ESA EOMD

PIPEMON

Ground and Structure Motion Monitoring Service using Persistent Scatterer Interferometry (PSI)

Service Portfolio Specifications

Version 2

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Content taken from the ESA Terrafirma Service Portfolio Specification S5
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Version 2 edited with comments from TRE.

ACRONYMNS

CR:	Corner Reflector
CRInSAR:	Corner Reflector SAR Interferometry
DifSAR:	Differential SAR Interferometry
DN:	Digital Number
EOMD:	Earth Observation Market Development
ESA:	European Space Agency
ETM:	Enhanced Thematic Mapper
InSAR:	Synthetic Aperture Radar Interferometry
PSI:	Persistent Scatterer InSAR (generic name for the advanced InSAR technique
SAR:	Synthetic Aperture Radar
TM:	(Landsat)Thematic Mapper

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1: INTRODUCTION

PIPEMON is a three-year integrated remote sensing and pipeline industry activity that is funded by the European Space Agency (ESA) as part of its Earth Observation Market Development (EOMD) Programme. As part of its portfolio PIPEMON offers a ground and structure motion monitoring service to detect and measure motion along pipelines or over specific installations in relation to landslip, river crossing, tectonic hazard zones and mining / extraction zones.

This *PIPEMON* service is based upon the application of SAR Interferometry (InSAR) technologies: mainly Persistent Scatterer Interferometry (PSI), but sometimes conventional 2-pass differential SAR Interferometry (DifSAR), and Site-Specific SAR Interferometry using corner reflectors (CRInSAR).

PSI is an advanced InSAR technique that overcomes many of the limitations of conventional, two-pass conventional DifSAR technique. However, there are applications where PSI is not wholly appropriate and the other InSAR techniques can be applied, such as in cases of fast movements over a very short time interval or areas with little or no natural scatterers.

This document provides the technical specification of the PSI service product only, but a second version is planned which will include specifications of the DifSAR and CRInSAR products.

2: THE PERSISTENT SCATTERER INTERFEROMETRY PRODUCT

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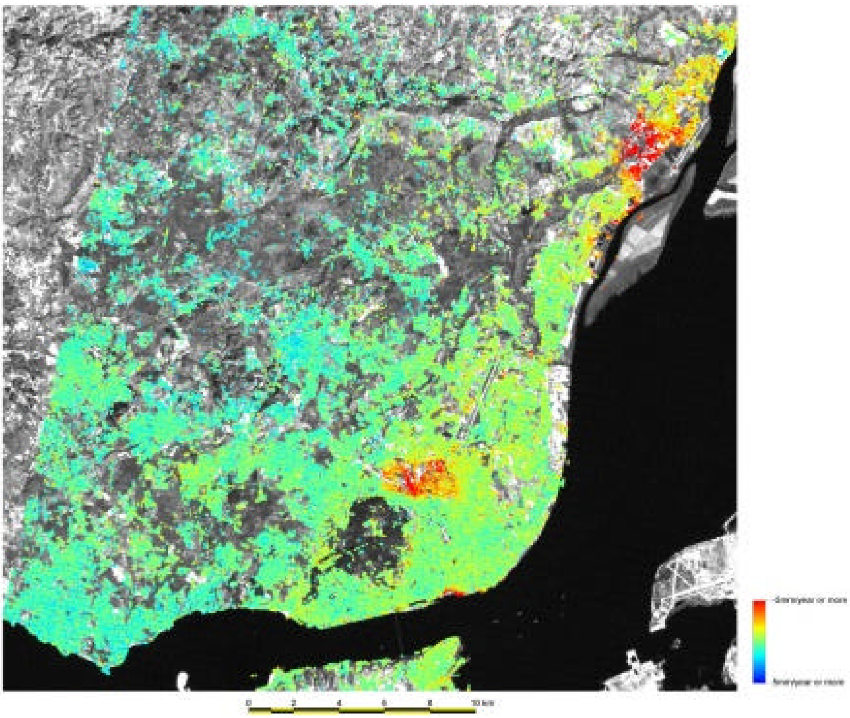
PSI is a non-invasive surveying technique used to calculate fine motions of individual ground and structure points over wide-areas covering urban and semi-urban environments. The technique uses an extensive archive of satellite radar data (dating back to 1992) to identify networks of persistently scattering (i.e. radar reflecting) features such as buildings and bridges, or natural features such as rocky outcrops, against which relatively-precise motion measurements are calculated retrospectively over the time spanned by the data archive. The exact location of the points cannot be predicted in advance of processing but over urban areas their densities are usually measured in the hundreds per square kilometre. The unique benefit of PSI is its ability to provide both annual motion rates and multi-year motion histories for individual scatterer points. The PSI technique takes conventional InSAR a step further by correcting for atmospheric, orbital and DEM errors to derive relatively-precise displacement and velocity measurements at specific points on the ground.

