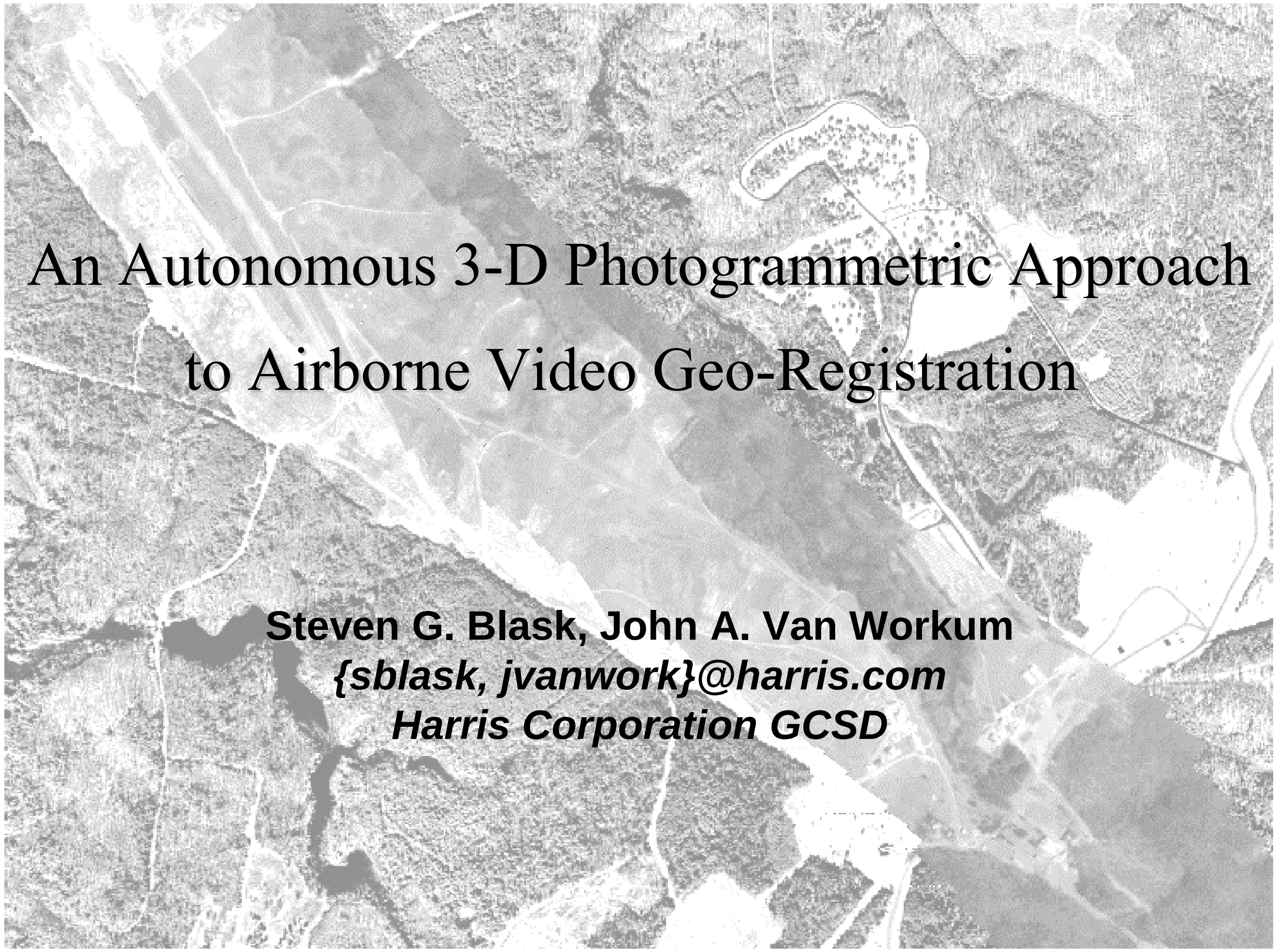
DARPA

HARRIS



An Autonomous 3-D Photogrammetric Approach to Airborne Video Geo-Registration

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Harris Corporation GCSD

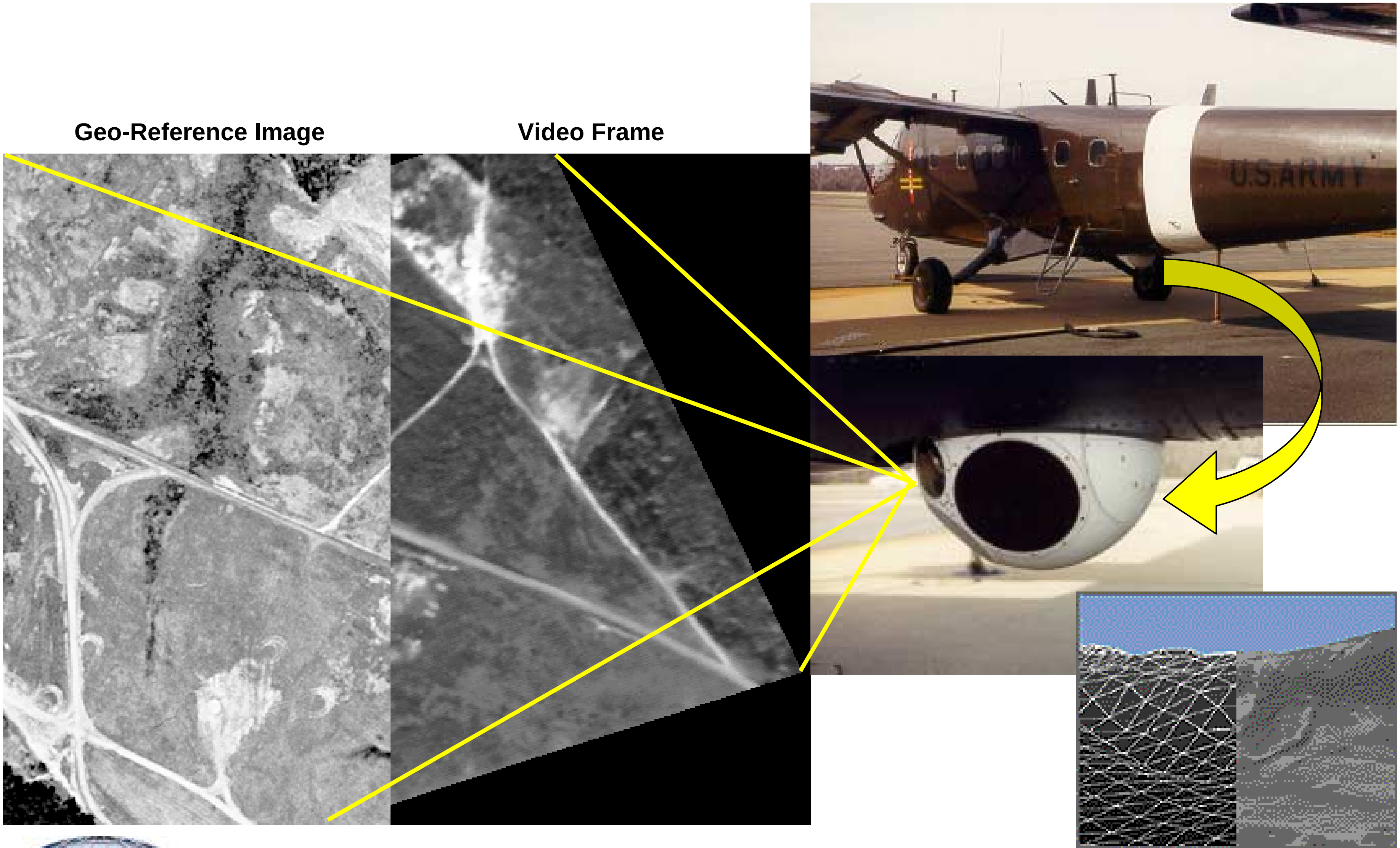
Outline

- Overview of Harris Registration Approach
- Airborne Video Extensions - PVR System
- DARPA AVS-PVR Processing Results
- Discussion

Impact of ESD Errors

Geo-Reference Image

Video Frame



Photogrammetric Model Based Registration Overview

HARRIS

Initial Transformation Process

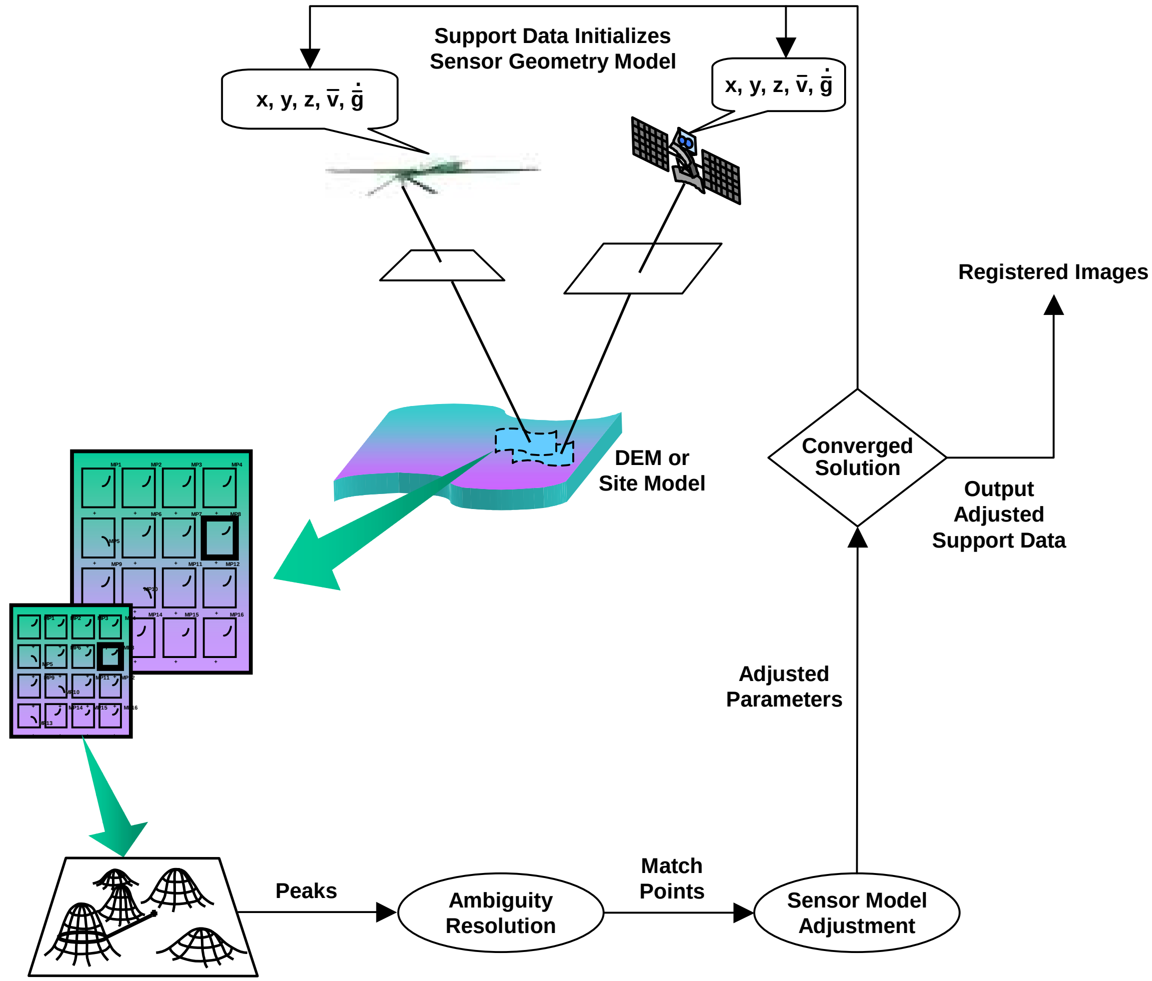
- Image -> 3-D Surface -> 2D View
- Tile Overlap Area in Scene Space
- Build Common Neighborhood Windows

Normalized X-Correlation

- In Enhanced Edge Space
- Build Correlation Surface
- Evaluate Correlation Peaks

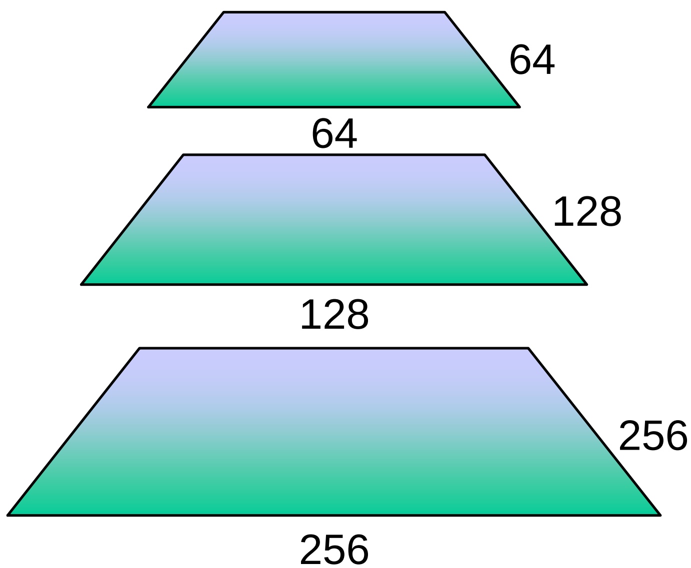
Consistent Subset Analysis

- Compute Mean Offset Vector
- Sequentially Sort Peaks
- Resolve Ambiguities & Outliers
- Adjust Sensor Parameters
- Repeat at Next Resolution Level

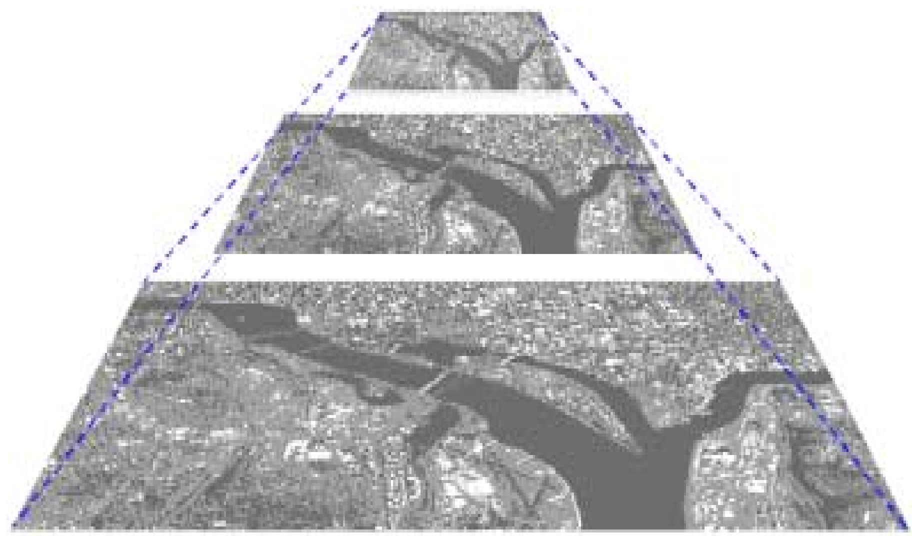


Initial Transformation Process

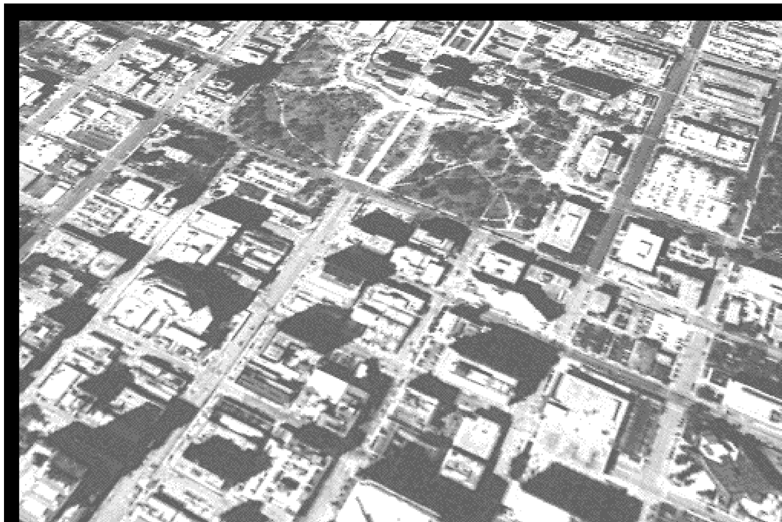
- The images are subsampled to create reduced resolution data sets
- Software resampler creates patches at any required GSD on demand



