

Spurious Fourth Stokes Parameter Signal in the SMAP Radiometer

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Abstract—The radiometer on the NASA SMAP (Soil Moisture Active/Passive) mission is fully polarimetric and operates at L-band in the spectrum window at 1413 MHz protected for passive use only. A unique feature of the radiometer is the fully digital back-end which permits direct computation of the third and fourth Stokes parameters (i.e., real and imaginary part of the correlation of signal at horizontal and vertical polarizations). The SMAP conical scanning geometry has provided the opportunity to look at the global distribution of the fourth Stokes parameter at constant incidence angle (40 degrees at the surface). A striking feature of these maps is the existence of a strong (± 10 K peak-to-peak) spurious signal at coastlines. There is also a weak coupling to Faraday rotation. This paper reports research to explain the existence of these spurious signals.

Index Terms—Radiometry, Passive Microwave Remote Sensing; L-band

I. INTRODUCTION

Among the unique features of the L-band radiometer on the NASA SMAP observatory are that it is polarimetric with a fully digital backend. In particular, the radiometer digitizes the voltages (phase and amplitude) at the vertical and horizontal ports and computes moments such as the third and fourth Stokes parameters directly in software. These data provided an opportunity to examine the global distribution of the fourth Stokes parameter at L-band to look for potential signatures from the surface. Among the surprises were large spikes at coastlines and evidence of Faraday rotation [1]. The residual remaining after removing these spurious signals showed a clear correlation with large scale features of the surface. This is shown in Fig 1 which shows the fourth Stokes parameter over land after removing the spikes as the surface and removing the coupling of Faraday rotation. Areas such as the Sahara desert and the desert areas of Australia (blue) clearly stand out as do the vegetation of the Amazon forest and vegetation in Indonesia and sub-Saharan Africa (red and yellow). The motivation for this work was to understand these signatures and to determine if, in fact, they were evidence that the fourth Stokes parameter could be used for remote sensing.

II. APPROACH

The approach to understand these features was to use the simulator developed for Aquarius and SMAP [2] to see if the spurious signals could be reproduced. The simulator

computes radiation from the surface to the spacecraft and then integrates over the antenna pattern to produce a model version of the antenna temperature. The simulator mimics the spacecraft (e.g. altitude and scan geometry) and employs the SMAP antenna patterns. In this case, elements that were unlikely to be involved in generating spurious signal such as radiation from the galaxy and attenuation and emission from the atmosphere were omitted. Nominal values were assumed for the surface parameters (i.e. salinity and temperature for the ocean and soil moisture and temperature for land) and kept constant as a function of position. Roughness was not included over the ocean (i.e. zero windspeed) and a small nominal value was included over land. Faraday rotation was assumed constant around the scan.

The simulation was applied to a SMAP scan over Baja California which included several land water crossings. Figure 2 is a schematic showing the scan. It starts near the northern end of the Gulf of California and moves counter clockwise across Baja California, over ocean and then crosses the peninsula again near the southern end before returning over land to the beginning. Figure 3 reports a comparison of the data and simulation. At the top is the fourth Stokes parameter, T4, observed by SMAP and the middle panel is the land fraction as the scan evolves. Large spikes in T4, on the order of 10-20 K, occur at the coastline and the sign depends on the direction (positive for land-to-water and negative for water-to-land). The bottom panel shows the results of the simulation.

III. ANALYSIS

The good agreement of simulation and data, and the fact that the simulation included no natural T4 from the surface, suggests that the spikes are not a feature of the surface but generated in the integration inherent in the physics of the radiometer antenna. Equation 1 is the expression for the fourth Stokes parameter observed by an antenna with col-pol gain G_{vv} and G_{hh} and cross-pol gain g_{vh} and g_{hv} [2]. The angle ϕ includes Faraday rotation and a term that accounts for the change in the antenna polarization basis within the antenna beam as one moves from boresight ([3] and Appendix B in [4]).

