CRD v2 Conversion Status

R. Ricklefs
University of Texas at Austin

CRD v2 Implementation Status

- 30 stations are providing CRD v1 and v2 data in parallel.
- Almost all of these have been vetted by Van Husson and Erricos Pavlis
- 8 of the Russian stations are missing
- 3 other stations that are having temporary station problems, etc. are also missing

Plans

- To deal with the non-compliant stations, the plan is for their data to be converted from CRD v1 to v2 by EDC until such time as they can provide the v2 data themselves
- 20-30 historical passes from each of the geodetic satellite passes will be converted for each station to test the conversion process
- Hopefully, the conversion and vetting process will finish in the next few months (July 31 or September 30?)

Dear ILRS colleagues,

We are writing to let you know that the ELSA-d Servicer has successfully completed controlled close approach with Client on 7th April 2022. We are grateful and thank you from the bottom of our heart for continuously tracking the two satellites during the challenging times of the ELSA-d Phase 3b demo. Accuracy of the orbit is very crucial for close approaches and the ILRS data was critical to increase the accuracy of the orbit solutions. We understand you had difficulties tracking the Servicer satellite after manoeuvres. Thank you for understanding the complexity of Rendezvous missions.

There were many challenges in the Phase 3b demo including failure of four thrusters of Servicer satellite. The biggest challenge was replanning the rendezvous approach with the use of only four of the eight thrusters on the servicer. This restricted the ability of the servicer to perform detailed rendezvous manoeuvers with the client as originally planned. However, on April 7, using the limited set of available thrusters, the servicer successfully manoeuvred to a distance of 159 meters from the client, and the ability of the servicer to search for and detect the client was validated, enabling a transition from absolute navigation, which relies on GPS and ground-based observations, to relative navigation, using on-board sensors.

Despite not yet being able to complete the autonomous capture demonstration, the ELSA-d mission has proven several key technologies required for capturing orbital debris, including autonomous guidance, navigation and control algorithms, closed loop control with on-board navigation sensors, autonomous thruster rendezvous manoeuvring and attitude control, navigation of a servicer spacecraft from 1,700 km to within 160 m of a client using absolute navigation techniques (GPS and ground-based observations), transition from absolute navigation to relative navigation using on-board Low Power Radio sensor, more than one year of servicer and client satellite in-orbit mission operations, and magnetic capture mechanism using a docking plate.

The Servicer and Client are now in separate orbits and healthy as we assess potential capture or close approach. Meanwhile Astroscale has few experiments lined up for the coming months. We are planning to conduction experiments to

- identify the effects of attitude change on drag, power, thermal, GPS and ILRS
- deduce the rate of spin of Servicer by tumbling the satellite
- assess potential recapture in few months time

We would share the schedule when we have formal plan in place. It would be interesting to understand how these studies can be used for future Rendezvous missions. We hope to see similar support from you in all our further experiments. Thank you once again. If you have any questions, please write to us at dlzzfdext@astroscale.com.

Regards,

Astroscale Flight Dynamics Team

Kind Regards,
Sharon Sara Saji
Flight Dynamics And Operations Engineer

M: +44 (0)7435455356
O: +44 (0) 1235 612238
E: s.saji@astroscale.com
www.astroscale.com

ILRS/ISRO IRNSS SLR Campaign April 17th-30th, 2022

ILRS/ISRO Report

NEWG Meeting

May 19th, 2022

IRNSS Campaign April 17th-30th, 2022

- Test Campaign on April17 – 30 on IRNSS 1C, 1D, and 1I;
- From past experience, we had very little daylight ranging, and the targets are very low in the sky.
- Difficult targets; IRNSS 1C was the prime target, IRNSS 1D and 1I were added to give one additional target in the East and the West;
- Stations that ranged successfully included Yarragadee (7090), Changchun (7237), Izaña (7701), Shanghai (7821), Wettzell (8834), and Grasse (7845). Grasse and Yarragadee obtained 110 and 51 Normal Points, respectfully; but most were very sparse;
- The newly commissioned ILRS station at Izaña (7701, Tenerife) obtained 22 NP to IRNSS-1I.
- Some of these satellites are more difficult than others because of their particular orbits and the location of the stations.

Thanks to all who tried to range to these difficult targets!

IRNSS Campaign April 17th-30th, 2022

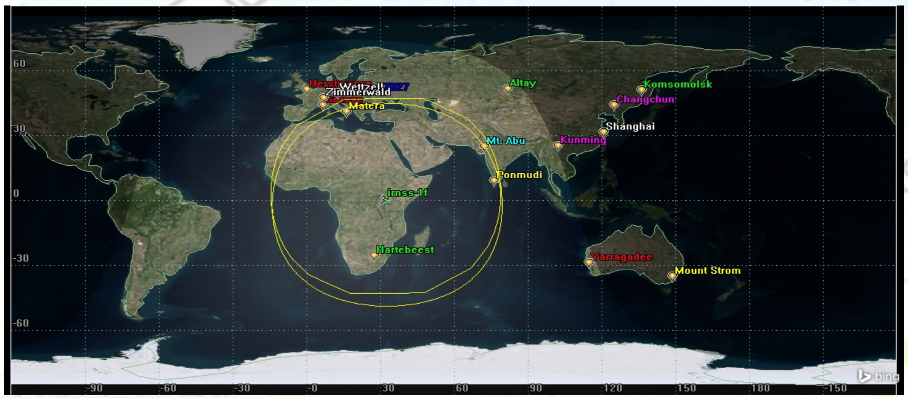
Table 1: IRNSS SLR Campaign April 17th-30th, 2022 (Number of Normal Points, NP)

Station	Satellites			
	IRNSS-1C	IRNSS-1D	IRNSS-1I	Total
7090 Yarragadee	103	22	0	125
7237 Changchun	2	0	0	2
7701 Izaña	0	0	22	22
7821 Shanghai	5	6	0	11
8834 Wettzell	0	0	18	18
7845 Grasse	0	0	110	110
Total	110	28	150	288

