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GNSS meteorology from ships as moving platforms

COSMEMOS Workshop
23 October 2013

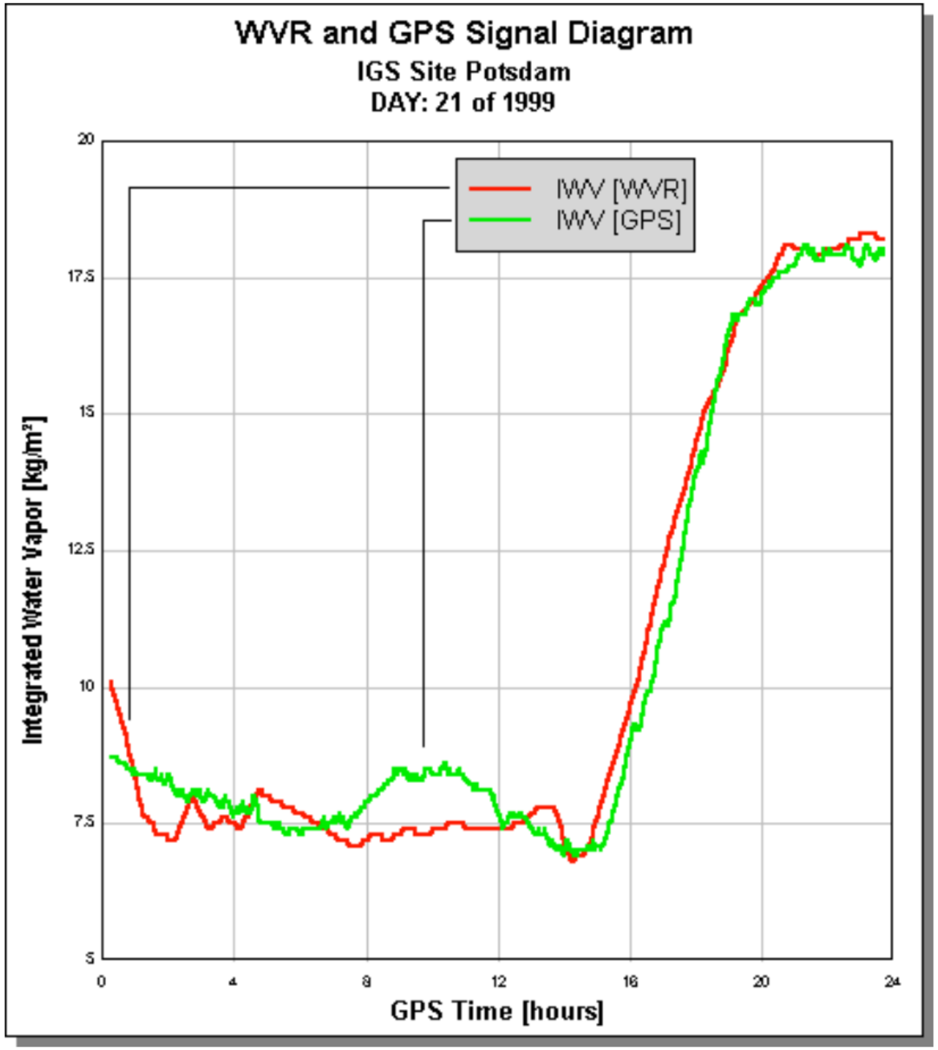
Livorno| Italy

INSTITUTE OF
SPACE TECHNOLOGY & SPACE APPLICATIONS

T H E M O T I V A T I O N

Static GPS-IWV-Retrieval

- Example for stationary estimation of GPS IWV (integrated water vapour)
- Reference data from water vapour radiometer
- Overall agreement (RMS) at a level of <0.8 kg/m² (very satisfactory result)



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THE HISTORY

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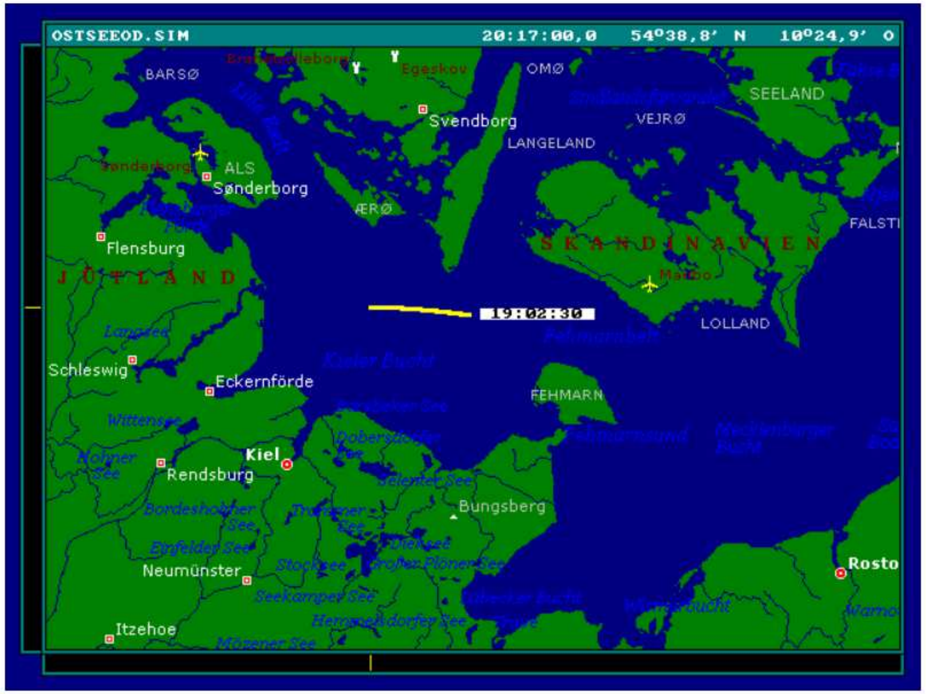
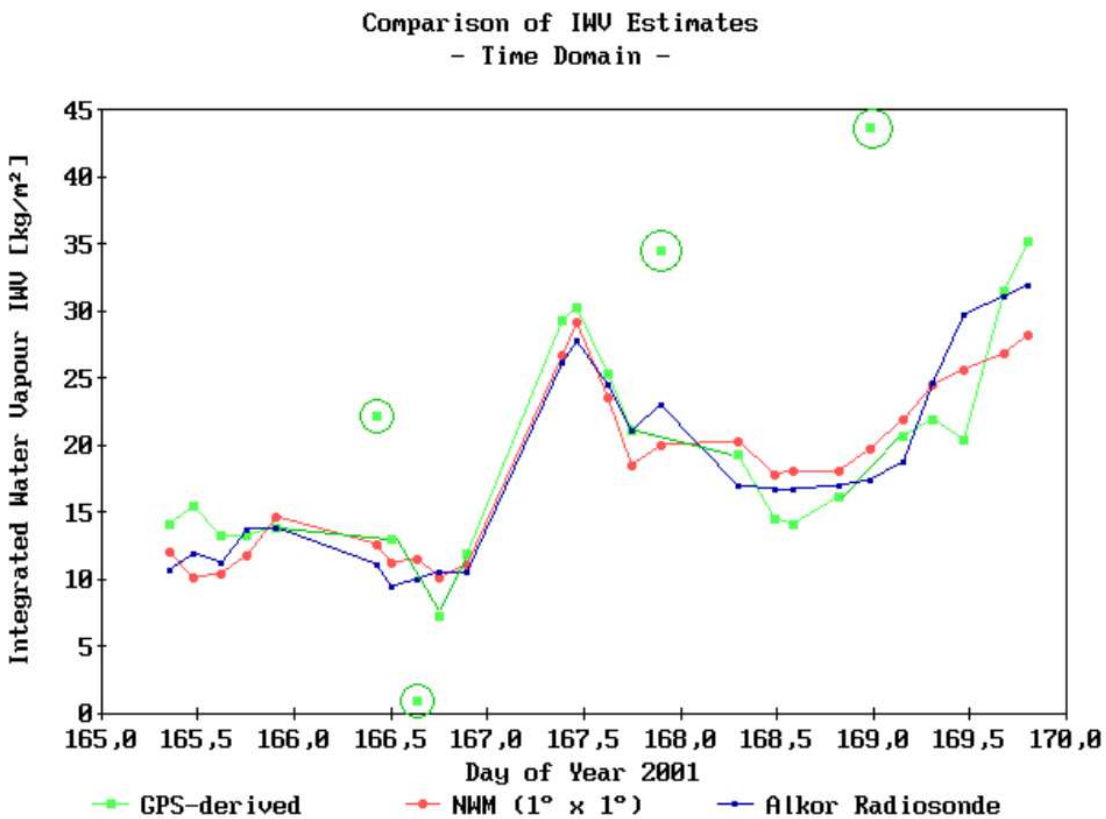
... and on ship (Baltic Sea)

- IWV on moving platforms
- Here: Oil recovery vessel “Bottsand”, two selected cruises



Research Vessel "Alkor"



T H E E F F O R T

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What can we do better?

