

GPS in Earth Sciences

As we have seen, GPS is used in many different industries, including aviation, marine, farming, military and science. In this worksheet we'll look specifically at how GPS is used within the Earth Science community. The term 'Earth Science' (otherwise known as 'Geoscience') refers to any scientific studies related to planet Earth. This includes the fields of Geology, Physical Geography, Geodesy, Geophysics, Ecology, Hydrology and Soil Sciences.

Geophysicists have been big users of high accuracy GPS since the early 1990's. Their job is to study the physics of the earth, including its shape, composition and movement. By installing high accuracy GPS receivers across the landscape, scientists can monitor any movement (both up/down and side-to-side) and relate this to underlying physical processes.

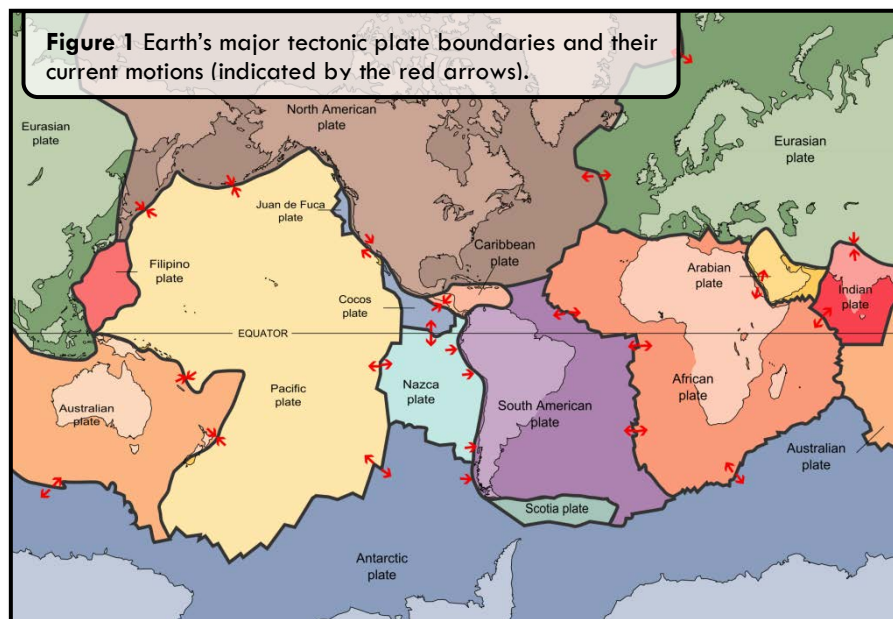
Tectonic Plates

The earth's surface is made up of massive slabs of rock known as tectonic plates (known as the lithosphere). There are 15 major plates which float on a softer layer of the earth called the asthenosphere (Figure 1). Because these tectonic plates are floating, changes underneath the plates and the earth's rotation cause them to 'drift' about at very small speeds. By installing high accuracy GPS receivers on each plate, scientists can record the speed and direction that each plate is travelling in. Once installed, these receivers can operate for decades, allowing scientists to analyse any changes to the direction of each plate's movement.

FAST FACTS



1. 'Earth Science' (also known as 'Geoscience') is any scientific study related to planet Earth.
2. GPS helps earth scientists to monitor how landscapes move and change shape over time.
3. When earthquakes occur, scientists use GPS to determine how far the landscape has moved.
4. High accuracy GPS can be used to monitor landslides and volcanoes, helping to issue warnings when they are close to collapse or eruption.
5. Australia has two active volcanoes, located on Heard Island and McDonald Island in the Southern Ocean. The volcano on Heard Island (called Big Ben) is Australia's tallest mountain outside Antarctica (at 2745 m).



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Earthquakes & Landslides

Because tectonic plates drift about on the asthenosphere, it is not uncommon for them to collide into each other from time to time. When the plates collide, the surrounding landscape shakes (and sometimes shatters), causing what we know as earthquakes. This is why cities which lie on or near plate boundaries are more prone to earthquakes than those that are located near the middle of a plate. When plates interact with each other, they result in a variety of different features. If both plate boundaries exist on land, they often produce features known as 'faults' throughout the landscape. The type of fault will depend on the direction that each plate is moving in, as shown in Figure 2.

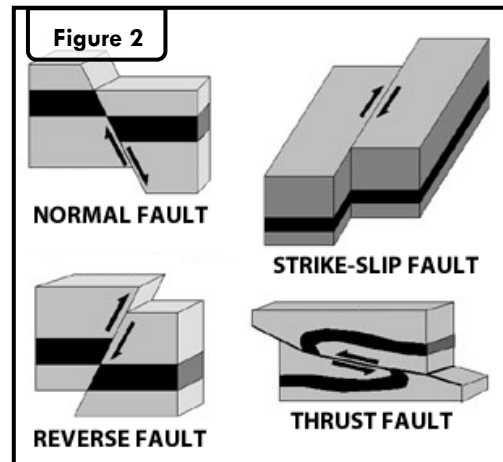


Figure 3 A permanent GPS receiver (left) installed in the United States.



Since the development of high accuracy GPS receivers, scientists have been using them to assess the severity of earthquakes across different parts of the globe. By installing permanent GPS receivers on either side of a fault line, it is possible to determine how much the landscape has shifted after each earthquake occurs. Faults can also occur on smaller scales due to landslides or other local stresses within the bedrock. High accuracy GPS can be setup on the moving parts of different landslides to determine how fast they're moving. If GPS shows that a landslide is moving progressively faster, it may be a sign that the landscape may soon collapse altogether, allowing scientists to warn the authorities and nearby residents.

Volcanoes

In recent years, high accuracy GPS has also been used to monitor volcanic activity across various parts of the world. Volcanic eruptions occur when molten rock (known as magma), ash and gases beneath the ground release on the earth's surface, often with tremendous force. As magma makes its way towards the surface, the immense pressure can often cause the landscape surrounding the volcano to 'bulge' slightly.

By deploying high accuracy GPS at strategic locations over volcanoes, scientists can monitor the height of the landscape. If any sudden or abnormal increases in position are detected, they may indicate that a chamber within the volcano is swelling with magma and that an eruption may occur in the future. GPS can therefore be a useful tool for predicting volcanic eruptions. This in turn leads to early warnings and the evacuation of both people and property prior to the disaster, which helps to minimise damage and ultimately save lives.



Figure 4 A scientist checks a GPS receiver (right) on Mt. Saint Helens (USA).

Further Information

Want to know more about Earth Sciences and how GPS is used within this industry? Check out the following resources:

Recommended Books

- 'Fundamentals of Physical Geography' by James Petersen (2014). ISBN: 9781133606536.
- 'Plate Tectonics – Continental Drift and Mountain Building' by Wolfgang Frisch (2010). ISBN: 9783540765035.

