WETLAND MAPPING AND MEASUREMENT OF FLOOD INUNDATED AREA USING GROUND-REFLECTED GNSS SIGNALS IN A BISTATIC RADAR SYSTEM

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ABSTRACT

Global Navigation Satellite System (GNSS) signals can be used as a kind of bistatic radar, with receivers opportunistically recording ground-reflected signals transmitted by the GNSS satellites themselves. The ground-reflected signals are sensitive to changes in surface permittivity, which for L-band is primarily a function of the moisture content of the surface. Here, we investigate the ability of GNSS signals, as recorded by a GPS receiver flown on a satellite, to measure changes in wetland extent and flood inundated area. We find that the ground-reflected signals give similar results as flood-inundation maps derived from other sources. Reflected power increases of over 10 dB in the vicinity of wetlands indicates that these signals could successfully map changes in wetlands around the globe.

1. INTRODUCTION

Ground-reflected Global Navigation Satellite Systems (GNSS) signals can be used to describe changes in the land or ocean surface. This technique, GNSS-Reflectometry (GNSS-R), has primarily been explored using receivers flown on aircraft or balloons, or in modeling studies. Many of these studies indicate that GNSS-R can be used to estimate geophysical parameters like ocean wind speed, surface soil moisture, vegetation water content, and snow structure [1]–[4]. However, to date, the only analysis of the detection of GNSS-R signals over land using spaceborne receivers has been limited to the small amount of data recorded nearly 10 years ago by the UK-DMC satellite.

Last year's launch of the TechDemoSat-1 (TDS-1) satellite, a precursor to the Cyclone Global Navigation Satellite System (CYGNSS) constellation, represents an enormous opportunity to investigate the potential of using spaceborne GNSS receivers to sense changes in the land surface, including changes in wetland extent and flood-inundated area. Although the primary mission of CYGNSS is to estimate changes in ocean wind speed, it is possible that the same measurements made over land could provide information about changes in the land surface. However, much research remains to be done in terms of quantifying how sensitive the signals are to changes in ground permittivity relative to surface roughness, as well as their spatial sensing scale. With a revisit time of only a few hours, the GNSS receivers that comprise the CYGNSS constellation, or similar constellations in the future, could provide data with a temporal resolution that would be unmatched by traditional remote sensing satellites.

Previous modeling studies have shown that ground-reflected GNSS signals are sensitive to changes in surface permittivity, which for the L-band wavelength is primarily a function of the moisture content of the surface [5]. In addition, the relatively long wavelength of these signals allows them to penetrate vegetation further than more commonly used wavelengths, such a X- or C-band. Therefore, it is possible that the reflected GNSS signals could be used to measure changes in wetland extent and flood inundated area, even in the presence of a vegetation canopy.

Wetlands are a large contributor of atmospheric methane, though the total amount of methane is still relatively unconstrained, in part because the sizes of wetlands and how their sizes change over time is not well known . Here, we analyze whether or not ground-reflected GPS signals recorded by TDS-1 could be used to map wetland extent and flood inundated area by comparing signals to existing remote sensing products.

2. METHODS

In this study, we analyze the peak power of the Delay Doppler Map (DDM) and how it is affected as the specular reflection point passes over known wetland areas. The DDM is the two dimensional cross-correlation between the received reflected signal and a replica contained within the receiver (Fig. 1). We do not presently take into consideration other parts of the DDM that are affected by the roughness of the surface, such as the slope of the trailing edge. However, it should be noted that the peak power of the DDM is also affected by surface roughness.

To compute the effective peak power of each DDM, we first normalize the peak power by the noise floor. Corrections for antenna gain, range, and incidence angle are also made. Once these corrections are made, the effective peak power across DDMs may be compared as a proxy for changes in surface permittivity.