- We have carried out a considerable effort within COSMEMOS project to care about the challenges imposed by kinematic tropospheric path delay retrieval.
- Estimation in static mode (i.e. for reference stations) is clearly more accurate, but we tried to implement useful enhancements for kinematic mode (based on previous experiences in the Baltic Sea) and hope to obtain an acceptable level of accuracy.
- Our hope to supply improved results in comparison to the previous experiences is based on the following aspects:
  - ***Optimized estimation intervals:*** **6 hours of GNSS data are analyzed in one data batch in kinematic mode (longer than in previous projects where we used a few hour[s] of data). This should warrant a better smoothing of the coordinates and the multipath errors.**

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How can we do better?

- Continued:
  - ***Separate troposphere estimator:*** **We have developed and implemented a separate block adjustment estimator for tropospheric delays. The main point is that this estimator works with tight horizontal constraints for the coordinate components. This means that the initial coordinates are taken from the ordinary "position + troposphere" estimation run, but in the special troposphere run, only "height + troposphere" are estimated. This makes the system of equations more stable (proof of evidence delivered in this presentation).**
  - ***Dual GNSS constellation:*** **We can make use of GPS + Galileo satellites in comparison to previous projects where we only used GPS. This increases the number of observations. Note that at least *<u>two</u>* Galileo satellites are needed to add a value in our algorithm, and we need *<u>precise orbits</u>* for it!**

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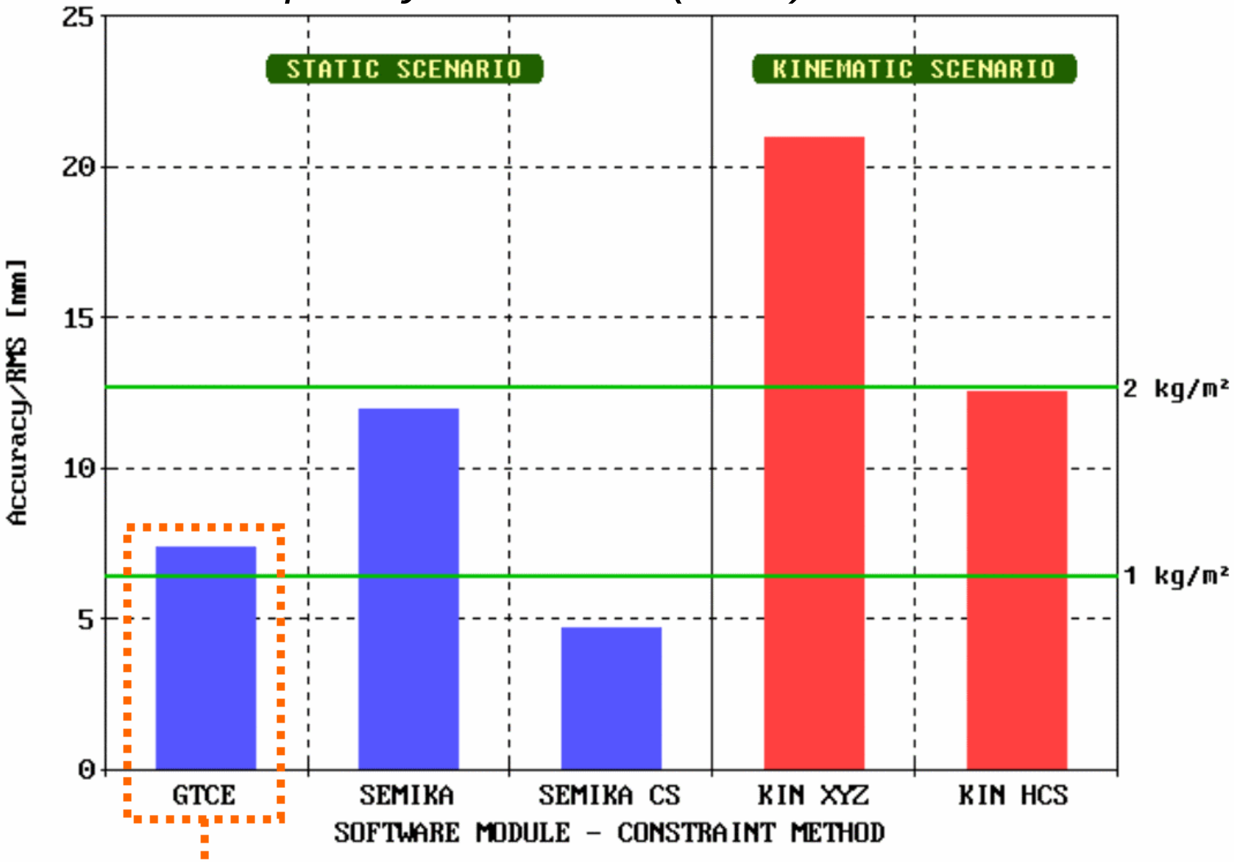
Network algorithm

GTCE is only suitable for the analysis of reference station net-works (but this is always a first step in kinematic analysis, because we will need 2-3 reference stations).

One complete year of data (2011) used for verification!



The accuracy of the GTCE implementation is quite convincing: We can estimate the zenith tropospheric path delay with an RMS of 7.3 mm. Approximately 6.1 to 6.5 mm correspond to 1 kg/m² of integrated water vapor (green line).

