Calibration Description: OSIRIS-REX Visible and Infrared Spectrometer (OVIRS)
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Changes: updated calibration steps for split pipeline processing (calv2)

Introduction

OVIRS is a point spectrometer that operates from 0.4 to 4.3 microns. All pixels see the same 4-mrad spot projected onto the target. The spectrum is made using 5 linear variable filter segments to cover the full spectral range. Each filter segment spans 512 pixels in the wavelength dimension. Readout is done over a predetermined number of rows, or region of interest (ROI) in each filter, typically 30 - 32 rows per segment, and they are not required to be contiguous. With dark pixel rows, a full frame is 512x180 pixels. Typically, the pixels are summed onboard in SuperPixel (SP) mode to reduce data volume. The normal operating mode sums 8 pixels (also called SP=8) of the same wavelength, after removing any known bad pixels. The other most common mode is SP=2, where two pixels are summed on board; this allows for fewer sums that may be corrupted by bad pixels. SP=8 results in 512x23 pixels, including 3 dark rows, in the Level 0 product, and SP=2 results in 512x78 pixels, including 3 dark rows. Level 2 data arrays will be 512x20 for SP=8 and 512x75 for SP=2.

The ground calibration pipeline converts the Level 0 data to physical units. Several processing and calibration steps are performed on the raw data to produce a Level 2 spectrum:

1. Subtract the average background (dark current) level
2. Multiply by the bad pixel map to adjust the sums for the numbers of pixels included in the SP.
3. Calculate and remove out-of-band contribution
4. Convert to radiance units
5. Screen for 3-sigma outliers

Calibrated data products produced by this calibration pipeline are indicated with a filename containing the filed “calv2”.

Description of the OVIRS Pipeline is provided in the SPOC-OVIRS Interface Control Document, UA-ICD-9.4.4-1004. Derivation of the calibration files is described in the instrument description paper (Reuter et al. 2018, *Space Science Reviews* **214**, 54, DOI:10.1007/s11214-018-0482-9), the first inflight calibration paper (Simon et al. 2018, *Remote Sensing* **10**, 1486, DOI: 10.3390/rs10091486), and final in-flight calibration paper (Simon et al. 2021 Journal of Astronomical Telescopes, Instruments and Systems 7, 020501. DOI: 10.1117/1.JATIS.7.2.020501)

1. Background Subtraction

Background levels are dependent on the detector temperature. Blocks of deep space spectra in the same SP mode, similar detector temperature, and acquired close in time, are used to calculate the average background level (Deep Space Calibration File), $B_{i,j}$. The deep space block is screened for outliers to avoid adding noise. Corrected counts, $C_{i,j}$, are produced by subtracting the average background frame.

$$C_{i,j} = DN_{i,j} - \frac{1}{n}\sum_{1}^{n} B_{i,j}$$

2. SuperPixel Sum Adjustment

As pixels have been summed onboard to create SP sums, but are not averaged, the counts at Level 0 do not reflect the actual count values. To determine the true data number, $C_{i,j}$ are corrected for the number of pixels using the corresponding bad pixel map ($BPM_{i,j}$). In flight, all science data use the appropriate 115K BPM, an original version through Sept. 18, 2019, and a new version for all dates thereafter.

$$C_{i,j} = C_{i,j} * \frac{8}{BPM_{i,j}}$$

3. Out-of-Band Correction

The next correction is to remove out-of-band signal, long wavelength photons that appear as signal in the short wavelength segments. This is performed in multiple steps:

- Convert $C_{i,j}$ to photon radiance, $P_{i,j}$, in photon/s/cm^2/sr/um, by multiplying b the radiometric coefficient, $R_{i,j}$ and dividing by integration time, t, and photon energy, $E_{i,j}$:

$$E_{i,j} = h * \frac{c}{\lambda_{i,j}}$$

Where h is the Planck constant, c is the speed of light and $\lambda_{i,j}$ is the wavelength of pixel (i,j):

$$P_{i,j} = \frac{R_{i,j} * C_{i,j}}{t * E_{i,j}}$$

Note: t is dependent on the SP mode and "drop frames" commanded, t =.3034*(df+1) for SP=8 and t =.3034*(df+1)*156./180. for SP=2.

- Integrate photon radiance from 2.8 to 3.9 um, S, using trapezoidal rule. Note: here the rows, j, to sum over are those in the 3rd filter segment (rows 53-84 in a full frame, row 19 to 33 in SP=2, and rows 8 to 11 in SP=8, before dark pixel rows are removed, and columns, i, are 111 to 253):

$$S = \iint P_{i,j}\, di\, dj$$

- Multiply sum by Out-of-Band Correction File, $OB_{i,j}$, for each pixel, convert back to counts, and subtract out-of-band counts from background-subtracted counts for final corrected counts, $CO_{i,j}$:

$$CO_{i,j} = C_{i,j} - S * OB_{i,j} * t$$

4. Radiance Unit Conversion

Corrected counts are converted to radiance units, $I_{i,j}$, in W/cm^2/sr/micron by first dividing by exposure time, t, to get counts/s. They are then multiplied by the Radiometric Conversion File, $R_{i,j}$:

$$I_{i,j} = \frac{CO_{i,j}}{t} * R_{i,j}$$

5. Outlier Screening

Although known bad pixels are removed in the earlier steps, some pixels may be affected by cosmic rays or occasionally do not calibrate properly. To prevent these pixels from affecting the spectra at higher processing levels, we screen for 3-sigma outliers. This is done by calculating a running mean and standard deviation of all pixels in a column +/- 2 columns, skipping the known bad pixels. An iterative approach loops through the check up to 3 times, and sets a minimum standard deviation based on the photon noise level (from the space file) and read noise. Outlier pixels more than 3-sigma from the mean are set to zero and marked in the data quality bit.

Data notes:

- Due to how the instrument is commanded, the first spectrum in each new observation block is likely corrupted.
- Data acquired when detector is above nominal operating temperature may show residual calibration and out-of-band mismatches, particularly at filter boundaries.
- A few spectra show saturation when the detector was very warm, and the surface very hot.
- Spectra acquired with an underfilled field of view (fill_fac <1) will have artifacts, as will spectra that cross sharp brightness boundaries (primarily at the limb)
- Note that the radiometric and OOB calibration files have array sizes of 512xLX2. This array format is the result of a previous generation of calibration. In all cases, use the first array for processing (although both arrays should be identical.)