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**Progress of positional accuracy of
orthophoto maps
based on GPS/INS systems**

Mircea JUC
IGC Eurotopo
Bucharest / Romania



Geometrical Accuracy of Orthophoto

Geometrical Accuracy of an Orthophoto depends of :

Absolute Orientation



Overall Accuracy

- Sensor (camera)
- GCP
- GPS
- IMU

Digital Terrain Model



Local Accuracy



Development of Absolute Orientation of aerial images

Absolute Orientation of aerial images based on :

Aerial Images, sensor



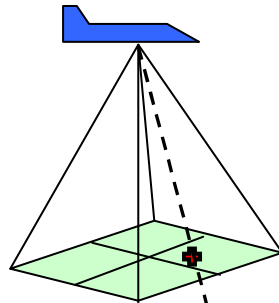
- Tie points & GCP \Rightarrow Aerial Triangulation, **a lot of GCPs**
- Tie points & GCP & GPS \Rightarrow Aerial Triangulation, **less GCPs**
- Tie points & GCP & GPS / INS \Rightarrow ISO, **few GCPs**
- [Tie points & GCP] GPS / INS \Rightarrow Direct Georeferencing, no GCPs

Direct Georeferencing vs. „Indirect Georeferencing“

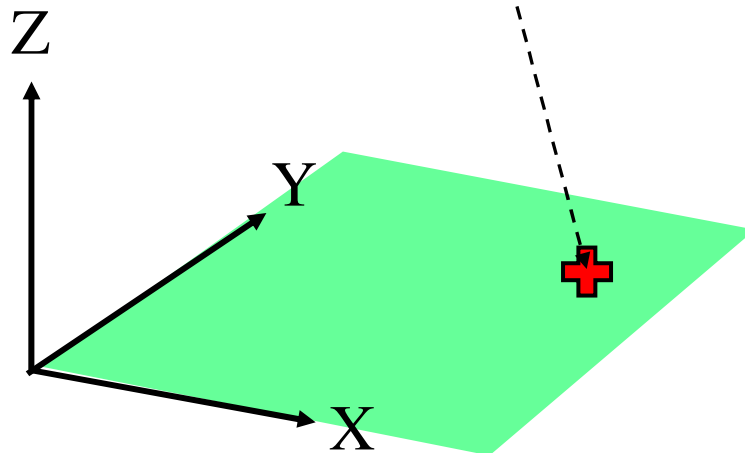
Georeferencing



connect information of an airborne sensor with a position in space



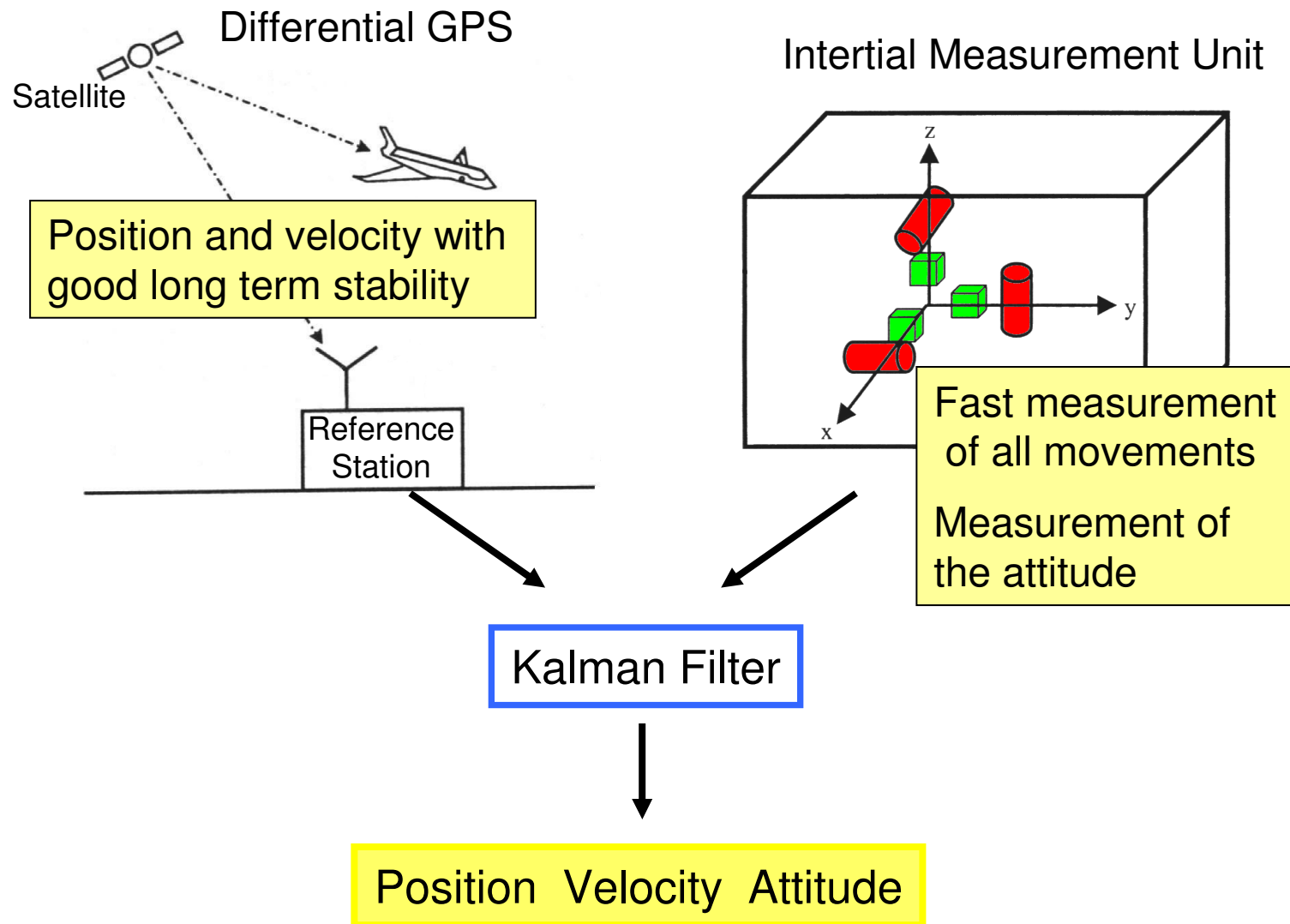
Indirect using the sensor data
Example: AT



