Land Information New Zealand
Toitū te whenua

SNAP Tutorial

1 November 2017

New Zealand Government

Contents

Introduction

This tutorial is designed to introduce the Land Information New Zealand's SNAP least squares adjustment software. The datasets accompanying this tutorial are simulated and have been constructed to highlight ways in which SNAP can be used with different types of survey data.

LINZ welcomes feedback/suggestions on the SNAP software and this tutorial. To provide feedback, please email customersupport@linz.govt.nz with the words "SNAP" and "geodetic" in the subject line.

Target audience

The tutorial is aimed at surveyors and others who have been previously introduced to SNAP and wish to learn how to use it to undertake more complex adjustments. It particularly focusses on functionality added to SNAP over the past few years.

It assumes some prior knowledge of least squares terminology and analysis. It also assumes basic knowledge of SNAP, such as the general file structure and how to use it to complete a straight-forward least squares adjustment.

SNAP version

This tutorial was developed using SNAP Version 2.7.7, dated Oct 18 2017. Some of the functionality covered is not available in older versions of the software. Future versions of SNAP are expected to be backwards-compatible, so it is recommended that the most recent version available from the LINZ website is used.

Download and install SNAP

The latest version of SNAP can be downloaded and installed from the Land Information New Zealand website https://www.linz.govt.nz/data/geodetic-services/download-geodetic-software/snap-concord-downloads

Perl and connection to Geodetic Database

Some of the SNAP utility programs used in this tutorial require a Perl interpreter. This can be downloaded and installed from:

https://www.activestate.com/activeperl

Importing stations from the LINZ Geodetic Database requires a connection to the Geodetic Database.

Files required

To run this tutorial, the following files contained in *linz_snap_tutorial_initial_20171101.zip* are required:

affected_area.wkt
demo_rotoiti_gnss.csv
demo_rotoiti_lvl.csv
demo_rotoiti_lvl.dtf
demo_rotoiti_pb_ed_lv.dat

min_RGMK_0.snx

All other files are created as required in the tutorial.

The final set of files used to run the adjustment by the end of the tutorial is contained in *linz_snap_tutorial_final_20171101.zip*. These may be useful if problems are experienced during the tutorial (eg if a step is accidentally missed).

SNAP help

This document should be used in conjunction with the in-software SNAP Help which can be accessed from *Help* > *Help* or by pressing F1 from within SNAP.

The SNAP Help provides full documentation of the commands, software operations and data file formats used in this tutorial.

Tutorial scenario

This tutorial is based on the following scenario:

- Survey five existing marks, which are not in the LINZ Geodetic Database, to LINZ Order 4 standards. These marks are named ALICE, BRODY, CRAIG, DEVON and ETHEL and were initially installed and surveyed in 1995.

- Connect this network to at least three reliable Order 3 or better geodetic marks.

- The height uncertainty at the 95% confidence interval for DEVON and ETHEL must be 0.005m relative to ALICE.

- Using bearings, distances and height changes observed in 1995, assess which of the five marks (ALICE, BRODY, CRAIG, DEVON and ETHEL) is subject to local deformation.

For our existing Order 3 or better control marks, we choose the following marks, these being the closest to our job: BE48, BXUJ and RGMK

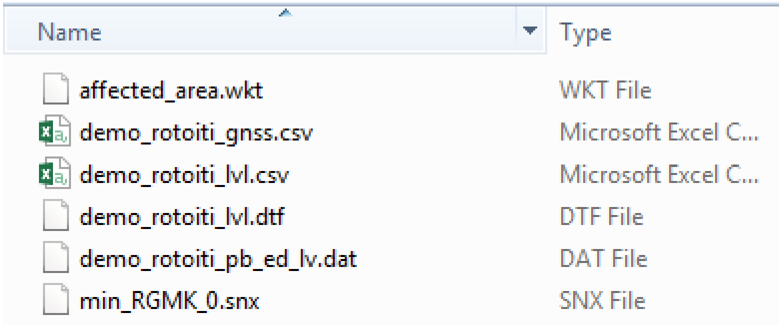
Note that BE48 and BXUJ are passive control marks, while RGMK is a Continuously Operating Reference Station (CORS) operated by GeoNet, with publically available data. Further details of these marks are available in the Geodetic Database:

http://apps.linz.govt.nz/gdb/index.aspx?code=BE48
http://apps.linz.govt.nz/gdb/index.aspx?code=BXUJ
http://apps.linz.govt.nz/gdb/index.aspx?code=RGMK

