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A MATLAB/GNU Octave toolbox for computation of velocity and strain rate field from GNSS coordinate time series
by Giordano Teza et al.

Supplementary material:

User’s guides:

- StaVel
- GridStrain

StaVel

A MATLAB/GNU Octave toolbox for the computation of the velocity of a network of GNSS stations starting from a database of coordinate time series

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User's guide

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1. Introduction

1.1 The `StaVel` toolbox

`StaVel` is a MATLAB^{TM} toolbox, described in Teza et al. (2022), which is conceived for an easy and quick calculation of the velocities of some GNSS stations starting from the corresponding coordinate time series. It is the first component of a toolbox aimed at computing the strain rate field starting from the coordinate time series of some GNSS station. The second component, whose input data are the velocities obtained by means of `StaVel`, is `GridStrain` (for more information about the second component, please see the `GridStrain` user's guide. `GridStrain` is an improved version of grid_strain, described in Teza et al., 2008). The complete workflow (`StaVel` and `GridStrain`) is shown in Fig. 1.1. A first application of these toolboxes, which at that time were not yet complete, is shown in Meschis et al. (2022). `StaVel` is described in detail in this user's guide. For more information about `GridStrain`, please refer to the corresponding user's guide.

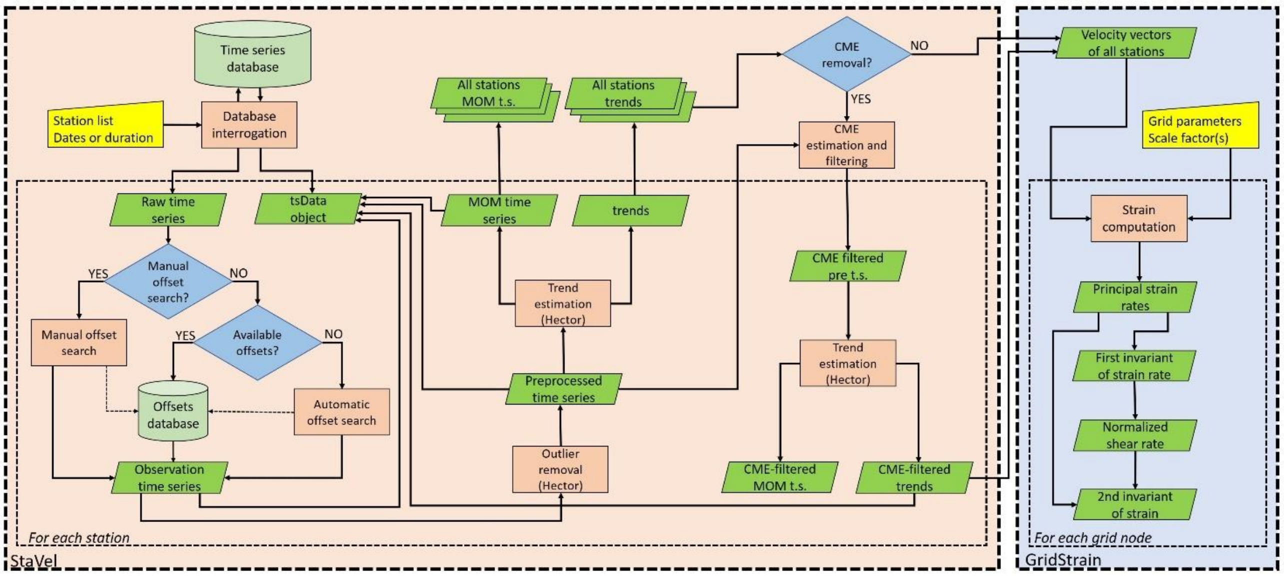


Figure 1.1. workflow of the whole process. `StaVel` is developed in order to carry out the steps inside the left, dashed rectangle (computations for each station). The computations carried out for each grid node, shown in the right, dotted rectangle, are carried out by means of `GridStrain`. The database interrogation is also carried out by means of `StaVel`.

These steps are carried out by means of `StaVel`:

- download of the time series of the selected GNSS stations from a data repository or, alternatively, access to a database of time series. Availability of time series provided by RINEX data processing is a precondition for the procedure described here;
- for each coordinate time series of each station:
  - offset recognition or offset importation from a database;
  - outlier recognition and modeling;
  - velocity computation based on Maximum Likelihood Estimation (MLE), carried out by means of the external software package Hector (Bos et al., 2013), automatically called by a MATLAB function (for other details about download and installation of Hector, please see Chapter 2);
  - (optional, if the estimation and removal of the common mode error, CME, is required):
    - × time series detrending, CME estimation and its removal from time series;
    - × MLE-based velocity computation with the CME-filtered time series.

The input and output data are described in the next chapters. An ASCII file which can directly managed by means of `GridStrain` can be generated by `StaVel` as the velocities are computed. These steps are carried out by means of `GridStrain` (please see the corresponding user's guide):

- strain rate field computation with the MLS method for one or more scale factors, including the computation of first and second invariant of the strain and of normalized shear;
- strain rate field visualization and interpretation.

The toolbox surely runs with all possible functionalities under MATLAB^{TM} 2018a or later releases. Some actions aimed at allowing use with much older versions of MATLAB were however implemented. For example, whether a figure is an object or not is automatically verified.

The toolbox can also run under GNU Octave. In this case, some functions must be used by means of command line because the user interface controls could be incompatible with such a free package. These cases are highlighted both in this User'a Guide and in the corresponding function helps. An example of such a function is the main `StaVel` function, i.e. `StaVelMain`, described in Chapter 4. The corresponding help can be shown by typing

```
help StaVelMain
```

on the MATLAB Command Window (MCW), or the equivalent in Octave.

For any question, or also suggestion, please contact the authors (the Email addresses are shown in the cover of this user's guide).

1.2 Tips for a quick approach to `StaVel`

Given that this guide requires reading the article Teza et al. (2022), the quick approach is reading the very short Chapter 2, reading Subsection 3.1 about the input files and taking a quick look at Section 3.2, then moving onto Chapter 5 (Tutorial), reserving the rest of Chapter 3 and Chapter 4 for further information and, above all, to understand how to set the inputs of the various functions used. Moreover, it is necessary to read the facts highlighted at the conclusion of Subsection 4.2 about the main function of `StaVel`, i.e. `StaVelMain`. If the user is interested in common mode error (CME) filtering, he should refer to Subsection 4.5.

Some files are also provided for tutorial purposes. The user is invited to elaborate the data also taking into account what is highlighted in Subsection 4.2.

1.3 Disclaimer

This toolbox is free. The authors require that the use of this software be intended for scientific use only (no commercial use). If a publication whose results were obtained by means of this software is accepted for the publication, the toolbox `StaVel` and their authors must be cited.

Disclaimer: The authors of this toolbox accept no responsibility for damages resulting from the use of these products and makes no warranty or representation, either express or implied, including but not limited to, any implied warranty of merchantability or fitness for a particular purpose. This software is provided "AS IS", and the user assumes all risks when using it.

2. Toolbox installation and program running

The toolbox `StaVel` is contained in the zip file `StaVel.zip`. The files should be extracted and saved in a MATLAB directory whose name should be `StaVel`. For example, if the MATLAB work directory is:

```
C:\Users\john.doe\Documents\MATLAB\,
```

the toolbox can be saved and accessed with this path:

```
C:\Users\john.doe\Documents\MATLAB\StaVel.
```

Please note that, if MATLAB operates under an Unix environment, "/"must be used instead of "\".
If the directory `StaVel` is saved in the default directory on which MATLAB command window operates, the directory change must be carried out before the toolbox run. This change is obtained simply typing on the MCW:

```
cd StaVel
```

In order to call the program whichever is the current MCW directory, a startup file can be written by the user. For example, if the toolbox is placed in the directory '`C:\Users\john.doe\Documents\MATLAB\StaVel`', the rows

```
addpath 'C:\Users\john.doe\Documents\MATLAB\StaVel';
```

should be added to the `startup.m` script. If a file named `startup.m` is placed in the MATLAB work directory, it is automatically executed at each MATLAB start. In this way, all the defined search paths are automatically added at each MATLAB start and the directory changes to use the toolbox are unnecessary. The functionalities of these toolboxes do not depend on user's choice about the startup. More information about `addpath` function in a startup file can be found in http://www.mathworks.it/it/help/matlab/ref/ addpath.html.

Another option is the use of the Set Path dialog box, which appears by typing

```
pathtool
```

on the MCW or by selecting `Set Path` in `Home menu` of MATLAB desktop. The button `Add Folders` allows the choice of the folder and other buttons allow the choice of the folder order for the search of the files. Please see http://www.mathworks.it/it/help/matlab/matlab_env/using-the-matlab-search-path.html to have more information about the `Set Path` dialog box.

All provided functions are MATLAB `.m` files that can the opened and, if necessary, modified by the user. In this way, an expert user can modify, for example, the data saving options.

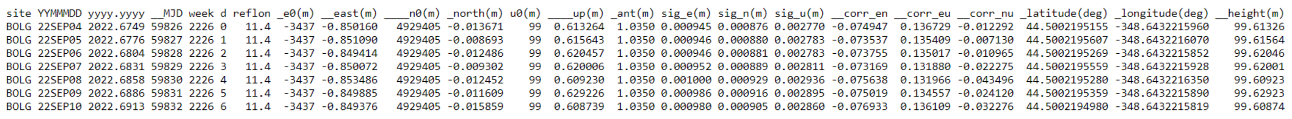
The toolbox calls an external free, open source software package, i.e. Hector (Bos et al., 2013). It is a high-performance, frequently upgraded package which runs under Linux. Hector must be separately downloaded and installed (current download page: http://segal.ubi.pt/hector/). Moreover, Hector runs under Linux regardless to the operating system (OS) used by MATLAB. If the OS is Windows, the automatic Hector call by MATLAB requires the Windows Subsystem for Linux 2 (WSL2). As Hector is installed, i.e. its executable files are placed in the chosen folder, this folder is managed by editing the corresponding row of `geneOpts` function (see Chapter 4).

Besides `StaVel` functions and scripts, some sample files are added for tutorial purposes in the file `StaVel.zip`.

3. Input and output data

3.1 Input data

Input data are coordinate time series, with time, East, North and Vertical, in this order, taken from Nevada Geodetic Laboratory (NGL) database (Blewitth et al., 2018) or from another similar database whose data are managed in the same way. The possible formats, correctly read by `StaVel`, are `tenv3`, `tenv` and `kenv`, which are described in http://geodesy.unr.edu/gps_timeseries/README_tenv3.txt for `tenv3` format, http://geodesy.unr.edu/gps_timeseries/README_tenv.txt for `tenv` format and, finally, http://geodesy.unr.edu/gps_timeseries/README_kenv.txt for the `kenv` format. All these files are ASCII files.



```
site YYMMMDD yyyy.yyyy __MJD week d reflon _e0(m) __east(m) ____n0(m) _north(m) u0(m) ____up(m) _ant(m) sig_e(m) sig_n(m) sig_u(m) __corr_en __corr_eu __corr_nu _latitude(deg) _longitude(deg) __height(m)
BOLG 22SEP04 2022.6749 59826 2226 0   11.4  -3437 -0.850160   4929405 -0.013671    99  0.613264  1.0350 0.000945 0.000876 0.002770 -0.074947  0.136729 -0.012292  44.5002195155 -348.6432215960    99.61326
BOLG 22SEP05 2022.6776 59827 2226 1   11.4  -3437 -0.851090   4929405 -0.008693    99  0.615643  1.0350 0.000946 0.000880 0.002783 -0.073537  0.135409 -0.007130  44.5002195607 -348.6432216070    99.61564
BOLG 22SEP06 2022.6804 59828 2226 2   11.4  -3437 -0.849414   4929405 -0.012486    99  0.620457  1.0350 0.000946 0.000881 0.002783 -0.073755  0.135017 -0.010965  44.5002195269 -348.6432215852    99.62046
BOLG 22SEP07 2022.6831 59829 2226 3   11.4  -3437 -0.850072   4929405 -0.009302    99  0.620006  1.0350 0.000952 0.000889 0.002811 -0.073169  0.131880 -0.022275  44.5002195559 -348.6432215928    99.62001
BOLG 22SEP08 2022.6858 59830 2226 4   11.4  -3437 -0.853486   4929405 -0.012452    99  0.609230  1.0350 0.001000 0.000929 0.002936 -0.075638  0.131966 -0.043496  44.5002195280 -348.6432216350    99.60923
BOLG 22SEP09 2022.6886 59831 2226 5   11.4  -3437 -0.849885   4929405 -0.011609    99  0.629226  1.0350 0.000986 0.000916 0.002895 -0.075019  0.134557 -0.024120  44.5002195359 -348.6432215890    99.62923
BOLG 22SEP10 2022.6913 59832 2226 6   11.4  -3437 -0.849376   4929405 -0.015859    99  0.608739  1.0350 0.000980 0.000905 0.002860 -0.076933  0.136109 -0.032276  44.5002194980 -348.6432215819    99.60874
```

Figure 3.1 Example of data from NGL database (`23-columns tenv3`)

An example of `tenv3` data is shown in Figure 3.1. In accordance with the instructions provided in the NVL site, a row should be read in this way (first row shown in Fig. 3.1):

Table 3.1 Meaning of the data of a tenv3 file

column	Sample value	Meaning
1	BOLG	station name (Bologna, Italy. Complete name: BOLG00ITA)
2	22SEP04	Date in the form YYMMMDD (4 September 2022)
3	2022.6749	decimal year in the form yyyy.yyyy
4	59826	modified Julian day (MJD)
5	2226	GPS week
6	0	day of GPS week
7	11.4	longitude (degrees) of reference meridian
8	-3437	eastings (m), integer portion (from ref. meridian)
9	-0.850160	eastings (m), fractional portion
10	4929405	northings (m), integer portion (from equator
11	-0.013671	northings (m), fractional portion
12	99	vertical (m), integer portion
13	0.613264	vertical (m), fractional portion
14	1.0350	antenna height (m) assumed from RINEX header
15	0.000945	east sigma (m)
16	0.000876	north sigma (m)
17	0.002770	vertical sigma (m)
18	-0.074947	east-north correlation coefficient
19	0.136729	east-vertical correlation coefficient
20	-0.012292	north-vertical correlation coefficient
21	44.5002195155	latitude(deg)
22	-348.6432215960	longitude(deg)
23	99.61326	height(m)

Please note that for some stations there are 20 columns instead of 23. The function for the data downloads automatically recognizes the kind of file and, in the case of a `tenv3`, the number of valid columns.

3.2 Automatic importation of GNSS time series from a database (`GetNevada` function)

Under the conditions that the input GNSS files are taken from the NGL database or from a database whose files are as in NGL, if a list of stations is defined, the corresponding `tenv3/tenv/kenv` files can be downloaded in an entirely automatic way. The function which carries out this is `GetNevada`, whose syntax is:

```
StatStatus = GetNevada(fileStations,PlateID,OutDir,AddName,Ext)
```

This function allows the time series download for the GNSS stations whose standard 4-length names (e.g. BOLG for the station BOLG00ITA, i.e. Bologna, Italy) are placed in the first column of the `.xlsx/.xls` file `fileStations`, from the second to the last row (the first row is the header) or on the only column of the ASCII file `fileStations`.
If `fileStations` is undefined or empty, it can be interactively chosen.

If `PlateID` is undefined, empty or is invalid (see below for the valid `PlateIDs`), an interactive box allows the choice of the kind of time series to be downloaded (`IGS14 ENV`, i.e. East-North-Vertical, `IGS14 XYZ`, plates `ENV`). In this case, a user interface control (Fig. 3.2) allows the choice of the plate for the velocity calculation; `IGS14 ENV` data can also be used for `StaVel` computations as well as for possible subsequent `GridStrain` computations. Moreover, for completeness `GetNevada` also allows the download of `IGS14 XYZ` data, i.e. time series in GNSS geocentric coordinates, but these data are unsuitable for `StaVel` computations.
The valid `PlateIDs` are (see also Fig.3.2):

```
'IGS14 - XYZ','IGS14 - ENV', 'AF','AN','AR','AU','BU','CA',
'CO','EU','IN','MA','NA','NB','NZ','OK','ON','PA','PM','PS',
'SA','SB','SC','SL','SO','SU','WL'.
```

The option valid `PlateID` is added in order to allow the use of this function under GNU Octave.

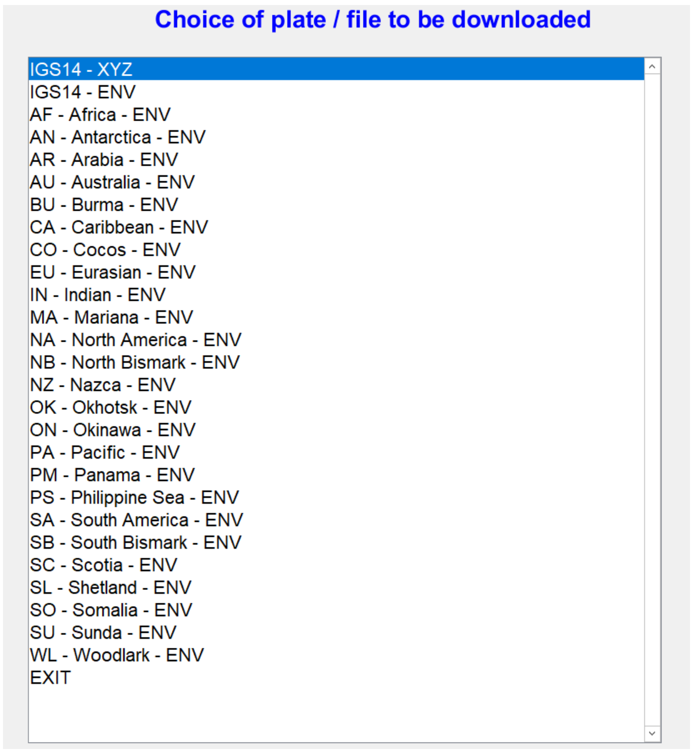


Figure 3.2 Choice of plate for `GetNevada` execution.

The successfully downloaded files have name

```
(OutDir)\(station name)(AddName)(Ext)    (Windows)
(OutDir)/(station name)(AddName)(Ext)    (Unix, MacOS)
```

were:

- If `OutDir` is undefined or empty, the downloaded files are placed in the current directory.
- If `AddName` is non-empty and its first character is not `'.'`, it is `AddName=['.' AddName]`.
  If `AddName` is empty, the possible name component is taken from the filename of Nevada database (for example, in the case of Eurasian plate the default `AddName` is `'.EU'`).
- If `Ext` is non-empty and `Ext(1)` is not `'.'`, it is `Ext=['.' Ext]`.
  If `Ext` is empty, the extension is taken from the filename of Nevada database (`.tenv3` for env files and `.txyz2` for XYZ files).

The output cell variable `StatStatus` is such that `StatStatus{k,1}` is the name of the k-th GNSS station and `StatStatus{k,2}` is true if the file download was successful and false elsewhere.

3.3 `tsData` object and input/output data

A MATLAB object of `tsData` class is defined for each continuous station managed by means of `StaVel`. Such an object is generated by using NGL data and is upgraded during the stages of velocity calculation (offset recognition, outlier removal, trend estimation). In particular, a `tsData` object is generated with the raw time series taken from a `tenv3`, `tenv` or `kenv` ASCII file; the function that recognizes the type of file and extracts these data from the file is a method of this object.

The script `tsData` is automatically called by `StaVelMain` function, which is described in Chapter 4. However, it can also be used by means of a command line. Possible syntaxes:

```
tsDataOut = tsData
tsDataOut = tsData(FILENA)
```

The output `tsData` object is generated with the data taken from a `tenv3`, `tenv` or `kenv .txt` ASCII file `FILENA` (the function that extracts these data is a method of this object). If `FILENA` is undefined or empty, the filename can be interactively managed by means of a combo box.

The properties of the generated object of `tsData` class are related to:

1) input time series (in this case, the data are managed by means of `tsData` methods);
2) time series processing (in this case, no `tsData` methods act on the data because the processing is based on Hector).

Complete list of properties related of input time series (please note that all these time series properties are defined only in the case of data taken from a `tenv3` file. In the case of `tenv` or `kenv` files some properties are undefined and, therefore, the corresponding values are empty):

Scalars/strings:

`statName`	station name (string)
`statLat`	station latitude (single value, degrees)
`statLon`	station longitude (single value, degrees)
`statHeight`	station heigh (single value, m)

Arrays:

`dateS`	date (string YYMMMDD)
`dateyfrac`	date (fractional year
`MJD`	modified julian date
`GPSweek`	GPS week
`GPSday`	GPS day
`t`	date (MATLAB serial form)
`reflon`	reference meridian longitude (degrees)
`E0`	eastings (m), integer portion (from ref. meridian
`Ed`	eastings (m), fractional portion
`E`	eastings (m), complete
`N0`	northings (m), integer portion (from equator)
`Nd`	northings (m), fractional portion
`N`	northings (m), complete
`V0`	vertical (m), integer portion
`Vd`	vertical (m), fractional portion
`V`	vertical (m), complete
`antH`	antenna height (m) assumed from RINEX header
`sE`	east sigma (m)
`sN`	north sigma (m)
`sV`	vertical sigma (m)
`cEN`	east-north correlation coefficient
`cEV`	east-vertical correlation coefficient
`cNV`	north-vertical correlation coefficient

Complete list of properties related to the time series processing and, therefore, are empty before such a processing:

`cleanedE`	cleaned time series after outlier removal - East
`cleanedN`	cleaned time series after outlier removal - North
`cleanedV`	cleaned time series after outlier removal - Vertical

`offsetsE`	offsets East
`offsetsN`	offsets North
`offsetsV`	offsets Vertical

The value of each property `offsetsE`, `offsetsN` and `offsetsV`, as the offset search is carried out, is an `offsets` struct variable (see below). The value of `offsetsOpts`:

- if the offsets recognition is carried out in an automatic way, it is `OptsGen.Offsets`, where `OptsGen` is the struct variable with the options for `StaVelMain` computations;
- if the offsets recognition is carried out in the manual way, it is the string `'Manual offsets recognition'`;
- if the offsets are taken from NGL database, it is the string `'Offsets taken from Nevada Geodetic Laboratory database'`;
- if the offsets are taken from another database, it is the string `'Offsets taken from file ....'`.

`outliersE`	outliers East
`outliersN`	outliers North

`outliersV`	outliers Vertical

The value of each property `outliersE`, `outliersN`, `outliersV`, as the outlier search is carried out, is an `outliers` struct variable (see below). The value of `outliersOpts` is `OptsGen.Outliers`, where `OptsGen` is as above.

`estimatedTrendE`	estimated trend East
`estimatedTrendN`	estimated trend North
`estimatedTrendV`	estimated trend Vertical
`estimatedTrendOpts`	estimated trend computation general options

The value of each property `estimatedTrendE`, `estimatedTrendN` and `estimatedTrendV`, as the trend estimation is carried out, is an `estimatedTrend` struct variable (see below). The value of `estimatedTrendOpts` is `OptsGen.Trend`, with `OptsGen` as above.

`detrendedZeroMeanE`	detrended zero mean East time series
`detrendedZeroMeanN`	detrended zero mean North time series
`detrendedZeroMeanV`	detrended zero mean Vertical time series

`CMEfiltered`	CME-filtered time series and data
`CMEfiltered.t` `CMEfiltered.E` `CMEfiltered.N` `CMEfiltered.V`	CME filtered time series
`CMEfiltered.estimatedTrendE` `CMEfiltered.estimatedTrendN` `CMEfiltered.estimatedTrendV`	`estimatedTrend` data for CME filtered time series
`CMEfiltered.Method`	Method for CME filtering

The fields of these processing-related struct variables, also depending on the kind of struct variable, i.e. `offsets`, `outliers` or `estimatedTrend`, as well as on the user's choices, are taken from the JSON files generated by Hector. They can be

`t1`	initial time
`t2`	final time
`N`	actual number of days (gaps are excluded from count)
`gap_percentage`	percentage of gaps
`K`	number of estimated parameters (it is not kappa!)
`Ln_L`	minimum value of log-likelihood ln(L)
`AIC`	Akaike Information Criterion (AIC=2*k+2*ln(L))
`BIC`	Bayesian Information Criterion (BIC=k*ln(N)+2*ln(L))
`BIC_tp`	another BIC value (BIC_tp=k*ln(N/(2π))+2 ln(L))
`BIC_c`	another BIC value, with some extra-penalties
`ln_det_I`	

`NoiseModel:`	struct variable depending on the user's choices:
	
	if white noise is chosen:
	`NoiseModel.White`
	`NoiseModel.White.sigma`
	`NoiseModel.White.fraction`
	
	if Powerlaw noise is chosen:
	`NoiseModel.Powerlaw`

```
         NoiseModel.Powerlaw.sigma
         NoiseModel.Powerlaw.d
         NoiseModel.Powerlaw.kappa
         NoiseModel.Powerlaw.fraction
```

if GGM (Powerlaw) noise is chosen:

```
NoiseModel.GGM
         NoiseModel.GGM.sigma
         NoiseModel.GGM.d
         NoiseModel.GGM.kappa
         NoiseModel.GGM.x1_phi
         NoiseModel.GGM.fraction
```

if FlickerGGM noise is chosen:

```
NoiseModel.FlickerGGM
         NoiseModel.FlickerGGM.sigma
         NoiseModel.FlickerGGM.d (0.5)
         NoiseModel.FlickerGGM.kappa (1)
         NoiseModel.FlickerGGM.x1_phi
         NoiseModel.FlickerGGM.fraction
```

if ARMA model is chosen:

```
NoiseModel.ARMA
         NoiseModel.ARMA.sigma
         NoiseModel.ARMA.AR
         NoiseModel.ARMA.MA
         NoiseModel.ARMA.d
         NoiseModel.ARMA.fraction
```

if ARFIMA model is chosen:

```
NoiseModel.ARFIMA
         NoiseModel.ARFIMA.sigma
         NoiseModel.ARFIMA.AR
         NoiseModel.ARFIMA.MA
         NoiseModel.ARFIMA.d
         NoiseModel.ARFIMA.fraction
```

`driving_noise`	driving noise standard deviation (mm)
`Trend`	estimated trend (mm/y)
`trend_sigma`	estimated trend standard deviation (mm/y)
`Sa_cos`	yearly cos coefficient
`Sa_cos_sigma`	yearly cos coefficient standard deviation
`Sa_sin`	yearly sin coefficient
`Sa_sin_sigma`	yearly sin coefficient standard deviation
`Sa_amplitude`	yearly oscillation amplitude
`Sa_amplitude_sigma`	yearly oscillation amplitude standard deviation
`Sa_phase`	yearly oscillation phase
`Sa_phase_sigma`	yearly oscillation phase standard deviation
`Ssa_cos`	half-yearly cos coefficient
`Ssa_cos_sigma`	half-yearly cos coefficient standard deviation
`Ssa_sin`	half-yearly sin coefficient

`Ssa_sin_sigma`	half-yearly sin coefficient standard deviation
`Ssa_amplitude`	half-yearly oscillation amplitude
`Ssa_amplitude_sigma`	half-yearly oscillation amplitude standard deviation
`Ssa_phase`	half-yearly oscillation phase
`Ssa_phase_sigma`	half-yearly oscillation phase standard deviation
`jumps_epochs`	
`jumps_sizes`	Jump parameters
`jumps_sigmas`	

For example, the trend value and standard deviation for the East component of the `tsData` object named `tsDataBOLG` are `tsDataBOLG.estimatedTrendE.trend` and `tsDataBOLG.estimatedTrendE.trend_sigma` respectively. If power law is among the chosen noise models, the corresponding `k` is `tsDataBOLG.estimatedTrendE.NoiseModel.Powerlaw.kappa` (if power law is not a chosen noise model, the field is empty).

Since all `.m` files are available to the user, he/she can make the toolbox compatible with other kinds of input files by editing the `tsData.m` file and adding other methods to `tsData` object in order to allow a successful data reading.

Note: a `tsData` object can be read as an object only if it is loaded in an appropriate way. If such a file is not correctly accessed, it is not read as a `tsData` object but such a warning message appears: "`Warning: Variable 'ts' originally saved as a tsData cannot be instantiated as an object and will be read in as a uint32.`" In order to solve this problem and allow a correct access to a `tsData` file whichever is its folded, the function `tsDataFileIn` can be used. Its syntax is:

```
[tsDataOut,IT]=tsDataFileIn(tsDataIn)
```

This function checks if the input variable `tsDataIn` is a `tsData` object.
If this test is passed, `tsDataOut=tsDataIn` and `IT` is true.
If the test is not passed and `tsDataIn` is a char variable, the function checks if it exists a MATLAB `.mat` file with this name and carrying a `tsData` object (see below for more details about this file).
If `tsDataIn` is undefined or empty, the MATLAB .mat file carrying a `tsData` object can be managed in an interactive way.
If the `tsData` object should be extracted by a file:

- if a single variable is carried by the file, it must necessarily be a `tsData` object;
- if two or more variables are carried by the file, one and only one of them must be a `tsData` object.

If the file loading is successful, the extracted `tsData` object is `tsDataOut` and `IT` is true. If no a valid `tsData` object is extracted, `tsDataOut` is empty, `IT` is false and a warning message is shown.

3.4 Other output files

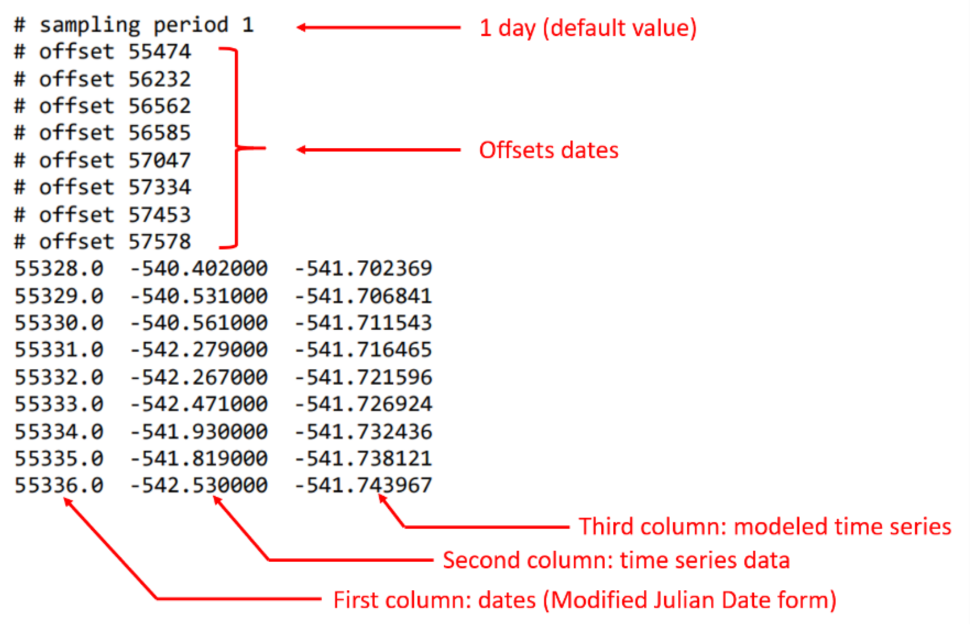
The above-described `tsData` object represents both the input data, downloaded from NGL or other compatible database, and the results of the processing. During the execution of the main function of `StaVel`, which call Hector several times, in addition to updating the `tsData` object for each station, some essential ASCII files are generated to allow Hector to proceed in the various calculation steps. These ASCII files are stored in some folders (if these folders do not exist at the time of initialization of `StaVelMain` program, they are automatically generated).

