Development, implementation, and verification of the

Loran TOA Measurement System

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Loran TOA measurement system

Why not an *ASF* measurement system?

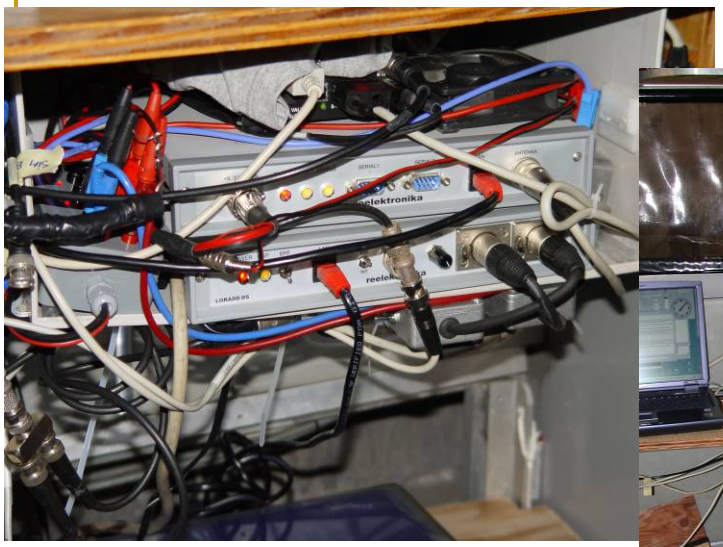
What is ASF?

- Local effects?
- Topography?
- Influence of altitude?

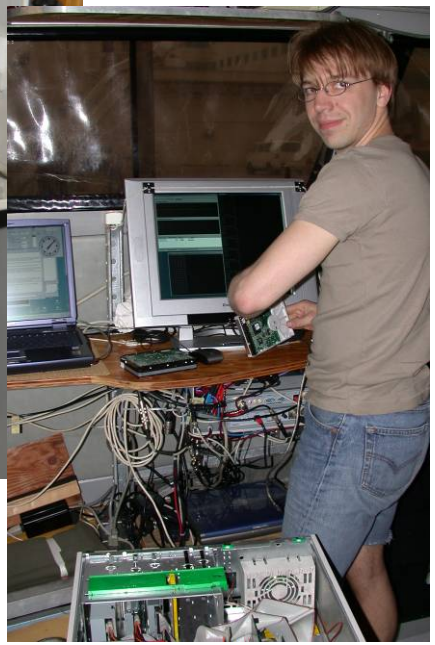
We measure the Loran TOAs with respect to UTC_{USNO} and can subtract PF + SF

Differential ASFs can be obtained by using a reference station (= stationary TMS)

Measurement equipment over the years



‘04 Tampa setup (maritime)



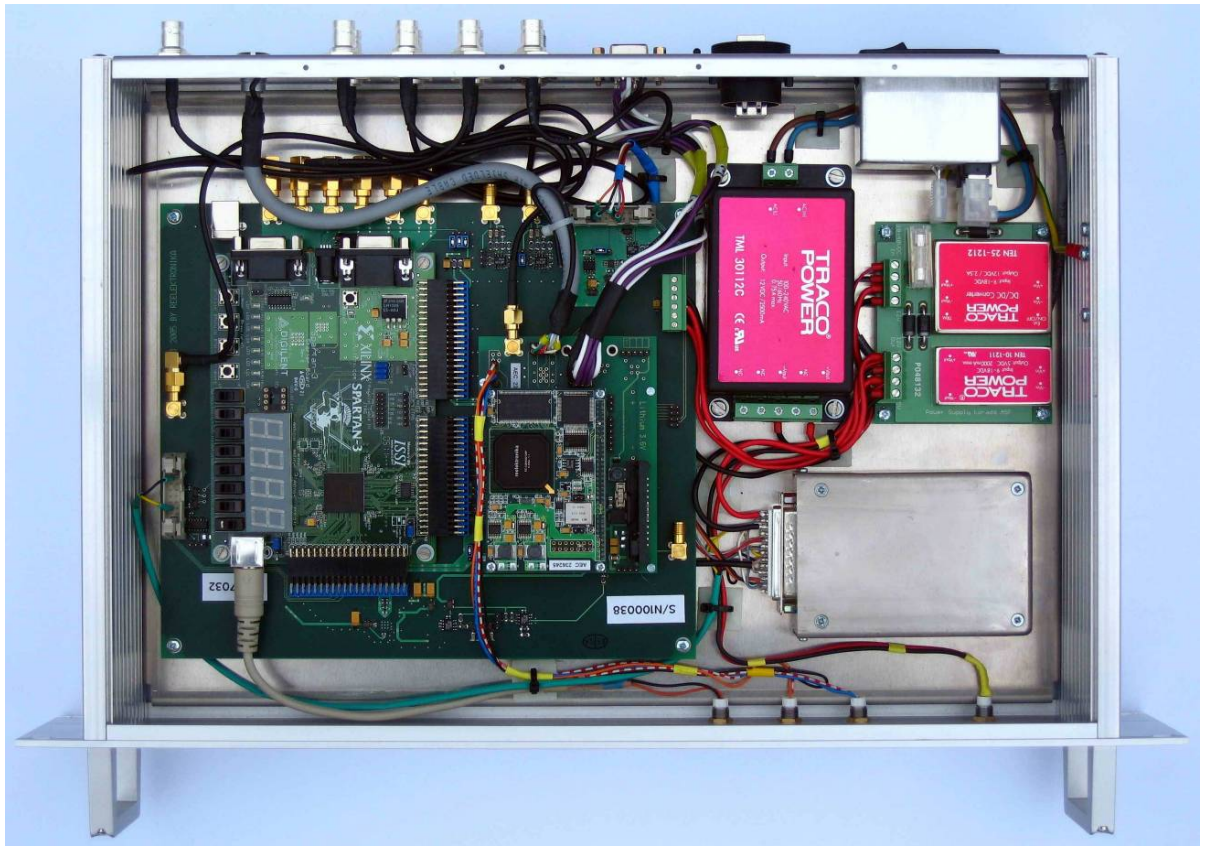
‘05 OU flight (aviation)

‘06 ASF Receiver (used for Harwich, maritime)

TMS design goals

- High quality TOA measurements
  - Advanced Loran signal processing
  - Accurate timing relation between GPS, Rb, and Loran receiver
  - Simulator for antenna calibration
- Reliable, Robust
- Turn-key, plug-and-play

Hardware development



Basis:
Reelektronika
Loradd-ASF Rx

Modifications:

- Improved PCB design
- Loran simulator output for continuous calibration of antenna and filter delays

Software development

- Tracking under high velocity
- Time and frequency domain Interference mitigation
- Station acquisition by UTC
- Continuous receiver calibration
  - AGC-correction
  - Processing of simulator response

Development and validation using live data (stationary / drive / fly) and raw data from e.g. December 05 flight test

System integration and validation

- Various antennas:
  - Reelektronika H-field
  - Locus H-field
  - Locus E-field
  - Apollo E-field
- Data collection setup
- Real-time performance validation
- Aircraft installation

Equipment validation: October flight test Ohio University

Objectives:

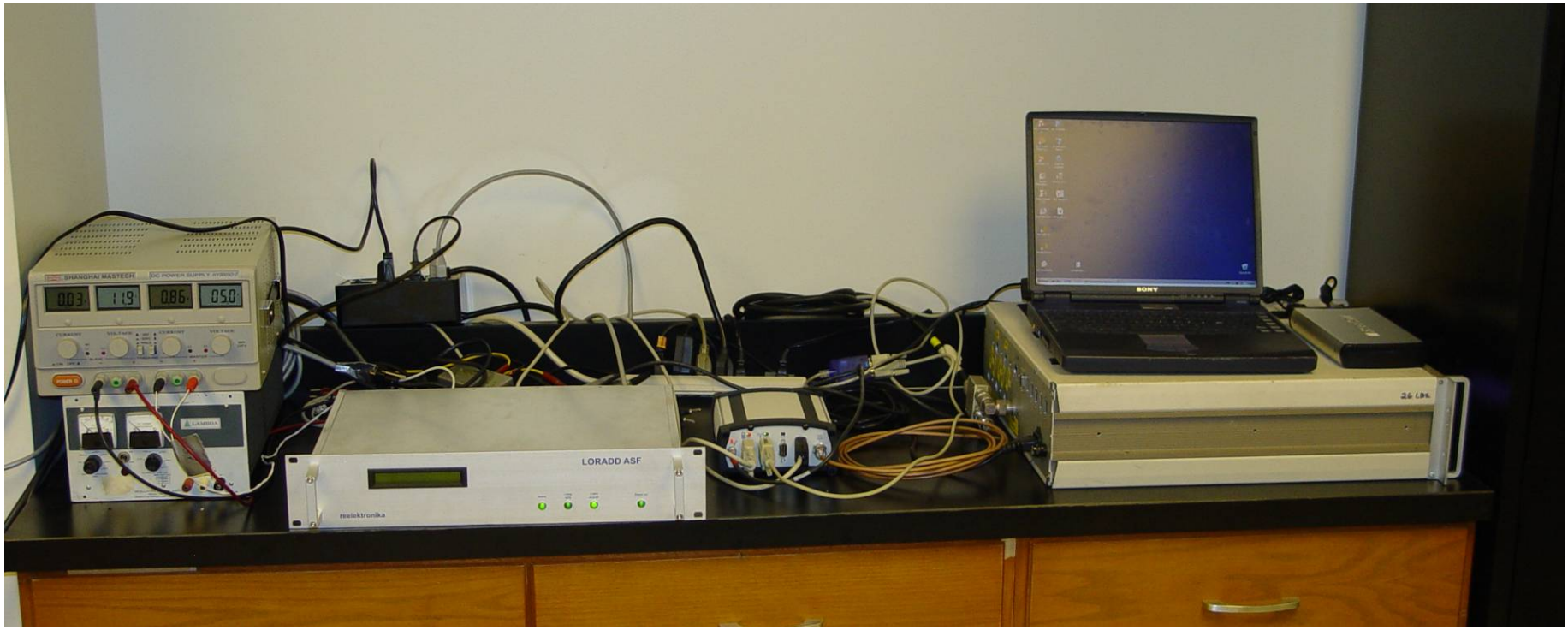
- Test of hardware platform by using modified Reelektronika ASF receiver
- Test of new firmware
- Assessment of overall system performance

Quality assessment by:

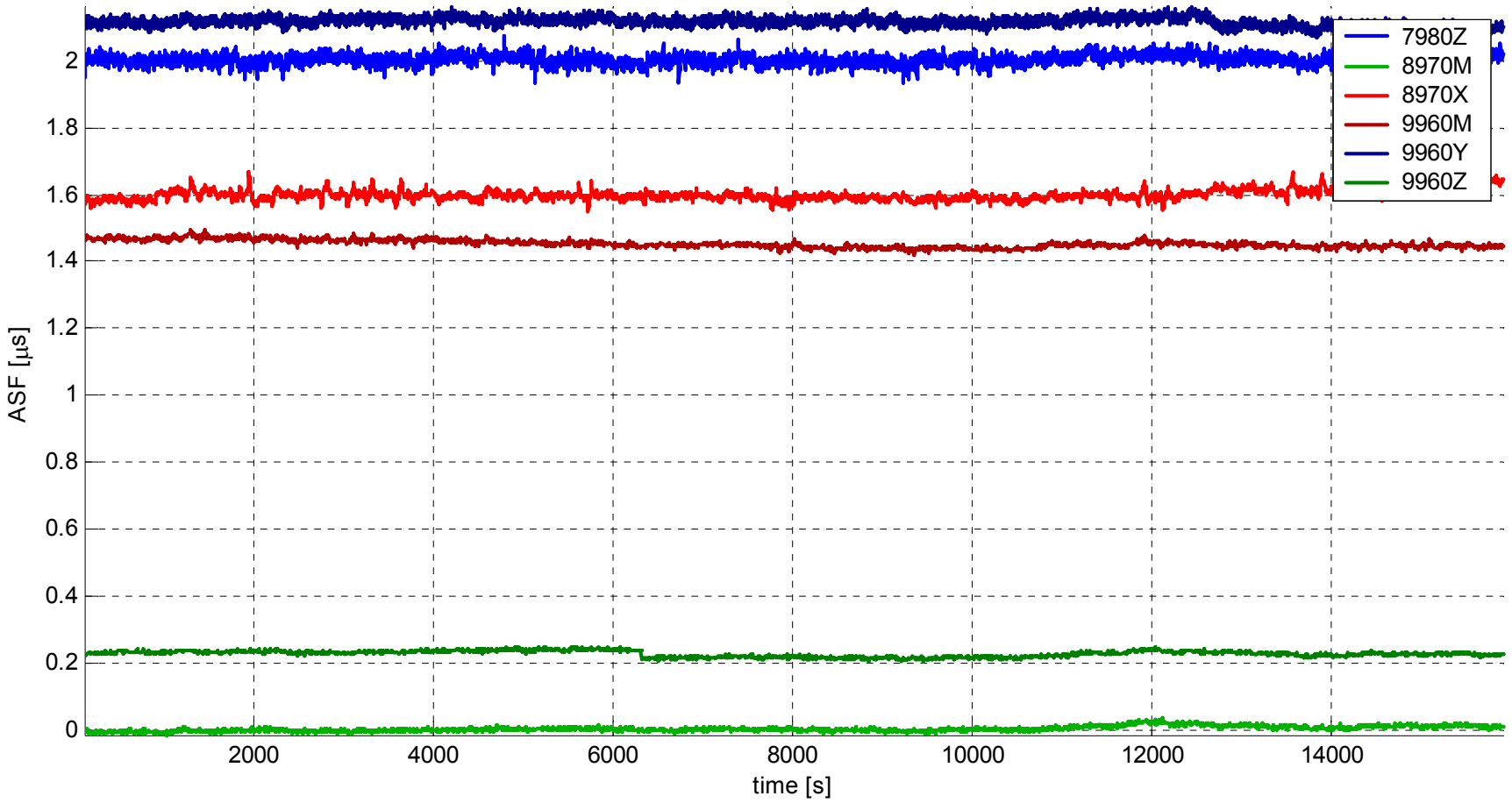
- Dual-rate repeatability
- Track-to-track repeatability
- Phase and position stability during circles
- Position error relative to GPS-WAAS

For this test we are primarily interested in equipment performance, *not* in “interesting” propagation phenomena. Although the latter may be scientifically interesting, it blurs the equipment performance validation