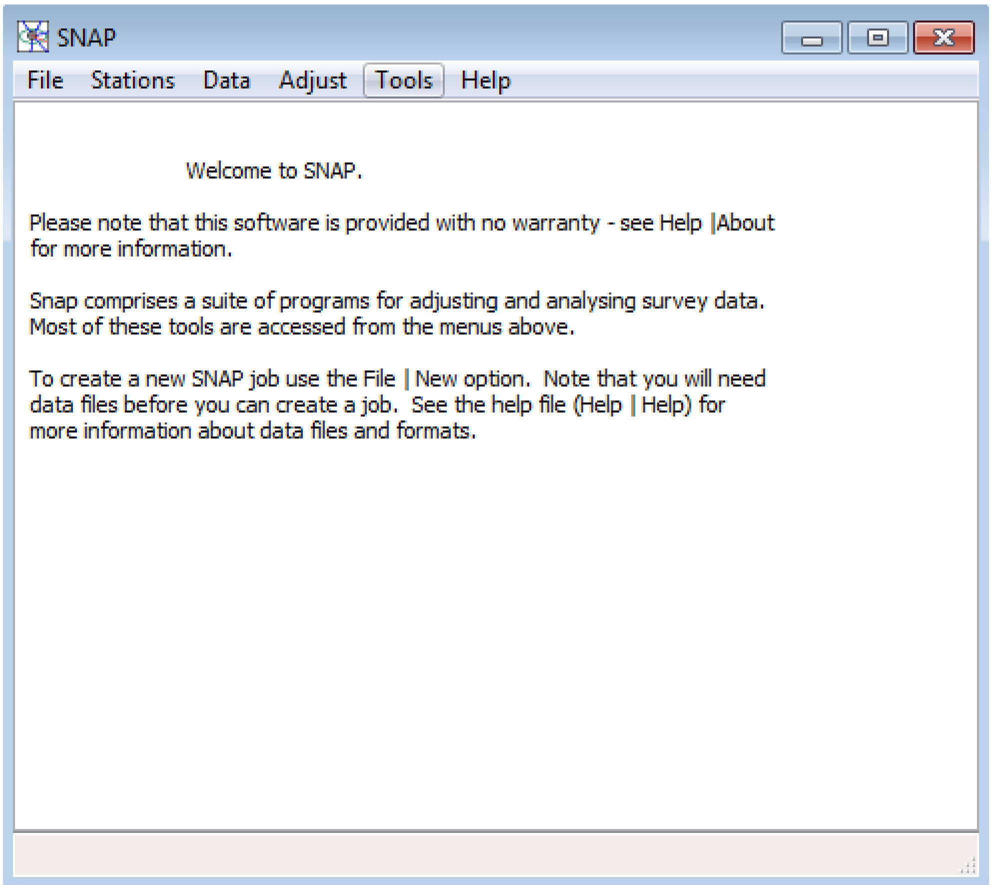
1 Setup a new SNAP job

1.1 Create a folder for the tutorial named *snap_demo_rotoiti*

1.2 Copy the six files from *linz_snap_tutorial_initial_20171101.zip* into this folder



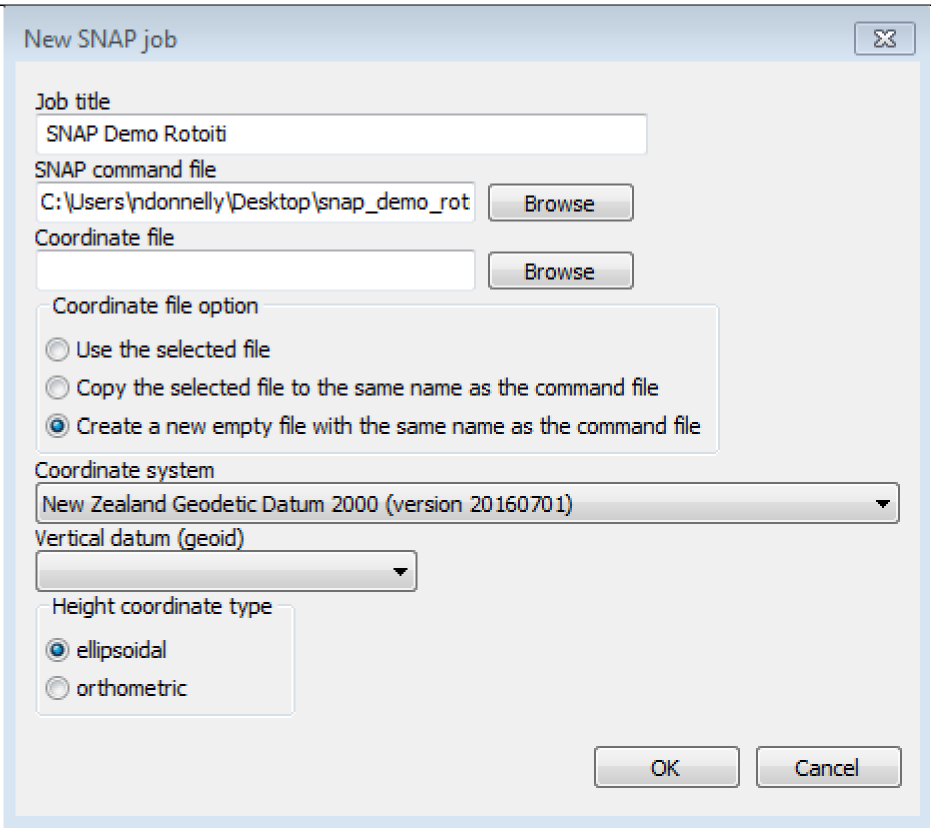
1.3 Open SNAP: eg *Start > Run SNAP*



1.4 *File > New* and complete the form as follows:

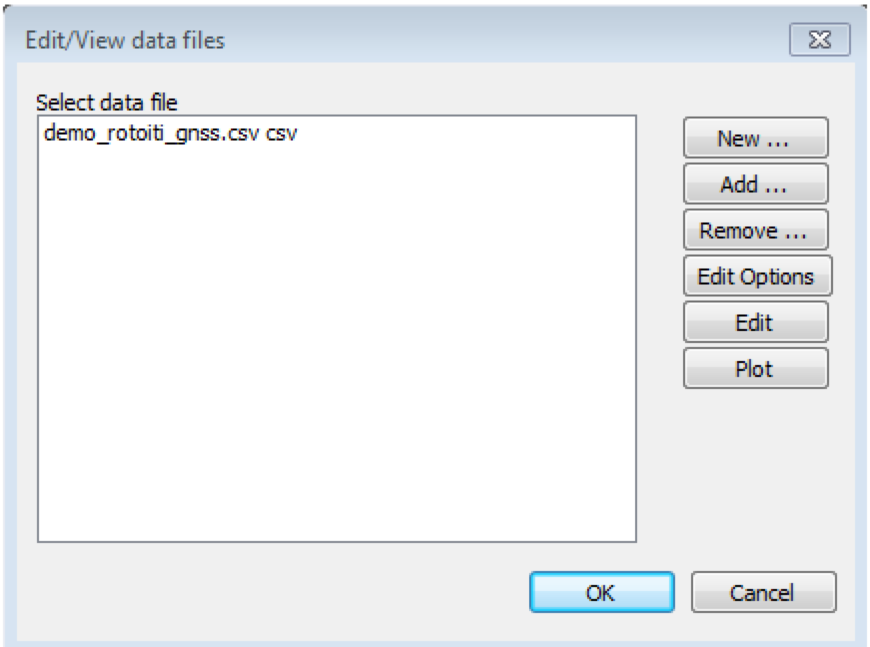
Job title: `SNAP Demo Rotoiti`
SNAP command file: Browse to your job folder and name the file `demo_rotoiti`
Coordinate file option: Select *Create a new empty file with the same name as the command file*

All other sections of the form use the defaults.



Click *OK*

In the *Edit/View data files* form, click *Add…* and select the file *demo_rotoiti_gnss.csv* from the job folder (if you can not see it initially, change the viewable file types to *All files (*.*)*)



Click *OK*

There should now be two new text files in the job folder:
demo_rotoiti.crd (SNAP coordinate/station file)
demo_rotoiti.snp (SNAP command file)

2 Edit the command file

2.1	Open the command file: *Adjust > Edit command file*
2.2	Delete all the comments, ie lines starting with (!), EXCEPT for: `! reference_frame ITRF2008 IERS_ETSR 2000.0 -4.8 -2.09 17.67 -1.40901 0.16508 -0.26897 -0.11984 -0.79 0.6 1.34 0.10201 0.01347 -0.01514 -0.01973` which will be used later in the tutorial
2.3	Delete the following lines: `max_iterations 5` `convergence_tolerance 0.0001` `max_adjustment 1000`
2.4	At this point, the command file should contain the following: `title SNAP Demo Rotoiti` `coordinate_file demo_rotoiti.crd` `data_file demo_rotoiti_gnss.csv csv` `mode 3d adjustment` `fix` `deformation datum` `! reference_frame ITRF2008 IERS_ETSR 2000.0 -4.8 -2.09 17.67 -1.40901 0.16508 -0.26897 -0.11984 -0.79 0.6 1.34 0.10201 0.01347 -0.01514 -0.01973`
2.5	Edit the data_file command to reference a SNAP csv format definition file (which will be created next) and enable the application of an error factor to the file: `data_file demo_rotoiti_gnss.csv csv format=demo_rotoiti_gnss error_factor 1.0`
2.6	Add a station to hold fixed for the minimally constrained adjustment, BE48: `fix BE48`
2.7	Add a command to hold the three Order 3 and better stations fixed for the constrained adjustment. Tell SNAP to ignore this line for the moment (since the minimally constrained adjustment will be completed first) by turning it into a comment using an exclamation mark at the start of the line. The fixed stations could also be listed by their station codes, but this command uses the order classification: `!fix order=2 order=3`
2.8	Add commands to output csv files, set observation and coordinate precisions and specify the statistical test for outliers: `output_csv all` `output_precision GB 3` `coordinate_precision 3` `flag_significance 95 maximum 95`
2.9	At this point, the SNAP command file should look like this: `title SNAP Demo Rotoiti` `coordinate_file demo_rotoiti.crd` `data_file demo_rotoiti_gnss.csv csv format=demo_rotoiti_gnss error_factor`