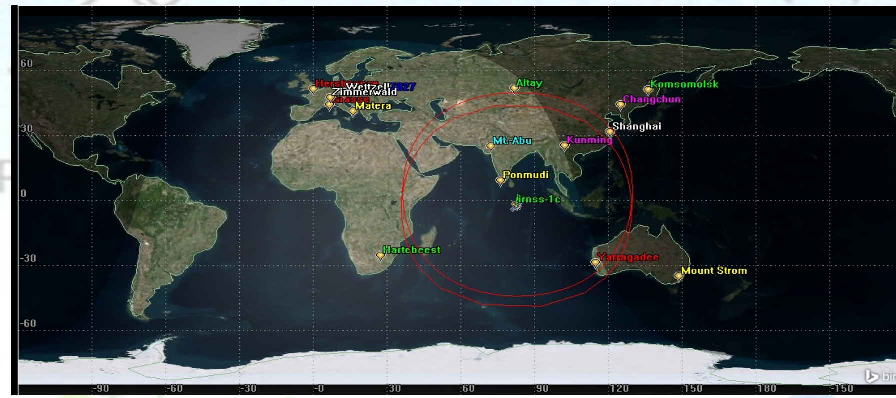
IRNSS Campaign April 17th-30th, 2022

Minimum Elevation: 35°

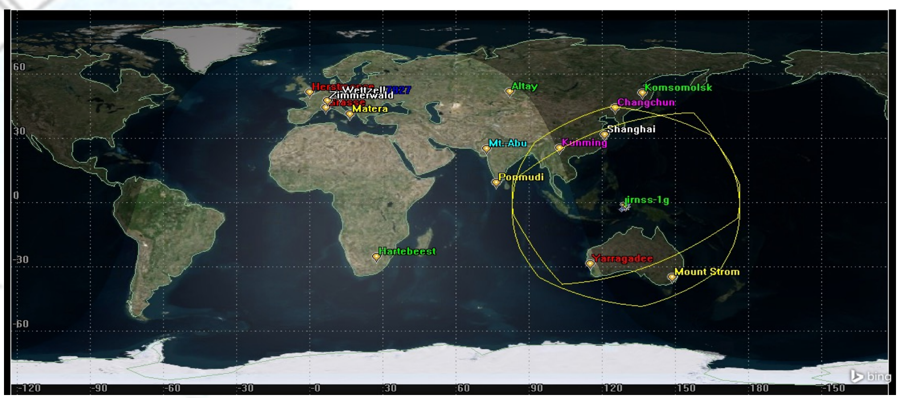
IRNSS 1F



IRNSS 1C



IRNSS 1G



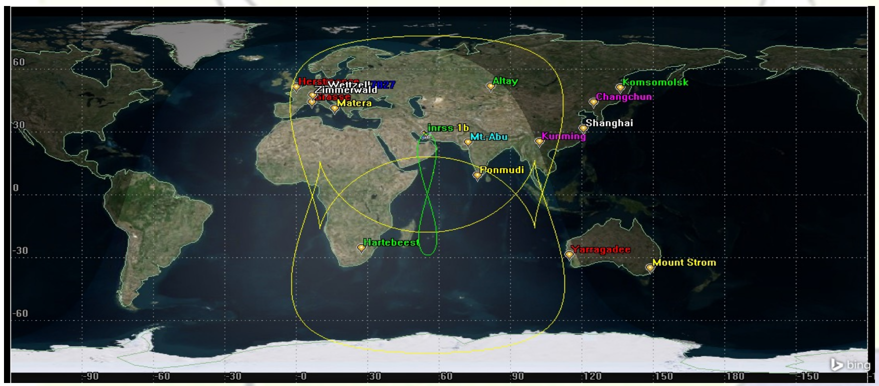
Area of visibility with a 35° minimum elevation for ILRS stations located within its limits.

After Slide provided by Erricos Pavlis & Keith Evans (GESTAR II, UMBC)

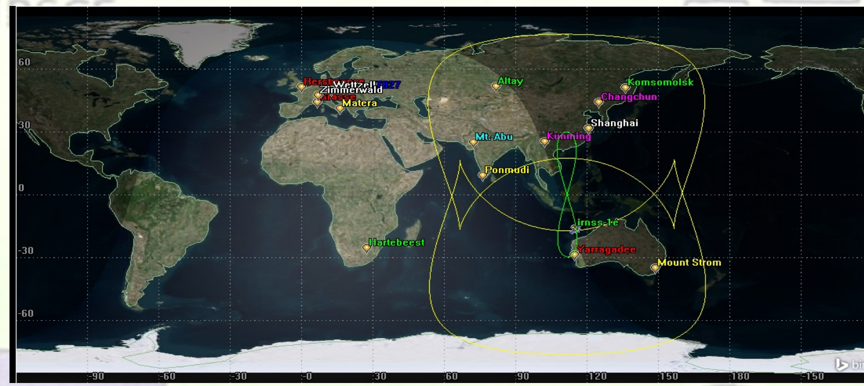
IRNSS Campaign April 17th-30th, 2022

Minimum Elevation: 35°

IRNSS 1I & 1B



IRNSS 1D & 1E



Area of visibility with a 35° minimum elevation for ILRS stations located within its limits.

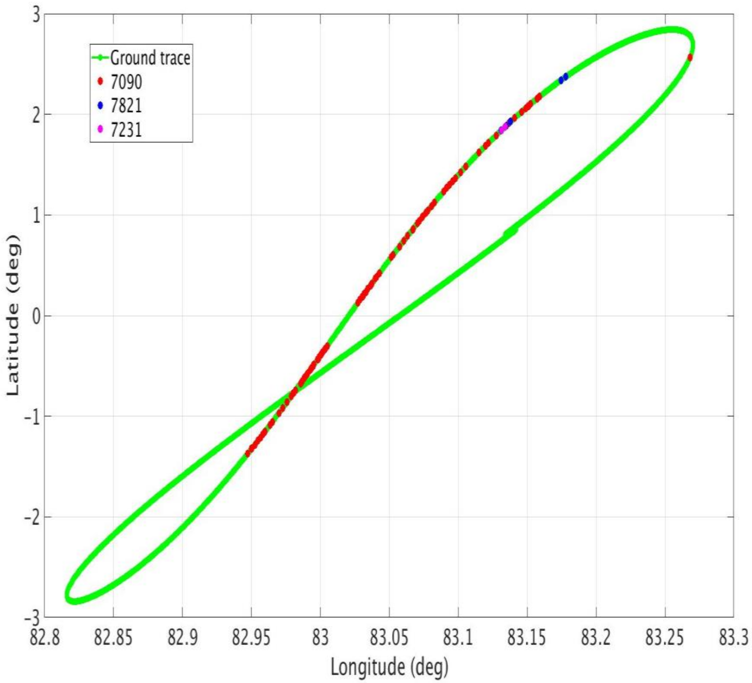
After Slide provided by Erricos Pavlis & Keith Evans (GESTAR II, UMBC)

IRNSS Campaign April 17th-30th, 2022

Statistics for IRNSS-1C tracking campaign during 17-30 Apr 2022

S. No	Date	Tracked Station IDs	No. of points
1	17-04-2022	7090	7
2	19-04-2022	7090	15
3	20-04-2022	7090	17
4	21-04-2022	7090, 7821	25 (20, 5)
5	22-04-2022	7237	2
6	23-04-2022	7090	5
7	24-04-2022	7090	10
8	28-04-2022	7090	8
9	29-04-2022	7090	14
10	30-04-2022	7090	7

