



HEXAGON



APN-086

Application Note

Datum Transformations and Plate Tectonics Compensation



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Introduction to Datum Transformations and Plate Tectonics Compensation

Consider the earth as if it were a large solid ball with a grid printed on it. The grid is an “Earth-Centered, Earth-Fixed” (ECEF) reference system, like ITRS or WGS. Earth-Fixed reference systems are realised by Earth-Fixed reference frames (datums) such as ITRF2014 or WGS84. If a survey marker was put directly on the ball, it would be in the same location in this system year after year.

Consider continental plates as stickers on the outside with grids printed on them. Over time, the different continental plates move slightly in different directions and rotations over the surface of the ball. These grids are “Plate-Fixed” reference systems, like NAD (North America), ETRS (Europe) and GDA (Australia). Plate-Fixed reference systems are realised by Plate-Fixed reference frames (datums) such as NAD83(CSRs), ETRF2014, and GDA2020. If a survey marker was put in the ground, it would have the same location in this system year after year, even as it moves around in the Earth Fixed system.



Figure 1: Earth-Centered, Earth-Fixed reference system (**left**) compared to a Plate-Fixed reference system (**right**).

The rigid outmost layer of earth’s crust is divided into several plates that float on the fluid-like layer below. These plates move slowly both relative to one another and to fixed, global definitions of the earth’s orientation. Relative to fixed global frames the plates can move up to 7 cm a year. The amount of motion can be significant for higher accuracy GNSS positioning types such as RTK and PPP.

Global PPP, SBAS and GNSS systems operate in fixed global frames and so earth-fixed coordinates are natively reported by a GNSS receiver. However, many users of GNSS are less-interested in their absolute earth-fixed coordinates than they are in the coordinates relative to nearby features on the plate they are operating on. Differential GNSS like RTK operates naturally in plate-fixed coordinates. The natural reference frame for each type of solution is called the service datum.

The mean motion of the plates is modelled by Plate Motion Models. These models track the movement of the bulk of the plates as if they are completely rigid using Euler’s spherical rotation theorem: each plate’s motion is parametrised as a rotation around a pole. Application of these models to Earth Fixed coordinates permits an order-of-magnitude increase in year over year repeatability over most of the plates: residual error is some millimeters per year, well below the actual plate motion of some centimeters per year. However, orogenic¹ regions near the edges of plates tend to stretch and deform in unmodelled ways.

¹ Mountainous areas formed by the folding and faulting of the Earth’s crust.

With plates possibly moving with respect to both earth-fixed and plate-fixed datums, the concept of a “coordinate epoch” becomes important. Since the plate moves with respect to the datum, the coordinate epoch answers the question “*At what point in time did this location on this plate have the given coordinates in the given datum?*”.

The answer to this question is significant when one considers Plate-Fixed datums and Earth-Fixed datums:

- For a Plate-Fixed datum the answer is “all the time”²;
- However, for an Earth-Fixed datum or for a datum fixed to a plate different than the one the user is on, we can find a location now from previously recorded coordinates by compensating for plate motion (similar to winding forward in time) if we know when those coordinates were recorded. Similarly, we can calculate the coordinates of a location at a previous or future time by compensating for plate motion. Thus, an Earth-Fixed reference frame can function like a Plate-Fixed datum by specifying a fixed coordinate epoch – all measurements are “rewound” to a fixed point in time, so they are repeatable year over year on the ground.

For example, NAD83 is often used in California, but the California plate is moving in a different direction from the rest of North America. Using NAD83 with a fixed coordinate epoch results in repeatable coordinates, except where the land is stretching near the fault lines.

Similarly, using ITRF2014 with a fixed epoch also provides repeatable coordinates anywhere the plate motion model is accurate. The accuracy of the plate motion model degrades in orogenic zones which can typically be found in regions with high volcanic activity or where two or more tectonic plates meet.

OUTPUTDATUM Handling Implementation

Datum handling implementation prior to 7.06.01 firmware, using commands [DATUM](#) and [USEREXPDATUM](#), applies the same datum transformation to all available positioning solutions regardless of the solution’s natural datum³. For example, if the user configures the datum transformation USEREXPDATUM to transform from NAD83 to WGS84, that transformation will be applied to SP/WAAS even though it is naturally in WGS84. Please see later section [Legacy Datum Transformation Commands](#) for more details on using DATUM and USEREXPDATUM.

With firmware 7.06.01 and beyond, the OUTPUTDATUM command helps transform different positioning solutions independently based on that positioning solution’s natural datum and outputs positions in the user specified datum. For example, if the user dictates the OUTPUTDATUM to be NAD83 then PPP position is shifted from ITRF2014 to NAD83 and SP/WAAS is shifted from WGS84 to NAD83. A list of datums available to the user is reported in the GEODETICDATUMS log. This implementation also accounts for the motion of plate tectonics allowing for year over year repeatability for even earth-fixed datums.

Another example of when OUTPUTDATUM command is beneficial is for receivers running RTK whilst having access to advanced PPP correction services such as [TerraStar-X](#)⁴. In RTK, if the base receiver is surveyed in a plate fixed datum providing corrections to the rover (i.e. the corrections move with the plate) and when PPP corrections (reported in their natural Earth-fixed datum) are also available to the rover, then a jump in position can occur when switching between PPP and RTK solutions. Datum handling implementation allows for improved accuracy and transition capability between PPP and RTK positioning solutions.

² Up to the accuracy of the plate motion model and excepting orogenic stretching of the plate.

³ A solution’s natural datum is set by the datum of the solutions correction source.

⁴ More details about TerraStar-X can be found within the [TerraStar on OEM7](#) Application Note.



It should be reminded that NovAtel's [RTK Assist™](#) feature has always correctly handled the position offsets due to differences in datums, reporting the assisted RTK solution in the RTK datum to avoid position jumps.

