

# Getting Started Processing TDOA and FDOA Data with ODTK

## 1 Introduction

The Ansys Orbit Determination Tool Kit® (ODTK®) application can simulate and process numerous flavors of *time difference of arrival* (TDOA) and *frequency difference of arrival* (FDOA) measurements. You can model these measurements in the following ways:

- a single receiver processing a single signal that has been propagated along two different paths
- two receivers processing a single signal
- a single receiver processing two separate signals

The specific types of measurements modeled in the ODTK application are listed in the table below. The strand notation in the table describes the signal path: E (emitter), S (satellite/satellite-based receiver), R (ground receiver), “-“ (sequential connection), and “,” (parallel connection).

Measurement	Strand	Description
TDOA	E-S,S-R	A signal emitted from a single ground-based emitter travels through two relay satellites to a common ground-based receiver.
FDOA	E-S,S-R	A signal emitted from a single ground-based emitter travels through two relay satellites to a common ground-based receiver.
TDOA Dot	E-S,S-R	This is the time derivative of TDOA.
SD TDOA	E,E-S,S-R	Signals emitted from two ground-based emitters travel through two relay satellites to a common ground-based receiver. This method cancels out most satellite-based errors and downlink errors.
SD FDOA	E,E-S,S-R	Signals emitted from two ground-based emitters travel through two relay satellites to a common ground-based receiver. This method cancels out most satellite-based errors and downlink errors.
TDOA 2 Receivers	E-S,S-R,R	A signal emitted from a single ground-based emitter travels through two relay satellites to two ground-based receivers.
FDOA 2 Receivers	E-S,S-R,R	A signal emitted from a single ground-based emitter travels through two relay satellites to two ground-based receivers.
TDOA 2 Emitters	E,E-S-R	Signals emitted from two ground-based emitters travel through a relay satellite to a single ground-based receiver.
FDOA 2 Emitters	E,E-S-R	Signals emitted from two ground-based emitters travel through a relay satellite to a single ground-based receiver.
TDOA Dot 2 Emitters	E,E-S-R	This is the time derivative of TDOA 2 Emitters.
SB TDOA	E-S,S	A signal emitted from a single ground-based emitter travels to two satellite-based receivers.
SB FDOA	E-S,S	A signal emitted from a single ground-based emitter travels to two satellite-based receivers.
SB TDOA Dot	E-S,S	This is the time derivative of SB TDOA.

SB TDOA SBE	E-S,S	A signal emitted from a single space-based emitter travels to two satellite-based receivers.
SB FDOA SBE	E-S,S	A signal emitted from a single space-based emitter travels to two satellite-based receivers.
GroundTDOA	E-R,R	A signal emitted from a single space-based emitter travels to two ground-based receivers.
GroundFDOA	E-R,R	A signal emitted from a single space-based emitter travels to two ground-based receivers.
GroundFDOADot	E-R,R	This is the time derivative of GroundFDOA.

In the following exercises, you will explore the TDOA, FDOA, SB TDOA, SB FDOA, SD TDOA, and SD FDOA measurement types. For TDOA and FDOA measurements, an emitted signal travels via relay satellites along two different routes to a common receiver, where the time of arrival (TOA) and the frequency of arrival (FOA) along each route are recorded. The difference in TOA between the two signal paths forms a TDOA measurement, and the difference in FOA between the two paths forms a FDOA measurement. TDOA and FDOA measurements can support orbit determination, geolocation of stationary Earth-fixed objects, or both. Operational use cases for TDOA and FDOA may use one emitter or two or more emitters simultaneously.

In the ODTK application, a signal path begins at an immobile Earth-based emitter. The signal is relayed through a single satellite and ends at a ground-based receiver. TDOA and FDOA measurements may exist when two satellites (signal paths) are concurrently visible to the emitter and its receiver. Time differences of signal reception are in the sense of Path 2 minus Path 1, where the time tag is relative to Path 1. For example, a positive TDOA observation indicates that the time of signal travel along Path 2 is longer than the time of signal travel along Path 1. The measurements may be tagged at the moment of ground receipt (TDOA/FDOA) or satellite receipt (SB TDOA/SB FDOA). If a measurement is tagged at "satellite-receipt" time, this implies that the effects of the satellite relay transponder and the downlink to the receiver are excluded from the observation.