Ground trace for IRNSS-1C tracking campaign during 17-30 Apr 2022



7090: Yarragadee, Australia (Total : 103 points)
7821: Shanghai, China (Total : 5 points)
7237: Changchun, China (Total : 2 points)

Observations:

- Out of 100 points, 103 points are tracked from a single **(Yarragadee)** station, and 7 points from a Chinese station (one time tracking).
- Hence, it is as good as single station tracking over a duration of 15 days; this not usable for precise Orbit Determination/navigation applications.
- The total number of normal points over the campaign period is adequate (as per requirement). However, it is expected that tracking is to be distributed across 4-5 stations, to provide good geometry.
- <u>Since tracking is from single stations, arc coverage is not over the entire orbit.</u>

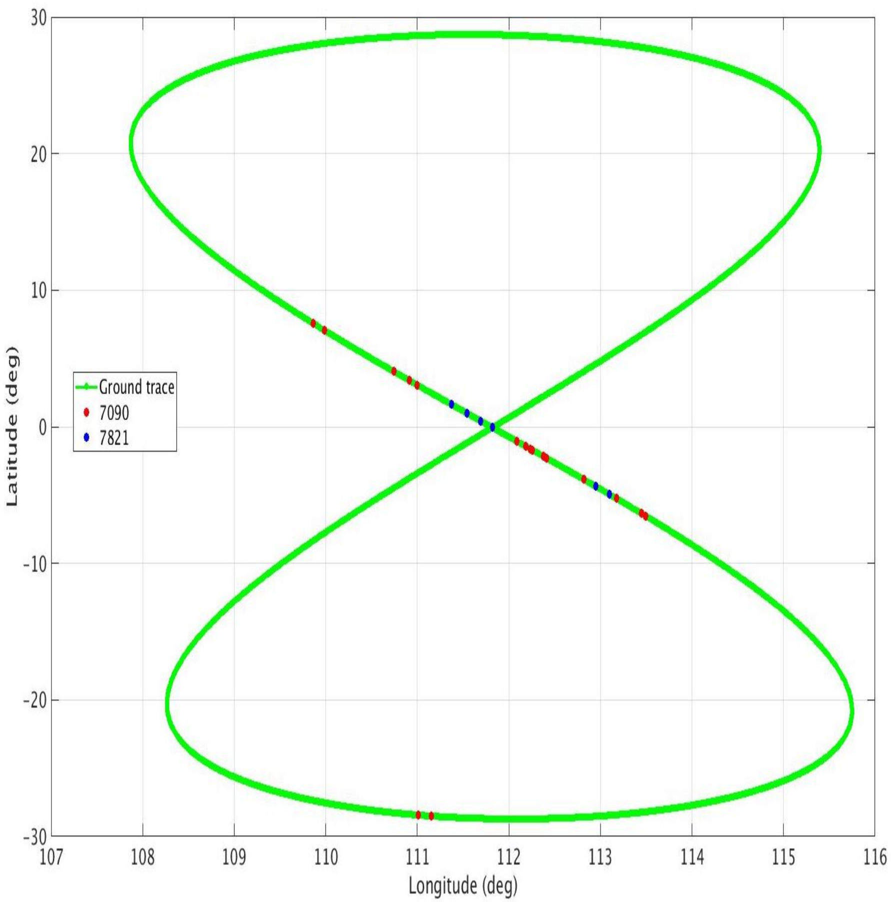
Modified after Slides provided by Sajith, ISRO

IRNSS Campaign April 17th-30th, 2022

Statistics for IRNSS-1D tracking campaign during 17-30 Apr 2022

S. No	Date	Tracked Station IDs	No. of points
1	18-04-2022	7090	5
2	21-04-2022	7090, 7821	11
3	24-04-2022	7090	3
4	27-04-2022	7090	1
5	29-04-2022	7090	4
6	30-04-2022	7090	4

Ground trace



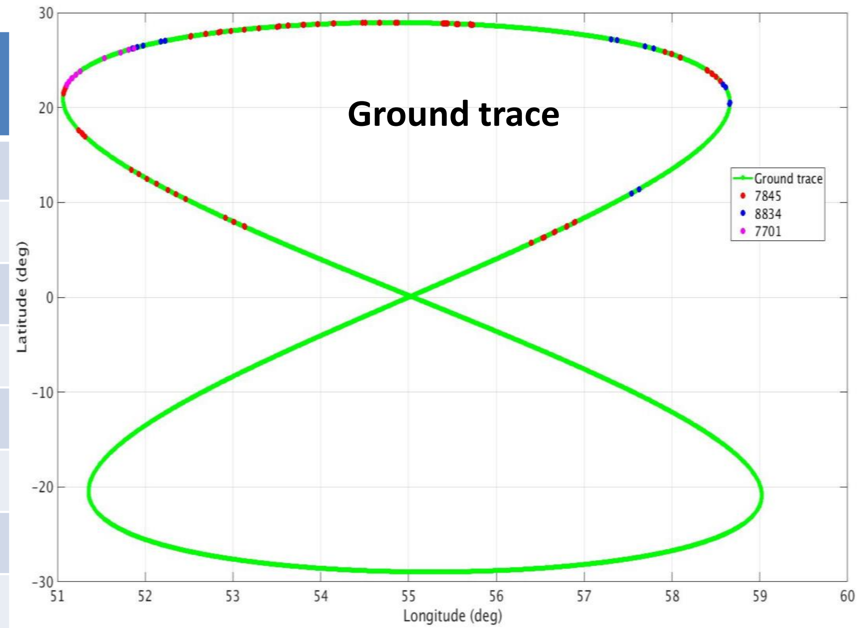
7090: Yarragadee, Australia
7821: Shanghai, China
(China tracked only once)

Slide provided by Sajith, ISRO

IRNSS Campaign April 17th-30th, 2022

Statistics for IRNSS-1I tracking campaign during 17-30 Apr 2022

S. No	Date	Tracked Station IDs	No. of points
1	18-04-2022	8834	2
2	19-04-2022	8834	2
3	21-04-2022	8834,7701	7
4	22-04-2022	8834	2
5	23-04-2022	8834	2
6	25-04-2022	8834,7845	27
7	26-04-2022	7845,7701	34
8	28-04-2022	7845	11
9	29-04-2022	7845,7701	29



8834: Wettzell, Germany
7845: Grasse, France
7701: Izana, Spain
All stations are in Europe (closely located)

Slide provided by Sajith, ISRO

IRNSS Campaign April 17th-30th, 2022

Stations feedback regarding the tracking of IRNSS satellites:

- **Yarragadee:** The station was able to get decent returns and quite a few NP per night before local midnight. They seemed to struggle after local midnight.

