Geometric and Radiometric Calibration Topics Relevant to Skybox Imaging

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outline

- satellite overview
- geometric calibration
  - RPCs that comes with L1B products
  - bundle adjusting Geo products to remove shear
- image quality - MTF
- radiometric calibration – bad pixels
- conclusions
SATELLITE OVERVIEW
These are the Skybox satellites

**SkySat-1**
- no propulsion
- launched on Dnepr, 21 Nov 2013
- ~600 km, 10:30 am sun sync orbit

**SkySat-2**
- no propulsion
- launched on Soyuz, 8 Jul 2014
- ~635 km, 9:00 am sun sync orbit

**SkySat-3**
- has propulsion
- current launch plans: 
  ~500 km, 9:30 am sun sync orbit
SkySat-3 has some improvements

SkySat-3 is our second generation satellite

SkySat-3 has some improvements:
- ~15 cm taller
- ~30 kg heavier

<table>
<thead>
<tr>
<th>SkySat-1, 2</th>
<th>SkySat-3</th>
</tr>
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<tbody>
<tr>
<td>reaction wheels</td>
<td>better reaction wheels</td>
</tr>
<tr>
<td>no propulsion</td>
<td>(5x slew rate)</td>
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<tr>
<td></td>
<td>propulsion</td>
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Skybox intends to launch more SkySat-3 class satellites!
SkySat-1, 2, and 3 use this focal plane

focal plane shown as projected to the ground!

“pushframe” sensor
entire arrays captured at each frame time

detector 2

detector 3

scan direction

detector 1
SkySats collect imagery like this

Aden, Yemen

north of the sub-solar point,
images are collected in this orientation,
with detector 2 lagging,
door down

animation frame rate set to 40 Hz, same as the real collect,
⇒ real time animation!
Skybox Imaging - approved for public release

SkySats collect imagery like this

Queenstown, New Zealand

south of the sub-solar point,
images are collected in this orientation,
with detector 2 leading,
door up

animation frame rate set to 40 Hz, same as the real collect,
⇒ real time animation!

RGB image courtesy of Landsat-8, bands 4, 3, 2
GEOMETRIC CALIBRATION
recall this focal plane collects pixels

![Diagram of detector layers:]

**detector 2**

- **PAN**
- blue
- green
- red
- NIR

**detector 3**

- **PAN**
- blue
- green
- red
- NIR

**detector 1**

- **PAN**
- blue
- green
- red
- NIR

**Scan direction**
L1Bs are made upon the PAN half

detector 2

PAN

each PAN tile is superresolved†, using 15-50 raw frames;
(exact number depends on ground scan rate of the boresight,
3.5 km/s ≈ when a point on the ground is seen in 15 frames)

detector 3

scan direction

detector 1

PAN

PAN

PAN

each MS band is registered to PAN, creating MS and pansharpen tiles
L1B RPCs match the rigorous model

project a point to the ground with the rigorous model...

...then unproject the ground location back into the image using the RPCs...

...and note the pixel coordinates are nearly the same:

$\Delta\text{line} = 0.084951$ rows

$\Delta\text{sample} = 0.035114$ columns
Skybox also makes Geo products

Geo product
L1B pixels projected to a constant height above geoid, then re-tiled

mosaicked! RPCs for each tile!

scan direction

PAN, MS, and pansharpened tiles
Geos are made from projected L1Bs

- projected L1Bs don’t fall in a perfectly straight line
- star tracker noise affects the georeferencing of individual L1B frames

(Attitude noise wildly exaggerated for emphasis)
bundle adjustment fixes the Geo

- tie points in overlap regions provide refinement
- a least squares fitter is tied into the projection model
  ⇒ quaternion (orientation, pose) for each anchor frame is rewritten
  ⇒ minimizes shear between anchor frames
    ! note how all three detectors are moved together, rigidly... sub-pixel interior orientation allows this! (see JACIE 2014 slides)

(least squares fit also wildly exaggerated for emphasis)
any collect can reveal the ECEF shear