## 2 ODTK application configuration

To accurately simulate TDOA and FDOA measurements, or to use TDOA and FDOA measurements for estimation, certain objects must be present and properly configured in the ODTK application.

Processing of ground-based or space-based measurements of a ground-based emitter requires an Emitter object attached to a Facility object. You must specify the transmission frequency of the emitter to accurately model FDOA measurements and to accurately account for ionospheric effects on TDOA measurements. ODTK processing also uses the transmission frequency for transponder selection on the relay satellites during simulation of measurements and for transponder

selection during estimation if an explicit transponder ID is not specified in the tracking data. To simulate or process measurements, the two relay satellites must also be within the visibility constraints of the emitter and receiver. ODTK processing can estimate the location of a Facility hosting an Emitter if the location is not precisely known.

## 2.1 Ground-based measurements

The ODTK objects required for processing TDOA and FDOA measurements tagged at ground-receipt time are: an Emitter object, two Satellite objects equipped with relay transponders, and a Facility object as the signal receiver. The receiver facility does not need be under or within the same TrackingSystem object as the emitter. The MeasurementStatistics properties are associated with the receiver facility. Note that the “2R” versions of these measurement models are used when the signal paths end at different receive locations.

Simulation of ground-based TDOA and FDOA measurements is based on the construction of tracking strands that start with the emitter, pass through the relay satellites of two different routes, and end at the receiver facility. Strands are possible for all emitters, all satellites hosting relay transponders, and all facilities with TDOA or FDOA measurement statistics.

TDOA measurements depend on (bold indicates estimation is possible):

- The **location** of the facility hosting the emitter
- The **troposphere** and ionosphere settings of the facility hosting the emitter
- The **orbits**, or trajectories, of the relays
- The **transponder** delays of the relays
- The **troposphere** and ionosphere settings of the receiver facility
- The location of the receiver facility
- A measurement **bias**

ODTK processing can estimate the delay for each transponder and model two or more transponders on each relay satellite. Selection of the transponder for ODTK processing to use in a particular observation is based first on a transponder ID provided as part of the measurement (real data only) and secondly by the frequency of the emitter. By default, the ODTK application configures transponders to have a very large bandwidth to simplify construction of basic simulations. Simulation and estimation do not model ground-system delays, so you must remove ground-system delays from observations when using two or more ground strands. However, when using a single ground strand, the receiver measurement bias can approximately compensate for ground delay.

FDOA measurements depend on (bold indicates estimation is possible):

- The **location** of the facility hosting the emitter
- The frequency of the emitted signal
- The **orbits**, or trajectories, of the relays
- The frequency translation through the relay transponders
- The location of the receiver facility

In addition to TDOA and FDOA measurements, ODTK software can also process the time rate of change in TDOA (TDOA Dot), singly differenced TDOA, and singly differenced FDOA measurements. ODTK software models TDOA Dot as the instantaneous time derivative of TDOA. Singly differenced TDOA and FDOA measurements are differences between the TDOA and FDOA measurements for two emitters whose signals traverse the same two relay satellites, though possibly using different transponders, and are received at the same receiver facility. All of the descriptions characterizing TDOA measurements above also apply to TDOA Dot measurements.

## 2.2 Space-based measurements

The ODTK objects required for processing space-based TDOA (SB TDOA) and space-based FDOA (SB FDOA) measurements tagged at satellite-receipt time are an Emitter object attached to a Facility and two Satellite objects. The satellite objects do not require relay transponders. The MeasurementStatistics properties are associated with one of the satellites.

Simulation of SB TDOA and SB FDOA measurements is based on the construction of tracking strands that start with the emitter and end at two satellites. Strands are possible between all emitters and satellites providing one (or both) of the satellites has SB TDOA or SB FDOA MeasurementStatistics properties active.

SB TDOA measurements depend on (bold indicates estimation is possible):

- The **location** of the facility hosting the emitter
- The **troposphere** and ionosphere settings of the facility hosting the emitter
- The **orbits**, or trajectories, of the relays
- A measurement **bias**

Space-based measurements require that all ground delays and satellite transponder delays be removed.

SB FDOA measurements depend on (bold indicates estimation is possible):

- The **location** of the facility hosting the emitter
- The frequency of the emitted signal

- The **orbits**, or trajectories, of the relays

In addition to SB TDOA and SB FDOA measurements, ODTK software can also process the time rate of change in SB TDOA (SB TDOA Dot) as a measurement. SB TDOA Dot is modeled as the instantaneous time derivative of SB TDOA.