Unconstrained algorithm

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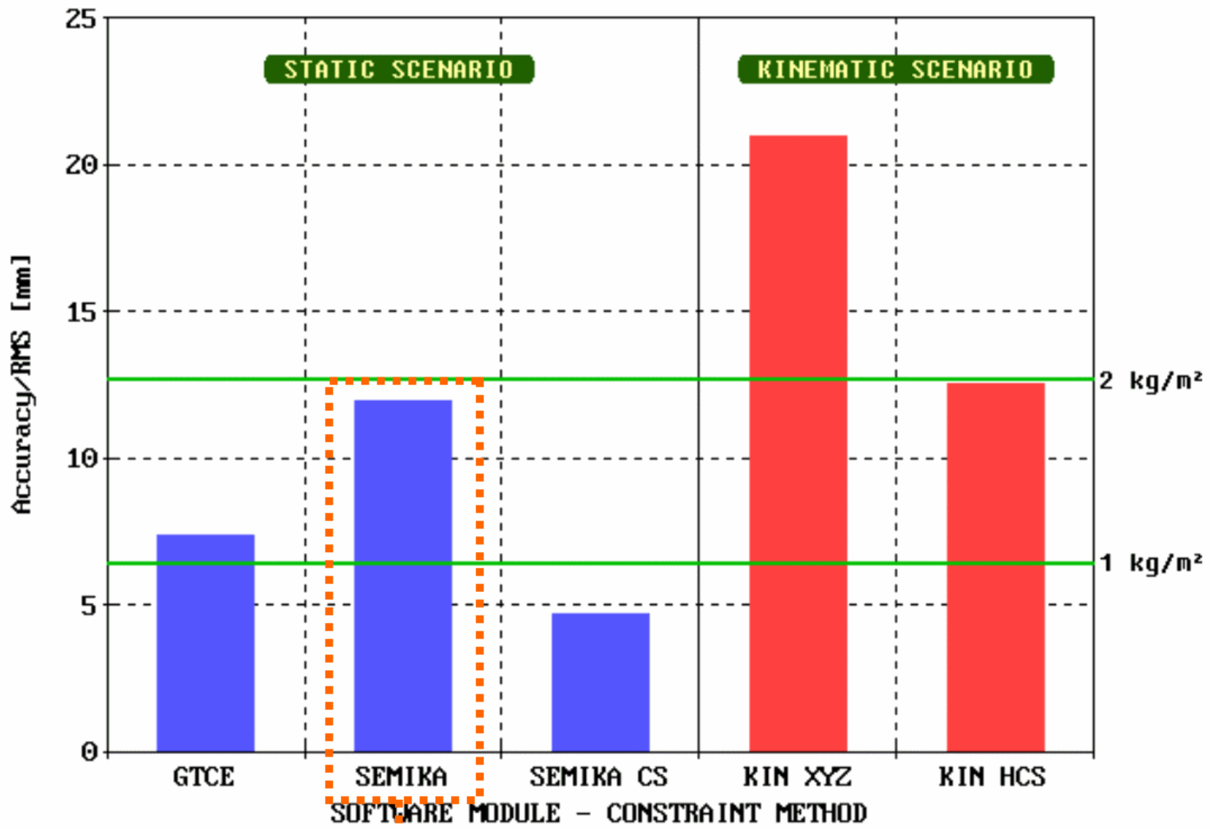
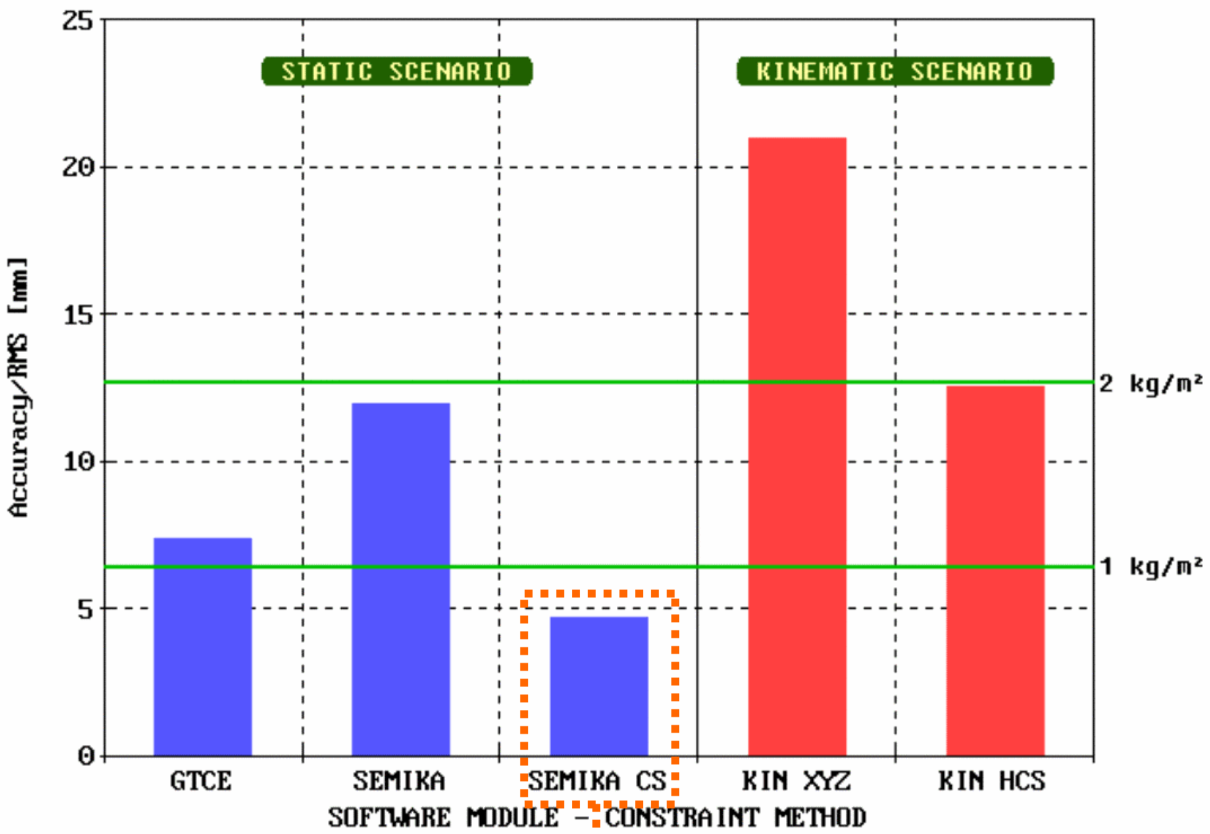


Semika can be operated in a fully unconstrained troposphere estimation mode; we determine tropo for both the user station as well as for all 3 reference stations. In this case, we arrive at a RMS of 11.9 mm (approx. 1.9 kg/m² of integrated water vapor). GTCE appears to be more accurate, because we "told" the filter to assume "typical troposphere conditions", whereas no such assumptions were told into Semika (i.e. fully free estimation, more robust).

Constrained algorithm

In this second run, we have operated Semika in reference station constrained mode, i.e. the tropo delays are <u>not</u> estimated for the reference stations, but taken from existing network solutions. We only estimate tropo for the user (central) site. The makes our system of equations much stronger, but we must rely on the reference stations' tropo data. RMS improves to 4.7 mm which is clearly better than 1 kg/m² - the best result in our test runs.



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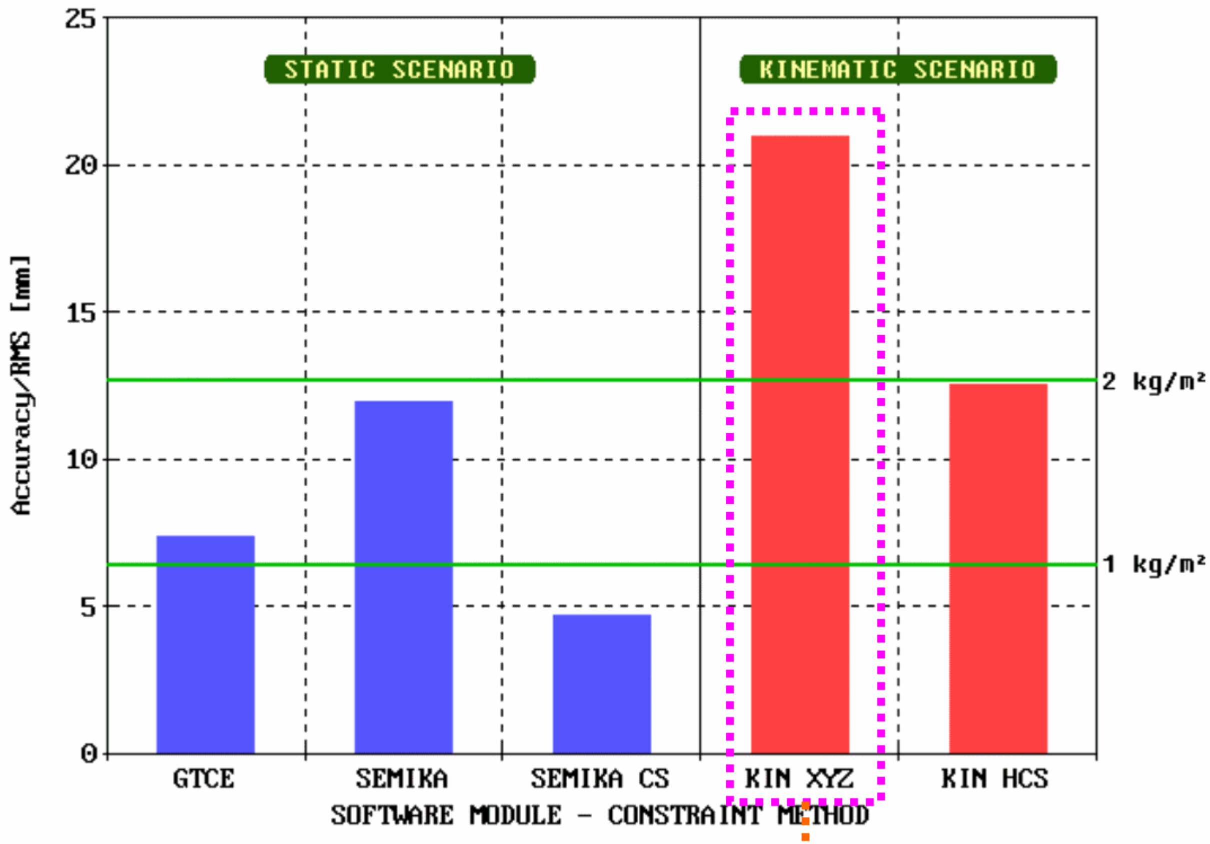
Kinematic algorithm



Estimation of tropo delays in kinematic mode is clearly more challenging. We have to estimate both the 3 coordinates per epoch and the tropo parameters. No doubt, this makes our system of equations weaker compared to static mode. Nevertheless, it works. The ordinary solution processed by Semika/eXpert shows an RMS of 20.9 mm what corresponds to 3.3 kg/m² of integrated water vapor. (Previous projects: we accepted values ≤ 4 kg/m²).

