Consolidated Laser Ranging Data Format (CRD)
Version 2.00
Version 2.01

for the ILRS Prediction Format Study Group
of the ILRS Data Format and Procedures Working Group
SIGNIFICANT CHANGES HIGHLIGHTED IN YELLOW OR CYAN

19 September 2019

Revision History

0. Revision Summary
   - v 0.25 12 February 2007 - Initial public release.
   - v 0.26 12 March 2007 - Updated based on community input.
   - v 0.27 15 November 2007 - Further updated based on community input.

0.1 0.25 – 12 February 2007
   - First public release.

0.2 0.26 – 12 March 2007
   - Added sample files.
   - Added "Common Abbreviations" and "Resources" sections.

0.3 0.27 – 15 November 2007
   - Added revision history.
   - Added target type to target header H3.
   - Added data quality alert to station header H4.
   - Refined clock offset fields in the transponder configuration record C4.
   - Added "stop number" to ranging record (10).
   - Added "origin of values" to meteorological record (20).
   - Clarified the use of terms "time-of-flight" and "range".
   - Revised station file naming conventions in Section 5.
   - Other changes for consistency or improved readability.

0.4 1.00 – 27 June 2008
   - Clarified the handling of free-format character fields.
   - Clarified the handling of the unknown stop time in H4 record.
   - Explicitly stated that C1 record pulse length is FWHM.
   - Changed the units of epoch delay correction in record C3 to microseconds.
   - Changed the record 21 Sky Clarity suggested format from integer to floating point.
   - Added detector channel to calibration record '40' and normal point record '11'.
   - Expanded "data type" in calibration record '40' to handle one- and two-way calibrations.
   - Added more sample data sets, including all possible records.
   - Added a table showing which records correspond with which data types.
   - Noted that 3.0 is being subtracted from kurtosis.
   - Explained 'full rate, fire only' files (.frf) for one-way transponders.
   - Explained the possibility of using '30' pointing angles as fundamental measurements (3.6.2).
   - Converted old section 7 and 8 to appendices A and B and inserted sections 7-9.
   - Changed normal point window length (record '11') from integer to floating point.

0.5 1.01 – 27 October 2009
   - Various clarifications and cleanup of wording.
   - Reflected changes from Errata page.
   - Made changes in handling new "Station Epoch Time Scale" values.
   - Added reference to EDC on-line format compliance checking.

0.6 2.00 – 14 September 2018, 19 September 2019
   - See Appendix D.

0.7 2.01 – 19 September 2019

- See Appendix D.
    - Used literal “na” instead of “-1” for fields that are not applicable or not avaiable.
    - Added “c7” calibration configuration record and “42” calibration “shot” record.

0.71 2.01 – 4 November 2019

- Correct description of Calibration Span in records “41” and “42” to match “40”.

Abstract

Due to technology changes, the previous International Laser Ranging Service (ILRS) formats for exchange of the 3 laser ranging data types – full rate, sampled engineering, and normal point - needed revision. The main technology drivers were the increased use of kilohertz firing-rate lasers, which made the previous full rate data format cumbersome, and the anticipated transponder missions, especially the Lunar Reconnaissance Orbiter (LRO), for which various field sizes were either too small or non-existent. Rather than patching the existing format, a new flexible format encompassing the 3 data types and anticipated target types was created. The development of the Consolidated laser Ranging Data (CRD) format provided the opportunity to include fields and features that were desired but not available in the old formats. After years of service, the CRD format needed some evolutionary changes to satisfy requests for additional information, which has resulted in version 2 of the format.

Introduction

The purpose of the CRD is to provide a flexible, extensible format for the ILRS full rate, sampled engineering, and normal point data. The primary motivations for creating a new format several years ago were to allow for transponder data, and to handle high-repetition-rate laser data without unnecessary redundancy. This format is based on the same features found in the ILRS Consolidated Prediction Format (CPF), including separate header and data record types assembled in a building block fashion as required for a particular target.

There are 3 separate sections to the CRD data format: 1) the header section which contains data on topics such as station, target, and start time; 2) the configuration section containing an expanded version of data previously described by the System Configuration Indicator (SCI) and System CHange Indicator (SCH) fields; and 3) the data section containing laser transmit and receive times, and other highly dynamic information. The data headers similar in content to those of the CPF files. All records are in free format with spaces between entries. Records can be added as needed for the specific data types and at frequencies commensurate with the data rate. For example, at a 2 kHz ranging rate, meteorological data and pointing angles are commonly read far less frequently than the ranges. Note that one-way out-bound, one-way in-bound, and two-way ranges can all appear within one file. Also note that multiple colors can appear in one file.

Some of the features of the CRD format are as follows;

Flexibility. The data files can be simple and compact for kilohertz ranging or comprehensive for more complex data structures, as appropriate.

The building block structure with multiple record types allows for including and omitting certain record types as needed by a station or target.

Station configuration descriptions are addressed in an explicit, logical and extensible manner.

A single integrated format can be used for current and future data and target types.

Multiple color data, multiple ranging modes (transponder one- and two-way ranges) and multiple configurations can be included naturally within a single data file.

The format can be expanded in the future as needs expand without abandoning the entire format.

All data types (full rate, sampled engineering, and normal point) can be managed in a single file if desired, e.g., for archival and reference purposes.

Fields in the Configuration records are compatible with the Satellite Laser Ranging (SLR) Engineering Data File (EDF) format.

There will often be cases where the value of a data record field is either unknown or not applicable. This is especially true when data is converted from an old format to the CRD format, since there will be fields (such as skew and kurtosis) that do not exist in the old format. ***In these cases, unless noted otherwise, numerical and character fields without information***

should be filled with "na" for "Not Available or Not Applicable".

In the following pages, sections 1 – 3 provide a description and discussion of the specific file sections and record types. Following that, section 4 gives examples of the file structure for various types of data. Section 5 addresses file naming conventions. Section 6 provides some real-world examples of the new format, while section 7 provides information about implementing and testing the CRD format on site. Section 8 is included to provide a quick overview of the new data fields and their use. Appendix A provides web references to formats and "official lists" as well as links to CRD test data sets and sample code containing format converters and CRD file check programs. Appendix B provides definitions of abbreviations. Appendix C lists the acceptable range of values for the fields in the format, as reflected in the NASA and EDC Operations Centers' data vetting software. These values pertain to Version 1, and will be updated for the new fields as time permits. Finally, Appendix D describes the changes in version 2 (this version) of the CRD format.

1. Header Records

These records are in **FREE FORMAT** (except that the record ID must be in columns 1-2) and rely on white spaces for parsing. **The field sizes (e.g., I5, F12.5) are suggestions; fields should be sized according to the stations' needs.** Upper and lower case characters are both acceptable: e.g., "H1" or "h1"; "CRD" or "crd" in H1. Character fields should be left-justified or sized to fit the string. The field specifiers are based on FORTRAN. Examples of the C equivalents are A3 → %3s; I2 → %2d; F12.5 → %12.5f.

1.1. Format Header

The format header describes information relating to the file: e.g., the version of the format used, time of production, etc.

1.1.1. Format:

A2(1-2)	Record Type (= "H1" or "h1")
A3	"CRD" or "crd" (Consolidated Ranging Data format)
I2	Format Version **= 2**
I4	Year of file production
I2	Month of file production
I2	Day of file production
I2	Hour of file production (UTC)

1.1.2. Notes

There must be one and only one format header record in the file and it (or a "00" comment record) must be the first record. Format version will be 1 for version 1.00 – 1.99, 2 for 2.00-2.99, etc. All changes between n.00 and n.99 must be backward compatible. This means no new fields will be added between existing fields, etc. New fields can be added to the end of a record or additional record types can be added.

1.2. Station Header

The station header describes information relating to the station or site collecting this laser data.

1.2.1. Format:

A2(1-2)	Record Type (= "H2" or "h2")
A10	Station name from official list (e.g., "MOB7 ", "MLRS ")
I4	System identifier: Crustal Dynamics Project (CDP) Pad Identifier for SLR
I2	System number: Crustal Dynamics Project (CDP) 2-digit system number for SLR
I2	System occupancy: Crustal Dynamics Project (CDP) 2-digit occupancy sequence number for SLR
I2	Station Epoch Time Scale - indicates the time scale reference. 3 = UTC (USNO) 4 = UTC (GPS) 7 = UTC (BIPM) 1-2, 5-6, 8-9 = reserved for compatibility with earlier data using obsolete time scales. 10 and above = UTC (Station Time Scales) **USE ONLY WITH ANALYSIS STANDING COMMITTEE (ASC) APPROVAL**
A10	Station network (e.g., "ILRS" for SLR/LLR/TLR)

1.2.2. Notes

For station-created files, there must be one and only one station header record in the file and it must be the second record. Data centers may combine files.

Values of the Station Epoch Time Scale other than 3, 4, and 7 on new data will not be understood by the SLR data analysts, and data including them will usually be discarded. Since time scales do evolve, and some experiments require higher accuracies than are available with the current techniques, it is necessary to include the possibility of new values (10-99) that do not conflict with current or obsolete historical values. If you believe there is a compelling reason to use another value (e.g., 10 or above), you **must** propose the new value and explain the reasons to the ILRS Analysis Standing Committee and the ILRS Data Formats and Procedures Standing Committee. If they grant approval, you may use the new value, and it will be documented in this manual.

The Crustal Dynamics Project Pad, site, and occupancy sequence number are often combined into the CDDIS Site Occupancy Designator (SOD) found in the official pad and code list mentioned in the introduction of this document. See https://ilrs.cddis.eosdis.nasa.gov/network/stations/active/index.html and https://ilrs.cddis.eosdis.nasa.gov/network/site_procedures/sod.html for details. For those non-ILRS stations using the CRD format, these fields may be the System/Sensor identifier, System/Sensor number, and Sequence Number, respectively.

The Station Network field must be set to “na” if no network is specified. Set to “ILRS” for data submitted to the ILRS. Set to other names for debris or other type of tracking.

1.3. Target Header

The target header describes static information relating to the target, whether it is a satellite, lunar or spacecraft target.

1.3.1. Format:

A2(1-2)	Record Type (= "H3” or “h3”)
A10	Target name from official list (e.g., "ajisai", "gps35")
I7	ILRS Satellite Identifier (Based on the COSPAR ID)
I4	SIC (Satellite Identification Code) (Provided by ILRS; set to “na” for non-ILRS targets without a SIC)
I5	NORAD ID (also known as “Satellite Catalog Number”)
I1	Spacecraft Epoch Time Scale (transponders only) 0=not used 1=UTC 2=Spacecraft Time Scale
I1	Target class 0=no retroreflector (including debris) 1=passive retroreflector 2=(deprecated - do not use) 3=synchronous transponder 4=asynchronous transponder 5=other
I2	Target location/dynamics na=unknown (for use when tracking a transponder using a Version 1 CPF) 0=other 1=Earth orbit 2=lunar orbit 3=lunar surface 4=Mars orbit 5=Mars surface 6=Venus orbit 7=Mercury orbit 8=asteroid orbit 9=asteroid surface 10=solar orbit/transfer orbit (includes fly-by)

1.3.2. Notes

There must be at least one target header (and associated child records) in a file, but there can possibly be more, e.g., for accumulating normal point data for many targets over a period (e.g., one day), for transmission to data centers.

For lunar surface targets (e.g., Apollo and Luna), set the NORAD ID to “na”, or the SIC value. There is no specific NORAD ID for these targets, and these values are based on current practice.

COSPAR ID to ILRS Satellite Identification Algorithm:

COSPAR ID Format: (YYYY-XXXA)

YYYY is the four-digit year of when the launch vehicle was put in orbit
XXX is the sequential launch vehicle number for that year
A is the alpha numeric sequence number within a launch
Example: LAGEOS-1 COSPAR ID is **1976-039A**
Explanation: LAGEOS-1 launch vehicle was placed in orbit in 1976; was the 39th launch in that year; and LAGEOS-1 was the first object injected into orbit from this launch.

ILRS Satellite Identification Format: (YYXXXAA), based on the COSPAR ID

YY is the two-digit year of when the launch vehicle was put in orbit
XXX is the sequential launch vehicle number for that year
AA is the numeric sequence number within a launch
Example: LAGEOS-1 ILRS Satellite ID is **7603901**

1.4. Session (Pass/Pass segment) Header

The session/pass header describes information relating to the period over which the data is collected. For many satellite targets, this is generally one pass, but can be associated with pass segments as well. For geostationary satellites and distant targets, the placement of this header must be related to pass segments as defined by the station. It will be necessary to specify that certain parameters or conditions remain constant or static during a session.

The session header is also the place to indicate what type of data records (e.g. normal point) follow. This ensures that data records are provided in blocks of consistent data type rather than allowing sampled engineering, full rate, and normal point records to be randomly intermingled.

Hence, there must be a Session Header preceding each block of data, and there may be more than one Session Header for a given pass or segment if different types of data follow. See section 4.

1.4.1. Format:

A2(1-2) Record Type (= "H4” or “h4”)

I2 Data type

0=full rate
1=normal point
2=sampled engineering

I4 Starting Year

I2 Starting Month

I2 Starting Day

I2 Starting Hour (UTC)

I2 Starting Minute (UTC)

I2 Starting Second (UTC)

I4 Ending Year (Set the ending date and time fields to “na” if not available.)

I2 Ending Month

I2 Ending Day

I2 Ending Hour (UTC)

I2 Ending Minute (UTC)

I2 Ending Second (UTC)

I2 A flag to indicate the data release:
0: first release of data
1: first replacement release of the data
2: second replacement release, etc.

I1 Tropospheric refraction correction applied indicator

0=False (not applied)
1=True (applied)

I1 Center of mass correction applied indicator

0=False (not applied)
1=True (applied)

I1 Receive amplitude correction applied indicator

0=False (not applied)
1=True (applied)

I1 Station system delay applied indicator

0=False (not applied)
1=True (applied)

I1 Spacecraft system delay applied (transponders) indicator

0=False (not applied)
1=True (applied)

I1 Range type indicator

0=no ranges (i.e., transmit time only)
1=one-way ranging
2=two-way ranging
3=receive times only
4=mixed (for real-time data recording, and combination of one- and two-way ranging, e.g., T2L2)

Important: If Range type indicator is **not** set to two-way (2) or mixed (4), all corrections must be written as one-way quantities. Specifically, this applies to range, calibration, refraction correction, center of mass correction, as well as all Root Mean Square (RMS) and other statistical fields. With "mixed", separate range data (10), normal point (11), and calibration (40) records will be needed for one-way and two-way data.

I1 Data quality alert indicator

0=good quality; nominal/uncompromised data
1=suspect quality; some concerns that the data has been compromised
but is still useful and can be used with caution
2=poor or unknown quality; test, experimental or compromised data,
not to be used for scientific purposes.

Note: Details of any data degradation can be included in comment ("00") records.

1.4.2. Notes

For normal point records, stations generating the file must set the center of mass applied and refraction applied flags to false and provide data consistent with these flags. The format, however, allows data to be provided where normal point data has these corrections applied, e.g., for special purpose users or for use by data centers themselves.

Note that several of the indicator fields, such as the refraction and the center of mass correction, have the opposite meaning of corresponding Merit II flags. For instance, in the Merit II full rate format, the center of mass applied flag is set to 0 if the correction is applied. Here, the flag is set to 1 if the correction is applied.

The station system delay applied indicator is normally set to true for normal points.

Ending time may be cumbersome to compute if data is being written directly into the CRD format in real-time. In this case, the ending date and time fields may be filled with “na”.<HAS THIS CHANGED?>

1.5. Prediction Header

The prediction record indicates the predictions used for tracking this pass.

1.5.1. Format

A2(1-2) Record Type (= "H5" or "h5")

I2 Prediction type

- 0=other
- 1=CPF
- 2=TLE

I2 Year of century from CPF or TLE

A6 or A12 Date and time:

- CPF starting date and hour (MMDDHH) from CPF “H2” record; or
- TLE epoch day/fractional day from line 1

A3 Prediction provider:

- CPF provider from CPF “H1” record;
- TLE does not include this field, but the source should be available

I5 Sequence number:

- CPF ephemeris sequence and sub-daily sequence numbers from the CPF “H1” record; or
- TLE revolution number from line 2

1.5.2. Notes:

Two line elements (TLE) are not used for ILRS laser ranging, but are for other techniques. The TLE format can be found at https://en.wikipedia.org/wiki/Two-line_element_set.

The CPF references pertain to both CPF v1 and v2. For v1, the 4 digit sequence number must be broken into daily and sub-daily (3 digits and 1 digit) fields. For both versions, the 5 digit sequence number above is created from daily*100+sub-daily.

1.6. End of Session (EOS) Footer

1.6.1. Format

A2(1-2) Record Type (= "H8" or “h8”)

1.6.2. Notes

Include even if it is immediately followed by the end of file footer.

1.7. End of File (EOF) Footer

1.7.1. Format

A2(1-2) Record Type (= "H9" or “h9”)

1.7.2. Notes

If an end-of-file footer is missing, the implication is that the file has been truncated and has therefore been corrupted. One response could be to request a retransmission of the file.

2. Configuration Records

Configuration records will hold static data that represents station specific configuration information used while collecting the data stored in this file. **All fields must be separated by spaces, and white spaces are *not* allowed within record fields.** These records are in **FREE FORMAT** (except that the record ID must be in columns 1-2) and rely on white spaces for parsing. **The field sizes (e.g., I5, F12.5) are suggestions, and should be sized according to the stations' needs. Character strings can be as short as 1 character and as long as 40 characters. Longer strings should be truncated to 40 characters on reading. See example 6.6. The field specifiers are based on FORTRAN. Examples of the C equivalents are A3 → %3s; I2 → %2d; F12.5 → %12.5f. ALL CHARACTER FIELDS must be written in 7 BIT FONT LATIN1 (aka ISO-8859-1) to avoid software problems.**

While detailed configuration records are strongly encouraged and are a vital part of the CRD format, the minimum requirement is a "C0" record containing the Transmit Wavelength and the System Configuration ID. The previously required "60" record is obsolete and is no longer accepted for new data. Record "C4" is always required for transponder data. Missing configuration records may result in warning messages from the Operations Centers.

The "detail type" field in the configuration records allows for future expansion of the configuration record format. At this time, this field always has the value "0".

2.1. System Configuration Record

The system configuration record provides a means for identifying all significant components of a system in operation during the collection of the data records contained within this file. This record is an extensible list of configuration records of components deemed necessary to characterize the system at any given time during which the data records are collected.

2.1.1. Format:

A2(1-2)	Record Type (= "C0" or "c0")
I1	Detail Type (= "0")
F10.3	Transmit Wavelength (nanometers)
A4	System configuration ID (unique within the file)
A4	Component A configuration ID (e.g., laser configuration ID)
A4	Component B configuration ID (e.g., detector configuration ID)
A4	Component C configuration ID (e.g., local timing system configuration ID)
A4	Component D configuration ID (e.g., transponder configuration ID)
A4	Component E configuration ID (e.g., software configuration ID)
A4	Component F configuration ID (e.g., meteorological configuration ID)
A4	Component G configuration ID (e.g., calibration target configuration ID)

Repeat as required.

2.1.2. Notes

The use of configuration records replaces the old Station Configuration Indicator (SCI) and Station CHange indicator (SCH) (but not the station site log) files.

The Transmit Wavelength represents the wavelength of the laser beam as transmitted into the atmosphere and is thus common to many of the station subsystems. Hence it is included explicitly in this record. One advantage of this is that the association of data records to wavelength used is more direct.

The file ***must*** contain at least one Configuration Header. If there are multiple system configurations used when generating the data records contained within the file for this pass, there should be multiple system Configuration Headers and associated configuration records in the file. See example in 6.4.

2.2. Laser Configuration Record

The file should contain at least one Laser Configuration record. If multiple wavelengths are used or there are significant changes to any of the other parameters within the data sets in the file, then there must be appropriate Laser Configuration records for each wavelength or configuration used.

2.2.1. Format:

A2(1-2)	Record Type (= "C1" or "c1")
I1	Detail Type (= "0")
A4	Laser Configuration ID (unique within the file)
A10	Laser Type (e.g., "Nd-Yag")
F10.2	Primary Wavelength (nm)
F10.2	Nominal Fire Rate (Hz)
F10.2	Pulse Energy (mJ): record when this field changes by 10%
F6.1	Pulse Width (FWHM in ps): record when this field changes by 10%
F5.2	Beam Divergence (full angle, arcseconds)
I4	Number of pulses in outgoing semi-train

2.2.2. Notes

Note that the primary wavelength is used here, e.g., use 1064 for a Nd-Yag laser even though only 532 is used.

Most fields are expected to be static for a given laser. Pulse energy and width should trigger the writing of a new record whenever they change by 10%.

2.3. Detector Configuration Record

The file should contain at least one Detector Configuration record. If multiple wavelengths are used or there are significant changes to any of the other parameters within the data sets in the file, then there must be an appropriate Detector Configuration record for each wavelength or configuration used.

2.3.1. Format:

A2(1-2)	Record Type (= "C2" or "c2")
I1	Detail Type (= "0")
A4	Detector Configuration ID (unique within the file)
A10	Detector Type (e.g., "SPAD", "CSPAD", "MCP", "APD", "GeDiode", …)
F10.3	Applicable Wavelength (nm)
F6.2	Quantum Efficiency at applicable wavelength (%)
F5.1	Applied Voltage (V)
F5.1	Dark Count (kHz)
A10	Output Pulse Type (ECL, TTL, photon-dependent, …)
F5.1	Output Pulse Width (ps)
F5.2	Spectral Filter (nm)
F5.1	% Transmission of Spectral Filter

F5.1 Spatial Filter (arcsec)

A10 External Signal Processing

F6.1 Amplifier Gain

F6.1 Amplifier Bandwidth (kHz)

I2 Amplifier In Use

"na" = Unknown

0 = No

1 = Yes

2.3.2. Notes

Most fields are expected to be static for a given detector. Spatial and spectral filter changes should be recorded when they change by 10% (for continuously variable filters), or whenever they change (for discrete filters). The field "external signal processing" can refer to a particular technique, algorithm, or software program used.

2.4. Timing System Configuration Record

The file should contain at least one station Timing System Configuration record. If multiple timing systems are used, then there must be an appropriate Timing System Configuration record for each system used.

2.4.1. Format:

A2(1-2) Record Type (= "C3" or "c3")

I1 Detail Type (= "0")

A4 Timing System Configuration ID (unique within the file)

A20 Time Source (e.g., "Truetime_XLi", "Truetime_XL-SD", "Datum_9390", "HP_58503A", "TAC", ...)

A20 Frequency Source (e.g., "Truetime_OCXO", "CS-4000", …)

A20 Timer (e.g., "MRCS", "SR620", "HP5370B", "Dassault", "Other", …)

A20 Timer Serial Number (for multiple timers of the same model)

F6.1 Epoch Delay Correction (µs)

2.4.2. Notes

Most of the fields in this record should effectively be pointers to items in the Site Log file, where associated static data on each device can be found. The epoch delay correction provides a measure of the propagation delay between the Time Source output and the point at which the timing epochs are registered. For example, in some systems, a 1 PPS signal is used to latch second boundaries. However, there must be some correction applied to the transmission delay between the source of the 1 PPS signal and the timer system. The epoch delay correction has been applied to the data, except in the case of transponders, where there is a choice. See record "C4" in section 2.5 below. Note the difference in units.

2.5. Transponder (Clock) Configuration Record

The transponder record describes static information relating to certain transponders.

2.5.1. Format:

A2(1-2) Record Type (= "C4" or "c4")

I1 Detail Type (= "0")

A4 Transponder Configuration ID (unique within the file)

F20.3 Estimated Station UTC Offset (nanoseconds)

F11.2 Estimated Station Oscillator Drift (UTC/station clock) in parts in 10^{15}.

F20.3 Estimated Transponder UTC Offset (nanoseconds)

F11.2 Estimated Transponder Oscillator Drift (UTC/spacecraft clock) in parts in 10^{15}

F20.12 Transponder Clock Reference Time (seconds, scaled or unscaled)

I1 Station clock offset and drift applied indicator

0=neither offset nor drift applied
1=only offset applied
2=only drift applied
3=both offset and drift applied

I1 Spacecraft clock offset and drift applied indicator

0=neither offset nor drift applied
1=only offset applied
2=only drift applied
3=both offset and drift applied

I1 Spacecraft time simplified

0=False
1=True

2.5.2. Notes

Note that standard sense used in all time and frequency metrology must be followed, e.g., local station offset is (UTC – local station).

A transponder configuration record is required only if the target contains a transponder or time transfer equipment.

To convert from spacecraft master clock units and timescale,

$$t_{UTC} = t_{master} + (t_{master} - t_o) * 10^{-15} * \text{Oscillator Drift} + \text{UTC offset},$$

where t_o is the Transponder Clock Reference Time, the time at which the master clock was calibrated against UTC (somehow), and the UTC offset is (UTC-master) at time t_o.

For the spacecraft time simplified mode (used for LRO), t_o has already been removed from t_{master} to allow passing of a much smaller number. The Transponder Clock Reference Time field is filled but only used for reference. The equation then becomes

$$t_{UTC} = t_{master} + (t_{master}) * 10^{-15} * \text{Oscillator Drift} + \text{UTC offset}.$$

The conversion for the station clock is analogous.

A new record should be written whenever a field changes value.

Information here supersedes similar information (i.e., Epoch delay correction) in the timing system configuration record.

2.6. Software Configuration Record

The software record describes software in the measurement path, including data collection and processing programs. Include a program if changing it could potentially change the data quality. Do not use spaces in these fields.

2.6.1. Format:

A2(1-2) Record Type (= "C5" or “c5”)

I1 Detail Type (= "0")

A4 Software Configuration ID (unique within the file)

A40 Tracking Software in measurement path (may be more than one program, comma delimited)

A20 Tracking Software Version(s) (comma delimited)

A40	Processing Software in measurement path (may be more than one program, comma delimited)
A20	Processing Software Version(s) (comma delimited)

2.6.2. Notes:

Show each program and version of software in the range measurement/processing data path, including tracking/ranging, meteorological sensor reading, data filtering, data normal pointing, data re-formatting software. This information can help analysts and stations correlate changes in data quality or quantity with changes of software versions. Do not use spaces in these fields.
Example:
C5 0 pgms Monitor,Sattrk 2.000Bm,2.00Cm conpro,crd_cal,PoissonCRD,gnp 2.4a,1.7,2.2a,CM-2.01a

2.7. Meteorological Instrumentation Configuration Record

The Meteorological Instrumentation record describes on-station devices that measure atmospheric pressure, temperature, humidity, and any other measurement path quantities. The information includes manufacturer, model, and serial number.

2.7.1. Format:

A2(1-2)	Record Type (= "C6" or “c6”)
I1	Detail Type (= "0")
A4	Meteorological Configuration ID (unique within the file)
A10	Pressure Sensor Manufacturer
A10	Pressure Sensor Model
A10	Pressure Sensor Serial Number
A10	Temperature Sensor Manufacturer
A10	Temperature Sensor Model
A10	Temperature Sensor Serial Number
A10	Humidity Sensor Manufacturer
A10	Humidity Sensor Model
A10	Humidity Sensor Serial Number

2.7.2. Notes:

Show each sensor whose data is included in the CRD data file. The same instrument can be given for 1, 2, or 3 of these sensor types, such as the Paroscientific Met4a, which provides pressure, temperature, and humidity. The detail type can be used to describe whether the record contains primary or secondary chain instruments. These entries should correspond to those in the ILRS Site Log. None of the fields may contain spaces.
Example:
C6 0 mets Paroscientific Met4 123456 Paroscientific Met4 123456 Paroscientific Met4 123456

2.8. Calibration Target Configuration Record

Each Calibration Target record describes one of the SLR calibration targets.

2.8.1. Format:

A2(1-2)	Record Type (= "C7" or “c7”)
I1	Detail Type (= "0")
A4	Calibration Configuration ID (unique within the file)
A10	Target Name or ID
F12.5	Surveyed target distance (m)
F6.2	Survey error (mm
F8.4	Sum of all constant delays (electronic, geometric, optical) that are not included in the time of flight measurements (m, one way)
F10.2	Pulse Energy (mJ): record when this field changes by 10%
A20	Processing software name
A20	Processing software version

2.8.2 Notes:

Target ID is a character string used to identify the particular calibration target, such as “a”, “b”, “c”, or “1”, “2”, “3”, or “internal 1”, “external 1”.

