GNSS Vector Exchange File Format (GVX)

Narrative Description of GVX Data Types and Elements

Version 1.0 (February 4, 2021)

Revision History

	Version 1.0
04 Feb 2021	Final release of original version of GVX Authors: Daniel Gillins, Ira Sellars

Introduction

In the late 1980s, researchers recognized the need to develop a standardized file format for static Global Positioning System (GPS) raw data. The reason for this need was that GPS receivers from different manufacturers were outputting raw GPS data in varying file formats. It was felt that a standard file format would make post-processing more efficient.

As a result of this need, the original Receiver Independent Exchange Format (RINEX) was developed. Since then, RINEX has been modified and undergone two new major format versions. It primarily involves carrier-phase, pseudorange, and observation time measurements and has become an industry and academic standard for exchanging static Global Navigation Satellite System (GNSS) data. It's a safe bet that all GNSS post-processing software can parse RINEX data.

Although RINEX has a mature history, a well-known and standard file format for GNSS *vectors* does not exist. A GNSS vector is derived from two GNSS receivers, one placed at each end of a baseline to be measured. During baseline processing, common satellite observables collected simultaneously at each receiver are differenced, producing a vector with Earth-Centered, Earth-Fixed differential components (as well as their variances and covariances). GNSS vectors are computed to represent a measurement of a baseline, and they are commonly used in a survey network (usually with other GNSS vectors; sometimes with other direct measurements, such as EDM-based distances) for the determination of coordinates (usually within a least squares adjustment). A GNSS vector is sometimes referred to as a "baseline solution" because it is a mathematical representation of the post-processing and differencing of the raw GNSS data collected at the receivers.

In addition to post-processing, GNSS vectors can also be computed in real-time during the course of a real-time kinematic (RTK) survey. Conventional practice is to set a single GNSS receiver,

known as a "base" station, over a known point. The second GNSS receiver, or "rover", is then used to make measurements on unknown point(s). Wireless communication is established between the base and rover, and baselines are processed in real-time in order to derive GNSS vectors from the base to the rover. Today, rovers can be set up to communicate and receive correction messages from a real-time network (RTN) consisting of multiple base stations.

RTK-derived vectors are frequently uploaded in software for evaluation, quality assessment, and least squares adjustment. However, this proves burdensome because, just as in the case of raw GNSS data, each vendor has chosen to output vector data in their own data formats. Like RINEX for raw GNSS data, a standardized file format for GNSS vector data of all sorts would enable the exchange of this common survey data, thereby enhancing the usefulness for all.

To this end, this document proposes a new standardized file format known as the GNSS Vector Exchange Format (GVX). GVX aims to provide a standard format for exchanging GNSS vectors derived from varying GNSS survey methods and manufacturer hardware. The file format includes all of the necessary data of a GNSS vector for inclusion in a survey network for least squares adjustment, as well as metadata which describes the vector. The format is meant for any type of GNSS vector, whether it was derived in real-time or from baseline post-processing. GVX has been written in extensible markup language (XML). XML was chosen because it was designed to carry and store data in plain text format, it is easy to expand and/or upgrade to new operating systems, and it can be read by both humans and machines.

Hyperlinks are given below to a simple data file in the proposed GVX format as well as to the schema (XML Schema Definition, XSD).

- Link to the GVX example file: https://geodesy.noaa.gov/data/formats/GVX/sample_gvx.xml
- Link to the GVX schema: https://geodesy.noaa.gov/data/formats/GVX/schema_gvx.xml

In addition to providing the above links, this document gives a detailed description of each of the elements of the proposed GVX file format. It also describes the data types, options, and restrictions for a valid GVX file.

Description of GVX Data Types

Note that in this document, data types are shown in *italics*. The GVX file format involves elements with various simple or complex data types. Several simple XML data types are used, including *Double*, *String*, *Integer*, *anyURI*, *Boolean*, and *unsignedInt*. Descriptions are not given for these basic types. Details for other specific types are given below.

CODEtype: a code assigned to any element. Each code shall contain only 0-9, a-z, A-Z, underscore (_), and colon (:) characters

Date: format as YYYY-MM-DD

Datetime: format as YYYY-MM-DDThh:mm:ss.ss in GPS Time only.

EMAILtype: a *string* with a pattern restricted to a valid email address.

IDtype: an identifier assigned to any element. Each identifier must be unique throughout the file and shall only contain 0-9, a-z, A-z, stop (.) and underscore (_) characters. Example:V00001. It must have at least one character.

LATITUDEtype: a *double* value for latitude, restricted to negative 90 to positive 90 degrees.

LONGITUDEtype: a *double* value for longitude. Values are restricted to negative 360 degrees to positive 360 degrees. Negative longitudes indicate a position west of the prime meridian, and positive longitudes indicate east of the prime meridian.

Description of GVX Elements

Each parent and its child element(s) for the GVX file structure are described in the list below. Names for each element are given in capital letters and in bold. Assigned types for each element are in *italics*. All elements are required for a valid GVX file except those noted as "<optional>". All required elements must occur at least once for a valid GVX file, unless otherwise noted.

