2023 CA Central Valley Crop Mapping UAS Processing Notes

Overview

Discuss datum and projection / coordinate system choices with Itiya and Adam:

WGS84 as the datum rather than NAD83(2011)

Flew 12 hyperspectral data collection flights at an altitude of 90 meters (~300ft) above ground level over crop fields in California's Central Valley: cotton, almond, pistachio, grape, rice (traditional and organic), and corn.
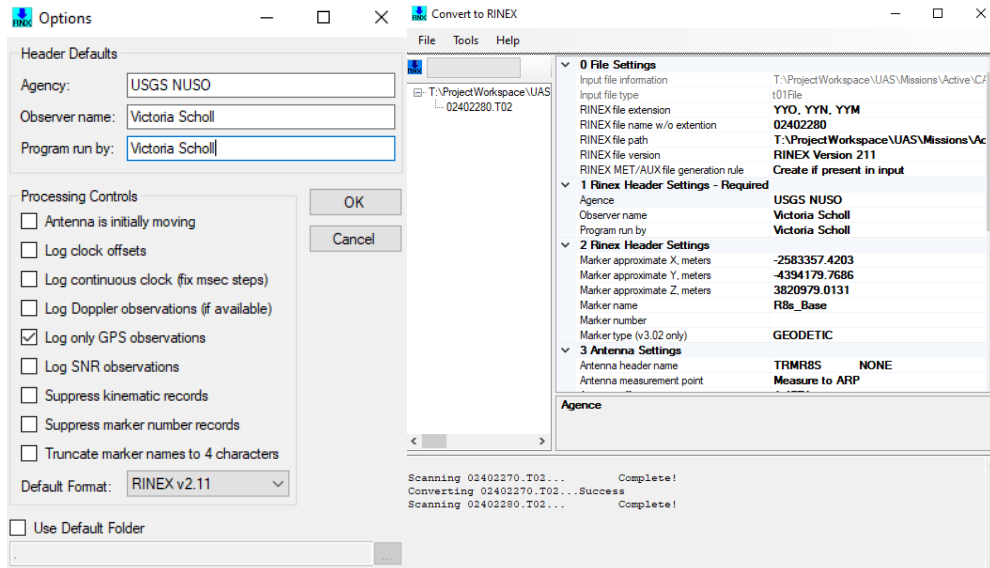
Ground Control

Base Station

Process the T02 files from our Trimble R8s GNSS base station for each day of data collection.

Convert T02 to RINEX

Convert T02 to RINEX (extension ".o") using the "Convert to RINEX" Trimble App. Format RINEX 2.11; Log only GPS observations.

OPUS-correct RINEX

We post-process our GNSS base station files using the NOAA National Geodetic Survey (NGS) Online Positioning User Service (OPUS) to improve our raw GPS results to within a few centimeters of accuracy.

On the NOAA OPUS upload page (https://geodesy.noaa.gov/OPUS/) upload the Rinex file (".o"). Select the GPS antenna. We used a Trimble R8s so I searched for "R8s" and selected "TRMR8S NONE" which contains predetermined measurements for this instrument.

Enter the respective antenna height corresponding to the survey date, measured to center of bumper:

- 08/15/2023: 1.405 m
- 08/16/2023: 1.515 m
- 08/17/2023: 1.502 m

Within "Options to customize your solution," select extended format and leave state plane as "let OPUS choose." Select Upload to Static. OPUS will email a correction to the email address provided. Save the email as a PDF and copy the text contents into a text file.

OPUS-corrected Base Station coordinates for POSPac Coordinate manager:

08/15/2023

- LAT: 36 51 **16.57832**
- W LON: 120 29 **21.53688**
- EL HGT: **13.357**(m)
- ARP HEIGHT: 1.405

08/16/2023

- LAT: 37 2 **25.22486**
- W LON: 120 27 **5.24524**
- EL HGT: **6.485**(m)
- ARP HEIGHT: 1.515

08/17/2023

- LAT: 36 55 **30.43960**
- W LON: 120 39 **32.58313**
- EL HGT: **6.778**(m)
- ARP HEIGHT: 1.502

Applanix in POSPac

The Headwall Nano-hyperspec is flown along with an Applanix APX-15 for direct georeferencing. We need to post-process the APX trajectory data using our Trimble R8s Base Station.

The APX-15 output a series of .T04 files. Determine which .T04 files correspond to each hyperspectral flight and place them in a subfolder labeled "APX" since the processing in POSPac must be done for each individual flight.

Open the "imu_gps.txt" file for each flight in a text editor and check the Altitude column to see when the aircraft appeared to take flight, and then check the date/times column. Each T04 file is named with the date and time at the end of it. The APX files determined to be associated with each flight are detailed below.

Files per flight

5 flights on Tuesday Aug 15:

20230815_T1_Cotton1_NS

- Start/end times based on altitude (~20m up to ~117m, 90m flight altitude)
    - 21.937980275647067   700260850   2023/08/15 **17:26**:30.700000
    - 21.221197125482544   790896622   2023/08/15 **17:34**:05.680000
- Applanix .T04 file range to encompass the identified start/end times:
    - 6035C00190202308151**1724**.T04 - 6035C0019020230815**1736**.T04

20230815_T2_Almond1_NS

- Start/end times: 21:09 - 21:19
- APX files: 6035C0019020230815**2106**.T04 - 6035C0019020230815**2121**.T04

20230815_T4_Cotton2_NS

- Start/end times: 18:09 - 18:16
- APX files: 6035C0019020230815**1806**.T04 - 6035C0019020230815**1818**.T04

20230815_T5_Cotton3_NS

- Start/end times: 18:50 - 18:57
- APX files: 6035C0019020230815**1848**.T04 - 6035C0019020230815**1900**.T04

20230815_T10_Almond2_NS

- Start/end times: 22:46 - 22:58
- APX files: 6035C0019020230815**2242**.T04 - 6035C0019020230815**2300**.T04

3 flights on Wednesday Aug 16:

20230816_T12_Grape_EW

- Start/end times: 17:57 - 18:09
- APX files: 6035C0019020230816**1754**.T04 - 6035C0019020230816**1812**.T04

20230816_T13_Grape_EW

- Start/end times: 19:17 - 19:29
- APX files: 6035C00190202308161915.T04 - 6035C00190202308161930.T04

20230816_T14_Grape_NS

- Start/end times: 21:24 - 21:34
- APX files: 6035C00190202308162121.T04 - 6035C00190202308162139.T04

4 flights on Thursday Aug 17:

20230817_T7_Rice_organic_EW

- Start/end times: 16:29 – 16:48   (*seems longer than usual flight time?*)
- APX files: 6035C00190202308171627.T04 - 6035C00190202308171651.T04

20230817_T16_T15_Rice_NS

- Start/end times: 19:48 - 20:04
- APX files: 6035C00190202308171945.T04 - 6035C00190202308172006.T04

20230817_T17_T18_T19_corn_NS_Exp8ms

- Start/end times: 21:47 – 22:01
- APX files: 6035C00190202308172145.T04 - 6035C00190202308172203.T04

