

# Getting Started Processing GNSS Data with ODTK

## 1 Introduction

ODTK can process GNSS (Global Navigation Satellite System) measurements in the form of pseudorange and Doppler phase-count measurements for a range of frequencies and from most of the existing GNSS constellations (GPS, Glonass, Galileo, QZSS, and Beidou). The IRNSS constellation is not supported. You can load the measurements via a RINEX GNSS Observation file or through a user-supplied measurement provider.

You can supply ODTK with GNSS navigation and space vehicle (SV) data via several message types. These include the HANU or Auxiliary User (AUX) message (GPS constellation only), the SP3 message, the RINEX GNSS Navigation message, the SEM almanac message, and the YUMA almanac message (see section 2.3). GNSS measurement processing is possible within the ODTK Filter, Smoother, Simulator, Least Squares, and Initial Orbit Determination (IOD) objects.

ODTK can also process navigation-solution measurements from a space-borne receiver. You can load these measurements via a special format (.NAVSOL), and the measurements do not require additional information about the GNSS constellation.

The purpose of this guide is to help you become familiar with using ODTK to process GNSS measurements. It focuses on data from the GPS constellation, but the same concepts apply to using data from the other GNSS constellations as well. This guide assumes that you have installed ODTK, have access to the ODTK Help documentation, and have some experience with ODTK processing non-GNSS measurement types.

## 2 GNSS ODTK inputs

### 2.1 GNSS measurement types

ODTK can simulate and process GNSS *pseudorange* and *phase-count* measurements — the raw measurements from the GNSS receiver — as well as GNSS receiver *navigation-solution* measurements, which are a sequence of instantaneous estimates of Cartesian receiver location generated on board.

#### 2.1.1 Pseudorange and phase-count measurements

ODTK can process pseudoranges and phase-counts associated with the coarse acquisition (CA) code and precise (P) codes for all frequencies used by the GNSS constellation (L1, L2, L5, E1, E5a, E5b, G1, G2, etc.). ODTK can model and process the measurements directly, or it can combine measurements using observation-set models. For pseudoranges and phase, the observation-set

models include a singly differenced (SD) and double-differenced (DD) models and a dual-frequency (DF) model. AGI recommends reviewing the RINEX observation specification [2] and the ODTK Help (OD Objects & Attributes | Measurement Types and Formats) for a more detailed description of the supported measurements.

You can choose measurement models by selecting the appropriate Measurement Type(s) to process; see the attribute MeasTypes under the Filter object and the attribute MeasurementStatistics under the GNSSReceiver object).

**NOTES:**

1. Some of these Measurement Types are mutually exclusive for selection with a filter object. Reference the Measurement Processing topic under ODTK Objects & Attributes > Satellites within the ODTK Help System for the rules for filter selection.
2. The simulator only generates the “raw” pseudorange and phase measurements on each frequency. ODTK combines these using the observation-set models when the filter runs to form DF, SD, and DF SD measurements.

## 2.1.2 Navigation solutions

ODTK can process the position components of navigation solutions generated by a space-borne GNSS receiver. ODTK reduces these position components in the Earth-Centered Fixed (ECF) reference frame, and considers the three components of position as independent measurements with the same noise characteristics.

You can use two types of navigation solutions: CA Nav Sol and DF Nav Sol. Each is the result of using the associated type of pseudorange in the reduction of the navigation solution (CA or DF, as defined above). You can define the white noise characteristics for each measurement type in the MeasurementStatistics list on the GNSS Receiver object. There are no bias estimates associated with the processing of navigation solutions. This means that biases in the CA navigation solutions due to unmodeled effects of the ionosphere can bias the orbit solution.

## 2.2 Observation files

### 2.2.1 RINEX

The way to load pseudorange measurements into ODTK is via a RINEX GNSS Observation file [2]. The RINEX 3.04 specification Section 5.1 identifies hundreds of different observation types that may be included for the various constellations. In general, ODTK will use the pseudorange (Cna), phase (Lna), and signal strength (Sna) measurements as observations, where “n” represents the band or frequency and “a” represents the tracking mode or channel.

