

The PRISM and PICARD Level-1C (L1C) Dataset for PACE-PAX

Author:

Kerry Meyer, *NASA Goddard Space Flight Center, Greenbelt, Maryland*

Algorithm/Technical Contributions:

G. Thomas Arnold, *Science Systems and Applications Inc., Lanham, Maryland*

Galina Wind, *Science Systems and Applications Inc., Lanham, Maryland*

Instrument Teams:

PRISM (JPL): David Thompson, John Chapman, Holly Bender, Regina Eckert

PICARD (NASA ARC): Tom Ellis, Gary Hoffman, Alok Shrestha, Nik Gibson, James Jacobson

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SUMMARY OF PRODUCT VERSIONS

Release 1 (R1)

- Fixes bug in PRISM/PICARD physical co-location algorithm that in some cases did not identify the nearest-neighbor PRISM pixel, resulting in those co-locations having center PRISM pixels offset from the center of the PICARD IFOV (though are still within the PICARD IFOV). Minor impact generally, though non-trivial changes in spatially averaged PRISM spectral reflectance are found in heterogeneous scenes.

Release 0 (R0)

- Initial product release.

1 INTRODUCTION

The PACE Post-Launch Airborne eXperiment (PACE-PAX), a NASA airborne field campaign based out of Armstrong Flight Research Center (AFRC) at Edward's Air Force Base in southern California during September 2024, was conducted to obtain a sub-orbital dataset to be used for calibration/validation activities for the PACE observatory. PACE-PAX included two airborne platforms – NASA's high-altitude ER-2 and the Naval Research Laboratory's Twin Otter – along with a host of land and sea-based assets. The instrument payloads on these platforms included an extensive suite of remote sensing and in situ instrumentation that provide both proxy observations analogous to the sensors on the PACE observatory and benchmark datasets for PACE ocean, atmosphere, and land remote sensing retrieval algorithm evaluation.

Among the remote sensing instrumentation on the ER-2 were two shortwave (SW) spectrometers that, coupled together, provide high spatial resolution imagery covering a spectral range analogous to the PACE Ocean Color Imager (OCI). Specifically, the Portable Remote Imaging Spectrometer (PRISM) was selected to cover OCI's spectrally contiguous UV/VIS/NIR observations, and the Pushbroom Imager for Cloud and Aerosol Research and Development (PICARD) was selected to cover OCI's narrowband NIR/SWIR channels. To facilitate the implementation of OCI algorithms on coupled PRISM/PICARD observations, a merged Level-1C (L1C) data product has been developed that provides physically co-located and spatially (PRISM into PICARD fields-of-view) and spectrally (PICARD observations into OCI narrowband channels) averaged top-of-atmosphere reflectance along with geolocation, angles, and other associated datasets.

This document provides details on the L1C methodology and data files, including brief overviews of the PRISM and PICARD sensors (Section 2), descriptions of the physical co-location and spatial/spectral averaging approaches (Section 3), and a catalog of the L1C file contents (Section 4).

2 INSTRUMENT DETAILS

Both PRISM and PICARD are pushbroom grating spectrometers that provide contiguous radiance observations across parts or most of the shortwave spectrum. Collectively, their spectral coverage is sufficient to serve as an analog for the entirety of the OCI spectral channels, including both the UV/VIS/NIR spectrometer and the NIR/SWIR narrowbands. **Fig. 1** shows radiance and reflectance spectra from both sensors for a marine stratocumulus scene observed on the 4 September 2024 PACE-PAX science flight (21:13-21:54 UTC flight track) off the coast of California (true color RGB from PICARD at top).

The key operating characteristics of both PRISM and PICARD that drive the L1C co-location and data merging approach are listed in **Table 1**, along with selected relevant characteristics of

PACE OCI. For PACE-PAX, PRISM operated in the ER-2 nosecone, while PICARD operated in the forebody of the right wing-mounted superpod.