20230817_T24_Rice_EW

- Start/end times: 17:49 – 18:01
- APX files: 6035C00190202308171745.T04 - 6035C00190202308171803.T04

POSPac processing steps
1. Launch POSPac UAV 8.8
2. File >> Open Project >> New Default Project
3. Project >> Import >> navigate to T04 files (trajectory files from an APX-15) >> select the files of interest >> Import.
4. Once loaded, there will be a purple trajectory shown in the plan view.
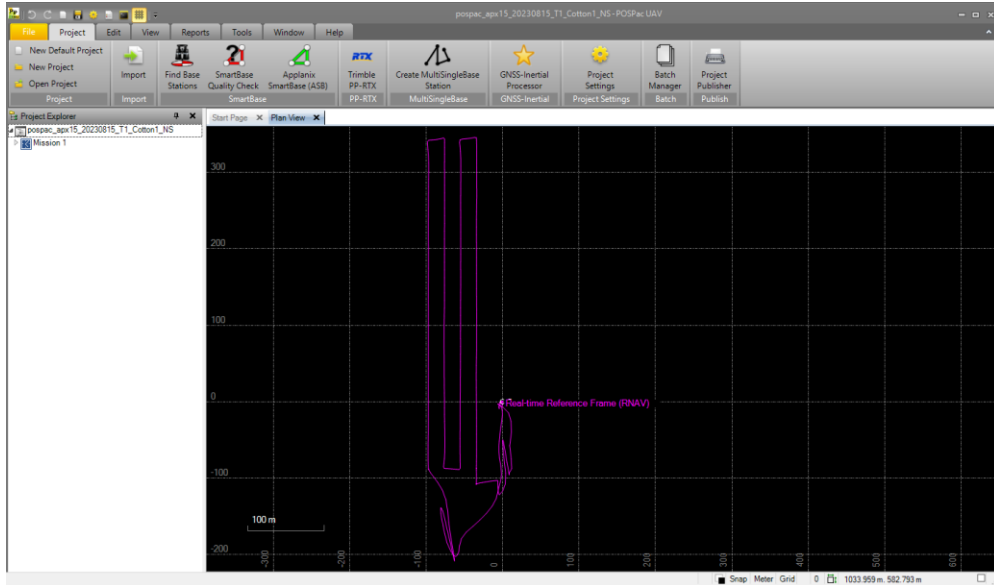
5. Import the OPUS-corrected Trimble R8s base station data.
   a. Expand Mission 1 details. Right-click "Base Stations" > Import the RINEX file (.o)
   b. Right-click on the imported R8s-Base > Coordinate Manager.
   c. Copy and paste Latitude, Longitude, Altitude (Ellipsoid height, "EL HGT" in the .22o text file) values from OPUS correction.
   d. Click "Apply changes". Close.
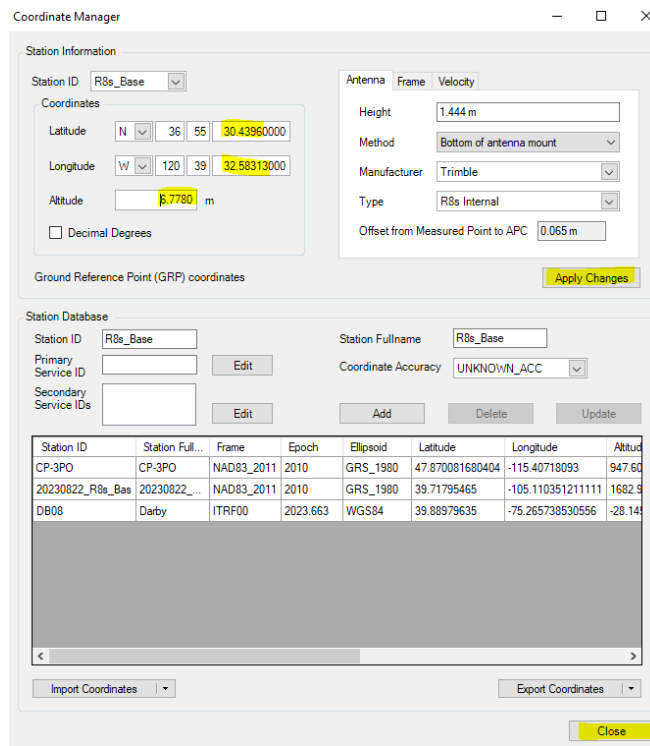
6. Right-click on the Base station >> Set Base Station. The GNSS QC Processor starts running.
   a. Check for Fixed Solution to be ~100%.
   b. A flag now appears at the R8s base station location.

Statistics	Min	Max	Mean
Baseline Length (km)	0.05	0.38	N/A
Number of GPS SV	4	9	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total Number of SV	4	9	8
PDOP	1.84	6.76	2.08
QC Solution Gap (s)	1.00	40.00	N/A

Fixed Epoch: 685.0 s Float Epoch: 18.0 s No Solution: 124.0 s
Fixed Solution: 82.83% Float Solution: 2.18% No Solution: 14.99%

Statistics	Min	Max	Mean
Baseline Length (km)	9.11	9.83	N/A
Number of GPS SV	5	9	7
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total Number of SV	5	9	7
PDOP	1.66	5.64	2.16
QC Solution Gap (s)	1.00	9.00	N/A

Fixed Epoch: 893.0 s Float Epoch: 20.0 s No Solution: 27.0 s
Fixed Solution: 95.00% Float Solution: 2.13% No Solution: 2.87%

| Statistics	Min	Max	Mean
Baseline Length (km)	0.25	0.49	N/A
Number of GPS SV	5	8	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total Number of SV	5	8	8
PDOP	2.17	6.84	2.22
QC Solution Gap (s)	2.00	19.00	N/A

Fixed Epoch: 717.0 s Float Epoch: 7.0 s No Solution: 21.0 s
Fixed Solution: 96.24% Float Solution: 0.94% No Solution: 2.82%

(Left) GNSS QC Stats for 08/15 first cotton flight, (middle) second almond, (right) second cotton.