Overall, the new OUTPUTDATUM firmware implementation includes the following:

1. Transforms the position types to a user-specified datum
2. Applies plate tectonic compensation
3. Automatically selects the correct tectonic plate, including warning at orogenic zones

For OUTPUTDATUM command differences between 7.06.01 and 7.08.00, please refer to the [Appendix](#) for more details.

Special Case – Differential Corrections (RTK/PSRDIFF)

Currently, there is no way to communicate the datum of the RTK/DGPS base station to the receiver (no corrections messages have been standardised), so the service datum of the RTK and PSRDIFF solutions are not known, so the correct transformation to the selected OUTPUTDATUM is not known. Therefore, no transformation is applied to RTK/PSRDIFF solutions, the position is in whatever datum the base station was surveyed in, and the datum is reported as UNKNOWN.

Datum Transformations

How it Works

The new implementation using the [OUTPUTDATUM](#) command transforms solutions independently based on the solution service datum, as opposed to transforming all solutions regardless of their service datum (like the older firmware implementation using [DATUM](#) and [USEREXPDATUM](#)). This requires the service datums to be known and their parameters be stored and available in the receiver. The transformation parameters between service and desired output datums must also be stored in the receiver.

The section below outlines the new logs and commands related to the new OUTPUTDATUM transformation implementation.

Commands/Logs related to OUTPUTDATUM

Positioning Logs and the Datum ID Field

The datum ID field of the position logs is deprecated and will show WGS84 for backwards compatibility, or USER. WGS84 is reported when the datum is earth-fixed, and USER is reported if the datum is plate-fixed. All the position log definitions have been updated to reflect this change.

Table 1: Datum ID in the position logs

8	datum id#	Datum ID number 61 = WGS84 63 = USER	Enum	4	H+36
---	-----------	--	------	---	------

Please refer to the following position log definitions for the update with respect to the datum id field:

[BESTPOS](#)
[BESTGNSSPOS](#)
[PSRPOS](#)
[PDPPOS](#)
[PPPPOS](#)
[RTKPOS](#)

Commands/Logs Available in 7.06.01 and Later

OUTPUTDATUM

The [OUTPUTDATUM](#) command is used to select the geodetic datum and the co-ordinate epoch to which to transform the solution.

The factory default is the service datum and service epoch, that is, no transformation for any solution. For example, for TerraStar and VERIPOS, the service datum is ITRF2014 and the current epoch, and for WAAS this is WGS84 and the current epoch. The current epoch is the current date represented as a decimal year, for example, the current epoch for AUG22,1999 is 1999.64. For a rover performing RTK, the datum of the base station is unknown to the rover so a transformation will not take place.

In order to choose a datum with the OUTPUTDATUM command⁵, the selected datum must exist in the list of datums reported by the [GEODETICDATUMS](#) log. For this to work, there must be a transformation between the current service datum of each solution and the target datum as reported in the [DATUMTRANSFORMATIONS](#) log. These two logs are described below.

⁵ From 7.06.01 until 7.08.00 this implementation is available only for PPP. For 7.08.00 and later this implementation was made available for PSR, PDP, PPP and INS. It will not apply to the RTK solution because the datum of the base station is unknown.



GEODETICDATUMS

The GEODETICDATUMS log shows a list of available datums. It lists the default datums and user specified datums that were added using the GEODETICDATUM command. Users can restore the GEODETICDATUMS log to the firmware default by issuing the “FRESET USER_DATUM” command.

```
<GEODETICDATUMS ICOM3 0 30.0 UNKNOWN 0 0.198 02040020 e7f2 17139
<      15
<      "WGS84" 6326 EARTH_FIXED 6378137.00 298.2572235630
<      "ITRF2000" 6656 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2005" 6896 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2008" 1061 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2014" 1165 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2020" 1322 EARTH_FIXED 6378137.00 298.2572221010
<      "ETRF2000" 1186 PLATE_FIXED 6378137.00 298.2572221010
<      "ETRF2005" 1204 PLATE_FIXED 6378137.00 298.2572221010
<      "ETRF2014" 1206 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(NSRS2011)" 1116 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(CSRS)" 6140 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(PA11)" 1117 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(MA11)" 1118 PLATE_FIXED 6378137.00 298.2572221010
<      "GDA94" 6283 PLATE_FIXED 6378137.00 298.2572221010
<      "GDA2020" 1168 PLATE_FIXED 6378137.00 298.2572221010
```


