OSIRIS (Observing System Including PolaRisation in the Solar Infrared Spectrum) instrument: a multi-directional, polarized radiometer in the visible and shortwave infrared, airborne prototype of 3MI / EPS-SG Eumetsat – ESA mission

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1. INTRODUCTION

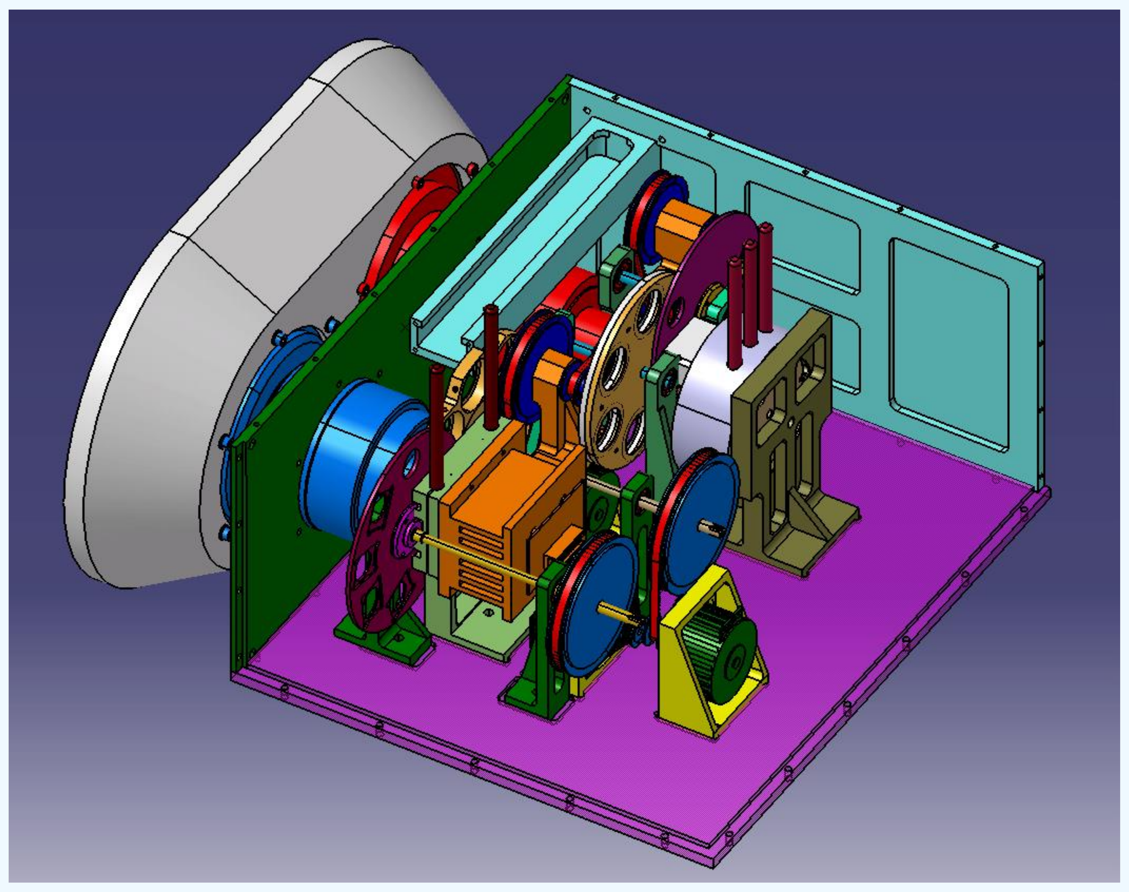
The aim of this project is to improve the characterization of radiative and microphysical properties of atmospheric aerosols and clouds. These two atmospheric components and their interactions are among the main sources of uncertainty in the forecast of climate change. In this context, we have designed a new airborne imaging polarimeter for measuring directional, total and polarized radiances in the 440 to 2200 nm spectral range.

The instrument design is presented here as well as results of in lab characterization and calibration using a new « advanced » radiometric model. Preliminary results recently obtained during the recent Aeroclo-sA airborne field campaign (August-September 2017) over Namibia are also presented.