If signal strength observations are available, you have the option to edit out the measurements for low signal-to-noise ratio (SNR). The RINEX format allows a signal strength “flag” to (optionally) be given with each observable. This flag is used in lieu of the “Sna” observations. If given, ODTK maps the SSI flag to these SNR values for the purpose of SNR editing.

SNR:	>500	>100	>50	>10	>5	>3	>1	>0	bad	n/a
SSI:	9	8	7	6	5	4	3	2	1	0

**NOTE :** ODTK supports RINEX file versions 3.0.3 and previous.

## 2.2.2 NAVSOL

Load navigation solutions to ODTK via a NAVSOL observation file. ODTK’s NAVSOL format enables you to specify the position components and their associated spherical uncertainty ( $1\sigma$ ). The format of the NAVSOL observation file is described in the ODTK Help System.

## 2.2.3 Connecting a RINEX observation file to a satellite receiver

The RINEX file format specification does not actually mandate adding a receiver ID (i.e., MARKER NUMBER record). However, ODTK requires a method to associate the observations in the given RINEX observation file to the GNSS Receiver ID given by the MeasurementProcessing.TrackingID attribute in the GNSS Receiver Object (see section 2.4.2). If no MARKER NUMBER record appears in the RINEX file, then you must do one of the following to associate the file to the receiver ID:

- Manually edit the file to include a MARKER NUMBER record into the header records. In the example below, the line in italics was inserted to associate this observation file to satellite GPS receiver ID 3902.

2	OBSERVATION DATA	GPS	RINEX VERSION / TYPE
BJfmtl_rnx	bai	2002-06-14 01:06:58	PGM / RUN BY / DATE
CHAMP-zenith			MARKER NAME
3902			<i>MARKER NUMBER</i>

- (Re)name the RINEX observation file to the form SATnnnn\_XXXXX.zzz, where “nnnn” indicates the receiver ID; that is, begin with “SAT”, followed by a series of digits “nnnn”, followed by underscore “\_”, followed by the rest of filename and extension. For example, the name SAT4000\_SACC1670.03O identifies the receiver ID as 4000.

## 2.3 GNSS Source Data

The pseudorange model takes the following navigation inputs:

1. SV ephemeris and clock correction estimates
2. SV ephemeris and clock correction estimate error covariance
3. Model parameters for high-accuracy correlation of GNSS (GPS, Glonass, etc.) time to UTC time (and TDT time); see Note 2 at the end of this section

The ephemeris and clock-correction estimates are required. Other inputs can be used if available from the GNSS source. ODTK accepts the following GNSS source messages:

1. GPS Auxiliary User (AUX) Message (HANU) – Defined by ICD-GPS-208, this message type includes a 26-hour post-pass Observation Message, a nine-hour high-accuracy Prediction Message, and a 40-hour prediction Look Ahead Message.
2. RINEX SP3 – This is an ASCII message containing SV ephemeris and clock parameters. Easily obtained from the International GNSS Service (IGS) at <http://igs.org/products> or from the National Geospatial Agency (NGA) at [http://earth-info.nga.mil/GandG/update/index.php?action=home#tab\\_gnss](http://earth-info.nga.mil/GandG/update/index.php?action=home#tab_gnss). The IGS SP3 files are referenced to the SV Center of Mass (COM) and therefore antenna offset corrections must be applied. The NGA SP3 files are available as referenced to the COM or Antenna Phase Center (APC).
3. RINEX GNSS Navigation Message – This is an ASCII message (defined in [2]) containing the navigation data defined in ICD-GPS-200 and RINEX 3.04. See <ftp://ftp.igs.org/pub/product>.
4. SEM Almanac – This is an ASCII message containing navigation message almanac information in SEM format. Reference <https://navcen.uscg.gov/gps-nanus-almanacs-opsadvisories-sof> for a definition and catalog of files.
5. YUMA Almanac – ASCII message containing navigation message almanac information in YUMA format. Reference <https://navcen.uscg.gov/gps-nanus-almanacs-opsadvisories-sof> for a definition and catalog of files.