Reference station setup

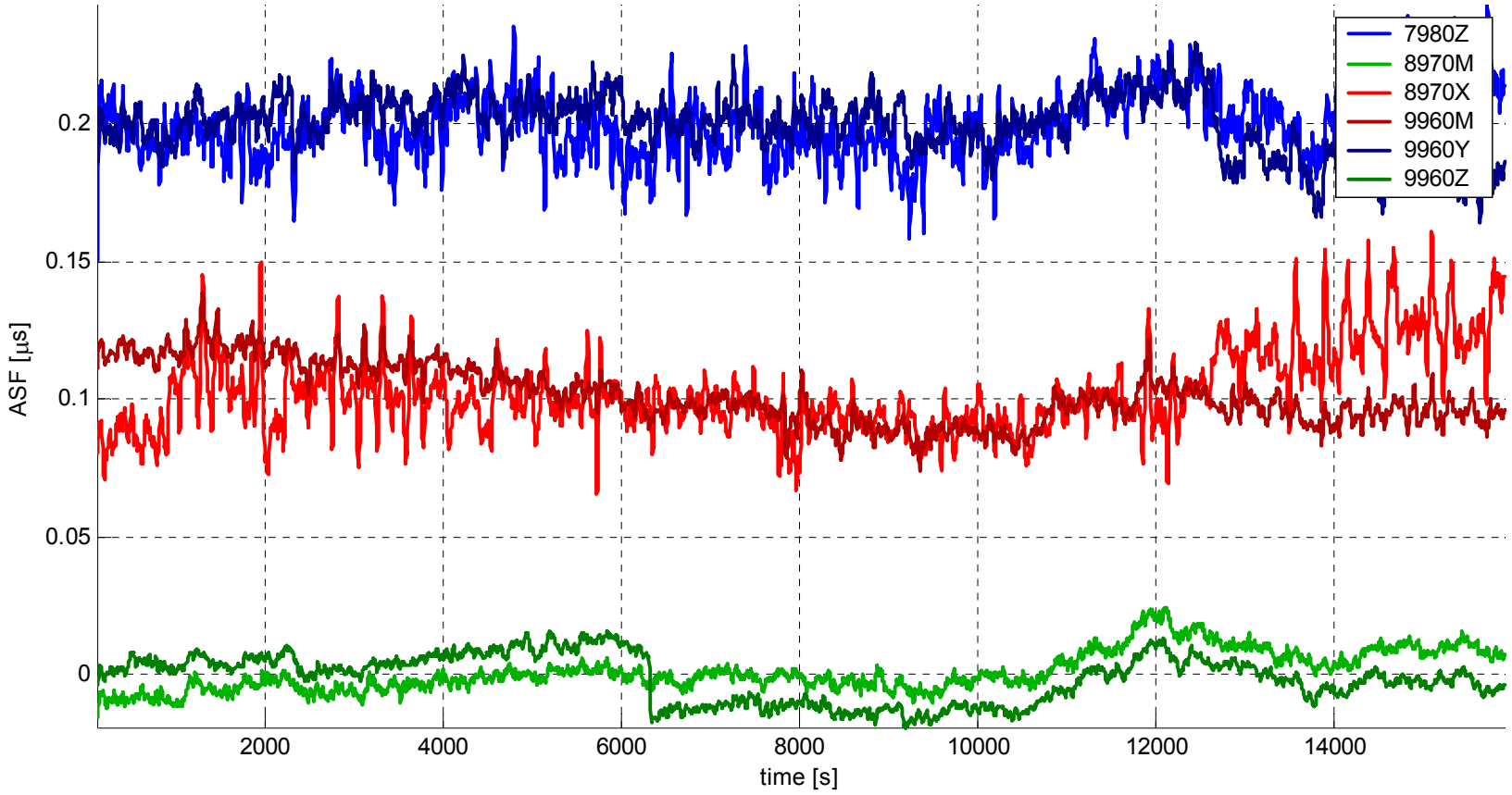


Reference station results – 5 sec average



Transmitter timing is incorrect: 2 stations from the same stick show different ASFs

