

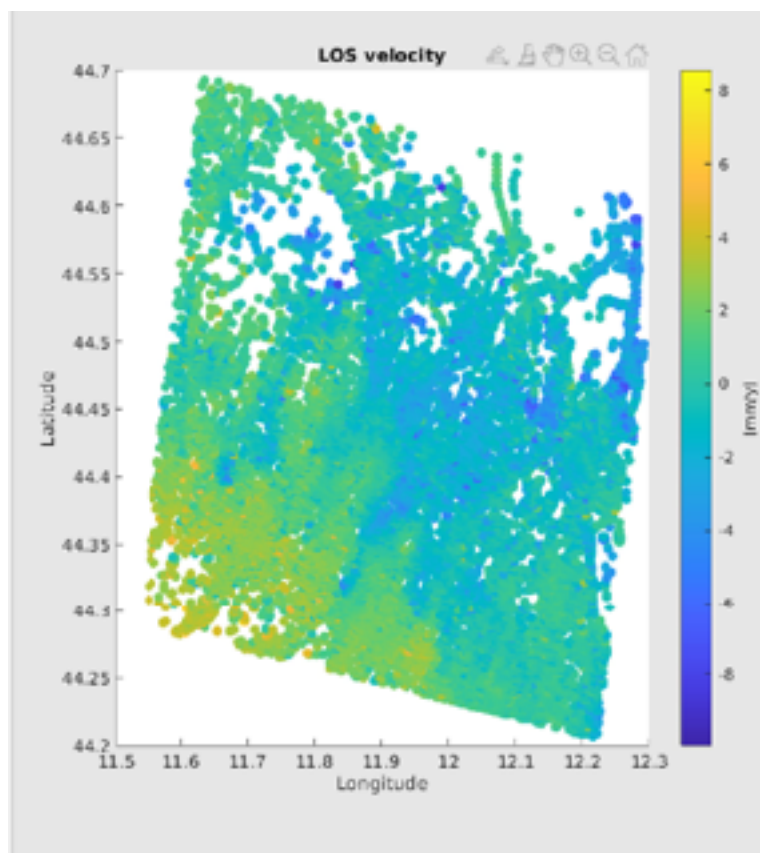
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# TimeSAPS

## 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:

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## 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.<sup>1,2</sup>

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 stratified 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 stratified topo-correlated atmosphere using TRAIN dependency and orbital ramps.\*

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

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<sup>1</sup> [https://homepages.see.leeds.ac.uk/~earahoo/stamps/StaMPS\\_Manual\\_v4.1b1.pdf](https://homepages.see.leeds.ac.uk/~earahoo/stamps/StaMPS_Manual_v4.1b1.pdf)

<sup>2</sup> Hooper, A., D. Bekaert, K. Spaans, and M. Arikian, 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 stratified 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 stratified 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 stratified 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 stratified 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. Known Periods ('kp') Analysis

To launch the 'kp' analysis, run the following command:

```
tsaps('kp', [p1, p2, ..., pn])
```

Where [p1, p2, ..., pn]: Vector of the known periods.

NOTE: If p1=0 only the regression line will be estimated and so the PS model is a linear model.

The estimated variables are:

- **m** slope
- **q** intercept
- **stdev** Standard deviation of the residues between the original time serie and the modelled one with the sinusoid signals estimated.
- **SNR** Signal to Noise Ration between the original time series and the difference between the original time series and the model.

If one or more period ( $\neq 0$ ) are insered, for each insered period:

- **U** amplitude
- **phi** phase

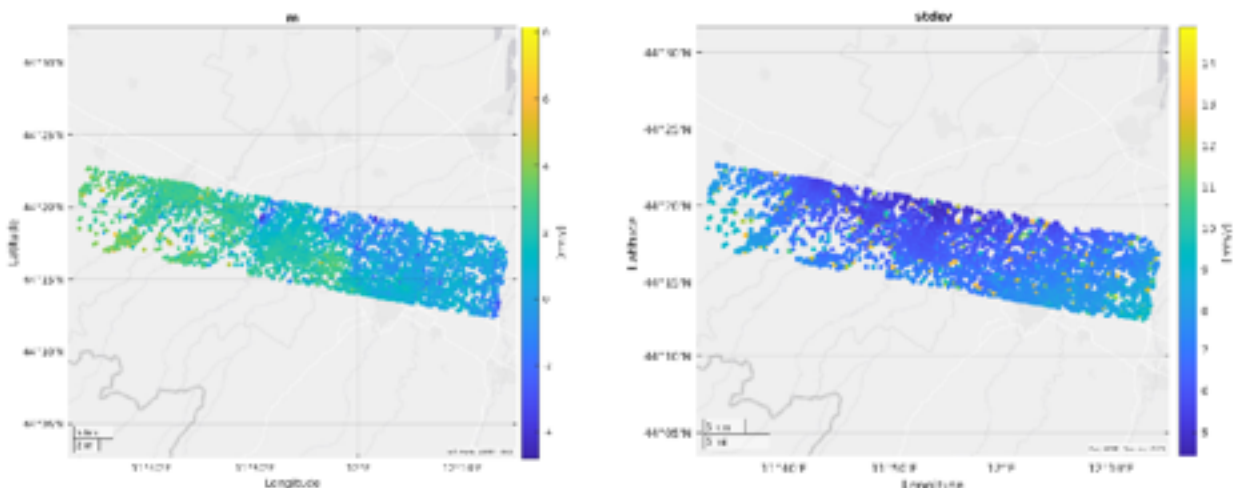
#### 2.1.1. Plotting the results

To plot the results of the 'kp' analysis, run the following command:

```
tsaps_plot('kp', 'var', n)
```

