SENSORS

# Qualification of a Hybrid GNSS and IMU Solution

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*Kongsberg Seatex*

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Dynamic Positioning Committee
Marine Technology Society

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# Qualification of a hybrid GNSS and IMU solution

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# Outline

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- Introduction
- Core technology
- Quality management
- Verification tools
- Validation
- Conclusion

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GNSS limitations and error sources

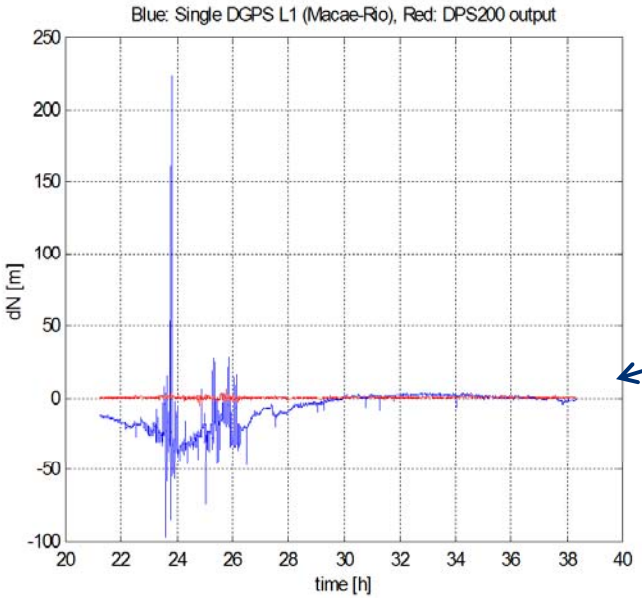
# INTRODUCTION

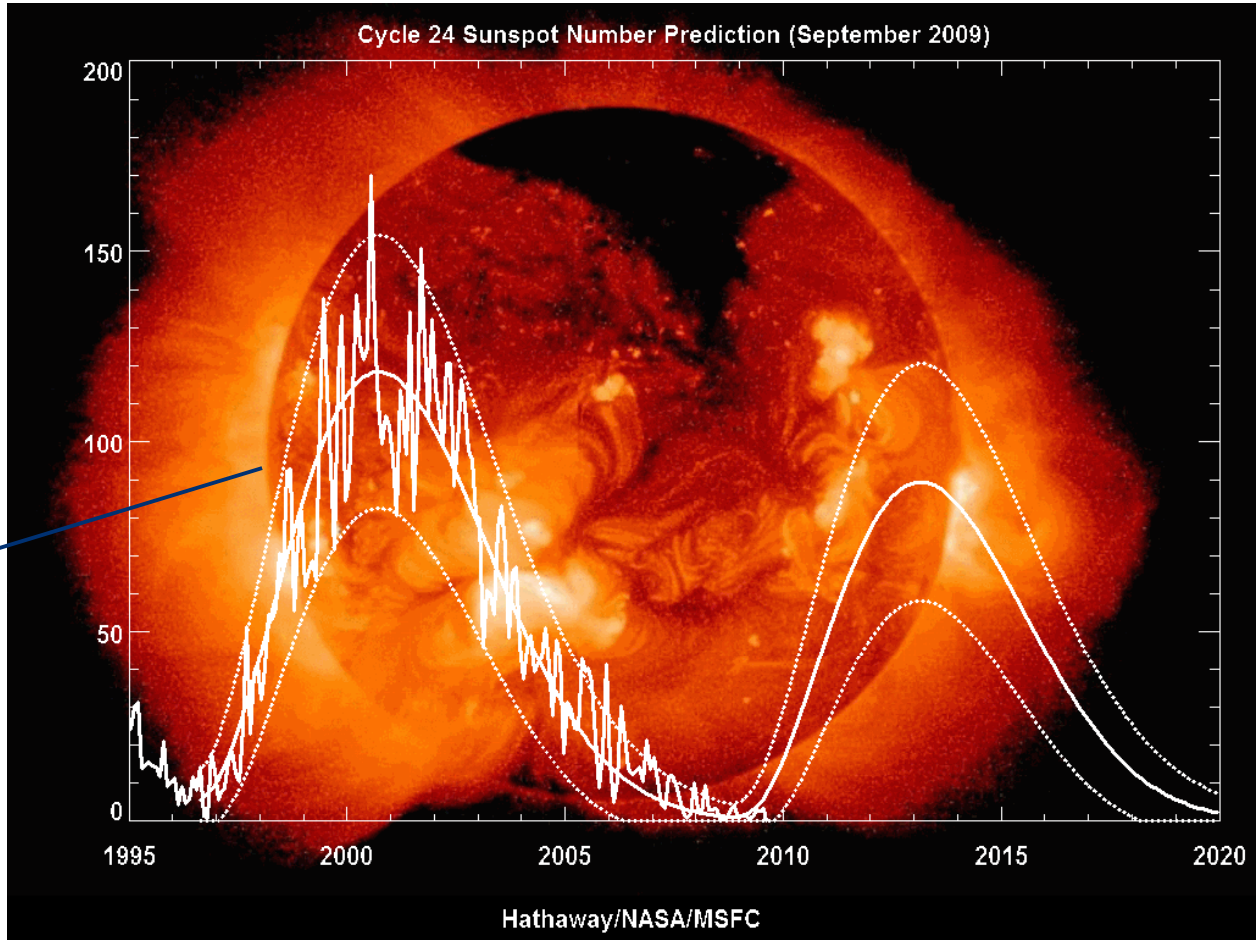
# GNSS Limitations

*Common mode GPS/Glonass failures...*

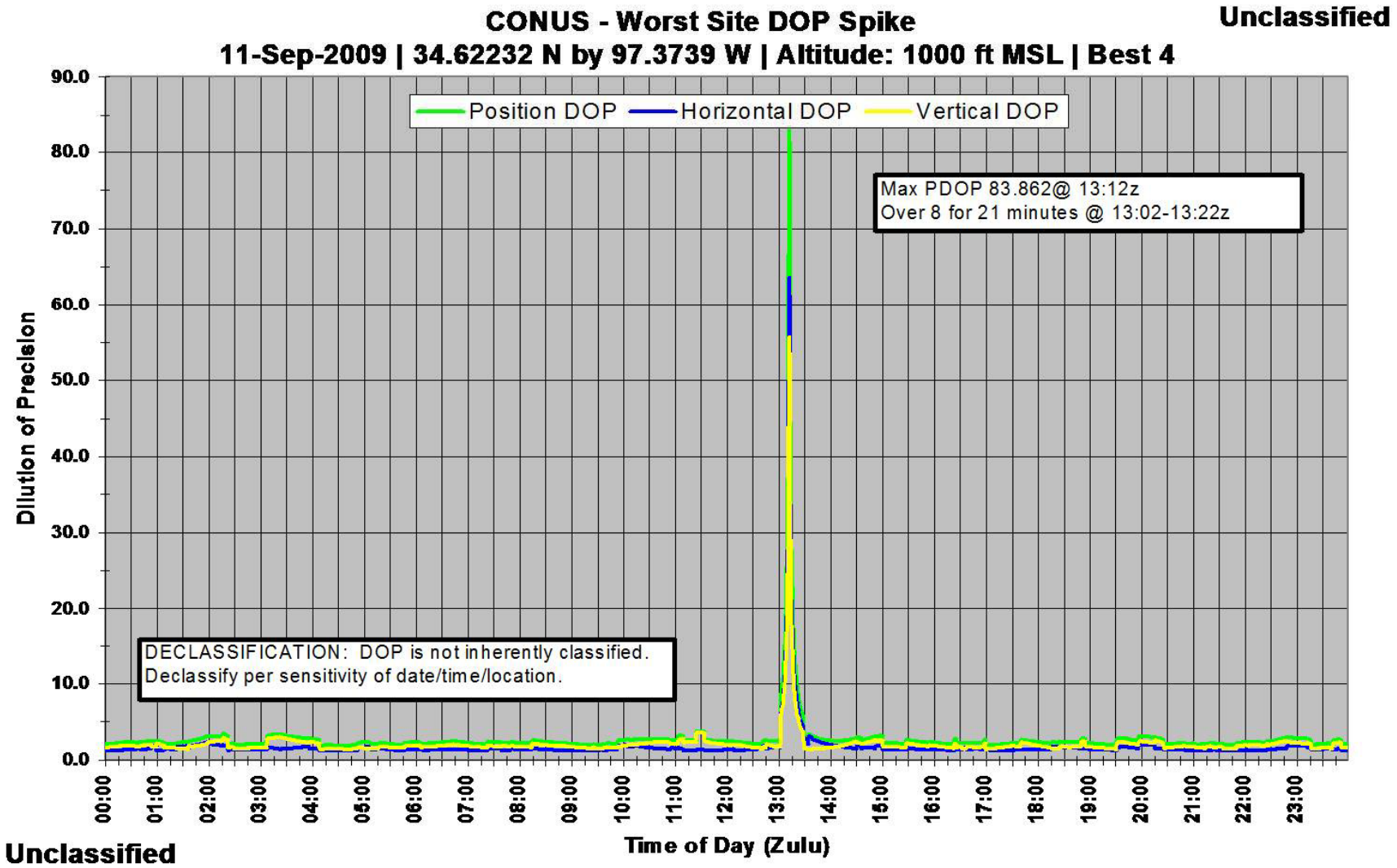
- Ionosphere
- Troposphere
- Electromagnetic environment
  - On purpose
  - Accidental
- Multipath
- Signal obstruction
- Hardware faults
- Software bugs

