Getting Started Processing TDRSS Data with ODTK

1 Introduction

ODTK has the capability to simulate and process two-way range and Doppler measurements from the Tracking and Data Relay Satellite System (TDRSS).[1,2] ODTK does not support one-way Doppler measurements through TDRSS. While satellites supported by TDRSS are typically also supported by ground tracking, this document only addresses the TDRSS tracking. For descriptions of TDRSS and additional information, see https://www.nasa.gov/directorates/heo/scan/services/networks/tdrs_main.html.

2 TDRSS components

TDRSS, which is part of the Spaceflight Tracking and Data Network (STDN), consists of a ground segment and a space segment.

2.1 TDRSS ground stations

TDRSS ground segment contains a set of ground stations that NASA uses to command and track the TDR satellites directly and to track user satellites using the TDR satellites as relays. These ground stations are primarily located at White Sands, New Mexico, but there is one ground station located in Guam.

2.2 BRTS ground stations

The TDRSS ground segment also contains another set of ground stations known as the Bilateral Ranging Transponder System (BRTS). These are ground stations with TDRSS transponders that are tracked for the purpose of performing orbit determination on the TDR satellites. The measurement types (two-way range and Doppler) are analogous to those used to track user satellites.

2.3 TDR satellites

The TDRSS space segment consists of a constellation of satellites in geosynchronous orbit. Each satellite has one multiple-access (MA) antenna and two high-gain single access antennas (SA) that are used for relay operations and a space-to-ground link (SGL) antenna used for telemetry, command and control, and direct ranging of the TDR satellites. On older TDR satellites, the MA antenna operates in S band (2106.4 MHz forward, 2287.5 return), while newer satellites operate over more frequencies. The SA antennas can operate in Ku band (13.775 GHz forward, 15.003

GHz return) or S band (2025 to 2120 MHz forward, 2200 to 2300 MHz return). The SGL antenna also operates in S band.

3 TDRSS tracking data and measurement types

Tracking data generated by the TDRSS is provided in the Universal Tracking Data Format (UTDF). When you use ODTK to generate simulated TDRSS tracking data, you should use the generic observation format. ODTK does not have the capability to generate UTDF files.

3.1 Four-legged range and BRTS range

The four-legged range and BRTS range measurements are two-way measurements beginning and ending at the same ground station. The ranging signal is sent through a TDRS to a user satellite and returned through the same path. The signal is subjected to forward and return link transponder delays through the TDRS and a single transponder delay at the user satellite or BRTS station. ODTK provides the capability to process four-legged range and BRTS range measurements. Specification of the measurement statistics appears in the attributes of the TDRSS ground stations. Transponder biases are specified through the addition of transponder objects on the TDRS and user satellites and on the BTRS facilities. Two options are available for modeling the TDRS transponder delay; these are controlled by the UTDF tracking data provider's TDRSPathTransponders flag. By default, this flag is set to false, causing ODTK to assume that all signal paths through a TDRS satellite are the same and all 4L Range and BRTS Range measurements will be subject to the path delay modeled by the first relay transponder on the TDRS satellite. If TDRSPathTransponders is true, then ODTK will model unique relay transponders depending on the signal path indicated in the tracking data. The transponders IDs must respect the following convention:

Transponder Path	Transponder ID
SA1 – SA1	11
SA2 – SA2	22
MA – MA – 1	331
MA – MA – 2	332
MA – MA – 3	333
MA – MA – 4	334
MA – MA – 5	335
MA – MA – 6	336

ODTK constructs the signal path using the forward and return link antenna information and MA channel, if the MA antenna is being used. If the desired transponder is not actually available on the TDRS satellite, then ODTK will generate an error message.

AGI recommends that you set TDRSPathTransponders to true, as testing with real measurements has shown that the improved path delay modeling results in better position consistency tests and measurement residual performance, albeit at the expense of modeling eight relay transponders and a larger filter state space. A typical initial relay transponder configuration is to use a half-life of 100 days, a bias of 0 ns, and a bias sigma of 50 ns. You should update these based on results from real measurements.

3.2   Five-legged Doppler and BRTS Doppler

The five-legged Doppler and BRTS Doppler measurements are two-way measurements beginning and ending at the same ground station. The ranging signal is sent through a TDRS to a user satellite and returned through the same path. The return signal is mixed, at the TDRS, with a separate pilot tone generated from the same ground station. ODTK provides the capability to process five-legged Doppler and BRTS Doppler measurements. Specification of the measurement statistics appears in the attributes of the TDRSS ground stations.

3.3   Return link (or three-legged) Doppler

Three-legged Doppler is a TDRSS measurement where the signal originates on a user spacecraft, such as HST or TOPEX, and is transmitted through a TDRS satellite to a TDRS ground terminal. The signal is mixed, at the TDRS, with a separate pilot tone generated by the receiving ground station (see previous measurement types). In this case the measurement is a function of the transmitting frequency, and is subject to time-varying biases, which can be estimated by the filter and

smoother. Specification of measurement statistics appears in the attributes of the receiving ground station. Experience with real data has shown that this is not sufficient, since the errors in the 3L Doppler are primarily determined by the reference clock on the user spacecraft and the same user satellite measurements can be received at two or more TDRS ground stations. Therefore, since version 6.1, ODTK can use a satellite reference clock.

4   Simultaneous orbit determination

You can use ODTK in two modes, with respect to the source of TDRS ephemeris information, for the processing of TDRSS tracking data. In the recommended mode, ODTK estimates the TDRSS orbit states simultaneously with the orbits of the user satellites. Alternatively, reference ephemerides can be provided for the TDR satellites, thus requiring that ODTK only estimate user satellite orbits. While the simultaneous orbit determination will require more time to complete due to the larger state space, the resulting orbit and covariance will be greatly improved.

