THE HARP HYPERANGULAR IMAGING POLARIMETER AND THE NEED FOR SMALL SATELLITE PAYLOADS WITH HIGH SCIENCE PAYOFF FOR EARTH SCIENCE REMOTE SENSING

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ABSTRACT

The largest uncertainties on estimating climate change revolve around the lack of quantitative information on aerosol and cloud microphysical properties, which limits our understanding of cloud-aerosol interaction processes and cloud feedbacks in the climate system. Part of this limitation comes from the small number of global satellite sensors which in turn only measures a restricted subset of aerosol and cloud microphysical properties. Enabling small satellites to perform high quality cloud and aerosol microphysical measurements is an important pathway to resolve this puzzle. The reduced cost of small satellites can enable the use of multiple platforms or even constellations to increase spatial and temporal coverage for the required measurements.

The HARP (HyperAngular Rainbow Polarimeter) is a 3U CubeSat sensor designed for the measurement of aerosol, clouds and surface properties with a wide FOV that enables nearly global coverage from multiple wavelengths and tens of different along track viewing angles. The technology developed for HARP allows for all these characteristics to be packaged within the envelope of a CubeSat sensor while preserving strict science requirements.

Index Terms— Aerosol, Clouds, Polarimeter, Multi-Angle, CubeSat

1. INTRODUCTION

Although the terminology "SmallSat" define a wide range of spacecraft sizes, the advent of highly capable spacecraft on the small end of this size spectrum (NanoSatellites) calls for the development of equally capable miniaturized small satellite payloads that can accurately collect Earth Sciences data. The reduced cost of the combination between high science payoff sensors and small satellites allow for a potential increase in spatial coverage, frequency and number of accurate variables measured from space. This concept allows for the development of constellations of satellites measuring the same or even complementary variables from different perspectives in time and space.

This manuscript describes the development of the Hyperangular Rainbow Polarimeter (HARP) as an example of a high payoff sensor concept miniaturized for use on NanoSatellites. HARP's science focuses on the measurement of detailed properties of aerosol and cloud particles in suspension in Earth's atmosphere and their potential effect on climate. Understanding and predicting climate change is the world's number one Earth Science and environmental priority [1,2]. One of the uncertainties holding us back from confident climate predictions *are the unknowns associated with aerosols*, specifically aerosol microphysical properties and how aerosols affect clouds. Accurate multi-angle polarization measurements over a broad spectral range (UV to SWIR) are the next frontier in measuring aerosols from space [3]. The French POLDER instrument has pioneered the use of polarization in multiple viewing angles for the retrieval of aerosol and cloud microphysical parameters [3, 4,5], followed by the HARP (Hyperangular Rainbow Polarimeter) CubeSat that is currently in preparation for launch in 2018.

HARP is a technology demonstration funded by NASA that intends to show how nanosatellites can measure the detailed microphysical properties of aerosol and cloud particles. As part of this development, an airborne version of HARP (the AirHARP instrument) has flown in the NASA ER2 and UC12 aircrafts providing preliminary data sets in preparation for the HARP CubeSat mission.

2. DESIGN AND SPECIFICATIONS OF THE HARP CONCEPT

The HARP concept consists of a compact system for the multiwavelength polarized imaging of Earth's atmosphere from different viewing perspectives. All these capabilities are concentrated in a single miniaturized sensor without any moving parts. Figure 1 shows a conceptual diagram of the

HARP data acquisition scheme, consisting of a collection of simultaneous pushbroom imagers resulting from the sampling of individual lines of a single detector array covered by a multiwavelength stripe filter. The stripe filter is used to separate the instrument spectral bands as well as the respective along track viewing angles. Each stripe of the detector is used to produce an independent pushbroom image correspondent to that particular along track viewing angle. The current HARP/AirHARP systems use a wide FOV front lens producind images with a 94° cross track swath and up to 113° along track. In the back of the lens there is a Philips prism that splits the original images in three geometrically equal images. A linear polarizer is placed in front of detectors A, B and C with relative angles at 0, 45 and 90°. The combination of the linearly polarized images from the three detectors in then calibrated to produce the three Stokes
parameters I, Q and U following the methodology describe in Fernadez-Borda at al. 2009 [7].

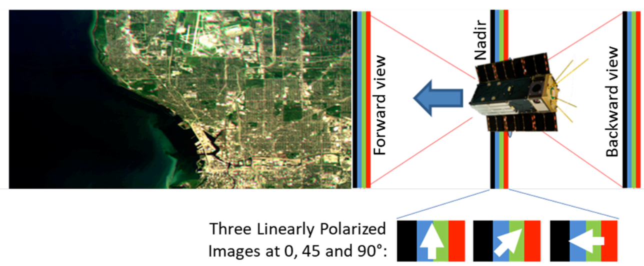

Figure 1 – Conceptual diagram of the HARP data acquisition scheme. The figure shows an example of three of the HARP pushbrooms (forward view, nadir and backward view, each one representing the stripe filters at four wavelengths. HARP can accommodate up to 60 viewing angles at 670 nm and up to 20 viewing angles at all other wavelengths. The figure also represents the three linear polarization states at 0, 45 and 90°. The image shows a RGB reconstruction of one of pushbrooms imagers.