# Sunspot cycle 23-24: status and NASA prediction



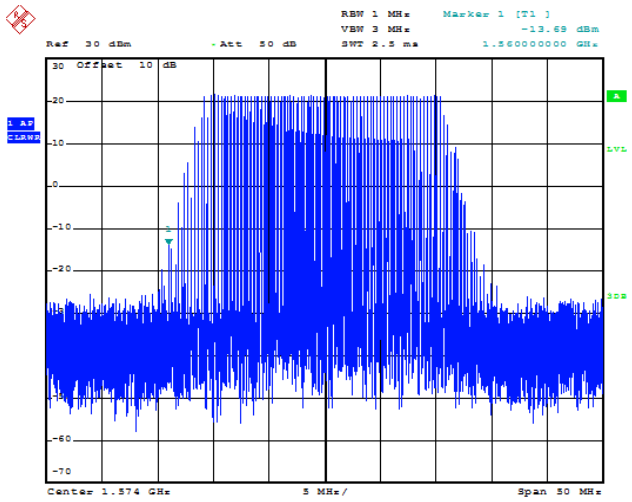



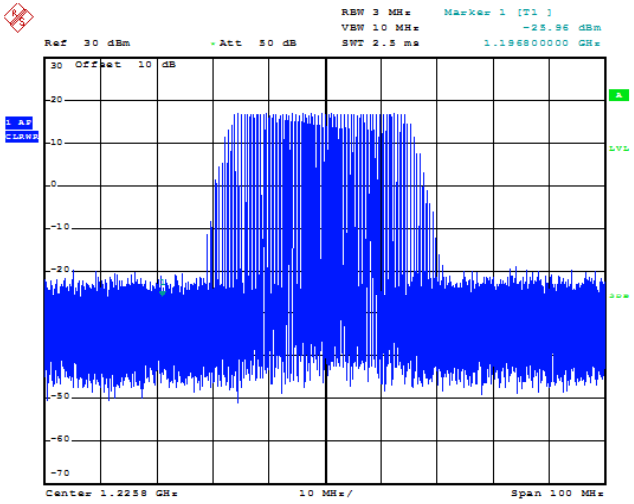
# USCG Navigation Center: Announced high HDOP event



# In-band interference

- Jamming does no more belong only to military forces or 007 James Bond
- GPS jammers are available on the Internet for a few 100 $
- Possible range is several km
- Jamming needs to be considered a real threat almost anywhere

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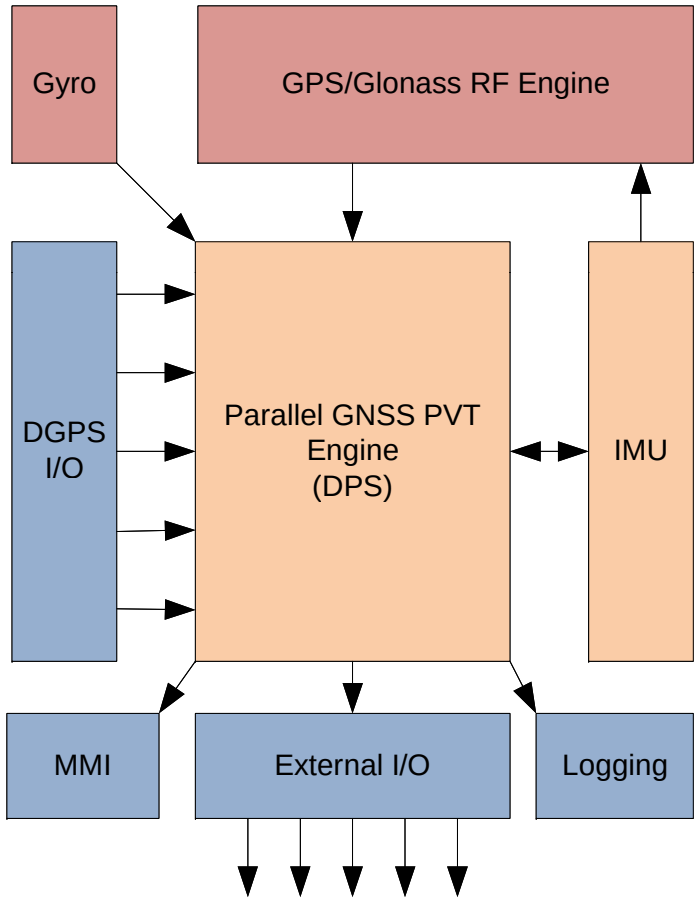
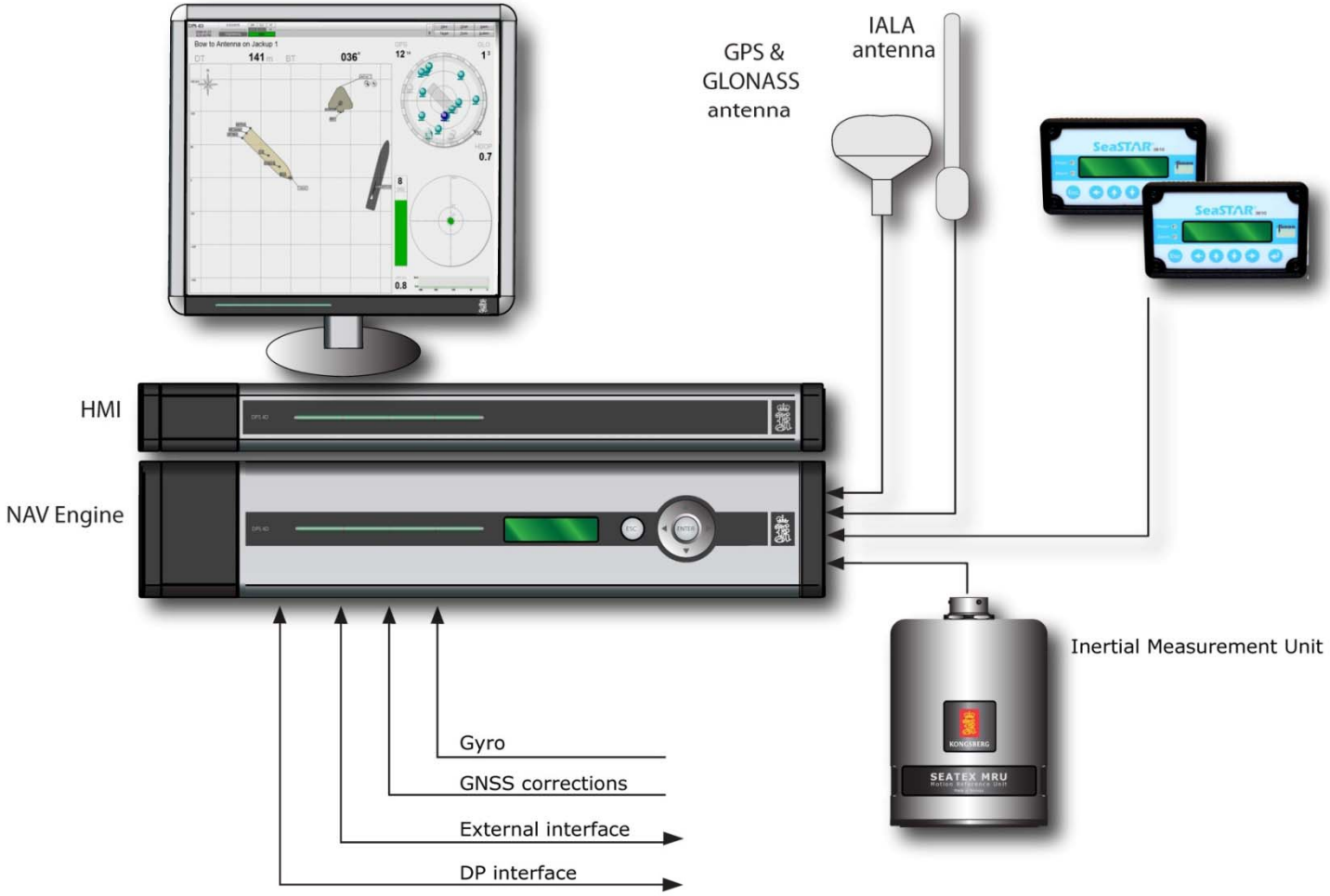
Integrating GNSS and IMU measurements