5   Sample TDRSS simulation exercise

The following procedure outlines the steps necessary to make a simple simulation of TDRSS tracking data. Due to the large amount of data input required to set up such an exercise from scratch, you can import some of the required objects in a preconfigured status.

1. Start ODTK.

2. Load the TDRSSGettingStarted scenario located in your ODTK install area under the directory:

   ODTK 7\ODTK\UserData\DemoScenarios\Processing TDRS Data

   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. The contents of the Object Browser, which represent a simplified TDRSS and the AQUA user satellite, should look like the image below. The complete TDRSS ground segment is defined in the NASA_BRTS and NASA_TDRS tracking systems delivered with ODTK.
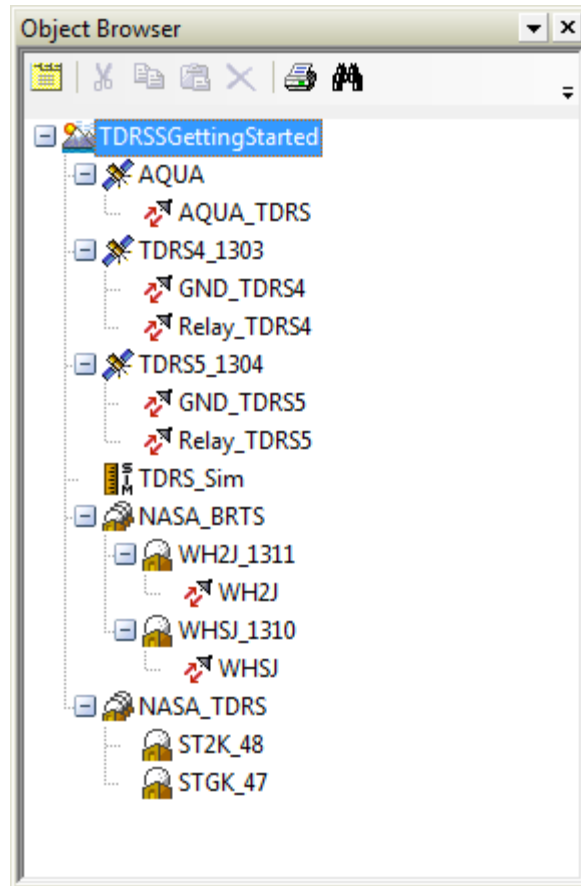
3. Double-click each one of the transponders and note the EstimateBias flag is set to true. This tells the simulator to randomly perturbed them during simulation. While you are doing this, note the different settings of the Type and how the transponder bias can be represented in either time or distance units. A Type of "Sat To Relay" specifies a TDRSS user transponder. A Type of "Relay" specifies a TDRS transponder on a relay satellite and a Type of "Ground To Sat" specifies a BRTS transponder. These are the transponder types that are involved in the 4L Range and BRTS Range measurement models. The failure to add the correct types of transponders to the appropriate objects will adversely affect your ability to correctly model the 4L Range and BRTS Range measurements. The other type of transponder that you will encounter is the "Sat To Ground" transponder, which is used in the ground-based two-way ranging model. This type of transponder is attached to each TDRS since the orbit determination for the TDR satellites is supported with ground-based ranging.

    The DefaultAntenna attribute enables you to specify an antenna and thus a location offset from satellite center of mass in a deterministic way, as defined by body coordinates and an attitude rule or attitude profile.
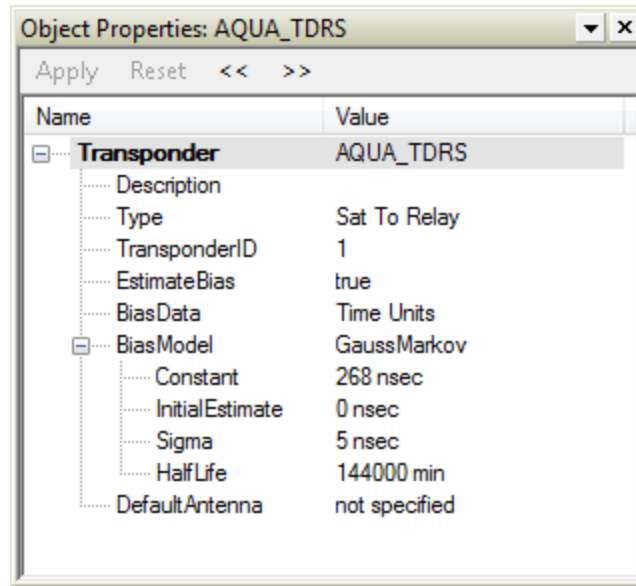
4. The TDRS relay transponders have similar properties, except that the Type is set to Relay and it is possible to have two antennas, as required for TDRS SA antenna operations.
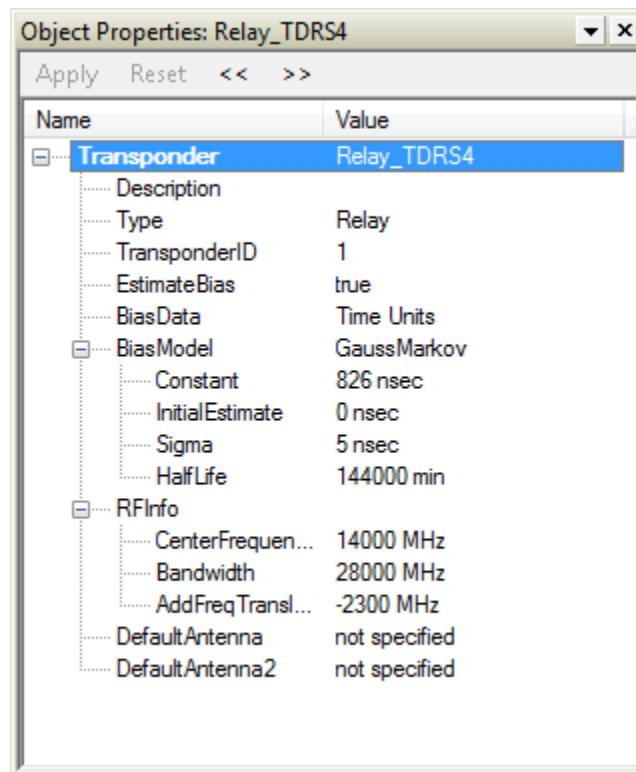
5. Open the properties for one of the NASA_TDRS ground stations and click the Measure-mentStatistics editing area to view the defined measurement types. In addition to the TDRSS measurement types 4L Range and 5L Doppler, which are used in the tracking of

the user satellite, the BRTS measurement models, and a two-way range measurement model used in the tracking of the TDR satellites are also present.

