Multi-Sensor
Precise Point Positioning for Ships

Dr. Patrick Henkel
Managing director of ANavS GmbH
www.anavs.de

Prepare Ships

Galileo/ EGNOS – Perspektiven und Anwendungen im maritimen Umfeld

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ANAVS
Advanced Navigation Solutions

ANavS – Advanced Navigation Solutions

- Founded in 2011 as Spin-off of
  the Technical University of Munich (TUM)

Dr. Patrick Henkel

- Founder & managing director of ANavS
- PhD & Habilitation at TUM on Precise Positioning
- Lecturer on Precise Point Positioning
- Acquired more than 5 million Euros for ANavS

- Further board members

Andreas Sperl, MBA

Peter Schmitz

Prof. Christoph Günther

I. ANavS Team

RTK/ PPP Positioning Group

Ulrich Mittmann, M.Sc.

Philipp Bohlig, M.Sc.

Julius Krause, M.Sc.

Further team members:

Julian Weiss, M.Sc.

Computer Vision Group

Dr.-Ing. Robert Bensch

Luka Sachße, M.Sc.

Medeea Horvat, B.Sc.

Further team members:

Nagaraj Desai, M.Sc.

Embedded Positioning Systems Group

Michael Heinrich, M.Sc.

Dipl-Ing. Markus Lamm

Further team members:

Ebenezer Samson, M.Sc.
Martin Lotz, B.Sc.
Valaenthin Tratter, M.Sc.

II. ANavS Business Divisions and Target Markets

Target Markets

Automotive

Robotics and Automation

Maritime

UAVs

Surveying

Hydrology

III. ANavS Products and Services

1. ANavS Sensor Fusion Framework with Artificial Intelligence (AI)
2. ANavS Multi-Sensor RTK/PPP module
3. ANavS Integrated Sensor Platform
4. ANavS RTK reference station
5. ANavS Services related to RTK Positioning
6. ANavS Mapping Services
7. ANavS Snow Monitoring Station

III. ANavS Products and Services

Multi-Sensor RTK/PPP module

Industrial Casing

3D-printed Casing

- up to 3 integrated Multi-frequency, Multi-GNSS receivers
- integrated industrial-grade MEMS-IMU with improved bias stability
- integrated LTE module for reception of RTK or PPP corrections
- integrated Quad-core processor (1.5 GHz, 8 GB RAM) running ANavS GNSS/ INS/ odometry tightly coupled positioning engine
- Various interfaces: Ethernet, WiFi, CAN, LTE

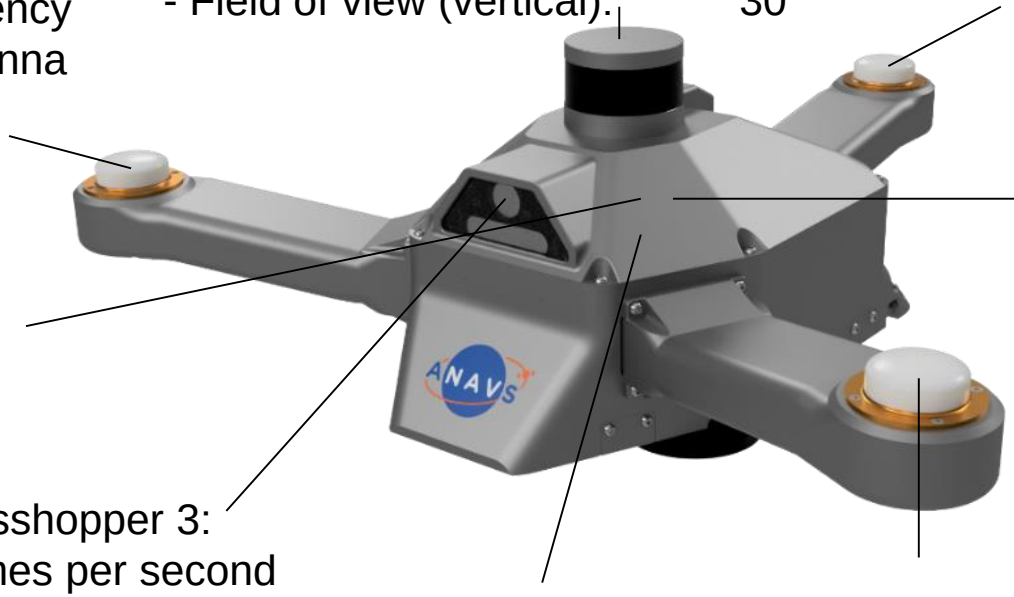
III. ANavS Products and Services

Integrated Sensor Platform (ISP)

Velodyne Puck (VLP 16) Lidar:
- measurement range: 100 m
- measurement accuracy: +/- 3 cm
- Field of view (horizontal): 360°
- Field of view (vertical): 30°

Multi-frequency GNSS antenna

Multi-frequency GNSS antenna



LTE

6-core Nvidia ARM:
GPU with
384 Nvidia Cuda cores
and
48 tensor cores

FLIR Grasshopper 3:
- 163 frames per second
- 1920 x 1200 resolution
- global shutter

IMU with
3 deg/h bias stability

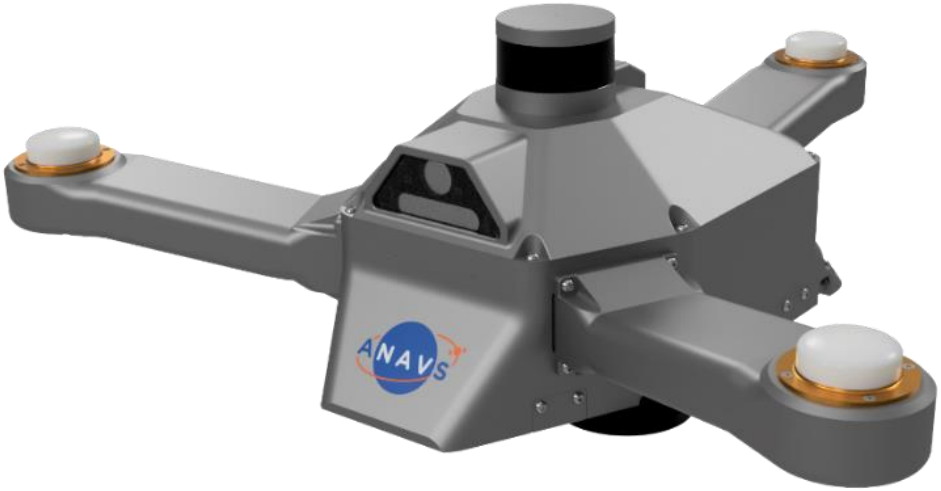
Multi-frequency GNSS antenna

III. ANavS Products and Services

Integrated Sensor Platform (ISP)