Figure 2 shows an example of multiangle data acquired with the AirHARP instrument onboard the NASA Langley UC12 aircraft during the LMOS (Lake Michigan Ozone Study). The figure shows a combination of data over land and over water collected at 670nm. In particular, the images over the lake exemplify the importance of the multi-angle data as some viewing geometries show strong contribution of sunglint while other geometries show a completely glint free image. The combination between the different geometries contain important information on the surface and on the angular scattering properties of aerosol and cloud particles allowing for a detailed inversion of the microphysical properties of the atmosphere and surface properties.

Table 1 shows the spectral characteristics of the HARP CubeSat sensor while table 2 shows its orbital and geometrical specifications. HARP will be released from the International Space Station (ISS) following similar orbit and is expected to start collecting autonomous data still in 2018.

Table 1 – Specification of the HARP-VNIR sensors

Wavelength (μm)	Bandwidth (nm)	# Along Track Viewing Angles	Polarized
440	17	20	Y
550	13	20	Y
670	16	60	Y
865	47	20	Y

Table 2 – Geometric parameters of the HARP CubeSat

	Km	deg
Orbit Altitude	~ 410*	
Orbit Inclination		51.6
Nadir Pixel Resolution	0.4	
Nadir Binned Resolution	< 4	
Cross Track Swath	1348	94
Along Track Swath		113

** The orbit altitude will vary according to the actual altitude of the ISS during the HARP release and will also affect the other parameters.*

3. HARP CALIBRATION

In order to produce high science payoff a sensor must be properly calibrated and characterized for its particular measurement. In particular, HARP's science requires high radiometric and polarimetric calibrations. The limited availability of onboard resources (power, volume, mass, etc.) by NanoSatellite platforms poses extra challenges for the inclusion of onboard calibrators and reference systems. Thus, HARP CubeSat does not carry an onboard calibration system but uses other strategies to assure appropriate calibration while in space:

1- Polarimetric and radiometric of the sensor on ground before launch.
2- Moon observations for in space radiometric calibration
3- Observation of Earth's limb for polarimetric calibration
4- Vicarious calibrations observing ground targets including ocean sunglint, desert targets, AERONET stations, etc.

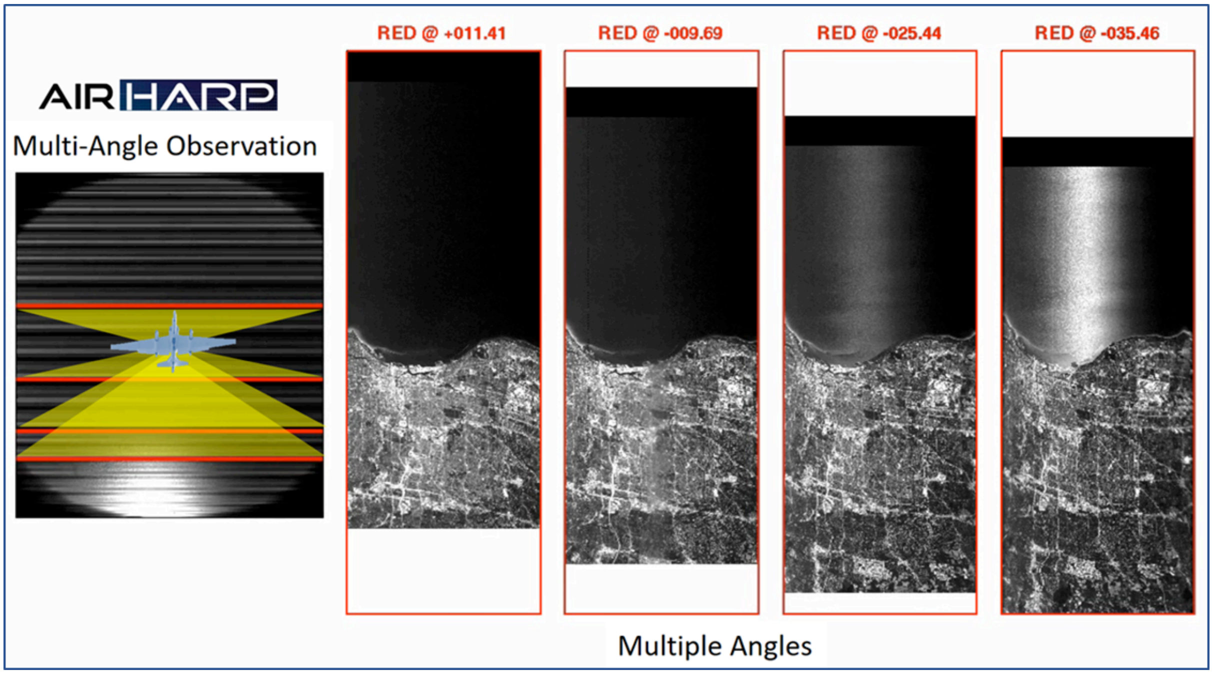

Figure 2 – Multi-Angle images collected with the AirHARP instrument onboard the NASA UC12 aircraft during the NASA LMOS campaign.

