# TimeSAPS

## A free and open-source code for Time Series Analysis of Persistent Scatterers

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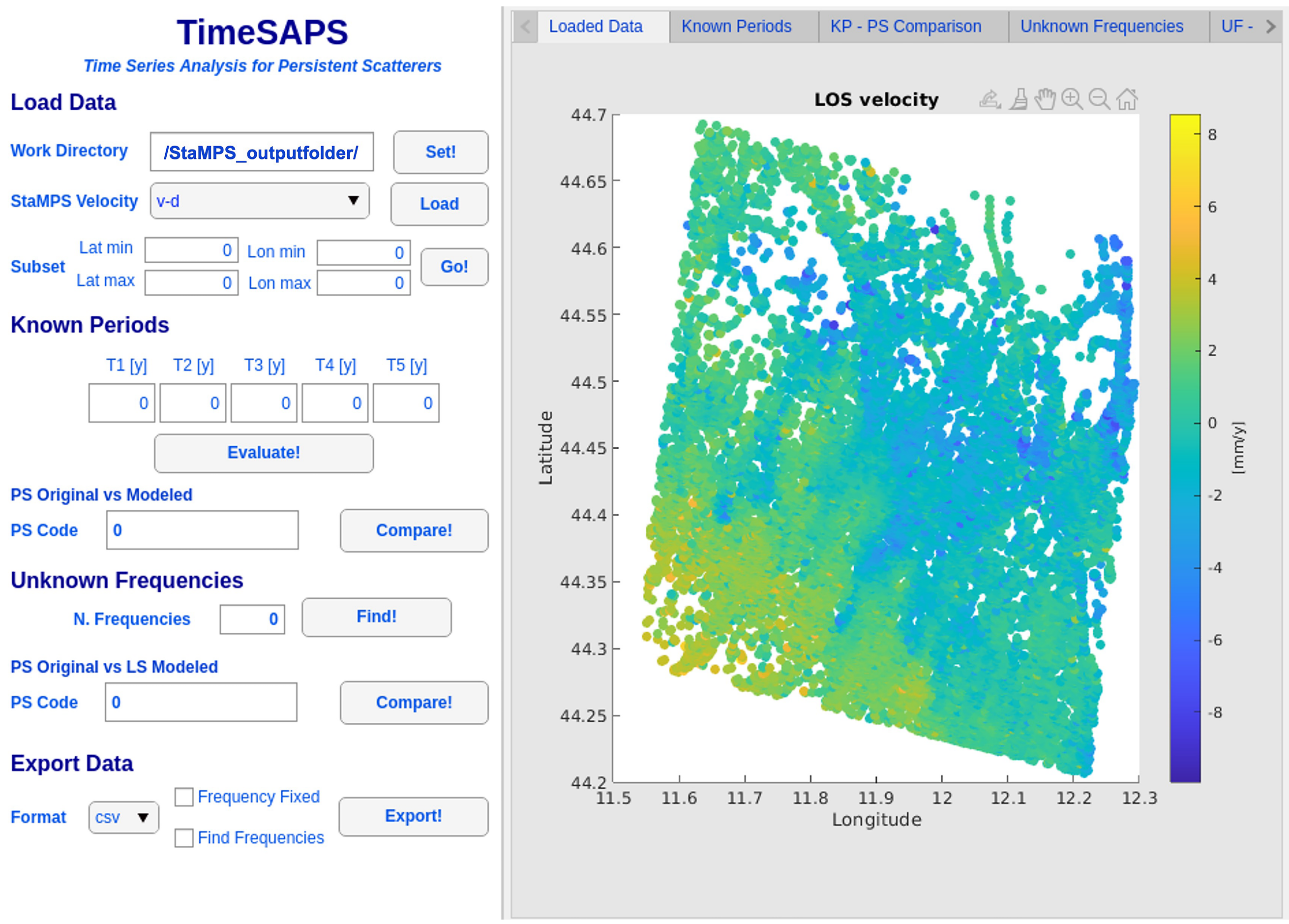

# Reference

POSTER - TimeSAPS

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If you use this tool please cite:

# TimeSAPS

The Interferometric Synthetic Aperture Radar (InSAR) technique allows the precise monitoring of ground displacements over wide areas based on radar data. Several satellites carrying synthetic radar antennas are orbiting around the Earth at the time. In particular, the Sentinel ESA mission provides open data from two SAR satellites operating at the global scale with a return time of six days. This allows the scientific community to dispose of consistent and daily updated dataset for a wide range of applications.

In this context, out of commercial missions, it is fundamental for the community to dispose of open-source and free software packages for SAR data processing. One of them is the widely used Stanford Method for Persistent Scatterers (StaMPS) for InSAR processing, which provides time series of range variations over a cluster of points starting from both amplitude and phase raw observations. These points are the so-called Persistent Scatterers (PS), namely pixels in a series of interferograms characterized by amplitude stability and signals not obscured by the phase noise. For each PS, StaMPS basically provides the mean velocities of displacement in the range direction over the inspected observing period. Besides, the software gives ancillary parameters such as the Phase Coherence, the RMS of the estimated velocities, the topography, the wrapped and unwrapped phase. StaMPS outputs are also the time series of unwrapped phase observations, expressed in terms of displacements, and the time series of corrections related to satellite ephemerids, atmosphere, orbits, master and slaves. To perform a smart and detailed analysis of these InSAR output time series, the TimeSAPS software package has been developed.