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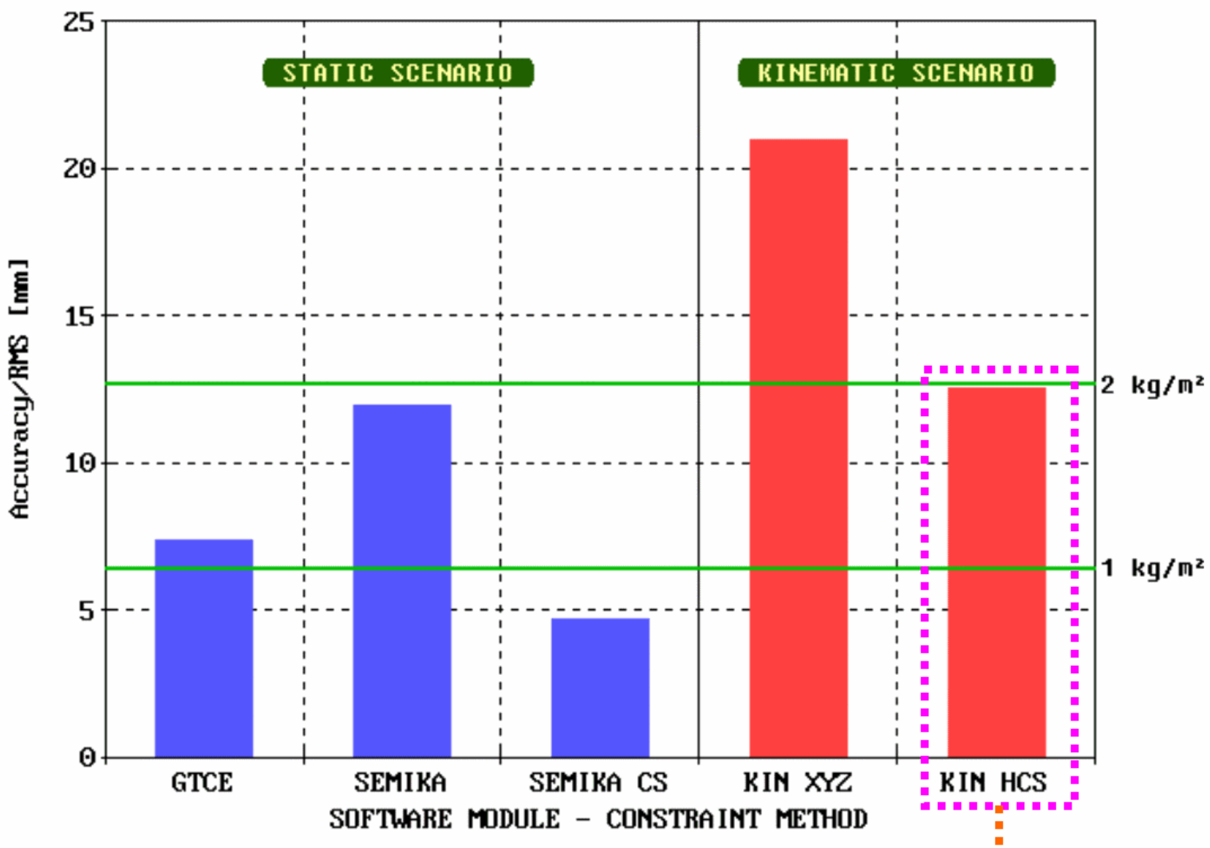
Kinematic + constrained



Now we are using our newly implemented tropo estimator. It is invoked after the KIN XYZ solution is actually computed, uses the positions determined in that previous run, fixes the horizontal coordinates (latitude and longitude) and only improves the radial coordinate (height) and the troposphere. This is still less stable than a fully static system of equations, but better than a fully kinematic algorithm. Clear improvement: RMS = 12.5 mm, i.e. 1.95 kg/m²

T H E   A P P L I C A T I O N

Kinematic ZPD results

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Golfo Aranci – Livorno: Mega Express Two

Kinematic ZPD results

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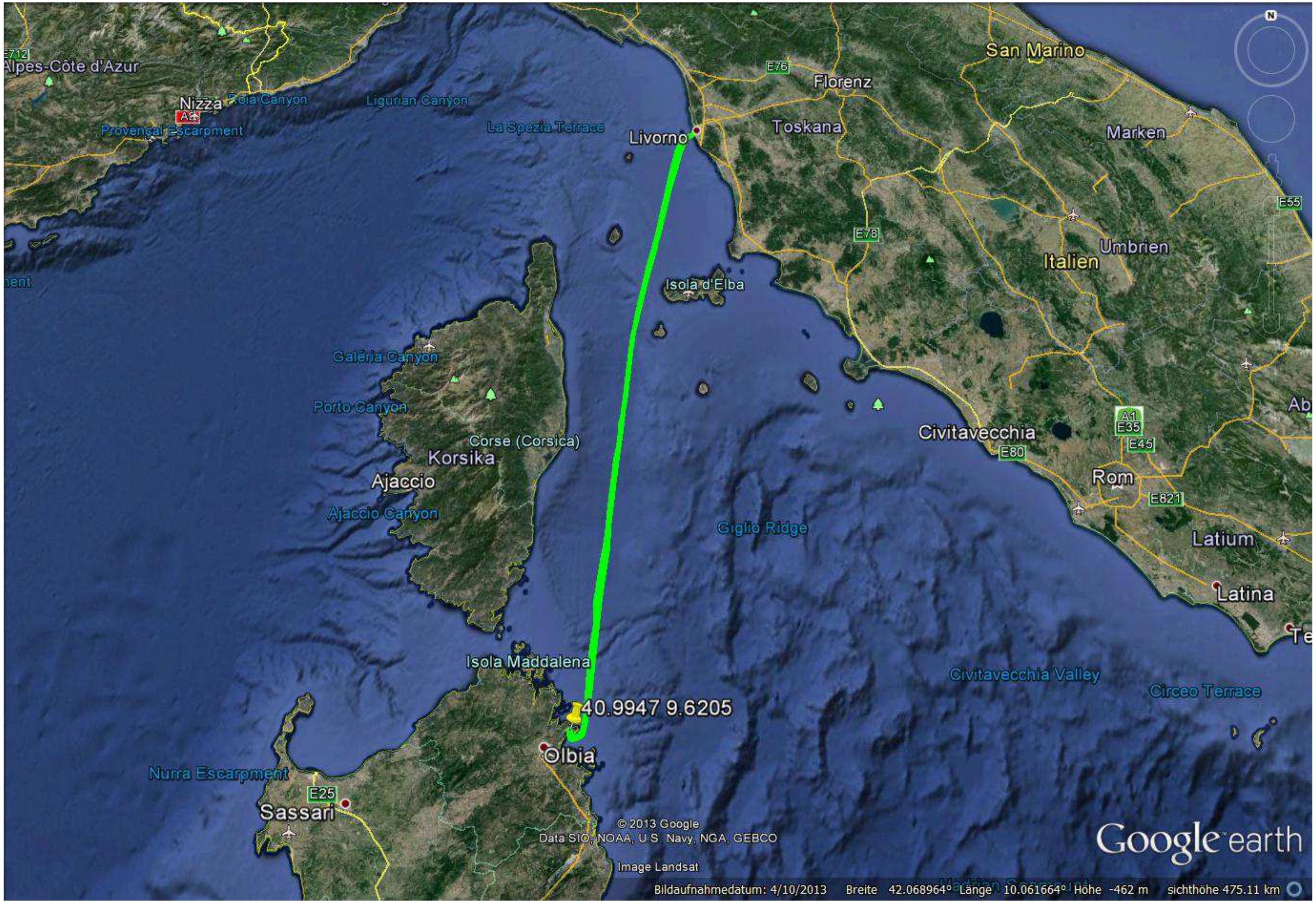

