NZGD2000 Deformation Model Format

Version 1.0

17 June 2013

Contents

1 Introduction

This document describes the format used to publish the New Zealand Geodetic Datum 2000 (NZGD2000) deformation model. For more information about NZGD2000 see http://www.linz.govt.nz/geodetic/datums-projections-heights/geodetic-datums/new-zealand-geodetic-datum-2000

2 Functional definition of the deformation model

The deformation model is defined as a component of the datum that is used to calculate the offset between the position of a mark at a given date (epoch) and the NZGD2000 reference coordinate, nominally its position on 1 January 2000. The offset can be determined at any time and location within the bounds of the model. Adding the offset to the reference coordinates gives the NZGD2000 epoch coordinate of the point at that time – for practical purposes the same as an ITRF96 coordinate.

At each location and time within its bounds the deformation model may define the following elements:

- horizontal displacement, represented as the east and north components of displacement in metres
- vertical displacement (upwards) in metres
- horizontal error, represented by the radius of the 95% confidence circle in metres
- vertical error, represented by the 95% confidence limit in metres.

The error model is simplistic, in that it does not model covariances between locations or allow different east and north errors.

The deformation model is built up from one or more submodels, representing different geophysical deformation sources. There is always a "national deformation model" (NDM) submodel, which represents the general tectonic deformation of the country. This may be supplemented by "patches", submodels representing the effect of specific earthquakes or other localised deformation events.

Each submodel is built of one or more components which when added together represent the total deformation due to the submodel. Submodels may define one or more of the four elements of the deformation at any time for which they are valid. Elements not defined by the component are assumed to be zero.

A component is built of a spatial representation which determines the value of the elements at any location within the bounds of the component, and a time function, which defines a time based scale factor that applies to the elements at any given time. Together they determine the values of the deformation for that component at the specified time and location.

The spatial representation may be defined by points on a regular grid aligned with latitude and longitude or by a nested grid. A nested grid is an ordered list of grid and representations, from which the first one that applies at a location defines the values of the elements at that location.

The time function can be one of a velocity, step, ramp, or exponential decay.

The details of calculating deformation elements for each component and for combining them to give the total deformation are described below. From the point of view of calculating deformation elements, the assignment of components to submodels is irrelevant – each component is calculated individually and combined as described below.

The NZGD2000 deformation is periodically updated with new versions, for example after earthquakes, or when the NDM or a patch has been recalculated. Versions are numbered according to the date on which they are defined. The published deformation model includes information for all previous versions as well as the current version. The model assigns each component an initial version in which it first applies, and optionally a version in which it is revoked (typically if it is replaced by a revised component). These attributes are used to determine which components are applicable to each version of the model.

Similarly the current model does not define error elements for the deformation model, or use exponential decay time functions.

2.1 Gridded spatial representation

Gridded spatial representations are defined as regular grids in terms of latitudes and longitudes. That is, longitude (x) and latitude (y) of a grid node is defined as

$x_i = x_o + i.dx$

$y_j = y_o + j.dy$

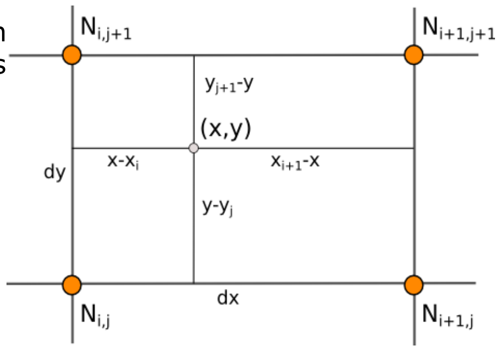
where x_o, y_o are the longitude and latitude of the southwest-most corner of the grid, dx and dy are the longitude and latitude grid spacing, and i and j are the column and row number of the grid cell (where the west-most column and southernmost row are numbered 0). Note that the longitude and latitude grid spacing need not be equal – it is preferred that dx is approximately equal to $dy/\cos(y_m)$, where y_m is the latitude of the middle of the grid, as this makes the grid cells approximately square (except at polar latitudes).

