CENTER FOR ASTROPHYSICS | HARVARD & SMITHSONIAN

HARVARD UNIVERSITY

A Rapid and Automatic Orthorectification of MethaneAIR/MethaneSAT Imagery thorough the A-KAZE Algorithm

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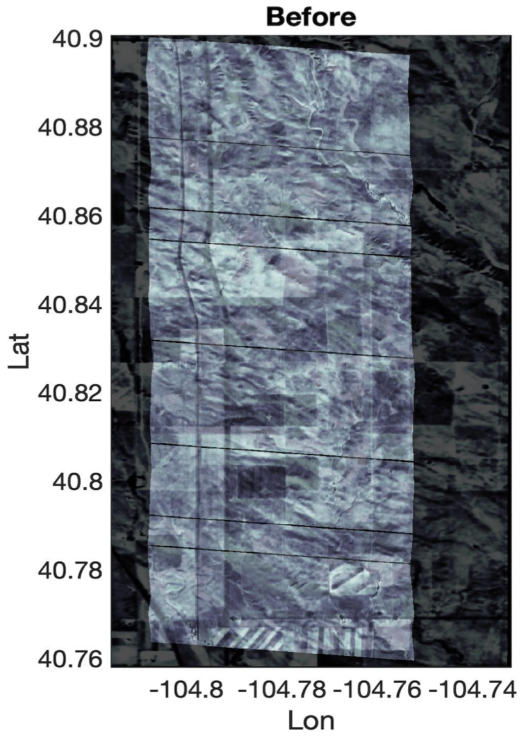
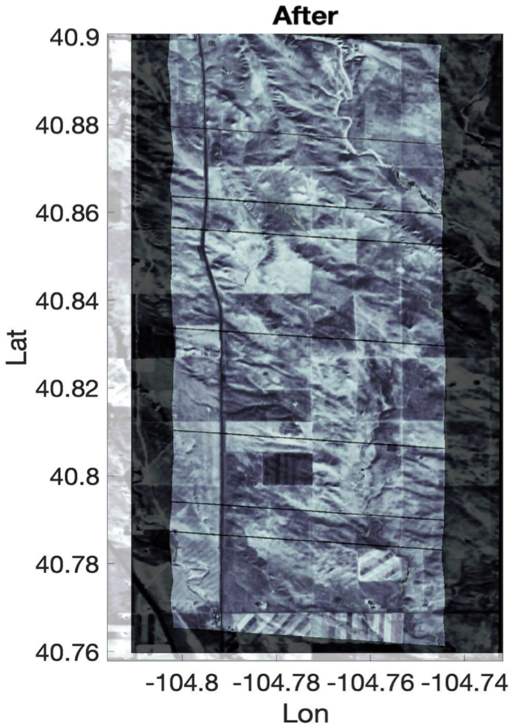
Geolocation errors are problematic in different ways:

i) Surface and atmospheric properties used in the retrieval may not represent the actual values.

ii) The geometry of the sensor is off resulting in a unrealistic air mass.





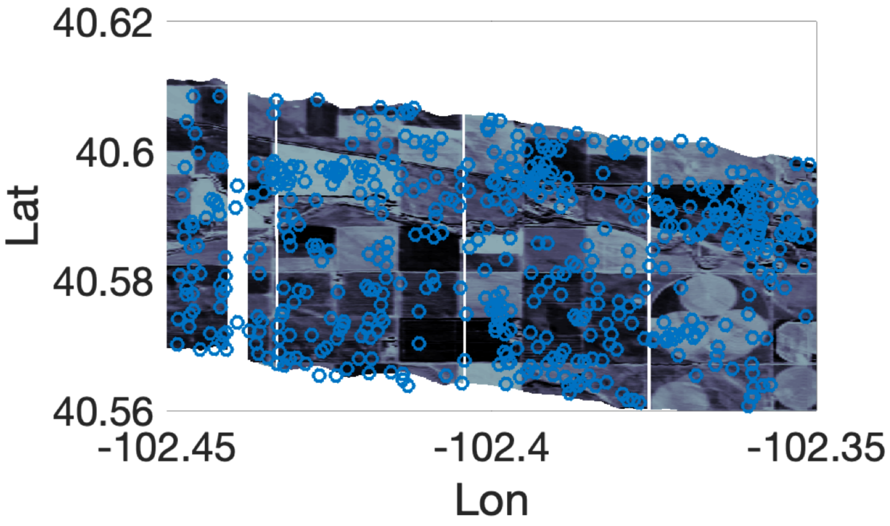
Automatic Geolocation Registration to the geo-rectified Landsat/MSI SWIR bands

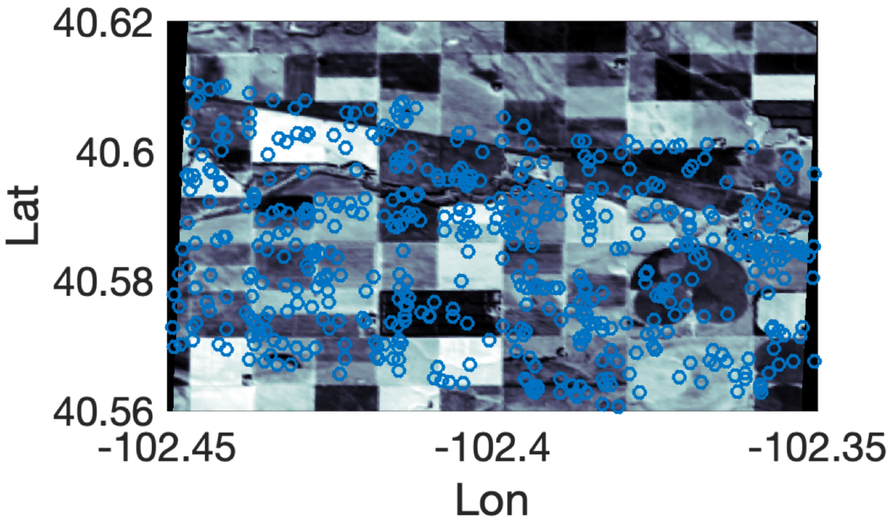
- Enhance Contrast
- Apply A-KAZE algorithm to get keypoints
- Match keypoints based on Hamming distance
- Remove outliers using RANSAC
- Estimate offsets and scales between two bands