2.INSTRUMENT DESIGN

OSIRIS instrument

Based on the POLDER concept [2,3,4,6,8], Osiris [1] instrument has two optical systems: one for the visible (VIS-NIR, from 440 to 940 nm) and one for the shortwave infrared (SWIR, from 940 to 2200 nm). Each optical system is composed of a wide field of view optical lens. Each optics is associated to two rotating wheels: one supporting the interferential filters and the other one for the analysers. The wheels turn thanks to four step by step motors. The imaging system consists in 2D arrays of detectors, one for the VIS-NIR and one for the SWIR. The polarizer wheels are also equipped with an opaque shutter for the estimation of the detector dark current.



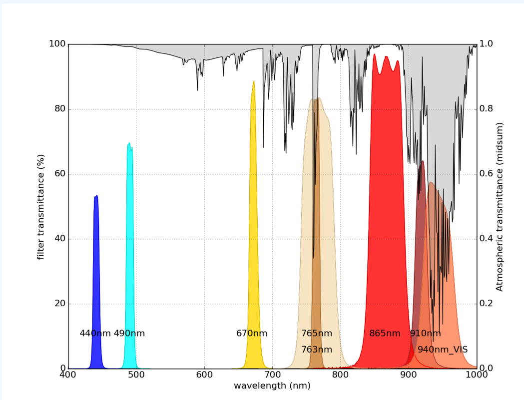
Instrument size: 325x286x188 mm
Weight: 12 kg
Power consumption:28V-3A (DC)
(without acquisition PC and visualization)

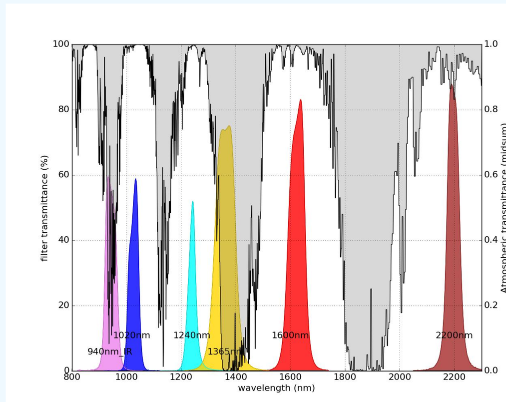
Spectral wavelengths

Osiris has 8 spectral bands in the VIS-NIR and 6 in the SWIR. The 940nm channel is common to both heads for inter-calibration purpose.
Thanks to the two separated and independant wheels and unlike the POLDER implementation, polarization measurements can be acquired (or not) at all available wavelengths.

Central Spectral wavelength (nm)	FWHM (nm)	Polarization Measurement	Filter Reference	Filter size (mm)
		VIS-NIR		
440	10	Yes	440FS10-25 (Andover)	25
490	10	Yes	490FS10-25 (Andover)	25
670	12	Yes	NB-0672-012 (Spectrogon)	25.4
763	10	No	100FC37-25 (Andover)	25
765	50	No	500FC47-25 (Andover)	25
865	55	Yes	BP-0865-055 (Spectrogon)	25.4
910	20	No	NB-0910-020 (Spectrogon)	25.4
940	50	No	500FC38-25 (Andover)	25
		SWIR		
940	50	No	500FC38-25 (Andover)	25
1020	40	Yes	BP-1026-040 (Spectrogon)	25.4
1240	35	Yes	NB-1236-035 (Spectrogon)	25.4
1365	80	No	BP-1360-080 (Spectrogon)	25.4
1600	65	Yes	BP-1625-065 (Spectrogon)	25.4
2200	48	Yes	NB-2200-048 (Spectrogon)	25.4

List of spectral wavelengths of the visible (VIS-NIR) and shortwave infrared (SWIR) part of OSIRIS instrument.

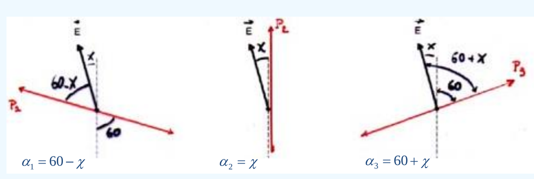




Polarization measurements

Polarization measurements are made using POLDER-like method [3,4,7,8]. In addition to the spectral filters, a second wheel carrying polarizers oriented at -60°, 0°,+60° is used to obtain 3 measurements (P_1, P_2, P_3) that can be recombined using Malus's law to obtain de degree of linear polarization and its direction.