TimeSAPS works starting from StaMPS outputs and for each PS it allows to perform analysis characterizing the time series in terms of linear trends, periodical signals and the related phase and amplitude, frequency power spectrum and residuals with respect to both linear and periodical models. In detail, linear trends and periodical signals are estimated at once using the Gauss-Markov model with a least squares approach. As for the characteristic frequencies of the periodical signals, these can be defined by the users or estimated through a Lomb-Scargle periodogram. In both cases, the composition of up to five sine-wave signals can be computed to represent deformation models characterized by highly irregular shapes. In other words, TimeSAPS provides users with a tool capable of analyzing the StaMPS outputs behind the linear characterization of the PS displacements.

Further strengths of the software packages are its implementation in the Matlab environment, the same used for StaMPS and its capability of producing output in the shapefile format, directly importable in whatever GIS environment. Furthermore, the analysis can be basically applied to any kind of InSAR output, independently by the used SAR processing software, just by converting them into the StaMPS file format.

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# 1. Installation

## 1.1. Configuration

MATLAB -> Signal Processing Toolbox is required.

## 1.2. Pre-processing with StaMPS

StaMPS (Stanford Method for Persistent Scatterers) is a software package that implements an InSAR persistent scatterer (PS) method developed to work even in terrains devoid of man-made structures and/or undergoing non-steady deformation. StaMPS/MTI (Multi-Temporal InSAR) is an extended version of StaMPS that also includes a small baseline method and a combined multi-temporal InSAR method.[1],[2]

To proceed with the frequency analysis, it is necessary to generate the plots for the time series to be analysed and to save the relevant variables by running the following commands:

- Mean LOS velocity [mm/y] without any phase correction.

```
ps_plot('v',-1)
ps_plot('v','ts',-1)
```

- Mean LOS velocity [mm/y] minus stratisfied topo-correlated atmosphere using TRAIN dependency.*

```
ps_plot('v-a','',-1)
ps_plot('v-a','','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error.

```
ps_plot('v-d',-1)
ps_plot('v-d','ts',-1)
```

- Mean LOS velocity in mm/yr minus orbital ramps.

```
ps_plot('v-o',-1)
ps_plot('v-o','ts',-1)
```

- Mean LOS velocity in mm/yr minus atmosphere and orbit error phase due to slave.

```
ps_plot('v-s',-1)
ps_plot('v-s','ts',-1)
```

- Mean LOS velocity in mm/yr minus stratisfied topo-correlated atmosphere using TRAIN dependency and orbital ramps.*

```
ps_plot('v-ao','',-1)
ps_plot('v-ao','','ts',-1)
```

---

[1] https://homepages.see.leeds.ac.uk/~earahoo/stamps/StaMPS_Manual_v4.1b1.pdf

[2] Hooper, A., D. Bekaert, K. Spaans, and M. Arikan, Recent advances in sar interferometry time series analysis for measuring crustal deformation, *Tectonophysics*, *514 - 517*, 1 - 13, 2012.

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated atmosphere using TRAIN dependency. *

```
ps_plot('v-da','',-1)
ps_plot('v-da','','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and orbital ramps.

```
ps_plot('v-do',-1)
ps_plot('v-do','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and atmosphere and orbit error phase due to slave.

```
ps_plot('v-ds',-1)
ps_plot('v-ds','ts',-1)
```

- Mean LOS velocity in mm/yr minus orbital ramps and atmosphere and orbit error phase due to slave.

```
ps_plot('v-so',-1)
ps_plot('v-so','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated and iono-correlated atmosphere using TRAIN dependency.*

```
ps_plot('v-dai','',-1)
ps_plot('v-dai','','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated and iono-correlated atmosphere using TRAIN dependency and tide error.*

```
ps_plot('v-dait','',-1)
ps_plot('v-dait','','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated atmosphere using TRAIN dependency and orbital ramps.*

```
ps_plot('v-dao','',-1)
ps_plot('v-dao','','ts',-1)
```

- Mean LOS velocity in mm/yr minus spatially correlated DEM error and orbital ramps and atmosphere and orbit error phase due to slave.

```
ps_plot('v-dso',-1)
ps_plot('v-dso','ts',-1)
```

NOTE: 'a' require an additional string to indicate which APS correction to be applied. Fore more information check the StaMPS Manual.

## 1.3.Pre-processing with other software

This script is fully compatible with the output of StaMPS, but it is also possible to perform frequency analysis of PS time series on products not generated by StaMPS.

It is necessary to create Matlab variables with the following structure.

1. Variable .mat with the PS's velocity information.

Name: `ps_plot_v.mat`

Variables: `ph_disp ref_ps`

`ph_disp`

Dimension: `[nPS x 1]`

Content: `Velocity of each PS`

`ref_ps`

Dimension: `[nPS x 1]`

Content: `Unique code for each ps`

2. Variable .mat with the PS's time series information.

Name: `ps_plot_ts_v.mat`

Variables: `ph_mm day lonlat`

`ph_mm`

Dimension: `[nPS x nEpoch]`

Content: `Displacement of each PS for each epoch`

`day`

Dimension: `[nEpoch x 1]`

Content: `Epochs of the SAR acquisitions in the format: datetime or duration value. Example:`

| Day | Date |
|---|---|
| **736052** | 2015 03 29 |
| **...** | ... |
| **738800** | 2022 10 06 |

