Data analysis demonstration –
data download and normal point computation

Alexander Kehm

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

First One-Day Introductory Course on Satellite Laser Ranging
Stuttgart, Germany, 2019-10-20

Data holding

Previous talk by C. Noll: Role and function of the Data Centers

- Two redundant data centers are operating within the framework of the ILRS:
  - CDDIS (Crustal Dynamics Data Information System) at NASA
    Website: https://cddis.nasa.gov/About/Background.html
    FTP server: ftp://cddis.gsfc.nasa.gov/
  - EDC (Eurolas Data Centre) at DGFI-TUM
    Website: https://edc.dgfi.tum.de/en/
    FTP server: ftp://edc.dgfi.tum.de/

Data formats

- SLR observation data is provided in the **Consolidated Range Data (CRD) format**
- Historical data is currently available only in older formats, e.g. Merit-2, Merit-3, …

- Two kinds of observation data are provided in the CRD format:
  - **Full-rate data** → actual observation data of a station
  - **Normal Point (NP) data** → “condensed range observations […] collected over several seconds to minutes”

- Satellite orbit predictions are provided in the **Consolidated Predictions Format (CPF)**

- Full-rate data and CPF predictions are the input for the generation of NPs
  - **NPs are the input for the “classical” SLR data analysis**

- For a detailed description of the data formats, refer to https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/index.html

The Consonidated Range Data (CRD) format

- ASCII-based format

```
H1 CRD  1 2019 09 23 00
H2       STL3 7825 90 01  4
H3    lageos1  7603901 1155     8820 0 1
H4  0 2019 09 22 22 10 05 2019 09 22 22 42 58  0 0 0 0 1 0 2 0
C0 0 532.10 IDAA IDAB IDAJ IDAV
C1 0 IDAB Nd-YAG 1064.00 60.00 20.00 12.0 0.00 1
C2 0 IDAJ CSPAD 532.00 20.00 11.0 100.0 ECL 12.0 2.00 90.0 0.1 na
C3 0 IDAV TrueTime_XLi TrueTime_OCXO MRCS na 0.2322
20 79809.396213999993 931.46 280.99 64.3 0
20 79829.403195000006 931.45 280.95 64.5 0
20 79850.087195000000 931.44 280.91 64.8 0
20 79879.502194999994 931.46 280.87 65.4 0
20 79920.058195000005 931.48 280.83 65.4 0
20 79940.058195000005 931.48 280.78 65.6 0
20 79960.059194999994 931.48 280.75 65.9 0
20 80000.061195000002 931.50 280.72 65.8 0
20 80020.061195000002 931.50 280.70 65.8 0
20 80060.063194999995 931.50 280.74 66.1 0
20 80080.063194999995 931.47 280.74 65.5 0
20 80120.076157999996 931.44 280.81 66.9 0
20 80140.077158000000 931.42 280.84 65.5 0
20 80180.079157999993 931.43 280.82 65.5 0
20 80240.082158000005 931.42 280.79 65.7 0
20 80260.083157999994 931.42 280.76 65.7 0
...
```

➢ **Header section**

- Format, station, target, session/pass

➢ **Configuration section**

- System configuration
- Laser cofiguration – technical specifications of the laser system (primary wavelength, nominal fire rate, etc.)
- Detector configuration, timing configuration, transponder configuration
- (Software configuration, Meteorological instruments configuration)