	1.0 mode 3d adjustment fix BE48 !fix order=2 order=3 deformation datum ! reference_frame ITRF2008 IERS_ETSR 2000.0 -4.8 -2.09 17.67 -1.40901 0.16508 -0.26897 -0.11984 -0.79 0.6 1.34 0.10201 0.01347 -0.01514 -0.01973 output_csv all output_precision GB 3 coordinate_precision 3 flag_significance 95 maximum 95

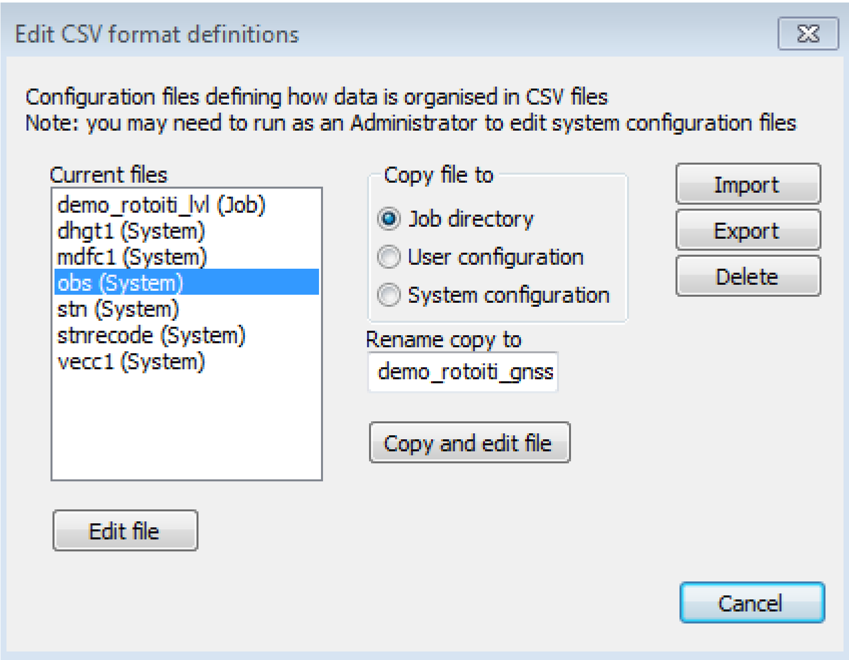
3 Setup the GNSS baseline CSV definition file

<table>
<tr><td>3.1</td><td>Copy an existing CSV observation definition file to your job folder:

File > Configuration > CSV format definitions

In the form, choose the following options:

Current files: Select obs (System)
Copy file to: Job directory
Rename copy to: <code>demo_rotoiti_gnss</code>



Click Copy and edit file</td></tr>
<tr><td>3.2</td><td>Edit the top line to describe the format:

<code>format_name SNAP CSV obs format for Rotoiti GNSS Baseline Demo</code></td></tr>
<tr><td>3.3</td><td>Remove obstype from the line starting required_columns (the default observation type will be specified further in the file):

<code>required_columns fromstn tostn</code></td></tr>
<tr><td>3.4</td><td>Set the default observation type to GNSS baseline by appending the line starting TYPE with DEFAULT "GB":

<code>TYPE @obstype DEFAULT "GB"</code></td></tr>
<tr><td>3.5</td><td>Specify the a priori observation uncertainties in the east, north and up components by amending the line starting ERROR as follows:

<code>ERROR @error DEFAULT "4 4 8 mm 0.5 0.5 1 ppm"</code></td></tr>
<tr><td>3.6</td><td>Set the line starting VECTOR_ERROR_TYPE to:

<code>VECTOR_ERROR_TYPE calculated</code></td></tr>
<tr><td>3.7</td><td>Delete the following lines, which are not needed for our particular data:

<code>ID @id</code></td></tr>
</table>

	`SET_ID @obsset` `INSTRUMENT_HEIGHT @fromhgt` `TARGET_HEIGHT @tohgt` `PROJECTION c_Projection`
3.8	The dtf file should now contain the following text: `format_name SNAP CSV obs format for Rotoiti GNSS Baseline Demo` `FORMAT CSV HEADER=Y` `required_columns fromstn tostn` `OBSERVATION` `TYPE @obstype DEFAULT "GB"` `REJECTED rejcode(@status)` `INSTRUMENT_STATION @fromstn` `TARGET_STATION @tostn` `DATETIME @date` `DATETIME_FORMAT YMDhms` `VALUE @value1 " " @value2 " " @value3 DEFAULT @value` `ERROR @error DEFAULT "4 4 8 mm 0.5 0.5 1 ppm"` `VECTOR_ERROR_TYPE calculated` `CLASSIFICATION_COLUMNS c_**` `END_OBSERVATION` `LOOKUP rejcode` `rej Y` `reject Y` `* Y` `default N` `END_LOOKUP`

4 Setup the coordinate file

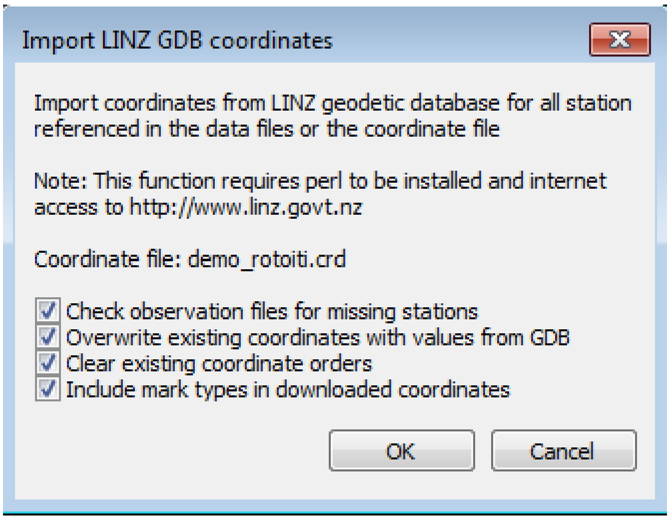
4.1 Open the station coordinate file: *Stations > Edit station file*

Note that it currently contains no station coordinates.