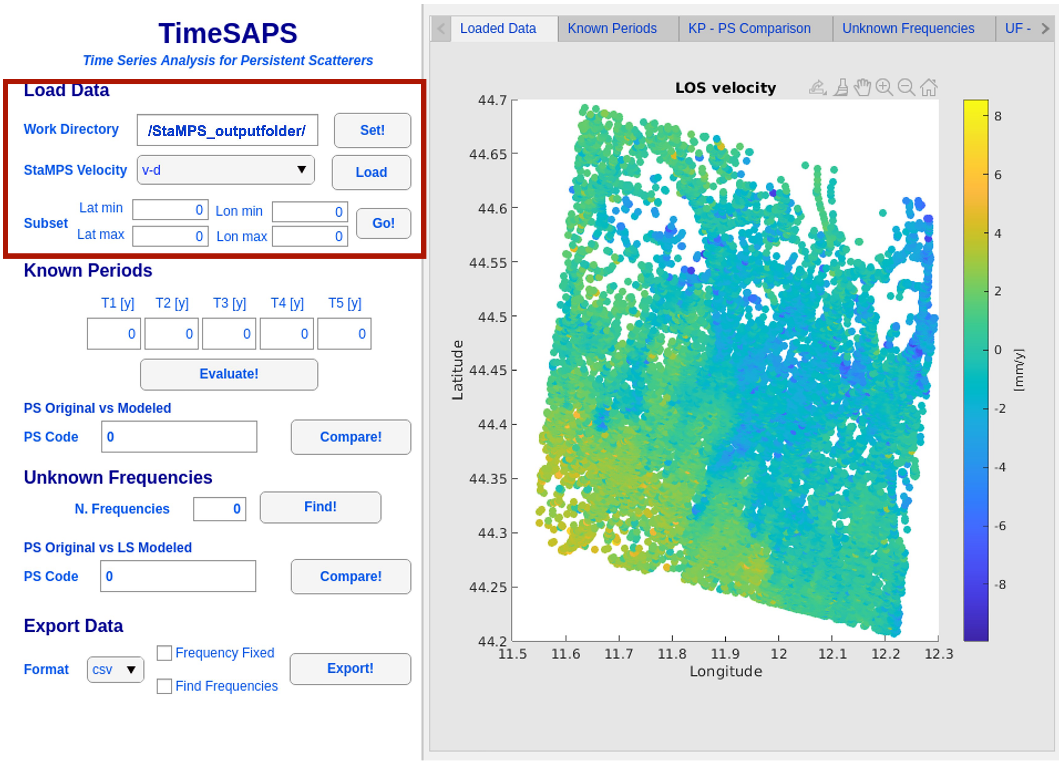
`lonlat`

Dimension: `[nPS x 2]`

Content: `Longitude (Column 1) and Latitude (column 2) of each PS`

# 2. PS Time Series Analysis

## 2.1.Load data




### 2.1.1.Work Directory

Insert the path of the StaMPS's output folder, typically named "INSAR_master_date". Press the button "**Set!**"

### 2.1.2.StaMPS velocity

Select which type of StaMPS's products we want to analyse, depending on the type of corrections applied to the PS's velocities and time series.

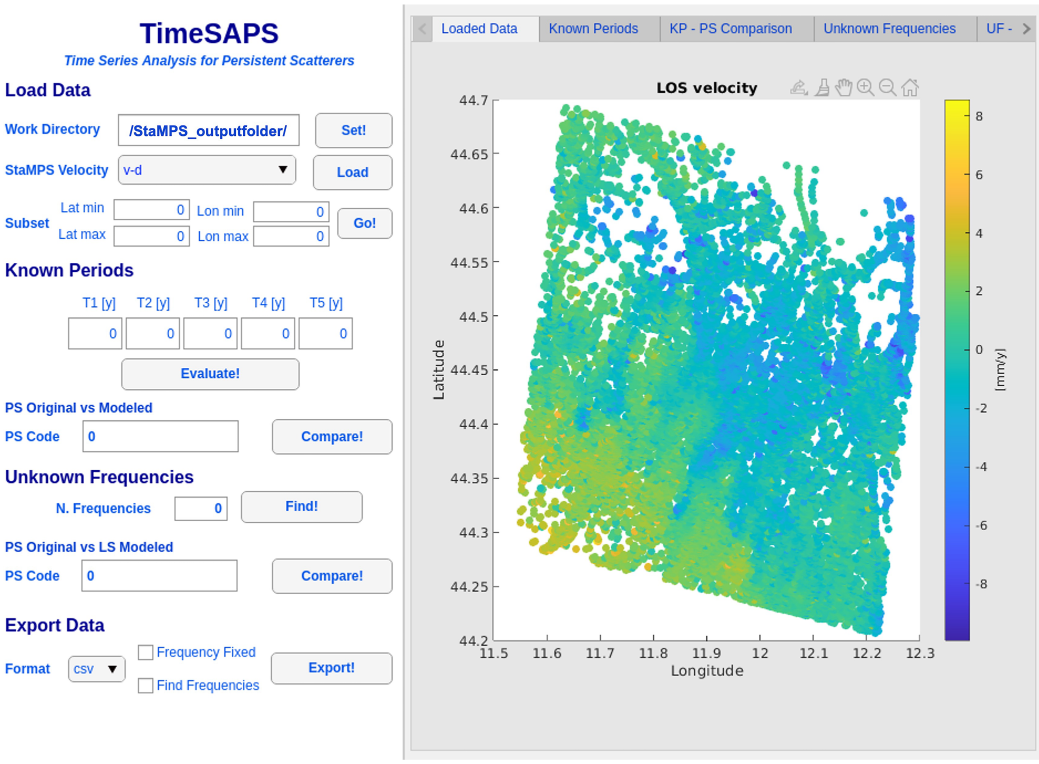
| Velocity | Corrections |
|---|---|
| v | Mean LOS velocity in mm/yr |
| v-a | Mean LOS velocity in mm/yr minus stratisfied topo-correlated atmosphere using TRAIN dependency |
| v-d | Mean LOS velocity in mm/yr minus spatially correlated DEM error |
| v-o | Mean LOS velocity in mm/yr minus orbital ramps |
| v-s | Mean LOS velocity in mm/yr minus atmosphere and orbit error phase due to slave |
| v-ao | Mean LOS velocity in mm/yr minus stratisfied topo-correlated atmosphere using TRAIN dependency and orbital ramps |

