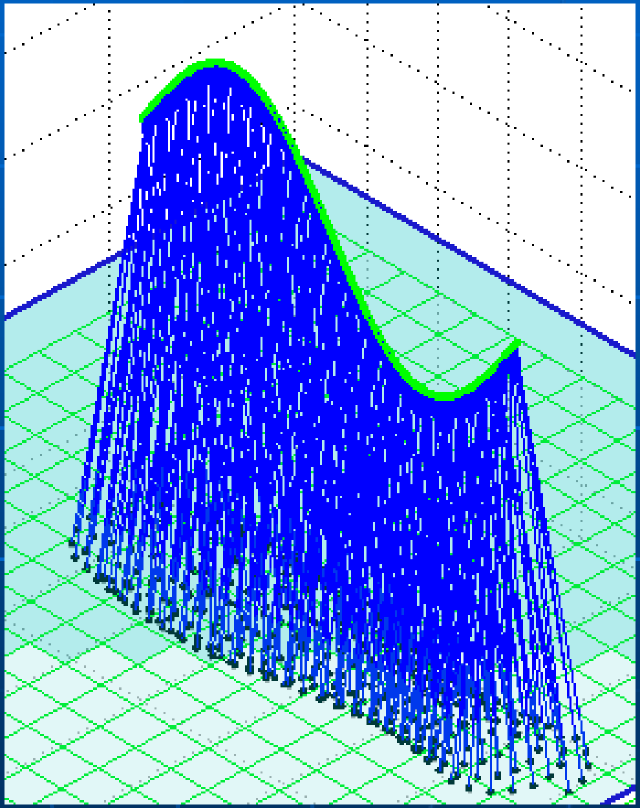
Contrasting a ship-based acoustic patch test with an automated calibration routine for a circular-scanning airborne lidar system.



Michael O. Gonsalves, LT/NOAA (NOS/NGS/RSD)

Canadian Hydrographic Conference

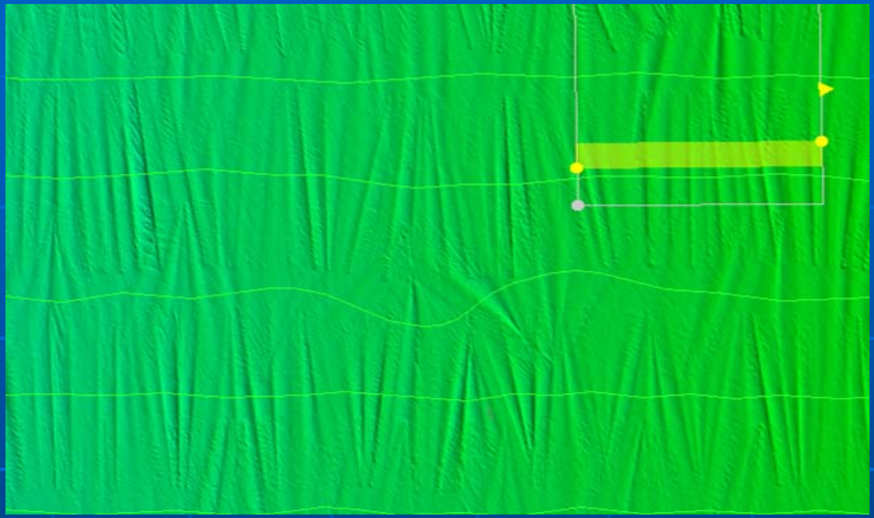
22 June 2010

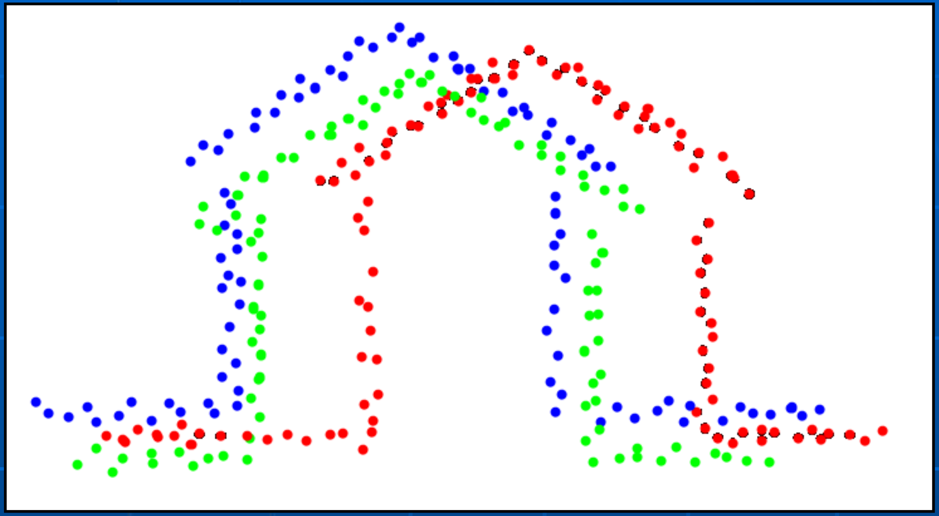
Presentation Overview

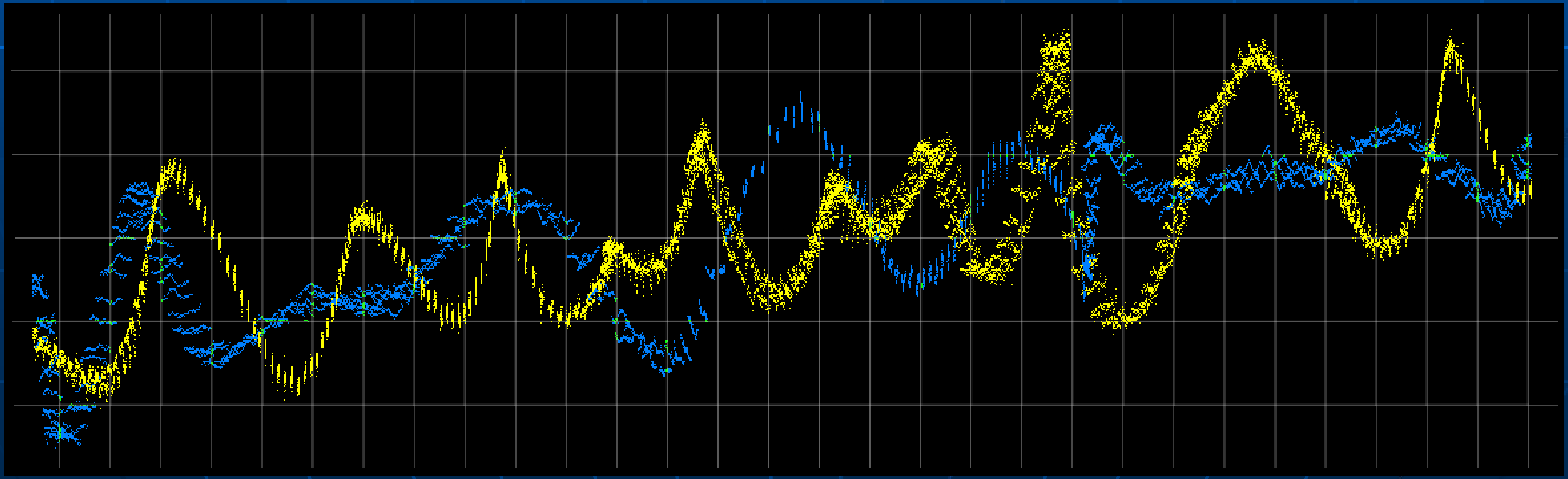
- Purpose of study & motivation
- Present calibration practices (sonar & lidar)
- Least-squares approach to lidar
  - Geometric argument
  - Advantages to the least-squares
- Potential application to acoustic multibeam

Purpose of study

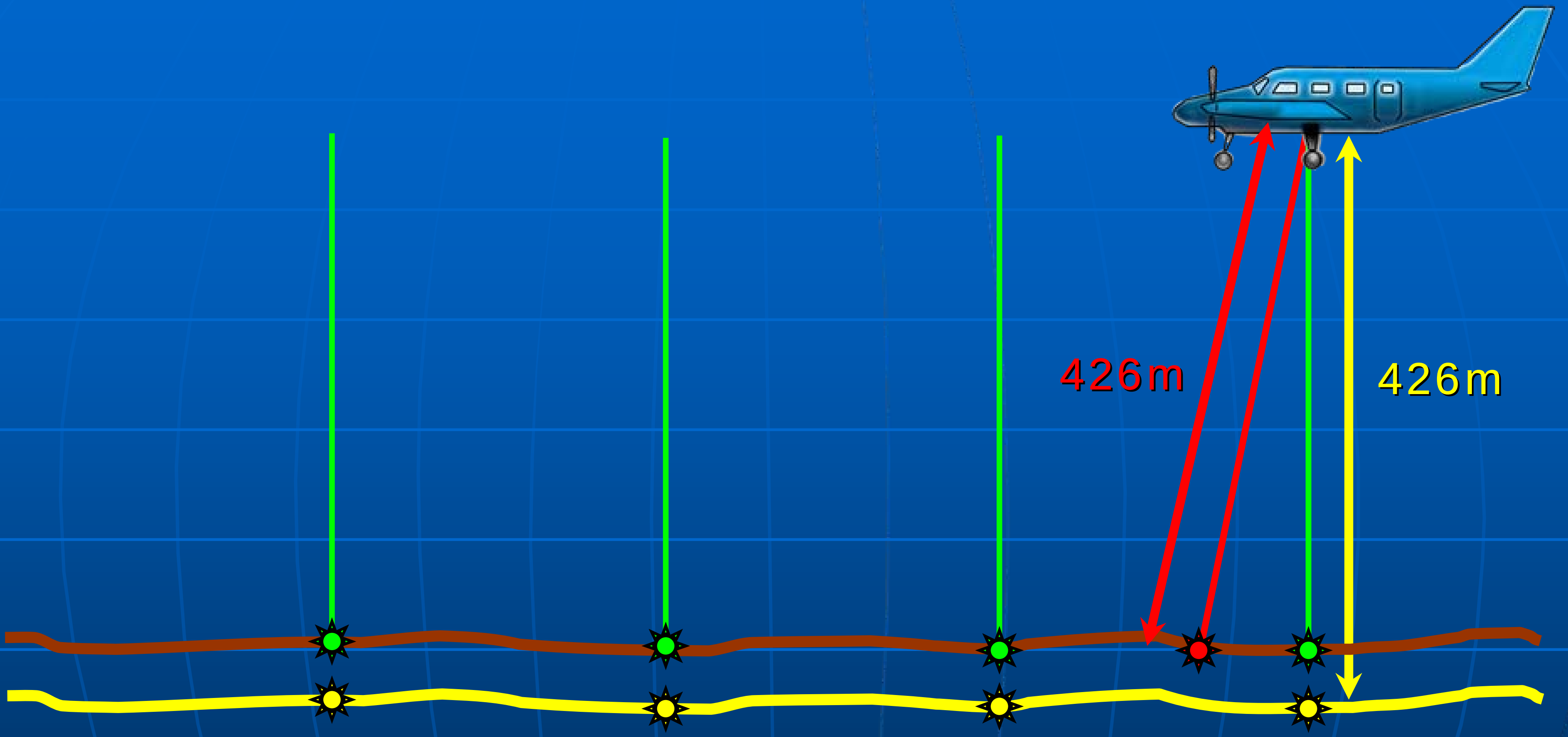
To develop a more robust, semi-automated, objective technique for system calibration with reported uncertainties.







The motivation: Why alignment matters

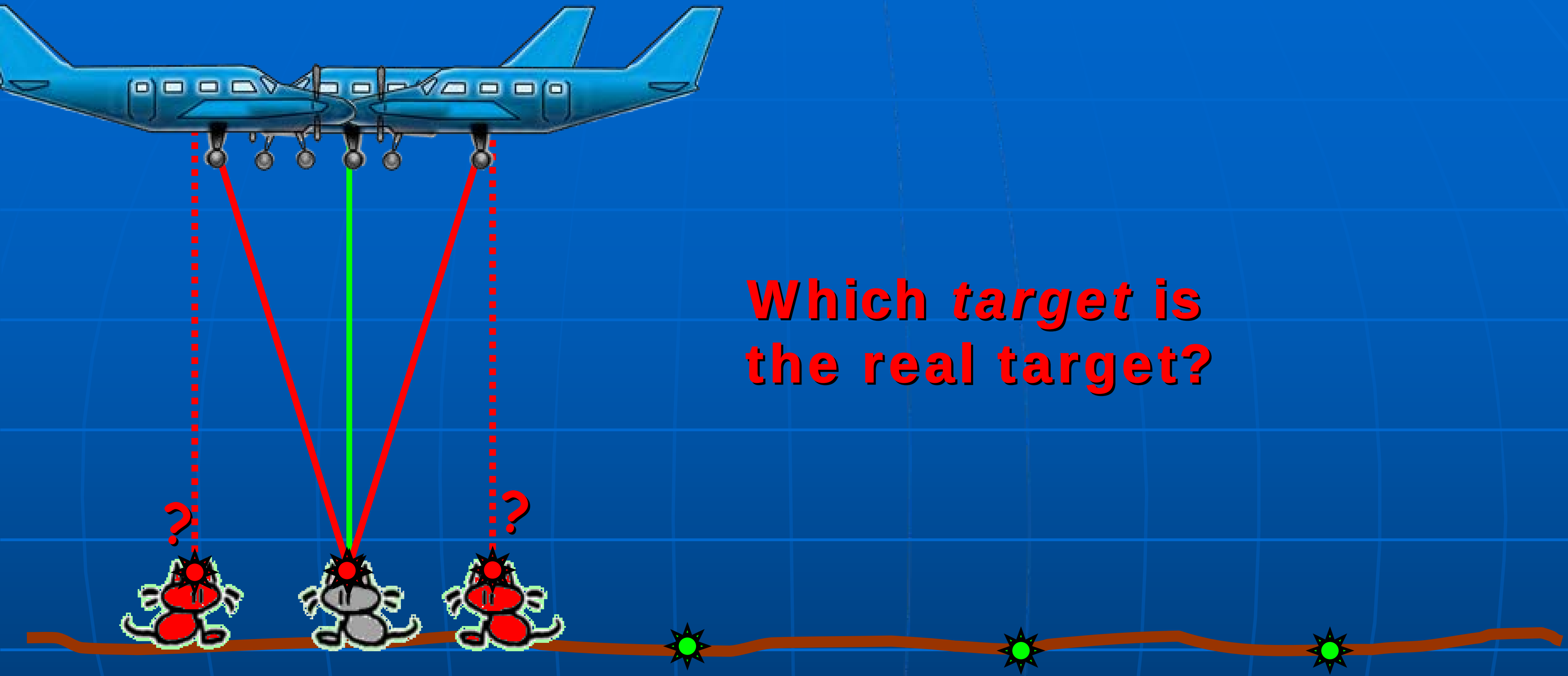


Imagine a downward-looking calibrated laser.

