Research Scanning Polarimeter (RSP) Level-1D data readme

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1. Introduction

The Research Scanning Polarimeter (RSP) is a passive, downward-looking optical instrument intended to retrieve cloud, aerosol and surface reflectance properties. Observations are made in nine narrow spectral channels, whose band centers range from 410 to 2264 nm. The measurements provide the radiance and linear polarization of the observed scene within a ~105° along-track swath. Two nearly identical versions are available: RSP1 and RSP2. RSP can be mounted on a wide range of (NASA) aircraft.

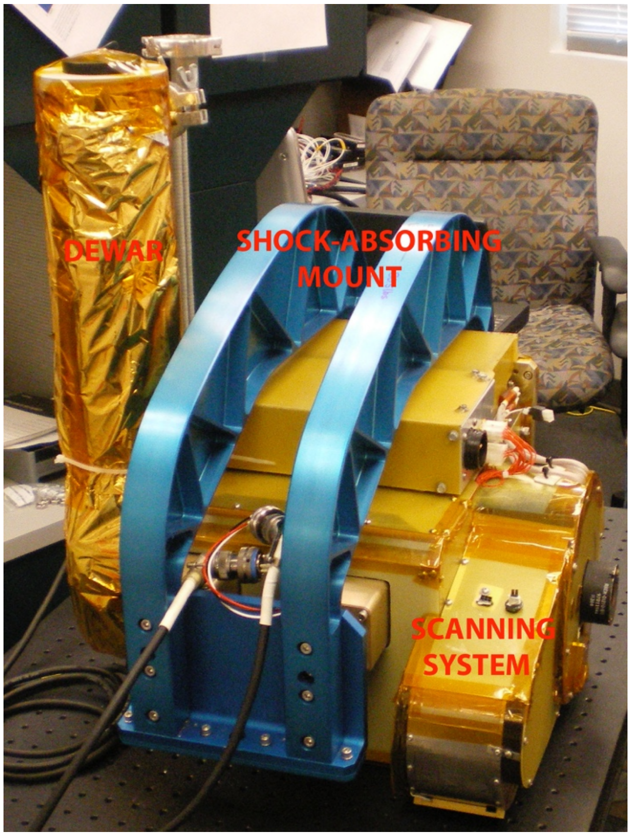


Fig. 1. One of the two NASA GISS Research Scanning Polarimeters (RSP 1), fit for integration on to the NASA Langley B200 King Air aircraft.

2. Data processing

The processing of RSP raw data to level-1C data consists of:

1. **Organizing all data into consecutive straight flight legs**: A straight leg is determined using the coordinates of the ground track. Since Earth is a spheroid, "straightness" is determined based on the distance of the projected sectors from the corresponding great circle. Once projected sectors start to veer off from the great circle, the leg is cut. A leg must contain at least 100 scans with scene data (i.e., with the door being open).

2. **Calibration**: Acquired signals are converted into normalized radiances for the three elements of the Stokes vector *I*, *Q* and *U* (see Sec. 4a below). A solar spectrum based on Thuillier et al. (1998; doi:10.1023/A:1004953215589) and Kurucz (1991; in Solar Interior and Atmosphere, Book ISBN: 9780816512294/9780816538614) as described in Lean (2000; doi: 10.1029/2000GL000043) together with a NIST traceable integration sphere calibration is used to determine normalized radiances.
3. **Geo-location**: The information from the aircraft Inertial Monitoring Unit (IMU) and RSP GPS is incorporated to project each RSP Instantaneous Field of View (IFoV), also named *sector*, to the ground. This defines the geometry of every sector.
4. **Mapping**: The processing routine searches for all sectors in adjacent scans that are projected the closest to each sector's footprint at nadir ("scene") on the surface and to other altitudes. For more information on mapping, please read the L1C quickstart guide.