The following table summarizes the types of data available from each data source:

	Type	Eph/Clock	Covariance	GPS/UTC	Ionosphere
<b>AUX Observation</b>	Post Pass	Interpolate Table	Yes	No	No
<b>AUX Prediction</b>	High Precision Pre-dict	Interpolate Table	Yes	No	No
<b>AUX Look Ahead</b>	Predict	Interpolate Table	No	Yes	No
<b>SP3</b>	Eph – PostPass Clock - Pre-dict	Interpolate Table	No	No	No
<b>RINEX NAV</b>	Predict	Element Propagation	No	Optional	Optional
<b>SEM</b>	Predict	Element Propagation	No	No	No
<b>YUMA</b>	Predict	Element Propagation	No	No	No

For ODTK processing, you can only select one source file for ephemeris / clock / covariance inputs and (optionally) one source file for GNSS/UTC high-accuracy correlation parameters. Enter GNSS source information via the GNSS Constellation object (*cf.* Section 2.4.1).

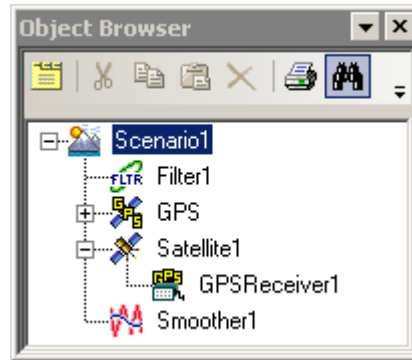
**NOTES:**

1. For real-world data processing, AGI highly recommends using the SP3 or AUX data files because they contain the most accurate information. Processing GNSS measurements with a NAV, SEM, or YUMA ephemeris is not recommended other than generating simulated measurements because these ephemeris sources are not accurate enough.
2. Because you can only enter one source file for ephemeris/clock/covariance data, you should limit the filter start/end time span to be consistent with the time span of this source file.
3. The GNSS/UTC high-accuracy correlation parameters refer to the A0 and A1 constants that identify the GPS-UTC offset (in the case of processing GPS measurements) in addition to the leap second offset. For CA L1 pseudorange processing, you can safely ignore these. See <https://usno.navy.mil/USNO/time/gps/usno-gps-time-transfer> for a discussion on GPS time transfer and <https://usno.navy.mil/USNO/time/gps/gps-timing-data-and-information> for SPS time differences.

4. ODTK expects a file extension of \*.aux for AUX messages, \*.sp3 for SP3 and SP3c messages, \*.rinex for RINEX NAV messages, \*.yuma for YUMA messages, and \*.sem for SEM messages.

## 2.4 ODTK objects unique to GNSS

The following is an example Object Browser view for an ODTK filter/smoothing run processing GNSS pseudorange measurements:



You should note the following two objects unique to GNSS processing:

1. A GNSS Constellation object under the Scenario object
2. A GNSS Receiver object under the Satellite object

Refer to the Insert menu in ODTK Help system (Using ODTK > Menus) for instructions on adding objects.

ODTK will only accept one GNSS Constellation object per GNSS constellation type in your scenario. ODTK will accept two or more GNSS Receiver objects per satellite and two or more Satellite objects with GNSS Receivers.

### 2.4.1 GNSS Constellation object

The GNSS Constellation object is documented in the ODTK Help System contents under OD Objects & Attributes → GNSS Constellation.

**NOTE:** A GNSS Constellation object is not required to filter navigation solutions (NAVSOL) as measurements, but one is required to simulate the raw pseudorange measurements that are then processed to build simulated navigation solutions.

### 2.4.2 GNSS Receiver object

The GNSS Receiver object is documented in the ODTK Help System under OD Objects & Attributes → GNSS Receivers.