- **Mt. Stromlo**: Canberra had cloudy weather for much of the campaign, which eased up only the last few days. The station was unable to get a single return even though they had a visual image. They verified the performance of their ranging system by also ranging to QZSS which gave an excellent return rate.

- **Grasse**: The station only had good weather for the 2nd week. They were able to track both day and night, on some passes they obtained data simultaneously at 1064 nm and 532 nm. They noticed that 200 mj per pulse in the green and 100 mj per pulse in the infrared produced the same return rate.

- **Izaña (Tenerife):** Only IRNSS-1I was visible from their station at a max. elevation of 22° for 3 hours, with the Sun opposite to the target in the sky. They found the prediction quality to be satisfactory, with a time bias of ~20 ms and a range bias of ~50 ns.

IRNSS Campaign April 17th-30th, 2022

Stations feedback regarding the tracking of IRNSS satellites (cont.):

- **Graz:** No returns; weather non ideal; will keep trying; able to see ETS-8.

- **Matera:** No returns; local analysis shows IRNSS-1C not visible for extended periods of time.

- **Zimmerwald:** Out of operation for maintenance; in the past IRNSS very difficult; signal strength at the limit; used minimum divergence and manual tracking corrections using the camera; requires very dedicated effort.

- **Herstmonceux:** No returns; problem of signal strength; very low elevation In the past, occasionally got lucky.

- **MOBLAS 8:** Down for repairs.

SLR Campaign on NavIC Constellation

Initial plans for ISRO/ILRS campaign:

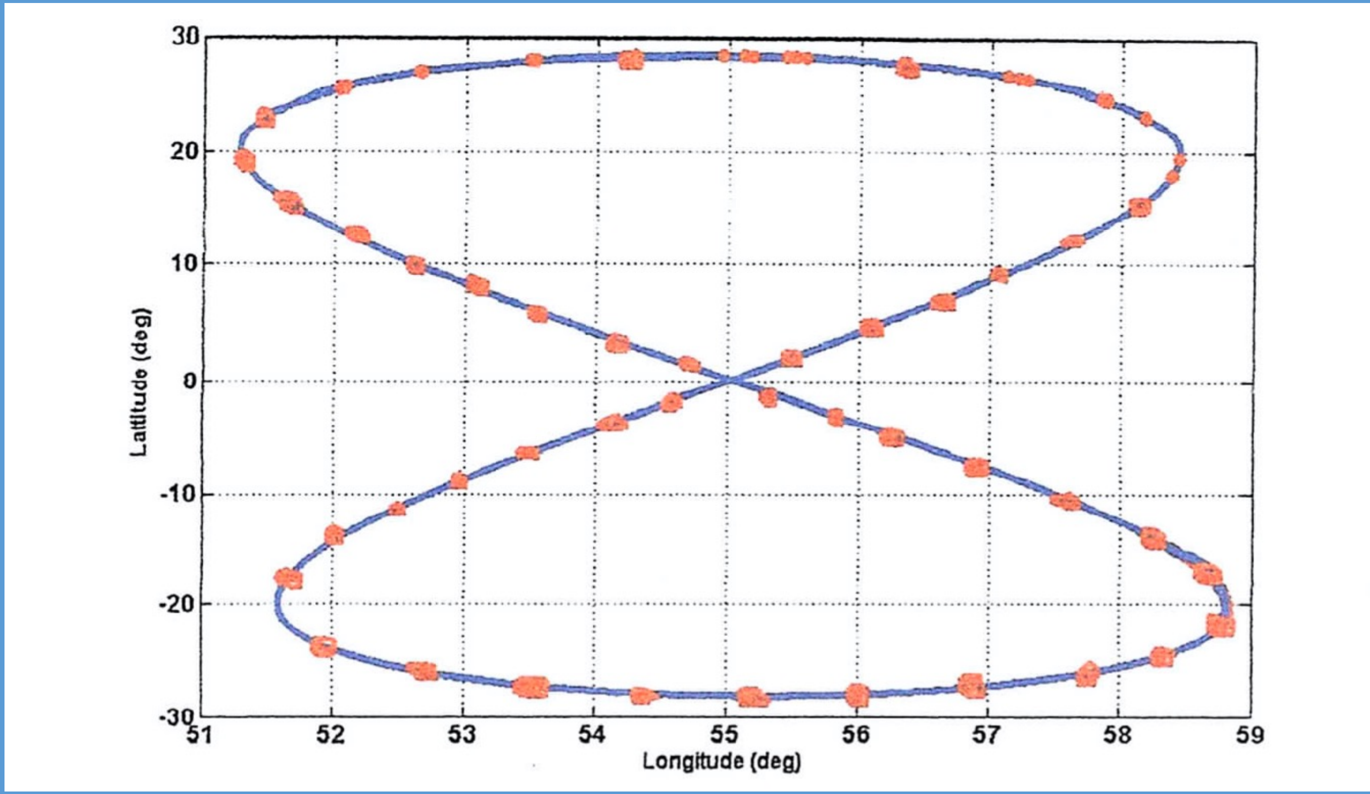
- ILRS network will track Indian Constellation of Navigation Satellites (IRNSS)
- Includes 2 new SLR Stations in India
- Tracking Campaigns will last a minimum of 10 days
- Seven satellites already in Geosynchronous orbit (on the ILRS tracking list)
- Timeframe - late 2022 – 23 (when Indian stations are operational)

Tracking requirements are summarized below:

- IRNSS Campaign shall last for at least 10 days.
- The IRNSS satellite for which the tracking campaign is being undertaken shall be tracked from at least 4 SLR Stations: Each station should track the IRNSS satellite for a minimum of 3 days, generating a minimum of 4 Normal Points every day.
- The tracking campaign shall ensure that the Normal Points are evenly distributed along the ground trace (see figures for desirable ground trace distribution of NP).
- A minimum of 65 Normal Points are required to be generated by the tracking network during the campaign.

Desired Distribution of NP during an ILRS Tracking Campaign

Desirable dispersion of Normal Points generated during an ILRS tracking campaign



Normal Points observations spaced uniformly over the orbital path.