Constrain **viewing geometry** and **the location of the sensor (known as exterior parameters)** using the estimated offsets/scales through Nelder-Mead optimization algorithm

Overview of the algorithm

- Accelerated-Kaze (A-Kaze) algorithm identifies image features (key points) and transforms them into 3 bits describing gradients/orientation with respect to neighboring pixels:
  - Find local minima/maxima (key points) using a non-linear diffusion filter
  - Compute the orientation and magnitude associated with each key point
  - Compute descriptors for each key point based on surrounding pixels and encapsulate them in 3 bits
  - Match key points between two images based on Hamming distance
  - Apply RANSAC to find a robust linear relationship between two paired images.

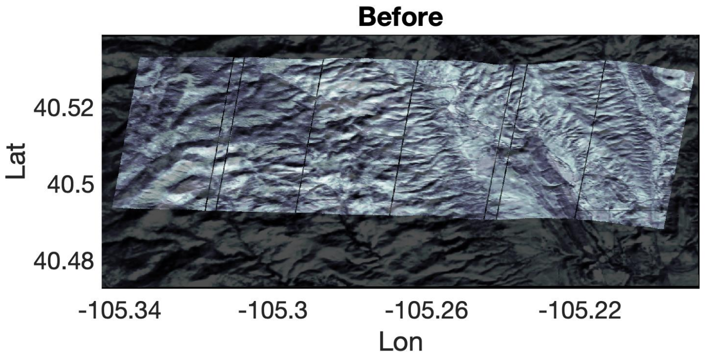


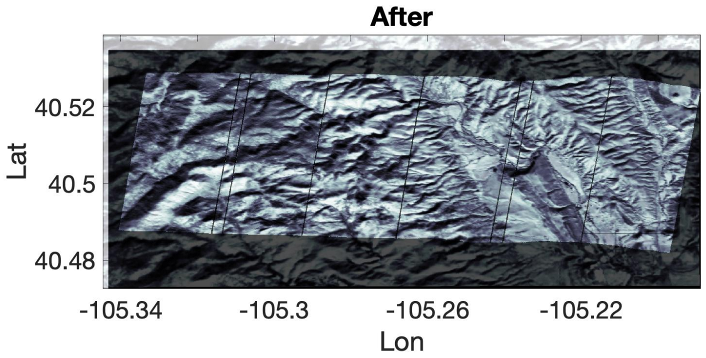


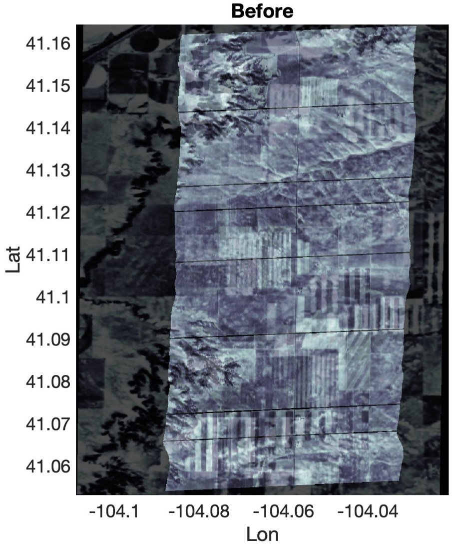
Datasets

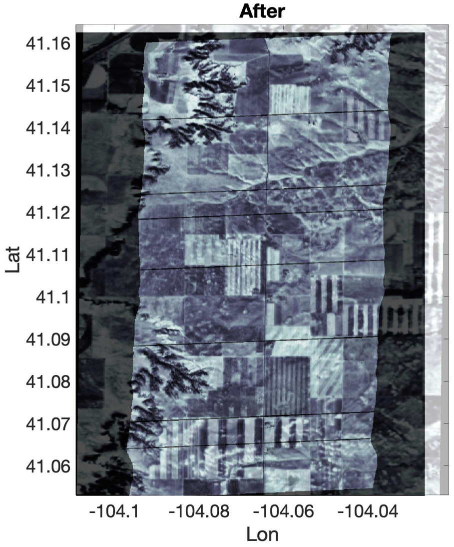
- Experiments have been conducted on both MethaneAIR O_2 and Landsat band 6 (1570-1650 nm) channels.
  - This indicates that we consider Landsat band 6 as a reference image and attempt to geographically register MethaneAIR O_2 correspondingly.
- We also have performed the image matching to stitch MethaneAIR CH_4 channel to O_2 , as there are significant offsets due to the differences in physical orientation of the detectors (known as bore-sight offset).
- It is advantageous to enhance the image contrast using an adaptive histogram equalizer.