7. Open the GNSS Inertial Processor (star icon) >> Open "Properties". Check the Lever Arms and Mounting Angles.
   a. Headwall documentation says Standard Deviation should be 0.1m.
   b. The auto-populated z value in the "Reference to IMU Lever Arm" is -0.635m but in the Headwall documentation, the value is much lower, -0.044m.
      i. *Joe measured from the center of the APX-15 board to the lens mount = -.04 so I changed the Reference to IMU Lever Arm z value from –0.635m to* **–0.04m**.
   c. Click OK to close the Properties window.
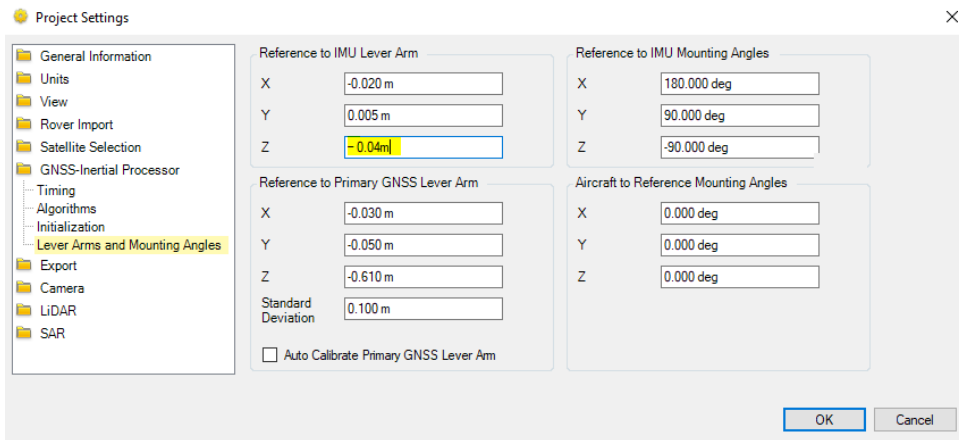
   d. GNSS Mode: IN-Fusion Single Base. Under "Stabilized Mount", select "Model" since we are using an active gimbal for the data collection.
   e. Click "Run" to start processing.
   f. The processing should complete with Normal status and position accuracy within 0.1m.
   g. After processing, the computed trajectory appears in green.
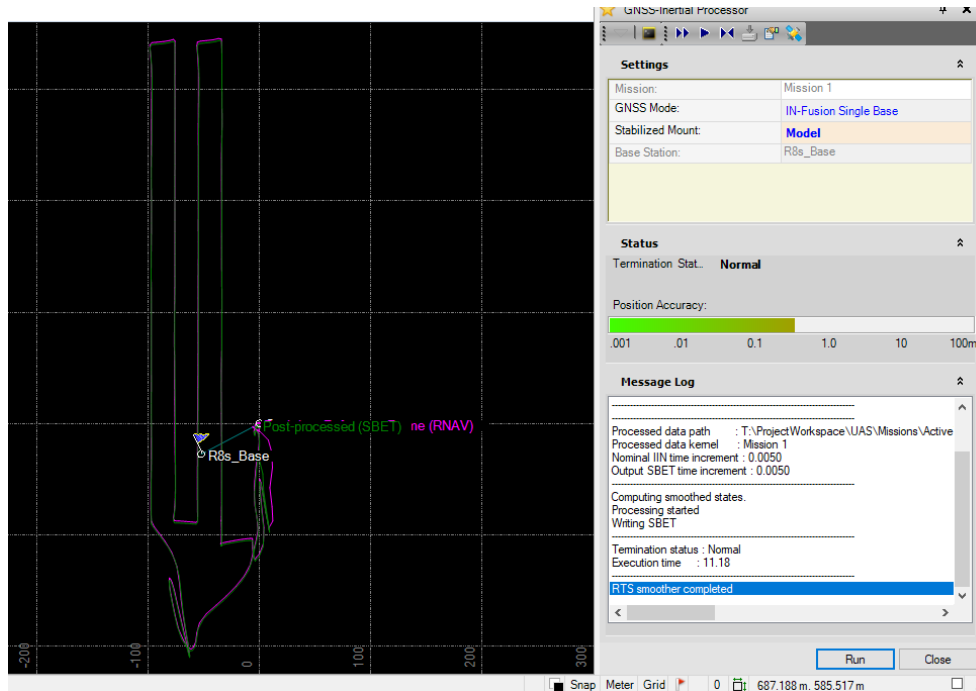
8. Reports >> QC Report >> specify the file location and name, template Diagnostic, and click Generate to have a PDF created with plots and statistics about the trajectory correction.
9. Export corrected trajectory as SBET file. Tools >> Export >> indicate the filename.
   a. Set the export path. Filename must include "SBET", e.g. "SBET_Mission1.out"
   b. Select file format "Custom Smoothed BET"
   c. Output height: Ellipsoid
   d. In the Mapping Frame tab, the Datum and Ellipsoid defaults are set to WGS84.
   e. Set Epoch to Custom Date, 2010. Click OK.
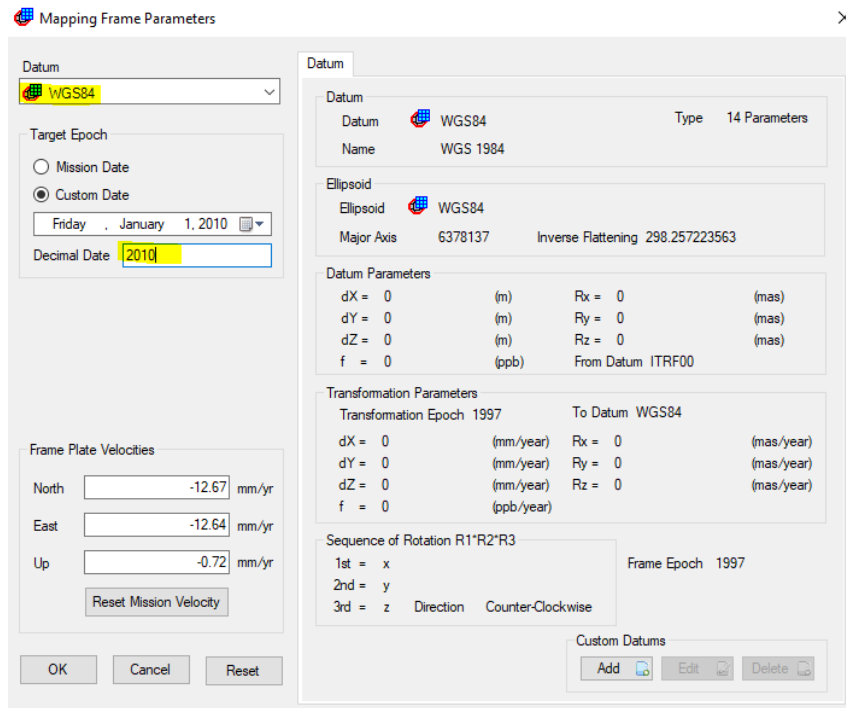
10. Click Export >> The exported SBET file will be used during ortho-rectification of the Nano data. You can view the exported log file in a text editor.
11. Save the POSpac project for future reference or modification.
12. Repeat for each hyperspectral flight's APX-15 trajectory.