4.2 Import the coordinates of the control stations from the LINZ Geodetic Database:

Stations > Import Stations > LINZ GDB

Accept all the defaults:



Click *OK*

This searches the data file(s) for existing geodetic codes from the LINZ Geodetic Database and imports coordinates. In this case, it adds the coordinates for BE48, BXUJ and RGMK.

4.3 Calculate approximate coordinates for the remaining five stations:

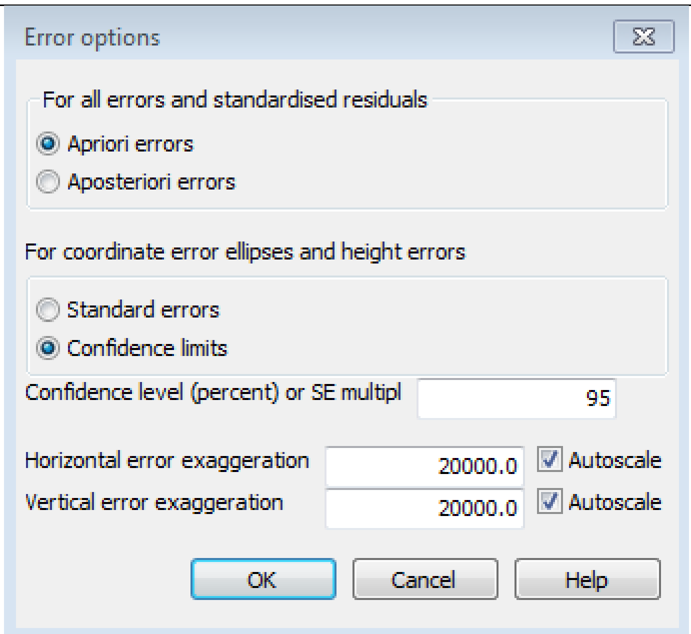
Stations > Calc missing stations…

4.4 The coordinate file should now contain the following text:

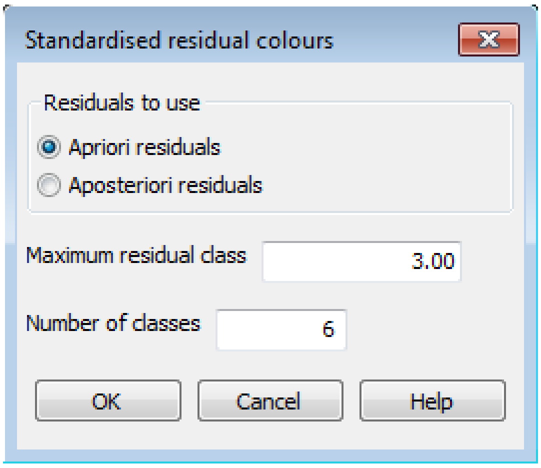
```
SNAP Demo Rotoiti
NZGD2000
options ellipsoidal_heights no_deflections no_geoid_heights c=Order c=MarkType

!Code      Latitude           Longitude         Ell.Hgt Order MarkType Name
RGMK   38 08 18.029742 S 176 28 01.606364 E   955.3660 2      FCTR   Makatiti
BE48   38 03 08.659555 S 176 27 06.853280 E   309.3430 3      PIN    GISBORNE POINT
BXUJ   38 02 27.544985 S 176 32 49.275629 E   336.6280 3      PIN    MANAWAHE ROAD
ETHEL  38 07 00.815605 S 176 28 15.525642 E   341.6487 -      -      ETHEL
CRAIG  38 06 34.545670 S 176 29 12.665351 E   307.7665 -      -      CRAIG
BRODY  38 06 02.628713 S 176 28 16.318197 E   327.9953 -      -      BRODY
ALICE  38 06 22.746023 S 176 27 23.525633 E   313.3123 -      -      ALICE
DEVON  38 06 54.776116 S 176 28 48.903854 E   320.2586 -      -      DEVON
```

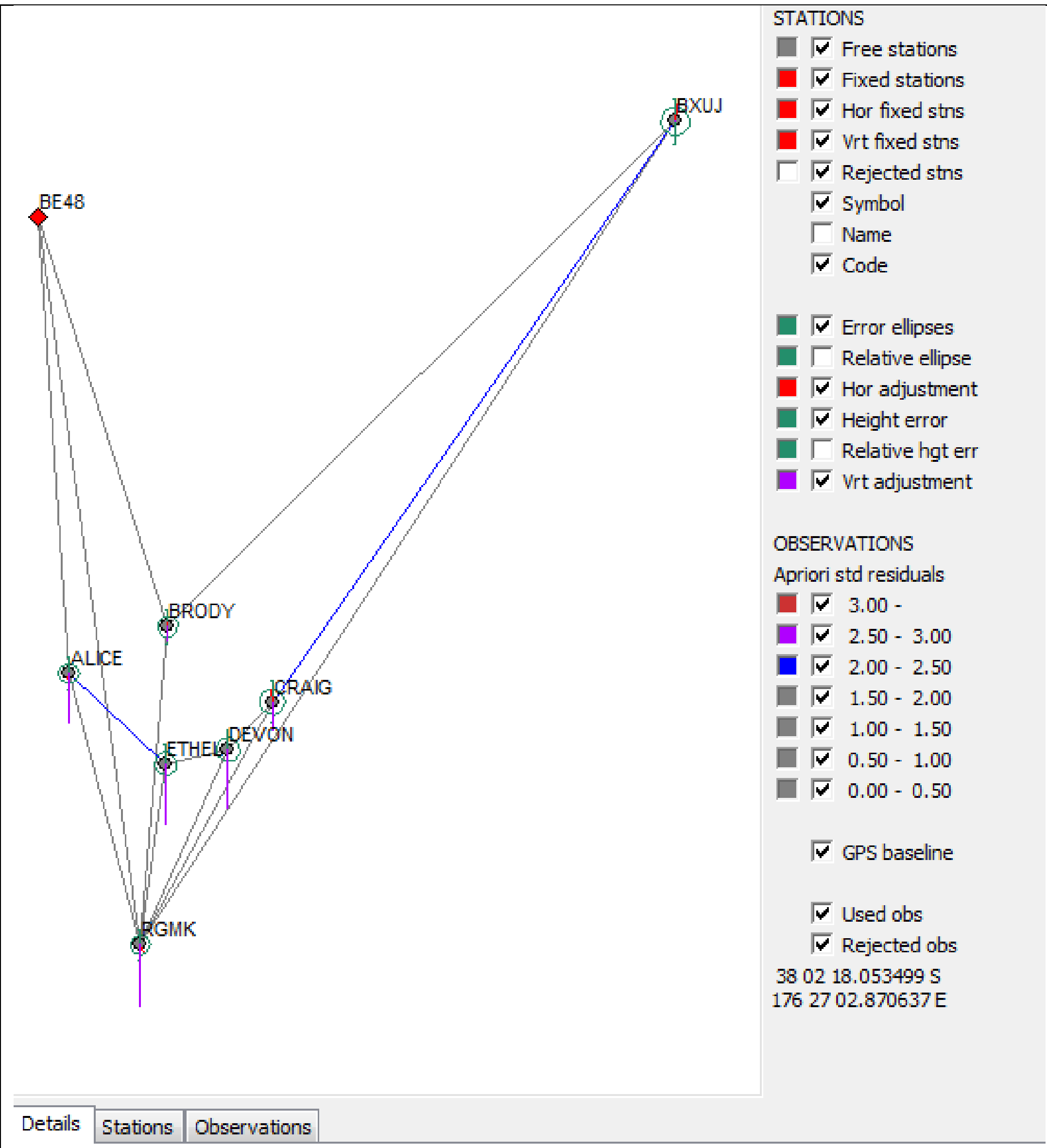
5 Minimally constrained GNSS baseline adjustment