1. **SOURCE_DATA:** Information on the original survey data file containing the points and vectors. Only one SOURCE_DATA record allowed per file.
   a. **NAME**: *String* for the original data file name, such as the survey job file name or project file name. Typically, this is the name of the file in the data collector or for the project on the computer.
   b. **CREATED_DATE**: *Datetime* when the original data file was created.
   c. **APPLICATION**: Information on which application was used to record the data.
      i. **NAME:** *String* for the name of the application software that was used to record the data. Examples are Trimble Access, Leica Captivate LandXML Export, or Magnet Field.
      ii. **VERSION:** *String* for the version of the APPLICATION.
      iii. **MANUFACTURER:** *String* for the name of the manufacturer of the APPLICATION. <optional>
      iv. **MANUFACTURER_URL**: *anyURI* for the website of the MANUFACTURER. <optional>

d. **CONVERTED_BY:** Information on which software was used to convert the original data file into GVX format. If the APPLICATION is capable of directly outputting a GVX file without conversion, then provide its NAME, VERSION, and URL as the converter software.
  i. **SOFTWARE_NAME:** *String* for the name of the software used to convert the original data file into GVX format.
  ii. **VERSION:** *String* for the version of the conversion software. <optional>
  iii. **SOFTWARE_URL:** *anyURI* for the website of the conversion software. <optional>
  iv. **CONVERTED_DATE:** *Datetime* when the original data file was converted to the GVX file or the date the GVX file was output directly without conversion.

```
- <SOURCE_DATA>
    <NAME>066.jxl</NAME>
    <CREATED_DATE>2018-03-07T06:55:16</CREATED_DATE>
  - <APPLICATION>
      <NAME>Trimble General Survey</NAME>
      <VERSION>2.90</VERSION>
      <MANUFACTURER>Trimble</MANUFACTURER>
      <MANUFACTURER_URL>https://www.trimble.com</MANUFACTURER_URL>
    </APPLICATION>
  - <CONVERTED_BY>
      <SOFTWARE_NAME>MATLAB_jxl2gvx.m</SOFTWARE_NAME>
      <VERSION>1.0</VERSION>
      <CONVERTED_DATE>2021-01-22T22:20:38</CONVERTED_DATE>
    </CONVERTED_BY>
  </SOURCE_DATA>
```

Figure 1. Example of the SOURCE_DATA element

2. **PROJECT_INFORMATION:** Information on the surveying project, points of contact, and start and end date of the survey. Only one PROJECT_INFORMATION record is allowed per file.
   a. **TITLE:** *String* providing a name or title for the survey project.
   b. **EMAIL_ADDRESS:** *EMAILtype* for the email address of the point of contact. <optional>
   c. **PARTY_CHIEF:** *String* providing the name of the party chief of the survey project.
   d. **AGENCY:** *String* providing the name of the agency or company.
   e. **START_DATE:** *Date* of the earliest vector in the file.
   f. **END_DATE:** *Date* of the oldest vector in the file.

g. **REMARK:** *String* providing any notes or a description of the project. <optional>

```
- <PROJECT_INFORMATION>
    <TITLE>RTN Study, Maryland</TITLE>
    <EMAIL_ADDRESS>galen.scott@noaa.gov</EMAIL_ADDRESS>
    <PARTY_CHIEF>Galen Scott</PARTY_CHIEF>
    <AGENCY>National Geodetic Survey</AGENCY>
    <START_DATE>2018-03-07T11:59:51.00</START_DATE>
    <END_DATE>2018-03-07T21:08:11.00</END_DATE>
  </PROJECT_INFORMATION>
```

Figure 2. Example of the PROJECT_INFORMATION element

3. **REFERENCE_SYSTEM:** Defines the units and 3-D reference frame(s) utilized for all of the points and orbits utilized during processing in the GVX file. A file may contain multiple REFERENCE_SYSTEM records if points or orbits in the file are in more than one system.

    a. **ID:** *IDtype* for setting a unique identifier for the 3-D reference frame. The value shall be set to equal the ID for a geodetic datum in the International Organization of Standardization (ISO) Geodetic Register (see https://geodetic.isotc211.org/ for full details). As examples, some of the ISO Geodetic Register IDs and geodetic datums are:

ID	ISO Geodetic Datum
126	NAD 83 (2011)
101	NAD 83 (MA11)
188	NAD 83 (PA11)
724	IGb14
153	IGS14
159	IGb08
106	IGS08
131	WGS 84 (G1762)
196	WGS 84 (G1674)
114	WGS 84 (G1150)

    b. **CODE:** *Codetype* allows assignment of a code for the REFERENCE_SYSTEM, if needed. <optional>

    c. **NAME:** *String* for the name of the REFERENCE_SYSTEM, meant to aid a human reading the file. Example is "NAD 83(2011)" or "IGS14".

d. **LINEAR_UNIT:** Defines which linear units are used for all distances, heights, Cartesian coordinates, and lengths in the file.

  i. **NAME:** *String* for the name of the linear units; for a valid GVX file, this string is restricted to <u>meters</u>.

  ii. **SIGNIFICANT_DIGITS:** *unsignedInt* listing the number of significant digits for the linear distances. <optional>

  iii. **CONVERSION_FACTOR:** *double* providing the conversion factor from the linear units in the original data file (if not in meters) to meters for the GVX file (if a conversion was necessary). <optional>

e. **ANGULAR_UNIT:** Defines the angular units for all angles, latitudes, and longitudes in the file.

  i. **NAME:** *String* for the name of the angular units; for a valid GVX file, this string is restricted to <u>decimal degrees</u>.