## 3 Sample procedures for ODTK run

### 3.1 Procedure for GPS Simulation run

The following procedure provides steps necessary to make a simple ODTK Simulation run to generate GPS measurements. The first part of the process is the same regardless of whether you wish to simulate a set of pseudoranges and phase-counts or a navigation solution. In the following example, there is one satellite that has one GNSS receiver processing GPS CA pseudorange.

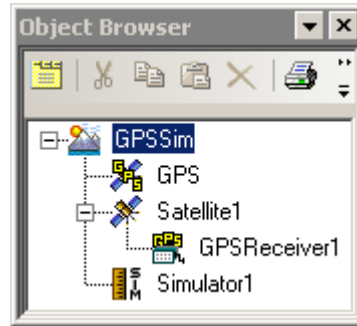
1. The first step is to obtain the GPS ephemeris data for the simulator; it needs to know where the GPS satellites are in order to simulate the pseudorange to them. This example contains the assumption that there are no measurements in hand and you must download data via the internet. Download the IGS GPS Precision Ephemeris SP3 file for 1 Jun 2019 UTC. This corresponds to GPS week 2055, day 6 (GPS days of the week are numbered 0-6).

Start with the IGS CDDIS site at <https://cddis.nasa.gov/archive/gnss/products/> to bring up access to SP3 ephemeris files. Descend into the 2055 directory.

- Select and download the igs20556.sp3.Z file to a local temporary folder on your computer. The \*.Z extension indicates it has been compressed using the UNIX “compress” utility.
  - Expand the file using 7-zip or another utility that understands “compress” format. This will produce the igs20556.sp3 file that you need.
2. Start ODTK.
  3. Create the ODTK objects necessary for the simulation:
    - Create a Scenario object.
    - Open the scenario’s properties. Set DefaultTimes.Processes.StartMode to Start-Time. Set DefaultTimes.Processes.StartTime to "1 Jun 2019 GPSG". This date corresponds with the SP3 file from Step 1. If UTCG units are specified as the default display units, the display will automatically change to "31 May 2019 23:59:42.000 UTCG".
    - Set DefaultTimes.Processes.StopMode to TimeSpan. Set DefaultTimes.Processes.TimeSpan to "4 hr". Click Apply to apply the scenario property changes.
    - Add a GNSS Constellation object to the Scenario object by clicking the Insert menu, selecting New..., and selecting GNSS Constellation. By default, GNSS Constellation will be a GPS constellation.
    - Add a Satellite object to the scenario. You will leave in place all the default settings, so this becomes a generic LEO satellite.

- Add a GNSS Receiver object to the satellite object.
- Add a Simulator object to the scenario object.

The resulting Object Browser structure should look like this:



- Open and edit the GNSS Receiver object properties. For this exercise, accept the defaults, except to edit the MeasurementStatistics attribute as follows:
  - Remove all measurement types except CA Pseudorange measurement and CA Nav Sol measurement.
  - If not there yet, add the CA Nav Sol measurement.
  - Click Apply.
- Open and edit the Simulator properties. For this exercise, accept the defaults, except as follows:
  - Edit the MeasTypes attribute by removing all measurement types except CA Pseudorange.
  - Edit the Output.Measurements.FileName attribute and change the output file format from Generic Simulation (\*.gobs) to GPS Rinex (\*.rnx).
  - Click Apply.

**NOTE:** The CA Nav Sol measurement type is not available in the Simulator because it is not available directly from the GNSS Constellation. ODTK creates simulated CA Nav Sol measurements by computing navigation solutions based on simulated pseudorange measurements.
- Open and edit the GNSS Constellation properties:
  - Edit the SVReference.Source.FileName attribute to select the SP3 file igs20556.sp3 that you extracted in Step 1. Click Apply.
- Save the scenario.