Displacement vector elements are calculated using bilinear interpolation with respect to latitude and longitude from the nodes at the corners of the grid cell within which the calculation point lies. Each element of the displacement is calculated independently (though of course the interpolation weighting will be the same for each, as they all refer to the same calculation point).

Bilinear interpolation is defined as follows:

The calculation point (x,y) is located in the grid cell between columns i and i+1, and rows j and j+1.

The displacement elements (de, dn, du) at the calculation point are weighted means of the corresponding elements at the four nodes.



The weights are calculated as follows:

$W_{i,j} = ((x_{i+1}-x)/dx) * ((y_{j+1}-y)/dy)$

$W_{i+1,j} = ((x-x_i)/dx) * ((y_{j+1}-y)/dy)$

$W_{i,j+1} = ((x_{i+1}-x)/dx) * ((y-y_j)/dy)$

$W_{i+1,j+1} = ((x-x_i)/dx)*((y-y_j)/dy)$

So for example the east displacement at the point (x,y) is calculated as

$de = W_{i,j}*de_{i,j} + W_{i+1,j}*de_{i+1,j} + W_{i,j+1}*de_{i,j+1} + W_{i+1,j+1}*de_{i+1,j+1}$

The error elements eh, ev are interpolated using a weighted average of the variances eh^2, ev^2, for example

$eh = \surd(W_{i,j}*eh_{i,j}^2 + W_{i+1,j}*eh_{i+1,j}^2 + W_{i,j+1}*eh_{i,j+1}^2 + W_{i+1,j+1}*eh_{i+1,j+1}^2)$

2.2 Time functions

The deformation model supports four time functions. Each may be used to calculate two scale factors that apply at any given time t. These are f_t which applies to the displacement elements of the component de, dn and du and $f_{e,t}$ which applies to the error elements eh and ev.

The time functions are defined in terms five parameters – start time t_0, end time t_1, start factor f_0, end factor f_1, and decay rate ε. Times are expressed as dates with or without times. Factors are undimensioned multiplication factors. Decay rate is the exponential decay rate expressed in years (ie representing the time taken for the remaining post-seismic displacement to reduce by a factor of e (=2.718...).

The time functions are defined as follows:

linear velocity	$f_t = (t - t_0)$	Currently used for the deformation model
linear ramp	$f_t = f_0$ for $t < t_0$ $f_t = (f_0.(t_1 - t) + f_1.(t-t_0))/(t_1-t_0)$ for $t_0 <= t < t_1$ $f_t = f_1$ for $t >= t_1$	Used for piecewise linear representation of, for example, post-seismic deformation
step function	$f_t = f_0$ when $t < t_0$, $f_t = f_1$ when $t >= t_0$	A special case of the linear ramp when $t_0 = t_1$. Used for conventional patch ($f_0 = 0$, $f_1 = 1$), or reverse patch ($f_0 = -1$, $f_1 = 0$)
exponential decay	$f_t = f_0$ for $t < t_0$ $f_t = f_0 + (f_1-f_0)(1-e^{\varepsilon\ (t0-t)})/(1- e^{\varepsilon\ (t0-t1)})$ for $t_0 <= t < t_1$ $f_t = f_1$ for $t >= t_1$	This is used to represent deformation resulting from post-seismic deformation

For the error elements eh, ev the scale factor $f_{e,t}$ is defined by:

Velocity function	$f_{e,t} = f_t$	Note this may be negative. However it is squared when it is used.
Step, ramp, and exponential function	$f_{e,t} = \sqrt{abs(f_t)}$	

This approach is used because the ramp, step, and exponential decay models typically have scale factors less than one, and the ramp and step models may be combined in a piecewise linear model. As error elements are added using the root sum of squares, the √f factor gives a more sensible error.

Where it is necessary to convert a number of days to a number of years, a year is defined as 365.2425 days.

2.3 Combination of components

At a given time and location the elements from each component of each submodel are combined to determine the overall displacement and errors.