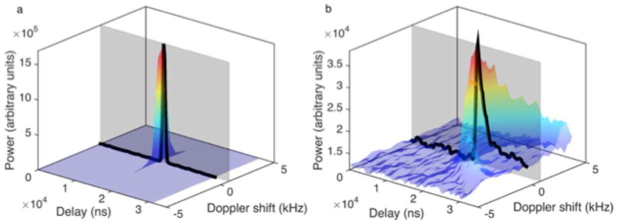

Figure 1: a. DDM recorded by TDS-1 over a rice field in the Ebro Delta, Spain. The black line indicates the DDM slice over constant Doppler that contains the maximum correlative power. b. DDM recorded over the Mediterranean Sea. The black line indicates the DDM slice over constant doppler that contains the maximum correlative power. Note that the z-axis in panel b. is an order of magnitude smaller than the z-axis in panel a.

Next, we compare our estimates of effective peak power to various remote sensing products, in particular land cover classes and estimates of flood inundated area derived from monostatic radar. We also compare peak reflected power in the vicinity of wetlands that fall underneath the Ramsar Convention, relative to peak reflected power in non-wetland areas.

3. RESULTS

Fig. 2 shows the land cover classifications derived from the SMAP radar backscatter data. On top of the land cover map, we have plotted effective reflected power from DDMs recorded by TDS-1. We see that there is excellent correlation between inundated vegetation and an increase in reflected power. This is an indication that reflection data can be used to generate similar results as the SMAP radar backscatter, even in the presence of vegetation.

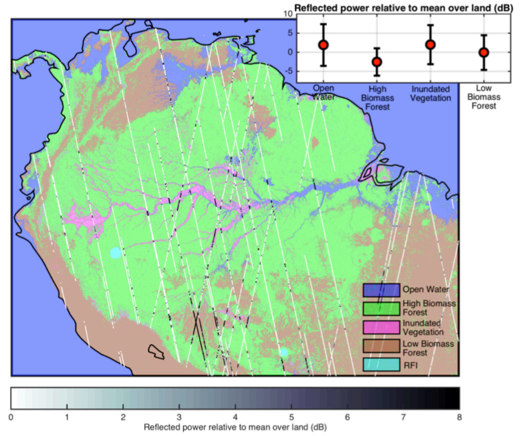

Figure 2: GPS reflected power (white-black colored dotes) on top of land cover classification map derived from Landsat and SMAP HH radar backscatter data for the Amazon. The inset shows the mean and standard deviation of reflected power for each land class (RFI, or radio frequency interference, omitted).

Fig. 3 shows the mean power within the vicinity of wetlands that fall underneath the Ramsar Convention. In many areas, such as the Mediterranean, Mexico, India, and eastern China, we see an increase in reflected power by more than 10 dB. This indicates that there is a strong response of GPS reflections to wetlands in many areas of the world. There are other areas, such as Central Africa, which do not show an increase in reflected power. This could be due either to the presence of thick vegetation, or perhaps the area was not flooded when the reflections were recorded.

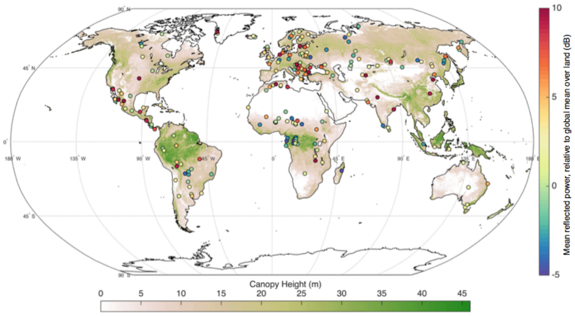

Figure 3: Mean reflected power in the vicinity of wetlands that fall underneath the Ramsar Convention.

4. CONCLUSIONS

GNSS signals show strong sensitivity to flood inundated areas, even in the presence of moderate vegetation. However, our results show that ground-reflected signals may not be sensitive to water underlying areas of extreme vegetation growth, such as in Central Africa. More research should be done with regards to quantifying the saturation point of these signals with regards to vegetation.

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