IAA 1.9: Atmosphere aerosol remote sensing: Aerosol-UA experiment

Status report for Bremen September IAA meeting 2018


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Ukrainian satellite mission
Aerosol-UA: polarimetric investigation atmospheric aerosol

Three segments:

Satellite: ScanPol + MSIP

Data processing: Mission products

AERONET: Validation

Idea for Aerosol-UA project come from Glory experiment and APS instrument
The advantages of ScanPol polarimetry

- Polarization is a relative measurement that can be made accurately at many scattering angles.
- Polarimetric ScanPol measurements will be calibrated on the orbit.
- Polarization change with scattering angle and wavelength gives microphysics: size, refractive index and shape of aerosol.
- Synergy of scanner and imager will produce new quality of data, hopefully different from similar aerosol missions.
Geometry ScanPol and MSIP measurements

ScanPol

MSIP

Field-Of-View

MSIP and ScanPol

MSIP track
ScanPol polarimeter optical design, updated in 2018

Spectral band: 370-1610 nm, six spectral channels:

- 370 nm – tropospheric aerosol and top of clouds
- 410 nm – aerosol over ocean and surface
- 555 nm – aerosol over ocean and surface, ocean color
- 865 nm – aerosol over ocean and surface
- 1378 nm – separate cirrus clouds, stratosphere aerosol, separation of troposphere and stratosphere aerosol in case of volcanic eruption
- 1610 nm – separation surface signal from aerosol over Earth' surface

Filter ½ width 20 - 60 nm

Observable Stokes parameters: I, Q, U (0, 90, 45, 135°)

Photometric accuracy: 4%

Polarimetric accuracy: 0.15%

On-board calibration: all three Stokes parameters

ScanPol is similar to APS Glory
The scan mirrors and calibration units layout of the ScanPol instrument: red segment is scan mirrors with rotation direction shown; blue element is quarts wedges of the depolarization unit seen at $\beta_{dep}$ angle; green element is the Glan prism polarizer unit seen at $\beta_{pol}$ angle, black element is the dark unit seen between $\beta_0$ and $\beta_i$ angles; solar calibration unit seen at $\beta_s$ angle. Scanning directions along-track between scan angle $\beta_{m1} = +50^\circ$ and $\beta_{m2} = -60^\circ$ from nadir ($\beta_{nadir}$).
Equivalent polarization scheme of the ScanPol polarimeter single spectral channel: scan mirrors M1 and M2, telescopes T1 and T2, Wollaston prisms W1 and W2, intensity signals $R_{0^\circ}$, $R_{45^\circ}$, $R_{90^\circ}$, and $R_{135^\circ}$. 
Multi-Spectral Imager-Polarimeter (MSIP)

- MSIP main purposes: aerosol/clouds parameters measurements and aerosol - clouds separation
- Three spectral polarimetric channels: 410, 555, 865 nm 0°, 45°, 90°, 135° polarization each
- Two intensity channels: (1) 410, 443, 470, 490; (2) 555, 670, 865, 910 nm
- Wide FOV: 60°x60°, 770x770 km, resolution 3-6 km
- Images rate 1.5 s⁻¹ ÷ 6.0 s⁻¹ (dependent on data rate transmission), exposure <0.5 s
- Intercalibration of the MSIP using ScanPol scans, <1% accuracy
MultiSpectral Imaging Polarimeter MSIP

FOV=770x770 km

4 images on the CCD detector with polarization components 0°, 45°, 90°, 135°

Detector 1Kx1K size 15x15 nm

Polarization 0°, 45°, 90°, 135°
410 nm, 555 nm, 865 nm

Overall 20 Sp/Pol channels

Intensity
410+443+470+490 nm
555+670+865+936 nm
MSIP optical channel

- Camera lens unit
- Collimator unit
- Polarizer and prism unit
- Input lens unit
MultiSpectral Imaging Polarimeter test measurements
MultiSpectral Imaging Polarimeter test measurements

Four images size in MSIP from the dot source

DoLP errors for MSIP test field registration
ScanPol and MSIP polarimeters: adaptation to YuzhSat platform

- Calibration parts
- Scanning mirrors unit
- ScanPol unit
- Calibration units
- Interface unit
- 5 MSIP channels
Assembling of ScanPol and MSIP details - 2
Aerosol-UA dimension-dynamical model and channel of MSIP polarimeter, 2018

Dimenion-dynamical model

MSIP polarimeter channel test, and splitted image
YuzhSat orbital platform for research payload DB “Yuzhnoe”

Payload mass 10-25 kg
Platform mass - 15-30 kg
Payload power - 20-80 W
ScanPol and MSIP polarimeters onboard of YuzhSat platform

Characteristics of payload

Orbit
Type: sun-synchronous
Inclination: $\sim 98^\circ$
Altitude: $\sim 705$ km

YuzhSat platform:
Pointing accuracy: $\sim 0.1^\circ$
Total mass of scientific payload estimated: $\sim 22$ kg
Power for payload: $\leq 25$ W
Design life: $> 3$ years

Small satellite platform YuzhSat designed by Design Bureau “Yuzhnoe”
Data processing: Generalized Retrieval of Atmosphere and Surface Properties

