

GMES

TERRAFIRMA

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**Validation of existing processing
chains in Terrafirma stage 2**



**TECHNICAL NOTE ON THE TEST SITE
SELECTION: ALKMAAR-AMSTERDAM**

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Final version

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1. INTRODUCTION

This technical note provides the key information needed to perform the site selection for the Validation Project of Terrafirma.

This note has been prepared considering two contrasting objectives. From one side, its goal is to inform all the Project partners on the main characteristics of the candidate test site, Alkmaar-Amsterdam. This document is supposed to provide the fundamental information to judge the suitability of the candidate site. From the other side, in order to guarantee a rigorous validation exercise in case the site is finally selected, the note does not distribute too much information on the available ground truth.

This note has been based on the draft version of the document “Ground truth Dossier”, prepared by TNO and TUDelft, which will represent the deliverable of the Project WP VAL.02, “Prepare ground truth”.

2. ALKMAAR - MAIN CHARACTERISTICS

Type of deformation:

- The main deformation is induced by natural gas production. The spatial extend of the largest subsidence bowl is about 30 km².
- There are localized deformations due to geotechnical instability and consolidation (roads and buildings).
- The deformation rates are in the region of a few mm/yr.

Available ground truth:

- The ground truths come from levelling campaigns. Benchmarks are mainly in the built-up areas, houses, bridges, etc.
- Data have been obtained from the Geo-Information and ICT Advisory Department (AGI) of the Directorate-General of Public Works and Water Management (Rijkswaterstaat, RWS).
- In the period 1991 – 2006, in total 172 benchmarks are available. The benchmarks are sufficient to sample the smooth and slow movement at hand.
- Deformation magnitude. In Figure 1 is shown the number of benchmarks falling within a given velocity class, where the velocity is the average velocity over the period 1991 – 2006. Note that the subsidence velocity is negative. The deformation rates are up to -4 mm/y, which corresponds to 6 cm of cumulated displacement in 15 years.
- Based on the levelling campaigns, the temporal behaviour of the subsidence can be considered as a linear process.
- Temporal frequency of levelling campaigns. Figure 2 shows the temporal distribution of acquisitions from the levelling campaigns, and the ERS1, ERS2 and ASAR sensors for track 423, frame 2542 (the optimal ERS/Envisat track, covering both the Alkmaar and the Amsterdam regions). Figure 3 shows the number of levelling benchmarks observed per epoch. During the interval of interest, 6 main surveys sampled a significant amount of benchmarks (50 or more). The distribution of the number of levelling observations over the period 1991 – 2006 is shown in Figure 4.

PSI success likelihood:

The likelihood of a successful PSI analysis depends on a number of factors: data availability; expectation of the magnitude and behaviour of the deformation signal; expected spatial PSI target density; and noise factors.

- Data availability can be considered more than sufficient for a successful PSI analysis, both for the ERS and the Envisat stack.
- From the interpolation of the levelling data over the area of interest, average deformation rates over the subsiding areas amount up to 3.5 mm/y. The overall smoothness of the entire area (including the deforming areas) can be characterized by an Gaussian variogram with a nugget of 0.2 (mm/y)², a sill of 1 (mm/y)² and a range of 2.5 km. The sill value for the non-deforming areas is estimated to be ~0.5 (mm/y)². Consequently, the deformation signal can be considered to be up to 5 times larger than the overall ‘deformation noise,’ and a reliable estimate of the deformation signal using PSI techniques is considered to be feasible. Over the entire time span (14 years) the cumulative deformation is in the order of 4.5 cm vertical or 1.5 fringes in slant range for C-band radar.
- An important aspect is given by the expected PSI target density, which can be estimated from analyses of areas with similar conditions. TU Delft processed data over the eastern side of the province of Noord-Holland (~20 km east of the Alkmaar region) and found

high density of points ($>200/\text{km}^2$) for the urbanized areas, and an average density of $\sim 10/\text{km}^2$ for the rural areas. In these rural areas, scattering originates mainly from farms, isolated buildings, and infrastructure (bridges, roads, train tracks, etc). With this experience a simulation was performed. For the urban areas derived from Google Earth images, a conservative point density of $100/\text{km}^2$ was used. For the rural areas, coherent scatterers are randomly distributed over the area, with an average density of $10/\text{km}^2$. With this density, it is expected that a most levelling benchmarks will have at least on PS within a distance of less 500 m, which is sufficiently dense for this type of deformation signal.