# CORE TECHNOLOGY

# GNSS/IMU Integration Scheme



# System Configuration

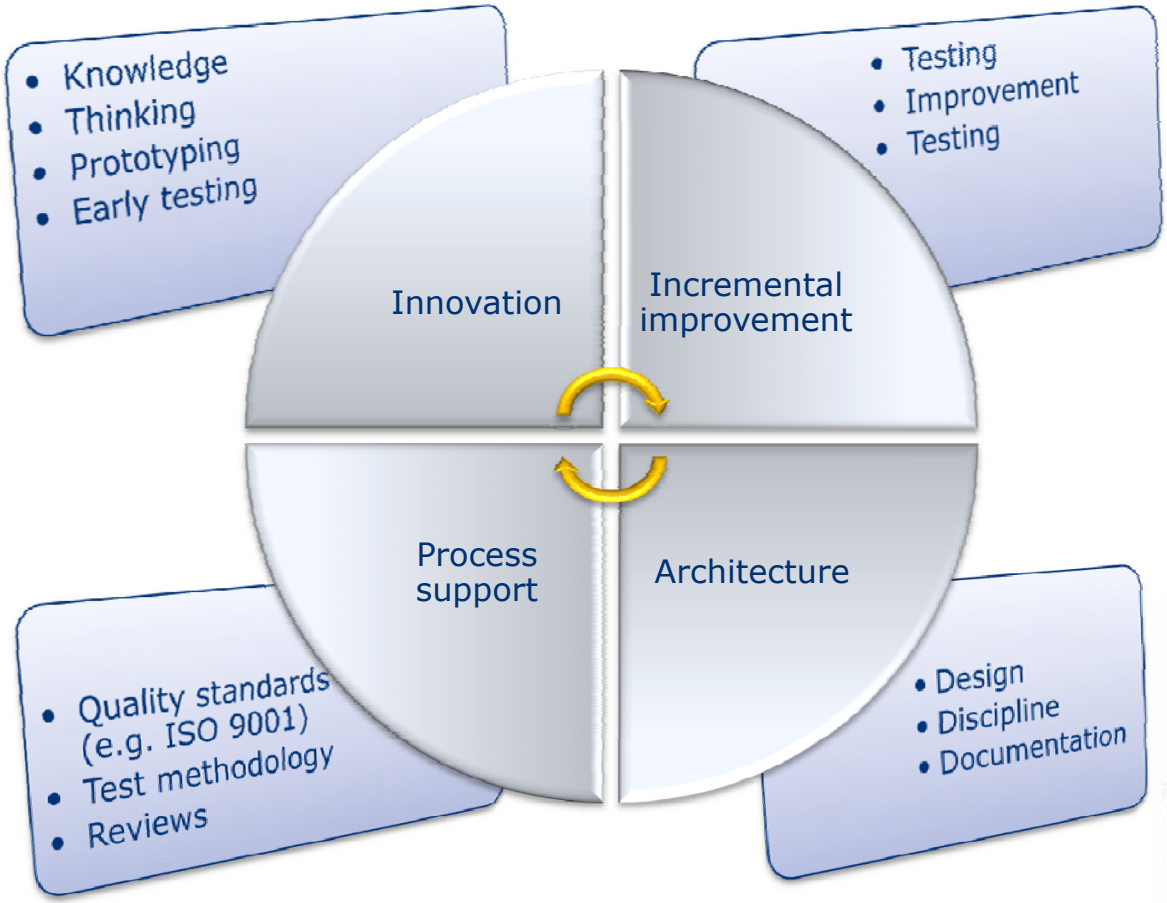


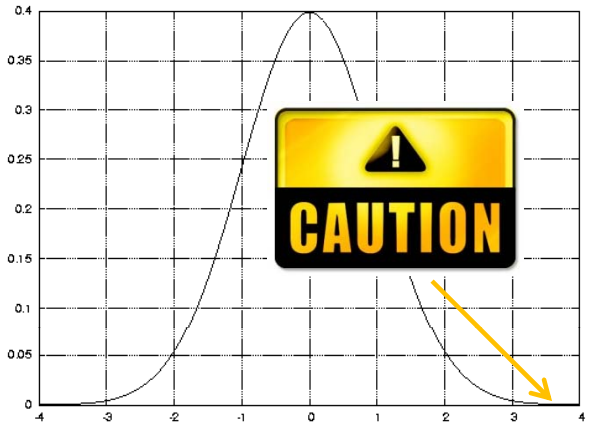
# QUALITY MANAGEMENT

# The 4D team

- Culture
- Commitment
- Continuity
- Competence

# An holistic quality improvement cycle



*"We need a leader who is not afraid to dream incremental dreams."*

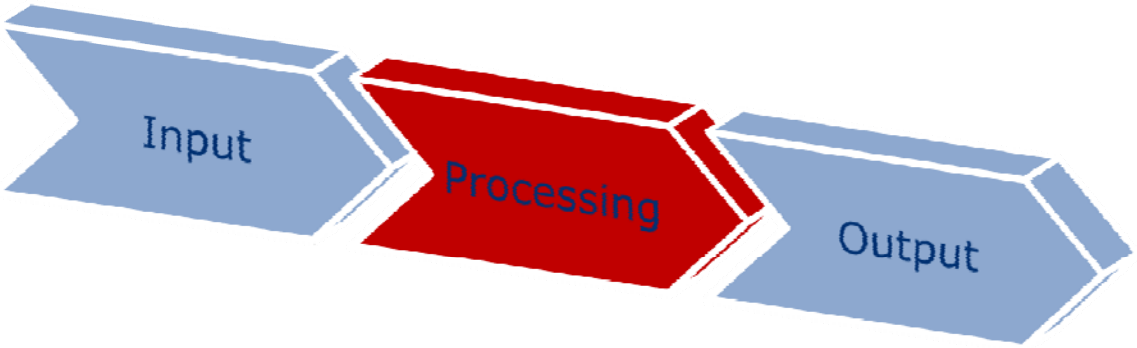
Test and simulation equipment and some results

# TEST PLATFORMS

# Signal simulation

- Exact control of input necessary to eliminate processing errors
- Live Signal-in-Space is exposed to error sources and cannot not be manipulated
- Signal simulators output deterministic RF signals
- A long list of parameters can be manipulated
- Failure modes can be induced

- GPS & Glonass simulators are invaluable tools in the development and test process



# Rate table for IMU testing and calibration

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- Two-Axis motion simulators: DC246 & DC2267L
- Payload: 60kg
- Temperature chamber capability: 45°C to +90°C
- Rotation rates:
  - Outer: 200°/s
  - Inner: 900°/s
- Rate stability: 0.0001%
- Position accuracy: 0.0008°
- Horizontal alignment a challenge due to MSL variations

# Rate table output

## Seatex MRU Calibration Certificate

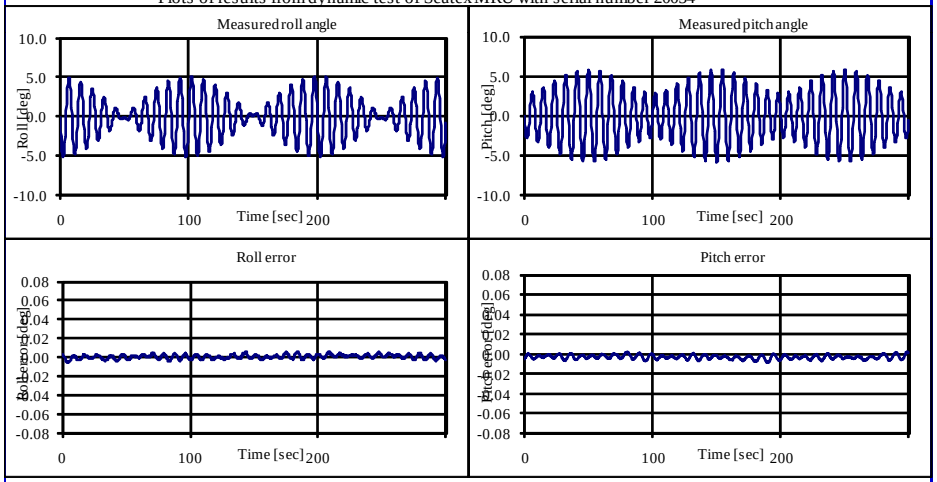
| | |
|---|---|
| Seatex MRU model number: | 5 |
| Serial number: | 20054 |
| Calibration certificate number: | 20090910-20054 |

**1. Roll and Pitch Accuracy Tests**

| Roll and pitch accuracy | Test requirement | Roll | Pitch | Approval |
|---|---|---|---|---|
| RMS static roll and pitch [deg] | 0.01 | 0.003 | 0.001 | *Passed* |
| RMS dynamic roll and pitch [deg] | 0.01 | 0.002 | 0.004 | *Passed* |

The static accuracy was measured by sampling at 4 Hz for 30 minutes, when the Seatex MRU is stationary.
The dynamic accuracy was measured in a rate table test with simultaneous sinusoidal exitation in two axes for 10 minutes.

