Radar Comparator Dual

User Manual

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Abstract

Module Radar Comparator Dual (RCD) is a dual-source sensor analysis software system. Target of opportunity data it is used to predict the majority of the performance parameters required by international ATC documents (ICAO and EUROCONTROL). The Radar Comparator Dual module is generally used to measure the radar systematic errors (range bias, range gain, azimuth bias and time bias) and sensor accuracy. The Radar Comparator Dual can use both radars and ADS-B data for radar and ADS-B performance characterization. Typical mode of operation consists of specifying 2 independent data sources, to build the reference using both data sets and then to compare both sources versus this reference. In a particular case one data set can be locked and used as a fixed reference, the comparison becomes relative. Specific errors related to the barometric height errors, refraction and/or encoder eccentricity are measured and if required corrected by the tool to obtain more accurate result.

Keywords

Systematic errors	Random errors	Target of opportunity	ADS-B
Barometric correction	Timestamp statistics	Refraction correction	Filtering
Trajectory reconstruction	Track association	Trajectory analysis	Measurement tolerance

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DOCUMENT APPROVAL

The following table identifies all authorities who have successively approved the present issue of this document.

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DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
1.0	18/04/08	New document, compatible with RCD version 1.1.0	All
1.1	30/01/09	Document rewritten to RCD version 1.2.0	All
003	29/10/09	Document renamed; Basic glossary of terms added; Document rewritten to RCD version 1.2.0; 5.1.3. Processing parameters are added; A lot of chapters are deleted and referenced to the user manual of the RCM [6]; Chapter 7 Tutorial is deleted. The tutorial can be found in the separate RASS-R demo DVD user manual.	All
004	02/12/10	Document to updated to RCD version 1.3.2; Height window parameter added in paragraph 5.1.1; Units added in paragraph 5.1.3; Table 7-1: Statistics explanation updated.	All
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010	16-Aug-16	Reviewed conform version 3.0.0 (added about window and user manual short cut)	P15
011	25-Oct-17	Review for release 3.8.1	All

Whilst all care has been taken in preparing this document, some parts of this manual might be outdated vs. the latest software releases. Those errors or omissions are unintentional. If you do find any errors or inconsistencies, please contact support@intersoft-electronics.com and the appropriate adjustments will be made.

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CONVENTIONS USED IN THIS MANUAL

The following conventions are used in this manual:

Note: This icon to the left of bold italicized text denotes a note, which alerts you to important information.

Caution: This icon to the left of bold italicized text denotes a caution, which alerts you to the possibility of data loss or a system crash.

Warning: This icon to the left of bold italicized text denotes a warning, which alerts you to the possibility of damage to you or your equipment.

GLOSSARY OF TERMS

ACC	Air traffic Control Centre
ACP	Azimuth Change Pulse
ADS-B	Automatic Dependent Surveillance, Broadcast
ARP	Azimuth Reference Pulse
Asterix	**A**ll Purpose **S**tructured **E**urocontrol **R**adar **I**nformation E**x**change
ATC	Air Traffic Control
CAT001	Monoradar Data Target Reports, from a Radar Surveillance System to an SDPS (plots and tracks from PSRs, SSRs, MSSRs, excluding Mode S and ground surveillance)
CAT002	Monoradar Service Messages (status, North marker, sector crossing messages)
CAT034	Monoradar Service Messages, next version of CAT002
CAT048	Monorader Data Target Reports, next version of CAT001
COTS	Commercial Off The Shelf
D6	Intersoft Electronics internal Radar data format, plot or track based.
DHM	Data Handling Module
EDR	Intersoft Electronics internal data format for record based data. Also stands for Extended Data Recorder, a device for generating and capturing serial data.
EDR V2	Second version of the EDR format.
Ethernet	A network specification developed by DEC, Intel, and Xerox which provides anywhere from 10 megabits to 1000 megabits per second transmission speeds.
GPS	Global Positioning System
IE	Intersoft Electronics
IP	Internet Protocol
LAN	Local Area Network
MB	Megabytes of memory.
Memory buffer	*See* buffer.
Monopulse	Radar-receiving processing technique used to provide a precise bearing measurement
MSSR	Monopulse Secondary Surveillance Radar
NM	Nautical Mile, unit of distance
Path	A path can be described as a file's address on your file system, describing where the file lives: An absolute path gives the complete path, starting at the root directory, or the very top of the file system; A relative path looks for a file from the directory you are currently in down.
POEMS	Pre-Operational European Mode-S
PSR	Primary Surveillance Radar
Radar	Radio Detection And Ranging
RASS-R	Radar Analysis Support Systems – Real-time measurements
RASS-S	Radar Analysis Support Systems – Site measurements
RCS	Radar Cross Section
Record	A collection of data forming a complete message.
RF	Radio Frequency
SAC	System Area Code
SIC	System Identification Code

SLS	Side Lobe Suppression, a technique to avoid eliciting transponder replies in response to interrogations transmitted via antenna sidelobes
SSR	Secondary Surveillance Radar
TCP	Transmission Control Protocol
TMD	Technical Maintenance Display
Transponder	Airborne unit of the SSR system, detects an interrogator's transmission and responds with a coded reply stating either the aircraft's identity or its flight level
UAP	User Application Profile, used in ASTERIX data for assigning Data Items to Data Fields.
UDP	User Datagram Protocol. A connectionless, unreliable Internet protocol.
UTC	Coordinated Universal Time

1. Introduction

1.1 RCD as a part of RASS-R

The Radar Comparator is a powerful radar evaluation tool. Within RASS-R the Radar Comparator can process data delivered by the DHM in order to generate performance figures for radar accordingly to the international standards. On the other hand the Radar Comparator may produce important correction parameters for the DHM and further production of the data streams.

In the design of the Radar Comparator, a number of general principles have been respected. First, everything was kept as simple as possible so that, it is really easy to use the tool and interpret the results. Second, the data processing has been made as transparent as possible so that, it is easy to check what is going on behind the scenes and detect specific problems quickly. The third rule was to process a necessary minimum of the data in this way it is physically possible to analyse the data with a common human being capacity and within a realistic period of time. The fourth rule was to use clean data, i.e. corrected for all known (and measured) significant systematic errors. The fifth principle was to provide estimates for the accuracy (tolerance) on the measurement. The ultimate goal of the analysis is to estimate radar performance according to the international standards.

The Radar Comparator has two main versions: the Radar Comparator Mono (RCM) and the Radar Comparator Dual (RCD). The Radar Comparator Mono (RCM) can be used in order to evaluate the Probability of Detection, Code Probabilities, False Plot Rate and Accuracy (random Range and Azimuth errors) generating separate performance figures for PSR-SSR and Mode-S, both plot and track data can be processed. The Radar Comparator Dual (RCD) can be used in order to evaluate the Systematic Errors, Random Errors, Accuracy and Systematic Errors per Trajectory, ADS-B Statistics, e.g. AC latency and transponder delay. It has been shown that in general two radars (other sensor types such as ADS-B can also be used) are necessary and sufficient for the absolute measurement of the systematic errors and the accuracy, as well as the corresponding confidence intervals for the inferred parameters.

Prior to the comparative analysis with the Radar Comparator Dual, the raw radar data may need to be pre-processed in order to take into account the real distribution of the barometric pressure vs. height (as opposed to the ICAO 1964 Standard Atmosphere), effects of the atmospheric refraction, and eventually ACP encoder eccentricity if any significant eccentricity is present. Applying the barometric correction to the height of aircraft is beneficial for more accurate 3D coordinate transformations. The integrity of the data and timestamp problems typically needs to be tested, this is essential for conducting the accurate systematic parameters measurement, for a wrong timestamp may induce additional position errors.

ADS-B is a surveillance technique that relies on the aircraft to broadcast their identity, position and other aircraft information. Intersoft Electronics investigated the usage of ADS-B data in measurement techniques for radar evaluation (measurement of systematic and random errors) [5], ADS-B data broadcasted by aircraft represents a great value for the radar evaluation, monitoring and parameter correction. However, not every ADS-B message can be used for this purpose, less accurate data must be distinguished and carefully discarded from the analysis. With the ADS-B data already available worldwide, the improvement in the Radar Comparator Dual (RCD) monitoring capability and accuracy can be called spectacular. However if required the tool can be used in the original mode, i.e. radar to radar evaluation mode.

2. Benefits and possibilities of the system

The benefits and advantages of the RCD radar analysis software are listed as follows:

- An efficient and user friendly software tool for the radar (sensor) performance analysis

- Transparent radar data processing, versatile cross-referencing displays and viewers throughout the analysis

- S4 format is directly usable for the RCD analysis

- Barometric correction of the target altitude based on the barometric sounding data

- Correction of the range for the atmospheric refraction

- Timestamp statistics (systematic and random)

- Sensor message statistics

- Track based systematic error and accuracy reporting

- ADS-B accuracy measurement and reporting

- Track data reporting

- Versatile universal filter interface

3. RASS-R toolbox

Refer to Reference [6].

4. RCD basic operation

4.1 User Interface

When opening the RCD (from the Windows start menu or the RASS-R toolbox), the following user interface panel will be activated:
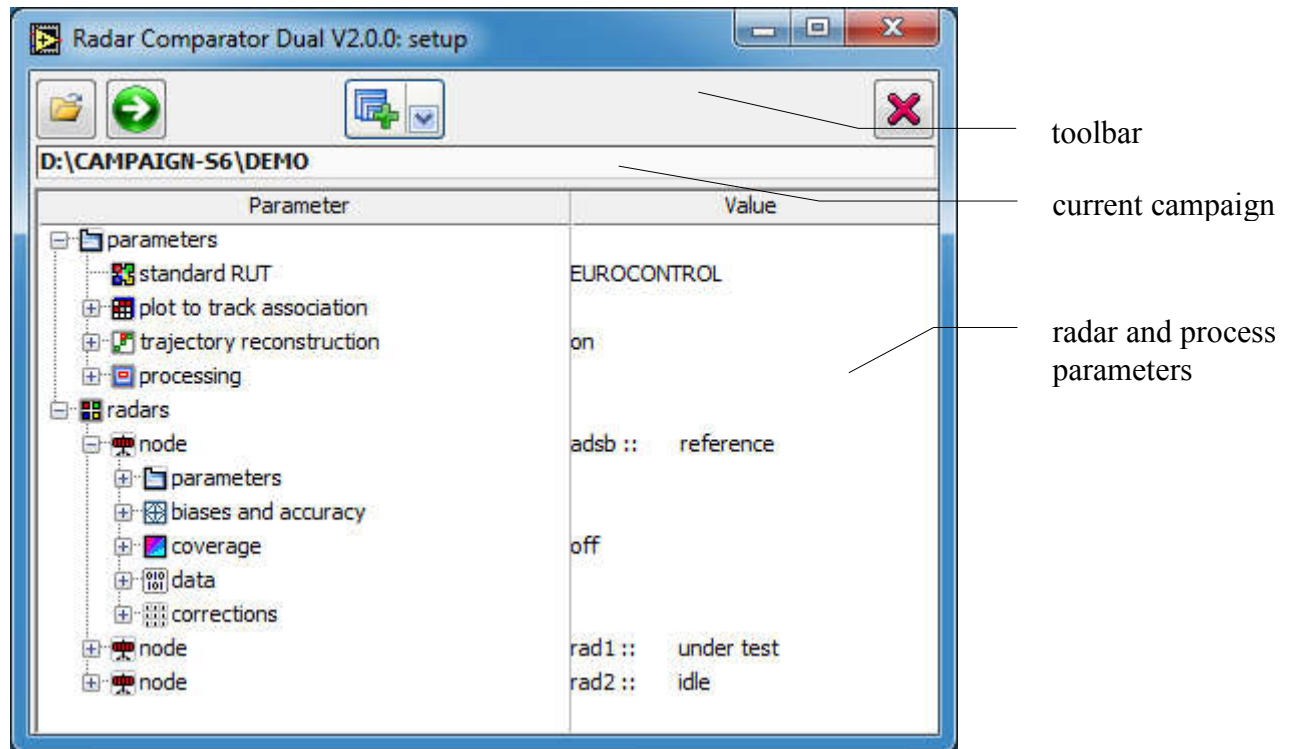
Figure 4-1: RCD user interface

The RCD user interface panel contains three main elements:
- The toolbar. (see section 4.2 for details)
- The current campaign field indicator. When running the RCD, it will automatically use the last campaign used by the RCD, or RCM, or the campaign selected using the RASS-R toolbox. (see chapter 3 RASS-R toolbox)
- The tree view field with parameters and node (radar information). (See section 5.1 for details)
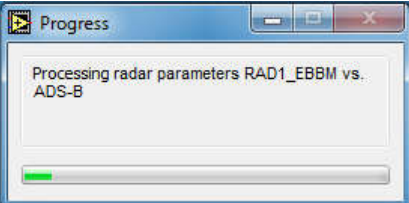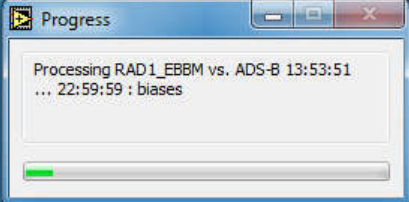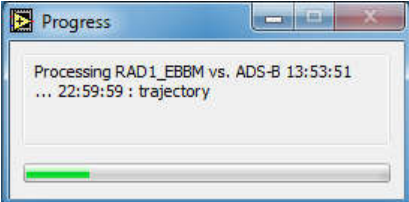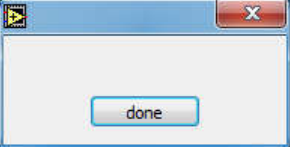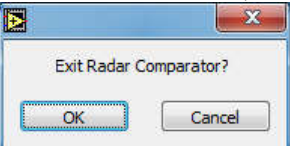
☞ ***The main window stays always topmost.***

4.2   Toolbar

The toolbar allows the user to load/save configuration setup files and access the different displays and viewers. An overview of all the available items is given in the table below.

