Geolocation Accuracy Topics Relevant to DigitalGlobe's Satellite Constellation

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outline

- **absolute geolocation accuracy topics**
  - **monoscopic geolocation accuracy statistics for**
    - **QB02**
    - **WV01**
    - **WV02**
  - **stereoscopic geolocation accuracy statistics for WV02**

- **relative geolocation accuracy topics**
  - **WV02 panchromatic camera calibration (criss crosses)**
    - **quick refresher**
    - **long term stability study**
  - **WV02 multispectral camera calibration (band-to-band registration)**
    - **definition**
    - **long term stability study**

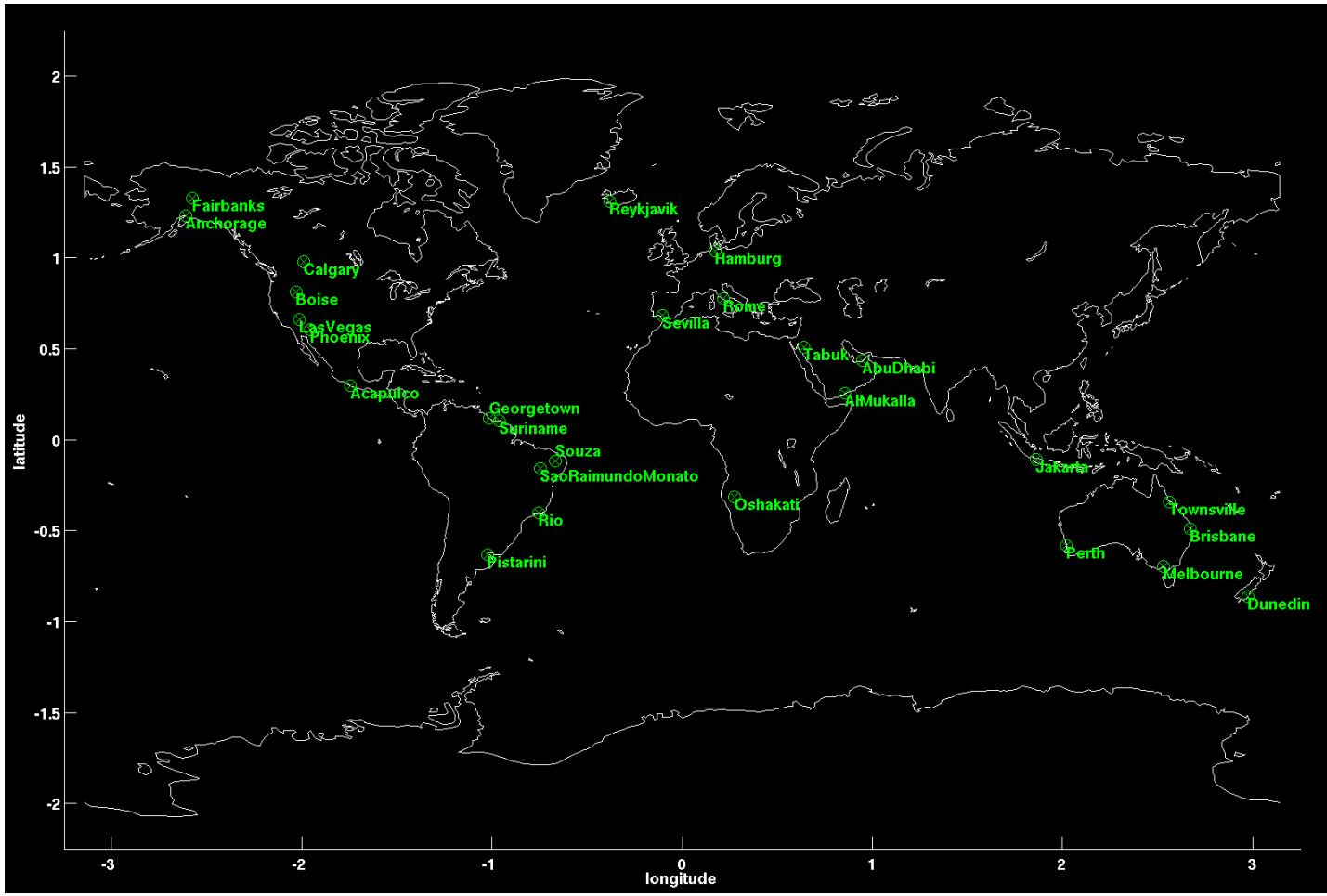
absolute geolocation accuracy

(or, what one can do with gcps)

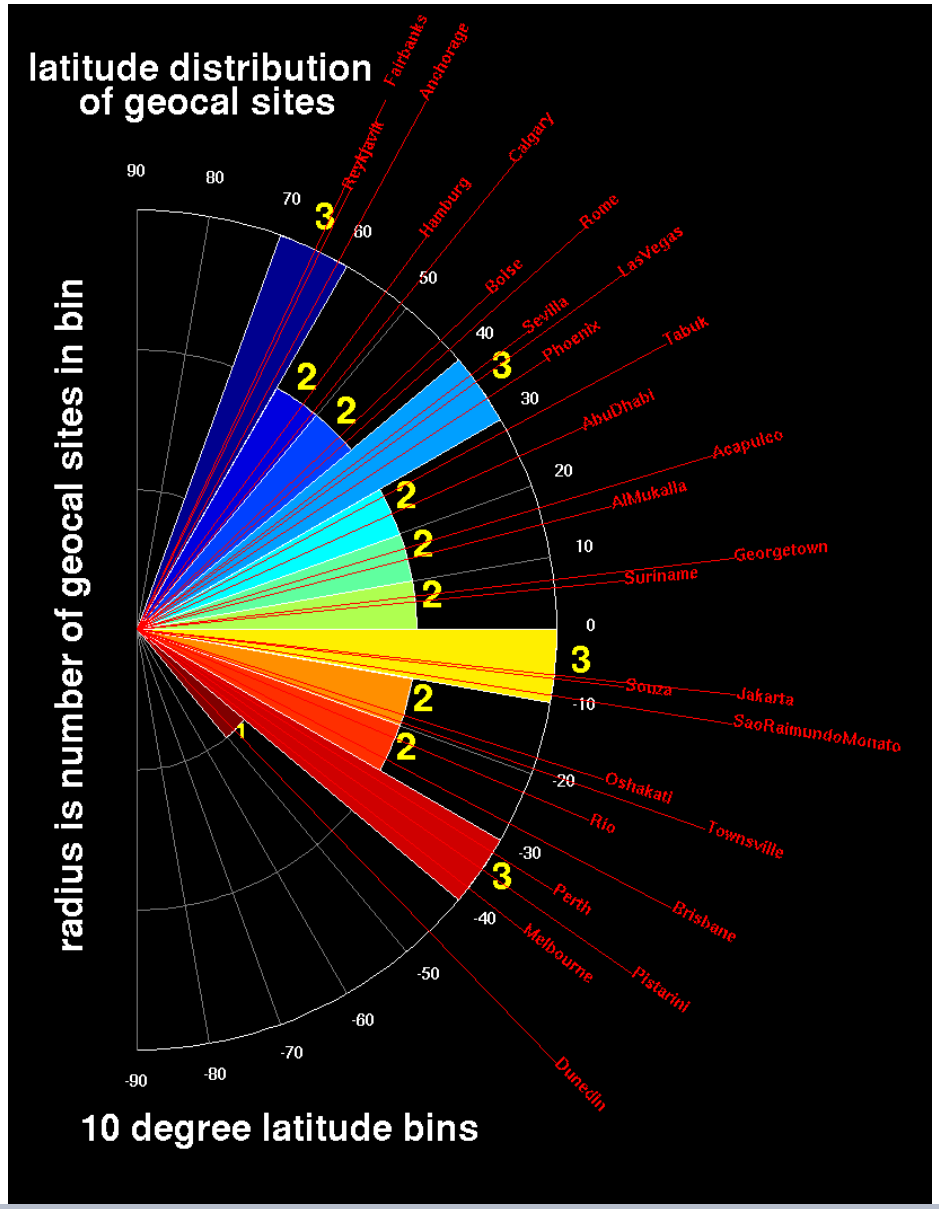
ground control points are the absolute reference of choice

site	ngcp
Abu Dhabi, United Arab Emirates	11
Acapulco, Mexico	8
Al Mukalla, Yemen	10
Anchorage, Alaska	14
Boise, Idaho	14
Brisbane, Australia	13
Calgary, Alberta	9
Dunedin, New Zealand	8
Fairbanks, Alaska	23
Georgetown, Guyana	9
Hamburg, Germany	11
Jakarta, Indonesia	10
Las Vegas, Nevada	48
Melbourne, Australia	22
Oshakati, Namabia	13
Perth, Australia	58
Phoenix, Arizona	92
Pistarini Airport, Argentina	20
Reykjavik, Iceland	8
Rio de Janeiro, Brazil	23
Rome, Italy	8
Sao Raimundo Monato, Brazil	13
Sevilla, Spain	9
Souza, Brazil	12
Paramaribo, Suriname	11
Tabuk, Saudi Arabia	9
Townsville, Australia	18

27 sites



geocal sites are evenly spread across latitude

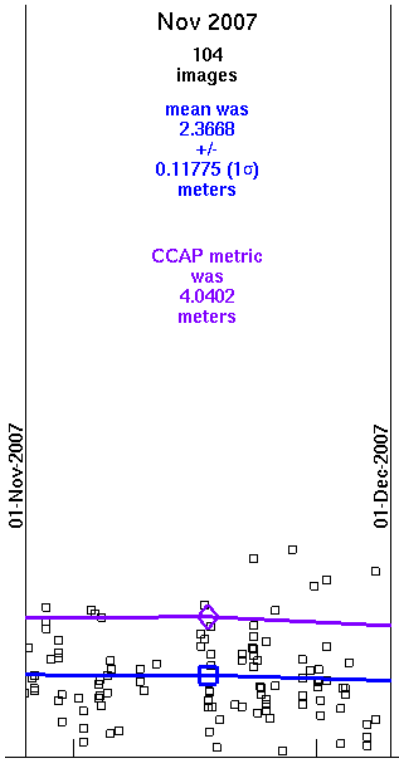


27 sites

strategy is to monitor the ingredients to geolocation, ***e.g. attitude, ephemeris***, down the orbital track

confirms good geolocation can be constructed at all latitudes with land

this 90th percentile is used for evaluation



if you represent each strip by the magnitude of the average error,

then take the NGA 90th percentile of a bin,

that's the ***CCAP metric***.

- Say there are N errors, r_1 to r_N
- Multiply N by 0.9, express result as an integer plus a fraction:

$$N*0.9 + 0.5 = i + f$$

- Stand f of the way between r_i and r_{i+1}

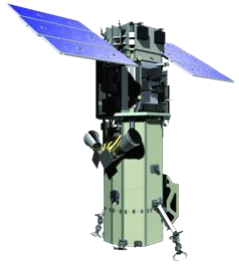
$$CE90 = r_i + (r_{i+1} - r_i)*f$$

- I call it NGA percentile in this talk

[1 2 3 4 5 6 7 8 9 10]

NGA percentile: if you have ten things, the 90th percentile is halfway between the ninth and tenth thing (it's unbiased, by construction through Monte Carlo studies)

monoscopic geolocation error analysis



WV02

WV01

QB02

770 km

496 km

450 km

δ

δ

locally horizontal !