Aerosol-UA

Laboratory

single scattering

GRASP

Surface reflectance

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MSIP data processing scheme

Input data

First processing block
- Forming
- Processing
- Calibration

Recalculating data using geometry parameters

Forming input GRASP data block
- Sorting
- Choosing
- Comparison

GRASP algorithm
Polarimetric modeling and calibration of the Aerosol-UA space mission instruments

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Introduction. We develop the numerical polarimetric models for the ScanPol polarimeter and the multi-spectral imagers of the Aerosol-UA space mission (Milievsky et al. 2016). Calibration of Instrumental polarization under realistic parameters for a large number of polarimetric missions is described. We use self-consistent way to describe polarimetric systems by using the Stokes-Mueller formalism. In the model we also include possible measurement in orientations of polarization axes of planes, finite extinction ratios of prisms, polarisation imperfections of telescopes and rarity in isotropic transmission of the internall channel. Numerical experiment has demonstrated that proposed calibration procedure for ScanPol polarimeter can have influence of instrumental effects on determination of desired Degree of Linear Polarization (DOLP) and Angle of Linear Polarization (ALP) to 0.2% and 0.1% respectively. Similar basic model has been developed for calibration of the MSIP imagier/polarimeter using ground-based calibration approach.

1. ScanPol polarimeter

ScanPol is the multi-channel scanning polarimeter with solar reflective spectral bands that measure the three Stokes parameters. The device acquires spatial, temporal, and spectral polarimetric measurements simultaneously to maximize instrumental configuration of the whole polarimeter. The position of the telescope, azimuth and elevation angles are determined by a computer program that plans out the observation strategy. The device is optimized for high-resolution imaging in the visible and near-infrared spectral regions (200-2500 nm). The device is designed to be used in a series of imaging systems that can be customized for different scientific applications.

1.1 Orbital calibration algorithm for ScanPol polarization data

The basic idea of the multi-channel scanning polarimeter with solar reflective spectral bands is to use three Stokes parameters: \( S_1 \), \( S_2 \), and \( S_3 \) that are normalized to a single target point. The device acquires spatial, temporal, and spectral polarimetric measurements simultaneously to maximize instrumental efficiency. The position of the telescope is determined by a computer program that plans the observation strategy.

\[
\begin{align*}
S_1 &= R_1 - R_2 \\
S_2 &= R_1 + R_2 \\
S_3 &= 2R_3
\end{align*}
\]

where \( R_1 \), \( R_2 \), and \( R_3 \) are the normalized Stokes parameters at each point of the observation.

1.2 Optical layout of single spectral channel of the ScanPol instrument

The optical layout of the single spectral channel of the ScanPol instrument is shown in Figure 1. The instrument comprises a multi-channel scanning polarimeter with solar reflective spectral bands that measure the three Stokes parameters. The device acquires spatial, temporal, and spectral polarimetric measurements simultaneously to maximize instrumental efficiency. The position of the telescope is determined by a computer program that plans the observation strategy.

2. MSIP polarization/Imager-Polarimeter (MSIP)

The multi-spectral imagers/Imager-Polarimeter MSIP will collect images on the slope of the atmosphere and surface in the case, where the ScanPol polarimeter will scan the sky in 3 spectral channels. The MSIP is designed to cover 3 spectral channels and two polarimetric measurements. Polarimetric channels measure Stokes parameters, while spectral channels measure reflectance. The MSIP will be designed to be used in a series of imaging systems that can be customized for different scientific applications.

2.1 Optical layout concept for MSIP Imager-polarimeter: the light passes through a set of linear polarizers, either 3 cylindrical prisms for MSIP polarimeter channels, three polarimetric and two intensity. The MSIP optical layout is shown in Figure 2. The MSIP system is designed to measure the Stokes vector components in several wavebands. The system is designed to be used in a series of imaging systems that can be customized for different scientific applications.

2.2 The optical system of MSIP (one channel). A view to input image of four polarized films with polarization angles 0°, 45°, 90°, 135°.

In Figure 2, the main elements of one MSIP channel which influence on quality of measurement of polarization parameters are shown.

3. Stokes polarization parameter

The Stokes polarization parameters are defined as the linear, circular, and elliptical polarization components of the light. Each component is defined by two angles: the polarization angle and the polarization ellipticity. The polarization angle is the angle between the polarization direction and the horizontal axis. The polarization ellipticity is the ratio of the minor to the major axis of the polarization ellipse.

4. Conclusion

The measurement of the Stokes polarization parameters is important for understanding the properties of the atmosphere and the surface. The MSIP system is designed to measure the Stokes vector components in several wavebands. The system is designed to be used in a series of imaging systems that can be customized for different scientific applications.
Conclusions and Timeline

In comparison to the several aerosol polarimetric missions planned for 2019-2021, the Aerosol-UA instrument concept at YuzhSat platform provides synergy of precision scanner-polarimeter and imager-polarimeter

1. Finalizing ScanPol calibration – end 2018
2. Construction of MSIP one channel – end 2018
3. Data processing algorithm – end 2018
4. On flight ScanPol testing – end 2019
5. MSIP construction – 2019