Recovering Usefulness of Inaccurate INS Data

Mads Fogh

Vectory Sensor Systems AS

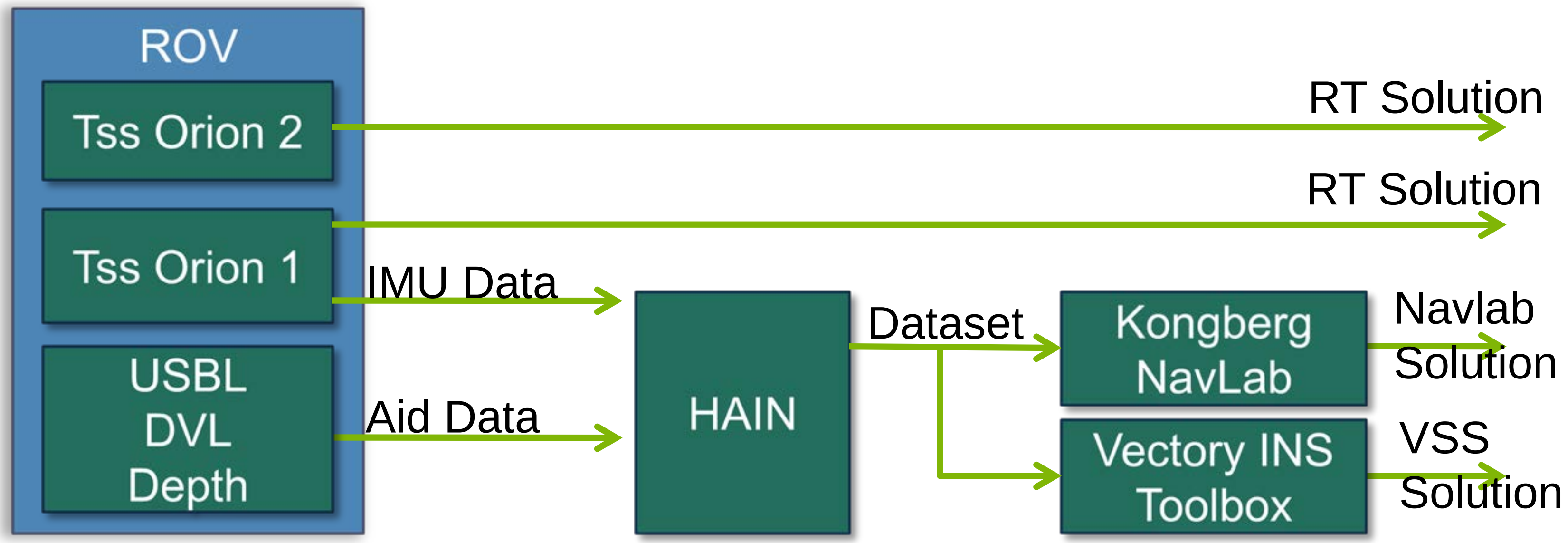
Vectory Sensor Systems AS
Background

Providing Inertial Operational Support:

- Background in Electronics Systems/Applied Mathematics Autonomous Intelligent Systems (Cybernetics)
- Specialist in Stochastic Modeling, Kalman Filtering, and the design of Inertial Systems for subsea and marine industries: MRU, AINS and standalone northseeking gyrocompass.
- Experience and expertise in tackling individual issues related to using RLG, FOG and MEMS based AHRS / INS, typically diagnosed as causes such as algorithm, HW, temperature and other inherent errors in the specific technology.

Introduction to Issues

- Approached by DOF Subsea to investigate issues with their TSS Orion units as presented by Julian Bell
- Faulty dataset from operation were given from two units mounted on a ROV each aided by DVL, Depth and USBL
- The following fault finding was done on operational data alone without the units leaving the ROV

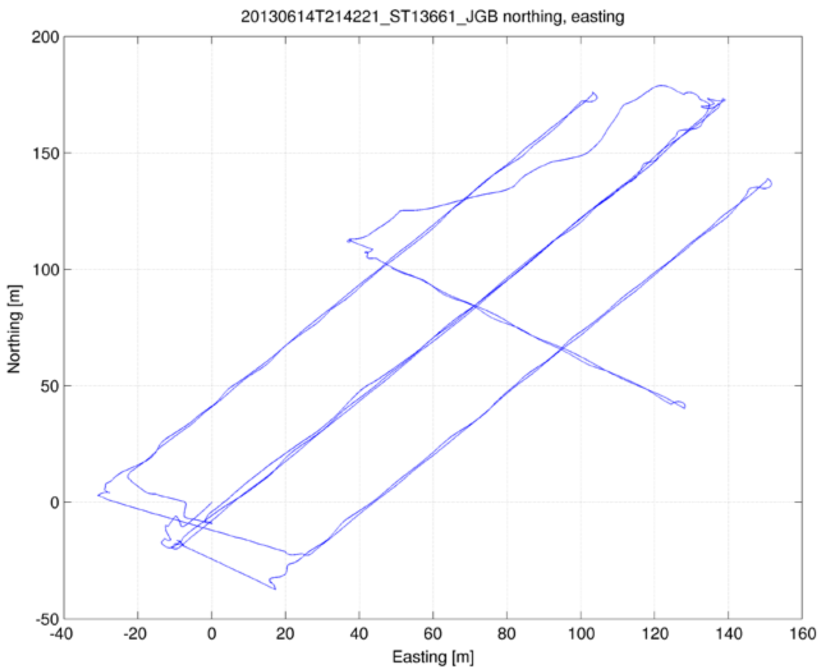


Presentation Outline

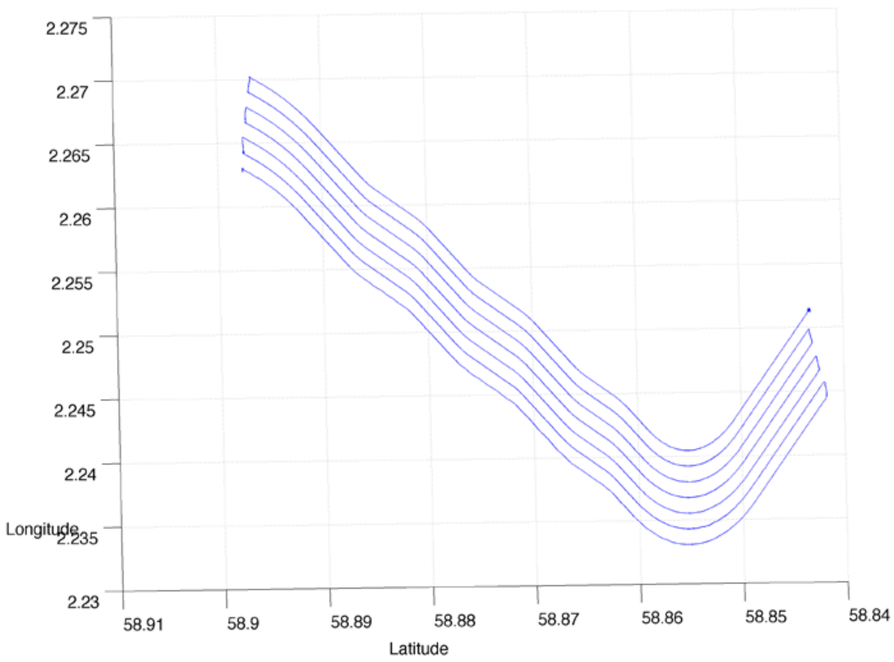
- **Orion 1:** Suffered from tilt instability
  - How the root cause initially can be observed
  - How the root cause can be found and compensated for
  - And last how the error also can be observed without data from MBE or a second system
- Brief Overview of QC data available within the INS it self
- **Orion 2:** Suffers primarily from heading (gyro) instability