Kinematic ZPD results

SEMIKA: Observation data (input)

- GNSS satellite orbit information from IGS
- EUREF station observations from BKG
- high precision coordinates of Livorno reference station (LIVO)
- ZPD information of EUREF station observations
- LIVO observations
- moving platform observations (MEII)
- GNSS Antenna information

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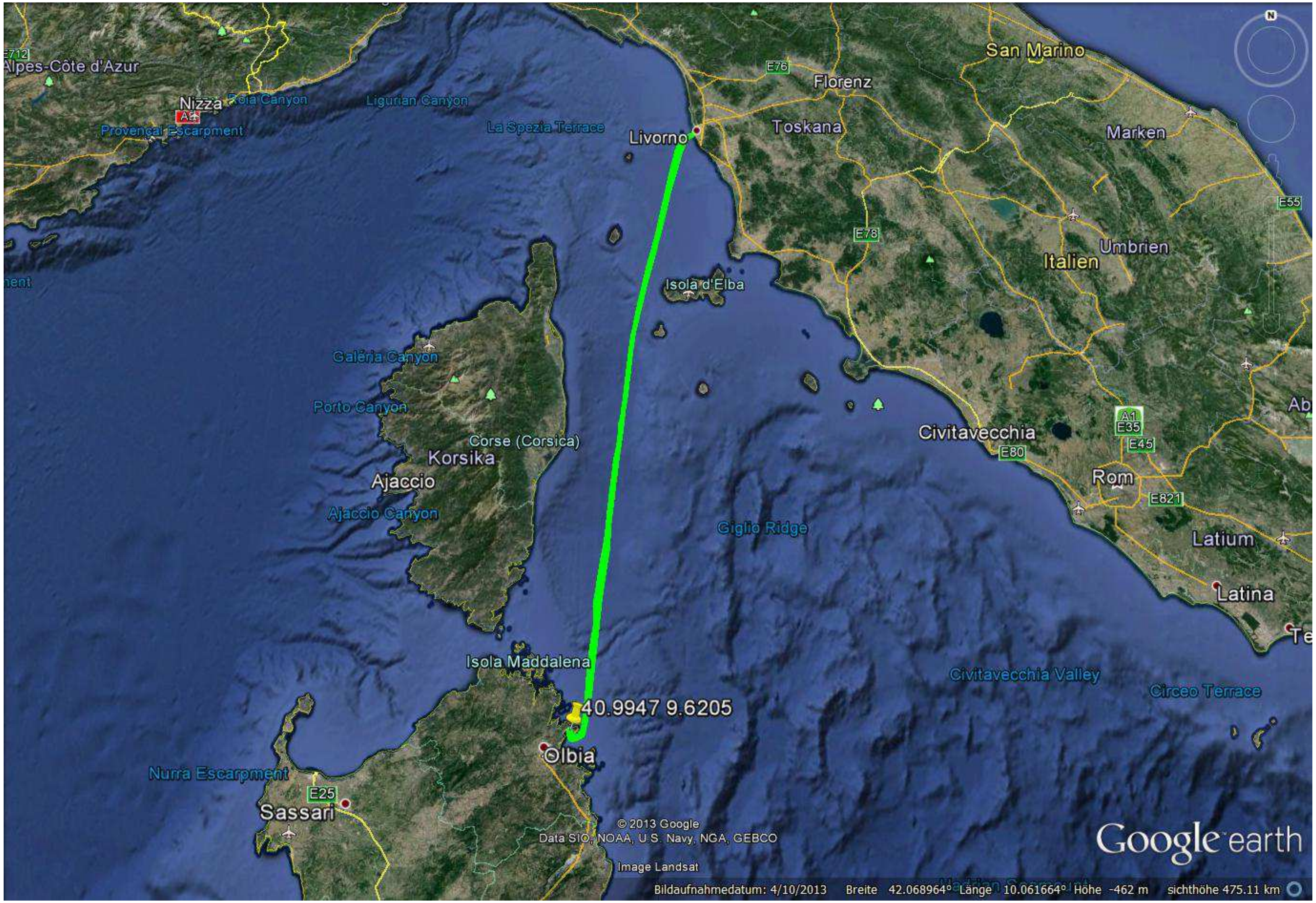
Kinematic ZPD results