Suppose laser is unknowingly tilted 20° forward.

If operator assumes laser is downward-looking, they will miscalculate the location of the ground.

LIDAR – Why alignment matters



Which *target* is the real target?

Now suppose there is a target on the ground.

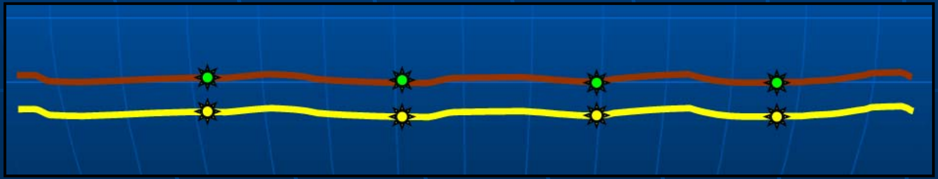
The downward-looking laser correctly identifies the targets location...

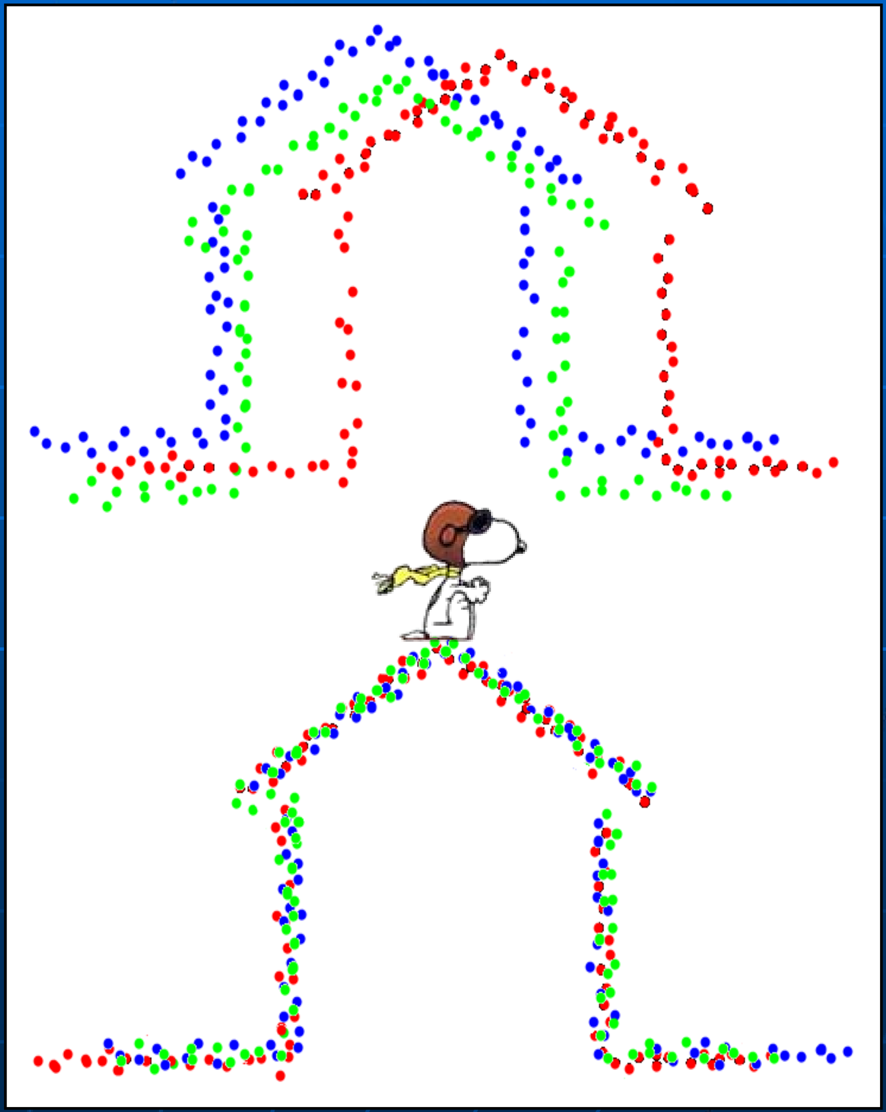
...while the forward-looking laser detects the target early, and thus miscalculates the position.

Motivation: why alignment matters

A poorly aligned system leads to:

- Incorrect elevations.
- Miscalculated target positions.
- A general *fuzziness*.





Present calibration practices: Sonar

Two methods – Using general bathymetric trends

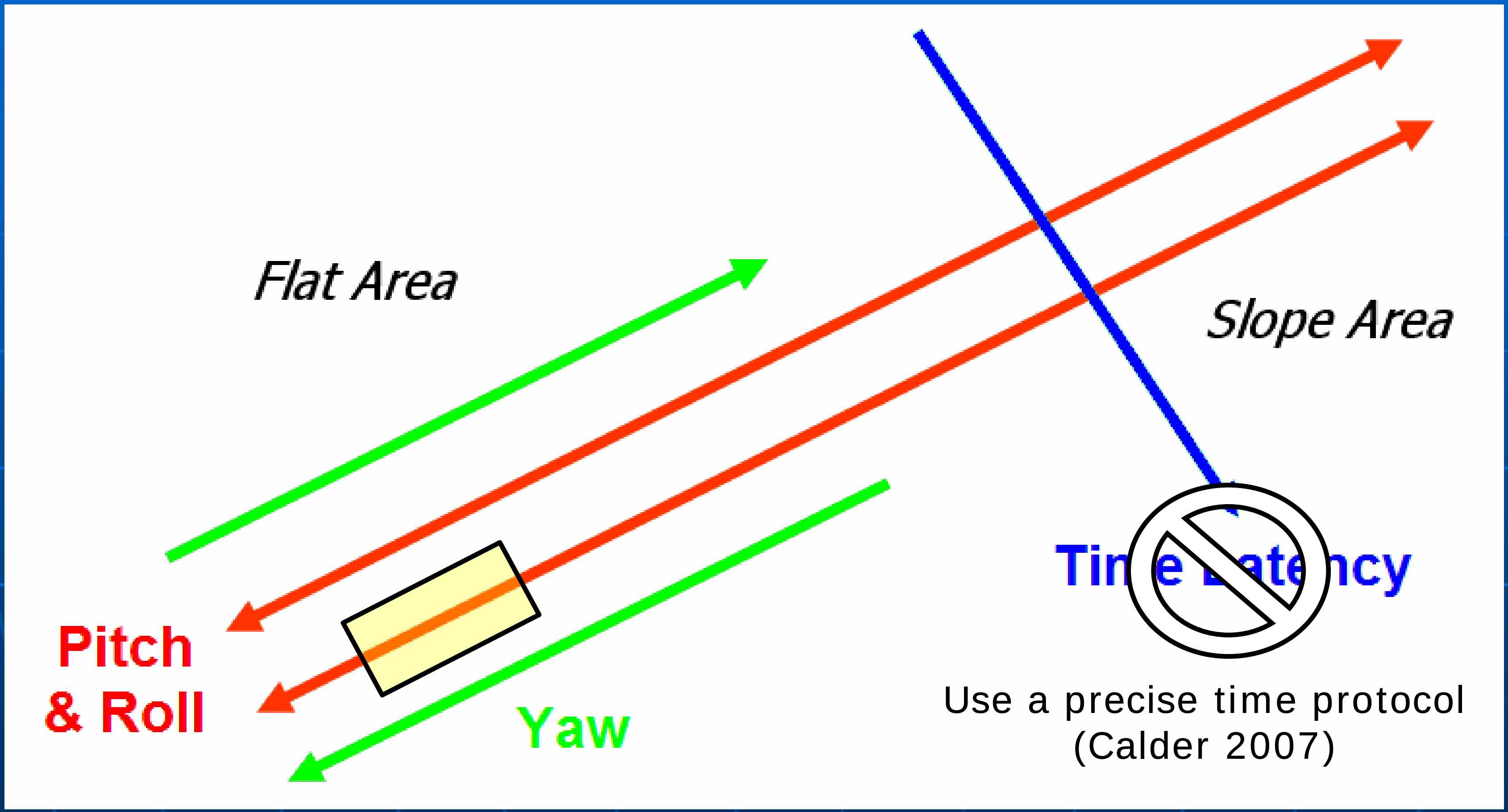
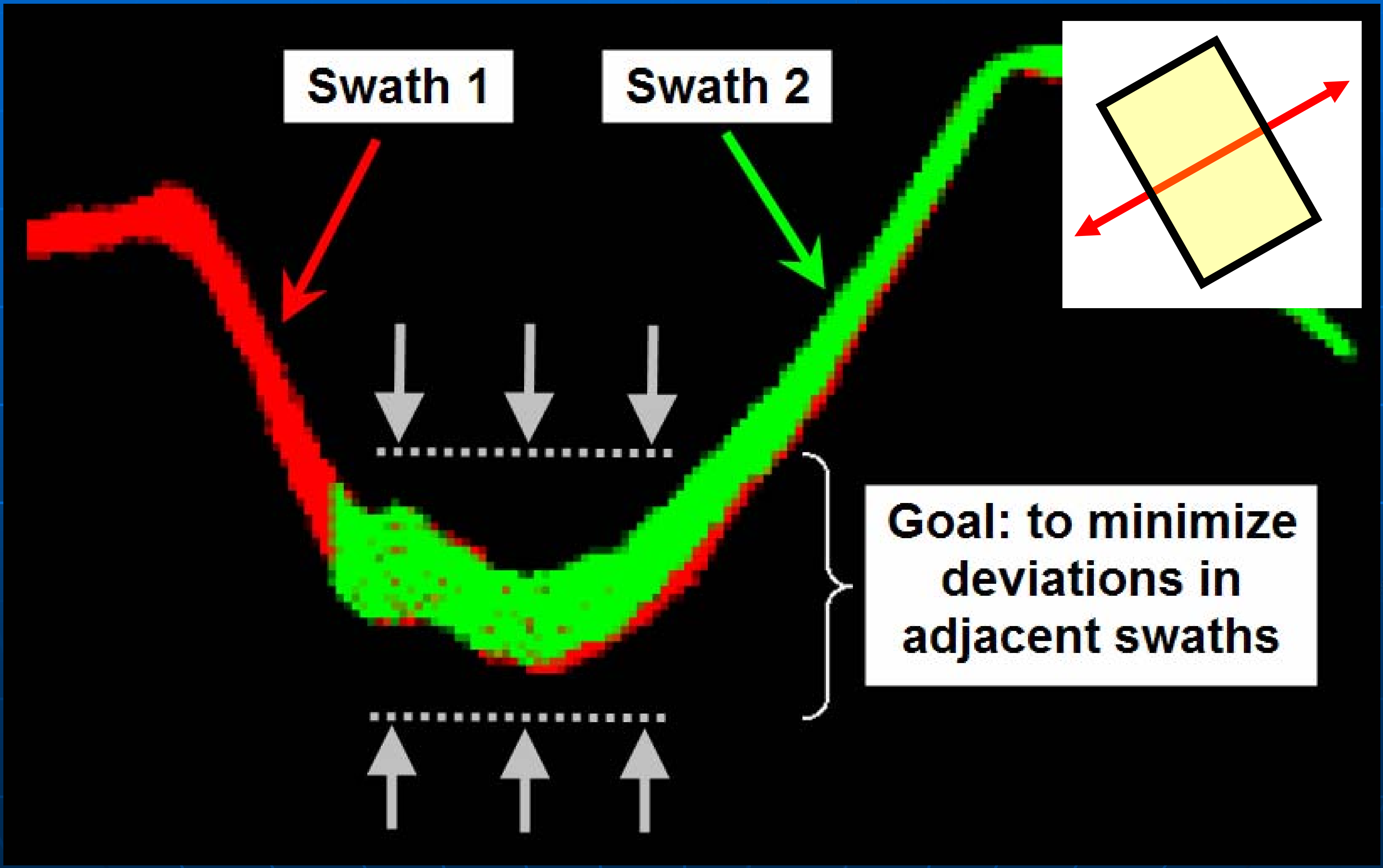


Image adapted from NOAA (2010a)