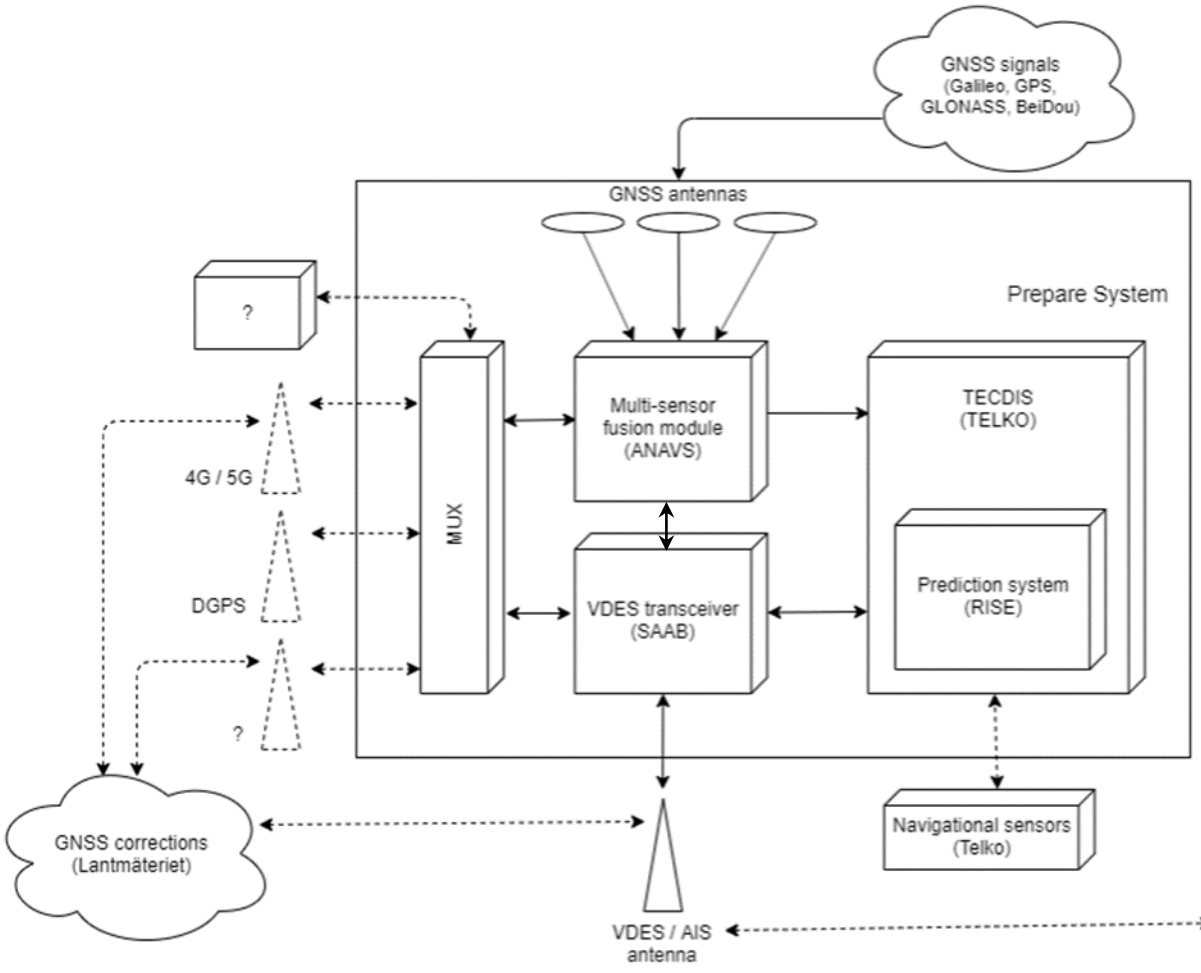
Customer benefits:

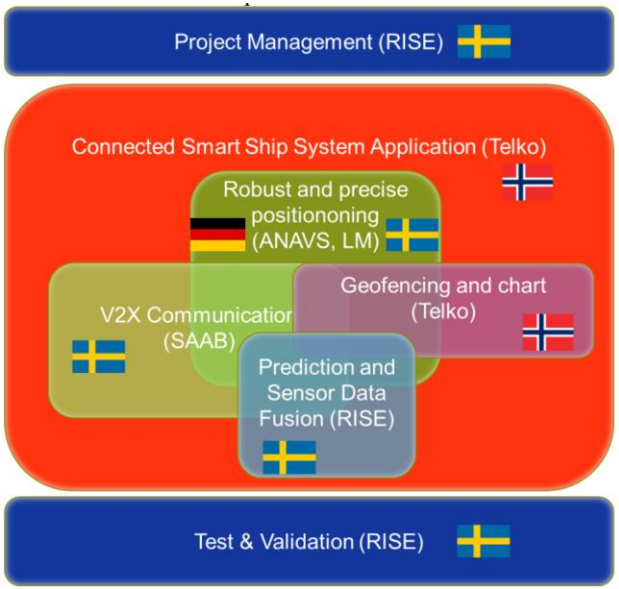
- Very easy and fast installation and de-installation
- No need for individual cabling of each sensor
- No need for manual and error-prone determination of lever arms
- No need for individual synchronization of sensors



- Very powerful sensor fusion
- Access to synchronized raw data
- Ideal platform for localization, mapping and object detection

