The Absolute and Relative Geolocation Accuracies of

QB02

and

WV01

Dr. Byron Smiley

DigitalGlobe

Geometric Calibration and Improvement at DigitalGlobe

Remote Sensing Sciences

- Principal Attitude Engineers fix the attitude
  - Chris Comp
  - Woodson Bercaw
- Geometric Calibration Engineer (Byron Smiley) evaluates attitude upgrades, also fixes the camera

Outline

- **methods**
- **absolute geolocation accuracy**
  - **QB02**
    - current absolute accuracy
    - planned improvements
  - **WV01**
    - current absolute accuracy
    - comparison of **QB02** versus **WV01**
    - *bonus:* attitude calibration(s) that got us there
- **relative geolocation accuracy**
  - current relative accuracy of **QB02**
  - **WV01**
    - current relative accuracy
    - comparison of **QB02** versus **WV01**
    - *bonus:* camera calibration that got us there

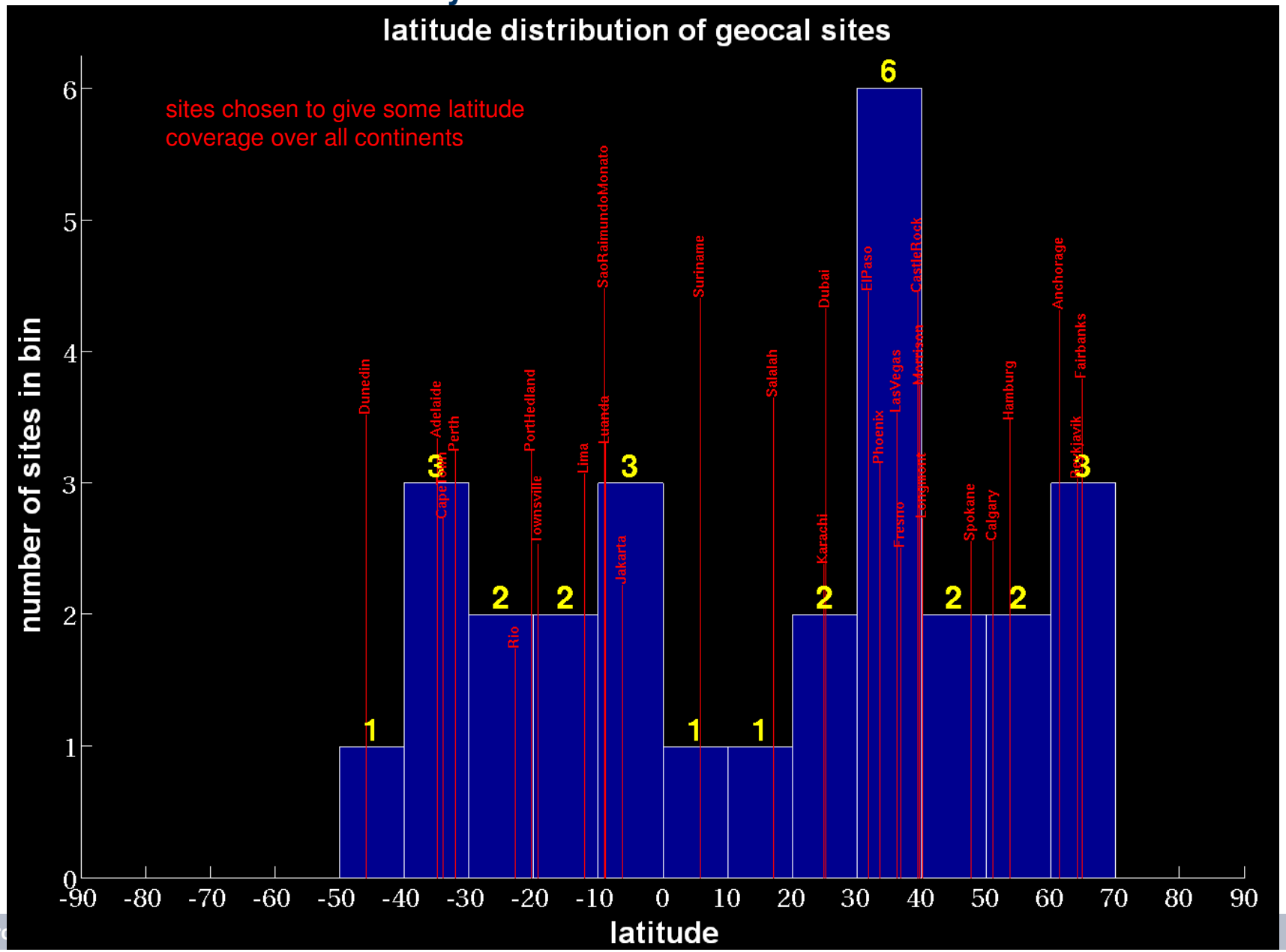
methods

Absolute Accuracy is Checked with Ground Control Points

28 sites used for geometric calibration and monthly geolocation analysis

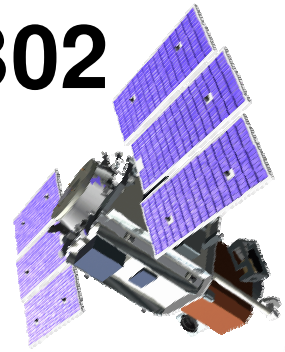
site	ngcp
Adelaide, Australia	74
Anchorage, Alaska	19
Calgary, Alberta	11
Cape Town, South Africa	45
Castle Rock, Colorado	65
Dubai, United Arab Emirates	61
Dunedin, New Zealand	10
El Paso, Texas	68
Fairbanks, Alaska	21
Fresno, California	73
Hamburg, Germany	11
Jakarta, Indonesia	10
Karachi, Pakistan	66
Las Vegas, Nevada	47
Lima, Peru	43
Longmont, Colorado	86
Luanda, Angola, Africa	10
Morrison, Colorado	16
Perth, Australia	82
Phoenix, Arizona	113
Port Hedland, Australia	53
Reykjavik, Iceland	9
Rio de Janeiro, Brazil	20
Salalah, Oman	47
Sao Raimundo Monato, Brazil	15
Spokane, Washington	45
Paramaribo, Suriname	16
Townsville, Australia	20

Absolute Accuracy is Checked with Ground Control Points



Geocal Conventions

QB02



The horizontal error is found, but converted to the *nadir-projected error*.

Why?

Strips with different nadir angles need meaningful comparison.
The camera coordinate system is advantageous:
the same camera took every strip
camera angles can be directly compared

450 km

geocal imagery collected at off nadir angles between 0 to 35°

true GCP location

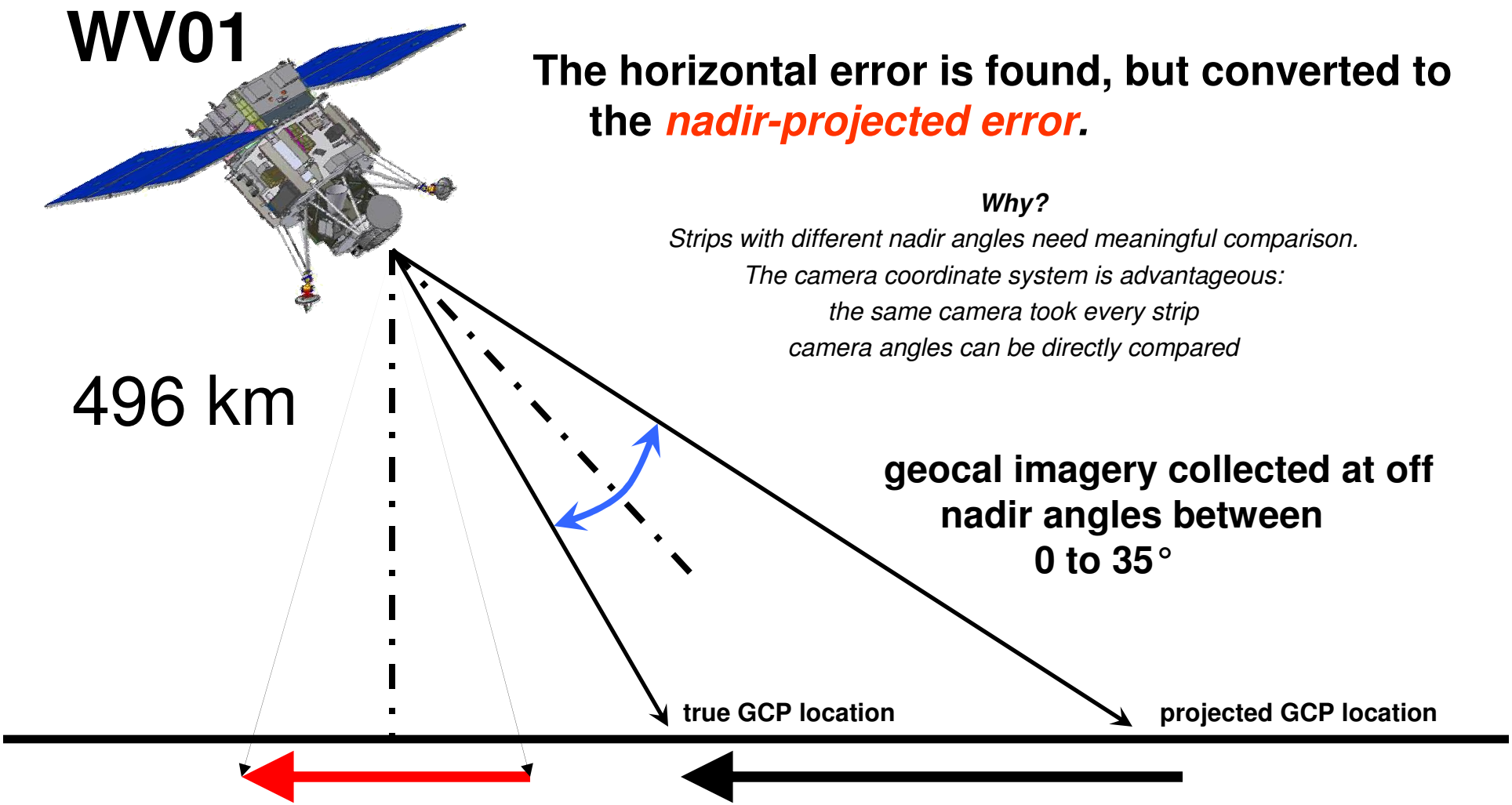
projected GCP location

nadir projected error

horizontal error* = truth - measured

*vertical error made zero by projecting to same height above ellipsoid as GCP

Geocal Conventions



The horizontal error is found, but converted to the *nadir-projected error*.

Why?

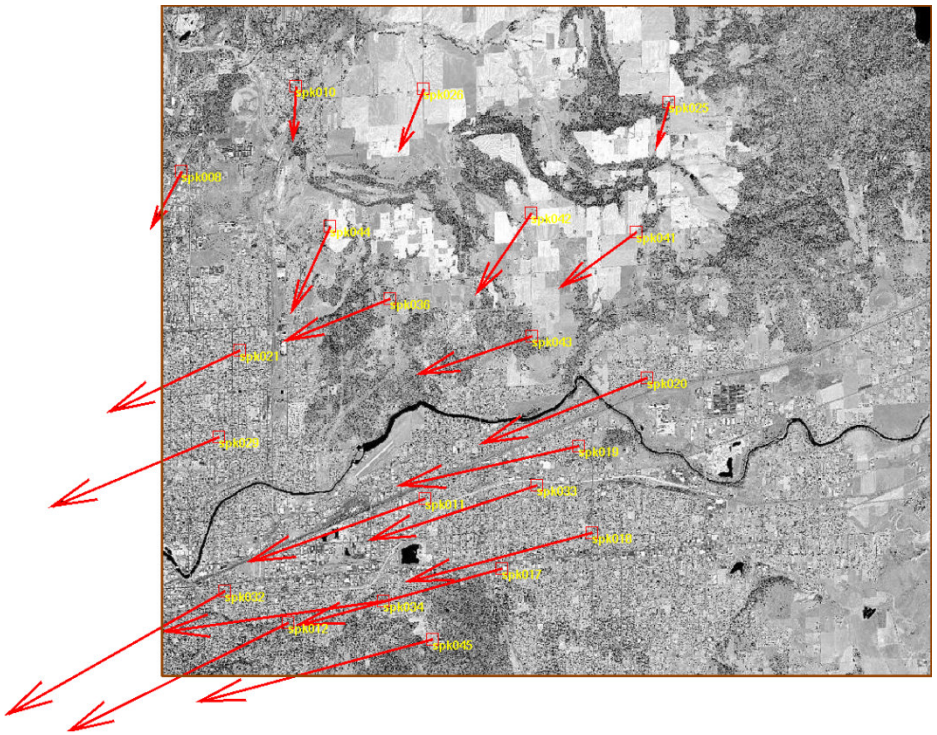
Strips with different nadir angles need meaningful comparison.
The camera coordinate system is advantageous:
the same camera took every strip
camera angles can be directly compared

geocal imagery collected at off nadir angles between 0 to 35°

* vertical error made zero by projecting to same height above ellipsoid as GCP

Absolute Geolocation Accuracy of a Strip

DigitalGlobe uses this 90th percentile to get CE90, and on bins of CE90s.



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

equal-to-or-less-than percentile: if you have ten things, the 90th percentile is the ninth thing
(it's conservative, tends to be a bit higher than other 90th percentiles)

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

$$N*0.9 = i + f$$

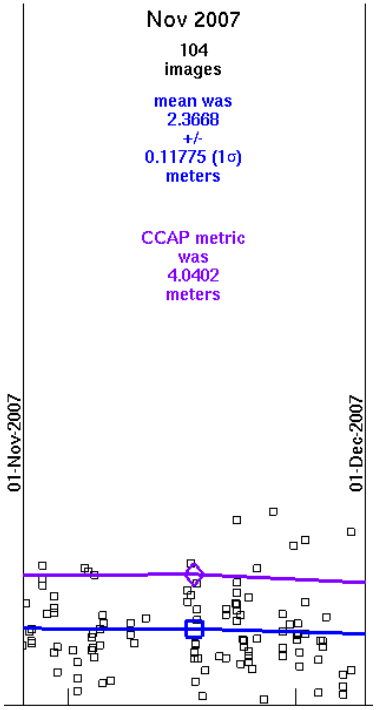
- Stand f of the way between r_i and r_{i+1}

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

- "linearized" percentile, as opposed to rounding up to the next element to be sure
- red throughout this talk

Another 90th Percentile

During CCAP evaluation of DG imagery, NGA used this 90th percentile on bins of strips



if you represent each strip by the magnitude of the bias, and then take the NGA 90th percentile of the 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}

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

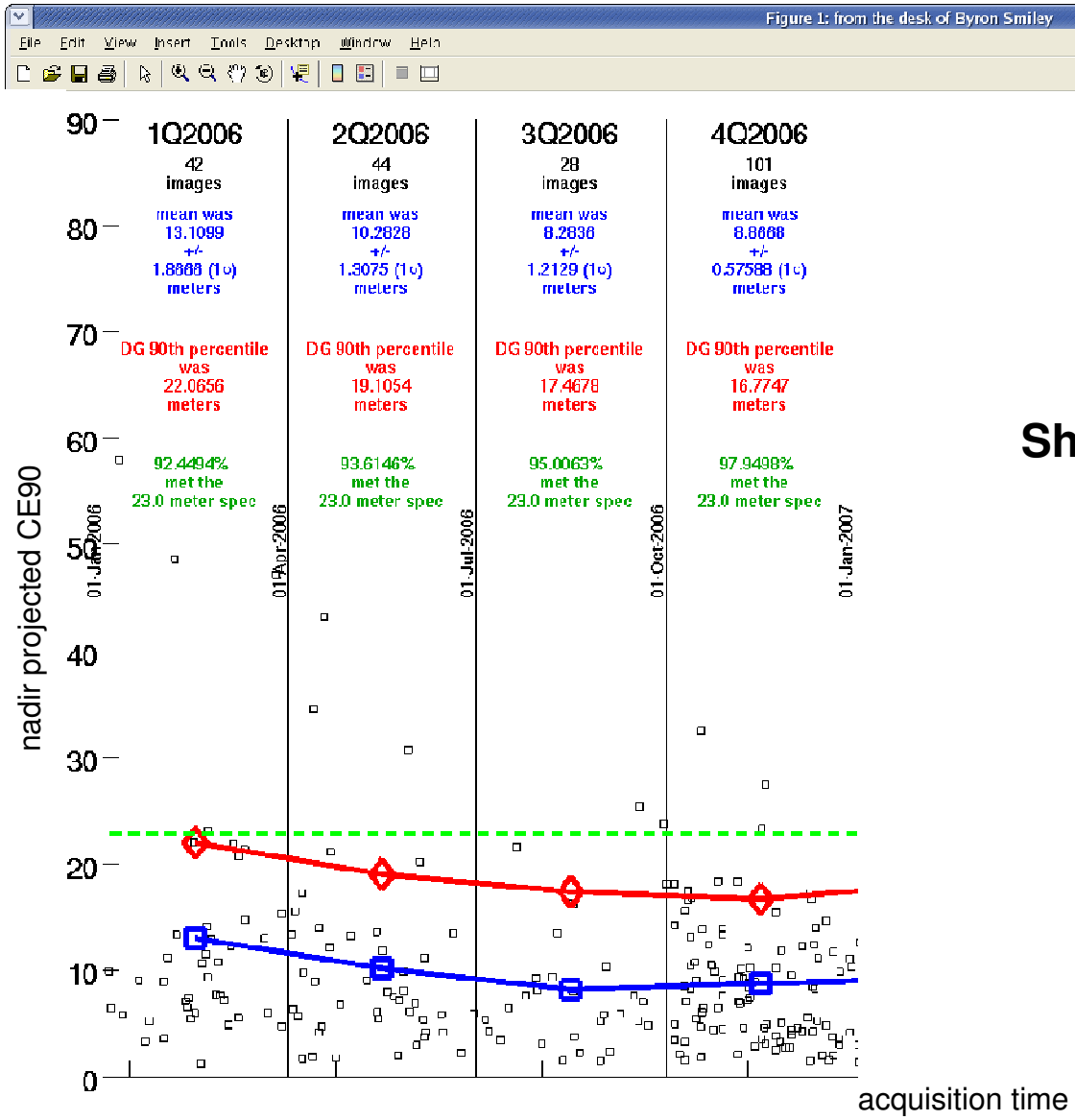
- also linearized percentile
- will call it NGA percentile in this talk

[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)