For each processed station, as the calculation steps progress, files are generated and placed in these folders, whose names can be managed by acting on `geneOpts` function, described in the next chapter:

- Folder of downloaded ASCII ENV files (`tenv3`, `tenv` or `kenv` files). Such a folder is filled by means of the above described `GetNevada` function. A possible folder name is `tenv_EU` if the EU plate is considered;
- Folder of `tsData` objects, generated by means of `tsData.m` called by `StaVelMain`, stored as `.mat` files and upgraded at each calculations step. The default folder name is `ts_files`;
- Folder of raw mom files. A mom (MJD-Observations-Model) file is an ASCII file with the time series in the first two columns (MJD dates in the first column and data in the second one. An optional third column has the modeled data). The extensions always is `.mom`, regardless to the number of columns (an example of mom file is shown in Fig. 3.3). This folder is filled by `StaVelMain` function. The default folder name is `raw_files`;
- Folder of control files for Hector. They are ASCII files, whose extension is `.ctl`, generated by `StaVelMain`, for each step in which Hector is involved, on the basis of options initially managed by means of `geneOpts` function. The default folder filename is `ctl_files`;
- Folder of observation mom files. They are generated as the offset recognition or acquisition from a database is carried out, regardless to the fact that they are provided by Hector, called by `StaVelMain`, or by other functions called by `StaVelMain`. The file header of an observation mom file (or of a mom file subsequently generated) provides information about possible offsets (see Figure 3.3). The default folder filename is `obs_files`;
- Folder of JSON files, generated by Hector as the calculation steps progress. The JSON files are read by `StaVelMain` in order to upgrade the `tsData` objects. The default folder filename is `JSON_files`;
- Folder of Hector output files, generated by `StaVelMain` on the basis of the Hector output. At present, these files are not used for `tsData` file upgrade, but they provide a little bit more information with respect to JSON files and could be manually read by the user, if necessary. The default folder filename is `out_files`;
- Folder of pre-processed mom files, generated by Hector as the outlier recognition is carried out. The default folder filename is `pre_files`;
- Folder of results mom files, generated by Hector as the trend estimation is carried out. These mom files have three columns, where the third one has the modeled time series (they are the only three-column files; in other cases where Hector provides three-column files, the third is removed from `StaVelMain` in order to prevent problems in the next calculation steps. The default folder filename is `mom_files`.

For more information about control and mom files, please see the Hector User's Guide. Information can also be taken by a look to the `StaVelMain.m` file.

Final note for use by expert users potentially interested in customizing the `StaVel` toolbox. As regards the management of the offsets in the functions of the toolbox, the binary-like convention shown in Table 3.2 is used (please also note that the dates are in this case expressed in the MJD form). In the functions that make use of it (for example, `InspOffsetMom`), the corresponding matrices are indicated with `MosMom`. Since the toolbox can also generate `.neu` files that might be used by CATS (Williams, 2008), the convention presented in Table 3.3 is also used; the corresponding matrices, in which the dates are presented in fractional year form, are indicated with `Mos`. For example, an offset in the East component only has code 3 with the mom convention, and code 2 with the neu convention (see the help of `writeNeuMom` and `MosMom2MosNeu` for more information).



```
# sampling period 1
# offset 55474
# offset 56232
# offset 56562
# offset 56585
# offset 57047
# offset 57334
# offset 57453
# offset 57578
55328.0  -540.402000  -541.702369
55329.0  -540.531000  -541.706841
55330.0  -540.561000  -541.711543
55331.0  -542.279000  -541.716465
55332.0  -542.267000  -541.721596
55333.0  -542.471000  -541.726924
55334.0  -541.930000  -541.732436
55335.0  -541.819000  -541.738121
55336.0  -542.530000  -541.743967
```

1 day (default value)
Offsets dates
Third column: modeled time series
Second column: time series data
First column: dates (Modified Julian Date form)

Figure 3.3 Example of a three-columns mom file.

Table 3.2 Binary convention for offsets (mom files)

East	North	Vertical	Code
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

Table 3.3 Binary convention for offsets (neu files)

North	East	Vertical	Code
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6
1	1	1	7

4. Main `StaVel` functions

From the point of view of the execution of all actions that can be implemented within the toolbox, the main MATLAB functions are:

- `GetNevada`, for the download of coordinate time series from Nevada Geodetic Laboratory (NGL) o from another similar database, already described in the previous chapter;
- `geneOpts`, for the management of `StaVel` options (models to be used for data processing, choice of folders and filename common parts);
- `StaVelMain`, main `StaVel` function, which is the heart of the toolbox;
- `geneGSfile`, for the generation of an ASCII file compatible with `GridStrain`.

These functions call, where necessary, other specifically developed functions.

4.1 Choice of `StaVel` general options: `geneOpts` function

The function `geneOpts` allows the generation of the option struct variable `Opts` which is used by `StaVelMain` and by other functions called by `StaVelMain` at the various stages of the computation. The syntax is:

```
Opts=geneOpts(Components,OffsetNM,TrendNM,…
       CommonFolder,CommonAdd,Lmin,Lmax)
```

Input arguments:

- `Components`: vector of components, where 0 means East, 1 means North and 2 means Vertical. For example, to analyze horizontal components only, the required choice is `Components=[0 1]`.
  If `Components` is undefined or empty, `Components=[0 1 2]` is used.
- `OffsetNM`: Noise models to be used for offset recognition. Allowed values are the strings:

`FNWN`	flicker noise and white noise
`PLWN`	power law and white noise
`RWFNWN`	random walk noise, flicker noise and white noise
`WN`	white noise

  If `OffsetNM` is undefined, empty of is no an allowed string, the default choice `WN` is used.
- `TrendNM`: Noise models to be used for trend computation. The argument must be either an allowed string (see below the list of allowed strings) for the case of a single noise model or a cell variable whose elements are allowed strings for the case of multiple noise models. The allowed strings are:

`WN`	white noise
`GGM`	generalized Gauss-Markov
`fGGM`	k-fixed GGM
`FN`	flicker noise
`FNGGM`	flicker noise GGM
`RW`	random walk
`RWGGM`	random walk GGM
`PL`	power law
`PLGGM`	power law GGM

MT	Matern
VA	varying annual
VSA	varying semi-annual
AR1	ARMA

If `TrendNM` is undefined, empty, or no valid strings are in `TrendNM`, the default choice `TrendNM={'WN','PL'}` is used.

- `CommonFolder` is an optional general folder, subfolder of the main `StaVel` folder, that will contain all the folders generated/filled by `StaVelMain`. If `CommonFolder` is undefined or empty, the general folder is the main `StaVel` folder.
- `CommonAdd` is the common string to be added to the file name. Options:
  - it is a char (included the empty char ‶″): it is used for all the generated files. For example, the generated raw file for a station `NAME` is `'./raw_files/NAME.EU.mom'` if `EU` is `CommonAdd` and `'./raw_files'` is the raw files folder. If `CommonAdd` is ‶″, in the same conditions the raw file is `'./raw_files/NAME.mom'`.
  - it is not a char (including `[]`, i.e. empty vector, but not empty char). No a common string is used and each generated file can have a specific added string (these strings are defined by editing the present function).
- `Lmin` and `Lmax` are the optional minimum and maximum lengths of the GNSS time series, expressed in years. If `Lmin` (`Lmax`) is undefined or empty, no minimum length (no maximum length) is considered. Good practices require `Lmin ≥ 4.5` (years).

Example of `Opts` struct variable:

```
     dirEnv    './Syr/tenv_AF'
      dirTs    './Syr/ts_files'
     dirRaw    './Syr/raw_files'
     dirObs    './Syr/obs_files'
     dirPre    './Syr/pre_files'
     dirMom    './Syr/mom_files'
     dirCtl    './Syr/ctl_files'
     dirOut    './Syr/out_files'
    dirJSON    './Syr/JSON_files'
  dirHector    '/mnt/c/GNSS/hector'
    extTenv    '.tenv3'
 Components    [0 1 2]
     AddNeu    '.EU'
      AddTs    '.EU'
     AddRaw    '.EU'
     AddObs    '.EU'
     AddPre    '.EU'
     AddMom    '.EU'
     AddOut    '.EU'
    AddJSON    '.EU'
       Lmin    4.5000
       Lmax    []
     Offset    [1×1 struct]
    Outlier    [1×1 struct]
      Trend    [1×1 struct]
```

In order not to make it necessary to introduce a complex user interface that is not compatible with GNU Octave, the fields relating to the names of the folders of the files generated or modified directly and indirectly by `StaVelMain` are managed by acting on the program lines of the `geneOpts` function (it is recommended to always have a backup copy of this function in order to facilitate any future changes). Please open the file `geneOpts.m` to see how this function is structured and how it can be modified.

The values of the `Offset`, `Outlier` and `Trend` fields are themselves struct variables, established on the basis of the options chosen by the input options of `geneOpt` and the choices on `foldernames`. These values act on generation of the corresponding Hector control (`.ctl`) files by `StaVelMain`. An example of `Opts.Trend` is the struct variable:

```
         Interpolate    'no'
        PhysicalUnit    'mm'
         ScaleFactor    1
      Seasonalsignal    'yes'
  Halfseasonalsignal    'yes'
                JSON    'yes'
     estimateoffsets    'yes'
         NoiseModels    'White Powerlaw'
```

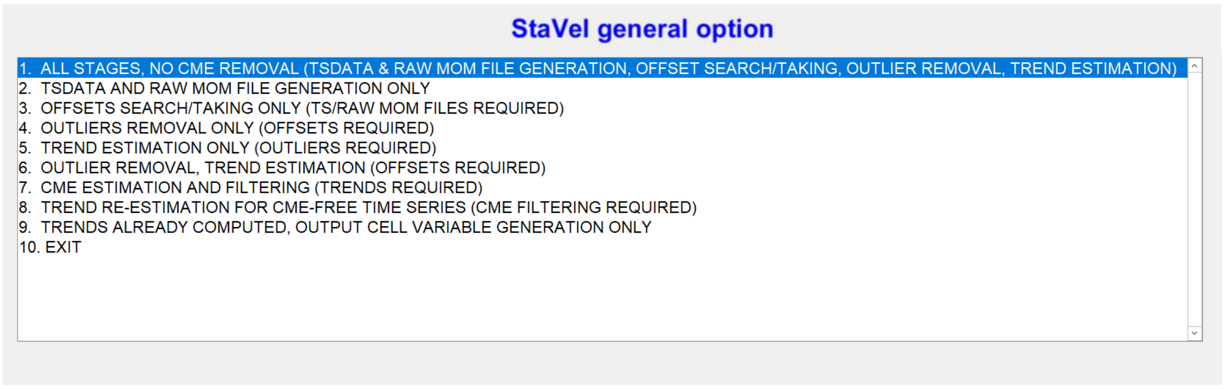
(meaning of these choices: differential coordinate data expressed in mm, to provide velocities in mm/y; no interpolation for the dates where data are missing; annual and semi-annual signals are modeled; the offsets at the already known offset dates are estimated[1]; the noise models are white noise and power law noise).

4.2 The main `StaVel` function: `StaVelMain`

The main component of `StaVel` toolbox is the function `StaVelMain.m`, whose syntax is:

```
COut=StaVelMain(fileStations,OptAct,OptsGen)
```

This function, which calls the external package Hector, can perform all computations necessary to obtain the velocities of the GNSS stations listed in the Excel or ASCII file `fileStations`. Each station must be represented by its standard 4-character name. In the case of an Excel file, the station names must be placed in the first column (no more than the first column is read). In the case of an ASCII file, only a column is admitted.
If `fileStations` is undefined or empty, the filename can be interactively managed.


StaVel general option

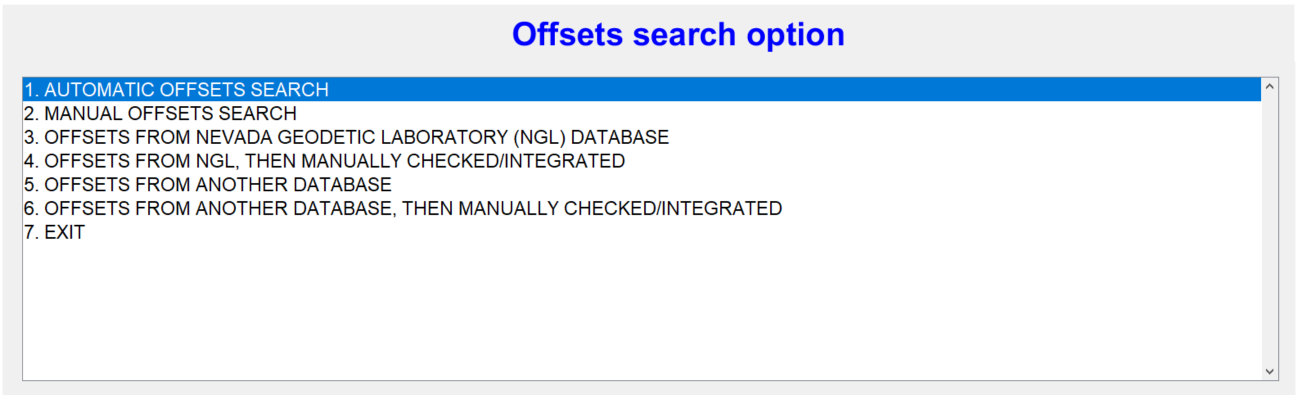
1. ALL STAGES, NO CME REMOVAL (TSDATA & RAW MOM FILE GENERATION, OFFSET SEARCH/TAKING, OUTLIER REMOVAL, TREND ESTIMATION)
2. TSDATA AND RAW MOM FILE GENERATION ONLY
3. OFFSETS SEARCH/TAKING ONLY (TS/RAW MOM FILES REQUIRED)
4. OUTLIERS REMOVAL ONLY (OFFSETS REQUIRED)
5. TREND ESTIMATION ONLY (OUTLIERS REQUIRED)
6. OUTLIER REMOVAL, TREND ESTIMATION (OFFSETS REQUIRED)
7. CME ESTIMATION AND FILTERING (TRENDS REQUIRED)
8. TREND RE-ESTIMATION FOR CME-FREE TIME SERIES (CME FILTERING REQUIRED)
9. TRENDS ALREADY COMPUTED, OUTPUT CELL VARIABLE GENERATION ONLY
10. EXIT

Figure 4.1 Interactive choice of General initial option for `StaVel`.

[1] Please note that “estimate offsets” does not mean “recognize the offsets”, i.e. recognize the offsets dates, but “Estimate the offsets at the dates reported in the headers of the mom files”.

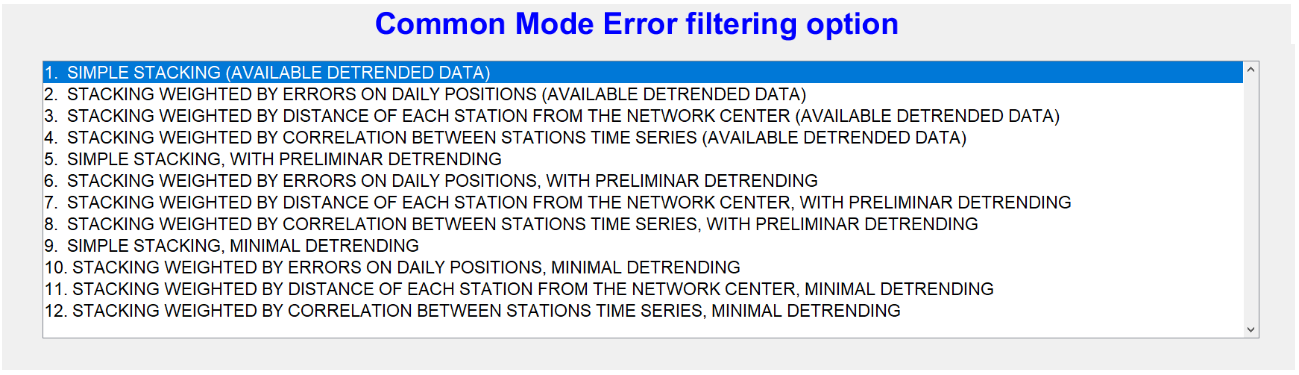
The second input argument, `OptAct`, allows the choice of the operation to be carried out. There are several options for such an argument. If `OptAct` is undefined, empty or outside 1:10, the choice can be carried out in an interactive way by means of a user interface (Fig. 4.1).

If `OptAct` is a scalar in the range 1:10, the corresponding action is carried out.
If `OptAct` is 1 or 3 (chosen as an input argument or by means of interactive choice), the option about the offset management (`OptOff`) can be interactively chosen with the user interface shown in Fig. 4.2.
If `OptAct` is 7 (chosen as an input argument or by means of interactive choice), the option about the CME estimation method can be interactively chosen with the user interface in Fig. 4.3 (see Subsection 4.5 for more information about CME estimation and filtering).
If `OptAct` is 9 (chosen as an input argument or by means of interactive choice) and CME-filtered data are available, the use can generate the output variable `COut` on the basis or non-filtered or filtered data. The option can be interactively chosen (Fig. 4.4).


Offsets search option

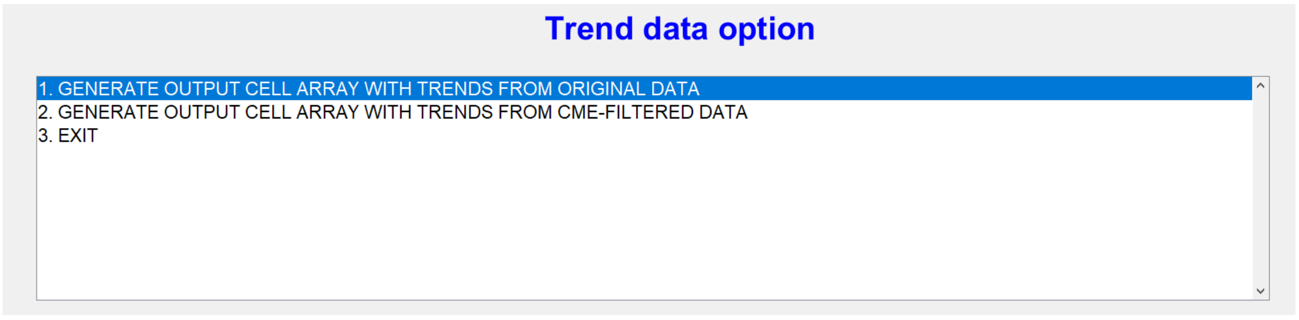
1. AUTOMATIC OFFSETS SEARCH
2. MANUAL OFFSETS SEARCH
3. OFFSETS FROM NEVADA GEODETIC LABORATORY (NGL) DATABASE
4. OFFSETS FROM NGL, THEN MANUALLY CHECKED/INTEGRATED
5. OFFSETS FROM ANOTHER DATABASE
6. OFFSETS FROM ANOTHER DATABASE, THEN MANUALLY CHECKED/INTEGRATED
7. EXIT

Figure 4.2 Choice of the modality for search/use of offsets if `OptAct` is 1 or 3.


Common Mode Error filtering option

1. SIMPLE STACKING (AVAILABLE DETRENDED DATA)
2. STACKING WEIGHTED BY ERRORS ON DAILY POSITIONS (AVAILABLE DETRENDED DATA)
3. STACKING WEIGHTED BY DISTANCE OF EACH STATION FROM THE NETWORK CENTER (AVAILABLE DETRENDED DATA)
4. STACKING WEIGHTED BY CORRELATION BETWEEN STATIONS TIME SERIES (AVAILABLE DETRENDED DATA)
5. SIMPLE STACKING, WITH PRELIMINAR DETRENDING
6. STACKING WEIGHTED BY ERRORS ON DAILY POSITIONS, WITH PRELIMINAR DETRENDING
7. STACKING WEIGHTED BY DISTANCE OF EACH STATION FROM THE NETWORK CENTER, WITH PRELIMINAR DETRENDING
8. STACKING WEIGHTED BY CORRELATION BETWEEN STATIONS TIME SERIES, WITH PRELIMINAR DETRENDING
9. SIMPLE STACKING, MINIMAL DETRENDING
10. STACKING WEIGHTED BY ERRORS ON DAILY POSITIONS, MINIMAL DETRENDING
11. STACKING WEIGHTED BY DISTANCE OF EACH STATION FROM THE NETWORK CENTER, MINIMAL DETRENDING
12. STACKING WEIGHTED BY CORRELATION BETWEEN STATIONS TIME SERIES, MINIMAL DETRENDING

Figure 4.3 Choice of the CME filtering option if `OptAct` is 7 (for more information, please see Subsection 4.5).


Trend data option

1. GENERATE OUTPUT CELL ARRAY WITH TRENDS FROM ORIGINAL DATA
2. GENERATE OUTPUT CELL ARRAY WITH TRENDS FROM CME-FILTERED DATA
3. EXIT

Figure 4.4 Choice for the generation of the output cell variable if `OptAct` is 9. Clearly, if the option 1 (respectively 9) is chosen, trends obtained from the original data (CME-filtered data) must be available.

If OptAct is a 2-length vector, OptAct(1) is the option 1-10 as above, and OptAct(2) is OptOff, i.e. the option for the offset management (1-6 to manage offsets, 7 to exit from StaVelMain), provided that OptAct(1) is 1 or 3, the option for the CME estimation, provided that OptAct(1) is 7, or the option for the choice of trends from original or CME-filtered data, provided that OptAct(1) is 9 and these trends exist. Clearly, the second element, i.e. OptAct(2), is actually used only if OptAct(1) is 1, 3, 7 or 9. The vector option about OptAct is introduced to allow the use of StaVelMain under GNU Octave.

OptsGen is the struct variable with the general StaVel options, generated by means of the already described geneOpts function. If OptsGen is undefined or empty, the name of the file carrying such a struct variable can be interactively managed. In this case, the file must have a field whose name is either Opts or OptsGen.

The output variable COut is non-empty if OptAct is 1, 5, 6, 8 or 9, empty elsewhere. If COut is non-empty, it is a N-by-11 cell array, where N is the number of managed stations, and the columns are:

```
[station name, initial time, final time,
station latitude, station longitude, station height (m a.s.l.),
estimated trend East, estimated trend East SD,
estimated trend North, estimated trend North SD,
estimated trend Vertical, estimated trend Vertical SD]
```

Such an output COut can be used as input of geneGSFile, described in Subsection 4.3.

If OptAct is 8, the trends are related to CME-filtered time series.

It is important to highlight these facts about StaVelMain:

1) Although, in principle, all operations could be implemented in fully automatic way (OptsAct 1), this is not recommended. It is recommended to at first generate the tsData and mom files for each station (option OptsAct 2), then proceed to search for the offsets (automatic or manual), or to download and verify them (OptsAct 3), when the offsets are at least verified, proceed to the recognition of the outliers and, finally, to the calculation of the trends (OptsAct 4, 5 and 6, based on the user’s wishes to proceed step-by-step or to perform the two steps automatically). It is therefore recommended to start StaVelMain several times. This is also shown in the short tutorial (Chapter 5);

2) If the user decides to use StaVelMain for OptsAct after 1 (”ALL STAGES”), it is essential that the previous operations have already been performed or that in any case the necessary data are already present. This is highlighted in the user interface. For example, in order to perform OptsAct 4 and 6, the offset dates, if any, must already be known and the necessary files in the Hector observation mom files folder (and those in the preprocessed mom files folder for OptsAct 6) must already be available;

3) It is not strictly necessary that the computer is online during the implementation of the StaVelMain calculations and of the external functions and programs controlled by StaVelMain (obviously, the computer had to be online at the time of the download of the files implemented by the GetNevada function). However, if the data taken from the database is of the type tenv, kenv or tenv3 with 20 columns, the computer must be online at the time the tsData objects are generated (OptsAct 1 and 2) in order to access the longitude, latitude and ellipsoidal height data (these data are instead taken directly from the file in case of tenv3 file with 23 columns);

4) `StaVelMain` operates for each station considered in the list placed in `filenaStations`, that is, all the operations selected through `OptsAct` are all performed, one after the other, for each station. The generation of the `tsData` objects, of the raw mom files and the management of the offsets, if selected, is carried out for all the components at the same time; the subsequent phases, if selected, are instead implemented component by component, before moving on to the next station;

5) If a user wants to repeat the calculation by changing one or more parameters, he/she can redefine the options using `geneOpts`, save a copy of the starting data in the necessary folders and proceed with a new `StaVelMain` session. For example, if the user intends to recalculate the trend on the basis of different noise models or periodic signals keeping the previously processed data, he/she can copy the preprocessed mom files into a new folder, whose name will be entered in `OptsGen` by acting on `geneOpts`, and then repeat the calculation by choosing `OptsAct 5` or `6`;

6) The folders defined by means of `geneOpts`, if not existing, are generated by `StaVelMain`. If a folder already exists, `StaVelMain` does not alter its contents except when writing the files. In case of files with the same name, `StaVelMain` rewrites without any warning. It should be noted that the user can repeat the analysis for some stations, or introduce new stations, simply by acting on `fileStations`. For example, he/she can consider a new file `fileStations1`, with only the names of the stations to recalculate and/or add, and proceed. He/she then redefine a third file `fileStations2` with all stations to implement `OptsAct=9` and then export the data for `GridStrain`. An example of this possibility is given in Chapter 5 for tutorial purposes;

7) The CME estimation and removal is carried out by means of `CMEstackFiltering`, which can be called by `StaVelMain` is `OptAct 7` is selected. However, the direct use of `CMEstackFiltering` offers more options with respect to the use of such a function called by `StaVelMain`. Please see Subsection 4.5 for more information.

4.3 Inspecting the coordinate time series: the `InspectOffsetSearch` function.

The time series inspection is an important stage of GNSS data analysis. The function `InspectOffsetSearch` allows the inspection of several time series and the manual check/search of the possible corresponding offsets.
This function can be used in two different ways:

- Direct use as an independent function (see below the corresponding command line);
- Use as a function called by `StaVelMain`. This function is called by `StaVelMain` if `OptAct` is 1 or 3 (or is a vector whose first element is 1 or 3) and the corresponding `OptOff` (interactively chosen or defined as second element of `OptAct` if this is a vector) is 4 or 6 (for the other options about `OptOff`, the offsets are managed in a non-interactive manner).

The syntax for the direct use is:

```
InspectOffsetSearch(fileStations,OptsGen,OptPre)
```

This function allows the visual inspection of GNSS time series on the stations listed in `fileStations` in accordance with the `StaVelMain` options stored in the struct variable `OptsGen`. This function requires the availability of `tsData` files related to the listed stations.
Input variables:

- `fileStations` carries the list of GNSS stations, represented by their standard 4-character names. This file can be either an Excel or an ASCII file. In the case of Excel file, the station names must be placed in the first column (no more than the first column is read). In the case of an ASCII file, only a column is admitted. If `filenaStations` is undefined or empty, the filename can be managed in interactive way. Let `statName` be the string array with the station names obtained from the loaded file.
- `OptsGen` is a struct variable generated by means of `geneOpts` function. For each station, the input `tsData` file is searched of the basis of the station name, `statName(k)`, and information carried by `OptsGen` in accordance with:

  ```
  filets=fullfile(OptsGen.dirTs,…
      [statName(k) OptsGen.AddTs '.mat']).
  ```

  The `tsData` file is upgraded according to the detected offsets. The corresponding mom observation files, whose names are stored in `OptsGen`, are also generated and/or upgraded. If `OptsGen` is undefined or empty, the `.mat` file with such a struct variable can be interactively managed.
- If `OptPre` is undefined, empty or false, no possible already available data about offsets are used, i.e. the offsets search is carried out starting from scratch. If `OptPre` is true, for each station the offsets search starts from the offsets resulting from the corresponding `tsData` object.

It is important to underline that the `InspectOffsetSearch` function allows not only to inspect the time series and to identify/verify the dates of the offsets, but also to identify any anomalous segments of them to be taken into consideration or, if necessary, to be removed. For an example of use of such a function, including the acquisition of information about the removal of time series segments, please see the tutorial Subsection 5.3.

4.4 Removal of time series segments: the `tsSegmentRemoval` function

In some cases, it is necessary to remove one or more segments of a time series because they are affected by excessive dispersion, progressive changes in position not related to crustal kinematics or other reasons. The `tsSegmentRemoval` function allows you to do this. It should be noted that this is a low-level automation function in order to avoid sudden deletion of data. The corresponding syntax is:

```
tsSegmentRemoval(statName,OptsGen,MdateRemove,OptStr)
```

This function allows the removal of one or more segments from the time series related to the station `statName`, on the basis of the general `StaVel` options represented by `OptsGen` struct variable.

The input argument `MdateRemove` is a `Nrem-by-2` matrix, where `Nrem` is the number of time series segments to be removed, `MdateRemove(k,1)` and `MdateRemove(k,2)` are the lower and higher date limit, expressed in MATLAB serial form, for the k-th segment.

The `tsData` file and the related mom files are automatically upgraded. If the input argument `OptStr` is `'Obs'`, the observation mom file is upgraded. If `OptStr` is `'Raw'`, the raw mom file is upgraded. If `OptStr` is undefined, empty or is not `'Obs'` or `'Raw'`, the default value `'Obs'` is used.

For an example of use of `tsSegmentRemoval` please see the tutorial Subsection 5.3.

4.5 Common Mode Error filtering: the `CMEstackFiltering` function

The function `CMEstackFiltering` performs the CME evaluation and filtering. It can be called by means of `StaVelMain` function or can be used in autonomous way. At present, these CME estimation procedures are implemented in CMEstackFiltering:

- Stacking (Wdowinski et al., 1997);
- Weighted Stacking Filtering Method (Nicolaidis, 2002);
- Distance Weighted Filtering Method (He et al., 2020);
- Correlation Weighted Stacking Filtering Method (Tian and Shen, 2011).