Prepare Ships – an ongoing Horizon 2020 Project





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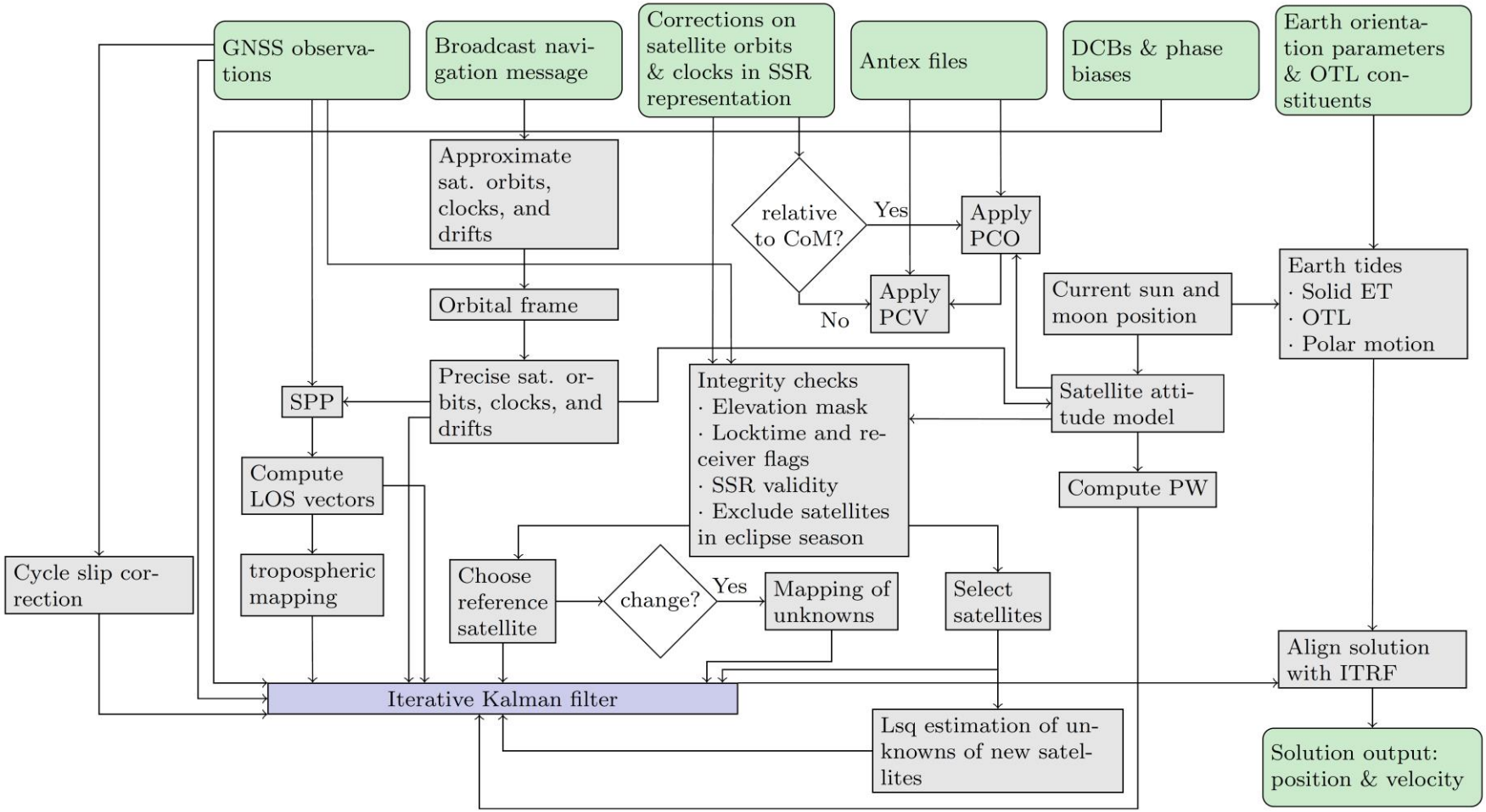
Precise Point Positioning

- Truly *absolute* positioning,
  i.e. processing of undifferenced and uncombined measurements
  without the use measurements from a reference station

- Application of satellite position, clock offset,
  phase and code bias corrections for improved measurement accuracy

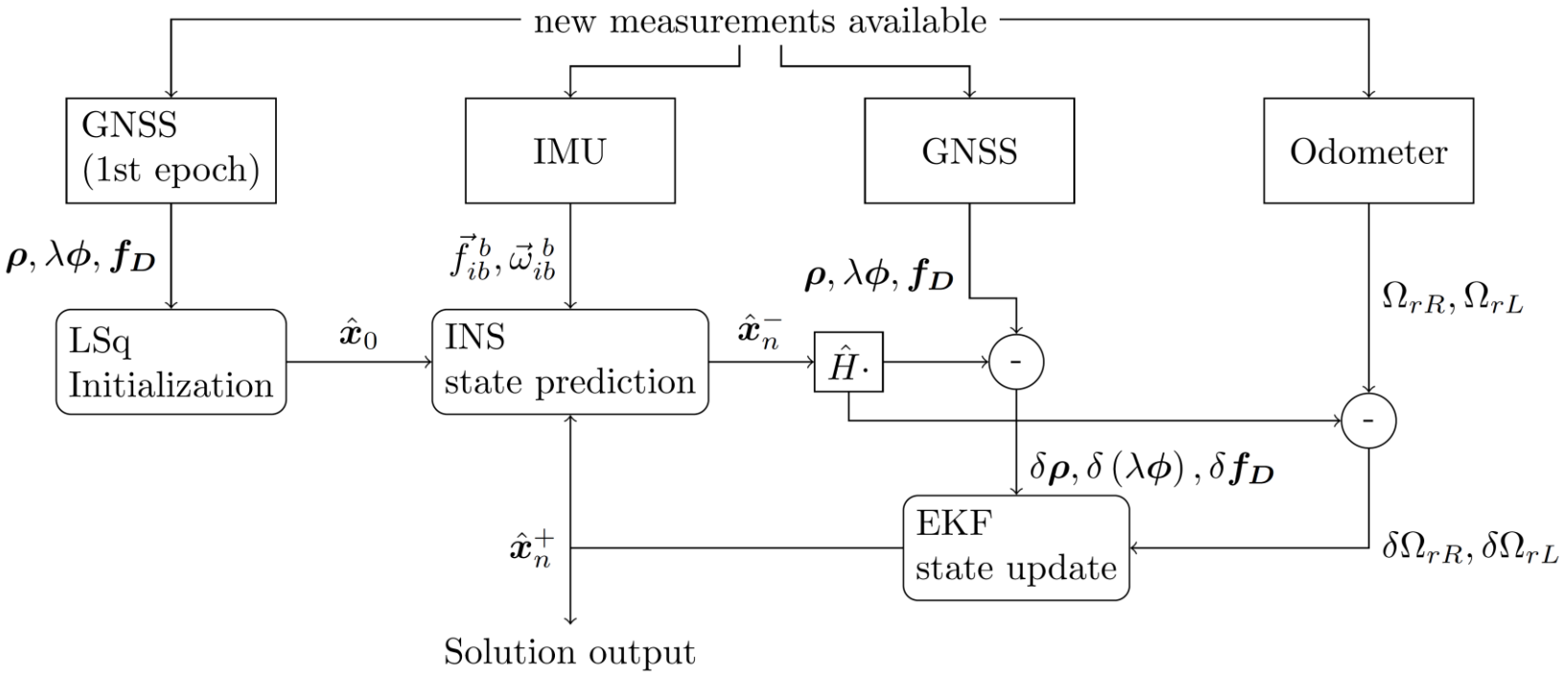
- Estimation of absolute receiver position, clock offset,
  tropospheric zenith delay, ionospheric slant delays
  and carrier phase ambiguities using a Kalman filter

Precise Point Positioning



Source: Philipp Bohlig, PPP expert at ANavS.

Tight Coupling of GNSS and INS measurements



Source: Philipp Bohlig, PPP expert at ANavS.