Reference station results – 30 sec average



Offsets applied for better visualization

Airplane setup

OU Piper Saratoga

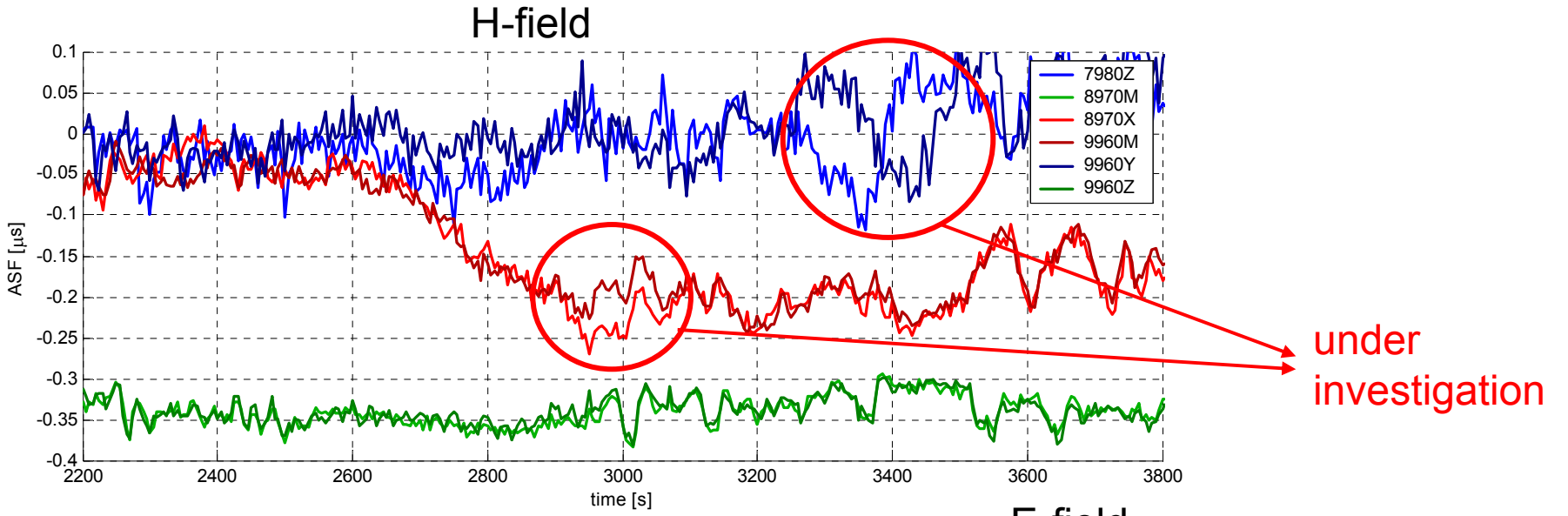
Flight track

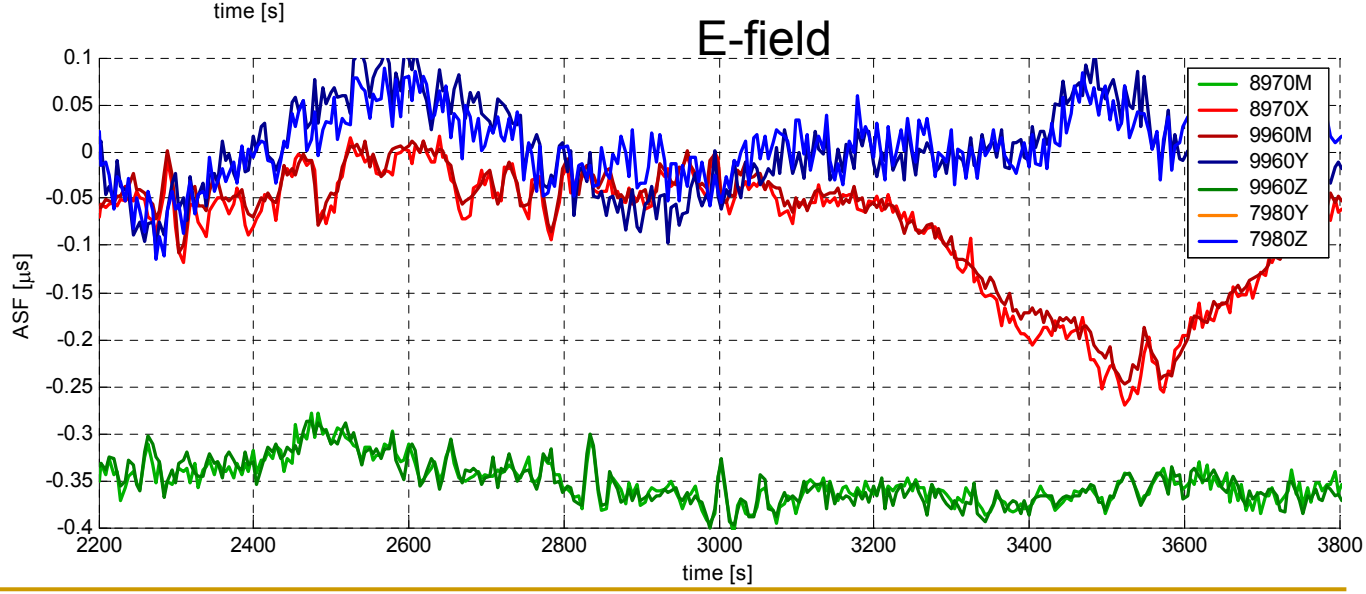
Altitude: 2000 ft
Average speed: 116 kt

H-field: 73 minutes / 250 km
E-field: 88 minutes / 340 km

Dual-rate repeatability

after reference station correction

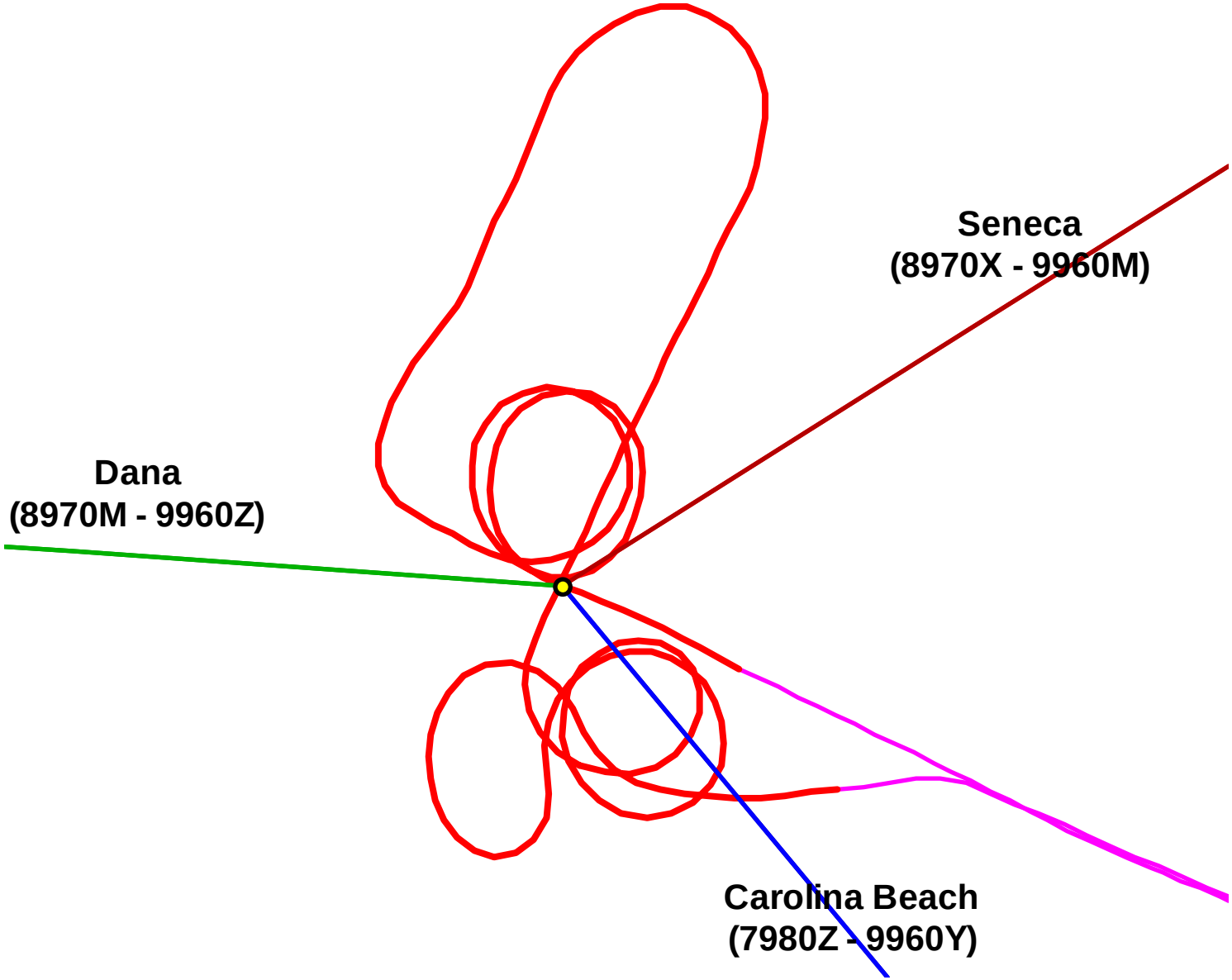




Notes:
E-field and H-field measured at different locations

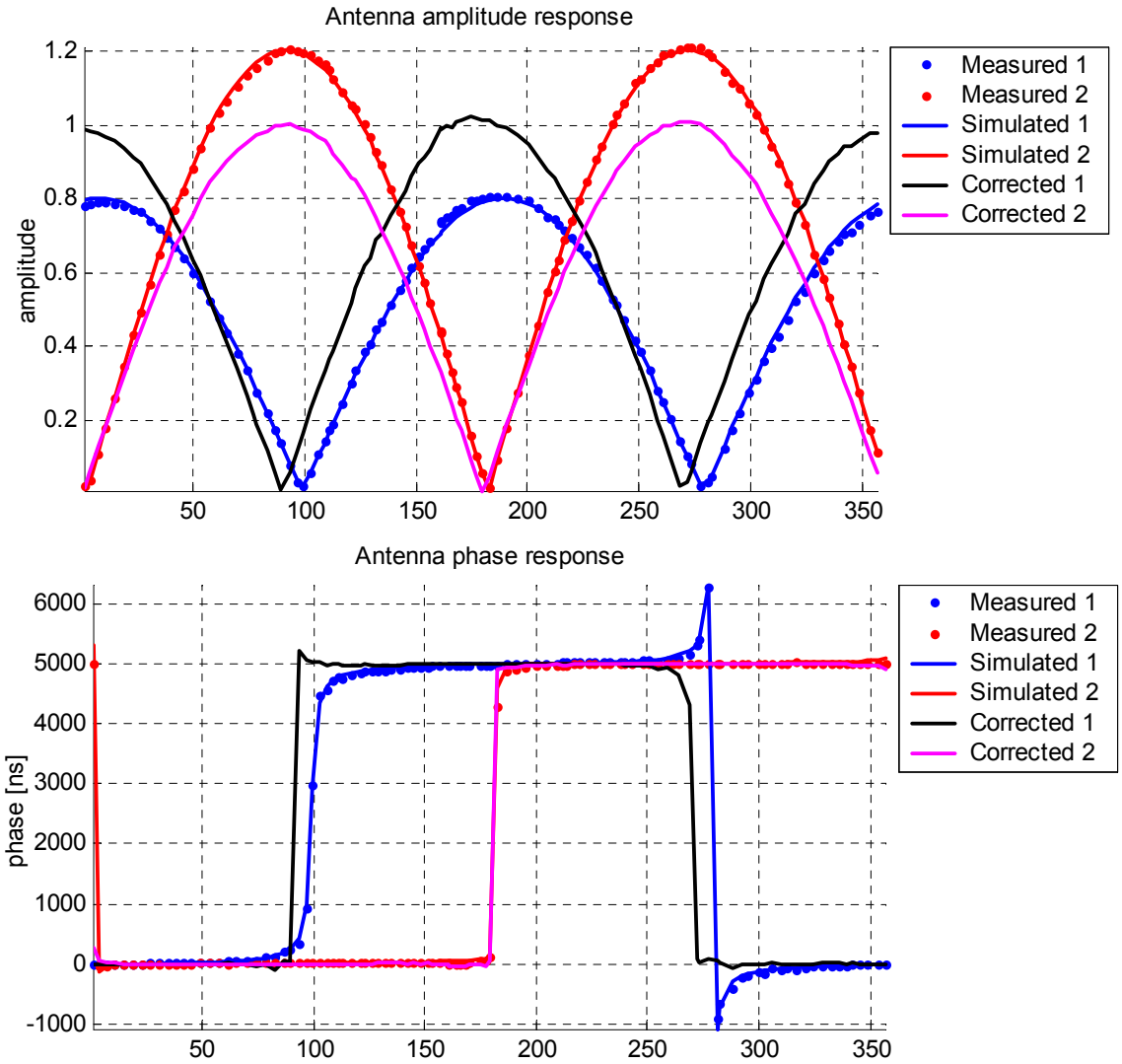
Dana is plotted with an offset of + 0.3 µs