DATUMTRANSFORMATIONS

The [DATUMTRANSFORMATIONS](#) log reports available datum transformations which the receiver can apply. The receiver can apply the transformations in either direction. The receiver will not combine transformations. It includes firmware default transformations and user-defined transformations (entered with the [DATUMTRANSFORMATION](#) command). Users can restore the DATUMTRANSFORMATIONS log to the firmware default by issuing the "FRESET USER_DATUM_TRANSFORMATION" command.

```
<DATUMTRANSFORMATIONS ICOM3 0 29.5 UNKNOWN 0 0.200 02040020 f957 17139
< 13
< "ITRF2014" "ITRF2000" 2010.000 0.0007 0.0012 -0.0261 0.0000 0.0000 0.0000 2.120
0.0001 0.0001 -0.0019 0.0000 0.0000 0.0000 0.110
< "ITRF2014" "ITRF2005" 2010.000 0.0026 0.0010 -0.0023 0.0000 0.0000 0.0000 0.920
0.0003 0.0000 -0.0001 0.0000 0.0000 0.0000 0.030
< "ITRF2014" "ITRF2008" 2010.000 0.0016 0.0019 0.0024 0.0000 0.0000 0.0000 -0.020
0.0000 0.0000 -0.0001 0.0000 0.0000 0.0000 0.030
< "ITRF2014" "ETRF2000" 2010.000 0.0547 0.0522 -0.0741 1.7010 10.2900 -16.6320
2.120 0.0001 0.0001 -0.0019 0.0810 0.4900 -0.7920 0.110
< "ITRF2014" "ETRF2005" 1989.000 0.0523 0.0490 -0.0372 0.0000 0.0000 0.0000 0.290
0.0003 0.0000 -0.0001 0.0540 0.5180 -0.7810 0.030
< "ITRF2014" "ETRF2014" 2010.000 0.0000 0.0000 0.0000 0.0000 1.7850 11.1510 -16.1700
0.000 0.0000 0.0000 0.0000 0.0850 0.5310 -0.7700 -0.000
< "ITRF2014" "NAD83(NSRS2011)" 1997.000 0.9950 -1.9014 -0.5228 -25.9147
-9.4264 -11.5993 1.305 0.0008 -0.0006 -0.0014 -0.0667 0.7574 0.0513 -0.072
< "ITRF2014" "NAD83(CSRS)" 1997.000 0.9950 -1.9014 -0.5228 -25.9147 -9.4264
-11.5993 1.305 0.0008 -0.0006 -0.0014 -0.0667 0.7574 0.0513 -0.072
< "ITRF2014" "NAD83(PA11)" 1997.000 0.9096 -2.0142 -0.5616 -27.7410 -13.4690
-2.7120 0.690 0.0001 0.0001 -0.0019 0.3840 -1.0070 2.1860 0.110
< "ITRF2014" "NAD83(MA11)" 1997.000 0.9096 -2.0142 -0.5616 -28.9710 -10.4200
-8.9280 0.690 0.0001 0.0001 -0.0019 0.0200 -0.1050 0.3470 0.110
< "ITRF2014" "GDA94" 1994.000 -0.0831 -0.0175 0.0360 0.4254 -2.2578 -2.4015 9.210
0.0014 0.0013 0.0008 -1.5461 -1.1820 -1.1551 0.139
< "ITRF2014" "GDA2020" 2020.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000
0.0000 0.0000 -1.5038 -1.1835 -1.2072 0.000
< "ITRF2020" "ITRF2014" 2015.000 -0.0014 -0.0009 0.0014 0.0000 0.0000 0.0000
-0.420 0.0000 -0.0001 0.0002 0.0000 0.0000 0.0000 0.000
```

In order to remove an existing datum from the NVM, the user should issue the DELETE command as shown in the example below. Once deleted, no additional SAVECONFIG command is necessary:

```
GEODETI CDATUM delete ETRS89
```



DATUMTRANSFORMATION

The DATUMTRANSFORMATION command allows the user to enter user-defined datum transformation parameters.

An example to enter the parameters of a transformation from ITRF2014 to ETRS89 is:

```
DATUMTRANSFORMATION SAVE ITRF2014 ETRS89 2010.0 0.0531 0.0503 -0.0765 1.701
10.290 -16.632 2.12 0.0001 0.0001 0.0019 0.08100 0.49 -0.79200 0.11
```

```
<DATUMTRANSFORMATIONS USB1 0 60.0 FINESTEERING 2258 242402.732 02000020 f957 17122
< 14
< "ITRF2014" "ITRF2000" 2010.000 0.0007 0.0012 -0.0261 0.0000 0.0000 0.0000 2.120
0.0001 0.0001 -0.0019 0.0000 0.0000 0.0000 0.110
< "ITRF2014" "ITRF2005" 2010.000 0.0026 0.0010 -0.0023 0.0000 0.0000 0.0000 0.920
0.0003 0.0000 -0.0001 0.0000 0.0000 0.0000 0.030
< "ITRF2014" "ITRF2008" 2010.000 0.0016 0.0019 0.0024 0.0000 0.0000 0.0000 -0.020
0.0000 0.0000 -0.0001 0.0000 0.0000 0.0000 0.030
< "ITRF2014" "ETRF2000" 2010.000 0.0547 0.0522 -0.0741 1.7010 10.2900 -16.6320 2.120
0.0001 0.0001 -0.0019 0.0810 0.4900 -0.7920 0.110
< "ITRF2014" "ETRF2005" 1989.000 0.0523 0.0490 -0.0372 0.0000 0.0000 0.0000 0.290
0.0003 0.0000 -0.0001 0.0540 0.5180 -0.7810 0.030
< "ITRF2014" "ETRF2014" 2010.000 0.0000 0.0000 0.0000 0.0000 1.7850 11.1510 -16.1700 0.000
0.0000 0.0000 0.0000 0.0850 0.5310 -0.7700 -0.000
< "ITRF2014" "NAD83(NSRS2011)" 1997.000 0.9950 -1.9014 -0.5228 -25.9147 -9.4264
-11.5993 1.305 0.0008 -0.0006 -0.0014 -0.0667 0.7574 0.0513 -0.072
< "ITRF2014" "NAD83(CSRs)" 1997.000 0.9950 -1.9014 -0.5228 -25.9147 -9.4264 -11.5993
1.305 0.0008 -0.0006 -0.0014 -0.0667 0.7574 0.0513 -0.072
< "ITRF2014" "NAD83(PA11)" 1997.000 0.9096 -2.0142 -0.5616 -27.7410 -13.4690 -2.7120
0.690 0.0001 0.0001 -0.0019 0.3840 -1.0070 2.1860 0.110
< "ITRF2014" "NAD83(MA11)" 1997.000 0.9096 -2.0142 -0.5616 -28.9710 -10.4200 -8.9280
0.690 0.0001 0.0001 -0.0019 0.0200 -0.1050 0.3470 0.110
< "ITRF2014" "GDA94" 1994.000 -0.0831 -0.0175 0.0360 0.4254 -2.2578 -2.4015 9.210
0.0014 0.0013 0.0008 -1.5461 -1.1820 -1.1551 0.139
< "ITRF2014" "GDA2020" 2020.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000 0.0000
0.0000 0.0000 -1.5038 -1.1835 -1.2072 0.000
< "ITRF2020" "ITRF2014" 2015.000 -0.0014 -0.0009 0.0014 0.0000 0.0000 0.0000 -0.420
0.0000 -0.0001 0.0002 0.0000 0.0000 0.0000 0.000
< "ITRF2014" "ETRS89" 2010.000 0.0531 0.0503 -0.0765 1.7010 10.2900 -16.6320 2.120
0.0001 0.0001 0.0019 0.0810 0.4900 -0.7920 0.110
```

Datum Information Logs

The logs PSRDATUMINFO, PDPDATUMINFO, PPPDATUMINFO, RTKDATUMINFO, INSDATUMINFO, BESTGNSSDATUMINFO and BESTDATUMINFO report the datum, EPSG code and coordinate epoch of the solution that is reported in the corresponding position log(s) along with a transformation status.