ANavS Maritime RTK/ PPP receiver

- 3 Multi-frequency, Multi-GNSS receivers
- MEMS IMU with high bias stability
- Processor with
  GNSS/ INS tightly coupled RTK/ PPP
- LTE module for reception of
  RTK/ PPP corrections

Ideal for
harsh environments:

- water-proof casing
- TNC instead of SMA antenna connectors
- fan-less
  heat pipe cooling
- VDES compatibility
  for reception of
  GNSS Corrections
  via secure channel
  independent of
  mobile communications

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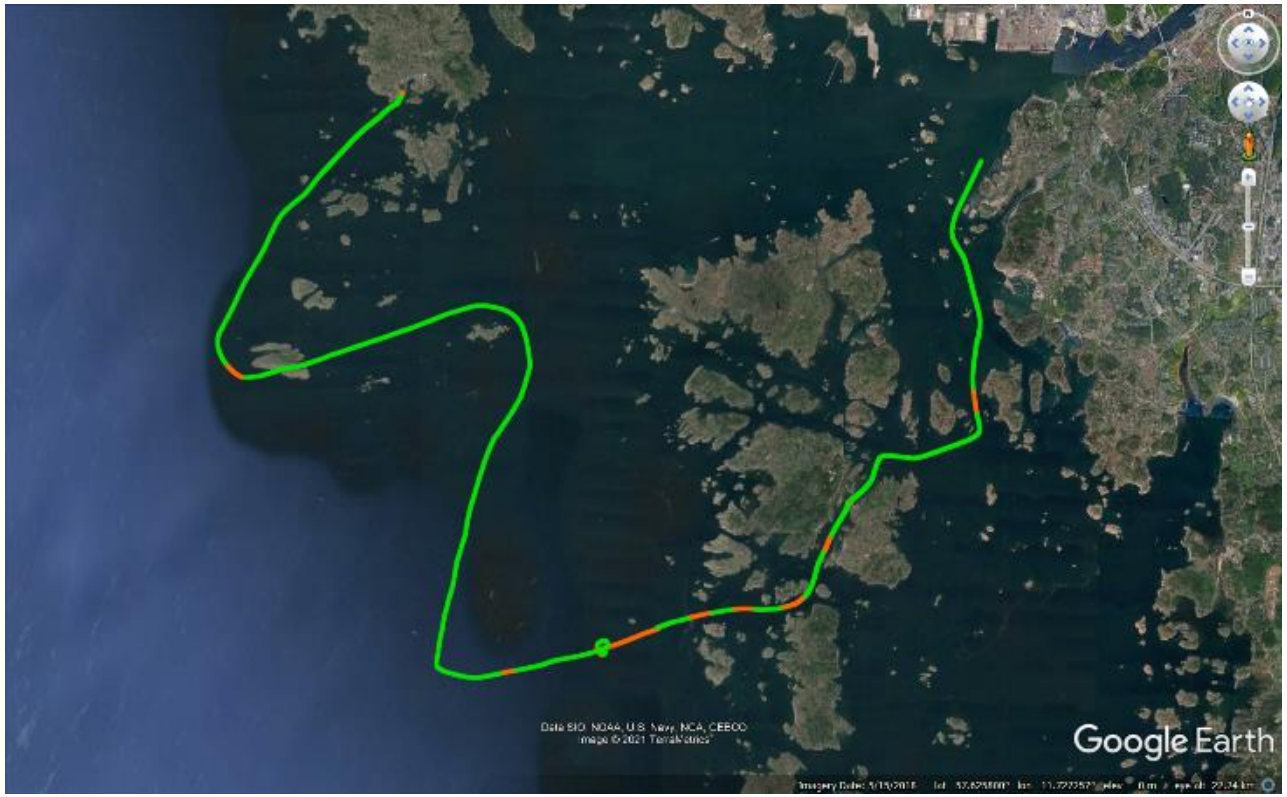
Targeting:
Internation Standard IEC 60945
Maritime navigation and radiocommunication equipment and systems – General requirements