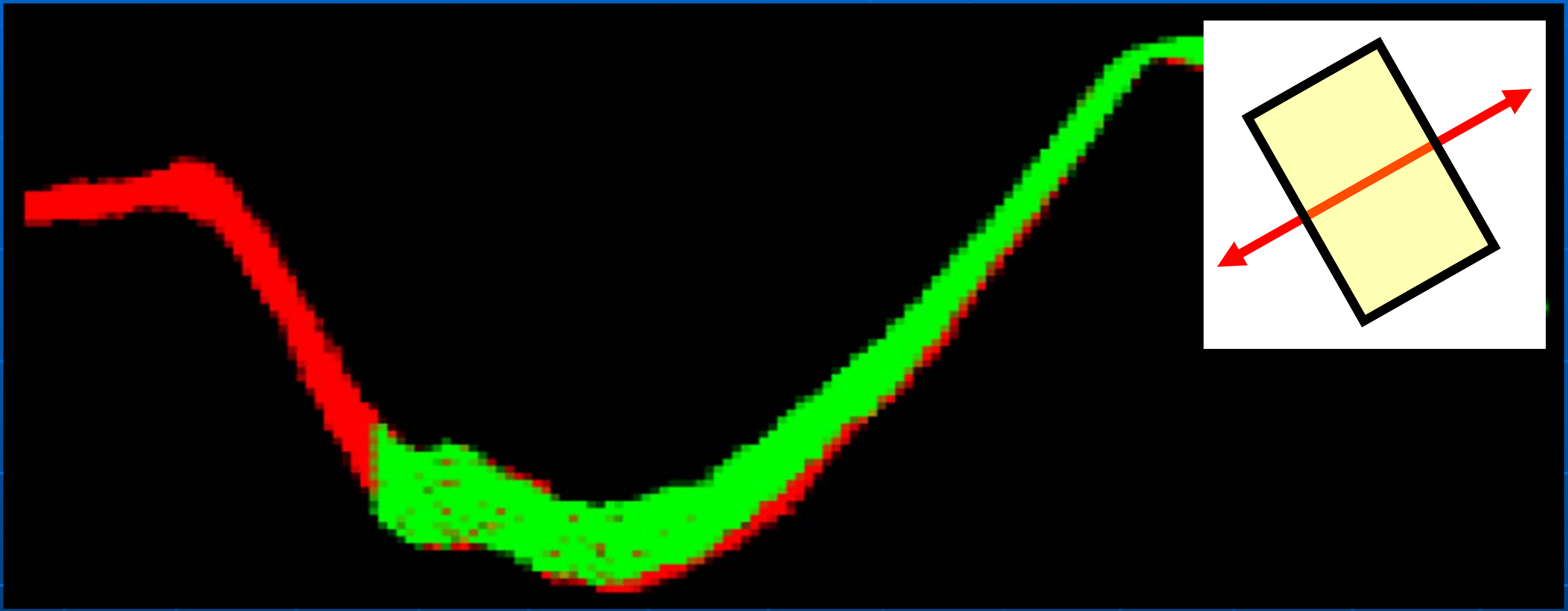
Present calibration practices: Sonar

Two methods – Using general bathymetric trends



Present calibration practices: Sonar

Two methods – Using general bathymetric trends

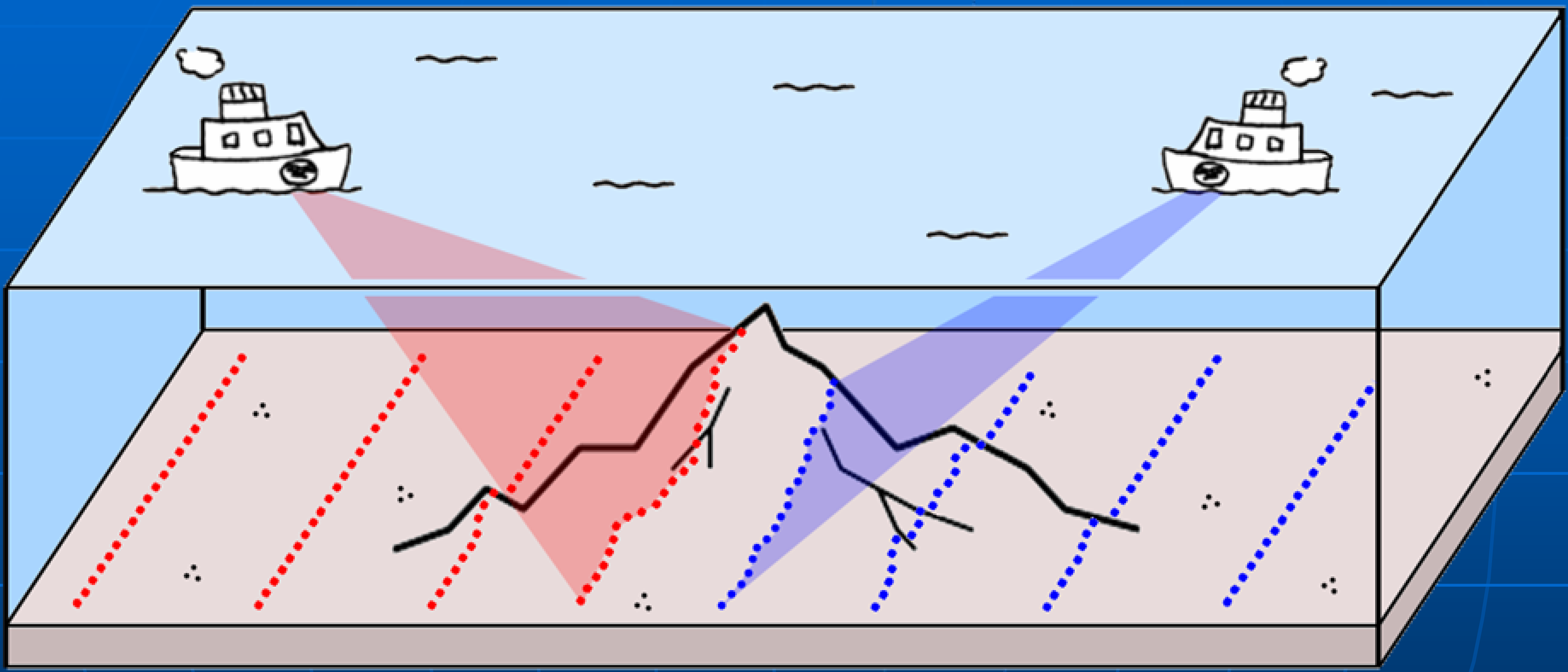


Disadvantages…

- Requires tightly controlled line plan
- Only a limited portion of swath can be used (without risking cross-talk)
- Subject to surveyor’s “eye ball”

Present calibration practices: Sonar

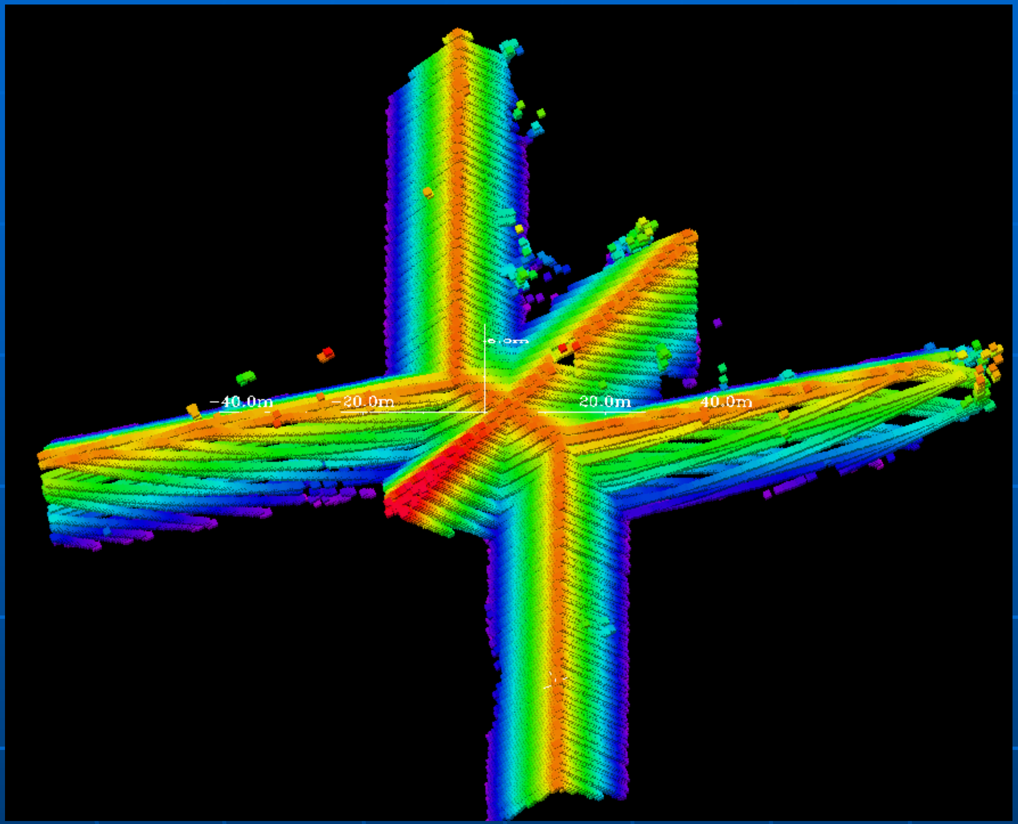
Two methods – Using prominent features

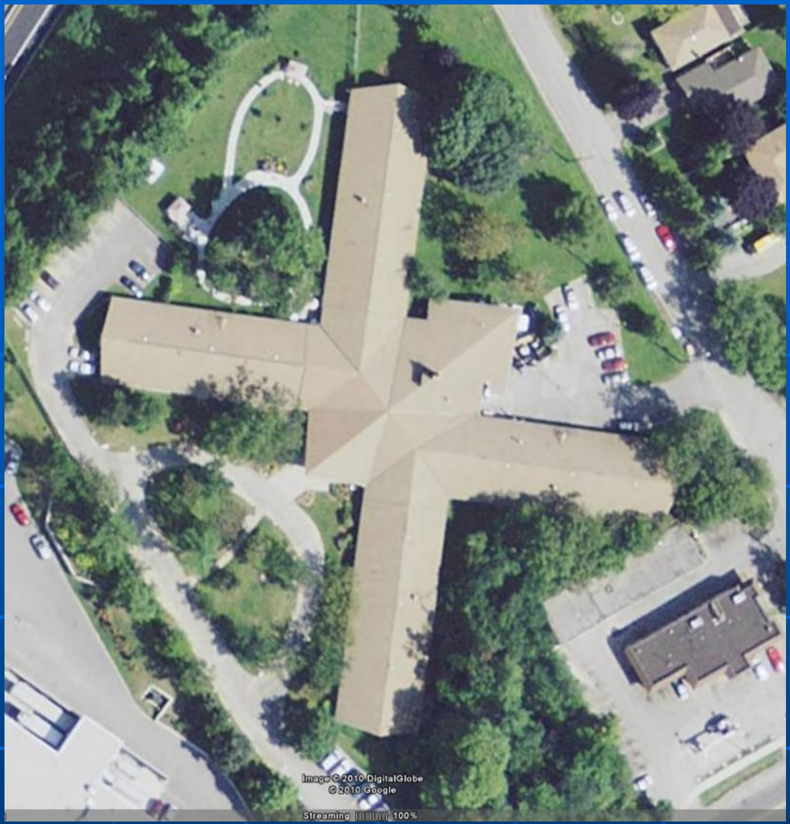


Disadvantages...

- Requires locating a suitable feature.
- A small number of pings contribute to solution.
- Assumes co-location of pings on opposing swaths.

Present calibration practices: Lidar



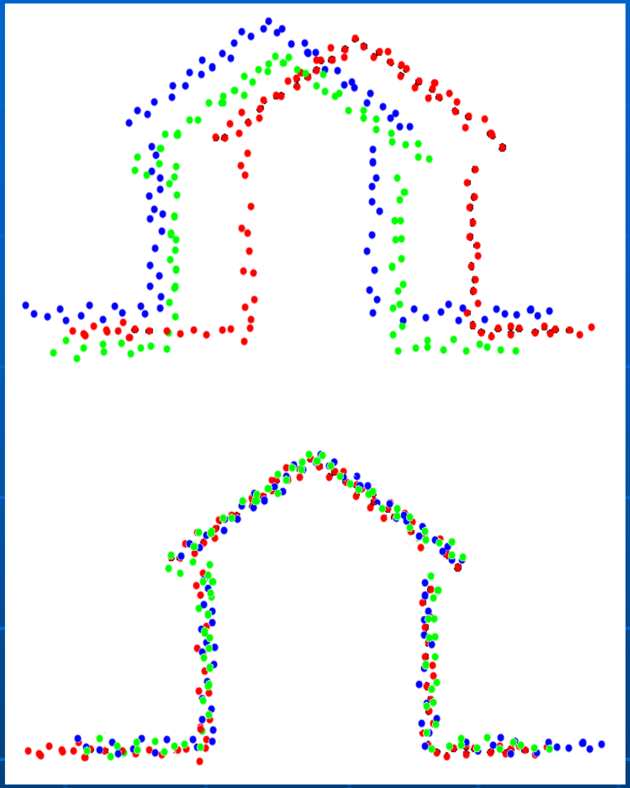


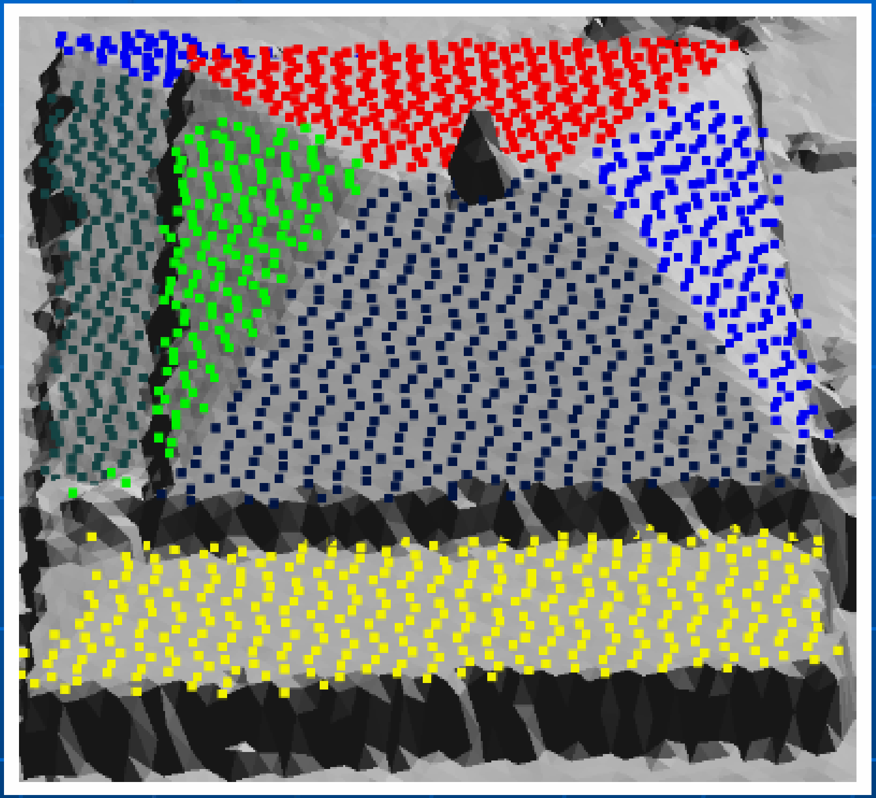
Advantages…

- Can be performed on land
    - No tide or sound velocity concerns
    - Simple to ground-truth