- Noise factors that may hamper the PSI analysis contain atmospheric errors, autonomous movements, and potential problems with phase ambiguity resolution. The latter is very unlikely in this case, as the processes involved are related to deep reservoirs (~ 2 km depth) and therefore have a smooth spatial behaviour. Furthermore, gas production rates are relatively constant. The only processes with a more dynamics temporal behaviour are related to the underground gas storage, but even there it is not expected that this will lead to errors in ambiguity resolution. Single interferograms will certainly be affected by atmospheric signal, as the region of interest is near the North Sea shore, and the climate of Netherlands is variable. Especially convective processes are expected to cause significant anomalies in atmospheric refractivity, leading to localized phase delays. Ample information on atmospheric signal is available for the region from previous studies. The atmospheric error signal can be approximately characterized by a Gaussian variogram with a zero-nugget, the square-root of the sill of 12 mm, and a range of 40 km.

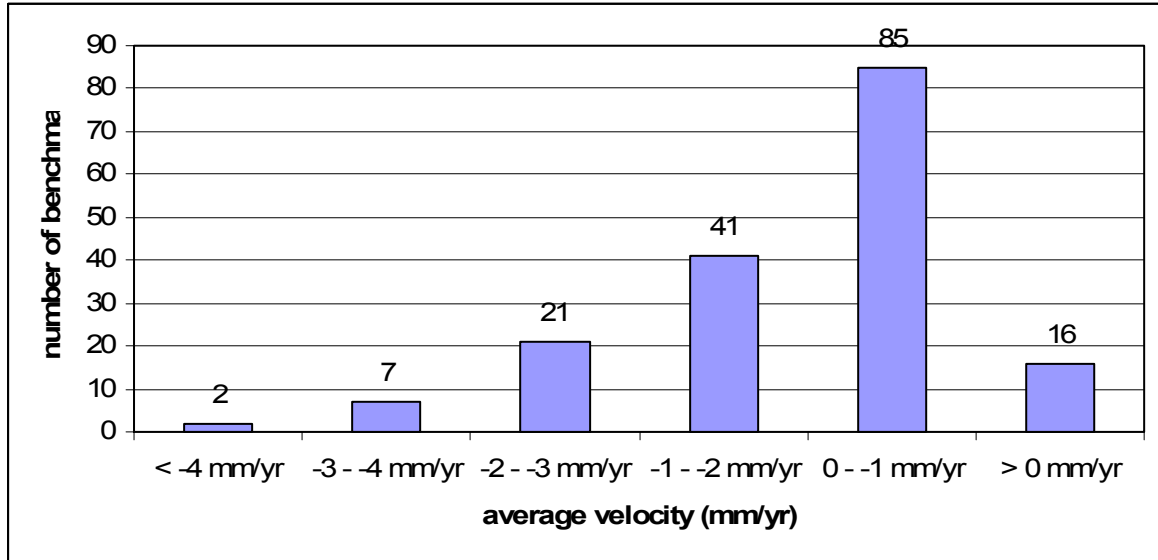


Figure 1: Number of benchmarks falling within a velocity class (velocity = average velocity over the period 1991 – 2006).

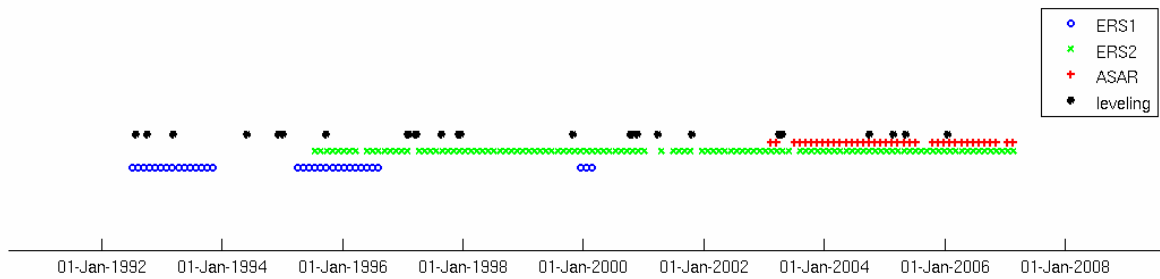


Figure 2: Temporal distribution of acquisitions from the levelling campaigns, and the ERS1, ERS2 and ASAR sensors for track 423, frame 2542. This track currently contains 150 ERS-1/2 acquisitions (latest ERS-2 acquisitions may be acquired under large squint angles), and 38 Envisat ASAR acquisitions.