The displacement elements de, dn, dh are combined by simply adding their values calculated for each component. For example, if there are n components for which the spatial representation calculates de as de_1, de_2, … to de_n, and the time function evaluates to f_1, f_2, … to f_n then the total model value for de is

$$de = f_1.de_1 + f_2.de_2 + \ldots + f_n.de_n$$

The error values eh, ev are combined by determining the root sum of squares (RSS) of the values determined for each component. So for example

$$eh = \sqrt{(f_{e,1}{}^2.eh_1{}^2 + f_{e,2}{}^2.eh_2{}^2 + \ldots + f_{e,n}{}^2.eh_n{}^2)}$$

2.4 Calculation of deformation between two epochs

Calculating the deformation between two times is straightforward for the displacement elements de, dn, and du as it is simply the difference between the values calculated at each time.

This approach is not appropriate for the error components eh, ev. Uncorrelated errors are combined as a root sum of squares, but the errors of displacements calculated for one component calculated at different times are clearly correlated.

While there is no mathematically correct way to define the errors without a much more complex error model, the following approach is recommended if these errors are required.

The time function error factor of the difference between t_0 and t_1 is calculated for each component separately as $f_{e,t1-t0}$. For step, ramp, and decay functions this is calculated as

$$f_{e,t1-t0} = \sqrt{abs(f_{e,t1}{}^2 - f_{e,t0}{}^2)}$$

For the velocity function this is calculated as

$$f_{e,t1-t0} = f_{e,t1} - f_{e,t0}$$

The eh and ev values from the spatial representation of each component are multiplied by these time function error factor values and then combined as the root sum of squares to give the total error of the deformation between the two epochs.

3 Distribution format

The model is distributed as a set of CSV (comma separated files) in a well defined directory structure, embedded in a zip file. Additionally it includes ANZLIC compliant metadata descriptions (http://www.linz.govt.nz/geospatial-office/about/projects-and-news/anzlic-metadata-profile), as well as documentation describing the format, version information, other reference information (eg about the models used), and optionally tools to process, test, or reformat the model.

The model will be versioned, with each release having a version number corresponding to the release date (eg 20130801). The version number does not imply anything about what deformation events are included in the model. The zip file will be named according to the latest version it contains, for example nzgd2000_deformation_20130801_full.zip.

The zip file root directory will contain subdirectories *model*, *documentation*, and optionally *tools* and *test.*

The *model* directory contains the data defining the actual model. Within it will be a directory *ndm* containing the national (secular) model, and a directory for each patch. The model directory will contain a file called *model.csv* defining the submodels of the model, a file called *versions.csv* with a table of version history, and a file called *metadata.xml* containing the ANZLIC metadata describing this data set. Some of the metadata is replicated in a CSV file *metadata.csv*. The *model.csv* will define each submodel. Within each submodel directory is a file *component.csv* specifying the names of the file(s) defining the grid displacement field, the spatial and temporal extents over which the patch applies, and the model versions for which it applies. The component subdirectory also contains the grid files.

3.1 Model specifications

- The model is released periodically. Each release is assigned a version number encoding the date of the release in format YYYYMMDD (year, month, day).
- The model comprises a "national deformation model" (NDM) defining the secular tectonic deformation of New Zealand and an arbitrary number of patches defining the deformation from specific events. Each of these is termed a submodel.
- The NDM and each of the patches may comprise a number of components used to represent the distribution of deformation in time and space
- Each component can define any of the following elements – horizontal displacement (de, dn), vertical displacement (du), horizontal error (eh), vertical error (ev). Horizontal and vertical are defined in terms of ellipsoidal coordinates (that is the north and east directions are aligned with true north and east, not grid north and east on a projection).
- The displacement field calculated at any given time will be uniquely invertible. That is, no two locations will transform to the same point after applying the displacement field. This is required to be able to transform locations uniquely between any two epochs. Note that this is a constraint on how precisely faulting can be represented. (For velocity models this will only be true over "reasonable" time frames)
- The displacement field calculated at any given time is spatially continuous – any patch that does not cover the full extent of the deformation model will calculate to zero at its edges. Note that if modelling close to a fault rupture the true displacement is discontinuous. This will not be properly reflected in the model – in order to ensure that the deformation is invertible it will include an arbitrary smoothing across areas of surface rupture. This is consistent with the purpose of the deformation model – it is not

intended to be an exact model of faulting deformation, but instead a practical approximation to it that allows combining data before and after an earthquake where it is reasonable to do so.

