Status Report: CGMS Action Item WGII A45.02: LEO-LEO and GNSS-RO+R OSSEs

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The following action was levied on IROWG and is now due at CMGS-46.

"Actionee"	AGN item	Action #	Description	Deadline	Status	HLPP ref
IROWG	4	A45.02	IROWG to develop a detailed proposal for OSSEs regarding LEO-LEO MW occultation and GNSS-RO&-reflectometry	~~1 Nov 2017~~ CGMS-46	OPEN	1.1.4

OSSEs for the LEO-LEO Microwave Occultation Concept

Below is brief background on the LEO-LEO concept, the need for and value of OSSEs and a summary of status.

GNSS RO has proven quite impactful for NWP, space weather and climate research. In some sense this is surprising because GNSS wavelengths were chosen specifically to minimize their interaction with the atmosphere. An observing system that would deliver far more information about the vertical structure of the atmosphere across the globe and be far more impactful on NWP is a satellite to satellite occultation system probing the atmosphere near absorption lines of water vapor and other key constituents in the atmosphere. Such a system would provide new, quantitative information about the vertical structure of the atmosphere in terms of temperature, pressure, winds, clouds, and precipitation and key constituents such as water vapor, ozone, and CO_2, with balloon-like vertical resolution for understanding processes. Because occultations are inherently self-calibrating, they are excellent for climate monitoring, and providing an anchor for bias correction schemes used in NWP systems. Sufficient prototyping of LEO-LEO instrumentation has been done to show that these instruments can be quite small and low power. This combined with recent advances in miniaturizing spacecraft means we have the ability to place many of these sensors into orbit and achieve the sampling densities required to impact NWP forecasts and analyses. Such a system promises to deliver thousands of SI-traceable, radiosonde like profiles from orbit, distributed across the globe, to initialize NWP forecasts, anchor bias correction schemes, and expose physical modeling errors as well as produce analyses more observationally constrained and less reliant on models, making them better suited for climate research.

A key step in enabling this vision is to achieve recognition by the operational and research communities of the information content and impact such an observing system could have on monitoring, understanding and predicting weather and climate. Observing System Simulation Experiments (OSSEs), if done correctly, are a good approach to reveal and deliver this message to the research and operations community. This conceptual approach has emerged via discussions with researchers at NOAA, GMAO, ECMWF and JCSDA. ***In these discussions, a clear first step that has emerged is to develop a LEO-LEO forward operator that can be used in NWP systems.*** This step is required to enable OSSEs that would provide an estimate of the theoretical impact that a LEO-LEO constellation would have on NWP forecasts and analyses. We also note that in parallel there must be an effort to place an initial LEO-LEO system or systems into orbit to demonstrate that a LEO-LEO system can really deliver the kind of vertical profiling information and performance that it promises.

At present, the key impediment for all three of these activities is the lack of funding required to support these activities.

OSSEs for Combined GNSS-RO and GNSS-Reflections Constellations

NASA's CYGNSS mission, launched in 2016, is demonstrating the value of a new type of GNSS-based remote sensing: using reflected GNSS signals from Earth's surface to infer its properties and those of surface winds above oceans. For technological reasons, it is synergistic to design future operational constellations of GNSS remote sensing instruments that can perform both RO and reflections simultaneously. The question that needs to be addressed is how to optimize such constellations given their multiple types of observables.

The NWP community has already developed OSSEs that assimilate ocean vector winds from microwave scatterometers, a measurement type related to what GNSS-R can provide. A crucial difference is that GNSS-R only provides wind speed, not direction. The promise of CYGNSS is that is can provide such information under heavily precipitating conditions (that scatterometers cannot) and from a constellation geometry, with favorable revisit time and spatial coverage for extreme weather applications.

OSSE work to assimilate GNSS-R observations has already started in the context of the CYGNSS mission (McNoldy et al., 2017). One approach is to use the tools developed for scatterometers but remove the direction information from the measurement. This is a straight-forward development task. Additional research is being conducted on how GNSS-R data are assimilated, by developing a forward operator for the "raw" GNSS-R data, rather than the wind speed retrieval. GNSS-R returns a data structure called "delay-doppler map" that represents the mean-square slope (MSS) of the ocean surface, which can be related to wind speed. However, the relationship between MSS and wind speed can become non-linear particularly at high speeds, so there may be advantages to developing a new forward operator.

What remains to be done is an OSSE that combines GNSS-RO+R information from a single satellite constellation, such that the constellation can be optimized and an understanding is gained of how to design such a combined constellation for the full range of weather conditions. Another element that needs to be considered is the emerging capabilities of GNSS-R to sense soil moisture over land (Chew and Small, 2018). The relationship between soil moisture and future weather patterns has been studied extensively.

The following steps are recommended:

1. Select a technical approach to assimilating GNSS-R ocean wind speed information
2. Develop tools to quantify the forecast value of different GNSS-RO+R constellation geometries, including selection of the appropriate weather simulations ("nature runs") that include extreme weather
3. Develop improved methods of assimilating "raw" GNSS-R observations over oceans

As future work, one could augment the OSSEs with an approach to GNSS-R based retrieval for soil moisture.

Acknowledgements

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References

Chew, C. C., and E. E. Small (2018), Soil Moisture Sensing Using Spaceborne GNSS Reflections: Comparison of CYGNSS Reflectivity to SMAP Soil Moisture, *Geophysical Research Letters*, *45*(9), 4049–4057, doi:10.1029/2018GL077905.

McNoldy, B., B. Annane, S. Majumdar, J. Delgado, L. Bucci, and R. Atlas (2017), Impact of Assimilating CYGNSS Data on Tropical Cyclone Analyses and Forecasts in a Regional OSSE Framework, *Marine Technology Society Journal*, *51*(1), 7–15, doi:10.4031/MTSJ.51.1.1.