The syntax of this function is:

```
CME=CMEstackFiltering(fileStations,OptsGen,OptStack,Ncomp,Nstaz)
```

This function carries out the CME filtering of the time series of the GNSS stations listed in the Excel or ASCII file fileStations on the basis of the chosen stacking approach (see below about possible options).

Warning: since CME filtering requires detrended, zero-mean time series, trend estimations must already be available!

If data about detrended, zero mean time series are available in a `tsData` file, they can be used (see below about the input variable OptStack). It they are unavailable, or the user wants to re-compute them, the detrended, zero-mean time series are computed and the corresponding `tsData` files are upgraded. As the calculations are completed, the `tsData` files of involved stations are automatically upgraded and the corresponding preprocessed mom files are generated.

The output `CME` is a struct variable whose fields are:

`deltat`	vector `[t1 t2]` of initial and final time (serial form)
`Ivv`	`nt-by-ns` matrix, where `nt` is the length of the daily time vector `t1->t2` and `ns` is the number of stations, where `Ivv(k,h)` is true if at the time `t(k)` there are valid values for all components of the station `h`
`CMEE`	`nt-by-1` vector (options `OptStack 1-3`, `5-7`, see below) or `nt-by-ns` matrix (`OptStack 4` or `8`) of common mode error for East component
`CMEN`	as above, North component
`CMEV`	as above, Vertical component

If the computations cannot be carried out, `CME=[]` is returned.

Each station must be represented by its standard 4-character name in `fileStation`. In the case of an Excel file, the station names must be placed in the first column (no more than the first column is read). In the case of an ASCII file, only a column is admitted. If `fileStations` is undefined or empty, the filename can be interactively managed.

`OptsGen` is the struct variable with the general `StaVel` options, generated by means of `geneOpts` function. If `OptsGen` is undefined or empty, the name of the file carrying such a struct variable can be interactively managed. In this case, the file must have a field whose name is either `Opts` or `OptsGen`.

`OptStack` is the option on stacking. The admitted values are:

1. simple stacking;
2. stacking weighted by errors on daily positions;
3. stacking weighted by distance of each station from the network center;

4. stacking weighted by correlation between stations time series;
   (note: if `OptStack` *options 1-4 are selected, for each station the existence of detrended zero-mean time series is checked. If such a time series exists, it is used for the CME estimation. If such a time series does not exist instead, it is computed like the case of options 5-8)*
5. simple stacking, with recalculation of possible existing detrended zero-mean time series;
6. stacking weighted by errors on daily positions, with recalculation of possible existing detrended zero-mean time series;
7. stacking weighted by distance of each station from the network center, with recalculation of possible existing detrended zero-mean time series;
8. stacking weighted by correlation between stations time series, with recalculation of possible existing detrended zero-mean time series;
9. simple stacking with minimal detrending, i.e. detrending based on simple least square fitting to a straight line (in this case, the Hector-based trend is not used);
10. stacking weighted by errors on daily positions with minimal detrending;
11. stacking weighted by distance of each station from the network center with minimal detrending;
12. stacking weighted by correlation between stations time series with minimal detrending.

If `OptStack` is undefined, empty or is not an admitted value, it can be interactively chosen.

`Ncomp` is the number of components. Allowed values: `2` (E-N), `3` (E-N-V). If `Ncomp` is undefined, empty or is not an allowed value, `Ncomp=3` is used.

`Nstaz` is the minimum number of stations to be used for stacking at each time. If, at a time `t(k)`, less than `Nstaz` stations have data, `CMEE(k)=0`, `CMEN(k)=0`, `CMEV(k)=0`, where `CMEE=CME.CMEE`, `CMEN=CME.CMEN` and `CMEV=CME.CMEV`. `Nstaz` must be at least 3, i.e. at a time `t(k)`, data from at least 3 stations are necessary to allow the computation of CME. If `Nstaz` is undefined, empty or lower than 3, the default `Nstaz=3` is used. If `Nstaz` is `Inf` or higher than the number of stations, `CMEs` are non-zero only at the times where all stations have data.

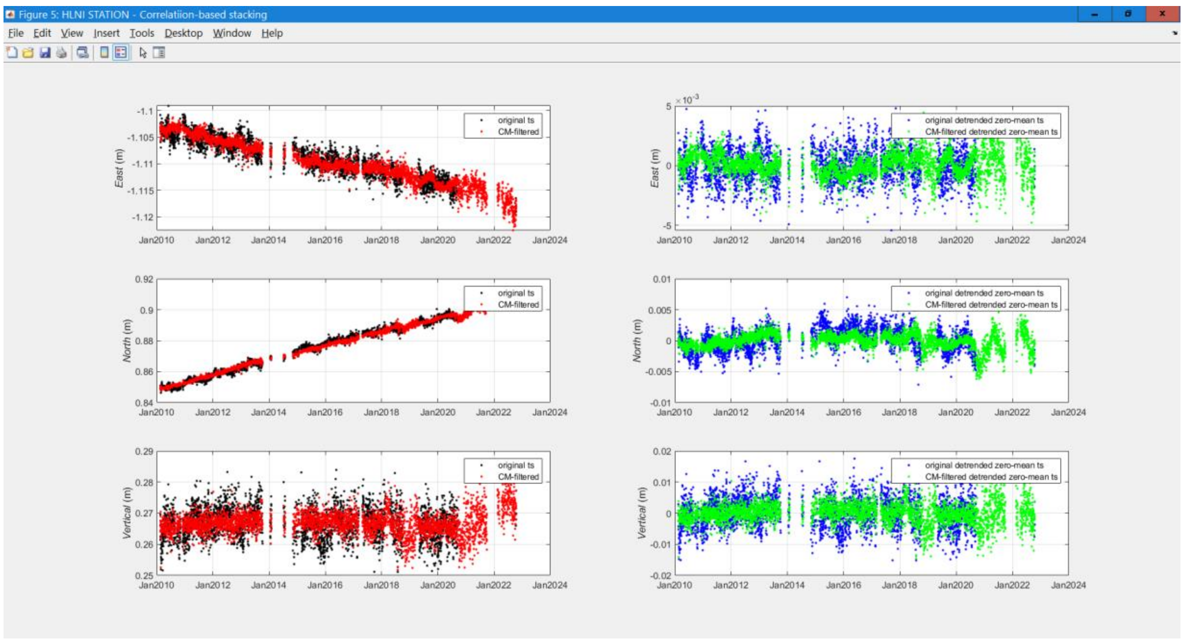


Figure 4.5 Example of plot provided by `CMEstackFiltering` function. The fact that the variance after CME filtering is lower than the one before filtering should be noted. The original and filtered time series coincide after October 2020 because data from no more than two stations are available (at a given time, the CME can be computed only if data from at least three stations are available).

Examples of plots provided by `CMEstackFiltering` function, with the option "correlation-based stacking" are shown in Figs. 4.4 and 4.5 for two stations belonging to the sample dataset included in `StaVel` toolbox. In this specific case, the limited area of the stations does not actually recommend filtering, which is only presented here for tutorial purposes. Instead, it is better to estimate and remove the CME, operating at the level of homogeneous areas, when there are many stations in a very large area. Once the homogeneous areas have been identified, each of them presumably affected by a specific CME, the user can proceed with the modeling and filtering of the time series of the stations within each of them (a trial-and-error approach could be necessary). In this way, the effects of the different CMEs which could give rise to huge uncertainties on the speed estimates will at least be attenuated.

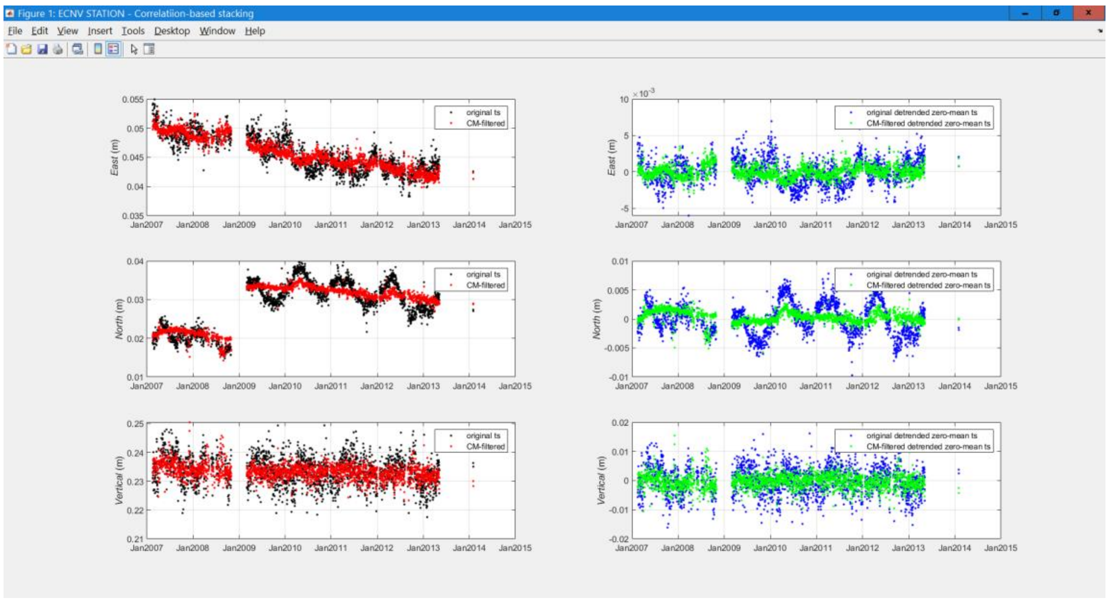


Figure 4.6 Another example of plot provided by `CMEstackFiltering` function.

4.6 Exporting the `StaVel` results to `GridStrain`: the `geneGSFile` function

As the velocity computations are completed, the results can be exported to `GridStrain` toolbox by means of geneGSFile function, whose syntax is:

```
CCompl=geneGSFile(CellIn,FilenaOut,N,DTY,UTMZzone,NameID)
```

This function generates the .txt file `FilenaOut` suitable for `GridStrain` (2D or 2.5D) on the basis of:

- Input cell data `CellIn` provided by a previous `StaVelMain` session.
  Options:
  - `CellIn` is a cell variable available in MATLAB command window (e.g. a `COut` variable provided by a `StaVelMain` session);
  - `CellIn` is a string (including or not including the extension `'.mat'`) with the filename of the MATLAB file which contains the cell variable. The file must contain no more than a field, regardless to its name;
  - `CellIn` is undefined or empty. In this case, the filename is interactively managed.
- Name of the output ASCII file `filenaOut`. If `filenaOut` is undefined or empty, the filename can be interactively managed.

- Number of coordinates to be taken into account. Valid choices are 2 (horizontal components only) and 3 (xyz coordinates). If `N` is invalid, undefined or empty, `N=2` is used.
- Time series minimum duration, in years, `dty`. The stations whose time series are shorter than `dty` are excluded from the output file. If `dty` is undefined or empty, no a minimum duration is considered.
- UTM zone expressed by the string `UTMzone` (e.g. `'33N'`). If `UTMzone` is undefined or empty, the default UTM zone which corresponds to the WGS84 coordinates is chosen.
- `NameID`. If `NameID` is undefined, empty or false, the station IDs are the station progressive numbers. If `NameID` is true, the station IDs are the station names.

5. Tutorial

In order to show how `StaVel` operates, the case of 5 GNSS stations, located in Southern Italy, for which data is available in the NGL database, is considered here. To do this, two files are added to the toolbox for tutorial purposes, i.e.:

- `SampleStations.txt`, with a list of stations;
- `SampleOpts.mat`, with a struct variable, named `OptsGen`, with the options for `StaVelMain`.

The user can use these files directly and can also modify them at will to vary the conditions and, above all, to change, if necessary, the link to the Hector folder.
Obviously, before using the `StaVel` toolbox, Hector must be installed (download page: http://segal.ubi.pt/hector/).

Note: the variable `OptsGen` saved in `SampleOpts` refers to the case in which the Hector's executables are placed in C:\GNSS\hector on a Windows machine equipped with WSL2 ("Windows subsystem for Linux"), so that these executables can be reached from MATLAB with the command `'/mnt/c/GNSS/hector/'` (note that Hector operates under Linux). The corresponding value must be modified if the path is different and, to generate other struct `OptsGen` variables, it is also necessary to act on the corresponding line of `geneOpts.m` (line 139 in the current version of the toolbox).

These steps are carried out within the tutorial:

- download of time series from NGL;
- generation of `tsData` and mom raw files through a first session of `StaVelMain`;
- use of the data available in NGL for the management of offsets with a second `StaVelMain` session;
- inspection of the time series and identification of possible stations that requires manual recognition of offsets and recognition of these offsets by using `InspectOffsetSearch` function;
- Search for outliers and trend estimation with a fourth use of `StaVelMain`;
- export of results.

Before the listed steps, the sample files are briefly discussed.
The file `SampleStations.txt` has a column with the names of five GNSS continuous stations located in Southern Italy. Information about the station ECNV can be found at http://geodesy.unr.edu/NGLStationPages/stations/ECNV.sta, and similar for the other stations:

```
ECNV
EDEN
EIIV
GALF
HLNI
```

An Excel file with the same information could also be used (in this case, more than a column are allowed, but only the first column is used).

As for the other sample file, the command line on MCW

```
load SampleOpts
```

loads the file SampleOpts and adds the struct variable OptsGen to the current workspace. A look to OptsGen shows that all folders will be placed inside the general folder Tutorial, subfolder of StaVel. The command lines required to obtain such a file where:

```
OptsGen=geneOpts([0 1],'PLWN',{'PL','WN'},'Tutorial','.EU',4.5);
```

```
save SaveOpts OptsGen
```

The user could modify the variable acting e.g. on noise models. Please see the description of geneOpts function in Chapter 4 or type help geneOpts on MCW for more information. In this case, horizontal components are considered ([0 1]), power law and white noise are the noise models used for all the Hector-based computations ('PLWN' for offset recognition and {'PL', 'WN'} for trend estimation), the general folder is 'Tutorial', all the file names contain '.EU' and the time series having at least 4.5 y length are considered.

5.1 Download of time series from Nevada Geodetic Laboratory

The first step is the download of time series from NGL. To carry out this, the command is:

```
status=GetNevada('SampleStations.txt','EU','Tutorial/tenv_files');
```

which reads the station names from the file Sample.Station.txt, uses the data related to the Eurasian plate ('EU'; if the second input argument is undefined or empty, the user interface shown in Fig. 3.2 appears to allow the choice of the plate. Clearly, the plate choice must be coherent, i.e. the corresponding NGL data must be available), and places the files in the folder (subfolder of the StaVel main folder) Tutorial/tenv_EU (if this folder does not exist, it is made by GetNevada function). For example, the name of the file related to the first station in a Windows machine is

```
Tutorial\ECNV.EU.tenv3
```

where '.EU' comes from the fact that EU (Eurasia) is the chosen plate and no an AddName input argument is defined and '.tenv3' is the default choice for the extension if the corresponding input argument is undefined as in this case (see Subsection 3.2 or type help GetNevada on the MCW for more information). Clearly, the input arguments of GetNevada function must be coherent with the StaVel general options about the Env files and the corresponding folder.
As GetNevada runs, these messages are shown by MCW:

```
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/ECNV.EU.tenv3 in progress...
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/ECNV.EU.tenv3 completed
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/EDEN.EU.tenv3 in progress...
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/EDEN.EU.tenv3 completed
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/EIIV.EU.tenv3 in progress...
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/EIIV.EU.tenv3 completed
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/GALF.EU.tenv3 in progress...
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/GALF.EU.tenv3 completed
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/HLNI.EU.tenv3 in progress...
Download of file http://geodesy.unr.edu/gps_timeseries/tenv3/plates/EU/HLNI.EU.tenv3 completed
```

The output variable status also shows that all the required data are successfully downloaded. Please note that, is not already available, the folder Tutorial, with the subfolder tenv_files, is generated.

5.2 Generation of tsData objects and raw mom files

The second step involves StaVelMain function. The option for the actions to be chosen in this case, i.e. OptsAct, is 2, to be entered in the command line or to be chosen with the user interface shown in Fig. 4.1 (GNU Octave users must necessarily use the command line with all the correctly defined input arguments). The two possibilities correspond to these command lines:

```
COut=StaVelMain('SampleStations.txt',2,OptsGen);
COut=StaVelMain('SampleStations.txt',[],OptsGen);
```

Please note that this command line

```
COut=StaVelMain;
```

is also valid in MATLAB (not in GNU Octave). In this case, all the input arguments are managed in an interactive way. Another example of valid command line is `COut= StaVelMain([],[],OptsGen)`. Other combinations of input arguments are also valid (please see Subsection 4.2 or type `help StaVelMain` for more information). Clearly, if `OptsGen` is among the input arguments, such a variable must be available in the workspace because a `geneOpts` session was carried out or the file `SampleOpts` was loaded before the specific `StaVelMain` session.

Regardless to the used command line, for the choice `OptAct=2` the `tsData` objects and the raw mom files are generated for each station listed in `SampleStations.txt` and placed in the folders chosen by means of `OptsGen`. Since no trends are estimated at this stage, the output variable `COut` is empty.

5.3 Download of data about offsets, inspection of the results, search of possible other offsets and generation of observation mom files

The NGL database also has data about offsets. Please note that in such a database the offsets are called steps. The reference page accessed by the function `NevadaAllOffset`, automatically called by `StaVelMain`, is http://geodesy.unr.edu/NGLStationPages/steps.txt. This tutorial shows the case of using the offsets available in the NGL database. The command line complete and also compatible with GNU Octave is:

```
COut=StaVelMain('SampleStations.txt',[3 3],OptsGen);
```

where `[3 3]` indicates Offsets recognition/taking ("first 3") and download of offsets by NGL database without subsequent manual offset check ("second 3"); see below for the manual offset check by using `StaVelMain`. MATLAB users can interactively select the corresponding options.
As `StaVelMain` runs with such a command, this is progressively shown on the MCW:

```
Offsets database loading in progress...
... Offsets database loaded
Station ECNV, no offsets from database
Station EDEN, offsets from database taken
Station EIIV, offsets from database taken
Station GALF, no offsets from database
Station HLNI, offsets from database taken
```

The `tsData` objects are upgraded and the observation mom files are generated. The message `no offsets from database` means that no offsets are known to NGL for the specific station. Also in this case, `COut` is empty.

It is undoubtedly advisable, and indeed necessary, to verify the validity of the information about offsets. For this reason, the next step is the inspection of the results, to be implemented using the `InspectOffsetSearch` function (please see Subsection 4.3 or type `help InspectOffsetSearch` on the MCW for more information about his function). As stated in Subsection 4.3, `InspectOffsetSearch` can the directly used, or called by StaVelMain.

5.3.1 *Direct use of* `InspectOffsetSearch`.

In the specific case, the command line is

```
InspectOffsetSearch('SampleStations.txt',OptsGen,1)
```

where the third input argument (`1`) allows the use of already available information on offsets, i.e., in this case, the information downloaded from NGL database (`true` is also a valid input for this option. If the user wants to exclude the available information, the third input variable should be `0`, `false`, `[]` or also undefined).
As the function runs, Fig. 5.1 appears (the figure name has the station name, in this case ECNV, and the whole time span of available data). A drop-down menu allows the choice of the zoom parameters to allow the choice of the offset dates, if this is required. The possible options are

```
ZOOM ON 14 DAYS TIME SERIES AROUND A SELECTED TIME
ZOOM ON 1 MONTH TIME SERIES AROUND A SELECTED TIME
ZOOM ON 6 MONTH TIME SERIES AROUND A SELECTED TIME
ZOOM ON ONE YEAR TIME SERIES AROUND A SELECTED TIME
FREE CHOICE OF TIME LIMITS
EXIT
```

If no offsets seem to exist, the better solution is `EXIT`. Please note that, when `EXIT` is pressed after the selection of one or more offsets, the specific `tsData` file is updated with the selected `offsetsE`, `offsetsN`, `offsetsV` properties. Similarly, the observation mom files are updated. If the observation mom files do not exist, they are generated.

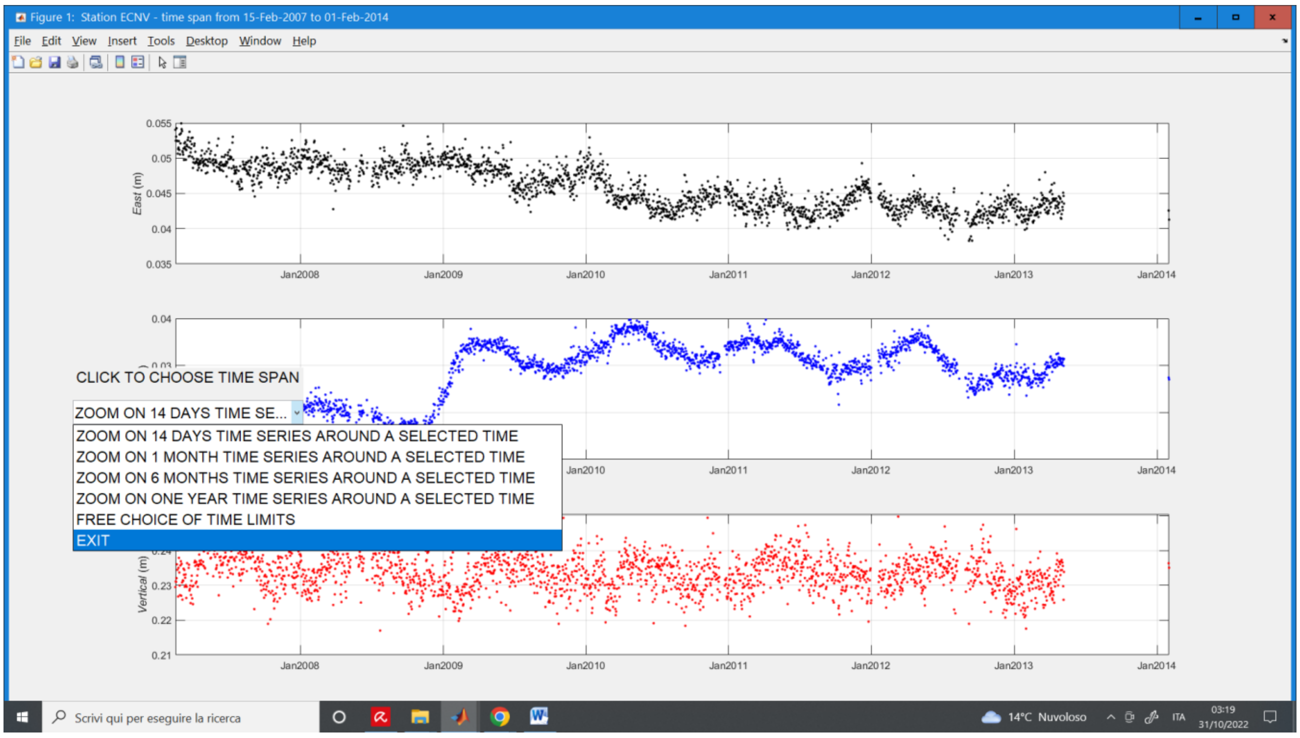


Figure 1: Station ECNV - time span from 15-Feb-2007 to 01-Feb-2014
File Edit View Insert Tools Desktop Window Help
East (m)
Vertical (m)
Jan2008
Jan2009
Jan2010
Jan2011
Jan2012
Jan2013
Jan2014
CLICK TO CHOOSE TIME SPAN
ZOOM ON 14 DAYS TIME SE...
ZOOM ON 14 DAYS TIME SERIES AROUND A SELECTED TIME
ZOOM ON 1 MONTH TIME SERIES AROUND A SELECTED TIME
ZOOM ON 6 MONTHS TIME SERIES AROUND A SELECTED TIME
ZOOM ON ONE YEAR TIME SERIES AROUND A SELECTED TIME
FREE CHOICE OF TIME LIMITS
EXIT
Scrivi qui per eseguire la ricerca
14°C Nuvoloso
ITA
03:19
31/10/2022

Figure 5.1 Time series related to the first station of the lists and related drop-down menu.

In the case of ECNV (first station of the sample list), no offsets are in the NGL database (if some such offsets existed, they would be shown in Fig. 5.1 in a similar way to that of Fig. 5.4 in the case of EIIV. However, an anomalous trend is observed for the N component around January 2009. This suggests the suppression of the corresponding segment of the time series of all the components and the introduction of an offset, limited to the N component, or the start time, or the termination of the deleted segment. To do this, the user first zooms on the time series, for example using the ass option, thus obtaining Fig. 5.2, whose drop-down menu offers various options:

```
OFFSET E-N-V (7)
OFFSET E-N (6)
OFFSET E-V (5)
OFFSET E ONLY (4)
OFFSET N-V (3)
OFFSET N ONLY (2)
OFFSET V ONLY (7)
DATE ACQUISITION ONLY
NO OFFSET, NO DATE
```

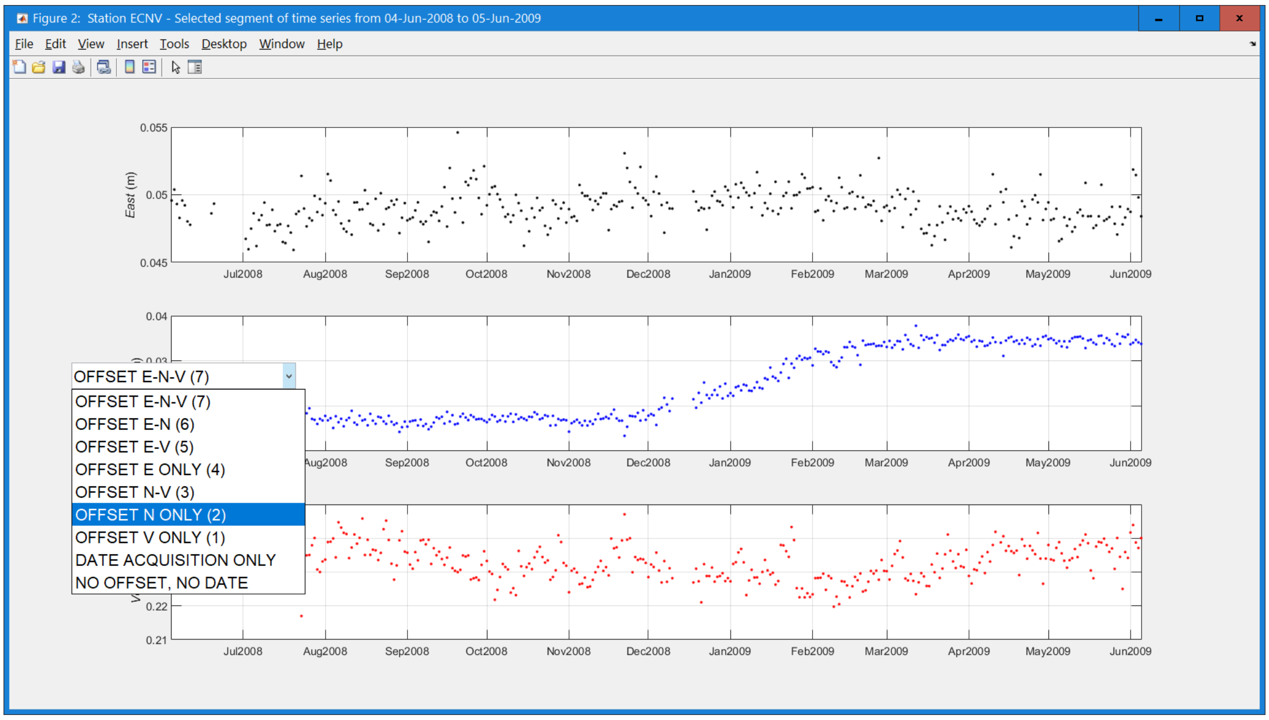
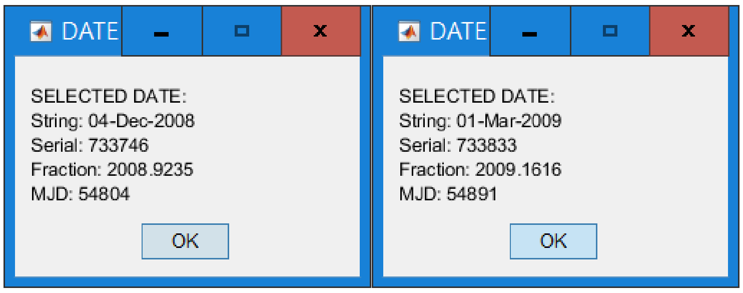


Figure 5.2 Zoom on time series and selection of the operation to be carried out.

The command `DATE ACQUISITION ONLY` allows the selection of the initial and final date of the segment to be removed (please note that the removal is not carried out in this stage; another function must be invoked, as shown below). As a selection is done, the zoom must be repeated on a figure like Fig. 5.1, where offsets, if selected, are shown as vertical lines. To allow escape is necessary, the command `NO OFFSET, NO DATE` closes the zoom figure without any change. In the specific case two dates are selected (Fig. 5.3) and an offset is recognized at the first of these dates. Therefore, three consecutive zooms are necessary.



SELECTED DATE:
String: 04-Dec-2008
Serial: 733746
Fraction: 2008.9235
MJD: 54804

SELECTED DATE:
String: 01-Mar-2009
Serial: 733833
Fraction: 2009.1616
MJD: 54891

Figure 5.3 Selection of initial and final date of the time series segment to be removed

As `EXIT` is selected, the time series of the second station, in this case EDEN, is shown, and so on. The `EDEN` time series does not require any action. The time series of the third station, `EIIV`, is more interesting (Fig. 5.4). An offset is provided by NGL database and anomalies can be seen around January 2019.