The 'C7' record must accompany the '42' records in the full-rate data, but it may be included with the normal point files as well.

3. Data Records

Data records contain non-static data, hence they all will contain a time-stamp field. **All fields *must* be separated by spaces, and white spaces are *not* allowed within data fields**. These records are in **FREE FORMAT** (except for the record type, which must be in columns 1-2) and rely on white spaces for parsing. **The field sizes for numerics (e.g., I5, F12.5) are suggestions, and should be sized according to the target's needs and the station's precision. Character fields may be as short as 1 character and as long as 40 characters. Longer strings should be truncated to 40 characters on reading. The exception is that the comment record (ID = "00") contents can be up to 80 characters and can contain white spaces.** There will be no unused or undefined fields. See example 6.6. The field specifiers are based on FORTRAN. Examples of the C equivalents are A3 → %3s; I2 → %2d; F12.5 → %12.5f.

Data records of the same type must be in chronological order. In other words, all normal point records must be in chronological order; all meteorological records must be in chronological order, etc. Meteorological records, for instance, may be either interleaved with the normal point records or kept together. Times assigned to the calibration ("40") and session ("50") records are at the discretion of the station, although if there are multiple calibration records in a pass, the times should be representative of the time for which they are applicable.

Seconds of day must be given modulo 86400. In other words, seconds of day must wrap around to 0 at the end of day. Using the pass start and stop times from the H4 header, it will be possible to unambiguously determine the day associated with the seconds of day field. To remove any ambiguity, the satellite pass must not be longer than 1 day (which could occur for geostationary satellites).

Several types of data records may need to be interpolated to the time of the range or normal point record by data users. These are the extended range information record ("12"), the meteorological records ("20" and "21"), the pointing angle record ("30"), and, although it is mainly present for documentation, the calibration record ("40"). Some fields (e.g., precipitation type) cannot be interpolated, while most can. Since these record types are present only after one or more of their values have changed "significantly", a 2-point linear interpolation will usually suffice.

3.1. Range Record (Full rate, Sampled Engineering/Quicklook)

The full rate range record contains single-shot measurement data. The file will contain blocks of one or more range records corresponding to a consistent data type (full rate, sampled engineering) and system configuration.

3.1.1. Format:

A2(1-2) Record Type (= "10")

F18.12 Seconds of day (typically to 100 ns precision for SLR/Lunar Laser Ranging (LLR) or 1 picosecond for transponder/time transfer). For transponders and time transfer, station clock correction may be applied.

F18.12 Time-of-flight in seconds (none, one-, or two-way depending on range type indicator); or (for Epoch Event 5) spacecraft receive time in units of the spacecraft master clock, or seconds if "Spacecraft offset and drift applied indicator" is true. Time-of-flight may be corrected for station system delay; receive time may be corrected for spacecraft system delay and/or clock correction.

A4 System configuration ID

I1 Epoch Event - indicates the time event reference

Currently, only 1 and 2 are used for laser ranging data.

0=ground receive time (at System Reference Point - SRP) (two-way)

1=spacecraft bounce time (two-way)

2=ground transmit time (at SRP) (two-way)

3=spacecraft receive time (one-way)

4=spacecraft transmit time (one-way)

5=ground transmit time (at SRP) and spacecraft receive time (one-way)

6=spacecraft transmit time and ground receive time (at SRP) (one-way)

I1 Filter flag

0=unknown

1=noise and excluded returns

2=data

I1 Detector channel

0=not applicable or “all”

1-4 for quadrant

1-n for many channels

I1 Stop number (in multiple-stop system)

0=not applicable or unknown

1-n=stop number

I5 Receive Amplitude - a positive linear scale value

I5 Transmit Amplitude - a positive linear scale value

3.1.2. Notes

The format allows multiple color data to be included in the same file, with separate normal point statistics, etc.

As noted above, transmit time only, receive time only, one-way, and two-way ranges, etc., can appear in the same file to accommodate transponders.

Note that station transmit and receive times are nominally with respect to the system reference point (SRP), which in many cases is the telescope invariant point. Computing precise transmit and receive times requires a knowledge of both the transmit delay and receive delay, which is critical for transponder ranging. It is less critical for normal satellite (two-way) ranging since errors in distributing the system delay to these components are canceled.

The full rate data file should include a swathe of data around the station-assessed signal adequate to reconstruct the normal point. The filter flag is used to record whether the station processing indicates that a return is signal, noise, or a signal return that is considered noise because it was excluded due to tight filtering."

If transmit or receive amplitude is not measured, the field should be set to “na”.

3.2. Range Record (Normal Point)

The normal point range record contains the average epoch and range computed from a filtered set of range data within the specified normal point time window by a normal pointing algorithm. The file contains blocks of one or more range records corresponding to a consistent data type and system configuration.

3.2.1. Format:

A2(1-2) Record Type (= "11")

F18.12 Seconds of day (typically to < 100 ns precision for SLR/LLR or < 1 ps for transponders/time transfer). Station clock corrections should be applied for all targets.

F18.12 Time-of-flight in seconds (none, one-, or two-way depending on range type indicator); or (for Epoch Event = 5) spacecraft receive time in units of the spacecraft master clock, or seconds if “Spacecraft offset and drift applied indicator” is true. Time-of-flight should be corrected for station system delay; receive time may be corrected for spacecraft system delay and/or clock correction.

A4 System configuration ID

I1 Epoch Event - indicates the time event reference

Currently, only 1 and 2 are used for laser ranging data.

0=ground receive time (at SRP) (two-way)

1=spacecraft bounce time (two-way)

2=ground transmit time (at SRP) (two-way)

3=spacecraft receive time (one-way)

4=spacecraft transmit time (one-way)

5=ground transmit time (at SRP) and spacecraft receive time (one-way)

6=spacecraft transmit time and ground receive time (at SRP) (one-way)

F6.1 Normal point window length (seconds)

I6 Number of raw ranges (after editing) compressed into the normal point

F9.1 Bin RMS from the mean of raw accepted time-of-flight values minus the trend function (ps)

F7.3 Bin skew from the mean of raw accepted time-of-flight values minus the trend function

F7.3 Bin kurtosis from the mean of raw accepted time-of-flight values minus the trend function

F9.1 Bin peak – mean value (ps)

F5.1 Return rate (%)

I1 Detector channel

0=not applicable or "all"

1-4 for quadrant

1-n for many channels

F5.1 Signal to noise ratio (S:N)

3.2.2. Notes

Note that the station transmit and receive times are nominally given with respect to the system reference point (SRP) which, in many cases, is the telescope invariant point. Computing precise transmit and receive times requires a knowledge of both the transmit delay and receive delay and is critical for transponder ranging. It is less critical for normal satellite (two-way) ranging since errors distributing the system delay between transmit and receive time components are canceled.

If there are too few data points to assess pass RMS, skew, or kurtosis, put "na" in the field. It is left to the station's discretion, subject to ILRS directives, whether to distribute normal points which have few data points. **Kurtosis calculations should follow the convention in which 3 is subtracted, so that the kurtosis for a normal distribution is 0.**

Detector channel is normally '0' even for multi-channel systems. This field is included for flexibility.

As an example of CRD flexibility, LRO normal points used F28.12 rather that F18.12 as the spacecraft receive time format.

3.3. Range Supplement Record

The range supplement record contains optional range data and is interspersed with range data to which it is associated. If this record is used, then it should be created whenever there is a ***significant*** change to one or more fields.

3.3.1. Format:

A2(1-2) Record Type (= "12")

F18.12 Seconds of day.

A4 System configuration ID

F6.1 Tropospheric refraction correction (picoseconds, one-way)

F6.4 Target center of mass correction (meters, one-way)

F5.2 Neutral density (ND) filter value

F8.4 Time bias applied (seconds)

F20.15 Range rate (seconds/second)

3.3.2. Notes

None.

3.4. Meteorological Record

This data record contains a minimal set of meteorological data. At least one record must appear in the data file.

3.4.1. Format:

A2(1-2) Record Type (= "20")

F18.12 Seconds of day (typically to 1 milllisec precision).

F7.2 Surface pressure (millibar)

F6.2 Surface temperature in degrees Kelvin

F4.0 Relative humidity at the surface in %

I1 Origin of values

0=measured values (written whenever a value changes "significantly")

1=interpolated values applicable at the time (seconds of day) given in this record

3.4.2. Notes

Meteorological records should only be written when one of the fields changes "significantly". As a minimum, a new record should be written whenever pressure changes by 0.1mB, the temperature changes by 0.1 K, or when the humidity changes by 5%. The time (seconds of day) of an interpolated record should match the time in the following normal point record.

Since meteorological records may be submitted in blocks and not interspersed with the normal point or range records, it is recommended that the meteorological records be accumulated and interpolated to the times needed (e.g., times of normal points or full rate records).

3.5. Meteorological Supplement Record

This data record contains an optional supplemental set of meteorological data. A file must contain at least one meteorological record and may contain one or more meteorological supplement records.

3.5.1. Format:

A2(1-2) Record Type (= "21")

F18.12 Seconds of day (typically to 1 milllisec precision).

F5.1 Wind speed (m/s)

F5.1 Wind direction (degrees azimuth, North is zero)

A5 Weather conditions (two-digit SYNOP/WMO "present weather" code, or "rain", "snow", "fog", "mist", "clear", "na", etc.)

I3 Visibility (km)

F4.2 Sky clarity (i.e., zenith extinction coefficient)

I2 Atmospheric seeing (arcsec)

I2 Cloud cover (%)

F6.2 Sky temperature in degrees Kelvin

3.5.2. Notes

Meteorological records should only be written when one of the fields changes “significantly”. The criteria should be at least 2 times the least significant bit of the sensor, to prevent noise in the lowest bit from constantly producing new records.

Present weather code can be found at https://www.nodc.noaa.gov/archive/arc0021/0002199/1.1/data/0-data/HTML/WMO-CODE/WMO4677.HTM. This code is produced by some common meteorological equipment. If such equipment is not available, a single word description, i.e., “fog” can be entered.

3.6. Pointing Angle Record

This record contains telescope or beam director pointing (azimuth and elevation) angles, and is optional for normal point data sets. If it is used, the source and nature of this data must be provided.

3.6.1. Format:

A2(1-2)	Record Type (= "30")
F18.12	Seconds of day (typically to 1 milllisec precision).
F8.4	Azimuth in degrees
F8.4	Elevation in degrees
I1	Direction flag 0=transmit & receive 1=transmit 2=receive
I1	Angle origin indicator 0=unknown 1=computed 2=commanded (from predictions) 3=measured (from encoders)
I1	Refraction corrected 0=False (in vacuo angles, i.e., angles as if there were no atmosphere)) 1=True (apparent angles with refraction included)
F10.7	Azimuth Rate in degrees/second
F10.7	Elevation Rate in degrees/second

3.6.2. Notes

Pointing angle records should only be written when one of the angles changes “significantly”**.** The meaning of “significantly” should be defined by the producers and the users of this data.

The pointing angles seem to be seldom used in practice. In most cases when pointing angles are used in data analysis, it is to cross check that the pass and the station location have been correctly identified. There may be cases where pointing angles are used with or without ranging data as a fundamental data type in precision orbit determination. In these cases, the frequency and care taken in compiling these angle measurements will be much greater. In this case, it is also possible that the pointing angle records will be needed with normal points.

If azimuth and elevation are not known, do not include this record. If azimuth rate or elevation rate are unknown, set them to “na.”

As a special case, the NASA collocation software has required that there be pointing angles for each range observation.

3.7. Calibration Record

The calibration record contains statistics of accepted calibration measurements. It may be associated with calibrations at the station or the target (i.e., for transponders). A CRD file can contain as many calibration detail records ("41") as required (one pre- and one post-calibration are expected for SLR/LLR), but there must be exactly one station calibration ("40") record for each SLR/LLR pass segment in the file. There can also be calibration records to represent several "types of data". For a transponder, for which all fires must be recorded as well as returns, there should be type 0 (normal ranging) and 1 (station transmit).

Stated another way, for each SLR/LLR pass segment (session), there should be
1) two calibration detail records ("41"), one with the pre-calibration information, and one with post-calibration information. Each record will include:
    the average (filtered) calibration value and
    the corresponding averaged seconds-of-day;
and
2) one overall calibration record (type "40") with:
    the AVERAGE of the pre-calibration and post-calibration values, and
    the seconds-of-day AT THE MIDDLE OF THE PASS SEGMENT.

Pre-calibrations should be taken no earlier than two hours before the pass segment and post-calibrations should be taken no later than two hours after the pass segment, making sure that the time difference between pre- and post-calibration is no longer than two hours. Larger spans are discouraged, but, if used, care must be taken that the calibration value is accurate. If the time difference between pre- and post-calibration values is larger than an interval the station finds acceptable, the stations must submit only the pre-calibration or post-calibration result, whichever is judged to be more reasonable (probably the one closer in time to the data). *If, under unusual circumstances, either the pre- or post-calibration was not taken, the calibration that was taken can be submitted in the "40" record and "41" record.* Real time calibrations will be handled with a single "40" record..

See examples in 6.5 and 6.7.

3.7.1. Format:

A2(1-2)	Record Type (= "40")
F18.12	Seconds of day (typically to < 100 ns precision for SLR/LLR, or <1 ps for transponder ranging). Station clock corrections should be applied for all targets. This should be the time at the middle of the pass segment.
I1	Type of data 0=station combined transmit and receive calibration ("normal" SLR/LLR) 1=station transmit calibration (e.g., one-way ranging to transponders) 2=station receive calibration 3=target combined transmit and receive calibrations 4=target transmit calibration 5=target receive calibration
A4	System configuration ID
I8	Number of data points recorded (= "na" if no information)
I8	Number of data points used (= "na" if no information)
F7.3	One-way target distance (meters, nominal) (= "na" if no information)
F10.1	Calibration System Delay (picoseconds)
F8.1	Calibration Delay Shift - a measure of calibration stability (picoseconds)
F6.1	RMS of raw system delay (ps). If pre- and post- pass calibrations are made, use the mean of the two RMS values, or the RMS of the combined data set.
F7.3	Skew of raw system delay values from the mean. If pre- and post- pass calibrations are made, use the mean of the two skew values, or the skew of the combined data set.

F7.3 Kurtosis of raw system delay values from the mean. If pre- and post- pass calibrations are made, use the mean of the two kurtosis values, or the kurtosis of the combined data set.

F6.1 System delay peak – mean value (ps). If pre- and post- pass calibrations are made, use the mean of the two peak-mean values, or the peak-mean of the combined data set.

I1 Calibration Type Indicator

0=not used or undefined

1=nominal (from once off assessment)

2=external calibrations

3=internal calibrations – telescope

4=internal calibrations – building

5=burst calibrations

6=other

I1 Calibration Shift Type Indicator

0=not used or undefined

1=nominal (from once off assessment)

2=pre- to post- Shift

3=minimum to maximum

4=other

I1 Detector Channel

0=not applicable or "all"

1-4 for quadrant

1-n for many channels

I1 Calibration Span

0 = not applicable (e.g. Calibration type indicator is "nominal")

1 = Pre-calibration only

2 = Post-calibration only

3 = Combined (pre- and post-calibrations or multiple)

4 = Real-time calibration (data taken while ranging to a satellite)

F5.1 Return Rate (%)

3.7.2. Notes

"Nominal" calibrations are intended for generally low accuracy systems that do not have access to high precision system delay measurements, but rather depend on fairly static and infrequent assessments of the system delay. For example, use "nominal" calibrations for engineering data while a station is being developed, or for other special purposes.

Kurtosis calculations should follow the convention in which 3 is subtracted, so that the kurtosis of a normal distribution is 0.

Two "internal calibration" values are specified, since the term has historically been used with two different meanings. "Telescope" means that the calibration target is attach to the telescope. This implies that calibrations can be taken at virtual any telescope orientation. This can also permit "real time" calibration during a satellite pass,. "Building" means that the calibration target is in a fixed position in the telescope dome or shelter and not attached to the telescope. It is basically an external calibration target move indoors.

It is expected that one calibration record is included for a normal point data block, i.e., for an entire pass or a pass segment (any data preceded by an "H4" session header and closed by an "H8" session footer).

3.8. Calibration Detail Record

The calibration detail record contains statistics of accepted calibration measurements for pre- or post-calibration. There must be at least two "41" detail records if the "calibration span" in the "40" calibration record is "3" (combined). It may be associated with calibrations at the station or the target (i.e., for transponders). The file can contain as many detail calibration records as required, but there must one station calibration ("40") record for each pass segment. Each calibration record is applicable to the subsequent block(s) of range records. There can also be calibrations records to represent several "types of data". For a transponder, for which all fires must be recorded as well as returns, there should be type 0 (normal ranging) and 1 (station transmit).

3.8.1. Format:

A2(1-2) Record Type (= "41")

F18.12 Seconds of day (typically to < 100 ns precision for SLR/LLR, or <1 ps for transponder ranging). Station clock corrections should be applied for all targets. This should be the average of the time of each filtered calibration measurement.

I1 Type of data

- 0=station combined transmit and receive calibration ("normal" SLR/LLR)
- 1=station transmit calibration (e.g., one-way ranging to transponders)
- 2=station receive calibration
- 3=target combined transmit and receive calibrations
- 4=target transmit calibration
- 5=target receive calibration

A4 System configuration ID

I8 Number of data points recorded (= "na" if no information)

I8 Number of data points used (= "na" if no information)

F7.3 One-way target distance (meters, nominal) (= "na" if no information)

F10.1 Calibration System Delay (picoseconds)

F8.1 Calibration Delay Shift - a measure of calibration stability (picoseconds)

F6.1 RMS of raw system delay (ps). If pre- and post- pass calibrations are made, use the mean of the two RMS values, or the RMS of the combined data set.

F7.3 Skew of raw system delay values from the mean. If pre- and post- pass calibrations are made, use the mean of the two skew values, or the skew of the combined data set.

F7.3 Kurtosis of raw system delay values from the mean. If pre- and post- pass calibrations are made, use the mean of the two kurtosis values, or the kurtosis of the combined data set.

F6.1 System delay peak – mean value (ps). If pre- and post- pass calibrations are made, use the mean of the two peak-mean values, or the peak-mean of the combined data set.

I1 Calibration Type Indicator

- 0=not used or undefined
- 1=nominal (from once off assessment)
- 2=external calibrations
- 3=internal calibrations – telescope

4=internal calibrations – building

5=burst calibrations

6=other

I1 Calibration Shift Type Indicator

0=not used or undefined

1=nominal (from once off assessment)

2=pre- to post- Shift

3=minimum to maximum

4=other

I1 Detector Channel

0=not applicable or "all"

1-4 for quadrant

1-n for many channels

I1 Calibration Span

0 = not applicable (e.g. Calibration type indicator is "nominal")

1 = Pre-calibration only

2 = Post-calibration only

3 = DO NOT USE

4 = DO NOT USE

5 = One of multiple calibrations (see below)

F5.1 Return Rate (%)

3.8.2. Notes

"Nominal" calibrations are intended for generally low accuracy systems that do not have access to high precision system delay measurements, but rather depend on fairly static and infrequent assessments of the system delay. For example, use "nominal" calibrations for engineering data while a station is being developed, or for other special purposes.

Kurtosis calculations should follow the convention in which 3 is subtracted, so that the kurtosis of a normal distribution is 0.

Two "internal calibration" values are specified for the Calibration Type Indicator, since the term has historically been used with two different meanings. "Telescope" means that the calibration target (e.g., a corner cube) is attached to the telescope. This implies that calibrations can be taken at virtual any telescope orientation. This can also permit "real time" calibration during a satellite pass. "Building" means that the calibration target is in a fixed position in the telescope dome or shelter and not attached to the telescope. It is essentially an external calibration target moved indoors.

It is expected that two calibration detail records are included for an SLR/LLR normal point data block (i.e., a pass segment) when the "41" Calibration Record's Calibration span is set to "3" (combined).

Use calibration span = 5 ("one of multiple") only if a non-linear fit of more than two calibration sessions is used to create the "40" calibration record. This is non-standard usage.

3.9. Calibration "Shot" Record (Full Rate)

The calibration "shot" record is similar to the Range Record ("10") in that it is written for every fire, although to the calibration target. The records from a pass should be sufficient to reconstruct the system delay records in the "40" and "41"

records. Note that the equation for the cal/system delay is assumed to be this:
cal= round trip time to target - round trip surveyed distance to the target -
other electronic and geometric corrections
on a shot-by-shot basis.

A2(1-2) Record Type (= "42")

F18.12 Seconds of day (typically to < 100ns for SLR/LLR or <1 ps for transponder ranging). Station clock corrections should be applied for all targets.

F18.12 Time-of-flight in seconds (two way) -- {Will there every be any reason for one-way calibration information?}

A4 System configuration ID

A4 Calibration configuration ID (unique within the file)

F8.4 Sum of all time or point angle varying electronic and geometric terms needed to compute calibration (m, one way); must be present to compute system delay)

I1 Type of data

- 0=station combined transmit and receive calibration ("normal" SLR/LLR)
- 1=station transmit calibration (e.g., one-way ranging to transponders)
- 2=station receive calibration
- 3=target combined transmit and receive calibrations
- 4=target transmit calibration
- 5=target receive calibration

I1 Calibration Type Indicator

- 0=not used or undefined
- 1=(do not use)
- 2=external calibrations
- 3=internal calibrations – telescope
- 4=internal calibrations – building
- 5=burst calibrations
- 6=other

I1 Filter flag

- 0=unknown
- 1=noise
- 2=data

I1 Detector channel

- 0=not applicable or "all"
- 1-4 for quadrant
- 1-n for many channels

I1 Stop number (in multiple-stop system)

- 0=not applicable or unknown
- 1-n=stop number

I1 Calibration Span

- 0 = not applicable (e.g. Calibration type indicator is "nominal")

1 = Pre-calibration only

2 = Post-calibration only

3 = Combined (pre- and post-calibrations or multiple)

4 = Real-time calibration (data taken while ranging to a satellite)

5 = One of multiple calibrations (see below)

I5 Receive Amplitude - a positive linear scale value

I5 Transmit Amplitude - a positive linear scale value

Two "internal calibration" values are specified for the Calibration Type Indicator, since the term has historically been used with two different meanings. "Telescope" means that the calibration target (e.g., a corner cube) is attached to the telescope. This implies that calibrations can be taken at virtual any telescope orientation. This can also permit "real time" calibration during a satellite pass. "Building" means that the calibration target is in a fixed position in the telescope dome or shelter and not attached to the telescope. It is essentially an external calibration target moved indoors.`

The "42" record is designed for inclusion in the full rate data file. A station may choose to include this record type. The ILRS ASC or ILRS CB may also request that a station or stations submit this record for old or future spans of data.

3.10. Session (Pass) Statistics Record

The session (pass) statistics record contains averaged statistics derived from measurements taken during the session (or over the duration of a pass). The file contains blocks of one or more range records corresponding to a consistent format. One session statistics record should be associated with each of these data blocks.

3.10.1. Format:

A2(1-2) Record Type (= "50")

A4 System configuration ID

F6.1 Session RMS from the mean of raw accepted time-of-flight values minus the trend function (ps)

F7.3 Session skewness from the mean of raw accepted time-of-flight values minus the trend function

F7.3 Session kurtosis from the mean of raw accepted time-of-flight values minus the trend function

F6.1 Session peak – mean value (ps)

I1 Data quality assessment indicator. For SLR and LLR data:

0=undefined or no comment

1=clear, easily filtered data, with little or no noise

2= clear data with some noise; filtering is slightly compromised by noise level

3=clear data with a significant amount of noise, or weak data with little noise. Data are certainly present, but filtering is difficult.

4=unclear data; data appear marginally to be present, but are very difficult to separate from noise during filtering. Signal to noise ratio can be less than 1:1.

5=no data apparent

3.10.2. Notes

This record is only required in combination with a number of normal point records. It is optional with full rate or engineering data records.

Kurtosis calculations should follow the convention in which 3 is subtracted, so that the kurtosis of a normal distribution is 0.

3.11. Compatibility Record

THIS RECORD IS OBSOLETE. The SCH and SCI have been replaced in the Station Change History File:
https://ilrs.cddis.eosdis.nasa.gov/network/site_procedures/configuration_files.html.
This record is provided ONLY to allow reformatting of old data from the ILRS normal point and full rate data to this format, without losing existing data.

3.11.1. Format:

A2(1-2)	Record Type (= "60")
A4	System configuration ID
I1	System CHange indicator (SCH) A flag that is incremented for every major change to the system (hardware or software). After the value '9', return to '0', and then continue incrementing. The station and the data centers should keep a log in a standard format containing the flag value, the date of the change, and a description of the change.
I1	System Configuration Indicator (SCI) A flag used to indicate alternative modes of operation for a system (e.g., choice of alternative timers or detectors, or use of a different mode of operation for high satellites). Each value of the flag indicates a particular configuration, which is described in a log file held at the station and the data centers. If only a single configuration is used, use a fixed value. If a new configuration is introduced, use the next higher flag value. If the value exceeds '9', then return to '0', which overwrites a previous configuration flag (it is not likely that a station will have 10 current possible configurations).

3.11.2. Notes

None.

3.12. User Defined Record

This record is provided to allow special interest users or groups to add non-standard data records. Other users must be able to ignore such records (if they exist in a file) without any impact. Record types outside this range will be reserved for future standard format use.

3.12.1. Format:

A2(1-2)	Record Type (= "9X", X = 0…9)
3-80	User defined format

3.12.2. Notes

These records should normally be stripped from the file before being sent to the operation center.

3.13. Comment Record

Comment records are optional, and allow users to insert comments or notes as deemed necessary and appropriate. This especially pertains to any data quality issues designated in the header H4.

3.13.1. Format:

A2(1-2)	Record Type (= "00")
A80	Free format ASCII comments must be written in **7 BIT FONT LATIN1 (aka ISO-8859-1)** (terminated by at least an end-of-line character)

3.13.2. Notes

To ensure line lengths do not become excessive, a limit of 80 characters is set. Assume that any lines exceeding this limitwill be truncated. Multiple comment lines are encouraged. Comment lines can occur anywhere within a file.

4. Record Structure

The records as defined have the potential for storing a complex mix of data types while maintaining the ability to separate them into the component data files later (e.g., different laser color data, full rate and normal point, or multiple passes for the same or different stations). The data in a CRD file is designed to be stored in a normalized database and/or expressed in the XML language. The definitions of the records have kept this in mind.

It is important that, unless totally unavoidable, data records are not repeated, as this has the potential for undermining the requirement for unambiguous and consistent data. It is also efficient in terms of file sizing and storage.

The following table shows the permissible combination of records by data type. Normally, files will contain only one data type - full rate, sampled engineering, or normal point. However, the format does allow combining these files as separate blocks within a data file. See example 6.5. Another way to do this for a single pass is to start with a common h1/h2/h3 record set. The first h4 through h8 block can contain full rate data, for instance. The second h4 through h8 block can contain sampled engineering, and the third such block can contain the normal points. This is possible because the h4 record contains the date type for the data following (through h8).

Record	**Full Rate**	**Sampled Engineering** n/r	**Normal Point**
Header Section			
H1 – Format	√	√	√
H2 – Station	√	√	√
H3 – Target	√	√	√
H4 – Session (Pass)	√	√	√
H5 – Prediction	recommended	recommended	recommended
H8 – EOS	√	√	√
H9 – EOF	√	√	√
Configuration Section			
C0 – System Configuration	√	√	√
C1 – Laser Configuration	recommended	recommended	recommended
C2 – Detector Configuration	recommended	recommended	recommended
C3 – Timing Configuration	recommended	recommended	recommended
C4 - Transponder Configuration	√ transponders; n/a for other targets	√ transponders; n/a for other targets	√ transponders; n/a for other targets
C5 – Software Configuration	recommended	recommended	recommended
C6 – Met Instrument Configuration	recommended	recommended	recommended
C7 – Cal Target Configuration	Recommended	n/r	n/r*
Data Section			
10 – Range	√	√	not allowed
11 – Normal point	not allowed	not allowed	√
12 – Range Supplement	as available	as available	as available**
20 – Meteorological	√	√	√
21 – Meteorological Supplement	as available	as available	as available
30 – Pointing Angles	√ ***	√	n/r (usually)

40 – Calibration Statistics	√	n/r	√
41 – Calibration Detail Statistics	√	n/r	√
42 – Calibration "Shot" record	tbd	n/a	n/a
50 – Session Statistics	n/r	n/r	√
60 – Compatibility	obsolete	obsolete	obsolete
9x – User Defined	usually not transmitted	usually not transmitted	usually not transmitted
00 – Comments	as needed	as needed	as needed

n/a = not applicable or not appropriate
n/r = not required
√ = required
tbd = to be determined. A station may choose to include this record type. The ILRS ASC or ILRS CB may also request that a station or stations submit this record for old or future spans of data.
* = The 'C7' record must accompany the '42' records in the full-rate data, but it may be included with the normal point files as well.
** = Some fields may change too quickly to be useful for normal points.
*** = NASA collocation analysis software has required pointing angles for each observation.