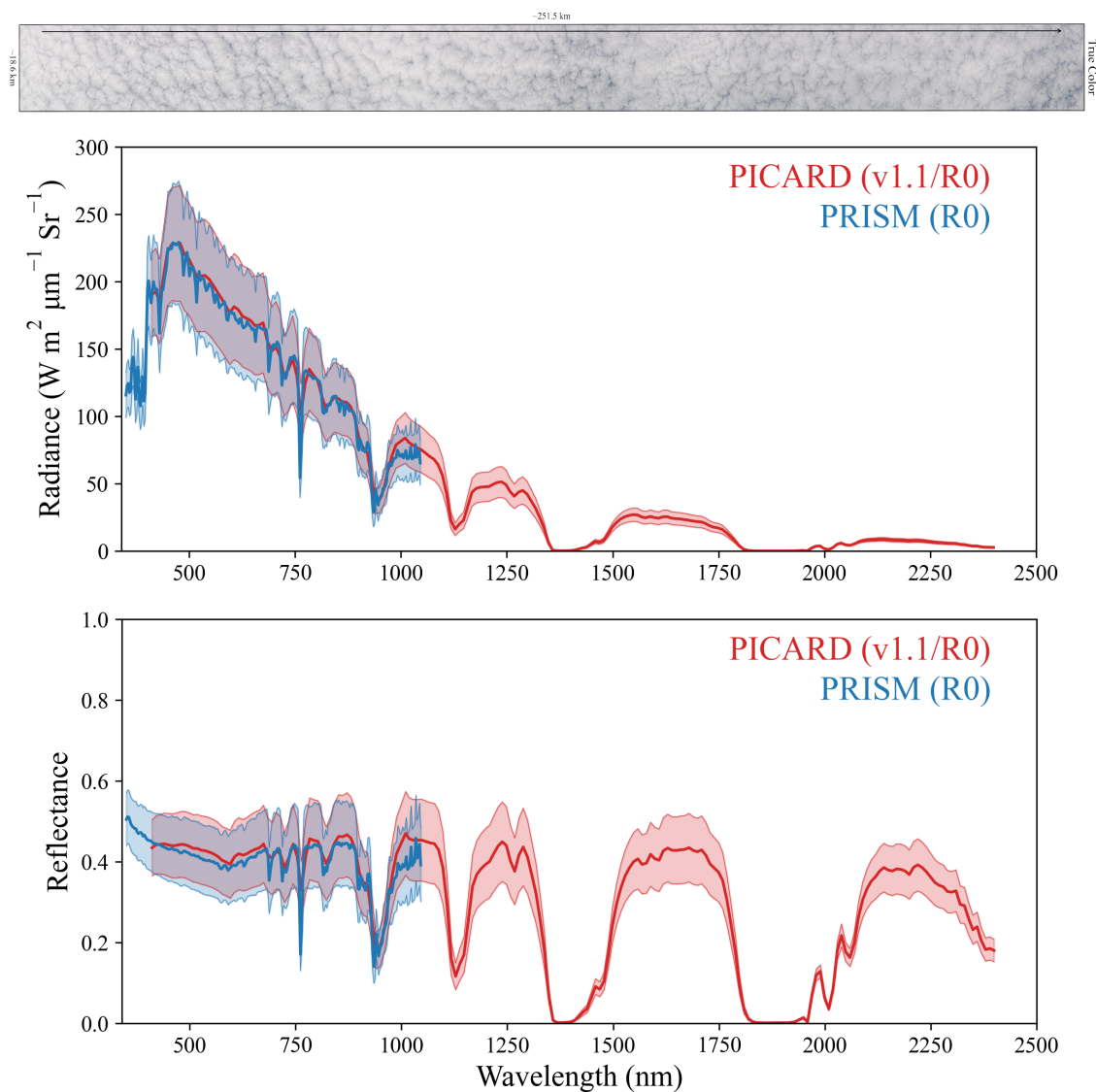


Fig. 1. Example radiance and reflectance spectra from PRISM (blue lines/shade) and PICARD (red lines/shade) for a marine stratocumulus scene observed during the 4 September 2024 (21:13-21:54 UTC flight track) PACE-PAX science flight. The RGB from PICARD for this flight segment is shown at top. The bolded lines denote the mean radiance/reflectance from the near-nadir (view zenith angle $< 10^\circ$) pixels from each imager over the full length of the segment, while the thin lines plus shading denote $\pm 1\sigma$ (standard deviation).

Table 1: Key PRISM, PICARD, and PACE OCI operating characteristics. Notes: ¹ Estimates at ground for a 65 kft (20 km) ER-2 flight altitude.