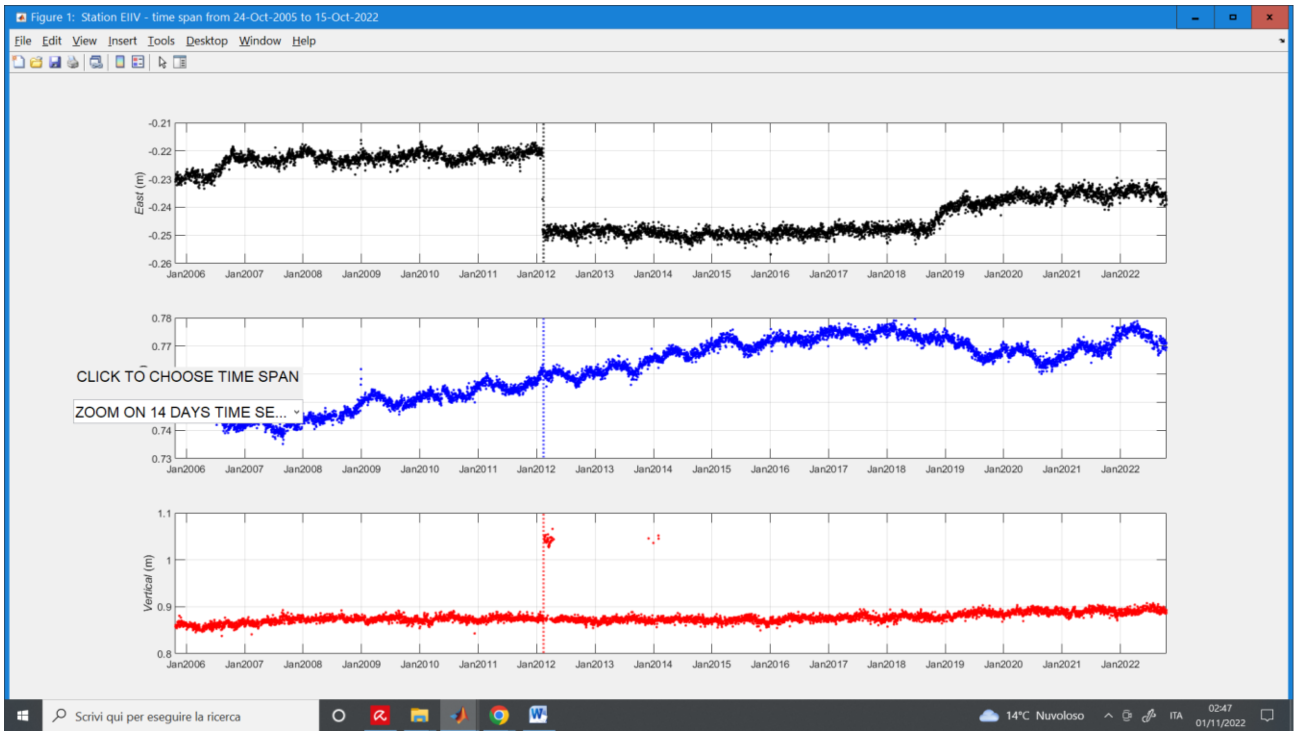


Figure 1: Station EIIV - time span from 24-Oct-2005 to 15-Oct-2022
File Edit View Insert Tools Desktop Window Help
East (m)
Vertical (m)
CLICK TO CHOOSE TIME SPAN
ZOOM ON 14 DAYS TIME SE...
Jan2006 Jan2007 Jan2008 Jan2009 Jan2010 Jan2011 Jan2012 Jan2013 Jan2014 Jan2015 Jan2016 Jan2017 Jan2018 Jan2019 Jan2020 Jan2021 Jan2022
Scrivi qui per eseguire la ricerca
14°C Nuvoloso
02:47 01/11/2022

Figure 5.4 Time series of a station where an offset is already known.

5.3.2 Calling `InspectOffsetSearch` *from* `StaVelMain`

The same result can be obtained by calling `InspectOffsetSearch` from `StaVelMain`. It the user wants to ignore possible already known offsets (such a choice corresponds to `InspectOffsetSearch` with third input argument undefined, empty of false), the command line should be

```
COut=StaVelMain('SampleStations.txt',[3 1],OptsGen);

COut=StaVelMain('SampleStations.txt',[3 2],OptsGen);

COut=StaVelMain('SampleStations.txt',[3 3],OptsGen);

COut=StaVelMain('SampleStations.txt',[3 5],OptsGen);
```

or equivalent interactive options.
If the user wants to manually check and, if necessary, integrate the offsets list, the command list should be

```
COut=StaVelMain('SampleStations.txt',[3 4],OptsGen);

COut=StaVelMain('SampleStations.txt',[3 6],OptsGen);
```

for the case of NGL or another database respectively.
In this case, NGL is used and, therefore, `OptAct=[3 4]` is the choice to carry out the above described activity in the same `StaVelMain` session in which the offset data are downloaded. The direct use of `InspectOffsetSearch` function, or the use of such a function called from `StaVelMain`, simply depends on user's wishes. There are no significant differences in the two cases.

5.3.3 Removal of time series segments

As an `InspectOffsetSearch` session (independent or called by `StaVelMain`) is completed, the problematic time series segments can be removed using the `tsSegmentRemoval` function (please see Subsection 4.4 or type `help tsSegmentRemoval` on MCW for more information about this function). The latter operates exclusively at the level of a single station in order to prevent incorrect cancellations. In the case of the `ECNV` station, the delete command is

```
tsSegmentRemoval('ECNV',OptsGen,[733746 733833]);
```

or, equivalently,

```
tsSegmentRemoval('ECNV',OptsGen,[733746 733833],'Obs');
```

where the dates, expressed in the serial MATLAB form, were previously found with `InspectOffsetSearch`. It is important to underline that the `tsSegmentRemoval` function updates and saves the `tsData` files and the observation mom files (or the raw mom files if indicated in the command line)[2]. The ECNV time series after this action is shown in Fig. 5.5. Such a figure can be obtained either with a new session of `InspectOffsetSearch`, or with a session of `InspOffsetMom` is the check is required for one or two stations and a manual approach is suitable. In this second case, the command line is

```
InspOffsetMom('ECNV',OptsGen,[],1)
```

(please type `help InspOffsetMom` on MCV for more information about this function).

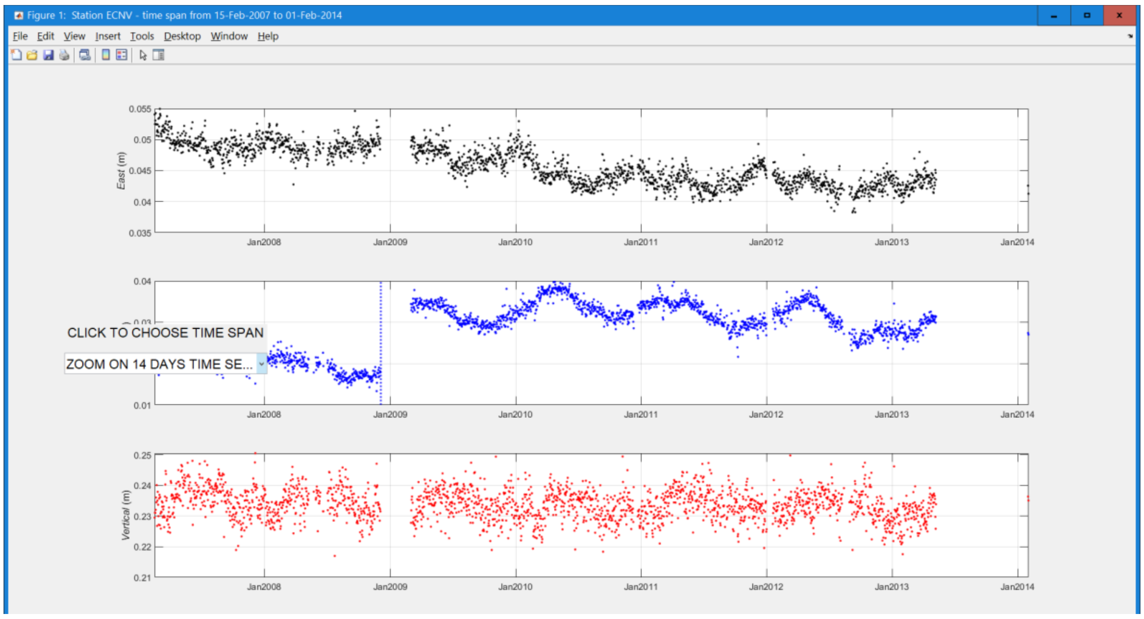


Figure 1: Station ECNV - time span from 15-Feb-2007 to 01-Feb-2014
File Edit View Insert Tools Desktop Window Help
East (m)
Vertical (m)
CLICK TO CHOOSE TIME SPAN
ZOOM ON 14 DAYS TIME SE...
Jan2008 Jan2009 Jan2010 Jan2011 Jan2012 Jan2013 Jan2014

Figure 5.5 ECNV time series after segment removal and offset recognition.

A similar action is required for EIIV time series. In this case, the corresponding command line is

```
tsSegmentRemoval('EIIV',OptsGen,[737365 737515]);
```

If the user is not interested to any previously known offsets, it is possible to obtain the same results achieved by means of `InspectOffsetSearch` using `StaVelMain` directly with the option

[2] The time series inspection and possible removal of time series sections can be carried out before or after the offset recognition. In this tutorial, the second approach is preferred, in which it is possible to observe the time series and make decisions on identifying offsets and removing any problematic time series segments at the same time. Clearly, if the inspection and eventual removal of time series segments are carried out before the search for offsets, the mom files to be updated are the raw ones (in this case, the fourth input argument for the `tsSegmentRemoval` function must be the string `'Raw'`).

`OptAct = [3 2]` (or interactive equivalent), i.e. the command line is `COut=StaVelMain('SampleStations.txt',[3 2],OptsGen)`. It is emphasized that this involves the loss of any previous information on offsets. The maintenance, if required, of previous data on offsets, possibly to be integrated by manual search, is the characterizing element of the `InspectOffsetSearch` function.

5.4 Outlier recognition, trend computation and evaluation of results

The data needed to complete the station velocity calculation are now available. To do this, the required command line is (`OptAct 6`)

```
COut=StaVelMain('SampleStations.txt',6,OptsGen);
```

(or, in MATLAB, the corresponding choices can be interactively taken).
Equivalently, it is possible to proceed first to search for outliers (`OptAct 4`), and then to compute velocities (`OptAct 5`).
As velocity data are available, the `COut` output variable is filled.
As the function works, this information is shown on the MCW for each station (in this case ECNV):

```
station ECNV, component 0 (E) - outlier removal in progress...
station ECNV, component 0 (E) - outlier removed
station ECNV, component 0 (E) - trend estimation in progress...
station ECNV, component 0 (E) - trend estimated
station ECNV - E, .\Tutorial\ts_files\ECNV.EU.mat tsData file updated
station ECNV, component 1 (N) - outlier removal in progress...
station ECNV, component 1 (N) - outlier removed
station ECNV, component 1 (N) - trend estimation in progress...
station ECNV, component 1 (N) - trend estimated
station ECNV - N, .\Tutorial\ts_files\ECNV.EU.mat tsData file updated
station ECNV, component 2 (V) - outlier removal in progress...
station ECNV, component 2 (V) - outlier removed
station ECNV, component 2 (V) - trend estimation in progress...
station ECNV, component 2 (V) - trend estimated
station ECNV - V, .\Tutorial\ts_files\ECNV.EU.mat tsData file updated
station ECNV, output cell row generated
```

The `tsData` file is upgraded for each component.

In the specific case, the output cell variable `COut` is:

```
ECNV  733088  735631  37.5956  14.7125  476.23   -1.398  -1.059  -0.372  0.186  0.263  0.283
EDEN  734629  738809  37.5231  14.3035  732.30   -1.996  3.250   -0.182  0.129  0.162  0.240
EIIV  732609  738809  37.5136  15.0821  88.89    0.734   2.372   1.485   0.112  0.114  0.266
GALF  733005  738048  37.7107  14.5665  731.40   -1.984  4.708   0.503   0.112  0.098  0.109
HLNI  734185  738809  37.3486  14.8719  133.272  -1.022  4.566   -0.048  0.053  0.090  0.153
```

The 12 columns are, in the order: station name; initial time (MATLAB serial form); final time; latitude (°); longitude (°); ellipsoidal elevation (m); East velocity (mm/y); North velocity (mm/y); Vertical velocity (mm/y); East velocity standard deviation (SD) (mm/y); North velocity SD (mm/y); Vertical velocity SD (mm/y).

It is possible to evaluate the obtained results by showing the time series and the modeled trends, i.e. the content of the mom files obtained by calculating the trend. The suitable function is `showMom` (please type `help showMom` on MCW for more information about this function). To show the results for all the mom time series and the final model, the command line is

```
showMom('SampleStations.txt',OptsGen,'mom')
```

As this function runs, a figure is generated for each station. This fact must be taken into account in the case of a large number of stations (if necessary, it may be advisable to split the contents of the station file).

The results in the case of HLNI station are shown in Fig. 5.6.

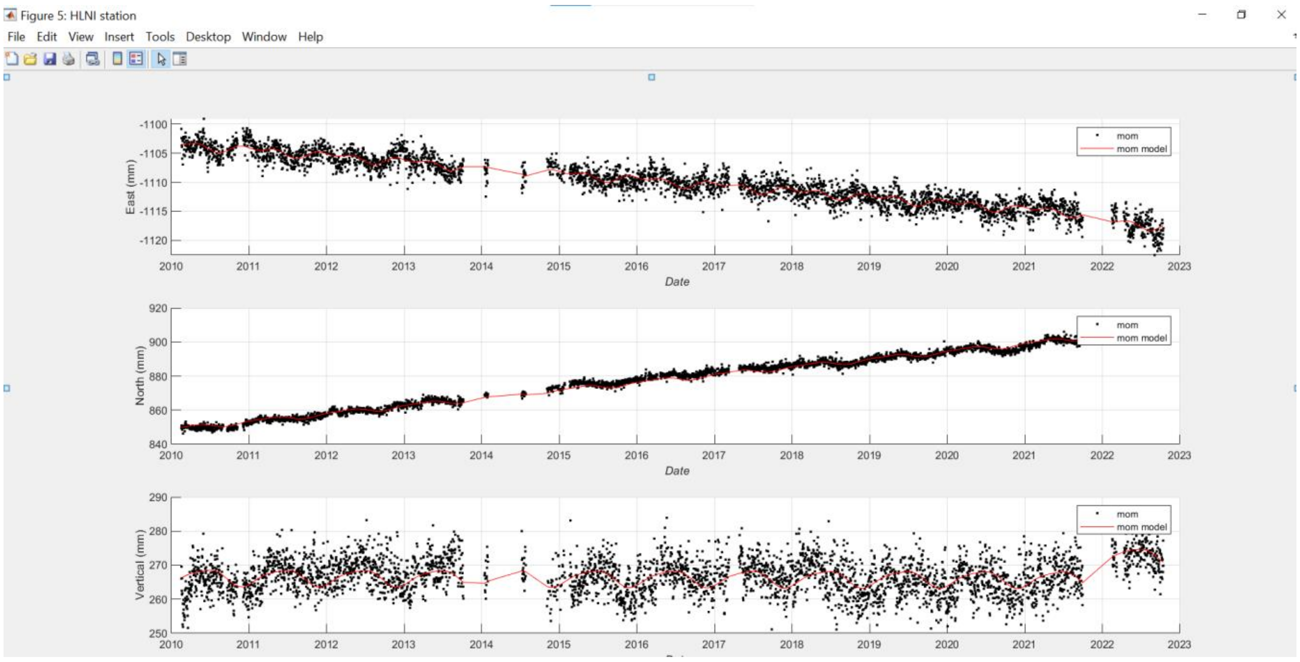


Figure 5.6 Mom time series and modeled time series for HLNI station.

The results seem to be satisfying for all the stations, except EDEN, for with a segment deletion and the introduction of offsets is required (this is left to the reader for exercise).

If the user wants to see the time series of all the mom files, including raw, observation and preprocessed, the command line is

```
showMom('SampleStations.txt',OptsGen,{'raw','obs','pre','mom'}).
```

If there are several stations and the user wants to see the time series for a station only, he/she can use `showMom` and redefine the file including the name of this station only, or use the function `showMomSingle`. In the case of HLNI, to show the mom time series and the model, i.e. to obtain the same result in Fig. 5.6 for this specific station, the command line is

```
showMomSingle('HLNI','.EU','Tutorial/mom_files','mom');
```

The different syntaxes of `showMom` and `showMomSingle` should be noted. Please refer to the corresponding helps for more information.

5.5 Velocity exportation to `GridStrain`

The obtained data can be exported to `GridStrain` by means of `geneGSFile` function (please see Subsection 4.5 or type `help geneGSFile` on the MCW). In order to generate the ASCII file 'TutorialVel.txt' with the station names (sixth input argument: is 1) starting from the cell variable provided by StaVelMain COut, with the horizontal components only (second input argument: 2), with minimum time series length 4.5 y, the command line is:

```
CCompl=geneGSFile(COut,'TutorialVel.txt',2,4.5,'33N',1);
```

This function also requires the choice of the UTM zone. This because `GridStrain` is incompatible with geographic coordinates but requires data expressed in a projected coordinate system. To obtain the results, the function `wgs2utm` by Alexandre Schimel (MetOcean Solutions Ltd, New Plymouth, New Zealand) is also used.

The output file shows these data:

```
ECNV   474617.6995  4160988.0314 -1.39845      -1.05895      0.186270      0.263388
EDEN   438454.0056  4153130.0115 -1.99602      3.249760      0.128591      0.161566
EIIV   507254.3131  4151853.8595 0.733491      2.371800      0.111879      0.113773
GALF   461792.5148  4173805.6890 -1.98372      4.707620      0.111877      0.0982456
HLNI   488658.5567  4133547.8445 -1.02225      4.565980      0.0529152     0.0902596
```

If the data are loaded within `GridStrain`, the resulting velocity vectors are in Fig. 5.7 (to obtain this figure, the files `TutorialMap.jpg` and `TutorialMap.mat` must be placed in `GridStrain` main folder together with the file generated by means of `geneGSFile`).

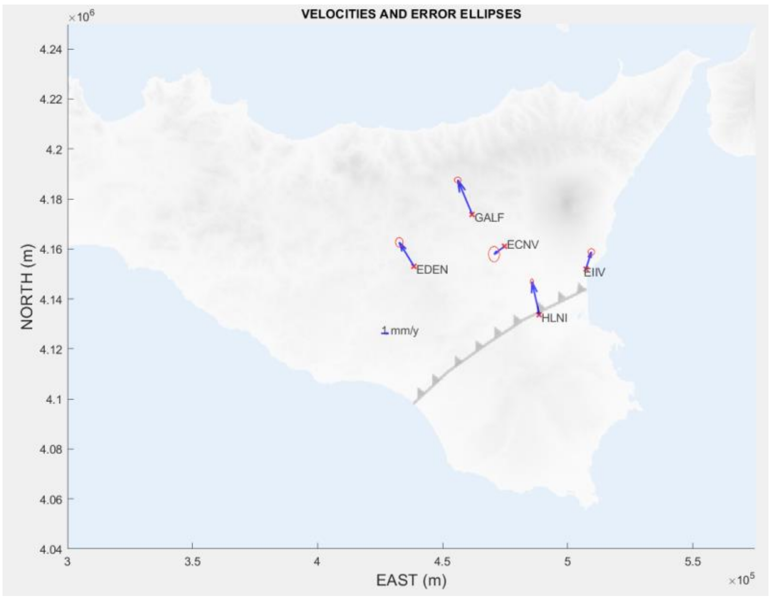


Figure 5.7 Velocities obtained with the tutorial, together with their 2-sigma (i.e. 95% confidence level) error ellipses (EU plate, WGS84UTM33 reference frame).

6. List of `StaVel` MATLAB functions

The list of MATLAB functions/scripts/objects is shown here. Besides the file name, a very brief description is shown for each function. The corresponding help can be seen by typing

```
help (function name)
```

on the MCW. For example, in the case of `StaVelMain`, the help can be accessed by typing

```
help StaVelMain
```

The main functions, which should be directly managed by the user in the standard `StaVel` computations, are highlighted with bold font. The other functions are generally called by the main functions, but can also be used in an autonomous way (please see the help for the allowed syntaxes). Please note that, if the toolbox is used under GNU Octave, some interactivities could be not allowed, i.e. the complete command lines should be used.

`addfromStruct`	Adding values to an object from a struct array
`CMEstackFiltering`	**Common mode error stack filtering**
`ctlFileEdit`	Editing a `.ctl` file (Hector control file)
`date2gpsw`	GPS week and day computation from date
`detrendZeroMean`	Computing detrended, zero mean time series
`frac2MJD`	Fractional year date to MJD conversion
`frac2serial`	Fractional year date to MATLAB serial date conversion
`geneGSfile`	**Generation of a .txt file for `GridStrain`**
`geneOpts`	**Generation of struct variable for `StaVel` options management**
`geneTrendFile`	Generates an Excel .xlsx file of GNSS station trends (this function is not used by `StaVelMain` but is proposed for those users who want to export the data to Excel).
`GetLonLat`	Get geodetic coordinates from Nevada Geodetic Laboratory (this function provides data only if the computer is online)
`GetNevada`	**Download one or more GNSS timeseries from Nevada database** (this function provides data only if the computer is online)
`gpsw2serial`	GPS week/day to serial date conversion
`InspectOffsetSearch`	**Inspection of several GNSS time series and offsets search**
`InspOffsetMom`	GNSS time series inspection and manual offset detection for a single station
`jsonRead`	Read a JSON file
`Leapy`	Search of leap years
`MJD2frac`	MJD to fractional year date conversion
`MJD2serial`	MJD to MATLAB serial year date conversion
`MosMom2MosNeu`	Conversion of a Mos matrix (i.e. an offsets matrix) from mom notation to CATS Neu notation
`MosMomGen`	Generation of a Mos matrix (mom notation) from a `tsData` object
`OptsGenLoad`	Interactive load of a `StaVel` options file
`NevadaAllSteps`	Takes all steps from Nevada database
`readStationList`	Read station list from an Excel or an ASCII file
`searchFilledFields`	Search of filled fields of a struct or an object
`serial2frac`	Date conversion from serial to fractional year

`serial2MJD`	Date conversion from serial to MJD
`serial2YMD`	Date conversion from serial to YYMMMDDD
`showMom`	**Show mom time series (several stations)**
`showMomSingle`	Show mom time series (single stations)
`StaVelMain`	**Main `StaVel` function**
`TrendExt`	Hector/CATS-based trend evaluation and data extraction (function not used by `StaVelMain` but added for the users who want use CATS instead of Hector)
`TrendExtJSON`	Trend extraction from a JSON file generated by Hector
`tsData`	Generation of a `tsData` object
`tsDataFileIn`	Access to a `tsData` file
`tsSegmentRemoval`	**Removal of one or more time series segments**
`txtReadData`	Header and data extraction from a txt file
`txtWriteData`	Header and data write to a txt file
`verCoorLonLat`	Verification and correction of lon/lat/height coordinates
`wgs2utm`	Coordinate conversion from WGS84 to UTM (external function by Alexandre Schimel, MetOcean Solutions Ltd, New Plymouth, New Zealand).
`wlinfit`	least square straight line fit
`writeNeuMom`	Write one or more .neu/.mom files for CATS/Hector
`YMD2serial`	Date conversion from YYMMMDD to MATLAB serial date

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GridStrain

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User's guide

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Table of contents

1. Introduction

`GridStrain` is the upgraded version of `grid_strain` MATLAB^{TM} toolbox described in and Pesci and Teza (2007), which is conceived for easy and quick calculation of the 2D deformation field (or the 2D deformation rate field) in a region, starting from the displacements (or the velocities) of a series of observational points adequately distributed in this region. The obtained deformation pattern is shown as a set of the principal components of the strain (strain rate) calculated on the nodes of a regular grid whose limits and steps can be chosen by the user. See Teza et al., (2008) and Pesci and Teza (2007) for a general description of the implemented approach and some examples of its application on GPS-based, regional scale analysis of a strain field. The computations are performed in a modified least square approach (MLS), as described in Shen et al. (1996). The upgraded version is described in Teza et al. (2022) together with an application.
The main changes with respect to the previous releases (i.e. the various versions of grid_strain toolbox) are:

- The introduction of a struct variable `GSS`, which can be updated as different `GridStrain` stages are executed, whose fields are all the data and results of computations. Although `GSS` is used like an object, it is not an object and, therefore, no methods are associated to it;
- Upgraded interactive interfaces. Menu boxes are removed and replaced by user interfaces and dialog boxes;
- Useless options are removed;
- Upgraded visualization functions;
- Upgraded data saving options. In particular, if ASCII data are to be exported, ArcGIS-like `.asc` files can be saved.

The 3D version of `GridStrain/grid_strain` is `grid_strain3`. The calculations are performed in this case on the points of a digital terrain model (DTM). See Teza *et al.* (2008a) for further information. The results of an application of both toolboxes to two landslides are presented in Teza *et al.* (2008b).

The toolboxes, which are sets of functions called by the main programs (`GridStrain.m` and `grid_strain3.m` respectively), also provide significance evaluations. This because a result related to a grid node (a DTM point in the 3D case) can be really used only if the observational points are well distributed around it. In particular, three levels of significance are defined: high, mid and low, according to the user's choice (see below).

The typical and simplest sequence to follow is:

1) Data logging, visualization and management;
2) Grid creation and/or modification;
3) Definition and/or change of the smoothing factor *d0*;
4) For each grid point, evaluation of:
    - strain rate tensor;
    - trace of the strain rate tensor, leading to rate of change in area and rate of normalized shear;
    - second invariant of the train;
    - geometric significance of the results;
5) Data visualization.

The function `StrainZero` (computation of 2D strain on a point without grid) is included in `GridStrain` toolbox.

The toolboxes surely run under MATLAB^{TM} 2018a or later releases (Some actions aimed at allowing use with much older versions of MATLAB were however implemented. For example, whether a figure is an object or not is automatically verified). For any question, or also suggestion, please contact the authors (the Email addresses are shown in the cover of this user’s guide).

2. Toolbox installation and program running

The toolbox `GridStrain` is contained in zip file `GridStrain.zip`. The files should be extracted and saved in a MATLAB directory whose name should be `GridStrain`. For example, if the MATLAB work directory is:

```
C:\Users\john.doe\Documents\MATLAB\,
```

the toolbox can be saved and accessed with this path:

```
C:\Users\john.doe\Documents\MATLAB\GridStrain .
```

Please note that, if MATLAB operates under an Unix environment, "/"must be used instead of "\".
If the directory `GridStrain` is saved in the default directory on which MATLAB command window operates, the directory change must carried out before the toolbox run. This change is obtained simply typing on the MATLAB command window (MCW):

```
cd GridStrain
```

The program runs by typing

```
GridStrain
```

on this MCW. All the necessary functions are automatically called by the principal program. The toolbox runs on different platforms (Windows, Linux).

The `grid_strain3` toolbox is contained in the directory `grid_strain3`, compressed in the zip file `grid_strain3.zip`.

In order to call the program whichever is the current MCW directory, a startup file can be written by the user. For example, if the `GridStrain` toolbox is placed in the directory '`C:\Users\john.doe\Documents\MATLAB\GridStrain`', `grid_strain3` is placed in the corresponding directory and Windows is the operating system, the rows

```
addpath 'C:\Users\john.doe\Documents\MATLAB\GridStrain;
addpath 'C:\Users\john.doe\Documents\MATLAB\grid_strain3'
```

should be added to the `startup.m` script. If a file named `startup.m` is placed in the MATLAB work directory, it is automatically executed at each MATLAB start. In this way, all the defined search paths are automatically added at each MATLAB start and the directory changes to use `GridStrain` and `grid_strain3` are unnecessary. The functionalities of these toolboxes do not depend on user's choice about the startup. More information about `addpath` function in a startup file can be found in http://www.mathworks.it/it/help/matlab/ref/ addpath.html.

Another option is the use of the Set Path dialog box, which appears by typing

```
pathtool
```

on the MCW or by selecting `Set Path` in `Home menu` of MATLAB desktop. The button `Add Folders` allows the choice of the folder and other buttons allow the choice of the folder order for the search of the files. Please see http://www.mathworks.it/it/help/matlab/matlab_env/using-the-matlab-search-path.html to have more information about the `Set Path` dialog box.

All provided functions are MATLAB `.m` files that can the opened and, if necessary, modified by the user. In this way, an expert user can modify, for example, the data saving options.

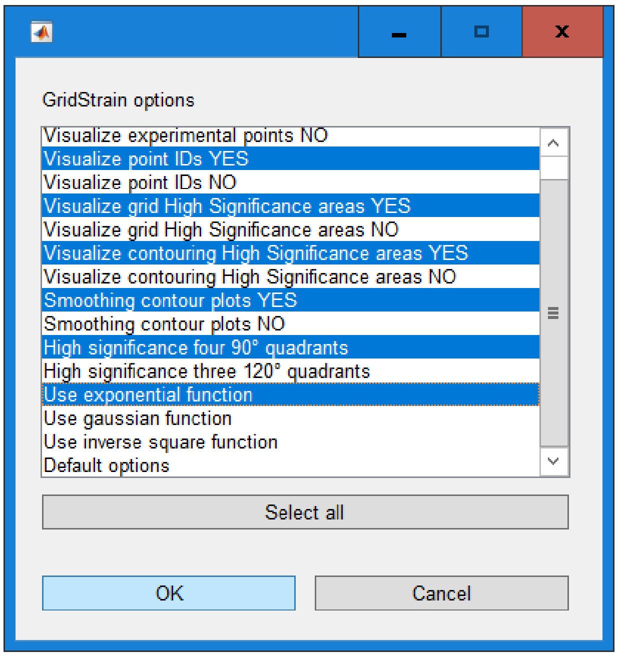
2D version (`GridStrain` *and* `StrainZero`)

3. Options

3.1 `GridStrain` general saved options

The `GridStrain` general saved options are managed by means of `GridStrainOptions` function.
Two possible syntaxes are allowed:

```
GridStrainOptions
Options=GridStrainOptions
```


GridStrain options

Visualize experimental points NO
Visualize point IDs YES
Visualize point IDs NO
Visualize grid High Significance areas YES
Visualize grid High Significance areas NO
Visualize contouring High Significance areas YES
Visualize contouring High Significance areas NO
Smoothing contour plots YES
Smoothing contour plots NO
High significance four 90° quadrants
High significance three 120° quadrants
Use exponential function
Use gaussian function
Use inverse square function
Default options

Figure 3.1 Interactive management of `GridStrain` options

If no output is considered, a modal box (Fig. 3.1) allows the management of main options related to `GridStrain` and save the file `GSOptions.mat`.
If an output is considered, no modal box is shown. In this case, if the file `GSOptions.mat` exists, the options related to this file are used. If the file `GSOptions.mat` does not exist, the default choices are used.
Options:

Option	Possible values	Default value
`Options.VisualizePoints`	`true / false`	`true`
`Options.VisualizePointIDs`	`true / false`	`true`
`Options.VisualizeGridHSA`	`true / false`	`true`
`Options.VisualizeContourHSA`	`true / false`	`true`
`Options.Function`	`'exp'/'gaussian'` `'inverse square'`	`'exp'`

where

`Options.VisualizePoints` is referred to the visualization of experimental points in strain plotting (i.e. this option does not apply in plotting for data loading and possible selection and removal of some stations);

`Options.VisualizePointIDs` is referred to the visualization of point IDs (numeric or station name, depending on input file) in both dataload and strain plotting (in the case of strain plotting, this option acts under the condition that `Options.VisualizePoints` is true);

`Options.VisualizeGridHSA` is referred to the grid visualization in case of plotting in high significance areas (or high and mean significance areas);

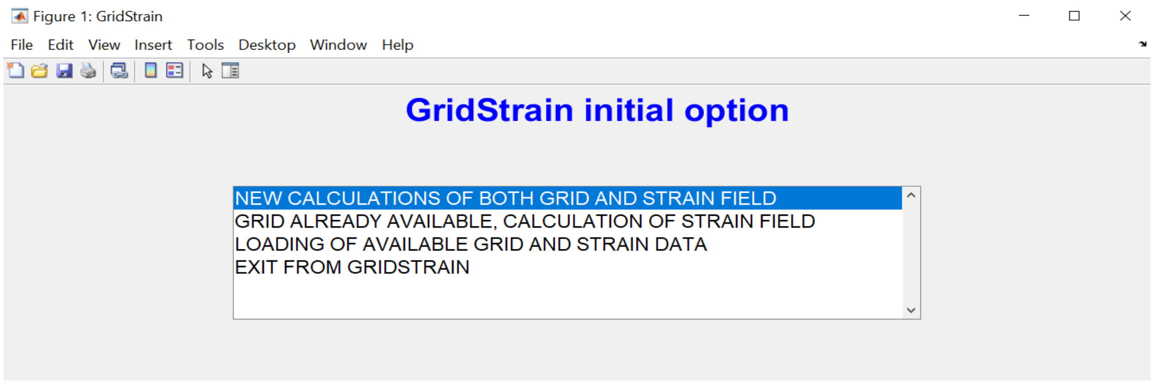
`Options.VisualizeContourHSA` is referred to the visualization of contour plots of strain in in high significance areas (or high and mean significance areas);

`Options.Function` is referred to the choice of the function, i.e. `'exp'` for $\exp(-d/d0)$, `'gaussian'` for $\exp(-(d/d0)^2)$ and `'inverse square'` for $1/[1+(d/d0)^2]$.