Datasets

- Orion 1 QC Dataset



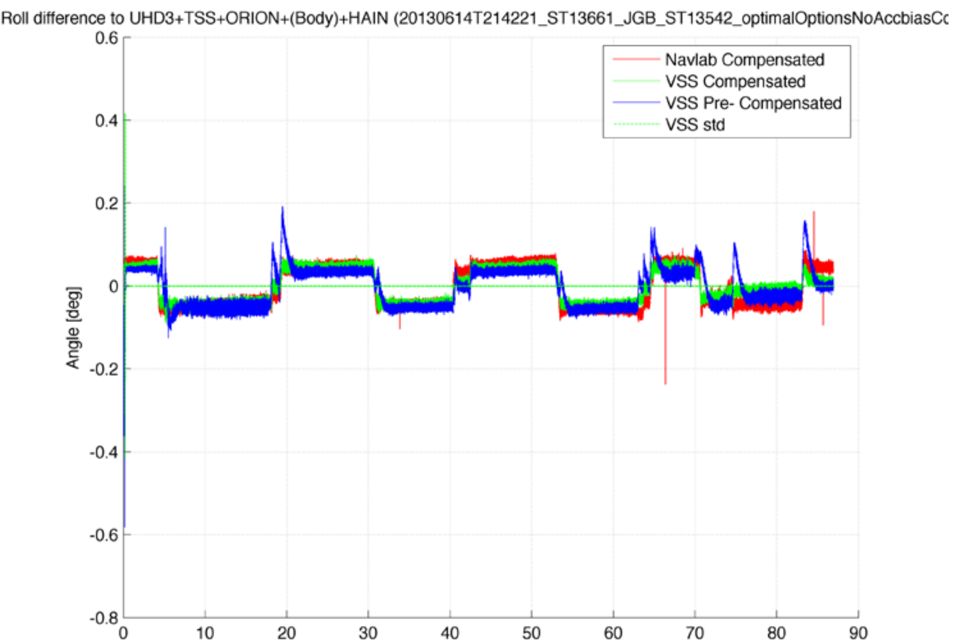
- Orion 2 QC Dataset



vectory sensor systems

Orion 1: Tilt Error

Error When Comparing



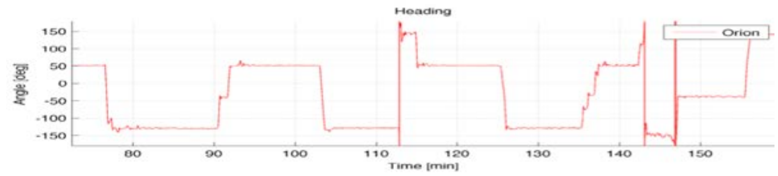
- The results are all rotated to the frame of Orion2 RT.
- When the Orion 2 are compared to the Orion 1 based solutions a clear stepping shows up on all three results. Showing a 0.05 deg error in the Orion 2
- The non compensated VSS solution shows an additional similar 0.05 deg tilt error in form of a “spike”
- In the following I will show how the compensated solution is made by correction of the IMU measurements

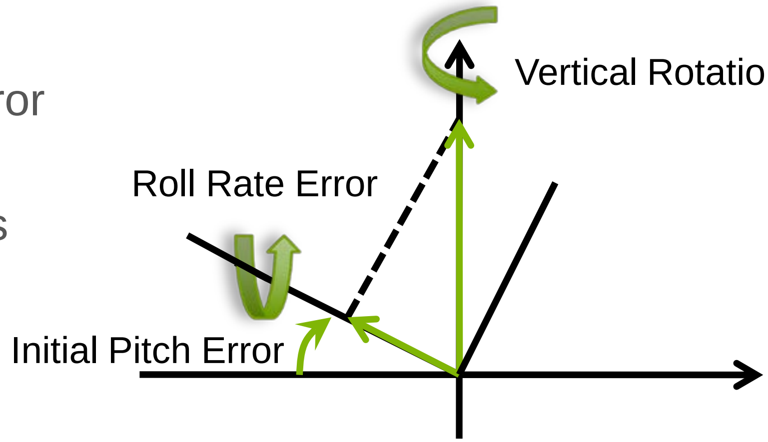
vectory sensor systems

Orion 1: Tilt Error

Explanation of Error Source

- There is a clear correlation between heading change and the tilt errors
- The “horizontal” gyro axis (tilt axis) measures part of the vertical axis
- Two explanations for initial tilt error:
  - Accelerometer Bias => Initial tilt error
  - Non-orthogonality or misalignment between gyros and accelerometers axis