Instrument Parameter	PRISM	PICARD	OCI
Swath FOV	30.7°	50°	-
Swath width	11 km ¹	18.4 km ¹	-
Instantaneous FOV	0.97 mrad	2.1 mrad	-
Pixel spatial resolution	19.4 m ¹	42 m ¹	1.2 km
Pixels per scan line	608	414	-
Spectral range (nm)	350-1050	400-1000 (VNIR camera), 1000-2400 (SWIR camera)	315-606 (“blue” CCD), 600-895 (“red” CCD); narrowbands at 940, 1038, 1250, 1378, 1615, 2130, 2260
Spectral channels	246	62 (VNIR), 140 (SWIR), 204 Total	119 (“blue” CCD), 163 (“red” CCD), 9 (NIR/SWIR narrowbands)
Spectral resolution (nm)	~3 nm	~10 nm	~2.5 nm

3 L1C METHODOLOGY

The instrument characteristics shown in Table 1 highlight differences between PRISM and PICARD (and OCI) that have important implications on the approach taken for merging their respective L1B datasets into an L1C data file. These include differences in pixel size (roughly 19.4 m for PRISM versus 42 m for PICARD) and swath width that necessitate geographically co-locating and spatially averaging PRISM into the coarser-resolution and wider swath PICARD. In addition, spectrally averaging the PICARD observations into the OCI NIR/SWIR narrowband channels using OCI’s relative spectral responses (RSRs) also is required. Details on these approaches taken to create the PRISM/PICARD L1C file are provided below, along with definitions regarding the reported L1C datasets.

3.1 Definitions

PACE OCI fundamentally measures the shortwave spectral reflectance of the Earth/atmosphere system (e.g., land/ocean surfaces, clouds, aerosols, etc.), a unitless quantity that is easiest understood as the fraction of the incoming solar radiation, estimated via use of onboard solar diffusers, that is reflected by the Earth/atmosphere system at the angle observed by the sensor. Conversely, both PRISM and PICARD, without having the benefit of direct sun observations, inherently measure reflected solar spectral radiance ($\text{W m}^{-2} \mu\text{m}^{-1} \text{Sr}^{-1}$). Because the PACE OCI L1B files report reflectance rather than radiance, the PRISM/PICARD L1C files for PACE-PAX report the same quantity, with their respective spectral radiance observations converted to reflectance using appropriate assumptions on the incoming solar irradiance at TOA (note: the use

of solar spectral irradiance at TOA, rather than at flight level, likely introduces some minor errors in the reflectance calculations for atmospheric absorption regions).

More specifically, the reflectance $R(\lambda)$ observed at sensor at wavelength λ is defined as

$$R(\lambda) = \frac{\pi I(\lambda)}{\mu_0 F_0(\lambda)} \quad (1)$$

where $I(\lambda)$ is the measured spectral radiance ($\text{W m}^{-2} \mu\text{m}^{-1} \text{Sr}^{-1}$) at wavelength λ , $F_0(\lambda)$ is the incoming solar spectral irradiance (also $\text{W m}^{-2} \mu\text{m}^{-1} \text{Sr}^{-1}$) at wavelength λ , and μ_0 is the cosine of the solar zenith angle. Note that $F_0(\lambda)$ is scaled to account for the Earth-Sun distance at the observation date and time. To maintain consistency with the calibration benchmarks used by the respective instrument teams, the F_0 dataset used for PRISM comes from Fontenla (Fontenla et al., 2011) and for PICARD comes from TSIS (Coddington et al., 2021); both F_0 datasets, pre-scaled for Earth-Sun distance, are provided within the L1C file.

3.2 Physical Co-Location and Spatial Averaging of PRISM into PICARD FOVs

Despite operating on the same aircraft, the pixel-level instantaneous fields-of-view (IFOVs) of PRISM and PICARD do not perfectly align – i.e., there are small along-/across-track offsets between the center of each PICARD pixel and the nearest PRISM pixel. Furthermore, the IFOV of PRISM is smaller than that of PICARD – 0.97 mrad, or roughly 19.4 m pixel size, for PRISM, and 2.1 mrad, or roughly 42 m pixel size, for PICARD (see Table 1). Therefore, a spatial averaging scheme is applied to the PRISM pixels that roughly fall within each PICARD pixel.