If the user interactively selects two incompatible choices (e.g. both true and false for `VisualizePoints`), the corresponding default value is used. In the no-choice case, all default values are used.

3.2 Initial options, data importation, visualization and management

When the program starts an interactive window appears and the user can import a new data file or use previously saved data.



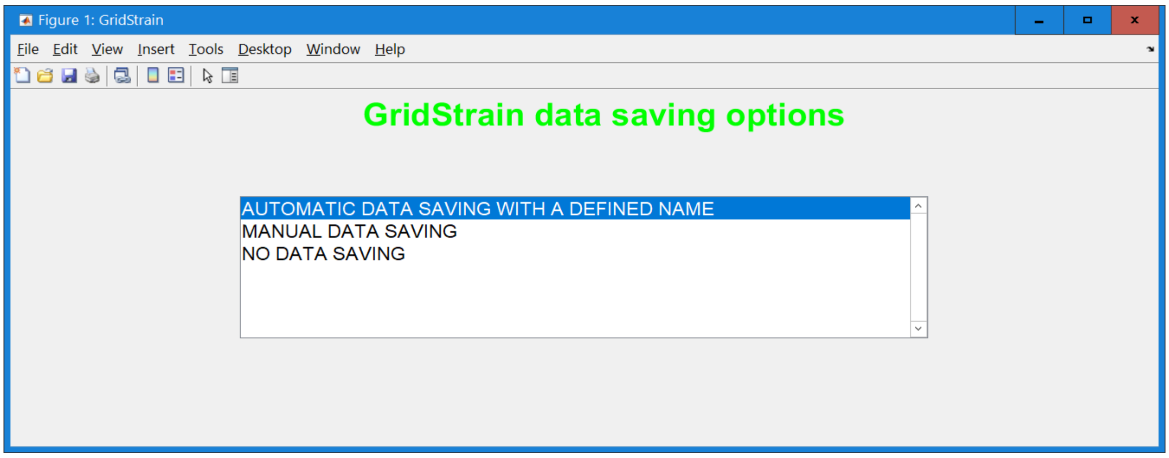
GridStrain initial option

NEW CALCULATIONS OF BOTH GRID AND STRAIN FIELD
GRID ALREADY AVAILABLE, CALCULATION OF STRAIN FIELD
LOADING OF AVAILABLE GRID AND STRAIN DATA
EXIT FROM GRIDSTRAIN

Figure 3.2. Top: the first menu interface. Bottom: dialog box for ASCII filename choice.

After the choice of the initial option, if an option different from “`EXIT FROM GRIDSTRAIN`” is chosen, a second interactive window allows the choice of the general saving option (Fig. 3.3). In this way, the user can choose one of the following options:

- Automatic data saving with a defined name of the generated files. In this case, the filenames are automatically generated. If, for example, `CommonPart` is the string chosen by means of a input dialog box which appears if the selected option is “`AUTOMATIC DATA SAVING WITH A DEFINED NAME`”, the automatically generated files are `CommonPart2DG.mat` (grid data) and `CommonPart2DSFxxx.mat`, where xxx is the chosen scale factor (e.g. 10000 if the scale factor is 10000 m, i.e. 10 km).
- Data saving with filenames interactively managed.
- No saving. In this case, the saving function is always excluded.

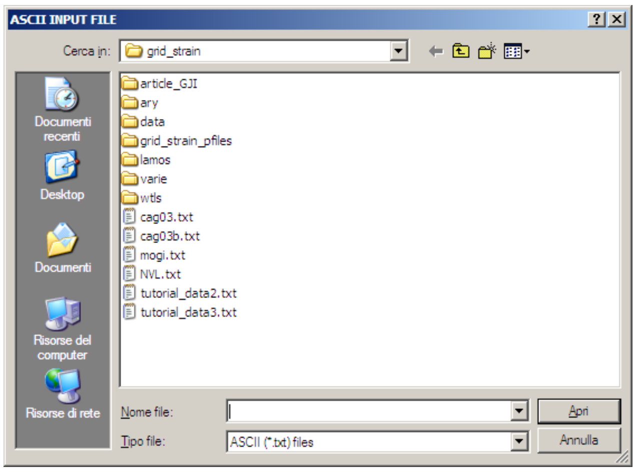


GridStrain data saving options

AUTOMATIC DATA SAVING WITH A DEFINED NAME
MANUAL DATA SAVING
NO DATA SAVING

Figure 3.3. Data saving options.

After the choice of the data saving option, if the chosen initial option is “`NEW CALCULATION OF BOTH GRID AND STRAIN FIELD`”, a combo box allows the choice of the input file name (Fig. 3.4), that must have ASCII format. The ASCII file `tutorialData2.txt` is added to the toolbox for tutorial purposes.



article_GJI
ary
data
grid_strain_pfiles
lamos
varie
wtls
cag03.txt
cag03b.txt
mogi.txt
NVL.txt
tutorial_data2.txt
tutorial_data3.txt

ASCII (*.txt) files

Figure 3.4 Interactive choice of the input ASCII file

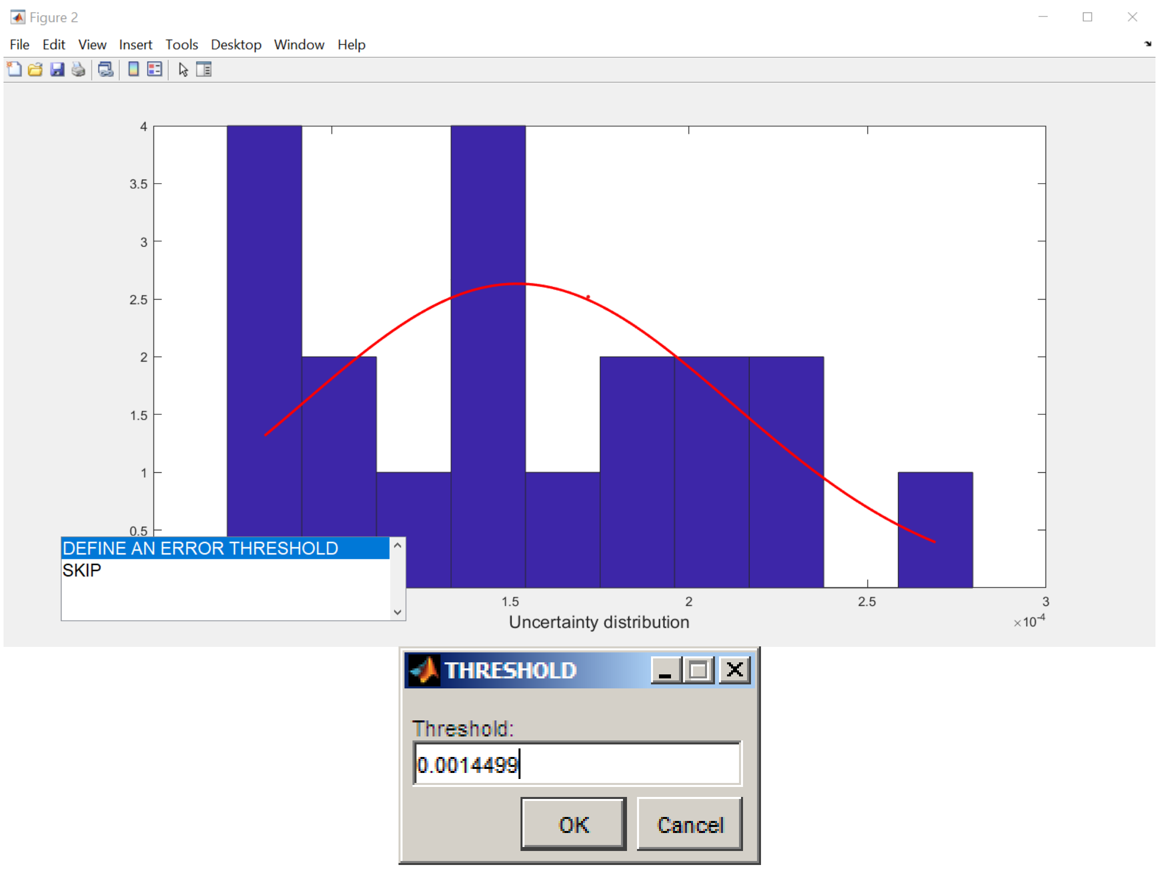
There are some options for the input file. It can be a 10-column numerical matrix. The columns represent the data (with this order):

1	*ns*	station identifier (an integer number)
2	*e*	east coordinate, expressed in m
3	*n*	north coordinate, m
4	*ve*	east velocity (or east displacement) expressed in mm/y (or mm)
5	*vn*	north velocity (or north displacement) mm/y (or mm)
6	*eve*	root mean square (rms) error on *ve*, mm/y (or mm)
7	*evn*	rms error on *vn*, mm/y (or mm)
8	*a*	length of major half-axis of error ellipse, mm/y (or mm), *optional*
9	*b*	length of minor half-axis of error ellipse, mm/y (or mm), *optional*
10	*theta*	azimuth of major axis of error ellipse, degrees, *optional*

The last three columns are optional. If the file contains 7 columns only, the error ellipses are assumed to have the axes parallel to east and north direction respectively, with half-axes length simply expressed by *eve* and *evn*. If the number of columns is smaller than 7, the data load cannot be performed. In this case, the choice of other filenames is possible. Although the coordinates are conceived as expressed in m and the displacements in mm, a check is performed in order to detect if the displacements are expressed in m instead. If this fact is suspected, a menu box in shown to allow the confirmation or exclusion of this suspect (the user is always guided in each choice).

Another option on the input ASCII file is:

1	*statName*	station name (four characters string)
2	*e*	east coordinate, expressed in m
3	*n*	north coordinate, m
4	*ve*	east velocity (or east displacement) expressed in mm/y (or mm)
5	*vn*	north velocity (or north displacement) mm/y (or mm)
6	*eve*	rms error on *ve*, mm/y (or mm)
7	*evn*	rms error on *vn*, mm/y (or mm)
8	*a*	length of major half-axis of error ellipse, mm/y (or mm), *optional*
9	*b*	length of minor half-axis of error ellipse, mm/y (or mm), *optional*
10	*theta*	azimuth of major axis of error ellipse, degrees, *optional*



Threshold:
0.0014499

Figure 3.5 Upper panel: distribution of the input displacements (or velocity) uncertainties, shown for a possible error-based thresholding. The Gaussian model of the distribution is also shown (obviously, in the specific case such a model is inadequate because a strong tail exists. Each result provided by `GridStrain` requires an interpretation. No abilities in Computer Science are necessary, but a good knowledge of the studied phenomenon, as well as of basic statistics, is required). Lower panel: threshold definition (this dialog box appears if "`DEFINE AN ERROR THRESHOLD`" is selected)

Obviously, also in this case the columns can be 7 instead of 10. As the input file is loaded, the distribution of displacements (or velocity) errors is shown (Fig. 3.5) together with a user interface

(UI) control for the choice of an optional error threshold (Fig. 3.5, top). In this way, the user can define a lower threshold for the uncertainties of the experimental points (EPs) by acting on an input dialog box (Fig. 3.5, down). This threshold is referred to the squared sum of the *x*- and *y*-component errors. In particular, if the user defines a threshold, for the EPs whose squared sum of the displacement (or velocity) uncertainties are lower than this threshold, the uncertainties for both the components are now equal to such a threshold. The uncertainties related to the EPs whose squared sum of the *x*- and *y*-component errors are higher than the threshold are the initial values instead. Finally, a menu box allows the conformation of the threshold, the choice of a different threshold, or also the exclusion of the threshold. The corresponding Gaussian distribution of probability density is also shown. It should be noted the fact that, if large part of the stations have very similar uncertainties, the distribution can be strongly peaked with a low-significance tail.

The next step is the visualization of the displacement (or velocity) vectors, which are plotted together with their error ellipses (Fig. 3.6). If the optional error thresholding was carried out (see above), the error ellipses are the ones defined by such a thresholding. The user can introduce a background image by acting on a UI control. In order to avoid license issues related to Google Earth, the background image should be already available and manageable in this way:

- The image is stored as a JPEG or a TIFF file with a filename like, e.g., `'MyBGImage.jpg'`;
- a MATLAB .mat file having the name `'MyBGImage.mat'`, i.e. the same name of the image file but extension `.mat`, having a variable `ALI` whose value is the vector `[Xdatamin, Xdatamax, Ydatamin, Ydatamax]` with the coordinates of the vertices of the area represented by the image, expressed in the same reference frame of the input velocity data.

If a background image is used, the axis limits are the ones of the input velocities, regardless to the limits related to the field `ALI` (see Figures 3.7 and 3.8). The filename of the input MATLAB file or of the image file can be interactively managed in the standard way by means of a combo box (in the second case, the name of the file carrying the struct variable must be the same of the image file, clearly unless file extensions).

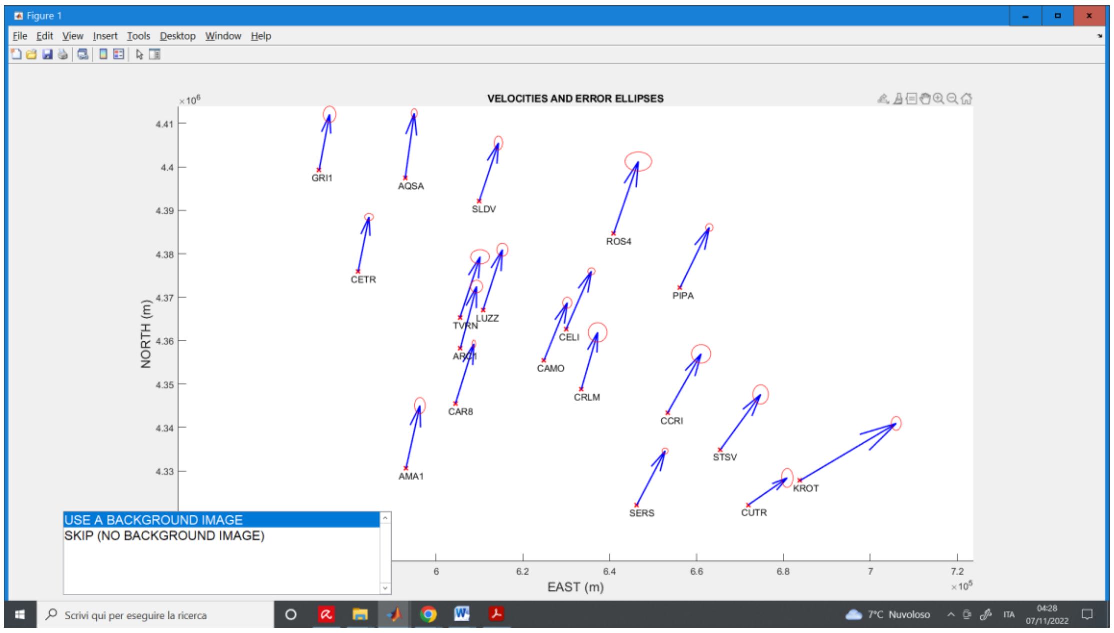


Figure 3.6 Velocity field and possible choice of a background image

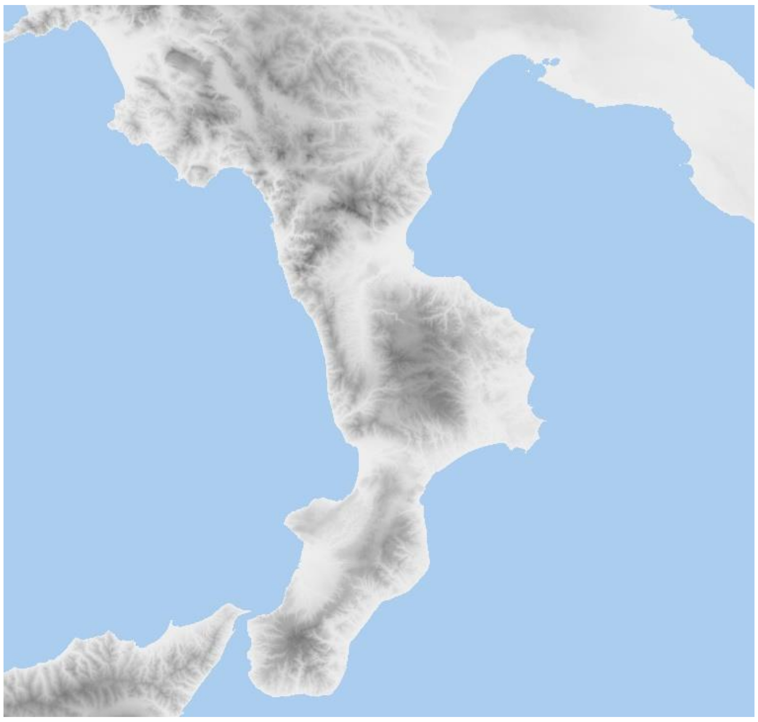


Figure 3.7 Example of background image, whose area is significantly higher than the one related to the velocity vectors (please see Figs. 3.6 and 3.8)

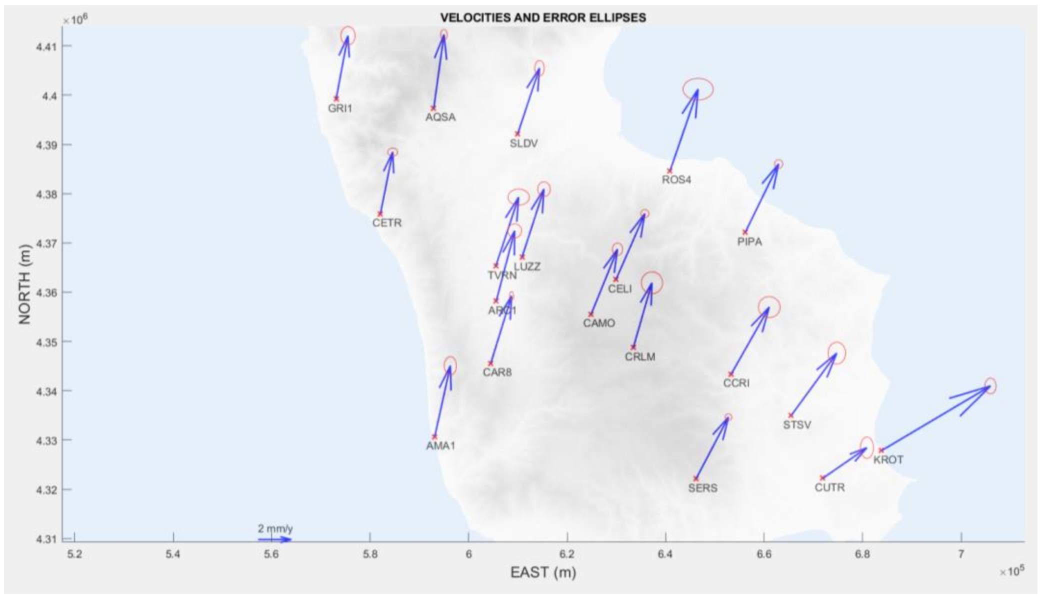


Figure 3.8 Velocities (with corresponding error ellipses) drawn on the background image

A complementary function allows the direct generation of a background image (included the struct variable above described) starting from an ASCII `.asc` digital elevation model (DEM) in ESRI format exported from a GIS software (please see the description of `gs_refDTMImage`, Chapter 8).

The input data are managed by means of `gs_dataload` function, which is automatically called by `GridStrain`. The function can be used autonomously. The valid syntaxes are

```
GSS=gs_dataload
GSS=gs_dataload(filena)
```

where `filena` is the input ASCII file. If `filena` is undefined or empty, the filename can be managed in an interactive way. Please type `help gs_dataload` on MCW for more information.

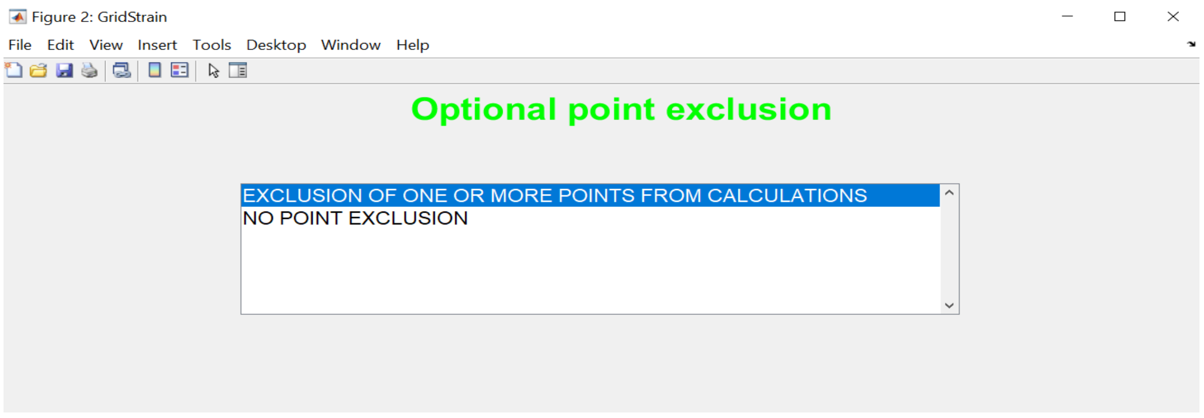
Regardless to the fact that `gs_dataload` is called by `GridStrain` or is used in autonomous way, the struct variable `GSS` is generated. The generation of `GSS` variable is the main innovation with respect to the `grid_strain` releases. In this first `GridStrain` stage, the `GSS` fields are:

`StationID`	(empty if `statName` is the first column in the input file)
`StationName`	(empty if `ns` is the first column in the input file)
`East`	
`North`	
`EastVelocity`	
`NorthVelocity`	
`EastVelocityError`	
`NorthVelocityError`	
`ErrorEllipsea`	(if the input file has 7 columns, it is equal to `EastVelocityError`)
`ErrorEllipseb`	(if the input file has 7 columns, it is equal to `NorthVelocityError`)
`ErrorEllipsetheta`	(if the input file has 7 columns, it is a vector of zeros)
`RefImageStruct`	(empty if no a background image is used)

The last field, i.e. `RefImageStruct`, if non-empty, is a struct variable with two subfields, i.e. `RefImageStruct.Image` (name of the background image file, including path) and `RefImageStruct.Vertices` (name of the vertices file, including path, see above).

Note that the output velocities and related uncertainties are always expressed in m/y to allow their direct use in strain computation, regardless to the unit used (m/y or mm/y) in the input ASCII file, and this despite the fact that the preferred input velocities are in mm/y. Clearly, if displacements are used, the `GSS` output data are expressed is mm.

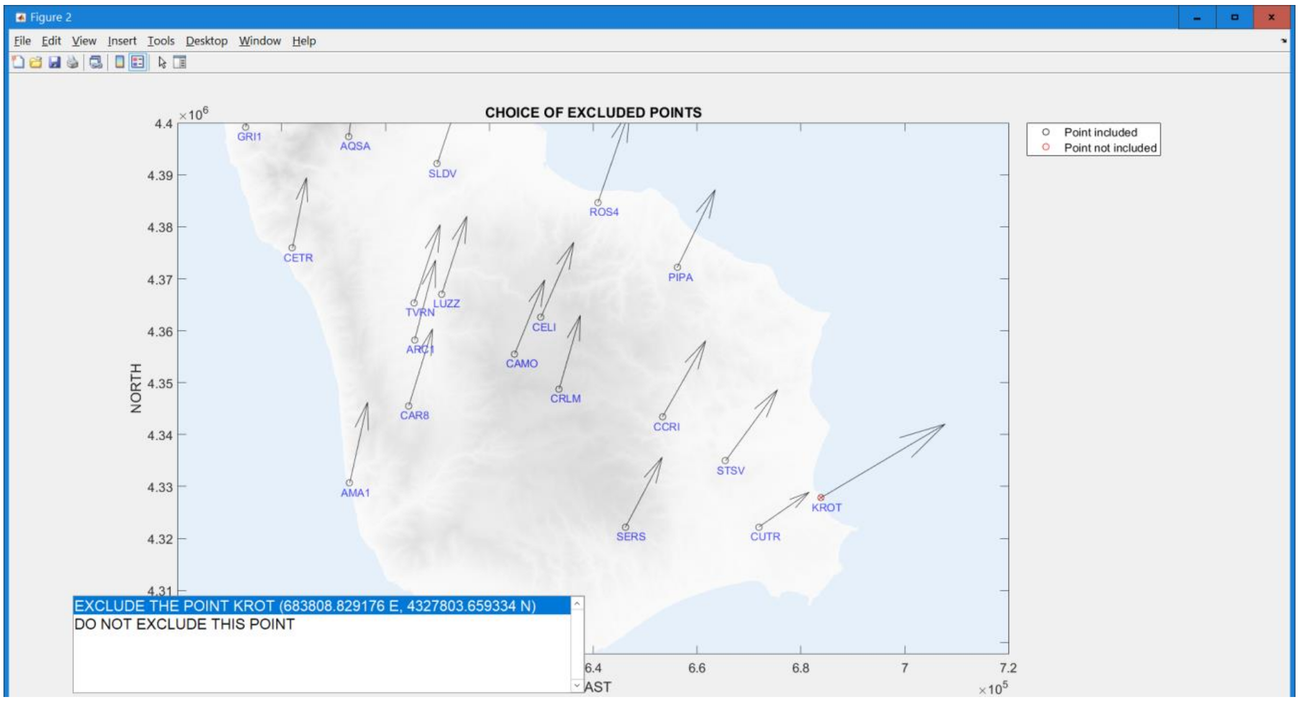
Regardless to the presence of the optional background image, the next step is the optional removal of one or more EPs. An interactive image allows the choice between "`EXCLUSION OF ONE OR MORE POINTS FROM CALCULATIONS`" and "`NO POINT EXCLUSION`" (Fig. 3.9). If the first option is chosen, the point to be removed can be chosen by means of mouse (the EP closest to the selected position on the screen is the selected one). The selected EP is highlighted in a figure and an UI allows the selection confirmation (Fig. 3.10). This operation can be repeated more times, until at least two data points are available.



Optional point exclusion

EXCLUSION OF ONE OR MORE POINTS FROM CALCULATIONS
NO POINT EXCLUSION

Figure 3.9 Optional point exclusion



EXCLUDE THE POINT KROT (683808.829176 E, 4327803.659334 N)
DO NOT EXCLUDE THIS POINT

Figure 3.10 Details on selected point and removal confirmation.

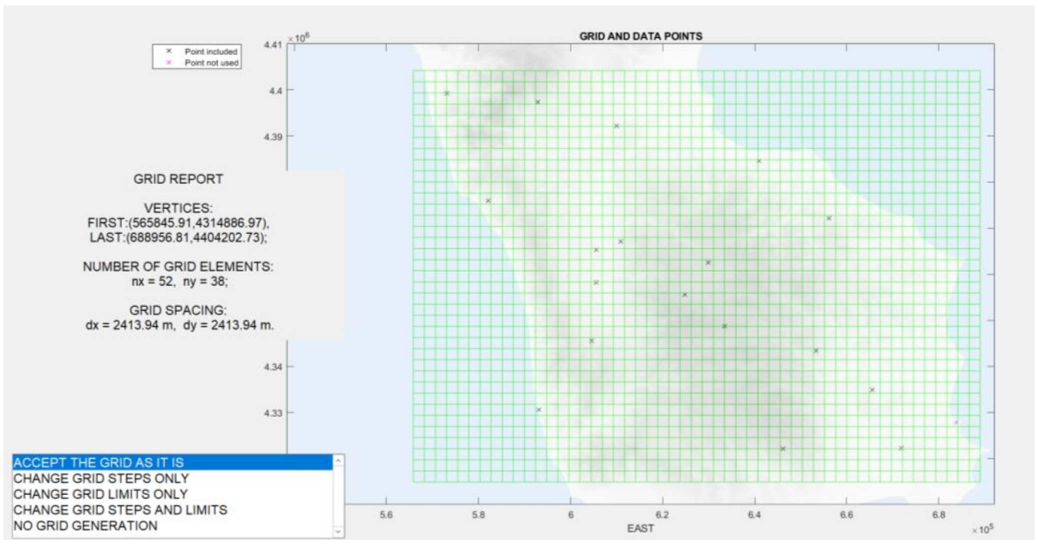
The optional exclusion of one or more EPs is carried out by means of `gs_nopoints` function, which is automatically called by `GridStrain`. This function can also be used in autonomous way. The valid syntax is:

```
GSSOut=gs_nopoints(GSS)
```

where the input struct variable `GSS` is as in `gs_dataload`. This function shows the points and the correspondent arrows and allows the exclusion of one or more points by means of magnification of the corresponding errors. The field `IncludedPoints`, whose value is a logical vector, is added to `GSS` (the name of the output variable also is `GSS` if `gs_nopoints` is called by `GridStrain`, an `GSSOut` if `gs_nopoints` is called by means of the above described command line). In particular, `npe=GSSOut.IncludedPoints` is such that the point `[e(m) n(m)]` is included if `npe(m)` is true and `[e(m) n(m)]` is excluded if `npe(m)` is false instead. If the field `IncludedPoints` already exists in GSS, the points for which `npei=GSS.IncludedPoints` is false are considered to be already excluded.