$$TA4 = 2 \operatorname{Im} \{ [(G_{vv} g_{vh}^*) [\cos(2\phi)T_v + \sin(2\phi)T_h] + (G_{hh} g_{hv}) [\sin(2\phi)T_v + \cos(2\phi)T_h] + (G_{vv} G_{hh}^*) \sin(2\phi) (T_v - T_h) + (g_{hv} g_{vh}^*) \sin(2\phi) (T_v - T_h)] d\Omega \} \quad (1)$$

It is clear from (1) that if the antenna were ideal (i.e. no

cross-pol gain and $G_{vv} = G_{hh}$) then $T_4 = 0$. Also, if the antenna were perfect (a delta function at boresight) there would be, at most, a change in level in going from land to water but no spike. Hence, for spikes to exist, there must be a finite beam and some imperfection (cross-pol coupling and/or phase mis-match). What happens with a real antenna is illustrated in Fig 4 which plots the integrand of the first term on the right in (1): $2\text{Im}[G_{vv} g_{vh}^* \cos(2\phi)]$. All the integrands in (1) have a similar shape.

Figure 4 is a polar plot with azimuth around the perimeter. Boresight is at the center and each circle corresponds to increasing polar angle. The value of this term is nearly zero (green) everywhere except for a negative (blue) and positive (red) peak near the center. When the antenna is looking at a uniform scene (e.g. ocean or land only). The two peaks cancel and the integration is nearly zero. But, when this antenna scans across a land water boundary rapid changes are possible. For example, consider the case when the antenna is over water, scanning to the left and approaching land. Initially the integral is zero. But as the land-water boundary reaches the blue area, the integral becomes negative, and more and more negative until the land-water boundary is at boresight. As the antenna continues to scan, the land water boundary moves into the red and the imbalance begins to decrease, until the antenna beam is entirely over land at which point the integral is zero again.

This explains the spikes at coastlines. The dependence on Faraday rotation is a manifestation of the dependence of T_4 in (1) on the angle ϕ . If any of the terms in (1) are not zero, they will depend on ϕ . In particular, the third term on the right $(G_{vv}G_{hh}^*) \sin(2\phi) (T_v - T_h)$ is likely to be strongly responsive to changes in ϕ caused by Faraday rotation. This will manifest as a shift in level as reported in [1] and not as a spike.

IV. DISCUSSION

Analysis was presented above supporting the hypothesis that the spikes at coastlines and dependence on Faraday rotation observed in SMAP measurements of T_4 are in fact spurious signal caused by realities of the radiometer antenna (finite beam width and existence of cross-polarization coupling). But, what about the question posed at the beginning of this manuscript: is the signal in Fig 1 spurious or evidence that T_4 being generated at the surface? One possibility is that sub-footprint inhomogeneity results in mini-spikes, just like at coastlines but which, taken together, are noise-like. Evidence for this can be seen in the data (Fig 3, top). Comparing the portion of T_4 over water with the portion of the scan over land, it is clear that T_4 over land is noisier. Perhaps Fig 2 is just a manifestation of differences in the scale of inhomogeneity over surface dominated by vegetation compared with barren land surface (i.e. desert). Confirmation is left for future work.

V. REFERENCES

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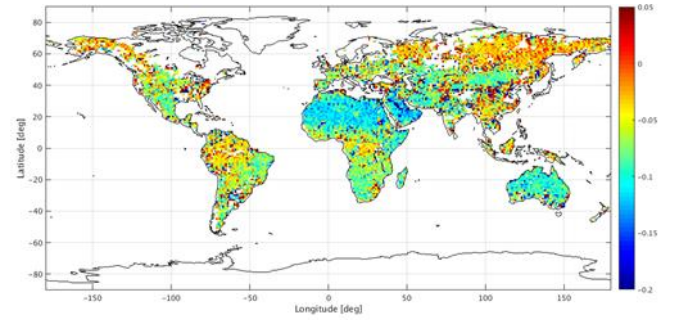


Fig 1: Residual features of fourth Stokes parameter after removing spurious spikes and coupling to Faraday rotation. The map is the average for 2016.

