# GMES

# TERRAFIRMA

ESRIN/Contract no. 19366/05/I-E

# Validation of existing processing chains in Terrafirma stage 2

# SPECIFICATION OF VALIDATION APPROACH
## PART 2: PRODUCT ANALYSIS TASKS

15th October 2007

Final version

M. Crosetto, M. Agudo (Institute of Geomatics)

C. Bremmer, S. Dortland (TNO)

R.F. Hanssen, F. van Leijen (TU Delft)

# INDEX

# 1. INTRODUCTION

This document is part of the Terrafirma Validation Project and describes the analysis tasks to be performed within the WP VAL.07 “Product analysis and reporting”. Its main goal is to define the product analysis tasks of the Terrafirma Validation project. It forms the basis to formulate all the key questions that should drive the validation analysis.

This document reflects the different characteristics of the two test sites of the project, Alkmaar and Amsterdam, in terms of their analysis.

For each task the following parts are identified:

- Leader
- Input information
- Procedure. As far as possible, the aim is to present simple and easy-to-understand validation procedures. Complex analysis procedures, whose outcomes are difficult to interpret, are avoided
- Output, including easy-to-understand validation figures.

## 2. PRODUCT ANALYSIS TASKS

The Terrafirma validation project includes two complementary analyses: a **process analysis** and a **product analysis**. The tasks of the process analysis include **(**provisional list):

- Comparison of the density and distribution of the PSI observations
- Comparison of the interferometric phases
- Comparison of the linear line-of-sight velocities
- Comparison of the elevation errors
- Comparison of the accuracy estimates for velocity and elevation errors
- Comparison of the coherences
- Comparison of the time-series data for selected points
- Comparison of the extent and delineation of observed motions
- Detailed analysis of differential motion and elevation errors.

Whereas the process analysis aims for internal validation based on the various PSI processing chains, the **product analysis** focuses on external validation, using complementary external data. Even though these external data cannot be considered as error-free (deterministic) ground truth as well, the degree of correspondence between the various data sets can be useful to improve understanding of the quality level of PSI products.

The list of the **product analysis** tasks includes

- Analysis of the geocoding
- Validation of the average annual displacement rates
- Validation of the displacement time series
- Validation in the *parameter space,* i.e., the products produced by the end-users
- Advanced analysis of the validation results

# 3. GENERAL REMARKS

Within the Terrafirma Validation Project two data sets in the Netherlands are analysed, (i) the region around Alkmaar, affected by the withdrawal of natural gas and (ii) an area in the city of Amsterdam, monitored extensively in relation to the planned construction of a metro tunnel (the so-called North-South N/S-line). These different driving mechanisms result in different expected deformation characteristics. The natural gas withdrawal in the Alkmaar region will result in a spatially correlated deformation field, leading to **area-based comparison**. Displacements in the N/S-metro line region in Amsterdam are caused by geotechnical instability and localized construction work. These displacements can be spatially variable, leading to **point-wise analyses**.

The second cause of difference between the two study areas is the available ground truth. For the Alkmaar area sparsely distributed (in space and time) levelling data are available. The results in the N/S-metro line region in Amsterdam will be validated against 3D displacement measurements obtained by automatically operated tachymeters, forming a very dense spatial network and having a high temporal sampling.

Finally, the two areas have different characteristics in terms of their geography. The area influenced by subsidence near Alkmaar consists of a mixture of forest, dunes, beach, and small villages, whereas the Amsterdam city area is completely urbanized, leading to different characteristics in their radar reflectivity behaviour.

These differences between the two data sets require a tuned product validation procedure, which is discussed in the following sections.

# 3. PRE-PROCESSING

The product analysis will be performed minimizing the pre-processing operations on the products of the OSPs. This has two advantages:

- Minimizing the “validation-induced errors”, i.e. errors induced by pre-processing.
- Simplifying the procedure and increasing the interpretability of the validation’s final results.

Nevertheless, the following pre-processing steps are inevitable, as discussed below.

## 3.1 Coordinate transformation input

*Leaders*: TNO and TUD.

In order to streamline the validation, coordinate transformation of the PSI products will be completely avoided by providing all the auxiliary data (DEM or DTM, orthoimages, cartographic maps, ground control points, etc.) and validation data strictly in the same cartographic reference system (WGS84).

In addition, strict rules will be fixed for the geocoding of the PSI products, using the above auxiliary data. All OSPs will provide the PSI results in the WGS84 system. This will be checked by IG before starting any product analysis.

## 3.2 Datum connection 1: Identification and selection of reference point

*Leader*: IG.

To enable validation and comparison, the PS results of all OSPs should be relative to the same datum, using a reference PS. Therefore, a PS needs to be identified which is common in all OSP products. To ease interpretation of the final results, it is desirable to use a reference PS which is assumed to have no displacement in time. This reference PS is selected based on a-priori information about the area.

This operation will be performed by IG before starting any product analysis.

## 3.3 Datum connection 2: Orientation of deformation vector components

*Leaders*: TNO and TUD.