4. Grid creation and/or modification

The program automatically computes the grid length based on station baselines (in general, on spacing of the experimental points). The standard deviation of all the inter-distances between point pairs is computed and proposed as default value. A first grid is shown together with the data about the grid (Fig. 4.1). Together the grid, both the accepted and refused points in the previous step are shown. The user can interactively accept or refuse the proposed grid. If the grid is not accepted, both the grid step and grid size can be modified. In particular, the grid step can be changed by means of an input dialog box. The grid vertices can be interactively changed by either selecting the new lower left and the upper right corners on the figure or by means of an input dialog box. An example of edited grid is shown in Fig. 4.2.



GRID REPORT

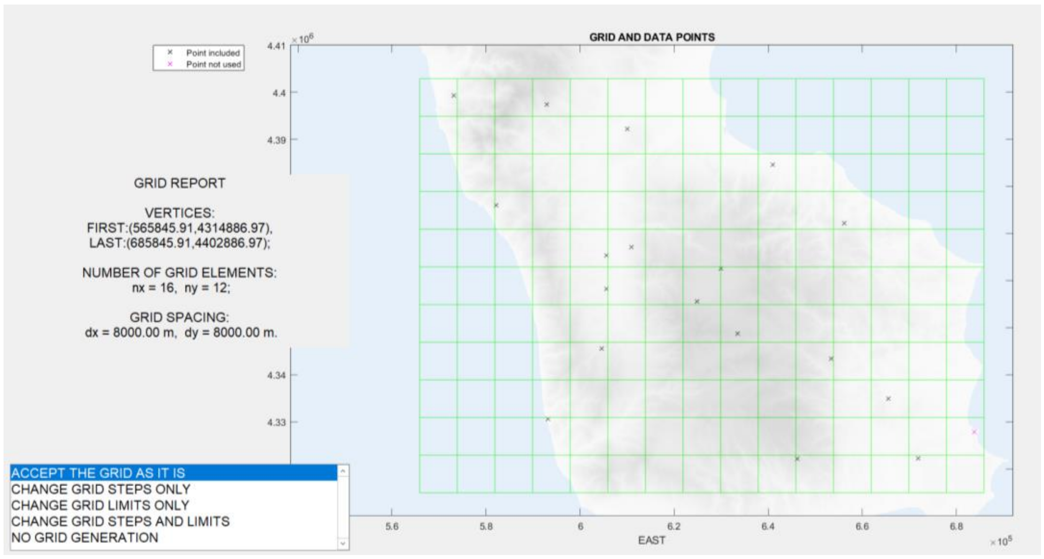
VERTICES:
FIRST:(565845.91,4314886.97),
LAST:(688956.81,4404202.73);

NUMBER OF GRID ELEMENTS:
nx = 52, ny = 38;

GRID SPACING:
dx = 2413.94 m, dy = 2413.94 m.

ACCEPT THE GRID AS IT IS
CHANGE GRID STEPS ONLY
CHANGE GRID LIMITS ONLY
CHANGE GRID STEPS AND LIMITS
NO GRID GENERATION

Figure 4.1 Example of default grid



GRID REPORT

VERTICES:
FIRST:(565845.91,4314886.97),
LAST:(685845.91,4402886.97);

NUMBER OF GRID ELEMENTS:
nx = 16, ny = 12;

GRID SPACING:
dx = 8000.00 m, dy = 8000.00 m.

ACCEPT THE GRID AS IT IS
CHANGE GRID STEPS ONLY
CHANGE GRID LIMITS ONLY
CHANGE GRID STEPS AND LIMITS
NO GRID GENERATION

Figure 4.2 Example of edited grid

Among the initial options (Fig. 3.1), the user can choose the option "`GRID ALREADY AVAILABLE, CALCULATION OF STRAIN FIELD`". In this case, the name of file that contains the grid parameters, generated in previous session of `GridStrain`, is managed in interactive way. Note that the user, in this case, can to remove other EPs (with the same interactive procedure described in Chapter 3), as well as to reintroduce one or more points that were excluded in the previous session with a similar procedure. Once that the grid configuration is accepted, the program execution is the same for both the first two options.

The initial grid generation is carried out by means of `gs_gridgene` function, which is automatically called by `GridStrain`. The same main program `GridStrain` calls the complementary functions `gs_nopoints` (exclusion of other EPs) and `gs_yepoints` (reintroduction of already excluded EPs). If the grid is already available, `GridStrain` calls `gs_gridmod` to allow possible grid changes.

The function `gs_gridgene` can also be used in autonomous way with the syntax

```
GSSOut=gs_gridgene(GSS)
```

The autonomous use of `gs_gridmod` is also possible and can be carried out with a similar syntax.

Regardless to the way in which `gs_gridgene` is called, these new fields are added to the input `GSS` variable, leading to the output `GSS` variable, whose name is `GSS` if `gs_gridgene` is called by `GridStrain`, `GSSOut` if `gs_gridgene` is called with the above described command line:

`GridReport`	(string, see below)
`XGridStep`	
`YGridStep`	
`XGridNumber`	
`YGridNumber`	
`DownLeftCorner`	(vector of down left corner coordinates)
`TopRightCorner`	(vector of top right corner coordinates)

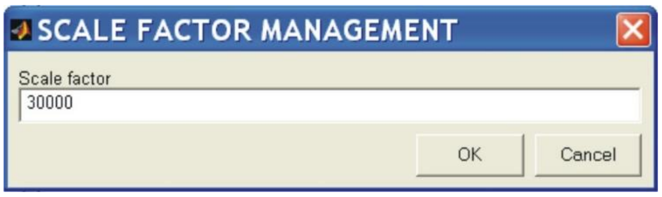
An example of `GridReport` is the string

```
GRID REPORT

     VERTICES:
      FIRST:(565845.91,4314886.97), LAST:(685845.91,4402886.97);

     NUMBER OF GRID ELEMENTS:
      nx = 16,  ny = 12;

     GRID SPACING:
      dx = 8000.00 m,  dy = 8000.00 m.
```

If the automatic data saving was chosen, as the grid is generated and accepted by means of `gs_gridgene` or modified and accepted by means of `gs_gridmod` automatically called by `GridStrain` (and possible EP exclusion or reintroduction, always managed by means of `GridStrain`, is completed), the `GSS` variable is saved in the file `CommonPart2DG.mat` (see data saving options, chapter 3). If the manual data saving was chosen, the output filename can be interactively managed. If the data saving was disabled, no data saving is carried out.

5. Definition and/or change of the scale factor

Once the grid satisfies the user preferences, the program automatically defines the smoothing parameter, or scale factor, for the modification of the least square weighting matrix in an MLS approach, as in Shen *et al.* (1996). This default value is defined as three time the grid spacing, but the user can modify it by means of an input dialog box (fig. 5.1). The scale factor characterizes the strain calculation. In particular, if data points are widely dense distributed, the local strain can be estimated at each node of the grid (or also in a defined point) using a weighting strategy to automatically lower contribution of far stations from the node. All available data are involved in computation but errors are rescaled using an appropriate function which increases with distance. Following Shen and Jackson (2000), the weigh function $\exp(-d/d0)$ can be used, where d is the distance between the node and the grid point and *d0* is the smoothing parameter (see 3.1 about other available scaling functions, i.e. Gaussial and inverse square). Except for the weighting function, which introduces a scale factor in the weight matrix used in the least square computations, the approach is exactly the same described e.g. in Livieratos (1980).


SCALE FACTOR MANAGEMENT

Scale factor: 30000

Figure 5.1. Definition of scale factor for weighting (default: three times the grid spacing)

6. Strain computation on the grid nodes and significance evaluation

The MLS computation lead, for each grid node, to the displacement gradient **L,** which is a tensor and can be written as $\boldsymbol{L} = \boldsymbol{E} + \boldsymbol{\Omega}$, where $\boldsymbol{E} = \varepsilon_{ij} = (\partial_i u_j + \partial_j u_i)/2$ is the strain tensor, $\boldsymbol{\Omega} = \omega_{ij} = (\partial_i u_j - \partial_j u_i)/2$ is the rotational part of **L**, u_i is the displacement u_x (u_y) for $i = 1$ $(i = 2)$, and ∂_i is the partial derivative operator $\partial/\partial x$ $(\partial/\partial y)$ for $i = 1$ $(i = 2)$. The strain tensor is symmetric and represents the internal deformation, whereas $\boldsymbol{\Omega}$ is antisymmetric and represents a rigid body motion. The formulas are

$$\boldsymbol{L} = \begin{bmatrix} \frac{\partial}{\partial x} u_x & \frac{\partial}{\partial y} u_x \\ \frac{\partial}{\partial y} u_y & \frac{\partial}{\partial y} u_y \end{bmatrix} = \boldsymbol{E} + \boldsymbol{\Omega}, \tag{6.1}$$

$$\boldsymbol{E} = \begin{bmatrix} \frac{\partial}{\partial x} u_x & \frac{1}{2}\left(\frac{\partial}{\partial y} u_x + \frac{\partial}{\partial x} u_y\right) \\ \frac{1}{2}\left(\frac{\partial}{\partial y} u_x + \frac{\partial}{\partial x} u_y\right) & \frac{\partial}{\partial y} u_y \end{bmatrix} = \begin{bmatrix} e_{11} & e_{12} \\ e_{21} & e_{22} \end{bmatrix}, \tag{6.2}$$

$$\boldsymbol{\Omega} = \begin{bmatrix} 0 & \frac{1}{2}\left(\frac{\partial}{\partial y} u_x - \frac{\partial}{\partial x} u_y\right) \\ -\frac{1}{2}\left(\frac{\partial}{\partial y} u_x + \frac{\partial}{\partial x} u_y\right) & 0 \end{bmatrix} = \begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix}. \tag{6.3}$$

Since the strain tensor **E** is real and symmetric, it can be diagonalized, i.e. there exists an invertible matrix **V** wherein $\boldsymbol{E_d} = \boldsymbol{V}^{-1}\boldsymbol{E}\boldsymbol{V}$, where $\boldsymbol{E_d}$ is a diagonal matrix. The eigenvalues $e_{\max}$ and $e_{\min}$ are the maximum and minimum principal strain respectively. The maximum (minimum) strain is the change of length per unit-length in the direction of maximum (minimum) extension, positive for extensions. In the reference frame having origin in the grid node and whose unit vectors are the orthonormal eigenvectors, no shear deformation is present and variations occur along the principal axes only.

The `GridStrain` toolbox computes, for each grid node, the eigenvalues $e_{\max}$ and $e_{\min}$, the principal directions (i.e. the corresponding normalized eigenvectors), the displacement and the rigid body rotation, i.e. ω in (6.3). Once a scale factor is available, the program starts the strain rate estimation over each grid node. The redundant equation system is estimated according to a standard linear least square approach where the weight function is introduced to provide an error scaling as described in Chapter 5.

In addition, the geometric significance of the results is evaluated in order to recognize the grid nodes where the results are really representative of the local strain for the chosen scale factor. The corresponding flag field is generated. In particular, to each grid node is associated a flag indicating if:

- The grid node has high significance (flag 2). In this case, in each of the three 120°-width regions in which the plane can be subdivided there exists at least a data point whose distance from the grid point is lower than (or equal to) the scale factor. The spatial distribution of the data points around the grid point is in this case in good.
- The grid point has mid significance (flag 1). In this case, in two of the three 120°-width regions in which the plane can be subdivided, there exists at least a data point whose distance between the grid point is lower than (or equal to) the scale factor. The spatial distribution of the data points around the grid point is in this case near to validity, but the estimate value of the strain is not completely representative of the compressive and/or tensional state of the area (insufficient data points, but situation not completely bad).
- The grid point has low significance (flag 0). In this case, the result cannot be used.

The computations are carried out by `gs_itera` function, which is automatically called by `GridStrain`. The function `gs_itera` can laso be used in autonomous way; in this case, the syntax is

```
GSSOut=gs_itera(GSS,d0)
```

where `GSS` is a `GSS` struct variable with the information about the grid (see Chapter 4) and `d0` is the scale factor. This function automatically calls the sub-function `gs_strain` for each grid node (the use of `gs_strain` as autonomous function is not recommended).

Regardless to the fact that `gs_itera` is automatically called by `GridStrain` or manually called by the used with the command shown above, these new fields are added to the resulting `GSS` struct variable:

`MaxStrainMatrix`	maximum strain matrix
`MinStrainMatrix`	minimum strain matrix
`AzimuthStrainMatrix`	matrix of azimuth, i.e. angle between north direction and maximum strain vector
`MaxStrainMatrixError`	error on maximum strain
`MinStrainMatrixError`	error on minimum strain
`NumberMatrix`	if `numb=GSS.NumberMatrix`, `numb(m,l)` is the number of experimental points whose distance from the grid node `[X(m,l),Y(m,l)]` is smaller than or equal to `d0`
`ComputationFlag`	is `1` in the grid nodes where the strain is actually computed, `0` otherwise
`SignificanceFlag`	Flag on significance. Let `FLS` be `GSS.SignificanceFlag`; - It is `FLS(m,l)=2` if all the three sectors with 120° angular width around the grid node `[X(m,l),Y(m,l)]` contain at least one experimental point whose distance by this grid node is lower than or equal to `d0` (`HIGH SIGNIFICANCE GRID POINT CASE`). - It is `FLS(m,l)=1` if two sectors contain at least one point as above (`MID SIGNIFICANCE GRID POINT CASE`). - It is `FLS(m,l)=0` otherwise (`LOW SIGNIFICANCE GRID POINT CASE).` Obviously, `FLS` is 0 in the grid nodes in which `FLC=0`, where `FLC=GSS.ComputationFlag`.
`UTranslation`	matrix of velocity/translation East components
`VTranslation`	matrix of velocity/translation North components
`UTranslationError`	error on `UTranslation`
`VTranslationError`	error on `VTranslation`
`Rotation`	for each grid node, it is the non-zero component of the rotation antisymmetric matrix

`RotationError`	error on `Rotation`

If, before the strain calculation, `GSS` already has the fields related to strain rate data because a previous session of `GridStrain` (or `gs_itera`) was carried out, the corresponding values are overwritten without any warning message.

As the computations for a defined scale factor are completed, if user did not excluded the data saving, the output `GSS` variable is saved. In case of automatic data saving, if the chosen filename common is, for example, `MyStrainData`, and the scale factor is 30 km, the name of the generated `GSS` file is `MyStrainData2DSF30000.mat`.

7. Data visualization

The next `GidStrain` step is data visualization. An interactive figure (Fig. 7.1) allows the choice of visualization; the data can be shown in all grid nodes, in high significance grid nodes only and in high and mean significance grid nodes.

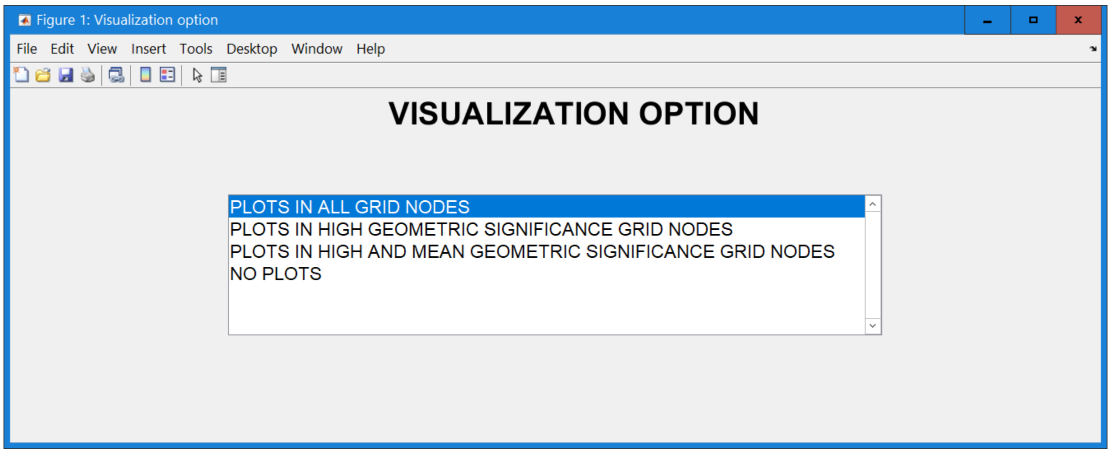


Figure 1: Visualization option
File Edit View Insert Tools Desktop Window Help

VISUALIZATION OPTION

PLOTS IN ALL GRID NODES
PLOTS IN HIGH GEOMETRIC SIGNIFICANCE GRID NODES
PLOTS IN HIGH AND MEAN GEOMETRIC SIGNIFICANCE GRID NODES
NO PLOTS

Figure 7.1 Choice of visualization option.

If an option different from "`NO PLOTS`" is chosen, the fist plot is the contour map of significance areas. An example is shown in Fig. 7.2. A continuous line represents the boundary of the high significance area.

If a background image was selected (see Chapter 3), it is shown in all plots. Moreover, in each plot the scale factor used in the computations is shown in the figure title.

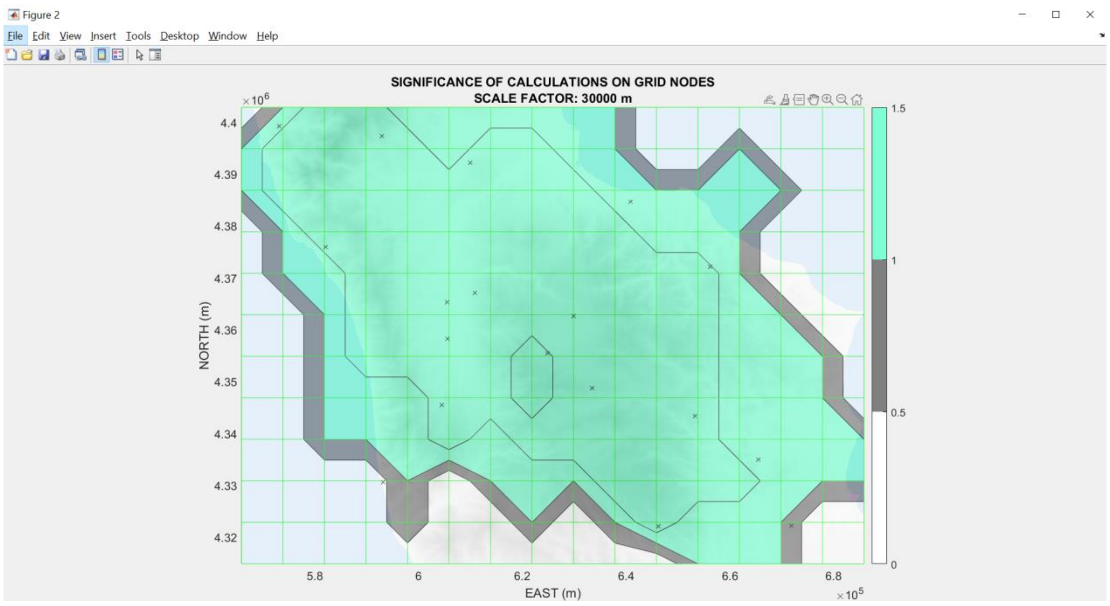


Figure 7.2 Geometric significance plot

These plots are shown:

1. Strain rate field. The eigenvectors are shown with their directions and two colors: if an eigenvalue is positive (extension) the color is blue, whereas the color is red in the case in which the eigenvalue is negative (compression). The arrow lengths are proportional to the absolute values of the corresponding eigenvalues (strictly speaking, an eigenvector is a unit vector). For representation purposes, the vector scale is such that the longest vector has length equal to the grid step. This plot also allows the selection of a grid node and the

presentation of the corresponding results (see below about the grid node data that can be shown) as well as an area selection. If the user choose the visualization of strain rate in both high and mean significance areas, the eigenvectors in the mean significance areas are shown with dashed lines (Figs. 7.3-7.5).

2. Contour plot of rate of change in area. For each grid node, it is the trace of the strain tensor, i.e. $e_{\max} + e_{\min}$, where $e_{\max}$ and $e_{\min}$ are the maximum and minimum eigenvalue respectively (Fig. 7.6). This plot allows the characterization of the kinematics areas.
3. Contour plot of the prevailing eigenvalues (Fig. 7.7), i.e., for each grid node, the eigenvalue having the highest absolute value.
4. Contour plot of the normalized shear rate, i.e. of engineering shear normalized to the change in area. It is $(e_{\max} - e_{\min})/(e_{\max} + e_{\min})$. Note that values near zero characterize strain tensors whose components are comparable in modulus, while values near ±1 are characterized by the predominance of a component on the other (Fig. 7.8). This plot allows the characterization of boundaries between different kinematic areas.
5. Contour plot of the second invariant of the strain rate, i.e. $\sqrt{\dot{\varepsilon}_{xx}^2 + \dot{\varepsilon}_{yy}^2 + 2\dot{\varepsilon}_{xy}^2} = \sqrt{\dot{\varepsilon}_{\max}^2 + \dot{\varepsilon}_{\min}^2}$, which represents the magnitude of total strain rate (Fig. 7.9).
6. Contour plots of the relative error on maximum and minimum strain, drawn on the same figure (Fig. 7.10). In order to avoid saturation effects due to areas characterized by very high errors, the contour plots of $\log_{10}(\sigma_{e\max}/|e_{\max}|)$ and $\log_{10}(\sigma_{e\min}/|e_{\min}|)$ in the high and mid significance areas are shown.
7. Plots of strain rate field (i.e. eigenvectors) overlapped on contour plots of prevailing eigenvalues in the high significance areas and in the high and mean significance areas, drawn in the same figure (Fig. 7.11).
8. Vectors of local rigid-body translation field (Fig. 7.12). Please note that the interpretation of this plot is not straightforward, and is scale factor dependent. For example, a very high scale factor is chosen, the result is the velocity field in uniform strain conditions.

Note that the figures 1-5 and 7 (i.e. Figs. 7.3-7.10 and 7.12 shown below) are drawn according to the user's choice about the strain on the grid nodes, i.e. all grid nodes, high significance nodes, high and mean significance nodes. Figure 6 (i.e. Fig. 7.11 shown below) is the same whichever is the option chosen about the data representation instead.

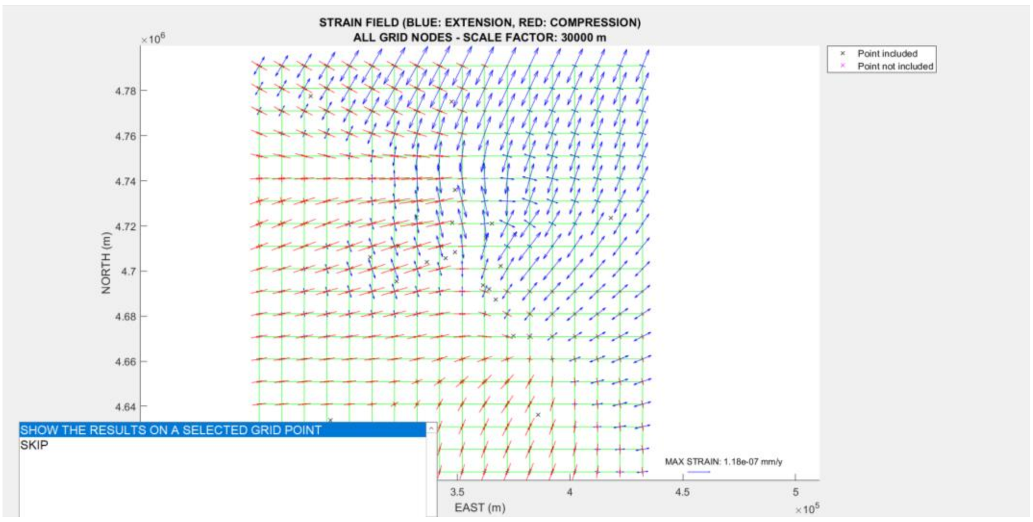

STRAIN FIELD (BLUE: EXTENSION, RED: COMPRESSION)
ALL GRID NODES - SCALE FACTOR: 30000 m
×10^6
4.78
4.76
4.74
4.72
4.7
4.68
4.66
4.64
NORTH (m)
Point included
Point not included
SHOW THE RESULTS ON A SELECTED GRID POINT
SKIP
MAX STRAIN: 1.18e-07 mm/y
3.5
4
4.5
5
EAST (m)
×10^5

Figure 7.3 Example of strain rate field representation in all grid nodes. Note the different colors and orientations of the vectors.

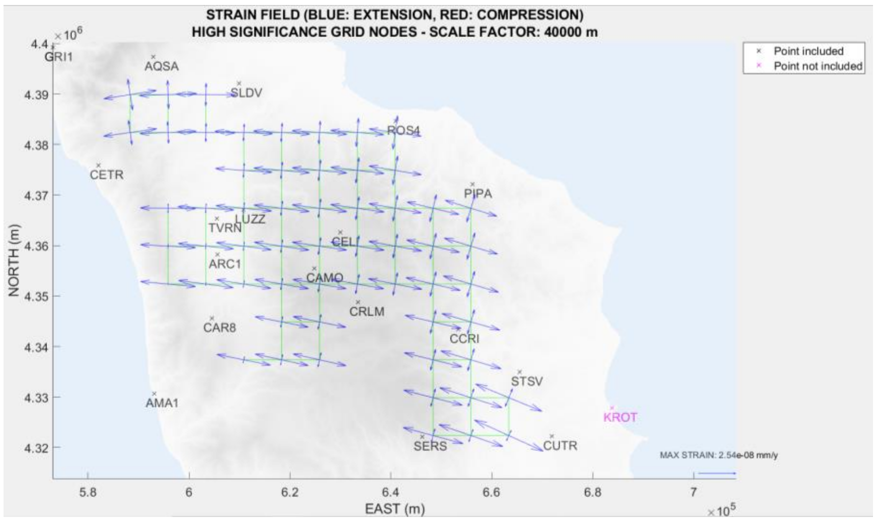
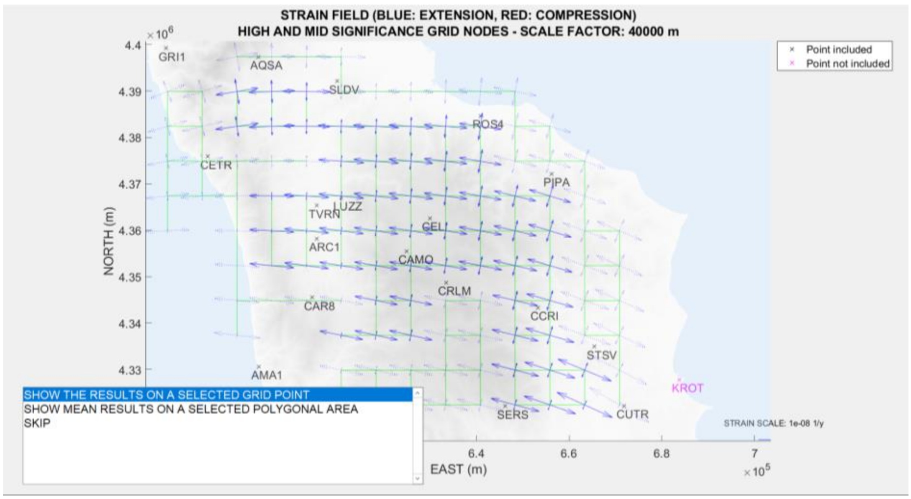

STRAIN FIELD (BLUE: EXTENSION, RED: COMPRESSION)
HIGH SIGNIFICANCE GRID NODES - SCALE FACTOR: 40000 m
Point included
Point not included
MAX STRAIN: 2.54e-08 mm/y
NORTH (m)
EAST (m)
GRI1
AQSA
SLDV
ROS4
CETR
PIPA
LUZZ
TVRN
CELI
ARC1
CAMO
CRLM
CAR8
CCRI
STSV
AMA1
KROT
SERS
CUTR

Figure 7.4 Example of strain rate field representation in high significance grid nodes.


STRAIN FIELD (BLUE: EXTENSION, RED: COMPRESSION)
HIGH AND MID SIGNIFICANCE GRID NODES - SCALE FACTOR: 40000 m
Point included
Point not included
STRAIN SCALE: 1e-08 1/y
NORTH (m)
EAST (m)

SHOW THE RESULTS ON A SELECTED GRID POINT
SHOW MEAN RESULTS ON A SELECTED POLYGONAL AREA
SKIP

Figure 7.5 Example of strain field representation in high (solid lines) and mean (dashed lines) significance grid nodes.

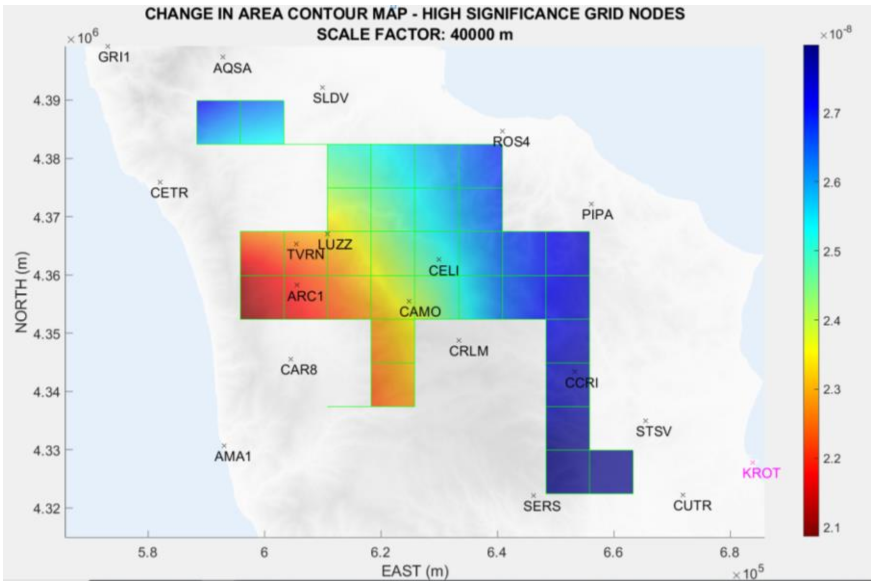


Figure 7.6 Example of rate of change in area contour map

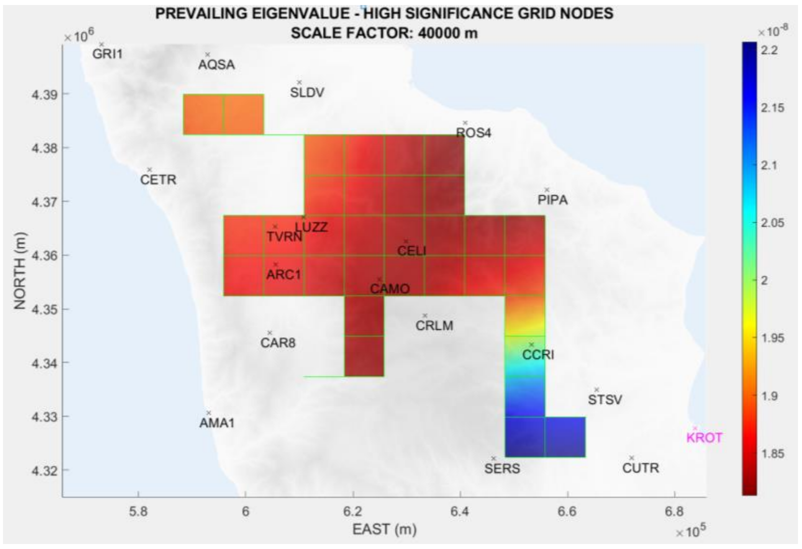


Fig. 7.7 Contour plot of prevailing eigenvalue.