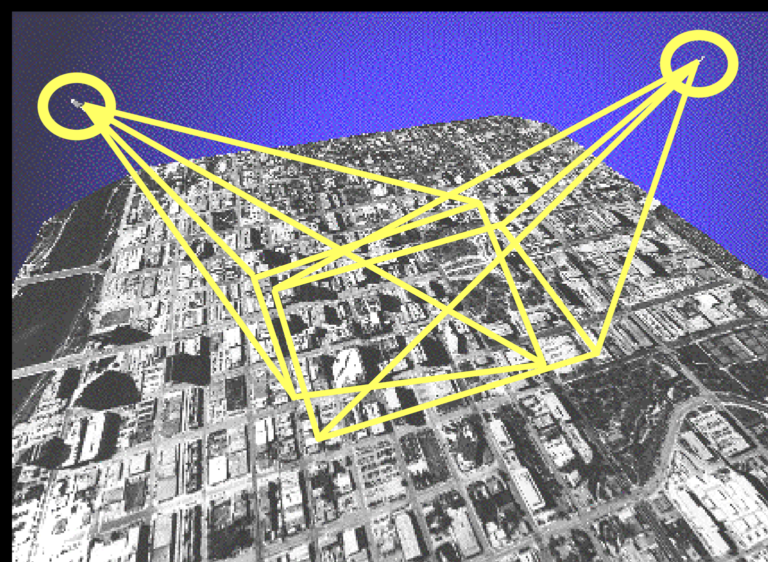
<u>Level</u>
5
.
.
2
1
0



Initial Transformation Process



Sensor 1

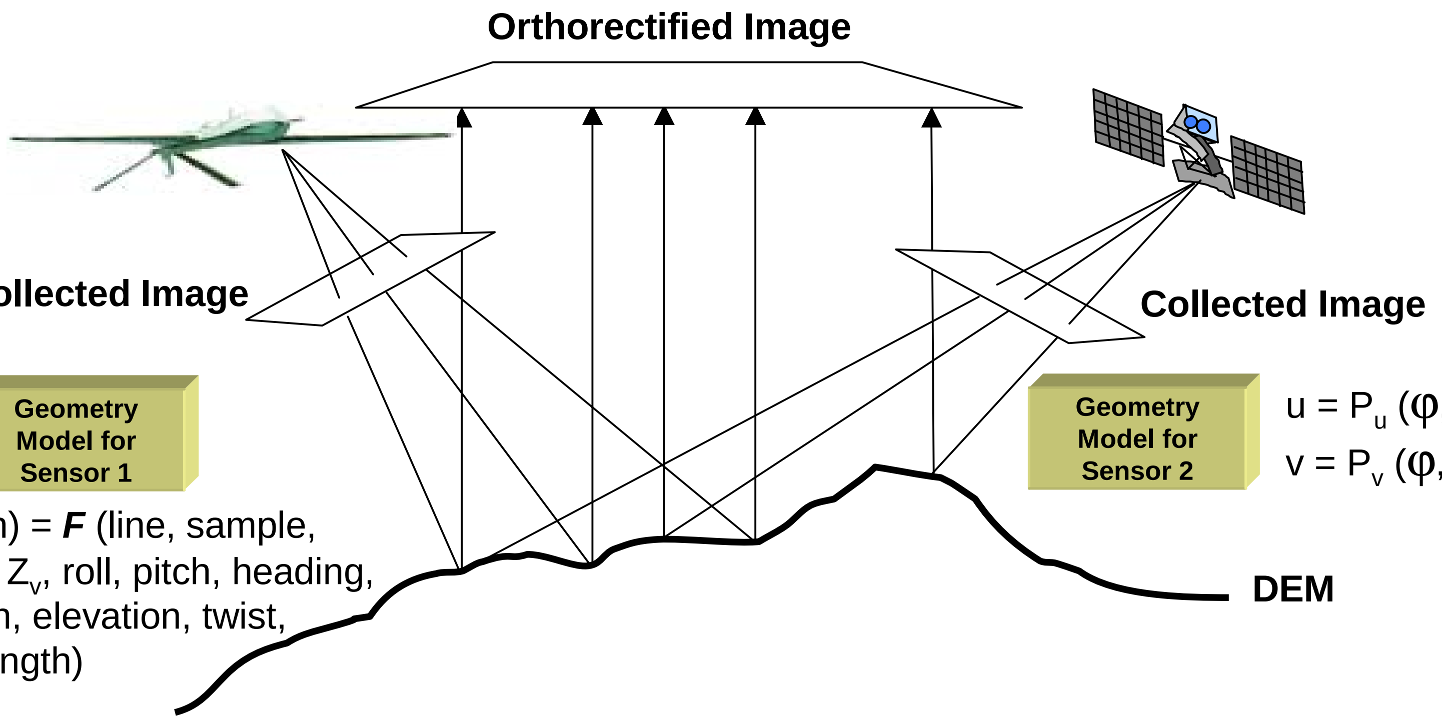


Sensor 2

next level solutions

Initial Transformation Process

- Use *a priori* knowledge of each sensor imaging event and a Digital Elevation Model (DEM) to project imagery to the 3D terrestrial surface



$(\varphi, \lambda, h) = \boldsymbol{F}$ (line, sample, X_v, Y_v, Z_v, roll, pitch, heading, azimuth, elevation, twist, focal length)

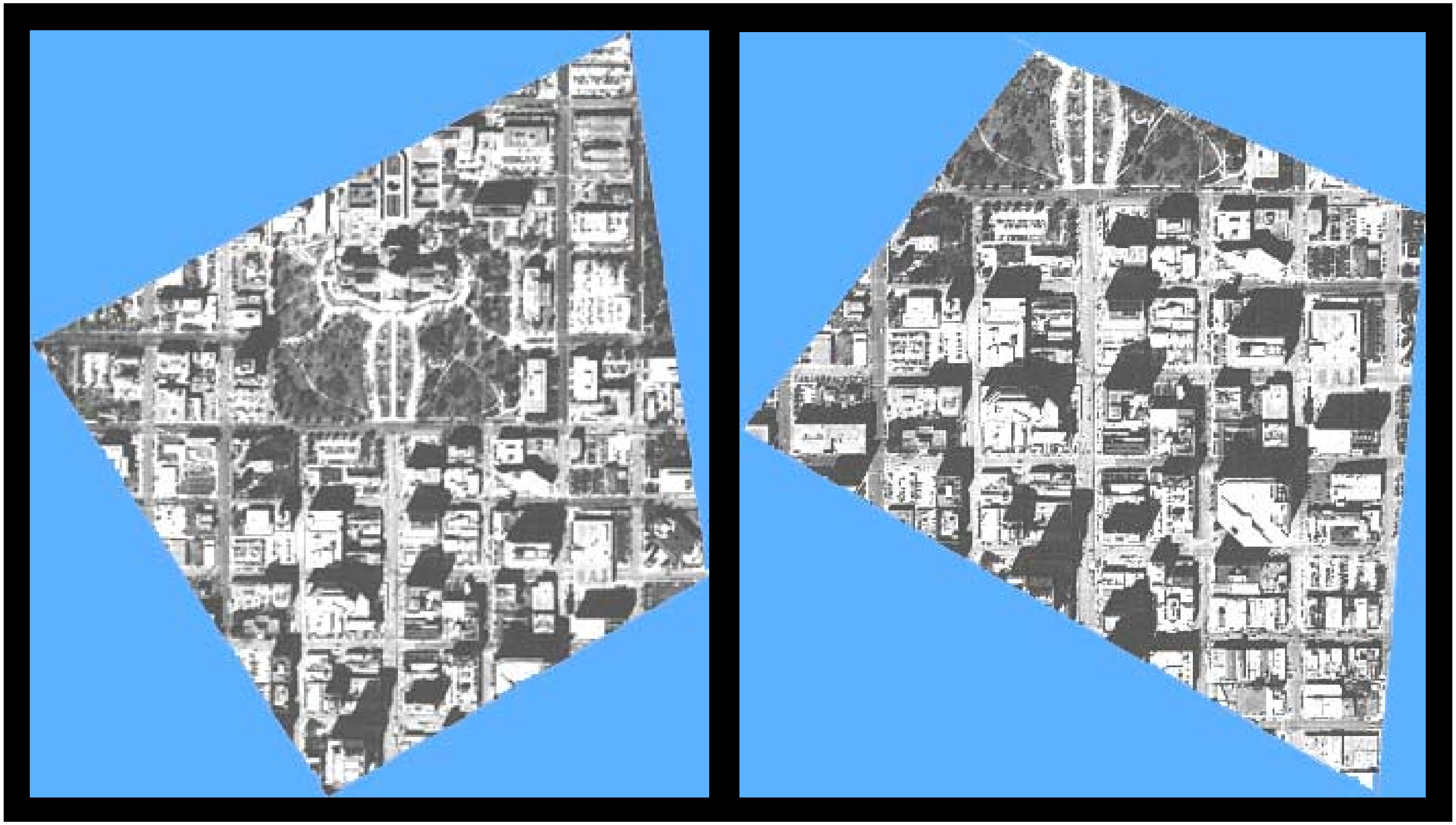
$u = P_u(\varphi, \lambda, h)$

$v = P_v(\varphi, \lambda, h)$

Initial Transformation Process

HARRIS

- Orthorectification places the images in a common orientation with minimal distortion present (unmodelled buildings & trees still layover)



DARPA

Normalized X-Correlation

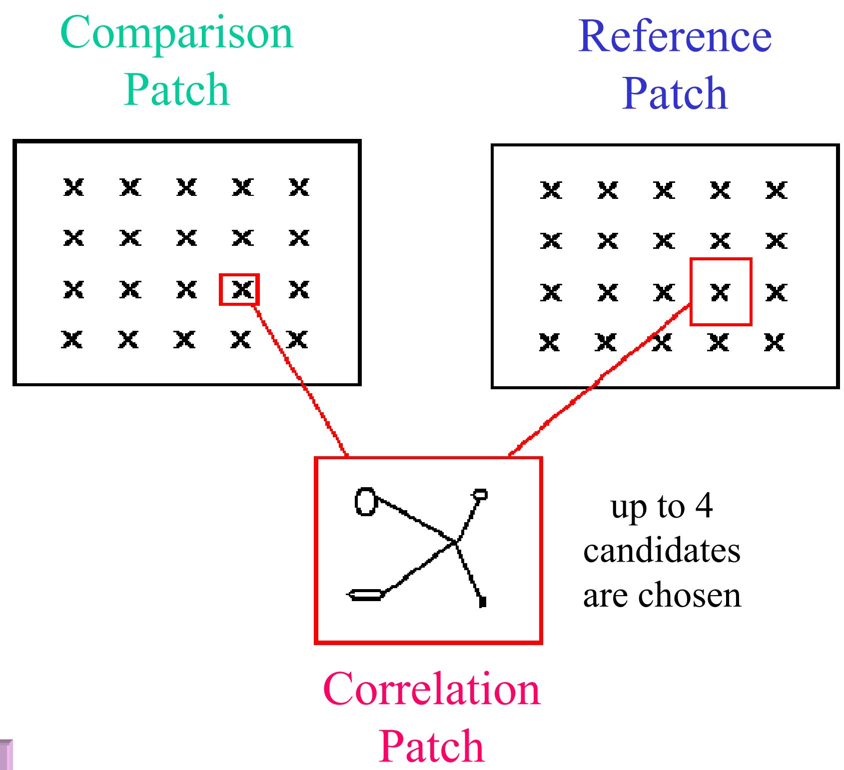
$$r = \sqrt{\frac{N_3}{N_2}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(x_{ij} - \bar{x}\right)y_{ij}}{\sqrt{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}^2 - \frac{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}\right)^2}{N_2}\right)\left(\sum_{i=1}^{n}\sum_{j=1}^{n} y^2{}_{ij} - \frac{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} y_{ij}\right)^2}{N_3}\right)}}$$