| Velocity | Corrections |
|---|---|
| **v-da** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated atmosphere using TRAIN dependency |
| **v-do** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and orbital ramps |
| **v-ds** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and atmosphere and orbit error phase due to slave |
| **v-so** | Mean LOS velocity in mm/yr minus orbital ramps and atmosphere and orbit error phase due to slave |
| **v-dai** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated and iono-correlated atmosphere using TRAIN dependency |
| **v-dait** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated and iono-correlated atmosphere using TRAIN dependency and tide error |
| **v-dao** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and stratisfied topo-correlated atmosphere using TRAIN dependency and orbital ramps |
| **v-dso** | Mean LOS velocity in mm/yr minus spatially correlated DEM error and orbital ramps and atmosphere and orbit error phase due to slave |

If you have create the Matlab variables, as describe in the Section

Press the button “**Load**”

On the *Loaded Data* tab the LOS velocity plot is upload.



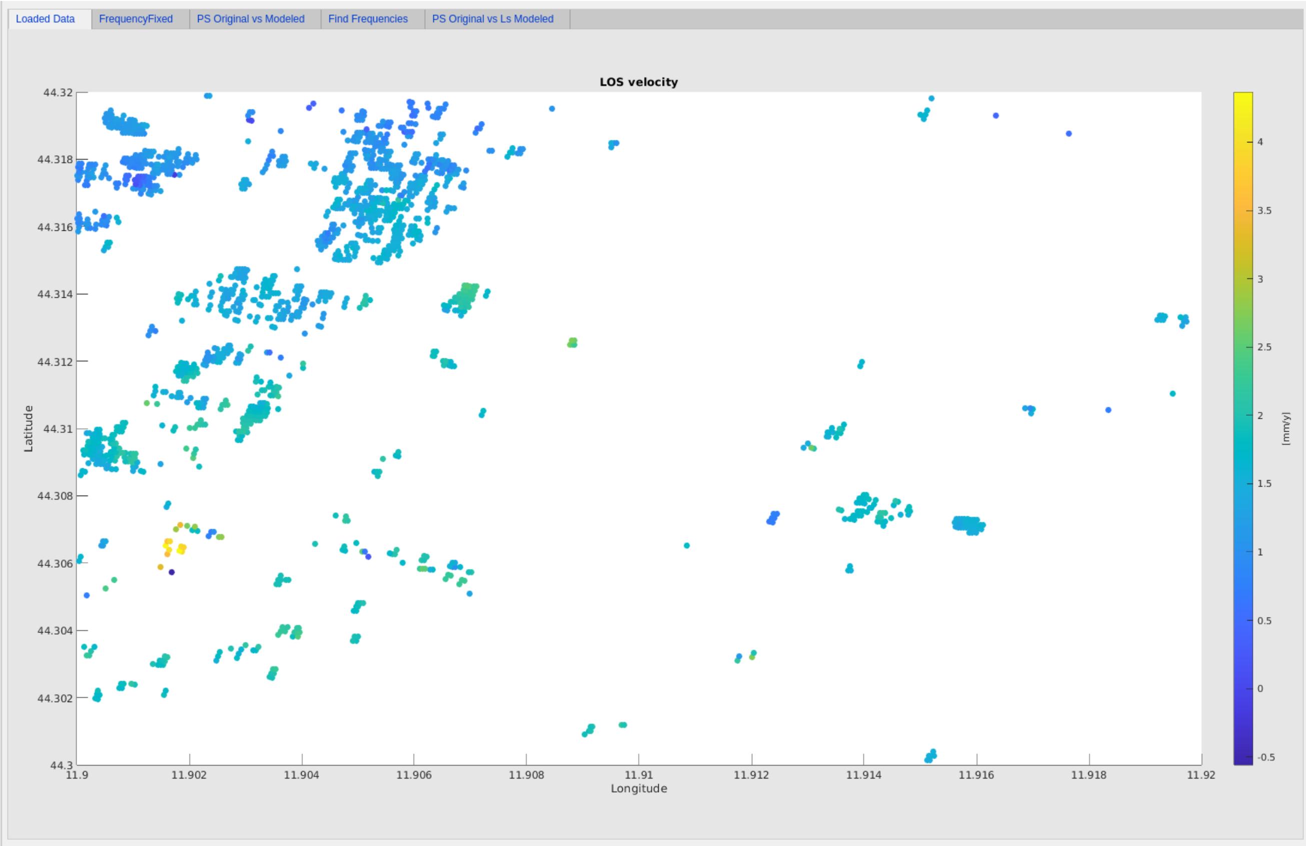
### 2.1.3.Subset

Fill the **Lat min - Lon min - Lat max - Lon max** data to define a subset area.