Combining the projection of Malus's law on the 3 analyzers:

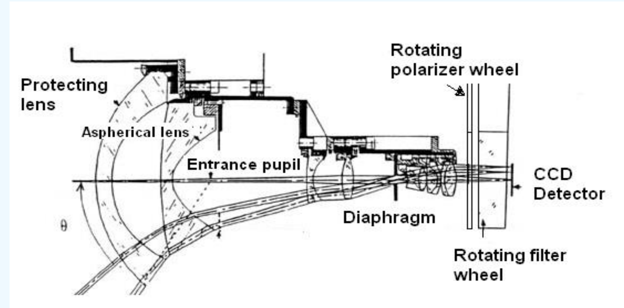


$$L_i = \frac{L_{nat}}{2} + L_{pol}\cos^2(\alpha_i)$$ leads to

$$L_{tot} = 2\frac{(L_1 + L_2 + L_3)}{3}$$ and

$$L_{pol} = \frac{2\sqrt{2}}{3}\sqrt{(L_1 - L_2)^2 + (L_2 - L_3)^2 + (L_1 - L_3)^2}$$

Optical blocks



Osiris visible lens

Each optical block consists in a wide field of view telecentric lens.

Total diagonal FOV: 114° (VIS-NIR)
105° (SWIR)

They are designed to resist to aeronautic conditions.

	VIS-NIR	SWIR
Focal length	3.6mm	5.2mm
Aperture	F/5.6	F/5
Horizontal Field Of View	+/- 51.1°	+/- 45.5°
Vertical Field Of View	+/- 42.9°	+/- 39.2°
Diagonal Field Of View	+/- 57.15°	+/- 52.5°
Mean transmission	>80%	>65%
Distortion	<4%	Max: 10%
Illumination homogeneity	>90%	Min: 60% at 2200nm
Induced polarization	Max: 8% at 865nm	Max: 10% at 2200nm
Mean FTM	>75%	>76%
Detector size	8.9x6.7mm	9.6x7.7mm
Pixel size	6.45µm*6.45µm	30µm*30µm
Number of pixels	1384*1032	320*256

Optical characteristics of Osiris lens (VIS-NIR and SWIR)

Detectors

VIS-NIR: 1384x1032 pixels progressive scan CCD cooled at 5°C, anti-bloomed
Pixel size: 6.45µm x 6.45µm
Spectral range: 400-1000nm
Integration time variable from 10 µs to 250ms

SWIR: 320x256 pixels HgCdTe Focal Plane array cooled at 195K, anti-bloomed
Pixel size: 30µm x 30µm
Spectral range: 900-2500nm
Integration time variable from 10µs to 25ms

Operational mode

A PC drives the acquisition and collects position and attitude data from an Inertial Navigation System, essential to data post-processing.

3. CALIBRATION-IN LAB CHARACTERIZATION

Dark current measurements (SWIR FPA)

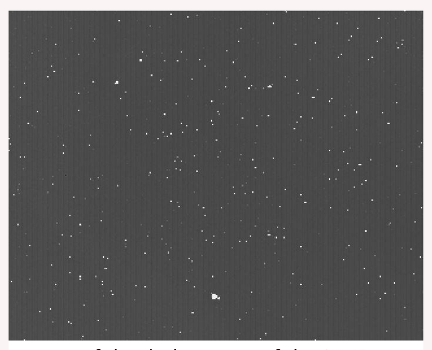
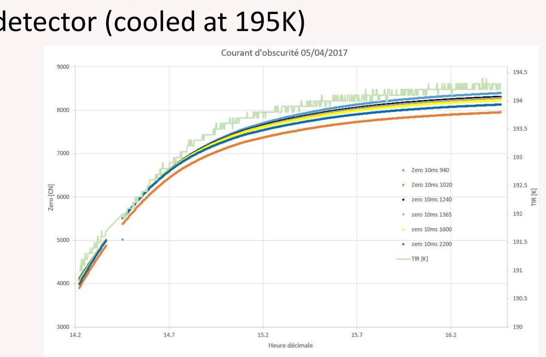


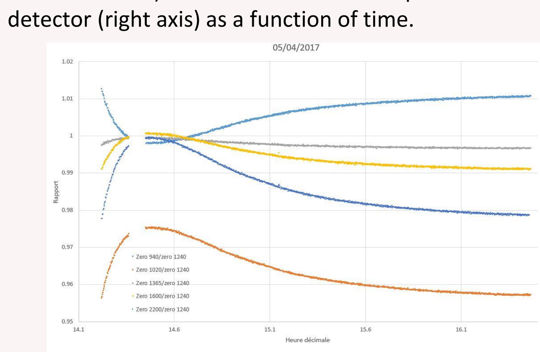
Image of the dark current of the SWIR matrix (for an integration time of 10ms)

This image highlights the presence of a lot of « dead pixels». They represent ~1.2% of the total number of pixels of the SWIR matrix.