Circles flown with H-field setup

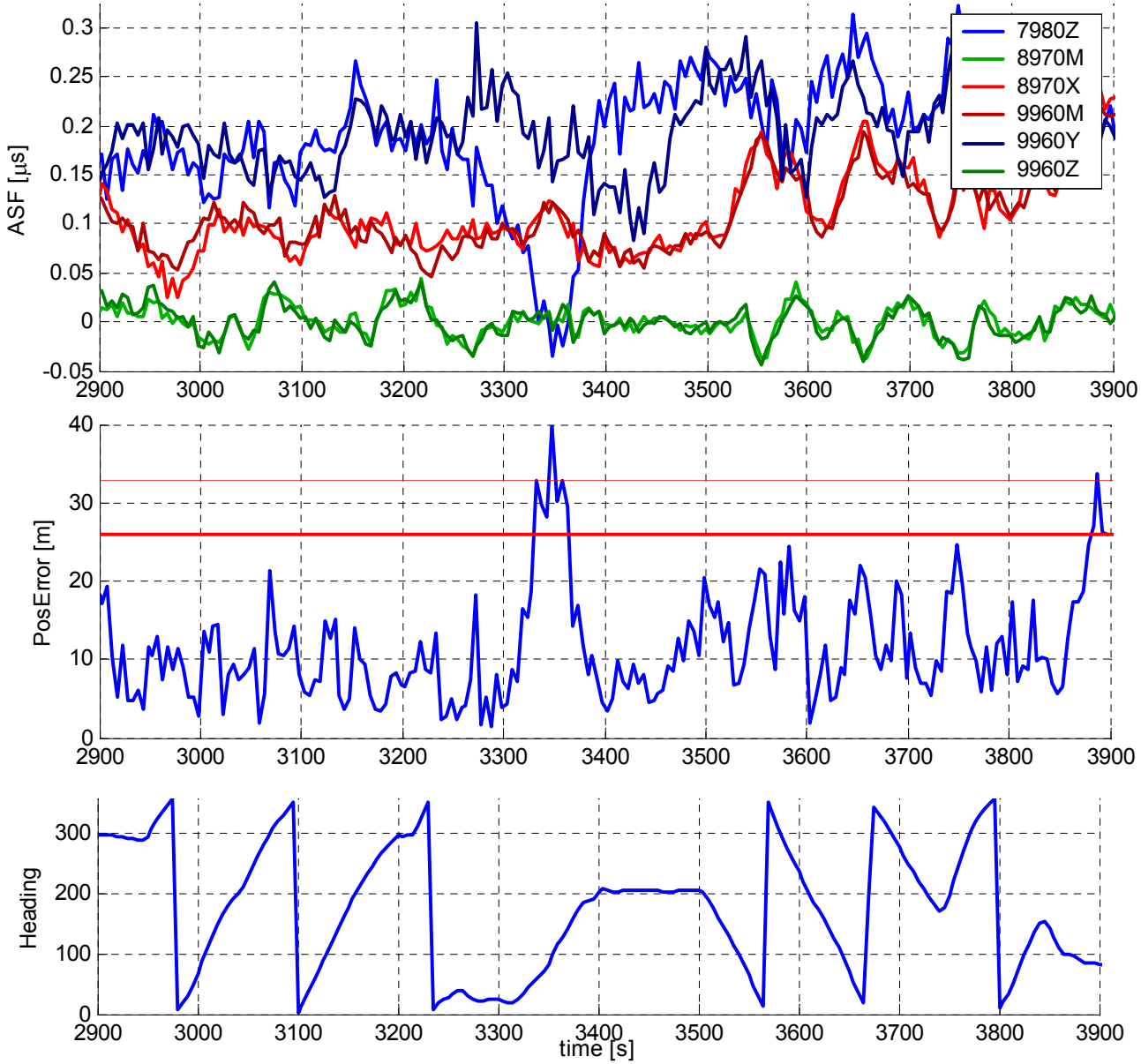


H-field antenna amplitude and phase response

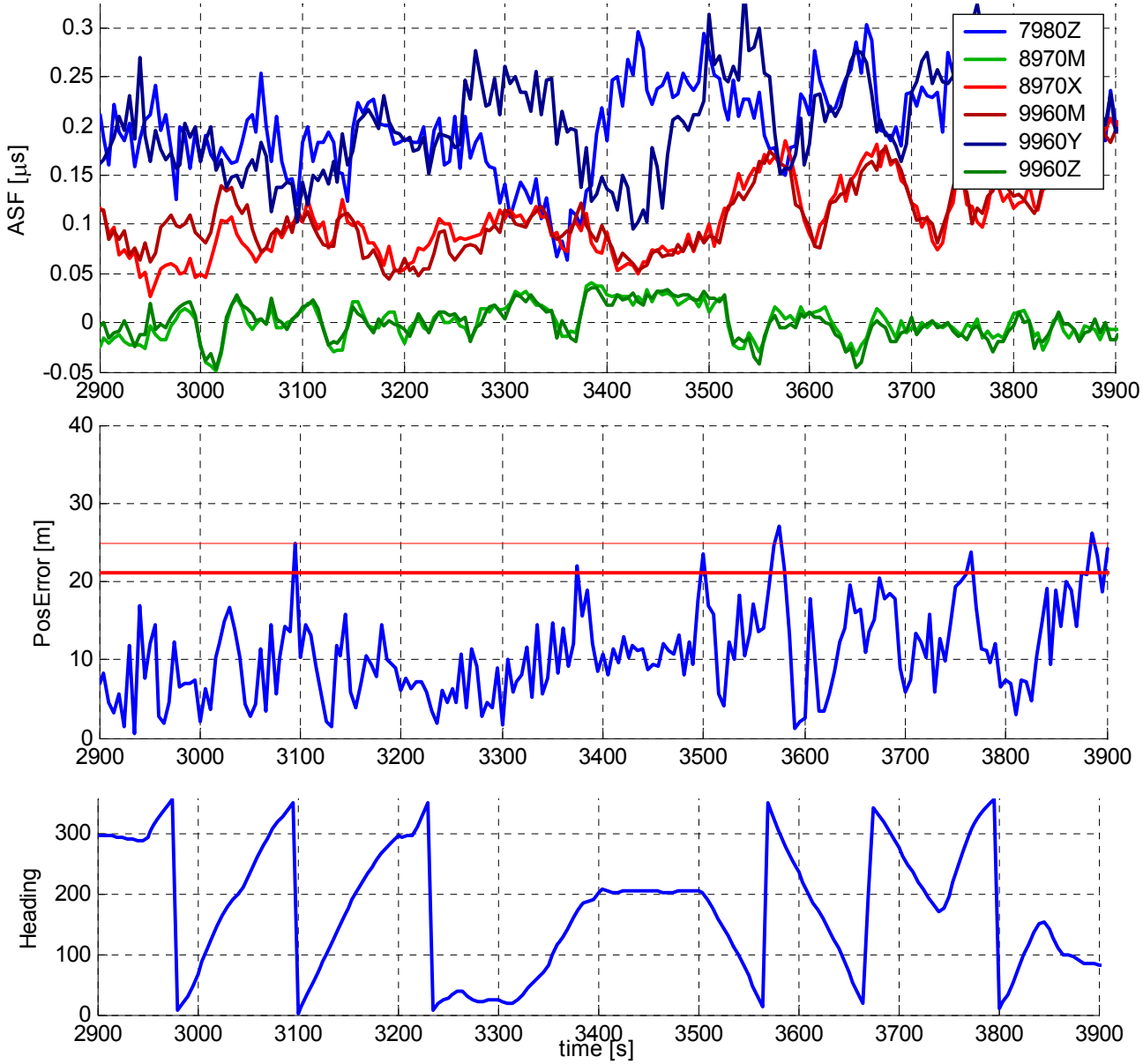
Locus H-field antenna mounted on the Saratoga