5.1	In the command file, ensure that only BE48 is fixed, then run the adjustment: *Adjust > Run adjustment*
5.2	View the SNAP report: *Adjust > View report* Note the following: 1) The standard error of unit weight is 1.31. This is a little higher than we would expect, which may indicate the presence of gross errors or that we have been overly optimistic when estimating the observation uncertainties: `Standard error of unit weight:        1.31043` `The probability of an SSR this high is 2.152% (from Chi squared (21))` `You may have under-estimated the errors of the data,` `or there may be gross errors in the data` `or the fixed stations may be incorrectly positioned` 2) There are two triple-flagged (???) observations. This indicates that statistically, these are outliers and may contain gross errors (although note that the actual residual is 15mm for the first outlier and 10mm for the second, neither of which is particularly large). `From  To     Type     Value      +/-       Calc      +/-     Res    +/-    S.R.` `                       X,Y,Z               X,Y,Z                E,N,U` `BXUJ  CRAIG  GB        5031.618  0.010    5031.602  0.007   0.000  0.004   0.03` `                        4983.211  0.006    4983.212  0.004  -0.015  0.004   3.39  ???` `                       -5977.595  0.009   -5977.589  0.006  -0.009  0.009   1.01` `                        9267.212           9267.200          0.017          2.04  ?` `ETHEL ALICE  GB        -622.729  0.007    -622.737  0.005   0.004  0.003   1.37` `                        1307.728  0.004    1307.732  0.003  -0.010  0.003   4.01  ???` `                         941.078  0.006     941.085  0.005  -0.003  0.005   0.50` `                        1727.302           1727.312          0.011          2.46  ???` 3) The RMS value for the standardised residuals for the north component is significantly larger than those for the east and up components. This could indicate that the observation uncertainties for the north component are too tight, relative to the other components. It could also indicate the presence of gross errors in the north component. `Classification                           Used        Unused       Total` `                                        RMS  Count   RMS  Count   RMS  Count` `GPS baseline                            1.38   42     -      -    1.38   42` `        East component                  0.65   14     -      -    0.65   14` `        North component                 2.23   14     -      -    2.23   14` `        Up component                    0.57   14     -      -    0.57   14`
5.3	View in SNAPPLOT: *Adjust > Plot adjustment*
5.4	Turn on station codes (*Code* checkbox in the right-hand panel)
5.5	Set error type to apriori 95% confidence interval: *Errors > Error options…*

<table>
<tr><td></td><td>
</td></tr>
<tr><td>5.6</td><td>Colour the observations by apriori standardised residual:

Observations > Colour coding… > Residual…


</td></tr>
<tr><td>5.7</td><td>SNAPPLOT should now look like this:</td></tr>
</table>



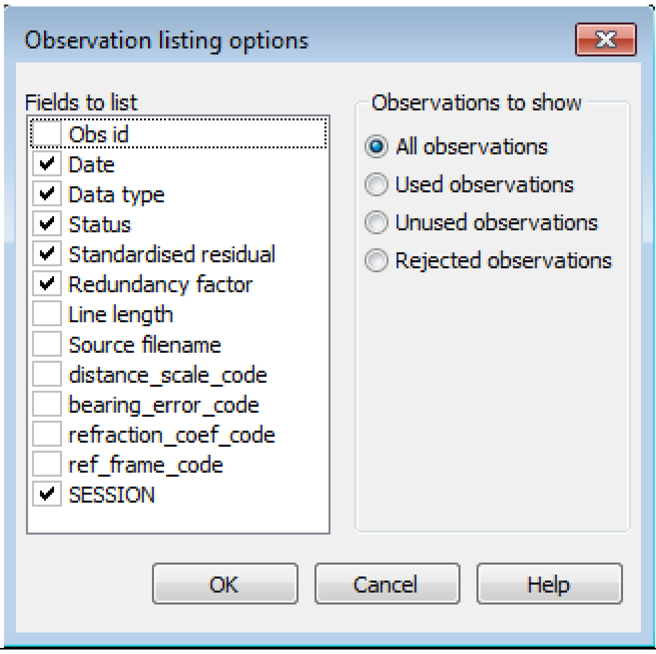

```
SNAP Demo Rotoiti

Coordinate system: New Zealand Geodetic Datum 2000 (version 20160701)
Displaying apriori errors
Error ellipses and height errors are 95.00% confidence limits
Ellipses exaggerated 30000 times
Height errors exaggerated 30000 times

Adjustment statistics
Number of observations:          42
Number of parameters:            21
Degrees of freedom:              21
Sum of squared residuals:        36.06181
Standard error of unit weight:    1.31043
```

5.8 Note that there are two 'blue' observations, indicating standardised residuals between 2.00 and 2.50. These are the same two observations identified in the report as having components that are potential outliers. Click on one of the blues lines and then the *GPS baseline* observation to see the full details of the observation.

In this case, the two observations are not really outliers, due to the fact that their residuals are reasonable for the type of observation. The flagging of these as outliers likely reflects that the observation uncertainties are not quite right, requiring some reweigting.

5.9 Click the *Observations* tab

Right-click in the header of the tab and add the *SESSION* field. *SESSION* was a category used in the GNSS CSV file to indicate which session a particular baseline belonged to.



5.10 Save this configuration so that it will be used by default whenever SNAPPLOT is opened for this job:

File > Save configuration…

Save in the job folder as *snapplot.spc*

5.11 Reweight the data file. Reweighting often requires considerable professional judgement. While the adjustment statistics (eg SEUW) provide useful guideance on how the data might be reweighted, the results (eg observation uncertainties and error ellipses) of any reweighting should always be considered to ensure they are reasonable and realistic. There are several potential approaches to reweighting, three of which are detailed below.

Approach 1 – Reweighting by SEUW

Probably the most common approach is to set the error factor to equal the SEUW, which will scale all the observation uncertainties by that amount.

Approach 2 – Reweighting by RMS component

But for this job there are two pieces of information which suggest that an alternative approach could be worthwhile:

1) The RMS values indicate that the uncertainty of the north component is more than the east component (these had been set in the dtf file to be equal)
2) We usually expect GNSS data to be a little less accurate in the north component compared to the east component due to the geometry of the satellite constellation (very few satellites to the south of New Zealand)

Scaling each of the components (east, north and up) by its RMS value would lead to observation uncertainties of `3 9 5 mm 0.3 1.1 0.6 ppm`.