Consider a number of cases. The first is a simple case where the station is performing basic satellite tracking and is creating full rate and normal point files. In practice, this will probably represent the majority of files most of the time, at least for the present.

A more complex case is when a station is performing two-color ranging and wants to store both full rate and normal point data in the same file, or when a site is publishing full rate data from experiments in time transfer using a transponder as the target.

4.1. Case 1

A file can contain either full rate or normal point data for one or more targets over a certain time period (for example, one day). This is typical for normal point (.npt) and full rate (.frd) files generated at many stations. (Comment records are not considered here.) As can be seen from the sample data in section 6, there can be some legitimate variations in record sequence.

Full rate file for one target, and a single system configuration.

Format Header

Station Header

Target Header

Laser Configuration Record

Detector Configuration Record

Timing System Configuration Record

System Configuration Record

Calibration Record

Session Header

Calibration Record (if required)

Pointing Record / Meteorological Record

Data Record (Full rate) (repeated)

Calibration Record / Pointing Record / Meteorological Record (as required)

Data Record (Full rate) (repeated)

Calibration Record (if required)

Pointing Record / Meteorological Record

End of session header

Session Header

Calibration Record (if required)

Pointing Record / Meteorological Record

Data Record (Full rate) (repeated)

Calibration Record / Pointing Record / Meteorological Record (as required)

Data Record (Full rate) (repeated)

Calibration Record (if required)

Pointing Record / Meteorological Record

End of session Header

…… (as many session as required)

End of file header

Normal point file for many targets, single system configuration.

Format Header

Station Header

Laser Configuration Record

Detector Configuration Record

Timing System Configuration Record

System Configuration Record

Calibration Record

Target Header

Session Header

Calibration Record (if required)

Meteorological Record

Data record (normal point) (repeated)

Meteorological Record

Data record (normal point) (repeated)

Meteorological Record

Pass Record

End of session header

….. other sessions for this target as required

Target Header

…. Repeat as above for as many targets as required

End of session header

End of file header

This corresponds to files having a record sequence such as

H1 H2 C0 C1 C2 C3 40 H3 H4 20 30 40 10 10 10...20 10 10...30 10 10...40...10 10 20 H8 H4 20 30 40 10 10 10...20 10 10...30 10 10...40...10 10 20 H8 H4...H8...H9

and

H1 H2 C0 C1 C2 C3 40 H3 H4 40 20 11 11 11...20 11 11...20.12 H8 H4 40 20 11 11 11...20 12 H8 H3 H4 40 20 11 11 11...20 11 11...20 12 H8 H4 40 20 11 11 11...20 12 H8...H8...H9

4.2. Case 2

One file contains full rate and normal point data for one target for one period (for example, one day) from a station performing two-color (or any other dual configuration) ranging.

Full rate and normal point file for one target, two system configurations.

Format Header

Station Header

Target Header

Laser Configuration L1 Record

Laser Configuration L2 Record

Detector Configuration D1 Record

Detector Configuration D2 Record

Timing System Configuration (TS) Record

System Configuration S1 Record (L1-D1-TS)

System Configuration S2 Record (L2-D2-TS), or whatever is appropriate

Calibration (system S1) Record C1

Calibration (system S2) Record C2, or whatever is appropriate.

Session Header (full rate)

Calibration Records C1 and/or C2 (if required)

Pointing Record / Meteorological Record

Data Record for S1 (Full rate) (repeated)

Data Record for S2 (Full rate) (repeated)

Calibration Records / Pointing Record / Meteorological Record (as required)

Data Records for S1 (Full rate) (repeated)

Data Records for S2 (Full rate) (repeated)

Calibration Records (if required)

Pointing Record / Meteorological Record

End of session Header

Session Header (normal point)

Meteorological Record

Data Record for S1 and/or S2 (normal point) (repeated)

Meteorological Record

Data Record for S1 and/or S2 (normal point) (repeated)

Meteorological Record

End of session Header

Session Header (full rate)

…. (Repeat as above for as many sessions as required)

End of session Header

End of file header

This corresponds to files having a record sequence such as

H1 H2 H3 C0 C0 C1 C1 C2 C2 C3 H4 20 30 40 40 10 10 10 10...20 10 10 10 10...30 10 10 10 10...40...10 10 20 H8 H4 20 11 11 11 11...20 11 11 11 11...11 11 11 11...11 11 20 H8 H4 20 30 40 40 10 10 10 10...20 10 10 10 10...30 10 10 10 10...40...10 10 20 H8 H4 20 11 11 11 11...20 11 11 11 11...11 11 11 11...11 11 20 H8…H8 H9.

4.3. Case 3

One file contains full rate data for one target from a station performing experiments in time transfer via a transponder in association with another station.

Full rate file for one target, two system configurations.

Format Header

Station Header

Target Header

Laser Configuration Record

Detector Configuration Record

Timing System Configuration Record

Transponder Configuration Record

System Configuration Record

Calibration Record (Site)

Calibration Record (Target)

Session Header (Full rate)

Calibration Record (Site) (if required)

Calibration Record (Target) (if required)

Pointing Record / Meteorological Record

Data Record (Full rate, time-of-flight and transmit epoch) (repeated)

Data Record (Full rate, receive epoch only) (repeated)

Pointing Record / Meteorological Record

End of session Header

End of file header

4.4. Case 4

In this case, several full rate or normal point sessions from one station are sent in a single file from the station to a data center. There are two ways of doing this:

4.4.1. Preferred method

H1 H2 H3 H4 ... H8

    H3 H4 ... H8

    ...

    H3 H4 ... H8 H9

This ordering is more hierarchical and more compatible with parsing into XML.

4.4.2. Acceptable, but not preferred, method

H1 H2 H3 H4 ... H8

H1 H2 H3 H4 ... H8

...

H1 H2 H3 H4 ... H8 H9

This ordering is syntactically correct, and may be easier to implement when converting data in the old format to CRD.

5. File Naming

Since the proposed data format is so flexible and a file can contain many data types and cover any period of time, file naming becomes a real issue. Therefore the following conventions have been adopted.

1. File names and file naming conventions do not form the basis for file processing except for files that have well defined and specific file extensions (such as .Z for extraction purposes). File processing will require files to be opened and parsed to determine what operations, if any, are to be performed.
2. File names ending in ".npt", ".frd", or ".qlk" contain single data types, but possibly multiple satellites and stations.
3. File names ending in ".crd" may contain multiple data types.
4. File names ending in ".frf" contain all the laser fire times and do not contain valid time-of-flights or receive times. This is for one-way transponder missions such as LRO. (For LRO-LR, the .frf files from ground stations comply with this rule, but the matched up .frf files after processing do contain laser fire times, time-of-flights, and receive times. These matched-up files, or some of them, from the 5-year LRO-LR operation have been delivered to CDDIS.)
5. Files are delivered to specific file repositories, in which it has been agreed and understood that certain file operations will be performed. Hence the onus is on the supplier to provide the appropriate type of file to the repository.
6. Published files will always have a unique file name. (This pertains to station naming conventions.)
7. Release versions are maintained within the data file headers for every pass or session. Station file names will echo this release number (if it is consistent within the file), but data center file names will not - those files will always contain the latest data release.

5.1. Station Naming Convention

This naming convention is for use with files transmitted from the station to the operations centers (unless there is a prior agreement for another protocol).

5.1.1 Single Pass and Data Type

5.1.1.1 Ftp or Scp

File names for ftp or scp transfer should be

ssss_satname_crd_yyyymmdd_hh[MM]_rr.typ

where

- ssss is the CDP Pad Identifier (station number)
- satname is from a standard ILRS list of spacecraft (lower case)
- yyyymmdd is the starting date of the pass (UTC) from the H4 header
- hh is the hour when the pass or pass segment begins (UTC time scale)
- MM is the minute when the pass or pass segment begins (optional, from the H4 header)
- rr is the release number (initial release = "00")
- typ is the data type:
    - frd – full rate data,
    - qlk – sampled engineering ("quicklook") data,
    - npt – normal point data,
    - crd – mixed or unspecified file contents, or

frf – full rate data with fire times only.

Geostationary satellite "passes" can be submitted in several files, depending on the tracking schedules. Files may contain the ".Z", ".z", ".gz", or ".zip" extension indicating a particular type of file compression.

5.1.1.2 E-mail Transmission

For e-mail submission, this filename should be part of the "Subject" field

Subject: npt data ssss_satellite_crd_yyyymmdd_hh_rr

5.1.2 Several Passes or Data Types

To submit several normal point, sampled engineering, full rate files or a combination of files at once, there are two recommended procedures. Note that these procedures can be used for ftp/scp transfers, not email.

5.1.2.1 Combined File

Send a single combined ASCII file. The description of a combined file name is:

ssss_[satname_]crd_yyyy[mm[dd[_hh]]]_rr.typ

where the fields are the same as above, and the brackets "[]" enclose fields that can be omitted depending on the file contents. Note that the station is always included, since the file comes from a single station. A split program (available in the sample code) will be required at the operation centers to break this file into its component files.

Examples:

7080_crd_20071012_14_00.npt	- normal points for several passes from different satellites, starting at a particular hour
7080_lageos1_crd_200206_99.crd	- LAGEOS-1 data for a month, with mixed releases
7080_crd_2003_99.frd	- full rate data for a year, with mixed releases

Notes:

1) This can cover mass resubmissions of data with a single (new) revision level.
2) When there are more than one revision level in a file, the release number should be "99".
3) In the case where several data types are mixed in a file, the type can be "crd".

5.1.2.2 Tar or Zipped File

'Zip' or 'tar' together several files into a larger file with an appropriate name:

ssss_crd_yyyy[mm[dd[_hh[MM]]]]_rr.com,

where

satname has been omitted,

mm is the minute, which has been added to permit more than one transmission in an hour, and

com is the compression program extension:

zip, or

tgz.

Examples:

7080_crd_2005_01.zip	- an update to some 2005 data files
7090_crd_20071012_1500_00.tgz	- a typical hourly transfer

5.1.3 Debris and other non-ILRS Tracking File Names

Non-ILRS tracking file names will be the same as above EXCEPT that they will start with the tracking network name. This addition will also prevent debris data from being accepted into the SLR data network.

networkname_ssss_satname_crd_yyyymmdd_hh_rr.xxx,

where

networkname is a debris or other non-ILRS tracking network. Examples could be “WPDEB”, “EURDEB”. The network names are not yet defined, but some name must be included.

5.2. Data Center Naming Convention

Data centers (e.g. Crustal Dynamics Data Information System (CDDIS) and the European Data Center (EDC)) will use these file names at their ftp and web sites. These are the file names the users will see when retrieving data for their analysis work. Each file will contain only one type of data.

satname_yyyymmddhh.typ (hourly)
satname_yyyymmdd.typ (daily)
satname_yyyymm.typ (monthly)
satname_yyyy.typ

where

- satname is from a standard ILRS list of spacecrafts,
- yyyy is the four-digit year,
- mm is the two-digit month,
- dd is the two-digit day,
- hh is the two-digit hour, and
- typ is
    - frd – full rate data,
    - qlk – sampled engineering data,
    - npt – normal point data.

Examples: starlette_2006091011.frd
lro_200810.npt

Files may contain the “.Z” or “.z” extension indicating the file compression.

6. Sample Files

This section includes passes and parts of passes represented in the CRD format. Note that record lengths were kept short by using "%.*x*f" C language formats for most floating point fields.

6.1. Full rate

Filename: 7080_ lageos2_crd_20061113_15_00.frd

```
H1 CRD 2 2007  3 20 14
H2 MLRS 7080 24 19 4 NASA
H3 LAGEOS2 9207002 5986 22195 0 1 1
H4 0 2006 11 13 15 23 52 2006 11 13 15 45 35 1 1 1 1 0 0 2 0
C0 0 532.000 std1
...
10 55432.0414338     0.047960587856 std1 2 0 0 0 na na
12 55432.0414338 std1 20735.0 1601.0000 0.00 0.0000 0.0000
20 55432.0414338  801.80  28.21   39 0
30 55432.0414338 297.2990  38.6340 0 2 1 0.0000000 0.0000000
40 55432.0414338 0 std1        na        na 0.000 -913.0 0.0 56.0 na na na 3 3 0 4 na
10 55435.6429746     0.047926839980 std1 2 0 0 0 na na
12 55435.6429746 std1 20697.0 1601.0000 0.00 0.0000 0.0000
30 55435.6429746 297.4480  38.7190 0 2 1 0.0000000 0.0000000
...
10 56735.8021609     0.046094881873 std1 2 0 0 0 na na
12 56735.8021609 std1 18092.0 1601.0000 0.00 0.0000 0.0000
30 56735.8021609  15.2330  45.7100 0 2 1
H8
H9
```

6.2. Normal Point

File name: 7080_lageos2_crd_20061113_15_00.npt

```
H1 CRD 2 2007  3 20 14
H2 MLRS 7080 24 19 4 NASA
H3 LAGEOS2 9207002 5986 22195 0 1 1
H4 1 2006 11 13 15 25 4 2006 11 13 15 44 40 0 0 0 0 1 0 2 0
C0 0 532.000 std1
...
11 55504.9728030 0.047379676080 std1 2  120      18       94.0 na na na 0.0 0 0.0
20 55504.9728030  801.80 282.10   39 1
40 55504.9728030 0 std1        na        na 0.000 -913.0 0.0 56.0 na na na 3 3 0 4 -1.0
11 55988.9809589 0.044893190432 std1 2  120      19       83.0 na na na 0.0 0 0.0
20 55988.9809589  801.50 282.80   39 1
11 56141.8467215 0.044635017248 std1 2  120      28       66.0 na na na 0.0 0 0.0
11 56223.2817254 0.044605221903 std1 2  120      25       87.0 na na na 0.0 0 0.0
20 56223.2817254  801.50 282.60   39 1
11 56373.5463612 0.044746486398 std1 2  120      25       78.0 na na na 0.0 0 0.0
20 56373.5463612  801.50 282.10   39 1
11 56439.9749454 0.044889147842 std1 2  120      25       99.0 na na na 0.0 0 0.0
11 56565.2288146 0.045288773098 std1 2  120      25       92.0 na na na 0.0 0 0.0
11 56680.8785419 0.045804632570 std1 2  120      10       55.0 na na na 0.0 0 0.0
20 56680.8785419  801.50 282.00   39 1
50 std1 86.0 -1.000 -1.000 -1.0 0
H8
H9
```

6.3. Sampled Engineering (Quicklook)

File name: 7080_lageos2_crd_20061113_15_00.qlk

```
H1 CRD 2 2007  3 20 14
H2 MLRS 7080 24 19 4 NASA
H3 LAGEOS2 9207002 5986 22195 0 1 1
H4 2 2006 11 13 15 24 17 2006 11 13 15 44 59 0 0 0 0 0 0 2 0
C0 0 532.000 std1
...
10 55457.0521861     0.047753624332 std1 2 0 0 0 na na
20 55457.0521861  801.80 282.10   39 0
30 55457.0521861 298.3470  39.2230 0 0 0 0.0000000 0.0000000
10 55482.4631214     0.047552685849 std1 2 0 0 0 na na
30 55482.4631214 299.4370  39.8100 0 0 0 0.0000000 0.0000000
...
10 56589.0390552     0.045383653062 std1 2 0 0 0 na na
20 56589.0390552  801.50 282.00   39 0
30 56589.0390552   6.7380  47.9120 0 0 0 0.0000000 0.0000000
10 56623.4538362     0.045531247776 std1 2 0 0 0 na na
30 56623.4538362   8.8120  47.4510 0 0 0 0.0000000 0.0000000
10 56657.6685552     0.045690091816 std1 2 0 0 0 na na
30 56657.6685552  10.8230  46.9570 0 0 0 0.0000000 0.0000000
10 56699.7866762     0.045901952309 std1 2 0 0 0 na na
30 56699.7866762  13.2310  46.3060 0 0 0 0.0000000 0.0000000
50 std1 86.0 -1.000 -1.000 -1.0 0
H8
H9
```

6.4. Sample 2-Color Normal Point file

File Name: 7810_lageos1_crd_20061230_07_00.npt

```
H1 CRD 2 2007  3 20 14
H2 ZIMMERWALD 7810 68 1 7 EUROLAS
H3 LAGEOS1 7603901 1155 8820 0 1 1
H4 1 2006 12 30  7 35 34 2006 12 30  8 12 29 0 0 0 0 1 0 2 0
C0 0 846.000 std1
...
C0 0 423.000 std2
...
11 27334.1080890 0.051571851861 std1 2  120     36     154.0 -1.000 -1.000 -1.0 0.0 0 0.0
20 27334.1080890  923.30 275.40   43 1
40 27334.1080890 0 std1        na        na 0.000 113069.0 0.0 138.0 na na na 2 2 0 1 na
11 27343.5080895 0.051405458691 std2 2  120     28      79.0 na na na 0.0 0 0.0
11 27372.6080888 0.050895050517 std2 2  120     30      76.0 na na na 0.0 0 0.0
11 27373.1080893 0.050886342010 std1 2  120     17     158.0 na na na 0.0 0 0.0
11 28003.8080894 0.042252027043 std1 2  120     19     170.0 na na na 0.0 0 0.0
20 28003.8080894  923.40 275.50   42 1
11 28008.7080899 0.042208378233 std2 2  120     85      71.0 na na na 0.0 0 0.0
11 28402.1080897 0.040251470202 std1 2  120      6     183.0 na na na 0.0 0 0.0
11 28406.5080897 0.040247878310 std2 2  120     45      78.0 na na na 0.0 0 0.0
11 28620.0080896 0.040574433849 std1 2  120     18     163.0 na na na 0.0 0 0.0
20 28620.0080896  923.50 275.50   42 1
11 28627.6080899 0.040603966534 std2 2  120    114      71.0 na na na 0.0 0 0.0
11 29151.2080895 0.045287136931 std2 2  120      7      65.0 na na na 0.0 0 0.0
11 29156.7080892 0.045360524908 std1 2  120      7     134.0 na na na 0.0 0 0.0
20 29156.7080892  923.50 275.80   42 1
11 29225.6080889 0.046314735294 std1 2  120     45     164.0 na na na 0.0 0 0.0
11 29237.7080892 0.046488750878 std2 2  120     50      78.0 na na na 0.0 0 0.0
11 29326.8080894 0.047825380133 std1 2  120     49     152.0 na na na0.0 0 0.0
11 29334.2080895 0.047940570614 std2 2  120     73      85.0 na na na 0.0 0 0.0
11 29461.4080892 0.050011219353 std2 2  120     29      76.0 na na na 0.0 0 0.0
11 29477.2080896 0.050279566397 std1 2  120     25     187.0 na na na 0.0 0 0.0
11 29544.4080897 0.051445695153 std1 2  120     19     164.0 na na na 0.0 0 0.0
11 29549.5080897 0.051535764981 std2 2  120     14      87.0 na na na 0.0 0 0.0
50 std1 165.0 na na na 0
50 std2 78.0 na na na 0
H8
```

```
H9
```

6.5. Sample showing all current record types

```
00 This is a recent MLRS normal point file.
00 Plausible '21' records have been added
00 Part of the full rate file has been added, so keep reading.
h1 CRD 2 2008  3 25 1
h2 MDOL 7080 24 19 4 NASA
h3 jason1 105501 4378 26997 0 1 1
h4 1 2008  3 25  0 45 17 2008  3 25  0 55  9 0 0 0 0 1 0 2 0
h5 1 08 032500 esa 8401
c0 0 532.000 std ml1 mcp mt1 swv met
c1 0 ml1 Nd-Yag 1064.00 10.00 100.00 200.0 -1.00 1
c2 0 mcp mcp 532.000 -1.00 3800.0 0.0 unknown -1.0 0.00 -1.0 0.0 none 5 10 1
c3 0 mt1 TAC TAC MLRS_CMOS_TMRB_TD811 na 445.9
c5 0 swv Monitor,Sattrk 2.000Bm,2.00Cm conpro,crd_cal,PoissonCRD,gnp 2.4a,1.7,2.2a,CM-2.01a
c6 0 met Paroscientific Met4 123456 Paroscientific Met4 123456 Paroscientific Met4 123456
40 2716.0000000 0 std 67 58 -1.000 -883.3 0.0 96.4 0.718 -0.126 364.4 3 3 0
20  2716.000  801.73 286.76  35. 0
21 2716.000 3.1 45 none 20 na 3 10 300.12
11  2726.697640514675     0.013737698432 std  2   15      1   72.7   1.494  -0.536  -32.4   0.67 0 20.7
11  2804.507921286791     0.011496837034 std  2   15      1   72.7   1.494  -0.536  -32.4   0.67 0 20.6
11  2810.908760187949     0.011334723870 std  2   15     16   65.4   1.229  -1.235  -33.5  10.67 0 85.6
20  2822.000  801.73 286.56  35. 0
11  2828.611102554046     0.010908518342 std  2   15      1   72.7   1.494  -0.536  -32.4   0.67 0 20.1
11  2850.814029348448     0.010424908601 std  2   15      3  116.6   0.649  -2.333  -86.7   2.00 0 40.1
11  3104.347543373788     0.010760099652 std  2   15      2  108.7   0.354  -2.750  -73.5   1.33 0 21.3
11  3113.248715491056     0.010963708963 std  2   15     11   78.5   1.345  -0.730  -45.8   7.33 0 62.3
11  3124.950255557618     0.011244819341 std  2   15     14   65.2   1.635   0.207    4.5   9.33 0 71.5
11  3142.652594816107     0.011696747487 std  2   15     12   74.2   1.369  -0.535 -161.6   8.00 0 68.9
11  3150.653650787761     0.011910674436 std  2   15      2  123.0   0.354  -2.750  -83.7   1.33 0 30.6
20  3151.000  801.73 286.16  35. 0
21 3152.000 2 80 fog 20  na 3 10 298.43
11  3169.356124039857     0.012431881802 std  2   15      1   72.7   1.494  -0.536  -32.4   0.67 0 20.4
50 std    72.7   1.494  -0.536  -32.4 0
h8
00 Note that there is no h9 "end of file" record after the "h8",
00 so this is a different part of the same file.
00
00 The following is part of the full-rate file from the same pass.
00 '21' records have been added to this example.
00 Even though this is not transponder data, a c4 record has been dummied.
00 The 'mc1' clock field id for the c4 record was added to the c0 record.
00 The file also contains 91, 92, and 93 records, which are user-defined.
00 Station-defined records will normally be stripped off by the station before transmittal.
00 Just bypass them as you do not know the format.
00 The analysts can also add their own 9x records if they wish.
h1 CRD  1 2008  3 25  1
h2 MDOL 7080 24 19 4
h3 jason1 105501 4378 26997 0 1 1
h4 0 2008  3 25  0 45 17 2008  3 25  0 55  9  0 0 0 0 1 0 2 0
c0 0 532.000 std ml1 mcp mt1 mc1 swv met spi
c1 0 ml1 Nd-Yag 1064.00 10.00 100.00 200.0 -1.00 1
c2 0 mcp mcp_varamp 532.000 -1.00 3800.0 0.0 unknown -1.0 0.00 -1.0 0.0 none 5 10 1
c3 0 mt1 TAC TAC MLRS_CMOS_TMRB_TD811 na 445.9
c4 0 mc1 0.000 0.00 1234567890123456.789 0.00 0.000000000000 0 0 0
c5 0 swv Monitor,Sattrk 2.000Bm,2.00Cm conpro,crd_cal,PoissonCRD,gnp 2.4a,1.7,2.2a,CM-2.01a
c6 0 met Paroscientific Met4 123456 Paroscientific Met4 123456 Paroscientific Met4 123456
c7 0 spi SpiderCCR na na 0 80 crdcal 1.7
91  8  85  2640 -2438728.97 -4909741.31  5429800.07  1474.0965 -5367.5721 -4187.1144 2
20 2716.000  801.73 286.76   35 0
21 2716.000 3.1 45 none 20 na 3 10 290.45
40 2716.0000000 0 std 67 58 -1.000 -883.3 0.0 96.4 0.718 -0.126 364.4 3 3 0 3 14.5
41 1016.0000000 0 std 37 28 -1.000 -883.2 0.0 96.2 0.715 -0.125 364.3 3 3 0 1 15.5
41 4416.0000000 0 std 30 30 -1.000 -883.4 0.0 96.6 0.721 -0.127 364.4 3 3 0 2 13.7
42  1006.1000000 -0.000000000780 std spi 18.612 3 3 2 0 0 4 na na
42  1006.2000000 -0.000000000783 std spi 18.611 3 3 2 0 0 4 na na
42  1006.5000000 -0.000000000779 std spi 18.609 3 3 2 0 0 4 na na
...
30 2717.996 326.8923 32.9177 0 1 1 0.0000000 0.0000000
12 2717.9964890 std 0.0 0.0000 0.00 0.0000 0.0000
30 2725.897 326.6035 33.9991 0 1 1 0.0000000 0.0000000
```

```
10 2726.697640514675 0.013737698432 std 2 2 0 0 na na
30 2734.998 326.2469 35.2830 0 1 1 0.0000000 0.0000000
10 2738.899248614531 0.013359440021 std 2 1 0 0 na na
30 2742.799 325.9195 36.4168 0 1 1 0.0000000 0.0000000
30 2752.100 325.4955 37.8239 0 1 1 0.0000000 0.0000000
10 2752.100991800282 0.012962363200 std 2 1 0 0 na na
30 2762.002 324.9939 39.3585 0 1 1 0.0000000 0.0000000
...
21 3309.000 2 80 fog 20 na 3 10
30 3309.224 164.3231 22.4342 0 1 1
10 3309.224609210523 0.016974823000 std 2 1 0 0 na na
93  3309.224609210523 std    0.000  16.660 -20.265   0.97511  -0.00099   -2416.305   35267.021
92 3309.000 -0.0003 0.0003
h8
h9
```

6.6. Sample demonstrating free format

The following data was written by two different programs, showing how field spacing and length can differ in each section.