  ii. **SIGNIFICANT_DIGITS:** *unsignedInt* listing the number of significant digits for the angles. <optional>

  iii. **CONVERSION_FACTOR:** *double* providing the conversion factor from the angular units in the original data file (if not in decimal degrees) to decimal degrees for the GVX file (if a conversion was necessary). <optional>

f. **REMARK:** *string* providing any notes or a description. <optional>

```
- <REFERENCE_SYSTEM>
    <ID>126</ID>
    <NAME>NAD 83(2011)</NAME>
  - <LINEAR_UNIT>
      <NAME>meters</NAME>
    </LINEAR_UNIT>
  - <ANGULAR_UNIT>
      <NAME>decimal degrees</NAME>
    </ANGULAR_UNIT>
  </REFERENCE_SYSTEM>
- <REFERENCE_SYSTEM>
    <ID>153</ID>
    <NAME>IGS14</NAME>
  - <LINEAR_UNIT>
      <NAME>meters</NAME>
    </LINEAR_UNIT>
  - <ANGULAR_UNIT>
      <NAME>decimal degrees</NAME>
    </ANGULAR_UNIT>
  </REFERENCE_SYSTEM>
```

Figure 3. Example of the REFERENCE_SYSTEM element

4. **EQUIPMENT:** Defines a pair (antenna and receiver) of GNSS equipment utilized during the GNSS survey. A valid GVX file must contain a minimum of two

EQUIPMENT records (one record each for the initial and terminal point of a GNSS vector).

    a. **ID:** *IDtype* for setting a unique identifier for the equipment pair.

    b. **RECEIVER:** Defines the GNSS receiver.

        i. **TYPE:** *String* providing the name of the GNSS receiver. Recommend using official IGS names, if they exist, or following the IGS receiver naming style if they do not, for all GNSS receivers. See ftp://igs.org/pub/station/general/rcvr_ant.tab for details on IGS naming conventions.

        ii. **SERIAL_NUMBER:** *String* for the receiver serial number.

        iii. **FIRMWARE_VERSION:** *String* for the firmware version utilized by the receiver.

    c. **ANTENNA:** Defines the GNSS antenna.

        i. **TYPE:** *String* for the official name of the GNSS antenna. Recommend using names accepted by NGS under its antenna calibration program, which include all official IGS antenna names. For details on IGS antenna names, see ftp://igs.org/pub/station/general/rcvr_ant.tab. For names from the NGS antenna calibration program, see https://www.ngs.noaa.gov/ANTCAL/. If the antenna is not on the NGS or IGS calibration lists, then recommend following IGS naming styles.

        ii. **CALIBRATION_TYPE:** *String* for naming the type of antenna phase center calibration model under use. Values are restricted to either "Absolute" or "Relative" models. <optional>

        iii. **CALIBRATION_SOURCE:** *String* for naming the source of the antenna phase center calibration model under use. Examples include "IGS", "NGS", "Trimble", "Leica", "Geo++", etc. <optional>

        iv. **SERIAL_NUMBER:** *String* for the antenna serial number. For integrated antennas/receivers, this serial number will be identical with the RECEIVER SERIAL_NUMBER.

```
- <EQUIPMENT>
     <ID>00000049</ID>
   - <RECEIVER>
        <TYPE/>
        <SERIAL_NUMBER/>
        <FIRMWARE_VERSION>0</FIRMWARE_VERSION>
     </RECEIVER>
   - <ANTENNA>
        <TYPE>AdV Null Antenna</TYPE>
        <CALIBRATION_TYPE>Unknown</CALIBRATION_TYPE>
        <CALIBRATION_SOURCE>Unknown</CALIBRATION_SOURCE>
        <SERIAL_NUMBER/>
     </ANTENNA>
  </EQUIPMENT>
- <EQUIPMENT>
     <ID>00000056</ID>
   - <RECEIVER>
        <TYPE>TRMR10</TYPE>
        <SERIAL_NUMBER>5631465932</SERIAL_NUMBER>
        <FIRMWARE_VERSION>5.33</FIRMWARE_VERSION>
     </RECEIVER>
   - <ANTENNA>
        <TYPE>TRMR10 NONE</TYPE>
        <CALIBRATION_TYPE>Absolute</CALIBRATION_TYPE>
        <CALIBRATION_SOURCE>IGS</CALIBRATION_SOURCE>
        <SERIAL_NUMBER>5631465932</SERIAL_NUMBER>
     </ANTENNA>
  </EQUIPMENT>
```

Figure 4. Example of the EQUIPMENT element

5. **SURVEY_SETUP:** Information on how the GNSS vectors were collected or derived. A GVX file may contain multiple SURVEY_SETUP records if varying methods of data collection were used or if the equipment OPERATOR changed during the course of the survey.

   a. **ID:** *IDtype* for setting a unique identifier for the setup of the survey.
   b. **SOLUTION_TYPE:** *String* for describing the method for how the GNSS vector was derived. Only the following strings are allowed: (1) "Single-baseRTK" for a vector from a real-time kinematic (RTK) survey using only a single base station; (2) "NetworkRTK" for a vector from an RTK survey using full network correctors from a real-time network; (3) "Post-processed" for a vector from baseline post-processing.
   c. **OPERATOR:** *String* providing the name of the person operating the RTK rover receiver or running the post-processing software.
   d. **PROCESSING_SOFTWARE:** Information on the baseline processing software used to derive the vector.
      i. **NAME:** *String* for the general or simple name of the baseline processing software. An example is "PAGES" or "TBC".

      ii. **VERSION:** *String* for the detailed name or version number of the baseline processing software. An example is "PAGE5 V1603.24".