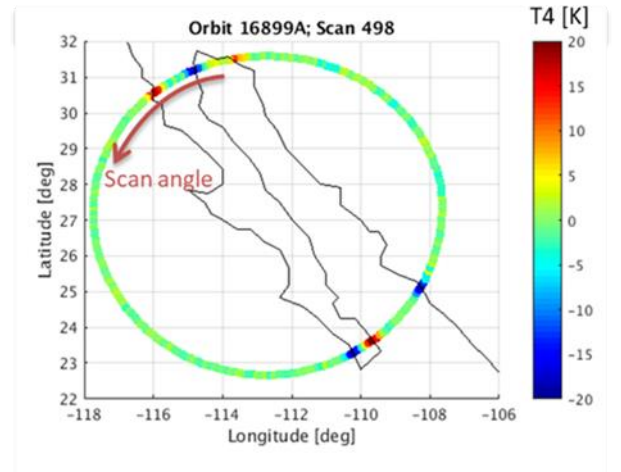


Fig 2: SMAP Scan over Baja California used in the simulation. The color scale along the scan path indicates the amplitude of the fourth Stokes parameter measured by SMAP.

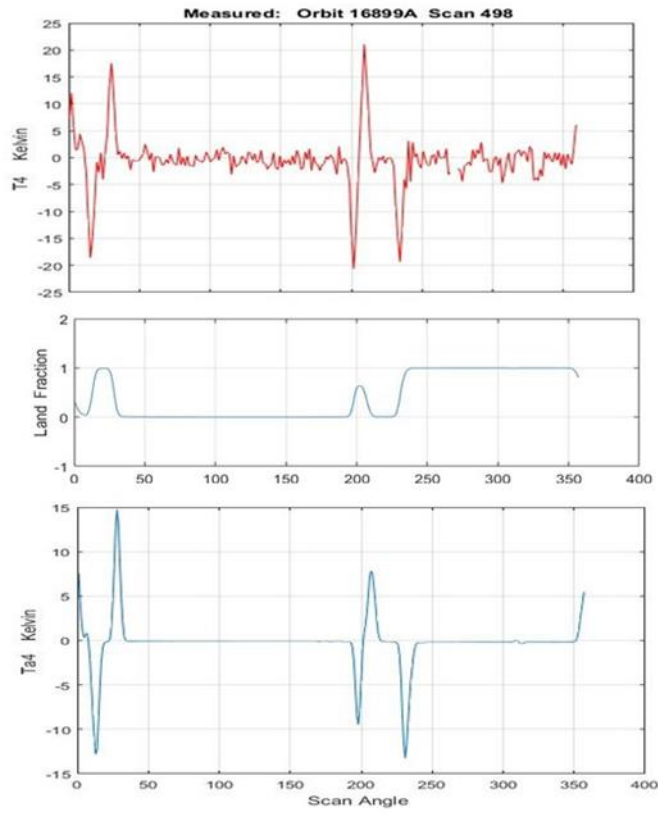


Fig 3: Results for Scan over Baja California. (Top) SMAP data; (Middle) Land fraction; (Bottom) Simulation

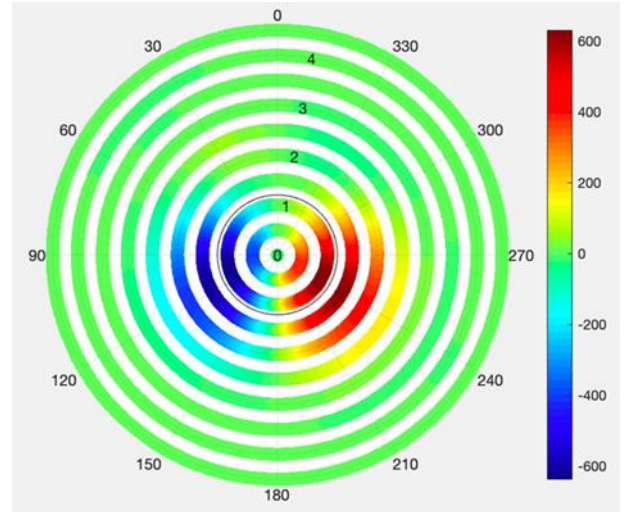


Fig 4 Antenna response. This is the first term in the integrand in (1): $2 \operatorname{Im} [(G_{vv} g_{vh}^*) \cos 2(\phi)]$