Kinematic ZPD results

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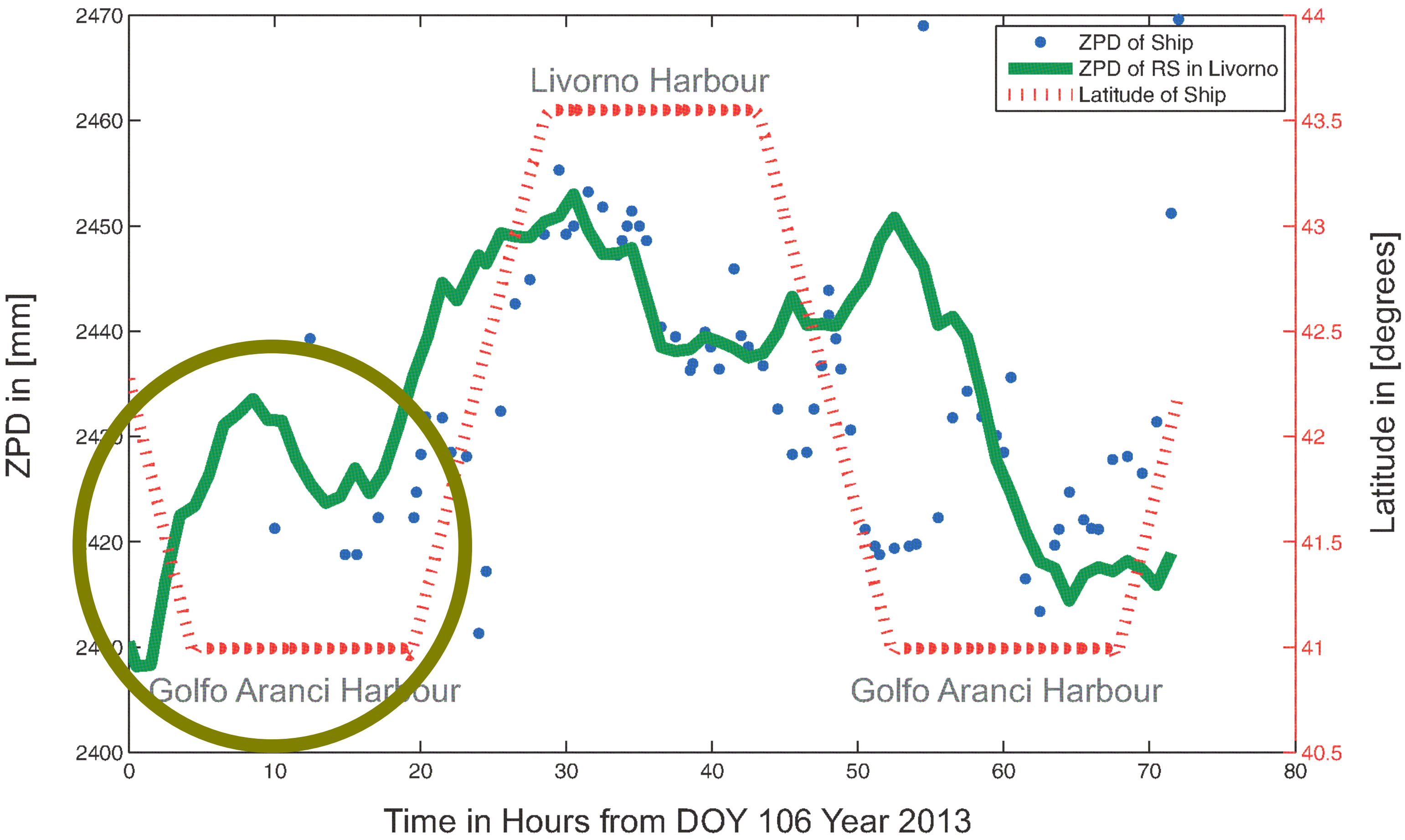
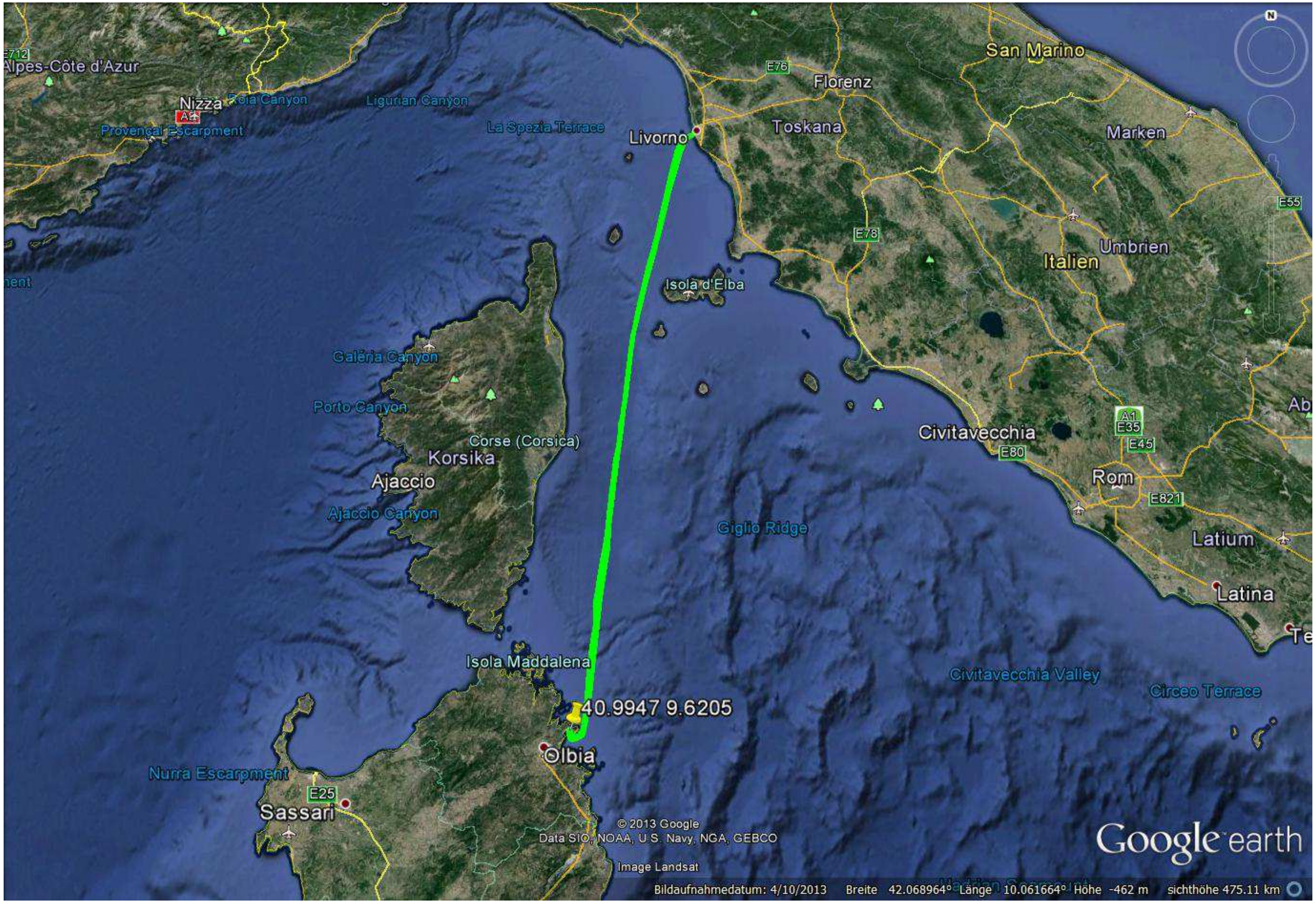
Comparision of kinematic ZPD with static ZPD results



Kinematic ZPD results



Kinematic ZPD results

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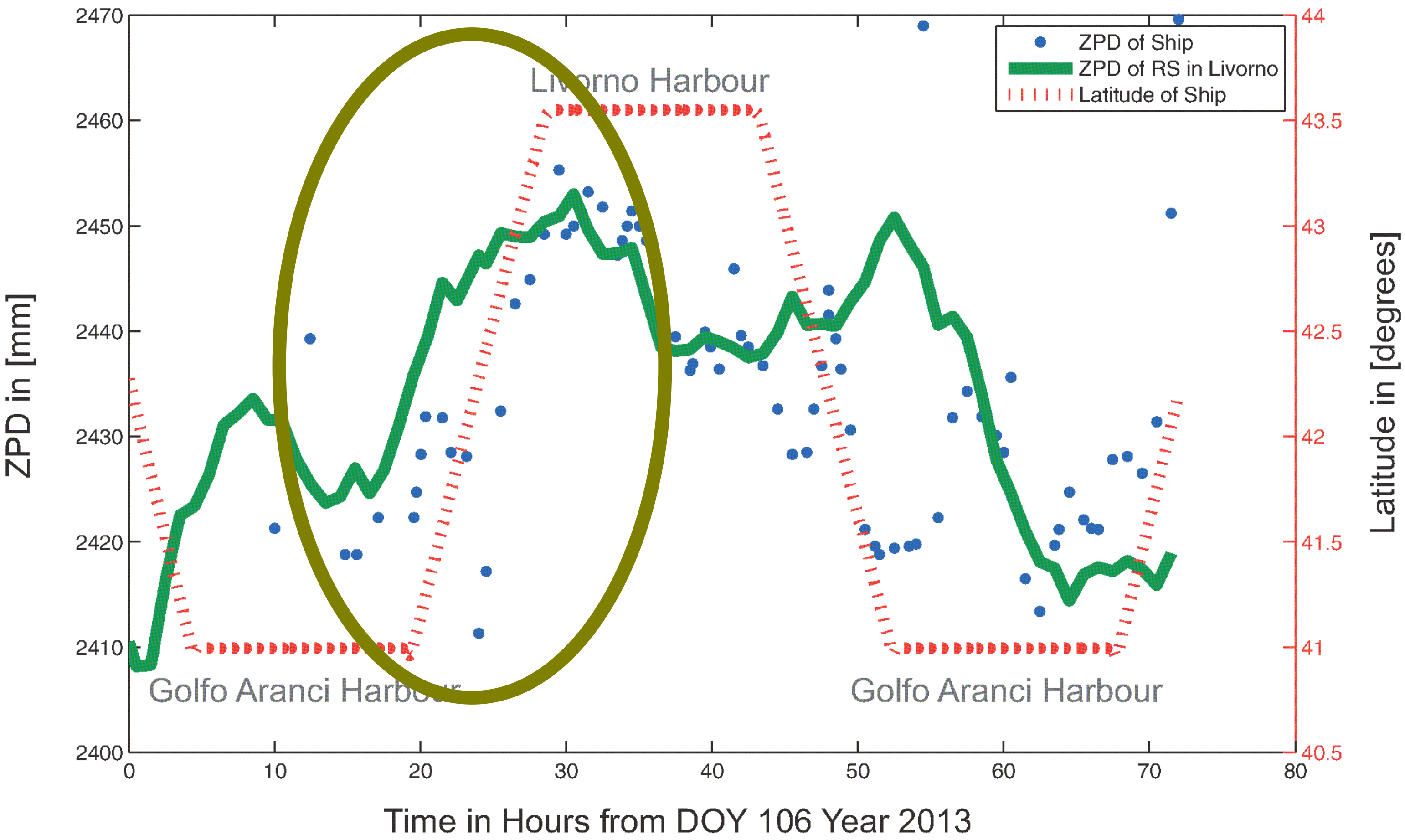
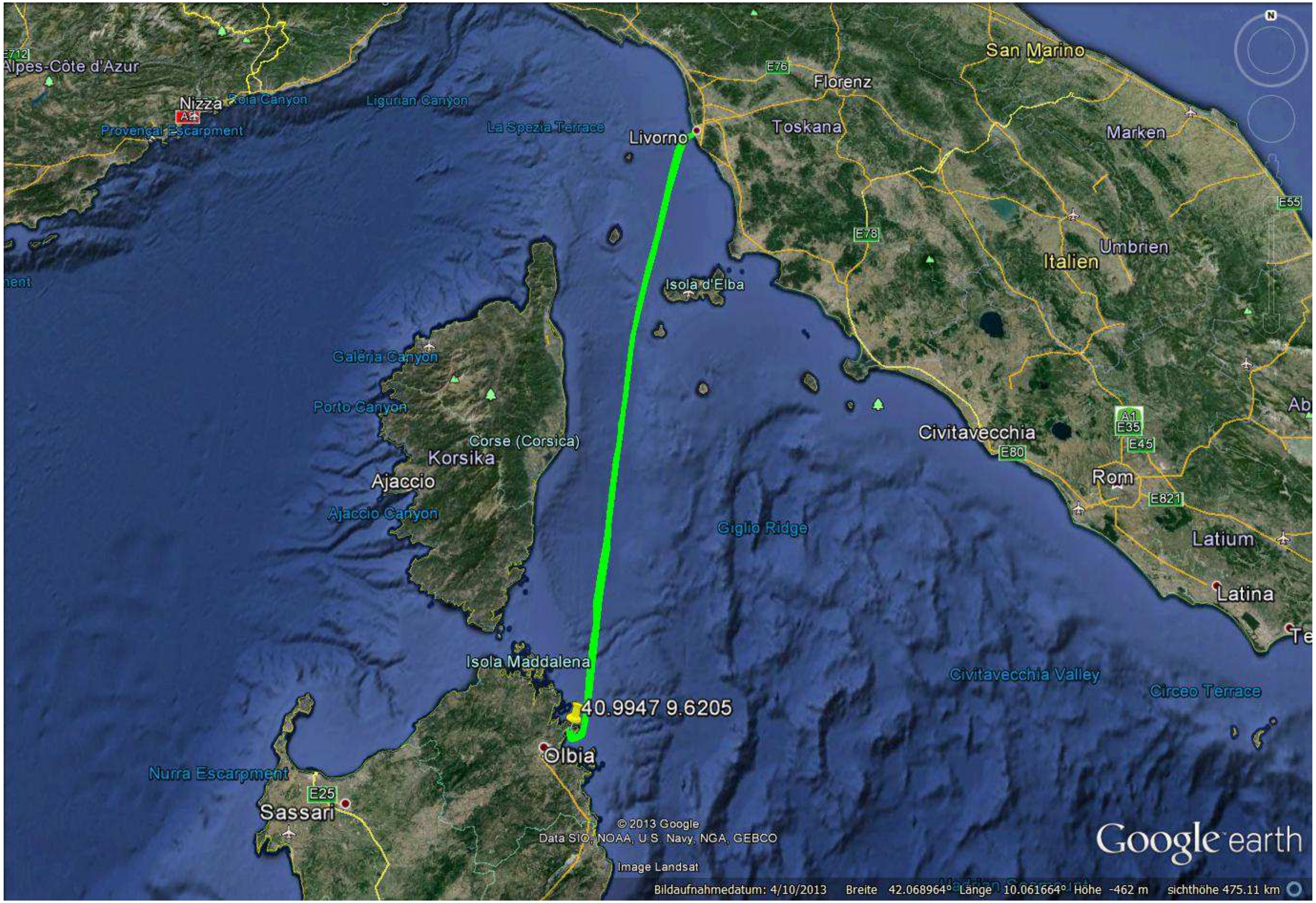