      iii. **SOFTWARE_URL:** *anyURI* for the website of the baseline processing software. <optional>

e. **CORRECTOR_FORMAT:** *String* describing the format of the corrector, if the vector resulted from an RTK survey. Examples are "RTCM v2", "RTCM v3", "CMR/CMR+". <optional>

f. **NETWORKRTK:** Information on the real-time network (RTN), required if one was used to derive the vector (whether using a single-base station in the RTN or using the full network corrector from multiple base stations in the RTN). If an RTN was not used for the vector, then it is not required. <optional>

      i. **NAME:** *String* for the name of the RTN. Example is "Oregon Real-time GNSS Network". <optional>

      ii. **MOUNT_POINT:** *String* for documenting the name of the mount point under use. RTN providers will assign a "mount point" or name for its unique settings for providing corrections, and a user will connect a rover to this mount point. An example is "VRS_RTCM3" which likely indicates the RTN is providing VRS solutions with correctors broadcast in RTCM version 3 format.

      iii. **TYPE:** *String* for the method of network corrector, if SOLUTION_TYPE is "NetworkRTK". Values are restricted to "VRS", "MAC", "MAX", "i-MAX", "FKP", "RTX", or "Other".

      iv. **IP_ADDRESS:** *anyURI* for IP address of the RTN.

      v. **IP_PORT:** *unsignedInt* for the IP port.

g. **REMARK:** *string* providing any notes or a description of the survey setup. <optional>

```xml
- <SURVEY_SETUP>
    <ID>00000042</ID>
    <SOLUTION_TYPE>NetworkRTK</SOLUTION_TYPE>
    <OPERATOR>FOB</OPERATOR>
  - <PROCESSING_SOFTWARE>
      <NAME>Trimble VRS</NAME>
      <VERSION>3.2</VERSION>
      <SOFTWARE_URL>https://www.trimble.com</SOFTWARE_URL>
    </PROCESSING_SOFTWARE>
    <CORRECTOR_FORMAT>RTCM 3.1</CORRECTOR_FORMAT>
  - <NETWORKRTK>
      <NAME>KeyNetGPS</NAME>
      <MOUNT_POINT>VRS_RTCM3</MOUNT_POINT>
      <TYPE>VRS</TYPE>
      <IP_ADDRESS>209.255.196.164</IP_ADDRESS>
      <IP_PORT>2101</IP_PORT>
    </NETWORKRTK>
  </SURVEY_SETUP>
```

Figure 5. Example of the SURVEY_SETUP element

6. **POINT:** Data for each set of coordinates (i.e., latitude, longitude, and ellipsoid height) for any point in the GVX file. A file will contain multiple POINT records.
    a. **ID:** *IDtype* for unique identifier within the GVX file assigned to every unique set of coordinates for any point.
    b. **NAME:** *String* giving the name assigned by the surveyor for the coordinates of the point. This is also often called the "point name", and it is typically entered by a surveyor in a data collector or in computer software.
    c. **CODE:** *CODEtype* for allowing entry of a code. <optional>
    d. **EQUIPMENT_ID:** *IDtype* for referencing its EQUIPMENT record, documenting what equipment was utilized to derive or key-in the coordinates of the point.
    e. **ARP_HEIGHT:** *Double* for providing the vertical height from the observed mark to the antenna reference point (ARP) of the GNSS antenna.
    f. **POINT_TYPE:** *String* for describing how the coordinates of the point were derived. Restricted values are: (1) "Keyed-in" for coordinates that were keyed in or entered to the file; (2) "Code" for coordinates that were derived from only the GNSS pseudorange codes; (3) "Float" for coordinates that were derived from GNSS phase angles without integer ambiguity fixing; (4) "Fixed" for coordinates that were derived with GNSS phase angles with fixed integer ambiguities; (5) "PartialFixed" for coordinates that were derived with GNSS phase angles with partially-fixed integer ambiguities; (6) "Adjusted" for coordinates derived in the office from a least squares adjustment of a survey network; (7) "PPP Solution" for coordinates derived from precise point positioning.
    g. **NETWORK_LOCATION:** *String* for describing if the coordinates were derived inside or outside the footprint of the real-time network, if used. Restricted values are "Inside", "Outside", or "Unknown". <optional>
    h. **TILT_COMPENSATOR:** *Boolean* for specifying a value of "1" (TRUE) if the coordinates were derived with the EQUIPMENT and a tilt compensator or "0" (FALSE) if a tilt compensator was not used. <optional>
    i. **COORDINATES:** Coordinates of the POINT.
        i. **REFERENCE_SYSTEM_ID:** *IDtype* for referencing the REFERENCE_SYSTEM record of the coordinates of the POINT.
        ii. **EPOCH:** *Double* for the epoch of the coordinates (in decimal years; recommended to at least 4 digits right of the decimal point).
        iii. **GEODETIC_COORDINATES:**
            1. **LATITUDE:** *LATITUDEtype* for the latitude. Value must be provided to a minimum of ten digits right of the decimal point

2. **LONGITUDE:** *LONGITUDEtype* for the longitude. Value must be provided to a minimum of ten digits right of the decimal point.
3. **ELLIPSOIDAL_HEIGHT:** *Double* for the height above the ellipsoid. Value must be provided to a minimum of four digits right of the decimal point.

iv. **GEOCENTRIC_COORDINATES:** Earth-Centered, Earth-Fixed (ECEF) Cartesian coordinates for the stated axes. Values must be provided to a minimum of four digits right of the decimal point. <optional>
1. **X:** *Double*.
2. **Y:** *Double*.
3. **Z:** *Double*.