Hyperspectral

Tarp images
20230815_T1_Cotton1_NS - **13136**
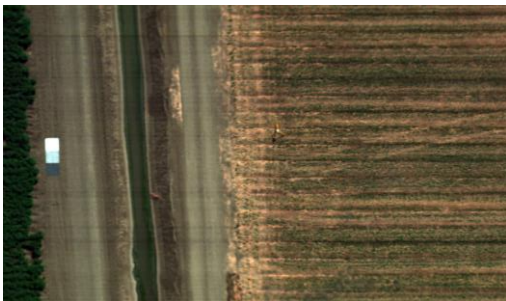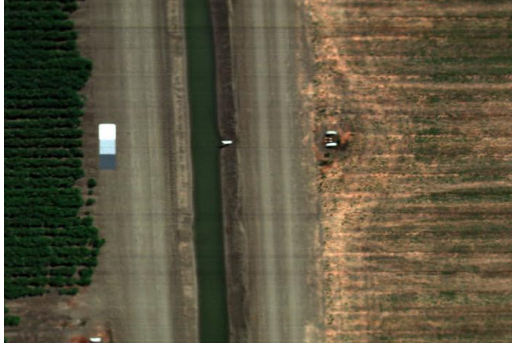

20230815_T2_Almond1_NS - **32088**

20230815_T4_Cotton2_NS – **13296**

20230815_T5_Cotton3_NS – **13440**

20230815_T10_Almond2_NS – **33448**

20230816_T12_Grape_EW - **37232**
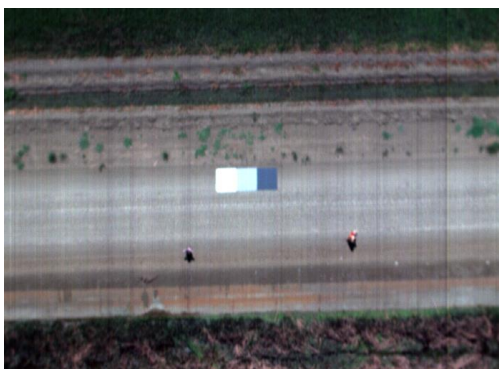

20230816_T13_Grape_EW – **33592**

20230816_T14_Grape_NS – **31536**

20230817_T7_Rice_organic_EW – **0**

20230817_T16_T15_Rice_NS – **39088**

20230817_T17_T18_T19_corn_NS_Exp8ms – **39856**

20230817_T24_Rice_EW – **21036**

Radiometric corrections

1. Raw to Radiance
   a. Batch > Radiance Batch > add hyperspectral files for current flight > Next >
   b. Ensure the proper radiometric calibration file is selected for the sensor (our sensor's serial number if nHS-266)
   c. Select Dark Reference collected with the lens cap on prior to flight.
   d. Make sure all 274 wavelength bands are selected. Next >
   e. Click "Start" to convert the raw files to radiance. "_rd" will be appended onto each radiance-corrected file.
2. Radiance to Reflectance
   a. For the current flight, open the radiance image (all 274 bands) containing the tarp.
   b. Right-click on a bright pixel within a tarp and select Classify to open the Spectral Angle Mapper classification window.
   c. We will use this tool to select many pixels within the tarp. Click and drag the blue bounding box to include only pixels within the tarp. Avoid edge and shadow regions.
      i. Select a minimum of 100 pixels.

d. Iteratively click "Recalculate" and "Test Calculated", adjusting the SAM limit as needed. Once the calculated spectrum matches with the Seed spectrum, this means the pixels highlighted in green are spectrally similar.
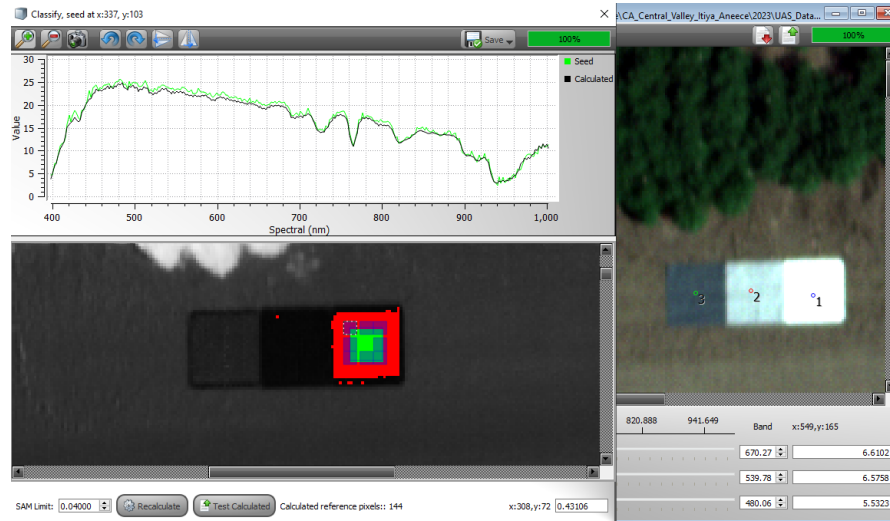
e. Save > Calculated as White Reference > load a reflectance profile.
   i. We have reference profiles for our tarp: C:\Headwall\sensorConfig\refProfiles
   ii. Since those are from 2017, we coud instead use more recent measurements. Copy the mean tarp reflectance into a csv file where column 1 is wavelength and column 2 is mean reflectance scaled between 0-100.
      1. In SpectralView, Tools >> Import Reflectance >> select .csv file and click Continue >> In the Headwall/sensorConfig/refProfiles folder, thr file was converted to Headwall's spectra format.
   iii. Select reference profile corresponding to dark, middle, or light tarp of interest and click OK and close the Classify window.
f. These white reference pixels will serve as examples of what __% reflectance looks like and will be used to correct the entire image to units of reflectance.
g. Open the Reflectance tool. Select the white reference file that you just created. Check all parameters (select all wavelengths) and create cube. Check the values before applying the correction to all images.
h. Batch > Reflectance Batch > add the radiance files ("_rd") and click Next > select the white reference profile and ensure that all 274 wavelengths are selected. Next >
i. Click Start to convert to reflectance. "_rf" will be appended onto each reflectance file.
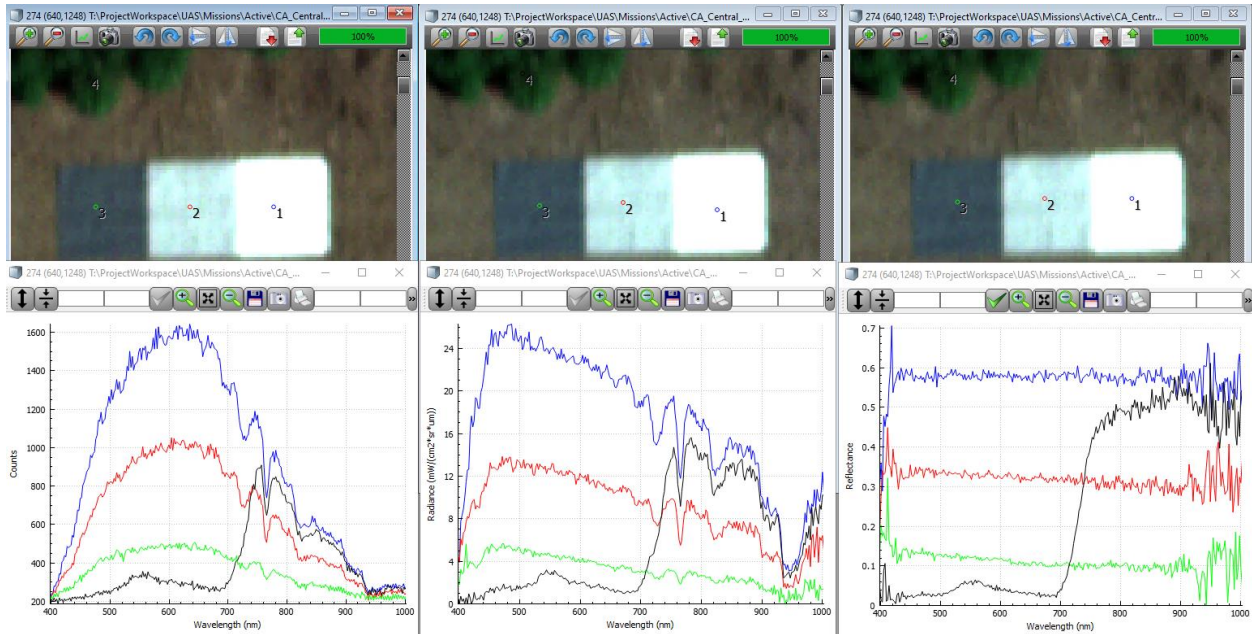
Raw to radiance to reflectance profiles over tarps and vegetation.