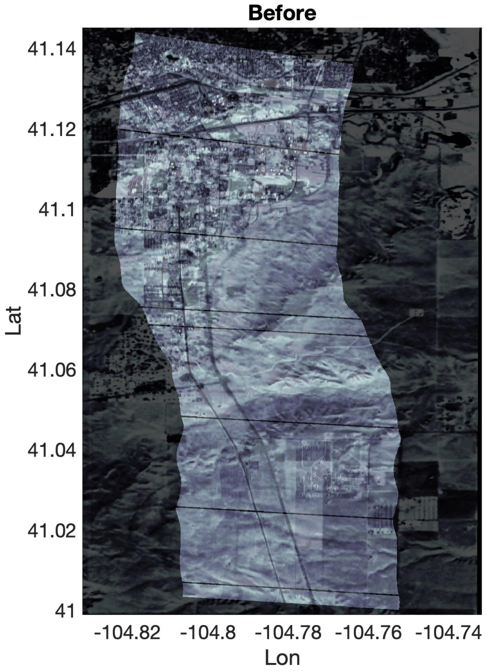
Examples (background: Landsat, foreground: MethaneAIR, 99% of cases were registered correctly on RF02 and 92% on RF01.)

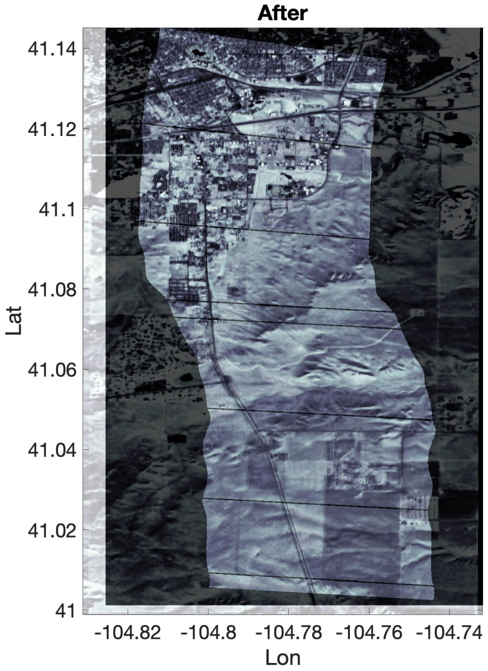


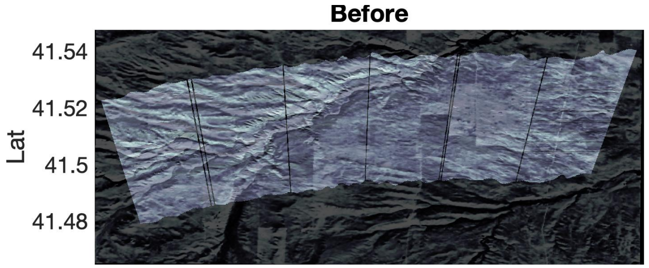


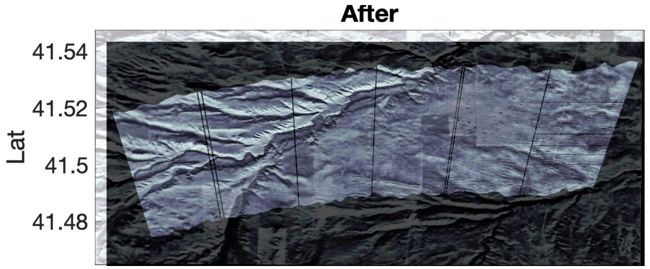


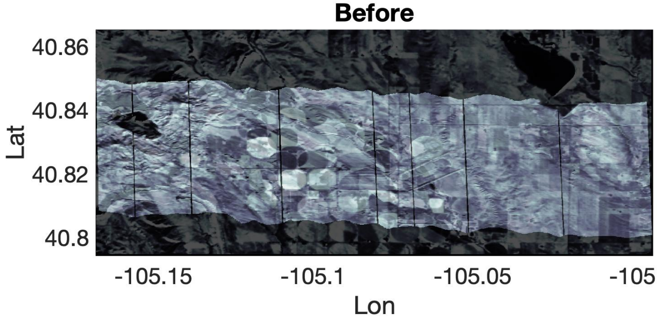


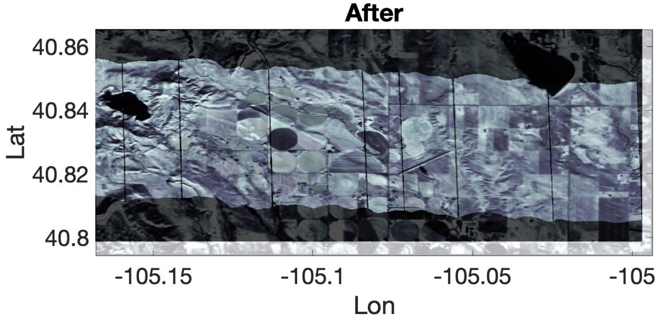








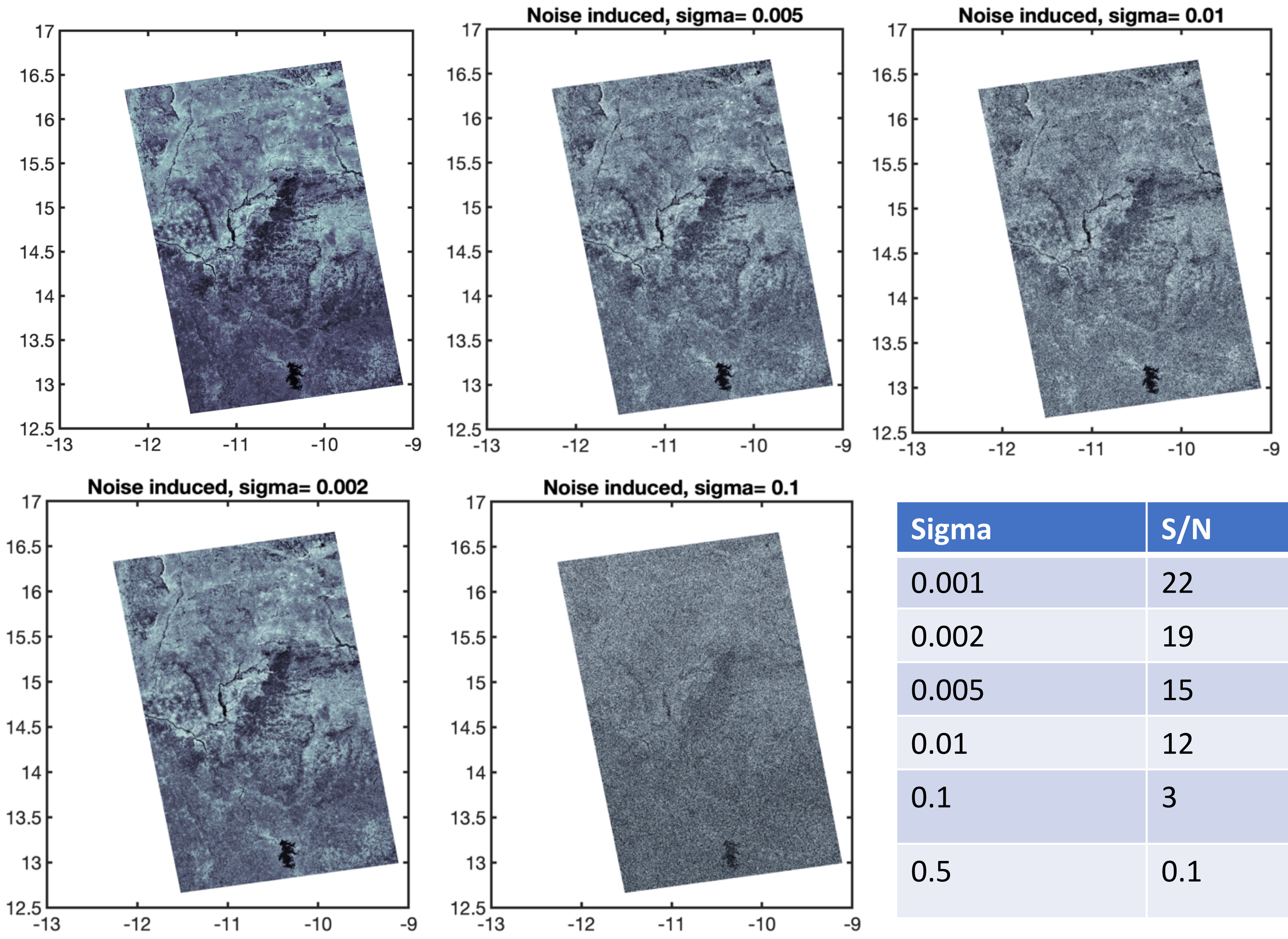




Geolocation – Experiments with MSI from MethaneSAT's view

- MSI Band 11 (1.614 μm on S2A and 1.610 μm on S2B) reflectance.
  - Downloaded and upscaled (from 15x15 m^2 to ~400x400 m^2) using google Earth engine.
  - Averaged over 2020, cloud-free.
- MethaneSAT geolocation from the orbit simulator
- Perturbed MethaneSAT geolocation (way more pessimistic than Ball's prediction)
- Cloud Fraction from GFS (0.25 degree)
  - Filtered out CF<20%
  - This is really pessimistic, we are losing 80% of clear pixels in that grid.
  - 0.25 degree consists of roughly 67x67 grid cells with 400 m^2 resolution.
  - So 80% will provide roughly 3600 pixels in 400 m^2 resolution.