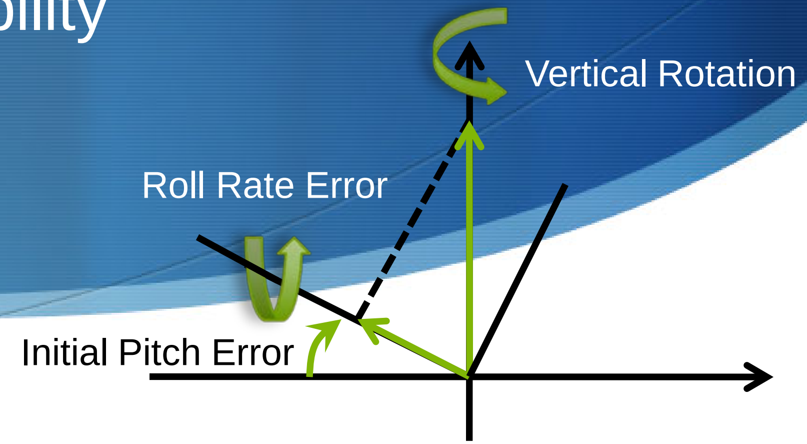




vectory
sensor systems

Orion 1: Tilt Error

Error Observability



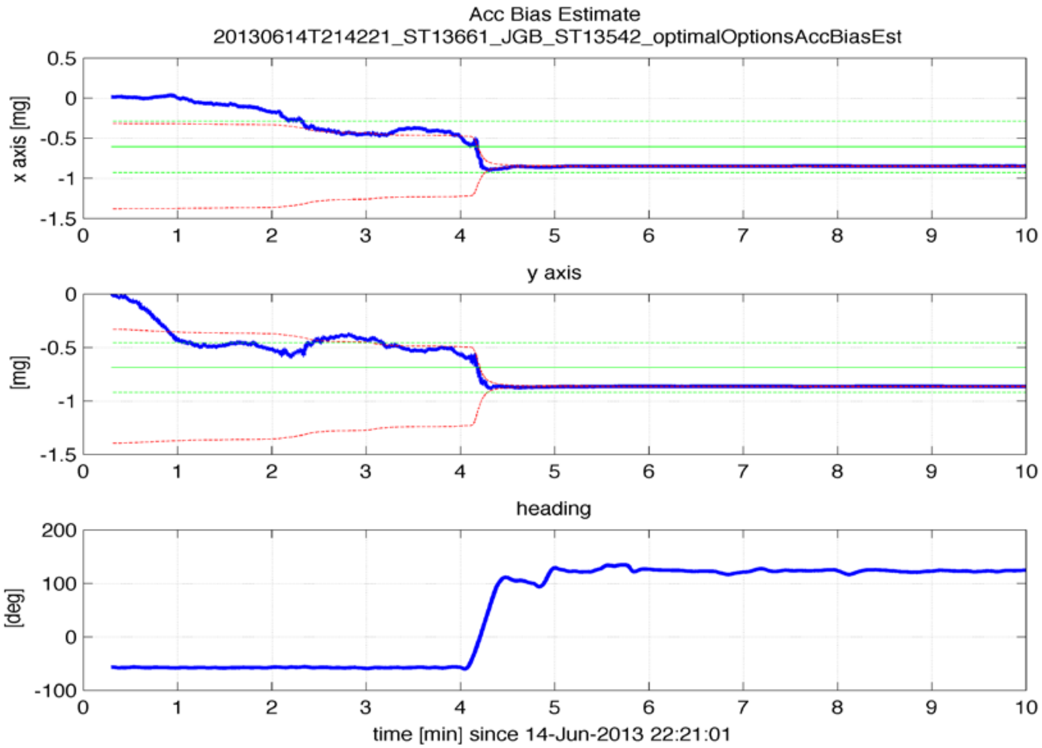
- Only a weak observable scalefactor distinguishes these two possible type of errors
- This scalefactor is not observable with the given dataset
- Due to this fact the resulting error in the tilt data is therefore also possible to be successfully compensated with either of the two error types
- In the following we have chosen to to solve for accelerometer bias

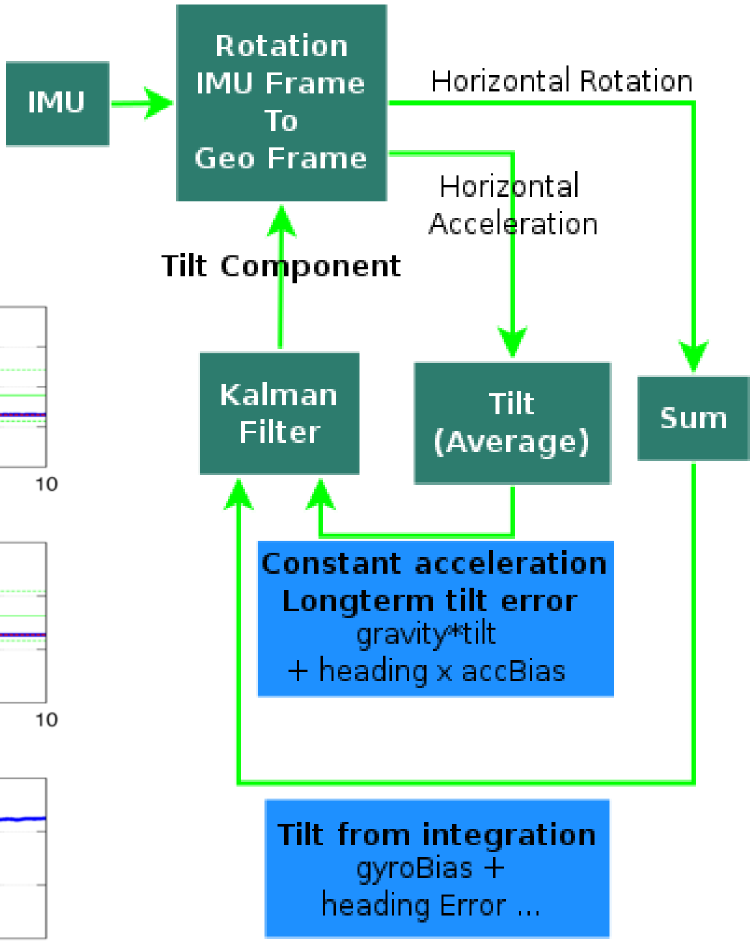
vectory sensor systems

Orion 1: Tilt Error

Accelerometer Bias Estimation

- Estimating the accelerometer bias is done by informing the Kalman filter of the accelerometer bias uncertainty
- An uncertainty estimate can be calculated from the magnitude of the stepping ~850ug