Direct NOT using the sensor data

- position
- attitude
- velocity

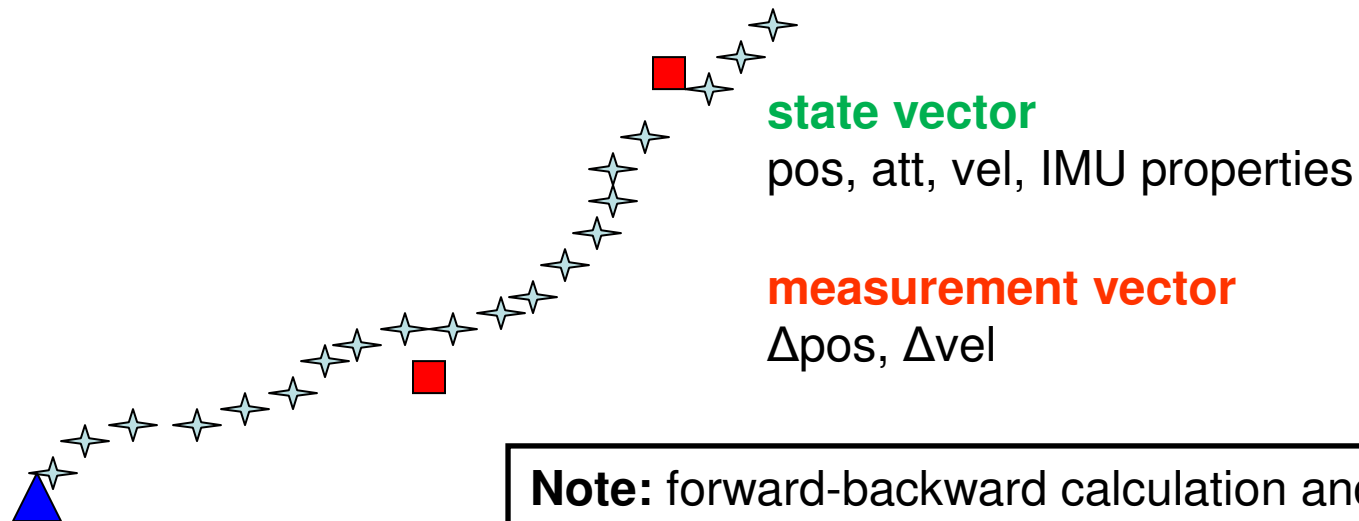
GPS/IMU Integration





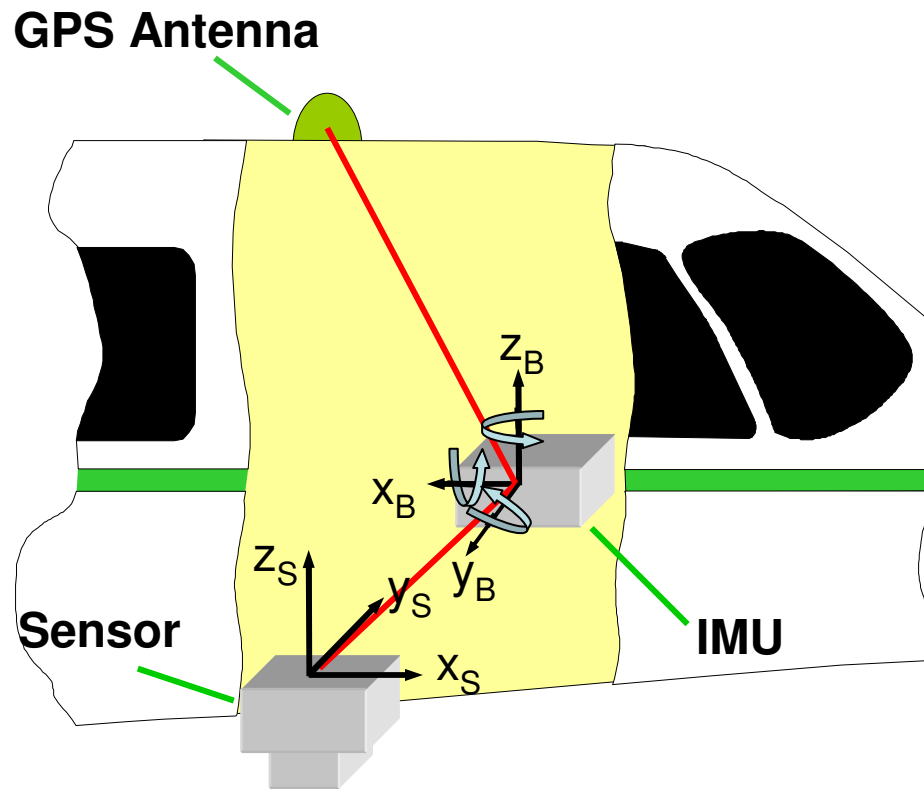
GPS/IMU Integration

1. Calculate initial position, attitude and velocity (the **initial state**)
2. Calculate the **actual state** with the IMU data
3. When GPS **measurements** occur: use Kalman Filter to estimate **optimal state**, including IMU properties



Note: forward-backward calculation and smoothing improve the result significantly

System Calibration



- Exact synchronization
- The lever-arms have to be taken into account
- Careful measurement of the attitude of the IMU
- Correct sensor model at the data collection time

IMU Calibration

Sensor Calibration

Misalignment Calib.