Table 4-1: Toolbar overview

Button	Usage
	Press to select an existing campaign or create a new campaign
	Use this button to start processing. After processing, this button becomes inactive until a parameter or node setting is changed. Then, you can press the button again. When processing is busy, one can see the following dialogs in consecutive order:
	Press and select tools and displays from the following drop-down menu (see the next sections for details)
	Press the button to exit, the RCD will exit after your confirmation

As explained above the RCD starts up with the last used campaign (by the RCM, RCD or RASS-R toolbox). To learn how to select or create a new campaign, refer to Reference [6].

4.3   General utilities and displays

The RCD has a number of general tools available for radar evaluation:
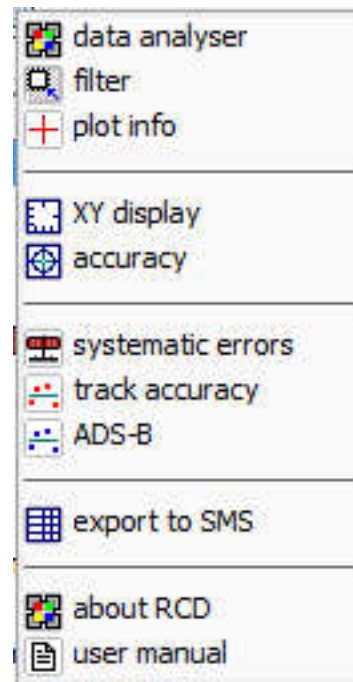
Figure 4-2: General utilities and displays

These tools include the following modules:

- **data analyser**: is used to detect or measure a number of possible non-specific errors in the input data, i.e. errors neglected by the used mathematical model but able to have the direct influence on the accuracy of the measurement.
- **filter**: is used to create, edit, load and store various filters. The filter content can be stored and retrieved locally (within a specific campaign), globally (visible for all campaigns) or to a file.
- **plot info**: is used to access the plot (track) information, addressed by the cursor in various graphs.

The following displays use the generic multi-layer displaying object so that the handling configuration procedures for all of them are similar.

- **XY display**: is used for dual-sensor plot (track) display. The user can easily redefine the amount and type of the data displayed. Coastline and relief can be displayed on this graph.
- **accuracy display**: is used to display the random range and random azimuth errors for the radar (or another source e.g. ADS-B) used as reference (REF) or the radar under test (RUT).

The following statistics tables are available:

- **systematic errors**: is used to display overall statistics for the analysed data set.
- **track accuracy**: is used to present statistics for all the processed trajectories.
- **adsb**: is used to present statistics for all the processed ADS-B trajectories.

Following SMS (Surveillance Monitoring System) related tool is available:

- **export:** Export active parameter subset and filter to upload into a SMS database

General information:

- **About RCD** displays the version numbers of RCM, license and the necessary contact information.
- **User Manual** short opens the RCD user manual.

5. Program setup

When you run the RCD, the user interface as in the figure below will be displayed. The parameter interface has a universal tree structure. Parameters are grouped according to their meaning and functions into two groups 'parameters', and 'radars'. Each group contains several subgroups.
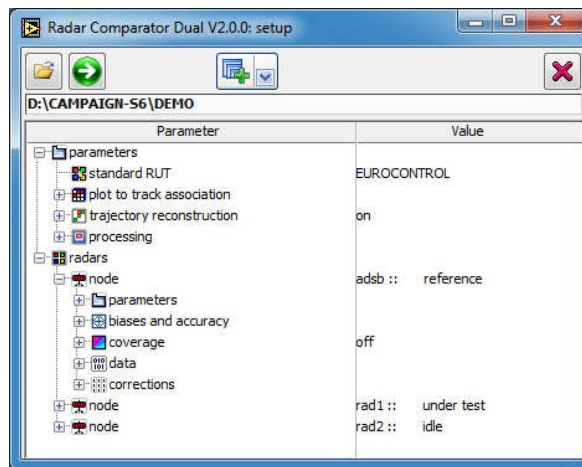
Figure 5-1: RCD User Interface

Right click inside the above tree control produces the following popup menu:
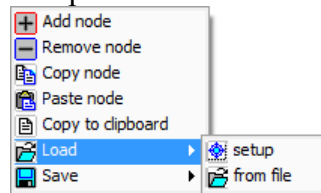
Figure 5-2: RCD right click

With this menu you may want to perform one of the following operations:

- **Add/Remove node**: creates a new node for a new radar (sensor) or removes it from the tree
- **Copy/Paste node**: copies the selected node or pastes it at the end of the tree
- **Copy to clipboard**: it makes a spreadsheet copy of the parameters that can be pasted to a document for reporting purposes. (E.g. Microsoft Excel, notepad)
- **Load setup:** load the default setup from the current campaign. (See Figure 5-3)
- **Load from file**: select a setup file[1] to load. This is handy when the evaluation of the radar has been already conducted before and the setup has been created and stored in a different campaign.
- **Save setup**: save to the default setup for the current campaign. (See Figure 5-3)
- **Save to file**: select a setup file to store with a new name or outside the current campaign. Select the path and filename using the standard file dialog.
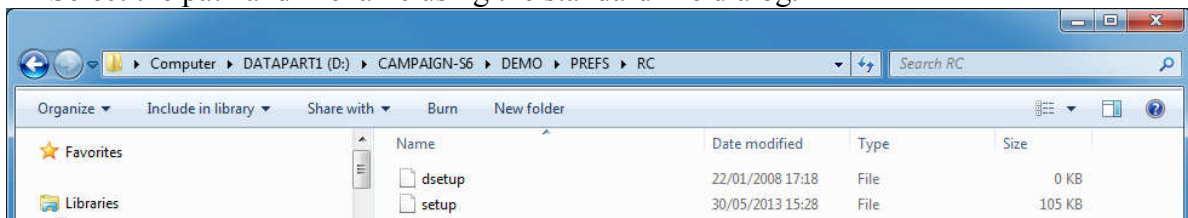
Figure 5-3: RCD default setup files inside own campaign

Setup files generated with the older version of RCD are only limitedly compatible with the newer RCD versions.

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[1] RCD setup files do not have a file extension.

5.1   Parameters

Changes of the most numeric, text and compound configuration parameters must be followed by pressing ENTER. Otherwise the old values will be maintained. Except the ring controls that are updated automatically when their values are changed.

- **Standard RUT:** this parameter defines the standard (EUROCONTROL or ICAO) to be used as reference for the RUT.

5.1.1   Plot-to-track correlation

This subgroup contains parameters for the Object Correlator (OC) performing multiple hypothesis plot-to-track correlation:
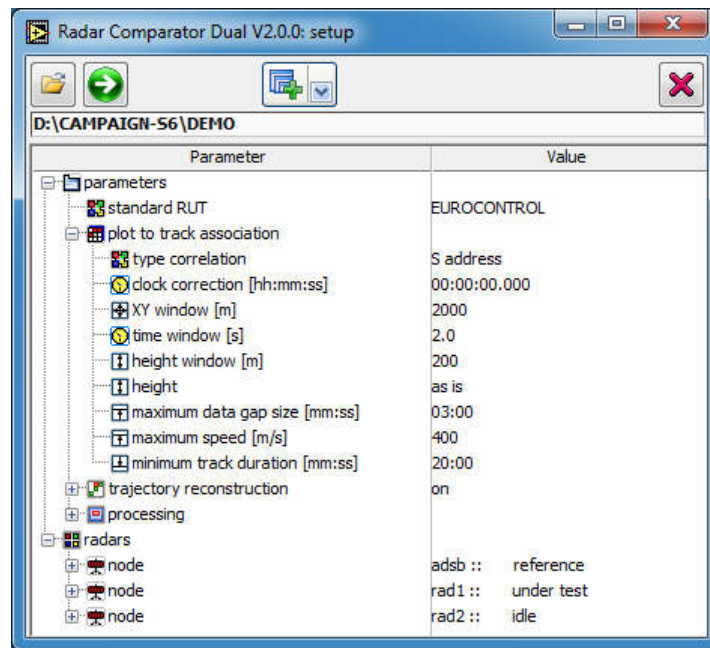
Figure 5-4: Parameters plot-to-track association

- **Type correlation**:   [**3/A code**, S-address, 3/A code to position, S-address to position, TrackNr to position**]**
  This selector depends on type of data to compare. For example, when comparing SSR with SSR or Mode-S, select "3A"; when comparing Mode-S to Mode-S (or ADS-B) select "S address"; when comparing PSR vs. SSR select "3A to position"; when comparing PSR or SSR vs. Mode-S (or ADS-B) select "S address to position"; when comparing any SSR, PSR or Mode-S vs. track data select "TrackNr to position" . Various settings can be used for rotating sensors both having 3A codes, S addresses and Track Numbers, however preferentially "3A code" or "S address" should be used if the corresponding codes are available for both sensors.
  When implementing a SMS system the following typical correlations apply:
    o PSR radar vs. ADS-B and/or SSR vs. ADS-B use "S address to position"
    o Mode-S radar vs. ADSB use "S address"
    o MRT vs. ADS-B use "S address to position"
    o ASDE vs. MRT use "TrackNr to position"
  Other correlation types may be applicable.

- **Clock correction [hh:mm:ss]:**   [**00:00:00.000**] a correction for possible timestamp bias between two data sets. Should be used only when a significant bias (>2s) is expected or might exist between the two data sets, e.g. when the time of detection is not available and the time of recording contains a significant bias with respect to UTC. If two data sources produce no correlation, however they look very consistent with each other positional wise in the XY viewer, clock might need to be corrected using this parameter. The correction will be applied to the reference node (timestamp of each REF report will be subtracted with the set value).
- **XY window [m]:**   [**2000**] is only used when the **Type correlation** is set to one of the following [3/A code to position, S-address to position, TrackNr to position]. Together with **Time window** parameter (see below), it is used to perform correlation of the data produced by sensors of different type (e.g. SSR radar and ADS-B). The selected value depends on the sensor type, accuracy, systematic errors and maximum range for rotating sensors.
- **Time window [s]:**   [**2.0**] the maximum timestamp discrepancy between the two sources. Sets the time window for the track data association. Larger values might be required with longer antenna revolution periods and/or for large time biases (e.g. excessive ADS-B latency for a particular transponder may result in uncorrelated tracks, however their XY positions might be very close). It is only used when the **Type correlation** is set to one of the following [3/A code to position, S-address to position, TrackNr to position].
- **Height window [m]:**   [**500**] is only used when the **Type correlation** is set to one of the following [3/A code to position, S-address to position, TrackNr to position]. Together with **Time window and XY window** parameters, it is used to perform correlation of the data produced by sensors of different type (e.g. SSR or Mode-S radar vs. 3DHeight radar systems/ADS-B).
- **Height:**   [**as is**, null, reconstruct]. The height data may be produced using barometric, radiometric, inertial, etc. height measurement techniques (barometric height measured with altimeter, 3D height measured by 3D radar, height measured with GPS, no height information in the case of PSR sensor). Depending on relative accuracy of the height method, the height data might be left unchanged (if the two sources have similar accuracy), alternatively the height for the RUT can be reconstructed using the height data of the reference (applied height field to be selected with the reference "height type" parameter – see 5.2.1), or null (for both sources).
- **Maximum data gap size [mm:ss]:**   [**01:00**] set the maximum gap size in the data chain without breaking it into two or more chains.
- **Maximum speed [m/s]:**   [**400**] discards the chain from the analysis if the average speed of AC exceeds the specified value. The upper speed limit is required for tracking filter to improve the correlation and avoid excessive false association rate. Depends on the sensor type, for example ASDE vs. MRT sensor analysis this speed should be reduced, for the typical speed of the AC is low in terminal areas.
- **Minimum track duration [mm:ss]:**   [**05:00**] discard the track from the overall statistics if the duration is less than the specified value.