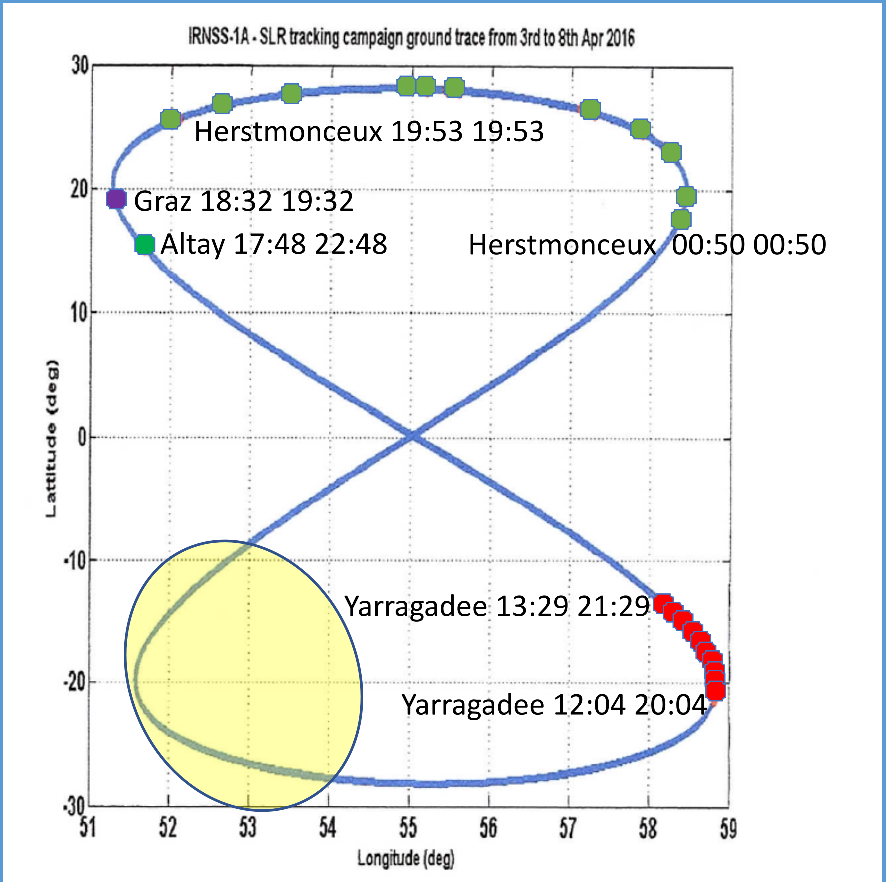
SLR Tracking History on IRNSS

To refresh your memory:

IRNSS Normal Points							
Satellite	2016	2017	2018	2019	2020	2021	Total
IRNSS-1A	364	309	96	16	41	32	858
IRNSS-1B	217	503	176	26	100	117	1139
IRNSS-1C	382	439	200	47	89	155	1312
IRNSS-1D	356	322	104	29	41	131	983
IRNSS-1E	574	484	199	70	126	158	1611
IRNSS-1F	246	9	2	2	16		275
IRNSS-1I			49	52	155	94	350
Grand Total	2139	2066	826	242	568	687	6528

IRNSS Normal Point Totals 2016 to 2021								
Station	**IRNSS-1A**	**IRNSS-1B**	**IRNSS-1C**	**IRNSS-1D**	**IRNSS-1E**	**IRNSS-1F**	**IRNSS-1I**	**Grand Total**
Yarragadee	451	592	1223	585	1075		134	4060
Changchun	3	17	59	355	533			967
Herstmonceux	122	195				23	87	427
Wettzell	69	210				20	118	417
Altay	121	84	30	34				269
Matera						198		198
Graz	27	60				3	6	96
Grasse	41	2				32	11	86
Zimmerwald	51	33						84
Beijing		2		4	17		20	43
Potsdam	15	7						22
Badary					9			9
Hartebeesthoek		6				2		8
Komsomolsk-Na-Amure				7				7
Mendeleevo	5							5
Mt Stromlo					3			3
Shanghai				2				2
Grand Total	**905**	**1208**	**1312**	**987**	**1637**	**278**	**376**	**6703**

IRNSS-1A Tracking Analysis (Apr 3-8, 2016)



LEGEND
- Yarragadee
- Altay
- Graz
- Herstmonceux

Past Experience, April 3rd-8th, 2016 Campaign:

- Night-time tracking only;
- It will be impossible to get complete coverage of the IRNSS orbits due to lack of daylight ranging and station locations;
- Gaps are the result of station and orbital geometry, and operational limitations;
- Station coordination might have reduced some of the gaps in tracking coverage;
- Mt Stromlo never tracked IRNSS-1A, -1B, -1F;
- No European Stations ever tracked IRNSS-1C, -1D or -1E;
- Can Yarragadee track IRNSS-1A, -1B or -1F when at or North of the equator?
- Need to consider longer tracking time interval (10 days or more)

SLR Campaign on NavIC Constellation

Initial plans for ISRO/ILRS campaign:

- ILRS network will track Indian Constellation of Navigation Satellites (IRNSS)
- Includes 2 new SLR Stations in India
- Tracking Campaigns will last a minimum of 10 days
- Seven satellites already in Geosynchronous orbit (on the ILRS tracking list)
- Timeframe - late 2022 – 23 (when Indian stations are operational)

Tracking requirements are summarized below:

- IRNSS Campaign shall last for at least 10 days.
- The IRNSS satellite for which the tracking campaign is being undertaken shall be tracked from at least 4 SLR Stations: Each station should track the IRNSS satellite for a minimum of 3 days, generating a minimum of 4 Normal Points every day.
- The tracking campaign shall ensure that the Normal Points are evenly distributed along the ground trace (see figures for desirable ground trace distribution of NP).
- A minimum of 65 Normal Points are required to be generated by the tracking network during the campaign.

SLR Campaign on NavIC Constellation

Issues:

- Stations do not have optimum conditions at the same time;
- Operational constraints (weather, staffing, station servicing, etc.);
- Needs well experienced observers;
- Needs persistence;
- Very challenging.

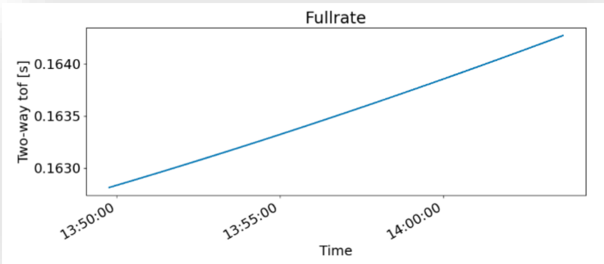
Some ideas for future for ISRO/ILRS campaigns:

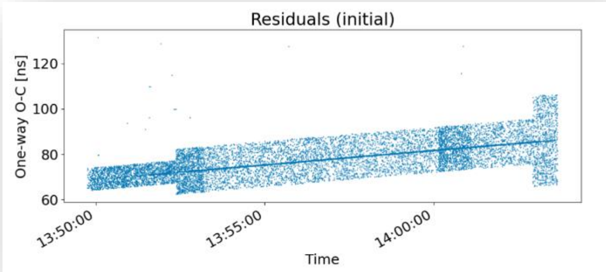
- Take a closer look at the retro array;
- Perform additional test campaigns with other IRNSS satellites;
- Extend the campaigns to 15 days;
- Energize the stations; too many gave up too quickly;
- Do a better job of choosing the right satellites for the stations;
- Encourage some communication among the stations.