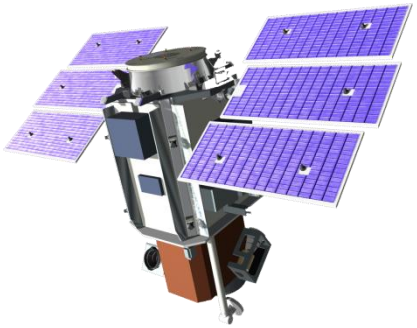
nadir projected error

projected location, measured location

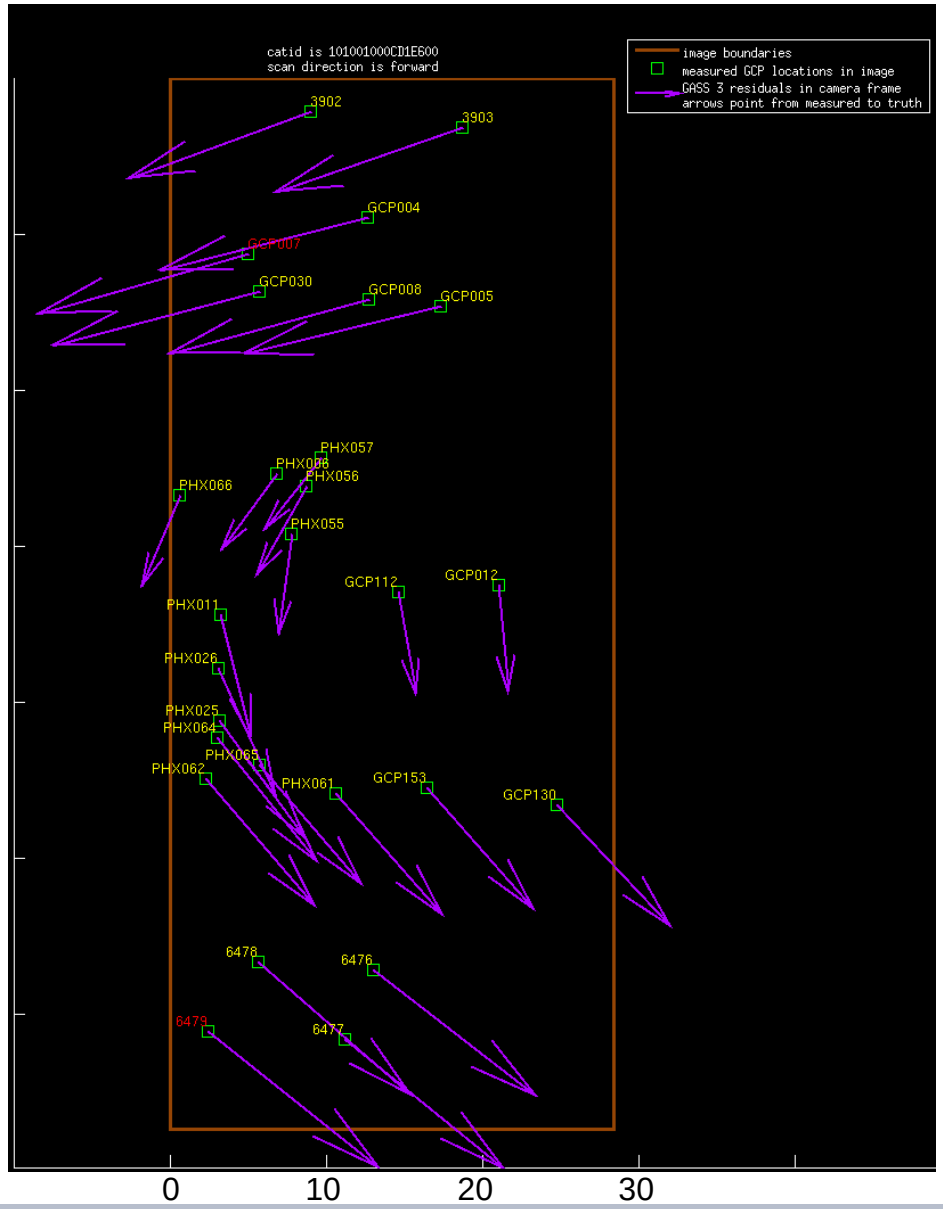
true location

full error

gcps are used to make quiver plots



QB02



10^3 lines/pixels for image borders, nadir projected meters for vectors

average geolocation error

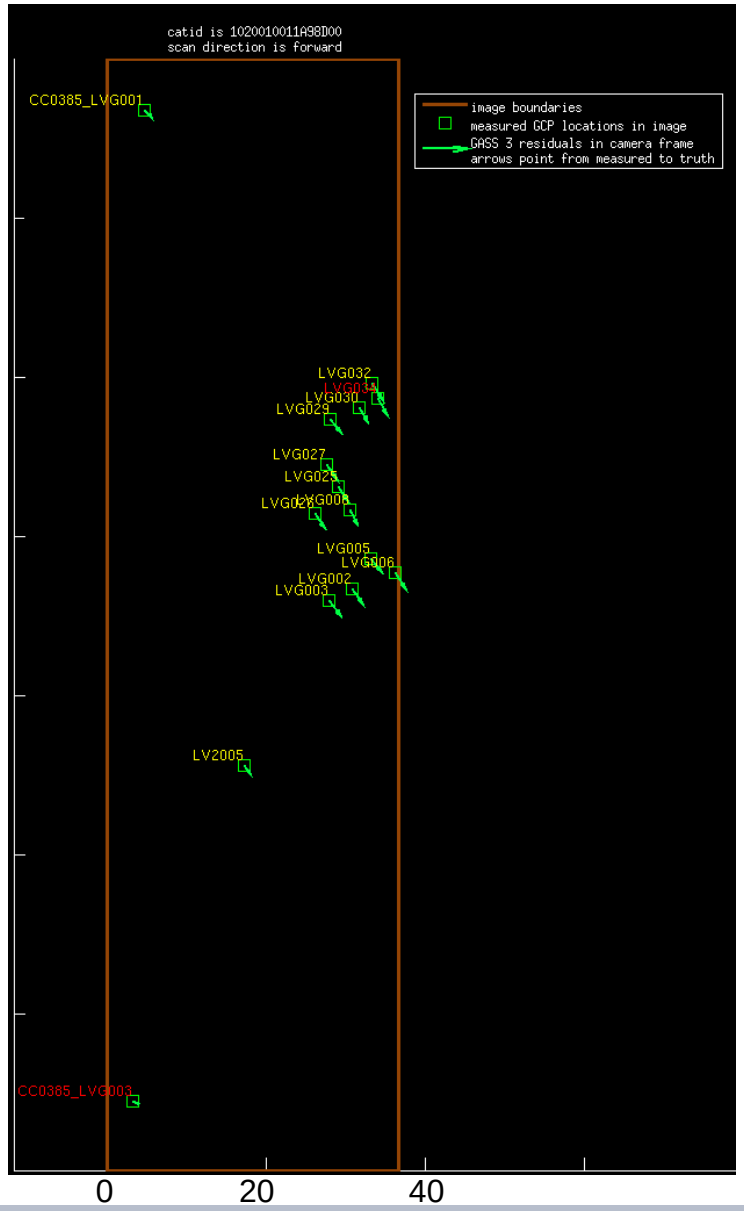
6.26 meters

6.25 meters

0.27 meters

gcps are used to make quiver plots

WV01



10^3 lines/pixels for image borders, nadir projected meters for vectors

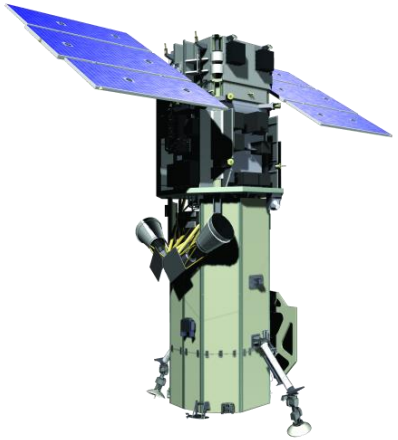
average geolocation error

1.99 meters

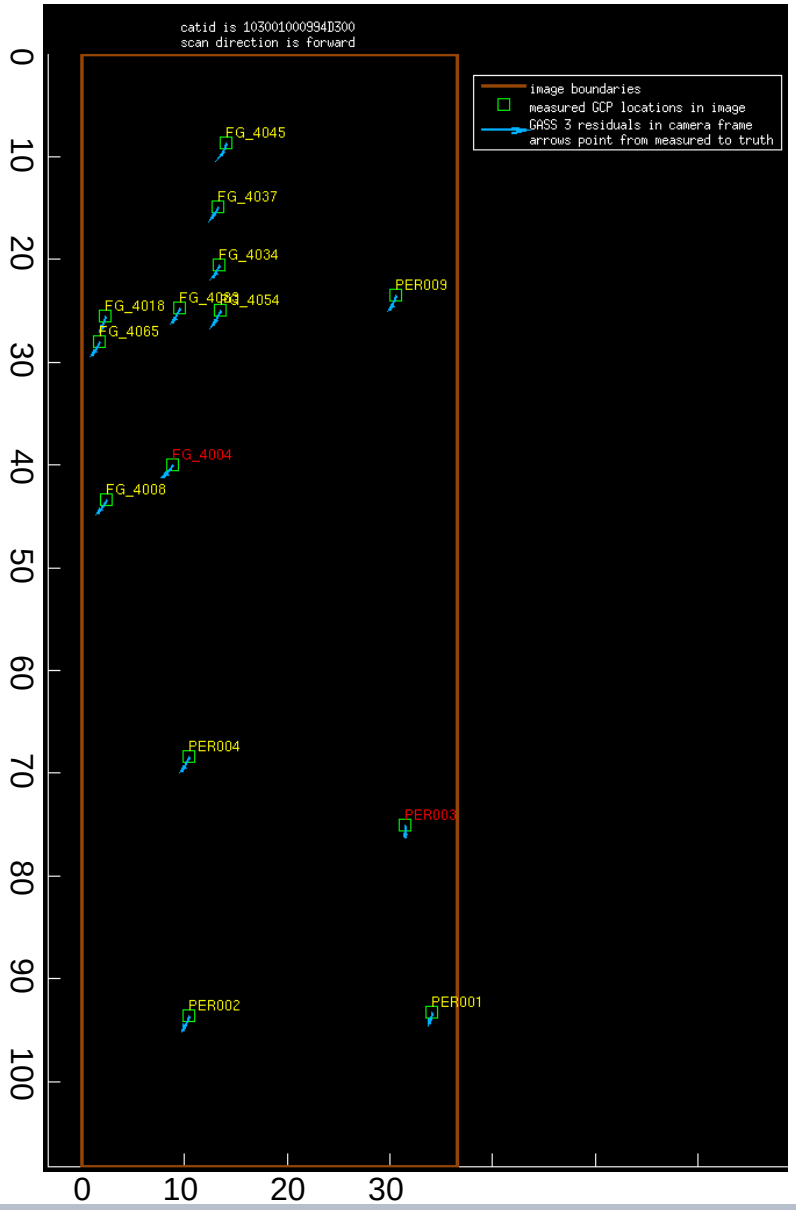
1.63 meters

1.14 meters

gcps are used to make quiver plots



WV02



10^3 lines/pixels for image borders, nadir projected meters for vectors

average geolocation error

1.37 meters

1.25 meters

0.56 meters

time bin plots, last 2 years

monoscopic analysis of all three satellites

desired absolute geolocation accuracy

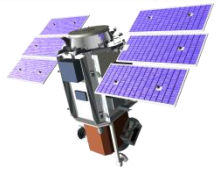
90th percentiles should be:

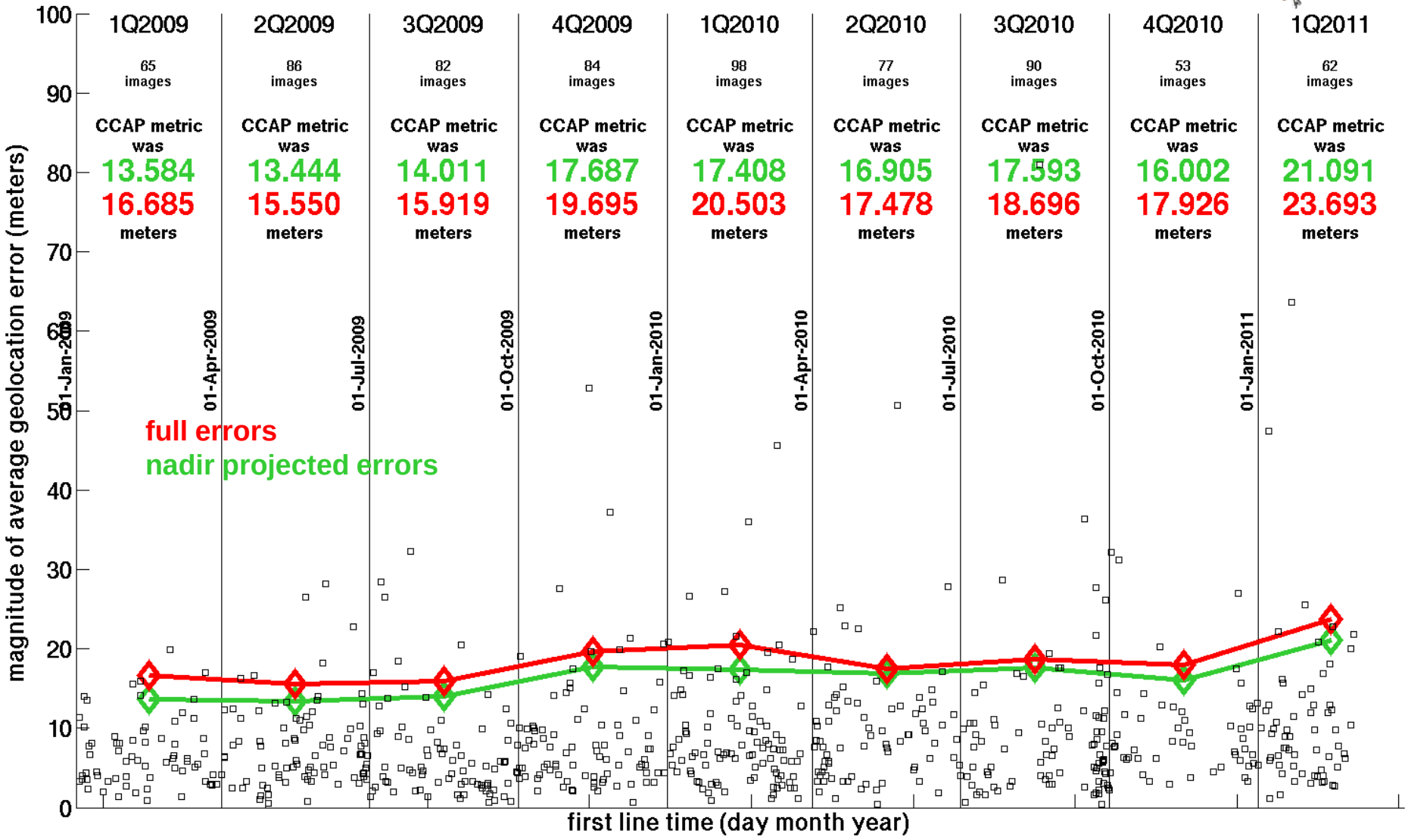
23 meters (at nadir) for ***QB02***

6.5 meters (at nadir) for

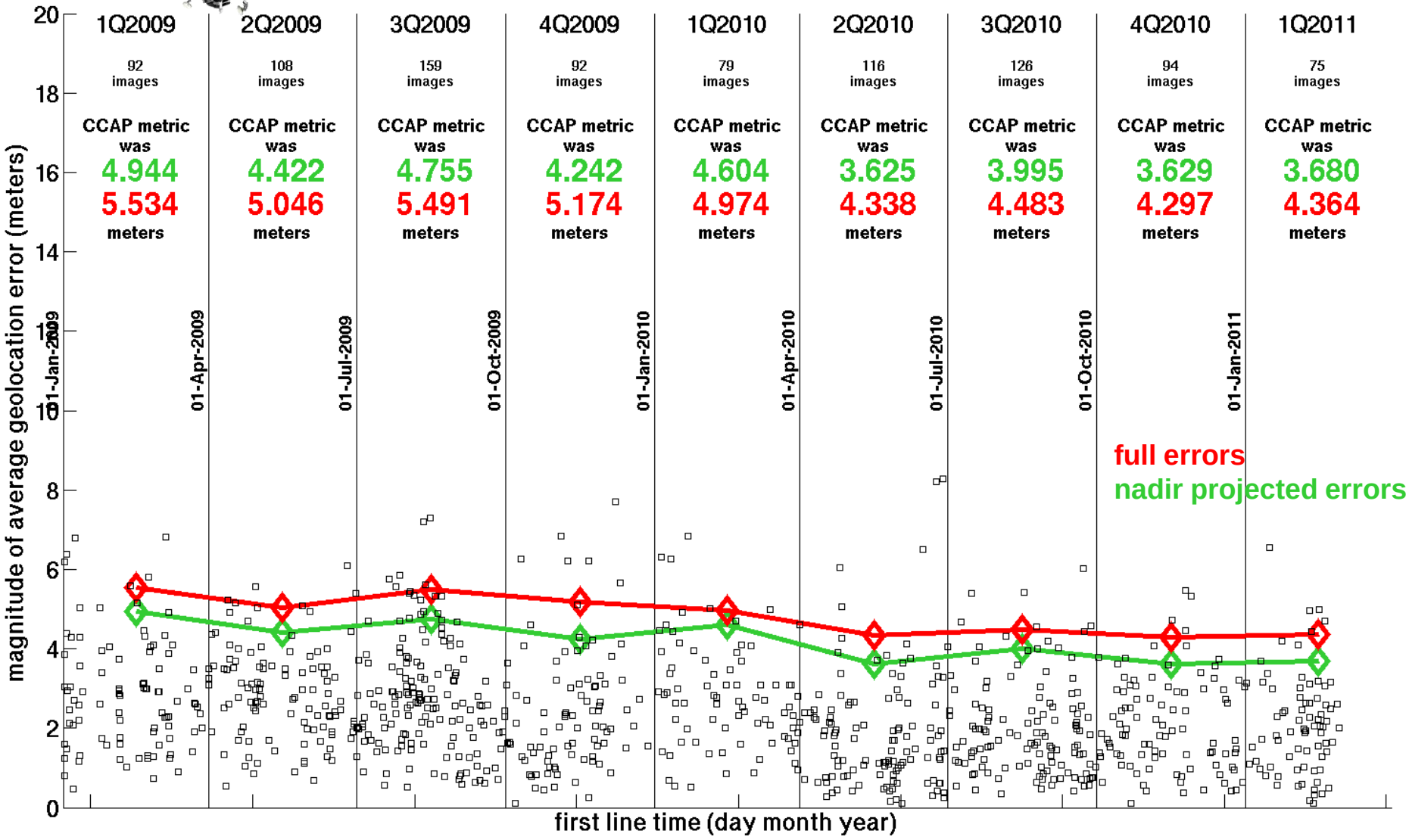
WV01, WV02

QB02 meets the 23 meter spec in all quarters

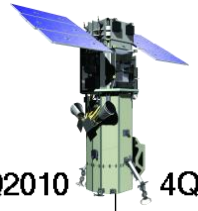


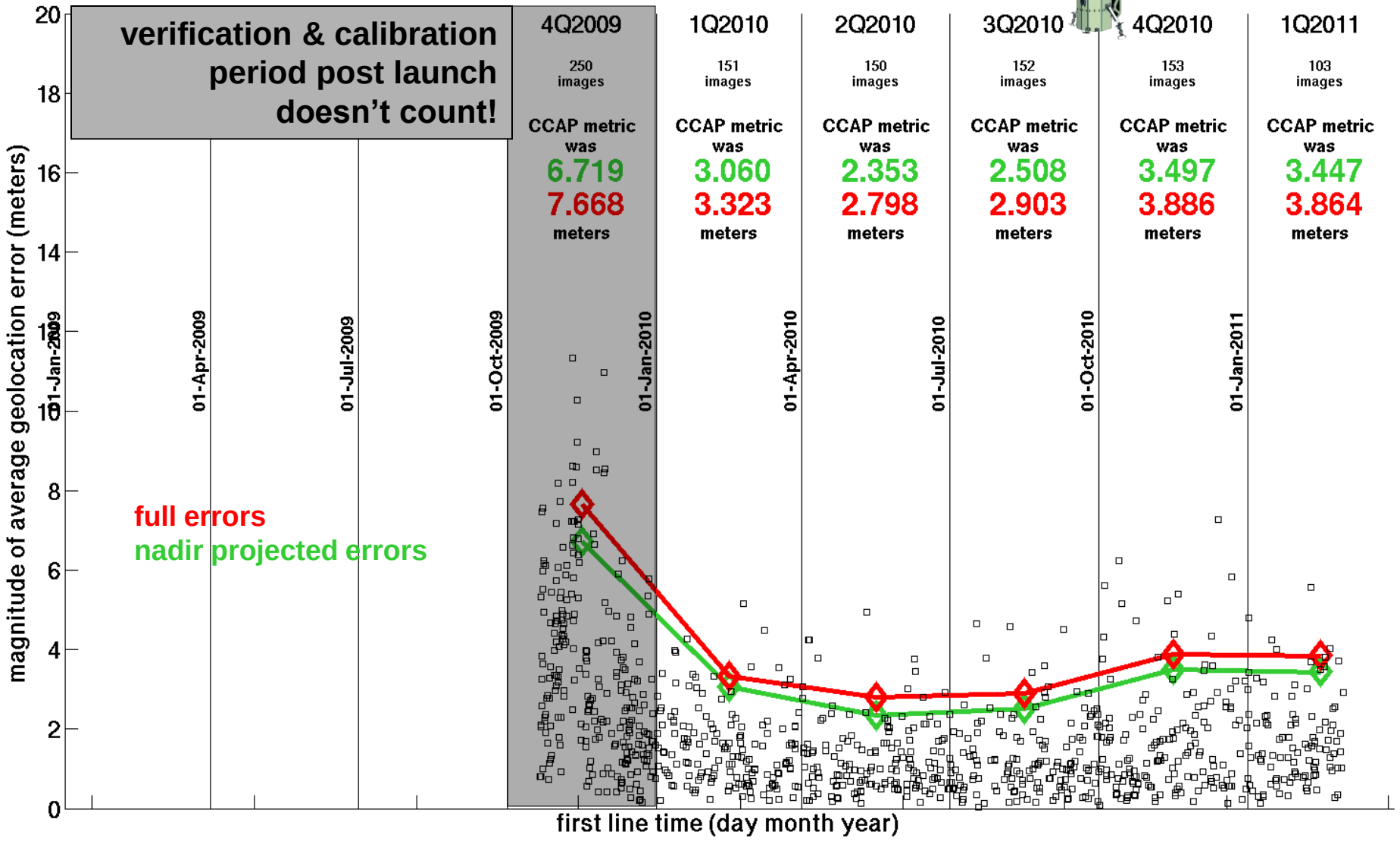


WV01 performs better than QB02



WV02 does best of all

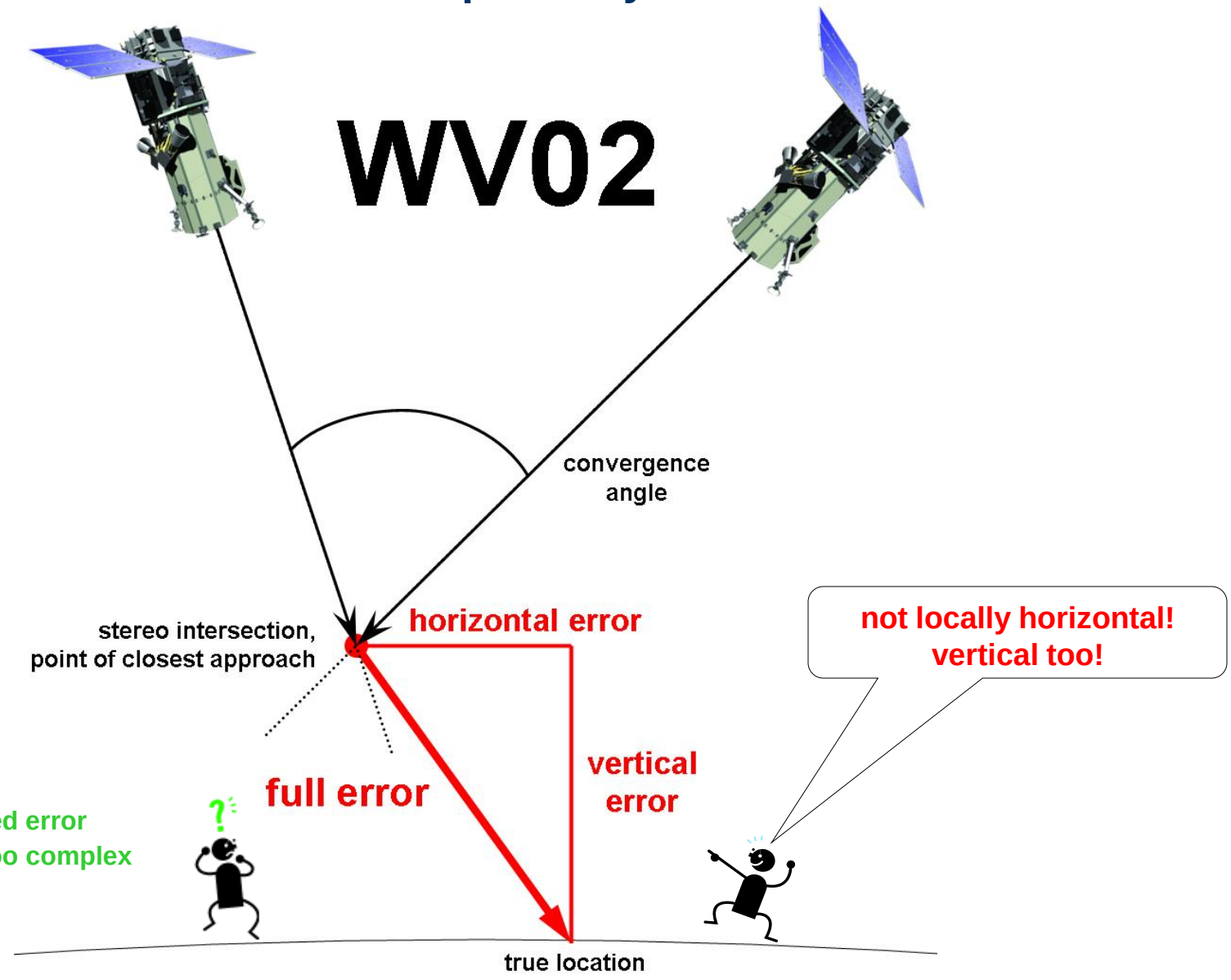




stereo geolocation

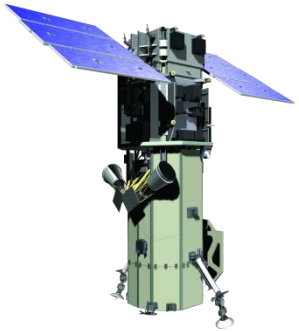
stereoscopic analysis of WV02

stereoscopic analysis

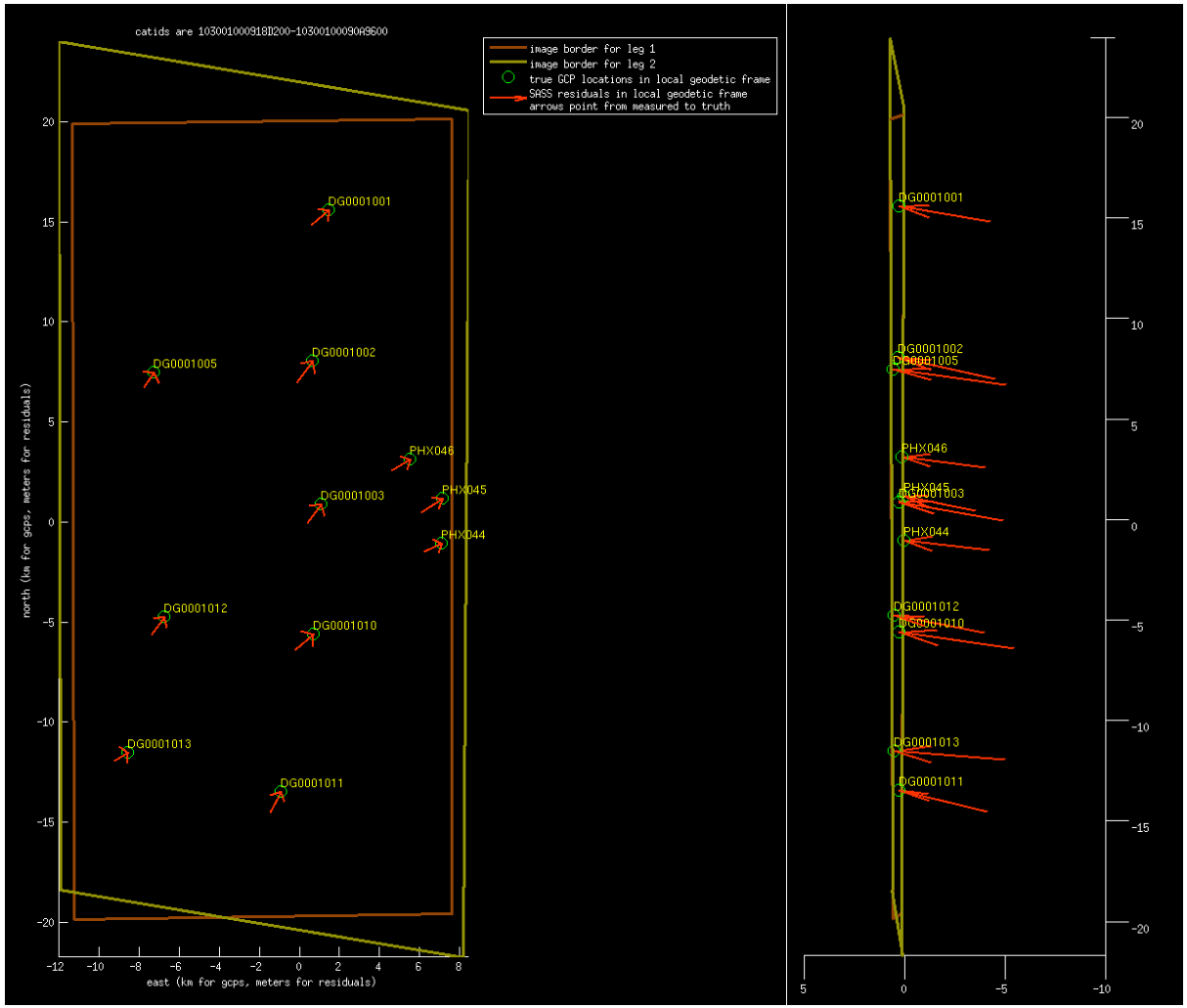


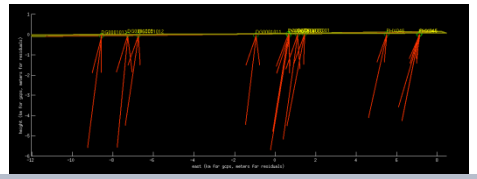