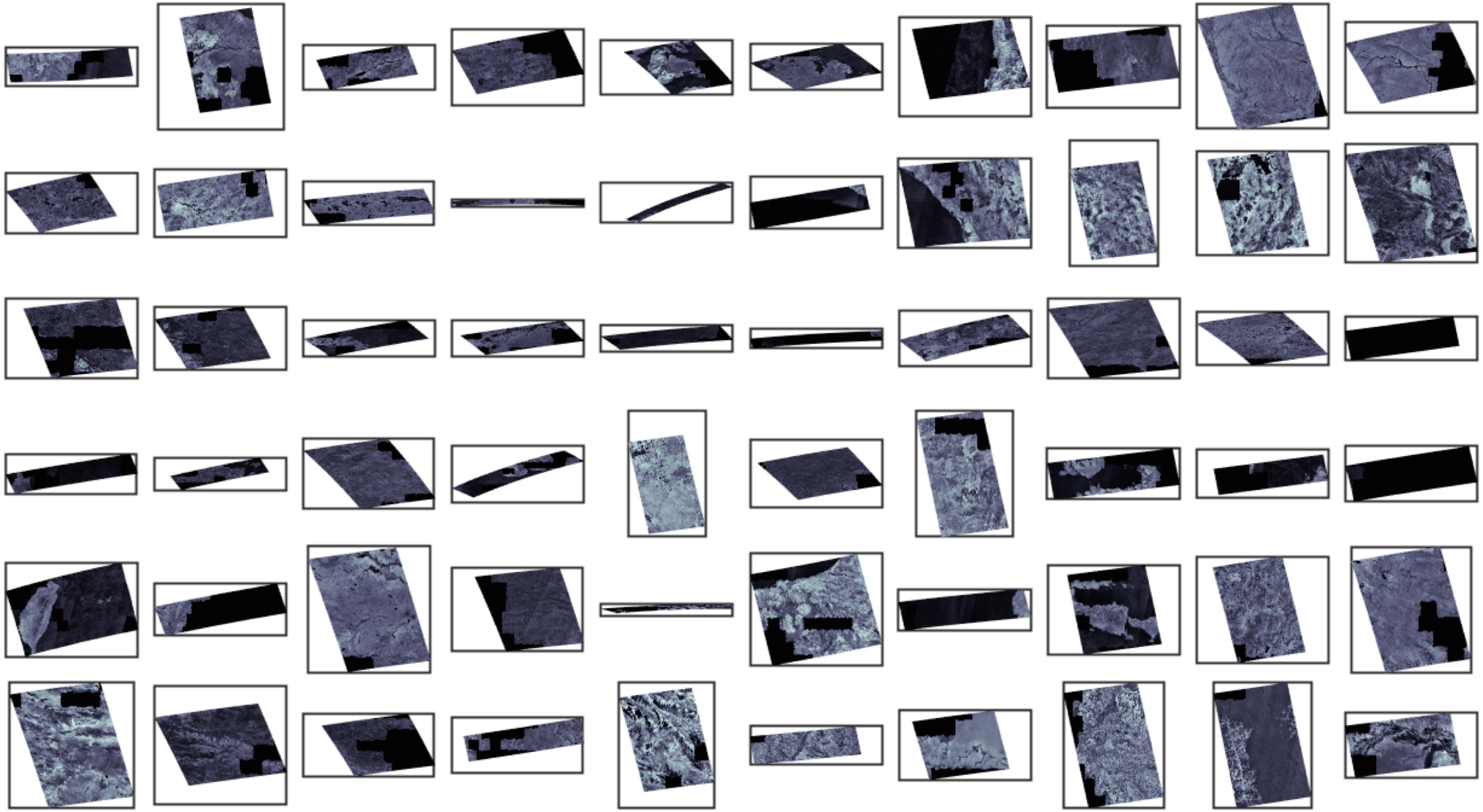
Sensitivity of AKAZE to noise



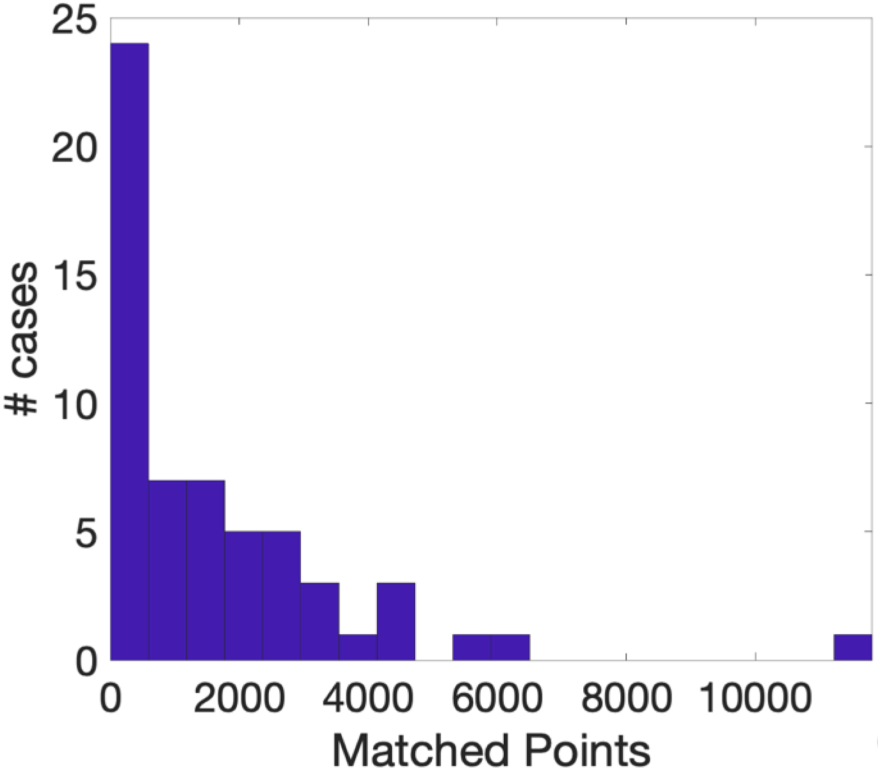
- AKAZE is able to deal with noise due to the quadratic function used during the keypoint selection.
- MethaneSAT will aim for S/N around 1000
- Any subgrid offset(< a pixel) is mostly a result of RANSAC or numerical diffusion.
- Noise will not get in the way of the geolocation algorithm from properly working.

Sigma	S/N	Keypoints	Offsets
0.001	22	3030	<30 m
0.002	19	2748	<52 m
0.005	15	2546	<37 m
0.01	12	2573	<75 m
0.1	3	2606	failed
0.5	0.1	2712	failed

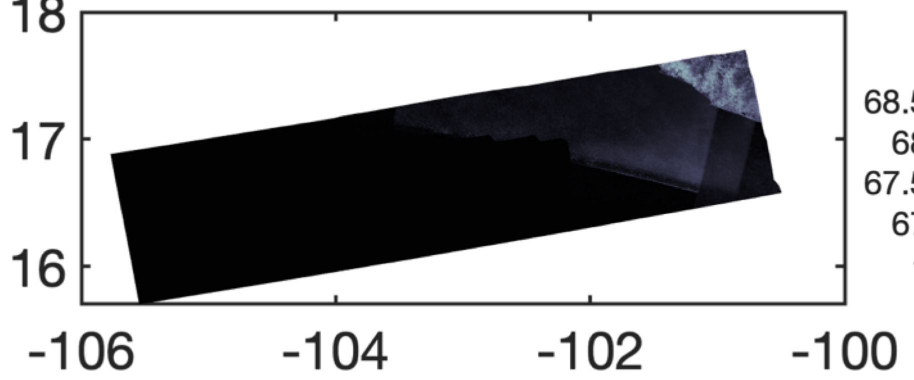
S/N = 25, CF<20%, 60 cases



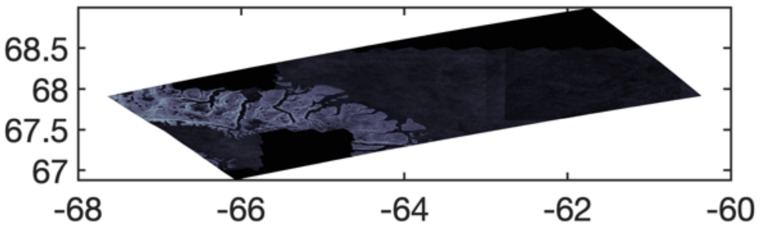
- 7 out of 60 failed (> 1pixel) = 88% success rate