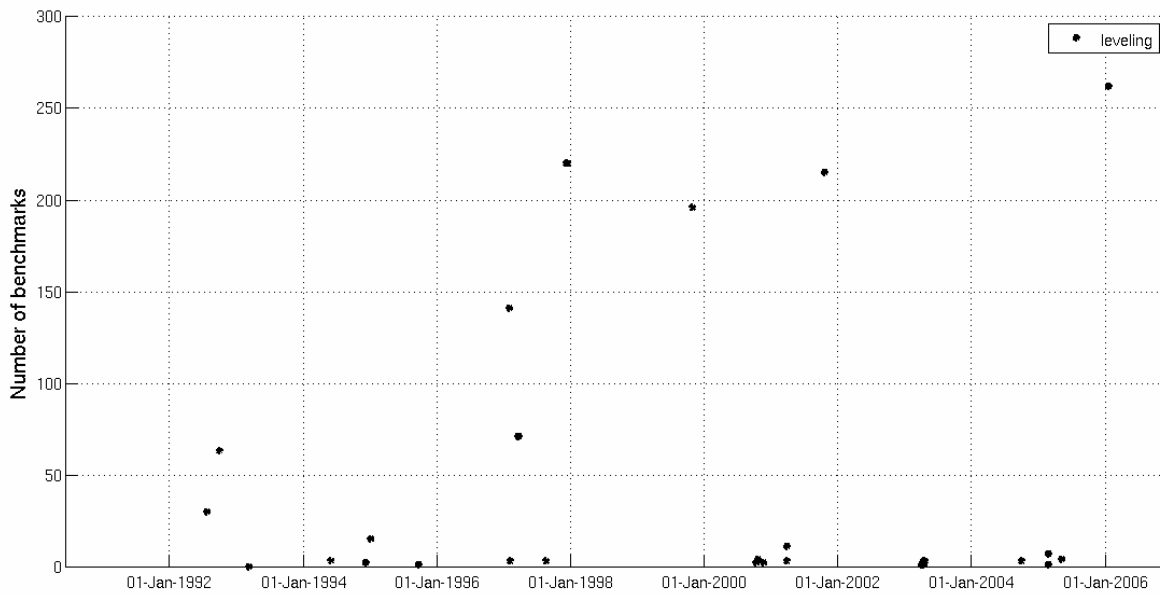


Figure 3: Number of levelling benchmarks observed per epoch.

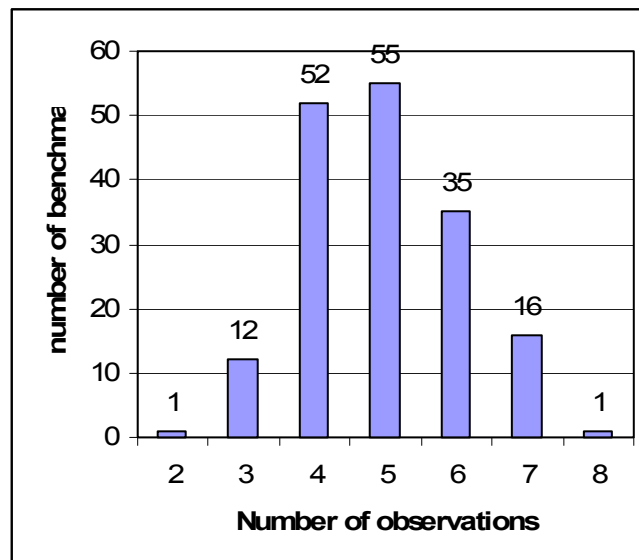


Figure 4: Distribution of the number of levelling observations over the period 1991 – 2006.