Press the button “**Go**”.

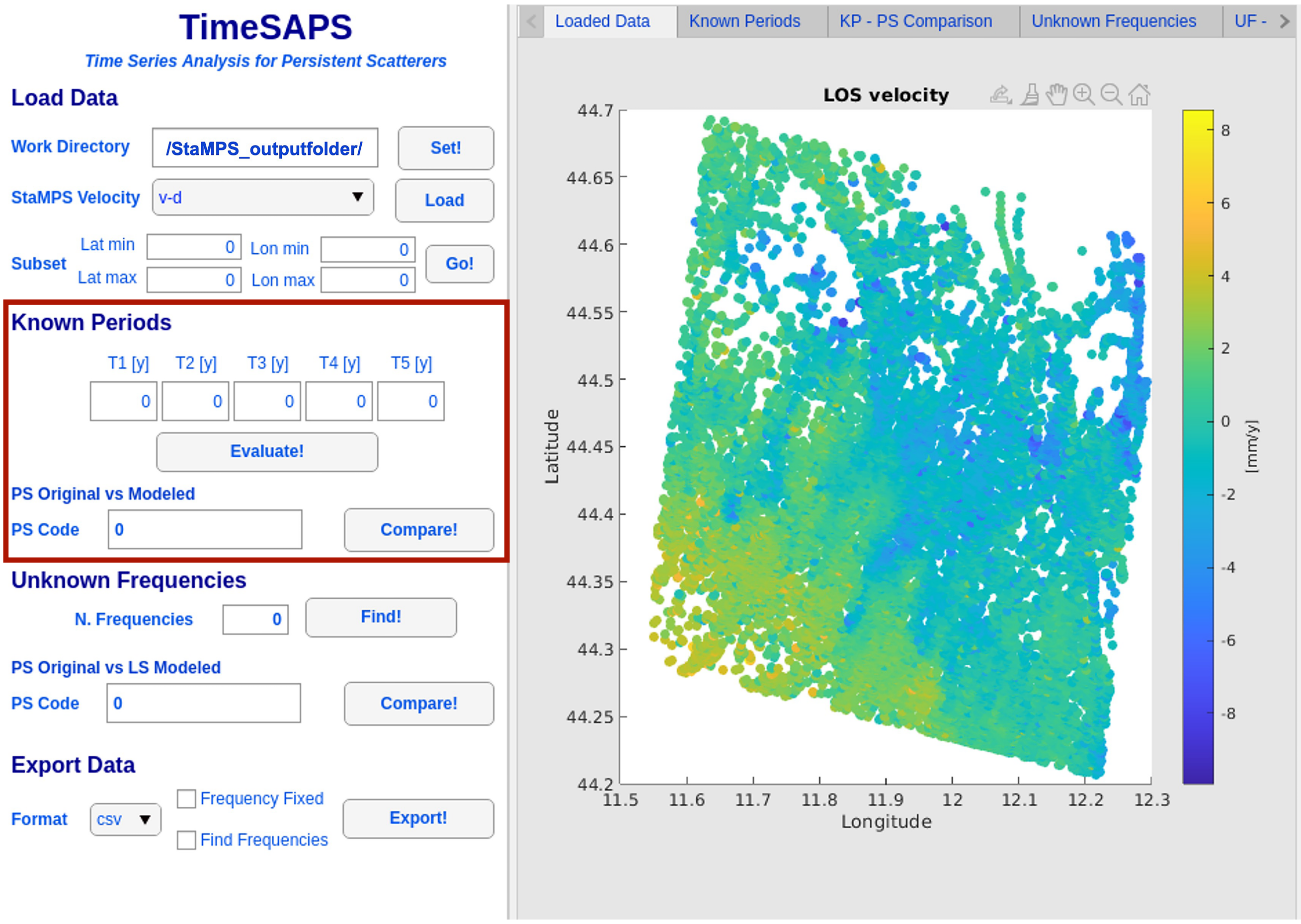
A waitbar will appear to show you  the progress of the process.

On the *Loaded Data* tab the LOS velocity plot is updated with the selected subset area.




Subset

## 2.2.Frequency (Period) Fixed




### 2.2.1.Known Periods

In the boxes provided, enter from 1 to 5 periods corresponding to the signals to be indentified in the PS time series.