Direct Georeferencing / Integrated Sensor Orientation

Direct Georeferencing

No GCP's and no AT

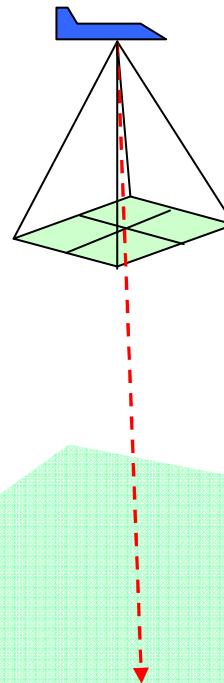
Very fast

Need for calibration

No redundancy
⇒ little error
tolerance

No selfcalibration

Limited accuracy



Integrated Sensor Orientation

Need for AT

No extra calibration

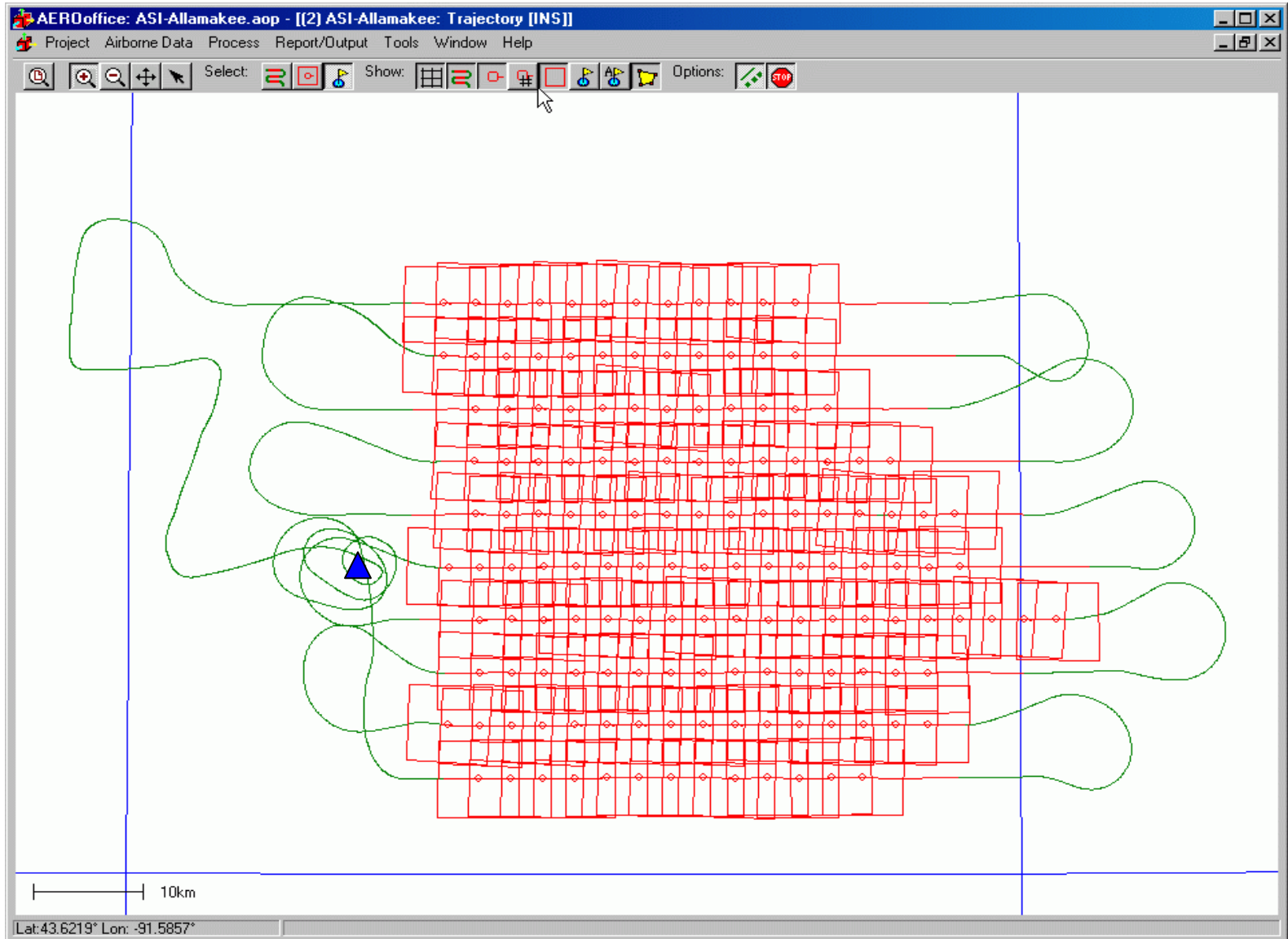
Redundant measurement
⇒ good error tolerance