The Consolidated Range Data (CRD) format

➢ Data records

```
...
40 79805.000000000000 0 IDAA 4407 1165 69.592 158512.3 0.0 22.7 0.100 -0.500 14.0 2 2 0
10 80881.662252241833   0.051422422457  IDAA 2 2 0 0     0
10 80882.912252239184   0.051423989203  IDAA 2 2 0 0     0
10 80897.878918937626   0.051444648398  IDAA 2 2 0 0     0
10 80907.095585644129   0.051459113085  IDAA 2 2 0 0     0
10 80907.645585635910   0.051460018356  IDAA 2 2 0 0     0
10 80907.995585635392   0.051460596779  IDAA 2 2 0 0     0
10 80910.178918941383   0.051464248296  IDAA 2 2 0 0     0
10 81074.962252238547   0.051952362973  IDAA 2 2 0 0     0
10 81076.528918944154   0.051958990146  IDAA 2 2 0 0     0
...
30 79807.779527999999 357.227514 56.145701 0  2 0
30 79809.091287999996 356.084046 55.265678 0  2 0
30 79810.383128000001 354.117748 53.558887 0  2 0
30 79811.694896000001 351.267680 51.061213 0  2 0
30 79812.996471999999 347.589620 48.457647 0  2 0
30 79814.298943999995 343.059331 45.850569 0  2 0
30 79815.619999999995 337.599700 43.207516 0  2 0
30 79816.941504000002 331.265347 40.563607 0  2 0
30 79818.253263999999 324.111367 37.937464 0  2 0
...
H8
```

- Range (full-rate data or NP data)
- Meteorological data, pointing angle, calibration data, session/pass statistics

➢ Format description:

- CRD v1: https://ilrs.cddis.eosdis.nasa.gov/docs/2009/crd_v1.01.pdf
- CRD v2 (to be used soon): https://ilrs.cddis.eosdis.nasa.gov/docs/2018/crd_v2.00h-4e.pdf

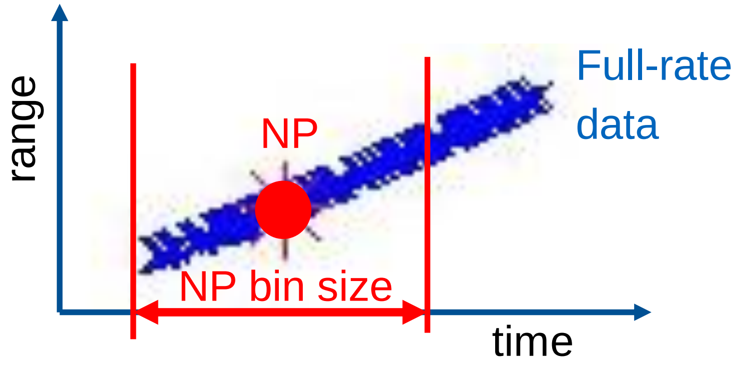
What is a Normal Point?

- A **Normal Point (NP)** is generated by averaging the full-rate data over a certain time span (‘bin size’)

- The NP bin size recommendation is satellite-dependent
  - Range from 5 seconds (h < 500 km) to 5 minutes (h > 15 000 km)

Nominal Satellite Altitude (km)	Bin Size (seconds)	NPT Indicator (from old format)	Example Satellites	Comments
N/A	N/A	0	N/A	Not a normal point
< 500	5	1	GRACE	
550 – 800	15	3	Sentinel-3	
800 – 2,000	30	5	Starlette, Stella	
2,000 – 5,000	60	6		
5,000 – 8,000	120	7	LAGEOS	
8,000 – 15,000	180	300		
> 15,000	300	9	Etalon, GNSS	
Lunar	Variable	2	Apollo, Luna	

Source: ILRS



- Recommendation by the *ILRS Networks and Standards Standing Committee (NESC)*:
  - Daytime Normal Points – minimum 6 full-rate data points per NP
  - Night time Normal Points – minimum 3 full-rate data points per NP

Normal Point generation – the Herstmonceux Algorithm

- Stage 1:

Full-rate data screening

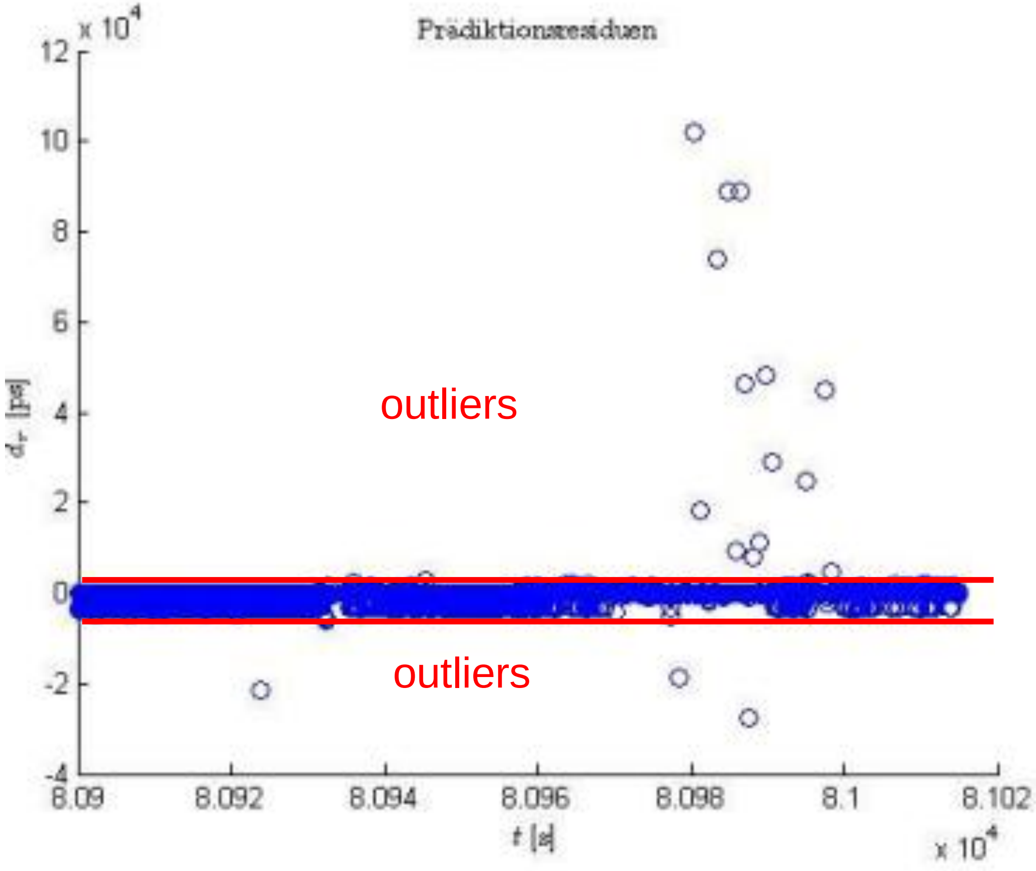
Compute prediction residuals
PR = observation – prediction