v. **CORRELATION_MATRIX_LOCAL:** Standard deviation and correlation coefficient estimates in a local geodetic horizon. Standard deviation values must be provided to a minimum of four digits right of the decimal point, and correlation values must be provided to a minimum of six digits right of the decimal point. <optional>
1. **SDN:** *Double* for the standard deviation in northing.
2. **SDE:** *Double* for the standard deviation in easting.
3. **SDU:** *Double* for the standard deviation in up.
4. **PNE:** *Double* for the correlation in northing and easting.
5. **PNU:** *Double* for the correlation in northing and up.
6. **PEU:** *Double* for the correlation in easting and up.

vi. **CORRELATION_MATRIX:** Standard deviation and correlation coefficient estimates in the Cartesian axes and REFERENCE_SYSTEM of the point. Standard deviation values must be provide to a minimum of four digits to the right of the decimal point, and correlation values to a minimum of six digits to the right of the decimal point. <optional>
1. **SDX:** *Double* for the standard deviation in X.
2. **SDY:** *Double* for the standard deviation in Y.
3. **SDZ:** *Double* for the standard deviation in Z.
4. **PXY:** *Double* for the correlation in X and Y.
5. **PXZ:** *Double* for the correlation in X and Z.
6. **PYZ:** *Double* for the correlation in Y and Z.

```
- <POINT>
    <ID>00000045</ID>
    <NAME>PRS87926747413</NAME>
    <EQUIPMENT_ID>00000049</EQUIPMENT_ID>
    <ARP_HEIGHT>0.0000</ARP_HEIGHT>
    <POINT_TYPE>Keyed-in</POINT_TYPE>
  - <COORDINATES>
        <REFERENCE_SYSTEM_ID>126</REFERENCE_SYSTEM_ID>
        <EPOCH>2010.0000</EPOCH>
      - <GEODETIC_COORDINATES>
            <LATITUDE>39.935084521832</LATITUDE>
            <LONGITUDE>-77.659293358481</LONGITUDE>
            <ELLIPSOIDAL_HEIGHT>169.771458608</ELLIPSOIDAL_HEIGHT>
        </GEODETIC_COORDINATES>
      - <GEOCENTRIC_COORDINATES>
            <X>1046708.79220401</X>
            <Y>-4784306.74711840</Y>
            <Z>4072570.41333930</Z>
        </GEOCENTRIC_COORDINATES>
      - <CORRELATION_MATRIX_LOCAL>
            <SDN>0.0100</SDN>
            <SDE>0.0100</SDE>
            <SDU>0.0100</SDU>
            <PNE>0.000000</PNE>
            <PNU>0.000000</PNU>
            <PEU>0.000000</PEU>
        </CORRELATION_MATRIX_LOCAL>
    </COORDINATES>
  </POINT>
- <POINT>
    <ID>00000057</ID>
    <NAME>TANE_TR_066A_01</NAME>
    <EQUIPMENT_ID>00000056</EQUIPMENT_ID>
    <ARP_HEIGHT>2.0000</ARP_HEIGHT>
    <POINT_TYPE>Fixed</POINT_TYPE>
  - <COORDINATES>
        <REFERENCE_SYSTEM_ID>126</REFERENCE_SYSTEM_ID>
        <EPOCH>2010.0000</EPOCH>
      - <GEODETIC_COORDINATES>
            <LATITUDE>39.663351509617</LATITUDE>
            <LONGITUDE>-77.183549366876</LONGITUDE>
            <ELLIPSOIDAL_HEIGHT>111.806363310</ELLIPSOIDAL_HEIGHT>
        </GEODETIC_COORDINATES>
      - <GEOCENTRIC_COORDINATES>
            <X>1090672.00390682</X>
            <Y>-4794238.86798448</Y>
            <Z>4049352.88271511</Z>
        </GEOCENTRIC_COORDINATES>
    </COORDINATES>
  </POINT>
```

Figure 6. Example of the POINT element

7. **GNSS_VECTOR:** Data for each GNSS vector in the GVX file. A file may contain multiple GNSS_VECTOR records.

a. **ID:** *IDtype* for unique identifier for the GNSS vector.
b. **INITIAL_POINT_ID:** *IDtype* for referencing the POINT record for the initial or starting point of the vector.
c. **TERMINAL_POINT_ID:** *IDtype* for referencing the POINT record for the terminal or ending point of the vector.
d. **SURVEY_SETUP_ID:** *IDtype* for referencing the SURVEY_SETUP record, providing information on how the vector was derived.
e. **OBSERVATION_TIME:**
    i. **START:** *Datetime* of the beginning time of the observation. Must be in GPS time.
    ii. **END:** *Datetime* of the ending time of the observation. Must be in GPS time.
    iii. **UTC_OFFSET:** *Double* for providing the offset from UTC time to the local time of the observation. Local time equals UTC time plus the UTC_OFFSET. <optional>
    iv. **LEAP_SECONDS**: *Integer* for providing the number of leap seconds between GPS time and UTC time. GPS time equals UTC time plus the LEAP_SECONDS. <optional>
f. **QUALITY_CONTROL:**
    i. **EPOCHS_USED:** *Integer* for providing the number of epochs used to compute the vector. <optional>
    ii. **MASK:**
        1. **ELEVATION:** *Double* for documenting the setting in the GNSS equipment for the minimum acceptable elevation angle (in decimal degrees) prior to masking satellite observables. If a mask was not used, enter zero. <optional>
        2. **PDOP_MASK:** *Double* for documenting the setting in the GNSS equipment for the maximum acceptable position dilution of precision (PDOP) prior to masking satellite observables. <optional>
    iii. **RMS:** *Double* for the root-mean-square error of the baseline solution, to a minimum of three significant figures. <optional>
    iv. **DILUTION_PRECISION:** Dilution of precision values computed for the GNSS vector. <optional>
        1. **GDOP:** *Double* for geometric dilution of precision. <optional>
        2. **HDOP:** *Double* for horizontal dilution of precision. <optional>
        3. **PDOP:** *Double* for position dilution of precision. <optional>
        4. **TDOP:** *Double* for time dilution of precision. <optional>
        5. **VDOP:** *Double* for vertical dilution of precision. <optional>