Plots of results from dynamic test of Seatex MRU with serial number 20054




**2. Rate Gyro Accuracy Tests**

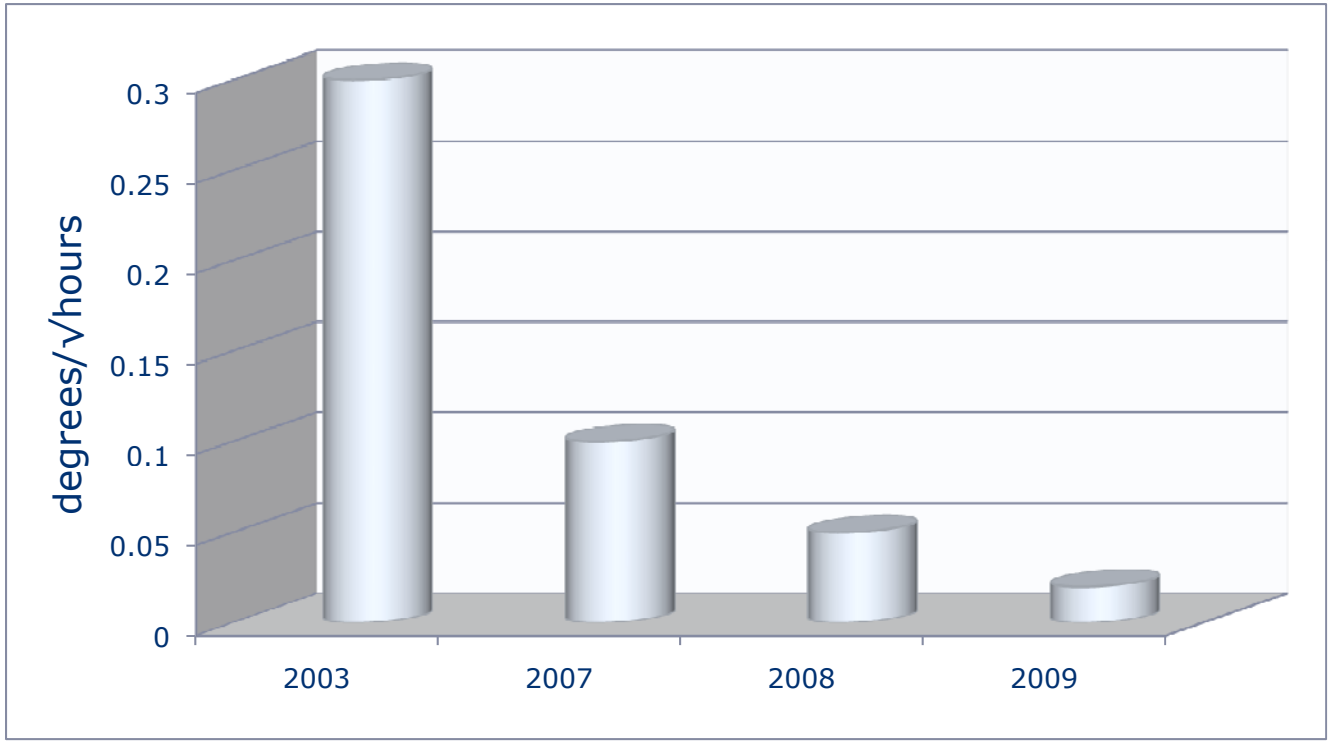
| Angular rate accuracy | Test requirement | R-axis | P-axis | Y-axis | Approval |
|---|---|---|---|---|---|
| RMS rate sensor noise [deg/s] | 0.025 | 0.007 | 0.009 | 0.008 | *Passed* |
| RMS rate sensor scale factor error [%] | 0.08 % | 0.00 % | 0.01 % | 0.00 % | *Passed* |

The angular rate sensor noise level was measured by sampling at 4 Hz for 30 minutes, when the Seatex MRU is stationary.
The rate gyro scale factor error was tested by single-axis rotations on a rate table at ±10°/s and at ±30°/s.

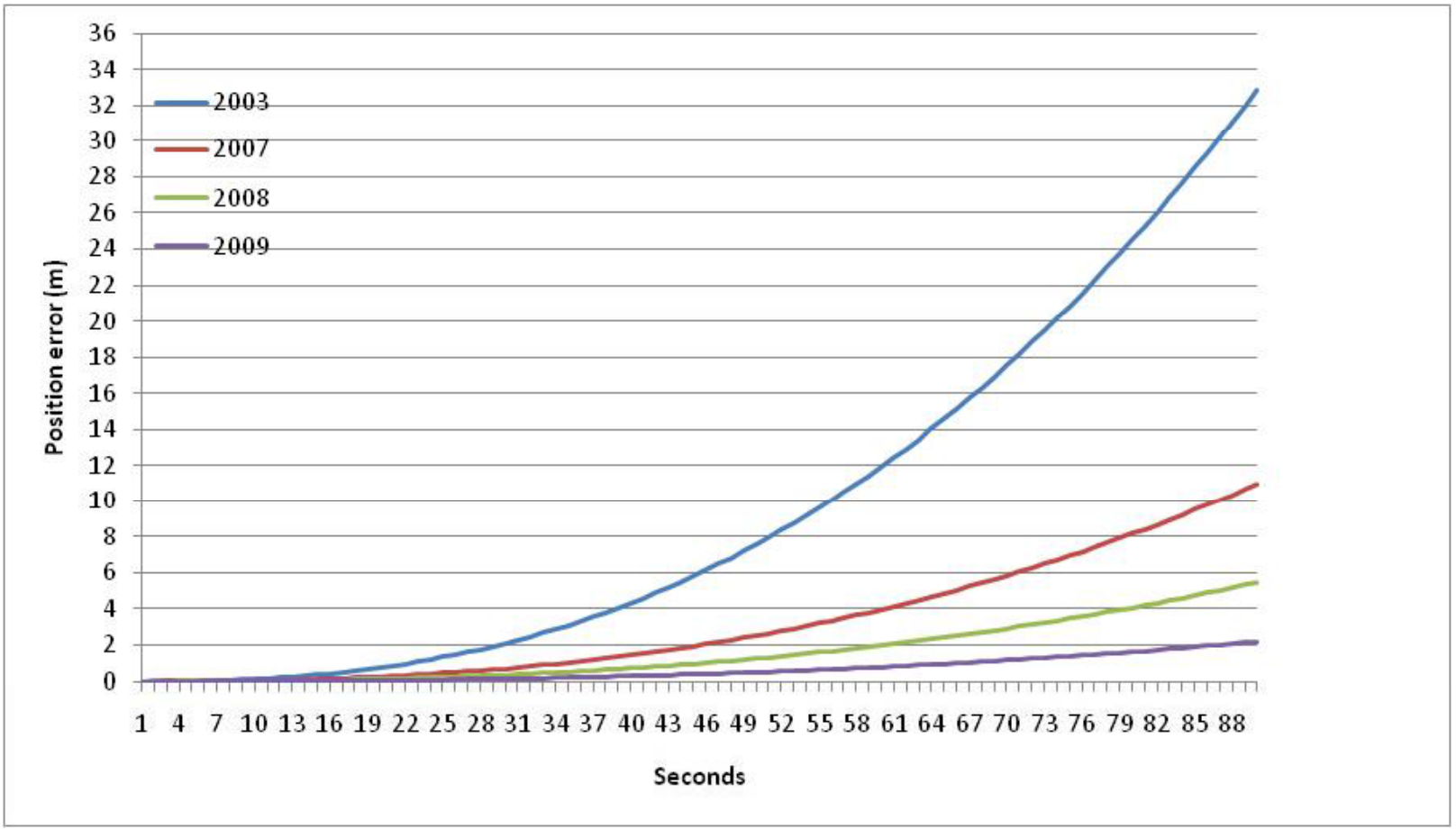
**3. Accelerometer Accuracy Tests**

| Linear acceleration accuracy | Test requirement | R-axis | P-axis | Y-axis | Approval |
|---|---|---|---|---|---|
| STD acceleration sensor noise [m/s$^2$] | 0.0017 | 0.0000 | 0.0001 | 0.0001 | *Passed* |
| RMS acceleration sensor scale factor error [%] | 0.020% | 0.002% | 0.000% | 0.004% | *Passed* |