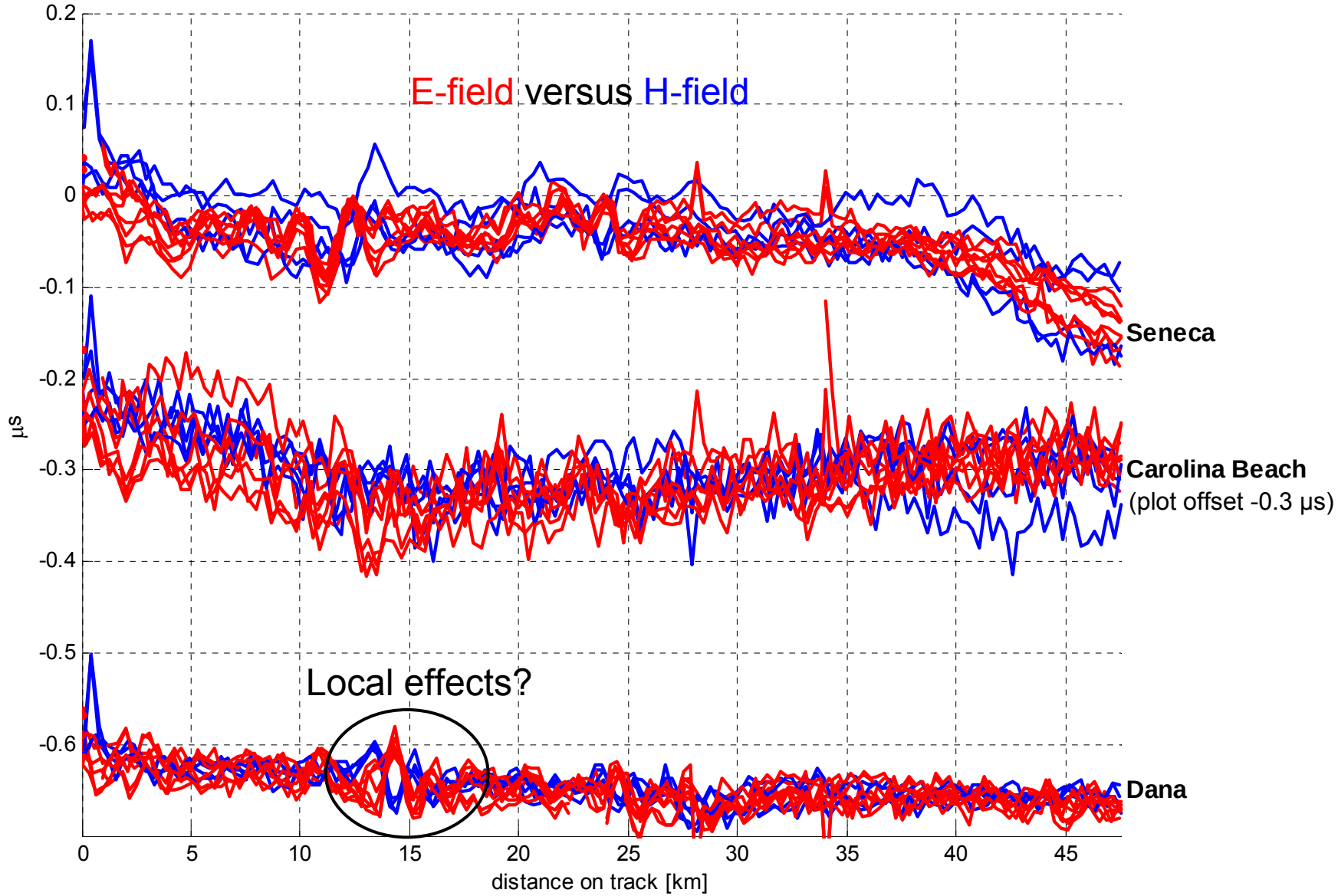
Before H-field antenna calibration



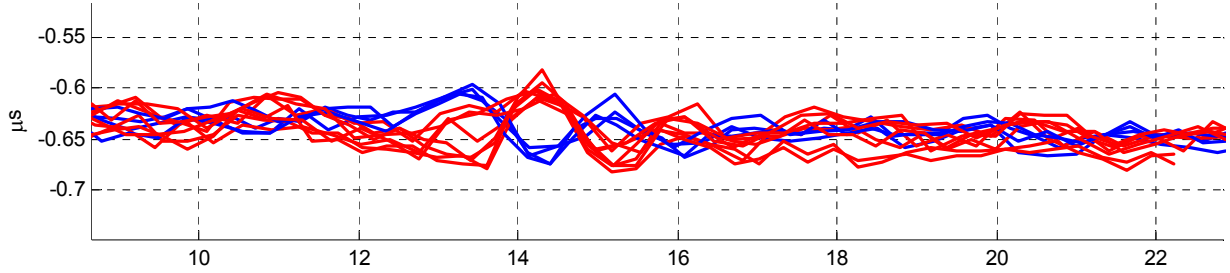
After H-field antenna calibration

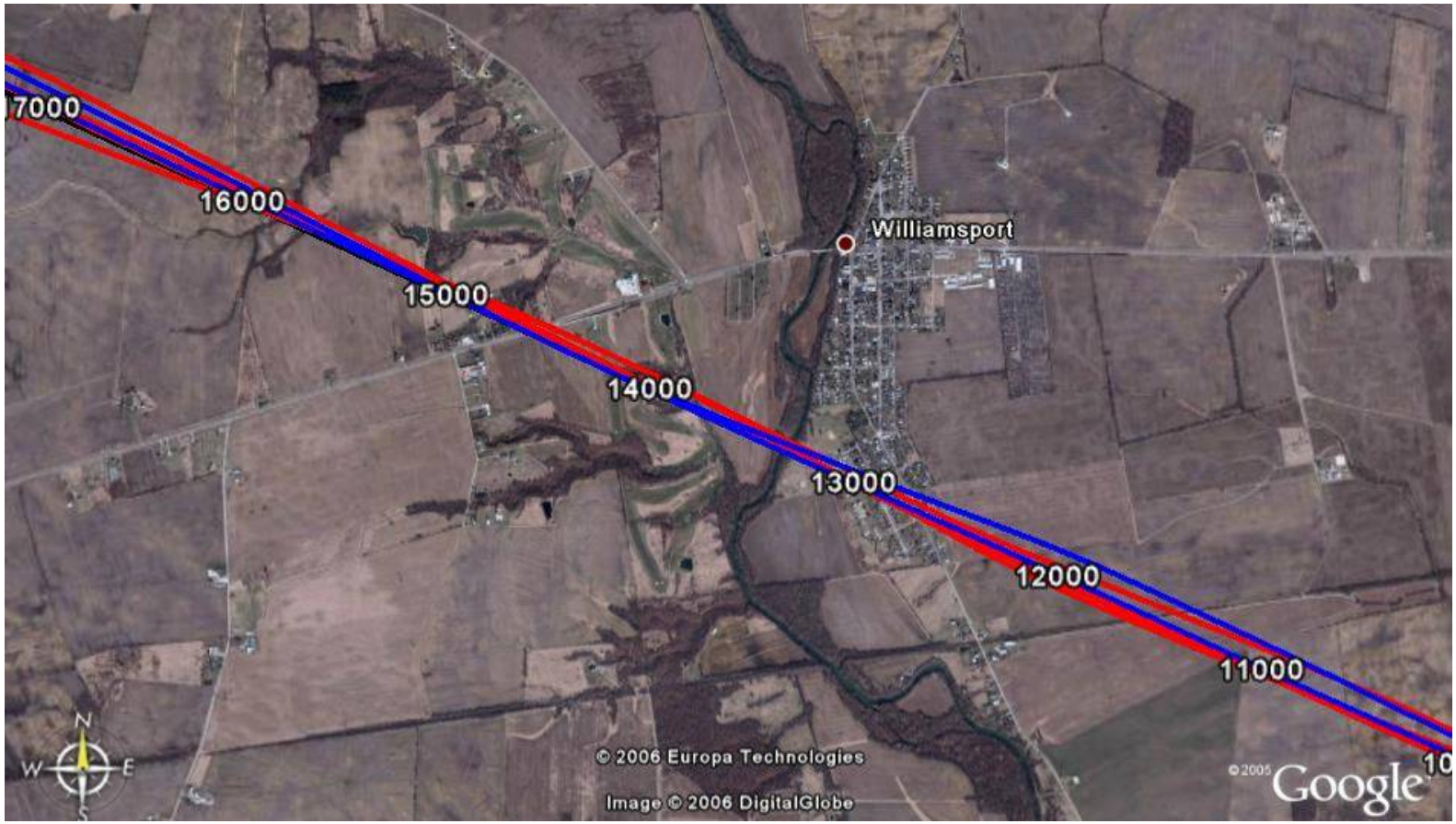


Run-to-run, dual-rate and E-field vs. H-field repeatability

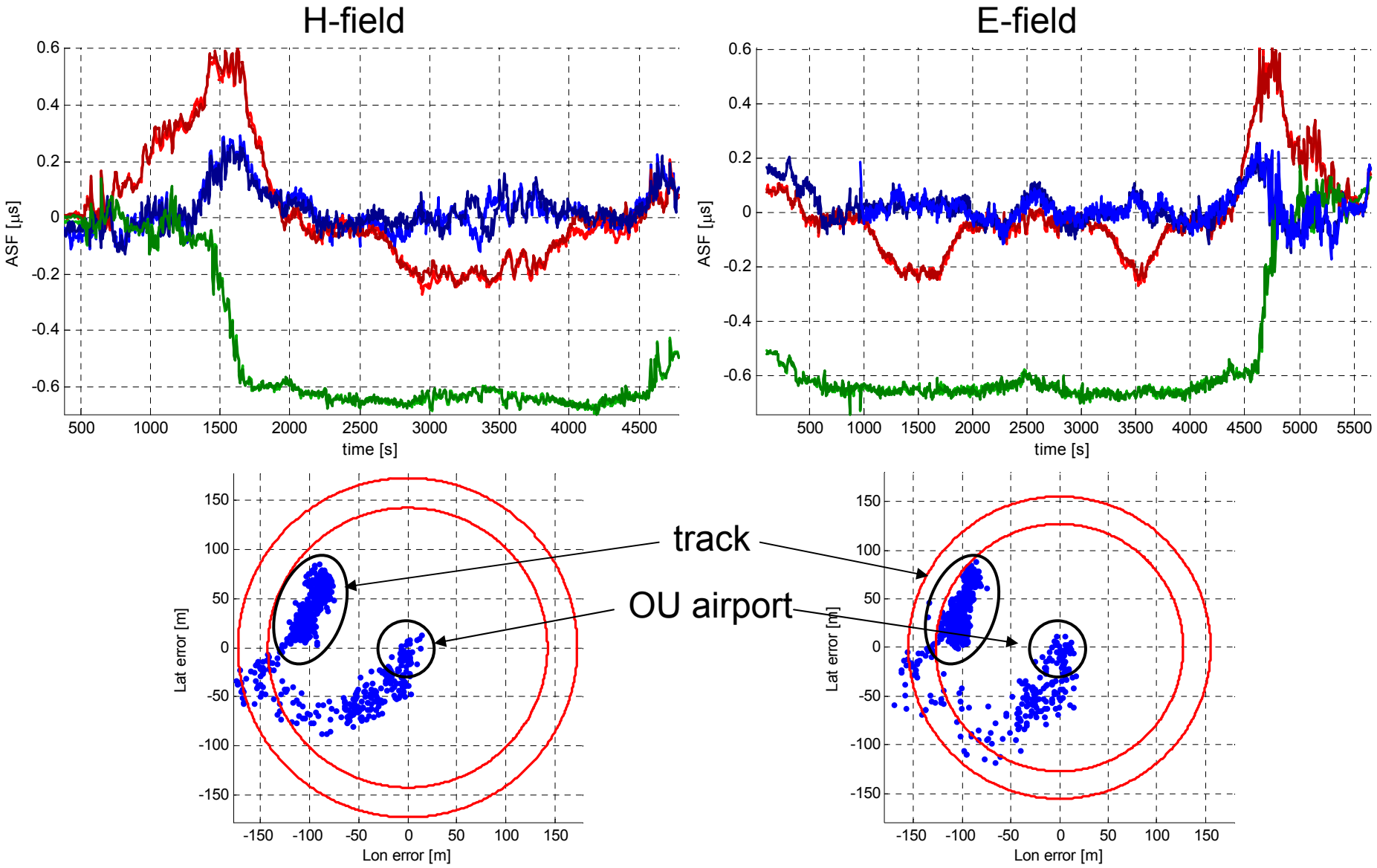


Local propagation phenomenon?