Measurement techniques such as levelling, GPS, tachymetric surveys, and PSI produce data in an intrinsically different datum. To facilitate a comparison between different data sources, a datum connection is required. Taking into account the datum differences in the techniques used here, either the PS line-of-sight (LOS) measurements should be converted to the vertical, or the ground truth data should be transformed to LOS. In contrast with the Alkmaar region, where only vertical deformation is registered, in Amsterdam both horizontal and vertical deformation data are available. Therefore, the Alkmaar data set will be analyzed in the vertical direction (converting the PSI datum to the levelling datum), whereas the Amsterdam data set will be analyzed in LOS (converting the 3D deformation from the tachymeter system to the PSI datum). Note that we can safely assume that for the area around Alkmaar, gravimetric changes are negligible, which enables us to consider the orthometric levelling information as geometric deformation.

The **null-space of PSI measurements** includes an **unknown bias** (the absolute phase of a reference point of choice), and a **spatially wide trend** (tilt) in the data, due to residual orbit effects. If the datum connection using a single reference point (PS) proves to be insufficient, an internal datum connection will be performed, solving for relative bias and trend of the OSP results. In this occurrence, the influence of this internal datum connection will be analyzed in detail. Equivalent product analyses will be performed both for the original OSP products and for the trend-corrected products. The results of both analyses will be clearly communicated in the product analysis report.

Furthermore, in Alkmaar the epochs of the PS and levelling measurements will generally differ. Therefore, the data sets cannot be simply referenced to a common epoch. To solve this problem, linear displacement models trough time series of both data sets are estimated and the unknown bias is found by a best fit of the models. Since the models are continuous in time, the reference in time can now be set arbitrary.

## 3.4 Preparation of levelling data in Alkmaar area

*Leaders*: TNO and TUD.

The preparation of the levelling data in the Alkmaar area consists of the following steps:

- selection of benchmarks with sufficient observations within PS time span.
- check for outliers.
- estimation of linear deformation rates.
- estimation of time series.

## 3.5 Preparation of tachymeter data in N/S-line area, Amsterdam

*Leaders*: TNO and TUD.

The preparation of the tachymeter data in the N/S-line area in Amsterdam consists of the following steps:

- selection of suitable prisms (based on PS results).
- estimation of linear deformation rates.
- transformation to radar line-of-sight.

# 4. TASK DESCRIPTION

## 4.1 Analysis of the geocoding

*Leader*: IG

*Inputs*: PS products after the “quality check” of IG

Ground truths.

*Detailed description of the procedure*:

1) Analysis of the geocoded OSP products, and estimation of global geocoding accuracy (i.e. estimation of the global shifts in the geocoded products).
2) Using common PS between different OSPs, which will be identified in the co-registered slant-range products, analyse the dispersion of the PS geocoded locations. This is in fact an inter-comparison, which is closely related to the inter-comparison of the so-called PS elevation error.

## 4.2 Validation of the PS results in the Alkmaar-area

*Leaders*: TNO and TUD.

*Inputs*:
- PS products after the process-validation and referenced against a common target.
- Ground truth (levelling data).

*Output*:

1) Preliminary analysis of original data
   - a) Plan view maps of PS and levelling velocities.
   - b) Plots of levelling time series vs. time series of all PS within a given distance from the levelling benchmark. Note: without any spatio-temporal interpolation.
   - c) Statistical parameters of goodness-of-fit between levelling and PS time series.
   - d) Screening on autonomous movement.
2) Analysis of spatio-temporal interpolated data
   - a) Plan view maps of spatio-temporal interpolated PS velocities at the levelling benchmark locations.
   - b) Plan view maps of difference between spatio-temporal interpolated PS velocities and levelling velocities at levelling benchmark locations.
   - c) Statistical parameters of goodness-of-fit between interpolated levelling and PS time series.
   - d) Analysis of likelihood of that PS and levelling data describe the same deformation regime.
3) Plots of analysis in the parameter space using several models
   - a) Plots of estimated subsidence bowls.
   - b) Plots of differences between estimated subsidence bowls.
   - c) Statistical analysis of the difference between subsidence bowls.

*Detailed description of the procedure*:

1) The plots of the original data are meant to compare the PS results with the levelling data without any modifications. The PS within a certain radius around a levelling benchmark are plotted, displacement velocities (a) as well as time series (b). A screening on autonomous

movement (deformation not related to gas withdrawal) and outliers is performed to isolate these PS from further analysis of the spatial correlated deformation phenomena.

2) To be able to compare the PS results directly with the levelling data a spatio-temporal interpolation is required. The interpolation is based on kriging, which takes the spatio-temporal correlation of the displacement field into account. The correlation is described by a variogram or covariance function, which is estimated directly from the data. The resulting PS displacement rates at the levelling benchmark locations are visualized in a plan view map (a), as are the differences with respect to the levelling displacement rates (b). As PS and levelling physically measure different objects, a direct comparison of the results is, in principle, not allowed. However, in a broader perspective, it needs to be assessed whether they measure the same deformation phenomenon (regime). The answer to this question is given in a statistical analysis. Given the levelling data, the likelihood is calculated that the spatio-temporal interpolated PSs describe the same deformation regime. These likelihoods are visualized in a plan view map.