Images courtesy of Optech, Inc. and Google Earth

Present calibration practices: Lidar





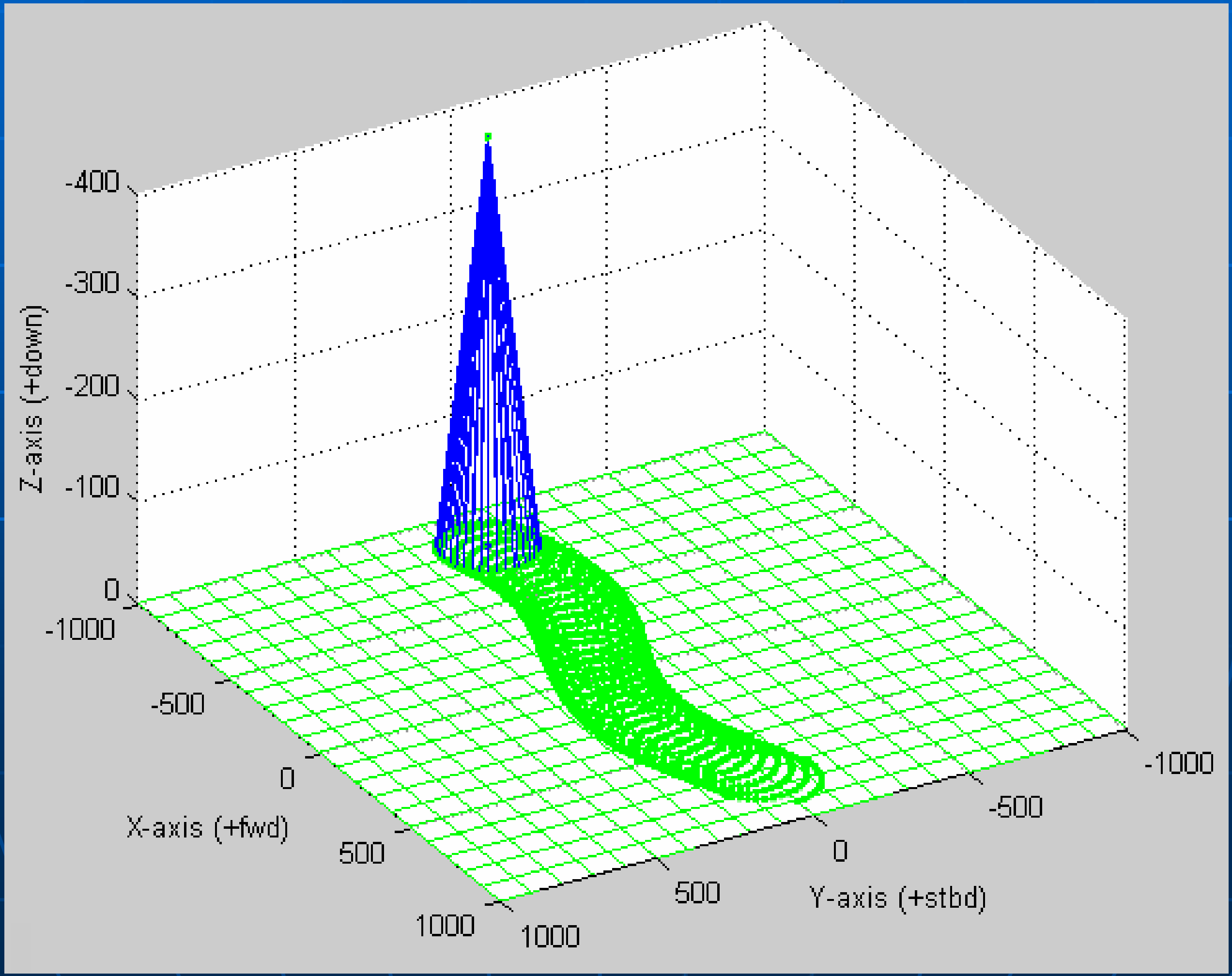
Disdvantages...

- Non-conjugate lidar points (requires adjustment to extracted features)
- Typically requires cultural features

Right image reproduced from Freiss (2006)

A new calibration approach

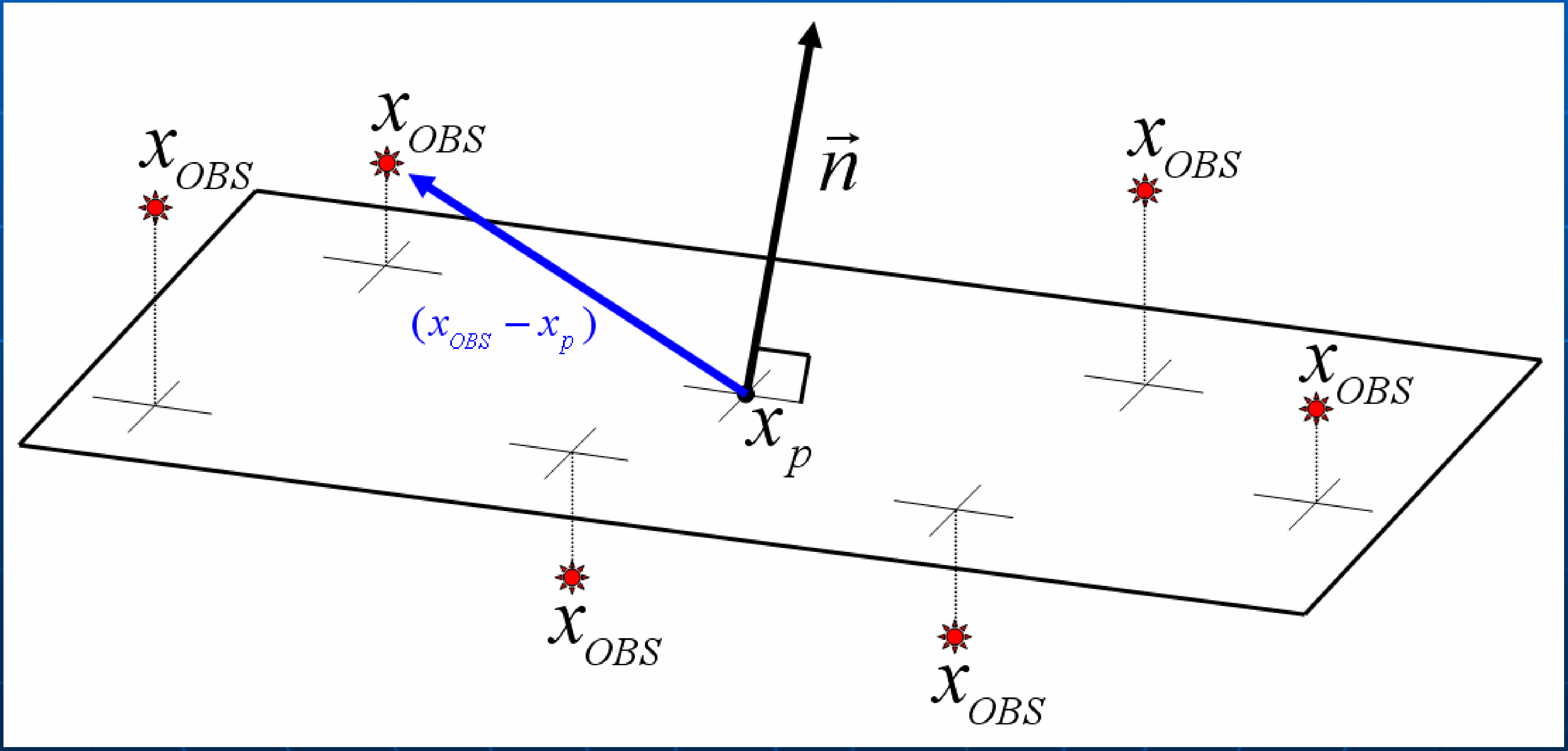
What if all the data was acquired over and adjusted to a single planar surface, like an airport runway (*or the ocean surface*)?



A weighted least-squares adjustment

Fitting the point cloud to a planar surface.

$$f(\vec{\ell}, \vec{x}) = \vec{n} \cdot \left(x_{OBS} - x_P \right)$$



A weighted least-squares adjustment

The gory details...

A generic function...

$$f(\vec{\ell},\vec{x}) = 0$$

Has a first-order approximation...

$$f(\vec{\ell},\vec{x}) \approx \underbrace{f(\vec{\ell}_0,\vec{x}_0)}_{\vec{g}} + \underbrace{(\vec{\ell}-\vec{\ell}_0)}_{\vec{r}} \underbrace{\left.\frac{\partial f}{\partial \ell}\right|_{\vec{\ell}=\vec{\ell}_0,\vec{x}=\vec{x}_0}}_{\mathbf{D}} + \underbrace{(\vec{x}-\vec{x}_0)}_{\vec{\delta}} \underbrace{\left.\frac{\partial f}{\partial x}\right|_{\vec{\ell}=\vec{\ell}_0,\vec{x}=\vec{x}_0}}_{\mathbf{A}} \approx 0$$

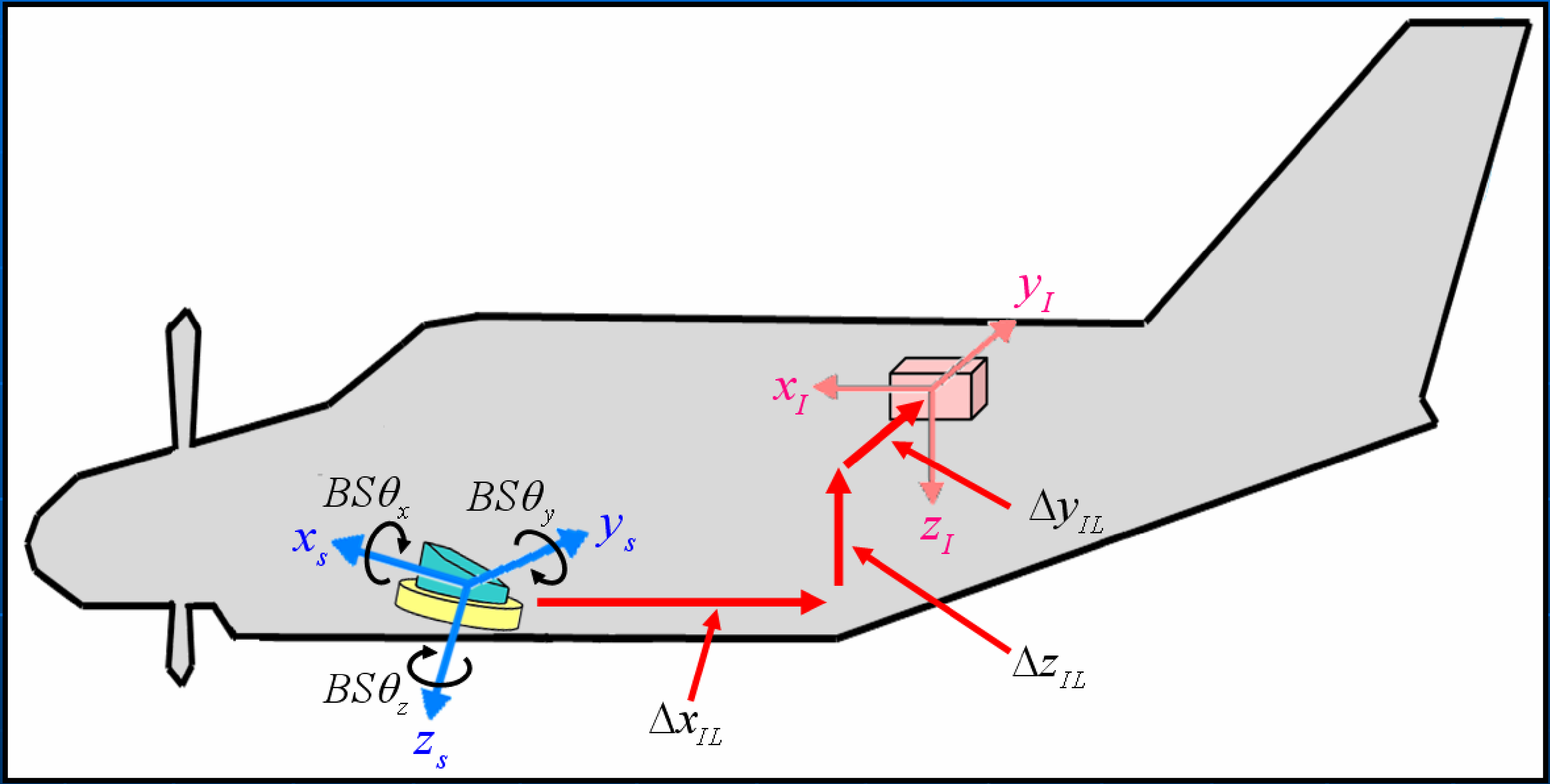
$$f(\vec{\ell},\vec{x}) \approx \vec{g} + \mathbf{D}\vec{r} + \mathbf{A}\delta \approx 0$$