The dark current varies as a function of the integration time (linearly which allows to deduce it from the measurement at 2 different integration times), the position of the detector in the matrix (which implies to remove it for each pixel individually) and the temperature of the SWIR detector (cooled at 195K)

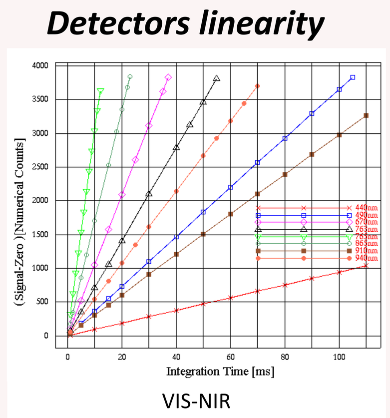


Variation of the dark current (left axis) for different spectral bands (spectral effect or effect of the emissivity of the material) and variation of the temperature of the detector (right axis) as a function of time.



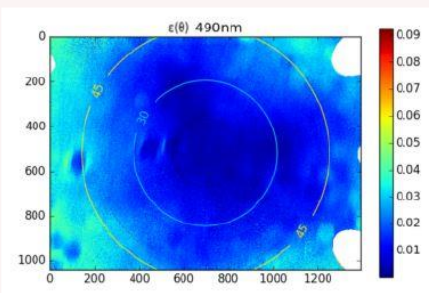
We measure the dark current only at one spectral wavelength (1240nm) and apply corrective factors.

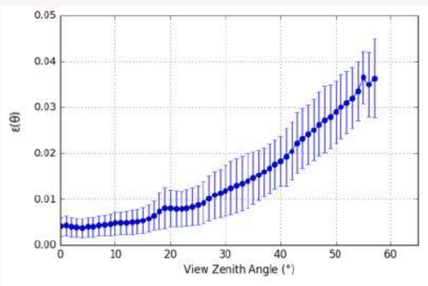
Detectors linearity



A good linearity is observed for both detectors as a function of integration time and source intensity.

Induced polarization



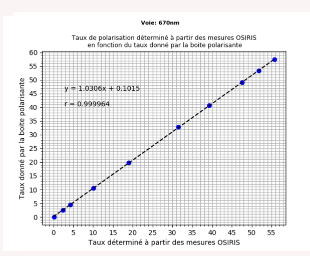


This parameter is part of the «advanced» radiometric model [9]. To characterize it, we calculate the polarization rate measured by the instrument, this one being placed in front of a uniform unpolarized source (integrating sphere).

Radiometric calibration

In absolute reflectance, is made using a calibrated (Nist traceable) integration sphere.
Accuracy: <4% for the VIS
<6% for the NIR and lower SWIR spectral bands
<10% from 1240 to 2200nm

Polarization calibration



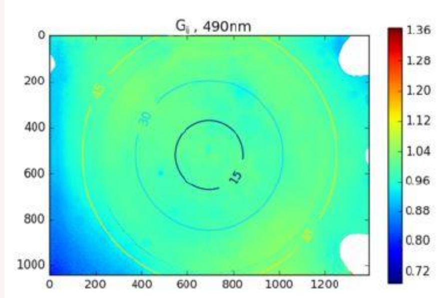
Calibration is performed against a polarizing device that allows to control the degree of linear polarization.
Accuracy of about 2-3%.

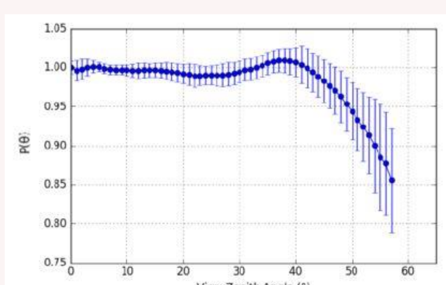
Uniformity correction coefficients Gij

To account for optics imperfections (low frequency: P(Θ)) and for inter-pixel different responses (high frequency: gij), we inter-calibrate the pixels, using a stable uniform source that covers the whole field of view of the instrument (integrating sphere).