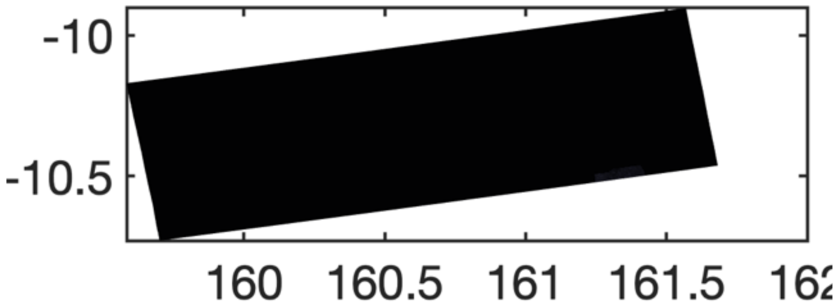
1.5 pixels



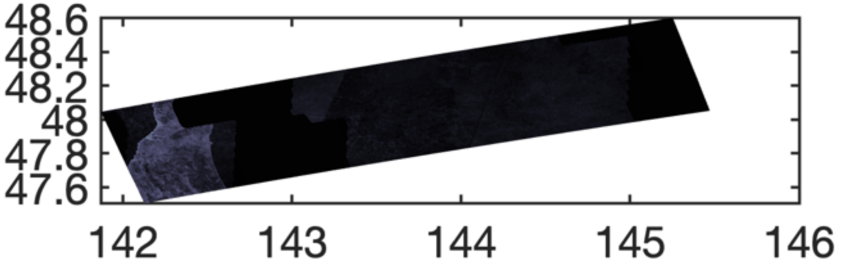
1.2 pixels



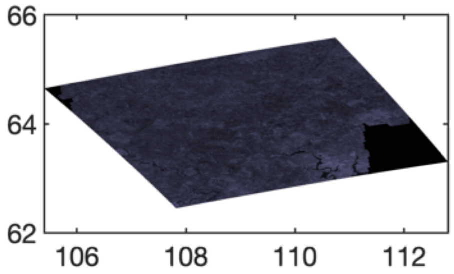
Failed



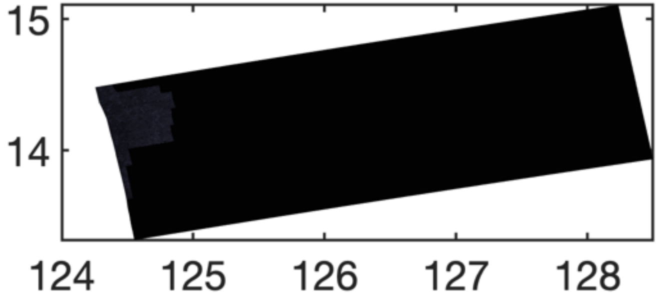
Failed



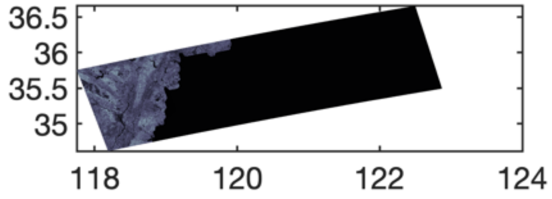
1.1 pixels



Failed



1.4 pixels

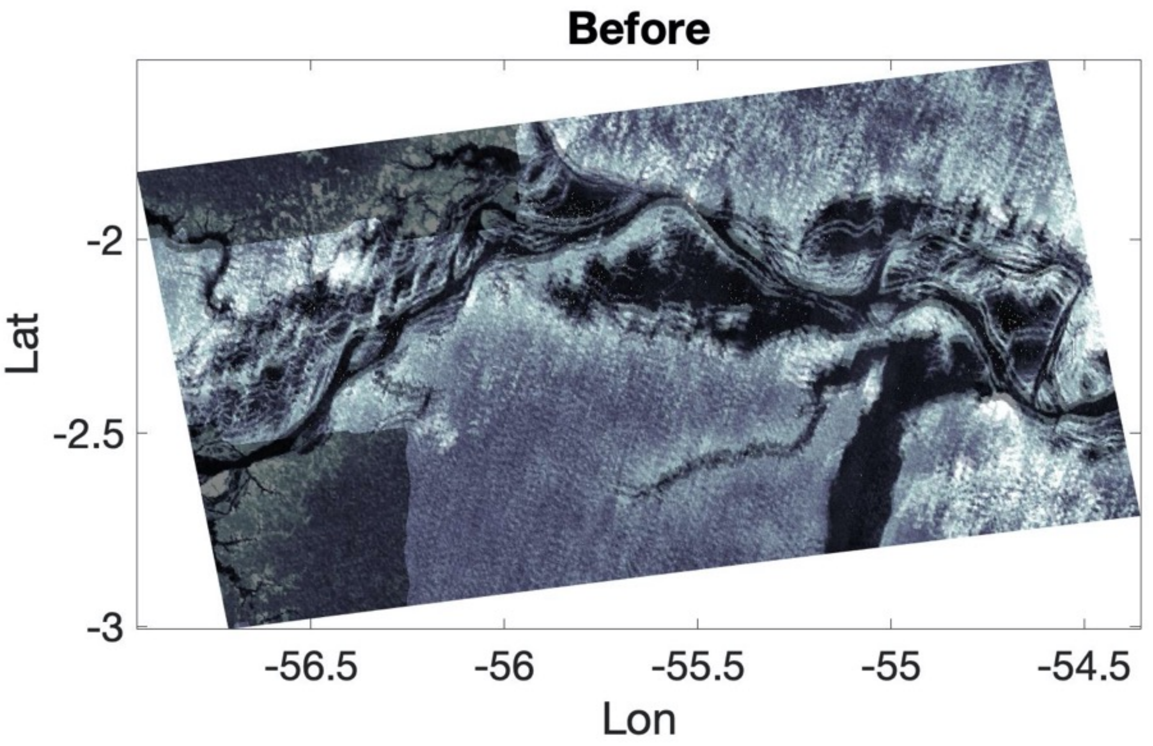