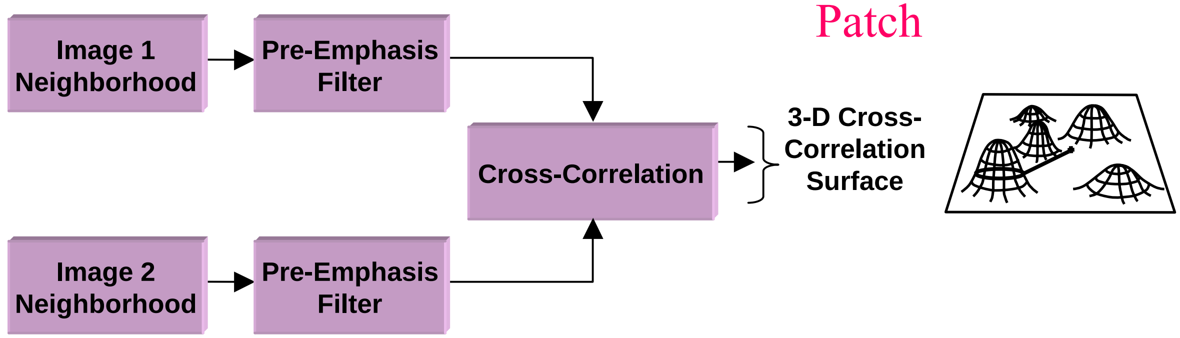
N_3 = # of elements in reference patch

N_2 = # of elements in comparison patch

x_{ij} = elements in comparison patch

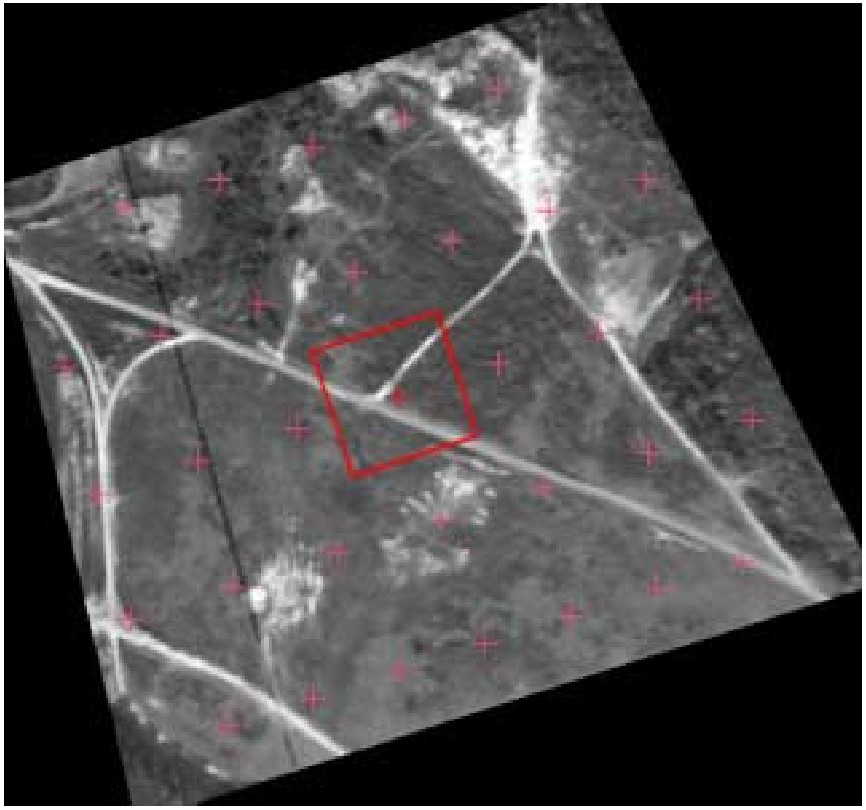
y_{ij} = elements in reference patch



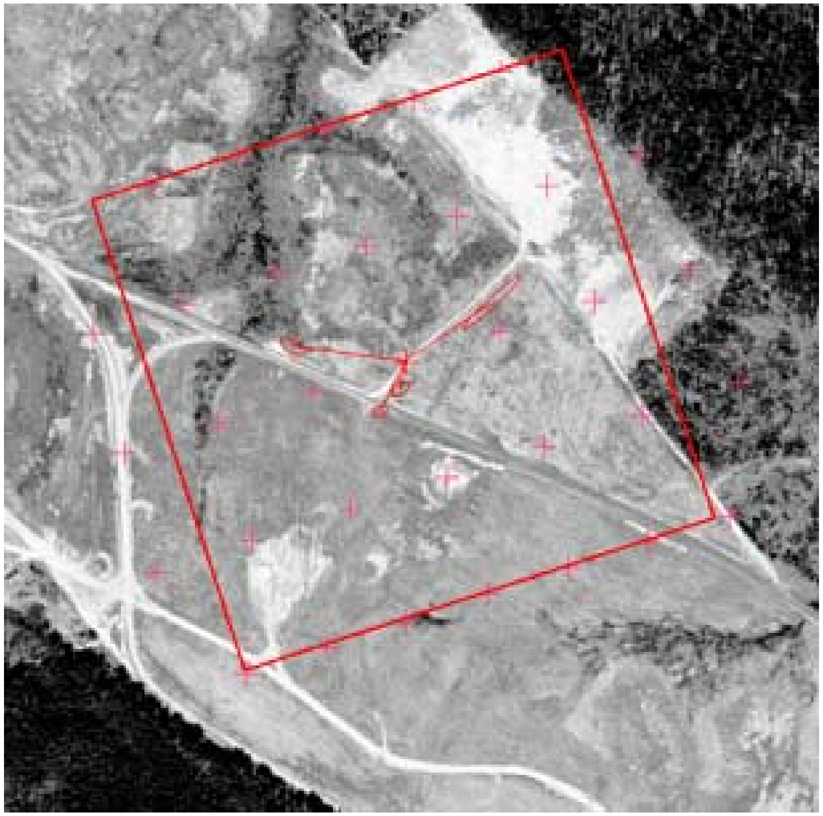


Matchpoint Display

Video Mission Image

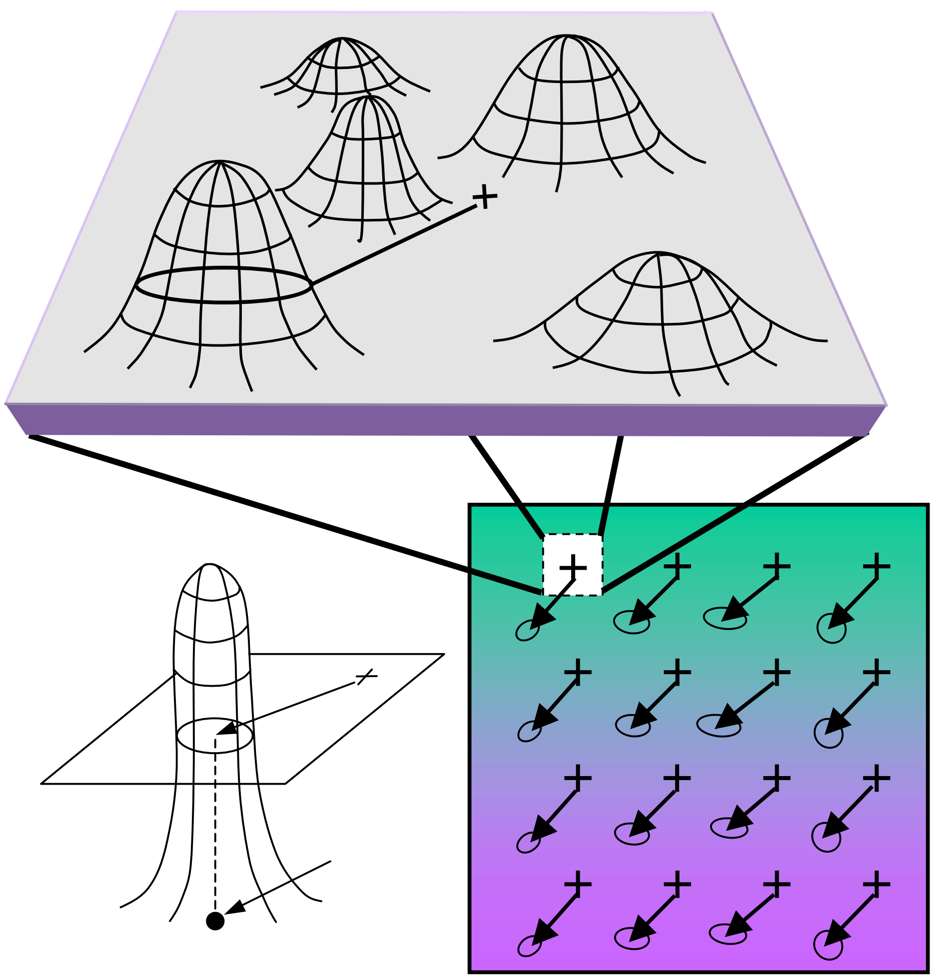


Geo-Reference Imagery



Estimate of Misalignment

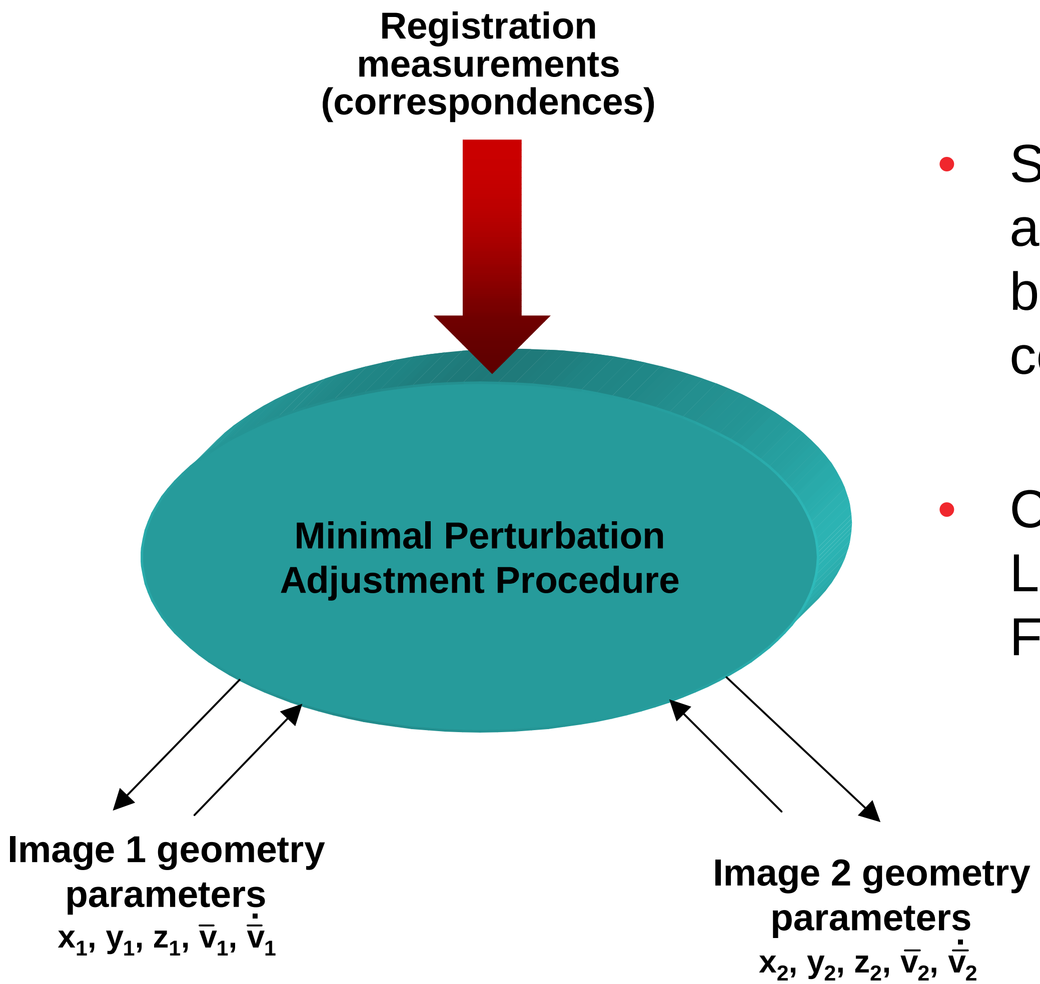
HARRIS



- Multiple correlation peaks are computed for each grid point neighborhood
- A parametric hill finder is used to evaluate each peak
- The mean and standard deviation of registration error are calculated from the offset and average ellipse
- The best consistent subset of correlation peaks is chosen by sequential sorting
- Offset vectors imply global ground “correction” needed to improve registration, wild pt. editing eliminates outliers

Sensor Adjustment Process

HARRIS



- Sensor parameters are adjusted to minimize the error between ground projections of common match points
- Conjugate Gradient Search, Least Squares, and Kalman Filter adjustment algorithms

Output & Derivative Products

- **Improved telemetry used by Geolocation & Mosaic**
  - Telemetry parameters initialize sensor model to define a 3D ray through any pixel in the image, which may be intersected with the DEM to produce a geolocation or orthorectify a video frame.

  - By improving telemetry, we improve geodetic accuracy of pixels.

Registration Solution

- Advantage of model-based approach: can perform rigorous error propagation to characterize geopositioning solutions and provide *a posteriori* error covariances for adjusted sensor model params

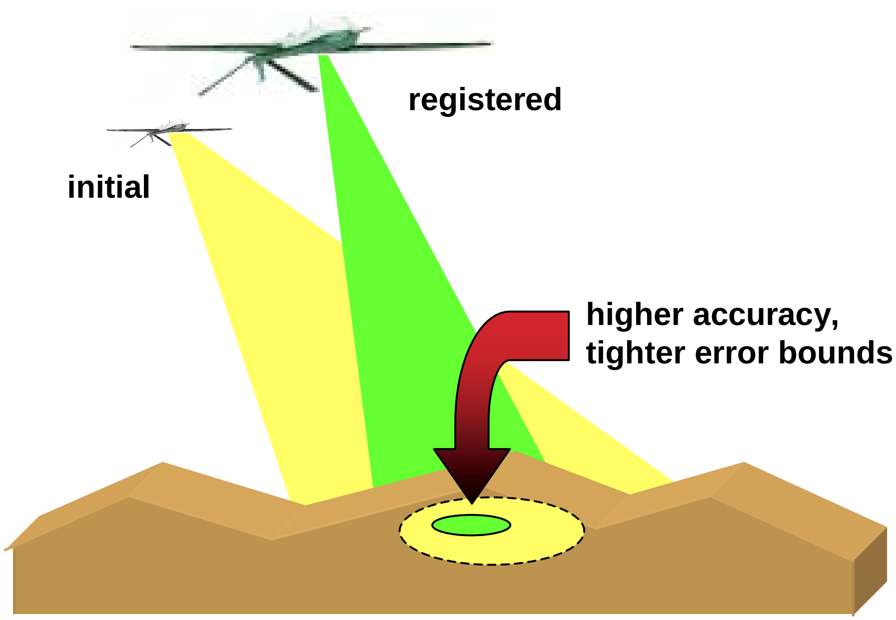
$$e = \sqrt{\left[\left(\frac{\partial f}{\partial x_1}\right)^2 \cdot \sigma_1^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 \cdot \sigma_2^2 + \ldots + \left(\frac{\partial f}{\partial x_n}\right)^2 \cdot \sigma_n^2\right]}$$