Recommended URL's

- 'Plate Tectonics' - <http://www.platetectonics.com/book/index.asp>
- 'Folding and Faulting – Physical Geography Fundamentals' - <http://www.physicalgeography.net/fundamentals/10l.html>
- 'Earthquakes in Australia – Geoscience Australia' - <http://www.ga.gov.au/earthquakes/>
- 'What causes Earthquakes? – Geoscience Australia' - <http://www.ga.gov.au/hazards/earthquakes/earthquake-basics/causes.html>
- 'What causes Volcanos? – Geoscience Australia' - <http://www.ga.gov.au/hazards/volcano/volcano-basics/causes.html>
- 'United States Plate Boundary Observatory' - <http://pbo.unavco.org/>
- 'Monitoring Volcano Deformation with GPS' - <http://volcanoes.usgs.gov/activity/methods/deformation/gps/>

Australian Curriculum Content Descriptors: ACMNA178, ACSIS124, ACSIS129, ACHGS048, ACSHE227, ACSIS145, ACHGK053, ACHGS059

Worksheet 4

Instructions: In this worksheet we'll look at GPS data that is used within the Earth Sciences community. Start by reading the information pages provided and then work through each of the following questions.

- To monitor earthquakes and tectonic plate motion, hundreds of high accuracy GPS receivers have been permanently installed across the San Andreas Fault in Southern California. Refer to the provided instructions to download the observations from GPS site 'P499' (see 'Downloading GPS data for site P499'), then explore the data and answer the relevant questions.

Note: This question assumes that you have access to the internet and plotting capabilities using Microsoft Excel. If this is not the case, please refer to the tables and graphs provided at the end of this document to answer the relevant questions.

- A) Once you have downloaded the site data, open it using Microsoft Excel (non-internet users: see 'Table 1: P499 GPS Data'). What is this site's 4 Character ID, Station Name, Beginning Date and End Date? Where is this station located? (Hint: Try entering the latitude and longitude into the search field inside Google Earth).

- B) Take a look at the dates for the first few data records. Ignoring the first record, what is the interval (i.e. frequency) of the observations?

- C) Use Excel to create three scatter graphs (with no lines) of the North and East data (second and third columns) vs. Time (first column) between 10th January 2006 and 31st May 2014 (inclusive). Refer to the included information sheet for specific details on how to plot data using Microsoft Excel (non-internet users: see 'Graph 1: P499 North Motion' and 'Graph 2: P499 East Motion').

- D) Looking at your graphs of the North and East components, which direction is site P499 *currently* travelling (i.e. between September 2012 and May 2014)? (Hint: A positive slope indicates north and east movement respectively).

- E) Focusing on the period between September 2012 and May 2014, use the formula for the slope of a line to estimate the speed at which site P499 is moving northwards and eastwards respectively. (Hint: It might be easier to refer to the provided graphs and use a ruler to estimate the average rate for this period).

$$\text{Rate} = \text{Slope} = \frac{\text{Rise}}{\text{Run}} = \frac{\text{Change in position}}{\text{Change in time}}$$

2. The map below shows the boundary between the Pacific Plate and the North American Plate with their relative directions of movement indicated.



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- A) Based on your answer to Question 1E, which plate do you think GPS site P499 is on? Justify your answer.

- B) The San Andreas Fault exists on the boundary between the Pacific Plate and the North American Plate, and extends approximately 1,300 km through California. Referring again to the map provided, what type of fault do you think this is? Justify your answer.

3. The website at <http://goo.gl/RNcdCx> provides the public with free GPS datasets from permanent, high accuracy GPS receivers right around the world. Each GPS site is shown on an interactive map, where users can click on each site to get a pop up display of the North, East and Up positions for that site over time. By clicking on the graph, you can find out more detailed information about each GPS site.

Note: This question assumes that you have access to the internet. If this is not the case, please refer to the graphs provided at the end of this document to answer the relevant questions.

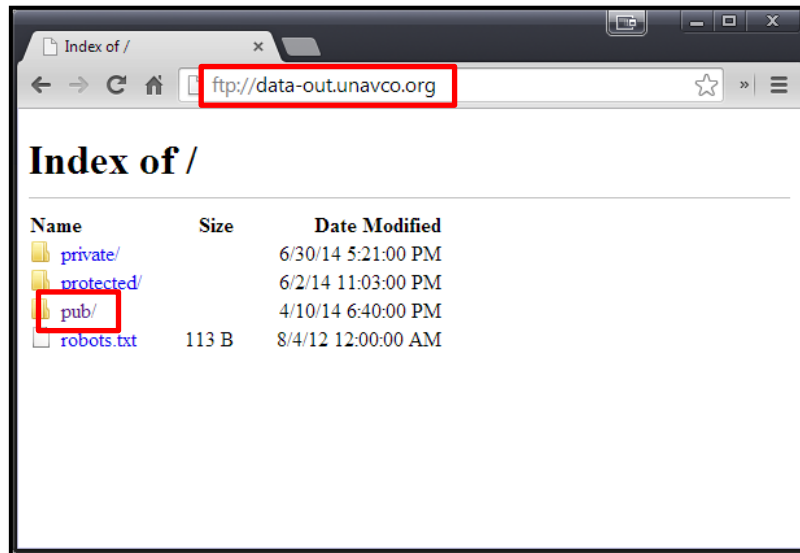
- A) Use the map to find your closest GPS receiver with a reliable amount of data (minimum of three years) (non-internet users: see 'Graph 2: MOBS (Melbourne) Position'). Looking at the plots of North and East for your selected station, which direction is your site currently travelling? (Hint: A positive slope indicates north and east movement respectively).

- B) How does this compare with the direction of site P499 in California? Explain why the direction of the two sites is significantly different.

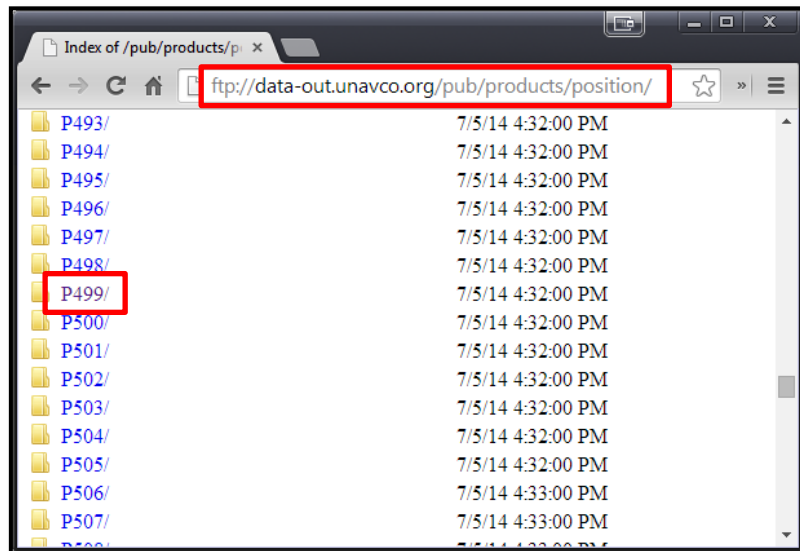
Downloading GPS data for site P499

The following provides a guide on how to download high accuracy GPS data that is free for public use. The dataset can then be plotted and the tectonic plate motion for this site can be analysed (see Plotting in Microsoft Excel).