The image below depicts the PSI product for Liege, Belgium though here, the 'raw' data has been superimposed on a background image for clarity



Example output product for Liege, Belgium (processed by NPA, UK)

2.1: Product inputs

The following table presents the datasets to be used as inputs for the generation of the PSI products.

Dataset	Notes
ERS SAR / ENVISAT ASAR data	N/A
Topographic map / Digital Elevation Model	A DEM is not obligatory for PS techniques. However use of a 3 arc second or better resolution DEM is encouraged.
Satellite state vectors	Either from Delft University or from DLR
Reference map or high resolution optical satellite data (for georeference purposes).	Output product georeference dependent on quality of reference data. The end-user should supply high-resolution reference data. If none is available then Landsat ETM/TM data will be used by default.
Ground-truth information regarding stable regions for reference point location.	Aids the calibration of the PSI measurements.

Master image

Analyses can use a single or multiple master images against which all displacement measurements are relative. In the case of a single master image, it should be chosen to be as 'temporally' central as possible within the spread of all the image dates within the dataset, and also spatially central so that the spread of satellite baselines is minimised. In addition, master images should only be used if the prevailing weather conditions at then time of acquisition were good, as severe weather, (e.g. snow or storms) will adversely affect the refractive properties of the atmosphere through which the satellite signal travels, giving rise to possible phase ambiguity.

Reference point

The reference point is the point within the study area against which all ground velocity and height measurements are relative. As such, it is critical that the reference point is itself not moving over time and any issues relating to it should be detailed in the corresponding Processing Report.

Coherence

PS points are identified by a thorough analysis of each pixels' response in every scene throughout the entire dataset. The initial interferometric results are corrected for atmospheric and orbital errors and the resulting displacement and velocity measurements are retrieved. Not all PS points and their measured displacements are of the same quality, and this is established by the scatterers' *coherence* or by the standard deviation of the point from linear motion. Those with high coherence are likely to exhibit measurements that are less noisy and more reliable. Points with low standard deviation will show good correlation to the linear motion rate. Points with high standard deviation will exhibit greater deviation from a linear motion rate – this can be due to higher noise levels or due to some degree of non-linear behaviour.

2.2: <u>Product outputs</u>

There are four outputs to the processing as follows:

1. Database of PSI time-series and average annual displacement rates.
2. Reference point table.
3. Processing report (metadata).
4. Raster of interpolated average annual displacement rates.

The following paragraphs describe these outputs in more detail.

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Database of PSI average annual displacement rates and time-series

Time-series data are provided as tabular data in dBase IV (.DBF) format with the following structure.

Field Name	**Definition**
CODE	PS unique identifier
EASTING	UTM, WGS84
NORTHING	UTM, WGS84
RANGE	Range pixel co-ordinate
AZIMUTH	Azimuth pixel co-ordinate
HEIGHT	Height of PS point (m)
VEL	Average annual displacement rate (mm/year)
COHERENCE	Coherence (quality indicator)
ST_DEV	Standard deviation of average annual displacement (mm/year)
YYYYMMDD (e.g. 19921127)	First date, displacement relative to master image (mm), 27 November 1992
YYYYMMDD (e.g. 20020903)	Final date, displacement relative to master image (mm), 3 September 2002

PS time series table structure

Reference point table.

Reference point data is provided as tabular data in dBase IV (.DBF) format with the following structure.

Field Name	**Definition**
CODE	PS unique identifier
EASTING	UTM, WGS84
NORTHING	UTM, WGS84

Reference point table structure

Processing report (metadata)

The processing summary report provides the user with the statistics relevant to the site processed and gives a number of quantitative and some qualitative information regarding the product delivered. It aims to provide the user with site specific information e.g. number of scenes used, date range of analysis, basic ground motion statistics, etc.