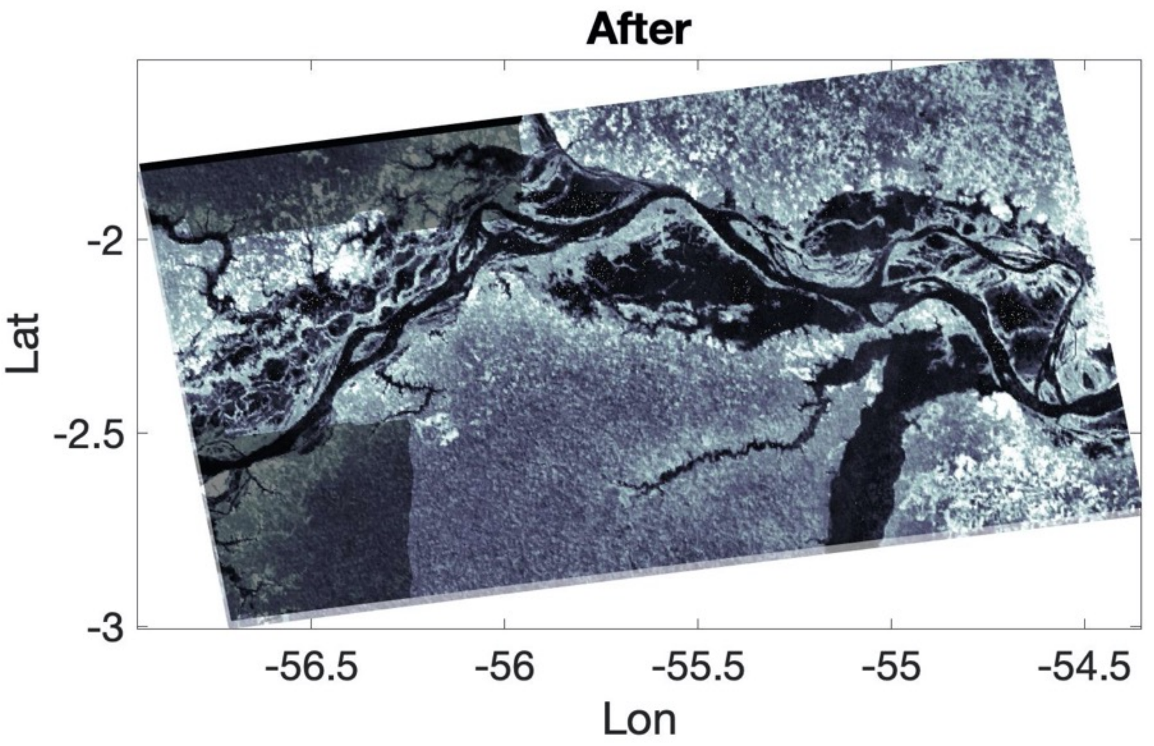
Backup

Sensitivity of AKAZE to cloudiness

CF cut off	Keypoints	Offsets
2%	662	<180 m
7%	856	<67 m
12%	1186	<46 m
17%	1251	<87 m
22%	1411	<150 m
27%	1611	<22 m

- Expectedly, keypoints are fewer for stricter thresholds
- We should be able to apply akaze, as long as the whole scene isn't fully cloudy.


Before
Lat
-2
-2.5
-3
-56.5
-56
-55.5
-55
-54.5
Lon


After
Lat
-2
-2.5
-3
-56.5
-56
-55.5
-55
-54.5
Lon

Summary

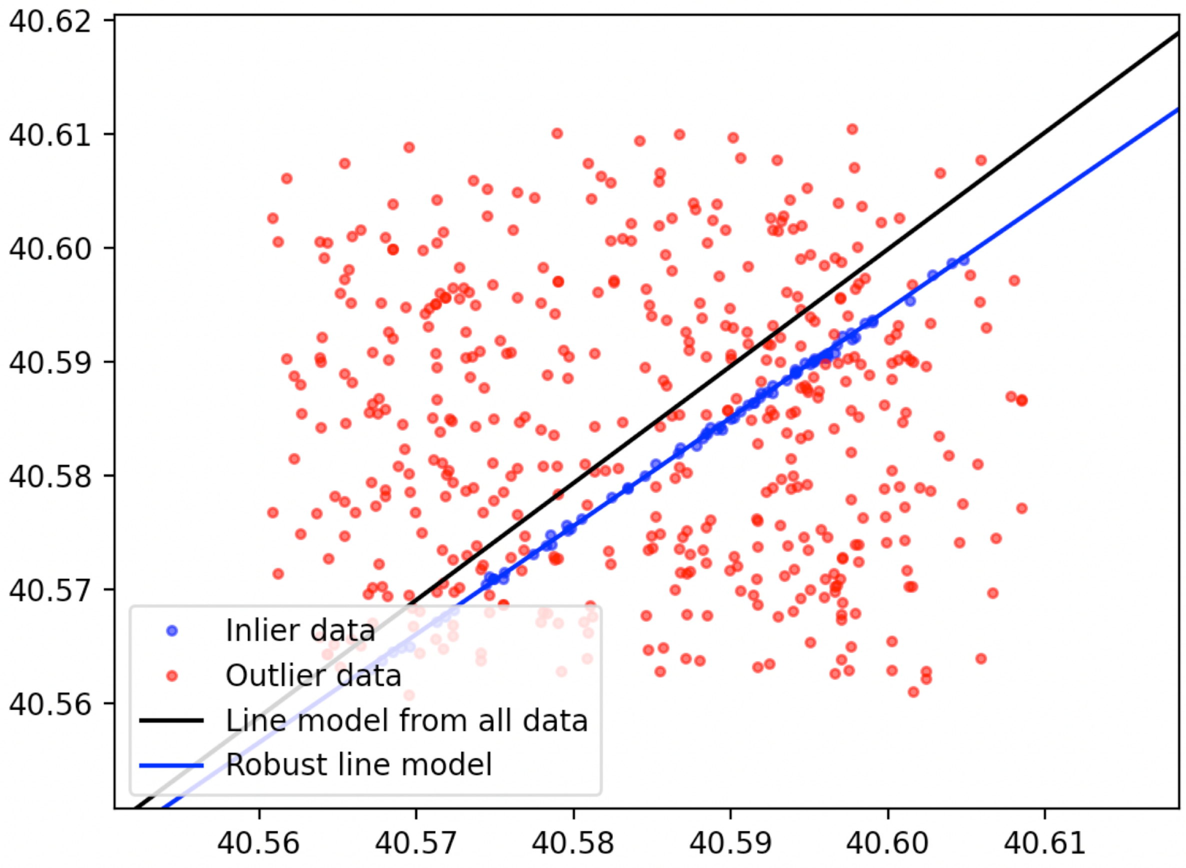
- AKAZE can handle low S/N (40 times lower than MethaneSAT) if we assume noise is dominantly a white noise.
- MethaneSAT swath is large enough that we can still extract a good number of keypoints in cloudy areas

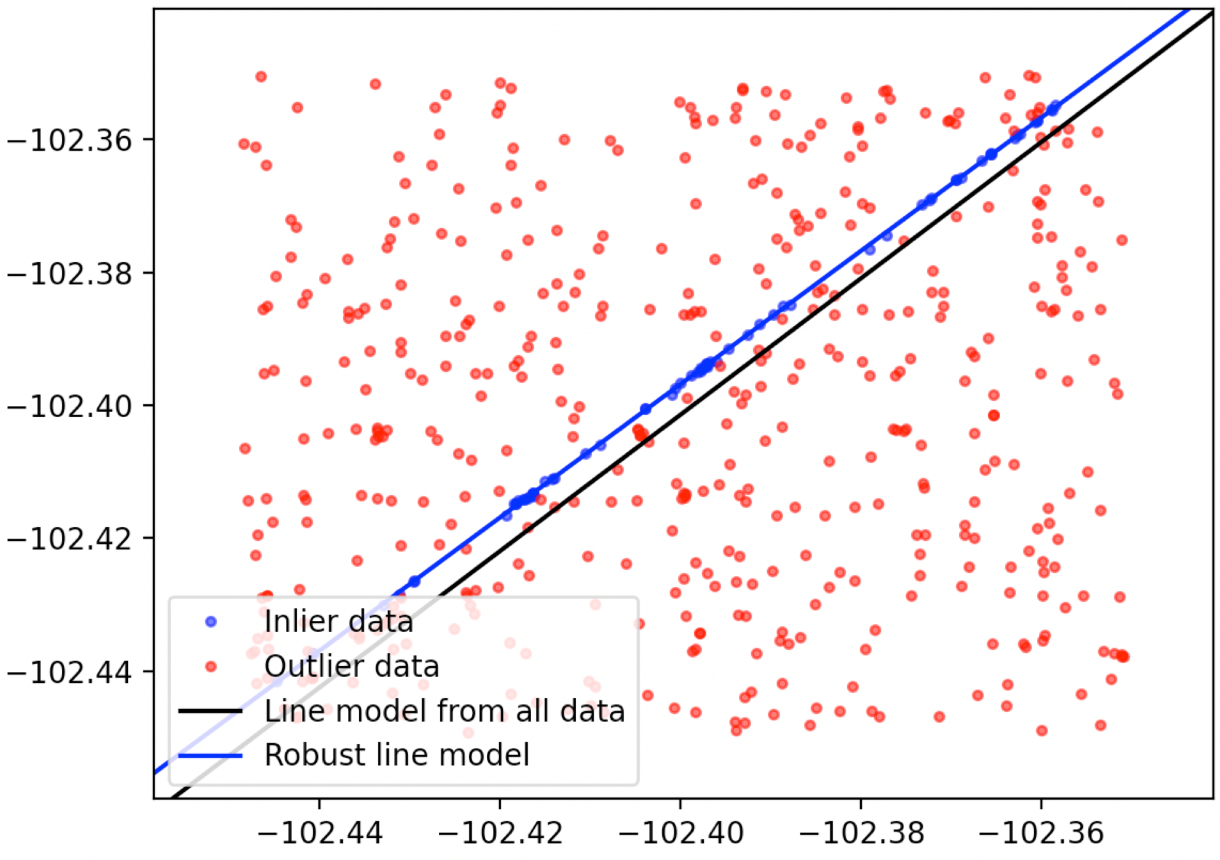
Fully cloudy scenes will obviously fail

We may have problems in offshores and snowy regions if we're aiming geolocation error < 1 pixel.

No data over ocean (offshores, or shallow areas have values from MSI).

Remove outliers





- We then fit a linear regression to matched latitudes and longitudes (<u>two scales and two offsets</u>).