File 1:

```
h1 CRD 2 2008 5 8 19
h2 MDOL 7080 24 19 4 NASA
h3 giovea 505101 7001 28922 0 1 1
h4 1 2008 5 8 9 40 23 2008 5 8 9 50 45 0 0 0 0 1 0 2 0
c0 0 532.000 std ml1 mcp_with_amp mt1
c1 0 ml1 Nd-Yag 1064.00 10.00 100.00 200.0 na 1
c2 0 mcp_with_amp mcp_and_avantek_amp 532.000 -1.00 3800.0 0.0 unknown na 0.00 na 0.0 none 5 10 0
c3 0 mt1 TAC TAC MLRS_CMOS_TMRB_TD811 na 439.45
40 34823.000 0 std 398 190 na 402.3 0.0 131.1 0.168 -0.130 494.4 3 3 0 4 -1.0
20 34823.000 796.55 287.86 24. 0
11 34945.620986680762 0.167738944021 std 2 300 116 193.32 1.821 0.904 -22.8 3.87 0 40.5
11 35237.103254500325 0.167288847260 std 2 300 143 173.04 1.601 -0.009 -61.3 4.77 0 38.5
11 35422.490473700898 0.167002428581 std 2 300 19 179.75 1.318 -0.974 -259.7 0.63 0 3.2
50 std 178.8 1.711 0.451 -128.2 0
h8
h9
```

File 2:

```
h1 CRD  1 2008  5  8 19
h2 MDOL 7080 24 19 4 NASA
h3 giovea 505101 7001 28922 0 1 1
h4  1 2008  5  8  9 40 23 2008  5  8  9 50 45  0 0 0 0 1 0 2 0
c0 0  532.000 std ml1 mcp mt1
c1 0 ml1 Nd-Yag    1064.00      10.00      100.00  200.0 na     1
c2 0 mcp mcp    532.000  na 3800.0   0.0 unknown  na  0.00  na  0.00 none 5 10 0
c3 0 mt1 TAC TAC MLRS_CMOS_TMRB_TD811 na  439.4
40 34823.000000 0 std      398      190  na      402.3      0.0  131.1   0.168  -0.130  494.4 3 3 0  4
1.0
20 34823.000  796.55 287.86  24. 0
11 34945.620986680762     0.167738944021 std 2  300    116  193.3   1.821   0.904  -22.8    3.87 0 40.3
11 35237.103254500325     0.167288847260 std 2  300    143  173.0   1.601  -0.009  -61.3    4.77 0 35.3
11 35422.490473700898     0.167002428581 std 2  300     19  179.7   1.318  -0.974 -259.7    0.63 0 2.5
50 std  178.8   1.711   0.451 -128.2 0
h8
h9
```

6.7. Sample demonstrating data blocks

During data validation, several stations provided data in which meteorological and calibration records were grouped by record type. While not originally anticipated in the format design, it is not precluded, either. This variation in the format highlighted the need to properly interpolate records of a different epoch from the range or normal point records.

```
H1 CRD 01 2009  5 10  7
H2 HERL 7840 35 01 04 EUROLAS
H3 Ajisai 8606101 1500 16908 0 1 1
H4 1 2009 5 10 5 29  2 2009 5 10 5 34 48 0 0 0 0 1 0 2 0
C0 0   532.080   ES 10hz SPD5  GPS NA
C1 0 10hz     Nd-Yag   1064.16     10.00     20.00 100.0 20.00   4
C2 0 SPD5 SPAD5        532.000 20.00   0.0   0.0      +0.7v   0.0  0.15  20.0   0.0 Single_fot na na 0
C3 0  GPS Radiocode_GPS_8000   Radiocode_GPS_8000   HxET_=_3x_dassault   No_Sn                  0.0
20 19560.960          1015.20 277.50  99. 0
20 19923.840          1015.23 277.70  98. 0
20 20096.640          1015.24 277.80  98. 0
20 20459.520          1015.23 278.10  98. 0
40 19185.120          0   ES      na      na  122.977  105423.9     0.0  35.4   0.2   2.8   0.0 2 2 0 3
-1.0
41 18014.400          0   ES      na      na  122.977  105420.9     0.0  35.4   0.2   2.9   0.0 2 2 0 1
-1.0
41 20355.840          0   ES      na      na  122.977  105426.9     0.0  35.4   0.1   2.7   0.0 2 2 0 2
-1.0
11 19755.5635353     0.015411425559   ES 2  30.0    42     217.0  0.000  0.000      0.0  5.4 0 0.0
11 19786.3810075     0.014973907243   ES 2  30.0    56     213.0  0.000  0.000      0.0  7.3 0 0.0
11 19813.6766125     0.014664455551   ES 2  30.0    87     213.0  0.000  0.000      0.0 11.3 0 0.0
11 19844.4141312     0.014410182562   ES 2  30.0    66     218.0  0.000  0.000      0.0  8.6 0 0.0
11 19871.9499495     0.014271511355   ES 2  30.0    70     208.0  0.000  0.000      0.0  9.1 0 0.0
11 19903.0875582     0.014219515428   ES 2  30.0    27     248.0  0.000  0.000      0.0  3.5 0 0.0
11 19939.9086510     0.014303031023   ES 2  30.0    36     213.0  0.000  0.000      0.0  4.7 0 0.0
11 19966.0837316     0.014456622851   ES 2  30.0    48     234.0  0.000  0.000      0.0  6.2 0 0.0
11 19993.1391490     0.014694794599   ES 2  30.0    56     208.0  0.000  0.000      0.0  7.3 0 0.0
11 20025.6374106     0.015082008815   ES 2  30.0    46     194.0  0.000  0.000      0.0  6.0 0 0.0
11 20053.0926792     0.015489205740   ES 2  30.0    59     185.0  0.000  0.000      0.0  7.6 0 0.0
11 20080.3882364     0.015960679555   ES 2  30.0    24     189.0  0.000  0.000      0.0  3.1 0 0.0
H8
H9
```

6.8. Sample Transponder Configuration Segment

The previous examples were converted from existing data files. For new data where configuration information is available while forming the CDR, the following could replace or supplement the C0 for MLRS tracking a lunar transponder. (The values are not necessarily realistic.)

One-way (detector not used):

```
C0 0 532.0 std1 las1 tim1 lro
C1 0  las1 Nd-Yag 1064.0 10.0 100 200 20 1
C3 0 tim1 TAC na MLRS na 0
C4 0 lro 100 5  325 8 12345678 1 0 1
```

Two-way:

```
C0 0 532.0 std1 slrd las1 tim1 lro
C1 0  las1 Nd-Yag 1064.0 10.0 100 200 20 1
C2 0 slrd MCP 532.0 8 1300 1 TTL 10 1.0 50 10 none 10 20 na
C3 0 tim1 TAC na MLRS na 0
C4 0 lro 100 5  325 8 12345678 1 0 1
```

7. Implementation Procedure

When the CRD format was introduced, implementation at the ranging station involved several steps. This discussion is mainly of historical value, although some of the choices made, e.g., whether to use sample code, and the procedure for testing data format changes, could be re-considered when there is an update to the CRD format. The methods of implementation should be considered for new or renovated laser stations to determine at what place in the data flow the format should first be implemented.

- Choosing where to make changes in the station software to write the CRD format files (7.1)
- Making the changes (7.2)
- Testing the changes on site (7.2, 7.3)
- Submitting the old and CRD formatted data in parallel for testing (7.3)
- Discontinuing the old formats (7.3)

These issues and more are addressed below.

7.1. Methods of implementation

There are several approaches that can be taken to implement the CRD format at a laser ranging station. Briefly they are as follows.

1) Record ranging data in the CRD format. Then the CRD format becomes the native format for the entire data system. This implies a great deal of work and the best chance to include all the new fields in the data. The difficulty of modifying and testing real-time ranging software may make this approach prohibitive. If the acquisition data format already has all the needed fields and precision for the CRD format, this approach is probably not necessary.

2) After ranging, convert the acquisition data files to the CRD format and proceed with calibration, filtering, normal pointing, and the like, using the CRD format as the native format. This takes less work than option 1), and insures that most or all of the new format features are incorporated in a natural way. As an example, this is the path chosen for MLRS. The reductions software suite was not written from scratch, but the read and write code in each was replaced with corresponding CRD routines, and some hitherto separate lunar and satellite laser ranging programs were consolidated into single programs.

3) Take old format normal points, full rate, etc. from the filtering and normal pointing system on site and convert to CRD-formatted file. Programs to convert old formats to the CRD format already exist in the sample code suite. This is quick and easy, but fails to take advantage of the new features of the format.

4) Some stations may use intermediate files or databases during data processing that already include all the desired new fields and extended precision. For these stations, conversion to the CRD format may be as simple as creating a new back-end formatter that writes data in the CRD format rather than the old distribution format.

7.2. Software resources

As with the CPF implementation, there is a suite of sample code that can help the CRD format conversion. This software is supplied “as is,” and there are no guarantees associated with it. The software has been tested with a limited amount of data, and there may still be errors and incomplete implementation of the CRD standards. This software is meant to be a starting place for those implementing and managing ranging data in the CRD format. Any bug corrections or software enhancements are welcomed by the authors.

The CRD sample software can be broken into several groups.

1) Code common to many applications
directory: common_c ('C' version)

read_crd.c - read and parse CRD records

write_crd.c - write CRD records
getfield.c - read undelimited data fields from a string

2) Code common to many applications
directory: common_f ('FORTRAN' version)
read_crdf.f - read and parse CRD records
write_crdf.f - write CRD records

3) CRD file checkers ('C' only).
directory: crd_chk_c
crd_chk.c - check CRD file for errors
crd_cstg_np_cmp – compare CRD and CSTG normal points from a single pass
crd_merit_fr_cmp – compare CRD and MERIT II full rate data from a single pass

4) Various conversion utilities between CRD and older SLR/LLR formats ('C' only).
directory: crd_conv_slr_c
crd_to_cstg_np.c - CRD normal points to old normal point format
crd_to_cstg_ql.c - CRD sampled engineering to old sampled engineering format
crd_to_merit.c - CRD full rate to old full rate format
cstg_to_crd.c - Old normal point and sampled engineering to CRD format
merit_to_crd.c - Old full rate to CRD format
read_cstg.c - Read old normal point and sampled engineering records
read_merit.c - Read old full rate records
write_cstg.c - Write old normal point and sampled engineering records
write_merit.c - Write old full rate records

5) Various conversion utilities from old lunar format to CRD ('C' only).
directory: crd_conv_llr_c
cllr_to_crd.c - Old COSPAR lunar to CRD format
read_llr.c - Read old lunar format records
cospar_llr.h - Header file with old lunar format information

6) Conversion between version 1 and version 2 CRD files.
directory: crd_conv_v1v2
crd_conv.c - Converts v1 to v2 or v2 to v1, depending on the input files. Does the best it can to fill in v2 fields not in a v1 file.
crd_create.c - Converts v1 to v2 or v2 to v1, depending on the input files. Uses an ancillary file to change station ID for testing and to help fill in v2 files.

7) Various CRD file split, merge, sort, and miscellaneous routines.
directory: crd_split_c
crd_split.c - Split multi-pass and multi-data-type file into separate files using station naming convention
frd_strip.c - Strip out station-dependent (9x) records and remove some white space from CRD full rate file
merge_crd_daily.c - merge single pass normal point, quicklook, and full rate files into single day files.

8) Various header and include files
directory: include ('C' and FORTRAN versions)
crd.h - Header file with CRD information ('C')

crd.inc	- Header file with CRD information (FORTRAN)
cstg.h	- Header file with old normal point and sampled engineering information
merit.h	- Header file with old full rate format information

To compile this code on a Linux system, just type

```
./make.sh
```

on the command line.

In selected directories there are scripts to test the program using supplied data. Data files ending in ".ref" are the reference (or "correct") output from the conversion programs. To run the tests and automatically compared results, type

```
./test.sh
```

in each of these directories. Any differences between the test and reference data files will be shown. Differences in dates in H1 records are normal, as they reflect the time of file creation.

7.3. CRD file testing procedures

Once software had been converted to produce CRD-formatted data files, the CRD files were tested for compliance with the CRD format and consistency with the old format data. Three tools in the sample code suite helped. The first is crd_chk, which checks the CRD data file (full rate, sampled engineering, or normal point) for compliance with the format. This generates a report for each file, breaking down the header information into easily readable lines. Some error messages show data fields that are out of compliance. Other error messages deal with issues such as out-of-sequence records, missing fields in records, and so forth. A tally of all record types is also provided.

Crd_chk will remain useful to test any changes to CRD file production. An updated version for CRD V2 is included in the sample code. The other programs referred to above, crd_cstg_np_cmp and crd_merit_fr_cmp, were useful for comparing CRD files with their older counterparts. They are not longer needed.

8. Notes on new data fields

8.1. Advantages to analysts

While the introduction to this document contains a list of advantages of the CRD over previous formats, what follows is a list of advantages the analysts will be most interested in.

1. Skew, kurtosis, and peak-mean are data fields that have been requested over the years but have not been available in the data set. This should allow analysis of over-filtering and anomalous data distributions.
2. The CRD format is capable of handling multi-channel, multi-stop, multi-color systems. Although the old formats could handle multiple color data, they could not be integrated into one normal point file. Multi-channel and multi-stop data is not explicitly recognized in the old formats.
3. Standard satellite, transponder, and lunar data can be fully represented in one format.
4. Using free-format data records means that the number of significant digits can be increased to the accuracy required by some missions without requiring all targets to carry additional digits.
5. Most station configuration information can now be embedded with the data. This can help with keeping track of station configurations at a finer granularity than the current SCH and SCI values. This will only help if stations use the new configuration section and if values are current. This is an area that many analysts will not be interested in, but the data is readily available for those who are.
6. The all-in-one, building-block nature of the format should make processing full rate and other special formats easier, if they are needed. Also, full rate files will be smaller than with the Merit II format.
7. Future enhancements to the format should not require starting over again.

8.2. Record-by-record Information

8.2.1. Headers

H1 – format header
- Date of file production (as distinct from release number in H4) tells when the current file was created (by the station, or the operation centers merge or split programs, etc.). This can help verify that the latest file is available.

H2 – station header
- The station name may be more recognizable than the pad ID.

H3 – target header
- All 3 commonly used satellite IDs are included.
- Spacecraft epoch time scale is available for transponders.
- Target type (passive satellite, passive lunar, transponder, mixed, etc.) allows sending data to the right processing steps for the target.

H4 – session header
- A flag tells whether this is full rate, normal point or sampled engineering data. This starts a data block for a particular station, satellite, and time span which ends with the next H8 record.
- Provides many of the fields in the Merit II format – but watch the sense of the flags.
- Indicates whether this is one- or two- way ranging, etc., information that is needed for processing decisions.
- Data quality alerts give some sense as to whether the data should be used in critical applications.

H5 – prediction information
- Helps the analysts and others correlate return rate, etc., with particular predictions used.

H8 – end of session/pass

H9 – end of file

8.2.2. Configuration

C0 – system configuration
- Provides wavelength and pointers to related configuration information for this wavelength.

C1 – laser configuration
- Various information including fire rate, pulse width, divergence, and number of pulses.
- These can all be of interest in analysis.

- For example, does the pulse width match the RMS of the calibrations and data?

C2 – detector configuration
- Contains detector and amplifier information, such as detector type, quantum efficiency, spectral and spatial filters.
- The data biases and corrections may depend on the detector type, e.g., whether the detector is a cspad or mcp.
- Is the change of signal processing algorithm the reason for changes to this station's biases?

C3 – timing system configuration
- Is a new station bias correlated with changes to any of these pieces of equipment?

C4 – transponder/clock configuration
- This record is needed for transponder analysis, when the spacecraft and ground station data need to be merged, and both are running on separate clocks.

C5 – software configuration
- A software version change may correlate with a change in station data quality.

C6 – meteorological Instrumentation
- Change in instrumentation may correlate with a change in station bias.

C7 – calibration target configuration
- Information on the calibration target and processing software.

8.2.3. Data

10 – range record
- Variable precision in seconds-of-day and the return field allows for increased precision for transponders.
- Epoch event tells how to interpret time-of-flight/receive time field, and allows for transponder data.
- Detector channel and stop number show where the data comes from. Each channel can have a separate bias.

11 - normal point
- Again, epoch event tells how to interpret time-of-flight/receive time field, and allows for transponder data.
- Normal point window length gives the length in seconds, for those targets that require variable normal point lengths (lunar, satellites with highly elliptical orbits).
- Skew, kurtosis and peak-mean can show anomalies in the data distribution that would indicate hardware or processing problems. Since lasers do not produce Gaussian distributions, a skew that is unusually symmetrical can indicate over-filtering.
- Return rate can give some sense of system performance, tempered by sky conditions.

12 - range supplement
- Nothing new except the time bias.

20 – meteorological record
- Origin of values specifies where the values came from (measured or interpolated value).

21 - meteorological supplement record
- This contains various ancillary data that can correlate with the return rate.

40 – calibration record
- Can include target system delays (transponder).
- Number of fires and points used can indicate quality of calibration results.
- Skew, kurtosis, and peak-mean are also included here.

41 – calibration detail record
- Can include target system delays (transponder).
- Number of fires and points used can indicate quality of calibration results.
- Skew, kurtosis, and peak-mean are also included here.

42 – calibration “shot” record (full rate)
- Similar to the #10 shot records, but for calibration.
- Contains raw calibration fire time and range
- Contains all the information needed to reproduce the results in the calibration and calibration detail records.
- Contains the filter flag, detector channel, stop number, and transmit and receive amplitudes like the number “10” records

50 – session (pass) statistics record
- Provides skew, kurtosis, and peak-mean for the entire pass.

60 – compatibility record
- OBSOLETE. Configuration records and Station Change History Log contain information previously contained in this record.

9x – user defined records

- Not applicable. The analysts will normally not see these.

00 – comment record

- If the station considers data suspect, or if there is anything unusual that is not covered in the configuration records, this record type can provide an explanation. It should be kept with the data by the OCs and DCs.

9. Conclusion

The CRD format offers a number of improvements over the former, separate normal point, sampled engineering, and full rate data formats. What stimulated the development of the new format was the need for extended fire time precision and additional fields for transponder missions, such as LRO, and the need for reduced size for full rate data from high-repetition-rate laser systems. In order to satisfy these needs, to add functionality not previously seen, and to make provision for additional revisions in the future, the formats were redesigned and combined into a single format. The CRD format has features in common with the Consolidated Predictions Format (CPF) introduced earlier. The files are separated into header records, data records, and, for the CRD format, configuration records. Each of these 3 sections has some records that are needed only for specific missions types or station capabilities, allowing a great deal of versatility. Care was taken to make the format compatible with the Engineering Data Format (EDF), and was developed with XML in mind.

The format was developed and maintained under the auspices of the ILRS Data Formats and Procedures Standing Committee. The authors would like to recognize the active participation and many contributions from the members of the DF&P SC and the world-wide laser ranging community, and the support of NASA and Electro Optic Systems Pty Limited.

Appendix A: Web Resources

The official list of satellite names can be found at:

https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_names.html .

Satellite numerical identifiers can be found at:

https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_missions/current_missions/index.html .

The official list of station names can be found in the “Code” column at:

https://ilrs.cddis.eosdis.nasa.gov/network/stations/active/index.html .

The official list of station monument (pad) numbers and codes can be found at:

https://ilrs.cddis.eosdis.nasa.gov/network/stations/active/index.html .

Find information on site files at:

https://ilrs.cddis.eosdis.nasa.gov/network/site_procedures/site_logs.html .

Find formats for the pre-CRD data formats at:

https://ilrs.cddis.eosdis.nasa.gov/data_and_products/data/npt/npt_format.html .

and

https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/frv3_format.html .

The latest official version of this document, CRD Sample Code, errata, and data can be found at:

https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/crd.html .

Appendix B: Common Abbreviations

ASC	Analysis Standing Committee; the committee of the official ILRS data analysts.
CRD	Consolidated laser Ranging Data Format
COSPAR	Committee on Space Research, a Committee of ICSU, the International Council for Science.
CPF	Consolidated laser ranging Prediction Format
DF&PSC	Data Formats and Procedures Standing Committee; the ILRS group is responsible for this and other formats.
FWHM	Full width at Half Maximum, relating to pulse width
ILRS	International Laser Ranging Service
LLR	Lunar Laser Ranging
LRO	Lunar Reconnaissance Orbiter
ND	Neutral Density, which describes the opacity of a broadband optical filter.
NORAD	The North American Aerospace Defense Command
m	meters
mm	millimeters
ns	nanoseconds
ps	picoseconds
RMS	Root Mean Square. Same as the standard deviation.
SLR	Satellite Laser Ranging
SCH	Station Change Indicator
SCI	Station Configuration Indicator
SIC	Satellite Identification Code, a 4-digit satellite descriptor created and maintained by the ILRS.
SRP	System Reference Point, usually described as the first non-moving point in the telescope light path.
TLR	Transponder Laser Ranging
μs	microseconds
UTC	Coordinated Universal Time, formerly known as Greenwich Mean Time (GMT).
XML	eXtensible Markup Language.

Appendix C: Limits for CRD Fields

Limits for values in the "C7" and "42" records are provisional.

Record Type	Record Name	Field Name	CRD Format Specification	New Spec	Error Type	Notes
H1	Format Header	H1	"H1" or "h1"	"H1" or "h1"	Error	
H1	Format Header	CRD	"CRD" or "crd"	"CRD" or "crd"	Error	
H1	Format Header	Format Version	1, 2	[0 (warning),1,…99]	Error	
H1	Format Header	Year of file production		[1950,…,2100]	Error	
H1	Format Header	Month of file production		[1,…,12]	Error	
H1	Format Header	Day of file production		[1,…,31]	Error	
H1	Format Header	Hour of file production (UTC)		[0,…23]	Error	
H1	Format Header	Other H1 Check	One and only one H1 Record Must Exist	One and only one H1 Record Must Exist	Error	
H1	Format Header	Other H1 Check		Date of file production must be valid	Error	
H1	Format Header	Other H1 Check		Date/time of file production must be before current time (recommended check against system time)	Error	
H1	Format Header	Other H1 Check	Fixed Format	Wrong pattern of record (spaces at wrong positions) or record length not exact 23 characters	Error	
H2	Station Header	H2	"H2" or "h2"	"H2" or "h2"	Error	
H2	Station Header	Station name from official list		Station name exists on official list	Error	
H2	Station Header	Crustal Dynamics Project 4-Digit Pad Identifier				
H2	Station Header	Crustal Dynamics Project 2-digit system number				
H2	Station Header	Crustal Dynamics Project 2-digit occupancy sequence number				
H2	Station Header	Station Epoch Time Scale – indicated the time scale reference	[0,1,…]	[3,4,7] others need advanced authorization	Error	

H2	Station Header	Other H2 Check	One and only one H2 Record Must Exist	One and only one H2 Record Must Exist	Error	
H2	Station Header	Other H2 Check		Station name and pad ID must be from the same station		
H2	Station Header	Other H2 Check		CDP and station occupancy numbers exist in station lists	Error	
H2	Station Header	Other H2 Check	Fixed Format	Wrong pattern of record (spaces at wrong positions) or record length not exact 27 characters	Error	
H3	Target Header	H3	"H3" or "h3"	"H3" or "h3"	Error	
H3	Target Header	Target name from official list		Target name must be found on official target name	Error	
H3	Target Header	Target name from official list		Target name should be in lowercase and right justified	Warning	
H3	Target Header	Target name from official list		Target Information must be correct/SIC must fit to satellite name	Error	
H3	Target Header	ILRS Satellite Identifier (Based on COSPAR ID)		Satellite Identifier must be found in ILRS list	Error	
H3	Target Header	SIC		Target SIC must be found on official target SIC list	Error	
H3	Target Header	SIC		SIC must fit to satellite name	Error	
H3	Target Header	NORAD ID		NORAD ID must be found on official target NORAD ID based in ILRS ID or -1	Error	CDDIS wants to ensure that all data is correct. If the IDs don't match, it'll be an error. If this causes problems, the standard can be revised.
H3	Target Header	NORAD ID		NORAD id must fit to satellite name	Error	
H3	Target Header	Spacecraft Epoch Time Scale	[0,1,2]	[0,1,2]	Error	
H3	Target Header	Target type	[1,2,3,4]	[1,…,4]	Error	
H3	Target Header	Target class	[0,1,2,3,4,5]	[0,1,3,4,5]; note that "2" is deprecated, should trigger an error	Error	In version 2, target class replaces target type
H3	Target Header	Target location/dynamics	[na,0,1,2,…,10]	[na,0,1,2,…,10]	Error	

H3	Target Header	Other H3 Check	One and only one H3 Record Must Exist	Only one H3 Record Must Exist	Error	
H3	Target Header	Other H3 Check		Target type must be found on official target type based on ILRS ID Target class must be found on official target class based on ILRS ID	Error	
H3	Target Header	Other H3 Check		If Target Type ==3 or ==4 Transponder Configuration C4 Record Required If Target class ==3 or ==4, Transponder Configuration C4 Record Required	Error	
H3	Target Header	Other H3 Check	Fixed Format	Wrong pattern of record (spaces at wrong positions) or record length not exact 40 characters	Error	
H4	Session (Pass) Header	H4	"H4" or "h4"	"H4" or "h4"	Error	
H4	Session (Pass) Header	Data Type	[0,1,2]	[0,1,2,]	Error	
H4	Session (Pass) Header	Data Type		Data type !=1 for normal points (11 record)	Error	
H4	Session (Pass) Header	Data Type		Data type !=0 for fullrate data (10 record)	Error	
H4	Session (Pass) Header	Starting Year		[1950,…,2100]	Error	
H4	Session (Pass) Header	Starting Month		[1,…,12]	Error	
H4	Session (Pass) Header	Starting Day		[1,…,31]	Error	
H4	Session (Pass) Header	Starting Hour		[0,…23]	Error	
H4	Session (Pass) Header	Starting Minute		[0,…,59]	Error	
H4	Session (Pass) Header	Starting Second		[0,…,59]	Error	
H4	Session (Pass) Header	Ending Year		[1950,…,2100]	Error	Removed -1 as input, it was causing data center problems
H4	Session (Pass) Header	Ending Month		[1,…,12]	Error	Removed -1 as input, it was causing data center problems

H4	Session (Pass) Header	Ending Day		[1,…,31]	Error	Removed -1 as input, it was causing data center problems
H4	Session (Pass) Header	Ending Hour		[0,…23]	Error	Removed -1 as input, it was causing data center problems
H4	Session (Pass) Header	Ending Minute		[0,…,59]	Error	Removed -1 as input, it was causing data center problems
H4	Session (Pass) Header	Ending Second		[0,…,59]	Error	Removed -1 as input, it was causing data center problems
H4	Session (Pass) Header	A flag to indicate the data release	[0, 1, 2,…]	[0,…,99]	Error	
H4	Session (Pass) Header	Tropospheric refraction correction applied indicator	[0,1]	[0,1]; if set to 1, a record 12 must exist	Error	
H4	Session (Pass) Header	Center of mass correction applied indicator	[0,1]	[0,1]; if set to 1, a record 12 must exist	Error	
H4	Session (Pass) Header	Received amplitude correction applied indicator	[0,1]	[0,1]	Error	
H4	Session (Pass) Header	Station system delay applied indicator	[0,1]	[0,1]	Error	
H4	Session (Pass) Header	Spacecraft system delay applied (transponders) indicator	[0,1]	[0,1]	Error	
H4	Session (Pass) Header	Range type indicator	[0,1,2,3,4]	[0,1,2,3,4]	Error	
H4	Session (Pass) Header	Data quality alert indicator	[0,1,2]	[0,1,2]	Error	
H4	Session (Pass) Header	Other H4 Check	One and only one H4 Record Must Exist	Only one H4 Record Must Exist	Error	
H4	Session (Pass) Header	Other H4 Check		Starting date must be valid (e.g. not June 31st)	Error	
H4	Format Header	Other H4 Check		Start date/time must be before current time (recommended check against system time)	Error	
H4	Session (Pass) Header	Other H4 Check		Ending date must be valid	Error	
H4	Format Header	Other H4 Check		End date/time must be before current time (recommended check	Error	

				against system time)		
H4	Format Header	Other H4 Check		End date/time must be after start date/time	Error	
H4	Session (Pass) Header	Other H4 Check	Fixed Format	Wrong pattern of record (spaces at wrong positions) or record length not exact 62 characters	Error	
H4	Session (Pass) Header	Other H4 Check		End Year - Start Year must be <=1, (iff end year != -1)	Error	
H4	Session (Pass) Header	Other H4 Check		Duration must be less than one day (MJD or unix or whatever)	Error	
H5	Prediction Header	H5	"H5" or "h5"	“H5” or “h5”	Error	
H5	Prediction Header	Prediction Type	[0,1,2]	[0,1,2]	Warning	
H5	Prediction Header	Year of century from CPF or TLE	[0,1,…99]	[0,1,…99]	Warning	
H5	Prediction Header	Date and Time	CPF H2 starting date and hour (MMDDHH); TLE epoch day/fraction from line 1	If Prediction Type ==1, then MMDDHH; If Prediction Type ==2, then [1.000000,… 366.999999]	Warning	
H5	Prediction Header	Prediction Provider	From CPF "H1" or TLE source			
H5	Prediction Header	Sequence Number	CPF sequence number from "H1" or TLE revolution number from line 2	[1, 2,…, 99999] (TLEs give 5 digits for revolutions)	Warning	
H8	End of Session Footer	H8	“H8” or “h8”	“H8” or “h8”	Error	
H8	End of Session Footer	Other H8 Check		Must contain H8 before H9	Error	
H8	End of Session Footer	Other H8 Check		One and only one H8 Record Must Exist in single pass file	Error	
H8	End of Session Footer	Other H8 Check		Must have same number of H4 and H8 records		
H9	End of File Footer	H9	“H9” or “h9”	“H9” or “h9”	Error	