# MRU 5: Angular Random Walk improvements



# MRU 5: Position extrapolation




$$\Delta X = \frac{1}{2} * \frac{pi}{180} * \frac{g}{60} * ARW * t^{2.5}\ [m]$$

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An incremental process

# VERIFICATION & VALIDATION

# Long term logging and data analyses

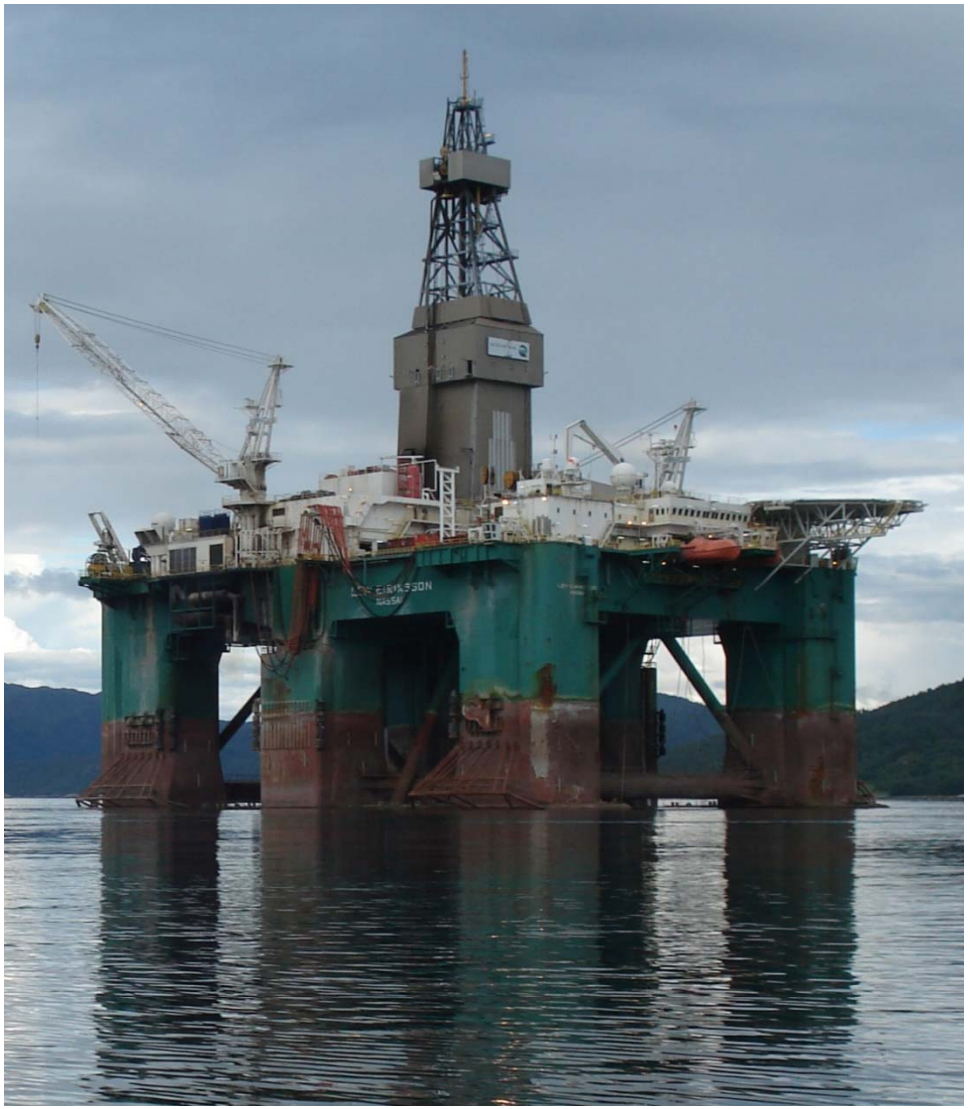
- Long term testing on target hardware (28 units)
- Continuous logging and analyses
- A new main release requires thousands of hours of data

- **Full replay capability of GNSS, clock / orbit corrections (e.g. Fugro G2) IMU data is essential for analysing data recorded under different situations**

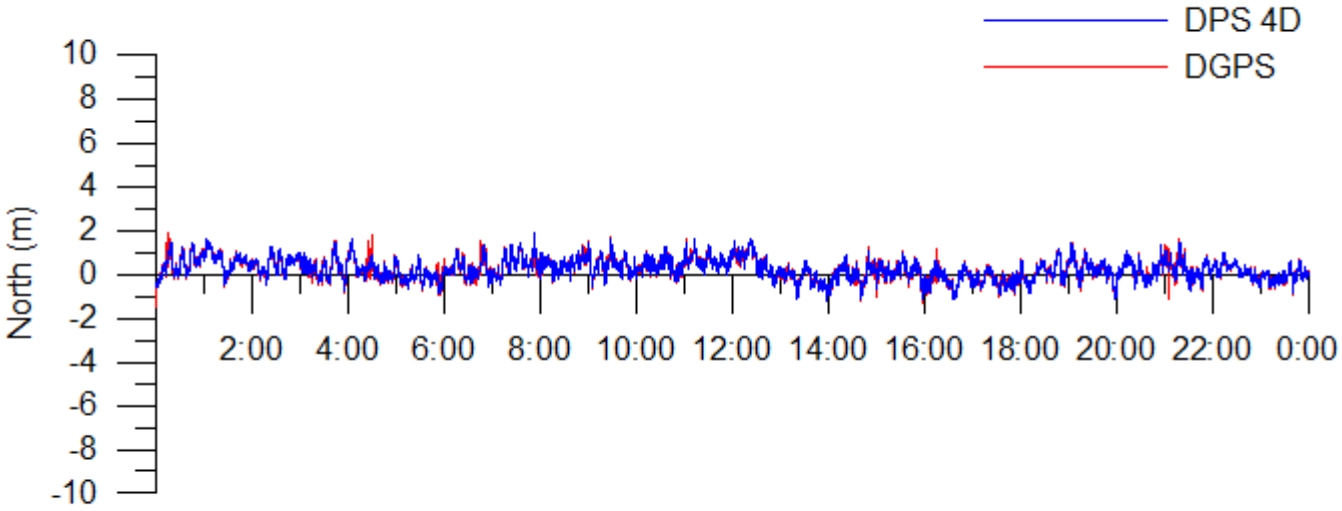
# Local test platforms

# Bourbon Topaz and Bourbon Oceanteam 101

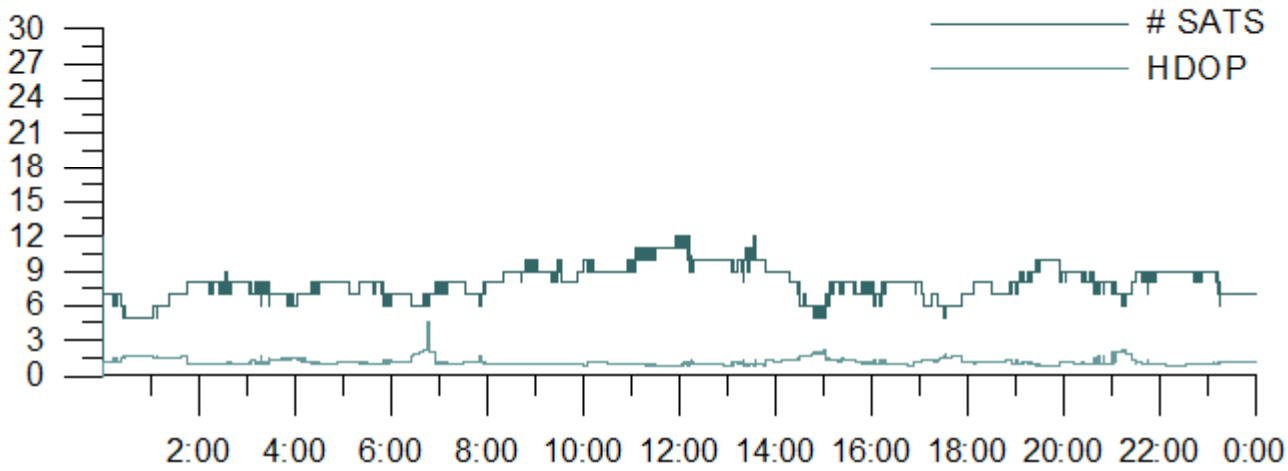
# Discoverer Deep Seas and Leiv Eriksson



