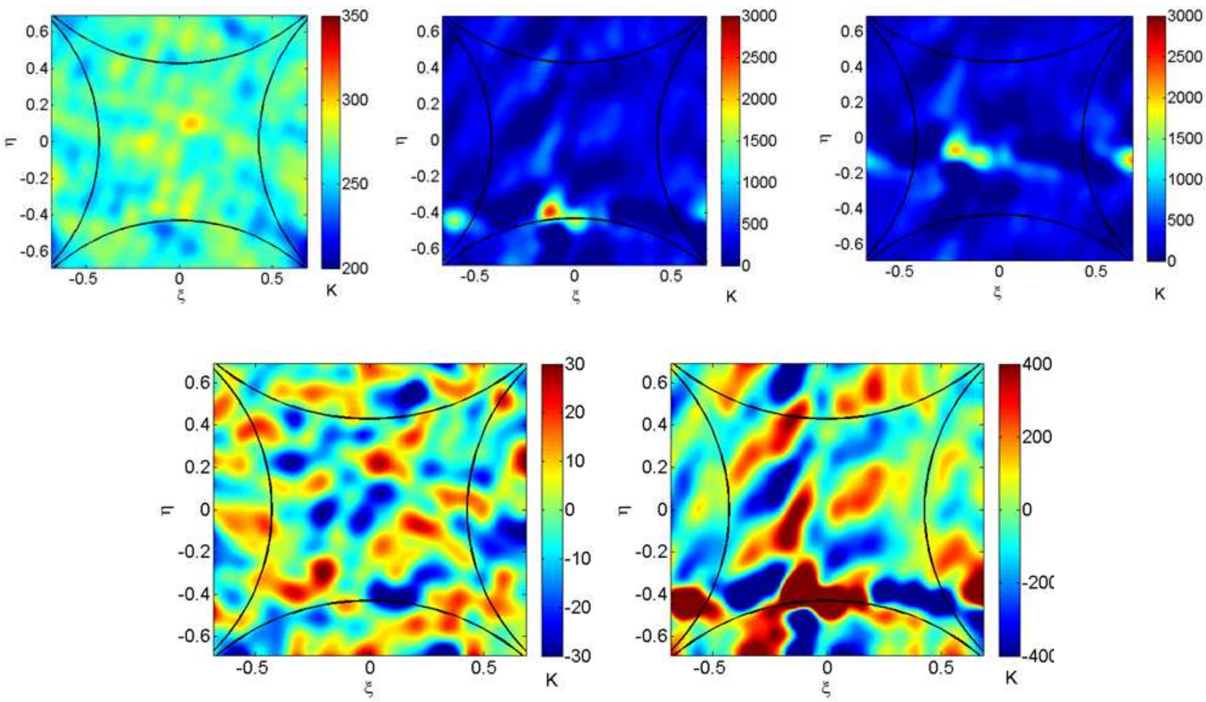

Figure 2. Top row: Three brightness temperature snapshots measured by HUT-2D. The left image shows an RFI-free snapshot over a coniferous forest area south of Seinäjoki (Fig. 2), whereas the middle and the right images show a strong point-like RFI-source crossing the field-of-view of the instrument. The ground resolution of HUT-2D is approximately 100 meters.

Bottom row, left: Difference of two consecutive HUT-2D snapshots over homogenous target (similar to the top left figure). Right: Difference of the RFI-contaminated snapshot (top, middle) and the RFI-free snapshot (top, left).

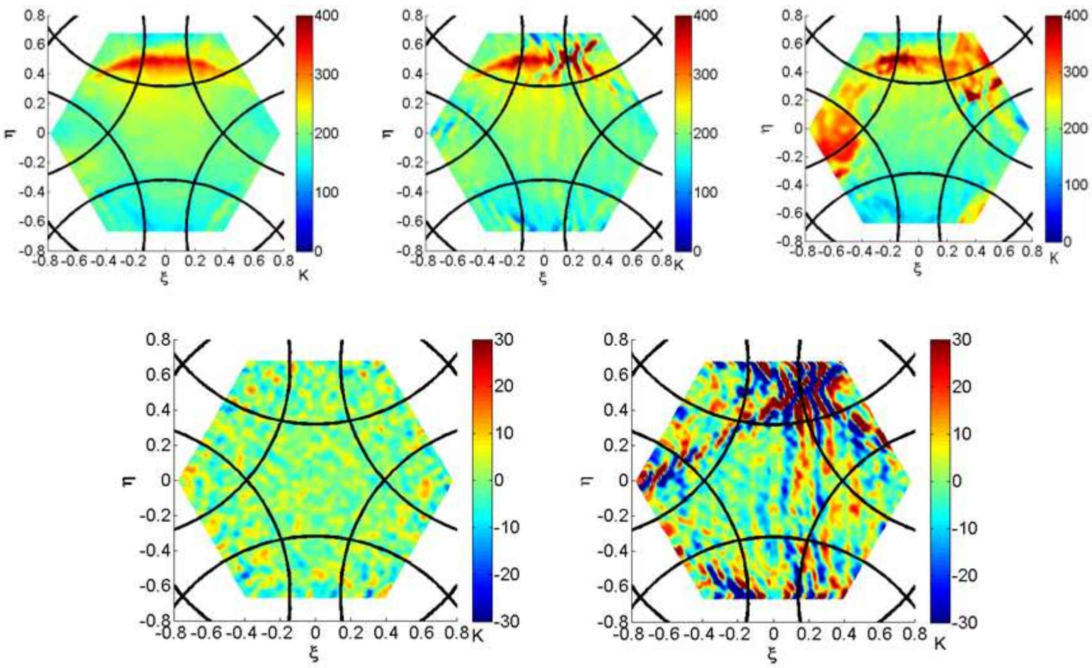

Figure 3. Top row: Three brightness temperature snapshots measured by SMOS over the Atlantic, heading north towards Greenland. Snapshots are separated by five minutes. The left image shows a measurement of ocean only. The coast of Greenland with a powerful RFI source appears in the middle and the right image. The ground resolution of SMOS snapshots is 30-50 km. Bottom row, left: Difference of two consecutive SMOS snapshots over the Atlantic (similar to the top left figure). Right: Difference of the RFI-contaminated snapshot (top, middle) and the RFT-free snapshot (top, left).

4. Conclusions

In this paper we have demonstrated, with the data collected with the airborne HUT-2D as well as space-borne MIRAS instrument, that point-like RFIs have severe impacts on the imaging area of the radiometers, even when the RFI is not physically located in the usable imaging area (the alias-free area) of the instrument. The main objectives of the forthcoming research is to develop methods and tools for detecting and classifying the radio frequency interference from L-band radiometer data collected with synthetic aperture radiometers. An important part of the research data is HUT-2D measurements conducted during the SMOS Cal/Val campaign in spring 2010, when SMOS covered the test sites simultaneously with HUT-2D, RFI affecting both instruments.

5. References

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