One problem with this approach is that the resulting observation uncertainties are unrealistic. For example, 3mm and 0.3ppm is quite tight for the east component. And having the north uncertainty almost twice the size of the up uncertainty is inconsistent with the fact that GNSS is typically 2-3 times less accurate in the up direction compared with the horizontal. Note that there are only 14 observations, which is a small number from which to calculate RMS values and could lead to them being unreliable.

Approach 3: Reconsider initial estimates of uncertainty

	In this approach, reconsider the initial estimates of observation uncertainty, perhaps after consulting equipment manuals or considering previous experience with the equipment. In this case, previous experience with the GNSS equipment suggests that the north component has a greater uncertainty than the east component by a factor of up to 1.5. This would result in observation uncertainties in the dtf file of `4 6 8 mm 0.5 0.75 1 ppm`. ***Decision*** Note that all three approaches produce satisfactory results, in that the SEUW is close to 1.0, reasonable observations are no longer triple-flagged as outliers and the observation and coordinate uncertainties are reasonable (except perhaps for Approach 2, where the north uncertainty is particularly large). In this case, Approach 3 is chosen, and uncertainties in the dtf file updated accordingly. After doing this and rerunning the adjustment, the SEUW is 0.95. This is close enough to one, so applying an error factor to the data file is not required.

6 Constrained GNSS baseline adjustment

6.1	Open the command file, comment `fix BE48` and uncomment `fix order=2 order=3` to ensure that the three existing control stations are held fixed.
6.2	Run SNAP and open SNAPPLOT. Note that the SEUW is 2.16 and there are a number of high standardised residuals. It appears that one or more of the fixed station coordinates is inconsistent with the observations. It cannot be assumed that the problem is with the fixed coordinates. It is possible that there is a systematic error in the observations, which is not apparent in a minimally constrained adjustment.
6.3	Determine if the inconsistency is limited to a particular control mark by freeing up each of the three control marks in turn and observing the impact on the network. For example, first free up BE48, making sure the 'free' command is below the 'fix' command, as SNAP reads the commands in sequence: `fix order=2 order=3` `free BE48` The table below summarises the results of doing this: Free control station / SEUW / Number of outliers: BE48 / 1.81 / 2 BXUJ / 1.83 / 3 RGMK / 1.04 / 0 Based on this, it appears that only RGMK has a conflict, because when BE48 and BXUJ only are fixed, the SEUW is close to one and there are no outliers.
6.4	Open SNAPPLOT and click on RGMK to view details of the coordinate change: `Station RGMK: Makatiti` `Order: 2` `MarkType: FCTR` `38 08 18.030226 S   176 28 01.606406 E   955.3112` `Adjusted horizontally, Adjusted vertically` `Apriori 95.00% conf. lim. error ellipse 10.7mm at N0E, 7.1mm at N90E` `Apriori 95.00% conf. lim. height error 11.4mm` `Station adjustment (E,N,Z):    0.001m  -0.015m  -0.055m` The vertical movement is 55mm downwards. That is, the surveyed position of RGMK (according to the GNSS baseline data) is 55mm below the position provided in the Geodetic Database. There are a number of possibilities for this conflict: 1) The 55mm spacer on RGMK was not correctly treated in the processing 2) The antenna phase centre model was not correctly applied in the GNSS processing software for this CORS 3) The coordinate in the Geodetic Database is incorrect 4) There has been localised subsidence at RGMK (which does not affect BE48 and BXUJ) After some investigation it is determined that RGMK is indeed subsiding, such that it has dropped about 5cm between the time its coordinate was calculated for the Geodetic Database and the time of this survey.

7 GNSS point (SINEX) data

Since RGMK is a CORS, data from it can be processed using PositioNZ-PP and included in the adjustment. This enables the network to be connected to additional reliable control stations without making additional field observations.

One of the products of the PositioNZ-PP processing is a minimally constrained SINEX file in terms of ITRF2008 called *min_RGMK_0.snx*

7.1	Update the command file to reference the SINEX file: `data_file min_RGMK_0.snx sinex ref_frame=ITRF2008 error_factor 1.0`
7.2	Uncomment the command to apply the ITRF2008 reference frame transformation
7.3	Comment out the reference to the *demo_rotoiti_gnss.csv* data file, so that only using the SINEX file is used
7.4	The SINEX file includes the PositioNZ stations TAUP, TRNG and WHKT. Add these to the coordinate file by updating from the Geodetic Database: *Stations > Import stations > LINZ GDB*
7.5	Run the adjustment. Note that this minimally constrained adjustment has no redundancy, so we cannot make a statistical assessment of the SINEX data. Note also that no stations were fixed to run the adjustment. This is because the GNSS point data is an absolute observation in terms of ITRF2008 (which SNAP uses to calculate NZGD2000 coordinates using a reference frame transformation and the NZGD2000 deformation model).
7.6	Open in SNAPPLOT and note the size of the coordinate changes at the PositioNZ stations. They are mostly less than 0.01m, which indicates that the SINEX data is consistent with the existing NZGD2000 coordinates.
7.7	Fix the PositioNZ stations by adding `order=0` to the fixed station command: `fix order=0 order=2 order=3`
7.8	Run the adjustment. From the SNAP report, the SEUW is 285 and the standardised residuals range from 46 to 403.
7.9	Open in SNAPPLOT. Click on RGMK and note that the error ellipse is 0.3mm and the height error 1.1mm. For the 24 hours of GNSS data at RGMK, values closer to 5mm horizontal and 10mm vertical at a 95% confidence level would be expected. These values are based on experience, but are also consistent with the residuals for this data file. Click on each of the PositioNZ stations and note that the residuals are almost all less than 0.01m. This indicates that the observations are fine, despite the very high standardised residuals. The problem is that the observation uncertainties (the covariance matrix in the SINEX file) are far smaller than they should be. This is a common challenge with GNSS point data, as the GNSS processing software is not able to account for all the sources of error that impact the observations.
7.10	Reweight the data file by scaling by the SEUW of 285: `data_file min_RGMK_0.snx sinex ref_frame=ITRF2008 error_factor 285.0`
7.11	Run the adjustment and open in SNAPPLOT.