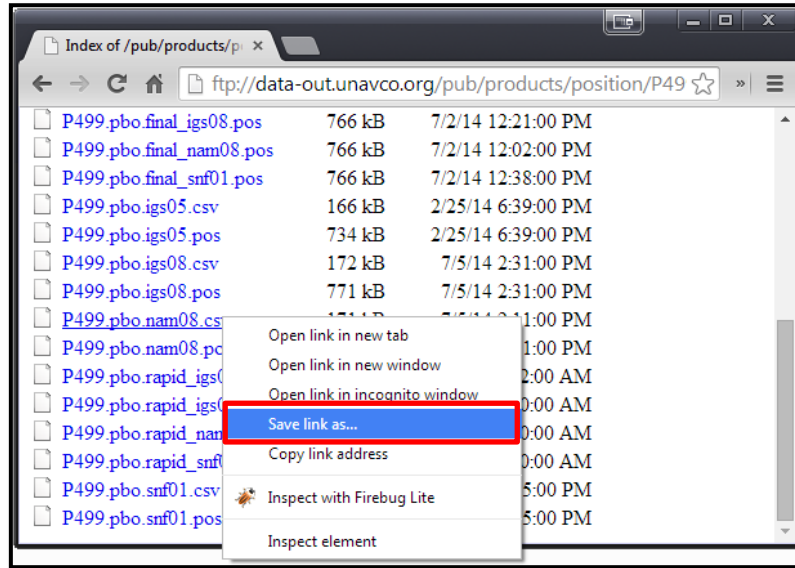
1. Navigate to <ftp://data-out.unavco.org/> in your web browser. The data server at UNAVCO provides free public access to data records from thousands of GPS sites across the United States (you can find out more by visiting <http://www.unavco.org/>).



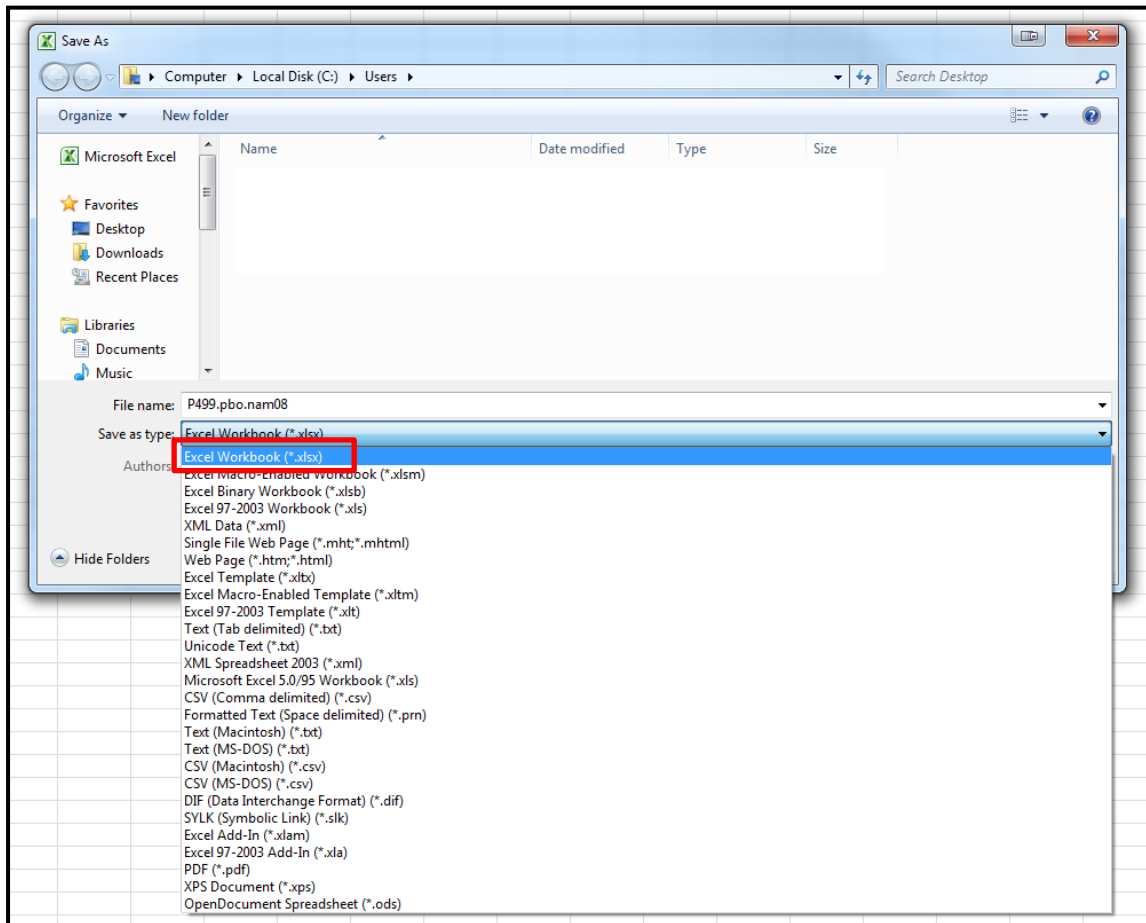
2. Once loaded, browse to the folder 'pub' → 'products' → 'position' → 'P499'.



- Right click on the file called 'P499.pbo.nam08.csv' and choose 'Save As'. Save the file to a directory somewhere on your local computer.