3. AMSTERDAM - MAIN CHARACTERISTICS

Type of deformation:

- The N/S-metro line is a 9.5 km long metro line which is currently under construction, see Figure 5. About 3.8 km of this line will be constructed by a tunnel boring machine. The soft soil, high groundwater levels and historic nature of many of the buildings (17th – 19th century) make it of paramount importance to have a proper settlement-monitoring system installed. Actually, construction of the stations has started in 2003, while boring of the tunnel is expected to start in 2008.
- Since the tunnelling has not started yet, the deformation is mainly due to geotechnical instability and localized construction works. Spatial extent of the deformation phenomenon at hand localized at certain buildings.
- Deformation rates. As a result of the local ground conditions the rates of deformation in the area of interest is about 1 to 3 mm/yr. This has been confirmed by PSI analysis in Stage 1 of Terrafirma. However, as the monitoring results of the N/S-line showed, sudden movements have been recorded at various locations either due to e.g. foundation repair or to ground movement caused by construction activities. Therefore, the site includes both gradual (mm/yr) and instantaneous (>10 mm) deformation.

Available ground truth:

- An extensive monitoring system has been set up and installed in 2001 along the 3,8 km transect of the proposed bored tunnel. The system consists of three components:
 - a) A fully automated system consisting of 74 robotic tacheometers (total stations, see Figure 6) aimed at 5350 prisms on 1500 constructions along the 3,8 km transect measuring individual prisms in (x,y,z).
 - b) Traditional precise levelling of reference objects along the tunnel transect in order to reference the local system of total stations.
 - c) Sub-surface monitoring of ground movement by a network of inclinometers, extensometers and piezometers.
- The data are stored in a database/GIS-system which enables the selection of time series of x,y,z,-deformation for individual locations. The system and data are owned by the Projectoffice North/South-line of the city of Amsterdam.
- The total stations are split into groups of up to four instruments each to form a local geodetic network. The on-line monitoring system determines the x,y,z-deformations of the prisms. Tilting or rotating movements are therefore included in the observations. The current frequency is about 1 measurement every 4 hours. For the system of total stations it is important that stable reference targets are available. These are defined outside the zone of influence of the construction works and reference the local system of total stations. In Amsterdam 8 local systems cover the whole area along the proposed tunnel boring of 3.8 km.
- The prisms (about 4 per building) and the total stations are installed in the front and side façade walls of the buildings in the area of influence (see Figure 7). The locations have been selected along the entire route so that each prism can be monitored by at least one total station. The prisms are measured within a range of 75 m to the required degree of accuracy. The system used, Cyclops of SolData, is reported to have an accuracy of +/- 0,5 mm over a distance of 60 m. For the North/South metro line between 50 and 100 prisms are monitored by one total station. They are linked to a data logger which collects the data and transfers it via radio link to the central monitoring office.
- Figure 8 is an example of the output of the monitoring system.