### 3 TDOA and FDOA tracking data

The ODTK application can simulate ground-based and space-based TDOA, FDOA, and TDOA Dot measurements in the GEOLOC or generic-observation (gobs) format. It can also use these same data as input for estimation. The generic-observation format is a binary format that has the benefit of maintaining the full precision of simulated measurements. It is only useful, however, for simulated measurements, since the format is not published. GEOLOC is a simple ASCII format that is documented as part of the ODTK help system and is therefore the best way to import real TDOA and FDOA measurements. ODTK software can also process singly differenced ground-based TDOA and singly differenced ground-based FDOA measurements. There are two ways in which you can import the differenced measurements: directly via the GEOLOC format or indirectly, where the difference measurements are computed from individual TDOA and FDOA measurements upon loading into the ODTK application from either generic-observation or GEOLOC tracking data files. Processing single-difference measurements in this latter manner is the subject of one of the exercises below.

### 4 Simultaneous orbit determination

The ODTK application can regard the ephemerides of relay-satellites in different ways while processing TDOA and FDOA measurements.

- The relay satellite orbits may be simultaneously estimated with any unknown emitter locations. This is the recommended mode for processing ground-tagged measurements. In some cases, all emitter locations may be known, in which case, estimation of the orbits is the primary objective. Simultaneous orbit determination will significantly improve the orbit and covariance (at the expense of more solution time).
- Reference ephemerides may be provided for the satellites, thus limiting estimation to emitter location(s) only. In the case of space-based measurements, an *a priori* estimate of the orbit is required to back up the observations to the time of satellite receipt. In this case, you have the option of using reference ephemerides (preferably the same ephemerides used in the construction of the measurement) or estimating the orbits while estimating the emitter location(s).

## 5 Sample TDOA and FDOA simulation

The following procedure steps through a simple simulation of ground-based TDOA and FDOA tracking data. You will use ground-based TDOA and FDOA measurements to simultaneously estimate two (2) satellite orbits and two (2) emitters with uncertain locations. You will also use data from three emitters with well-known locations. Due to the large amount of input required to initially set up such an exercise, you will import some of the required objects in a preconfigured status via an ODTK demonstration scenario.

1. Start the ODTK application.
2. Load the GS\_GeoLocation demonstration scenario located in your STK\_ODTK install area under the directory:

```
<Install_Dir>\ODTK\UserData\DemoScenarios\Geolocation with TDOA and FDOA Measurements
```


After loading the scenario, go to the File menu and perform a Save As operation to save a copy of the scenario to your local user area.

3. You must use the expanded versions of the Earth Orientation Parameters (EOP) and Space Weather because the scenario epoch is outside of the range of the default file time span for these parameters. Double-click the Scenario object (TDRSSGettingStarted) to open its Properties window. Scroll down to EarthDefinition > EOPData > Filename. If the current file path is not C:\ProgramData\AGI\STK\_ODTK 13\DynamicEarthData\EOP-All-v1.1.txt, then click the file path and change it to this one. Also under EarthDefinition, go to FluxData > InputFluxFile. If the current file path is not C:\ProgramData\AGI\STK\_ODTK 13\DynamicEarthData\SpaceWeather-All-v1.2.txt, then click the file path and change it to this one. Click Apply to accept the changes and then close the Scenario Properties window.
4. Check that the appropriate measurement statistics (TDOA, FDOA) exist under the "Monitor" Facility object, which serves as the receiver facility for this example.
5. Check the properties of each Emitter object. Each emitter has its own transmit frequency, and the facilities hosting "unknown" emitters are configured for estimation of their locations.
6. To simulate ground-based TDOA and FDOA measurements routed through the geostationary satellites, add transponders to each satellite and set each transponder type to "Relay". When the transponder type changes, new transponder attributes appear under a heading of RFIInfo. The center frequency and bandwidth fields define the range of received frequencies for this transponder. The default values, which are designed to cover all commonly used frequencies, are adequate for this exercise, but the modeling real systems will likely require that two or more transponders, each with its own frequency range, be added to the relay satellites. During the creation of simulated measurements, frequency-based selection is used to pick the correct transponder. During estimation,

ODTK processing first attempts explicit selection via the transponder ID with frequency-based selection used if there is no transponder ID. AddFreqTranslation is the frequency translation that is added to the received signal in generating the downlink carrier frequency. For example, if a ground signal is received at 14.3 GHz and a frequency translation of -2300 MHz is specified, the satellite transponder broadcasts the relayed signal at 12.0 GHz. Use the default value of -2300 MHz for this exercise.