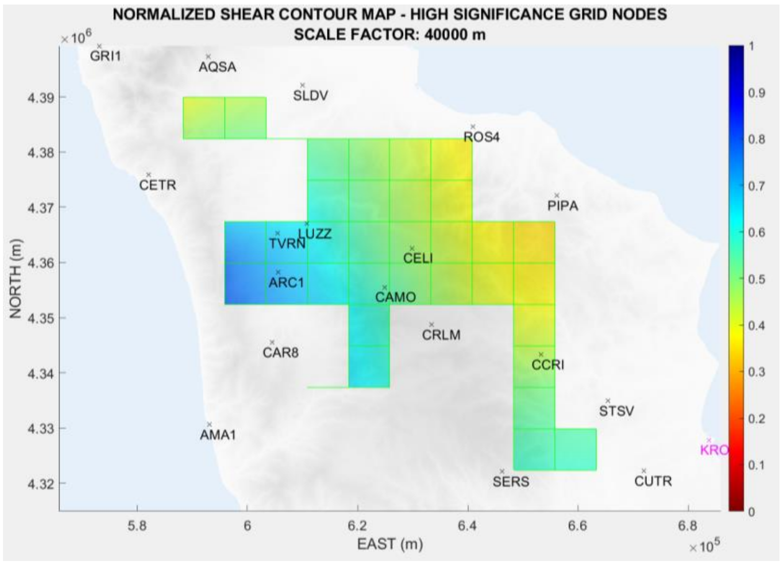


Figure 7.8 Contour plot of rate of engineering shear normalized to the change in area.

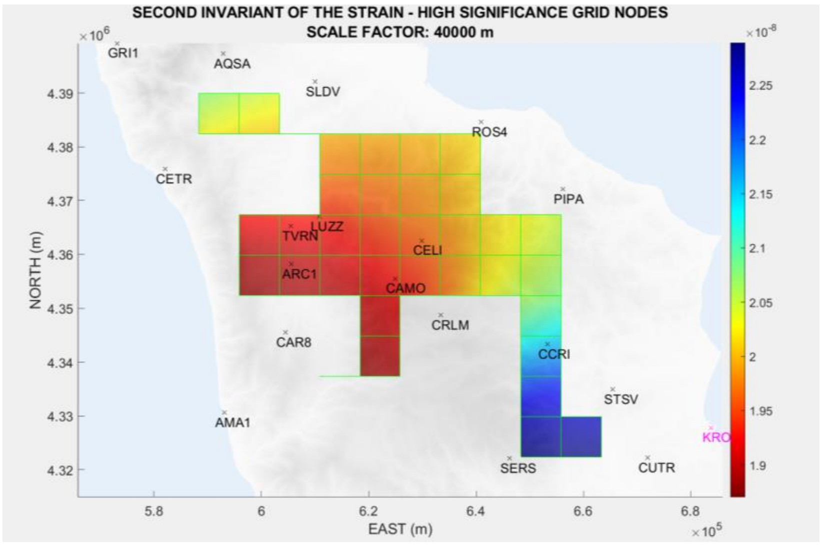

SECOND INVARIANT OF THE STRAIN - HIGH SIGNIFICANCE GRID NODES
SCALE FACTOR: 40000 m
NORTH (m)
EAST (m)

Figure 7.9 Contour plot of second invariant of the strain rate.

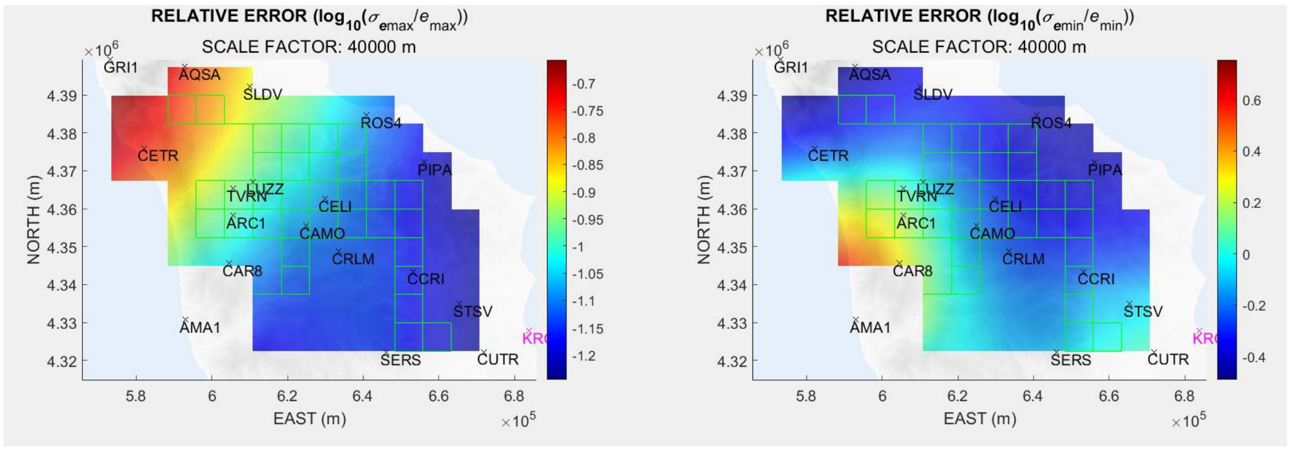


Figure 7.10 Contour plots of relative errors on strain computation, expressed as logarithms.

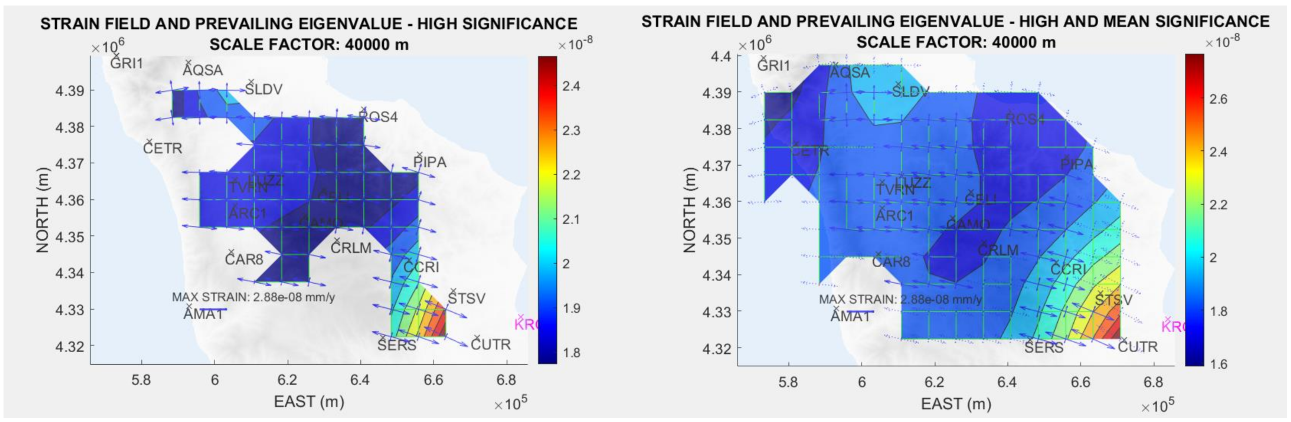

STRAIN FIELD AND PREVAILING EIGENVALUE - HIGH SIGNIFICANCE
SCALE FACTOR: 40000 m
STRAIN FIELD AND PREVAILING EIGENVALUE - HIGH AND MEAN SIGNIFICANCE
SCALE FACTOR: 40000 m
MAX STRAIN: 2.88e-08 mm/y
NORTH (m)
EAST (m)

Figure 7.11 Strain rate fields in high (left panel) and high-mean significance areas (right panel) overlapped to the contour maps of prevailing eigenvalue.

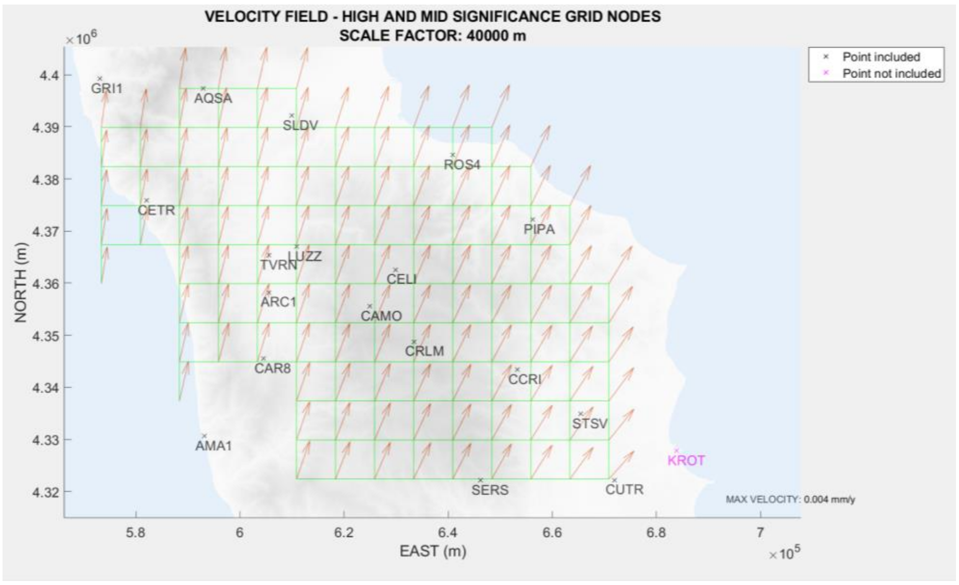
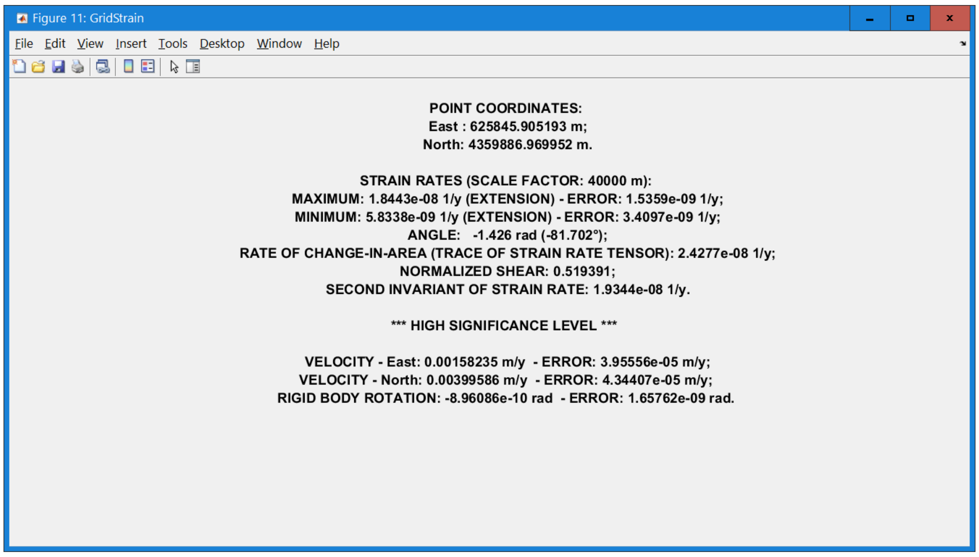


Figure 7.12 Velocity field estimated from strain field.



```
POINT COORDINATES:
East : 625845.905193 m;
North: 4359886.969952 m.

STRAIN RATES (SCALE FACTOR: 40000 m):
MAXIMUM: 1.8443e-08 1/y (EXTENSION) - ERROR: 1.5359e-09 1/y;
MINIMUM: 5.8338e-09 1/y (EXTENSION) - ERROR: 3.4097e-09 1/y;
ANGLE:   -1.426 rad (-81.702°);
RATE OF CHANGE-IN-AREA (TRACE OF STRAIN RATE TENSOR): 2.4277e-08 1/y;
NORMALIZED SHEAR: 0.519391;
SECOND INVARIANT OF STRAIN RATE: 1.9344e-08 1/y.

*** HIGH SIGNIFICANCE LEVEL ***

VELOCITY - East: 0.00158235 m/y  - ERROR: 3.95556e-05 m/y;
VELOCITY - North: 0.00399586 m/y  - ERROR: 4.34407e-05 m/y;
RIGID BODY ROTATION: -8.96086e-10 rad  - ERROR: 1.65762e-09 rad.
```

Figure 7.13 Example of data about a selected grid node.

As mentioned above, the program allows, at this stage, the interactive selection of one or more points and the visualization of the corresponding strain rate by acting on the figure which represents the strain rate field. No more computations are carried out; the data about the nearest grid node to the selected point are shown. If the user wants to have the data about a well-defined point, regardless to the grid used for `GridStrain` computations, must use the `StrainZero` program instead of `GridStrain` (see Chapter 9). The results of this selection are contemporarily shown in a menu box and in the command window (note that no commands are typed using this command window after the program initialization; it is used for visualization only). An example of visualization of these results is shown in Fig. 7.13 (this visualization is repeated on the MCW). The shown data are: coordinates of the nearest grid point, strain eigenvalues, angle for the definition of the direction of the first strain eigenvector, rate of change-in-area, rate of normalized shear, geometric significance of the results, scale factor, and rigid-body kinematic parameters (velocity and rotation).

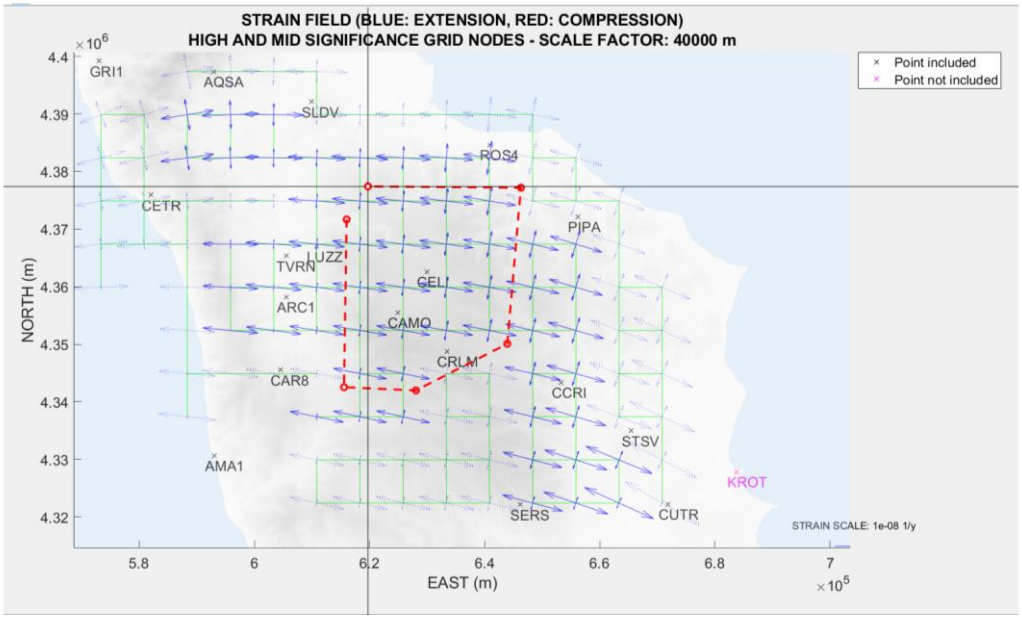
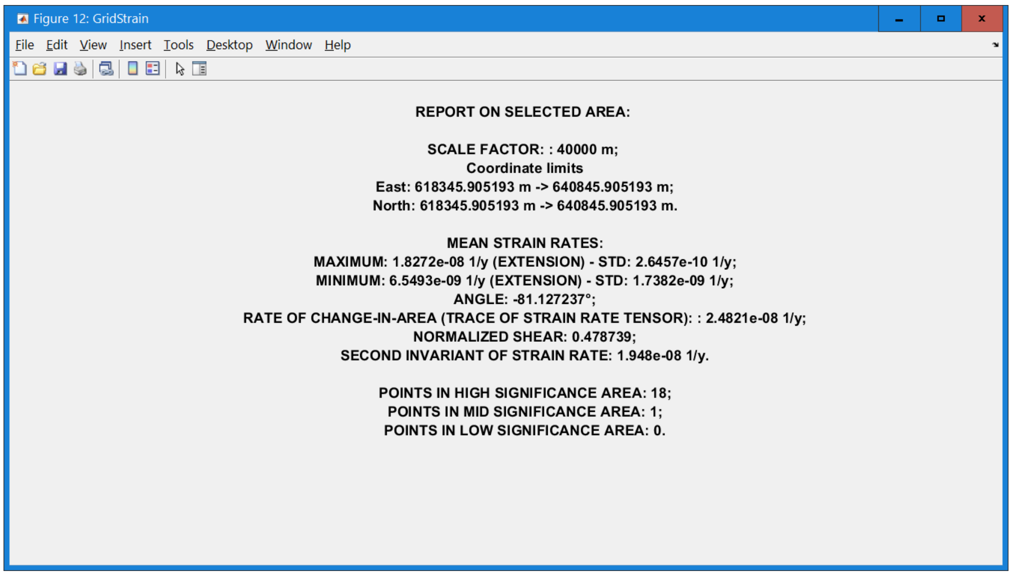


Figure 7.14 Polygonal area selection.

The user can also interactively select an area and visualize the mean values in this area (option SHOW MEAN RESULTS IN A SELECTED POLYGONAL AREA, Fig. 7.5). An example of interactive selection, carried out by means of mouse (right button) is shown in Fig. 7.14. To complete the selection and acquire the polygon vertices, the used should use the return button on keyword (please note that the last acquired vertex is the one selected with the last righ-selected by mouse. An example of visualization of the corresponding results is shown in Fig. 7.15.



```
REPORT ON SELECTED AREA:

SCALE FACTOR: : 40000 m;
Coordinate limits
East: 618345.905193 m -> 640845.905193 m;
North: 618345.905193 m -> 640845.905193 m.

MEAN STRAIN RATES:
MAXIMUM: 1.8272e-08 1/y (EXTENSION) - STD: 2.6457e-10 1/y;
MINIMUM: 6.5493e-09 1/y (EXTENSION) - STD: 1.7382e-09 1/y;
ANGLE: -81.127237°;
RATE OF CHANGE-IN-AREA (TRACE OF STRAIN RATE TENSOR): : 2.4821e-08 1/y;
NORMALIZED SHEAR: 0.478739;
SECOND INVARIANT OF STRAIN RATE: 1.948e-08 1/y.

POINTS IN HIGH SIGNIFICANCE AREA: 18;
POINTS IN MID SIGNIFICANCE AREA: 1;
POINTS IN LOW SIGNIFICANCE AREA: 0.
```

Figure 7.15 Example of results of polygonal area selection.

The visualization of strain data on a selected grid point and/or a selected area can be repeated as many as the user wants.

The data visualization is carried out by means of `gs_strashow` function, which is automatically called by `GridStrain`. This function can also be used in autonomous way. The valid syntaxes are

```
gs_strashow(GSS)
gs_strashow(GSS,visScale)
```

The input argument `visScale` defines the scale of representation. If it is undefined or empty, it is

```
  visScale=min(dx,dy)/max(mean(abs(EMAX(:))),mean(abs(EMIN(:)))),
```

where `dx`, `dy`, `EMAX` and `EMIN` are taken from `GSS`.

As the visualization managed by means of `GridStrain` is completed, the user can choose a different scale factor and repeat the calculations. Please note that this option is also available if `GridStrain` is used to display existing strain rate data. If the data visualization is carried out by calling `gs_strashow` with a command line, no other scale factors can be considered in the same session.

8. Complementary functions and options

Some complementary functions are available in order to allow the implementation of some activities:

- Generation of a background image from a DTM;
- Data exportation in ESRI `.asc` ASCII format.

8.1 Generation of a background image from a DTM

A background image can be used for all the `GridStrain` visualization. As described in Chapter 3, the background image should be already available and manageable by means of two files:

1. A JPEG or a TIFF image file with a filename like, e.g., `'MyBGImage.jpg'`;
2. A MATLAB .mat file having the same name of the image file but extension `.mat`, (e.g. `'MyBGImage.mat'`) with the field `ALI` whose value is the vector `[Xdatamin, Xdatamax, Ydatamin, Ydatamax]` with the coordinates of the vertices of the area represented by the image, expressed in the same reference frame of the input velocity data.

If a DTM file in ESRI `.asc` format (see 8.3 for more information about this format) or in GeoTiff `.tiff` format[1] provided by a GIS package is available, a complementary function allows the generation of these two files. This function is `gs_genDTMImage`; the syntax is:

```
ALI=gs_GenDTMImage(filenaDTM,OtherNoData,OutName)
```

The input arguments are:

`filenaDTM`	name of input ESRI `.asc` file or GeoTiff `.tiff` file. If it is undefined or empty, the filename can be interactively managed;
`OtherNoData`	possible second no-data value (the file already has a no-data value. However, the generation of a DTM by adding different sources could lead to a second no-data value in elements of the DTM for which there are no sources). If it is undefined or empty, no a second no-data value is considered;
`OutName`	name of the output files. If it is undefined or empty, the default name `'refDTMIm'` is used. If `OutName` includes the extension, it is used for the image file (allowed extensions: `'.jpg'`, `'.jpeg'`, `'.tif'`, `'.tiff'`). If `OutName` does not include the extension, `'.tif'` is used. In each case, the second generated file has the same name of the image one (except for the extension);
`OptSea`	option about sea. If it is true or is the string `'light'` or `'dark'`, the sea (DTM level zero) is colored in blue. In particular, if `OptSea` is `'light'` or `'dark'`, the sea is in light blue or dark blue respectively. If `OptSea` is simply true, `'light'` is used. If `OptSea` is undefined, empty or false, the DTM is drawn as a grey-level image using all valid data.

[1] Please note that the output files are an image (jpeg or tiff) and a MATLAB .mat file with the georeferencing data. In particular, if the output image is a tiff file, it is a standard RGB image. If the input file is a GeoTiff image, even if the extension is the same, its nature is completely different; it is a DTM, i.e. a matrix with the parameters necessary to georeferencing the grid nodes and reconstruct the elevations. It is therefore important to avoid confusion between two types of different objects (images and DTMs) even if they can be represented by files with the same extension.

The output variable is `ALI=[Xdatamin, Xdatamax, Ydatamin, Ydatamax]`, taken from the header of the input file.

Depending on the options chosen by the user for generating the output image, this function can make use of the external function `customcolormap` by Víctor Martínez-Cagigal, Biomedical Engineering Group (University of Valladolid), Spain (download page: https://it.mathworks.com/matlabcentral/fileexchange/69470-custom-colormap), which is added to `GridStrain` toolbox.

The user can customize the function `gs_GenDTMImage` or write a script using this function as a reference in order to solve his/her specific problem of generating a background image, for example in order to represent the sea level with a specific color (e.g. light blue `[171,205,239]`). The `GridStrain` developer is available to provide assistance in the eventual creation of a customized function or script, provided that the objective of the toolbox use is scientific research (email: giordano.teza@gmail.com, giordano.teza@unibo.it) .

8.2 Data export in ESRI ASCII `.asc` format

The GSS struct variable can be saved in a MATLAB `.mat` file. As above mentioned, the data saving can be also carried out in automatic way. However, the user may want to export the output data in ASCII format. In order to allow this, the `gs_saveAsc` function is available. The corresponding syntax is

```
gs_saveAsc(GSS,CommonPart,optVec)
```

This function allows the saving of data related to a GSS struct variable. Each generated file is an .asc ASCII file in ESRI DTM style, with a six rows header and a data matrix. The header is:

```
ncols           xxx
nrows           xxx
xllcorner       xxx
yllcorner       xxx
cellsize        xxx
NODATA_value    xxx
```

where

- `ncol` and `nrows` are the integer number of grid lines along X-axis and Y-axis respectively (taken from the matrices stored in GSS);
- `xllcorner` and `yllcorner`) are the X-coordinate and Y-coordinate of the grid origin, taken from `GSS.DownLeftCorner`;
- `cellsize` is the cell size, taken from `GSS.DownLeftCorner` and `GSS.TopRightCorner` (note that a square grid is required);
- `NODATA_value` is the value assigned to `NaN` matrix elements (default value: −`9999`).

If the string `CommonPart` is assigned, the data saving procedure managed by `gs_saveAsc` is completely automatic. In this case, each file has name

```
     (CommonPart)(TypeofData)(ScaleFactor).asc
```

For example, if `CommonPart` is `'MyArea'`, `TypeofData` is `'MaxStrain'` and the scale factor is 40000 m, the generated file is

```
     MyAreaMaxStrain40000.asc.
```

If `CommonPart` is undefined or empty, each data saving is interactively managed.

The input argument `optVec` is a vector with integer numbers in the range `1:14`.

If `optVec = 1:14`, all files are generated. If `OptVec=[n1 n2 ... nr]`, with `n1`, `n2`, `nr` natural numbers in the range 1:14, the file related to these indices are generated (see below the list).
If `optVec` is undefined or empty, a list dialog box allow the choice of the files to be generated (Fig. 8.2). A multiple choice is allowed; all files can also be generated.

List of files that can be generated:

1. Maximum strain (rate) field
2. Error on maximum strain (rate) field
3. Minimum strain (rate) field
4. Error on minimum strain (rate) field
5. Azimuth strain (rate) field
6. Number matrix
7. Computation flag
8. Significance flag
9. U translation (velocity) field
10. Error on U translation (velocity) field
11. V translation (velocity) field
12. Error on V translation (velocity) field
13. Rotation field
14. Error on rotation field

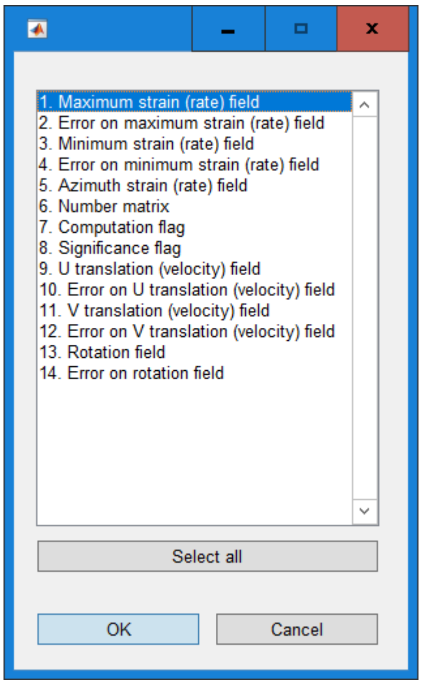

1. Maximum strain (rate) field
2. Error on maximum strain (rate) field
3. Minimum strain (rate) field
4. Error on minimum strain (rate) field
5. Azimuth strain (rate) field
6. Number matrix
7. Computation flag
8. Significance flag
9. U translation (velocity) field
10. Error on U translation (velocity) field
11. V translation (velocity) field
12. Error on V translation (velocity) field
13. Rotation field
14. Error on rotation field

Figure 8.2 Choice of ASCII files to be generated

9. Strain rate computation without a grid : `StrainZero`.

It is a simplified version of `GridStrain`. For a data points file structured exactly as in the case of `GridStrain`, it calculates the strain in one or more points. The provided results are like the ones provided by `GridStrain`, but the generation of grid and the iteration on it are not performed. In addition, the user can choose a scale factor or exclude it (in the latter case, an infinite scale factor is used). Note that this program should be used in those cases where the user wish to have the strain data on a well-defined point and the nearest grid point is too far from it to allow a meaningful representation.

Unlike `GridStrain`, which is a MATLAB script, `StrainZero` is a MATLAB function. A function has input and output parameters, whereas the variables on which a script operates are the ones hard-coded into this script and the variables taken from external files called from the script. Moreover, all variables created in the script are added to the current workspace. `The StrainZero` syntax is

```
StrainZero(GSS)
```

The input argument is a `GSS` variable provided in a `GridStrain` session, see Chapters 3and 4 of this User's Guide (since `GridStrain` is a script, if ran, `GSS` is available on the current workspace). If the user is not interested in evaluating the strain rate field in a regular grid, he can select "`NO GRID GENERATION`" in the UI to confirm / modify the grid parameters (Fig. 4.1). No more than data about positions, velocities, velocity errors (including, if available, error ellipses) and (optionally) excluded points are required in `GSS`. All other data in `GSS`, if available, are ignored by `StrainZero`. If `GSS` is undefined or empty, the name of a file with such a variable can be interactively managed.

As `StrainZero` runs, the user can define the scale factor, or use an infinite scale factor (Fig. 9.1). The second option corresponds to the strain computation under uniform strain hypothesis.

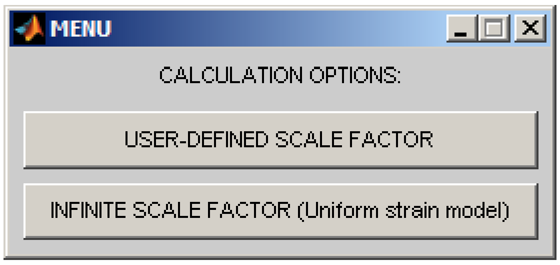

MENU
CALCULATION OPTIONS:
USER-DEFINED SCALE FACTOR
INFINITE SCALE FACTOR (Uniform strain model)

Figure 9.1. Choice of the scale factor

The strain can be computed either on the available stations (i.e. on the points whose coordinates are in the ASCII input data file, also called experimental points), or in interactively-selected points. Moreover, if at least a point was excluded from the computations, another option is available; for the experimental points, the strain can be computed either on all the experimental points on or the kept experimental points only. A menu box allows the choice of the general option on strain computation (Fig. 9.2).