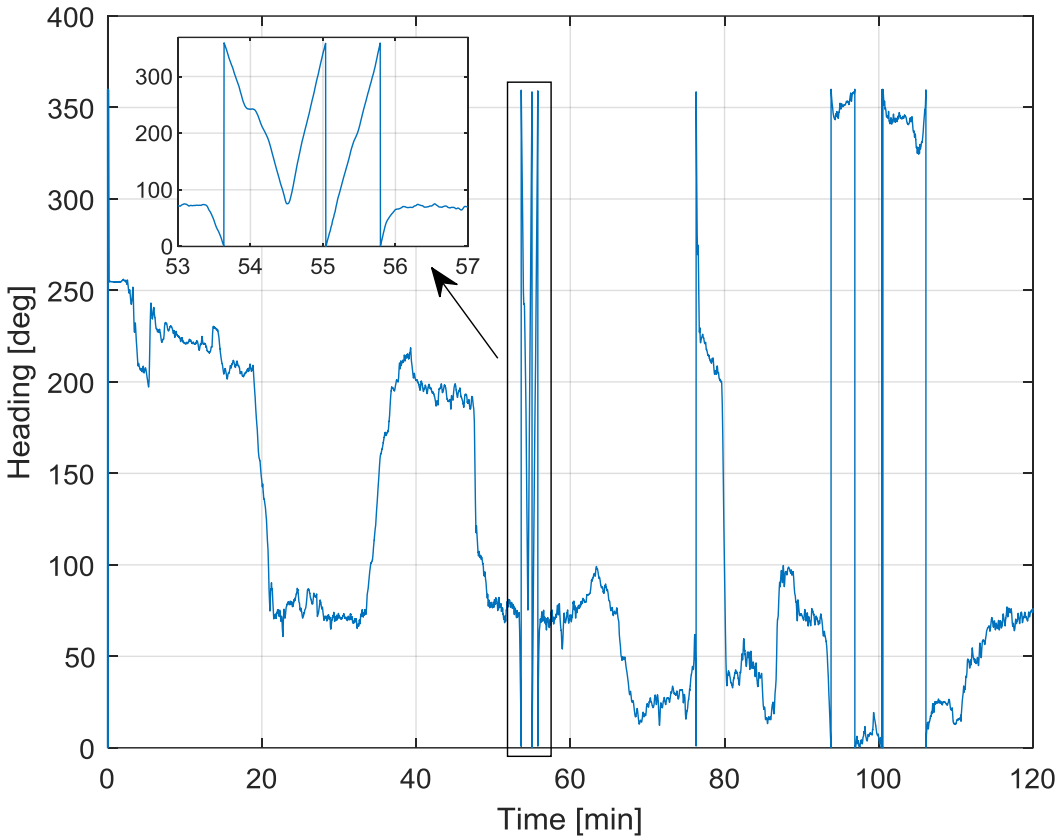
RTK Performance Results

- Map of Gothenburg area with fixed (green) and float (red) solution



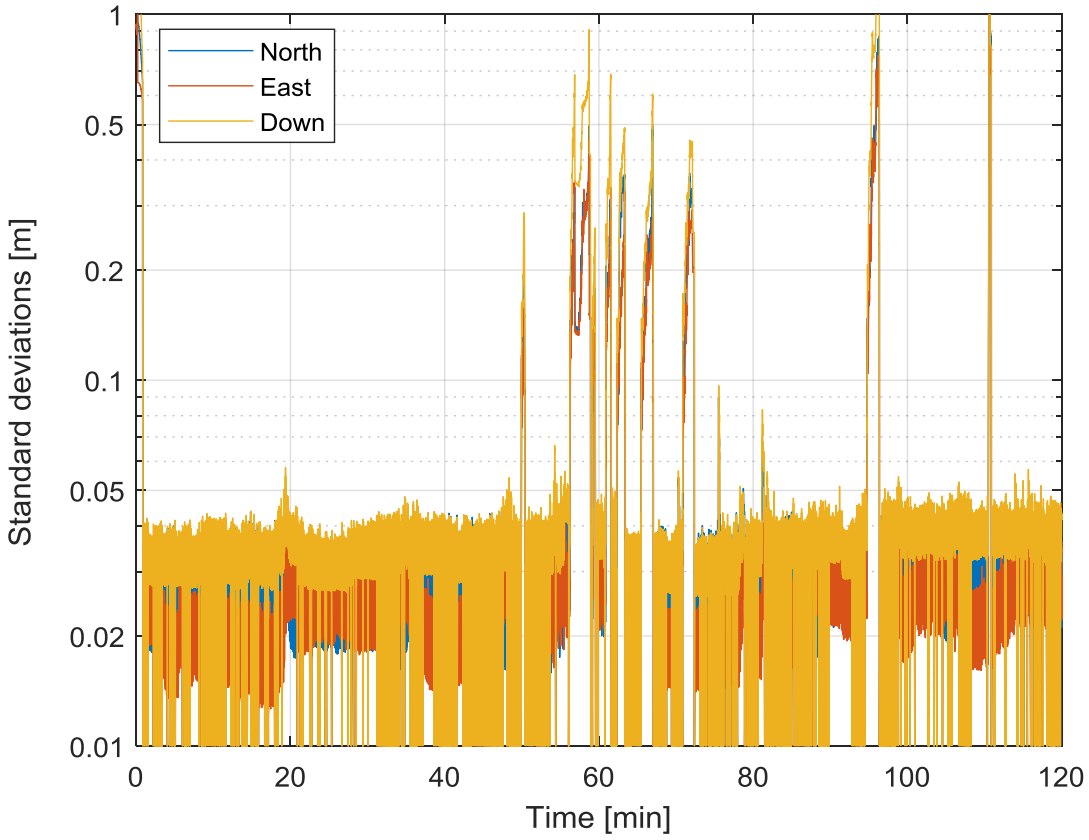
RTK Performance Results

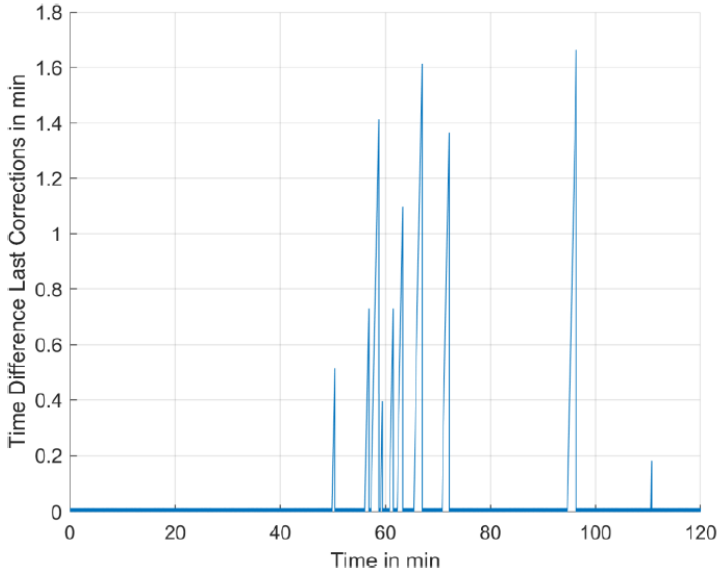
- Heading as determined by GNSS/ INS tightly coupled solution



RTK Performance Results

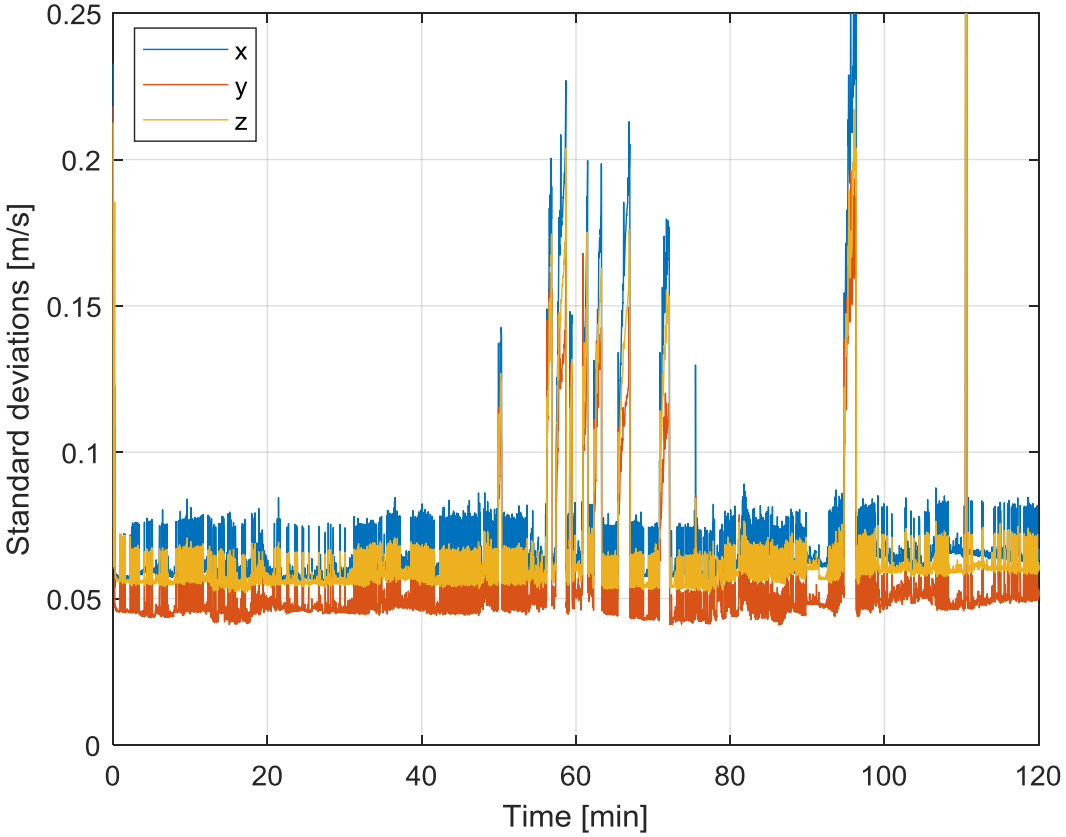
- Precision of RTK solution as determined by tightly coupled GNSS/ INS RTK