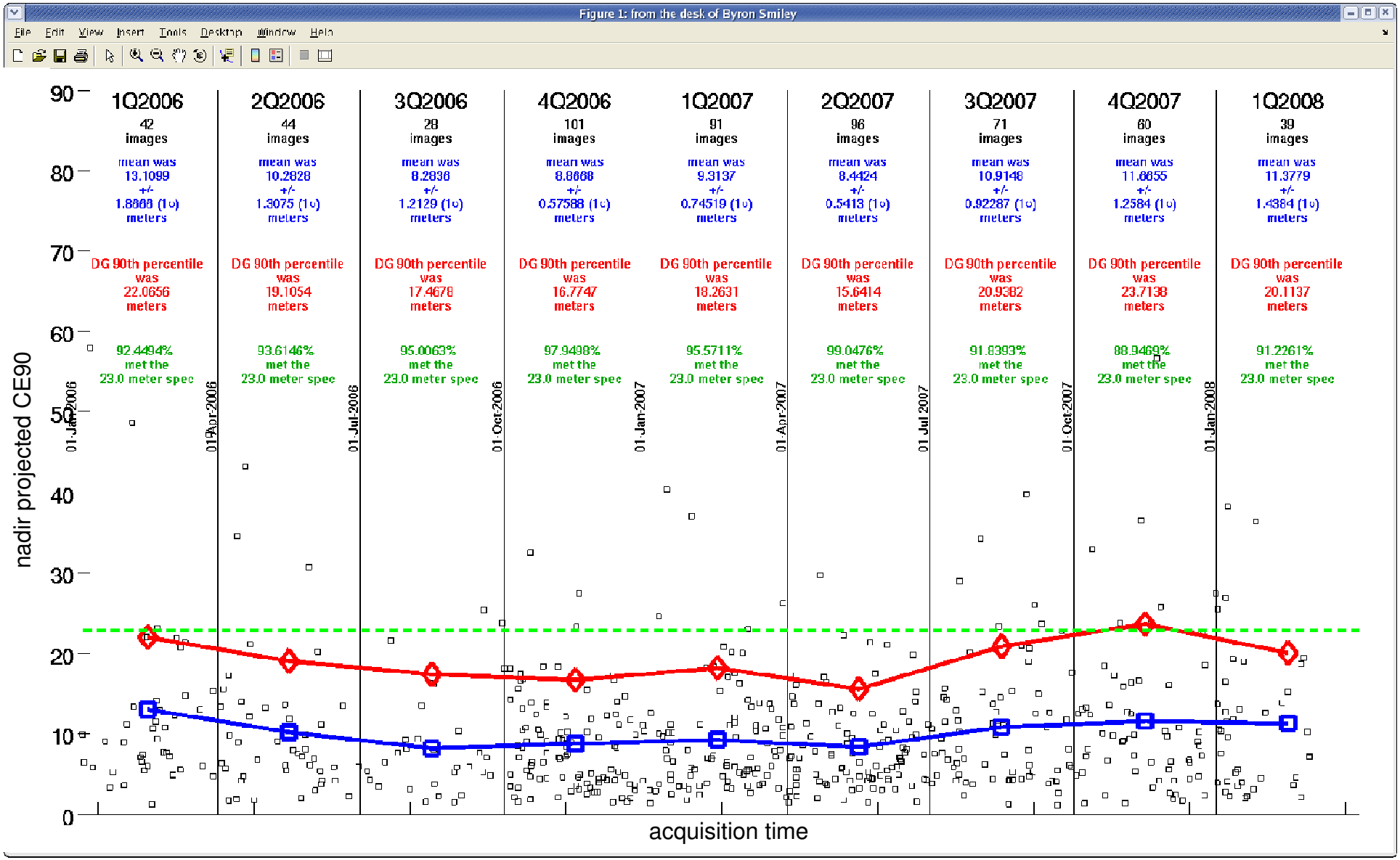
Absolute Geolocation for QB02

Quarterly Absolute Geolocation Statistics for QB02



Shown last year at JACIE 2007

Quarterly Absolute Geolocation Statistics for QB02



Attitude Largely Determines Geolocation for QB02

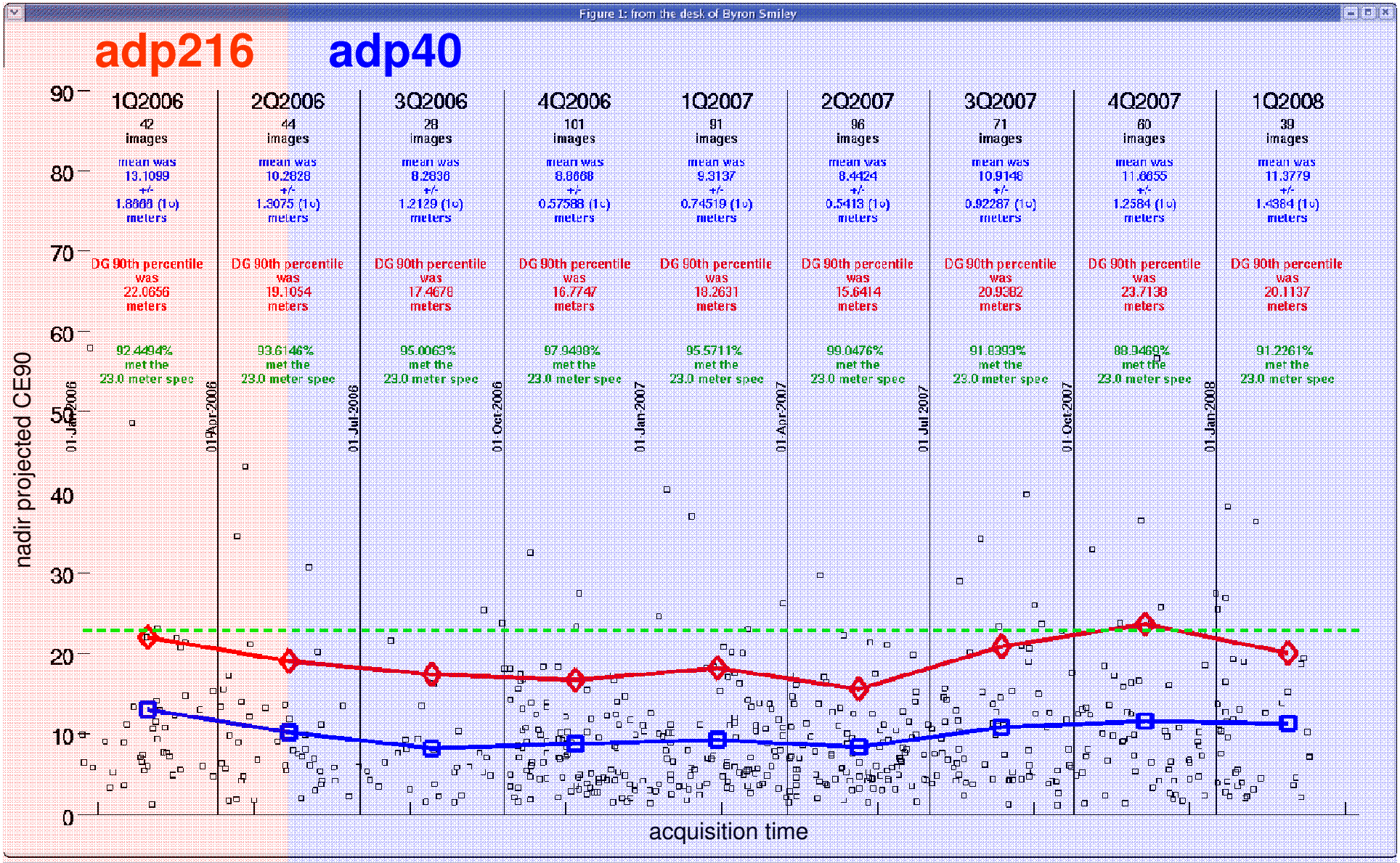
(A)ttitude (D)etermination (P)rogram

old: adp216

new: adp40

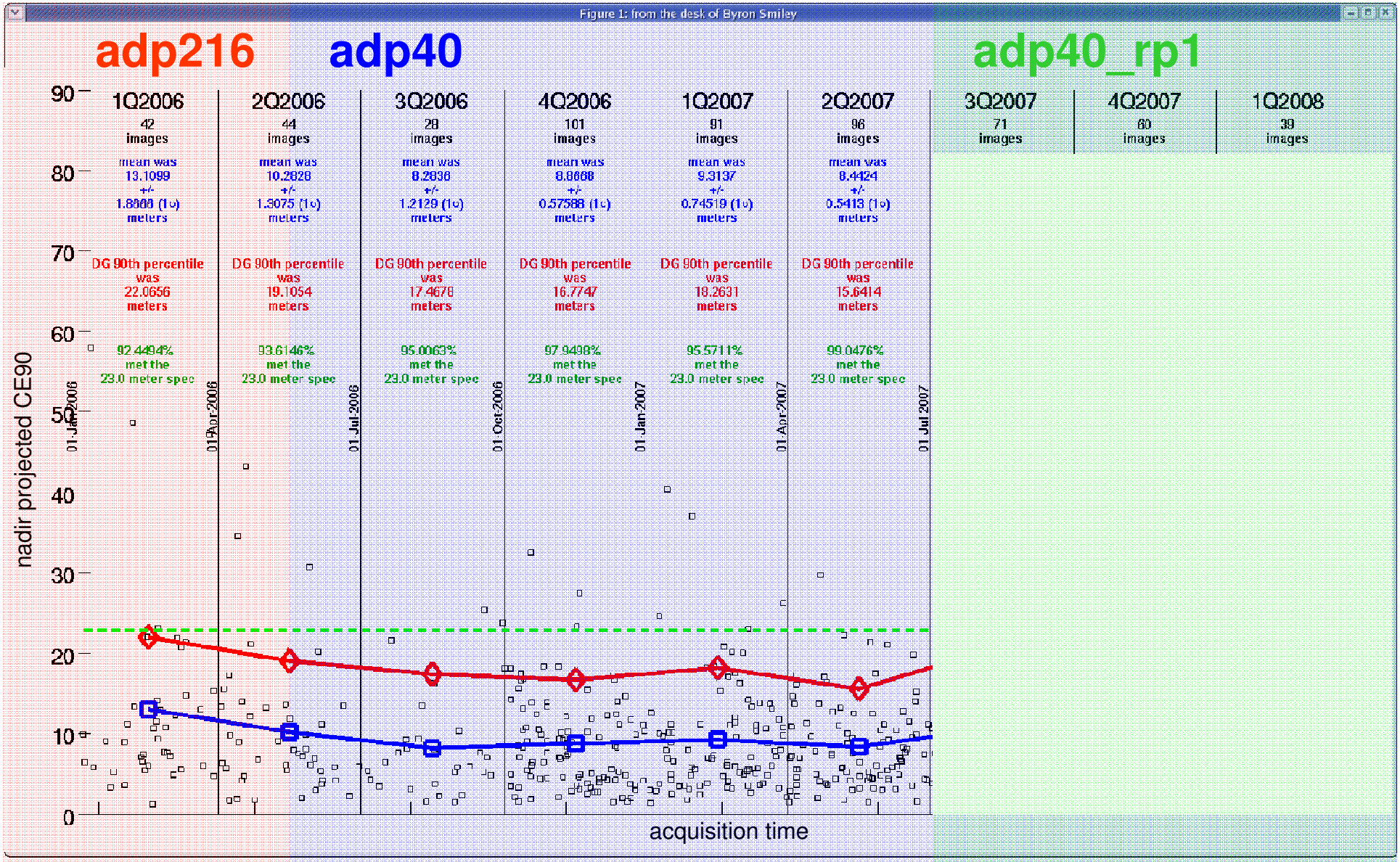
newest: adp40_rp1

Attitude Largely Determines Geolocation for QB02

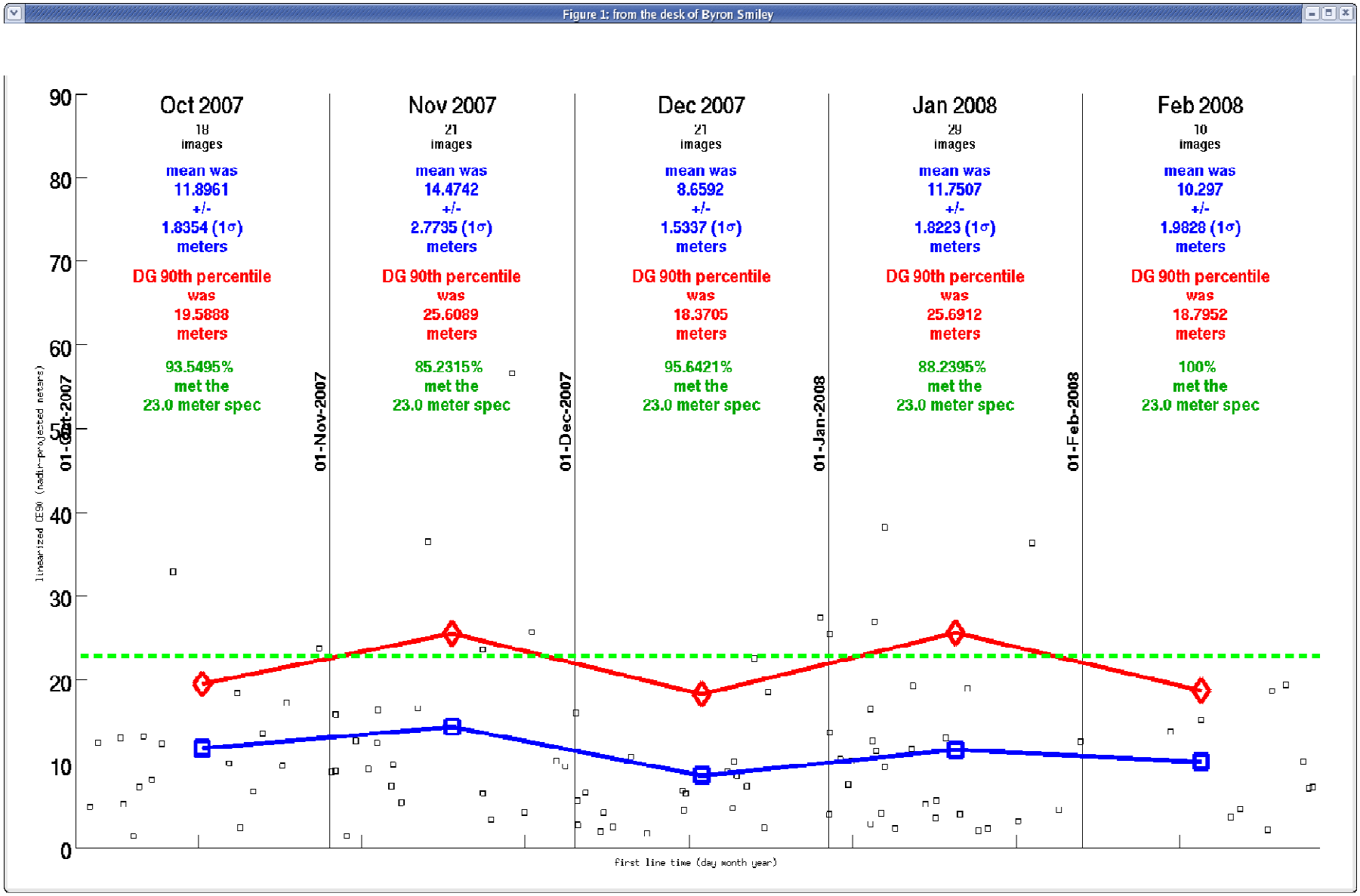


Upcoming Improvements for QB02