The resulting image is then normalized by the mean signal measured in the central zone of the matrix.

For each wavelength and each pixel, a correction coefficient (Gij=P(Θ)×gij) is then applied to get a uniform image.

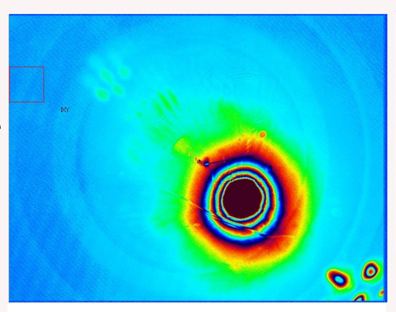




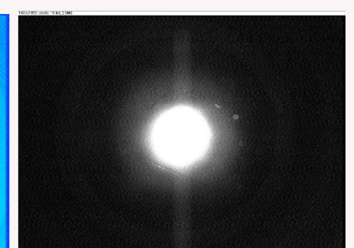
Stray light charecterization [5] *(to be continued…)*

1st and 2nd type

- Stray light of the 1st type:
  - enlargement of the image of the source
- Stray light of the 2nd type:
  - continuous background
  - « ghosts »
  - rings
- Smearing



440nm, ghosts and rings
(the source is a powerful led)



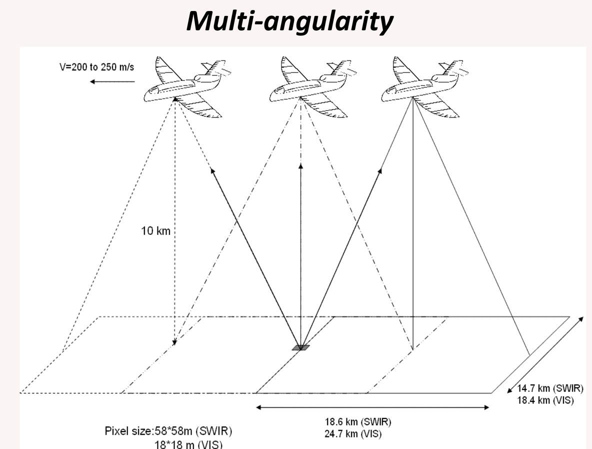
765nm, smearing and rings

4. AIRCRAFT SETUP AND RESULTS

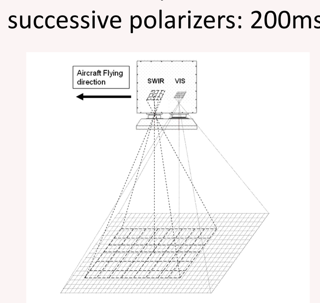
Setup on the Safire Falcon20 during the Aeroclo-sA field campaign

OSIRIS is certified for flying on the french research aircraft Falcon20 (INSU/CNRS/Météo France/CNES), operated by SAFIRE. Here the Falcon20 on the tarmac of Walvis Bay airport (Namibia).

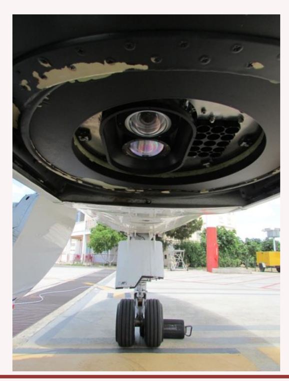
Multi-angularity



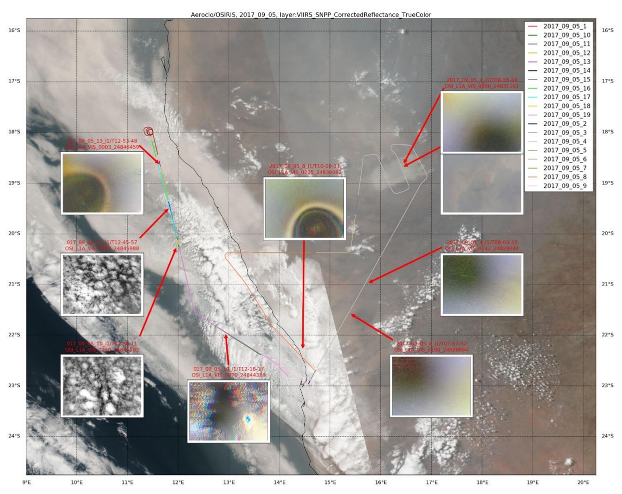
Thanks to the large FOV of the optics any target is seen under about 20 different viewing angles (depending on the acquisition setup) during the aircraft motion (with a typical aircraft height of 10km and a speed of 200-250m/s).
Acquisition duration of a complete spectral wheel (VIS-NIR and SWIR): ~ 5s. Time between the acquisition of 2 successive polarizers: 200ms