v. **SATELLITE_USED:** Counts both the total number of satellite vehicles used to derive the GNSS vector as well as a count of the subtotal of vehicles from each GNSS. <optional>
1. **TOTAL:** *Integer.*
2. **GPS:** *Integer.*
3. **GLONASS:** *Integer.*
4. **GALILEO:** *Integer.*
5. **QZSS:** *Integer.*
6. **BEIDOU:** *Integer.*
vi. **ORBIT:** Information on the type of orbits used during baseline processing.
1. **TYPE:** *String* for naming which orbits were used when deriving the GNSS vector. Restricted values are "Final", "Rapid", "Ultra-rapid observed half", "Ultra-rapid predicted half", and "Broadcast".
2. **SOURCE:** *String* for naming the source of the orbits. An example is "IGS" or "Broadcast".
3. **REFERENCE_SYSTEM_ID:** *IDtype* for referencing the REFERENCE_SYSTEM record of the ORBIT. <optional>
4. **DOWNLOAD_DATE:** *Datetime* when the ORBIT was downloaded from its SOURCE. <optional>
vii. **CORRECTOR_AGE:** *Integer* for the number of seconds of delay in the real-time corrector, if the vector was derived in real-time. <optional>
g. **ECEF_DELTAS:** Differential, Earth-Centered, Earth-fixed mark-to-mark vector components in the Cartesian axes and reference system of the ORBIT (from the initial point to the terminal point). Values must be provided to a minimum of four digits right of the decimal point.
i. **DX:** *Double.*
ii. **DY:** *Double.*
iii. **DZ:** *Double.*
h. **CORRELATION_MATRIX:** Standard deviation and correlation coefficient values for the vector components, in the Cartesian axes and reference system of the ORBIT. Standard deviation values must be provide to a minimum of four digits to the right of the decimal point, and correlation values to a minimum of six digits to the right of the decimal point.
i. **SDX:** *Double* for the standard deviation in X.
ii. **SDY:** *Double* for the standard deviation in Y.
iii. **SDZ:** *Double* for the standard deviation in Z.
iv. **PXY:** *Double* for the correlation in X and Y.
v. **PXZ:** *Double* for the correlation in X and Z.

vi. **PYZ:** *Double* for the correlation in Y and Z.

```
- <GNSS_VECTOR>
    <ID>V1</ID>
    <INITIAL_POINT_ID>00000045</INITIAL_POINT_ID>
    <TERMINAL_POINT_ID>00000057</TERMINAL_POINT_ID>
    <SURVEY_SETUP_ID>00000042</SURVEY_SETUP_ID>
  - <OBSERVATION_TIME>
        <START>2018-03-07T11:59:51.00</START>
        <END>2018-03-07T12:04:51.00</END>
        <UTC_OFFSET>-5</UTC_OFFSET>
    </OBSERVATION_TIME>
  - <QUALITY_CONTROL>
        <EPOCHS_USED>301</EPOCHS_USED>
      - <MASK>
            <ELEVATION>10</ELEVATION>
            <PDOP_MASK>6</PDOP_MASK>
        </MASK>
      - <DILUTION_PRECISION>
            <GDOP>2.3560023443209</GDOP>
            <HDOP>0.88247835636139</HDOP>
            <PDOP>1.8524643182755</PDOP>
            <VDOP>1.6287826299667</VDOP>
        </DILUTION_PRECISION>
      - <SATELLITE_USED>
            <TOTAL>14</TOTAL>
            <GPS>7</GPS>
            <GLONASS>7</GLONASS>
            <GALILEO>0</GALILEO>
            <QZSS>0</QZSS>
            <BEIDOU>0</BEIDOU>
        </SATELLITE_USED>
      - <ORBIT>
            <TYPE>Ultra-rapid predicted half</TYPE>
            <SOURCE>IGS</SOURCE>
            <REFERENCE_SYSTEM_ID>153</REFERENCE_SYSTEM_ID>
            <DOWNLOAD_DATE>2018-03-07T11:59:51.00</DOWNLOAD_DATE>
        </ORBIT>
        <CORRECTOR_AGE>1</CORRECTOR_AGE>
    </QUALITY_CONTROL>
  - <ECEF_DELTAS>
        <DX>43963.2117028116</DX>
        <DY>-9932.1208660826</DY>
        <DZ>-23217.5306241941</DZ>
    </ECEF_DELTAS>
  - <CORRELATION_MATRIX>
        <SDX>0.00562616507579</SDX>
        <SDY>0.01601647336245</SDY>
        <SDZ>0.01478952423068</SDZ>
        <PXY>-0.45317068576054</PXY>
        <PXZ>0.36179992590177</PXZ>
        <PYZ>-0.78267735403562</PYZ>
    </CORRELATION_MATRIX>
</GNSS_VECTOR>
```