Kinematic ZPD results



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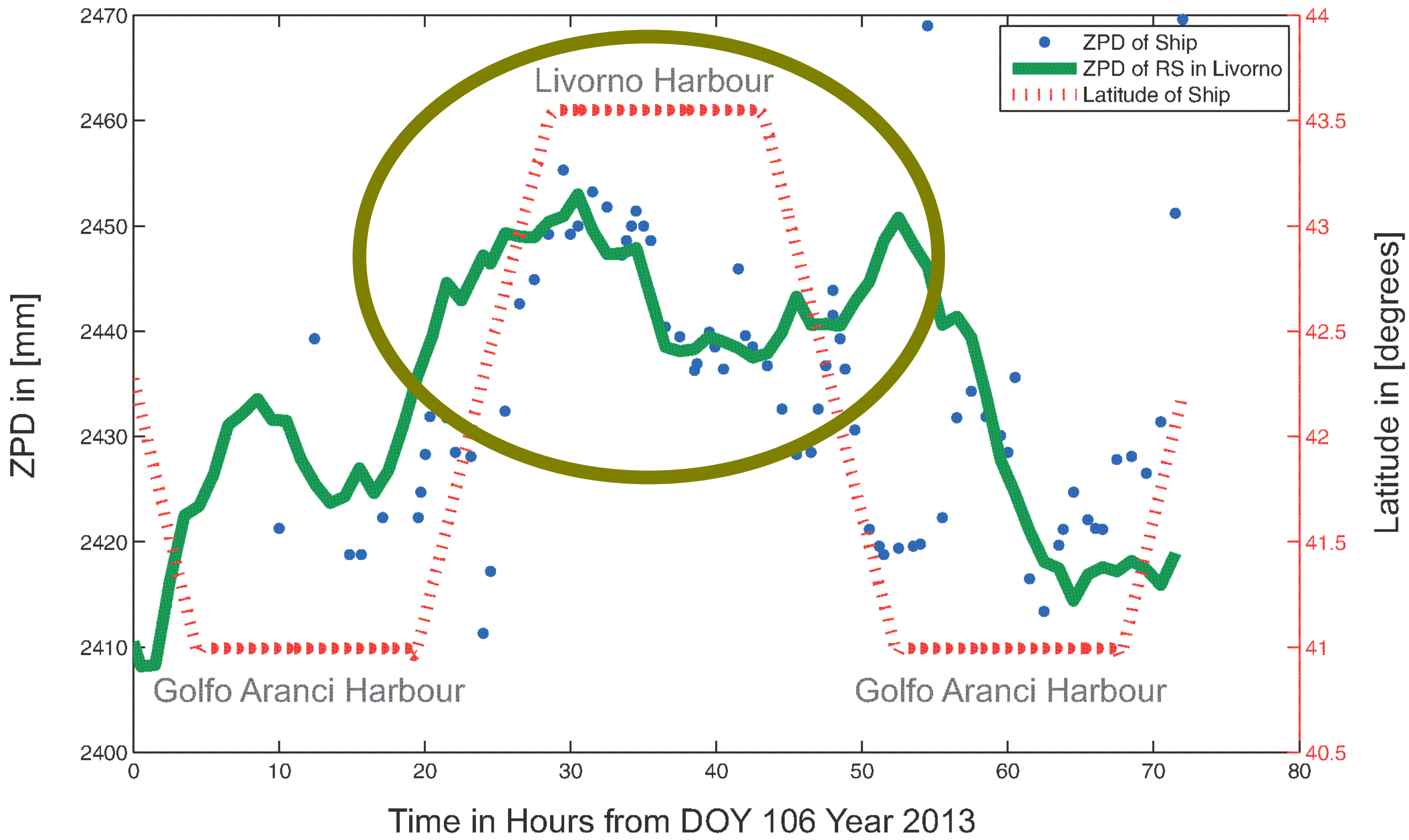
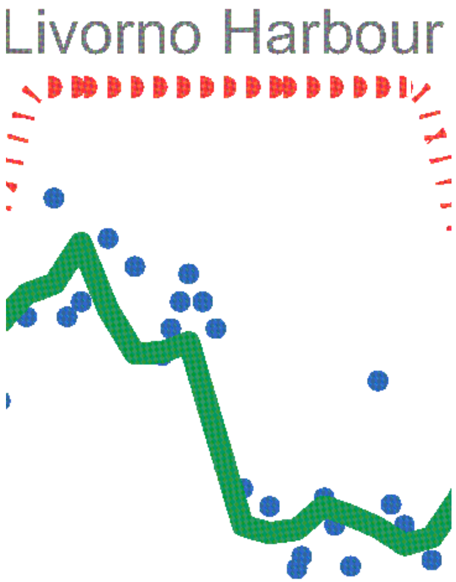