With OUTPUTDATUM defaulted to SERVICE, no transformation is applied, and the datum info log will report the service datum and epoch of the solution, with a status of GOOD. The corresponding position log datum field will be WGS84.

If an OUTPUTDATUM is selected and the exact transformation is found and applied, this datum and epoch will be reported, and the status will be GOOD. The corresponding position log datum field will be WGS84 if the OUTPUTDATUM is earth-fixed or will be USER if the OUTPUTDATUM is plate-fixed.

If an OUTPUTDATUM is selected and no exact transformation is found, but one of the datums is an ECEF datum and a transformation from another ECEF datum is found, this best-approximation transformation will be selected and applied. The selected datum and epoch are reported with a status of ECEF_EQUIVALENCY. Single point and SBAS positions have a combination of ECEF service datums from different constellations so all transforms for them will use this ECEF equivalency. The corresponding position log datum field will be WGS84 if the OUTPUTDATUM is earth-fixed or will be USER if the OUTPUTDATUM is plate-fixed.

If an OUTPUTDATUM is selected and no transformation is found and no ECEF equivalency is found, no transformation will be applied, the position will be reported in its service datum with the status REQUESTED_TRANSFORMATION_UNAVAILABLE. The corresponding position log datum field will be WGS84.

If the position is derived from RTK or PSRDIFF then the service datum is unknown because the receiver does not know the base station datum, so it cannot compute any transformation. No transformation is applied, and the datum is reported as "UNKNOWN", the EPSG code is "0", the epoch is "0.000" and the transformation status is "SERVICE_DETAILS_UNKNOWN". The corresponding position log datum field will be WGS84.

Datum Information logs and the reporting of ECEF

All the GNSS constellations use different coordinate frames and revisions, but all are earth-centered-earth-fixed (ECEF) frames, therefore in cases where multiple coordinate frames are used in the solution, the Datum Information log(s) reports ECEF as the service datum in the datum field. For example, when a datum transformation is not applied and the position type is Single-point or WAAS/SBAS, the Datum Information log will report ECEF in the datum field with an EPSG code of 0.

Table 2: GNSS constellation coordinate frames

Constellation	Coordinate Frame
GPS/WAAS	WGS-84
GLONASS	PZ-90
Galileo	GTRF
BEIDOU	CGCS2000

PPPDATUMINFO

The [PPPDATUMINFO](#) log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the [PPPPOS](#) log with the transformation status.

```
<PPPPOS COM1 0 71.5 FINESTEERING 2266 316295.000 02000020 9078 17139
< SOL_COMPUTED PPP 51.15043702303 -114.03067911971 1097.3757 -17.0001 WGS84
0.0163 0.0142 0.0316 "TSTR" 15.000 0.000 35 35 35 34 00 00 3f 37
```

```
[ICOM3]<PPPDATUMINFO ICOM3 0 40.5 FINESTEERING 2266 402600.000 02000020 ea8d 17139
< "ECEF" 0 2023.454 GOOD
```



BESTDATUMINFO

The [BESTDATUMINFO](#) log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the BESTPOS log with the transformation status. It will have the same values as the datum info log of the solution that BESTPOS is derived from.

```
<BESTPOS COM1 0 70.0 FINESTEERING 2104 422259.000 02040048 cdba 32768
< SOL_COMPUTED WAAS 51.15043646192 -114.03068113014 1097.1317 -17.0000 WGS84
0.7425 0.6739 1.0421 "133" 6.000 0.000 24 21 21 20 00 0a 00 33
<BESTDATUMINFO COM1 0 66.5 FINESTEERING 2104 422100.000 02040048 1790 32768
< "ECEF" 0 2020.350 GOOD
```

BESTGNSSDATUMINFO

The [BESTGNSSDATUMINFO](#) log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the [BESTGNSSPOS](#) log with the transformation status. It will have the same values as the datum info log of the solution that BESTGNSSPOS is derived from.

```
<BESTGNSSPOS COM1 0 70.0 FINESTEERING 2104 422259.000 02040048 cdba 32768
< SOL_COMPUTED WAAS 51.15043646192 -114.03068113014 1097.1317 -17.0000
WGS84 0.7425 0.6739 1.0421 "133" 6.000 0.000 24 21 21 20 00 0a 00 33
<BESTGNSSDATUMINFO COM1 0 66.5 FINESTEERING 2104 422100.000 02040048 1790 32768
< "ECEF" 0 2020.350 GOOD
```

Logs Available in 7.08.00 and Later

PSRDATUMINFO

The [PSRDATUMINFO](#) log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the [PSRPOS](#) log with the transformation status.

Single point and SBAS based PSR positions are based on multiple ECEF coordinate frames, so the service datum is reported as "ECEF" with an EPSG code of 0 and epoch of "0.000". See [Datum Information logs and the reporting of ECEF](#) above. All transformations use ECEF equivalency.

```
<PSRPOS COM1 0 70.0 FINESTEERING 2246 316810.000 02000020 28ff 32768
< SOL_COMPUTED WAAS 51.15044058567 -114.03068530319 1097.0848 -17.0000 WGS84
1.4464 0.9719 2.5008 "135" 6.000 0.000 38 6 0 0 00 06 00 03
<PSRDATUMINFO COM1 0 70.5 FINESTEERING 2246 316800.000 02000020 f85f 32768
< "ECEF" 0 2023.068 GOOD
```

For PSRDIFF the service datum is UNKNOWN and no transformations are applied.

```
<PSRPOS COM1 0 68.0 FINESTEERING 2104 423984.000 02040048 28ff 32768
< SOL_COMPUTED PSRDIFF 51.15043943188 -114.03068105964 1098.4715 -17.0000
WGS84 0.6108 0.4260 1.0295 "0" 2.000 0.000 21 17 0 0 00 08 00 11
<PSRDATUMINFO COM1 0 68.0 FINESTEERING 2104 423900.000 02040048 f85f 32768
< "UNKNOWN" 0 0.000 SERVICE_DETAILS_UNKNOWN
```



PDPDATUMINFO

The [PDPDATUMINFO](#) log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the [PDPPOS](#) log with the transformation status.