H9	End of File Footer	Other H9 Check	One and only one H9 Record Must Exist	One and only one H9 Record Must Exist at the end of file	Error	
C0	System Configuration	C0	“C0” or “c0”	“C0” or “c0”	Error	
C0	System Configuration	Detail Type	0	0	Error	
C0	System Configuration	Transmit Wavelength (nm)		[354, 423, 532, 694, 847, 1064] with any decimal value permitted	Error	List based on JCET and EDC lists of values seen in data.
C0	System Configuration			C0 record Transmit Wavelength < = C1 Primary Wavelength		
C0	System Configuration			C0 record Transmit Wavelength < = C2 Applicable Wavelength		
C0	System Configuration	System Configuration ID				
C0	System Configuration	Component A configuration ID				
C0	System Configuration	Component B configuration ID				
C0	System Configuration	Component C configuration ID				
C0	System Configuration	Component D configuration ID				
C0	System Configuration	Component E configuration ID				
C0	System Configuration	Component F configuration ID				
C0	System Configuration	Other C0 Check		The record length must be at least 4 characters	Error	
C1	Laser Configuration	C1	“C1” or “c1”	“C1” or “c1”	Error	
C1	Laser Configuration	Detail Type	0	0	Error	
C1	Laser Configuration	Laser Configuration ID		Laser configuration id match C0 record Component A configuration id	Warning	
C1	Laser Configuration	Laser Type				
C1	Laser Configuration	Primary wavelength (nm)		[354, 423, 532, 694, 847, 1064, 2000] with any decimal value permitted	Error	List based on JCET and EDC lists of values seen in data. Note that 2000 is included here and

						not under transmit wavelength.
C1	Laser Configuration	Nominal Fire Rate (Hz)		[na,0,1,…10000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Pulse Energy (mJ)		[na,0,1,…1000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Pulse Width (FWHM in ps)		[na,0,1,…10000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Beam Divergence (arcsec)		[na,0,1,…400] (n.a. -1)	Warning	Full angle
C1	Laser Configuration	Number of pulses in outgoing semi-train		[na,0,1,…1000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Other		The record length must contain 10 fields	Error	
C2	Detector Configuration	C2	"C2" or "c2"	"C2" or "c2"	Error	
C2	Detector Configuration	Detail Type	0	0	Error	
C2	Detector Configuration	Detector Configuration ID		Detector Configuration ID match C0 record Component B configuration id	Warning	
C2	Detector Configuration	Detector Type				
C2	Detector Configuration	Applicable wavelength (nm)		[354, 423, 532, 694, 847, 1064] with any decimal value permitted	Error	List based on JCET and EDC lists of values seen in data.
C2	Detector Configuration	Quantum efficiency at applicable wavelength (%)		[na,0,…,100]	Warning	
C2	Detector Configuration	Applied voltage (V)		[na,-1.e4,…,1e4]	Warning	
C2	Detector Configuration	Dark Count (kHz)		[na,0,…,1e3]	Warning	
C2	Detector Configuration	Output pulse type				
C2	Detector Configuration	Output pulse width (ps)		[na,0,…,1e6]	Warning	
C2	Detector Configuration	Spectral Filter (nm)		[na,0,…,1064]	Warning	
C2	Detector Configuration	% Transmission of Spectral Filter		[na,0,…,100]	Warning	

C2	Detector Configuration	Spatial Filter (arcsec)		[na,0,…,3600]	Warning	
C2	Detector Configuration	External Signal processing				
C2	Detector Configuration	Amplifier Gain				
C2	Detector Configuration	Amplifier Bandwidth (kHz)				
C2	Detector Configuration	Amplifier in Use	[-1,0,1]	[na,0,1]	Warning	
C2	Detector Configuration	Other		The record length must contain 14 (17) fields	Error	Only catches lunar data from Matera
C3	Timing Configuration	C3	"C3" or "c3"	"C3" or "c3"	Error	
C3	Timing Configuration	Detail Type	0	0	Error	
C3	Timing Configuration	Timing System Configuration ID		Timing system configuration id match C0 record Component C configuration id	Warning	
C3	Timing Configuration	Time Source				
C3	Timing Configuration	Frequency Source				
C3	Timing Configuration	Timer				
C3	Timing Configuration	Timer Serial Number				
C3	Timing Configuration	Epoch Delay Correction (µs)		[na,-5.e5,...,5.e5]	Warning	
C3	Timing Configuration	Other		The record length must contain 8 fields	Error	
C4	Transponder (Clock)	C4	"C4" or "c4"	"C4" or "c4"	Error	
C4	Transponder (Clock)	Detail Type	0	0	Error	
C4	Transponder (Clock)	Transponder Configuration ID		Transponder configuration if match C0 record Component D configuration id	Warning	
C4	Transponder (Clock)	Estimated Station UTC offset (ns)		[-1000, …, 1000]	Warning	
C4	Transponder (Clock)	Estimated Station Oscillator Drift (in parts in 1015)		[-1000,…,1000]	Warning	
C4	Transponder (Clock)	Estimated Transponder UTC offset (ns)		[-100,…,100]	Warning	

C4	Transponder (Clock)	Estimated Transponder Oscillator Drift (in parts in 1015)		[-1e8,…,1e8]	Warning	
C4	Transponder (Clock)	Transponder Clock Reference Time (seconds, scaled or unscaled)		[-100,…100]	Warning	
C4	Transponder (Clock)	Station clock offset and drift applied indicator	[0,1,2,3]	[0,1,2,3]	Warning	
C4	Transponder (Clock)	Spacecraft clock offset and drift applied indicator	[0,1,2,3]	[0,1,2,3]	Warning	
C4	Transponder (Clock)	Spacecraft time simplified	[0,1]	[0,1]	Warning	
C4	Transponder (Clock)	Other		The record length must contain 11 fields	Error	
C5	Software Config	C5	"C5" or "c5"	"C5" or "c5"	Error	
C5	Software Config	Detail Type	0	0	Error	
C5	Software Config	Software Configuration ID				
C5	Software Config	Tracking Software in Measurement Path	(if more than one program, comma delimited)			
C5	Software Config	Tracking Software Version(s)	(if more than one program, comma delimited)			
C5	Software Config	Processing Software in Measurement Path	(if more than one program, comma delimited)			
C5	Software Config	Processing Software Version(s)	(if more than one program, comma delimited)			
C6	Meteorological Intrumentation Configuration	C6	"C6" or "c6"	"C6" or "c6"	Error	
C6	Meteorological Intrumentation Configuration	Detail Type	0	0	Error	
C6	Meteorological Intrumentation Configuration	Meteorological Configuration ID	unique within the file			
C6	Meteorological Intrumentation Configuration	Pressure Sensor Manufacturer				

C6	Meteorological Intrumentation Configuration	Pressure Sensor Model				
C6	Meteorological Intrumentation Configuration	Pressure Sensor Serial Number				
C6	Meteorological Intrumentation Configuration	Temperature Sensor Manufacturer				
C6	Meteorological Intrumentation Configuration	Temperature Sensor Model				
C6	Meteorological Intrumentation Configuration	Temperature Sensor Serial Number				
C6	Meteorological Intrumentation Configuration	Humidity Sensor Manufacturer				
C6	Meteorological Intrumentation Configuration	Humidity Sensor Model				
C6	Meteorological Intrumentation Configuration	Humidity Sensor Serial Number				
C7	Calibration Configuration	C7	"C7"	"C7"	Error	
C7	Calibration Configuration	Detail type	0	0	Error	
C7	Calibration Configuration	Calibration Configuration ID	unique within the file			
C7	Calibration Configuration	Target Name or ID				
C7	Calibration Configuration	Surveyed target distance (m)	[na,0,1,…]	[na,0.0,…1.e6]	Error	
C7	Calibration Configuration	Survey error (mm)	[na,0,1,…]	[na,0.0,…1.e3		
C7	Calibration Configuration	Sum of all constant delays	[na,0,1,…]	[na,0.0,…1.e3]		
C7	Calibration Configuration	Pulse Energy (mJ)	[na,0,1,…]	[na,0.0,…1.e7]		

C7	Calibration Configuration	Processing software name				
C7	Calibration Configuration	Processing software version				
10	Range (Full rate)	10	“10”	“10”	Error	
10	Range (Full rate)	Seconds of day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
10	Range (Full rate)	Seconds of day		Time falls between the start and end times in H4 record. E.g. H4 start date/time ≤ H4 start date + 10 record seconds of day ≤ H4 end date/time	Error	LLR exempt because much LLR data is delivered as many sessions in one file.
10	Range (Full rate)	Time of flight in seconds		[na,0, …,3]	Error	Round trip time to the moon is under 3 seconds; if we will receive data to a distant object, we should revisit.
10	Range (Full rate)	System configuration id		System configuration ID must be in C0-record	Error	
10	Range (Full rate)	Epoch event	[0,1,2,3,4,5,6]	[0,1,2,3,4,5,6]	Warning	
10	Range (Full rate)	Filter flag	[0,1,2]	[0,1,2]	Warning	
10	Range (Full rate)	Detector channel		[0,1,…, 99]	Error	
10	Range (Full rate)	Stop number	[0,1,…]	[0,1,…, 99]	Error	
10	Range (Full rate)	Receive Amplitude		[na, 0,...,99999]	Warning	
10	Range (Full rate)	Transmit Amplitude		[na, 0,...,99999]	Warning	
10	Range (Full rate)	Other 10 Check		The record length must contain 9 (10) fields	Error	
11	Range (Normal Point)	11	“11”	“11”	Error	
11	Range (Normal Point)	Seconds of day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
11	Range (Normal Point)	Seconds of day		Time falls between the start and end times in H4 record. E.g. H4 start date/time ≤ H4 start date + 11 record seconds of day ≤ H4 end date/time	Error	LLR exempt because much LLR data is delivered as many sessions in one file.

11	Range (Normal Point)			Must be in same revolution	Error	
11	Range (Normal Point)	Time of flight in seconds		[na,0, …,3]	Error	Round trip time to the moon is under 3 seconds.
11	Range (Normal Point)	System configuration id		Valid System Configuration ID/ System configuration ID must be in C0-record	Error	
11	Range (Normal Point)	Epoch event	[0,1,2,3,4,5,6]	[0,1,2,3,4,5,6]	Warning	
11	Range (Normal Point)	Normal point window length (sec)		[0,1,…300]	Error	LLR exempt; satellites have specific bins, LLR is highly variable
11	Range (Normal Point)	Normal point window length (sec)		Must match bin size for satellite from ILRS list	Error	
11	Range (Normal Point)	Normal point window length (sec)		Each normal point must be from a different bin.	Warning	
11	Range (Normal Point)	Number of raw ranges	6-digit integer	[0,1,…]	Warning	
11	Range (Normal Point)	Bin RMS from mean of raw accepted time of flight values minus the trend function (ps)		[0,…6667]	Warning	Equivalent to 1m RMS
11	Range (Normal Point)	Bin skew from mean of raw accepted time of flight values minus the trend function		[na,-2,…,2]	Warning	
11	Range (Normal Point)	Bin kurtosis from mean of raw accepted time of flight values minus the trend function		[na,-2,…,3]	Warning	LLR exempt
11	Range (Normal Point)	Bin peak – mean (ps)		[na,-1000,..,1000]	Warning	LLR exempt
11	Range (Normal Point)	Return rate		[na,0,1,…,100]	Warning	
11	Range (Normal Point)	Detector channel	[0, 1,…]	[0,1,…, 99]	Error	
11	Range (Normal Point)	Signal-to-Noise Ratio (S:N)				
11	Range (Normal Point)	Other 11 Check		The record length must contain 13 (14) fields	Error	
12	Range	12	“12”	“12”	Error	

	Supplement					
12	Range Supplement	Seconds of day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
12	Range Supplement	Seconds of day		Time falls between the start and end times in H4 record. E.g. H4 start date/time ≤ H4 start date + 12 record seconds of day ≤ H4 end date/time	Error	
12	Range Supplement	System configuration id		Valid system configuration id/ System configuration id must be in C0 record	Error	
12	Range Supplement	Tropospheric refraction correction, ps, one-way		[na,0,..,1e4]	Warning	Comments indicate 2.5m/c, which is 8.34ns.
12	Range Supplement	Target center of mass correction, m, one-way		[na,0,...,100]	Warning	
12	Range Supplement	Neutral density filter value		[na,0,…,100]	Warning	
12	Range Supplement	Time bias applied (seconds)		[na,-10,...,10]	Warning	
12	Range Supplement	Range Rate (seconds/seconds)				
12	Range Supplement	Other 12 Check		The record length must contain 7 (8) fields	Error	
20	Meterological	20	“20”	“20”	Error	
20	Meterological	Seconds of day		[0,…,86400]	Error	Note: Normal data would be 00000 through 86399. A leap second would use 86400.
20	Meterological	Seconds of day		Time falls between the start and end times in H4 record +/- 1 hr E.g. H4 start-1 hr < 20 record sec of day < H4 end +1 hr	Error	

20	Meterological	Seconds of day		Time falls between the start and end times in H4 record +/- 10min. E.g. H4 start-10min < 20 record sec of day < H4 end +10min	Warning	
20	Meterological	Surface pressure		[700,…,1100]	Error	
20	Meterological	Surface temperature (K)		[240,…,330]	Error	
20	Meterological	Relative humidity (%)		[0,…,100]	Error	
20	Meterological	Origin of values	[0,1]	[na,0,1]	[0,1]	
20	Meterological	Other 20 Check		The record length must contain 6 fields	Error	
20	Meterological			There must be at least one meteorological record	Error	
21	Meterological Supp	21	"21"	"21"	Error	
21	Meterological Supp	Seconds of Day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
21	Meterological Supp	Seconds of day		Time falls between the start and end times in H4 record +/- 10min. E.g. H4 start-10min < 20 record sec of day < H4 end +10min	Warning	
21	Meterological Supp	Wind Speed (m/s)		[na,…,33]	Warning	Hurricane threshold
21	Meterological Supp	Wind Direction (deg az, north=0)		[na, -180, … , 360]	Warning	
21	Meterological Supp	Precipitation type				
21	Meterological Supp	Weather Conditions	two-digit SYNOP/WMO code or description, e.g. "rain"			replaces Precipitation Type
21	Meterological Supp	Visibility (km)		[na,0,…,100]	Warning	
21	Meterological Supp	Sky Clarity (zenith extinction coeff)		[na,0,…,100]	Warning	

21	Meterological Supp	Atmospheric seeing (arcsec)		[na,0,…,100]	Warning	
21	Meterological Supp	Cloud cover (%)		[na,0,…,100]	Warning	
21	Meterological Supp	Sky Temperature (deg K)		[220,…300]	Warning	
21	Meterological Supp	Other 21 Check		The record length must contain 9 (10) fields	Error	
30	Pointing Angles	30	"30"	"30"	Error	
30	Pointing Angles	Seconds of Day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
30	Pointing Angles	Seconds of day		Time falls between the start and end times in H4 record. E.g. H4 start date/time ≤ H4 start date + 30 record seconds of day ≤ H4 end date/time	Error	
30	Pointing Angles	Azimuth in degrees		[na, -180, … , 360]	Warning	
30	Pointing Angles	Elevation in degrees		[na,0,…,90]	Warning	
30	Pointing Angles	Direction Flag	[0,1,2]	[na,0,…,2]	Warning	
30	Pointing Angles	Angle origin indicator	[0,1,2,3]	[0,…,3]	Warning	
30	Pointing Angles	Refraction corrected	[0,1]	[0,1]	Warning	
30	Pointing Angles	Azimuth rate (deg/sec)				
30	Pointing Angles	Elevation rate (deg/sec)				
30	Pointing Angles	Other 30 Check		The record length must contain 7 (9) fields	Error	
40	Calibration	40	"40"	"40"	Error	
40	Calibration	Seconds of day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
40	Calibration	Seconds of day		Within 2 hours of the pass E.g. H4 start date/time - 2hr ≤ 40 record seconds of day ≤ H4 end date/time + 2hr	Warning	
40	Calibration	Type of data	[0,1,2,3,4,5]	[0,…,5]	Error	
40	Calibration	System configuration id		Valid System configuration ID must be in C0 record	Error	

40	Calibration	Number of data points recorded	[na,0,1,…]	[na,…,1.e8]	Warning	
40	Calibration	Number of data points used	[na,0,1,…]	[na,…,1.e8]	Warning	
40	Calibration	One way target distance (m)	[na,0,1,…]	[na,0.0,…1.e4]	Warning	
40	Calibration	Calibration System Delay (ps)		[-1.e5,…,1.e6]	Error	
40	Calibration	Calibration Delay Shift (ps)		[-6671,…,6671]	Error	Based on 1m
40	Calibration	RMS of raw system delay	[na,…,2.e5]	[na,0,…,667]	Error	Based on 10cm
40	Calibration	Skew of raw system delay values from the mean		[na,-2,…,2]	Warning	
40	Calibration	Kurtosis of raw system delay values from the mean		[na,-2,…,3]	Warning	
40	Calibration	System delay peak – mean		[na,-1000,..,1000]	Warning	
40	Calibration	Calibration Type Indicator	[0,1,2,3,4,5,6]	[0,1,2,3,4,5,6]	Warning	
40	Calibration	Calibration Shift Type Indicator	[0,1,2,3,4]	[0,1,2,3,4]	Warning	
40	Calibration	Detector channel	[0,1,…]	[0,…,99]	Warning	
40	Calibration	Calibration Span	[0,1,2,3,4]	[0,1,2,3,4]	Warning	
40	Calibration	Return Rate	[na,0,…100]	[na,0,…100]	Warning	
40	Calibration	Other 40 Check		The record length must contain 16 (18) fields	Error	
41	Calibration	41	"41"	"41"	Error	
41	Calibration	Seconds of day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
41	Calibration	Seconds of day		Within 2 hours of the pass E.g. H4 start date/time - 2hr ≤ 41 record seconds of day ≤ H4 end date/time + 2hr	Warning	
41	Calibration	Type of data	[0,1,2,3,4,5]	[0,…,5]	Error	
41	Calibration	System configuration id		Valid System configuration ID must be in C0 record	Error	
41	Calibration	Number of data points recorded	[na,0,1,…]	[na,0,…,1.e8]	Warning	
41	Calibration	Number of data points used	[na,0,1,…]	[na,0…,1.e8]	Warning	
41	Calibration	One way target	[na,0,1,…]	[na0.0,…1.e4]	Warning	

		distance (m)				
41	Calibration	Calibration System Delay (ps)		[-1.e5,…,1.e6]	Error	
41	Calibration	Calibration Delay Shift (ps)		[-6671,…,6671]	Error	Based on 1m
41	Calibration	RMS of raw system delay	[na,…,2.e5]	[na,0,…,667]	Error	Based on 10cm
41	Calibration	Skew of raw system delay values from the mean		[na,-2,…,2]	Warning	
41	Calibration	Kurtosis of raw system delay values from the mean		[na.-2,…,3]	Warning	
41	Calibration	System delay peak – mean		[na,-1000,..,1000]	Warning	
41	Calibration	Calibration Type Indicator	[0,1,2,3,4,5,6]	[0,1,2,3,4,5,6]	Warning	
41	Calibration	Calibration Shift Type Indicator	[0,1,2,3,4]	[0,1,2,3,4]	Warning	
41	Calibration	Detector channel	[0,1,…]	[0,…,99]	Warning	
41	Calibration	Calibration Span	[0,1,2,3,4]	[0,1,2,3,4]	Warning	
41	Calibration	Return Rate	[“na”,0,…100]	[“na”,0,…100]	Warning	
41	Calibration	Other 41 Check		The record length must contain 16 (18) fields	Error	
42	Calibration	42	“42”	“42”	Error	
42	Calibration	Seconds of day		[0,…,86400]	Error	Normal data would be 00000 through 86399. A leap second would use 86400.
42	Calibration	Time of Flight		Within 2 hours of the pass E.g. H4 start date/time - 2hr ≤ 41 record seconds of day ≤ H4 end date/time + 2hr	Warning	
42	Calibration	System configuration id		Valid System configuration ID must be in C0 record	Error	
42	Calibration	Calibration configuration ID				
42	Calibration	Sum of varying delays				
42	Calibration	Type of Data	[0,1,2,3,4,5]	[0,1,2,3,4,5]	Warning	
42	Calibration	Calibration Type Indicator	[0,1,2,3,4,5,6]	[0,1,2,3,4,5,6]	Warning	
42	Calibration	Filter Flag	[0,1,2]	[0,1,2]	Warning	

42	Calibration	Detector channel	[0,1,…]	[0,…,99]	Warning	
42	Calibration	Stop Number	[0,1,…]	[0,1,...]	Warning	
42	Calibration	Calibration Span	[0,1,2,3,4]	[0,1,2,3,4]	Warning	
42	Calibration	Receive Amplitude		[na 0,...,99999]	Warning	
42	Calibration	Transmit Amplitude		[na, 0,...,99999]	Warning	
42	Calibration	Other 10 Check		The record length must contain 13(14) fields	Error	
50	Session (Pass) Statistics	50	"50"	"50"	Error	
50	Session (Pass) Statistics	System Configuration id		Valid system configuration ID/ System configuration ID must be in C0-record	Error	
50	Session (Pass) Statistics	Session RMS from the mean of raw, accepted time of flight values minus the trend function		[na,0,…,667]	Warning	Based on 10cm
50	Session (Pass) Statistics	Session skewness from the mean of raw accepted time of flight values minus the trend function		[na,-2,…,2]	Warning	
50	Session (Pass) Statistics	Session Kurtosis from the mean of raw accepted time of flight values minus the trend function		[na,-2,…,5]	Warning	
50	Session (Pass) Statistics	Session peak – mean		[na,-1000,..,1000]	Warning	
50	Session (Pass) Statistics	Data quality assessment indicator	[0,1,2,3,4,5]	[0,1,2,3,4,5]	Warning	
50	Session (Pass) Statistics	Other 50 Check		The record length must contain 7 fields	Error	
60	Compatibility Record	60	"60"	"60"	"60"	
60	Compatibility Record	System configuration id		"Valid System Configuration ID" or "Valid system configuration ID/ System configuration ID must be in C0-record"	Error	
60	Compatibility Record	System change indicator	[0,1,2,3,4,5,6,7,8,9]	[-1,0,…,9]	Warning	

60	Compatibility Record	System Configuration indicator		[-1,0,…,9]	Warning	
60	Compatibility Record	Other 60 Check		The record length must contain 4 fields	Error	
9X	User-defined	9X	“9”+[0,1,2,3,4,5,6,7,8,9]	not in ['9x']	Error	
00	Comment	00	“00”	“00”		
00	Comment	Other Comment Check		Length of Line must be less than or equal to 80 characters	Error	
global	Other Format Check	Other Format Check	Record type must be recognized	Record type must be recognized	Error	
global	Other Format Check	Other Format Check	There must be a C1-3 or 60 record	There must be a C1-3 or 60 record	Error	

Appendix D: Changes from CRD v. 1 to CRD v. 2

CRD and CPF Format and Manual Updates
28 February 2018
Updated for v2.01: 19 September 2019

Both the CPF and CRD formats have become a flexible way to distribute laser ranging predictions and data, respectively. Now that there have been years of experience with these formats, it is clear that there are some improvements that would make them more complete for several types of users.

1. **In general**
   a) Both formats will now be at version 2.
   b) Sample code changes will allow the reading of both version 1 and 2 CPF and CRD files.
   c) Manuals and included web links have been updated.

2. **CPF changes**
   a) The European Laser Transfer (ELT) mission required a change to the "H4" header record to include the epoch of the transponder oscillator drift.
   b) Due to the large drag effects on the International Space Stations (ISS), the ELT mission also required the ability to distribute more than 10 CPF versions each day. To accommodate this change, the sub-daily part of the sequence number will now be 2 digits long, with values from 1-99, with zero-fill.
   c) Target type in header H2 has been split into the following two fields to clarify functionality.
      1. "Target class" describes the reflector hardware: none, passive, synchronous transponder, or asynchronous transponder.
      2. "Dynamics/location" describes the location of the reflector: in orbit, on a surface, and the body (earth orbit, lunar orbit, lunar surface, etc.), other, or unknown.
   d) Stations are encouraged to build in the capability to handle CPFs written in the inertial reference frame ("H2" record, Reference frame = 2). While CPFs have so far only been allowed to be released in the body-fixed frame of reference, the ILRS would benefit from having this capability.
   e) The manual has been rewritten, eliminating dated information on conversion from IRV to CPF files and from older data formats to CRD. Other areas have been updated as needed.
   f) Proposed lunar/planetary one-way relativity correction records to use with transponders are not being added this time, and will be considered in the future only if there is a demonstrated need.
   g) NOTE: Read and observe the new method of handling leap seconds instituted in 2016, in which there is no tracking through the leap second.
   h) NOTE: Various prediction centers handle the start time and the length of CPF files differently. Some start on the even day. Some start 5 records early, so that the full accuracy of the 10-point interpolation will be available at the start of the day. Also, although the standard length of a CPF file is 5 days, certain providers have chosen to make their files longer or shorter.
   i) The time on the CPF file name is now defined as being the same as the start time on the H2 record; and the sequence number is now defined as being the day of year corresponding to the ephemeris production date on the H1 record, without adding 500.

3. **CRD changes**
   a) NOTE: The Station Epoch Time Scale ("H2") must be set to 3 (UTC USNO), 4 (UTC GPS), or 7 (UTC BIH). Stations MUST NOT use any other values without agreement from the Analysis Standing Committee.

b) Target type in header H2 has been split into two fields to allow for clearer functionality.
   1. "Target class" describes the reflector hardware: none, passive, synchronous transponder, asynchronous transponder.
   2. "Location/Dynamics" describes the location of the reflector: in orbit, on a surface, and the body (earth orbit, lunar orbit, lunar surface, etc.).
c) The CRD Seconds of Day field in any of the data record types is still not allowed to exceed 86400. A problem that seemed to require extending the upper bound beyond 86400 has been solved in another way.
d) Operations Centers' (OCs') range of acceptable values for each field will be included in an appendix. (For now this will only include fields from CPF version 1.)
e) Shot records ("10") now include the fire energy; the return energy is already recorded.
   1. The energy fields are still in arbitrary units and are unlikely to be meaningful for comparison between stations. These fields are not in normal point ("11") records.
f) The normal point record ("11") has been keeping the return rate for SLR and the S:N for LLR in the same field. They are now in separate fields: Return Rate, and Signal to Noise Ratio.
g) APOLLO lunar ranging station LLR processing version and other processing details will continue to be recorded in comment records ("00"), not in new lunar-specific records.
h) CRD software versions are now included in the new "C5" software configuration record.
   1. Capturing software versions can help analysts and stations isolate data anomalies created by software changes.
   2. The record(s) include ranging, calibration, filtering, normal pointing and related software that are in the data path. In other words, this is software which could alter the quality of the data if an incorrect modification were made.
i) Models and serial numbers of meteorological equipment used in the current pass are recorded in the new "C6" configuration record.
   1. Equipment listed are those which measure pressure, temperature, humidity. This record should correspond to the meteorological equipment listed in the ILRS Site Log.
j) More meteorological data can be added to the Meteorological Supplement Record ("21").
   1. Sky temperature.
   2. The "precipitation" field has been renamed "weather conditions". Previous character strings (e.g. "fog") will continue to be accepted as well as the 2-digit SYNOP/WMO present weather code.
k) NOTE: The "Epoch delay correction" in the "Timing System Configuration Record" ("C3") is essentially the same as the "Estimated Station UTC Offset" in the "Transponder (Clock) Configuration Record" ("C4"), but their units are different due to different applications – microseconds vs. nanoseconds. When the "C4" record is present, its value supersedes the value in the "C3" record.
l) The Compatibility record ("60") is obsolete and should no longer be sent.
m) The Prediction Record (H5) has been added to log the CPF or TLE filename used in tracking.