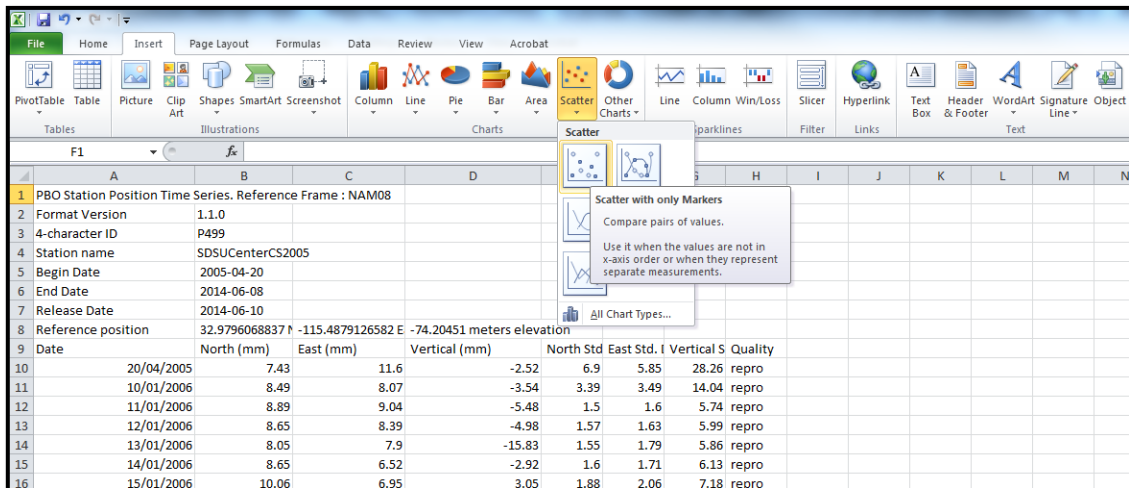
- Open the file in Microsoft Excel and re-save it as a Microsoft Office Spreadsheet (XLSX format).



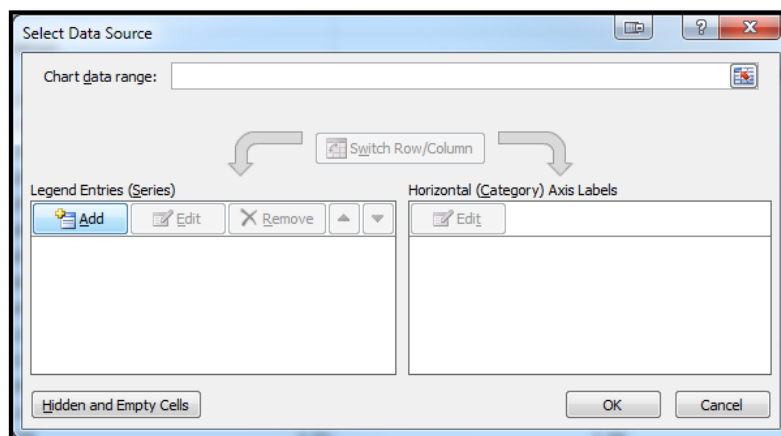
Plotting in Microsoft Excel

The following provides a guide on how to plot high accuracy GPS data using Microsoft Excel. In this example, the North dataset is plotted against time, but the process is the same for the East and Up directions as well.

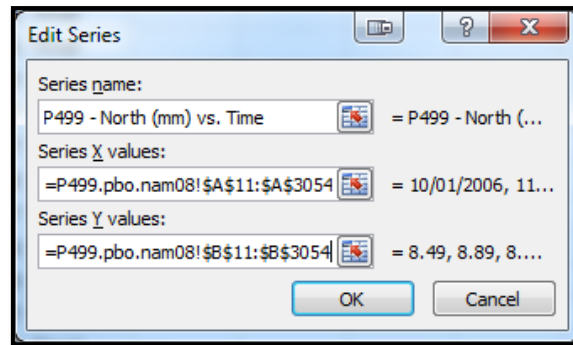
1. From the ribbon menu, choose 'Insert', 'Scatter', 'Scatter with only Markers'. The graph may or may not have some data in it (this doesn't matter, as we'll be choosing the data we want in the next step).



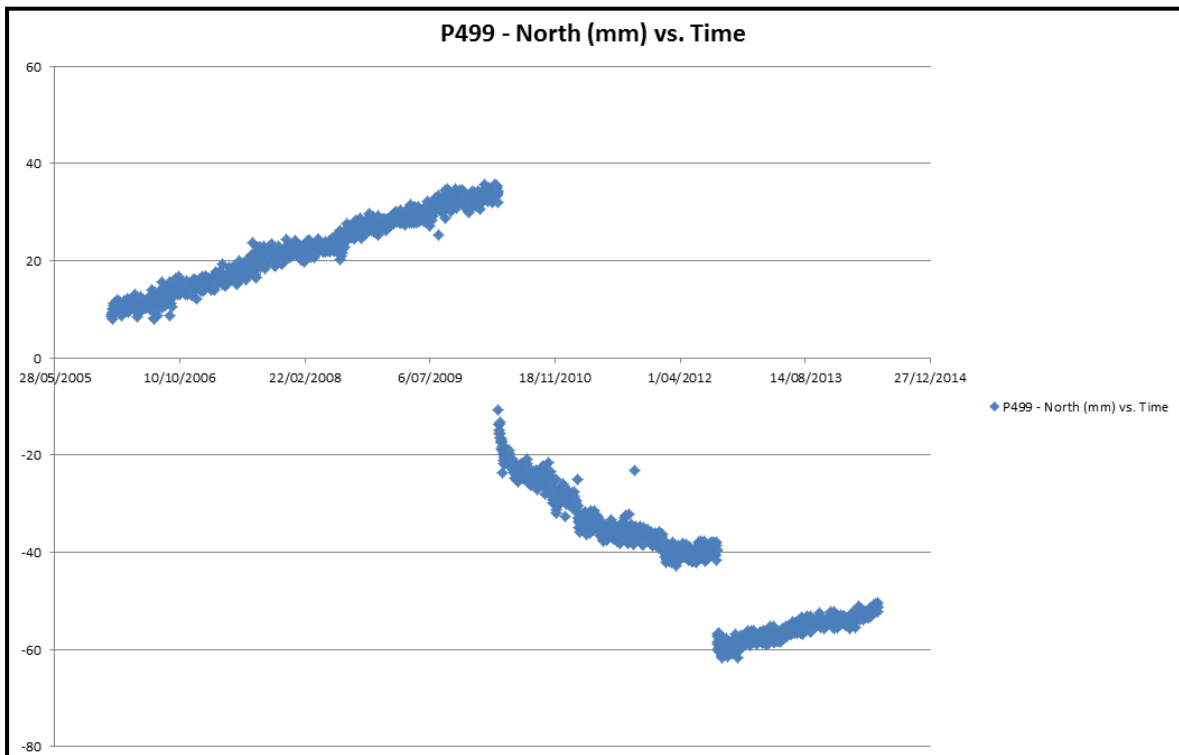
2. With the graph selected, choose 'Select Data'. The 'Select Data Source' window will appear. Clear any existing legend entries and axis labels, then press 'Add'.