Ortho-rectification

To ortho-rectify the hyperspectral data, we need to use a Digital Elevation Model (DEM) which captures the three-dimensional structure of the area that we mapped. We prefer the DEM to include trees, buildings, etc. since these objects appear in the hyperspectral imagery, as opposed to a terrain model which only captures the underlying ground surface.

Here are the DEM requirements from Headwall Tech Support
- *GeoTIFF can be in either Universal Transverse Mercator (UTM) in units of meters or WGS84 Latitude and Longitude.*
- *Specific version of the WGS84 Latitude and Longitude is the EPSG 4326. DEMs need units of meters or degrees.*
- *The vertical datum should be the EGM96 vertical datum (EPSG SR-ORG:7428) and ellipsoid heights.*

Place the DEMs (not cropped, if possible, to ensure there are elevation values at all locations of hyperspectral data) in the folder where Headwall will search for it by default: C:\Headwall\dem

Make sure the flight's trajectory file ("SBET_Mission1.out"), post-processed SBET from POSPac, is in the flight directory.

3DEP DEMs

Using the USGS Lidar Explorer, I downloaded the following DEM data for each crop field location:

Cotton, Almond, Organic Rice, Traditional Rice, Corn

> 3DEP 1/3 Arc Second (approximately 10 meters) DEM:
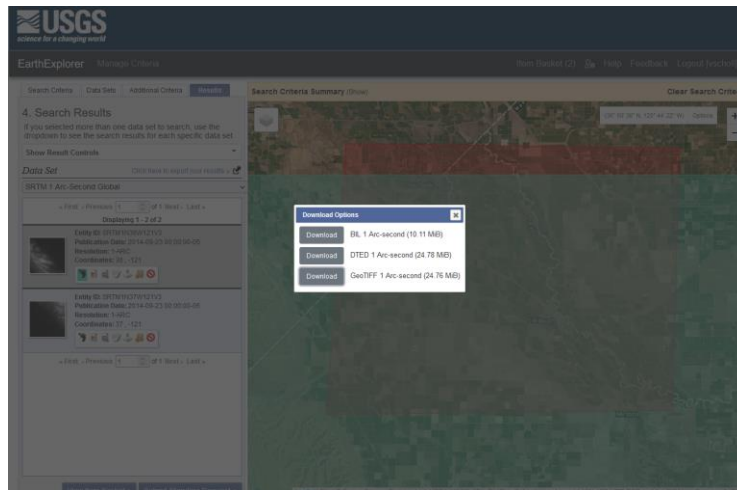> USGS 1/3 Arc Second n37w121 20211006
> https://www.sciencebase.gov/catalog/item/615fd080d34e52f49c821f2f

Cotton

> 3DEP 1-meter DEM:
> USGS 1 Meter 10 x72y409 CA_FEMAR9Fresno_2019_D20
> https://www.sciencebase.gov/catalog/item/619c3796d34eb622f6931ddb

Had issues using the above lidar DEMs, so I also downloaded SRTM digital elevation file: (1 Arc Second)
SRTM1**N36**W121V3

Grape - 3DEP 1-meter DEM (USGS 1 Meter 10 x72y411 CA_FEMAR9Fresno_2019_D20,
https://www.sciencebase.gov/catalog/item/619c3795d34eb622f6931dd7) and 3DEP 10-meter DEM
(USGS 1/3 Arc Second n38w121 20220103,
https://www.sciencebase.gov/catalog/item/61d3e27dd34ed79293fe7362) gave me errors when trying
to read them in SpectralView.