Fig. 2 shows a schematic approximating the PRISM (blue circles) and PICARD (red circle) IFOV sampling in relation to each other. While the schematic is for illustrative purposes only, the relative sizing of the circles shown is proportional to the respective sensor IFOVs such that it can inform on the physical co-location and spatial averaging approach used for the L1C. Note that multiple PRISM pixels overlap the PICARD IFOV, though most only partially and to varying extents. Thus, the PRISM aggregation into the PICARD IFOV employs a weighted averaging approach using only a subset of the overlapping pixels.

The process starts with physical co-location, i.e., finding the PRISM pixel whose center latitude/longitude is closest to the PICARD pixel center latitude/longitude using the great circle (haversine) distance between pixels. The spatial averaging then considers only this nearest-neighbor pixel, denoted P in Fig. 2, and the immediately adjacent pixels in the along-/across-track directions, denoted S_1 - S_4 in Fig. 2. To approximate a realistic spatial response (or point spread function), a weighted averaging scheme is employed, namely:

$$\overline{R_{PRISM}}(\lambda) = 0.5 \cdot R_P(\lambda) + \sum_{n=1}^4 0.125 \cdot R_{S_n}(\lambda) \quad 2$$

Using these weightings, the nearest-neighbor PRISM pixel P contributes 50% of the signal and the four adjacent pixels (S_1 - S_4) cumulatively contribute the other 50%.

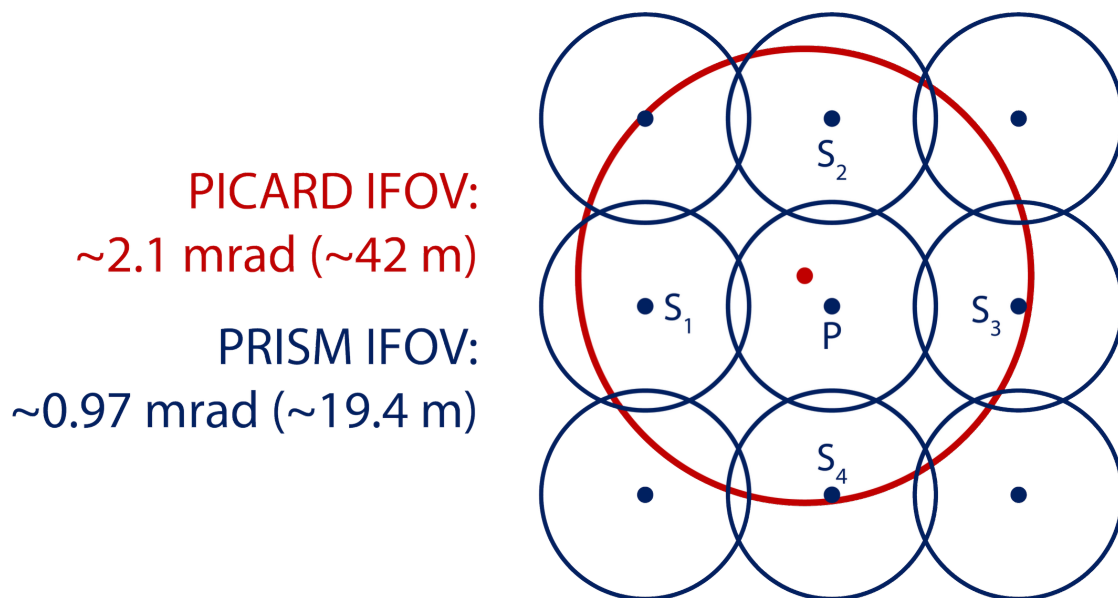


Fig. 2. Schematic illustrating the instantaneous fields-of-view (IFOVs) of PRISM (blue circles) in relation to the coarser PICARD (red circle). Note that this is for illustrative purposes only, i.e., actual pixel center locations may differ, though the circle sizes are drawn proportional to the IFOV difference between the two imagers. The PRISM pixels that are used for spatially averaging into the PICARD IFOV are denoted P and S_1 - S_4 .