Facility.MeasurementStatistics

| Name	Value1
MeasurementStatistics	
Element 0	Range
Type	Range
Representation	OneWay
BiasModel	GaussMarkov
Constant	0 m
InitialEstimate	0 m
Sigma	5 m
HalfLife	360 min
WhiteNoiseSigma	1.5 m
EstimateBias	false
TropoSigma	0.05
LightTimeDelay	true
BoresightBiasModel	false
Element 1	4L Range
Type	4L Range
BiasModel	GaussMarkov
Constant	0 m
InitialEstimate	0 m
Sigma	5 m
HalfLife	144000 min
WhiteNoiseSigma	2 m
EstimateBias	true
TropoSigma	0
EditOnDoppler	false
RejectFirstNMeas	0
Element 2	5L Doppler
Type	5L Doppler
BiasModel	GaussMarkov
Constant	0 Hz
InitialEstimate	0 Hz
Sigma	0.05 Hz
HalfLife	5 min
WhiteNoiseSigma	0.075 Hz
EstimateBias	false
CountInterval	1 sec
Element 3	BRTS Range
Type	BRTS Range
BiasModel	GaussMarkov
Constant	0 m
InitialEstimate	0 m
Sigma	5 m
HalfLife	144000 min
WhiteNoiseSigma	3 m
EstimateBias	true
TropoSigma	0
EditOnDoppler	false
RejectFirstNMeas	0
Element 4	BRTS Doppler
Type	BRTS Doppler
BiasModel	GaussMarkov
Constant	0 Hz
InitialEstimate	0 Hz
Sigma	0.05 Hz
HalfLife	5 min
WhiteNoiseSigma	0.05 Hz
EstimateBias	false
CountInterval	1 sec

Add...
Remove
Remove All
Load...

OK   Cancel   Help

6. Open the properties for one of the NASA_BRTS facilities and click the MeasurementStatistics editing area to view the defined measurement types. There are no measurement models defined because the BTRS stations are not trackers.

7. Open the properties of the Simulator object, TDRS_Sim, and make sure the start and stop times are "9 Jun 2004 00:00:00.00" and "10 Jun 2004 00:00:00.00" respectively. Also set the simulation time step to 30 seconds.

8. Click the simulator's TrackingStrandList edit area; then click the Add button on the resulting dialog box to view the list of generic tracking strands that you can use in the simulation. A generic tracking strand consists of a tracker, in this case the TDRSS ground stations, a satellite of interest designated by an asterisk (*), and possibly other objects in the scenario. ODTK constructs the list of possible tracking strands based on objects in the scenario and the measurement models that are defined on those objects. In this case, the two-way range model defines tracking strands from the ground stations to a satellite of interest. The 4L Range and 5L Doppler models define tracking strands from the ground stations through a relay satellite to a satellite of interest. 3L Doppler strands are defined in the order of the signal path, from satellite of interest to TDRS to ground. Finally, the BRTS Range and BRTS Doppler models define tracking strands from the ground stations through a relay satellite of interest to a BRTS station. You will not use the tracking strand list in this exercise. Instead, you will use a custom tracking schedule to be even more explicit, but it is important to understand the concept of tracking strands.
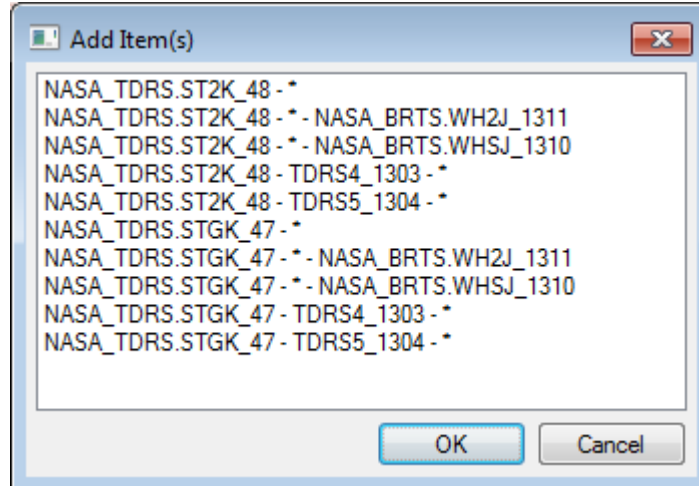
9. For the CustomTrackingIntervals property, set the Enabled option to true. Click the Schedule edit area to bring up a list of preconstructed custom intervals. If not already so, set the Enabled option to true to use all the entries in the simulation process. Click OK on the dialog box and then Apply to save all your Properties changes. Under Schedule, you should have a list similar to the following:
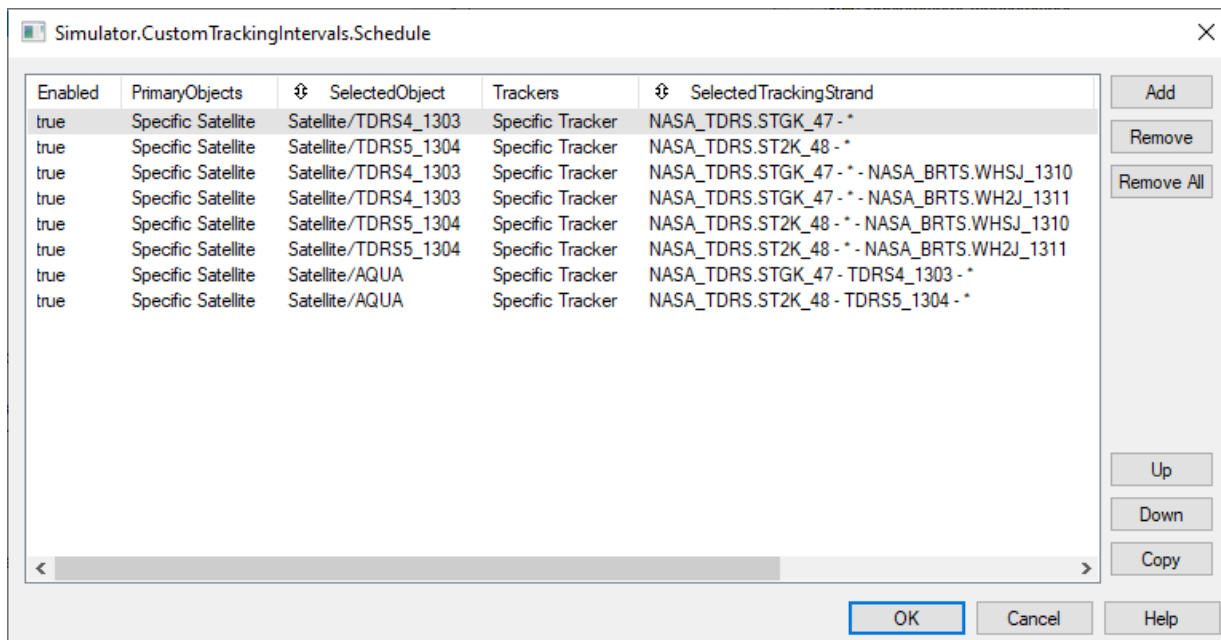
Note: Check to make sure the TimeStep is set to 30 seconds for all intervals. Also, for each custom tracking entry, check that the start and stop times in the column Inclusion-Intervals appear as follows:

Strand	Start	Stop
STGK_47 – TDRS4_1303	00:00:00	00:30:00
STGK_47 – TDRS4_1303	06:30:00	06:50:00
STGK_47 – TDRS4_1303	10:20:00	10:40:00
STGK_47 – TDRS4_1303	18:00:00	18:25:00
ST2K_48 – TDRS5_1304	00:00:00	00:30:00
ST2K_48 – TDRS5_1304	06:15:00	06:45:00
ST2K_48 – TDRS5_1304	10:10:00	10:20:00
ST2K_48 – TDRS5_1304	17:20:00	17:40:00
STGK_47 – TDRS4_1303 – WHSJ_1310	02:10:00	02:30:00

|		
STGK_47 – TDRS4_1303 – WHSJ_1310	14:45:00	15:05:00
STGK_47 – TDRS4_1303 – WH2J_1311	02:35:00	02:55:00
STGK_47 – TDRS4_1303 – WH2J_1311	14:20:00	14:40:00
ST2K_48 – TDRS5_1304 – WHSJ_1310	00:45:00	01:05:00
ST2K_48 – TDRS5_1304 – WHSJ_1310	13:25:00	13:45:00
ST2K_48 – TDRS5_1304 – WHSJ_1311	01:10:00	01:30:00
ST2K_48 – TDRS5_1304 – WHSJ_1311	13:00:00	13:20:00
STGK_47 – TDRS4_1303 – AQUA	03:05:00	03:35:00
STGK_47 – TDRS4_1303 – AQUA	07:50:00	08:10:00
STGK_47 – TDRS4_1303 – AQUA	13:50:00	14:10:00
STGK_47 – TDRS4_1303 – AQUA	16:55:00	17:20:00
STGK_47 – TDRS4_1303 – AQUA	18:30:00	18:55:00
STGK_47 – TDRS4_1303 – AQUA	20:10:00	20:30:00
ST2K_48 – TDRS5_1304 – AQUA	02:10:00	02:40:00
ST2K_48 – TDRS5_1304 – AQUA	05:15:00	05:45:00
ST2K_48 – TDRS5_1304 – AQUA	09:45:00	10:05:00
ST2K_48 – TDRS5_1304 – AQUA	11:10:00	11:30:00
ST2K_48 – TDRS5_1304 – AQUA	15:00:00	15:15:00
ST2K_48 – TDRS5_1304 – AQUA	21:50:00	22:10:00

Once you have inspected all of the data above, save your scenario.

10. Run the simulator, which should generate 2158 measurements if you have configured your scenario properly. You can see this count in the Message Viewer as the simulator runs. When the simulator completes, view the fruits of your labor by clicking the "View Measurements" button on the toolbar. The generated report does not show the complete tracking strands for the four- and five-legged measurements.

11. Now it is time to perform orbit determination based on the measurements that you just generated. Create a new Filter object in your scenario and rename it to "TDRS_Filter". Set the StopMode = StopTime and the StopTime to 10 Jun 2004 00:00:00. Also, turn on the generation of smoother information from the filter, as shown below.
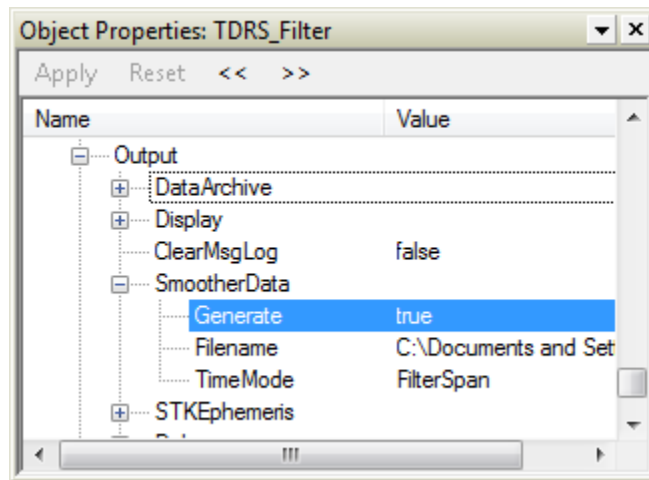

12. Run the Filter. You can monitor the process by the percent complete bar at the bottom of the ODTK window.

13. When the filter run finishes, you can examine output from the run using the Static Product Builder. Try using the "Residuals with Bias By Strand" report style to view a version of a residual report that displays the measurement strands.