In the case of computation on user-defined points, three options are available for the point selection (Fig. 9.3, left): by coordinates (Fig. 9.3, right), by click on plot, or on the center of mass, i.e. the point whose coordinates are the weighted means of the station coordinates, where the weights are the inverse squares of the uncertainties.

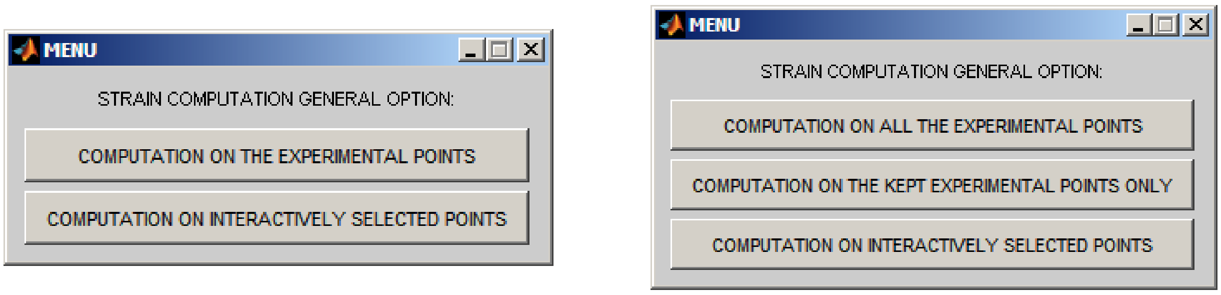
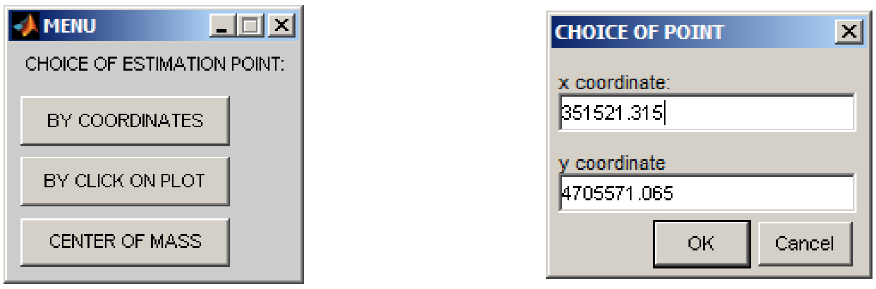

MENU
STRAIN COMPUTATION GENERAL OPTION:
COMPUTATION ON THE EXPERIMENTAL POINTS
COMPUTATION ON INTERACTIVELY SELECTED POINTS
MENU
STRAIN COMPUTATION GENERAL OPTION:
COMPUTATION ON ALL THE EXPERIMENTAL POINTS
COMPUTATION ON THE KEPT EXPERIMENTAL POINTS ONLY
COMPUTATION ON INTERACTIVELY SELECTED POINTS

Figure 9.2. General options on strain computation: left, menu in the cases where no excluded points exist. Right: menu in the cases where at least a point has been excluded.

Fig. 9.4 shows the results of the `StrainZero` application to the sample file in the case of the choice of the computation on the EPs only. Please note that, if an EP is excluded from the computations, the strain in this point is computed, obviously without the effect of the corresponding experimental vector. The result in such an EP can be used to estimate the corresponding expected kinematics without the conditions that led to its exclusion from the strain computation, in particular, the modeled velocity vector can be compared with the experimental one (see below, in particular Fig. 9.7).



x coordinate: 351521.315

y coordinate 4705571.065

Figure 9.3. Choice of the estimation point in the case of interactive choice (left) and example of choice of the point in the case of selection of the option “by coordinates” (right).

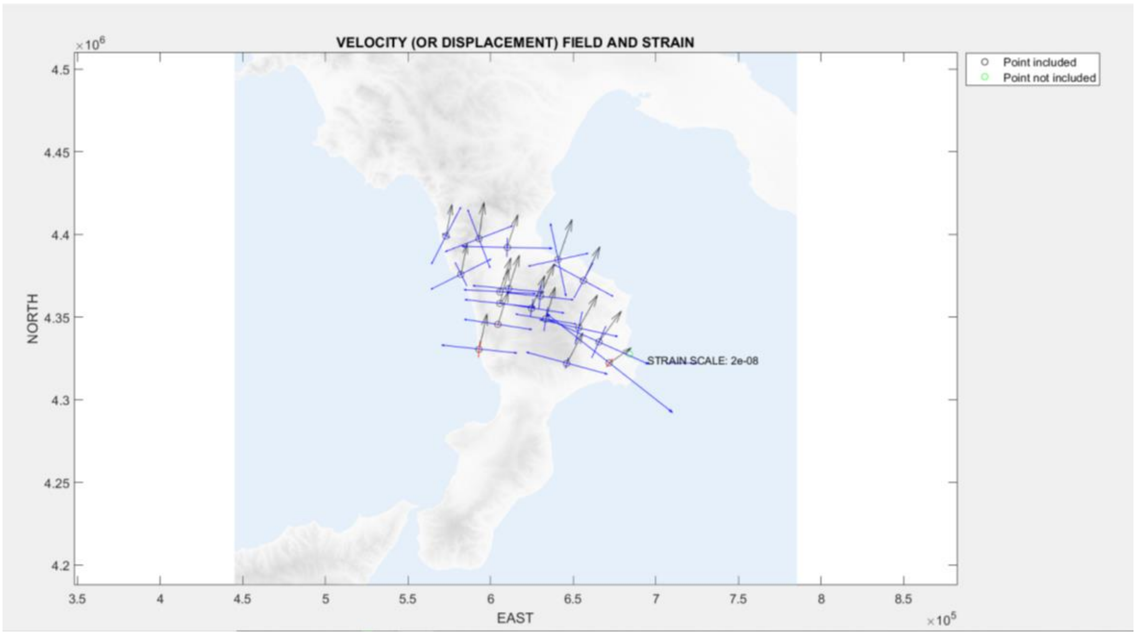


Figure 9.4 Example of computation in the experimental points based on the use of `StrainZero`.

Figs. 9.5 and 9.6 show the results of strain computation on a selected point and the corresponding report respectively (note that the point selection can be repeated how many times the User wants). Since the velocity field estimated in the experimental points can be compared with the input velocity data, the corresponding chi-square χ^2 is evaluated (see Fig. 9.7 for an example of velocity comparison. Please note that the EP 32 seems to be an outlier. This impression is well founded because this EP actually is affected by local motion due to a landslide). If at least a point is excluded from the computation, such an evaluation can be carried out either on the effectively used points (suggested option) or on all the experimental points. If no points are excluded, the χ^2 is automatically provided if the option "`COMPUTATION ON THE EXPERIMENTAL POINTS`" is chosen. Besides χ^2, the reduced chi-square χ^2_ν is also computed, where the number of degrees of freedom, ν, is $2N$-6 (N is the number of kept experimental points and 6 is the number of estimated parameters). The chi-square can be very interesting in those cases where an uniform strain is modeled, i.e. an infinite scale factor is used. The corresponding report, shown on the MCW, is

```
CHI-SQUARE COMPUTATION (SCALE FACTOR: Inf):
 COMPLETE: 234.09;
 REDUCED: 5.85;
 DOFs: 40
```

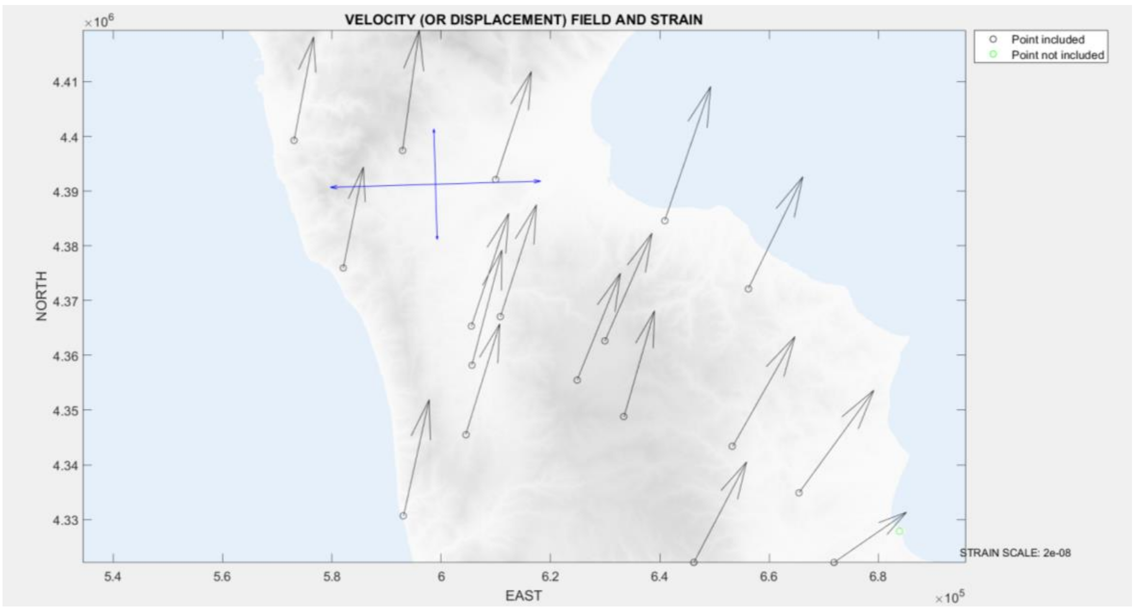
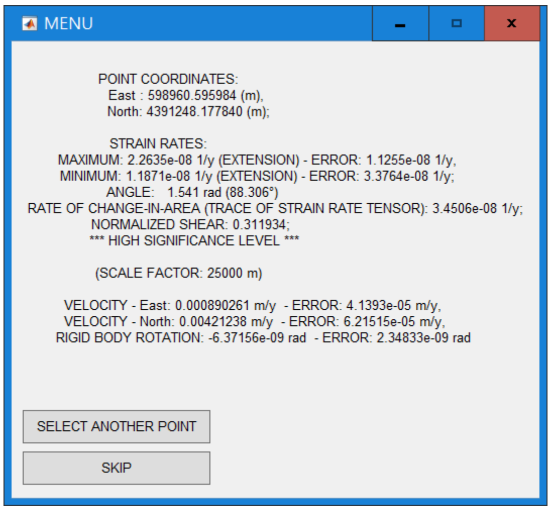


Figure 9.5 Example of strain computation on a point by using `StrainZero`.



```
POINT COORDINATES:
  East : 598960.595984 (m),
  North: 4391248.177840 (m);

STRAIN RATES:
MAXIMUM: 2.2635e-08 1/y (EXTENSION) - ERROR: 1.1255e-08 1/y,
MINIMUM: 1.1871e-08 1/y (EXTENSION) - ERROR: 3.3764e-08 1/y;
ANGLE:   1.541 rad (88.306°)
RATE OF CHANGE-IN-AREA (TRACE OF STRAIN RATE TENSOR): 3.4506e-08 1/y;
NORMALIZED SHEAR: 0.311934;
*** HIGH SIGNIFICANCE LEVEL ***

(SCALE FACTOR: 25000 m)

VELOCITY - East: 0.000890261 m/y  - ERROR: 4.1393e-05 m/y,
VELOCITY - North: 0.00421238 m/y  - ERROR: 6.21515e-05 m/y,
RIGID BODY ROTATION: -6.37156e-09 rad  - ERROR: 2.34833e-09 rad
```

Figure 9.6 Example of report on strain computation on a single point by means of `StrainZero`. Please note that the number of digits shown is overabundant. To actually use the data in a publication, one must consider that, for example, the maximum strain is 2.3±1.1 y^{-1}.

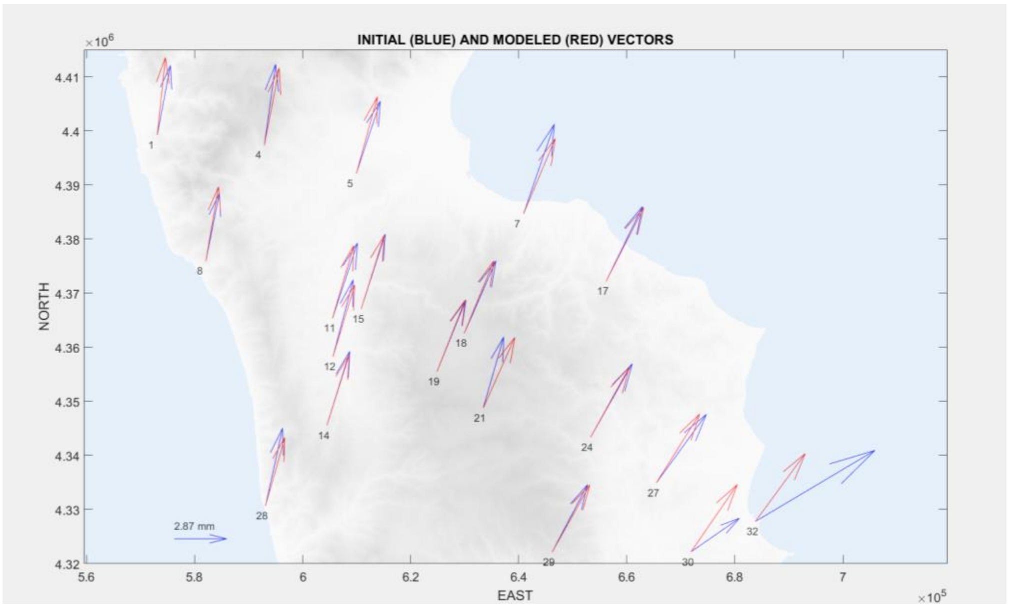


Figure 9.7 Example of experimental (blue vectors) and modeled (red vectors) velocities

The `StrainZero` function also allows the saving of the obtained results as an ASCII file. In particular, if the options "`COMPUTATION ON THE EXPERIMENTAL POINTS`" (if no exclusion is performed) or "`COMPUTATION ON ALL THE EXPERIMENTAL POINTS`" (if at least a point has been excluded from the computations), the output file contains a matrix having the same number of rows of the input ASCII file and these 21 columns:

ns e n ve vn eve evn a b theta Emax Emin eEmax eEmin Phi u0 v0 eu0 ev0 omeg eomeg

where *ns e n ve vn eve evn a b theta* are defined as in Chapter 3 (please note that *a*, *b* and *theta* are defined even if they are unavailable in the input file[2]), *Emax*, *Emin*, *eEmax* and *eEmin* are the principal strains and the corresponding errors, *Phi* is the angle for the eigenvector direction characterization, *u0*, *v0*, *eu0* and *ev0* are the rigid body translations and the corresponding errors, and *omeg*, *eomeg* are the rigid body rotation and the corresponding error respectively. If at least a point has been excluded from the computations and the option "Computation on the kept experimental points only" has been chosen, the file has 21 columns and the rows corresponding to the kept points.

If the computations are carried out on user defined points, a matrix having a number of rows equal to the number of selected points, and 14 columns is saved. The columns are in this case

k xp yp Emax Emin eEmax eEmin Phi u0 v0 eu0 ev0 omeg eomeg

where *k* is the row identifier (from 1 to the number of selected points), *xp* and *yp* are the coordinates of each selected point, and the other variables are as above.

[2] In this case, it is *a* = *eve*, *b*= *evn*, and *theta* = 0, i.e. an error ellipse whose axes are parallel to the East and North direction is defined.

3D version (`grid_strain3`)

This program is like `GridStrain`, with the difference that the strain tensors, now having three components instead of two, are computed on the points of a digital terrain model (DTM). For this reason, only the main differences are reported here. However, the current release of `grid_strain3` is like the older releases of `grid_strain` and, therefore, is not based on the use of a struct variable like `GSS` for all the quantities used and elaborated as the main program runs (for this reason, the old-style name `grid_strain3` is used). The upgrade of `grid_strain3`, leading to `GridStrain3`, is planned and is soon to be implemented.

10. Data importation in the 3D case

The ASCII file containing the data of displacements must have 13 columns (the last three are optional):

1. ns (experimental point identifier);
2. e (x coordinates, expressed in m);
3. n (y coordinates, m);
4. z (z coordinates, m);
5. ve (x displacements, m);
6. vn (y displacements, m);
7. vz (z displacements, m);
8. eve (rms error on ve, m);
9. evn (rms error on vn, m);
10. evz (rms error on vz, m);
11. a (length of major half-axis of xy error ellipse, m);
12. b (lenght of minor half-axis of xy error ellipse, m);
13. theta (azimuth of major axis of error ellipse, degrees).

Note that the displacements are now assumed to be expressed in m, since the displacement data are generally provided by terrestrial laser scanner (TLS), aerial laser scanner, digital photogrammetry or other topography techniques. This is an important difference between `grid_strain3` and `GridStrain`. In the case of `GridStrain`, the displacements are often obtained by GPS measurements and mm is used as default unit. As in the 2D case, a check on the used unit is performed, and a menu-message is presented to the user if the data could expressed in an unit different from the meter.

The optional three columns contain the data about the error ellipses of the *x* and *y* components of the displacements. In this way, if the data are provided by GPS measurements and the error ellipses are defined, the corresponding information is used[3]. The function `pp_to_gs.m` is conceived for the generation of the ASCII file using the displacements obtained by application of `PAMpoly` software to TLS data. The `PAMpoly` software implements the Piecewise Alignment method for the displacement field computation starting from two or more multi-temporal TLS observations (Teza *et al.*, 2007). In this case, the data file for the `grid_strain3` execution has 10 columns.

If the user types

[3] Generally, in a GPS measurement, the error on the third coordinate is higher than the errors on the first two ones. The error ellipse is defined on the horizontal plane only.

```
grid_strain3
```

on the command window, the program `grid_strain3` runs. The general option is shown:

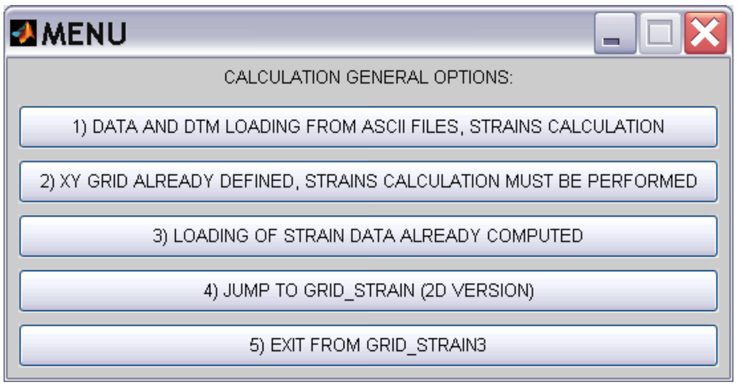

MENU
CALCULATION GENERAL OPTIONS:
1) DATA AND DTM LOADING FROM ASCII FILES, STRAINS CALCULATION
2) XY GRID ALREADY DEFINED, STRAINS CALCULATION MUST BE PERFORMED
3) LOADING OF STRAIN DATA ALREADY COMPUTED
4) JUMP TO GRID_STRAIN (2D VERSION)
5) EXIT FROM GRID_STRAIN3

Fig. 10.1. General options menu. Note that a direct passage to `GridStrain` is possible.

The DTM used for the computations must have either the Surfer `.grd` ASCII format or the `.asc` ESRI ASCII Raster format. In all the cases, the data must be space separated (in particular, comma-separated data cannot be managed). In the Surfer-like case, the DTM data are stored in a `.grd` ASCII file whose rows are structured as follows:

`id`	:	Identification string, that identifies the file as an ASCII grid file;
`nc, nr`	:	integer numbers of grid lines along the *x*-axis (columns) and *y*-axis respectively (rows);
`xlo, xhi`	:	minimum and maximum values of *x* along the grid;
`ylo, yhi`	:	minimum and maximum values of *y* along the grid;
`zlo, zhi`	:	minimum and maximum values of *z* along the grid;
`row 6` … `last row`	:	row 6 corresponds to *ylo* and the last grid row corresponds to *yhi*. Within each row, the *z*-values are arranged from *xlo* to *xhi*. In other words, the rows 6, 7, …, last contain the matrix whose elements are the DTM's elevations.

An ESRI ASCII `.asc` grid file, generated e.g. by ArcGIS, contains six header lines that provide information about the size and limits of the grid, followed by the list of Z values. The fields within ASCII grid files must be space % delimited. The header of an ASCII `.asc` grid file is:

```
ncols          xxx
nrows          xxx
xllcorner      xxx
yllcorner      xxx
cellsize       xxx
NODATA_value   xxx
```

or, alternatively,

```
ncols          xxx
nrows          xxx
xllcenter      xxx
yllcenter      xxx
cellsize       xxx
NODATA_value   xxx
```

where

`ncols, nrows`	:	integer numbers of grid lines along the *X*-axis (columns) and *Y*-axis respectively (rows);
`xllcorner`	:	*X*-coordinate of the grid origin by lower-left corner of the cell;
`yllcorner`	:	*Y*-coordinate of the grid origin by lower-left corner of the cell;
`xllcenter`	:	*(alternative with respect to xllcorner) X*-coordinate of the grid origin by center of the cell;
`yllcenter`	:	*(alternative with respect to yllcorner) Y*-coordinate of the grid origin by center of the cell;
`cellsize`	:	Cell size (equal for X- and Y-directions);
`NODATA_value`	:	It is the value related to no data cells (`NaN` in the oputput matrix managed by MATLAB)). Although the row is compulsory (the header of an ESRI raster file must have six rows), the value can be omitted. In this case, the default `NODATA_value` (-9999) is considered, i.e. -9999.

The headers of the `.grd` and `.asc` file related to a same DTM are show below. It should be noted that the nodata value, -32767, is explicitly shown, and therefore automatically managed, only in the case of an `.asc` file.

```
DSAA
5944   5439
1757839.024   1758189.558
5143731.543   5144052.297
527.815   650.878

ncols        5944
nrows        5439
xllcorner    1757839.024005563
yllcorner    5143731.543726818
cellsize     0.05897279999999135
NODATA_value -32767.000
```

Please note that:

- In an ESRI ASCII `.asc` Raster file, the rows from the 7th one are arranged from the maximum to the minimum *y*, i.e. the row arrangement is inverted with respect to the case of a Surfer `.grd` ASCII file (ESRI: 7-th row: highest *y*, end row: lowest *y*; Surfer: 6-th row: lowest *y*, end row: highest *y*). The output MATLAB .mat DTM is arranged as a Surfer matrix, according to conventions used in MATLAB;
- the main script `grid_strain3` (through the function `gs_dtmread`) automatically discriminates between a Surfer or an ESRI file on the basis of the extension, `.grd` in the first case and `.asc` in the second one. Since some users adopt the extension `.grd` for the ESRI ASCII files, if a `grid_strain3` user do not know the origin of a DTM ASCII file, he should check the header (a warning message is provided if the file header does not correspond to the expected one);
- a combined use of the functions `gs_dtmread` and `gs_dtmwrite` allows a conversion between a `.grd` and an `.asc` ASCII DTM file (see the helps of these functions).

Obviously, other software can be used to generate the DTM, but the data must be arranged either in Surfer ASCII or in ESRI ASCII raster format. Since the ASCII file containing the DTM data is read by using the standard MATLAB function `dlmread`, non-zero values are assumed to represent the elevations (zero-values are assumed to be related to empty fields).

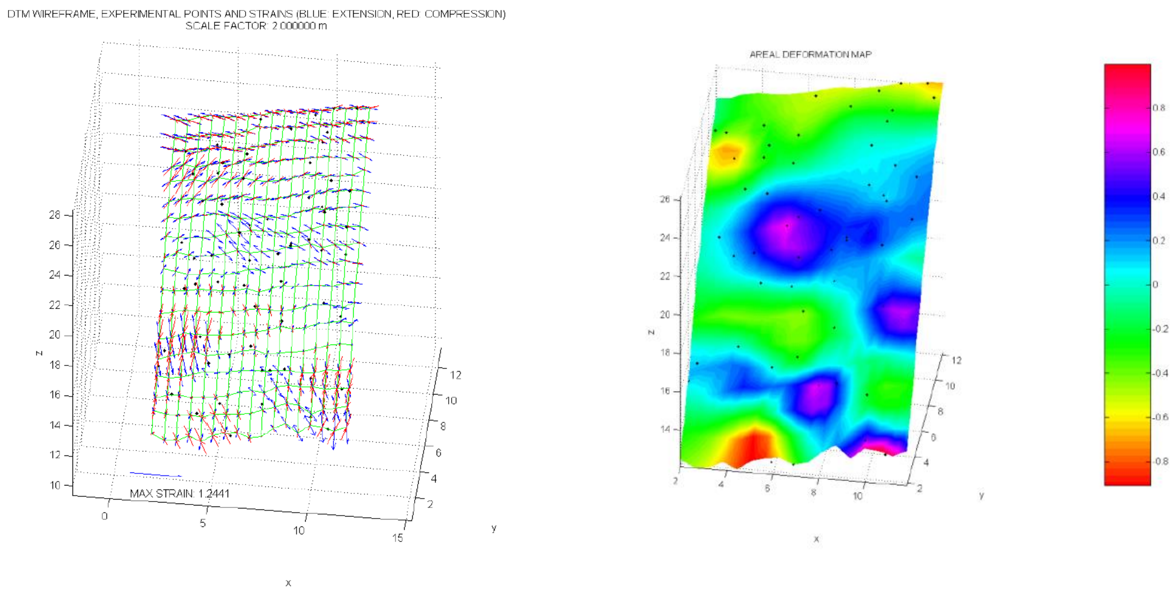
Please note that:

1. **if an elevation value is exactly zero, a small, but not-zero, value must be used to obtain correct computations[4];**
2. **the loss elevations (i.e., grid nodes where the interpolation algorithm did not provided results) must be characterized by abnormally high values, with a Surfer-like notation;**
3. **In the elevation matrix, each value outside the *z* range (if a Surfer .grd raster file is used) or equal to NODATA_value (if an ESRI Raster file is used) is assumed to be a not-modeled point, and no computations are performed by `grid_strain3` in this point.**

[4] Each number strictly higher than the spacing of floating point numbers (`eps`) can be used to model a zero-elevation point. To known `eps`, please type `eps` in the MCW. It is `eps` = 2^(-52)= 2.2204e-016.

11. Strain computation in the 3D case and visualizations

The strain field is computed on the DTM nodes. A subsampling can be carried out if one or both the DTM grid side are too large. Clearly, in order to properly use the information contained in a displacement field, the strain field should be computed with a similar step. The subsampled points are always elements of the original DTM, no interpolations are carried out. In particular, the options "x2", "x4" and "x8" are available for the DTM sampling step along *x* and/or *y*.



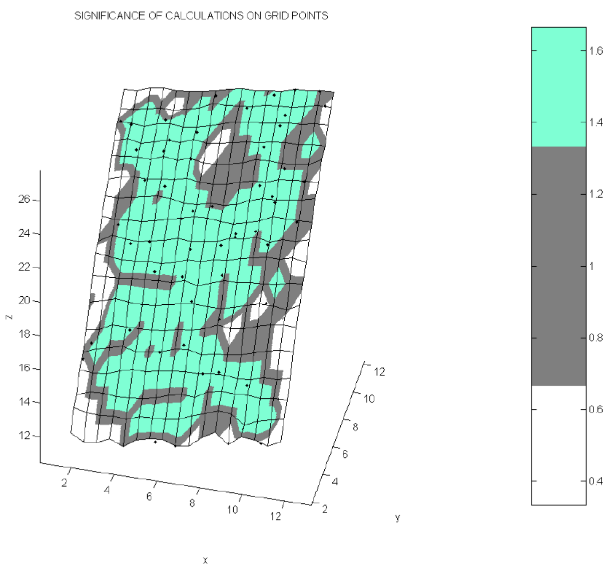


Fig. 11.1. Some plots that can be generated by grid_strain3. Top left panel: strain field. The colors of the vectors shown their nature (blue: extension; red: compression). Top right panel: change-in-area contouring, that is the field of strain traces (sums of eigenvalues). An inversion of sign in this plot shows a significant change, since the behavior passes form extensive (compressive) to compressive (extensive). Bottom panel: significance areas, on the basis of the distribution of the experimental points.

The principal strain directions are now three in each point where the calculations are performed. Flags are as in `GridStrain`, with the difference that a good distribution of the experimental points in checked in 3D.

Regarding to the eventual exclusion of one or more points from the calculations, the following facts should be taken in account:

a) All the experimental points outside the chosen DTM limits are automatically excluded.

b) Since in MATLAB environment no selection can be directly operated from a 3D view, the eventual manual exclusion is actuated on a 2D projection of the scene. The user can choose the projection (*xy*, *xz*, or *yz*).

The final data are shown by means of 3D plots. In particular, the strain field is overlapped to a wireframe representation of the DTM. In this way, if a subsampling has been chosen, only the sampled model points are shown (Fig. 11.1). The change in volume, the maximum shear strain, the errors on calculations, and the significance map are instead shown as contour maps on the DTM surface. Regarding to the shear, the user can chose the representation: natural scale, logarithmic scale (in this case, the logarithms of the absolute values are shown), or both. Also in 3D, the representation of the strain can be limited to the high significance area only, or to the high and mid significance areas. A sample data set and the corresponding DTM are available and attached to grid_strain3 software. Fig. 11.1 shows some plots can are obtained using the sample data and DTM.

In the 3D case, the following output data are provided:

1. The strain field tensors, consisting of the principal strain directions (normalized eigenvectors) and eigenvalues in each DTM point where the computations can effectively be performed. In each computation point the ellipsoid's semi-axes are plotted. Since such a plot is very memory consuming, a menu box allows the choice of the plot of the strain tensors (the memory consuming for all the other plots is low).
2. Change-in-volume, i.e. the trace of the strain tensor, presented as a contour plot rendered on DTM surface.
3. Prevailing eigenvalue, i.e. the eigenvalue having the largest modulus, shown as a contour plot.
4. Flinn's k-value, presented as a contour plot. This parameter encodes the shape of the strain ellipsoid. Let be $a = (1 + \varepsilon_{\text{max}})/(1 + \varepsilon_{\text{int}})$, $b = (1 + \varepsilon_{\text{int}})/(1 + \varepsilon_{\text{min}})$, the Flinn's k value is defined by $k = (a - 1)/(b - 1)$. The cases $k < 1$ and $k > 1$ mean respectively flattening and constriction, while $k = 1$ is the case of a planar strain.
5. Shear normalized to the strain trace, shown as a contour plot.
6. Relative errors on strain estimates, presented as a contour plot.
7. Geometrical significance of the results, shown as a contour plot.

The ASCII files `tutorial_data3.txt` (experimental points), `tutorial_dtm_in.grd` (initial DTM, i.e. DTM of a landslide before the displacement), `tutorial_dtm_fin.grd` (final DTM, related to the same landslide after the displacement) are provided within the toolbox for tutorial purposes.

13. References

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