7. Add a simulator object to the scenario and double-click it to open its properties.
8. Under ProcessControl, change TimeStep to 2 minutes and change StopTime to "15 Jun 2006 00:00:00.00 UTCG".
9. For Output > Measurements > Filename, make sure the file extension is for "Generic Simulation" (.gobs).
10. Back near the top of the properties window, click next to the TrackingStrandList attribute of the simulator to bring up the list of assigned tracking strands, which should be empty. Remember, an empty tracking strand list means "use all strands." Click the Add button to view the list of available strands; you will see that only one strand is available. Cancel out of editing the TrackingStrandList. *(Optional: Temporarily change one of the transponders to a type other than relay, then re-examine the available tracking strands for the simulator. Note that selecting the Add button no longer displays a selection window because no tracking strands are available. This is because simulation of ground-based TDOA and FDOA measurements requires that the satellites have relay transponders. Change the transponder type back to relay.)*
11. Click Apply and close the Simulator Properties window.
12. Run the simulation. This can take several minutes. The simulator initially perturbs the unknown emitter locations and the satellite initial conditions by a varying amount.
13. Now add a Filter object to the scenario to perform orbit determination using the simulated measurements.
14. Double-click the Filter object to open its properties. Scroll down to Output > SmootherData and change the Generate attribute to true. Click Apply and close the Filter Properties window.
15. Select the Dynamic Product Selector from the View menu and create a dynamic Measurement Update report for either of the satellites in the scenario.
16. Run the Filter while monitoring the dynamic report. Once the filter appears to be running correctly, close the dynamic report window to allow the run to finish more quickly. This process can take several minutes to complete.
17. When the filter is finished, examine its output using the Static Product Builder. Try using the "Residuals" graph style to view TDOA then FDOA residuals. Use the data-limiting selections on the Inputs tab of the Static Product Builder to create separate graphs for

each measurement type. The TDOA residuals are reported in nanoseconds and the FDOA residuals are reported in Hz.

18. Generate a “Position Uncertainty” graph containing information for both satellites. The data for the two satellites are almost identical because the satellites are close to each other in geostationary orbit and experience nearly identical tracking geometry.
19. It is possible to difference the estimated state from the simulated *truth* state to see how closely the filter recovered the original simulated state. The first step in this process is to run the State Difference Tool (StateDiffTool.htm), which you can launch using the  toolbar button. Select the filter output (.filrun) as the target file and the simulator output (.simrun) as the reference file; these files will be located in your DataArchive directory. Click the Run button to generate the state-difference output.
20. Now select the State Difference output (.difrun) as the data-source file for the Static Product Builder. On the Inputs tab of the Static Product Builder, limit reporting to the GEO\_1 satellite only. Then generate the “Differenced Pos R”, “Differenced Pos I”, and “Differenced Pos C” graphs to see how the filter/simulator radial, in-track, and cross-track position differences compare to the filter covariance. Change the data limiting on the Inputs tab to create the same graphs for the GEO\_2 satellites to see those results.
21. Change the data limiting for Facility Name on the Inputs tab of the Static Product Builder to show only information for the Unknown1 emitter. Now generate the “Differenced Fac Loc Topo” graph to see how well the Filter was able to recover the deviated location. Generate the same graph and examine the results for the Unknown2 emitter.
22. Now create a new smoother object. Assign the .rough file created by the filter as the input for the smoother by adding it to the Input.Files list.
23. Run the smoother.
24. Run the State Difference tool again, this time using the smoother output (.smtrun) as the target file and the simulator output (.simrun) as the reference file. Select an output file name that will not write over your prior filter-simulator difference run should you want to compare the two results.
25. Generate the “Differenced Fac Loc Topo” report for the Facility “Unknown1” using the new smoother-simulator difference output. The smoother does not improve the estimate of the unknown emitter locations. Feel free to also examine the orbit differences, transponder delay differences, etc.
26. Run the State Difference tool again, using the smoother output (.smtrun) as the target file and the filter output (.filrun) as the reference file. Select an output file name that will not write over your prior filter-simulator or smoother-simulator difference runs.
27. Select the latest State Difference output file from Step 24 above (smoother minus filter) as the data-input file for the static product builder. Generate a “Position Consistency”

graph, then a “Facility Location Consistency” graph. Filter/smooth consistency tests are good indicators of the sufficiency of the adopted model. Ideally, 99% of the test-statistic values for each parameter should remain between -3 and 3. All parameters perform well in this simulation.