14. You will now run the smoother process to create a definitive ephemeris for each satellite over the span of the simulated tracking data. Add a smoother object to your scenario and rename it to TDRS_Smoother. Assign the rough file created by the filter as the input for the smoother by adding it to the Input.Files list. Click the Filename edit area under Output to change it to assign the rough file.

15. Run the smoother. Once again, you can examine the smoother output using the Static Product Builder.

16. You can perform state differencing to see how well the filter or smoother runs versus the *truth* state created during the simulation run. For the purposes of this exercise, you will examine the differences between the smoother output and the simulator output. The first step in this process is to create a state difference run using the State Difference Tool, which you can launch using the toolbar icon. Select the smoother output

(.smtrun) as the target file and the simulator output (.simrun) as the reference file. These files will be located in your DataArchive directory. Click Go! to generate the difference output.
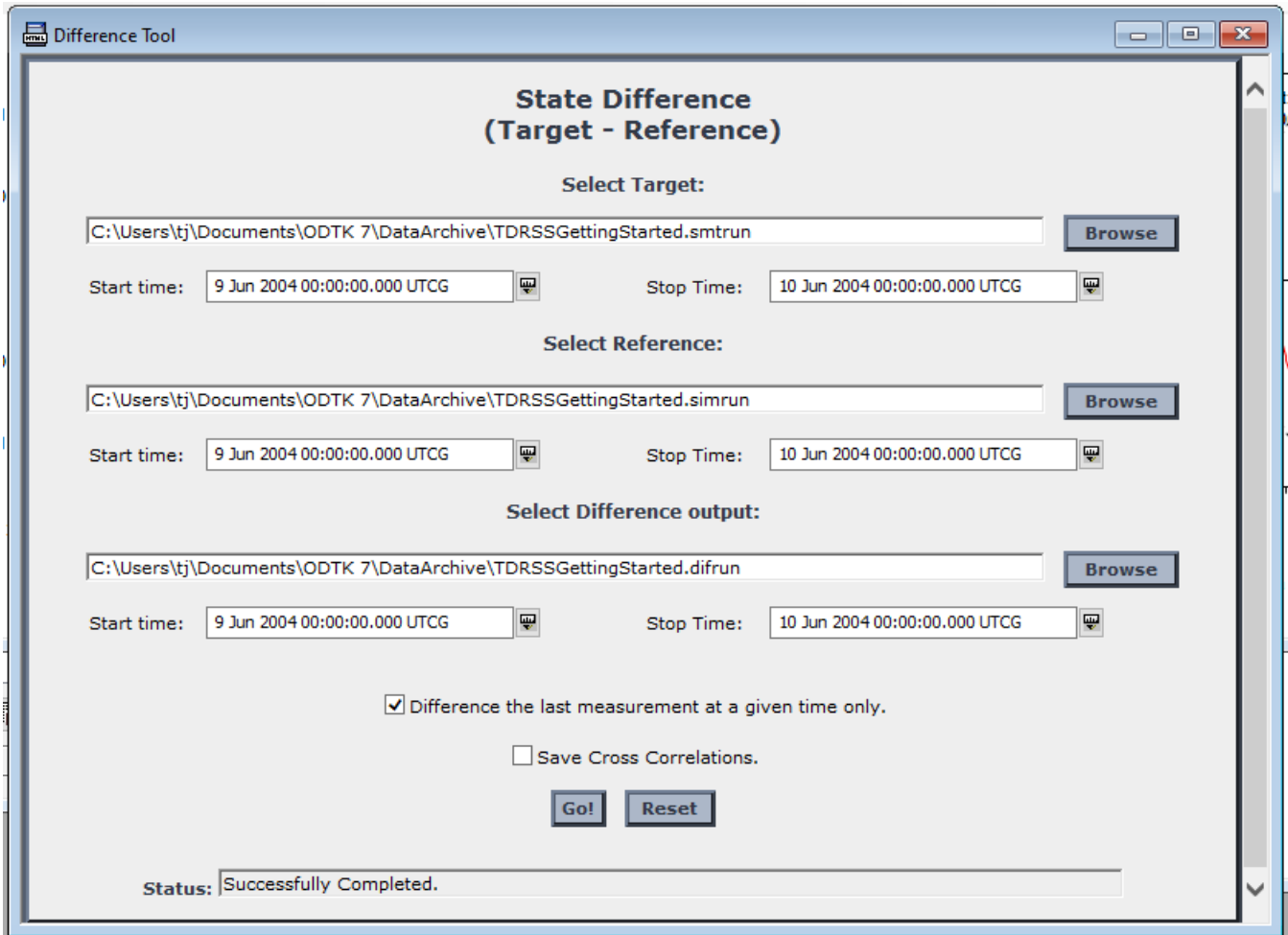
17. Select the difference run (.difrun) output that you just created as the input file for the Static Product Builder.