Kinematic ZPD results

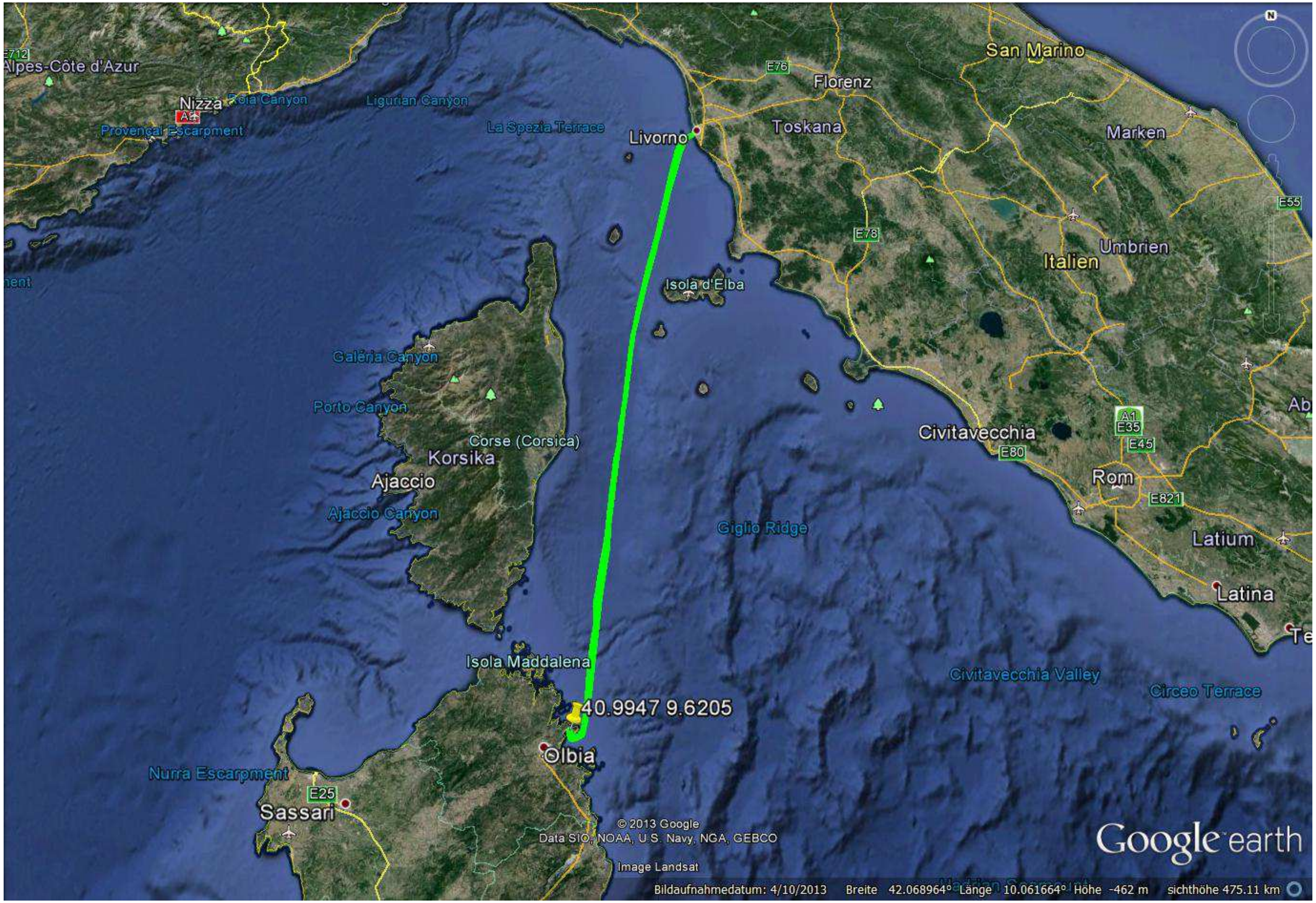
Comparision of kinematic ZPD with static ZPD results



standard deviation in Livorno Harbour: 7.1 mm

mean standard deviation: 8.4 mm

Kinematic ZPD results



Kinematic ZPD results

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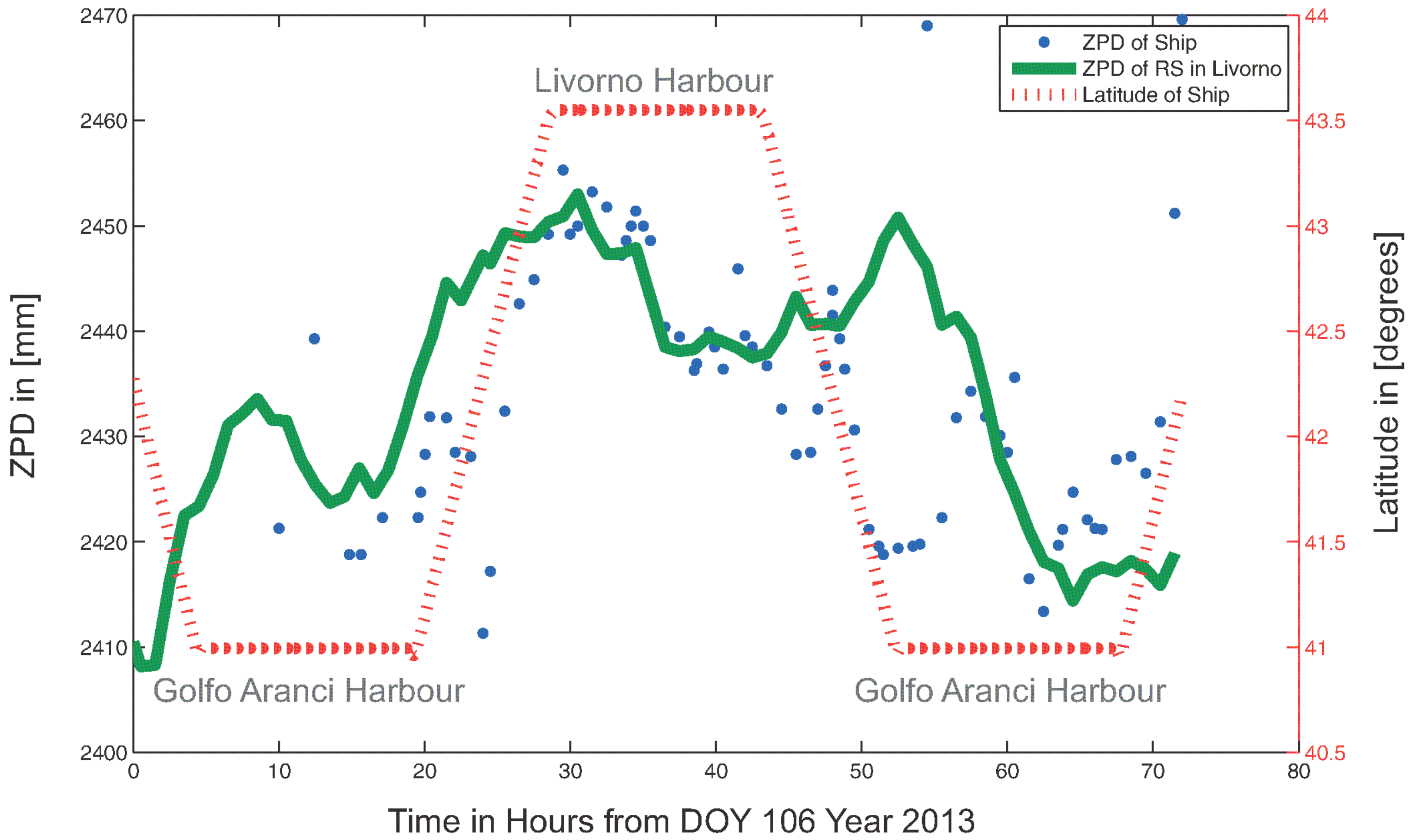
Comparision of kinematic ZPD with static ZPD results



Conclusions

- Based on previous experiences in the Baltic Sea, an improved retrieval algorithm for GNSS-based tropospheric path delay estimation was developed.
- An initial verification study pin-points at a precision around 2 kg/m² (IWV) or 1,25 cm (path delay) in kinematic mode.
- Data sets for MEGA EXPRESS II processed so far show a good agreement at sites co-located with reference station Livorno.