5.1.2   Trajectory reconstruction

This subgroup contains parameters required to setup the trajectory reconstruction engine, and the accuracy filter. The trajectory reconstruction is performed after all the systematic errors (biases) are correctly measured and compensated, so that the only remaining errors are purely random. For the trajectory reconstruction several statistical quantities are required, such as expected accuracy of the sources expressed in terms of standard deviation for range and azimuth or X and Y depending on the nature of the measurement. It requires as well a trajectory speed noise estimate also expressed in terms of standard deviation (see below). The trajectory reconstruction algorithm tries to minimize the following quantities: random range errors, random azimuth errors, trajectory speed noise. These quantities are minimized using the corresponding expected accuracies on the sensor errors and trajectory speed noise as the weighting coefficients.
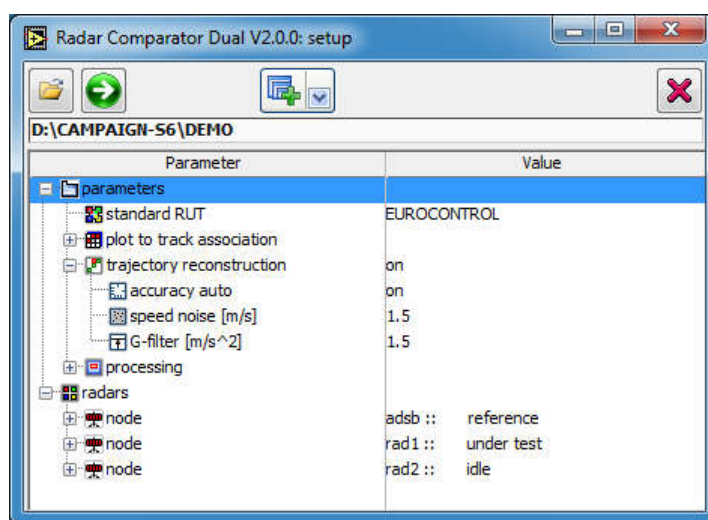
Figure 5-5: Parameters trajectory reconstruction

Trajectory reconstruction: [**on**, off] reconstructs the true trajectory for each AC based on the data from both sources. The random errors for both reference REF and radar under test RUT are evaluated using this trajectory as a reference. Setting this flag to **off** means that the true trajectory will be built using the reference sensor only (in this case the accuracy of RUT is evaluated in a relative way, the accuracy of REF is not evaluated). This flag should be set to off when the accuracy of RUT is expected to be much less accurate compared to REF. Whenever both REF and RUT are expected to have comparable positional accuracy, true trajectory reconstruction is recommended.

- **Accuracy auto**:   [**on**, off] if the flag is on, the random errors estimates (range, azimuth, X, Y) used for the trajectory reconstruction engine are evaluated for each source separately from the data itself, using RCM radar accuracy measurement techniques. Alternatively, if the flag if off, the estimates are taken from the radar parameters (see below **node** subgroup **biases and accuracy**)
- **Speed noise [m/s]**:   [**1.5**] parameter estimates the trajectory speed noise (standard deviation) required for the true trajectory reconstruction. Smaller values typically produce more trajectory smoothing, at the expense of seriously overestimating random errors (in particular range accuracy) on manoeuvring sections.
- **G-filter [m/s^2]**:   [**1.5**] acceleration filter that removes sections, with the longitudinal or lateral acceleration exceeding the specified limit, from the random error (accuracy) computation. Typically this filter discards the turning segments from the random error computation.

5.1.3   Processing

This subgroup contains parameters for processing:
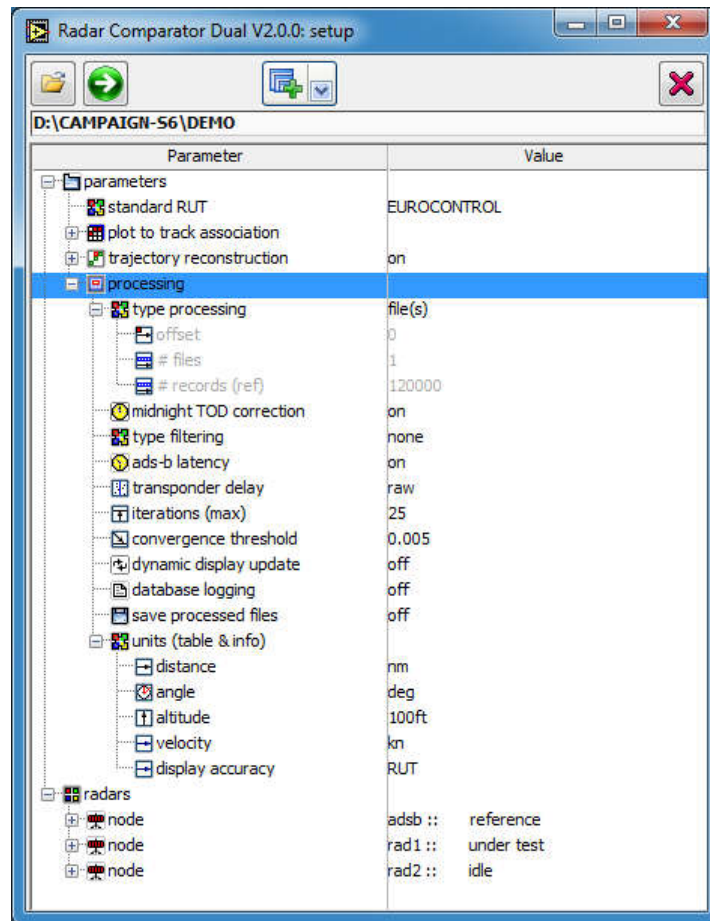
Figure 5-6: Parameters processing

- **Type processing:**   [**file(s)**, records[2]] the recorded data may be organized as a collection of a number of recordings of fixed time intervals (e.g. 15, 30, 60 min). In the selected data storage directory these recordings will be represented as a collection of the corresponding S4 files. User may manually select a subset of these if mode **file(s)** is selected. In selection mode **records**[2], the software will open a file specified by the **offset** position in the file list, and will use as many files as required to collect the specified count of the data records for REF.
    - o **offset**   [0]   the first file proceed in the **records** mode
    - o **# files**   [1]   not used
    - o **# records (ref)**   [120000]   count of records (plot/track messages) to process in the **records** mode

When type processing is set to [records], the data belonging to different nodes must be set in different subfolders. For example:
\CAMPAIGN-S6\MYCAMPAIGN\DATA\RASDATA\Radar1*.S4
\CAMPAIGN-S6\MYCAMPAIGN\DATA\RASDATA\Radar2*.S4

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[2] This feature is temporarily not supported by RCD version 4.0.0

- **Midnight TOD Correction**:   [**on**, off] must be set if the data recording is taken over midnight and time of **detection** is used. Note both sources REF and RUT must use the same timestamp type.
- **Type filtering**:   [**none**, sliding window] set up the filtering algorithm for the data of both sources applied before running the systematic error engine. Sliding window filtering produces better accuracy of the systematic error evaluation on moderate- to low- manoeuvring traffic.
- **ADS-B latency**:   [on, **off**] activates the ADS-B latency parameter in seconds per each trajectory in the model (to be used for ADS-B reference source only).
- **Transponder delay**:   [**raw**, range bias compensated] since the range bias and the transponder delay cannot be measured separately, each predicted transponder delay contains the radar range bias. On the other hand the average value of the transponder delays is likely to be very close to the actual radar range bias. The transponder delays can be either determined with this range bias component **raw**, or **range bias compensated** to be closer to the actual transponder delay value.
- **Iterations (max)**:   [**25**] set the maximum number of the iterations for the systematic error analysis engine.

☞ *The number of required iterations is dependent on the accuracy of the radar under test. A sensor with poor accuracy will not benefit from a higher number of iterations. In rare occasions will the result even drift away from the ideal solution (indicated by an unusual high residual error). On the other hand, for a sensor with high accuracy (small random errors) shall the accuracy on the measurement of the systematic errors typically improve with each iteration, and is it recommended to increase this maximum.*

- **Convergence threshold**:   [**0.001**] sets the minimum threshold on the average residual change between two consecutive iterations. The systematic error evaluation process stops if the maximum number of iterations or the convergence threshold is reached.
- **Dynamic display update**:   [on, **off**] updates the displays at each iteration if set to **on**, which may slow-down the processing. Use the flag to check visually that the process of the minimization of residual errors produces a reasonable result.
- **Database logging**:   [on, **off**] store the results of the evaluation (i.e. systematic errors and ADS-B statistics in a database. The database storage file is located in **\CAMPAIGN-S6\General\RC\ RCD_DB.DB3** and can be accessed using general database software.
- **Save processed files**:   [on, **off**] see 5.1.4 for a detailed explanation

- **units (table & info)**:   define appropriate units for tables and viewers
    - **distance**   [m, **nm**, km]
    - **angle**   [rad, **deg**]
    - **altitude**   [m, ft, **100ft**]
    - **velocity**   [m/s, **kn**, km/h]
    - **display accuracy**   [REF, **RUT**] select what the accuracy display will show, the errors for the RUT or the errors for the REF (only if trajectory reconstruction is ON).

5.1.4   Save processed files

This parameter may be used to save the processed source files of **REF** and **RUT** (in S4 format) on disc for further analysis using for example RASS-S Inventory (see *RASS-S user manual, volume 4, chapter III*). The files are stored in a subfolder RESULTS created in the data folder as follows:

if the source data file for example is located in
\CAMPAIGN-S6\MYCAMPAIGN\DATA\RASDATA\080124_1100,
the corresponding processed files will be stored in
\CAMPAIGN-S6\MYCAMPAIGN\DATA\RASDATA\080124_1100\RESULTS.
The file name will indicated time and day when the .S4RA was made and with what software (RCM or RCD).

Each target report, which passed the filter, will be saved into the new file with the following information added or updated:

- Range error [NM]   this field in S4 format is the same field as the latitude field. Therefore if position type used in analysis is longitude/latitude than the range error will be saved in the X field. If reference type is ADS-B the field will be populated with error along the track, while if it is MRT the field will hold the X error.
- Azimuth error [deg]   this field in S4 format is the same field as the longitude field. Therefore if position type used in analysis is longitude/latitude than the range error will be saved in the Y field. If reference type is ADS-B the field will be populated with error across the track, while if it is MRT the field will hold the Y error.
- Altitude [ft]   this field will be the original altitude unless barometric correction was set ON and/or height reconstruction was enabled. In the inventory plot info window this field is called "SSR Height".

5.2   Radars

The group contains radar specific parameters. A number of sensors might be created and configured here.

node: [*name*] [**idle**, reference, under test] is used to specify the name for the data source as well as its current status:

- **idle**: the node parameters are configured, but the node is not taken into account for analysis
- **reference**: during analysis, the radar under test (RUT) is compared with this node (REF), statistical results will be produced for this sensor if it is unlocked
- **under test**: this node is under test, statistical results will be produced for this sensor

☞ *For an absolute measurement using two radars the designation "reference" – "under test" is arbitrary, except for a comparison with ADS-B (ADS-B source must be designated as reference). For a relative measurement, the better radar should be used as reference.*
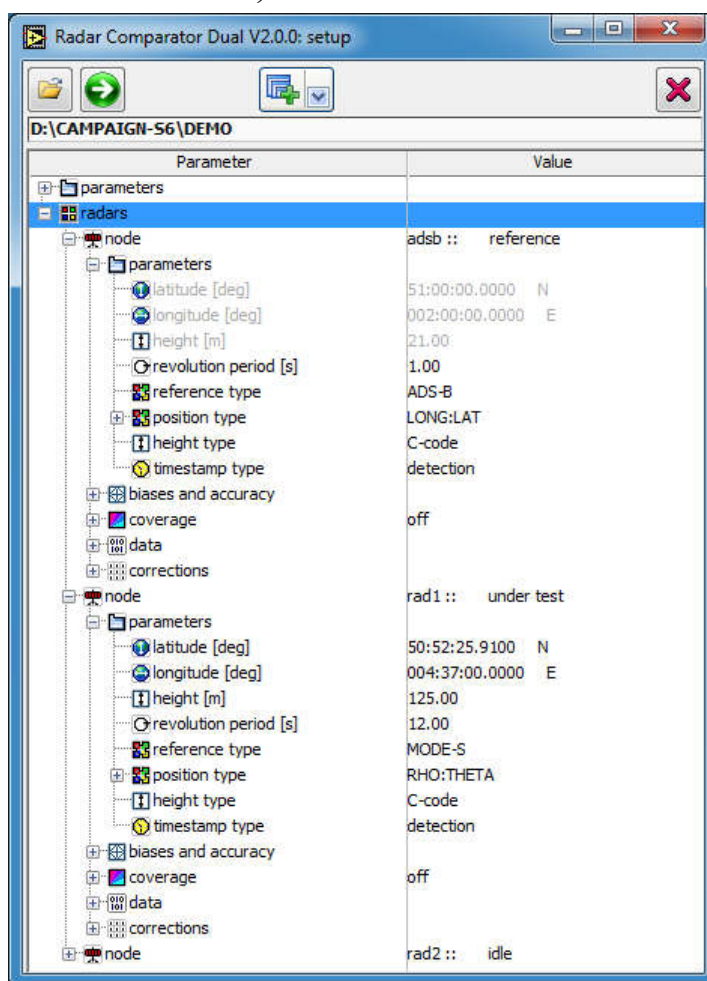

Figure 5-7: Node – parameters

☞ *You need to select two sources designated as reference and under test. The software warns you if the selection is not valid:*
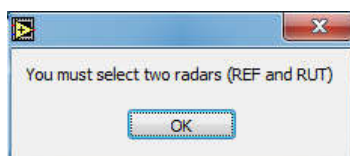

Figure 5-8: RCD analysis error dialog

5.2.1   Parameters

The parameters subgroup contains the following settings:

- **latitude [deg]**:   [**52:00:00.0000**][**N**, S] Geodetic latitude of the radar
- **longitude [deg]**:   [**002:00:00.0000**][**E**, W] Geodetic longitude of the radar
- **height [m]**:   [**m**] the height of the centre of the radar antenna measured using WGS84 model. All heights have to be Height above WGS84 ellipsoid.
- **revolution period [s]**:   [**s**] antenna revolution period in seconds. For asynchronous reference type this parameter will define the expected update rate. For ADS-B you should select a fixed update period (value 1), to produce more consistent timestamp analysis results.
- **reference type**:   [**PSR**, SSR, MODE-S, ADS-B, MRT] set up according to the required reference type. The selected data type will determine the used mathematical model and set of statistics that will be computed.