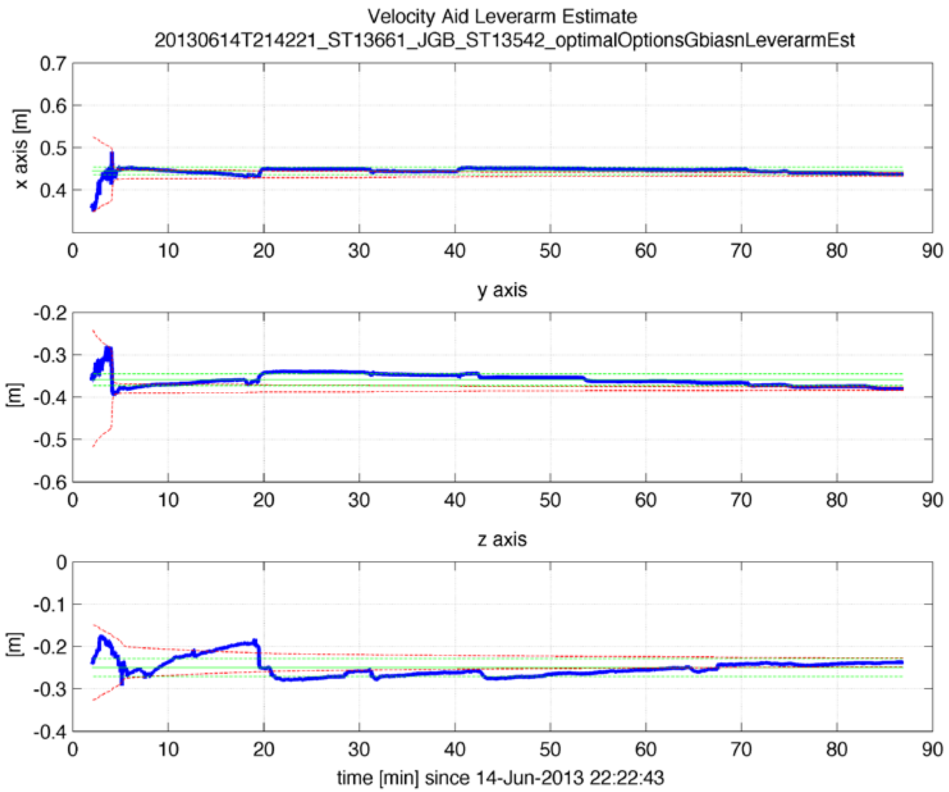
vectory sensor systems

Orion 1: Tilt Error

General QC

The following has been QCed using the dataset

- The DVL leverarms has been successfully estimated on the dataset and QC'ed against surveyed values. Remaining residual: [-0.53 -1.4 -22.16] cm
- Additionally the timing for DVL aiding has been QC´ed

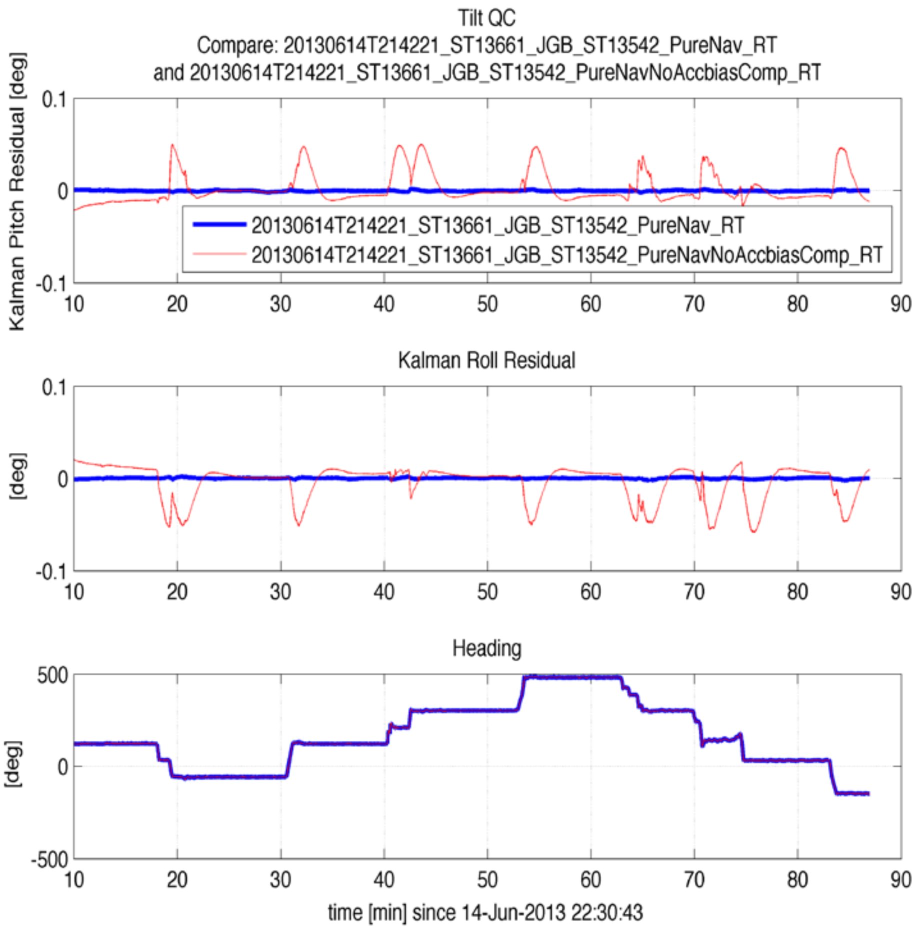


vectory sensor systems

Orion 1: Tilt Error

QC with only one unit

- Errors are clear when compared to a second system
- The errors and its magnitude can however also be pinpointed without a second INS system involved as show in the tilt QC figure
- This approach can be used for other system states as well
- This provides a valuable tool in ensuring the INS is performing to specifications, hence saving time in troubleshooting the full MBE package