no nadir projected error
two cameras = too complex

stereo quiver plots have height components



WV02





kilometers for image borders, gcps
meters for vectors

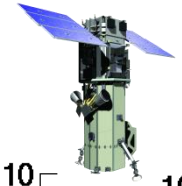
average geolocation error

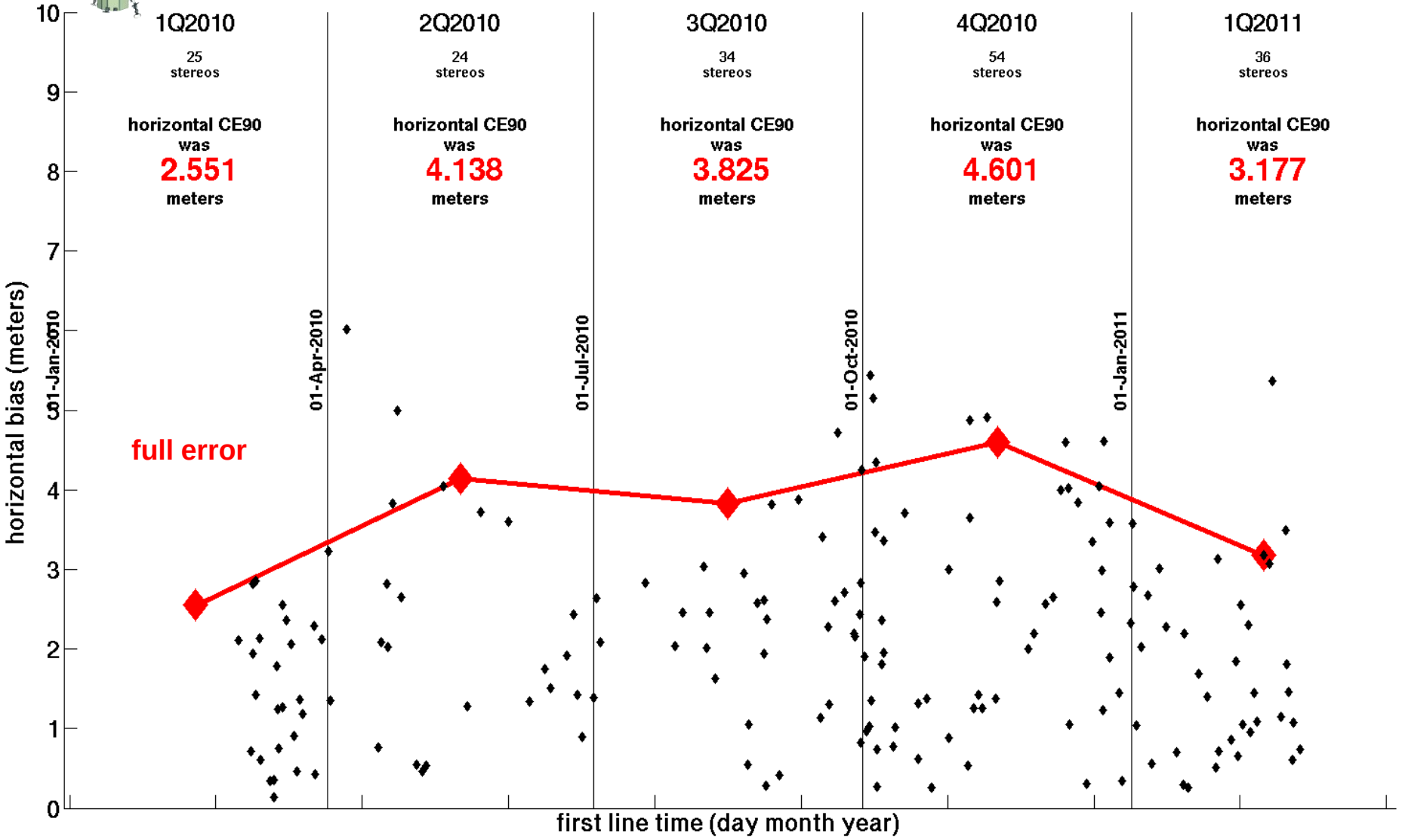
4.85 meters

4.73 meters

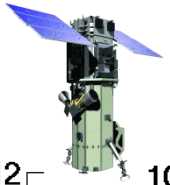
1.05 meters

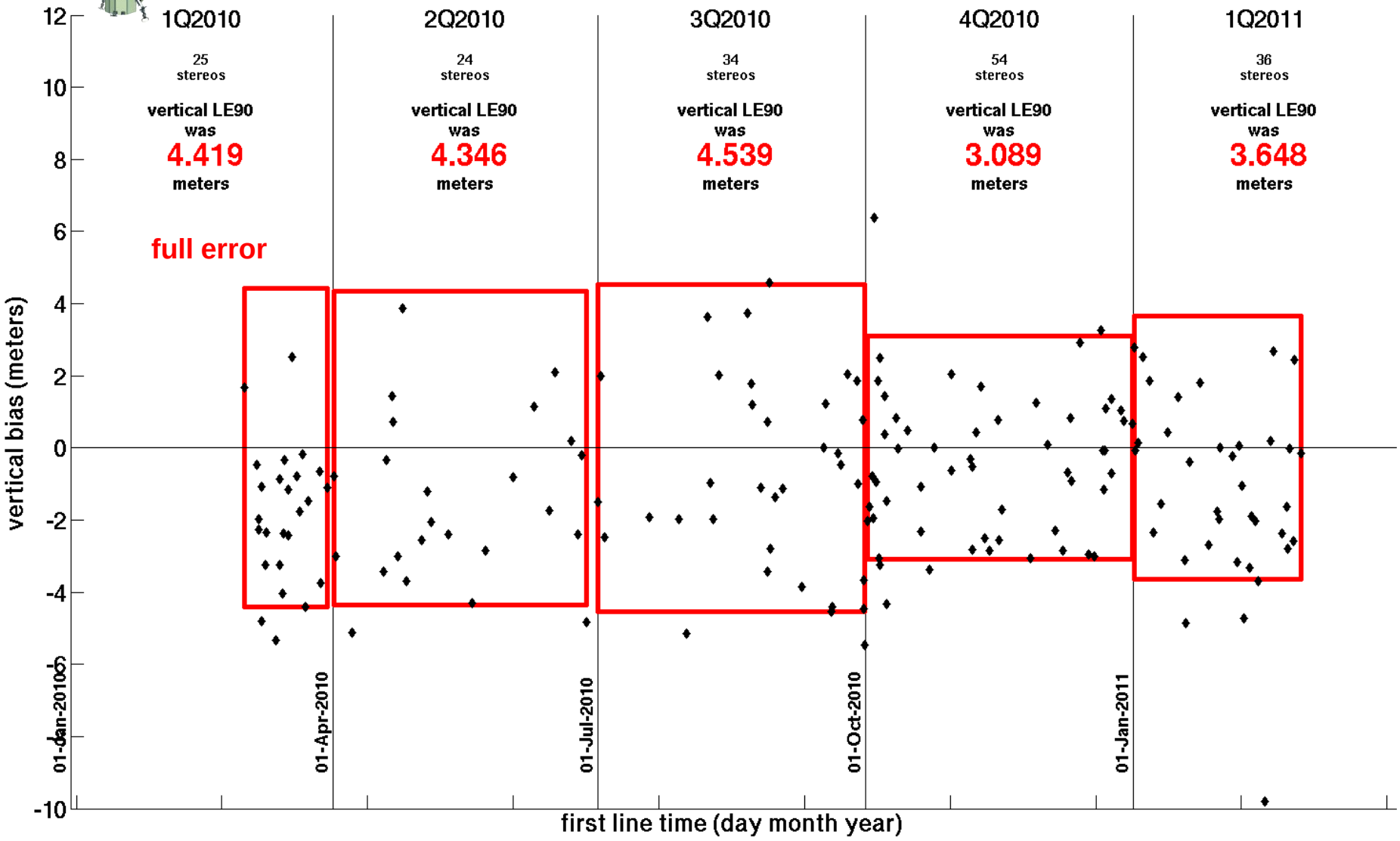
horizontal component of WV02 stereoscopic geolocation error





vertical component of WV02 stereoscopic geolocation error





relative geolocation accuracy

(or, what one can do with tie points)