A2	Record Type (= "H5" or "h5")
I2	Prediction type 0 = Other 1 = CPF 2 = TLE
I2	CPF or TLE year of century
A6/A12	CPF date and hour (MMDDHH) from "H1" record; or TLE Epoch day/fractional day from line 1
A3	Prediction provider from CPF H1; TLE does not include this field, but it

should be available at the station.

I5 CPF Ephemeris sequence and sub-daily sequence numbers from H1; or TLE Revolution number from line 2

n) The “41” calibration detail record has been added to provide separate information on pre- and post- (or multiple) calibrations for each pass or pass segment. Every pass or pass segment must have a “40” record to give the overall calibration used to compute the “10” or “11” records’ time-of-flight and may have “41” records for more detailed information. Both record types now include “calibration span” and “return rate” fields.
o) The “42” calibration “shot” record has been added to the full rate data to allow analysts to reconstruct the statistics in the “40” and “41” calibration records. (V2.01)
p) The “C7” configuration record contains data on the calibration target(s) in use for the data set. (V2.01)
q) The “C2” Detector configuration record now includes amplifier information on gain, bandwidth, and whether the amplifier is used.
r) Debris and other non-ILRS tracking uses
   1. H2: There are now alternate names for Crustal Dynamics Project (CDP) pad ID, system number, and move number for non-ILRS tracking stations, e.g., System/Sensor identifier, System/Sensor number, and Sequence number.
   2. H2: The tracking network name (A10) is added to the end of the record for network data exchange. For SLR, this field contains the network, such as “NASA”, “WPLTN”, etc. For debris tracking, this is the debris tracking network, etc.
   3. H3: “no reflector” has been added to the list of possible target types.
   4. 12, 30: Azimuth, elevation, and range rates have been included in appropriate records.
   5. Filename conventions (debris and other non-ILRS tracking ONLY, not to go through OCs) include the network name to uniquely identify a station, e.g.,
      “networkname_ssss_satname_crd_yyyymmdd_hh_rr.xxx,

where the networkname represents a debris or other network, the names of which are not yet defined.

q) If a field's value is not available or not applicable to the station or file set, write “na” in the field, not “-1”. The choice of “-1” conflicts with valid values in many fields. (V2.01)

4. CPF and CRD

a) Added “Satellite Catalog Number” to NORAD ID field name, since they are interchangeable.
b) Made the header records free format. The configuration and data records already are free format.
   1. This is definitely not backward-compatible, though the software modifications should be minor.
   2. CPF note field will include up to 10 non-spaces following the target name.
c) There have been cases where the COSPAR ID to ILRS ID conversion did not follow the documented conversion scheme. This has only happened for two satellites so far and will be dealt with on a case-by-case basis. A general fix would probably require a change from 7 to 8 digits in the ILRS ID, which is not justified at this time.

5. Implementation plans

CPF update implementation plans:

a) What needs to be changed?
   1. The manual.
   2. Sample code: Needs backward compatibility for reading both version 1 and 2.
   3. Prediction Providers: At the beginning, version 2 CPFs will be provided by the ELT mission and a few others.

    4. OCs and DCs must provide space and handling for the V2 CPFs.
    5. Station software: Ingest new format at the stations, especially those intending to track ELT.
- b) Milestones and associated dates will be provided in other communications.

CRD update implementation plans:

- a) What needs to be changed?
    1. The manual.
    2. Sample code: Needs backward compatibility for reading both version 1 and 2.
    3. OC software: Validation code must handle new fields.
    4. OCs and DCs must provide space and handling for the V2 CRDs.
    5. Analysis software: Analysis Standing Committee needs to address the changes and ensure that the users can read both versions of the format.
    6. Station software: Mainly processing and normal point code.
    7. OCs, Data Centers, analysts, and debris tracking SC must accept original and new versions.
- b) Milestones and associated dates will be provided in other communications.

6. Implications for Producers and Users

- a) Manuals: Should be easier to read. They will be passed on to editors adept at making documentation clear for those not having English as their first language. A glossary of terms may be included with the CPF manual; one already exists in the CRD manual. Including debris or other tracking means, there is a more generic wording for several fields, e.g., satellite and station identification.
- b) Sample code will be able to read both versions 1 and 2 and write version 2. This should make incompatibilities easier to manage. Conversion programs to convert version 1 to version 2 format and vice versa can be written and added to the sample code if necessary. Note that converting CRD v1 to v2 does not exercise some of the new fields and new records. This conversion is for debugging and data flow uses, only.
- c) Free format headers:
    1. Users, including analysts, should be able to read version 1 or 2 of CRD or CPF.
    2. CPF producers should produce version 1 and 2 fixed format headers for the next couple years, or until stations have converted to the new format.
    3. This change requires little work for those using the new version of CPF and CRD sample code.
- d) Software and meteorological sensor configuration records (C5 and C6) should be included, but should not generate error messages from the Data OCs for some time.
- e) Prediction file record (H5) should be included, but should not generate error messages from the OCs for some time.
- f) The Compatibility Record (60) is no longer needed or used. It should be eliminated, and a warning should be issued by the OCs if it is present.

Normal Points from orbitNP cf. station-generated

Sample data set January 2020

Check Form and Format

Chrome File Edit View History Bookmarks Profiles Tab Window Help 92% Thu 12:06 PM Peter Dunn

7090_lageos1_crd_200114_1842_0 (1).npt

```
h3 lageos1     7603901 1155     8820 0 1
h4  1 2020  1 14 18 42 15 2020  1 14 18 59 48  0 0 0 0 1 0 2 0
c0 0  532.000 std la1 mcp ti1
c1 0 la1 Nd:Yag     532.00       5.00      100.00  150.0 15.00    1
c2 0 mcp MCP-PMT    532.000  15.5 3000.0  31.0 analog 400.0  1.00  80.0 30.00 none
c3 0 ti1 Truetime_XLDC Truetime_XLDC Cybi_ETM na   -1.0
60  std 6 1
40 67335.400561699993 0 std      -1       -1  -1.000   85991.0      0.0   13.0  -1.000  -1.000   -1.0
20 67361.801  977.40 295.30  68. 0
11 67361.800559700001     0.051738182789 std 2  120.0      1   36.0   0.000  -3.000      -1.0   0.17 0
20 67533.801  977.50 295.30  68. 0
11 67533.800560000003     0.050979344345 std 2  120.0      5   30.0   0.651  -0.668      -1.0   0.83 0
20 67655.001  977.50 295.30  68. 0
11 67655.000561900000     0.050720084900 std 2  120.0     11   45.0   0.049  -0.807      -1.0   1.83 0
20 67736.601  977.50 295.30  68. 0
11 67736.600560599996     0.050676510558 std 2  120.0     35   36.0   0.142  -1.090      -1.0   5.83 0
20 67867.801  977.50 295.30  68. 0
11 67867.800563199999     0.050827814419 std 2  120.0     13   28.0   0.096  -0.636      -1.0   2.17 0
20 67941.401  977.40 295.30  68. 0
11 67941.400561400005     0.051030990717 std 2  120.0      5   27.0  -0.204  -1.290      -1.0   0.83 0
20 68132.001  977.40 295.20  68. 0
11 68132.000562600006     0.051939628224 std 2  120.0      5   27.0   0.323  -1.702      -1.0   0.83 0
20 68235.801  977.30 295.20  68. 0
11 68235.800562100005     0.052655631655 std 2  120.0     20   35.0   0.234  -1.444      -1.0   3.33 0
20 68295.801  977.30 295.20  68. 0
11 68295.800562100005     0.053136411718 std 2  120.0      5   31.0  -0.115  -1.545      -1.0   0.83 0
50 std   35.6   0.144   2.145   -1.0 0
h8
h9
```

7090_lageos1_crd_200114_1842_0.npt — Edited

```
20 68239.801  977.30 295.20  68. 0
20 68240.601  977.30 295.20  68. 0
20 68241.401  977.30 295.20  68. 0
20 68243.801  977.30 295.20  68. 0
20 68257.001  977.30 295.20  68. 0
20 68258.201  977.30 295.20  68. 0
20 68259.001  977.30 295.20  68. 0
20 68261.601  977.30 295.20  68. 0
20 68263.401  977.30 295.20  68. 0
20 68279.401  977.30 295.20  68. 0
20 68280.201  977.30 295.20  68. 0
20 68290.801  977.30 295.20  68. 0
20 68295.801  977.30 295.20  68. 0
20 68384.801  977.40 295.20  68. 0
20 68388.401  977.40 295.20  68. 0
50 std   35.6   0.144   2.145   -1.0 0
11 67361.800559700001     0.051738182789   KS 2  120.0     1      0.0  0.000 -3.000     -0.1  0.2 0
11 67533.800560000003     0.050979344346   KS 2  120.0     5     29.4  0.636 -0.644     -6.9  2.9 0
11 67655.000561900000     0.050720084900   KS 2  120.0    11     44.7  0.068 -0.795     -5.4  1.9 0
11 67736.600560599996     0.050676510558   KS 2  120.0    35     35.9  0.144 -1.102    -15.3  6.2 0
11 67867.800563199999     0.050827814419   KS 2  120.0    13     28.3  0.059 -0.589     -8.4  2.6 0
11 67941.400561400005     0.051030990717   KS 2  120.0     5     25.6  0.025 -1.497     -7.4  1.0 0
11 68132.000562600006     0.051939628224   KS 2  120.0     5     27.5  0.248 -1.678    -10.1  1.6 0
11 68235.800562100005     0.052655631656   KS 2  120.0    20     35.0  0.330 -1.366    -18.9  4.3 0
11 68295.800562100005     0.053136411723   KS 2  120.0     5     30.3 -0.385 -1.474     10.5  0.9 0
H8
H9
```

utexas.app.box.com/s/opqrdwplq9k8ayiorkb00kpi6ac4v3xj/folder/142709964484

Apps | Intellicast - Hillan... | FairPoint My Acc... | Goddard Sailing A... | Google | Inbox (3,889) - pe... | Calendar of autom... | Verizon TV & Movi... | iCloud | Reading List

Log in | Sign up

Hx_Tests_Jan2020_data-0721 > full_1pt_npt

1 of 39 | Download

Name	Updated	Size
7090_lageos1_crd_200111_1552_0.npt	Today by Randall Ricklefs	3.9 KB
7237_lageos1_crd_200116_1300_0.npt	Today by Randall Ricklefs	2.7 KB
7811_lageos1_crd_200122_1924_0.npt	Today by Randall Ricklefs	54.9 KB

Details

Folder Properties

Owner
Randall Ricklefs

Enterprise Owner
The University of Texas at Austin

	OrbitNP					Station Generated				
Station	RMS in mm	Skew	Kurtosis	Peak-Mean in mm	#NPs	RMS in mm	Skew	Kurtosis	Peak-Mean in mm	#NPs
1824	38.3	-0.22	-1.43	0.3	3	41.5	0.16	2.00	20.8	6
1868					0	36.0	0.09	2.43	-2.7	130
1873	11.0	0.08	-1.09	0.5	39	11.0				41
1874	32.5	0.21	-0.17	-4.9	11	32.5	0.18	1.93	-4.0	11
1879					0	32.1	0.16	2.46	-5.7	92
1884	11.7	0.21	-0.64	-2.9	10	12.8	0.20	-0.62	0.0	28
1886					0	30.4	0.14	2.32	-2.9	82
1887					0	32.6	0.21	2.34	2.5	6
1888	201.3	0.70	4.16	-88.8	48	32.7	0.27	2.48		45
1890	40.6	0.19	0.18	0.5	126	36.7	0.00	2.46		129
1891	75.8	0.38	5.42	-3.7	58	38.2	0.18	2.18	-7.1	86
1893	25.3	0.19	-0.70	-2.9	49	9.4				71
7090	5.3	0.13	-0.53	-0.4	688	5.0	0.13	-0.79		964
7105	8.8	0.11	-0.22	-0.5	284	8.4	0.12	-0.27		291
7110	7.5	0.12	-0.27	-0.4	264	7.3	0.11	-0.47		324
7119	7.2	0.04	-0.26	-0.3	108	8.5	0.03	-0.60		125
7237	48.4	0.16	-0.60	11.9	255	11.8	0.14	2.26	-0.4	301
7249	24.9	0.32	0.15	-10.9	18	12.1				17
7407					0	25.1	0.16	2.34	-6.1	17
7501	7.1	0.19	-0.18	-0.5	79	7.1	0.18	-0.42		103
7503					0	24.2	0.07	2.21	-4.1	76
7810	12.4	0.43	-0.38	-2.7	952	11.7	0.43	-0.40	28.6	1042
7811	18.1	0.30	-0.50	-2.5	87	17.9	0.29	-0.52	-4.2	98
7819					0	11.5	0.04	2.22	24.4	148
7821	7.4	0.09	-0.92	-1.0	77	7.0	0.03	2.04	2.4	79
7824	14.6	0.79	0.84	-1.2	6	14.4				11
7825	6.9	0.06	-0.96	-0.3	57	7.1	0.12	-0.92	1.0	44
7827	12.4	0.08	-0.62	-0.9	209	11.8	0.05	-0.90	-0.3	209
7838	15.8	0.38	-0.28	-2.4	213	15.5	0.32	-0.33	0.0	241
7839	6.0	0.04	3.29	-0.8	262	5.2	0.10	-0.96	-0.9	307
7840	11.9	0.56	-0.30	-3.5	416	11.9				478
7841	7.7	0.18	-0.95	-1.7	103	7.4	0.17	-0.95	0.0	136
7845	14.9	0.29	-0.40	-1.9	319	14.9	0.28	-0.42		392
7941	3.2	0.17	-0.25	-0.3	374	3.1	0.19	-0.29		500
8834	10.8	0.17	-0.59	-1.5	212	10.9				230

7237_lageos1_crd_200116_1300_0.npt

7237_lageos1_crd_200116_1300_0.npt

```
30 47247.722000895235 157.4339  67.8661 1 3 1
30 47266.276000902981 157.9958  68.8864 1 3 1
30 48601.994000896397 327.9511  38.3161 1 3 1
30 48625.165000897978 328.1350  37.3147 1 3 1
30 48648.638000894425 328.3169  36.3136 1 3 1
30 48672.368000896982 328.4972  35.3131 1 3 1
30 48696.335000898333 328.6758  34.3131 1 3 1
30 48720.605000902287 328.8536  33.3122 1 3 1
30 48745.115000893857 329.0303  32.3119 1 3 1
30 48769.946000896263 329.2067  31.3119 1 3 1
50 KS       65.5  0.321 -0.441      0.0 0
11 46895.278000905804      0.044501295488   KS  2  120.0 16921      63.5  0.249 -0.475      -9.7 21.3
0
11 46957.801000896085      0.043672896734   KS  2  120.0 16247      69.8  0.355 -0.588     -20.9 13.5
0
11 47137.448000897559      0.041625621136   KS  2  120.0  2071      70.2  0.504 -0.376     -19.5  1.7
0
11 47193.424160906739      0.041098820772   KS  2  120.0 13056      61.5  0.259 -0.377      -7.7 10.9
0
11 47282.233000898210      0.040381470320   KS  2  120.0     2      21.7  0.000 -2.000      -4.2  1.3
0
11 48660.567000896772      0.049062810107   KS  2  120.0 13123      62.9  0.288 -0.410      -8.3 11.1
0
11 48746.718000897337      0.050550666738   KS  2  120.0  4129      71.0  0.249 -0.732     -18.4  6.7
0
H8
H9
```

7237_lageos1_crd_200116_1300_0 (1).npt

7237_lageos1_crd_200116_1300_0 (1).npt

```
1 CRD  1 2020  1 16 15
2 CHAL       7237 19  1  4
3 lageos1      7603901 1155      8820 0 1
4  1 2020  1 16 13  0 40 2020  1 16 13 33  1  0 0 0 0 1 0 2 0
0 0   532.000  std  CL1  CD1  CT1
1 0  CL1 RG30-L        1064.00    1000.00      1.50   10.0 92.82    0
2 0  CD1 CSPAD         532.000  20.00    5.0  60.0 TTL         0.0  1.70   0.0   0.0 none
3 0  CT1 Meridian            Meridian             ET-A033            003309            0.0
0  std 9 1
0 46080.000000000000 0  std     3046     1858   3.699   184842.0      0.0   20.8   0.042   2.714    0.0
 0 0
0 48784.000000000000  997.30 252.00  92.  0
1 46895.281000905576     0.044501254423  std 2  120.0  16921     63.4   0.249   2.516     -7.0  14.1

1 46957.803000900174     0.043672871132  std 2  120.0  16247     69.2   0.368   2.374    -15.0  13.5

1 47193.424160906739     0.041098820774  std 2  120.0  13056     61.5   0.216   2.547     -6.0  10.9

1 48660.571160903644     0.049062880421  std 2  120.0  13123     62.7   0.261   2.547     -7.0  10.9

1 48746.718000897337     0.050550666741  std 2  120.0   4129     70.9   0.246   2.259    -12.0   3.4

0  std   65.0   0.291   2.486   -9.1 0
8
```

Notes on GLTN Station Barometric Equipment

E. C. Pavlis and Keith Evans

August 2021

Results of a Review of Current Site Logs

- Reviewed the latest summary of the current site logs for all active SLR stations and identified which of these listed more than one barometer on site
- Some of these have a proper “Installation date” but a blank “Date removed”, so this had to be clarified to ensure it was not an omission on the station’s side to insert the date they removed what seems now to be a second (online) barometer
- We sent email to all stations to ask for clarification and more details
- All stations except Simeiz (1873) replied almost immediately

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
1873	Simiez	1	6466	USSR				no automatic recorders
1873	Simiez	2	MET3A	Paroscientific,Inc.				

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
7811	Borowiec	1	PTB200A	Vaisala	1998-07-01 HH:MM UT	EVERY FEW YEARS	N.A.	Pressures are compared daily : against a second barometer.
7811	Borowiec	2	Bosch 200	CBK, Poland	2017-12-15 HH:MM UT	EVERY 2 YEARS	N.A.	N.A.

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
7819	Kunming	1	Vantage Pro2	Davis Instruments	2016-09-01 HH:MM UT			
7820	Kunming	1	PTH	China	2000-10-15 HH:MM UT			last calibrated 2008-10-28

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
7825	Mount Stromlo	1	PMT16A	Vaisala	2004-04-08 HH:MM UT	As required	2011-09-21 HH:MM UT	Monitored daily against local reference.
7825	Mount Stromlo	2	PTB220A	Vaisala Oyj	2004-04-08 HH:MM UT	2 years		Factory calibrated. Used as back-up : barometer. Local eference.
7825	Mount Stromlo	3	WXT520	Vaisala Oyj	2011-10-06 HH:MM UT	2 years	2012-01-04 HH:MM UT	Factory calibrated.
7825	Mount Stromlo	4	PMT16A	Vaisala	2012-01-04 HH:MM UT	As required	2016-10-10 HH:MM UT	Monitored daily against local reference.
7825	Mount Stromlo	5	PTB220A	Vaisala Oyj	2016-10-10 HH:MM UT	2 years	2017-01-23 HH:MM UT	Factory calibrated. Local reference.
7825	Mount Stromlo	6	PTB330	Vaisala Oyj	2017-01-23 HH:MM UT	2 years		nstalled as part of an AWS310. : Factory calibrated.
7826	Mount Stromlo	1	PTB330	Vaisala	2017-01-24 HH:MM UT	As required		

UMBC

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
7827	Wettzell	1	Digiquartz 740-16B	Paroscientific	1990-01-01 12:00 UT	YEARLY	2019-05-28 18:15 UT	NO BAROMETER AT ALL ???

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
7839	GRAZ	1	DigiQuartz 740-16B	Paroscientific	1995-04-01 HH:MM UT	YEARLY	2002-12-10 00:00 UT	In 2002-06-10, the travelling baro from : RGO was in Graz at that time, the Graz : ParoScientific showed a -0.5 mB offset; : i.e. Graz reading was 0.5 mB lower than the : RGO reading.
7839	GRAZ	2	MET3A	Paroscientific	2002-12-10 00:00 UT	YEARLY	2020-12-10 00:00 UT	The older Digiquartz has been re-calibrated, and is used now as a secondary standard. Both readings are now routinely compared and checked against each other, so that any deviations should be detected early enough; the differences are usually below 0.05 mB. Replaced by PTU300 on 2020-12-10
7839	GRAZ	3	PTU300	Vaisala	2020-12-10 00:00 UT	YEARLY	2021-03-26 12:00 UT	SN: L1110324 Last calibration: 2020-10-16 Location: outside; in the shadow
7839	GRAZ	4	PTU300	Vaisala	2021-03-26 12:00 UT	YEARLY		SN: T0210974 ration: 2021- Jan New PTU300 with two barometers; Location: laser room

UPDATED: 06/14/21

Site Number	Location	Entry	Pressure Sensor Model	Manufacturer	Date Installed	Calibration Interval	Date Removed	Additional Information
7865	NRL OPTICAL TEST FACILITY	1	MET3A	PAROSCIENTIFIC	2002-08-01 HH:MM UT	YEARLY	2015-09-23 HH:MM UT	RECALIBRATED Sep 2002
7865	NRL OPTICAL TEST FACILITY	2	MET4A-1	PAROSCIENTIFIC	2015-09-23 HH:MM UT	9/23/15		New
7865	NRL OPTICAL TEST FACILITY	3	MET4A-1	PAROSCIENTIFIC	2019-06-03 HH:MM UT	3/28/19		REFURBISHED AND UPGRADED MET3A

Station Responses

- Simeiz 1873:
  - Andriy corrected their site log, clarifying the status of the two units he reported as actively measuring at the site (USSR 6466 & Paroscientific MET3A)
- Borowiec 7811:
  - Currently we are using only one barometer, BOSCH, the old VAISALA is OFF
- Kunming 7819/7820:
  - we used old system(7820) observe space debris and lunar surface retro - reflector, and we are going to do regular lunar laser ranging in future (7820)
  - a second email clarified that both barometers are in operation
- Mt. Stromlo 7825/7826:
  - PTB330 (2017) provides primary pressure data to both #7825 and #7826
  - PTB220A is a backup unit used to provide validation data for the PTB330

Station Responses (cont.)

- Graz 7839:

  They have two Vaisala PTU300 units:

  - #1:

    -- installed in Dec. 2020, **outside**;

    -- delivers barometric values to SLR data: Dec. 2020 until Mar. 2021;

    -- delivers temperature and rel. humidity to SLR as well since Dec. 2020.

  - #2:

    -- installed in Mar. 2021, **in laser room**;

    -- with TWO barometric measurement modules A & B;

    -- "A" delivers barometric values to SLR since Mar. 2021 replacing #1;

    -- temperature and rel. humidity values are **stored but not used for SLR**.

  - Since Mar. 2021 their s/w reads all three barometric values (one from #1, two: A & B, from #2), and a warning pops-up in case of a difference > 0.05 mbar (after height correction) between these three values. The other two old systems are running and recorded/archived but not used.
  - In principle, Graz has FIVE (5) barometers taking measurements simultaneously at all times.

Station Responses (cont.)

- NRL OTF Stafford 7865:

  They have two Paroscientific MET4A-1 units:

  - They are operating both of them in parallel for internal monitoring

- SOSW Wettzell 7827:
  - Although from the site log it seems that they have no barometer installed, it seems that they share the same barometer with WLRS (8834), probably shared as well with VLBI, GNSS, etc.
  - Need to get a clarification of this guess.

Summary

- **Simeiz 1873** two barometers, one is historical only
- **Kunming 7819/7820** runs two barometers, one for each system
  - CB needs to discuss with Kunming the conversion of 7820 to a LLR system and the review of a revised site log (yet to be submitted)
- **Mt. Stromlo 7825/7826** runs two barometers in parallel for QA
- **Graz 7839** is a unique station that runs 5 barometers in parallel (only one provides data for the SLR observations)
- **NRL OTF 7865** runs two barometers in parallel for QA
- **SOS Wettzell 7827** needs to verify that they use the same barometer as WLRS 8834, may need to amend their site log too
- None of the other active sites seem to run more than one barometer.

Meteorological Analysis
10-Aug-2021

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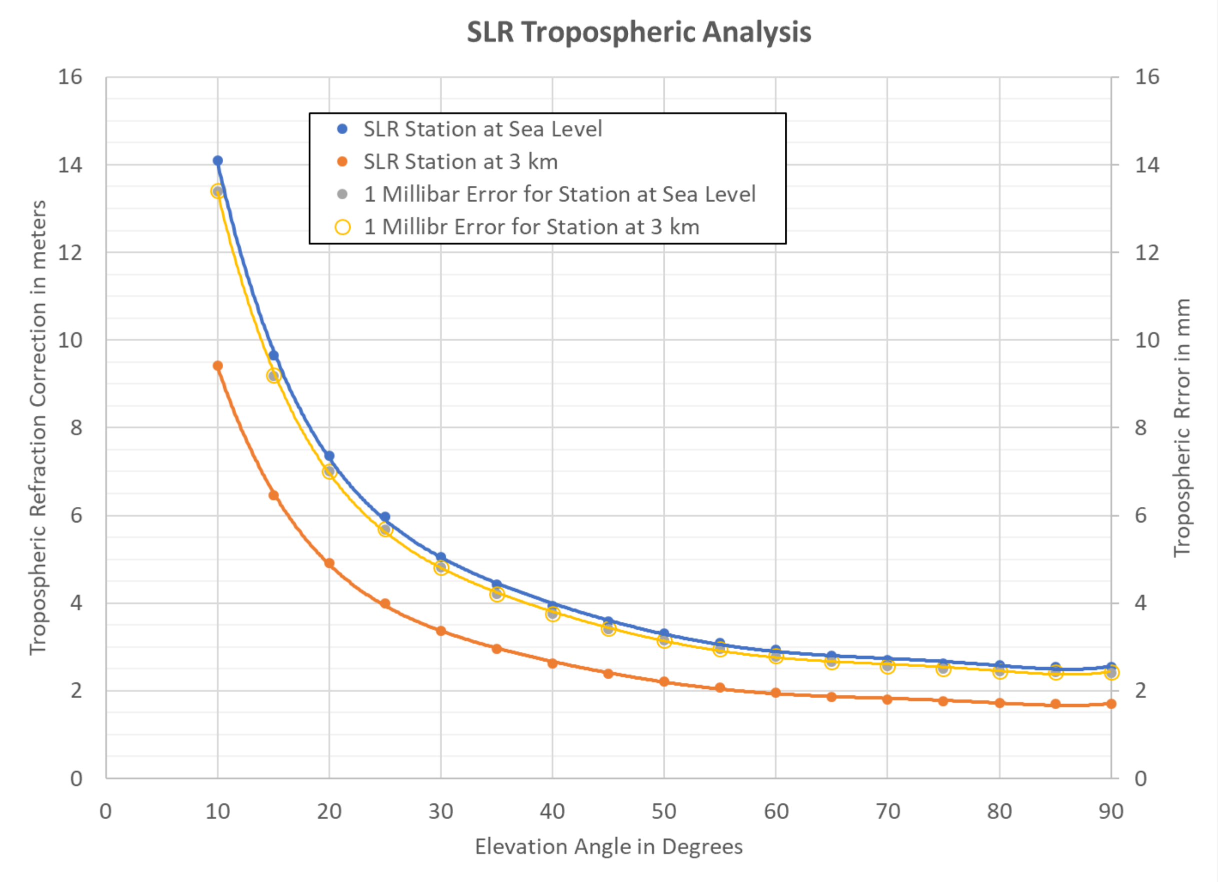
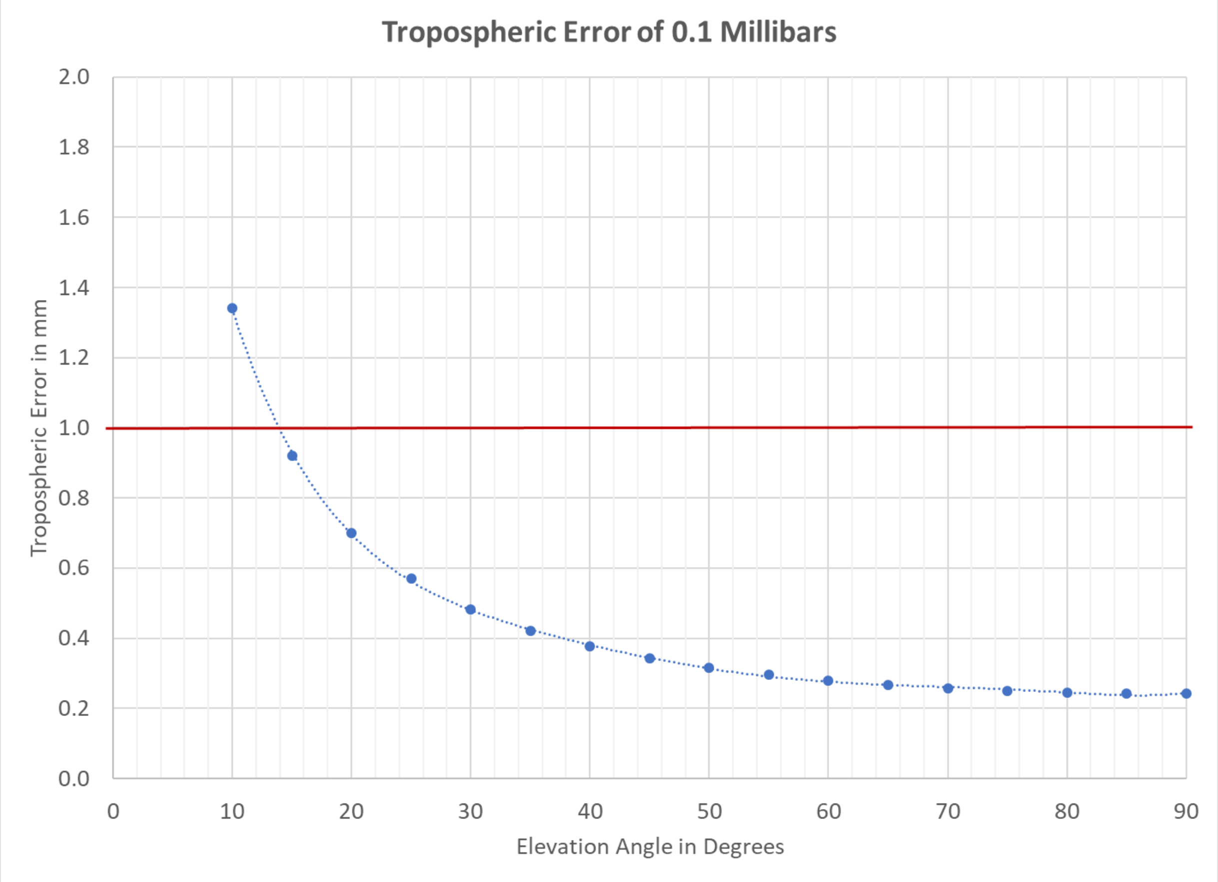
SLR Tropospheric Refraction Analysis





The tropospheric refraction correction increases as elevation angle decreases. The correction also decreases with station height; however; a 1 millibar error in the measurement has the same impact irregardless of station height. If the barometric error is less than 0.1 millibars, then the systematic error is sub-mm for elevation angles above 15 degrees.