Introducing the filtering tool chain at ESA's IZN-1, Tenerife

19.05.2022

IZN-1 Filtering Tool Chain – An Overview






```
H1 CRD 2 2022 4 25 20
H2 IZ1L 7701 57 01 4 ILRS
H3 galileo223 2111601  7223 49809    0 1 1
H4 1 2022 4 25 20 10 27 2022 4 25 20 29 5 0 0 0 0 1 0 2 0C0 0 1064.
C1 0 las1 Nd_YAG 1064.00 400.00 0.55 10.0 20.00 0
C2 0 det2 SPAD 1064.000 40.00 5.0 0.4 NIM 9000.0 0.40 50.0 30.0 non
C3 0 tim3 gps LANTIME A033-ET SN033200 0.0
C6 0 met1 Vaisala PTU300 P4510531 Vaisala PTU300 P4510531 Vaisala P
11 72810.332891436148 0.165779255085 cfg1  2 300.0  1880      90.9
20 72810.332891436148  762.01 276.06   62 1
11 72941.507891530782 0.165905269264 cfg1  2 300.0  1217      90.2
20 72941.507891530782  762.01 276.07   62 1
11 73458.440391552649 0.166438548684 cfg1  2 300.0   222     128.7
20 73458.440391552649  762.07 276.12   63 1
11 73641.207891440368 0.166641773728 cfg1  2 300.0  1057     112.5
```

input
- noisy full-rate CRD
- matching CPF

requirements
- **mostly automatic**
- **possibility of manual adjustments**

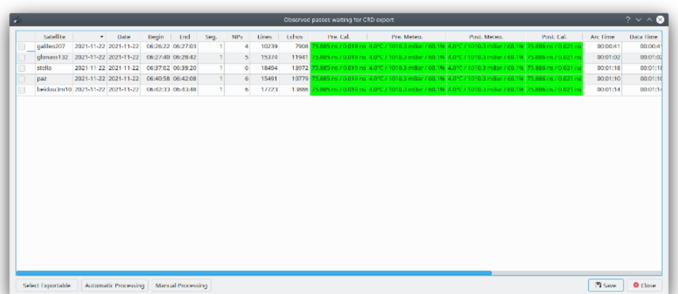
output
- filtered full-rate CRD
- normal point CRD

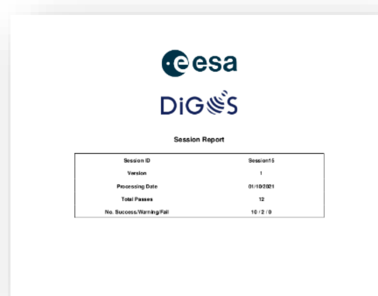
IZN-1 Filtering Tool Chain – An Overview

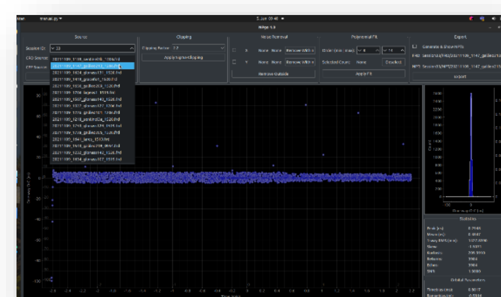
Automatic mode
Automatic filtering of full-rate data after a tracking session

Session report
Manual adjustments to problematic passes

Manual mode
Overview of the autmatic processing results







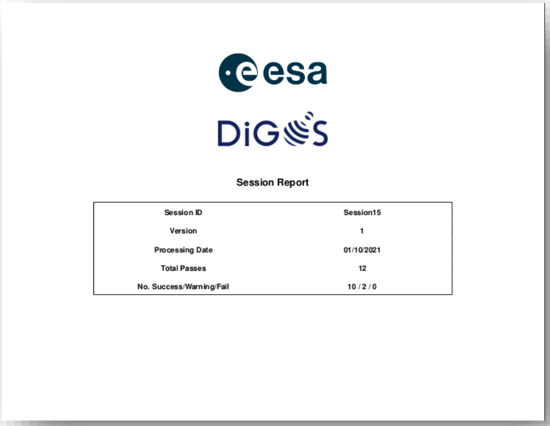
Automatic Processing Mode: Featuring

DiGOS

- Atmospheric refraction correction (Mendis & Pavlis)
  - ILRS Technical Note 36: 9. Models for atmospheric propagation delays
- Orbital fit
  - orbitNP.py by Matthew Wilkinson
- Polynomial fit with respect to the Leading Edge
  - Kirchner et al. (2008), Millimeter Ranging to Centimeter Targets
- Sigma-clipping
  - orbitNP.py by Matthew Wilkinson
- LEHM clipping for LAGEOS and Ajisai
  - Kirchner et al. (2008), Millimeter Ranging to Centimeter Targets
  - Wilkinson et al. (2018), Implementing Consistent Clipping in the Reduction of SLR Data from SGF, Herstmonceux
- Normal point formation
  - orbitNP.py by Matthew Wilkinson
  - ILRS normal point algorithm, Normal point formation

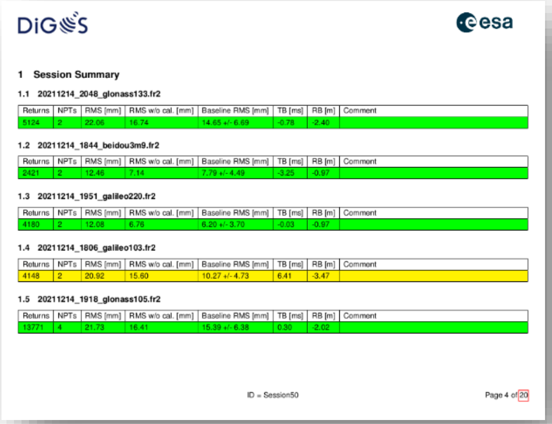
Session Report: An Overview

- Title Page – basic information about the report
- Session Summary – summary of processing results for each pass
- Pass Details – pass details and visual output



Session Report

Session ID	Session15
Version	1
Processing Date	01/10/2021
Total Passes	12
No. Success/Warning/Fail	10 / 2 / 0



1 Session Summary

1.1 20211214_2048_glonass133.fr2

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
5124	2	22.06	16.74	14.65 +/- 6.69	-0.78	-2.40	

