BASIC L1A All-Frames

USER GUIDE

FEBRUARY 2021

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1. DESCRIPTION

The SkySats capture up to 50 frames per second per Collect. The All-frames asset includes all of the originally captured frames in a Collect, uncalibrated and in a raw digital number format. Delivered as a zip file containing all frames as basic L1A panchromatic DN imagery files, with accompanying RPC txt files, and a JSON pinhole camera model.

Item-type: SkySat Collect
Asset-type: basic_l1a_all_frames

- Display name: Zip file containing all L1A frames, RPCs, and pinhole json files
- Display description: Compressed folder with all basic l1a panchromatic frames and accompanying RPCs and pinhole json files that make up the collect

2. CONTENTS

2.1 TIFF Imagery Files

The All-Frames images are delivered in .TIFF format, as basic L1A panchromatic DN scenes.

2.2 RPC .txt Files

The Basic Scene products are designed for users with advanced image processing capabilities and a desire to geometrically correct the product themselves. The imagery data is accompanied by Rational Polynomial Coefficients (RPCs) to enable orthorectification by the user.

RPCs are generated using the rectification tiedown process wherein tie points are identified across the source images and a collection of reference images (NAIP, ALOS, Landsat, and high resolution image chips).

2.3 RPC Attributes

Parameter	Description	Sample
LINE_OFF	Row offset of center point	534.896219421794
SAMP_OFF	Column offset of center point	1267.3960612691
LAT_OFF	Latitude coordinate of center point	-18.1132
LONG_OFF	Longitude coordinate of center point	178.4441
HEIGHT_OFF	Altitude of center point	123
LINE_SCALE	Scaling factor for row coordinate	534.896219421794
SAMP_SCALE	Scaling factor for column coordinate	1267.39606126914
LAT_SCALE	Scaling factor for latitude coordinates	-0.0264
LONG_SCALE	Scaling factor for longitude coordinates	0.0331
HEIGHT_SCALE	Scaling factor for altitude coordinates	77
LINE_NUM_COEFF_	Numerator coefficient in row RPC equation (1-20)	4.27902854674
LINE_DEN_COEFF_	Denominator Coefficient in row RPC equation(1-20)	0.00174493132019
SAMP_NUM_COEFF_	Numerator coefficient in column RPC equation(1-20)	0.0110620153979
SAMP_DEN_COEFF_	Denominator coefficient in column RPC equation (1-20)	0.00174477677906

2.4 Frame Index .csv

Field	Value	Sample
name	Frame image filename(w/o file extension)	1207431805.69566202_sc00110_c2_PAN
datetime	Time of frame capture	2018-04-10T21:43:07Z
gsd	Ground Sample Distance	0.964506
sat_az	Avg satellite azimuth for frame	48.3168
sat_elev	Avg satellite elevation for frame	55.477
x_sat_eci_km	X-axis aligned ECI coordinate	3074.73

y_sat_eci_km	Y-axis aligned ECI coordinate	3057.87
z_sat_eci_km	Z-axis aligned ECI coordinate	5338.56
qw_eci	First pointing quaternion coordinate in ECI coordinate system	0.28172862
qx_eci	Second pointing quaternion coordinate in ECI coordinate system	-0.55973753
qy_eci	Third pointing quaternion coordinate in ECI coordinate system	-0.74397115
qz_eci	Fourth pointing quaternion coordinate in ECI coordinate system	-0.23201253
x_sat_ecef_km	X-axis aligned ECEF coordinate	3816.34769
y_sat_ecef_km	Y-axis aligned ECEF coordinate	4718.37789
z_sat_ecef_km	Z-axis aligned ECEF coordinate	2999.05659
qw_ecef	First pointing quaternion coordinate in ECEF coordinate system	0.3396504
qx_ecef	Second pointing quaternion coordinate in ECEF coordinate system	-0.3795945
qy_ecef	Third pointing quaternion coordinate in ECEF coordinate system	0.85021459
qz_ecef	Fourth pointing quaternion coordinate in ECEF coordinate system	-0.13296909
bit_dpth	Pixel bit depth of frame	16
geom	Frame dimensions	POLYGON((-123.132 49.2933,-123.089 49.294,-123.092 49.2825,-123.135 49.2818))
integration_time_ms	Capture integration time, in ms	433.59375
filename	Full filename with 12 digit timestamp	1289391430.33374000_sc00114_c3_PAN_i0000000604.tif

2.5 Pinhole Camera Model .json

Described here is the JSON pinhole model that accompanies each all-frames asset. The pinhole model is based on projective matrices, omitting the optical distortion model. As built, the SkySat telescopes have ~1 pixel or less of distortion across all three sensors.

Projective Model

Note that this model uses 3D and 2D homogeneous coordinates.

Let $\mathbf{x}_{ECEF} = \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$ be a position in ECEF coordinates, with values in meters, in 3D homogeneous coordinates.

Let $\mathbf{im} = \begin{pmatrix} wu \\ wv \\ w \end{pmatrix}$ be a position in imaging plane coordinates, with values in pixels (or fractional pixels), in 2D homogeneous coordinates.

The projective model is described by three matrices,

$P_{extrinsic} \in R^{4x4}, P_{intrinsic} \in R^{4x4}, P_{camera} \in R^{3x4}$ such that $im = P_{camera} P_{intrinsic} P_{extrinsic} X_{ECEF}$

For efficiency, we can also combine all three components into a single projective matrix,
$P_{projective} \in R^{3x4}$ such that $P_{projective} = P_{camera} P_{intrinsic} P_{extrinsic}$

A given value of ***im*** describes a projective ray in the pinhole camera frame, representing the projection of X_{ECEF} onto the camera sensor. Note that ***w=0*** indicates a ray parallel to the imaging plane and will never intersect the sensor. For ***w≠0***, we can simply solve for *u* and *v*.