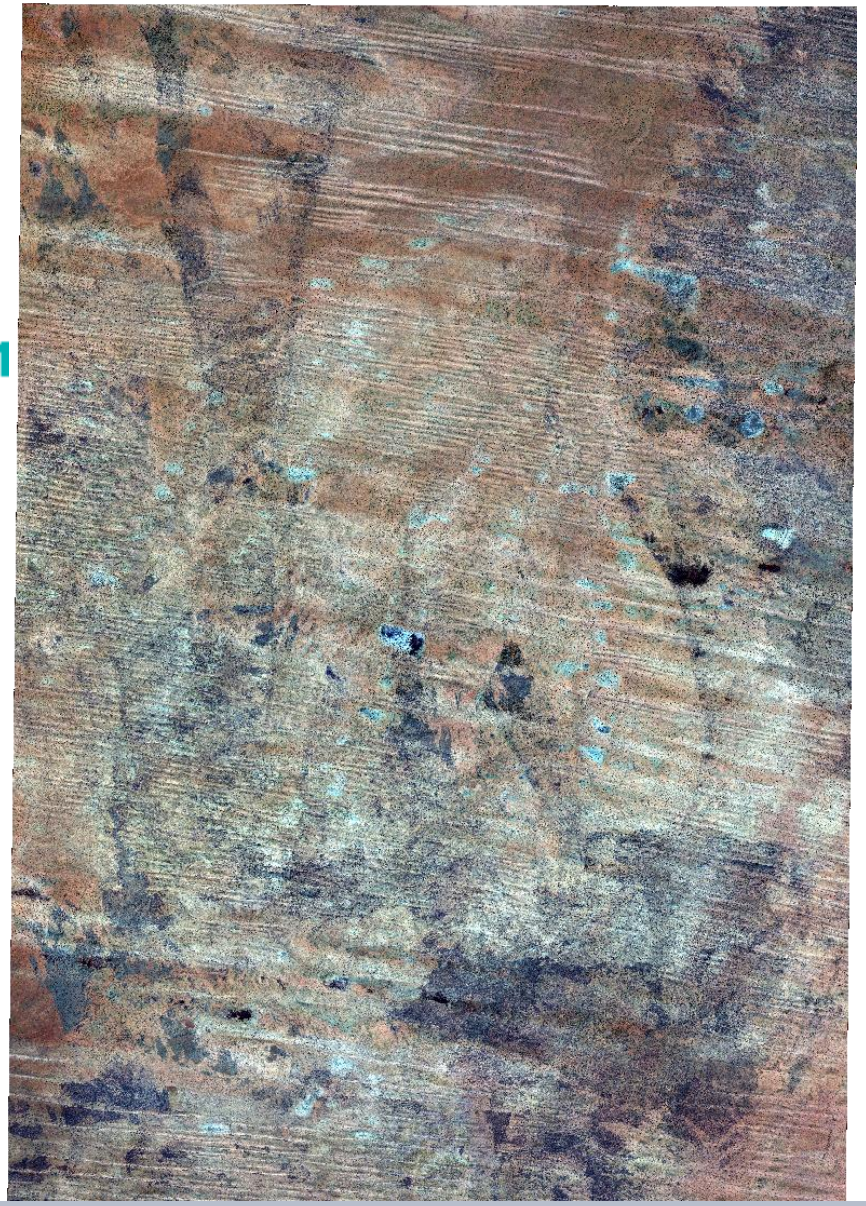
tie points are the relative reference of choice

One wilderness area that worked well for both PAN and MS camera calibration was

“central Australia 1”
latitude: -19.894929°
longitude: 130.912897°

PAN and MS calibration work performed with tie points over this site will be shown

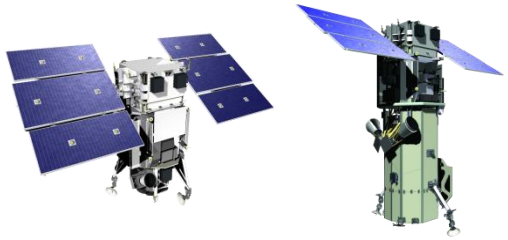
(affiliated poster shows other wilderness areas that were used for these two tasks)



PAN camera calibration

initial calibration, and long term stability

initial calibration of the WV02 PAN camera used WV01 PAN



before calibration

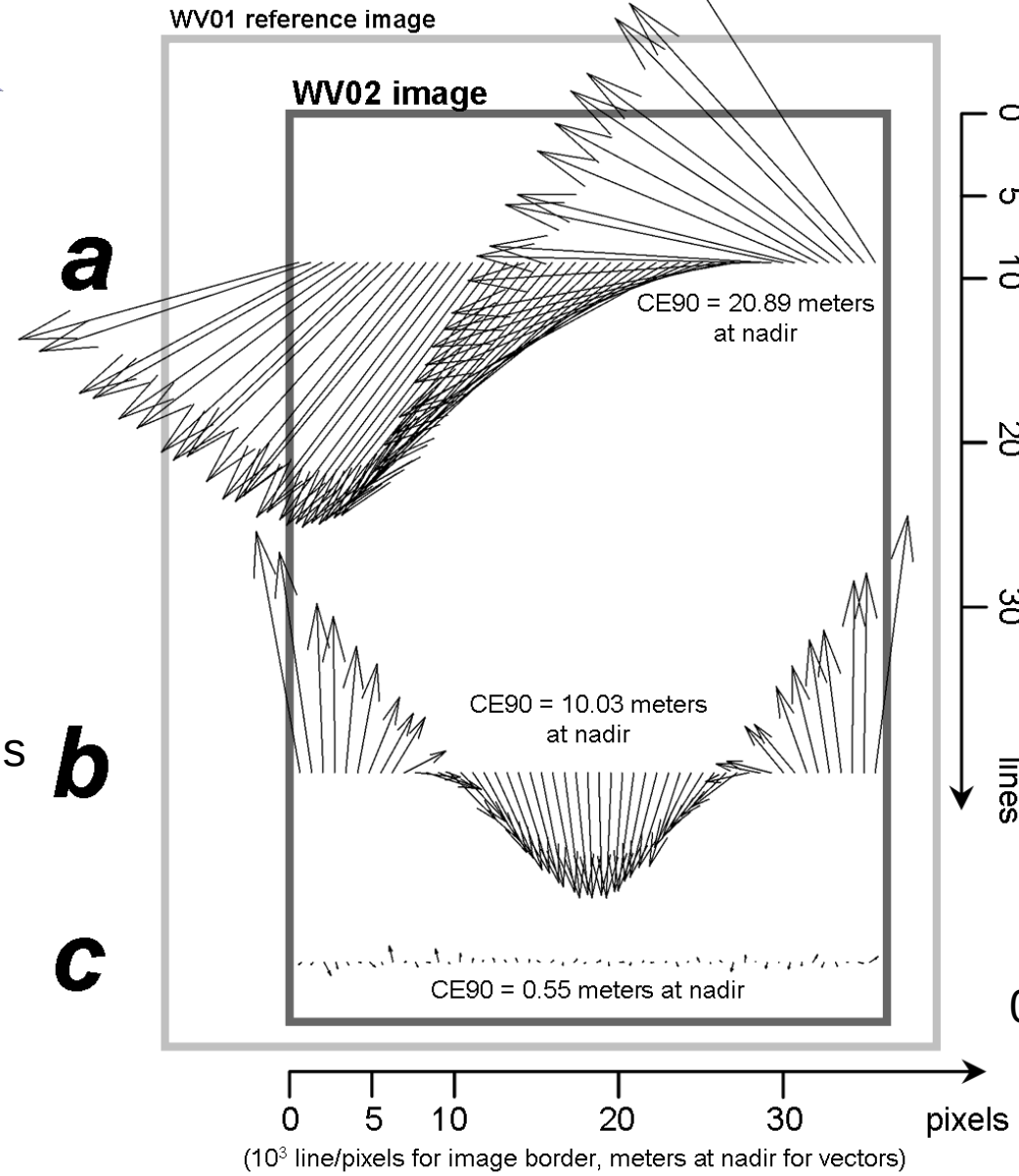
a

same as ***a***, but minus the average error

b

after calibration

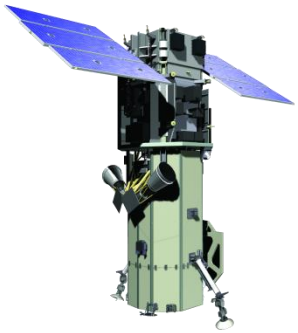
c

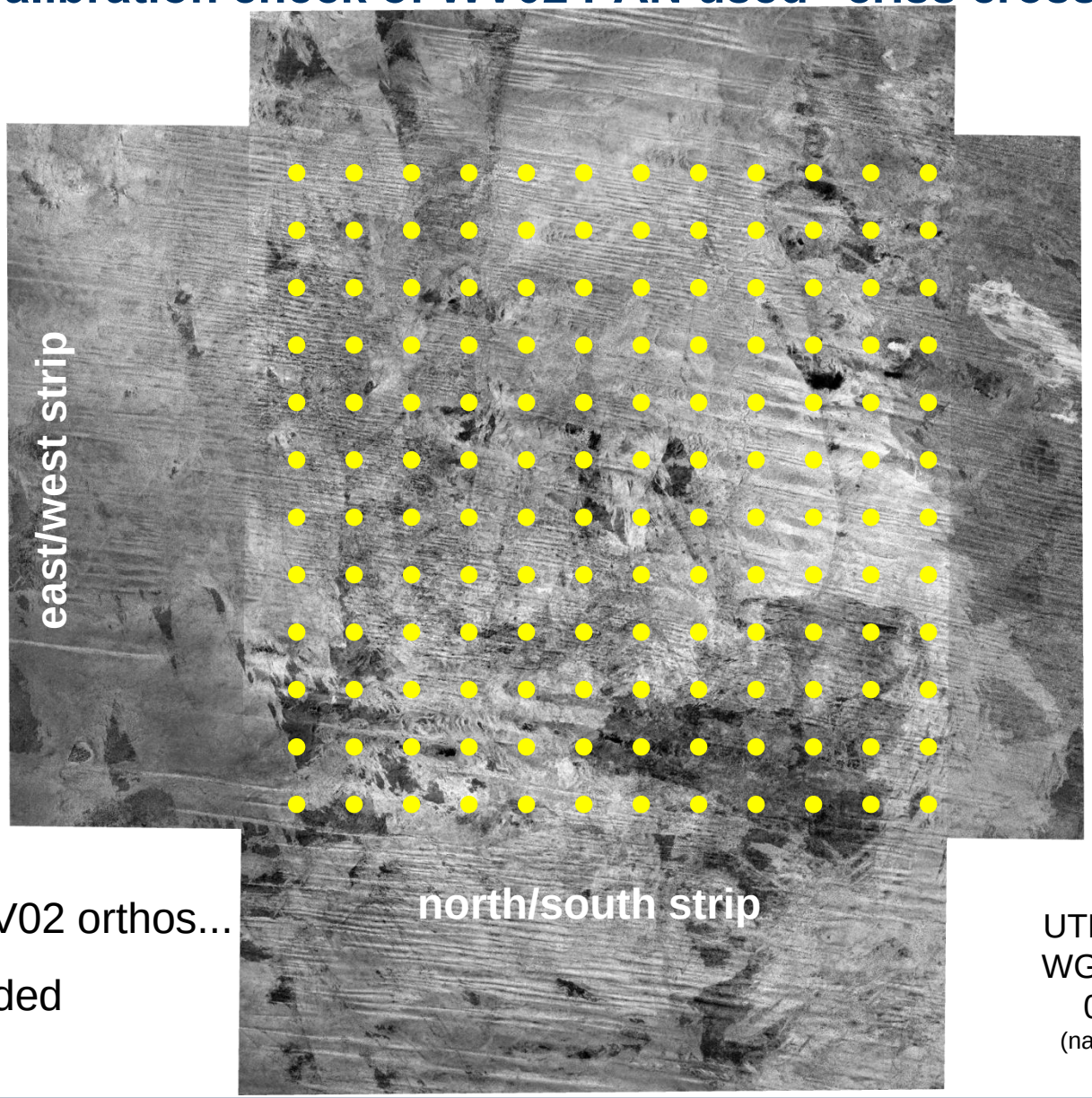


a line of tie points across the focal plane

1 PAN pixel = 0.46 meters at nadir

post-calibration check of WV02 PAN used “criss crosses”