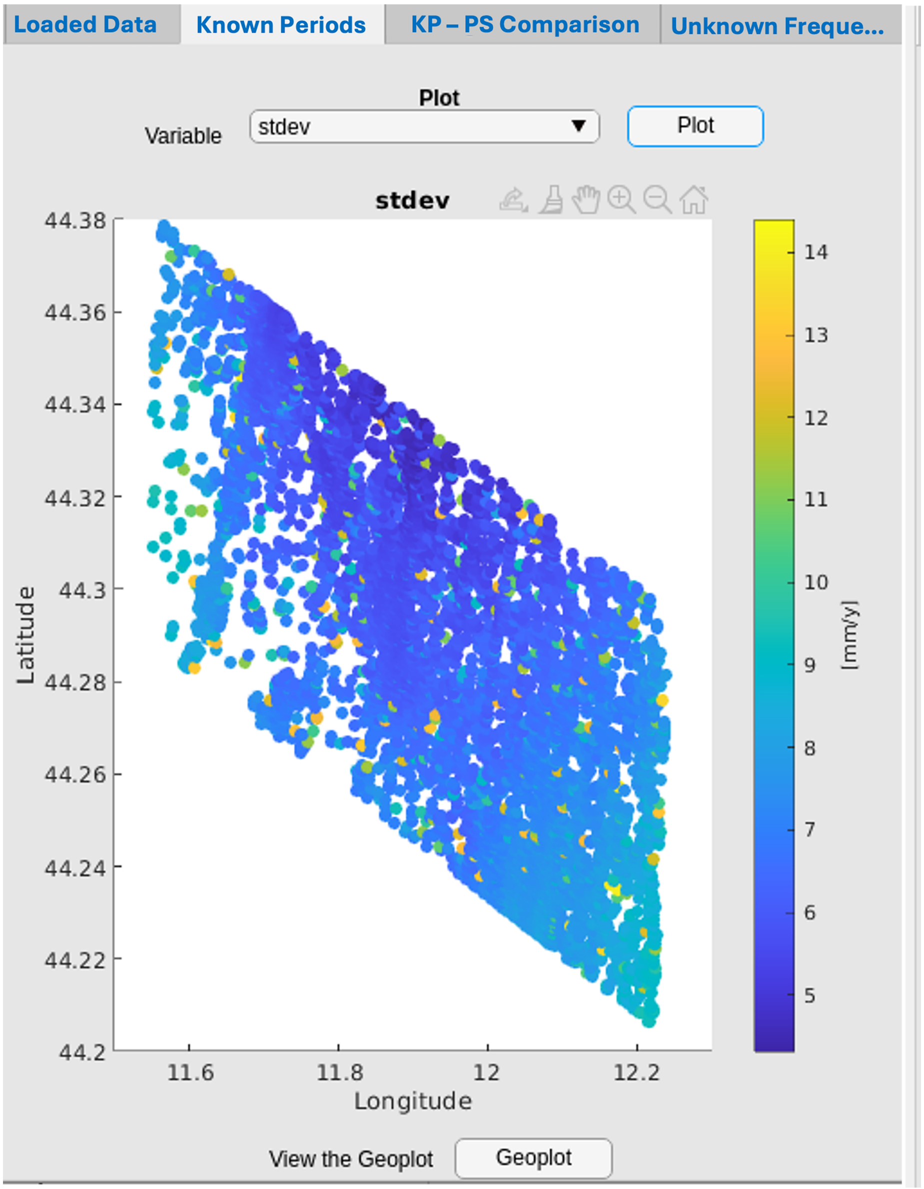
If no periods are entered, the parameters **m** (slope) and **q** (intercept) of the regression line of the PS series are estimated.

If at least one period is entered, the following parameters are estimated:

- **m** slope
- **q** intercept
- **A1, A2** amplitudes
- **stdev** Standard deviation of the residues between the original time serie and the modelled one with the sinusoid signals estimated.

Press the button “**Evaluate!**”

A waitbar will appear to show you  the progress of the process.



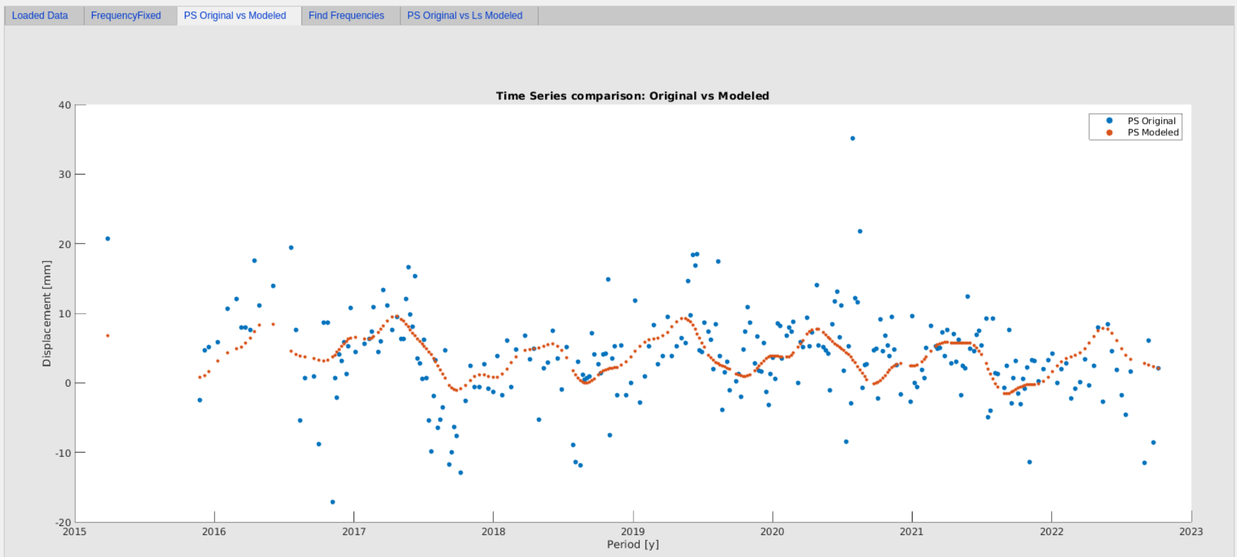

Known Periods: stdefv plot

On the *KnownPeriods* tab the LOS velocity plot is loaded. The user can choose with variable display, between **m**, **q**, **stdev**, and **A1**, **A2** for each period selected.