Remove large outliers

Solve for (orbital) parameters and compute fit residuals FR

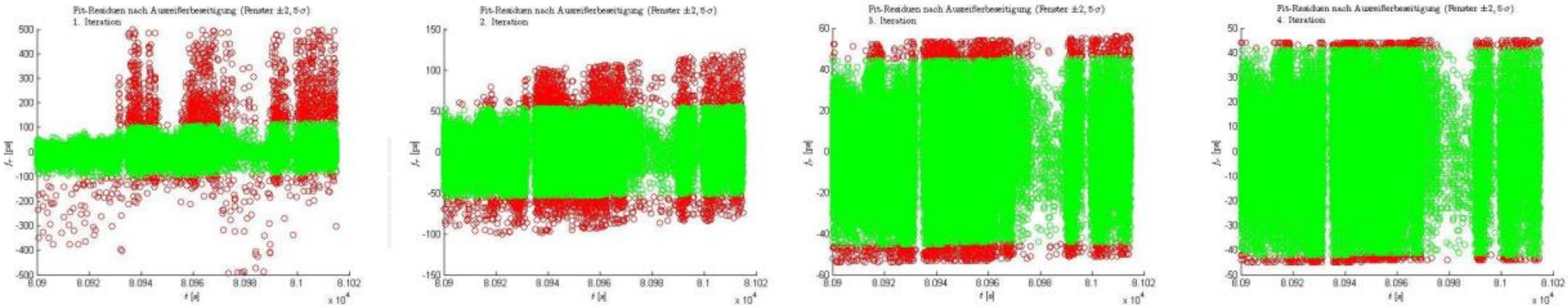
Remove outliers and systematics

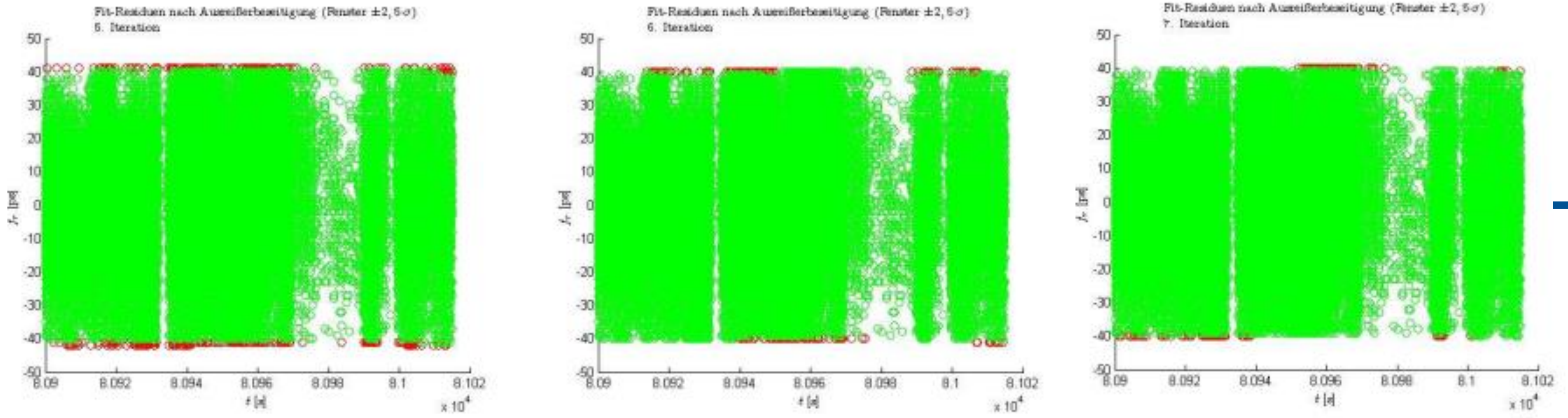
Example: prediction residuals for a CHAMP pass