- The deformation at any given time and place is determined by summing the values calculated for each component of each submodel (NDM and patches) at that time and place. The calculation is based on the latitude and longitude of the point ignoring elevation.
- A component can evaluate as undefined at a given time and location. If any component evaluates as undefined, then the entire deformation model is undefined at that time and location. For the New Zealand model this may apply to parts of the grid that are offshore, as well as points beyond the extents of the NDM. A component can be specified to evaluate as either 0 or undefined beyond its spatial extents. For example a patch due to an earthquake will evaluate to a zero deformation for points outside the patch. Similarly if a component is defined for a limited time extent then it may be treated as 0 or undefined outside this range of times. There is no specifically defined behaviour where the deformation is undefined – it is implementation dependent.
- Each component defines a spatial representation and time function. The spatial representation defines a displacement vector and/or error components at any location within the range of the model, and the time function defines a scale factor at any time within the valid date range of the component.
- The spatial model is defined by values on a rectangular grid in terms of latitude and longitude definitions. The displacement field is defined at each node of the grid and interpolated across grid cells using bilinear interpolation (grids).
- Where the spatial representation is defined by a grid or nested grid (an ordered list of grids). The value of a nested grid at any location is the value of the first grid in the group which is defined at that location (typically this would apply for nested grid definitions, where the finest grid applying at a location would be used to calculate the deformation).
- Several components may use the same grid spatial representation with different time functions.
- The time function can use one of four time functions, “velocity”, “step”, “ramp”, “decay”.
- Horizontal deformation at each node is defined in terms of metres (or for velocities, metres/year) in the east and north direction as defined at the latitude and longitude of the node on the ellipsoid (ie at ellipsoidal height 0). (While it would be simpler to define the horizontal components in terms of degrees east and north this is less intuitive for reading – an implementation may apply this conversion).
- Vertical deformation at each node is defined in terms of metres upwards.
- Horizontal and vertical errors represent the 95% circular confidence and 95% confidence level of the deformation at each node in metres.

3.2 Data specifications

- All coordinates are supplied as NZGD2000 longitude and latitude (note: in principle this creates an issue when reverse patches are applied, as technically the coordinates change. However in practice this will not make any difference unless we create models that fit within a few metres of a fault trace – not currently proposed). Longitudes and latitudes are expressed as decimal degrees.

- All displacements are defined in terms of metres, and velocities in metres/year. These are defined (optionally) for the east, north, and up displacements, where these directions are in terms of the datum ellipsoidal coordinate system.
- Dates are specified in CSV files using the format YYYY-MM-DD or YYYY-MM-DD hh:mm:ss. Date/times are assumed to be UTC (where it matters)

3.3 File specifications

- Each version of the model is released in two single zip files. The file nzgd2000_deformation_*yyyymmdd*.zip contains the information required to calculate the deformation for the version yyyymmdd, and the file *nzgd2000_deformation_yyyymmdd_full.zip* contain the information required to calculate the deformation for version yyyymmdd and all previous releases of the model.
- The zip file base directory contains subdirectories *model*, *documentation*, and optionally *tools* and *test*.
- The zip file base directory contains a file VERSION, containing a single line of text with just the version number
- The model directory provides all the information required to calculate any released version of the deformation model at any location and time for which it is defined
- The model directory contains a file *metadata.xml* which contains the model metadata following the ANZLIC metadata standard (ref)
- The model directory contains a free format text file *metadata.csv* holding some basic metadata.
- The model directory contains a directory called *ndm* containing the national deformation model data
- The model directory contains a directory for each patch containing the data for that patch. The directory is called *patch_xxxxx* where *xxxxx* is an arbitrary text string (typically representing the deformation event, eg chch201112)
- The model directory contains a CSV format file called *model.csv* which defines all the submodels (ndm and patches) of the current and previous versions of the deformation model
- The ndm and each patch directory contains a file called *component.csv,* which defines the components of the current and previous versions of the NDM or patch.
- Grid data is stored in CSV files named *grid_xxxx.csv* – one for each grid.
- Documentation is supplied as either PDF formatted files, or HTML encoded text (plus stylesheets, PNG images, etc)
- All file and directory names are case sensitive. For example the model.csv file is not included as Model.csv. The case of the ndm and patch directories have the same case as specified in the model.csv file, and the grid files have the same case as specified in the component.csv files.
- All files and directory names differ by more than case (ie file names are not ambiguous on a case insensitive file system)
- File and directory names comprise only the characters a-z, numbers 0-9, and the

underscore and point characters (they do not include spaces)