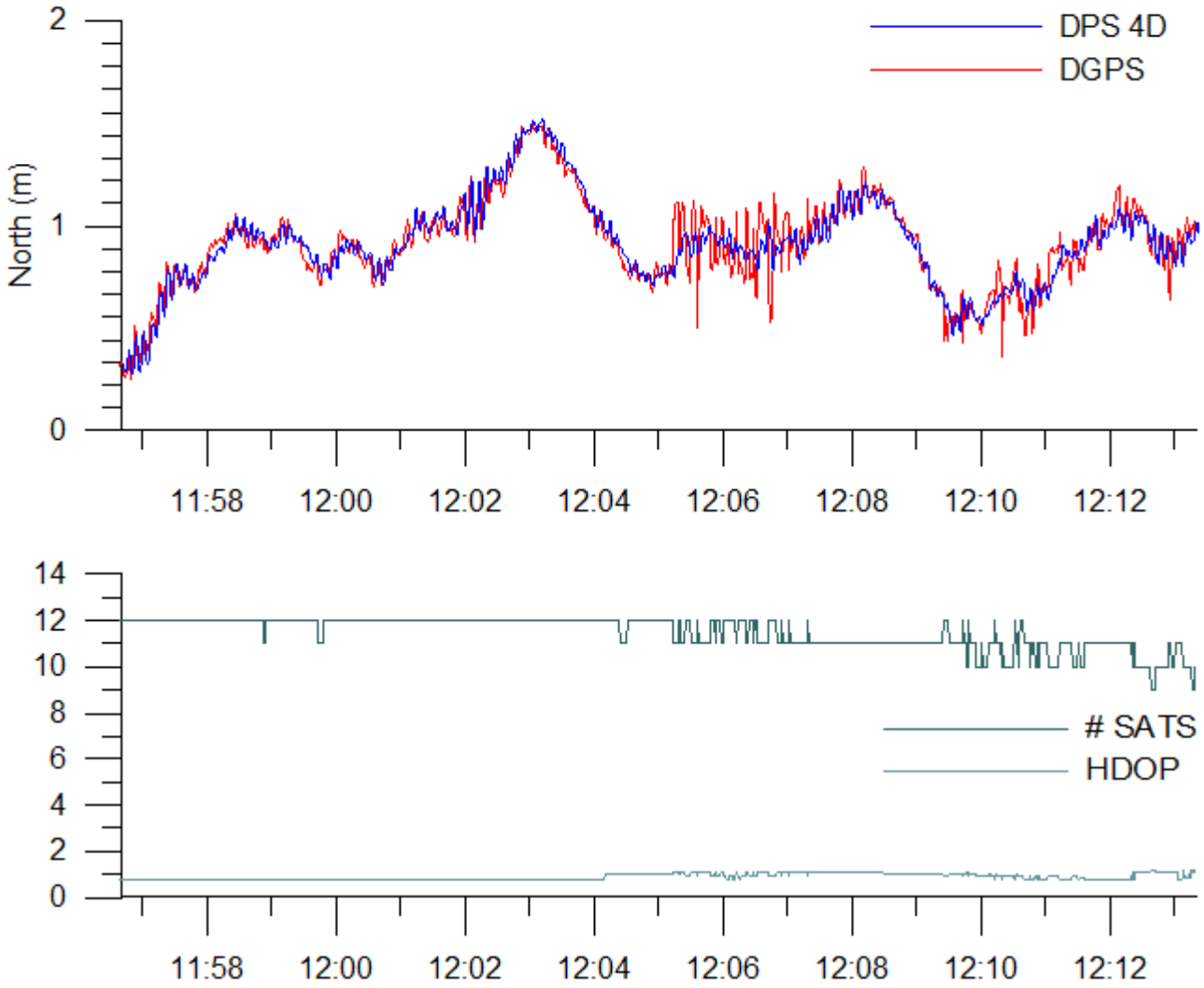
# Normal conditions




- +/- 2 m vessel movements
- Standard DGPS corrections
- Strong correlation between DPS 4D and DGPS

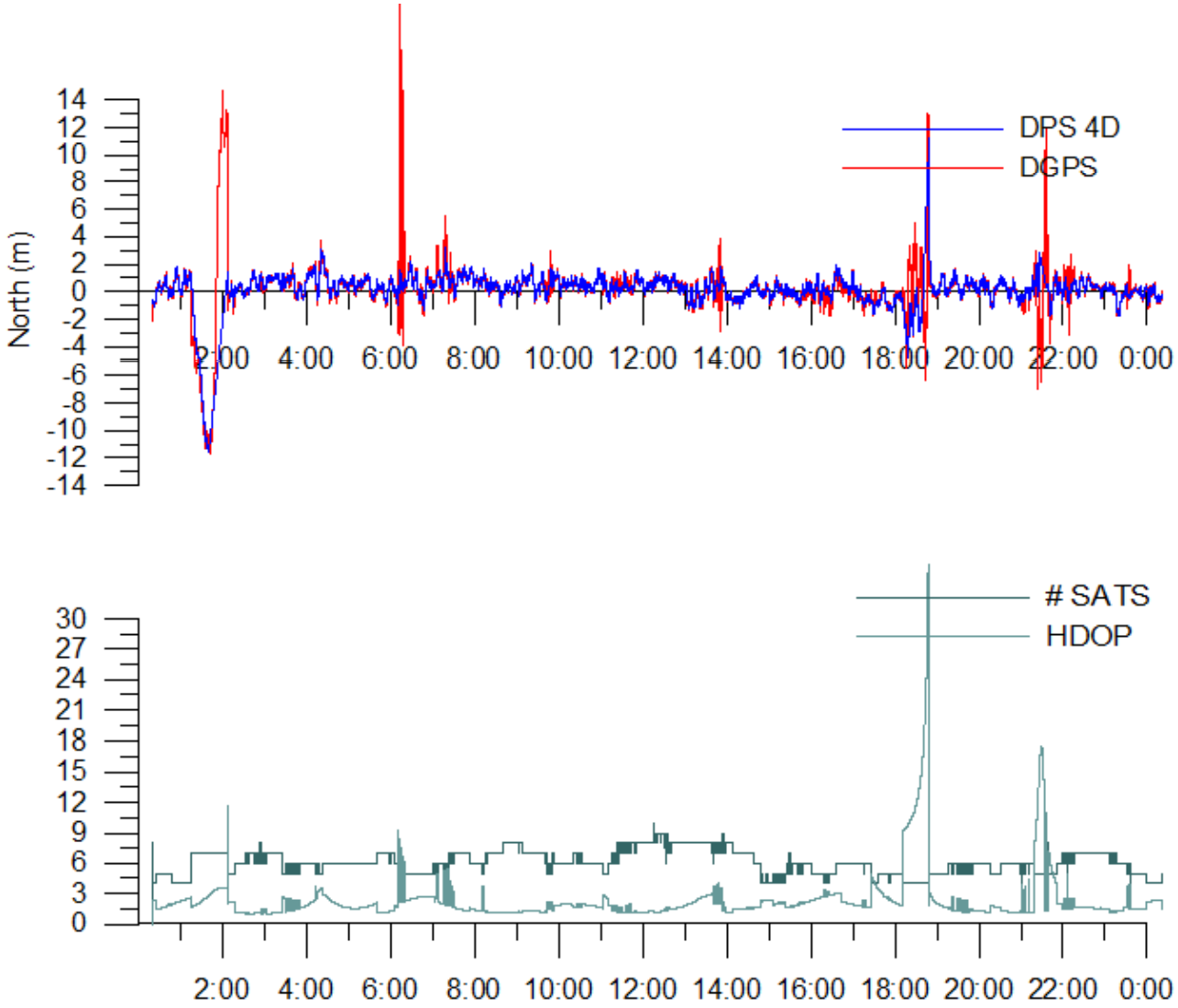


# Normal condition – zooming in



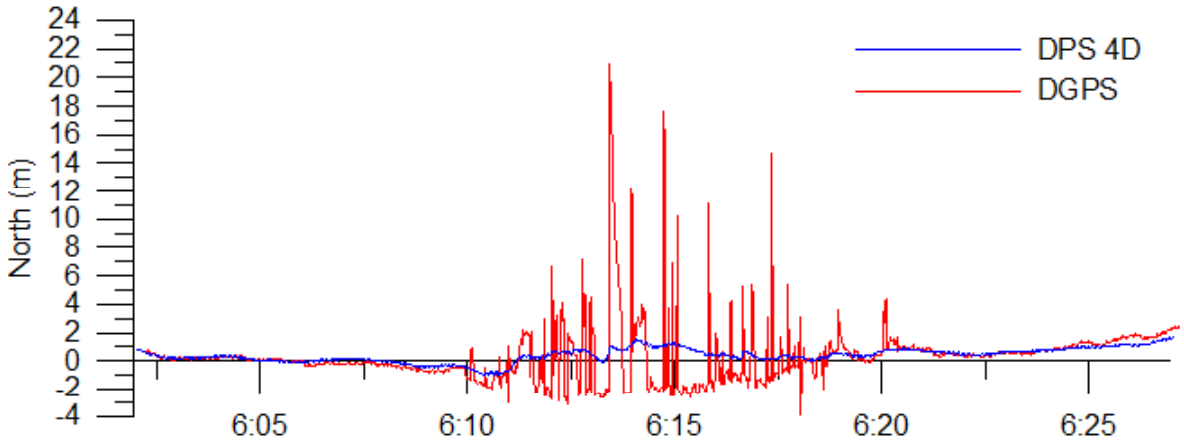

- Zooming in on a period with a low elevation satellite
- Standard DGPS corrections
- Noise in DGPS positions
- DPS 4D variations follow vessel movement

# Satellite signal blocking

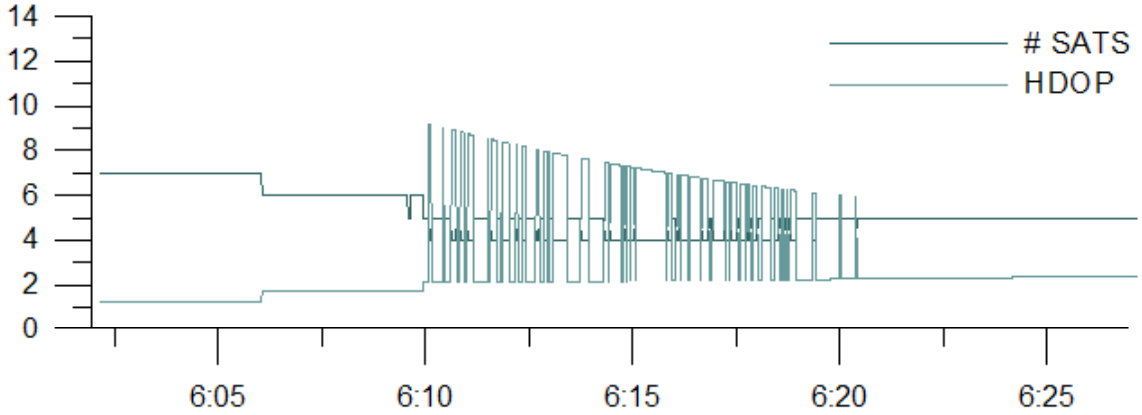



- Large shadow sector
- Standard DGPS corrections
- No HDOP mask
- Spikes in DGPS positions
- DPS 4D variations follow vessel movement