Example: Full-rate data screening for CHAMP SLR data

- Data screening: 2.5 sigma criterion for CHAMP SLR full-rate data: 7 iterations





→ Reduced full-rate data (fit residuals) as input for NP generation

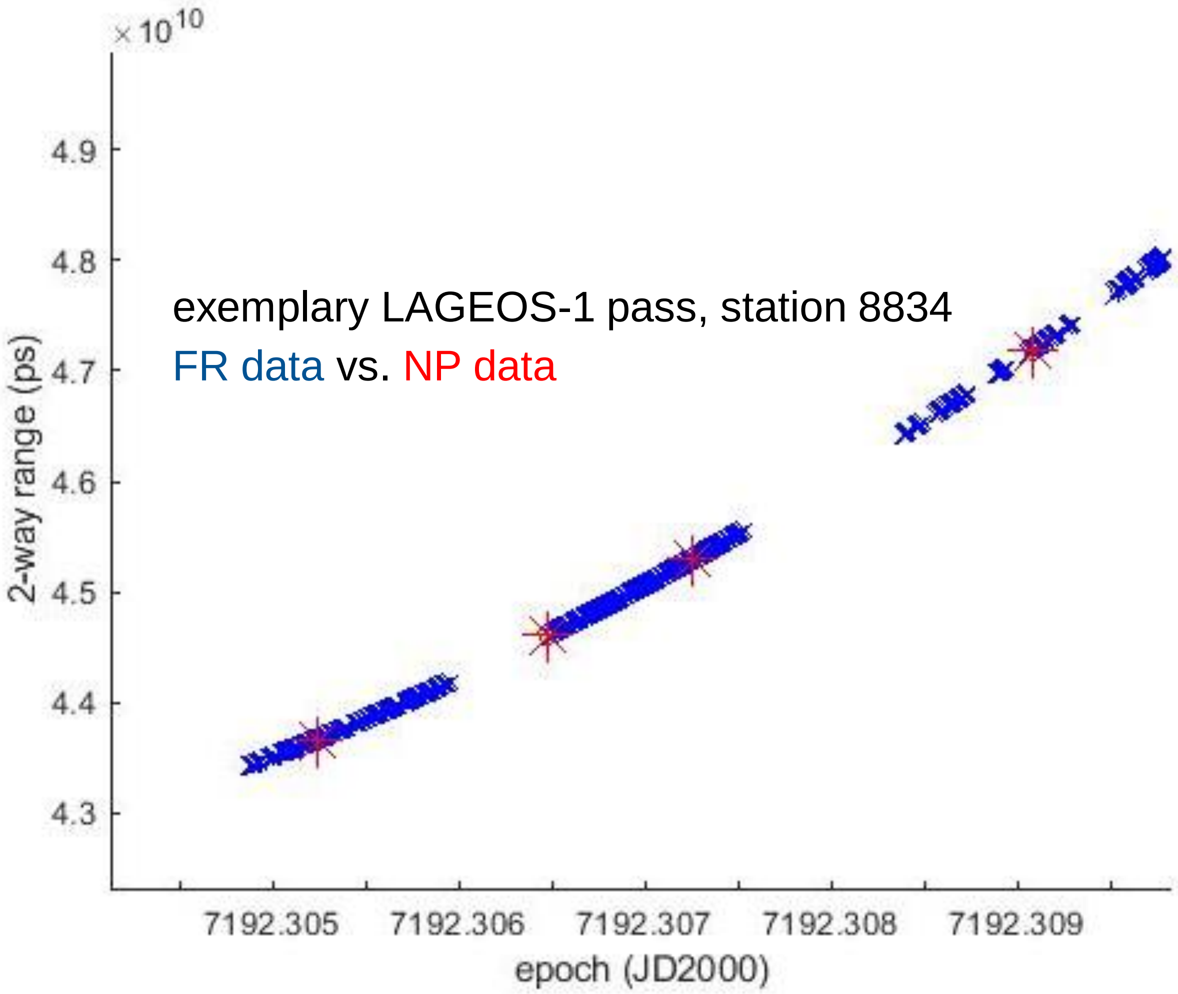
Example: NP formation for September 2019 for Wettzell Laser (8834)

➢ Stage 2:
Normal point formation

Subdivide the accepted data points into bins
Compute mean value and mean epoch
Locate the real observation O_i at epoch t_i nearest to the mean epoch
$NP_i = O_i - FR_i + \overline{FR_i}$ $RMS_i = \sqrt{\frac{1}{n_i}\sum_j \left(FR_j - \overline{FR_i}\right)^2}$

LAGEOS-1 data station 8834, September 2019

- Full rate data: 140 718 observations
- NP data: 311 data points



NP generation software: orbitNP.py

Within the following slides, we are going to perform an exemplary workflow from full-rate data download from a data centre to NP generation with the software `orbitNP.py`

- `orbitNP.py`: NP generating software by M. Wilkinson/NERC (2018) available from https://ilrs.cddis.eosdis.nasa.gov/technology/software/orbitNP_1.0.tar.gz

- Step 1: Download of full-rate observation data from EDC (or CDDIS)

```
# Step 1: Download the Full-rate observation data file from EDC and uncompress .Z file (if required)

wget ftp://edc.dgfi.tum.de/pub/slr/data/fr_crd/lageos1/2019/lageos1_201909.frd.Z
uncompress lageos1_201909.frd.Z
```

- Step 2: Download of CPF satellite orbit prediction file (if required, see next slide)

```
# Step 2: Get required .CPF predictions file (if required)
#  As we are going to calculate NPs for the 4th pass of station 7841 in September, we
#  need a file covering 2019-09-14, the date the pass has been measured.

wget ftp://edc.dgfi.tum.de/pub/slr/cpf_predicts/2019/lageos1/lageos1_cpf_190914_7581.jax
```