vectory sensor systems

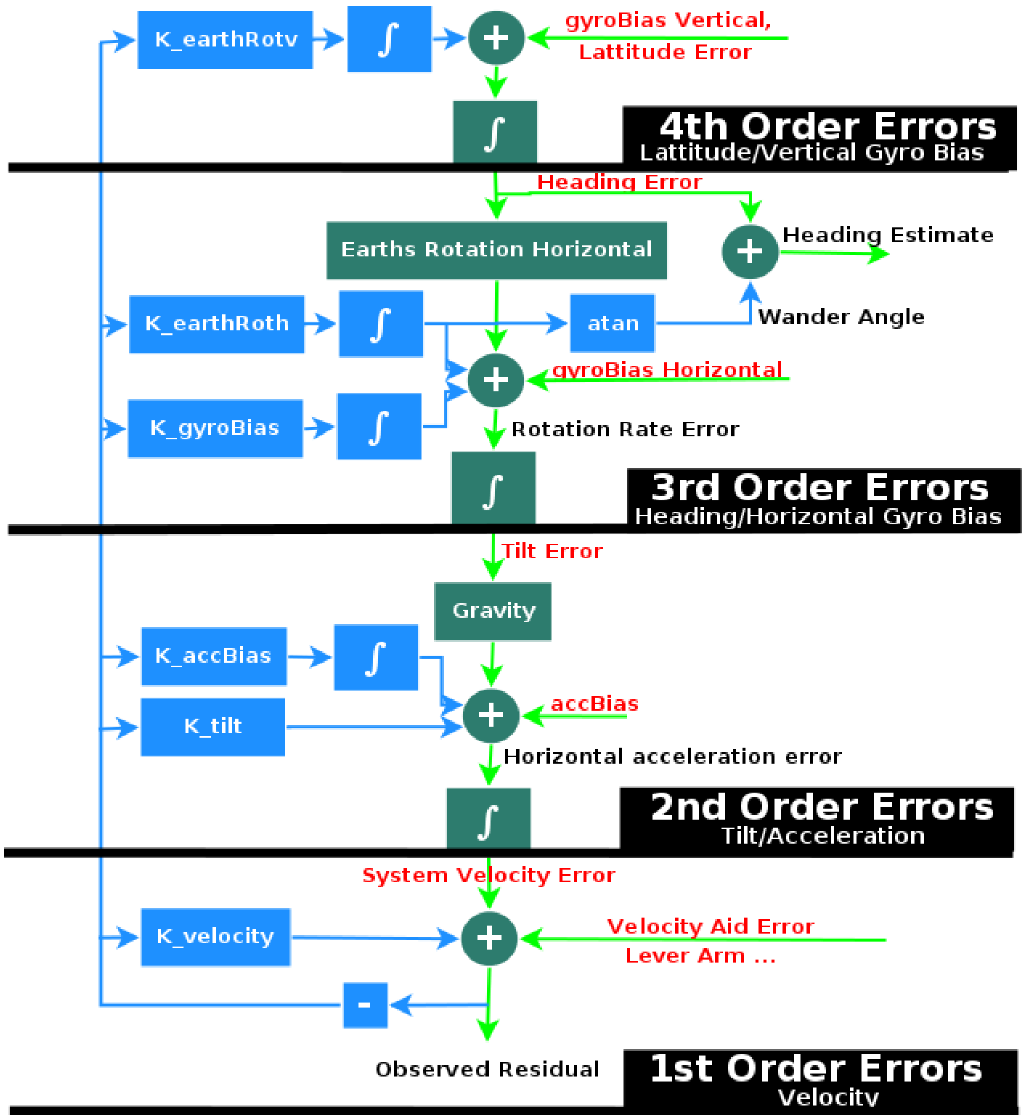
Presentation Outline

- **Orion 1** Suffered from tilt instability
  - How the root cause initially can be observed
  - How the root cause can be found and compensated for
  - And last how the error also can be observed without data from MBE or a second system

- Brief Overview of QC data available within the INS it self

- **Orion 2** Suffers primarily from heading (gyro) instability
  - Observation of heading instability (Heading QC)
  - Estimation of random and systematic gyro bias errors
  - Improvements to the data set
  - Conclusion

Error Observability (QC)

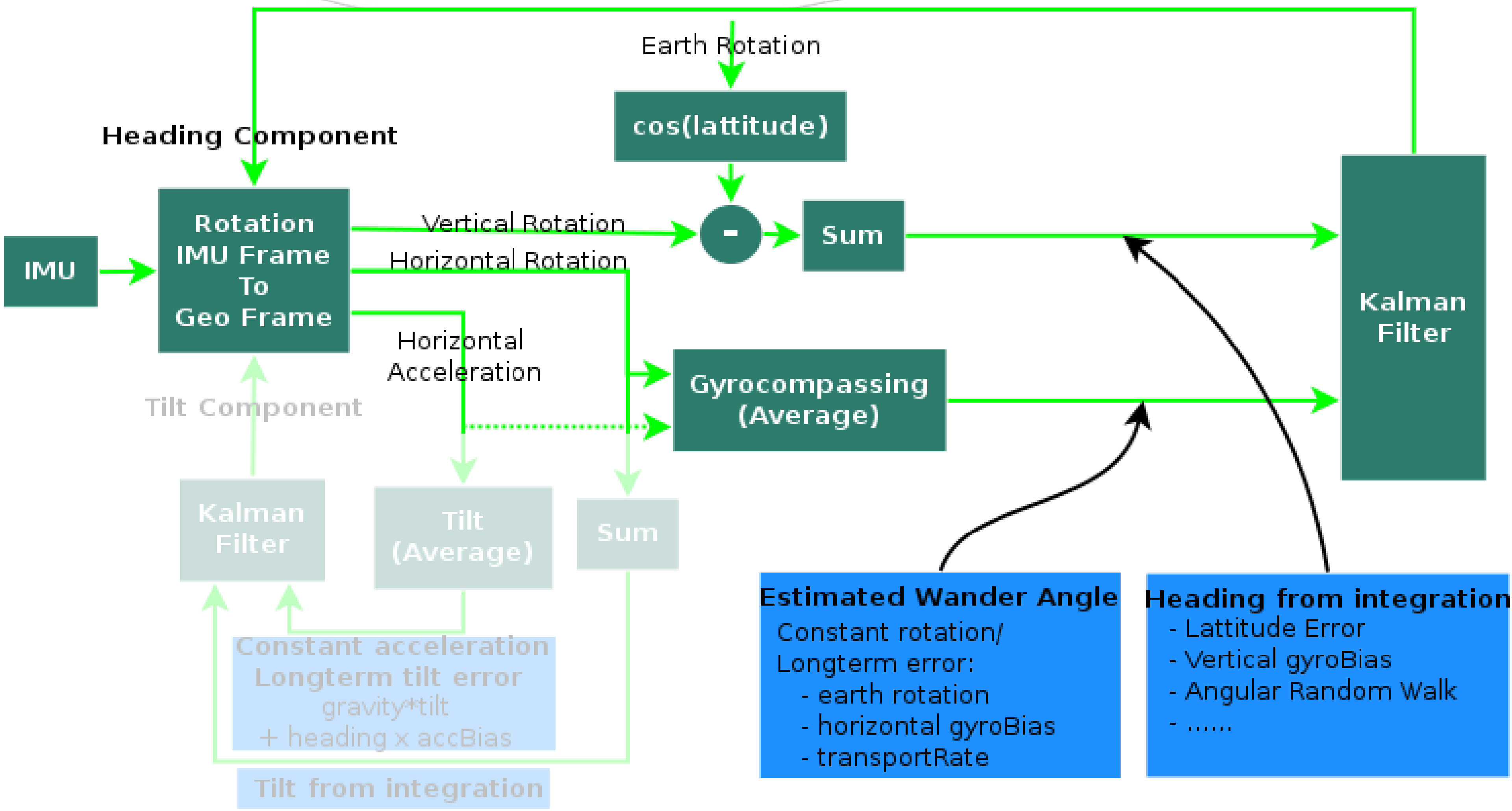


- Error states oscillate in the Kalman feedback loops
- To distinguish the individual errors residuals at different orders can be observed
- Time constant of disturbing error loops can be adjusted to make the suspected fault easier to observe
- Similar to the Tilt QC in the previous slide, heading and velocity type errors can be QCed using INS data alone