3. Data quality

Optimal RSP data quality depends upon:

- **Straight and level course**. The RSP instrument is an along-track scanner and therefore benefits from minimal and stable aircraft yaw and roll. Variations in aircraft pitch can be easily corrected for by offsetting the viewing angle. When scanning spatially limited features (clouds in broken cloud fields, inhomogeneous ground, aerosol plumes, etc.), aircraft yaw significantly affects signal collection since a small feature that is viewed at nadir will not be observed at all other viewing angles. Aircraft roll affects both polar and azimuthal viewing angle and, if not limited to few degrees, causes the RSP instrument to scan uncertain locations therefore spoiling data quality. When flying over specific targets the autopilot should be disengaged, as it tends to overshoot the attitude corrections while manual controls provide provides more stable attitude.
- **Accurate records of aircraft attitude and GPS**. Time stamps should ideally be ≥1Hz. RSP mapping relies on attitude information provided by the aircraft navigation or by other onboard sensors.
- **Accurate alignment information**. The alignment of the RSP instrument with respect to attitude is generally accurately determined post-campaign using observations of reflection features on the surface, or of cloudbows and glories in atmospheric scattering.
- **Instrument cooling**. Shortwave infrared channels (1594, 1880, 2264 nm) require instrument cooling by liquid nitrogen. If liquid nitrogen is not available for a flight, data from the shortwave channels cannot be used (and are filled with fill values).
- **"Housekeeping", instrument health monitoring**. Accurate, time-stamped records of the OPTICS temperature and the TEMP ERR value are available from the instrument's interface.
- **Clear atmosphere above the aircraft**. (Cirrus) clouds or aerosol above the aircraft introduce a source of uncertainty in the determination of the incoming state of solar radiation. RSP data are not corrected for any cirrus or aerosol above the aircraft.

4. Definitions

a. Total and polarized reflectance factors

Total and polarized bi-directional reflectance factors R_I, R_Q, R_U are related to the first three components of the Stokes vector *I, Q and U* (W m^{-2} Sr^{-1}) as follows:

$$R_I = \frac{r_0^2}{\mu_0}\frac{\pi I}{F_0},$$

$$R_Q = \frac{r_0^2}{\mu_0}\frac{\pi Q}{F_0},$$

$$R_Q = \frac{r_0^2}{\mu_0}\frac{\pi U}{F_0},$$

where F_0 is the annual average extraterrestrial irradiance (W m^{-2}), r_0 (dimensionless) is the solar distance in AU, and μ_0 is the cosine of the Solar Zenith Angle (SZA) (Schaepman-Strub et al. 2006; doi:10.1016/j.rse.2006.03.002). Note that $1/\pi$ stands for the BRDF (Sr^{-1}) of a Lambertian surface; hence, reflectance factors R_I, R_Q, R_U are unitless. RSP L1C and L1B data files provide unitless normalized radiances

"*Intensity*" $= \frac{\pi I}{F_0}$,

"*Stokes_Q*" $= \frac{\pi Q}{F_0}$,

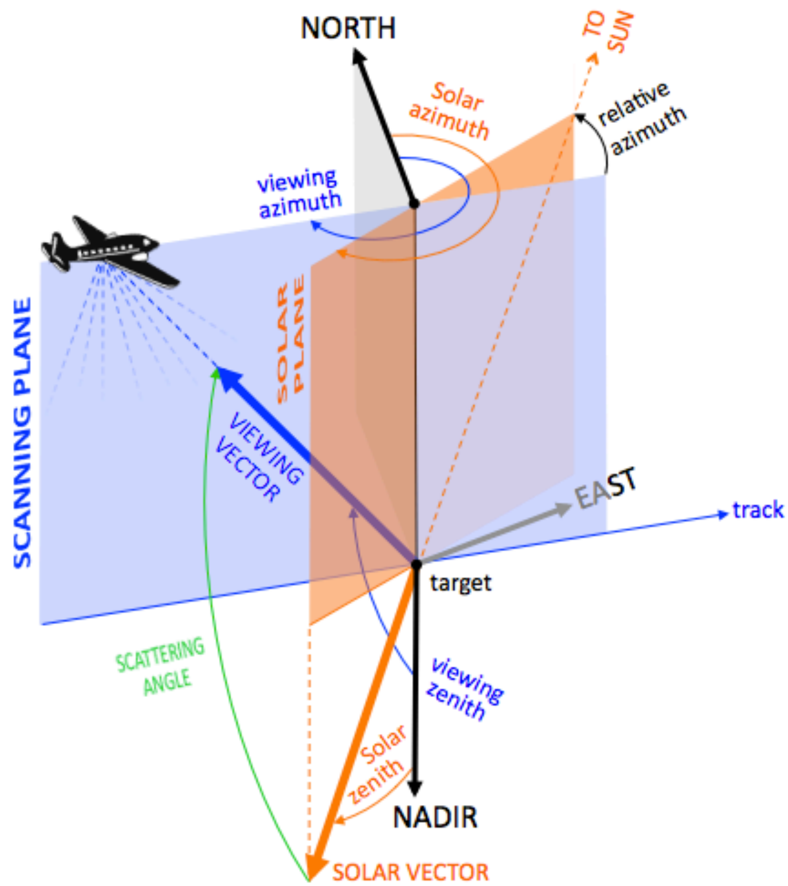
"*Stokes_U*" $= \frac{\pi U}{F_0}$.