Figure 7. Example of the GNSS_VECTOR element

8. **SESSION:** Record for vectors derived from simultaneous baseline processing. A file may contain multiple sessions, one for each set of vectors processed together with simultaneous observations to common satellites. <optional>
    a. **Attributes:**
        i. **ID:** *IDtype* for unique identifier for the GNSS session.
        ii. **TOTAL_VECTORS:** *Integer* count of the total number of vectors in a session.
    b. **SESSION_TIME:**
        i. **START:** *Datetime* of when the session began. Must be in GPS time.
        ii. **END:** *Datetime* of when the session ended. Must be in GPS time.
        iii. **UTC_OFFSET:** *Double* for providing the offset from UTC time to the local time of the session. Local time equals UTC time plus the UTC_OFFSET. <optional>
        iv. **LEAP_SECONDS**: *Integer* for providing the number of leap seconds between GPS time and UTC time. GPS time equals UTC time plus the LEAP_SECONDS. <optional>
    c. **CROSS_CORRELATION_MATRIX:** All correlation coefficients between every pair of vectors in the session, in the Cartesian axes and reference system of the ORBIT. Each SESSION will have one CROSS_CORRELATION_MATRIX element. See Appendix A for an example of how to build this matrix.
        i. **Attributes:**
            1. **ORDER:** *String* for describing the order of the listed correlation coefficients, in terms of the Cartesian axes. An example is "XYZ".
        ii. **CCM_BLOCK:** A 3x3 block of correlation coefficients between a pair of vectors in a session. For a session containing *n* TOTAL_VECTORS, there must be [*n* (*n* – 1)]/2 blocks to describe a complete cross-correlation matrix.
            1. **Attributes:**
                a. **VECTOR_ID_COL:** *IDtype* for referencing the GNSS_VECTOR in the columns of the 3x3 block.
                b. **VECTOR_ID_ROW:** *IDtype* for referencing the GNSS_VECTOR in the rows of the 3x3 block.
            2. **CORRELATIONS:** *String* listing the 9 correlation coefficients from the 3x3 block of values between the identified pair of vectors. Values are expressed to at least 6 digits to the right of the decimal, separated by commas, in the identified ORDER.

APPENDIX A. Example for Handling a Full Correlation Matrix

Figure A1 presents an example correlation matrix for a simultaneously processed session of 5 GNSS vectors. The diagonal contains standard deviations for each vector differential component (yellow cells), and all other values are correlation coefficients (green and blue cells).

The standard deviations (yellow cells) and correlation coefficients (green cells) along the 3x3 band-diagonal of the matrix are stored in the CORRELATION_MATRIX for each individual GNSS_VECTOR. For the data presented in Figure A1, the CORRELATION_MATRIX for each of the five vectors would be populated like shown in Figure A2.

The other correlation coefficients (blue cells) off of the 3x3 band-diagonal of the matrix are considered "cross-correlations". A 3x3 block of these cells represents correlations between two vectors in the session. For instance, the values in columns 4 to 6 and rows 1 to 3 of the matrix represent the correlations between vector 2 and vector 1. Each off-diagonal 3x3 block of values is stored as a comma delimited list in the CCM_BLOCK of the CROSS_CORRELATION_MATRIX record for the SESSION. For a session containing n vectors, there must be $[n(n-1)]/2$ blocks (i.e., CCM_BLOCK) to fully describe all values. So, for Figure A1 consisting of five vectors, the CROSS_CORRELATION_MATRIX will have ten CCM_BLOCK records. Figure A3 presents a populated CROSS_CORRELATION_MATRIX for the data in Figure A1.

By combining the CCM_BLOCK records of the CROSS_CORRELATION_MATRIX with the CORRELATION_MATRIX of each of the individual GNSS_VECTOR records, it is possible to construct a full correlation matrix for the session.

	VECTOR 1			VECTOR 2			VECTOR 3			VECTOR 4			VECTOR 5		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
VECTOR 1 X	0.000405	-0.674221	0.775253	-0.509209	0.298034	0.257034	0.253795	0.791754	0.193256	-0.639295	0.597485	-0.610140	0.523686	0.099108	0.984302
VECTOR 1 Y		0.002328	-0.202975	-0.652557	0.043531	0.116217	-0.908680	-0.080583	-0.629678	0.321014	-0.052642	-0.299856	0.987440	0.403217	0.416175
VECTOR 1 Z			0.005467	0.228385	0.583920	0.580984	-0.239217	0.768268	0.313219	0.686572	-0.193054	-0.805117	0.418503	0.215832	0.320711
VECTOR 2 X				0.001822	-0.642737	0.343691	0.782238	0.734354	-0.984808	-0.328404	0.905440	-0.025916	-0.730406	-0.078659	-0.635347
VECTOR 2 Y					0.003746	-0.073597	0.456162	0.433486	-0.814330	0.428120	0.275459	0.910117	-0.611051	0.944213	-0.289733
VECTOR 2 Z						0.009820	-0.690216	0.835892	0.262298	-0.281938	0.544641	0.737189	0.347740	-0.908073	-0.086859
VECTOR 3 X							0.008301	-0.266955	0.665920	0.511132	0.510525	-0.237698	0.528545	0.326278	0.387525
VECTOR 3 Y								0.002328	0.959702	0.911129	0.757233	-0.819999	0.256224	0.710261	-0.455859
VECTOR 3 Z									0.001923	0.472967	0.306437	0.753184	-0.491392	0.371125	-0.696796
VECTOR 4 X										0.006783	-0.985821	0.735367	0.443609	-0.269284	-0.390866
VECTOR 4 Y											0.001721	-0.498073	-0.706717	-0.029156	-0.305930
VECTOR 4 Z												0.008807	0.202469	0.228891	0.793981
VECTOR 5 X													0.004353	0.838423	0.169365
VECTOR 5 Y														0.003442	-0.715525
VECTOR 5 Z															0.003847