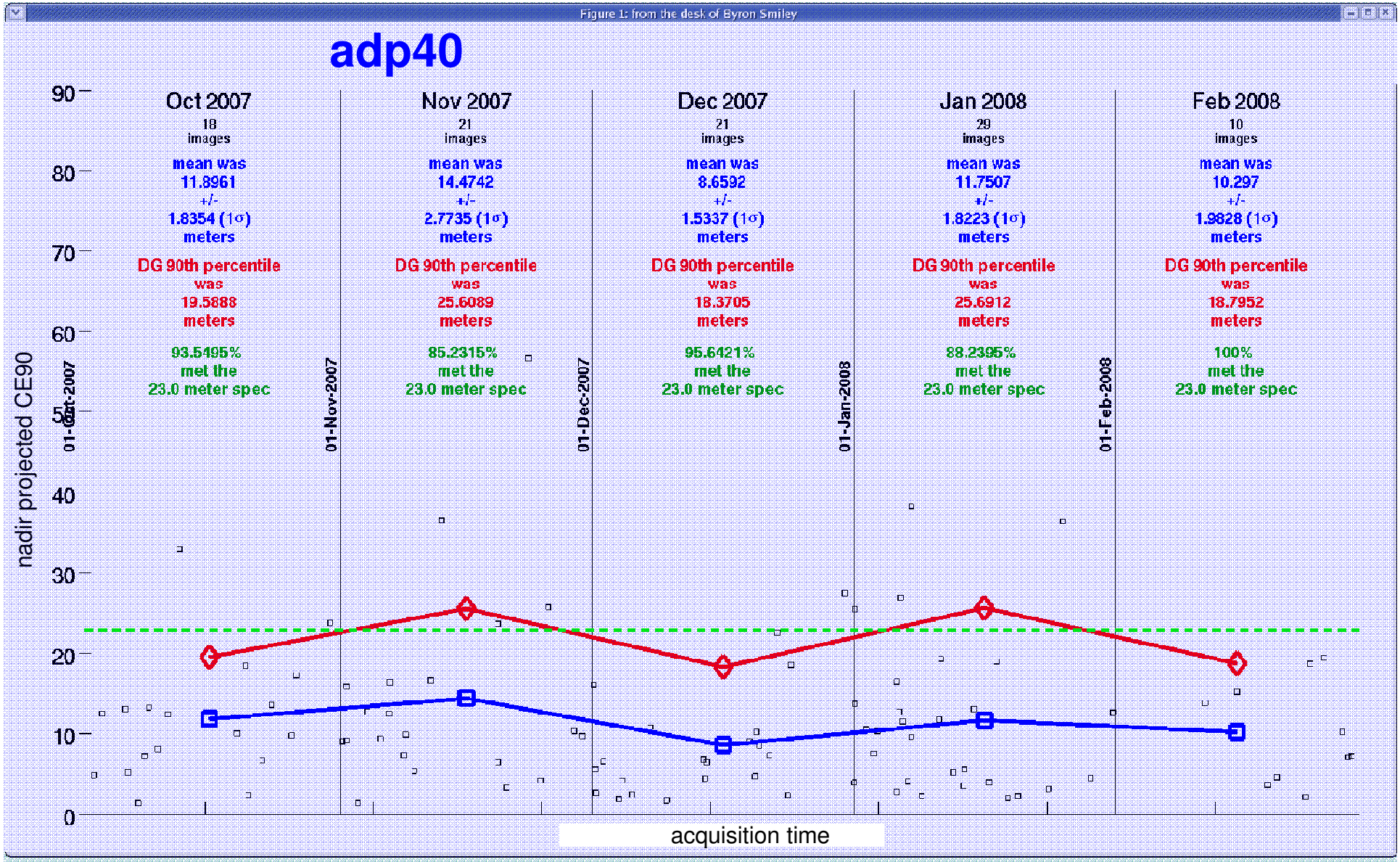
Upcoming Improvements for QB02



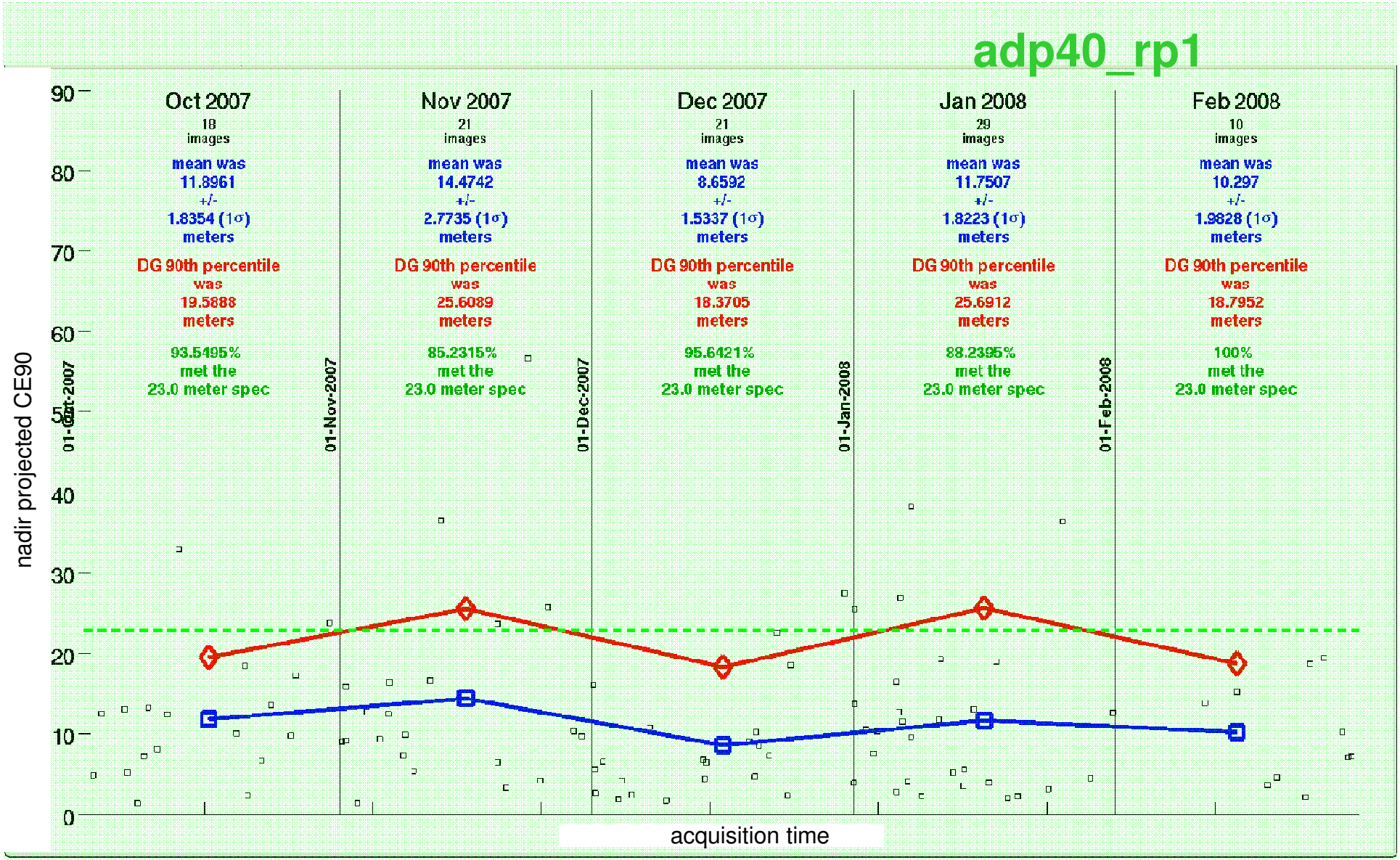
Upcoming Improvements for QB02



QB02 adp40_rp1 Reprocessing in Progress

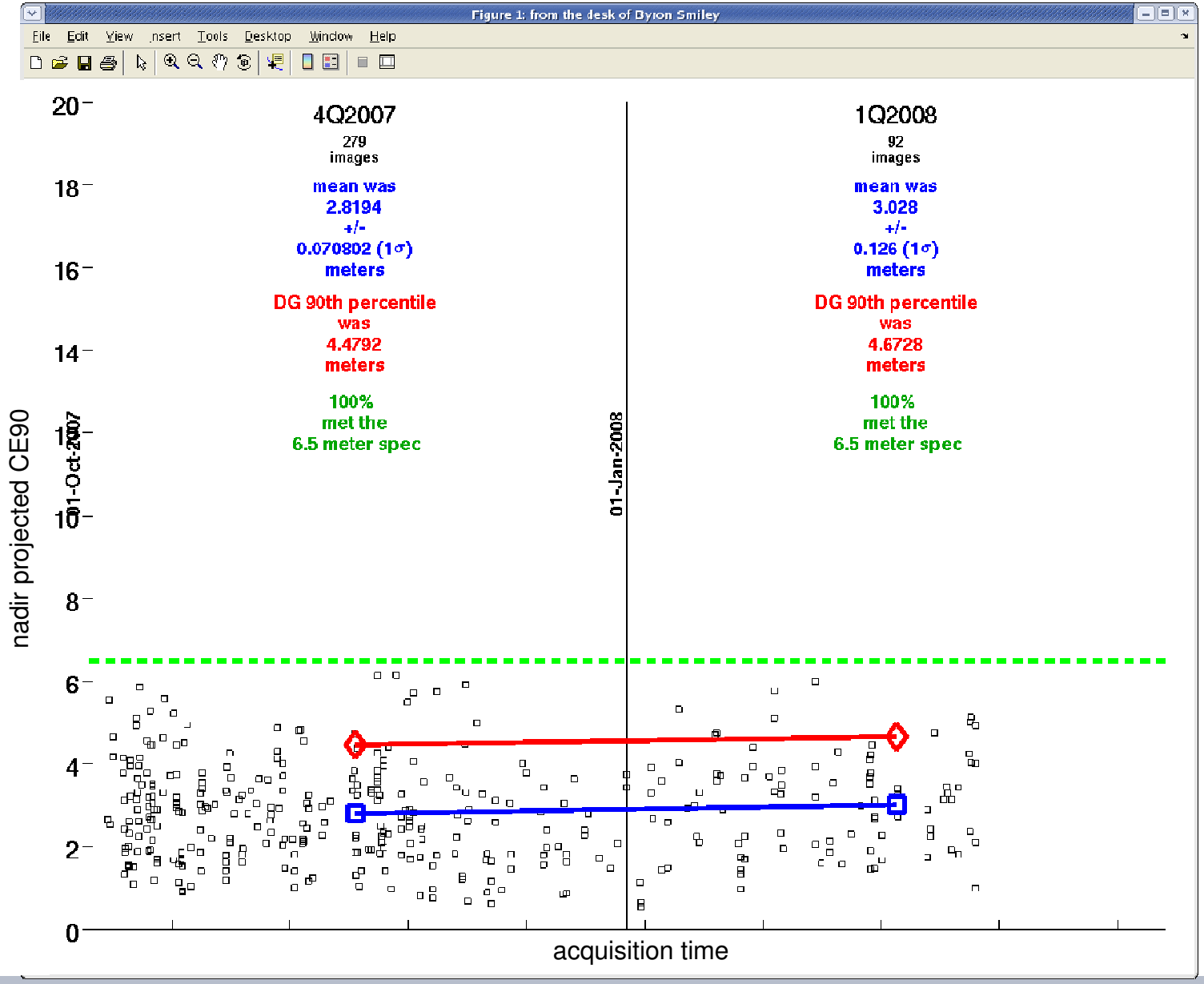


QB02 adp40_rp1 Reprocessing in Progress

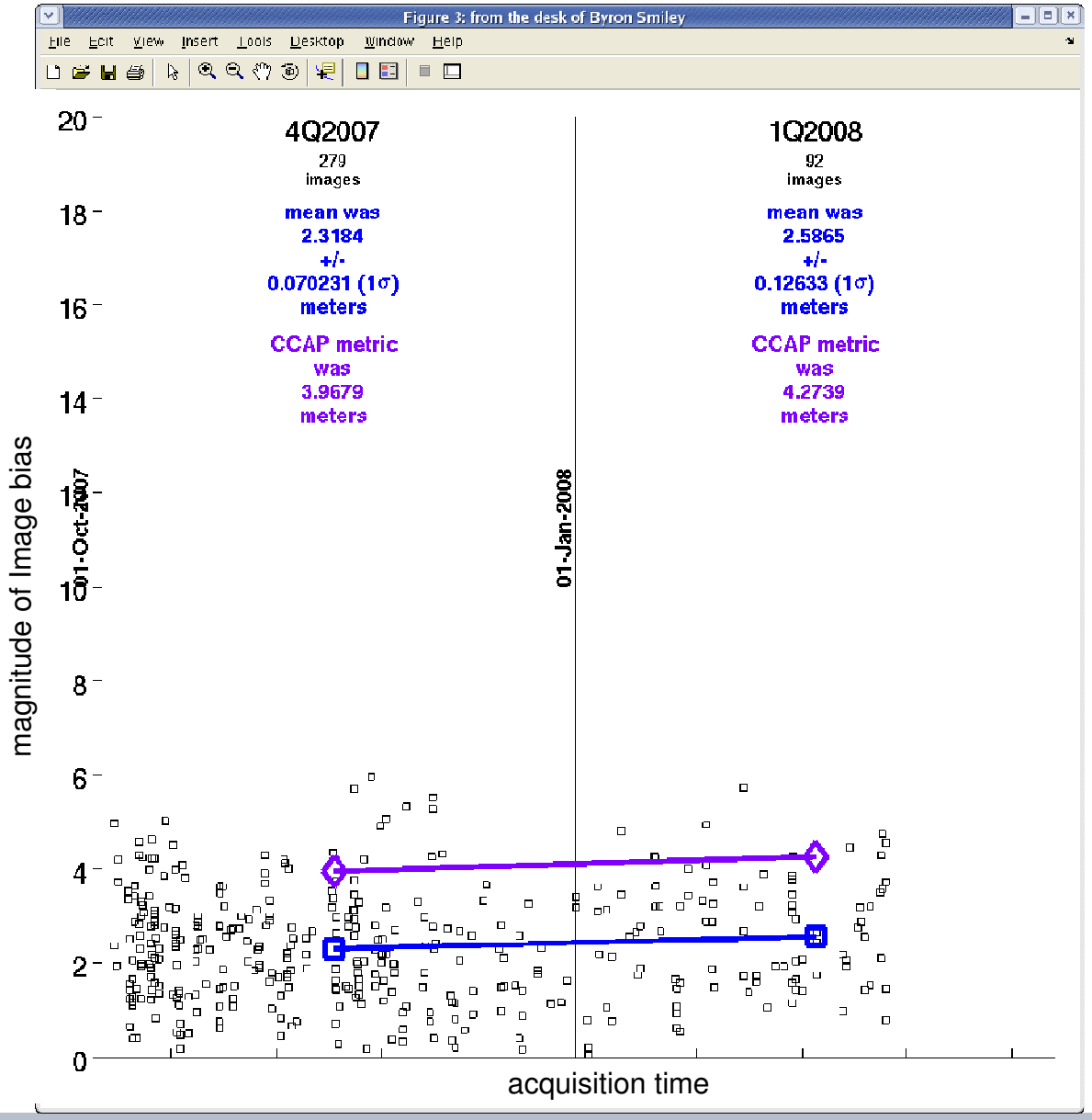


Absolute Geolocation for WV01

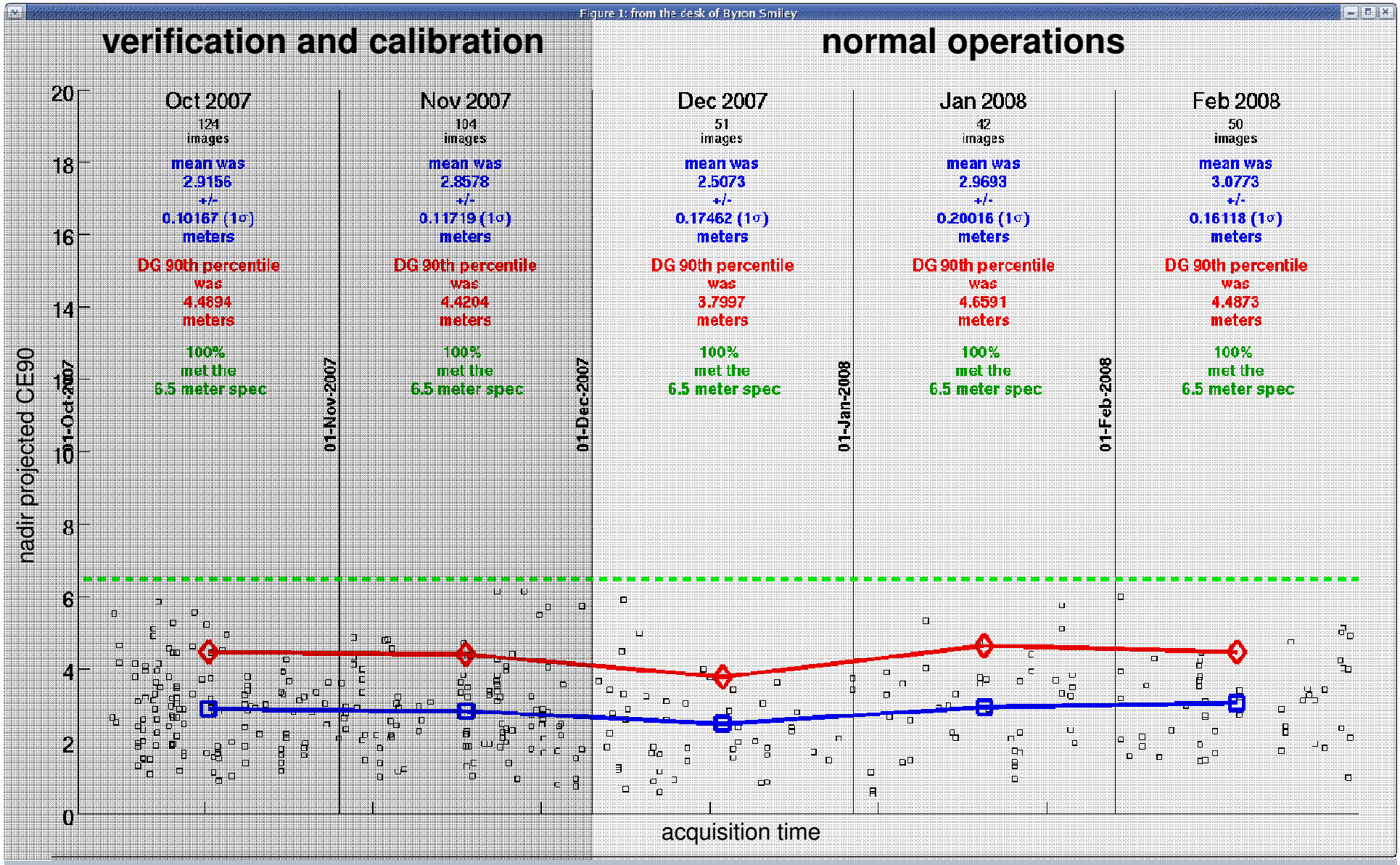
Quarterly Absolute Geolocation Statistics for WV01



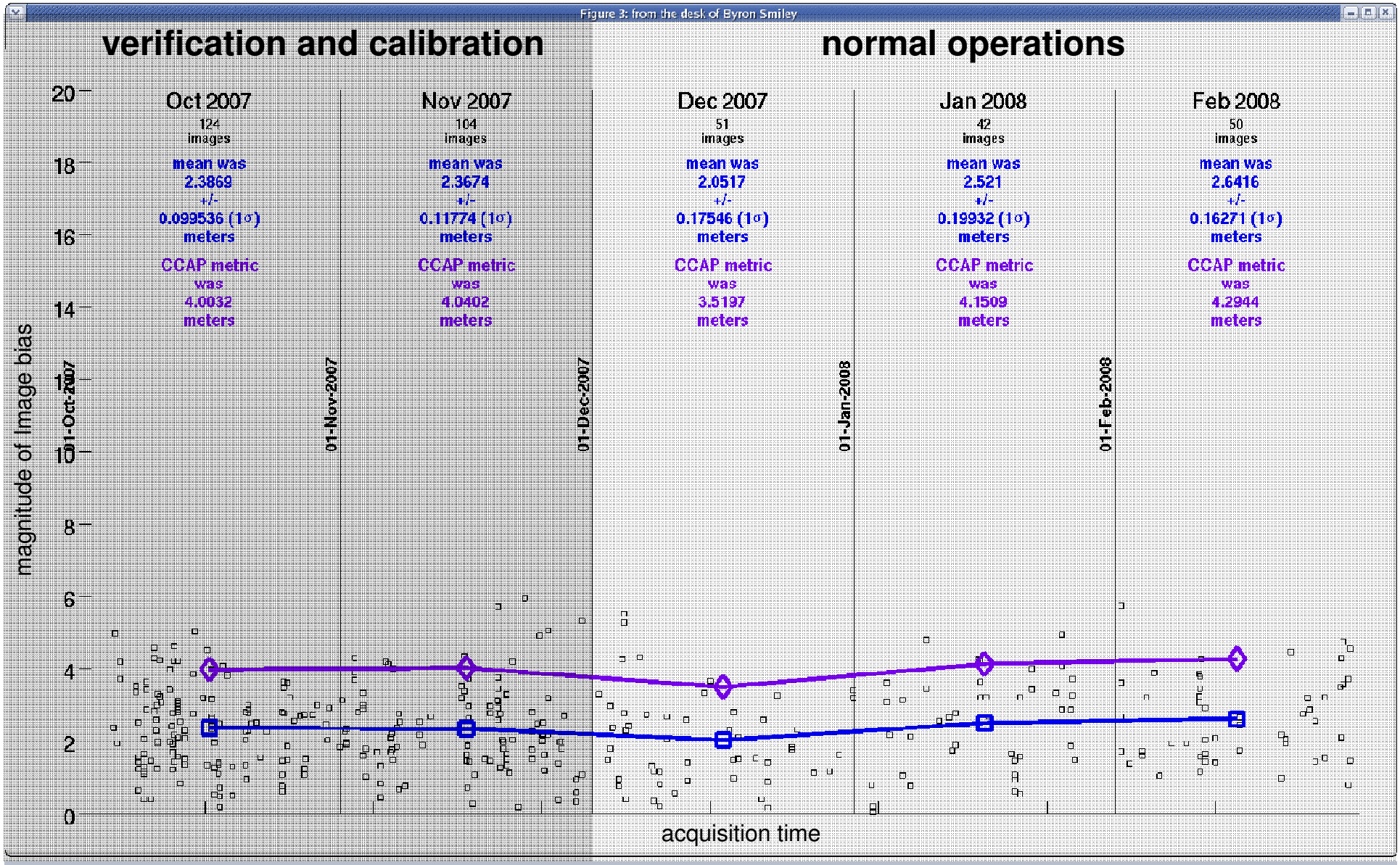
Quarterly Absolute Geolocation Statistics for WV01