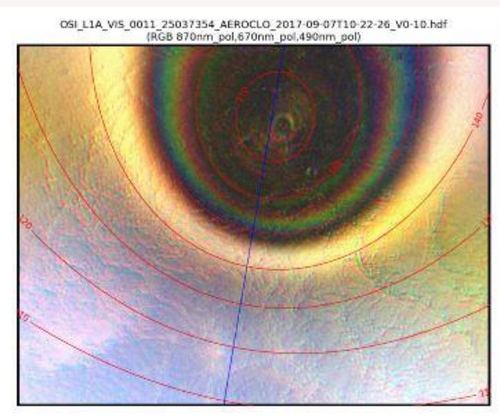
Along track orientation of the instrument



AEROCLO-sA campaign preliminary results



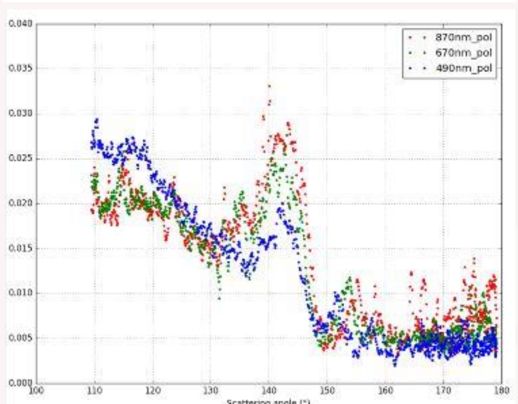
Quicklook of the 2 flights on 05/09/2017 with some typical Osiris images (bows, glints…)



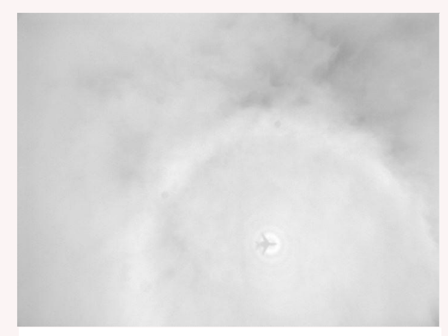
Colored composition (RGB) of polarized radiances measured at 490, 670 and 865nm.

Flight AEROCLO-sA on 05/09/2017: biomass burning aerosols above a stratocumulus (10h23 TU)

We can observe the primary rainbow (specific bright ring of polarized light reflected by liquid clouds). The usual color is modified by the presence of aerosols which strongly attenuate the cloud bow in the blue and green bands, advantaging the red one which gives it this brown appearance.



Polarized radiance measured at 490, 670 and 865nm along the transect defined above (blue line) as a function of the scattering angle.



OSIRIS unpolarized radiance at 670nm: glory optical phenomenon observed during the 07/09/2017 flight at 11h18 above a stratocumulus cloud (wave interferences of light internally refracted within small liquid water droplets).

5. CONCLUSION

We have developped an imaging radiopolarimeter for the remote sensing of aerosols and clouds. OSIRIS is an airborne prototype of the future spaceborne instrument 3MI which will be launched on the Post-EPS plateform of EUMETSAT-ESA spatial agencies in 2021. It allows to measure the total and polarized radiances and the degree of linear polarization in different narrow spectral bands between 440nm and 2200nm. Thanks to the wide field of view of the instrument and the motion of the plane, these parameters are obtained, for a same scene, under different viewing angles. For the calibration and the complete characterization of the radiometric model we need to develop specific protocols which are implemented in the laboratory. OSIRIS has recently participated to the Aeroclo-sA campaign that took place in August/September 2017 over and off Namibia. It has been mounted onboard the french research aircraft Falcon20 (Safire/CNRS/INSU/Météo-France/CNES). During this experiment, a wealth of data have been acquired under various meteorological conditions. Preliminary analyses demonstrated good performance of the instrument and illustrate again the unique capabilities of OSIRIS for cloud and aerosol characterization.

AGU, 11-15 Dec. 2017, New Orleans

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