Process Date	
Software used	
Version	
Number of scenes used	
Date range of analysis	
Satellite data used	
Master Scene Date	
Georeference (X,Y) accuracy	
Reference data used for georeference	
Projection system used	
Reference point location	
Area of results	

Interferograms used for analysis			
Master Date	**Slave Date**	**Bperp**	**Temporal Separation**
….	**….**	**….**	**….**
Number of PS identified			
PS density (PS/km^2)			
Point motion statistics (mm/year classes)		**% of points in each mm/year class**	
-max to -3.5			
-3.5 to -1.5			
-1.5 to +1.5			
+1.5 to +3.5			
+3.5 to +max			
Average annual motion rate of the entire processed area			
Standard deviation of average annual motion rate			
Observations			
Uncompensated atmospherics			
Visible tilt or phase trends in motion map			
Are there any regions not covered by InSAR results? If so, where and why?		**Lack of scatterers/coherence** **Suspected significantly non-linear motion** **Suspected high motion rates (above 4.5 cm/year)**	

Raster of interpolated average annual displacement rates

This data layer is produced using the average annual displacement rate field of the PS table, and is useful for gaining an initial understanding as to the nature of the result. This product should also always be provided to the Project Co-ordinator for his records, general promotion and inclusion within the PIPEMON brochure, being a compendium of all products and value-statements.

The interpolation method employed minimises the distance to 50m over which the PS results are extrapolated. The PS average annual displacement rate is interpolated using a surface-fitting algorithm to produce a displacement rate map of the study area. The interpolation is carried out using a minimum curvature, surface-fitting algorithm for a distance up to 50m from any one PS point. Null cells are inserted in areas that are further than 50m from a PS point. This image is used primarily for visualisation purposes as the DN values contain only an RGB colour value. An accompanying legend object is provided for reference. The interpolated average annual displacement rate raster is provided in the format detailed below:

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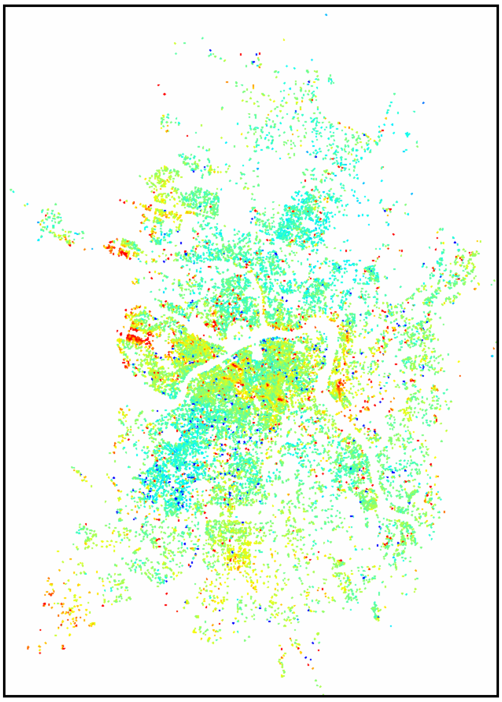
Georeference	Latitude/Longitude or as per geocoding imagery (by default UTM, WGS84)
Data type	8-bit unsigned
Byte order	N/A
Format	GeoTIFF
Georeference information	Integral GeoTIFF tags, Arc Info World file (.tfw) and text file of corner co-ordinates (.txg)
Colour table applied	Rainbow: Red-Orange-Yellow-Green-Cyan-Blue
Contrast stretch applied	Linear, min -5 mm/year, max +5 mm/year, or as appropriate if very rapid displacements are present
Null value	255



Example image – St Petersburg, Interpolated PSI Result

Interpolated average annual displacement raster format (GeoTIFF data)

N.B. It should be borne in mind that the actual PS measurements were made only on the PS point location itself (the centre of the interpolation circle), raster values beyond this point do not represent real measurements. No Interpretations should be made of the extrapolated values.

2.3: Limitations of PSI

Data quantities

PSI relies on a large number of multi-temporal SAR scenes. For some locations outside Europe, insufficient data may be available to apply the technique.