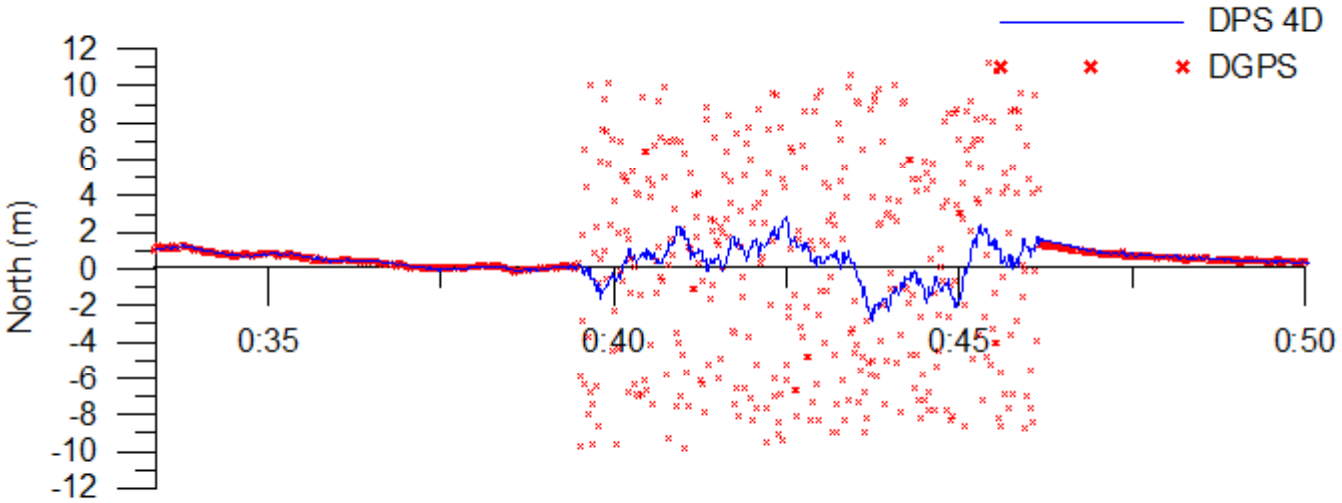
# Satellite signal blocking – zooming in



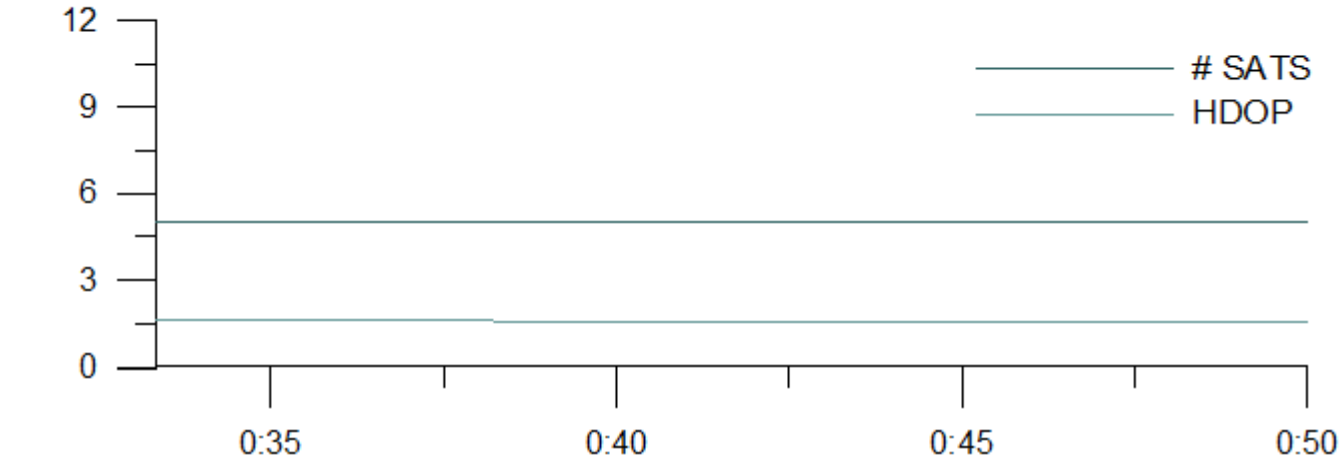

- Standard DGPS corrections
- Large shadow sector
- High HDOP periods
- Spikes in DGPS positions
- DPS 4D variations follow vessel movement

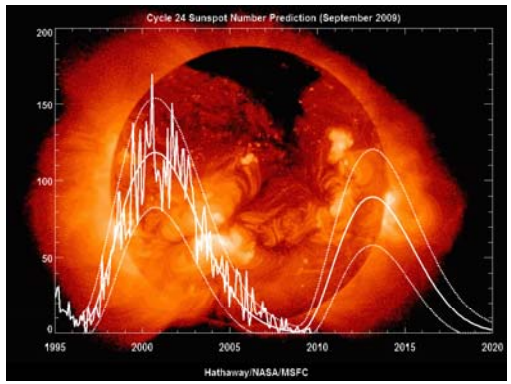


# Measurement noise

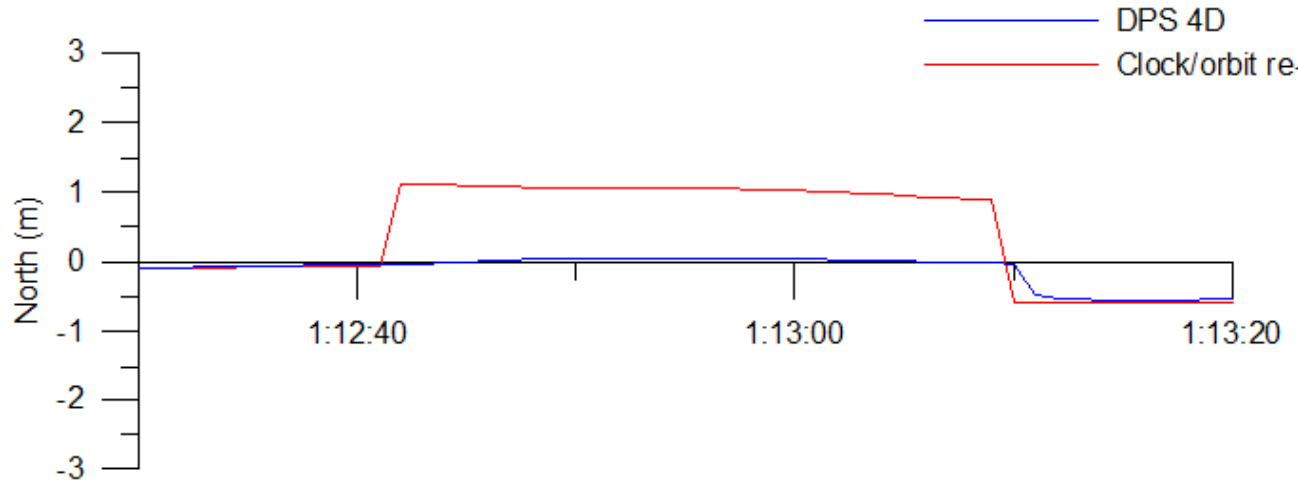


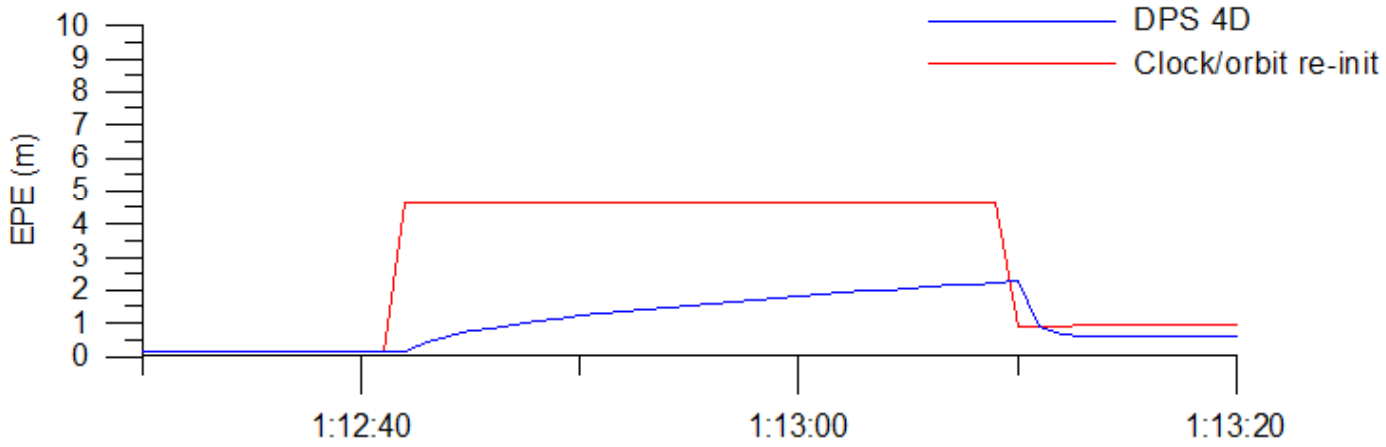

- Noise simulation on GPS measurements
- Position errors in DGPS solution
- DPS 4D variations follow vessel movements