Single point and SBAS based PDP positions are based on multiple ECEF coordinate frames, so the service datum is reported as "ECEF" with an EPSG code of 0 and epoch of "0.000". See "[Datum Information logs and the reporting of ECEF](#)" above. All transformations use ECEF equivalency.

```
<PDPPOS COM1 0 69.0 FINESTEERING 2104 422317.000 02040048 0649 32768
< SOL_COMPUTED WAAS 51.15043645160 -114.03068046909 1097.2599 -16.9999 WGS84
0.7010 0.6555 0.9131 "131" 6.000 0.000 24 21 0 0 00 0b 00 33
<PDPDATUMINFO COM1 0 69.0 FINESTEERING 2104 422100.000 02040048 f611 32768
< "ECEF" 0 2020.350 GOOD
```

For PSRDIFF the service datum is UNKNOWN and no transformations are applied.

```
<PDPPOS COM1 0 66.5 FINESTEERING 2104 423985.000 02040048 0649 32768
< SOL_COMPUTED PSRDIFF 51.15043850431 -114.03067888597 1097.7428 -17.0000
WGS84 0.5404 0.4645 0.7463 "0" 3.000 0.000 21 18 0 0 00 0a 00 33
<PDPDATUMINFO COM1 0 66.5 FINESTEERING 2104 423900.000 02040048 f611 32768
< "UNKNOWN" 0 0.000 SERVICE_DETAILS_UNKNOWN
```

RTKDATUMINFO

The [RTKDATUMINFO](#) log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the [RTKPOS](#) log with the transformation status. Currently, the receiver does not know the base station datum, so the service datum is UNKNOWN and it cannot compute any transformation.

```
<RTKPOS COM1 0 68.5 FINESTEERING 2104 424042.000 02040048 69d3 32768
< SOL_COMPUTED NARROW_INT 51.15043735702 -114.03067807906 1097.3594 -16.9999
WGS84 0.0081 0.0066 0.0152 "0" 1.000 0.000 21 18 18 17 00 01 00 33
<RTKDATUMINFO COM1 0 68.5 FINESTEERING 2104 423900.000 02040048 0b0c 32768
< "UNKNOWN" 0 0.000 SERVICE_DETAILS_UNKNOWN
```



INSDATUMINFO

The INSDATUMINFO log reports the datum, the EPSG code and the co-ordinate epoch of the solution that is reported in the following INS position logs: INSPVA, INSPVAX, INSPVACMP, INSPOS, INSPOSX, MARKxPVA, and TAGGEDMARKxPVA.

The service datum of the INS solutions is that of the GNSS solution used for position updates. The datum info log will have the same values as that of the positions the INS solution is derived from.

```
<INSPVAX USB3 0 56.0 FINESTEERING 2110 330910.000 020000a0 46eb 32768
<    INS_ALIGNMENT_COMPLETE INS_SBAS 51.15043756776 -114.03067463573 1097.5570
-17.0000 0.0024 0.0012 0.0000 -1.300744848 -0.562895137 0.043494063 0.9913 0.9083
1.1908 0.0264 0.0264 0.0184 0.5602 0.5602 6.9687 13000005 0
<INSDATUMINFO USB3 0 58.5 FINESTEERING 2110 330900.000 020000a0 f6f5 32768
<    "ECEF" 0 2020.463 GOOD 0.000000000 0
```

As a final note, from 7.08.00 and later, datum handling is available for:

- the PSRDATUMINFO log in the case of single point, SBAS positioning
- the PDPDATUMINFO log in the case of single point, SBAS positioning
- the PPPDATUMINFO log in the case of PPP positioning
- the BESTDATUMINFO log in the case of single point, SBAS, PPP positioning
- the BESTGNSSDATUMINFO log in the case of single point, SBAS, PPP positioning
- the INSDATUMINFO log in the case of single point, SBAS, PPP positioning

Although the new OUTPUTDATUM handling implementation as of 7.08.00 is implemented for PSR (DGPS), PDP (DGPS), RTK and INS (DGPS, RTK), currently, the datum information is not readily available in the corrections transmitted from the base station. Therefore, in the following scenarios the *DATUMINFO log is *not* updated to report the datum information of the base:

- the PSRDATUMINFO log in the case of DGPS positioning
- the PDPDATUMINFO log in the case of DGPS positioning
- the RTKDATUMINFO log in the case of RTK positioning
- the BESTDATUMINFO log in the case of DGPS, RTK positioning
- the BESTGNSSDATUMINFO log in the case of DGPS, RTK positioning
- the INSDATUMINFO log in the case of DGPS, RTK positioning

Plate Tectonics Compensation

Plate compensation is important when an earth-fixed datum (such as that of Terrastar-X or Terrastar-C-Pro) is used. For an earth-fixed output datum, using a fixed epoch will help compensate for plate motion giving users repeatability of coordinates over time (year over year) for a location. The transformation for a plate- fixed datum already includes plate motion, but a fixed epoch can also compensate when a datum fixed to a different plate is used (such as NAD83 in California).

How It Works

The receiver automatically detects the tectonic plate on which the receiver operates and considers its plate motion. However, it will not actually perform anything until it has been given an epoch (a date) to compensate to via the OUTPUTDATUM command by specifying "FIXED_EPOCH" and a decimal year. "FIXED_EPOCH" means that the



output coordinates will be with respect to the specified epoch (decimal year) provided. Please see [Example of Tectonic Compensation](#).