SRTM file that covers Grape coordinates: SRTM1N37W121V3
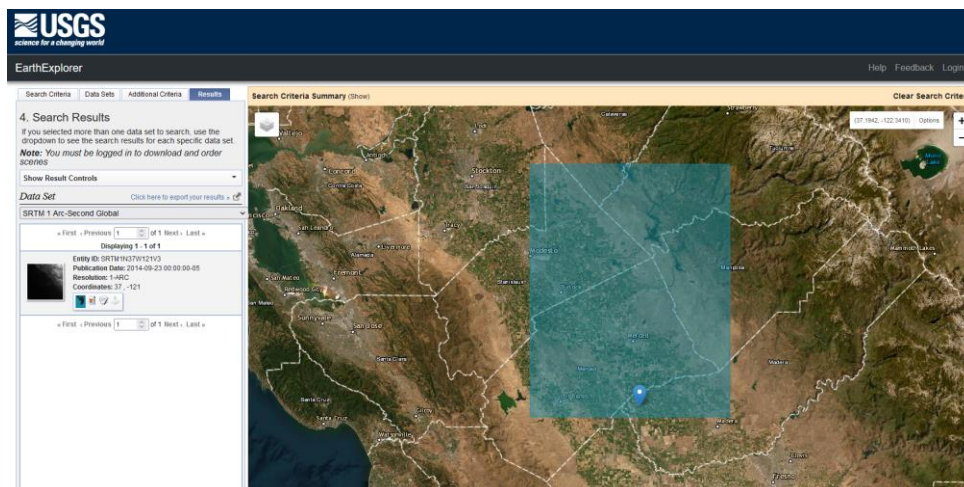
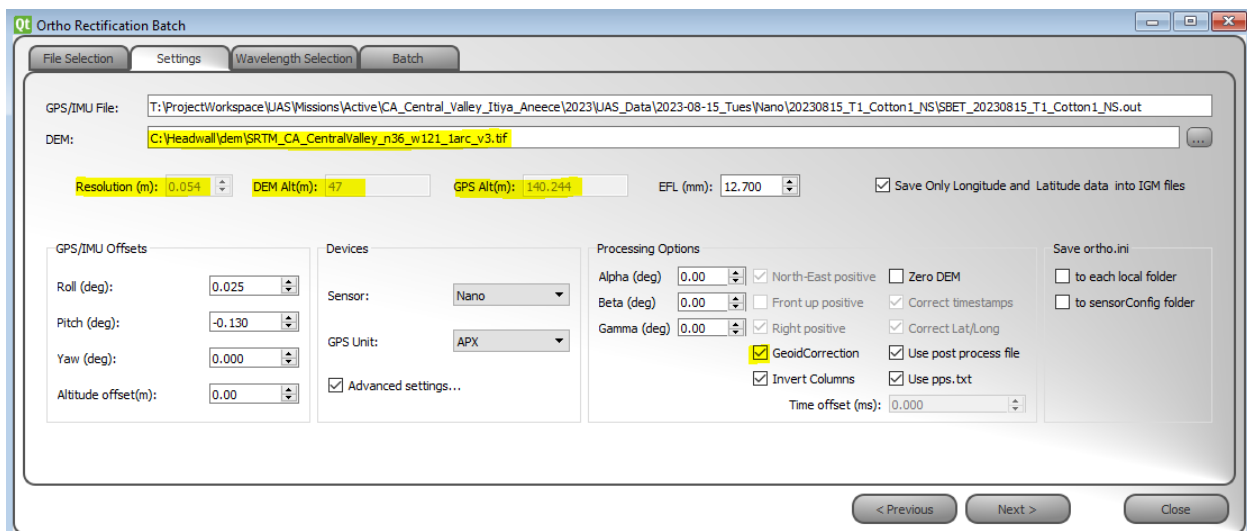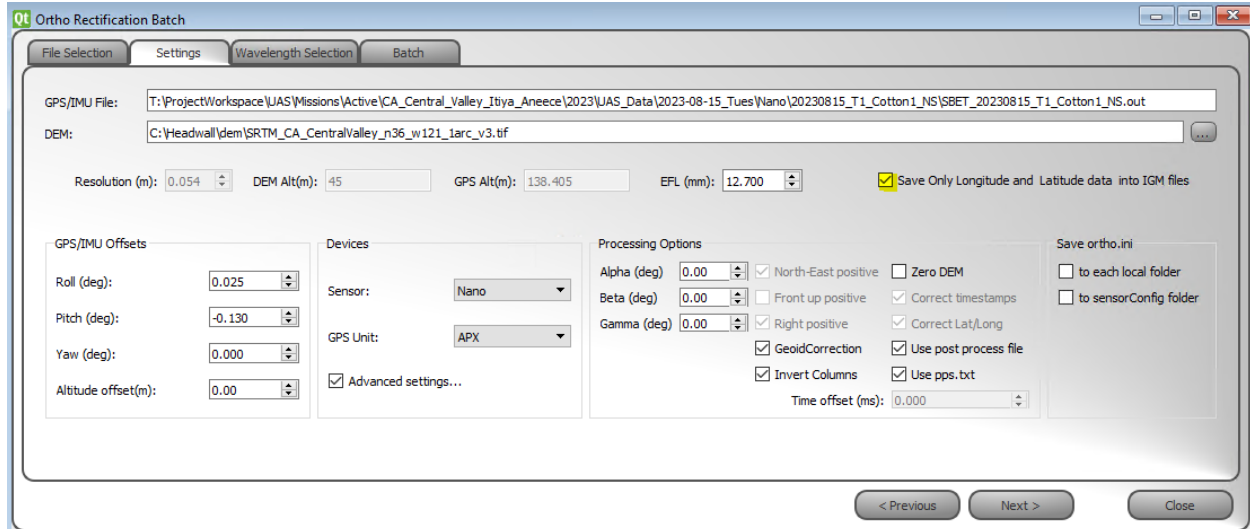## Single image ortho-rectification

1. In Headwall's SpectralView software, open the reflectance-corrected datacube containing the tarp (you can select just the R,G,B bands to save processing time), e.g. "raw_13136_rd_rf.hdr".
2. Paste the ortho.ini file from Headwall tech support with good starting parameters (a copy is located here: C:\Headwall\sensorConfig\nHS-266) in the current project folder.
   a. Parameters of interest:
      i. Altitude offset = 0
      ii. EFL = 12.7
3. Single cube parameter tuning: Open the Ortho Rectification tool.
   a. Specify SBET file, corrected Applanix trajectory file exported from POSpac.
   b. Specify Digital Surface Model (aka DEM). SpectralView will search for one in the C:\Headwall\dem folder.
   c. The software will automatically calculate the altitude of a corner of the DEM.
      i. "DEM Alt"
   d. The software will calculate the altitude of the UAS based on the SBET data.
      i. "GPS Alt"
   e. *I had to enable the "GeoidCorrection" processing option to get the following values:*
      i. *DEM Alt = 47 m*
      ii. *GPS Alt = 140 m*
      iii. *Subtract (GPS Alt – DEM Alt) to determine the calculated flight alt = 93m. We flew at a flight altitude of 90m (~300ft) so this calculation is close to what we expect.*
   f. The software will calculate an image spatial Resolution (m).
      i. *0.054m is close to the expected resolution of 5.6cm at 300ft altitude.*
   g. Default effective focal length (EFL) is 12.7 for our sensor.
      i. Altitude offset should be 0.
   h. Check "Advanced Settings" to see additional parameters
      i. GPS unit = APX
      ii. Ensure GeoidCorrection is enabled when the DSM has orthometric heights.
   i. Check "save to ortho.ini locally" to save the selected settings

Multiple image parameter tuning

1. Identify multiple images with overlapping features, ideally with straight lines on the terrain surface such as the road.
2. Batch > Orthorectification batch > select those images, Next > ensure the proper DEM is loaded with the saved ortho.ini settings. Check the box for IGM files > Next > Start.