a grid of tie points fills the overlap region

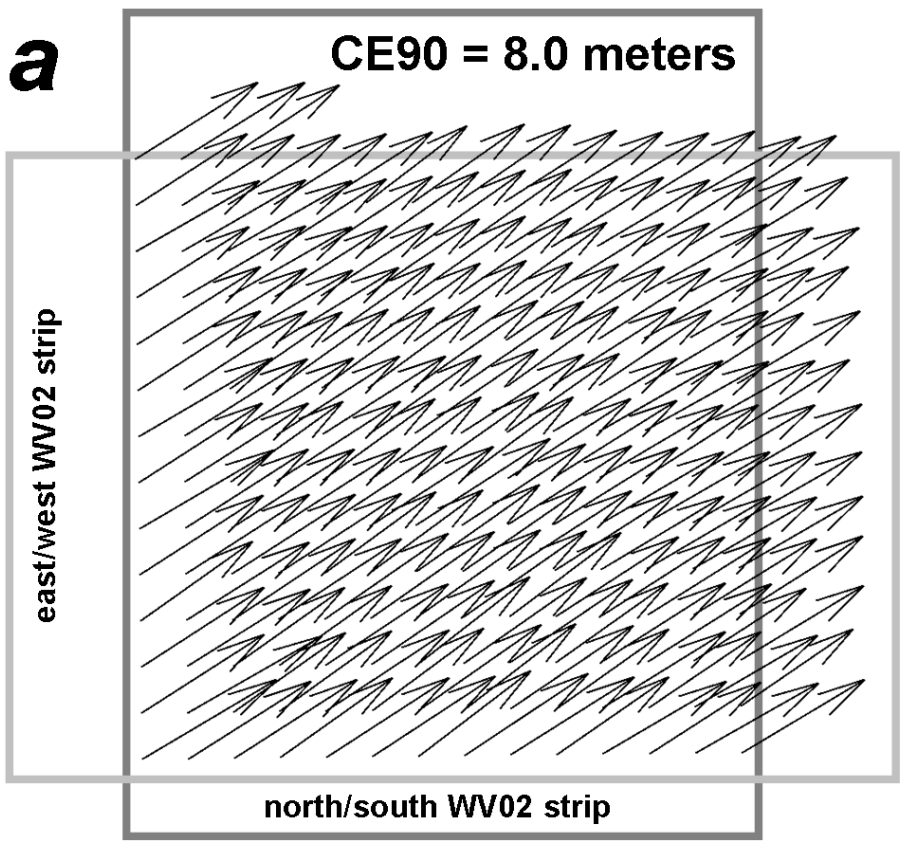
grid spacing is 300 lines/pixels

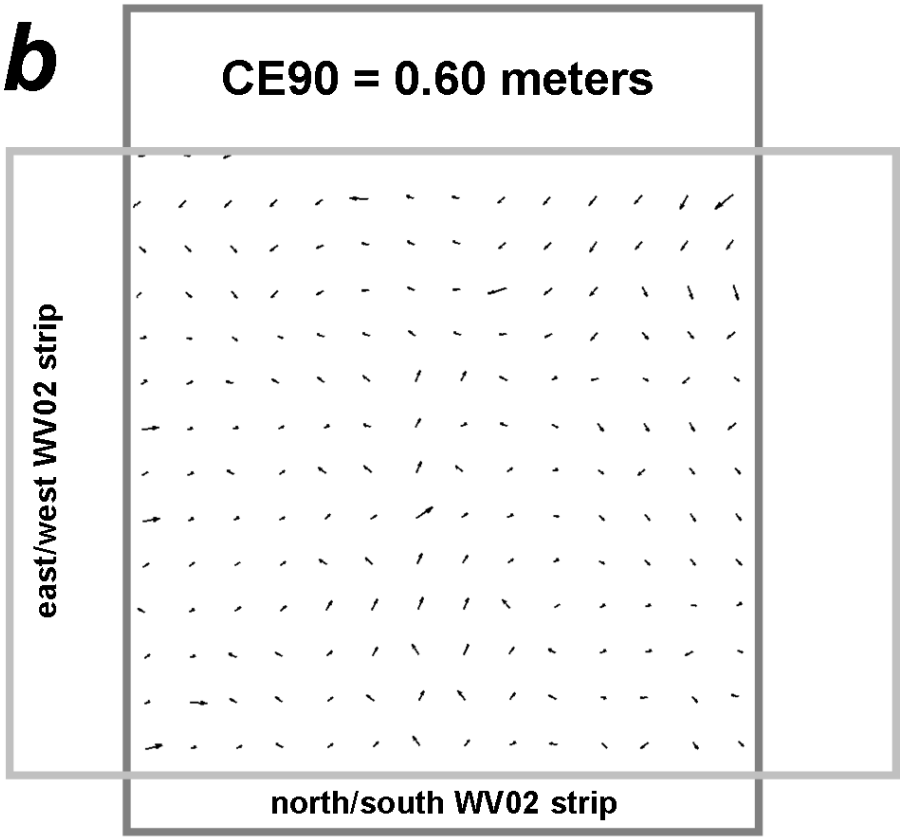
just a pair of WV02 orthos...

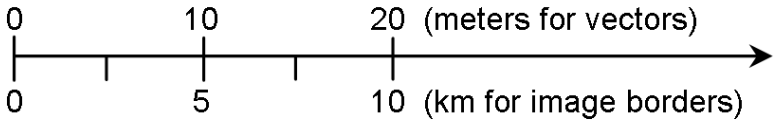
WV01 not included

UTM projection
WGS-84 datum
0.46 GSD
(native PAN GSD)

criss crosses start with a bias; once removed, nothing remains



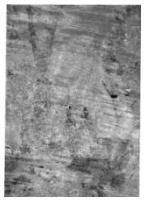




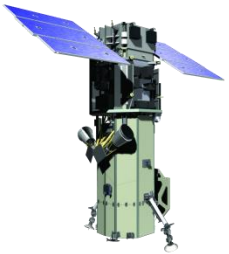
1 PAN pixel = 0.46 meters at nadir

*this figure is symbolic, it has been thinned by a factor of 9... real criss cross grid has over 100 rows, columns!

WV02 PAN stability study used an “endless criss cross”

1	2	3	4	5	6	7	8	9	10
									
25-Dec-2009	16-Jan-2010	27-Jan-2010	7-Feb-2010	18-Feb-2010	24-Jun-2010	16-Jul-2010	7-Aug-2010	18-Aug-2010	28-Dec-2010

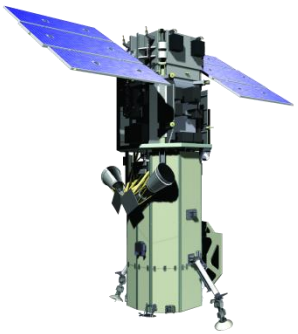
10 acquisitions over cAustralia1 during 2010



at first glance, looks like 5 criss crosses...

...but could be 25 if every north/south is combined with every east/west!

WV02 PAN relative accuracy was great, regardless of criss cross!



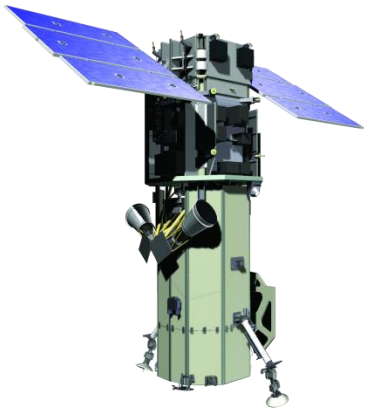
strip pair	CE90 after throwing out the average error	days between collects
3,2	0.64	11
3,4	0.54	11
5,4	0.65	11
9,8	0.55	11
1,2	0.68	22
7,6	0.67	22
7,8	0.61	22
5,2	0.65	33
1,4	0.55	44
9,6	0.49	55
5,6	0.67	126
9,10	0.52	132
3,6	0.69	148
7,4	0.47	159
7,10	0.63	165
5,8	0.46	170
1,6	0.67	181
7,2	0.60	181
3,8	0.65	192
9,4	0.65	192
9,2	0.47	214
1,8	0.60	225
5,10	0.47	313
3,10	0.64	335
1,10	0.53	368

1 PAN pixel = 0.46 meters

all criss crosses have a CE90 equal to or just over 1 PAN pixel ***regardless of the time between collects!***

implies the PAN camera model is rock solid, has no time dependence

WV02 PAN relative accuracy is great!



Since there's no pattern, average the column of CE90s!

Declare the relative accuracy of the WV02 PAN camera to be

0.59 +/- 0.08 meters (1σ)

1.28 +/- 0.2 PAN pixels (1σ)

MS camera calibration

or, band-to-band calibration

the goal of MS camera calibration

a particular feature should have
the same geodetic coordinates
in every spectral band!

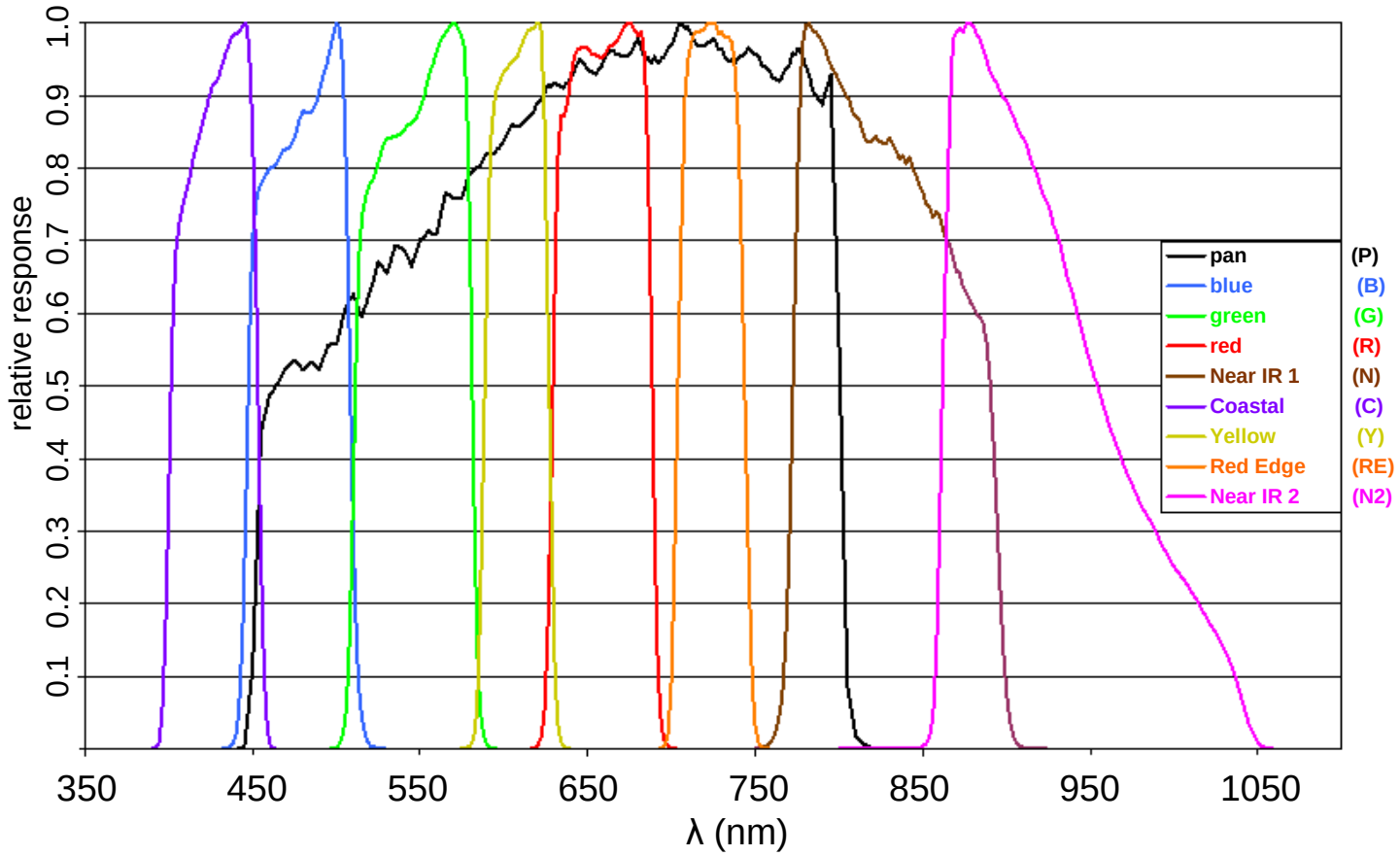
(perfect band-to-band registration)

Camera calibrations methods dial it in to 1 PAN pixel, even though it's MS

Process is essentially identical to PAN camera calibration

band-to-band registration for WV02

There are 9 spectral bands...



...so that makes $\binom{9}{2}$ = 36 possible two-band combinations

all possible 2 band combinations for WV02

B	1							
G	2	9						
R	3	10	16					
N	4	11	17	22				
C	5	12	18	23	27			
Y	6	13	19	24	28	31		
RE	7	14	20	25	29	32	34	
N2	8	15	21	26	30	33	35	36
band	P	B	G	R	N	C	Y	RE

36 subcases

real band-to-band registration fall into three coarse bins

P to MS

B	1							
G	2	9						
R	3	10	16					
N	4	11	17	22				
C	5	12	18	23	27			
Y	6	13	19	24	28	31		
RE	7	14	20	25	29	32	34	
N2	8	15	21	26	30	33	35	36
band	P	B	G	R	N	C	Y	RE

MS to MS, same band group

MS to MS, different band group

performance bins can be explained by focal plane layout

(but I can't show the exact blueprint!)