Example: NP generation with orbitNP.py

```
# Step 3: Run the NP generating software
#  This demonstration scenario is based on the examples given in the README file provided with the software.
#  For further options, please refer to the README file.

# Version 1: Own download of CPF file
# -f : Full-rate data file (CRD format)
# -c : Orbit predictions file (CPF format)
# -x : Save plot of final results as .png
# -s : Station 4-digit code (here: 7841 for Potsdam, Germany)
# -N : Normal Point length in seconds (here: 120 sec for LAGEOS,
#       cf. https://ilrs.cddis.eosdis.nasa.gov/missions/NPT_BinSize_Recommendations.html)
# -n : Output normal points to file normalp.dat

python3 orbitNP.py -f lageos1_201909.frd -c lageos1_cpf_190914_7581.jax -x -s 7841 -N 120 -n
```

Step 3: Start the software …

… either with previously downloaded CPF orbit prediction file

Site: 7841 (Potsdam, Germany)

NP bin size: 120 s (LAGEOS)

```
# Version 2: Choose CPF file automatically --> Step 2 can be omitted.
#  (more convenient: you do not need to think about the required CPF file in advance)
# -f : Full-rate data file
# -A : Choose CPF predictions automatically (from EDC server)
# -x : Save plot of final results as .png
# -s : Station 4-digit code
# -N : Normal Point length in seconds
# -n : Output normal points to file normalp.dat

python3 orbitNP.py -f lageos1_201909.frd -A -x -s 7841 -N 120 -n       # pass no. 4
```

… or with automatically chosen CPF orbit prediction file

Read full-rate observation data file

Output: Information about and check of the settings ...

```
-- Check input parameters
       + FRD file is lageos1_201909.frd
       + Attempt to fetch corresponding CPF from EDC Data Cetre
       + SLR Station is 7841
       + Station Latitude, Longitude and Height:  52.383 13.0614 123.5
       - Minimum number of observations for a Normal Point NOT defined, using default 30
       + Output normal points to file normalp.dat in CRD format
       + Produce plot and save and display

-- Read FRD file ...
```

Choose a pass for analysis and NP generation

Pass overview for the chosen station: choose pass for analysis!

```
        Index    Station Name       Num Records          H4 Start/End Entry
        0        Potsdam              2716          H4   0 2019   9   4 20   8 12 2019   9   4 20 11 33   0 0 0 0 1 0 2 0
        1        Potsdam              2119          H4   0 2019   9   4 23 25 15 2019   9   4 23 35 48   0 0 0 0 1 0 2 0
        2        Potsdam             25529          H4   0 2019   9 21 21 56 50 2019   9 21 22   3 33   0 0 0 0 1 0 2 0
        3        Potsdam             37327          H4   0 2019   9 19 20 38 58 2019   9 19 20 50 31   0 0 0 0 1 0 2 0
        4        Potsdam              5858          H4   0 2019   9 14 13 34 53 2019   9 14 13 47 46   0 0 0 0 1 0 2 0
        5        Potsdam             25707          H4   0 2019   9 10 22 30 30 2019   9 10 22 54 54   0 0 0 0 1 0 2 0
        6        Potsdam              2908          H4   0 2019   9   5 22   6 21 2019   9   5 22   9 33   0 0 0 0 1 0 2 0
        7        Potsdam              7774          H4   0 2019   9 22 20 22 27 2019   9 22 20 27 32   0 0 0 0 1 0 2 0
        8        Potsdam              9149          H4   0 2019   9 11 13 59 56 2019   9 11 14 21 10   0 0 0 0 1 0 2 0
        ...

        23       Potsdam             10655          H4   0 2019   9 22 16 35 26 2019   9 22 16 42 26   0 0 0 0 1 0 2 0
        24       Potsdam             20509          H4   0 2019   9 14 20 29 25 2019   9 14 21   5 55   0 0 0 0 1 0 2 0
        25       Potsdam              1330          H4   0 2019   9 12 16 46 55 2019   9 12 16 49 36   0 0 0 0 1 0 2 0
        26       Potsdam              6303          H4   0 2019   9   6   1 47 29 2019   9   6   1 48 42   0 0 0 0 1 0 2 0
        27       Potsdam             29805          H4   0 2019   9 13 14 49 18 2019   9 13 15 21 50   0 0 0 0 1 0 2 0
        28       Potsdam              1786          H4   0 2019   9   3 21 33 57 2019   9   3 21 44   3   0 0 0 0 1 0 2 0
        29       Potsdam              7522          H4   0 2019   9   3 17 50 58 2019   9   3 17 57 37   0 0 0 0 1 0 2 0
        30       Potsdam              9411          H4   0 2019   9   5 18 46   5 2019   9   5 18 50 38   0 0 0 0 1 0 2 0
        31       Potsdam             20423          H4   0 2019   9 17 16 26 13 2019   9 17 16 57   6   0 0 0 0 1 0 2 0

 FRD file contains 32 passes for station 7841                  (q to quit)
Enter pass number: 4
```