$x_1, x_2, \ldots x_n$ represents the parameters

$\sigma_1, \sigma_2, \ldots \sigma_n$ represents the variances of x_i

f represents the function of the parameters

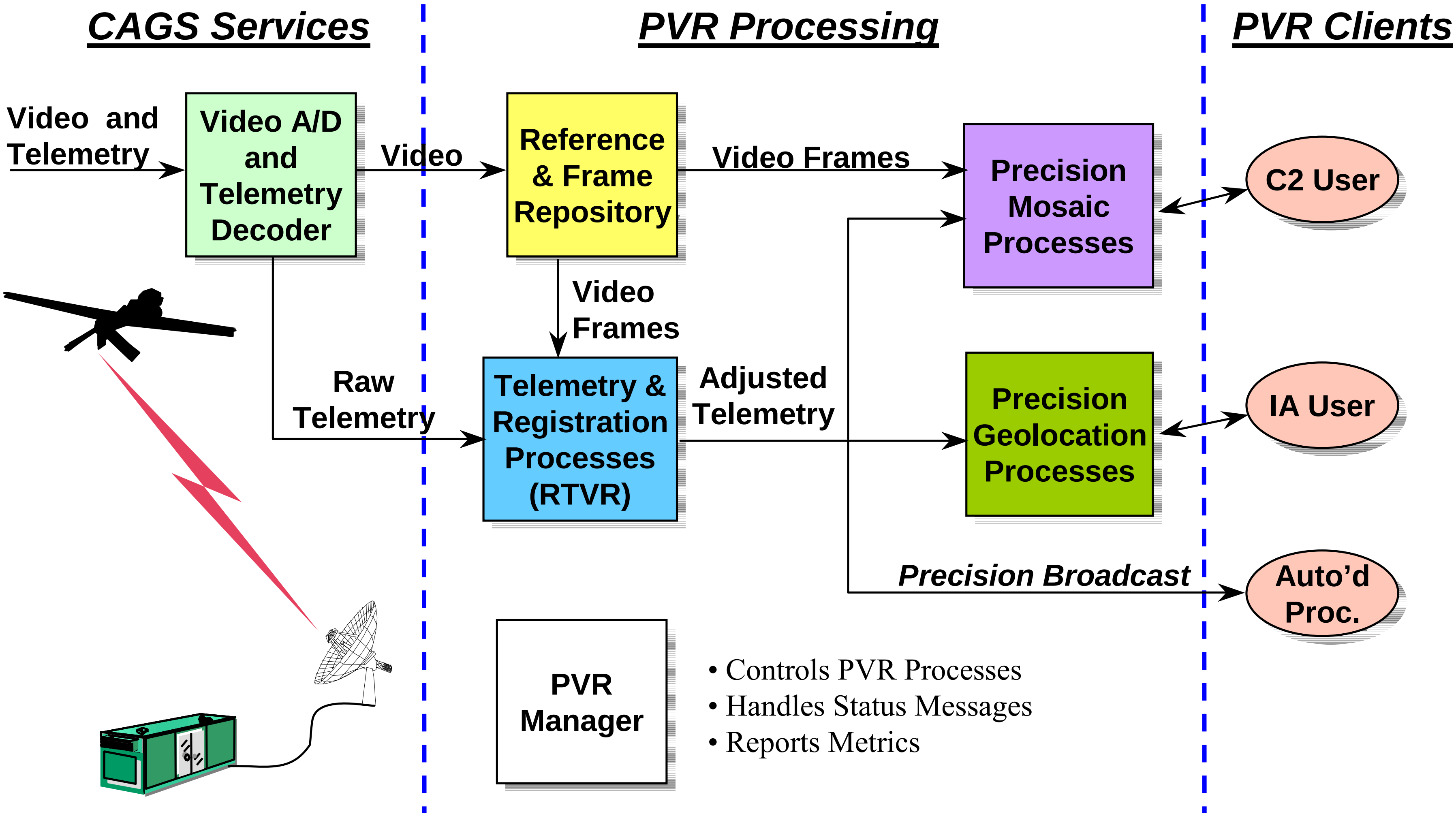
Registered Sensor 1 & Sensor 2



Airborne Video Extensions

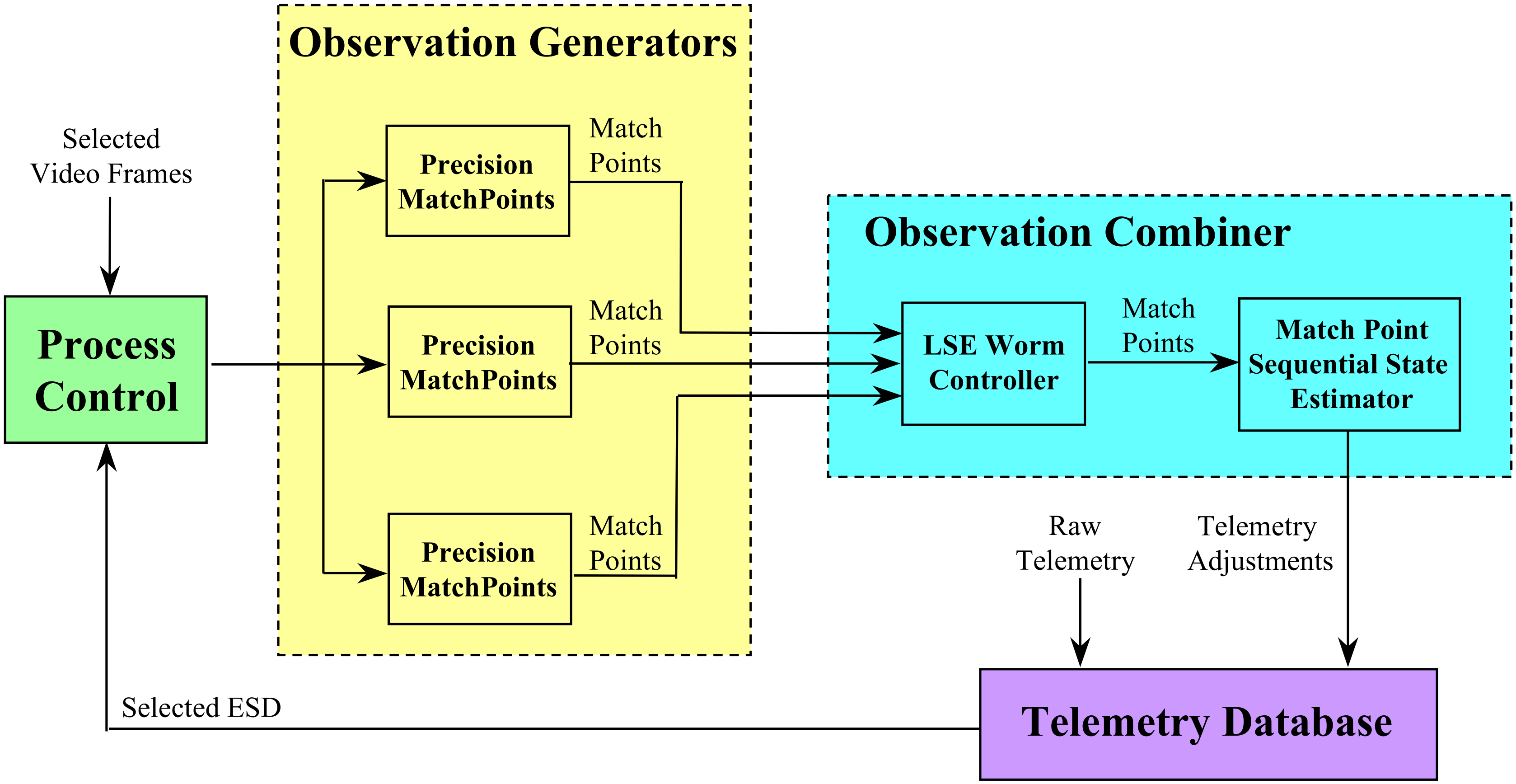
Precision Video Registration System

PVR Architecture

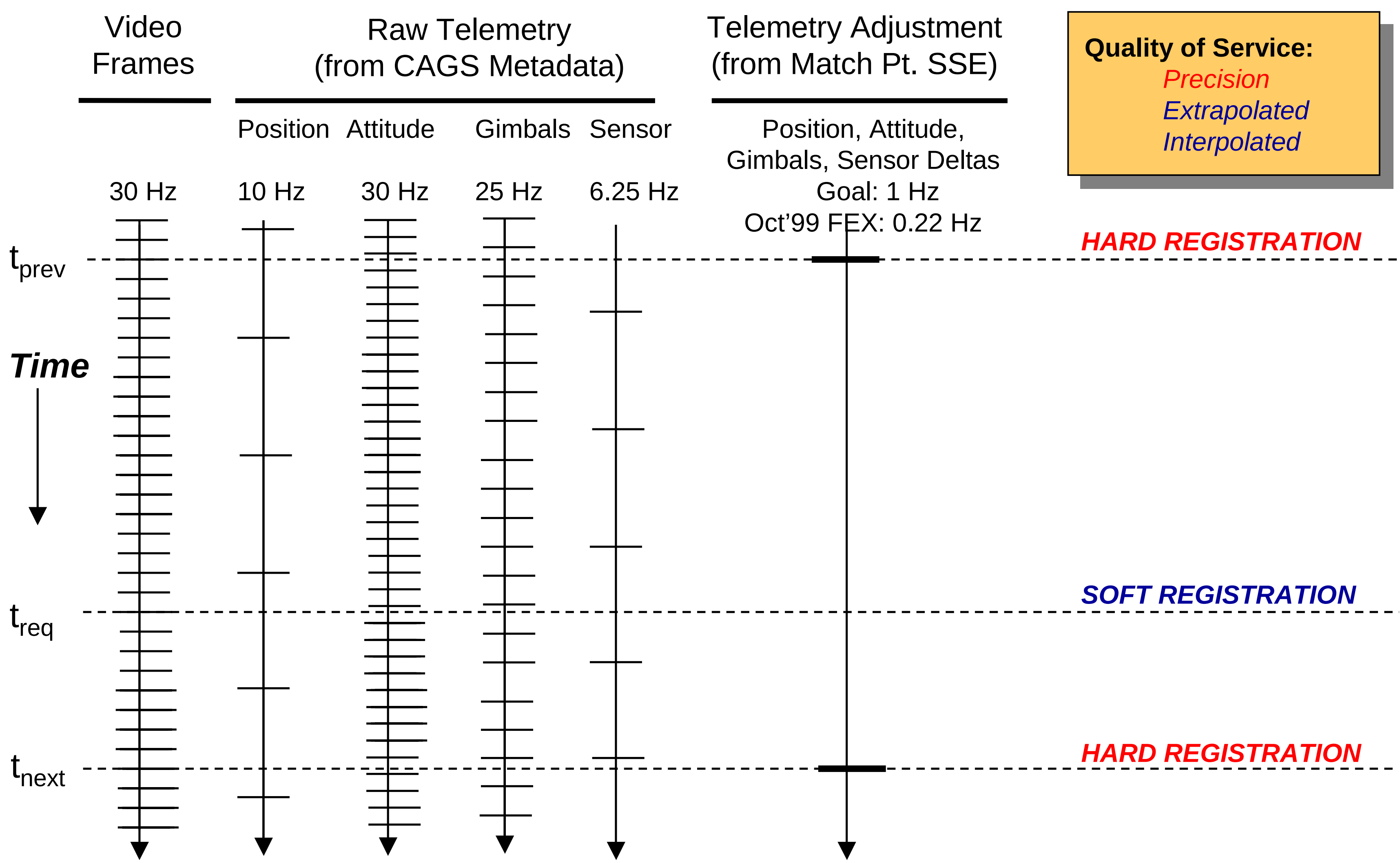


- Controls PVR Processes
- Handles Status Messages
- Reports Metrics

RTVR Architecture

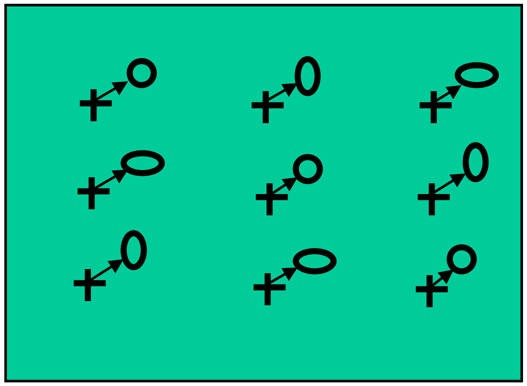


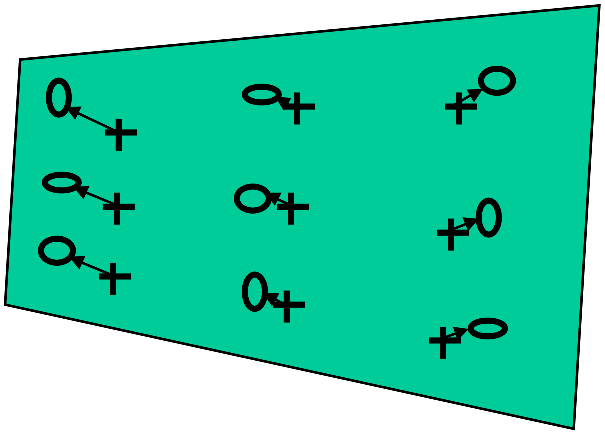
Telemetry Queue/Database

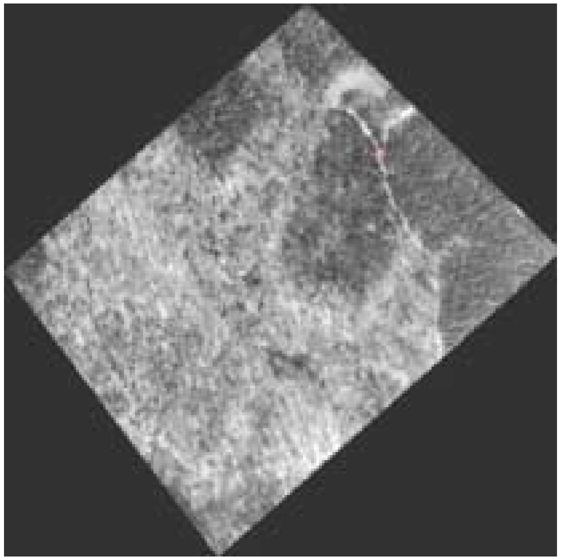


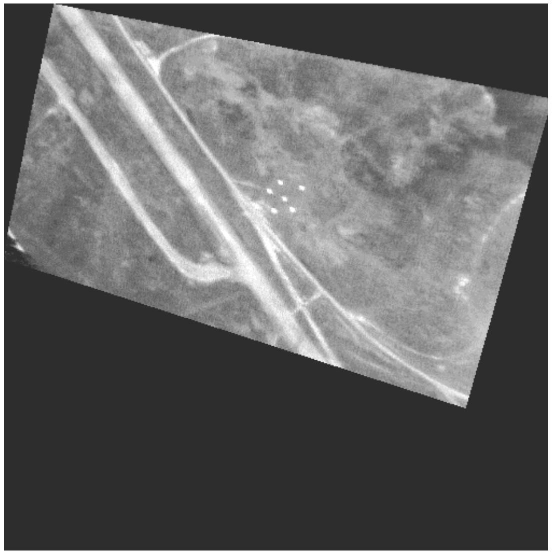
Affine Consistent Subset

- Required to account for scale and rotation distortion

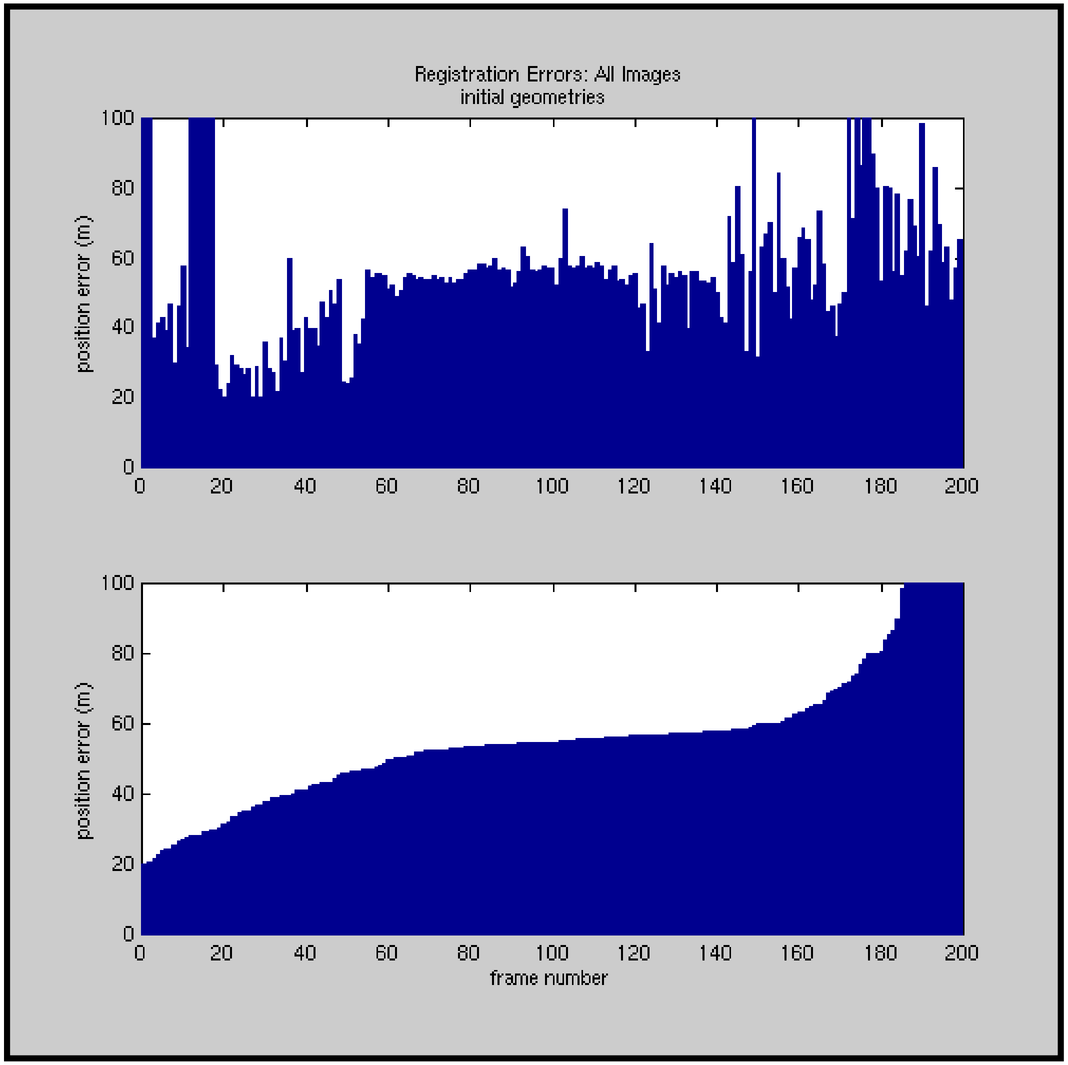








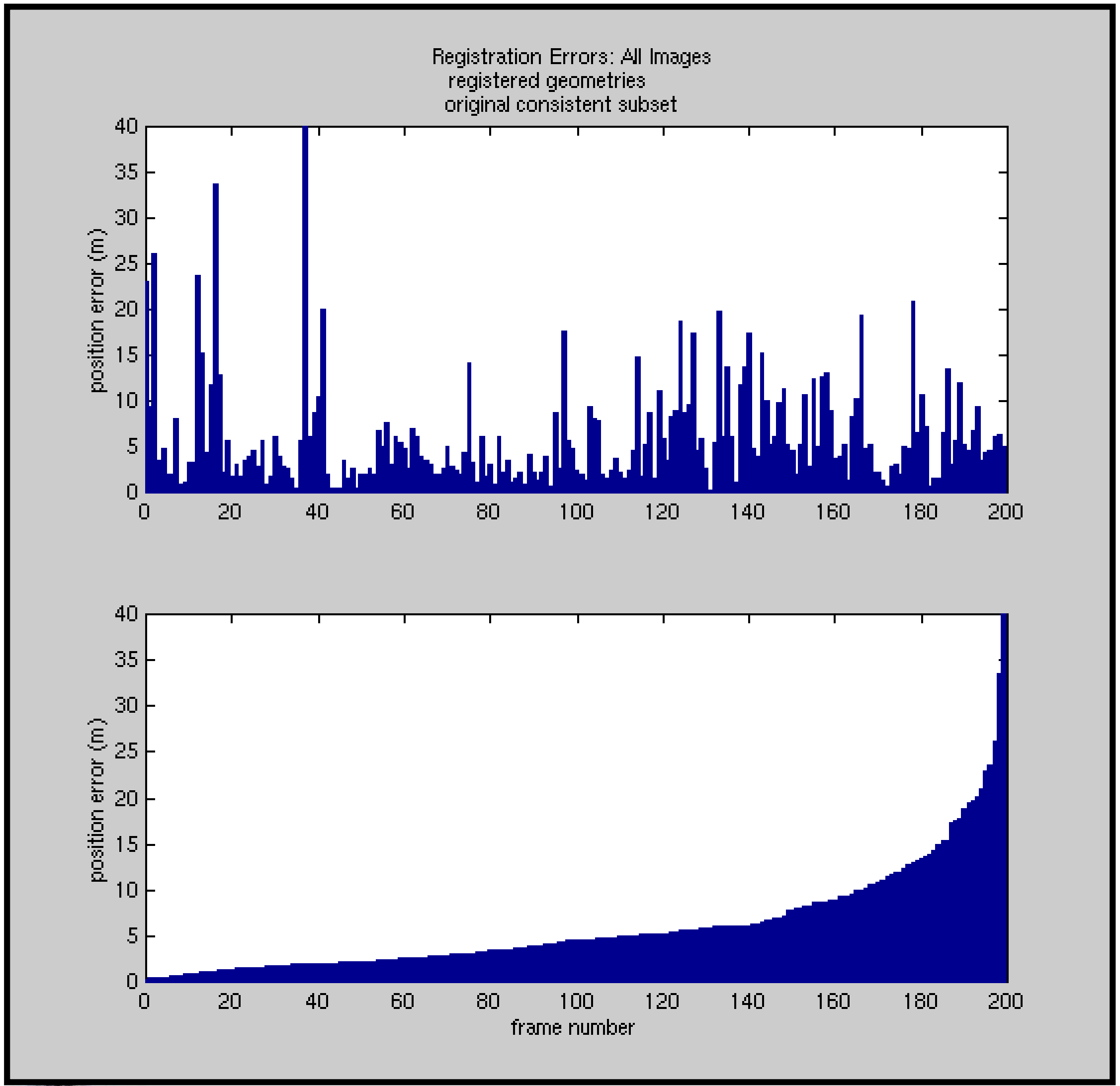
200 Unregistered Frames



Selected frames from (in order) 1 hour, sparse features, class1, and class2 data sets, 29Mar99.

Raw telemetry errors in ascending order.

Original CSS Results

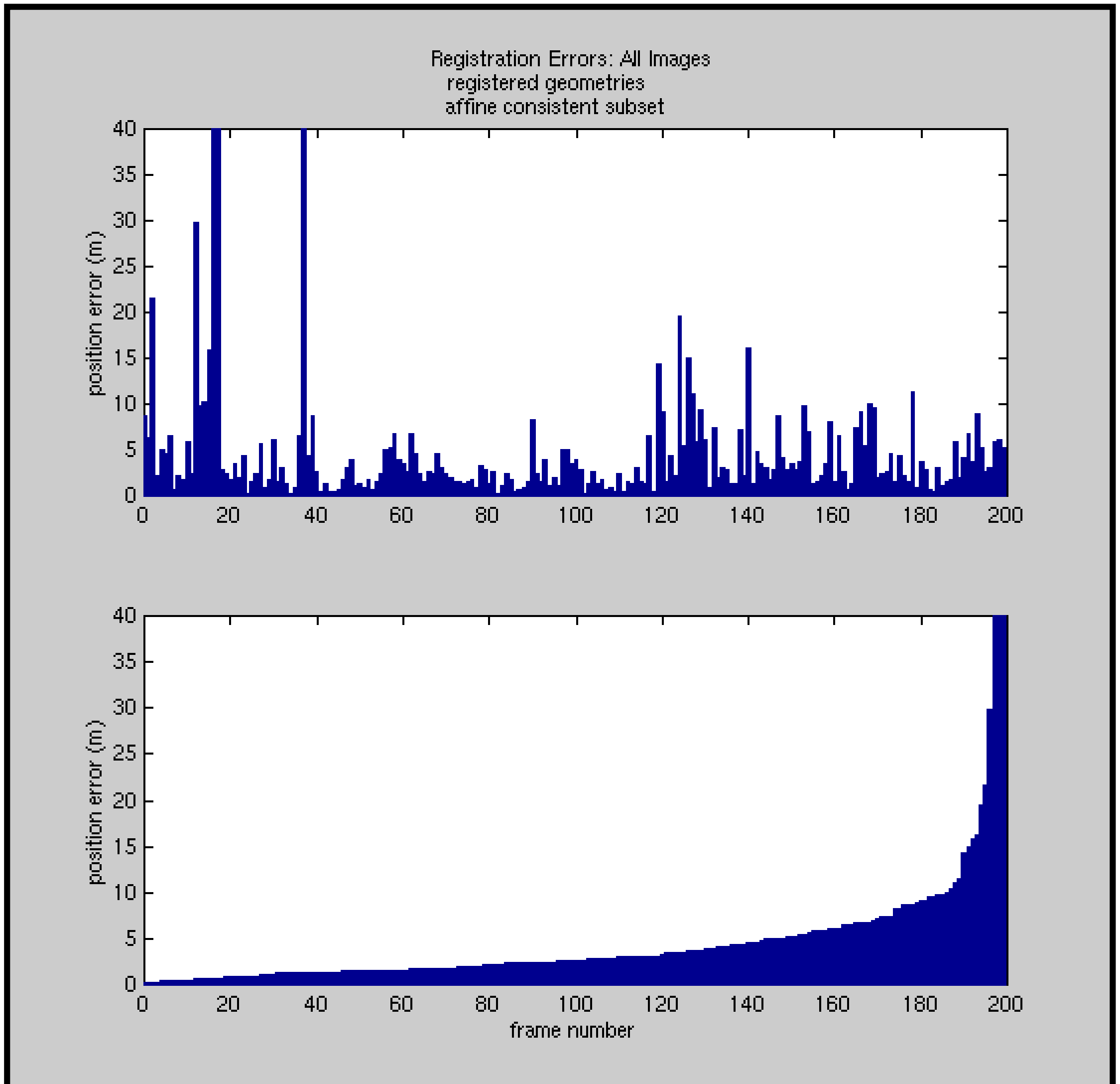


Selected frames from (in order) 1 hour, sparse features, class1, and class2 data sets, 29Mar99.

