THE GLOBAL L-BAND OBSERVATORY FOR WATER CYCLE STUDIES (GLOWS) – SMAP CONTINUITY MISSION

David Long[1], Rajat Bindlish[2], Jeffrey Piepmeier[2], and Mark Bailey[3]

[1]Brigham Young University, Provo, UT, USA
email: long@ee.byu.edu
[2]NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA
[3]MMA Design LLC.

ABSTRACT

SMOS and SMAP radiometers have demonstrated the ability to monitor soil moisture and sea surface salinity and continue to provide high quality radiometric measurements to this day in extended mission operations. It is important to maintain data continuity for these science measurements. The proposed instrument concept (Global L-band active/passive Observatory for Water cycle Studies - GLOWS) will enable low-cost L-band data continuity (that includes both L-band radar and radiometer measurements). The objective of this project is to develop key instrument technology to enable L-band observations using an Earth Venture class satellite. Specifically, a new deployable reflectarray lens antenna is being developed that will enable a smaller EELV Secondary Payload Adapter (ESPA) Grande-class satellite mission to continue the L-band observations at SMAP and SMOS resolution and accuracy at substantially lower cost, size, and weight.

Index Terms — SMAP, SMOS, Soil Moisture, Active microwave, Passive microwave

1. INTRODUCTION

Low frequency (L-band) observations collected by the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission and the United States (US) National Aeronautics and Space Administration (NASA) Aquarius and Soil Moisture Active Passive (SMAP) missions have demonstrated the capability for satellite observations of soil moisture (SM) and sea surface salinity (SSS). While SMOS and SMAP continue operation, they are beyond their design lives and it is critical to consider a follow-on mission to continue the time series observations. The proposed ESA Copernicus Imaging Microwave Radiometer (CIMR) mission will continue the passive time series at a slightly coarser resolution, but active (radar) global observations at L-band are also needed for optimum soil moisture spatial resolution (<10 km). The expected L-band 3-dB resolution of the CIMR radiometer is expected to be close to 60 km as compared to the SMAP/SMOS resolution of 40 km (without the radar).

The Global L-band active/passive Observatory for Water cycle Studies (GLOWS) mission is designed as a low-cost follow-on to SMAP that will provide both active and passive L-band observations using a 6-meter aperture antenna. The key to reducing the cost of GLOWS is the use of a new deployable reflectarray lens antenna that is lightweight and has a simple flat geometry. This enables the GLOWS sensor to fit on an Earth Venture class satellite. GLOWS will continue the science observations of SMAP and SMOS at the same resolution and accuracy at substantially lower cost, size, and weight.

In this paper we describe progress in the development of the GLOWS mission, including technology demonstrations of the lens antenna deployment and its compact feed. We describe the tradeoffs made in developing the compact radiometer and technological improvements in the radar design.

2. SCIENCE GOALS

Satellite remote sensing of soil moisture has advanced significantly over the last decade due to the success of the SMOS [1] and SMAP [2] missions, both of which provide global soil moisture retrievals on approximate 3 day repeat intervals at an accuracy of approximately 0.04 m^3/m^3. It is critical to extend this dataset beyond the life of the current missions in order to study the impact of soil moisture at climatologically relevant time scales on weather prediction, energy and carbon cycles, climate change on soil moisture dynamics, ocean salinity, and sea ice thickness among other studies possible with L-band observations. The major challenge of a future high-resolution low frequency microwave mission will be to strike the correct balance between antenna size/design (what is technically possible), performance (swath coverage, resolution, instrument noise), and cost/efficiency of operation.