8. Run the Simulator. It will automatically create the simulated measurements and add the new RINEX file to the Scenario.Measurements.Files list as a source of measurement data.
9. Verify output using the Measurement File Preview and View Measurements buttons on the main tool bar.
10. Optional: Generate a file of navigation solutions based on the simulated pseudorange.
  - Bring up the ODTK LaunchPad, click the ODTK Utilities tab, and then expand Installed Utilities.
  - Double-click the GenerateNAVSolutions.htm tool from the list box.
  - Browse to select the RINEX file (.rnx) you just generated from the Simulator as the input for the tool. A default output name will be generated for you.
  - Click Go to generate the NAVSOL file. This will cause ODTK to pretend it's a GNSS receiver and process the pseudorange measurements to create NAVSOL measurements. The resulting \*.navsol file is NOT automatically added to the Scenario's measurement file list.

## 3.2 Procedure for Filter run

### 3.2.1 Pseudorange processing

The following procedure outlines the steps necessary to make a simple ODTK Filter run. In this example, there is one satellite that has one GNSS receiver processing GPS CA pseudorange. This filter object uses the simulation outputs from section 3.1 above.

1. Start with the Scenario and outputs from the simulation in 3.1 above.
2. Add a Filter object to the Scenario.
3. Open and edit the Filter object attributes. In this example, you will accept the defaults, except as follows:
  - Edit the Output.SmootherData.Generate flag and set it to True so that the Filter will create the .rough file the Smoother will need.
  - By default, the MeasTypes list is blank, indicating that the Filter will try to process any measurements available in the Scenario's measurement file list.
4. Run the Filter.
5. Use the Static Product builder to analyze the run by producing Residual Ratio and Position Uncertainty plots.
6. Add a Smoother object to the Scenario.

7. Open and edit the Smoother object attributes. In this example, you will accept the defaults, except as follows:
  - Edit the Input.Files list and add the .rough file produced by the Filter.
  - Edit the Output.FilterDifferencingControls.Generate flag and set it to True to configure the Smoother to automatically produce the difference file between the Filter and Smoother.
8. Run the Smoother.
9. Use the Static Product builder to analyze the results by producing Position Uncertainty (using the .smtrun as an input file) and Position Consistency (using the .difrun as input file) plots.

### 3.2.2 Navigation solution processing

Follow the same procedure for pseudorange processing listed above, with the following changes:

1. Start with the Scenario and outputs from the simulation in 3.1 above.
2. Open and edit the Filter object attributes.
  - Edit the MeasTypes list attribute and add the CA Nav Sol measurement. Since the list is no longer blank, ODTK will process ONLY the CA Nav Sol measurements, even though the RINEX file with our CA pseudorange measurements is still in the Scenario measurement file list.
3. Open and edit the Scenario object attributes. Add the generated navigation solution file (\*.NAVSOL, from Section 3.1, step 10) to the Measurements.Files list. You can choose to remove or disable the RINEX file that was placed in the list by the simulator; it doesn't matter since you configured the Filter to only use the CA Nav Sol measurements.
4. Run the Filter
5. Use the Static Product builder to analyze the results.

**NOTE:** The performance of the Filter may be poor while processing of navigation solutions, even with simulated measurements. This poor performance is a result of the effect of the ionosphere on the CA navigation solutions and the lack of a precise relationship between the noise on the pseudorange measurements and the noise on the navigation solutions. Edit the properties of the GNSS Constellation object to turn off the effects of the ionosphere on the CA pseudorange measurements and rerun the simulator and recreate the navigation solution.

6. Open and edit the properties of the GNSS Constellation object to turn off the effects of the ionosphere (set GPS.Ionosphere.IonosphereModel = none).

7. Run the Simulator.
8. Regenerate the navigation solutions following the process described in last step of Section 3.1.
9. Reset the Measurements. Files list in the Scenario to use the navigation solutions and disable the RINEX data file created by the simulator.
10. Run the Filter and Smoother.
11. Use the Static Product Builder to analyze the results.

## 4 References

[1] Oliver Montenbruck, Remco Kroes, *In-Flight Performance Analysis of the CHAMP BlackJack GPS Receiver*, GPS Solutions, Revision 1, 31 March 2003.

[2] International GNSS Service RINEX Version 3.04 <https://acc.igs.org/misc/rinex304.pdf>