☝ *EUROCONTROL or ICAO standards have been applied. In case no standard method is available, e.g. ADS-B probability of detection, ICAO guidance material is implemented.*

☝ *The reference type is not a filter like in RCM. If for example correlation type is "... to position" any primary, secondary or mode-s plot (track) from the RUT could get correlated, no matter what reference type was selected. It is thus often required to set a proper filter (see 6.3).*

- **position type**:   [**RHO::THETA,** XY (radar plane), XY (Cartesian), LONG::LAT] set to the corresponding coordinate type applied by the sensor. The radar plane stays for the **azimuthal projection**, **XY Cartesian** is the **orthogonal projection** to the local horizontal plane (if unknown, check ICD of the recorded data transmission format).
    - **height (convert)**   [**C-code**, 3D Height] this setting becomes only active when the position type is LONG::LAT. Then, if C-code or 3D Height field is available, you can use it to convert LONG::LAT into RHO::THETA or XYZ.
    - **Barometric (convert)**   [**off,** on] applies height error correction for ADS-B coordinate conversion (LONG, LAT, height to RHO, THETA), based on the most recent atmospheric balloon soundings. When no geometric height is available, correcting the C-code produces the most accurate reference for the radar under test range estimate.
- **height type**:   [**C-code**, 3D Height] is selectable according to the available height data. *For ADS-B reference it is the geometric height that will be used when 3D height is selected.*
- **timestamp type**:   [recording, **detection**] is selectable according to the available timestamp data, time of detection should be used whenever available.

☝ *Several parameters are not applicable (greyed out) when e.g. reference type is ADS-B or position type LONG::LAT is selected.*

5.2.2   Biases and accuracy

The biases and accuracy subgroup contains the following settings:
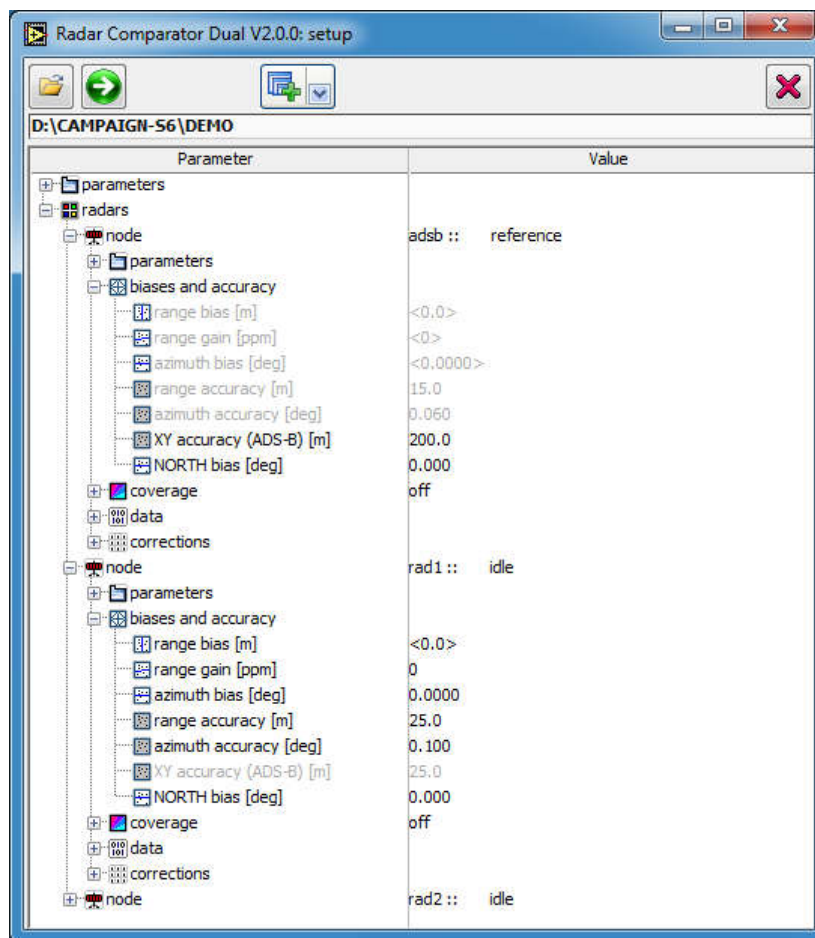
Figure 5-9: Node - biases and accuracy

- **range bias [m]**: [**0.0**] is used to correct the range using the specified value. The raw data will be temporarily corrected before performing the track correlation. However the reported systematic error will remain absolute. If <value> locking brackets are active the parameter is excluded from the systematic errors determination. For example set this parameter to <0.0> for an ADS-B source.

- **range gain [ppm]**: [**0**] is used to correct the range gain using the specified value. The raw data will be temporarily corrected before performing the track correlation. The reported systematic error will however be relative to the uncorrected values. If <value> locking brackets are active the parameter is excluded from the systematic errors determination. For example set this parameter to <0.0> for an ADS-B source.

- **azimuth bias [deg]**: [**0.0000**] is used to correct the azimuth using the specified value. The raw data will be temporarily corrected before performing the track correlation. The reported systematic error will however be relative to the uncorrected values. If <value> locking brackets are active the parameter is excluded from the systematic errors determination. For example set this parameter to <0.0> for an ADS-B source. You may use the <value> locking brackets whenever the parameter is known and can be excluded from the systematic errors determination.

- **range accuracy [m]**: [**15.0**] is the expected range accuracy of the radar (standard deviation) adjust if necessary. This value is used for the correlation, as well as the trajectory reconstruction algorithm if **accuracy auto** flag is set to **off.**

- **azimuth accuracy [deg]**: [**0.060**] is the expected azimuth accuracy of the radar (standard deviation); adjust if necessary. This value is used for the correlation, as well as the trajectory reconstruction algorithm if **accuracy auto** flag is set to **off.**
- **XY accuracy (ADS-B) [m]**:   [**25**] is the expected XY position accuracy of the ADS-B source (standard deviation). This value is used for the correlation, as well as the trajectory reconstruction algorithm if **accuracy auto** flag is set to **off.**
- **NORTH bias[deg]:**   [**0.000]** set the bias correction if radar is aligned with magnetic north instead of true north. Unlike a value set in the azimuth bias parameter, the correction will be permanent. The bias reported in the systematic errors will be the bias vs. the true North.

5.2.3   Coverage

Coverage information is not currently used in the RCD.
The max range parameter will however influence the XY-display. Refer to Reference[6] for further details.

5.2.4   Data

Refer to Reference [6].

5.2.5   Corrections

The corrections subgroup contains the following settings:
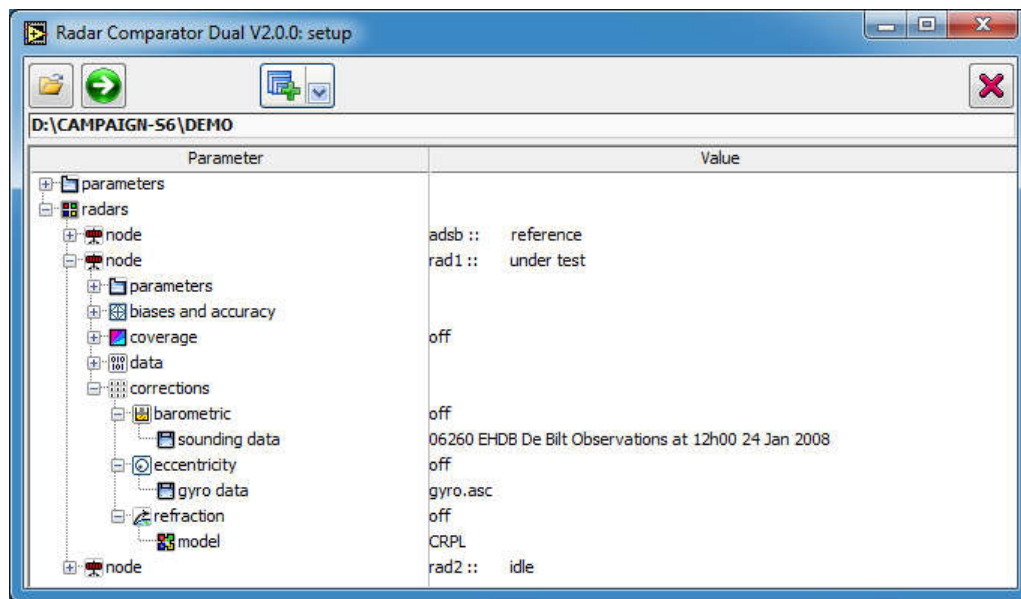
Figure 5-10: Node - corrections

- **barometric**:   [**off**, on] applies height error correction based on the most recent atmospheric balloon soundings. This correction limits the XY discrepancies when converting (RHO, THETA and Height) to XYZ coordinates. Use the **data analyser** first in order to measure the existing errors and retrieve the barometric data.
    - **sounding data**:   [**filename**] a filename of the sounding retrieved from Atmospheric Sounding Website (http://weather.uwyo.edu/upperair/sounding.html)
- **eccentricity**:   [**off**, on] enables eccentricity correction of the data.
    - **gyro data**:   [**filename.asc**] a filename of the eccentricity measurement file performed with RASS-S radar gyroscope measurement.
- **refraction**:   [**off**, on] enables refraction correction of the data.
    - **model**:   [**CRPL**] the refraction model developed by Central Radio Propagation Laboratory (USA)

6. Tools and displays

All tools and displays can be accessed using the same menu button as shown in Figure 6-1.
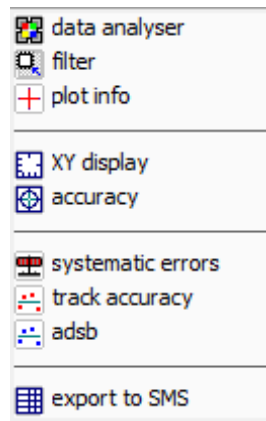
Figure 6-1: Tools and displays

You can change the transparency of all displays, tables and dialogs. The transparency can be circularly changed from 0 to 80 percent in 5 steps by pressing the F3 key. Transparency of the main RCD window cannot be changed and it remains topmost at all times.

6.1 Displays configuration

Refer to Reference [6].

6.2 Data Analyser

The radar data analyser (in older versions of the Radar Comparator it was named preprocessor) has been developed to measure errors of different nature that might be present in the data and therefore affect the radar analysis. The RCD data analyser takes four error types into consideration. The barometric height correction should be performed in order to produce more accurate 3D coordinate transformations.

Timestamp errors can only be evaluated. Timestamp error analysis is often important for radar diagnostics and the program parameter adjustment, to check the integrity of the data, find scan based Pd drops etc. The eccentricity and refraction corrections were found to be important when performing dual-source analysis (RCD).
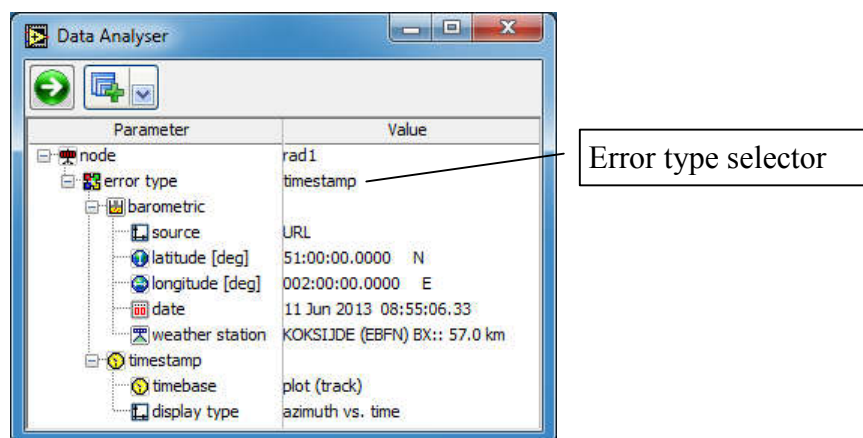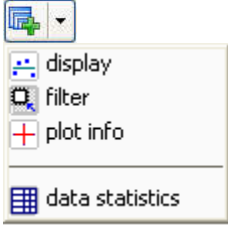
Figure 6-2: RCD Data analyser

The Data Analyser has a tree-structure configuration interface similar as the main window (see Figure 6-2). Use the node-selector to select the appropriate radar source.

Table 6-1: Data Analyser window: Control buttons

Button	Usage
⬤	Press to process the data according to the selected error type
▣▾ display filter + plot info data statistics	Press 'display' to open the data analyser display for timestamp analysis and the different corrections. Press 'filter' to open the filter configuration window Press 'plot info' to enable the plot info display Press 'data statistics' to open a table for timestamp statistics.

As opposed to the early versions of the Radar Comparator, the data analyser is only used for error analysis. To correct the selected errors the user must enable the corresponding correction flags in the RCD main window (subgroup Corrections).

6.2.1   Timestamp analysis

Refer to Reference [6].