Knowledge of long-term patterns of soil moisture variability, as opposed to short-term, is particularly desirable, as it offers a critical time window for tracking the formation and evolution of terrestrial hydrological trends over a variety of regional and continental spatial scales. These trends are often indicators of slow but persistent hydrological threats such as drought, deforestation, and flood/landslide risk that result in significant economic and societal impacts. Statistical studies have shown that the precision of a trend estimate increases with the duration of available observations. For typical values of variance and autocorrelation of observations, the duration of available observations needed to detect a trend (i.e., 5% per decade) can vary from ~10 to > 20 years. The usefulness of any long-term Earth Science Data Record (ESDR) depends on how consistent the resulting geophysical parameter remains after the raw observations from multiple satellites have been combined to derive that parameter. Any discontinuity in data level within the combined time series, whether due to discrepancies among satellites in calibration, viewing geometry, orbital parameters, or sensing frequency, could lead to overestimation or underestimation of trends and increase the number of years of observations required to detect a trend of a given magnitude.

Clearly, construction of such a long record of available observations can only be accomplished by merging observations in a consistent manner from multiple satellites operating in different eras that together span the entire multi-decadal period with accurate, well-calibrated active and passive measurements. This is exactly what we aspire to accomplish with the GLOWS mission concept.

The five science goals of the GLOWS instrument are to, at SMAP resolution and accuracy,

- Estimate global water and energy fluxes at the land surface.
- Understand the processes that link the terrestrial water, energy and carbon cycles.
- Quantify net carbon flux in boreal landscapes.
- Develop improved flood prediction and drought monitoring capability.
- Enhance weather and climate forecast skill.

The SMOS, Aquarius, and SMAP L-band missions have demonstrated the utility of low-frequency microwave observations for estimating various Earth science variables in addition to soil moisture and ocean salinity. Their observations have also contributed to the study of vegetation, sea ice thickness, ocean surface winds, ice sheets, and snow. It is vital to continue these critical measurements in the future. Further, it is essential to augment the passive time-series with a longer time series of active measurements that were planned with the SMAP mission.

GLOWS payload performance requirements are based on, and justified by, the original SMAP mission performance requirements that addressed both active and passive channels [3]. The GLOWS instrument payload provides performance, mission utility and reliability similar to NASA's SMAP payload at lower cost and in a smaller package. The goal of GLOWS is flagship performance at venture-class cost to provide continuation of high-quality active and passive L-band data measurements.

3. THE GLOWS SENSOR

The major challenge of high-resolution, low frequency microwave missions is the required antenna aperture. GLOWS addresses this by use of an innovative membrane lens antenna that is lightweight and can be deployed from a very small package. The deployed lens antenna also has a flat geometry which greatly simplifies requirements for the hosting spacecraft compared to SMAP. GLOWS also exploits improvements in radar electronics to minimize the size, weight, and power (SWaP) of the radar component of the active/passive GLOWS instrument system. Figure 1 compares SMAP and GLOWS integrated onto an ESPA-class spacecraft.

Deployable RF apertures have been available for decades, but these systems have limitations on packaging factors and can require significant mission budgets. Recently, membrane reflectarray antennas have demonstrated that smaller packaging, lower mass, and lower cost than deployable mesh reflector antennas can be obtained. Further, the reflectarray antenna can provide beam steering, which greatly simplifies beam scanning and mass balancing of the spinning antenna.

4. GLOWS DEVELOPMENT STATUS

One of the key questions that the GLOWS mission study is investigating is related to the radiometric performance of the reflectarray lens antenna. We will describe the progress in characterizing the performance of the reflectarray lens antenna. The presentation will also describe our progress in validating the packaging and RF performance of a compact radiometer and radar electronics. The dramatic stowed volume and mass reductions of the antenna and the reduction in SWaP of the electronics shrink the instrument and enable it to be deployed on a small platform, which further reduces mission costs. A summary comparison of SMAP and GLOWS is shown in Table 1.

The SMAP mission incorporated a spinning 6-meter diameter deployable perimeter truss-supported-metallic mesh parabolic reflector deployed at a 35.5° angle on the end of a reflector support mast. This configuration required significant stowed volume and complex balancing of an asymmetric rotating antenna. The deployable reflector was paired with a large horn feed and the antenna was jointly shared by a radar and radiometer.