Which has an iterative approximation for $\vec{x}$ of...

$$\vec{\delta} = \left(\mathbf{C}_{x_0}^{-1} + \mathbf{A}^T\left(\mathbf{D}\mathbf{C}_\ell\mathbf{D}^T\right)^{-1}\mathbf{A}\right)^{-1}\mathbf{A}^T\left(\mathbf{D}\mathbf{C}_\ell\mathbf{D}^T\right)\vec{g}$$

A geometric argument

Sensor reference frame to INS reference frame

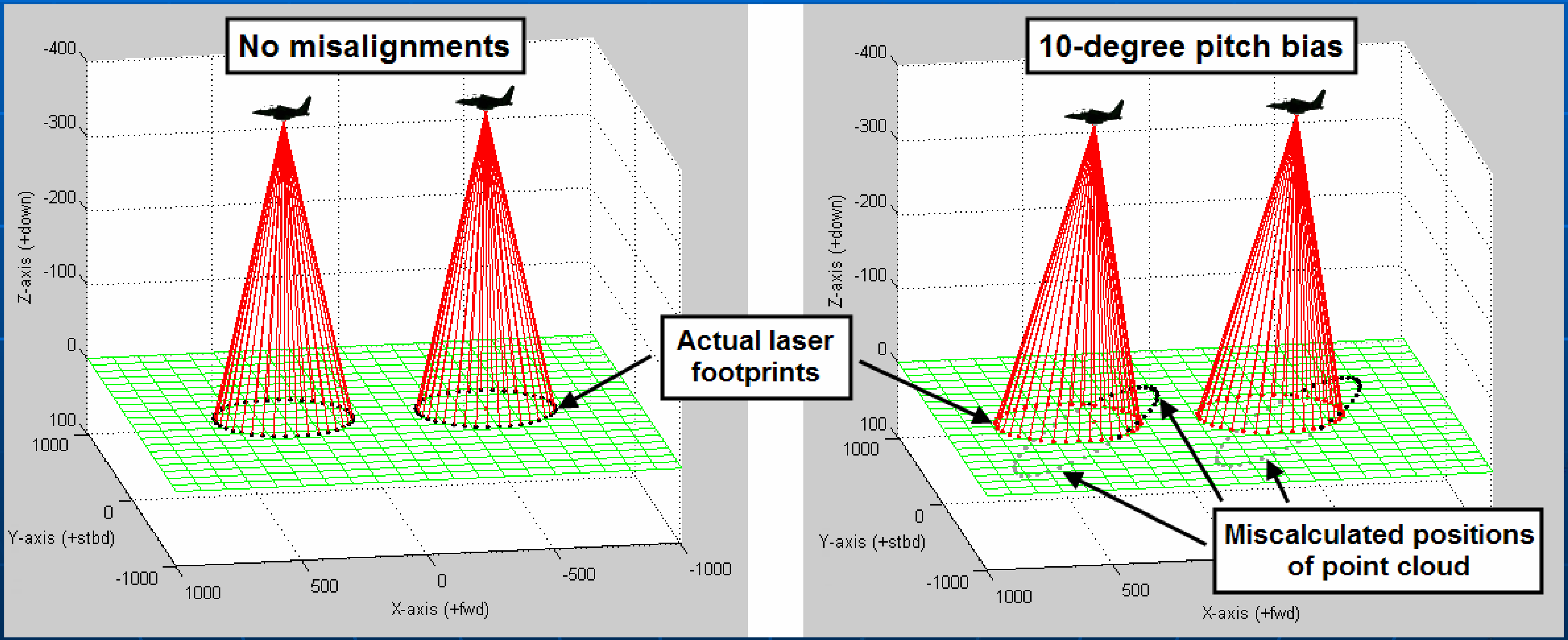


- Lidar = boresight misalignments
- Sonar = patch test values

A geometric argument

Fitting the data to a planar surface

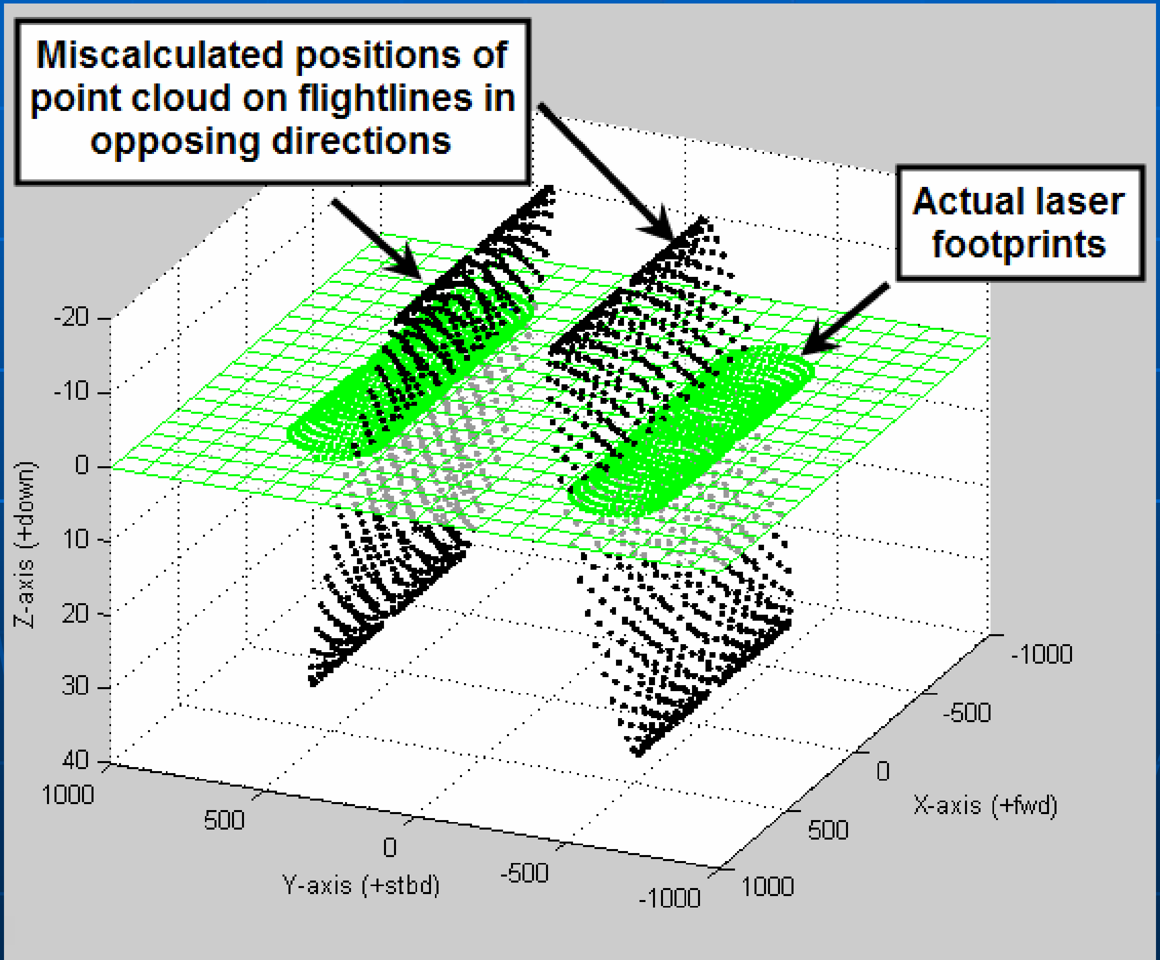
- Data is initially acquired over a flat surface
- Adjustment procedure is then designed to fit data to a planar surface.



Pitch!

A geometric argument

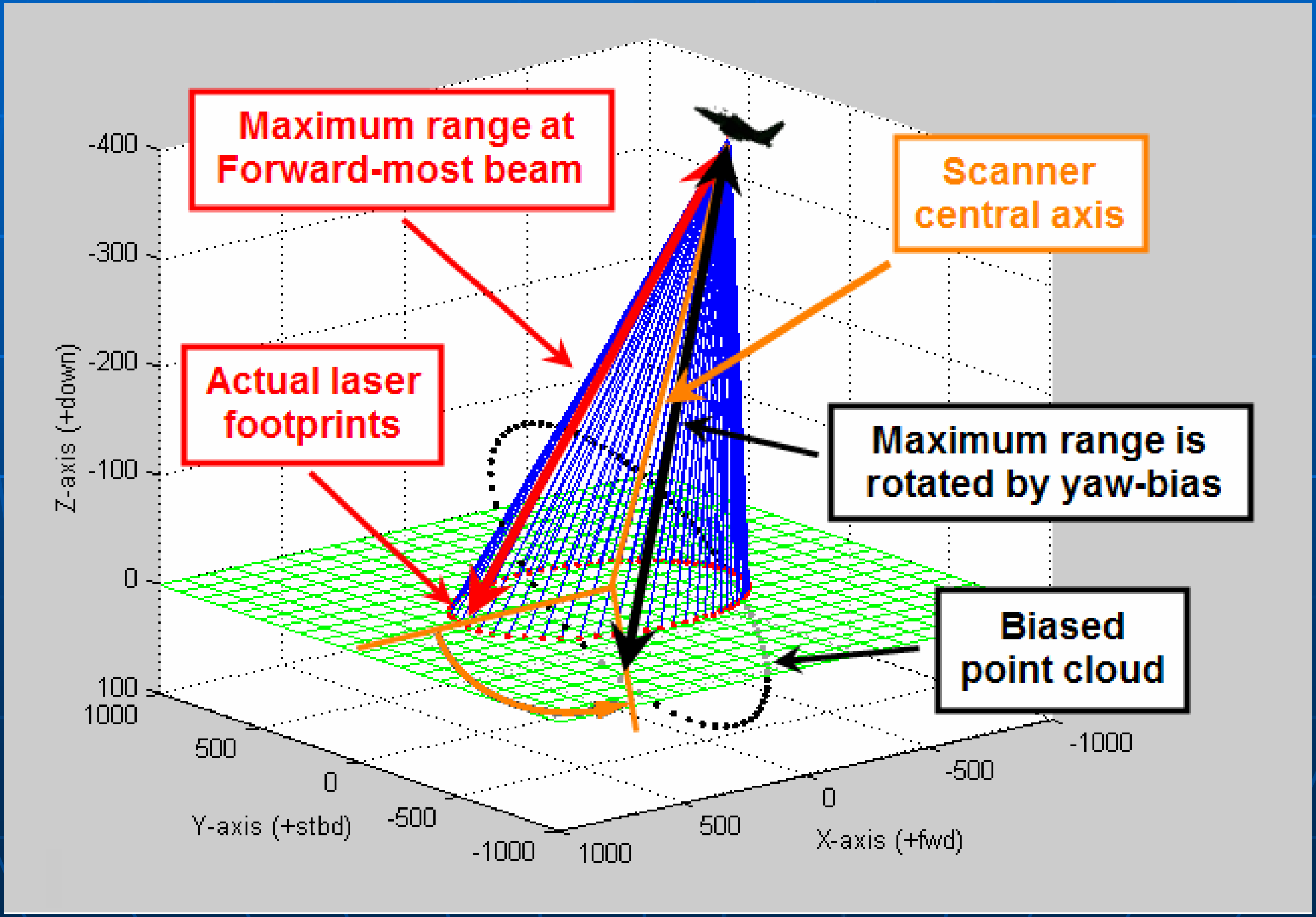
- A single, straight flight line will not yield enough information to extract the roll boresight misalignment.
- The popular approach is to fly opposing flight lines, *although…*



Roll!