North West Cape, Australia

SkySat-2 collection
20150413_7f6f4af34a4e

featured in the next slide
the ECEF shear is removed

ECEF shear (meters)

post-adjustment ECEF shear very low, but not zero

Why not zero? Because most tie points didn’t lie at that constant elevation above the geoid!
(although tie points with less than a meter of shear afterward probably did...)
IMAGE QUALITY

MTF
Skybox imaged Stennis, cloud-free!

multiple times by SkySat-1, two examples will be shown today:

- 20140409_163120_004000 - wideraw
- 20150126_27a255383ca5 - conventional

John C. Stennis Space Center (30.385571° N, 89.628521° W)
L1B processing preserves contrast

the L1B PAN tile was used for this MTF measurement

SkySat-1 collect
20140409_163120_004000

this was a “wideraw” collect, meaning the imagery was downlinked as tiff, NOT j2k

⇒ MTF not affected by j2k compression! Just the optics and superresolution† algorithm
pansharpen MTF was also checked
the L1B pansharpen tile was used for this MTF measurement

SkySat-1 collect
20150126_27a255383ca5

this was a conventional collect, meaning the imagery was downlinked as j2k

⇒ MTF influenced by:
  • optics
  • j2k compression
  • superresolution† algorithm
  • pansharpening algorithm

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MTF50 = 0.391 C/pxl = 1056 LW/PH

MTF30P = 0.461 C/pxl
MTF @ 0.25 C/P = 0.759
MTF at Nyquist = 0.19

graphs prepared by Dr. Mike Shearn

we’re working to reduce the blue sharpening...
bad pixels

RADIOMETRIC CALIBRATION
bad pixels spoil images and videos

radiometric artifacts are called many things: bad, hot, dead pixels

representative detector array

and they constantly appear due to radiation! (and rarely go away by themselves)
Skybox corrects bad pixels
bad pixels are typically discovered at three times:

1. **post-launch calibration** – “we expected trouble”
2. **add single** – specific product failures – “our QC/QA team found trouble”
3. **reassess all** – periodic investigation to find them - “Alexandra went looking for trouble”

**Timeline of bad pixel detection**

- **SkySat-1**
  - Launch SkySat-1
  - Post-launch cal
  - Post-launch cal
  - Add single
  - Reassess all
  - Add single

- **SkySat-2**
  - Launch SkySat-2
  - Post-launch cal
  - Add single
  - Reassess all

Bad pixels appear on **monthly** timescales, mostly from radiation

**Timeline prepared by Dr. Alexandra Chau**
bad pixels hover in Raw Videos

in an unstabilized Raw Video product, bad pixels dwell in a single spot

*Nishinoshima Island*

30 Hz Raw Video

*the bad pixel lived here on detector 2*
Raw Videos look better after correction applying the bad pixel mask during processing removes the artifact.
bad pixels traverse a pansharpen, MS

a bad pixel leaves a line of artifacts* in a pansharpen, it’s where the bad pixel lived in the raw MS frames

*similar effect to a bad pixel on a TDI sensor

number of artifacts proportional to the ground scan rate

SkySat-2 collect 20140808_79aa74dc14c9
~11 km outside Norberg, Sweden
pansharps look better after correction

all the artifacts are removed by applying the bad pixel mask to the MS raw frames, prior to pansharpening (note the PAN tiles never showed this, due to superresolution†)

number of artifacts proportional to the ground scan rate

SkySat-2 collect 20140808_79aa74dc14c9
~11 km outside Norberg, Sweden
CONCLUSIONS
conclusions

- SkySat-3 will be different than SkySat-1, 2 in these ways:
  - smaller pixels
  - increased agility to collect more area
  - propulsion for orbit stationing

- Geo products are corrected in post-processing – ECEF shear minimized at that height above geoid

- analysis of a wideraw L1B collect shows that our contrast/MTF is preserved by:
  - good construction; instrument is not misaligned, out-of-focus, etc
  - the superresolution\(^\dagger\) algorithm

- Skybox has mature processes for detecting and correcting bad pixels, in area collects and videos
references

† superresolution algorithm detailed in the following publication: