



Relative Geolocation Accuracy Topics Relevant to DigitalGlobe's Multiband Satellites:

Camera Calibration, Band to Band Registration

Dr. Byron Smiley
DigitalGlobe



outline

- camera calibration methods
 - how to check imagery and detect issues (WV02 correlation to WV01)
 - how to correct issues (cameraCal animation)
 - how to check again (making sure you did what you think you did)
 - WV02 correlation to WV01
 - criss crosses
 - WV02 correlation to WV02
 - WV01 correlation to WV01
- band to band registration
 - what it is
 - measurement of post calibration band to band registration
 - correlating each MS to PAN
 - band to band histograms

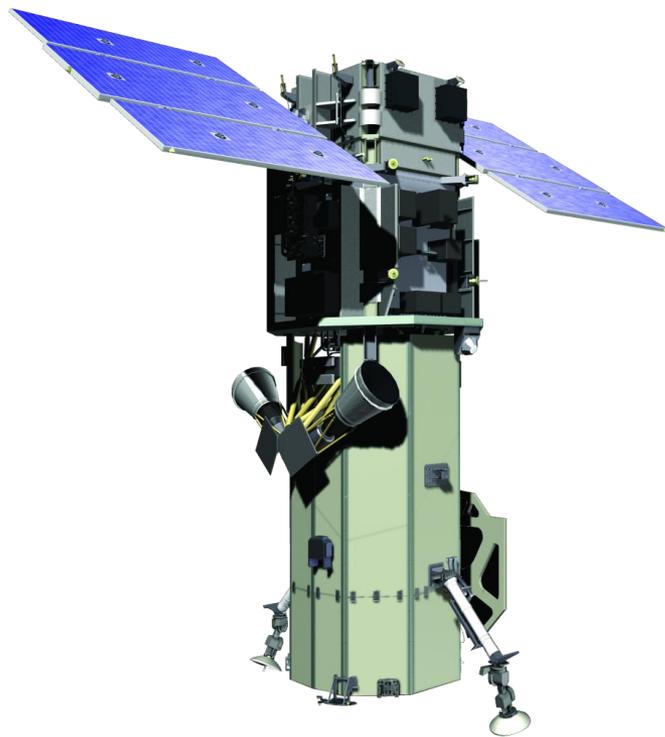


(PAN) camera calibration



step 1: looking for trouble

At launch, the last few PAN camera parameters are unknown



Most of the WV02 camera model is known in advance:

- ✓ detector mountings
- ✓ attitude quaternions
- ✓ prelaunch estimate/measurement of focal length

However, crucial parts for best relative geolocation accuracy are still unknown:

- × final focal length
- × optical distortion correction



methods are needed to complete the PAN camera model

Solution: take a picture of the desert!

Many places work for this...

this location will be revealed for discussion:

Atacama1

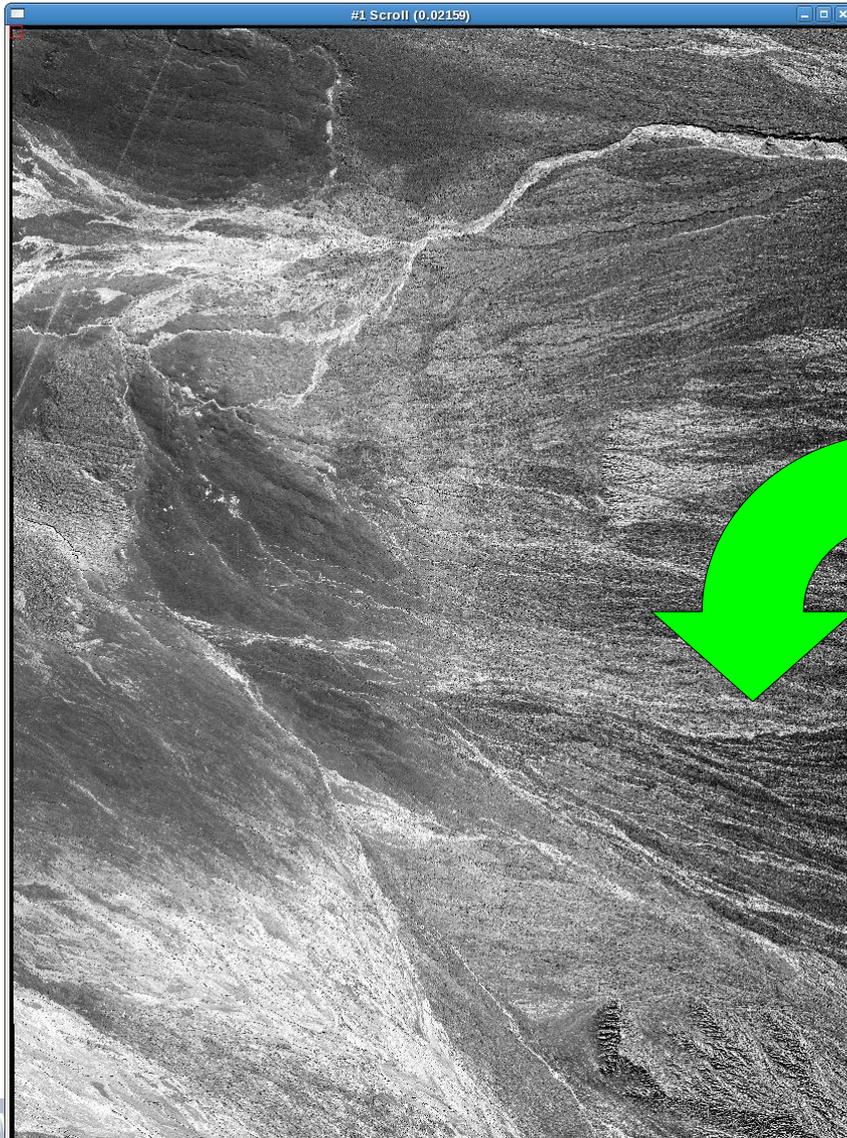
latitude: -21.513818°

longitude: -69.293876°

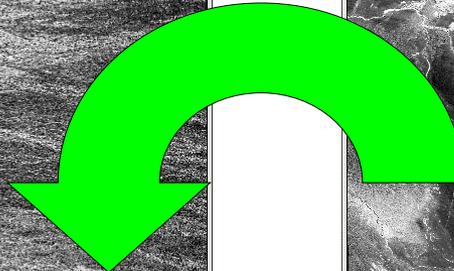


how to check for PAN camera issues

WV01 reference strip



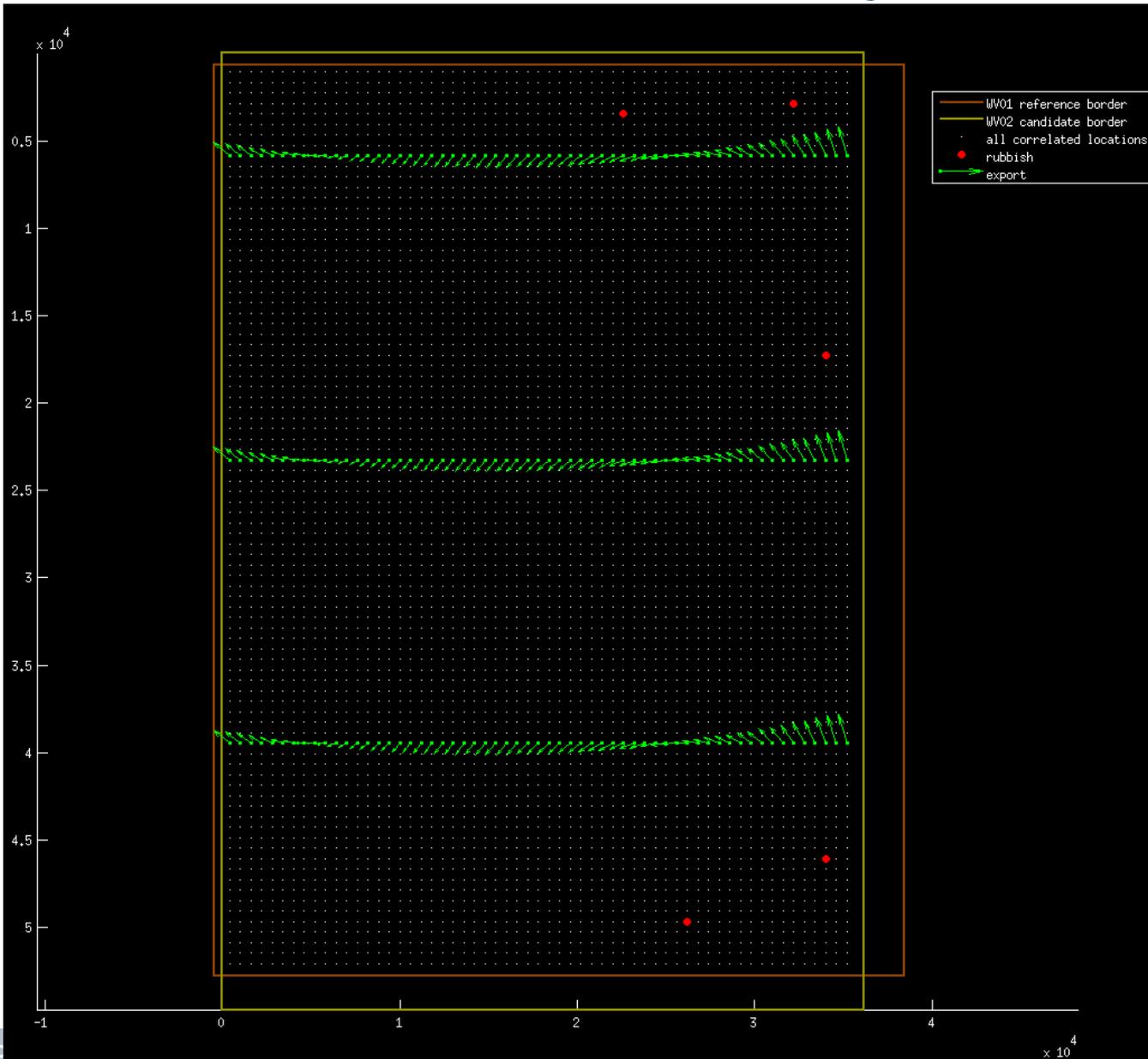
WV02 candidate strip



correlation to a
WV01 reference
reveals...



real camera calibration data just after launch

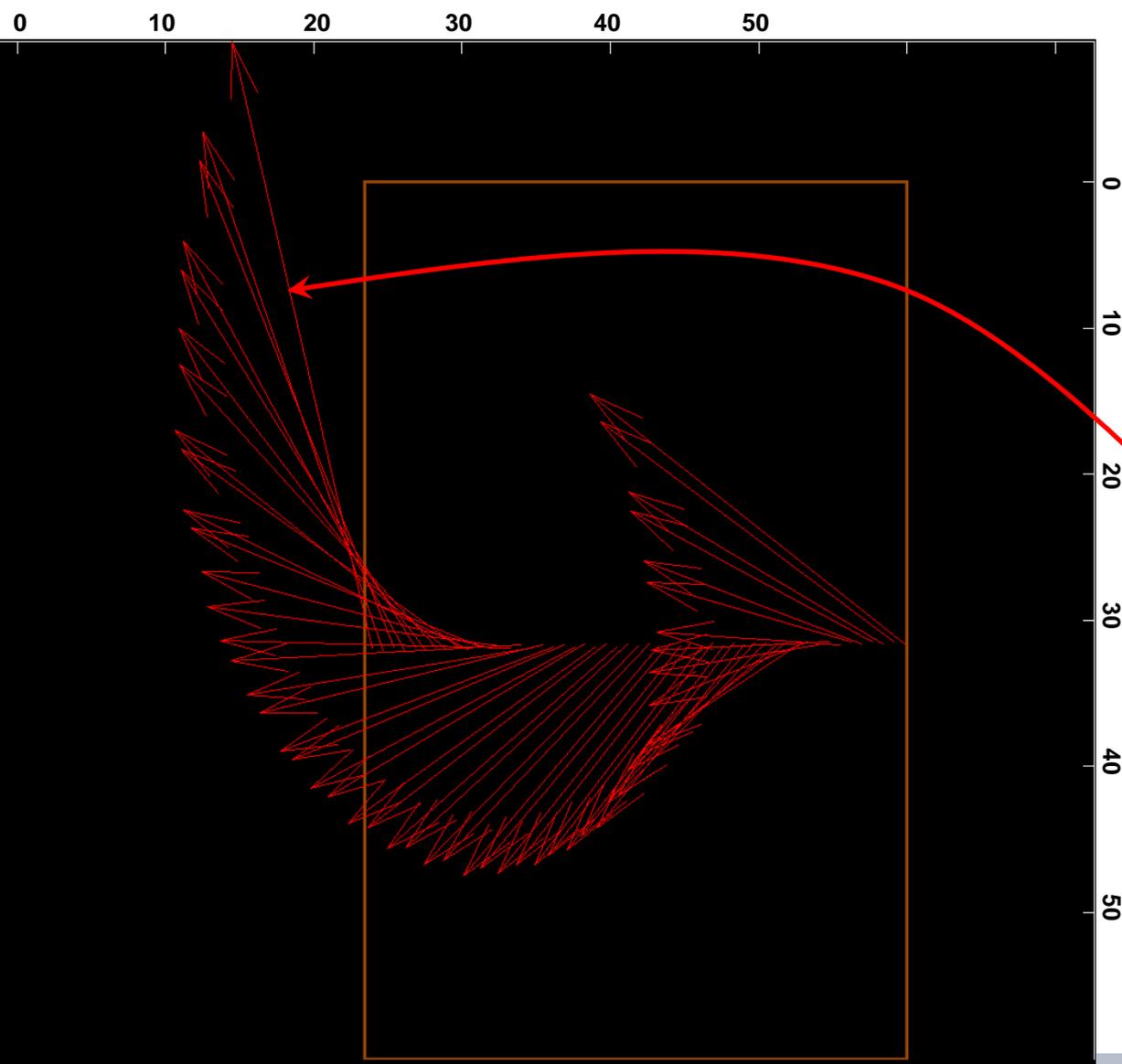


correlated on a 600
PAN pixel grid

WV02 obviously a
pushbroom imager,
line doesn't matter



same data reverse transformed back into the camera frame, at nadir

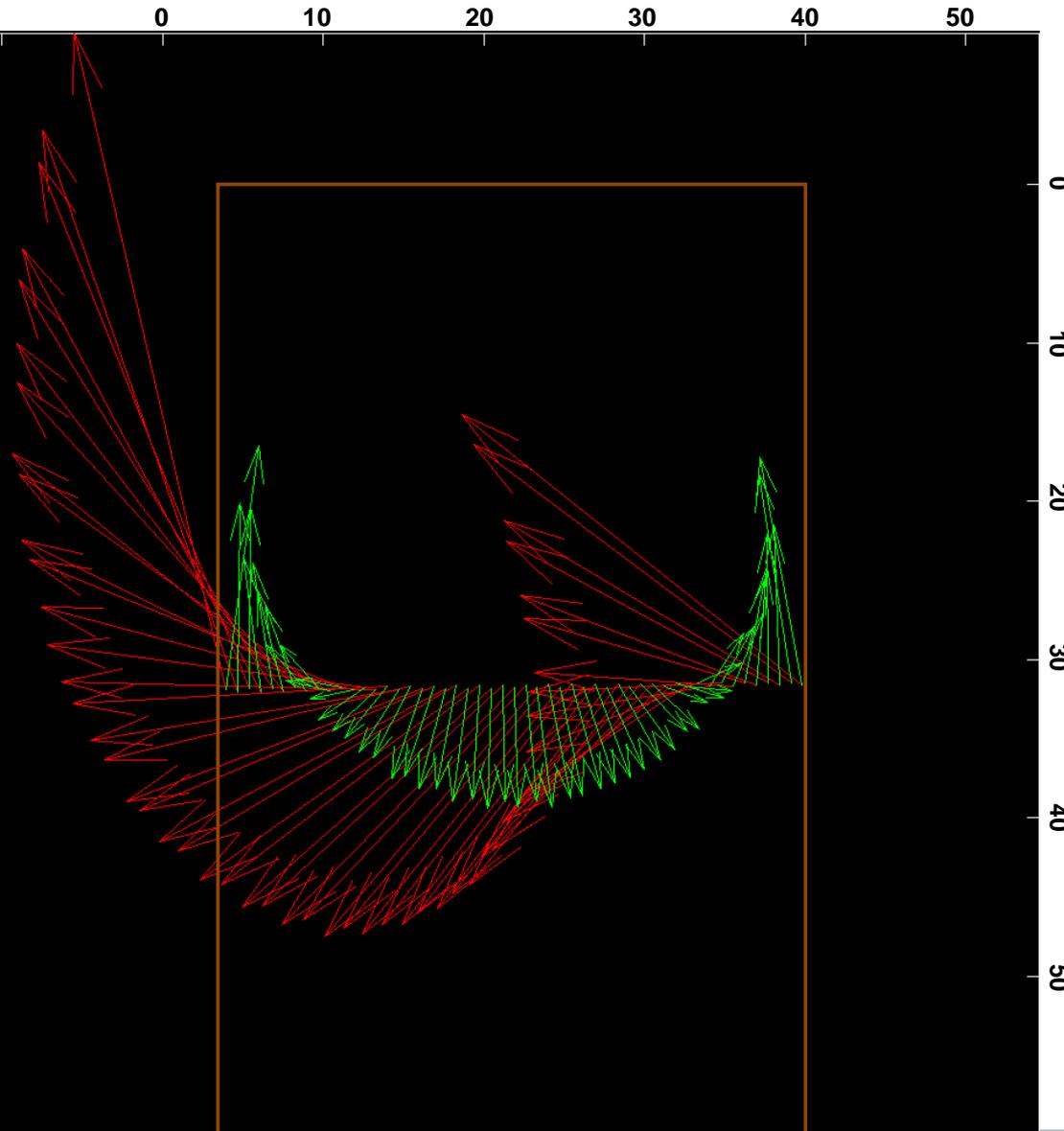


units are
kilometers for strip border
meters for error vectors

9.43 meters horizontal
41.4 meters vertical
(!)



removing the average error isolates the distortion

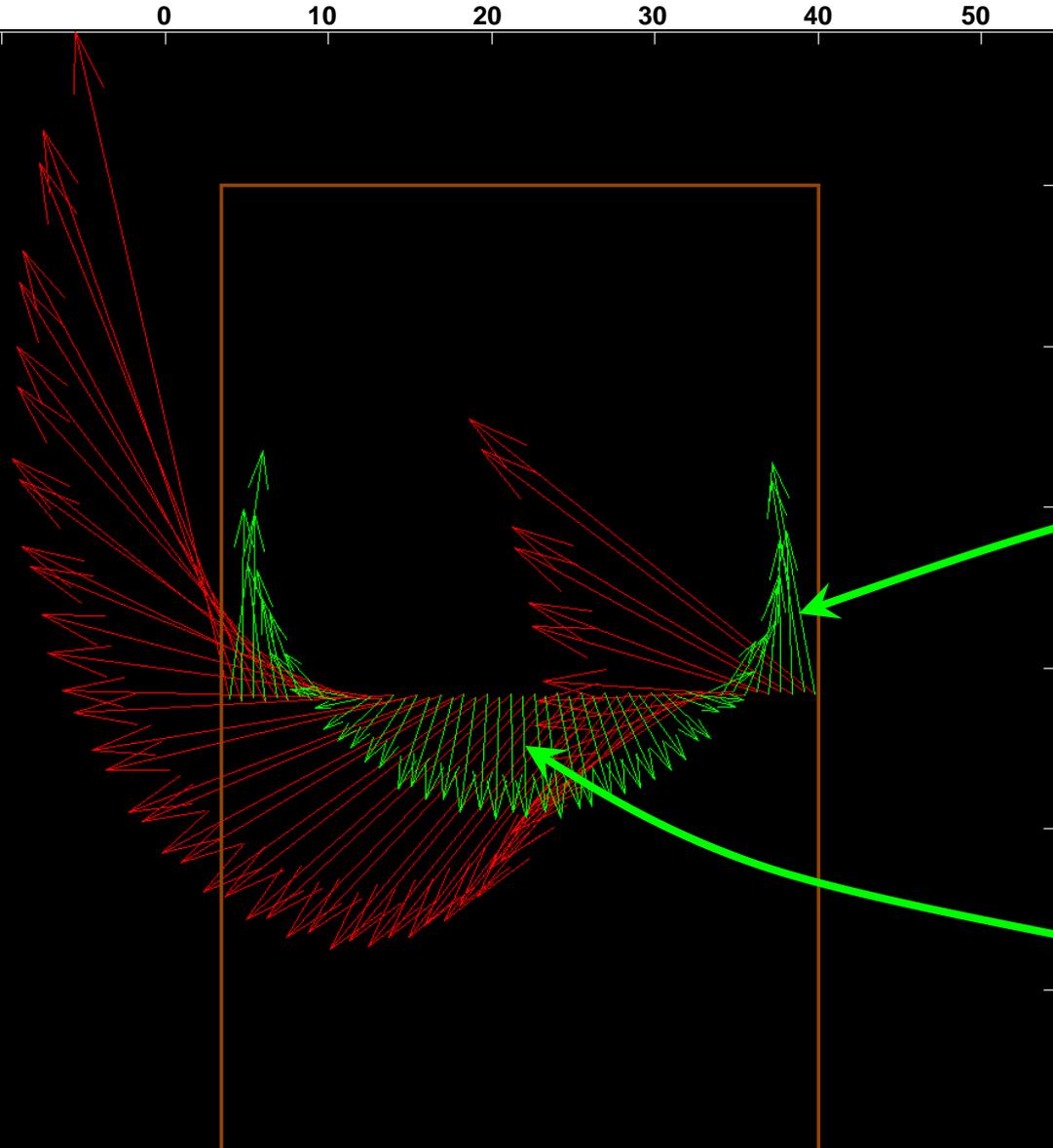


units are
kilometers for strip border
meters for error vectors

red: before "attitude detrending"
green: after "attitude detrending",
(fancy talk for removing bias with direct
attitude manipulation)



removing the average error isolates the distortion



units are
kilometers for strip border
meters for error vectors

horizontal: 2.03 meters
vertical: 15.4 meters

horizontal: 0.27 meters
vertical: 7.54 meters

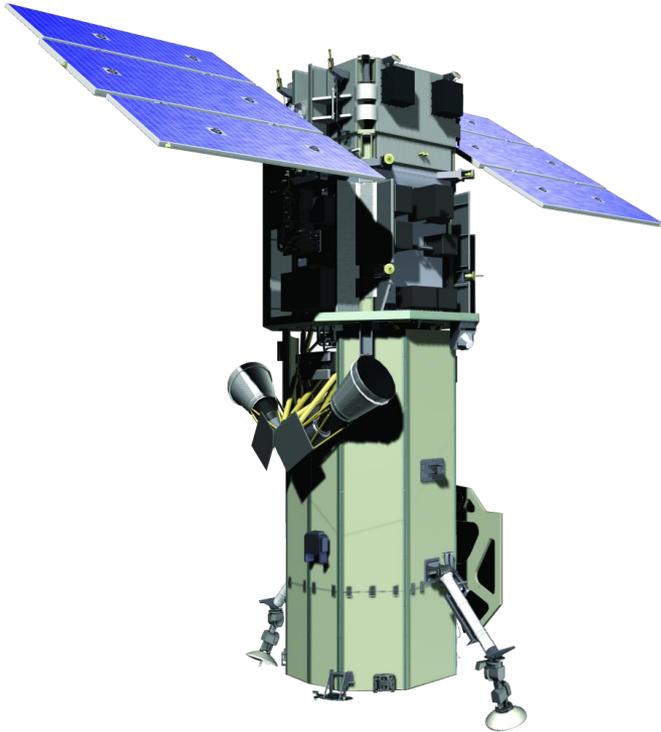
(!)



step 2:
removing the PAN camera distortion
or, fixing the relative geolocation accuracy



PAN camera distortion evident, cannot be ignored

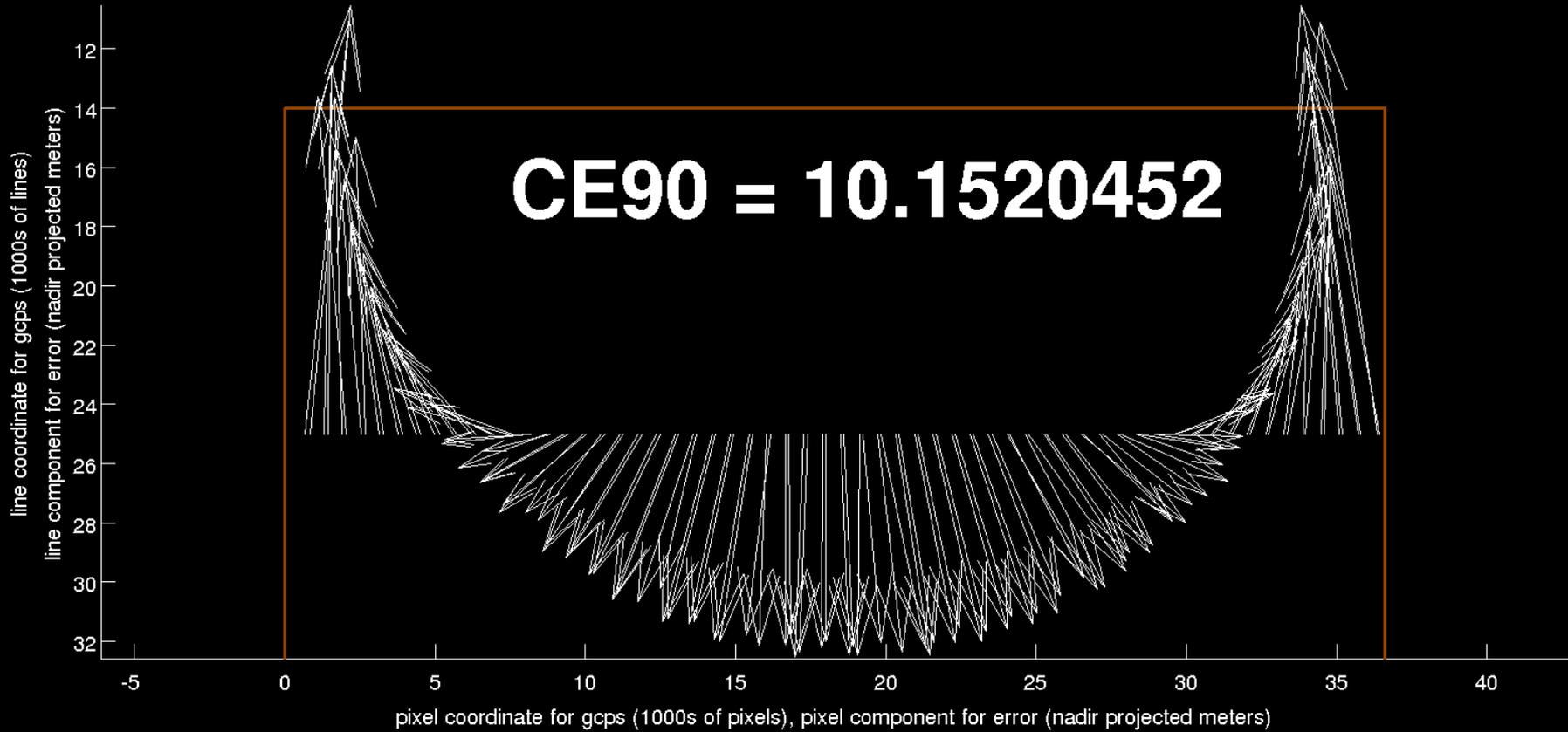


Time to find those parameters (as quickly as possible)!

- final focal length
- final optical distortion correction

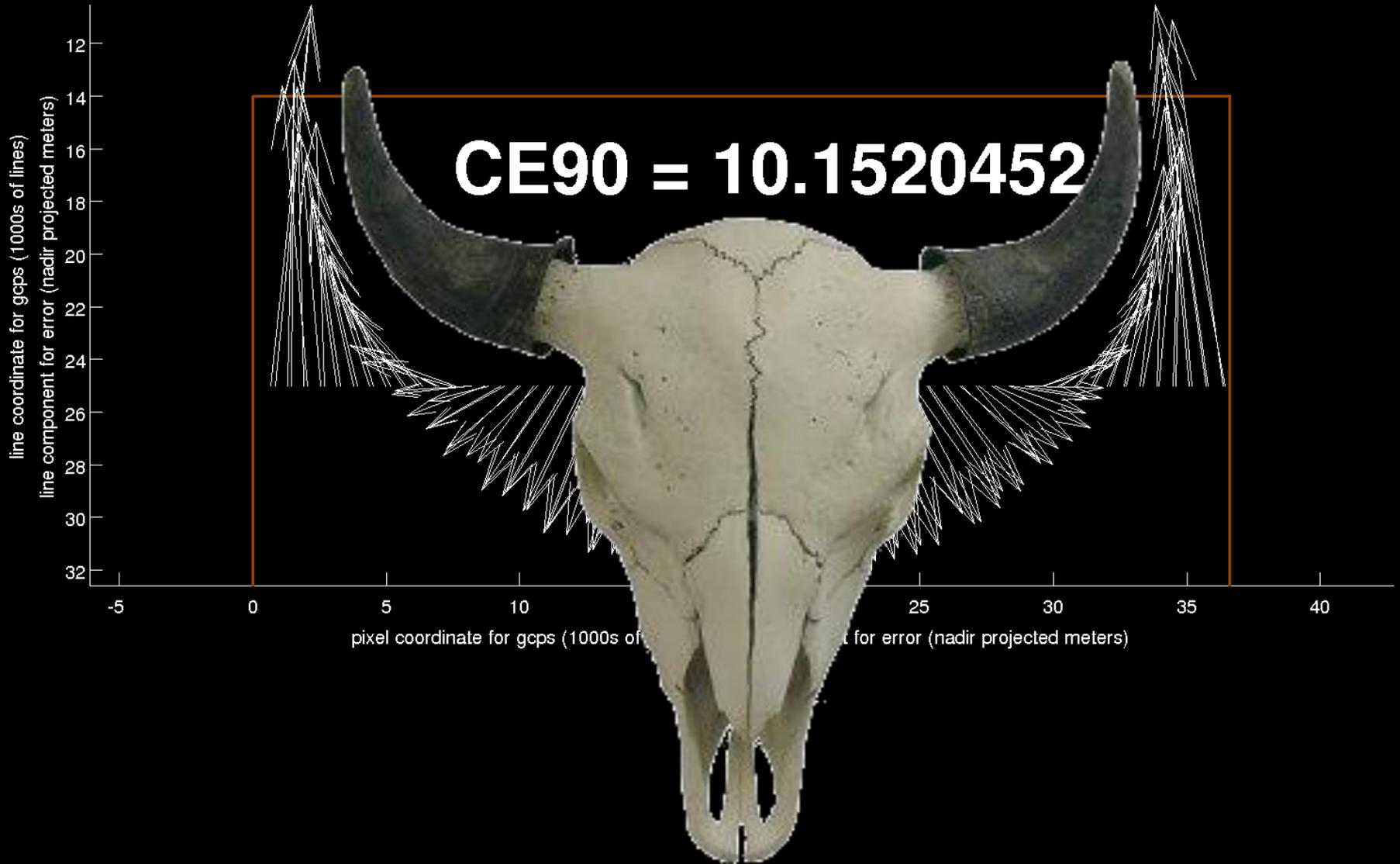


first step is (re)fitting focal length



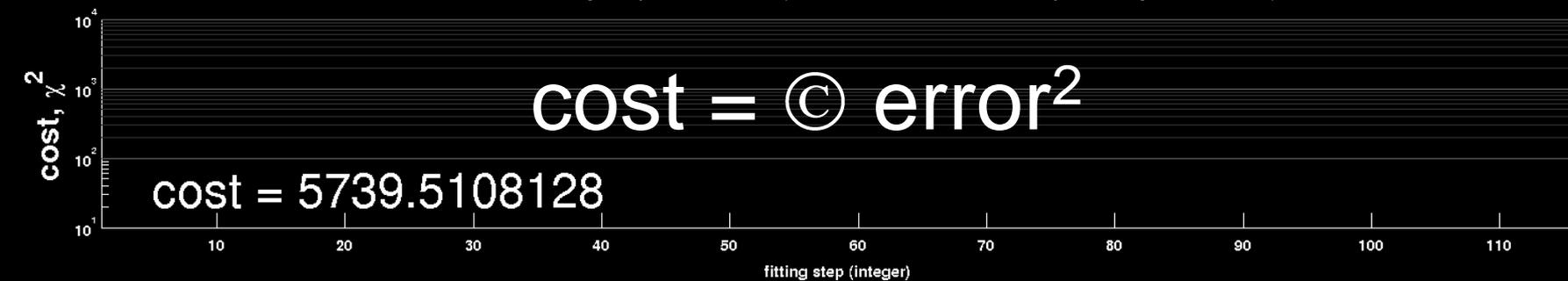
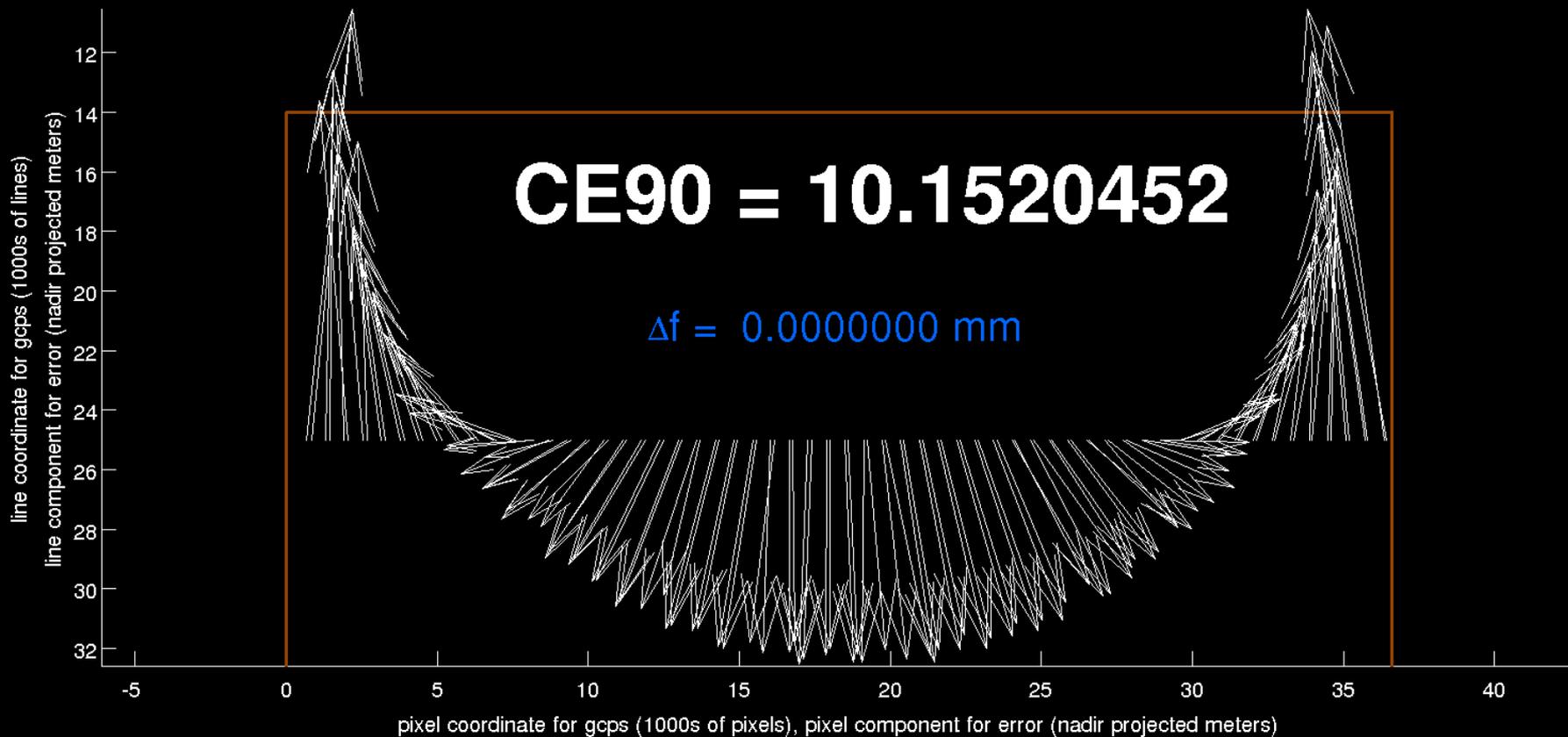


More bovine error sources?





first step is (re)fitting focal length





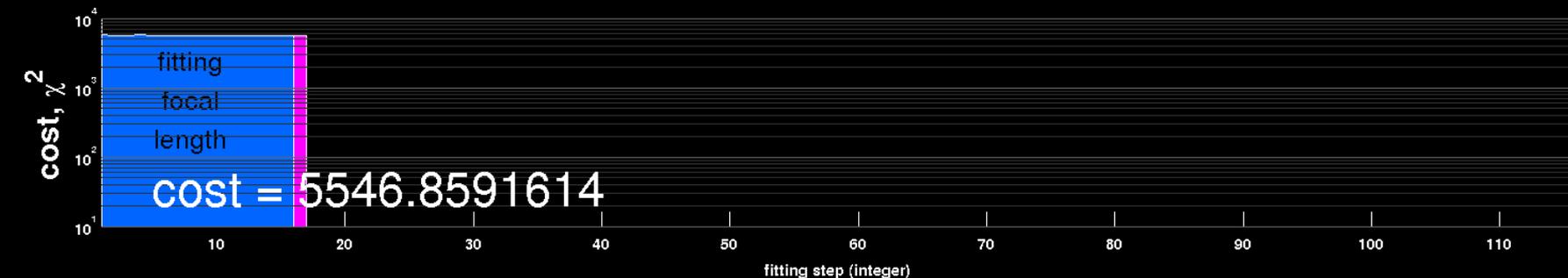
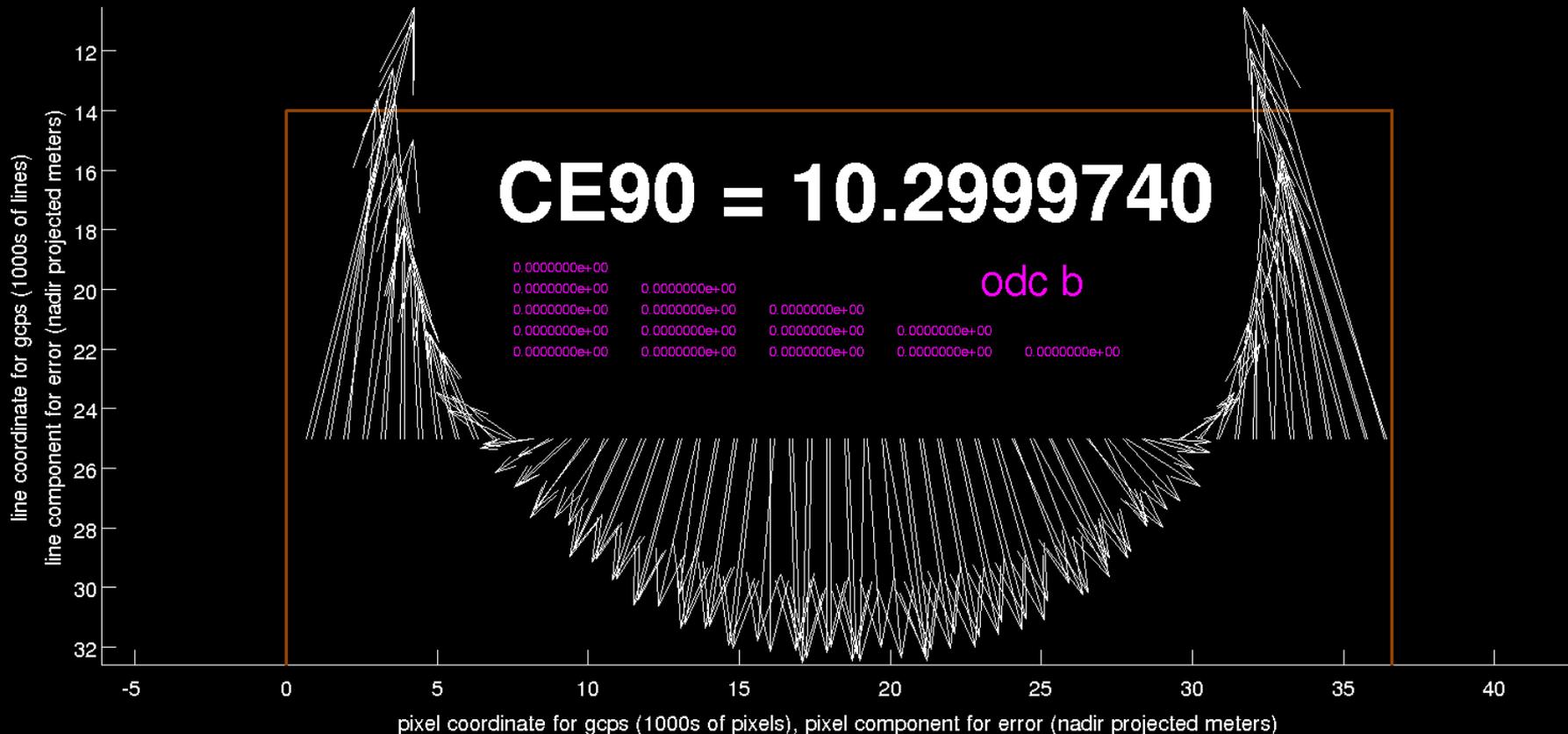
(re)fitting focal length: animation





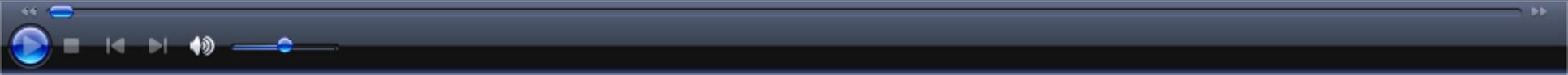
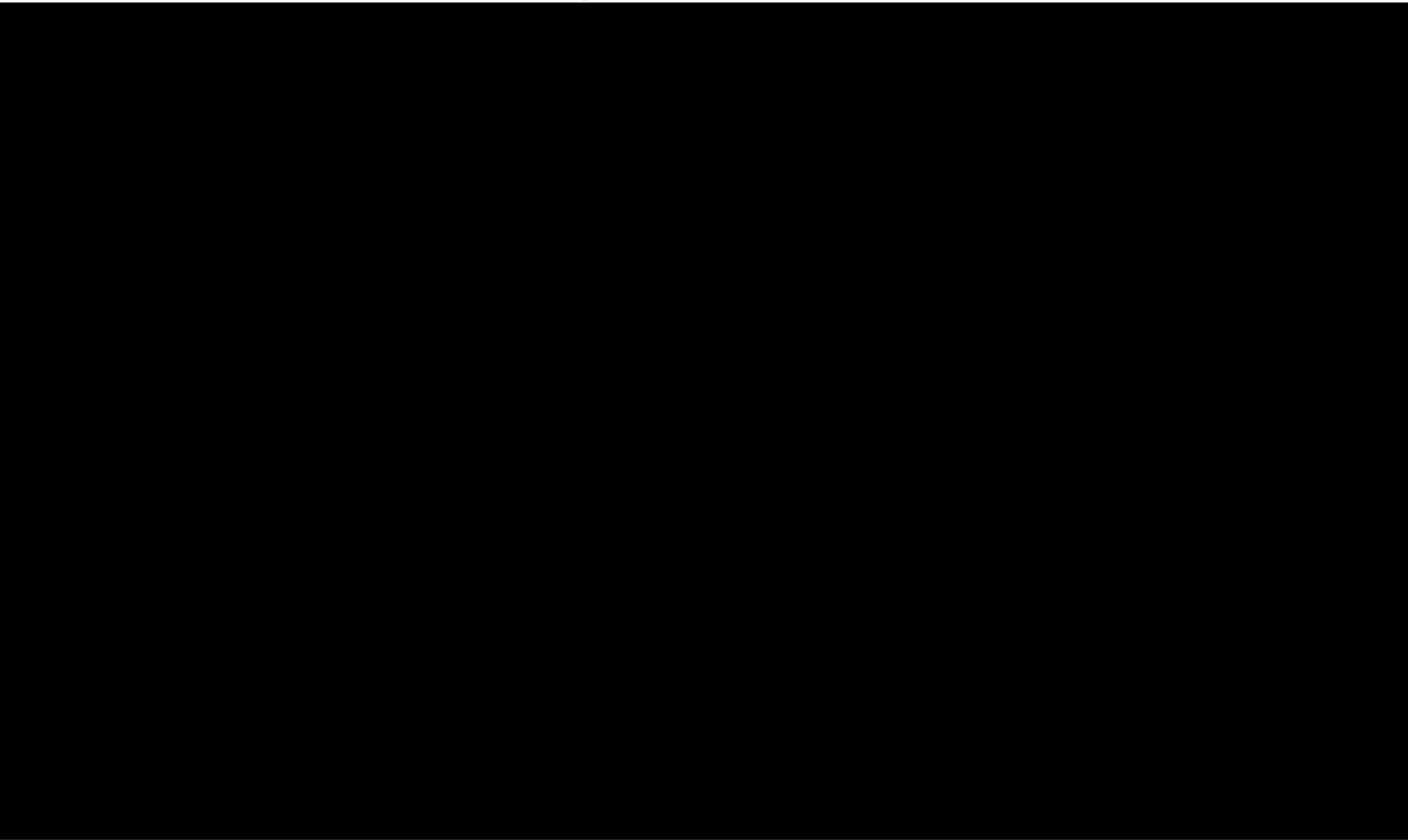
second step is fitting odc b

odc b controls horizontal component of distortion





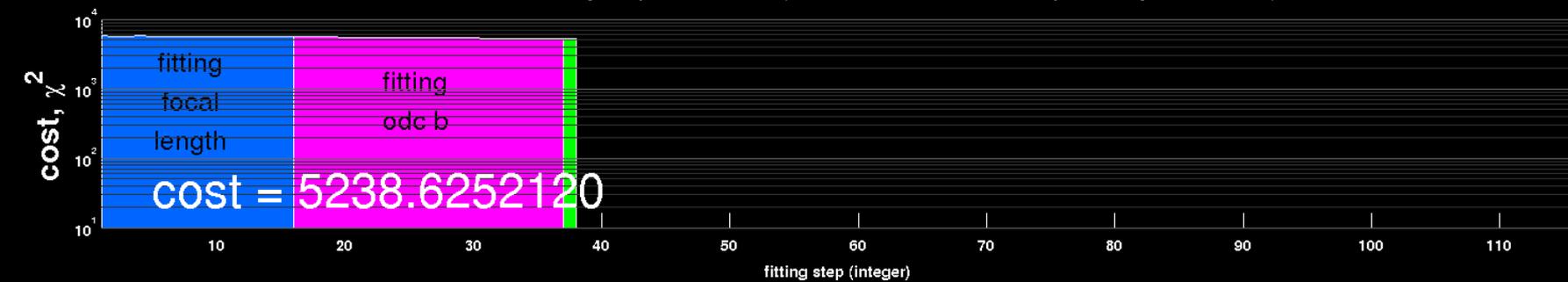
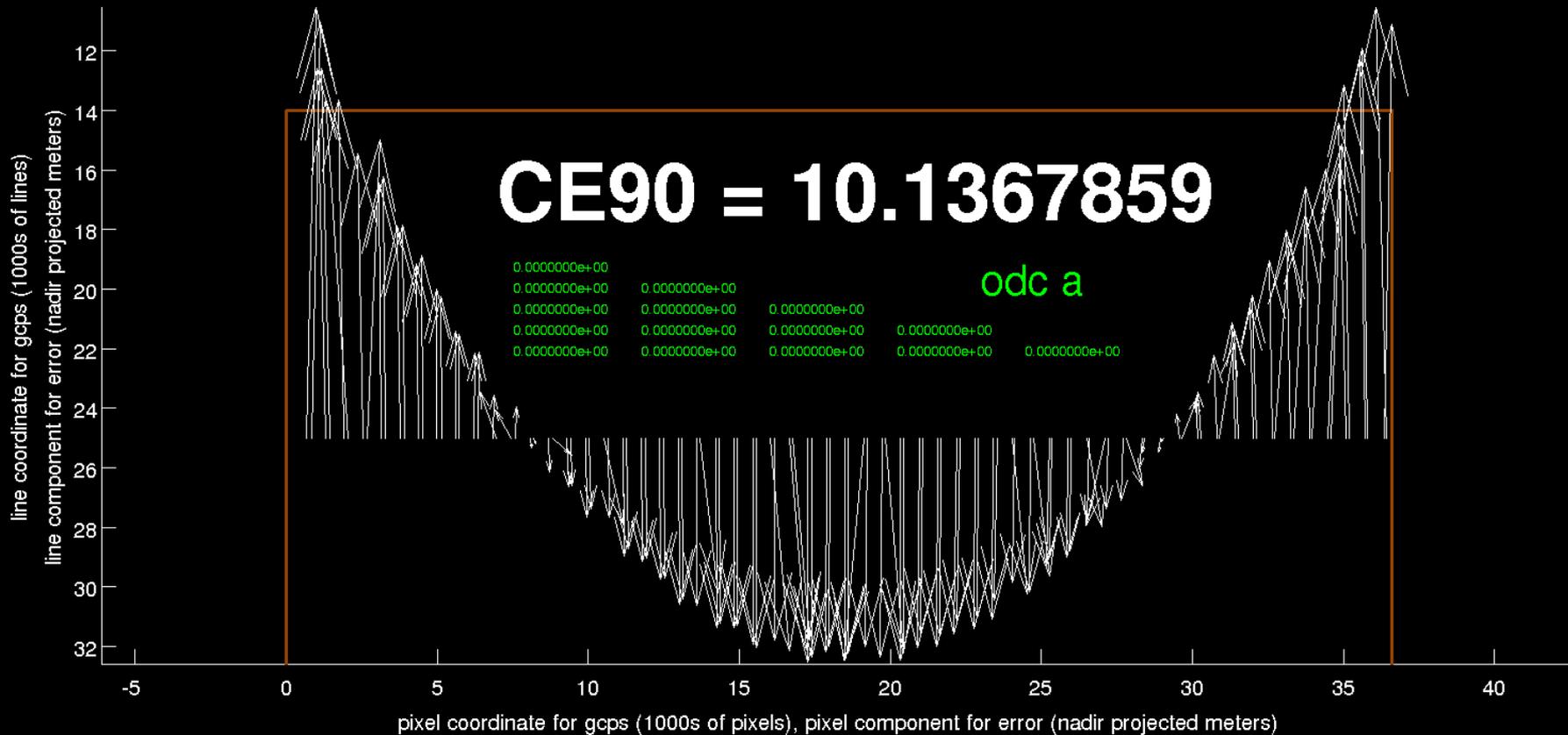
fitting odc b: animation





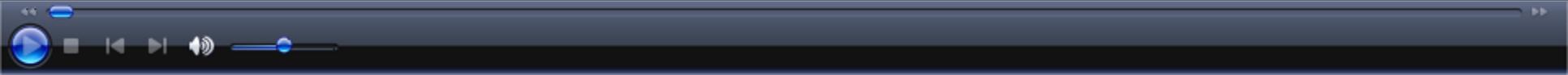
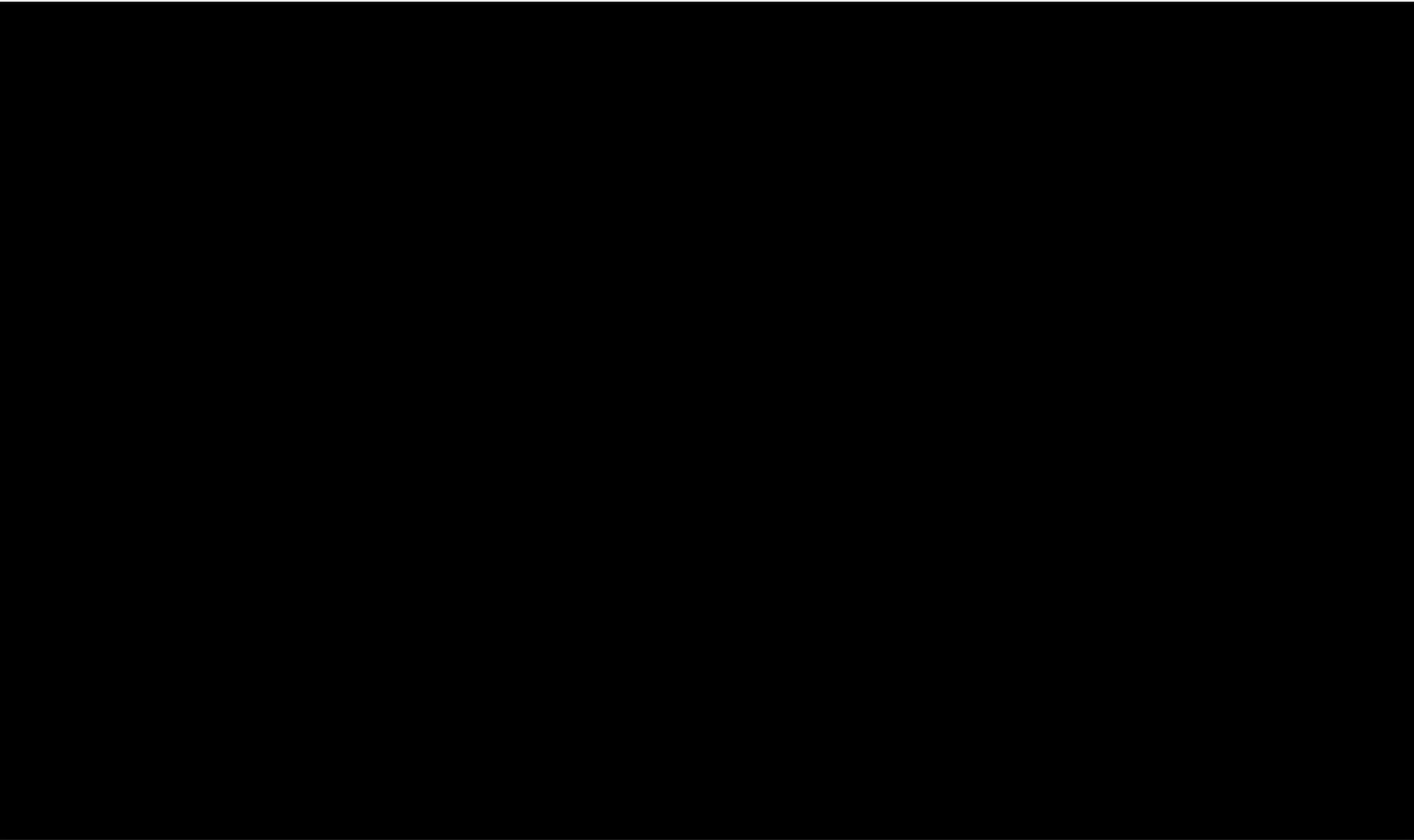
third step is fitting odc a

odc a controls vertical component of distortion





fitting odc a: animation

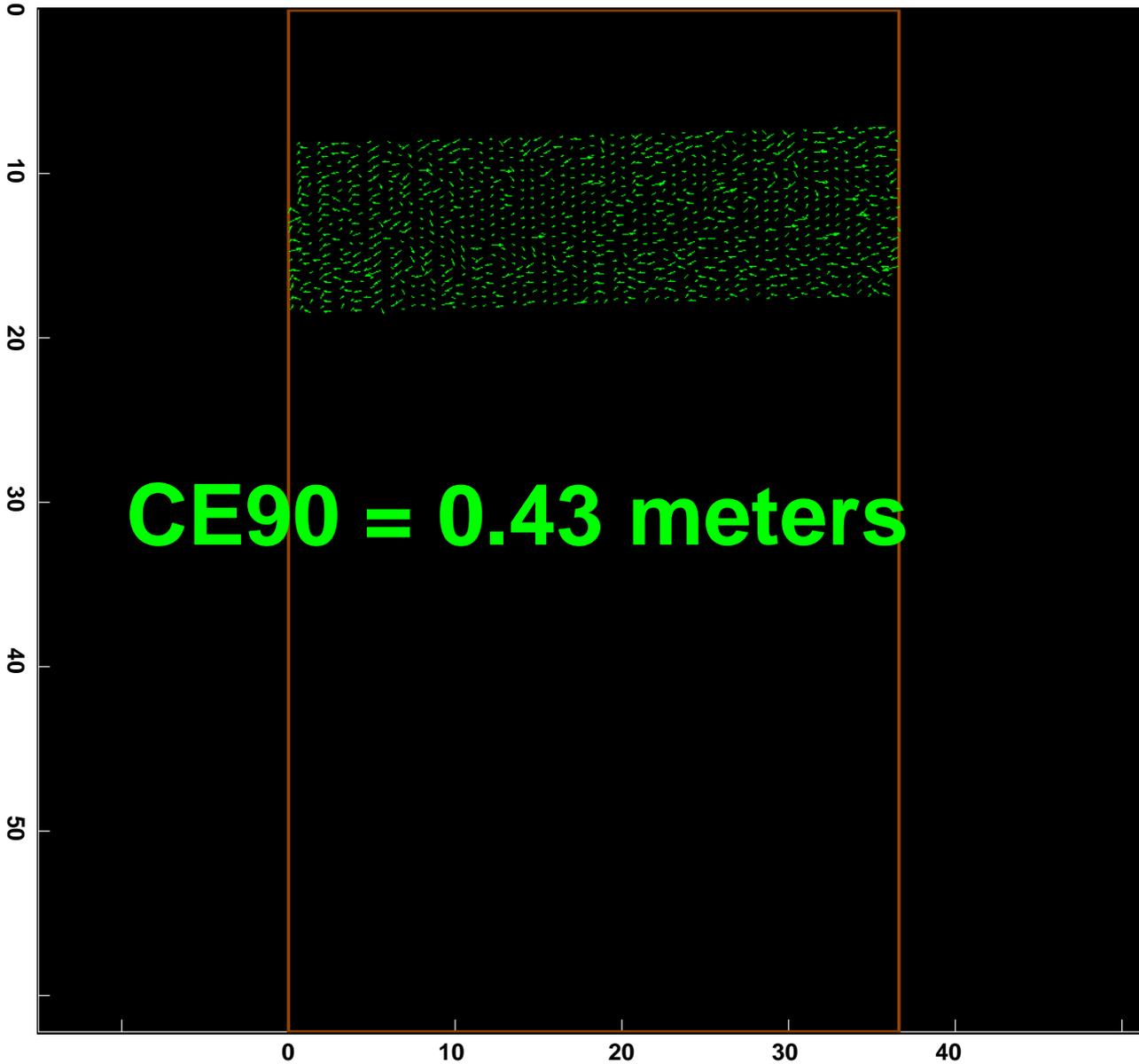




step 3:
checking to see if the PAN camera is really fixed



one can correlate WV02 back to a WV01 reference, again



units are

kilometers for strip border

meters for error vectors

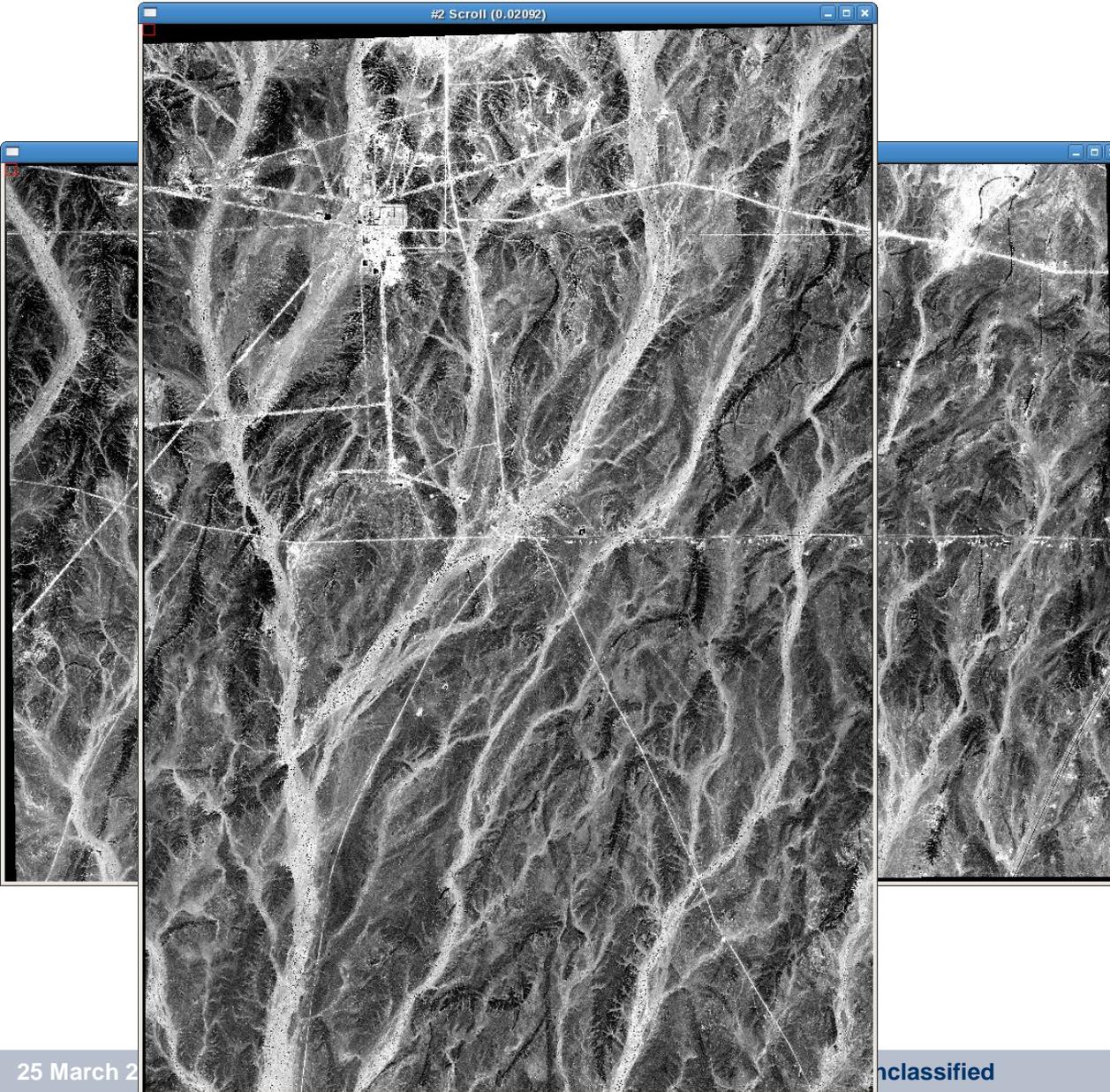
results displayed have
been attitude detrended

just under a PAN pixel!
(0.46 meters)





one can also correlate WV02 to WV02 in a “criss cross”



in this example,

first an east/west strip,
then a north/south strip
(11 days apart)

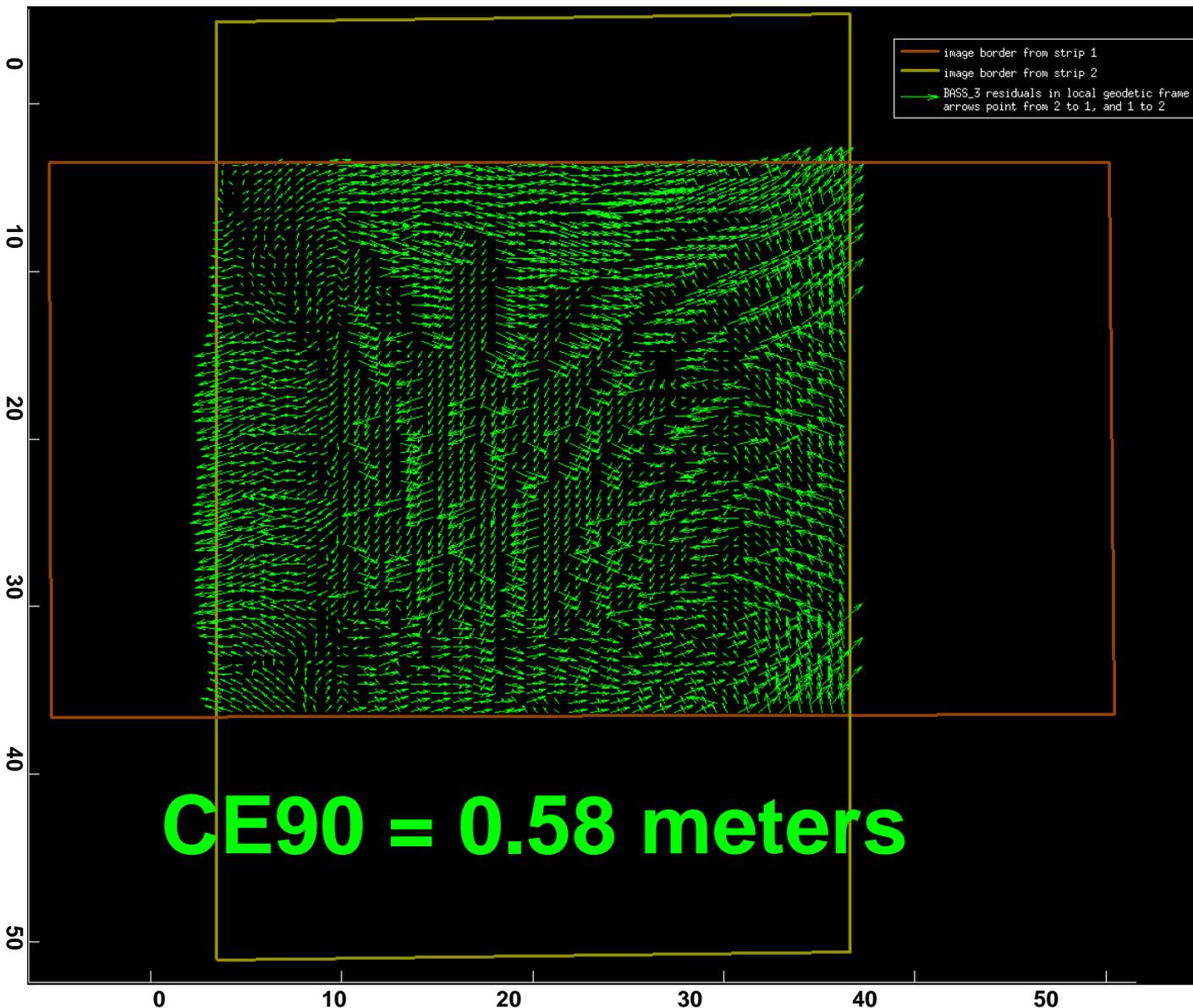
were collected over

Oman0

latitude: 22.025890°
longitude: 57.346039°



one can correlate WV02 to WV02 in a “criss cross”



units are
kilometers for strip
border
meters for error
vectors

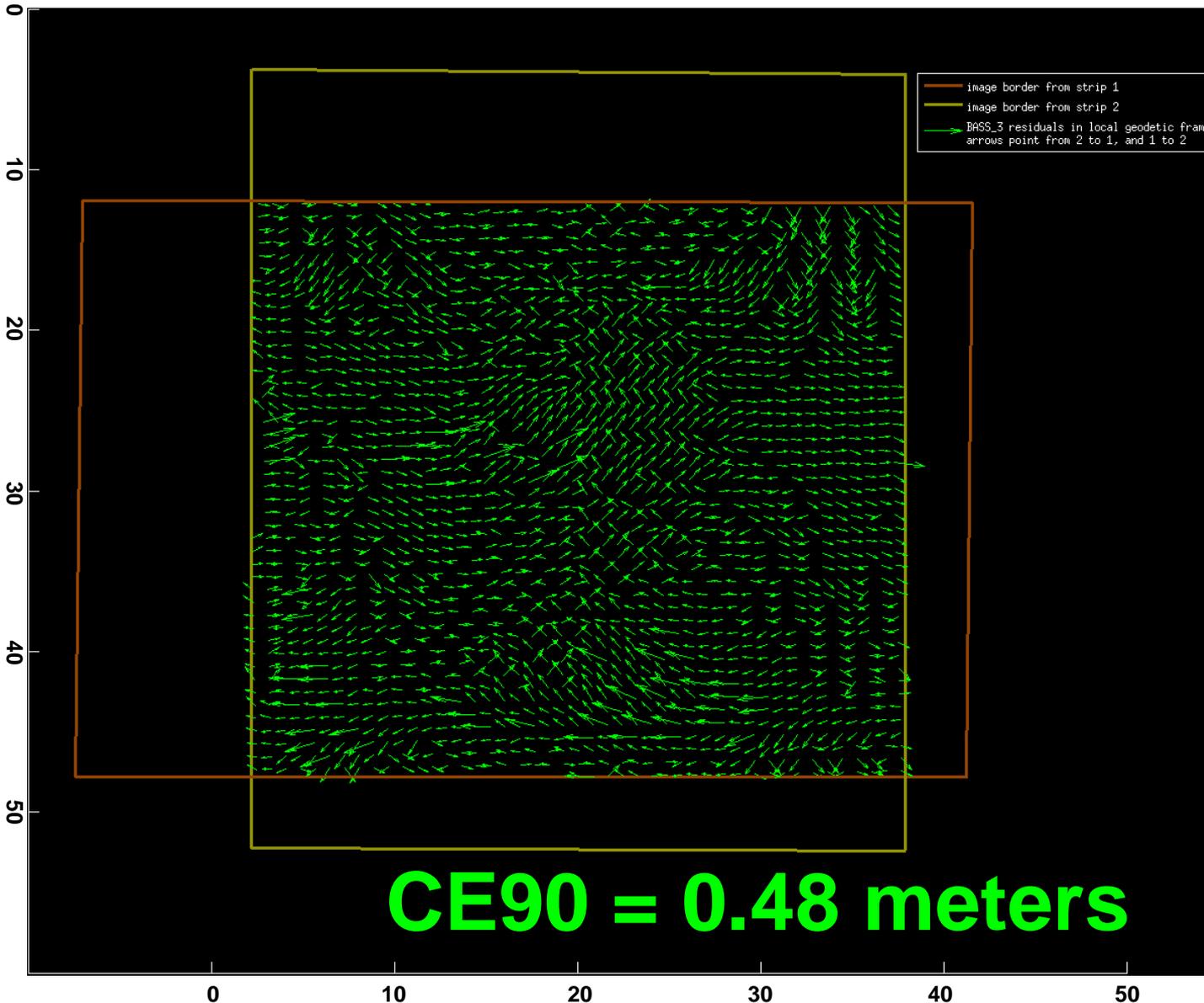
results displayed
have been attitude
detrended

just over a PAN pixel!
(0.46 meters)





WV01 criss crosses also performed, similar results



units are
kilometers for strip
border
meters for error
vectors

results displayed
have been attitude
detrended

just under a PAN pixel!
(0.50 meters)



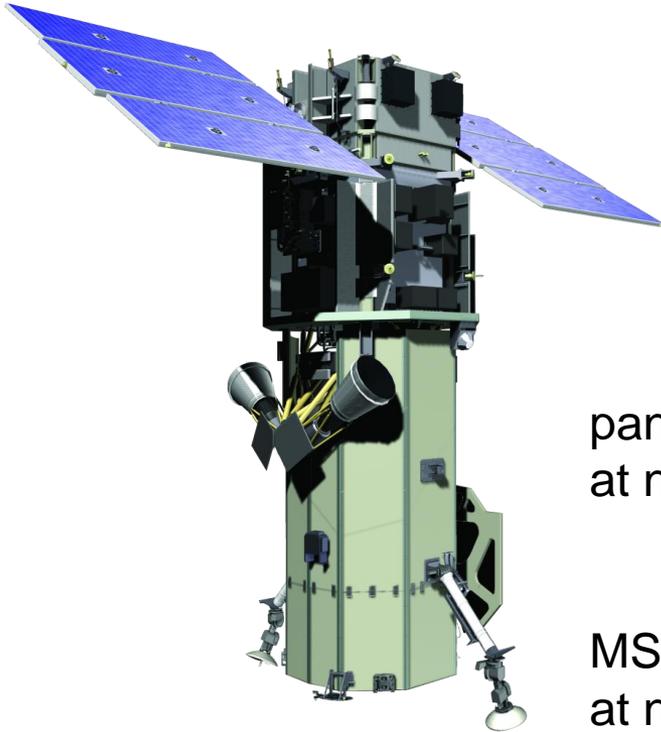


band to band registration or, MS camera calibration

What is good band to band registration?

It's when identical features have identical geolocation in all bands.

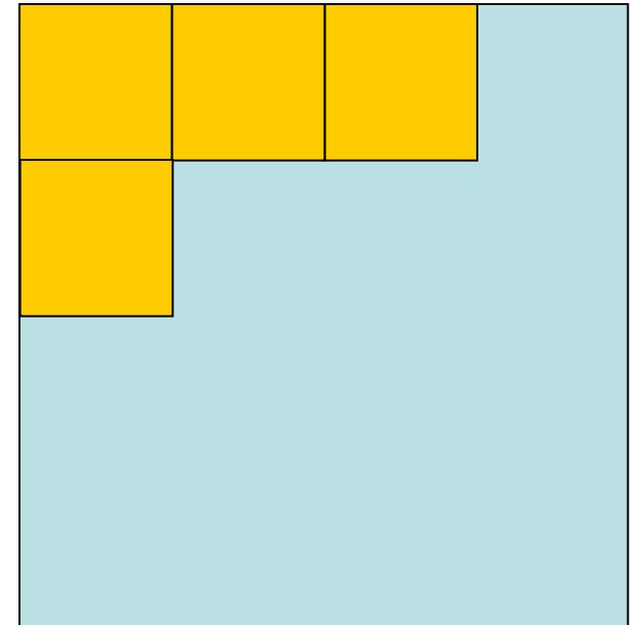
My focus is MS-PAN registration.



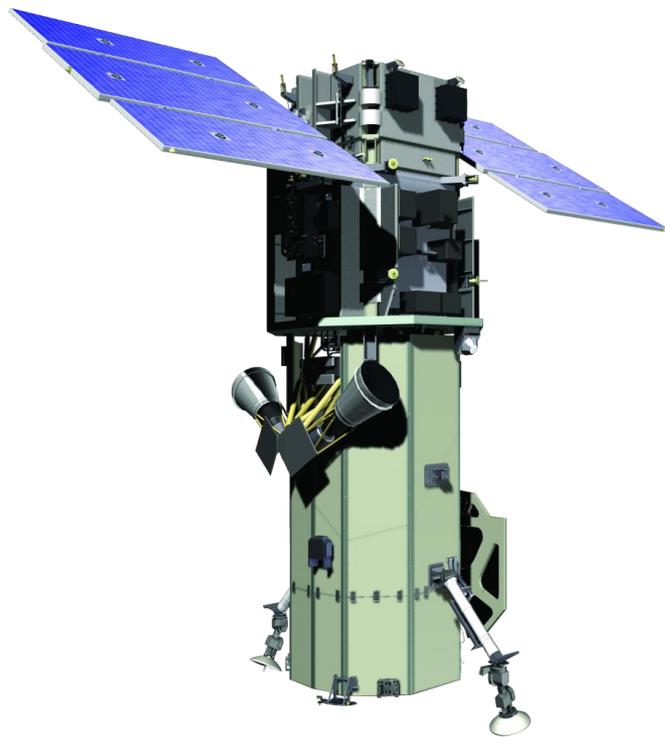
pan GSD = 0.46 meters
at nadir

MS GSD = 1.84 meters
at nadir

factor of 4 difference !



unknown MS camera parameters prevent good band to band



Most of the WV02 MS camera models are known in advance:

- ✓ detector mountings
- ✓ attitude quaternions
- ✓ prelaunch estimate/measurement of focal length

However, crucial parts for best relative geolocation accuracy still unknown:

- × final focal lengths
- × final optical distortion corrections



methods are needed to complete all 8 MS camera models

Solution: take a picture of another desert!

another location revealed for discussion:

Oman1

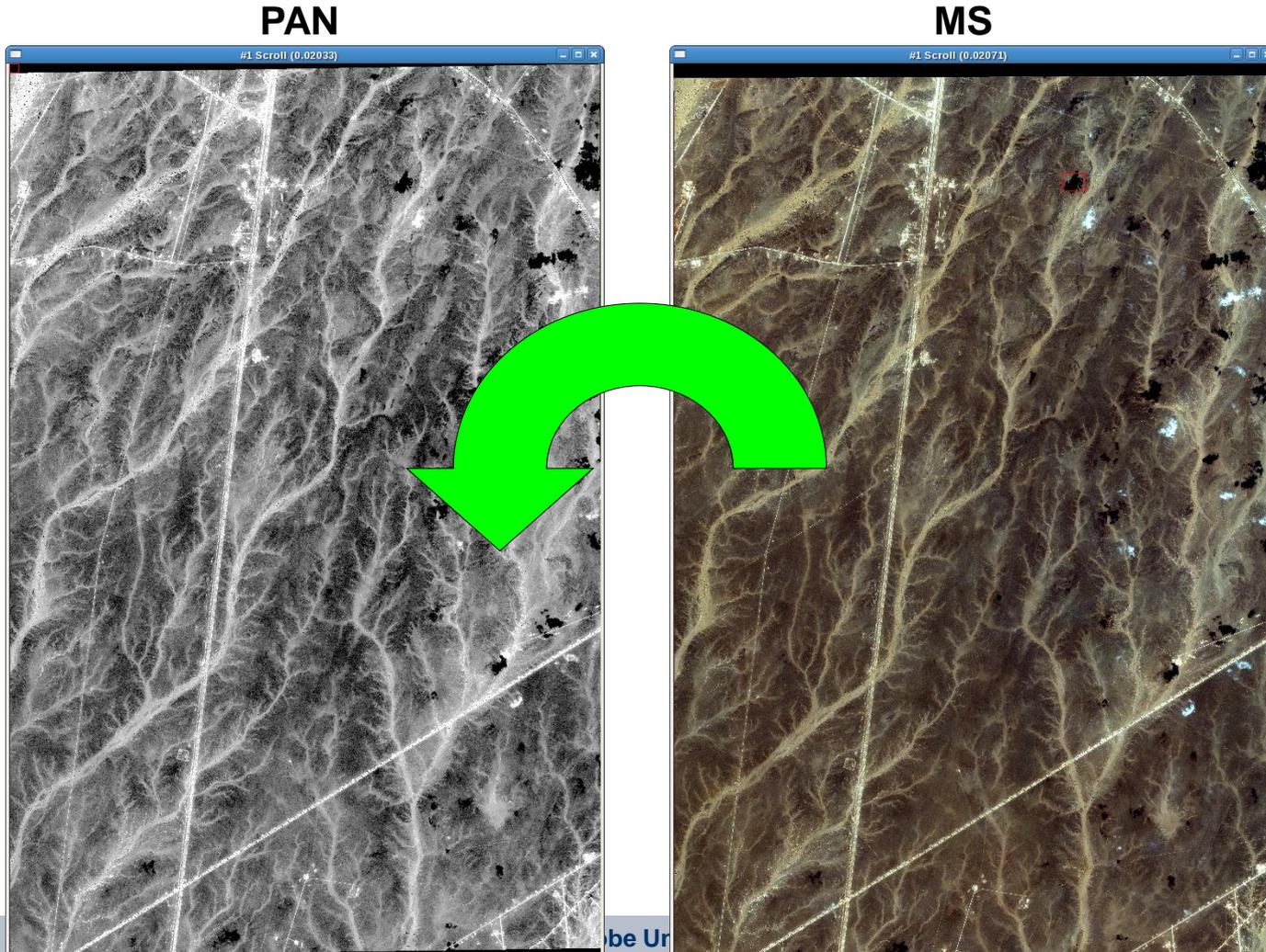
latitude: 21.696399°

longitude: 57.174376°



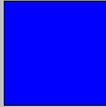
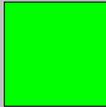
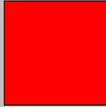
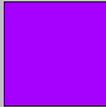
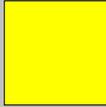
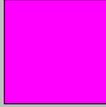
similar correlation methods used to fix MS cameras

But this time, *the PAN band of WV02 is used as the truth*, rather than something exterior and external like WV01 during PAN camera calibration



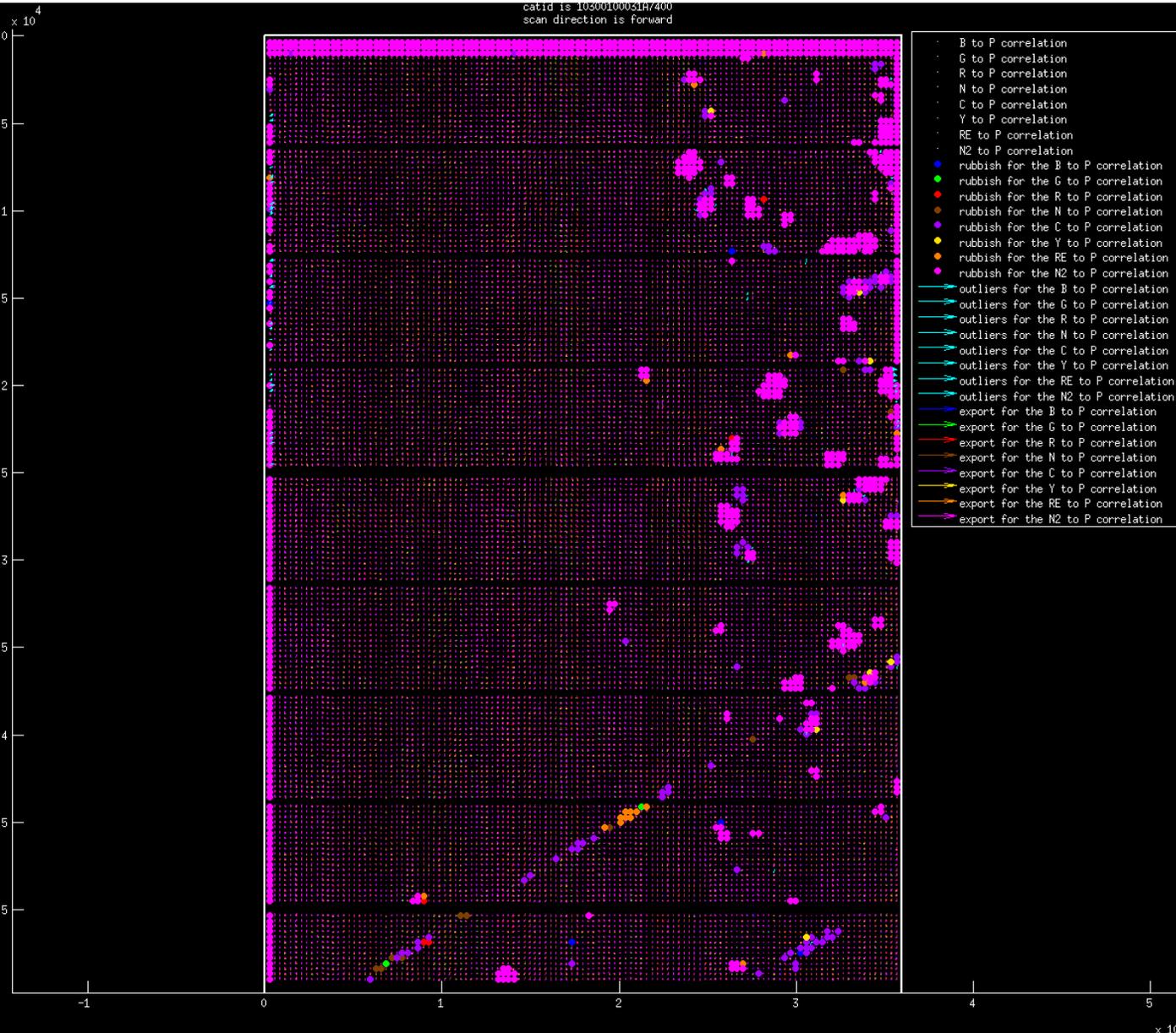


Byron's WV02 band coloring, for all following plots

	B, blue
	G, green
	R, red
	N, near infrared 1
	C, coastal
	Y, yellow
	RE, red edge
	N2, near infrared 2



8 layer quiver plot showing final, corrected registration back to PAN



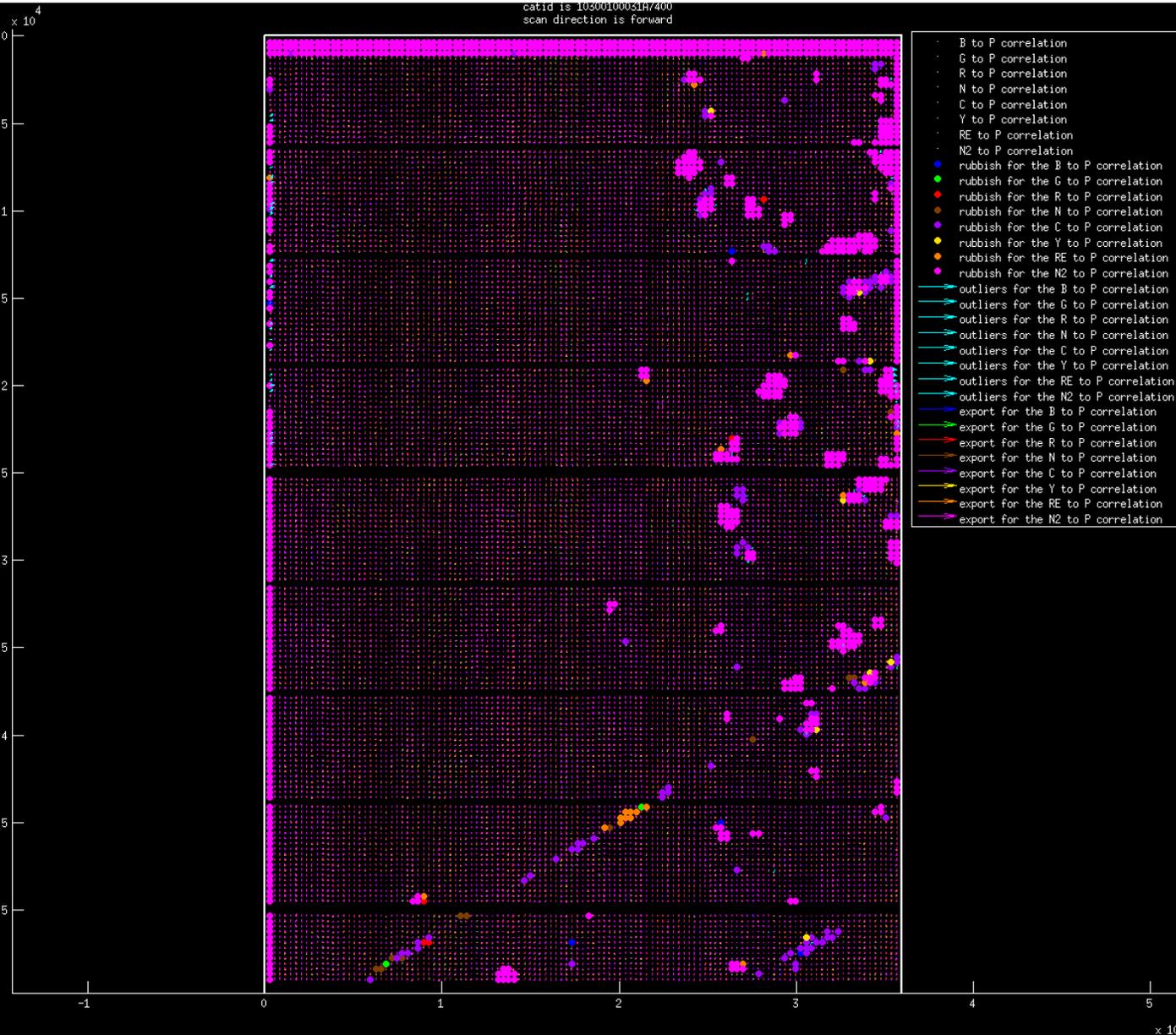
All 8 bands
correlated on a 300
pixel grid

All 8 MS bands
plotted sequentially

looks magenta
because N2 was
plotted last



Some spots did NOT correlate to PAN at all



○ = rubbish

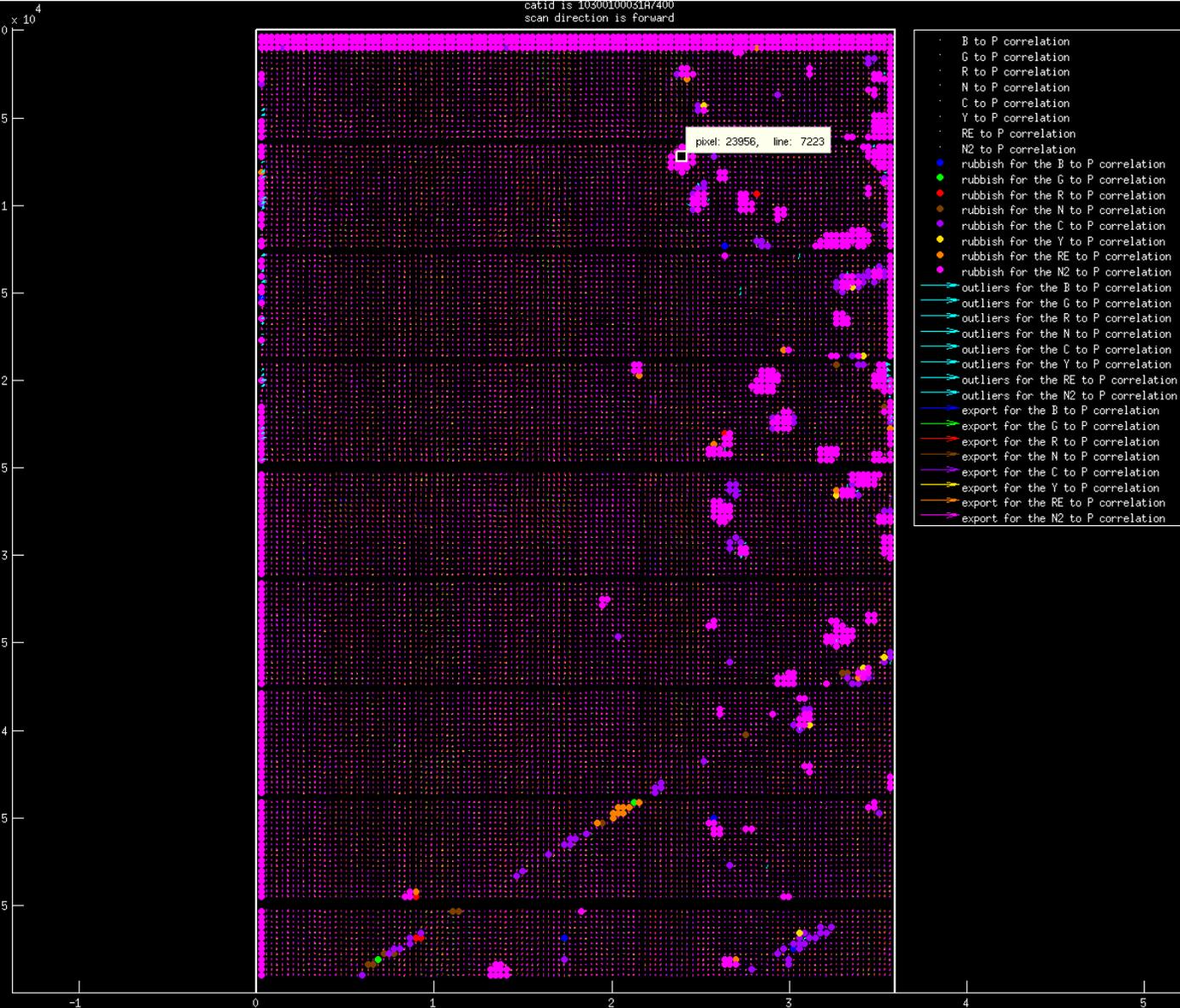
All 8 MS bands
have outliers

most rubbish is
magenta because
N2 was plotted
last...

but occasionally
other bands show
through



cloud shadows don't correlate well between MS and PAN

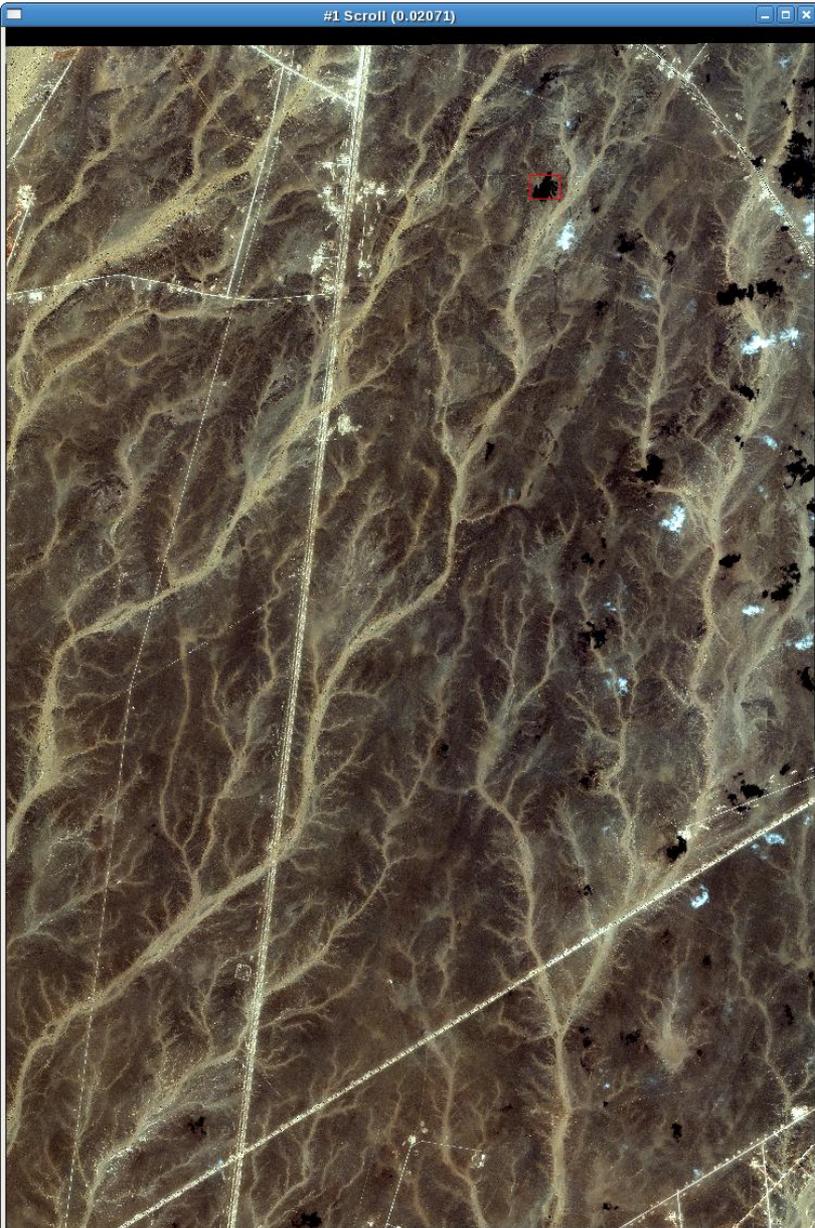


○ = rubbish

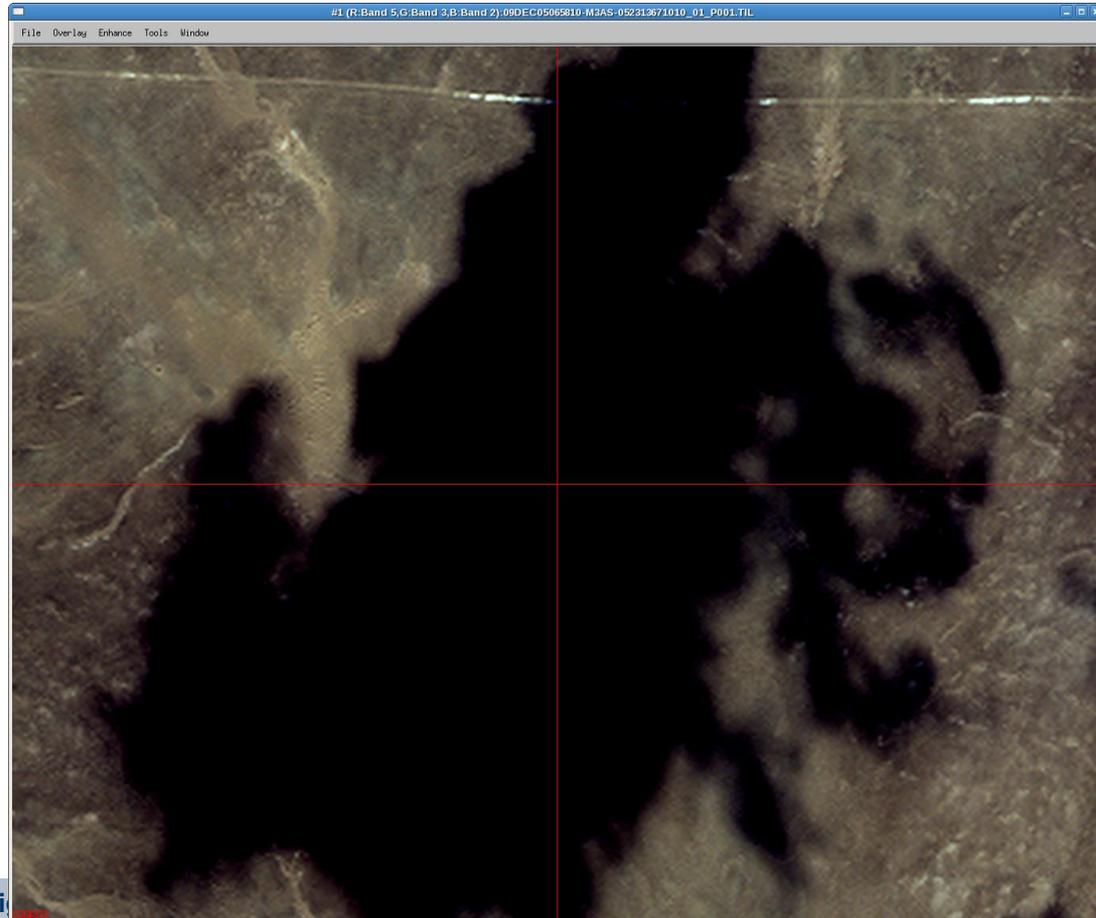
This spot fails to correlate in all 8 bands



cloud shadows don't correlate well between MS and PAN

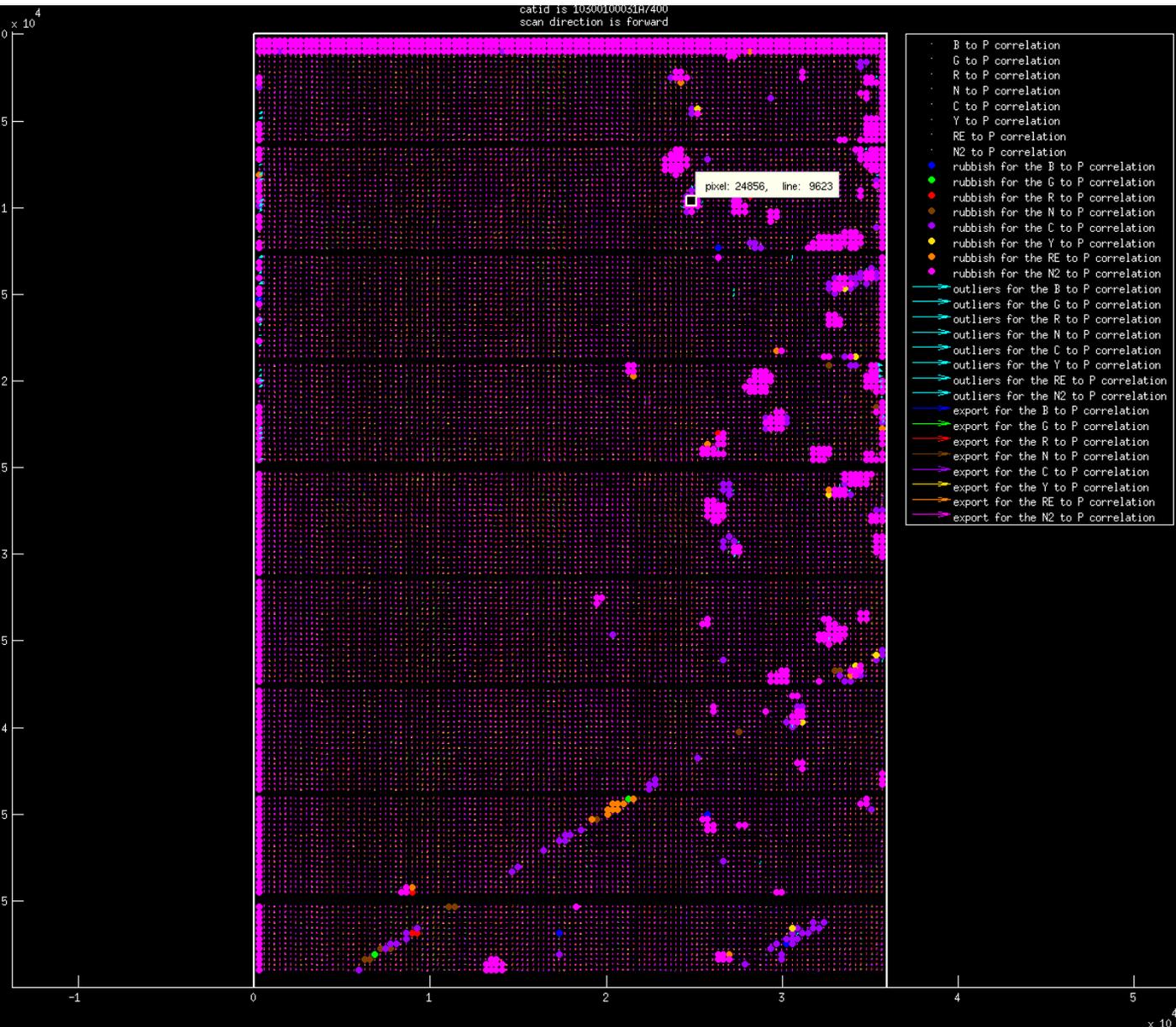


too much black in the correlation window





clouds themselves don't correlate well between MS and PAN, either

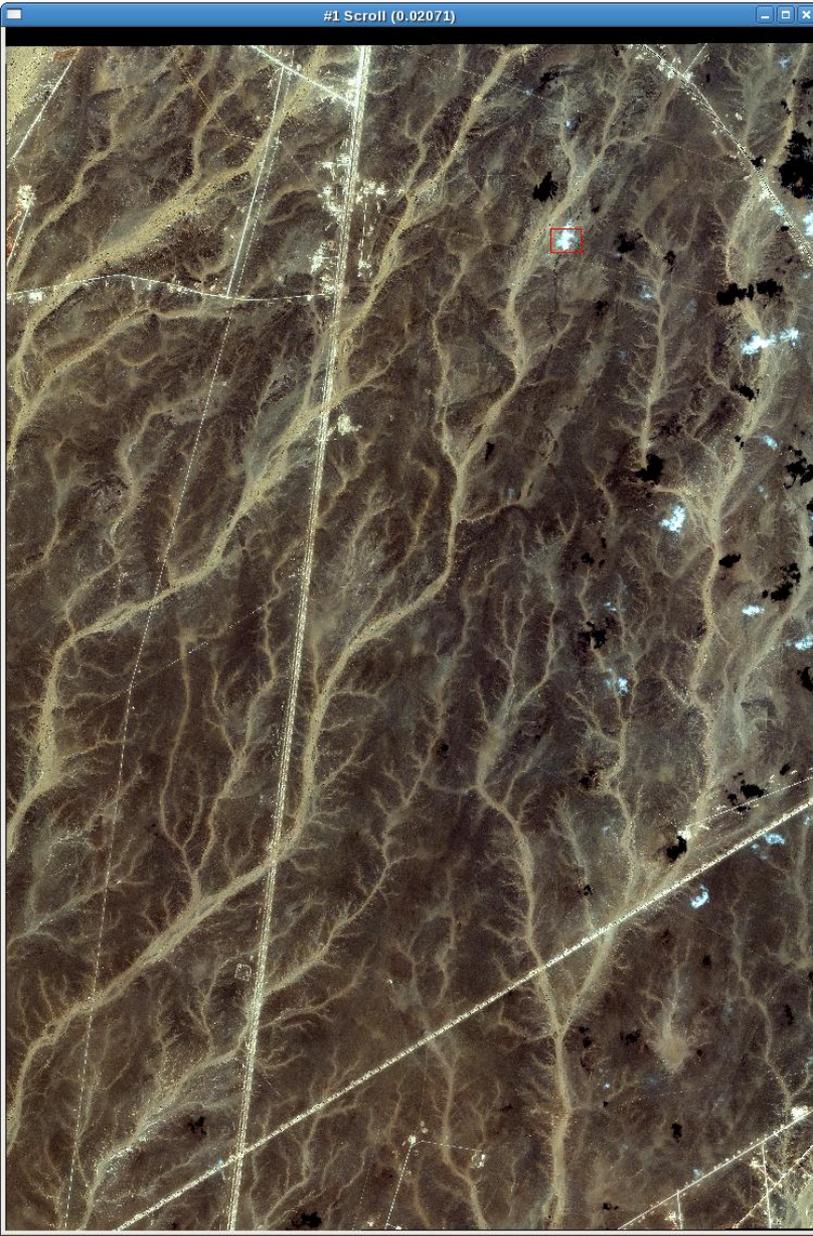


○ = rubbish

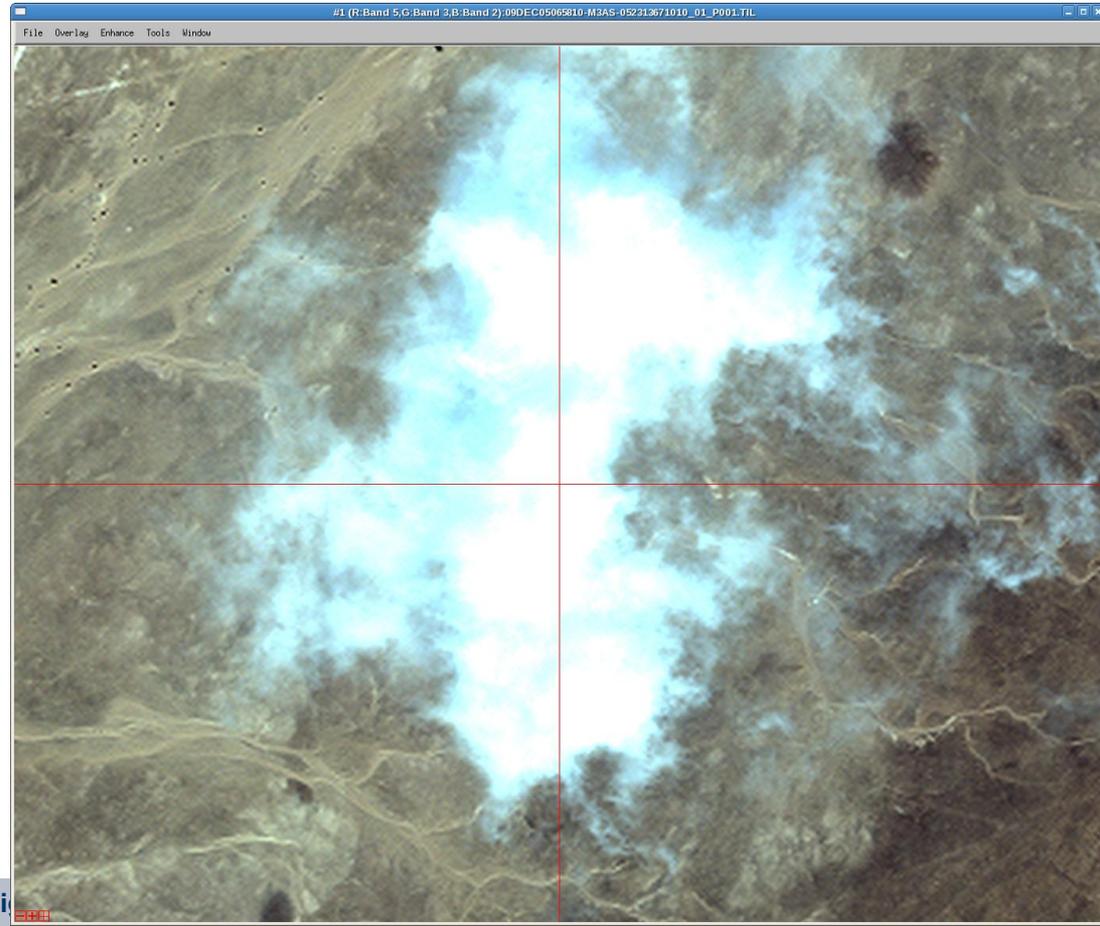
This spot fails to correlate in all 8 bands



clouds themselves don't correlate well between MS and PAN, either

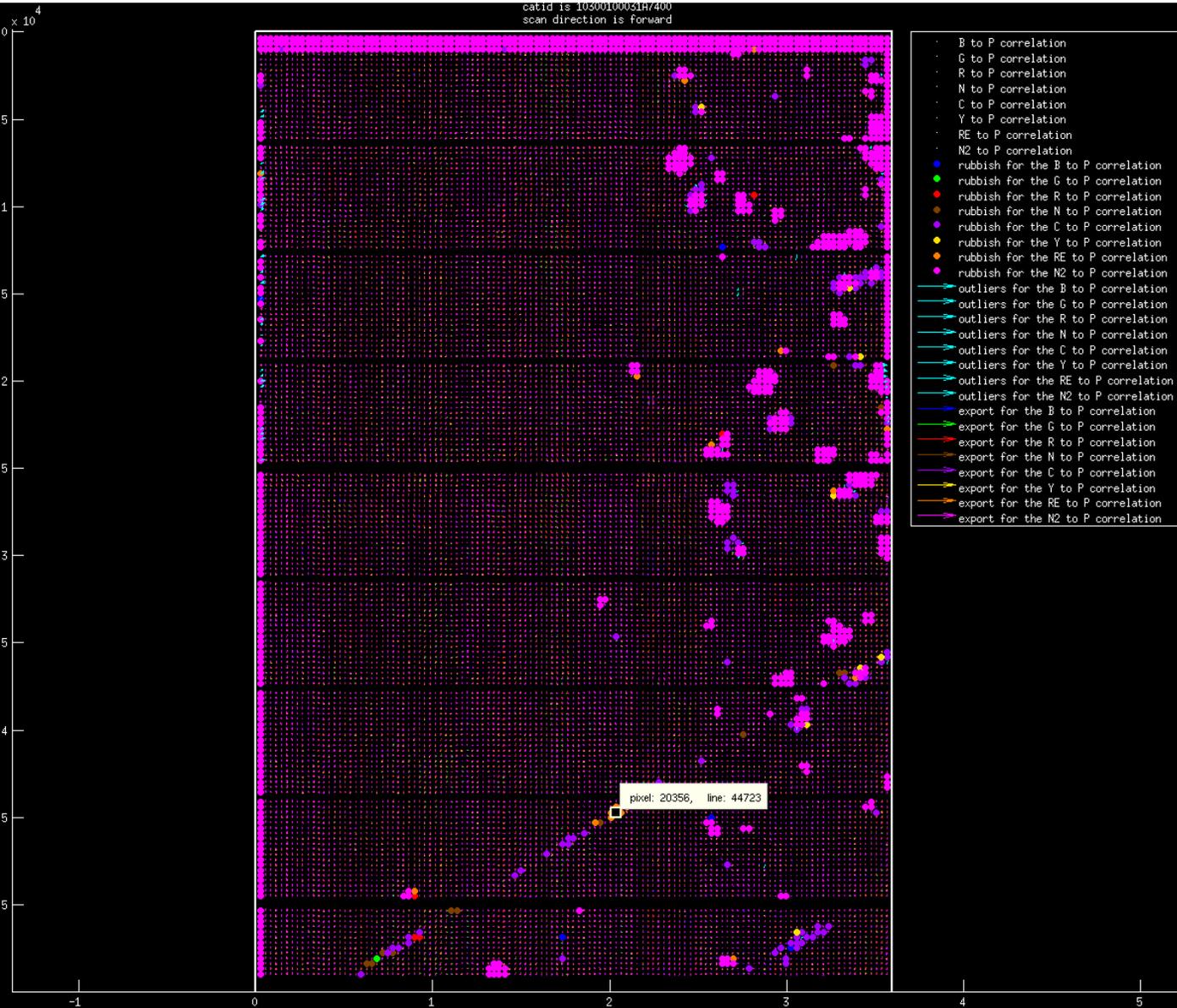


too much white in the correlation window





roads (sometimes) don't correlate well between MS and PAN



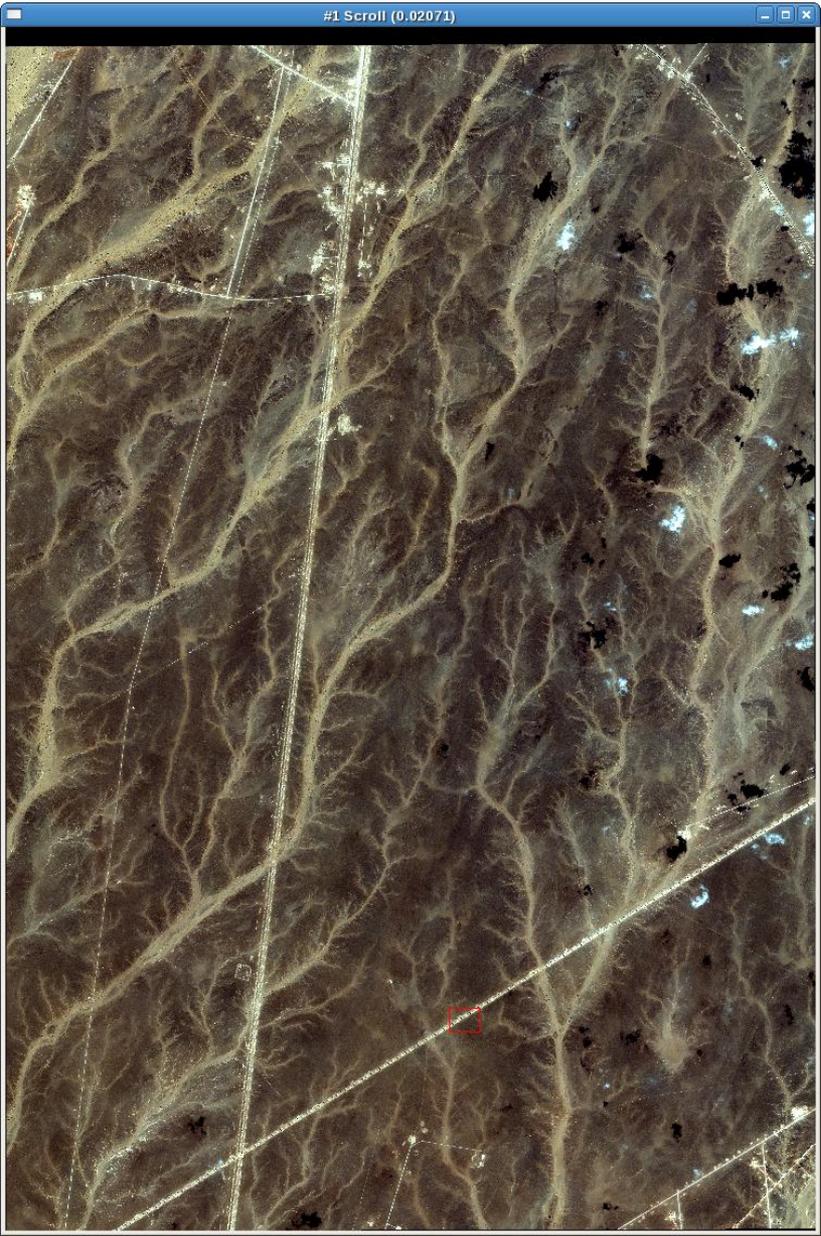
○ = rubbish

This spot fails to correlate in some bands, but not all.

RE rubbish point plotted last on this spot.

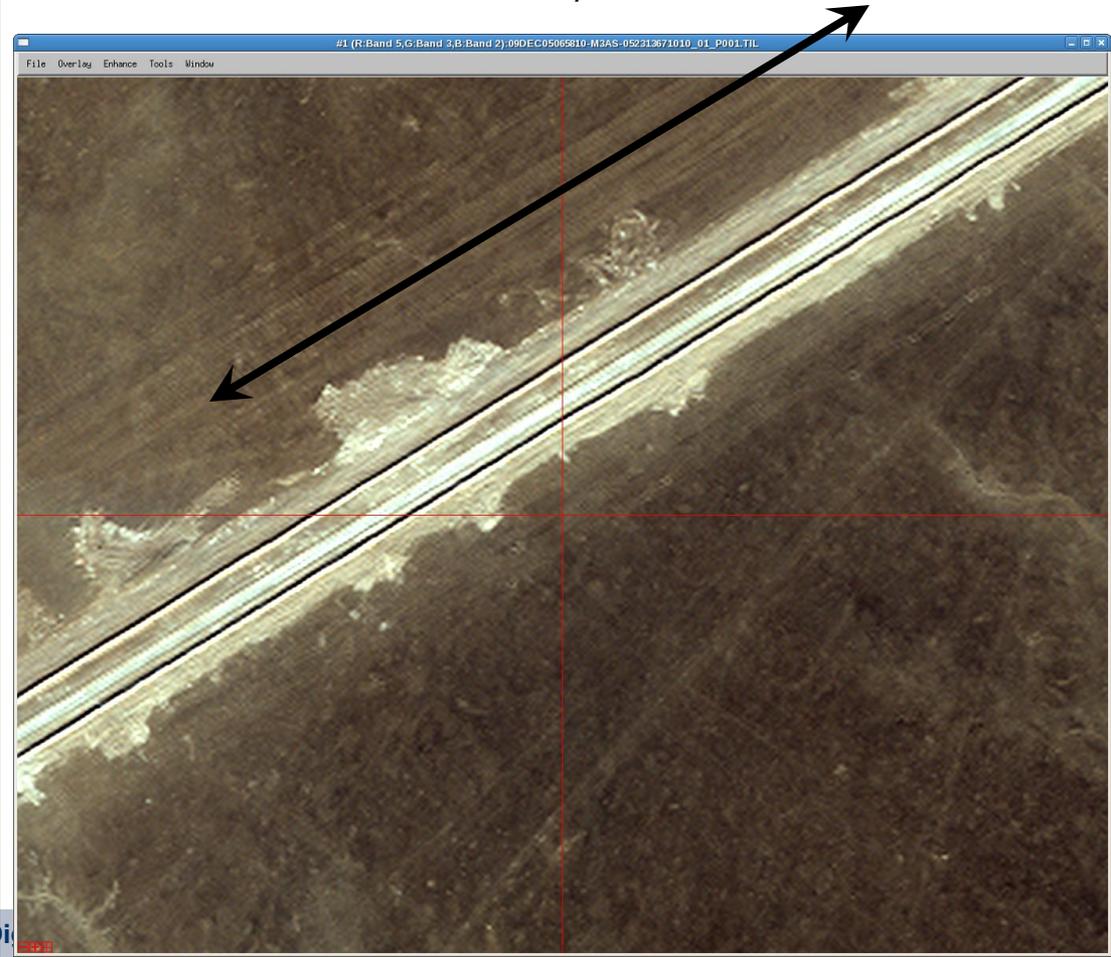


roads (sometimes) don't correlate well between MS and PAN



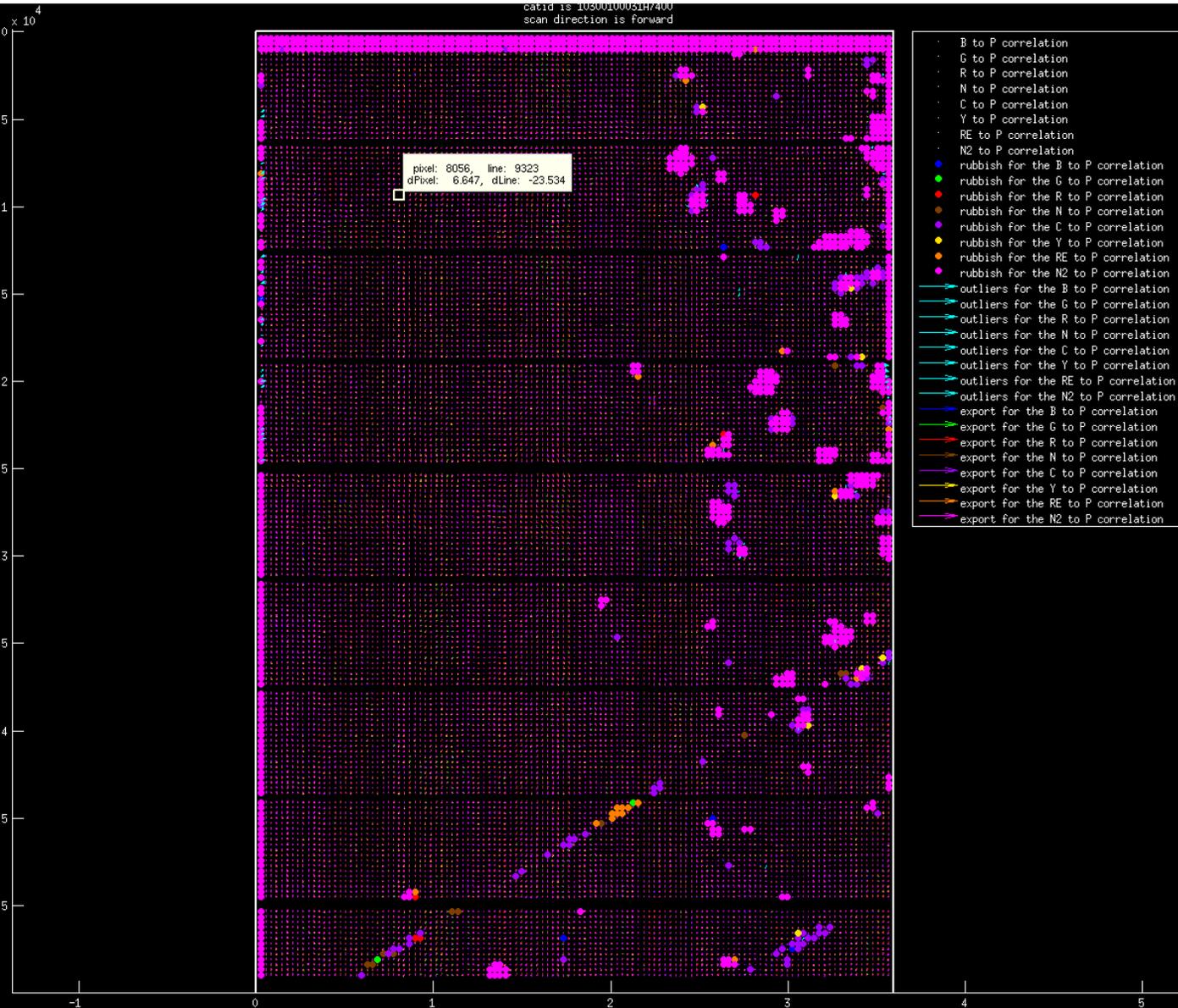
man made features can interfere with the correlation

searching along the feature yields many similar correlations, unique lock lost





natural ground cover correlates very well between MS and PAN

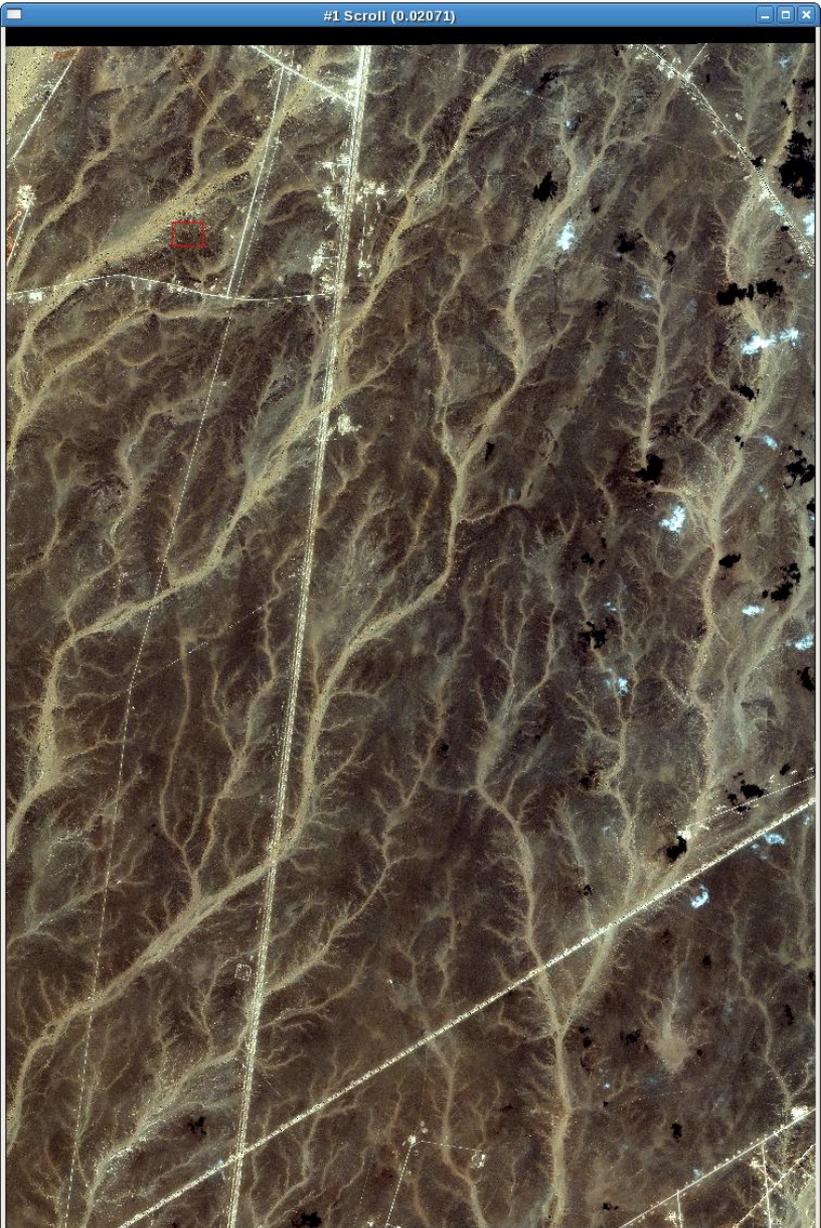


Nearly the entire image correlates well.

Full width regions are valued most.



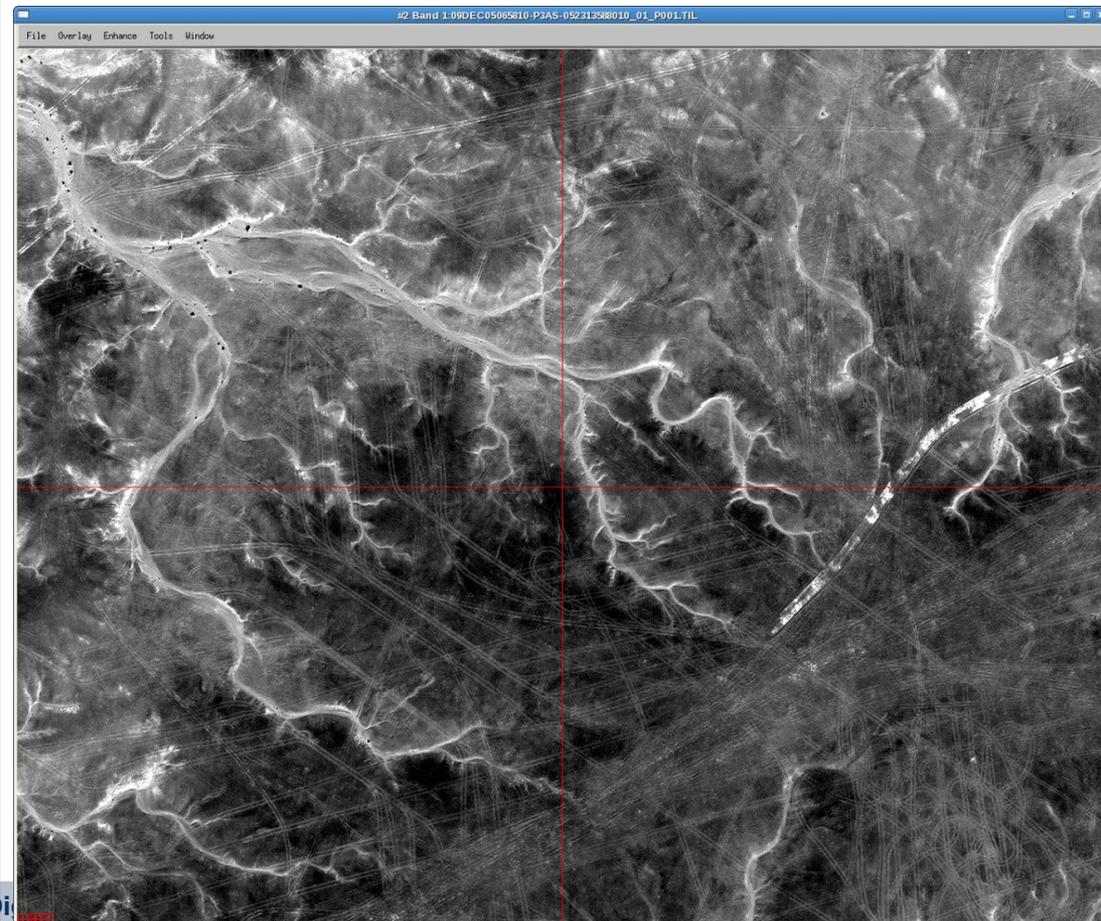
natural ground cover correlates very well between MS and PAN



fractal river tributaries, random
tire tracks, easily correlates

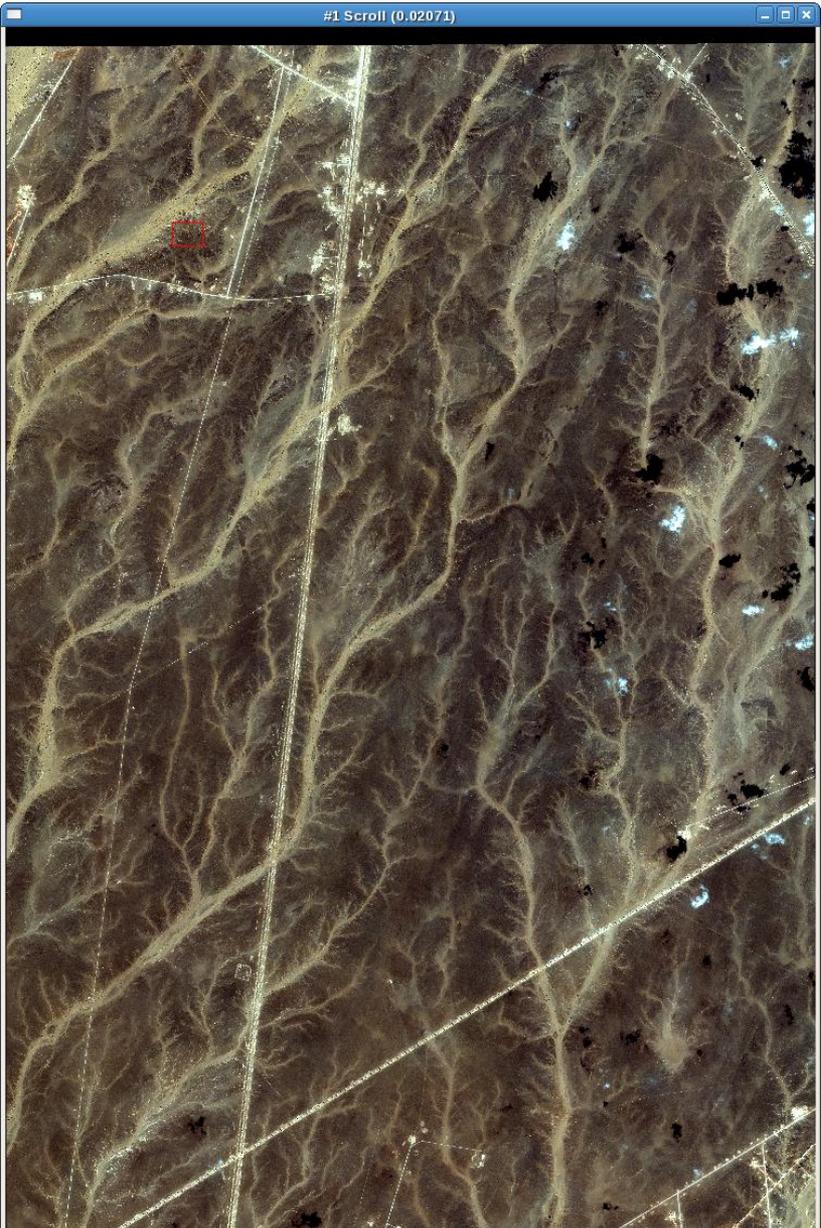
PAN

*PAN image subsampled by factor of 0.94 to increase GSD from 47 cm to 50 cm for public viewing!





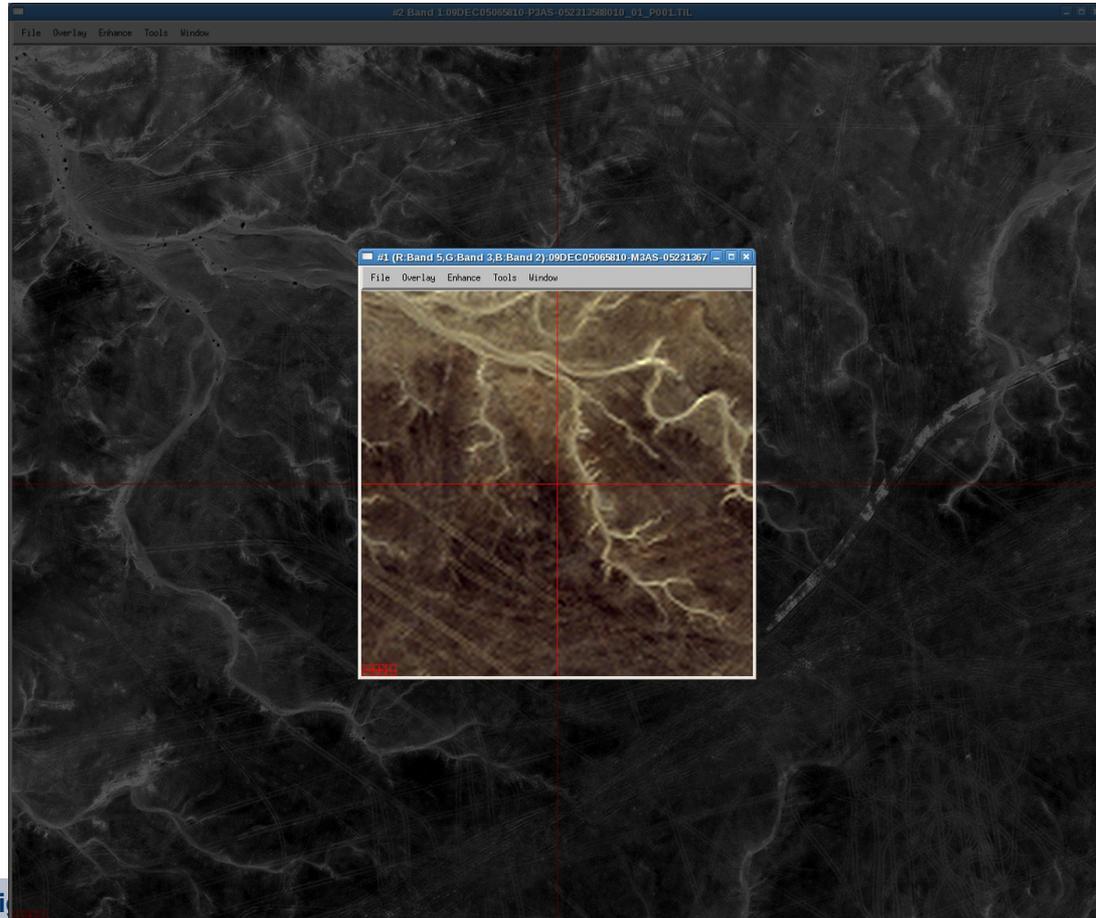
natural ground cover correlates very well between MS and PAN



actual size of correlation window used,
500 square PAN pixels

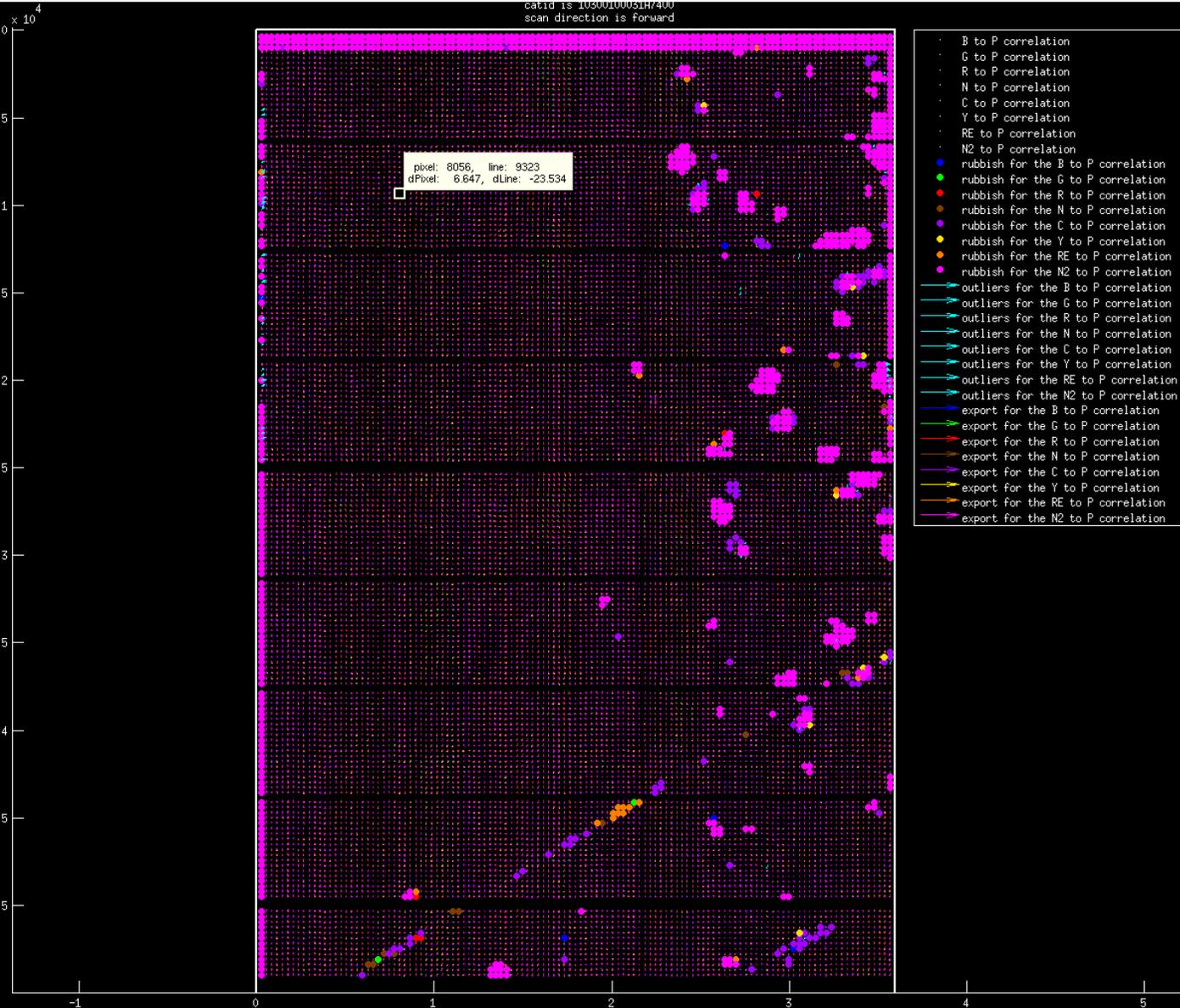
B,G,R

*both PAN images subsampled by factor of 0.94 to increase GSD from 47 cm to 50 cm for public viewing!





misregistration vectors are well under 1 PAN pixel

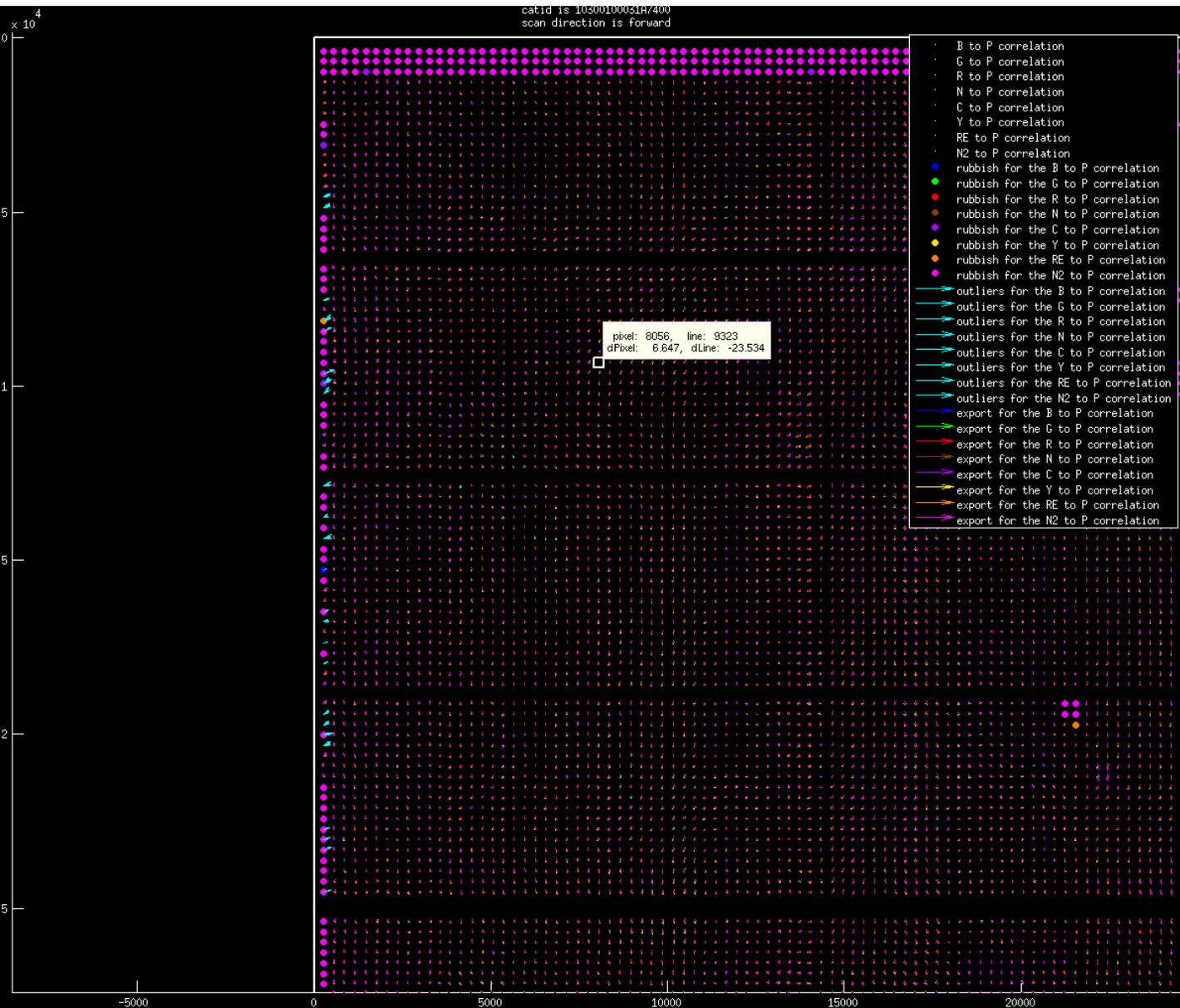


Nearly the entire image correlates well.

zoom level 0



misregistration vectors are well under 1 PAN pixel

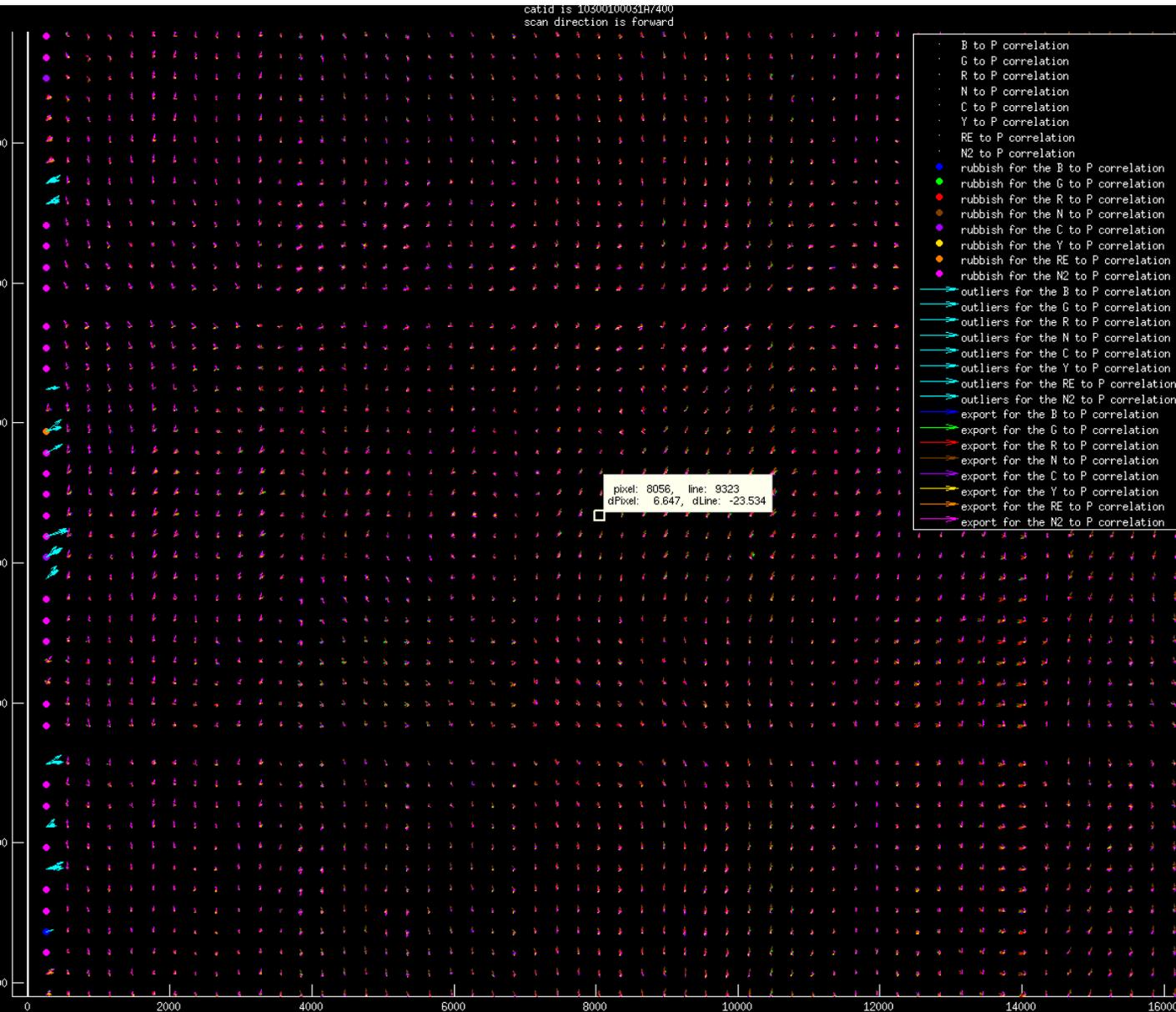


Nearly the entire image correlates well.

zoom level 1



misregistration vectors are well under 1 PAN pixel

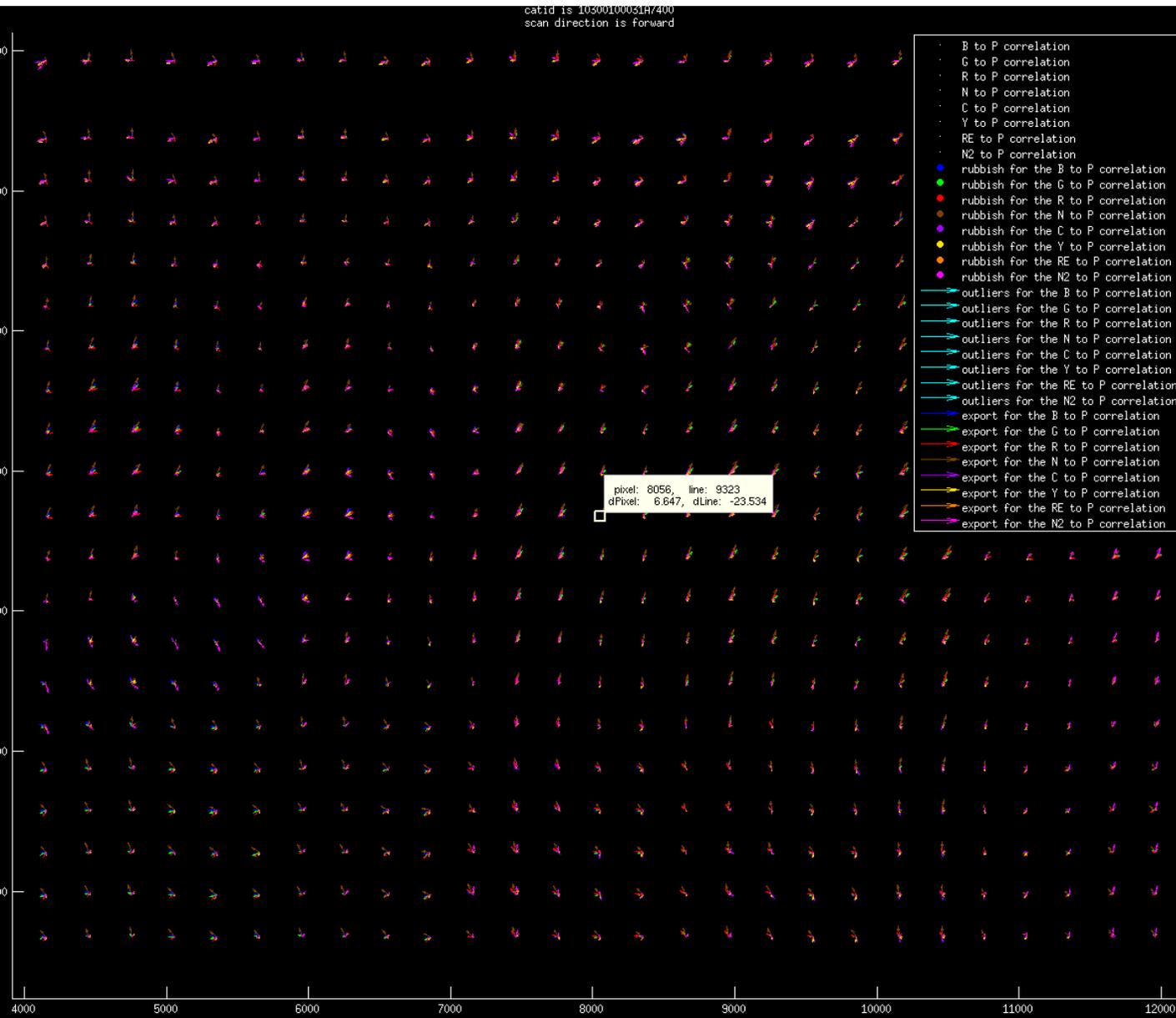


Nearly the entire image correlates well.

zoom level 2



misregistration vectors are well under 1 PAN pixel

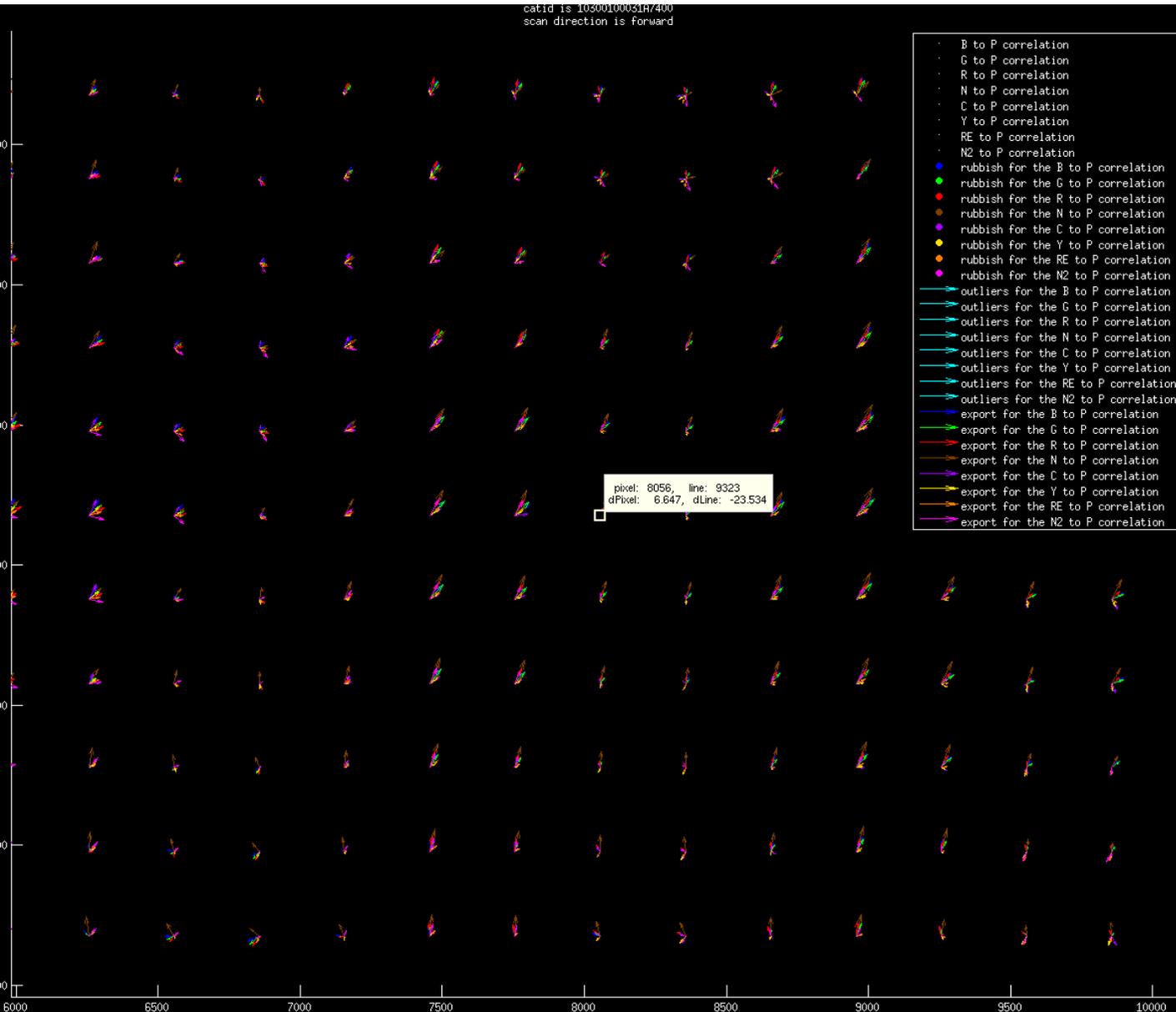


Nearly the entire image correlates well.

zoom level 3



misregistration vectors are well under 1 PAN pixel

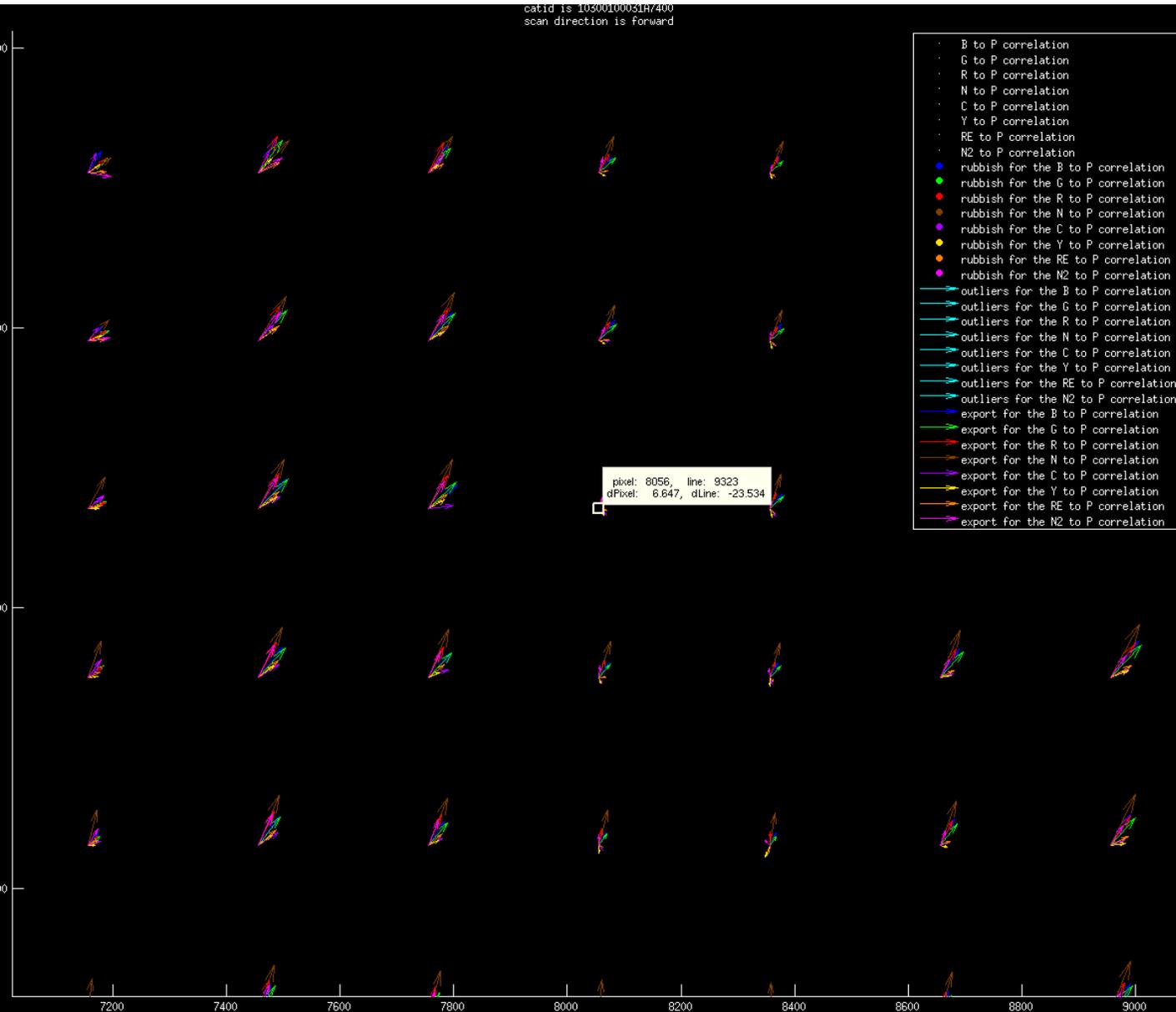


Nearly the entire
image correlates
well.

zoom level 4



misregistration vectors are well under 1 PAN pixel

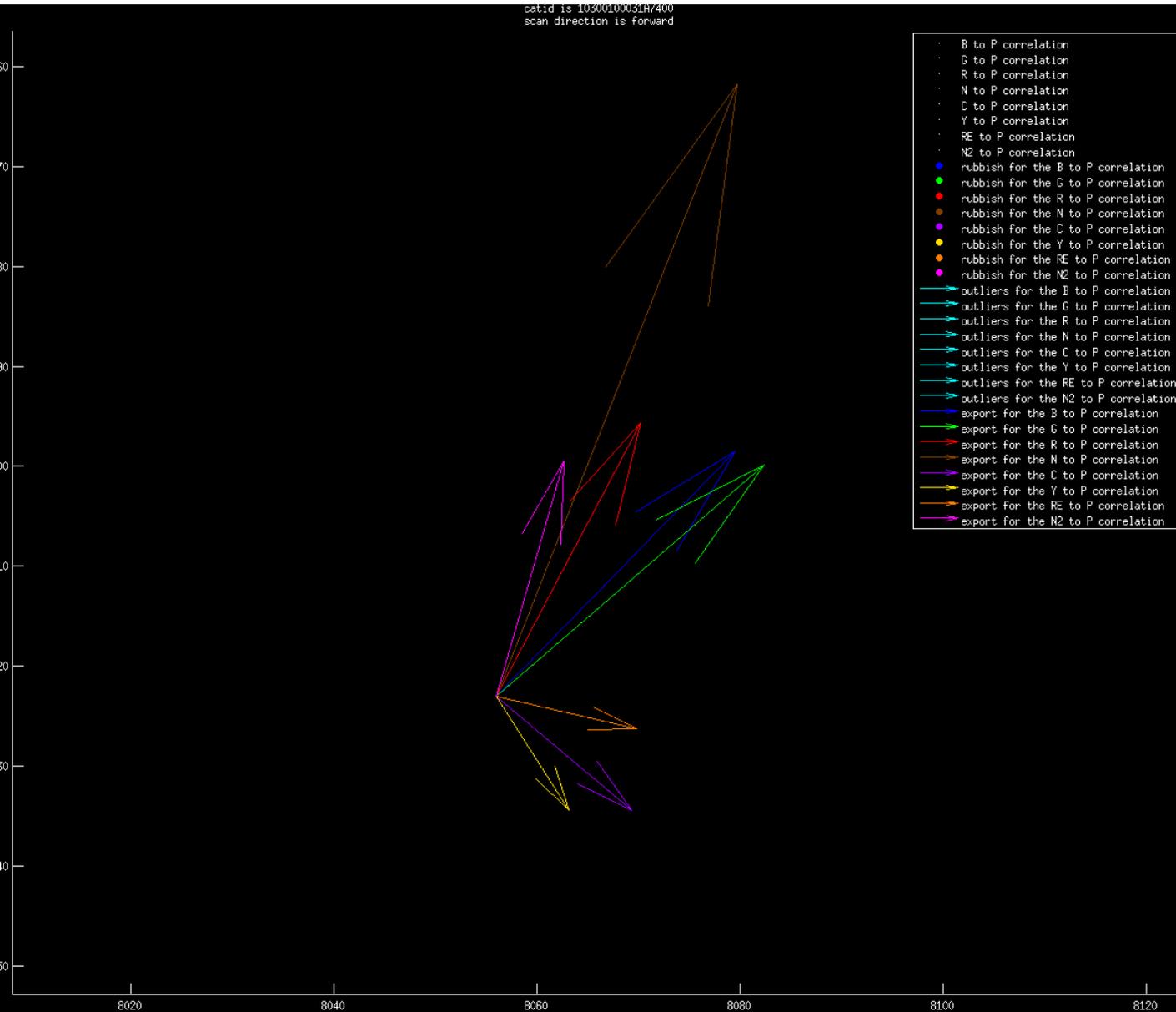


Nearly the entire
image correlates
well.

zoom level 5



misregistration vectors are well under 1 PAN pixel

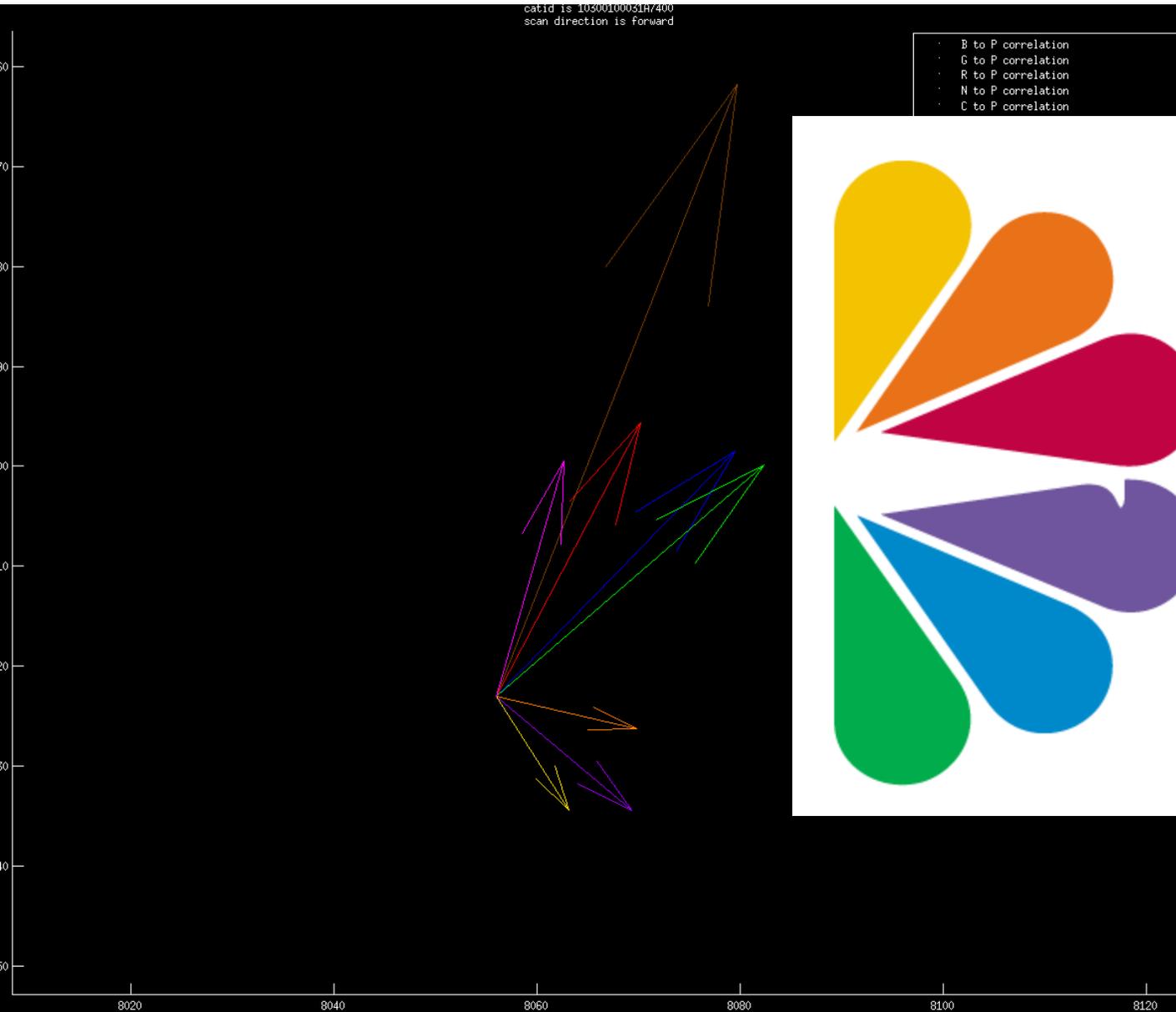


Nearly the entire image correlates well.

zoom level 6



no formal affiliation with peacock



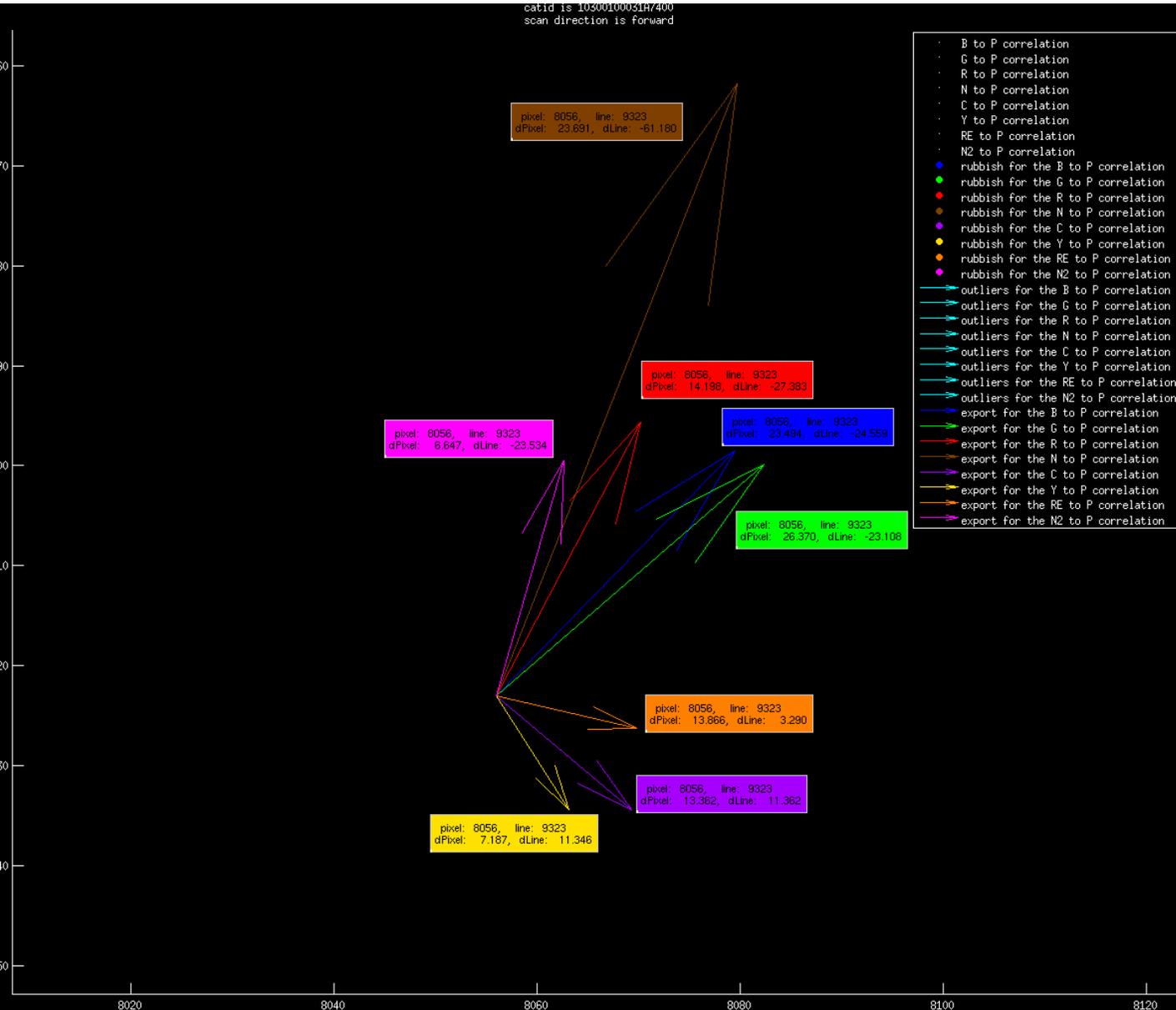
Nearly the entire image correlates well.

zoom level 6

(except when DG imagery used on the news, perhaps)



typical misregistration vectors are under 1 PAN pixel



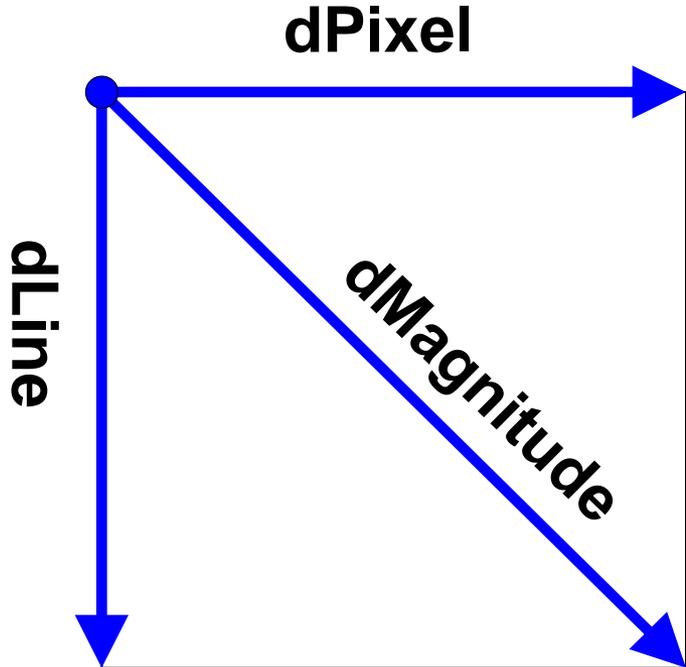
Nearly the entire image correlates well.

These dLines, dPixels are in units of **hundredths of a line/pixel (!)**

dLines, dPixels here under 100, so good.



(nadir projected) band to band statistics can be compiled

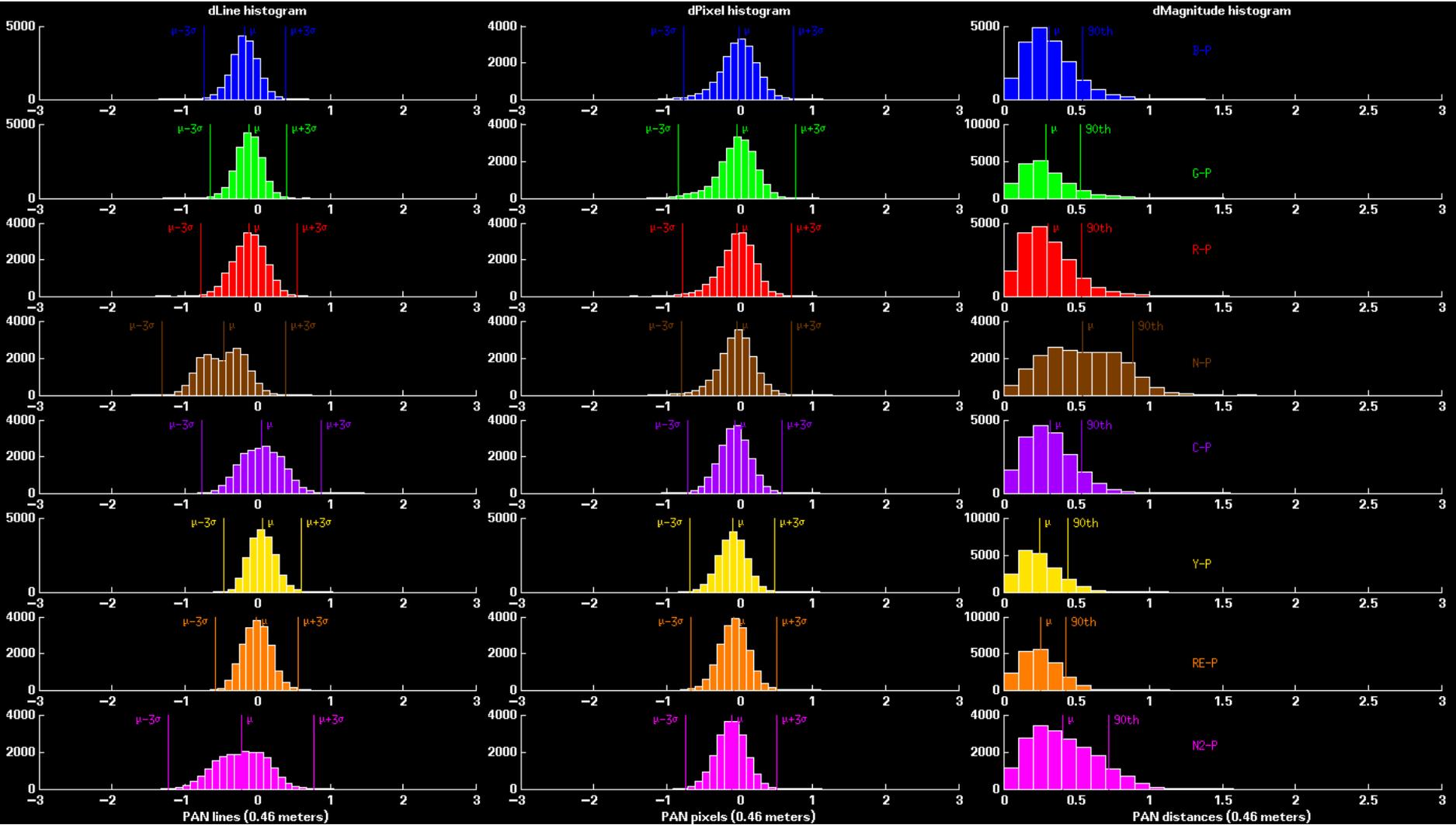


histograms can be made for

- dLine
- dPixel
- dMagnitude

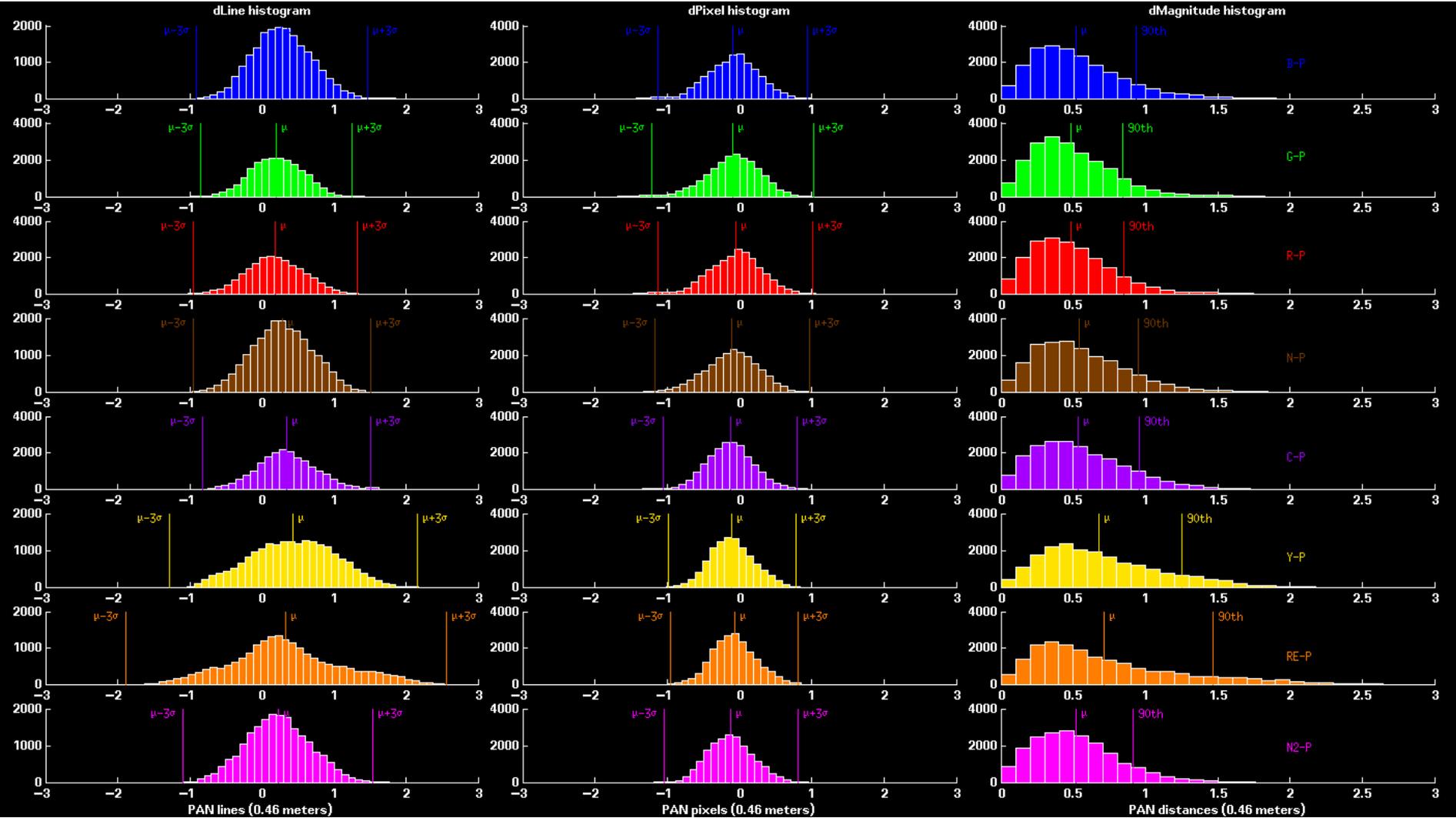


WV02 Forward scan histogram, only points common to all 8 bands



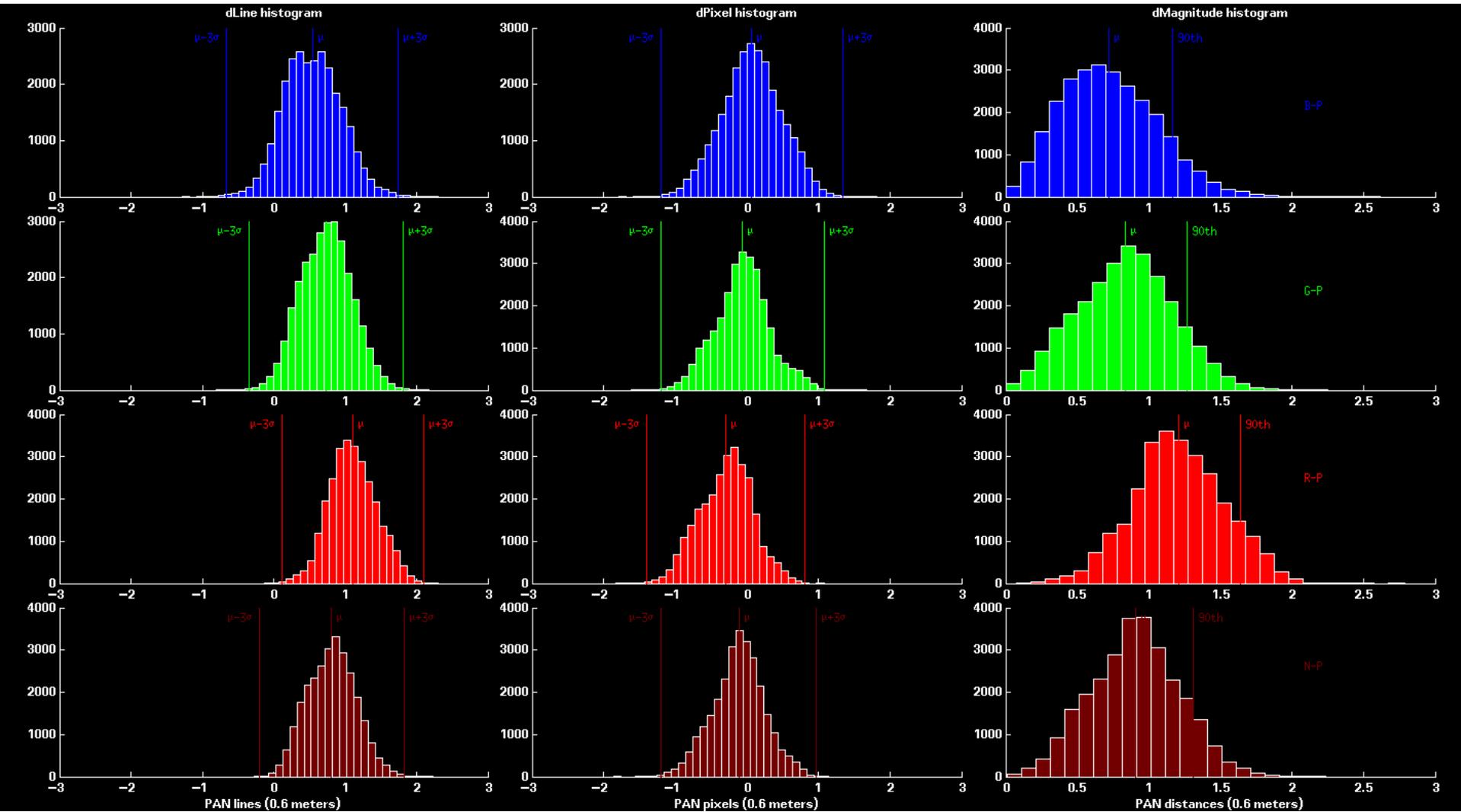


WV02 Reverse scan histogram, only points common to all 8 bands





QB02 histograms on 27817 points common to all 4 bands





conclusions



PAN camera calibration conclusions

- The WV02 (and WV01) panchromatic bands have great relative geolocation accuracy. Repeated results show CE90s just over and just under one PAN pixel at nadir.
- Relative accuracy of PAN band could be characterized as
 - CE90 ~ 1 PAN pixel at nadir, using image units
 - CE90 ~ 0.46 meters at nadir, using meters
 - 1 part in 35420 at nadir as a unitless ratio, since that's the width of the WV01/WV02 PAN band. $1/35420 \sim 2.8e-5$, or 28 ppm



MS band to band registration conclusions

- WV02 has great band to band registration! For all 8 bands,
 - mean misregistration (μ) always well under 0.5 PAN pixels
 - 90th percentiles never over 1.5 PAN pixels
- QB02 not as great, but only slightly worse than WV02. For all 4 bands,
 - mean misregistration (μ) closer to 0.75 PAN pixels, and can be higher
 - Most 90th percentiles near 1.5 PAN pixels, can jump over 1.5 PAN pixels