### 2.2.2.PS Original vs Modeled

Enter the code of a PS of interest in the "**PS Code**" box and press "**Compare!**".
In the *PS Original vs Modeled* tab will be shown:

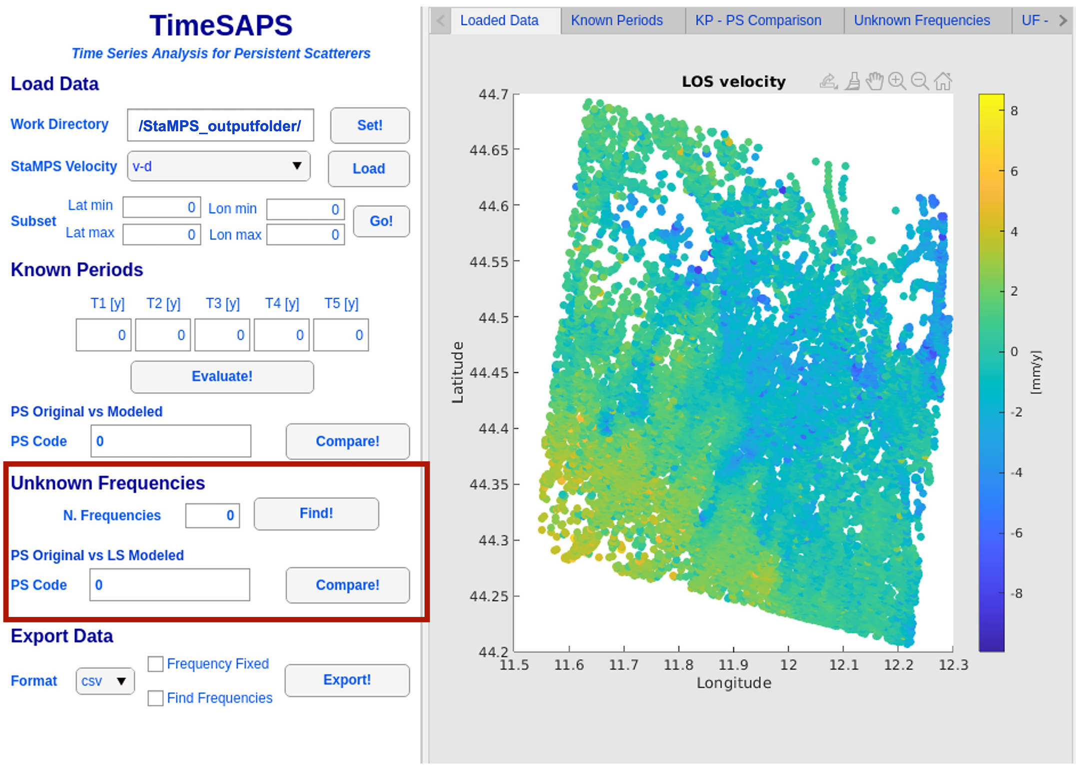
- Plot with the time series of the original PS and the modelled ones
- Table with all the estimated data related to the indicated PS




| PS_ref | lon | lat | m | q | stdev | f1-A1 | f1-A2 | f2-A1 | f2-A2 | f3-A1 | f3-A2 | f4-A1 | f4-A2 | f5-A1 | f5-A2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80327 | 11.9811 | 44.3123 | -0.1662 | 4.5249 | 5.7615 | 3.0161 | -0.8354 | -0.0250 | -1.0879 | 1.3472 | -0.1802 | -0.8025 | 0.2280 | 0.6486 | -0.0747 |

Known Periods: Originale PS Time Series vs Modeled

# 2.3.Unknown Frequencies




## 2.3.1.Unknown Frequencies

Select how many signals to search for within the time series of the PS.

Press the button "**Find!**"

A waitbar will appear to show you the progress of the process.

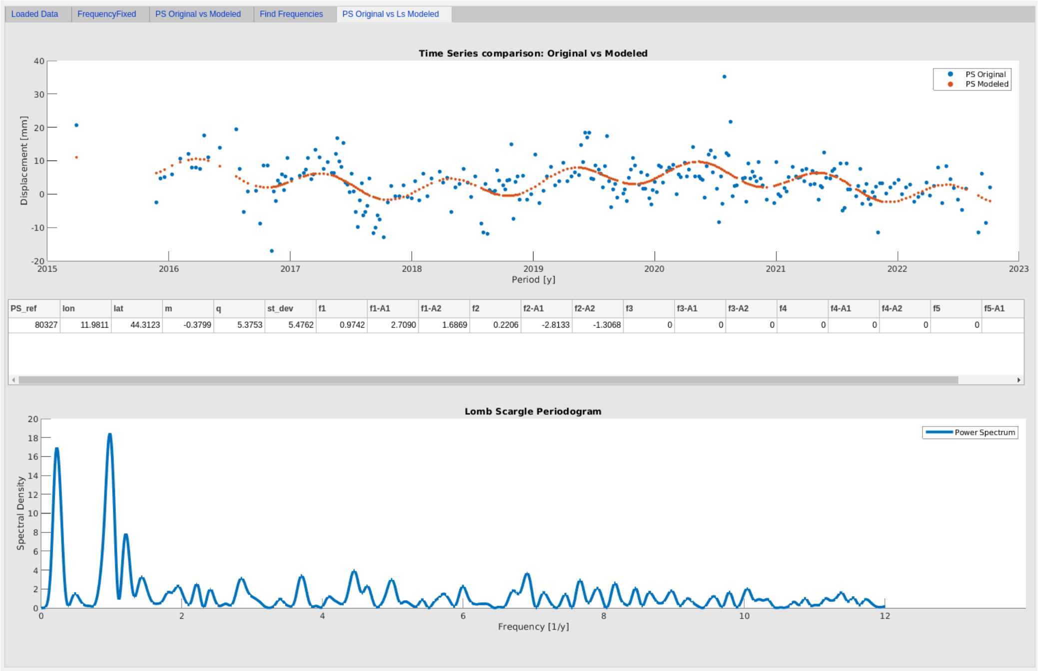
On the *FindFrequencies* tab the LOS velocity plot is loaded. The user can choose with variable display, between **m**, **q**, **stdev**, and **f**, **A1**, **A2** for each searched signals.