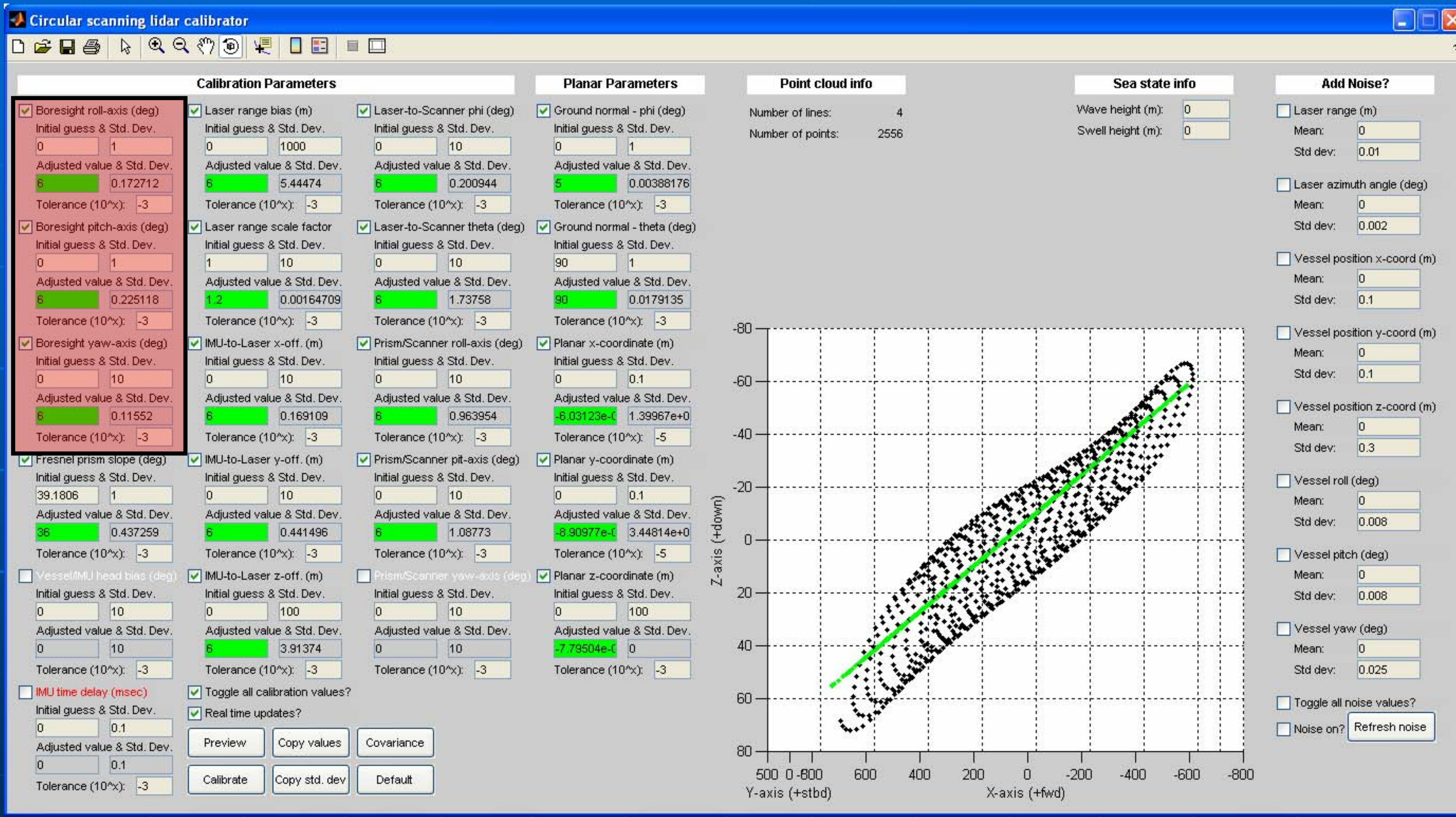
A geometric argument

- Even heading boresight misalignments can be determined from a flat featureless surface – provided the vessel surveys with ~attitude~ (not altitudes)



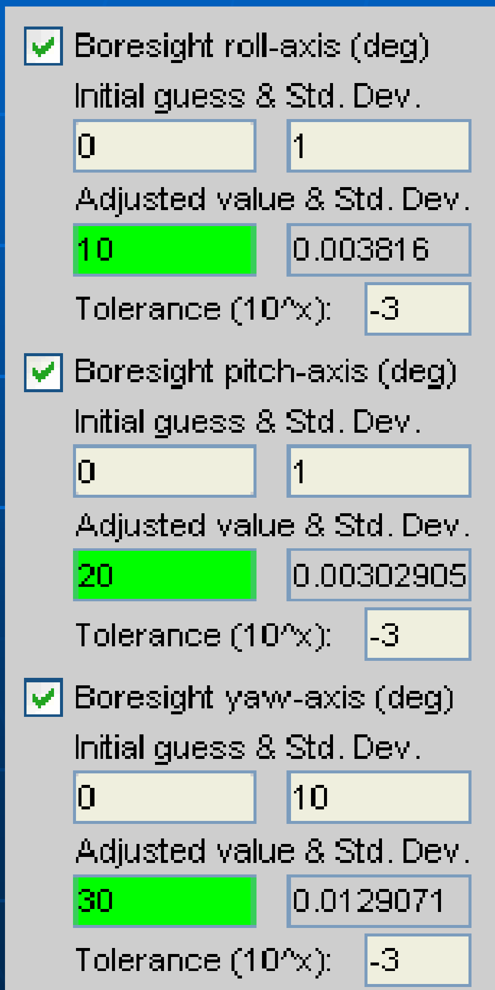
Yaw!

The Geometric Calibrator



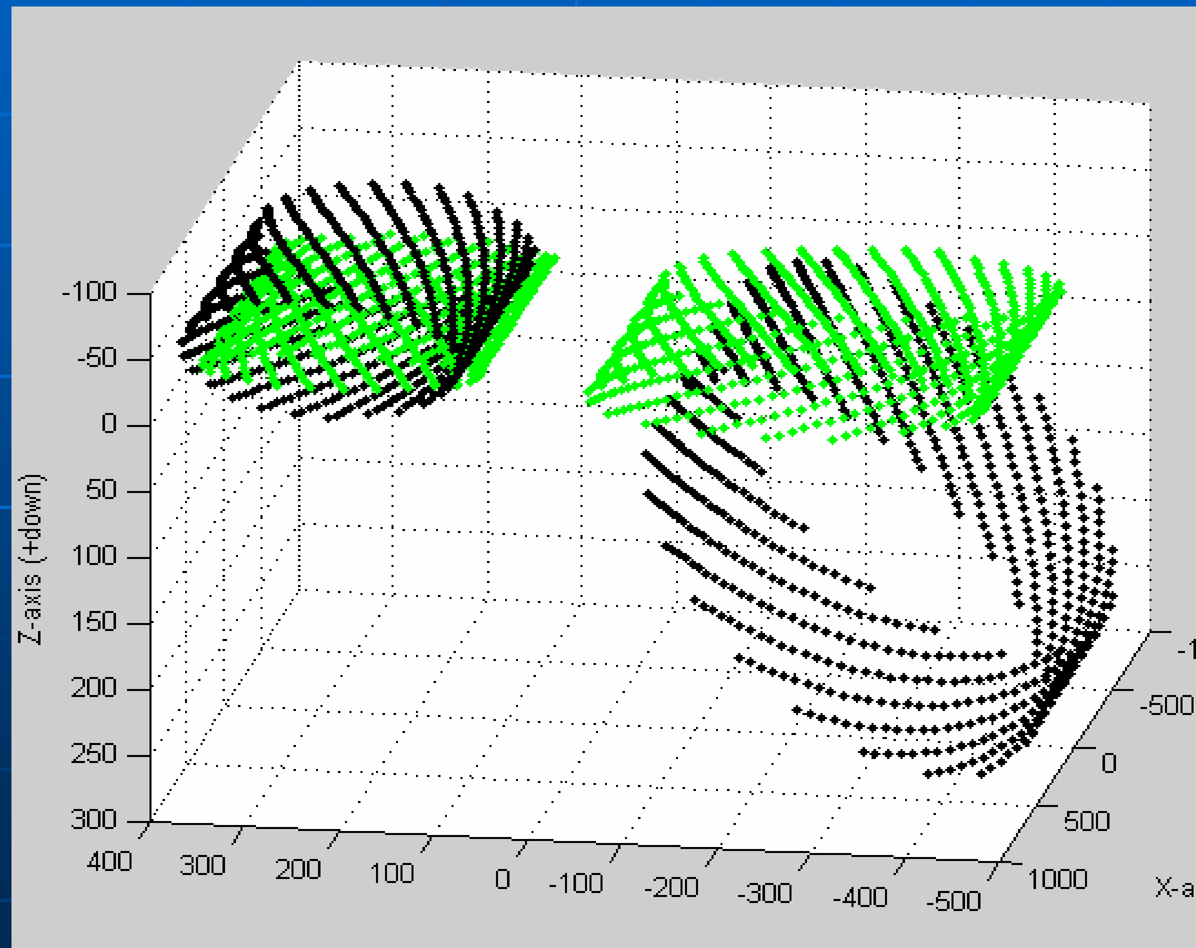
The calibrator in action

- Misalignments: 10° roll, 20° pitch, 30° yaw biases
- Flight plan: Two lines – opposite heading (0° & 180°) and opposite attitude (± 20° pitch)


Boresight roll-axis (deg)
Initial guess & Std. Dev.
0 | 1
Adjusted value & Std. Dev.
10 | 0.003816
Tolerance (10^x): -3

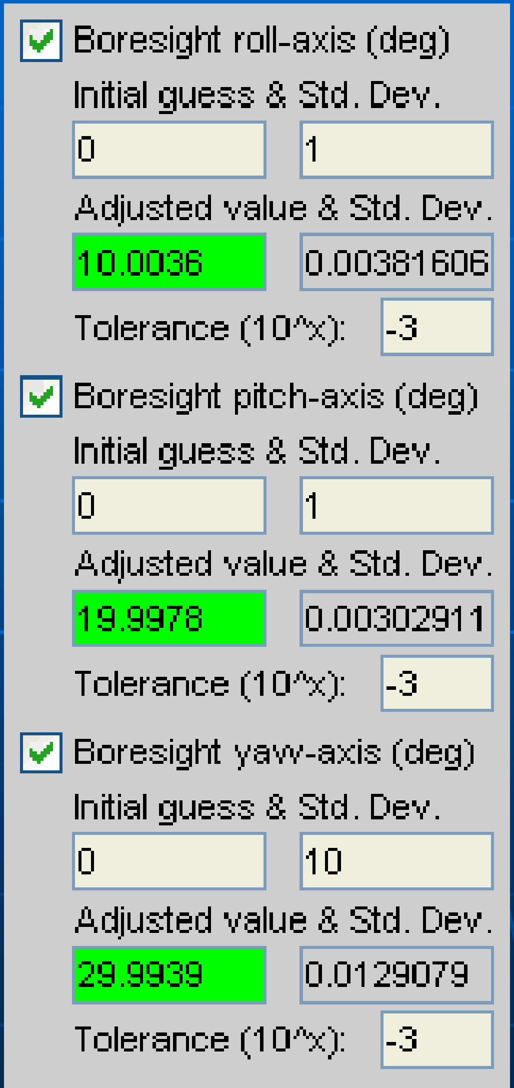
Boresight pitch-axis (deg)
Initial guess & Std. Dev.
0 | 1
Adjusted value & Std. Dev.
20 | 0.00302905
Tolerance (10^x): -3

Boresight yaw-axis (deg)
Initial guess & Std. Dev.
0 | 10
Adjusted value & Std. Dev.
30 | 0.0129071
Tolerance (10^x): -3



Also works with noisy data

- Anticipated sensor noise added to all observations

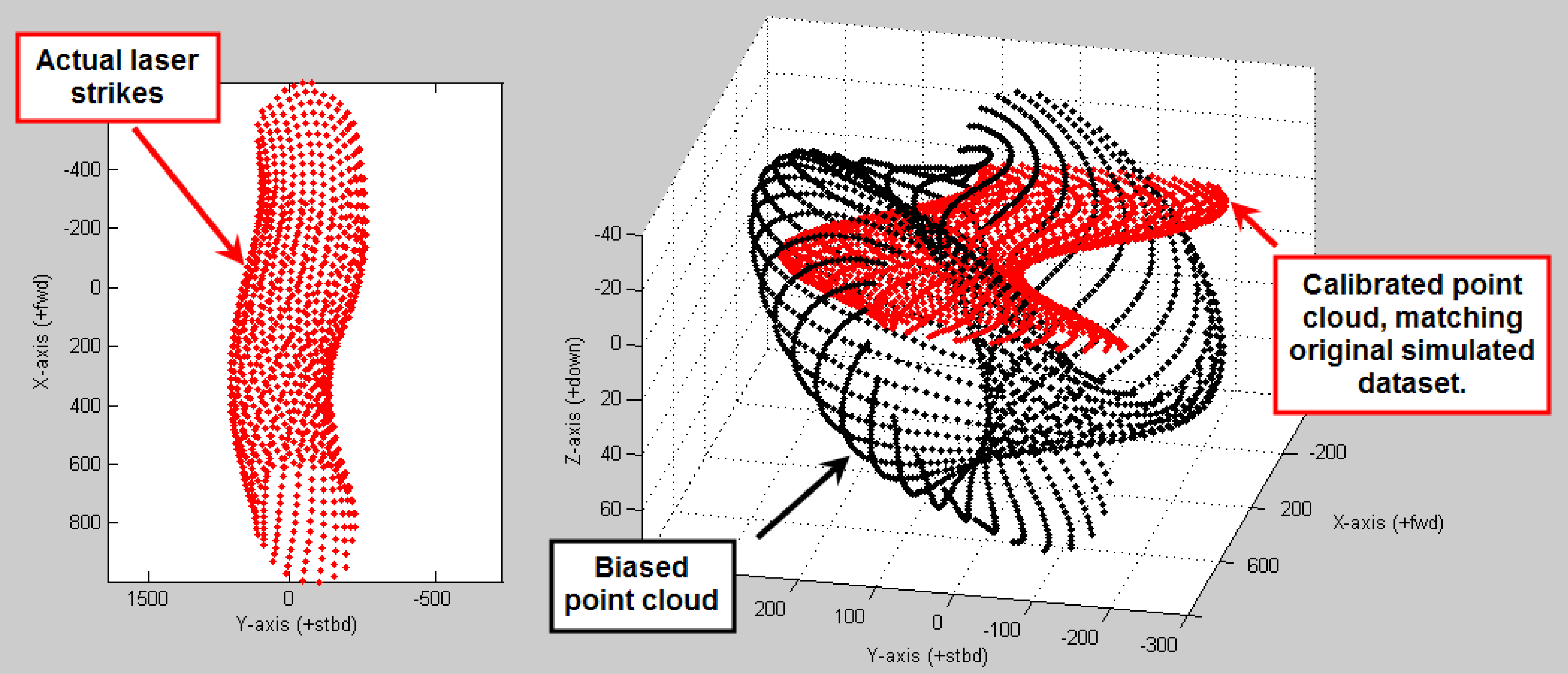


Measurement noise (1-sigma) for various system components	
Laser range (m)	0.01
Laser azimuth (deg)	0.002°
GPS x-position (m)	0.10
GPS y-position (m)	0.10
GPS z-position (m)	0.30
Vessel roll (deg)	0.008°
Vessel pitch (deg)	0.008°
Vessel yaw (deg)	0.025°