Monthly Absolute Geolocation Statistics for WV01

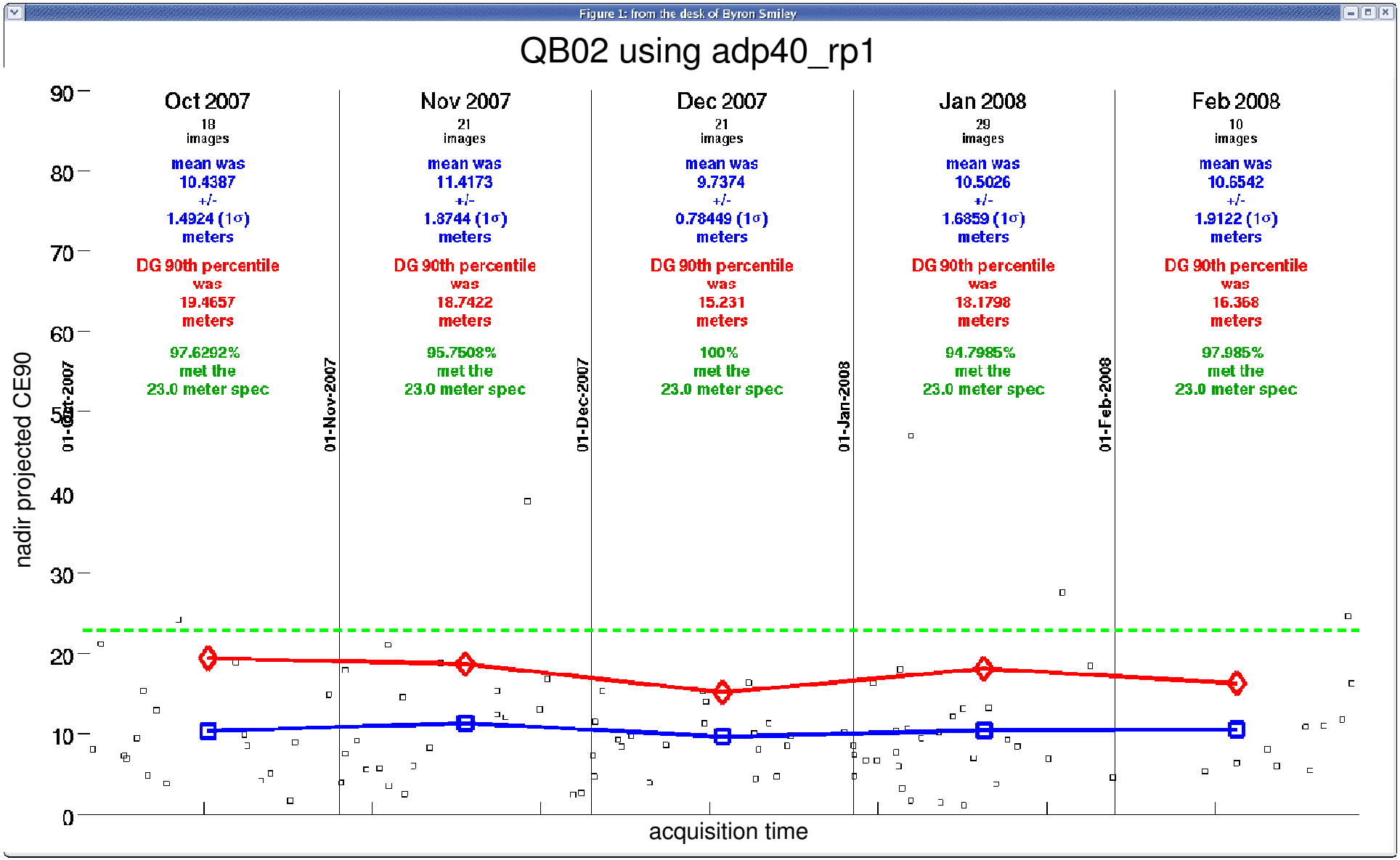


Monthly Absolute Geolocation Statistics for WV01

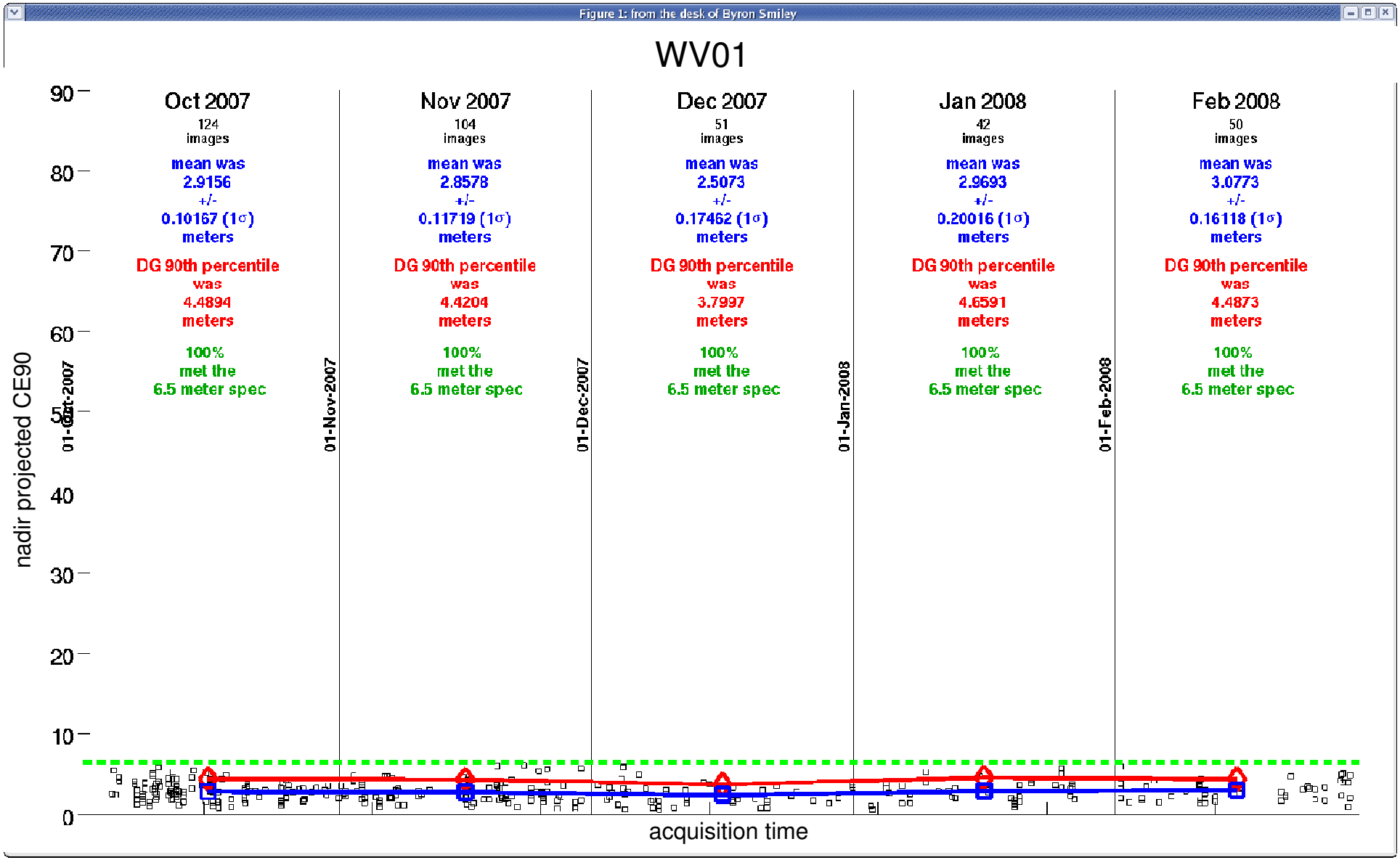


Absolute Geolocation QB02 versus WV01

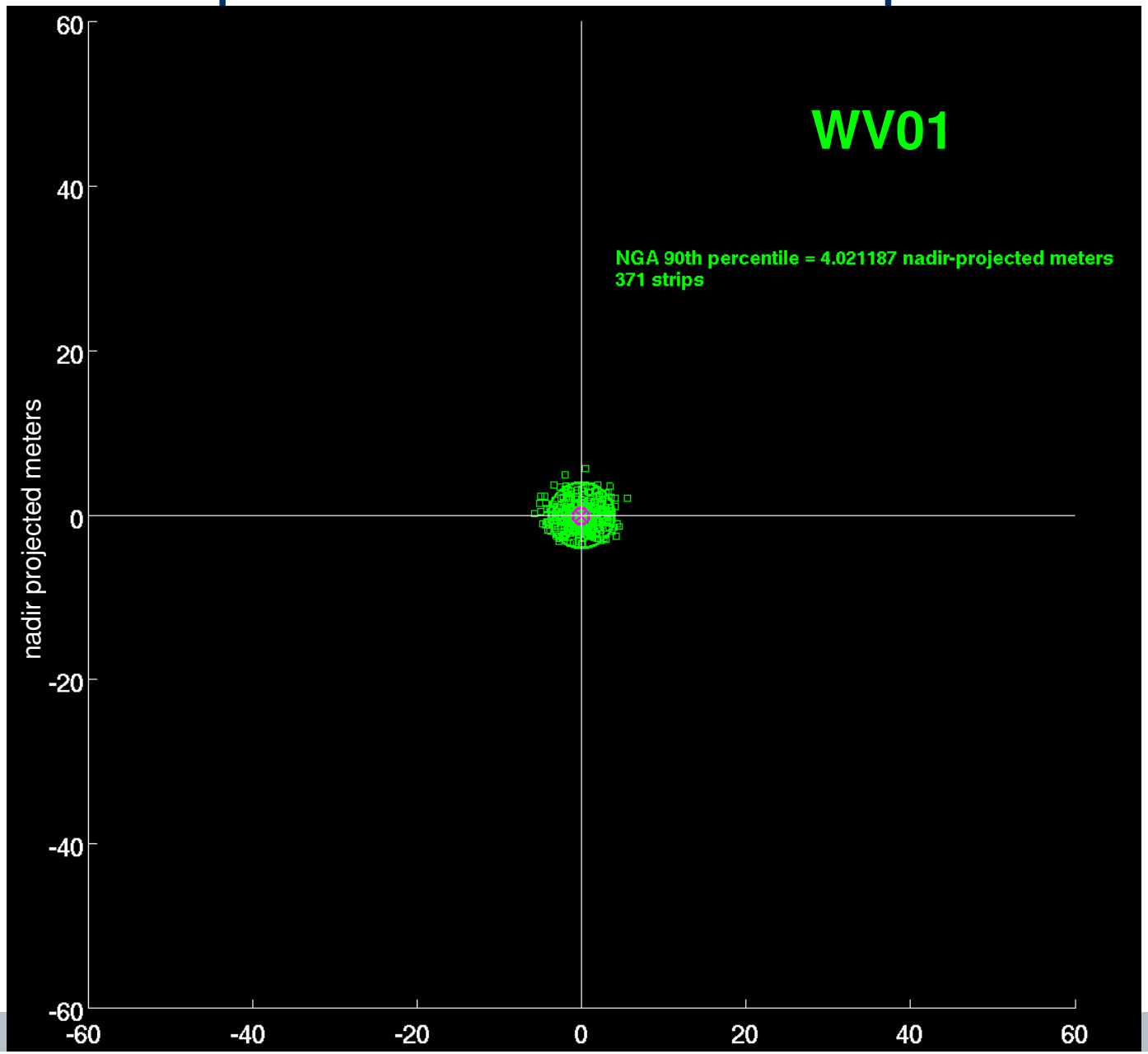
Compare the Nadir Projected CE90s



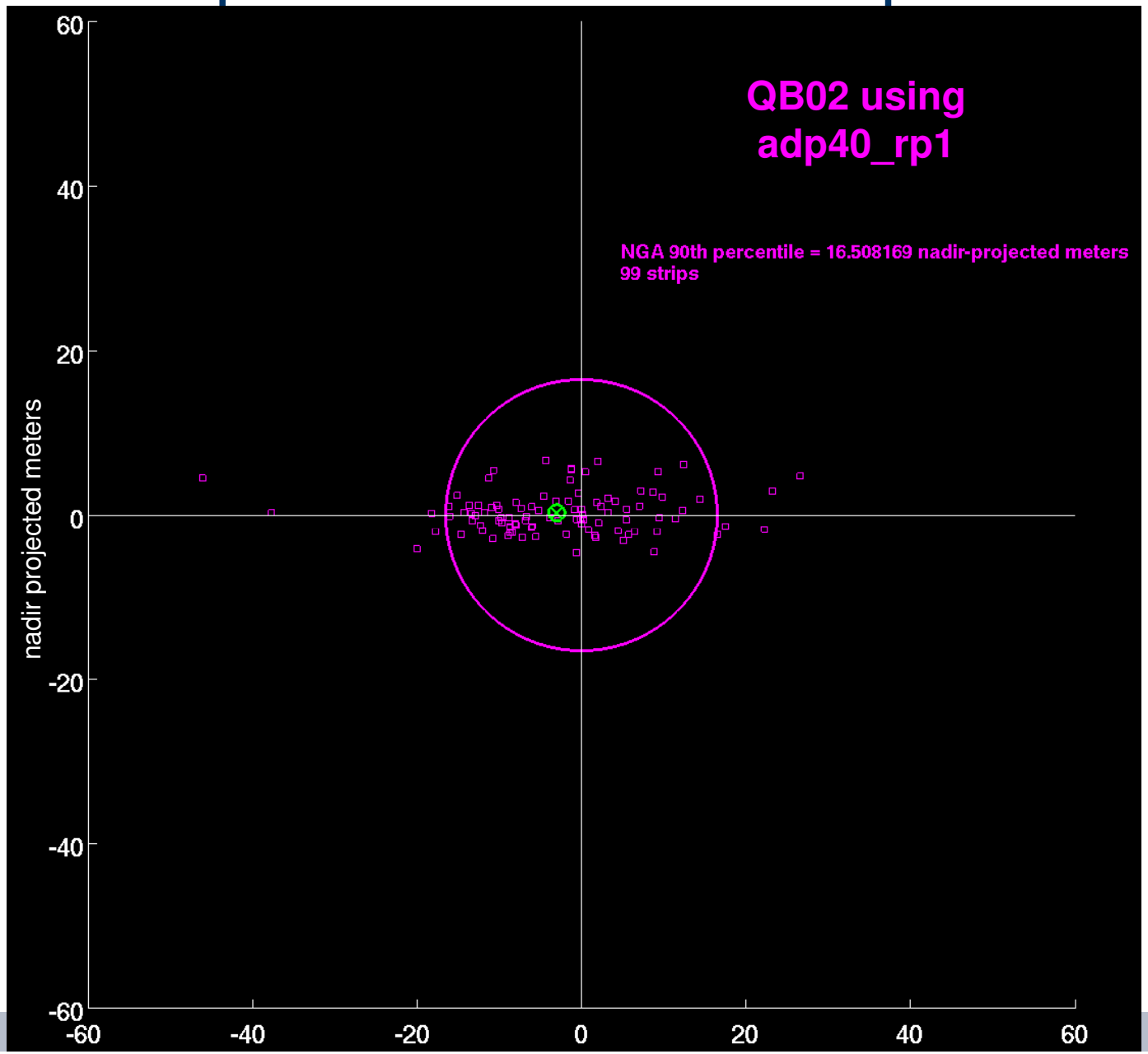
Compare the Nadir Projected CE90s



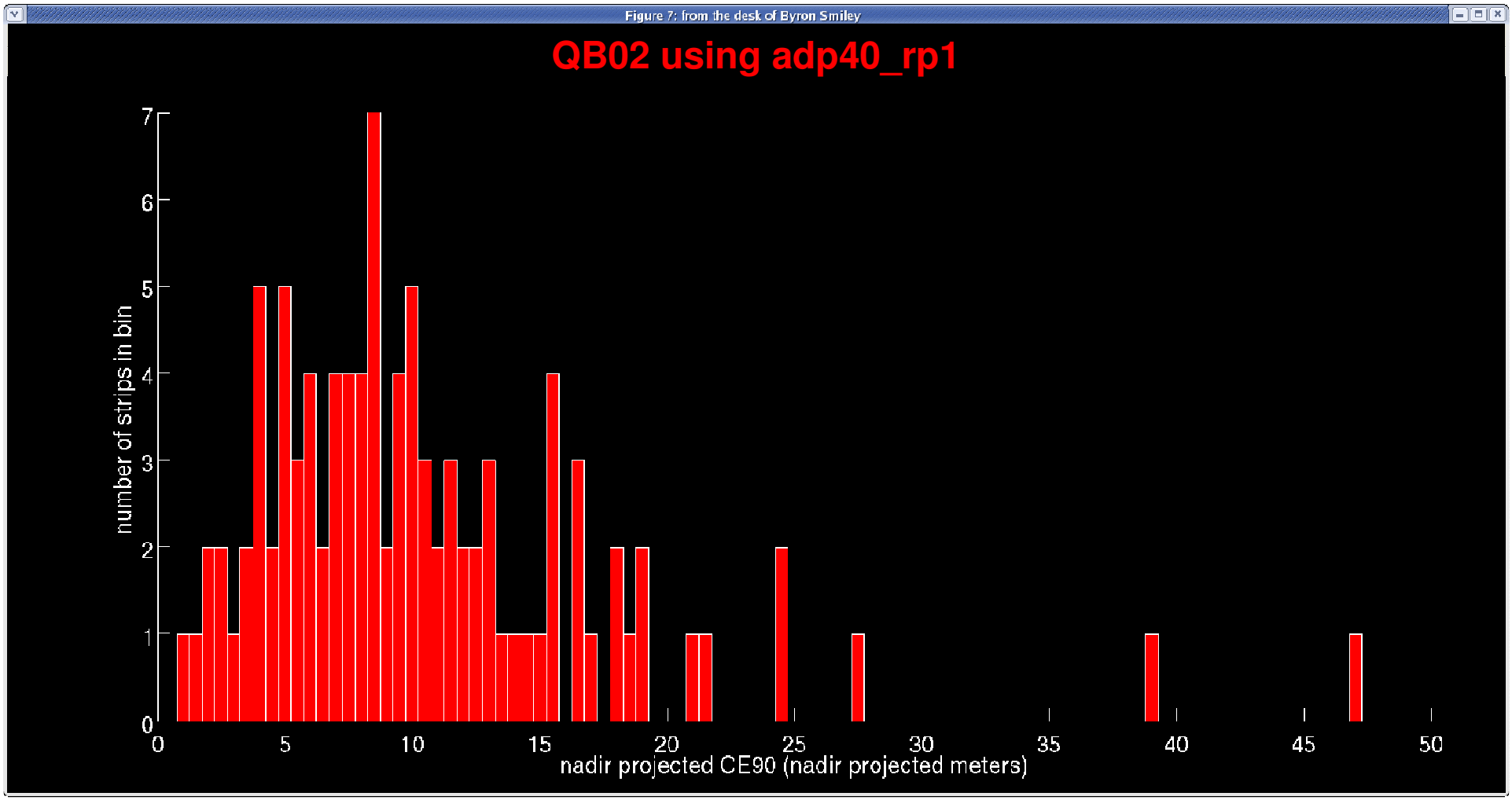
Compare the CCAP Metric of the Strips in 2D



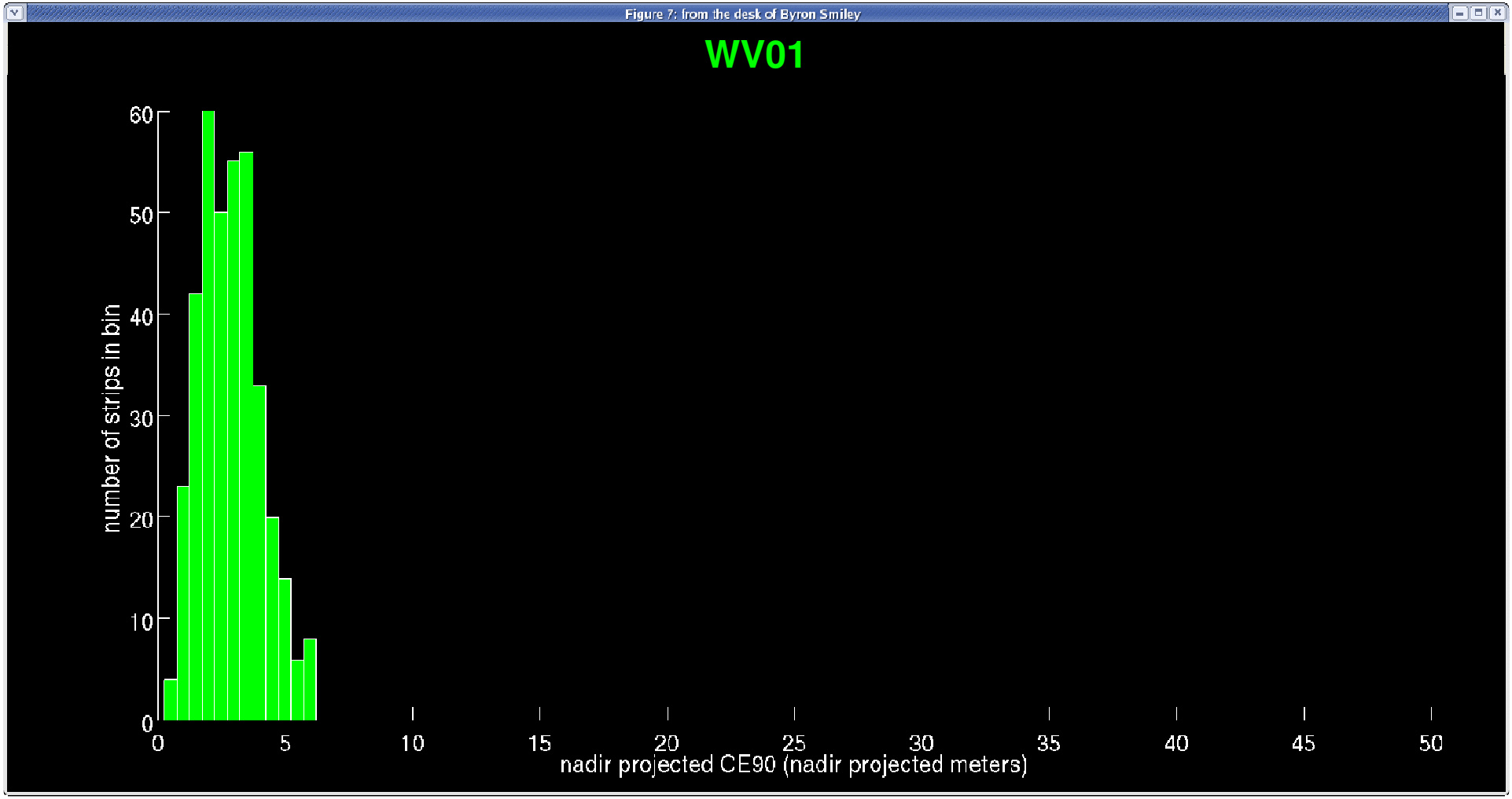
Compare the CCAP Metric of the Strips in 2D