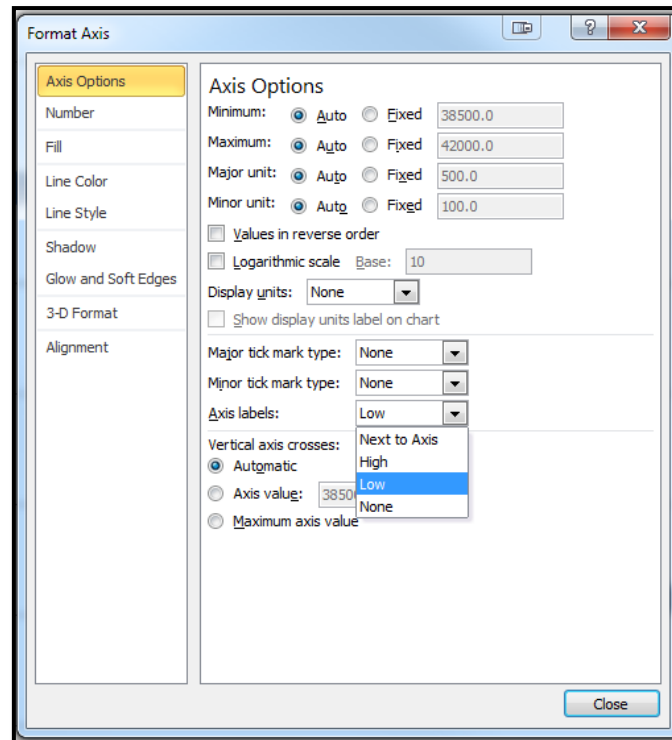
3. In the 'Series Name', enter the name of the data you're plotting (e.g. P499 – North Vs. Time). Use the keyboard or cursor to select your Series X and Y values, remembering that the X values should be the 'Time' column and the Y values should be the 'Data' column (e.g. East, North or Up).



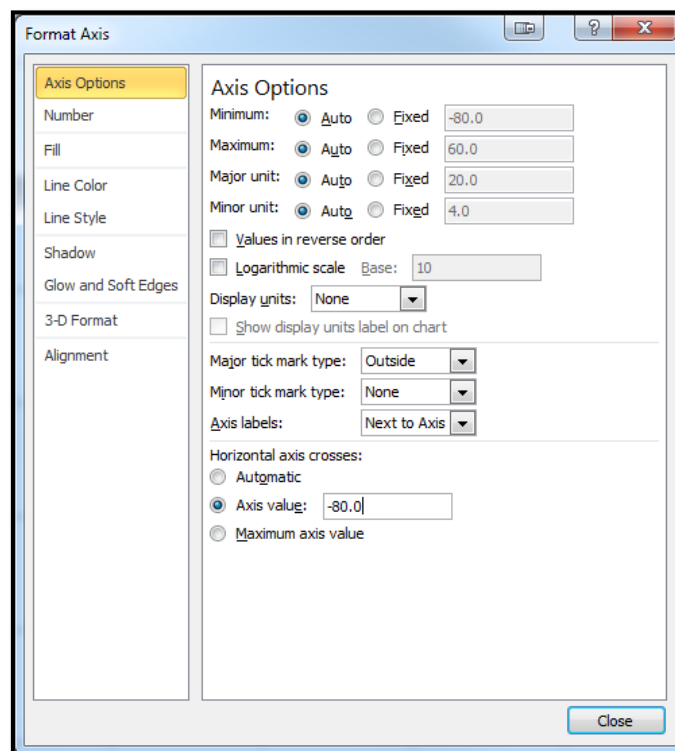
4. This will result in a scatter graph that looks something like the following:



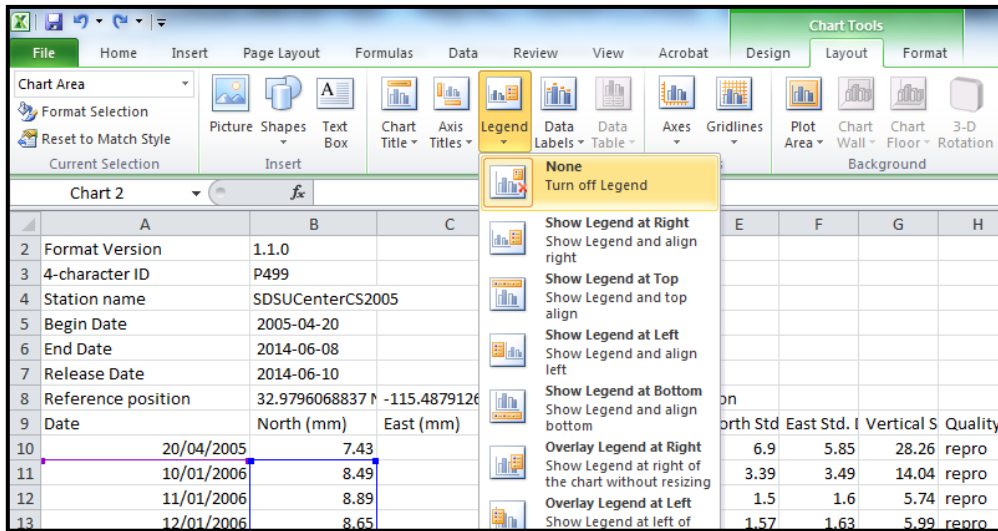
5. Now we need to adjust the layout of the graph so it is easier to read. Right click on the date axis labels and select 'Format Axis'. Change the 'Axis Options' so that the 'Axis labels' option is set to 'Low'.



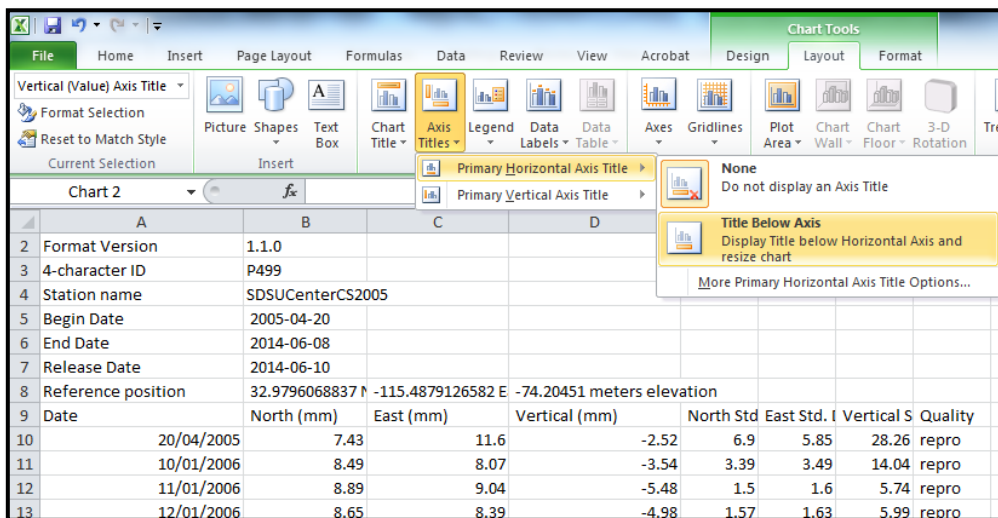
6. Right click on the horizontal grid lines and select 'Format Axis'. Change the 'Axis Options' so that the 'Horizontal axis crosses' is set to the minimum Y value on the graph (in this case it's -80 mm).