vectory
sensor systems

Orion 2: Heading Error

Heading QC

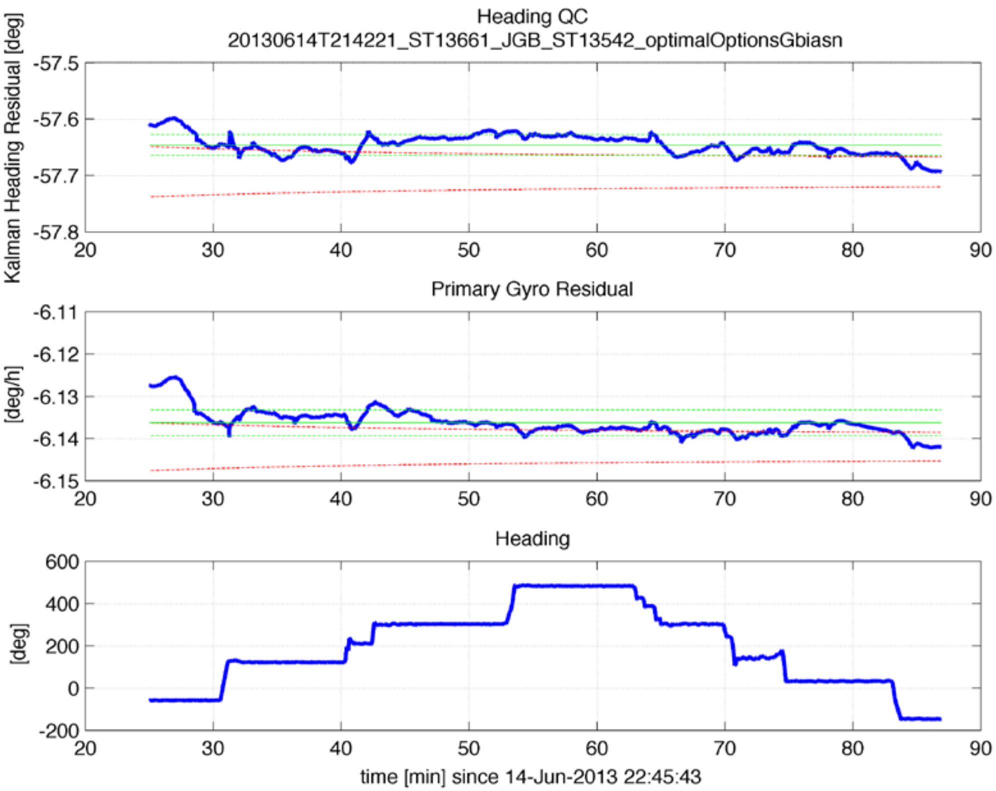


vectory sensor systems

Orion 2: Heading Error

Heading Instability QC

- **Example using Orion 1:** The difference between gyrocompassing and pure integration is stable if the gyro bias is stable.
- On the Orion 1 this is true also when turning



vectory sensor systems

Orion 2: Heading Error

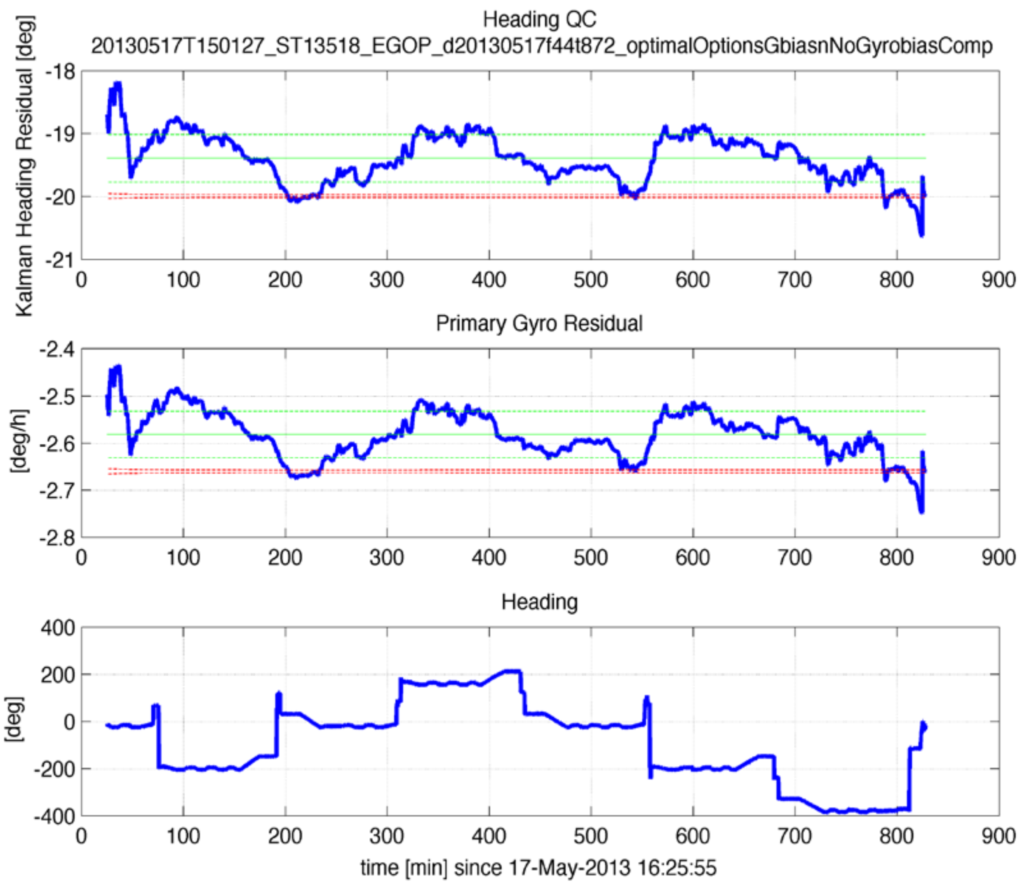
Heading Instability QC

- **Orion 2:** The difference between gyrocompassing and pure integration shows instability

- This is especially true when turning indicating gyro biases

- If the gyrobias are constant one should be able to read one compensation value for this graph