18. On the Inputs tab of the Static Product Builder, limit the reporting to show only information for the AQUA satellite. Then generate the Differenced Pos R, Differenced Pos I, and Differenced Pos C graphs to see how the smoother/simulator radial, in-track, and cross-track position differences compare to the smoother covariance. Change the data limiting on the Inputs tab to create the same graphs for the TDRS satellites if you would like to see those results.
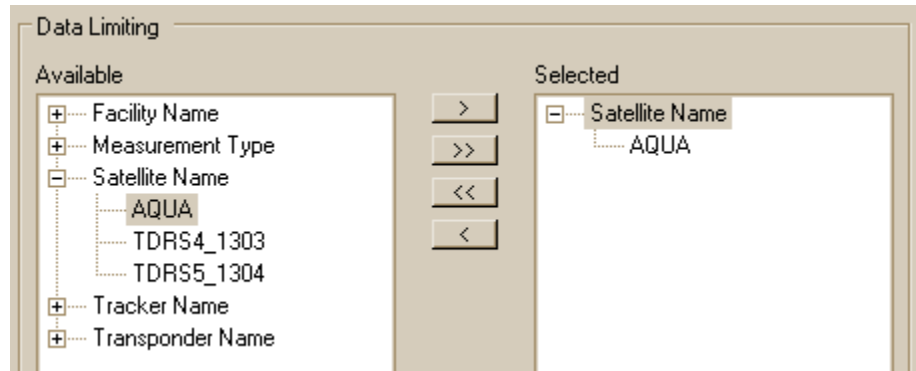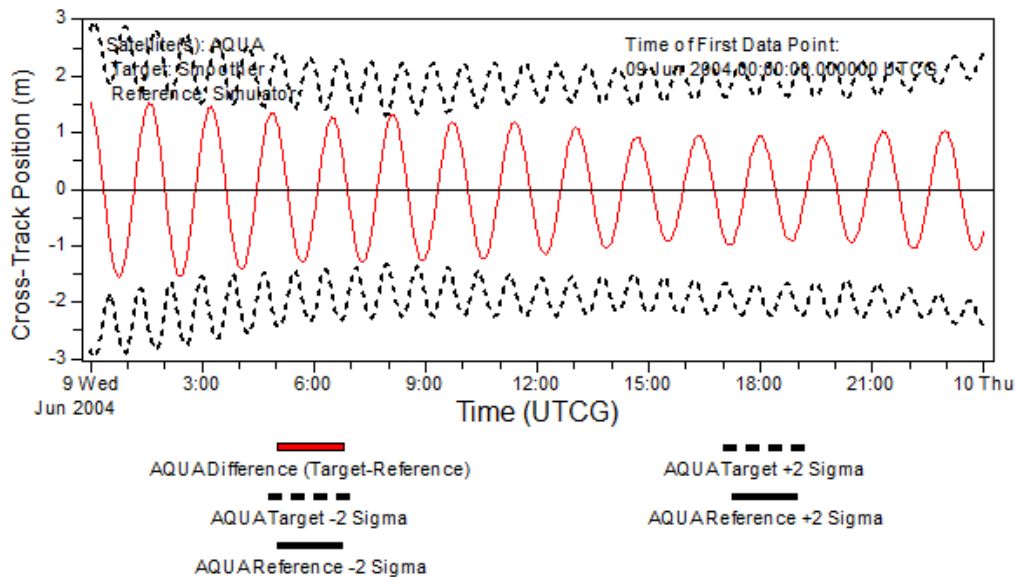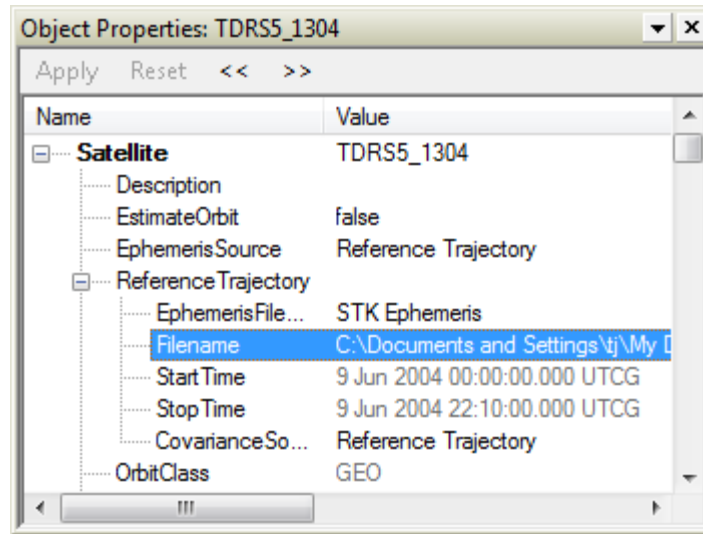
19. Remove the satellite data limiting and limit reporting to the AQUA_TDRS transponder. Now create the Differenced Trans Bias graph to see how well the smoother did recovering the simulated transponder bias on the AQUA satellite. You can create the same types of graphs for all parts of the state, including the recovery of measurement biases and force model parameters.

20. In certain situations, you may want to use a provided ephemeris for the TDRS satellites in lieu of estimating their trajectories simultaneously with the user satellite orbit. To emulate this situation, open the properties editor for each TDRS satellite and change the EstimateOrbit flag to false. Use the reference trajectory attribute that appears to point to the appropriate ephemeris file created by the smoother. The files will have names such as "Sat_TDRS4_1303_Smooth_20040609_000000.e". Remember that these files do not contain the exact same ephemeris as was used by the simulator.

Object Properties: TDRS5_1304

Name	Value
Satellite	TDRS5_1304
⋯ Description	
⋯ EstimateOrbit	false
⋯ EphemerisSource	Reference Trajectory
⋯ Reference Trajectory	
⋯ EphemerisFile…	STK Ephemeris
⋯ Filename	C:\Documents and Settings\tj\My D
⋯ Start Time	9 Jun 2004 00:00:00.000 UTCG
⋯ Stop Time	9 Jun 2004 22:10:00.000 UTCG
⋯ CovarianceSo…	Reference Trajectory
⋯ OrbitClass	GEO

21. Rerun the filter. The current configuration cannot properly account for the errors in the TDRS orbits because they are not being estimated. This fact will result in the filter covariance being unrealistic. You could increase the noise on the measurements to partially account for the errors in the TDRS orbits, but this would treat the time-correlated errors in the reference orbits as white noise errors and the solution would remain nonoptimal.