Selfcalibration possible

Accuracy not limited by
GPS or IMU



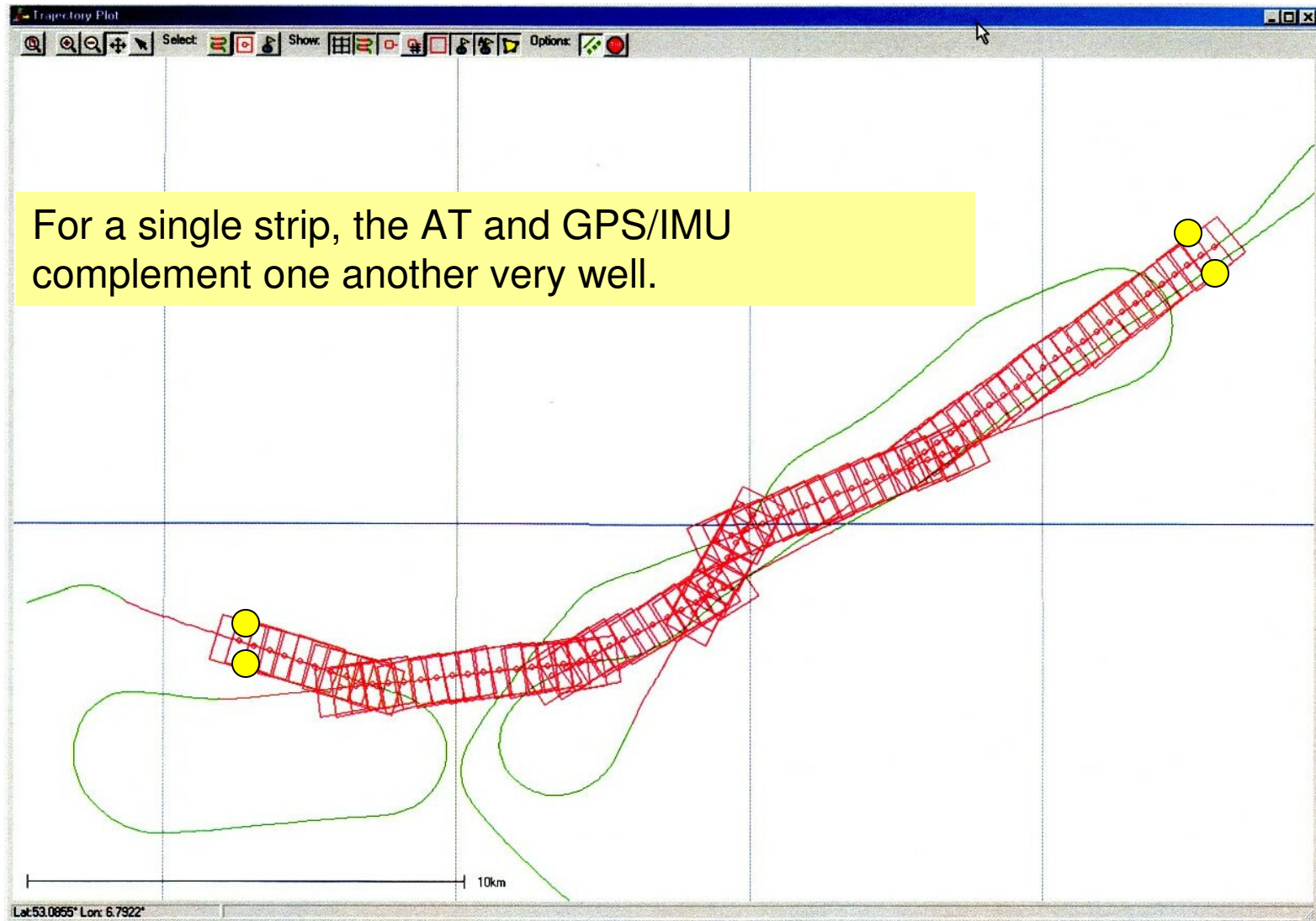
Example: Integrated Sensor Orientation, Block





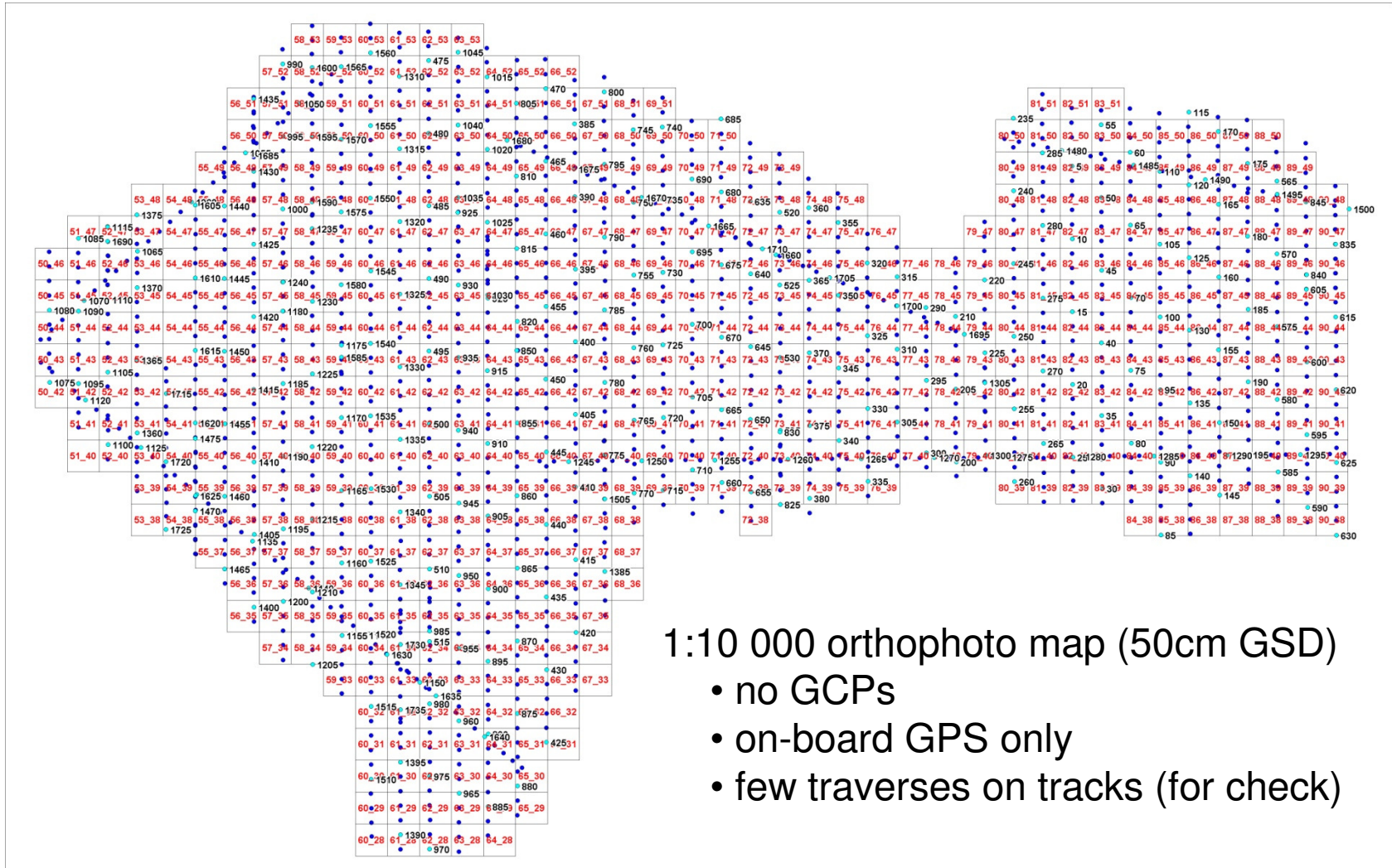
ONLY 4 GCPs for blocks & strips

For a single strip, the AT and GPS/IMU complement one another very well.