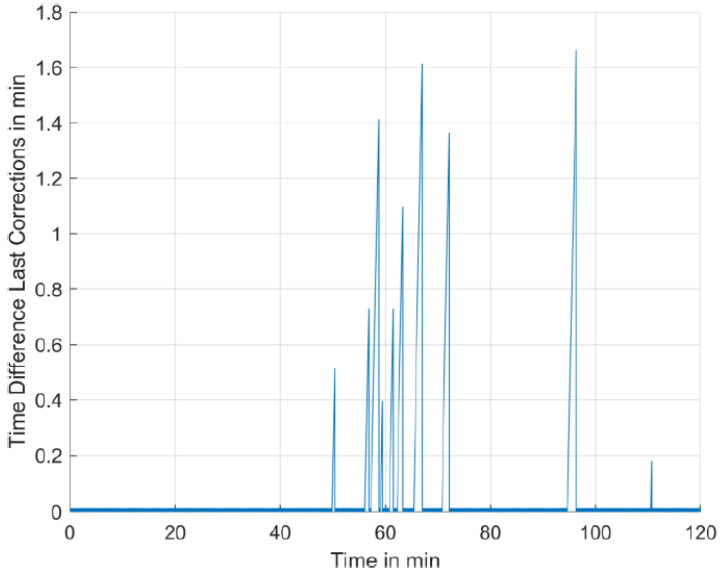




RTK Performance Results

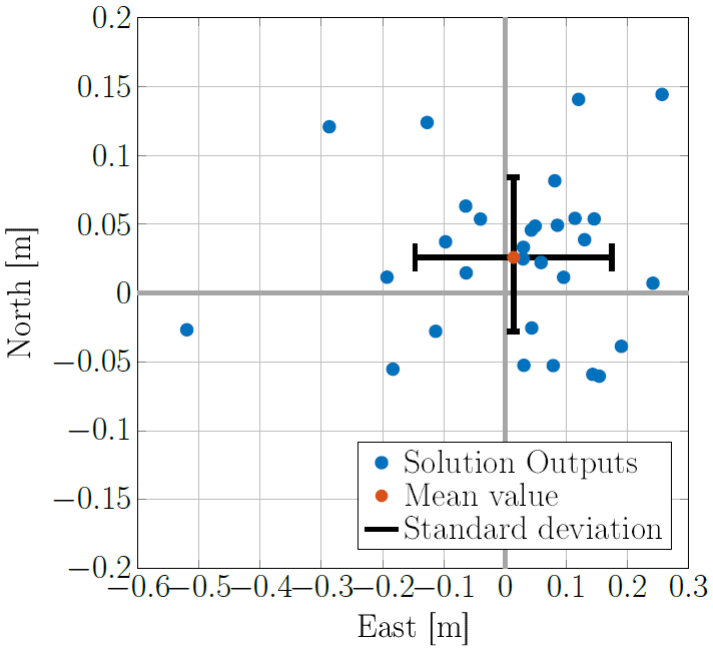
- Precision of 3D velocity solution in local coordinate frame

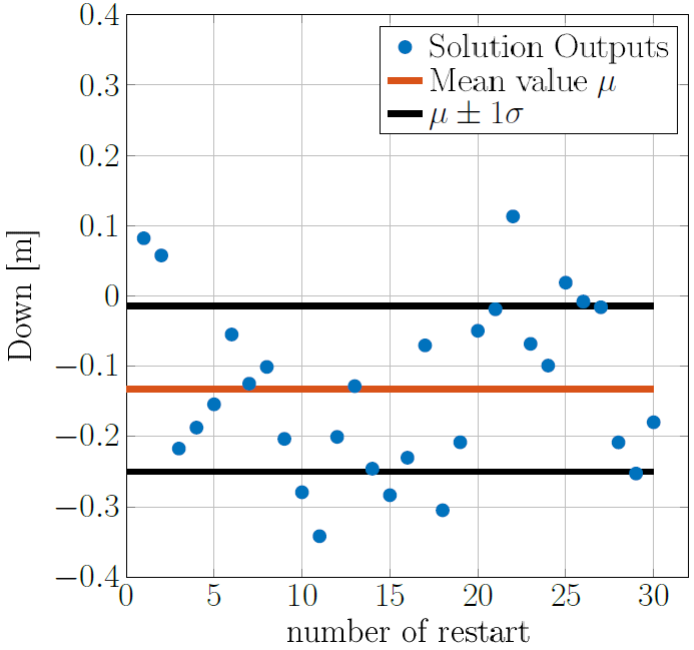




Precise Point Positioning Performance Results

- Evaluation of static PPP solution of IGS station
  with respect to surveyed solution using NAVCAST PPP corrections

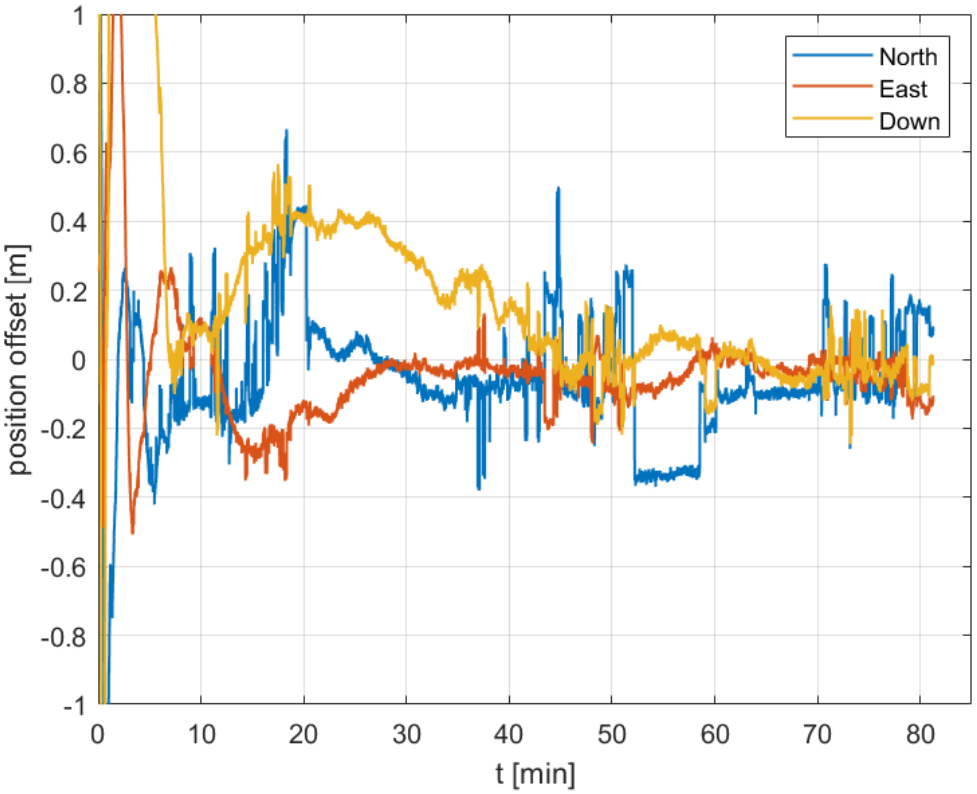




Offset to the IGS coordinates for 30 consecutive runs of 30 minutes in
a) the horizontal plane b) the vertical direction

Precise Point Positioning Performance Results

- Evaluation of PPP solution with respect to RTK solution



Already corrected for the frame offset between between RTK coordinate system (SWEREFF 99) and PPP coordinate frame (ITRF 2014).