Uncertainty estimates from
POS AV 410 (with post processing)

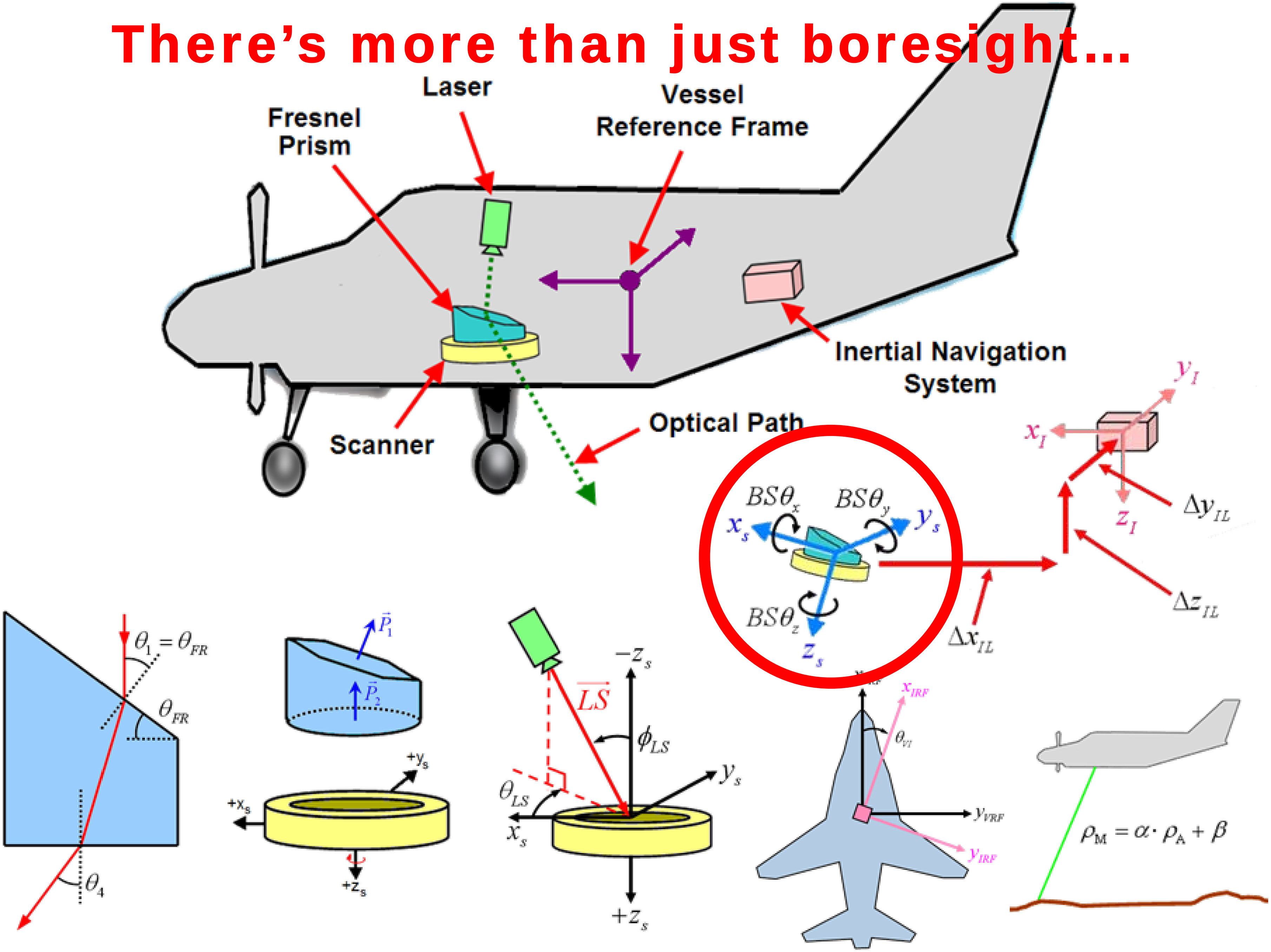
Calibration of a single wiggly flight line

- Rather than flying multiple directions, the roll bias can be determined provided the aircraft just changes heading.



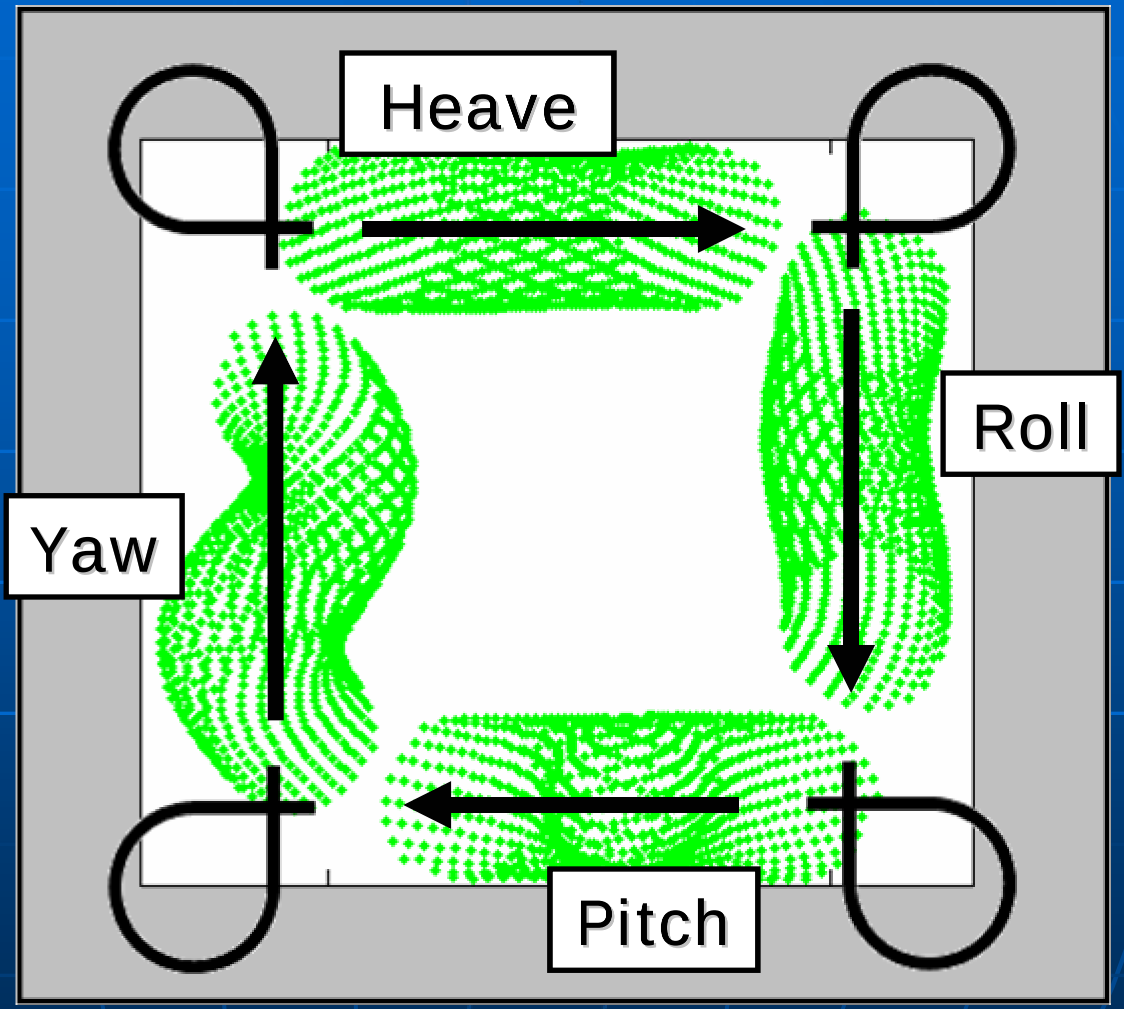
- The greater the change, the better the results and more confident the reported uncertainty.

There's more than just boresight…



There's more than just boresight…

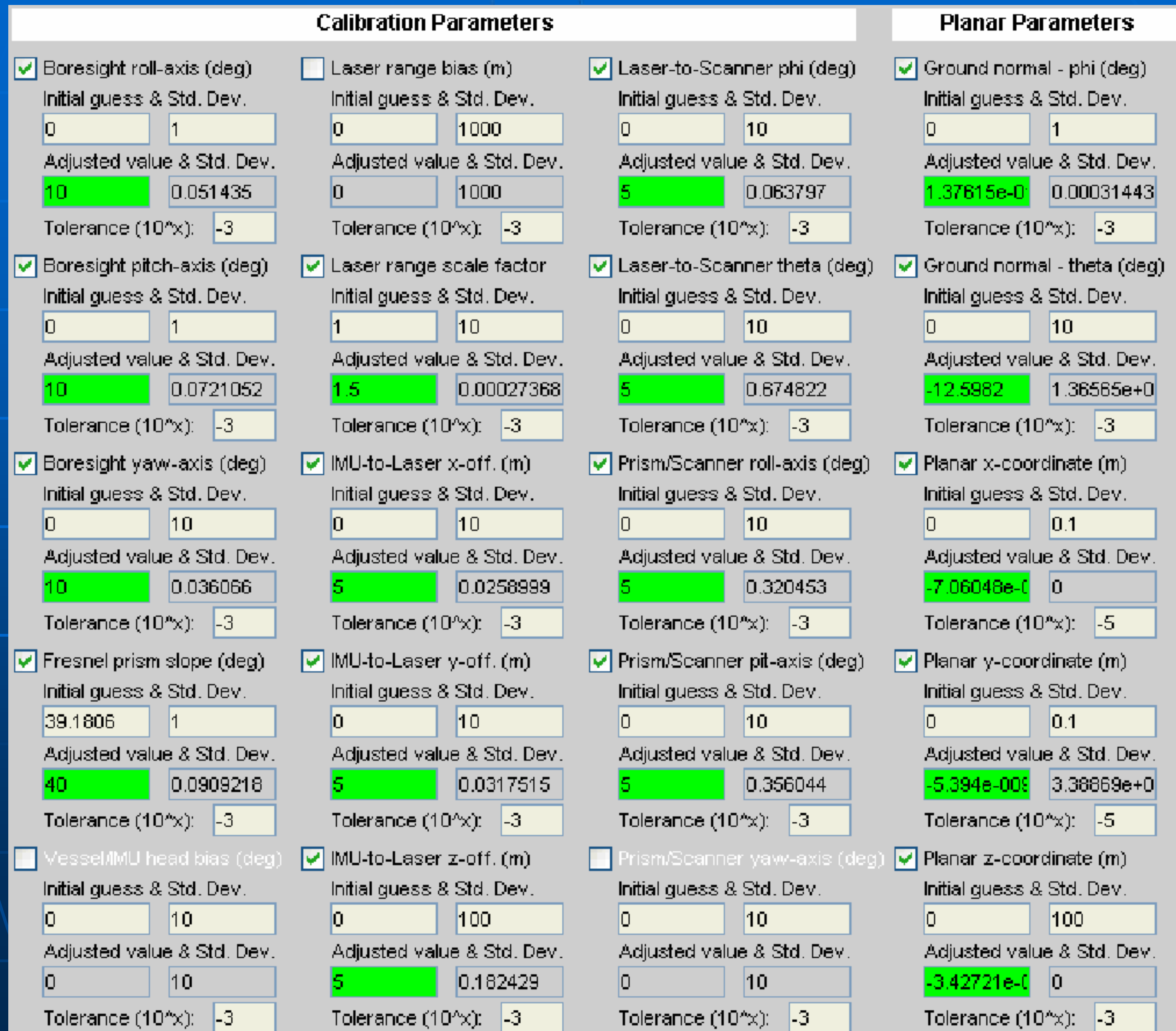
- 4 flight lines (36K points)
- Rolling, Yawing, Pitching, Heaving
- 12 calibration parameters