	The SEUW is now 1.0 and there are no outliers. Click on RGMK and note that the error ellipse is now 76mm and the height error 323mm. So the coordinate uncertainties have gone from being unrealistically small to unrealistically large. Above, it was suggested that reasonable uncertainty values for RGMK would be 5mm horizontal and 10mm vertical. This suggests the original uncertainties of 0.3mm and 1.1mm need to be scaled by about 15 for the horizontal component and 9 for the vertical component. Therefore scale the data file by the larger of these values: `data_file min_RGMK_0.snx sinex ref_frame=ITRF2008 error_factor 15.0`
7.12	Run the adjustment and open in SNAPPLOT. The SEUW is now 19 and there are still large standardised residuals (although the residuals themselves are still similar to what they were previously). Click on RGMK and note that the error ellipse is now 4mm and the height error 17mm. These are much more realistic values. Even though the weighting of the SINEX file is now reasonable, the high SEUW and standardised residuals are problematic as they have the potential to hide real issues with other datasets that we add to this adjustment. The reason for the high SEUW is that the fixed PositioNZ coordinates are in conflict with the GNSS point data, including the covariances within the SINEX file which act as constraints on how the observations can be adjusted to fit the fixed coordinates. One approach to resolve this conflict is to recognise that assuming the fixed stations are error-free is not realistic. In SNAP, uncertainties can be assigned to fixed stations to account for this, which is referred to as floating the station. In this case, the uncertainty in the fixed stations is estimated to be 5mm horizontally and 10mm vertically.
7.13	Add the following commands to the command file, below the last 'fix' command: `horizontal_float_error 0.005` `vertical_float_error 0.010` `float order=0 order=3` Note that the Order 2 station (ie RGMK) is not floated because it is known that this station has a discrepancy in the height and therefore should not be constrained to the height in the coordinate file.
7.14	Comment out all the fix commands.
7.15	Run the adjustment and view in SNAPPLOT. Note that the PositioNZ stations now have coordinate changes. The SEUW is now 1.1 and there are no observations flagged as outliers.
7.16	Uncomment the reference to the GNSS baseline file and rerun the adjustment. Note that the issue with the height conflict at RGMK is now resolved.

8 Levelling data

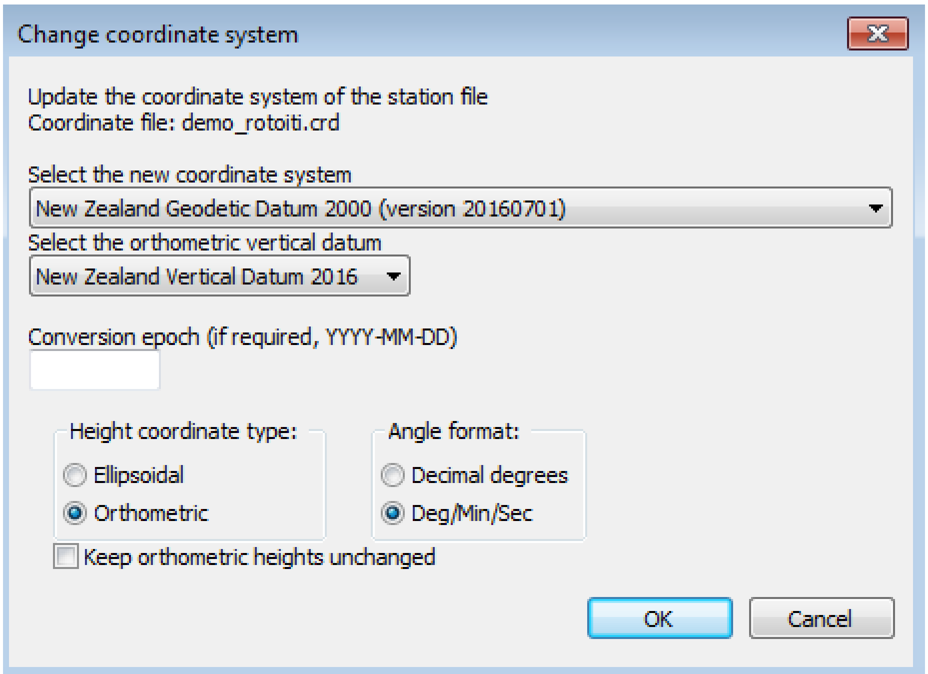
<table>
<tr><td>8.1</td><td>Comment out the two GNSS data files and add references to the levelling data file:

```
!data_file demo_rotoiti_gnss.csv csv format=demo_rotoiti_gnss error_factor
1.0
!data_file min_RGMK_0.snx sinex ref_frame=ITRF2008 error_factor 15.0
data_file demo_rotoiti_lvl.csv csv format=demo_rotoiti_lvl error_factor
1.0
```
</td></tr>
<tr><td>8.2</td><td>Change the vertical coordinate system to NZVD2016.

Stations > Change coordinate system…

Select the following:

Orthometric vertical datum: New Zealand Vertical Datum 2016
Height coordinate type: Orthometric

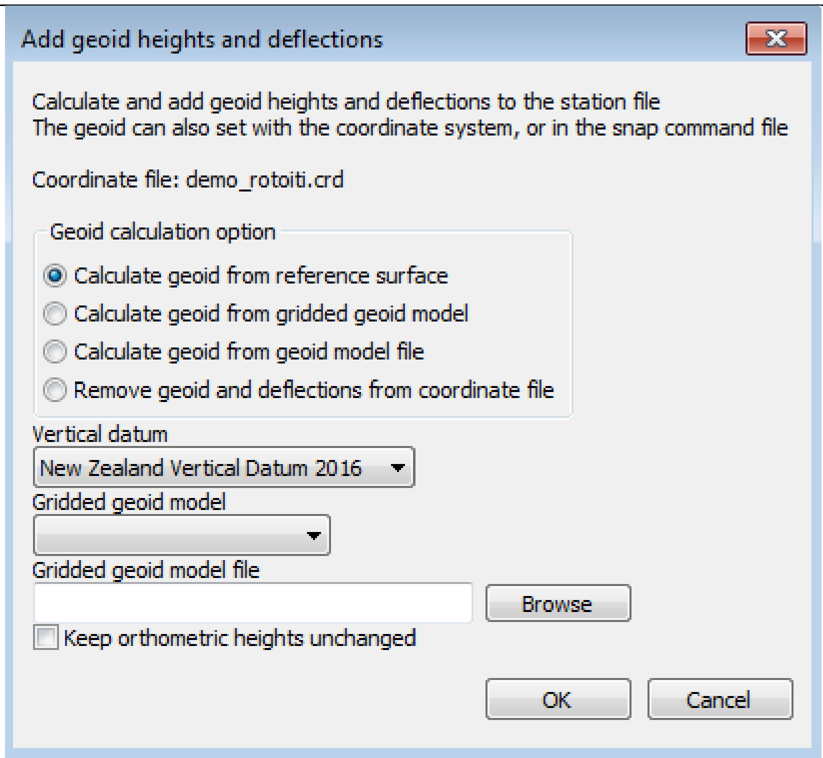


</td></tr>
<tr><td>8.3</td><td>Add NZGeoid2016 geoid heights:

Stations > Add geoid heights…

Select the following:

Geoid calculation option: Calculate geoid from reference surface
Vertical datum: New Zealand Vertical Datum 2016.
</td></tr>
</table>

<table>
<tr><td></td><td>


</td></tr>
<tr><td>8.4</td><td>Setup a minimally constrained levelling adjustment.