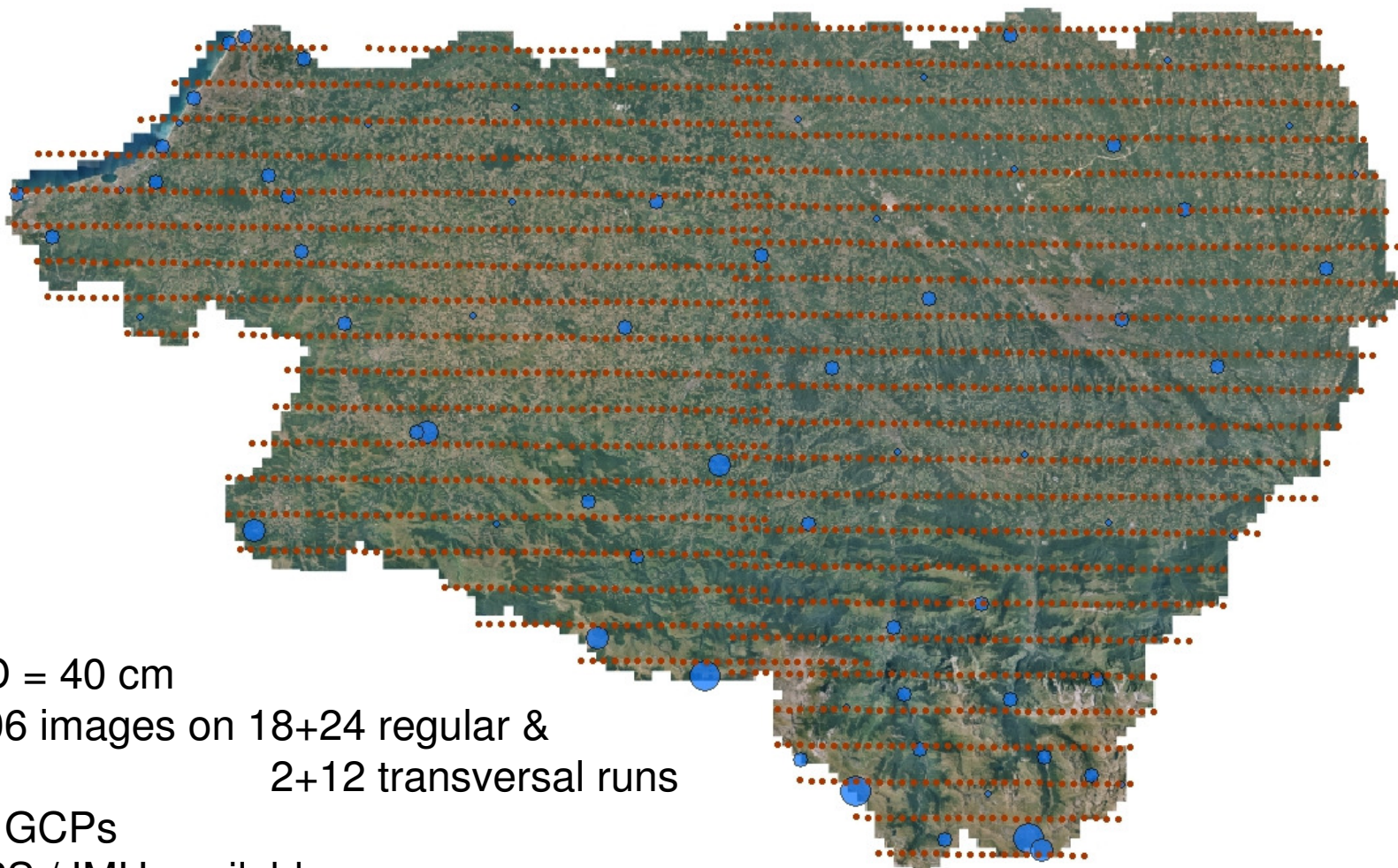


Example: Forest Project / Central African Republic





Example: BD Ortho© / France



GSD = 40 cm

• 2406 images on 18+24 regular &
2+12 transversal runs

- 85 GCPs
- GPS / IMU available

	RMSx	RMSy	RMSxy	RMSz	No pts
Control pts	0.32	0.24	0.40	0.26	67
Check pts	0.44	0.37	0.57	0.54	18



Example: BD Ortho / France

GPS / IMU accuracy:

$$s_x = 0.83\text{m}$$

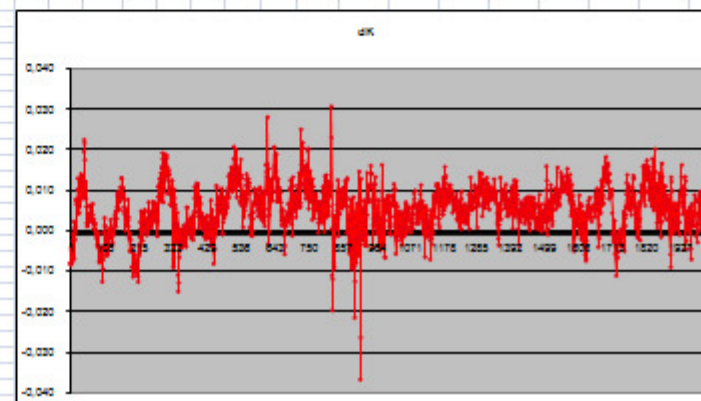
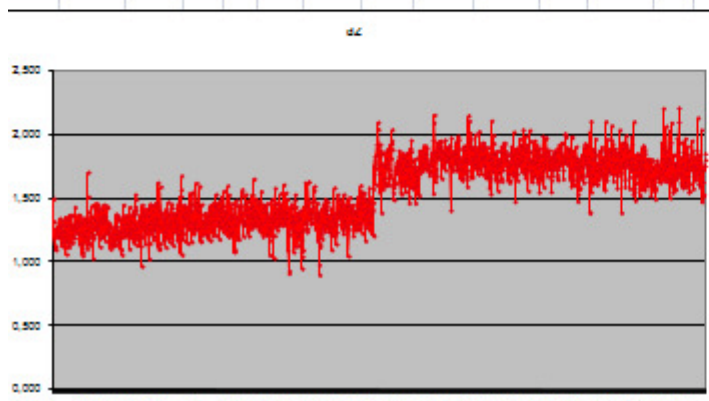
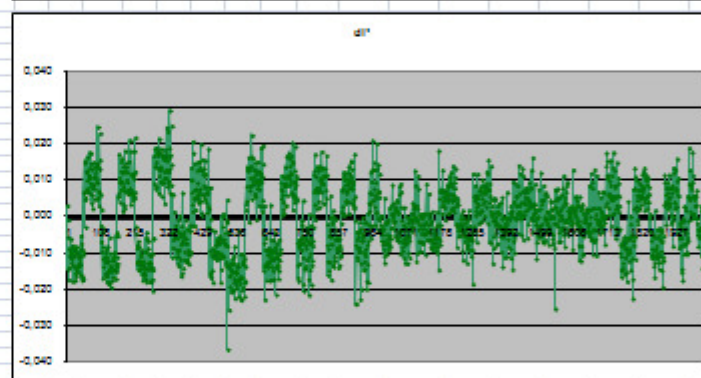
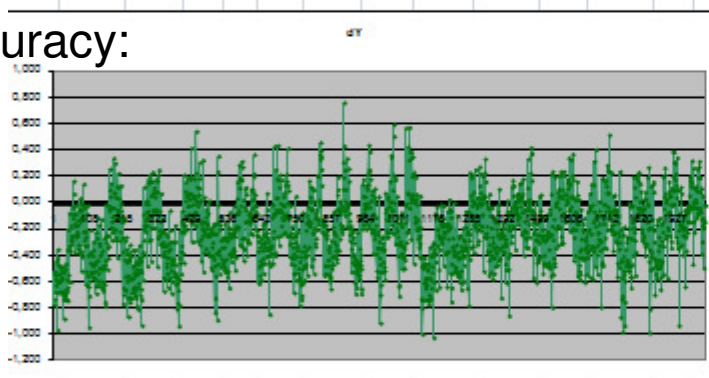
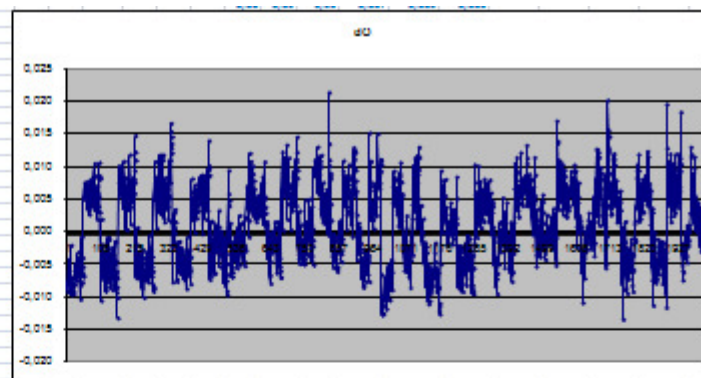
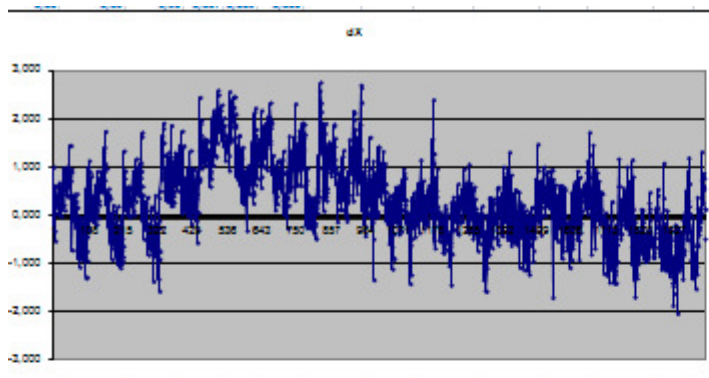
$$s_y = 0.35\text{m}$$

$$s_z = 1.57\text{m}$$

$$s_o = 0.006$$

$$s_p = 0.009$$

$$s_k = 0.008$$





Example: AT for 25cm GSD / Alger

The screenshot displays the ORIMA Orientation Management software interface. The main window shows a triangulation network with various control points and observations. A dialog box titled "Object Display Features for Triangulation" is open in the bottom right corner, allowing users to customize the display of triangulation features. The "Residuals Enlarged" option is highlighted with a red box, and its value is set to 15000 times.

Object Display Features for Triangulation

Display Features

- IDs
- Residual Vectors
- Height Vector in East-North Window
- Residuals Numerically
- Sigma a priori
- Error Ellipses (95%)
- Std. Dev. Numerically
- Error Ellipse Parameters
- GPS Parameter Effects
- GPS Parameter Height in East-North
- Reliability
- Reliability Height in East North
- Apply to Activated Objects Only

Close Apply

Show

- Full Control Points
- Planimetric Control Points
- Height Control Points
- Terrain Points
- Projection Centers
 - Footprint
 - Connections
 - Coverage %
 - Camera X-Axis
 - Pairs Points
 - GPS Antenna Centers
 - IMU Angle Residuals