Replay at 20x normal speed

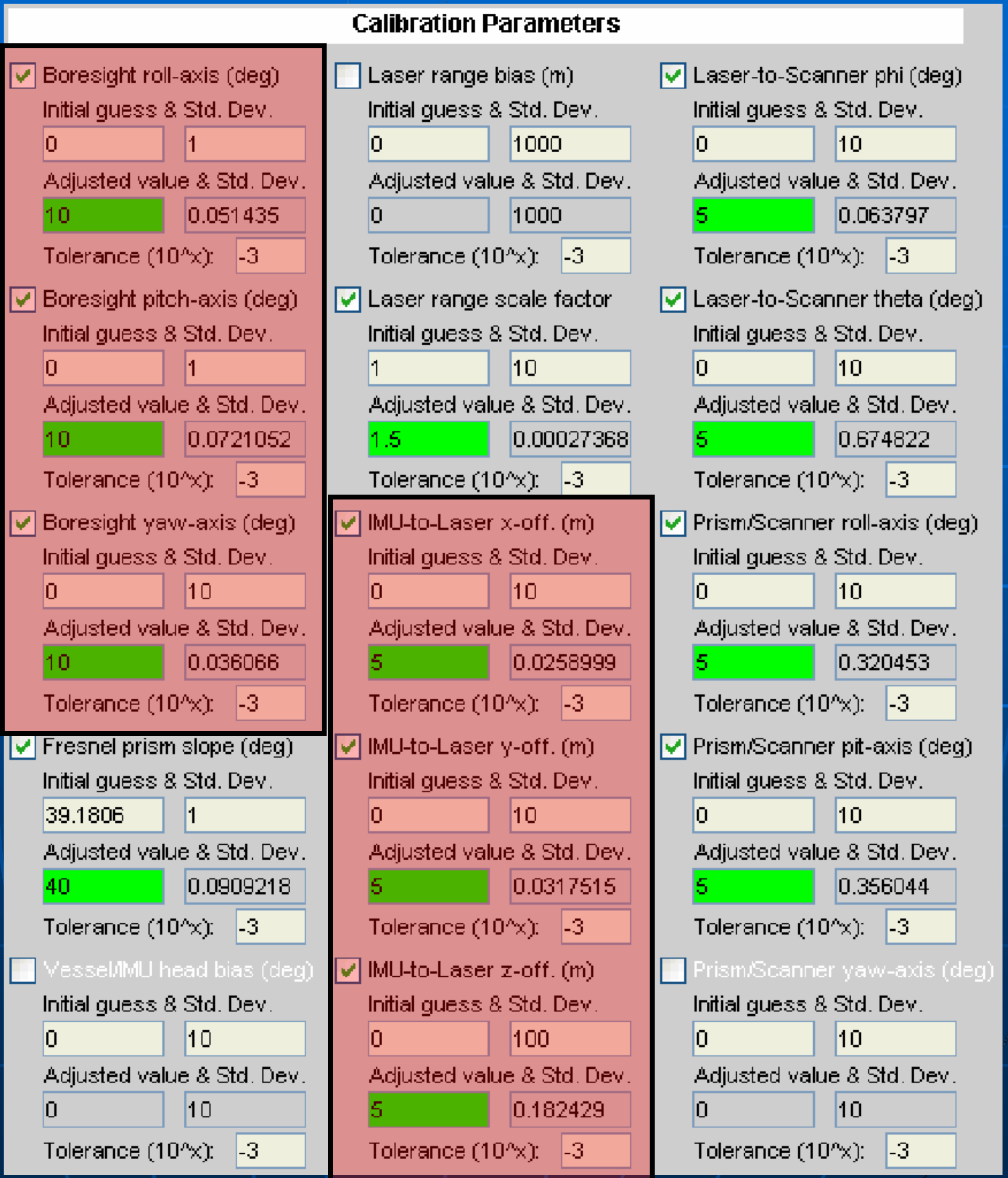
There's more than just boresight…

- 4 flight lines (36K points)
- Rolling, Yawing, Pitching, Heaving
- 12 calibration parameters



There's more than just boresight…

- 4 flight lines (36K points)
- Rolling, Yawing, Pitching, Heaving
- 12 calibration parameters



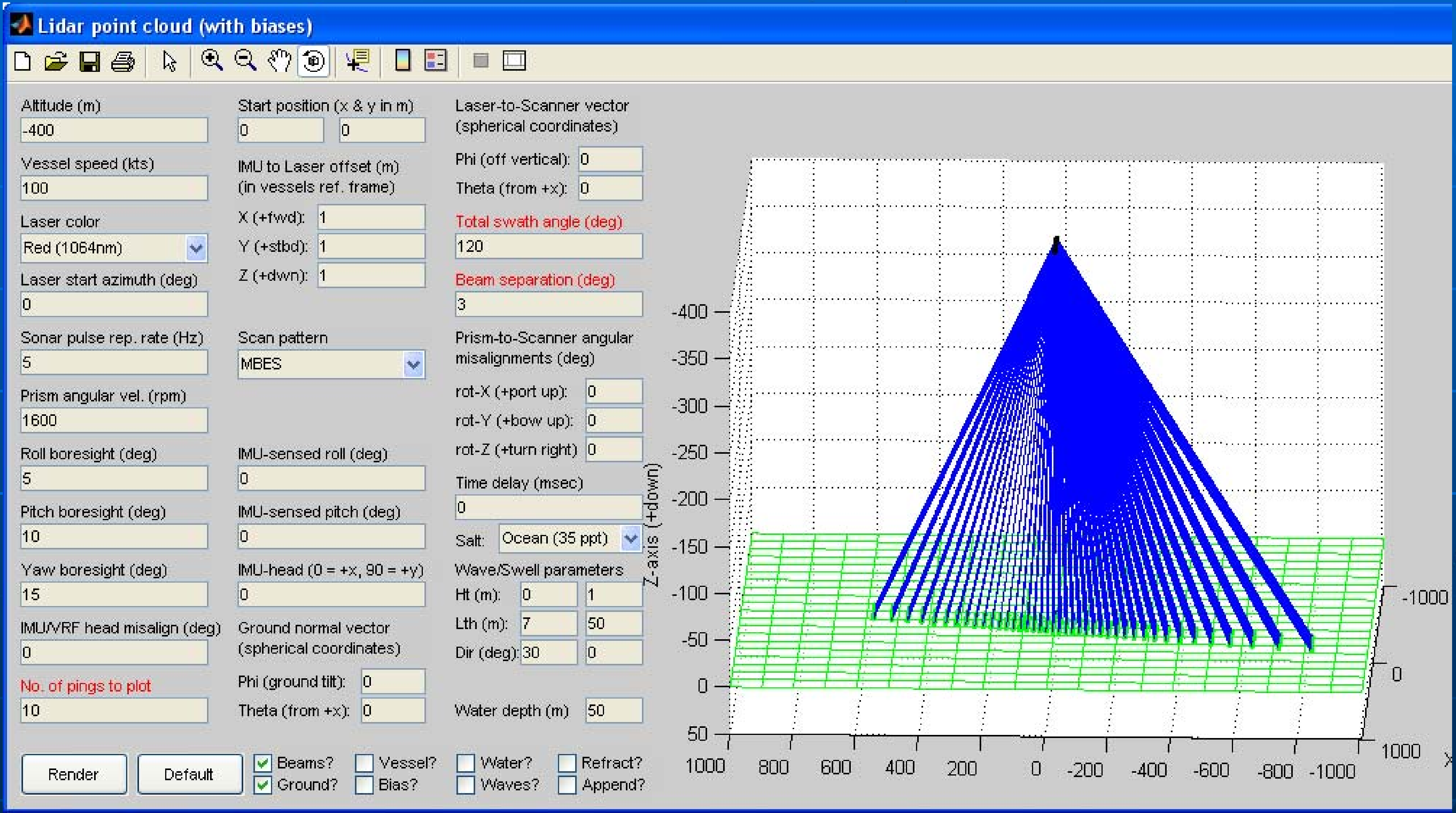
Advantages to a weighted least-squares adjustment model

- Simultaneous adjustment of several parameters from a *single* dynamic flight line (yet flexible in number of parameters pursued)
- Produces uncertainty estimates for calibration parameters (used to initialize a TPU model)
- Automated, objective method
- Covariance matrix shows correlation among parameters
- Examination of residuals can identify fliers

- Potential *real-time* calibration (no longer separating calibration lines and acquisition lines).
- Potential *background* calibration (system warns operator when a misalignment is detected)

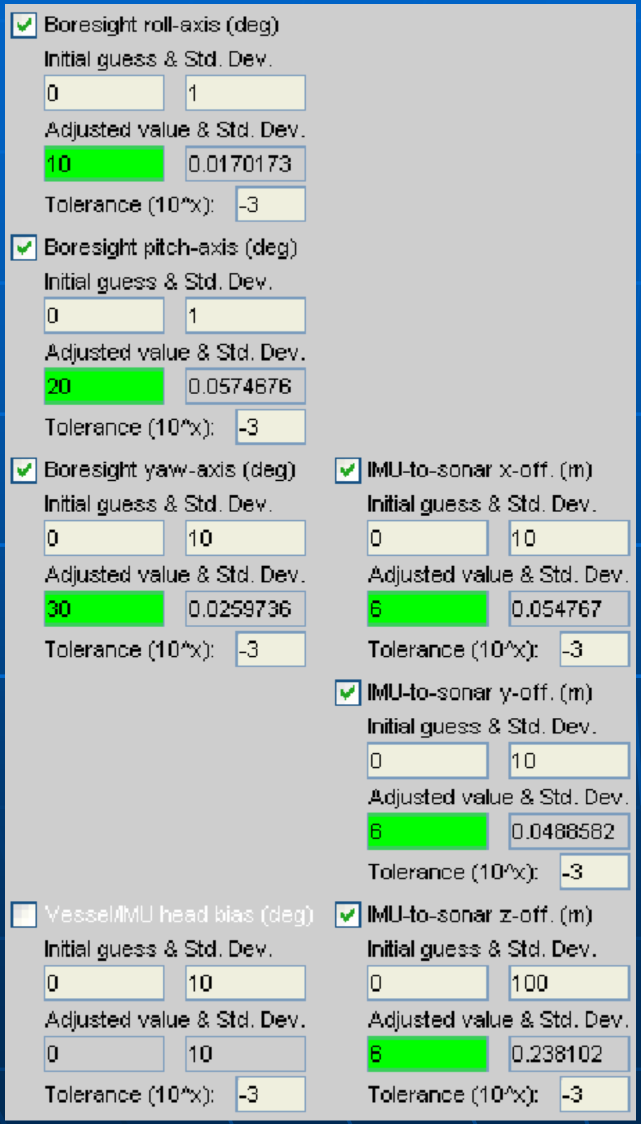
Bonus Content!!!

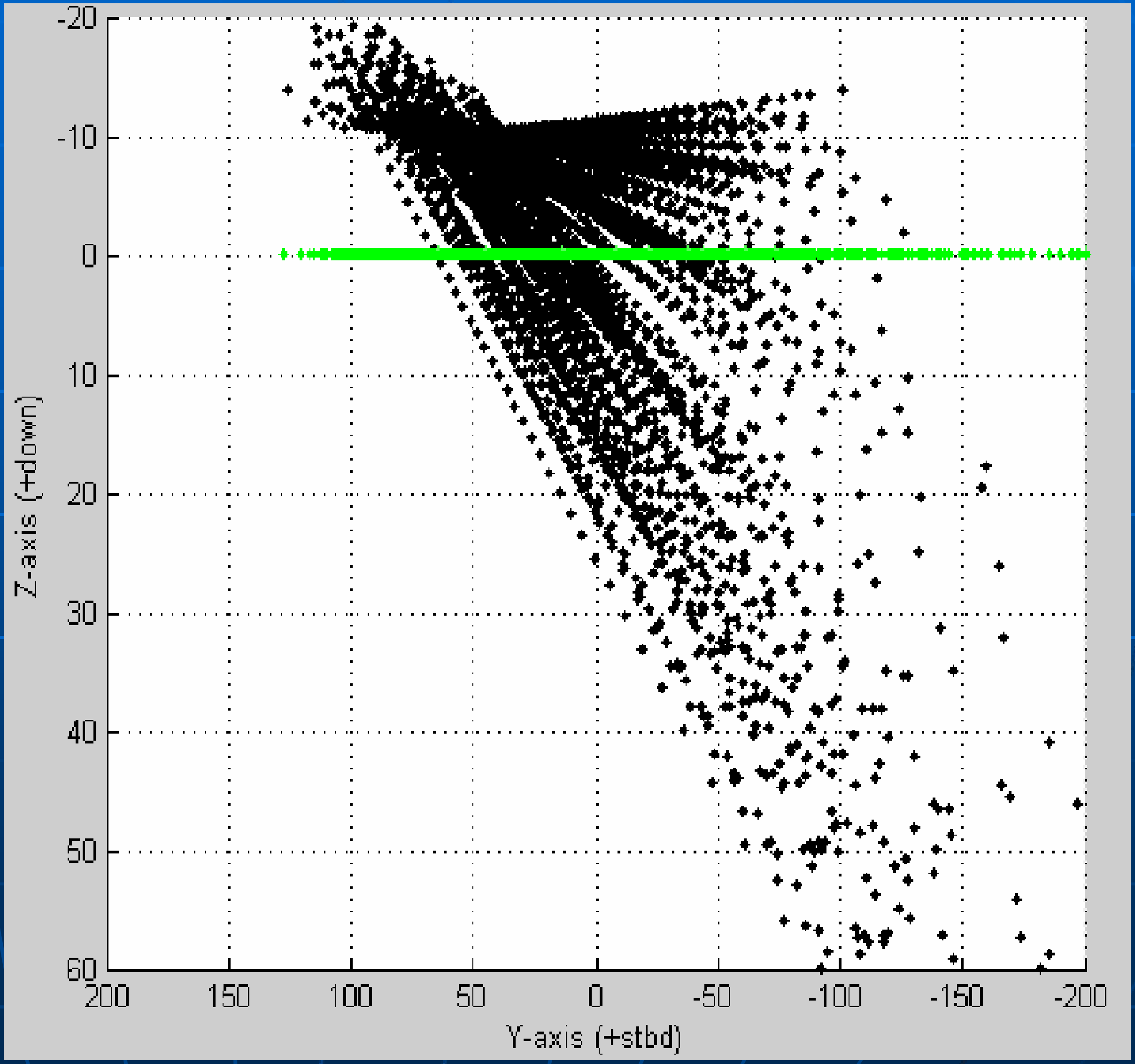
Potential applications to multibeam?...



Bonus Content!!!

Potential applications to multibeam?...





References…

- Calder, B. R. & McLeod, A. (2007). Ultraprecise absolute time synchronization for distributed acquisition systems. *IEEE Journal of Oceanic Engineering*, 32(4), 772-785.
- Freiss, P. (2006). Toward a rigorous methodology for airborne laser mapping. *International Calibration and Orientation Workshop EuroCOW*. Castelldefels, Spain.
- National Oceanic and Atmospheric Administration (2010). *Field Procedures Manual*, Maryland: U.S. Dept. of Commerce.

Questions?

michael.gonsalves@noaa.gov

Cool painting shamelessly photographed from Optech offices, 2010