22. Rerun the smoother and create the smoother versus simulator state difference. Regenerate the AQUA cross-track difference graph and note the optimistic nature of the smoother covariance resulting from not estimating the TDRS orbits.

(Target-Reference) Crosstrack Position Difference
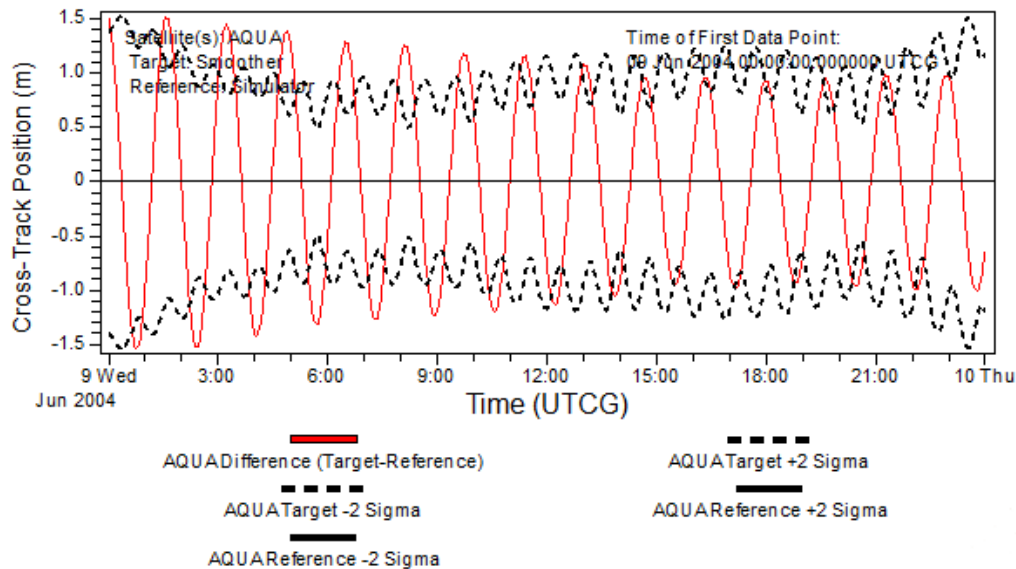
6 State content

The content of the simulation or estimation state constructed by ODTK will depend on the contents of the SatelliteList and TrackingStrandList elements of the simulator and the SatelliteList and TrackerList elements of the filter. ODTK uses these lists to limit the set of objects operated on by the specified process. An empty list indicates that all possible entries should be used. Inclusion of satellite states is straightforward. If a satellite appears in the SatelliteList or the SatelliteList is empty, then ODTK includes all state parameters associated with the satellite and its subobjects in state space. The relationship between the TrackingStrandList or TrackerList and the state content is more complicated. In the case of the simulator, ODTK includes in state space all state parameters associated with objects included in at least one of the *selected* tracking strands. In the case of the filter, ODTK includes in state space all state parameters associated with objects included in at least one of the *potential* tracking strands. Potential tracking strands consist of all tracking strands that ODTK may construct using the selected set of trackers and satellites.

Of specific interest to TDRS users: You should not configure BRTS stations as trackers in ODTK, since they do not directly produce tracking data. ODTK considers ground stations to be trackers if they have one or more entries in their MeasurementStatistics list. While having entries in the MeasurementStatistics list of a BRTS station will not affect the estimate produced by the filter, the estimation state may be expanded to include unnecessary measurement bias states, resulting in longer filter/smoother run times. ODTK includes in state space transponder bias estimates for transponders on BRTS stations via inclusion of the BRTS station in a tracking strand.
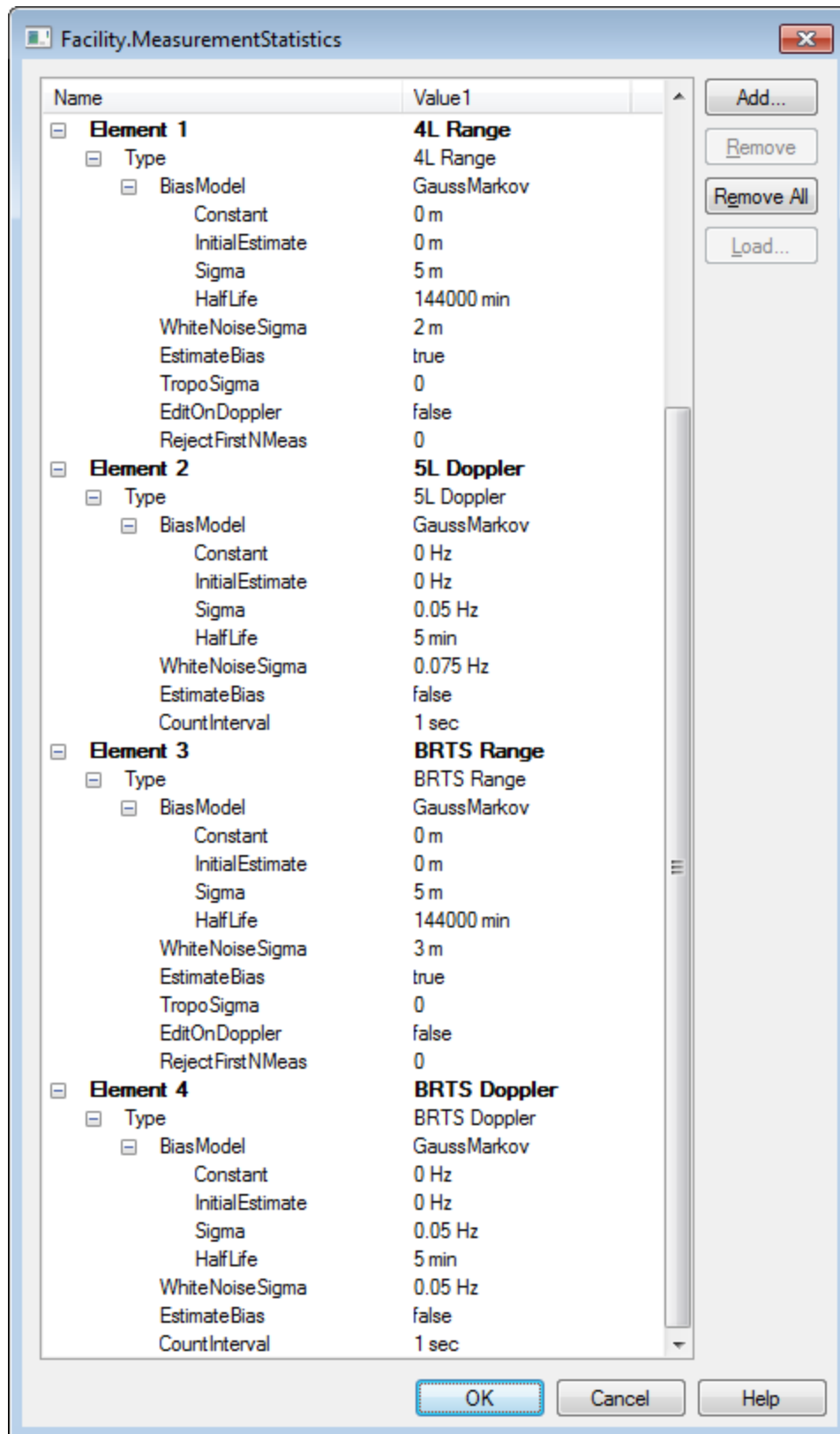
7 Porting to ODTK considerations