Outliers due to fuselage obscuration and low elevation angles

Registration errors for original consistent subset criterion in ascending order.

Affine CSS Results



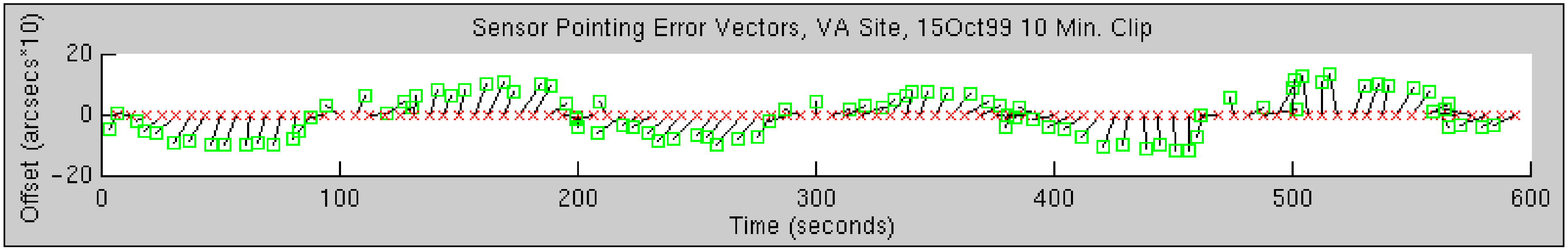
Selected frames from (in order) 1 hour, sparse features, class1, and class2 data sets, 29Mar99.

Outliers due to fuselage obscuration and extremely low low elevation angles (17-20 deg)

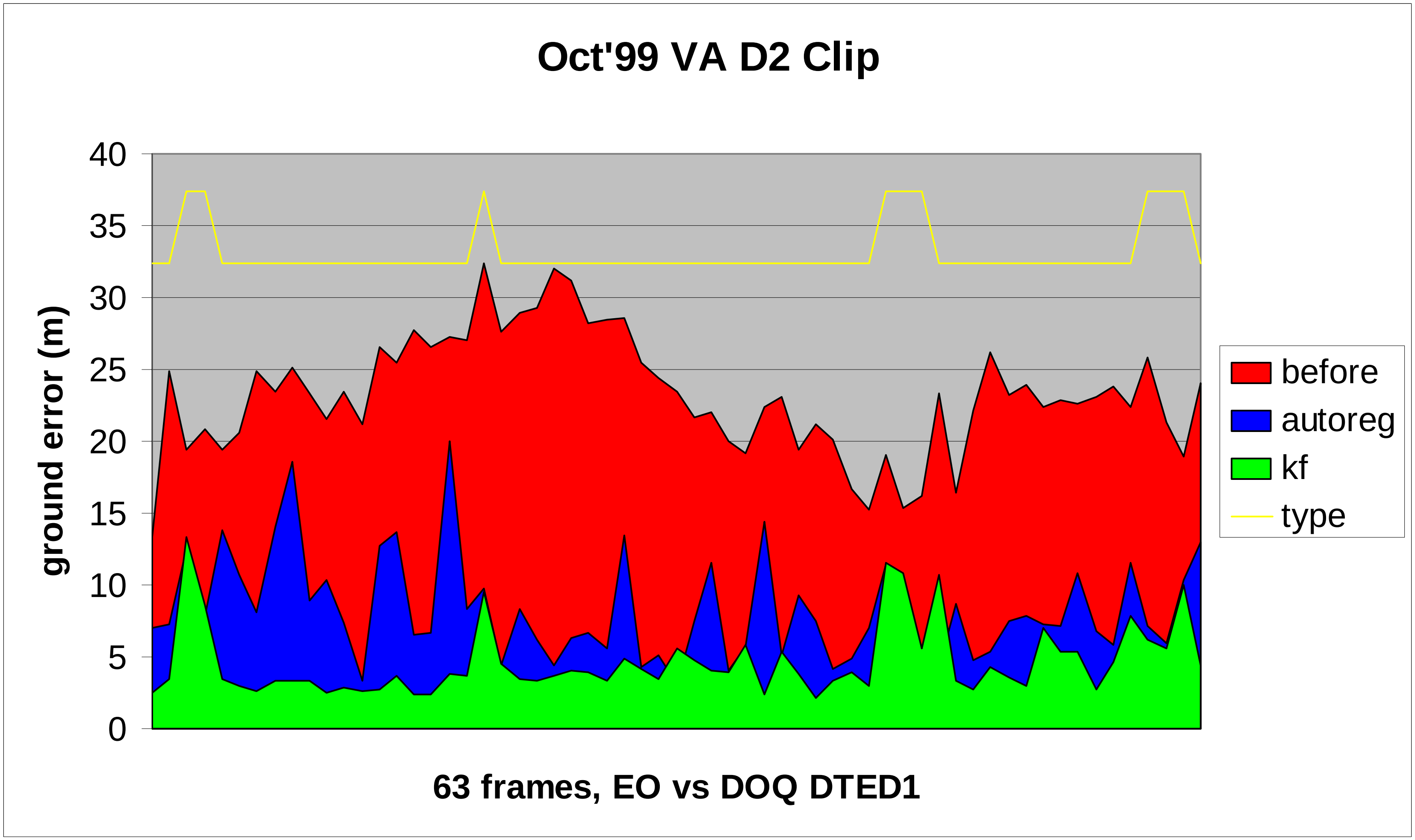
Registration errors for affine consistent subset criterion in ascending order.

KF Adjustment Algorithm

- Sparse scene content of Airborne video requires accumulation of match points over space and time
- Kalman filter adjustment vs. N-frame co-registration
  - Adds one image at a time to solution
  - Only need to estimate parameters for one image
  - Smaller set of equations
  - No waiting for additional images
- State vector **X** models *adjustments* to telemetry; slowly varying bias suggests constant state model is suitable:

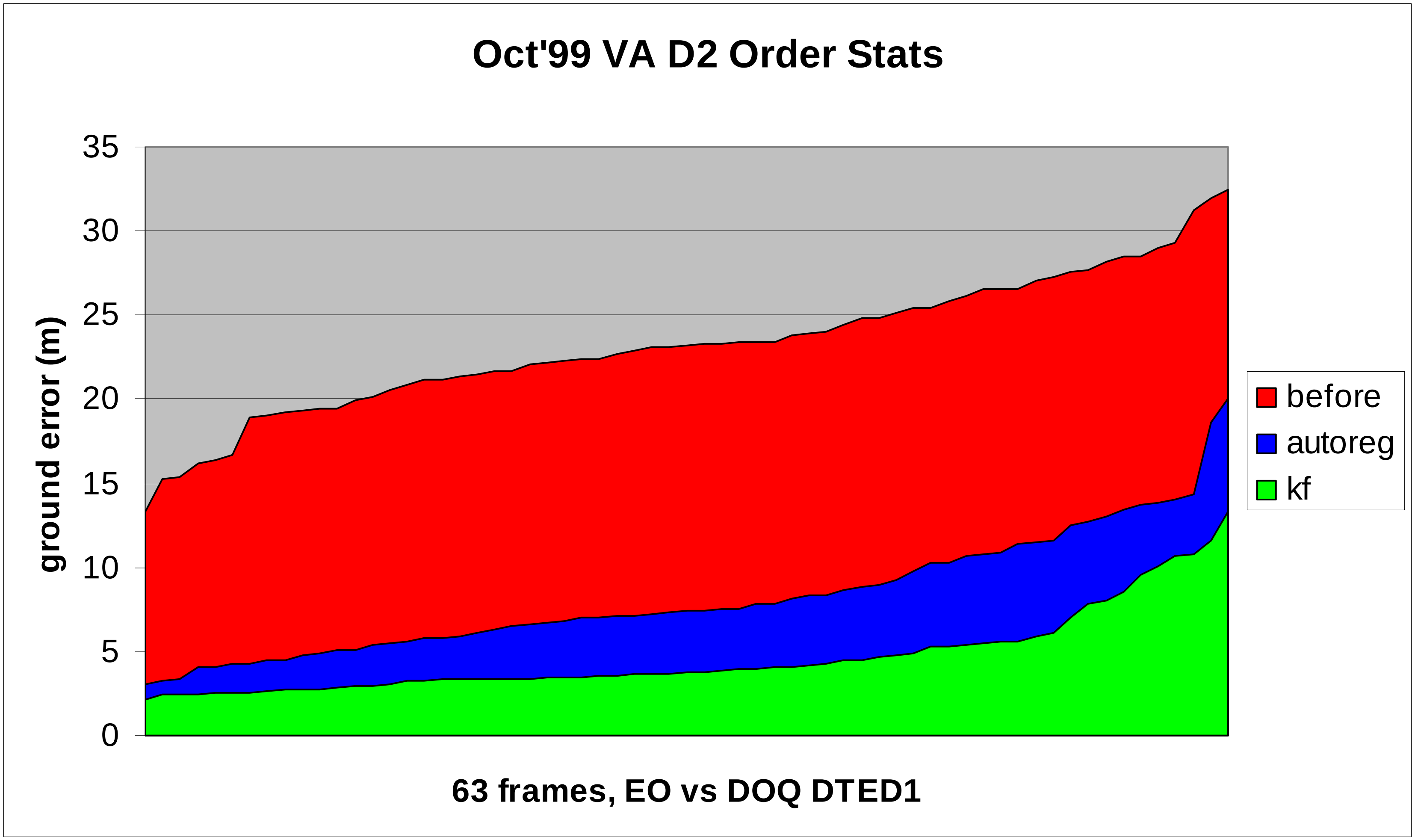


KF vs. Single Frame Results

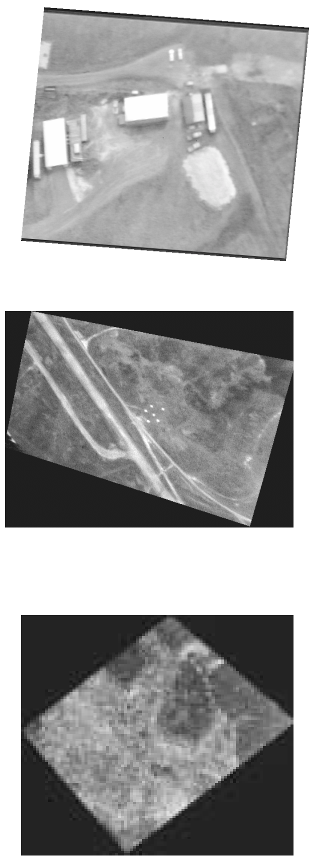


kf:	median:	3.80	90th:	8.44	mean:	4.70	std dev:	2.50	<10m:	93.3%
autoreg:	median:	7.44	90th:	13.33	mean:	8.27	std dev:	3.62	<10m:	71.6%
before:	median:	23.25	90th:	28.43	mean:	23.24	std dev:	4.08	<10m:	0.0%

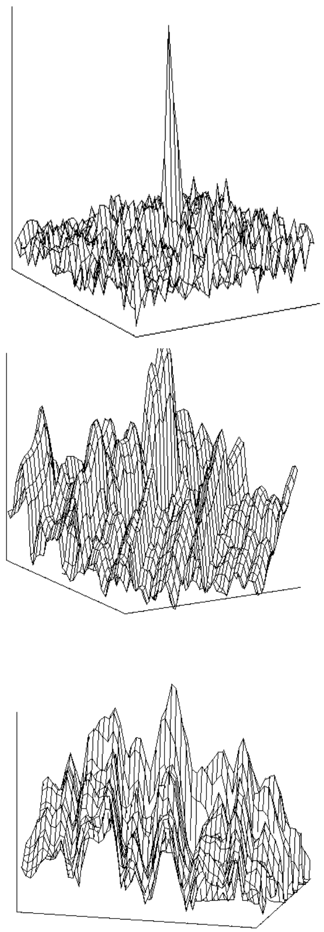
KF vs. Single Frame Results



Scene Content & Prescreener



Scene content examples



Strong Peak

Ridges

Weak Peaks

Correlation surface examples

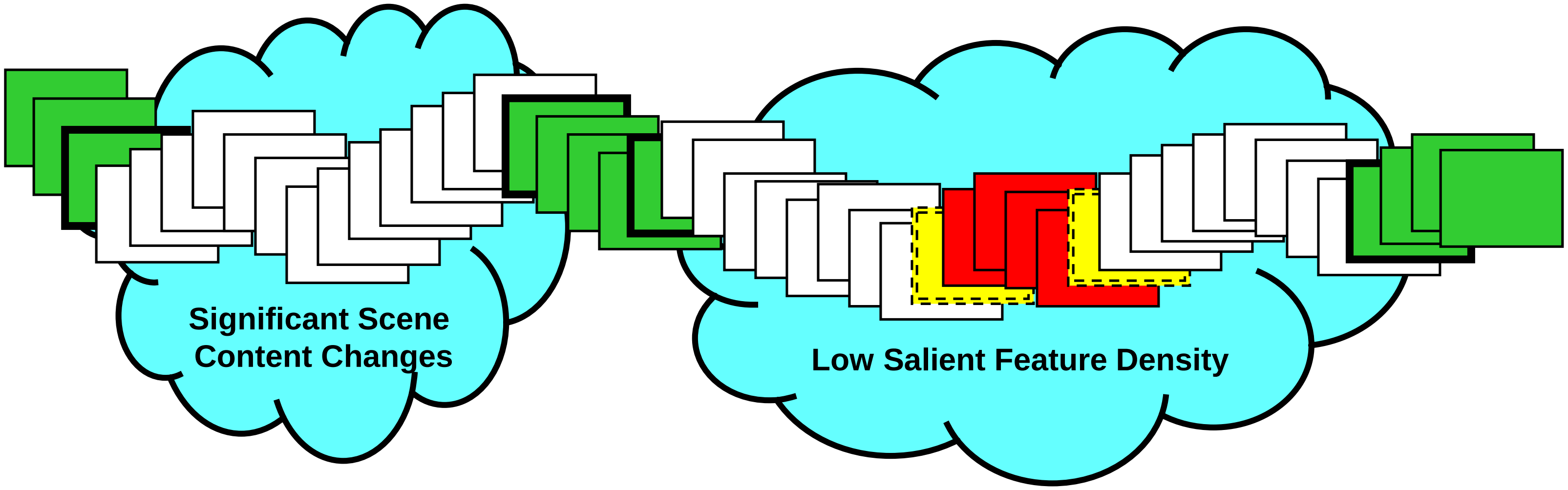
- Compute MPt normalized image space residuals:

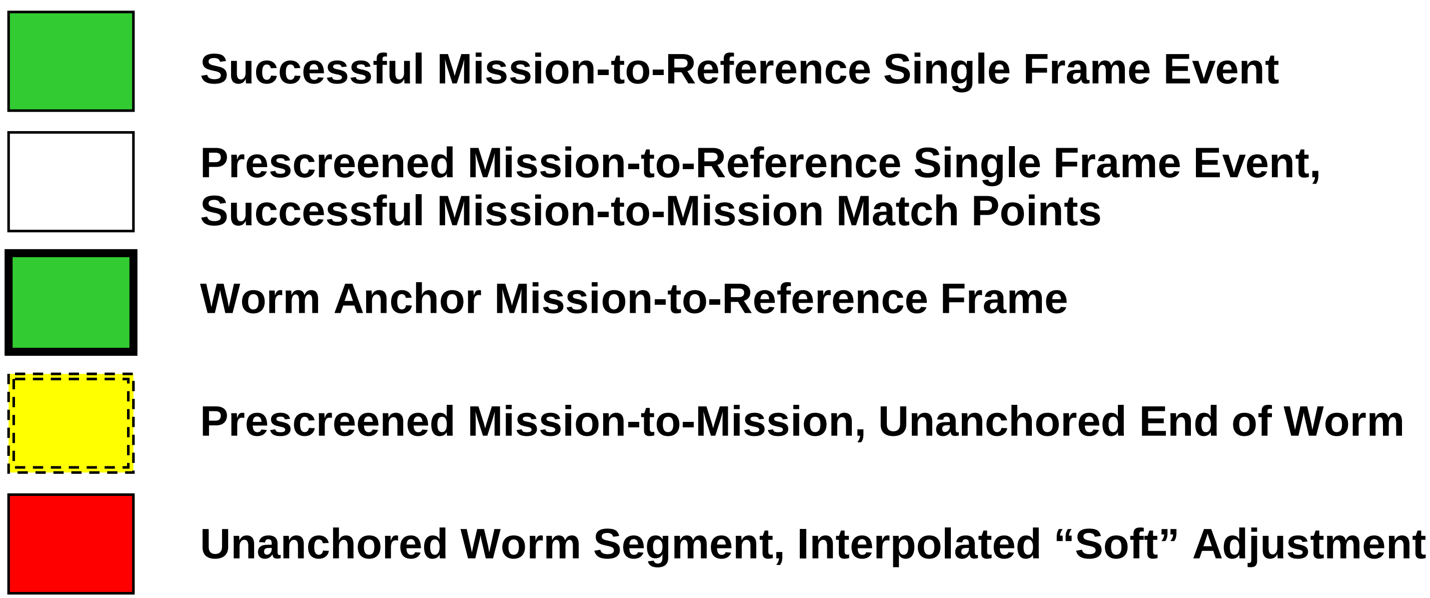
$$\rho = \boldsymbol{\varepsilon}^{T}\Sigma^{-1}\boldsymbol{\varepsilon}$$

$$\boldsymbol{\varepsilon} = \begin{bmatrix} y_1 - x_1 \\ y_2 - x_2 \end{bmatrix}$$