Choose a CPF orbit prediction file (if required)

Information about the processing (applied calibration and meteorological data) …

```
-- Read FRD file for epochs, ranges and meteorological data...

-- System Delay Calibration already applied

-- Interpolate meteorological records ...
```

If a specific CPF prediction file has been predefined at routine call: Info about chosen file.

```
-- Read CPF prediction file: lageos1_cpf_190914_7581.jax
```

If automatic CPF prediction file lookup has been selected: Choose provider!

```
 -- Fetching CPF prediction file corresponding to FRD file ...
wget -Nq ftp://edc.dgfi.tum.de/pub/slr/cpf_predicts/2019/lageos1/lageos1_cpf_190914_* -P CPF

        0       CPF/lageos1_cpf_190914_7571.hts
        1       CPF/lageos1_cpf_190914_7581.jax
        2       CPF/lageos1_cpf_190914_7581.sgf

 Select prediction provider: 1
```

Iterative range data fitting and data screening

Information and statistics from the iterative fitting process …

```
-- Begin orbit adjustment to fit range data

         #     pts          rms2          rms3          rmsa
         1     5740       334.803       318.067          0.000
         2     5740         9.080         8.695          9.362
         3     5740         9.045         8.660          9.054
         4     5740         9.040         8.653          9.041
         5     5740         9.038         8.651          9.039
         6     5740         9.038         8.650          9.038
         7     5740         9.038         8.649          9.038
         8     5740         9.038         8.649          9.038
         9     5740         9.038         8.649          9.038

       Satellite orbital time bias (ms)       1.518   0.051
       Satellite radial error (m)            -5.176   0.016
       Rate of time bias (ms/minute)         -0.272   0.016
       Rate of radial error (m/minute)       -0.000   0.005
       Acceleration of time bias             -0.000   0.000
       Acceleration of radial error           0.041   0.002
```

Result: Normal Points and analysis

Output of NPs and plot, information on applied default settings (not predefined by the user)

```
-- Normal Points
      11 48926.559100907114     0.049645478316   KS 2  120.0   466      61.9  0.238 -0.916      0.0  0.4 0
      11 49061.113600905126     0.049385518432   KS 2  120.0   511      58.3  0.402 -0.824      0.0  0.4 0
      11 49088.253100902424     0.049361961687   KS 2  120.0   234      61.0  0.307 -0.886      0.0  0.8 0
      11 49385.301100905846     0.049746830890   KS 2  120.0  2936      63.2  0.080 -1.045      0.0  1.4 0
      11 49518.979100896860     0.050300744994   KS 2  120.0   981      60.0  0.324 -0.879      0.0  0.6 0
      11 49606.233600901855     0.050785416669   KS 2  120.0   730      64.6  0.067 -0.886      0.0  0.3 0

-- Plot Results
      Save fig  pics/7841_lageos1_201909_4.png

-- Summary:
      Warning:  Minimum number of observations for a Normal Point NOT defined, using default 30
```