- All text files use UTF-8 encoding and are not prefixed with a byte order marker (BOM).
- The model.csv, component.csv, and grid csv file contents are restricted to the ASCII character set (ie UTF-8 is equivalent to ASCII for these files)
- The CSV format follows excel conventions. That is fields are delimited by a single comma character. Any field containing a comma, double quote, carriage return, line feed or other non-ASCII character must be delimited with double quotes ("). Double quotes within quoted fields are represented by a pair of double quote characters. End of record is delimited by CR/LF (ie Microsoft Windows format). The presence of quotes does not imply data type – that is numeric fields may be quoted, and text fields may be unquoted (unless their content requires quoting)
- The first row of each CSV file contains the names of the fields in the file. The required fields for each csv file type are listed below. Fields will be in the order listed – reading the header to determine the fields is optional but recommended. Grid CSV files included optional fields, depending on the components of deformation that they define. Optional fields will be omitted if not required. The list of fields in a grid file may be inferred from the data in the component.csv file that references it.

3.3.1 metadata.csv specification

The metadata.csv file contains some simple metadata about the model. It contains the following fields:

item	The name of the metadata item
value	The value of the item

The file will contain at least the following items (which may be blank):

model_name	A name for the model
description	A description of the model
version	The current version of the model
datum_code	A code for the datum for which the model applies (NZGD2000)
datum_name	The name of the datum
datum_epoch	The reference date for the datum coordinates
datum_epsg_srid	The spatial reference id of the datum latitude/longitude coordinate system
ellipsoid_a	The length of the semi-major axis of the ellipsoid in metres, used for converting north/east displacements to latitude/longitude displacements
ellipsoid_rf	The reciprocal of the flattening of the ellipsoid, used for converting north/east displacements to latitude/longitude displacements
authority	The name of the authority sourcing the deformation model
authority_website	URL of the authority website
authority_address	Contact address for the authority

authority_email	Contact email for the authority
source_url	Url for downloading the latest version of the deformation model

3.3.2 version.csv specification

The version.csv file provides a brief history of the versions of the model used. It contains the following fields:

version	The version number of the version described
release_date	The release date of the version (should match the version)
reverse_patch	'Y' if the version includes a new reverse patch – meaning that "reference coordinates" should change. The required reference coordinate change can be determined from the model data (by extracting components added or revoked in the version which have a non-zero displacement at the reference epoch)
reason	Text description of the reason for releasing the version

3.3.3 model.csv specifications

The model.csv file defines the submodels of the model and contains the following fields in the order specified.

submodel	The name of the submodel directory (ndm or patch name)
version_added	The version of the deformation model in which this component was first defined
version_revoked	The version of the deformation model in which the component was revoked – 0 if it still applies to the current version
reverse_patch	'Y' if the submodel implements a reverse patch (requires a change to reference coordinates).
description	Free text description of the submodel

3.3.4 component.csv specifications

The component.csv files defines components of the NDM or patch. Components which have a grid representation are defined by a single record in the file. Components using a nested grid spatial representation have a record for each grid file. The "component" field in the file identifies the component to which the record refers. All records relating to a nested grid component have the same component id.

The component.csv file includes the following fields in the order specified. See the data specifications above for units and format of entries