Check the [TECTONICSCOMPENSATION](#) log for information on the plate model currently used.

TECTONICSCOMPENSATIONSOURCE

The [TECTONICSCOMPENSATIONSOURCE](#) command enables or disables tectonics compensation. Tectonic compensation is enabled by default and can be disabled with:

```
TECTONICSCOMPENSATIONSOURCE NONE
```

To re-enable compensation, issue:

```
TECTONICSCOMPENSATIONSOURCE PLATE_MOTION_MODEL
```

TECTONICSCOMPENSATION

The [TECTONICSCOMPENSATION](#) log reports the status of the tectonics compensation. A warning is reported to the user if tectonics compensation may not be very precise in a region.

Example of OUTPUTDATUM Handling Implementation

1. To transform a solution from one datum to another, the datum must first exist in the GEODETICDATUMS log. The receiver firmware includes a default set of datums as seen below:

```
<GEODETICDATUMS ICOM3 0 39.0 UNKNOWN 0 0.343 02400020 e7f2 17139
<    15
<    "WGS84" 6326 EARTH_FIXED 6378137.00 298.2572235630
<    "ITRF2000" 6656 EARTH_FIXED 6378137.00 298.2572221010
<    "ITRF2005" 6896 EARTH_FIXED 6378137.00 298.2572221010
<    "ITRF2008" 1061 EARTH_FIXED 6378137.00 298.2572221010
<    "ITRF2014" 1165 EARTH_FIXED 6378137.00 298.2572221010
<    "ITRF2020" 1322 EARTH_FIXED 6378137.00 298.2572221010
<    "ETRF2000" 1186 PLATE_FIXED 6378137.00 298.2572221010
<    "ETRF2005" 1204 PLATE_FIXED 6378137.00 298.2572221010
<    "ETRF2014" 1206 PLATE_FIXED 6378137.00 298.2572221010
<    "NAD83(NSRS2011)" 1116 PLATE_FIXED 6378137.00 298.2572221010
<    "NAD83(CSRS)" 6140 PLATE_FIXED 6378137.00 298.2572221010
<    "NAD83(PA11)" 1117 PLATE_FIXED 6378137.00 298.2572221010
<    "NAD83(MA11)" 1118 PLATE_FIXED 6378137.00 298.2572221010
<    "GDA94" 6283 PLATE_FIXED 6378137.00 298.2572221010
<    "GDA2020" 1168 PLATE_FIXED 6378137.00 298.2572221010
```



2. If a datum does not exist in the GEODETICDATUMS log it can be created using the GEODETICDATUM command. To add a new datum, you will require the following information:

- Name of the datum
- EPSG⁶ code (zero if a custom datum is used)
- Datum type: either earth fixed, plate fixed, or unknown
- Semi-major axis of the datum's ellipsoid in meters
- Inverse flattening of the datum's ellipsoid

A sample command to add ETRS89 would be:

```
GEODETICDATUM save ETRS89 6258 PLATE_FIXED 6378137.0 298.257222101
```

Where:

- ETRS89 is the name of the datum
- 6258 is the EPSG code
- PLATE_FIXED is the datum type
- 6378137.0 is the semi-major axis in meters
- 298.257222101 is the flattening value

The new datum "ETRS89" can be seen in the GEODETICDATUMS log as the last entry:

```
<GEODETICDATUMS ICOM3 0 45.5 FINESTEERING 2266 403062.803 02000020 e7f2
17139
<      16
<      "WGS84" 6326 EARTH_FIXED 6378137.00 298.2572235630
<      "ITRF2000" 6656 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2005" 6896 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2008" 1061 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2014" 1165 EARTH_FIXED 6378137.00 298.2572221010
<      "ITRF2020" 1322 EARTH_FIXED 6378137.00 298.2572221010
<      "ETRF2000" 1186 PLATE_FIXED 6378137.00 298.2572221010
<      "ETRF2005" 1204 PLATE_FIXED 6378137.00 298.2572221010
<      "ETRF2014" 1206 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(NSRS2011)" 1116 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(CSRS)" 6140 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(PA11)" 1117 PLATE_FIXED 6378137.00 298.2572221010
<      "NAD83(MA11)" 1118 PLATE_FIXED 6378137.00 298.2572221010
<      "GDA94" 6283 PLATE_FIXED 6378137.00 298.2572221010
<      "GDA2020" 1168 PLATE_FIXED 6378137.00 298.2572221010
<      "ETRS89" 6258 PLATE_FIXED 6378137.00 298.2572221000
```

⁶ The EPSG Geodetic Parameter Database (<https://epsg.org/home.html>) is a commonly referenced database of coordinate reference systems and coordinate transformations.



Now that the new datum has been saved, it can be selected for output with the OUTPUTDATUM command:

```
OUTPUTDATUM ETRS89 FIXED_EPOCH 2018.000
```

For PPP, the service datum is ITRF2014 and since there is no transformation from ITRF2014 to ETRS89 available, the PPPDATUMINFO log will indicate that the requested transformation is not possible:

```
[ICOM3]<PPPDATUMINFO ICOM3 0 28.5 FINESTEERING 2266 403336.000 02040020 ea8d
17139
< "ECEF" 0 2018.000 REQUESTED_TRANSFORMATION_UNAVAILABLE
```

3. A desired transformation between any two datums can be added using the DATUMTRANSFORMATION command. The receiver can also apply a reverse transformation when a transform exists from desired to service datum by flipping the sign on all parameters of transformation. For example, if the user wants to transform a PPP solution from ITRF2014 to ETRS89 but a transformation from ETRS89 to ITRF2014 is available, this will be applied automatically. To create a new transformation, a user will need the following information:

- Service datum⁷ the solution is in (in the GEODATICDATUMS log)
- Datum the user wishes to transform to (in the GEODETICDATUMS log)
- Reference epoch of the parameters (decimal year)
- Translations at the reference epoch in meters (tx, ty, and tz)
- Rotations at the reference epoch in milliarcseconds (rx, ry, and rz)
- Scale difference at reference epoch in parts per billion
- Translation rates in meters/year (tx_vel, ty_vel, and tz_vel)
- Rotation rates in milliarcseconds/year (rx_vel, ry_vel, and rz_vel)
- Scale difference rate in parts per billion/year

Ensure the parameters use the sign conventions and units defined in the [DATUMTRANSFORMATION](#) command documentation. Alternate sign conventions and units are used by different reporting agencies. They are also different from those of the legacy USEREXPDATUM command.