Additional considerations include the narrower swath width of PRISM compared to PICARD (11 km vs 18.4 km, respectively; see Table 1), as well as differences in temporal data coverage dictated by the different operating principles employed by the two imager teams (e.g., science line data acquisition start/stop times) and sporadic instrument issues affecting the data acquisition of either imager that inevitably arise during field campaigns. Given these differences, and acknowledging the need for the coarser spatial resolution PICARD to define the IFOV/pixel size, the spatial/temporal coverage of the L1C datasets therefore is defined by the swath width and data availability of PICARD. Thus, the PRISM/PICARD L1C files directly correspond to the PICARD L1B files in terms of flight segment temporal coverage and spatial dimensions, though PRISM data may at times not be available for all or parts of the PICARD flight segments. Summary plots of data acquisition segments from both imagers and temporal overlap for each PACE-PAX science flight are provided in Appendix A. **Fig. 3** shows example L1C imagery from a 4 September 2024 science flight segment, with the PRISM true color RGB (469, 548, 665 nm, co-located and spatially averaged to the PICARD IFOVs) plotted over the grayscale PICARD 862 nm reflectance, highlighting the swath width differences between the two imagers.

3.3 Spectral Selection and Averaging for OCI Channel Analogs

As shown in Table 1, OCI provides contiguous sampling across the UV/VIS and into the NIR, namely 315-895 nm, along with seven narrowband channels in the NIR/SWIR. To create an appropriate analog for these OCI spectral observations, the L1C includes PRISM data at native

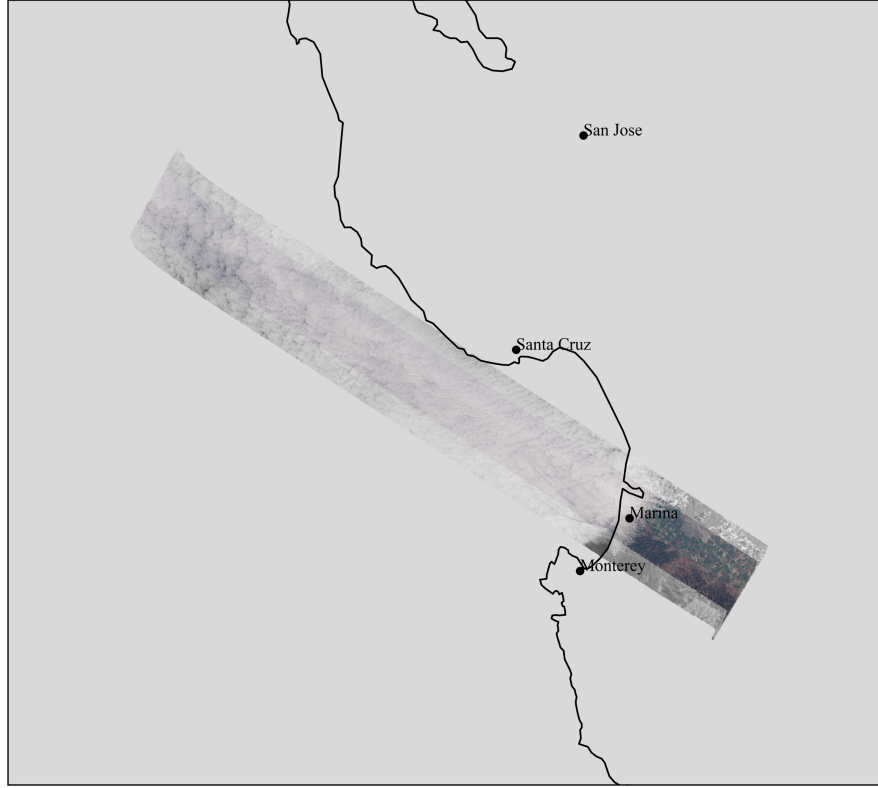


Fig. 3. Example L1C imagery from PICARD and PRISM for a flight segment on 4 September 2024 (~22:09-22:20 UTC) over Monterey Bay and the adjacent coast of California. Here, the PICARD reflectance at 862 nm is shown as grayscale with the PRISM true color RGB (469, 548, 665 nm) overplotted. Note that the PRISM data have been physically co-located and spatially averaged into the PICARD IFOVs.

spectral resolution from 350-895 nm (covering the “red” and most of the “blue” OCI CCDs) and PICARD data averaged over the OCI NIR/SWIR narrowband relative spectral responses (RSRs). Also included in the L1C are two VIS/NIR PICARD channels, centered at 665 and 862 nm, that provide instrument consistency with the PICARD-derived NIR/SWIR L1C narrowband channels to facilitate use by OCI algorithms that use those spectral regions simultaneously (e.g., cloud optical properties, etc.). **Fig. 4** shows a schematic of the OCI spectral analogs (gray dashed lines and shaded regions, including the OCI NIR/SWIR narrowband RSRs) and their mapping to the PRISM and PICARD spectral observations, plotted over the PRISM/PICARD radiance spectra from Fig. 3.