Residuals Enlarged [times] Help



Example: GPS/IMU for 25cm GSD / Algeria

GPS / IMU (in)accuracy:

$$s_x = 1.75m$$

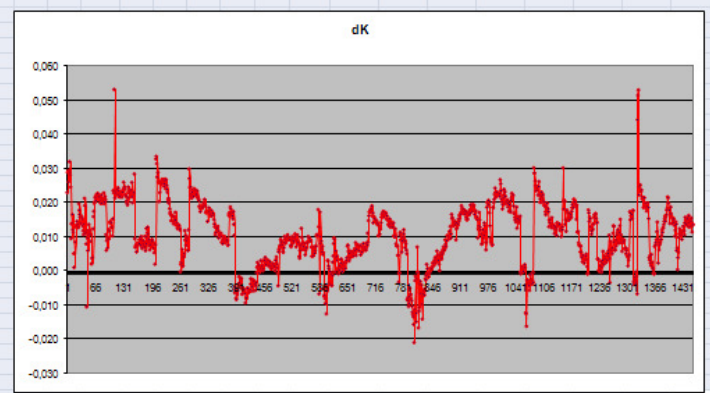
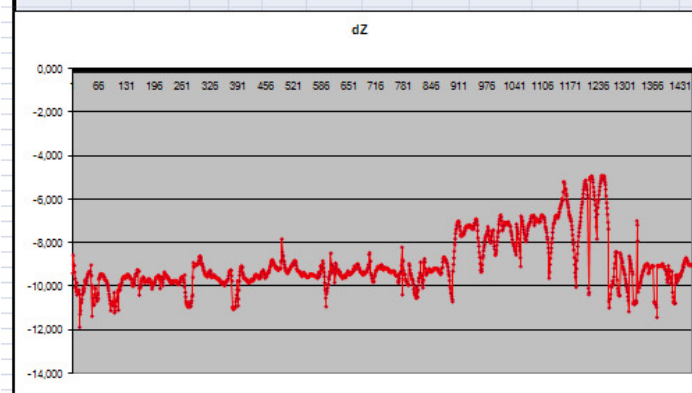
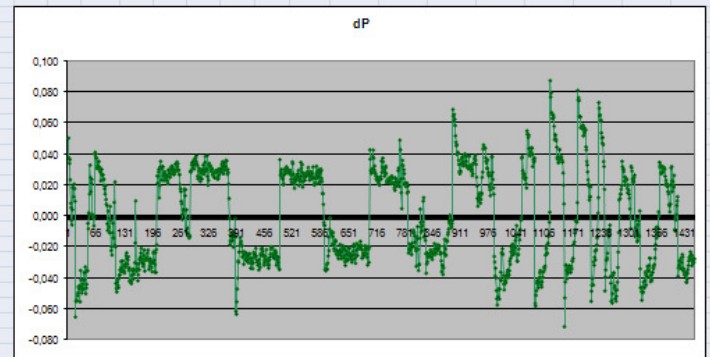
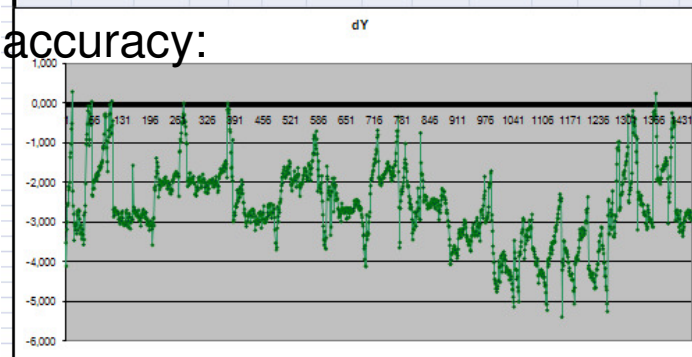
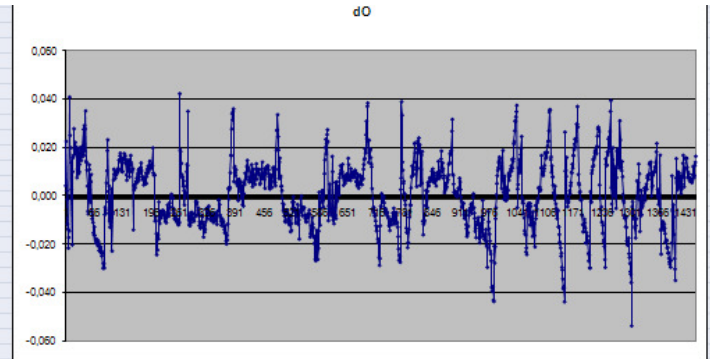
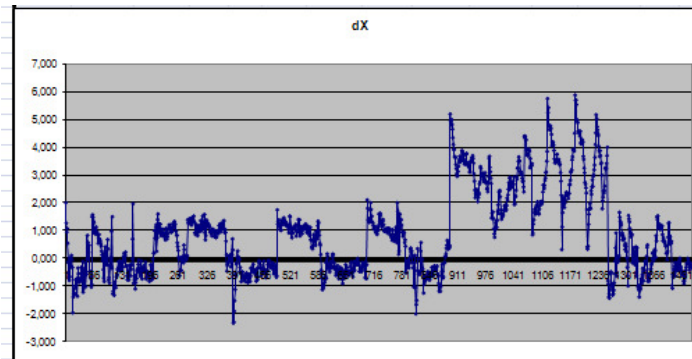
$$s_y = 2.76m$$