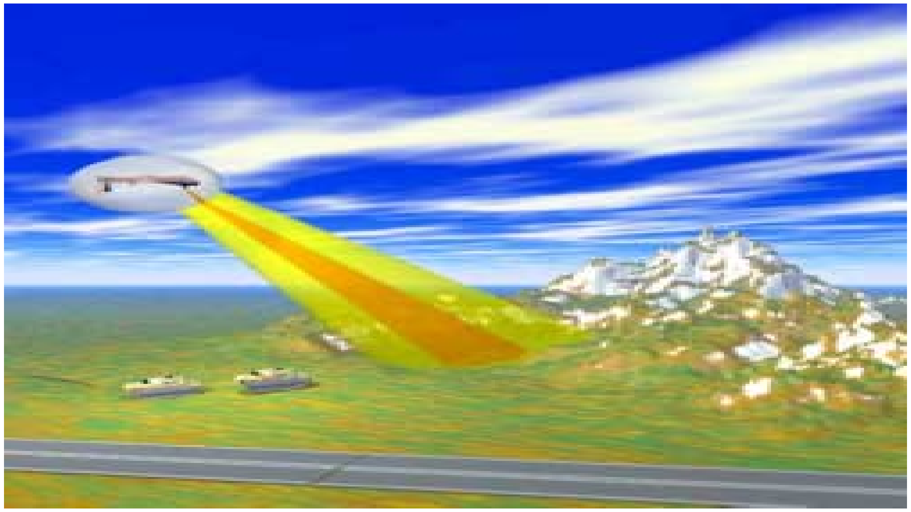
- Apply thresholds
  – min. no. match points
    - 9 for frame-to-mono ref.
    - 5 for frame-to-stereo ref.
    - 4 for frame-to-frame
  – avg. norm. res. ≤ 1 pixel
  – max. norm. res. ≤ 2 pixels

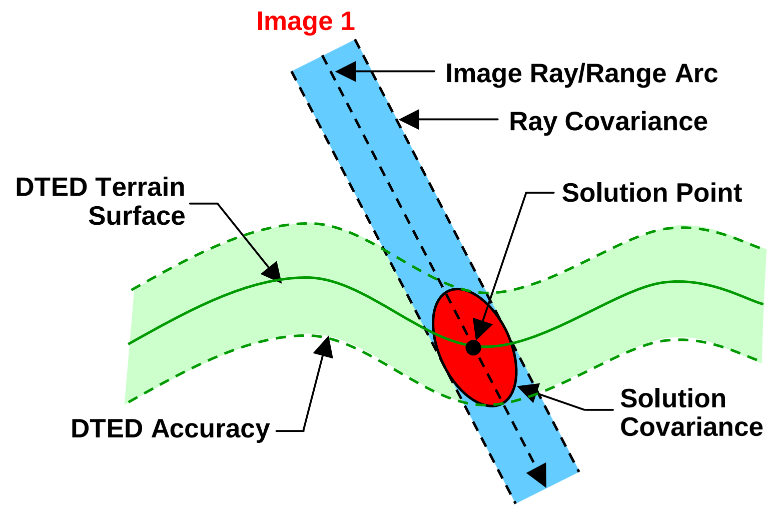
Dynamic Video Worm

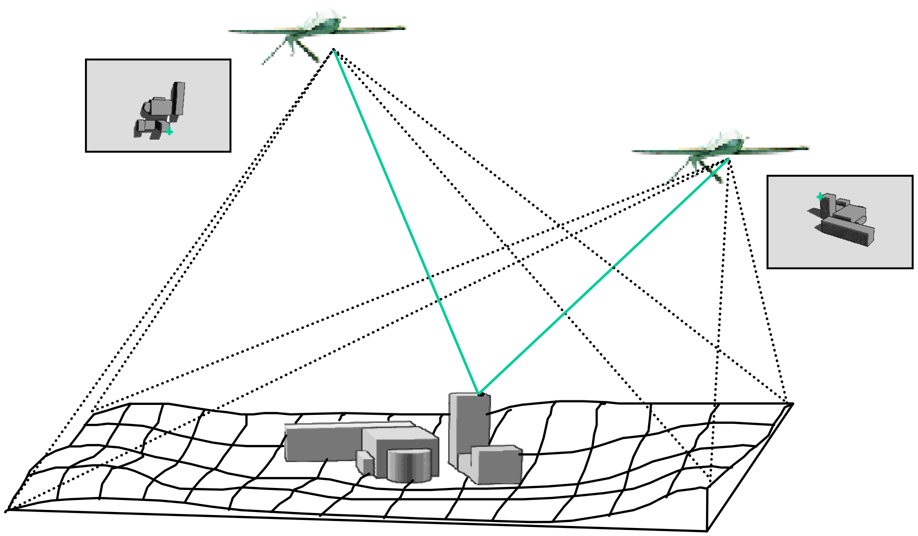




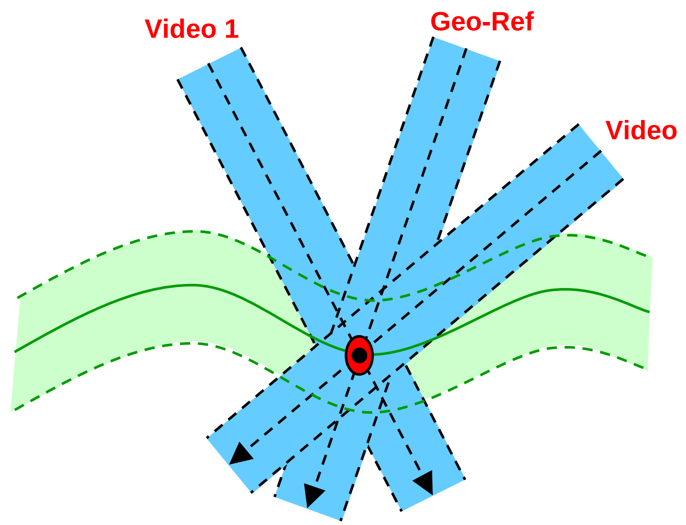
Further Accuracy Improvement







Geometry effects



PVR Georegistration Performance Using DOQ & DTED

Dynamic Worm

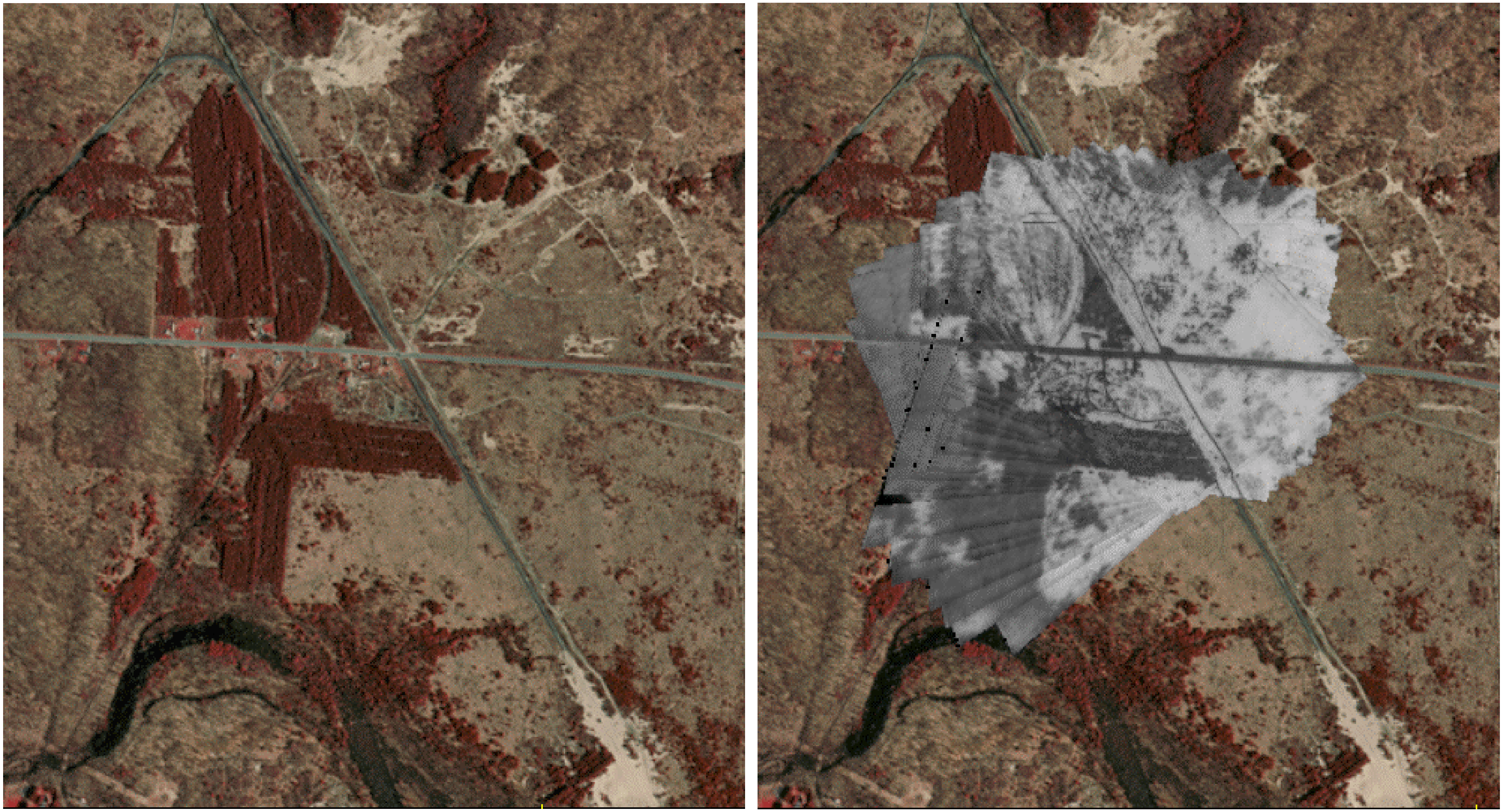
(LSE, KF, & Prescreener)

DOQ Timing

- Reference Data
  - USGS Digital Ortho Quarter-Quad (1m GSD)
  - NIMA Digital Terrain Elevation Data (100m posts)

- Timing Data
  - SGI Octane
  - Dual 225MHz R10,000 cpu’s
  - 512Mb RAM total
  - Controller, Generator, Worm Combiner thread