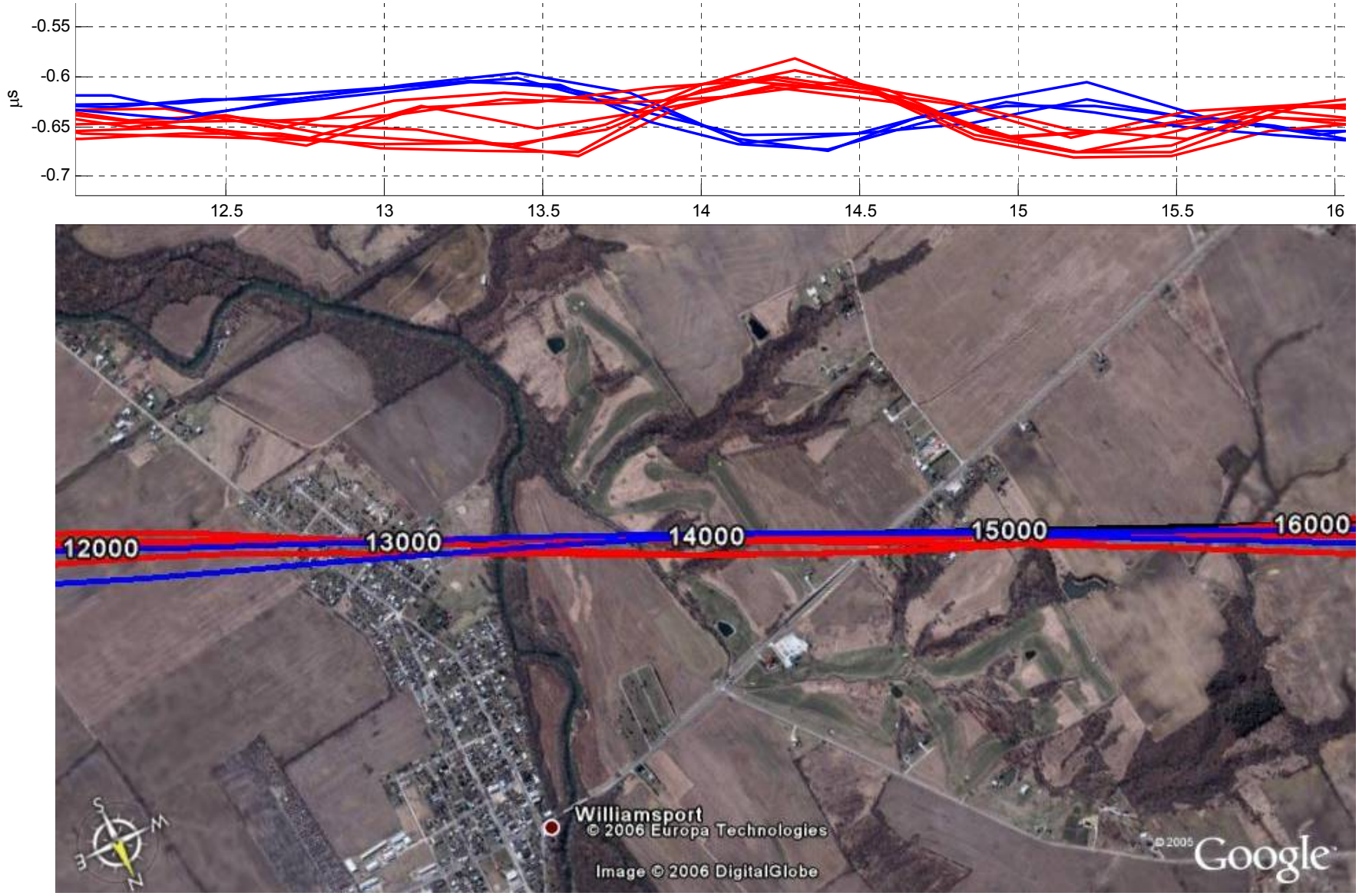
Position domain



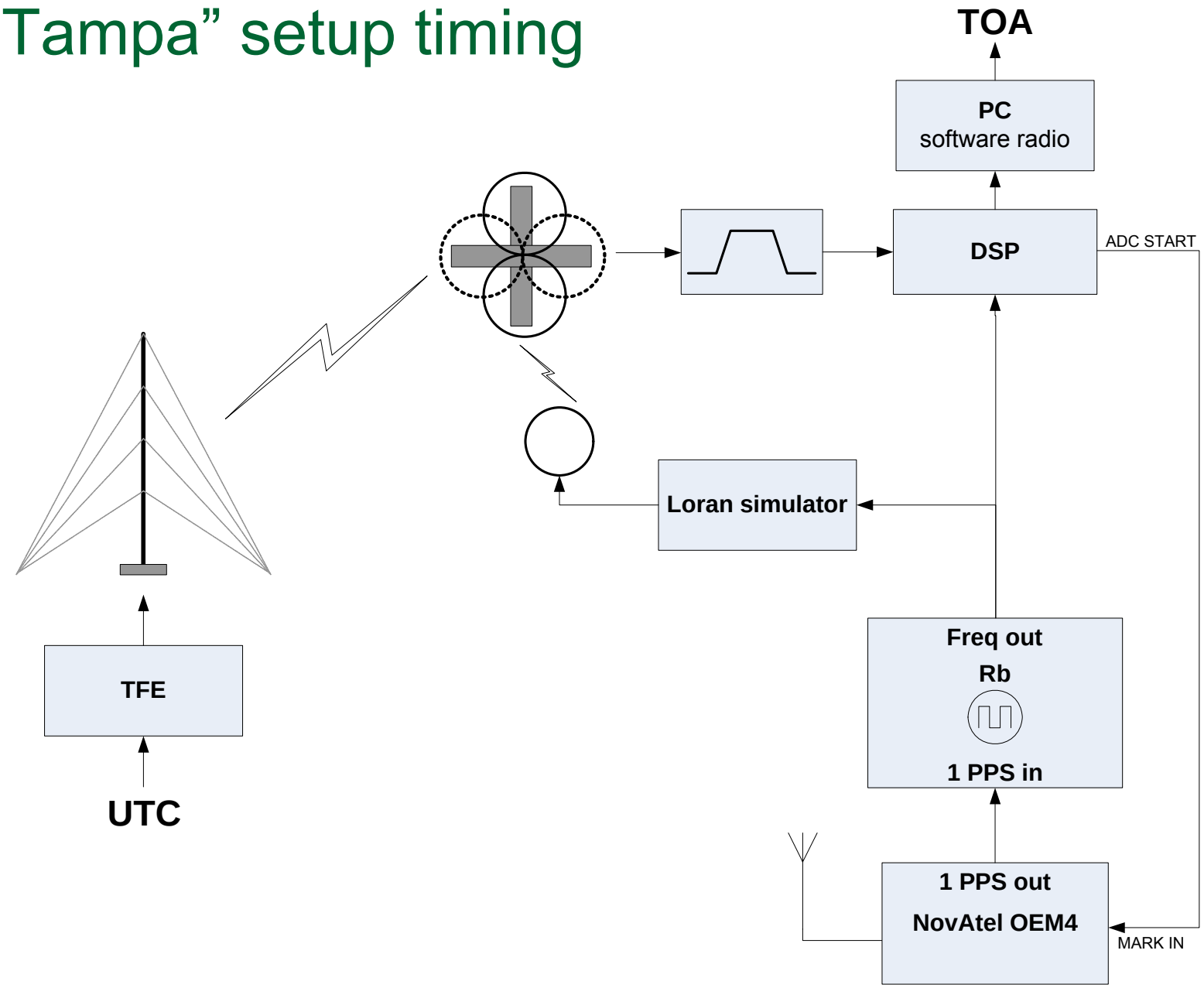
Summary

- Hardware design
  - Proof of concept through modified prototype
  - Version 2.0 hardware in production
- Software design
  - 90% finished
- System integration and testing
  - Successful adaptation to various antennas
  - Successful validation of prototype by flight test
  - In-flight quality assessment through real-time analysis tools