28. Extra Credit: Configure and run the filter to process only TDOA measurements; then filter only FDOA measurements. Note the amount of time required in each case for the filter to significantly reduce the uncertainty in the emitter locations, and compare to the results when two data types were processed together.

## 6 Sample SB TDOA and SB FDOA Simulation

The following procedure steps through a simple simulation of space-based TDOA and FDOA tracking data tagged at the receipt time of the satellites. You will use space-based TDOA and FDOA measurements to simultaneously estimate two emitters with uncertain locations, given the reference ephemerides of the receiver satellites. You will also use data from three well-known emitters. Due to the large amount of input required to initially set up such an exercise, you will import some of the required objects in a preconfigured status via another ODTK demonstration scenario. The space-based exercise is streamlined relative to the earlier ground-based exercise to point out the differences in the processing and to avoid redundant tasks.

1. Start the ODTK application.
2. Load the GS\_GeoLocation\_II scenario located in your ODTK install area under the directory:

```
<Install_Dir>\ODTK\UserData\DemoScenarios\Geolocation with TDOA and FDOA Measurements
```

After loading the scenario, go to the File menu and perform a Save As operation to save a copy of the scenario to your local user area.

3. Again, you must use the expanded versions of the Earth Orientation Parameters (EOP) and Space Weather because the scenario epoch is outside of the range of the default file time span for these parameters. Double-click the Scenario object (TDRSSGettingStarted) to open its Properties window. Scroll down to EarthDefinition > EOPData > Filename. If the current file path is not C:\ProgramData\AGI\STK\_ODTK 13\DynamicEarthData\EOP-All-v1.1.txt, then click the file path and change it to this one. Also under EarthDefinition, go to FluxData > InputFluxFile. If the current file path is not C:\ProgramData\AGI\STK\_ODTK 13\DynamicEarthData\SpaceWeather-All-v1.2.txt, then click the file path and change it to this one. Click Apply to accept the changes and then close the Scenario Properties window.

4. Check that the appropriate measurement statistics (SB TDOA, SB FDOA) exist in a TrackingInstrument under one of the satellite objects. In this example, the measurement statistics are associated with GEO\_1. The measurement names are preceded by "SB", indicating that they are space-based measurements.
5. Check that both satellites are configured to use a reference trajectory ephemeris source (Satellite.EstimateOrbit is "false"). Verify that the reference trajectory refers to a file with "truth" in the filename. Verify that the CovarianceSource associated with the selected reference trajectory is set to "None" indicating that the ephemeris will be considered to be without uncertainty.
6. Run the simulator. This can take several minutes.
7. Bring up the Dynamic Product Selector from the View menu and create a dynamic Measurement Update report for either of the satellites in the scenario.
8. Run the Filter. No updates appear because the filter is not estimating the satellite orbit. Close the dynamic report window to allow the run to finish more quickly. This process can take several minutes to complete.
9. When the filter is finished, plot residuals and histograms for "SB TDOA" and "SB FDOA". The "SB TDOA" residuals will be reported in nanoseconds and the "SB FDOA" residuals will be reported in Hz. Leave these plots open for a later comparison.
10. Use the State Difference Tool to generate a Filter/Simulator difference run file, where the (.simrun) file is the reference file.
11. Select the difference run (.difrun) output just created as the input file for the Static Product Builder. Generate the "Differenced Fac Loc Topo" graph to see how well the Filter was able to recover the deviated emitter locations.
12. Create a new smoother object and double-click it to open its properties. For Input > Files, select the \*.rough file created by the filter. Also Click Apply and close the Smoother Properties window.
13. Run the smoother. Recall from the last exercise that the smoother did not provide any additional improvement relative to the filter result for station-location estimation, so the smoother output does not need to be examined directly.
14. Generate a difference run using the smoother output (.smtrun) as the target file and the filter output (.filrun) as the reference file. Select a difference-output file name that will not write over prior difference run output.
15. Using the new difference output file (filter/smoothing) as the input to the static product builder, generate the "Facility Location Consistency" graph. Leave this plot open for a later comparison.