An example command to create a new transformation from ITRF2014 to ETRS89 datum is:

```
DATUMTRANSFORMATION SAVE ITRF2014 ETRS89 2010.0 0.0531 0.0503 -0.0765 1.701
10.290 -16.632 2.12 0.0001 0.0001 0.0019 0.08100 0.49000 -0.79200 0.11
```

Where:

- 2010.0 is the reference epoch of the parameters
- 0.0531, 0.0503 and -0.0765 are the translations at the reference epoch
- 1.701, 10.290, and -16.632 are the rotations at the reference epoch
- 2.12 is the scale difference at the reference epoch
- 0.0001 0.0001 and 0.0019 are the translation rates
- 0.08100 0.49000 and -0.79200 are the rotation rates
- 0.11 is the scale difference rate

⁷ Service datum for TerraStar and VERIPOS is ITRF2014.



The transformation parameters for this newly added datum can be seen in the last entry of DATUMTRANSFORMATIONS log:

```
<DATUMTRANSFORMATIONS ICOM3 0 27.0 FINESTEERING 2266 403400.067 02040020 f957 17139
<      14
<      "ITRF2014" "ITRF2000" 2010.000 0.0007 0.0012 -0.0261 0.0000 0.0000 0.0000
2.120 0.0001 0.0001 -0.0019 0.0000 0.0000 0.0000 0.110
<      "ITRF2014" "ITRF2005" 2010.000 0.0026 0.0010 -0.0023 0.0000 0.0000 0.0000
0.920 0.0003 0.0000 -0.0001 0.0000 0.0000 0.0000 0.030
<      "ITRF2014" "ITRF2008" 2010.000 0.0016 0.0019 0.0024 0.0000 0.0000 0.0000
-0.020 0.0000 0.0000 -0.0001 0.0000 0.0000 0.0000 0.030
<      "ITRF2014" "ETRF2000" 2010.000 0.0547 0.0522 -0.0741 1.7010 10.2900
-16.6320 2.120 0.0001 0.0001 -0.0019 0.0810 0.4900 -0.7920 0.110
<      "ITRF2014" "ETRF2005" 1989.000 0.0523 0.0490 -0.0372 0.0000 0.0000 0.0000
0.290 0.0003 0.0000 -0.0001 0.0540 0.5180 -0.7810 0.030
<      "ITRF2014" "ETRF2014" 2010.000 0.0000 0.0000 0.0000 0.0000 1.7850 11.1510
-16.1700 0.000 0.0000 0.0000 0.0000 0.0850 0.5310 -0.7700 -0.000
<      "ITRF2014" "NAD83(NSRS2011)" 1997.000 0.9950 -1.9014 -0.5228 -25.9147
-9.4264 -11.5993 1.305 0.0008 -0.0006 -0.0014 -0.0667 0.7574 0.0513 -0.072
<      "ITRF2014" "NAD83(CSRS)" 1997.000 0.9950 -1.9014 -0.5228 -25.9147 -9.4264
-11.5993 1.305 0.0008 -0.0006 -0.0014 -0.0667 0.7574 0.0513 -0.072
<      "ITRF2014" "NAD83(PA11)" 1997.000 0.9096 -2.0142 -0.5616 -27.7410
-13.4690 -2.7120 0.690 0.0001 0.0001 -0.0019 0.3840 -1.0070 2.1860 0.110
<      "ITRF2014" "NAD83(MA11)" 1997.000 0.9096 -2.0142 -0.5616 -28.9710
-10.4200 -8.9280 0.690 0.0001 0.0001 -0.0019 0.0200 -0.1050 0.3470 0.110
<      "ITRF2014" "GDA94" 1994.000 -0.0831 -0.0175 0.0360 0.4254 -2.2578 -2.4015
9.210 0.0014 0.0013 0.0008 -1.5461 -1.1820 -1.1551 0.139
<      "ITRF2014" "GDA2020" 2020.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.000 0.0000 0.0000 0.0000 -1.5038 -1.1835 -1.2072 0.000
<      "ITRF2020" "ITRF2014" 2015.000 -0.0014 -0.0009 0.0014 0.0000 0.0000
0.0000 -0.420 0.0000 -0.0001 0.0002 0.0000 0.0000 0.0000 0.000
<      "ITRF2014" "ETRS89" 2010.000 0.0531 0.0503 -0.0765 1.7010 10.2900
-16.6320 2.120 0.0001 0.0001 0.0019 0.0810 0.4900 -0.7920 0.110
```

Now that the transformation exists, the PPPDATUMINFO log will indicate that the requested transformation to ETRS89 was successful:

```
<PPPDATUMINFO COM1 0 29.0 FINESTEERING 2266 403400.500 02040020 ea8d 32768
<      "ETRS89" 6258 2018.000 GOOD
```



Example of Tectonic Compensation

Tectonics Compensation is enabled by default; however, it will not actually perform anything until it has been given an epoch to compensate to. An epoch to compensate to can be provided by sending the OUTPUTDATUM command. For example:

```
OUTPUTDATUM ITRF2014 FIXED_EPOCH 2010.000
```

This will enable tectonics compensation to output the ITRF2014 coordinates that this physical location had on January 1st 2010 (Epoch 2010.000).