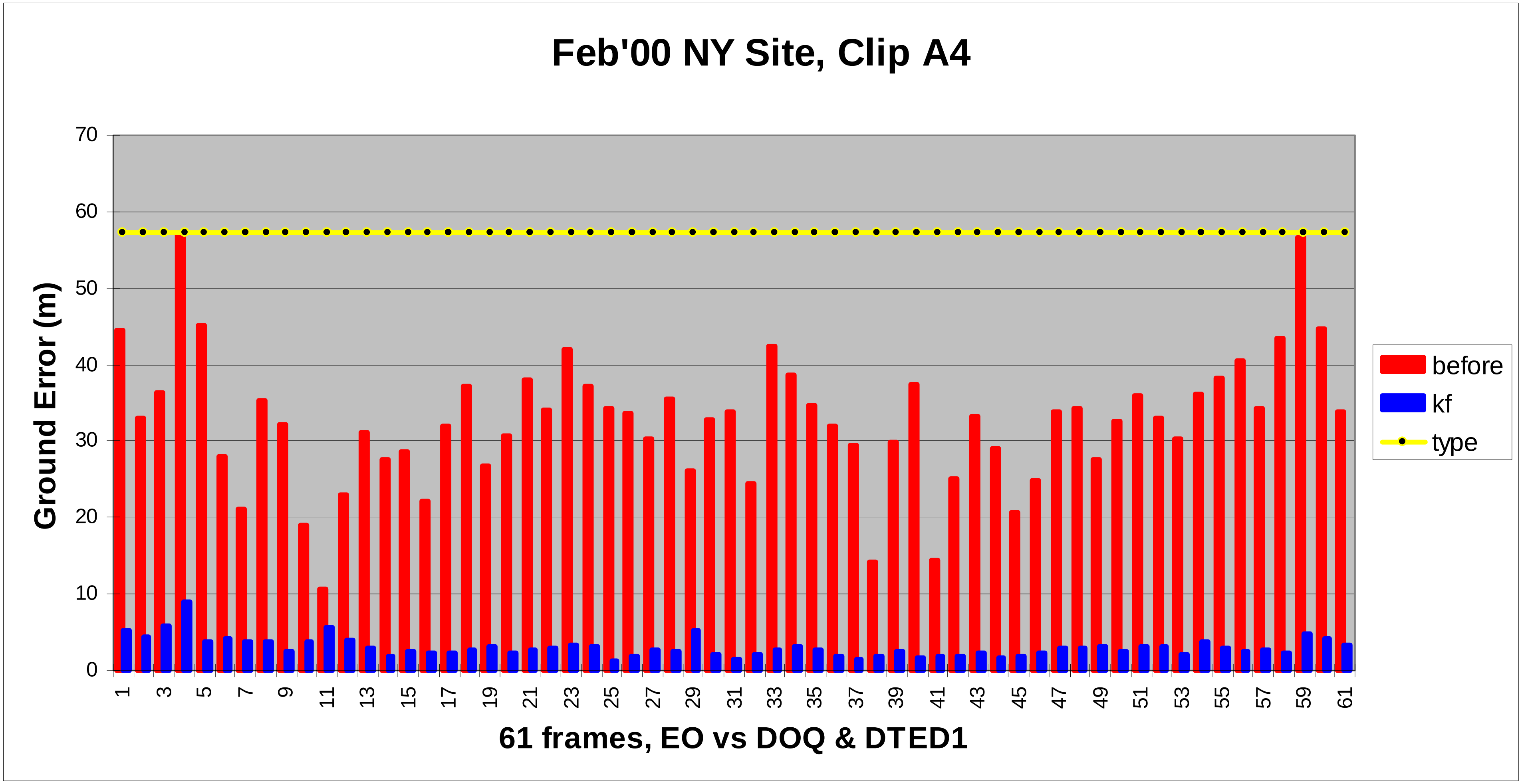
NY Intersection Circle Stare



13 July 2001

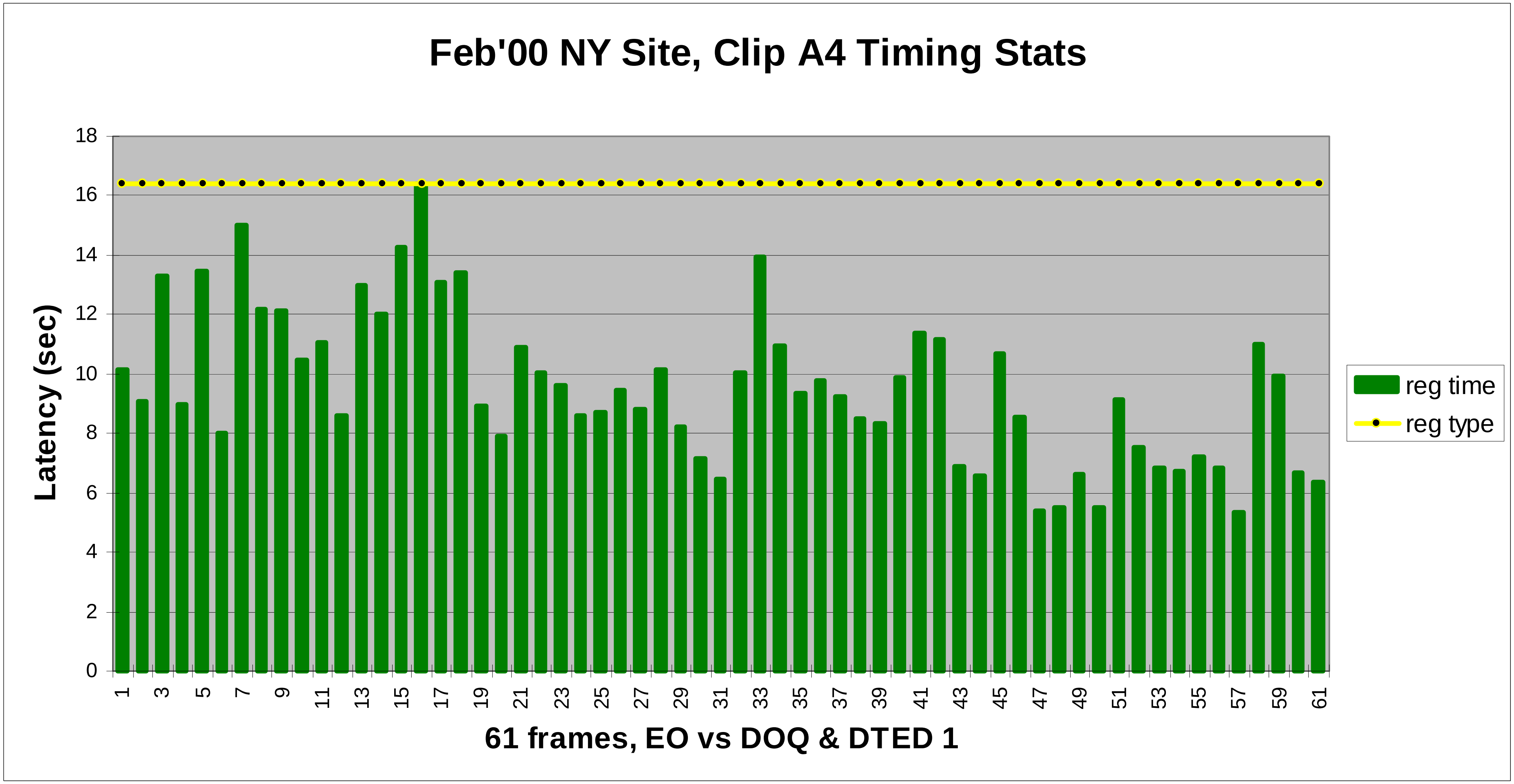
next level solutions

NY Intersection Circle Stare



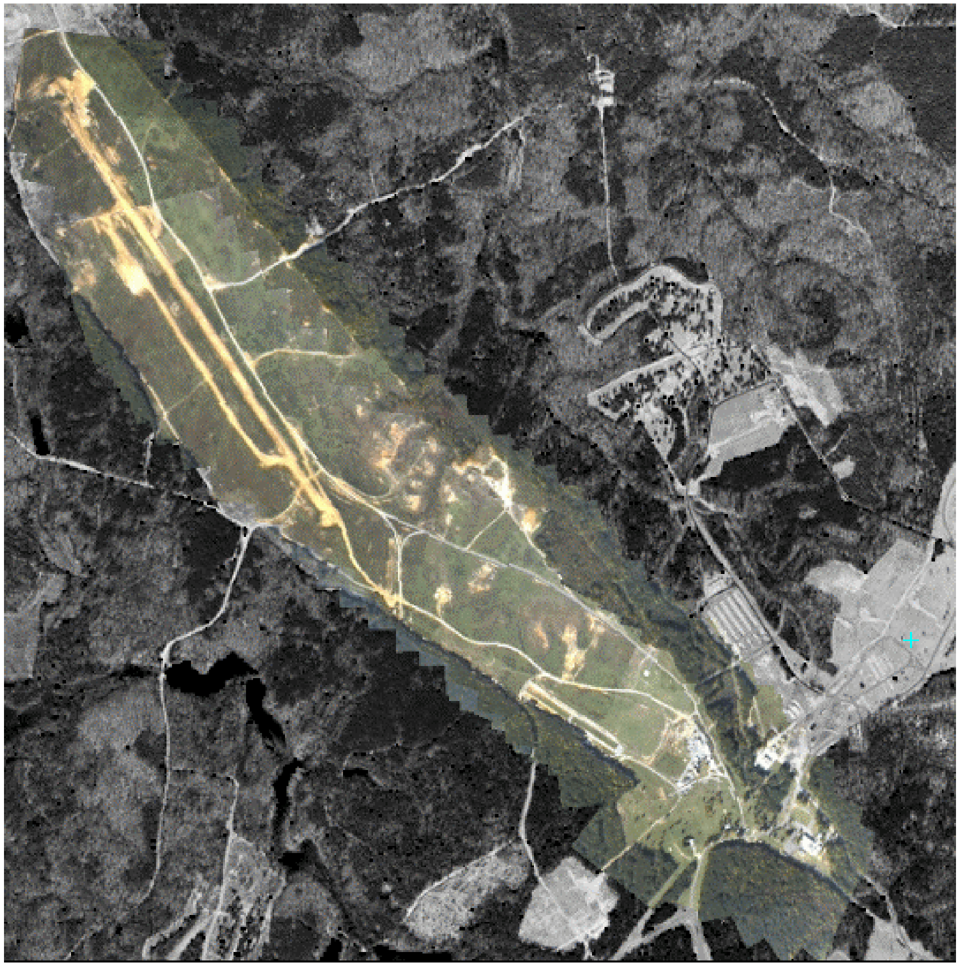
before:	median:	33.1	90th:	42.4	mean:	32.5	std dev:	8.6	<10m:	0%
kf:	median:	2.7	90th:	4.4	mean:	3.0	std dev:	1.3	<10m:	100%

NY Intersection Circle Stare

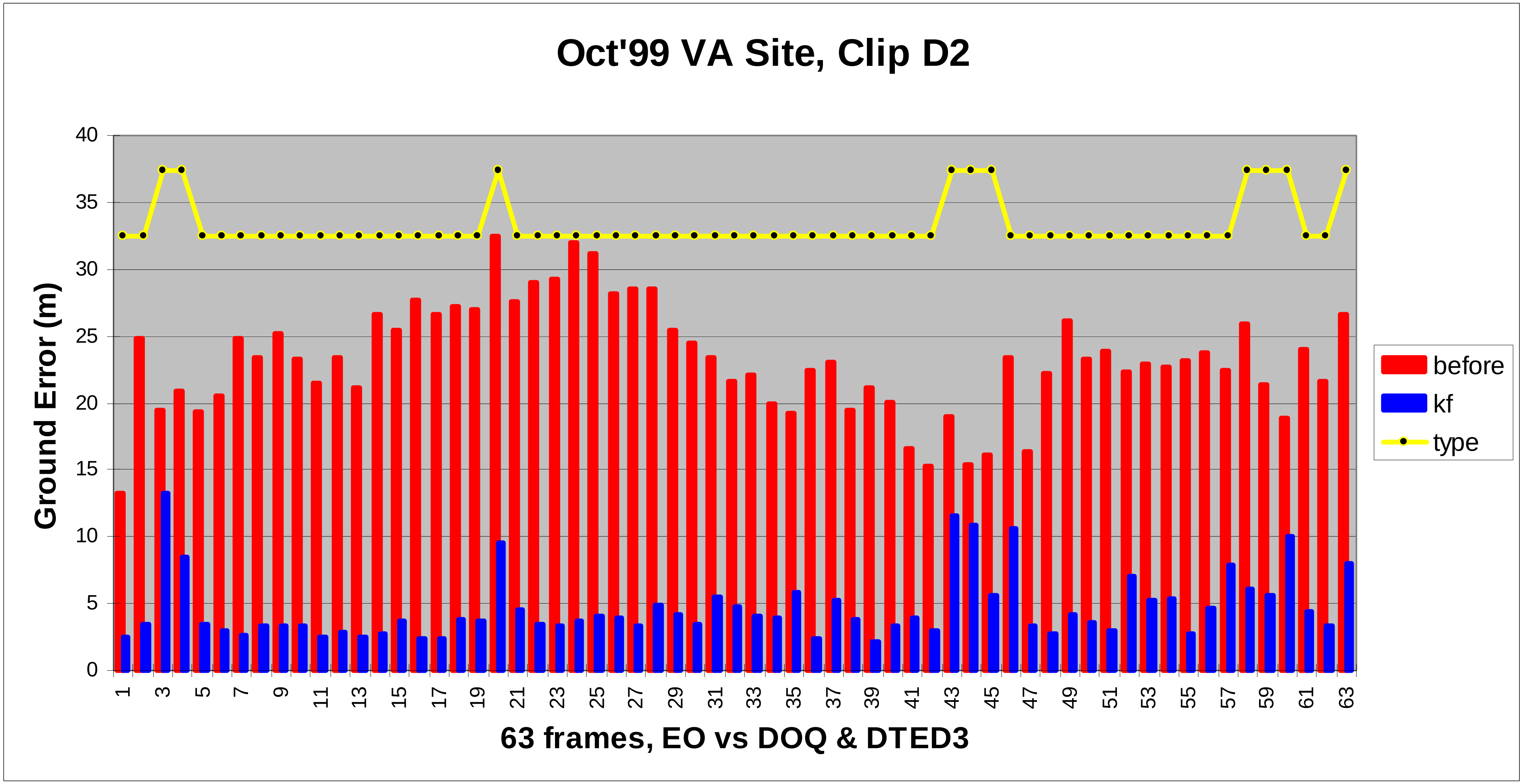


mean:	9.5
stdev:	2.6

VA 15-Oct Fast Straight Line

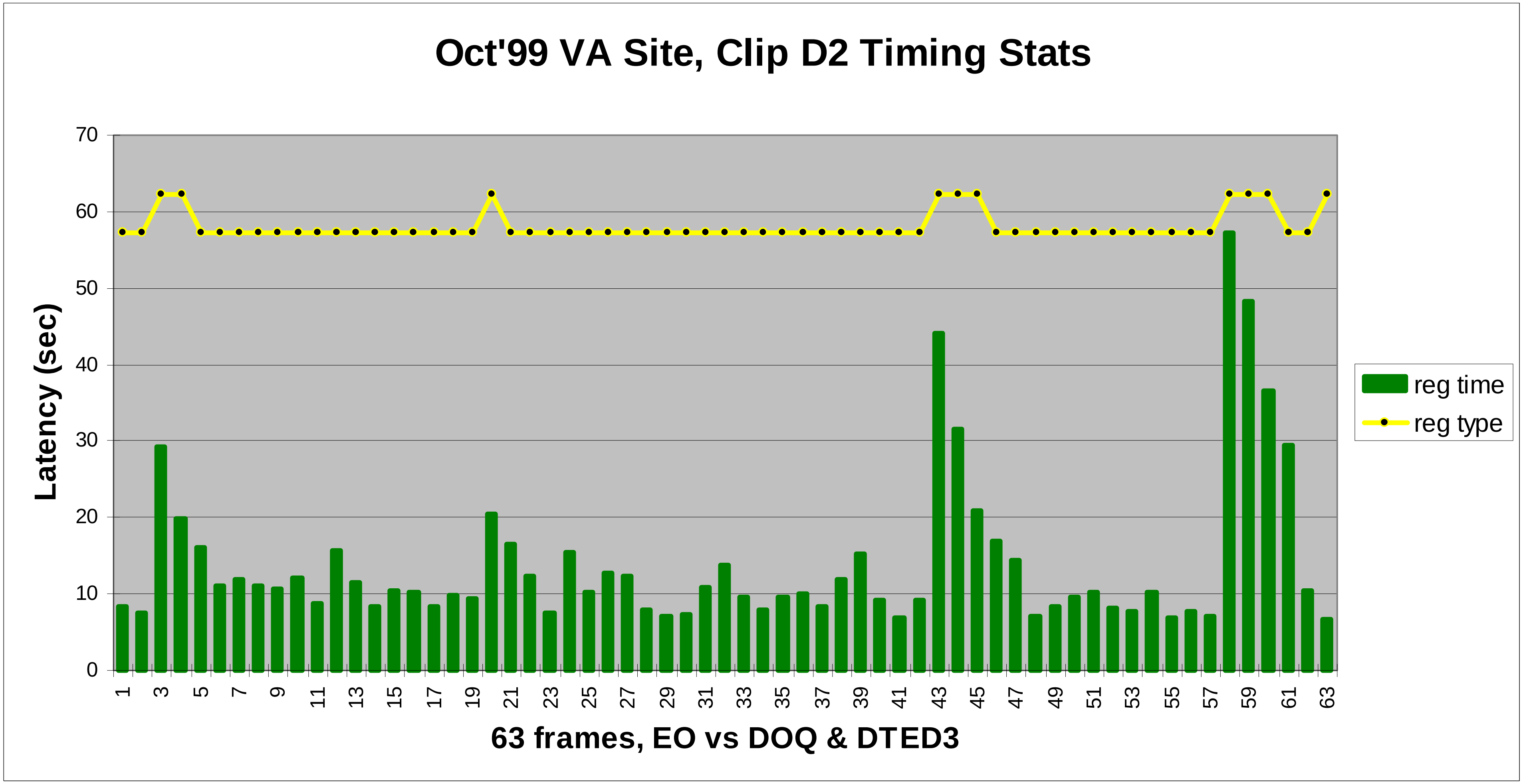


VA 15-Oct Fast Straight Line

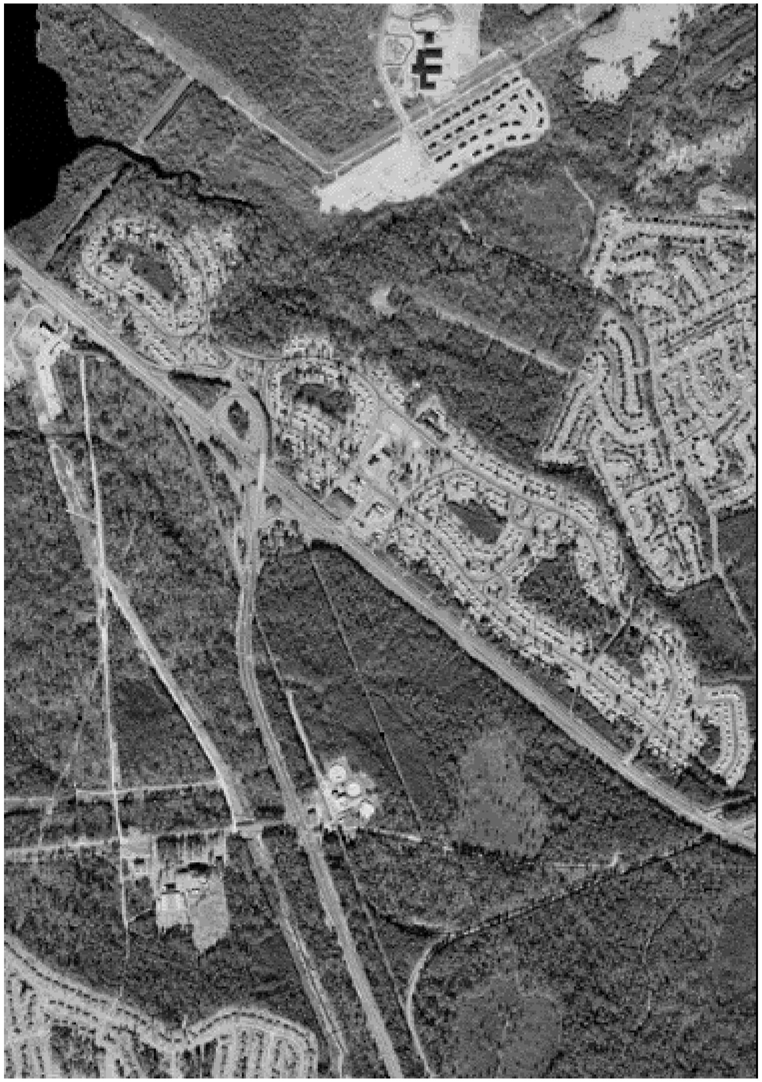


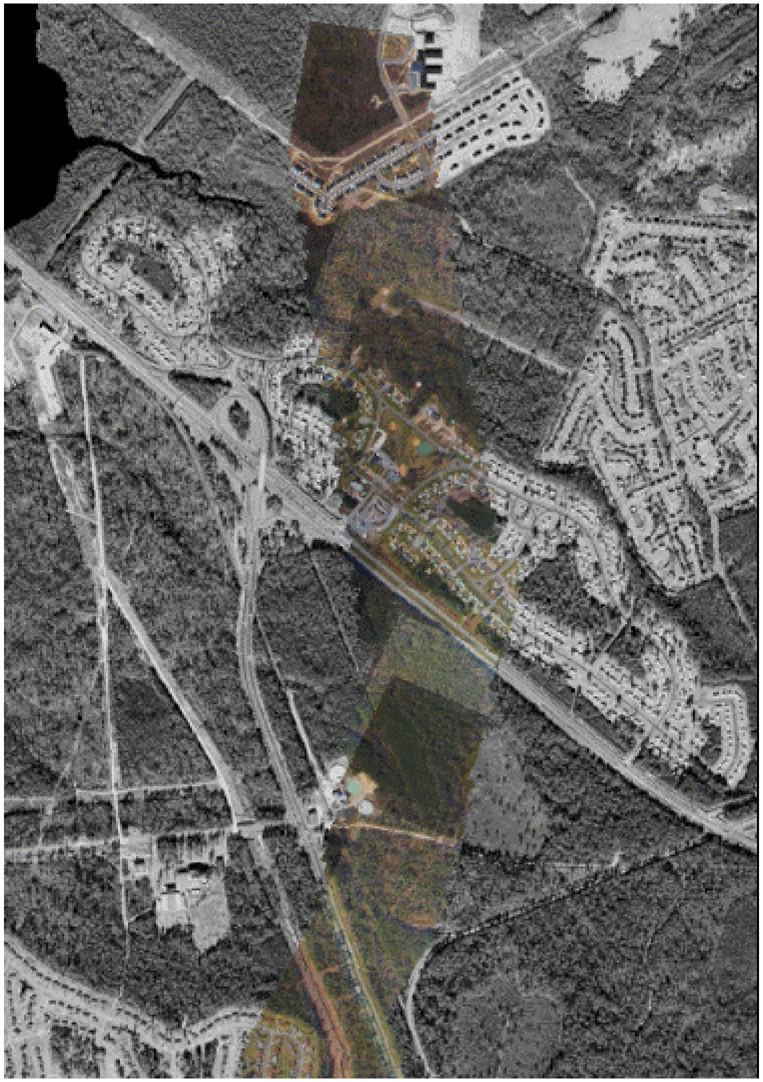
before:	median:	23.2	90th:	28.4	mean:	23.2	std dev:	4.1	<10m:	0%
kf:	median:	3.8	90th:	8.4	mean:	4.7	std dev:	2.5	<10m:	93%