## 2.3.2.PS Original vs LS Modeled

Enter the code of a PS of interest in the "**PS Code**" box and press "**Compare!**".

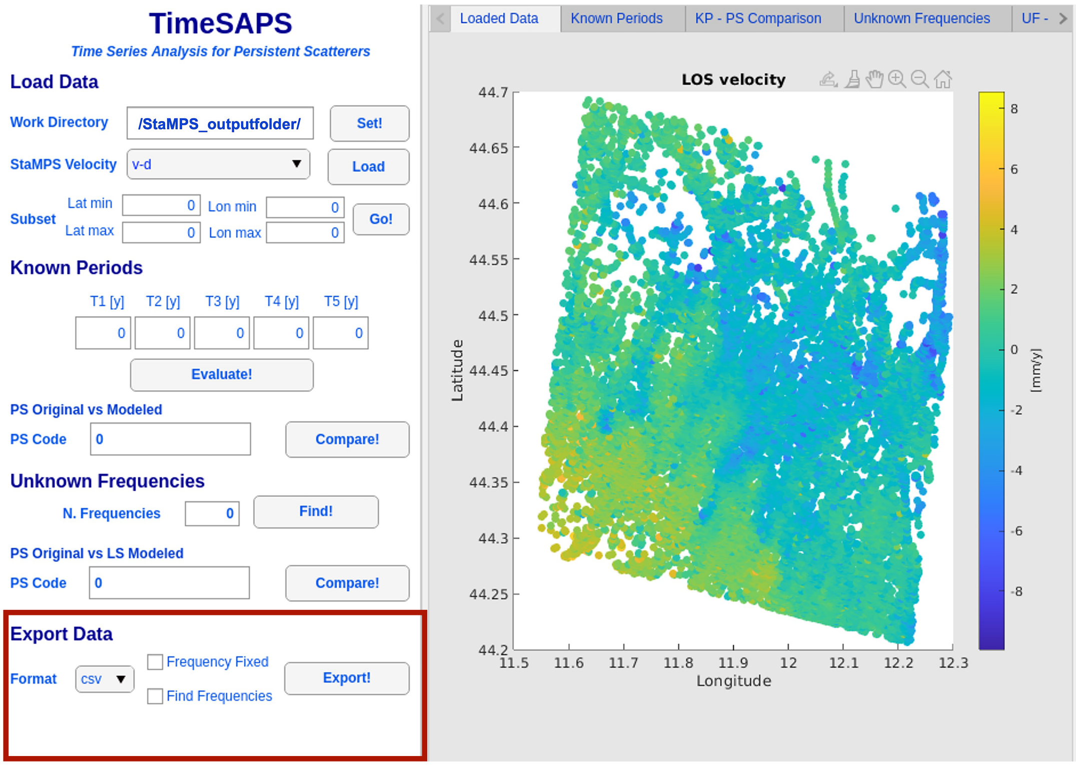
In the *PS Original vs Modeled* tab will be shown:

- Plot with the time series of the original PS and the modelled ones
- Table with all the estimated data related to the indicated PS
- Power spectrum fo the frequencies found




Unknown Frequencies: Original PS Time Series vs Modeled

## 2.4.Export Data




In the Format panel, select which kind of data format you want to export between *.csv* and *.shp*. In the **checkbox** click on the signals that you want to export:

- Known Periods
- Unknown Frequencies

Press "**Export!**".

In the project folder you will find the following files:

- [csv] Known Periods: Signals

***TimeSAPS_KnownP_Signals.csv***

| Ref_ps | Lon | Lat | m | q | st_dev | $A1(f_1)$ | $A2(f_1)$ | ... | $A1(f_n)$ | $A2(f_n)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

- [csv] Known Periods: Models

***TimeSAPS_knownP_Model.csv***

Table [nPS x Epoch] with all the displacements.

- [csv] Unknown Frequencies: Signals

***TimeSAPS_UnknownFreq_Signals.csv***

| Ref_ps | Lon | Lat | m | q | st_dev | $f_1$ | $A1(f_1)$ | $A2(f_1)$ | ... | $f_n$ | $A1(f_n)$ | $A2(f_n)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |

- [csv] Unknown Frequencies: Models

***TimeSAPS_UnknownFreq_Model.csv***

Table [nPS x Epoch] with all the displacements.

For the *.shp* file, the same structure of the csv files above is used to fill the attribute tables of the Shapefiles. For each of the Known Periods and the Unknown Frequencies mode, two shapefiles will be created: one with the velocity and the signals information and one with the displacement informations.