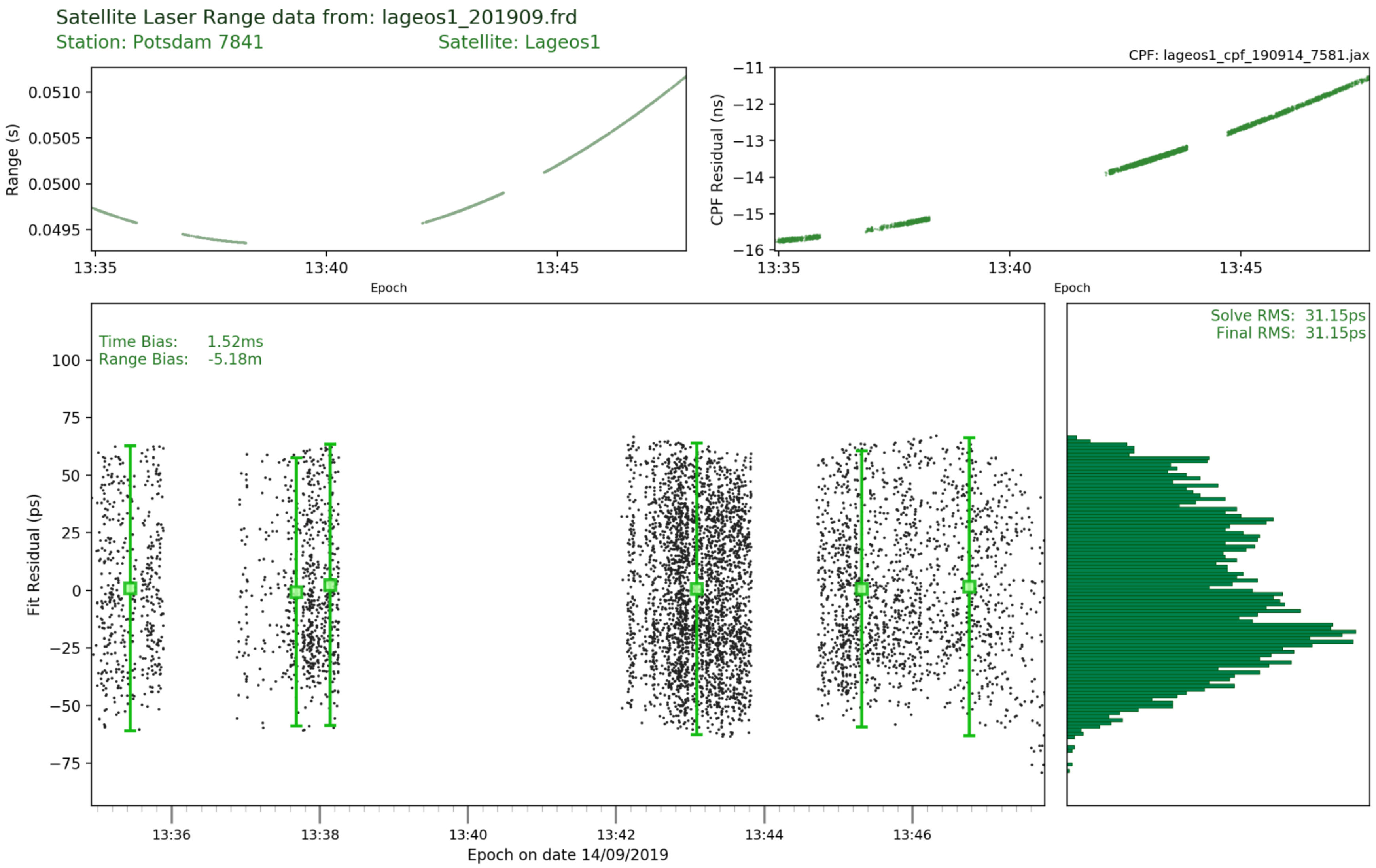
No. of full-rate data per NP

Analysis plot

Full-rate data

Prediction residuals

Fit residuals: NPs and statistics



Plot from orbitNP.py, © M. Wilkinson/NERC (2018)

Summary and Conclusions

- Normal Points (NPs) are a robust „condensed“ input for SLR analysis, reducing the amount of data to process
- An NP is formed from full-rate data averaged over a certain mission-dependent time span
- However, the impact of the algorithm on the results and the „best“ algorithm to generate NPs are subject to discussion (e.g., the data screening approach)
- There are several algorithms used by the stations, i.e. not all SLR stations generate their NPs in a similar way
- **All „standard“ SLR products are based on the processing of NPs**

Next talk by M. Bloßfeld: Analyzing of SLR observations – what do we do with the data?