Compare the Histograms of the Nadir Projected CE90s

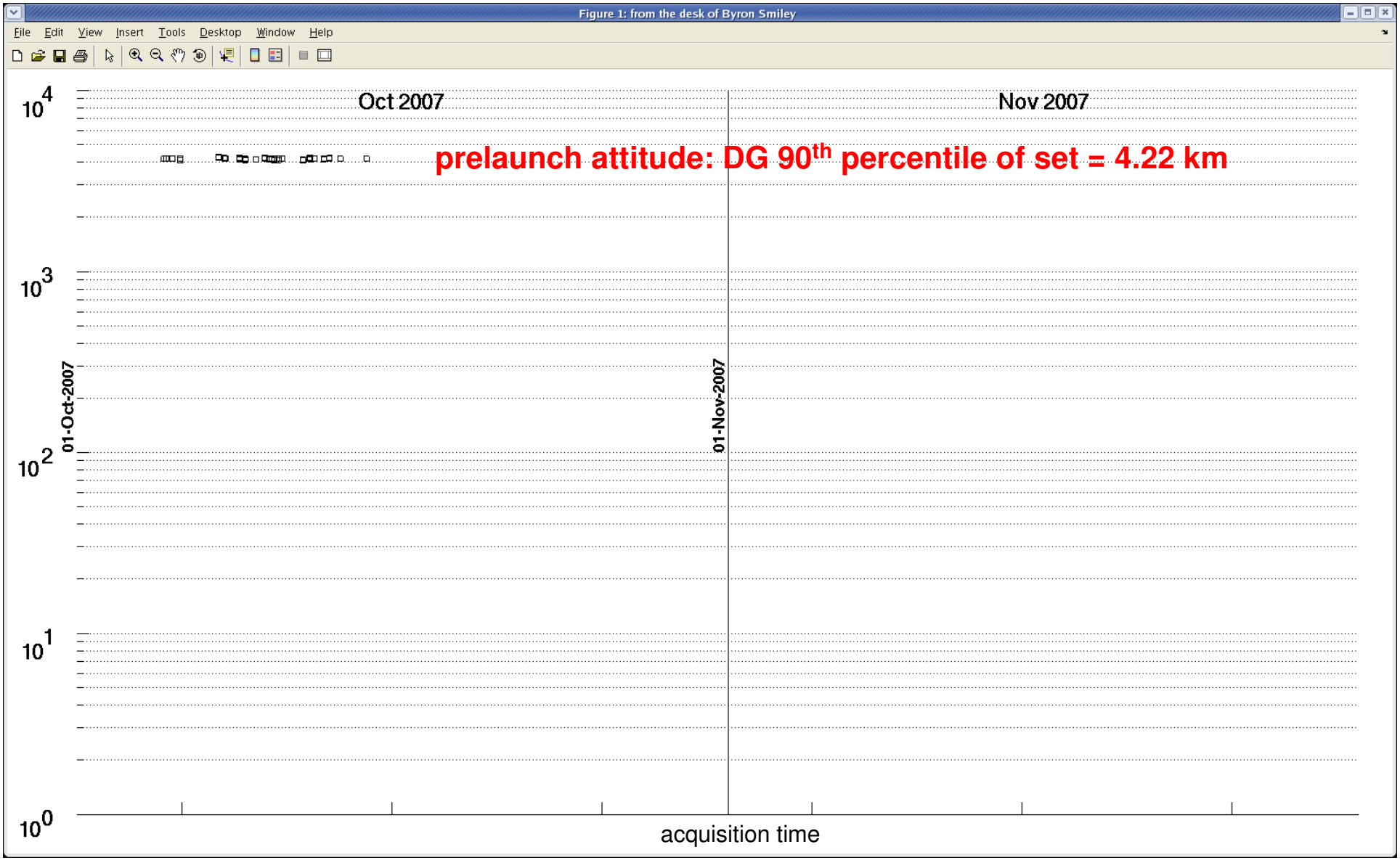


Compare the Histograms of the Nadir Projected CE90s

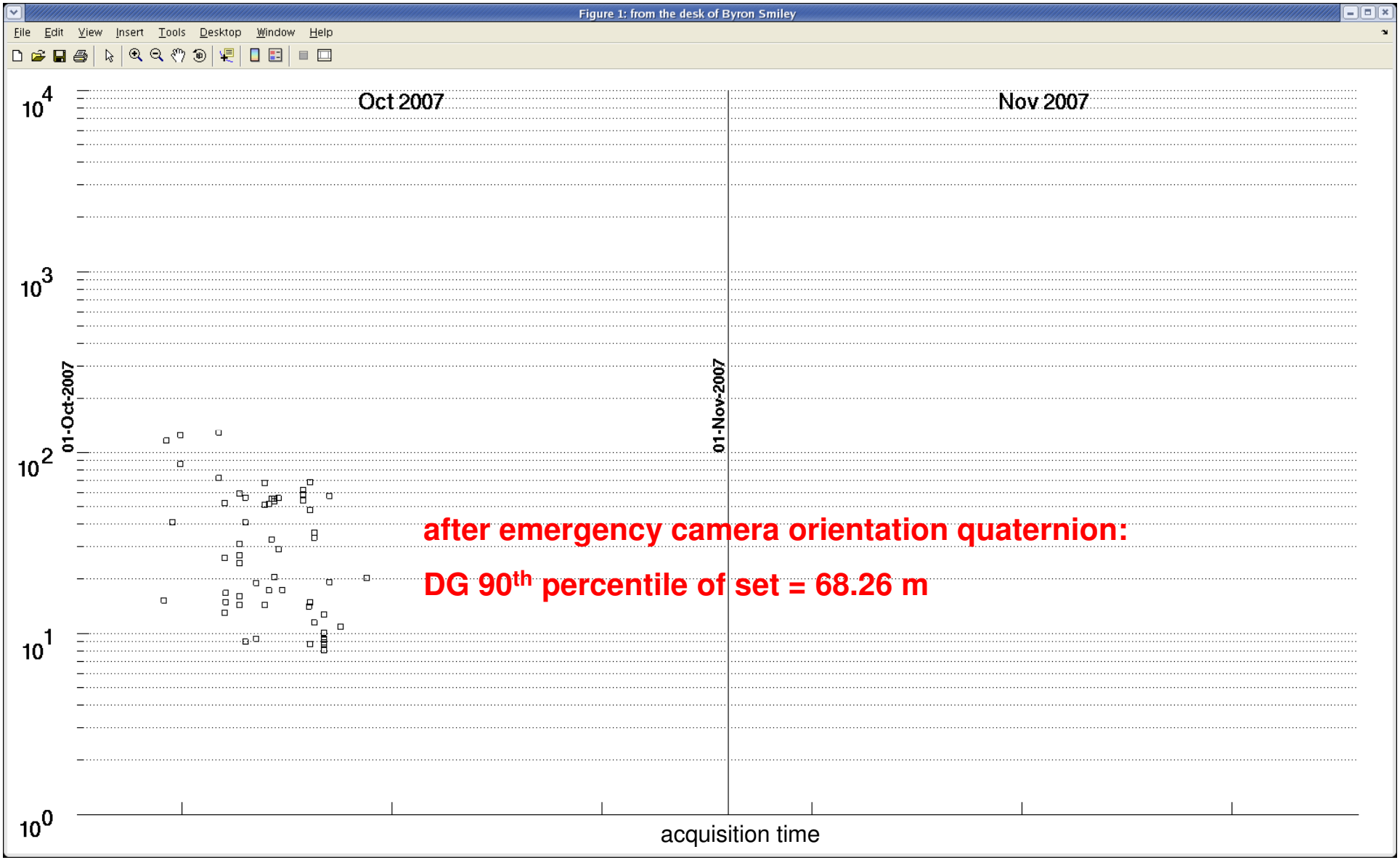


Attitude Calibration of WV01

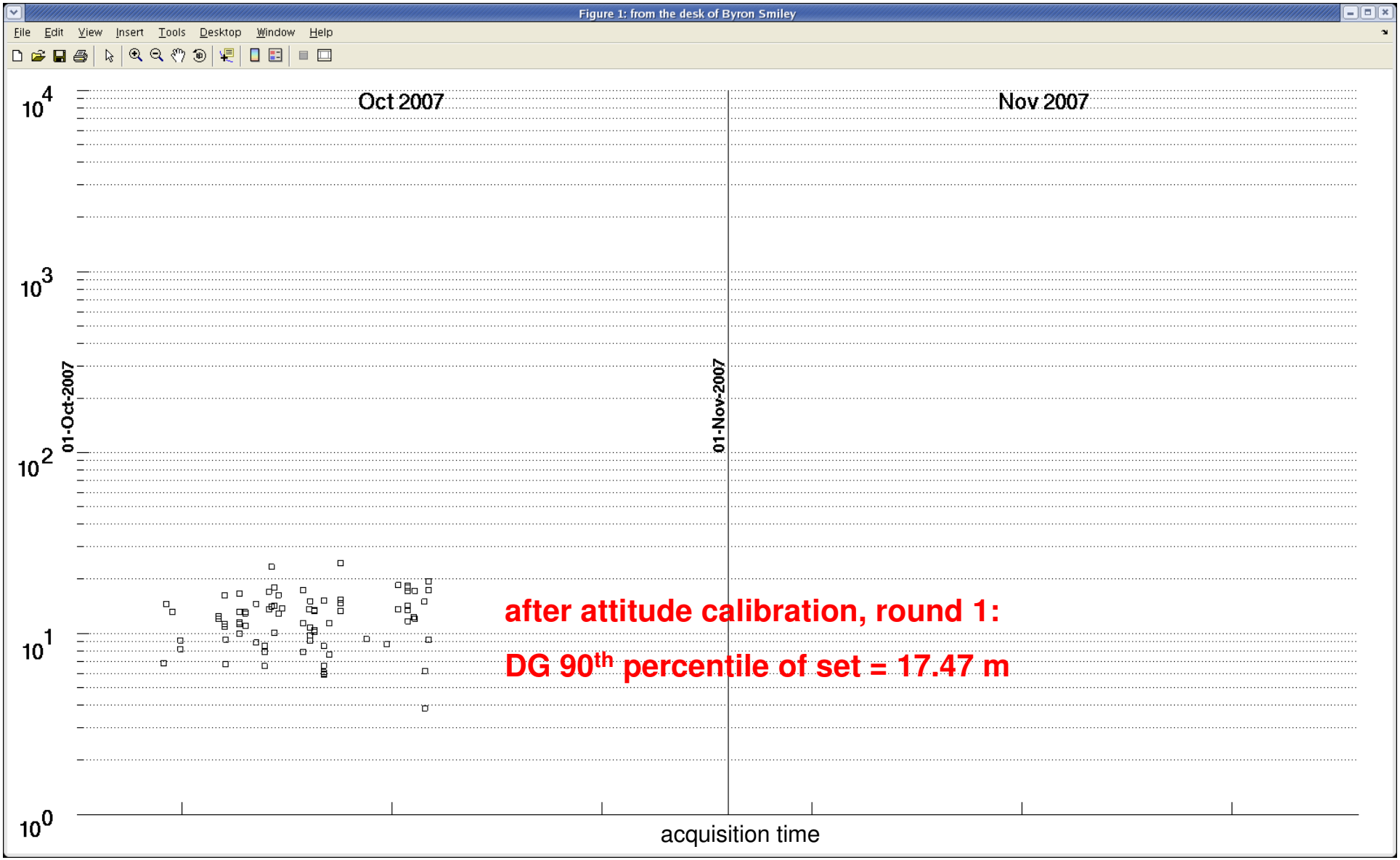
Achieving the Absolute Accuracy of WV01



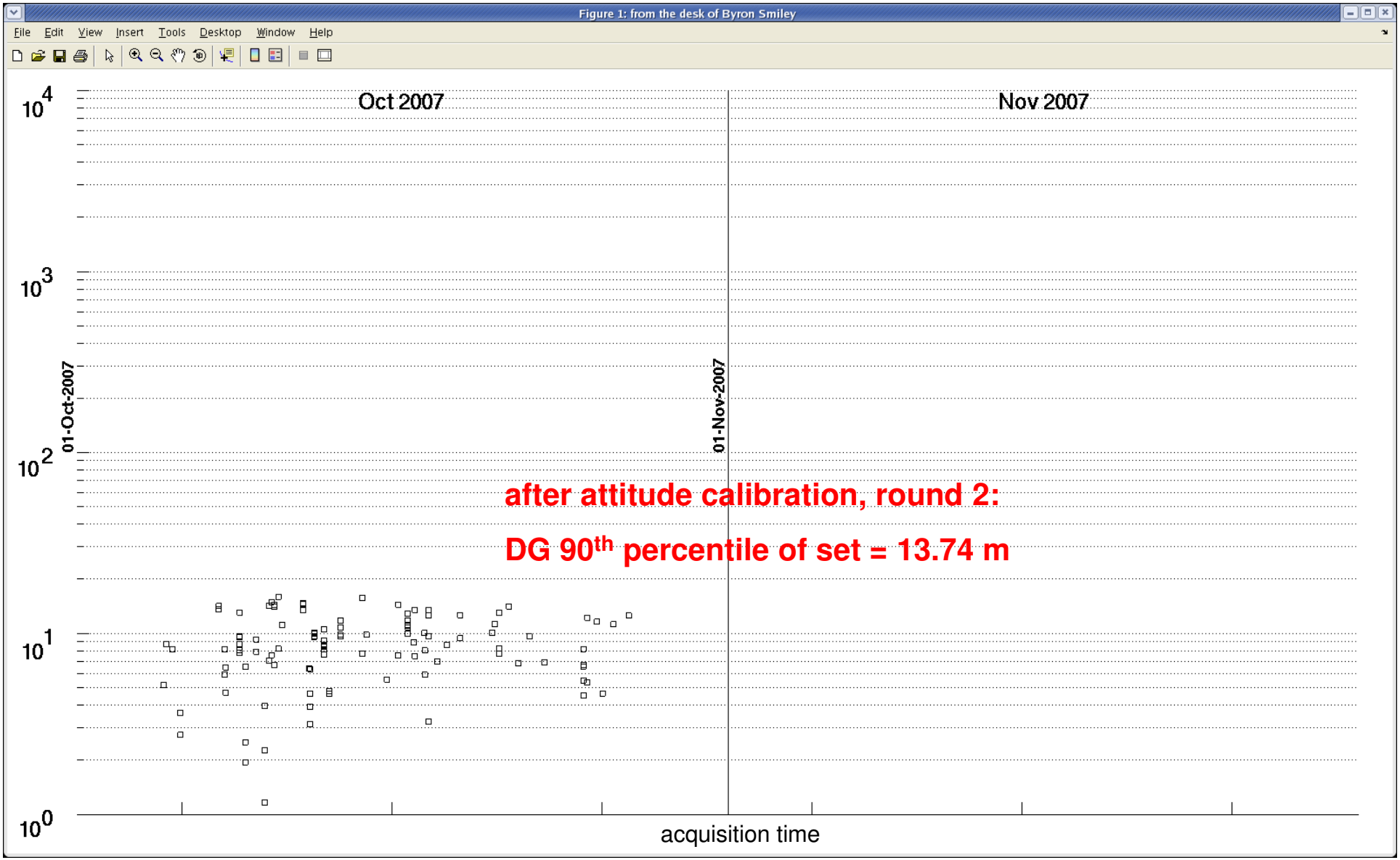
Achieving the Absolute Accuracy of WV01



Achieving the Absolute Accuracy of WV01



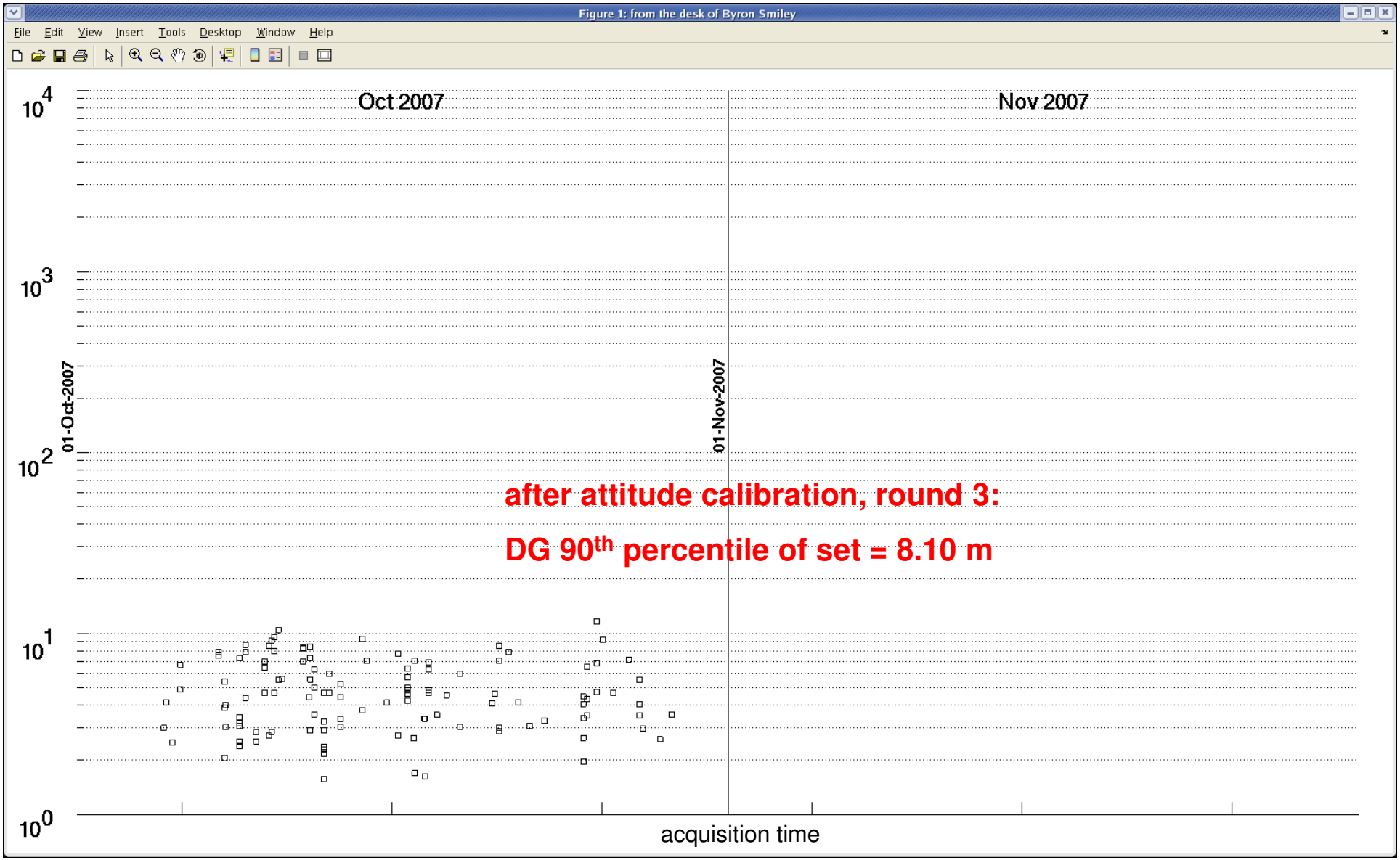
Achieving the Absolute Accuracy of WV01



after attitude calibration, round 2:

DG 90th percentile of set = 13.74 m

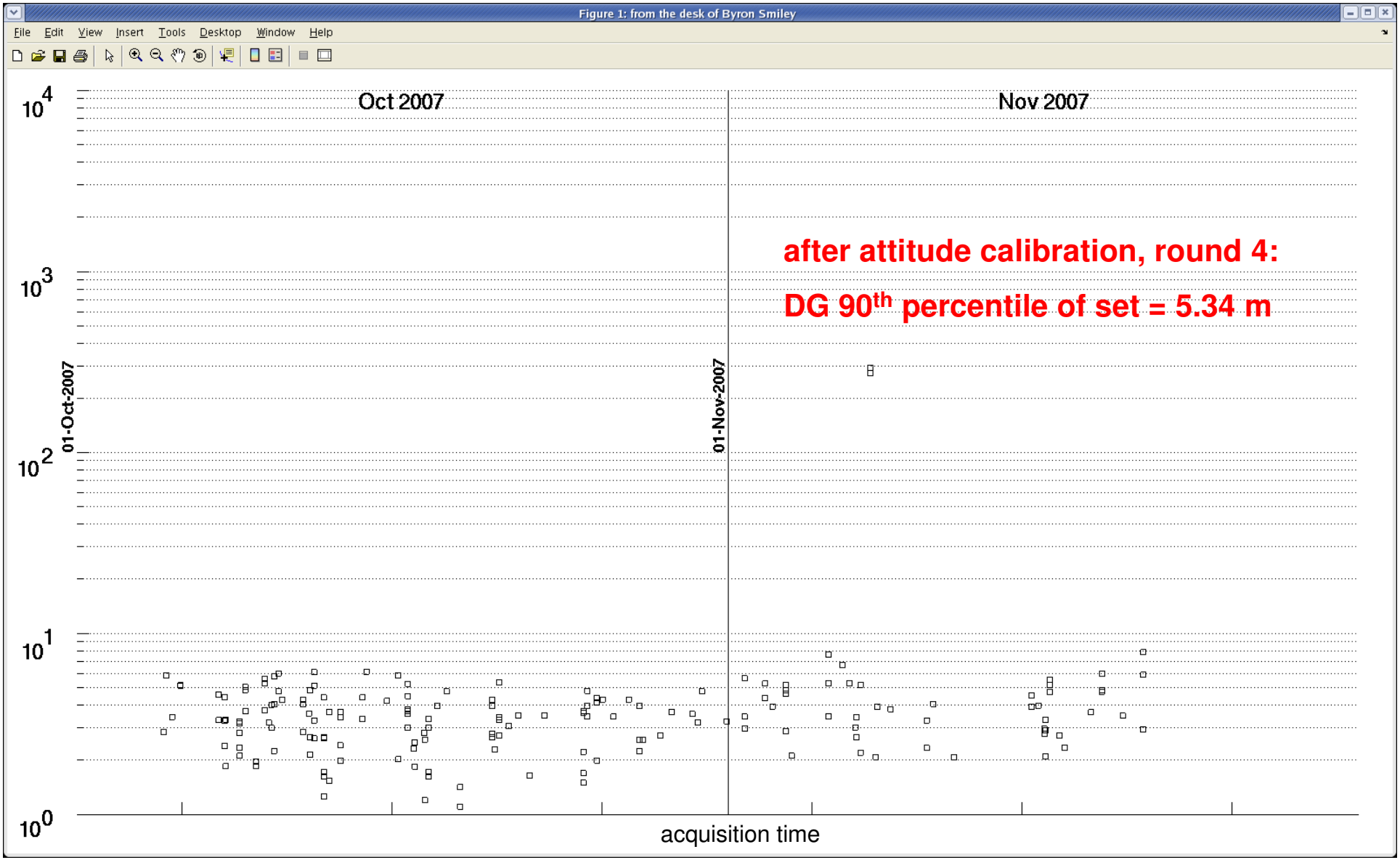
Achieving the Absolute Accuracy of WV01



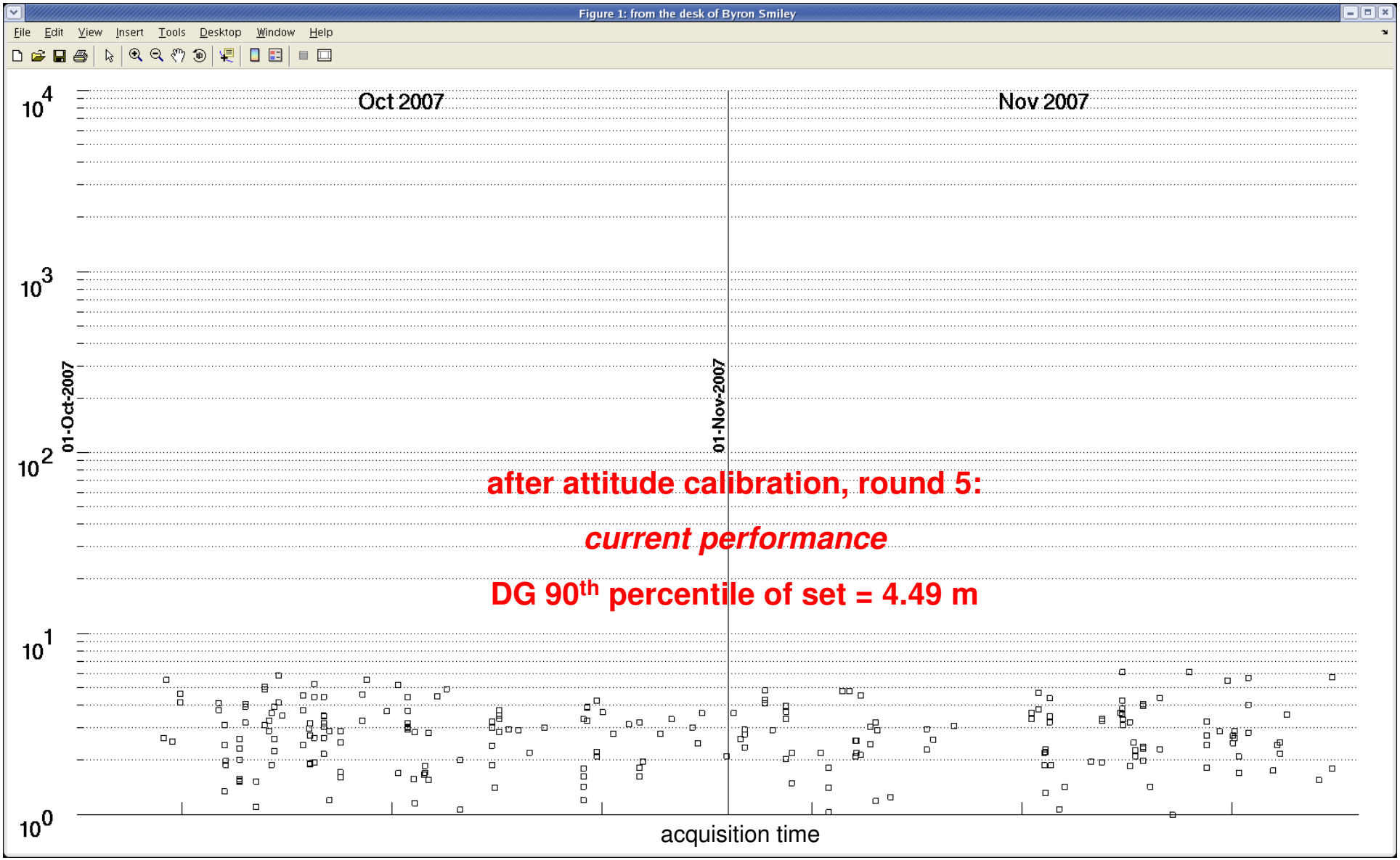
after attitude calibration, round 3:

DG 90th percentile of set = 8.10 m

Achieving the Absolute Accuracy of WV01



Achieving the Absolute Accuracy of WV01



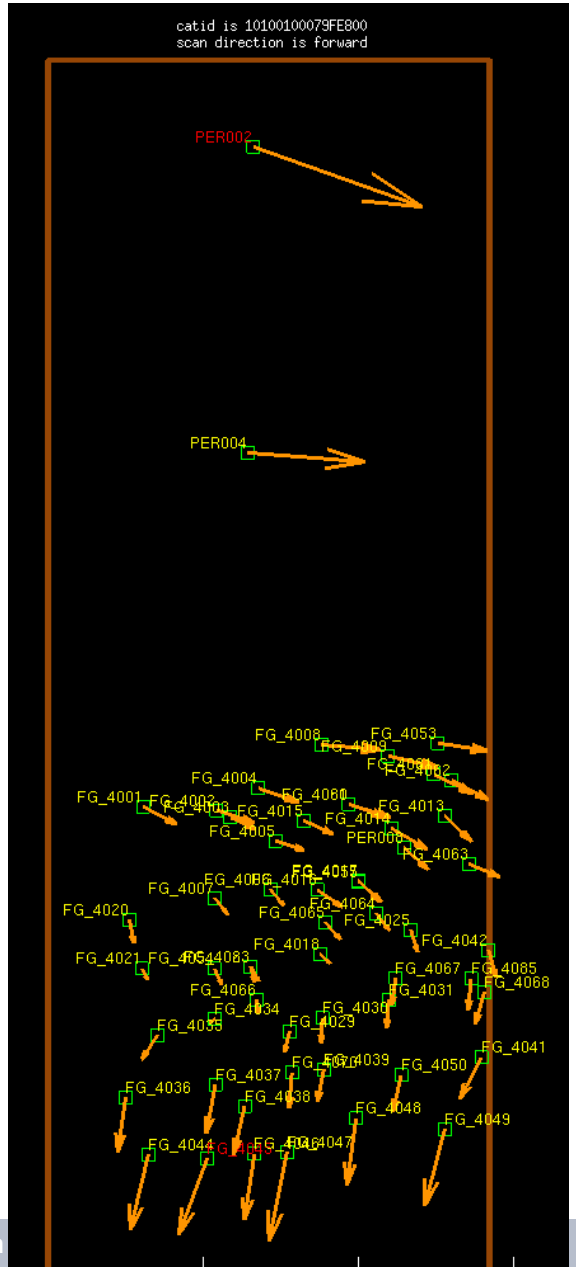
after attitude calibration, round 5:

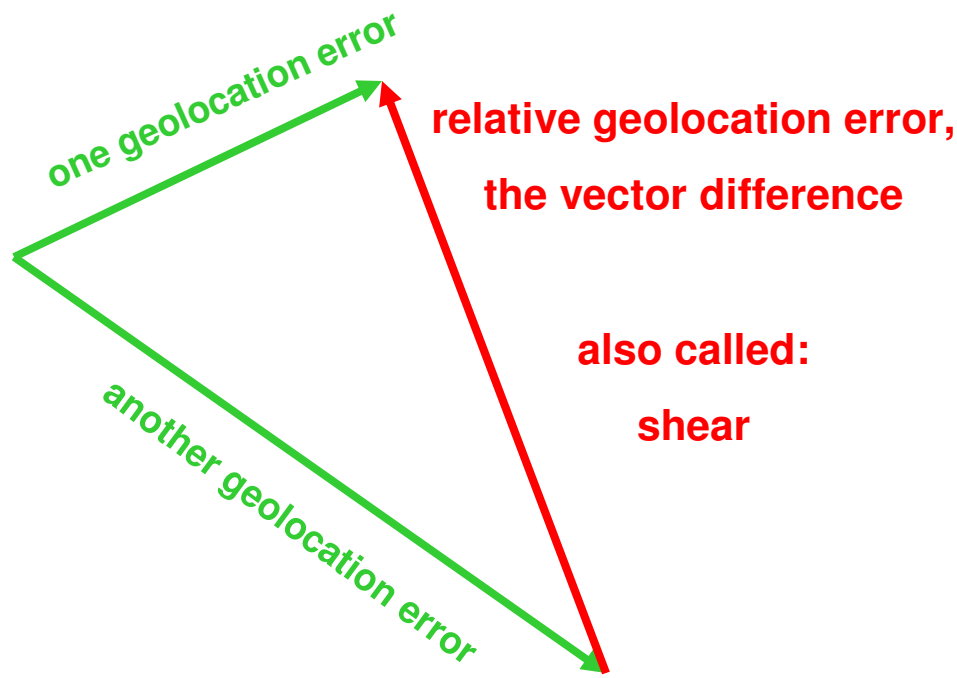
current performance

DG 90th percentile of set = 4.49 m

Relative Geolocation for QB02

Relative Geolocation Can Be Checked with Vector Differences

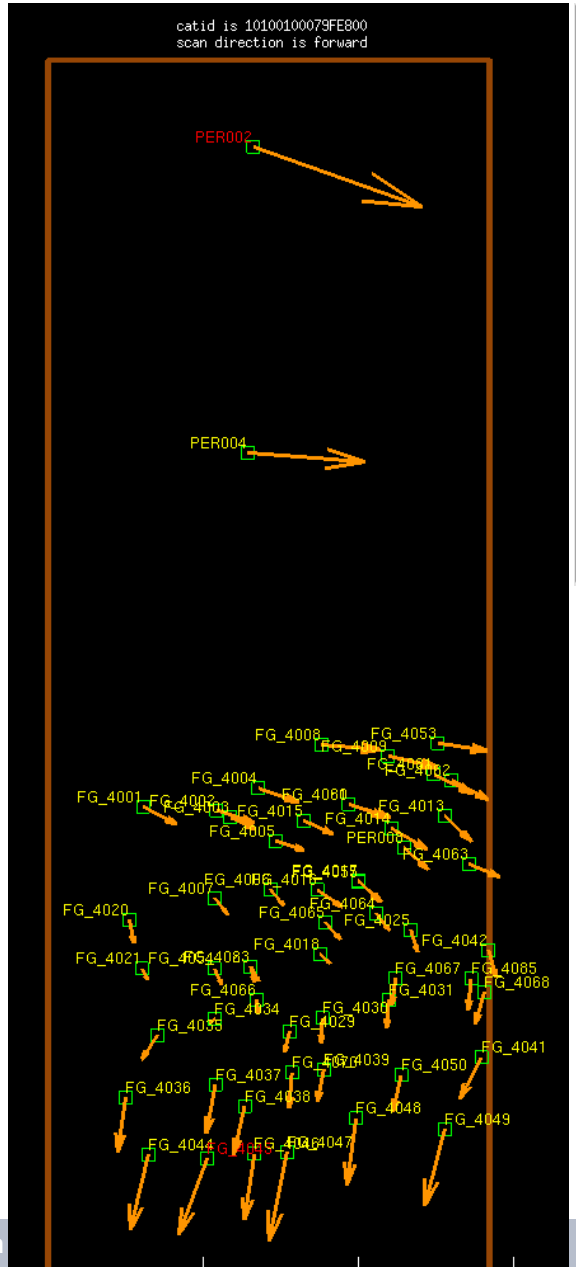


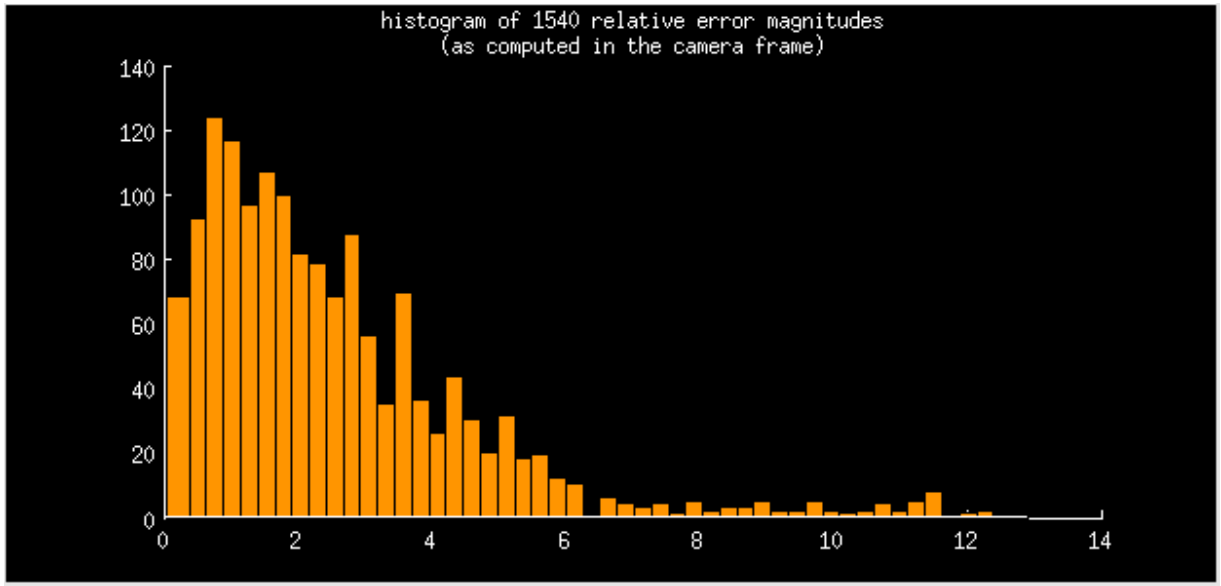


this can be done on every possible vector pair

for n errors, n(n-1)/2 pairs.