The proposed GLOWS instrument incorporates a tensioned aperture of flat membranes that shape and direct the RF energy of the instruments through passive phase-shifting elements on the membrane. The phase shifting steers the beam to a 35.5° angle from the flat membrane. This results in the same ground incidence angle as SMAP. Like SMAP, the flat GLOWS lens is rotated at 14.6 rpm to sweep out a wide observation swath. The membrane design is combined with a patch array feed dramatically improving the packing factor of the antenna system. The compact antenna system, combined with volume reductions in the radar, and radiometer, result in an extremely favorable launch envelope, see Fig. 2.

The flat membrane aperture is deployed symmetrically with the instrument/satellite centered and orthogonal to the rotating membrane, greatly simplifying the balancing of the rotating aperture. The lens aperture in operation is illustrated in Fig. 3. This downward-facing architecture eliminates the concerns of shadowing of the solar arrays as well as blockage of signal reception from the GPS satellite constellation (concerns from SMAP). We note that the same reflectarray phase-shifting technology can be employed as a reflector instead of a lens, with many of the packaging benefits compared to a traditional mesh antenna. The use of a phase-shifting membrane reflector has been flight demonstrated as part of a RF Risk Reduction Deployment Demonstration mission.

5. REFERENCES

[1] Y. H. Kerr, et al., "The SMOS Mission: New Tool for Monitoring Key Elements of the Global Water Cycle," *Proc. IEEE*, vol. 98, no. 5, pp.666-687, 2010.

[2] D. Entekhabi, et al., "The Soil Moisture Active Passive (SMAP) mission," *Proc. IEEE*, vol. 98, no. 5, pp. 704–716, May 2010.

[3] J. R. Piepmeier et al., "SMAP L-Band Microwave Radiometer: Instrument Design and First Year on Orbit," *IEEE Trans. Geosci. Remote Sensing*, vol. 55, no. 4, pp. 1954-1966, 2017, doi: 10.1109/TGRS.2016.2631978.

Table 1. Comparison of SMAP and GLOWS missions*

	SMAP	GLOWS
Mission Stowed Volume	3.18 meters^3	<0.74 meters^3**
Mission Power beginning of life (BOL)	2 kW	1.5 kW
Average Power*	448W	<500W
Mission Mass	944 Kg	<400 Kg**
Radar/Radiometer/Antenna Mass	356 Kg	124.1 Kg
Launch	Delta II Payload	F9 4-meter Secondary

** Mission/Instrument Power are based on published SMAP data and GLOWS projections. GLOWS power budget includes 25% margin. GLOWS volume and mass budgets are preliminary and include ~50% margin*