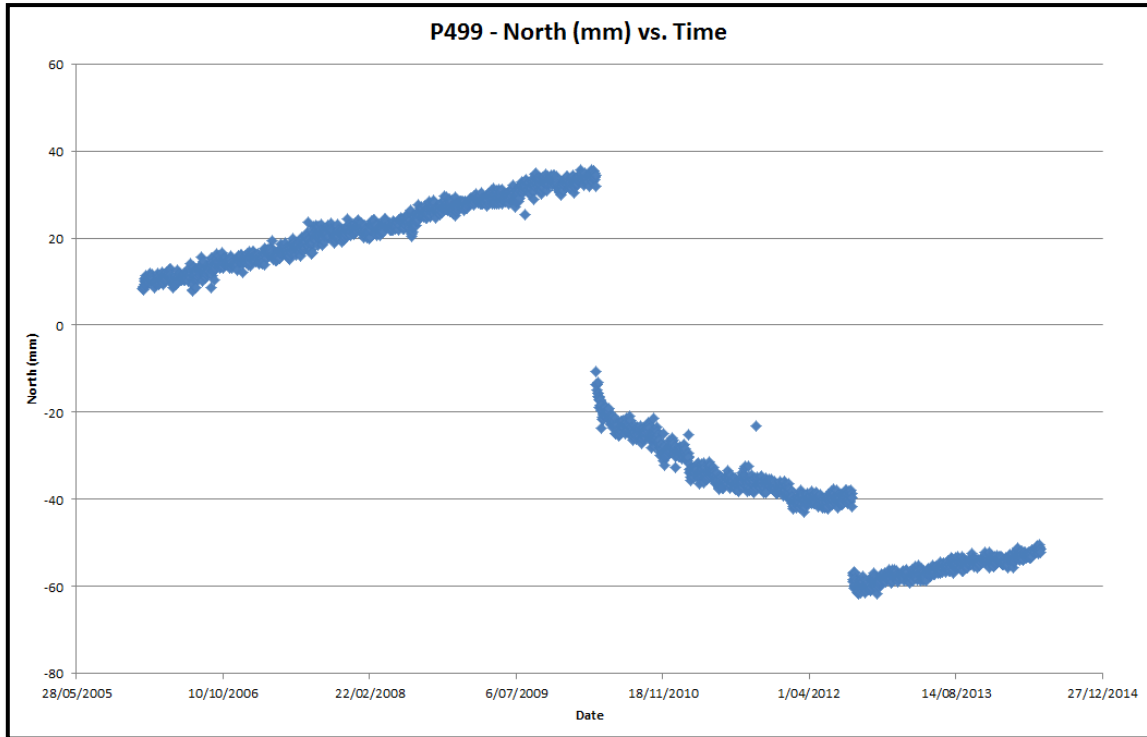
7. With the graph selected, click on the 'Layout' option in the 'Chart Tools' Ribbon. Select 'Legend' and set it to 'None' (a legend isn't required as we're only plotting a single dataset on each graph).



8. With the graph selected, click on the 'Layout' option in the 'Chart Tools' Ribbon. Select 'Axis Titles' and set the Primary Horizontal Axis Title to 'Title Below Axis' and the Primary Vertical Axis Title to 'Rotated'. This will add an axis label to the X and Y axes. Double click on each label to edit the name (be sure to specify the units as well!).



9. Congratulations! Your graph should now look something like the following. Be sure to save your spreadsheet, then repeat the process to plot the East and Up directions of the GPS dataset (you should end up with three different graphs).



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Table 1: P499 GPS Data (Header)

PBO Station Position Time Series. Reference Frame : NAM08		
Format Version	1.1.0	
4-character ID	P499	
Station name	SDSUCenterCS2005	
Begin Date	2005-04-20	
End Date	2014-07-03	
Release Date	2014-07-05	
Reference position	32.9796068861 North Latitude	-115.4879126589 East Longitude
Date	North (mm)	East (mm)
20/04/2005	7.17	11.67
10/01/2006	8.23	8.14
11/01/2006	8.63	9.11
12/01/2006	8.39	8.46
13/01/2006	7.78	7.97
14/01/2006	8.39	6.59
15/01/2006	9.8	7.02
16/01/2006	9.21	6.35
17/01/2006	10.48	7.39
18/01/2006	9.2	9.51
19/01/2006	9.55	8.51
20/01/2006	11.01	6.96
21/01/2006	10.55	7.45
22/01/2006	9.8	7.26
23/01/2006	10.01	7.81
24/01/2006	9.94	8.38
25/01/2006	9.93	7.78
26/01/2006	10.19	8.58
27/01/2006	10.02	8.44
28/01/2006	9.54	9.63
29/01/2006	9.7	7.5
30/01/2006	11.29	7.36
31/01/2006	10.99	6.45
1/02/2006	10.42	6.79
2/02/2006	11.69	6.99
3/02/2006	10.72	7.52
4/02/2006	10.79	7.64
5/02/2006	10.64	6.81
6/02/2006	10.65	7.21
7/02/2006	10.82	7.37

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Table 2: P499 GPS Data (April 2010)

PBO Station Position Time Series. Reference Frame : NAM08		
Format Version	1.1.0	
4-character ID	P499	
Station name	SDSUCenterCS2005	
Begin Date	2005-04-20	
End Date	2014-07-03	
Release Date	2014-07-05	
Reference position	32.9796068861 North Latitude	-115.4879126589 East Longitude
Date	North (mm)	East (mm)
1/04/2010	33.8	-14.85
2/04/2010	33.65	-13.09
3/04/2010	34.01	-13.45
4/04/2010	31.71	-11.99
5/04/2010	-10.91	-6.98
6/04/2010	-13.98	-6.04
7/04/2010	-13.9	-5.02
8/04/2010	-13.91	-2.75
9/04/2010	-15.07	-3.93
10/04/2010	-15.91	-3.01
11/04/2010	-16.69	-5.06
12/04/2010	-13.42	-2.05
13/04/2010	-15.88	-4.33
14/04/2010	-16.75	-3.61
15/04/2010	-16.94	-3.5
16/04/2010	-17.36	-3.25
17/04/2010	-19.14	-2.72
18/04/2010	-17.66	-4.04
19/04/2010	-17.51	-3.63
20/04/2010	-18.55	-4.17
21/04/2010	-23.93	-11.31
22/04/2010	-19.38	-3.29
23/04/2010	-18.61	-2.36
24/04/2010	-19.89	-2.28
25/04/2010	-19.54	-3.05
26/04/2010	-21.99	-3.98
27/04/2010	-19.61	-2.89
28/04/2010	-21.4	-5.71
29/04/2010	-22.02	-0.04
30/04/2010	-20.85	-2.65