3) Instead of a direct comparison of measurements (levelling and PSI in the measurement space), derived parameters are compared (parameter space), e.g. an estimated subsidence bowl. These are normally the end products of a geodetic analysis and they are of interest for the user (who is not interested in the individual measurements). Advantage is that the influence of the difference in measurement technique is reduced.

Combination/validation in the measurement space means to link a levelling benchmark directly to a nearby PS point. If possible, this is a good approach, but in many cases it is unsure whether the same phenomenon is observed. Intrinsically, levelling/GPS benchmarks will always be different from effective scattering centres in PSI.

Combination/validation in the parameter space means that different types of data are used to estimate a geometric shape of, e.g., a subsidence bowl[1]. The 'parameters' are thus defining the bowl. By estimating the same parameters from two different sets of data (levelling and radar) one can show that it is possible to reliably estimate the same parameters, even though the actual measurements are at totally different locations.

---

[1] This idea stems from a mathematical description $E\{y\}=Ax$, where $y$ is the vector of observations, in the measurement space, and x is the set of unknown parameters (parameter space). The (linearized) design matrix $A$ relates observations to the parameters. By working with the same design matrix, it is possible to show that PSI is able to estimate the same parameters as levelling, which is a convincing way of validating geodetic measurements. In this case a subsidence bowl is estimated from the levelling data as well as from the PS data. Plots of the estimated bowls (a) as well as the difference between the PS based and levelling based bowls (b) are given, together with a statistical analysis of the difference (c).

## 4.3 Validation of the PS results in the Amsterdam-area (selected buildings along the N/S-line)

*Leaders*: TNO and TUD

*Inputs*:

- PS products after the process-validation and referenced against a common target.
- Ground truths (tachymeter measurements (*x,y,z*))

*Output*:

1) Histograms and plan view maps of PS velocities, heights and coherences.
2) Histogram and plan view map of tachymeter velocities.
3) Plots of tachymeter time series vs. time series of all PS within a given distance from the prisms/buildings.
4) Statistical parameters of goodness-of-fit between tachymeter and PS time series.

*Detailed description of the procedure*:

The monitoring data of the N/S-line are available on about 1800 buildings along the 3.5-km stretch of the proposed tunnel and have a sampling rate of once every 4 hours. The method proposed is:

1. Select an appropriate set of buildings for which PS-estimates have been obtained by all OSPs. A minimum of 25 and a maximum of 50 is taken as appropriate. Care is taken of comparing buildings showing a variation in displacement characteristics and magnitudes,
2. Refer all ground truth and PS to a common velocity-frame,
3. Estimate LOS-displacement from the *x,y,z*-data for each building,
4. Estimation of LOS-velocities for each building.

The LOS-displacement time series are plotted with the OSP results. A final comparison will be performed by computing the standard error or RMSE. Statistical parameters of goodness-of-fit between tachymeter and PS time series will be tabulated. Furthermore, a comparison will be made between PS velocities and estimated tachymeter velocities.

## 4.4 Independent quality assessment

| | |
|---|---|
| *Leaders*: | TNO and TUD |
| *Inputs*: | - PS products after the process-validation and referenced against a common target.<br>- Estimate of spatial correlation of subsidence signal (Alkmaar region). |
| *Output*: | 1) Spatio-temporal consistency measures.<br>2) Histogram and plan view map of spatio-temporal consistency. |

*Detailed description of the procedure*:

As 'coherence' is a sub-optimal quality parameter in the context of PSI deformation measurements, due to its inherent dependency on distance to the reference point and its dependency of the assumed deformation model, an alternative local quality parameter will be estimated, which is the **local spatio-temporal consistency**. This parameter has the advantage of being independent on the distance to the reference point, and as an identical deformation model is used for all measurements, the influence of the deformation model can be eliminated.

For each evaluation point, the time series of displacement residues with respect to the initial deformation model are differenced with the residues of detected PS points in close proximity (excluding side-lobes). Weighting is applied based on the distance to the evaluation point. Spatio-temporal consistency values (with rms as principal unit) are calculated in a relative sense.

## 4.5 Advanced analysis of the validation results

*Leader*: IG, assisted by TNO and TU Delft

*Inputs*: Output of process and product analyses.

*Detailed description of the procedure*:

This will **represent one of the key tasks of the entire project**. We will analyze in depth the project results through the following procedure:

- Collect the key results.
- **Brainstorming**, e.g. one- or two-day meeting IG-TNO-TU Delft, to prepare the Project Meeting n. 3.
- Project Meeting n. 3: round table, discussion, etc.
- Prepare the final report (with multiple contributions).
- Organize other dissemination activities.

*Outputs*:

- Advanced synthesis of project results: process and product analysis results. In this context it is important to note that PSI observations in general may measure motion phenomena different from those observed by the reference ground truth data. The analysis will distinguish between explainable and unexplained deviations between the data.
- Characterize the *Terrafirma* H.
- Clarify the product limitations.
- Recommendations as to product improvement as appropriate, e.g.
  - Detection Product, lowest level, delineating stable and non-stable only.
  - Average Annual Velocity Product, middle level, showing average values.
  - Time Series Product, highest level.