VA 15-Oct Fast Straight Line

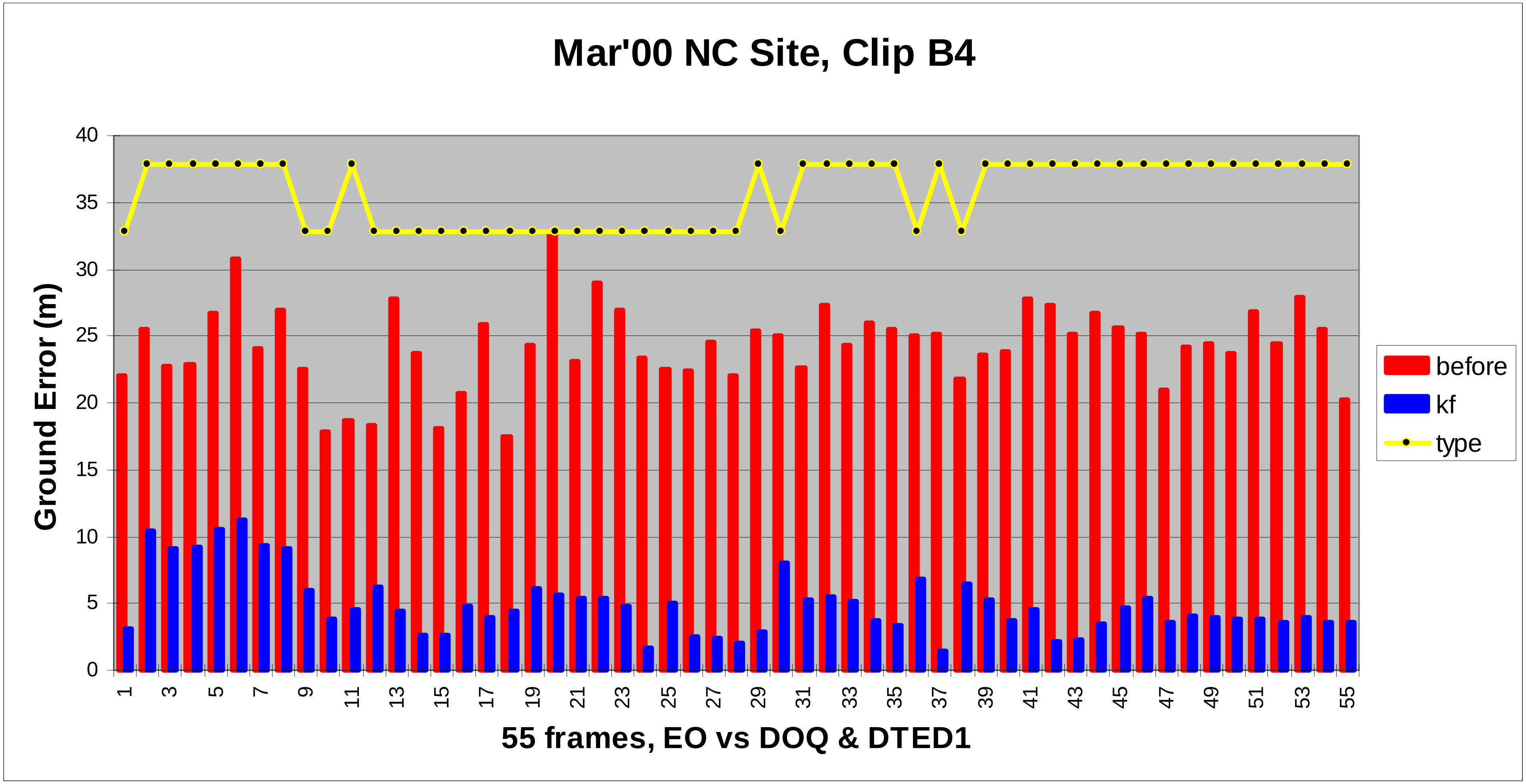


NC Suburban Run



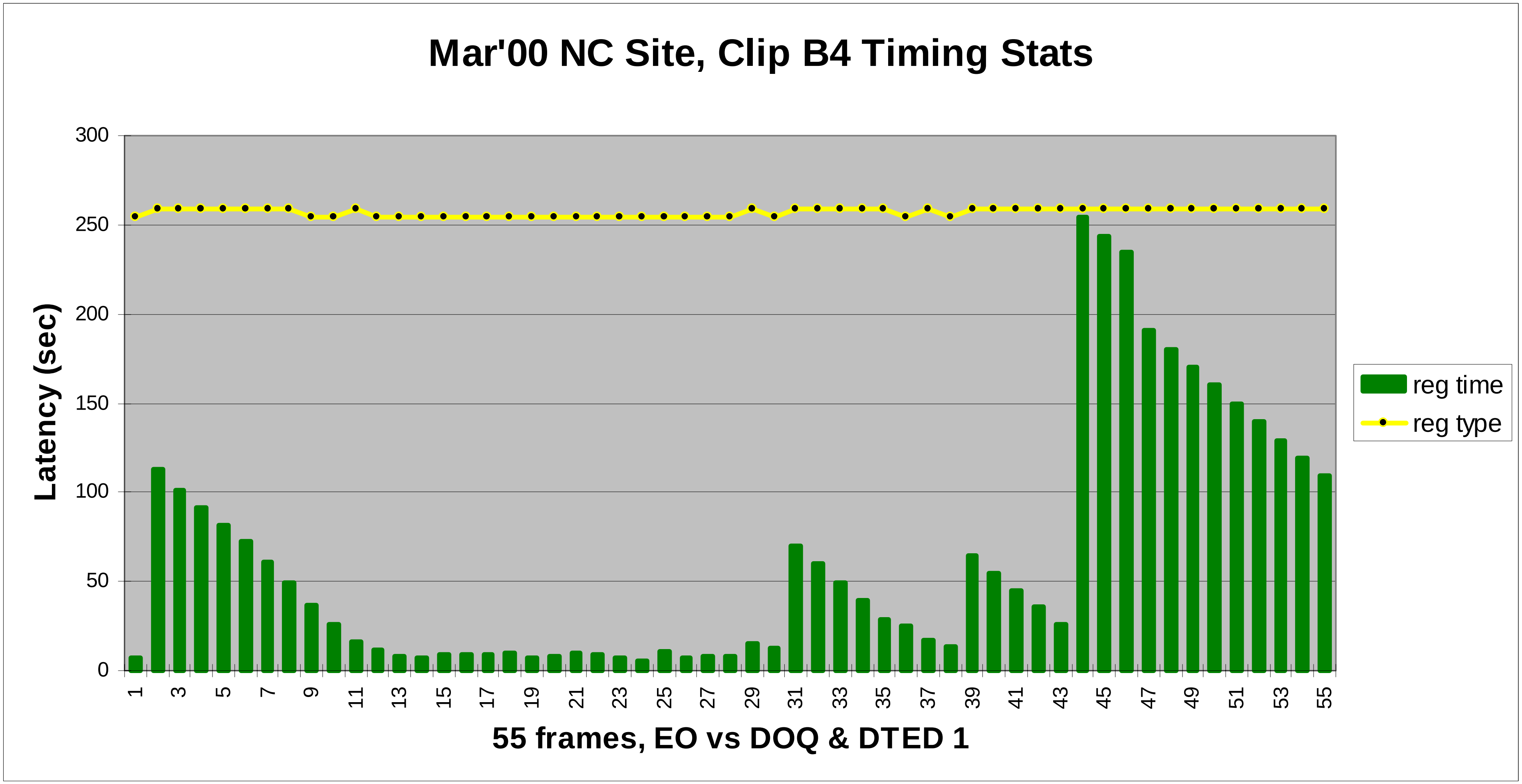


NC Suburban Run

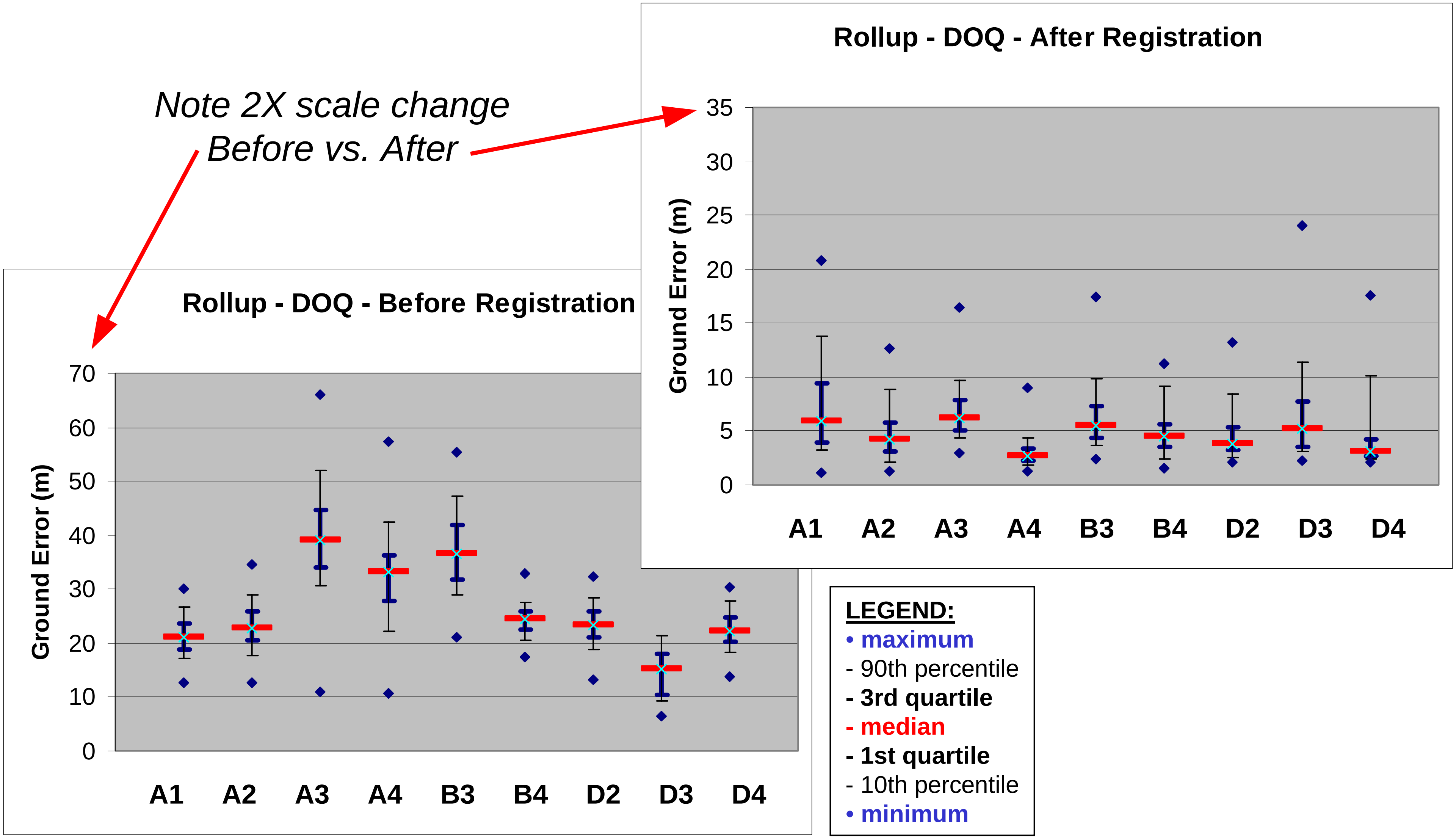


before:	median:	24.4	90th:	27.6	mean:	24.3	std dev.	3.1	<10m:	0%
kf:	median:	4.5	90th:	9.1	mean:	4.9	std dev.	2.3	<10m:	96%

NC Suburban Run

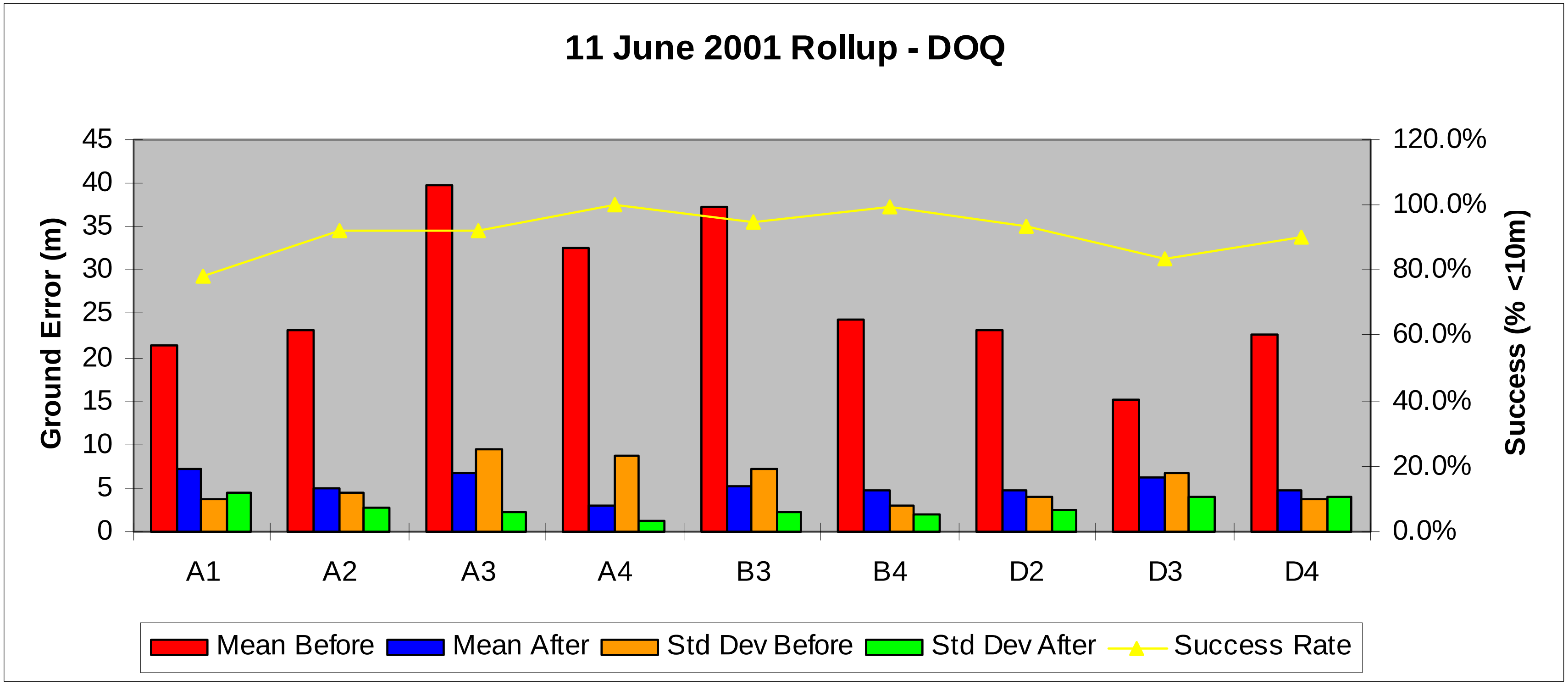


DOQ Validation Summary



LEGEND:
- • maximum
- - 90th percentile
- **- 3rd quartile**
- **- median**
- **- 1st quartile**
- - 10th percentile
- • minimum

DOQ Validation Summary



Look Angle	GSD	# Frames
High	Fine	0
High	Medium	273
High	Coarse	6
Moderate	Fine	0
Moderate	Medium	134
Moderate	Coarse	165
Low	Fine	0
Low	Medium	12
Low	Coarse	60
DOQ	**Total:**	650

High > 55	Fine .15-.3
Mod 35-55	Med .3 - 1
Low < 35	Coarse > 1

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J. Hackett, D. Trask, and R. Cannata, "Automated Near-Real Time Registration and Geopositioning Based Upon Rigorous Photogrammetric Modeling," *ASPRS-RTI Conf. Proc.,* Tampa, FL, 1998.

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S. G. Blask and J.A. Van Workum, "An Autonomous 3D Photogrammetric Approach to Airborne Video Geo-Registration," Invited Talk at *IEEE Workshop on Video Registration* held with *The Eighth IEEE International Conference on Computer Vision,* Vancouver, BC, Canada, July 13, 2001, `http://www.cs.ucf.edu/~vision/workshop/workshop.html`.