Exterior Orientation

Let $\mathbf{x}_{SAT,ECEF} = \begin{pmatrix} x_{sat} \\ y_{sat} \\ z_{sat} \end{pmatrix}$ describe the satellite position at a particular time, in ECEF coordinates and with values in meters.

Let $\mathbf{q}_{SAT,ECEF} = \begin{pmatrix} q_w \\ q_x \\ q_y \\ q_z \end{pmatrix}$ be a quaternion describing the rotation from the ECEF frame to the boresight frame (positive z-axis aligned with telescope boresight).

$P_{extrinsic}$ is constructed from the exterior orientation by translating the origin to the satellite position and applying the ECEF-to-boresight rotation (following the conventions in https://en.wikipedia.org/wiki/Conversion_between_quaternions_and_Euler_angles#Rotation_matrices):

$$\mathbf{P}_{extrinsic} = \begin{bmatrix} 1-2(q_y^2+q_z^2) & 2(q_x q_y - q_w q_z) & 2(q_w q_y + q_x q_z) & 0 \\ 2(q_x q_y + q_w q_z) & 1-2(q_x^2+q_z^2) & 2(q_y q_z - q_w q_x) & 0 \\ 2(q_x q_z - q_w q_y) & 2(q_w q_x + q_y q_z) & 1-2(q_x^2+q_y^2) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -x_{sat} \\ 0 & 1 & 0 & -y_{sat} \\ 0 & 0 & 1 & -z_{sat} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Interior Orientation

$P_{intrinsic}$ and P_{camera} are based on the rigorous model from "SkySat Imaging Geometry." Their derivation involves multiple frame changes and axis flips and is not described here. We expect that these will remain nearly constant over time for each satellite and camera. $P_{extrinsic}$ is unique to each satellite and imaging time, but shared across cameras for each capture event.

3. PRODUCT ATTRIBUTES

Product Attribute	Description
Product Components and Format	All frames - folder - Image Frame File – TIFF format - Rational Polynomial Coefficients – Text File - Pinhole camera model - JSON format Metadata File – JSON format
Information Content	
Image Configurations	1-band L1A Panchromatic DN Image (Pan)
Product Orientation	Spacecraft/Sensor Orientation
Sensor Type	CMOS Frame Camera with Panchromatic and Multispectral halves
Spectral Bands	Pan: 450 - 900 nm
Processing	**Basic L1A Scene**
Bit Depth	16 Unsigned Integer
Radiometric Corrections	Cross-Sensor Non Uniformity Correction (1%)
Geometric Corrections	Idealized sensor model and Rational Polynomial Coefficients (RPC)
Horizontal Datum	WGS84
Map Projection	N/A

Resampling Kernel	N/A
Ground Sample Distance	[SkySat-3 - SkySat-13] Panchromatic: 0.81m
	[SkySat-16 - SkySat-21] Panchromatic: 0.58m Multispectral: 0.72m
Geometric Accuracy	<50m RMSE

4. USAGE

Reference NASA Ames Stereo User Guide for specific algorithms used for SkySat data here: https://ti.arc.nasa.gov/tech/asr/groups/intelligent-robotics/ngt/stereo/#Documentation

This section provides a brief overview of a sample stereo workflow using the L1A assets, specifically within the NASA Ames pipeline. The NASA Ames Stereo Pipeline (ASP) is a suite of free and open source automated geodesy and stere-
ogrammetry tools designed for processing stereo images captured from satellites, with detailed instructions on how to use SkySat L1A data.

One customer challenge with SkySat imagery is that the camera extrinsics are not fully reliable. In addition, the provided RPC files are often not robust enough to support accurate downstream 3D reconstruction. Planet is currently working on improving the pinhole camera model that accompanies the All-Frames product to resolve these issues. Using APS, customers can either update the Planet provided camera model and RPCs, or create new versions from scratch using Ames' Pinhole camera model.

Represented below is a very high level view of the steps and tools provided by ASP to allow users to produce Digital Elevation Models (DEM) from satellite stereo imagery. For the specific commands and parameters to use, please reference the *SkySat Images* section in the full User Guide linked above.

5. AMES PROCESSING

Each L1A panchromatic frame is roughly 2560 x 1080 pixels. Assume the geometric center is the optical center. The focal length of each SkySat is 3.6m with a pixel pitch of 6.5 x 10^-6 m, hence the focal length in pixels is:

3.6/6.5 × 10^-6 = 553846.153846

ASP utilizes an SRTM DEM of the area as reference for registration. The overlapping SkySat imagery is then clipped to the DEM, buffered slightly to allow sufficient overlap. Using ASP tools, customers may create an initial camera model and GCP files per image. This is achieved by reading each image's corner coordinates provided in the frame_index.csv file. The produced camera model and GCP files will be utilized later in bundle adjustment.

Bundle Adjustment

Using the imagery files and GCP + camera model files either created or modified above, ASP tools can then be used to perform bundle adjust between the images. Here the camera is further optimized for location, and a residual file is created with heights of triangulated interest points and a list of reprojection errors. This can be considered the earliest form of the DEM ASP is developing.

Alignment

Registration is then performed to further align the camera model relative to the ground. Ideally after registration overall geolocation of the images should be within just a few meters of the reference data. Another rough DEM may be created from the residual file after registration/alignment, which can then be visualized in ASP tools to compare against the reference DEM.

Assuming the camera models are now highly accurate and alignment succeeds, customers can perform another bundle adjustment which applies an alignment transform to the updated camera models to make them consistent with the reference DEM.

Creating the Terrain Model

Lastly ASP provides a command to produce the final DEM file, ideally with no more than 3 or 4 meters of elevation variation from the reference data.