Precise Point Positioning Performance Results

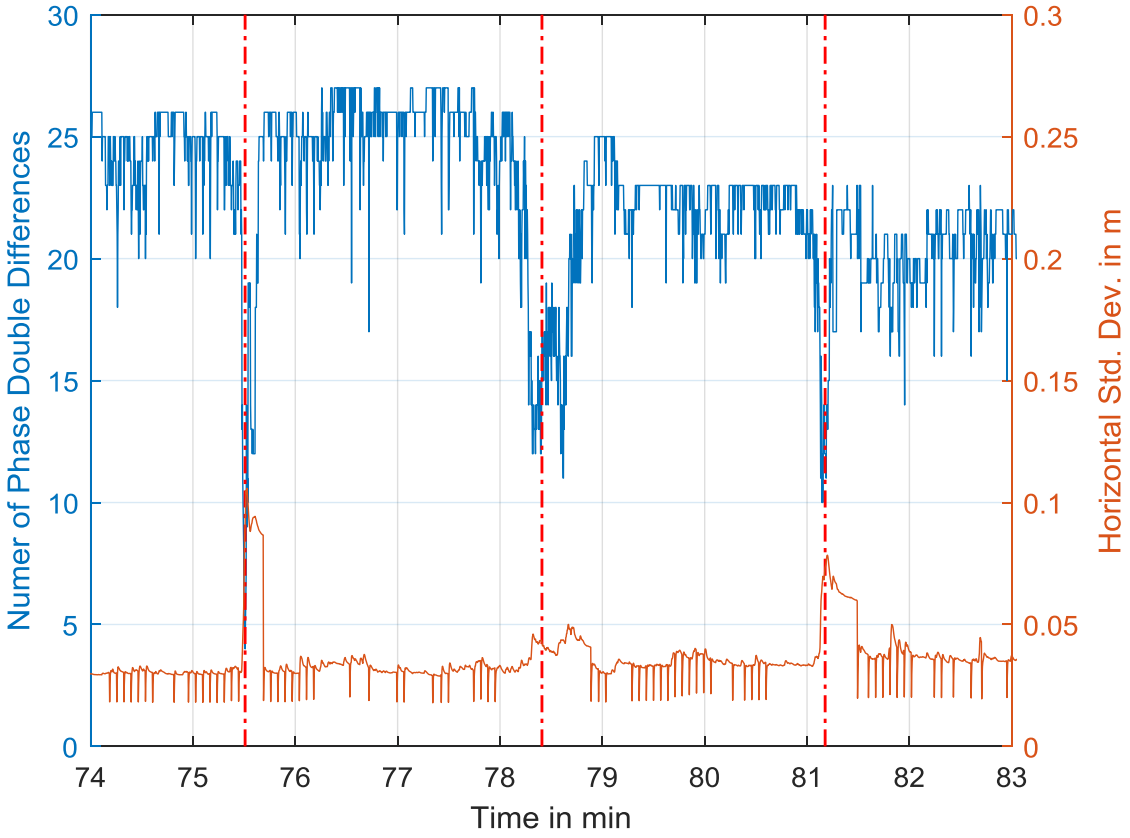
- Evaluation of PPP solution with respect to RTK solution

Position offset	6 s < t < 20 min			t ≥ 20 min		
	Max (abs.)	Mean (abs.)	Mean (bias)	Max (abs.)	Mean (abs.)	Mean (bias)
North	1.850 m	0.246 m	-0.048 m	0.501 m	0.120 m	-0.060 m
East	1.161 m	0.243 m	-0.008 m	0.237 m	0.048 m	-0.040 m
Vertical	3.755 m	0.606 m	+0.501 m	0.512 m	0.137 m	+0.099 m
Horizontal (2D-RMS)	1.936 m	0.381 m	x	0.501 m	0.137 m	x
Position (3D-RMS)	3.789 m	0.764 m	x	0.627 m	0.224 m	x

- Bias consistency to a few cm
- Longer convergence time for the vertical offset
- After convergence (20 min): mean absolute consistency
  14 cm horizontally, 22 cm 3D-RMS

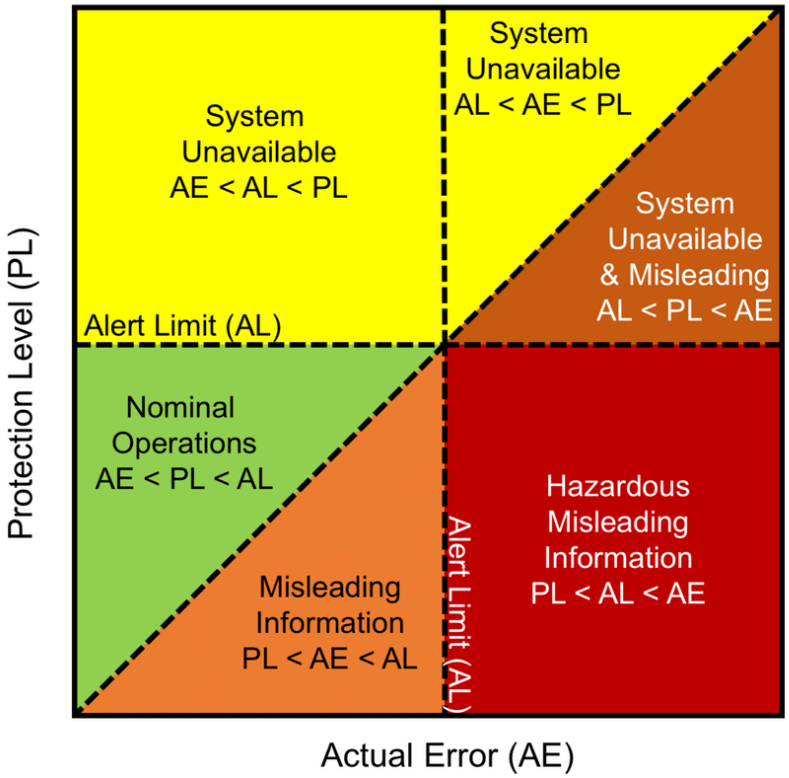
Benefit of Tight Coupling with Inertial Sensor