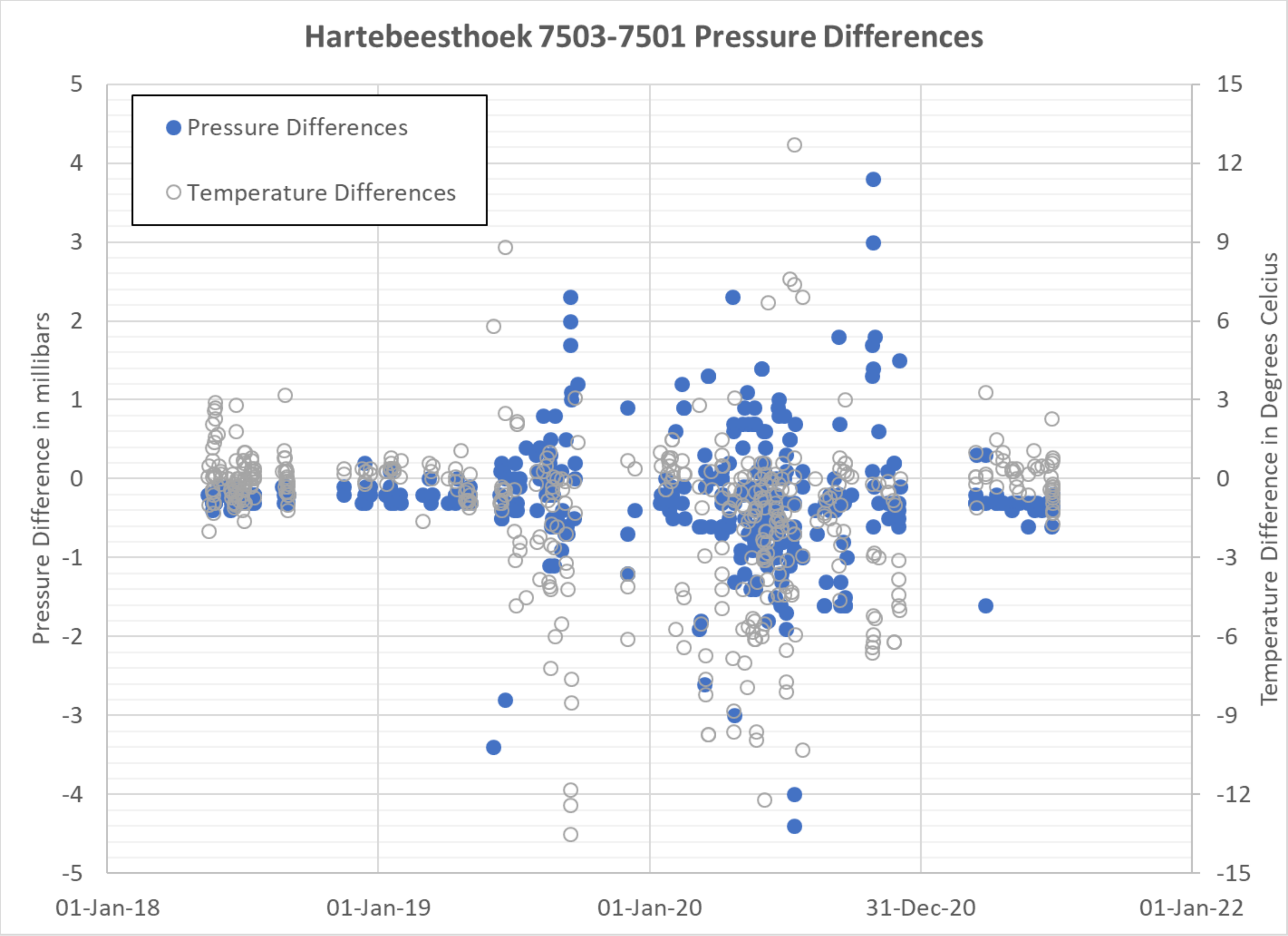
ILRS Barometric Sensors

Barometric Sensor Model	Count	Stations	Total Accuracy (mbar)	Drift per year (mbar)	Temperature Dependence (mbar)
Vaisala PTB220	10	Russian (ROSCOSMOS)	0.15	0.10	0.10
Paroscientific MET4	7	NASA SLR	0.08	0.10	
Paroscientific Digiquartz 740-16B	3	Zimmerwald, Wettzell (7827 and 8834)	0.10	0.10	0.08
Vaisala PTU200	3	Potsdam, Beijing, San Juan	0.15	0.10	0.10
Vaisala PTU300	3	Wuhan, Graz, Grasse	0.15	0.10	0.10
Bosch BMP280	2	Golosiiv, Borowiec	1.00		
Paroscientific Met3A	2	Simeiz, Changchun	0.10	0.10	
Vaisala PTB330	2	Mt Stromlo, Geochang	0.15	0.10	0.10
	2	Apache Point, Komsomolsk-na-Amure			
Davis Instruments Vantage Pro2	1	Kunming	1.00		
Druck DPI 141	1	Herstmonceux	0.15	0.05	0.10
Nippon Electric Instrument RPT-301	1	Tanegashima	0.10	0.10	0.20
Oregon Scientific WMR928N	1	Katzively	1.00		
Ota Keiki Seisakusho Co, LTD OW-7-420	1	Simosato	0.70		
Paroscientific 1016B-01 (appears to be a part number and not a model number)	1	Matera	0.10		
SEAC EMA V (can't find on the internet)	1	San Fernando	0.30		
Vaisala (no model number provided)	1	Shanghai	0.10		
Vaisala BAROCAP	1	Riga	0.15	0.10	0.10
Vaisala WXT520	1	Sejong	0.50		

Legend
Total Accuracy >0.15 millibars
Not provided in Data Sheet

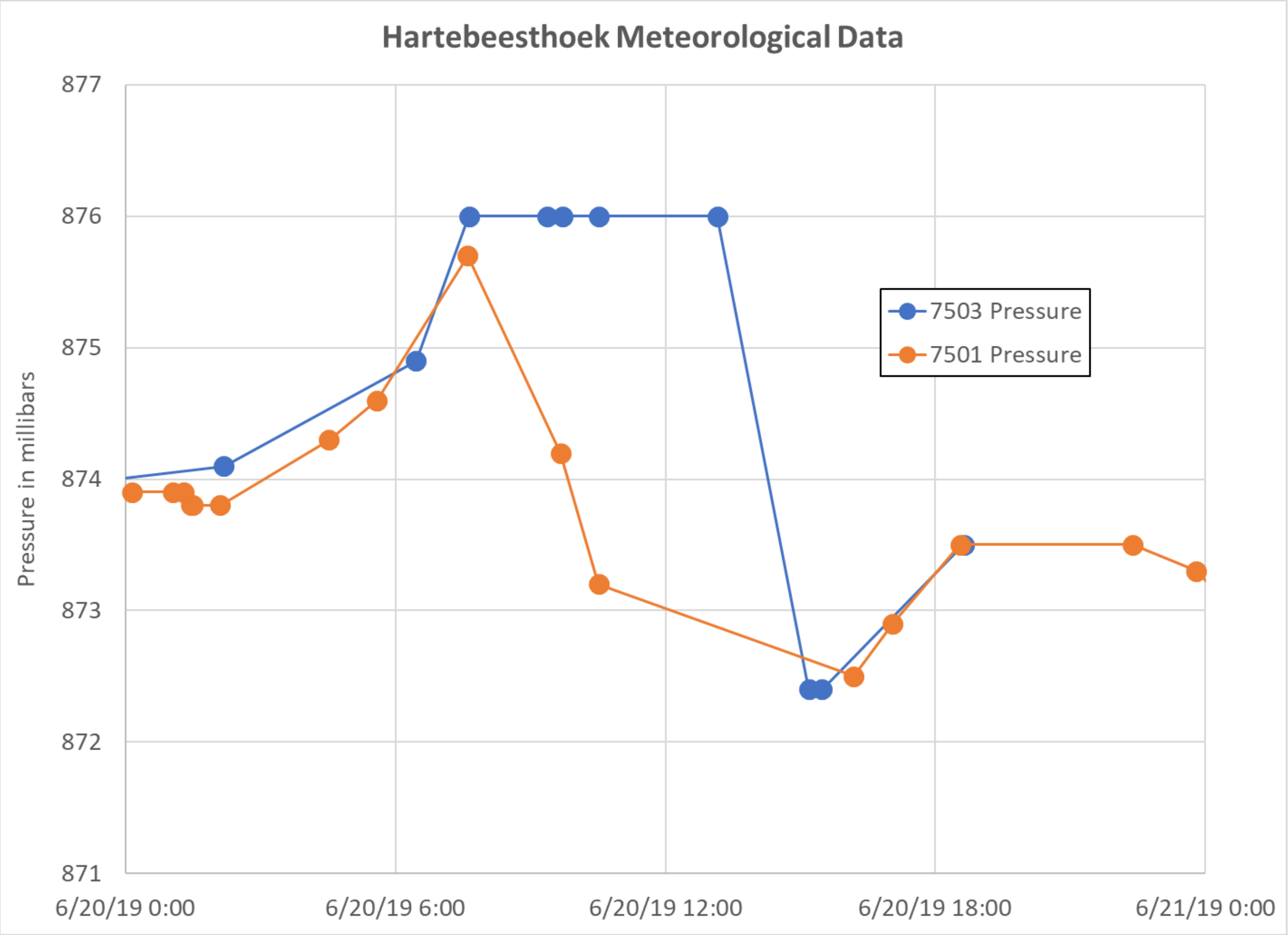
- The Table is grouped by the Barometric Sensor based on the site logs
- Barometric sensors have accuracy limitations (i.e. total accuracy, stability/drift and temperature dependence)
- A second barometer and yearly calibrations to a known standard hopefully can eliminate drifts in our barometric measurements and minimize systematic errors

Hartebeesthoek Meteorological Analysis



- Pressure and Temperatures differences from simultaneous passes between the two Hartebeesthoek stations that are less than 100 meter apart
- It appears one of the stations changed something in the middle of 2019

Hartebeesthoek Meteorological Analysis



- These are the pressures recorded in the CRD for both stations on 20-Jun-2019
- For some reason, the 7503 meteorological measurements (pressure, temperature, humidity) did not update for several hours. This occurred on other days as well causing the large dispersion in differences on the previous slide
- Need to inquire if this was an issue in data processing and/or an equipment issue

Jan 2020 LAGEOS-1 Normal Point (NP) Comparison
OrbitNP vs Station Generated NPs
Aug 2021

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Introduction

- Randy Ricklefs generated normal points from the January 2020 LAGEOS-1 fullrate data using Matt's November 2020 orbitNP_1.1_beta.py software (with a couple of minor fixes) to create new normal points (NPs)
- One- and two-point NPs were excluded in this initial analysis
- The following stations provided NPs, BUT did NOT provide fullrate data

Pad	Location	# of NP CRDs
1868	Komsomolsk-na-Amure, Russia	22
1879	Altay, Russia	16
1886	Arkhyz, Russia	12
1887	Baikonur, Kazakhstan	2
7407	Brasilia, Brazil	7
7503	Hartebeesthoek, South Africa	12
7819	Kunming, China	34

Introduction (con't)

- The following stations did not provide LAGEOS-1 NPs in January 2020

Pad	Location
7124	Tahiti, French Polynesia
7358	Tanegashima, Japan
7394	Sejong City, Republic of Korea
7395	Geochang, Republic of Korea
7396	Wuhan, China
7403	Arequipa, Peru
7406	San Juan, Argentina

Introduction (con't)

Pad	OrbitNP CRDs	Station CRDs	Difference	Comment
1824	2	1	-1	OrbitNP had two versions of same pass, duplicate fullrate?
1873	9	8	-1	There appears to be a missing NP CRD from Jan 13, 2020
1874	1	1	0	
1884	2	4	2	
1888	7	7	0	
1890	26	27	1	
1891	17	19	2	
1893	7	9	2	
7090	160	192	32	
7105	41	41	0	
7110	37	44	7	
7119	17	19	2	
7237	34	43	9	
7249	3	3	0	
7501	19	23	4	
7810	79	88	9	
7811	8	9	1	
7821	7	8	1	
7824	2	4	2	
7825	12	12	0	
7827	40	40	0	
7838	21	24	3	
7839	38	48	10	
7840	34	39	5	
7841	23	30	7	
7845	29	36	7	
7941	57	74	17	
8834	45	50	5	
Total	777	903	126	

- Here is a comparison of CRD NP totals
- There appears to be some missing fullrate from some of the stations from either the beginning and/or end of January 2020. Reason unknown.
- Action: Investigate why there appears to be missing fullrate data

Introduction (con't)

- The following 11 NP record comparisons were done when the OrbitNPs and the station generated NPs had the same epochs
  - Epoch
  - Range
  - Bin RMS
  - Skew
  - Kurtosis
  - Peak minus Mean
  - Return Rate
- The following comparisons were done for the 50 session record that were common to both OrbitNP and the station
  - Bin RMS
  - Skew
  - Kurtosis
  - Peak minus Mean

11 Record Normal Point Comparisons

NP Bin Epoch Comparisons

Pad	Location	Epoch Difference (Station-OrbitNP) in ns	Std Dev in ns	Peak to Peak Variation in ns	# of NPs	Comments
1824	Golosiiv, Russia (former Ukraine)	0	0	0	3	
1873	Simeiz, Russia (former Ukraine)	0	0	0	33	
1874	Mendeleevo, Russia	0	0	0	11	
1884	Riga, Latvia	0	0	0	10	
1888	Svetloe, Russia	0	0	0	39	
1890	Badary, Russia	0	0	0	123	
1891	Irkutsk, Russia	0	0	0	33	
1893	Katzively, Russia (former Ukraine)	-1	29	95	49	NP Epoch resolution is 100 ns, fullrate epochs have more resolution?
7090	Yarragadee, Australia	0	0	0	688	
7105	Greenbelt, Maryland	0	0	0	284	
7110	Monument Peak, California	0	0	0	264	
7119	Haleakala, Hawaii	0	0	0	108	
7237	Changchun, China	0	0	0	229	
7249	Beijing, China	0	0	0	17	
7501	Hartebeesthoek, South Africa	0	0	0	79	
7810	Zimmerwald, Switzerland	0	0	0	945	
7811	Borowiec, Poland	0	0	0	87	
7821	Shanghai, China	0	0	0	67	
7824	San Fernando, Spain	100	187	400	6	NP Epoch resolution is 100 ns, fullrate epochs have more resolution?
7825	Mt Stromlo, Australia	0	0	0	44	
7827	Wettzell, Germany	N/A	N/A	N/A	82	Epochs not compliant with Herstmonceux NP algorithm
7838	Simosato, Japan	0	0	0	213	
7839	Graz, Austria	0	0	0	238	
7840	Herstmonceux, United Kingdom	39	25	92	415	NP Epoch resolution is 100 ns, fullrate epochs have more resolution?
7841	Potsdam, Germany	0	0	0	103	
7845	Grasse, France (LLR)	0	0	0	312	
7941	Matera, Italy (MLRO)	0	0	0	374	
8834	Wettzell, Germany (WLRS)	0	0	0	207	

- For some stations, the resolution of the epochs can be different between fullrate and NPs
- 7827 Epochs are non-compliant with the Herstmonceux definition (see next slide)

7827 Wettzell NP Epoch Analysis

Pad	Type	Date	Rec Typ	Tme (second	Tof	Cfg	Epo	bin size	pts
7827	Station	1/2/20 8:00	11	28836.6950066	0.056344386762	d2c2	2	120	1274
7827	OrbitNP	1/2/20 8:00	11	28837.8780066	0.056337479489	KS	2	120	1274
7827	Station	1/2/20 8:04	11	29088.8320066	0.055160716617	d2c2	2	120	658
7827	OrbitNP	1/2/20 8:04	11	29093.6520066	0.05514396280 4	KS	2	120	658
7827	Station	1/2/20 8:13	11	29633.7780066	0.054780494734	d2c2	2	120	673
7827	OrbitNP	1/2/20 8:13	11	29635.3130065	0.054783852245	KS	2	120	673
7827	Station	1/2/20 8:14	11	29649.4240066	0.054815889921	d2c2	2	120	1642
7827	OrbitNP	1/2/20 8:14	11	29656.4640066	0.054832663965	KS	2	120	1642
7827	Station	1/2/20 8:20	11	30035.7130066	0.056497531667	d2c2	2	120	592
7827	OrbitNP	1/2/20 8:20	11	30036.9220066	0.056505156665	KS	2	120	592
7827	Station	1/2/20 11:31	11	41502.5390066	0.050629564564	d2c2	2	120	1075
7827	OrbitNP	1/2/20 11:31	11	41505.0570066	0.050585327444	KS	2	120	1075

- When the number of points (pts) in a NP bin are the same, the NP epochs between the station and the OrbitNP should and do agree except for station 7827. See a few examples above where the difference in epochs can be a few to several seconds (see the time column in seconds above). There must be a difference in how the bin boundaries are computed.

NP Bin Range Comparisons

Pad	Location	Mean Difference in mm	Std Dev in mm	Peak-to-Peak in mm	# of NPs
1824	Golosiiv, Russia (former Ukraine)	-30,802.2	1.6	3.0	3
1873	Simeiz, Russia (former Ukraine)	-2.9	18.6	76.6	33
1874	Mendeleevo, Russia	0.1	0.5	1.5	11
1884	Riga, Latvia	-0.3	1.1	3.6	10
1888	Svetloe, Russia	-1.5	4.8	26.1	39
1890	Badary, Russia	-1.8	6.4	65.4	123
1891	Irkutsk, Russia	-0.9	2.4	12.9	33
1893	Katzively, Russia (former Ukraine)	-0.2	1.8	9.9	49
7090	Yarragadee, Australia	0.0	0.9	17.2	688
7105	Greenbelt, Maryland	0.0	1.6	32.1	284
7110	Monument Peak, California	0.0	1.0	15.4	264
7119	Haleakala, Hawaii	0.0	5.5	72.4	108
7237	Changchun, China	0.5	4.1	36.6	229
7249	Beijing, China	1.1	4.6	14.8	17
7501	Hartebeesthoek, South Africa	0.0	0.7	5.4	79
7810	Zimmerwald, Switzerland	0.0	0.7	6.0	945
7811	Borowiec, Poland	0.0	1.2	9.1	87
7821	Shanghai, China	0.2	0.5	3.4	67
7824	San Fernando, Spain	-17,171.9	4.3	10.0	6
7825	Mt Stromlo, Australia	-0.8	3.1	15.4	44
7827	Wettzell, Germany				
7838	Simosato, Japan	-0.1	2.3	33.0	213
7839	Graz, Austria	0.0	0.9	9.6	238
7840	Herstmonceux, United Kingdom	-0.1	0.5	3.0	415
7841	Potsdam, Germany	0.0	0.5	2.2	103
7845	Grasse, France (LLR)	-0.1	0.7	6.1	312
7941	Matera, Italy (MLRO)	0.0	0.6	5.1	374
8834	Wettzell, Germany (WLRS)	0.1	0.6	4.2	207

- Range comparisons when the epochs matched, the points in bins may vary between the station generated NPs and OrbitNP
- Eliminated outliers when there were large differences in the Bin RMSs
- Overall excellent agreement and repeatability except for 2 stations
  - High performing systems have sub-mm agreement with <2 mm repeatability
  - 1824 has a 30 meter difference, appears system delay is not applied to the fullrate, except the system delay is 39 meters
  - 7824 full-rate data does not have the system delay removed
  - 7827 did not have any matching epochs even though the points in the bin were identical

NP BIN RMS Comparison

	Orbit NP		Station			
Pad	Average Bin RMS in mm	Std Dev of Bin RMS in mm	Average Bin RMS in mm	Std Dev of Bin RMS in mm	Station - OrbitNP Average Bin RMS in mm	# of NPs
1824	38.3	10.2	44.2	13.0	5.9	3
1873	11.2	5.8	11.0	5.9	-0.2	33
1874	32.5	3.9	32.5	3.9	0.0	11
1884	11.7	1.1	11.5	1.2	-0.2	10
1888	37.3	4.3	33.2	2.3	-4.1	39
1890	40.6	6.5	36.6	4.1	-3.9	123
1891	37.6	7.4	36.4	5.9	-1.2	33
1893	25.3	7.2	8.4	2.9	-16.9	49
7090	5.3	1.4	5.1	1.3	-0.2	688
7105	8.8	2.9	8.5	1.7	-0.3	284
7110	7.5	1.6	7.4	1.6	-0.1	264
7119	7.2	1.6	7.9	4.6	0.7	108
7237	10.6	3.1	10.1	2.9	-0.5	229
7249	12.4	4.0	12.1	3.5	-0.4	17
7501	7.1	1.0	7.0	1.0	-0.1	79
7810	11.9	4.0	11.7	1.6	-0.2	945
7811	18.1	1.7	17.9	1.5	-0.1	87
7821	7.4	2.2	6.9	0.6	-0.5	67
7824	14.6	1.9	13.1	1.3	-1.5	6
7825	7.2	1.4	7.1	1.3	-0.1	44
7827	11.5	1.6	11.4	1.3	-0.1	81
7838	15.8	3.7	15.8	3.2	0.0	213
7839	5.3	0.7	5.2	0.3	-0.1	238
7840	12.0	1.4	12.0	1.4	0.0	415
7841	7.7	1.6	7.6	1.6	0.0	103
7845	15.0	2.7	15.0	2.3	-0.1	312
7941	3.2	0.4	3.1	0.3	-0.1	374
8834	10.9	1.3	10.9	1.3	0.0	207

- Moment outliers were eliminated (see next slide) prior to generation of these statistics.
- Bin RMSs agree well (<1mm) for the high performing systems
- The bin RMSs for 1893 Katsively are quit different

Moment Comparison Outlier Examples

Pad	Date	Rec Type	time in secs	Range in ps	pts	RMS in ps	Skew	Kurtosis	Range Diff in mm	RMS Diff in mm	Skew Diff	Kurt Diff
1888	10-Jan-20	11	78648.3863426	0.050128472059	67	3788	-5.55	29.22				
1888	10-Jan-20	11	78657.9830683	0.050036426354	65	232	0.17	2.73		3556	-5.73	26.49
1888	10-Jan-20	11	78888.2854784	0.048165848884	55	186	0.18	2.87				
1888	10-Jan-20	11	78888.2854784	0.048165849025	57	1094	6.92	47.85	21	136	6.7	45.0
1888	11-Jan-20	11	35183.4544516	0.045037238866	11	5503	-0.57	-1.67				
1888	23-Jan-20	11	26827.4456497	0.048839667809	43	1956	-2.70	5.60				
1888	23-Jan-20	11	26870.5177835	0.048463252865	22	156	0.43	2.50		1800	-3.13	3.10
1888	24-Jan-20	11	61396.2551924	0.041445624724	36	1185	5.34	28.02				
1888	24-Jan-20	11	61397.3573883	0.041455949881	33	196	-0.38	2.41		988	5.72	25.60
1888	24-Jan-20	11	61472.0969562	0.042206303272	21	195	-0.38	2.47				
1888	24-Jan-20	11	61472.0969562	0.042206303730	25	1662	4.42	18.38	69	220	4.8	15.9
1891	13-Jan-20	11	11921.3530518	0.045931382307	6	229	-0.71	1.69				
1891	13-Jan-20	11	11921.3530518	0.045931381068	9	2896	-1.21	-0.16	-186	400	-0.5	-1.8
1891	27-Jan-20	11	6325.5851075	0.051299439485	48	360	-0.05	2.70				
1891	27-Jan-20	11	6325.5851075	0.051299440075	58	2296	1.44	3.53	88	290	1.5	0.8
7237	16-Jan-20	11	9653.5430009	0.045711065812	1449	674	-0.04	2.14				
7237	16-Jan-20	11	9653.5430009	0.045711053071	1449	17677	-1.16	-0.15	-1910	2549	-1.1	-2.3
7237	16-Jan-20	11	9789.0031609	0.044011623152	1070	628	0.09	2.23				
7237	16-Jan-20	11	9789.0031609	0.044011616023	1070	10120	-0.39	-1.33	-1069	1423	-0.5	-3.6
7237	16-Jan-20	11	9899.5580009	0.042817744204	958	615	-0.03	2.30				
7237	16-Jan-20	11	9899.5580009	0.042817743784	958	2609	0.03	-0.16	-63	299	0.1	-2.5
7237	16-Jan-20	11	10016.5870009	0.041766112144	1333	665	-0.04	2.18				
7237	16-Jan-20	11	10016.5870009	0.041766110540	1333	2835	0.09	-0.43	-240	325	0.1	-2.6
7810	15-Jan-20	11	80741.3872023	0.048555362993	33	77	0.45	-0.09				
7810	15-Jan-20	11	80741.3872023	0.048555363738	33	2968	1.90	1.70	112	433	1.4	1.8
7827	03-Jan-20	11	50869.2640066	0.044065124166	404	600	6.50	46.19				
7827	03-Jan-20	11	50871.1950066	0.044084098004	404	81	0.10	-0.79		518	6.4	6.4
7827	25-Jan-20	11	82346.7880068	0.050710498675	35	357	-1.64	2.36				
7827	25-Jan-20	11	82354.4480068	0.050778082322	35	96	0.15	-1.15				
7839	06-Jan-20	11	939.7818636	0.059645266038	991	60	-15.32	377.95				
7839	06-Jan-20	11	939.7818636	0.059645266031	991	36	-0.03	-1.08	-1	-4	15.3	-379.0
7839	06-Jan-20	11	71864.0604636	0.052127441502	430	36	-0.01	-1.14				
7839	06-Jan-20	11	71864.0604636	0.052127441502	430	42	1.94	13.82	0	0	-0.9	-2.0
7839	06-Jan-20	11	85076.8531636	0.057508509536	179	33	0.13	-0.68				
7839	06-Jan-20	11	85076.8531636	0.057508509520	179	217	-11.60	141.65	-2	28	-11.7	142.3
7839	07-Jan-20	11	79785.9733636	0.054201410076	351	37	-0.18	-1.12				
7839	07-Jan-20	11	79785.9733636	0.054201410050	351	139	-7.43	62.17	-4	15	-7.2	63.3
7839	08-Jan-20	11	38299.8630636	0.040583213133	2650	34	0.21	-0.93				
7839	08-Jan-20	11	38299.8630636	0.040583213130	2650	38	-1.17	8.67	0	1	-1.4	9.6
7839	08-Jan-20	11	50514.5848636	0.047316800026	169	34	0.50	-0.60				
7839	08-Jan-20	11	50514.5848636	0.047316800040	169	102	10.49	124.05	2	10	10.0	124.6