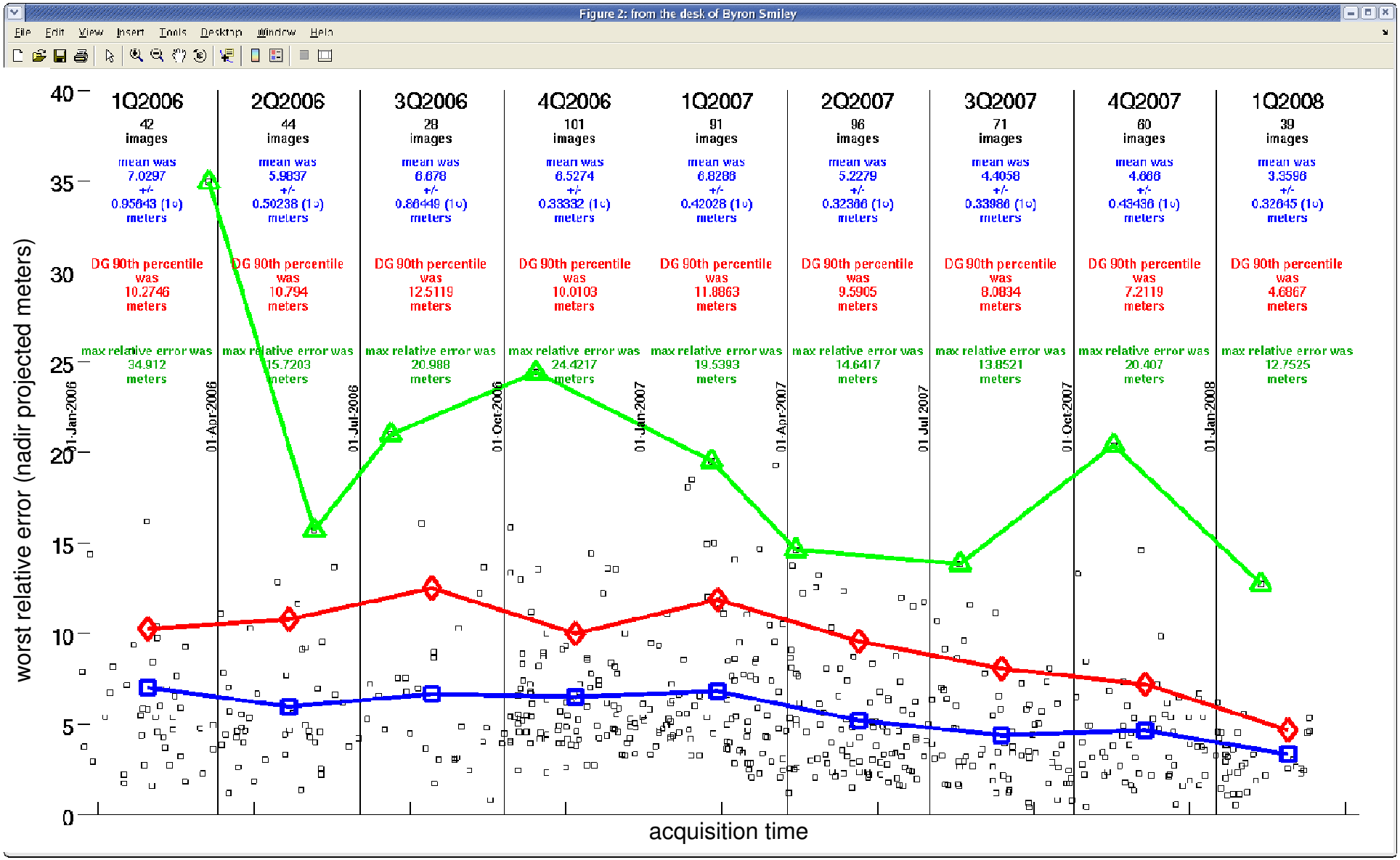
Relative Accuracy Can Be Represented by the Worst Relative Error



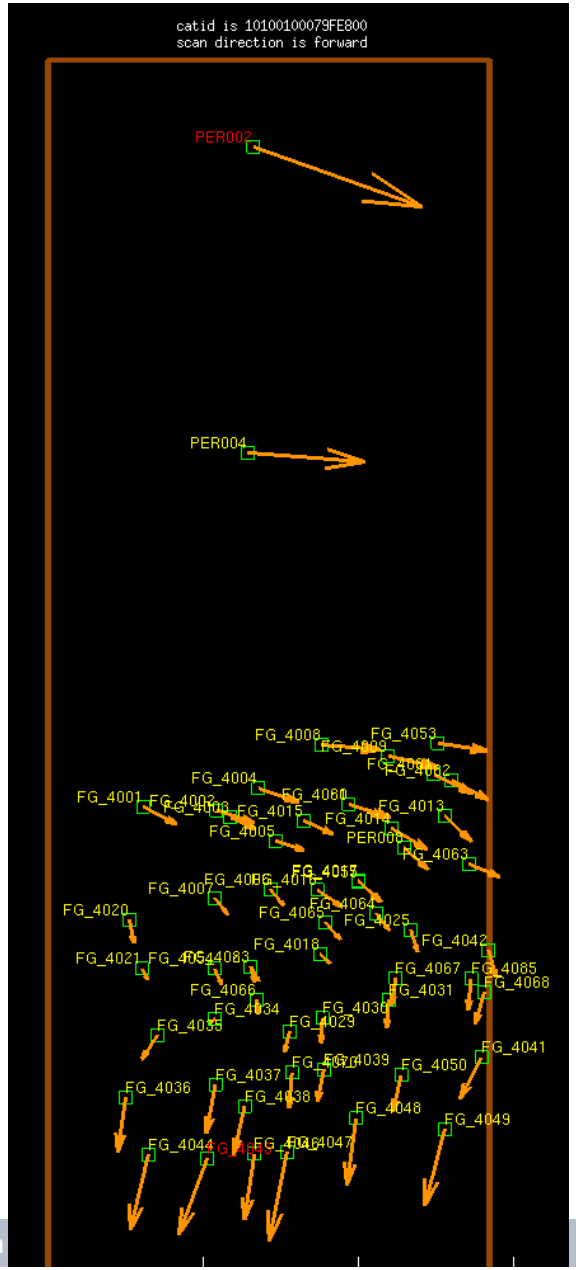


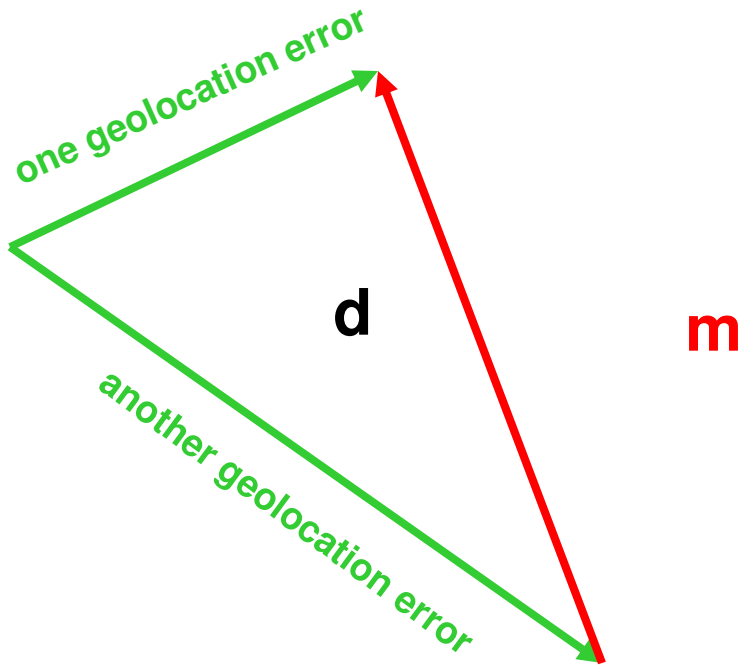
This can be a harsh measure.
Here, it's ~12 nadir projected meters

Worst Relative Error in QB02 Strips Over the Last Two Years

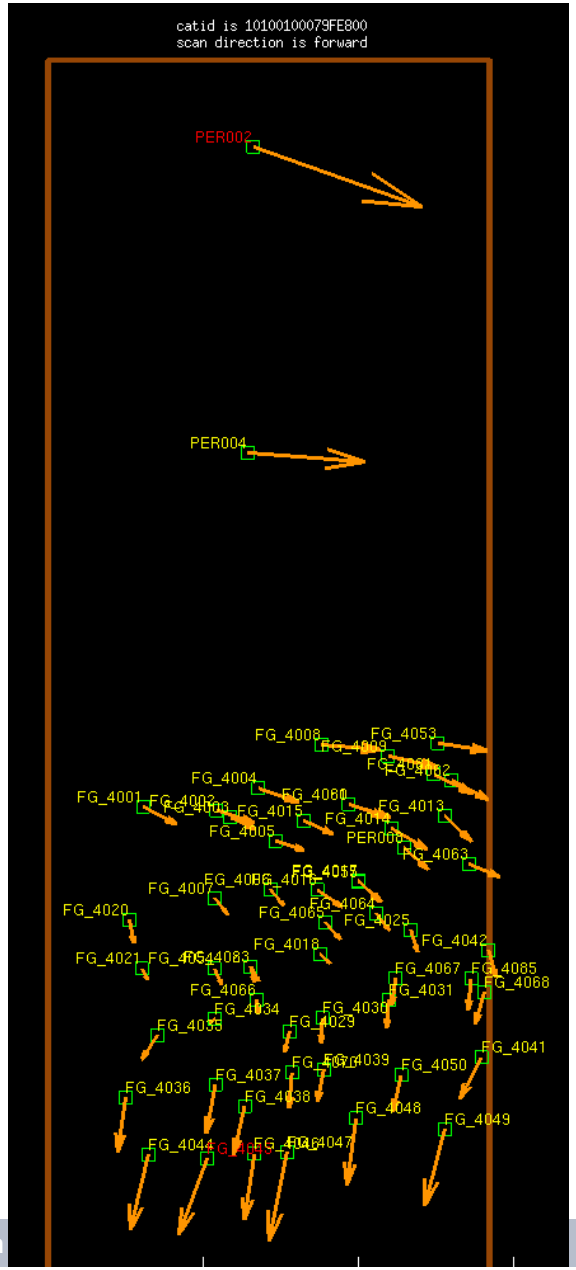


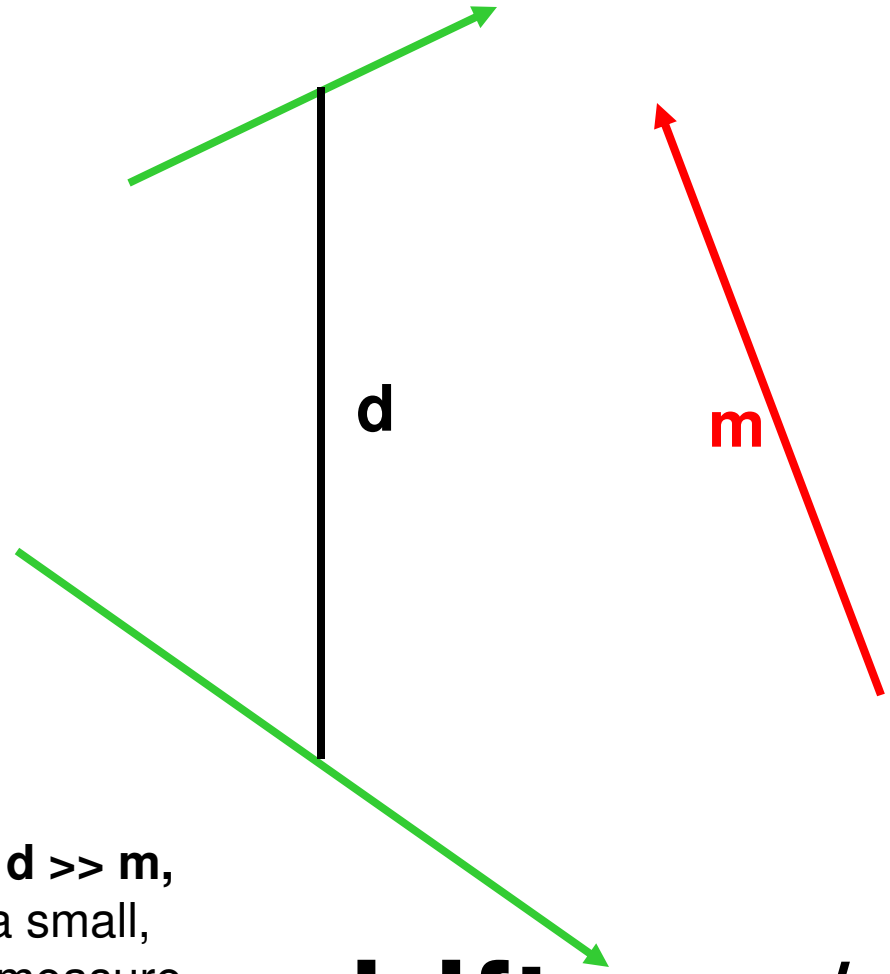
Worst Relative Error Can be Divided by Separation Distance





Worst Relative Error Can be Divided by Separation Distance

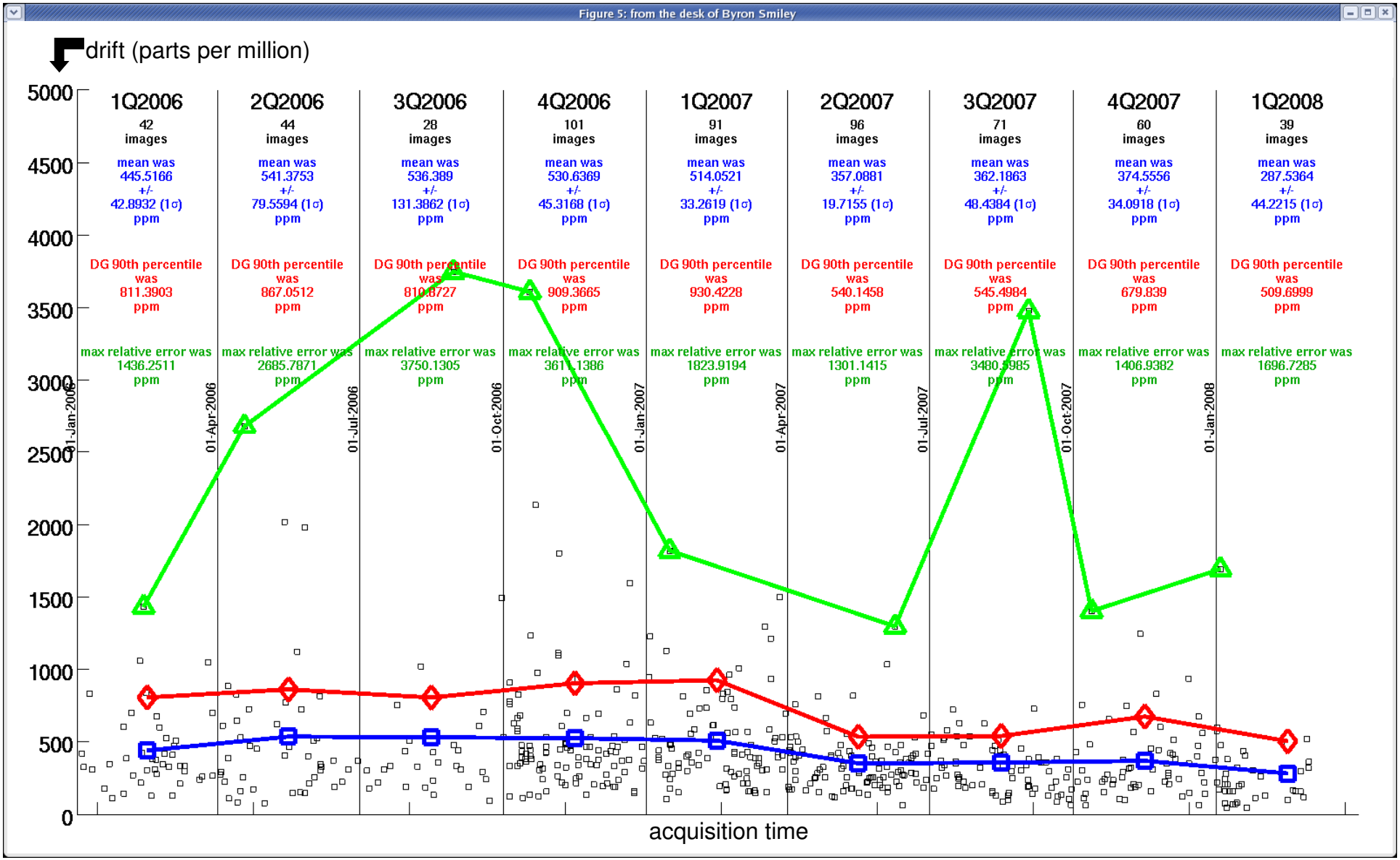




usually d >> m,
so it's a small,
unitless measure
~100s of ppm
(parts per million)