SYMMETRIC

(yellow)	= standard deviation
(green)	= correlation coefficient
(cyan)	= cross-correlation coefficient

Figure A1. Example full correlation matrix for 5 vectors in a session, post-processed simultaneously.

```
<GNSS_VECTOR>
    <ID>V1</ID>
  - <CORRELATION_MATRIX>
        <SDX>0.000405</SDX>
        <SDY>0.002328</SDY>
        <SDZ>0.005467</SDZ>
        <PXY>-0.674221</PXY>
        <PXZ>0.775253</PXZ>
        <PYZ>-0.202975</PYZ>
    </CORRELATION_MATRIX>
</GNSS_VECTOR>
<GNSS_VECTOR>
    <ID>V2</ID>
  - <CORRELATION_MATRIX>
        <SDX>0.001822</SDX>
        <SDY>0.003746</SDY>
        <SDZ>0.009820</SDZ>
        <PXY>-0.642737</PXY>
        <PXZ>0.343691</PXZ>
        <PYZ>-0.073597</PYZ>
    </CORRELATION_MATRIX>
</GNSS_VECTOR>
<GNSS_VECTOR>
    <ID>V3</ID>
  - <CORRELATION_MATRIX>
        <SDX>0.008301</SDX>
        <SDY>0.002328</SDY>
        <SDZ>0.001923</SDZ>
        <PXY>-0.266955</PXY>
        <PXZ>0.665920</PXZ>
        <PYZ>0.959702</PYZ>
    </CORRELATION_MATRIX>
</GNSS_VECTOR>
<GNSS_VECTOR>
    <ID>V4</ID>
  - <CORRELATION_MATRIX>
        <SDX>0.006783</SDX>
        <SDY>0.001721</SDY>
        <SDZ>0.008807</SDZ>
        <PXY>-0.985821</PXY>
        <PXZ>0.735367</PXZ>
        <PYZ>-0.498073</PYZ>
    </CORRELATION_MATRIX>
</GNSS_VECTOR>
<GNSS_VECTOR>
    <ID>V5</ID>
  - <CORRELATION_MATRIX>
        <SDX>0.004353</SDX>
        <SDY>0.003442</SDY>
        <SDZ>0.003847</SDZ>
        <PXY>0.838423</PXY>
        <PXZ>0.169365</PXZ>
        <PYZ>-0.715525</PYZ>
    </CORRELATION_MATRIX>
</GNSS_VECTOR>
```

Figure A2. Example CORRELATION_MATRIX records for the standard deviation and correlation coefficients along the 3x3 band diagonal of the matrix in Figure A1.

```xml
<SESSION TOTAL_VECTORS="5" ID="S1">
  - <CROSS_CORRELATION_MATRIX ORDER="XYZ">
    - <CCM_BLOCK VECTOR_ID_ROW="V1" VECTOR_ID_COL="V2">
        <CORRELATIONS>-0.509209,0.298034,0.257034,-0.652557,0.043531,0.116217,0.228385,0.583920,0.580984</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V1" VECTOR_ID_COL="V3">
        <CORRELATIONS>0.253795,0.791754,0.193256,-0.908680,-0.080583,-0.629678,-0.239217,0.768268,0.313219</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V1" VECTOR_ID_COL="V4">
        <CORRELATIONS>-0.639295,0.597485,-0.610140,0.321014,-0.052642,-0.299856,0.686572,-0.193054,-0.805117</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V1" VECTOR_ID_COL="V5">
        <CORRELATIONS>0.523686,0.099108,0.984302,0.987440,0.403217,0.416175,0.418503,0.215832,0.320711</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V2" VECTOR_ID_COL="V3">
        <CORRELATIONS>0.782238,0.734354,-0.984808,0.456162,0.433486,-0.814330,-0.690216,0.835892,0.262298</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V2" VECTOR_ID_COL="V4">
        <CORRELATIONS>-0.328404,0.905440,-0.025916,0.428120,0.275459,0.910117,-0.281938,0.544641,0.737189</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V2" VECTOR_ID_COL="V5">
        <CORRELATIONS>-0.730406,-0.078659,-0.635347,-0.611051,0.944213,-0.289733,0.347740,-0.908073,-0.086859</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V3" VECTOR_ID_COL="V4">
        <CORRELATIONS>0.511132,0.510525,-0.237698,0.911129,0.757233,-0.819999,0.472967,0.306437,0.753184</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V3" VECTOR_ID_COL="V5">
        <CORRELATIONS>0.528545,0.326278,0.387525,0.256224,0.710261,-0.455859,-0.491392,0.371125,-0.696796</CORRELATIONS>
      </CCM_BLOCK>
    - <CCM_BLOCK VECTOR_ID_ROW="V4" VECTOR_ID_COL="V5">
        <CORRELATIONS>0.443609,-0.269284,-0.390866,-0.706717,-0.029156,-0.305930,0.202469,0.228891,0.793981</CORRELATIONS>
      </CCM_BLOCK>
  </CROSS_CORRELATION_MATRIX>
</SESSION>
```

Figure A3. Example CROSS_CORRELATION_MATRIX records for the correlation coefficients for the off-diagonal 3x3 blocks of the matrix in Figure A1.