3. Corrections > Multi-ortho > select the IGM files > select RGB > Check the preview to see overlap between image extents > Create cube > Open the multi-ortho.
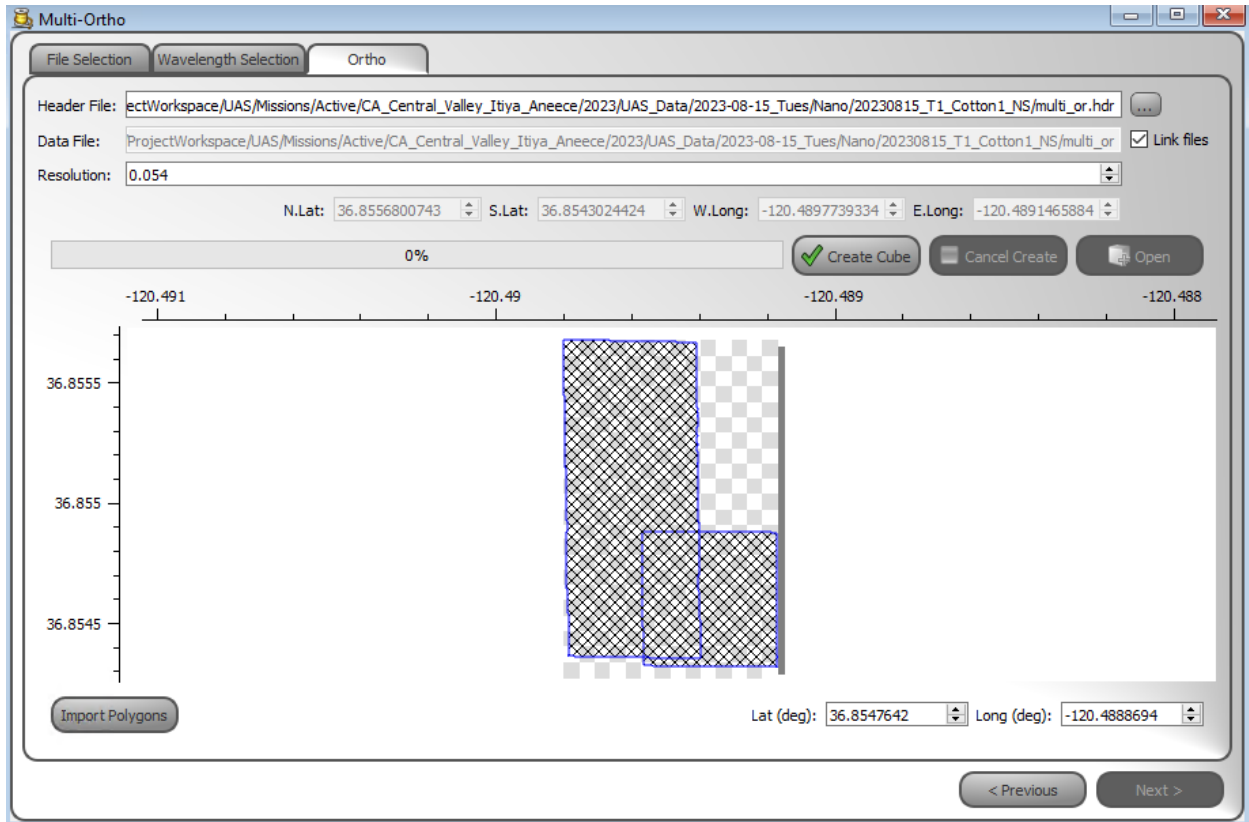
4. Iteratively change parameters, run batch ortho-rectification and multi-ortho, checking alignment.
   a. Roll = 0.025, Pitch = -0.13

   b. Roll = 0.025, Pitch = -0.15

c.   Roll = 0.025, Pitch = -0.1

d.   Roll = 0.025, Pitch = -0.08

5.   Incroporate additional images to see how well the alignment looks with the same parameters over a larger area. Difficult to find one parameter set that optimizes alignment across the entire

scene. Mismatch between features present in the scene and what is captured by the DEM will also affect the alignment.

    a.   Roll = 0.025, Pitch = -0.08

    b.   Roll = 0.025, Pitch = -0.12

Alignment is decent across the scene. Not perfect, but we can't achieve perfection.

6. Back in the Ortho Rectification Batch tool, apply the best parameters to all images. Select all wavelengths and be sure to uncheck the "Save Only Longitude and Latitude Data".
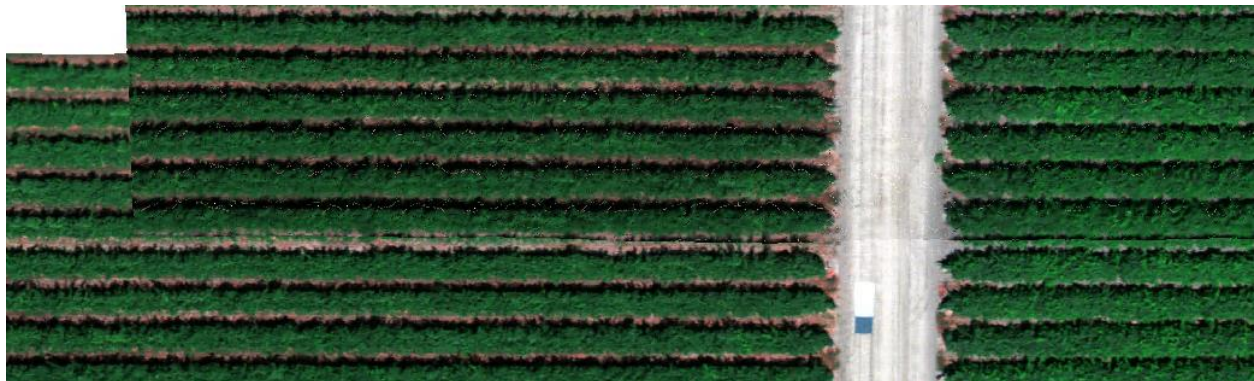
Utilized these parameters across the sites. Appears to work decently well.

Grape ortho-rectification params using SRTM DEM:
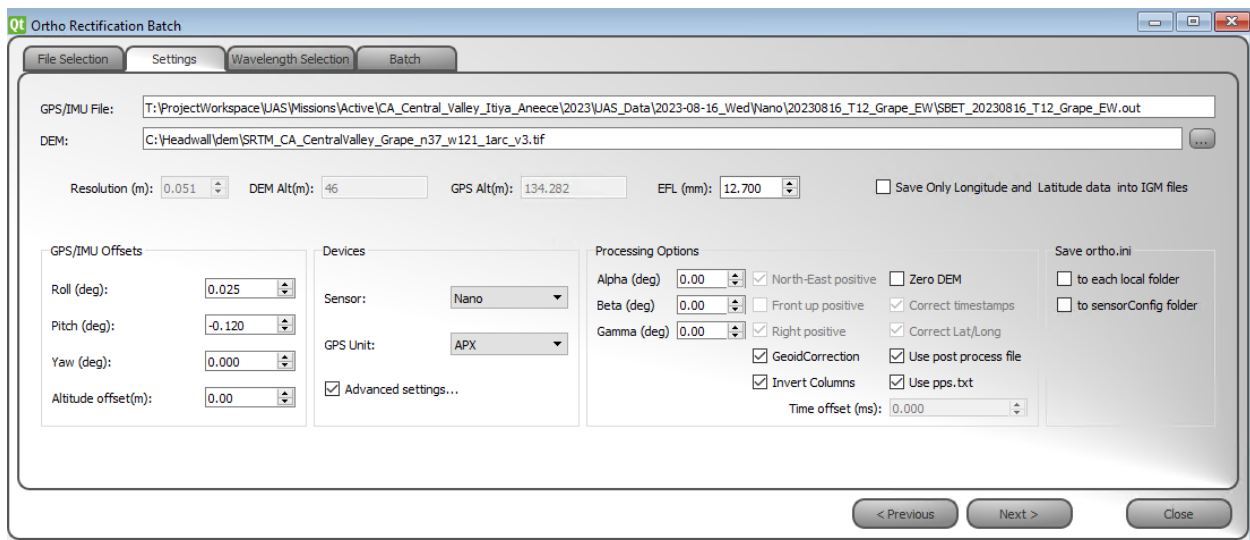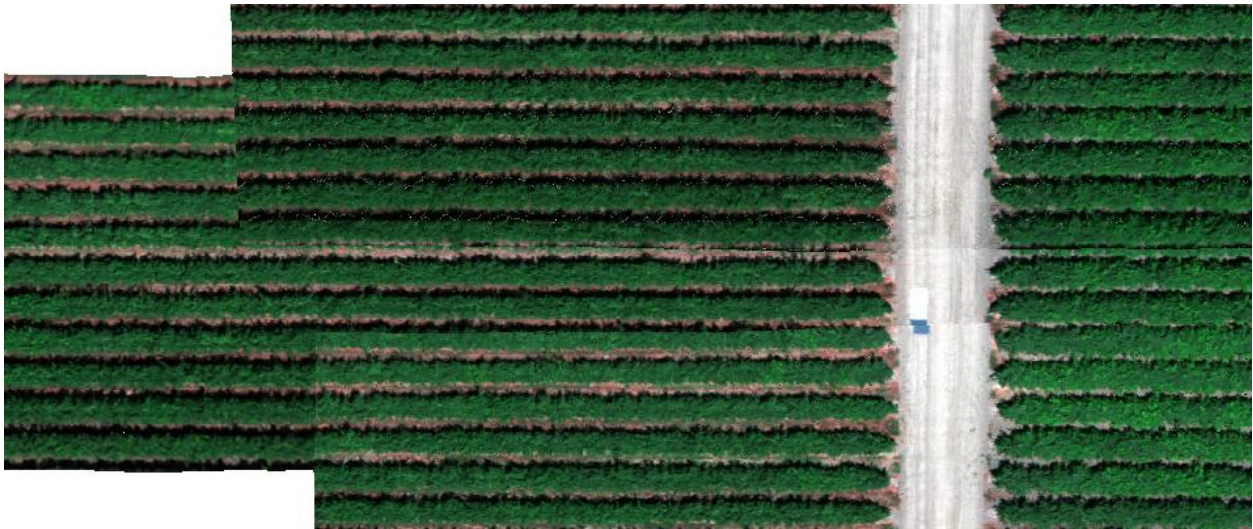