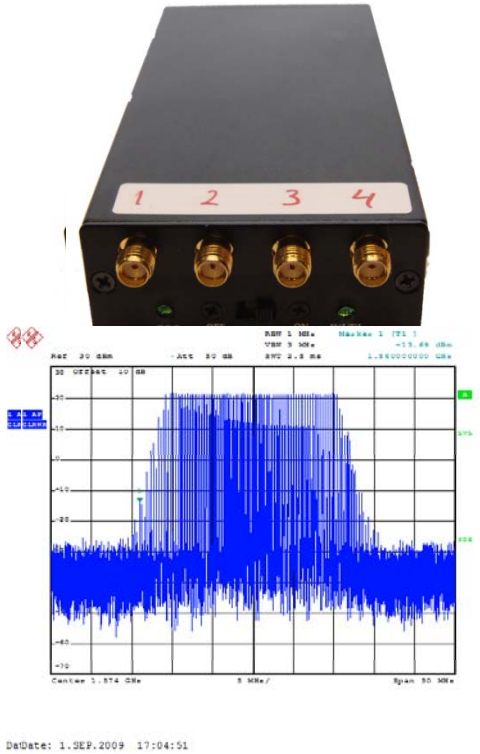



# GPS/Glonass clock/orbit re-init



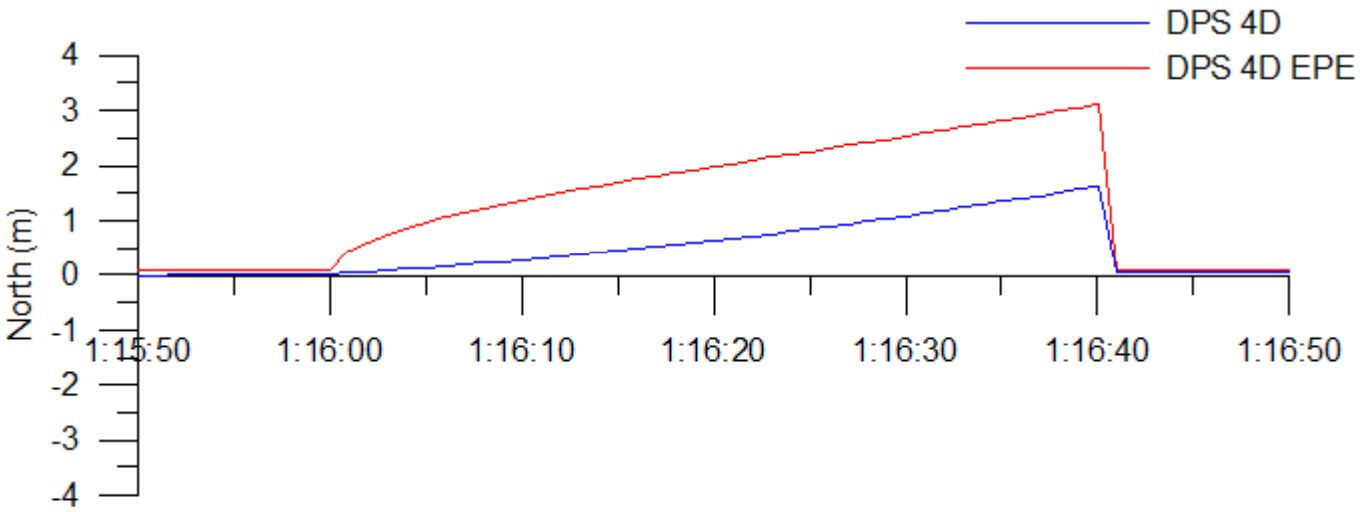



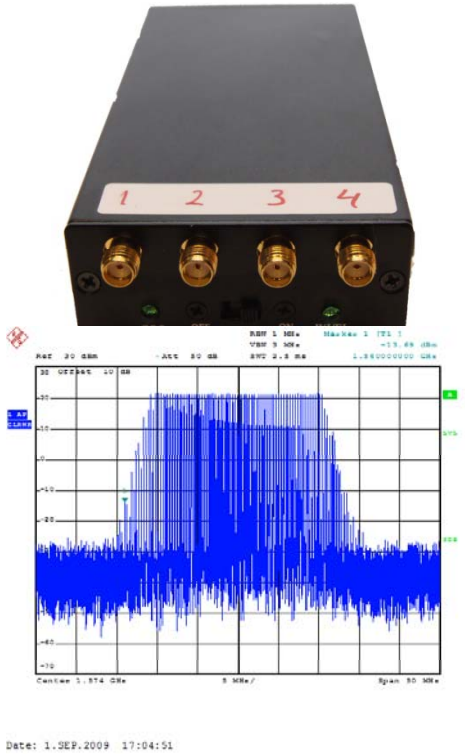

- Forced DGPS clock/orbit re-init
- GPS/Glonass in standard DGPS mode
- DPS 4D bridges initialization period



# GPS/Glonass: temporary loss-of-signal

- Forced GPS/Glonass loss-of-signal
- No GPS/Glonass solution
- DPS 4D bridges outage period with degraded accuracy



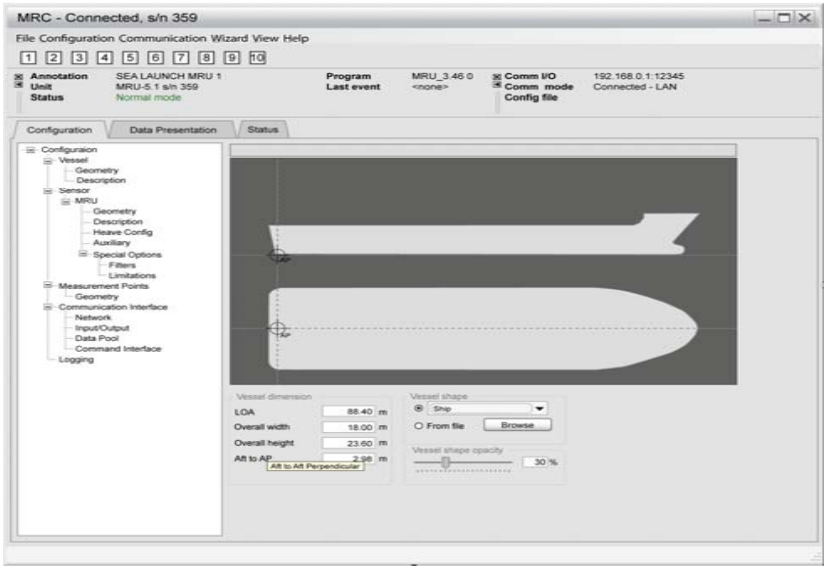



Getting everything right

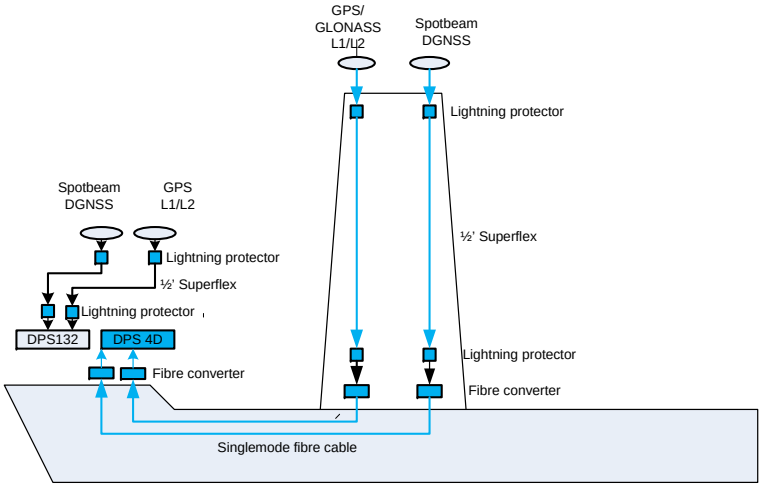
# INSTALLATION

# Installation aspects

- Combining GNSS and IMU increases installation complexity
- Single mode errors can easily be introduced by careless installation
- Documentation and necessary auxiliary equipment is essential




- The application should preferably support installation aspects



# CONCLUSION

# Conclusion

- Integrating GNSS and IMU offer improved accuracy, reliability and availability
- The quality is a matter of how the individual systems are integrated
- Eliminating failure modes requires intelligent and endurable testing
- Verification and validation confirms high performance and reliability

# Kongsberg Maritime