version_added	The version of the deformation model in which this component was first defined
version_revoked	The version of the deformation model in which the component was revoked – 0 if it still applies to the current version
reverse_patch	'Y' if the component implements a reverse patch (ie requires a change to reference coordinates).
component	Positive integer id of the nested group to which this record belongs. value of 0 indicates that this item is a complete grid component.
priority	Positive or 0 integer id of the priority of the item. Only applies to nested groups. To calculate the deformation for the component at a location highest priority subcomponent that is defined at that location is used.
min_lon	The minimum longitude value of the points defining the grid
max_lon	The maximum longitude value of the points defining the grid
min_lat	The minimum latitude value of the points defining the grid
max_lat	The maximum latitude value of the points defining the grid
spatial_complete	"Y" if the component is 0 outside the longitude/latitude range, "N" if it is undefined outside this range (typically this will be N for the NDM, Y for patches)
min_date	The earliest date for which the time function is non-zero, or 0 if is unbounded
max_date	The latest date for which the time function is non-zero, or 0 if it is unbounded
time_complete	"Y" if the component is 0 outside the date range, "N" if it is undefined
npoints1	The number of columns (longitude values) of a grid
npoints2	The number of rows (latitude values) of a grid
displacement_type	One of "horizontal", "vertical", "3d", or "none".
error_type	One of "horizontal", "vertical", "3d", or "none".
max_displacement	The maximum length of a displacement vector in the spatial definition (ie using the displacement vectors defined at the grid without scaling to account for the time function)
spatial_model	Always "llgrid" (longitude/latitude grid)
time_function	One of "velocity", "step", "ramp", "decay"
time0	The t0 value of the time function
factor0	The f0 value of the time function
time1	The t1 value of the time function
factor1	The f1 value of the time function
decay	The exponential decay rate for post-seismic movement
file1	The name of the grid file
description	Free text description of the model component

Notes:

- the version_added and version_revoked fields determine whether the component applies to a specific version of the model. The current model comprises all components for which the revoked_version is 0. To calculate a specific version use all the components for which version_added <= version < version_revoked.

- Rows with the same non-zero component id (ie rows that comprise a nested grid definition) can only differ in the priority, min_lon, min_lat, max_lon, max_lat, npoints1, npoints2, file1, and description fields. The priority must be unique for each row with the same non-zero component id.
- the reverse_patch flag identifies whether the time function is zero at the coordinate reference epoch. If it is non zero then the reverse_patch flag is Y, otherwise N.
- the minimum and maximum values of longitude, latitude, and date are used to define the spatial and temporal range within which the model is defined. The result of calculating the component at a location or time outside this range is either 0 or undefined, depending upon the values of spatial_complete and temporal_complete.
- If spatial_complete is N then the component is undefined outside the the latitude/longitude range. Otherwise it evaluates to a zero displacement vector.
- If temporal_complete is N then the time function is undefined outside the date range of the model. Otherwise it evaluates to a zero scale factor outside this range.
- the values npoints1 and npoints2 are to simplify reading grid, allowing storage to be allocated before the model is read. For a grid model they can also be used with the min and max longitude and latitude to calculate all the grid node coordinates (the values in the grid CSV file are redundant).
- several rows in the component.csv file (both current and historical) may refer to the same grid file.
- "displacement_type" and "error_type" cannot both be "none".

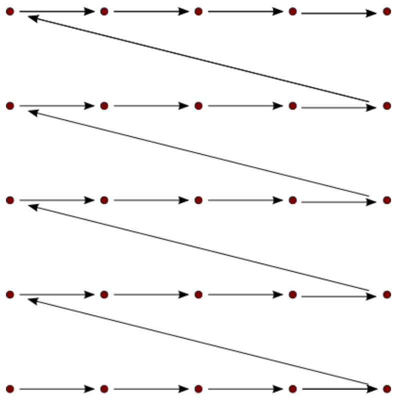
3.3.5 Grid representation csv specifications

The fields in a grid file depend on the displacement type and error_type value in the component.csv file which references the grid. The grid representation CSV files contain the following fields in order :

lon	The longitude of the point
lat	The latitude of the point
de	The east displacement/velocity (present if displacement_type is horizontal or 3d)
dn	The north displacement/velocity (present if displacement_type is horizontal or 3d)
du	The vertical displacement/velocity (present if displacement_type is vertical or 3d)
eh	The horizontal error at the point in metres (present if error_type is horizontal or 3d)
ev	The horizontal error at the point in metres (present if error_type is vertical or 3d)

Note:

- the grid nodes are entered in the CSV file in the order illustrated, starting at the southernmost row, ordering the values of the row from west to east, repeating for each row and finishing at the NE corner of the grid.



- The displacement components may be undefined at a node. Undefined values are represented by a blank (zero length string) entry