In the command file, fix ALICE:

<code>fix ALICE</code></td></tr>
<tr><td>8.5</td><td>Change the mode from 3d to 1d:

<code>mode 1d adjustment</code></td></tr>
<tr><td>8.6</td><td>Run the adjustment and view the results in SNAPPLOT. Note the SEUW is 1.2 and there are no outliers.</td></tr>
<tr><td>8.7</td><td>Reweight the levelling data using an error factor of 1.2:

<code>data_file demo_rotoiti_lvl.csv csv format=demo_rotoiti_lvl error_factor 1.2</code></td></tr>
<tr><td>8.8</td><td>Uncomment the GNSS data files</td></tr>
<tr><td>8.9</td><td>Change mode from 1d to 3d</td></tr>
<tr><td>8.10</td><td>Comment out the fix command for ALICE</td></tr>
<tr><td>8.11</td><td>Run the adjustment and view results in SNAPPLOT. Note the SEUW is 0.96.

Select the vector between ALICE and ETHEL and note that because levelling data is now included, the relative vertical uncertainty is much less than the horizontal uncertainty:

<code>From ETHEL: ETHEL</code>
<code>To   ALICE: ALICE</code>

<code>Slope dist 1727.311 Ell dist 1726.990   Az 312 48 50.2 Hgt diff -28.413</code>

<code>Apriori 95.00% conf. lim. error ellipse 11.4mm at N0E, 7.6mm at N90E</code>
<code>Apriori 95.00% conf. lim. height error 2.1mm</code></td></tr>
</table>

9 Survey plan data (plus levelling)

9.1	Add a reference to the survey plan and levelling data file to the command file: `data_file demo_rotoiti_pb_ed_lv.dat error_factor 1.0`
9.2	Comment out all the other data files
9.3	Hold ALICE fixed
9.4	Hold BRODY fixed in the vertical component (because there is no levelling data to BRODY)
9.5	Run the adjustment and view in SNAPPLOT
9.6	Apply an error factor of 1.1 (since the SEUW is 1.1)
9.7	Uncomment the other data files and unfix ALICE and BRODY
9.8	Run the adjustment and view in SNAPPLOT. The SEUW is 4.0 and there are several high standardised residuals, all relating to ALICE, CRAIG, DEVON and ETHEL. The terrestrial observations between ALICE and BRODY, and BRODY and CRAIG, have low standardised residuals. This indicates that ALICE, BRODY and CRAIG are in terms with each other. This suggests a problem with DEVON and ETHEL. Specifically, the 1995 observations from the survey plan and levelling do not agree with the 2017 observations in the other data files. After further investigation, DEVON and ETHEL are found to be located in an area of known localised deformation, which is defined by the well-known text file *affected_area.wkt*
9.9	Separate the 2017 observations from the 1995 observations within the affected area by recoding stations within the affected area: `recode suffix _A before 2017-01-01 for inside NZTM affected_area.wkt`
9.10	Run the adjustment and view in SNAPPLOT. The SEUW is now 0.96 and there are no outliers. Zoom in on DEVON and note that SNAP has split out the pre-2017 observations and connected them to the recoded mark DEVON_A. Double-click on DEVON and single-click on DEVON_A. SNAPPLOT calculates these two positions are separated by 0.061m horizontally and 0.199m vertically. ETHEL and ETHEL_A are similarly separated. The observations therefore confirm that DEVON and ETHEL have been subject to localised deformation since the original survey in 1995.
9.11	Since the bearings are in terms of Bay of Plenty Circuit 1949, there could be an orientation error between NZGD1949 and NZGD2000. Note that SNAP's "bearing orientation error" has the opposite sign convention to the "bearing swing" or "bearing correction" familiar in New Zealand cadastral surveying. Add the following to the command file: `bearing_orientation_error calculate PLENTM1949`

9.12	Run the adjustment and open the SNAP report. Find the "OTHER PARAMETERS" section and note the bearing error: `Parameter                              value         +/-` `Bearing error PLENTM1949                -1.45381      1.18428` The bearing error is -1.5 seconds with a 95% uncertainty of 2.3 seconds (multiplying the standard error of 1.18 by 1.96). Since the bearing orientation error is not significantly different from zero, it does not need to be calculated, so comment out this command and rerun the adjustment.

10 Specification testing

10.1	For specification testing, comment out the station recoding and instead reject all observations to stations within the affected area made before 2017 using this command: `reject_observations before 2017-01-01 using_stations inside NZTM affected_area.wkt` Note that we would achieve the same outcome by rejecting, using an asterisk (*), all the observations between ALICE, DEVON, ETHEL and CRAIG in *demo_rotoiti_pb_ed_lv.dat*
10.2	Set up the Order 4 specification and the 5mm vertical specification by adding the following to the command file: `specification order_4 confidence 95% horizontal 10mm 10ppm 50mm_abs vertical 10mm 50ppm 135mm_abs` `specification rotoiti_vert confidence 95% vertical 5mm`
10.3	Specify which specification and which stations to test against each specification by adding the following: `test_specification order_4 ALICE BRODY CRAIG DEVON ETHEL` `test_specification rotoiti_vert ALICE DEVON ETHEL`
10.4	Specify that only failed results are to be listed: `spec_test_options list_fail`
10.5	Run the adjustment and open the SNAP report. Find the ACCURACY SPECIFICATION TESTS section and note the results. If the ratio of error to tolerances is less than 1, then the test passes. If the ratio is greater than 1, then the test fails. The absolute accuracy tests pass, as do the relative accuracy tests, for both accuracy specifications.

Appendix A: Final command file

```
title SNAP Demo Rotoiti

coordinate_file demo_rotoiti.crd

data_file demo_rotoiti_gnss.csv csv format=demo_rotoiti_gnss error_factor 1.0
data_file min_RGMK_0.snx sinex ref_frame=ITRF2008 error_factor 15.0
data_file demo_rotoiti_lvl.csv csv format=demo_rotoiti_lvl error_factor 1.2
data_file demo_rotoiti_pb_ed_lv.dat error_factor 1.1

mode 3d adjustment

!fix ALICE
!fix vertical BRODY
!fix BE48

!fix order=0 order=2 order=3

horizontal_float_error 0.005
vertical_float_error 0.010

float order=0 order=3

free RGMK

!recode suffix _A before 2017-01-01 for inside NZTM affected_area.wkt
reject_observations before 2017-01-01 using_stations inside NZTM affected_area.wkt

!bearing_orientation_error calculate PLENTM1949

deformation datum

reference_frame ITRF2008 IERS_ETSR 2000.0 -4.8 -2.09 17.67 -1.40901 0.16508 -0.26897 -
0.11984 -0.79 0.6 1.34 0.10201 0.01347 -0.01514 -0.01973

output_csv all
output_precision GB 3
coordinate_precision 3
flag_significance 95 maximum 95

specification order_4 confidence 95% horizontal 10mm 10ppm 50mm_abs vertical 10mm 50ppm
135mm_abs
specification rotoiti_vert confidence 95% vertical 5mm
test_specification order_4 ALICE BRODY CRAIG DEVON ETHEL
test_specification rotoiti_vert ALICE DEVON ETHEL
spec_test_options list_fail
```