- Precision during passages below bridges



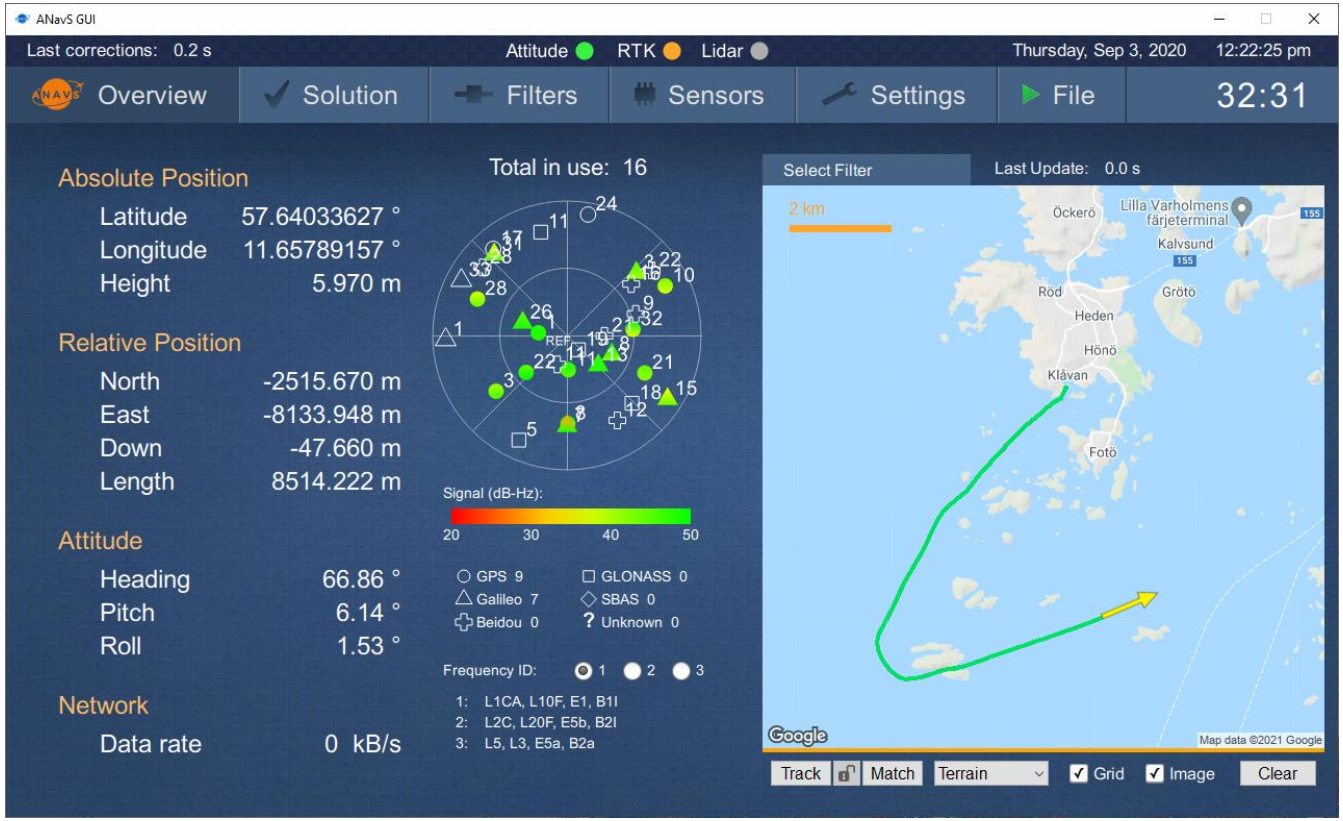
Integrity of Position Solution - Stanford diagram

- Classification of system status: protection level versus actual error



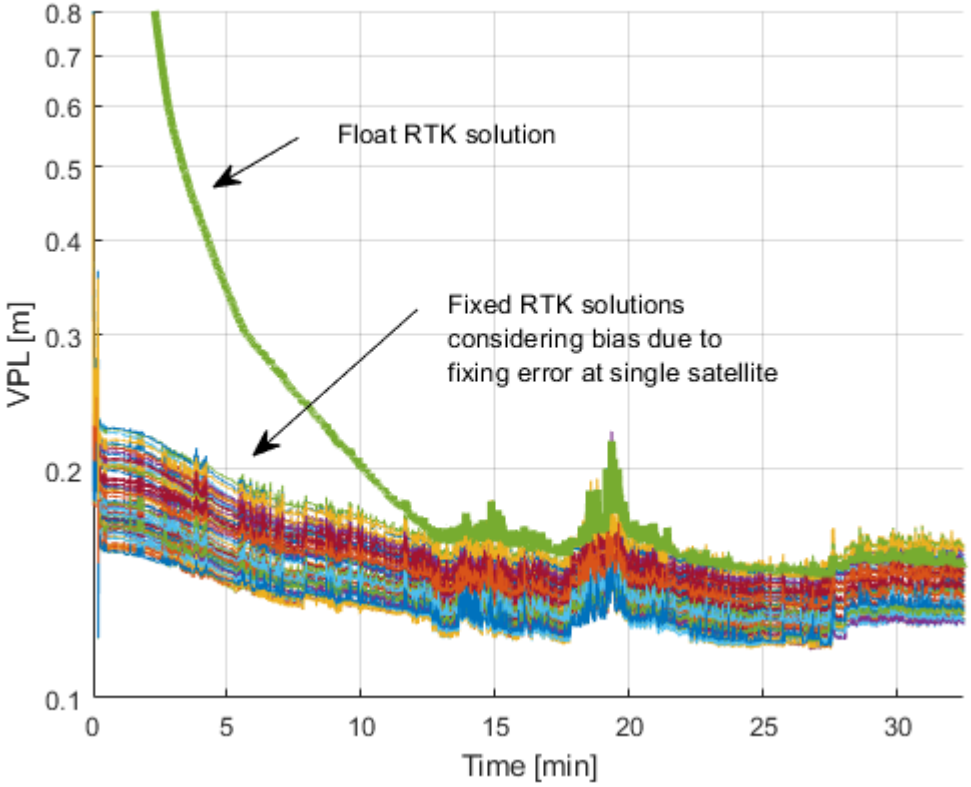
Integrity Analysis of Position Solution

- Track of pilot boat in Gothenburg area



Integrity Analysis of Position Solution

- Vertical Protection Level determination for RTK solution



Conclusion

- RTK and PPP are attractive for high accuracy positioning
- Multi-frequency and Multi-GNSS is needed for fast convergence
- Galileo will provide in the near-future
  the Galileo High Accuracy Service (HAS) corrections –
  ANavS develops the reference user algorithm for EUSPA
- ANavS offers with its Multi-Sensor RTK/ PPP module
  an innovative solution that fulfills the user needs.