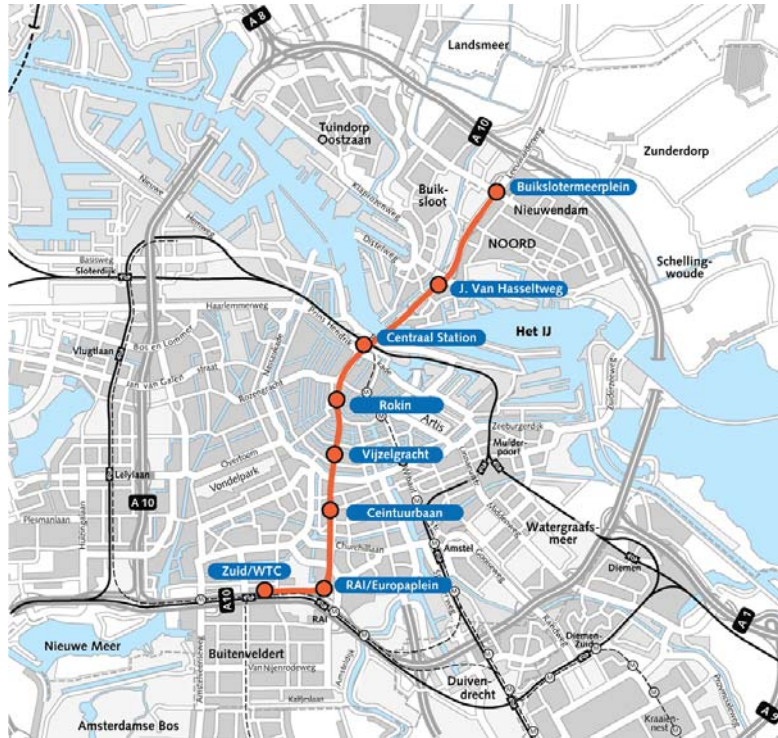


Figure 5: Plan of the North/South metro line. Monitoring system is between the Central Station and station Ceintuurbaan.



Figure 6: Example of a Total Station.



Figure 7: Monitoring system North/South metro line.

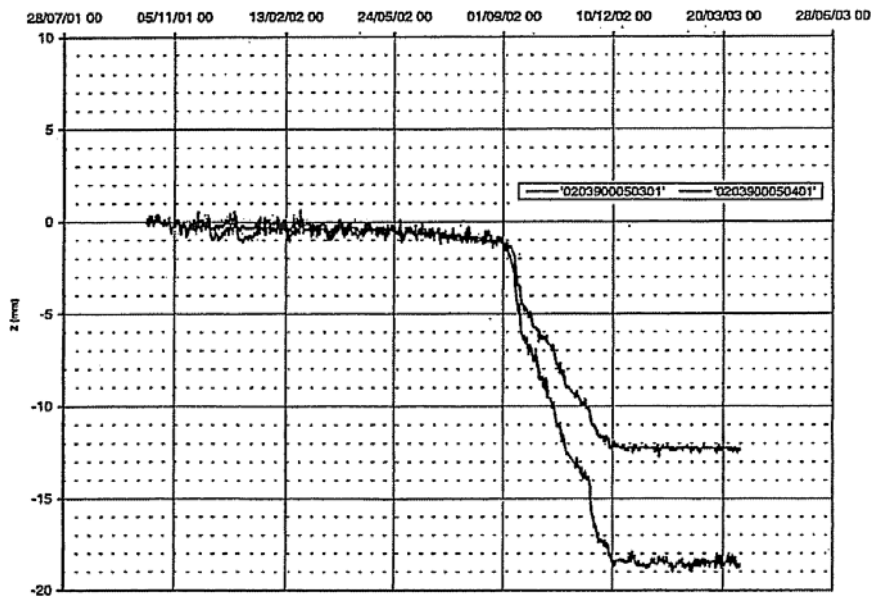


Figure 8: Example of the output of the monitoring system of the North/South metro line. Sudden movements have been recorded at various locations either due to e.g. foundation repair or to ground movement caused by the activities related to the construction of the stations.

4. CONCLUSIONS

- Considering the characteristics of Alkmaar and Amsterdam, the test site offers two valuable and **complementary datasets**:
 - ALKMAAR, with a spatially correlated deformation field.
 - AMSTERDAM N/S- metro line, with autonomous and (mainly) spatially uncorrelated movements, and a dense network of benchmarks.

Note that the complementarity between the two sites is useful for the two key goals of the Terrafirma Validation Project: validation and inter-comparison of the PSI results.

- In the test site **different types of deformation phenomena occur**, which include terrain deformation, settlement of water-defence structures, and settlement of ordinary constructions. Autonomously moving targets are expected in the area of interest. Soil types in relation to (localized) changes in ground water heads will result in anomalous PS, when considering the wide scale deformation processes. However, such results should not necessarily be filtered out, since they may give extra insight in the dynamic processes in this coastal area. The different types of deformation phenomena in the same site are **important to highlight the PSI deformation measurement and monitoring capabilities**.
- **Pros of Alkmaar.** The Alkmaar area is a good location to validate PSI algorithms and to prove the applicability of the PSI techniques for these reasons:
 - It complies with the main objectives of the Terrafirma project: spatially smooth deformation signal of significant magnitude, covering both urbanized and rural areas, and high chance of success of the PSI measurements.
 - The high societal relevance of the deformation phenomena at hand¹.
 - The availability of reference data.
 - The proven subsidence processes and the knowledge of driving mechanisms.
 - The public debate about the interpretation of the currently available ground truth data².
- **Cons of Alkmaar.** One of the major concerns regards the relatively small magnitude of the deformation over the site (deformation rates up to 3-4 mm/yr). Even though we could wish bigger deformation rates, there are a few aspects to be considered:
 - Firstly, the moderate deformation rates avoid the unwrapping-related problems experienced in PSIC4, and make the **PSI deformation analysis feasible**.