For the OCI analog reflectance $R(\lambda_{\text{NIR/SWIR}})$ at the narrowband NIR/SWIR central wavelengths $\lambda_{\text{NIR/SWIR}}$, the PICARD contiguous spectral reflectance observations, $R_{\text{PICARD}}(\lambda_n)$, are averaged over the OCI RSRs with additional weighting by the solar spectral irradiance $F_0(\lambda_n)$:

$$R(\lambda_{NIR/SWIR}) = \frac{\sum \lambda_n R_{PICARD}(\lambda_n) \cdot RSR_{NIR/SWIR}(\lambda_n) \cdot F_0(\lambda_n)}{\sum \lambda_n RSR_{NIR/SWIR}(\lambda_n) \cdot F_0(\lambda_n)} \quad 3$$

where λ_n is the PICARD spectral channel central wavelength.

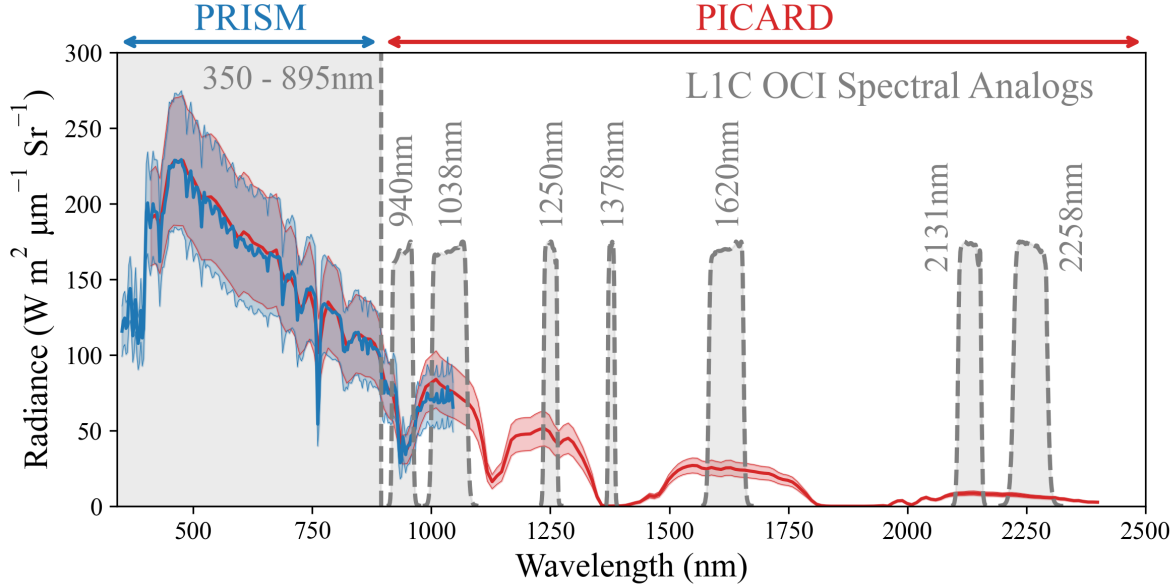


Fig. 4. Schematic of the L1C spectral mapping of the PRISM and PICARD imagers to OCI spectral analogs. PRISM provides the contiguous UV/VIS observations (350-895 nm), while PICARD observations are spectrally averaged into the OCI NIR/SWIR relative spectral responses (RSRs; dashed gray curves).