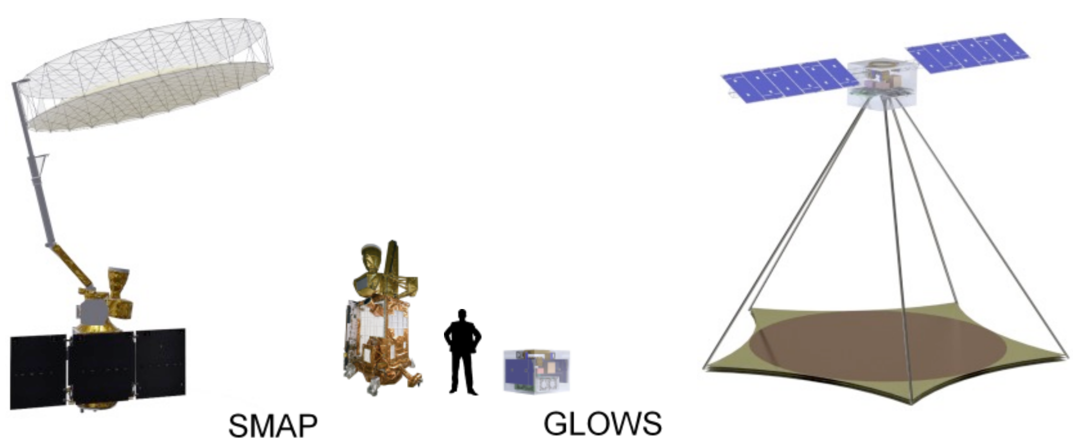

Figure 1. Comparison of SMAP and GLOWS integrated in an ESPA-class spacecraft. Note the similarity of deployed configurations and the contrast of launch configurations.

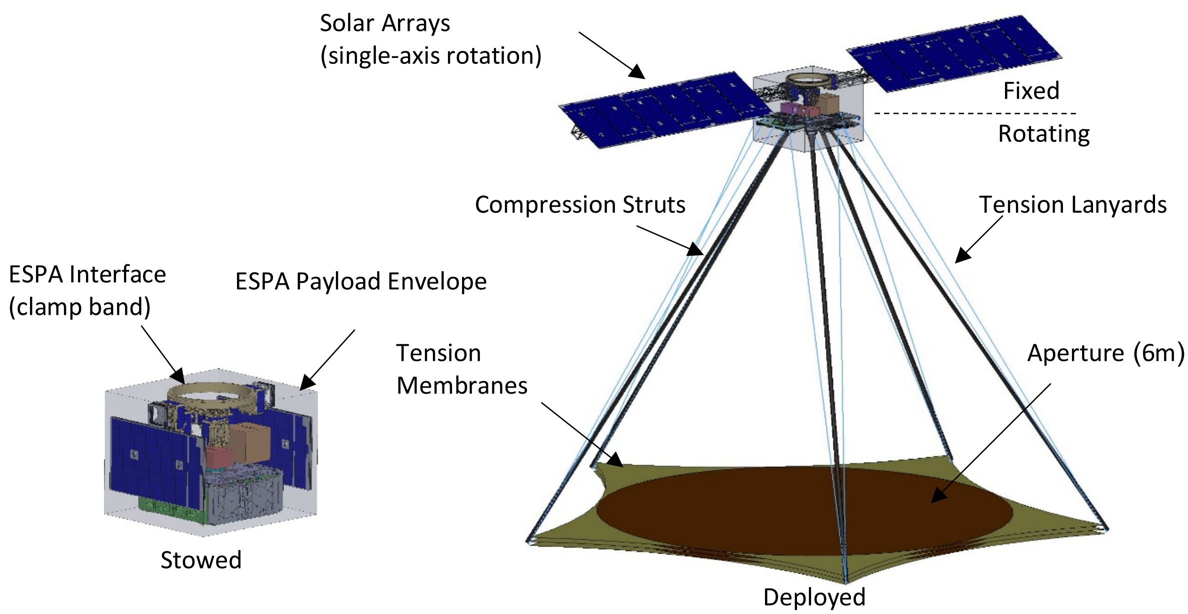

Figure 2. Illustration of the GLOWS launch and deployed configurations.

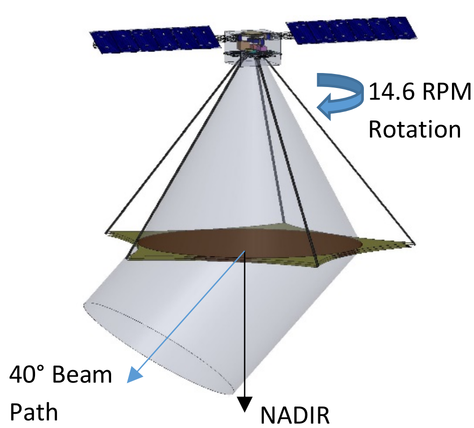

Figure 3. Illustration of the GLOWS antenna beam steering provided by its phase-shifting lens antenna.