6.2.2   Barometric error analysis and correction

Refer to Reference [6].

6.2.3   Eccentricity correction

The eccentricity correction is very important when performing multi-radar analysis. On several occasions eccentricity as high as 0.2° peak-to-peak was measured on operational radars. If this non-random error remains non-corrected it can contaminate results of the analysis for other radars and the accuracy of the systematic error determination will be affected. On the other hand the strength of the RCD is in fact that comparing the pairs of the radars one can discover the singularity in the results pointing out to a particular radar station (refer to reference [5]).

In order to visualize the eccentricity error file select the error type [**eccentricity**] and press pushbutton ⬤ to proceed.

Figure 6-3: Data Analyser: Eccentricity correction

Select the display option in the menu button ▣▾. The display below will be shown:
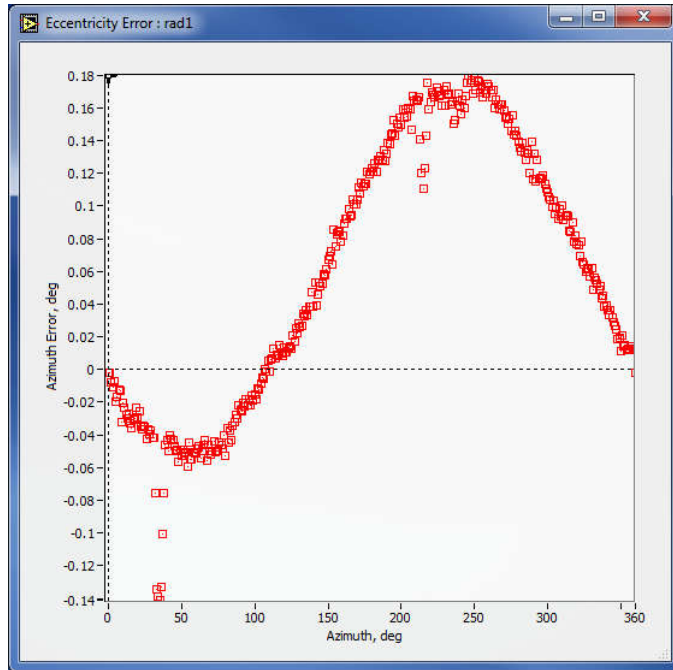
Figure 6-4: Eccentricity correction

Eccentricity correction can be applied using and eccentricity file. This is data generated by an eccentricity measurement with the RASS-S toolbox and the gyroscope RGI 59x.
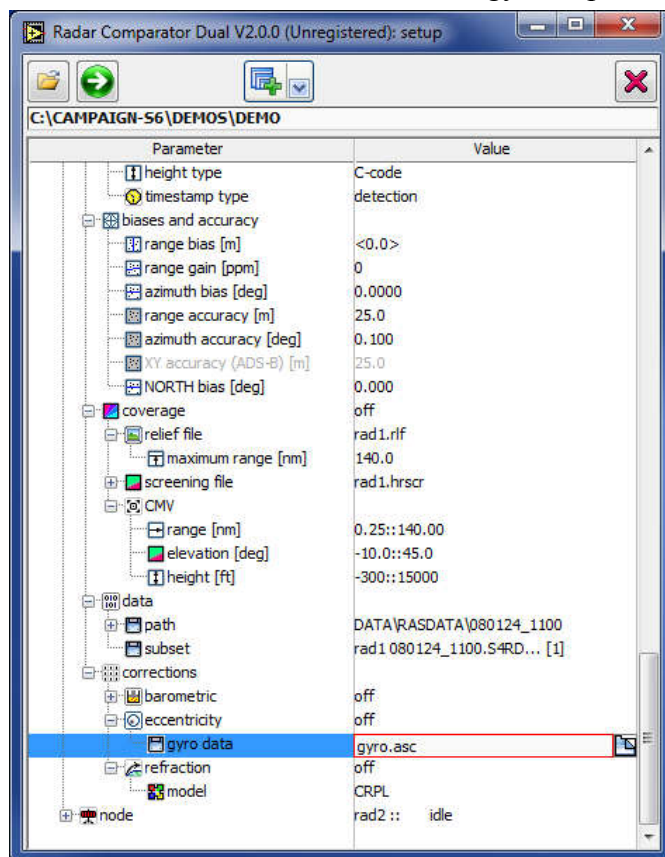
Figure 6-5: Select an eccentricity file

Click the **eccentricity data** selector: When pressing this, a dialog pointing to the suggested path where the eccentricity files are saved (MYCAMPAIGN/VIDEO/GYRO), will appear. Then, select the appropriate .asc file.

6.2.4   Refraction correction

Refraction of the radio waves in the atmosphere is due to the exponential change of the refraction coefficient with height. In the result the radar beam is not straight but slightly curved downwards, so that the range is slightly overestimated because it is measured along a curve, and not along the straight line between the two points in the 3D metrics. Very often this error doesn't exceed a few-meter level, but for ranges of around 250 NM, the error may grow up to around 30m, which if not taken into account, produces wrong estimates for the systematic errors (range bias and range gain), see an example below. As can be seen errors are significant even for shorter ranges, thus for 150 NM the typical correction is about 7-13m depending on the elevation angle. The correction is computed based on the CRPL model atmosphere (CRPL Central Radio Propagation Laboratory of National Bureau of Standards). First, successive layers of the atmosphere are approximated then the refractivity is computed for each set of layers. The model assumes the exponential decrease of the refractivity with height. However it is likely that the local atmospheric conditions are offset from the standard, so that the refractivity coefficient is a subject of temperature, humidity and pressure.

The gradient of the air density in the atmosphere produces the gradient of speed of light and is responsible for the atmospheric refraction. The main effect is that the radio-waves travel along slightly curved downwards trajectories. This produces an error in elevation angle and range. The effect is negligible for all but low elevation angles and long ranges. Using a stratified model for the atmosphere recurrent formulae allow evaluating the range error as follows. The refractive index of the troposphere is approximated by [5]:

$$N(h) = N_S \exp\left(-\frac{h}{7}\right) \qquad\qquad (1)$$

where $N_S \approx 313$. Iterative process based on CRPL model with number of layers $\gamma = 16$.

In order to visualize the refraction error file select please the error type [**refraction**] and press pushbutton ![button] to proceed.
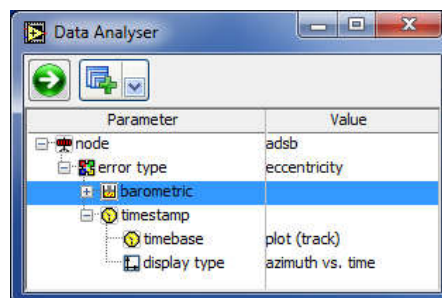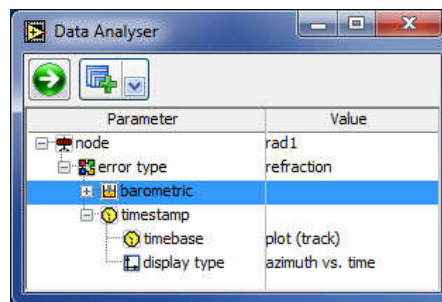

Figure 6-6: Data Analyser: Refraction correction

Select the display option in the menu button [icon]. Then, the display below will be shown:
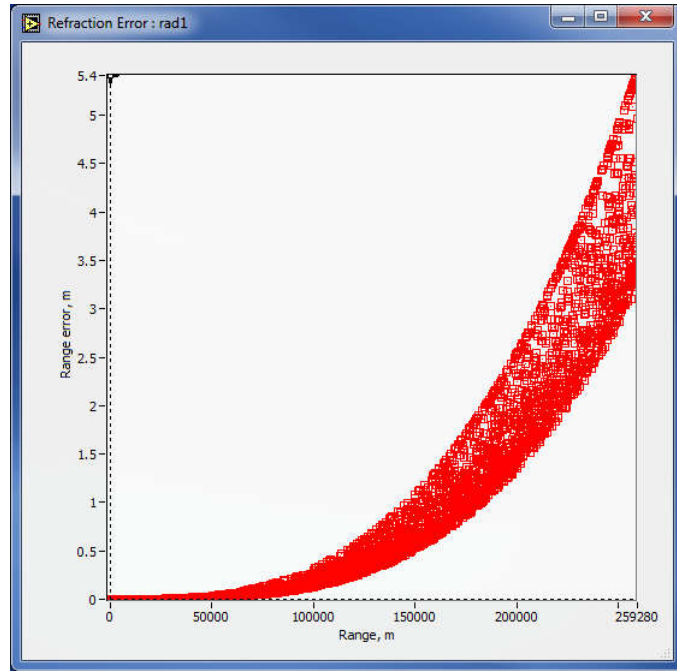
Figure 6-7: Refraction correction

6.3   Filter

Refer to Reference [6].

6.3.1   Typical filter examples

Example 1: Filter when using ADS-B as reference
Note: the ADS-B reference source in this example has radar index "0", while the RUT is radar "1". The filter will pass all plots from radar 1 or all plots with a Figure of Merit >= 6 and 3D height not zero (S/D is the name of the field in S4 where 3D height is stored, in the altitude field the C-code is stored)
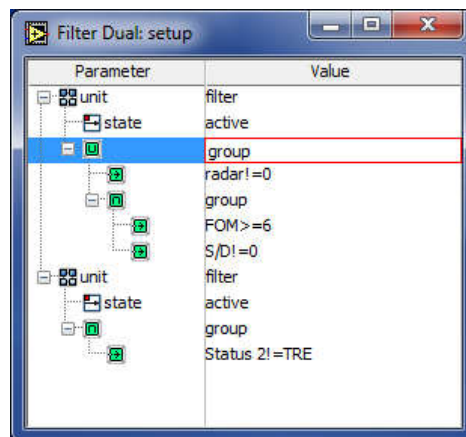
Figure 6-8: Filter Example 1

6.4   Plot (track) info

Refer to Reference [6].

6.5   Displays

6.5.1   XY display

The XY display displays maps, relief, airports and runways, correlated and non-correlated tracks originated from both sources (REF and RUT), the reconstructed trajectory and the error between RUT target report and trajectory. The display can be readjusted to fit the available viewable area, and easily reconfigured to display required amount of the data.
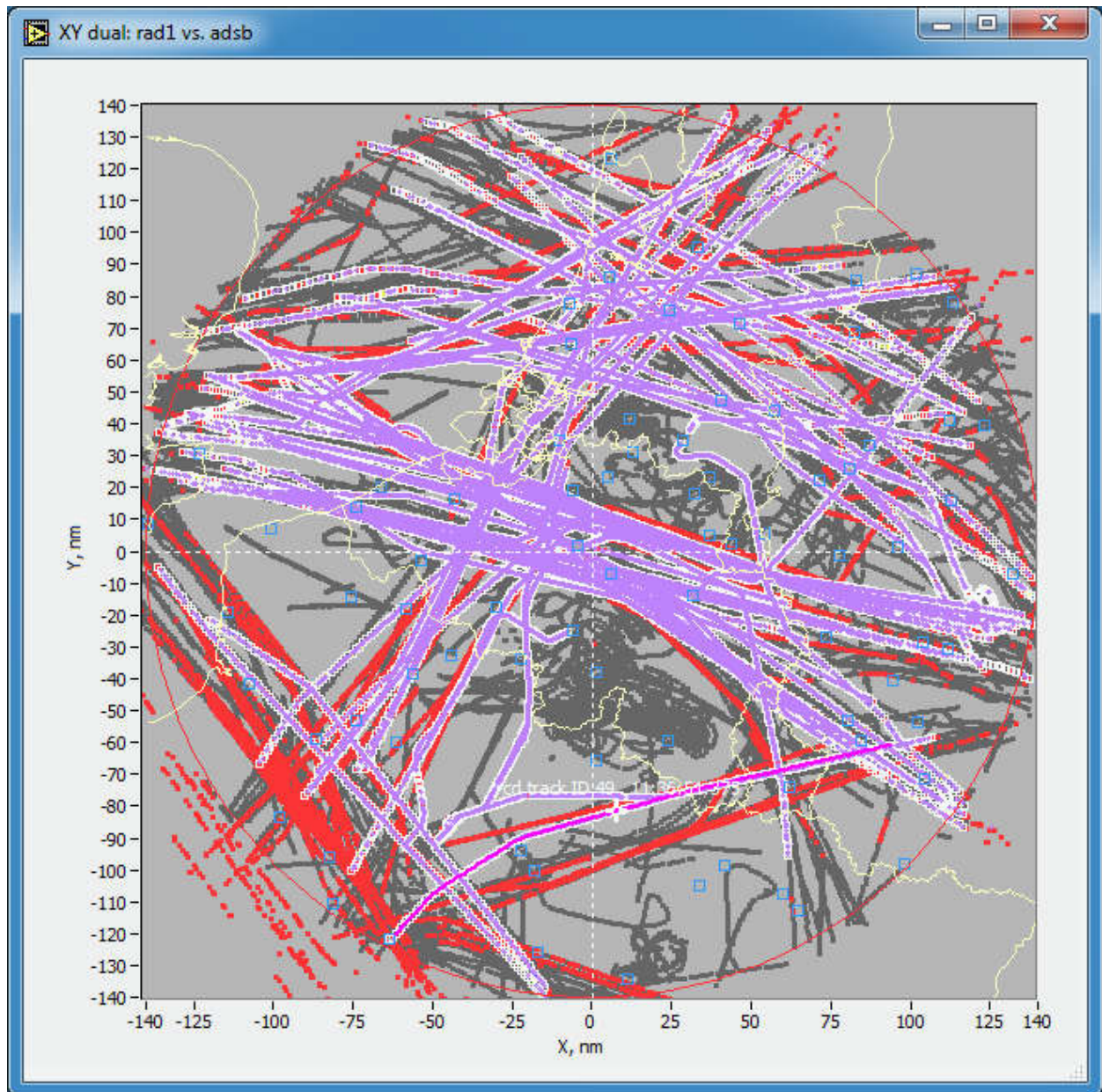
Figure 6-9: XY display

6.5.2   Accuracy display

The accuracy (random errors) displays graphically present the calculated random range errors vs. random azimuth errors. For an ADS-B source the diagram plots the corresponding positional errors along the track (L) and tangential to the track (T). The errors are inferred using the true trajectory reconstruction. The presentation can use multicolour error scattering feature showing errors for each trajectory in a different colour that facilitates finding problematic transponders. Or alternatively, when selecting a plot with the cursor, all plots linked to the same trajectory will be selected and highlighted both in the accuracy display and simultaneously in the XY display. Finding problematic transponders and discarding them from the analysis has an important benefit for more accurate radar analysis results.