1.2 20211214_1844_beidou3m9.fr2

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
2421	2	12.46	7.14	7.79 +/- 4.49	-3.25	-0.97	

1.3 20211214_1951_galileo220.fr2

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
4180	2	12.08	6.76	6.20 +/- 3.70	-0.03	-0.97	

1.4 20211214_1806_galileo103.fr2

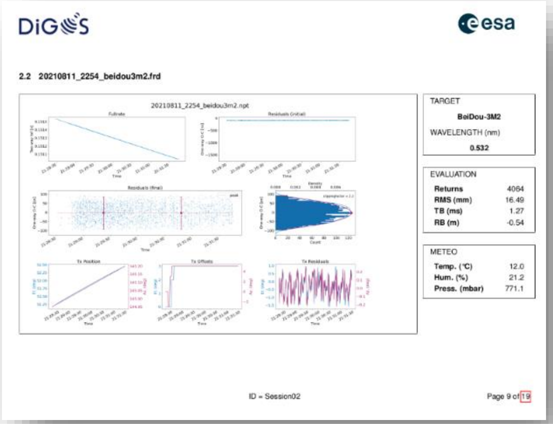
Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
4148	2	20.92	15.60	10.27 +/- 4.73	6.41	-3.47	

1.5 20211214_1918_glonass105.fr2

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
13771	4	21.73	16.41	15.39 +/- 6.38	0.30	-2.02	

ID = Session50

Page 4 of 20



2.2 20210811_2254_beidou3m2.frd

TARGET

BeiDou-3M2

WAVELENGTH (nm)

0.532

EVALUATION

Returns	4064
RMS (mm)	16.49
TB (ms)	1.27
RB (m)	-0.54

METEO

Temp. (°C)	12.0
Hum. (%)	21.2
Press. (mbar)	771.1

ID = Session02

Page 9 of 19

Session Report: Color Code

	Success
	Warning
	Fail

- The automatic processing did not complete;
- Possible reasons include:
  - CRD does not contain any calibration records;
  - CPF file is missing;
  - Orbital fit resulted in an error;
  - …
- The error message is displayed in the comment column of the session summary;

1.197 20220305_0600_tandemx.frd

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
							Could not perform orbital fit.

Session Report: Color Code

	Success
	Warning
	Fail

- The average normal point RMS of the pass is larger than the target specific baseline value OR
- There is no baseline available for the target;
- **The operator should check these cases manually by looking at the pass details;**

1.261 20220310_1507_gracefo1.fr2

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
1962	4	4.24	2.36	0.72 +/- 0.52	2.11	-5.41	

Session Report: Color Code

■	Success
■	Warning
■	Fail

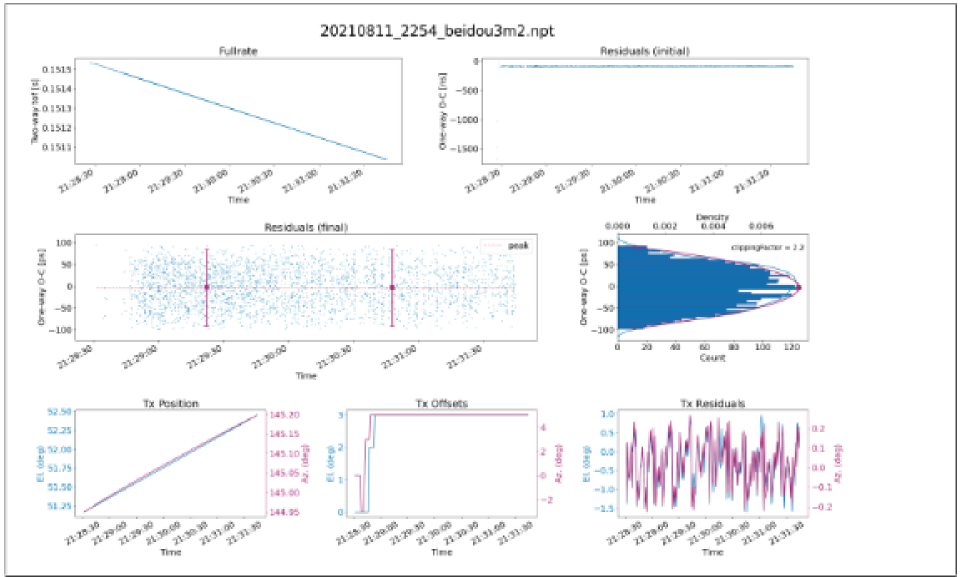
- No errors;
- The normal point RMS is in the tolerance range;
- **The CRD files can (likely) be sent without manual modification;**

1.2 20220420_1048_galileo103.fr2

Returns	NPTs	RMS [mm]	RMS w/o cal. [mm]	Baseline RMS [mm]	TB [ms]	RB [m]	Comment
4279	4	22.56	17.39	22.00 +/- 4.73	-0.06	-0.64	

Session Report: Pass Details

2.2 20210811_2254_beidou3m2.frd



TARGET

BeiDou-3M2

WAVELENGTH (nm)

0.532

EVALUATION

Returns	4064
RMS (mm)	16.49
TB (ms)	1.27
RB (m)	-0.54

METEO

Temp. (°C)	12.0
Hum. (%)	21.2
Press. (mbar)	771.1

ID = Session02

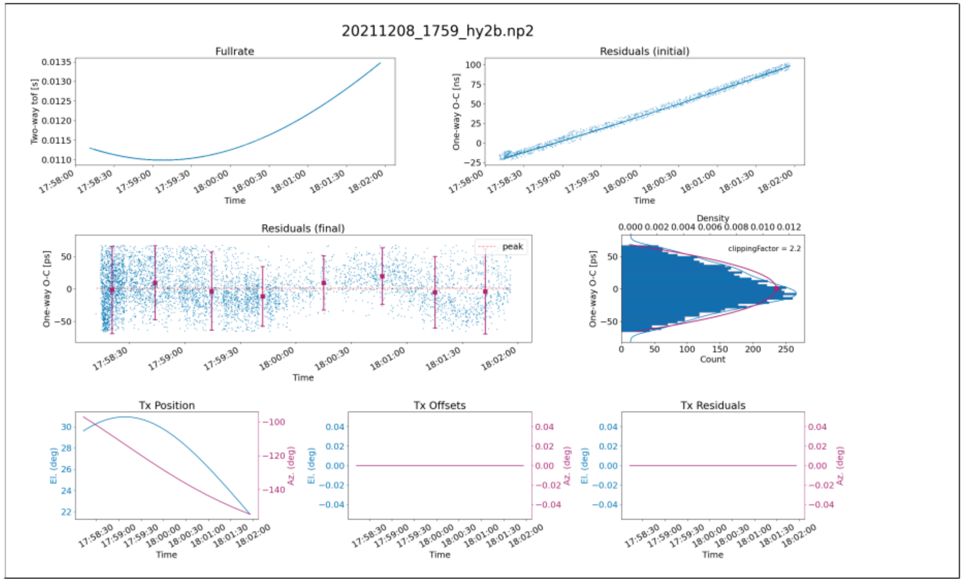
Page 9 of 19

Session Report: Pass Details

DiGOS

esa

2.9 20211208_1759_hy2b.fr2



TARGET

HY-2B

WAVELENGTH (nm)