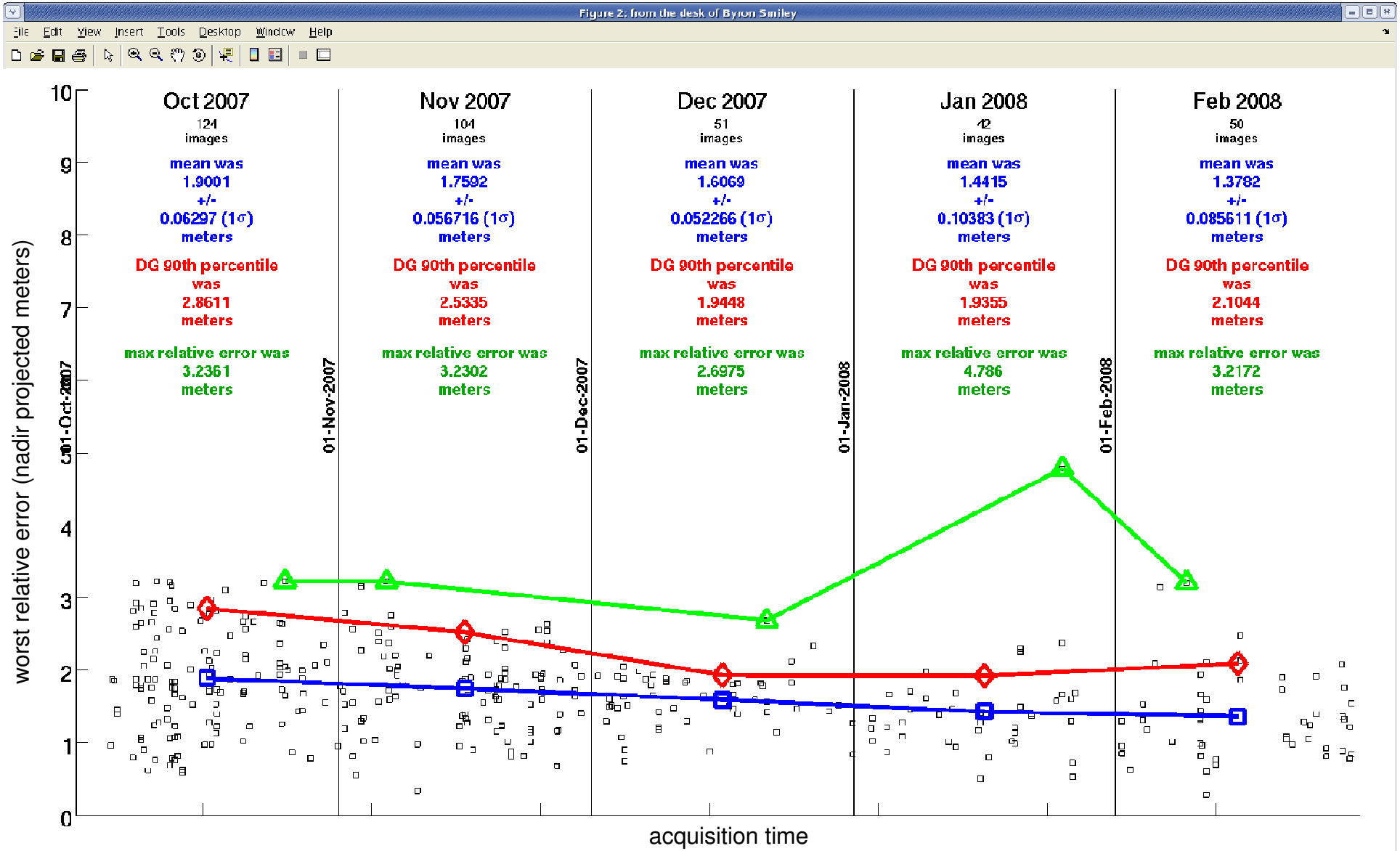
drift = m/d

Drift for QB02 strips over the last two years

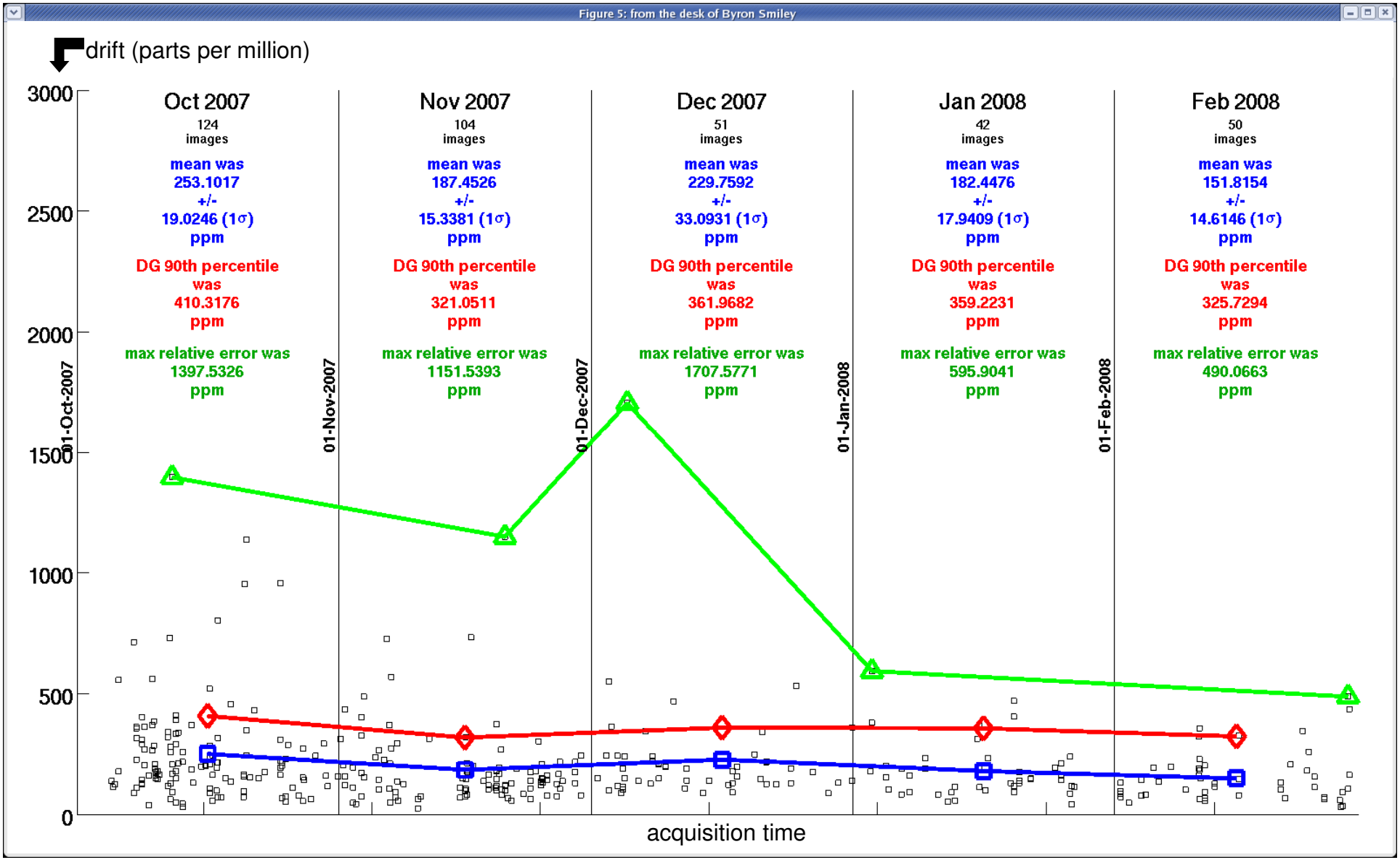


Relative Geolocation for WV01

Worst Relative Error in WV01 Strips Over the Last 5 Months

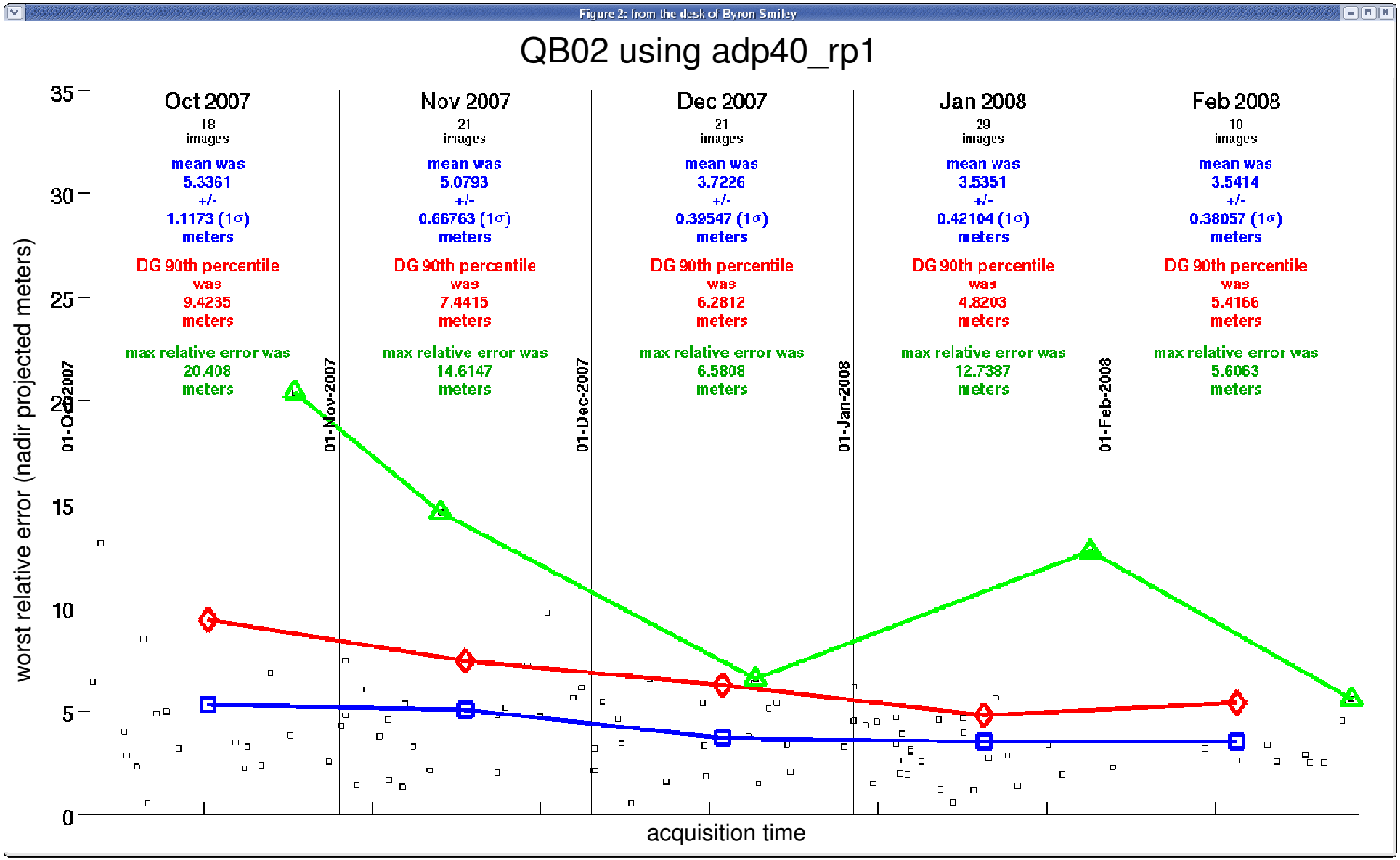


Drift for WV01 strips over the last 5 months

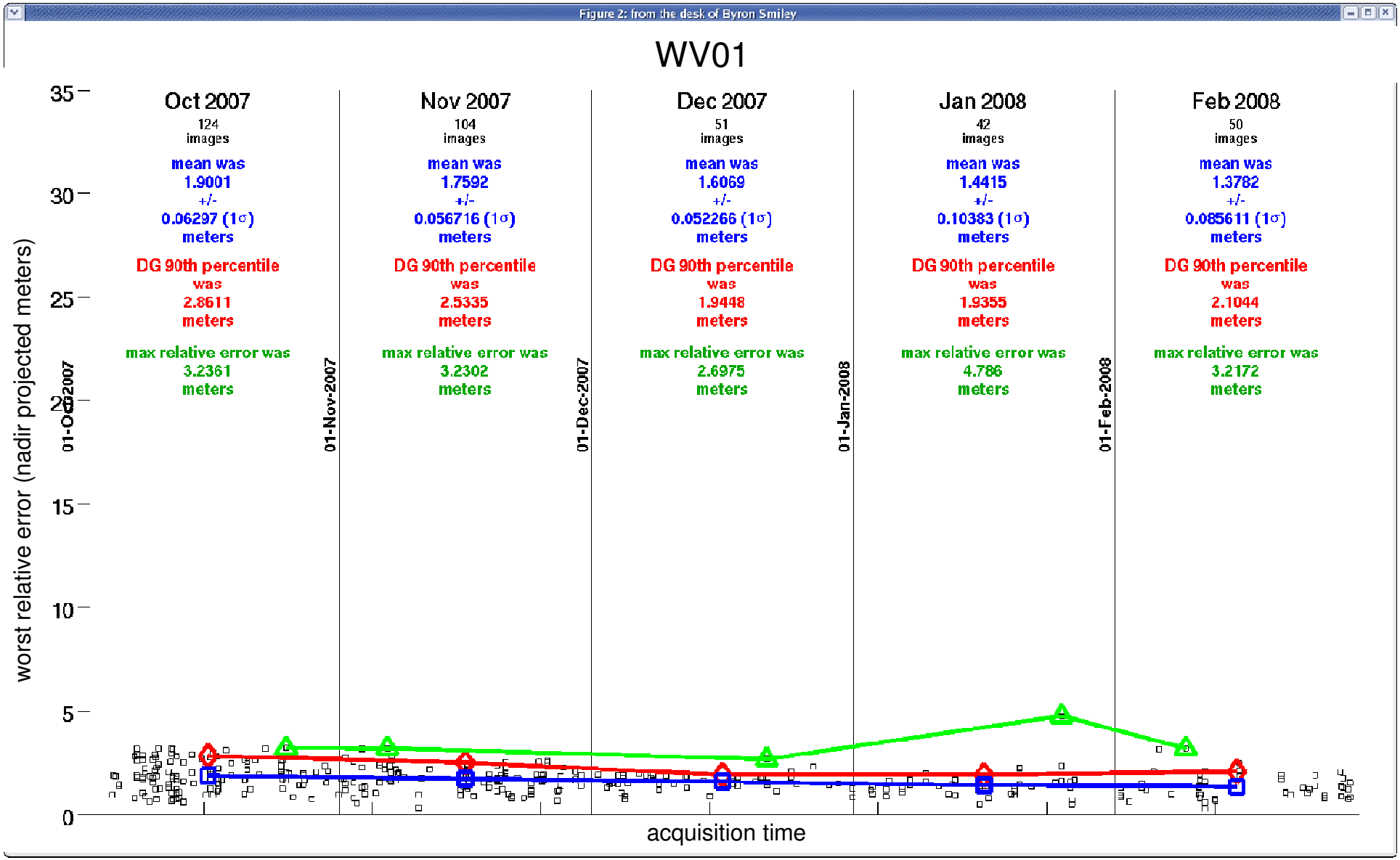


Relative Geolocation QB02 versus WV01

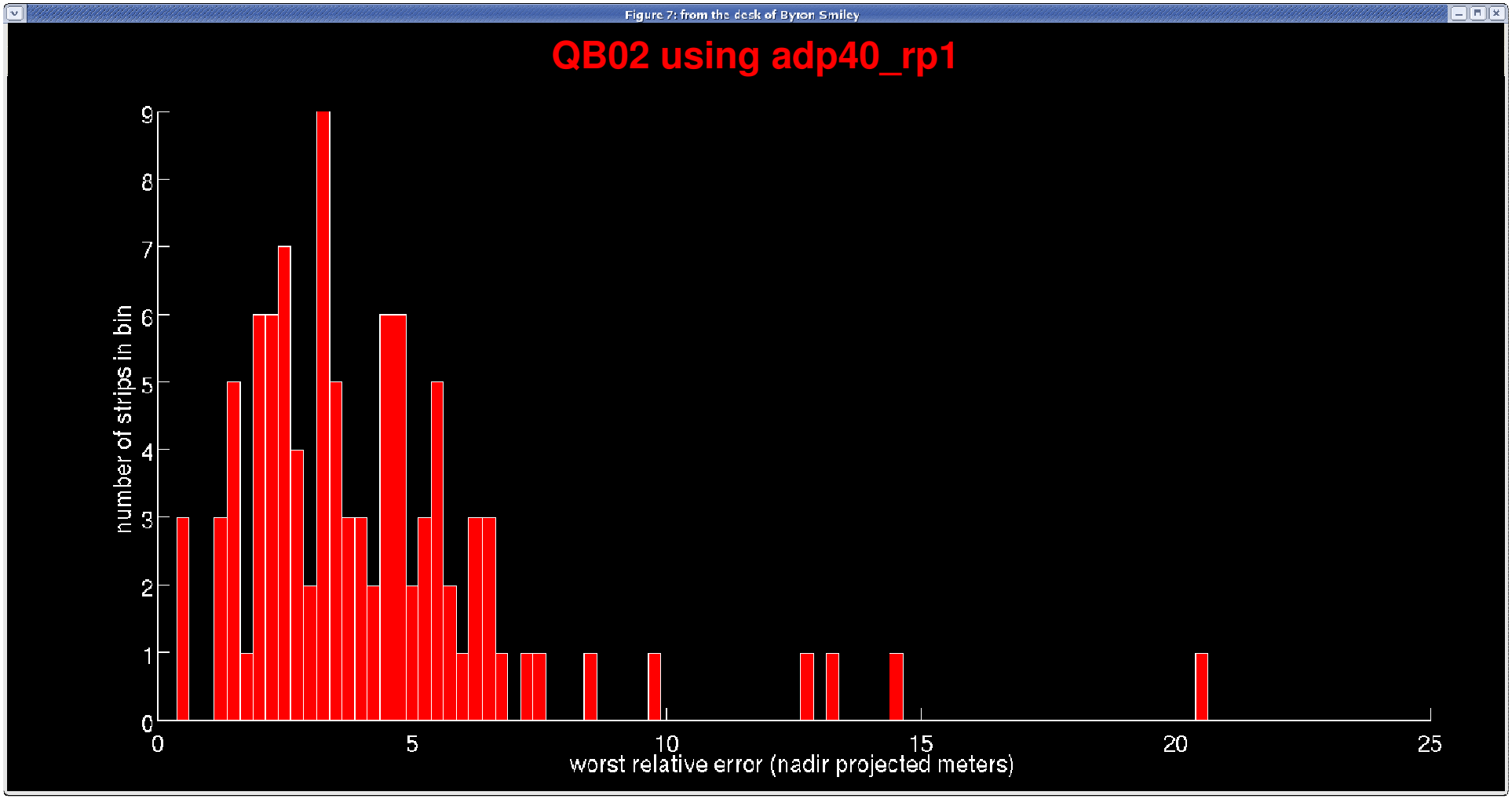
Worst Relative Error: QB02 versus WV01



Worst Relative Error: QB02 versus WV01



Compare the Histograms of the Worst Relative Error



Compare the Histograms of the Worst Relative Error

Camera Calibration of WV01

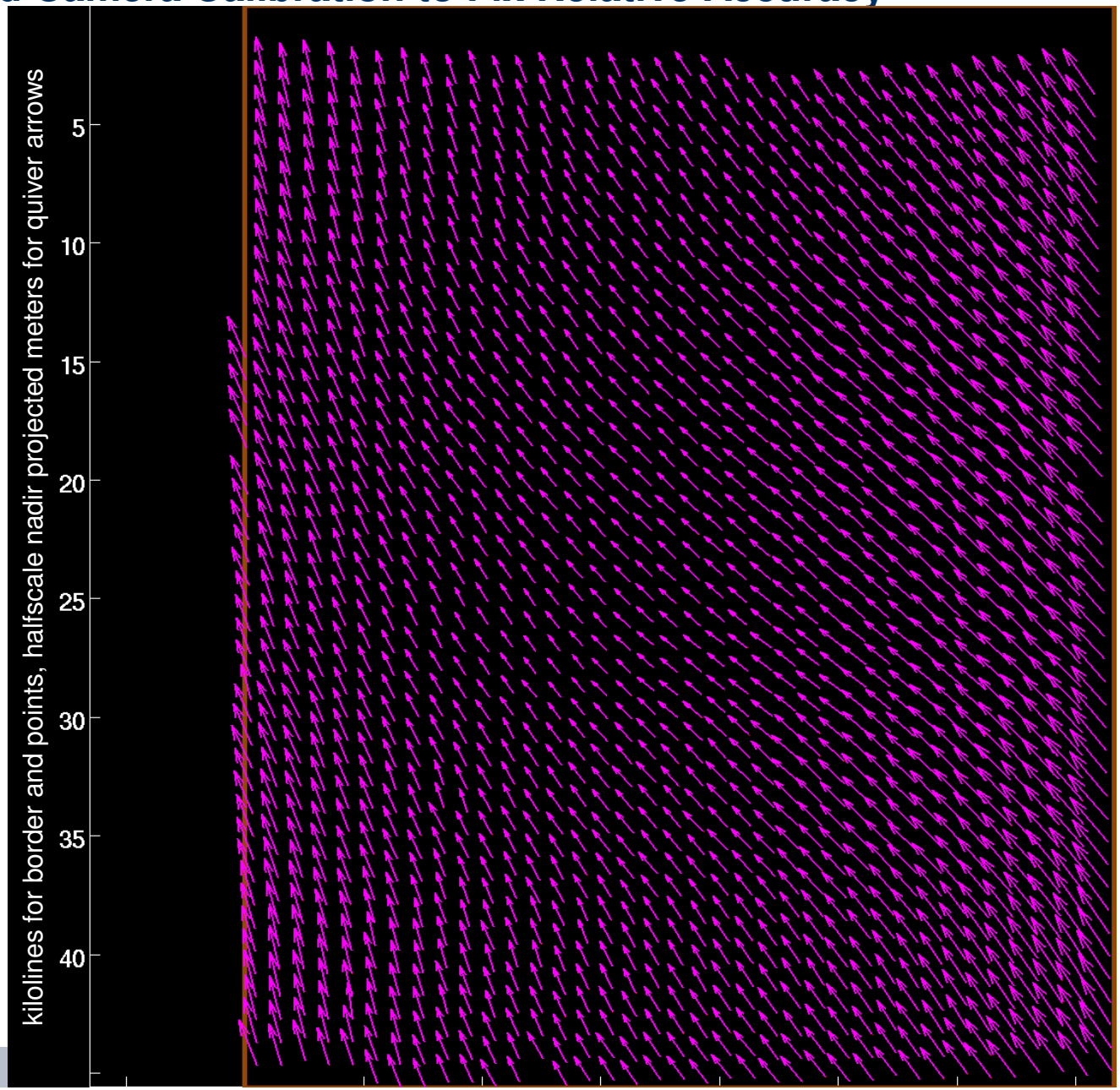
WV01 Required Camera Calibration to Fix Relative Accuracy

"Dense" control sites (not on the previous list) used to create "dense" quiver plots like this →

nadir projected CE90 = 6.805660 meters

But it's full of attitude error… how to get at the contribution of the camera?

Do a least squares fit.



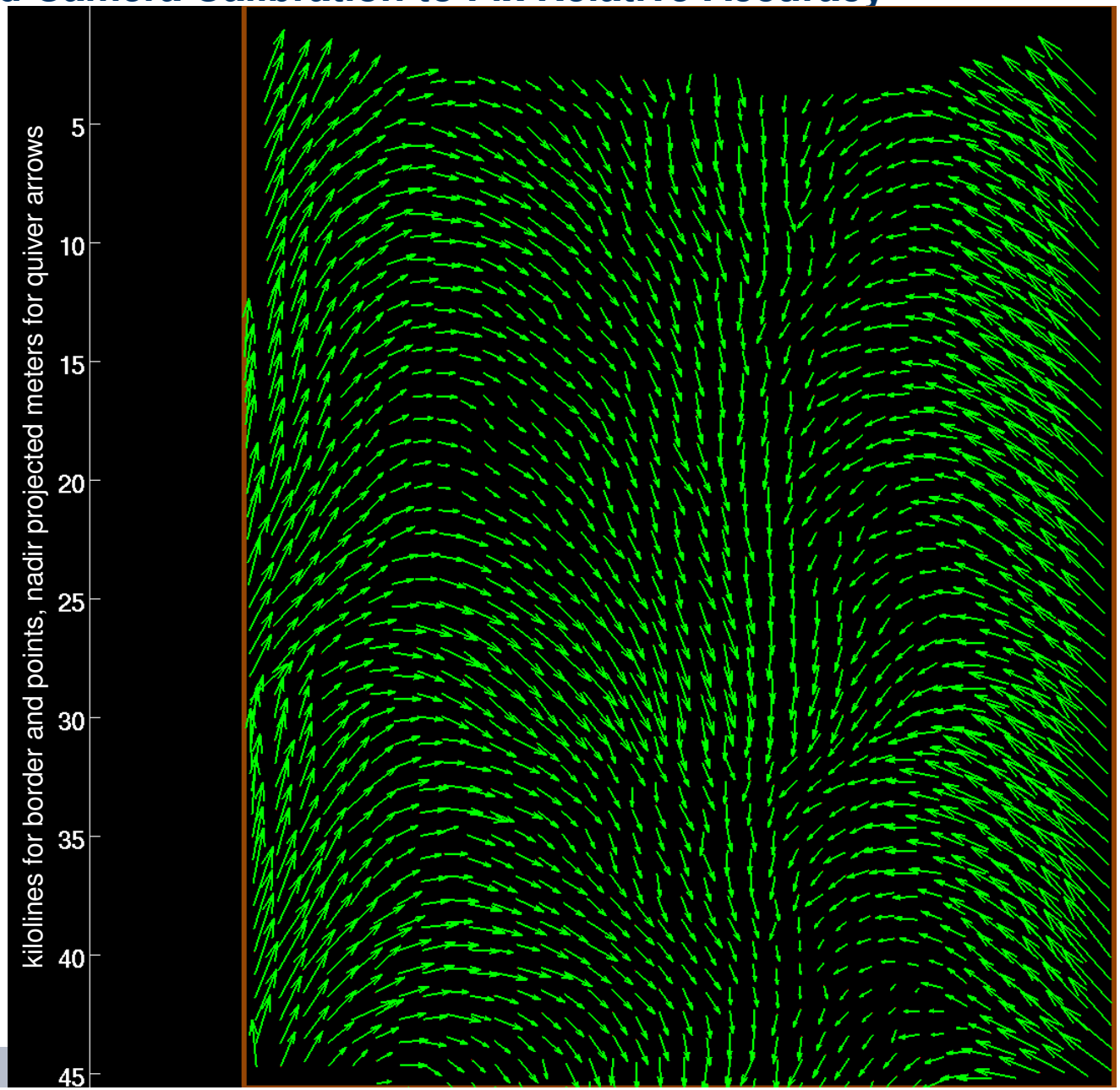
WV01 Required Camera Calibration to Fix Relative Accuracy

After “attitude detrending”, relative geolocation errors from the camera show themselves.

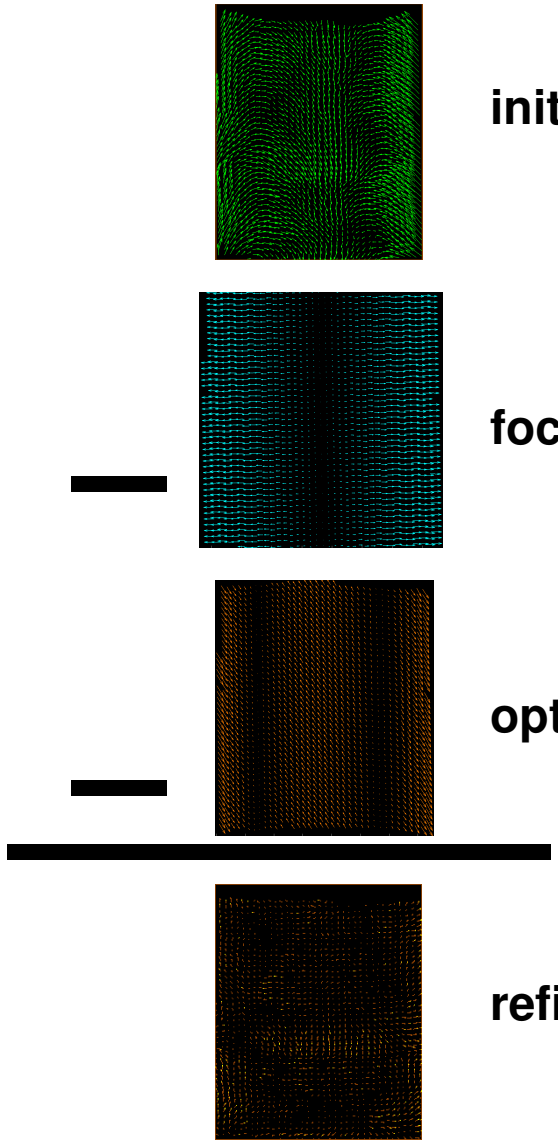
nadir projected CE90 = 2.244594 meters

They come from the camera model not using the proper

- focal length (some)
- optical distortion correction (remaining)