What error is displayed (RUT or REF) is controlled with the display accuracy parameter (see 5.1.3)
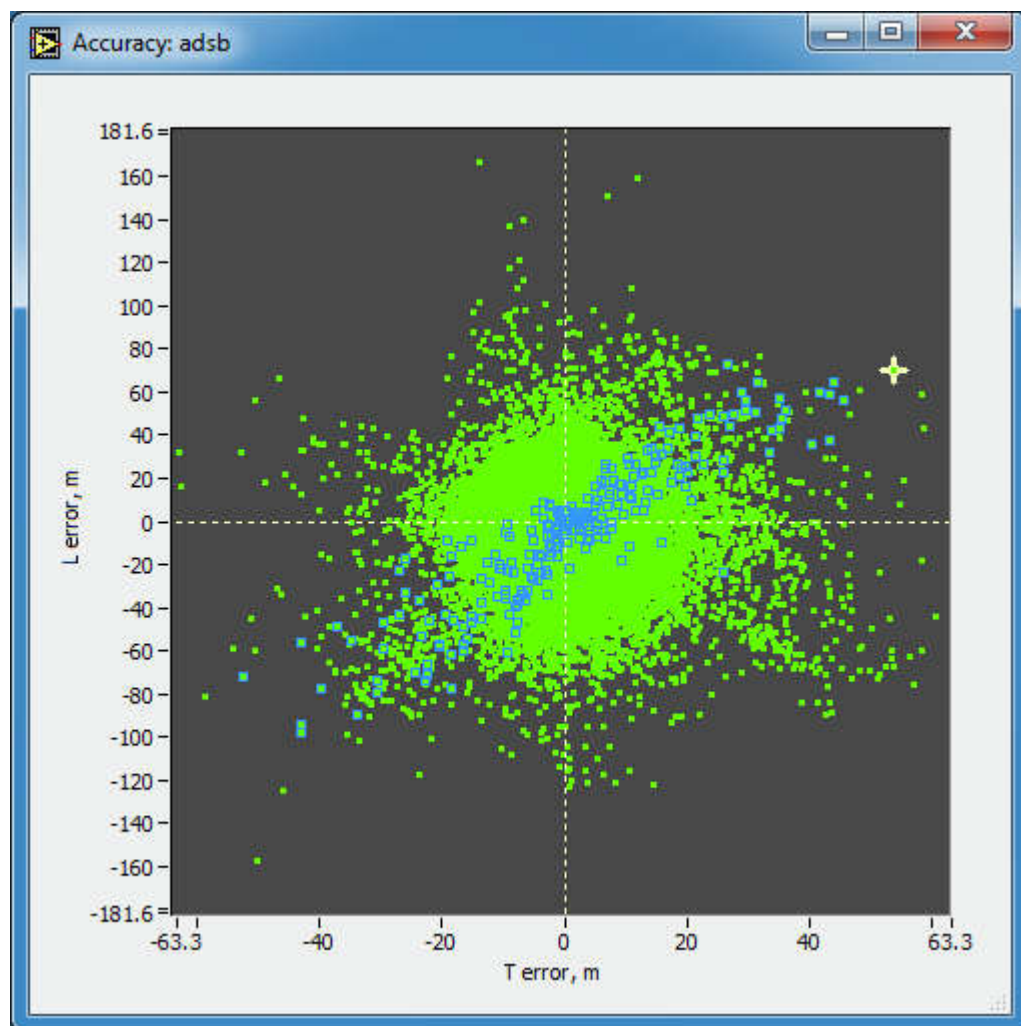
Figure 6-10: Accuracy display, ADS-B reference XY error
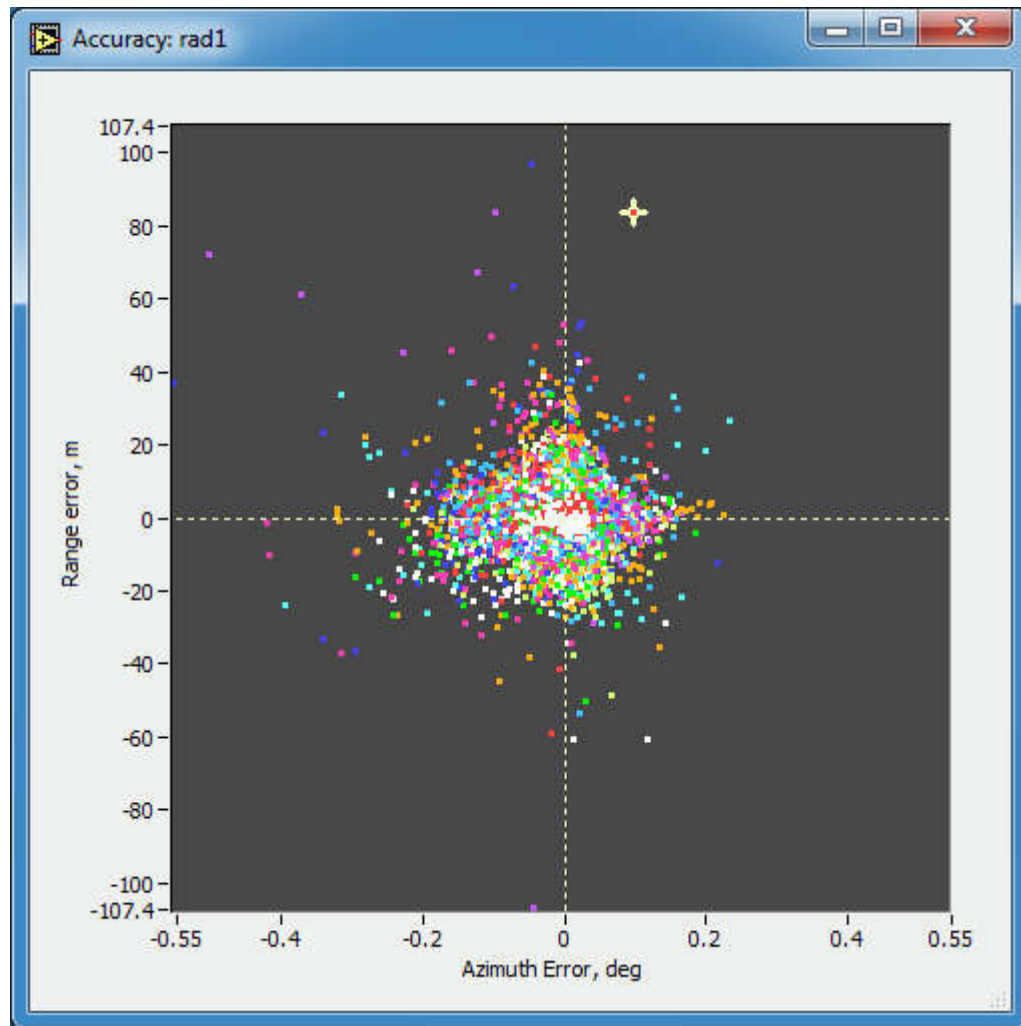
Figure 6-11: Accuracy display, each track is represented by a different color

6.6   Export to SMS

Refer to Reference [6].

7. Statistics

Open the tabular displays using the **tool & displays** menu button in the main window. All the tabular displays are handled in the same way.
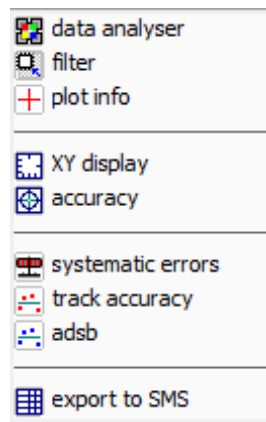
Figure 7-1: Select to open the tabular displays

The user can adjust window sizes, column widths, number of rows and columns etc. Should you make a right mouse click in the window, one of the following menus will appear:
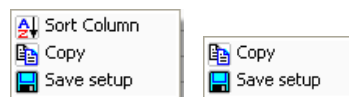
The popup menu entries have the following meaning and functionality:

- **Sort Column**:   used to sort the table according to the contents of the selected column
- **Copy**:   used to copy the table data to the clipboard. From here, it can be pasted in for example a spreadsheet. (e.g. Microsoft Excel)
- **Save setup**:   used to save the layout of the statistics table

The typical outlook of the tables **systematic errors, track accuracy and ads-b** are given below in (Figure 7-2 through Figure 7-4)
In the track accuracy and ADS-B table, a selected row is linked to each table, the XY display and the accuracy display, allowing visual inspection of the corresponding plot (track).

7.1   Systematic and Random Errors

The Systematic and Random Errors lists a set of parameters for the active nodes.
The first column shows the parameter name. The second column will be populated with the value measured for the reference while the 3rd column will report the confidence interval (one sigma) for certain values. 4th and 5th column will hold values for the RUT. The last column will show the target values based on the selected standard.

Parameters	adsb	std	rad1	std	EUROCONTROL
Start Time	11:00:00		11:00:16		
Length	00:59:57		00:59:42		
	NA				
Samples	120707		63880		
Samples Correlated	78018		10210		
Radar Offset, nm	0.0				
Biases: Samples Used	77918		10105		
Range Bias, m	<0.00>	NA	[-6.98]	4.87	14.0
Range Gain, ppm	<0>	NA	-196	56	
Azimuth Bias, deg	<0.0000>	NA	0.0827	0.0011	0.022
Range Error at max range, m			-90.05		
Time Bias, ms			0.0	NA	
Accuracy: Samples Used	67305		9313		
Range Accuracy, m			10.74		15.0
Azimuth Accuracy, deg			0.0549		0.068
Range Error RMS, m			37.85		
Azimuth Error RMS, deg			0.1095		
X Accuracy, m					
Y Accuracy, m					
X Error RMS, m					
Y Error RMS, m					
L Accuracy, m	18.16				
T Accuracy, m	6.33				
Speed Noise, m/s	0.6783				
Heading Noise, deg	0.1940				
Iteration	25				
Average Residual, m	57.992				
Elapsed Time Biases	2.23				
Elapsed Time Trajectory	2.43				
Corrections:					
barometric	off		off		
barometric convert	off		off		
eccentricity	off		off		
refraction	off		off		
Mono-radar accuracy estimates:					
Range Accuracy (mono), m			5.96		
Azimuth Accuracy (mono), deg			0.0343		
XY Accuracy (mono), m	9.80				

Figure 7-2: Systematic errors table

The following table explains the different parameters. Refer to References [2], [3] and [7] for further details:

Table 7-1: Statistics explanation

Parameters	Explanation
Start Time	Timestamp of first message in the data
Length	Length of the selected data.
Samples	Number of plot (track) messages present after filtering
Correlated Samples	Number of plot (track) messages associated to a trajectory
Radar Offset, NM	Distance in NM between the 2 nodes. Together with the confidence intervals used to confirm the quality of the evaluation. RCD conducts an absolute measurement which assumes that the radars must not be co-located. Accuracy of the measurement may be seriously compromised when radars are closely spaced. For practical consideration offsets more than 20NM typically produce good accuracy. The same must be noted for the radars very distant from each other, evaluation performed on the radars only having very limited common coverage may be inaccurate. Not applicable when ADS-B is used as reference.
Biases: Samples Used	Number of target messages used for Bias computation
Range Bias, m	[] used when ADS-B is used as reference, means the range bias is inferred as a weighted average of the measured transponder delays
Range Gain, ppm	<-293> means range gain was fixed in the computation at -293ppm
Azimuth Bias, deg	
Range Error at max range, m	The formulae used for the range error at the maximum range: **Rerr=(dR+Rg*Rmax)+3*sigmaR**, if (dR+Rg*Rmax) is positive **Rerr=(dR+Rg*Rmax)-3*sigmaR**, if (dR+Rg*Rmax) is negative Where **dR** is the range bias and **Rg** is the range gain **Rmax** is the theoretical maximum range of the radar
Time Bias, ms	Time bias is not calculated for ADS-B if the latency flag is set to ON
	The following quantities (standard deviation and RMS) are computed after true trajectory reconstruction, using data of both sources if trajectory reconstruction was ON.
Accuracy: Samples Used	Number of target messages used for Accuracy computation
	Following group is populated for reference types PSR, SSR, MODE-S
Range Accuracy, m	Random radar range error (standard deviation)
Range Error RMS, m	Random radar range error (RMS)
Azimuth Accuracy, deg	Random radar range error (standard deviation)
Azimuth Error RMS, deg	Random radar azimuth error (RMS)
	Following group or errors are only calculated for reference type MRT
X accuracy, m	Random X error (standard deviation)
Y accuracy, m	Random Y error (standard deviation)
X error RMS, m	Random X error (RMS)
Y error RMS, m	Random Y error (RMS)
	Following group is only populated for reference type ADS-B
Random L Error, m	Random ADS-B error (standard deviation) along the track
Random T Error, m	Random ADS-B error (standard deviation) across the track
Speed Noise, m/s	Measured average trajectory speed noise (standard deviation)
Heading Noise, deg	Measured average trajectory heading noise (standard deviation)
Iteration	Number of the performed iterations
Average Residual, m	Average distance between the synchronized plot positions
Elapsed Time Biases, ms	Processing time of the systematic errors computation