1064.0

EVALUATION

Returns	6032
RMS (1w, mm)	8.17
RMS (2w, ps)	54.54
TB (ms)	-0.46
RB (m)	-2.22

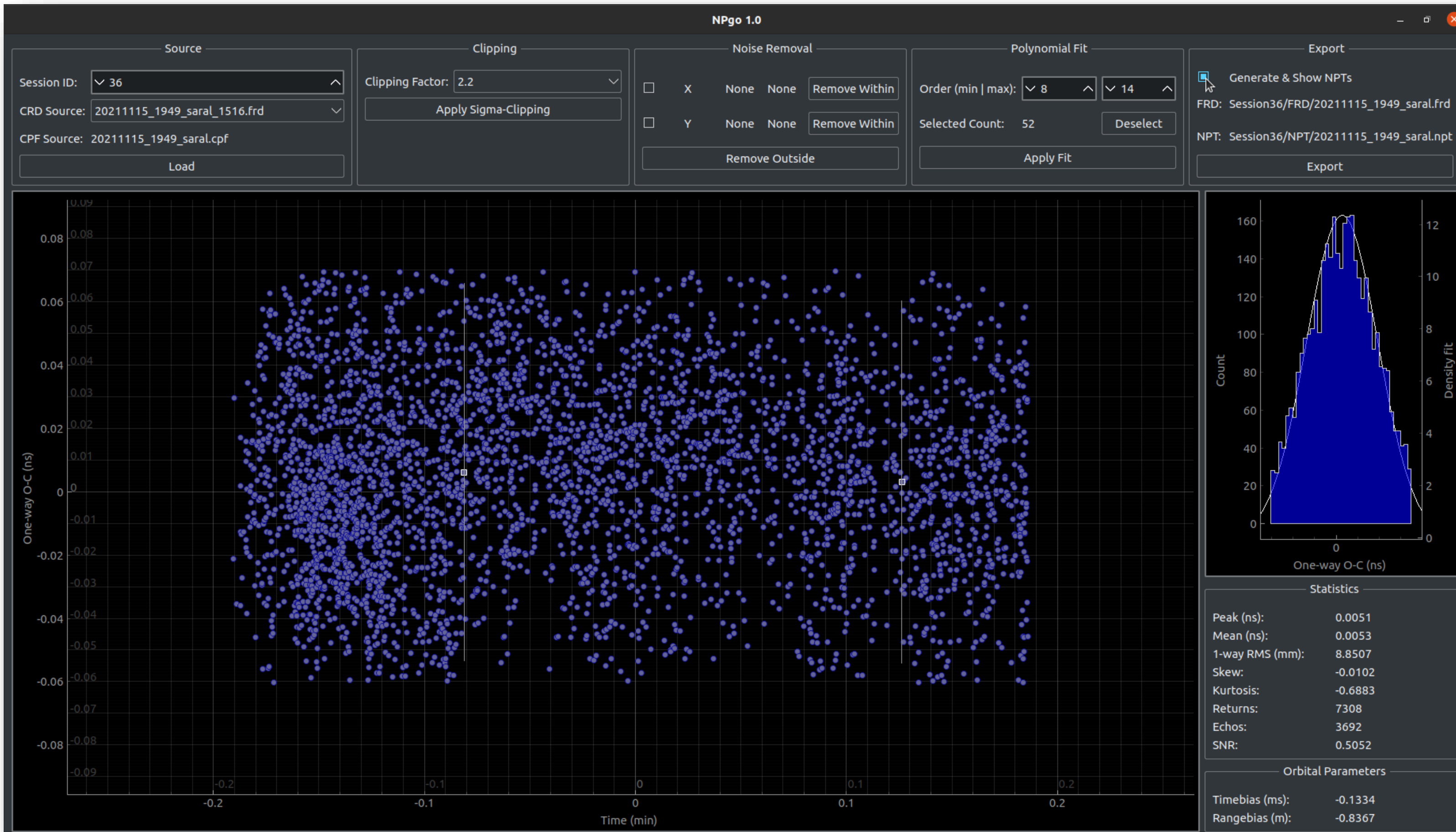
METEO

Temp. (℃)	4.0
Hum. (%)	71.6
Press. (mbar)	771.8

ID = Session46

Page 17 of 27

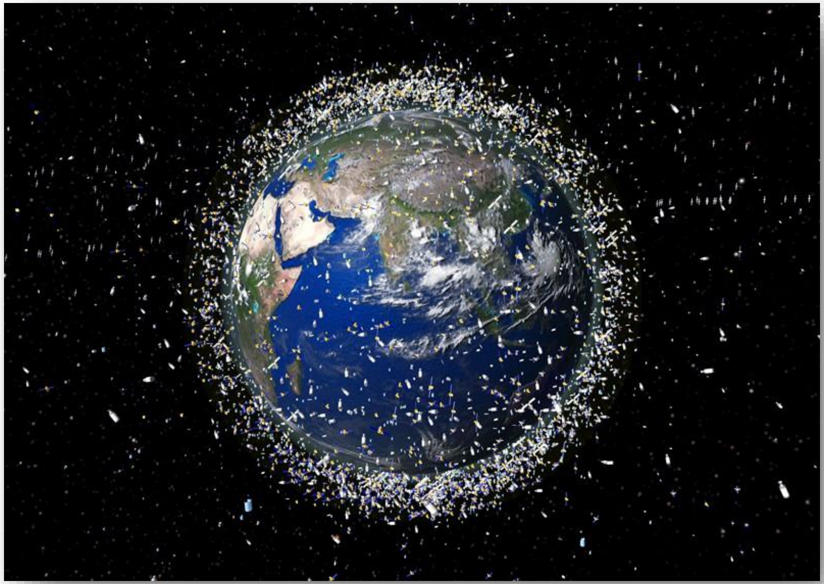
Manual Processing Mode (see demonstration)



Outlook

- Integration into GFZ SLR Station Potsdam/Germany
- Extension for optimizing the filtering of space debris observations

Laser station Potsdam. Credit: L. Grunwaldt, GFZ



Credit: European Space Agency / SPL

Thank you!