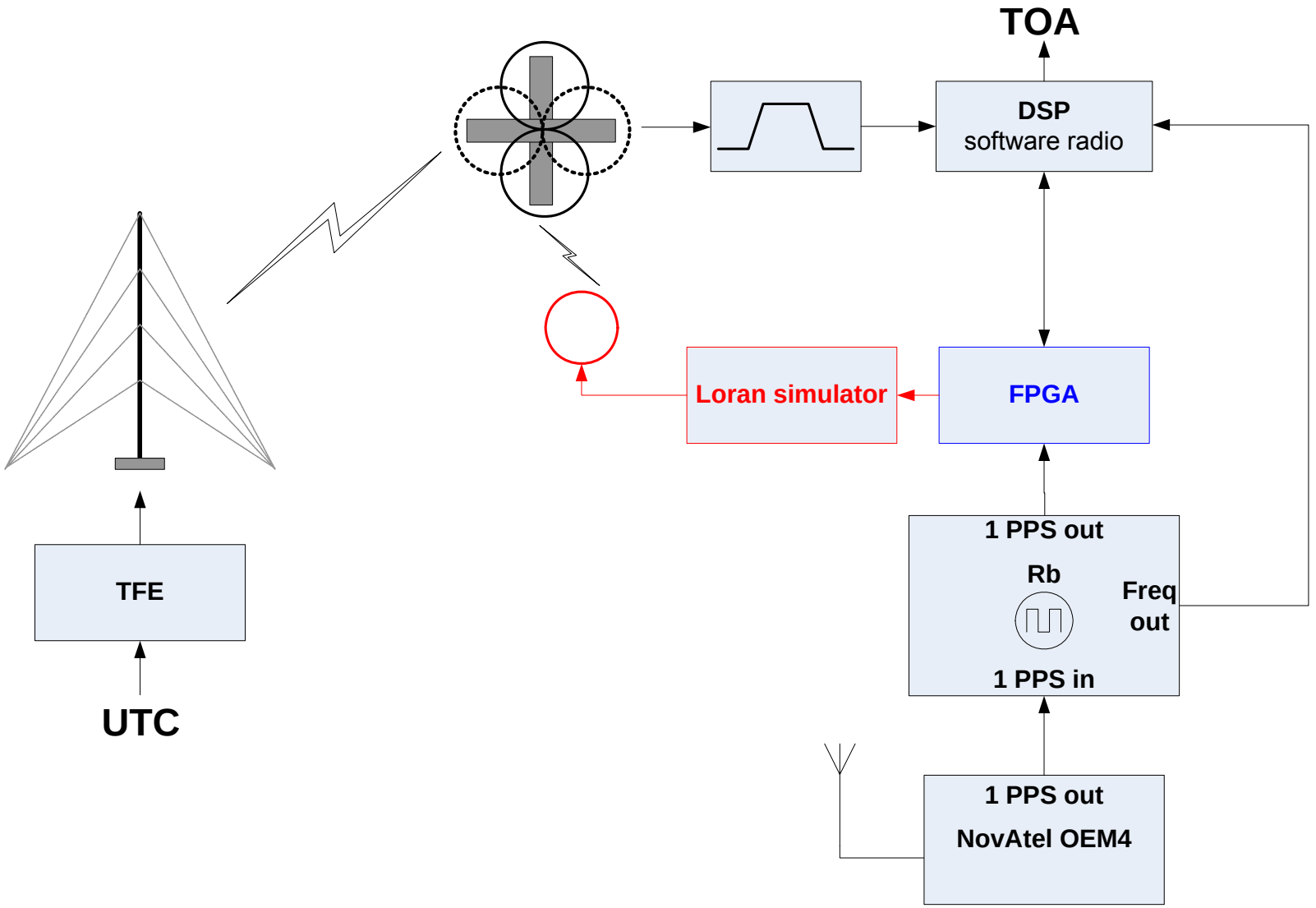
Local phenomenon measured at 2000 ft



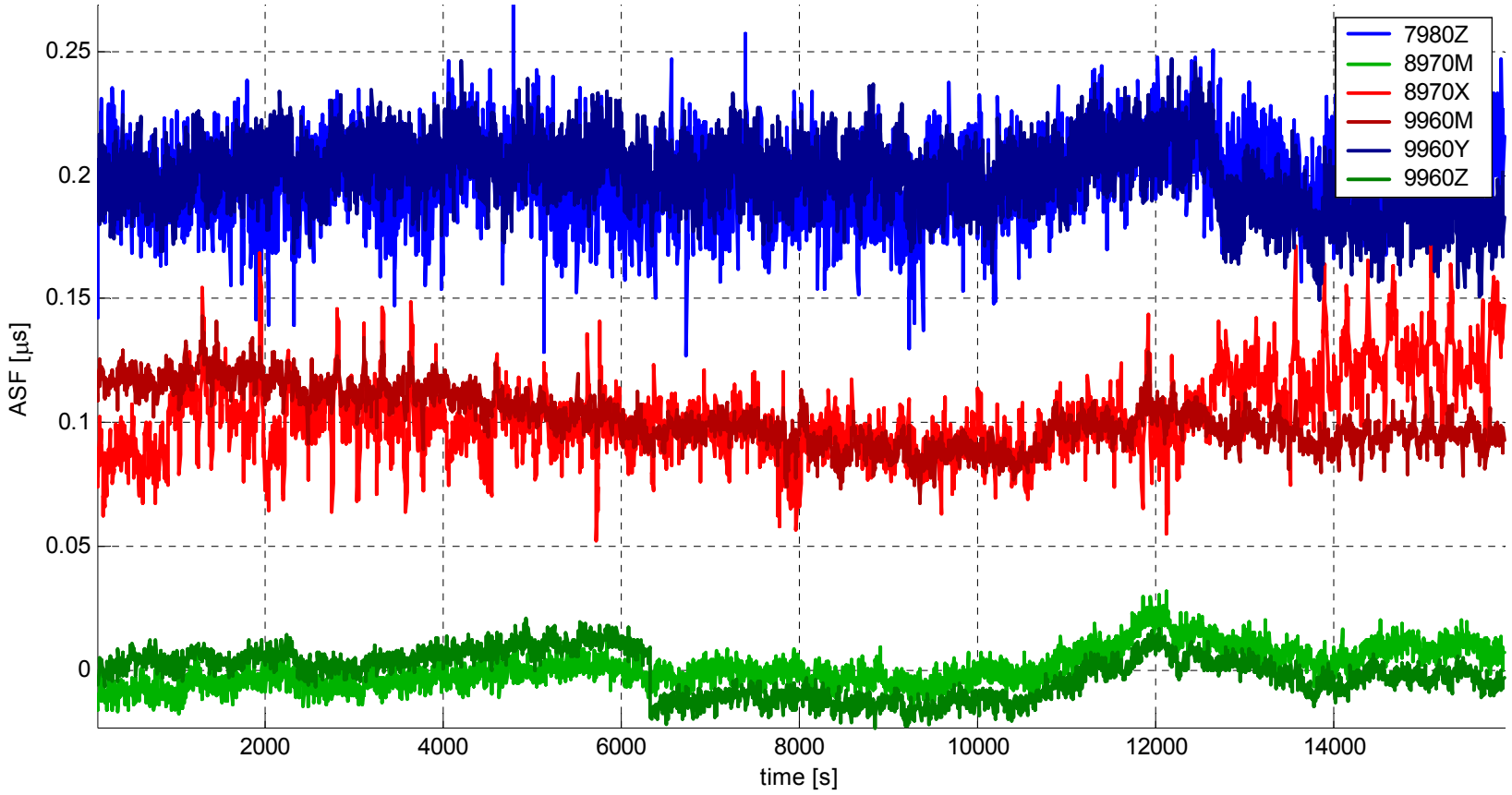
“Tampa” setup timing



TMS “2.0” timing



Reference station results – 5 sec average



Flight track

Altitude: 2000 ft
Average speed: 116 kt

H-field: 73 minutes / 250 km
E-field: 88 minutes / 340 km

Dual-rate repeatability

- GPS time and positioning cancel
- Instantaneous (in-flight assessment)
- Transmitter timing errors can be removed in post-processing by using reference station data