4. CURRENT LIMITATIONS FROM THE HARP CUBESAT PLATFORM

Due to the wide cross track swath, number of pixels, high angular density and multiple wavelengths, the HARP payload cannot collect data for global coverage or even produce very large amounts of data. Due to intrinsic limitations in power, heat dissipation, data storage, internal data transfer, processing, and space to ground data downlink, the HARP 3U CubeSat spacecraft can only accommodate a relatively small amount of data on the order of a few thousand km per day, depending on the selected number of angles and spatial resolution. In order to increase the data collection flexibility, HARP's payload allow for a flexible data acquisition scheme that can be programmed from the ground to change the binning resolution, the selected number of angles, and wavelengths.

The same HARP payload can be used with its full potential, including larger data collection (up to global coverage), higher special resolution, increased signal to noise ratio, etc., when accommodated in a larger/more capable spacecraft.

5. AIRCRAFT DEMONSTRATION OF THE HARP DATA SAMPLING AND CAPABILITIES

The AirHARP sensor is basically a copy of the HARP CubeSat payload adapted for aircraft operations. The main differences between both systems are the doghouse enclosure that isolates the sensor from the pressure boundary of the aircraft and the computer system in the aircraft which is a regular PC104 computer board rather than a space qualified computer. Also, the HARP components were the selected parts with higher quality whereas AirHARP mostly used leftover parts from the CubeSat payload. On the other hand, all the technical specifications and science requirements were kept the same.

AirHARP has first been demonstrated on the UC12 aircraft from NASA Langley flying at altitudes around 9km during the Lake Michigan Ozone Study (LMOS) and secondly on the high-altitude NASA ER2 aircraft flying around about 20km above sea level during the NASA ACEPOL campaign. A large collection of data has been collected covering a variety of atmospheric and surface conditions including water and ice clouds, aerosol cases at different optical depths, and a variety of water (lake and ocean) and land surfaces (desert, vegetation, urban areas, mountains, etc.).

6. RESULTS FROM AIRHARP AIRCRAFT CAMPAIGNS

Preliminary results have been produced with the AirHARP data sets consisting on radiometrically and polarimetrically calibrated data sets, corrected for the aircraft attitude and projected over a geo-referenced, absolutely geolocated grid. The produced level 1 data set consists of geolocated pixels containing the degree of linear polarization (DoLP), calibrated radiances (or I), and the additional Q and U stokes parameters. All the quantitative data was collected for the 4 wavelengths and the different along track viewing angles described in table 1 above. All this information is grouped in an HDF5 data file that will shortly be submitted to a public archive for general distribution. The AirHARP HDF file also contains latitude and longitude information as well as the viewing and the solar geometry for each gridded pixel.

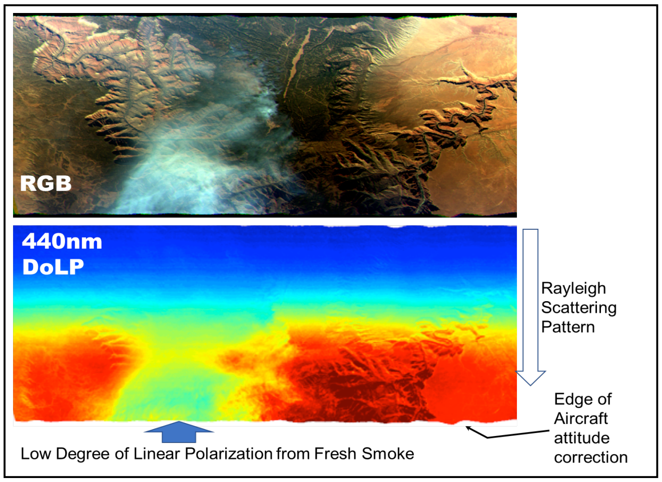

Figure 3 – AirHARP data collected from the NASA ER2 aircraft during the ACEPOL campaign.

As an example of the data collected with AirHARP and a preview of the expected data set from HARP, figure 3 shows one case over land in Arizona where the instrument observed smoke from a prescribed fire in November 2017 during the ACEPOL campaign. The figure shows a RGB image reproduced from the 3 visible wavelengths and the Degree of Linear Polarization (DoLP) measured at 440nm. The DoLP image exemplifies the effect of smoke on the polarization signal. In particular, the fresh smoke particles show the depolorization of the signal as compared to a cleaner atmosphere. The combination of multiangle, polarization and multiple wavelengths will be used as input to the inversion algorithm aimed to the retrieval of aerosol and cloud microphysical properties [4, 8]

6. CONCLUSION

The HARP sensor is a powerful miniaturized sensor that allows for the measurement of aerosol and cloud microphysical properties within a wide cross track swath and moderated pixel resolution. HARP helps to fill the gap of high payoff science payloads for NanoSatellites. Aircraft measurements were used to demonstrate HARP capabilities and to prepare algorithms for future space missions including the HARP CubeSat satellite to be launched in 2018.

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