WV01 Required Camera Calibration to Fix Relative Accuracy



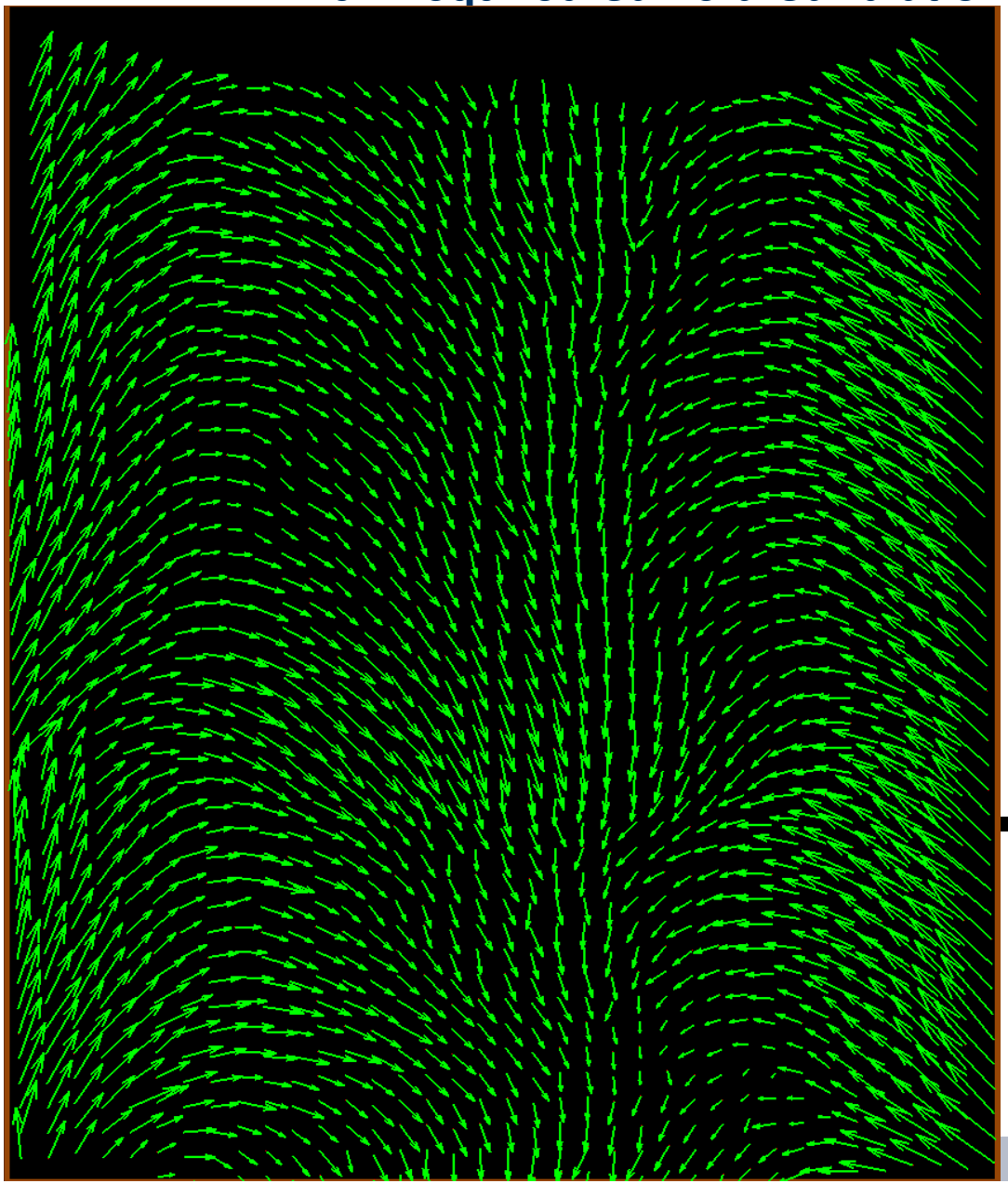
initial camera error

focal length contribution

optical distortion contribution

refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy



initial camera error

focal length contribution

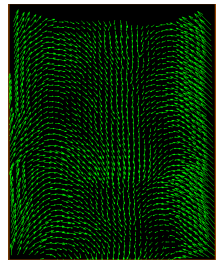
optical distortion contribution

refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy

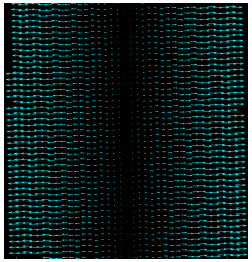
nadir projected CE90 =

2.244594 meters



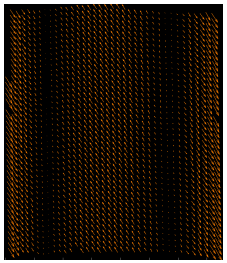
initial camera error

−



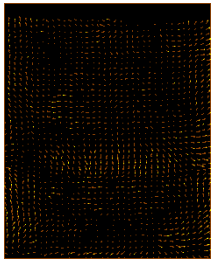
focal length contribution

−



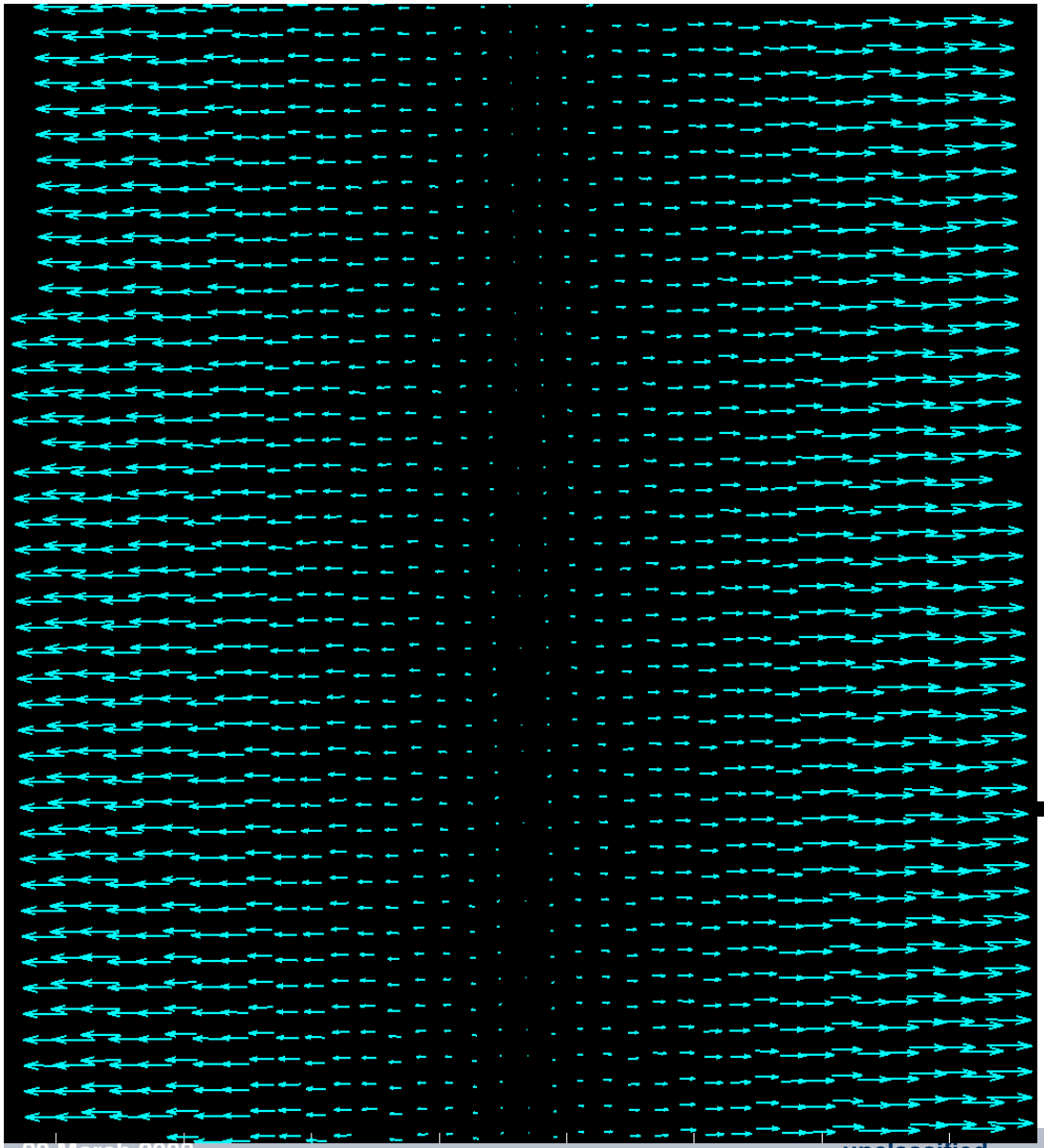
optical distortion contribution

=



refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy



initial camera error

<u>focal length contribution</u>

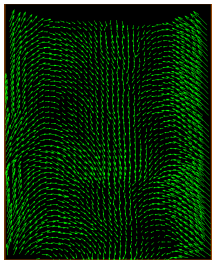
optical distortion contribution

refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy

nadir projected CE90 =

2.244594 meters

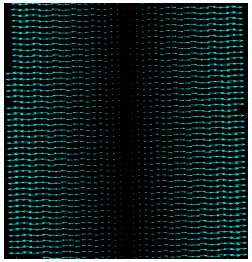


initial camera error

cleans up 0.430926 meters in the

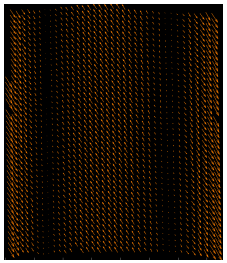
nadir projected CE90

–

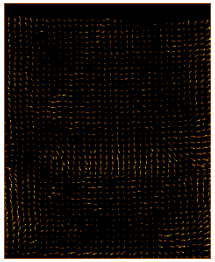


focal length contribution

–

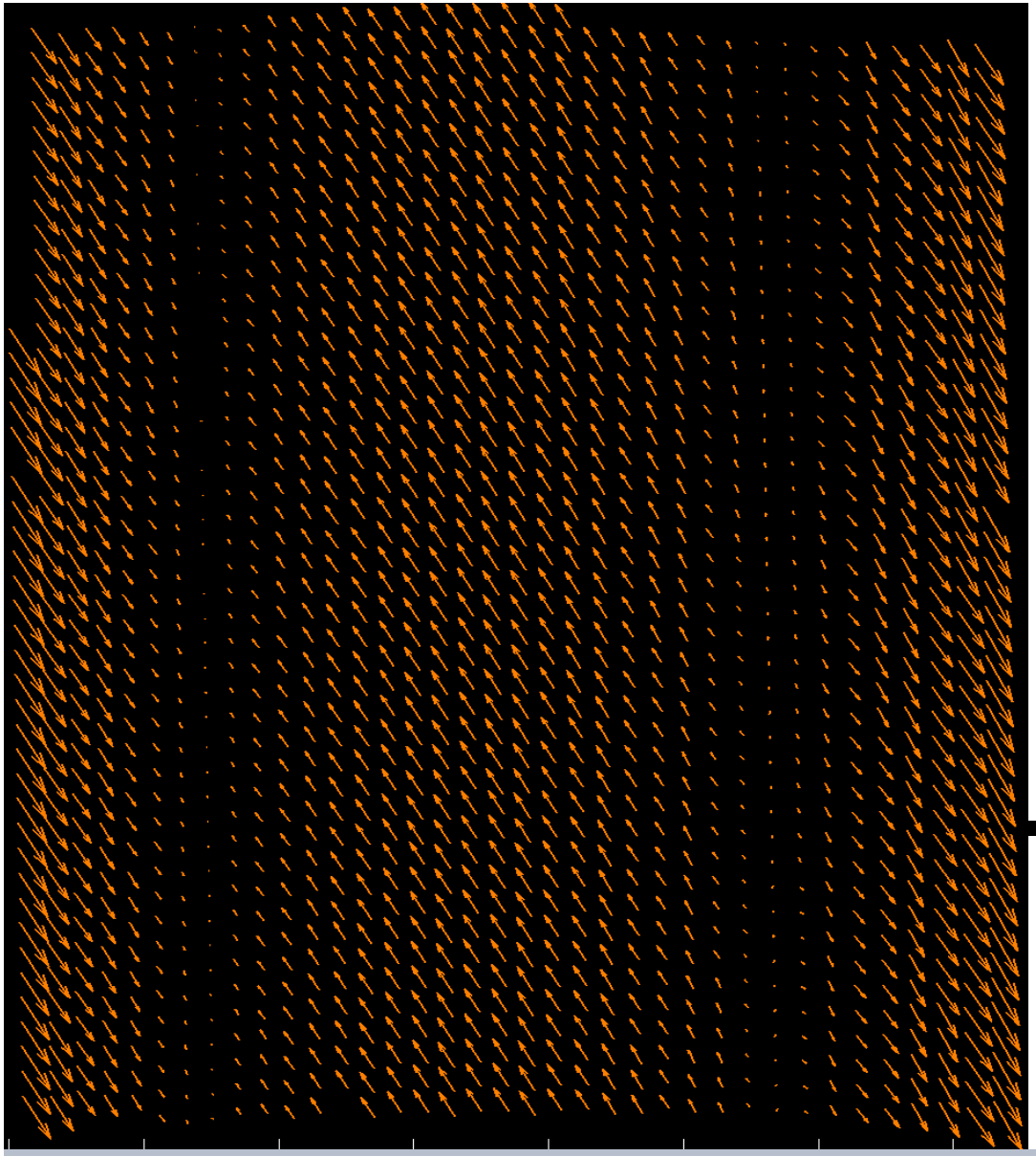


optical distortion contribution



refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy



initial camera error

focal length contribution

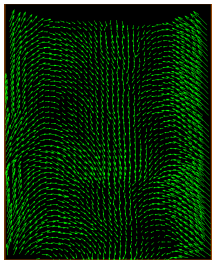
<u>optical distortion contribution</u>

refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy

nadir projected CE90 =

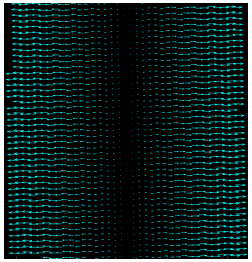
2.244594 meters



initial camera error

cleans up 0.430926 meters in the

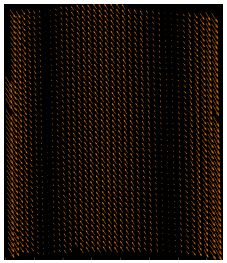
nadir projected CE90



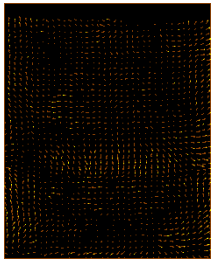
focal length contribution

cleans up 1.121792 meters in the

nadir projected CE90

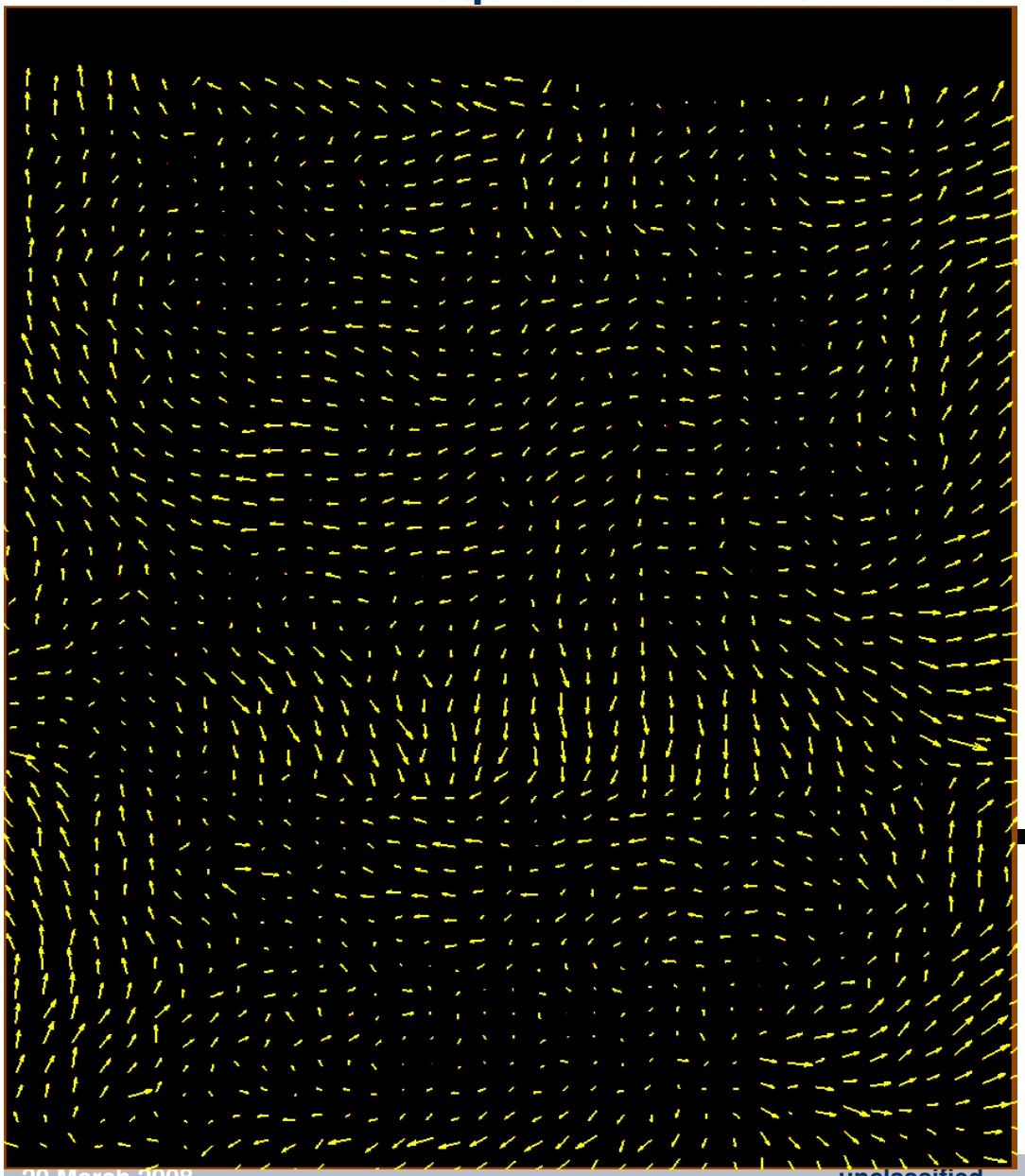


optical distortion contribution



refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy



initial camera error

focal length contribution

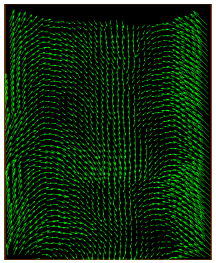
optical distortion contribution

<u>refined camera error</u>

WV01 Required Camera Calibration to Fix Relative Accuracy

nadir projected CE90 =

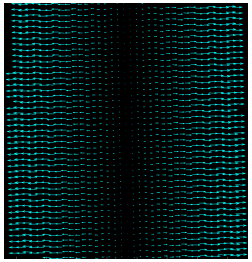
2.244594 meters



initial camera error

cleans up 0.430926 meters in the

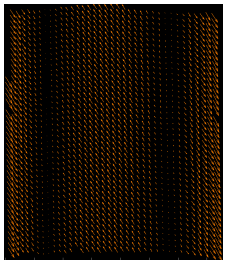
nadir projected CE90



focal length contribution

cleans up 1.121792 meters in the

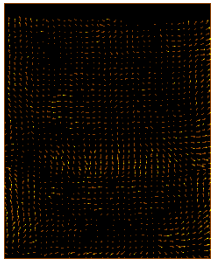
nadir projected CE90



optical distortion contribution

nadir projected CE90 =

0.691876 meters

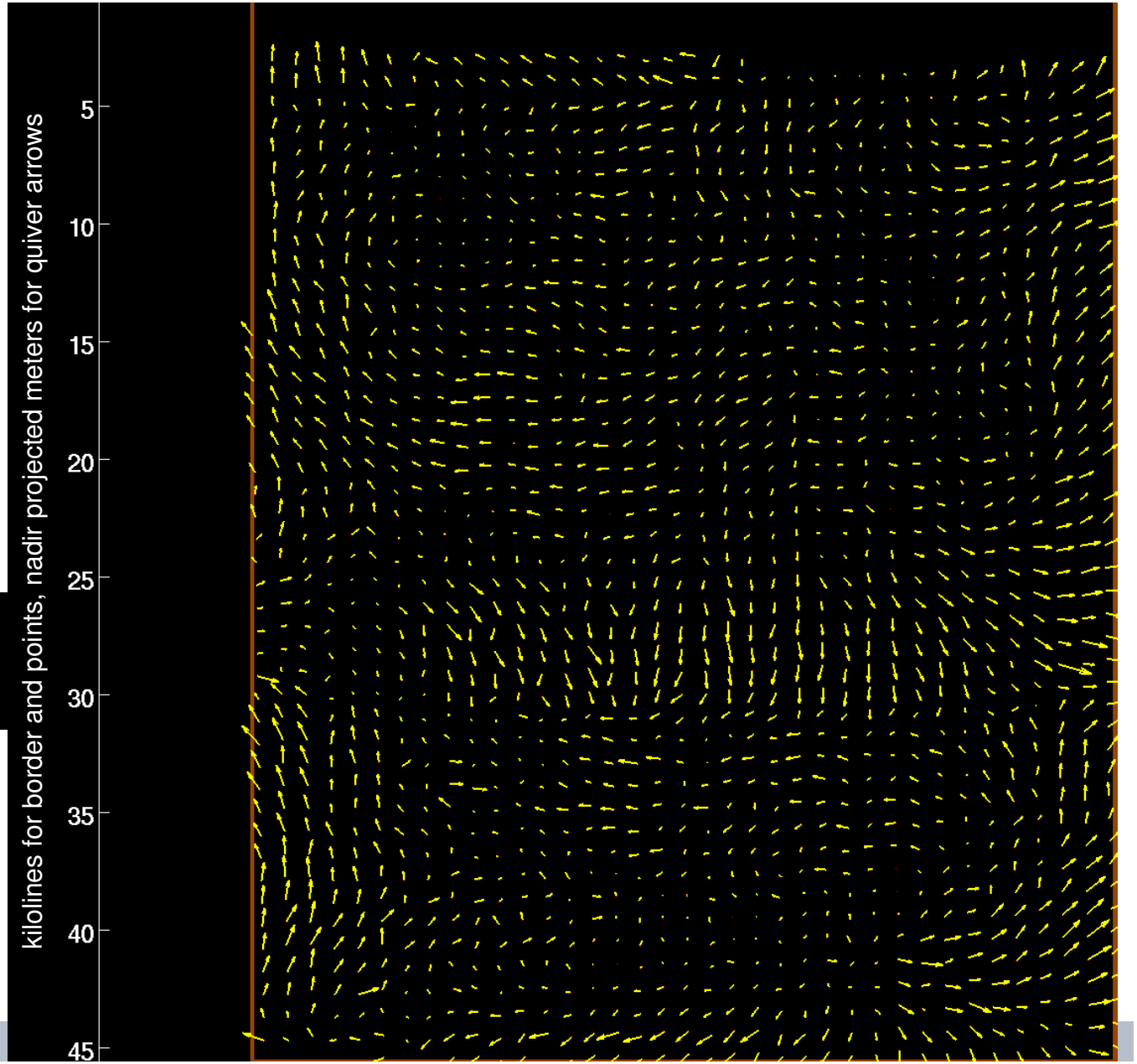


refined camera error

WV01 Required Camera Calibration to Fix Relative Accuracy

camera calibration directly from beginning to end:

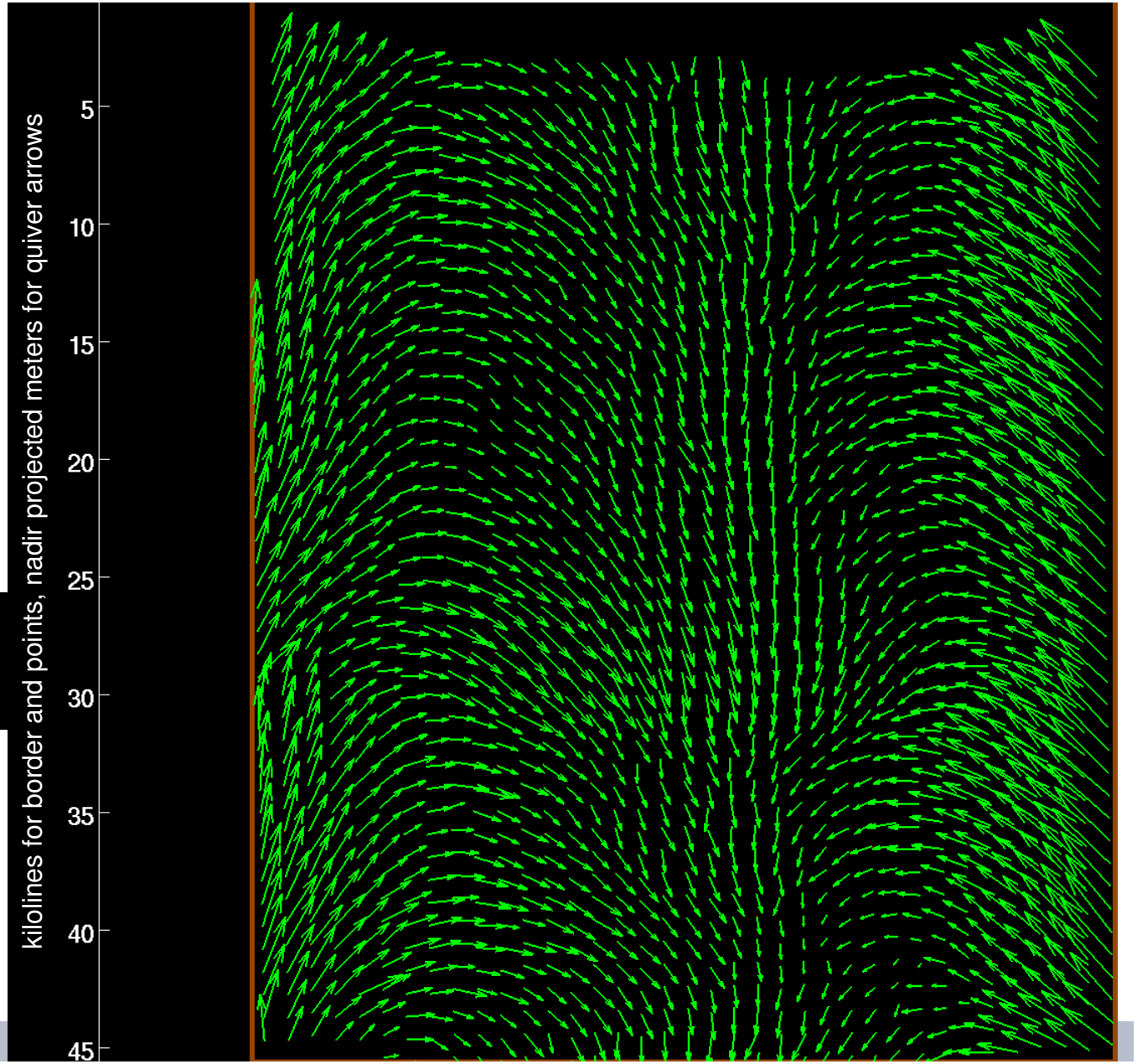
nadir projected CE90 = 0.691876 meters



WV01 Required Camera Calibration to Fix Relative Accuracy

camera calibration directly from beginning to end:

nadir projected CE90 = 2.244594 meters



Conclusions

- **QB02 in spec**
  - typical open loop CE90 is 15-18 nadir projected meters
  - absolute accuracy is under spec of 23 nadir projected meters
  - typical worst relative error is in the 10s of nadir projected meters
  - typical drift is in the high 100s of ppm
  - attitude reprocessing will address poor quarters (3Q2007 – 1Q2008)
- **WV01 in spec**
  - typical open loop CE90 is 4.5 nadir projected meters, CCAP metric was ~ 4 nadir projected meters
  - absolute accuracy is under spec of 6.5 nadir projected meters
  - typical worst relative error is in the 1s of nadir projected meters
  - typical drift in the low 100s of ppm
  - perhaps a future round of camera cal to remove additional 0.5 meter (1 pixel) of camera error