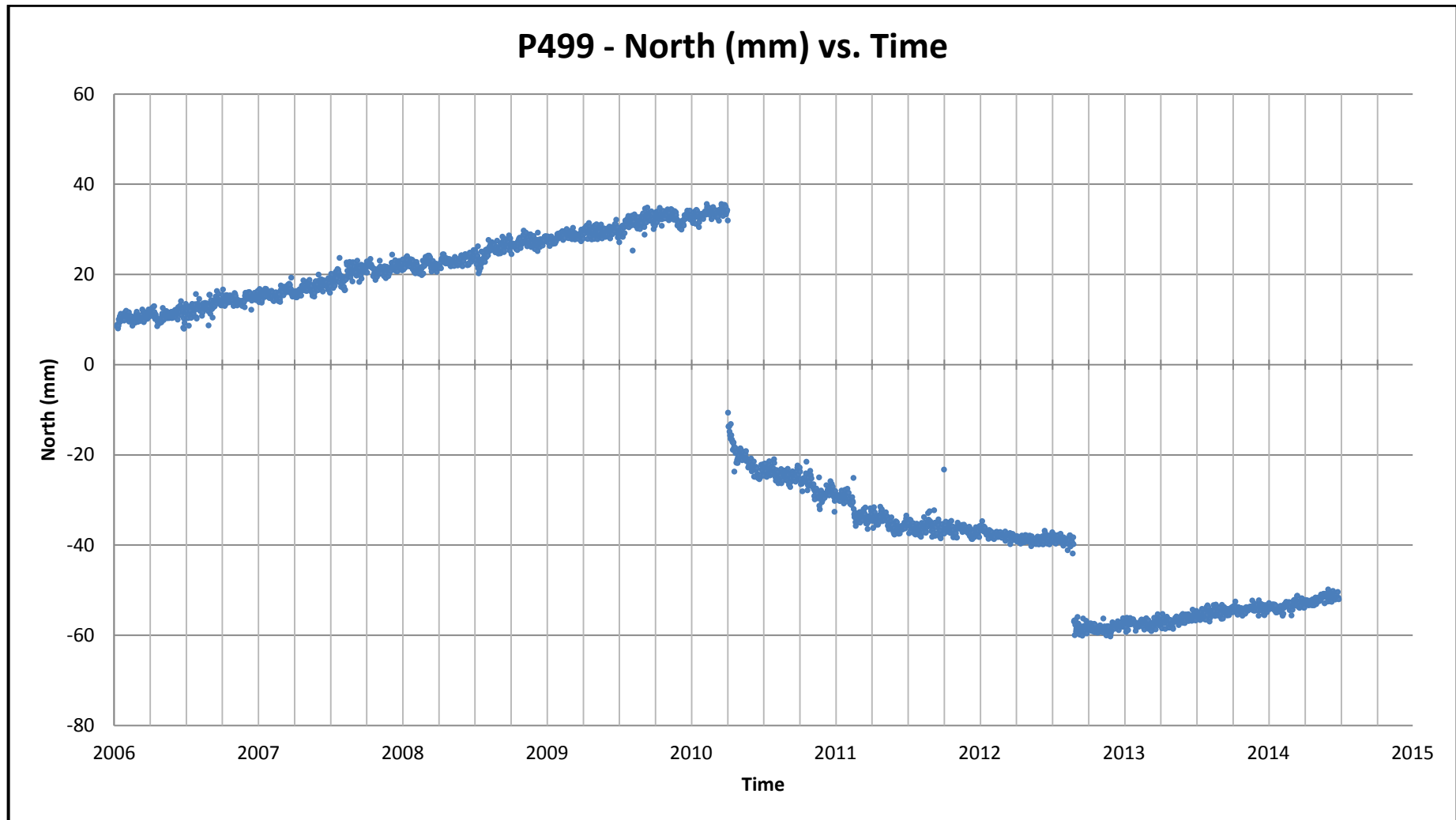
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Table 3: P499 GPS Data (August 2012)

PBO Station Position Time Series. Reference Frame : NAM08		
Format Version	1.1.0	
4-character ID	P499	
Station name	SDSUCenterCS2005	
Begin Date	2005-04-20	
End Date	2014-07-03	
Release Date	2014-07-05	
Reference position	32.9796068861 North Latitude	-115.4879126589 East Longitude
Date	North (mm)	East (mm)
1/08/2012	-38.55	2.91
2/08/2012	-38.86	3.09
3/08/2012	-39.84	1.88
4/08/2012	-39.1	1.97
5/08/2012	-39.36	1.98
6/08/2012	-39.01	2.97
7/08/2012	-39.12	3.18
8/08/2012	-38.85	2.46
9/08/2012	-39.09	2.9
10/08/2012	-39.93	0.65
11/08/2012	-41.4	3.14
12/08/2012	-39.89	1.27
13/08/2012	-38.8	2.51
14/08/2012	-39.34	1
15/08/2012	-39.02	2.71
16/08/2012	-38.13	2.42
17/08/2012	-38.06	3.64
18/08/2012	-40.57	1.66
19/08/2012	-40.4	1.69
20/08/2012	-39.8	2.36
21/08/2012	-39.39	2.17
22/08/2012	-39.53	3.76
23/08/2012	-38.57	2.78
24/08/2012	-42.14	1.75
25/08/2012	-38.54	-0.77
26/08/2012	-40.03	5.29
27/08/2012	-57.22	44.72
28/08/2012	-56.98	45.81
29/08/2012	-60.21	45.95
30/08/2012	-57.93	46.31