Thus, to convert these normalized radiances to reflectance factors R_I, R_Q, R_U they have to be divided **by μ_0 and multiplied by r_0^2**. The solar zenith angle and solar distances are provided in the data file.

Note that the RSP design yields two independent measurements of total intensity provided by two redundant telescopes, and stored in the data file as *Intensity_1* and *Intensity_2*. Generally, *the average of both should be used as intensity*.

b. Solar and viewing geometries

The viewing geometry is defined with respect to a right-handed reference system where the x-axis is due north, the y-axis is due east and the z-axis points at nadir (see figure below). The viewing vector, shown in blue for one of the RSP forward sectors, points from the target to RSP along the axis of the Instantaneous Field of View (IFoV). According to this reference system, solar zenith angles are found in the [0°, 90°] range (0˚ for overhead sun and 90˚ when the Sun is at the horizon), and viewing zenith angles in the [90°, 180°] range (**the nadir-looking direction corresponding to a viewing zenith angle of 180˚).** By subtracting the viewing azimuth angle from the solar azimuth angle (both referenced clockwise from due north and varying in the [0°, 360°) range), one obtains the *relative* azimuth angle, which varies in the (-180°, 180°] range. For example, when flying towards the Sun as in the figure, the relative azimuth of the forward RSP sectors is close to 0°, and that of the aft sectors (move the plane along the track past the target) is close to 180° or -180° depending on whether the Sun is on the left or on the right.



5. Rotation into scattering plane

For some applications, it is helpful to convert (or 'rotate') the polarized radiances as were they observed in the scattering plane. In the case of single scattering, the U component of the Stokes vector is zero after rotation. Polarized reflectances rotated into the scattering plane are used for the retrievals of droplet size distribution by matching these observations directly to P12 elements of scattering phase matrices corresponding to various drop size distributions. The L1B files contain arrays in the GEOMETRY folder to perform this rotation, namely Sin_Rot_Scatt_Plane and Cot_Rot_Scatt_Plane. For observed values of Q and U, the rotated values Q_rot and U_rot are obtained as

Q_rot = Cot_Rot_Scatt_Plane * Q + Sin_Rot_Scatt_Plane * U
U_rot = Sin_Rot_Scatt_Plane *Q - Cot_Rot_Scatt_Plane * U

6. Wavelengths

Approximate band centers (bandwidths) are 410 (30); 470 (20); 555 (20); 670 (20); 865 (20); 960 (20); 1590 (60); 1880 (90); 2264 (120) nm. Spectral response functions for these wavelength bands can be obtained at:
https://data.giss.nasa.gov/pub/rsp/RSP_Utilities/Responses/

7. Data structure

The hdf file names are structured as this example:
CAMP2EX-RSP1-L1B_P3B_20190803155302_R2

The various parts of the filename are explained below

- CAMP2EX: Indicating these data are collected during the CAMP2Ex campaign
- RSP1: RSP1 collected this data, as opposed to RSP2
- L1B: Denoting level 1B data
- P3B: RSP was mounted on the P-3 aircraft
- 20190803155302: UTC date (yyymmdd) and time (hhmmss) at the start of the flight leg
- R2: Processing algorithm version

The hdf file contents is organized in 5 folders (‘groups’), namely

- DATA: Normalized radiances, cloud flag and water vapor data
- GEOMETRY: Solar and viewing geometries, target height and location
- PLATFORM: Aircraft and flight path information, land/water mask, solar distance
- CALIBRATION: Instrument calibration settings
- ENGINEERING: Housekeeping, instrument health information

The data structure and variables are listed in the appendix.