$$s_z = 9.06m$$

$$s_o = 0.014$$

$$s_p = 0.031$$

$$s_k = 0.014$$

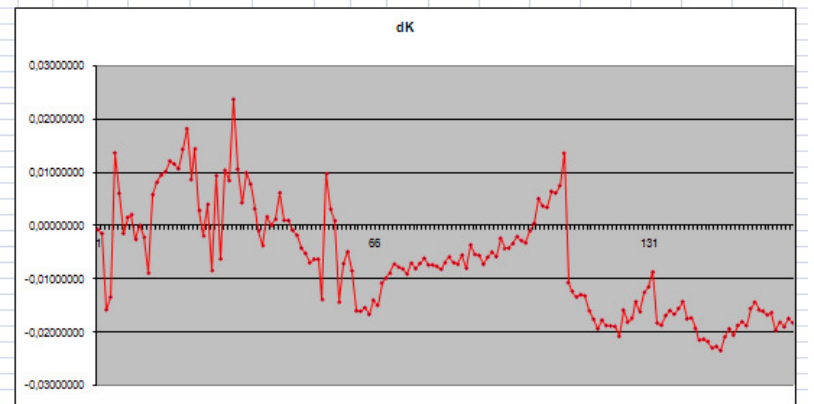
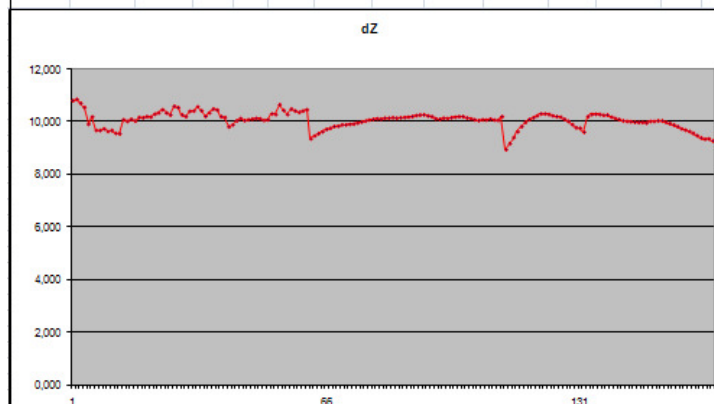
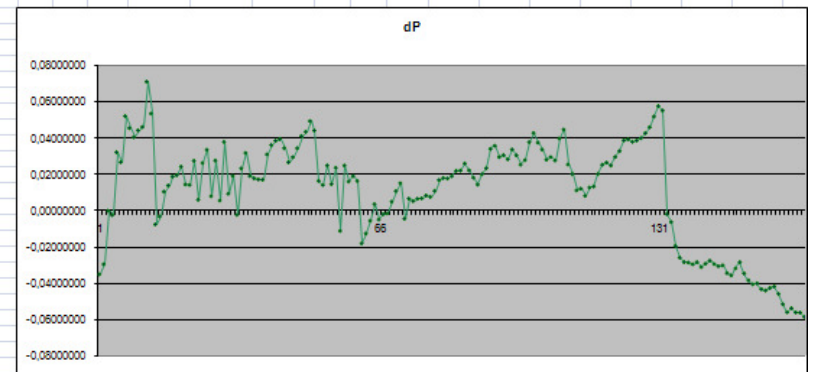
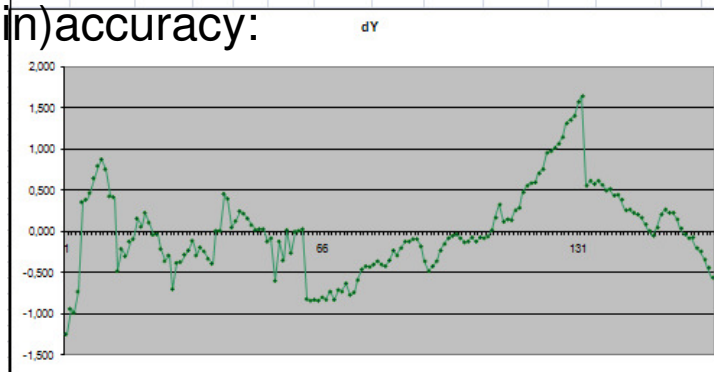
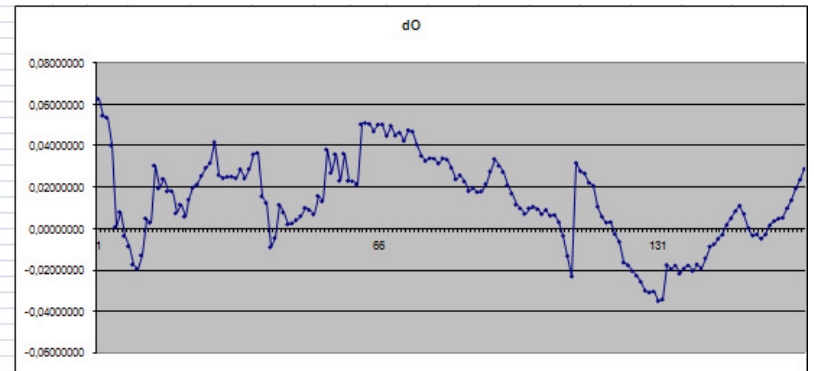
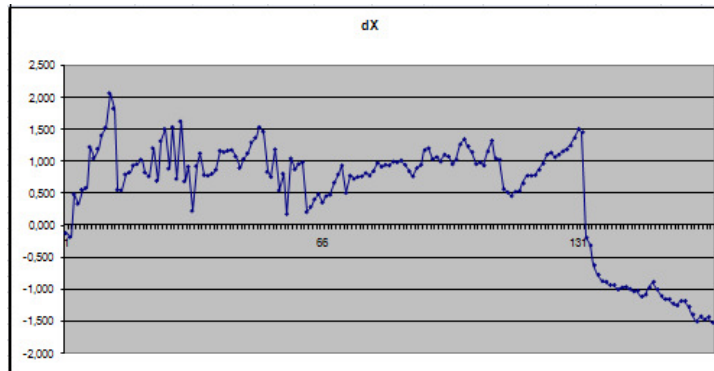




Example: GPS/IMU for 12.5cm GSD / Algeria

GPS / IMU (in)accuracy:

- $s_x = 1.02m$
- $s_y = 0.52m$
- $s_z = 10.05m$
- $s_o = 0.025$
- $s_p = 0.030$
- $s_k = 0.012$





Conclusion

- Georeferencing with GPS/IMU data is a well established method.
- The decision to use DG or ISO depends on the project parameters (scale, required accuracy ...).
- The proper use of GPS/IMU technology can save much time and money
- Improvements in GNSS will improve reliability and accuracy.
- The all digital workflow of the sensor orientation with GPS/IMU data together with automatic matching techniques speed up the processing times from years and months today to days and weeks.
- The use of GNSS/IMU systems for Direct Georeferencing and Integrated Sensor Orientation becomes a standard tool.