T13 Grape param tuning:

- Roll = 0.025, Pitch = -0.12. images 0, 33592. Visible misalignment in the cross-track direction. Adjusting roll to see if it can be improved.

- Roll = 0.02, Pitch = -0.12. images 0, 33592, 37328. I think this made it worse.

- Roll = 0.035, Pitch = -0.12. images 0, 33592, 37328. Adjusted Roll in the opposite direction.
  - I don't see a difference?

Processing Tasks - Checklist

- ✓ Trimble R8s: convert T02 to RINEX; OPUS-correct RINEX for all 3 dates (Aug 15, 16,17)
- ☐ Aeropoints: correct using base station; download CSVs, PDF, and KML
- ☐ Multispectral SfM photogrammetric processing
  - Dual – Aug 16
  - RedEdge-P – Aug 16
- ✓ Identify tarp image in each flight
- ✓ Identify APX files for each flight
- ✓ Download DEMS from 3DEP for ortho-rectification

- ✓ **Hyperspectral radiometric corrections: raw to radiance**
  - ✓ Aug 15
    - ✓ 20230815_T1_Cotton1_NS
    - ✓ 20230815_T2_Almond1_NS
    - ✓ 20230815_T4_Cotton2_NS
    - ✓ 20230815_T5_Cotton3_NS
    - ✓ 20230815_T10_Almond2_NS
  - ✓ Aug 16
    - ✓ 20230816_T12_Grape_EW
    - ✓ 20230816_T13_Grape_EW
    - ✓ 20230816_T14_Grape_NS
  - ✓ Aug 17
    - ✓ 20230817_T7_Rice_organic_EW
    - ✓ 20230817_T16_T15_Rice_NS
    - ✓ 20230817_T17_T18_T19_corn_NS_Exp8ms
    - ✓ 20230817_T24_Rice_EW
- ✓ **POSPac: post-process Applanix APX-15 files**; export corrected trajectory per hyperspectral flight
  - ✓ Aug 15
    - ✓ 20230815_T1_Cotton1_NS
    - ✓ 20230815_T2_Almond1_NS
    - ✓ 20230815_T4_Cotton2_NS
    - ✓ 20230815_T5_Cotton3_NS
    - ✓ 20230815_T10_Almond2_NS
  - ✓ Aug 16
    - ✓ 20230816_T12_Grape_EW
    - ✓ 20230816_T13_Grape_EW
    - ✓ 20230816_T14_Grape_NS
  - ✓ Aug 17
    - ✓ 20230817_T7_Rice_organic_EW
    - ✓ 20230817_T16_T15_Rice_NS
    - ✓ 20230817_T17_T18_T19_corn_NS_Exp8ms
    - ✓ 20230817_T24_Rice_EW
- ✓ **Hyperspectral radiometric corrections: radiance to reflectance**
  - ✓ Aug 15
    - ✓ 20230815_T1_Cotton1_NS - *used Headwall 2017 56% white spectrum*
    - ✓ 20230815_T2_Almond1_NS - *used Headwall 2017 56% white spectrum*
    - ✓ 20230815_T4_Cotton2_NS - *used Headwall 2017 56% white spectrum*
    - ✓ 20230815_T5_Cotton3_NS - *used Headwall 2017 56% white spectrum*
    - ✓ 20230815_T10_Almond2_NS - *used Headwall 2017 56% white spectrum*
  - ✓ Aug 16
    - ✓ 20230816_T12_Grape_EW- *used Headwall 2017 56% white spectrum*
    - ✓ 20230816_T13_Grape_EW - *used Headwall 2017 56% white spectrum*
    - ✓ 20230816_T14_Grape_NS - *used Headwall 2017 56% white spectrum*
  - ✓ Aug 17

- ✓ 20230817_T7_Rice_organic_EW - *used Headwall 2017 56% white spectrum*
- ✓ 20230817_T16_T15_Rice_NS- *used Headwall 2017 56% white spectrum*
- ✓ 20230817_T17_T18_T19_corn_NS_Exp8ms - *Headwall 2017 56% spectrum*
- ✓ 20230817_T24_Rice_EW- *Headwall 2017 56% spectrum*

- ✓ **Hyperspectral ortho-rectification using POSpac-corrected trajectory and DEM data**
  - ○ Aug 15
    - ✓ 20230815_T1_Cotton1_NS - *used SRTM DEM.*
    - ✓ 20230815_T2_Almond1_NS - *used SRTM DEM*
    - ✓ 20230815_T4_Cotton2_NS - *used SRTM DEM*
    - ✓ 20230815_T5_Cotton3_NS- *used SRTM DEM*
    - ✓ 20230815_T10_Almond2_NS - *used SRTM DEM*
  - ✓ Aug 16
    - ✓ 20230816_T12_Grape_EW- *used SRTM DEM*
    - ✓ 20230816_T13_Grape_EW- *used SRTM DEM*
    - ✓ 20230816_T14_Grape_NS- *used SRTM DEM*
  - ✓ Aug 17
    - ✓ 20230817_T7_Rice_organic_EW- *used SRTM DEM*
    - ✓ 20230817_T16_T15_Rice_NS - *used SRTM DEM*
    - ✓ 20230817_T17_T18_T19_corn_NS_Exp8ms - *used SRTM DEM*
    - ✓ 20230817_T24_Rice_EW - *used SRTM DEM*
- ✓ Write technical metadata content for hyperspectral products