- In this case that is not possible

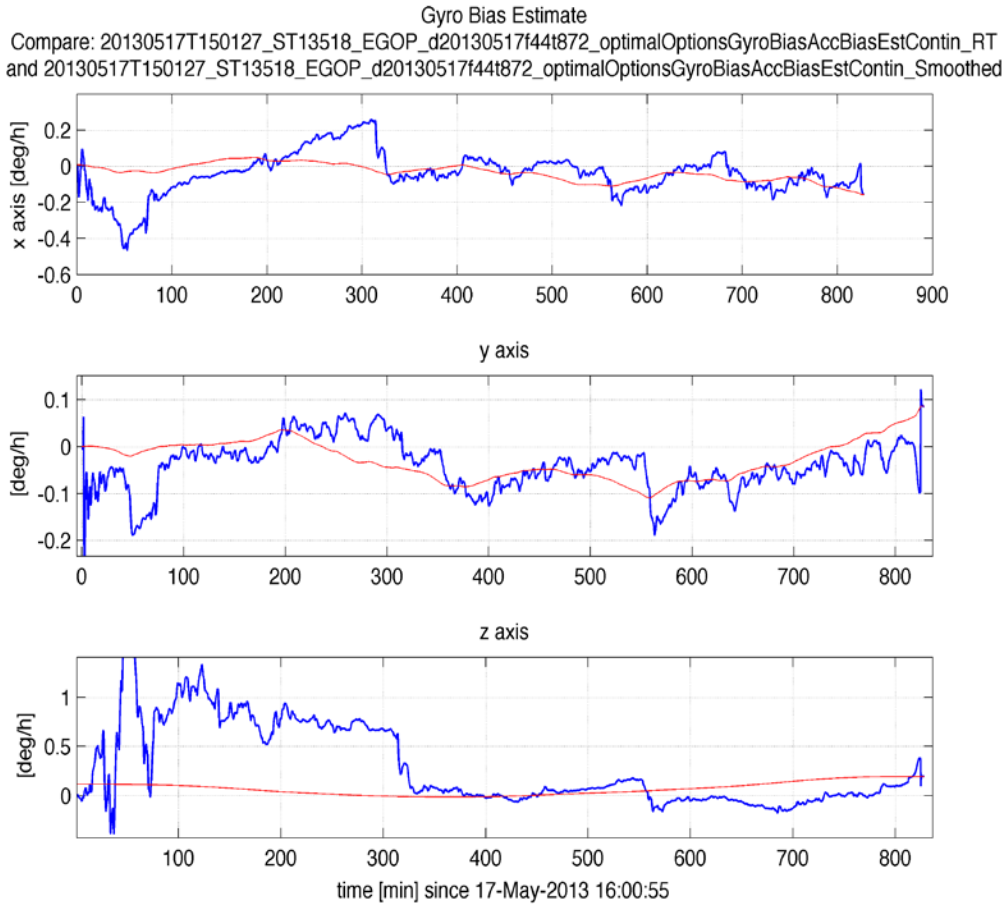


vectory sensor systems

Orion 2: Heading Error

Gyro Bias Estimation

- The gyro bias is estimated continuously during the dataset
- Gyro bias instability is found on all 3 axis

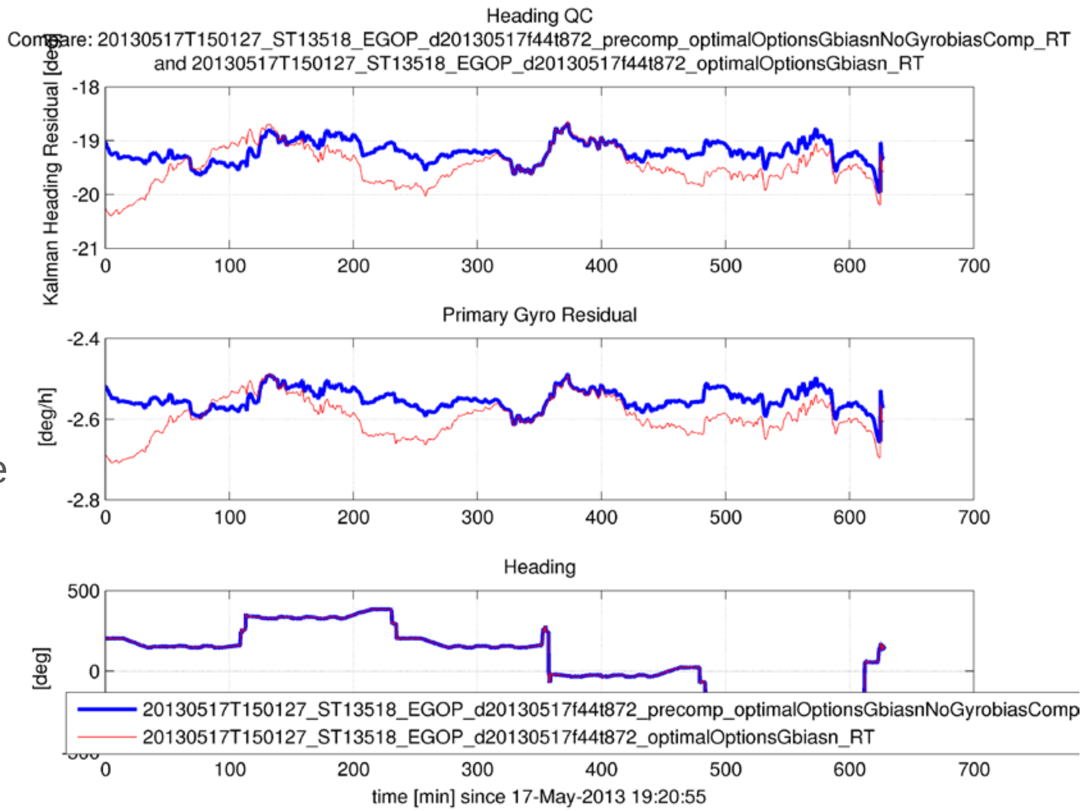


vectory sensor systems

Orion 2: Heading Error

Resulting Accuracies In RT

- To prove the solution is genuine the two results has been run with exactly the same settings, only the gyro measurements has been pre-compensated with the previously estimated gyrobias
- This ensures that we have not just stabilized the heading by relaying all residuals to the gyro bias estimation
- Improvements show that it is possible to half the STD instability even in RT processing
  - 0.05 to 0.025 deg/h
  - or 0.2 to 0.1 deg · sec(lat)