Persistent Scatterer locations

A feature of PSI is that the number and location of persistent scatterers cannot be predicted before processing as a good 'back-scattering' point depends on the dielectric properties of the target materials and the planes of surfaces (geometry) in relation to the satellite. In typical built-up urban areas, one may reasonably expect many hundred points per square kilometre. However, this density falls off rapidly as more rural environments are considered. Landslide products often rely on the scattering properties of bare rock.

It should also be recognised that a proportion of PSI measurements might in fact be reflections from buildings as opposed to the ground, or indeed the result of 'multi-path' reflections (e.g. from satellite to pavement, to building, to another building, then back to satellite). These phenomena should be taken in account, especially when considering the nature of individual, or 'spurious' points.

High displacement rates

InSAR phase measurements are recorded as wrapped phase in the range -? to +?. Phase unwrapping solves this ambiguity by calculating the correct number of phase cycles that need to be added to each wrapped phase measurement so that the correct slant range distance can be computed. However in areas where more than one phase cycle of movement has occurred between sampling, i.e. between contiguous satellite acquisitions, the phase unwrapping may fail. Areas of such high displacement rates (e.g. areas of active mining) can appear as regions devoid of PS points or indeed points where the displacement rate given is inaccurate. The processing report and discussions with the corresponding OSP should clarify where such phenomena might occur.

Significantly non-linear motion

The standard PSI process assumes ground motion that is largely linear in nature, and the standard algorithms employed may therefore average out non-linear motions. Where significant non-linear motion is suspected, the algorithm employed may be modified, e.g. through application of polynomial models or a reduction in the coherence threshold. Again, such phenomena should be fully discussed before any processing begins during the feasibility assessment phase, and detailed by the OSP in the associated Processing Report.

2.4: Accuracy and validation of PSI

Given perfect conditions, the relative line-of-sight accuracy of the PSI measurements can be sub-millimetre. However, there are variables determining accuracy, and these need to be understood before any tolerance can be specified. Variables include the temporal distribution of SAR data, the spatial distribution and character of the target, land cover characteristics, rates of motion, the linearity of motion, validity of the reference point, and the distance of the measurement from the reference point.

It is also significant that in urban environments most radar reflections are from buildings and not the ground: the stability of a building may be an expression of the state of the ground on which it stands, but it may not be if the building is moving independently (the sensitivity of PSI has for example shown the thermal dilation of metal roofs). Also, a PSI measurement might be of good accuracy, but is not in fact the simple radar reflection of the presumed target (e.g. ground *vs* building). Furthermore, some PSI measurements might be summations of multi-path reflections where the radar signal is bounced from one element to another before returning to the satellite. For the analysis of some ground motion phenomena it is often appropriate to ignore isolated measurements and focus on clusters of points which include several buildings.

All these factors mean that the specification of an overall accuracy figure for PSI is not straight forward, but is rather the result of an integration of many factors, some of which will always remain unknown. For this reason, interpreting *H-1* products should always be done in collaboration with the OSP who made them, as they will have an in-depth understanding of these issues and how they might relate to particular measurements.

It is however entirely reasonable that users should expect PIPEMON to offer product accuracies, and ESA projects such as TERRAFIRMA are in the process of developing a specific validation campaign to provide a more robust framework by which the above information can be quoted and quantified. Until TERRAFIRMA undertakes its own product validation campaign and determines a method by which accuracy can be realistically specified, the following figures are provided that relate to a 'perfect' scenario, and should therefore be used as a guide only:

Motion Resolution

Displacement rate resolution: 0.1mm/year.

Spatial Accuracy and Precision

Absolute X, Y accuracy: 15m - dependent on reference layer.
Relative X, Y accuracy: +/-5m East-West, +/- 2m North/South.

Displacement Rate Precision

The precision of the relative average annual displacement rate between two neighbouring points is of the order of +/- 0.1mm/year.

Absolute Displacement Accuracy

Absolute displacement accuracy is dependant on the specific dataset parameters: number of images, time interval covered, baselines of data used, DEM accuracy and the nature of the site. The error due to the uncompensated atmospheric component increases with distance from the reference point. The standard deviation of the average annual displacement rate for each PS point is listed in the PS data table. Absolute displacement accuracies can be derived by subtracting measurements gained from trusted methods (such as digital levelling or total station) from those made by the InSAR technology.

Tolerances

Minimum number of images required: 30 in urban areas.
Minimum point density: 5 PS/km^2.

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