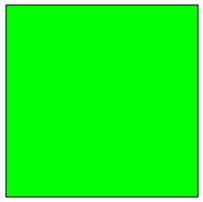
WV02 focal plane has these band groups

B R
G N

P

C RE
Y N2

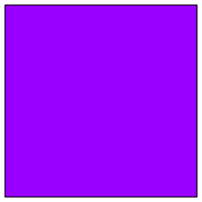
"MS1"



1.84 meters at nadir

0.46 meters at nadir

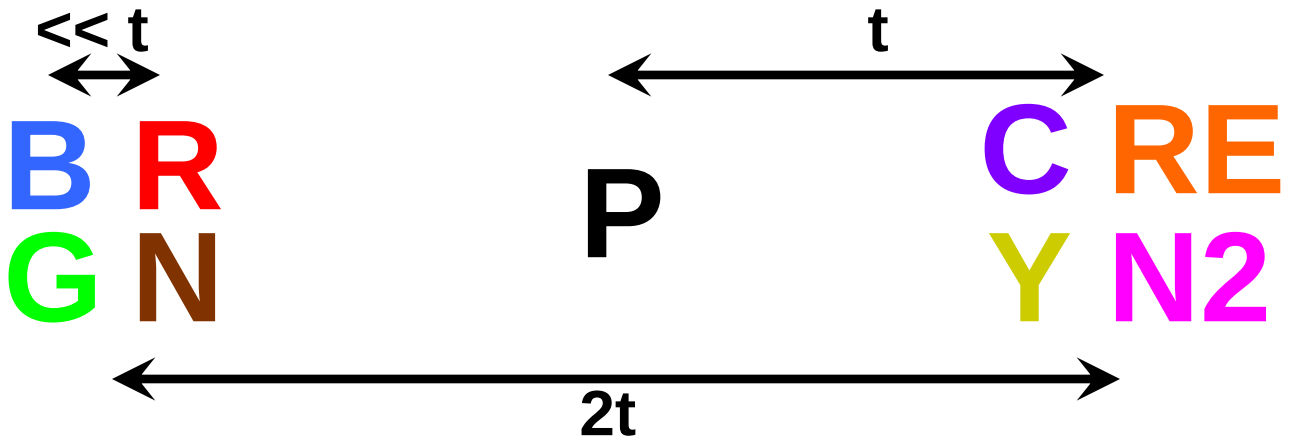
"MS2"



1.84 meters at nadir

quality of registration depends on time between bands

t ≈ 0.13 seconds



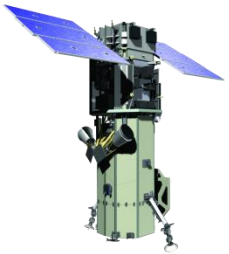
the less time between two bands,

the better the registration between those two bands !

WV02 MS study used the same “endless criss cross”

1	2	3	4	5	6	7	8	9	10
									
25-Dec-2009	16-Jan-2010	27-Jan-2010	7-Feb-2010	18-Feb-2010	24-Jun-2010	16-Jul-2010	7-Aug-2010	18-Aug-2010	28-Dec-2010

10 acquisitions over cAustralia1 during 2010

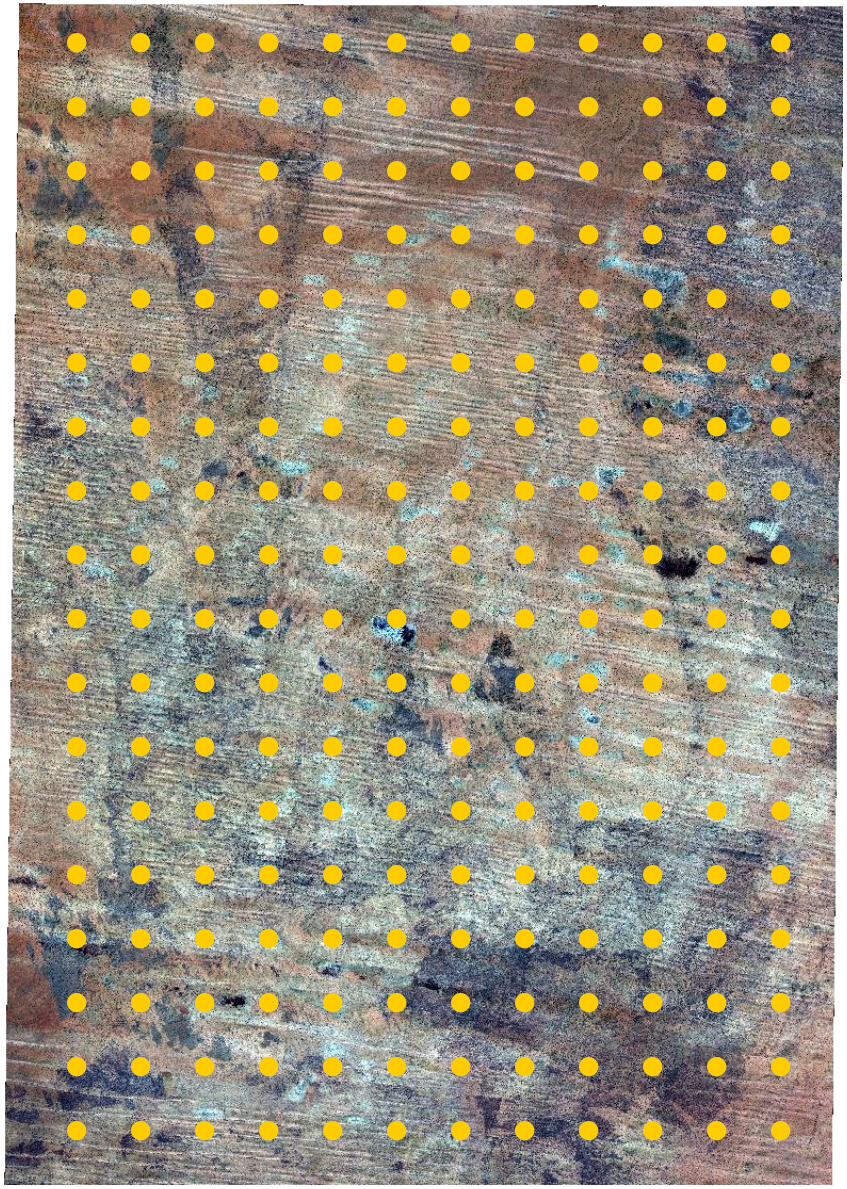


for the MS study, this sequence counts as
10 consecutive measurements of band-to-band registration

each strip provides ~20,000 band-to-band registration measurements
for every subcase (x36)

band-to-band registration was checked in each strip

tie points are made between all 36 possible 2-band combinations



a grid of tie points fills the entire strip

grid spacing is 300 lines/pixels

full grid is ~20,000 points per strip

UTM projection
WGS-84 datum
0.46 GSD
(native PAN GSD... even for MS bands!)

no time dependence observed in WV02 band-to-band registration

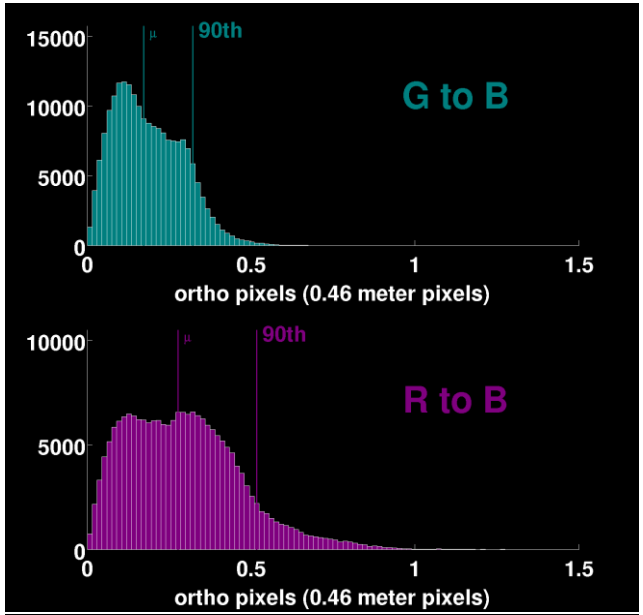
for each of the 36 band-to-band subcases,
there was no time dependence
(similar to PAN results)

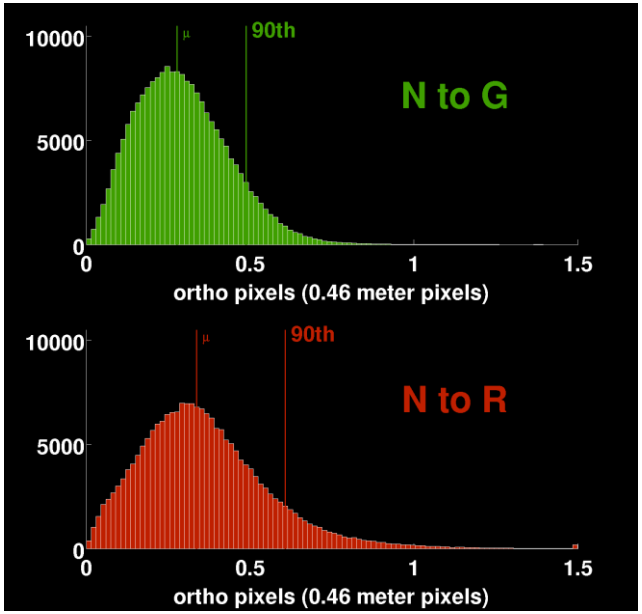
performance depended on which band groups were involved

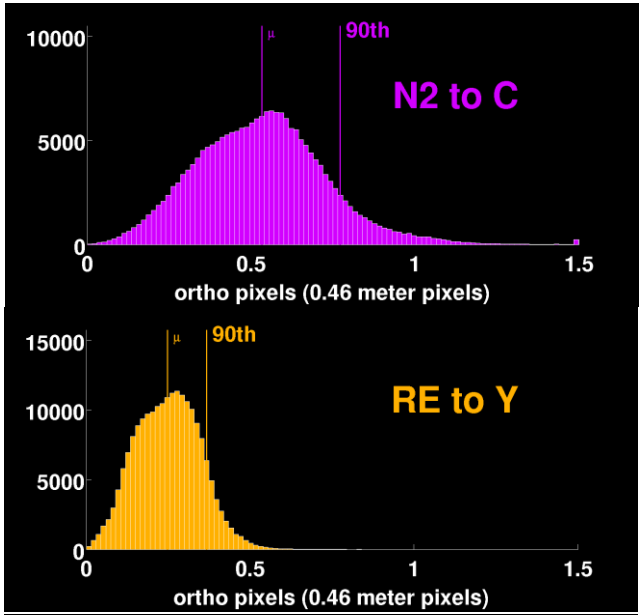
Therefore, the band-to-band histograms for all 10 strips can be summed by subcase...

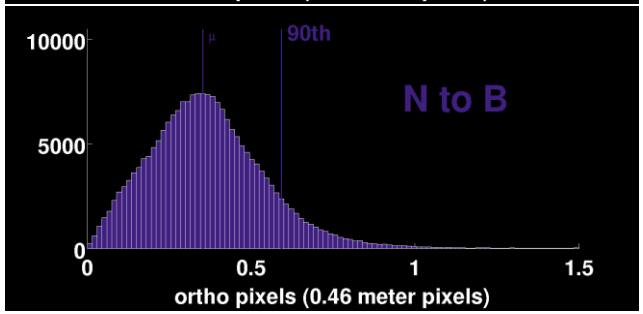
...results were so tiny, PAN pixels were the ideal unit of measure!

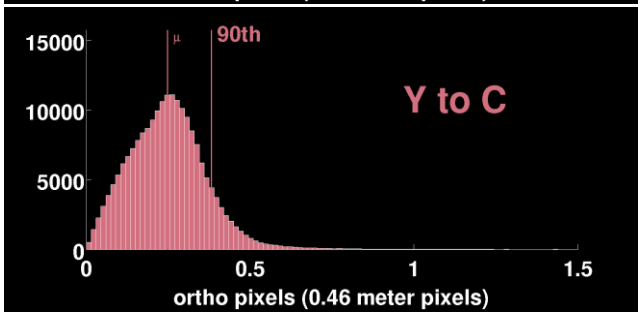
MS-MS (same band group) registration histograms