16. The filter and smoother that you just ran had an unfair advantage. Although the satellite orbits were not estimated, they were provided to the estimator without error. Now, change each satellite configuration to reference the supplied ephemerides having "reference" in the filename. The supplied reference ephemerides have one-sigma ( $1\sigma$ ) error uncertainties of 10, 50, and 100 meters in the radial, in-track, and cross-track directions, respectively.
17. Select a filter output file name that will not write over prior output.
18. Run the filter.
19. When the filter is finished, plot residuals and histograms for "SB TDOA" and "SB FDOA". Compare these plots to the ones you generated using the truth ephemeris. There is a mild periodic pattern in the "SB FDOA" residuals plot; otherwise, the results compare favorably.
20. Generate a new filter/simulator difference run using the output from the new filter run.
21. Examine the errors in the emitter-location estimates relative to the filter covariance using the "Differenced Fac Loc Topo" graph. The errors are well outside the covariance bounds of the filter. This is the result of not accounting for the errors in the satellite ephemeris. Of course, you would not have the luxury of comparing against the truth when processing actual tracking data.
22. Select a smoother output file name that will not write over prior output.
23. Run the smoother.
24. Generate a difference run using the smoother output (.smtrun) as the target file and the filter output (.filrun) as the reference file. Select a difference output file name that will not write over prior output.
25. Using the new difference output file (filter/smoothing) as the input to the Static Product Builder, generate the "Facility Location Consistency" graph. Since the test statistic for each parameter should remain between -3 and 3, 99% of the time, this plot indicates a modeling problem that could adversely affect the results of the estimation process. This indicates a need for highly accurate reference ephemerides to support emitter location estimation if the uncertainty in the reference ephemeris is ignored.
26. Start Extra Credit: Investigate whether or not estimating satellite orbits can improve the results. In the following steps, you will estimate the satellite orbits to see if that can improve your results.
27. Change the EstimateOrbit settings on both satellites to true.
28. Use the Initial State Tool to generate initial conditions for both satellites from the "reference" ephemeris files. Select the epoch for each set of initial conditions as the start time in the ephemeris file.

29. Redo steps 18-25. Does this simulation indicate possible improvement in results by estimating the orbit?
30. So, it appears that the uncertainty in the spacecraft is an important component of processing the measurements. Is there a way to accommodate that uncertainty without adding the satellites to state space? We could associate uncertainty with the reference trajectories by either using a constant representation in the RIC or by using the formal uncertainty in the reference ephemeris file to compute additive deweighting of the measurements. This can be done by changing the ReferenceTrajectory.CovarianceSource setting on the satellite objects. This will improve our results somewhat, but it still provides an inadequate representation of the ephemeris errors since the correlations

## 7 Sample single-differenced TDOA and FDOA simulation

The following procedure outlines the steps necessary to simulate nondifferenced (ND) ground-based TDOA and FDOA tracking data and then process the data as single-differenced (SD) measurements. In this case, all of the emitter locations will be known and the primary objective will be to estimate the orbits of the two relay satellites. Due to the large amount of input required to initially set up such an exercise, you will import some of the required objects in a preconfigured status via another ODTK demonstration scenario.

1. Start the ODTK application.
2. Load the GS\_GeoLocation\_SD scenario located in your ODTK install area under the directory:

```
<Install_Dir>\ODTK\UserData\DemoScenarios\Geolocation with TDOA and FDOA Measurements
```

After loading the scenario, go to the File menu and perform a Save As operation to save a copy of the scenario to your local user area.

3. Again, you must use the expanded versions of the Earth Orientation Parameters (EOP) and Space Weather because the scenario epoch is outside of the range of the default file time span for these parameters. Double-click the Scenario object (TDRSSGettingStarted) to open its Properties window. Scroll down to EarthDefinition > EOPData > Filename. If the current file path is not C:\ProgramData\AGI\STK\_ODTK 13\DynamicEarthData\EOP-All-v1.1.txt, then click the file path and change it to this one. Also under EarthDefinition, go to FluxData > InputFluxFile. If the current file path is not C:\ProgramData\AGI\STK\_ODTK 13\DynamicEarthData\SpaceWeather-All-v1.2.txt, then click the file path and change it to this one. Click Apply to accept the changes and then close the Scenario Properties window.