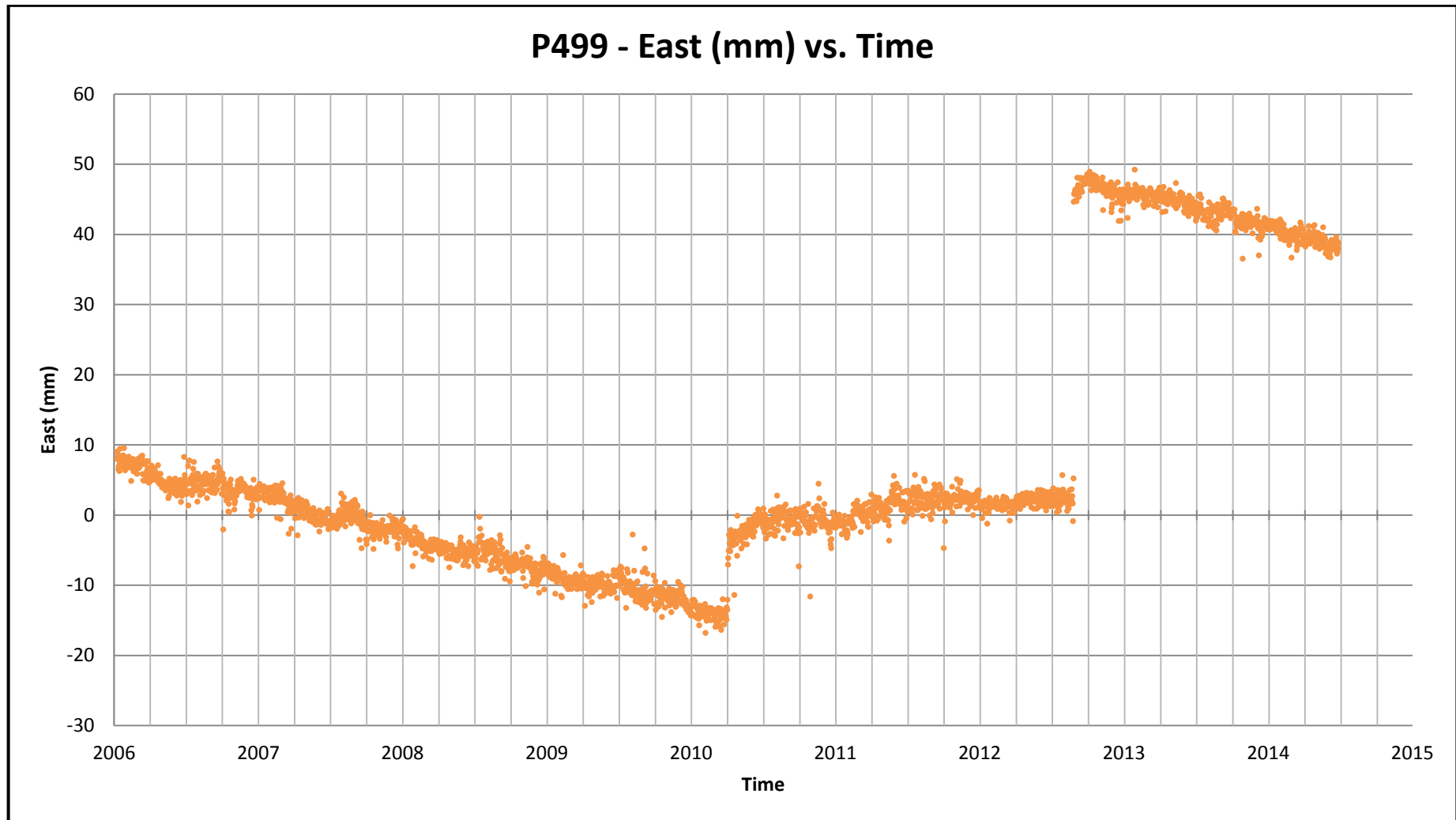
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Graph 1: P499 North Motion (January 2006 to May 2014)



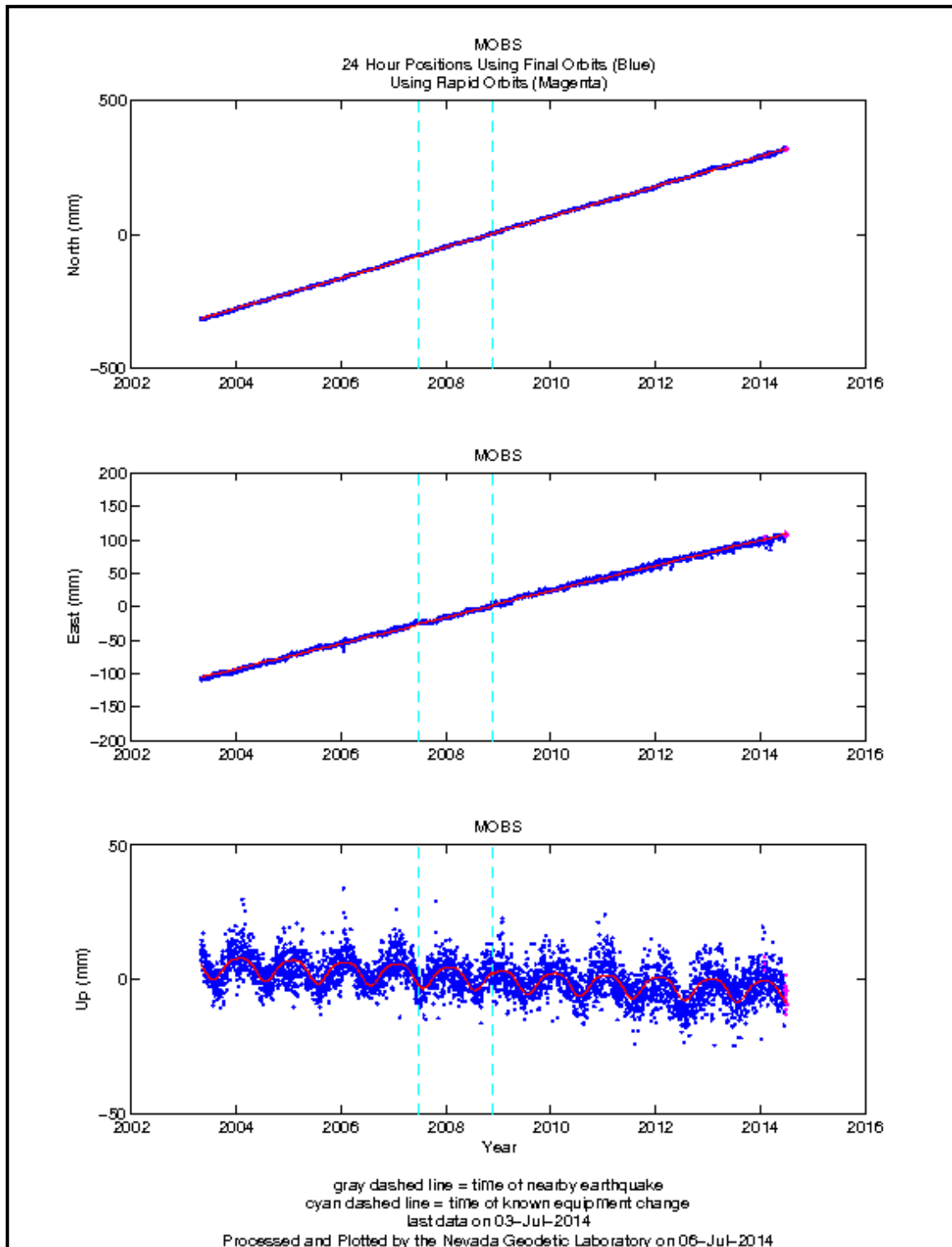
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Graph 2: P499 East Motion (January 2006 to May 2014)



Produced by the University of Tasmania in conjunction with Geoscience Australia as part of the AuScope GPS in Schools Project – 2014.

Graph 3: MOBS (Melbourne) Position (May 2003 to July 2014)



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