Enable tectonic compensation as shown below. The actual epoch that tectonics compensation outputs to is controlled by the OUTPUTDATUM command:

```
TECTONICSCOMPENSATIONSOURCE PLATE_MOTION_MODEL
```

Then request the log below to see the information on the currently used plate model:

```
LOG TECTONICSCOMPENSATION ONCHANGED
```

The receiver will output the following data:

```
<TECTONICSCOMPENSATION COM1 0 73.5 FINESTEERING 2062 151968.341 1a000000 3af4  
15731  
< AVAILABLE "North America" -0.018 -0.000 -0.006
```

Where:

- "AVAILABLE" indicates that compensation is available
- "North America" is the name of the plate used to determine station velocities
- "-0.018 -0.000 -0.006" are the station velocities for the location of the receiver in m/year

If the user disables tectonic compensation as shown below, then the TECTONICSCOMPENSATION log will report "UNAVAILABLE" for compensation status:

```
TECTONICSCOMPENSATIONSOURCE NONE  
<TECTONICSCOMPENSATION COM1 0 70.5 FINESTEERING 2062 151968.341 1a000000 3af4  
15731  
< UNAVAILABLE "" 0.000 0.000 0.000
```

Legacy Datum Transformation Commands

DATUM

The [DATUM](#) command (legacy) is used to select the datum (and its corresponding ellipsoid) for converting Cartesian coordinates to geodetic (latitude, longitude and height) and the transformation applied to positions calculated by the receiver before they are output.

The datum transformation selected by this command is applied to all solutions calculated by the receiver regardless of service datum. Differential solutions such as RTK and PSRDIFF are naturally in the datum of the base station and naturally plate fixed, while PPP, SBAS and Single point solutions are in ITRF2014 or WGS84 Earth Fixed. If different solutions are in different datums then a single transformation will not work in all cases, this is the disadvantage of the legacy datum transformation.

With RTK, it is normally intended to output a position in the datum of the base station. A transformation applied to the receiver position solution will shift it out of the base station datum. Therefore, the DATUM command is generally not suitable for use with RTK.

Use of the factory default setting “WGS84” will result in no transformation being applied to any solution. That is, “WGS84” does not transform into the WGS84 datum, it simply assumes all solutions are already in WGS84.

Datum transformations matter mostly for precise solutions like PPP and RTK, where the difference between datums can be significant compared to the solution accuracy. As already outlined, RTK solutions are typically already in the desired datum.

In most cases, PPP solutions will need datum transformation and for that purpose the new OUTPUTDATUM command should be used. Do not use both OUTPUTDATUM and DATUM commands at the same time as the outcome is not defined.

USERDATUM / USEREXPDATUM

[USERDATUM](#) command (legacy) is like [USEREXPDATUM](#) command (legacy) but without the rate parameters. When USERDATUM command is issued, the receiver internally issues the USEREXPDATUM⁸ command with the values from USERDATUM command and zero rates.

User defined datums can be used after first being created with the [USERDATUM](#) or [USEREXPDATUM](#) command.

The USERDATUM command permits entry of customised ellipsoid and datum transformation parameters. At any given time, only a single set of USERDATUM or USEREXPDATUM command parameters are valid. Any new parameter entry overwrites the previously entered parameters.

The command DATUM USER must be sent for the parameters set by the user in the USERDATUM command to take effect. Furthermore, the DATUM USER command should not be mixed with the OUTPUTDATUM command. While the DATUM USER sets the datum to be the one defined by the user (by using the USERDATUM command to enter customised ellipsoid and datum transformation parameter values), OUTPUTDATUM sets the output datum for the position solution based on what is selected from the supported datums in the GEODETICDATUMS logs.

⁸ RXCONFIG log reports the USEREXPDATUM command.



Ensure the parameters use the sign conventions and units defined in the [USEREXPDATUM](#) command. Additional care should also be taken when inputting datum transformations because alternate sign conventions and units are used by different reporting agencies. The convention used by this command differs from that used by the [DATUMTRANSFORMATION](#) command.

Additional Resources

Commands (new and legacy)

- [OUTPUTDATUM](#)
- [GEODETICDATUM](#)
- [DATUMTRANSFORMATION](#)
- [TECTONICSCOMPENSATIONSOURCE](#)
- [USERDATUM](#) / [USEREXPDATUM](#)
- [DATUM](#)

Logs (new and legacy)

- [GEODETICDATUMS](#)
- [DATUMTRANSFORMATIONS](#)
- [TECTONICSCOMPENSATION](#)
- [BESTDATUMINFO](#)
- [BESTGNSSDATUMINFO](#)
- [PSRDATUMINFO](#)
- [PDPDATUMINFO](#)
- [RTKDATUMINFO](#)
- [PPPDATUMINFO](#)
- [INSDATUMINFO](#)

References

- [New For OEM 7.06.01](#)
- [RTK ASSIST](#)

Appendix

OUTPUTDATUM Differences between 7.06.01 and 7.08.00

From firmware versions 7.06.01 until 7.08.00, datum handling was available *only* for the PPP solution so users could transform the PPP solution to a plate fixed datum, for year over year repeatability and often to match an RTK datum in use.



Support

To help answer questions and/or diagnose any technical issues that may occur, the [NovAtel Support website](#) is a first resource.

Remaining questions or issues, including requests for test subscriptions or activation resends, can be directed to [NovAtel Support](#).

Before contacting Support, it is helpful to collect data from the receiver to help investigate and diagnose any performance-related issues. A list of appropriate troubleshooting logs can be found on the [OEM7 Documentation Portal](#) (the LOG command with the recommended trigger and data rate is included with each log).

The data can also be collected using [NovAtel Application Suite](#).

Documentation

For any questions on logs and commands, please visit the [OEM7 Documentation Portal](#).

Contact Hexagon | NovAtel

support.novatel@hexagon.com 1-800-NOVATEL (U.S. and Canada) or 1-403-295-4900
For more contact information, please visit novatel.com/contact-us