Elapsed Time Trajectory, ms	Processing time of the random errors computation
Corrections:	Actually selected corrections
barometric	
barometric convert	
eccentricity	
refraction	
Mono-radar accuracy estimates	
Range Accuracy (mono), m	radar mono-source measured range accuracy estimate
Azimuth Accuracy (mono), deg	radar mono-source measured range accuracy estimate
XY position error for ADS-B (mono), m	ADS-B mono-source measured position accuracy estimate

7.2   Track accuracy

Figure 7-3: Track accuracy and statistics table

The track accuracy (track based statistics) is very useful to detect AC with anomalous systematic and random errors etc. This kind of anomalies may have nothing to do with the radar functioning, but related to the transponder problems. Trajectories with abnormal statistics in common airspace with the other trajectories with "normal" accuracy must be carefully handled and should be filtered out to obtain objective radar performance figures. However this type of the filtering must be performed with caution. Excessive filtering may compromise the measurement objectivity and trustworthiness. The track accuracy table can be sorted according to the column contents and has cross-cursor links with the other displays.

The displayed errors for each trajectory are first the systematic errors, random errors and number of used target reports (count) for the REF and than for the RUT. These reported error change depending on the selected reference type for REF and RUT (see 5.2.1). In above example the REF was ADS-B and RUT was MODE-S.

7.3   Using ADS-B source as a reference

The RCD software performs track to track association for the data originated from two independent sources. Whenever ABS-B data can be available, it is preferable for the radar performance analysis as opposed to radar to radar evaluation type. The main advantage of ADS-B data is that ADS-B is intrinsically bias-free and typically contains the true height of the AC, which produces a more accurate reference for the range compared with that produced using C-code (even corrected for the barometric error using atmospheric soundings data). Radar range accuracy depends almost solely on the clock quality and typically is comparable with GPS position accuracy or better. Radar to radar comparison prediction accuracy often suffers from the barometric errors, eccentricity errors, refraction errors, as well as transponder delays. That is why the range bias estimation derived from a radar to radar comparison campaign usually is less accurate than similar radar to ADS-B comparison campaign. Typically, evaluation using two radars produces the range bias values that change in time according to the weather in the order of magnitude 0÷100m. The corresponding result, calculated for the case when the barometric correction is applied, the variation band shrinks to 0÷50m. Obviously the barometric correction is a must to obtain more accurate measurements. But due to the fact that the barometric error depends also on the geographic position, the full correction has to be as well depending on the volume and time and not only on the height, so that unfortunately the barometric correction doesn't completely compensate the errors, especially when the atmospheric conditions are non-uniform in space and time.

ADS-B may be configured to have the *true height* (presumable GPS height) correction as opposed to the barometric height. Note how the true height is determined is not documented and may depend on the transponder manufacturer. On several occasions significant differences were observed between the reported true height corrections and the barometric height errors measured with atmospheric soundings. In such cases using C-code for the coordinate transformations (Longitude, Latitude, C-code to Range, Azimuth) applying the barometric correction, often produces more accurate results compared with (Longitude, Latitude, true height to Range, Azimuth) coordinate transformation. ADS-B may also have substantial inaccuracy both in XY position and time. Most of the significant positional errors can be filtered out using the Figure of Merit field (FOM). Aircraft presenting lower accuracy measurement must not be used for the analysis. On the other hand, given ADS-B message doesn't contain timestamp and timestamp is assigned by the ground station, ADS-B position reports are prone to significant latency ranging from a few hundred milliseconds up to several seconds on some rare occasions. If the data are analysed without taking into account these effects, the accuracy (random range and azimuth errors) as well as systematic errors measurements (to somehow lower extent, according to the percentage of such AC compared with the rest of the traffic) may contain significant errors.

A side result that is typically produced using the ADS-B vs. radar comparison is a quantity that characterizes the individual transponder deviation from the standard 3μs or 128μs values (respectively for secondary and Mode-S transponders). Typically according to ICAO standard (Annex 10), a response on the secondary interrogation must be delayed by 3.0±0.5μs for SSR reply and 128±0.25μs for Roll Call reply. The radar assumes all the transponders have the nominal 3μs or 128μs delays which are typically subtracted from the time of arrival. However actual deviation of an individual transponder can produce an additional bias on a trajectory up to about ±37.5m, ±75m respectively. The collection of individual transponders would produce a distribution that can be seen as a histogram which may significantly affect the systematic error results (in the first place range bias) and the inferred range accuracy (random errors), especially if the radar range accuracy is expected to be much better than ±37.5m or ±75m (one sigma 12.5m and 25m respectively). This is very likely for the latest generation of the modern radars

having the range accuracy capability of 5m (standard deviation). These radars measured with SASS-C type comparison will often have the range accuracy of about 20-25m.

Due to the intrinsically bias-free character of ADS-B, these range biases per trajectory can be effectively evaluated. Moreover the transponder delays can be measured in comparing ADS-B data with different radars and in such way to confirm their independence from the other parameters. Once confirmed, these delays can be subtracted for each trajectory and the true range accuracy of the radar can be evaluated.

Since RCD v1.2.0 the biases per trajectory are inferred on the basis of the comparison between raw radar and ADS-B data. A difference must be made between SSR and Mode-S replies for these delays are different. Residual range biases per trajectory determined by comparing ADS-B source with Mode-S radar (**rad1**), and them comparing the same ADS-B source with another Mode-S radar (**rad2**). Obviously, a very good correlation between the two data series confirms the idea that these small range biases per trajectory is nothing else than the actual deviations of the transponders delays from 128µs, expressed in meters as can be seen in Figure 7-5. In Figure 7-6 the corresponding results of the latency measurement performed for the same two Mode-S radar data sets compared with ADS-B. The good agreement between the two sources is obvious. For further reading about the method and applications please refer to Reference [5].

#	S Address	date	time	duration	radar	L, s	std L, s	Xp A/C, m	Xp S, m	std Xp, m	std V, m/s	std H, deg	FOM
0	6A04E	24 Jan 2008	11:23:11.738	26:41.8	rad2	0.062	0.035		-9.42	12.95	0.703	1.130	6
1	3415CE	24 Jan 2008	11:09:50.468	22:32.4	rad2	-0.459	0.037		-34.45	13.88	0.311	0.159	7
2	3420D9	24 Jan 2008	11:00:23.031	22:07.9	rad2	-0.053	0.037		-65.94	11.52	1.009	0.370	7
3	34224C	24 Jan 2008	11:16:11.589	24:30.4	rad2	-0.090	0.025		-70.39	11.43	1.302	0.415	7
4	342558	24 Jan 2008	11:39:45.707	20:06.0	rad2	-0.144	0.056		-18.44	11.16	1.131	1.980	7
5	394A62	24 Jan 2008	11:24:28.101	26:29.8	rad2	-0.469	0.042		-62.28	7.91	0.570	0.418	6
6	3950CE	24 Jan 2008	11:00:29.460	22:25.4	rad2	-0.177	0.045		-68.26	17.11	1.049	1.008	6
7	3C6665	24 Jan 2008	11:36:49.117	23:08.4	rad2	-0.742	0.088		-49.34	33.43	3.231	0.655	7
8	400140	24 Jan 2008	11:00:22.179	21:14.8	rad2	-0.100	0.058		-1.90	14.53	0.704	1.357	6
9	400774	24 Jan 2008	11:23:00.777	30:53.2	rad2	-0.355	0.032		-13.17	5.65	0.719	0.084	6

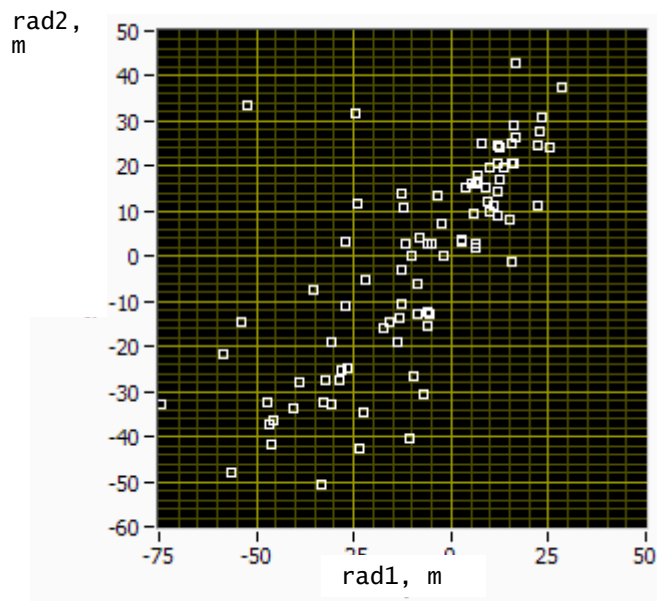*Figure 7-4: ADS-B statistics table measured vs. rad2*

Figure 7-5: Residual range biases in meters per track measured by comparing ADS-B source with rad1, and then comparing the same ADS-B source with rad2
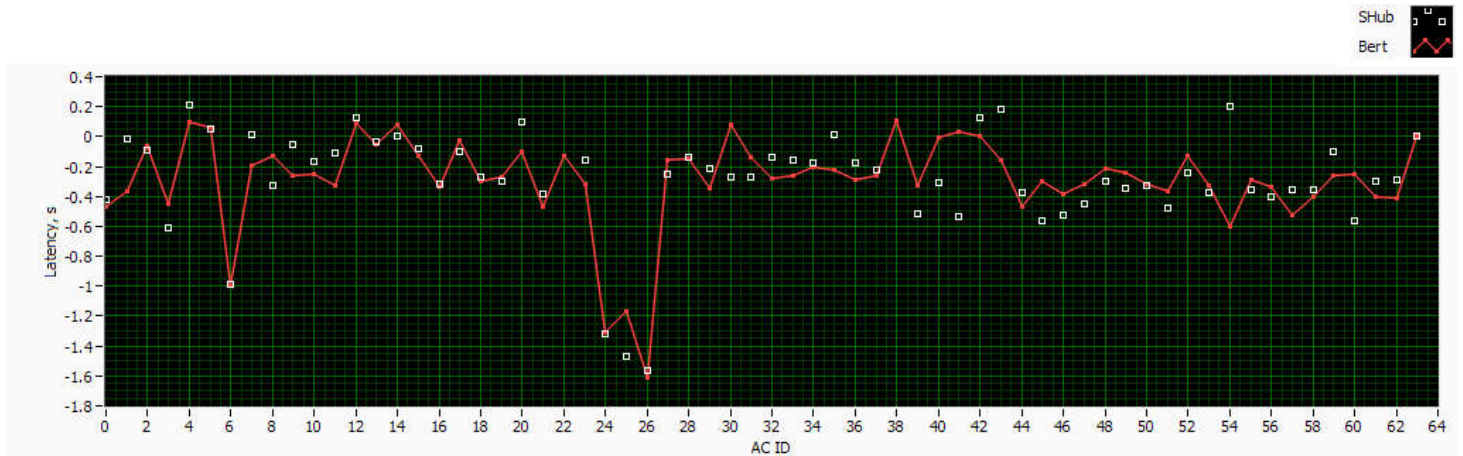
Figure 7-6: ADS-B latency per track measured by comparing ADS-B source with rad1, and them comparing the same ADS-B-source with rad2

8. Multiple radar analysis

The main window can contain a number of radar sources {nodes} able to have common coverage volume amongst them. In this case RUT can be compared to a number of the other sources (REFs) in order to check consistency of the inferred values. The procedure of the evaluation is the following. User selects a radar under test (RUT) and changes the references, every time the results of the systematic errors determination can be directly stored in the data base (DB3 file), or user can manually copy and paste them in an appropriate program (e.g. Microsoft Excel). Changing the RUT the procedure can be repeated to all the sources of interest in the radar set. Analysis of the obtained results is very efficient to detecting radar malfunctioning and problems hidden in a combined multi-source measurement. Please see here below an example of such an evaluation session. The data set contained 6 radars (2 Mode-S and 4 MSSR) and ADS-B source, as given in Figure 8-1. Some results of the evaluation of these vs. ADS-B source during 5 days are given in Table 8-1. An outstanding accuracy and consistency of the range bias measurements can be observed. This type of accuracy is definitely became possible due to the ADS-B data containing true height of AC used for the range conversion as opposed to the C-code which is affected by the local atmospheric conditions. A similar comparison performed by comparing the radars with radars typically produces less accurate results for the range bias. Range biases variations due but not limited to the weather effects have been reported being on average of about 100m peak-to-peak (about 17m standard deviation). For more details about the method and applications please refer to Reference [5]