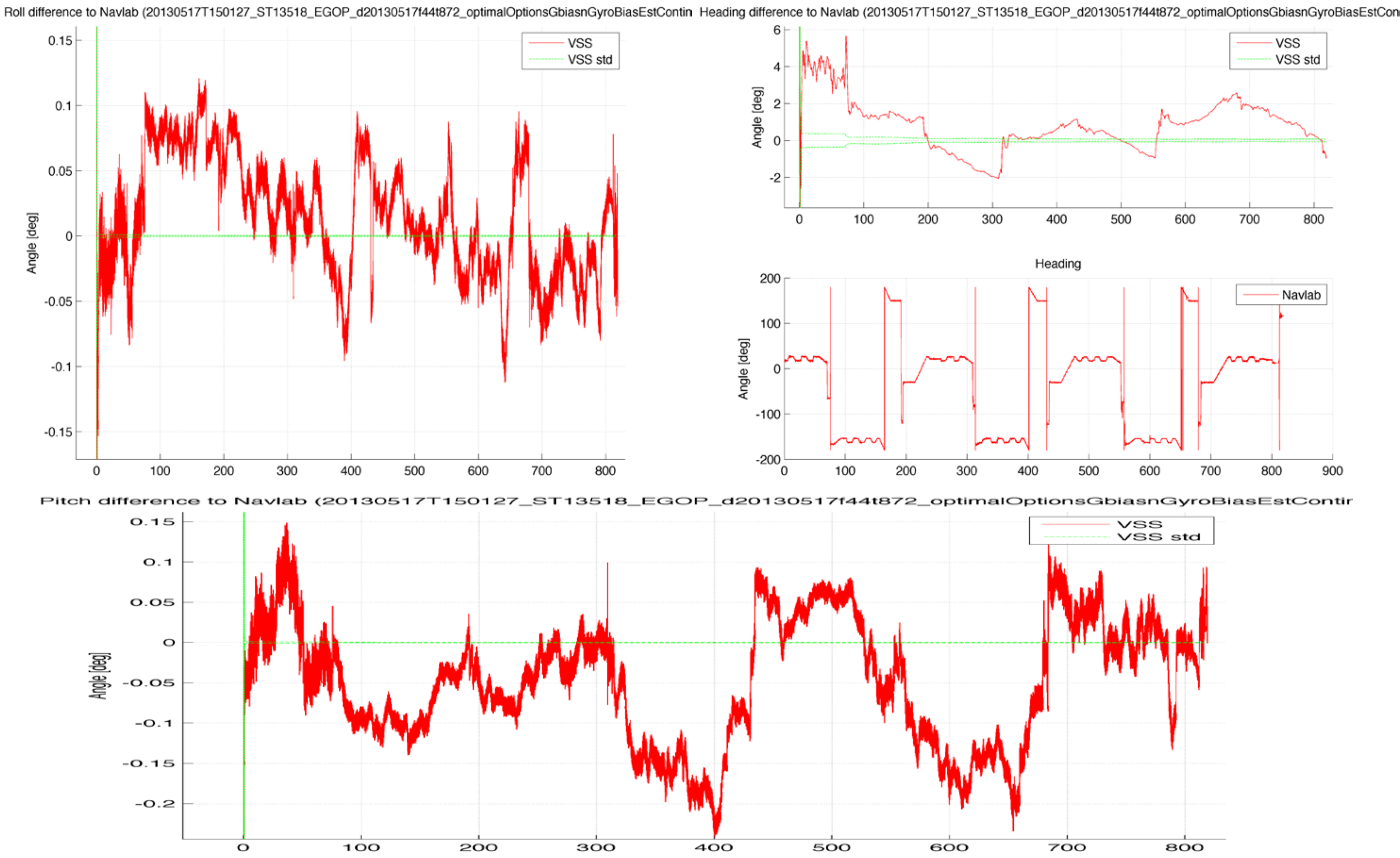


vectory sensor systems

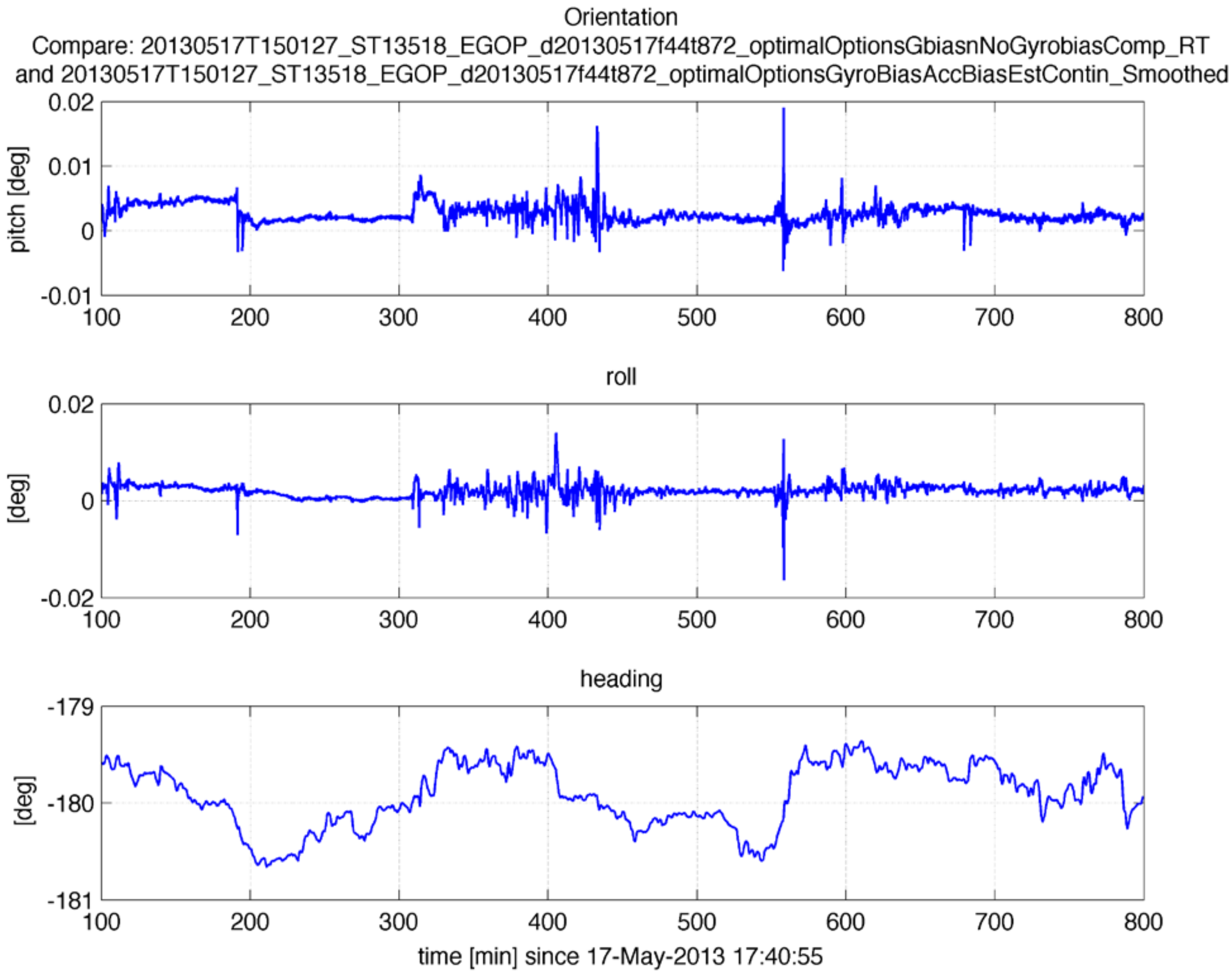
Conclusion

- Orion1 Results
  - A constant accelerometer bias of ~850 ug equal to 0.049 deg tilt error was found
  - It was shown that accelerometer/tilt error also could be identified/QCed without the use of two units and independent of MBE data
- Orion2 Results
  - It was shown that also gyro bias/heading error also could be identified/QCed without the use of two units and independent of MBE data
  - Indications that gyro instability on both x, y and z axis is root cause to heading instability issues
  - Further backup of the claim was made by clear improvements to heading stability by pre- compensating the IMU gyro
- Next step is to get the result tested on MBE data

HPR compare of Navlab corrected VSS



HPR compare of none corrected and corrected VSS solution



vectory sensor systems