¹ In the Netherlands, several regions are subject to land subsidence. Particularly in the west of the Netherlands, subsidence is a significant problem, due to the following reasons. First, this is one of the most densely populated areas in the world, the majority of which is located below sea level. Second, various processes contribute to surface movement.

² Even though the Dutch first order national levelling monitoring network is one of the oldest in Europe, starting in the late 1800's, the interpretation of these data and subsequent 2nd and 3rd order levelling campaigns is subject of public debate and controversy. Recently, publications appeared stating that up to 40 cm subsidence per century was possible in the coastal regions. In relation to the expected sea level rise, this would imply that the safety and stability of the coastal defence works (dunes, dikes) cannot be guaranteed with the standard yearly measures [Schokking, 2004]. Public safety would not be guaranteed anymore without profound and costly infrastructural improvements. These publications caused national headlines, and caused authorities to further investigate the issues. The main problems were (i) the availability of reliable information, and (ii) the interpretation of the available information. Reference: F. Schokking, Bodemdaling erger dan broeikaseffect; Risico's op versnelde daling langs Nederlandse kust, Land en Water, (11), p 2-3, Nov 2004, [In Dutch].

- Validate the PSI techniques in a site with “small and moderate deformation rates”, say a few mm/yr, is **useful to highlight the PSI capability in detecting and measuring small deformations**.
- Even though the deformation rates are moderate, the test site cannot be considered “too easy or trivial” for at least two technical reasons:
 1. The PSI analysis in Alkmaar is challenging due to the expected PSI density.
 2. The PSI analysis has to carefully taking into account the strong atmospheric contribution, which is expected over the area, see the comments of TUDelft³ and DLR⁴.
- **Pros of Amsterdam.** The second area of interest is Amsterdam, related to the construction of a metro tunnel, commonly referred to as the North-south line. Tunnel boring is envisaged to start in 2008/2009. However, already in 2001 an extensive monitoring system, consisting of 74 Total Stations, 5300 prisms and conventional levelling has started in order to monitor the stability of 1200 constructions along the proposed route. The sheer amount of data, the fact that PS-InSAR and monitoring data are well overlapped in space as well in time, **make this an excellent case for validation**.
- To conclude, both Alkmaar and Amsterdam suit the conditions aimed at in Terrafirma as they are urbanized and experience typical subsidence phenomena. The use of both sites for the Validation Project offers the key advantage of providing different and complementary types of deformation. This is important for the purposes of validating and inter-comparing the PSI results.

³ Single interferograms will certainly be affected by atmospheric signal, as the region of interest is near the North Sea shore, and the climate of Netherlands is variable. Especially convective processes are expected to cause significant anomalies in atmospheric refractivity, leading to localized phase delays. Ample information on atmospheric signal is available for the region from previous studies. The atmospheric error signal can be approximately characterized by a Gaussian variogram with a zero-nugget, the square-root of the sill of 12 mm, and a range of 40 km.

⁴ From an email of Nico Adam (DLR): [...]. In the city areas the PS density is perfect. I'm sure we can demonstrate the performance of the PSI-technique and the validity of the Terrafirma product in these areas. (I hope that the deformation is linear.) But we can expect difficulties for the APS estimation and finally for the resulting displacement accuracy in the rural areas. Usually the test site area is affected by strong atmospheric effects. I have attached a typical example for the region. The spatial PS distribution (i.e. density) influences the APS estimation. It needs to be clear that the quality of the estimation will vary depending on the local PS density. A second difficulty caused by the APS and the sparse PS grid between the cities is the final global integration (i.e. the transformation from the relative measurements into absolute). I propose to restrict the validation and any assessments on the local city areas only. Could you please report my comment to the relevant partners?