Legend
Station
OrbitNP

- OrbitNP NP Bin moments (i.e. RMS, Skew, Kurtosis) on occasion are suspect
- Despite OrbitNP having occasional large skew and kurtosis values for 7839 NPs, the ranges still agree very well

NP Bin Skew Comparisons

	OrbitNP		Station				
Pad	Average of Skew	StdDev of Skew	Average of Skew	StdDev of Skew	# of NPs	Station - OrbitNP Skew	Comments
1824	-0.22	0.30	0.16	0.00	3	0.39	
1873	0.08	0.38	-1.00	0.00	33	N/A	Station does not compute skew
1874	0.21	0.26	0.18	0.18	11	-0.03	
1884	0.21	0.12	0.20	0.12	10	-0.01	
1888	0.48	0.26	0.30	0.15	39	-0.18	
1890	0.19	0.43	-0.01	0.25	123	-0.20	
1891	0.46	0.55	0.21	0.35	33	-0.25	
1893	0.19	0.54	-1.00	0.00	49	N/A	Station does not compute skew
7090	0.13	0.45	0.13	0.45	688	-0.01	
7105	0.11	0.31	0.12	0.31	284	0.01	
7110	0.12	0.40	0.14	0.40	264	0.02	
7119	0.04	0.44	0.03	0.39	108	-0.01	
7237	0.18	0.13	0.14	0.11	229	-0.05	
7249	0.34	0.60	-1.00	0.00	17	N/A	Station does not compute skew
7501	0.19	0.29	0.20	0.24	79	0.01	
7810	0.43	0.20	0.42	0.19	945	0.00	
7811	0.30	0.20	0.29	0.20	87	-0.01	
7821	0.08	0.18	0.02	0.05	67	-0.06	
7824	0.79	0.26	-1.00	0.00	6	N/A	Station does not compute skew
7825	0.15	0.28	0.12	0.27	44	-0.02	
7827	0.05	0.06	0.05	0.06	81	0.00	
7838	0.38	0.46	0.35	0.48	213	-0.04	
7839	0.09	0.17	0.09	0.17	238	0.00	
7840	0.56	0.16	-1.00	0.00	415	N/A	Station does not compute skew
7841	0.18	0.14	0.17	0.13	103	0.00	
7845	0.30	0.31	0.29	0.31	312	0.00	
7941	0.17	0.20	0.19	0.19	374	0.02	
8834	0.17	0.13	-1.00	0.00	207	N/A	Station does not compute skew

- Moment outliers were eliminated prior to generation of these statistics
- Bin skews agree well for all stations that compute it

NP Bin Kurtosis Comparison

	OrbitNP		Station				
Pad	Average of Kurtosis	StdDev of Kurtosis	Average of Kurtosis	StdDev of Kurtosis	# of NPs	Station - OrbitNP Kurtosis	Comments
1824	-1.43	0.48	2.00	0.00	3	3.42	Station does not subtract 3 from kurtosis
1873	-1.13	0.42	-1.00	0.00	33	N/A	Station does not compute Kurtosis
1874	-0.17	0.80	1.93	1.00	11	2.10	Station does not subtract 3 from kurtosis
1884	-0.64	0.28	-0.69	0.29	10	-0.05	
1888	0.23	0.67	2.46	0.25	39	2.22	Station does not subtract 3 from kurtosis
1890	0.21	0.90	2.46	0.36	123	2.25	Station does not subtract 3 from kurtosis
1891	0.36	1.56	2.10	0.86	33	1.74	Station does not subtract 3 from kurtosis
1893	-0.70	0.66	-1.00	0.00	49	N/A	Station does not compute Kurtosis
7090	-0.53	0.67	-0.54	0.68	688	-0.01	
7105	-0.22	0.51	-0.22	0.51	284	0.01	
7110	-0.27	0.63	-0.27	0.61	264	0.01	
7119	-0.26	0.59	-0.33	0.57	108	-0.07	
7237	-0.59	0.23	2.26	0.16	229	2.85	Station does not compute Kurtosis
7249	0.27	1.53	-1.00	0.00	17	N/A	Station does not compute Kurtosis
7501	-0.18	0.55	-0.23	0.43	79	-0.05	
7810	-0.38	0.31	-0.40	0.32	945	-0.03	
7811	-0.50	0.26	-0.51	0.25	87	-0.01	
7821	-0.94	0.14	2.03	0.11	67	2.97	Station does not subtract 3 from kurtosis
7824	0.84	0.81	-1.00	0.00	6	N/A	Station does not compute Kurtosis
7825	-0.86	0.44	-0.92	0.38	44	-0.06	
7827	-0.87	0.07	-0.90	0.06	81	-0.02	
7838	-0.28	0.74	-0.28	0.68	213	0.00	
7839	-0.92	0.20	-0.98	0.17	237	-0.06	
7840	-0.30	0.30	-1.00	0.00	415	N/A	Station does not compute skew
7841	-0.95	0.17	-0.97	0.17	103	-0.02	
7845	-0.38	0.49	-0.40	0.48	312	-0.02	
7941	-0.25	0.34	-0.26	0.33	374	-0.01	
8834	-0.59	0.21	-1.00	0.00	207	N/A	Station does not compute Kurtosis

- Moment outliers were eliminated prior to generation of these statistics
- Some stations do not subtract 3 from kurtosis
- Bin kurtosis agrees well for all stations that compute it and that subtract 3

NP Peak minus Mean Comparisons

	OrbitNP		Station				
Pad	Average of Peak-Mean in mm	StdDev of Peak-Mean in mm	Average of Peak-Mean in mm	StdDev of Peak-Mean in mm	# of NPs	Station - OrbitNP Peak-Mean in mm	Comments
1824	0.3	23.0	22.1	6.5	3	21.9	
1873	0.4	4.1	-1	0	33	N/A	Station does not compute peak-mean
1874	-4.9	8.9	-4.0	18.4	11	0.9	
1884	-2.9	1.7	0	0	10	N/A	Station does not compute peak-mean
1888	-6.9	8.2	-1	0	39	N/A	Station does not compute peak-mean
1890	0.5	7.9	-1	0	123	N/A	Station does not compute peak-mean
1891	-4.7	9.5	-9.1	11.6	33	-4.4	
1893	-2.9	8.4	-1	0	49	N/A	Station does not compute peak-mean
7090	-0.4	1.4	-1	0	688	N/A	Station does not compute peak-mean
7105	-0.5	1.8	-1	0	284	N/A	Station does not compute peak-mean
7110	-0.4	1.7	-1	0	264	N/A	Station does not compute peak-mean
7119	-0.3	1.5	-1	0	108	N/A	Station does not compute peak-mean
7237	-1.2	1.7	-0.7	1.4	229	0.5	
7249	-2.4	2.4	-1	0	17	N/A	Station does not compute peak-mean
7501	-0.5	1.2	-1	0	79	N/A	Station does not compute peak-mean
7810	-2.7	2.3	28.7	3.8	945	31.3	Station provides their maximum residual
7811	-2.5	3.5	-4.0	7.9	87	-1.5	
7821	-1.0	1.4	3.2	4.3	67	4.1	
7824	-1.2	1.5	-1	0	6	N/A	Station does not compute peak-mean
7825	-0.7	2.3	1.0	4.3	44	1.6	
7827	-0.8	1.7	-0.2	0.4	81	0.6	
7838	-2.4	3.9	-0.1	8.3	213	2.2	
7839	-0.7	1.3	-0.9	2.3	237	-0.2	
7840	-3.5	1.6	-1	0	415	N/A	Station does not compute peak-mean
7841	-1.7	2.0	0	0	103	1.7	Station computes it, but value is very small
7845	-1.9	3.3	-1	0	312	N/A	Station does not compute peak-mean
7941	-0.3	0.4	-1	0	374	N/A	Station does not compute peak-mean
8834	-1.5	1.7	-1	0	207	N/A	Station does not compute peak-mean

- Many stations don’t compute bin peak-mean
- 7810 Zimmerwald provides the maximum residual for bin peak-mean
- 7841 Potsdam computes bin peak-mean, but the value is extremely small (near 0)
- Action: The QCB need to define a standard peak-mean algorithm

NP Return Rate Comparison

	OrbitNP		Station				
Pad	Average return rate in %	StdDev return rate in %	Average return rate in %	StdDev return rate in %	# of NPs	Return Rate Differences in %	Comments
1824	1.0	0.9	0	0	3	N/A	Station provides a zero vs -1
1873	1.7	1.7	0	0	33	N/A	Station provides a zero vs -1
1874	20.6	26.9	-1	0	11	N/A	Station does not compute peak-mean
1884	31.8	10.8	87.0	7.6	10	N/A	Station provides signal to noise ratio vs return rate
1888	1.8	2.7	-1	0	39	N/A	Station does not compute peak-mean
1890	0.7	0.7	-1	0	123	N/A	Station does not compute peak-mean
1891	48.2	35.5	-1	0	33	N/A	Station does not compute peak-mean
1893	2.1	1.6	-1	0	49	N/A	Station does not compute peak-mean
7090	8.5	9.4	5.2	6.2	688	-3.3	
7105	28.8	27.5	23.9	23.8	284	-5.0	
7110	11.9	10.6	9.9	9.7	264	-2.0	
7119	14.6	16.7	10.3	9.4	108	-4.3	
7237	9.1	8.5	6.4	6.8	229	-2.6	
7249	22.7	13.8	-1	0	17	N/A	Station does not compute peak-mean
7501	34.4	26.9	25.2	24.3	79	-9.2	
7810	6.3	3.3	-1	0	945	N/A	Station does not compute peak-mean
7811	11.9	6.4	10.8	6.6	87	-1.1	
7821	1.3	1.2	1.3	1.2	67	0.0	
7824	12.1	6.3	0	0	6	N/A	Station provides a zero vs -1
7825	0.4	0.2	3.0	4.1	44	2.6	
7827	3.3	2.3	8.2	5.9	81	4.9	
7838	4.6	3.8	0	0	213	N/A	Station provides a zero vs -1
7839	3.1	3.0	1.2	1.2	237	-1.9	
7840	4.2	2.1	2.0	1.7	415	-2.2	
7841	1.2	1.5	50.7	17.0	103	N/A	Station provides signal to noise ratio vs return rate
7845	7.4	7.0	6.0	4.6	312	-1.4	
7941	43.8	25.1	35.3	25.4	374	-8.5	
8834	1.9	1.2	0	0	207	N/A	Station provides a zero vs -1

- Return rates are tricky to compute, especially for LAGEOS, because no one knows when a station may have encountered a cloud or switched to another satellite.
- The NASA systems, dependent upon the LAGEOS range, can switch from 10 to 5 pps
- Many stations don’t compute return rates.
- Two stations (1884, 7841) are reporting signal to noise ratio vs return rate.
- OrbitNP, in general, has higher return rates vs station generated return rates.

50 Session Record Comparisons

Session RMS Comparison

Pad	OrbitNP Average of Session RMS in mm	OrbitNP StdDev of RMS in mm	Station Average of Session RMS in mm	Station StdDev of RMS in mm	Station - OrbitNP in mm	# of CRDs
1824	33.877	N/A	38.823	N/A	4.947	1
1873	15.593	7.856	14.739	1.840	-0.854	8
1884	10.823	1.420	10.823	1.420	0.000	2
1888	37.879	0.594	34.176	0.848	-3.702	2
1890	40.151	1.683	36.323	2.011	-3.828	26
1891	0.000	0.000	31.163	2.399	N/A	15
1893	28.635	2.108	29.355	4.145	0.720	6
7090	5.300	0.944	5.300	0.944	0.000	160
7105	8.532	1.458	8.532	1.458	0.000	41
7110	7.622	1.649	7.622	1.649	0.000	37
7119	9.816	6.743	9.816	6.743	0.000	17
7237	11.068	3.576	10.452	3.535	-0.616	33
7249	12.391	4.285	12.341	4.203	-0.050	3
7501	7.281	0.686	7.281	0.686	0.000	19
7810	11.906	1.456	11.906	1.456	0.000	79
7811	18.561	1.186	17.781	0.863	-0.779	8
7821	6.852	0.616	6.831	0.664	-0.021	7
7825	7.967	1.306	7.560	1.030	-0.407	12
7827	11.536	0.623	12.524	3.832	0.988	35
7838	16.089	1.504	16.089	1.504	0.000	21
7839	5.287	0.201	5.185	0.195	-0.102	30
7840	11.833	1.163	11.833	1.163	0.000	34
7841	7.709	1.732	7.709	1.732	0.000	23
7845	15.364	1.606	14.834	1.247	-0.531	28
7941	3.231	0.250	3.083	0.195	-0.148	54
8834	10.828	1.140	10.793	1.133	-0.035	45

- For some stations (1884, 7090, 7105, 7110, 7119, 7501, 7810, 7838, 7840, 7841), does OrbitNP compute an independent session RMS since the values appear to be identical to the station’s NP CRD 50 records?
- For some reason, OrbitNP didn’t compute session RMS for station 1891 Irkutsk

Session Outliers

Pad	Day	Type	Rec	cfg1	RMS in ps	Skew	Kurtosis	peak-mean in ps
1874	1/11/2020	OrbitNP	50	STD	0	0.00	0.00	0
1874	1/11/2020	Station	50	STD	203	0.11	2.20	-72
1888	1/10/2020	OrbitNP	50	KS	1777	-11.20	143.96	0
1888	1/10/2020	Station	50	std	219	0.13	2.44	-1
1888	1/11/2020	OrbitNP	50	KS	324	-15.54	550.10	0
1888	1/11/2020	Station	50	std	222	0.39	2.52	-1
1888	1/23/2020	OrbitNP	50	KS	319	-9.83	209.34	0
1888	1/23/2020	Station	50	std	209	0.32	2.47	-1
1888	1/24/2020	OrbitNP	50	KS	1018	6.58	47.63	0
1888	1/24/2020	Station	50	std	231	0.04	2.41	-1
1888	1/24/2020	OrbitNP	50	KS	14990	11.19	128.34	0
1888	1/24/2020	Station	50	std	237	0.27	2.35	-1
1893	1/25/2020	Station	50	PDAS	146	-1.00	-1.00	-1
1893	1/25/2020	OrbitNP	50	KS	5373	-3.96	14.09	0
7237	1/16/2020	OrbitNP	50	KS	18463	-1.88	2.84	0
7237	1/16/2020	Station	50	std	658	-0.05	2.19	-63
7824	1/9/2020	OrbitNP	50	KS	137	10.64	200.15	0
7824	1/9/2020	Station	50	std	89	-1.00	-1.00	-1
7824	1/25/2020	Station	50	std	73	-1.00	-1.00	-1
7824	1/25/2020	OrbitNP	50	KS	143	2.16	6.57	0
7827	1/2/2020	OrbitNP	50	KS	584	-3.12	8.03	0
7827	1/2/2020	Station	50	d2c2	75	0.06	-0.90	-2
7827	1/3/2020	OrbitNP	50	KS	112	0.97	4.93	0
7827	1/3/2020	Station	50	d2c2	119	0.00	-0.77	-1
7827	1/3/2020	OrbitNP	50	KS	470	8.32	77.76	0
7827	1/3/2020	Station	50	d2c2	84	0.13	-0.79	-6

Pad	Day	Type	Rec	cfg1	RMS in ps	Skew	Kurtosis	peak-mean in ps
7827	1/6/2020	OrbitNP	50	KS	86	1.09	5.44	0
7827	1/6/2020	Station	50	d2c2	109	0.07	-0.93	-6
7827	1/25/2020	OrbitNP	50	KS	238	-8.97	89.96	0
7827	1/25/2020	Station	50	d2c2	78	0.14	-0.97	-7
7839	1/4/2020	OrbitNP	50	KS	38	-0.23	1.67	0
7839	1/4/2020	Station	50	902	36	0.09	-1.14	-25
7839	1/6/2020	OrbitNP	50	KS	36	0.28	1.13	0
7839	1/6/2020	Station	50	902	34	0.03	-0.94	2
7839	1/7/2020	OrbitNP	50	KS	36	-0.31	6.70	0
7839	1/7/2020	Station	50	902	35	0.16	-1.02	-15
7839	1/7/2020	OrbitNP	50	KS	39	-5.37	170.38	0
7839	1/7/2020	Station	50	902	35	0.12	-1.04	-19
7839	1/8/2020	OrbitNP	50	KS	37	4.86	168.89	0
7839	1/8/2020	Station	50	902	34	0.00	-0.94	3
7839	1/8/2020	OrbitNP	50	KS	40	8.22	313.53	0
7839	1/8/2020	Station	50	902	35	-0.05	-1.07	12
7839	1/13/2020	OrbitNP	50	KS	36	-0.83	9.62	0
7839	1/13/2020	Station	50	902	34	0.11	-0.97	-14
7845	1/29/2020	OrbitNP	50	KS	171	1.83	5.13	0
7845	1/29/2020	Station	50	me08	127	0.04	-0.47	-1
7941	1/10/2020	OrbitNP	50	KS	26	-6.06	144.73	0
7941	1/10/2020	Station	50	std1	21	0.20	-0.16	-1
7941	1/21/2020	OrbitNP	50	KS	137	-6.51	41.70	0
7941	1/21/2020	Station	50	std1	20	0.30	-0.12	-1
7941	1/23/2020	OrbitNP	50	KS	24	8.18	256.18	0
7941	1/23/2020	Station	50	std1	20	0.21	-0.19	0

Legend
Station
OrbitNP

- For some reason, OrbitNP has large magnitude skew and kurtosis on passes from leading edge stations like 7839 Graz and 7941 Matera. The station results were provided for comparisons.

Session Skew Comparison

	OrbitNP		Station			
Pad	Average of Session skew	StdDev of Session Skew	Average of Session skew	StdDev of Session Skew	Station - OrbitNP Skew	# of CRDs
1824	-0.281	N/A	0.162	N/A	0.443	1
1873	-0.205	0.711	0.120	0.102	0.325	8
1884	0.144	0.151	0.144	0.151	0.000	2
1888	0.627	0.121	0.342	0.042	-0.285	2
1890	0.268	0.250	0.015	0.101	-0.254	26
1891	0.000	0.000	0.150	0.135	0.150	15
1893	0.285	0.537	-1.000	0.000	N/A	6
7090	0.175	0.338	0.175	0.338	0.000	160
7105	0.174	0.166	0.174	0.166	0.000	41
7110	0.159	0.254	0.159	0.254	0.000	37
7119	-0.017	0.389	-0.017	0.389	0.000	17
7237	0.229	0.199	0.148	0.104	-0.081	33
7249	-1.000	0.000	-1.000	0.000	N/A	3
7501	0.248	0.132	0.248	0.132	0.000	19
7810	-1.000	0.000	-1.000	0.000	N/A	79
7811	0.245	0.276	0.103	0.046	-0.143	8
7821	0.022	0.047	0.022	0.047	0.000	7
7825	-0.027	0.417	0.073	0.149	0.100	12
7827	0.069	0.067	0.052	0.036	-0.016	35
7838	0.395	0.213	0.395	0.213	0.000	21
7839	0.104	0.123	0.122	0.116	0.018	28
7840	0.528	0.058	0.528	0.058	0.000	34
7841	0.152	0.082	0.152	0.082	0.000	23
7845	0.308	0.162	0.293	0.137	-0.014	28
7941	0.150	0.197	0.196	0.069	0.046	54
8834	0.170	0.072	-1.000	0.000	N/A	45

- For some stations (1884, 7090, 7105, 7110, 7119, 7501, 7810, 7821, 7838, 7840, 7841), does OrbitNP compute an independent session skew since the values appear to be identical to the station's NP CRD 50 records?
- A few stations (1893, 7249, 7810, 8834) don't compute session skew
- For some reason, OrbitNP didn't compute session skew for 1891, 7249 and 7810

Session Kurtosis Comparison

	OrbitNP		Station			
Pad	Average of Session Kurtosis	StdDev of Kurtosis	Average of Session Kurtosis	StdDev of Kurtosis	Station - OrbitNP Kurtosis	# of CRDs
1824	-1.007	N/A	1.997	N/A	3.004	1
1873	0.410	2.515	-0.466	0.048	-0.875	8
1884	-0.768	0.380	-0.768	0.380	0.000	2
1888	0.610	0.784	2.555	0.028	1.946	2
1890	0.723	1.491	2.474	0.108	1.751	26
1891	0.000	0.000	2.318	0.189	2.318	15
1893	-0.127	0.382	-1.000	0.000	NA	6
7090	2.876	0.515	2.876	0.515	0.000	160
7105	2.979	0.304	2.979	0.304	0.000	41
7110	3.005	0.309	3.005	0.309	0.000	37
7119	3.089	0.621	3.089	0.621	0.000	17
7237	-0.488	0.471	2.289	0.157	2.777	33
7249	-1.000	0.000	-1.000	0.000	NA	3
7501	2.921	0.214	2.921	0.214	0.000	19
7810	-1.000	0.000	-1.000	0.000	NA	79
7811	-0.252	0.510	-0.481	0.068	-0.230	8
7821	2.030	0.091	2.030	0.091	0.000	7
7825	-0.313	0.838	-0.917	0.196	-0.603	12
7827	-0.772	0.209	-0.911	0.036	-0.139	35
7838	-0.004	0.271	-0.004	0.271	0.000	21
7839	-0.744	0.311	-0.992	0.100	-0.248	28
7840	-0.436	0.056	-0.436	0.056	0.000	34
7841	-0.971	0.079	-0.971	0.079	0.000	23
7845	-0.243	0.344	-0.402	0.185	-0.159	28
7941	-0.089	0.340	-0.182	0.114	-0.093	54
8834	-0.570	0.083	-1.000	0.000	NA	45

- A few stations (1893, 7249, 7810, 8834) don’t compute session kurtosis
- Several stations (1824, 1888, 1890, 1891, 7090, 7105, 7110, 7119, 7237, 7501, 7821) don’t subtract 3 from session kurtosis (blue cells)
- For some stations (1884, 7090, 7105, 7110, 7119, 7501, 7810, 7838, 7840, 7841), does OrbitNP compute an independent session kurtosis since the values appear to be identical to the station’s NP CRD 50 records?
- For some reason, OrbitNP didn’t compute session skew for 1891, 7249 and 7810

Session Peak minus Mean Comparisons

	OrbitNP		Station		
Pad	Average of peak-mean in mm	StdDev of peak-mean in mm	Average of peak-mean in mm	StdDev of peak-mean in mm	# of CRDs
1824	0	N/A	0	N/A	1
1873	0	0	-2.09855	1.419781	8
1884	-1	0	-1	0	2
1888	0	0	-1	0	2
1890	0	0	-1	0	26
1891	0	0	-5.60112	10.64571	15
1893	0	0	-1	0	6
7090	-1	0	-1	0	160
7105	-1	0	-1	0	41
7110	-1	0	-1	0	37
7119	-1	0	-1	0	17
7237	0	0	-0.88303	0.852989	33
7249	-1	0	-1	0	3
7501	-1	0	-1	0	19
7810	0	0	0	0	79
7811	0	0	-4.95782	3.617208	8
7821	-0.6831	0.809294	-0.6831	0.809294	7
7825	0	0	0	0	12
7827	0	0	-0.31607	0.478238	35
7838	-6.40557	4.823374	-6.40557	4.823374	21
7839	0	0	-1.61138	1.669246	28
7840	-3.8973	1.420124	-3.8973	1.420124	34
7841	-1	0	-1	0	23
7845	0	0	-1	0	28
7941	0	0	-0.05552	0.1211	54
8834	0	0	-1	0	45

- Most station don’t provide a session peak minus mean value and some provide a ‘0’ vs a ‘-1’
- It appears OrbitNP does not compute an independent session peak minus mean since for some systems since the peak minus mean is identical to the peak minus mean value from the station’s NP CRD 50 record.

Summary

- RCOSMOS Stations and Kunming didn't provide full-rate data
- There appears to be missing full-rate data from select stations near the beginning and the end of January 2020
- Two stations (1824 and 7824) don't remove the system delay in their full-rate data but this is permissible. Need a system delay applied flag in the format, so users can tell if system delay was applied.
- Station 7827 does not adhere to the Herstmonceux NP definition in terms of computing the NP epoch
- NP range comparisons between OrbitNP and the stations are excellent
- There is a need for a standard peak minus mean algorithm
- OrbitNP sometimes have issues computing the higher moments (skew and kurtosis) for the leading edge systems
- Does OrbitNP compute independent session higher moments (RMS, skew, kurtosis) and peak minus mean?
- Can we do similar analysis by comparing CRD V1 vs V2 station generated NPs to qualify CRD V2 NPs?

SOS-W Status Report

Stefan Riepl

Recent Occurences

- SOS-W inactive since 1/2021 due to guiding camera failure (fiber coupling damaged), automatic procedures affected (mount modeling and automatic Coude adjustment)
- Repair delayed due to Corona situation until 3/2021
- Software inoperability due to change in network infrastructure, new department G6 has been formed, new responibilities, IT-services outsourced in separate department within BKG, Corona circumstances limit availability of IT-services
- Failure of airconditioning device in 4/2021 caused overheating of further temperature stabilizing devices, spare chiller is used at WLRS, damaged chiller not available until repairment finished in 7/2021
- Laser readjustment and new network configuration terminated in 7/2021, calibration stability test ongoing and positive, new failure of circulation chiller noticed on 2021-08-09
- Telescope issues (gearbox vibrations, frequent emergency halts, main mirror misalignment caused by vibration) and mitigation actions under discussion with Carl Zeiss Jena since spring 2020.
- Feasability test for replacement of Ti:Sa oscillator with Cr:LiSAF oscillator in 8/2021 applying new pump laser technology (Semiconductor Optical Amplifier delvering 1.5W @ TEM00)
- Oprability expected in 9/2021

Wiener Filter Metrics QCB Report

1. Automated system configuration scanning in progress
- GANTT – graph visualization
- retrieval of electronic data processing parameters (like constant fraction discriminator (CFD) parameters)

2. Data modeling for Wiener Filter transfer function identified four configurations used by ILRS core stations, which require different modeling strategies in terms of reference point:

a) Single Photon Data from APDs:
- data can be taken as is
- residual time walk effects will be modeled from return rate
- reference will be the mean of the reflectivity (transfer) function as published in “Upgraded modelling for the determination of centre of mass corrections of geodetic SLR satellites: impact on key parameters of the terrestrial reference frame” or further refined models.

b) MCP-PMT (ITT) multiphoton systems:
- reference will be modeled from CFD parameters and laser pulse shape constant fraction value published in the site logs
- additional parameters (e.g. walk compensation for Tennelec CFDs) could be modeled using time walk measurements to zero signature calibration targets (is there a standardized data base for time walk measurements within the ILRS ?)

c) CSPAD systems:
- the reference seems to be unclear. Literature says CSPAD takes the first photon arriving, BUT what is the distance from the COM it comes from ?

d) PMT (Hamamatsu) (e.g. Zimmerwald) and novel MCP-PMT’s (photek, as used in WLRS for 532nm) with novel discriminator:
- for single photon operation reference point is the mean of the transfer function
- time walk measurements required for modeling higher return rates