Figure 8-1: Multi-radar evaluation example

Table 8-1: RCD multiple radar comparison with ADS-B data
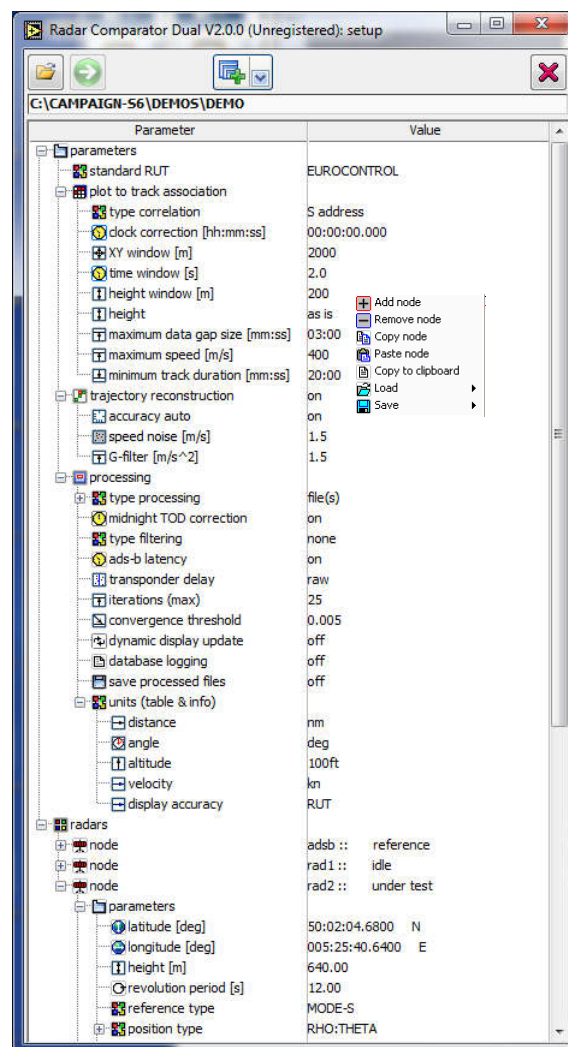
Dates	24-01-2008		25-01-2008		26-01-2008		27-01-2008		28-01-2008		average	stdev
Radar 1 On Mtd												
Parameters	ADS-B	Radar 1 On	ADS-B	Radar 1 On	ADS-B	Radar 1 On	ADS-B	Radar 1 On	ADS-B	Radar 1 On		
Correlated Samples	139219	19488	134666	17819	150734	20169	143518	19099	118904	15181		
Radar Offset, NM	0		0		0		0		0			
Range Bias, m	<0.000>	5.288	<0.000>	5.843	<0.000>	10.172	<0.000>	-2.18	<0.000>	5.305	4.9	4.4
Range Gain, ppm	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>		
Azimuth Bias, deg	<0.000>	0.086	<0.000>	0.096	<0.000>	0.094	<0.000>	0.084	<0.000>	0.078	0.088	0.007
Iteration	12		11		11		6		11			
Average Residual, m	54.4		53.13		54.86		61.79		55.94			
Radar 2 On Mtd												
Parameters	ADS-B	Radar 2 On	ADS-B	Radar 2 On	ADS-B	Radar 2 On	ADS-B	Radar 2 On	ADS-B	Radar 2 On		
Correlated Samples	124451	15692	121873	14509	134314	15822	125487	15344	106049	12063		
Radar Offset, NM	0		0		0		0		0			
Range Bias, m	<0.000>	0.933	<0.000>	-2.426	<0.000>	1.786	<0.000>	-6.441	<0.000>	-0.999	-1.4	3.2
Range Gain, ppm	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>		
Azimuth Bias, deg	<0.000>	0.051	<0.000>	0.044	<0.000>	0.038	<0.000>	0.02	<0.000>	0.023	0.035	0.013
Iteration	11		9		11		13		15			
Average Residual, m	52.88		52.73		51.61		58.32		52.8			
Radar 3												
Parameters	ADS-B	Radar 3	ADS-B	Radar 3	ADS-B	Radar 3	ADS-B	Radar 3	ADS-B	Radar 3		
Correlated Samples	135876	35713	133236	33818	147164	37341	137894	34684	118844	29468		
Radar Offset, NM	0		0		0		0		0			
Range Bias, m	<0.000>	5.314	<0.000>	3.583	<0.000>	4.808	<0.000>	16.228	<0.000>	7.54	7.5	5.1
Range Gain, ppm	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>		
Azimuth Bias, deg	<0.000>	0.069	<0.000>	0.035	<0.000>	0.034	<0.000>	0.065	<0.000>	0.067	0.054	0.018
Iteration	12		8		7		15		9			
Average Residual, m	58.01		60.12		60.5		59.73		58.5			

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Dates Radar 4		24-01-2008		25-01-2008		26-01-2008		27-01-2008		28-01-2008		average	stdev
Parameters	ADS-B	Radar 4	ADS-B	Radar 4	ADS-B	Radar 4	ADS-B	Radar 4	ADS-B	Radar 4		
Correlated Samples	127877	37084	126299	35898	136378	37568	127082	35198	110584	29963		
Radar Offset, NM	0		0		0		0		0			
Range Bias, m	<0.000>	-24.831	<0.000>	-22.143	<0.000>	-21.286	<0.000>	-20.772	<0.000>	-24.484	-22.7	1.9
Range Gain, ppm	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>		
Azimuth Bias, deg	<0.000>	-0.036	<0.000>	-0.036	<0.000>	-0.039	<0.000>	-0.044	<0.000>	-0.036	-0.038	0.003
Iteration	12		13		12		15		10			
Average Residual, m	51.37		55.26		50.7		54.14		47.7			
Elapsed Time	57.06		55.94		63.6		71.72		38.77			
Radar 2 Off Mtd												
Parameters	ADS-B	Radar 2 Off	ADS-B	Radar 2 Off	ADS-B	Radar 2 Off	ADS-B	Radar 2 Off	ADS-B	Radar 2 Off		
Correlated Samples	121086	12562	119813	11781	132590	13252	121815	12060	103731	10031		
Radar Offset, NM	0		0		0		0		0			
Range Bias, m	<0.000>	-13.013	<0.000>	-10.57	<0.000>	-10.474	<0.000>	-6.984	<0.000>	-10.411	-10.3	2.1
Range Gain, ppm	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>		
Azimuth Bias, deg	<0.000>	-0.058	<0.000>	-0.058	<0.000>	-0.059	<0.000>	-0.064	<0.000>	-0.063	-0.060	0.003
Iteration	7		8		6		8		7			
Average Residual, m	56.6		56.87		56.94		50.02		56.75			
Elapsed Time	22.09		22.58		21.05		25.28		16.44			
Radar 1 Off Mtd												
Parameters	ADS-B	Radar 1 Off	ADS-B	Radar 1 Off	ADS-B	Radar 1 Off	ADS-B	Radar 1 Off	ADS-B	Radar 1 Off		
Correlated Samples	134406	15188	130410	13881	146167	15843	139007	15046	115983	12088		
Radar Offset, NM	0		0		0		0		0			
Range Bias, m	<0.000>	-26.711	<0.000>	-24.772	<0.000>	-21.898	<0.000>	-24.527	<0.000>	-25.842	-24.8	1.8
Range Gain, ppm	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>	<0.000>	<-293.000>		
Azimuth Bias, deg	<0.000>	0.007	<0.000>	0.013	<0.000>	0.01	<0.000>	0.008	<0.000>	0.01	0.010	0.002
Iteration	6		8		6		8		6			
Average Residual, m	53.84		50.26		57.44		50		58.3			
Elapsed Time	20.86		24.11		24.06		29.34		16.39			

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9. Troubleshooting/Q&A

Problem: When running the Data Analyser without a filter, you see the following message:
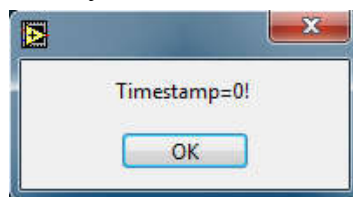

Figure 9-1: Timestamp=0

Reason: One or more fields of the selected timestamp type (TOR or TOD) are 0. This may indicate some problems with the source data or, the conversion software. The timestamp analysis can't be conducted.
Solution: Use the filter sentence (timestamp!=0) to remove the messages.

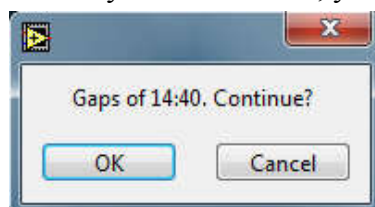**Warning:** When running the Data Analyser with a filter, you see the following message:

Figure 9-2: Gaps in data

Reason: An interruption in the data stream is detected. The results will be produced if OK is selected, however some artefacts might exist near the gap, due to the inaccurate timestamp interpolation over longer gaps.

Solution: Warning message, caution is required to interpret the results.

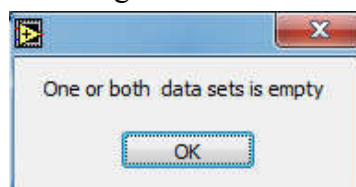**Problem:** When running RCD the message "One or both data sets is empty" is produced.

Figure 9-3: One or both data sets is empty

Reason: When reading the file(s) and after applying the filter no data is present for one or both of the nodes. The file may be deleted, or the filter doesn't pass any data.

Solution: Use the data analyser to identify which source produces the empty data set, adjust the filename or the filter.

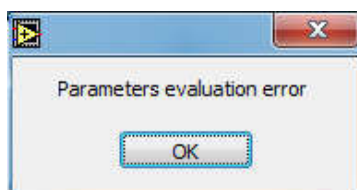**Problem:** Processing results in a "Parameter evaluation error"

Figure 9-4: Parameter evaluation error

Reason: RCD can not produce a result. This type of error might be generated when:
- the correlated data set is very small (0÷few hundred samples),
- wrong sensor parameters (e.g. incorrect position of the sensor, incorrect reported plot/track position type etc.),
- unexpected errors in the data are present (e.g. C-code is zero for all the reports).

Solution: The message is produced because the parameter evaluation process doesn't converge, due to a badly conditioned matrix, etc. Double check the sensor parameters (position and reported plot/track position type) and the filtering settings (the data analyzer can be used). Try to estimate the data quality (make sure the acquired data don't represent any strange trend, strange field values etc.) In the case when the count of correlated samples is less than expected (i.e. the number of samples in the files is large, but low count of the correlated samples), check expected sensor biases, including time bias and accuracy (e.g. if one of the radars is aligned to magnetic north, make sure to set a North bias), increase XY window size if "3/A-code to Position" or "S-address to Position" are used and the sensor is known to have poor accuracy.

If everything seems to be ok, check if the processing parameters are not too limiting. If you are using for example a recording of only 30 minutes and the minimum track length is set to 20 min it is very likely that only a few trajectories will qualify.

If you are attempting to analyze radar vs. radar and they are co-located or offset by a distance less than 20Nm you might need to lock the range bias, range gain and/or azimuth bias of the reference node.

Question: When should one lock a systematic error?
Answer: The RCD uses matrix inversions to calculate the systematic errors. In some cases the variables may become dependent and can not be resolved simultaneously, then locking of a variable is required. Alternatively, if certain variable is well known, one can fill in the value and lock it so that the parameter will become a constant instead of a variable. In some cases the software will automatically lock biases and disable these (e.g. selecting ADS-B as REF will lock and disable range, range gain and azimuth biases), because for ADS-B the positional error is uniform and bias free. Unfortunately ADS-B doesn't have synchronous position detection (see 7.3), and therefore cannot be used to calculate a time bias. When ADS-B is used as reference one can also calculate the transponder delay for each aircraft, when locking the range bias of the RUT the range bias will still be calculated as the average of the measured transponder delays.
Also when comparing two co-located (or closely spaced) radars, one may need to lock the biases of one of the radars in order to get a valid result. Keeping the biases unlocked may still produce some results with abnormally large confidence intervals, or may produce parameter evaluation error.

REFERENCES

Reference   **Document**
  [1]   RASS-R User Manual, Intersoft Electronics 2005
  [2]   ICAO Document 8071 Volume III Manual on Testing of Radio Navigation
            Aids , Testing of Surveillance Radar Systems
  [3]   EUROCONTROL Standard Document for Radar Surveillance in En-Route
            Airspace and Major Terminal Areas
  [4]   SASS-C Study on MURATREC Multi Radar Trajectory Reconstruction
            Toolbox. Part Two, Intersoft Electronics 2003
  [5]   Radar Alignment and Accuracy Tool, RASS-R Radar Comparator Dual,
            Intersoft Electronics 2009 (published at ATCA 2009), see website
  [6]   Usermanual of the Radar Comparator Mono (IE-UM-00029-xxx RCM.pdf)
  [7]   EUROCONTROL Standard Document for RADAR SENSOR
            PERFORMANCE ANALYSIS