Where var: Variable to display (m, q, std, SNR, f, A, phi)

N: relative number of periods (only for the f, A, and phi variable)

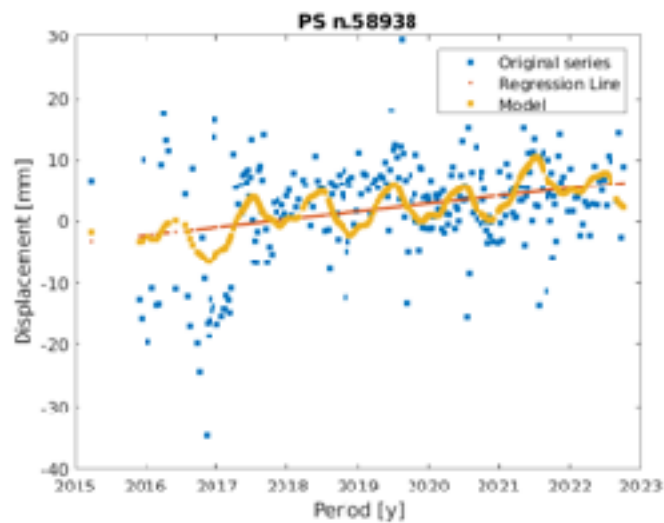




### 2.1.1. Plot the PS' time series

```
tsaps_plot_ps('kp',code)
```

Where code: Number of the PS that we want to display



## 2.2.Unknown Frequencies

To launch the 'uf' analysis, run the following command:

```
tsaps('uf',n)
```

Where n: Number of sinusoids to be used for evaluating the model.

The estimated variables are:

- **m** slope
- **q** intercept
- **stdev** Standard deviation of the residues between the original time serie and the modelled one with the sinusoid signals estimated.
- **SNR** Signal to Noise Ration between the original time series and the difference between the original time series and the model.

If one or more period ( $\neq 0$ ) are insered, for each insered period:

- **U** Amplitude
- **f** Frequence
- **phi** phase

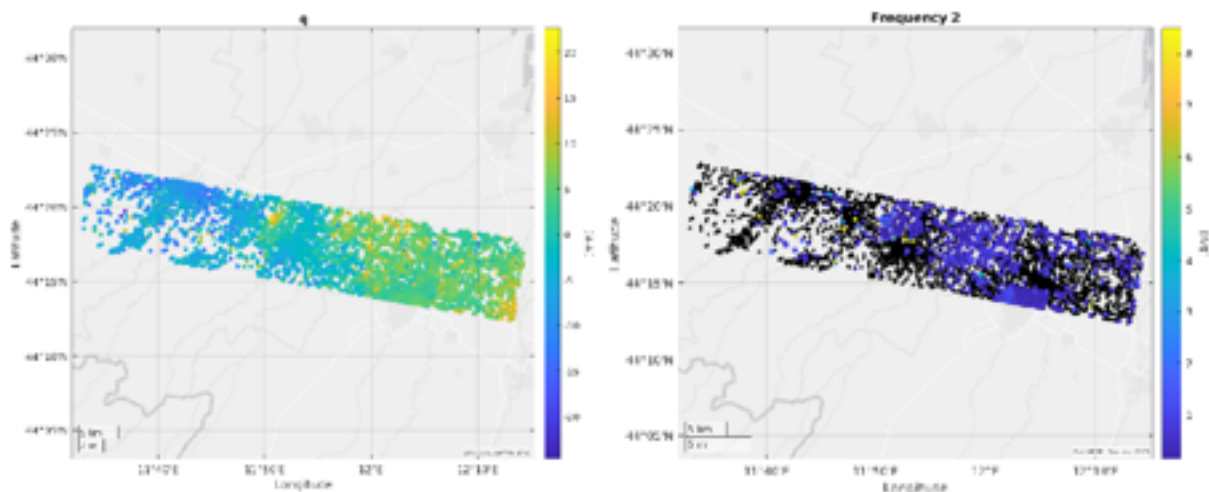
### 2.1.1. Plotting the results

To plot the results of the 'kp' analysis, run the following command:

```
tsaps_plot('kp','var',n)
```

Where var: Variable to display (m, q, std, SNR, f, A, phi)

N: relative number of periods (only for the f, A, and phi variable)



### 2.1.1. Plot the PS' time series and the Lomb-Scargle Periodogram

```
tsaps_plot_ps('kp',code)
```

Where code: Number of the PS that we want to display.