When building a TDRS scenario using initial biases from other orbit determination systems, it's important to know what the bias represents. ODTK treats all transponder biases as the total (or "two-way") delay through the transponder. Other systems such as GTDS often treat the transponder bias as a "one-way" bias, meaning it is half the total delay. In such cases you must double the bias value to use it correctly within ODTK.

8 Real data considerations

Real data typically comes at a high data rate, usually 1 Hz, and can be safely thinned to decrease the run time for the filter and smoother. You can specify thinning using the scenario attribute Measurements.ViewAndSave.CustomDataEditing or the filter attribute CustomDataEditing. A value of 10 seconds has been found to be reasonable.

When processing real data, as opposed to simulated data, a couple of special settings are helpful. These settings are available in the MeasurementStatistics of the NASA_TDRS ground stations. The attributes EditOnDoppler and RejectFirstNMeas are defined for the 4L Range and BRTS Range measurement models. If set to true, the EditOnDoppler flag will cause all range measurements to be rejected when a valid Doppler measurement does not exist at the same time. AGI recommends a setting of true for the processing of real data. You must use a setting of false

when using simulated data due to the manner in which the Generic Obs tracking data provider passes the tracking data back into ODTK. If set to a positive integer, N, RejectFirstNMeas causes the first N measurements of each pass to be rejected. Setting this value so that the first 30 seconds of data is rejected has been seen to be beneficial. The following image is an example set of measurement statistics, accounting for data thinning to 10 seconds.

Facility.MeasurementStatistics

Name	Value 1
Element 1	**4L Range**
Type	4L Range
BiasModel	GaussMarkov
Constant	0 m
InitialEstimate	0 m
Sigma	5 m
HalfLife	144000 min
WhiteNoiseSigma	2 m
EstimateBias	true
TropoSigma	0
EditOnDoppler	false
RejectFirstNMeas	0
Element 2	**5L Doppler**
Type	5L Doppler
BiasModel	GaussMarkov
Constant	0 Hz
InitialEstimate	0 Hz
Sigma	0.05 Hz
HalfLife	5 min
WhiteNoiseSigma	0.075 Hz
EstimateBias	false
CountInterval	1 sec
Element 3	**BRTS Range**
Type	BRTS Range
BiasModel	GaussMarkov
Constant	0 m
InitialEstimate	0 m
Sigma	5 m
HalfLife	144000 min
WhiteNoiseSigma	3 m
EstimateBias	true
TropoSigma	0
EditOnDoppler	false
RejectFirstNMeas	0
Element 4	**BRTS Doppler**
Type	BRTS Doppler
BiasModel	GaussMarkov
Constant	0 Hz
InitialEstimate	0 Hz
Sigma	0.05 Hz
HalfLife	5 min
WhiteNoiseSigma	0.05 Hz
EstimateBias	false
CountInterval	1 sec

Add...
Remove
Remove All
Load...

OK   Cancel   Help

With real data processing, it is also of concern whether all of the biases in the measurement models can be separated. Simulation tests have shown that TDRS relay transponder biases are separable from the user satellite transponder biases. Effective separation has not been achieved, however, in the presence of significant initial errors between the ground 4L range bias and the TDRS relay transponder bias estimates. This is most likely due to the persistent tracking of specific TDR satellites from specific ground stations so that the two biases are always in the same additive combination. In such a case, it may be sufficient to estimate one while fixing the other.

9 References

1. Phung, P.B., Guedeney, V.S., Teles, J., "Tracking and Data Relay Satellite System (TDRSS) Range and Doppler Tracking System Observation Measurement and Modeling", NASA X-572-80-26, September 1980.

2. Benjamin, M., Cappellari, J., Hendry, S., et al., "Tracking and Data Relay Satellite System (TDRSS) Second TDRSS Ground Terminal (STGT) Description of Observation Measurement and Modeling, Vector Processing Ground Rules, and FDF Support Procedures Reference Manual", NASA FDF Code 550, October 1992.