4 L1C FILE DETAILS

The L1C files are stored in netCDF-4 format, with each file corresponding to a PICARD L1B science data acquisition line. The file naming convention is as follows:

PACEPAX-PRISM-PICARD-L1C_ER2_YYYYMMDDTHHMMSS_HHMMSS_RR.nc

- YYYYMMDDTHHMMSS: science data line date and acquisition start time in ISO8601 time format, where YYYY is the four-digit year, MM is the two-digit month, DD is the two-digit day; T indicates the time follows this character; and HHMMSS are the two-digit hour, two-digit minutes, and two-digit seconds, respectively
- HHMMSS: second instance of time, corresponding to the science data line acquisition stop time
- RR: data revision number, e.g., RA for Revision A, R0 for Revision 0, etc.

The contents of the L1C files are shown in Tables 2-4 for the three variable “groups,” namely aircraft_platform (**Table 2**), geolocation_data (**Table 3**), and observation_data (**Table 4**). The variable (dataset) names and descriptions within each group are provided. Further details on each

variable, including units, valid range, etc., can be found in the metadata for each variable inside the file itself.

Table 2: aircraft_platform group

Dataset Name	Description
platform_asl	ER-2 GPS altitude above mean sea level (meters)
platform_date	Calendar year, month, and day
platform_heading	ER-2 heading angle (degrees)
platform_lat	ER-2 GPS latitude (degrees)
platform_lon	ER-2 GPS longitude (degrees)
platform_pitch	ER-2 pitch angle (degrees)
platform_roll	ER-2 roll angle (degrees)
platform_utc	ER-2 UTC time (seconds from start of day)

Table 3: geolocation_data group

Dataset Name	Description
latitude	Pixel-level latitude, from PICARD (degrees)
longitude	Pixel-level longitude, from PICARD (degrees)
sensor_azimuth_angle	Pixel-level sensor azimuth angle, from PICARD (degrees)
sensor_zenith_angle	Pixel-level sensor zenith angle, from PICARD (degrees)
solar_azimuth_angle	Pixel-level solar azimuth angle, from PICARD (degrees)
solar_zenith_angle	Pixel-level solar zenith angle, from PICARD (degrees)

Table 4: observation_data group

Dataset Name	Description
fwhm_vis_PRISM	Full width at half maximum (FWHM) for PRISM vis channels
r_swir_PICARD	Top-of-atmosphere (TOA) SWIR narrowband spectral reflectance from PICARD, spectrally averaged over the OCI spectral response functions
r_vis_PICARD	Top-of-atmosphere (TOA) spectral reflectance from PICARD at select VIS/NIR channels relevant for cloud optical property retrievals
r_vis_PRISM	Top-of-atmosphere (TOA) UV/VIS/NIR spectral reflectance from PRISM, spatially averaged within PICARD pixels
solarirradiance_swir_PICARD	SWIR narrowband solar spectral irradiance from TSIS for PICARD, spectrally averaged over the OCI spectral response functions and orbit corrected
solarirradiance_vis_PICARD	VIS/NIR solar spectral irradiance from TSIS for PICARD at the select channels relevant for cloud optical property retrievals, orbit corrected
solarirradiance_vis_PRISM	UV/VIS/NIR solar spectral irradiance from Fontenla for PRISM, sensor weighted and orbit corrected
wavelength_swir_PICARD	Center wavelengths of SWIR narrowband spectral channels derived from PICARD
wavelength_vis_PICARD	Center wavelengths of VIS/NIR cloud spectral channels sampled from PICARD
wavelength_vis_PRISM	Center wavelengths of UV/VIS/NIR spectral channels from PRISM

REFERENCES

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- Fontenla, J. M., Harder, J., Livingston, W., Snow, M., & Woods, T. (2011). High-resolution solar spectral irradiance from extreme ultraviolet to far infrared. *Journal of Geophysical Research: Atmospheres*, 116(D20). <https://doi.org/10.1029/2011JD016032>

APPENDIX A: PRISM/PICARD DATA ACQUISITION SEGMENTS AND TEMPORAL OVERLAP

Plots of the temporal data acquisition segments for PRISM (blue lines) and PICARD (red lines), along with the temporally overlapping segments (gray lines), are shown here for each PACE-PAX science flight. As discussed in Section 3.2, the PRISM/PICARD L1C file segments and temporal coverage are defined by the data acquisition of PICARD (and the availability of the PICARD L1B files). Thus, the red lines here denote the L1C temporal coverage for each flight, and the gray lines denote the periods when the L1C files contain observational data from both imagers.