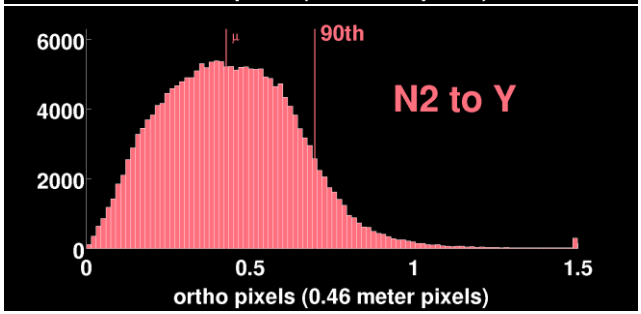


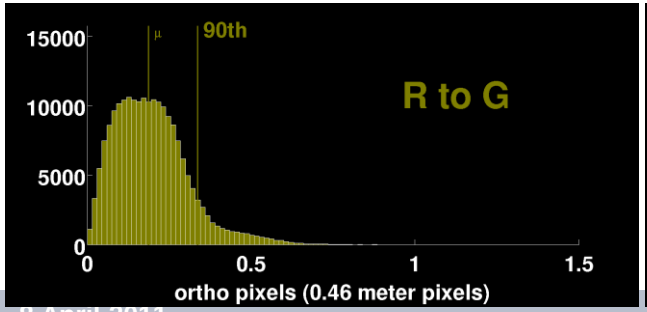


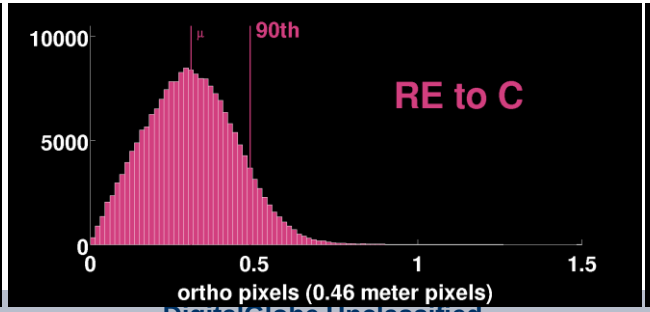


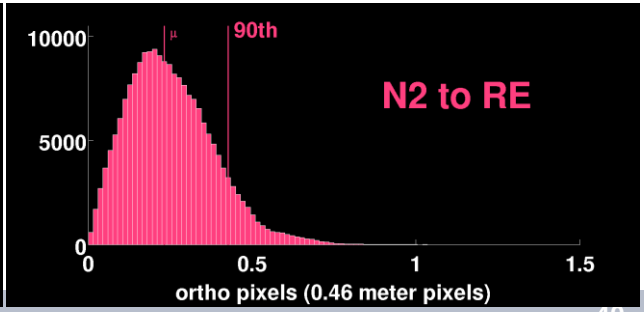




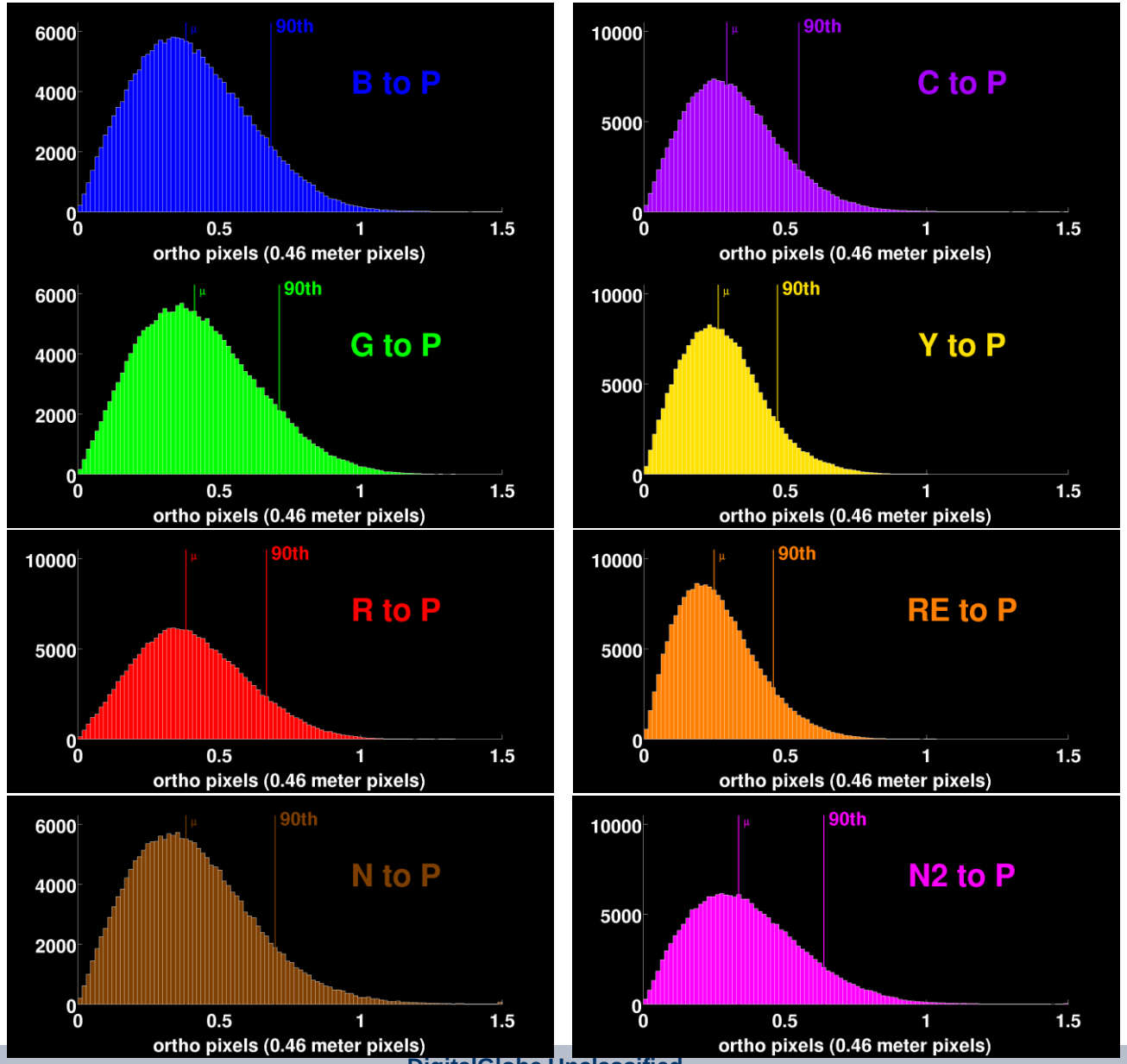




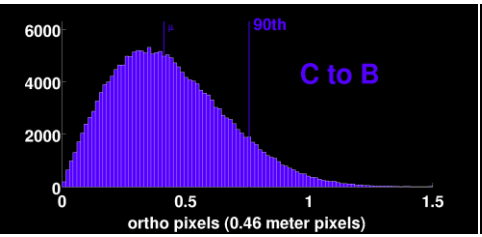


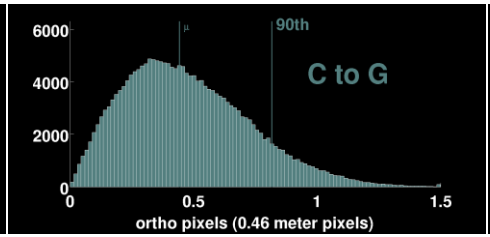


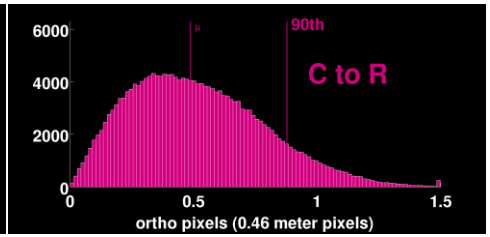
P-MS registration histograms

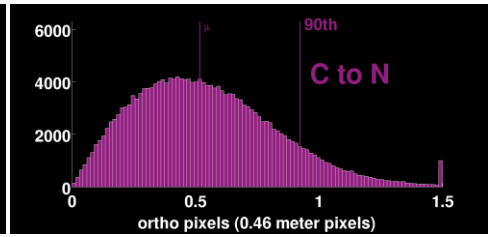


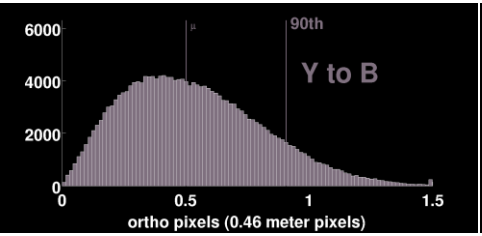
MS-MS (different band group) registration histograms

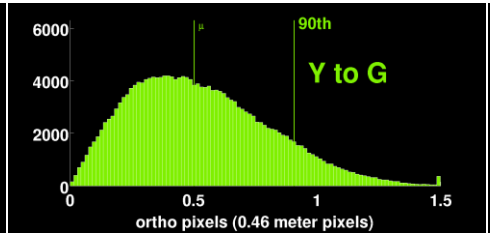


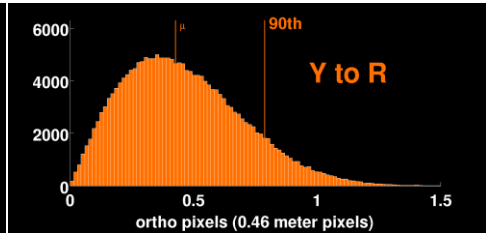


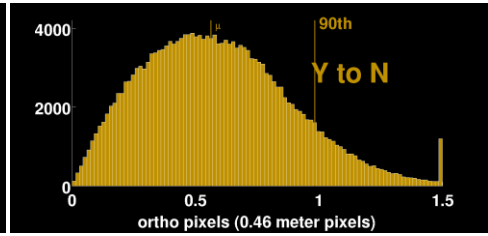


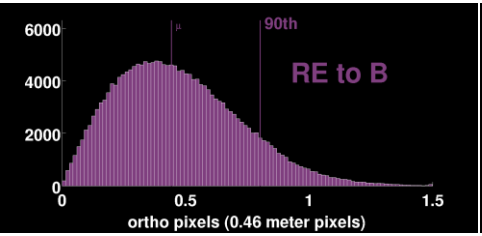


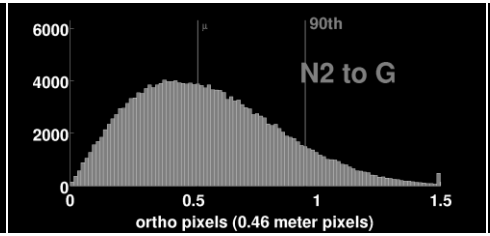


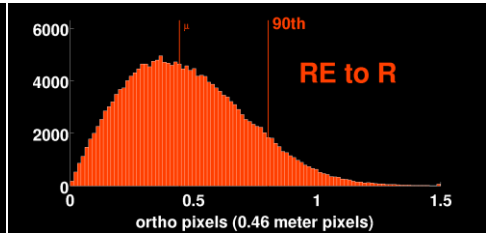


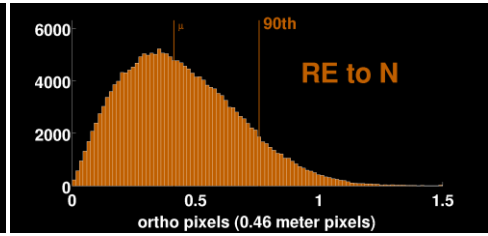


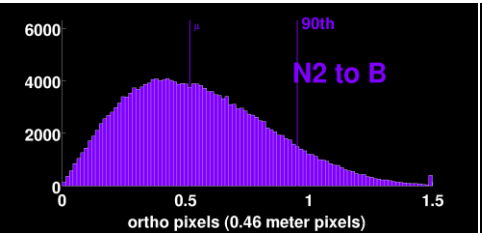


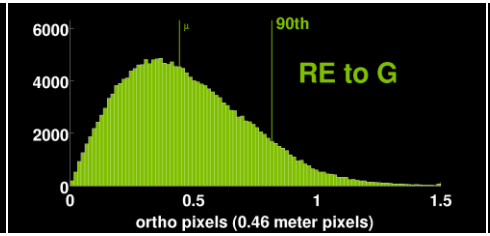


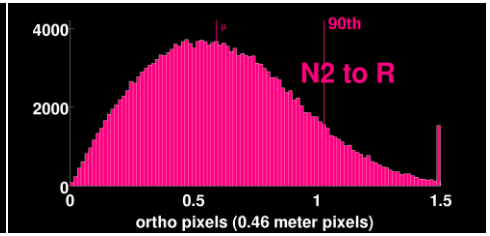


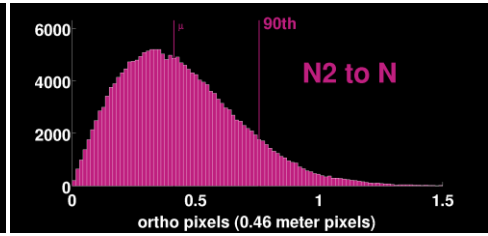












conclusions

absolute geolocation accuracy conclusions

- **monoscopic geolocation accuracy goals are met by all three satellites**
  - **QB02 has CCAP metrics between 13 to 21 meters at nadir, < 23 meters**
  - **WV01 has CCAP metrics between 3.6 to 4.9 meters at nadir, < 6.5 meters**
  - **WV02 has CCAP metrics between 2.4 to 3.5 meters at nadir, < 6.5 meters**

- **WV02 stereo geolocation accuracy components also within 6.5 meters**
  - **horizontal CCAP metrics (CE90s) between 2.6 and 4.6 meters**
  - **vertical CCAP metrics (LE90s) between 3.1 to 4.5 meters**

relative geolocation accuracy conclusions

- **PAN camera has a time independent relative geolocation accuracy**
  - **0.59 +/- 0.08 meters (1σ)**
  - **1.28 +/- 0.2 PAN pixels (1σ)**

- **all nine spectral bands have time independent band-to-band registration**
  - **MS-MS (same band group) had some 90th percentiles under 0.5 PAN pixel**
  - **PAN-MS had all 90th percentiles under 1 PAN pixel**
  - **MS-MS (different band group) had some 90th percentiles just over 1 PAN pixel**