4. Examine the measurement statistics for the Monitor facility. Both SD and ND measurement statistics are defined. The statistics for the SD and ND measurements are related via:

$$\sigma_{SD} = \sqrt{2\sigma_{ND}^2}$$

5. Set the ReferenceEmitter property of the Monitor facility to point to the emitter named Reference. This step is required to support the generation of SD measurements when the filter is run. The SD measurements will be computed as TDOA or FDOA for each emitter minus the TDOA or FDOA for the reference emitter. The number of each type of SD measurement available at each time will therefore be one less than the number of ND measurements available at that time.
6. Check the enabled MeasTypes on the simulator and filter objects. The simulator does not have the SD measurement types enabled, while the filter does not have the ND measurement types enabled. The simulator cannot simulate SD measurements directly. The inclusion of the ND measurement types in the simulator MeasTypes was, therefore, not necessary for proper execution, but was done for illustrative purposes. The filter will construct the SD measurements upon loading of the ND measurements if the following conditions are met:
  - SD measurements are specified in the MeasTypes for the filter or the MeasTypes list is empty.
  - SD measurements are specified in the MeasTypes for the satellites or the MeasTypes list is empty.
  - SD measurements are specified in the MeasurementStatistics for the receive facility.
  - A reference emitter is specified in the properties of the receive facility.
7. Run the simulation. This may take several minutes.
8. Bring up the Dynamic Product Selector from the View menu and create a dynamic Measurement Update report for either of the satellites in the scenario.
9. Run the Filter. Monitor the filter run using the dynamic report. Once you are satisfied that the filter is running correctly, close the dynamic report window to allow the run to finish more quickly. This process may take several minutes to complete.
10. Generate “Residuals” graphs to view SD TDOA then SD FDOA residuals. The SD TDOA residuals will be reported in nanoseconds and the SD FDOA residuals will be reported in Hz. Also generate residual histograms for each type of measurement.
11. Generate a “Position Uncertainty” graph containing information for both satellites. The data for the two satellites is almost identical. This is due to the fact that the satellites

are close to each other in geostationary orbit and experience nearly identical tracking geometry. Leave this graph around for a later comparison.

12. Generate a difference run using the filter output (.filrun) as the target file and the simulator output (.simrun) as the reference file. Select an output file name that will not overwrite your prior difference runs.
13. Use the difference output to generate the “Differenced Pos R”, “Differenced Pos I”, and “Differenced Pos C” graphs for each satellite. The differences lie mostly within the two-sigma covariance bounds with exceptions mainly limited to the radial direction. Also note the increasing envelope of the in-track uncertainty.
14. Assign the rough file created by the filter as the input for the smoother by adding it to the Input.Files list.
15. Run the smoother.
16. Generate a difference run using the smoother output (.smtrun) as the target file and the simulator output (.simrun) as the reference file. Select an output file name that will not overwrite your prior filter-simulator difference run if you would like to compare the two results.
17. Use the difference output to generate the “Differenced Pos R”, “Differenced Pos I”, and “Differenced Pos C” graphs for each satellite. The excursions of the radial difference outside the two-sigma covariance bounds in the radial direction are more severe in the smoother result. The smoother appears to give good improvement in the in-track direction, but the uncertainty is still large.
18. Generate a difference run using the smoother output (.smtrun) as the target file and the filter output (.filrun) as the reference file. Select an output file name that will not overwrite your prior filter-simulator or smoother-simulator difference runs.
19. Using the new difference output file (filter/smoothing) as the input to the static product builder, generate a “Position Consistency” graph. While the in-track and cross-track consistency looks good, the radial consistency graph indicates a possible modeling problem. While it has not yet been proven, the current theory is that this inconsistency is the result of not accounting for the correlation between the single-differenced measurements.
20. Extra Credit: The effect of ignoring the correlation between the measurements is to tell the filter that it has more information on the orbits than it really does. We can partially compensate for this misinformation by increasing the noise on the measurements. Try increasing the noise on the single differenced measurements and rerunning the filter and smoother. Do the results appear to improve? How do the measurement residual plots and residual histogram plots look?